Belle II Data Analysis

$B^0 \to \tau^+\tau^-$ Decay Mode as an Example

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Contents

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  - Physics with "Parameter Perspective"
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  - **How many Parameters are in the Standard Model?**
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  - $B^0 \to \tau^+\tau^-$ Example: SM / BSM Theories with "Parameter Perspective"

- Part II: Analysis Procedure
  - What / How have I studied so far?
  - Analysis Procedure
  - **Think the Final Stage of the Analysis, first**

Contents

Purpose of This Talk

- Share my current Understanding
  - Validation
  - Get Advice

Part I: What we want to know from Belle II Analysis

Physics with “Parameter Perspective”

※ WARNING: My Personal Opinion!

Theory: "Number of Parameters" Perspective

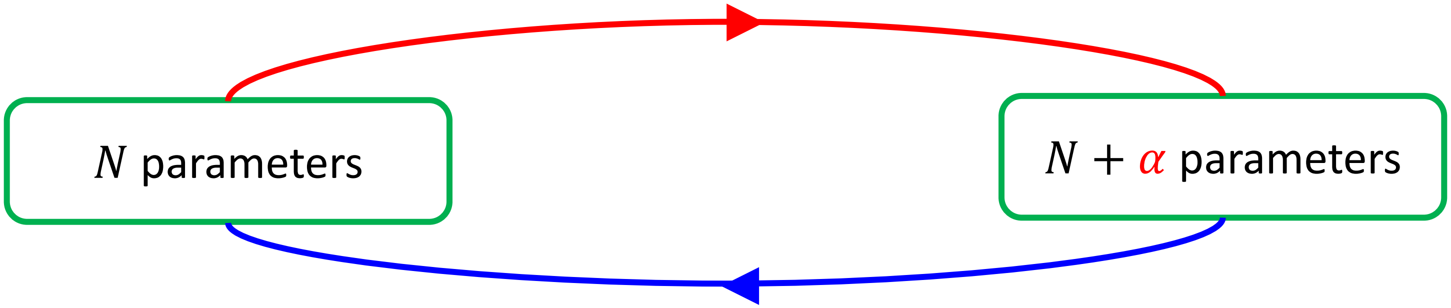
(※ Note: Not always true. Other types also exist.)

Keyword
- Generalization
- Extension

Technique
- Hint from T^{-1}
- Other clever ideas

Standard (Existing) Theory
ex) SM

New (Extended) Theory
ex) BSM



Effective Theory
- Easier (in most cases)

Keyword
- Simplification

Techniques (T)
- Approximation: Limit (0 or ∞)
- Integrate out
- etc.

Standard (Existing) Theory

Outsourcing…

- Rationalization of Increasing / Decreasing Parameters
  - Rationalization by Logic (Mathematics) ⇒ Theorist
  - Rationalization by Reality ⇒ Experimentalist
- What do theorists do?
  - Logical (mathematical) Rationalization
  - Interpretation of the Parameters ⇒ Physics Meaning

Parameter vs. Variable

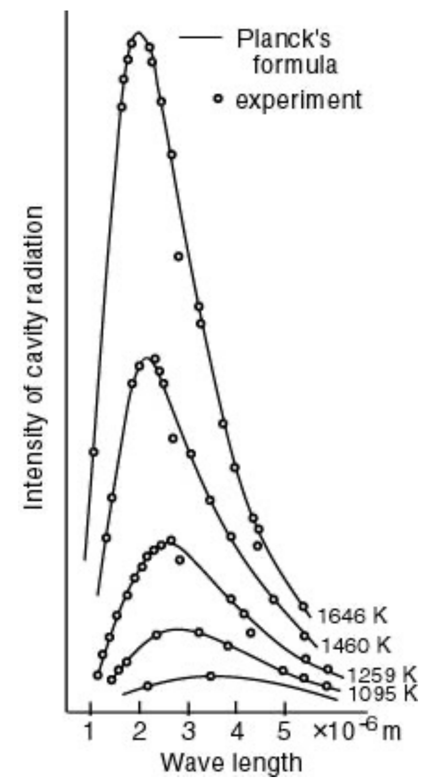
- Parameter
  - Keyword: “**Fixed**”
  - Example) Factor, Coefficient, Constant, etc.
    (※ This also can be variable, depending on purposes.)
    - ex) Form Factor, Wilson Coefficient
    - ex) Physical Constant: c, h, …

- Variable
  - Keyword: “**Varying**,” literally able to vary

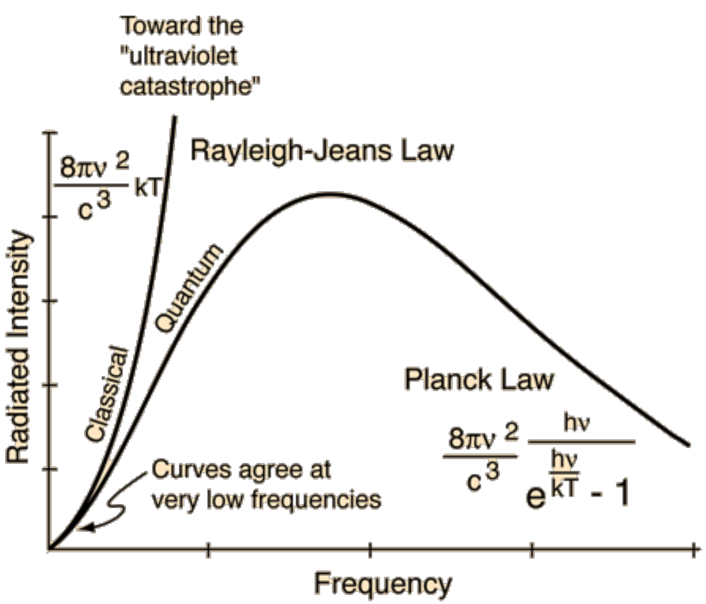
Extract Parameters from Variables

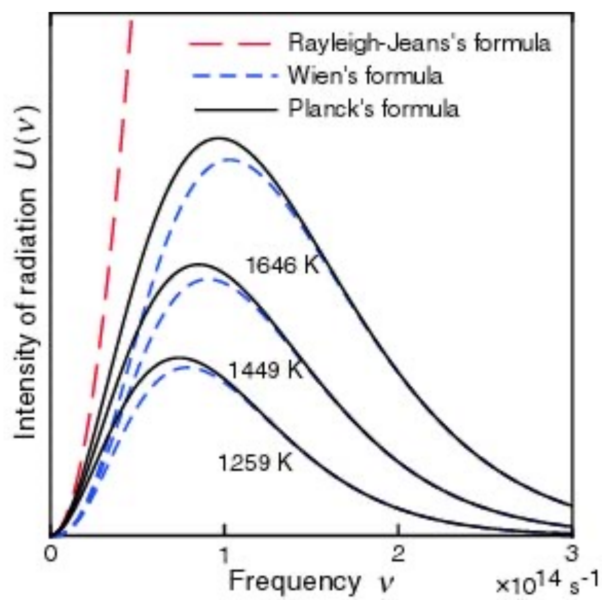
Example: New Theory – Parameter Perspective

- Discovery of Plank Constant (Blackbody Radiation)
  - Rayleigh-Jeans Dist.: Single Parameter in the Standard theory (**1 parameter: c**)
    - $\frac{8\pi\nu^2}{c^3} kT$ ($\nu \to 0$ limit of Plank Dist.)
  - Wein's Dist. (Approx.): Add One more Parameter to a New Theory (**2 parameters: c and h**)
    - $\frac{8\pi\nu^2}{c^3} h\nu\, e^{-\frac{h\nu}{kT}}$ (Experimental Formula) ($\nu \to \infty$ limit of Plank Dist.)
  - Plank's Dist.: Add One more Parameter to a New Theory (**2 parameters: c and h**)
    - $\frac{8\pi\nu^2}{c^3} \frac{h\nu}{e^{\frac{h\nu}{kT}}-1}$(More suitable (generalized) Formula)
    - Rationalization
    - Interpretation, Physical Meaning ⇒ Energy is Quantized… etc.



※ Let the Boltzmann constant $k = 1$ ※ **Variables**: ν, T





How to add more Parameters in Particle Physics?

- **New Particle**
  - New particle invariant mass
  - Interaction constant/factor/coefficient of this new particle

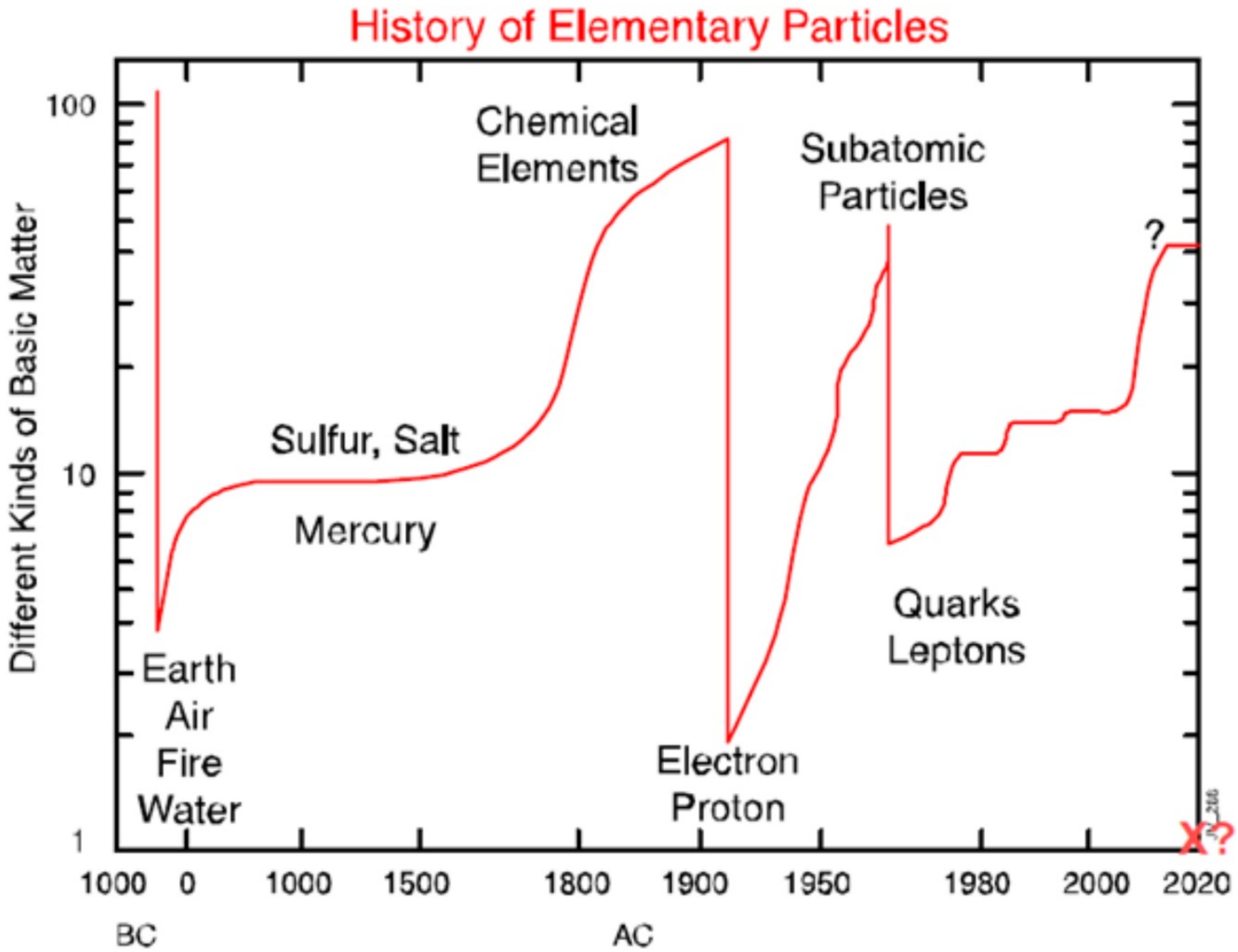
- **New Interaction**
  - coupling constants
  - new factor
  - new coefficient, etc.

- Method
  - Energy Frontier (Mainly focus on discoveries of **new particles**)
  - Intensity Frontier (Mainly focus on the **new couplings**)

  ※ Note: Not always true.

History of the Number of Elements

"Reductionism"



※ https://maxmakukov.wordpress.com/2014/12/17/history-of-elementary-particles/
※ https://arxiv.org/abs/1311.1769

How Many Parameters in the Standard Model?

Elementary particles

Elementary fermions

Half-integer spin

Obey the Fermi-Dirac statistics

Quarks and antiquarks

Spin = $\frac{1}{2}$

Have color charge

Participate in strong interactions

Three generations

1. Up (u),
   Down (d)
2. Charm (c),
   Strange (s)
3. Top (t),
   Bottom (b)

Leptons and antileptons

Spin = $\frac{1}{2}$

No color charge

Electroweak interactions

Three generations

1. Electron (e^-), [†]
   Electron neutrino (ν_e)
2. Muon (μ^-),
   Muon neutrino (ν_μ)
3. Tau (τ^-),
   Tau neutrino (ν_τ)

Elementary bosons

Integer spin

Obey the Bose-Einstein statistics

Gauge bosons

Spin = 1, 2 [‡]

Force carriers

Four kinds

1. Photon
   (γ; electromagnetic interaction)
2. W and Z bosons
   (W^+, W^-, Z; weak interaction)
3. Eight types of gluons
   (g; strong interaction)
4. Graviton (hypothetical)
   (G; gravity) [‡]

Scalar bosons

Spin = 0

Unique

Higgs boson (H^0)

※ [Wikipedia, Elementary Particles] https://en.wikipedia.org/wiki/Elementary_particle

Standard Model Lagrangian

Belle II

$$
\begin{gathered}
\boxed{1}\; -\tfrac{1}{2}\partial_\nu g^a_\mu \partial_\nu g^a_\mu - g_s f^{abc}\partial_\mu g^a_\nu g^b_\mu g^c_\nu - \tfrac{1}{4} g_s^2 f^{abc} f^{ade} g^b_\mu g^c_\nu g^d_\mu g^e_\nu + \\
\tfrac{1}{2} i g_s^2 (\bar{q}^\sigma_i \gamma^\mu q^\sigma_j) g^a_\mu + \bar{G}^a \partial^2 G^a + g_s f^{abc} \partial_\mu \bar{G}^a G^b g^c_\mu - \partial_\nu W^+_\mu \partial_\nu W^-_\mu - \\
\boxed{2}\; M^2 W^+_\mu W^-_\mu - \tfrac{1}{2}\partial_\nu Z^0_\mu \partial_\nu Z^0_\mu - \tfrac{1}{2c_w^2} M^2 Z^0_\mu Z^0_\mu - \tfrac{1}{2}\partial_\mu A_\nu \partial_\mu A_\nu - \tfrac{1}{2}\partial_\mu H \partial_\mu H - \\
\tfrac{1}{2} m_h^2 H^2 - \partial_\mu \phi^+ \partial_\mu \phi^- - M^2 \phi^+ \phi^- - \tfrac{1}{2}\partial_\mu \phi^0 \partial_\mu \phi^0 - \tfrac{1}{2c_w^2} M \phi^0 \phi^0 - \beta_h [\tfrac{2M^2}{g^2} + \\
\tfrac{2M}{g} H + \tfrac{1}{2}(H^2 + \phi^0\phi^0 + 2\phi^+\phi^-)] + \tfrac{2M^4}{g^2}\alpha_h - i g c_w [\partial_\nu Z^0_\mu (W^+_\mu W^-_\nu - \\
W^+_\nu W^-_\mu) - Z^0_\nu (W^+_\mu \partial_\nu W^-_\mu - W^-_\mu \partial_\nu W^+_\mu) + Z^0_\mu (W^+_\nu \partial_\nu W^-_\mu - \\
W^-_\nu \partial_\nu W^+_\mu)] - i g s_w [\partial_\nu A_\mu (W^+_\mu W^-_\nu - W^+_\nu W^-_\mu) - A_\nu (W^+_\mu \partial_\nu W^-_\mu - \\
W^-_\mu \partial_\nu W^+_\mu) + A_\mu (W^+_\nu \partial_\nu W^-_\mu - W^-_\nu \partial_\nu W^+_\mu)] - \tfrac{1}{2} g^2 W^+_\mu W^-_\mu W^+_\nu W^-_\nu + \\
\tfrac{1}{2} g^2 W^+_\mu W^-_\nu W^+_\mu W^-_\nu + g^2 c_w^2 (Z^0_\mu W^+_\mu Z^0_\nu W^-_\nu - Z^0_\mu Z^0_\mu W^+_\nu W^-_\nu) + \\
g^2 s_w^2 (A_\mu W^+_\mu A_\nu W^-_\nu - A_\mu A_\mu W^+_\nu W^-_\nu) + g^2 s_w c_w [A_\mu Z^0_\nu (W^+_\mu W^-_\nu - \\
W^+_\nu W^-_\mu) - 2 A_\mu Z^0_\mu W^+_\nu W^-_\nu] - g\alpha [H^3 + H\phi^0\phi^0 + 2H\phi^+\phi^-] - \\
\tfrac{1}{8} g^2 \alpha_h [H^4 + (\phi^0)^4 + 4(\phi^+\phi^-)^2 + 4(\phi^0)^2\phi^+\phi^- + 4H^2\phi^+\phi^- + 2(\phi^0)^2 H^2] - \\
g M W^+_\mu W^-_\mu H - \tfrac{1}{2} g \tfrac{M}{c_w^2} Z^0_\mu Z^0_\mu H - \tfrac{1}{2} i g [W^+_\mu (\phi^0 \partial_\mu \phi^- - \phi^- \partial_\mu \phi^0) - \\
W^-_\mu (\phi^0 \partial_\mu \phi^+ - \phi^+ \partial_\mu \phi^0)] + \tfrac{1}{2} g [W^+_\mu (H \partial_\mu \phi^- - \phi^- \partial_\mu H) - W^-_\mu (H \partial_\mu \phi^+ - \\
\phi^+ \partial_\mu H)] + \tfrac{1}{2} g \tfrac{1}{c_w} (Z^0_\mu (H \partial_\mu \phi^0 - \phi^0 \partial_\mu H) - i g \tfrac{s_w^2}{c_w} M Z^0_\mu (W^+_\mu \phi^- - W^-_\mu \phi^+) + \\
i g s_w M A_\mu (W^+_\mu \phi^- - W^-_\mu \phi^+) - i g \tfrac{1 - 2c_w^2}{2c_w} Z^0_\mu (\phi^+ \partial_\mu \phi^- - \phi^- \partial_\mu \phi^+) + \\
i g s_w A_\mu (\phi^+ \partial_\mu \phi^- - \phi^- \partial_\mu \phi^+) - \tfrac{1}{4} g^2 W^+_\mu W^-_\mu [H^2 + (\phi^0)^2 + 2\phi^+\phi^-] - \\
\tfrac{1}{4} g^2 \tfrac{1}{c_w^2} Z^0_\mu Z^0_\mu [H^2 + (\phi^0)^2 + 2(2s_w^2 - 1)^2 \phi^+\phi^-] - \tfrac{1}{2} g^2 \tfrac{s_w^2}{c_w} Z^0_\mu \phi^0 (W^+_\mu \phi^- + \\
W^-_\mu \phi^+) - \tfrac{1}{2} i g^2 \tfrac{s_w^2}{c_w} Z^0_\mu H (W^+_\mu \phi^- - W^-_\mu \phi^+) + \tfrac{1}{2} g^2 s_w A_\mu \phi^0 (W^+_\mu \phi^- + \\
W^-_\mu \phi^+) + \tfrac{1}{2} i g^2 s_w A_\mu H (W^+_\mu \phi^- - W^-_\mu \phi^+) - g^2 \tfrac{s_w}{c_w} (2c_w^2 - 1) Z^0_\mu A_\mu \phi^+ \phi^- - \\
g^1 s_w^2 A_\mu A_\mu \phi^+ \phi^- - \bar{e}^\lambda (\gamma\partial + m_e^\lambda) e^\lambda - \bar{\nu}^\lambda \gamma\partial \nu^\lambda - \bar{u}^\lambda_j (\gamma\partial + m_u^\lambda) u^\lambda_j - \\
\boxed{3}\; \bar{d}^\lambda_j (\gamma\partial + m_d^\lambda) d^\lambda_j + i g s_w A_\mu [-(\bar{e}^\lambda \gamma^\mu e^\lambda) + \tfrac{2}{3}(\bar{u}^\lambda_j \gamma^\mu u^\lambda_j) - \tfrac{1}{3}(\bar{d}^\lambda_j \gamma^\mu d^\lambda_j)] + \\
\tfrac{ig}{4c_w} Z^0_\mu [(\bar{\nu}^\lambda \gamma^\mu (1 + \gamma^5) \nu^\lambda) + (\bar{e}^\lambda \gamma^\mu (4s_w^2 - 1 - \gamma^5) e^\lambda) + (\bar{u}^\lambda_j \gamma^\mu (\tfrac{4}{3} s_w^2 - \\
1 - \gamma^5) u^\lambda_j) + (\bar{d}^\lambda_j \gamma^\mu (1 - \tfrac{8}{3} s_w^2 - \gamma^5) d^\lambda_j)] + \tfrac{ig}{2\sqrt{2}} W^+_\mu [(\bar{\nu}^\lambda \gamma^\mu (1 + \gamma^5) e^\lambda) + \\
(\bar{u}^\lambda_j \gamma^\mu (1 + \gamma^5) C_{\lambda\kappa} d^\kappa_j)] + \tfrac{ig}{2\sqrt{2}} W^-_\mu [(\bar{e}^\lambda \gamma^\mu (1 + \gamma^5) \nu^\lambda) + (\bar{d}^\kappa_j C^\dagger_{\lambda\kappa} \gamma^\mu (1 + \\
\gamma^5) u^\lambda_j)] + \tfrac{ig}{2\sqrt{2}} \tfrac{m_e^\lambda}{M} [-\phi^+ (\bar{\nu}^\lambda (1 - \gamma^5) e^\lambda) + \phi^- (\bar{e}^\lambda (1 + \gamma^5) \nu^\lambda)] - \\
\boxed{4}\; \tfrac{g}{2} \tfrac{m_e^\lambda}{M} [H (\bar{e}^\lambda e^\lambda) + i\phi^0 (\bar{e}^\lambda \gamma^5 e^\lambda)] + \tfrac{ig}{2M\sqrt{2}} \phi^+ [-m_d^\kappa (\bar{u}^\lambda_j C_{\lambda\kappa} (1 - \gamma^5) d^\kappa_j) + \\
m_u^\lambda (\bar{u}^\lambda_j C_{\lambda\kappa} (1 + \gamma^5) d^\kappa_j] + \tfrac{ig}{2M\sqrt{2}} \phi^- [m_d^\lambda (\bar{d}^\lambda_j C^\dagger_{\lambda\kappa} (1 + \gamma^5) u^\kappa_j) - m_u^\kappa (\bar{d}^\lambda_j C^\dagger_{\lambda\kappa} (1 - \\
\gamma^5) u^\kappa_j] - \tfrac{g}{2} \tfrac{m_u^\lambda}{M} H (\bar{u}^\lambda_j u^\lambda_j) - \tfrac{g}{2} \tfrac{m_d^\lambda}{M} H (\bar{d}^\lambda_j d^\lambda_j) + \tfrac{ig}{2} \tfrac{m_u^\lambda}{M} \phi^0 (\bar{u}^\lambda_j \gamma^5 u^\lambda_j) - \\
\tfrac{ig}{2} \tfrac{m_d^\lambda}{M} \phi^0 (\bar{d}^\lambda_j \gamma^5 d^\lambda_j) + \bar{X}^+ (\partial^2 - M^2) X^+ + \bar{X}^- (\partial^2 - M^2) X^- + \bar{X}^0 (\partial^2 - \\
\boxed{5}\; \tfrac{M^2}{c_w^2}) X^0 + \bar{Y} \partial^2 Y + i g c_w W^+_\mu (\partial_\mu \bar{X}^0 X^- - \partial_\mu \bar{X}^+ X^0) + i g s_w W^+_\mu (\partial_\mu \bar{Y} X^- - \\
\partial_\mu \bar{X}^+ Y) + i g c_w W^-_\mu (\partial_\mu \bar{X}^- X^0 - \partial_\mu \bar{X}^0 X^+) + i g s_w W^-_\mu (\partial_\mu \bar{X}^- Y - \\
\partial_\mu \bar{Y} X^+) + i g c_w Z^0_\mu (\partial_\mu \bar{X}^+ X^+ - \partial_\mu \bar{X}^- X^-) + i g s_w A_\mu (\partial_\mu \bar{X}^+ X^+ - \\
\partial_\mu \bar{X}^- X^-) - \tfrac{1}{2} g M [\bar{X}^+ X^+ H + \bar{X}^- X^- H + \tfrac{1}{c_w^2} \bar{X}^0 X^0 H] + \\
\tfrac{1 - 2c_w^2}{2c_w} i g M [\bar{X}^+ X^0 \phi^+ - \bar{X}^- X^0 \phi^-] + \tfrac{1}{2c_w} i g M [\bar{X}^0 X^- \phi^+ - \bar{X}^0 X^+ \phi^-] + \\
i g M s_w [\bar{X}^0 X^- \phi^+ - \bar{X}^0 X^+ \phi^-] + \tfrac{1}{2} i g M [\bar{X}^+ X^+ \phi^0 - \bar{X}^- X^- \phi^0]
\end{gathered}
$$

(1) Gluon
- Gluon: Boson that carries the strong force
- 8 Types, Color Charge

(2) W and Z bosons
- Interactions between W and Z bosons

(3) Elementary Matter Particles
- Elementary Matter Particles interact with Weak Force
- 3 generations of elementary matter particles
- Neutrino mass is assumed to be zero

(4) Ghosts
- To clean up redundancies in the mathematical formulation, these terms are introduced
- Virtual Particles

(5) Faddeev-Popov ghosts (Additional Ghosts)
- Cancel out redundancies that occur in interactions through the weak force

※ [SM Lagrangian organized by T.D. Gutierrez] http://nuclear.ucdavis.edu/~tgutierr/files/stmL1.html
※ [Image] https://www.symmetrymagazine.org/article/the-deconstructed-standard-model-equation

How Many Parameters in SM?

2.2 Standard Model of Particle Physics

The main features of the current version of the SM of Particle Physics are now given. A more thorough review can be found for example in [40]. The Standard Model is a non abelian gauge field theory based on the symmetry group $SU(3)_C \otimes SU(2)_L \otimes U(1)_Y$. $SU(3)_C$ denotes the color (C) group of Quantum Chromo Dynamics (QCD). $SU(2)_L \otimes U(1)_Y$ describes the electroweak (EW) interactions where the weak hypercharge Y is the U(1) generator and can be linked to the electric charge (Q) and the Weak Isospin (T_3) by the formula $Y = 2(Q - T_3)$. In total, the SM counts 58 objects, 118 degrees of freedom and 28 free parameters, that will be detailed in this section.

Overall most of the 28 fundamental SM parameters [3] are a consequence of the presence of the Higgs field. Before 2012, all these parameters have been measured by experiments, except 7 (m_H, $\Theta_{\rm QCD}$, the two Majorana phases of the PMNS matrix and the 3 neutrino masses) which are only constrained. However these constraints are generally weak. Therefore final values could have dramatic consequences on cosmology: m_H will be discussed extensively in the following, while $\Theta_{\rm QCD}$ and neutrino parameters are discussed in Section 3.4 and 3.5, respectively.

[3] Originally, the neutrinos were assumed massless and the PMNS matrix diagonal, hence the 19 parameters mentioned in Section 2.1.

Parameters of the Standard Model [hide]

#	Symbol	Description	Renormalization scheme (point)	Value
1	m_e	Electron mass		0.511 MeV
2	m_μ	Muon mass		105.7 MeV
3	m_τ	Tau mass		1.78 GeV
4	m_u	Up quark mass	$\mu_{\overline{MS}}$ = 2 GeV	1.9 MeV
5	m_d	Down quark mass	$\mu_{\overline{MS}}$ = 2 GeV	4.4 MeV
6	m_s	Strange quark mass	$\mu_{\overline{MS}}$ = 2 GeV	87 MeV
7	m_c	Charm quark mass	$\mu_{\overline{MS}} = m_c$	1.32 GeV
8	m_b	Bottom quark mass	$\mu_{\overline{MS}} = m_b$	4.24 GeV
9	m_t	Top quark mass	On shell scheme	173.5 GeV
10	θ_{12}	CKM 12-mixing angle		13.1°
11	θ_{23}	CKM 23-mixing angle		2.4°
12	θ_{13}	CKM 13-mixing angle		0.2°
13	δ	CKM CP violation Phase		0.995
14	g_1 or g'	U(1) gauge coupling	$\mu_{\overline{MS}} = m_Z$	0.357
15	g_2 or g	SU(2) gauge coupling	$\mu_{\overline{MS}} = m_Z$	0.652
16	g_3 or g_s	SU(3) gauge coupling	$\mu_{\overline{MS}} = m_Z$	1.221
17	$\theta_{\rm QCD}$	QCD vacuum angle		~0
18	v	Higgs vacuum expectation value		246 GeV
19	m_H	Higgs mass		125.09 ± 0.24 GeV

※ https://arxiv.org/abs/1311.1769

※ [Wikipedia] https://en.wikipedia.org/wiki/Standard_Model

$B^0 \rightarrow \tau^+\tau^-$ *example: Motivation*

Rare Decay?

- Two cases
  - Measure **Enhancement**
    - Higher value than SM prediction
    - It could be a clue about New Physics…
    - ~~However, in most cases, mistakes…~~
  - No Enhancement
    - Give better precision to SM
      - SM will have better expectation ability
    - ~~Probably upper limit setting analysis~~

Motivation

Previous studies on $B^0 \rightarrow \tau^+\tau^-$ topic

- *Belle*
  - No publication, stopped.
  - Belle note exist (BN-1390 v0.8, Michael Ziegler, October 11, 2016)
  - Dr. Seokhee Park (with Belle data)
- *BABAR*
  - B. Aubert et al, "Search for the Rare Decay $B^0 \rightarrow \tau^+\tau^-$ at BABAR", BABAR collaboration, PRL (2006)
- *LHCb*
  - R. Aaij et al, "Search for the Decays $B_s^0 \rightarrow \tau^+\tau^-$ and $B^0 \rightarrow \tau^+\tau^-$", LHCb collaboration, PRL (2017)

Belle Analysis List: EWP

On-going Analyses

※ 2021.11.04 capture

If you would have the referee team, please prepare the Belle note and contact the convener so that the convener can ask Tom to form the referee team.

bn#	mode	Topic	contact	referees	status
√	B→tau+ tau-	search	Seokhee Park (KEK)		analysis started
	B→(rho,omega)gamma	BF, A_CP	Shun Watanuki (Yonsei)		analysis started
	B→K*l+l-	angular analysis	Daniel Ferlewicz, Phill Urquijo (Melbourne)		analysis started
	B→Lambda0 p gamma	angular analysis	Valentina Zhukova, Simon Eidelman (Lebedev)		analysis started
	B0→Lambda0 DM	search	Christos Hadjivasiliou (PNNL)		review finished, open the box (202105)
	B→K*tautau	search	Thanh Dong (Fudan)		review finished, open the box (202105)
	B0→KsKsgamma	tensor resonances	Hyebin Jeon, Hwanbae Park (KNU)		review on-going (202105)

Uncovered Topics

※ 2021.07.16 capture

One cannot take two modes. If these are similar modes, it might be OK but please let convener know so that convener can make the decision.

	mode	Topic	previous publication	lumi	comments
	B→(rho,omega) gamma	BF, Delta_0-, ACP	605		Taniguchi paper
	B→(a1,b1) gamma	search			
	B→K l+ l-	Angular analysis			Sensitive to scalar and tensor couplings. LHCb did with 3/fb.
√	B→tau+ tau-	Search			LHCb gave the most stringent upper limit with 3 prong tau decays
	B→nu nu (gamma) with semileptonic tagging	Search			Babar gave the most stringent upper limit with SL tagging
	B→K pi gamma (not from K*)	BF, AI, ACP, Delta ACP	BF	30	
	B→K pi pi gamma	ACP, Delta ACP	BF, K1(1270)	30, 140	
	B→K* gamma, gamma converted to e+e-	photon polarization	none		
	B→K* e+e-	very low q2 analysis (A_T_2, A_T_im)	none		LHCb published
	B→K omega gamma	Search	none		BN1199 analysis stalled

WG2 EWP list

※ Sep. 10. 2021. Belle II EWP WG Convener Elisa Manoni agreed.
※ Sep. 11. 2021. Belle II EWP WG Convener Saurabh Sandilya agreed.
※ Sep. 12. 2021. assigned.

B→Kττ using feiHadronicB0, feiHadronicBplus (+ new "semi-inclusive" method)	@Gaetano de Marino @Trabelsi Karim			
B→K*ττ	(@Simon Wehle) @Rahul Tiwary	INACTIVE	BIIANA-78 - Search for the decay B→K*ττ 열림	
B→ττ	@Cheolhun Kim	Assigend		
B→ Λ + invisible	@Bryan Fulsom @Christos Hadjivasiliou @알 수 없는 사용자 (mschran @Jan Strube	ACTIVE **B2GM**: June 25, 2020 (slides)	~~BIIANA-117~~ - B→ Λ + invisible 닫힘	
B→ Λ_c + X	@Leonardo Benjamin Rizzuto	Lubjana	~~BIIANA-119~~ - B→ Λ_c + invisible 닫힘	

- B2: EWP analysis (https://confluence.desy.de/display/BI/EWP+Analyses)

WG1 SLMissing: Leptonic subgroup list

Sub-groups: Leptonic sub-group

Florian Bernlochner posted on 06. 1월. 2018 08:44h - last edited by Bruce Yabsley on 06. 4월. 2021 02:44h

Conveners: Steve Robertson (McGill) & Bruce Yabsley (Sydney); outgoing: Mario Merola (Napoli)

Topics

- B → l nu gamma
- B → tau nu
- B → mu nu
- B → e nu
- B0 → nu nubar
- √ B0 → tau+ tau-
- LFV B0 → tau+ l-

Members

Feel free to add your contribution and/or modify the info reported if uncorrect.

Name	Institution	Analysis	Expertise / Role / Task / Notes
Steve Robertson	McGill University, Staff		Sub-group convener
Mario Merola	University of Napoli, Staff	B → tau nu with FEI (hadronic tag)	Sub-group convener and SL&L group data production liaison
Guglielmo de Nardo	University of Napoli, Staff	B → tau nu with FEI (hadronic tag)	
Bruce Yabsley	University of Sydney, Staff	B → tau l	Also doing long-term E_{extra} R&D
Andrea Fodor	McGill University, Student	B → mu nu untagged	
Yen-Ting Chin	National Taiwan University	B → mu nu untagged	
Robert Seddon	McGill University, PhD	B → Lambda pbar nu nubar with FEI	Presented in Physics General Meeting 2019-12-06 (link)
Trevor Shillington	McGill University, Student	B → K tau l	
Moritz Gelb	KIT, PhD	B → l nu gamma with FEI and B2BII	
Markus Prim	KIT, PhD	B → mu nu with inclusive tagging and B2BII	
Chanseok Park	Yonsei Univ., Student	B → nu nubar with FEI and B2BII	
Thomas Keck	KIT, PhD	B → tau nu with FEI on Belle data (using B2BII converter)	Main developer of the Full Event Interpretation
William Sutcliffe	KIT		Takes over the FEI maintenance from Thomas Keck, Vxb sub-group convener
Shanette De La Motte	University of Adelaide	B → mu nu with FEI (SL tag)	WG1 Skim Liasion, experience with hadronic/SL FEI
Priyanka Cheema	University of Sydney	B → tau l	Taking over beam-background suppression for E_{extra} from Kyle
Nathalie Eberlein	LMU	B → tau l with B2Bii	
√ Cheolhun Kim	Hanyang University, Ph.D. student	B → tau tau with FEI	

※ https://confluence.desy.de/display/BI/Sub-groups%3A+Leptonic+sub-group

Motivation

τ sub-decay mode (Belle-BN1390 vs. BABAR vs. LHCb)

- Belle

Name	τ decay modes
e^+e^-	$\tau \to e\nu_e\nu_\tau$, $\tau \to e\nu_e\nu_\tau$
$e^\pm\mu^\mp$	$\tau \to e\nu_e\nu_\tau$, $\tau \to \mu\nu_\mu\nu_\tau$
$e^\pm\pi^\mp$	$\tau \to e\nu_e\nu_\tau$, $\tau \to \pi\nu_\tau$
$\mu^+\mu^-$	$\tau \to \mu\nu_\mu\nu_\tau$, $\tau \to \mu\nu_\mu\nu_\tau$
$\mu^\pm\pi^\mp$	$\tau \to \mu\nu_\mu\nu_\tau$, $\tau \to \pi\nu_\tau$
$\pi^+\pi^-$	$\tau \to \pi\nu_\tau$, $\tau \to \pi\nu_\tau$

6 modes ↓ after study

Simulation

UL of BR: $(0.16 \pm 0.30)\times10^{-3}$

Data

Final state	$N_{\rm sig}$	$\mathcal{B}(B^0 \to \tau^+\tau^-)$ (in 10^{-3})
e^+e^-	33 ± 21	$3.33^{+2.23}_{-2.08}$
$e^\pm\mu^\mp$	73 ± 27	$5.52^{+2.09}_{-1.97}$
$e^\pm\pi^\mp$	70 ± 34	$3.05^{+1.53}_{-1.47}$
$\mu^+\mu^-$	40 ± 18	$7.87^{+3.68}_{-3.40}$
$\mu^\pm\pi^\mp$	63 ± 26	$4.76^{+2.03}_{-1.88}$
$\pi^+\pi^-$	44 ± 18	$4.56^{+1.96}_{-1.84}$
Combined	325 ± 27	$4.39^{+0.80}_{-0.83}$

- BABAR

Selection mode	$\mathcal{B}(\%)$ [12]	$N_e + N_\mu$	N_{π^0}	$m_{\pi\pi^0}$
$\tau^+\tau^- \to \ell\nu\bar{\nu}/\ell'\nu\bar{\nu}$	12.4	2	0	
$\tau^+\tau^- \to \ell\nu\bar{\nu}/\pi\nu$	7.8	1	0	
~~$\tau^+\tau^- \to \ell\nu\bar{\nu}/\rho\nu$~~	17.7	1	1	[0.6, 1.0] GeV
$\tau^+\tau^- \to \pi\nu/\pi\nu$	1.2	0	0	
~~$\tau^+\tau^- \to \pi\nu/\rho\nu$~~	5.6	0	1	[0.6, 1.0] GeV
$\tau^+\tau^- \to \rho\nu/\rho\nu$	6.3	0	2	[0.6, 1.0] GeV

10 modes ↓ after study

Selection mode	$\epsilon_{\rm sig}(\%)$	$N_{\rm expected}$	$N_{\rm obs}$
$\tau^+\tau^- \to \ell\nu\bar{\nu}/\ell'\nu\bar{\nu}$	0.9 ± 0.2	46 ± 4	54 ± 7
$\tau^+\tau^- \to \ell\nu\bar{\nu}/\pi\nu$	1.5 ± 0.3	122 ± 6	105 ± 11
$\tau^+\tau^- \to \pi\nu/\pi\nu$	1.5 ± 0.3	89 ± 6	80 ± 11
$\tau^+\tau^- \to \rho\nu/\rho\nu$	0.3 ± 0.1	21 ± 3	15 ± 6

※ $\rho(770)^\pm \to \pi^\pm\pi^0$

※ I think the reason why the BABAR collaboration used ***ρ* sub-decay mode** is that the branching fraction of this mode is **relatively larger** than other modes, so in order to increase yield.

※ π^0/η separation uncertainty (trade-off)

- LHCb

$\tau^- \to \pi^-\pi^+\pi^-\upsilon_\tau$

τ sub-decay mode (Belle-BN1390 vs. BABAR vs. LHCb)

		Mode	Fraction (Γ_i/Γ)	Scale Factor/ Conf. Level	P(MeV/c)
		Modes with one charged particle			
	Γ_1	particle$^-$ ≥ 0 neutrals $\geq 0K^0\ \nu_\tau$ ("1-prong")	$(85.24 \pm 0.06)\%$		
	Γ_2	particle$^-$ ≥ 0 neutrals $\geq 0K^0_L\ \nu_\tau$	$(84.58 \pm 0.06)\%$		
√	Γ_3	$\mu^-\bar{\nu}_\mu\nu_\tau$	$(17.39 \pm 0.04)\%$		885
	Γ_4	$\mu^-\bar{\nu}_\mu\nu_\tau\gamma$	$(3.67 \pm 0.08) \times 10^{-3}$		885
√	Γ_5	$e^-\bar{\nu}_e\nu_\tau$	$(17.82 \pm 0.04)\%$		888
	Γ_6	$e^-\bar{\nu}_e\nu_\tau\gamma$	$(1.83 \pm 0.05)\%$		888
	Γ_7	$h^- \geq 0K^0_L\ \nu_\tau$	$(12.03 \pm 0.05)\%$		883
	Γ_8	$h^-\nu_\tau$	$(11.51 \pm 0.05)\%$		883
√	Γ_9	$\pi^-\nu_\tau$	$(10.82 \pm 0.05)\%$		883
	Γ_{10}	$K^-\nu_\tau$	$(6.96 \pm 0.10) \times 10^{-3}$		820
	Γ_{11}	$h^- \geq 1$ neutrals ν_τ	$(37.01 \pm 0.09)\%$		
	Γ_{12}	$h^- \geq 1\ \pi^0\nu_\tau$ (ex.K^0)	$(36.51 \pm 0.09)\%$		
	Γ_{13}	$h^-\pi^0\nu_\tau$	$(25.93 \pm 0.09)\%$		878
√	Γ_{14}	$\pi^-\pi^0\nu_\tau$	$(25.49 \pm 0.09)\%$		878
	Γ_{15}	$\pi^-\pi^0$ non-$\rho(770)\ \nu_\tau$	$(3.0 \pm 3.2) \times 10^{-3}$		878

Belle II

τ sub-decay mode (Belle-BN1390 vs. BABAR vs. LHCb)

$\Gamma(\tau^- \to \pi^-\pi^0\nu_\tau)/\Gamma_{total}$ Γ_{14}/Γ

VALUE (%)		EVTS	DOCUMENT ID		TECN	COMMENT
25.49 ± 0.09	**OUR FIT**					
25.46 ± 0.12	**OUR AVERAGE**					
$25.471 \pm 0.097 \pm 0.085$		81k	[1] SCHAEL	2005C	ALEP	1991-1995 LEP runs
• • • We use the following data for averages but not for fits. • • •						
25.36 ± 0.44			[2] ARTUSO	1994	CLEO	E^{ee}_{cm} = 10.6 GeV
• • We do not use the following data for averages, fits, limits, etc. • •						
$25.30 \pm 0.15 \pm 0.13$			[3] BUSKULIC	1996	ALEP	Repl. by SCHAEL 2005C
$21.5 \pm 0.4 \pm 1.9$		4400	[4, 5] ALBRECHT	1988L	ARG	E^{ee}_{cm} = 10 GeV
$23.0 \pm 1.3 \pm 1.7$		582	ADLER	1987B	MRK3	E^{ee}_{cm} = 3.77 GeV
$25.8 \pm 1.7 \pm 2.5$			[6] BURCHAT	1987	MRK2	E^{ee}_{cm} = 29 GeV
$22.3 \pm 0.6 \pm 1.4$		629	[5] YELTON	1986	MRK2	E^{ee}_{cm} = 29 GeV

[1] See footnote to SCHAEL 2005C $\Gamma(\tau^- \to e^-\overline{\nu}_e\nu_\tau)/\Gamma_{total}$ measurement for correlations with other measurements.

[2] Not independent of ARTUSO 1994 B($h^-\pi^0\nu_\tau$) and BATTLE 1994 B($K^-\pi^0\nu_\tau$) values.

[3] Not independent of BUSKULIC 1996 B($h^-\pi^0\nu_\tau$) and B($K^-\pi^0\nu_\tau$) values.

[4] The authors divide by ($\gamma(3)$ + $\gamma(5)$ + $\gamma(9)$ + $\gamma(10)$)/Γ = 0.467 to obtain this result.

[5] Experiment had no hadron identification. Kaon corrections were made, but insufficient information is given to permit their removal.

[6] BURCHAT 1987 value is not independent of YELTON 1986 value. Nonresonant decays included.

References:

SCHAEL	2005C	PRPL 421 191	Branching Ratios and Spectral Functions of τ Decays: Final ALEPH Measurements and Physics Implications
BUSKULIC	1996	ZPHY C70 579	Tau Hadronic Branching Ratios
ARTUSO	1994	PRL 72 3762	A Measurement of the Branching Fraction B($\tau^- \to h^-\pi^0\nu_\tau$)
ALBRECHT	1988L	ZPHY C41 1	Measurement of the Decays $\tau^- \to K^{*-}\nu_\tau$ and $\tau^- \to \rho^-\nu_\tau$ √
ADLER	1987B	PRL 59 1527	Measurement of the Decay $\tau \to \rho\nu$ √
BURCHAT	1987	PR D35 27	Measurement of the Branching Fractions of the τ Lepton using a Tagged Sample of τ Decays
YELTON	1986	PRL 56 812	Measurement of the Branching Fractions $\tau^- \to \rho^-\nu_\tau$ √ and $\tau^- \to K^{*-}\nu_\tau$

τ sub-decay mode (Belle-BN1390 vs. BABAR vs. LHCb)

τ Decay Modes

▸ Expand all decays

τ^+ modes are charge conjugates of the modes below. ``$h^\pm$'' stands for $\pi^\pm$ or $K^\pm$. ``ℓ'' stands for e or μ. ``Neutrals'' stands for γ's and/or π^0's.

	Mode		Fraction (Γ_i/Γ)	Scale Factor/ Conf. Level	P(MeV/c)
▸ Modes with one charged particle					
▸ Modes with K^0's					
▾ Modes with three charged particles					
Γ_{62}	$h^-h^-h^+ \geq 0$ neutrals $\geq 0K_L^0\ \nu_\tau$		$(15.20 \pm 0.06)\%$		861
Γ_{63}	$h^-h^-h^+ \geq 0$ neutrals ν_τ (ex. $K_S^0 \to \pi^+\pi^-$)(``3-prong'')		$(14.55 \pm 0.06)\%$		861
Γ_{64}	$h^-h^-h^+\nu_\tau$		$(9.80 \pm 0.05)\%$		861
Γ_{65}	$h^-h^-h^+\nu_\tau$ (ex.K^0)		$(9.46 \pm 0.05)\%$		861
Γ_{66}	$h^-h^-h^+\nu_\tau$ (ex.K^0,ω)		$(9.43 \pm 0.05)\%$		861
√ Γ_{67}	$\pi^-\pi^+\pi^-\nu_\tau$		$(9.31 \pm 0.05)\%$		861
Γ_{68}	$\pi^-\pi^+\pi^-\nu_\tau$ (ex.K^0)		$(9.02 \pm 0.05)\%$		861
Γ_{69}	$\pi^-\pi^+\pi^-\nu_\tau$ (ex.K^0), non-axial vector		$< 2.4\%$	CL=95%	861
Γ_{70}	$\pi^-\pi^+\pi^-\nu_\tau$ (ex.K^0,ω)	[1]	$(8.99 \pm 0.05)\%$		861
Γ_{71}	$h^-h^-h^+ \geq 1$ neutrals ν_τ		$(5.29 \pm 0.05)\%$		
Γ_{72}	$h^-h^-h^+ \geq 1\ \pi^0\nu_\tau$ (ex. K^0)		$(5.09 \pm 0.05)\%$		

Motivation

Amount of data

	Cross section (nb)	Integrated lum. (ab^{-1})	$B\bar{B}$ data
BABAR	1.1	0.210 [2]	$232 \pm 3\times10^6$ [2]
LHCb	~500000*	0.003 [4]	$\sim1500\times10^6$
Belle	0.81	0.953	772×10^6
Belle II LS	1.1	427.79	471×10^6
Belle II 5 ab^{-1}	1.1	5.0	5500×10^6
Belle II 50 ab^{-1}	1.1	50.0	55000×10^6

Table 1. Cross section, Integrated luminosity, and $B\bar{B}$data (black: given, blue: rough calculation)

※ LS: Long Shutdown

[References]
[1] Andrzej J. Buras, "Weak Hamiltonian, CP Violation and Rare Decays", Lecture note (1998)
[2] B. Aubert et al, "Search for the Rare Decay $B^0 \to \tau^+\tau^-$ at BABAR", BABAR collaboration, PRL (2006)
[3] Christoph Bobeth et al, "$B_{s,d} \to l^+l^-$ in the Standard Model with Reduced Theoretical Uncertainty", PRL (2014)
[4] R. Aaij et al, "Search for the Decays $B_s^0 \to \tau^+\tau^-$ and $B^0 \to \tau^+\tau^-$", LHCb collaboration, PRL (2017)
[5] E. Kou et al, "The Belle II Physics Book (B2TIP)" Belle II collaboration (2019)
* LHCb $b\bar{b}$ cross section: https://iopscience.iop.org/article/10.1088/1748-0221/3/08/S08005

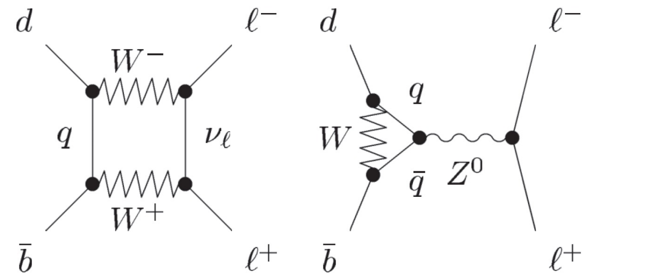
Motivation

Only Belle II data

- Plan to use only Belle II data
  - Since, we already have comparable amount of data with BaBar (~ 200 fb^{-1}).
  - ~~promising (~ 500 fb^{-1}) data on around next summer.~~
  - ~~~880 (or ~600) fb^{-1} data before the planned long shutdown.~~
  - ~~$\sim$460 fb^{-1} data (?)~~
  - **~427.79 fb^{-1} data (long shutdown data)**
  - The amount of data seems competitive with BaBar.
    - However, efficiencies of detector differ …

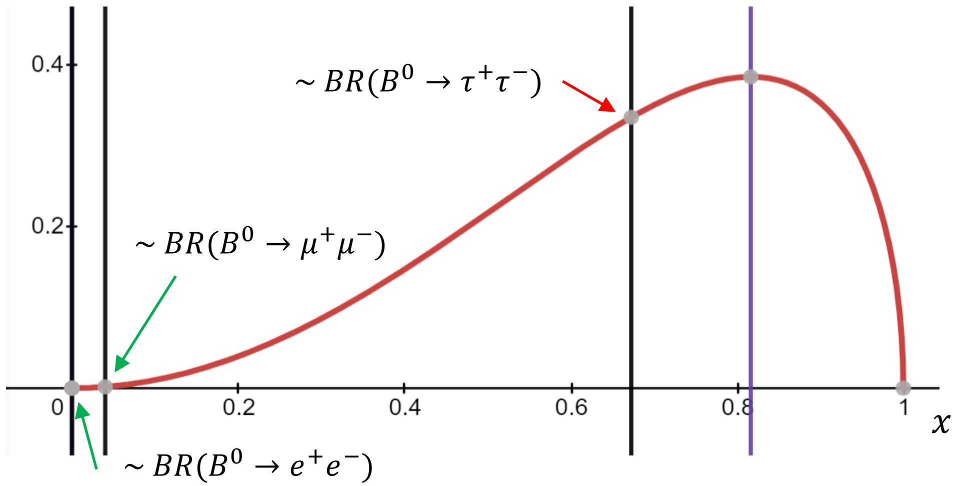
Theoretical calculation with the Effective Field Theory (SM prediction)

$$\mathcal{B}(B^0 \to \ell^+\ell^-) = \frac{G_F^4 M_W^4 M_B^3}{8\pi^5 \Gamma_B} \cdot \underbrace{f_B^2}_{\text{Decay constant}} \cdot \underbrace{|V_{tb}^* V_{td}|^2}_{\text{CKM elements}} \cdot \underbrace{\frac{4m_\ell^2}{M_B^2}}_{\text{Helicity suppression (HS)}} \cdot \underbrace{\sqrt{1 - \frac{4m_\ell^2}{M_B^2}}}_{\text{Phase space factor (PSF)}} \cdot |C_A(\mu)|^2$$



Standard Model Box and Penguin Diagram of $B^0 \to \ell^+\ell^-$

HS×*PSF*



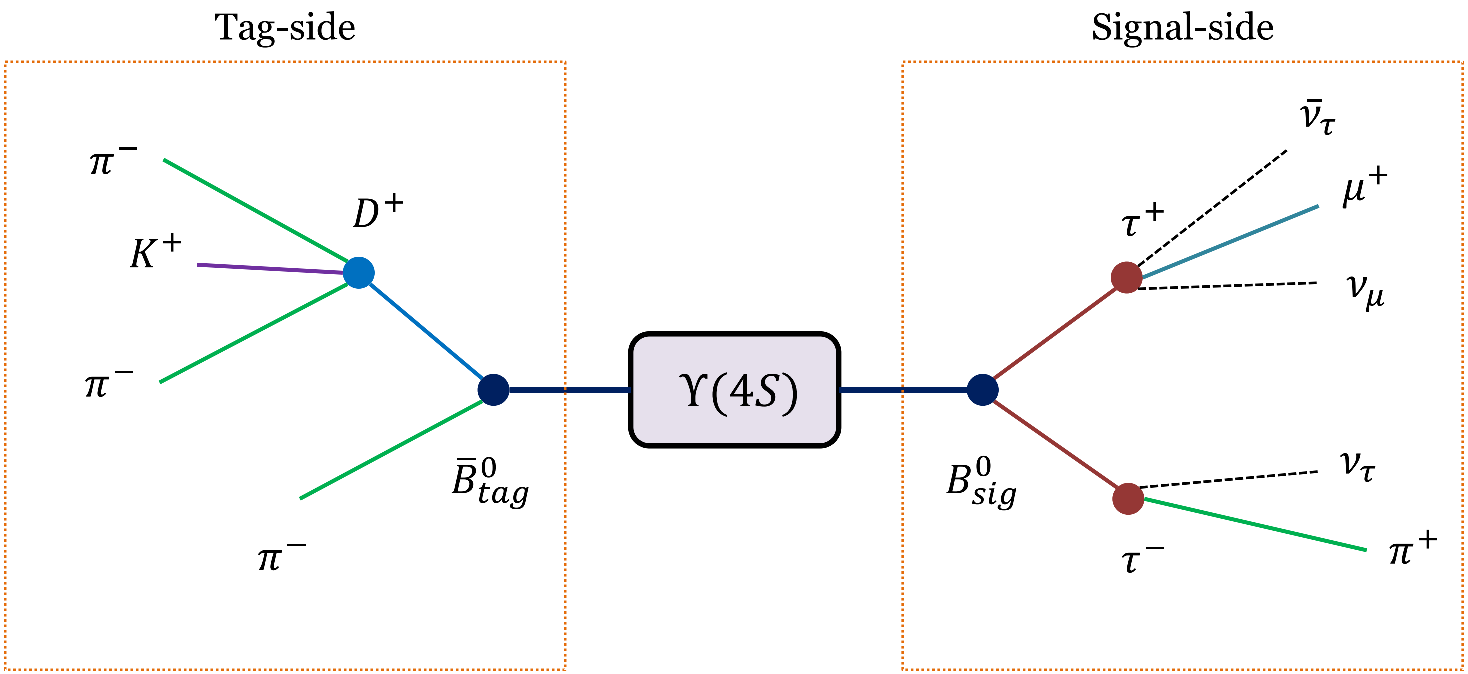
- For $B \to \tau\tau$, ***BR*** is **much higher** because of its **large mass**
  - However, it is **hard** to deal with because
    - τ cannot be detected directly by the detector
    - Sub-decay modes have missing particle
  - **No observation** yet.
- For $B \to \mu\mu$, ***BR*** is **100** times smaller,
  - but muons can be identified with detector level, so it is relatively **easier** to deal with.
- For $B \to ee$, ***BR*** is too small to measure.

Beyond the Standard Model (BSM)

Theory		Branching fraction	Free parameters (for Enhancement)
SM prediction		$(2.22 \pm 0.19)\times 10^{-8}$ (2014)	-
BSM	2HDM	It can be several orders of magnitude higher	$tan\beta, M_{H^+}$
	Leptoquark		$\frac{\lvert\lambda^{33}\lambda^{13*}\rvert}{M_S^2}$

- Free parameters of BSM models make it possible to expect **enhancement** in the **rare** decay modes.
- The study of $B^0 \to \tau^+\tau^-$ can help to **constraint free parameters** of BSM models
- **Better Theory!**

Utilizing FEI



※ FEI: Full Event Interpretation

Motivation: Physics / Theory

$B^0 \to ll$ Branching fraction: SM prediction and measurement

	SM prediction	Measurement		
		Detector	Upper Limit	Measurement
$B^0 \to e^+e^-$	$(2.48 \pm 0.21)\times10^{-15}$ [1] (2014)	LHCb	2.5×10^{-9} [2] (2020) (90 % CL) 3.0×10^{-9} [2] (2020) (95 % CL)	-
$B^0 \to \mu^+\mu^-$	$(1.06 \pm 0.09)\times10^{-10}$ [1] (2014)	ATLAS	2.1×10^{-10} [3] (2019) (95 % CL)	$(-0.19 \pm 0.16)\times10^{-9}$ [3] (2019)
		LHCb	3.4×10^{-10} [4] (2017) (95 % CL)	$(0.15^{+0.12}_{-0.10}{}^{+0.02}_{-0.01})\times10^{-9}$ [4] (2017)
$\boldsymbol{B^0 \to \tau^+\tau^-}$	$(2.22 \pm 0.19)\times10^{-8}$ [1] (2014) ?!!	LHCb	1.6×10^{-3} [5] (2017) (90 % CL) 2.1×10^{-3} [5] (2017) (95 % CL)	-
		Belle	-	$(4.39^{+0.80}_{-.083} \pm 0.45)\times10^{-3}$ [6] (2016) ?!!
		BABAR	4.1×10^{-3} [7] (2006) (90 % CL)	-

Table. Recent & Best values of Branching fraction $B^0 \to \ell\ell$

※ Not published, Not official

[1] Christoph Bobeth et al., "$B_{s,d} \to l^+l^-$ in the Standard Model with Reduced Theoretical Uncertainty", PRL (2014)
[2] R. Aaij et al., "Search for Rare Decay $B_s^0 \to e^+e^-$ and $B^0 \to e^+e^-$", LHCb Collaboration, PRL (2020)
[3] M. Aaboud et al., "Study of the rare decays of B_s^0 and B^0 mesons into muon pairs using data collected during 2015 and 2016 with the ATLAS detector", ATLAS collaboration, JHEP (2019)
[4] R. Aaij et al., "Measurement of the $B_s^0 \to \mu^+\mu^-$ Branching Fraction and Effective Lifetime and Search for $B^0 \to \mu^+\mu^-$ Decays", LHCb Collaboration (2017)
[5] R. Aaij et al, "Search for the Decays $B_s^0 \to \tau^+\tau^-$ and $B^0 \to \tau^+\tau^-$", LHCb collaboration, PRL (2017)
[6] M. Ziegler, "Search for the rare decay $B^0 \to \tau^+\tau^-$ with Belle", Belle collaboration, Belle Note (BN-1390) (2016)
[7] B. Aubert et al, "Search for the Rare Decay $B^0 \to \tau^+\tau^-$ at BABAR", BABAR collaboration, PRL (2006)
[8] A.M. Sirunyan et al., "Measurement of properties of $B_s^0 \to \mu^+\mu^-$ decays and search for $B^0 \to \mu^+\mu^-$ with the CMS experiment", CMS collaboration, JHEP (2020)

$B_s^0 \to ll$ Branching fraction: SM prediction and measurement

	SM prediction	Measurement		
		Detector	Upper Limit	Measurement
$B_s^0 \to e^+e^-$	$(8.54 \pm 0.55)\times 10^{-14}$ [1] (2014)	LHCb	9.4×10^{-9} [2] (2020) (90 % CL) 11.2×10^{-9} [2] (2020) (95 % CL)	-
$B_s^0 \to \mu^+\mu^-$	$(3.65 \pm 0.23)\times 10^{-9}$ [1] (2014) √	CMS	-	$(2.9 \pm 0.6 \pm 0.4)\times 10^{-9}$ [8] (2020) √
		ATLAS	-	$(2.8^{+0.8}_{-0.7})\times 10^{-9}$ [3] (2019)
		LHCb	-	$(3.0 \pm 0.6^{+0.3}_{-0.2})\times 10^{-9}$ [4] (2017)
$B_s^0 \to \tau^+\tau^-$	$(7.73 \pm 0.49)\times 10^{-7}$ [1] (2014)	LHCb	5.2×10^{-3} [5] (2017) (90 % CL) 6.8×10^{-3} [5] (2017) (95 % CL)	-

Table. Recent & Best values of Branching fraction $B_s^0 \to \ell\ell$

[1] Christoph Bobeth et al., "$B_{s,d} \to l^+l^-$ in the Standard Model with Reduced Theoretical Uncertainty", PRL (2014)
[2] R. Aaij et al., "Search for Rare Decay $B_s^0 \to e^+e^-$ and $B^0 \to e^+e^-$", LHCb Collaboration, PRL (2020)
[3] M. Aaboud et al., "Study of the rare decays of B_s^0 and B^0 mesons into muon pairs using data collected during 2015 and 2016 with the ATLAS detector", ATLAS collaboration, JHEP (2019)
[4] R. Aaij et al., "Measurement of the $B_s^0 \to \mu^+\mu^-$ Branching Fraction and Effective Lifetime and Search for $B^0 \to \mu^+\mu^-$ Decays", LHCb Collaboration (2017)
[5] R. Aaij et al, "Search for the Decays $B_s^0 \to \tau^+\tau^-$ and $B^0 \to \tau^+\tau^-$", LHCb collaboration, PRL (2017)
[6] M. Ziegler, "Search for the rare decay $B^0 \to \tau^+\tau^-$ with Belle", Belle collaboration, Belle Note (BN-1390) (2016)
[7] B. Aubert et al, "Search for the Rare Decay $B^0 \to \tau^+\tau^-$ at BABAR", BABAR collaboration, PRL (2006)
[8] A.M. Sirunyan et al., "Measurement of properties of $B_s^0 \to \mu^+\mu^-$ decays and search for $B^0 \to \mu^+\mu^-$ with the CMS experiment", CMS collaboration, JHEP (2020)

$B^0 \to \tau^+\tau^-$ *example:*
SM / BSM Theories
with "Parameter Perspective"

Standard Model

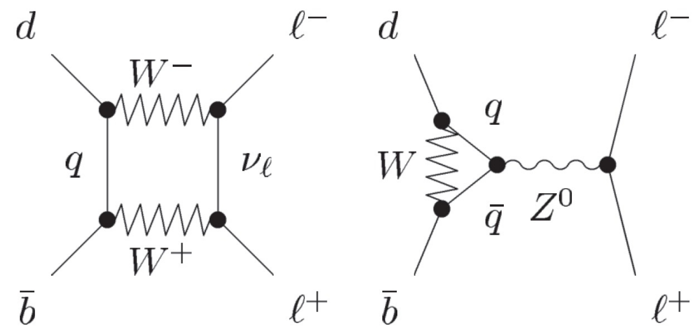
- Effective Hamiltonian (Effective Field Theory)

$$\mathcal{H}_{\text{eff}} = \frac{G_{\text{F}}}{\sqrt{2}} \sum_i V^i_{\text{CKM}} C_i(\mu) Q_i$$

$$Q_S = m_b(\bar{b} P_L d)(\bar{\ell}\ell)$$

$$Q_P = m_b(\bar{b} P_L d)(\bar{\ell}\gamma_5 \ell)$$

$$Q_A = (\bar{b}\gamma^\mu P_L d)(\bar{\ell}\gamma_\mu\gamma_5\ell)$$



$$\mathcal{H}_{\text{eff}} = \frac{G_F}{\sqrt{2}} \frac{\alpha_{\text{em}}}{\sin^2\theta_W} V^*_{tb} V_{td} \left[C_S(\mu) Q_S + C_P(\mu) Q_P + C_A(\mu) Q_A \right]$$

※ m_b: 4.2 GeV
※ M_W: 80 GeV

※ SM Higgs Penguin
⇒ suppressed by a factor of m_b^2/M_W^2

※ "would-be" neutral Goldstone Boson
⇒ suppressed by a factor of m_b^2/M_W^2

$$\mathcal{H}_{\text{eff}} = \frac{G_F}{\sqrt{2}} \frac{\alpha}{\sin^2\theta_W} V^*_{tb} V_{td} C_A(\mu) (\bar{b}\gamma^\mu P_L d)(\bar{\ell}\gamma_\mu\gamma_5\ell)$$

After a complex, but a straight-forward calculation

$$\mathcal{B}(B^0 \to \ell^+\ell^-) = \frac{G_F^4 M_W^4 M_B^3}{8\pi^5 \Gamma_B} \cdot \underbrace{f_B^2}_{\text{Decay constant}} \cdot \underbrace{|V^*_{tb} V_{td}|^2}_{\text{CKM elements}} \cdot \underbrace{\frac{4m_\ell^2}{M_B^2}}_{\text{Helicity suppression}} \cdot \underbrace{\sqrt{1 - \frac{4m_\ell^2}{M_B^2}}}_{\text{Phase space factor}} \cdot |C_A(\mu)|^2$$

※ Reference: [BN1390]

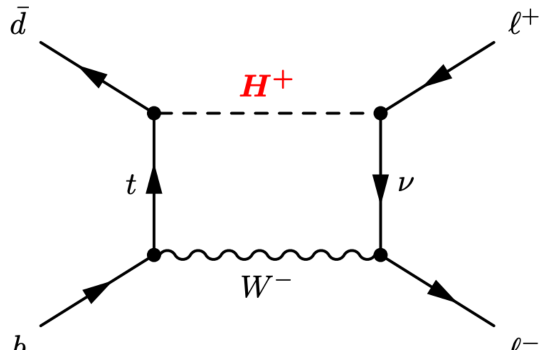
Beyond Standard Model (BSM): Higgs Doublet (HDM)

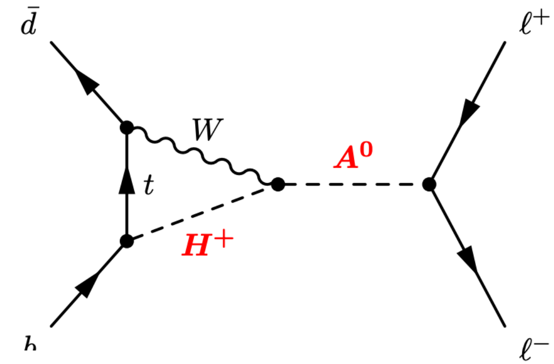
- Effective Hamiltonian (Effective Field Theory)

$$\mathcal{H}_{\text{eff}} = \frac{G_{\text{F}}}{\sqrt{2}} \sum_i V^i_{\text{CKM}} C_i(\mu) Q_i$$

※ H^+ and A^0 replace W^+ and Z^0, respectively

※ **No longer negligible**, depending on M_{H^+} and M_{A^0} 5





$$\mathcal{H}_{\text{eff}} = \frac{G_F}{\sqrt{2}} \frac{\alpha_{\text{em}}}{\sin^2\theta_W} V^*_{tb} V_{td} \left[C_S(\mu) Q_S + C_P(\mu) Q_P + C_A(\mu) Q_A \right]$$

※ H^+ and A^0 replace W^+ and Z^0, respectively

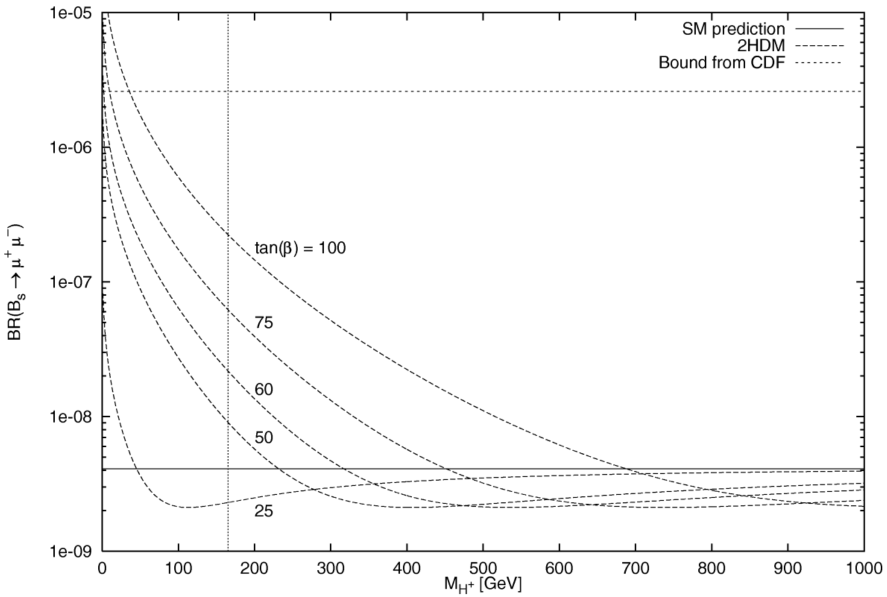
※ **No longer negligible**, depending on M_{H^+} and M_{A^0}

After a complex, but a straight-forward calculation

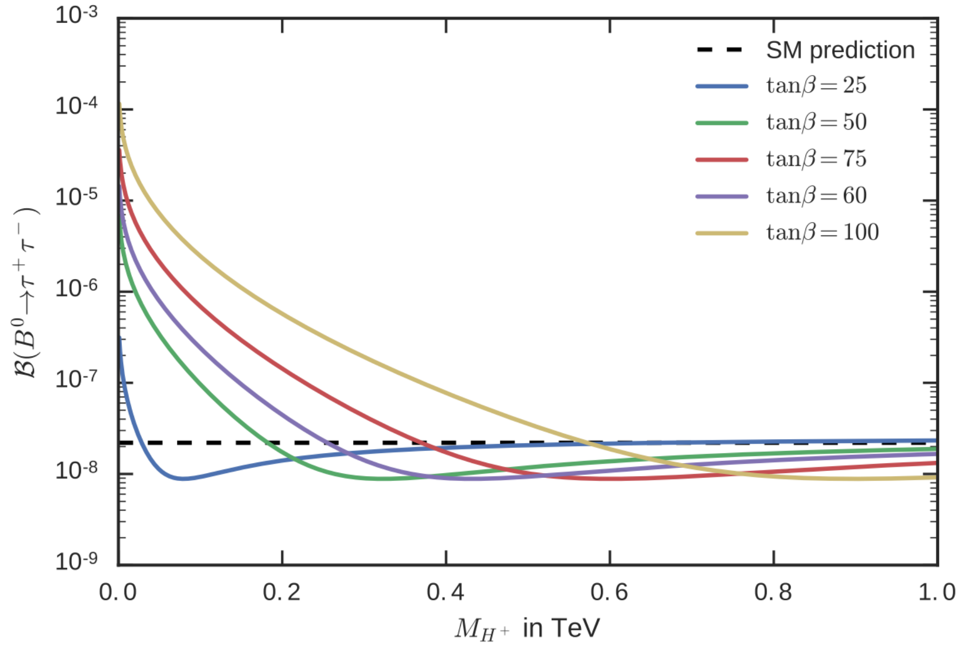
$$\mathcal{B}(B^0 \to \ell^+\ell^-)_{\text{2HDM}} = \frac{G_F^4 M_W^4}{8\pi^5} \frac{M_B^3}{\Gamma_B} f_B^2 |V^*_{tb} V_{td}|^2 \sqrt{1 - \frac{4m_\ell^2}{M_B^2}} \times \left[\left(M_B C_{\text{P}}(\mu) - \frac{2m_\ell}{M_B} C_{\text{A}}(\mu) \right)^2 + \left(1 - \frac{4m_\ell^2}{M_B^2} \right) M_B C_{\text{S}}(\mu) \right],$$

※ References: [H2010], [BN1390]

- $C_S, C_P \Rightarrow M_{H^+}, tan\beta$ **TWO MORE PARAMETERS!**



From Ref. [H2000] (2000)



From [BN1390] (2016)

Beyond Standard Model: Leptoquark Model

- Decide Leptoquark Model Couplings based on branching fractions of $B_{s,d} \to \ell\ell$
- Better Leptoquark model parameters ⇒ ex) Better LFV process prediction precision

TABLE I. Constraints obtained from the leptoquark couplings from various leptonic $B_{s,d} \to l^+ l^-$ decays.

Decay Process	Couplings involved	Upper bound of the couplings (GeV^{-2})
$B_s \to \mu^\pm \mu^\mp$	$\frac{\lvert\lambda^{23}\lambda^{22*}\rvert}{M_S^2}$	$\leq 5 \times 10^{-9}$
$B_s \to e^\pm e^\mp$	$\frac{\lvert\lambda^{13}\lambda^{12*}\rvert}{M_S^2}$	$< 2.54 \times 10^{-5}$
$B_s \to \tau^\pm \tau^\mp$	$\frac{\lvert\lambda^{33}\lambda^{32*}\rvert}{M_S^2}$	$< 1.2 \times 10^{-8}$
$B_d \to \mu^\pm \mu^\mp$	$\frac{\lvert\lambda^{23}\lambda^{21*}\rvert}{M_S^2}$	$(1.5 - 3.9) \times 10^{-9}$
$B_d \to e^\pm e^\mp$	$\frac{\lvert\lambda^{13}\lambda^{11*}\rvert}{M_S^2}$	$< 1.73 \times 10^{-5}$
$B_d \to \tau^\pm \tau^\mp$	$\frac{\lvert\lambda^{33}\lambda^{31*}\rvert}{M_S^2}$	$< 1.28 \times 10^{-6}$

From Ref. [S2016] (2016)

※ References: [S2016], [S2015], [R2014]

Beyond Standard Model: Leptoquark Model I

- Effective Hamiltonian (Effective Field Theory)

$$\mathcal{H}_{\text{eff}} = \frac{G_F}{\sqrt{2}} \sum_i V^i_{\text{CKM}} C_i(\mu) Q_i$$

⋮

$$\mathcal{H}_{eff} \sim [C_S^{NP} Q_S + C_P^{NP} Q_P + C_A Q_A]$$

$$\sim \frac{|\lambda^{33}\lambda^{31*}|}{M_S^2}$$

b, tau tau, d

M_S: leptoquark mass

1 MORE PARAMETERS!

※ Ref. [R2014]

A. Model I: $X = (\mathbf{3}, \mathbf{2}, 7/6)$

In this model the interaction Lagrangian for the coupling of scalar leptoquark $X = (3, 2, 7/6)$ to the fermion bilinears is given as [11]

$$\mathcal{L} = -\lambda_u^{ij} \bar{u}_R^i X^T \epsilon L_L^j - \lambda_e^{ij} \bar{e}_R^i X^\dagger Q_L^j + \text{H.c.}, \quad (4)$$

where i, j are the generation indices, Q_L and L_L are the left-handed quark and lepton doublets, u_R and e_R are the right-handed up-type quark and charged lepton singlets and $\epsilon = i\sigma_2$ is a 2×2 matrix. More explicitly these multiplets can be represented as

$$X = \begin{pmatrix} V_\alpha \\ Y_\alpha \end{pmatrix}, \quad L_L = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix}, \text{ and } \epsilon = \begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix}. \quad (5)$$

After expanding the SU(2) indices the interaction Lagrangian becomes

$$\mathcal{L} = -\lambda_u^{ij} \bar{u}_{\alpha R}^i (V_\alpha e_L^j - Y_\alpha \nu_L^j) - \lambda_e^{ij} \bar{e}_R^i (V_L^\dagger u_{\alpha L}^j + Y_\alpha^\dagger d_{\alpha L}^j) + \text{H.c.} \quad (6)$$

Thus, from Eq. (6), one can obtain the contribution to the interaction Hamiltonian for the $b \to s\mu^+\mu^-$ process after Fierz rearrangement as

$$\mathcal{H}_{\text{LQ}} = \frac{\lambda_\mu^{23}\lambda_\mu^{22*}}{8M_Y^2} [\bar{s}\gamma^\mu(1-\gamma_5)b][\bar{\mu}\gamma_\mu(1+\gamma_5)\mu] \equiv \frac{\lambda_\mu^{23}\lambda_\mu^{22*}}{4M_Y^2} (O_9 + O_{10}), \quad (7)$$

which can be written analogous to the SM effective Hamiltonian (1) as

$$\mathcal{H}_{\text{LQ}} = -\frac{G_F \alpha}{\sqrt{2}\pi} V_{tb} V_{ts}^* (C_9^{\text{NP}} O_9 + C_{10}^{\text{NP}} O_{10}) \quad (8)$$

with the new Wilson coefficients

$$C_9^{\text{NP}} = C_{10}^{\text{NP}} = -\frac{\pi}{2\sqrt{2} G_F \alpha V_{tb} V_{ts}^*} \frac{\lambda_\mu^{23}\lambda_\mu^{22*}}{M_Y^2}. \quad (9)$$

Beyond Standard Model: Leptoquark Model II

- Effective Hamiltonian (Effective Field Theory)

$$\mathcal{H}_{\text{eff}} = \frac{G_F}{\sqrt{2}} \sum_i V_{\text{CKM}}^i C_i(\mu) Q_i$$

⋮

$$\mathcal{H}_{eff} \sim [C_S'^{NP} Q_S' + C_P'^{NP} Q_P' + C_A Q_A]$$

$$\sim \frac{|\lambda^{33}\lambda^{31*}|}{M_S^2}$$

b, tau tau, d

M_S: leptoquark mass

1 MORE PARAMETERS!

※ Ref. [R2014] **B. Model II: $X = (3, 2, 1/6)$**

Analogous to the previous subsection the interaction Lagrangian for the coupling of $X = (3, 2, 1/6)$ leptoquark to the fermion bilinear can be given as

$$\mathcal{L} = -\lambda_d^{ij} \bar{d}_R^i X^T \epsilon L_L^j + \text{H.c.}, \tag{10}$$

where the notations used are the same as the previous case. Expanding the SU(2) indices one can obtain the interaction Lagrangian as

$$\mathcal{L} = -\lambda_d^{ij} \bar{d}_{\alpha R}(V_\alpha e_L^j - Y_\alpha \nu_L^j) + \text{H.c.} \tag{11}$$

After performing the Fierz transformation the interaction Hamiltonian describing the process $b \to s\mu^+\mu^-$ is given as

$$\begin{aligned}\mathcal{H}_{\text{LQ}} &= \frac{\lambda_s^{22}\lambda_b^{32*}}{4M_V^2}[\bar{s}\gamma^\mu P_R b][\bar{\mu}\gamma_\mu(1-\gamma_5)\mu] \\ &= \frac{\lambda_s^{22}\lambda_b^{32*}}{4M_V^2}(O_9'^{\text{NP}} - O_{10}'^{\text{NP}}),\end{aligned} \tag{12}$$

where O_9' and O_{10}' are the four-fermion current-current operators obtained from $O_{9,10}$ by making the replacement $P_L \leftrightarrow P_R$. Thus, the exchange of the leptoquark $X = (3, 2, 1/6)$ gives new operators with the corresponding Wilson coefficients as

$$C_9'^{\text{NP}} = -C_{10}'^{\text{NP}} = \frac{\pi}{2\sqrt{2}G_F \alpha V_{tb} V_{ts}^*} \frac{\lambda_s^{22}\lambda_b^{32*}}{M_V^2}. \tag{13}$$

After obtaining the new physics contributions to the process $b \to s\mu^+\mu^-$, we will proceed the constrain the new physics parameter space using the recent measurement of $B_s \to \mu^+\mu^-$.

Part II: Analysis Procedure

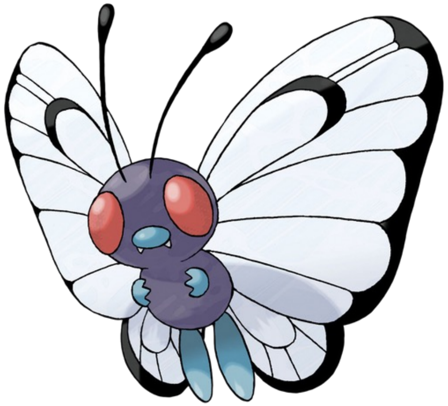
What / How have I studied so far?

Analysis Phases: What/How have I studied so far?

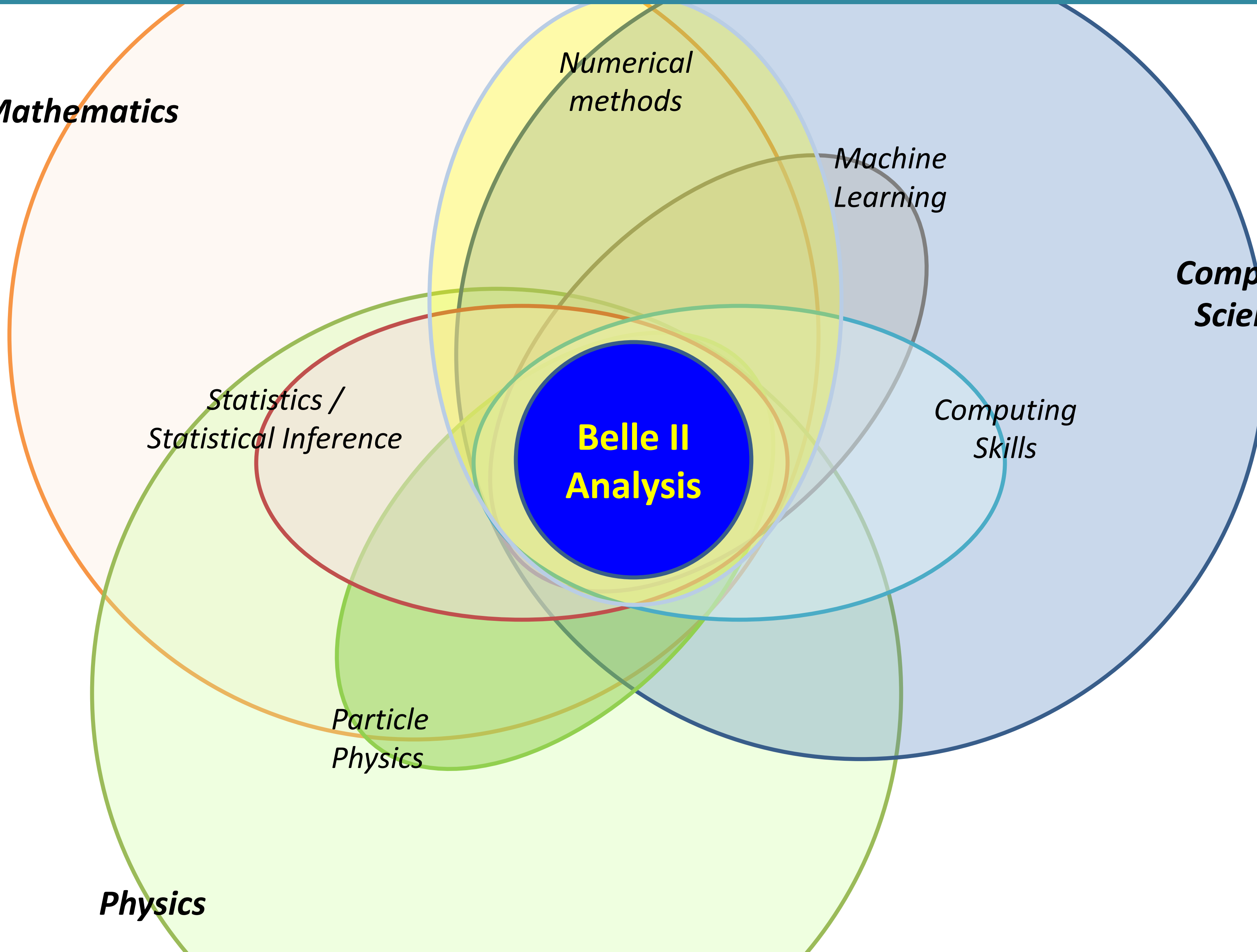
- [Done] <u>Phase I</u>: ***Learn by doing*** phase
  - Belle II Beginner's tutorial (Sphinx)
  - Belle II StarterKit
  - Other's talks, Belle II ongoing works …
  - ***Collecting information!***

- [Done] <u>Phase II</u>: Systemization phase, ***Human learning*** phase
  - ***Strategy*** setting, ***Skill acquisition***, etc.
  - "Human learning". (A human is a machine. A human is a system.)
  - Revisit Belle II ongoing works
    - motivation / introduction - studying related theories (**not too deep**)
    - Belle II ongoing works!
      - Read **almost all** Belle II notes of WG1 and WG2 analysis topic

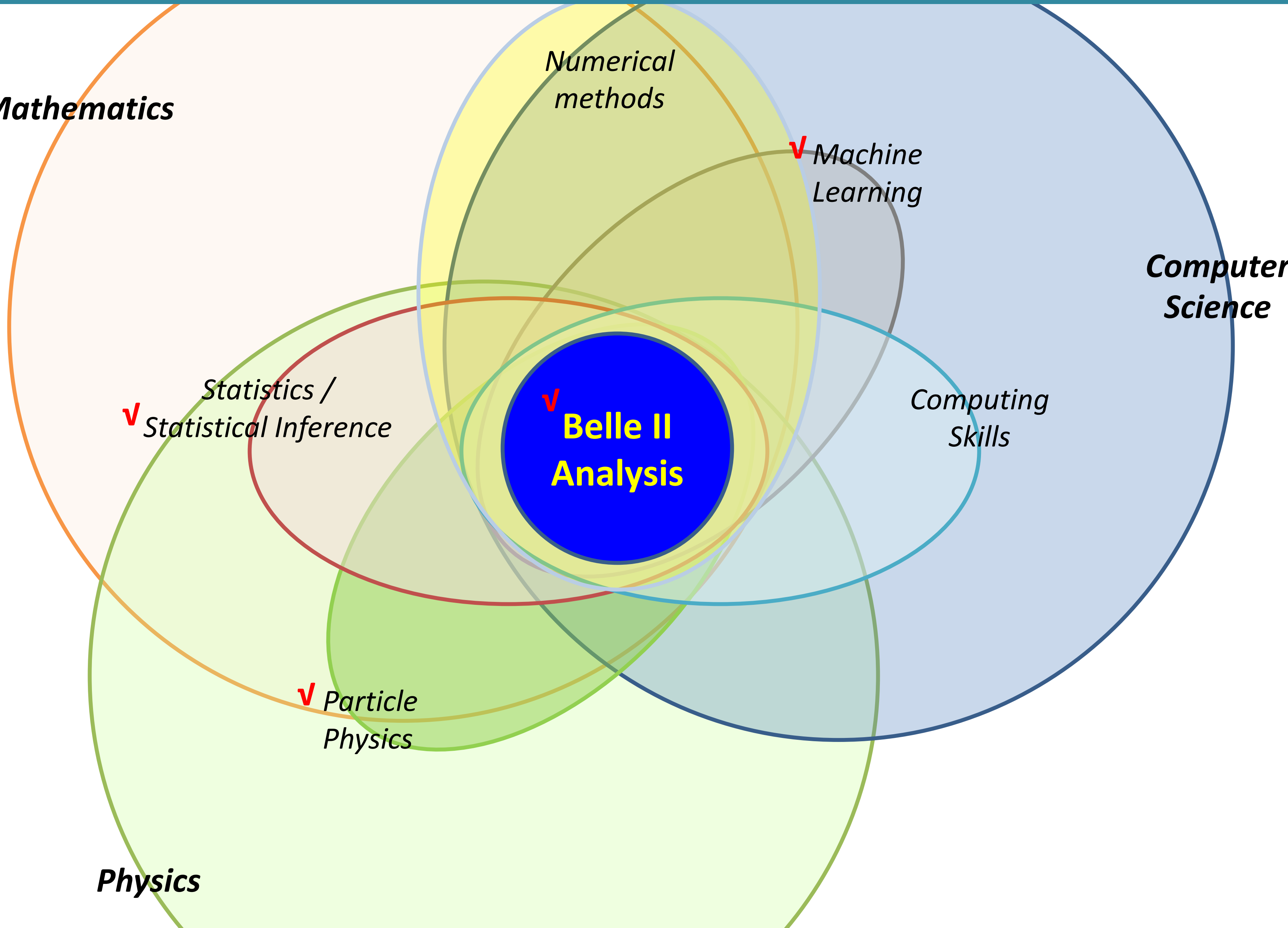
- [Ongoing] <u>Phase III</u>: ***Actual analysis*** phase
  - Make it real! Realization stage.
  - To enjoy phase III,
    - Phase I and II are required.
  - **Please help!**



Required knowledge for Belle II analysis



Required knowledge for Belle II analysis (Result of the phase I)



Phase II: HUMAN LEARNING

- [Done] ***Statistics (Probability) + Statistical Inference***
  - [Done] Harvard Statistics 110 (OCW)
  - [Done] IIT Statistical Inference (OCW)

- [Done] ***Machine Learning***
  - [Done] Signal Processing & Computer Science Perspective
    - [Done] Signals & System
    - [Done] Deep Learning
    - [Done] Reinforcement Learning
    - [Done] Optimization
  - [To do] Mathematics / Applied Mathematics Perspective **(Optional)**

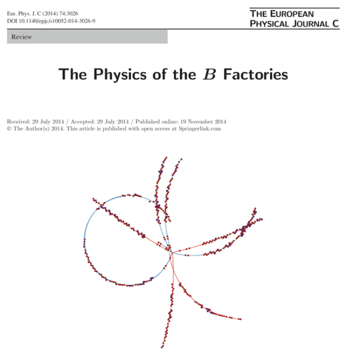
- [Done] ***Knowledge for the Belle II analysis***
  - [Done] Physics books
    - [Done] Physics of the B factories (Belle & BaBar)
      - [Done] Part A. The facilities
      - [Done] **Part B. Tools and methods**
      - [Done] Part C. The results and their interpretation
        ※ My analysis-related part only
    - [Done] Belle II Physics book (Belle II, B2TIP)
      - [Done] chapter 1 to 7, WG1 (chapter 8) & WG2 (chapter 9) Part


PTEP

Prog. Theor. Exp. Phys. 2019, 123C01 (654 pages)
DOI: 10.1093/ptep/ptz106

The Belle II Physics Book

B2TIP


Eur. Phys. J. C (2014) 74:3026
DOI 10.1140/epjc/s10052-014-3026-9

THE EUROPEAN PHYSICAL JOURNAL C

Review

The Physics of the B Factories

B physics book

Human Learning Stage

- [Done] ***Theory***
  - [Done] Theoretical minimum by Leonard Susskind (※ https://theoreticalminimum.com/)
    - [Done] Particle physics lecture I: Basic concepts (10/10)
    - [Done] Particle physics lecture II: Standard model (10/10)
    - [Done] Particle physics lecture III: Supersymmetry and Grand Unification (10/10)
  - [Done] Lecture note: Weak Hamiltonian, CP violation and Rare Decays (1998) by A. J. Buras
  - [Done] Theory Papers
  - [To do] Effective Field Theory (MIT) **(Optional)**
    - (https://www.youtube.com/playlist?list=PLUl4u3cNGP60TvpbO5toEWC8y8w51dtvm)

- [Done] Reading Belle II notes (for benchmarking)
  - [Done] WG1 analysis topics
  - [Done] WG2 analysis topics

Analysis Strategies

Similar Analyses

Target	Year	Author	Exp.	Paper	Note	Method	MVA (amount of signal MC)	Signal Extracting Variables (#)
$B^0 \to \tau^+\tau^-$	2016	M. Ziegler	Belle	-	BN-1390	Hadronic FR, **BDT-based**	BDT for Continuum BG (1) BDT for each signal channel (6) 10 M (training) / 5 M (testing) Each channel: 15 M, 90 M in total	E_{ECL} (1)
$B^0 \to \tau^+\tau^-$	2006	BaBar Collaboration	BaBar	PRL	-	Hadronic full recon., Cut-based	-	m_{ES} (1) (M_{bc}^{tag} in Belle language)
$B^+ \to K^+\tau^\pm\ell^\mp$	2022	S. Watanuki	Belle (B1-635)	Submitted to PRL	BN-1576	Hadronic FEI, **BDT-based**	FBDT for $B\bar{B}$ (4 channels) (4) FBDT for $q\bar{q}$ (4 channels) (4) 5 times 5.2 M, total 26 M	M_{recoil} (1) ($= m_\tau$)
$B \to X\tau\nu$	2022	H. Junkerkalefeld	Belle II	-	B2N-PH-2021-042	Hadronic FEI, **BDT-based**	BDT for $q\bar{q}$ vs. $B\bar{B}$ (1)	M_{miss}^2, p_ℓ^* (2)
$B \to X_s\nu\bar{\nu}$	2022	Junewoo Park	Belle II	-	B2N-PH-2022-028	Hadronic FEI, **BDT-based**	FBDT for Sig. vs Bkg. (1) Total 140 M	FBDT output (1)
$B^+ \to K^+\nu\bar{\nu}$	2020	F. Dattola	Belle II (B2-004)	PRL	B2N-PH-2020-057	Inclusive tagging, **BDT-based**	Special BDTs for Inclusive tagging: BDT_1 and BDT_2 (2)	kaon p_T, BDT_2 output (2)
$B \to X_c\ell\nu_\ell$	2021	M. Welsch	Belle II (B2-006)	Submitted to PRD	B2N-PH-2021-002	Hadronic FEI, Cut-based	-	q^2 (1) ($= (p_\ell + p_\nu)^2 = (p_B - p_X)^2$)
$B^0 \to \ell^\pm\tau^\mp$	2020	Kyungho Kim	Belle	PhD. Thesis	BN-1531	SL FEI, TMVA MLP	MLP for each signal channel (4) 2 M (training) / 18 M (Testing) Each channel: 20 M, 80 M in total	p_ℓ^* (1)

This Analysis VS.

$B^0 \to \tau^+\tau^-$	-	**Cheolhun Kim**	Belle II	-	-	Hadronic FEI, **BDT-based**	**BDT for Continuum BG (1) ?** **BDT for signal channels (< 6) ?**	E_{ECL} **(1) ?**

Analysis Procedure

Analysis Procedure

Physics Parameter

- Theories – Hypothesis Test

Branching Fraction (Ratio)

- Measurement or Upper Limit Setting

N_{sig} (N_{bkg})

Distribution ⇒ Fit

- Event Number Distribution / Signal Extracting Variable(s)
- **Fitter Design**
- Fitter Validation
  - Statistical Inference Techniques
  - Ensemble study (toy study), Asimov dataset, etc.

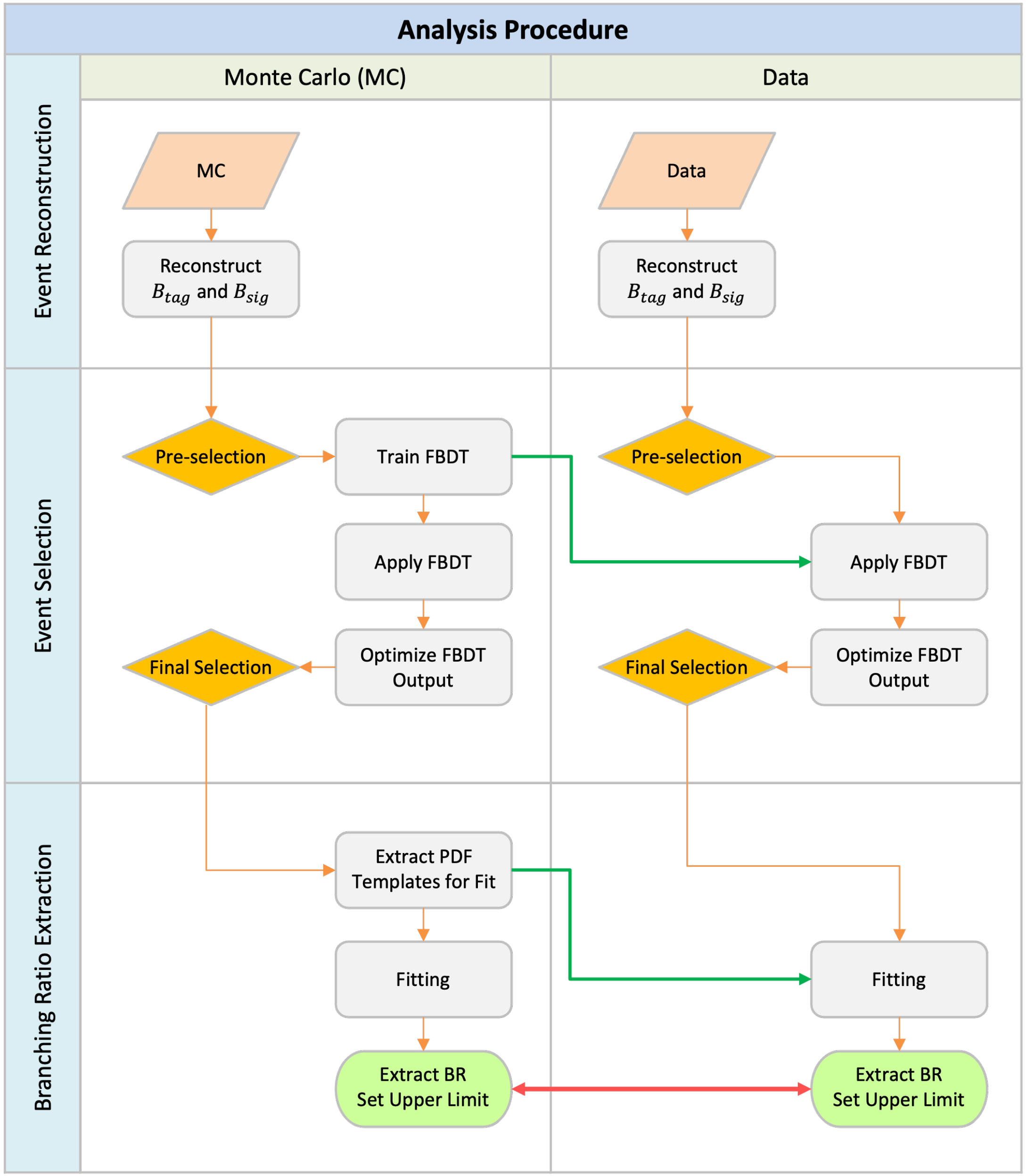
Pre-Processes

※ Currently Working on This Stage!

- Purpose

  Suppress as many BG as possible with minimum loss of Signal

Analysis Procedure: $B^0 \to \tau^+\tau^-$ example



Think the Final Stage of the Analysis, first

Think the Final Stage of the Analysis, first

- One of the famous problem-solving (understanding) strategies!

- **Simple Example**
  - Hypothesis test
  - Signal and its significance

※ [210924 Lab Meeting]

Exercise 3.2 Ω_c peak at ARGUS

In 1992, the ARGUS e^+e^- experiment reported the observation of the charmed and doubly strange baryon Ω_c through its decay channel $\Xi^- K^- \pi^+ \pi^+$ [26]. The obtained mass spectrum is shown in Figure 3.9. Try to make your own assessment of the signal and its significance.

1. *Fluctuation probability:* Under the assumption that there is only background with constant density:

   a) Estimate the average number of background events per mass bin (note: the histogram contains 43 entries in 50 bins);
   b) Define a $\pm 2\sigma$ mass window around the peak (note: the resolution σ is approximately 12 MeV, the histogram bin width);
   c) Count the total number of candidates $N_{\mathrm{cand,s}}$ in the $\pm 2\sigma$ region around the peak;
   d) Estimate the number of expected background events μ_{b} in this region;
   e) Estimate the probability for the Poisson distribution to fluctuate from μ_{b} to $N_{\mathrm{cand,s}}$ or larger values.

2. *Signal significance:* Under the signal-plus-background hypothesis try to estimate the signal and its significance:

   a) Estimate the number of background events per bin from the average density of events in the regions outside the peak. Estimate from this density the number of expected background events μ_{b} in the $\pm 2\sigma$ region around the peak;
   b) Obtain the number $N_{\mathrm{s}} = N_{\mathrm{cand,s}} - \mu_{\mathrm{b}}$, estimate an error $\sigma_{N_{\mathrm{s}}}$ and determine the signal significance $N_{\mathrm{s}}/\sigma_{N_{\mathrm{s}}}$.

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H_0: null hypothesis (background only)

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   c) Count the total number of candidates $N_{\text{cand,s}}$ in the $\pm 2\sigma$ region around the peak;
   d) Estimate the number of expected background events μ_b in this region;
   e) Estimate the probability for the Poisson distribution to fluctuate from μ_b to $N_{\text{cand,s}}$ or larger values.

H_1: alternative hypothesis (signal + background)

2. *Signal significance:* Under the signal-plus-background hypothesis try to estimate the signal and its significance:
   a) Estimate the number of background events per bin from the average density of events in the regions outside the peak. Estimate from this density the number of expected background events μ_b in the $\pm 2\sigma$ region around the peak;
   b) Obtain the number $N_s = N_{\text{cand,s}} - \mu_b$, estimate an error σ_{N_s} and determine the signal significance N_s/σ_{N_s}.

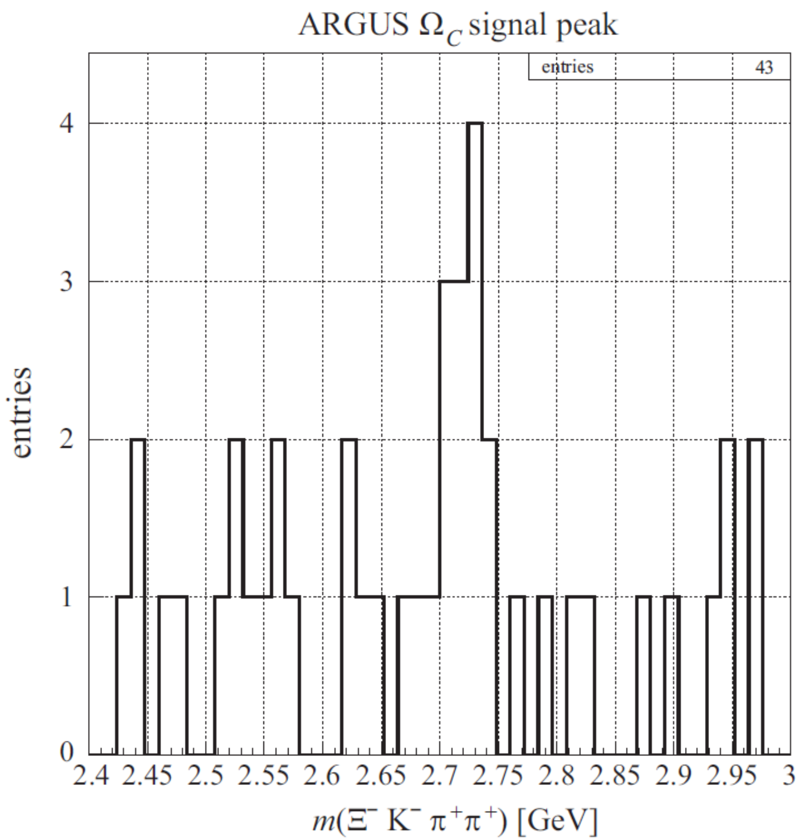


Figure 3.9 The invariant-mass spectrum used in Exercise 3.2.

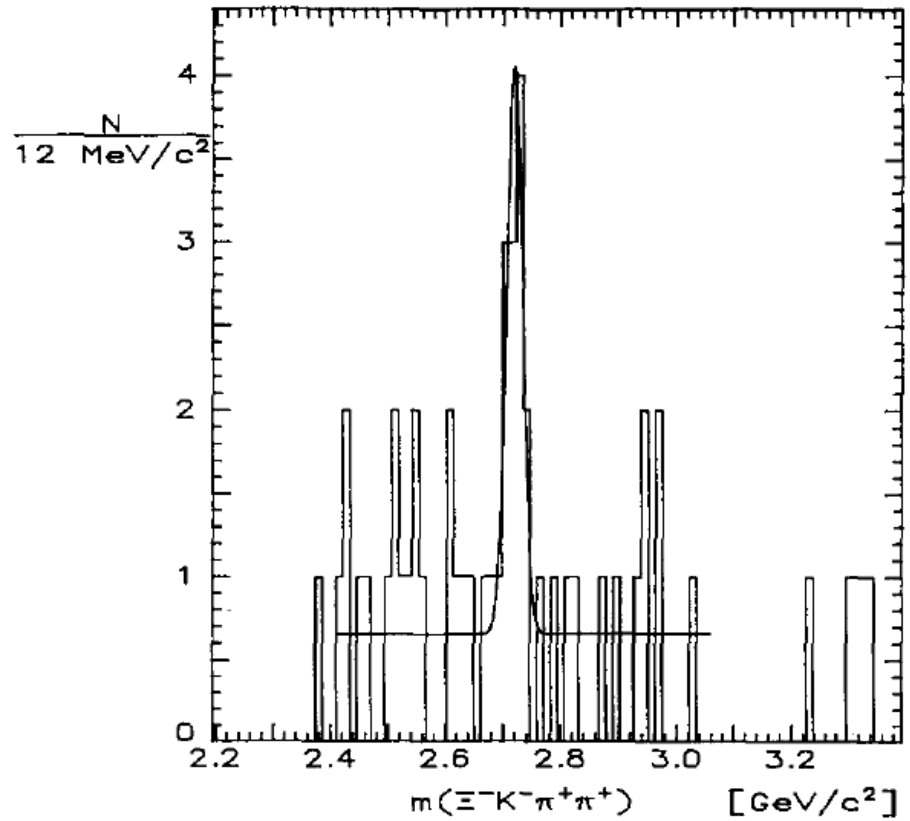
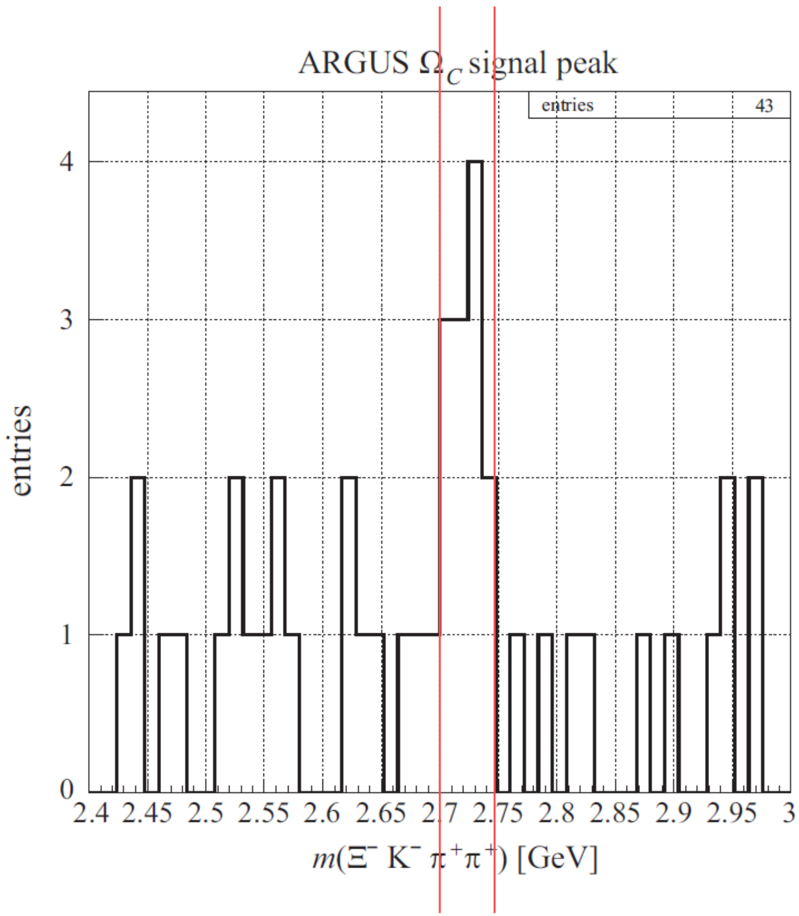


Fig. 4. Invariant $(\Xi^- K^- \pi^+ \pi^+)$ mass spectrum, after applying additional cuts on kaon likelihood and multiplicity (see text). The full curve shows the result of the fit.



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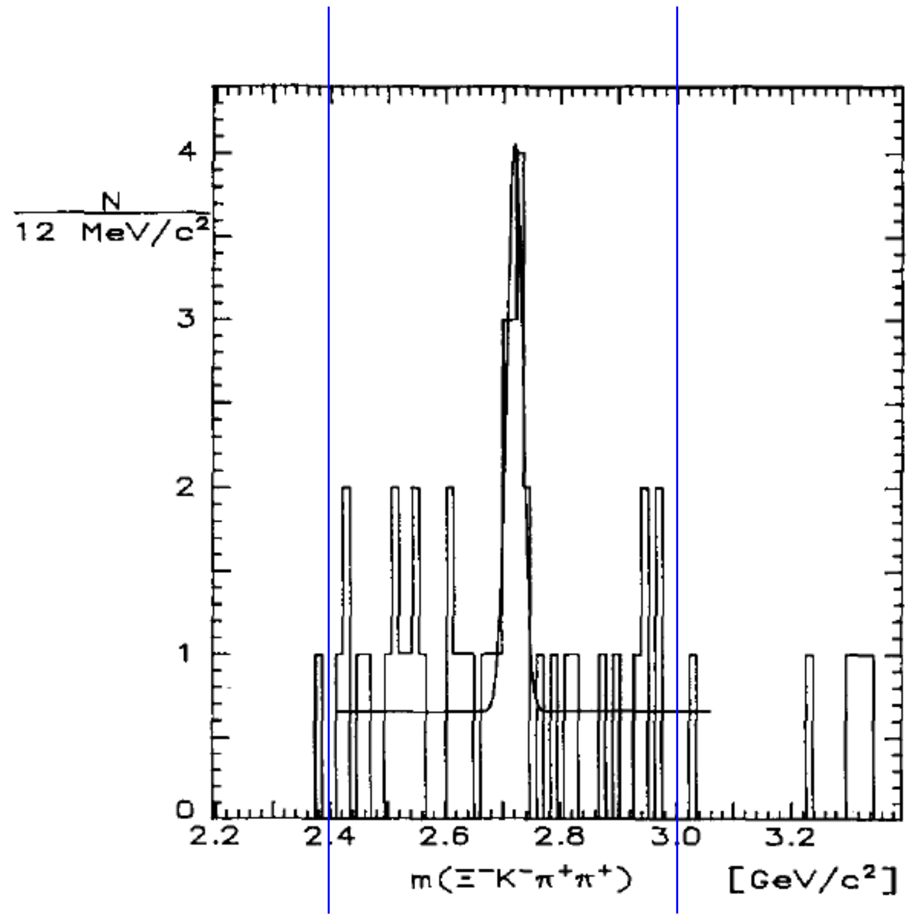

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Ω_c peak at ARGUS

H_0:
null hypothesis
(background only)

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   a) Estimate the average number of background events per mass bin (note: the histogram contains 43 entries in 50 bins);

$$\frac{43\ [bg.evt.]}{50\ [bin]} = 0.83\ [bg.evt./bin]$$

H_0:
null hypothesis
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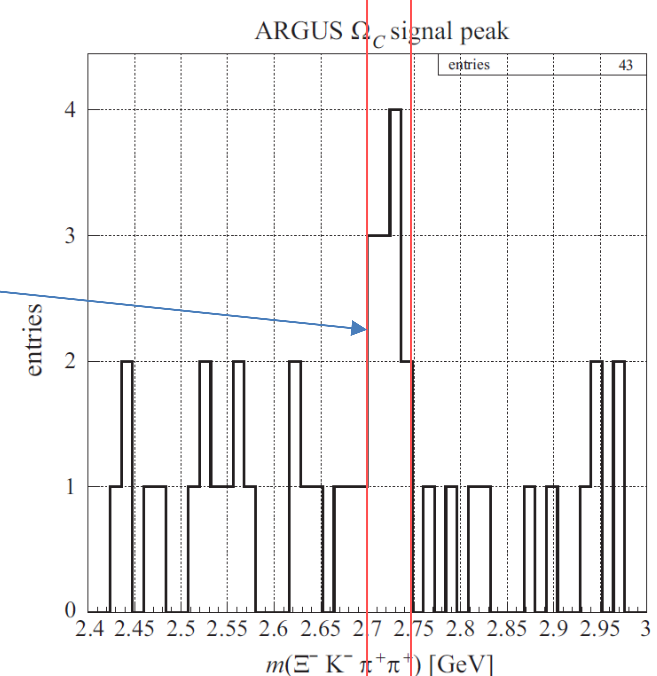
   b) Define a $\pm 2\sigma$ mass window around the peak (note: the resolution σ is approximately 12 MeV, the histogram bin width);

$$\sigma_{res} = 12\ MeV$$

Mass Window: $[2.7, 2.748]\ MeV$



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Ω_c peak at ARGUS

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   c) Count the total number of candidates $N_{\mathrm{cand,s}}$ in the $\pm 2\sigma$ region around the peak;

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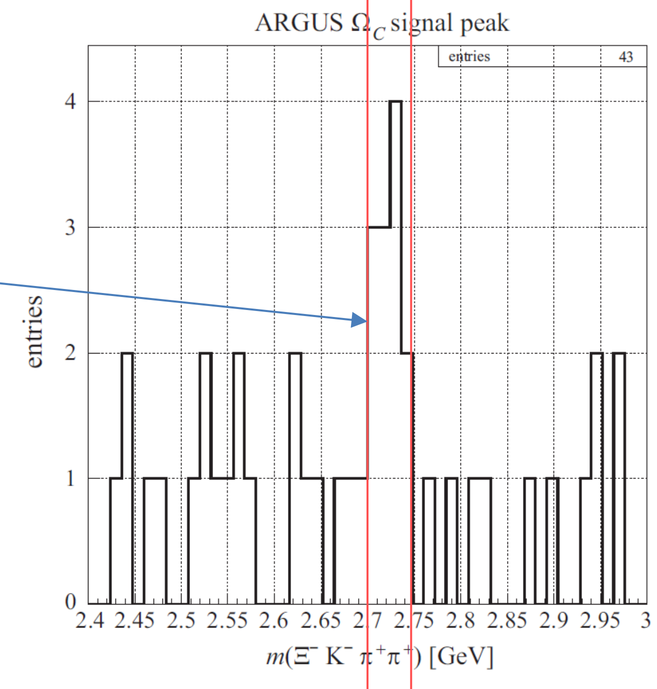
H_0: null hypothesis (background only)

1. *Fluctuation probability:* Under the assumption that there is only background with constant density:

c) Count the total number of candidates $N_{\mathrm{cand,s}}$ in the $\pm 2\sigma$ region around the peak;

$N_{cands} = 12$



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H_0:
null hypothesis (background only)

1. *Fluctuation probability*: Under the assumption that there is only background with constant density:

d) Estimate the number of expected background events μ_b in this region;

Ω_c peak at ARGUS

Exercise 3.2 Ω_c peak at ARGUS

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H_0: null hypothesis (background only)

1. *Fluctuation probability:* Under the assumption that there is only background with constant density:

d) Estimate the number of expected background events μ_b in this region;

Result of a) $\frac{43\ [bg.evt.]}{50\ [bin]} = 0.83\ [bg.evt./bin]$

$$4\ [bins] \times 0.83\ [bg.evt./bin] = 3.44\ [bg.evt.]$$

$$\therefore \mu_b = 3.44$$

Exercise 3.2 Ω_c peak at ARGUS

In 1992, the ARGUS e^+e^- experiment reported the observation of the charmed and doubly strange baryon Ω_c through its decay channel $\Xi^- K^- \pi^+ \pi^+$ [26]. The obtained mass spectrum is shown in Figure 3.9. Try to make your own assessment of the signal and its significance.

H_0:
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1. *Fluctuation probability*: Under the assumption that there is only background with constant density:

   e) Estimate the probability for the Poisson distribution to fluctuate from μ_b to $N_{\text{cand,s}}$ or larger values.

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H_0**:**
null hypothesis
(background only)

1. *Fluctuation probability:* Under the assumption that there is only background with constant density:

e) Estimate the probability for the Poisson distribution to fluctuate from μ_b to $N_{cand,s}$ or larger values.

$$p = \sum_{n=N_{cands}}^{\infty} \frac{\mu_b^n}{n!} e^{-\mu_b} = \sum_{n=12}^{\infty} \frac{(3.44)^n}{n!} e^{-(3.44)} \sim 2.48 \times 10^{-4}$$

$\mu_b = 3.44$
$N_{cands} = 12$

∴ Significance Z ~ 3.5 (or 3.5 σ_b , $\sigma_b = \mu_b = \sqrt{3.44}$)

[Meaning]
How Strange (if we assume all are BG)?
N_{cands} (> 12) are far from average μ_b (3.44) !

Ω_c peak at ARGUS

WolframAlpha computational intelligence.

poisson distribution probability

NATURAL LANGUAGE | MATH INPUT | EXTENDED KEYBOARD | EXAMPLES | UPLOAD | RANDOM

Computational Inputs:

» mean: 3.44

» endpoint: 11

Compute

Assuming endpoint | Use left endpoint and right endpoint instead

Input information

probabilities for the Poisson distribution	
mean	3.44
endpoint	11

Probabilities

$x < 11$	0.999111
$x = 11$	0.00064123
$x > 11$	0.00024789

WolframAlpha computational intelligence.

1/2 (1 + erf(x/sqrt(2))) = 1-2.48*10^(-4)

NATURAL LANGUAGE | MATH INPUT | EXTENDED KEYBOARD | EXAMPLES | UPLOAD | RANDOM

Input interpretation

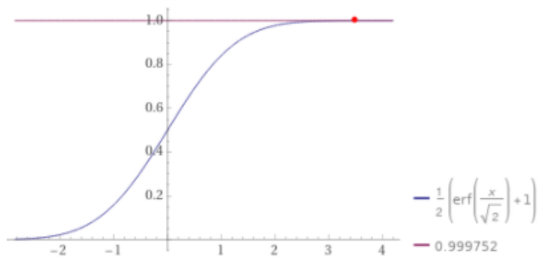
$$\frac{1}{2}\left(1+\operatorname{erf}\left(\frac{x}{\sqrt{2}}\right)\right)=1-2.48\times10^{-4}$$

erf(x) is the error function

Result

$$\frac{1}{2}\left(\operatorname{erf}\left(\frac{x}{\sqrt{2}}\right)+1\right)=0.999752$$

Plot



Alternate form assuming x is real

$$\operatorname{erf}\left(\frac{x}{\sqrt{2}}\right)=0.999504$$

Expanded forms — Step-by-step solution

$$\frac{1}{2}\operatorname{erf}\left(\frac{x}{\sqrt{2}}\right)+\frac{1}{2}=0.999752$$

$$\operatorname{erf}\left(\frac{x}{\sqrt{2}}\right)=0.999504$$

Numerical solution — More digits

$x \approx 3.48290734420640\ldots$

H_1: alternative hypothesis (signal + background)

Exercise 3.2 Ω_c peak at ARGUS

In 1992, the ARGUS e^+e^- experiment reported the observation of the charmed and doubly strange baryon Ω_c through its decay channel $\Xi^- K^- \pi^+ \pi^+$ [26]. The obtained mass spectrum is shown in Figure 3.9. Try to make your own assessment of the signal and its significance.

2. *Signal significance:* Under the signal-plus-background hypothesis try to estimate the signal and its significance:

   a) Estimate the number of background events per bin from the average density of events in the regions outside the peak. Estimate from this density the number of expected background events μ_b in the $\pm 2\sigma$ region around the peak;

Exercise 3.2 Ω_c peak at ARGUS

In 1992, the ARGUS e^+e^- experiment reported the observation of the charmed and doubly strange baryon Ω_c through its decay channel $\Xi^- K^- \pi^+ \pi^+$ [26]. The obtained mass spectrum is shown in Figure 3.9. Try to make your own assessment of the signal and its significance.

H_1: alternative hypothesis (signal + background)

2. *Signal significance:* Under the signal-plus-background hypothesis try to estimate the signal and its significance:

   a) Estimate the number of background events per bin from the average density of events in the regions outside the peak. Estimate from this density the number of expected background events μ_b in peak;

$$\frac{43 - 12\,[bg.evt.]}{50 - 4\,[bin]} = 0.67\,[bg.evt./bin]$$

(outside of the mass window)

$$4\,[bins] \times 0.67\,[bg.evt./bin] = 2.7\,[bg.evt.]$$

$$\therefore \mu_b = 2.7$$

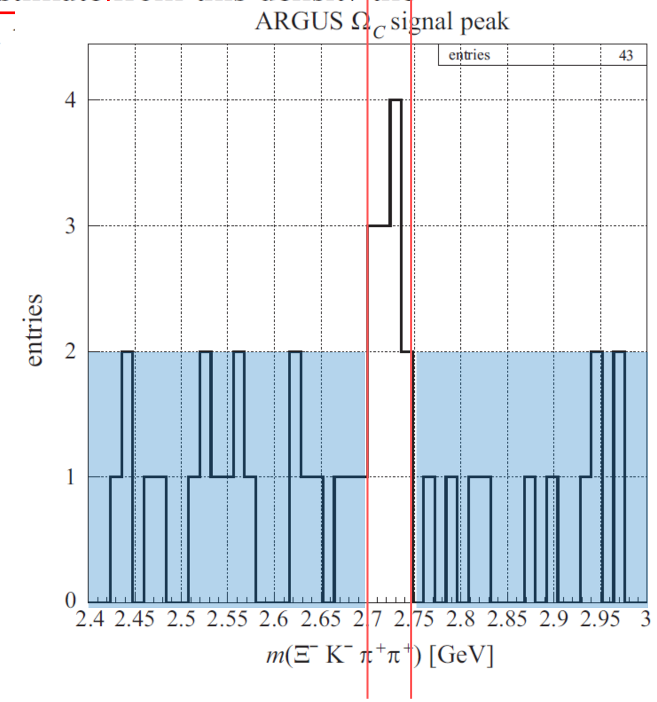


Figure 3.9 The invariant-mass spectrum used in Exercise 3.2.

H_1: alternative hypothesis (signal + background)

Exercise 3.2 Ω_c peak at ARGUS

In 1992, the ARGUS e^+e^- experiment reported the observation of the charmed and doubly strange baryon Ω_c through its decay channel $\Xi^- K^- \pi^+ \pi^+$ [26]. The obtained mass spectrum is shown in Figure 3.9. Try to make your own assessment of the signal and its significance.

2. *Signal significance:* Under the signal-plus-background hypothesis try to estimate the signal and its significance:

   b) Obtain the number $N_s = N_{cand,s} - \mu_b$, estimate an error σ_{N_s} and determine the signal significance N_s/σ_{N_s}.

Ω_c peak at ARGUS

Exercise 3.2 Ω_c peak at ARGUS

In 1992, the ARGUS e^+e^- experiment reported the observation of the charmed and doubly strange baryon Ω_c through its decay channel $\Xi^- K^- \pi^+ \pi^+$ [26]. The obtained mass spectrum is shown in Figure 3.9. Try to make your own assessment of the signal and its significance.

H_1: alternative hypothesis (signal + background)

2. *Signal significance:* Under the signal-plus-background hypothesis try to estimate the signal and its significance:

   b) Obtain the number $N_s = N_{cand,s} - \mu_b$, estimate an error σ_{N_s} and determine the signal significance N_s/σ_{N_s}.

$$N_s = N_{cands} - \mu_b = 12 - 2.7 = 9.3$$

$$\sigma_{N_s} = \sqrt{N_{cands}} = \sqrt{N_s + \mu_b} = \sqrt{12} = 3.5$$

Significance (approx.): $\frac{N_s}{\sigma_{N_s}} = \frac{N_s}{\sqrt{N_s+\mu_b}} = 2.7$

[Meaning]
Under assumption: Signal + BG
How Strange, if we regard Signal as BG?

Exercise 3.2 Ω_c peak at ARGUS

In 1992, the ARGUS e^+e^- experiment reported the observation of the charmed and doubly strange baryon Ω_c through its decay channel $\Xi^- K^- \pi^+ \pi^+$ [26]. The obtained mass spectrum is shown in Figure 3.9. Try to make your own assessment of the signal and its significance.

H_1: alternative hypothesis (signal + background)

2. *Signal significance:* Under the signal-plus-background hypothesis try to estimate the signal and its significance:

   b) Obtain the number $N_s = N_{cand,s} - \mu_b$, estimate an error σ_{N_s} and determine the signal significance N_s/σ_{N_s}.

$$p = \sum_{n=N_{cands}}^{\infty} \frac{\mu_b^n}{n!} e^{-\mu_b} = \sum_{n=9}^{\infty} \frac{(2.7)^n}{n!} e^{-(2.7)} \sim 1.91 \times 10^{-3}$$

$$\mu_b = 2.7$$
$$N_{cands} = 9 \ (\sim 9.3)$$

∴ Significance Z ~ 2.89 (or 2.89 σ_b , $\sigma_b = \mu_b = \sqrt{2.7}$)

Ω_c peak at ARGUS

WolframAlpha computational intelligence.

poisson distribution probability

NATURAL LANGUAGE | MATH INPUT | EXTENDED KEYBOARD | EXAMPLES | UPLOAD | RANDOM

Computational Inputs:

» mean:
2.7

» endpoint:
8

Compute

Assuming endpoint | Use left endpoint and right endpoint instead

Input information

probabilities for the Poisson distribution	
mean	2.7
endpoint	8

Probabilities

$x < 8$	0.993379
$x = 8$	0.00470755
$x > 8$	0.00191363

WolframAlpha computational intelligence.

1/2 (1 + erf(x/sqrt(2))) = 1 - 0.00191363

NATURAL LANGUAGE | MATH INPUT | EXTENDED KEYBOARD | EXAMPLES | UPLOAD | RANDOM

Input interpretation

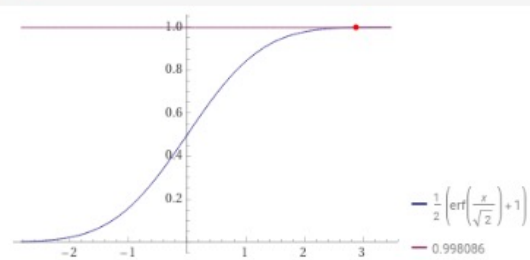
$$\frac{1}{2}\left(1+\operatorname{erf}\left(\frac{x}{\sqrt{2}}\right)\right) = 1 - 0.00191363$$

$\operatorname{erf}(x)$ is the error function

Result

$$\frac{1}{2}\left(\operatorname{erf}\left(\frac{x}{\sqrt{2}}\right)+1\right) = 0.998086$$

Plot



Alternate form assuming x is real

$$\operatorname{erf}\left(\frac{x}{\sqrt{2}}\right) = 0.996173$$

Expanded forms Step-by-step solution

$$\frac{1}{2}\operatorname{erf}\left(\frac{x}{\sqrt{2}}\right)+\frac{1}{2} = 0.998086$$

$$\operatorname{erf}\left(\frac{x}{\sqrt{2}}\right) = 0.996173$$

Numerical solution More digits

$x \approx 2.89205905488551\ldots$

Download Page

POWERED BY THE **WOLFRAM LANGUAGE**

Ω_c peak at ARGUS

21.09.24 (금)
Lab meeting

<statistics 예제 풀이>

- olaf Data Analysis
- exercise 3.3 Ω_c peak at ARGUS

- physics 보단 statistics 위주로 설명
- 1-a) $\frac{43 \text{ event (bg)}}{50 \text{ bin}} = 0.83$ [bg. evt. / bin] (average)
- 1-b) σ_{res} = bin = 12 MeV

  [2.7 , 2.748] MeV
- 1-c) 12개
- 1-d) 4 bins × 0.83 [bg. evt. / bin] = 3.44 [bg. evt.]
- 1-e) $\sum_{n=N_{cand,s}}^{\infty} \frac{\mu_b^n}{n!} e^{-\mu_b} \sim 2.48 \times 10^{-4}$

  ↳ significance? □? ~ 3.5 $\sigma_{N_{cand,s}}$

  (normal) 에 gaussian으로 변환하는가? [illegible] abnormal 한가?

  * poisson으로 추정하는 이유? 시행횟수 많고 (N→∞), 확률이 작은 (p→0) 그 가정에 따른 dist.

  → 뭔가 이상하다!

  예시: μ_b = 3.44 일때
  이 경우 $N_{cand,s}$ 개(12)로 fluctuate 하거나 2 이상 fluctuate 하는 확률.
  ⇒ 평균 3.44 일때 12개 이상이 발견 되는가?

- 2-a) $\frac{43-12}{50-4} = \frac{31}{44} = 0.67$ [bg. evt. / bin]

  4 bins × 0.67 [bg. evt. / bin] ~ 2.7 [bg. evt.]
- 2-b) $N_s = 12 - 2.7 = 9.3$

  $\sigma_{N_s} = \sqrt{N_s} = 3.5$

  $\frac{N_s}{\sigma_{N_s}} = 2.7$ or $2.7\ \sigma_{N_s}$

  → 신호, bg 다 있을 때, sg를 bg라고 하면 얼마나 이상한가?

Ω_c peak at ARGUS

Appendix. The relationship btw the error function and the normal cumulative dist. func.

- The error func.

$$erf(x) = \frac{2}{\sqrt{\pi}}\int_0^x e^{-t^2}dt$$

- The normal cumulative dist. func.

$$\Phi(x) = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^x e^{-\frac{t^2}{2}}dt$$

$$\Rightarrow \Phi(x) = \frac{1}{2}\left(1+erf\left(\frac{x}{\sqrt{2}}\right)\right)$$

pf) $t = \frac{y}{\sqrt{2}}$

$$erf(x) = \frac{2}{\sqrt{\pi}}\int_0^x e^{-t^2}dt \rightarrow \frac{2}{\sqrt{\pi}}\int_0^{\sqrt{2}x} e^{-\frac{y^2}{2}} \cdot \frac{dy}{\sqrt{2}}$$

$$= \frac{2}{\sqrt{2\pi}}\int_0^{\sqrt{2}x} e^{-\frac{t^2}{2}}dt \rightarrow erf\left(\frac{x}{\sqrt{2}}\right) = \frac{2}{\sqrt{2\pi}}\int_0^x e^{-\frac{t^2}{2}}dt$$

$$= 2\int_0^x N(0,1)\,dt$$

$$\Phi(x) = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^x e^{-\frac{t^2}{2}}dt = \text{[sketch]} + \text{[sketch]} = \frac{1}{2}\left(1+erf\left(\frac{x}{\sqrt{2}}\right)\right)$$

$\frac{1}{2}$ $\quad$ $\frac{1}{2}erf\left(\frac{x}{\sqrt{2}}\right)$

$$\frac{1}{2}erf\left(\frac{x}{\sqrt{2}}\right) = \frac{1}{2} - \alpha$$

References

- [1] Olaf Behneke et al, “Data Analysis in High Energy Physics, A Practical Guide to Statistical Methods”, WILEY-VCH, 2013
- [2] H. Albrecht et al, “Evidence for the production of the charmed, doubly strange baryon Ω_c in e^+e^- annihilation (ARGUS collaboration)”, Physics Letter B, 1992
- Manual Link: https://www.terascale.de/statisticsbook/index_eng.html#e149984

Part III:
$B^0 \to \tau^+\tau^-$ *with hadronic FEI*
– Analysis Detail

Basic Strategy

Basic Strategy

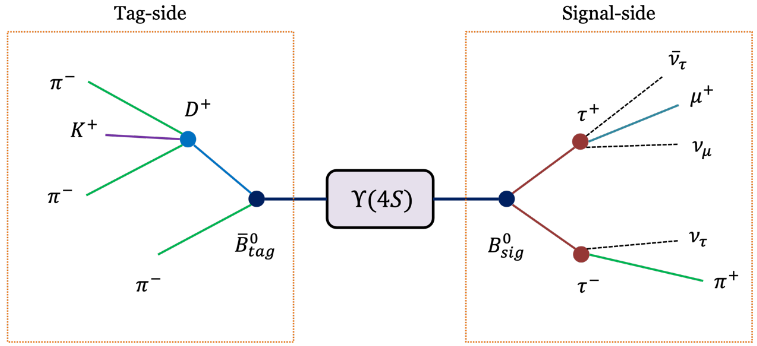
- Follow the way of the **unpublished** Belle note by M. Ziegler (**BN-1390**)
  - Why is this note not published? (my guess)
    - Too big Branching Fraction?!
      - $(4.39^{+0.80}_{-.083} \pm 0.45) \times 10^{-3}$ (cf. SM prediction: $(2.22 \pm 0.19) \times 10^{-8}$ *)

- Add other (better) method based on Belle / Belle II differences

Analysis Status Summary

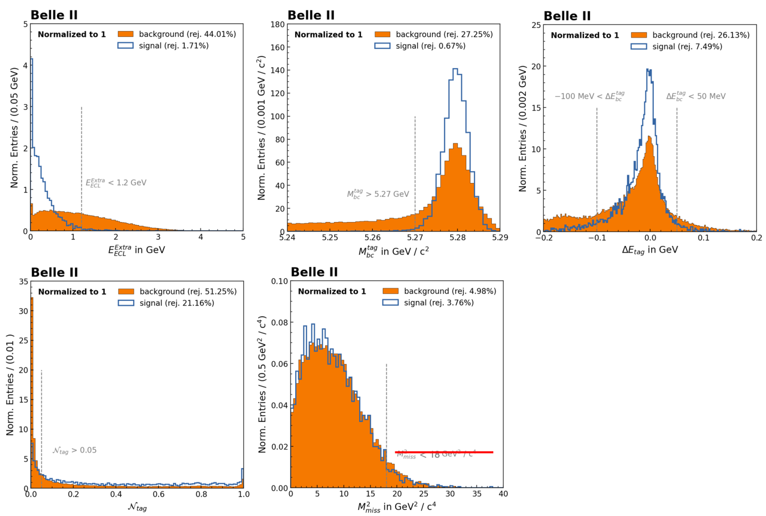
Workflow

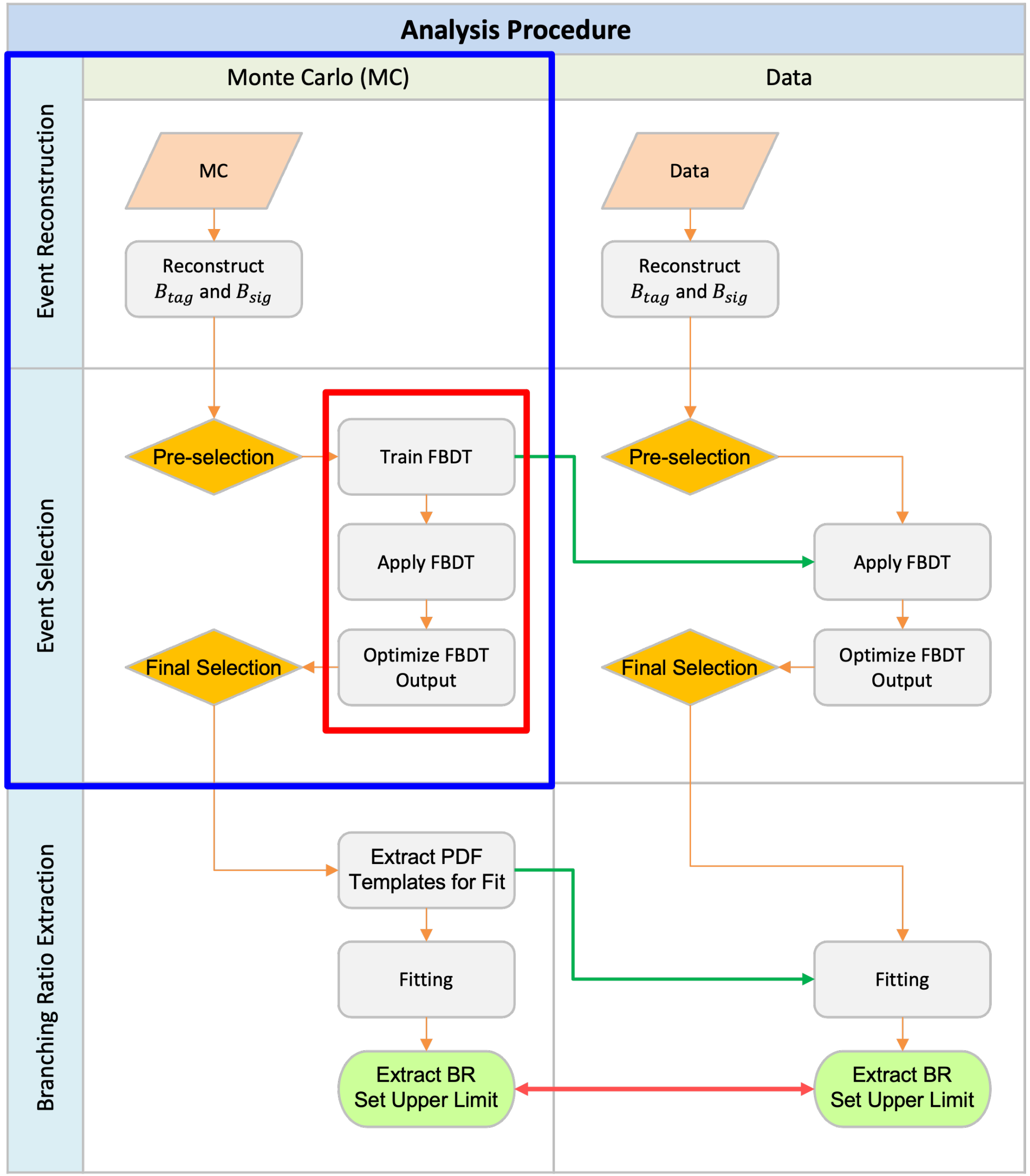
hadronic FEI (B_{tag} Reconstruction)



Pre-selection

Cut	Signal rejection in %	Background rejection in %
$E_{ECL}^{Extra} < 1.2$ GeV	1.71 (99/5788)	44.01 (120849/274604)
$M_{bc}^{tag} > 5.27$ GeV/c²	0.67 (38/5689)	27.25 (41897/153755)
-100 MeV $< \Delta E_{tag} <$ 50 MeV	7.49 (423/5651)	26.13 (29228/111858)
$\mathcal{N}_{tag} > 0.05$	21.16 (1106/5228)	51.25 (42349/82630)
$M^2_{miss} < 18$ (GeV/c²)²	3.76 (155/4122)	4.98 (2005/40281)
Total	31.46 (1821/5788)	86.06 (236328/274604)





MC Sample Information

MC Sample Information

- Signal
  - $B^0 \to \tau\tau$, 20 M generated
    - BGx0: 4 M (0.2)
    - BGx1: **16 M** (0.8)
  - Only BGx1 sample is used
    - skimmed with hadronic FEI

- Background: MC14ri_a, $\Upsilon(4S)$ => **SkimM14ri_ax1** (Skimmed with **hadronic FEI**)
  - Generic
    - $B^0\bar{B}^0$ (mixed): **~ 900 fb^{-1} ***
    - B^+B^- (charged): **~ 900 fb^{-1} ***
  - Continuum
    - u,d,s,c (each): **~ 1000 fb^{-1} ***
  - Others are added later ($BD\ell\nu_\ell$, Rare, and $u\ell\nu_\ell$)

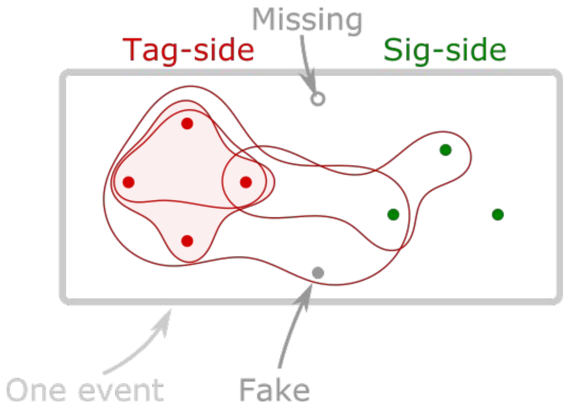
※Should be updated to MC15

Belle II “FEI” Algorithm

Tagging *metrics* and *objectives*:

- **High *efficiency***: fraction of events with a "good" tag
- **High *purity***: fraction of identified tags that are "good"
- Good kinematic information (minimize missing/fake)

A schematic view of an event with 4 tag candidates



The FEI is an algorithm specifically designed to maximize these things, with two flavors…

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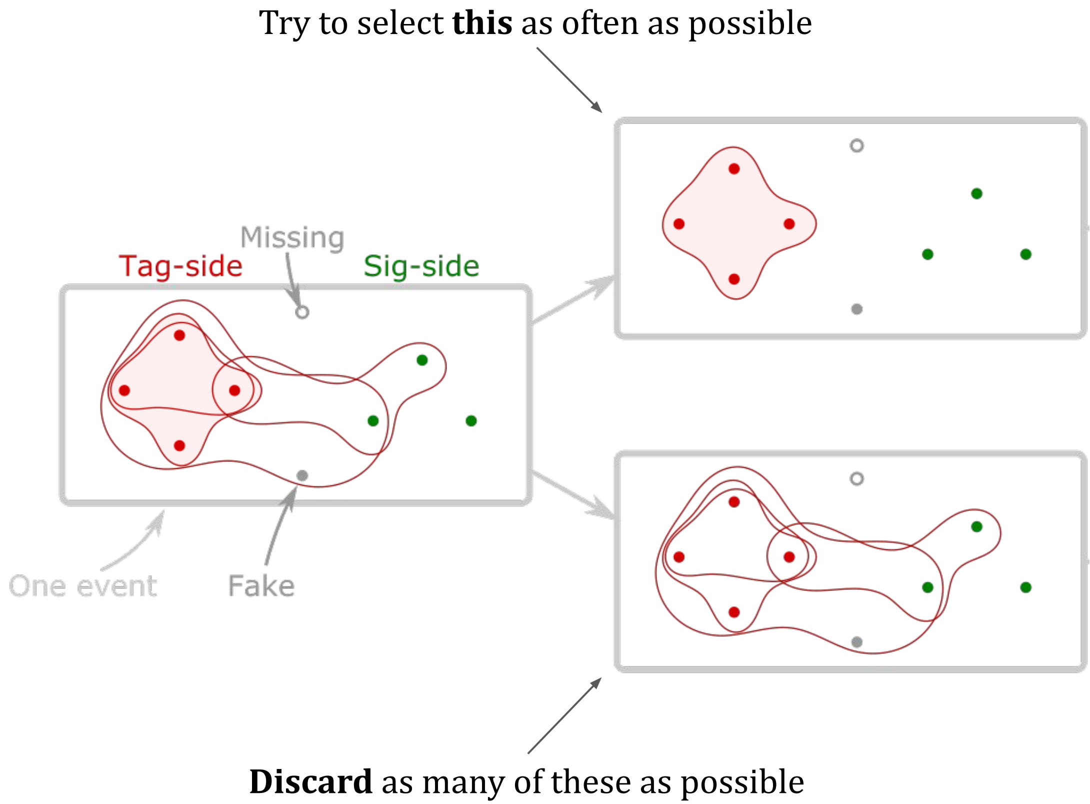
※ [Belle II Physics Week 2022, Spain, 2022.Dec.01: FEI Lecture]
https://indico.belle2.org/event/7825/contributions/49619/attachments/19751/29288/FEI.pdf

Best tag selection (BTS)

Can be helpful to select the "best" tag candidate in each event

Typically: highest $\mathscr{P}_{\text{tag}}$ in an event…

…*after* other selections.



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※ [Belle II Physics Week 2022, Spain, 2022.Dec.01: FEI Lecture]
https://indico.belle2.org/event/7825/contributions/49619/attachments/19751/29288/FEI.pdf

FEI Channels

In basf2

Load the FEI

Get the tag list you want:

```
B+:generic
B0:generic
```
Hadronic tag candidates

```
B+:semileptonic
B0:semileptonic
```
Semileptonic tag candidates

Get the variables you want:

- `Mbc` $\longrightarrow M_{bc}$
- `deltaE` $\longrightarrow \Delta E$
- `extraInfo(SignalProbability)` $\longrightarrow \mathscr{P}_{\text{tag}}$
- `extraInfo(decayModeID)`
- `cosThetaBetweenParticleAndNominalB` $\longrightarrow \cos\theta_{\text{BY}}$

[Tip: Particle List Name]

※ Signal MC ⇒ B_{tag} = B0:generic

※ Background MC (Continuum / Generic)⇒ B_{tag} = B0:feiHadronic

0 :	$B^0 \to D^- \pi^+$
1 :	$B^0 \to D^- \pi^+ \pi^0$
2 :	$B^0 \to D^- \pi^+ \pi^0 \pi^0$
3 :	$B^0 \to D^- \pi^+ \pi^+ \pi^-$
4 :	$B^0 \to D^- \pi^+ \pi^+ \pi^- \pi^0$
5 :	$B^0 \to \overline{D^0} \pi^+ \pi^-$
6 :	$B^0 \to D^- D^0 K^+$
7 :	$B^0 \to D^- D^{*0} K^+$
8 :	$B^0 \to D^{*-} D^0 K^+$
9 :	$B^0 \to D^{*-} D^{*0} K^+$
10 :	$B^0 \to D^- D^+ K_S^0$
11 :	$B^0 \to D^{*-} D^+ K_S^0$
12 :	$B^0 \to D^- D^{*+} K_S^0$
13 :	$B^0 \to D^{*-} D^{*+} K_S^0$
14 :	$B^0 \to D_s^+ D^-$
15 :	$B^0 \to D^{*-} \pi^+$
16 :	$B^0 \to D^{*-} \pi^+ \pi^0$
17 :	$B^0 \to D^{*-} \pi^+ \pi^0 \pi^0$
18 :	$B^0 \to D^{*-} \pi^+ \pi^+ \pi^-$
19 :	$B^0 \to D^{*-} \pi^+ \pi^+ \pi^- \pi^0$
20 :	$B^0 \to D_s^{*+} D^-$
21 :	$B^0 \to D_s^+ D^{*-}$
22 :	$B^0 \to D_s^{*+} D^{*-}$
23 :	$B^0 \to J/\psi K_S^0$
24 :	$B^0 \to J/\psi K^+ \pi^-$
25 :	$B^0 \to J/\psi K_S^0 \pi^+ \pi^-$
26 :	$B^0 \to \overline{\Lambda_c^-} p^+ \pi^+ \pi^-$
27 :	$B^0 \to \overline{D^0} p^+ \overline{p^-}$
28 :	$B^0 \to D^- p^+ \overline{p^-} \pi^+$
29 :	$B^0 \to D^{*-} p^+ \overline{p^-} \pi^+$
30 :	$B^0 \to \overline{D^0} p^+ \overline{p^-} \pi^+ \pi^-$
31 :	$B^0 \to \overline{D^{*0}} p^+ \overline{p^-} \pi^+ \pi^-$
32 :	No B^0 FEI decay

0 :	$B^+ \to \overline{D^0} \pi^+$
1 :	$B^+ \to \overline{D^0} \pi^+ \pi^0$
2 :	$B^+ \to \overline{D^0} \pi^+ \pi^0 \pi^0$
3 :	$B^+ \to \overline{D^0} \pi^+ \pi^+ \pi^-$
4 :	$B^+ \to \overline{D^0} \pi^+ \pi^+ \pi^- \pi^0$
5 :	$B^+ \to \overline{D^0} D^+$
6 :	$B^+ \to D^+ \overline{D^0} K_S^0$
7 :	$B^+ \to D^+ \overline{D^{*0}} K_S^0$
8 :	$B^+ \to D^{*+} \overline{D^0} K_S^0$
9 :	$B^+ \to D^{*+} D^{*0} K_S^0$
10 :	$B^+ \to \overline{D^0} D^0 K^+$
11 :	$B^+ \to \overline{D^{*0}} D^0 K^+$
12 :	$B^+ \to \overline{D^0} D^{*0} K^+$
13 :	$B^+ \to \overline{D^{*0}} D^{*0} K^+$
14 :	$B^+ \to D_s^+ \overline{D^0}$
15 :	$B^+ \to \overline{D^{*0}} \pi^+$
16 :	$B^+ \to \overline{D^{*0}} \pi^+ \pi^0$
17 :	$B^+ \to \overline{D^{*0}} \pi^+ \pi^0 \pi^0$
18 :	$B^+ \to \overline{D^{*0}} \pi^+ \pi^+ \pi^-$
19 :	$B^+ \to \overline{D^{*0}} \pi^+ \pi^+ \pi^- \pi^0$
20 :	$B^+ \to D_s^{*+} \overline{D^0}$
21 :	$B^+ \to D_s^+ \overline{D^{*0}}$
22 :	$B^+ \to \overline{D^0} K^+$
23 :	$B^+ \to D^- \pi^+ \pi^+$
24 :	$B^+ \to D^- \pi^+ \pi^+ \pi^0$
25 :	$B^+ \to J/\psi K^+$
26 :	$B^+ \to J/\psi K^+ \pi^+ \pi^-$
27 :	$B^+ \to J/\psi K^+ \pi^0$
28 :	$B^+ \to J/\psi K_S^0 \pi^+$
29 :	$B^+ \to \overline{\Lambda_c^-} p^+ \pi^+ \pi^0$
30 :	$B^+ \to \overline{\Lambda_c^-} p^+ \pi^+ \pi^- \pi^+$
31 :	$B^+ \to \overline{D^0} p^+ \overline{p^-} \pi^+$
32 :	$B^+ \to \overline{D^{*0}} p^+ \overline{p^-} \pi^+$
33 :	$B^+ \to D^0 p^+ \overline{p^-} \pi^+ \pi^-$
34 :	$B^+ \to D^{*0} p^+ \overline{p^-} \pi^+ \pi^-$
35 :	$B^+ \to \overline{\Lambda_c^-} p^+ \pi^+$
36 :	No B^+ FEI decay

※ [Belle II Physics Week 2022, Spain, 2022.Dec.01: FEI Lecture]
https://indico.belle2.org/event/7825/contributions/49619/attachments/19751/29288/FEI.pdf

Utilizing FEI

In analysis

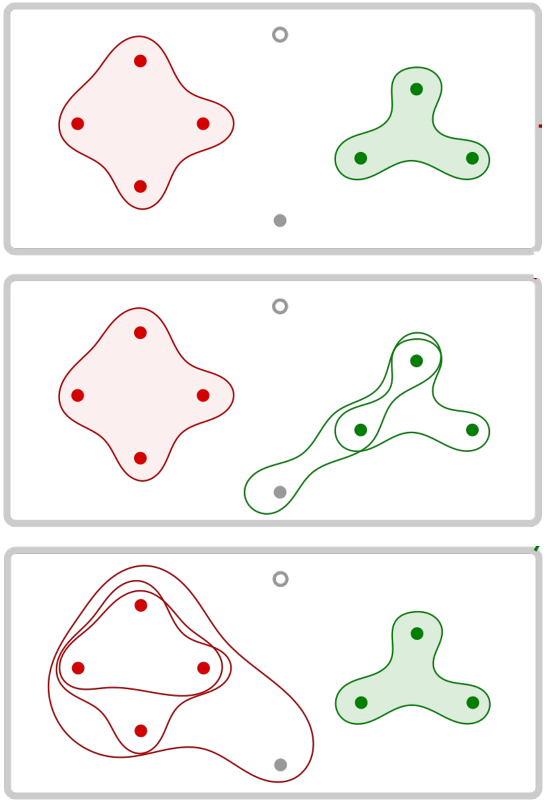
So you have your tags… *what do you do now?*

1. Build your *signal-side B* candidate
2. Combine *tag* and *signal Bs* to make $\Upsilon(4S)$ candidates

FEI efficiency ϵ_{FEI} enters in one of two ways:

- BF(signal): $\epsilon_{\text{total}} = \epsilon_{\text{FEI}} * \epsilon_{\text{sig}}$
- BF(signal)/BF(normalization): FEI efficiency *cancels*

But FEI is trained on MC: ϵ_{FEI} needs a *calibration*…



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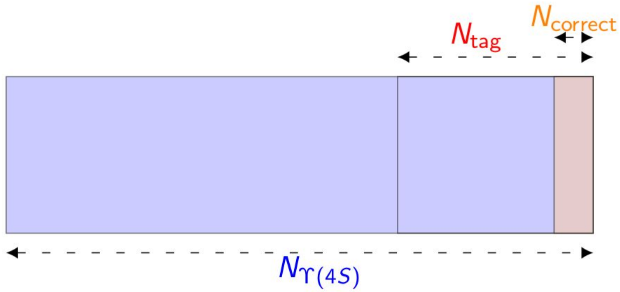
※ [Belle II Physics Week 2022, Spain, 2022.Dec.01: FEI Lecture]
https://indico.belle2.org/event/7825/contributions/49619/attachments/19751/29288/FEI.pdf

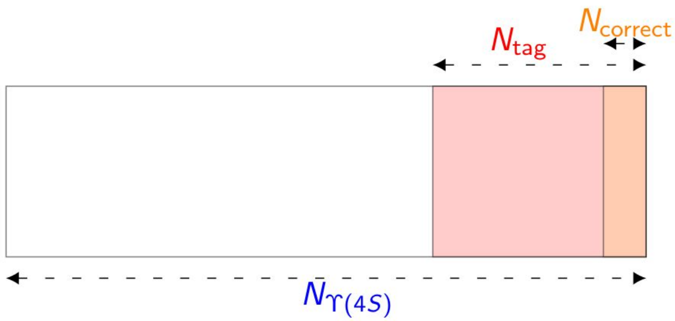
FEI Performance



- **tagging efficiency** $= N_{\text{tag}} / N_{\Upsilon(4S)}$
- **tag-side efficiency** $= N_{\text{correct}} / N_{\Upsilon(4S)}$

※ [Belle II Physics Week 2022, Spain, 2022.Dec.01: FEI brainstorm]
https://indico.belle2.org/event/7825/contributions/49609/attachments/19763/29306/FEI-Brain-Storm-final.pdf

FEI Performance metrics



- **tagging efficiency** $= N_{\text{tag}} / N_{\Upsilon(4S)}$
- **tag-side efficiency** $= N_{\text{correct}} / N_{\Upsilon(4S)}$
- **purity** $= N_{\text{correct}} / N_{\text{tag}}$

※ [Belle II Physics Week 2022, Spain, 2022.Dec.01: FEI brainstorm]
https://indico.belle2.org/event/7825/contributions/49609/attachments/19763/29306/FEI-Brain-Storm-final.pdf

Full Event Interpretation (FEI)

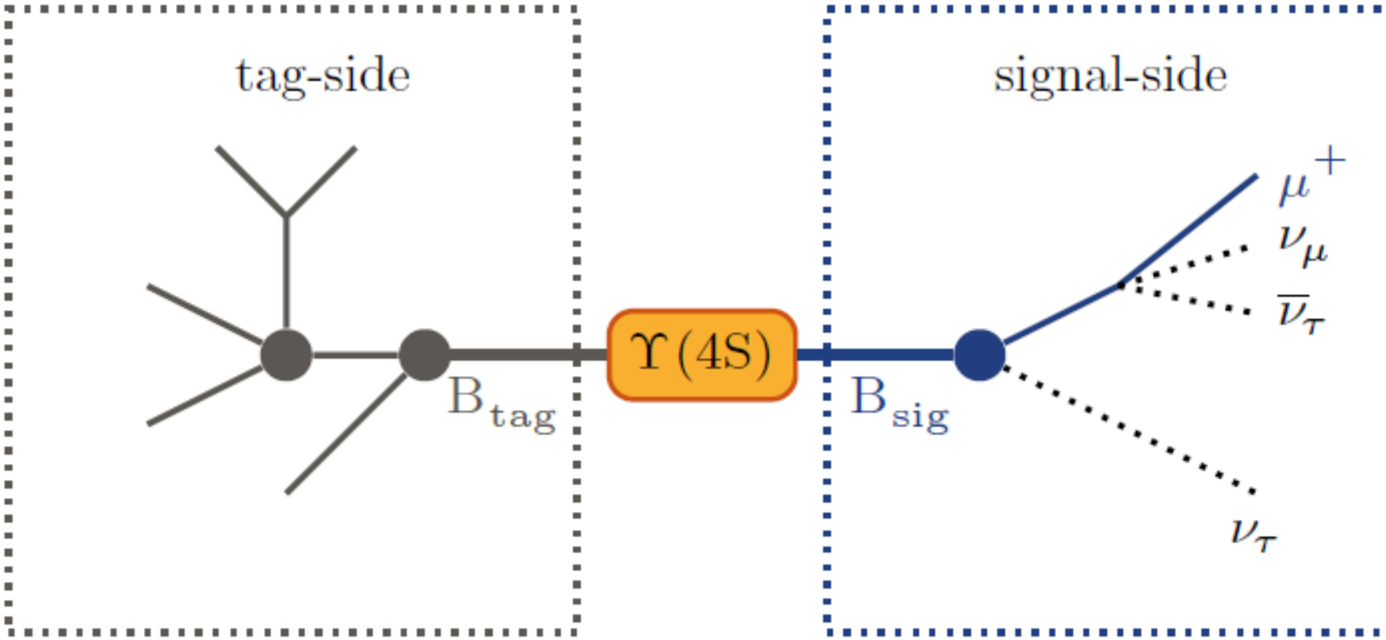


Fig. 1 Schematic overview of a $\Upsilon(4S)$ decay: (Left) a common tag-side decay $B^-_{tag} \rightarrow D^0(\rightarrow K^0_s(\rightarrow \pi^-\pi^+)\pi^-\pi^+)\pi^-$ and (right) a typical signal-side decay $B^+_{sig} \rightarrow \tau^+(\rightarrow \mu^+\nu_\mu\bar{\nu}_\tau)\nu_\tau$. The two sides overlap spatially in the detector, therefore the assignment of a measured track to one of the sides is not known a priori

Full Event Interpretation (FEI)

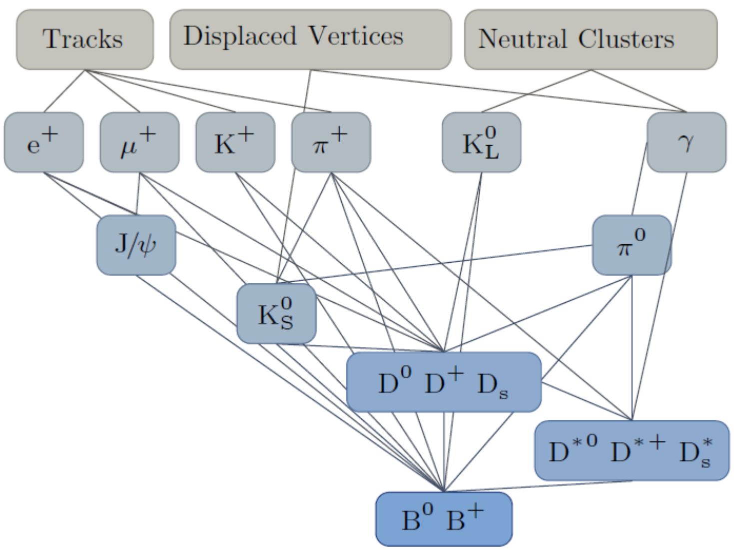


Fig. 2 Schematic overview of the FEI. The algorithm operates on objects identified by the reconstruction software of the Belle II detectors: charged tracks, neutral clusters and displaced vertices. In six distinct stages, these basics objects are interpreted as final-state particles (e^+, μ^+, K^+, π^+, K^0_L, γ) combined to form intermediate particles (J/ψ, π^0, K^0_S, D, D^*) and finally form the tag-side B mesons

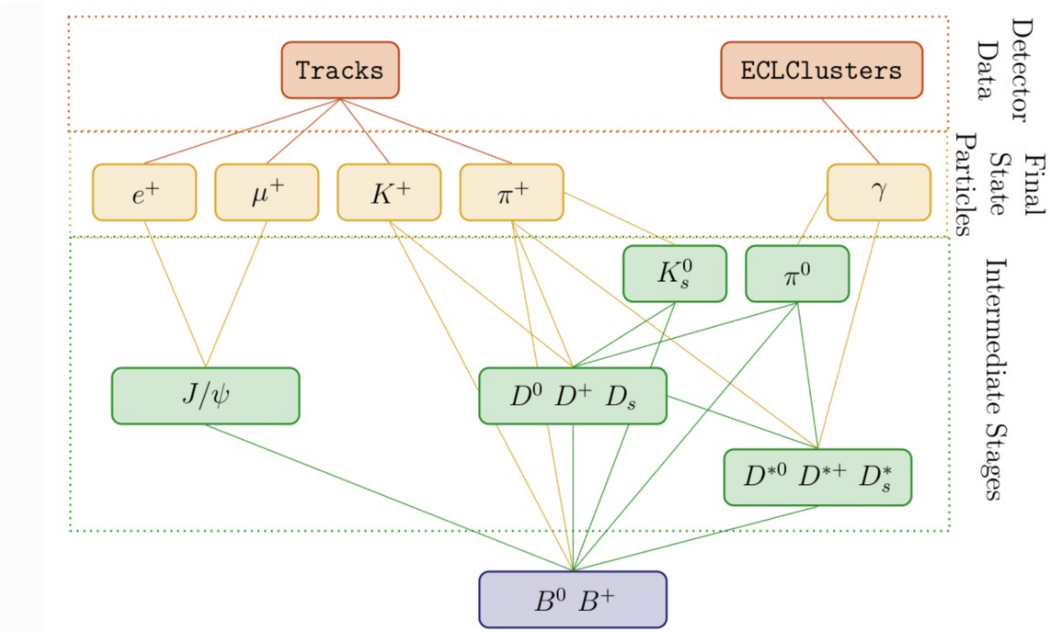


Fig. 7.9 *Hierarchical reconstruction applied by the FEI, which starting from tracks and EM clusters reconstructs initial state particles, intermediate particles in several stages and finally candidate B tags.*

https://b2-master.belle2.org/software/development/sphinx/analysis/doc/FullEventInterpretation.html

cf. Belle II detector: detectable (identifiable) particles

	TOP & ARICH				ECL	KLM	
Charged	$\pi^\pm$	$K^\pm$	$p^\pm$	$d^\pm$	$e^\pm$	$\mu^\pm$	CDC
Neutral	-	-	-	-	γ	K^0_L	-

※ Not that good table… Please see particle identification section in B2TIP for further information (5.5 and 5.6).

Full Event Interpretation (FEI)

- tagging efficiency
  - the fraction of Υ(4S) events which can be tagged.
  - $\frac{N_{tag}}{N}$
- tag-side efficiency
  - the fraction of Υ(4S) events with a correct tag.
  - $\frac{N_{correct,\,tag}}{N}$
- tag-side purity
  - the fraction of the tagged Υ(4S) events with a correct tag.
  - $\frac{N_{correct,\,tag}}{N_{tag}}$
  - where
    - N : number of $\Upsilon(4S)$ events.

FEI algorithm official paper review

Full Event Interpretation (FEI)

Table 1 Summary of the maximum tag-side efficiency of the Full Event Interpretation and for the previously used exclusive tagging algorithms

	$B^{\pm}$ (%)	B^0 (%)
Hadronic		
FEI with FR channels	0.53	0.33
FEI	0.76	0.46
FR	0.28	0.18
SER	0.4	0.2
Semileptonic		
FEI	1.80	2.04
FR	0.31	0.34
SER	0.3	0.6

For the FEI simulated data from the last official Monte Carlo campaign of the Belle experiment were used. The maximum tag-side efficiency on recorded data is lower (see "Hadronic tag" section). The numbers for the older algorithms (see "Previous work" section), are not directly comparable due to different selection criteria, like best candidate selections and selections to suppress non-$\Upsilon(4S)$ events

- Belle II: FEI
  - Full Event Interpretation
- Belle: FR
  - Full Reconstruction
- BABAR: SER
  - Semi-Exclusive B reconstruction

Table 28. B^+, B^0, and D decay modes included in FEI. The modes listed in the lower part of the table were not considered in the Belle FR.

B^+ modes	B^0 modes	D^+, D^{*+}, D_s^+ modes	D^0,D^{*0} modes
$B^+ \to \bar{D}^0\pi^+$	$B^0 \to D^-\pi^+$	$D^+ \to K^-\pi^+\pi^+$	$D^0 \to K^-\pi^+$
$B^+ \to \bar{D}^0\pi^+\pi^0$	$B^0 \to D^-\pi^+\pi^0$	$D^+ \to K^-\pi^+\pi^+\pi^0$	$D^0 \to K^-\pi^+\pi^0$
$B^+ \to \bar{D}^0\pi^+\pi^0\pi^0$	$B^0 \to D^-\pi^+\pi^+\pi^-$	$D^+ \to K^-K^+\pi^+$	$D^0 \to K^-\pi^+\pi^+\pi^-$
$B^+ \to \bar{D}^0\pi^+\pi^+\pi^-$	$B^0 \to D_s^+D^-$	$D^+ \to K^-K^+\pi^+\pi^0$	$D^0 \to \pi^-\pi^+$
$B^+ \to D_s^+\bar{D}^0$	$B^0 \to D^{*-}\pi^+$	$D^+ \to K_S^0\pi^+$	$D^0 \to \pi^-\pi^+\pi^0$
$B^+ \to \bar{D}^{*0}\pi^+$	$B^0 \to D^{*-}\pi^+\pi^0$	$D^+ \to K_S^0\pi^+\pi^0$	$D^0 \to K_S^0\pi^0$
$B^+ \to \bar{D}^{*0}\pi^+\pi^0$	$B^0 \to D^{*-}\pi^+\pi^+\pi^-$	$D^+ \to K_S^0\pi^+\pi^+\pi^-$	$D^0 \to K_S^0\pi^+\pi^-$
$B^+ \to \bar{D}^{*0}\pi^+\pi^+\pi^-$	$B^0 \to D^{*-}\pi^+\pi^+\pi^-\pi^0$	$D^{*+} \to D^0\pi^+$	$D^0 \to K_S^0\pi^+\pi^-\pi^0$
$B^+ \to \bar{D}^{*0}\pi^+\pi^+\pi^-\pi^0$	$B^0 \to D_s^{*+}D^-$	$D^{*+} \to D^+\pi^0$	$D^0 \to K^-K^+$
$B^+ \to D_s^{*+}\bar{D}^0$	$B^0 \to D_s^+D^{*-}$	$D_s^+ \to K^+K_S^0$	$D^0 \to K^-K^+K_S^0$
$B^+ \to D_s^+\bar{D}^{*0}$	$B^0 \to D_s^{*+}D^{*-}$	$D_s^+ \to K^+\pi^+\pi^-$	$D^{*0} \to D^0\pi^0$
$B^+ \to \bar{D}^0K^+$	$B^0 \to J/\psi\, K_S^0$	$D_s^+ \to K^+K^-\pi^+$	$D^{*0} \to D^0\gamma$
$B^+ \to D^-\pi^+\pi^+$	$B^0 \to J/\psi\, K^+\pi^+$	$D_s^+ \to K^+K^-\pi^+\pi^0$	
$B^+ \to J/\psi\, K^+$	$B^0 \to J/\psi\, K_S^0\pi^+\pi^-$	$D_s^+ \to K^+K_S^0\pi^+\pi^-$	
$B^+ \to J/\psi\, K^+\pi^+\pi^-$		$D_s^+ \to K^-K_S^0\pi^+\pi^+$	
$B^+ \to J/\psi\, K^+\pi^0$		$D_s^+ \to K^+K^-\pi^+\pi^+\pi^-$	
		$D_s^+ \to \pi^+\pi^+\pi^-$	
		$D_s^{*+} \to D_s^+\pi^0$	
$B^+ \to D^-\pi^+\pi^+\pi^0$	$B^0 \to D^-\pi^+\pi^0\pi^0$	$D^+ \to \pi^+\pi^0$	$D^0 \to K^-\pi^+\pi^0\pi^0$
$B^+ \to \bar{D}^0\pi^+\pi^+\pi^-\pi^0$	$B^0 \to D^-\pi^+\pi^+\pi^-\pi^0$	$D^+ \to \pi^+\pi^+\pi^-$	$D^0 \to K^-\pi^+\pi^+\pi^-\pi^0$
$B^+ \to \bar{D}^0D^+$	$B^0 \to \bar{D}^0\pi^+\pi^-$	$D^+ \to \pi^+\pi^+\pi^-\pi^0$	$D^0 \to \pi^-\pi^+\pi^+\pi^-$
$B^+ \to \bar{D}^0D^+K_S^0$	$B^0 \to D^-D^0K^+$	$D^+ \to K^+K_S^0K_S^0$	$D^0 \to \pi^-\pi^+\pi^0\pi^0$
$B^+ \to \bar{D}^{*0}D^+K_S^0$	$B^0 \to D^-D^{*0}K^+$	$D^{*+} \to D^+\gamma$	$D^0 \to K^-K^+\pi^0$
$B^+ \to \bar{D}^0D^{*+}K_S^0$	$B^0 \to D^{*-}D^0K^+$	$D_s^+ \to K_S^0\pi^+$	
$B^+ \to \bar{D}^{*0}D^{*+}K_S^0$	$B^0 \to D^{*-}D^{*0}K^+$	$D_s^+ \to K_S^0\pi^+\pi^0$	
$B^+ \to \bar{D}^0D^0K^+$	$B^0 \to D^-D^+K_S^0$	$D_s^{*+} \to D_s^+\pi^0$	
$B^+ \to \bar{D}^{*0}D^0K^+$	$B^0 \to D^{*-}D^+K_S^0$		
$B^+ \to \bar{D}^0D^{*0}K^+$	$B^0 \to D^-D^{*+}K_S^0$		
$B^+ \to \bar{D}^{*0}D^{*0}K^+$	$B^0 \to D^{*-}D^{*+}K_S^0$		
$B^+ \to \bar{D}^{*0}\pi^+\pi^0\pi^0$	$B^0 \to D^{*-}\pi^+\pi^0\pi^0$		

16 B^+ channels
14 B^0 channels

12 B^+ additional channels
12 B^0 additional channels

Ref [5]. B2Tip (2019)

Cf. FR for Belle / FEI for Belle II

Full Event Interpretation (FEI)

※ Sphinx (latest release: release-06-00-00)
https://b2-master.belle2.org/software/sphinx/release-06-00-00/skim/doc/02-physics.html

Hadronic

B^0 (31)

B0 channels:

0. $B^0_{\text{had}} \to D^- \pi^+$
1. $B^0_{\text{had}} \to D^- \pi^+ \pi^0$
2. $B^0_{\text{had}} \to D^- \pi^+ \pi^0 \pi^0$
3. $B^0_{\text{had}} \to D^- \pi^+ \pi^+ \pi^-$
4. $B^0_{\text{had}} \to D^- \pi^+ \pi^+ \pi^- \pi^0$
5. $B^0_{\text{had}} \to \overline{D}^0 \pi^+ \pi^-$
6. $B^0_{\text{had}} \to D^- D^0 K^+$
7. $B^0_{\text{had}} \to D^- D^{0*} K^+$
8. $B^0_{\text{had}} \to D^{-*} D^0 K^+$
9. $B^0_{\text{had}} \to D^{-*} D^{0*} K^+$
10. $B^0_{\text{had}} \to D^- D^+ K^0_S$
11. $B^0_{\text{had}} \to D^{-*} D^+ K^0_S$
12. $B^0_{\text{had}} \to D^- D^{+*} K^0_S$
13. $B^0_{\text{had}} \to D^{-*} D^{+*} K^0_S$
14. $B^0_{\text{had}} \to D_s^+ D^-$
15. $B^0_{\text{had}} \to D^{-*} \pi^+$
16. $B^0_{\text{had}} \to D^{-*} \pi^+ \pi^0$
17. $B^0_{\text{had}} \to D^{-*} \pi^+ \pi^0 \pi^0$
18. $B^0_{\text{had}} \to D^{-*} \pi^+ \pi^+ \pi^-$
19. $B^0_{\text{had}} \to D^{-*} \pi^+ \pi^+ \pi^- \pi^0$
20. $B^0_{\text{had}} \to D_s^{+*} D^-$
21. $B^0_{\text{had}} \to D_s^+ D^{-*}$
22. $B^0_{\text{had}} \to D_s^{+*} D^{-*}$
23. $B^0_{\text{had}} \to J/\psi K^0_S$
24. $B^0_{\text{had}} \to J/\psi K^+ \pi^-$
25. $B^0_{\text{had}} \to J/\psi K^0_S \pi^+ \pi^-$
26. $B^0_{\text{had}} \to \Lambda_c^- p \pi^+ \pi^-$
27. $B^0_{\text{had}} \to \overline{D}^0 p \bar{p}$
28. $B^0_{\text{had}} \to D^- p \bar{p} \pi^+$
29. $B^0_{\text{had}} \to D^{-*} p \bar{p} \pi^+$
30. $B^0_{\text{had}} \to \overline{D}^0 p \bar{p} \pi^+ \pi^-$
31. $B^0_{\text{had}} \to \overline{D}^{0*} p \bar{p} \pi^+ \pi^-$

B^+ (35)

B+ channels:

0. $B^+_{\text{had}} \to \overline{D}^0 \pi^+$
1. $B^+_{\text{had}} \to \overline{D}^0 \pi^+ \pi^0$
2. $B^+_{\text{had}} \to \overline{D}^0 \pi^+ \pi^0 \pi^0$
3. $B^+_{\text{had}} \to \overline{D}^0 \pi^+ \pi^+ \pi^-$
4. $B^+_{\text{had}} \to \overline{D}^0 \pi^+ \pi^+ \pi^- \pi^0$
5. $B^+_{\text{had}} \to \overline{D}^0 D^+$
6. $B^+_{\text{had}} \to \overline{D}^0 D^+ K^0_S$
7. $B^+_{\text{had}} \to \overline{D}^{0*} D^+ K^0_S$
8. $B^+_{\text{had}} \to \overline{D}^0 D^{+*} K^0_S$
9. $B^+_{\text{had}} \to \overline{D}^{0*} D^{+*} K^0_S$
10. $B^+_{\text{had}} \to \overline{D}^0 D^0 K^+$
11. $B^+_{\text{had}} \to \overline{D}^{0*} D^0 K^+$
12. $B^+_{\text{had}} \to \overline{D}^0 D^{0*} K^+$
13. $B^+_{\text{had}} \to \overline{D}^{0*} D^{0*} K^+$
14. $B^+_{\text{had}} \to D_s^+ \overline{D}^0$
15. $B^+_{\text{had}} \to \overline{D}^{0*} \pi^+$
16. $B^+_{\text{had}} \to \overline{D}^{0*} \pi^+ \pi^0$
17. $B^+_{\text{had}} \to \overline{D}^{0*} \pi^+ \pi^0 \pi^0$
18. $B^+_{\text{had}} \to \overline{D}^{0*} \pi^+ \pi^+ \pi^-$
19. $B^+_{\text{had}} \to \overline{D}^{0*} \pi^+ \pi^+ \pi^- \pi^0$
20. $B^+_{\text{had}} \to D_s^{+*} \overline{D}^0$
21. $B^+_{\text{had}} \to D_s^+ D$
22. $B^+_{\text{had}} \to \overline{D}^0 K^+$
23. $B^+_{\text{had}} \to D^- \pi^+ \pi^+$
24. $B^+_{\text{had}} \to D^- \pi^+ \pi^+ \pi^0$
25. $B^+_{\text{had}} \to J/\psi K^+$
26. $B^+_{\text{had}} \to J/\psi K^+ \pi^+ \pi^-$
27. $B^+_{\text{had}} \to J/\psi K^+ \pi^0$
28. $B^+_{\text{had}} \to J/\psi K^0_S \pi^+$
29. $B^+_{\text{had}} \to \Lambda_c^- p \pi^+ \pi^0$
30. $B^+_{\text{had}} \to \Lambda_c^- p \pi^+ \pi^- \pi^+$
31. $B^+_{\text{had}} \to \overline{D}^0 p \bar{p} \pi^+$
32. $B^+_{\text{had}} \to \overline{D}^{0*} p \bar{p} \pi^+$
33. $B^+_{\text{had}} \to D^+ p \bar{p} \pi^+ \pi^-$
34. $B^+_{\text{had}} \to D^{+*} p \bar{p} \pi^+ \pi^-$
35. $B^+_{\text{had}} \to \Lambda_c^- p \pi^+$

Semileptonic

B^0 (7)

B0 channels:

0. $B^0_{\text{SL}} \to D^- e^+$
1. $B^0_{\text{SL}} \to D^- \mu^+$
2. $B^0_{\text{SL}} \to D^{-*} e^+$
3. $B^0_{\text{SL}} \to D^{-*} \mu^+$
4. $B^0_{\text{SL}} \to \overline{D}^0 \pi^- e^+$
5. $B^0_{\text{SL}} \to \overline{D}^0 \pi^- \mu^+$
6. $B^0_{\text{SL}} \to \overline{D}^{0*} \pi^- e^+$
7. $B^0_{\text{SL}} \to \overline{D}^{0*} \pi^- \mu^+$

B^+ (7)

B+ channels:

0. $B^+_{\text{SL}} \to \overline{D}^0 e^+$
1. $B^+_{\text{SL}} \to \overline{D}^0 \mu^+$
2. $B^+_{\text{SL}} \to \overline{D}^{0*} e^+$
3. $B^+_{\text{SL}} \to \overline{D}^{0*} \mu^+$
4. $B^+_{\text{SL}} \to D^- \pi^+ e^+$
5. $B^+_{\text{SL}} \to D^- \pi^+ \mu^+$
6. $B^+_{\text{SL}} \to D^{-*} \pi^+ e^+$
7. $B^+_{\text{SL}} \to D^{-*} \pi^+ \mu^+$

Best Candidate Selection with FEI

B tag reconstruction / BCS with FEI

- Reconstruct B tag side first
- **Best Candidate Selection (BCS)** with FEI probability (FEI BDT output)
  - Choose the highest FEI probability as the **Best Candidate**

- Recommendation from the FEI expert
  - Recon. B tag side with FEI, BCS before signal reconstruction

WARNING:

MY PERSONAL (only vaguely scientific)

OPINION

…until we have *official* usage guidelines from the task force… 50

Recommended procedure

1. (measure a ratio if you can)
2. Start with FEI skim
3. Build your tag list *first*
   a. Apply *standardized tag selections** [if you are using calibration, you ***must*** match its selections. If not, *it still may be a good idea.*]
   b. Apply best tag selection via $\mathscr{P}_{tag}$ [this does not *solve* tag/sig entanglement, but I believe that it **minimizes** it]
4. Build signal side and combine with tags
   a. Good tag definition must match calibration if using it [*probably*: isSignal!]
5. Always check for *differential* mismodeling in `decayModeIDs`…

*[*Request for task force*: provide FEI skims at multiple working points with **official** tag reconstruction, selection, and BTS]

51

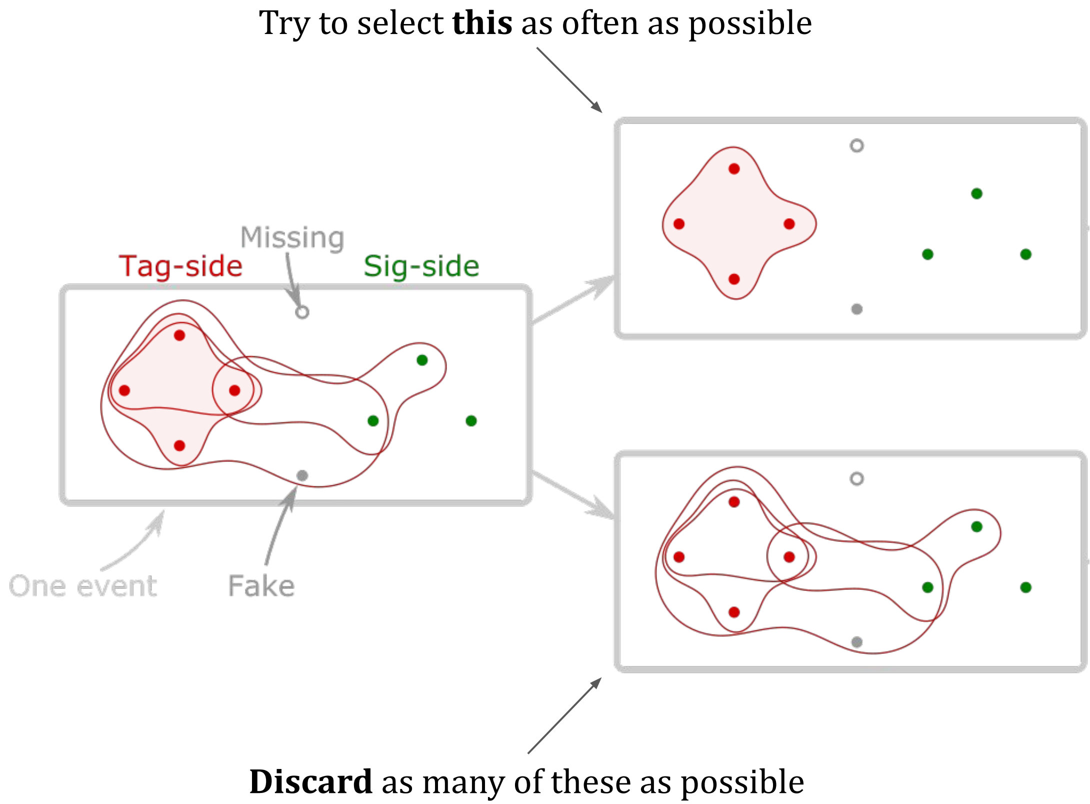
※ [Belle II Physics Week 2022, Spain, 2022.Dec.01: FEI Lecture]
https://indico.belle2.org/event/7825/contributions/49619/attachments/19751/29288/FEI.pdf

Best tag selection (BTS)

Can be helpful to select the “best” tag candidate in each event

Typically: highest $\mathscr{P}_{\text{tag}}$ in an event…

…*after* other selections.



※ [Belle II Physics Week 2022, Spain, 2022.Dec.01: FEI Lecture]
https://indico.belle2.org/event/7825/contributions/49619/attachments/19751/29288/FEI.pdf

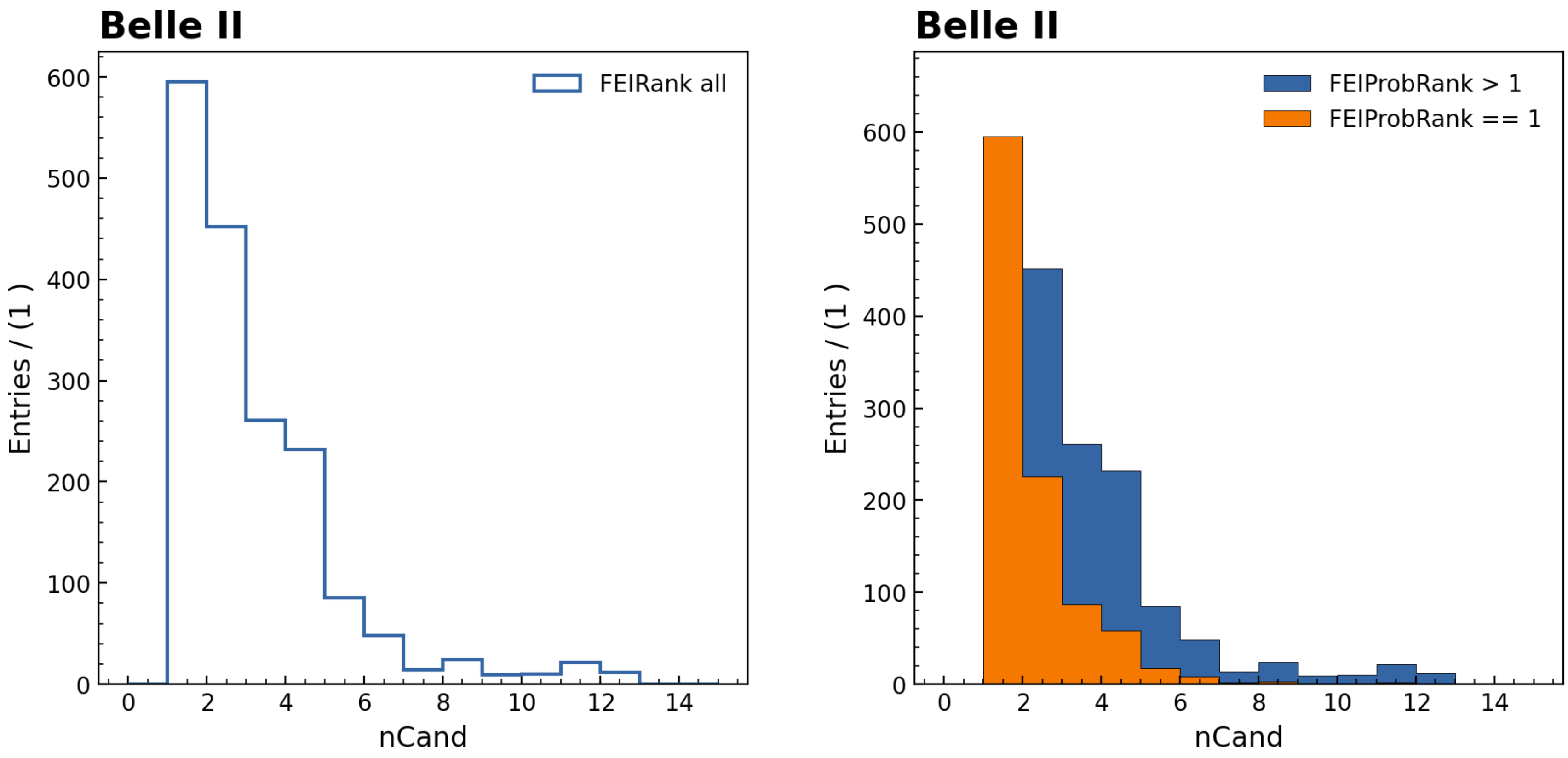
Best Candidate Selection

- BaBar
  - BCS
    - More than one B candidate is reconstructed in the same mode
      - Smallest $|\Delta E|$
    - B candidates are reconstructed in more than one mode
      - Highest

- Belle II (This Analysis Case)
  - BCS with **FEI**
    - Highest FEI probability (BDT output)

reconstructions with one or more π^0. If more than one B candidate is reconstructed in the same mode, the reconstructed B with the smallest $|\Delta E|$ is selected. For each mode, the purity B_{pur} is the ratio of the number of events before signal selection in the fitted peak to the total number of events in the region $5.27 < m_{\mathrm{ES}} < 5.29$ GeV. Only events reconstructed in a mode with $B_{\mathrm{pur}} > 0.12$ are selected, which results in the reconstruction of 147 distinct modes in the data sample. If B candidates are reconstructed in more than one mode, the B reconstructed in the mode with the highest B_{pur} is selected as the companion B.

Best Candidate Selection



Sub-decay modes

Software Version:
light-2210-devonrex

Strategy: Simpler (?) one first!

Reconstruction: current version

- $\Upsilon(4S) \rightarrow B_{tag} B_{sig}$
  - 01: $B_{sig} \rightarrow e^+ e^-$
  - 02: $B_{sig} \rightarrow e^+ \mu^-$
  - 03: $B_{sig} \rightarrow e^+ \pi^-$
  - 04: $B_{sig} \rightarrow \mu^+ \mu^-$
  - 05: $B_{sig} \rightarrow \mu^+ \pi^-$
  - 06: $B_{sig} \rightarrow \pi^+ \pi^-$

Name	τ decay modes
e^+e^-	$\tau \rightarrow e\nu_e\nu_\tau,\ \tau \rightarrow e\nu_e\nu_\tau$
$e^\pm\mu^\mp$	$\tau \rightarrow e\nu_e\nu_\tau,\ \tau \rightarrow \mu\nu_\mu\nu_\tau$
$e^\pm\pi^\mp$	$\tau \rightarrow e\nu_e\nu_\tau,\ \tau \rightarrow \pi\nu_\tau$
$\mu^+\mu^-$	$\tau \rightarrow \mu\nu_\mu\nu_\tau,\ \tau \rightarrow \mu\nu_\mu\nu_\tau$
$\mu^\pm\pi^\mp$	$\tau \rightarrow \mu\nu_\mu\nu_\tau,\ \tau \rightarrow \pi\nu_\tau$
$\pi^+\pi^-$	$\tau \rightarrow \pi\nu_\tau,\ \tau \rightarrow \pi\nu_\tau$

$B^0 \rightarrow \tau^+\tau^-$ sub-decay channels

Reconstruction: Add ρ (future?)

- $\Upsilon(4S) \rightarrow B_{tag} B_{sig}$
  - 01: $B_{sig} \rightarrow e^+ e^-$
  - 02: $B_{sig} \rightarrow e^+ \mu^-$
  - 03: $B_{sig} \rightarrow e^+ \pi^-$
  - 04: $B_{sig} \rightarrow \boldsymbol{e^+ \rho^-}$
  - 05: $B_{sig} \rightarrow \mu^+ \mu^-$
  - 06: $B_{sig} \rightarrow \mu^+ \pi^-$
  - 07: $B_{sig} \rightarrow \boldsymbol{\mu^+ \rho^-}$
  - 08: $B_{sig} \rightarrow \pi^+ \pi^-$
  - 09: $B_{sig} \rightarrow \boldsymbol{\pi^+ \rho^-}$
  - 10: $B_{sig} \rightarrow \boldsymbol{\rho^+ \rho^-}$
    - $\rho^+ \rightarrow \pi^0\pi^+$
      - $\pi^0 \rightarrow \gamma\gamma$

Final State Particle Selection

Software Version:
light-2210-devonrex

Final State Particle Selection

- All Charged Tracks
  - Impact Parameter
    - $|dz| < 4\ cm$
    - $dr < 2\ cm$
      - [Old] Ref: [4.2.1. Chaoyi's study] https://docs.belle2.org/record/2801/
      - [Old] Ref: [Early Phase III Recommendation] https://confluence.desy.de/display/BI/Selection+Cuts+and+Modes+for+WG1+Early+Phase+III+Studies
      - [Old] Ref: [Phase II Recommndation] https://confluence.desy.de/display/BI/Phase+2+Best+Practices+for+Data
      - [Old] Ref: [B2-006 B2note] https://docs.belle2.org/record/2204
        - For ROE, Looser cuts, in order to include V0 particles (?), Why?
      - Ref: Performance Webhome
        - https://confluence.desy.de/display/BI/Physics+Performance+Webhome
  - CDC variables
    - nCDCHits > 20
    - ThetaInCDCAppectance

Software Version:
light-2210-devonrex

Final State Particle Selection

- electron
  - electronID_noSVD_noTOP > 0.9
- muon
  - muonID_noSVD > 0.9
- π^+
  - binaryPID(211, 321) > 0.6
    ※ 211: π^+, 321: K^+

Software Version:
light-2210-devonrex

Pages / ... / Charged PID performance 2 Jira links

Hadron ID Performance

Torben Ferber posted on 21. Aug. 2019 07:44h - last edited by Marco Milesi on 28. Apr. 2022 15:44h

This page contains details about ongoing activities/tasks on hadron identification.

Guidelines

Recommended track selection for hadron ID performance studies:

- `[abs(dr) < 2] and [abs(dz) < 4]`
- `nCDCHits > 20`

※ [Confluence: Hadron ID Performance] https://confluence.desy.de/display/BI/Hadron+ID+Performance

Performance Group Recommendation

Software Version:
light-2210-devonrex

ICHEP 2020

Recommended data/MC combinations

	MC13a	MC13b	MC13a_proc11	MC13b_proc11
proc10	yes	yes	no	no
proc11 + bucket 9/10/11/12 (off-resonance)	**yes (default)**	**no**	**yes**	**yes (performance study)**

MC13a_proc11 (run-independent with some updated payloads since the start of MC13a) status:
- [x] ~~BIIDP-2791~~ - MC13 run-independent MC corresponding to proc11 CLOSED

MC13b_proc11 (run-dependent with conditions based on proc11) status:
- [x] ~~BIIDP-2695~~ - MC13 run-dependent MC corresponding to proc11 RESOLVED

The default sample for ICHEP physics is proc11 + bucket 9/10/11 and MC13a. MC13a_proc11 will not be ready in time for ICHEP for most analyses.

Recommendations and performance results

We do not provide recommendations for analysis-dependent selections for charged particles, but report the selections used to obtain performance (PID, tracking) results. We also provide studies how variations of selection parameters modify the performance results.

We provide recommendations for neutrals (photons and pi0).

	Selection used in performance study	Sensitivity of performance to changes of selection
Lepton ID	|dr| < 2 cm, |dz| < 5 cm	Should be robust against IP cuts, certainly OK to be tighter than these - TBA.
Hadron ID	|dr| < 2cm, |dz| < 4cm, nCDCHits > 20	
Tracking	|dz| < 3cm, dr<1cm	• variation in IP cuts: *TBA* • nCDCHits cut: *TBA*
Neutrals	pi0 Recommendations	

※ [Confluence: Conference Readiness] https://confluence.desy.de/display/BI/Conference+readiness

Software Version: **light-2210-devonrex**

Pages /... / Lepton ID Performance 1 Jira link

Recommendations for Lepton ID - release 6

Marco Milesi posted on 10. Oct. 2022 00:31h - last edited by Marco Milesi on 23. Dec. 2022 12:41h

PID method	Global/Binary	Electrons	Muons
Likelihood ratio	G	electronID_noSVD_noTOP	muonID_noSVD
Likelihood ratio	B	binaryElectronID_noSVD_noTOP_pi	binaryMuonID_noSVD_pi
BDT	G (multi-classification)	pidChargedBDTScore_e	pidChargedBDTScore_mu
BDT	B (binary classification)	pidPairChargedBDTScore_e_pi	pidPairChargedBDTScore_mu_pi

※ [E-mail] [coll-members:8561] First version of lepton ID recommendations for **Moriond2023**
※ [Recommendations for Lepton ID - release 6]
https://confluence.desy.de/pages/viewpage.action?spaceKey=BI&title=Recommendations+for+Lepton+ID+-+release+6

"[coll-members:8514] PID recommedations for Moriond 2023"

Dear All,

we would like to clarify what are the recommended PID variables for release-06 and MC15 (Moriond 2023 data set).

1) **electronID:**

The recommended variables are the BDT based (pidChargedBDTScore), as they provide much lower fake rates than the likelihood based variables for equivalent efficiency.

Likelihood based variables are still ok to use and maintained by the PID group, but please note that a significant issue with the SVD electron likelihoods for high momentum particles in the MC has been discovered, see:

https://indico.belle2.org/event/8230/contributions/50028/attachments/19872/29453/2022.12.07-PP_kuno.pdf

The likelihood based variables that we recommend to use are:

electronID_noSVD_noTOP, binaryElectronID_noSVD_noTOP_pi

(unfortunately we could not catch the issue during the validation phase, as we used only a Ks sample, that gives only low momentum pions)

2) **muonID:**

For muons there is no clear preference between BDT and likelihood based variables (in some corners of the phase space the likelihood variables perform better), so please spend some time testing which ones are best for your analysis.

If you are using the likelihood based variables, please use:

muonID_noSVD, binaryMuonID_noSVD_pi

3) **hadronID:**

The default likelihood based variables (global or binary, depending on your needs) are recommended.

The reweighted PID variables (pidWeightedProbabilityExpert, ...) can be used, but they require some care: check that the performance is better that the default variables and if needed re-train the weights in order to match your needs. You should use the Systematics Framework (ntuples) to make your own correction tables. If you need help, please get in touch with us.

The leptonID data/MC correction tables should become available in a very few days. For more details, please see this JIRA ticket: https://agira.desy.de/browse/BIIPERF-185

Best regards,

Marco, Kenta, Ale

Conclusions / recommendations

- ElectronID: **pidChargedBDT** or **electronID_noSVD_noTOP**;
  (very large data/MC discrepancies if you use e likelihoods from SVD)

- MuonID: **pidChargedBDT** or **muonID_noSVD**;
  (no clear preference between the two)

- HadronID: the binary likelihood ratios are perfectly fine as long as they don't involve electrons. The global likelihood ratios should be ok in most cases.
  The reweighted likelihood is also an option, but it's not guaranteed to be better than the standard and possibly needs retraining (which you can easily do).

As always:

- take a look to a data control sample as soon as possible;
- if the data/MC correction factors are not far from 1, you are going to be ok;
- any problems/doubts/questions? Talk to us!

December 12th 2022 15

※ [SL WG Meeting, 2022.Dec.13] https://indico.belle2.org/event/8248/#7-introduction

Final State Particle: Code

```
def FinalStateParticles(Path):

    # Charged Particles
    from stdCharged import stdE, stdMu, stdPi

    # Track cuts
    # Performance Group Recommendation
    # [Confluence: Conference Readiness => ICHEP 2020]
    # https://confluence.desy.de/display/BI/Conference+readiness

    trackCuts = '-4.0 < dz < 4.0'
    trackCuts += ' and dr < 2.0'
    trackCuts += ' and nCDCHits > 20'
    trackCuts += ' and thetaInCDCAcceptance'

    # (S)L WG (WG1) Group Recommendation
    # [2022.Dec.13 (S)L WG Introduction Slide]
    # https://indico.belle2.org/event/8248/#7-introduction
    eCut  = trackCuts + ' and electronID_noSVD_noTOP > 0.9'
    muCut = trackCuts + ' and muonID_noSVD > 0.9'
    piCut = trackCuts + ' and binaryPID(211, 321) > 0.6' # 211: pi+, 321: K+

    ma.fillParticleList('e+:cut', eCut, path=Path)
    ma.fillParticleList('mu+:cut', muCut, path=Path)
    ma.fillParticleList('pi+:cut', piCut, path=Path)
```

Rest of Event (ROE)

ROE Selection

Software Version:
light-2210-devonrex

Rest of Event (ROE)

ROE Track

- **ROE Good Tracks == 0**
  - ROE Good Tracks
    - $|dz| < 4\ cm$
    - $dr < 2\ cm$
    - nCDCHits > 20
    - ThetaInCDCAppectance

ROE Clusters

- Currently applied
  - clusterNHits > 1.5
  - $\theta_{cluster}$ in CDCAcceptance
    ※ 0.296706 < theta < 2.61799
  - clusterE $> [80, 30, 60] MeV$ (fwd, brr, bwd)
  - |clusterTiming| $< 200\ ns$
  - |clusterTiming / ErrorTiming| > 2.0
  - minC2TDist $> 20\ cm$

※ ROE cuts, Ref: $B^0 \to K^{*0}\tau^+\tau^-$ by Stefano Moneta
Indico Link (2022.Sep.13, 28th EWP meeting): https://indico.belle2.org/event/7723/#2-b-ktautau-with-fei

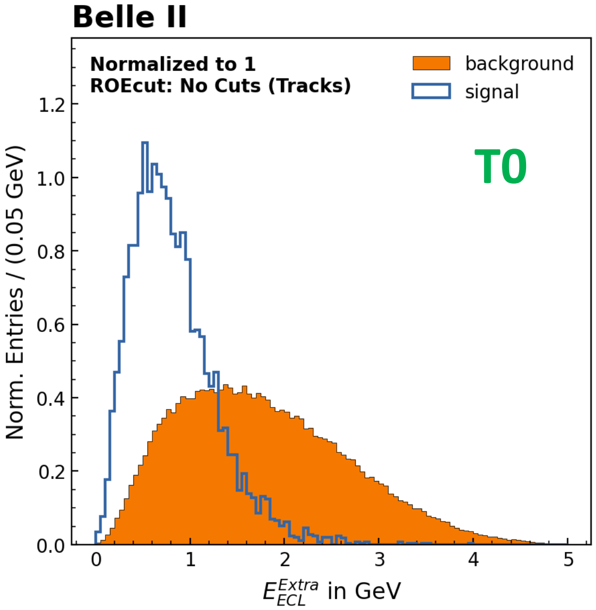
ROE cuts

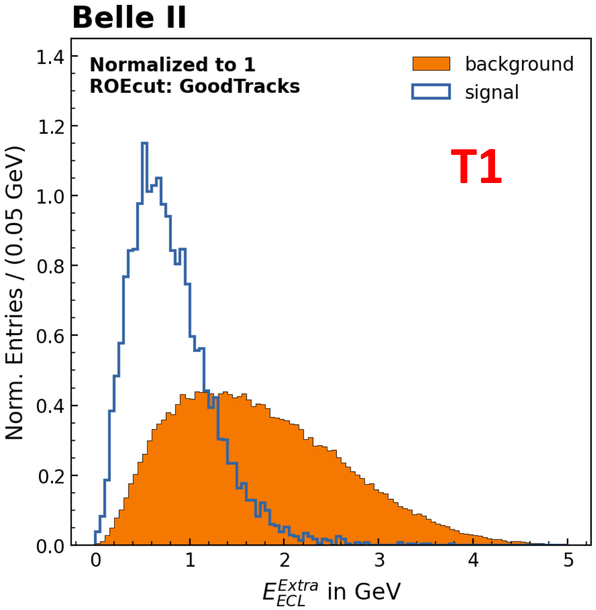
ROE Mask name	Track Cuts	Cluster Cuts
Tracks **T0**	No cuts	No cuts
GoodTracks **T1**	▪ $dr < 2\ cm$ ▪ $\|dz\| < 4\ cm$ ▪ nCDCHits > 20 ▪ ThetaInCDCAppectance	No cuts
Clusters_loc **C1**	No cuts	▪ clusterNHits > 1.5 ▪ $\theta_{cluster}$ in CDCAcceptance ※ 0.296706 < theta < 2.61799 ▪ clusterE $> [80, 30, 60]MeV$ (fwd, brr, bwd)
Clusters_loc_timing **C2**	No cuts	Cluster_loc + |clusterTiming| $< 200\ ns$
Clusters_loc_timing_errtiming **C3**	No cuts	Cluster_loc_timing + |clusterTiming / ErrorTiming| > 2.0
Clusters_distance **C4**	No cuts	Cluster_loc_timing_errtiming + minC2TDist $> 20\ cm$
~~Cluters_splitoff~~	~~No cuts~~	Cluster_loc_timing ~~+ beamBackgroundProbabilityMVA~~ > 0.1

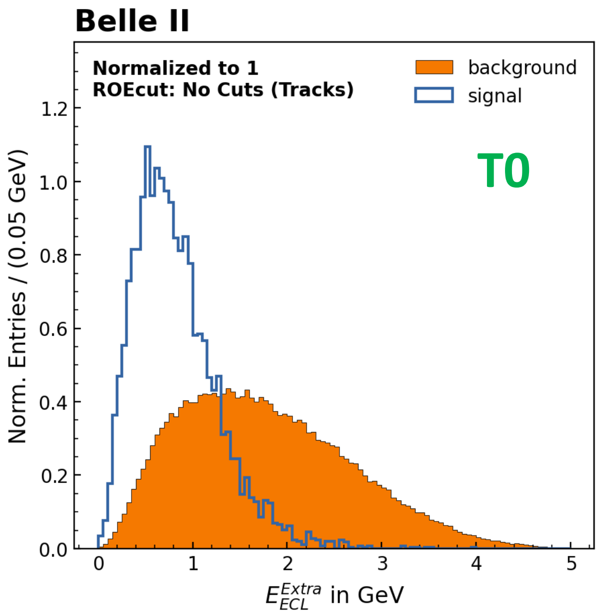
※ ROE cuts, Ref: $B^0 \to K^{*0}\tau^+\tau^-$ reconstruction code by Stefano Moneta
- Code Link: https://gitlab.desy.de/stefano.moneta/btokst_tau_tau/-/tree/main/reconstruction
- Indico Link (2022.Sep.13, 28th EWP meeting): https://indico.belle2.org/event/7723/#2-b-ktautau-with-fei

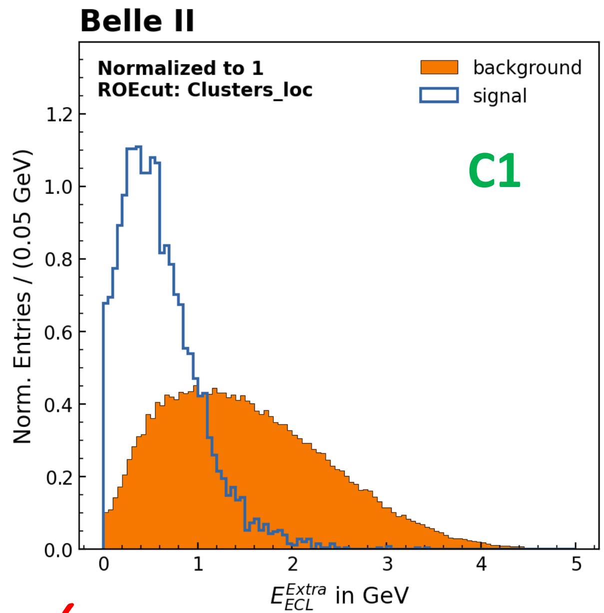
※ Ref: [Confluence Page] Neutral Performance, $E_{ECL}(E_{Extra})$ Selections
- Link: https://confluence.desy.de/display/BI/Neutrals+Performance

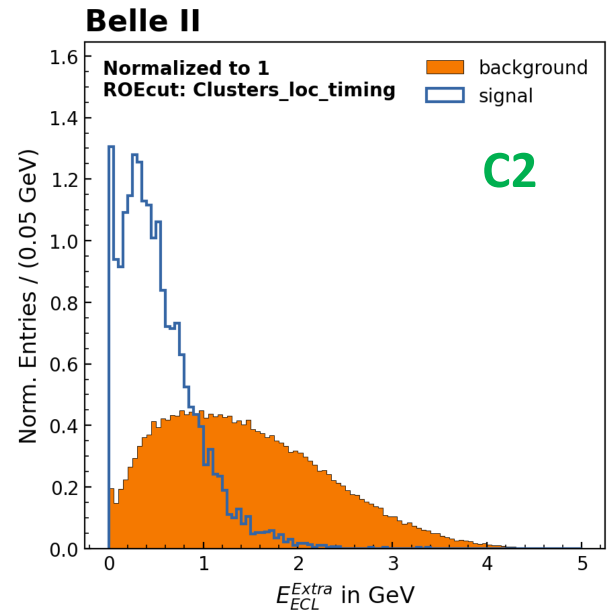
ROE cuts: Tracks Cuts

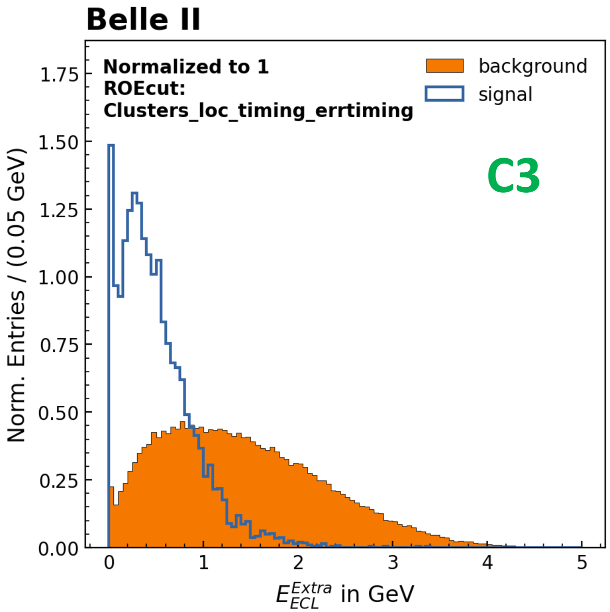


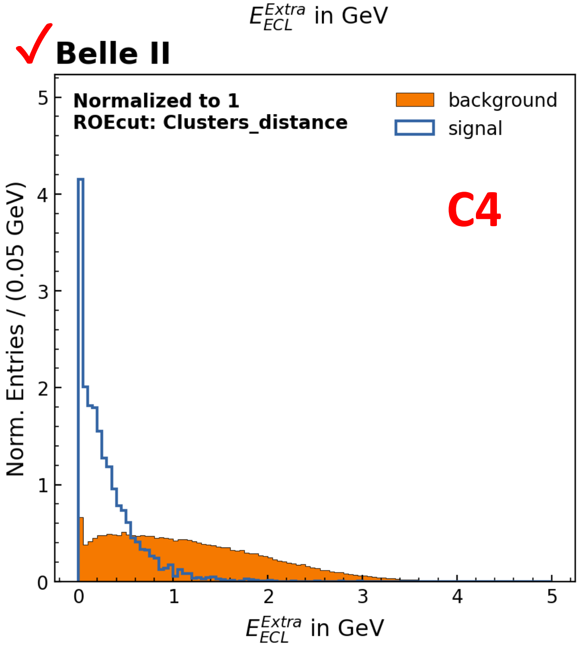



Belle II
Normalized to 1
ROEcut: No Cuts (Tracks)
background
signal
T0
Norm. Entries / (0.05 GeV)
E_{ECL}^{Extra} in GeV

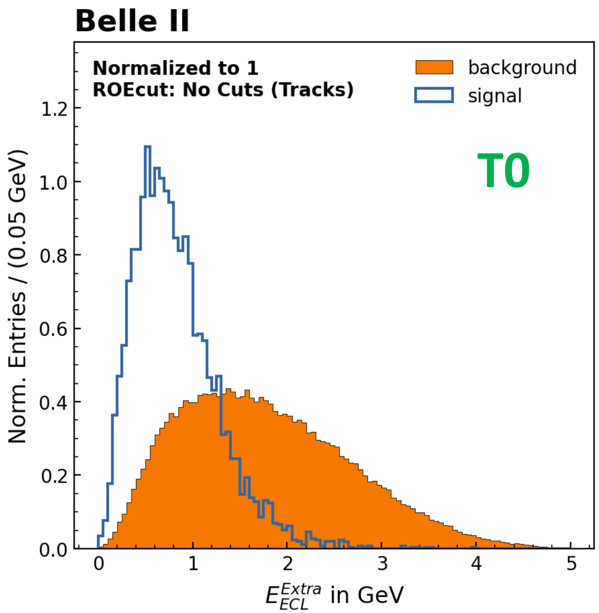

Belle II
Normalized to 1
ROEcut: Clusters_loc
background
signal
C1
Norm. Entries / (0.05 GeV)
E_{ECL}^{Extra} in GeV

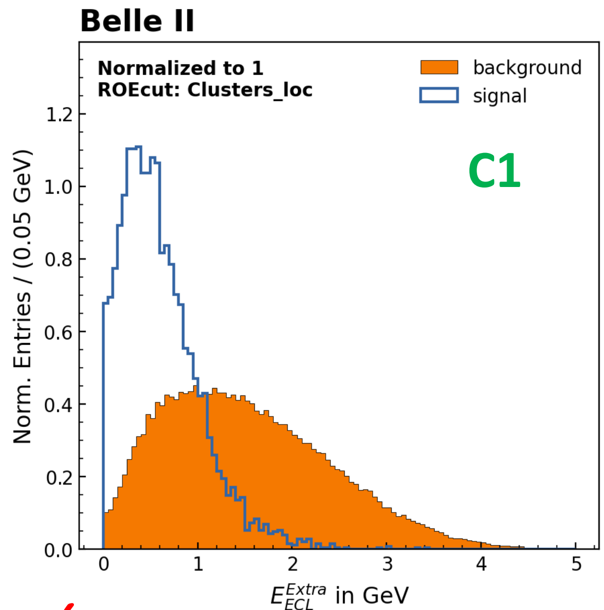

Belle II
Normalized to 1
ROEcut: Clusters_loc_timing
background
signal
C2
Norm. Entries / (0.05 GeV)
E_{ECL}^{Extra} in GeV

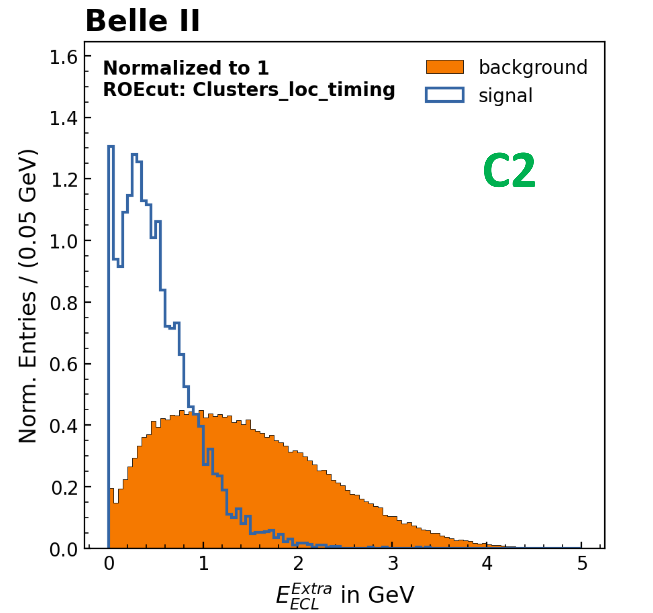

Belle II
Normalized to 1
ROEcut:
Clusters_loc_timing_errtiming
background
signal
C3
Norm. Entries / (0.05 GeV)
E_{ECL}^{Extra} in GeV

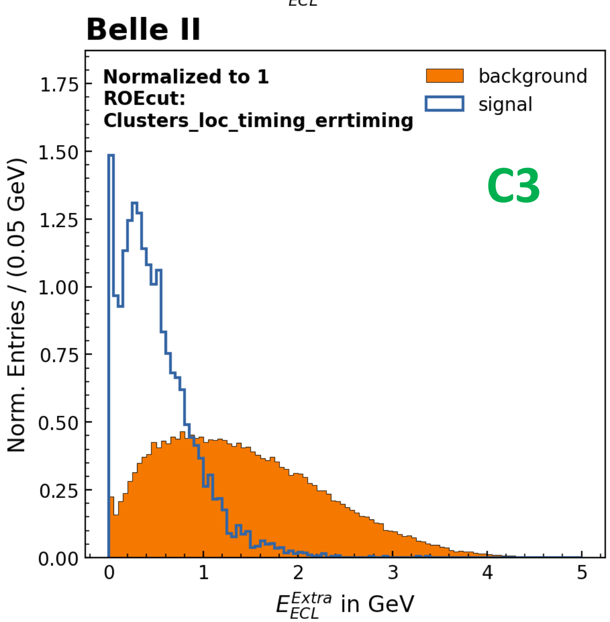

Belle II
Normalized to 1
ROEcut: Clusters_distance
background
signal
C4
Norm. Entries / (0.05 GeV)
E_{ECL}^{Extra} in GeV

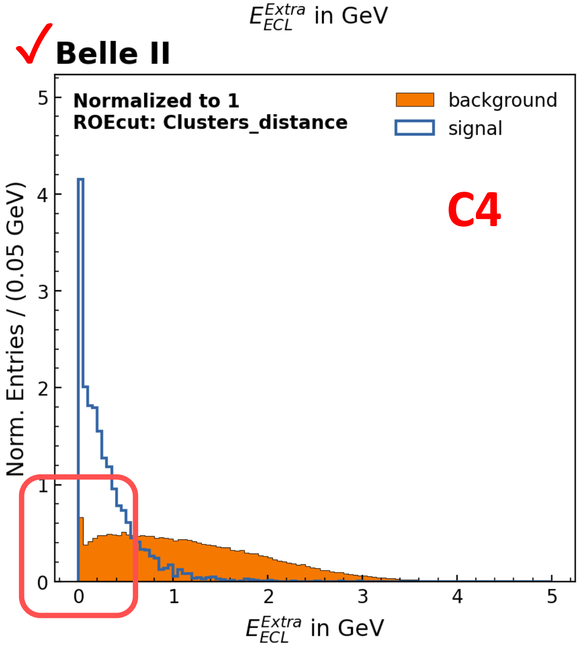
ROE cuts: Cluster Cuts











Pre-Selection for BDT input

Pre-Selection

- **Signal MC study (main)**
  - E_{ECL}^{extra} plot by **ROE cuts**
  - **Pre-selection**
    - Major variables: E_{ECL}^{extra}, M_{bc}^{tag}, ΔE^{tag}, $\mathcal{N}_{tag}$, M_{miss}^{2}

Belle pre-selection (BN-1390): Table 6.2

Pre-selection cuts and corresponding values for the signal and background rejection in percent. The cuts are applied successively.

Cut	Signal rejection in %	Background rejection in %
$E_{\mathrm{ECL}} < 1.2$ GeV	2.65	58.23
$M_{\mathrm{bc}}^{\mathrm{tag}} > 5.27$ GeV/c^2	0.84	76.52
$\lvert\Delta E_{\mathrm{tag}}\rvert < 50$ MeV	14.26	47.29
$\mathcal{N}_{\mathrm{tag}} > 0.05$	34.78	72.08
$M_{\mathrm{miss}}^2 > 0.5$ (GeV/c^2)^2	0.84	2.01
Total	46.47	98.59

Belle II pre-selection (exactly same cuts as Belle)

Pre-selection cuts and corresponding values for the signal and background rejection in percent. The cuts are applied successively.

Cut	Signal rejection in %	Background rejection in %
$E_{ECL}^{Extra} < 1.2$ GeV	1.71 (99/5788)	44.01 (120849/274604)
$M_{bc}^{tag} > 5.27$ GeV/c^2	0.67 (38/5689)	27.25 (41897/153755)
$\lvert\Delta E_{tag}\rvert < 50$ MeV	17.94 (1014/5651)	40.65 (45468/111858)
$\mathcal{N}_{tag} > 0.05$	19.58 (908/4637)	47.05 (31234/66390)
$M_{miss}^2 > 0.5$ (GeV/c^2)^2	7.88 (294/3729)	6.24 (2195/35156)
Total	40.65 (2353/5788)	88.00 (241643/274604)

Belle II pre-selection (exactly same cuts as Belle)

Pre-selection cuts and corresponding values for the signal and background rejection in percent. The cuts are applied successively.

Cut	Signal rejection in %	Background rejection in %
$E_{ECL}^{Extra} < 1.2$ GeV	1.71 (99/5788)	44.01 (120849/274604)
$M_{bc}^{tag} > 5.27$ GeV/c²	0.67 (38/5689)	27.25 (41897/153755)
$\lvert\Delta E_{tag}\rvert < 50$ MeV	17.94 (1014/5651)	40.65 (45468/111858)
$\mathcal{N}_{tag} > 0.05$	19.58 (908/4637)	47.05 (31234/66390)
$M_{miss}^2 > 0.5$ (GeV/c²)²	7.88 (294/3729)	6.24 (2195/35156)
Total	40.65 (2353/5788)	88.00 (241643/274604)

Belle II pre-selection

Pre-selection cuts and corresponding values for the signal and background rejection in percent. The cuts are applied successively.

Cut	Signal rejection in %	Background rejection in %
$E_{ECL}^{Extra} < 1.2$ GeV	1.71 (99/5788)	44.01 (120849/274604)
$M_{bc}^{tag} > 5.27$ GeV/c²	0.67 (38/5689)	27.25 (41897/153755)
-100 MeV $< \Delta E_{tag} <$ 50 MeV	7.49 (423/5651)	26.13 (29228/111858)
$\mathcal{N}_{tag} > 0.05$	21.16 (1106/5228)	51.25 (42349/82630)
$M_{miss}^2 < 18$ (GeV/c²)²	3.76 (155/4122)	4.98 (2005/40281)
Total	**31.46** (1821/5788)	**86.06** (236328/274604)

Belle II pre-selection (exactly same cuts as Belle)

Pre-selection cuts and corresponding values for the signal and background rejection in percent. The cuts are applied successively.

Cut	Signal rejection in %	Background rejection in %
$E_{ECL}^{Extra} < 1.2$ GeV	1.71 (99/5788)	44.01 (120849/274604)
$M_{bc}^{tag} > 5.27$ GeV/c²	0.67 (38/5689)	27.25 (41897/153755)
$\lvert\Delta E_{tag}\rvert < 50$ MeV	17.94 (1014/5651)	40.65 (45468/111858)
$\mathcal{N}_{tag} > 0.05$	19.58 (908/4637)	47.05 (31234/66390)
$M_{miss}^2 > 0.5$ (GeV/c²)²	7.88 (294/3729)	6.24 (2195/35156)
Total	40.65 (2353/5788)	88.00 (241643/274604)

Belle II pre-selection

Pre-selection cuts and corresponding values for the signal and background rejection in percent. The cuts are applied successively.

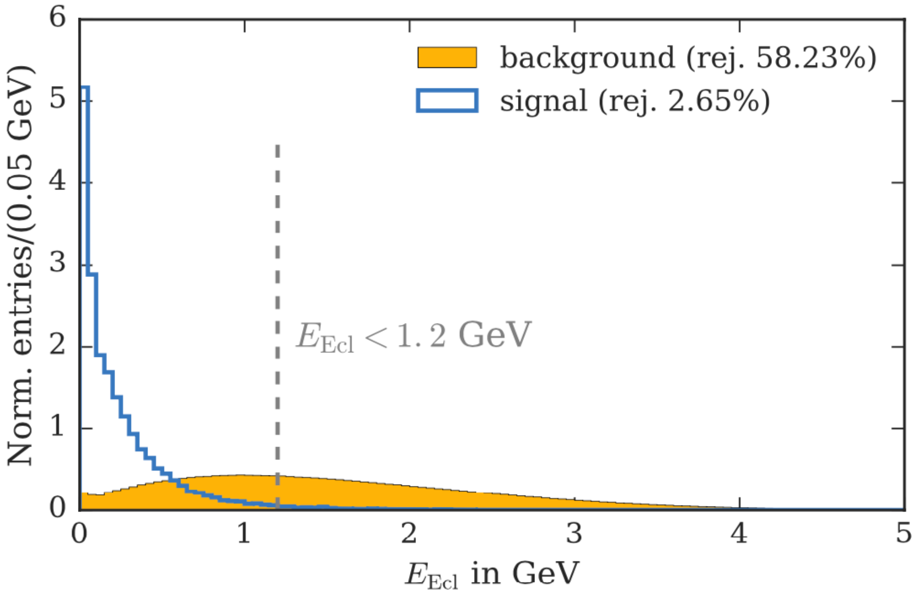
Cut	Signal rejection in %	Background rejection in %
$E_{ECL}^{Extra} < 1.2$ GeV	1.71 (99/5788)	44.01 (120849/274604)
$M_{bc}^{tag} > 5.27$ GeV/c²	0.67 (38/5689)	27.25 (41897/153755)
$\mathbf{-100\ MeV < \Delta E_{tag} < 50\ MeV}$	7.49 (423/5651)	26.13 (2922[illegible]/111858)
$\mathcal{N}_{tag} > 0.05$	21.16 (1106/5228)	51.25 (42349/82630)
$\mathbf{M_{miss}^2 < 18}$ **(GeV/c²)²**	3.76 (155/4122)	4.98 (2005/40281)
Total	**31.46** (1821/5788)	**86.06** (236328/274604)

SHOULD BE UPDATED!

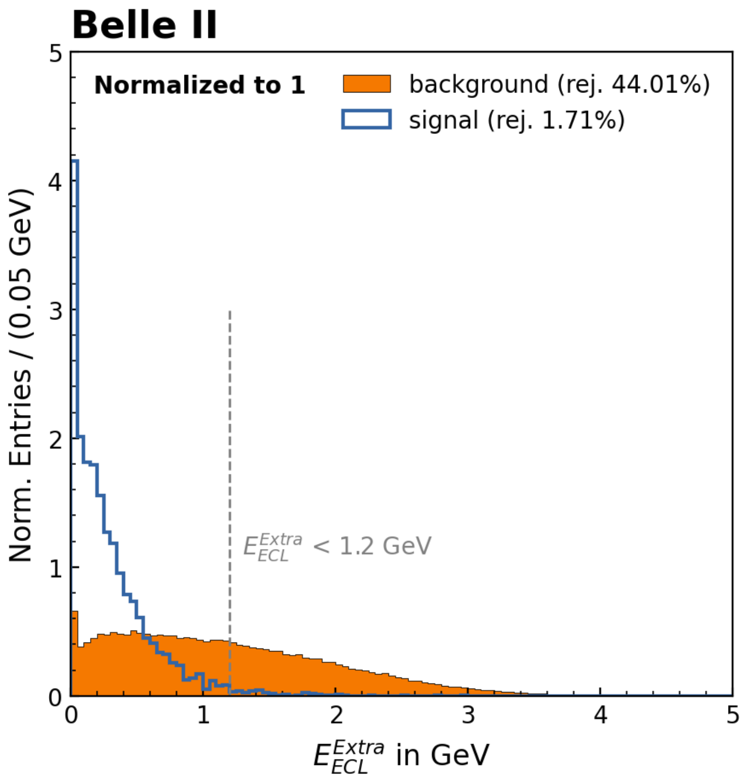
- Major variables: $\boldsymbol{E_{ECL}^{Extra}}$, M_{bc}^{tag}, ΔE^{tag}, $\mathcal{N}_{tag}$, M_{miss}^2

"Extra energy in ECL cluster"

Belle pre-selection (BN-1390)



Signal and background E_{ECL} distributions.
Events with $E_{ECL}^{Extra} < 1.2$ GeV are selected.

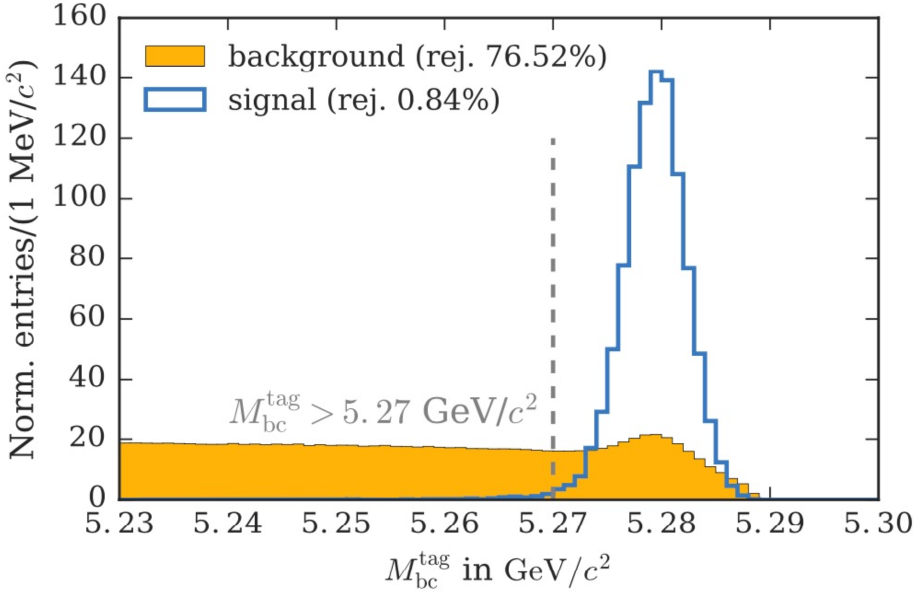


Signal and background E_{ECL} distributions.
Events with $\boldsymbol{E_{ECL}^{Extra} < 1.2}$ **GeV** are selected.

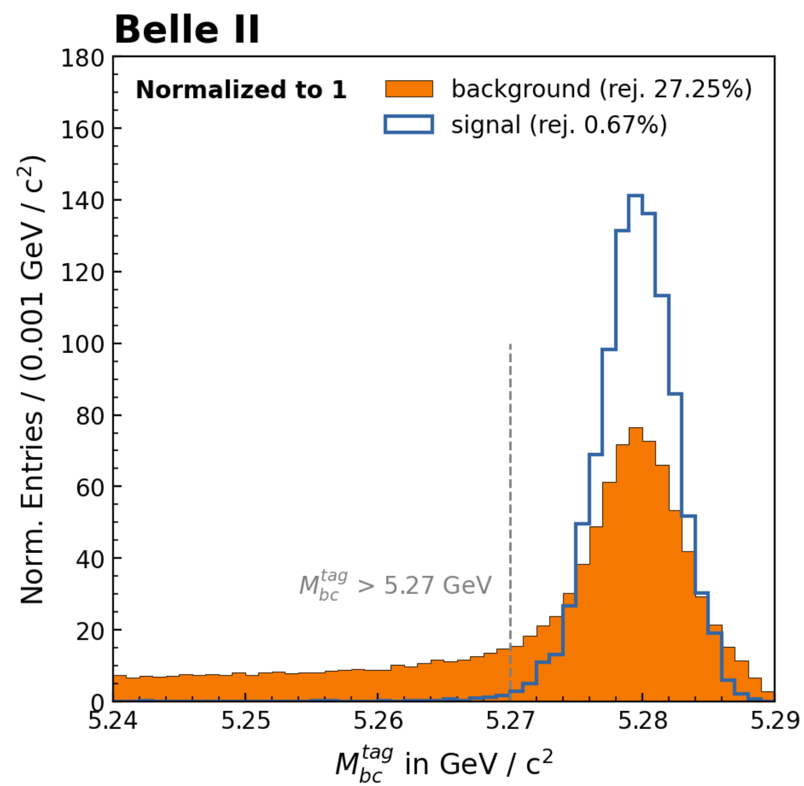
- Major variables: E_{ECL}^{Extra}, $\boldsymbol{M_{bc}^{tag}}$, ΔE^{tag}, $\mathcal{N}_{tag}$, M_{miss}^2

"Tag-side M_{bc}"

Belle pre-selection (BN-1390)



Signal and background M_{bc}^{tag} distributions.
Events with $M_{bc}^{tag} > 5.27$ GeV/c² are selected.
(E_{ECL}^{Extra} cut is applied.)



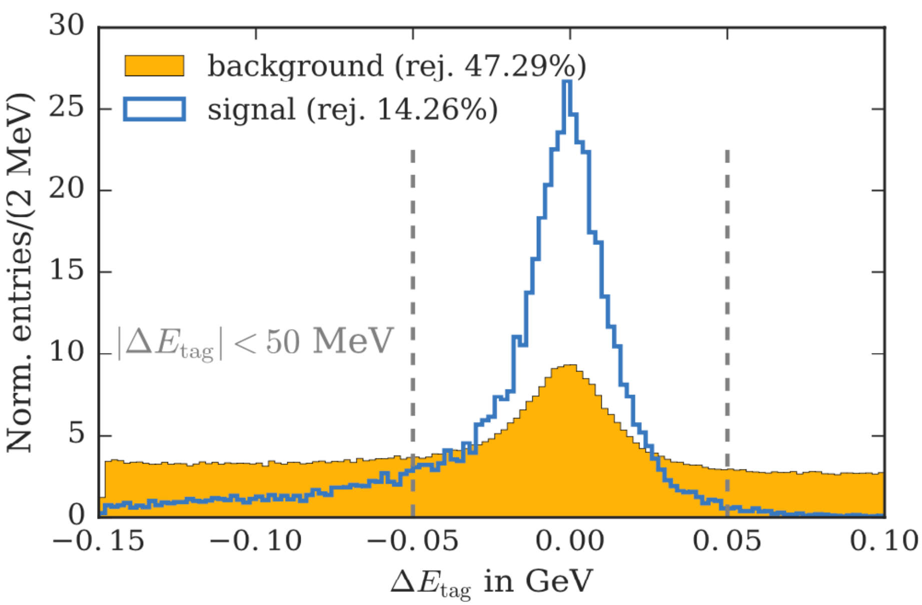
Signal and background M_{bc}^{tag} distributions.
Events with $\boldsymbol{M_{bc}^{tag} > 5.27}$ **GeV/c²** are selected.
(E_{ECL}^{Extra} cut is applied.)

Pre-selection: ΔE^{tag} plot

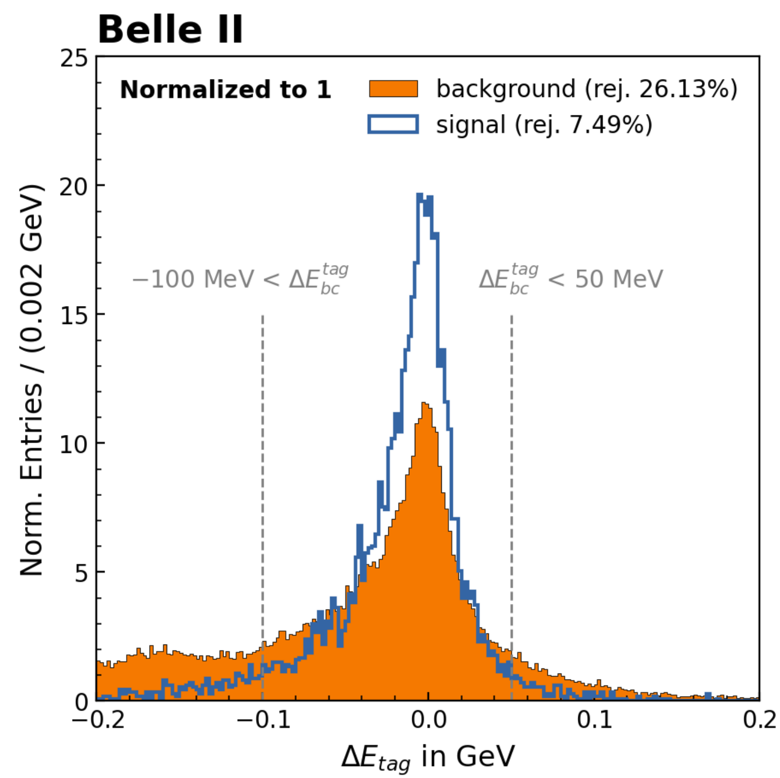
- Major variables: E_{ECL}^{Extra}, M_{bc}^{tag}, **ΔE^{tag}**, $\mathcal{N}_{tag}$, M_{miss}^{2}

"Tag-side ΔE"

Belle pre-selection (BN-1390)



Signal and background ΔE_{tag} distributions.
Events with $|\Delta E_{tag}| < 50$ MeV are selected.
(E_{ECL}^{Extra}, M_{bc}^{tag} cuts are applied.)



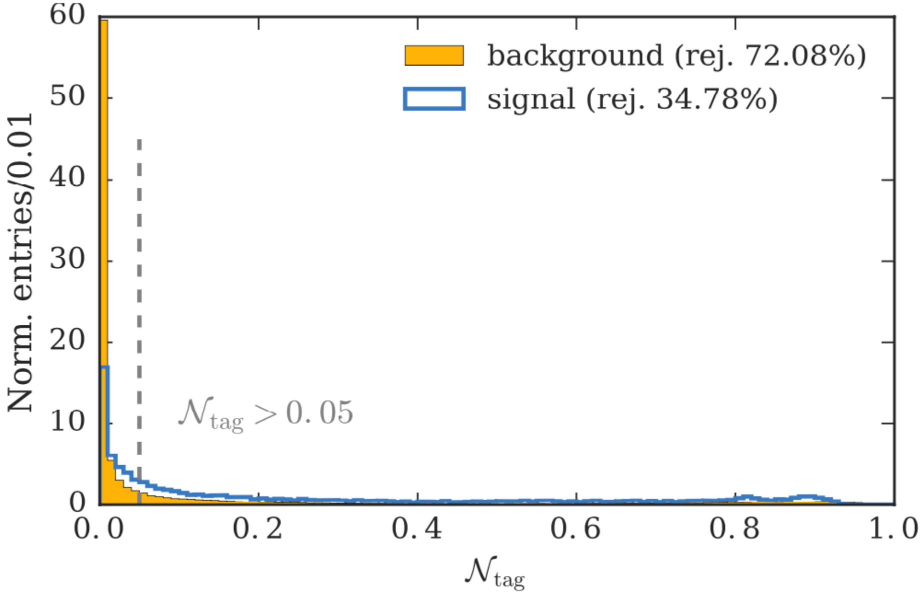
Signal and background ΔE_{tag} distributions.
Events with -100 **MeV** $< \Delta E_{tag} <$ **50 MeV** are selected.
(E_{ECL}^{Extra}, M_{bc}^{tag} cuts are applied.)

Pre-selection: $\mathcal{N}_{tag}$ plot

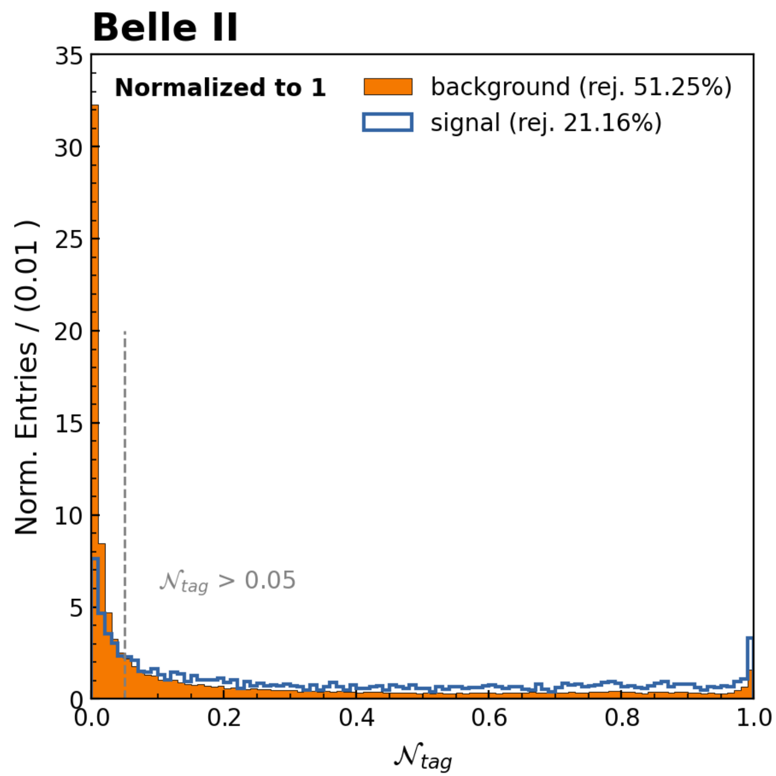
- Major variables: E_{ECL}^{Extra}, M_{bc}^{tag}, ΔE^{tag}, $\boldsymbol{\mathcal{N}_{tag}}$, M_{miss}^2

"Tag-side (FEI) Signal Probability"

Belle pre-selection (BN-1390)



Signal and background $\mathcal{N}_{tag}$ distributions.
Events with $\mathcal{N}_{tag} > 0.05$ are selected.
(E_{ECL}^{Extra}, M_{bc}^{tag}, ΔE^{tag} cuts are applied.)

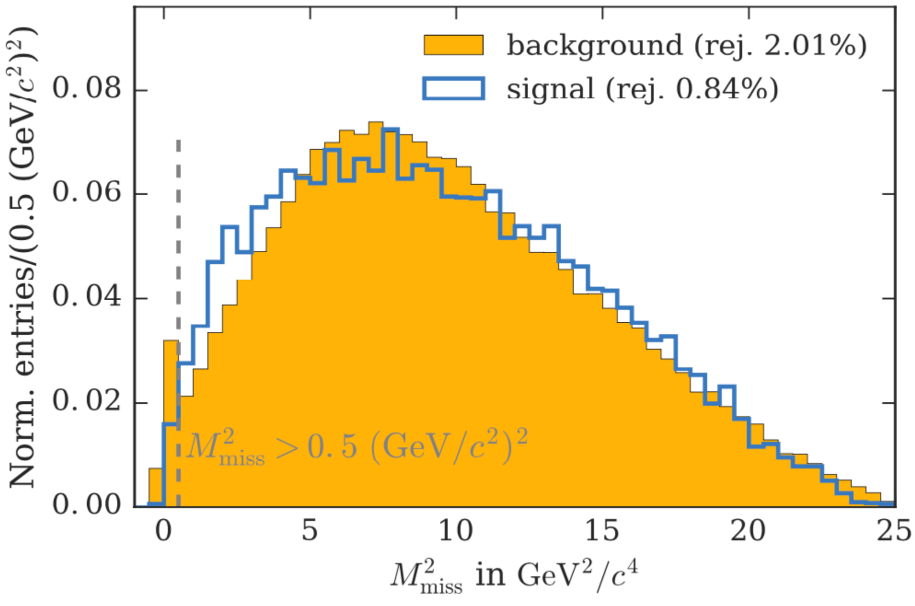


Signal and background $\mathcal{N}_{tag}$ distributions.
Events with $\boldsymbol{\mathcal{N}_{tag} > 0.05}$ are selected.
(E_{ECL}^{Extra}, M_{bc}^{tag}, ΔE^{tag} cuts are applied.)

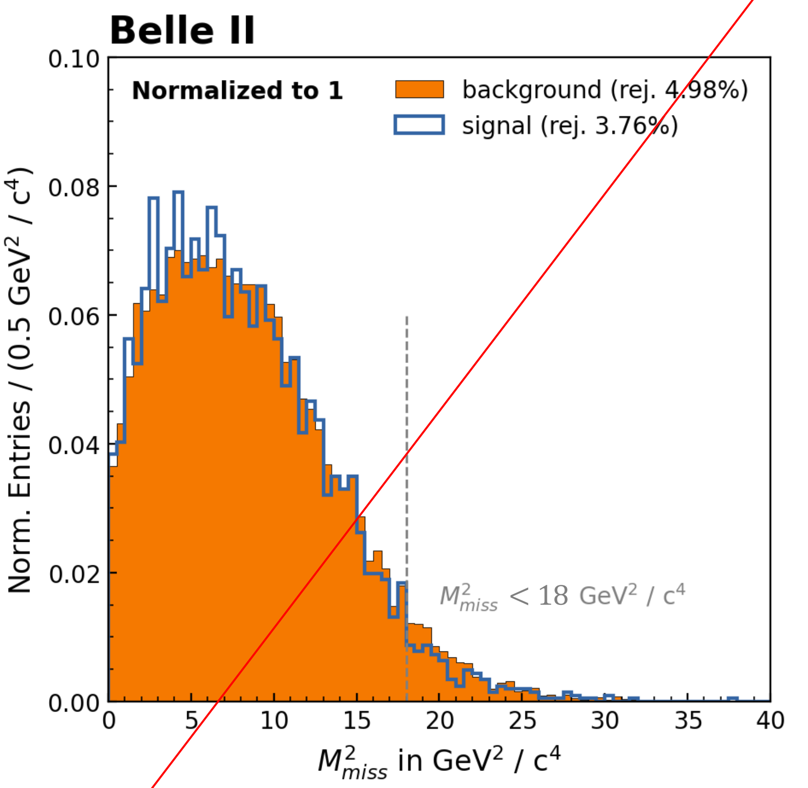
- Major variables: E_{ECL}^{Extra}, M_{bc}^{tag}, ΔE^{tag}, $\mathcal{N}_{tag}$, $\boldsymbol{M_{miss}^2}$

"Missing Mass Squared"

Belle pre-selection (BN-1390)



Signal and background M_{miss}^2 distribution.
Events with $M_{miss}^2 > 0.5$ (GeV/c²)² are selected.
(E_{ECL}^{Extra}, M_{bc}^{tag}, ΔE^{tag}, $\mathcal{N}_{tag}$ cuts are applied.)



Signal and background M_{miss}^2 distribution.
Events with $\boldsymbol{M_{miss}^2 < 18}$ **(GeV/c²)²** are selected.
(E_{ECL}^{Extra}, M_{bc}^{tag}, ΔE^{tag}, $\mathcal{N}_{tag}$ cuts are applied.)

MVA Test

MVA Test

- Testing is ongoing. Something is ongoing.
- Subsequent slides are not that meaningful… Just test results

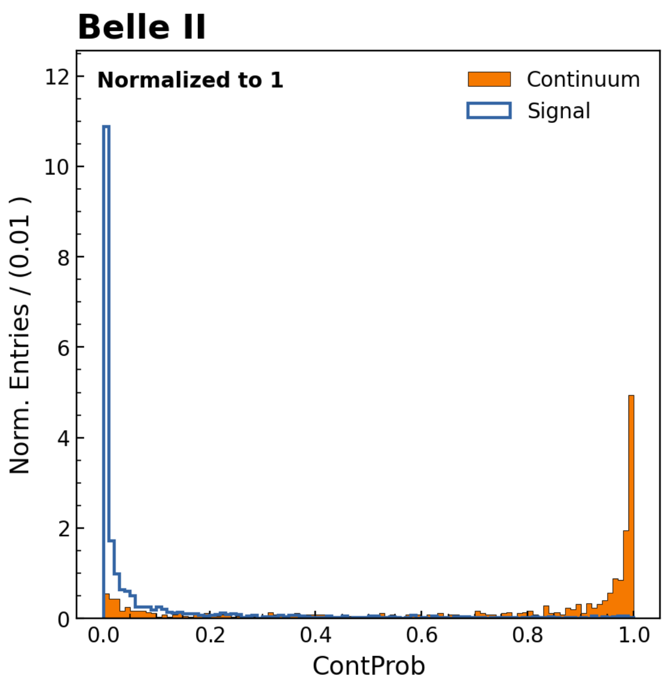
BDT Input Variables: Continuum Suppression

#	Variables
1	"R2"
2	"thrustBm"
3	"thrustOm"
4	"cosTBTO"
5	"cosTBz"
6	"KSFWVariables(et)"
7	"KSFWVariables(mm2)"
8	"KSFWVariables(hso00)"
9	"KSFWVariables(hso02)"
10	"KSFWVariables(hso04)"
11	"KSFWVariables(hso10)"
12	"KSFWVariables(hso12)"
13	"KSFWVariables(hso14)"
14	"KSFWVariables(hso20)"
15	"KSFWVariables(hso22)"

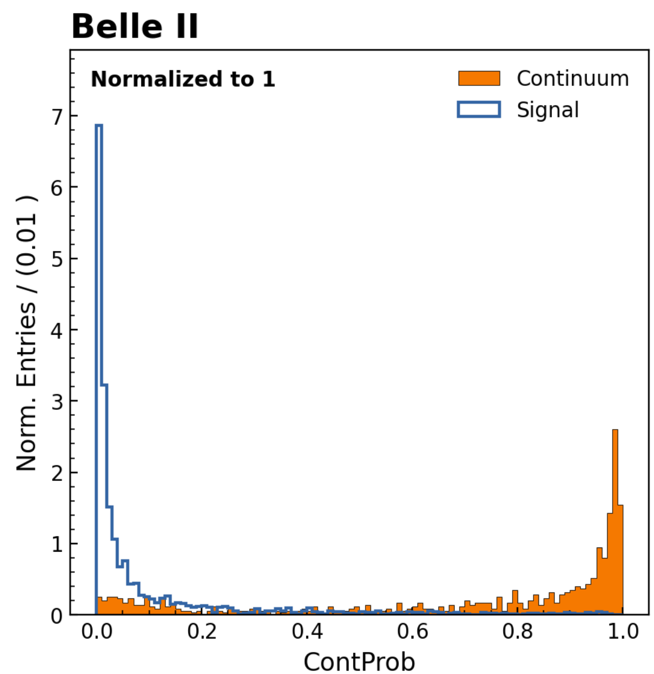
#	Variables
16	"KSFWVariables(hso24)"
17	"KSFWVariables(hoo0)"
18	"KSFWVariables(hoo1)"
19	"KSFWVariables(hoo2)"
20	"KSFWVariables(hoo3)"
21	"KSFWVariables(hoo4)"
22	"CleoConeCS(1)"
23	"CleoConeCS(2)"
24	"CleoConeCS(3)"
25	"CleoConeCS(4)"
26	"CleoConeCS(5)"
27	"CleoConeCS(6)"
28	"CleoConeCS(7)"
29	"CleoConeCS(8)"
30	"CleoConeCS(9)"

BDT Tool Test

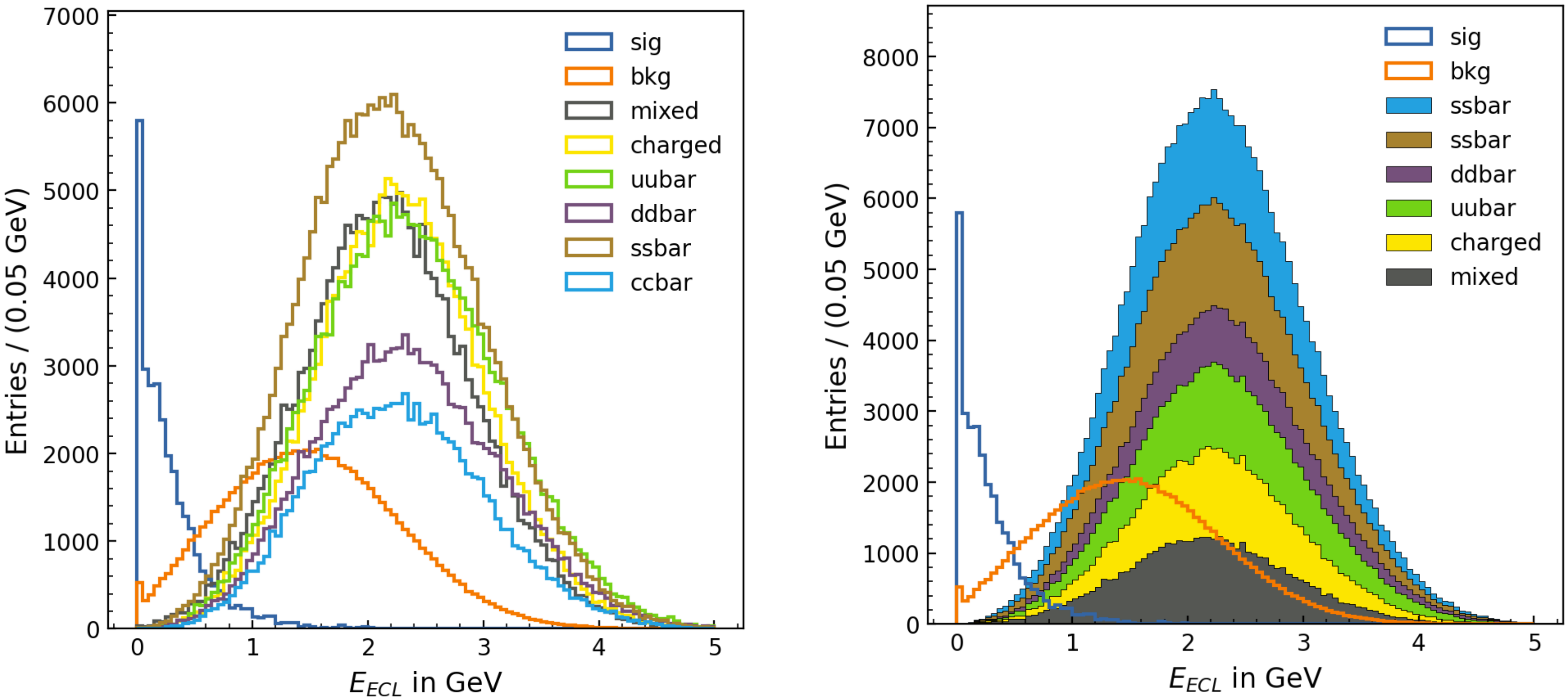
- Testing Code with a small amount of MC sample
  - BASF2 Internal MVA FBDT
  - Thomas Keck's External MVA FBDT



Internal FBDT



External FBDT


7000
6000
5000
4000
3000
2000
1000
0
0
1
2
3
4
5
Entries / (0.05 GeV)
E_{ECL} in GeV
sig
bkg
mixed
charged
uubar
ddbar
ssbar
ccbar
8000
7000
6000
5000
4000
3000
2000
1000
0
Entries / (0.05 GeV)
E_{ECL} in GeV
sig
bkg
ssbar
ssbar
ddbar
uubar
charged
mixed

Multiple BDT Test

A Simple Test: "Single BDT" vs. "Two BDTs"

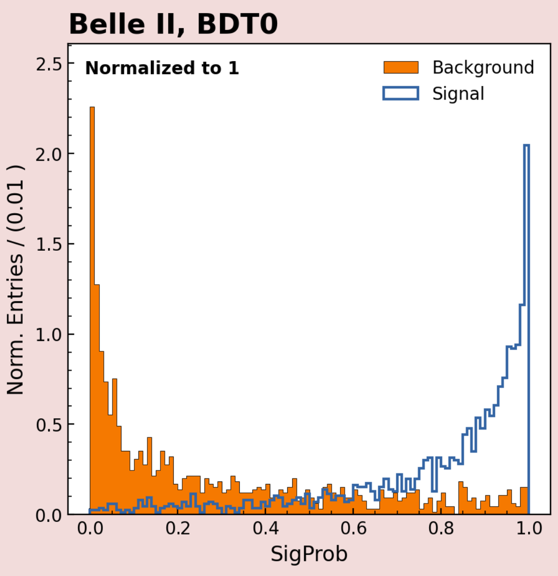
Purpose: To practice comparing BDT strategies

- Training
  - $BDT_{(cg,\,s)}$: Train BDT with "Cont. + Gen. vs. Sig." samples
  - $BDT_{(c,\,s)}$: Train BDT with "Cont. vs. Sig." samples
  - $BDT_{(g,\,s)}$: Train BDT with "Gen. vs. Sig." samples

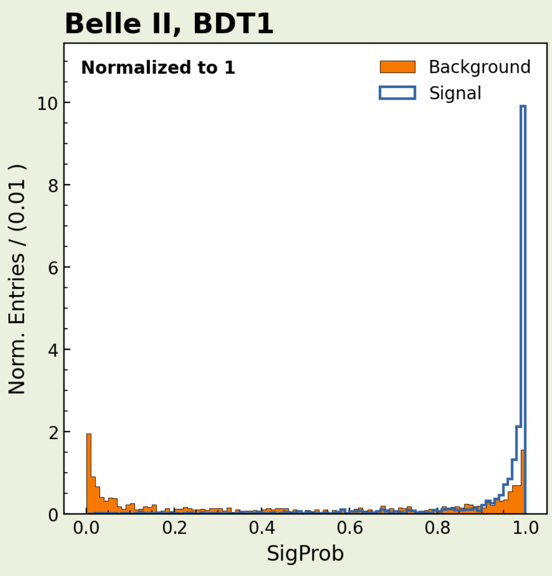
- Testing
  - Test with "Cont. + Gen. + Sig." sample
    - $BDT_{(cg,\,s)}(cgs) \equiv BDT_0$
    - $BDT_{(c,\,s)}(cgs) \equiv BDT_1$
    - $BDT_{(g,\,s)}(cgs) \equiv BDT_2$

- Compare BDTs
  - "BDT_0" vs. "$BDT_1 \oplus BDT_2$"

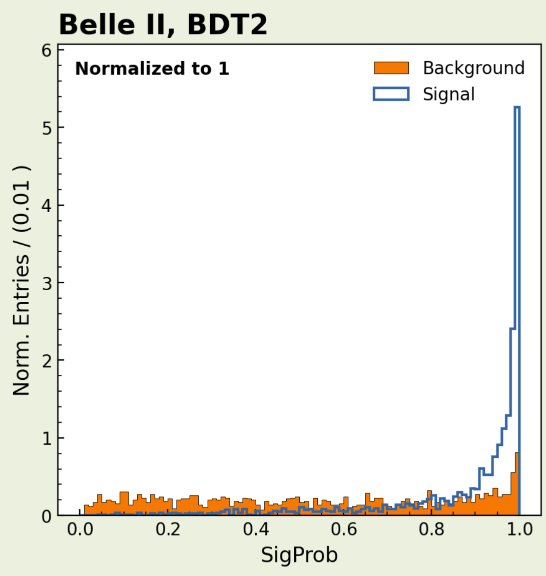
Results: “BDT0” vs. “BDT1 ⊕ BDT2”



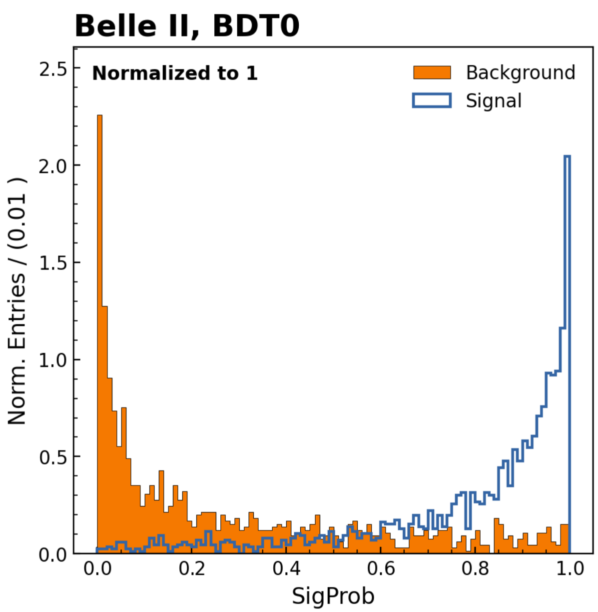
vs.

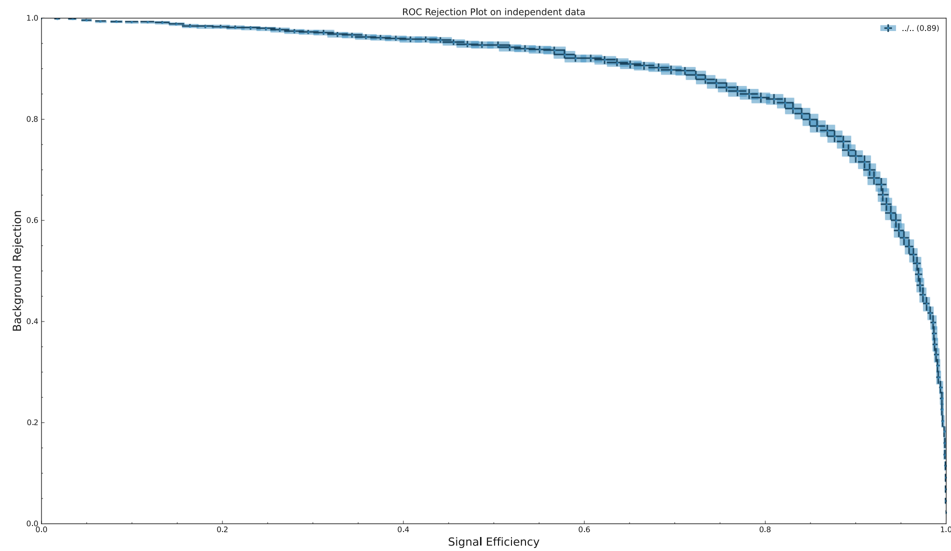


⊕

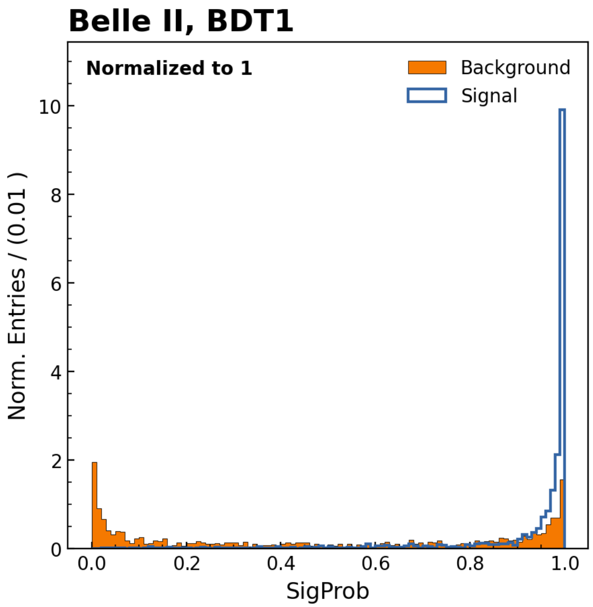


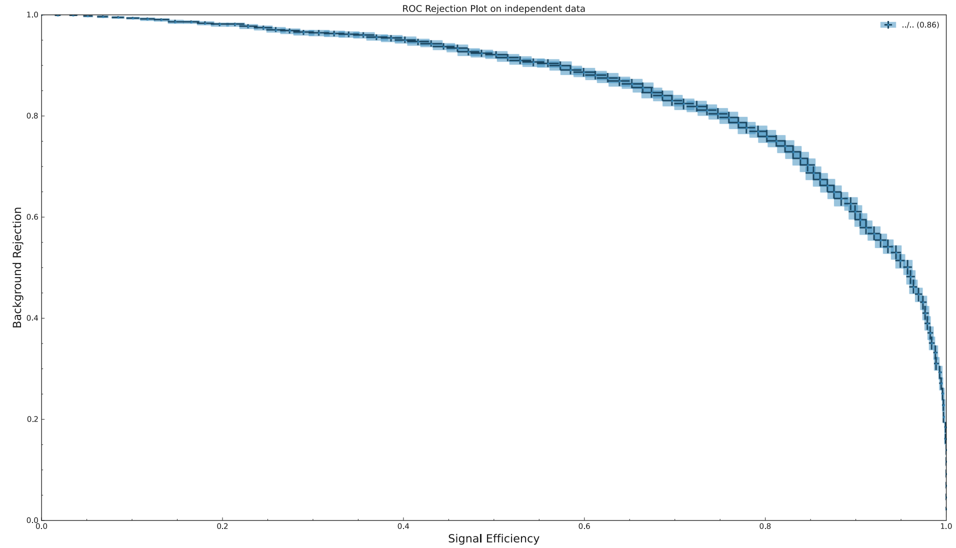
Results: BDT0 – ROC

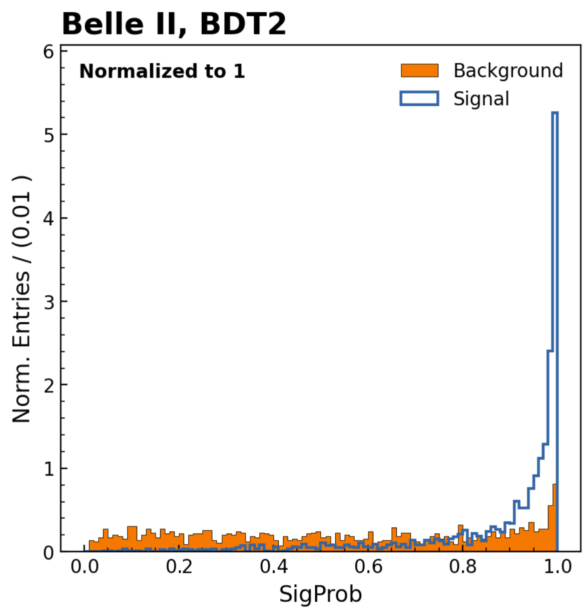




Results: BDT1 & BDT2 – ROC







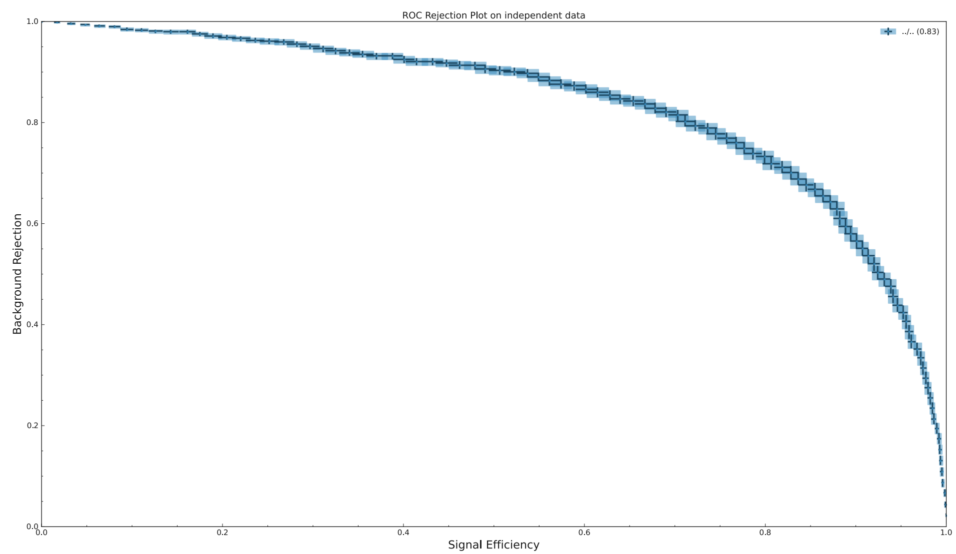


Table 6.5.: Input variables of the neural nets.

	Variable	Short description
Lab. frame	$\boldsymbol{p_{\mathrm{T},i}}$	Transverse momentum of B_{sig} daughters
	$\boldsymbol{E_i}$	Energy of B_{sig} daughters
	$\boldsymbol{\cos\theta_i}$	Polar angle of B_{sig} daughters
	$\boldsymbol{\cos\theta_{0\triangleleft 1}}$	Angle between B_{sig} daughters
	$\boldsymbol{A_{01}}$	Momentum asymmetry of B_{sig} daughters
	$\boldsymbol{M(B_{\mathrm{sig}})}$	Reconstructed mass of B_{sig}
	$\boldsymbol{p_{\mathrm{T}}}$	Reconstructed transverse momentum of B_{sig}
	$\boldsymbol{M^2_{\mathrm{miss}}}$	Squared missing mass of the event
	$\boldsymbol{\lvert\vec{p}_{\mathrm{miss}}\rvert}$	Absolute value of the missing momentum in the event
	$\boldsymbol{\lvert\vec{p}_{\mathrm{T,miss}}\rvert}$	Absolute value of the transverse component of the missing momentum in the event
	$\boldsymbol{d_{\mathrm{IP}}}$	Distance of B_{sig} vertex and IP
	$\boldsymbol{\Sigma(d_{\mathrm{IP}})}$	Significance of d_{IP}
B_{sig} rest frame	$\boldsymbol{\lvert\vec{p}^{\,*}_i\rvert}$	Absolute value of the momentum of B_{sig} daughters
	$\boldsymbol{\cos\theta^*_{0\triangleleft 1}}$	Angle between B_{sig} daughters
	$\boldsymbol{\cos\theta^*_{\tau\triangleleft\pi}}$	Angle between τ and B_{sig} daughter with π hypothesis
	$\boldsymbol{\cos\theta_{\mathrm{hel},0}}$	Angle between daughter 0 and the reconstructed momentum of B_{sig}

※ $B^0 \to \tau^+\tau^-$, BN-1390, M. Ziegler (2016)

Summary / Plan

Summary / Plan

- Summary
  - My personal perspective on Physics and Parameters is introduced.
  - Motivation detail is given, especially BSM ideas.
  - General Analysis Procedure / Strategy is explained.
  - Analysis status is reported briefly.
- What should I be or do?
  - Be patient
  - Getting familiar with Analysis Tools
  - Make result step by step
  - **Learn actual tool usage: Please Help!**
- Specific Plan
  - Test with MC14
    - Edit Pre-selection / BCS with FEI probability / Final state Particle Identification
    - **BDT study**: Continuum / Generic vs. Signal
      - Using characteristics of π
      - Consider the effect of $\mathrm{B}^0 \to K_L^0 \tau^+ \tau^-$ (the main source of fake signal)
    - Design Fitter / Fitter Validation / Choose Control Sample
    - Signal Extraction
    - …
  - MC15
    - Ask WG1 DP Liaison to generate Signal MC

To-do list

- BCS with FEI
  - “Before” Signal B meson reconstruction
    - Conservative way
    - Excluding Signal Reconstruction Dependency
- Code Architecture
  - Comprehensive Code
  - Reusability
  - etc.
- Continuum Suppression
  - MVA FBDT
  - Test with MC14
- Generic vs. Signal
  - MVA FBDT
  - **Choose Signal Distinguishing Variables**
  - Test with MC14
- Choose Control Sample
- MC15
  - CS / Generic

Backup

Backup

Backup

- Previous Talks
- References
- Tool Advertisement
  - Jupyterlab
- Concepts
  - Particle Physics Experiments
  - Event number / Luminosity Concept
  - Belle / Belle II Center of Mass Energy
  - B-meson Flight Mean Distance
  - B counting Method
- Analysis
  - BDT benchmark
  - (FEI-Skimmed) MC Sample Info.
  - (FEI) Skim Level Selection

Previous Talks

Previous talks

2021

- 2021.09.14. 25th EWP Meeting
  - https://indico.belle2.org/event/5190/#5-b0-tautau
- 2021.11.06. KB2GM at Jeonnam
  - https://yhep-indico.yonsei.ac.kr/event/425/#22-b-tau-tau
- 2021.12.02. Leptonic Subgroup Meeting
  - https://indico.belle2.org/event/5728/#3-b0-to-tau-tau-analysis-statu

2022

- 2022.01.20. WG1 pre-session, 41st B2GM
  - https://indico.belle2.org/event/6017/#20-b0-to-tau-tau
- 2022.05.31. WG1 pre-session, 42nd B2GM
  - https://indico.belle2.org/event/6930/#sc-2-14-b-tau-tau
- 2022.Aug.04. Leptonic subgroup meeting
  - https://indico.belle2.org/event/7366/#7-b-to-tau-tau-preselection
- 2022.Oct.05. WG1 pre-session, 43rd B2GM
  - https://indico.belle2.org/event/7826/#sc-1-29-b-tau-tau
- 2022.12.16. KB2GM at Gyeryong
  - https://yhep-indico.yonsei.ac.kr/event/493/timetable/#12-b-tau-tau-decay

References

References

- Belle note
  - [BN1390]: $B^0 \to \tau^+\tau^-$, BN-1390, M. Ziegler (2016)
    - https://belle.kek.jp/secured/belle_note/gn1390/bn1390_v0.8.pdf
- HDM
  - [H2000] Heather E. Logan, Ulrich Nierste, Nuclear Physics B (2000)
    - "$B_{s,d} \to \ell^+\ell^-$ in a two-Higgs-doublet model"
    - https://doi.org/10.1016/S0550-3213(00)00417-X
- Leptoquark
  - [S2016] Suchismita Sahoo and Rukmani Mohanta, PRD (2016)
    - "Lepton flavor violating B meson decays via a scalar leptoquark"
    - https://doi.org/10.1103/PhysRevD.93.114001
  - [S2015] Suchismita Sahoo and Rukmani Mohanta, PRD (2015)
    - "Scalar leptoquarks and the rare B meson decays"
    - https://doi.org/10.1103/PhysRevD.91.094019
  - [R2014] Rukmani Mohanta, PRD (2014)
    - "Effect of scalar leptoquarks on the rare decays of Bs meson"
    - https://doi.org/10.1103/PhysRevD.89.014020
- Blackbody Radiation Images
  - http://hyperphysics.phy-astr.gsu.edu/hbase/mod6.html
  - http://ne.phys.kyushu-u.ac.jp/seminar/MicroWorld1_E/Part3_E/P34_E/Planck_formula_E.htm

Jupyterlab

Install on the KEKCC server

How to install

~~Install on the KEKCC server (※ "jupyter-server" version problem occur)~~
~~$ pip3 install --user jupyterlab~~

Install on the KEKCC server

```
$ pip3 install --user 'jupyter-server<2.0.1'
$ pip3 install --user jupyterlab
```

How to Run

```
$ jupyter lab --port={port number} --no-browser
```

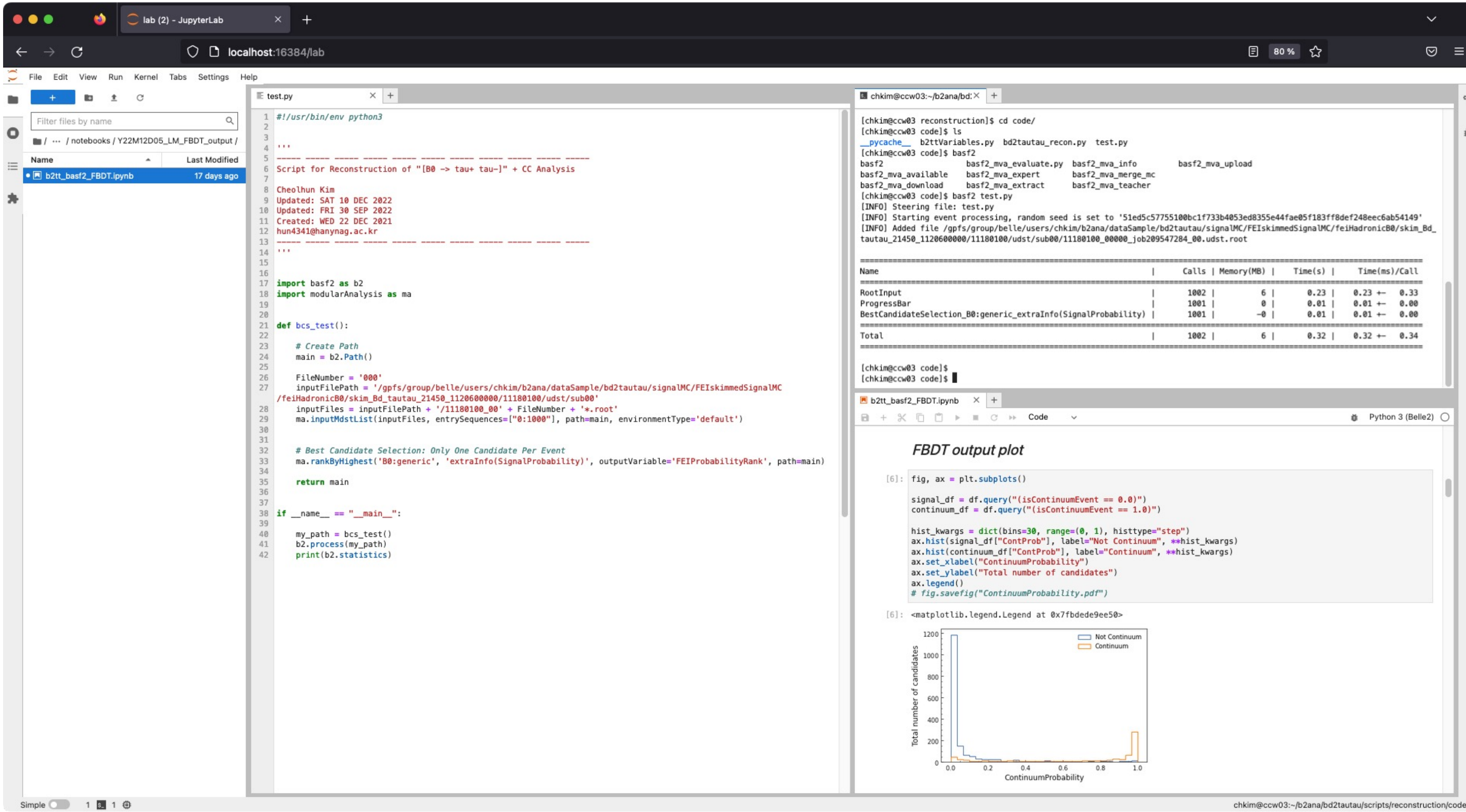
※ port number: even numbers are recommended

example) `$ jupyter lab --port=24816 --no-browser`

Alias ".bashrc"

```
# Jupyter (notebook, lab)
alias jpnb16384='jupyter notebook --port=16384 --no-browser'
alias jplab16384='jupyter lab --port=16384 --no-browser'
```

Jupyter Lab


lab (2) - JupyterLab
localhost:16384/lab
File Edit View Run Kernel Tabs Settings Help
/ … / notebooks / Y22M12D05_LM_FBDT_output /
Name
Last Modified
b2tt_basf2_FBDT.ipynb
17 days ago
test.py
#!/usr/bin/env python3
'''
----- ----- ----- ----- ----- ----- ----- ----- ----- ----- -----
Script for Reconstruction of "[B0 -> tau+ tau-]" + CC Analysis
Cheolhun Kim
Updated: SAT 10 DEC 2022
Updated: FRI 30 SEP 2022
Created: WED 22 DEC 2021
hun4341@hanynag.ac.kr
----- ----- ----- ----- ----- ----- ----- ----- ----- ----- -----
'''
import basf2 as b2
import modularAnalysis as ma
def bcs_test():
# Create Path
main = b2.Path()
FileNumber = '000'
inputFilePath = '/gpfs/group/belle/users/chkim/b2ana/dataSample/bd2tautau/signalMC/FEIskimmedSignalMC/feiHadronicB0/skim_Bd_tautau_21450_1120600000/11180100/udst/sub00'
inputFiles = inputFilePath + '/11180100_00' + FileNumber + '*.root'
ma.inputMdstList(inputFiles, entrySequences=["0:1000"], path=main, environmentType='default')
# Best Candidate Selection: Only One Candidate Per Event
ma.rankByHighest('B0:generic', 'extraInfo(SignalProbability)', outputVariable='FEIProbabilityRank', path=main)
return main
if __name__ == "__main__":
my_path = bcs_test()
b2.process(my_path)
print(b2.statistics)
chkim@ccw03:~/b2ana/bd:
[chkim@ccw03 reconstruction]$ cd code/
[chkim@ccw03 code]$ ls
__pycache__ b2ttVariables.py bd2tautau_recon.py test.py
[chkim@ccw03 code]$ basf2
basf2 basf2_mva_evaluate.py basf2_mva_info basf2_mva_upload
basf2_mva_available basf2_mva_expert basf2_mva_merge_mc
basf2_mva_download basf2_mva_extract basf2_mva_teacher
[chkim@ccw03 code]$ basf2 test.py
[INFO] Steering file: test.py
[INFO] Starting event processing, random seed is set to '51ed5c57755100bc1f733b4053ed8355e44fae05f183ff8def248eec6ab54149'
[INFO] Added file /gpfs/group/belle/users/chkim/b2ana/dataSample/bd2tautau/signalMC/FEIskimmedSignalMC/feiHadronicB0/skim_Bd_tautau_21450_1120600000/11180100/udst/sub00/11180100_00000_job209547284_00.udst.root
Name | Calls | Memory(MB) | Time(s) | Time(ms)/Call
RootInput | 1002 | 6 | 0.23 | 0.23 +- 0.33
ProgressBar | 1001 | 0 | 0.01 | 0.01 +- 0.00
BestCandidateSelection_B0:generic_extraInfo(SignalProbability) | 1001 | -0 | 0.01 | 0.01 +- 0.00
Total | 1002 | 6 | 0.32 | 0.32 +- 0.34
[chkim@ccw03 code]$
[chkim@ccw03 code]$
b2tt_basf2_FBDT.ipynb
Code
Python 3 (Belle2)
FBDT output plot
[6]: fig, ax = plt.subplots()
signal_df = df.query("(isContinuumEvent == 0.0)")
continuum_df = df.query("(isContinuumEvent == 1.0)")
hist_kwargs = dict(bins=30, range=(0, 1), histtype="step")
ax.hist(signal_df["ContProb"], label="Not Continuum", **hist_kwargs)
ax.hist(continuum_df["ContProb"], label="Continuum", **hist_kwargs)
ax.set_xlabel("ContinuumProbability")
ax.set_ylabel("Total number of candidates")
ax.legend()
# fig.savefig("ContinuumProbability.pdf")
[6]: <matplotlib.legend.Legend at 0x7fbdede9ee50>
Not Continuum
Continuum
Total number of candidates
ContinuumProbability
Simple
chkim@ccw03:~/b2ana/bd2tautau/scripts/reconstruction/code

“jupyer_server” version

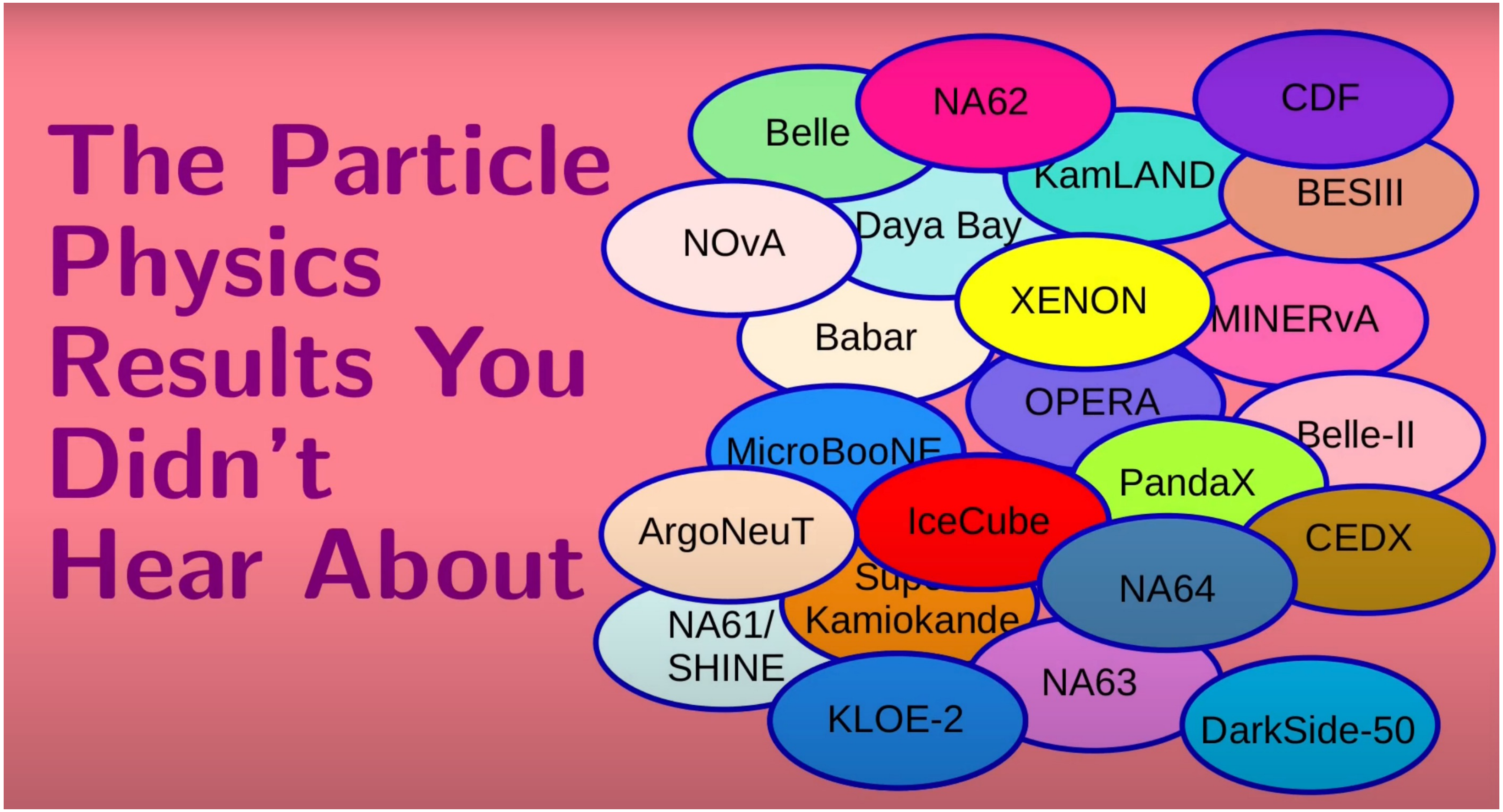
Version Check

```
$ jupyter --version
```

- Latest Version (2022.Dec.14.(WED)): 2.0.1
- Downgraded version
  - 1.23.3

Particle Physics Experiments

Particle Physics Experiments



※ https://www.youtube.com/watch?v=y-ieIrNAnmw&t=912s

Event Number / Luminosity Concept

How many events per beam crossing?

- LHCb
- pp
- RF frequency: 400 MHz (40? MHz)
  - 2.5 ns
- Bunch spacing
  - 50 ns / 25 ns
  - It was 50 ns
  - In the past, it was too many events per beam crossing if 25 ns.
  - Tech improved, 25 ns can be handled.
  - Thus, currently 25 ns.
- 25 ns, 40 MHz
- 100 us (30 km / c)
  - Actual value:
- 40 MHz x 100 us = 4000 bunches
- Actual, # of bunches: 2808
- ineleastic pp: 60 mb
- ~60000 event per 1 revolution (2808 bunch crossing)
- 20 event per 1 rev per 1 bunch

- Belle II
- ee
- RF frequency: 500 MHz
  - 2 ns
- Bunch Spacing (4~6 ns)
  - 4 ns: 2500 bunches
  - 6 ns 1666 bunches
    - cf. Belle 1584 bunches
- 10 us (3 km / c)
  - Actual value:
- 2500 bunches (designed)
  - Actual value: 2376 (current? actual?)
  - ※ where can I find this info. This info. only exist in sphinx..
- Bhabha: 125 nb
- 1 event per 1 revolution (2376 bunch crossing)
- 1/2376 event per 1 rev per 1 bunch

Luminosity Concept

Moving beams: requires a Kinematic Factor →

$\mathbf{K} = \sqrt{((\vec{v_1} - \vec{v_2})^2 - (\vec{v_1} \times \vec{v_2})^2)/c^2}$

For head-on collisions: $\vec{v_1} = -\vec{v_2}$ → $\mathbf{K}_{bb} = \mathbf{2}$ **(Space charge:** $\mathbf{K}_{sc} = \mathbf{1} - \beta$**)**

With revolution frequency f **and number of bunches** n_b **the luminosity** L **becomes:**

$$L = \mathbf{K} \cdot N_1 N_2 \cdot f \cdot n_b \int_{-\infty}^{\infty} \rho_x(x)\rho_y(y)\rho_s(s - s_0) \cdot \rho_x(x)\rho_y(y)\rho_s(s + s_0)$$

In principle: should know all distributions ρ **and** ρ**, but Gaussian distributions are usually a good approximation, tails can be ignored**

transverse : $\rho(x) = \frac{1}{\sigma_x\sqrt{2\pi}} \exp\left(-\frac{x^2}{2\sigma_x^2}\right)$ $\rho(y) = \frac{1}{\sigma_y\sqrt{2\pi}} \exp\left(-\frac{y^2}{2\sigma_y^2}\right)$

※ [211015, 211126 Lab Meeting]
※ [CERN, Luminosity Lecture] https://cas.web.cern.ch/sites/default/files/lectures/constanta-2018/l1.pdf

Belle / Belle II
Center of Mass Energy

The reasons why we use asymmetric beam energy

- To get benefit to measure time-dependent CP. Extending flight time.

- Vertex separation by utilizing difference of flight distance(?)
- Please explain it again..

< Why the asymmetricity is decreased >
- To increase luminosity (current ↑)

- High energy positron can be stored better in the damping ring.

- Vertex detection technique should be improved.

※ How to increase luminosity
- current ↑
- cross section ↑ (by pencil beam, beam diameter(beta function related))

Belle & Belle II beam energy

If the beam energy of the electron beam is chosen as E_- and the center of mass energy of the colliding beams equals the mass of the $\Upsilon(4S)$ meson, calculate the energy of the positron beam, E_+, in the laboratory frame. Momenta perpendicular to the beam direction are zero [1].

(a) For Belle case, $E_- = 8$ GeV

(b) For Belle II case, $E_- = 7$ GeV

<$\Upsilon(4S)$ Rest mass frame(CM)>

$b\bar{b}$

$\Upsilon(4S)$

<Lab frame>

$b\bar{b}$

e^- $\Upsilon(4S)$ e^+

$$M_{\Upsilon(4S)} = 10.58\ GeV$$

$$M_{B_0} = M_{\bar{B}_0} = 5.28\ GeV$$

$$E_\Upsilon{}' = M_\Upsilon \qquad p_\Upsilon{}' = 0$$

<Lab> <CM>

$$\begin{pmatrix} E_\Upsilon \\ p_\Upsilon \end{pmatrix} = \begin{pmatrix} \gamma_\Upsilon & \gamma_\Upsilon\beta_\Upsilon \\ \gamma_\Upsilon\beta_\Upsilon & \gamma_\Upsilon \end{pmatrix} \begin{pmatrix} E_\Upsilon{}' \\ p_\Upsilon{}' \end{pmatrix}$$

$$E_\Upsilon = \gamma_\Upsilon E_\Upsilon{}' \qquad p_\Upsilon = \gamma_\Upsilon \beta_\Upsilon E_\Upsilon{}' \qquad \therefore \beta_\Upsilon = \frac{p_\Upsilon}{E_\Upsilon}$$

$$E_\Upsilon = E_- + E_+$$

$$p_\Upsilon = p_- - p_+ = E_- - E_+$$

$$E_-{}^2 = m_-{}^2 + p_-{}^2 \quad \Rightarrow \quad p_- = E_- \quad (\because p_- \gg m_-)$$

$$E_+{}^2 = m_+{}^2 + p_+{}^2 \quad \Rightarrow \quad p_+ = E_+ \quad (\because p_+ \gg m_+)$$

$$\beta_\Upsilon = \frac{p_\Upsilon}{E_\Upsilon} = \frac{E_- - E_+}{E_- + E_+} \quad \Rightarrow \quad 1 - \beta_\Upsilon{}^2 = 1 - \frac{(E_- - E_+)^2}{(E_- + E_+)^2} = \frac{4E_-E_+}{(E_- + E_+)^2} \quad \Rightarrow \quad \gamma_\Upsilon^2 = \frac{(E_- + E_+)^2}{4E_-E_+}$$

$$\left(\gamma = \frac{1}{\sqrt{1-\beta^2}} \quad \Rightarrow \quad 1 - \beta_\Upsilon{}^2 = \frac{1}{\gamma^2} \right)$$

Belle & Belle II beam energy

	β_Υ	γ_Υ
Belle I	$\frac{8-3.5}{8+3.5} = 0.39$	1.086
Belle II	$\frac{7-4}{7+4} = 0.27$	1.036

$$E_+ = \frac{1}{4E_-}\frac{(E_- + E_+)^2}{\gamma^2} = \frac{1}{4E_-}\frac{E_\Upsilon^2}{\gamma^2} = \frac{1}{4E_-}{E_\Upsilon}'^2 = \frac{1}{4E_-}M_\Upsilon^2$$

(a) For Belle case, $E_- = 8$ GeV $\quad\therefore E_+ = 3.5$ GeV

(b) For Belle II case, $E_- = 7$ GeV $\quad\therefore E_+ = 4$ GeV

References

References

[1] http://electron6.phys.utk.edu/PhysicsProblems/Mechanics/8-Relativity/relcoll.html

B-meson
Flight Mean Distance

A neutral B meson flight mean distance

Estimate(calculate) the mean distance of nuetral B meson.
Lifetimes of the nuetral B mesons are $\tau'_B = 1.52\ ps$ (The prime denote the B meson rest frame.) [3]
(Of course, you can find the lifetime values on the Wikipedia.) [4]
(To make this problem simpler, let's assume momenta perpendicular to the beam direction are zero.)
(a) For Belle case, $E_- = 8$ GeV, $E_+ = 3.5$ GeV
(b) For Belle II case, $E_- = 7$ GeV, $E_+ = 4$ GeV

<Υ(4S) Rest mass frame (CM)>

$b\bar{b}$

$\Upsilon(4S)$

<Lab frame>

$b\bar{b}$

e^- $\Upsilon(4S)$ e^+

$$M_{\Upsilon(4S)} = 10.58\ GeV$$

$$M_{B_0} = M_{\bar{B}_0} = 5.28\ GeV$$

$$E_\Upsilon{}' = M_\Upsilon$$

$$p_\Upsilon{}' = 0$$

$$\begin{pmatrix} E_\Upsilon \\ p_\Upsilon \end{pmatrix} = \begin{pmatrix} \gamma_\Upsilon & \gamma_\Upsilon\beta_\Upsilon \\ \gamma_\Upsilon\beta_\Upsilon & \gamma_\Upsilon \end{pmatrix} \begin{pmatrix} E_\Upsilon{}' \\ p_\Upsilon{}' \end{pmatrix}$$

$$E_\Upsilon = \gamma_\Upsilon E_\Upsilon{}'$$

$$p_\Upsilon = \gamma_\Upsilon \beta_\Upsilon E_\Upsilon{}'$$

$$\therefore \beta_\Upsilon = \frac{p_\Upsilon}{E_\Upsilon}$$

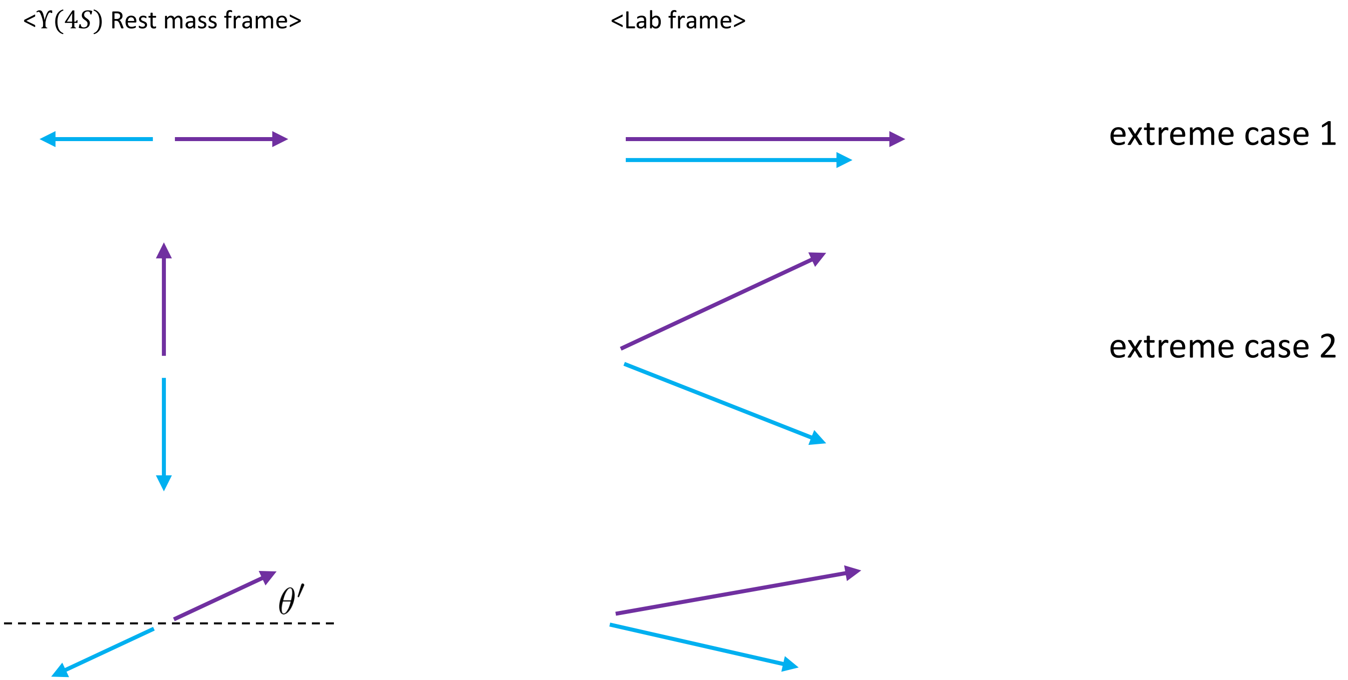
$$M_{B_0} = M_{\bar{B}_0} = 5.28\ GeV := M_B$$

$$E'_{B^0} = E'_{\bar{B}^0} = M_\Upsilon/2 = 5.289\ GeV := E'_B$$

$$p'_{B^0} = p'_{\bar{B}^0} = (E'_B{}^2 - M_B^2)^{1/2} = 0.33\ GeV := p'_B$$

$$\therefore \beta'_B = \frac{p'_B}{E'_B} = 0.063$$

A neutral B meson flight mean distance



$$E'_B = 5.289\ \ GeV$$

$$p'_B = 0.33\ \ GeV$$

$$\begin{pmatrix} E_B \\ p_B \end{pmatrix} = \begin{pmatrix} \gamma_\Upsilon & \gamma_\Upsilon\beta_\Upsilon \\ \gamma_\Upsilon\beta_\Upsilon & \gamma_\Upsilon \end{pmatrix} \begin{pmatrix} E_B{}' \\ p_B{}'cos(\theta') \end{pmatrix}$$

$$E_B = \gamma_\Upsilon E'_B + \gamma_\Upsilon\beta_\Upsilon p'_B cos(\theta')$$

$$p_B = \gamma_\Upsilon\beta_\Upsilon E'_B + \gamma_\Upsilon p'_B cos(\theta')$$

A neutral B meson flight mean distance

$$E_B = \gamma_\Upsilon E'_B + \gamma_\Upsilon \beta_\Upsilon p'_B cos(\theta')$$
$$= \gamma_\Upsilon E'_B + \gamma_\Upsilon \beta_\Upsilon \beta'_B E'_B cos(\theta')$$
$$= \gamma_\Upsilon E'_B (1 + \underline{\beta_\Upsilon \beta'_B cos(\theta')})$$

This term is much smaller than 1.

$$\approx \gamma_\Upsilon E'_B$$

$$p_B = (E_B^2 - M_B^2)^{1/2}$$

$$\beta_B = \frac{p_B}{E_B} \qquad \gamma_B = \frac{1}{\sqrt{1-\beta_B^2}}$$

	β_Υ	γ_Υ	β'_B	$\beta_\Upsilon \beta'_B$	E_B	p_B	β_B	γ_B	$\beta_B \gamma_B$
Belle I	$\frac{8-3.5}{8+3.5} = 0.39$	1.086	0.063	0.024	5.74	2.25	0.39	1.086	0.42
Belle II	$\frac{7-4}{7+4} = 0.27$	1.036	0.063	0.017	5.47	1.43	0.26	1.036	0.27

$$\therefore d_B = \tau_B v_B$$
$$= (\gamma_B \tau'_B)(\beta_B c)$$
$$= \begin{cases} 194\ \mu m, & for\ Belle\ I \\ 124\ \mu m, & for\ Belle\ II \end{cases}$$

cf) For extreme case 1, $cos(\theta') = 1$

$$= \gamma_\Upsilon E'_B (1 + \beta_\Upsilon \beta'_B cos(\theta'))$$

p_B is calculated with $p_B = (E_B^2 - M_B^2)^{1/2}$

	E_B	p_B	β_B	γ_B	d_B
Belle I	5.88	2.58	0.44	1.113	2.23
Belle II	5.56	1.75	0.32	1.053	1.52

p_B is calculated with $p_B = \gamma_\Upsilon \beta_\Upsilon E'_B + \gamma_\Upsilon p'_B cos(\theta')$

	E_B	p_B	β_B	γ_B	d_B
Belle I	5.88	2.60	0.44	1.115	2.25
Belle II	5.56	1.82	0.32	1.057	1.57

Backup

Table 2.1: Parameters about SuperKEKB accelerator.

Parameters	Value
Energy (GeV)(e^+/e^-)	4.0/7.0
$\beta\gamma$	0.28
Current (A)	3.60/2.62
β_y^* (mm)	0.27/0.41
Luminosity(10^{34}cm^{-2}s^{-1})	80
Integrated luminosity (ab^{-1})	50
Crossing angle (mrad)	83
Perimeter of ring (km)	3

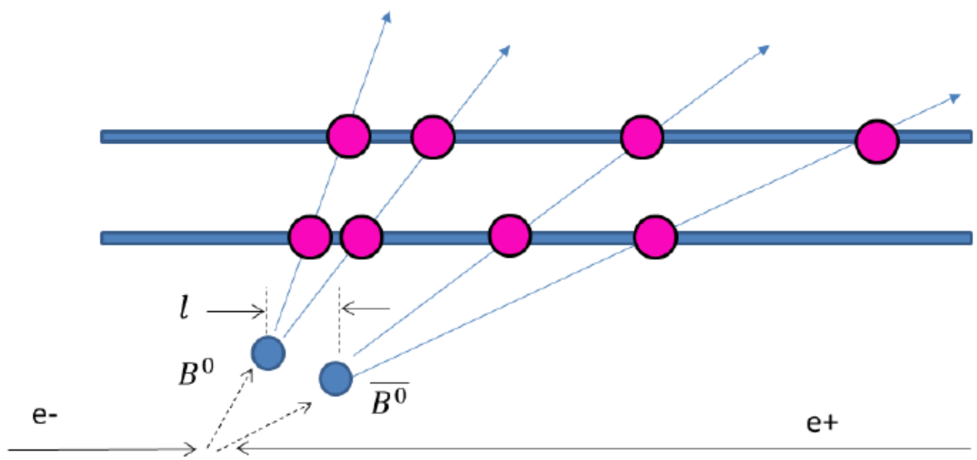


Figure 3.1: A role of vertex detector for Belle II. Difference of distance between $B^0\overline{B}^0$ vertices is measured. Red points represent hit position in layers of the vertex detector. Intersect points of obtained lines are regarded as decay point of particles.

Backup

3.2.2 High spacial resolution

Vertex resolution

Because $\beta\gamma$ of Belle II is 0.28, average distance of B^0 flight would be roughly $c \times 1.5$ ps $\times 0.28 \sim 130$ μm. So if we would like to measure that lifetime, we need a vertex detector whose vertex resolution is sufficiently less than O(100 μm).

References

References

[1] http://electron6.phys.utk.edu/PhysicsProblems/Mechanics/8-Relativity/relcoll.html
[2] Thomson M.-Modern Particle Physics-Cambridge University Press (2013) problem 14.12
[3] Thomson M.-Modern Particle Physics-Cambridge University Press (2013) problem 14.13
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[5] Nobuhiro Shimizu Aihara/Yokoyama lab. “Development of the Silicon Vertex Detector for Belle II experiment(2014.01)”

B Counting Method

B counting method: BABAR & Belle

3.6.2.1 B-counting in *BABAR*

For the $\Upsilon(4S)$ running periods, the number of $B\overline{B}$ events in *BABAR* was computed by subtracting the number of hadronic events due to continuum interactions from the total number of the events in the on-resonance data set:

$$N_{B\overline{B}} = (N_H - N_\mu \cdot R_{off} \cdot \kappa)/\epsilon_{B\overline{B}} \quad (3.6.1)$$

where

- N_H is the number of events satisfying the hadronic event selection in the on-resonance data;
- N_μ is the number of events satisfying muon pair selection criteria in the on-resonance data;
- R_{off} is the ratio of selected hadronic events to selected muon pair events in the off-resonance (continuum) data;
- $\kappa \equiv \frac{\epsilon'_\mu \cdot \sigma'_\mu}{\epsilon_\mu \cdot \sigma_\mu} \cdot \frac{\sum_i \epsilon_i \cdot \sigma_i}{\sum_i \epsilon'_i \cdot \sigma'_i}$ corrects for the changes in continuum production cross section (σ) and efficiency for satisfying the selection criteria (ϵ) between on and off-resonance center-of-mass energies. Off-resonance quantities are denoted by a prime. The subscript μ refers to muon pair events; the various contributions to the continuum hadronic cross section, primarily $e^+e^- \to q\overline{q}$, are denoted by the subscript i. Since the muon pair and $q\overline{q}$ cross sections vary similarly with $\sqrt{s}$ (0.7% difference between on- and off-resonance), κ has a value close to 1. The quantity $N_\mu \cdot R_{off} \cdot \kappa$ is then the number of continuum hadronic events in the on-resonance dataset.
- $\epsilon_{B\overline{B}} = 0.940$ is the efficiency for produced $B\overline{B}$ events to satisfy the hadronic event selection, calculated under the assumption that

$$\mathcal{B}(\Upsilon(4S) \to B^+B^-) = \mathcal{B}(\Upsilon(4S) \to B^0\overline{B}^0) = 0.5. \quad (3.6.2)$$

Variations in the amount of non-$B\overline{B}$ decays of the $\Upsilon(4S)$, and in the branching ratios of B^+B^- and $B^0\overline{B}^0$, are included in the systematic error, but are not significant.

3.6.2.2 B-counting in Belle

The final Belle $\Upsilon(4S)$ dataset contains $(771.6 \pm 10.6) \times 10^6$ $B\overline{B}$ events. As in the *BABAR* B-counting scheme, this number is obtained by a subtraction of off-resonance hadronic contributions, as measured by the number of events in the previously described $HadronBJ$ skim, from the total number of on-resonance hadronic events. In the Belle case, this is calculated as:

$$N_{B\overline{B}} = \frac{N_{on} - r(\epsilon_{q\bar{q}})\alpha N^{off}_{q\bar{q}}}{\epsilon_{B\overline{B}}} \quad (3.6.3)$$

where

- N_{on} is the number of events satisfying the hadronic event selection in the on-resonance data;
- $r(\epsilon_{q\bar{q}})$ is the ratio of efficiency for $q\bar{q}$ events off-resonance to the efficiency for those on-resonance;
- α is the ratio of the number of Bhabha (e^+e^-) events or μ-pair events observed on-resonance to those observed off-resonance. This is described in more detail below;
- $N^{off}_{q\bar{q}}$ is the number of events satisfying the hadronic event selection in the off-resonance data;
- $\epsilon_{B\overline{B}}$ is the efficiency of the $\Upsilon(4S) \to B\overline{B}$ event selection criteria for on-resonance data.

※ [The Physics of the B factories: p55~56]
A. J. Bevan et al., Eur. Phys. J. C 74, 3026 (2014)

4.2 Derivation of the B Counting Formula

Suppose we wish to calculate the number of B mesons in a sample of on-peak data of luminosity $\mathcal{L}$, using an off-peak data sample of luminosity $\mathcal{L}'$. For simplicity, off-peak quantities are primed, and hadronic, mu-pair, $B\overline{B}$ and continuum quantities have the subscripts H, μ, B and X respectively. The numbers produced of each quantity (as opposed to those counted by the B Counting selectors) have the superscript "0".

In a sample of on-peak data, the number of $B\overline{B}$ events is equal to the total number of hadronic events (N_H^0) less the number of non-$B\overline{B}$ hadronic events (N_X^0).

$$N_B^0 = N_H^0 - N_X^0 \tag{4.4}$$

The number of on-peak continuum events can be found by scaling (by luminosity) an off-peak sample (in which all events are non-$B\overline{B}$). The small decrease in energy from on-peak to off-peak data-taking changes all continuum production rates slightly, but almost all of these events scale in similar ways with luminosity.

For any particular type of event, the number counted is equal to the number produced multiplied by the efficiency (ε). So for example,

$$N_\mu = \varepsilon_\mu N_\mu^0 = \varepsilon_\mu \sigma_\mu \mathcal{L} \tag{4.5}$$

and

$$N'_\mu = \varepsilon'_\mu N'^0_\mu = \varepsilon'_\mu \sigma'_\mu \mathcal{L}'. \tag{4.6}$$

For off-peak data, there is no $\Upsilon(4S)$ production, so we can assume that all hadrons are from continuum events (and hence the symbols N'_H and N'_X are equivalent):

$$N'_H = N'_X = \varepsilon'_X N'^0_X = \varepsilon'_X \sigma'_X \mathcal{L}'. \tag{4.7}$$

We define:

$$\kappa \equiv \frac{\varepsilon'_\mu \sigma'_\mu}{\varepsilon_\mu \sigma_\mu} \cdot \frac{\varepsilon_X \sigma_X}{\varepsilon'_X \sigma'_X} \tag{4.8}$$

$$\equiv \kappa_\mu \cdot \kappa_X. \tag{4.9}$$

※ McGregor 2008 [Chapter 4. B Counting]:
G. D. McGregor. "B Counting at BABAR" 0812.1954.

B counting method: BABAR - detail

We combine (4.6), (4.7) and (4.8) to give:

$$\frac{N'_X}{N'_\mu}\kappa = \frac{\varepsilon'_X \sigma'_X \mathcal{L}'}{\varepsilon'_\mu \sigma'_\mu \mathcal{L}'}\kappa = \frac{\varepsilon_X \sigma_X}{\varepsilon_\mu \sigma_\mu}. \tag{4.10}$$

The hadronic events in the on-peak sample consist of continuum and $B\overline{B}$ events:

$$N_H^0 = N_X^0 + N_B^0 \tag{4.11}$$

and the number of *counted* hadronic events is

$$N_H = \varepsilon_X N_X^0 + \varepsilon_B N_B^0. \tag{4.12}$$

Hence from (4.10), we can write

$$\begin{aligned}
\varepsilon_B N_B^0 &= N_H - \varepsilon_X N_X^0 && (4.13)\\
&= N_H - \varepsilon_X \sigma_X \mathcal{L} && (4.14)\\
&= N_H - \frac{N'_H}{N'_\mu} \cdot \kappa \cdot \varepsilon_\mu \sigma_\mu \cdot \frac{N_\mu}{\varepsilon_\mu \sigma_\mu} && (4.15)\\
&= N_H - N_\mu \cdot \frac{N'_H}{N'_\mu} \cdot \kappa. && (4.16)
\end{aligned}$$

Hence, the number of $B\overline{B}$ mesons produced in the on-peak sample is given by:

$$N_B^0 = \frac{1}{\varepsilon_B}(N_H - N_\mu \cdot R_{\mathit{off}} \cdot \kappa), \tag{4.17}$$

where

$$R_{\mathit{off}} \equiv \frac{N'_X}{N'_\mu}. \tag{4.18}$$

In general, κ is close to unity. The exact values and uncertainties of κ_μ and κ_X are discussed in detail later.

※ McGregor 2008 [Chapter 4. B Counting]:
G. D. McGregor. “B Counting at BABAR” 0812.1954.

Physics Cross Sections Table

알 수 없는 사용자 (asifmoh) posted on 02. 6월. 2016 14:09h - last edited by Sam Cunliffe on 24. 9월. 2020 16:24h

Preliminary!

At 10.5738 GeV, all "Process" and "Cross section" cuts applied in the nominal CM frame (smearing applied for KKMC), all "Visible fraction" cuts applied in the nominal Belle II lab frame.

"Visible fraction" is based on generator truth information using primary stable particles only. CDC acceptance is 17-150deg, ECL acceptance is 12.4-155.1deg in the lab frame.

ee->qqbar contains the QED and QCD corrections from KKMC (par(53)=1)!

Process	Cross Section [nb]	Visible fraction	Trigger Rate [Hz]	Generator/Reference
$ee \to \mu\mu(\gamma)$	1.148 ± 0.005 (full angle)	both charged in ECL (p>0.5GeV): 0.76 both charged in CDC (p>0.5GeV): 0.72 gamma (E > 0.5GeV) in ECL, no charged in CDC: < 0.01 gamma (E > 0.5GeV): 0.40 gamma (E > 0.5GeV) untagged: 0.49 gamma (E > 0.5GeV) tagged: 0.21	-	KKMC
$ee \to \tau\tau(\gamma)$	0.919 ± 0.003 (full angle)	-	-	KKMC
$ee \to ee(\gamma)$ (Bhabha)	125 ± 1 (MC statistics) (15-165deg) 201 ± 1 (MC statistics) (12-168deg) 294 ± 2 (MC statistics) **(10-170deg)**	(10-170)deg: both charged in ECL (p>0.5GeV): 0.252 both charged in CDC (p>0.5GeV): 0.151 gamma (E > 0.5GeV) in ECL, no charged in CDC: 0.016 gamma (E > 0.5GeV): 0.205 gamma (E > 0.5GeV) untagged: 0.172 gamma (E > 0.5GeV) tagged: 0.091 (15-165)deg: both charged in ECL (p>0.5GeV): 0.594 both charged in CDC (p>0.5GeV): 0.357 gamma (E > 0.5GeV) in ECL, no charged in CDC: 0.025 gamma (E > 0.5GeV): 0.2143 gamma (E > 0.5GeV) untagged: 0.395 gamma (E > 0.5GeV) tagged: 0.216	-	BABAYAGA.NLO
$ee \to \gamma\gamma(\gamma)$	3.89 ± 0.02 (MC statistics) (15-165deg) 4.96 ± 0.02 (MC statistics) **(10-170deg)**	at least 2 g in ECL (E>0.5 GeV): 0.662 1 g in ECL (E > 0.5GeV), no more g in ECL (E > 0.1GeV): 0.129	-	BABAYAGA.NLO

⋮

※ [Physics Cross Sections Table]
https://confluence.desy.de/display/BI/Physics+Cross+Sections+Table

Belle Physics Cross Sections Table

⋮

$ee \to u\bar{u}(\gamma)$	1.605 (NLO without QCD, full angle) **(used in production)** 1.034 (massless Born, full angle)		-	KKMC
$ee \to d\bar{d}(\gamma)$	0.401 (NLO without QCD, full angle) **(used in production)** 0.258 (massless Born, full angle)	-	-	KKMC
$ee \to s\bar{s}(\gamma)$	0.383 (NLO without QCD, full angle) **(used in production)** 0.258 (massless Born, full angle)	-	-	KKMC
$ee \to u\bar{u}(\gamma)/d\bar{d}(\gamma)/s\bar{s}(\gamma)$	2.389 (NLO, full angle) 1.55 (massless Born, full angle)	-	-	KKMC
$ee \to c\bar{c}(\gamma)$	1.329 (NLO without QCD, full angle) **(used in production)** 1.034 (massless Born, full angle)	-	-	KKMC
$ee \to \Upsilon(4S) \to B\bar{B}$	1.100 **(used in production)**	-	-	
$ee \to \Upsilon(4S) \to B^{+}B^{-}$	0.5654 **(used in production)**			
$ee \to \Upsilon(4S) \to B^{0}\bar{B}^{0}$	0.5346 **(used in production)**			

※ [Physics Cross Sections Table]
https://confluence.desy.de/display/BI/Physics+Cross+Sections+Table

Belle BB cross section (PDG)

The $e^+e^- \to b\bar{b}$ production cross-section at the $\Upsilon(4S)$ ($\Upsilon(5S)$) resonance is about 1.1 nb (0.3 nb). At the Z resonance (SLC, LEP) all species of b-flavored hadrons could be studied for the first time. The $e^+e^- \to b\bar{b}$ production cross-section at the Z resonance is about 6.6 nb.

※ [PDG, p814] P. A. Zyla et al. (Particle Data Group), Prog. Theor. Exp. Phys. 2020, 083C01 (2020)

In practice, the exact properties of the colliding beams, such as the transverse profiles, are not known precisely and it is not possible to accurately calculate the instantaneous luminosity. For this reason, cross section measurements are almost always made with reference to a process where the cross section is already known. Hence, a cross section measurement is performed by counting the number of events of interest N, and the number of observed events for the reference process N_{ref}, such that the measured cross section is given by

$$\sigma = \sigma_{\text{ref}} \frac{N}{N_{\text{ref}}}.$$

※ [Modern Particle Physics, Mark Thomson, p27]

References

- [The Physics of the B factories: p55~56] A. J. Bevan et al., Eur. Phys. J. C 74, 3026 (2014)
- McGregor 2008 [Chapter 4. B Counting]: G. D. McGregor. "B Counting at BABAR" 0812.1954.
- [Physics Cross Sections Table] https://confluence.desy.de/display/BI/Physics+Cross+Sections+Table
- [PDG] P. A. Zyla et al. (Particle Data Group), Prog. Theor. Exp. Phys. 2020, 083C01 (2020)
- [Modern Particle Physics, Mark Thomson, p27]

※ [220107 Lab Meeting]

Propagation of Uncertainty

Function	Variance	Standard Deviation
$f = aA$	$\sigma_f^2 = a^2\sigma_A^2$	$\sigma_f = \|a\|\sigma_A$
$f = aA + bB$	$\sigma_f^2 = a^2\sigma_A^2 + b^2\sigma_B^2 + 2ab\,\sigma_{AB}$	$\sigma_f = \sqrt{a^2\sigma_A^2 + b^2\sigma_B^2 + 2ab\,\sigma_{AB}}$
$f = aA - bB$	$\sigma_f^2 = a^2\sigma_A^2 + b^2\sigma_B^2 - 2ab\,\sigma_{AB}$	$\sigma_f = \sqrt{a^2\sigma_A^2 + b^2\sigma_B^2 - 2ab\,\sigma_{AB}}$
$f = A - B,$	$\sigma_f^2 = \sigma_A^2 + \sigma_B^2 - 2\sigma_{AB}$	$\sigma_f = \sqrt{\sigma_A^2 + \sigma_B^2 - 2\sigma_{AB}}$
$f = aA - aA,$	$\sigma_f^2 = 2a^2\sigma_A^2(1-\rho_A)$	$\sigma_f = \sqrt{2}\,\|a\|\,\sigma_A(1-\rho_A)^{1/2}$
$f = AB$	$\sigma_f^2 \approx f^2\left[\left(\frac{\sigma_A}{A}\right)^2 + \left(\frac{\sigma_B}{B}\right)^2 + 2\frac{\sigma_{AB}}{AB}\right]$ [9][10]	$\sigma_f \approx \|f\|\sqrt{\left(\frac{\sigma_A}{A}\right)^2 + \left(\frac{\sigma_B}{B}\right)^2 + 2\frac{\sigma_{AB}}{AB}}$
$f = \frac{A}{B}$	$\sigma_f^2 \approx f^2\left[\left(\frac{\sigma_A}{A}\right)^2 + \left(\frac{\sigma_B}{B}\right)^2 - 2\frac{\sigma_{AB}}{AB}\right]$ [11]	$\sigma_f \approx \|f\|\sqrt{\left(\frac{\sigma_A}{A}\right)^2 + \left(\frac{\sigma_B}{B}\right)^2 - 2\frac{\sigma_{AB}}{AB}}$
$f = aA^b$	$\sigma_f^2 \approx \left(abA^{b-1}\sigma_A\right)^2 = \left(\frac{fb\sigma_A}{A}\right)^2$	$\sigma_f \approx \left\|abA^{b-1}\sigma_A\right\| = \left\|\frac{fb\sigma_A}{A}\right\|$
$f = a\ln(bA)$	$\sigma_f^2 \approx \left(a\frac{\sigma_A}{A}\right)^2$ [12]	$\sigma_f \approx \left\|a\frac{\sigma_A}{A}\right\|$
$f = a\log_{10}(bA)$	$\sigma_f^2 \approx \left(a\frac{\sigma_A}{A\ln(10)}\right)^2$ [12]	$\sigma_f \approx \left\|a\frac{\sigma_A}{A\ln(10)}\right\|$
$f = ae^{bA}$	$\sigma_f^2 \approx f^2(b\sigma_A)^2$ [13]	$\sigma_f \approx \|f\|\,\|(b\sigma_A)\|$
$f = a^{bA}$	$\sigma_f^2 \approx f^2(b\ln(a)\sigma_A)^2$	$\sigma_f \approx \|f\|\,\|(b\ln(a)\sigma_A)\|$
$f = a\sin(bA)$	$\sigma_f^2 \approx [ab\cos(bA)\sigma_A]^2$	$\sigma_f \approx \|ab\cos(bA)\sigma_A\|$
$f = a\cos(bA)$	$\sigma_f^2 \approx [ab\sin(bA)\sigma_A]^2$	$\sigma_f \approx \|ab\sin(bA)\sigma_A\|$
$f = a\tan(bA)$	$\sigma_f^2 \approx [ab\sec^2(bA)\sigma_A]^2$	$\sigma_f \approx \|ab\sec^2(bA)\sigma_A\|$
$f = A^B$	$\sigma_f^2 \approx f^2\left[\left(\frac{B}{A}\sigma_A\right)^2 + (\ln(A)\sigma_B)^2 + 2\frac{B\ln(A)}{A}\sigma_{AB}\right]$	$\sigma_f \approx \|f\|\sqrt{\left(\frac{B}{A}\sigma_A\right)^2 + (\ln(A)\sigma_B)^2 + 2\frac{B\ln(A)}{A}\sigma_{AB}}$
$f = \sqrt{aA^2 \pm bB^2}$	$\sigma_f^2 \approx \left(\frac{A}{f}\right)^2 a^2\sigma_A^2 + \left(\frac{B}{f}\right)^2 b^2\sigma_B^2 \pm 2ab\frac{AB}{f^2}\,\sigma_{AB}$	$\sigma_f \approx \sqrt{\left(\frac{A}{f}\right)^2 a^2\sigma_A^2 + \left(\frac{B}{f}\right)^2 b^2\sigma_B^2 \pm 2ab\frac{AB}{f^2}\,\sigma_{AB}}$

※ https://en.wikipedia.org/wiki/Propagation_of_uncertainty#cite_note-11

22.01.05 (수)

B Counting Method.

<BABAR>

• $N_{B\bar{B}} = (N_H - N_\mu \cdot R_{off} \cdot k)/\epsilon_{B\bar{B}}$

<Belle>

• $N_{B\bar{B}} = \frac{N_{on} - r(E_{q\bar{q}})\,\alpha\, N^{off}_{q\bar{q}}}{\epsilon_{B\bar{B}}}$

Step 1. $N_{B\bar{B}} = N^{MC}_{B\bar{B}}$ (assumption 1)

step 2. $\epsilon^{MC}_{B\bar{B}} = \frac{N^{MC}_{B\bar{B},cut}}{N^{MC}_{B\bar{B}}}$ ※ cut: counted

$\Rightarrow N^{MC}_{B\bar{B}} = \frac{N^{MC}_{B\bar{B},cut}}{\epsilon^{MC}_{B\bar{B}}}$

assumption 2: $N_{B\bar{B},cand} = N^{MC}_{B\bar{B},cut}$

Then, $\epsilon_{B\bar{B}} = \frac{N_{B\bar{B},cut}}{N_{B\bar{B}}} = \frac{N^{MC}_{B\bar{B},cut}}{N^{MC}_{B\bar{B}}} = \epsilon^{MC}_{B\bar{B}}$ corollary 1

$\Rightarrow N_{B\bar{B}} = N^{MC}_{B\bar{B}}$ (by assumption 1)

$= \frac{N^{MC}_{B\bar{B},cut}}{\epsilon^{MC}_{B\bar{B}}}$

$= \frac{N_{B\bar{B},cut}}{\epsilon_{B\bar{B}}}$ by assumption 2, by corollary 1

$\Rightarrow N_{B\bar{B},cut} = \epsilon_{B\bar{B}} N_{B\bar{B}}$

For simplicity, let's change notation

$\Rightarrow N_B = \epsilon_B N_B^0$

step 3. • On-resonance

$N_H^0 = N_B^0 + N_X^0$, $N_H = N_B + N_X$ } assumption

$= \epsilon_B N_B^0 + \epsilon_X N_X^0$

prime(') denote off, no prime on

$N_\mu = \epsilon_\mu N_\mu^0 = \epsilon_\mu \sigma_\mu \mathcal{L}$

$N'_\mu = \epsilon'_\mu N'^0_\mu = \epsilon'_\mu \sigma'_\mu \mathcal{L}'$

$N_B^0 = \frac{1}{\epsilon_B}(N_H - \epsilon_X N_X^0)$

$= \frac{1}{\epsilon_B}(N_H - \epsilon_X \sigma_X \mathcal{L})$

$\mathcal{L} = \frac{N_\mu}{\epsilon_\mu \sigma_\mu}$

• off-resonance

$N'_H = N'_B + N'_X$

$= N'_X$

assumption: There is no $\Upsilon(4S)$ in off-resonance data. Thus, $N'_B = 0$

$= \epsilon'_X N'^0_X = \epsilon'_X \sigma'_X \mathcal{L}'$

Step 4: Express the formula with measurable quantities. Minimize syst. uncertainties.

$N_B^0 = \frac{1}{\epsilon_B}(N_H - \epsilon_X \sigma_X \mathcal{L})$

$= \frac{1}{\epsilon_B}\left(N_H - \epsilon_X \sigma_X \frac{N_\mu}{\epsilon_\mu \sigma_\mu}\right)$ — K_μ, K_X

$= \frac{1}{\epsilon_B}\left(N_H - N_\mu \frac{\epsilon'_\mu \sigma'_\mu}{\epsilon_\mu \sigma_\mu} \frac{\epsilon_X \sigma_X}{\epsilon'_X \sigma'_X} \frac{\epsilon'_X \sigma'_X}{\epsilon'_\mu \sigma'_\mu}\right)$

define it as k

$= \frac{1}{\epsilon_B}\left(N_H - N_\mu k \frac{\epsilon'_X \sigma'_X \mathcal{L}'}{\epsilon'_\mu \sigma'_\mu \mathcal{L}'}\right)$ — N'_X, N'_μ

$= \frac{1}{\epsilon_B}\left(N_H - N_\mu \cdot \frac{N'_X}{N'_\mu} \cdot k\right)$ — define it as R_{off}

$= \frac{1}{\epsilon_B}(N_H - N_\mu \cdot R_{off} \cdot k)$ ∎

B Counting

- Why ratio? To factor out syst. uncertainty
- ϵ_B : Get it from MC truth matching
- N_H and N_μ : Measure these with on-resonance data.
- $N_X'(N_H')$ and N_μ' : Measure these with off-resonance data.
- $k \sim 1$ ($\because \sigma \sim \frac{1}{s}$ for $\mu\mu$ and hadronic ($q\bar{q}$) cut.s)

$$k_\mu = \frac{\epsilon_\mu' \sigma_\mu'}{\epsilon_\mu \sigma_\mu} \sim \frac{10.58^2}{10.54^2} \sim 1.0076$$

$$k_X = \frac{\epsilon_X \sigma_X}{\epsilon_X' \sigma_X'} \sim \frac{10.54^2}{10.58^2} \sim 0.9925$$

off resonance diff.
※ Belle : 60 MeV
BABAR : 40 MeV

- ϵ_μ and ϵ_X : MC
- σ_μ and σ_X : MC (with choosing $\sigma_B = 1.1\ nb$)

<Belle>

$$N_{B\bar{B}} = \frac{N_{on} - r(\epsilon_{q\bar{q}})\, \alpha\, N_{q\bar{q}}^{off}}{\epsilon_{B\bar{B}}}$$

Same as BABAR ($\mu \to \ell$ (e or μ))
depend on Experiment (data taking period)

Step 4.

$$N_B^\circ = \frac{1}{\epsilon_B} \left(N_H - N_\ell \frac{\epsilon_\ell' \sigma_\ell'}{\epsilon_\ell \sigma_\ell} \frac{\epsilon_X \sigma_X}{\epsilon_X' \sigma_X'} \frac{\epsilon_X' \sigma_X'}{\epsilon_\ell' \sigma_\ell'} \right)$$

~1, ~1
define it as $r(\epsilon_{q\bar{q}})$

$$= \frac{1}{\epsilon_B} \left(N_H - r(\epsilon_{q\bar{q}})\, N_\ell \frac{\epsilon_X' \sigma_X' \mathcal{L}'}{\epsilon_\ell' \sigma_\ell' \mathcal{L}'} \right)$$

$$= \frac{1}{\epsilon_B} \left(N_H - r(\epsilon_{q\bar{q}})\, N_\ell \frac{N_X'}{N_\ell'} \right)$$

$N_H' = N_{q\bar{q}}^{off}$

$\alpha \equiv \frac{N_\ell}{N_\ell'}$

$$= \frac{1}{\epsilon_B} \left(N_H - r(\epsilon_{q\bar{q}})\, \alpha\, N_{q\bar{q}}^{off} \right)$$

BDT Benchmark

BDT input variables: Belle ($\mathcal{N}_{sig}$)

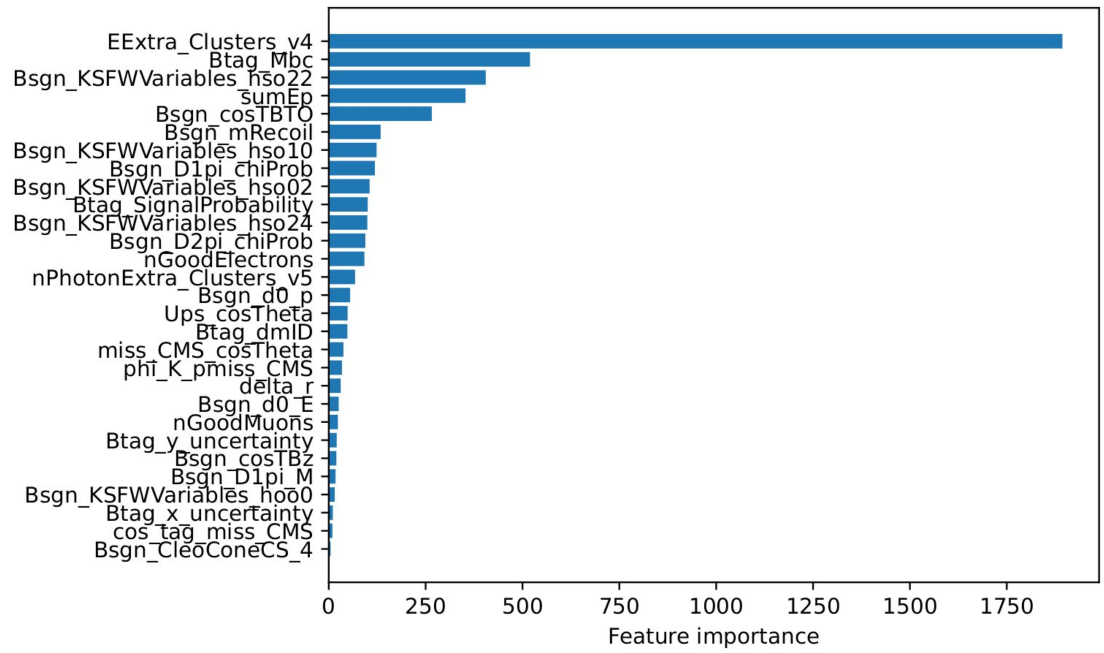
Table 6.5.: Input variables of the neural nets.

	Variable	Short description
Lab. frame	$\boldsymbol{p_{\mathrm{T},i}}$	Transverse momentum of B_{sig} daughters
	$\boldsymbol{E_i}$	Energy of B_{sig} daughters
	$\boldsymbol{\cos\theta_i}$	Polar angle of B_{sig} daughters
	$\boldsymbol{\cos\theta_{0\triangleleft 1}}$	Angle between B_{sig} daughters
	$\boldsymbol{A_{01}}$	Momentum asymmetry of B_{sig} daughters
	$\boldsymbol{M(B_{\mathrm{sig}})}$	Reconstructed mass of B_{sig}
	$\boldsymbol{p_{\mathrm{T}}}$	Reconstructed transverse momentum of B_{sig}
	$\boldsymbol{M^2_{\mathrm{miss}}}$	Squared missing mass of the event
	$\boldsymbol{\lvert\vec{p}_{\mathrm{miss}}\rvert}$	Absolute value of the missing momentum in the event
	$\boldsymbol{\lvert\vec{p}_{\mathrm{T,miss}}\rvert}$	Absolute value of the transverse component of the missing momentum in the event
	$\boldsymbol{d_{\mathrm{IP}}}$	Distance of B_{sig} vertex and IP
	$\boldsymbol{\Sigma(d_{\mathrm{IP}})}$	Significance of d_{IP}
B_{sig} rest frame	$\boldsymbol{\lvert\vec{p}^{\,*}_i\rvert}$	Absolute value of the momentum of B_{sig} daughters
	$\boldsymbol{\cos\theta^*_{0\triangleleft 1}}$	Angle between B_{sig} daughters
	$\boldsymbol{\cos\theta^*_{\tau\triangleleft\pi}}$	Angle between τ and B_{sig} daughter with π hypothesis
	$\boldsymbol{\cos\theta_{\mathrm{hel},0}}$	Angle between daughter 0 and the reconstructed momentum of B_{sig}

※ $B^0 \to \tau^+\tau^-$, BN-1390, M. Ziegler (2016)

BDT overview

- BDT based on XGBoost trained on 1ab^{-1} of skimmed bkg events and 50M skimmed signal events
- Samples split 50/50 for training/testing. Background randomly sampled to get n_{bkg} = 5 x n_{sig}
- Variables used in the training:
  - Continuum suppression (KSFW moments, $\cos\theta_{TBTO}$, ...)
  - Signal K^+ kinematics (E_K, p_K, ...)
  - D meson suppression variables
  - Missing variables (E_{miss}, p_{miss}, ...)
- Pre/post processing with QuantileTransformer so that signal input variables and classifier output uniformly distributed between 0 and 1



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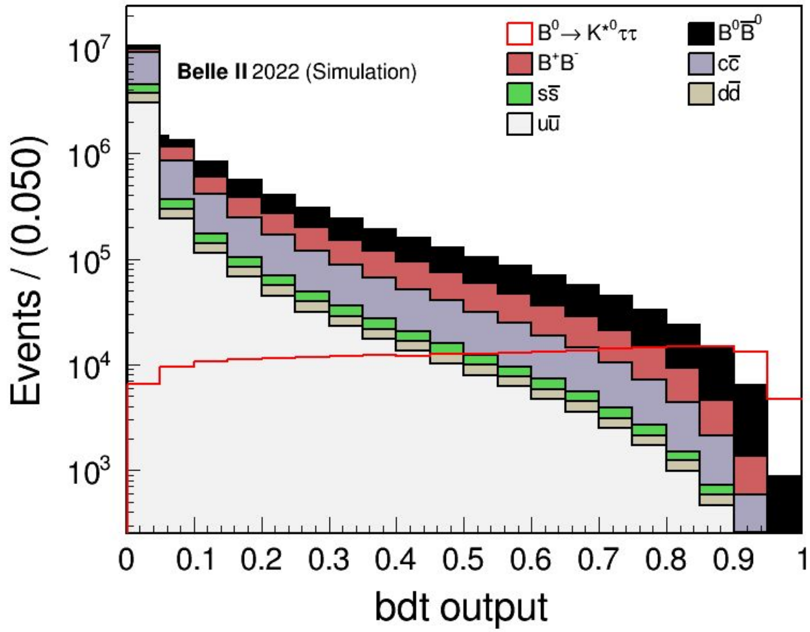
※ $B^+ \to K^+\nu\bar{\nu}$, Lucas Martel (31st EWP group meeting, 2022.Oct.04)
Link: https://indico.belle2.org/event/7846/#2-b-knunu-belle-ii-had-tag

Signal selection

- Train XGBoost **BDT** to discriminate signal against all backgrounds → distinguish $\tau\tau$ decay topologies during the training

Training variables

1. Bsgn_KSFWVariables_hoo0
2. sumEp
3. EExtra_Clusters_distance
4. Bsgn_d0_M
5. foxWolframR2
6. Bsgn_thrustBm
7. M_tautau2
8. Btag_SignalProbability
9. Btag_Mbc
10. delta_r
11. Btag_dmID
12. miss_CMS_cosTheta
13. Bsgn_cosTBTO
14. Btag_deltaE



For BDT>0.95 :

ε = 9.4 10^{-5}

~800 BBbar events for 1/ab

- ✅ "**Improved**" scenario assumed for snowmass projections (x3 signal efficiency with same bkg as Belle)

- **To be updated**
  - Training with new preselection (see slide 9)
  - Change variable inputs list (D-veto)

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※ $B^0 \to K^{*0}\tau^+\tau^-$, Stefano Moneta (31st EWP group meeting, 2022.Oct.04)
Link: https://indico.belle2.org/event/7846/#4-b0-k0-tautau

BDT input variables: Belle II (Continuum Suppression)

Solution ▶

```
#!/usr/bin/env python3

import basf2_mva

general_options = basf2_mva.GeneralOptions()
general_options.m_datafiles = basf2_mva.vector("ContinuumSuppression.root")
general_options.m_treename = "tree"
general_options.m_identifier = "MVAFastBDT.root"  # outputted weightfile
general_options.m_variables = basf2_mva.vector(
    "R2",
    "thrustBm",
    "thrustOm",
    "cosTBTO",
    "cosTBz",
    "KSFWVariables(et)",
    "KSFWVariables(mm2)",
    "KSFWVariables(hso00)",
    "KSFWVariables(hso02)",
    "KSFWVariables(hso04)",
    "KSFWVariables(hso10)",
    "KSFWVariables(hso12)",
    "KSFWVariables(hso14)",
    "KSFWVariables(hso20)",
    "KSFWVariables(hso22)",
    "KSFWVariables(hso24)",
    "KSFWVariables(hoo0)",
    "KSFWVariables(hoo1)",
    "KSFWVariables(hoo2)",
    "KSFWVariables(hoo3)",
    "KSFWVariables(hoo4)",
    "CleoConeCS(1)",
    "CleoConeCS(2)",
    "CleoConeCS(3)",
    "CleoConeCS(4)",
    "CleoConeCS(5)",
    "CleoConeCS(6)",
    "CleoConeCS(7)",
    "CleoConeCS(8)",
    "CleoConeCS(9)",
)
general_options.m_target_variable = "isContinuumEvent"
fastbdt_options = basf2_mva.FastBDTOptions()

basf2_mva.teacher(general_options, fastbdt_options)
```

※ [Sphinx manual (light-2207-bengal): 3.4.10. Continuum Suppression (CS)]
Link: https://b2-master.belle2.org/software/sphinx/light-2207-bengal/online_book/basf2/cs.html

(FEI-Skimmed) MC Sample Information

MC Sample / Skimmed MC Sample Information

- ***MC Sample Information***
  - #69, Signal at $\Upsilon(4S)$, Mode: B0 → tau tau, Nickname: Bd_tautau [1]
  - Number of events: $\mathbf{20 \times 10^6}$ [1]
  - Ratio without/with background: **0.20 / 0.80** [1]
  - Btag decay type: **generic** [1]
  - Bsig decay type: **tau+ tau-** [1]
  - Campaign: **MC14ri_a** [2]
  - Location: /belle/MC/release-05-02-00/DB00001330/MC14ri_a/prod00021450/s00/e1003/4S/r00000/1120600000/mdst/sub00 [2]

- ***Skimmed MC Sample Information***
  - Beam background type: **BGx1** [2]
  - The Signal MC is generated with basf2 version **release-05-02-11** [2].
  - MC Signal mode: B0 → tau tau [2, 3]
  - MC Signal Code: 1120600000 [2, 3]
  - Skim Type: **feiHadronicB0 / feiSLB0** [2, 3]
  - Location: /belle/user/shdelamo/skim_Bd_tautau_21450_1120600000 [2]
  - Location: /belle/group/physics/SLME/skim_Bd_tautau_21450_1120600000 [2, 3]

- ***Additional information***
  - The skim was done before the MC14 data deletion accident [2].
  - MC Sample: **No longer exist** [2]
  - Skimmed MC Sample: Exist

[References]
[1] [MC Samples WG1] https://confluence.desy.de/display/BI/MC+Samples+WG1
[2] [JIRA ticket for Signal MC] https://agira.desy.de/browse/BIIDP-4785
[3] [WG1 Skimming Advice and Resources] https://confluence.desy.de/display/BI/WG1+Skimming+Advice+and+Resources

MC Sample / Skimmed MC Sample Information

- ***MC Sample Information***
  - #69, Signal at $\Upsilon(4S)$, Mode: B0 → tau tau, Nickname: Bd_tautau [1]
  - Number of events: $\mathbf{20\times10^6}$ [1]
  - Ratio without/with background: **0.20 / 0.80** [1]
  - Btag decay type: **generic** [1]
  - Bsig decay type: **tau+ tau-** [1]
  - Campaign: **MC14ri_a** [2]
  - Location: /belle/MC/release-05-02-00/DB00001330/MC14ri_a/prod00021450/s00/e1003/4S/r00000/1120600000/mdst/sub00 [2]

BGx0 / BGx1 → 4×10^6 (4M) / 16×10^6 (16M)

- ***Skimmed MC Sample Information***
  - Beam background type: **BGx1** [2]
  - The Signal MC is generated with basf2 version **release-05-02-11** [2].
  - MC Signal mode: B0 → tau tau [2, 3]
  - MC Signal Code: 1120600000 [2, 3]
  - Skim Type: **feiHadronicB0 / feiSLB0** [2, 3]
  - Location: /belle/user/shdelamo/skim_Bd_tautau_21450_1120600000 [2]
  - Location: /belle/group/physics/SLME/skim_Bd_tautau_21450_1120600000 [2, 3]

- ***Additional information***
  - The skim was done before the MC14 data deletion accident [2].
  - MC Sample: **No longer exist** [2]
  - Skimmed MC Sample: Exist

[References]
[1] [MC Samples WG1] https://confluence.desy.de/display/BI/MC+Samples+WG1
[2] [JIRA ticket for Signal MC] https://agira.desy.de/browse/BIIDP-4785
[3] [WG1 Skimming Advice and Resources] https://confluence.desy.de/display/BI/WG1+Skimming+Advice+and+Resources

(FEI) Skim Level Selection

Skim Level Selection: Pre-selection

static **fei_precuts**(*path*) [source]

Skim pre-cuts are applied before running the FEI, to reduce computation time. This setup function is run by all FEI skims, so they all have the save event-level pre-cuts:

- $n_{\text{cleaned tracks}} \geq 3$
- $n_{\text{cleaned ECL clusters}} \geq 3$
- $\text{Visible energy of event (CMS frame)} > 4\ \text{GeV}$
- $2\ \text{GeV} < E_{\text{cleaned tracks \& clusters in ECL}} < 7\ \text{GeV}$

We define "cleaned" tracks and clusters as:

- Cleaned tracks (`pi+:FEI_cleaned`): $d_0 < 0.5$ cm, $|z_0| < 2$ cm, and $p_T > 0.1$ GeV *
  Cleaned ECL clusters (`gamma:FEI_cleaned`): $0.296706 < \theta < 2.61799$, and $E > 0.1$ GeV $\Rightarrow 17° < \theta < 150°$

※ From Sphinx manual, basf2 version: **05-02-18**: "17.2.1. Physics skims - Full event interpretation skims"
(cf. basf2 version which was used to skim: 05-02-11)
※ https://b2-master.belle2.org/software/sphinx/release-05-02-18/skim/doc/02-physics.html#module-skim.fei

Skim Level Selection: Tag side selection

class **skim.fei.feiHadronicB0**(**, OutputFileName=None, additionalDataDescription=None, udstOutput=True, validation=False*) [source]

Note

- **Skim description**: FEI-tagged neutral B's decaying hadronically.
- **Skim name**: feiHadronicB0
- **Skim LFN code**: 11180100
- **Category**: physics, Full Event Interpretation
- **Authors**: Racha Cheaib, Hannah Wakeling, Phil Grace
- **Contact**: Shanette De La Motte

This skim includes a selection on the HLT flag `hlt_hadron`.

Tag side B cuts:

- $M_{\mathrm{bc}} > 5.24\ \mathrm{GeV}$
- $|\Delta E| < 0.2\ \mathrm{GeV}$
- $\mathrm{signal\ probability} > 0.001$ (omitted for decay mode 23)

All available FEI B^0 hadronic tags are reconstructed. From Thomas Keck's thesis, "the channel $B^0 \to \overline{D}^0 \pi^0$ was used by the FR, but is not yet used in the FEI due to unexpected technical restrictions in the KFitter algorithm".

※ From Sphinx manual, basf2 version: **05-02-18**: "17.2.1. Physics skims - Full event interpretation skims"
(cf. basf2 version which was used to skim: 05-02-11)
※ https://b2-master.belle2.org/software/sphinx/release-05-02-18/skim/doc/02-physics.html#module-skim.fei