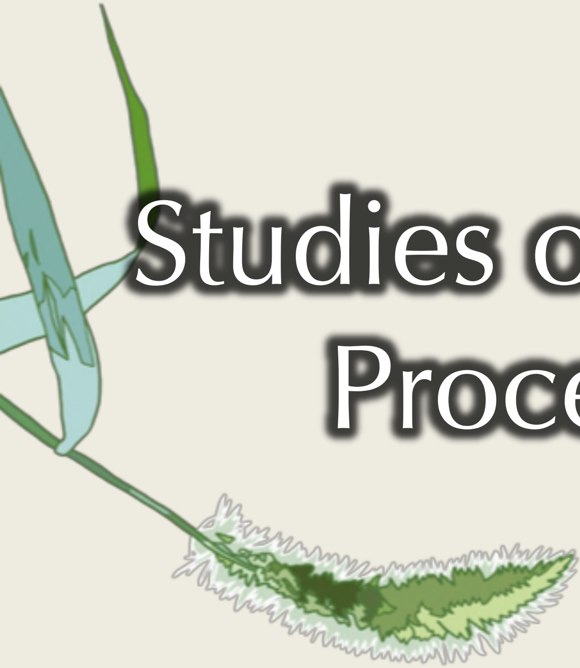
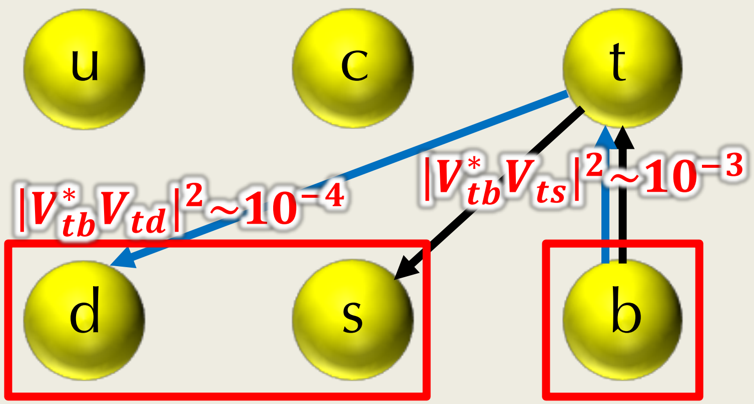
Studies of Electro Weak Penguin Process at Belle / Belle II



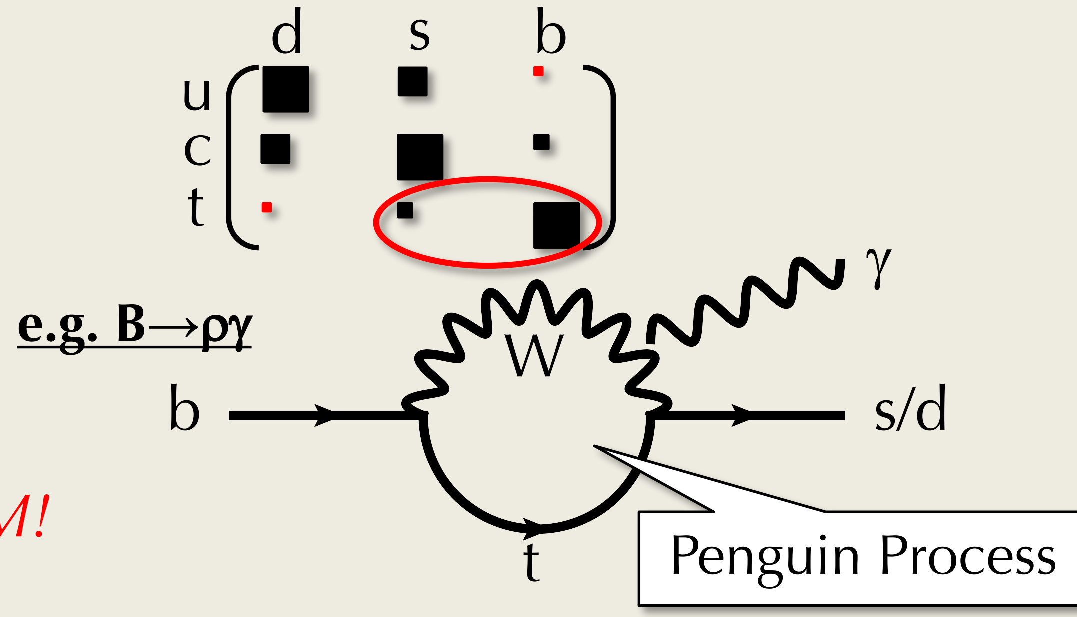
2022.1.21

S. Watanuki
(Yonsei University)

Introduction

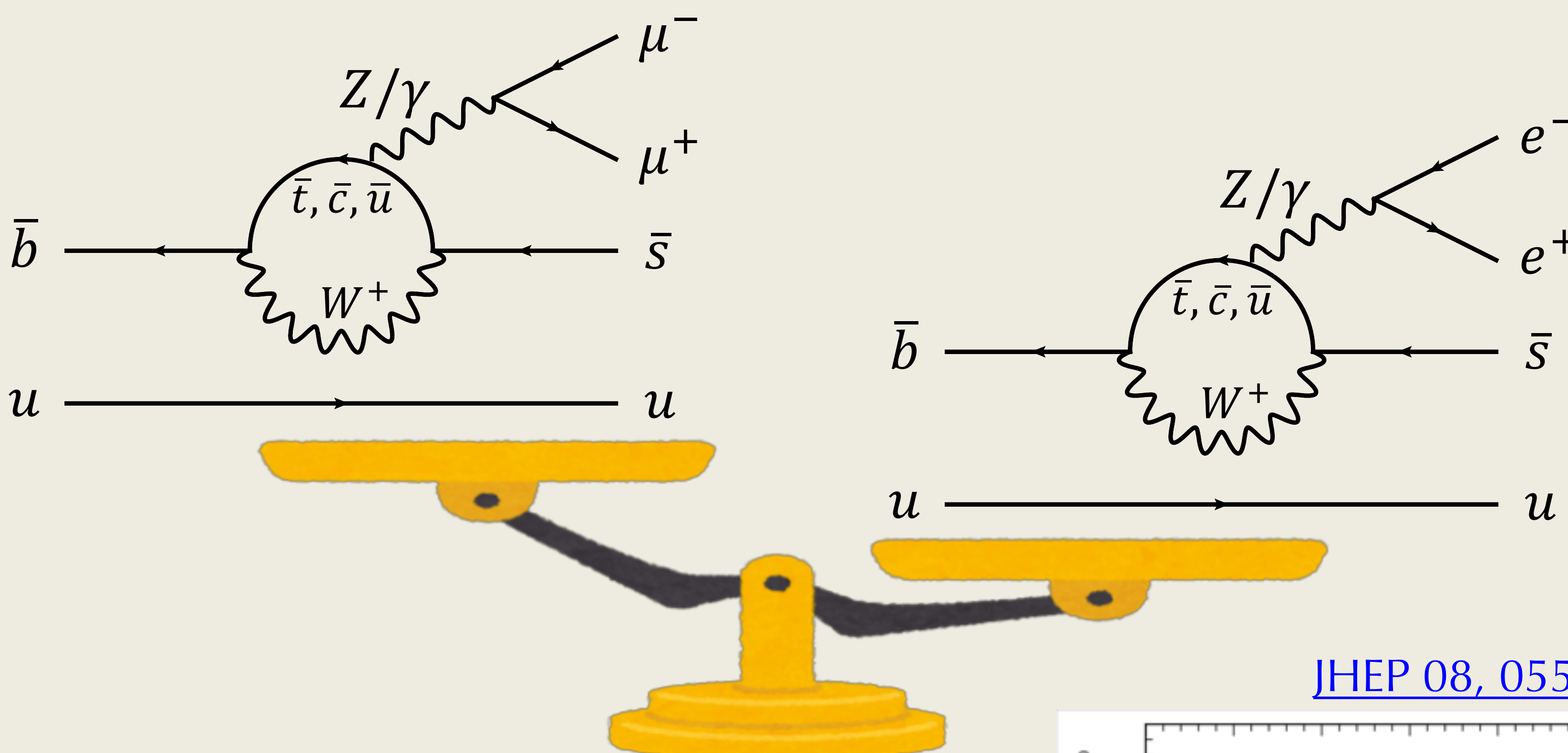


※Tree level is forbidden in SM!

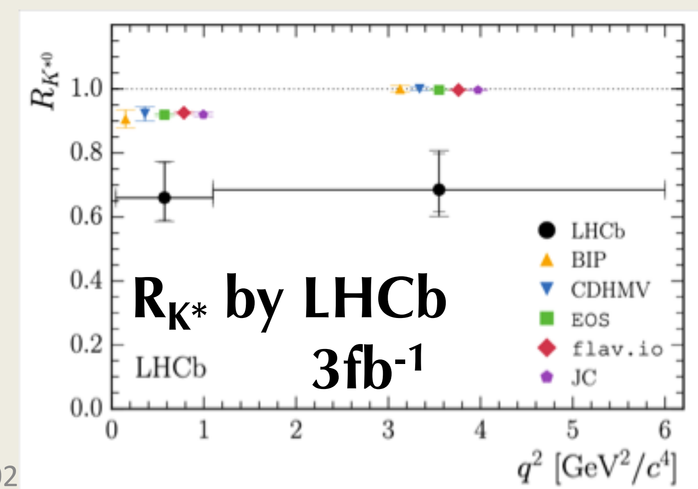


- Flavor changing neutral current (FCNC) is possible only by loop diagram in SM.
  - Sensitive to new physics appearing in the loop.
- FCNC of B decay (b→s/d) is comparably high BR thanks to $V_{tb}\sim1$.
- B factory (Belle, Belle II, BaBar) provides ideal environment to investigate the FCNC.

Example



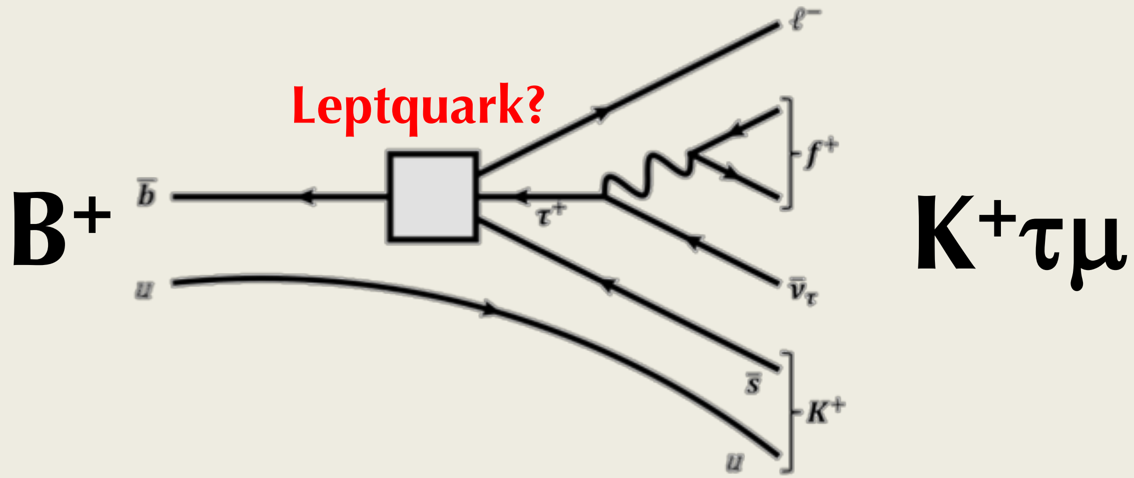
[JHEP 08, 055(2017)]



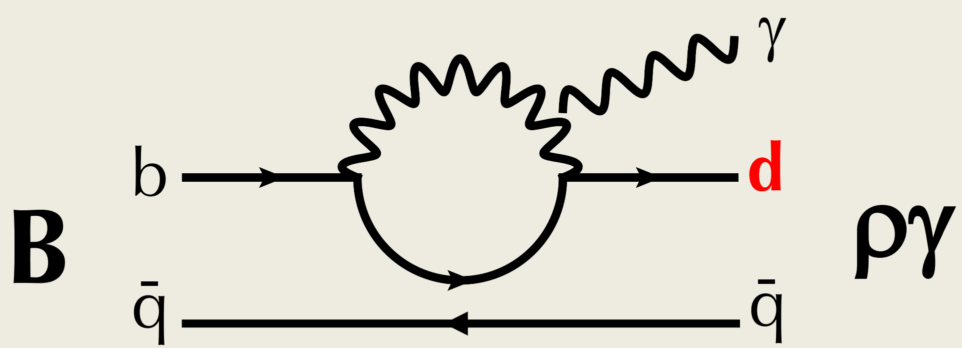
- LHCb recently reported a tension of $R_{K^{(*)}}$, which indicates Lepton flavor universality violation (LFUV).
- The same study at Belle (II) is possible and important.
- **More unique approaches** are also possible at Belle II.

Topics

1. Search of LFV $B \to K\tau\ell$ ($\ell=\mu,e$)



2. Study of $B \to \rho\gamma$

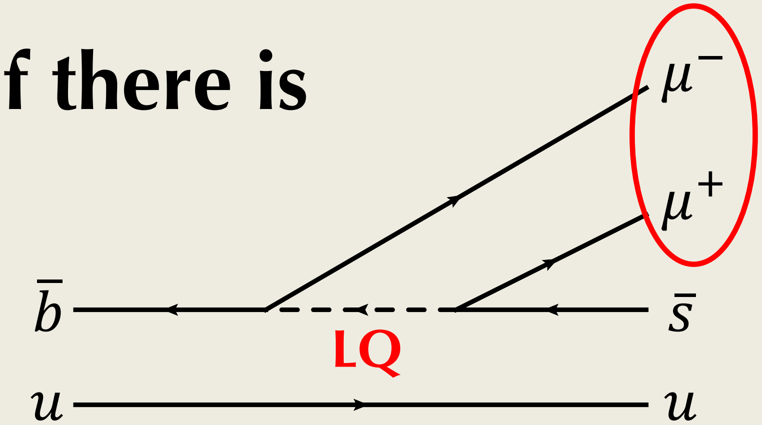


LFV ($B \rightarrow K\tau\mu$)

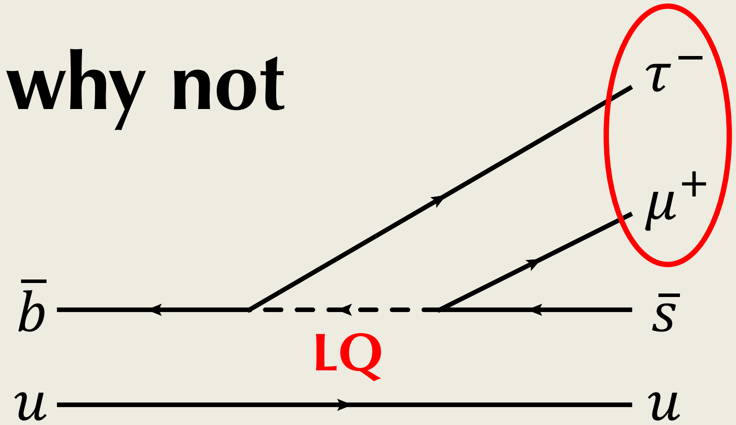
Motivation (LFV)

- Once LFU is violated, lepton flavor violation (LFV) is **no longer forbidden** in the model;

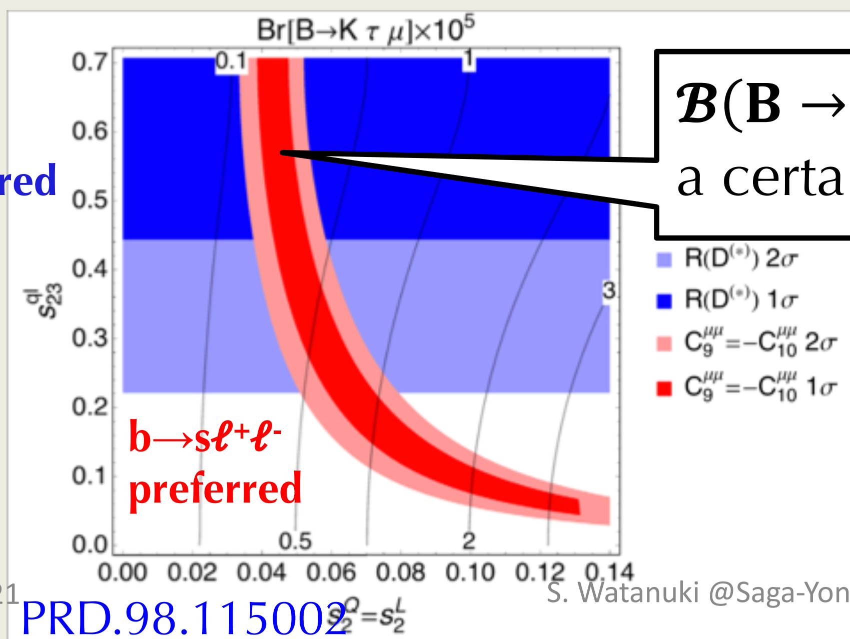
If there is



why not



R(D(*)) preferred

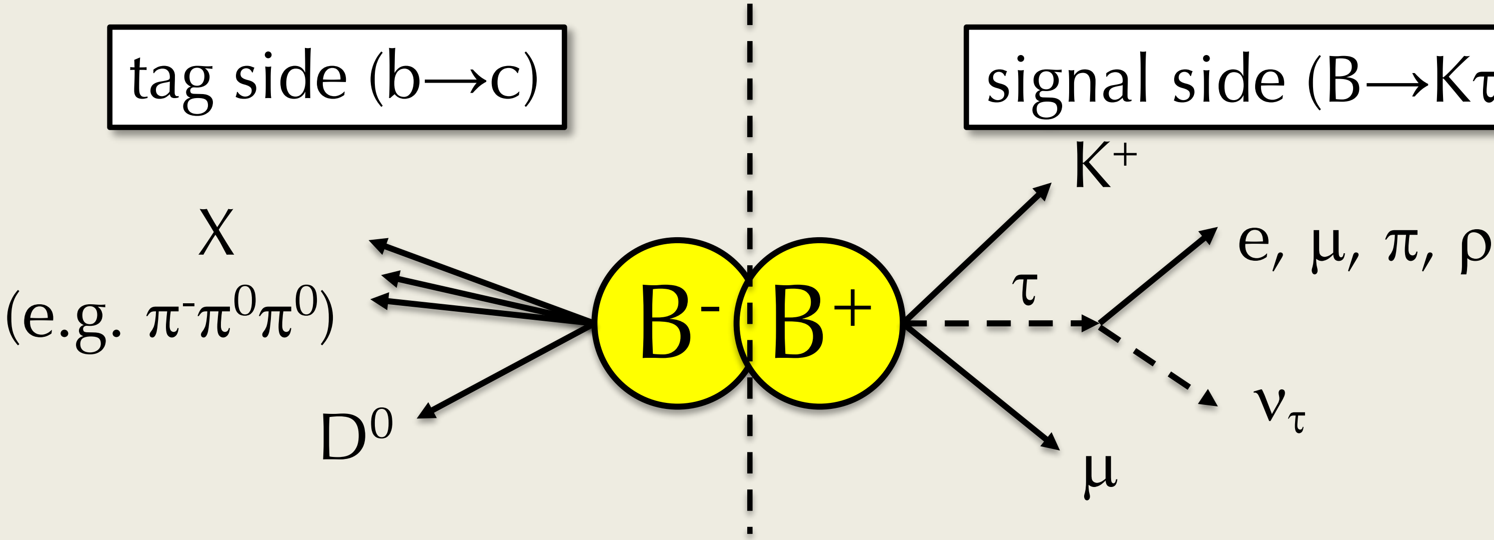


$\mathcal{B}(\mathrm{B} \to \mathrm{K}\tau\mu) \sim O(10^{-6})$ is preferred in a certain VLQ model, for example.

PRD.98.115002

Searching LFV is also a fascinating topic!

Unique Analysis Procedure at Belle

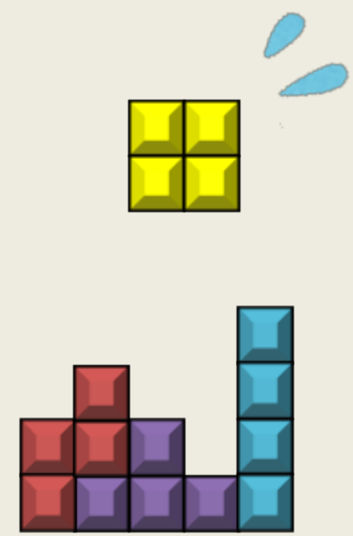


We can try 3 methods to solve this challenging puzzle game.

(A) Hadronic tag (**S. Watanuki**)

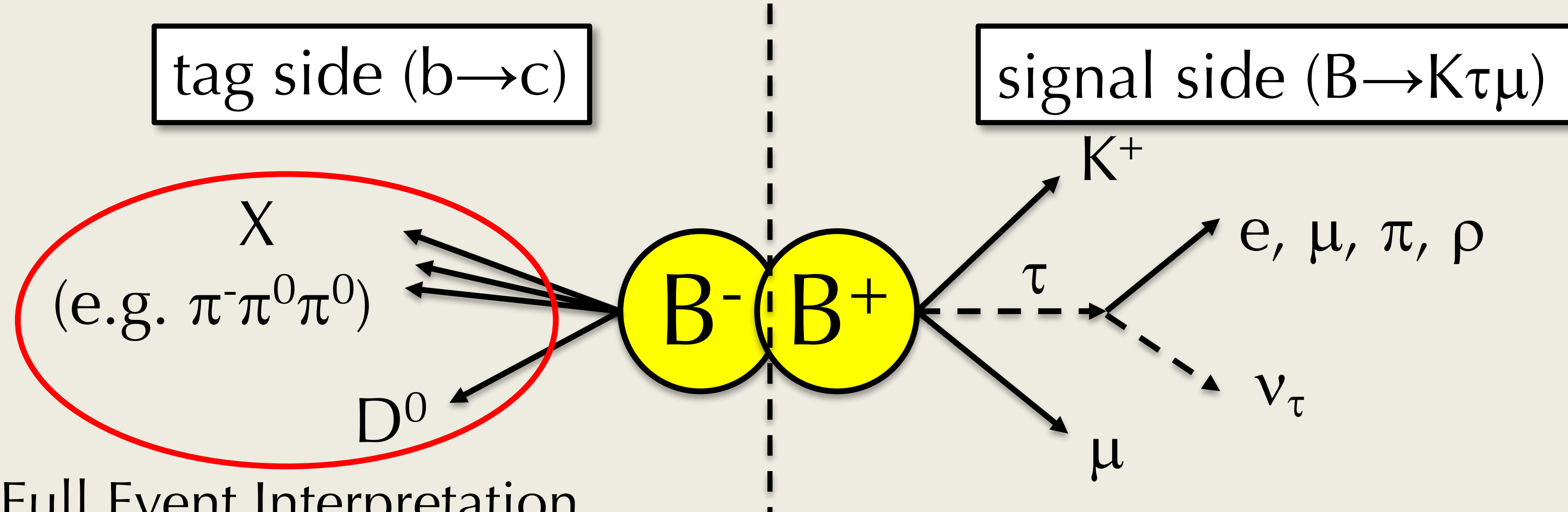
(B) D tag (**G. de Marino**)

(C) Inclusive (**S. Sandilya**)



1. Hadronic tag

※ For other methods, please see backup slides.

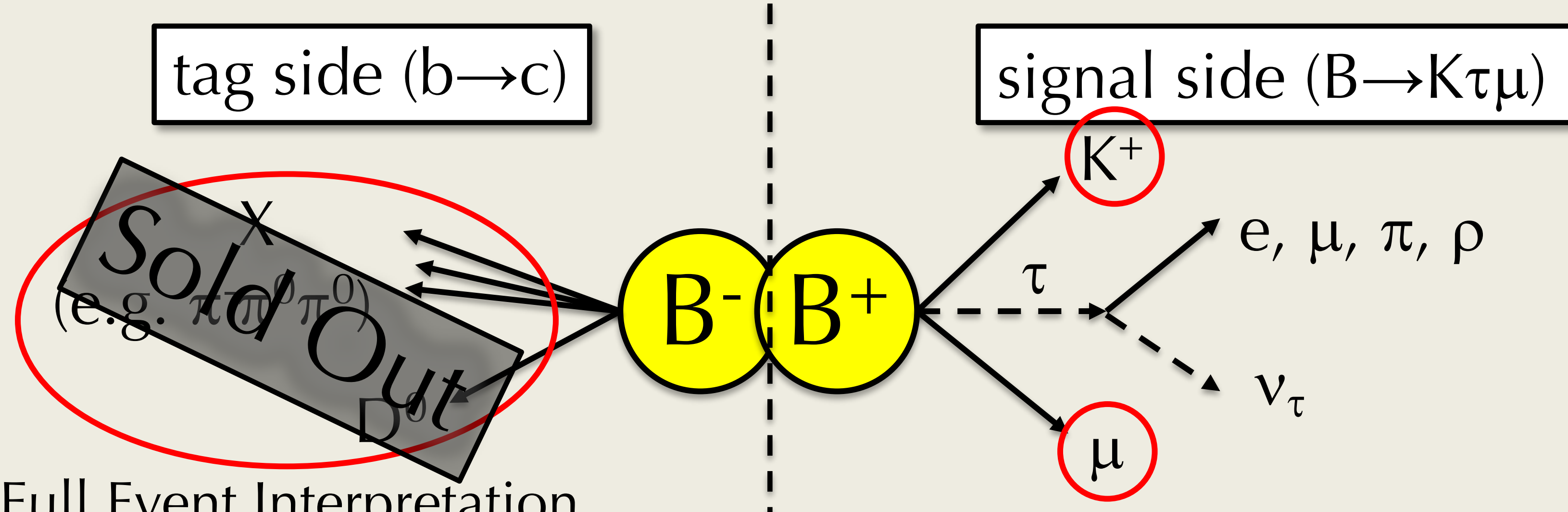


Full Event Interpretation (FEI)

1. Reconstruct tag side B with as many modes as possible.

1. Hadronic tag

※ For other methods, please see backup slides.

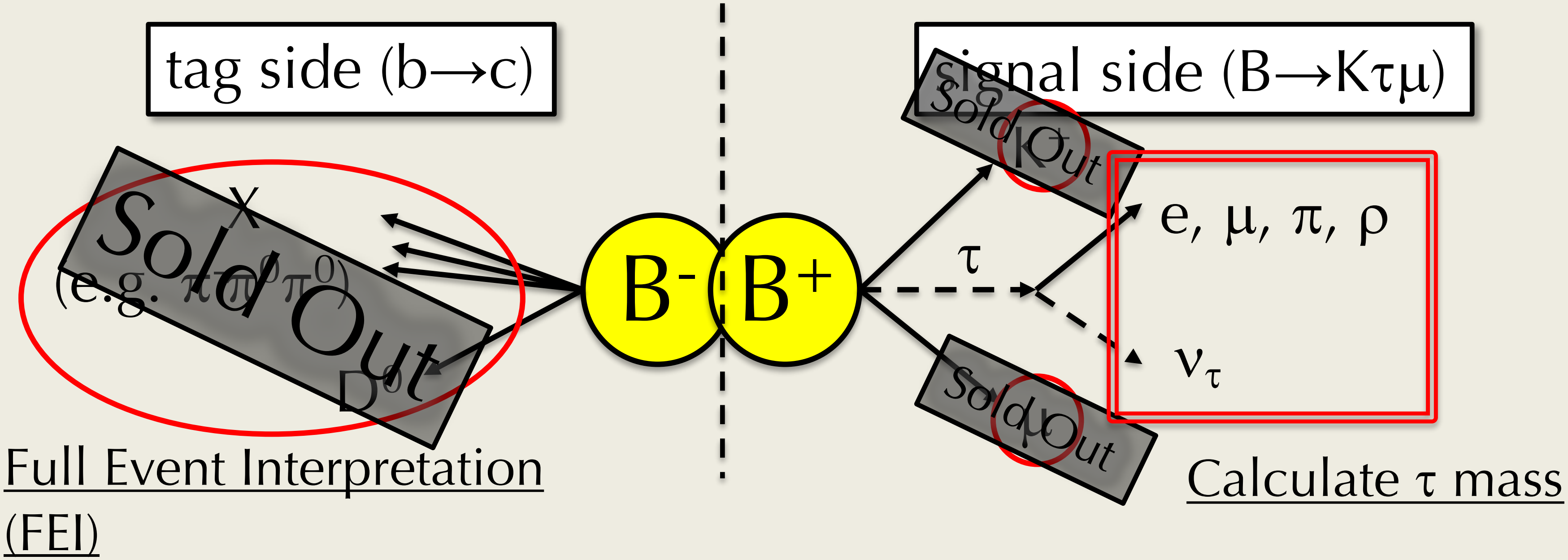


Full Event Interpretation (FEI)

1. Reconstruct tag side B with as many modes as possible.
2. Select K^+ and μ in the rest of event for tag side B.

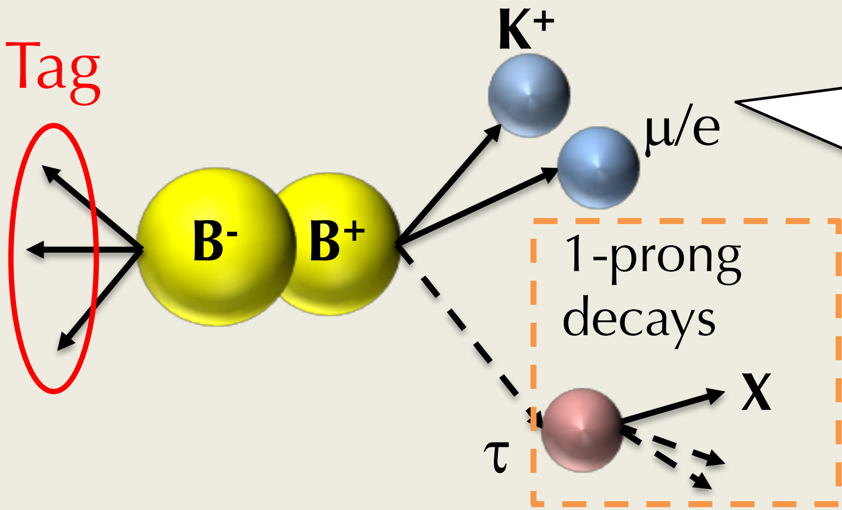
1. Hadronic tag

※For other methods, please see backup slides.



1. Reconstruct tag side B with as many modes as possible.
2. Select K^+ and μ in the rest of event for tag side B.
3. The rest of event of $B^-K^+\mu$ system is τ.

Hadronic Tag Method



Charged tracks

$PID_{\pi} > 0.6$ for p^+, $PID_K > 0.6$ for K^+

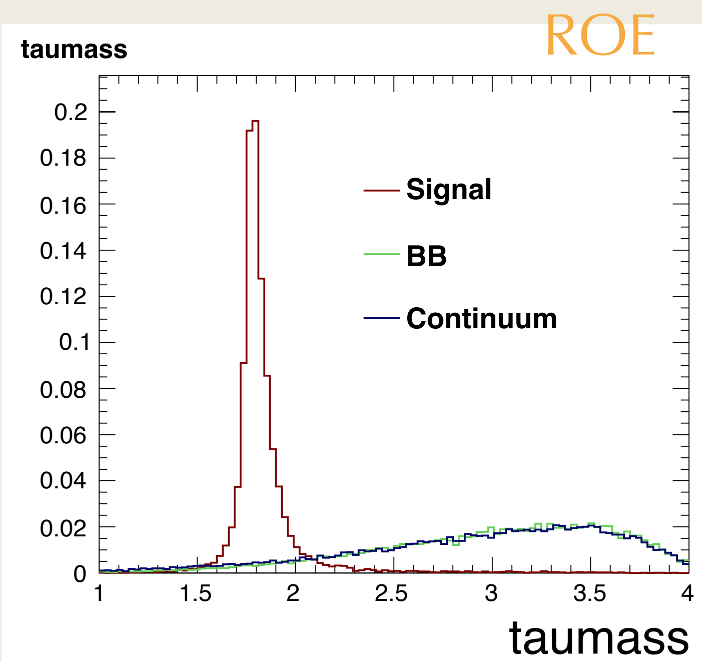
mID > 0.9 for μ

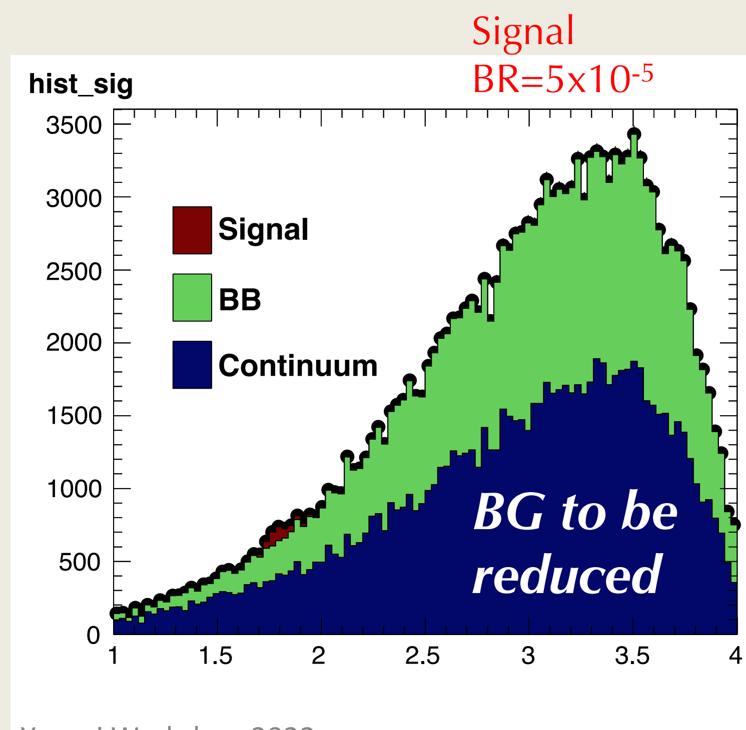
eID > 0.9 for e

Primary tracks (K, μ/e)

$|d_0| < 0.5$cm

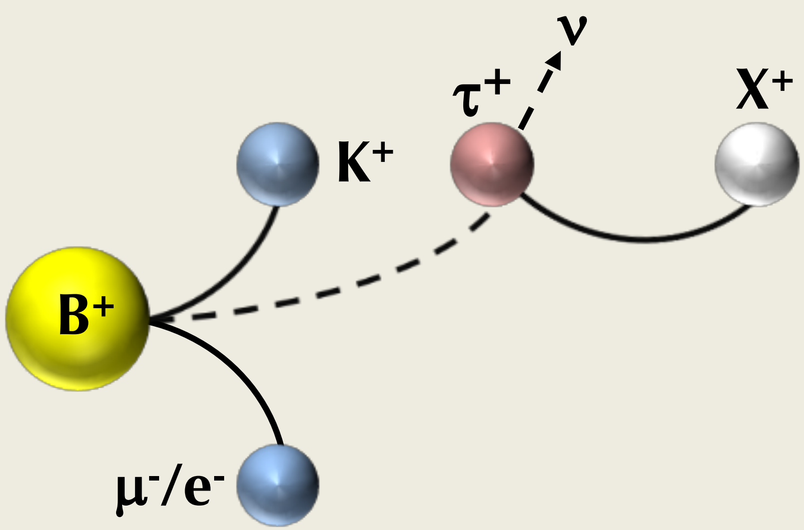
$|z_0| < 5.0$cm



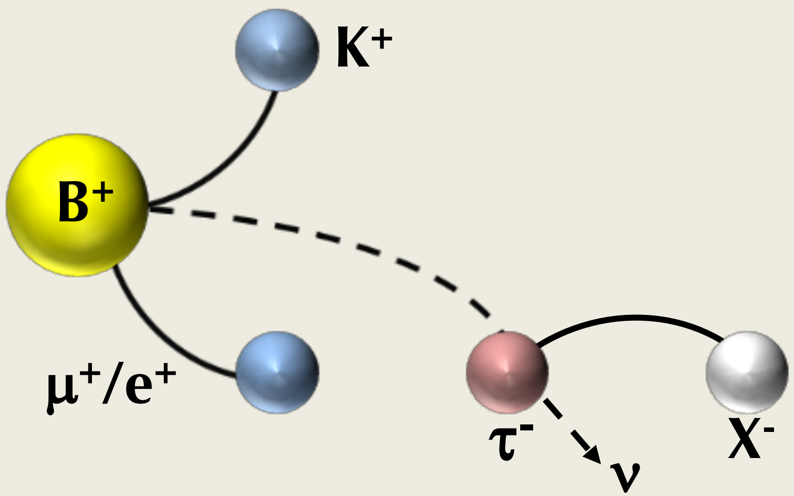


2 types of signal decay

Opposite Sign channel (OS)



Same Sign channel (SS)



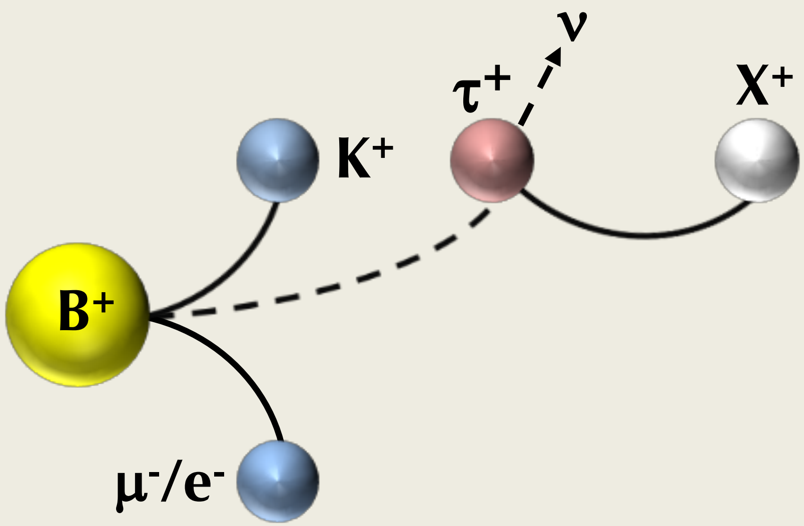
- 2 types of signal decay with charge combination of primary tracks.
  - As long as staying on model-independence, we must consider both channels.
- The reconstruction strategy is same.
- However **main BG types are different**, thus cut strategies are also differently optimized.

- **SS** has huger size of BG, hardly separate signal/BG, etc...

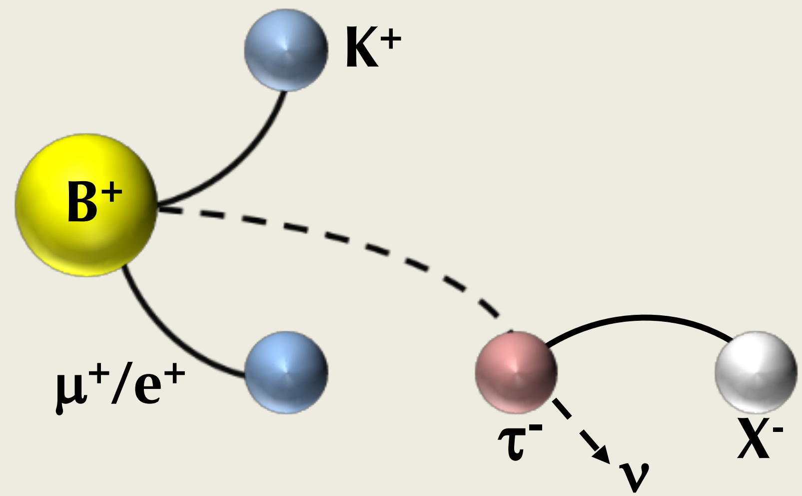
→ **Much more difficult channel** 😇

2 types of signal decay

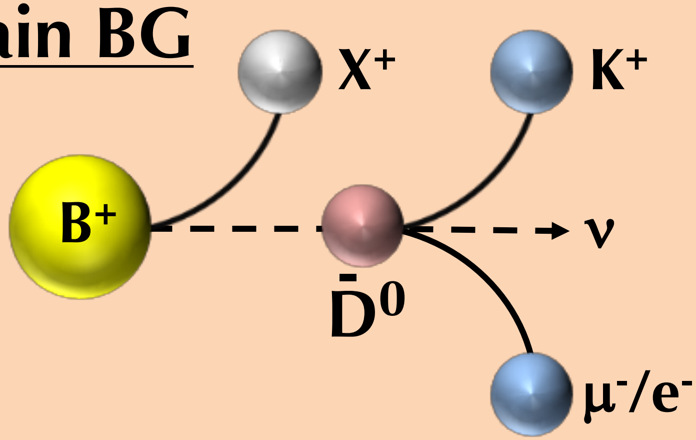
Opposite Sign channel (OS)

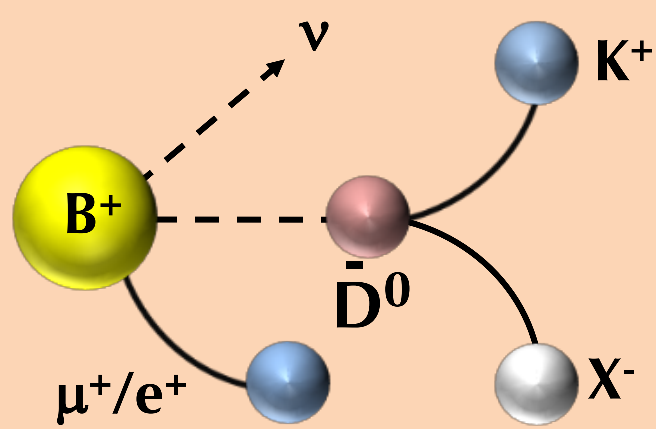


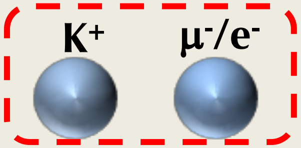
Same Sign channel (SS)



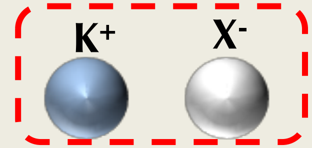
Main BG

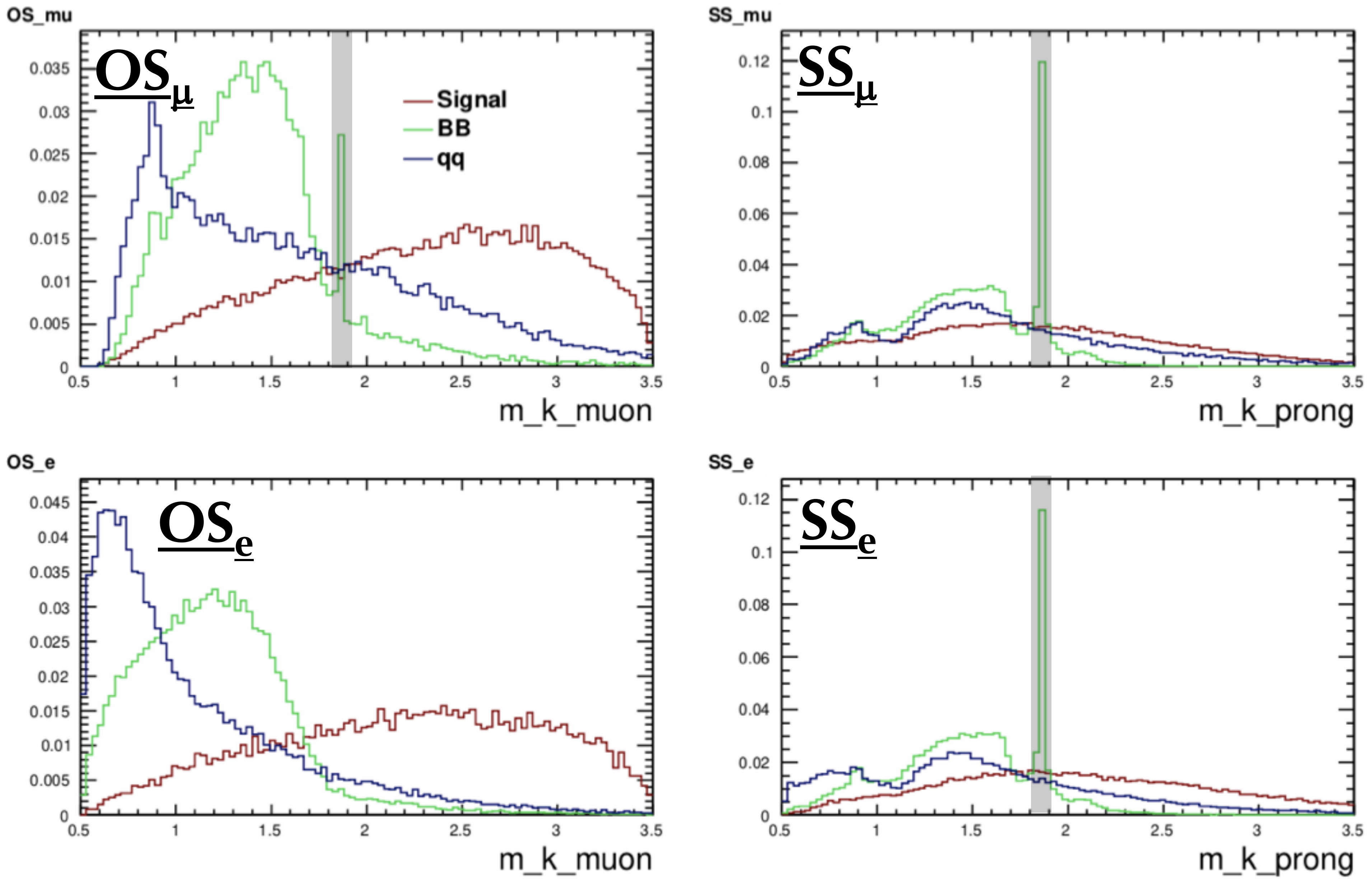





K+
μ-/e-

D veto


K+
χ-


OS_mu
OSμ
Signal
BB
qq
m_k_muon
SS_mu
SSμ
m_k_prong
OS_e
OSe
m_k_muon
SS_e
SSe
m_k_prong

MVA training (BB)

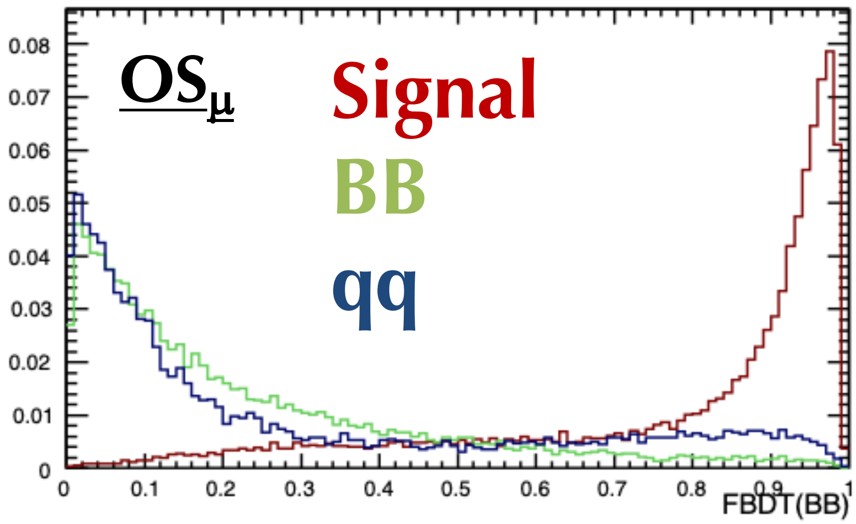
1. **Kinematic information**
   – Invariant mass of primary K and lepton (**only for OS**)
   – Invariant mass of primary K and τ prong (**only for SS**)

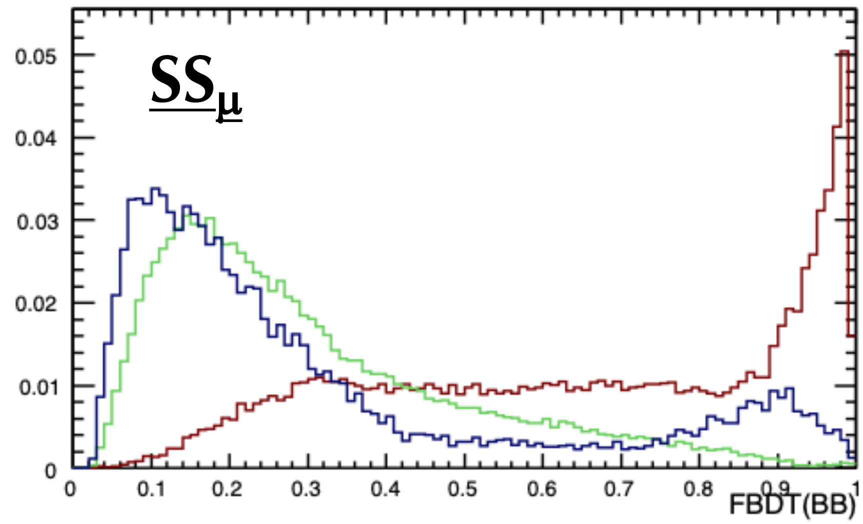
2. **The decay topology**
   – KSFW parameters
   – B vertices position (dr, dz)
   – The distance between primary K and lepton

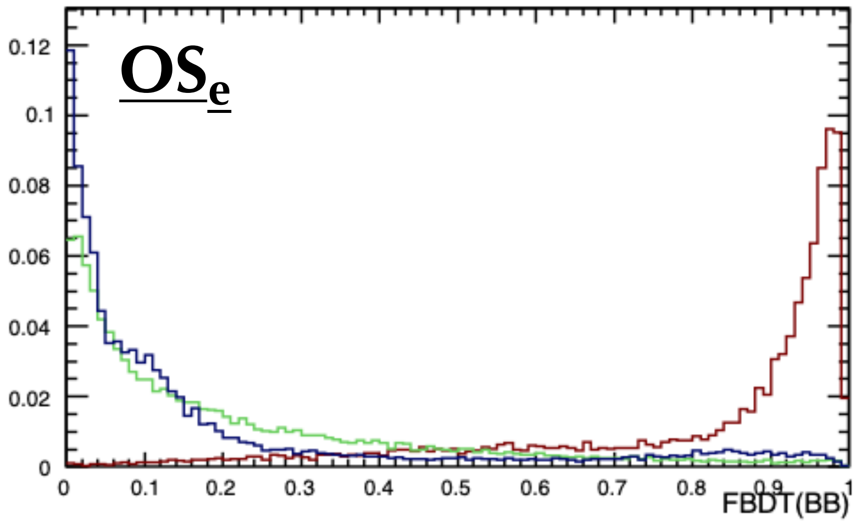
3. **Neutral remnant particle**
   – Number of extra ECL neutral clusters
   – Energy deposit of extra ECL neutral cluster (E_{ECL})

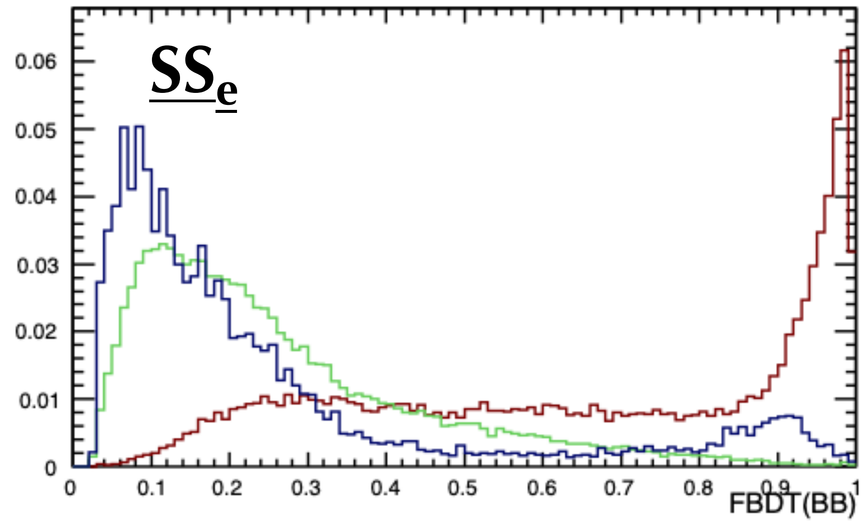
4. **Fake particle BG**
   – Signal probability of B_{tag}
   – PID (or LID) of the particles

MVA outputs (BB)

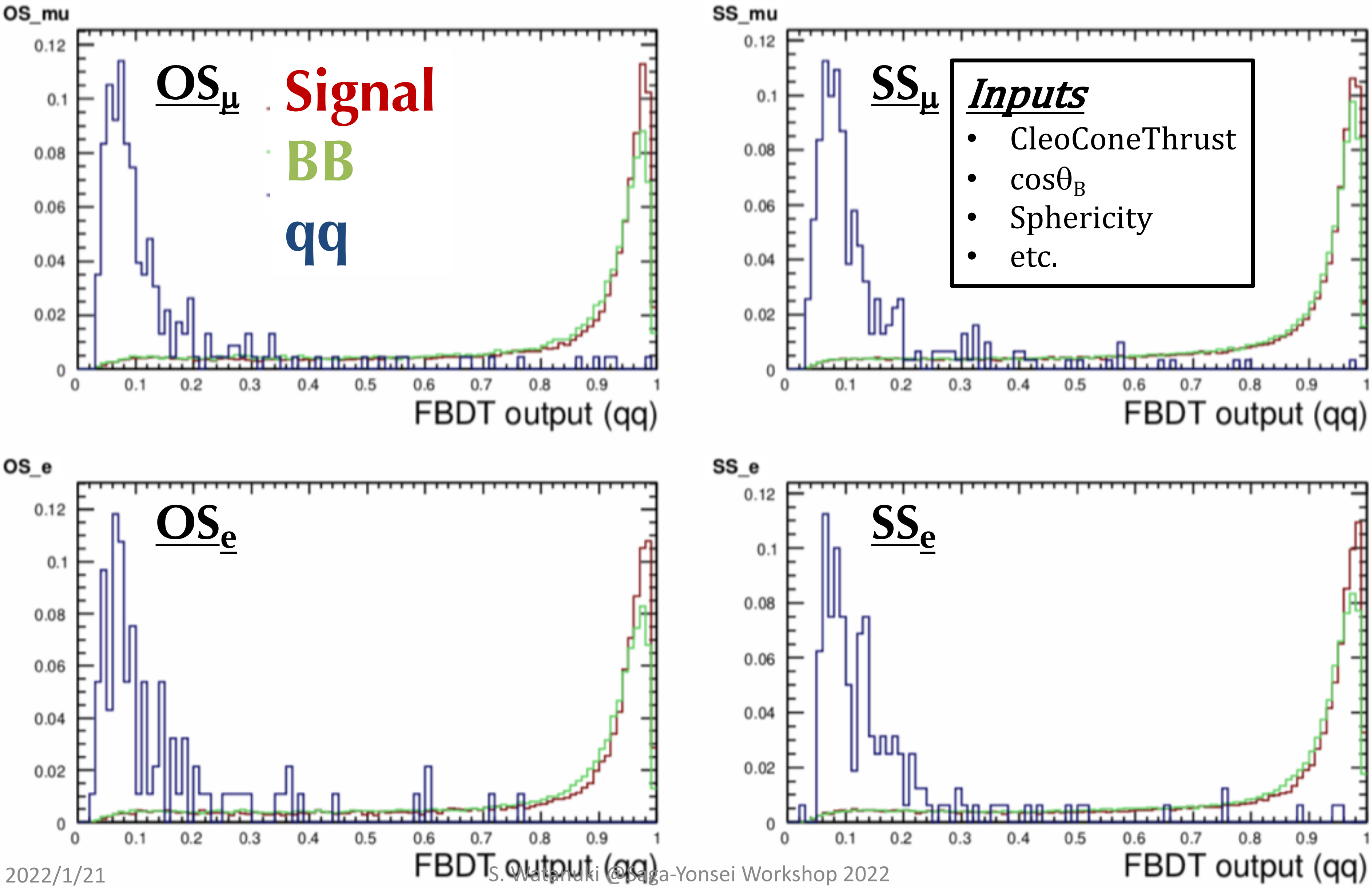




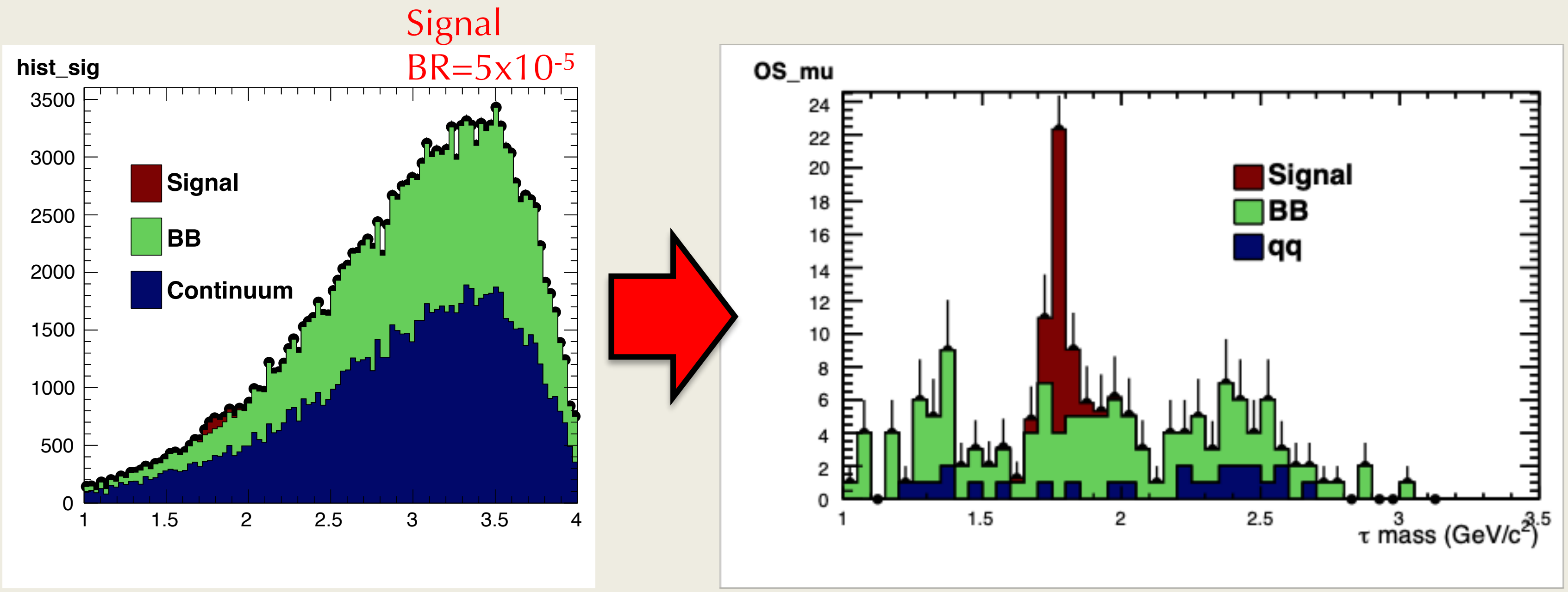




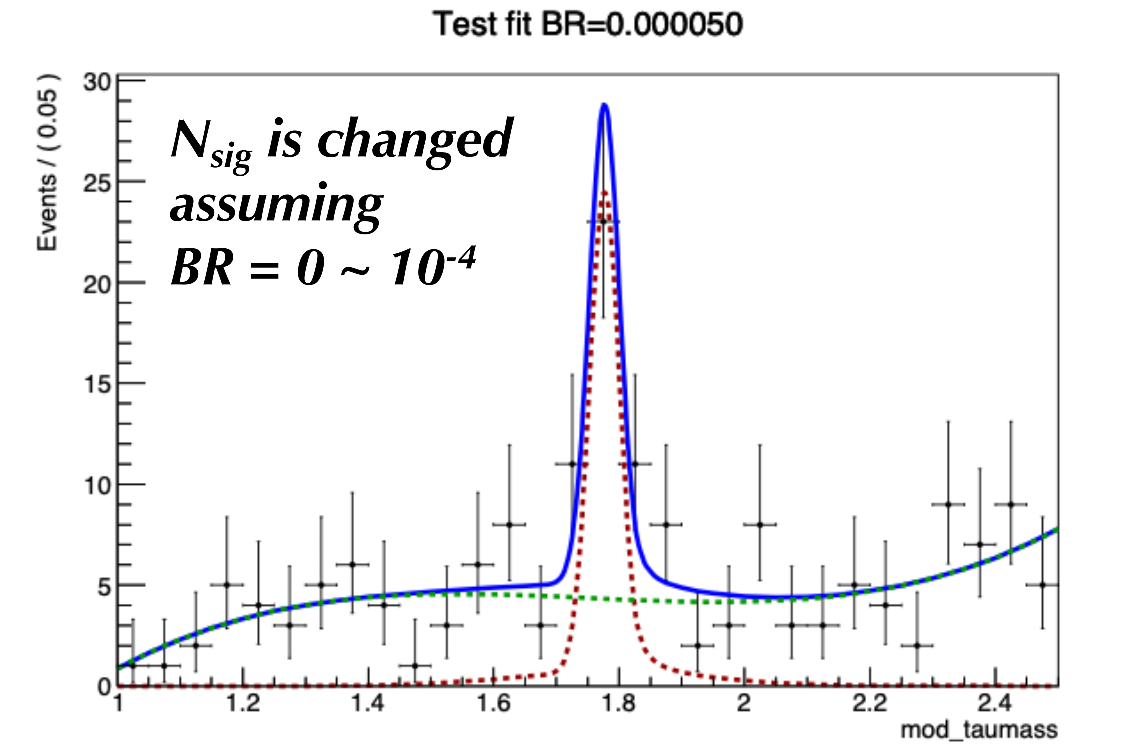
MVA outputs (qq)

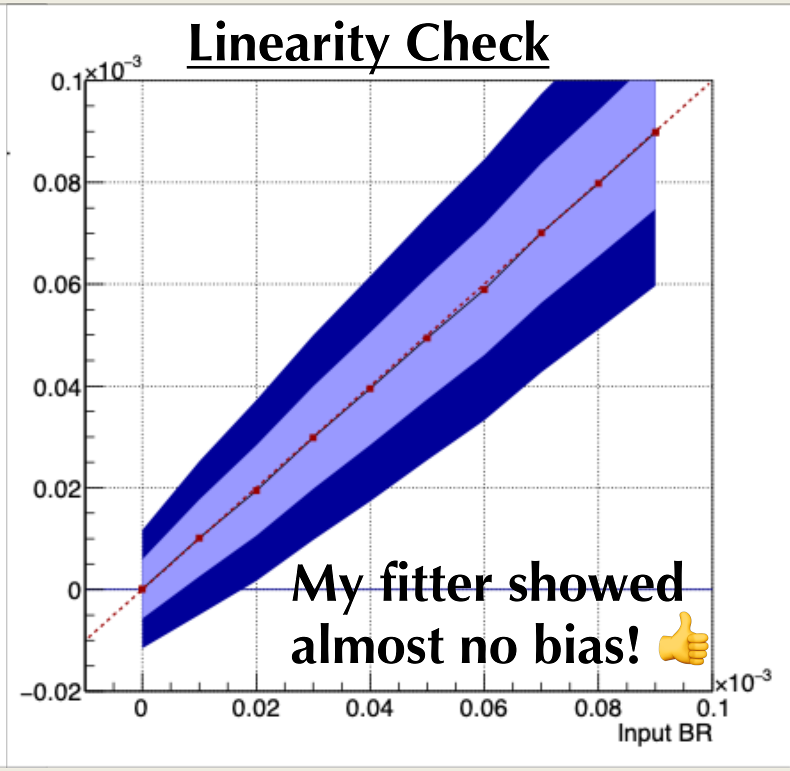


τ Mass after the Cuts



Fitting to Extract the Signal





Signal

Crystal Ball + Gaussian

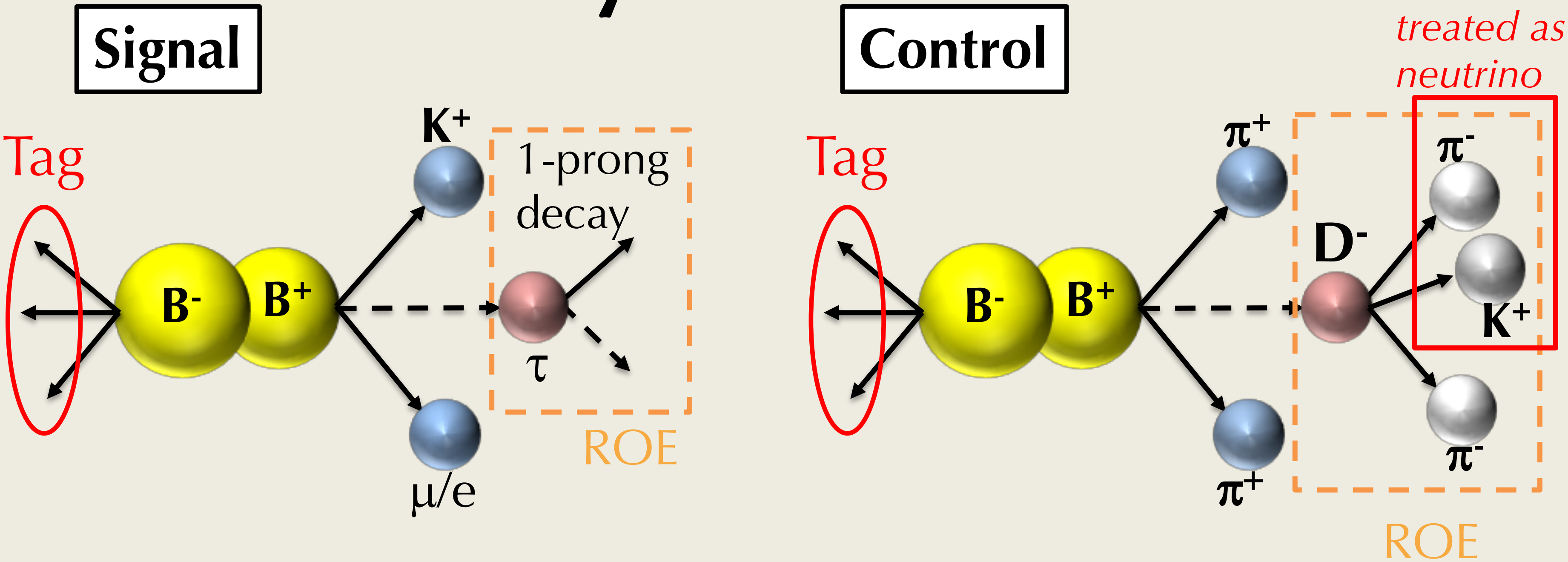
BG (BB+qq)

3rd order Chebychev polynomial

90% C.L.	OS_mu	SS_mu	OS_e	SS_e
BR U.L.	<1.2e-5	<1.8e-5	<1.4e-5	<1.8e-5

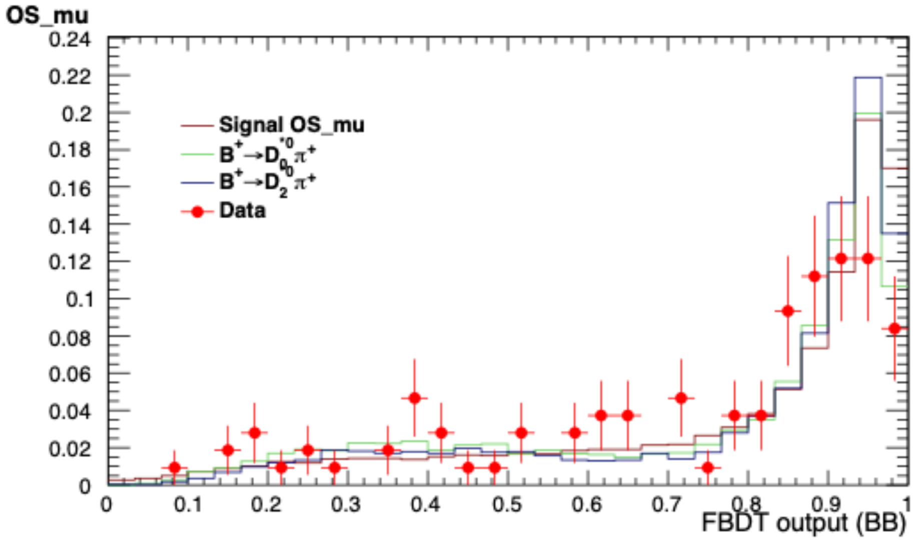
Only stats. error is assigned.

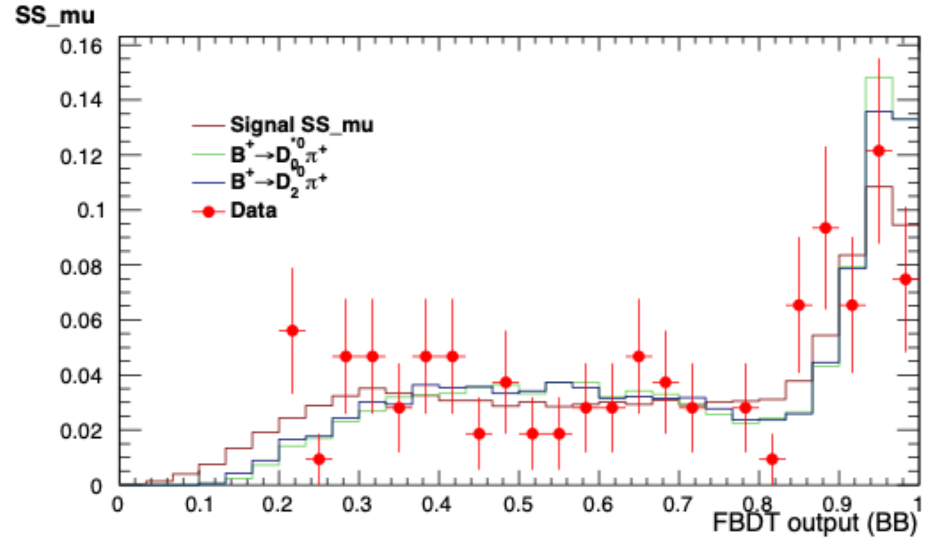
Systematics

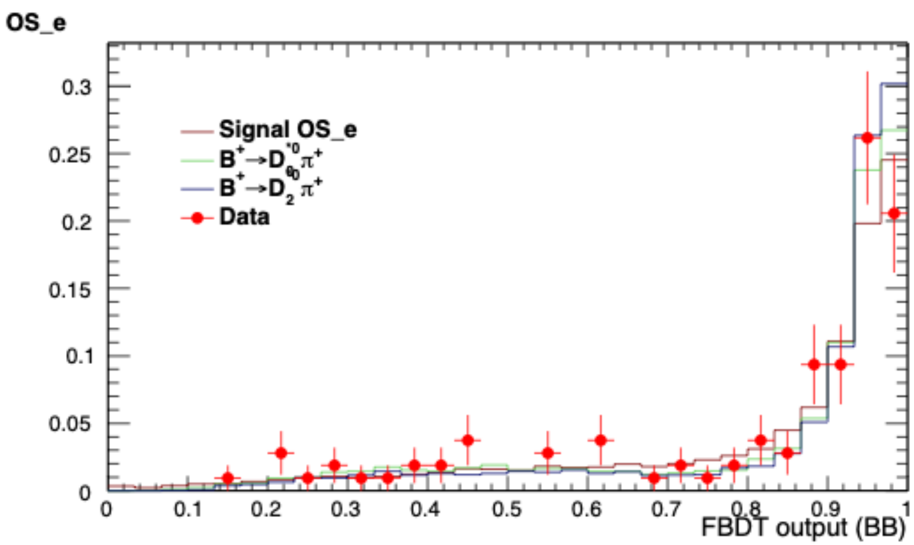


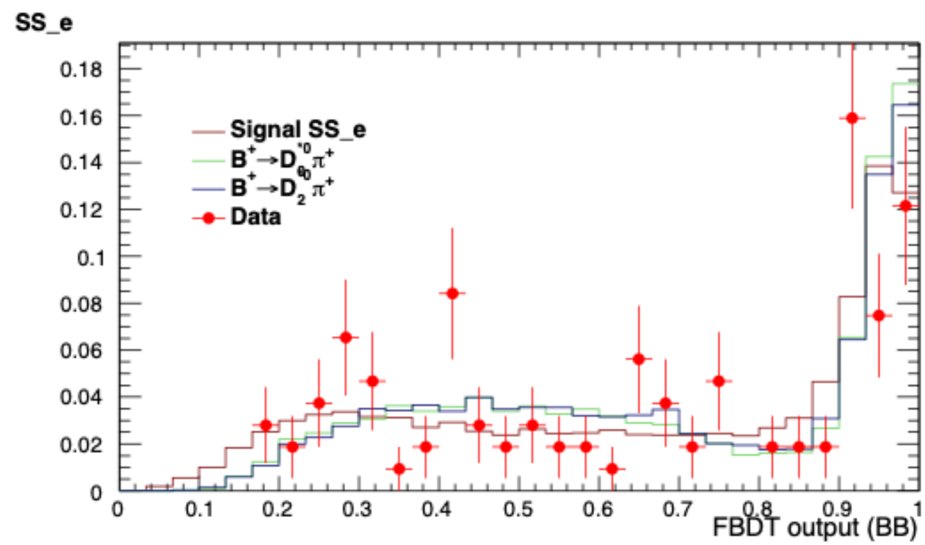
- The results in previous page is based on MC.
- **We always have to calibrate the Data/MC discrepancy in a data driven way.**
- Main control sample of this study is **$B^+ \to D^-(\to K^+\pi^-\pi^-)\pi^+\pi^+$**, which provides very similar kinematics as signal.

FBDT Data/MC Calibration





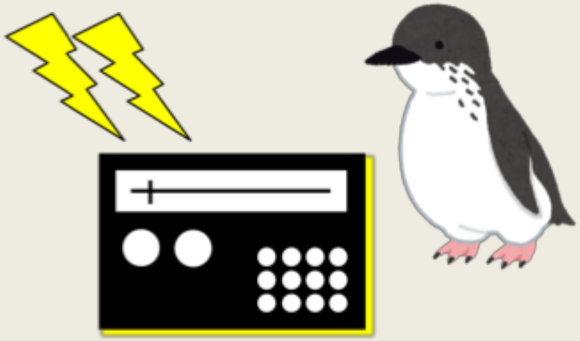




Source of Systematics

Sources	OS_μ ($\times 10^{-5}$)	SS_μ ($\times 10^{-5}$)	OS_e ($\times 10^{-5}$)	SS_e ($\times 10^{-5}$)
Efficiency calibration				
FEI	0.0215	0.0637	0.0271	0.1104
Tracking	0.0091	0.0270	0.0115	0.0468
LID of primary lepton	0.0027	0.0082	0.0075	0.0306
LID of τ prong μ	0.0002	0.0007	0.0011	0.0063
LID of τ prong e	0.00[illegible]	0.0016	0.0006	0.0031
PID prim K	0.0006	0.0018	0.0008	0.0031
PID $\tau \to \pi$	0.0003	0.0011	0.0004	0.0017
PID $\tau \to \rho \to \pi$	0.0002	[illegible]000[illegible]	0.0002	0.0005
pi0 reconstruction	0.0037	0.[illegible]65	0.0051	0.0117
BB sup. and D-veto	0.1248	0.54[illegible]	0.1061	0.7831
qq sup.	0.0760	0.16[illegible]	0.0724	0.3783
Other parameters				
$N_{B\overline{B}}$	0.0119	0.0353	0.0150	0.0611
f_{+-}/f_{00}	0.0096	0.0284	0.01[illegible]1	0.0492
MC stats.	0.0087	0.0235	0.0173	0.0485
Linearity	0.0379	0.0551	0.0261	0.1077
Fixed PDF shape				
Mean	0.0184	0.0160	0.0186	0.0177
Width	0.0363	0.0971	0.0174	0.0499
PDG τ mass	0.0208	0.0291	0.0040	0.0494
Total	0.1599	0.5849	0.1358	0.8845

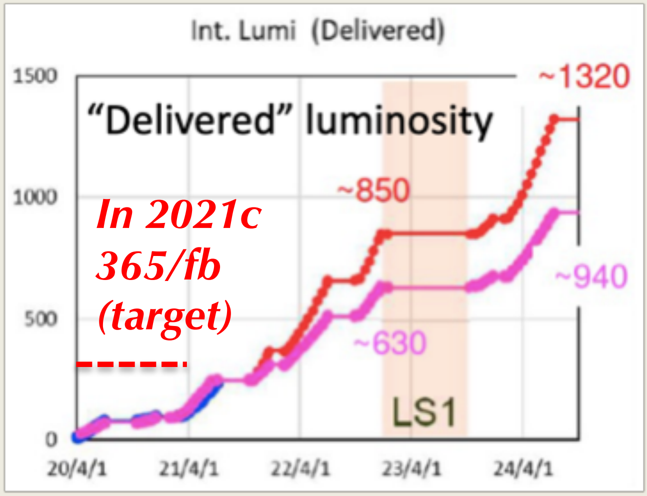
Preliminary



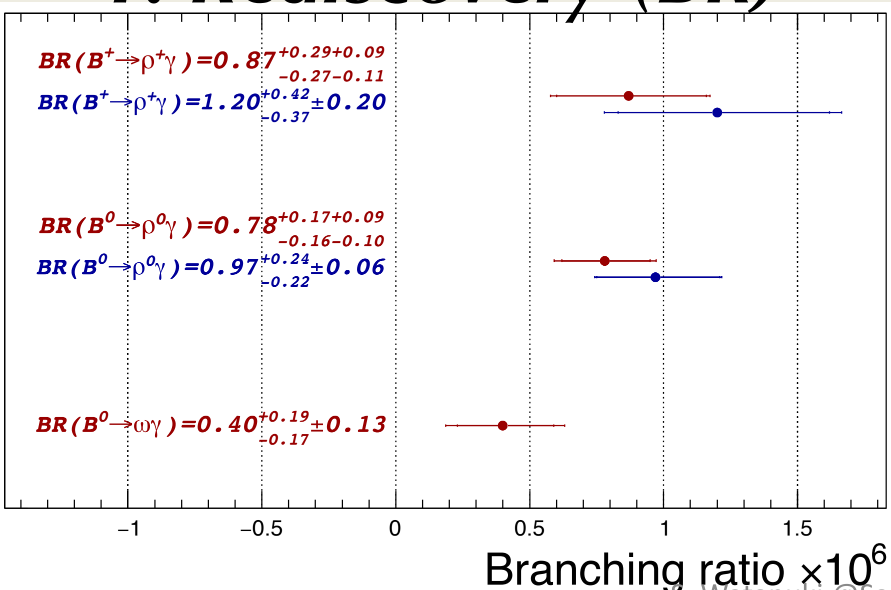
Radiative ($\rho\gamma$)

Motivation

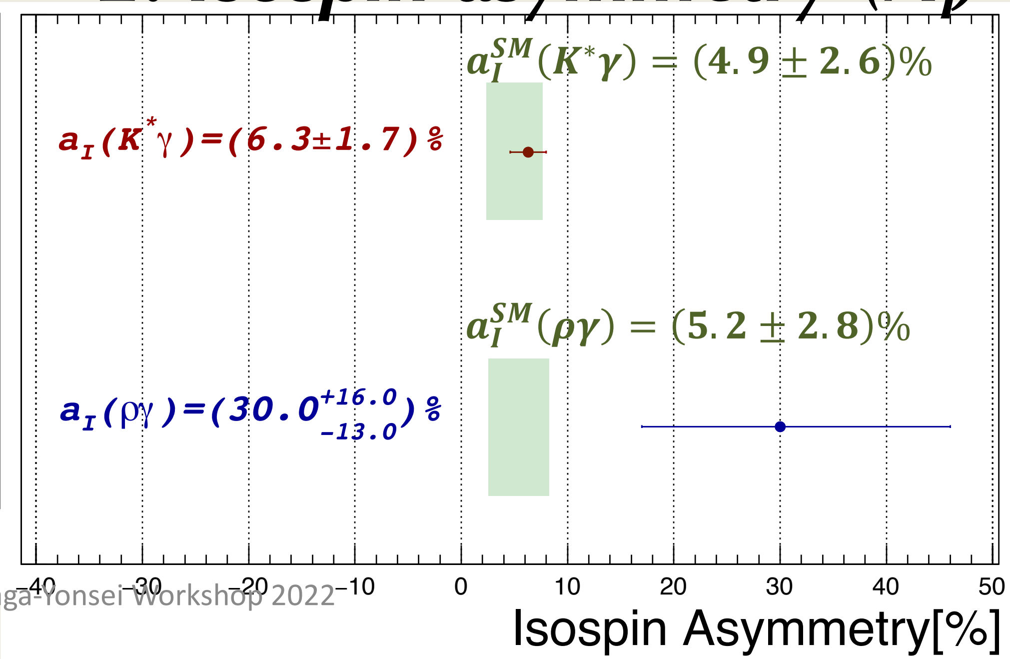
- We are targeting **~365fb^{-1}** integrated luminosity in 2021c.
  - **Belle + Belle II** will reach more than 1/ab.
- This is enough to measure $B^{0(+)} \to \rho^{0(+)}\gamma$ with more than 5.6σ (3.7σ) assuming with Belle study sensitivity.
- The mode would be **first step of b→d EWP** transition at Belle II.



1. Rediscovery (BR)



2. Isospin asymmetry (A_I)



Reconstruction

BELLE

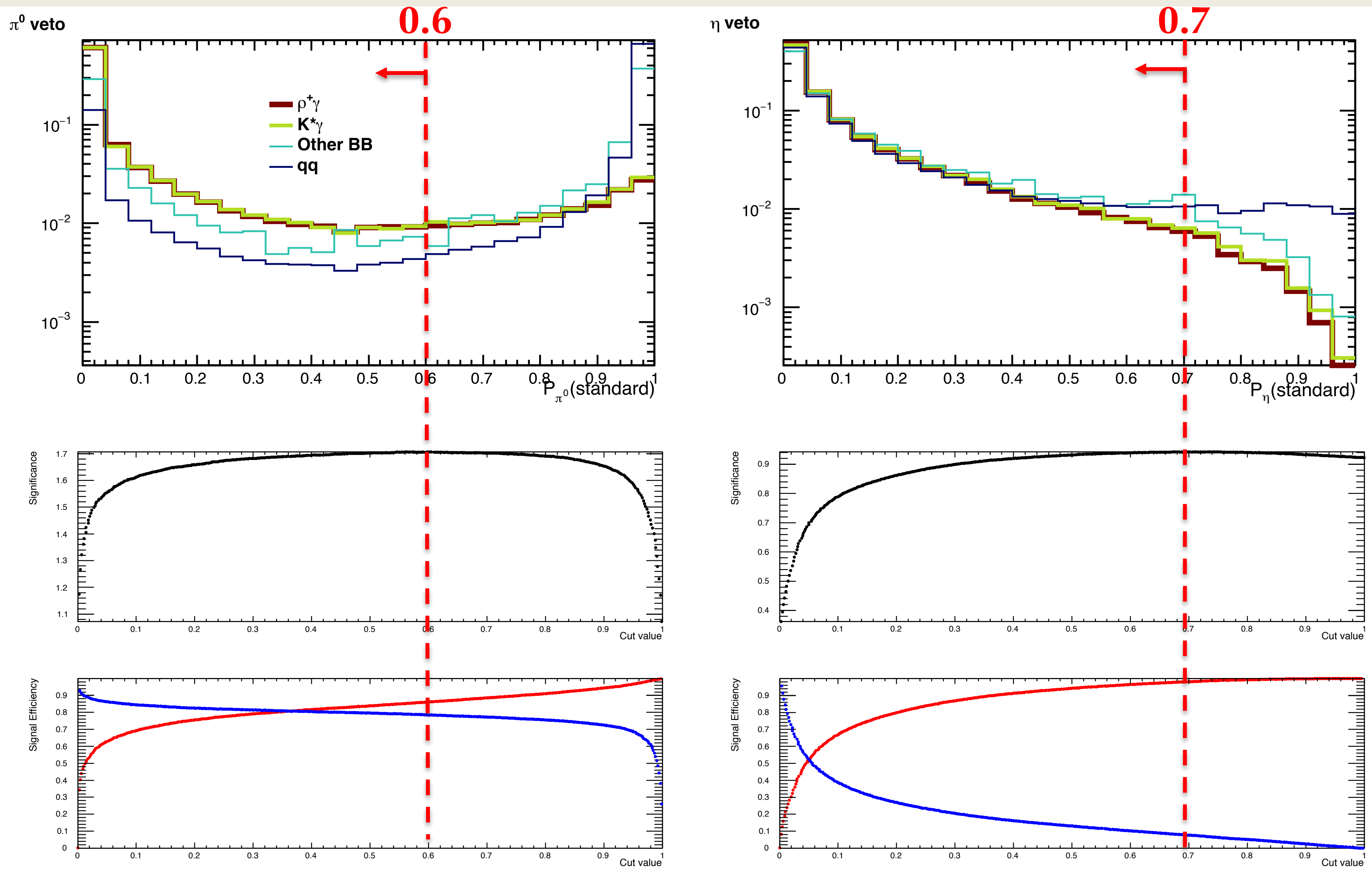
- **Primary Photon**
  - $1.8 < E^* < 2.8$ GeV
  - Cluster region == 2
  - E9oE25>=0.95
  - Cluster second moment <= 1.5
  - Cluster # Hits >= 8
- **Charged particles**
  - $PID_{\pi/K} > 0.6$ for π^+
  - $PID_{K/\pi} > 0.6$ for K^+
  - $dr < 0.5$cm
  - $|dz| < 2$cm
- **Neutral π^0** (for $\rho^+ \to \pi^+\pi^0$ channel)
  - $M_{\pi^0} \in (119, 151)\ \mathrm{MeV}/c^2$
  - $E_\gamma > 50$MeV
  - $\cos\Delta\phi_\gamma > 0.58$
  - $\cos\theta_{\gamma\gamma} > 0.50$

BELLE II

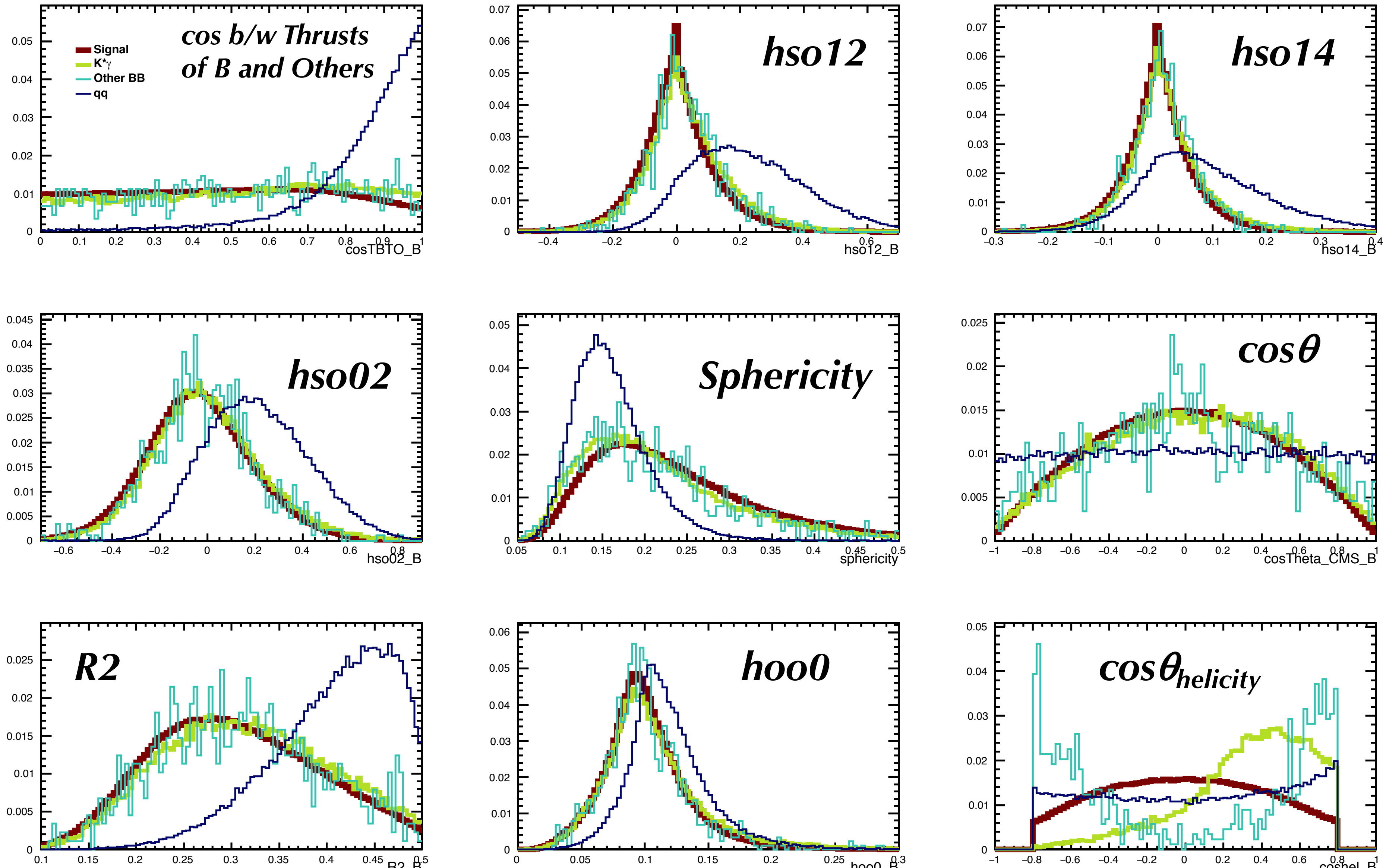
- **Event level**
  - foxWolframR2 < 0.5
  - nTracks >= 3

  BtoXgamma skim adopted
- **Primary Photon**
  - $1.8 < E^* < 2.8$ GeV
  - Cluster region == 2
  - E9oE21>=0.95
  - Cluster second moment <= 1.5
  - Cluster # Hits >= 8
- **Charged particles**
  - $PID_{\pi/K} > 0.6$ for π^+
  - $PID_{K/\pi} > 0.6$ for K^+
  - $dr < 0.5$cm
  - $|dz| < 2$cm
- **Neutral π^0** (for $\rho^+ \to \pi^+\pi^0$ channel)
  - $M_{\pi^0} \in (120, 145)\ \mathrm{MeV}/c^2$
  - $E_\gamma > 50$MeV
  - $\cos\Delta\phi_\gamma > 0.58$
  - $\cos\theta_{\gamma\gamma} > 0.50$

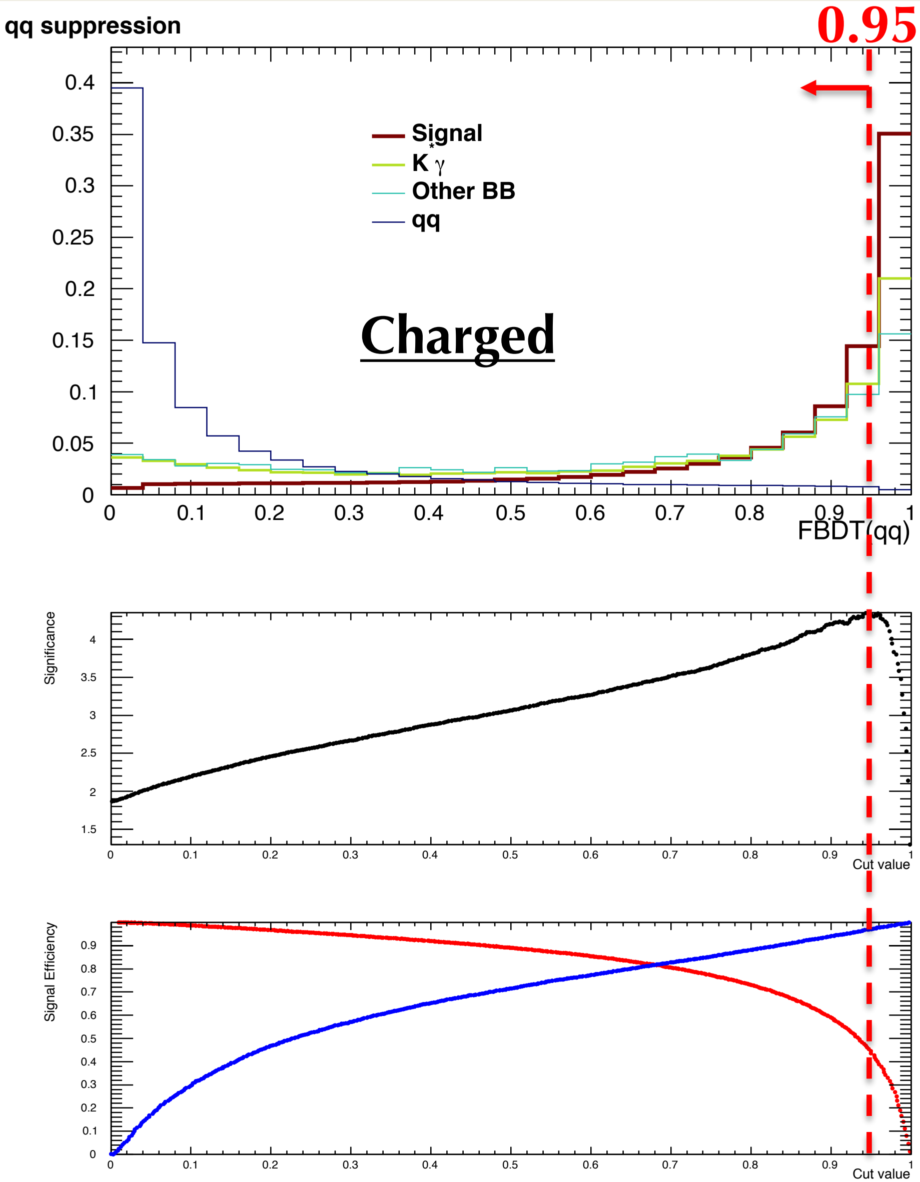
π^0/η veto ($\rho^+\gamma$)

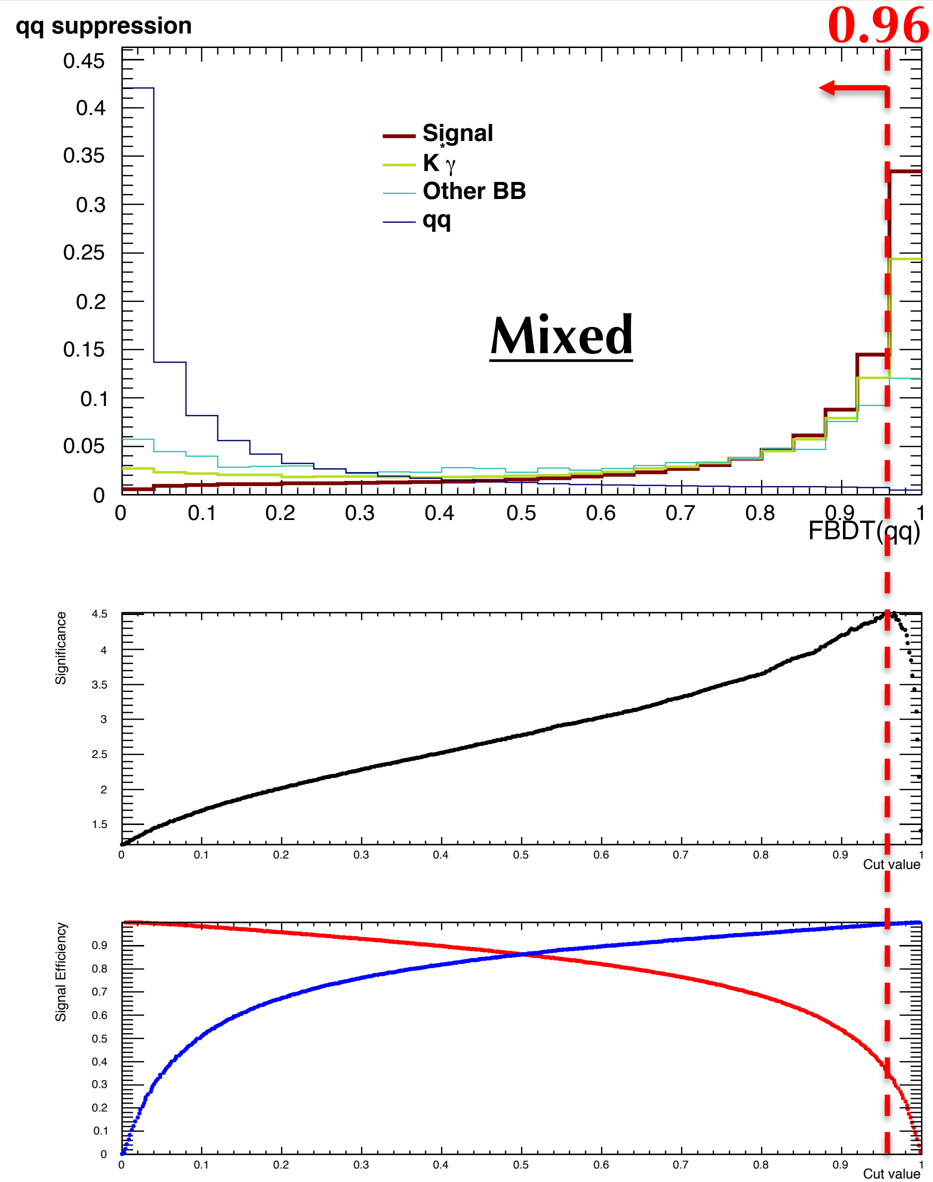


qq suppression ($\rho^+\gamma$)

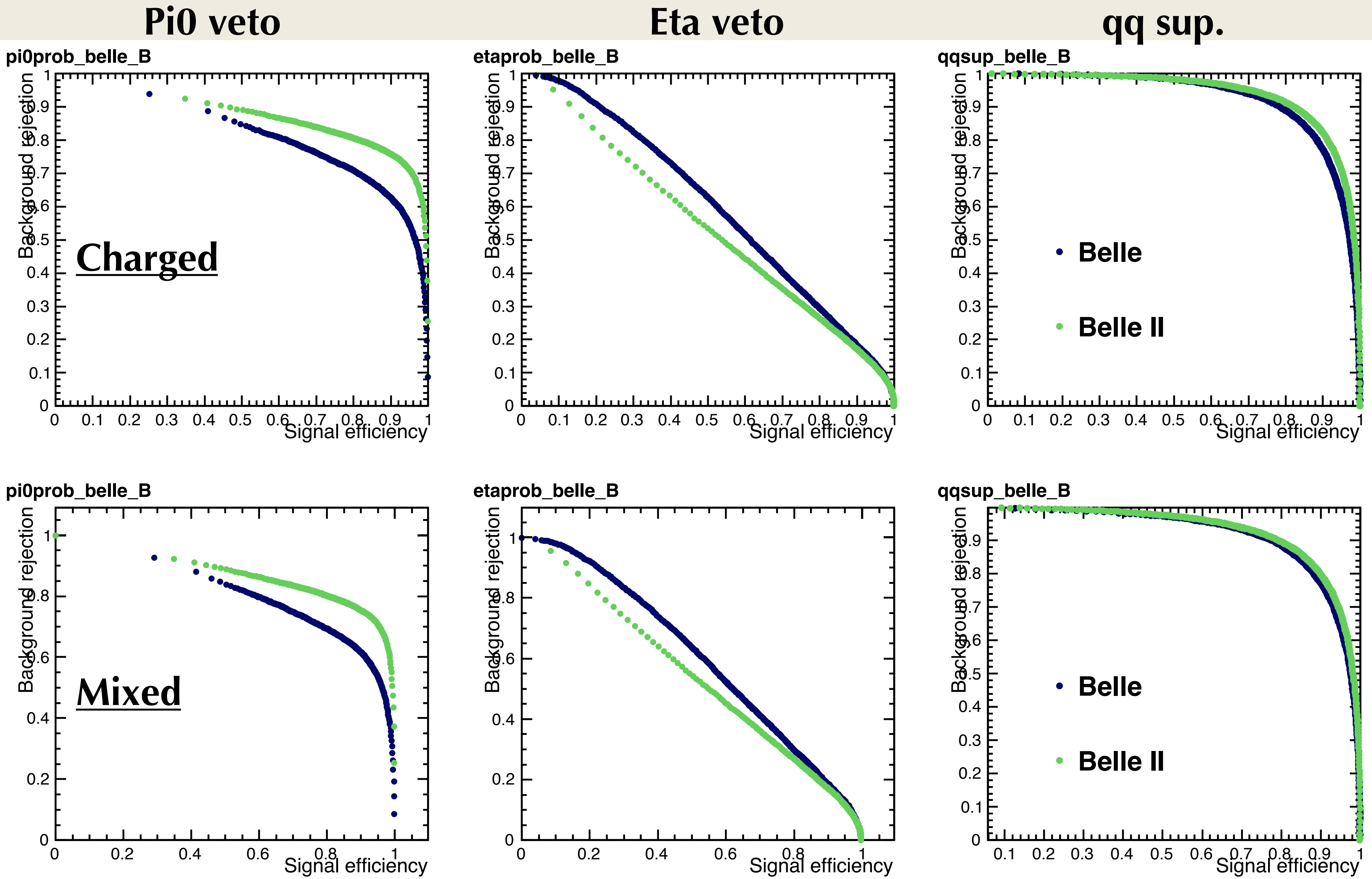


FBDT output for qq sup.





Performance Comparison with Belle



Cut Table (Charged)

Belle II	Signal	K*gamma	BB	qq	
No cut	204	424	2646	599173	0.263
Window	156	93	504	39979	0.773
Pi0 veto	134	79	215	8416	1.425
Eta veto	132	77	213	6711	1.563
qq sup.	58	25	65	136	**3.442**

Belle	Signal	K*gamma	BB	qq	
No cut	145	380	1474	299656	0.264
Window	114	75	220	22670	0.750
Pi0 veto	95	61	128	6785	1.130
Eta veto	93	59	124	5710	1.202
qq sup.	54	26	47	215	**2.920**

- Luminosity is scaled to Belle full data set (**711/fb**) for fair comparison.
- "Window" means M_{bc}>5.27 and ΔE in (-0.2, 0.1).

Cut Table (Mixed)

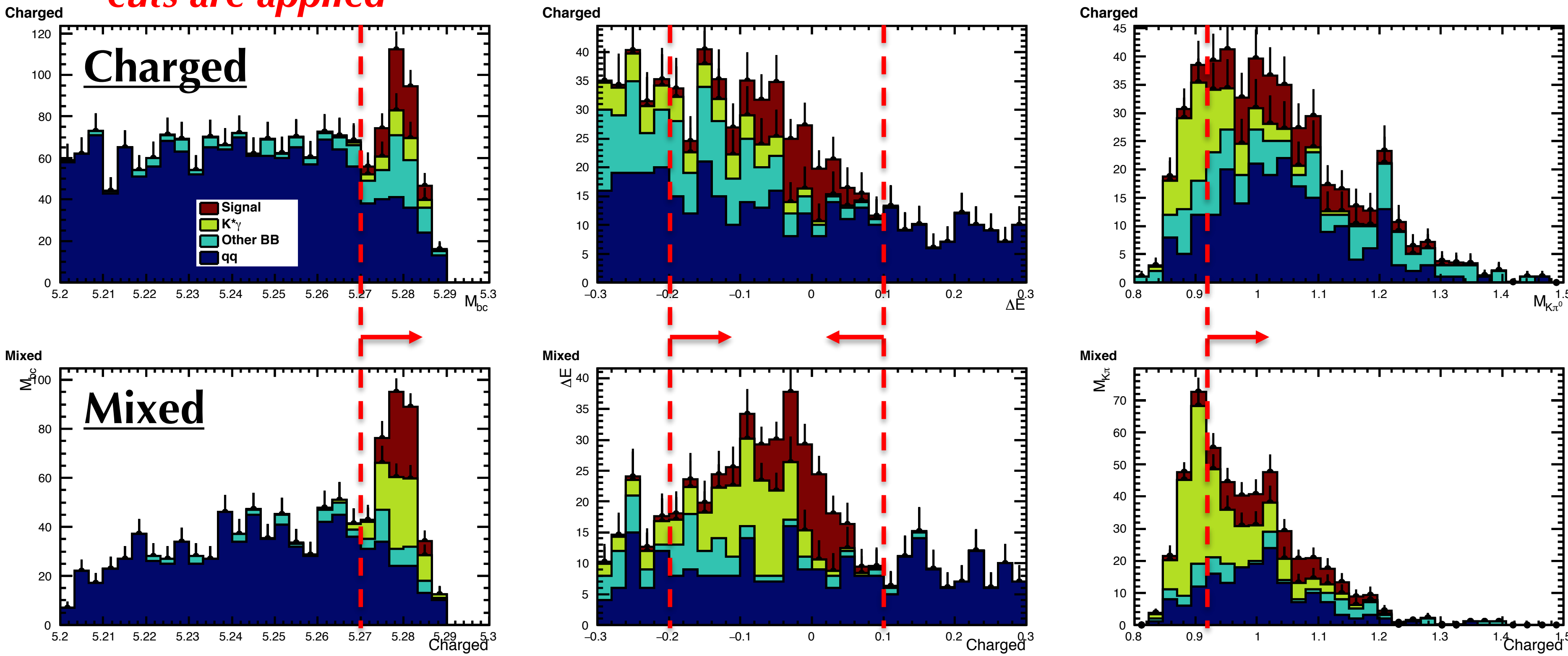
Belle II	Signal	K*gamma	BB	qq	
No cut	206	709	1517	402674	0.324
Window	165	235	169	26498	1.003
Pi0 veto	142	201	113	5473	1.844
Eta veto	139	197	106	4267	2.026
qq sup.	51	59	22	72	**3.571**

Belle	Signal	K*gamma	BB	qq	
No cut	188	721	997	218666	0.400
Window	150	208	136	15782	1.176
Pi0 veto	124	170	88	4597	1.757
Eta veto	121	166	83	3734	1.889
qq sup.	69	87	32	124	**3.906**

- On the other hand, mixed mode showed slightly worse significance.
- Because of twice larger size of qq background?
  - though, the condition of qq seems be same for charged mode.

Fitting Strategy

※Signal enhanced cuts are applied



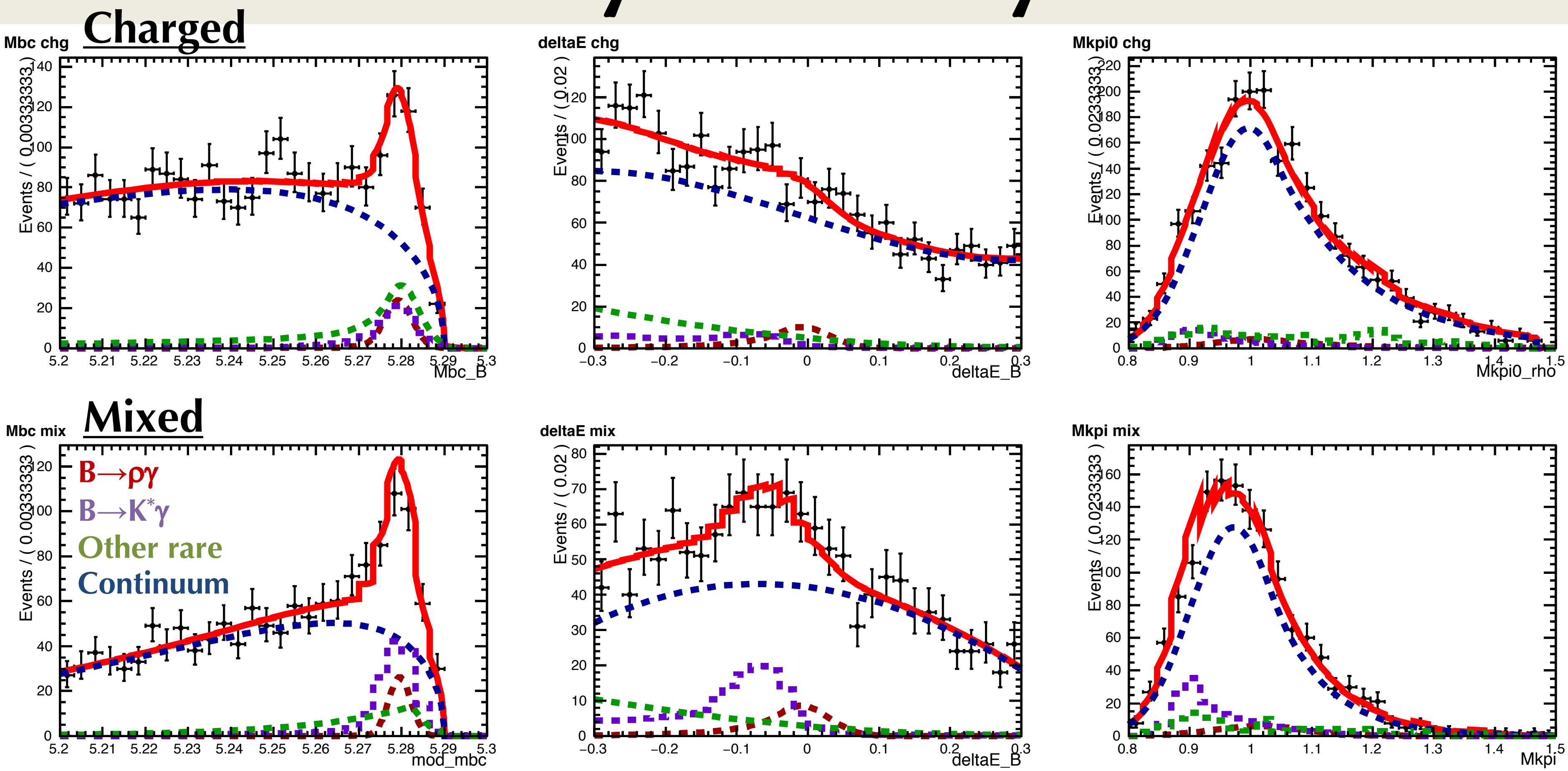
- Same as Belle strategy (see my BAM talk).

Updates from BAM

- Functional PDFs have been adopted as much as possible.

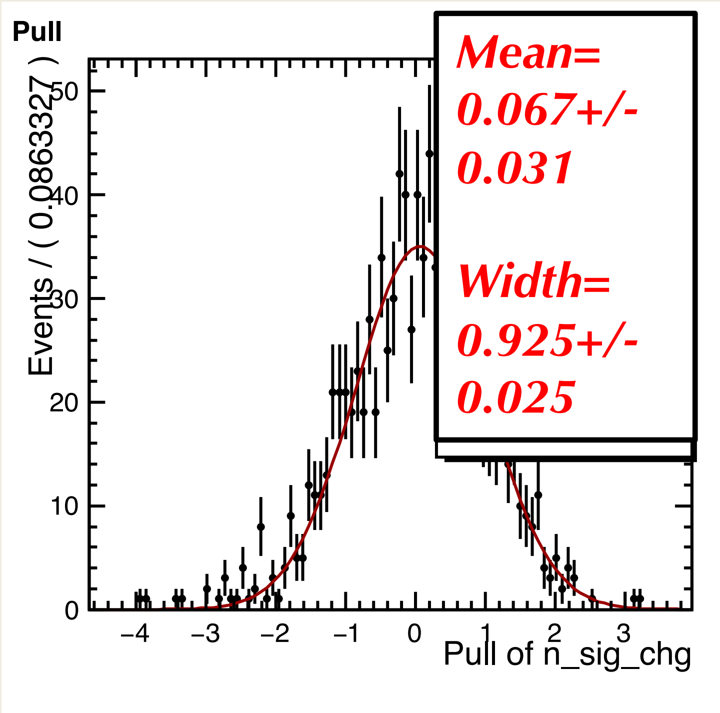
	Signal	K*gamma	Rare	qq
Mbc	CBall	3D histogram	CBall+ Argus	Argus
deltaE	CBall		2^{nd} poly.	3^{nd} poly.
Mkpi	CBall		Histogram	CBall

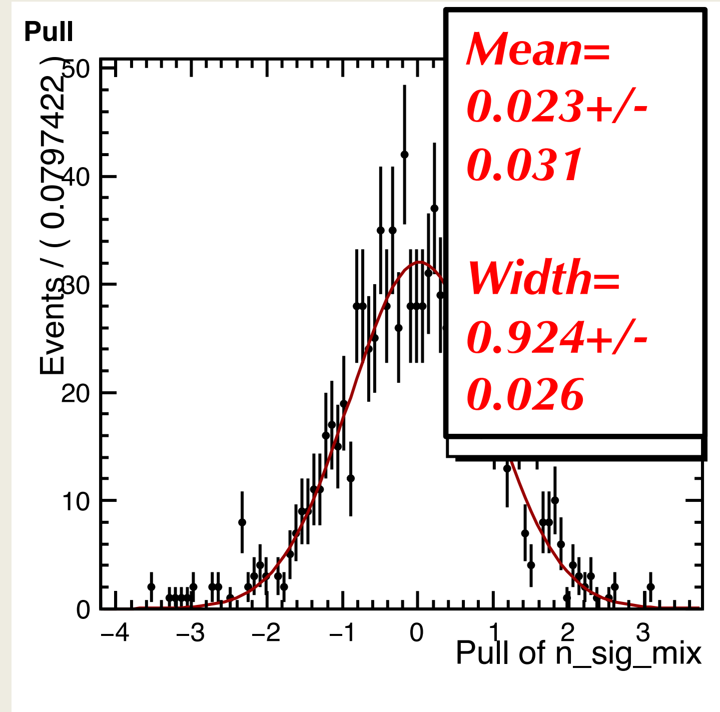
Toy-MC Study



- 1k Toy-MC study is performed to check **possible bias** and **estimate sensitivity**.
- Floating parameters: N_{sig}, N_{qq}, shapes of qq except Mkpi.
  - **Shape parameters of qq for Mkpi(0) are all fixed for fitting stability.**
  - The fixed parameters will be calibrated by off-resonance.

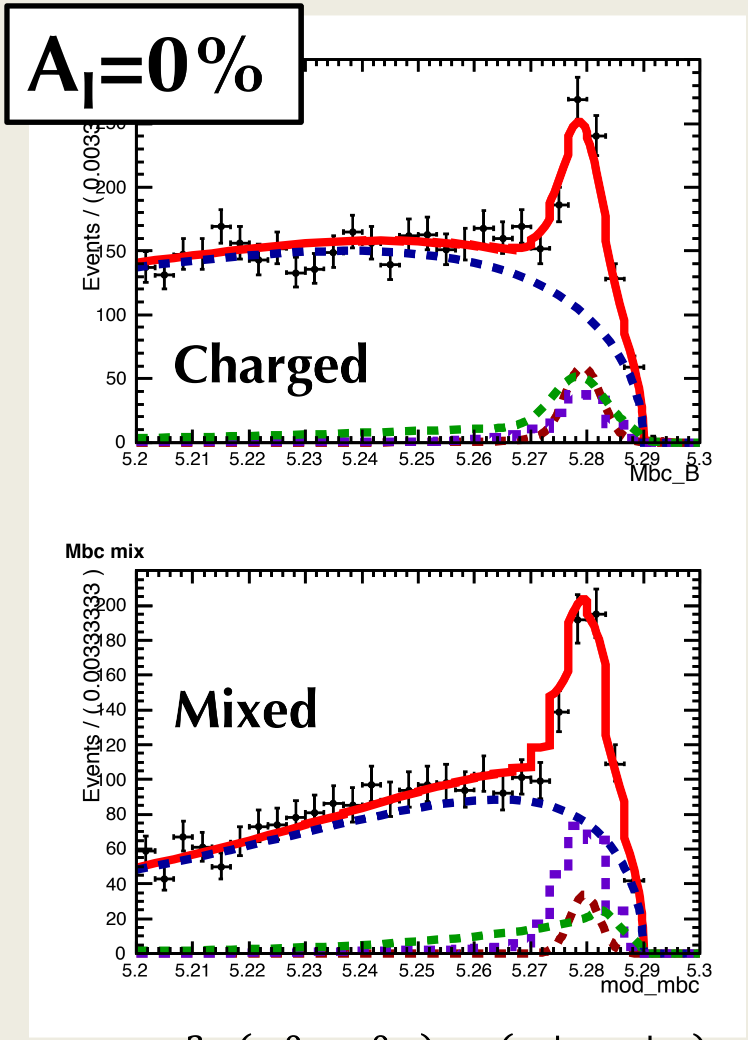
Pull and Sensitivities to BR





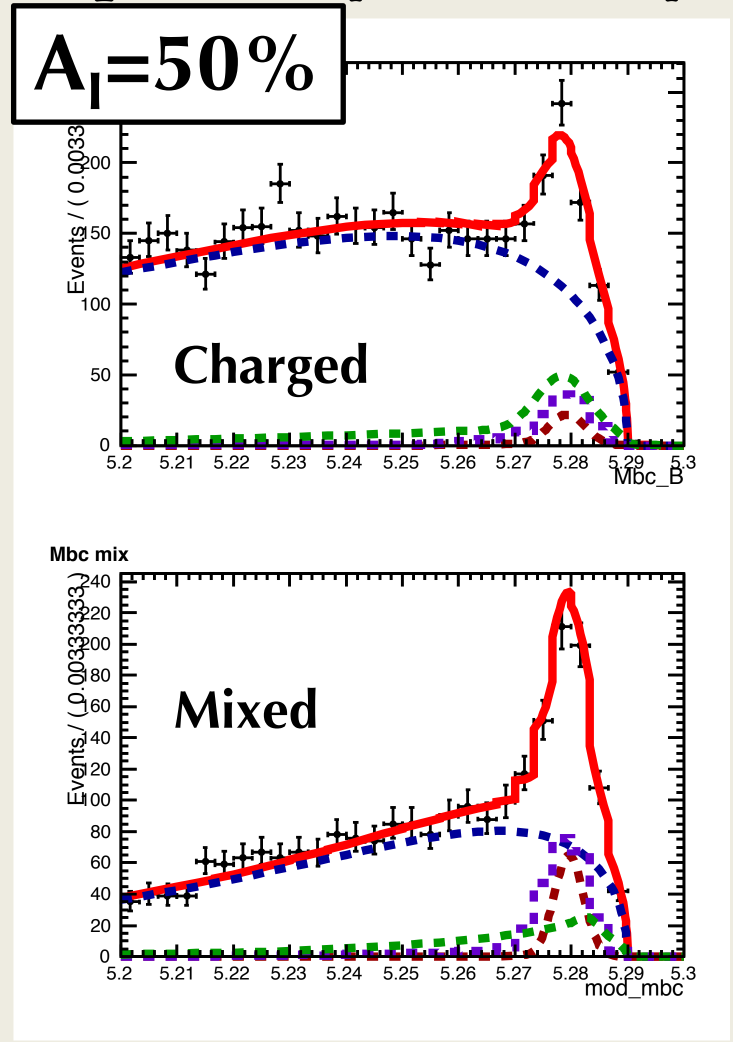
Assuming 657M BB	Charged		Neutral	
My Belle II Study	57.5 ± 14.1	**~24% (stat.)**	58.1 ± 12.7	**~22% (stat.)**
My Belle Study	58.4 ± 17.1	**~29% (stat.)**	72.2 ± 15.3	**~21% (stat.)**
Taniguchi-san's BR x 10^7 (with 657M BB)	$(8.7^{+2.9+0.9}_{-2.7-1.1})$	**~33% (stat.)** ~13% (syst.)	$(7.8^{+1.7+0.9}_{-1.6-1.0})$	**~21% (stat.)** ~13% (syst.)

Simultaneous Fit for Isospin Asymmetry



+=5%

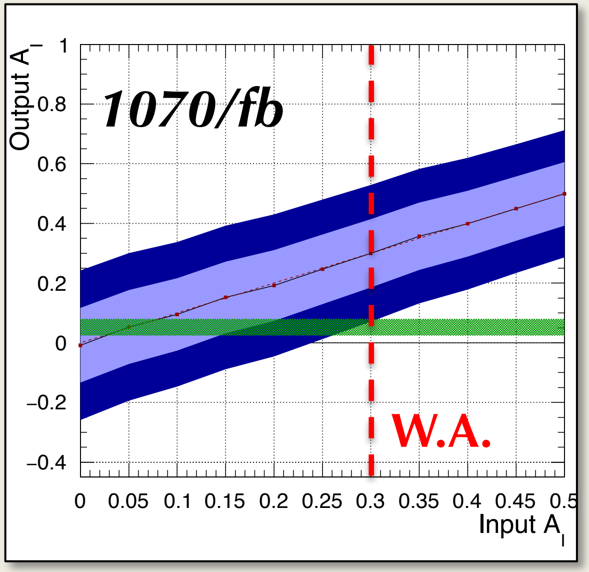
•••

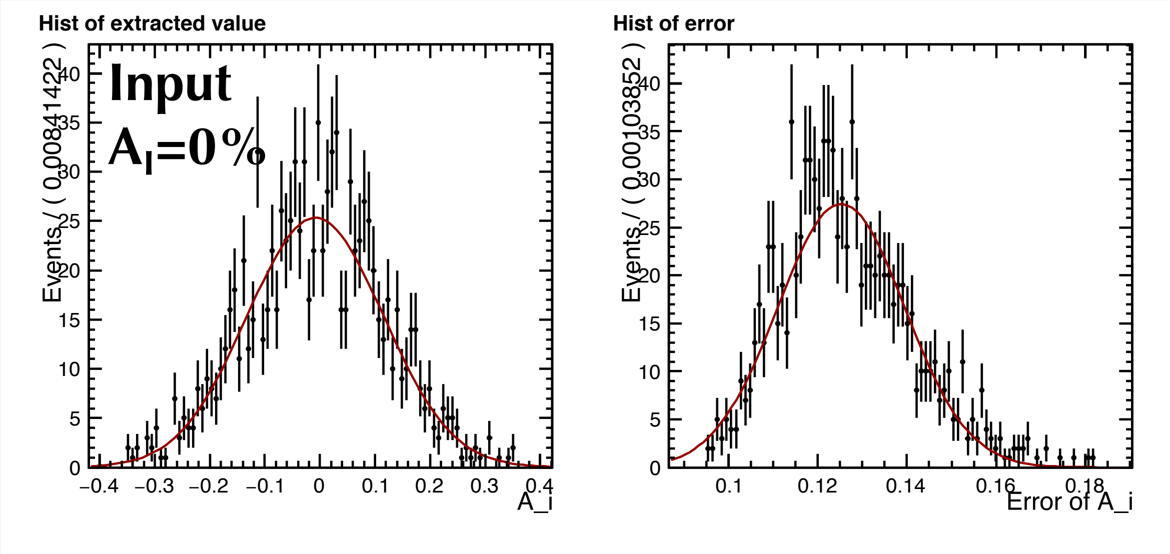


- $A_I^{0-} \equiv \frac{c_\rho^2\Gamma(B^0\to\rho^0\gamma)-\Gamma(B^+\to\rho^+\gamma)}{c_\rho^2\Gamma(B^0\to\rho^0\gamma)+\Gamma(B^+\to\rho^+\gamma)}$, where $c_\rho = \sqrt{2}$
- Simultaneous 3D (M_{bc}, ΔE, $M_{K\pi}$) fit is performed between charged and mixed modes.

Sensitivity to Isospin Asymmetry

Estimated with 1070/fb ~ Belle (711/fb) + Belle II (360/fb) assuming Belle II environment.





- Toy-MC is based on Belle II study.
  - though Belle environment showed almost same sensitivity.
  - Finally simultaneous fitting between Belle and Belle II will be performed.
- **1/ab seems to be enough to measure A_I=30% (W.A.) with 2.6σ.**

Summary

LFV B→Kτμ Search

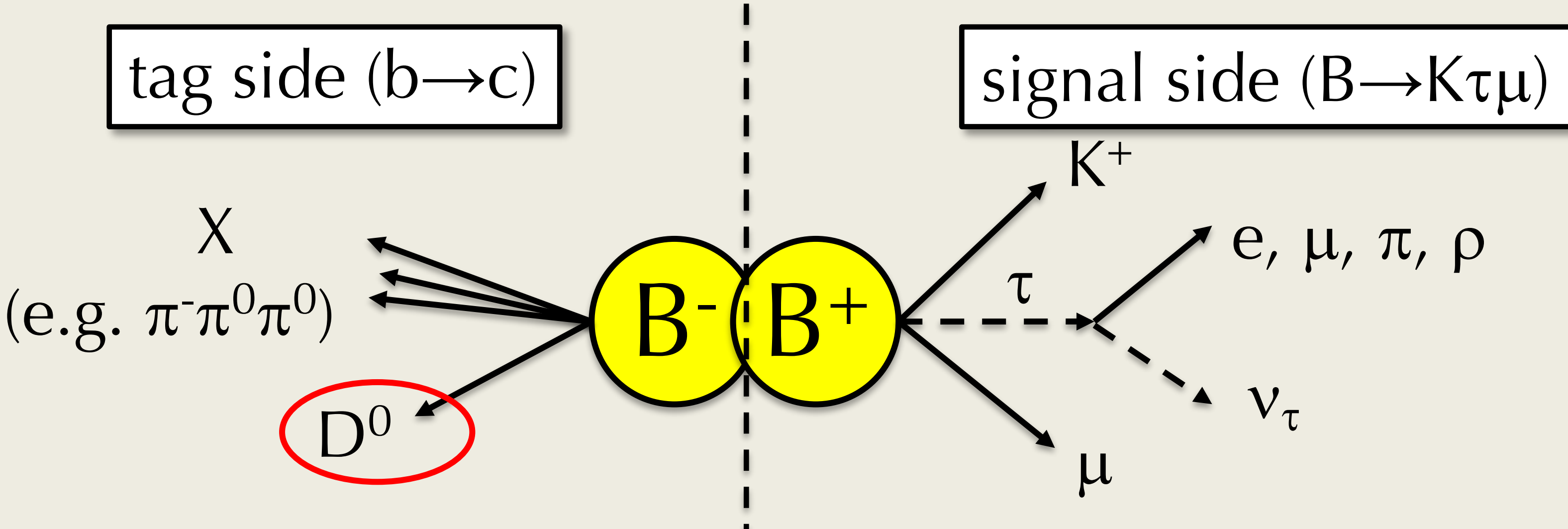
- There are several unique methods in Belle.
- Hadronic tag would provide basic (robust) sensitivity to BR.
- The **U.L. will be much improved** according to MC study.
- Box open will come soon!

Rediscovery and A_I of B→ργ

- This is the major mode of b→d EWP process; the first step of such a mode at Belle II.
- Belle II currently showed similar sensitivity as Belle.
  - There should be some room to improve, assuming Belle II potential.
- Even with near future statistics of Belle II, combined dataset **Belle + Belle II will provide significant results** of BR and isospin asymmetry.

Backup

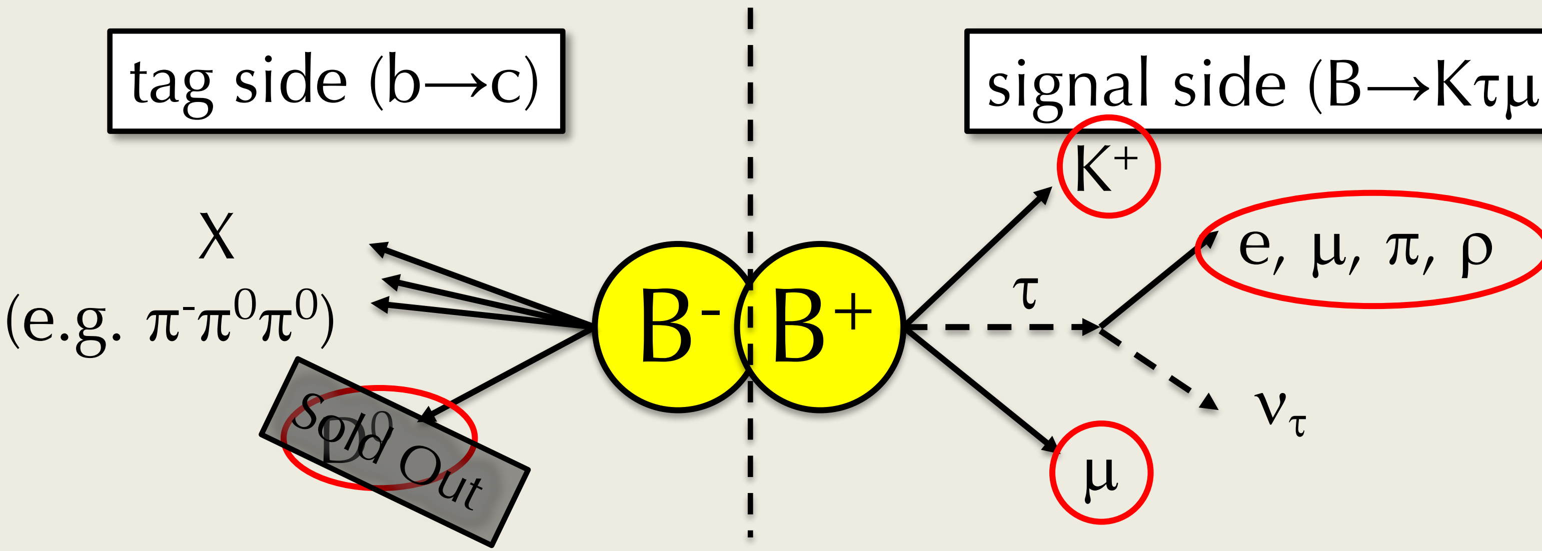
2. D tag



* D^0 including modes count ~80% of B^- decay

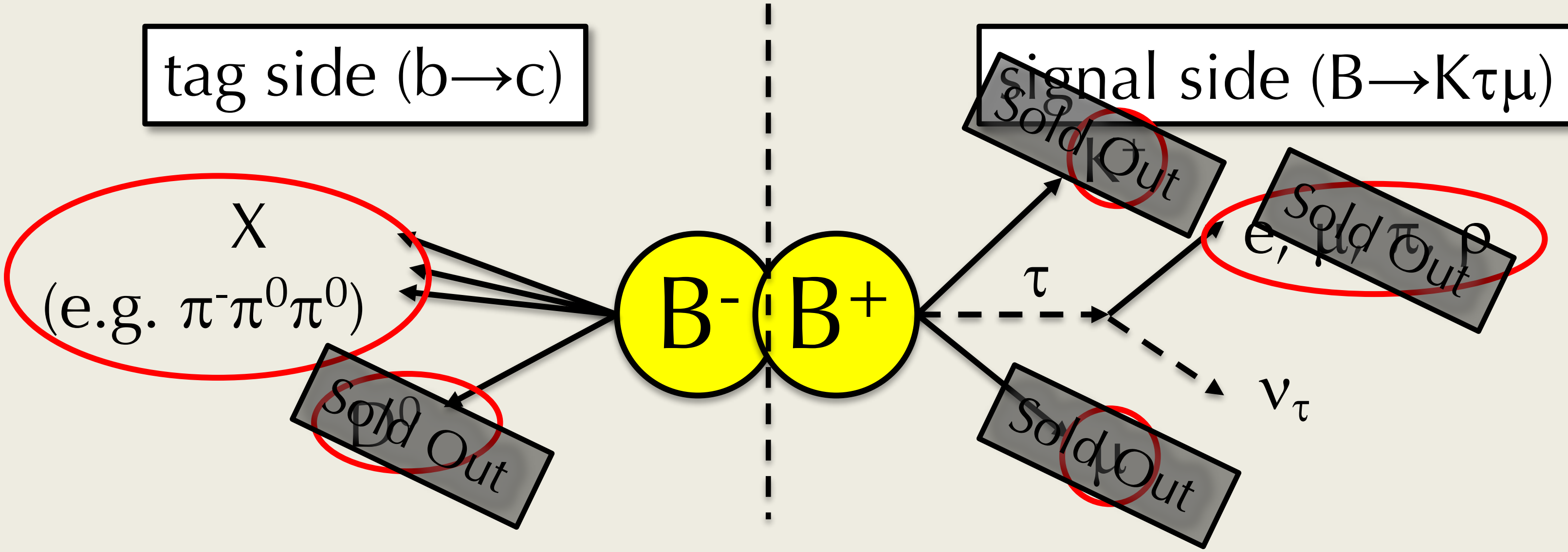
1. Reconstruct D^0 meson.

2. D tag



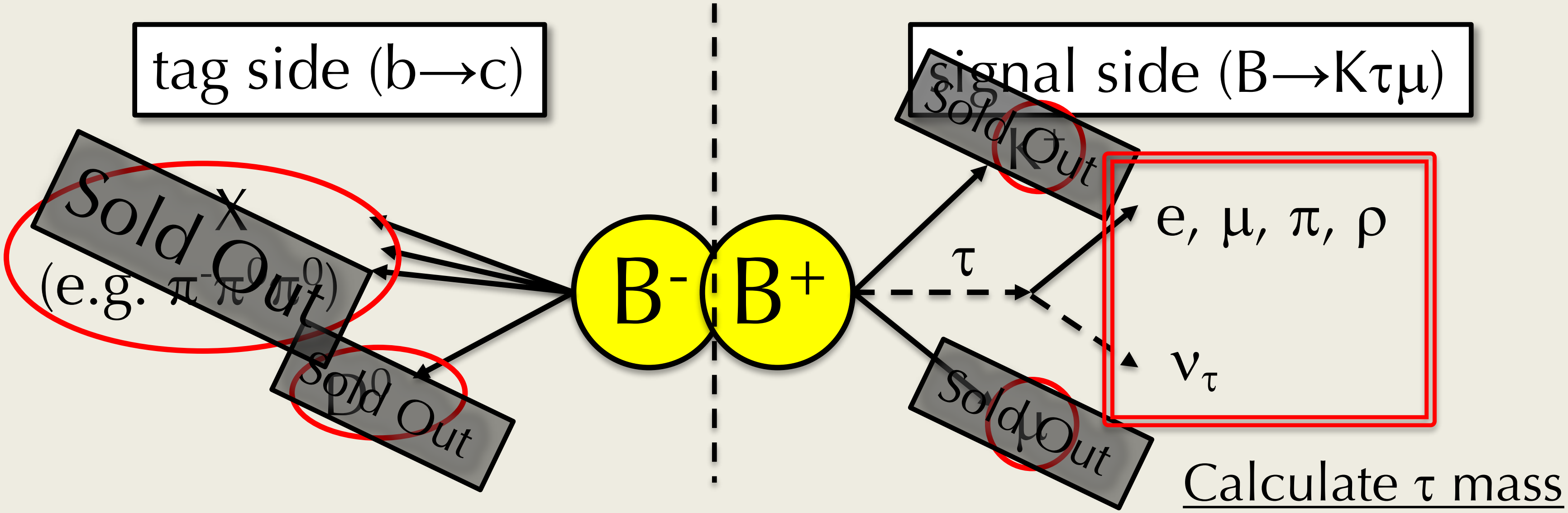
1. Reconstruct D^0 meson.
2. Select K^+, μ and a τ prong in the rest of event for tag side D^0.

2. D tag



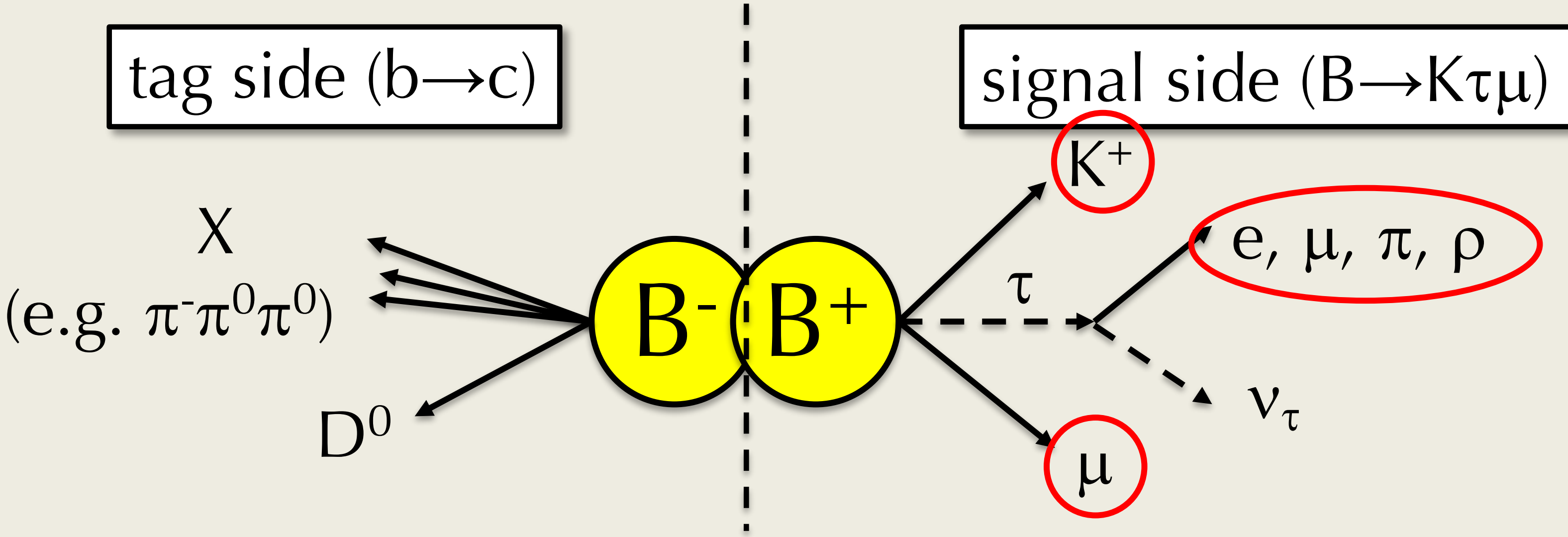
1. Reconstruct D^0 meson.
2. Select K^+, μ and a τ prong in the rest of event for tag side D^0.
3. Sum 4-momenta over the rest of visible particles → X in tag side.

2. D tag



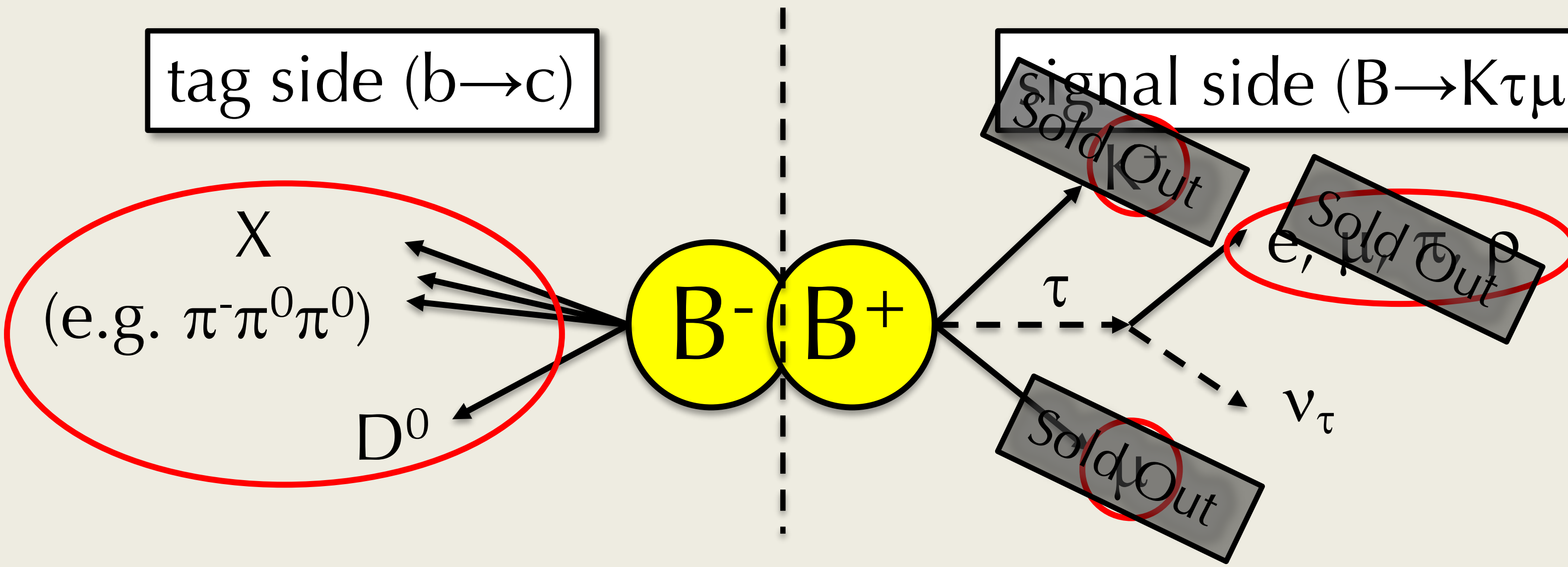
1. Reconstruct D^0 meson.
2. Select K^+, μ and a τ prong in the rest of event for tag side D^0.
3. Sum 4-momenta over the rest of visible particles → X in tag side.
4. Calculate τ mass as a rest of $X^- D^0 K^+ \mu$ system.

3. Inclusive



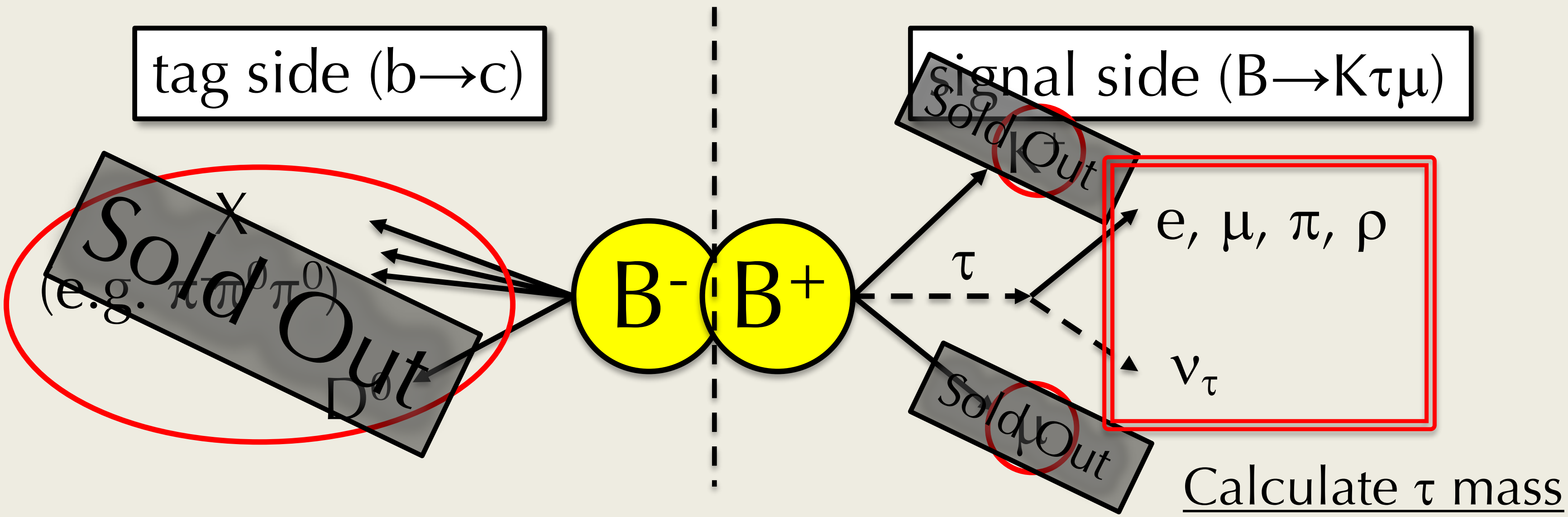
1. Select K^+, μ and a τ prong candidates.

3. Inclusive



1. Select K^+, μ and a τ prong candidates.
2. Sum 4-momenta over the rest of visible particles → tag side B^-.

3. Inclusive



1. Select K^+, μ and a τ prong candidates.
2. Sum 4-momenta over the rest of visible particles → tag side B^-.
3. Calculate τ mass as a rest of $B^-K^+\mu$ system

Breakdown of BB after Cuts

Charged

	N_{evt}	Frac.
Xsdgamma	157	16.60%
Xsugamma	153	16.20%
pi+pi0pi0	114	12%
rho+eta	48	5.07%
K''*+gamma	47	4.96%
rho+pi0	41	4.33%
rho+D0	35	3.70%
K_2*+gamma	29	3.06%
K_2*0gamma	22	2.32%

~70%

Mixed

	N_{evt}	Frac.
Xsdgamma	147	24.10%
Xsugamma	77	12.60%
K''*+gamma	39	6.40%
K'*+gamma	23	3.78%
K_2*+gamma	22	3.61%
K_1+gamma	15	2.46%
K_2*0gamma	15	2.46%
rho+D0	14	2.30%
rho+rho0	13	2.13%

~60%

Used Functional PDFs