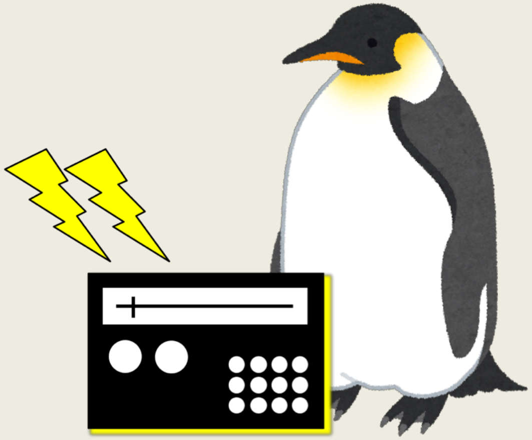
Radiative decay of B meson at Belle and Belle II

2023.1.16

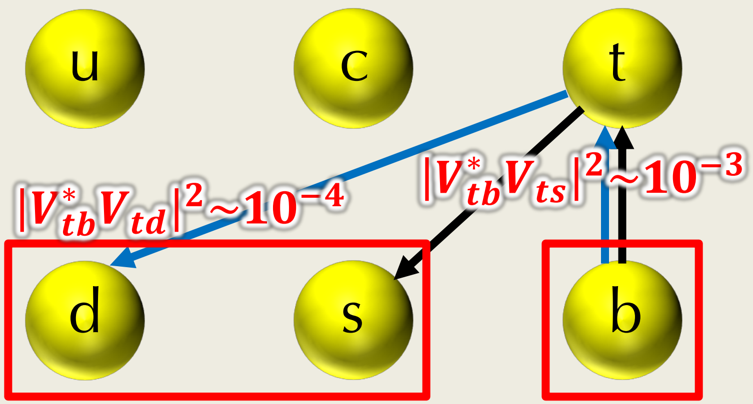
S. Watanuki

Introduction

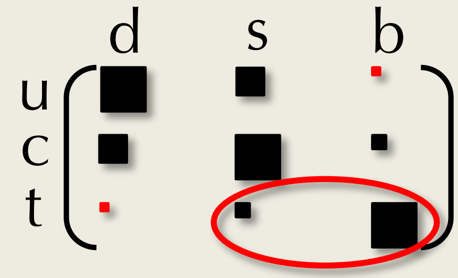


Emperor penguin
(コウテイペンギン/황제펭귄)

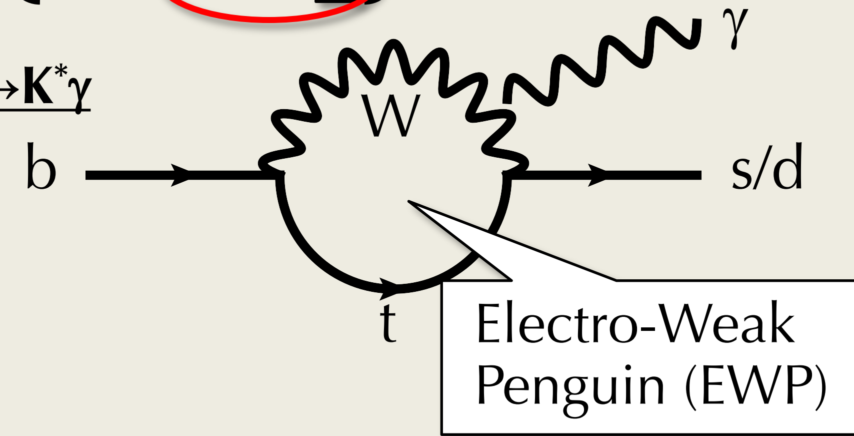
Flavor Changing Neutral Current



In the SM, this occurs only via loop



<u>e.g. $B \to K^{*}\gamma$</u>



- Flavor changing neutral current (FCNC) is possible only via loop diagrams in the SM.
  - Sensitive to NP appearing in the loop.
- Such a loop diagram tends to be a small branching fraction (D, K mesons).
- <u>**FCNC of B meson is relatively large thanks to $V_{tb} \sim 1$**</u>.

Effective theory

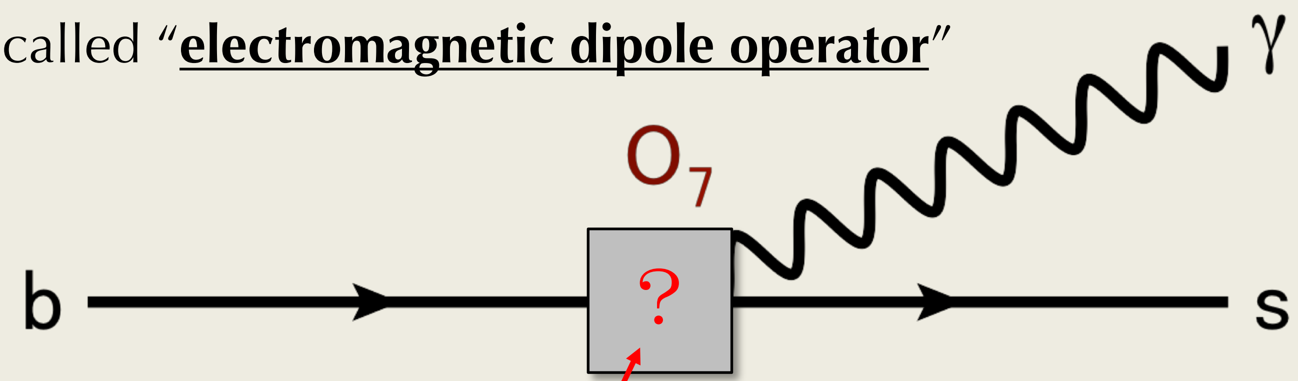
- In effective theory, B decay can be written as:

$$H_{eff} = -\frac{4G_f}{\sqrt{2}}\left[\lambda_q^t \sum_{i=1}^{10} C_i O_i + \lambda_q^u \sum_{i=1}^{2} C_i (O_i - O_i^u)\right]$$

→ 10 operators (O_i) and corresponding Wilson coefficients (C_i)

e.g. 7th operator is called "**electromagnetic dipole operator**"

C_7 ×

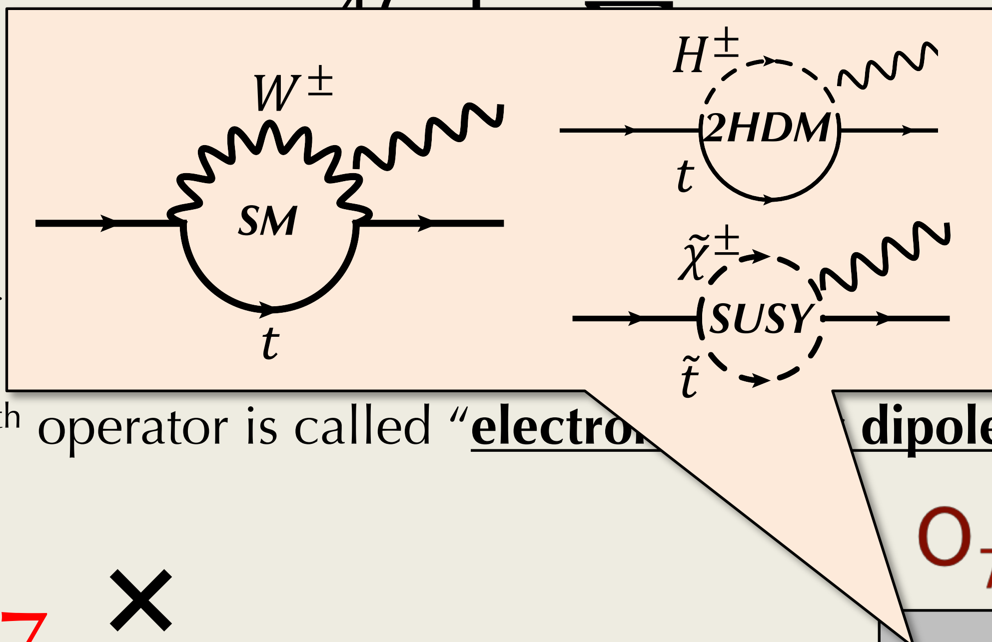


The interaction for heavy particles (W and t) are integrated out and treated as short distance effect
→ If there is NP effects, it appears in Wilson coefficients

Effective theory

- In effective theory, B decay can be written as:

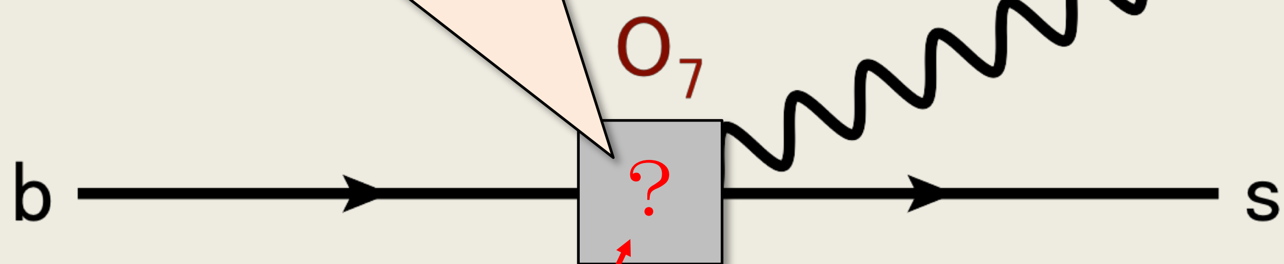
$$4G \Big[\sum^{10} \quad \sum_{i=1}^{2} C_i(O_i - O_i^u) \Big]$$



→ … ng Wilson coefficients (C_i)

e.g. 7th operator is called "**electro** … **dipole operator**"

C_7 ×

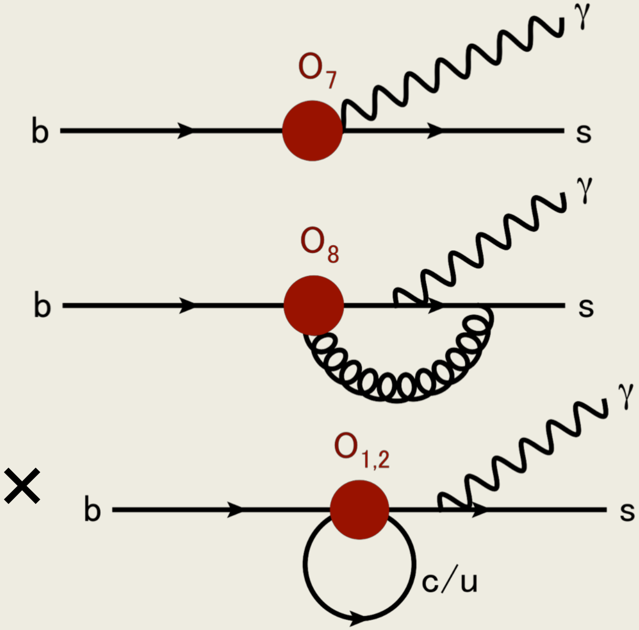


The interaction for heavy particles (W and t) are integrated out and treated as short distance effect
→ If there is NP effects, it appears in Wilson coefficients

Long distance effects

Non-perturbative effects on b→sγ

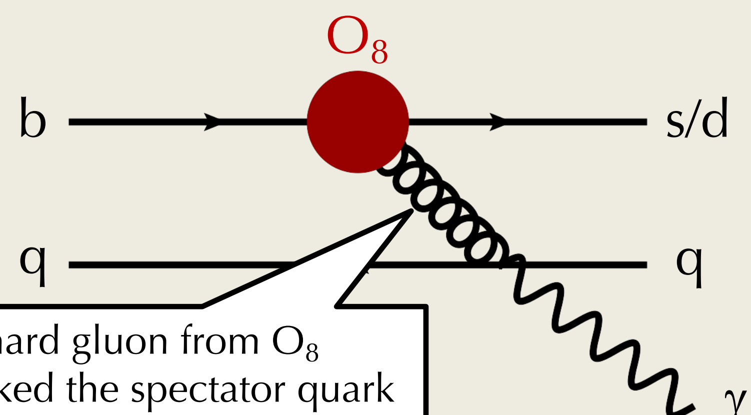
$H_{b\to s\gamma}$ { $C_7\times$, $C_8\times$, $C_{1,2}\times$



Effects which cannot be treated only by C_7 (**long distance effect**)

It cannot be calculated by perturbative.
= Major sources of theoretical uncertainty

For example, the **resolved photon** is one of the annoying sources of theoretical error for the radiative study.



The hard gluon from O_8 knocked the spectator quark which emit the hard photon.

Motivation of radiative

EWP is dominated; compared to QCD penguin (i.e. charmless decays), the theoretical uncertainty is small

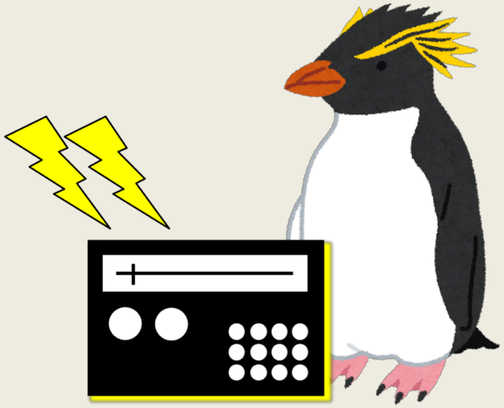
- **BR measurements of inclusive $B \to X_{s(d)}\gamma$**
  - Constraint on $|C_7|^2 + |C_7'|^2$
  - Very strong to constrain charged Higgs (2HDM)

- **CP asymmetry**
  - Constraint on $Im(C_7)$

- **Isospin asymmetry**
  - NP appearing in weak annihilation

- **Right handed photon process**
  - Constraint on C_7'
  - Left right symmetric model (LRSM)

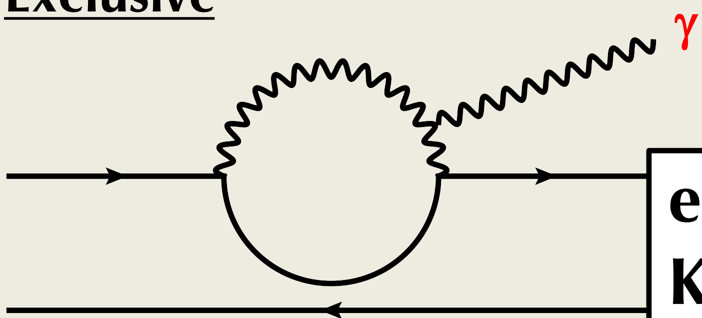
Reviews of analyses



Southern rockhopper penguin
(イワトビペンギン/남부바위뛰기펭귄)

Exclusive vs Inclusive

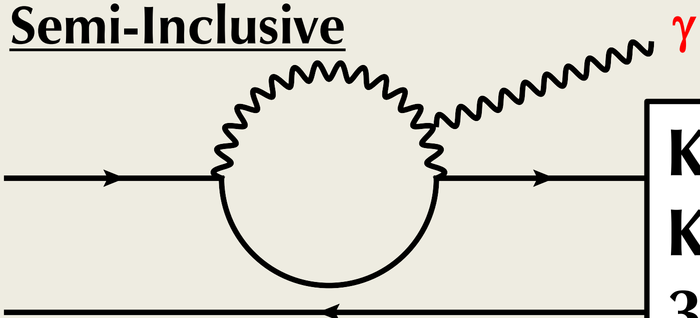
1. Exclusive



e.g.
$K^* \to K\pi$

	Advantage	Disadvantage
Ex.	High purity	Large theory uncertainty
Inc.	Theoretically clean	Large BG, Complicated systematics

2. Semi-Inclusive

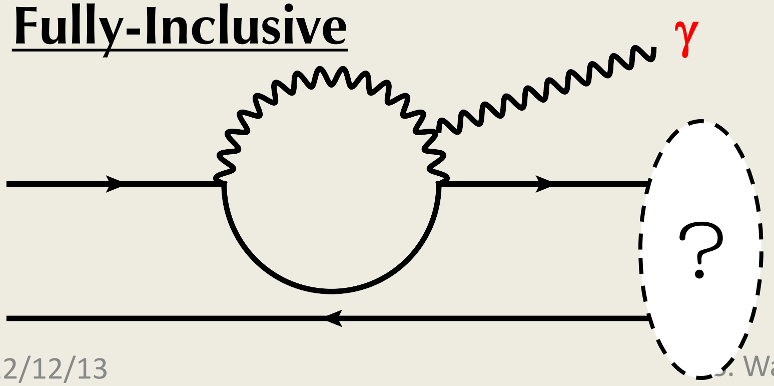


$K\pi$, $K2\pi$, $K3\pi$, ...
$K\eta$, $K\eta\pi$, $K\eta 2\pi$, ...
$3K$, $3K\pi$, $3K2\pi$, ...

denoted as X_s

Up to ~80% is possible

3. Fully-Inclusive



Not reconstructed

Very roughly categorized:

- **Hadronic tag**
- **Semi-leptonic tag**
- **Untagged**

Fully inclusive analyses

Hadronic-tag

- $B_{tag} \rightarrow hadronic$ is **fully reconstructed**
- Low BG, low signal efficiency
- Charged/neutral can be separated

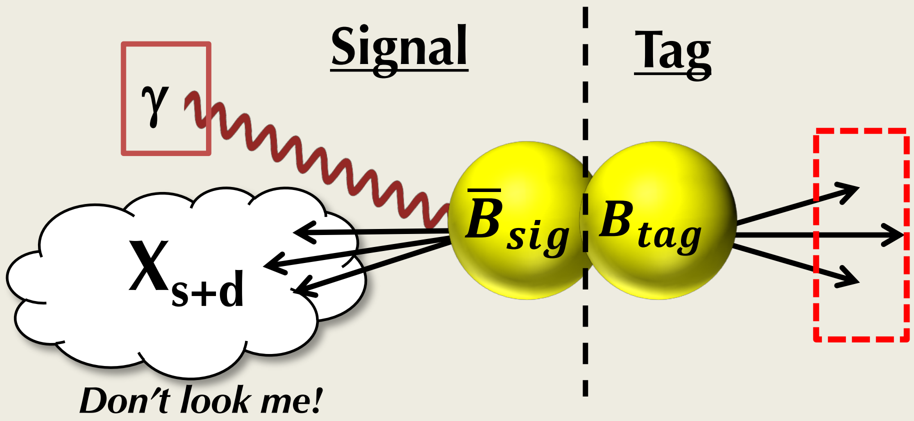
Leptonic-tag

- **High momentum lepton** is required for $B_{tag} \rightarrow D^{(*)}\ell\nu$ to reduce continuum BG
- B-flavor can be determined by lepton charge
- Kinematic constraint is not possible for neutrino in tag side

Untagged

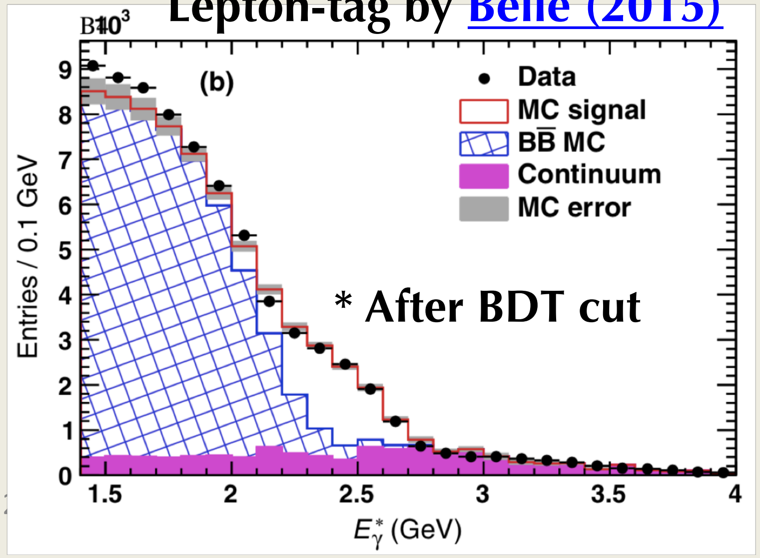
- Nothing is reconstructed other than γ
- No efficiency loss, but a huge BG

[Note]
Had-tag and Lep-tag are independent, so one can merge the results.



	Had.	Lep.	Untagged
Eff.	Very low	Moderate	Very good
Purity	Very good	Good	Very low

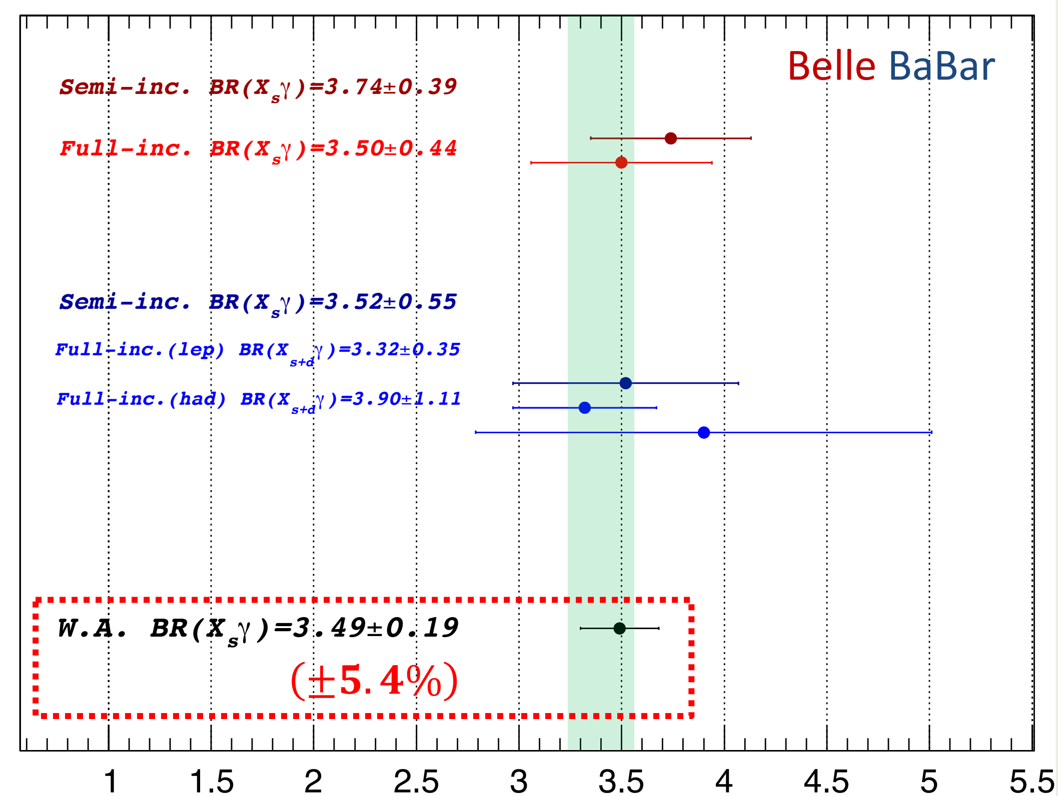
Lepton-tag by Belle (2015)



Branching fraction of inclusive $B \to X_s \gamma$

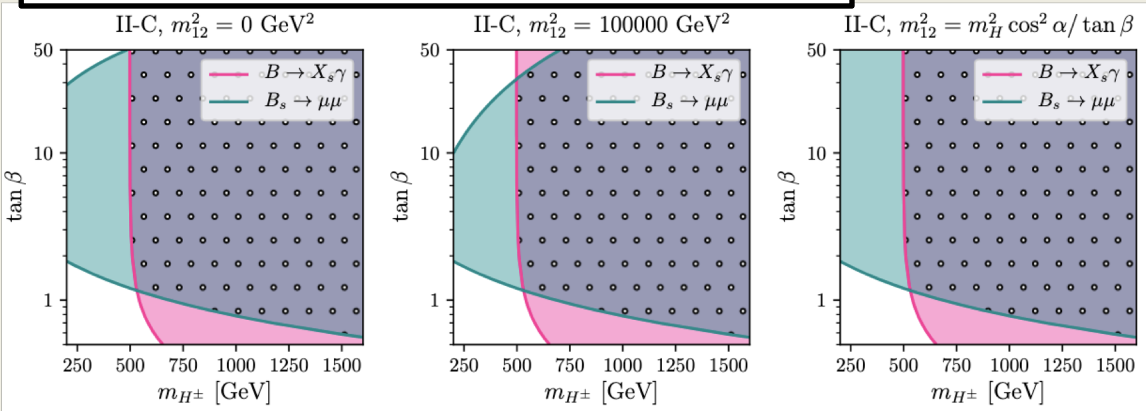
- BR is consistent with SM
  - Constraint on charged Higgs mass for Type-II 2HDM
  - **More stringent than LHC** in high tanβ region
- **$\sigma_{SM} \sim \sigma_{exp}$**
  - This is a bottle neck in Belle II
  - σ_{exp} can be reduced to ~2.6%
- Main sources of σ_{SM}
  - Higher order (±3%)
  - Interpolation to m_c (±3%)
  - Parametric (±2.5%)

(SM) 3.40±0.17 (M. Misiak, 2020)



$BR(B \to X_s \gamma) \times 10^4$

Constraint on charged Higgs (Type II)



2020

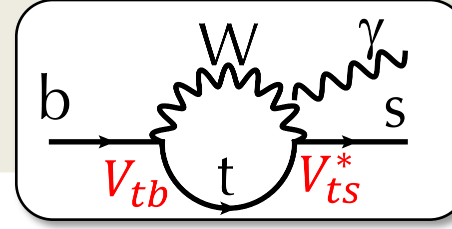
arXiv:2005.10576

$B \to X_s\gamma$ by Belle

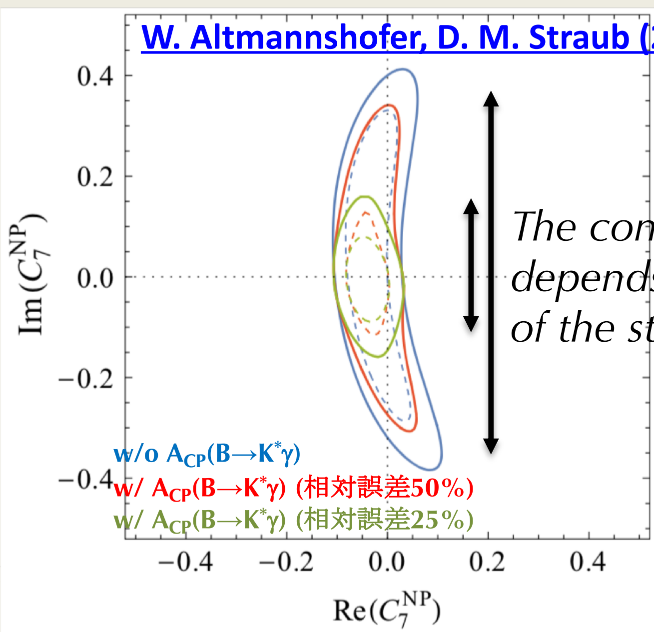
$B_s \to \mu\mu$ by LHC

$mH^+ >$ ~500GeV

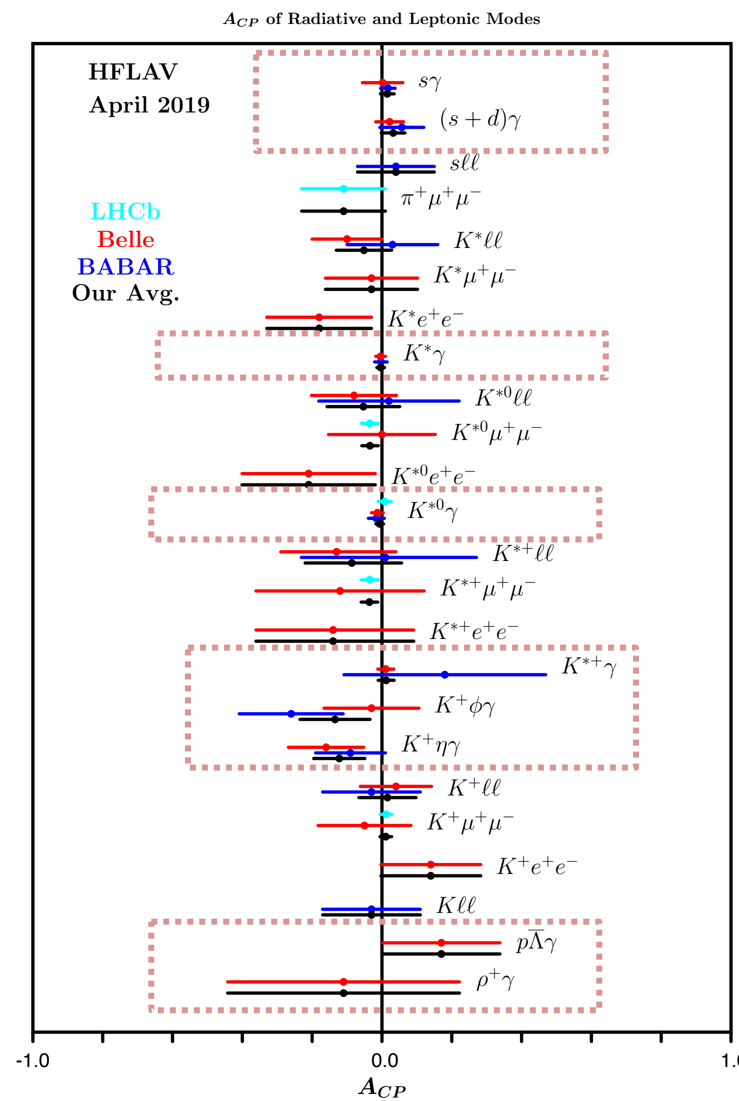
Direct CP asymmetry



- B radiative decays are dominated by EWP, thus ACP is expected to be tiny
  - Interference of other diagram is small
  - For $b \to s\gamma$, V_{tb}~1 and V_{ts} has small weak-phase
    → Interference term should be small
- **<u>In fact, experimental results are all consistent with 0</u>** (both exclusive and inclusive)
- Exclusive A_{CP} can be used to constraint **$Im(C_7)$**
  - depending on strong-phase
- On the other hand, $b \to d\gamma$ can have a sizable A_{CP} for the large weak-phase of V_{td}



The constraint on Im(C7) depends on the uncertainty of the strong-phase



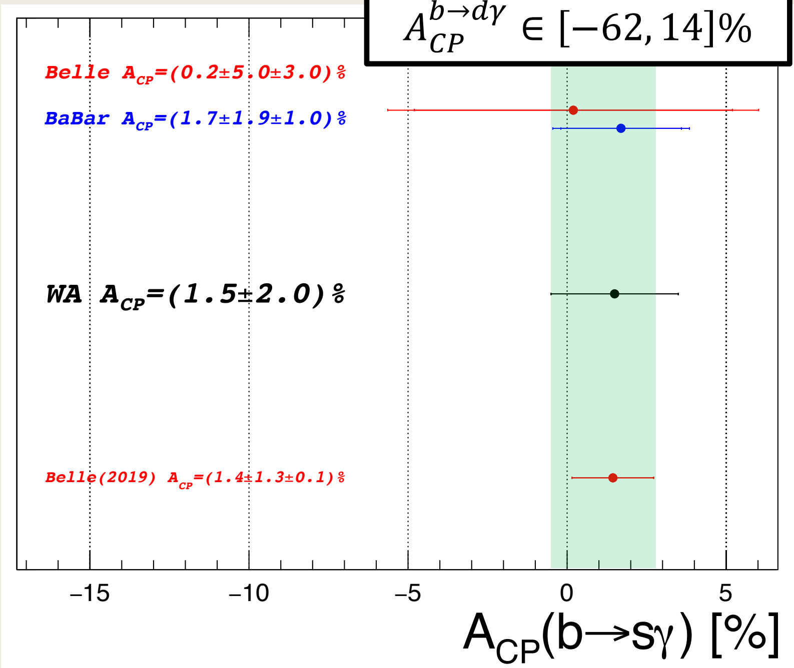
CP asymmetry of inclusive

- Inclusive A_{CP} is suffered from the large theoretical error due to the resolved photon
  - Poor sensitivity to NP, especially in case of $X_d\gamma$…

SM predections

$A_{CP}^{b\to s\gamma} \in [-0.6, 2.8]\%$

$A_{CP}^{b\to d\gamma} \in [-62, 14]\%$



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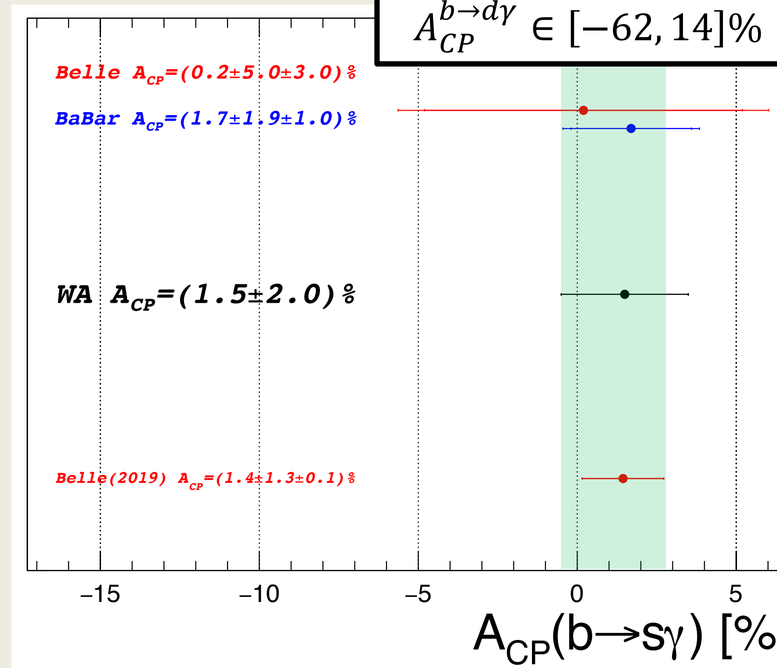
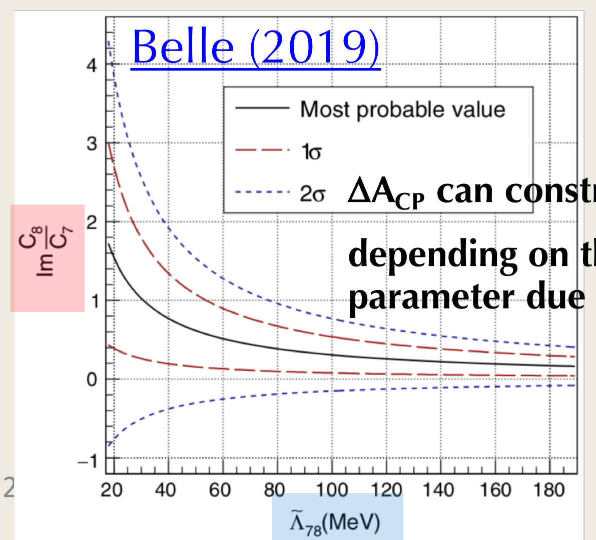


<u>**What we can do**</u>:

1. Take the difference b/w A_{CP}^{+} and A_{CP}^{0} to **cancel the long-distance effects**;

$$\Delta A_{CP} \equiv A_{CP}(B^+ \to X_s^+\gamma) - A_{CP}(B^0 \to X_s^0\gamma)$$

$$\approx 4\pi^2\alpha_s \frac{\tilde{\Lambda}_{78}}{m_b} Im\left(\frac{C_8}{C_7}\right) = 0\ (SM)$$



ΔA_{CP} can constraint $Im\left(\frac{C_8}{C_7}\right)$ depending on the hadronic parameter due to O_8 interference

CP asymmetry of inclusive

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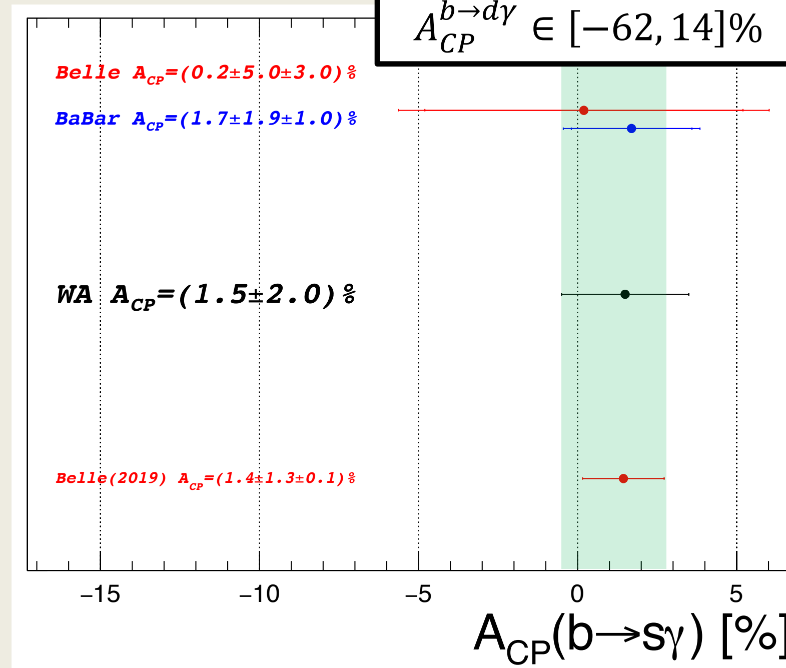
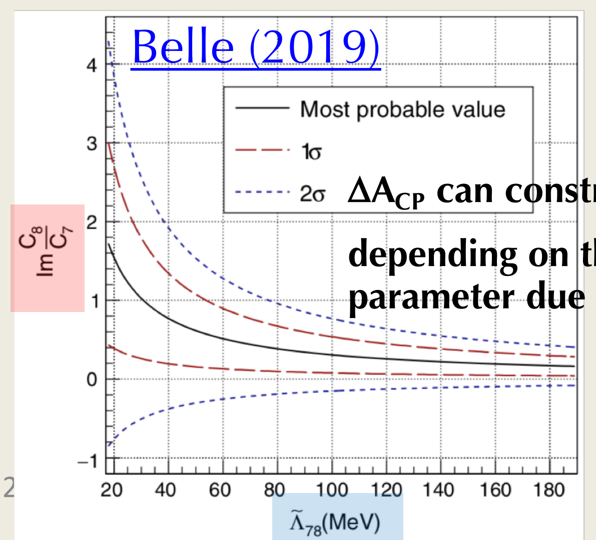
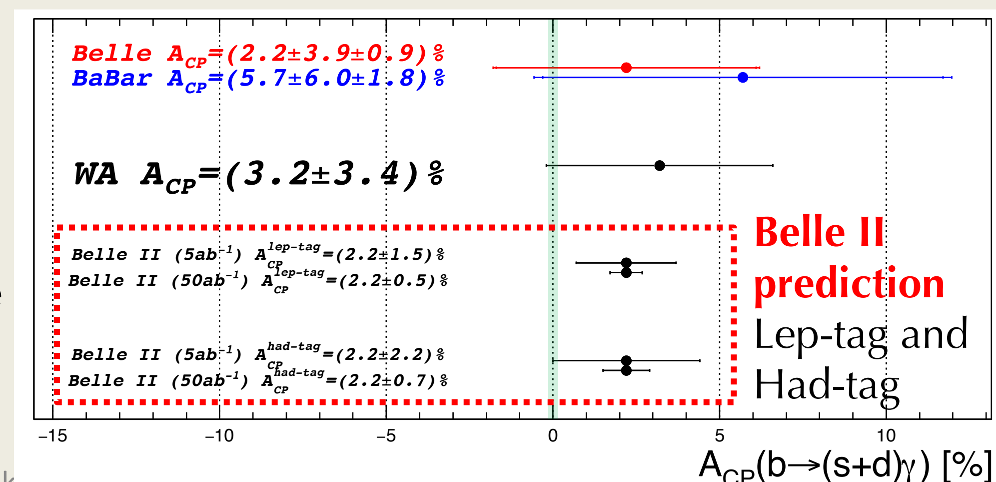
2. Fully inclusive study will include $b \to (s+d)\gamma$, which **cancels b/w X_s and X_d uncertainties**;

$$A_{CP}(b \to (s+d)\gamma) \approx 0\ (SM)$$

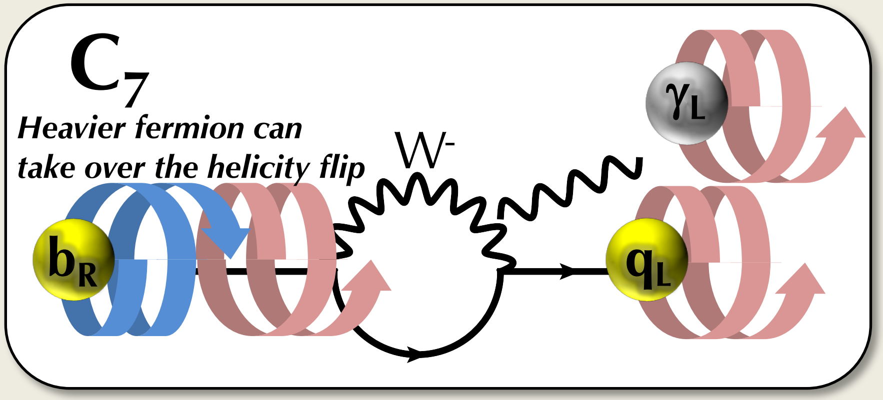


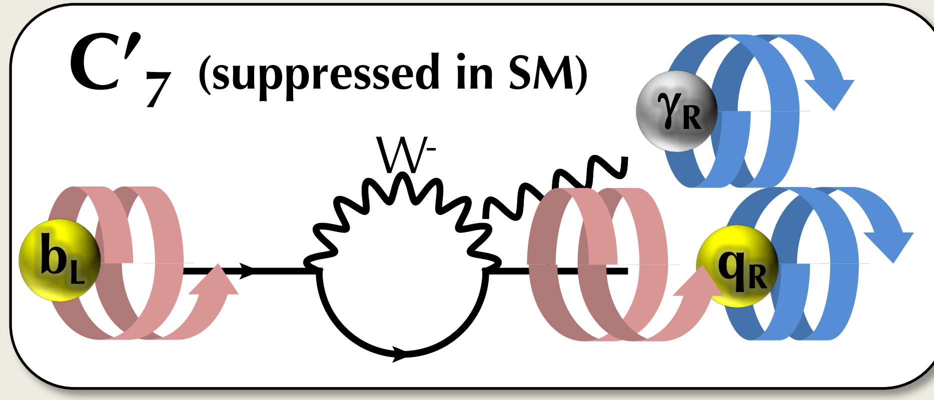


ΔA_{CP} **can constraint** $Im\left(\frac{C_8}{C_7}\right)$ **depending on the hadronic parameter due to O_8 interference**



Search for right-handed γ process

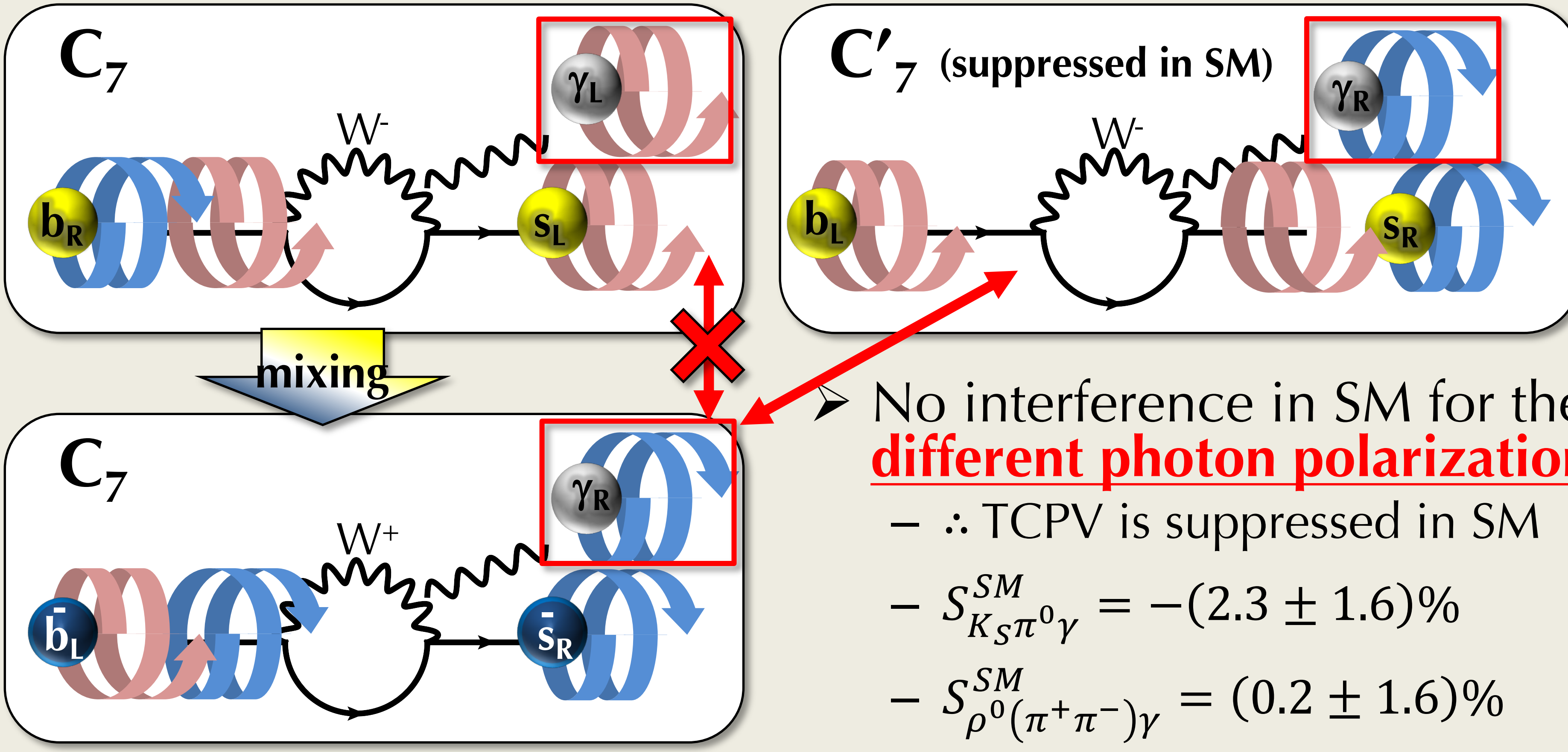




- SM EWP occurs via qq-W coupling.
  - Only left (right) handed (anti-)fermion can couple
  - In the γ_R process, the lighter quark in the final states must take over the helicity flip → **helicity suppressed in SM**
- The process will enhance if there is a contribution from new mediator particle (W′) which couples with only right (left) handed (anti-)fermions
  - Left right symmetric model ($SU(3)_c xSU(2)_L xSU(2)_R xU(1)_Y$)

- **How to measure**
  - Time dependent CP study for $B^0 \to f_{CP}\gamma$ (e.g. $B^0 \to K_S\pi^0\gamma$, $B^0 \to \rho^0\gamma$, etc.)
  - $\gamma \to e^+e^-$ conversion using $B^0 \to K^-\pi^+\gamma$
  - Up-down asymmetry using $B \to K\pi\pi\gamma$

Time dependent CPV (TCPV)

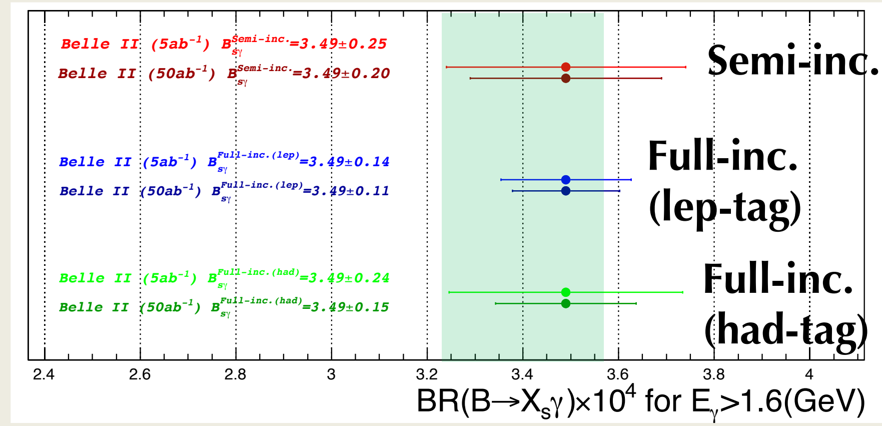


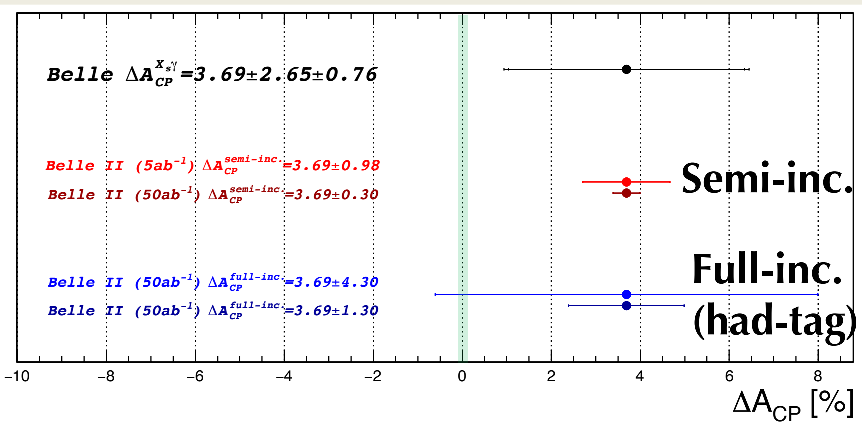
- No interference in SM for the **different photon polarization**
  - ∴ TCPV is suppressed in SM
  - $S^{SM}_{K_S\pi^0\gamma} = -(2.3 \pm 1.6)\%$
  - $S^{SM}_{\rho^0(\pi^+\pi^-)\gamma} = (0.2 \pm 1.6)\%$
- In NP, however, **non-0 TCPV is possible for enhanced C′7**
  - e.g. Left right symmetric model (LRSM)

Belle II prospects

Branching ratio of $B \to X_s\gamma$

- Systematics dominant:
  - **Fake photon** (fully-inclusive)
    → Further study for ECL cluster
  - **X_s hadronization model** (semi-inclusive)
    → Additional modes to be reconstructed
- Theory uncertainty should be updated



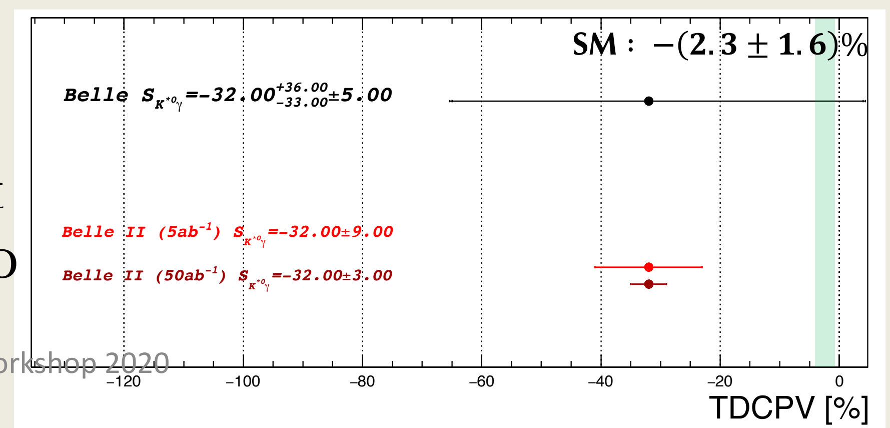


ΔA_{CP}

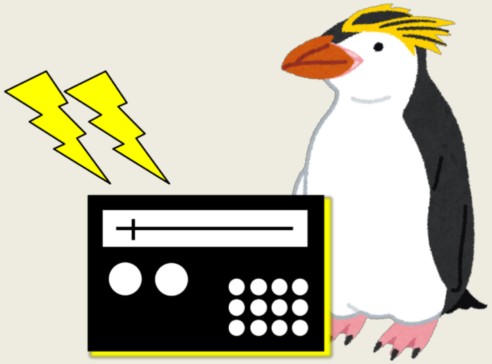
- Statistical uncertainty dominant
- Systematics is dominated by peaking BG yields (**can be reduced by stat.**)
- Fully inclusive is also possible by Hadronic-tag

Time dependent CPV

- Statistical uncertainty dominant
  - Expected the significant improvement
- Other modes than $B^0 \to K^{*0}\gamma$ are also possible ($K_S\rho^0\gamma$, $\rho^0\gamma$, etc.)



My current study;
$B \to \rho\gamma$ with Belle + Belle II

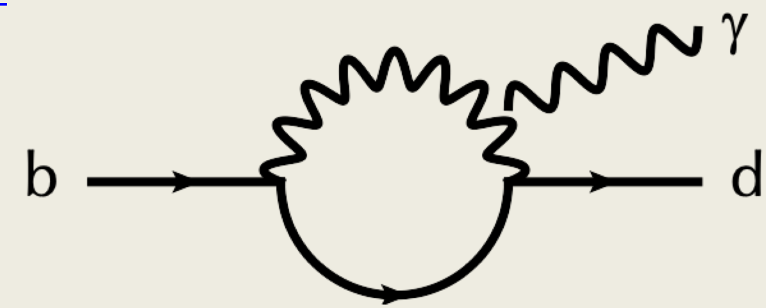


Royal penguin
(ロイヤルペンギン/로열펭귄)

Introduction

https://docs.belle2.org/record/2992/files/BELLE2-NOTE-PH-2022-020_v3.pdf

- Rediscovery of B→ργ is a first step of FCNC b→dγ process in Belle II.
  - BR is one order of magnitude less than $K^*\gamma$.
  - Independent NP search with $K^*\gamma$.
- Currently A_I of B→ργ shows a slight tension with SM prediction.

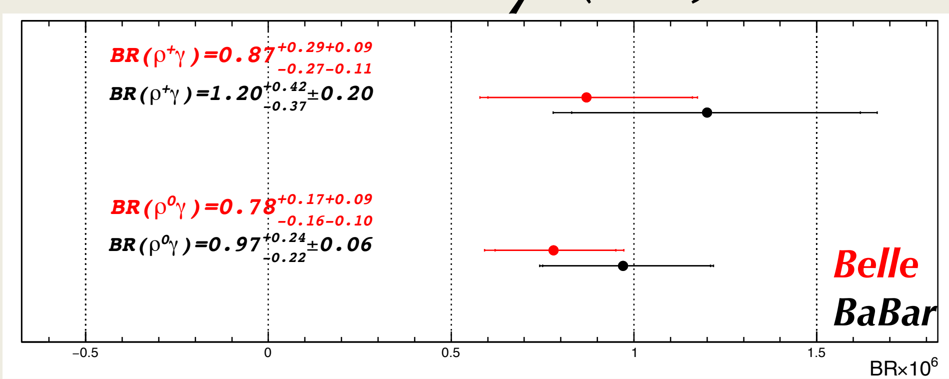


$$A_I^{\rho\gamma} \equiv \frac{c_\rho^2\Gamma(\rho^0\gamma)-\Gamma(\rho^+\gamma)}{c_\rho^2\Gamma(\rho^0\gamma)+\Gamma(\rho^+\gamma)},\quad c_\rho = \sqrt{2}$$

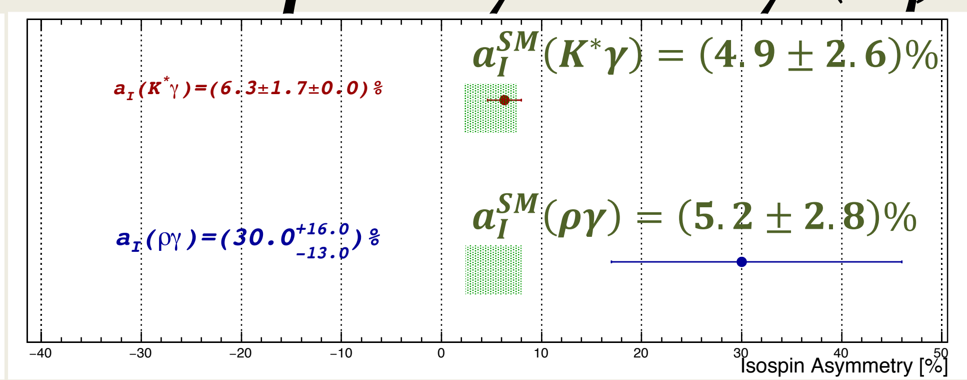
Targets

- BR(+), BR(0), A_I and A_{CP} by Belle (711/fb) + Belle II (364/fb)
- Aims to publish paper

1. Rediscovery (BR)



2. Isospin asymmetry (A_I)



Selections

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

BELLE II

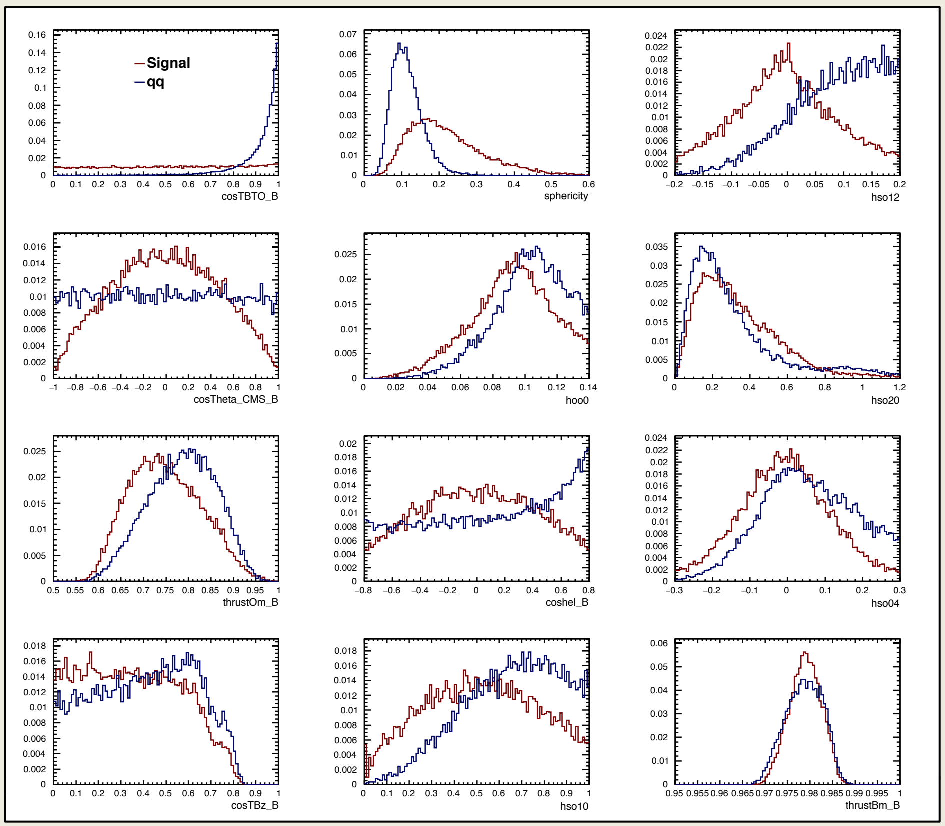
- **Event level**
  - foxWolframR2 < 0.7
  - nTracks >= 3

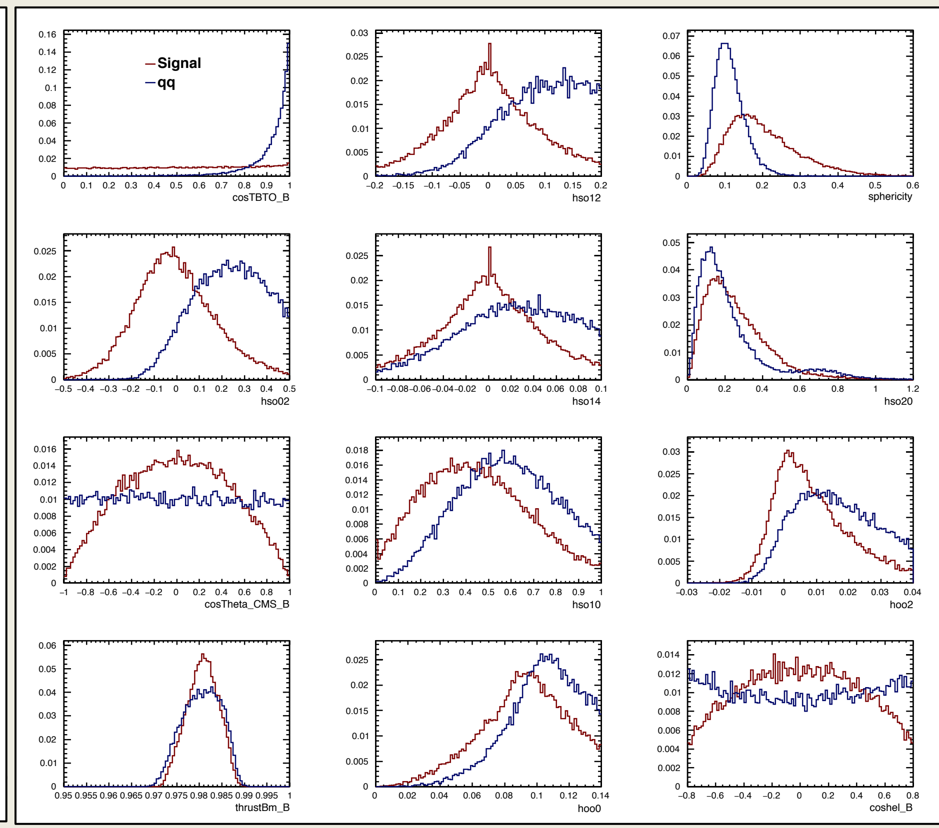
  BtoXgamma skim adopted
- **Primary Photon**
  - $1.8 < E^* < 2.8$ GeV
  - Cluster region == 2
  - E9oE21>=0.95
  - Cluster second moment <= 1.5
  - Cluster # Hits >= 8
- **Charged particles**
  - $PID_{\pi/K} > 0.6$ for π^+
  - $PID_{K/\pi} > 0.6$ for K^+
  - $dr < 0.5$cm
  - $|dz| < 2$cm
- **Neutral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

qq suppression

Rank	B^+ mode (Belle)	B^0 mode (Belle)	B^+ mode (Belle II)	B^0 mode (Belle II)
1	cosTBTO	cosTBTO	cosTBTO	cosTBTO
2	sphericity	hso12	hso12	hso12
3	hso12	sphericity	hso14	hso02
4	$\cos\theta$	hso02	hso02	hso14
5	hoo0	hso14	sphericity	$\cos\theta$
6	hso20	hso20	$\cos\theta$	hso10
7	thrustOm	$\cos\theta$	R2	hso20
8	$\cos\theta_{hel}$	hso10	hoo0	R2
9	hso04	hoo2	$\cos\theta_{hel}$	sphericity
10	cosTBz	thrustBm	hso20	$\cos\theta_{hel}$

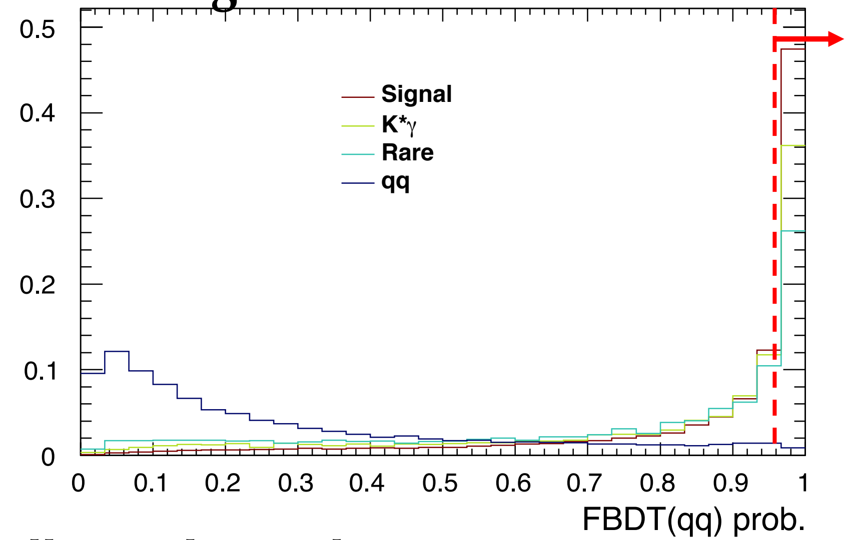
- Optimized for (charged, mixed) x (Belle, Belle II) independently.
  - Belle II adopted R2<0.5 cut for training samples while Belle did not.
  - This would lead an issue in B→Dπ control sample study… (later)
- **cosTBTO** is the largest contribution.



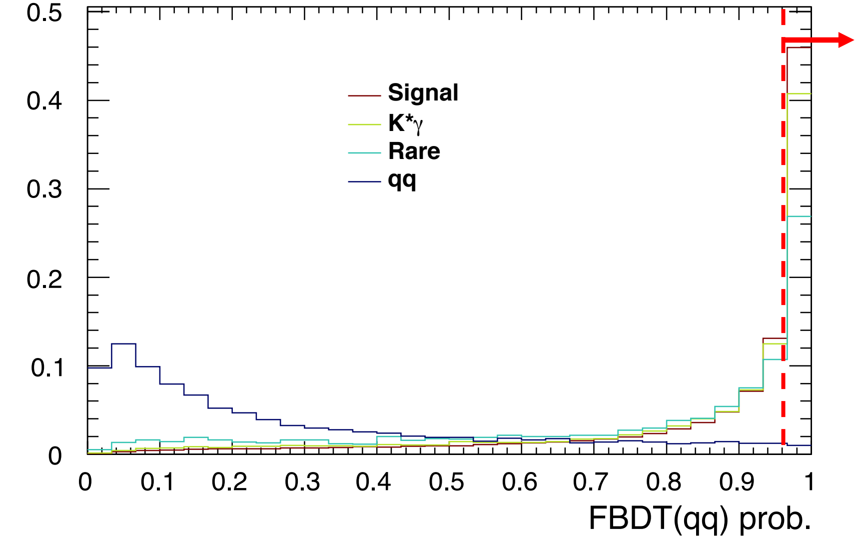


qq suppression

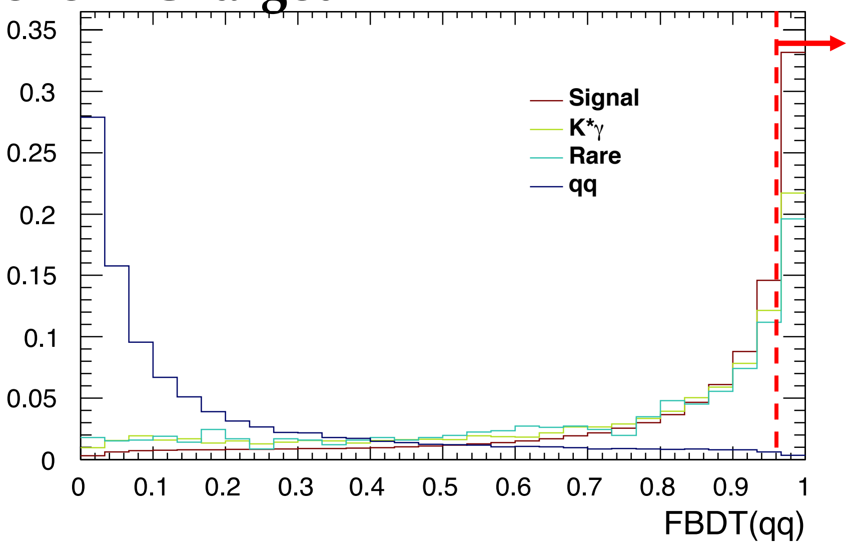
Belle Charged



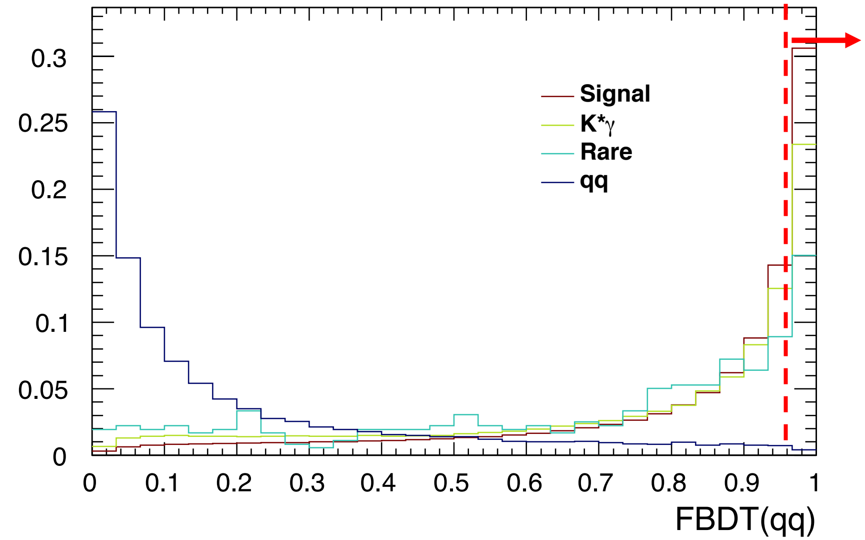
Belle Neutral



Belle II Charged

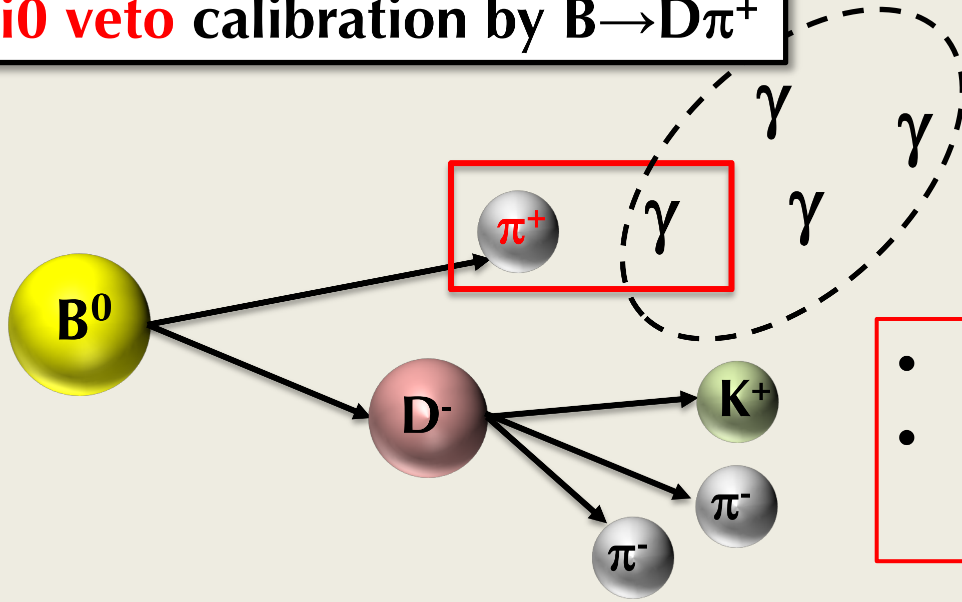


Belle II Neutral



Control samples

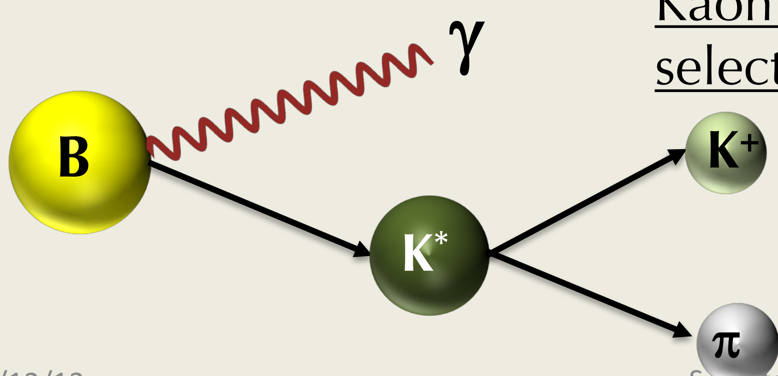
Pi0 veto calibration by $B \to D\pi^+$



Soft photon candidates

- High statistics
- Evt shape disagree with $B \to \rho\gamma$ (couldn't be used for qq sup.)

Eta veto and qq sup. calibration by $B \to K^*\gamma$



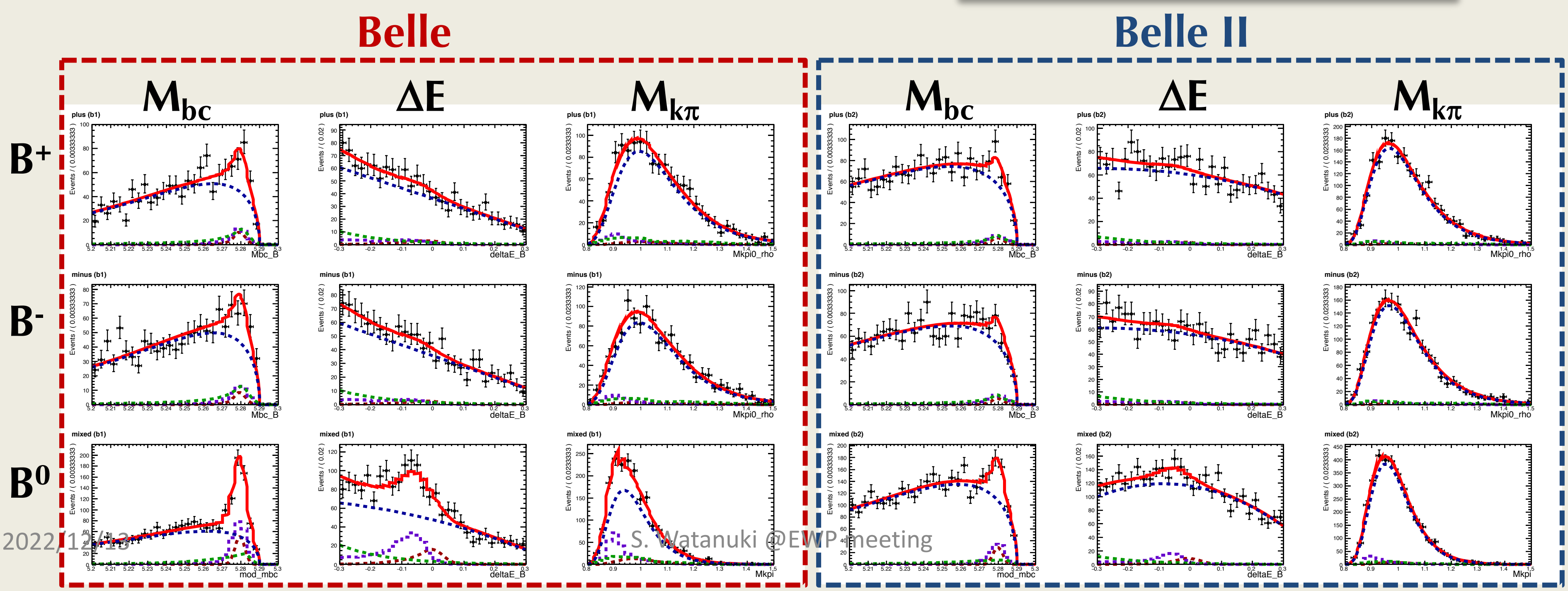
Kaon is explicitly selected (kaonID>0.6)

- Almost perfect control sample
- Also used for signal PDF shape parameters calibration

Fitting

- Simultaneous 3D fitting with 3x2=6 samples to determine target observables.
  - **(M_{bc}, ΔE, $M_{k\pi}$)** for **(B^+, B^-, B^0)** x **(Belle, Belle II)**
  - Floating parameters:
    - $A_I \equiv \frac{rc_\rho^2 BR(B^0\to\rho^0\gamma)-BR(B^\pm\to\rho^\pm\gamma)}{rc_\rho^2 BR(B^0\to\rho^0\gamma)+BR(B^\pm\to\rho^\pm\gamma)}$, where $c_\rho = \sqrt{2}$ *and* $r \equiv \frac{f_{+-}}{f_{00}}\frac{\tau_{B^\pm}}{\tau_{B^0}}$
    - $A_{CP} \equiv \frac{BR(B^+\to\rho^+\gamma)-BR(B^-\to\rho^-\gamma)}{BR(B^+\to\rho^+\gamma)+BR(B^-\to\rho^-\gamma)}$
    - $\Gamma \equiv rc_\rho^2 BR(B^0\to\rho^0\gamma) + BR(B^\pm\to\rho^\pm\gamma)$

- $BR(B^\pm\to\rho^\pm\gamma) = \frac{\Gamma}{2}(1-A_I)$
- $BR(B^0\to\rho^0\gamma) = \frac{\Gamma}{4r}(1+A_I)$



Systematics summary

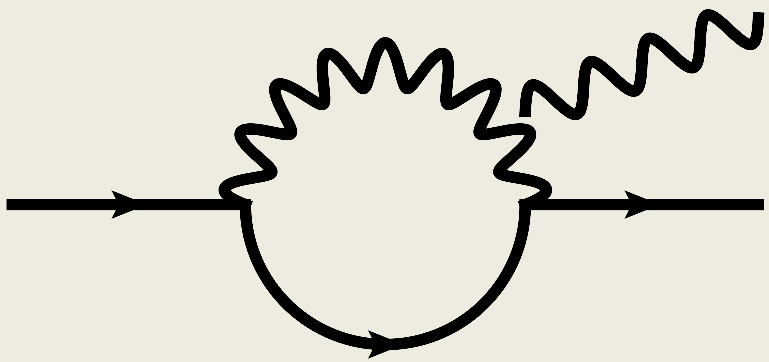
	BR(+)		BR(0)		AI		ACP	
recon eff (B1)	1.67E-08	1.67E-08	1.74E-08	1.70E-08	0.52%	0.49%	0.21%	0.21%
recon eff (B2)	1.76E-08	1.81E-08	4.30E-09	4.08E-09	0.79%	0.75%	0.40%	0.40%
cut eff (B1)	7.19E-08	6.68E-08	3.98E-08	3.77E-08	3.64%	3.71%	0.66%	0.66%
cut eff (B2)	3.19E-08	3.25E-08	1.32E-08	1.33E-08	1.61%	1.56%	0.54%	0.54%
PDF para (B1)	1.46E-08	1.53E-08	3.11E-08	5.66E-08	1.70%	3.09%	1.04%	1.03%
PDF para (B2)	1.15E-08	5.16E-09	4.92E-09	3.20E-09	0.36%	0.55%	0.32%	0.28%
Signal calib (B1)	4.55E-09	2.37E-08	2.86E-09	7.97E-09	1.08%	0.45%	0.56%	0.56%
Signal calib (B2)	1.72E-09	1.31E-08	5.58E-10	3.84E-09	0.59%	0.20%	0.36%	0.34%
Histogram PDF	1.43E-08	3.93E-09	2.34E-08	9.89E-10	1.22%	0.65%	0.61%	0.51%
K* yields	2.73E-08	2.61E-08	4.34E-08	4.12E-08	1.89%	1.87%	0.55%	0.55%
BB peak yields	5.15E-09	5.38E-09	2.78E-09	2.68E-09	0.28%	0.25%	0.21%	0.20%
Peaking ACP	8.13E-10	1.08E-09	2.28E-10	2.69E-10	0.05%	0.04%	0.94%	0.89%
Number of BB	1.67E-08	1.62E-08	1.71E-08	1.69E-08	0.23%	0.25%	0.22%	0.22%
Others	1.43E-08	1.39E-08	1.59E-08	1.58E-08	2.39%	2.47%	0.07%	0.07%
Total	**9.28E-08**	**9.11E-08**	**7.79E-08**	**8.62E-08**	**5.68%**	**6.10%**	**2.06%**	**1.99%**

- All systematics are reasonably smaller than stat.
- The dominant source comes from **Belle cut efficiency calibration** due to statistics of control sample.

Toy-MC results (711/fb + 364/fb)

- $BR(B^+ \to \rho^+\gamma) = (9.81 \pm 2.31^{+0.93}_{-0.91})\times10^{-7}$
- $BR(B^0 \to \rho^0\gamma) = (8.63 \pm 1.38^{+0.78}_{-0.86})\times10^{-7}$
- $A_I = (33.5 \pm 12.9^{+5.7}_{-6.1})\%$
- $A_{CP} = (0.3 \pm 23.6^{+2.1}_{-2.0})\%$

Thank you



Electroweak Penguin
(電弱ペンギン/전기-약 펭귄)

Analysis setup

Signal MC	Belle	Belle II
$B^+ \to \rho^+\gamma$	520K (~700str)	5M (MC15)
$B^0 \to \rho^0\gamma$	520K (~700str)	20M (MC15)
Data	711/fb	364/fb (Proc13+Buckets)

← **Belle II neutral is accidentally 4 times larger**

- **Release:** light-2207-bengal
- **Skim:**
  - radb_b skim for Belle
  - BtoXgamma for Belle II

rad_b skim for Belle	BtoXgamma skim for Belle II
$1.4 < E^*_\gamma < 3.4$ GeV $E9/E25 > 0.9$	foxWolframR2 < 0.7 $n_{\mathrm{tracks}} \geq 3$ cluster$E9/E21 > 0.9$ $1.4 < E^*_\gamma < 3.4$ GeV

- **Background samples:**
  - 2 streams (1 for qq sup. training)
50 streams rare B for Belle
  - 1/ab generic MC for Belle II (MC15ri_b)

Selections

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

BELLE II

- **Event level**
  - foxWolframR2 < 0.7
  - 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

Cut tables

B1

Charged

Cut	Signal	$K^{*+}\gamma$	$B\overline{B}$	$q\bar{q}$	Significance
No cut	145	380	2241	299656	0.26
Window	114	75	248	22670	0.75
π^0 veto	95	61	143	6785	1.13
η veto	93	59	139	5710	1.20
$q\bar{q}$ sup.	54	26	51	215	2.90

Neutral

Cut	Signal	$K^{*0}\gamma$	$B\overline{B}$	$q\bar{q}$	Significance
No cut	188	721	1243	218666	0.40
Window	150	208	145	15782	1.18
π^0 veto	124	170	95	4597	1.76
η veto	121	166	89	3734	1.89
$q\bar{q}$ sup.	69	87	34	124	3.89

B2

Charged

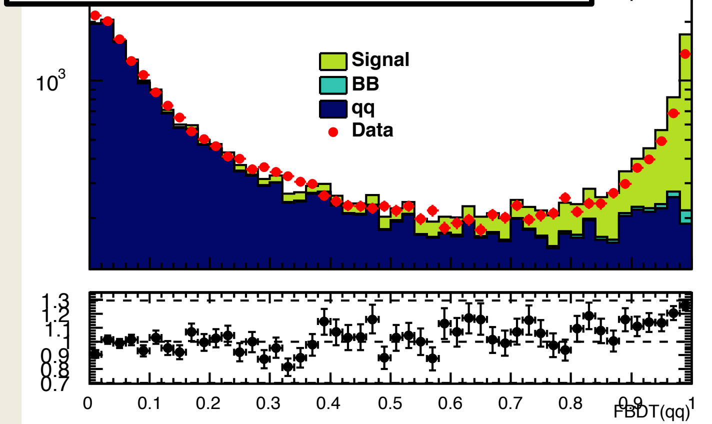
Cut	Signal	$K^{*+}\gamma$	$B\overline{B}$	$q\bar{q}$	Significance
No cut	91	188	1062	702370	0.11
Window	72	41	162	51163	0.32
pi0 veto	63	35	98	10640	0.61
eta veto	60	33	96	7695	0.68
qq sup.	36	15	38	221	2.06

Neutral

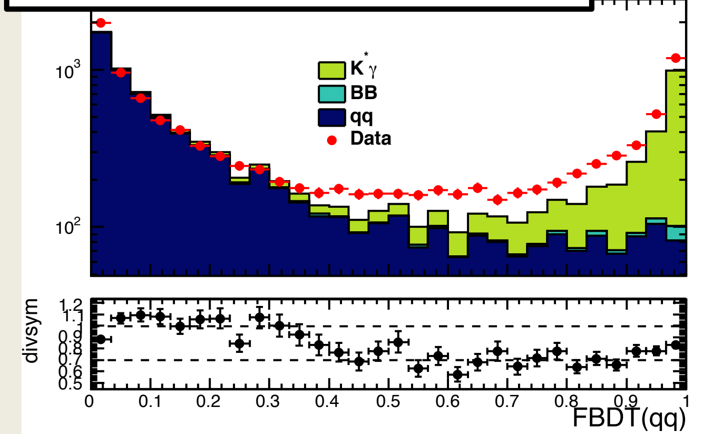
Cut	Signal	$K^{*0}\gamma$	$B\overline{B}$	$q\bar{q}$	Significance
No cut	84	235	447	356802	0.14
Window	69	71	55	26167	0.43
pi0 veto	60	61	37	5132	0.83
eta veto	56	58	34	3655	0.92
qq sup.	40	36	19	244	2.20

Signal efficiency calibration

FBDT(qq) for B1mix $B \to K^*\gamma$



FBDT(qq) for B2mix $B \to K^*\gamma$



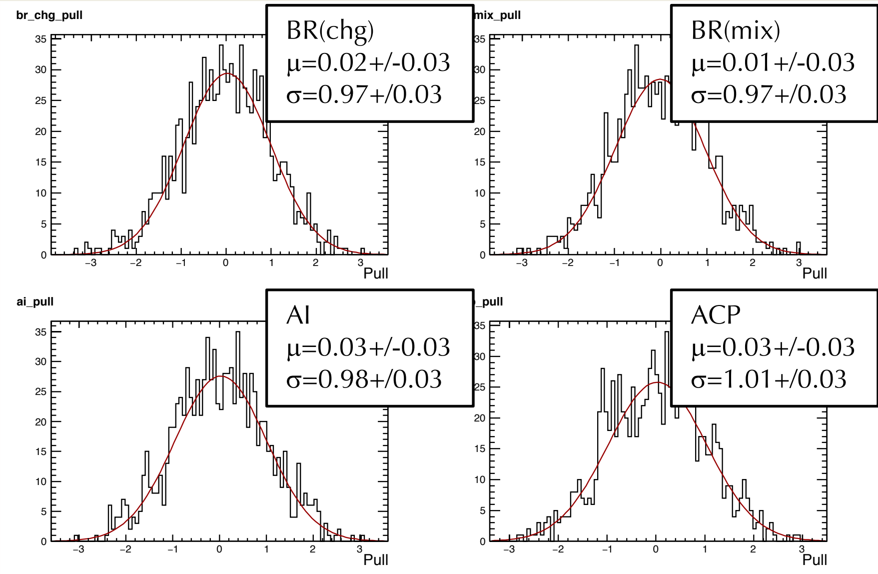
Belle		Cut	Control	Eff ratio
Charged	pi0veto	0.50	$B \to D\pi^+$	0.967+/-0.007
	etaveto	0.96	$B^+ \to K^{*+}\gamma$	0.815+/-0.082
	qq sup	0.95		
Mixed	pi0veto	0.50	$B \to D\pi^+$	0.967+/-0.007
	etaveto	0.95	$B^0 \to K^{*0}\gamma$	1.000+/-0.037
	qq sup	0.95		

Belle II		Cut	Control	Eff ratio
Charged	pi0veto	0.60	$B \to D\pi^+$	1.058+/-0.012
	etaveto	0.50	$B^+ \to K^{*+}\gamma$	0.984+/-0.074
	qq sup	0.94		
Mixed	pi0veto	0.53	$B \to D\pi^+$	1.058+/-0.012
	etaveto	0.50	$B^0 \to K^{*0}\gamma$	0.981+/-0.039
	qq sup	0.87		

- Control samples ($B \to D\pi^+$ and $B \to K^*\gamma$) show good agreements of the cut variables with $B \to \rho\gamma$.
- Efficiency ratio is calculated by fitting M_{bc} before and after the same cuts.
- For pi0veto, calibration depending on the 2D plane of (E^*,θ^*) are obtained to take the kinematic difference into account.

Fitting models

Comp.	M_{bc}	ΔE	$M_{K\pi}$
Signal	Crystal Ball	Crystal Ball	Novosibirsk x Gaussian
K*γ	3D Histogram		
BB	Crystal Ball + ARGUS	Exponential	1D Histogram
qq	ARGUS	2nd Chebychev polynomial	Novosibirsk x Gaussian



- 3D product PDFs are obtained.
- **Floating parameters:**
  - Signal ... A_I, A_{CP} and Γ
  - qq ... Yields, curvature (M_{bc}), c1, c2 (ΔE), mean, width of Novosibirsk ($M_{K\pi}$) independent on datasets

  ※ *Note that B^+ and B^- use common qq parameters*

- Totally **27 floating parameters** are simultaneously decided.
- Pulls are consistent with mean=0 & width=1 (1000 toys).

Systematics

- **Reconstruction efficiency calibration**
  - Photon, tracking, PID, π^0 (for charged)
  - Official values for calibration (Belle, Belle II independently)

- **Cut efficiency calibration**
  - Calibration by $B\rightarrow D\pi$ and $B\rightarrow K^*\gamma$ control sample

- **Fixed PDF shape**
  - +/-1σ fluctuation for function PDF (Signal, BB, and $M_{K\pi}$ tail of qq)
  - For histogram PDF ($K^*\gamma$ and BB $M_{K\pi}$);
    kernel estimation → generate toy-MC for new histogram PDF

- **Peaking components**
  - For $K^*\gamma$, fluctuated by $\pi\rightarrow K$ fake rate uncertainty and measured BR uncertainty
  - For other combinatorial, the BR uncertainty is taken for each components
  - A_{CP} of peaking components are also taken into account

- **Others**
  - N(BB), f+-/f00, lifetime of B^+/B^0

Yields of Peaking Components

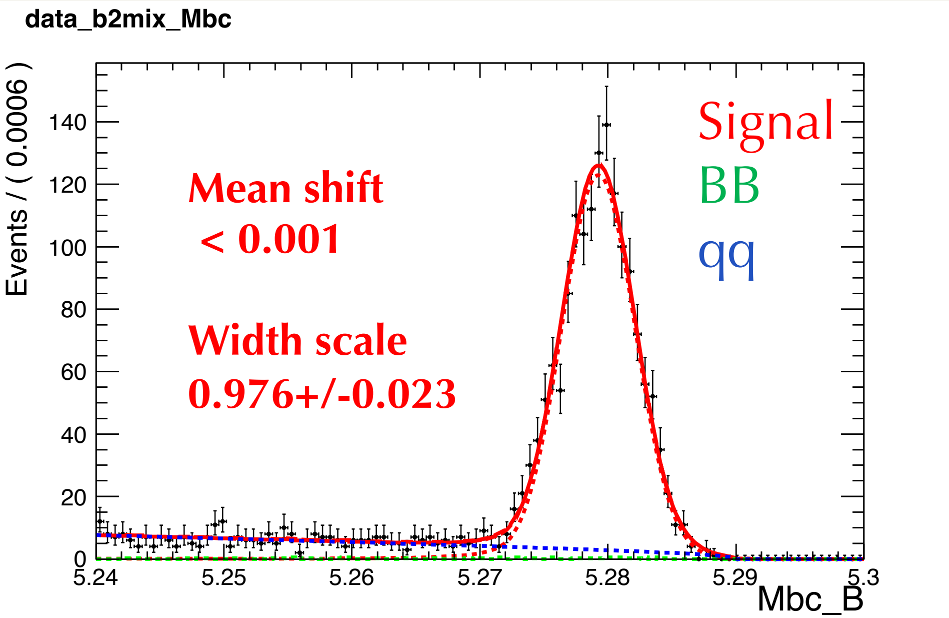
K*γ

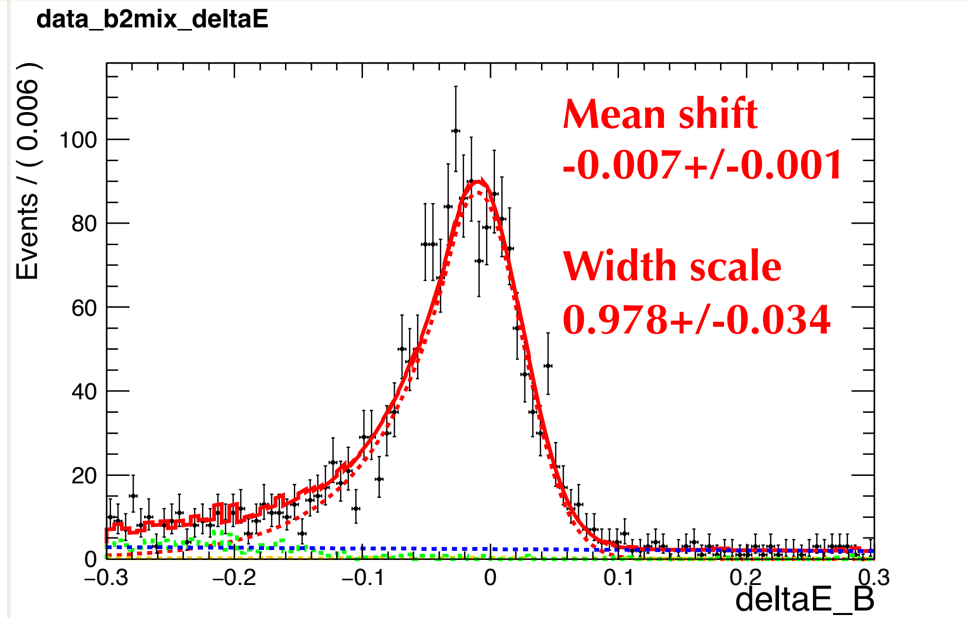
- $N_{rec}(K^*\gamma) = 2N_{BB}\times BR(B \to K^*\gamma)\times R_{fake}(K \to \pi)\times \epsilon$
- The uncertainty of BR and R_{fake} are taken as systematics.
- The uncertainty of ε had been already taken as well as calibration of signal (categorized as "cut eff.").

Other BB

- $N'_{peak} = N_{peak}\left(F_{X_s\gamma}w_{X_s\gamma} + F_{X_d\gamma}w_{X_d\gamma} + F_{\pi^0}w_{\pi^0} + F_\eta w_\eta + F_{other}w_{other}\right)$
- Fluctuate each components:
  - $BR(B\to X_s\gamma)=(3.49+/-0.19)\times10^{-4}$
  - $BR(B\to X_d\gamma)=(9.2+/-3.0)\times10^{-6}$
  - For π^0 origin, η origin γ, weighted average is taken assuming σBR in breakdown.
  - For the "others", +/-50% is taken to estimate systematics conservatively.

Signal shape calibration





- Shapes of M_{bc} and ΔE are calibrated by $B \to K^*\gamma$ control sample.
- Treatment of BB:
  - For Mbc, it is fixed by MC
  - For deltaE, histogram PDF is adopted and yield is kept floating

Correlation

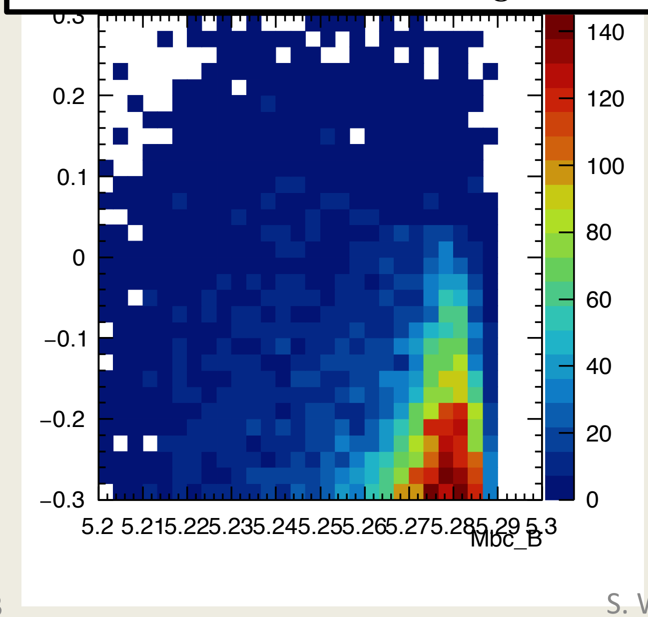
B1chg	Mbc vs deltaE	deltaE vs Mkpi	Mkpi vs Mbc
Signal	0.121	0.010	0.011
K*gamma	-0.032	-0.181	-0.194
BB	-0.247	0.004	0.056
qq	-0.006	0.024	0.026

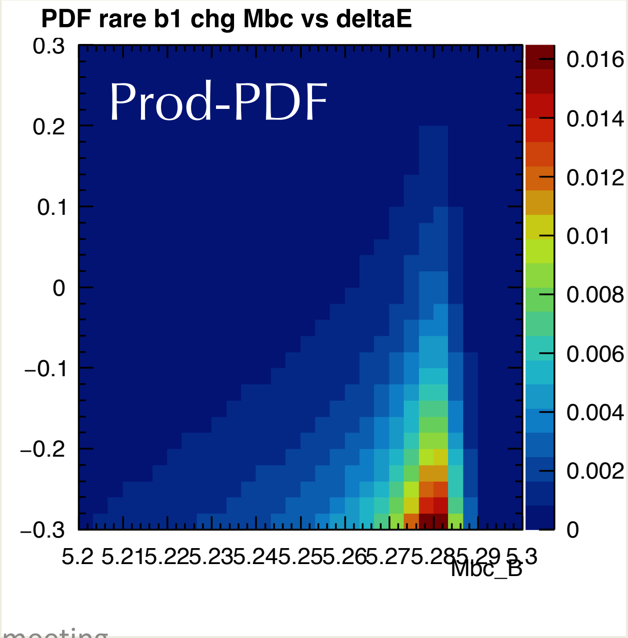
B1mix	Mbc vs deltaE	deltaE vs Mkpi	Mkpi vs Mbc
Signal	0.093	0.018	0.018
K*gamma	0.227	-0.090	-0.046
BB	-0.312	0.098	0.082
qq	-0.004	0.102	0.057

B2chg	Mbc vs deltaE	deltaE vs Mkpi	Mkpi vs Mbc
Signal	0.069	-0.006	-0.015
K*gamma	-0.019	-0.132	-0.197
BB	-0.170	0.040	0.041
qq	0.035	0.014	0.032

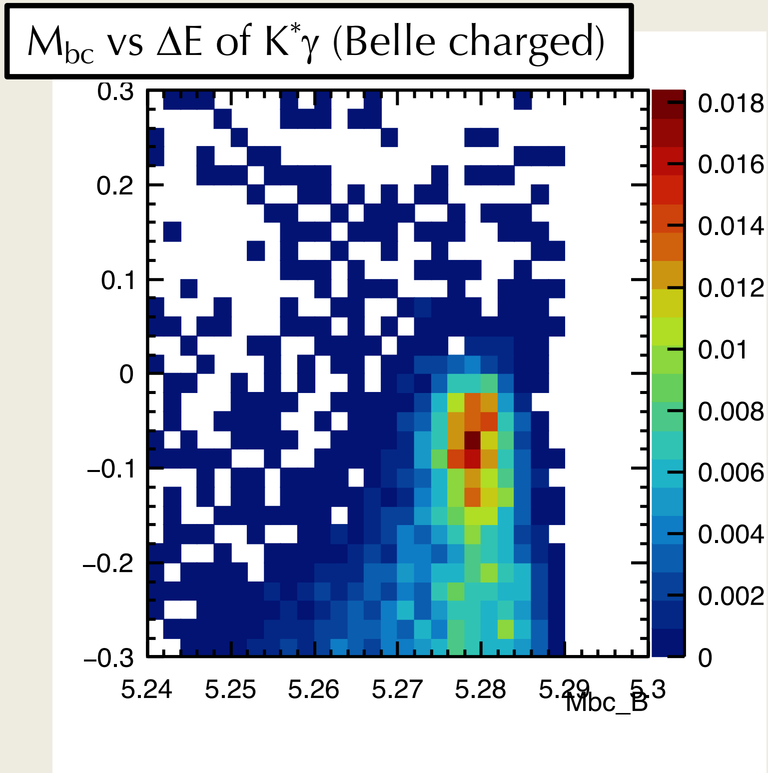
B2mix	Mbc vs deltaE	deltaE vs Mkpi	Mkpi vs Mbc
Signal	0.036	0.010	0.008
K*gamma	0.223	-0.139	-0.075
BB	-0.250	0.144	0.032
qq	0.028	0.032	0.025

Mbc vs deltaE (Belle charged BB)

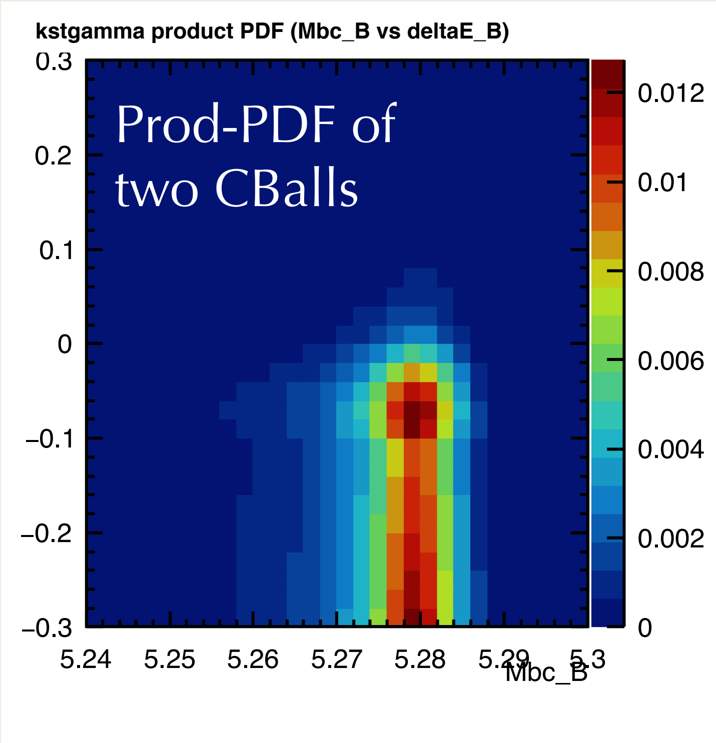




Availability of prod-PDF



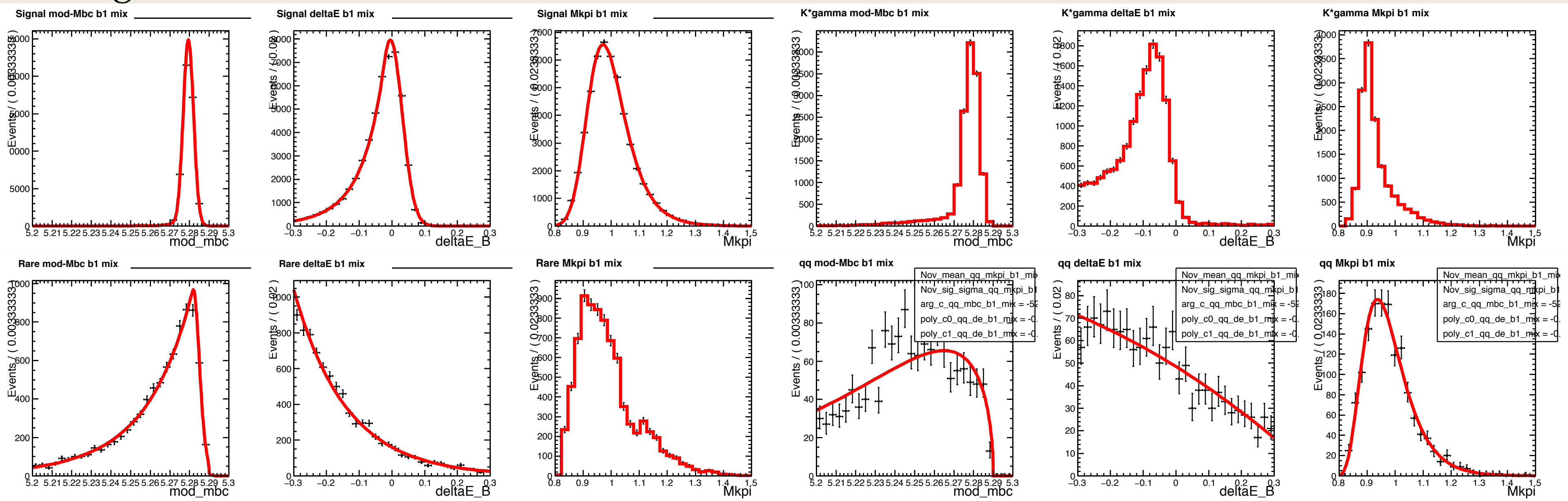
Irrelevant to model



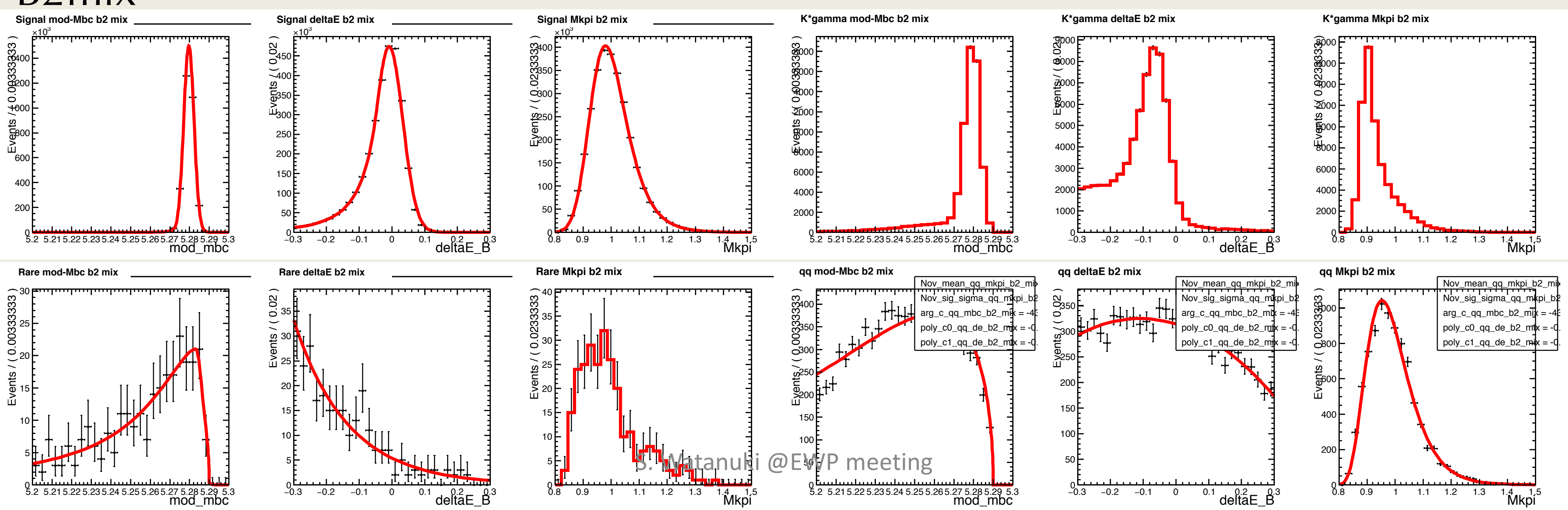
- Only $K^*\gamma$ component is fitted by 3D histogram-PDF instead of production of functional PDFs.
- This is because prod-PDF is clearly not relevant for fitting (though χ^2 of above fit is not that bad, 1.63).

Fitting models

B2chg

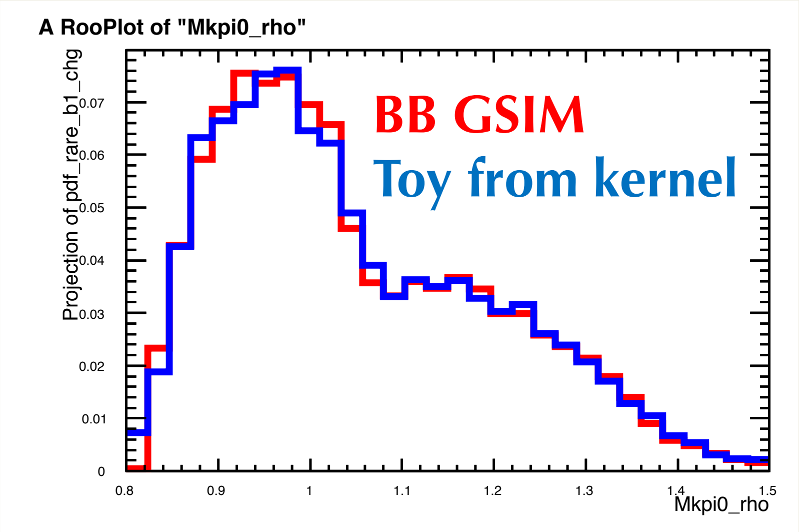


B2mix



Histogram PDF

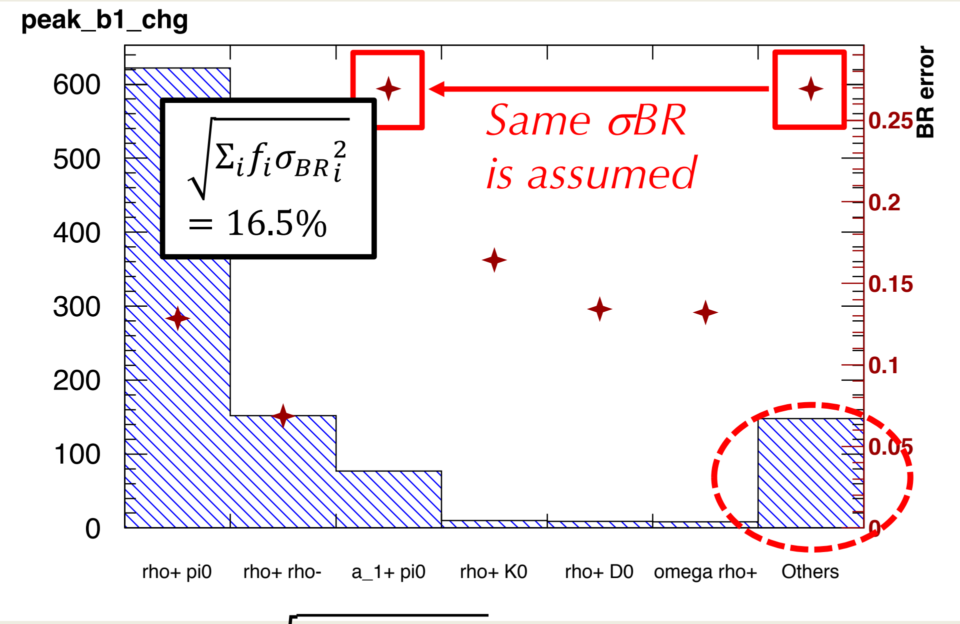
- Histogram PDF in my fitter:
  - 3D histogram (M_{bc}, ΔE, $M_{k\pi}$) for $K^*\gamma$
  - 1D histogram ($M_{k\pi}$) for other BB background
- Procedure
  1. Make kernel estimation to get smooth line.
  2. Create toy-MC by same statistics of MC for each fitting trials (1000 times).
  3. Use the toy-MC histogram as new PDF.

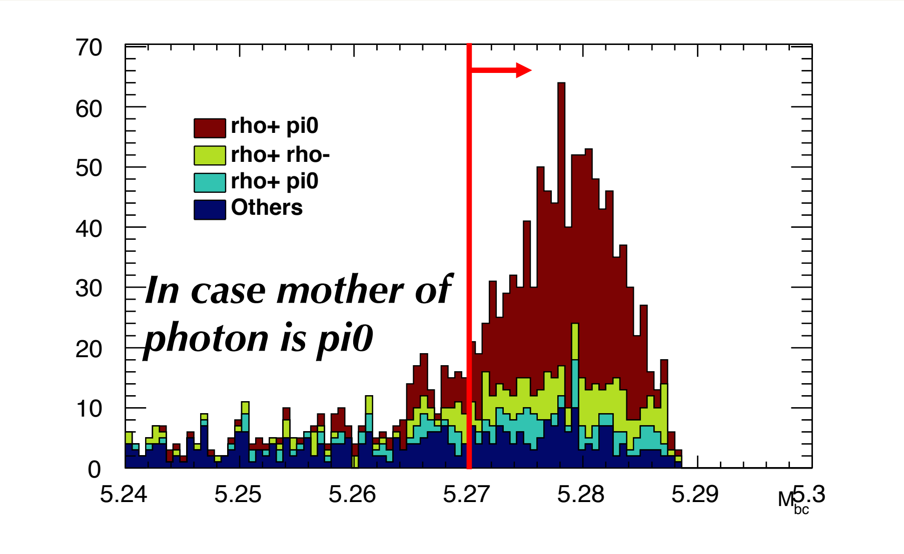


$$\sigma_{sys} = \mathcal{O}(GSIM) - \underline{\mathcal{O}(Toy)}$$

Newly generated for each toy fitting trials

Peaking due to π^0 origin γ BG





- $\sigma_{BR}^{tot} = \sqrt{\Sigma_i f_i \sigma_{BR}{}_i^2}$ is used for fluctuation to estimate systematics.
- The "others" in the breakdown is a sum of:
  1. **Tons of garbage**
  2. **Modes whose BR has not been measured yet**
- σBR of "others" is assumed to be same as the largest σBR(i) so far.
  - In case of Belle charged mode, the uncertainty of BR($B^+ \to a_1^+ \pi^0$).
  - Not sure if this criteria is enough conservative.
  - +/-50% (for example) should be adopted?

Toy-MC Sensitivity