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Radiative B Decays at Belle

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科研費 KAKENHI

BELLE

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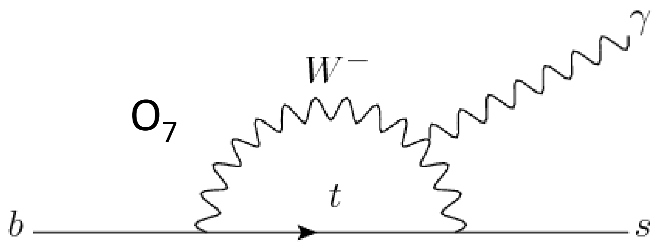
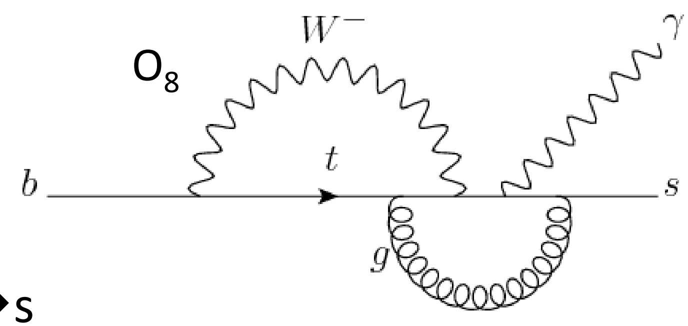
Contents

- Evidence for Isospin Violation in $B \rightarrow K^*\gamma$
- Time Dependent CP Violation in $B \rightarrow K_S\eta\gamma$
- New Measurements of ΔA_{CP} and Isospin asymmetry in $B \rightarrow X_s\gamma$ with sum-of-exclusive technique

All the analyses used a full data sample of $711 fb^{-1}$ containing 772×10^6 BB events.
$89 fb^{-1}$ off resonance data is used for the third analysis.

Wilson Coefficients in b→sγ process





- In effective Hamiltonian approach, b→s transition in the SM can be described by real Wilson coefficients which correspond to short distance couplings
  - b→sγ : $C_7^{SM} \sim -0.3$
  - b→sg : $C_8^{SM} \sim -0.15$

at m_b scale

$$\mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_{i=1}^{10} C_i(\mu) O_i(\mu)$$

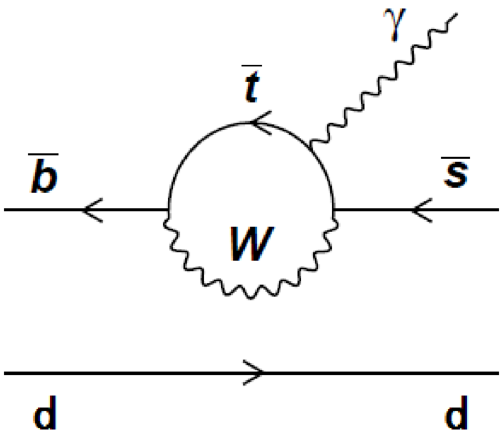
- If NP contributes,
  - Deviation from the SM values
  - New coefficients appear
    - Imaginary parts; $Im(C_7)$, $Im(C_8)$
    - Chirality flipped coefficients ; C_7' and C_8'
      - $q_{L(R)} \to q_{R(L)}$

$$\mathcal{O}_7 = \frac{e}{16\pi^2} m_b \left(\bar{s}_L \sigma_{\mu\nu} b_R\right) F^{\mu\nu}$$

$$\mathcal{O}_8 = \frac{g}{16\pi^2} m_b \left(\bar{s}_L \sigma_{\mu\nu} T^a b_R\right) G^{a\mu\nu}$$

O_2 also contributes

$b \rightarrow s\gamma$



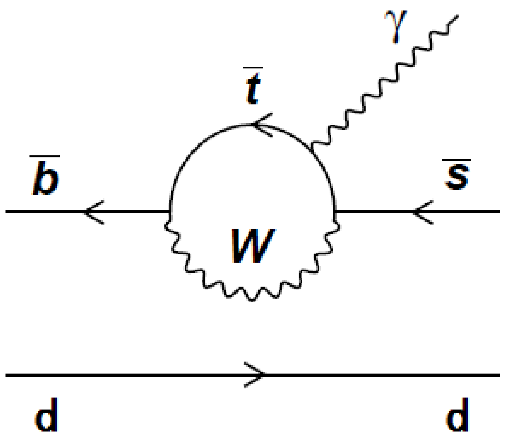
- The decay
  - Dominated by one loop penguin diagrams (FCNC)
    - Sensitive to new physics (NP) in the loop
  - The photon is polarized predominantly left-handed in the SM
    - If sizable right-handed photon contribution (C_7') found → clear NP signal

- Inclusive BF is consistent with the SM prediction
  - Strong constraint on $|C_7|^2+|C_7'|^2$ and thus NP
- Direct CP Violation in $B \rightarrow X_s\gamma$ consistent with theory
  - Constraint on combination of C_7 and C_8,
- Time dependent CP Violation in $B \rightarrow K^{*0}\gamma$ consistent with 0 but still uncertainty large
  - Mild constraint on $Im(C_7 C_7' e^{-i2\phi_1})$

T. Horiguchi, A. Ishikawa et al. PRL 119 191802 (2017)

Evidence for Isospin Violaton in $B \rightarrow K^*\gamma$

B→K*γ



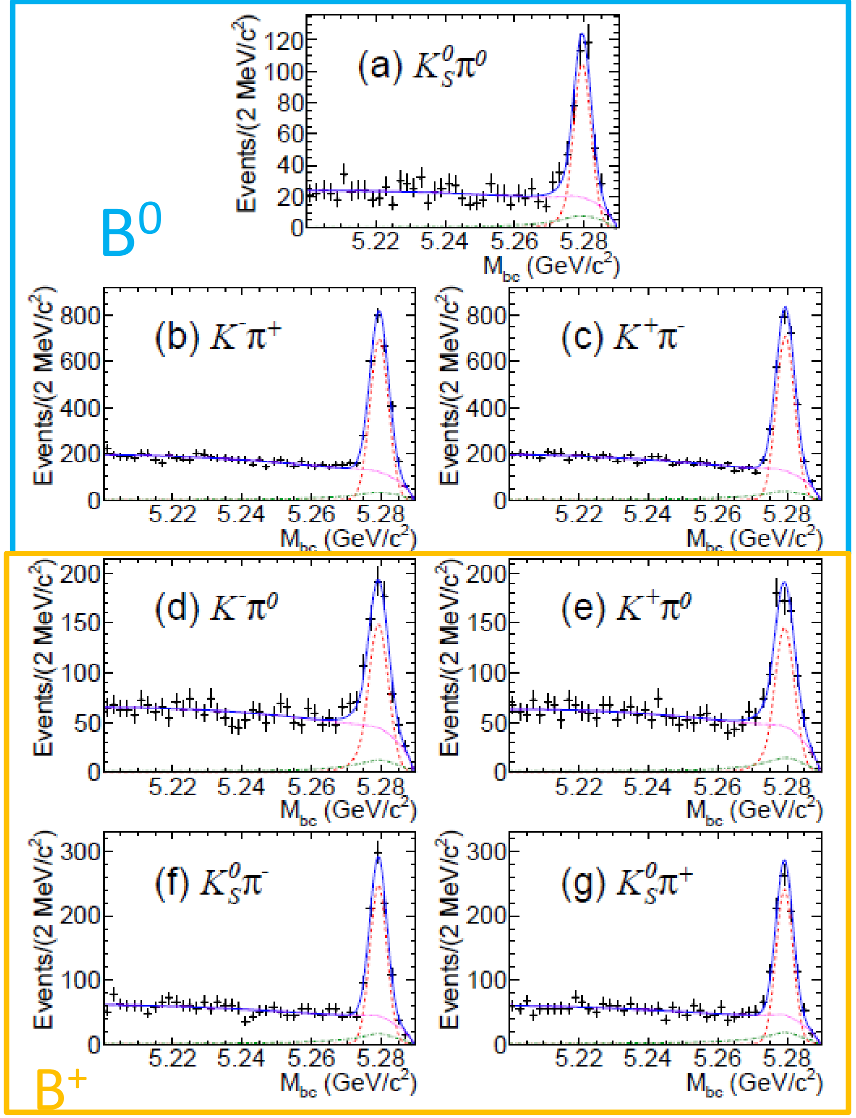
- Cleanest exclusive b→sγ decay.
  - BF ~ 4 x 10^{-5}
    - About 12% of inclusive B→Xsγ rate
  - Prediction of branching fraction is limited by an uncertainty of tensor form factor at $q^2=0$; $T_1(0)$, and not so sensitive to NP
- By taking a ratio of decay widths (or BF), a dominant uncertainty due to $T_1(0)$ cancels out thus sensitive to new physics
  - Isospin Asymmetry; Δ_{0+}
    - Sensitive to new physics in annihilation diagrams

$$\Delta_{0+} = \frac{\Gamma(B^0 \to K^{*0}\gamma) - \Gamma(B^+ \to K^{*+}\gamma)}{\Gamma(B^0 \to K^{*0}\gamma) + \Gamma(B^+ \to K^{*+}\gamma)}$$

Results

- Four subdecay modes are reconstructed and simultaneous fit is performed.
- First Evidence for Δ_{0+} with 3.1σ

$$
\begin{aligned}
\mathcal{B}(B^0 \to K^{*0}\gamma) &= (3.96 \pm 0.07 \pm 0.14) \times 10^{-5}, \\
\mathcal{B}(B^+ \to K^{*+}\gamma) &= (3.76 \pm 0.10 \pm 0.12) \times 10^{-5}, \\
A_{CP}(B^0 \to K^{*0}\gamma) &= (-1.3 \pm 1.7 \pm 0.4)\%, \\
A_{CP}(B^+ \to K^{*+}\gamma) &= (+1.1 \pm 2.3 \pm 0.3)\%, \\
A_{CP}(B \to K^{*}\gamma) &= (-0.4 \pm 1.4 \pm 0.3)\%, \\
\Delta_{0+} &= (+6.2 \pm 1.5 \pm 0.6 \pm 1.2)\%, \\
\Delta A_{CP} &= (+2.4 \pm 2.8 \pm 0.5)\%,
\end{aligned}
$$



Mode	N_S^B	N_S^{B}	ϵ [%]	$\mathcal{B}$ [10^{-5}]	A_{CP} [%]
$B^0 \to K_S^0\pi^0\gamma$	$349 \pm 23 \pm 15$		1.16 ± 0.04	$4.00 \pm 0.27 \pm 0.24$	–
$B^0 \to K^+\pi^-\gamma$	$2295 \pm 56 \pm 27$	$2339 \pm 56 \pm 30$	15.61 ± 0.49	$3.95 \pm 0.07 \pm 0.14$	$-1.3 \pm 1.7 \pm 0.4$
$B^+ \to K^+\pi^0\gamma$	$572 \pm 32 \pm 12$	$562 \pm 31 \pm 11$	3.66 ± 0.12	$3.91 \pm 0.16 \pm 0.16$	$+1.0 \pm 3.6 \pm 0.3$
$B^+ \to K_S^0\pi^+\gamma$	$745 \pm 32 \pm 8$	$721 \pm 32 \pm 9$	5.01 ± 0.14	$3.69 \pm 0.12 \pm 0.12$	$+1.3 \pm 2.9 \pm 0.4$

Δ_{0+}

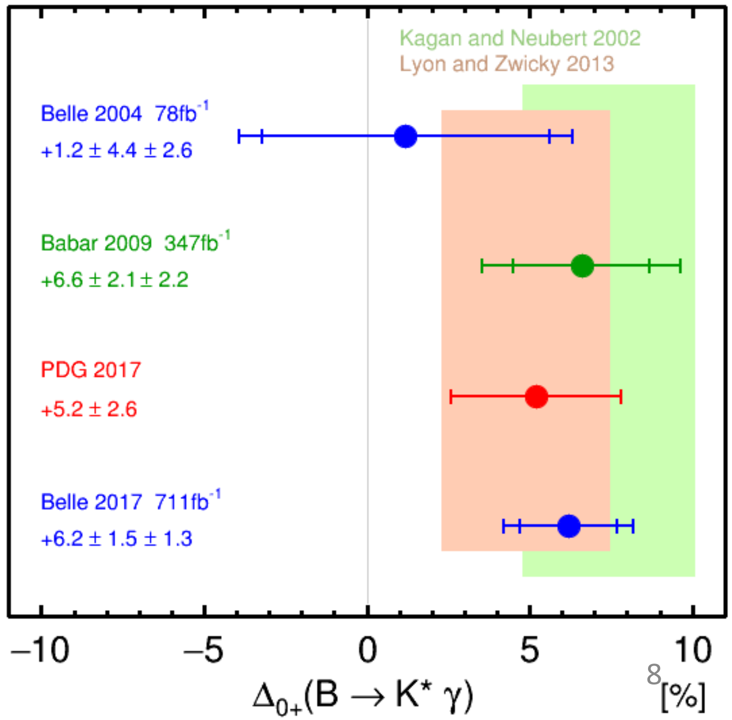
- First evidence of isospin violation in b→s transition with 3.1σ significance.

$$\Delta_{0+} = (+6.2 \pm 1.5(\text{stat.}) \pm 0.6(\text{syst.}) \pm 1.2(f_{+-}/f_{00}))\%$$

- Dominant uncertainties are statistical one and due to f_{+-}/f_{00}.
- New Belle result is consistent with Babar, and also theoretical predictions within the SM by Kagan and Neubert, and Lyon and Zwicky

- This result will be used to constrain new physics

For example,
Mahmoudi, JHEP 12 (2007) 026
Descotes-Genon, Ghosh, Matias, Ramon, JHEP 06 (2011) 099
Lyon, Zwicky, PRD 88, 094004 (2013).



H. Nakano, A. Ishikawa et al. PRD97,092003 (2018)

Time Dependent CP Violation in $B \rightarrow K_S \eta \gamma$

Time Dependent CP Violation in B→$P^0Q^0\gamma$

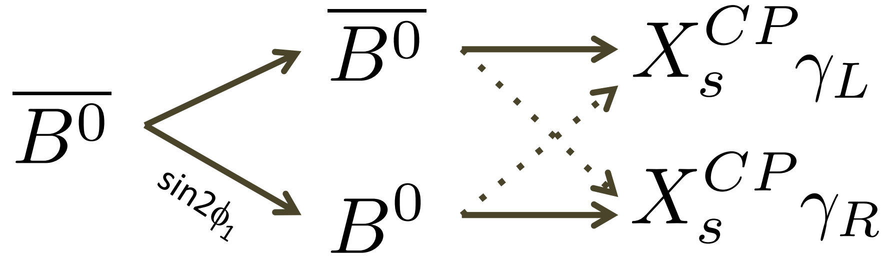
- Photons in b→sγ is predominantly polarized left-handed.
  - No time dependent CPV in B→$P^0Q^0\gamma$, where P and Q are pseudo-scalar mesons

$$|S_{CP}| \approx \frac{2m_s}{m_b} \sin 2\phi_1 \sim 2\ \%$$

- If NP which has right-handed current contributed to b→sγ , large CPV is possible.
- We search for the time dependent CPV with B→$K_S\eta\gamma$ for the first time at Belle

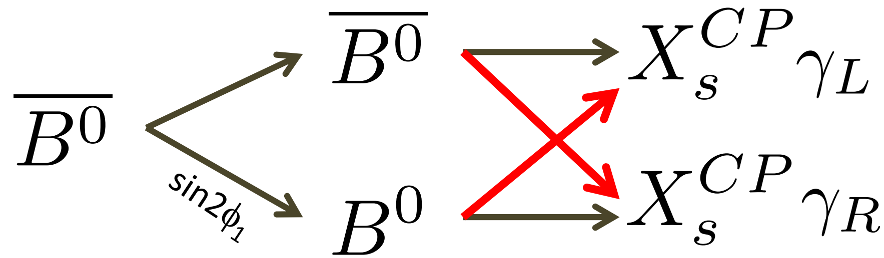
$$A(t) = \frac{\Gamma(\bar{B}^0 \to f_{CP};t) - \Gamma(B^0 \to f_{CP};t)}{\Gamma(\bar{B}^0 \to f_{CP};t) + \Gamma(B^0 \to f_{CP};t)} = \mathcal{S}_{f_{CP}} \sin(\Delta m_d t) + \mathcal{A}_{f_{CP}} \cos(\Delta m_d t)$$

SM case



dotted : helicity flip
Small interference

NP case



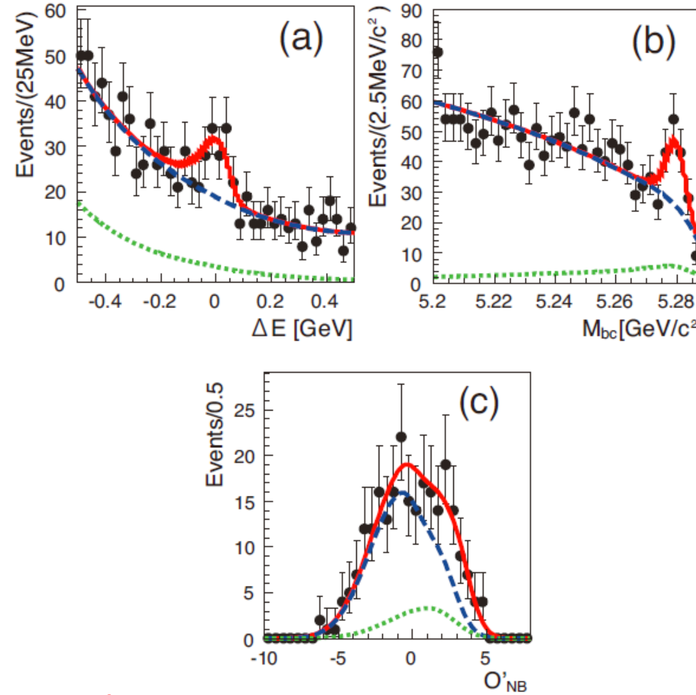
red : helicity flip + NP
Large interference → CPV

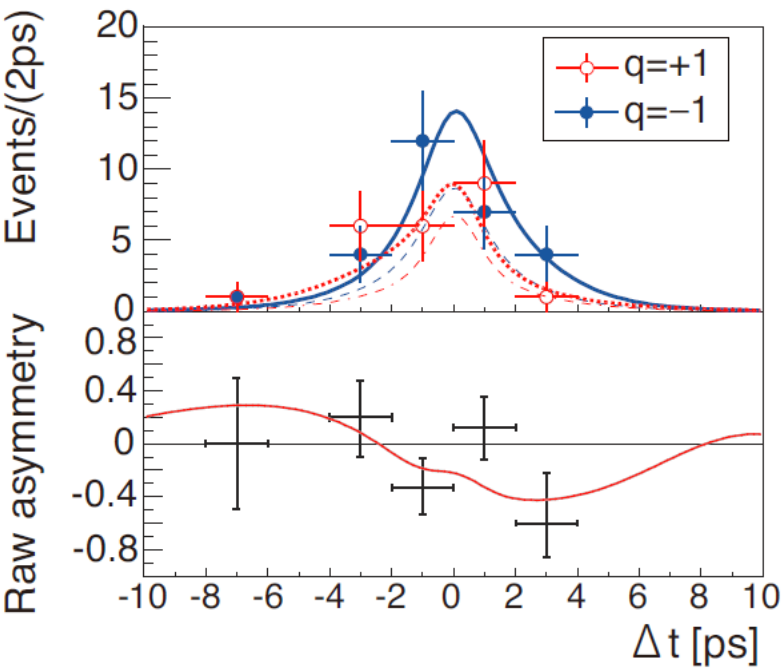
Result

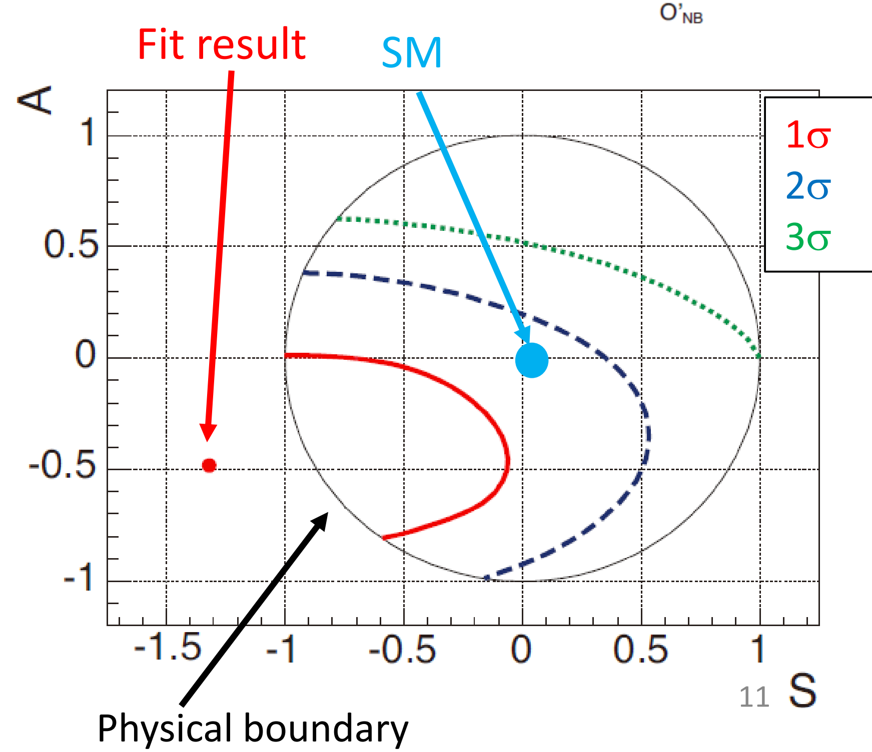
- We obtained

$$\mathcal{S} = -1.32 \pm 0.77(\text{stat.}) \pm 0.36(\text{syst.}),$$
$$\mathcal{A} = -0.48 \pm 0.41(\text{stat.}) \pm 0.07(\text{syst.})$$

- The central value is outside the physical boundary $S^2+A^2=1$ but is consistent with null asymmetry within 2σ







S. Watanuki, A. Ishikawa et al. to be submitted to PRD

BELLE-CONF-1801

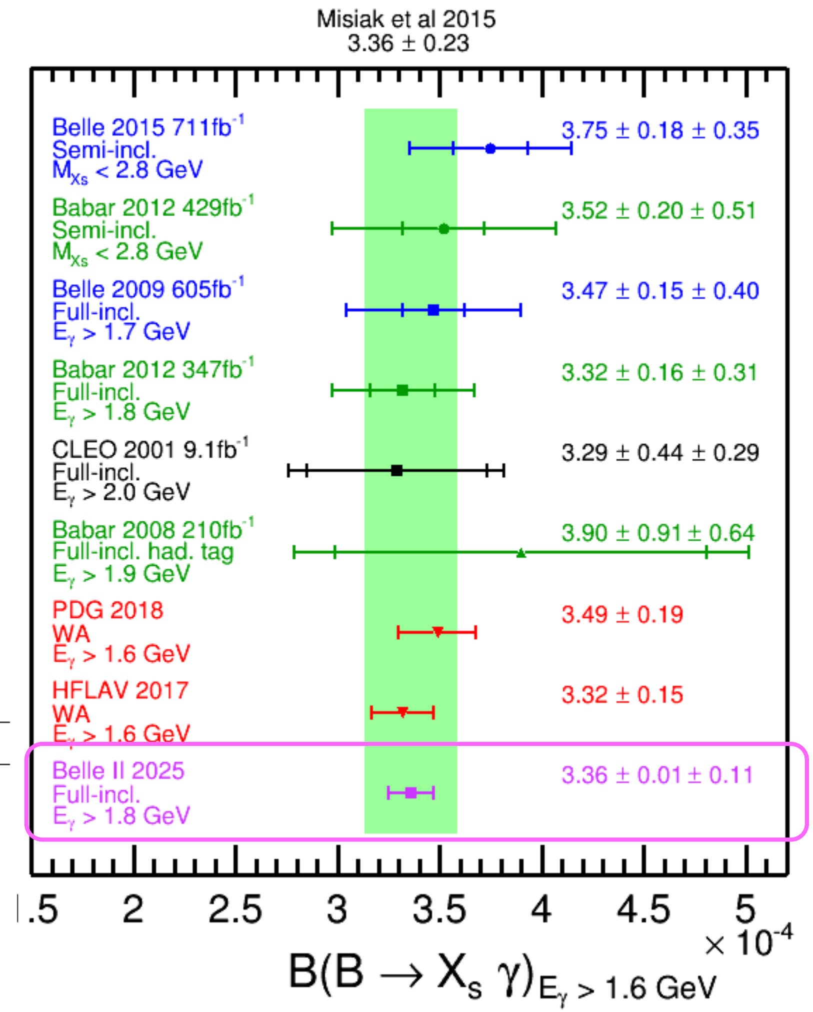
New Measurements of ΔA_{CP} and Isospin asymmetry in $B \rightarrow X_s \gamma$ with sum-of-exclusive technique

BF(B→Xs γ)

- The BF(B→Xs γ) is very sensitive to NP models
- WA and theoretical prediction are consistent and comparable precision ~7%
  - Strong constraint on NP
- At Belle II, the precision on the BF will be 3% level.

Need to reduce theoretical uncertainty to search for NP!

Observables	Belle 0.71 ab^{-1}	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
$Br(B \to X_s\gamma)^{\text{lep-tag}}_{\text{inc}}$	5.3%	3.9%	3.2%
$Br(B \to X_s\gamma)^{\text{had-tag}}_{\text{inc}}$	13%	7.0%	4.2%
$Br(B \to X_s\gamma)_{\text{sum-of-ex}}$	10.5%	7.3%	5.7%
$\Delta_{0+}(B \to X_s\gamma)_{\text{sum-of-ex}}$	2.4%	0.94%	0.69%
$\Delta_{0+}(B \to X_{s+d}\gamma)^{\text{had-tag}}_{\text{inc}}$	9.0%	2.6%	0.85%



B2TiP edited by E. Kou and P. Urquijo
Chapter 9 "Radiative and Electroweak Penguin B Decays" edited by T. Feldmann, U. Haisch, A. Ishikawa and J. Yamaoka, to be published in PTEP.

Theory uncertainty on BF(B→Xsγ)

- Theory uncertainty in total : 7%

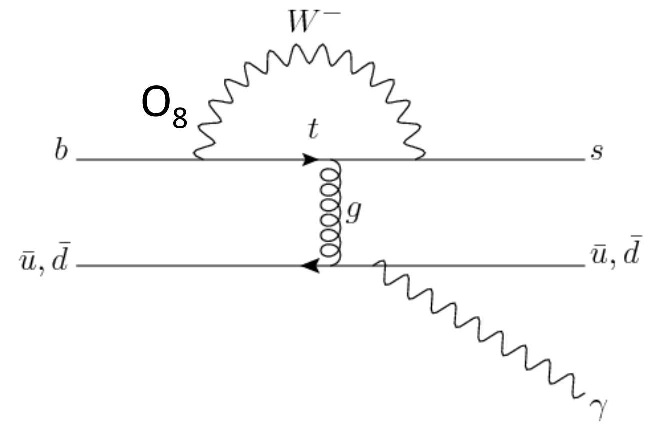
Individual contributions to the total uncertainty are of nonperturbative (±5%), higher-order (±3%), interpolation (±3%), and parametric (±2%) origin. They are combined

M. Misiak et al, PRL 114, 221801 (2015)

  – Largest one is nonperturbative effects which are dominated by resolved photon contributions ($\Delta B_{s\gamma}$). A hard gluon (O_8) absorbed by a (spectator) quark, and then a photon emitted.
    - Interference between this effect and leading hard process is proportional to quark charge
  – $\Delta B_{s\gamma}$ can be related to Isospin Asymmetry (Δ_{0+})

$$\Delta_{0+} = \frac{\Gamma(B^0 \to X_s\gamma) - \Gamma(B^+ \to X_s\gamma)}{\Gamma(B^0 \to X_s\gamma) + \Gamma(B^+ \to X_s\gamma)}$$

$$\frac{\Delta\mathcal{B}}{\mathcal{B}} \simeq -\frac{Q_d + Q_u}{Q_d - Q_u}\Delta_{0-}(1 \pm 0.3) = -\frac{(1 \pm 0.3)}{3}\Delta_{0-}$$



resolved photon contributions

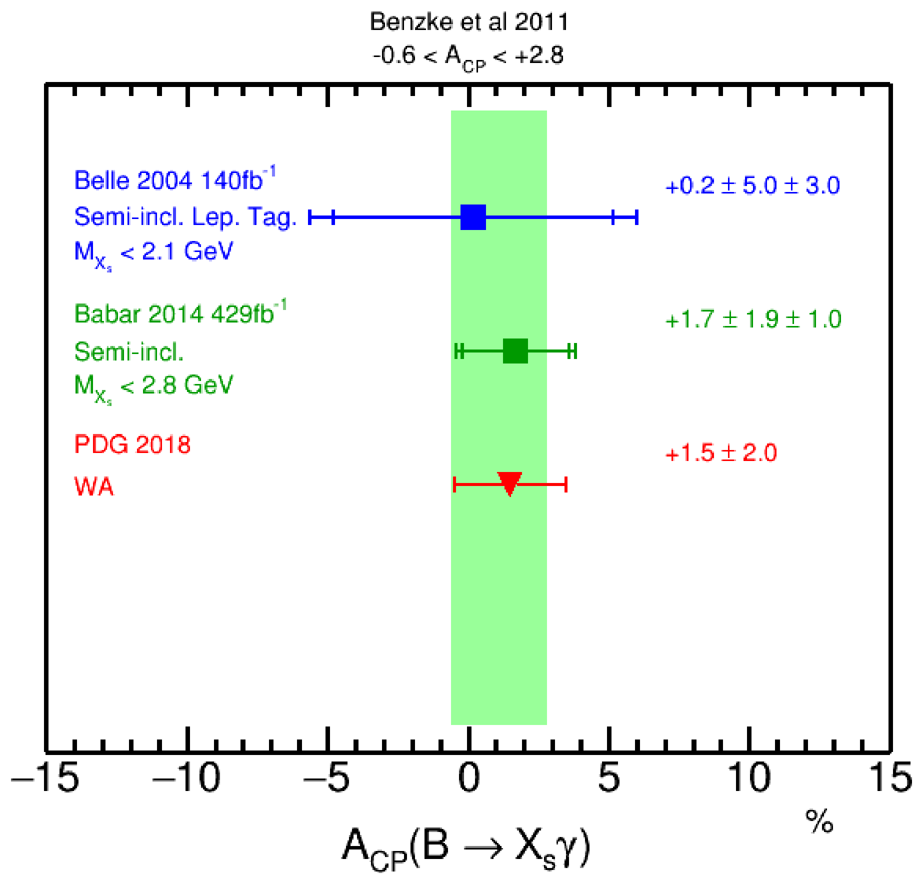
S. J. Lee, M. Neubert, G. Paz, PRD **75**, 114005 (2007).

M. Misiak, Acta Phys. Polon. B **40**, 2987 (2009)
M. Benzke, S. J. Lee, M. Neubert, G. Paz, JHEP 08 (2010) 099

Measurement of Isospin Asymmetry improves the theoretical uncertainty if the value is consistent with zero

$A_{CP}(B \rightarrow X_s\gamma)$

- $A_{CP}(B \rightarrow X_s\,\gamma)$ is sensitive probe to search for new phases in NP models.
- The WA of $A_{CP}(B \rightarrow X_s\,\gamma)$ is consistent with null asymmetry.
- The experimental precision 2% is already comparable to theory uncertainty ~1.7%, which is dominated by resolved photon contributions.



Difference of A_{CP} (ΔA_{CP})

- However, by taking the difference of A_{CP} between charged and neutral B (ΔA_{CP}), the terms having CPV in SM cancel out, and only the term proportional to $\mathrm{Im}(C_8/C_7)$ remains.
- In the SM, both C_7 and C_8 are real while in NP models, this observable could be a level of 10% in magnitude.
- If finite ΔA_{CP} is measured, it is clear sign of new physics.

$$\begin{aligned}\Delta A_{CP} &= A_{CP}(B^+ \to X_s^+ \gamma) - A_{CP}(B^0 \to X_s^0 \gamma) \\ &= 4\pi^2 \alpha_s \frac{\tilde{\Lambda}_{78}}{m_b} \mathrm{Im}\left(\frac{C_8}{C_7}\right), \\ &\approx 0.12 \left(\frac{\tilde{\Lambda}_{78}}{100\ \mathrm{MeV}}\right) \mathrm{Im}\left(\frac{C_8}{C_7}\right),\end{aligned} \qquad 17\,\mathrm{MeV} < \tilde{\Lambda}_{78} < 190\,\mathrm{MeV}$$

M. Benzke, S. J. Lee, M. Neubert and G. Paz, PRL 106, 141801 (2011)

- We performed measurement of Δ_{0-} and ΔA_{CP} as well as A_{CP} for charged, neutral, averaged and combined B decays

Measurement of Δ_{0-} and ΔA_{CP}

- We reconstruct 38 Xs decay modes with M_{Xs}<2.8GeV
  - 11 flavor non specific (fns) modes as marked * are only used for Δ_{0-} measurement.
- Five M_{bc} distributions (B+, B-, B0, B0 and B_{fns}) for on resonance data and three M_{bc} distributions (charged, neutral and fns B) for off-resonance data are fitted simultaneously to extract physics parameters.

$$\Delta_{0-} = \frac{\frac{\tau_{B^+}}{\tau_{B^0}}\frac{f_{+-}}{f_{00}}(N_{\bar{B}^0} + N_{B^0} + N_{B_{\rm fns}}) - (N_{B^-} + N_{B^+})}{\frac{\tau_{B^+}}{\tau_{B^0}}\frac{f_{+-}}{f_{00}}(N_{\bar{B}^0} + N_{B^0} + N_{B_{\rm fns}}) + (N_{B^-} + N_{B^+})},$$

$$A_{CP}^{C} = \frac{N_{B^-} - N_{B^+}}{N_{B^-} + N_{B^+}},$$ Chargd A_{CP}

$$A_{CP}^{N} = \frac{N_{B^0} - N_{B^0}}{N_{B^0} + N_{B^0}},$$ Neutral A_{CP}

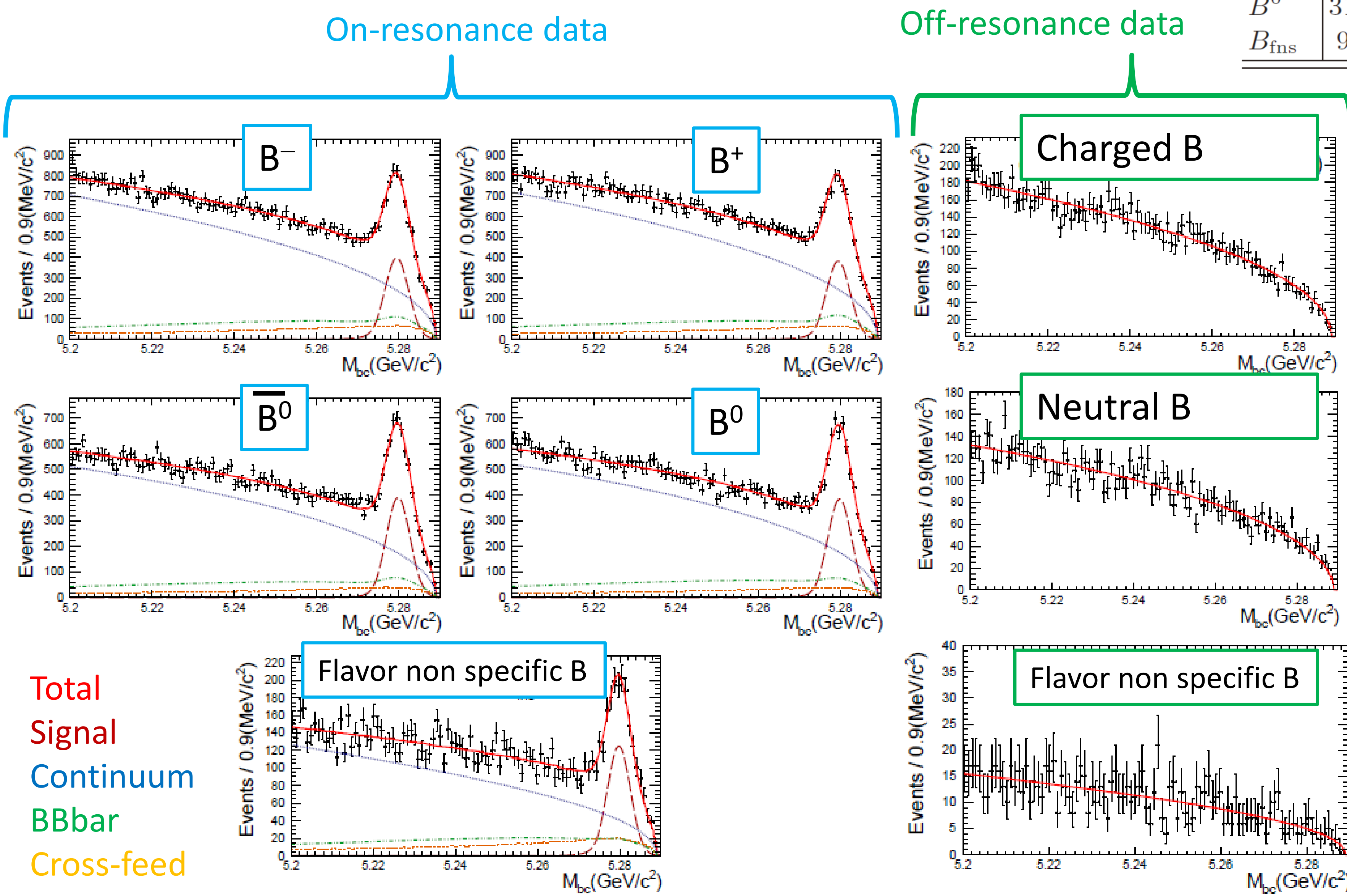
$$A_{CP}^{\rm tot} = \frac{(N_{B^-} + N_{B^0}) - (N_{B^+} + N_{B^0})}{(N_{B^-} + N_{B^0}) + (N_{B^+} + N_{B^0})},$$ Combined A_{CP}

Mode ID	Final State	Mode ID	Final State
1	$K^+\pi^-$	20	$K_S^0\pi^+\pi^0\pi^0$
2	$K_S^0\pi^+$	21	$K^+\pi^+\pi^-\pi^0\pi^0$
3	$K^+\pi^0$	22*	$K_S^0\pi^+\pi^-\pi^0\pi^0$
4*	$K_S^0\pi^0$	23	$K^+\eta$
5	$K^+\pi^+\pi^-$	24*	$K_S^0\eta$
6*	$K_S^0\pi^+\pi^-$	25	$K^+\eta\pi^-$
7	$K^+\pi^-\pi^0$	26	$K_S^0\eta\pi^+$
8	$K_S^0\pi^+\pi^0$	27	$K^+\eta\pi^0$
9	$K^+\pi^+\pi^-\pi^-$	28*	$K_S^0\eta\pi^0$
10	$K_S^0\pi^+\pi^+\pi^-$	29	$K^+\eta\pi^+\pi^-$
11	$K^+\pi^+\pi^-\pi^0$	30*	$K_S^0\eta\pi^+\pi^-$
12*	$K_S^0\pi^+\pi^-\pi^0$	31	$K^+\eta\pi^-\pi^0$
13	$K^+\pi^+\pi^+\pi^-\pi^-$	32	$K_S^0\eta\pi^+\pi^0$
14*	$K_S^0\pi^+\pi^+\pi^-\pi^-$	33	$K^+K^+K^-$
15	$K^+\pi^+\pi^-\pi^-\pi^0$	34*	$K^+K^-K_S^0$
16	$K_S^0\pi^+\pi^+\pi^-\pi^0$	35	$K^+K^+K^-\pi^-$
17	$K^+\pi^0\pi^0$	36	$K^+K^-K_S^0\pi^+$
18*	$K_S^0\pi^0\pi^0$	37	$K^+K^+K^-\pi^0$
19	$K^+\pi^-\pi^0\pi^0$	38*	$K^+K^-K_S^0\pi^0$

Fit Results

More than 10000 events are reconstructed

Mode	N_S
B^-	3235 ± 82
B^+	3105 ± 83
$\bar{B}^0$	3165 ± 78
B^0	3116 ± 78
$B_{\rm fns}$	984 ± 42



Results

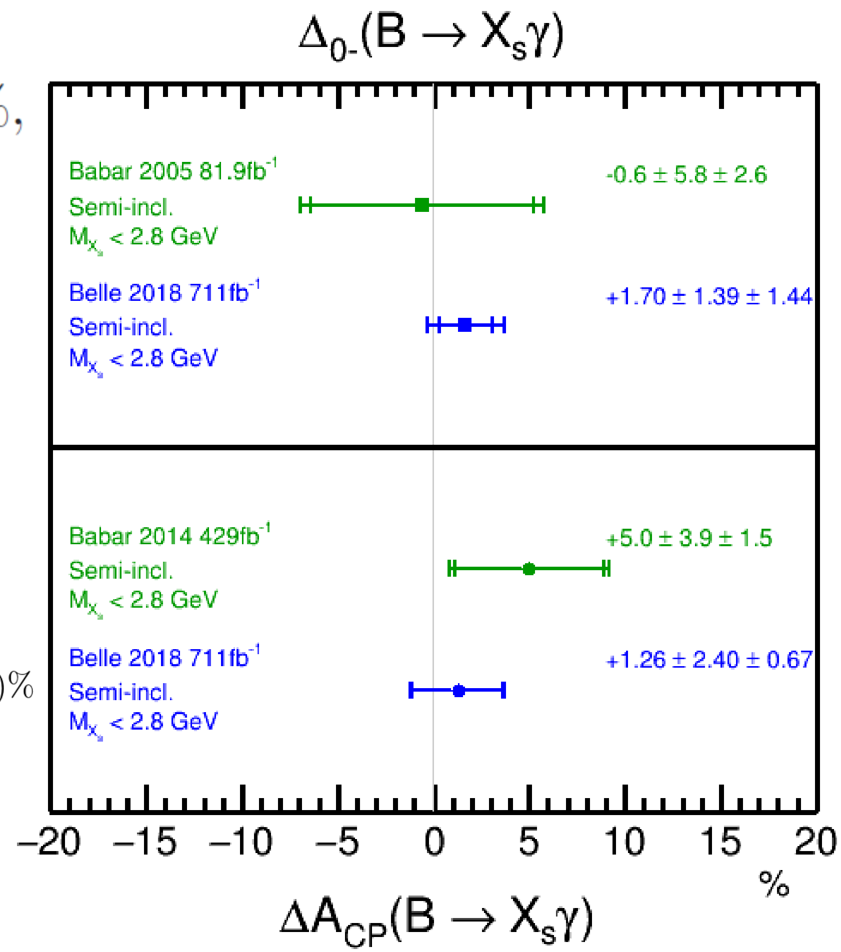
Preliminary

$$\Delta_{0-} = (+1.70 \pm 1.39 \pm 0.87 \pm 1.15)\%,$$
$$\Delta A_{CP} = (+1.26 \pm 2.40 \pm 0.67)\%,$$

- The result for Δ_{0-} is consistent with zero
  - Can be used to reduce the theory uncertainty for BF($B \rightarrow X_s\gamma$)
  - The resolved photon contributions to the BF is less than 1.9% at 2σ (1.3% at 1σ) in magnitude

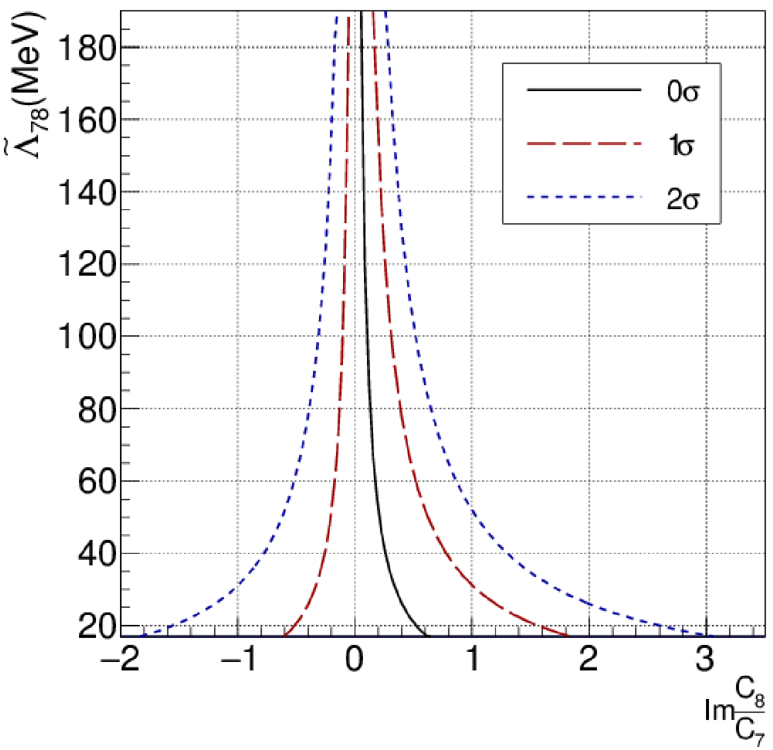
$$\frac{\Delta\mathcal{B}}{\mathcal{B}} \simeq -\frac{(1 \pm 0.3)}{3}\Delta_{0-} = (-0.57 \pm 0.46 \pm 0.29 \pm 0.38 \pm 0.17)\%$$

- The result for ΔA_{CP} is consistent with zero
  - Constrains NP models
  - Strong limit on $Im(C_8/C_7)$ → next page
- Both results are most precise to date.



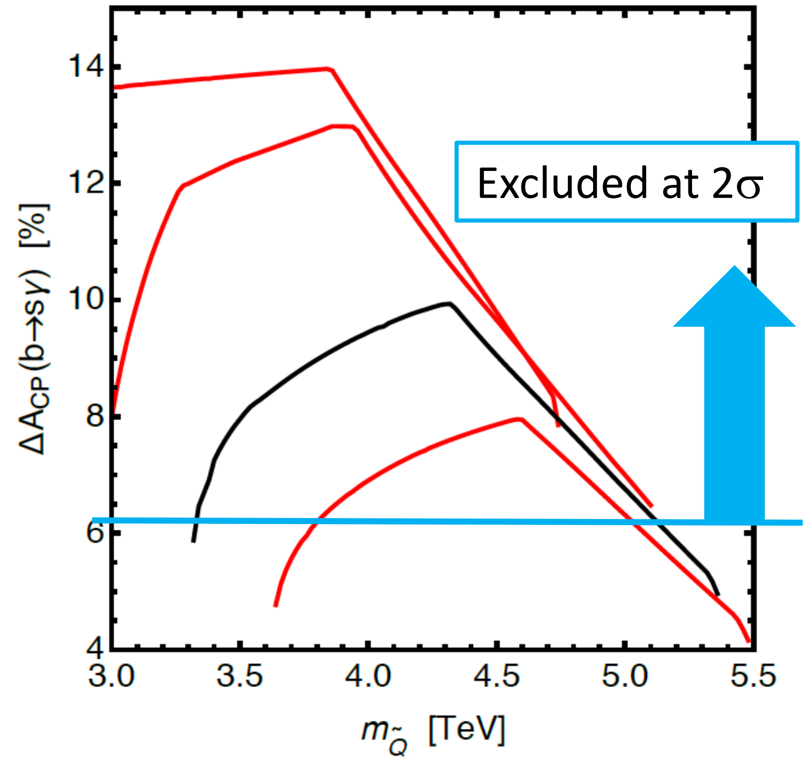
Constraint on Im(C_8/C_7) and a NP model

- Our result excludes positive region of Im(C_8/C_7) better than Babar with a factor of 3.



$-0.34 < \mathrm{Im}(C_8/C_7) < 0.58$ for $\tilde{\Lambda}_{78} = 89$ MeV

- Exclude parameter space in SUSY.
  - Gluino mediated EWP which explains ε'/ε from CPV trilinear couplings



M. Endo, T. Goto, T. Kitahara, S. Mishima, D. Ueda and K. Yamamoto, JHEP 04 (2018) 019.

Summary

- First evidence for Isospin Violation in $B \rightarrow K^*\gamma$
  - All the measurements are most precise to date.
- Time Dependent CP Violation in $B \rightarrow K_S\eta\gamma$
  - Consistent with the SM
- Measurement of Δ_{0-} and ΔA_{CP} in $B \rightarrow X_s\gamma$ with sum-of-exclusive technique
  - The result of Δ_{0-} consistent with null thus can be used to improve the prediction of the BF.
  - Most stringent limit on ΔA_{CP} and $\mathrm{Im}(C_8/C_7)$

- All the measurements are most precise to date, and to be improved at already started Belle II experiment with substantial data.

Acknowledgements

- A. I. is supported by the Japan Society for the Promotion of Science (JSPS) Grant No. 16H03968.

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backup

Systematic Uncertainty for B→Xsγ

- The largest uncertainty for Δ_{0-} is due to f_{+-}/f_{00} which can be reduced at both Belle and Belle II
- Dominant uncertainties for ΔA_{CP} are due to peaking background from π^0, and charged particle detection asymmetry.

Source	Δ_{0-}	ΔA_{CP}	A_{CP}^{C}	A_{CP}^{N}	A_{CP}^{tot}	$\bar{A}_{CP}$
tracking	± 0.02	–	–	–	< 0.01	–
K/π ID	± 0.04	–	–	–	< 0.01	–
π^0/η recon.	± 0.01	–	–	–	< 0.01	–
K_S^0 recon.	± 0.01	–	–	–	< 0.01	–
detection asym.	–	± 0.39	± 0.11	± 0.29	± 0.05	± 0.10
ΔE selection	$^{+0.03}_{-0.06}$	–	–	–	< 0.01	–
f_{+-}/f_{00}	± 1.15	–	–	–	–	–
lifetime ratio	± 0.19	–	–	–	–	–
fragmentation	± 0.58	–	–	–	± 0.01	–
K^*-X_s transition	± 0.12	–	–	–	< 0.01	–
missing fraction	< 0.01	–	–	–	< 0.01	–
background A_{CP}	–	± 0.05	± 0.03	± 0.04	± 0.02	± 0.03
background Δ_{0-}	± 0.01	–	–	–	< 0.01	–
fixed parameters	$^{+0.60}_{-0.47}$	$^{+0.53}_{-0.50}$	$^{+0.27}_{-0.25}$	$^{+0.28}_{-0.29}$	$^{+0.09}_{-0.08}$	$^{+0.08}_{-0.06}$
fitter bias	± 0.08	± 0.11	± 0.02	± 0.09	± 0.02	± 0.03
MC stat.	± 0.03	–	–	–	< 0.01	–
total	$^{+1.44}_{-1.39}$	$^{+0.67}_{-0.64}$	$^{+0.29}_{-0.27}$	$^{+0.41}_{-0.42}$	$^{+0.12}_{-0.10}$	$^{+0.14}_{-0.12}$

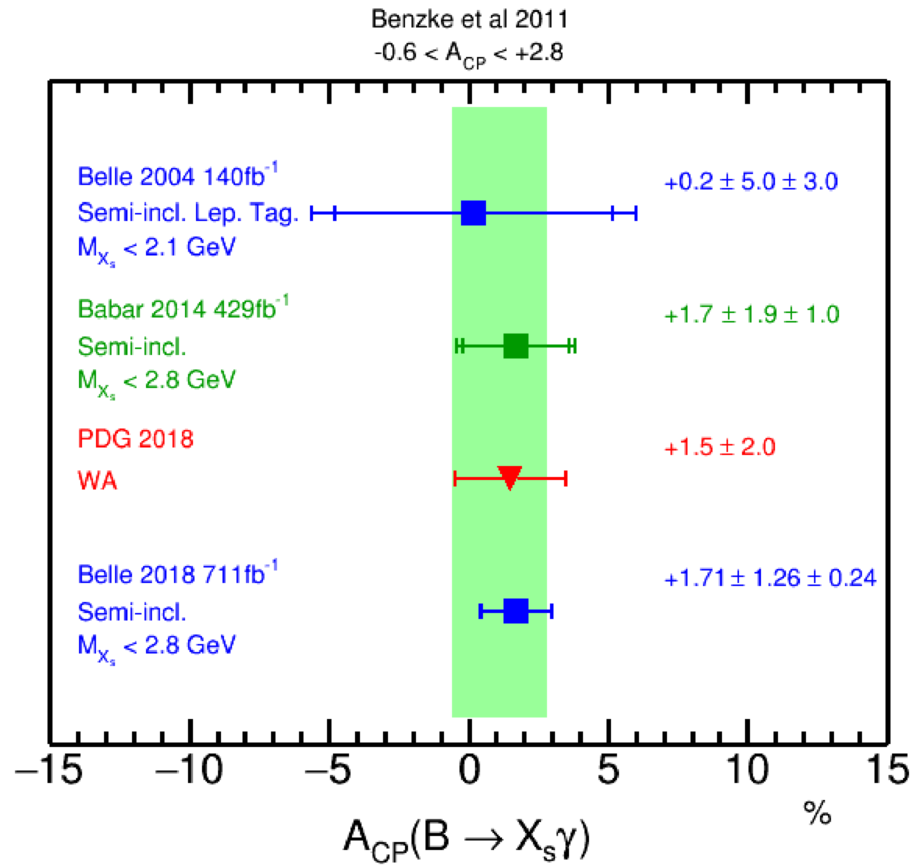
Results on $A_{CP}(B \rightarrow X_s\gamma)$ and Correlation

- All the results are most precise to date

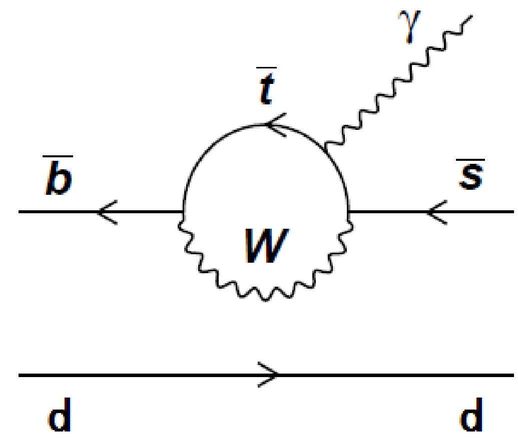
Preliminary

$$A^{C}_{CP} = (+2.16 \pm 1.72 \pm 0.29)\%,$$
$$A^{N}_{CP} = (+0.90 \pm 1.67 \pm 0.42)\%,$$
$$A^{tot}_{CP} = (+1.71 \pm 1.26 \pm 0.12)\%,$$
$$\bar{A}_{CP} = (+1.53 \pm 1.20 \pm 0.14)\%,$$

	Δ_{0-}	ΔA_{CP}	A^{C}_{CP}	A^{N}_{CP}	A^{tot}_{CP}	$\bar{A}_{CP}$
Δ_{0-}	1.00	0.06	0.06	−0.04	0.01	0.01
ΔA_{CP}	0.06	1.00	0.72	−0.71	0.26	0.01
A^{C}_{CP}	0.06	0.72	1.00	−0.03	0.87	−0.70
A^{N}_{CP}	−0.04	−0.71	−0.03	1.00	0.47	0.69
A^{tot}_{CP}	0.01	0.26	0.87	0.47	1.00	0.95
$\bar{A}_{CP}$	0.01	0.01	−0.70	0.69	0.95	1.00



$B \rightarrow K^*\gamma$



- Cleanest exclusive $b \rightarrow s\gamma$ decay.
  - BF ~ 4×10^{-5}
    - About 12% of inclusive $B \rightarrow X_s\gamma$ rate
  - Prediction of branching fraction is limited by an uncertainty of tensor form factor at $q^2=0$; $T_1(0)$.
  - The exclusive BF is not so sensitive to new physics but is a probe for $T_1(0)$ or QCD.
    - Precise measurements of $BF(B \rightarrow X_s\gamma)$ constrain new physics in $|C_7|$ so much.

Ratios with B→K*γ

- By taking a ratio of decay widths (or BF), a dominant uncertainty due to $T_1(0)$ cancels out thus sensitive to new physics
  - Isospin Violation; Δ_{0+}
    - New physics in annihilation diagrams

$$\Delta_{0+} = \frac{\Gamma(B^0 \to K^{*0}\gamma) - \Gamma(B^+ \to K^{*+}\gamma)}{\Gamma(B^0 \to K^{*0}\gamma) + \Gamma(B^+ \to K^{*+}\gamma)}$$

  - CP Violation; A_{CP}
    - New phases
    - Sensitive to $Im(C_7)$
    - Insensitive to chirality flipped operator C_7'

$$A_{CP} = \frac{\Gamma(\bar{B} \to \bar{K}^*\gamma) - \Gamma(B \to K^*\gamma)}{\Gamma(\bar{B} \to \bar{K}^*\gamma) + \Gamma(B \to K^*\gamma)}$$

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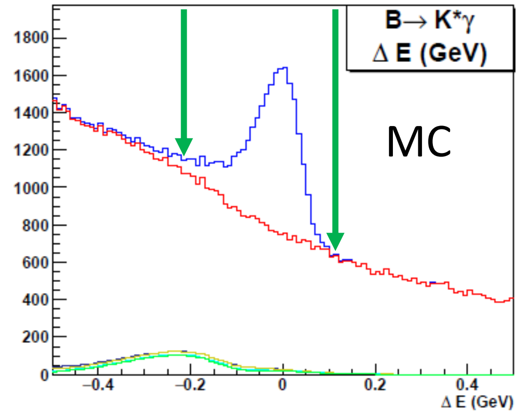
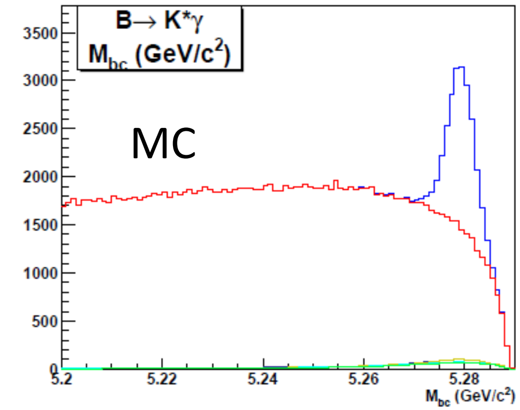
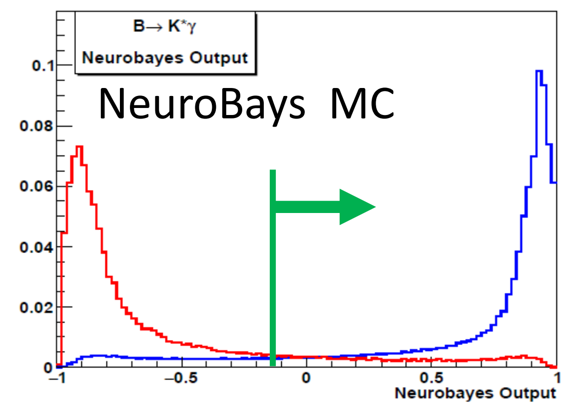
Reconstruction of B→K*γ

- Four subdecay modes
  - $K^{*0} \to K_s^0\pi^0$, $K^+\pi^-$
  - $K^{*+} \to K^+\pi^0$, $K_s^0\pi^-$
  - Flavor eigenstates except for $K_s^0\pi^0$
    - Self-flavor tagged modes
- B selection
  - -0.2 GeV < ΔE < 0.1 GeV
  - 5.20 GeV < Mbc < 5.29 GeV
  - $M_{K\pi}$ < 2.0GeV : to check feed down from higher resonances
- Background suppression
  - BB : π^0/η veto with $M_{\gamma\gamma}$
  - Continuum : NeuroBays with event shape variables
    - To maximize the FoM
- Best candidate selection
  - Number of candidates per event is 1.16 with MC.
  - Randomly selected in order not to bias other variables
- K* selection
  - $|M_{K\pi} - M_{K^*}|$ < 75MeV







Signal

Continuum

B→Xsγ

Rare B other than B→Xsγ

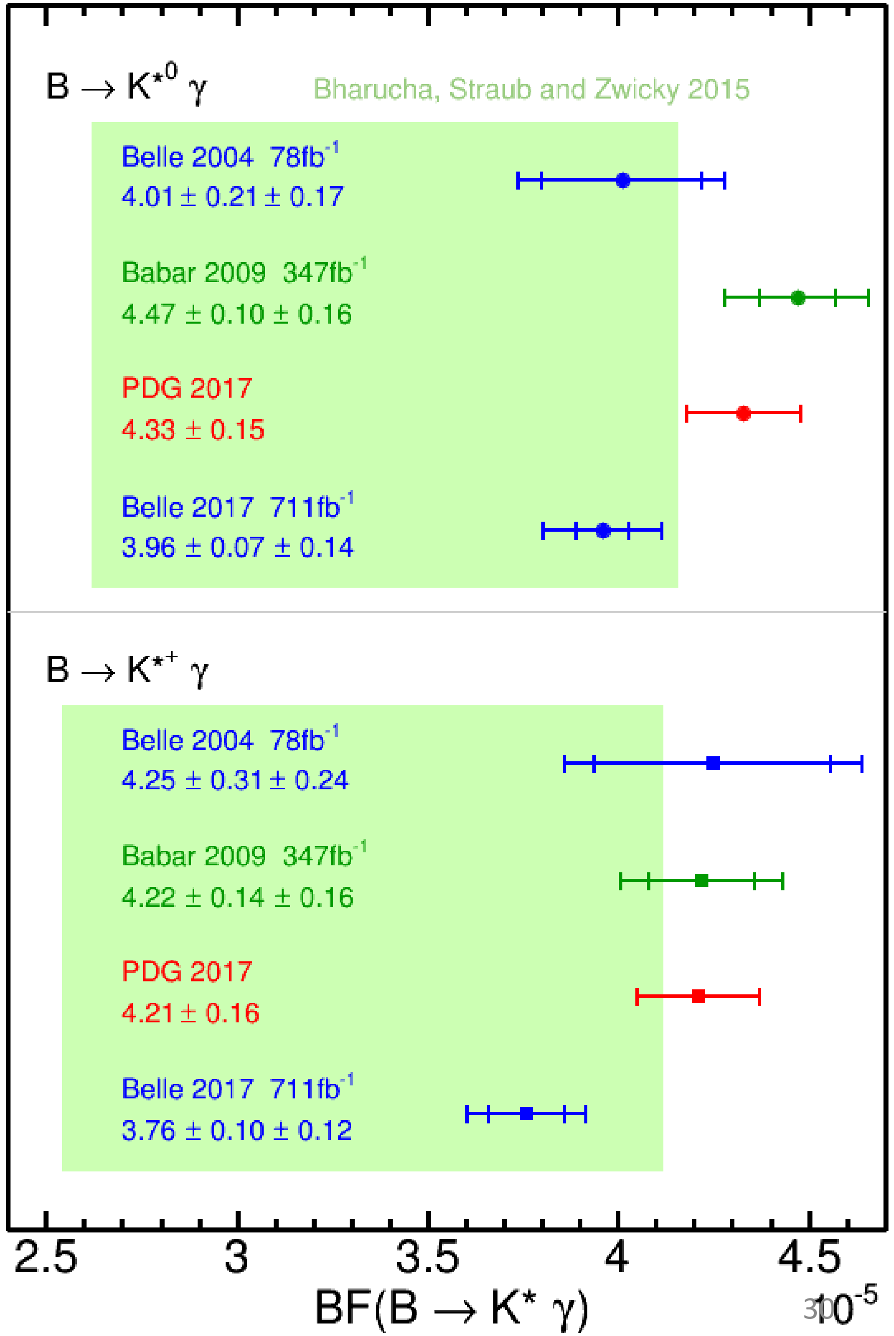
Extraction of BF, A_{CP}, Δ_{0+} and ΔA_{CP}

- Unbinned maximum likelihood fit to M_{bc} distributions.
  - Signal w/o π^0 (w/ π^0) : Gaussian (Crystal Ball)
  - Cross-feed : ARGUS + Bifurcated Gaussian (the yield is proportional to signal yield)
  - Continuum background : ARGUS
  - BB background : ARGUS + Bifurcated Gaussian
- To extract the BF and A_{CP} for each subdecay, separate fit is performed.
- To measure the combined BFs, Δ_{0+}, A_{CP}, and ΔA_{CP}, simultaneous fit is performed to seven M_{bc} distributions with the likelihood.
  - With input parameters of efficiencies, number of $B\bar{B}$ pairs, lifetime ratio and production of B^+B^- and $B^0\bar{B}^0$ in $\Upsilon(4S)$ decays

$$
\begin{aligned}
&\mathcal{L}(M_{\rm bc}|\mathcal{B}^N, \mathcal{B}^C, A_{CP}^N, A_{CP}^C) \\
&= \Pi\mathcal{L}^{K_S^0\pi^0}(M_{\rm bc}|\mathcal{B}^N) \\
&\times \Pi\mathcal{L}^{K^-\pi^+}(M_{\rm bc}|\mathcal{B}^N, A_{CP}^N) \times \Pi\mathcal{L}^{K^+\pi^-}(M_{\rm bc}|\mathcal{B}^N, A_{CP}^N) \\
&\times \Pi\mathcal{L}^{K^-\pi^0}(M_{\rm bc}|\mathcal{B}^C, A_{CP}^C) \times \Pi\mathcal{L}^{K^+\pi^0}(M_{\rm bc}|\mathcal{B}^C, A_{CP}^C) \\
&\times \Pi\mathcal{L}^{K_S^0\pi^-}(M_{\rm bc}|\mathcal{B}^C, A_{CP}^C) \times \Pi\mathcal{L}^{K_S^0\pi^+}(M_{\rm bc}|\mathcal{B}^C, A_{CP}^C),
\end{aligned}
$$

BF(B→K*γ)

- New Belle results consistent with previous measurements
  - But slightly (~10%) smaller than Babar results which dominated the WA.
- Also consistent with theoretical predictions by Bharucha, Starub and Zwicky.
  - Belle results a bit closer to theory than before
- Most precise measurements
  - Can be used to constrain the $T_1(0)$
  - Already systematic dominant
    - Photon detection and PID



BF($B^0 \rightarrow K^{*0}\gamma$)/($B_s \rightarrow \phi\gamma$)

- Calculation
  - Used Belle measurement of BF($B_s \rightarrow \phi\gamma$) with 121fb^{-1} D. Dutta et al. PRD 91 01101 (2015)

$$\mathcal{B}(B_s^0 \to \phi\gamma) = (3.6 \pm 0.5(\text{stat.}) \pm 0.3(\text{syst.}) \pm 0.6(f_s)) \times 10^{-5}$$

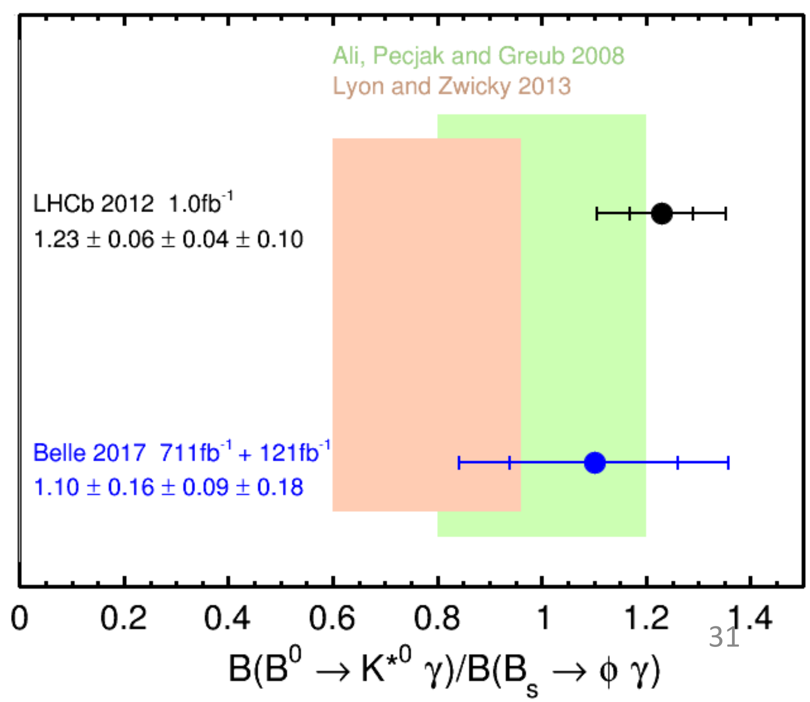
  - Only used $K^{*0} \rightarrow K^+\pi^-$ mode to cancel out common systematics

$$\mathcal{B}(B^0 \to K^{*0}\gamma) = (3.95 \pm 0.07 \pm 0.14) \times 10^{-5}$$

- Result

$$\frac{\mathcal{B}(B^0 \to K^{*0}\gamma)}{\mathcal{B}(B_s^0 \to \phi\gamma)} = 1.10 \pm 0.16 \pm 0.09 \pm 0.18$$

  - The uncertainty dominated by uncertainties of BF($B_s \rightarrow \phi\gamma$)
    - The third uncertainty due to f_s, which is a fraction of $Bs^{(*)}Bs^{(*)}$ production from Υ(5S)
- Belle result Consistent with **LHCb**, and theoretical predictions by Ali, Pecjak and Greub and Lyon and Zwicky
  - Can be used to constrain $T_1^{B\rightarrow K^*}(0)/T_1^{Bs\rightarrow\phi}(0)$



A_{CP}

- New Belle results are most precise to date
- Consistent with zero and previous measurements by Babar and **LHCb**
  - Also PDG
- Consistent with theoretical predictions within the SM by Matsumori et al and Paul and Straub
  - Strong constraints to $Im(C_7)$

Altmannshofer, Straub EPJC 75, 82 (2015)
Paul, Straub 1608.02556