Radiative and EW Penguin B Decays at Belle

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BELLE

Contents

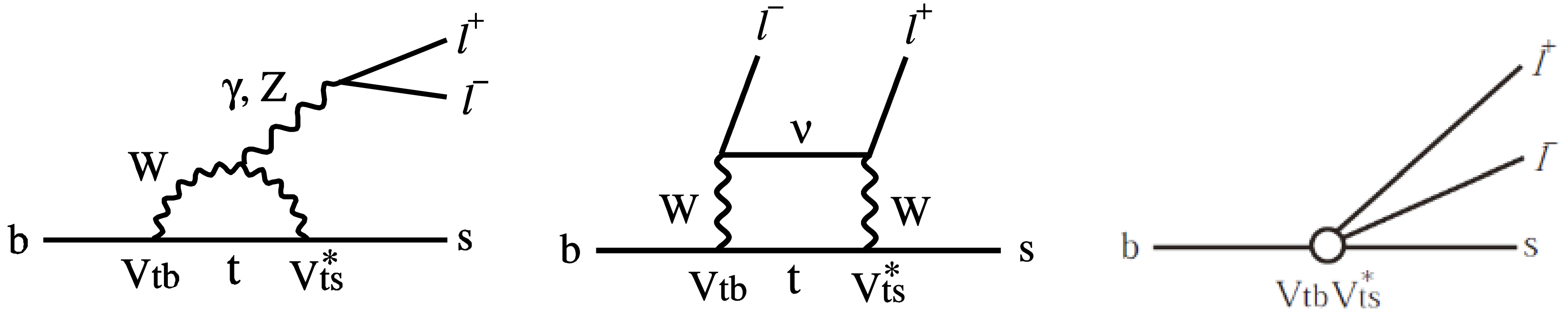
- New Measurements of $B \rightarrow K^*\gamma$
  - About nine times larger statistics than previous analysis

- Lepton Flavor Dependent Angular Analysis of $B \rightarrow K^*l^+l^-$

- Search for $B \rightarrow h^{(*)}\nu\nu$ with semileptonic tagging

All the analyses used a full data sample of $711 fb^{-1}$
containing 772×10^6 BB events

Wilson Coefficients in b→s processes



- In the SM, b→s transition can be written by real Wilson coefficients which correspond to short distance couplings in effective Hamiltoniam approach
  - b→sγ : C_7
  - b→sll : C_7, C_9 and C_{10}
  - C_7 ~ -0.3, C_9 ~ 4, C_{10} ~ -4
- If NP contributes,
  - Deviation from the SM values
  - Lepton flavor dependent $C_{9e} \neq C_{9\mu}$
  - New coefficients appear
    - Imaginary parts $Im(C_i)$
    - Chirality flipped coefficients (C_i')
      - $P_{L(R)} \rightarrow P_{R(L)}$
    - Scalar and Tensor coefficients (C_S , C_P , C_T and C_{T5})

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

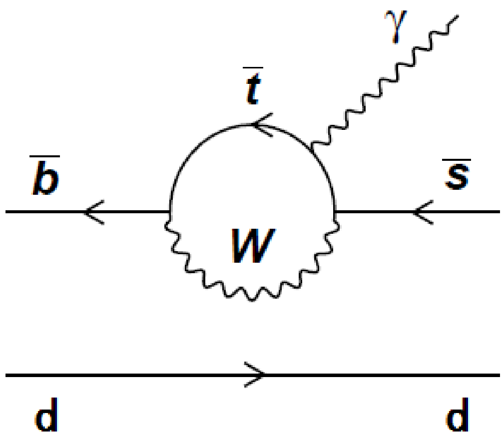
$$\mathcal{O}_7 = \frac{e}{16\pi^2} m_b (\bar{s}\sigma^{\mu\nu} P_R b) F_{\mu\nu},$$

$$\mathcal{O}_9 = \frac{e^2}{16\pi^2} (\bar{s}\gamma^\mu P_L b)(\bar{\ell}\gamma_\mu \ell),$$

$$\mathcal{O}_{10} = \frac{e^2}{16\pi^2} (\bar{s}\gamma^\mu P_L b)(\bar{\ell}\gamma_\mu \gamma_5 \ell)$$

New Measurements of B→K*γ

$B \rightarrow K^*\gamma$



- The decay
  - Dominated by one loop penguin diagrams (FCNC)
    - Sensitive to NP in the loop
  - Relatively small contributions from weak annihilation diagrams
    - Some sensitivity to NP in the tree
- Cleanest exclusive $b \rightarrow s\gamma$ decay.
  - BF ~ 4 x 10^{-5}
    - About 12% of inclusive $B \rightarrow Xs\gamma$ rate
  - Prediction of branching fraction is limited by a 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 $B \to K^*\gamma$

- By taking a ratio of decay widths (or BF), a dominant uncertainty due to $T_1(0)$ cancels out (partially) thus sensitive to new physics
  - Ratio of $\mathcal{B}(B \to K^*\gamma)/\mathcal{B}(B_s \to \phi\gamma)$
    - New Physics in annihilation diagrams
    - $T_1^{B\to K^*}(0)/T_1^{Bs\to\phi}(0)$
  - Isospin Violation; Δ_{0+}
    - New physics in annihilation diagrams
  - CP Violation; A_{CP}
    - New phases
    - Sensitive to $\mathrm{Im}(C_7)$
    - Insensitive to chirality flipped operator C_7'
  - Difference of A_{CP} between B^+ and B^0; ΔA_{CP}
    - Prediction for inclusive $b\to s\gamma$: sensitive to $\mathrm{Im}(C_8/C_7)$
    - but not for exclusive decays yet

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

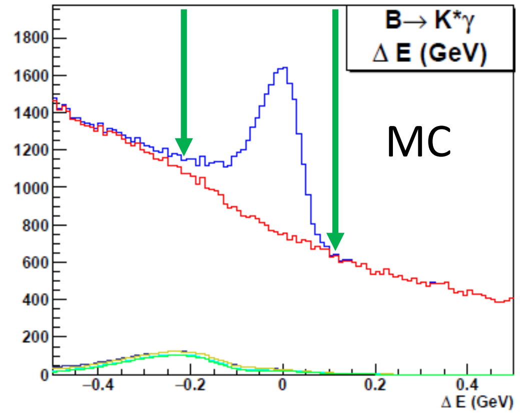
$$A_{CP} = \frac{\Gamma(\bar{B} \to \bar{K}^*\gamma) - \Gamma(B \to K^*\gamma)}{\Gamma(\bar{B} \to \bar{K}^*\gamma) + \Gamma(B \to K^*\gamma)}$$

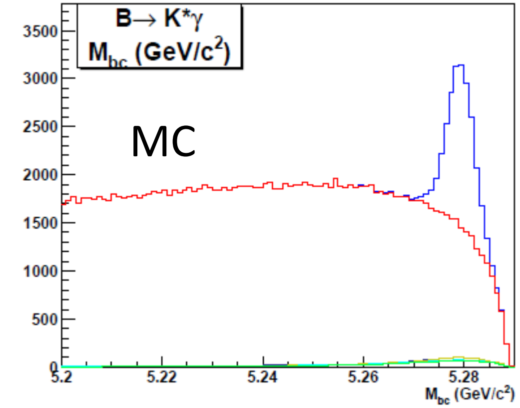
Altmannshofer, Straub EPJC 75, 82 (2015)
Paul, Straub 1608.02556

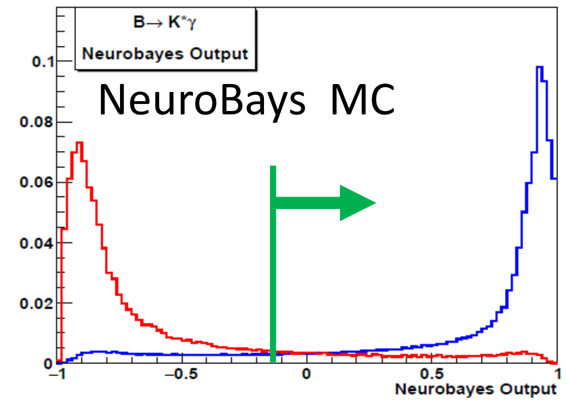
$$\Delta A_{CP} = A_{CP}(B^+ \to K^{*+}\gamma) - A_{CP}(B^0 \to K^{*0}\gamma)$$

Reconstruction of $B \to K^*\gamma$

- 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
$B \to Xs\gamma$
Rare B other than $B \to Xs\gamma$

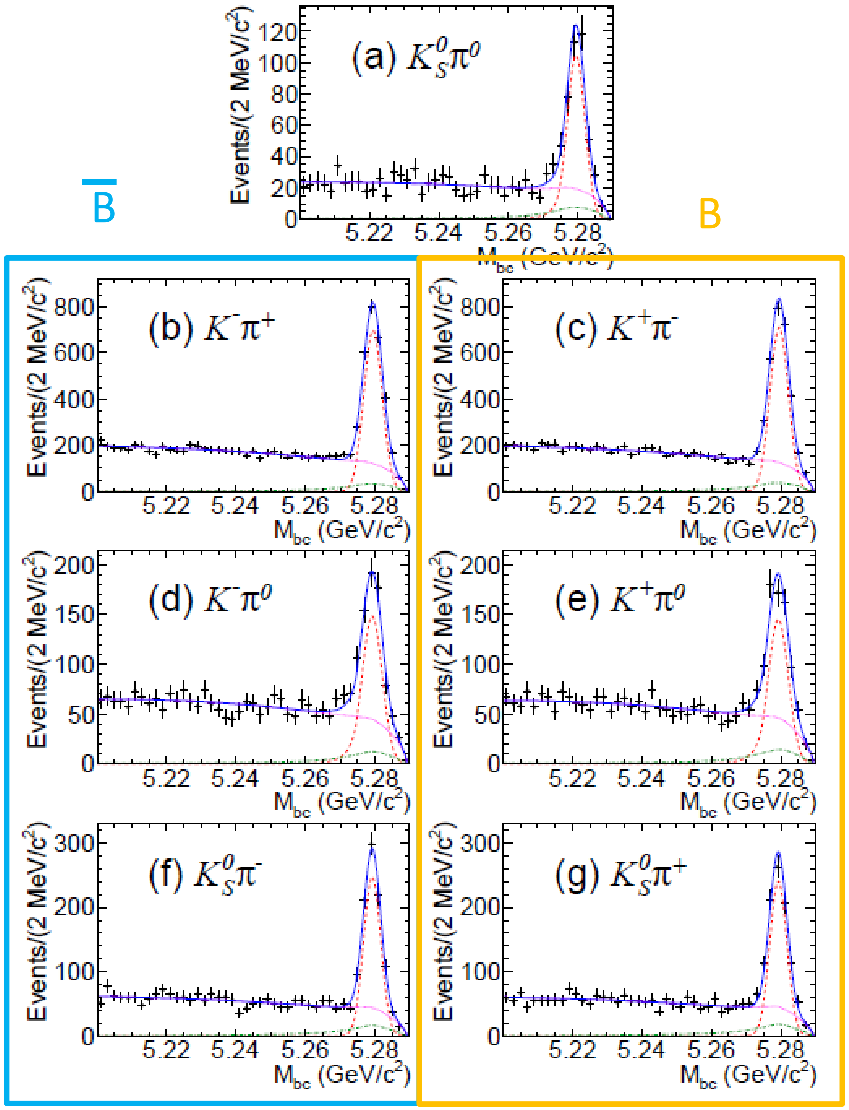
Extraction of BF, A_{CP}, Δ_{0+} and ΔA_{CP}

- 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 Y(4S) decays

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

Results

- First Evidence for Δ_{0+} with 3.1σ
- First measurement of ΔA_{CP}
  - Consistent with zero

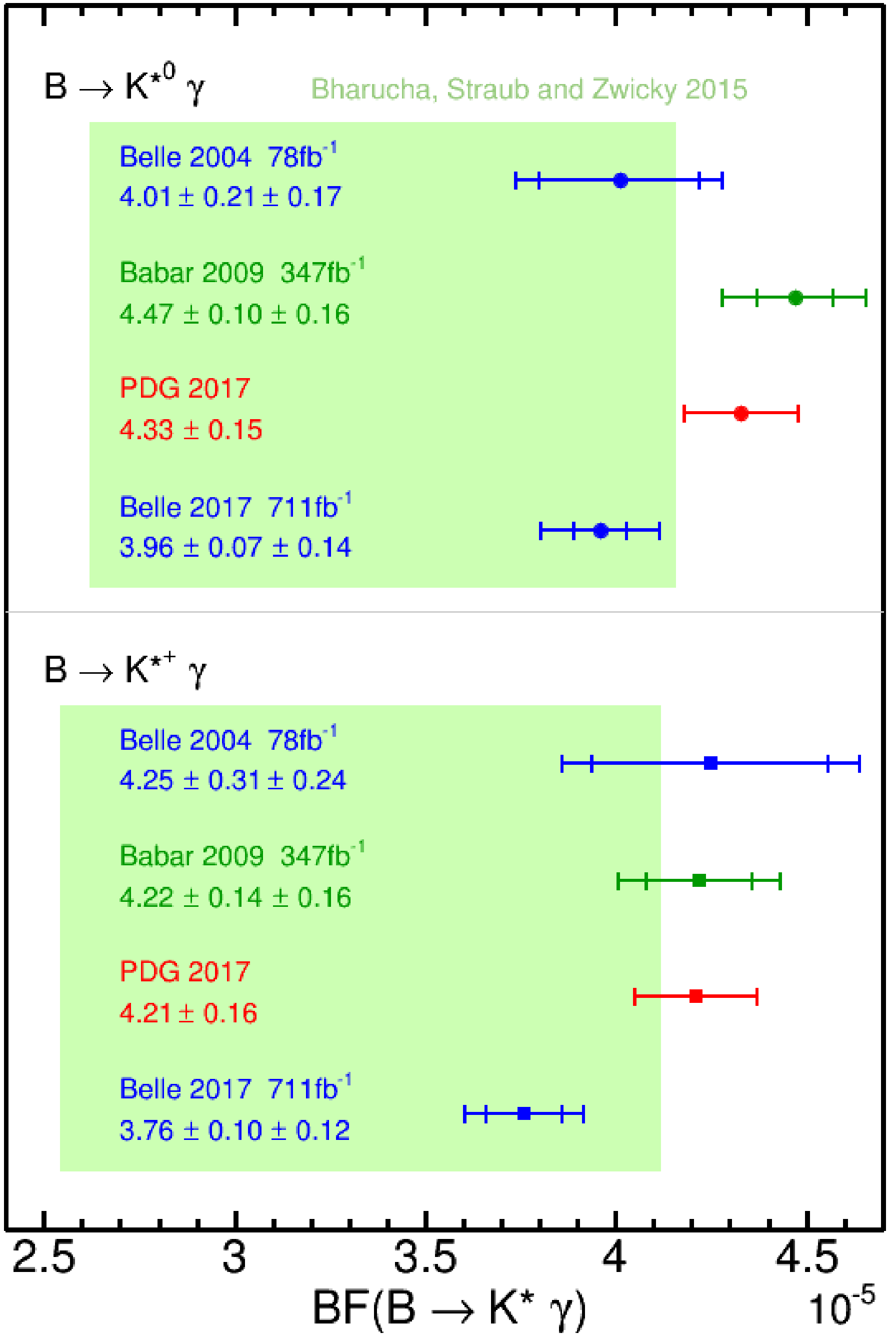


$$\mathcal{B}(B^0 \to K^{*0}\gamma) = (3.96 \pm 0.07 \pm 0.14) \times 10^{-5},$$
$$\mathcal{B}(B^+ \to K^{*+}\gamma) = (3.76 \pm 0.10 \pm 0.12) \times 10^{-5},$$
$$A_{CP}(B^0 \to K^{*0}\gamma) = (-1.3 \pm 1.7 \pm 0.4)\%,$$
$$A_{CP}(B^+ \to K^{*+}\gamma) = (+1.1 \pm 2.3 \pm 0.3)\%,$$
$$A_{CP}(B \to K^{*}\gamma)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

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	$3.69 \pm 0.12 \pm 0.12$	$+1.3 \pm 2.9 \pm 0.4$

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 check $T_1(0)$
  - Already systematic dominant
    - Photon detection and PID



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

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

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

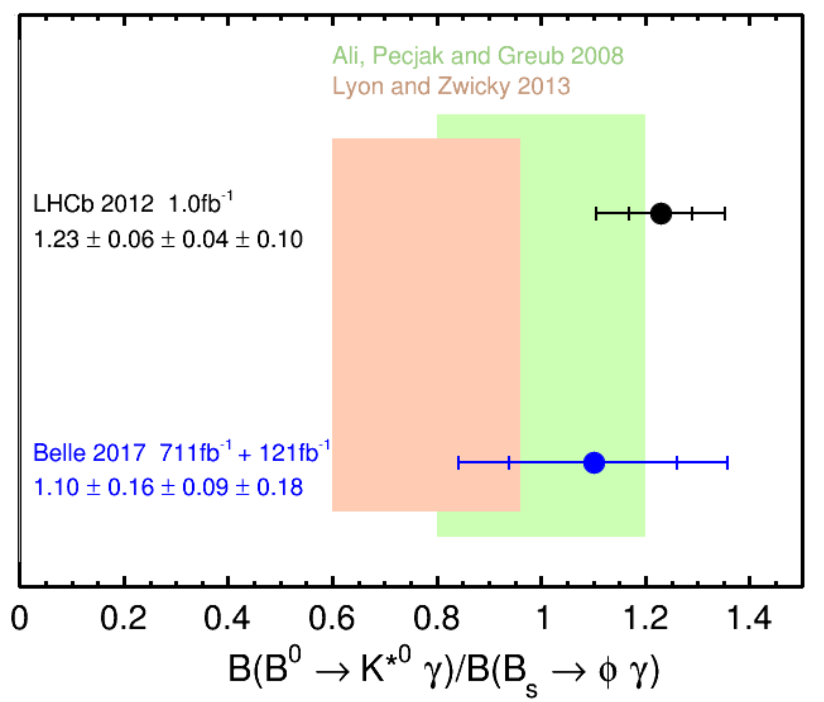
  - Only used $K^{*0} \to K^+\pi^-$ mode to cancel out common systematics

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

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



Δ_{0+}

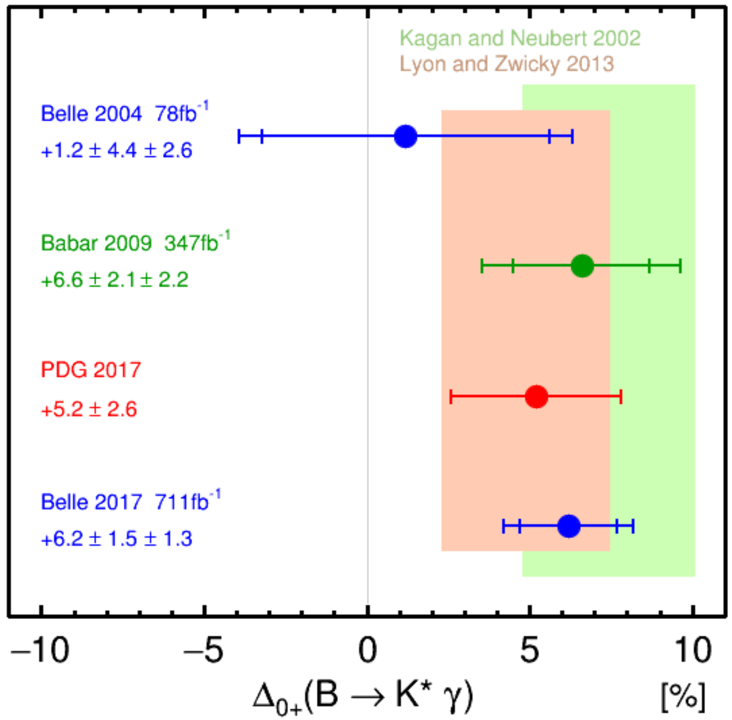
- First evidence of isospin violation in b→s transition with 3.1σ significance.

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

- 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

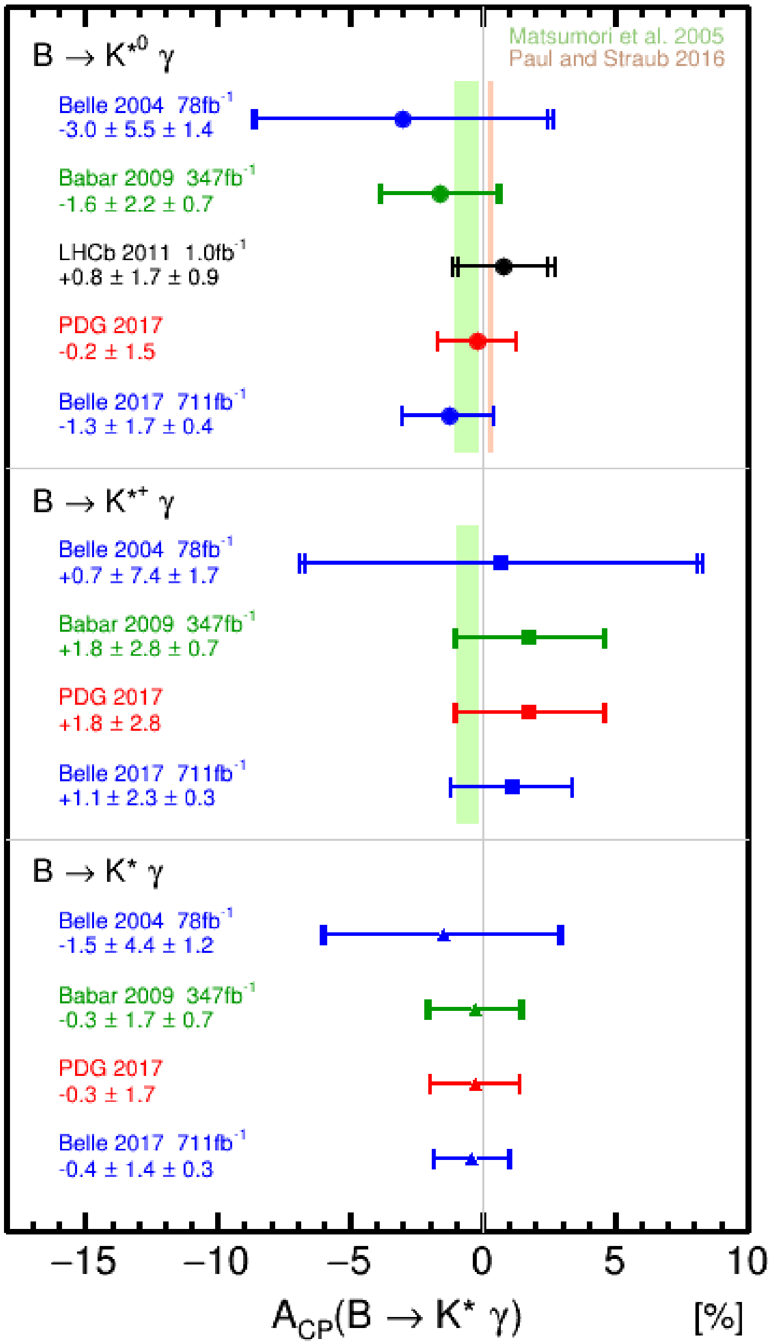
For example,
Mahmoudi, JHEP 12 (2007) 026
Descotes-Genon, Ghosh, Matias, Ramon, JHEP 06 (2011) 099
Lyon, Zwicky, PRD 88, 094004 (2013).



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

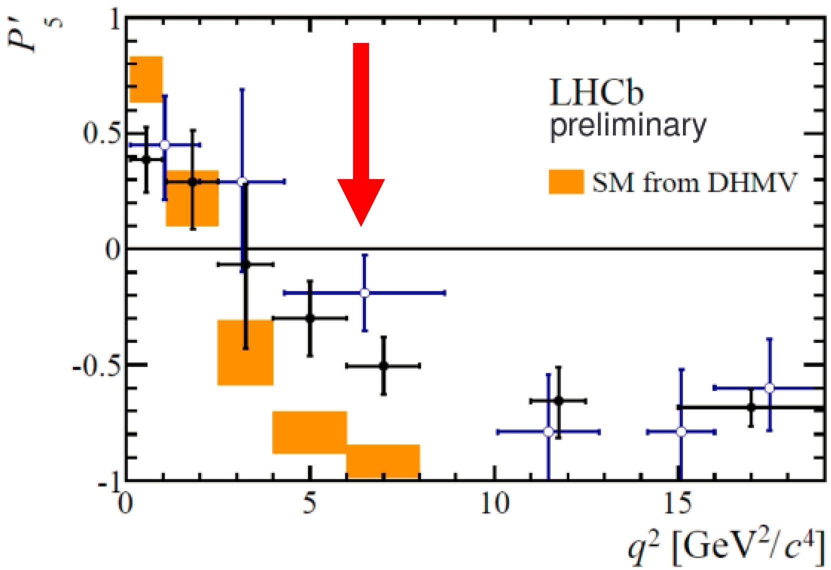


S. Wehle et al, PRL118, 111801 (2017 Mar 13)

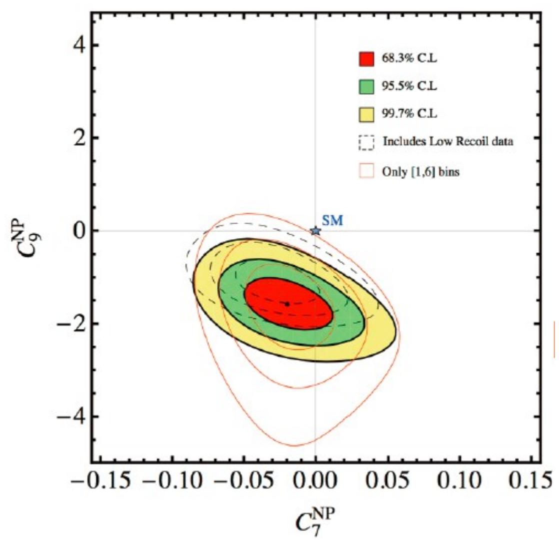
Lepton Flavor Dependent Angular Analysis of $B \rightarrow K^* l^+ l^-$

Angular Analysis of $B^0 \to K^{*0} l^+ l^-$

- LHCb reported 3.4σ deviation from a SM prediction in P_5' for $4 < q^2 < 8 GeV^2$ which was obtained from full angular analysis of $B^0 \to K^{*0}\mu\mu$
  - There is a discussion that the deviation can be explained by a charm loop
- Global fit to radiative and EW penguin B decays gives Wilson coefficient C_9 deviated about -1 from SM values (or C_{LL})
  - Driven by P5', F_L, $B(Bs \to \phi\mu\mu)$ etc.
- Independent analyses/checks are desired.



S.Descotes-Genon et al, PRD 88 074002 (2013)

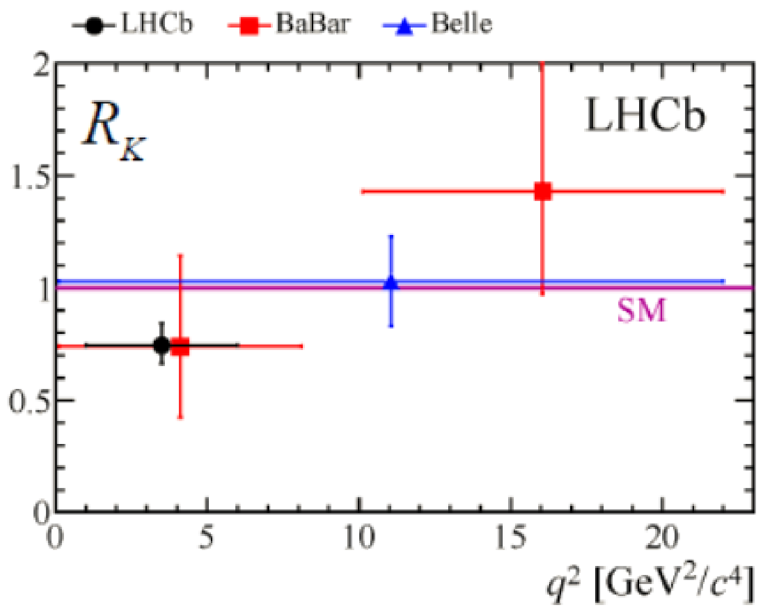


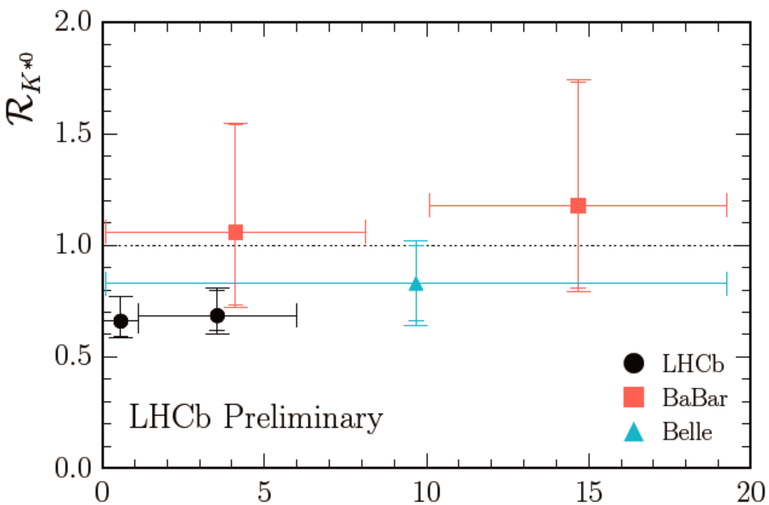
R_K and R_K*

- LHCb also reported anomaly in Lepton Flavor Universality observables, R_K and R_{K^*}

$$R_K = \Gamma(B \to K\mu\mu)/\Gamma(B \to Kee)$$
$$R_{K^*} = \Gamma(B \to K^*\mu\mu)/\Gamma(B \to K^*ee)$$

- Next measurement should be lepton flavor universality in angular observables

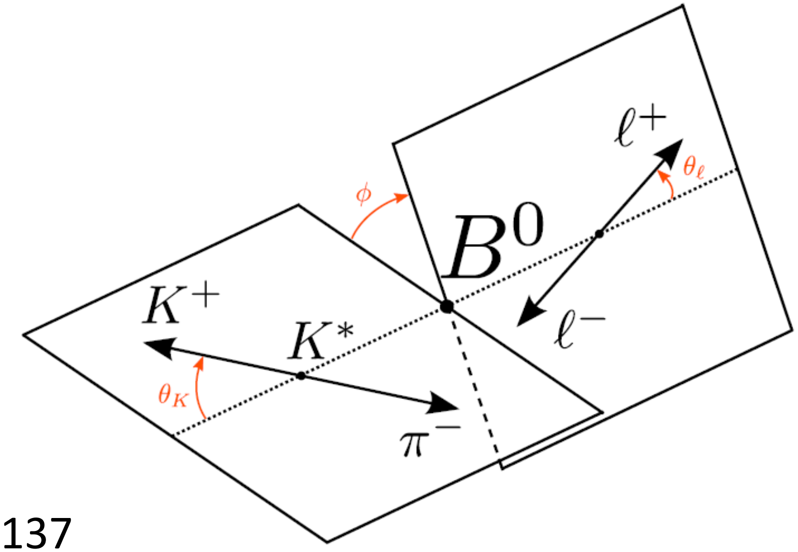




- PRD 86 (2012) 032012
- PRL 103 (2009) 171801

Differential Decay Width for B→K*ll

- Differential decay width as a function of 4 variables, q^2, θ_l, θ_K, and ϕ, is expressed in terms of form factor independent observables, P_i'.

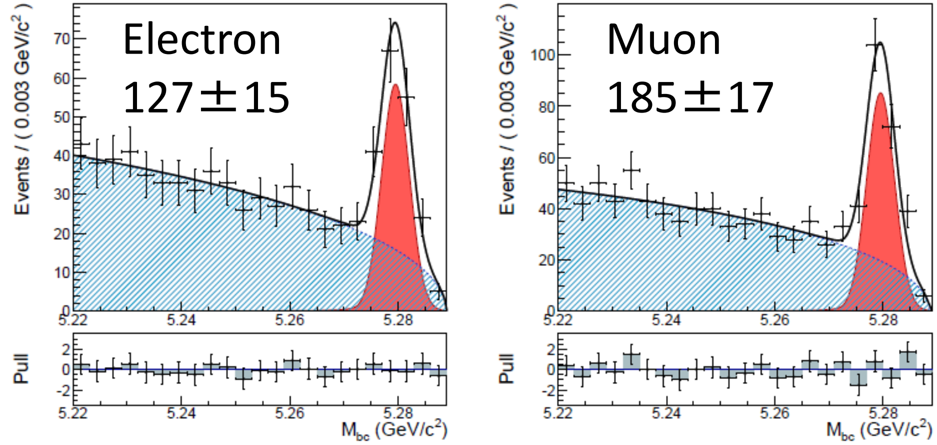


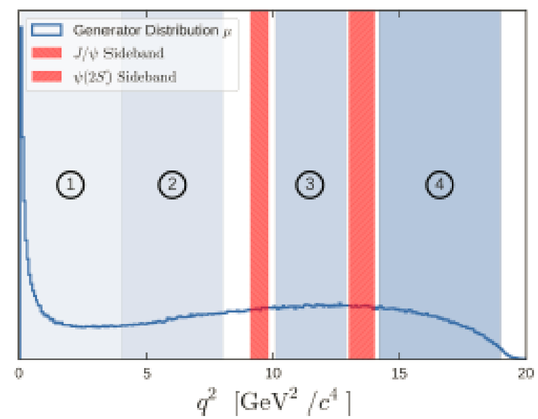
S. Descotes-Genon et al. JHEP 05 (2013) 137

$$\frac{1}{\mathrm{d}\Gamma/\mathrm{d}q^2}\frac{\mathrm{d}^4\Gamma}{\mathrm{d}\cos\theta_L\ \mathrm{d}\cos\theta_K\ \mathrm{d}\phi\ \mathrm{d}q^2} = \frac{9}{32\pi}\Big[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_L - F_L\cos^2\theta_K\cos 2\theta_L + S_3\sin^2\theta_K\sin^2\theta_L\cos 2\phi + S_4\sin 2\theta_K\sin 2\theta_L\cos\phi + S_5\sin 2\theta_K\sin\theta_L\cos\phi + S_6\sin^2\theta_K\cos\theta_L + S_7\sin 2\theta_K\sin\theta_L\sin\phi + S_8\sin 2\theta_K\sin 2\theta_L\sin\phi + S_9\sin^2\theta_K\sin^2\theta_L\sin 2\phi\Big]$$

$$P'_{i=4,5,6,8} = \frac{S_{j=4,5,7,8}}{\sqrt{F_L(1-F_L)}}$$

Reconstruction





- Decay modes
  - $B^0 \rightarrow K^{*0} l^+ l^-$, $K^{*0} \rightarrow$ K+pi-
  - $B^+ \rightarrow K^{*+} l^+ l^-$, $K^{*+} \rightarrow Ks\pi^+, K^+\pi^0$
  - 312±23events (LHCb 2398±57)
- Signal fraction as a function of Mbc
- Separate electron and muon modes to test Lepton Flavor Universality, $Q_i = 0$ in the SM
  - $P_i'^e$, $P_i'^\mu$ and $Q_i = P_i'^e - P_i'^\mu$
- Only measured P_4', P_5' , Q_4, Q_5

Folding

- Since statistics is small, we performed folding technique as LHCb did in 2013
  - Use symmetry of trigonometric function to eliminate coefficients other than F_L, S_3 and another one

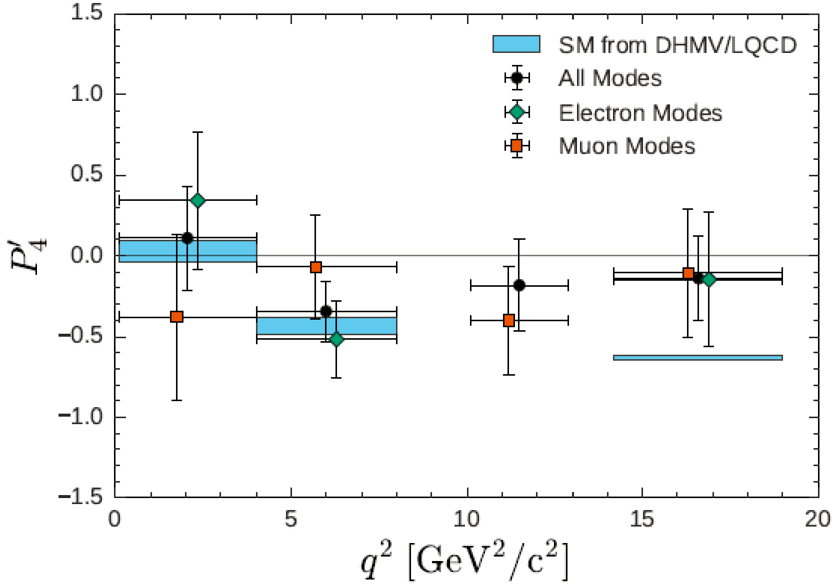
$$P'_4, S_4 : \begin{cases} \phi \to -\phi & \text{for } \phi < 0 \\ \phi \to \pi - \phi & \text{for } \theta_\ell > \pi/2 \\ \theta_\ell \to \pi - \theta_\ell & \text{for } \theta_\ell > \pi/2, \end{cases} \quad P'_5, S_5 : \begin{cases} \phi \to -\phi & \text{for } \phi < 0 \\ \theta_\ell \to \pi - \theta_\ell & \text{for } \theta_\ell > \pi/2, \end{cases}$$

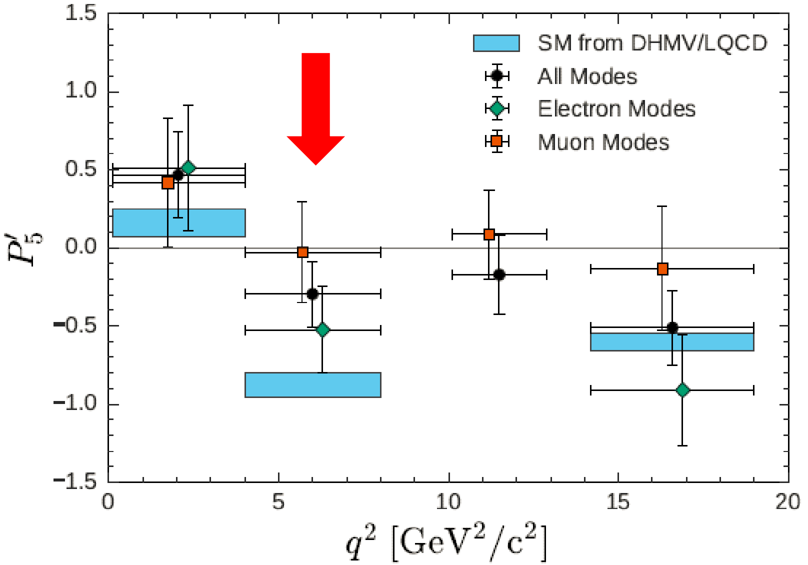
$$\begin{aligned} \frac{1}{\mathrm{d}\Gamma/\mathrm{d}q^2} \frac{\mathrm{d}^4\Gamma}{\mathrm{d}\cos\theta_L\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi\,\mathrm{d}q^2} = \frac{9}{32\pi} \Big[& \frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K \\ & + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_L \\ & - F_L\cos^2\theta_K\cos 2\theta_L + S_3\sin^2\theta_K\sin^2\theta_L\cos 2\phi \\ & + S_4\sin 2\theta_K\sin 2\theta_L\cos\phi + S_5\sin 2\theta_K\sin\theta_L\cos\phi \\ & + S_6\sin^2\theta_K\cos\theta_L + S_7\sin 2\theta_K\sin\theta_L\sin\phi \\ & + S_8\sin 2\theta_K\sin 2\theta_L\sin\phi + S_9\sin^2\theta_K\sin^2\theta_L\sin 2\phi \Big] \end{aligned}$$

$$P'_{i=4,5,6,8} = \frac{S_{j=4,5,7,8}}{\sqrt{F_L(1-F_L)}}$$

Results P_4' and P_5'

- Observed 2.6σ deviation from the SM prediction by DHMV
  - Systematic error small (taken very conservatively)

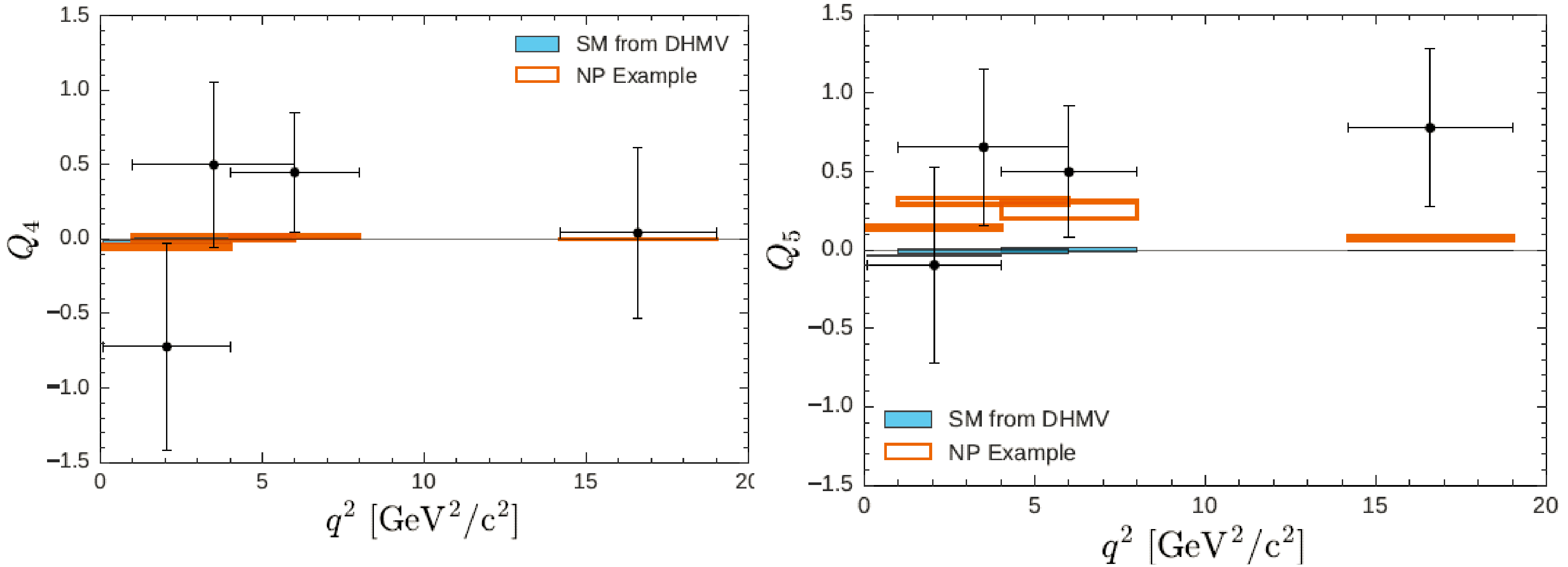




q^2 in GeV^2/c^2	P_4'	P_5'
$[1.00, 6.00]$	$-0.45^{+0.23}_{-0.22} \pm 0.09$	$0.23^{+0.21}_{-0.22} \pm 0.07$
$[0.10, 4.00]$	$0.11^{+0.32}_{-0.31} \pm 0.05$	$0.47^{+0.27}_{-0.28} \pm 0.05$
$[4.00, 8.00]$	$-0.34^{+0.18}_{-0.17} \pm 0.05$	$-0.30^{+0.19}_{-0.19} \pm 0.09$
$[10.09, 12.90]$	$-0.18^{+0.28}_{-0.27} \pm 0.06$	$-0.17^{+0.25}_{-0.25} \pm 0.01$
$[14.18, 19.00]$	$-0.14^{+0.26}_{-0.26} \pm 0.05$	$-0.51^{+0.24}_{-0.22} \pm 0.01$

Results Q_4 and Q_5

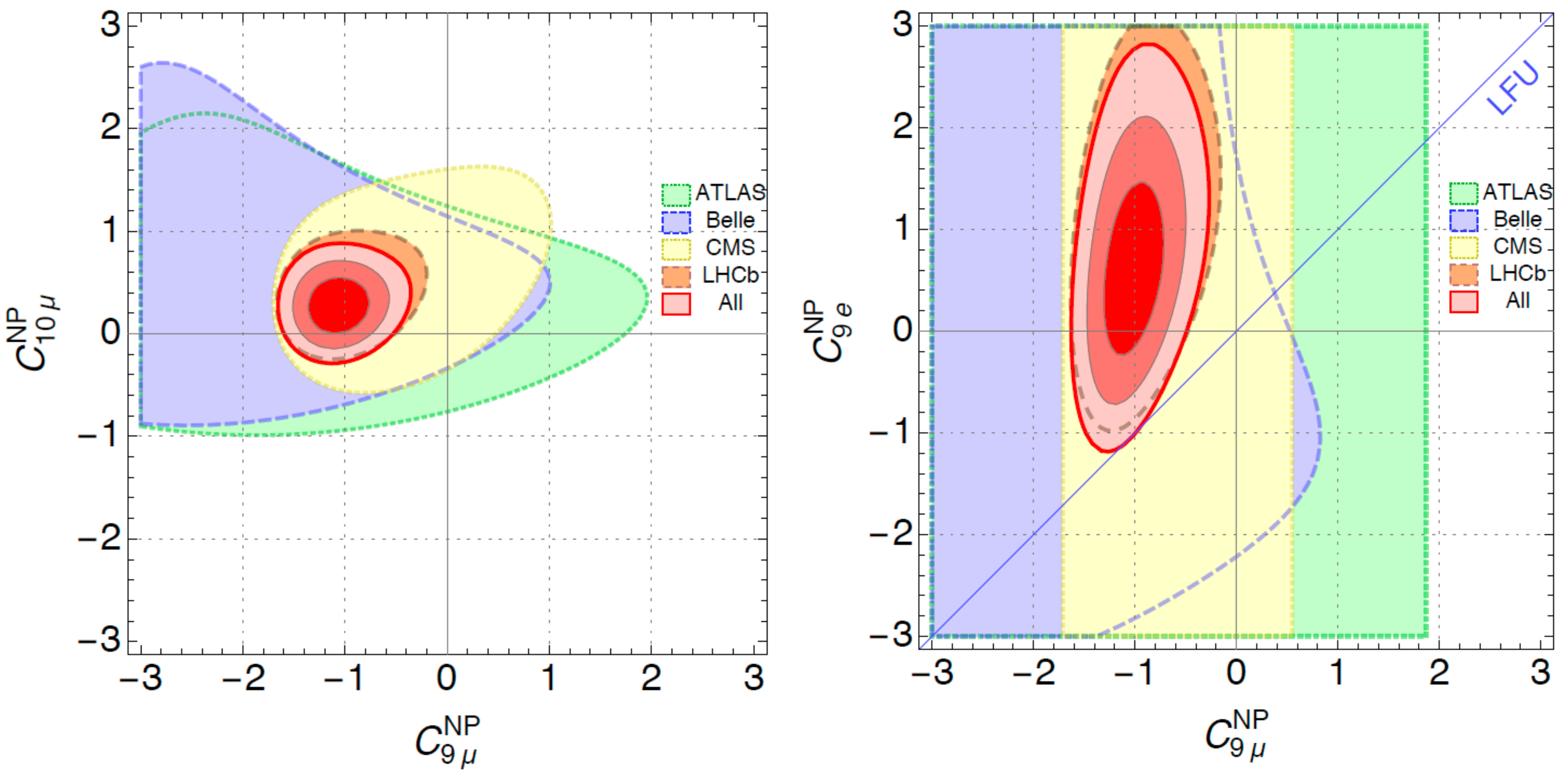
- Consistent with both SM and NP with $C_9^{\mu}{}_{NP} = -1$
  - Systematic error small (taken very conservatively)



q^2 in GeV$^2/c^2$	Q_4	Q_5
[1.00, 6.00]	$0.498 \pm 0.527 \pm 0.166$	$0.656 \pm 0.485 \pm 0.103$
[0.10, 4.00]	$-0.723 \pm 0.676 \pm 0.163$	$-0.097 \pm 0.601 \pm 0.164$
[4.00, 8.00]	$0.448 \pm 0.392 \pm 0.076$	$0.498 \pm 0.410 \pm 0.095$
[14.18, 19.00]	$0.041 \pm 0.565 \pm 0.082$	$0.778 \pm 0.502 \pm 0.065$

Global Fit to b→s

- Including P_5', Q_5 etc, $R_{K(*)}$, Bs→μμ, b→sγ
  - Suggest $C_{9\mu}^{NP}$ ~ -1

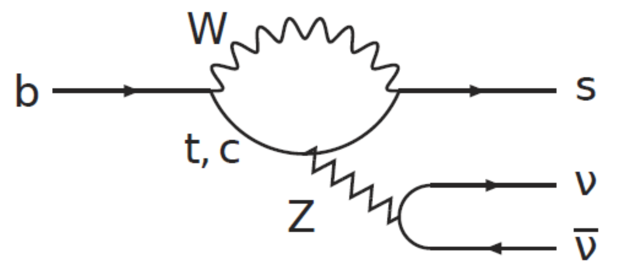


J. Grygier et al., arXiv:1702.03224 submitted to PRD

Search for B→hνν with semileptonic tagging

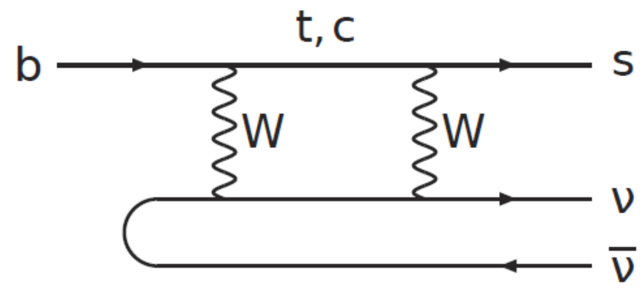
Search for $B \to h^{(*)}\nu\nu$

- If C_9 is deviated from the SM value, vector current in $b \to s\nu\nu$ could be also affected in some BSM models.



- Proceeds via penguin or box diagrams
- Theoretically very clean.
  - No charm loop as in $b \to sl^+l^-$
- Experimentally, need to tag the other B meson due to final states having multiple neutrinos.
- Hadronic B tagging already done.

- Semileptonic B tagging are used this analysis

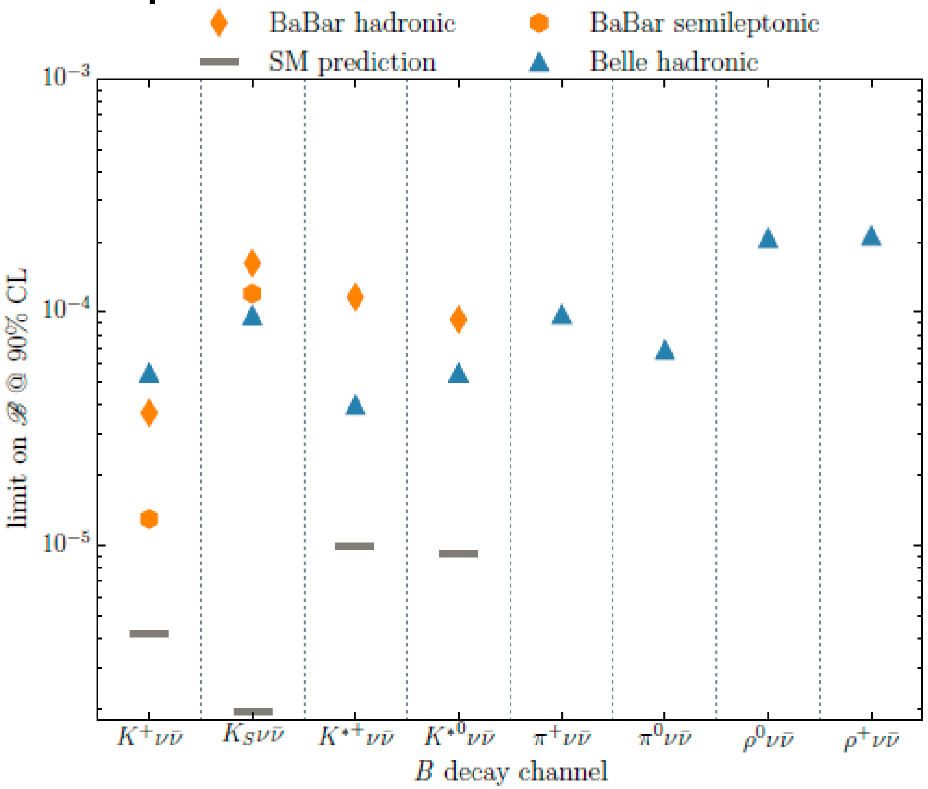


A. Buras, et al. JHEP 02 184 (2015)

Mode	$\mathcal{B}$ $[10^{-6}]$
$B^+ \to K^+\nu\bar{\nu}$	$3.98 \pm 0.43 \pm 0.19$
$B^0 \to K^0_S\nu\bar{\nu}$	$1.85 \pm 0.20 \pm 0.09$
$B^+ \to K^{*+}\nu\bar{\nu}$	$9.91 \pm 0.93 \pm 0.54$
$B^0 \to K^{*0}\nu\bar{\nu}$	$9.19 \pm 0.86 \pm 0.50$

Current Status

- For K^+ , K^{*0} and K^{*+} modes, ULs are about 3~5 times larger than theoretical predictions in the SM



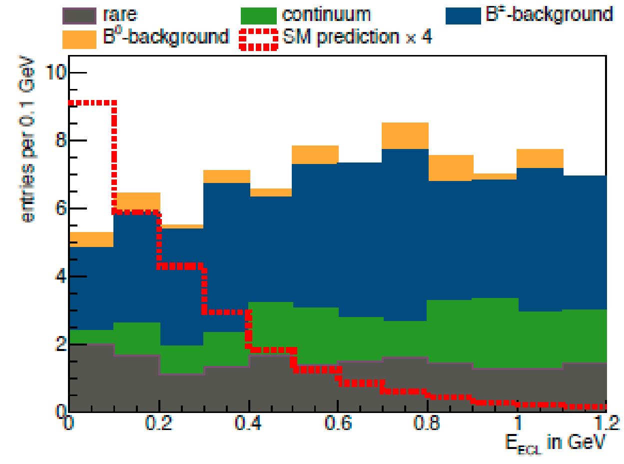
A. Buras, et al. JHEP 02 184 (2015)

PRD 82, 112002 (2010), ◇ PRD 87, 112005 (2013), PRD 87, 111103(R) (2013)

$459 M\, B\overline{B}$ $471 M\, B\overline{B}$ $772 M\, B\overline{B}$

Reconstruction

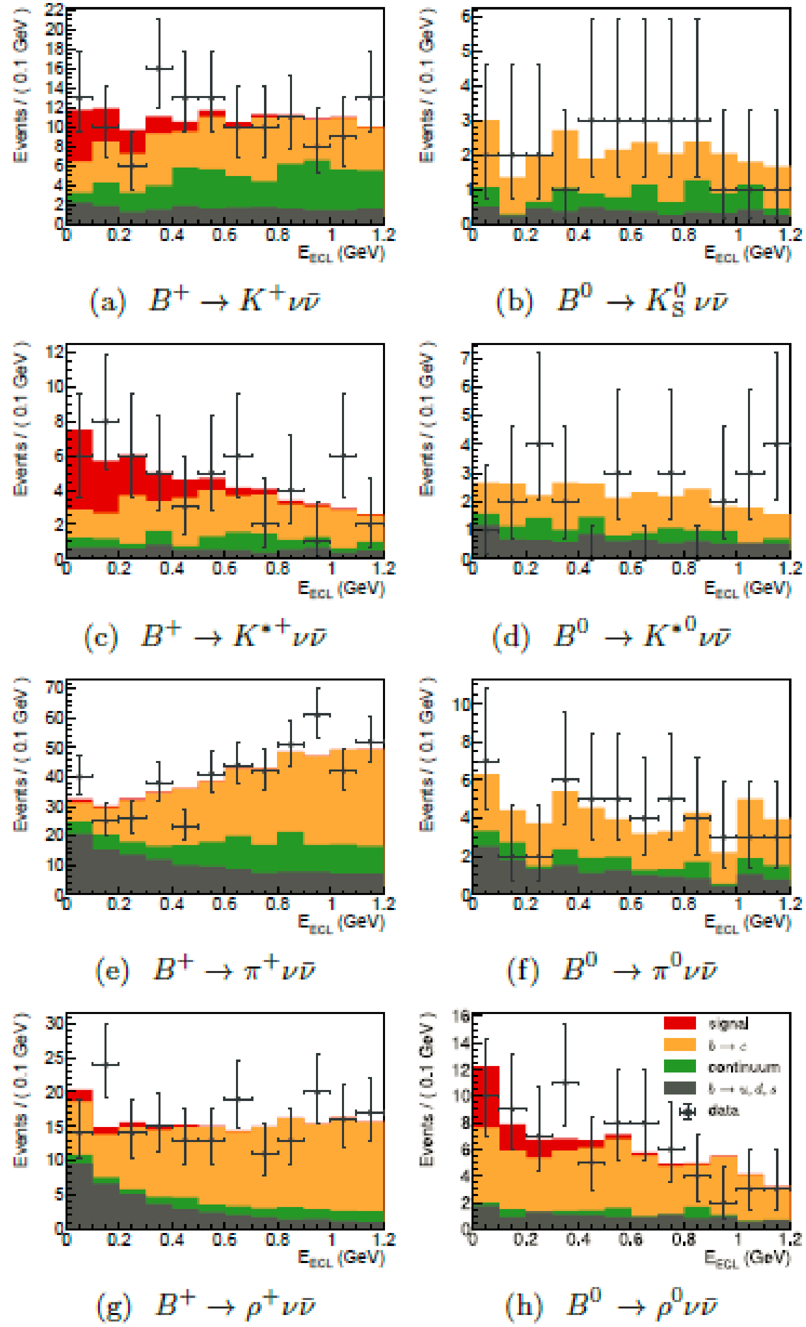
- Semileptonic tagging
  - Hierarchical reconstruction of $B \rightarrow D^{(*)} l \nu$ using NeuroBays
  - More efficient than hadronic tagging
- Signal hadron decay modes
  - $h^{(*)} = K^+, K_S^0, K^{*+}(K_S^0\pi^+, K^+\pi^0)$, $K^{*0}(K^+\pi^-)$, $\pi^+, \pi^0, \rho^+, \rho^0$
- Requirement of no other particles
  - No charged tracks, π^0 nor K_L^0
- Background suppression
  - Continuum : event shape
- Signal is extracted from extra energy in ECL



Results

- Fit with histogram templates
  - Signal
  - Backgrounds
    - b→c, continuum, b→u,d,s
    - Relative fractions are fixed to MC values
- Signal yields consistent with zero
  - But signal seen for K^+ and K^{*+}?

Channel	Observed signal yield	Significance
$K^+\nu\bar{\nu}$	$17.7 \pm 9.1 \pm 3.4$	$1.9\,\sigma$
$K^0_S\,\nu\bar{\nu}$	$0.6 \pm 4.2 \pm 1.4$	$0.0\,\sigma$
$K^{*+}\nu\bar{\nu}$	$16.2 \pm 7.4 \pm 1.8$	$2.3\,\sigma$
$K^{*0}\nu\bar{\nu}$	$-2.0 \pm 3.6 \pm 1.8$	$0.0\,\sigma$
$\pi^+\nu\bar{\nu}$	$5.6 \pm 15.1 \pm 5.9$	$0.0\,\sigma$
$\pi^0\nu\bar{\nu}$	$0.2 \pm 5.6 \pm 1.6$	$0.0\,\sigma$
$\rho^+\nu\bar{\nu}$	$6.2 \pm 12.3 \pm 2.4$	$0.3\,\sigma$
$\rho^0\nu\bar{\nu}$	$11.9 \pm 9.0 \pm 3.6$	$1.2\,\sigma$

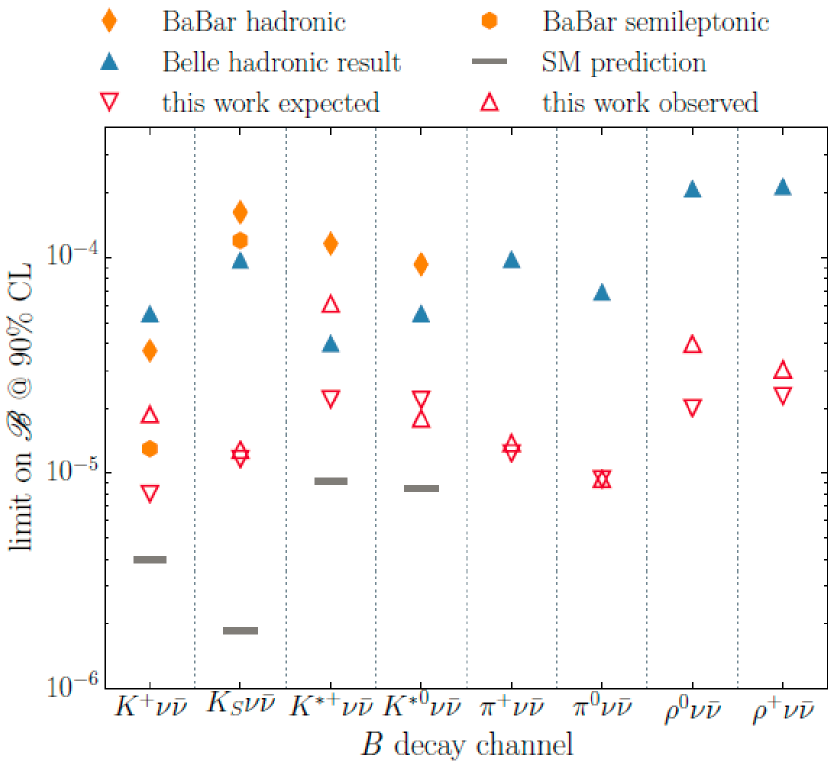


(a) $B^+ \to K^+\nu\bar{\nu}$
(b) $B^0 \to K^0_S\,\nu\bar{\nu}$
(c) $B^+ \to K^{*+}\nu\bar{\nu}$
(d) $B^0 \to K^{*0}\nu\bar{\nu}$
(e) $B^+ \to \pi^+\nu\bar{\nu}$
(f) $B^0 \to \pi^0\nu\bar{\nu}$
(g) $B^+ \to \rho^+\nu\bar{\nu}$
(h) $B^0 \to \rho^0\nu\bar{\nu}$

Upper Limits

- Worlds most stringent upper limits on
  - $h^{(*)} = K_S^0, K^{*0}, \pi^+, \pi^0, \rho^+, \rho^0$
  - Upper limit on BF($B \rightarrow K^{*0}\nu\nu$) is just two times larger than a SM prediction
- The BF and F_L measurable at Belle II

Channel	Efficiency	Expected limit	Observed limit
$K^+\nu\bar{\nu}$	2.16×10^{-3}	0.8×10^{-5}	1.9×10^{-5}
$K^0_S\,\nu\bar{\nu}$	0.91×10^{-3}	1.2×10^{-5}	1.3×10^{-5}
$K^{*+}\nu\bar{\nu}$	0.57×10^{-3}	2.4×10^{-5}	6.1×10^{-5}
$K^{*0}\nu\bar{\nu}$	0.51×10^{-3}	2.4×10^{-5}	1.8×10^{-5}
$\pi^+\nu\bar{\nu}$	2.92×10^{-3}	1.3×10^{-5}	1.4×10^{-5}
$\pi^0\nu\bar{\nu}$	1.42×10^{-3}	1.0×10^{-5}	0.9×10^{-5}
$\rho^+\nu\bar{\nu}$	1.11×10^{-3}	2.5×10^{-5}	3.0×10^{-5}
$\rho^0\nu\bar{\nu}$	0.82×10^{-3}	2.2×10^{-5}	4.0×10^{-5}



Summary

- New measurement of $B \rightarrow K^*\gamma$ performed.
  - First evidence for Isospin Violation in $b \rightarrow s\gamma$ decay
  - All the measurements are most precise to date.
  - Used to constrain new physics
- Lepton flavor dependent angular analysis of $B \rightarrow K^*l^+l^-$
  - Consistent with both SM and NP with $C_{9\mu}^{NP} = -1$
- Search for $B \rightarrow h\nu\nu$
  - The upper limit on K^{*0} modes just two times larger than SM predictions $\rightarrow$ BF and F_L at Belle II

backup

Systematics Table for BF and Δ_{0+} in B→K*γ

Source	$K_S^0\pi^0$	$K^+\pi^-$	$K^+\pi^0$	$K_S^0\pi^+$	K^{*0}	K^{*+}	Δ_{0+}
photon reconstruction effi.	2.0	2.0	2.0	2.0	2.0	2.0	–
tracking effi.	0.7	0.7	0.4	1.1	0.7	0.8	0.05
K/π identification effi.	–	1.7	0.8	0.8	1.6	0.8	0.38
π^0 reconstruction effi.	1.6	–	1.6	–	0.1	0.5	0.21
K_S^0 reconstruction effi.	0.2	–	–	0.2	<0.1	0.1	0.05
$\mathcal{O}_{\rm NB}$ and π^0/η veto effi.	0.6	0.6	0.6	0.6	0.6	0.6	–
ΔE selection effi.	1.1	<0.1	1.1	0.1	0.1	0.4	0.15
charge asymmetry in effi.	–	<0.1	<0.1	< 0.1	< 0.1	<0.1	<0.01
MC stat.	0.4	0.1	0.3	0.2	0.1	0.2	0.11
number of $B\bar{B}$ pairs	1.4	1.4	1.4	1.4	1.4	1.4	–
f_{+-}/f_{00}	1.2	1.2	1.2	1.2	1.2	1.2	1.16
lifetime ratio	–	–	–	–	–	–	0.19
higher kaonic resonance	0.3	0.3	0.3	0.3	0.3	0.3	–
cross-feed	0.2	0.2	0.3	0.2	0.2	0.2	0.03
peaking backgrounds	1.6	1.2	1.2	1.1	1.2	1.1	0.14
background A_{CP} and Δ_{0+}	0.2	<0.1	<0.1	0.1	<0.1	<0.1	0.03
fixed parameters in fit	3.9	0.1	1.5	<0.1	0.1	0.2	0.10
fitter bias	2.4	0.2	1.3	0.7	0.2	0.2	0.08
total	5.9	3.5	4.2	3.3	3.5	3.3	1.29

Systematics Table A_{CP} and ΔA_{CP} in B→K*γ

Source	$K^+\pi^-$	$K^+\pi^0$	$K_S^0\pi^+$	K^{*0}	K^{*+}	K^*	ΔA_{CP}
tracking effi.	–	–	–	<0.01	<0.01	<0.01	<0.01
K/π identification effi.	–	–	–	<0.01	<0.01	<0.01	<0.01
π^0 reconstruction effi.	–	–	–	<0.01	<0.01	<0.01	<0.01
K_S^0 reconstruction effi.	–	–	–	<0.01	<0.01	<0.01	<0.01
charge asymmetry in K/π detection	0.40	0.04	0.41	0.40	0.25	0.28	0.48
cross-feed	0.02	0.04	0.03	0.02	0.02	0.02	0.02
peaking backgrounds	0.04	0.06	0.08	0.04	0.06	0.05	0.04
background A_{CP} and Δ_{0+}	0.10	0.13	0.09	0.10	0.10	0.10	0.05
fixed parameters in fit	<0.01	0.13	0.02	<0.01	0.02	<0.01	0.02
fitter bias	0.07	0.16	0.12	0.07	0.09	0.08	0.12
total	0.42	0.26	0.45	0.42	0.30	0.31	0.50

Difference of BF between Belle and Babar

- There is slight difference. I think one of the reasons might be due to modeling of $B \to X_s\gamma$ background
  - Dominant peaking background from $B \to X_s\gamma$ is $B \to K\pi\pi\gamma$
- Belle models $B \to X_s \gamma$ background as
  - Exclusive $B \to K\rho\gamma$ and $B \to K^*\pi\gamma$ with measured BFs
  - Inclusive $B \to X_s \gamma$ (other than $B \to K^*\pi\gamma$ and $B \to K\rho\gamma$) decayed with PYTHIA.
- Babar modeled $B \to X_s \gamma$ background as
  - Inclusive $B \to X_s \gamma$ decayed with PYTHIA.

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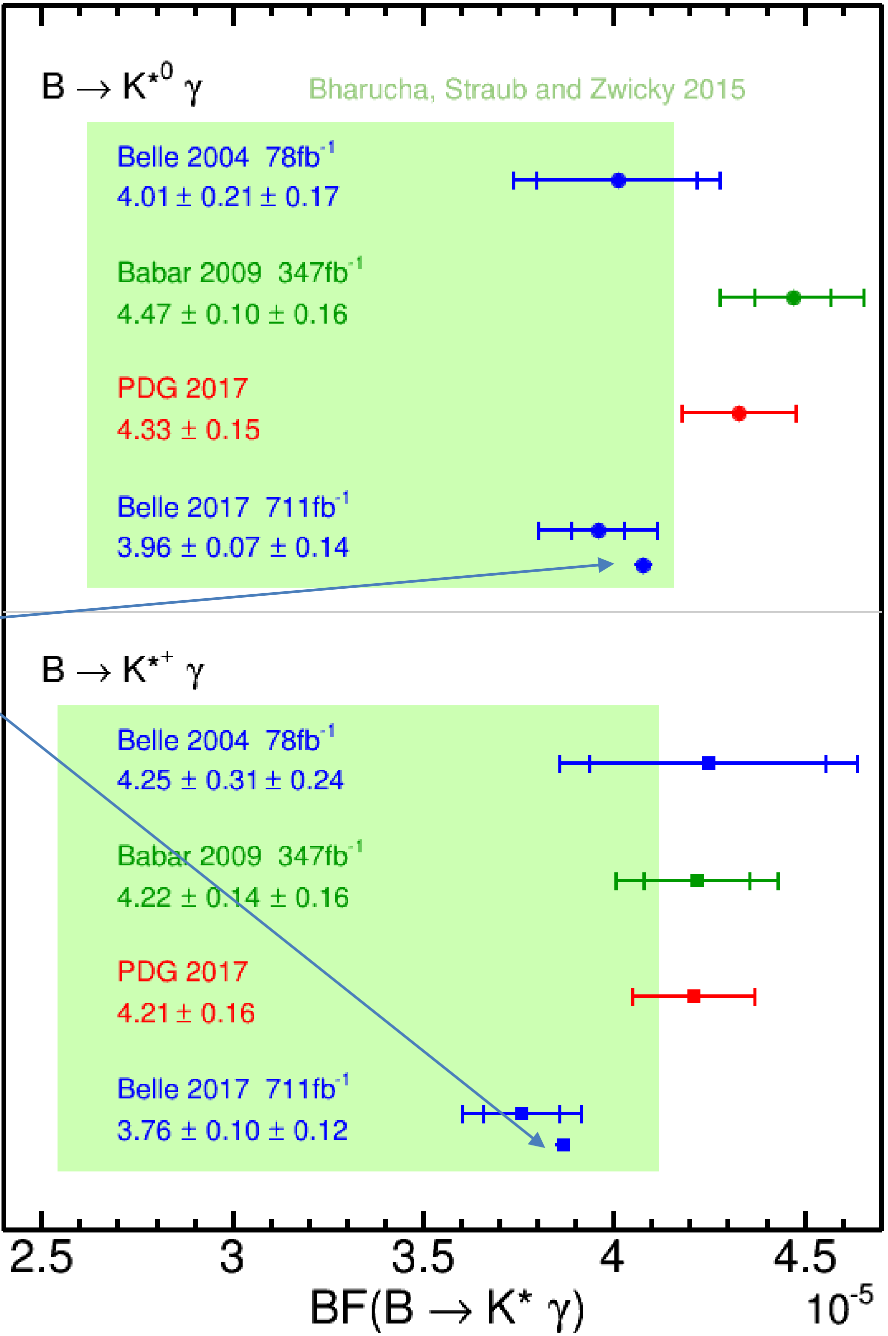
- We simulated $B \to X_s\gamma$ with Belle PYTHIA setting and found that fraction of $B \to K\pi\pi\gamma$ is significantly smaller than PDG value.
  - If we used the PYTHIA background (wrong background description), the BFs of $B \to K^*\gamma$ become about 3% higher.

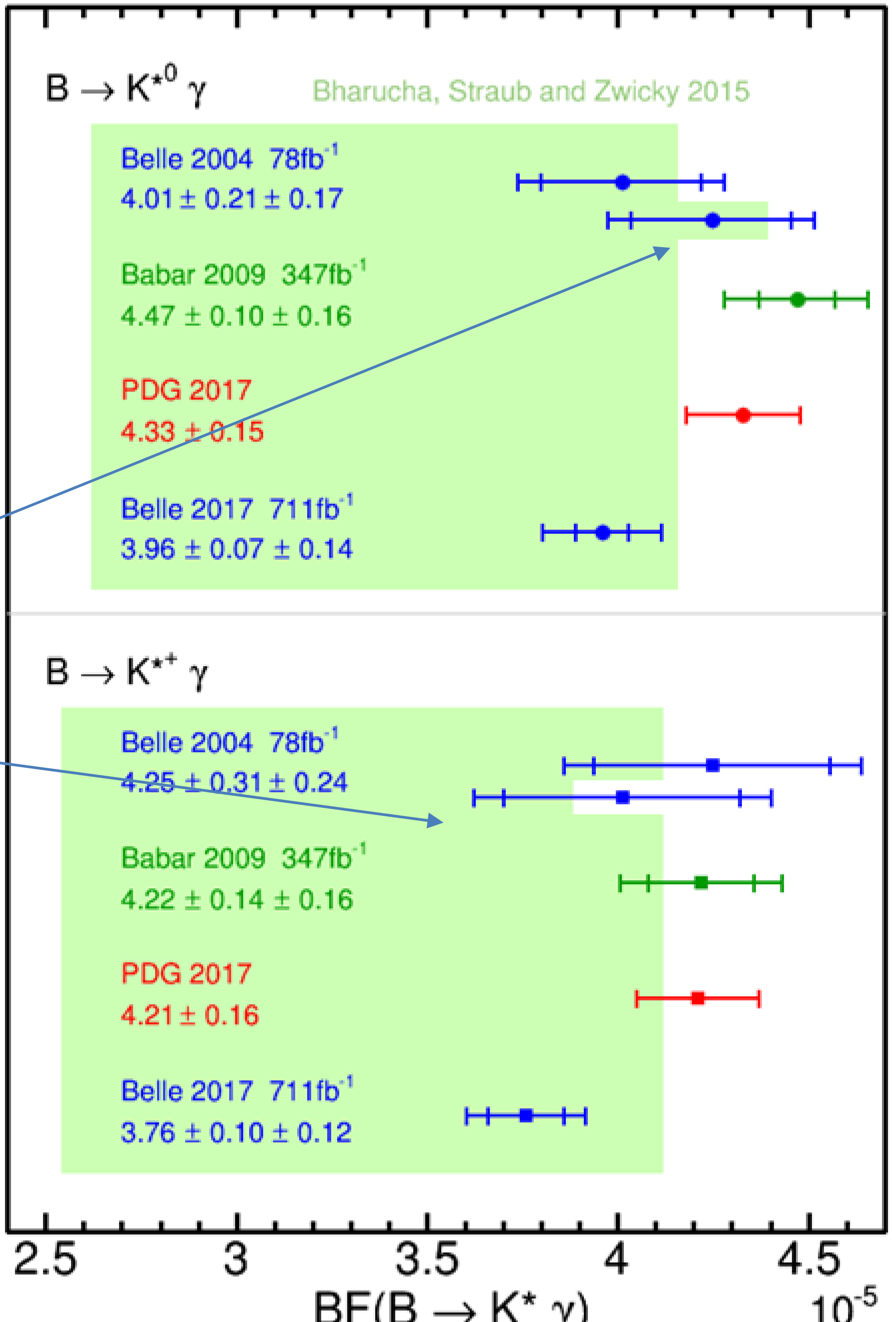
BF with wrong assumption

- Wrong BF(B→Kππγ) assumption



Previous Belle BF

- Previous Belle assumed
  - $f_{+-}/f_{00} = 1$
- If we take latest value
  - $f_{+-}/f_{00} = 1.058.$
  - $BF(B \to K^{*0}\gamma) = 4.24 \times 10^{-5}$
  - $BF(B \to K^{*+}\gamma) = 4.02 \times 10^{-5}$



Previous Belle Results on Δ_{0+}

- Previous Belle assumed
  - $f_{+-}/f_{00} = 1$
  - $\tau_{B+}/\tau_{B0} = 1.086$
- If we take latest value
  - $f_{+-}/f_{00} = 1.058$
  - $\tau_{B+}/\tau_{B0} = 1.076$

  - $\Delta_{0+} = +6.3\%$