Recent results on FCNC B meson decays at Belle

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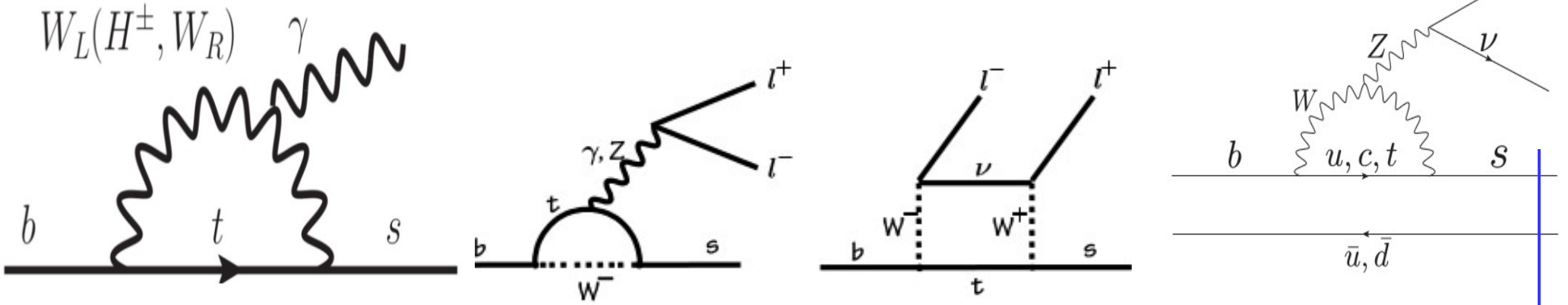
Outline

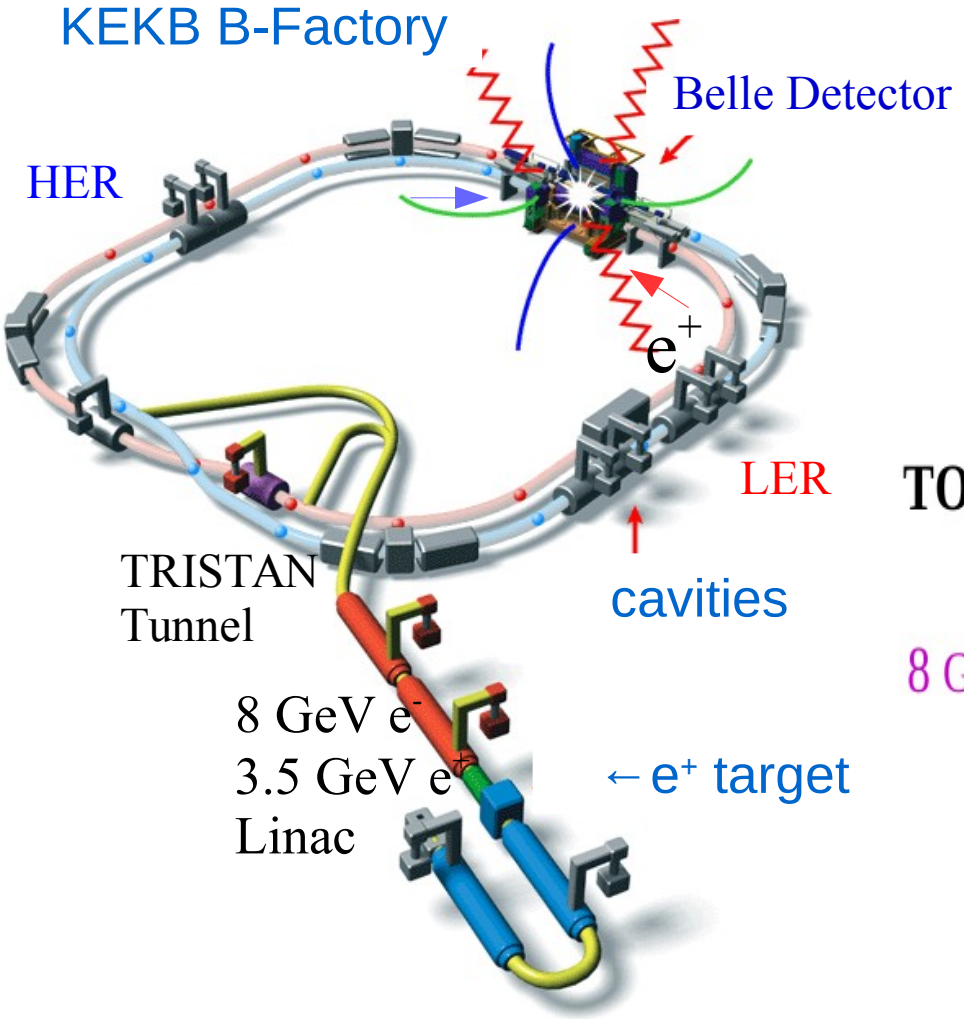
- Measurements in $B \to K^*(892)\gamma$ **Phys. Rev. Lett. 119, 191802 (2017)**
- Angular Analysis of $B \to K^* l^+ l^-$ **Phys. Rev. Lett. 118, 111801 (2017)**
- Search for $B \to h(*)\nu\nu$ **arXiv:1702.03224 [Submitted to Phy. Rev. D]**

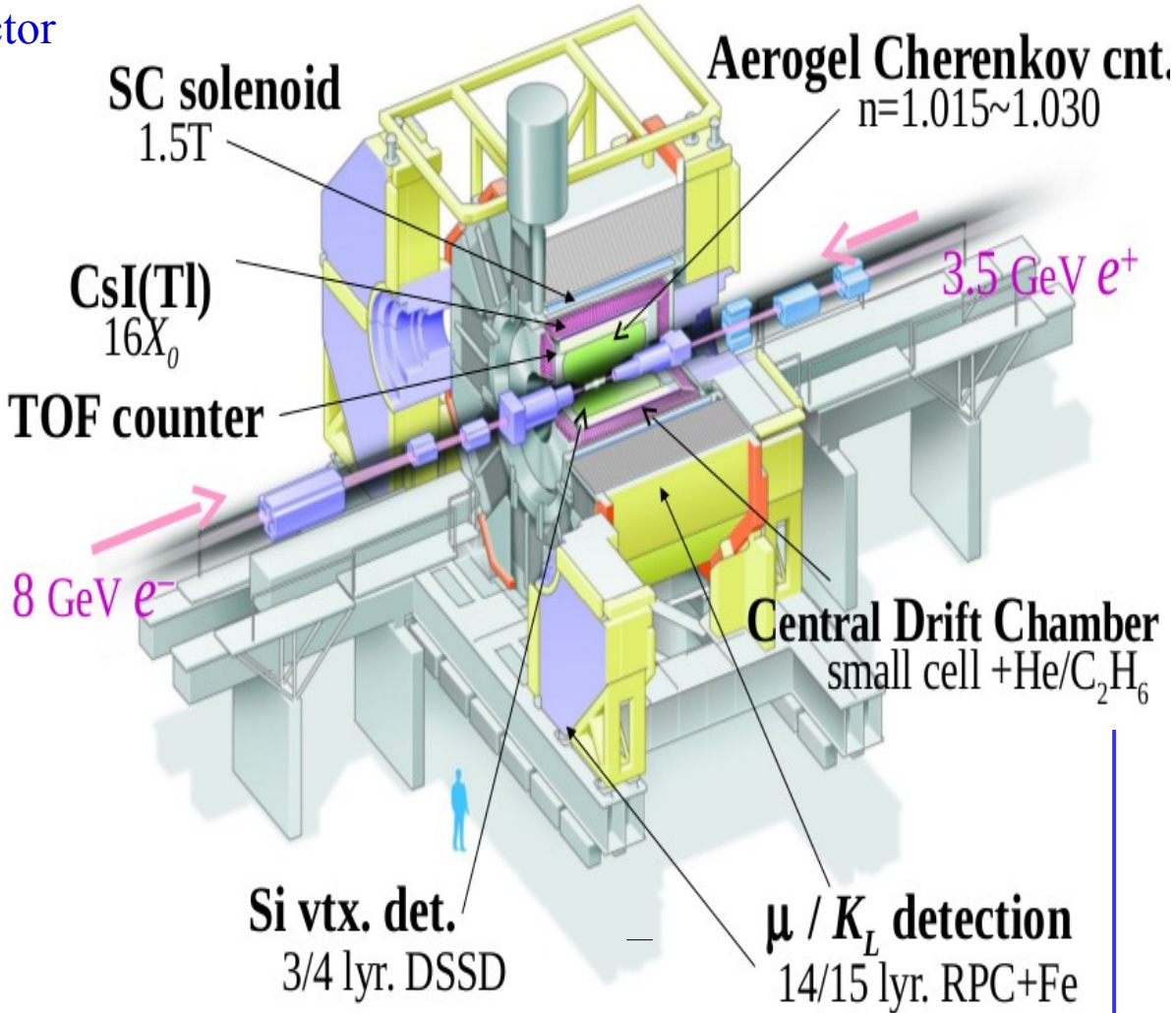
FCNC are strongly suppressed in the SM: only loops
Any new particle generating new diagrams can change the amplitudes



All the analysis is based on the data sample containing 772 Million $B\bar{B}$ pairs; collected with the Belle detector at the KEKB energy-asymmetric e^+e^- collider.

Belle Detector



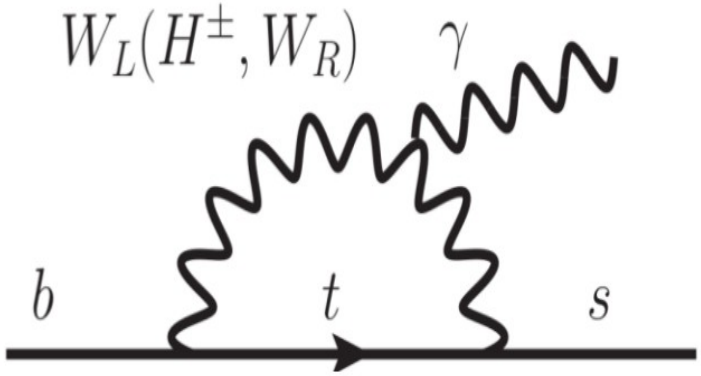


772 Million $B\bar{B}$ pairs produced

$B \rightarrow K^*(892)\gamma$

• The decay $B \rightarrow K^*(892)\gamma$ proceeds dominantly via one loop electromagnetic penguin diagram so-called radiative penguin ($b \rightarrow s\gamma$) transition.

• These diagrams are sensitive to the particles from the NP models, that can also enter in to the loop.



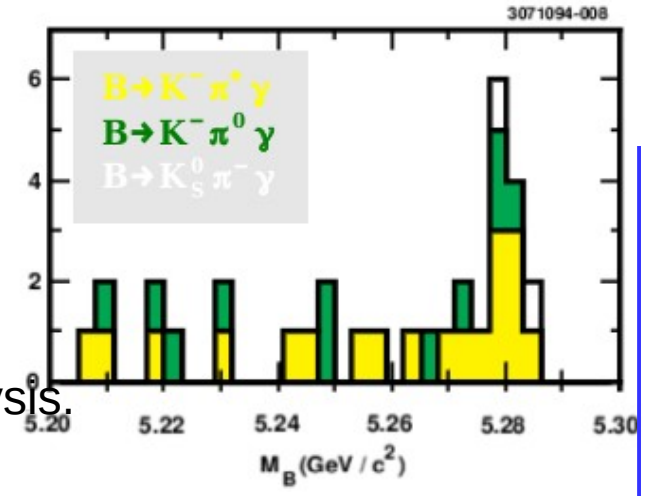
• Among $b \rightarrow s\gamma$ transitions, $\mathbf{B \rightarrow K^*\gamma}$ is one of the most important channel:

Cleanest exclusive decay among $\mathbf{B \rightarrow X_s\gamma}$

Large BF: ~ 4 *10^{-5} about 12% of inclusive $\mathbf{B \rightarrow X_s\gamma}$

• The BFs give weak constraints on the NP as the SM predictions suffer from large uncertainties (~30 %) in the form factor.

CLEO observation of $B \rightarrow K^*\gamma$ [1993]



• About nine times larger statistics than the previous Belle analysis.

Observables of $B \to K^*(892)\gamma$

- $B(B \to K^*(892)\gamma)$ — **Branching fraction**

- $$\frac{\Gamma(B^0 \to K^{*0}\gamma)}{\Gamma(B^+ \to K^{*+}\gamma)} = \frac{\tau_{B^+}}{\tau_{B^0}} \frac{f_{+-}}{f_{00}} \frac{N(B^0 \to K^{*0}\gamma)}{N(B^+ \to K^{*+}\gamma)},$$

  Ratio of the B.Fs.

  Ratios of BF cancels important uncertainties (including the form-factor related)

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

  CP asymmetry (A_{CP})

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

  Isospin asymmetry (Δ_{0+})

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

  - **Difference** of CP asymmetry between charged and neutral B (ΔA_{CP})
  - useful to identify NP once A_{CP} is observed

- $$\bar{A}_{CP} = \frac{A_{CP}(B^+ \to K^{*+}\gamma) + A_{CP}(B^0 \to K^{*0}\gamma)}{2},$$

  Average of A_{CP} between charged and neutral B mesons ($\overline{A_{CP}}$)

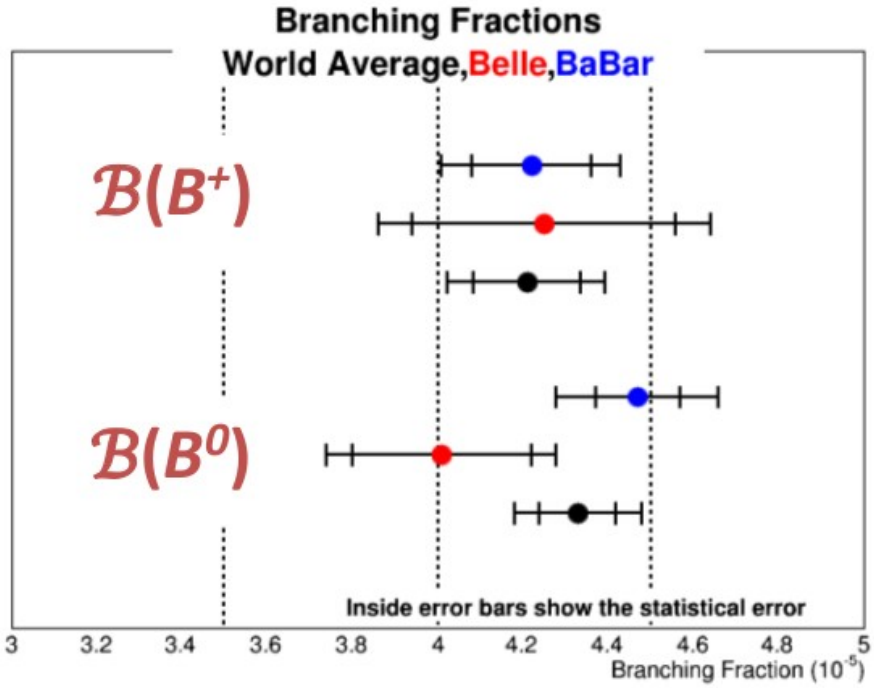
Previous measurement status

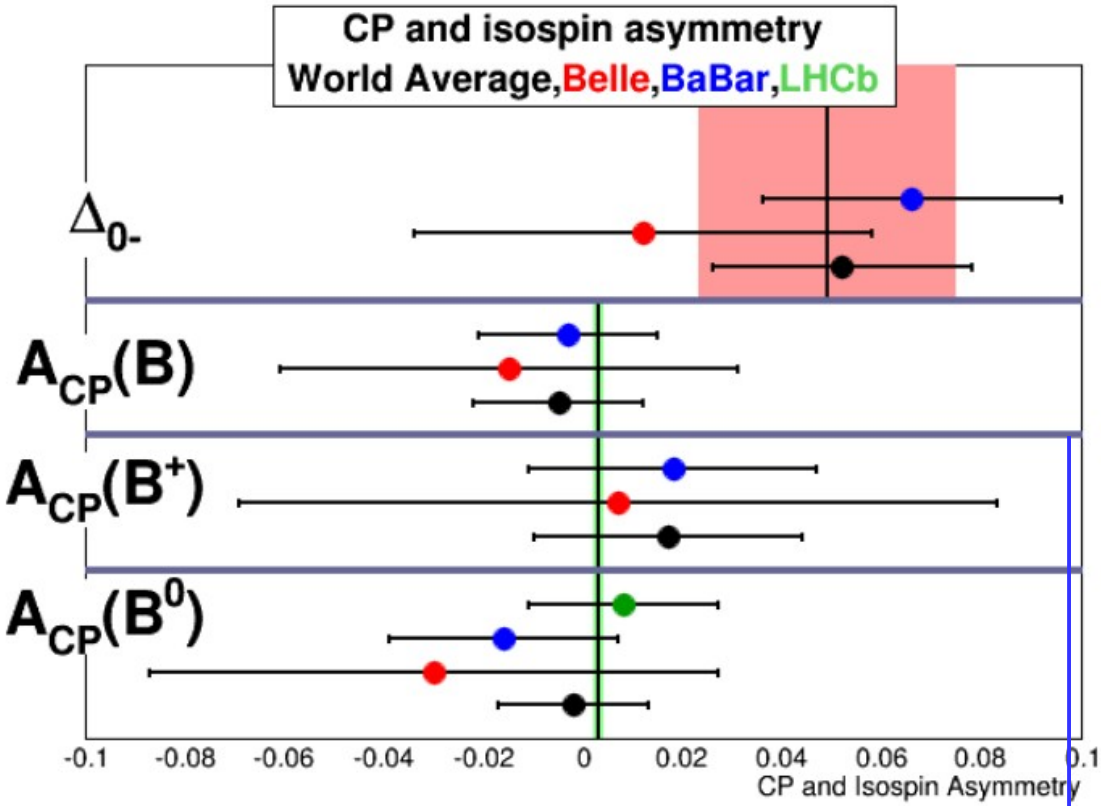
The precisions of all observables are dominated by BaBar's results except A_{CP} ($B^0 \to K^{*0}\gamma$) by LHCb.

– Branching fraction measurement : Systematic error dominant
– Asymmetry measurement : Statistical error dominant

772 M BB pairs

85 M at Belle / 383 M at BaBar





Reconstruction of B → K*(892)γ

Four sub-decay modes:

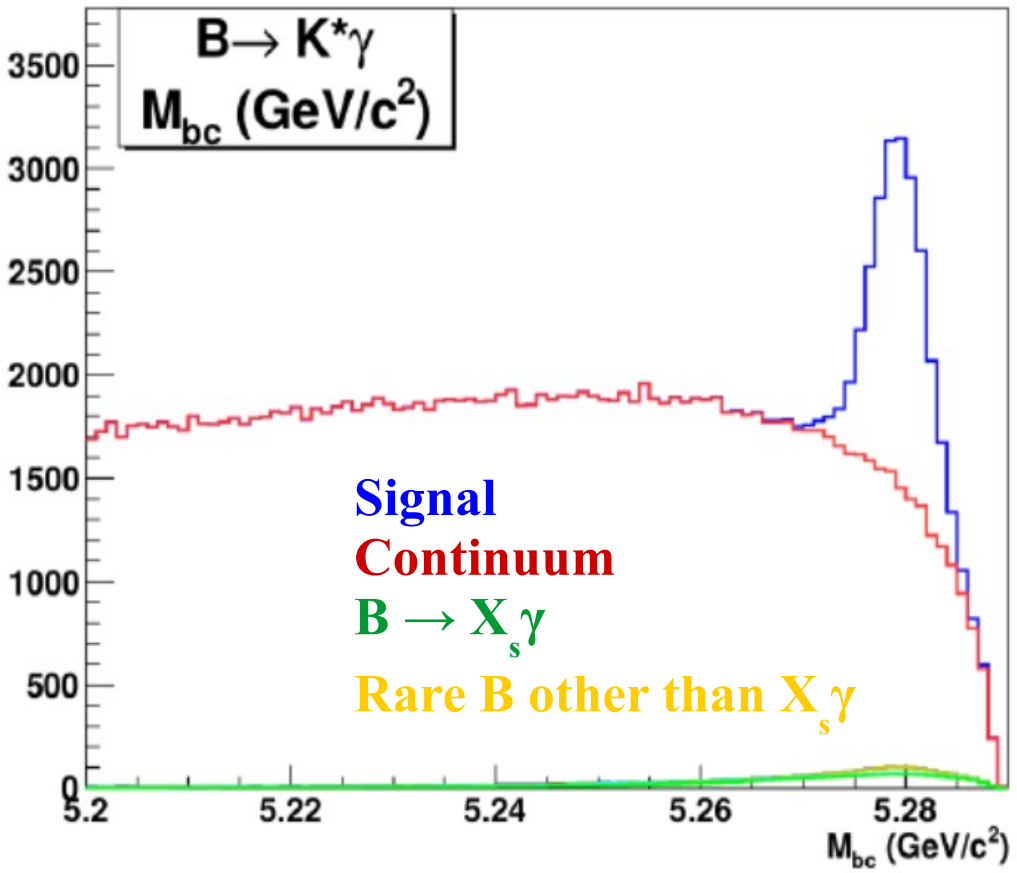
- K^{*0} : $K_s^0\pi^0$, $K^+\pi^-$ **Self-tagging**
- K^{*+} : $K_s^0\pi^+$, $K^+\pi^0$

Signal Selection:

- $-0.2\ \text{GeV} < \Delta E < 0.1\ \text{GeV}$
- $5.20\ \text{GeV}/c^2 < M_{bc} < 5.29\ \text{GeV}/c^2$
- $|M_{k\pi} - M_{K^*}| < 75\ \text{MeV}/c^2$

Background Suppresion:

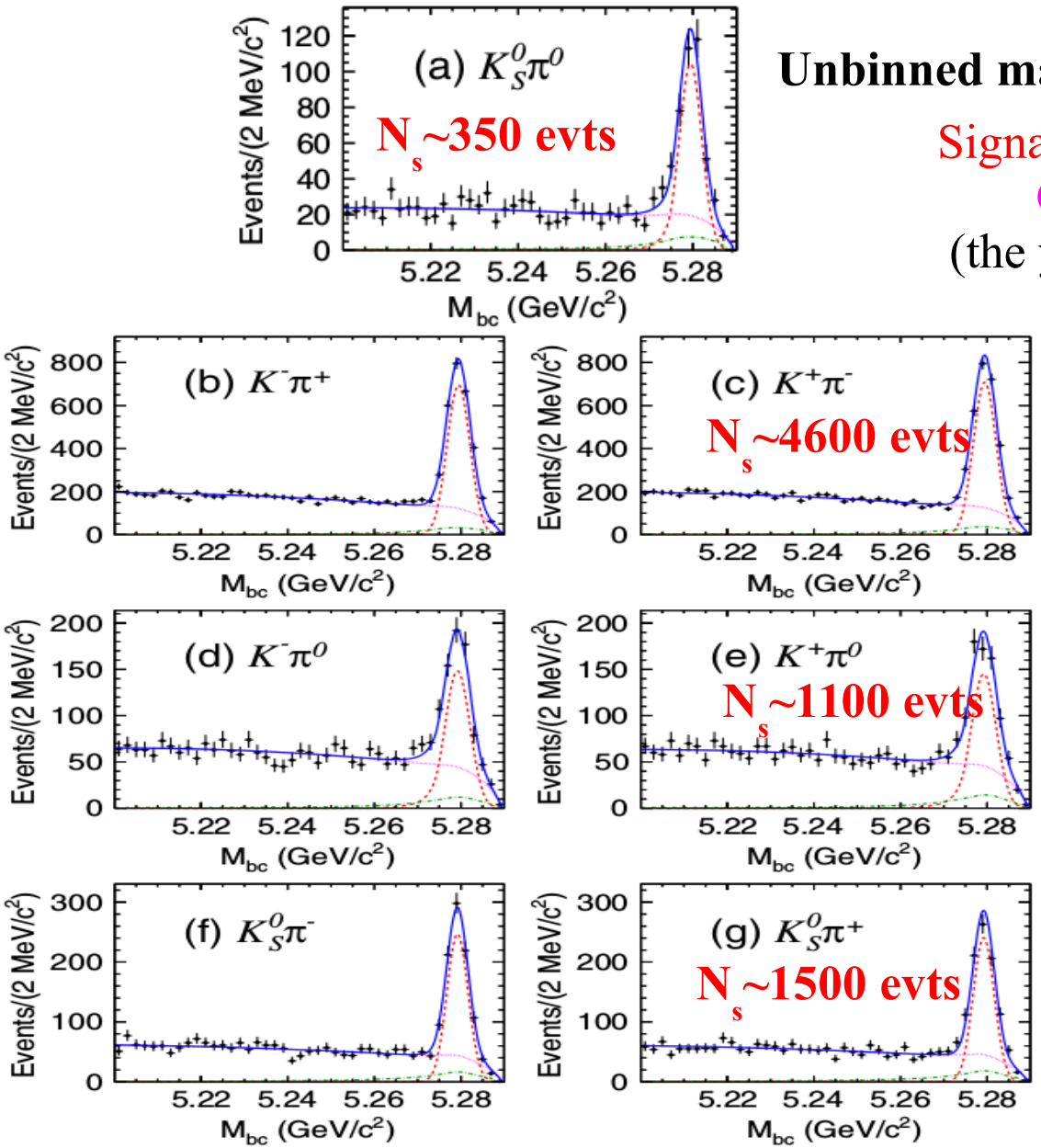
- Continuum: Neural network with event shape variables
- photon selection with π^0 and η veto
- Best candidate selection:
  - Number of candidates per event is 1.16 with MC.
  - Random candidate selection.



M_{bc} distribution summed four channels With M(kπ) selection after π^0 and η veto

- BF, A_{CP}, Δ_{0+} and ΔA_{CP} are extracted in simultaneous fit performed to seven M_{bc} distributions with the likelihood

Extraction of BF, A_{CP} , Δ_{0+} , 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 bkg : ARGUS

$B\bar{B}$ bkg : ARGUS + Bifurcated Gaussian

Likelihood for a simultaneous fit

$$\mathcal{L}(M_{bc}|\mathcal{B}^N,\mathcal{B}^C,A_{CP}^N,A_{CP}^C)$$
$$=\Pi\mathcal{L}^{K^0_S\pi^0}(M_{bc}|\mathcal{B}^N)$$
$$\times\Pi\mathcal{L}^{K^-\pi^+}(M_{bc}|\mathcal{B}^N,A_{CP}^N)\times\Pi\mathcal{L}^{K^+\pi^-}(M_{bc}|\mathcal{B}^N,A_{CP}^N)$$
$$\times\Pi\mathcal{L}^{K^-\pi^0}(M_{bc}|\mathcal{B}^C,A_{CP}^C)\times\Pi\mathcal{L}^{K^+\pi^0}(M_{bc}|\mathcal{B}^C,A_{CP}^C)$$
$$\times\Pi\mathcal{L}^{K^0_S\pi^-}(M_{bc}|\mathcal{B}^C,A_{CP}^C)\times\Pi\mathcal{L}^{K^0_S\pi^+}(M_{bc}|\mathcal{B}^C,A_{CP}^C),$$

Results of $B \to K^*(892)\gamma$

Mode	$N_S^{\bar{B}}$	N_S^B	ϵ [%]
$B^0 \to K_S^0\pi^0\gamma$	$349 \pm 23 \pm 15$		1.16 ± 0.04
$B^0 \to K^+\pi^-\gamma$	$2295 \pm 56 \pm 27$	$2339 \pm 56 \pm 30$	15.61 ± 0.49
$B^+ \to K^+\pi^0\gamma$	$572 \pm 32 \pm 12$	$562 \pm 31 \pm 11$	3.66 ± 0.12
$B^+ \to K_S^0\pi^+\gamma$	$745 \pm 32 \pm 8$	$721 \pm 32 \pm 9$	5.01 ± 0.14

$$\mathcal{B}(B^0 \to K^{*0}\gamma) = (3.96 \pm 0.07 \pm 0.14) \times 10^{-5},$$
$$\mathcal{B}(B^+ \to K^{*+}\gamma) = (3.76 \pm 0.10 \pm 0.12) \times 10^{-5},$$

$$A_{CP}(B^0 \to K^{*0}\gamma) = (-1.3 \pm 1.7 \pm 0.4)\%,$$
$$A_{CP}(B^+ \to K^{*+}\gamma) = (+1.1 \pm 2.3 \pm 0.3)\%,$$
$$A_{CP}(B \to K^*\gamma) = (-0.4 \pm 1.4 \pm 0.3)\%,$$

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

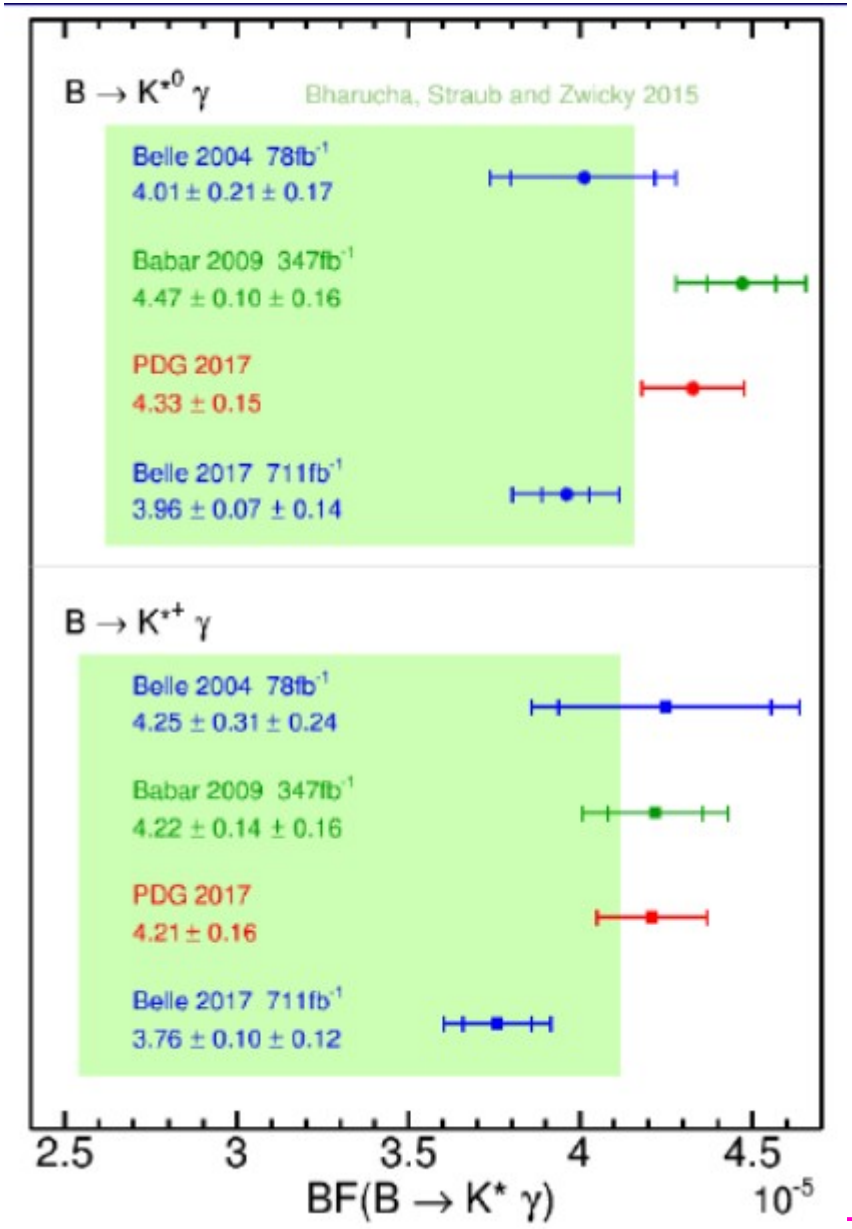
$$\Delta_{0+} = (+6.2 \pm 1.5 \pm 0.6 \pm 1.2)\%,$$
$$\Delta A_{CP} = (+2.4 \pm 2.8 \pm 0.5)\%,$$
$$\bar{A}_{CP} = (-0.1 \pm 1.4 \pm 0.3)\%,$$

first evidence of isospin violation in $K^*\gamma$!

Improvements are mentioned in next slides...

BF of $B \rightarrow K^*(892)\gamma$

- New **Belle** result is consistent with the previous measurements
- smaller (~10%) than **BaBar [Phys. Rev. Lett. 103, 211802 (2009)]** result which dominated the **PDG** average.
- Also consistent with the theoretical predictions by **Bharucha, Starub and Zwicky.** [J. High Energy Phys. 08 (2016) 098.]
- Most precise measurement of the BF(**$B \rightarrow K^*(892)\gamma$**) and splits the difference Between theory and experiment.



Result: BF ratio

- Sensitive to annihilation diagrams
- Belle measurement from 121 fb^{-1} of data at Y(5S) for BF ($B_s \rightarrow \varphi\gamma$) is used

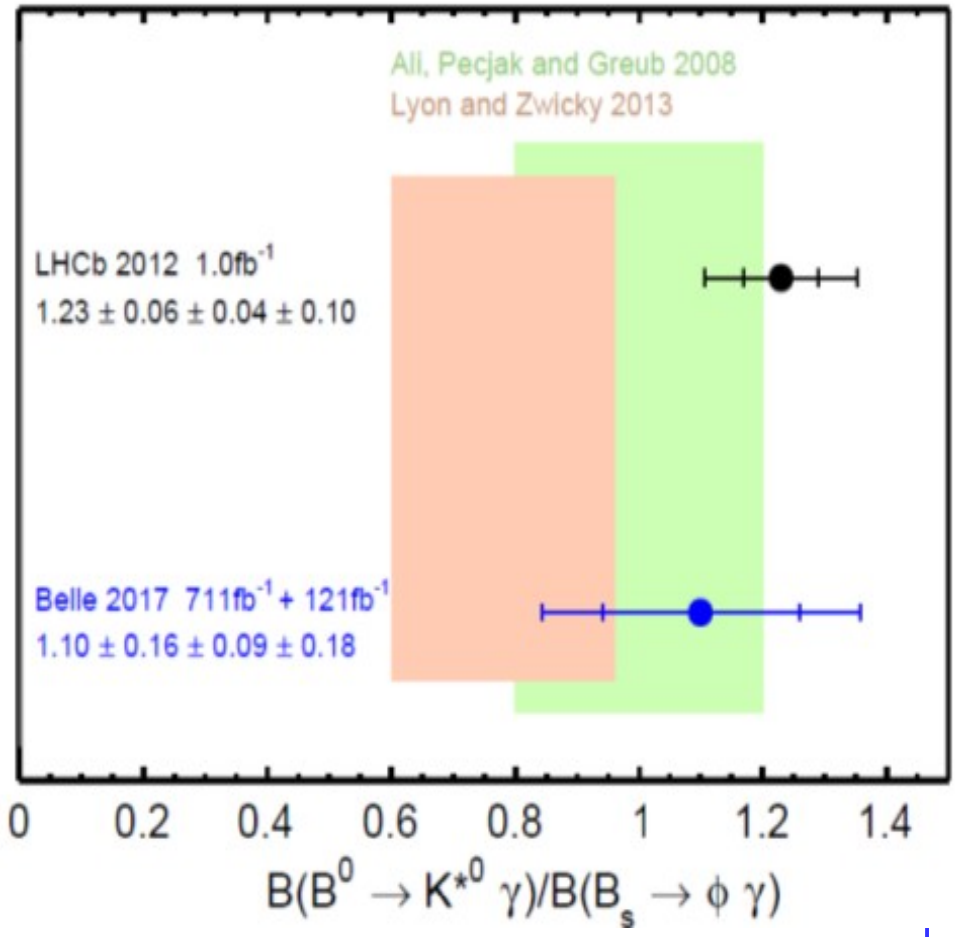
[Phys. Rev. D 91, 011101 (2015)]

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

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

$1.10 \pm 0.16 \pm 0.09 \pm 0.18$

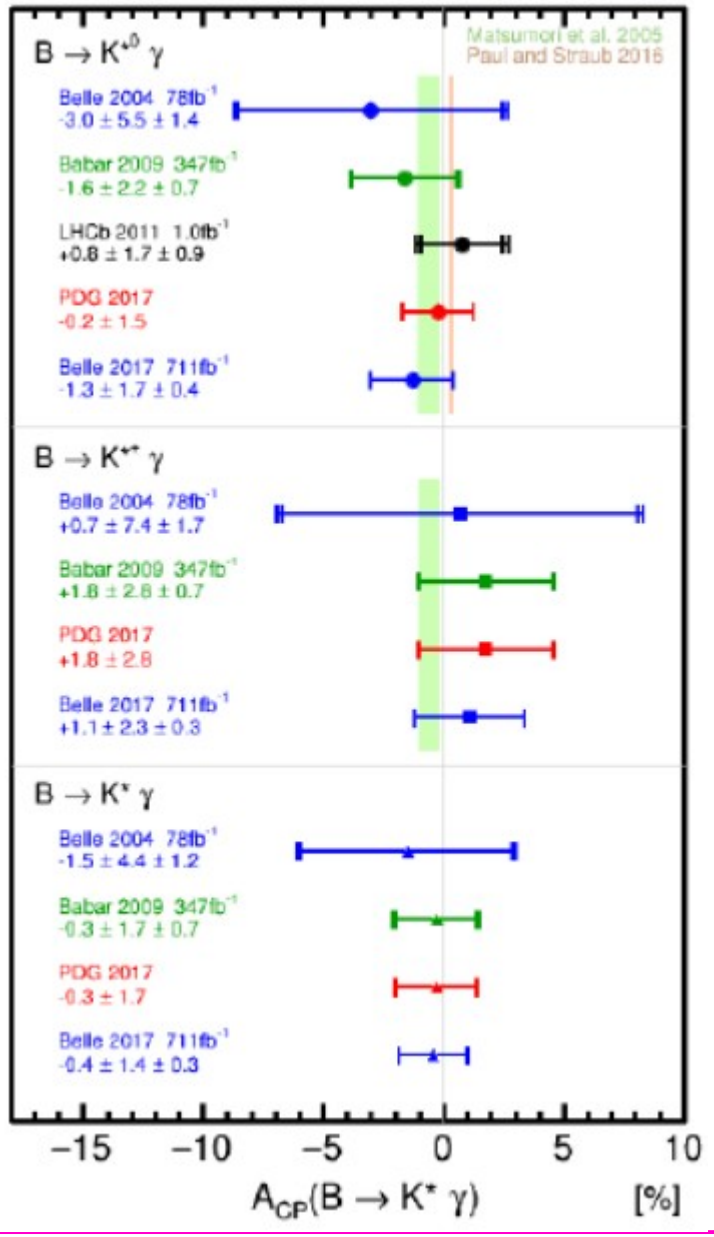
- **Belle** result is consistent with **LHCb** [Nucl. Phys. B 867, 1 (2013)], and theoretical predictions by **Ali, Pecjak and Greub** [Eur. Phys. J. C 55, 577 (2008)] and **Lyon and Zwicky** [Phys. Rev. D 88, 094004 (2013)]



Result : A_{CP} ($B \rightarrow K^*(892)\gamma$)

- New **Belle** results are most precise to date

- Consistent with zero and previous measurements by **BaBar** [Phys. Rev. Lett. 103, 211802 (2009)] and **LHCb** [Nucl. Phys. B 867, 1 (2013)].
- Consistent with theoretical predictions within the SM by **Matsumori *et al*** [Phys. Rev. D 72, 014013 (2005)] and **Paul and Straub** [arXiv:1608.02556].
- $\Delta A_{CP} = (+2.4 \pm 2.8 \pm 0.5)\%$ consistent with zero.



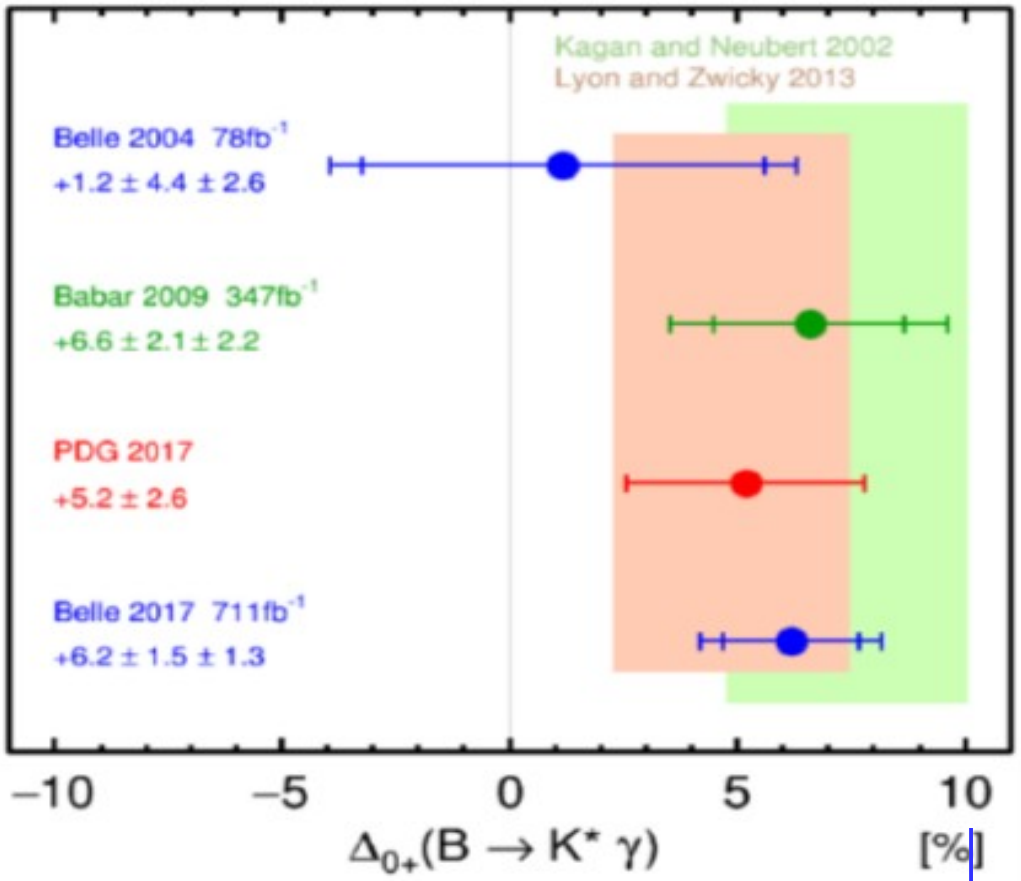
Result : Δ_{0+} ($B \rightarrow K^*(892)\gamma$)

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

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

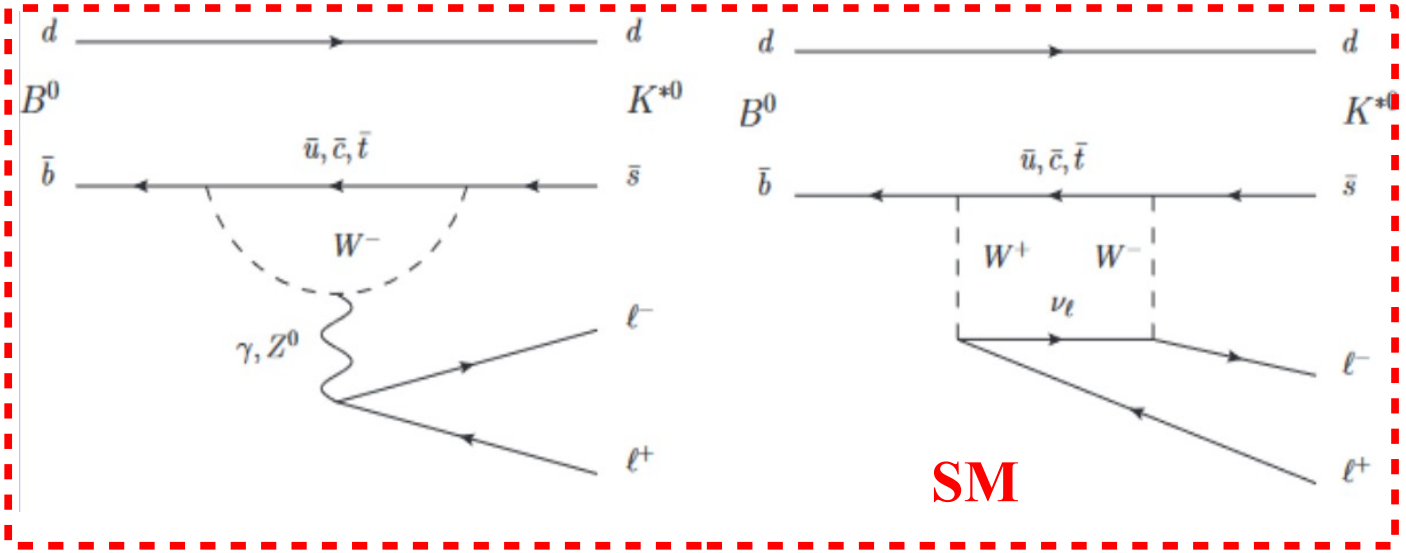
- Dominant uncertainties are statistical one and due to f_{+-}/f_{00}

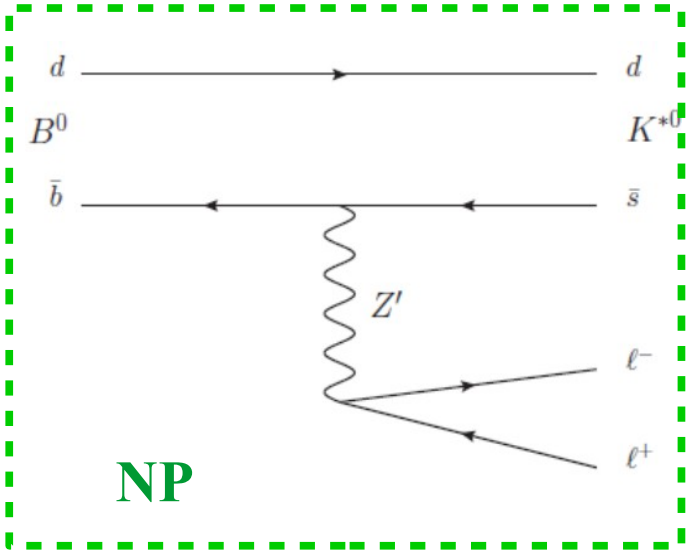
- New **Belle** result is consistent with **BaBar** [Phys. Rev. Lett. 103, 211802 (2009)], and also theoretical predictions within the SM by **Kagan and Neubert** [Phys. Lett. B 539, 227 (2002)] and **Lyon and Zwicky** [Phys. Rev. D 88, 094004 (2013)]



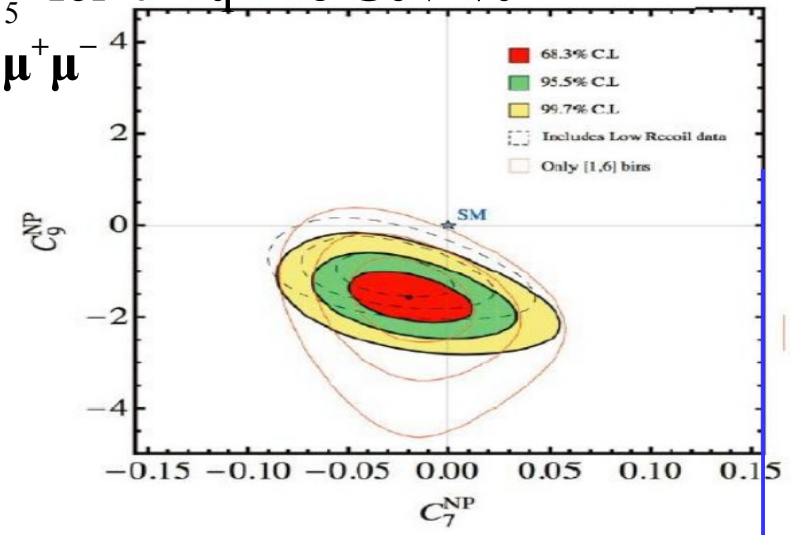
first evidence of isospin violation in $K^*\gamma$!

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





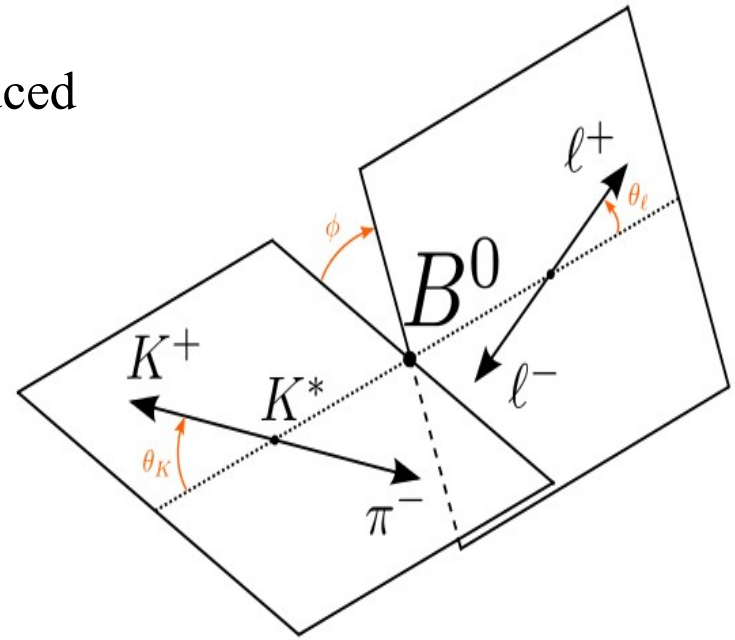
- LHCb reported 3.4σ deviation from a SM prediction in P_5' for $4 < q^2 < 8$ GeV^2 /c^2 which was obtained from full angular analysis of $B^0 \to \mathbf{K^* \mu^+ \mu^-}$
- Global fit to radiative and EW penguin B decays gives Wilson coefficient C_9^{NP} deviated about -1 from SM values
- Motivates to check lepton flavor dependence in angular analysis.



P'_4 and P'_5 observables

With a transformation of the angles, the dimension is reduced to three free parameters

Each transformation remains three observables S_j , F_L and S_3

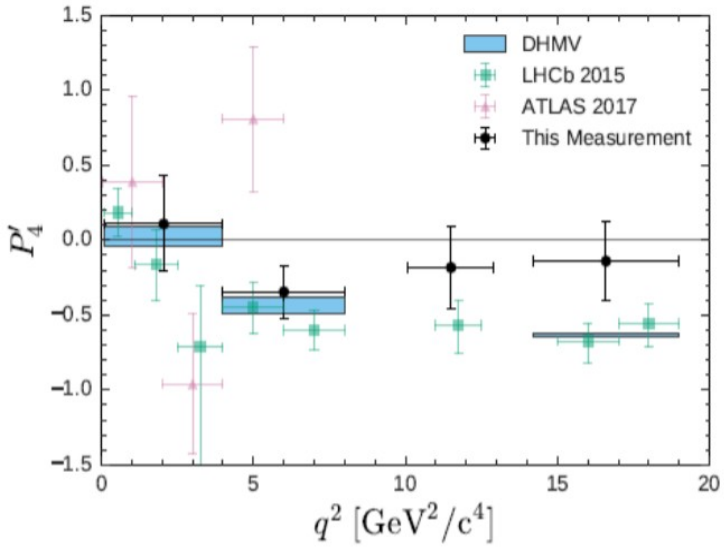


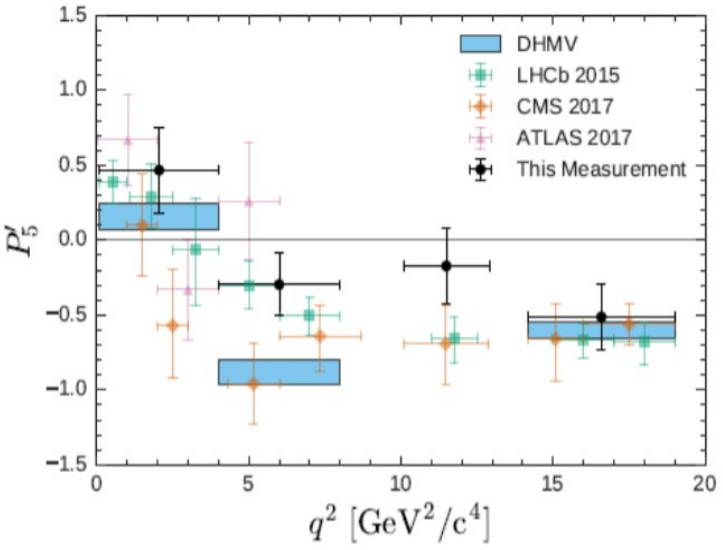
$$P'_{i=4,5,6,8} = \frac{S_{j=4,5,7,8}}{\sqrt{F_L(1-F_L)}},$$

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

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

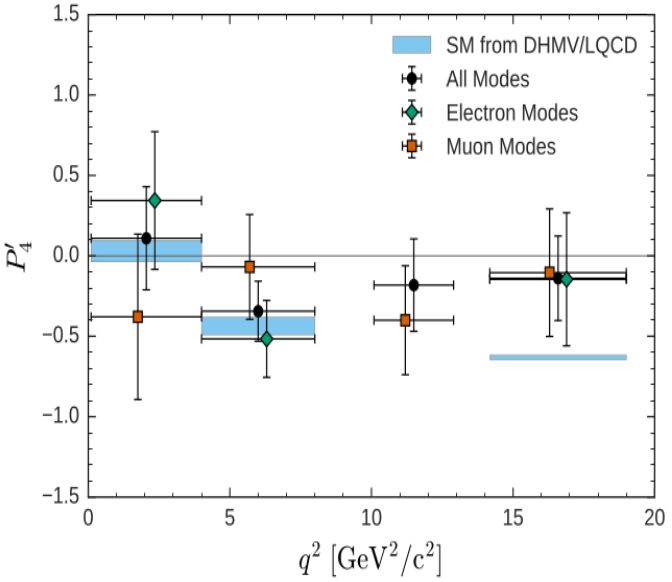
P'_4 and P'_5 observables

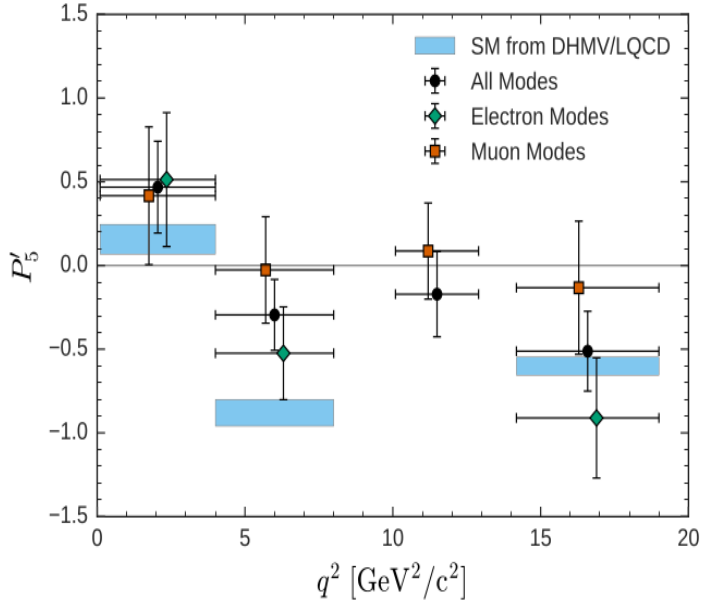




Combined Lepton Flavor

- Compatible with the SM
- Similar central values for the P_5' anomaly with 2.5σ tension.



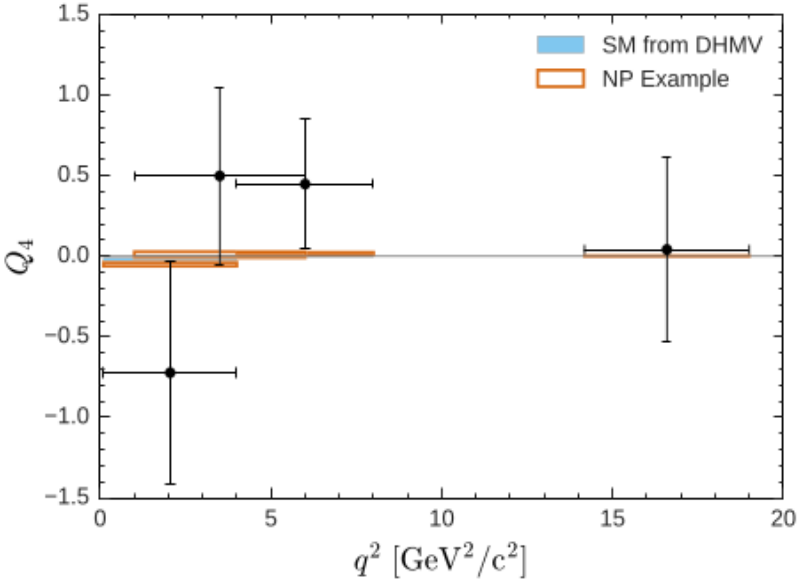


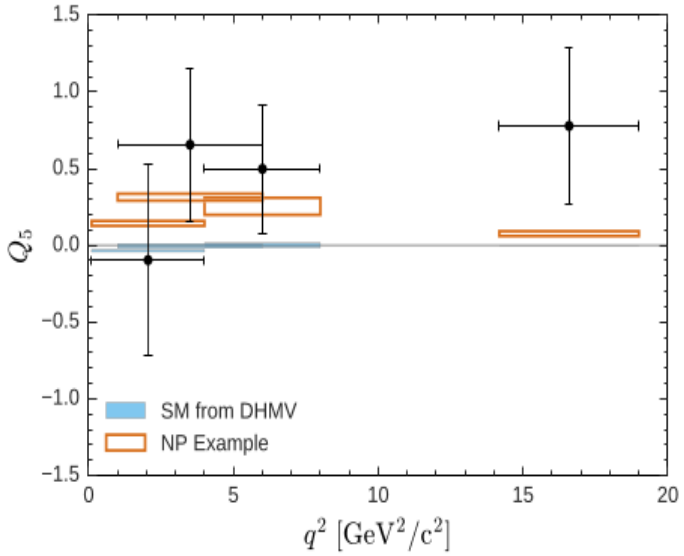
Separate Lepton Flavor

- **Muon** mode with 2.6σ (largest deviation)
- **Electron** mode with 1.1σ
- Test on lepton flavor universality

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

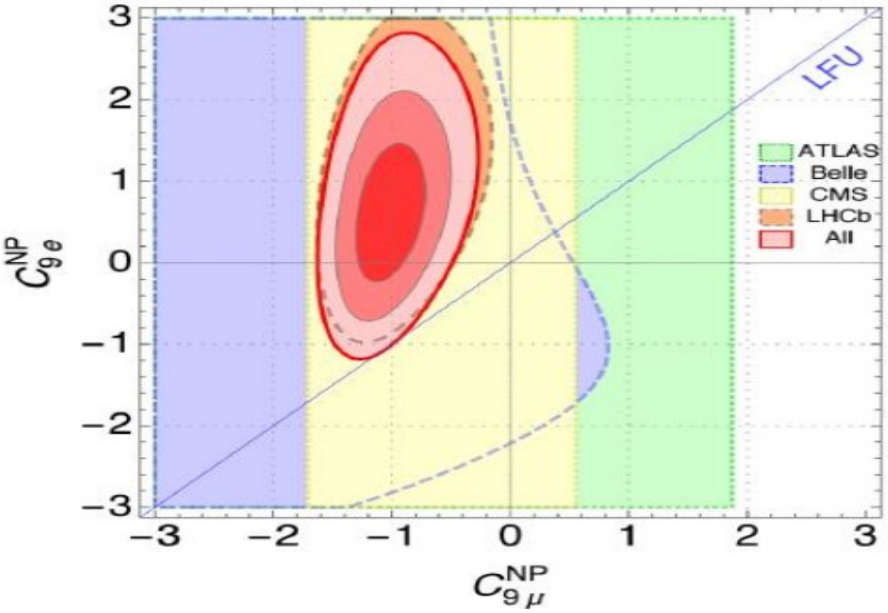
Lepton flavor universality





•$Q_i = P'_i(\mu) - P'_i(e)$
[JHEP 10, 075 (2016)]

• Deviation from zero very sensitive to NP

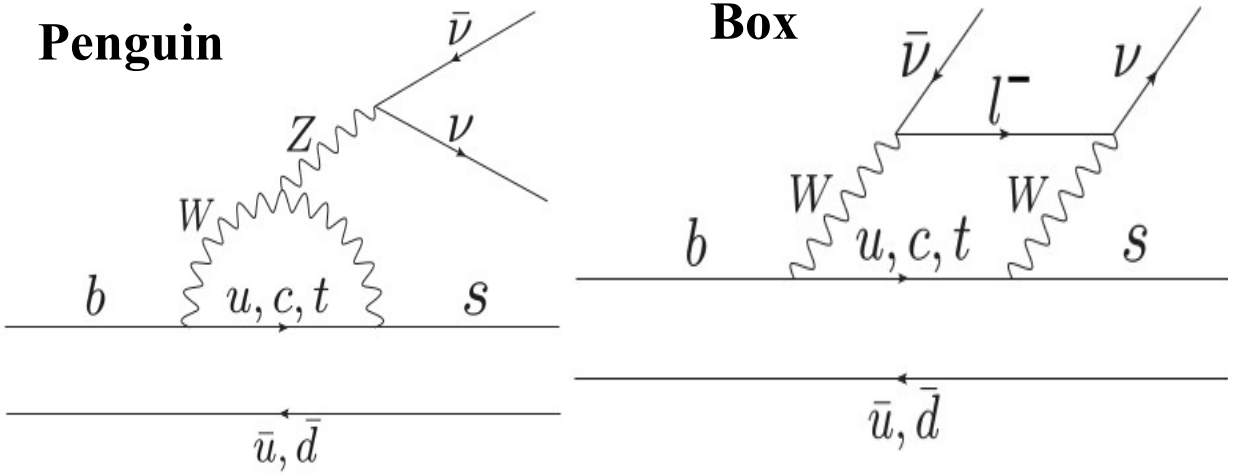


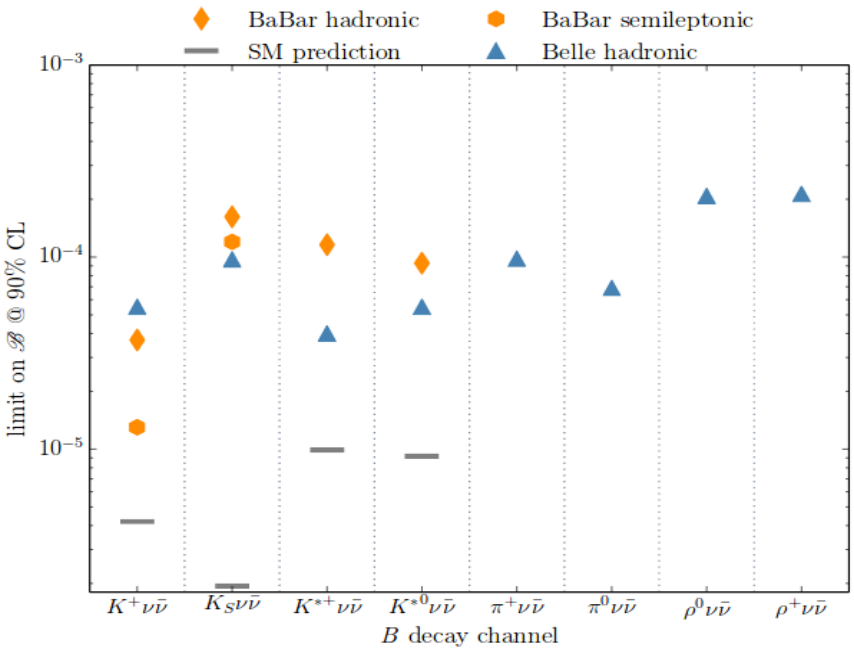
• No significant deviation from zero is discerned.
• Q_4 and Q_5 observables in agreement with SM and favoring NP scenario.
[Phys. Rev. Lett. 118, 111801 (2017)]

• Global fits including P_5' Q_5 R(K*), $B_s \rightarrow \mu\mu$, $b \rightarrow s\gamma$ suggests $C_{9\mu}^{NP} \approx -1.1$

arXiv:1704.05340

Search for B→h(*)νν





- Proceeds via penguin or box diagrams
- Theoretically very clean channel (no charm loops)
- Experimentally challenging, tagging of companion B meson needed
- Hadronic tagging already measured at Belle
  [Phys.Rev.D87 111103 (2013)]
- Semileptonic tagging in this analysis.

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

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

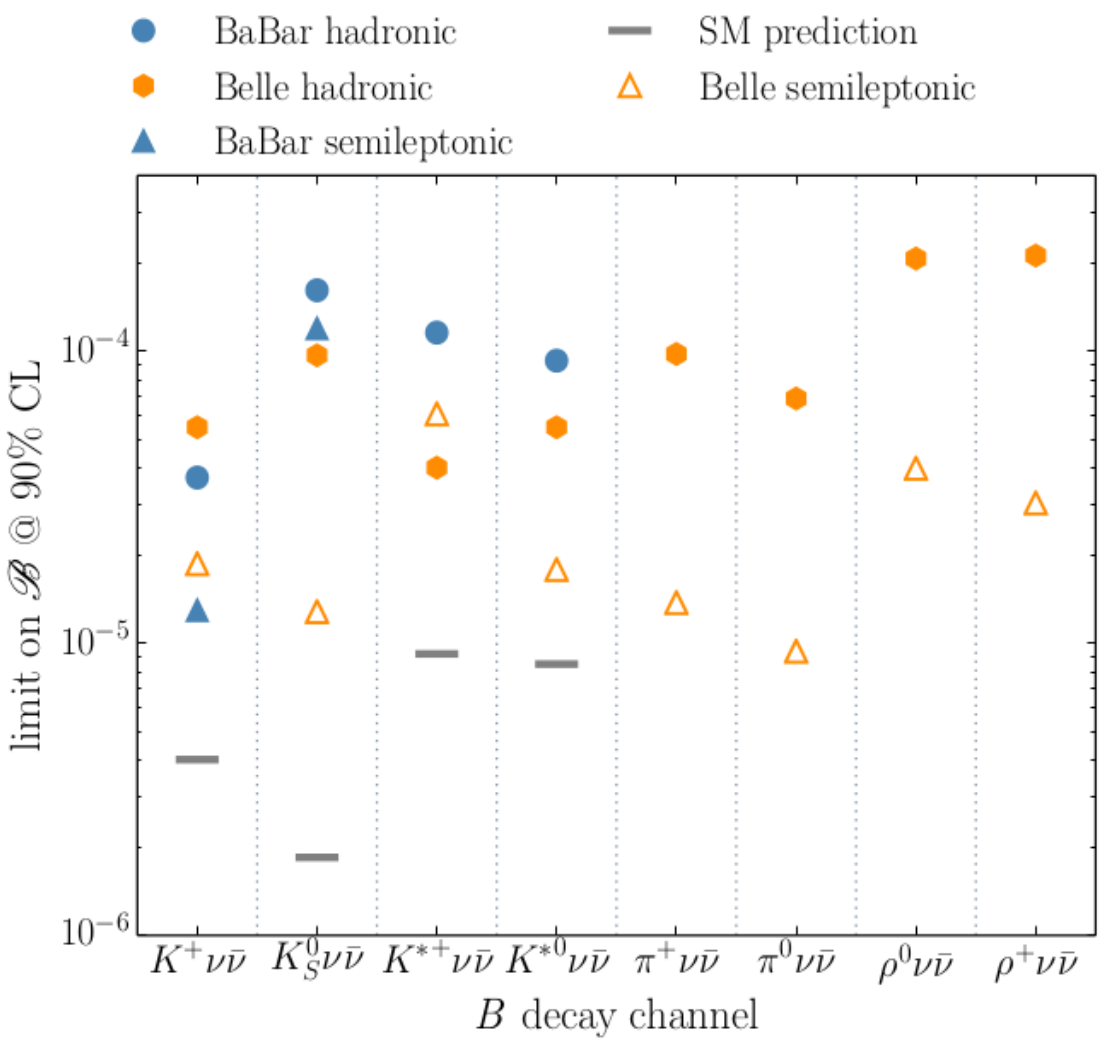
- h (*) = K^+ , K_S^0, K^{*0},π^+ , π^0 ,ρ^+ and ρ^0

Results of B→h(*)νν

- h (*) = K^+ , K_S^0, K^{*0},π^+ , π^0 ,ρ^+ and ρ^0

- The limits on the branching fraction for the $B^0 \to K_S^0 \nu\bar{\nu}$, $B^0 \to K^{*0} \nu\bar{\nu}$, $B^+ \to \pi^+ \nu\bar{\nu}$, $B^0 \to \pi^0 \nu\bar{\nu}$, $B^+ \to \rho^+ \nu\bar{\nu}$, and $B^0 \to \rho^0 \nu\bar{\nu}$ channels are the most stringent to date

$$\mathcal{B}(B \to K\nu\bar{\nu}) < 1.6 \times 10^{-5},$$
$$\mathcal{B}(B \to K^*\nu\bar{\nu}) < 2.7 \times 10^{-5},$$
$$\mathcal{B}(B \to \pi\nu\bar{\nu}) < 0.8 \times 10^{-5},$$
$$\mathcal{B}(B \to \rho\nu\bar{\nu}) < 2.8 \times 10^{-5}.$$



- B→Kνν and of B →K^*νν :

R_K < 3.9 R_{K^*}<2.7 @ C.L 90%

The largest signal contribution is observed in the $B^+ \to K^{*+} \nu\bar{\nu}$ with a significance of 2.3σ

Summary

• New measurement of $B \rightarrow K^*(892)\gamma$ performed

First evidence for Isospin Violation in $b \rightarrow s$ transition with 3.1σ significance

All the measurements are most precise to date

Used to constrain new physics

• Current A_{CP} measurements are dominated by the statistical uncertainty; thus, the upcoming Belle II experiment will further reduce the uncertainty. To observe the isospin violation with 5σ significance at Belle II, reduction of the dominant uncertainty due to f_{+-}/f_{00} is essential, and can be performed at both Belle and Belle II.

• First Lepton Flavor dependent angular analysis of $B \rightarrow K^* l^+ l^-$ performed

*** See Saurabh's talk on 14th December 2017**

Consistent with both SM and NP with $C_{9\mu}^{NP} \approx -1.1$

• Search for $B \rightarrow h(*)\nu\nu$

Most stringent limits till date in most channels

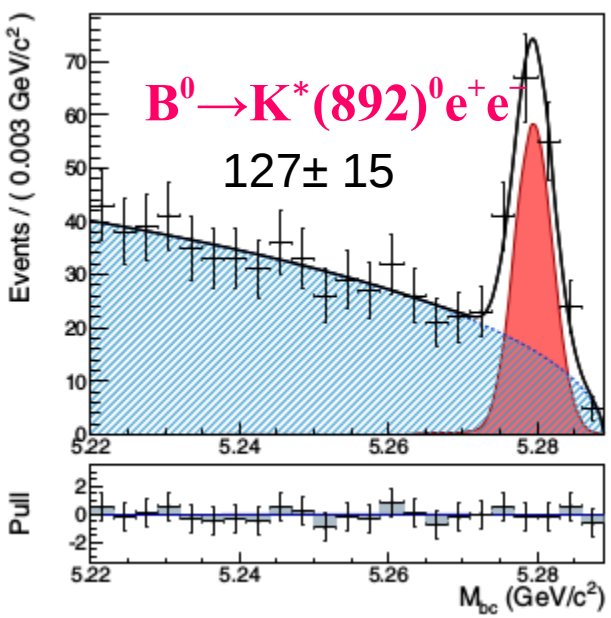
Close to SM prediction in K (*) mode

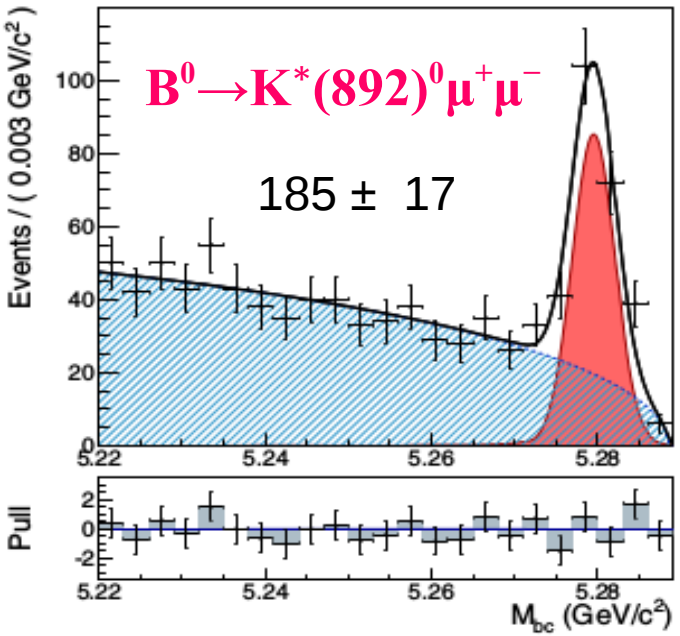
Golden channel for Belle II

Thank you !!

Backup

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





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

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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]	$0.041 \pm 0.565 \pm 0.082$	$0.778 \pm 0.502 \pm 0.065$