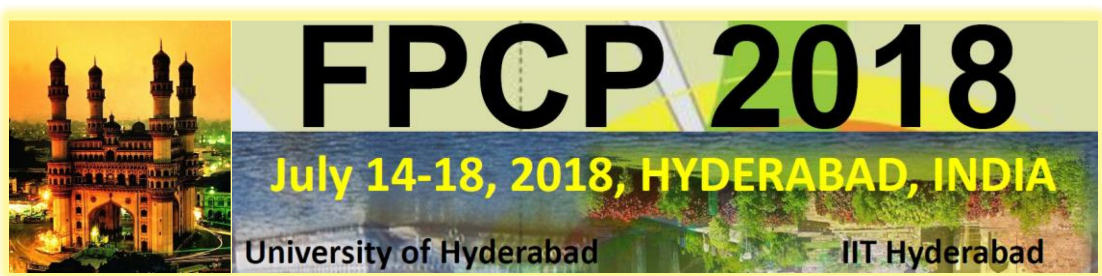
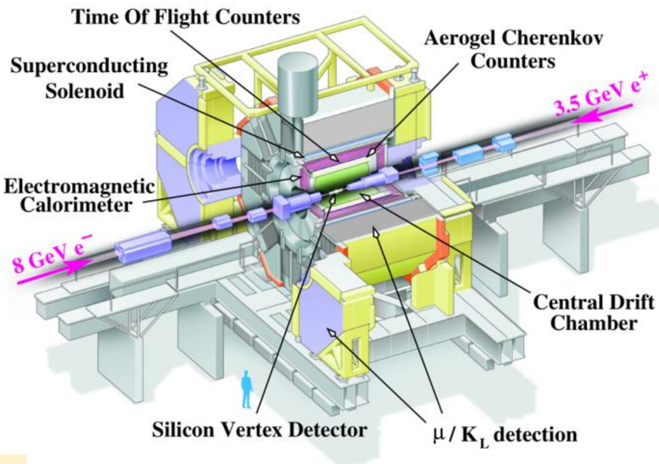
Radiative and EW penguin decays at e^+e^- B-factories

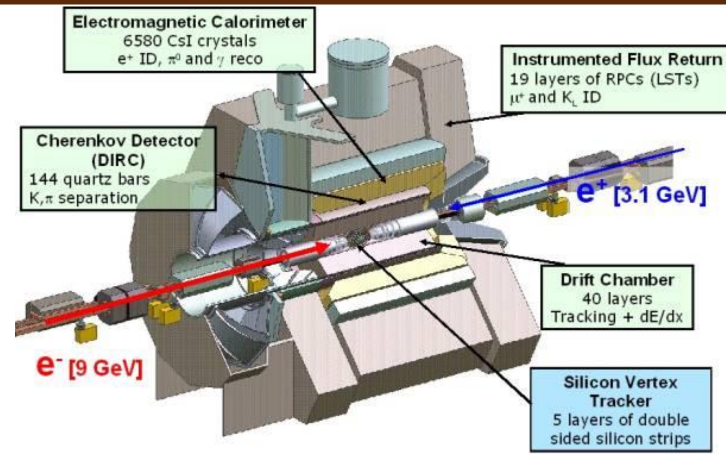
Saurabh Sandilya

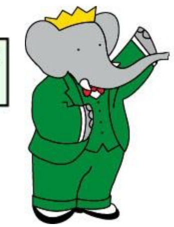
University of Cincinnati
(On Behalf of the Belle/BaBar Collaboration)



B-factories



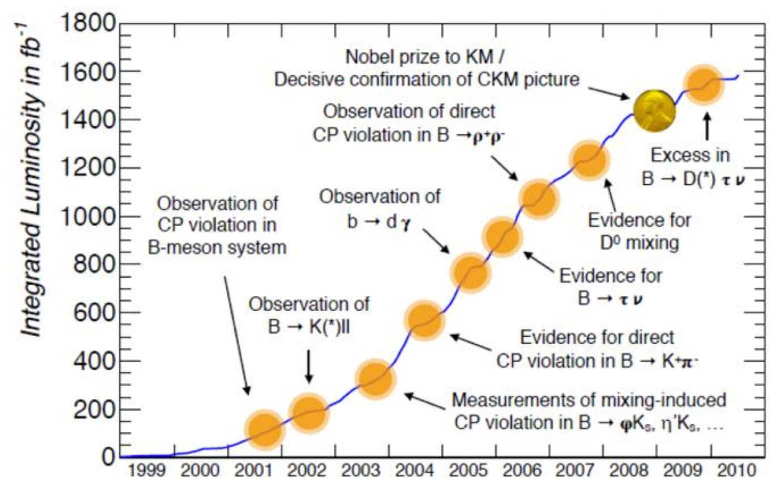




Success

(Belle and BaBar) had successful operational period with a total recorded sample over 1.5 ab^{-1} (1.25 x 10^9 B-meson pairs).

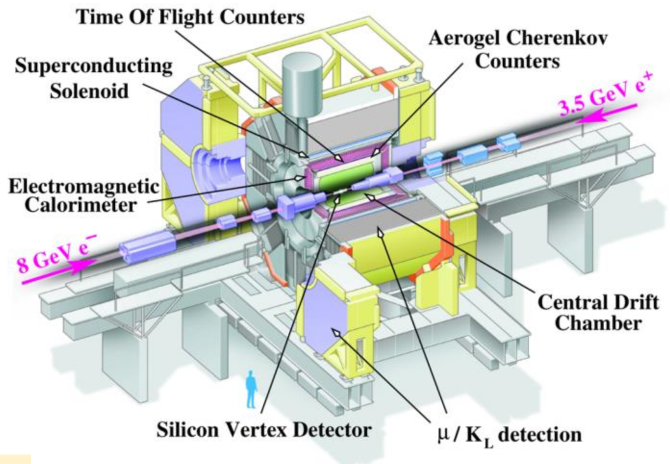
- Observation of CPV in B-meson system and confirmation of CKM paradigm.
- Still room for NP searches.

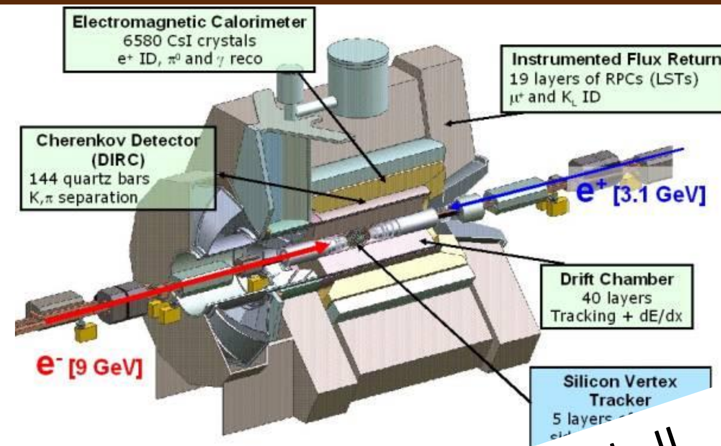


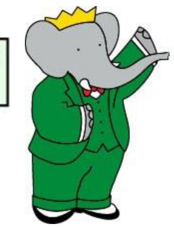
Advantages

- Very clean sample of quantum correlated B-meson pairs.
- Low background environment $\rightarrow$ efficient reconstruction of neutrals (π^0, η, ..)
- Dalitz plot analyses, missing mass analyses straight-forward.

B-factories







Success

(Belle and BaBar) had successful operational period with a total recorded sample over 1.5 ab^{-1} (1.25 x 10^9 B-meson pairs).

- Observation of CPV in B-meson system and confirmation of CKM paradigm.
- Still room for NP searches.

New born B-factory : Belle II
More on this: T. Browder (18^{th} July)

Advantages

- Very clean sample of quantum correlated B-meson pairs.
- Low background environment $\rightarrow$ efficient reconstruction of neutrals (π^0, η, ..)
- Dalitz plot analyses, missing mass analyses straight-forward.

Outline

- **Measurement of $B \to K^*\gamma$ and $B \to X_s\gamma$** NEW

  [Belle, PRL 119, 191802 (2017)] and [Belle conf., arXiv:1807.04236]

- **Measurement of time-dep. CP asymmetries $B^0 \to K_S^0\eta\gamma$**

  [Belle, PRD 097, 092003 (2018)]

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

  [Belle, PRL 118, 111801 (2017)]

- **Search for LFV decay $B \to K^{*0}\mu^+e^-$** NEW

  [Belle, arXiv:1807.03267 [submitted to PRD (R)]

- **Search for the $B^+ \to K^+ \tau^+ \tau^-$**

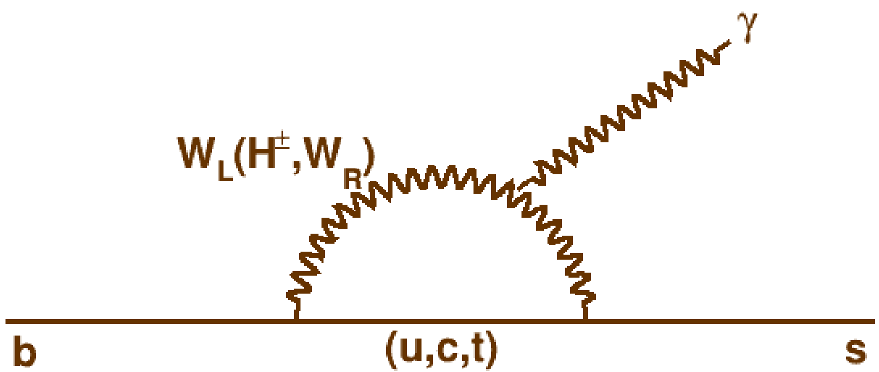
  [BaBar, PRL 118, 031802 (2017)]

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

  [Belle, PRD (R) 96, 091101 (2017)]

$B \to K^*\gamma$

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



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

- Among $b \to s\gamma$ transitions, $B \to K^*\gamma$ is one of the most important channel:
  - Cleanest exclusive decay among $B \to X_s\gamma$
  - Large BF: $\sim 4 \times 10^{-5} \to$ about 12% of inclusive $B \to X_s\gamma$

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

Ratios with $B \to K^*\gamma$

- Ratios of BF cancels important uncertainties (including the form-factor related).
- CP asymmetry (A_{CP}):

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

- Isospin asymmetry (Δ_{0+}):

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

- Difference of CP asymmetry between charged and neutral B (ΔA_{CP}):

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

(ΔA_{CP} will be useful to identify NP once A_{CP} is observed)

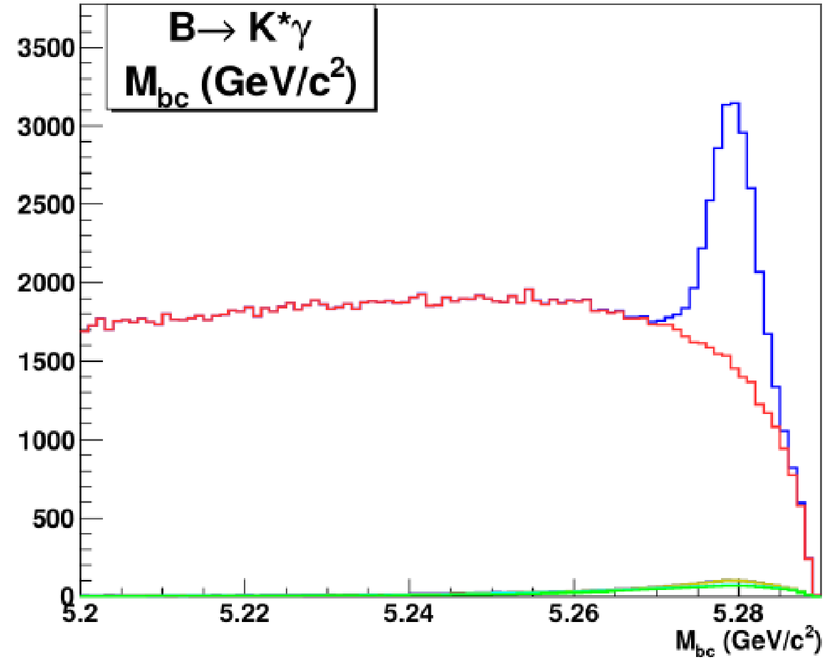
- Ratio of the B.Fs. : $BF(B^0 \to K^{*0}\gamma)/BF(B_s \to \phi\gamma)$

- Four sub-decay modes:
  - K^{*0} : $K_s^0\pi^0$ $K^+\pi^-$
  - K^{*+} : $K_s^0\pi^+$ $K^+\pi^0$

Self-tagging

- Signal Selection:
  - -0.2 GeV < ΔE < 0.1 GeV
  - 5.20 GeV/c^2 < M_{bc} < 5.29 GeV/c^2
  - $|M_{K\pi} - M_{K^*}|$ < 75 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.

Signal
Continuum
$B \to X_s\gamma$
Rare B other than $X_s\gamma$



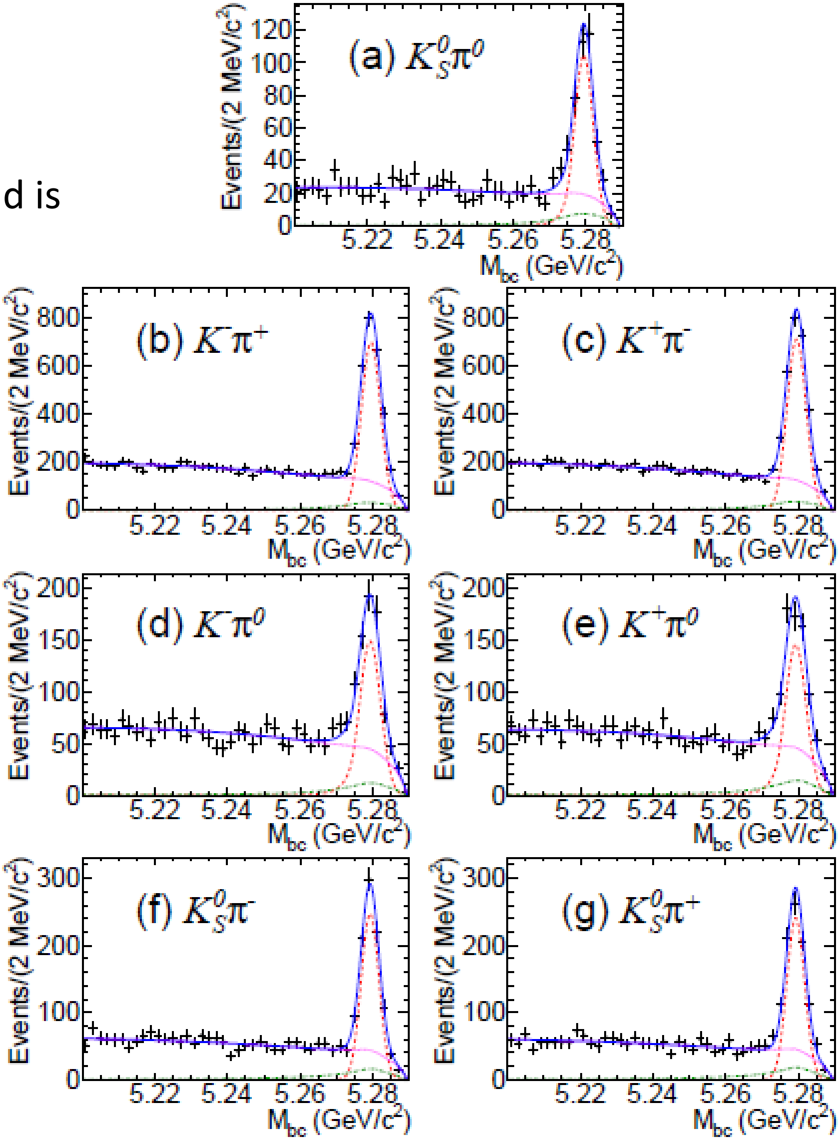
$M_{\rm bc}$ distribution summed four channels "with" $M(K\pi)$ selection after $\pi^0\eta$ veto

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
  - BB bkg : ARGUS + Bifurcated Gaussian

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

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



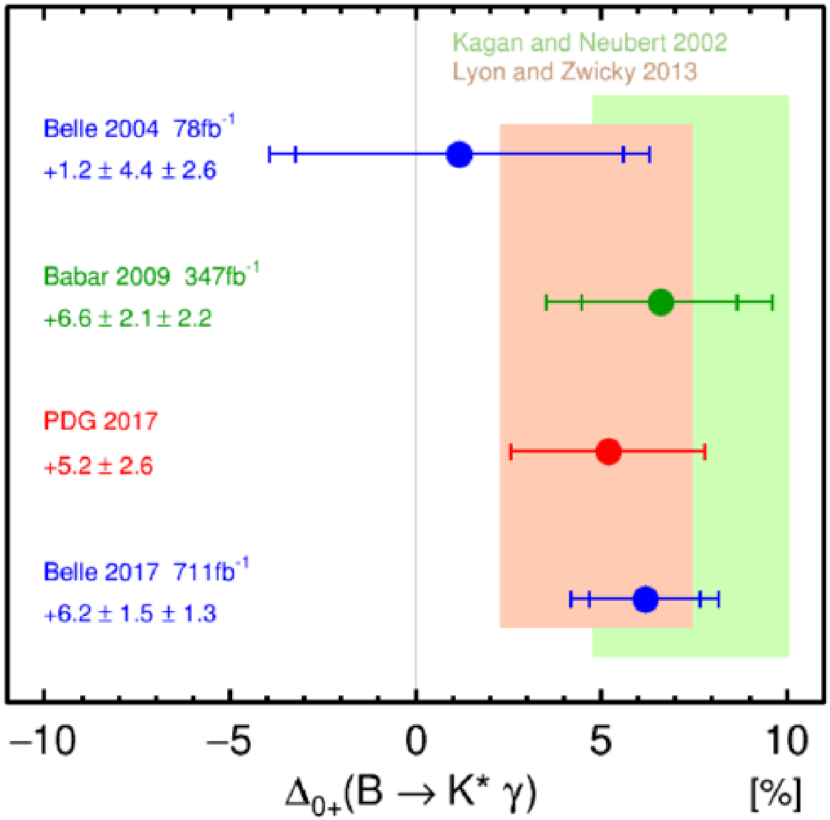
Result: Δ_{0+}

- First evidence of isospin violation in $b \to s$ transition with 3.1σ significance.

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

- 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)].

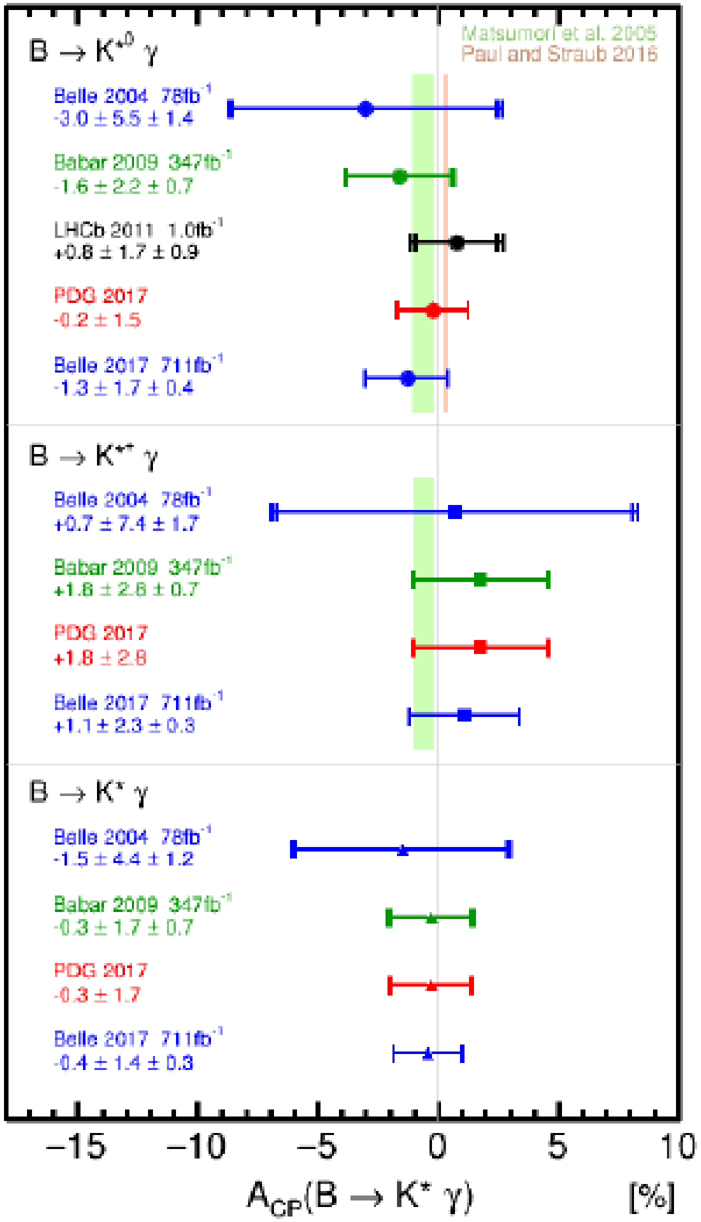


- This result will be used to constrain NP

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

Result: A_{CP}

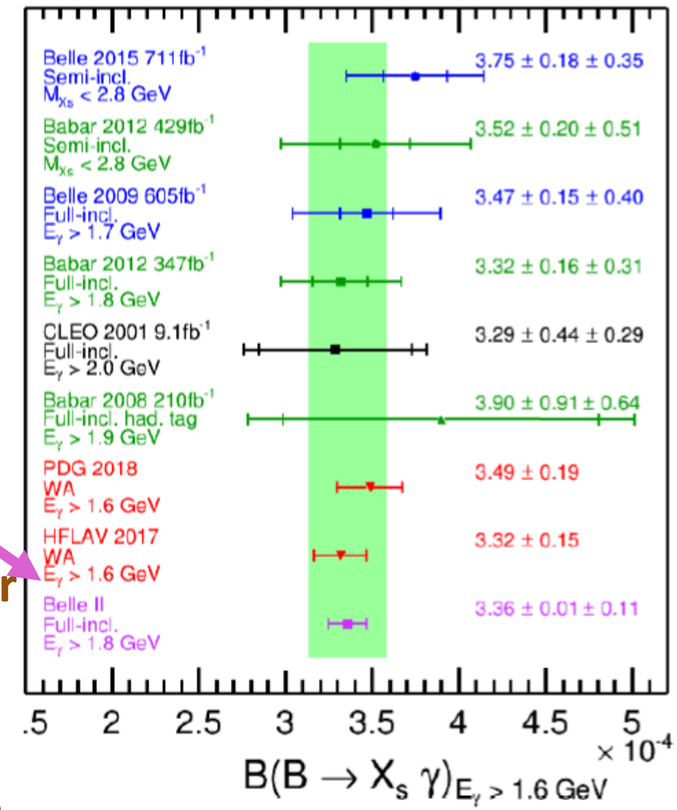
- New **Belle** results are most precise to date.
- Consistent with zero and previous measurements by **BaBar** [Phys. Rev. Lett. 103, 211802 (2009)] and **LHCb** [Nucl. Phys. B 867, 1 (2013)].
- Consistent with theoretical predictions within the SM by **Matsumori et al** [Phys. Rev. D 72, 014013 (2005)] and **Paul and Straub** [JHEP04(2017)027].
- $\Delta A_{CP} = (+2.4 \pm 2.8 \pm 0.5)\%$ consistent with zero.



$B \to X_s \gamma$

- For BF. [$B \to X_S \gamma$] Exp. and theory are consistent – puts a strong limit on NP
- **Evaluation of constraint on BSM scenario depends crucially on both the central value and the uncertainties on the B.F.**
- **WA** and **theoretical prediction** and comparable precision ~ 7%.
- At Belle II, precision on the BF will be 3% level.
- **Need to reduce theoretical uncertainty to search for NP!**
- Measurement of Isospin Asymmetry improves the theoretical uncertainty if the value is consistent with zero.

Misiak et. al (PRL 2015)



M. Misiak, Acta Phys. Polon. B 40, 2987 (2009)

M. Benzke, S. J. Lee, M. Neubert, G. Paz, JHEP 08 (2010) 099

- Also, If finite ΔA_{CP} is measured, it is clear sign of new physics

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

$B \to X_s\gamma$

- We reconstruct 38 Xs decay modes with M[Xs] < 2.8 GeV/c^2.
- 11 flavor non specific **(fns)** modes as marked * are only used for Δ_{0-} measurement.
- Five M_{bc} distributions (B+, B⁻,B^0 $\overline{B^0}$and fnsB) for on resonance data and three M_{bc} distributions (charged neutral and fns) for off-resonance data are fitted simultaneously to extract physics parameters.

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

$$A_{CP}^{\rm C} = \frac{N_{B^-} - N_{B^+}}{N_{B^-} + N_{B^+}}$$ charged

$$A_{CP}^{\rm N} = \frac{N_{\bar{B}^0} - N_{B^0}}{N_{\bar{B}^0} + N_{B^0}}$$ neutral

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

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*	$K^+K^-K_S^0\pi^0$

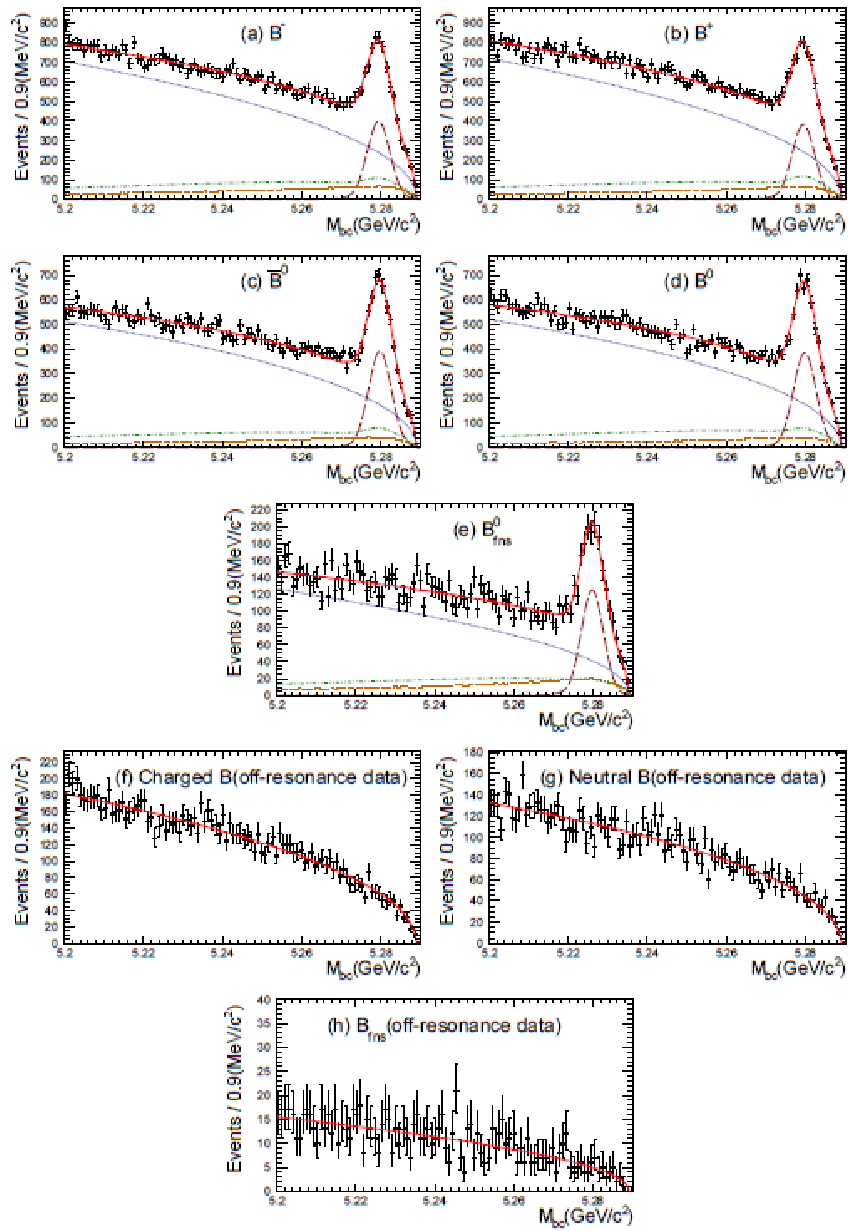
- We reconstruct 38 Xs decay modes with M[Xs] < 2.8 GeV/c^2.
- 11 flavor non specific **(fns)** modes as marked * are only used for Δ_{0-} measurement.
- Five M_{bc} distributions (B+, B⁻,B^0 $\overline{B^0}$ and fnsB) for on resonance data and three M_{bc} distributions (charged neutral and fns) for off-resonance data are fitted simultaneously to extract physics parameters.

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

$$A_{CP}^{\rm C} = \frac{N_{B^-} - N_{B^+}}{N_{B^-} + N_{B^+}}$$ charged

$$A_{CP}^{\rm N} = \frac{N_{\bar{B}^0} - N_{B^0}}{N_{\bar{B}^0} + N_{B^0}}$$ neutral

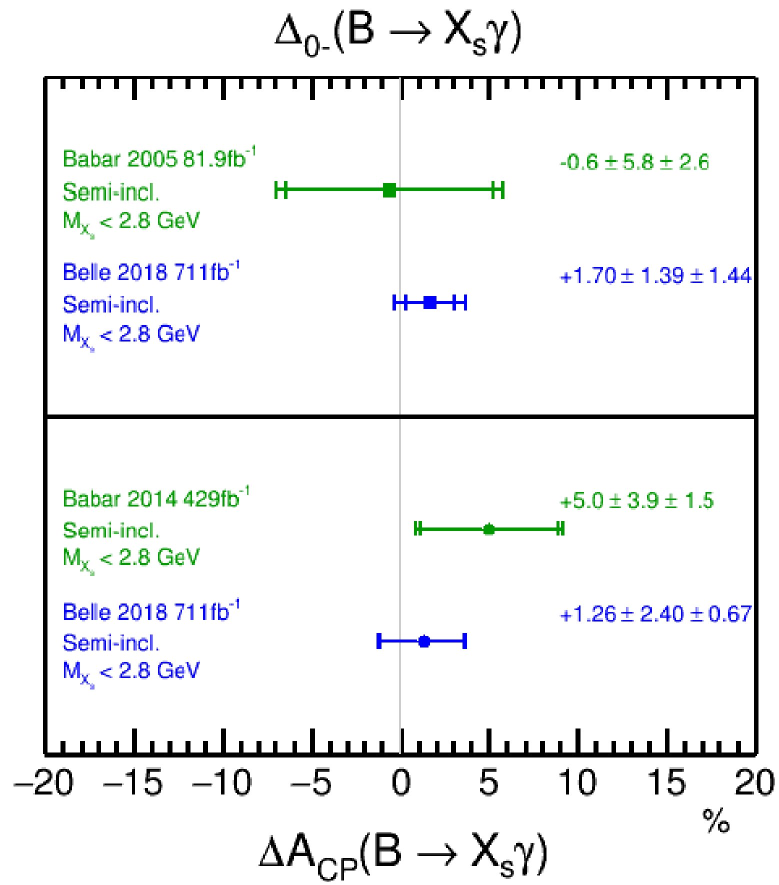
$$A_{CP}^{\rm tot} = \frac{(N_{B^-} + N_{\bar{B}^0}) - (N_{B^+} + N_{B^0})}{(N_{B^-} + N_{\bar{B}^0}) + (N_{B^+} + N_{B^0})}$$ combined



Results: $B \to X_s\gamma$

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

- The result for Δ_{0-} is consistent with zero:
  - Can be used to reduce the theory uncertainty for **BF[$B \to X_s\gamma$]**
- The result for ΔA_{CP} is consistent with zero:
  - Constrains NP models.
  - Strong limit on $\mathrm{Im}(C_7/C_8)$.
- Our A_{CP} measurement is also most precise till date, and is consistent null asymmetry and with WA value.

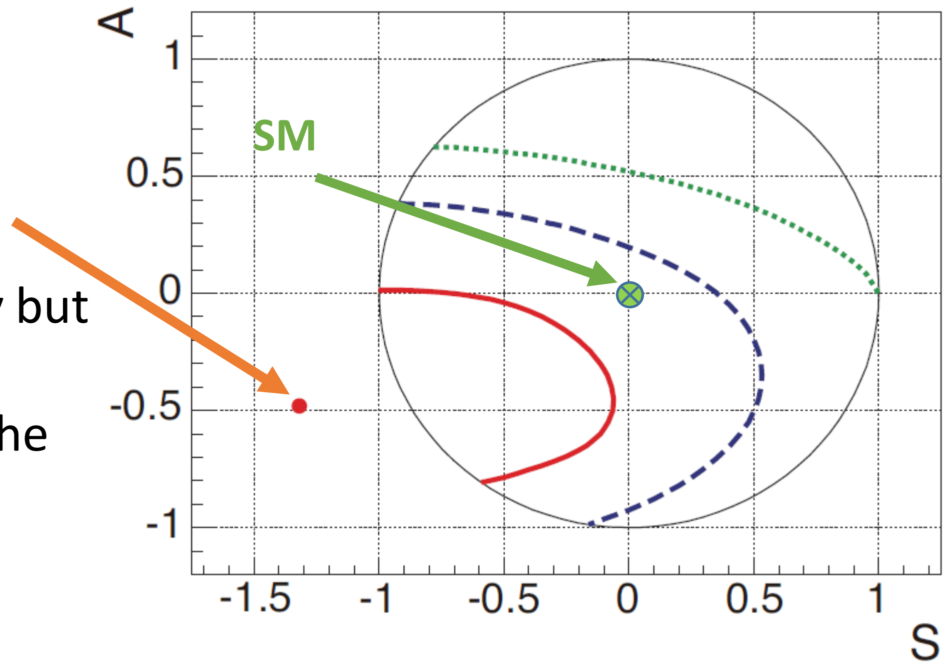


Measurement of time-dep. CP asymmetries $B^0 \to K_S^0 \eta\gamma$

- Mixing-induced CP asymmetry in an exclusive $b \to s\gamma$ CP eigenstate mode such as $\mathbf{B^0 \to K_S^0 \eta\gamma}$ is an excellent probe for particular class of NP scenario.
- In the SM, expected asymmetry $|S_{CP}| \approx \frac{2m_s}{m_b}\sin(2\phi_1) \sim$ a few %.
- NP with right handed current increases the fraction of right handed photon.
  - Interfere with the SM occurs and **large TDCPV possible**

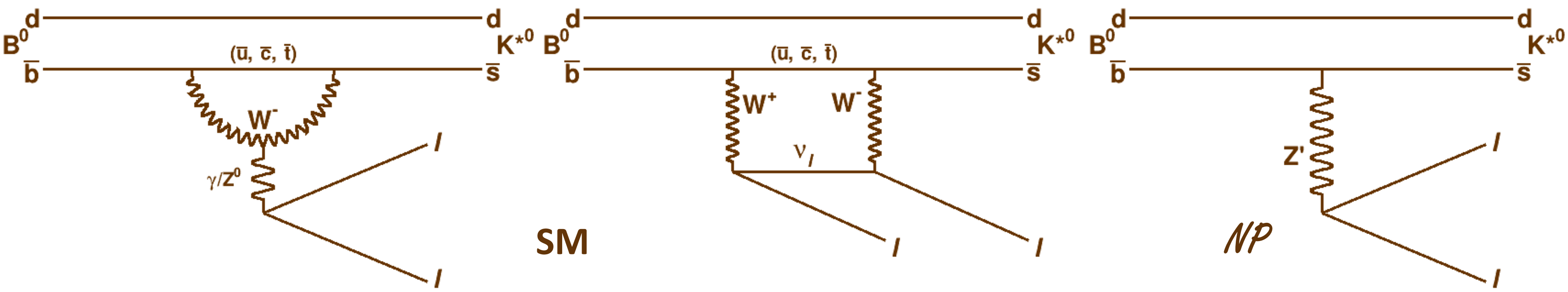
S = −1.32 ± 0.77(stat.) ± 0.36 (syst.)
A = −0.48 ± 0.41(stat.) ± 0.07(syst.)

This result is out of physical boundary but consistent with the null-asymmetry hypothesis within 2σ as well as with the SM predictions.



Belle [PRD97, 092003 (2018)]

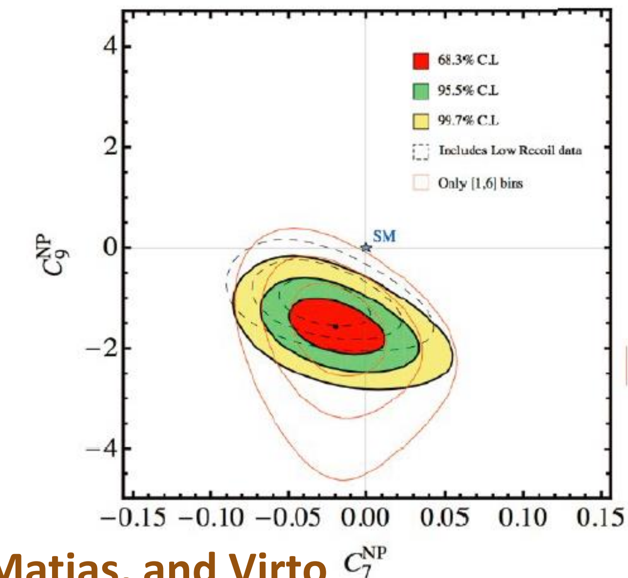
Angular Analysis of $B \to K^{*}\ell^{+}\ell^{-}$



- 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 $B^0 \to K^{*0}\mu^+\mu^-$.

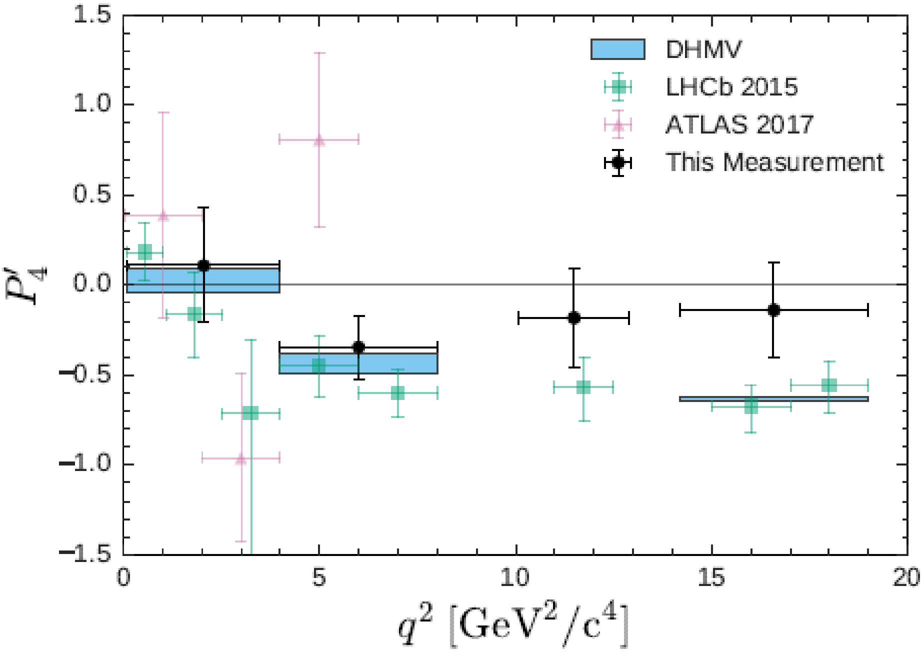
- Global fit to radiative and EW penguin B decays gives Wilson coefficient C_9^{NP} deviated about -1 from SM values

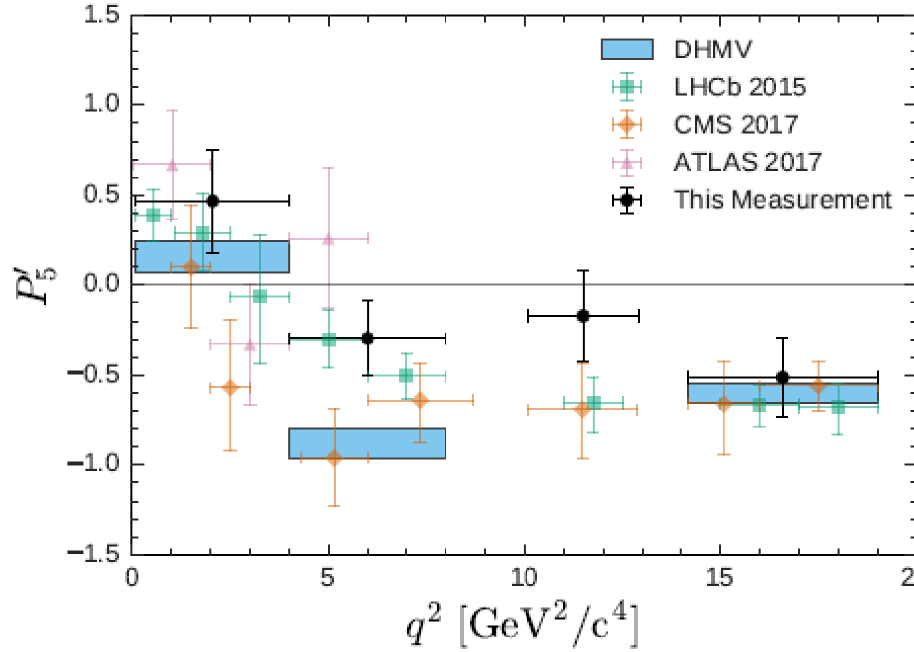
- Motivates to check lepton flavor dependence in angular analysis.



Descotes-Genon, Matias, and Virto
PRD 88 074002 (2013)

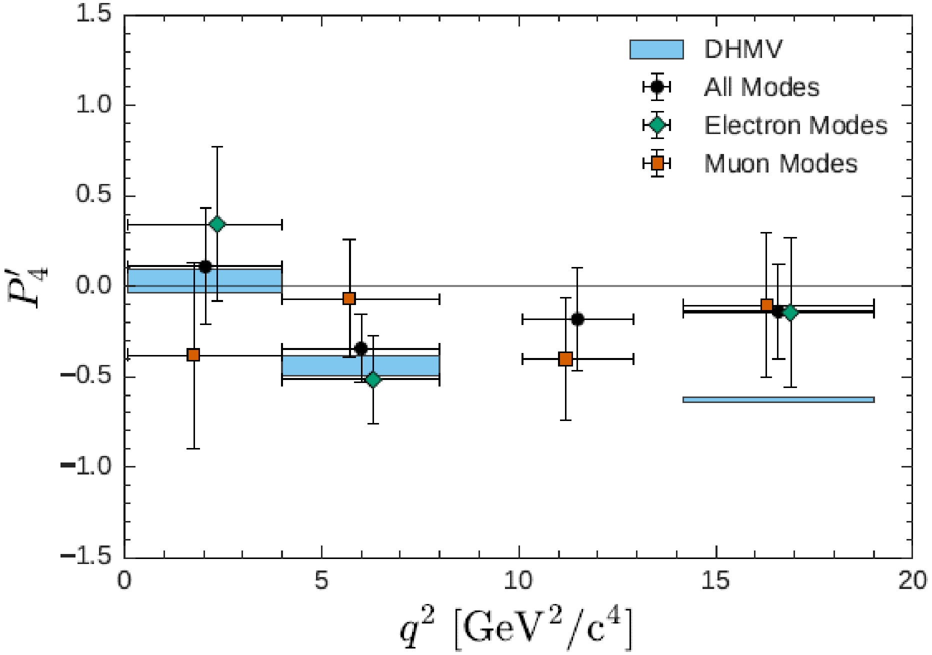
Result P_5': for Combined Data

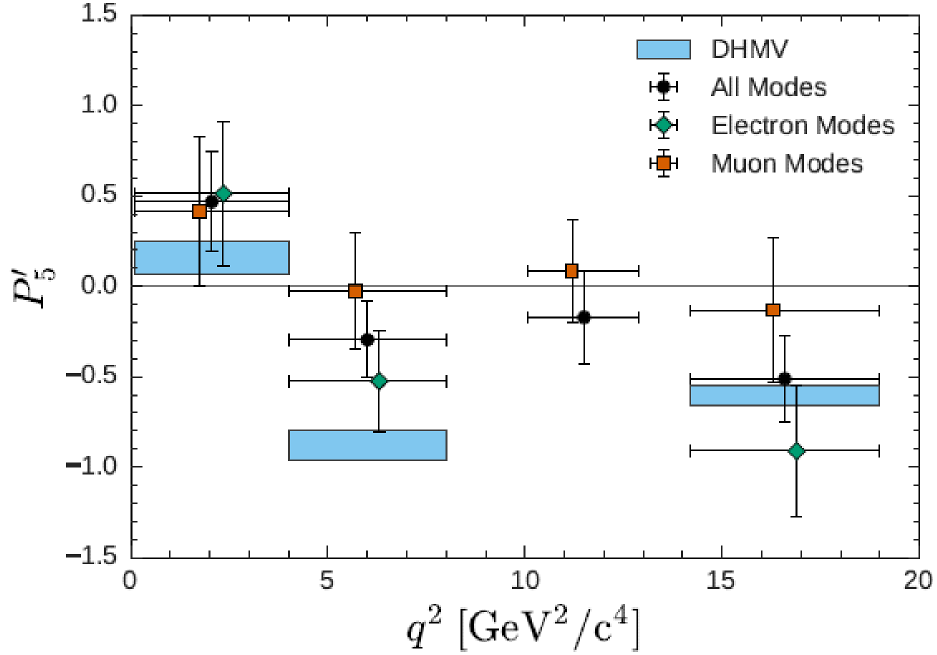




- Measurements are compatible with the SM.
- Similar central values for the P_5' anomaly with 2.5σ tension.

Result - Separate Lepton Flavor!

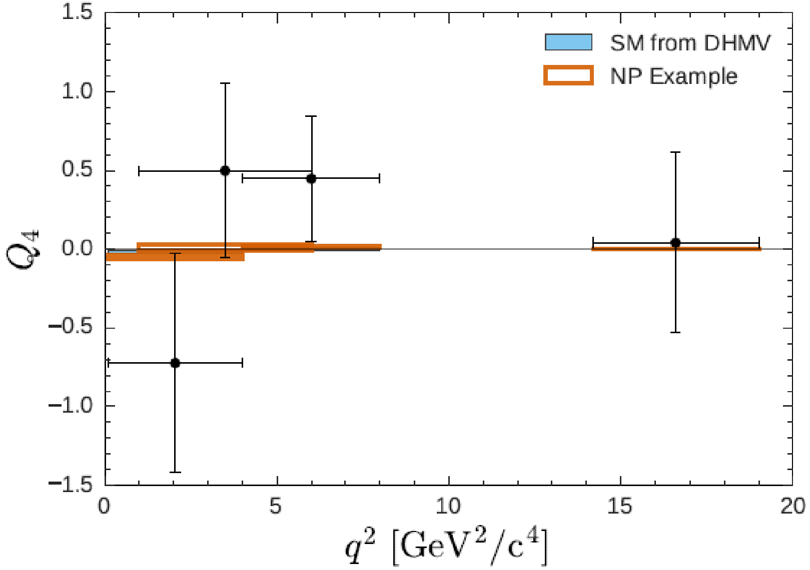


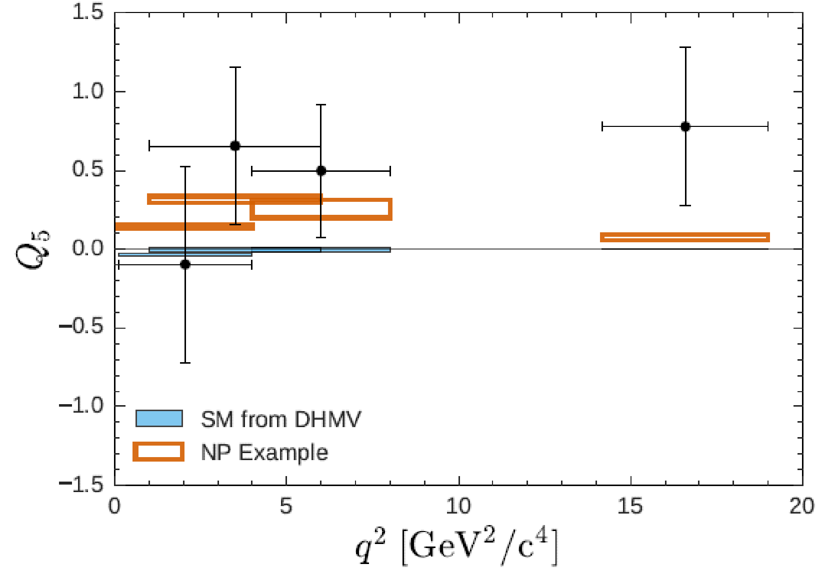


- The Largest deviation in the muon mode with 2.6σ.
- Electron mode is deviating with 1.1σ.

Result - Separate Lepton Flavor!

- Test lepton flavor universality.
- Observables $Q_i = P'^{\mu}_i - P'^{e}_i$. [JHEP 10, 075 (2016)]
- Deviation from zero very sensitive to NP.

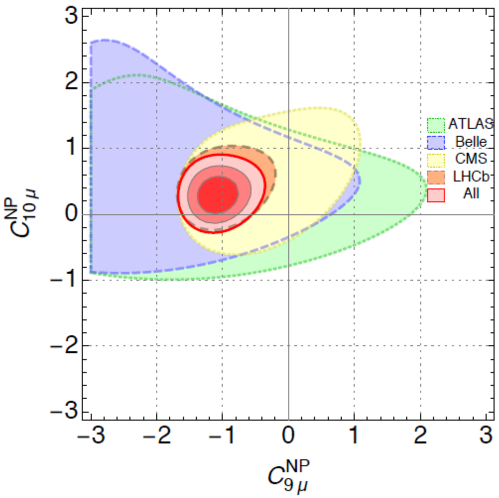


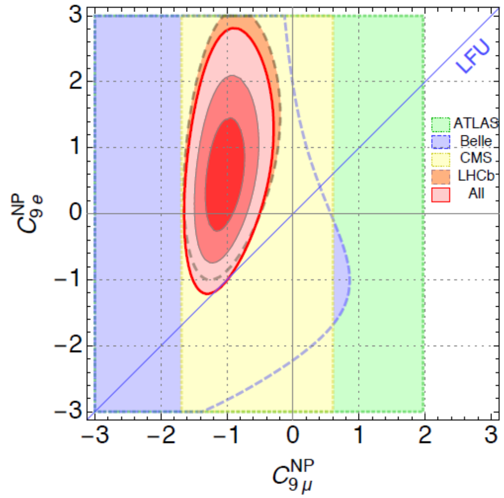


- No significant deviation from zero is discerned.
- Q_4 and Q_5 observables in agreement with SM and favoring NP scenario.

Belle [Phys. Rev. Lett. 118, 111801 (2017)]

- Including P_i', Q_i, $b \to s\gamma$, $R[K^{(*)}]$, $B_s \to \mu\mu$

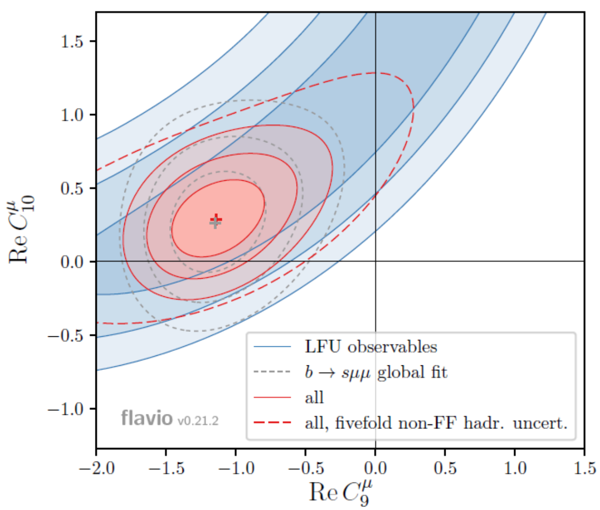


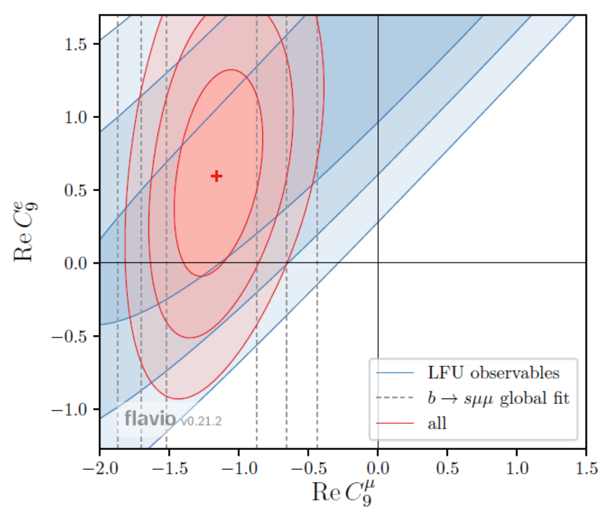


Capdevila, Crivellin, Descotes-Genon, Matias, and Virto
JHEP 1801 (2018) 093

suggests $C_{9\mu}^{NP} \approx -1.1$

- Including $R[K^{(*)}]$ and Belle's P_i', Q_i





Altmannshofer, Stangl, and Straub
Phys. Rev. D 96, 055008 (2017)

A combined fit singles out NP in the Wilson coefficient C_9^{μ} as a possible explanation.

Search for LFV decay $B^0 \to K^{*0}\mu^{\pm}e^{\mp}$

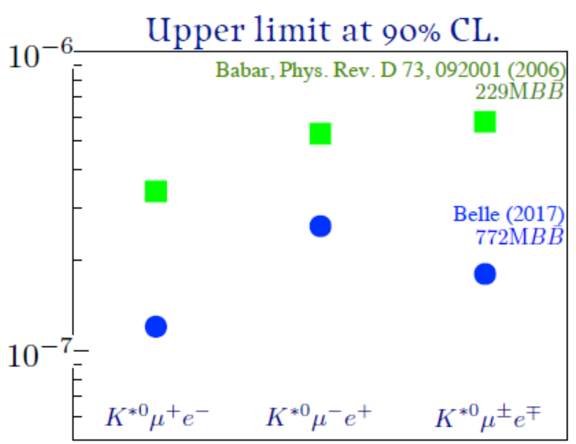
- Measurements from the LHCb have exhibited **possible deviations in R(K) and R(K*)** from LFU.
  PRL 113, 151601 (2014), JHEP 08, 055 (2017)
- **Violation of LFU** is accompanied by **LFV**. **S. L. Glashow et.al PRL 114, 091801 (2015)**
- Recently, LFV decay $\mathbf{B^0 \to K^{*0}\mu^{\pm}e^{\mp}}$ is searched at **Belle**.
  arXiv:1807.03267 **[submitted to PRD(RC)]**

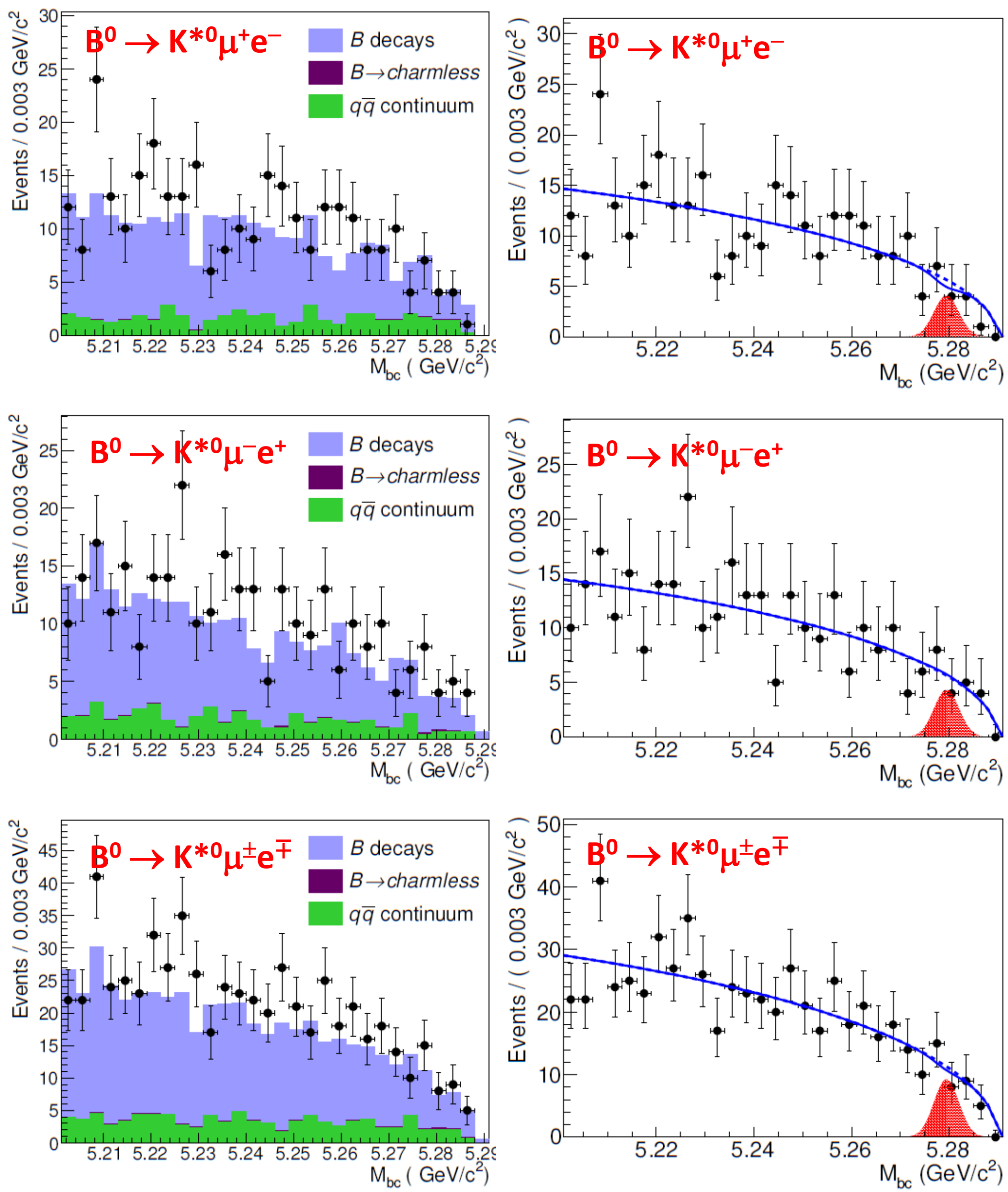
- $\mathbf{K^{\pm}, \pi^{\pm}, \mu^{\pm}}$ **and** $\mathbf{e^{\pm}}$ candidates are selected from tracks **near IP** and **satisfying PID** requirements. Inv. mass from K-π should be within **100 MeV window around K^{*0}** nominal mass.
- **continuum** background events are suppressed using input variables based on event topology in a **NN**. Another NN is used to suppress background originating from **B-decays**. $\mathbf{B^0 \to K^{*0}J/\psi}$ was a good control sample and it is also used to **calibrate** the NNs.
- **set of vetoes** applied to suppress events from $\mathbf{B^0 \to K^{*0}[K^+\pi^-]J/\psi[\ell^+\ell^-]}$ decays in which one of the **leptons is misidentified and swapped with the K^+ or π^-.**

Search for LFV decay $B^0 \to K^{*0}\mu^\pm e^\mp$

- **good agreement** between **data and MC** for both the **number of events observed** and the **shapes** of the distributions.
- **No signal** is observed → **UL** is derived.

Mode	ε (%)	N_{sig}	$\mathcal{B}^{UL}$ (10^{-7})
$B^0 \to K^{*0}\mu^+e^-$	8.8	$-1.5^{+4.7}_{-4.1}$	1.2
$B^0 \to K^{*0}\mu^-e^+$	9.3	$0.40^{+4.8}_{-4.5}$	1.6
$B^0 \to K^{*0}\mu^\pm e^\mp$	9.0	$-1.2^{+6.8}_{-6.2}$	1.8



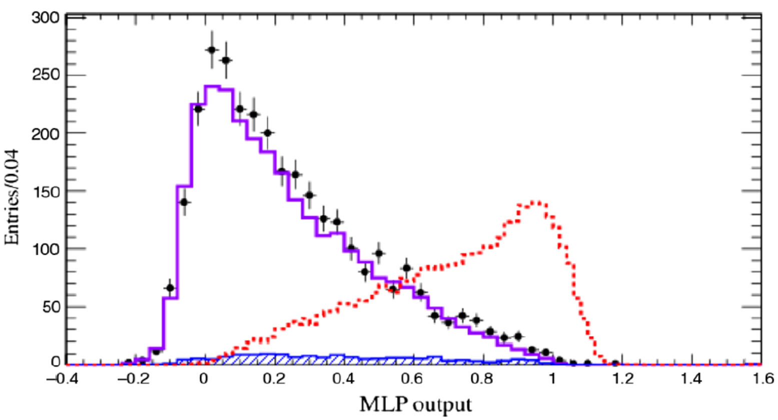


Search for the $B^+ \to K^+ \tau^+ \tau^-$

- The decay $\mathbf{B^+ \to K^+\tau^+\tau^-}$ is the **third gen. family** equivalent of $B^+ \to K^+\ell^+\ell^-$; may provide **additional sensitivity** to NP. L. Calibbi *et. al* [PRL **115** 181801 (2015)]
- An important potential contribution to this decay is from **neutral Higgs boson** couplings, where the lepton-lepton-Higgs vertices are proportional to the **mass squared of the lepton**. T. M. Aliev *et. al* [J. Phys. G **24** 49 (1998)]
- Analysis based on the 424 fb^{-1} (**471M $B\bar{B}$ pairs**) data sample at **BaBar**.
- **Hadronic B-tagging** technique is employed. ($\boldsymbol{\tau^+ \to \mu^+\nu_\mu\bar{\nu}_\tau}$ **and** $\boldsymbol{\tau^+ \to e^+\nu_e\bar{\nu}_\tau}$)

Signal with arbitrary norm.
Combinatorial.
Peaking in M_{bc}
Data

	e^+e^-	$\mu^+\mu^-$	$e^+\mu^-$
$N^i_{\rm bkg}$	$49.4 \pm 2.4 \pm 2.9$	$45.8 \pm 2.4 \pm 3.2$	$59.2 \pm 2.8 \pm 3.5$
$\epsilon^i_{\rm sig}\ (\times 10^{-5})$	$1.1 \pm 0.2 \pm 0.1$	$1.3 \pm 0.2 \pm 0.1$	$2.1 \pm 0.2 \pm 0.2$
$N^i_{\rm obs}$	45	39	92
Significance (σ)	−0.6	−0.9	3.7



The UL on the BF($B^+ \to K^+\tau^+\tau^-$) with all the 3 modes combined at 90% CL is:

$< 2.25 \times 10^{-3}$.

BaBar [Phys. Rev. Lett. 118, 031802 (2017)]

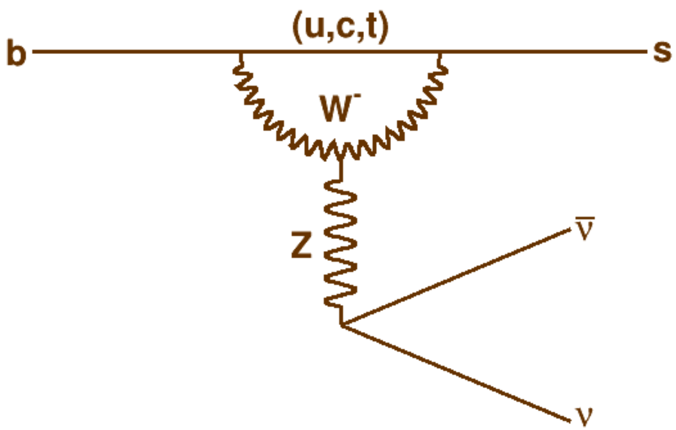
[SM prediction: 1-2 $\times 10^{-7}$]

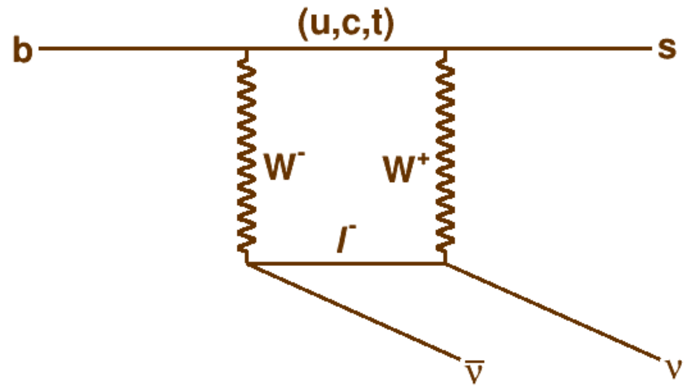
C. Bouchard *et. al* [PRL **111** 16202 (2013)]

J. L. Hewitt [PRD **53** 4964 (1996)]

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

- Search for $B \to h^{(*)} \nu\nu$ at **Belle**, where **h =** K^+, K^0_S, K^{*+}, K^{*0}, π^+, π^0 ρ^+, ρ^0
- Proceeds via penguin or box diagrams:





Belongs to the theoretically cleanest modes in the field of FCNC processes. As the transition mediates by a Z-boson alone

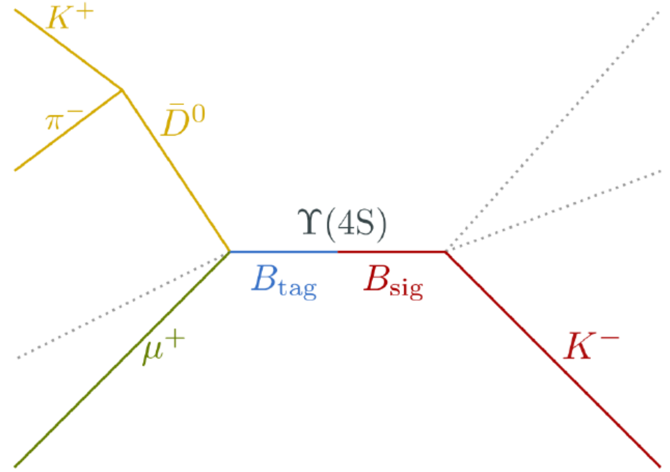
- SM prediction for the BF ranges from 1.2×10^{-7} ($B \to \pi^0\nu\nu$) to 9.2×10^{-6} ($B \to K^{*+}\nu\nu$).
  [A. Buras *et al.* J. High Energy Phys. 02 (2015) 184; C. Hambrock *et al.* Phys. Rev. D 92, 074020 (2015).]

- Experimentally challenging, tagging of companion B meson needed.
  - measured at **Belle** using Hadronic tagging [**Phys.Rev.D87 111103 (2013)**].
  - measured at **BaBar** utilizing both hadronic [**Phys. Rev. D 87, 112005 (2013)**] and semileptonic tagging [**Phys. Rev. D 82, 112002 (2010)**]
  - Semileptonic tagging in this analysis.

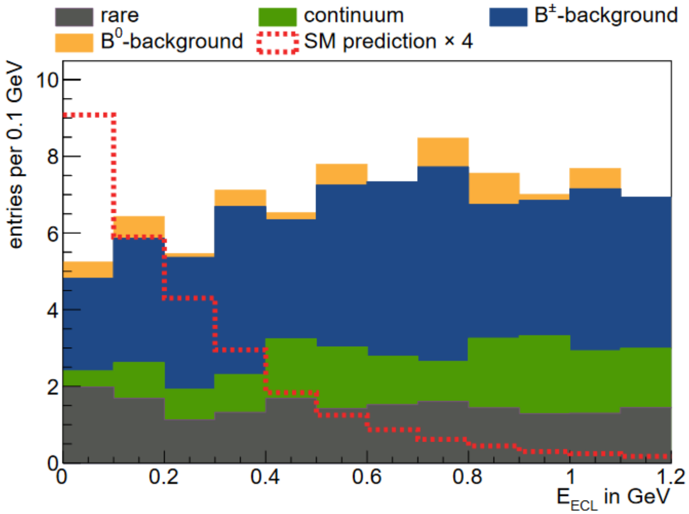
Belle [Phys. Rev. D 96, 091101(R) (2017)]

Reconstruction of $B \to h^{(*)}\nu\nu$

- Semileptonic tagging for companion B (**B_{tag}**):
  - Hierarchical reconstruction of $B \to D^{(*)}\ell\nu$ using Neural Network.
  - 2 – 3 times efficient than hadronic tagging.
- **B_{tag}** candidate is combined with the reconstructed signal (**B_{sig}**) decay product to form an $\Upsilon(4S)$ candidate or signal event candidate.
- No additional charged track, π^0 or K_L^0 in an event.
- Continuum events are suppressed with the event shape variables.
- Signal extracted in extra (additional) energy in the calorimeter



for eg. $B^+ \to K^+\nu\nu$



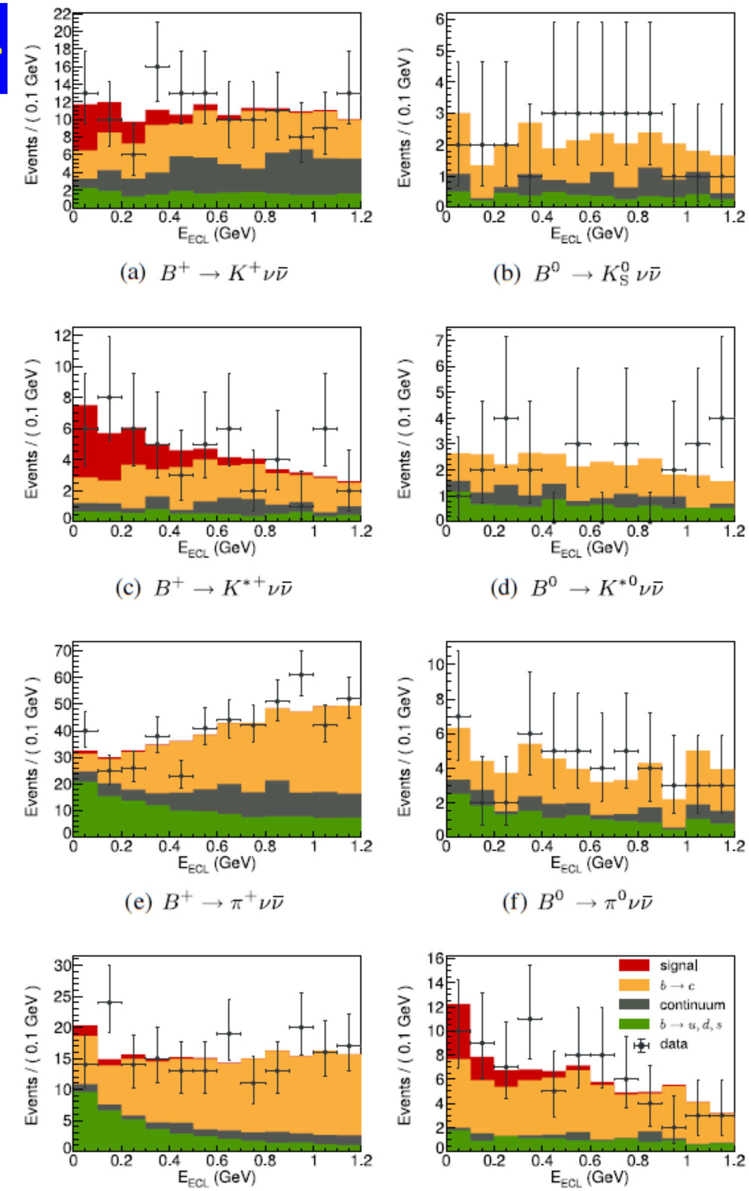
Results

- Signal Extraction:
  - Fit with template histograms.
  - Signal and Background ($b \rightarrow c$, continuum, light quark pairs).
  - Relative fractions are fixed to MC values.

- No statistically significant signal yield observed.

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

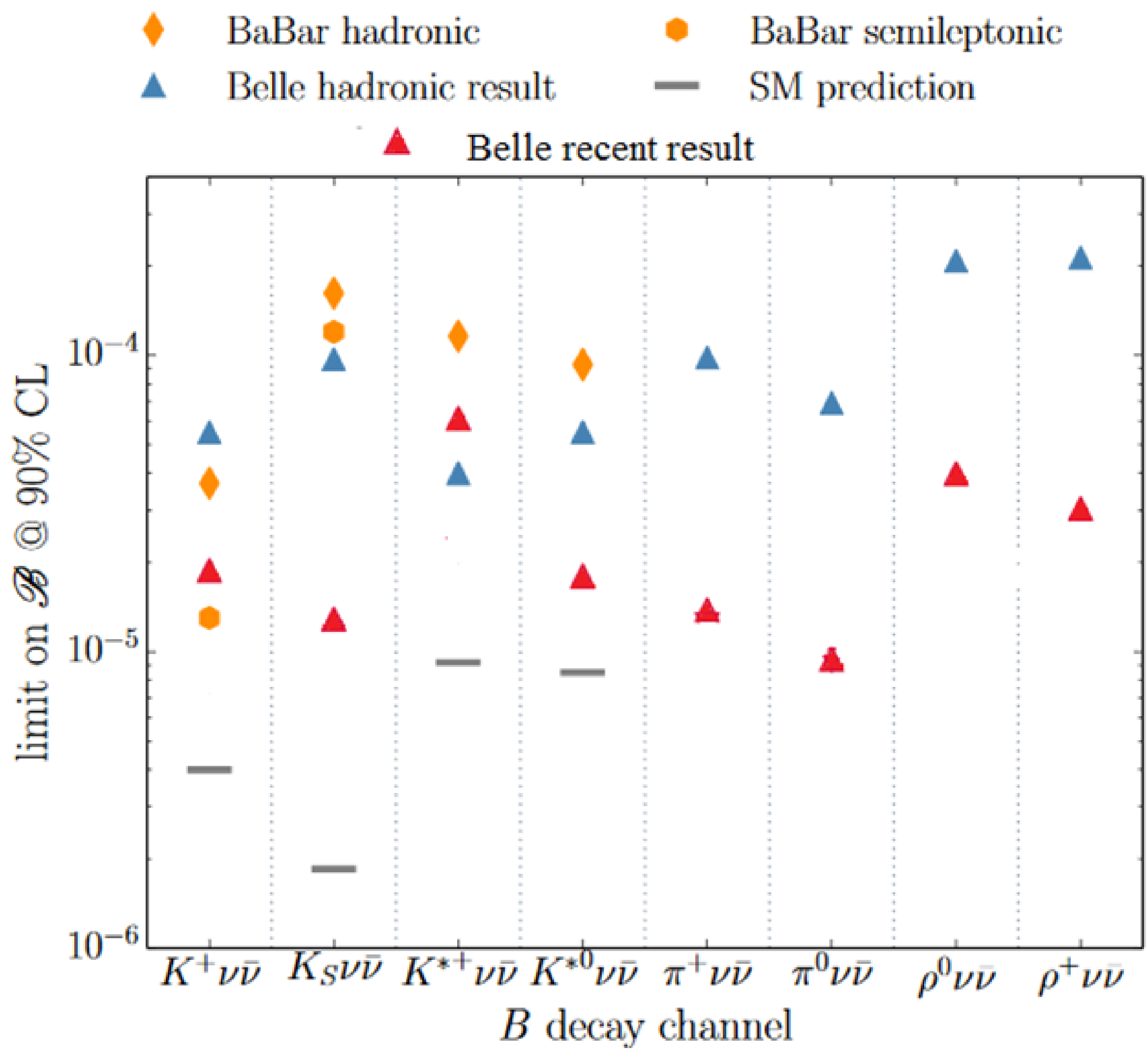
Belle [Phys. Rev. D 96, 091101(R) (2017)]



(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

- Most stringent upper limits on BF[$B \rightarrow h^{(*)}\nu\nu$], where $h^{(*)} = K^+, K_s^0$, **K^{*0}**, π^+, π^0, ρ^+ and ρ^0 .
- Golden channel for Belle II.



Summary

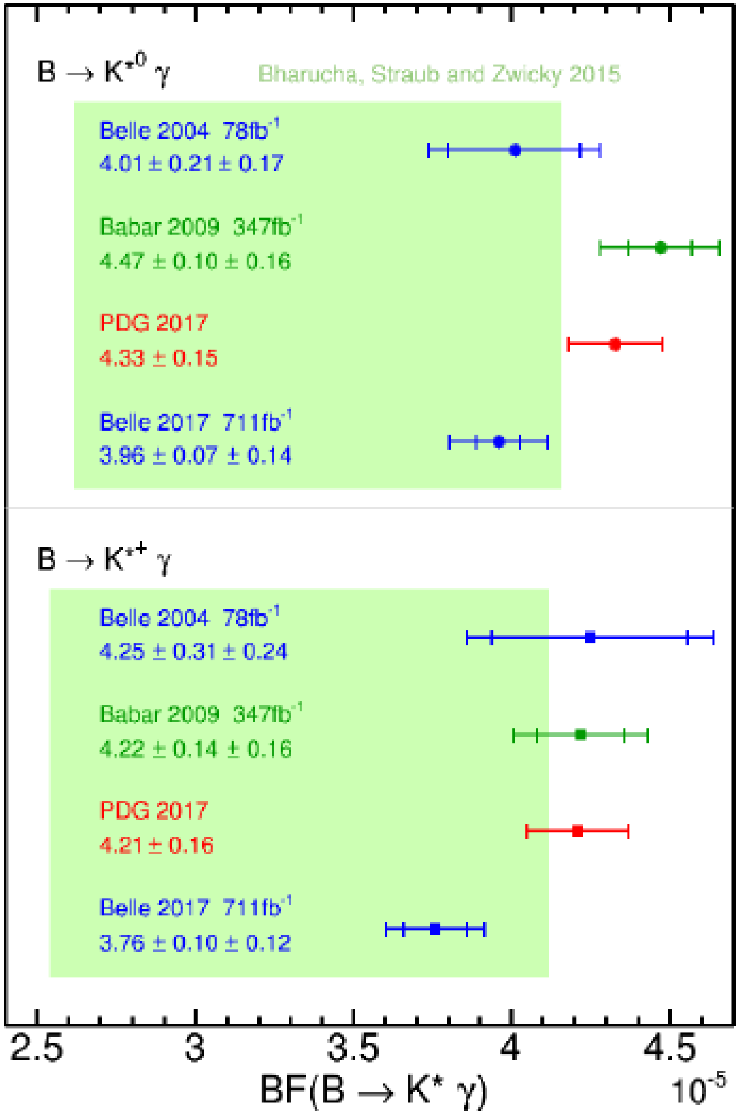
- Measurement for $B \to K^* \gamma$ is performed and First evidence for Isospin Violation in $b \to s$ transition with 3.1σ significance.
- New measurement of $B \to X_s\gamma$ is performed Δ_{0-} and ΔA_{CP} are studied.
- First Lepton Flavor dependent angular analysis of $B \to K^*\ell^+\ell^-$ performed: Consistent with both SM and NP with $C_{9\mu}^{NP} \approx -1.1$.
- Searched for the LFV decay $B^0 \to K^{*0}\mu^\pm e^\mp$ at Belle, and the most stringent limit derived.
- $B^+ \to K^+\tau^+\tau^-$ is searched at BaBar. No significant signal is observed and UL is derived $< 2.25 \times 10^{-3}$ (90% CL).
- Search for $B \to h^{(*)}\nu\nu$ is performed. Most stringent limits till date in most channels. Close to SM prediction in $K^{(*)}$ mode. Golden channel for Belle II.

Thank you ధన్యవాదాలు धन्यवाद

Extra Slides

Result : BF ($B \to K^*\gamma$)

- 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($B \to K^*\gamma$) and splits the difference between theory and experiment.



Belle measurement from 121 fb^{-1} of data at $\Upsilon(5S)$ for BF ($B_s \to \phi\gamma$) is used for the:
BF($B^0 \to K^{*0}\gamma$)/BF($B_s \to \phi\gamma$) = $1.10 \pm 0.16 \pm 0.09 \pm 0.18$

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

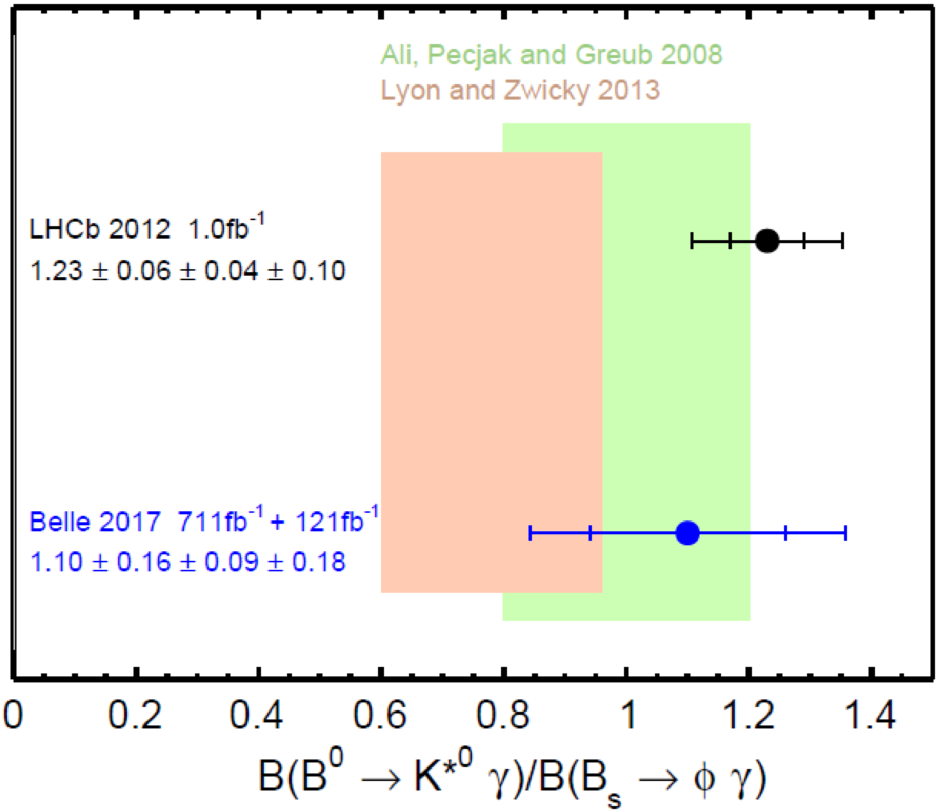
Result : $BF(B^0 \to K^{*0}\gamma)/BF(B_s \to \phi\gamma)$

- Belle measurement from 121 fb^{-1} of data at $\Upsilon(5S)$ for BF ($B_s \to \phi\gamma$) is used. [Phys. Rev. D 91, 011101 (2015)]

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

- $BF(B^0 \to K^{*0}\gamma)/BF(B_s \to \phi\gamma)$:
  $1.10 \pm 0.16 \pm 0.09 \pm 0.18$

- **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)]

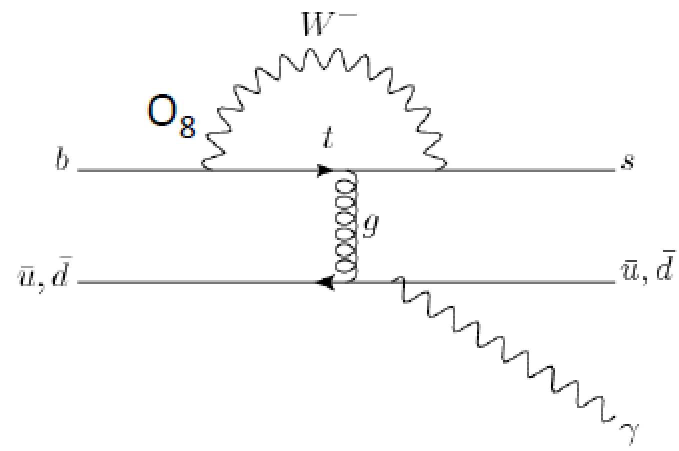


Theory uncertainty on BF[$B \to X_s \gamma$]

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)



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

- 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+})

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

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

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

ΔA_{CP} in $[B \to X_s \gamma]$

- 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 $Im(C_8/C_7)$ 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.

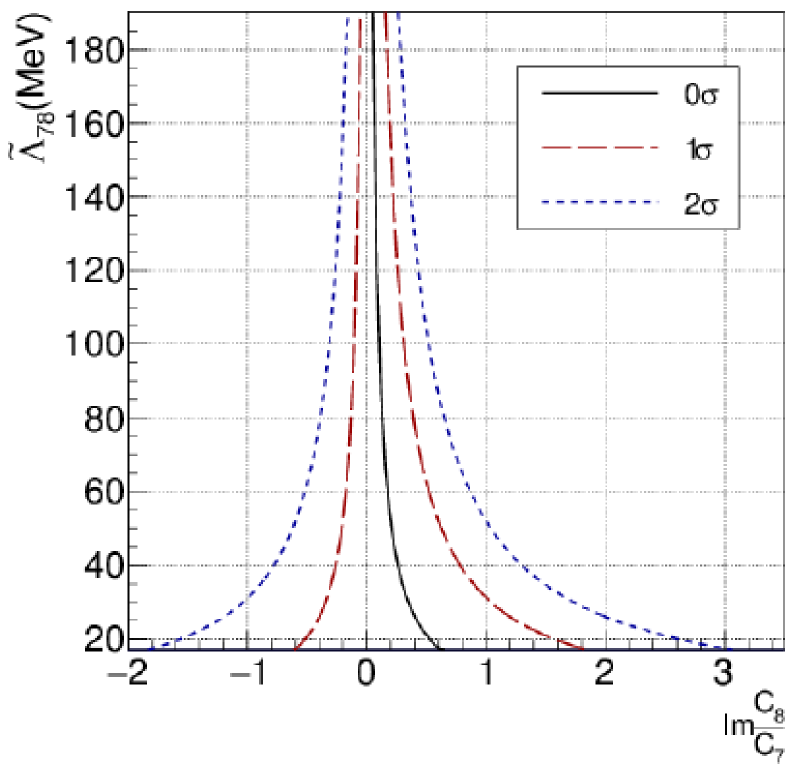
$$\begin{aligned}\Delta A_{CP} &= A_{CP}(B^+ \to X_s^+\gamma) - A_{CP}(B^0 \to X_s^0\gamma)\\ &= 4\pi^2\alpha_s \frac{\tilde{\Lambda}_{78}}{m_b}\mathrm{Im}\left(\frac{C_8}{C_7}\right),\\ &\approx 0.12\left(\frac{\tilde{\Lambda}_{78}}{100\ \mathrm{MeV}}\right)\mathrm{Im}\left(\frac{C_8}{C_7}\right),\end{aligned}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

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

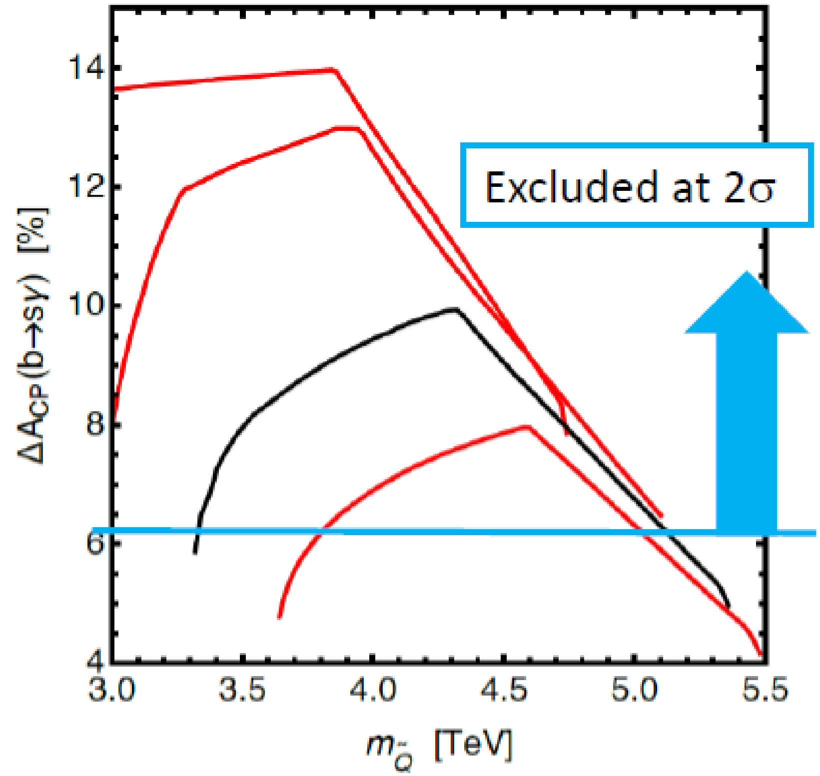
Constraint on Im(C_8/C_7) and a NP model

- 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



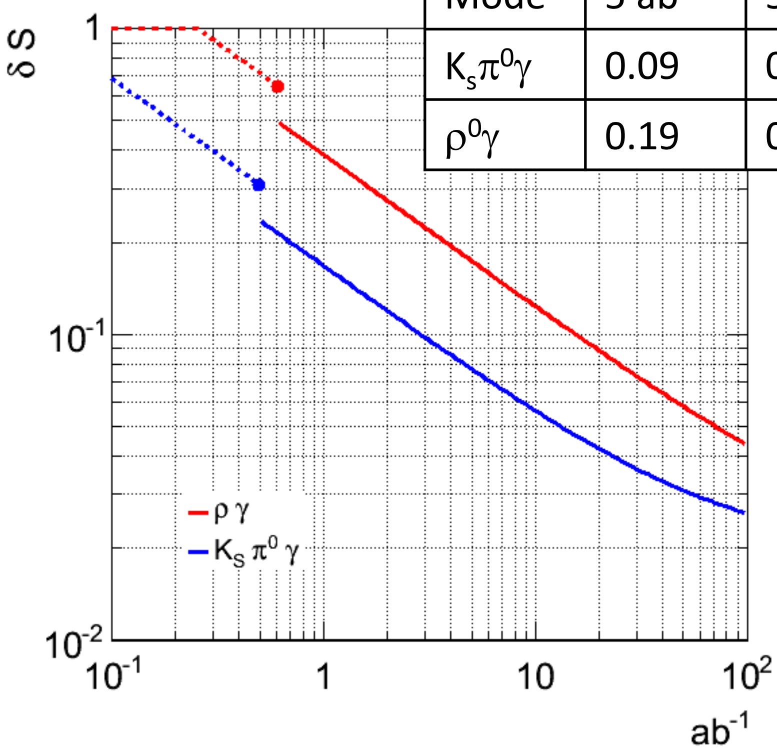
M. Endo, T. Goto, T. Kitahara, S. Mishima, D. Ueda and K. Yamamoto, JHEP 04 (2018) 019.

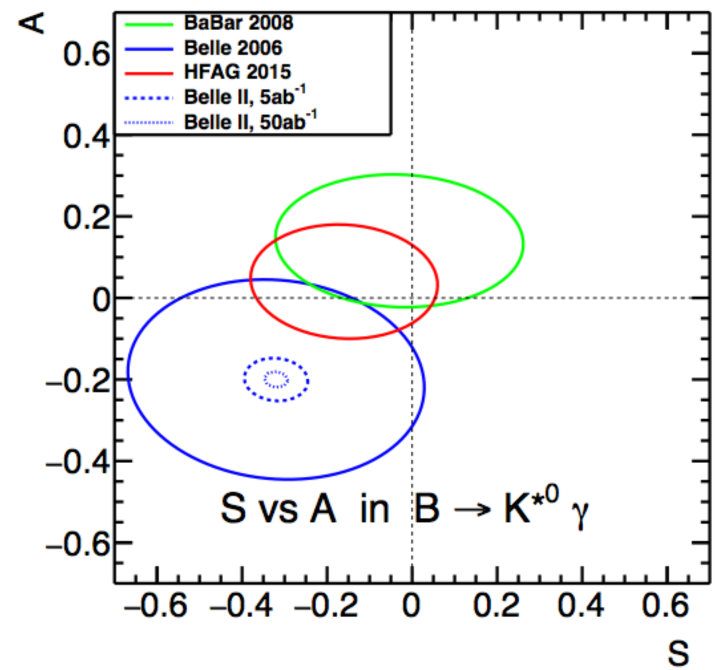
Time dependent CPV

- At Belle II, significant improvement in the determination of $A_{CP}(t)$ in $K_s\pi^0\gamma$ is expected.
  - $\rightarrow$ Belle II vertex detector is larger than Belle (6cm $\rightarrow$ 11.5cm).
  - $\rightarrow$ 30% more Ks with vertex hits available.
  - $\rightarrow$ Effective tagging efficiency is 13% better (conservative estimation).

- Expected errors for ***S*** measurements of $K_s\pi^0\gamma$ and $\rho^0\gamma$.

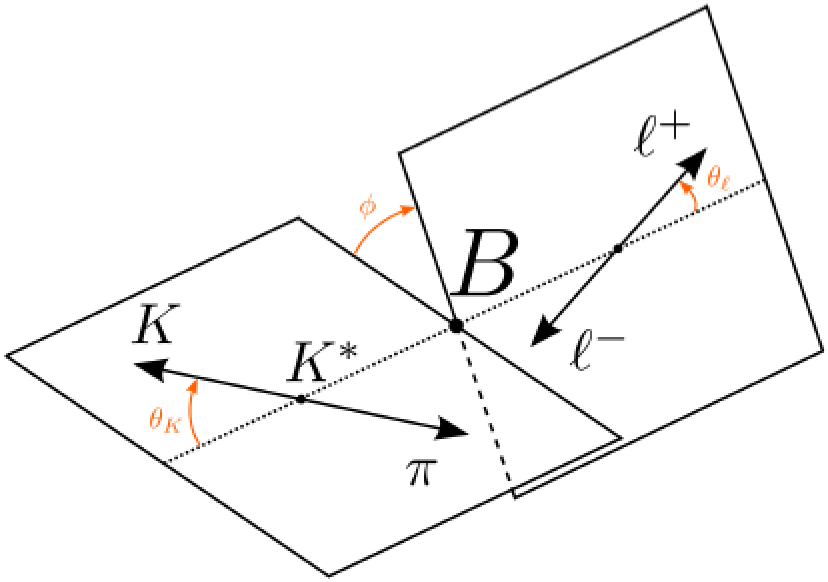
Mode	5 ab^{-1}	50 ab^{-1}
$K_s\pi^0\gamma$	0.09	0.030
$\rho^0\gamma$	0.19	0.064

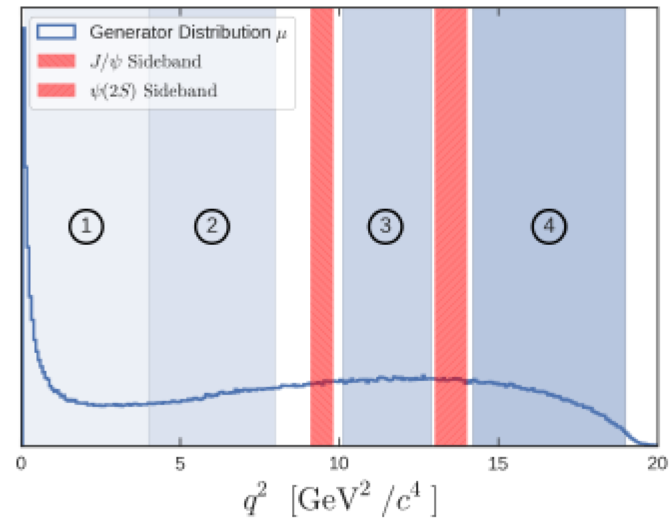




16σ deviation with 50 ab^{-1}.

Full Angular Analysis





The observables are depended on $q^2 = M^2_{\ell^+\ell^-}$

The differential decay rate for $B \to K^*\ell^+\ell^-$ can be written as

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

Folding Procedure

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

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

- 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
- The observables

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

are considered to be largely free from form-factor uncertainties (J. High Energy Phys. 05 (2013) 137).

- Transverse polarization asymmetry

$$A_T^{(2)} = \frac{2S_3}{(1-F_L)}$$