November 30, 2016

$b \to s\ell\ell$ and Radiative Decays at Belle

For the Belle Collaboration

Presented by Simon Wehle

Deutsches Elektronen-Synchrotron

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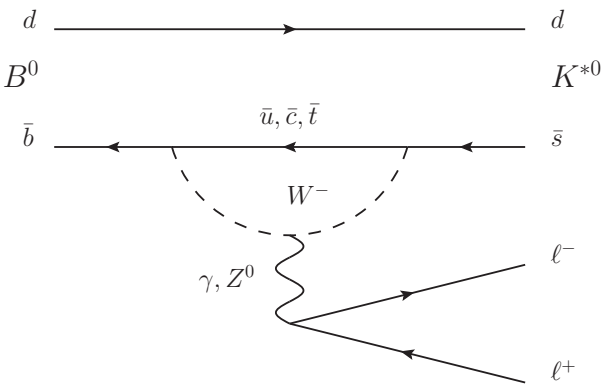
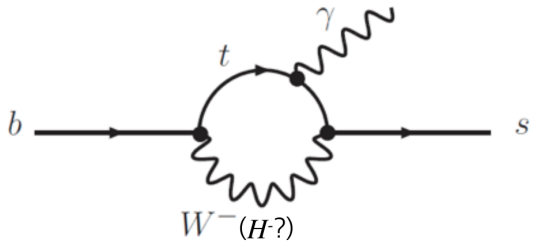
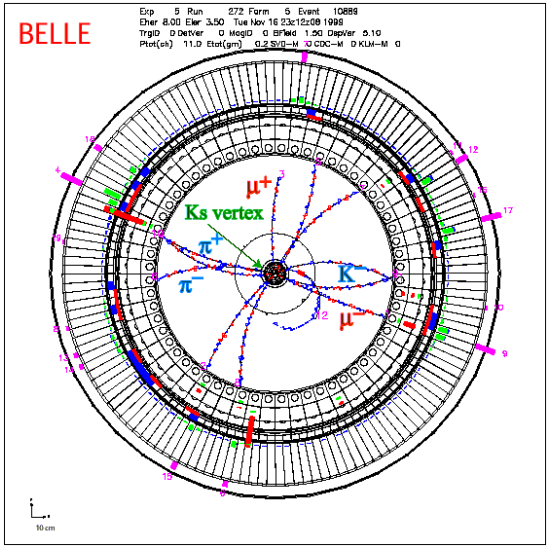
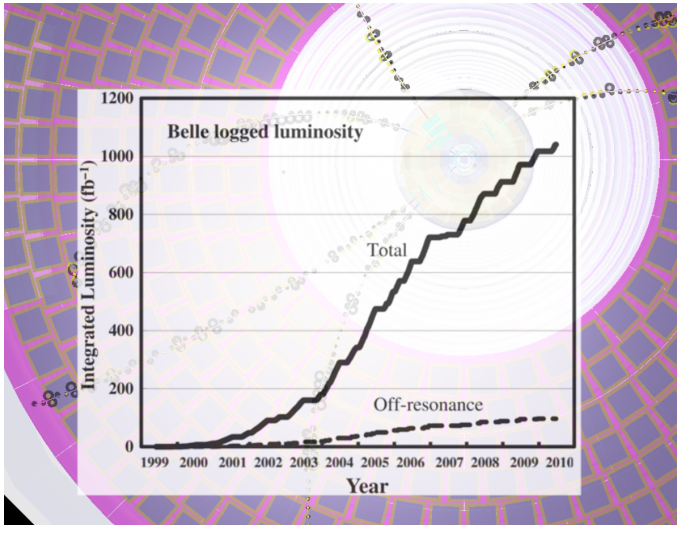






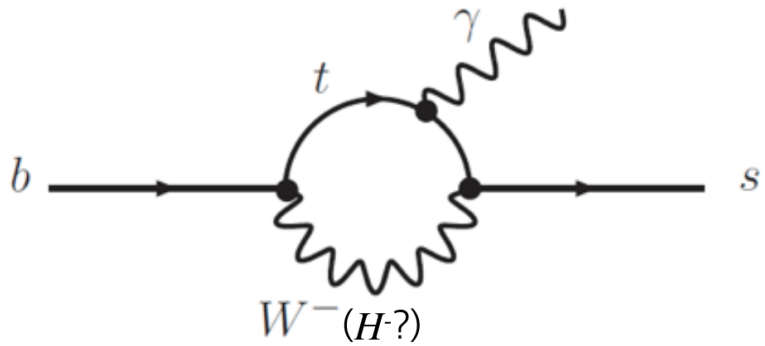


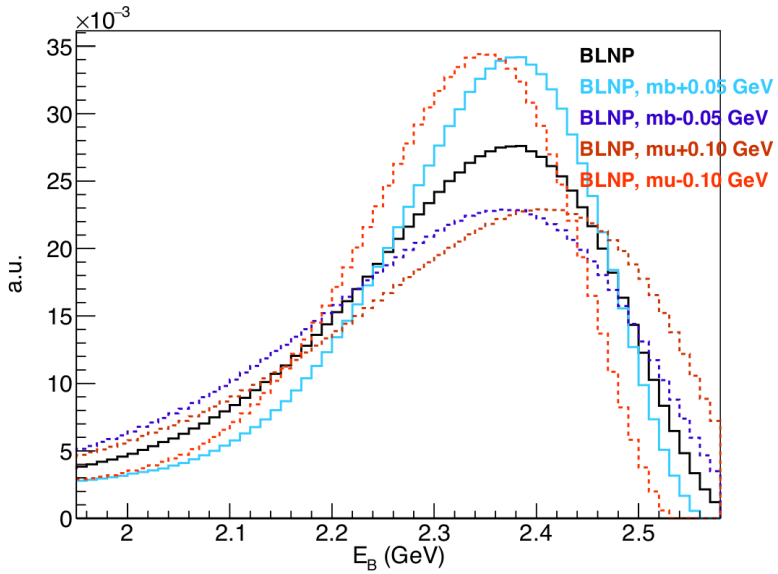
Outline

- Inclusive $b \to (s + d)\gamma$
- New results for angular analysis of $B \to K^* \ell^+ \ell^-$

Introduction $b \to s\gamma$ decay

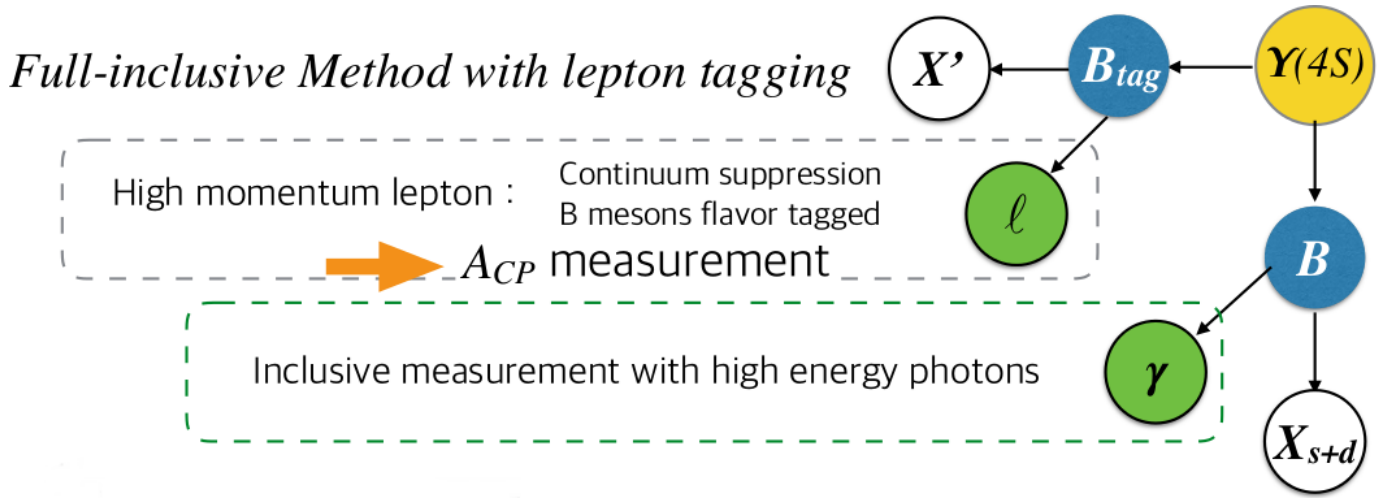
- Electroweak penguin FCNC process
- Sensitive to H^+ in 2HDM Type-II

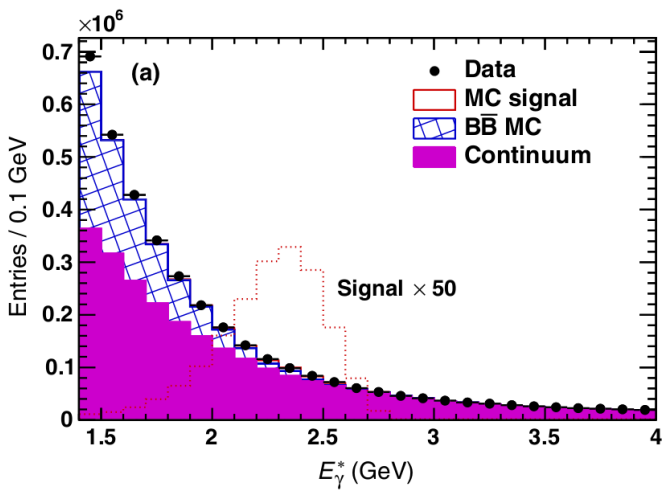




- Measured photon energy spectrum can be used to constrain HQE parameter e.g. m_b

$\bar{B} \to X_{(s+d)}\gamma$

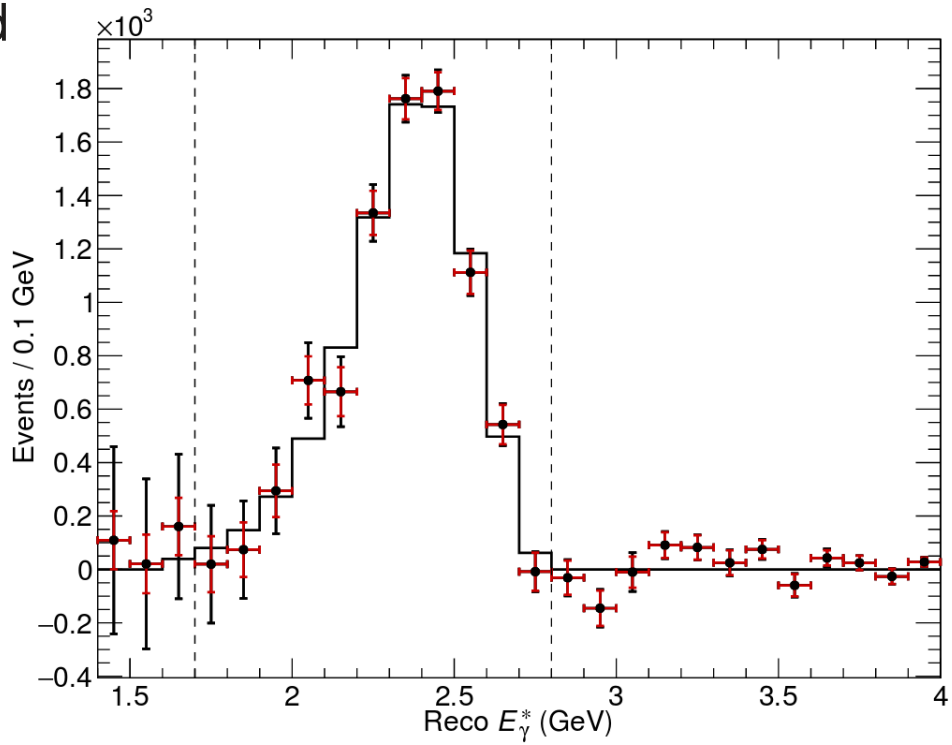




- BDT for background suppression
- Calibrated using control samples (π^0, η)
- MC background corrected with sideband events

$\bar{B} \to X_{(s+d)}\gamma$

- Detector resolution effect unfolded
- $b \to d\gamma$ subtracted using $|V_{td}/V_{ts}|^2 \sim 4\%$
- HQE parameter fit result
  - $m_b = 4.626 \pm 0.028\ \mathrm{GeV}/c^2$
  - $\mu_\pi^2 = 0.301 \pm 0.063\ \mathrm{GeV}/c^2$
  - correlation $\rho = -0.701$
- Limit on THDM-II: $M_{H^+} > 580\ \mathrm{GeV}$ with 95% CL
- BELLE-CONF-1606 [arXiv:1608.02344]



***Belle** preliminary* **Results**

$$\mathcal{B}(\bar{B} \to X_s\gamma)_{E_\gamma > 1.6GeV} = (3.12 \pm 0.10_{\mathrm{stat}} \pm 0.19_{\mathrm{syst}} \pm 0.08_{\mathrm{model}}) \times 10^{-4}$$

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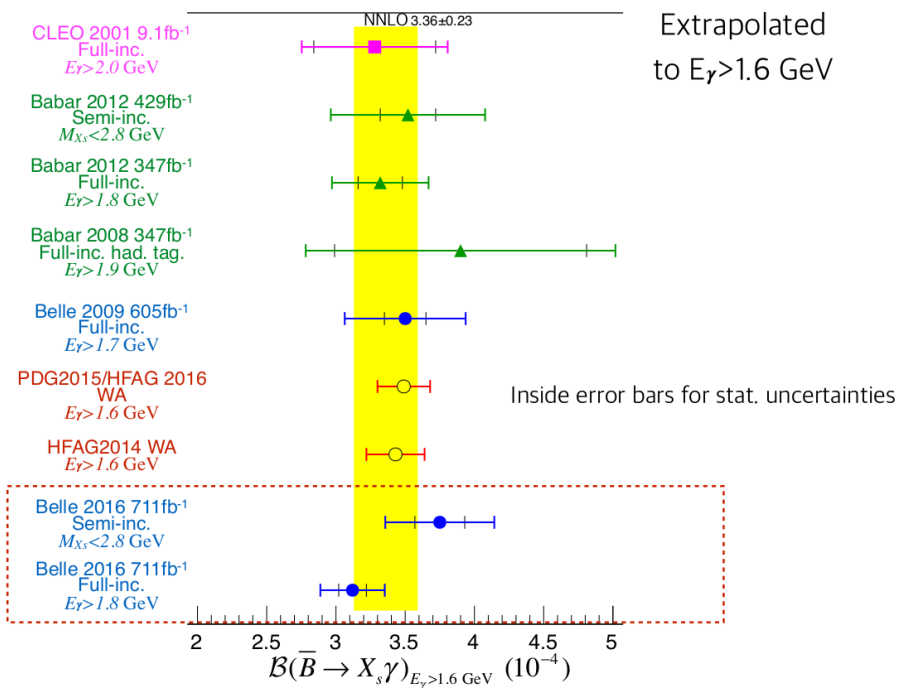

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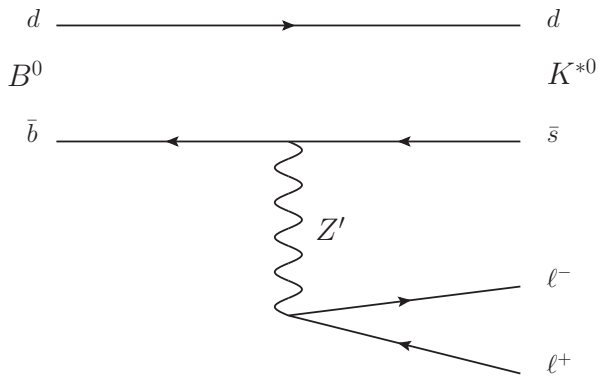
Introduction $b \to s\ell\ell$

- $b \to s\ell^+\ell^-$ prime candidate for NP
- New particles can enter the decay rate
- Many deviations from the SM!



3.3σ suppressed branching ratio of $B_s \to \phi\mu^+\mu^-$

$> 3\sigma$ anomalies in angular distributions of $B \to K^*\ell\ell$

2.6σ lepton flavor non-universality in $B \to K\mu^+\mu^-$ vs. $B \to Ke^+e^-$

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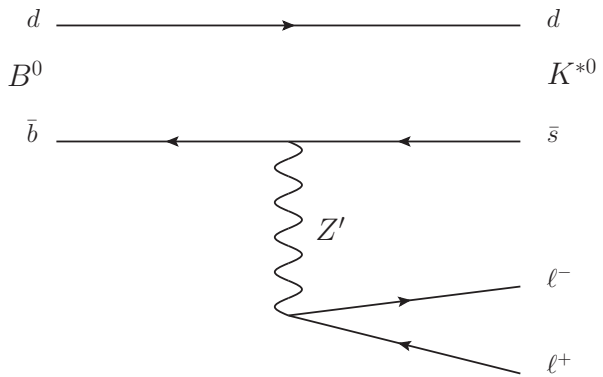

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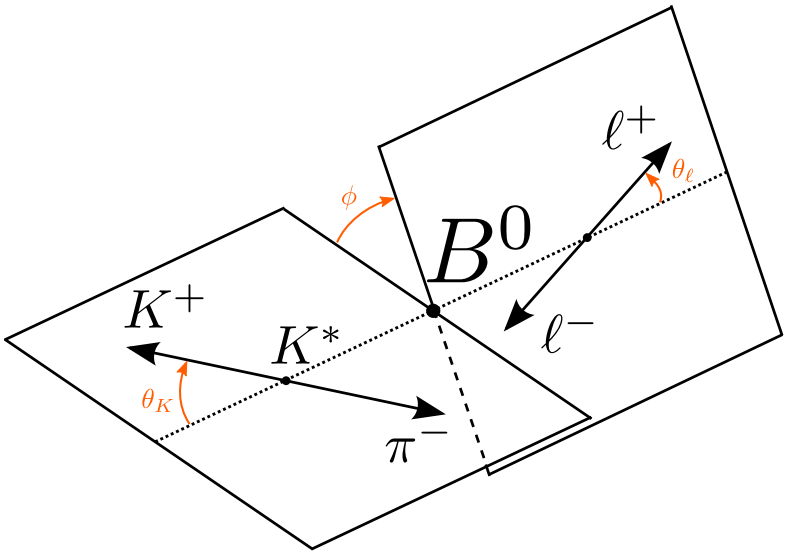
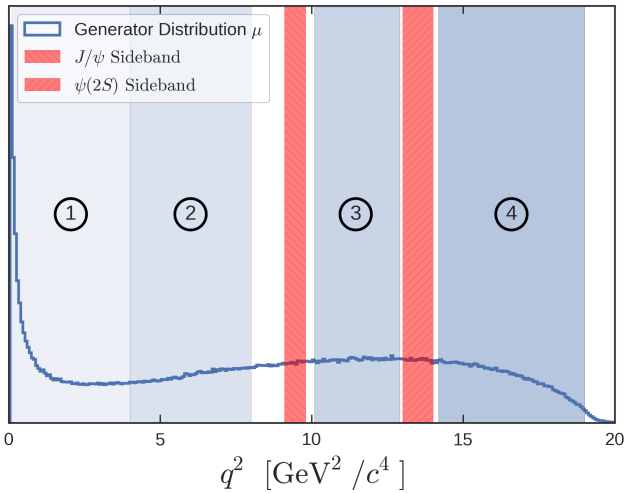
2.6σ lepton flavor non-universality in $B \to K\mu^+\mu^-$ vs. $B \to Ke^+e^-$

Covered in this talk

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

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

Folding Procedure

$$P_4', S_4 : \begin{cases} \phi \to -\phi & \text{for } \phi < 0 \\ \phi \to \pi - \phi & \text{for } \theta_L > \pi/2 \\ \theta_L \to \pi - \theta_L & \text{for } \theta_L > \pi/2, \end{cases}$$

$$P_5', S_5 : \begin{cases} \phi \to -\phi & \text{for } \phi < 0 \\ \theta_L \to \pi - \theta_L & \text{for } \theta_L > \pi/2, \end{cases}$$

Introduced by LHCb in Phys. Rev. Lett. 111, 191801.

- 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

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

Reconstruction of $B \to K^*\ell^+\ell^-$

- Reconstructing $\mathbf{B^0}$ **and** $\mathbf{B^+}$ **modes**
- Using **muon** and **electron** modes
- K^* is reconstructed in (K^+, π^-), (K^0_S, π^+) and (K^+, π^0)

Electron Modes

- $B^0 \to K^*(892)^0 e^+ e^-$
- $B^+ \to K^*(892)^+ e^+ e^-$

Muon Modes

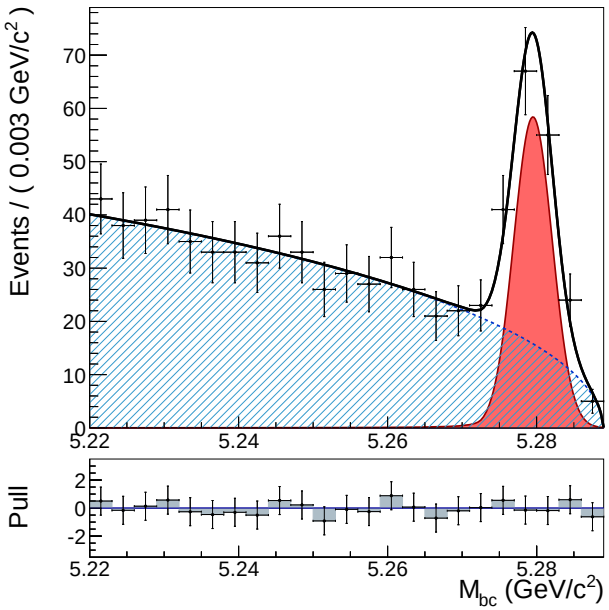
- $B^0 \to K^*(892)^0 \mu^+ \mu^-$
- $B^+ \to K^*(892)^+ \mu^+ \mu^-$

Signal selection:

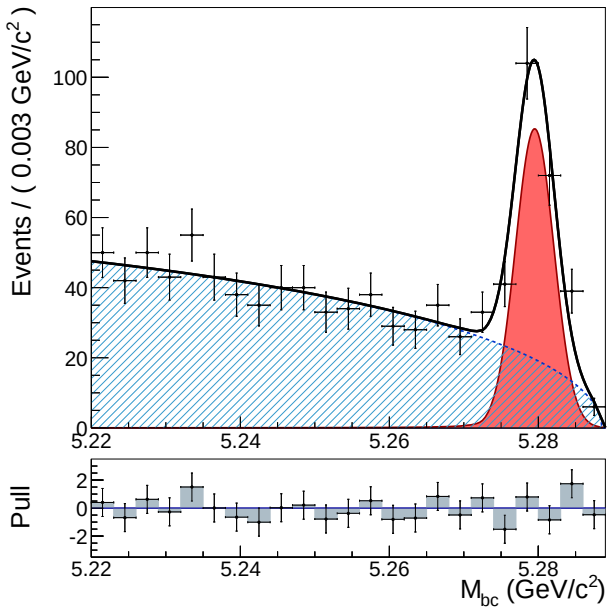
- Neural network (NN) classifier for all particles in the decay chain
- Final signal selection on four B meson NN
- NN cut optimization on 2D figure of merit separate for the lepton flavor

Signal Extraction $B \to K^*\ell^+\ell^-$

- Signal is extracted in Beam Constrained Mass: $M_{\rm bc} \equiv \sqrt{E^2_{\rm Beam} - |\vec{p}_B|^2}$
- Signal pdf: Crystal Ball shape, Background pdf: Argus shape

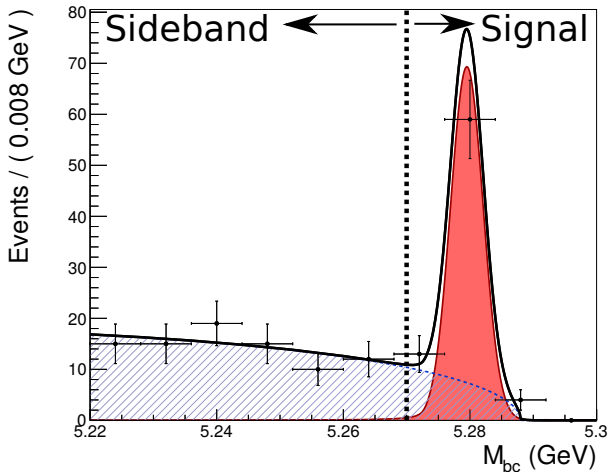


$B^0 \to K^*(892)^0 e^+ e^-$
$B^+ \to K^*(892)^+ e^+ e^-$
127 $\pm$ 15 signal candidates



$B^0 \to K^*(892)^0 \mu^+ \mu^-$
$B^+ \to K^*(892)^+ \mu^+ \mu^-$
185 $\pm$ 17 signal candidates

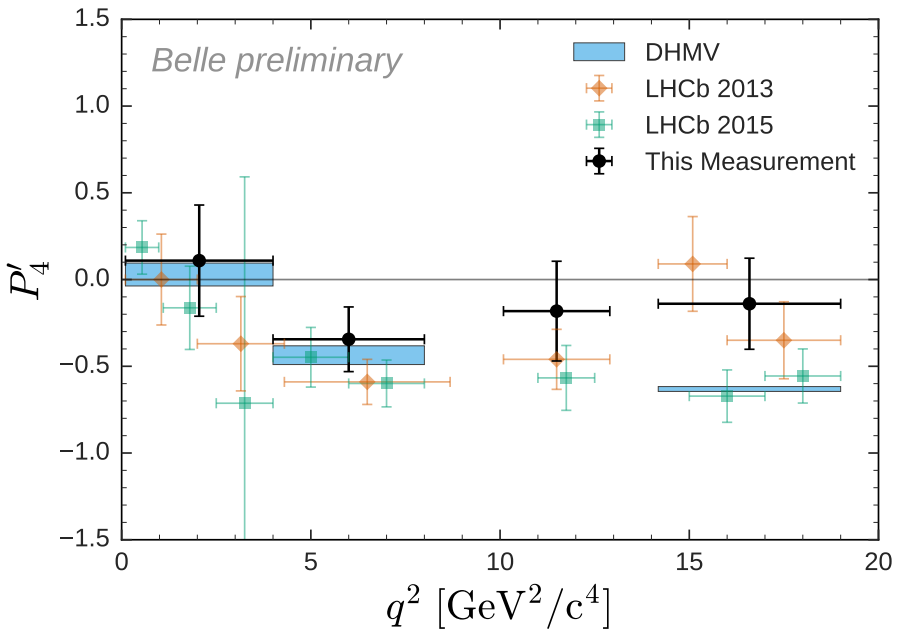
Fit Procedure

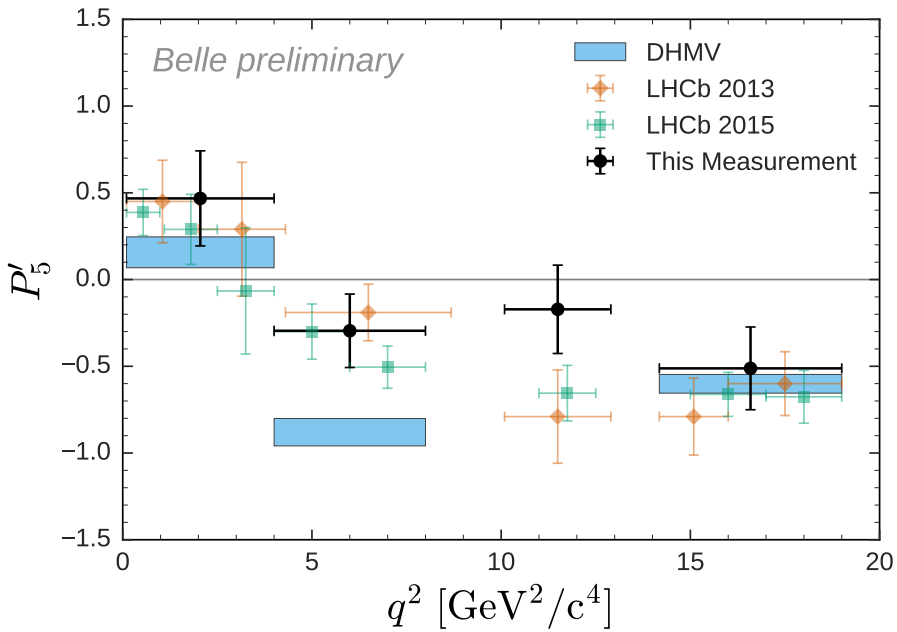


- Signal: Transformed differential decay rate
- Background: Kernel Density Estimation
- independent 3D unbinned maximum likelihood fit for:
  - q^2 bin: (1, 6), (0.1, 4), (4, 8), (10.09, 12.9), (14.18, 19)
  - P_4' and P_5'

1. The data is split into bins of q^2
2. M_{bc} is fitted to determine the signal and background fractions
3. The data is split into a sideband and signal region
4. The shape of the background is determined and fixed in the sideband with smoothed histograms
5. The final fits are performed as 3D maximum likelihood fit in θ_L, θ_K and ϕ for $P_{4,5,6,8}$ each treated as an independent measurement

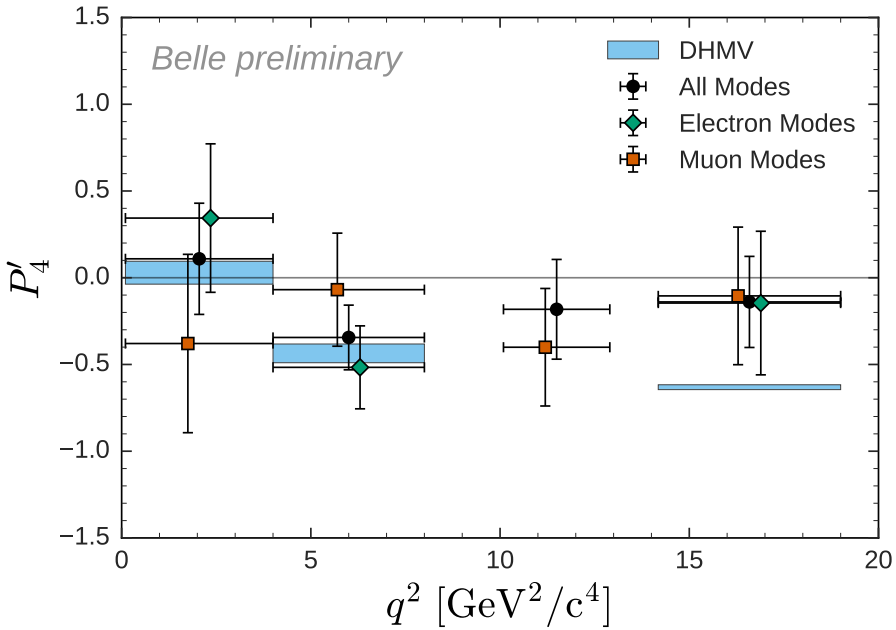
Result P_5' - Result for Combined Data

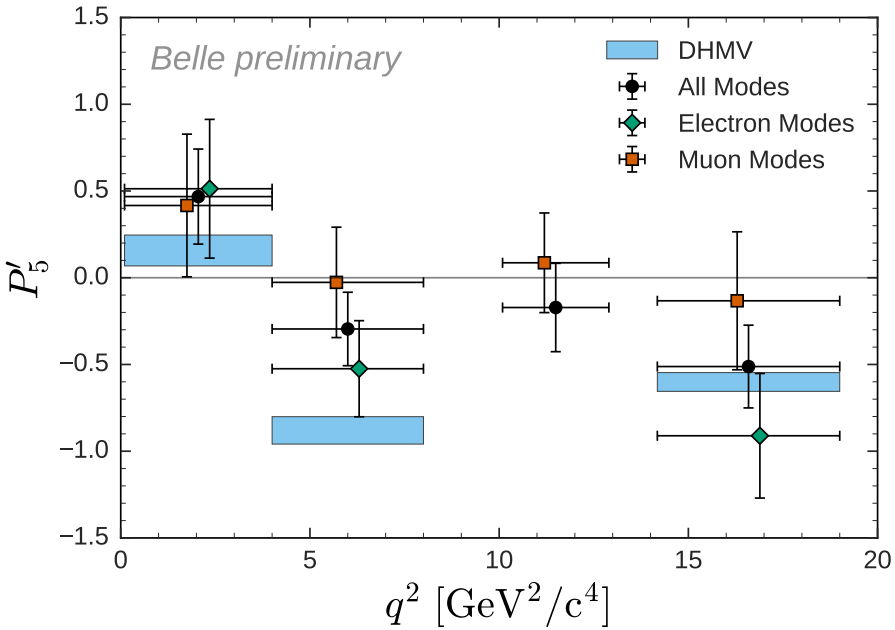




- Measurements are compatible with the SM
- Similar central values for the P_5' anomaly with 2.5σ tension
- But we can do more...

Result - Separate Lepton Flavor!

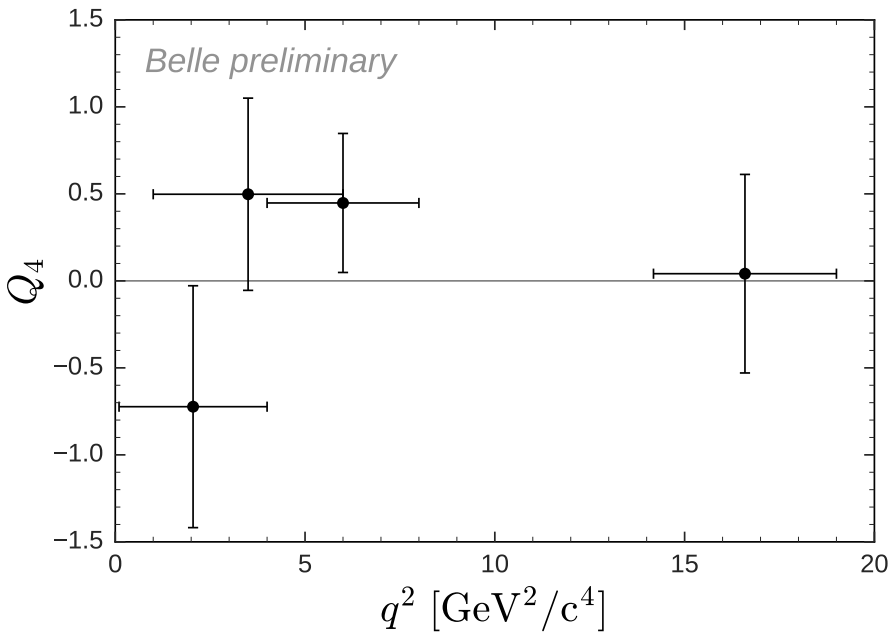


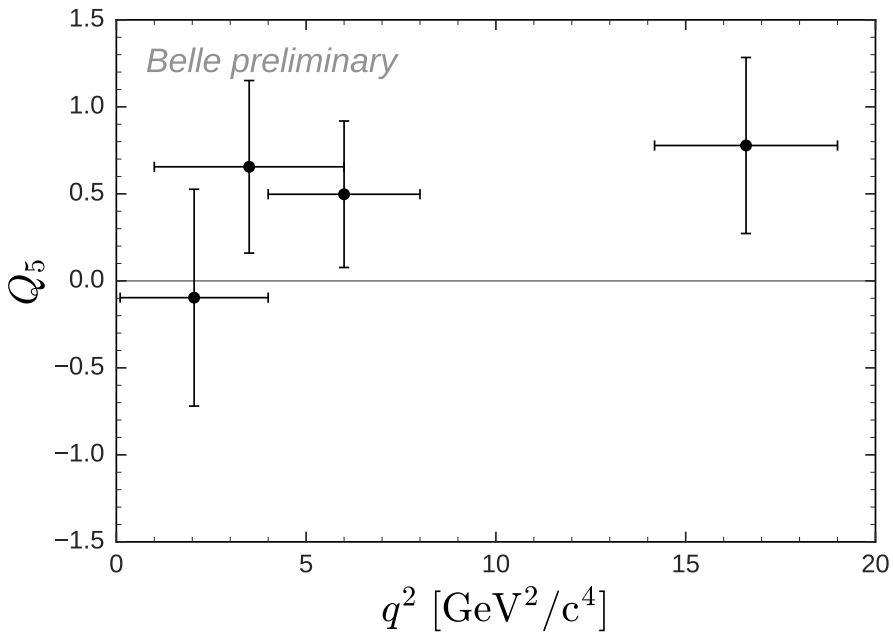


- The Largest deviation in the muon mode with 2.6σ
- Electron mode is deviating with 1.1σ
- Test on Lepton flavor universality

Result - Separate Lepton Flavor!

- Test lepton flavor universality
- Observables $Q_i = P_i^\mu - P_i^e$, JHEP 10, 075 (2016)
- Deviation from zero very sensitive to NP [Reference]
- First presentation of observables Q_i!
- See theoretical introduction by Quim Matias (Lepton universality violation in b->sll)





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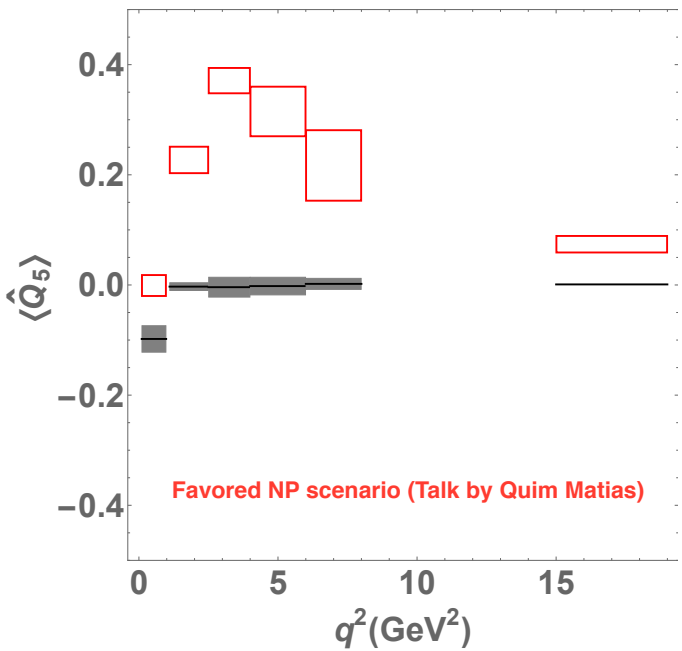
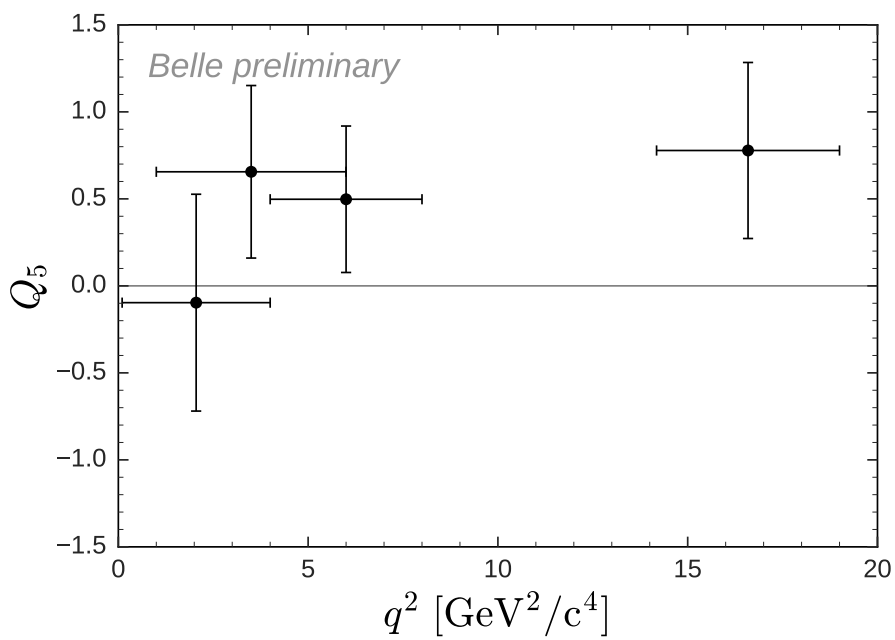
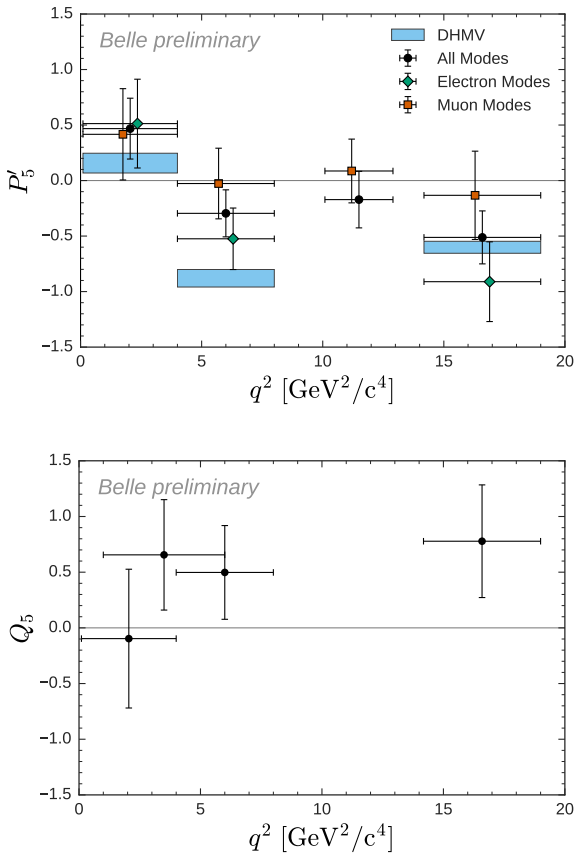




Resume



Inclusive $b \to s\gamma$ with lepton tagging

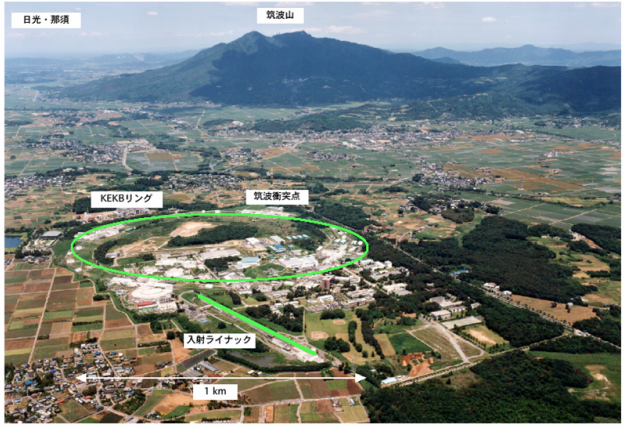
$$\mathcal{B}(\bar{B} \to X_s\gamma)_{E_\gamma > 1.6\mathrm{GeV}} =$$
$$(3.12 \pm 0.10\,(\mathrm{stat}) \pm 0.19(\mathrm{sys}) \pm 0.08(\mathrm{model})) \times 10^{-4}$$

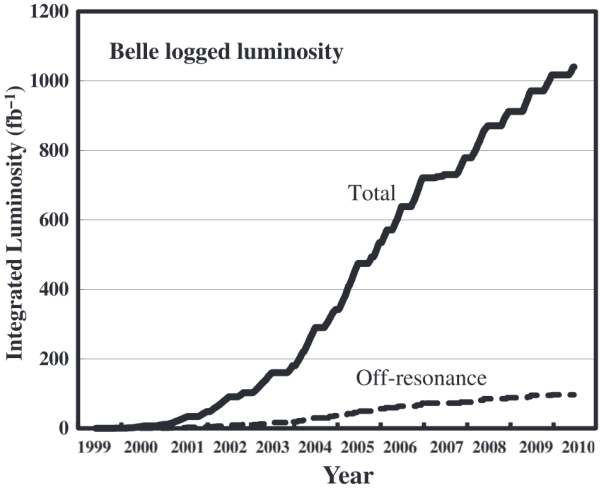
Angular Analysis of $B \to K^*\ell^+\ell^-$

- Demonstrated that Belle can make a contribution to the $b \to s\ell^+\ell^-$ puzzle
- Found 2.6σ deviation from the Standard Model prediction
- Shows P_5' anomaly is unlikely to be a statistical fluctuation
- No significant lepton flavor non-universality is found

Thank you!

The Belle Experiment





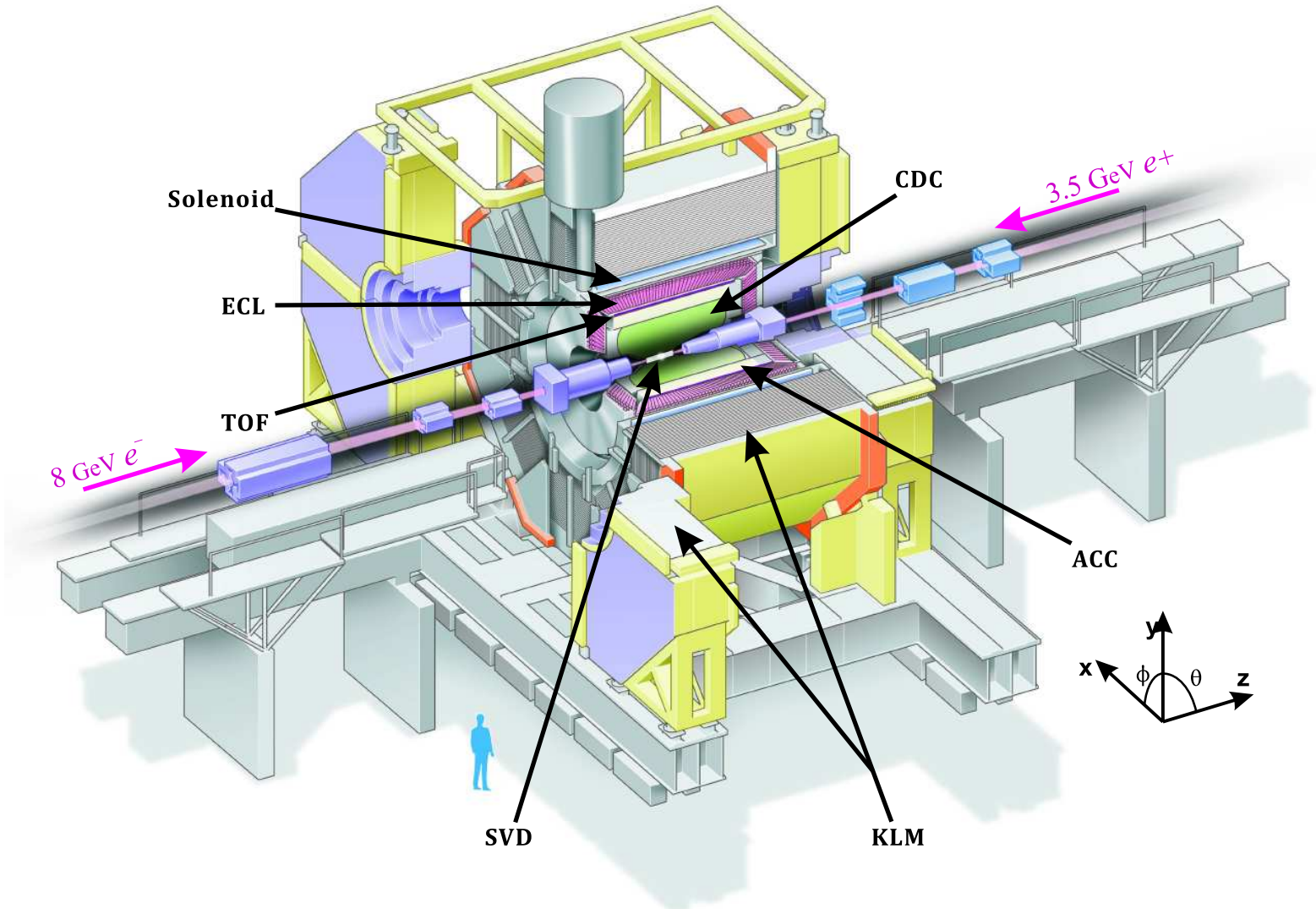
- The Belle experiment is located at the KEKB accelerator in Tsukuba, Japan
- Data taking from 1999 to 2010
- It is designed as a “B factory”
- 772 million $B\bar{B}$ meson pairs

$$e^+e^- \to \Upsilon(4S) \to B\bar{B}$$

- World record for integrated luminosity

$$\int L dt = 1\ \mathrm{ab}^{-1}$$

The Belle Detector



Systematics

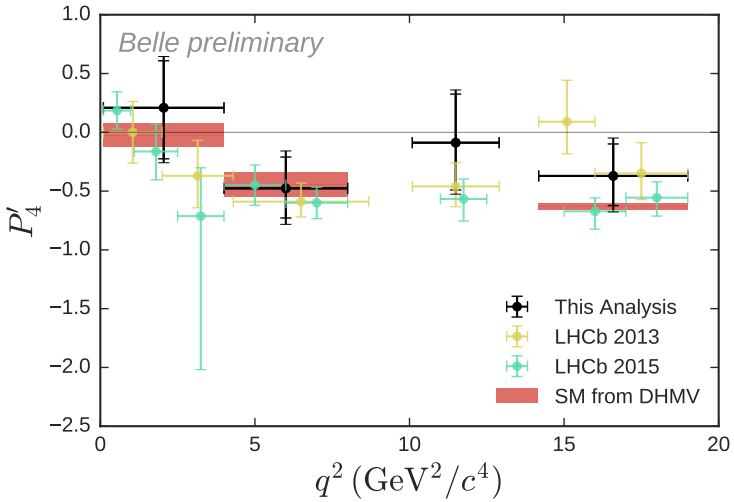
Considered

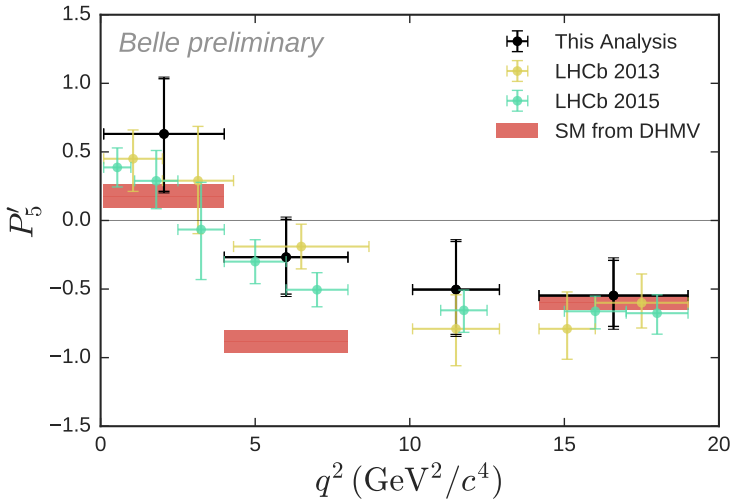
- Efficiency correction/Data MC , $\mathcal{O}(0.045)$
- Peaking backgrounds , $\mathcal{O}(0.02)$
- Background parametrization , $\mathcal{O}(0.028)$
- Signal parametrization , $\mathcal{O}(10^{-4})$

Determined insignificant

- K^* S-wave decays
- Crossfeed
- $\mathcal{CP}$ asymmetry

Old Result


Belle preliminary
P_4'
$q^2\,(\mathrm{GeV}^2/c^4)$
This Analysis
LHCb 2013
LHCb 2015
SM from DHMV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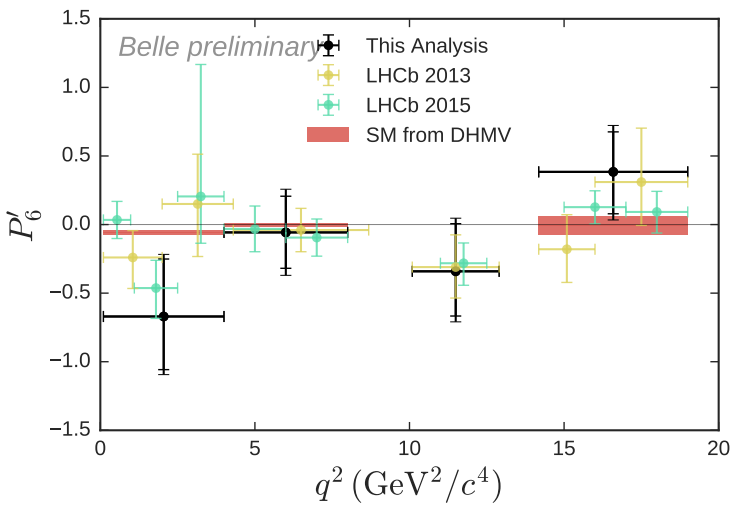
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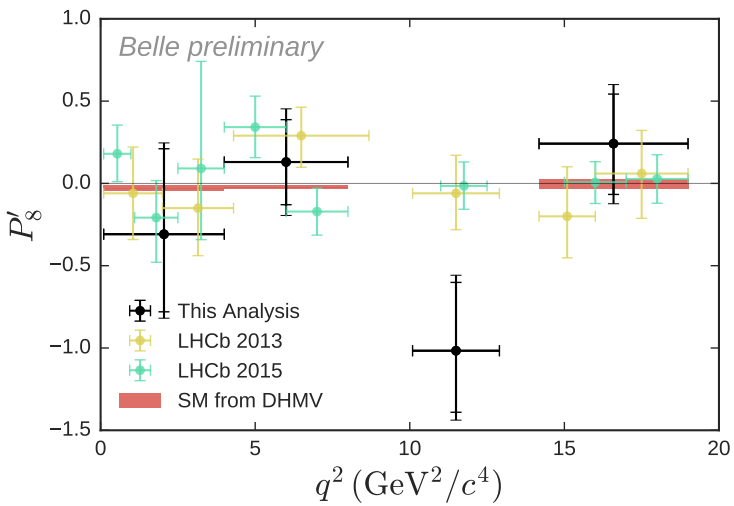
Belle preliminary
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This Analysis
LHCb 2013
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SM from DHMV