Search for Beyond the SM Physics in Electroweak B Decays at Belle

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16 | August | 2013

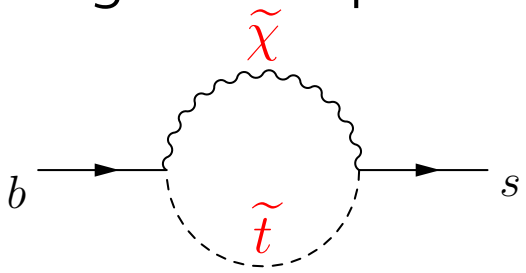
DPF 2013

Outline

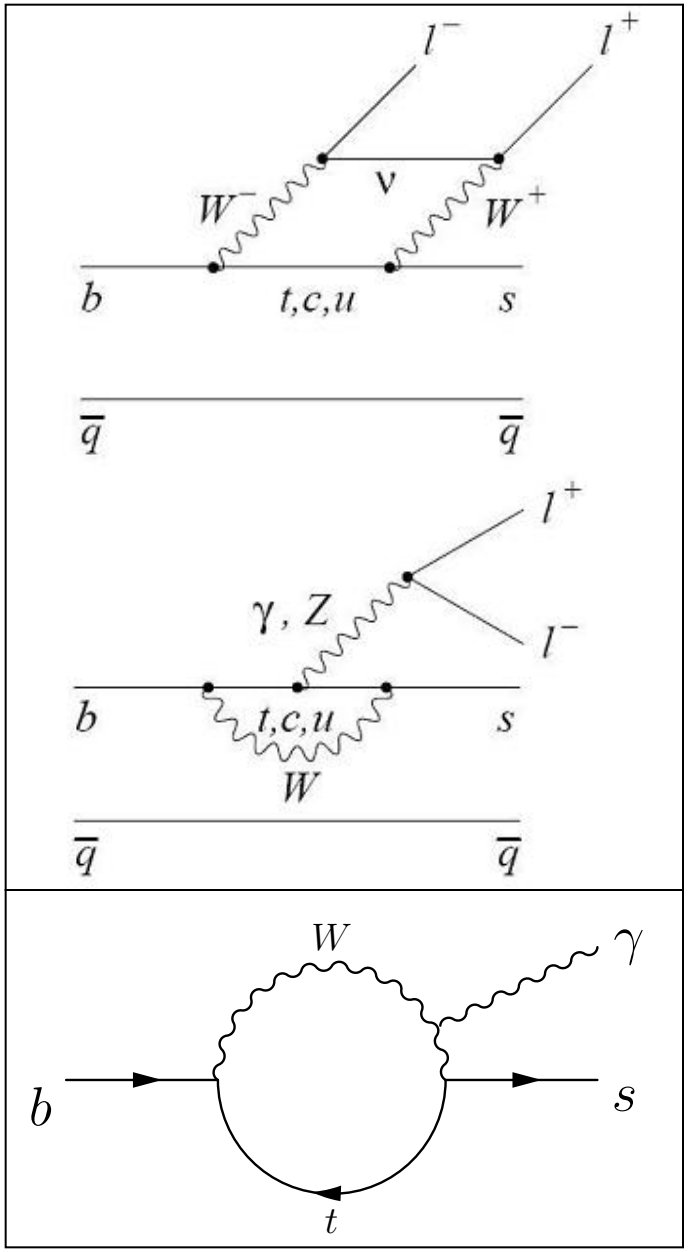
- Introduction to Electroweak physics at Belle
- Belle and KEKB
- Analyses: **Flavor Changing Neutral Current**
  - Radiative decay: $b \to s\gamma$ ($\boldsymbol{B^0 \to p\Lambda\pi\gamma}$)
  - Penguin decay: $b \to s\, l^+l^-$ (e,μ)
    - Inclusive: $\boldsymbol{B \to X_s\, l^+l^-}$
    - Exclusive: $\boldsymbol{B \to K^{(*)}\, l^+l^-}$

$b \rightarrow s$ Electroweak Decay

- **$b \rightarrow s$**: Flavor Changing Neutral Current (FCNC). Not possible at tree level
- Penguin diagrams: Sensitive to new particles entering the loops

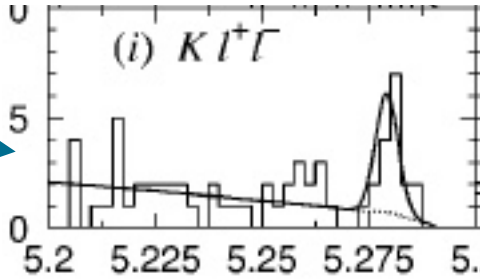


- Beyond the SM contributions can be large. Observable via:
  - **Lepton Decay Angle (A_{FB})**
  - **Decay Rate**

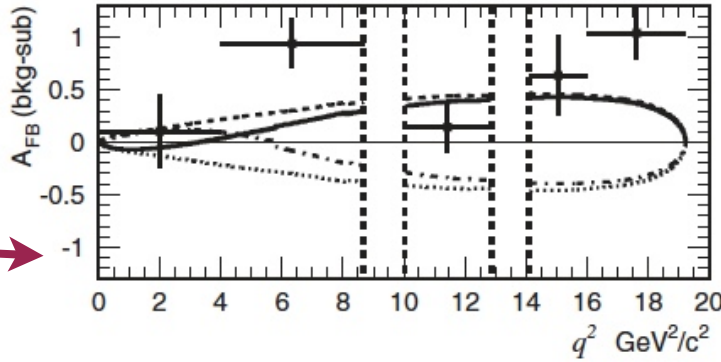


Belle's Legacy on EWP

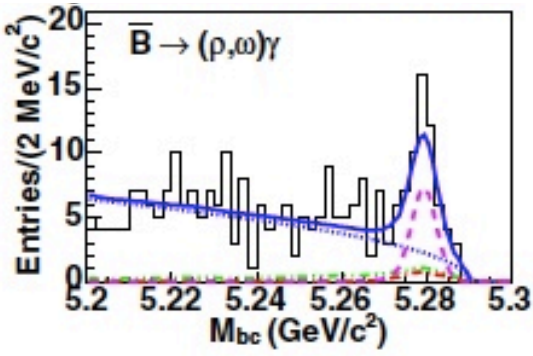
- First observation of $B \to K l^+ l^-$
  PRL **88**, 021801 (2002)



- First observation of $B \to K^* l^+ l^-$
  PRL **91**, 261601 (2003)
- First observation of $B \to X_s l^+ l^-$
  PRL **90**, 021801 (2003)
- First measurement of A_{FB} of $B \to K^* l^+ l^-$
  PRL **96**, 251801 (2006)

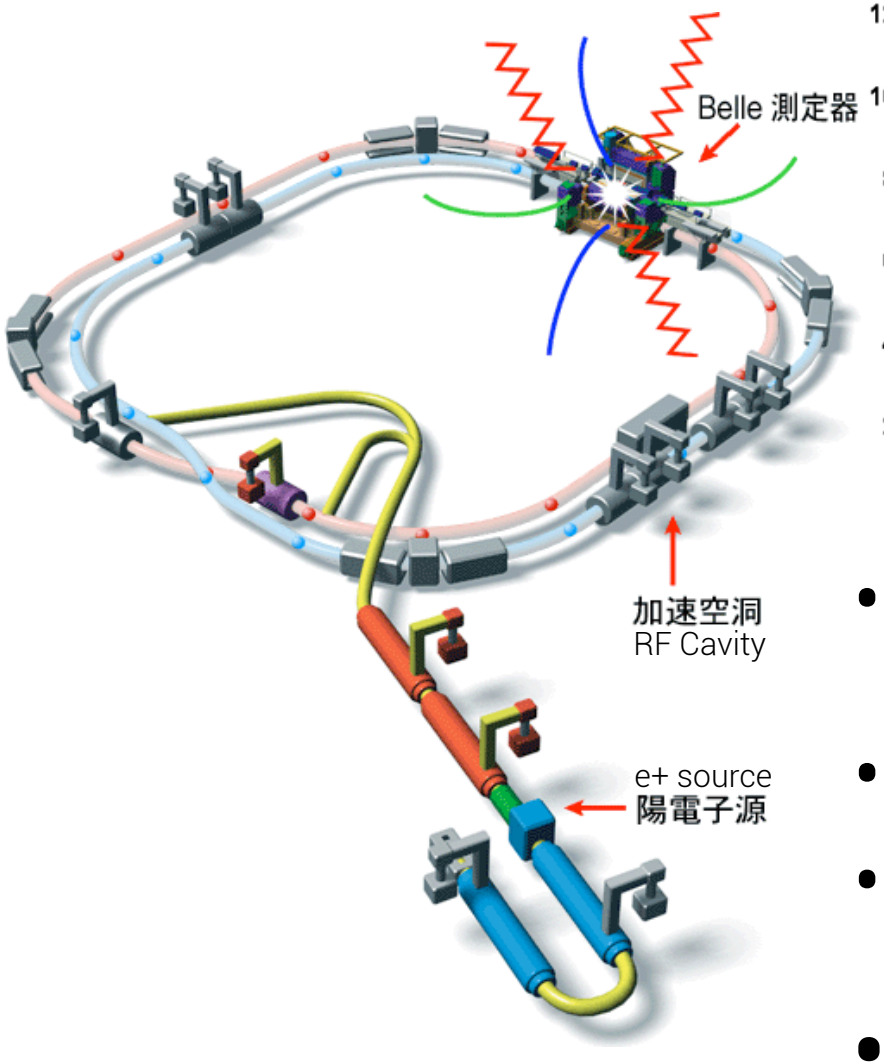


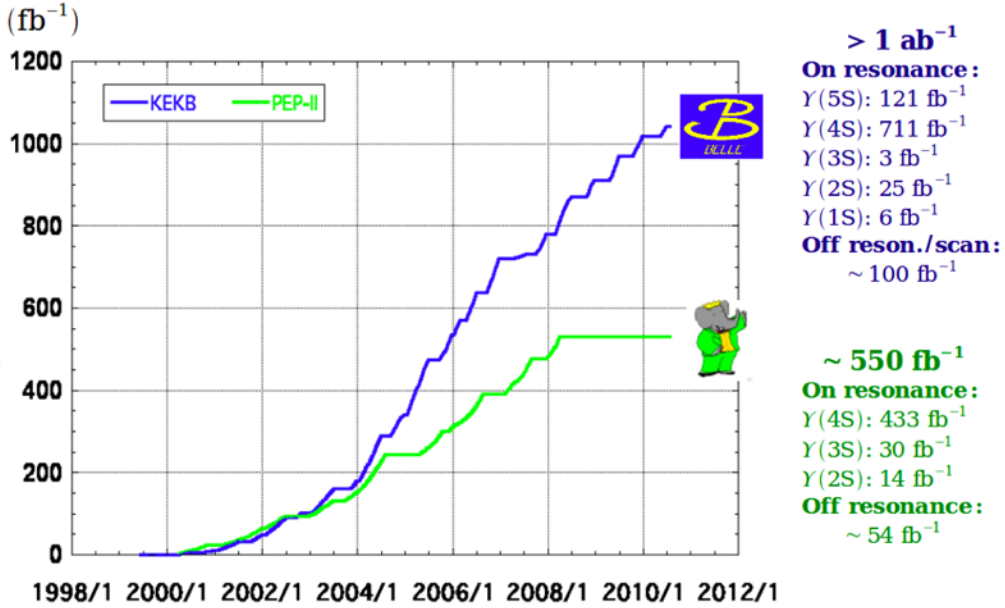
- First observations of several radiative modes, $\Phi K\gamma$, $K_1\gamma$, etc.
- First observation of $B \to (\rho,\omega)\gamma$
  PRL **96**, 221601 (2006)



- Most precise measurement of $B \to X_s\gamma$ covering the widest E_γ range. PRL **103**, 241801 (2009)
- **.... and many more published results**

KEKB at KEK Tsukuba

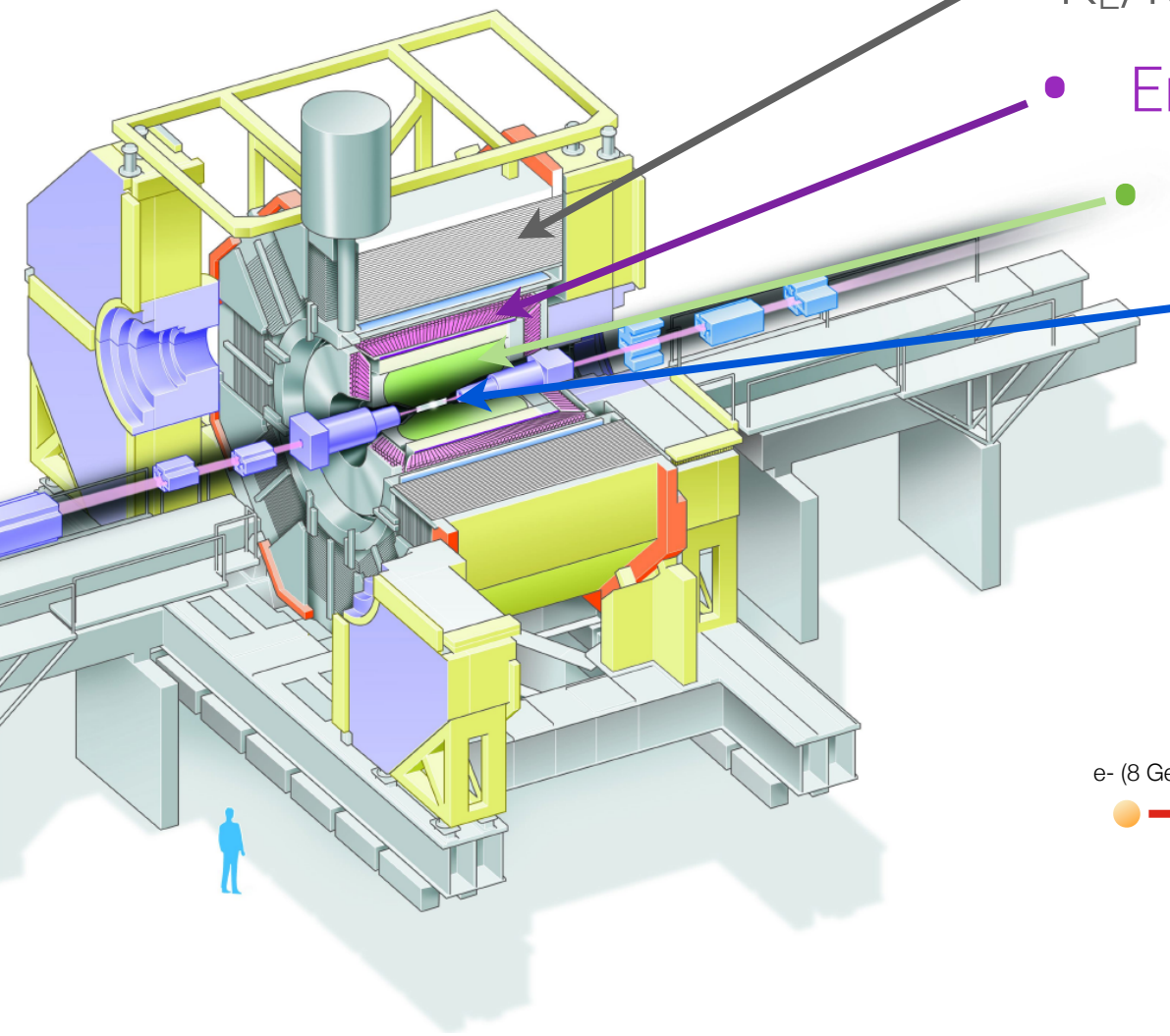


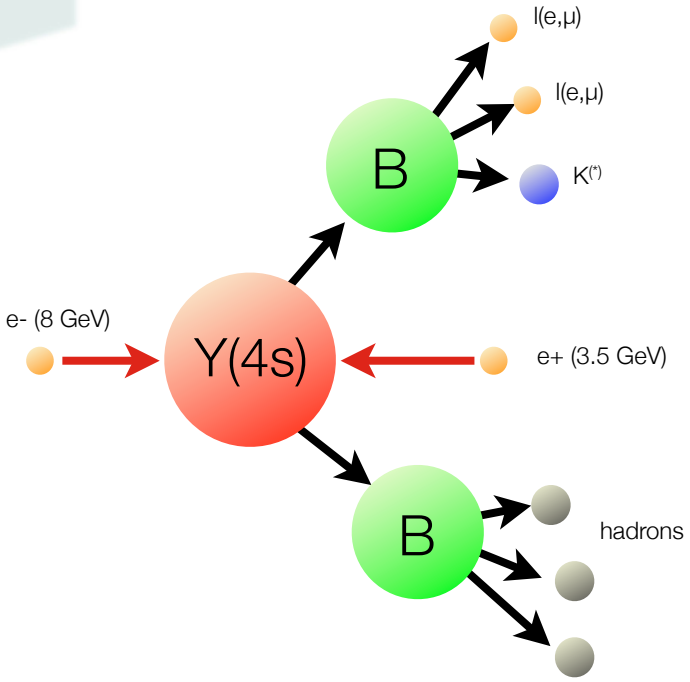


- Results use World's Largest ***Υ(4s)*** Data Set
- 772 Million BB pairs
- Currently being upgraded, SuperKEKB to collect ~50 times the current data set
- **Preliminary: to be published soon**

Belle Detector

- K_L/Muon
- Energy Measurement
- PID
- Tracking





Belle Detector

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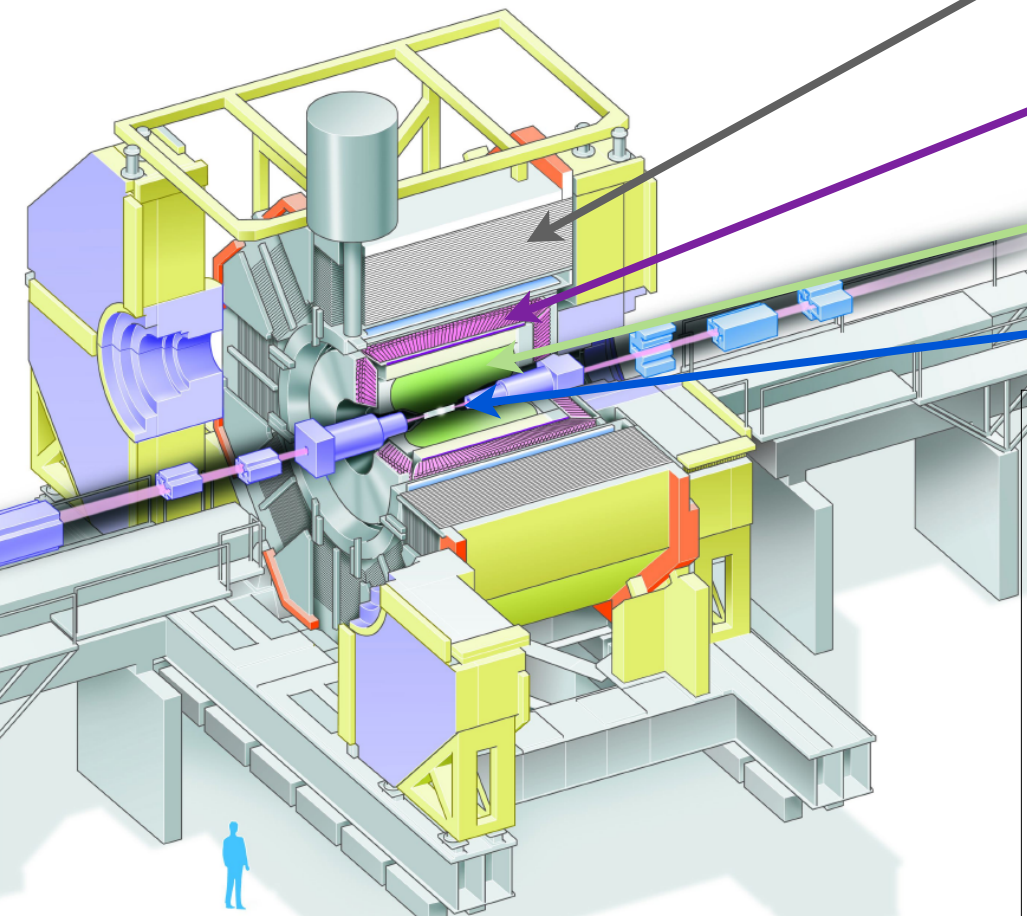
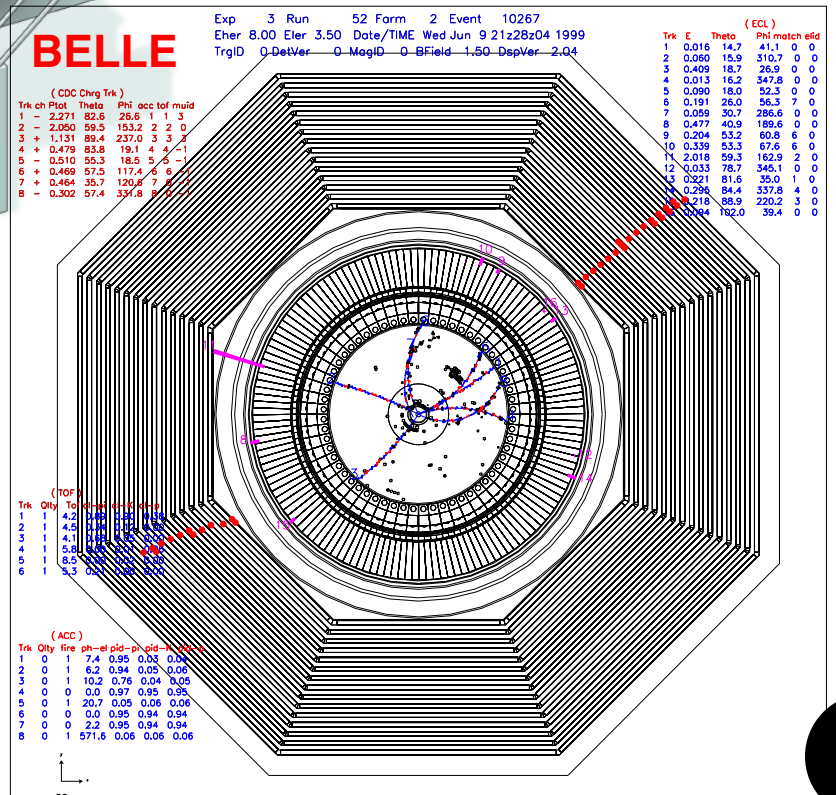
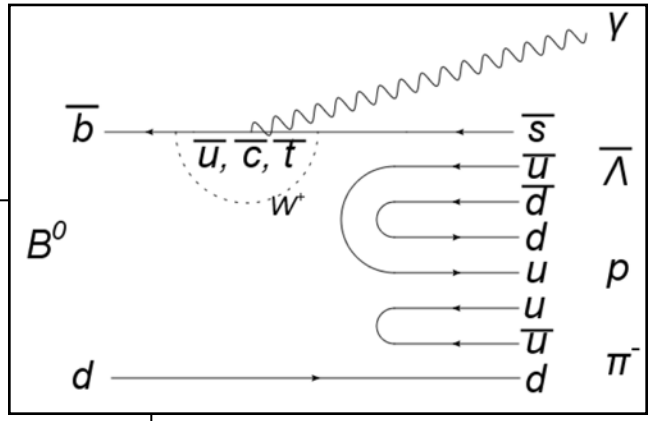




Radiative decay: $b \to s\gamma$ ($B^0 \to p\bar{\Lambda}\pi\gamma$)



Hierarchy has been observed in the $b \to s$ and $b \to c$ baryonic transitions

$$\mathcal{BR}(B^+ \to p\Lambda\pi^+\pi^-) > \mathcal{BR}(B^0 \to p\Lambda\pi^-) > \mathcal{BR}(B^+ \to p\Lambda)$$

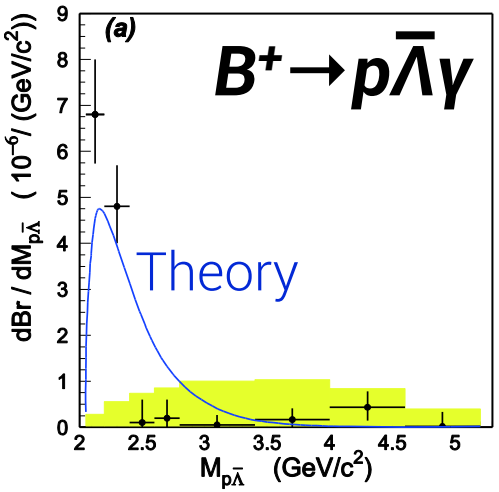
$$\mathcal{BR}(B^+ \to p\Lambda_c\pi^+\pi^-) > \mathcal{BR}(B^0 \to p\Lambda_c\pi^-) > \mathcal{BR}(B^+ \to p\Lambda_c)$$

... check $b \to s\gamma$

Belle observed interesting excess in $M_{p\bar{\Lambda}}$ in $B^+ \to p\bar{\Lambda}\gamma$

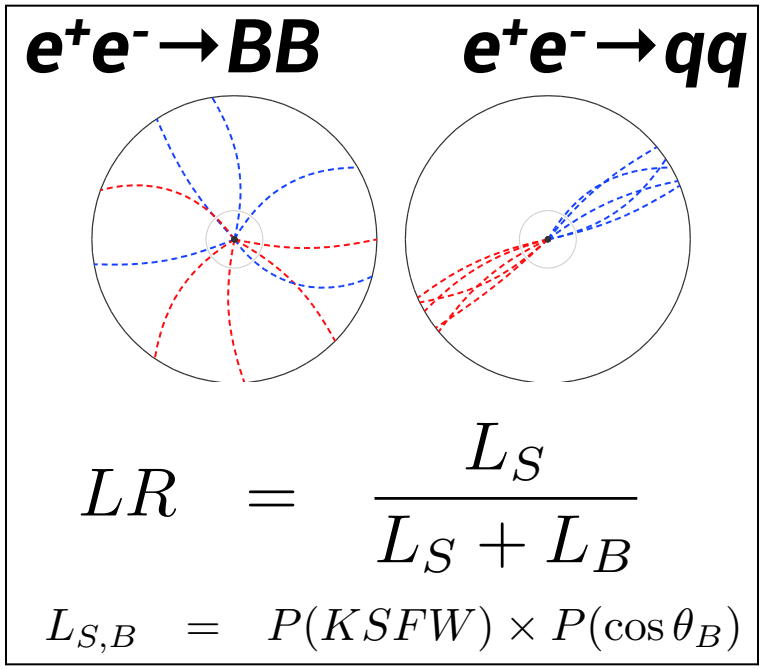
$$\mathcal{B}r(B^+ \to p\bar{\Lambda}\gamma) = (2.45^{+0.44}_{-0.38} \pm 0.22) \times 10^{-6}$$

M.-Z. Wang et al. (Belle Collaboration), Phys. Rev. D. 76, 052004 (2007).



Radiative decay: $b \to s\gamma$ ($B^0 \to p\bar{\Lambda}\pi\gamma$)

- Main background **continuum** $e^+e^- \to qq$ (u,d,s,c)
- Likelihood Ratio (***LR***) is constructed from event shape variables (Fox-Wolfram, cos θ_B)



Signal yield extracted with 2D fit to M_{bc} and ΔE

$$M_{\rm bc} \equiv \sqrt{E^2_{beam} - |\vec{p}_B|^2}$$

$$\Delta E \equiv E_B - E_{beam}$$

Radiative decay: $b \to s\gamma$ ($B^0 \to p\bar{\Lambda}\pi\gamma$)

- Fit Result:

$$N_{sig} = 9.49^{+11.50}_{-10.67}(stat) \pm 1.08(syst).$$

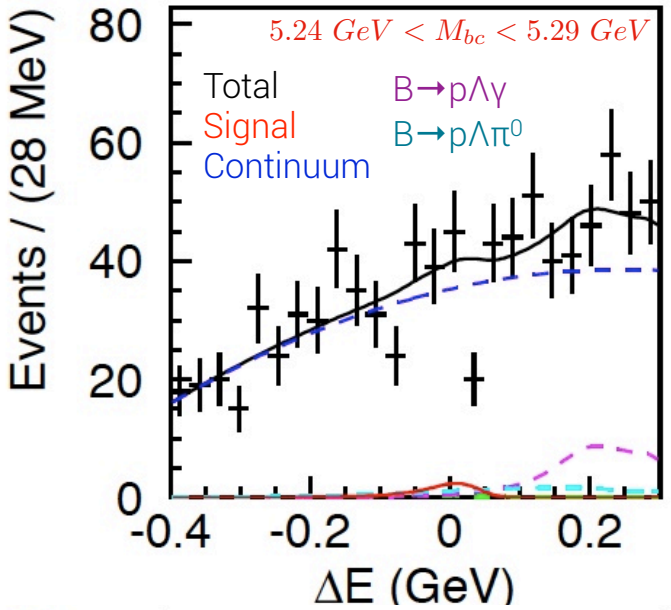
- Dominant systematic is uncertainty on other rare B decays
- Place a limit on the $\mathcal{BR}$

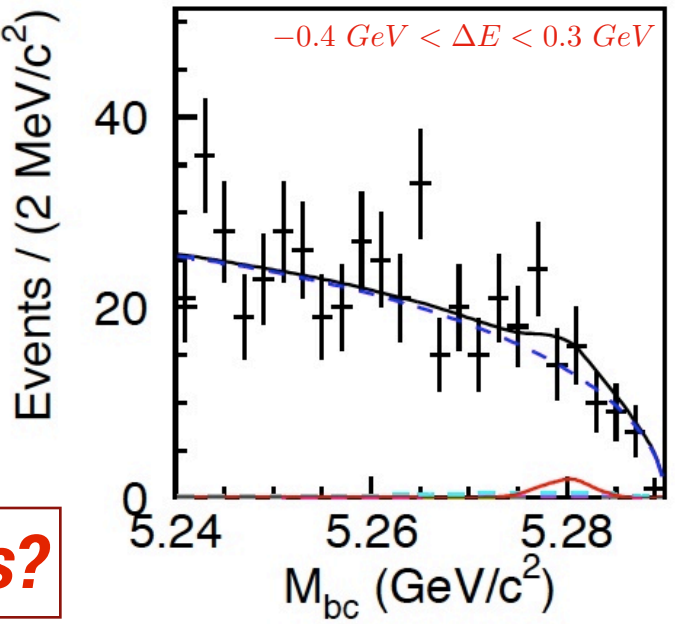
$$\mathcal{BR}(B^0 \to p\bar{\Lambda}\pi^-\gamma) < 6.48 \times 10^{-7}(90\% C.L.)$$

Hierarchy not as expected

$$\mathcal{BR}(B^0 \to p\bar{\Lambda}\pi^-\gamma) \not> \mathcal{BR}(B^+ \to p\bar{\Lambda}\gamma)$$

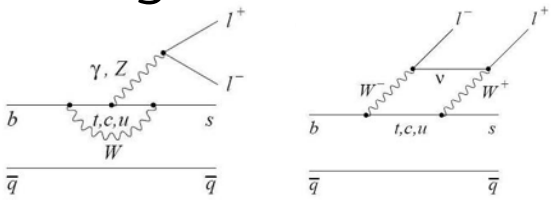
New Physics?





Penguin decay: $b \to s\, l^+ l^-$

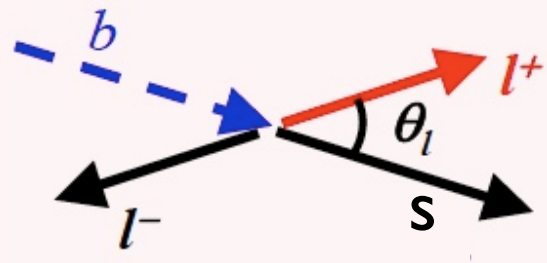
- **Many observables sensitive to new physics** *(See Tues. Plen.)*
- Interference: Penguin and box diagrams



  - **Lepton (e,μ) forward-backward asymmetry (A_{FB}).**
  - **Analysis binned in $q^2 = m_{ll}^2$**

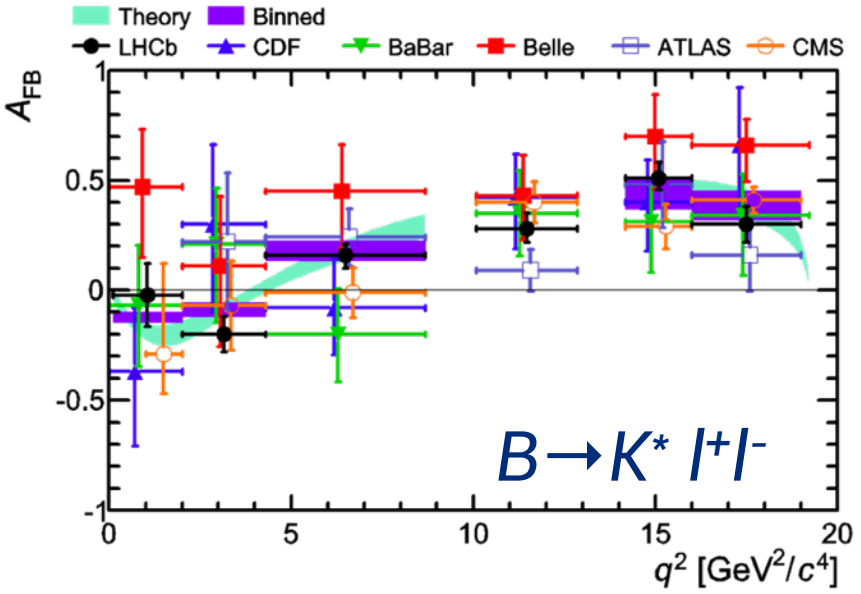
- SM predicts some A_{FB}
- Large asymmetry seen in an earlier analysis at Belle

$$A_{FB} \equiv \frac{N(\cos\theta > 0) - N(\cos\theta < 0)}{N(\cos\theta > 0) + N(\cos\theta < 0)}$$



Sensitive to Wilson Coefficients

$$A_{FB} \propto -\mathrm{Re}\left[\left(2C_7^{eff} + \frac{q^2}{m_b^2} C_9^{eff}\right) C_{10}^*\right]$$



Penguin decay: $b \to s\, l^+l^-$ ($B \to X_s\, l^+l^-$)

- Inclusive has less theoretical uncertainty than $B \to K^{(*)}\, l^+l^-$
- Semi-inclusive (sum of exclusive) method, with 36 modes of which 20 are used for A_{fb}
- The fraction of all X_s decays covered by 20 final states is ~50 %

- Neural network is employed for backgrounds suppression
  - Semi-leptonic B decays
  - Continuum (u,d,s,c)

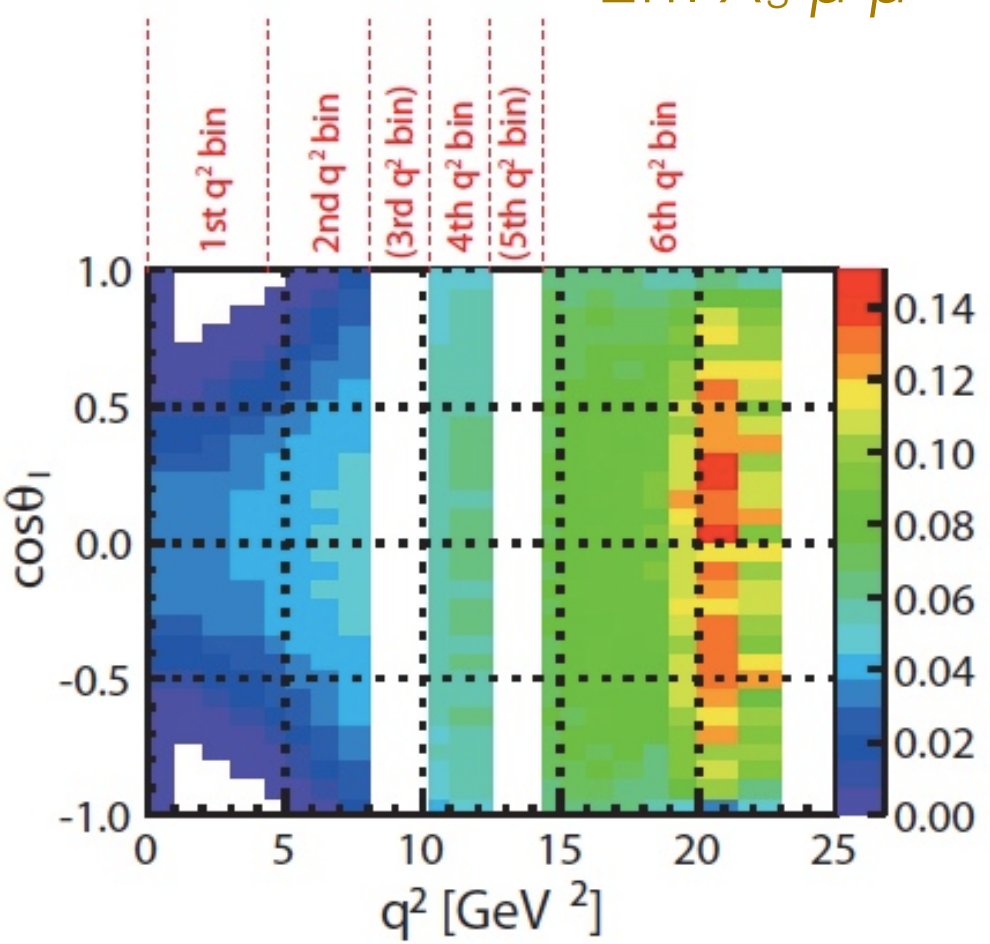
	$B^0/\bar{B}^0$		$B^\pm$	
K	K_S^0		$K^\pm$	
$K\pi$	$K^\pm\pi^\mp$	$K_S^0\pi^0$	$K^\pm\pi^0$	$K_S^0\pi^\pm$
$K2\pi$	$K^\pm\pi^\mp\pi^0$	$K_S^0\pi^\pm\pi^\mp$	$K^\pm\pi^\mp\pi^\pm$	$K_S^0\pi^\pm\pi^0$
$K3\pi$	$K^\pm\pi^\mp\pi^\pm\pi^\mp$	$K_S^0\pi^\pm\pi^\mp\pi^0$	$K^\pm\pi^\mp\pi^\pm\pi^0$	$K_S^0\pi^\pm\pi^\mp\pi^\pm$
$K4\pi$	$K^\pm\pi^\mp\pi^\pm\pi^\mp\pi^0$	$K_S^0\pi^\pm\pi^\mp\pi^\pm\pi^\mp$	$K^\pm\pi^\mp\pi^\pm\pi^\mp\pi^\pm$	$K_S^0\pi^\pm\pi^\mp\pi^\pm\pi^0$

Penguin decay: $b \rightarrow s\, l^+ l^-$ ($B \rightarrow X_s\, l^+ l^-$)

- Signal extraction: Divide into q^2 bins and **fit M_{bc} for forward/backward events** in e/μ channels.

- After we correct for efficiency, we then apply a linear scale factor determined from MC to obtain the **final A_{FB}**

Eff. $X_s\, \mu\, \mu$



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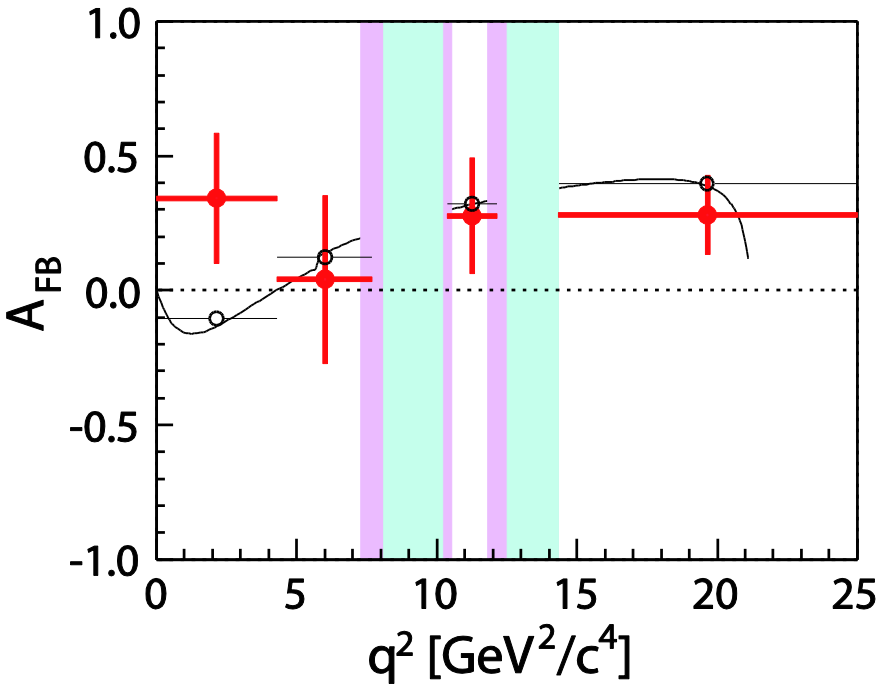
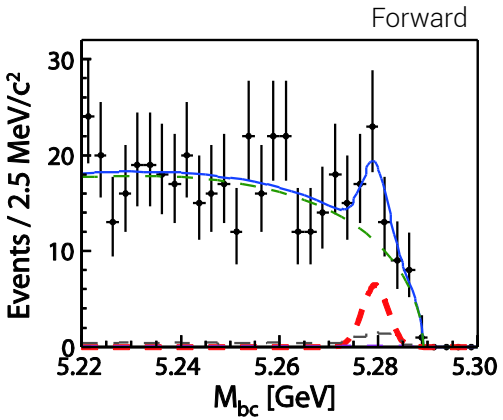
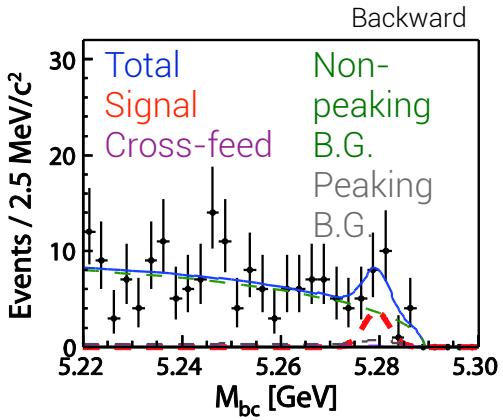






Fit $X_s\mu\mu$ 2nd q^2 bin: N_{sig} = 23.9±10.5 (stat)

- **Consistent with SM**
- Total Signal Yields
  - N_{sig}^{ee} = 139.9 ± 18.6 (stat)
  - $N_{sig}^{\mu\mu}$ = 160.8 ± 20.0 (stat)

Bin 1: **Consistent with SM at 1.8σ** (6.6% C.L.)

Bin 3/4: **Exclude C_{10}*C_9 > 0 with 2.3σ** (97.9% C.L.)

Penguin decay: $b \to s\, l^+l^-$

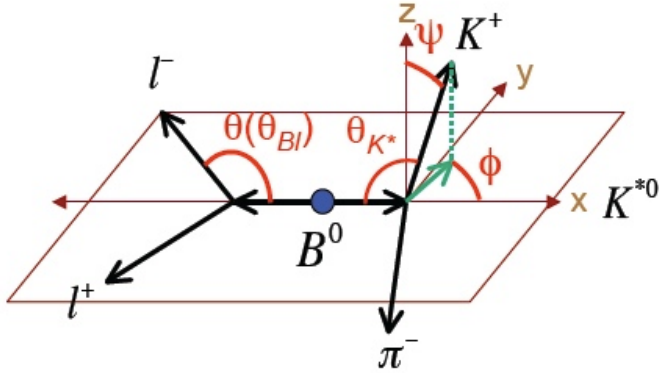
($B \to K^{(*)}\, l^+l^-$)

20 Decay Channels

$B \to K^{*0}e^+e^- \to (K^+\pi^-)e^+e^-$
$B \to K^{*0}e^+e^- \to (K_S^0\pi^0)e^+e^-$
$B \to \overline{K}^{*0}e^+e^- \to (K^-\pi^+)e^+e^-$
$B \to K^{*+}e^+e^- \to (K_S^0\pi^+)e^+e^-$
$B \to K^{*+}e^+e^- \to (K^+\pi^0)e^+e^-$
$B \to K^{*-}e^+e^- \to (K_S^0\pi^-)e^+e^-$
$B \to K^{*-}e^+e^- \to (K^-\pi^0)e^+e^-$
$B \to K^+e^+e^-$
$B \to K_S^0e^+e^-$
$B \to K^-e^+e^-$

$B \to K^{*0}\mu^+\mu^- \to (K^+\pi^-)\mu^+\mu^-$
$B \to K^{*0}\mu^+\mu^- \to (K_S^0\pi^0)\mu^+\mu^-$
$B \to \overline{K}^{*0}\mu^+\mu^- \to (K^-\pi^+)\mu^+\mu^-$
$B \to K^{*+}\mu^+\mu^- \to (K_S^0\pi^+)\mu^+\mu^-$
$B \to K^{*+}\mu^+\mu^- \to (K^+\pi^0)\mu^+\mu^-$
$B \to K^{*-}\mu^+\mu^- \to (K_S^0\pi^-)\mu^+\mu^-$
$B \to K^{*-}\mu^+\mu^- \to (K^-\pi^0)\mu^+\mu^-$
$B \to K^+\mu^+\mu^-$
$B \to K_S^0\mu^+\mu^-$
$B \to K^-\mu^+\mu^-$

- Use likelihood to suppress background
- Fit signal and background in q^2 bin
  - M_{bc}... and $M_{K\pi}$ (for K*)
  - Fix: N_{sig}, N_{bkg}
- Calculate Diff. *B* and A_l
- Fit for f_L (in q^2 bin). Fix f_L
- Fit A_{FB}



f_L vs. q^2 : (f_L = longitudinal polarization fraction for K*)

$$\frac{3}{2} f_L \cos^2\theta_{K^*} + \frac{3}{4}(1 - f_L)(1 - \cos^2\theta_{K^*})$$

A_{FB} vs. q^2:

$$\frac{3}{4} f_L (1 - \cos^2\theta_{Bl}) + \frac{3}{8}(1 - f_L)(1 + \cos^2\theta_{Bl}) + A_{FB}\cos\theta_{Bl}$$

F. Kruger and J. Matias, Phys. Rev. D71, 094009 (2005).

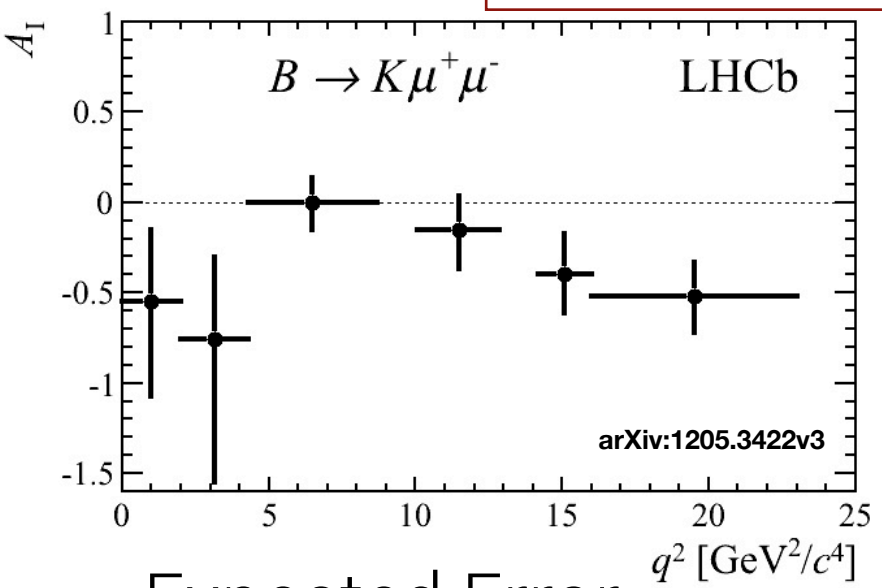
Penguin decay: $b \rightarrow s\, l^+l^-$ ($B \rightarrow K^{(*)}\, l^+l^-$)

New Physics?

CP averaged isospin asymmetry (A_I)

$$A_I \equiv \frac{(\tau_{B^+}/\tau_{B^0}) \times \mathcal{B}(K^{(*)0}ll) - \mathcal{B}(K^{(*)\pm}ll)}{(\tau_{B^+}/\tau_{B^0}) \times \mathcal{B}(K^{(*)0}ll) + \mathcal{B}(K^{(*)\pm}ll)}$$

- **Expected to be small**
- LHCb sees a large negative A_I at in $K\mu\mu$ [arXiv:1205.3422v3]
- Calculate our expected sensitivity using MC

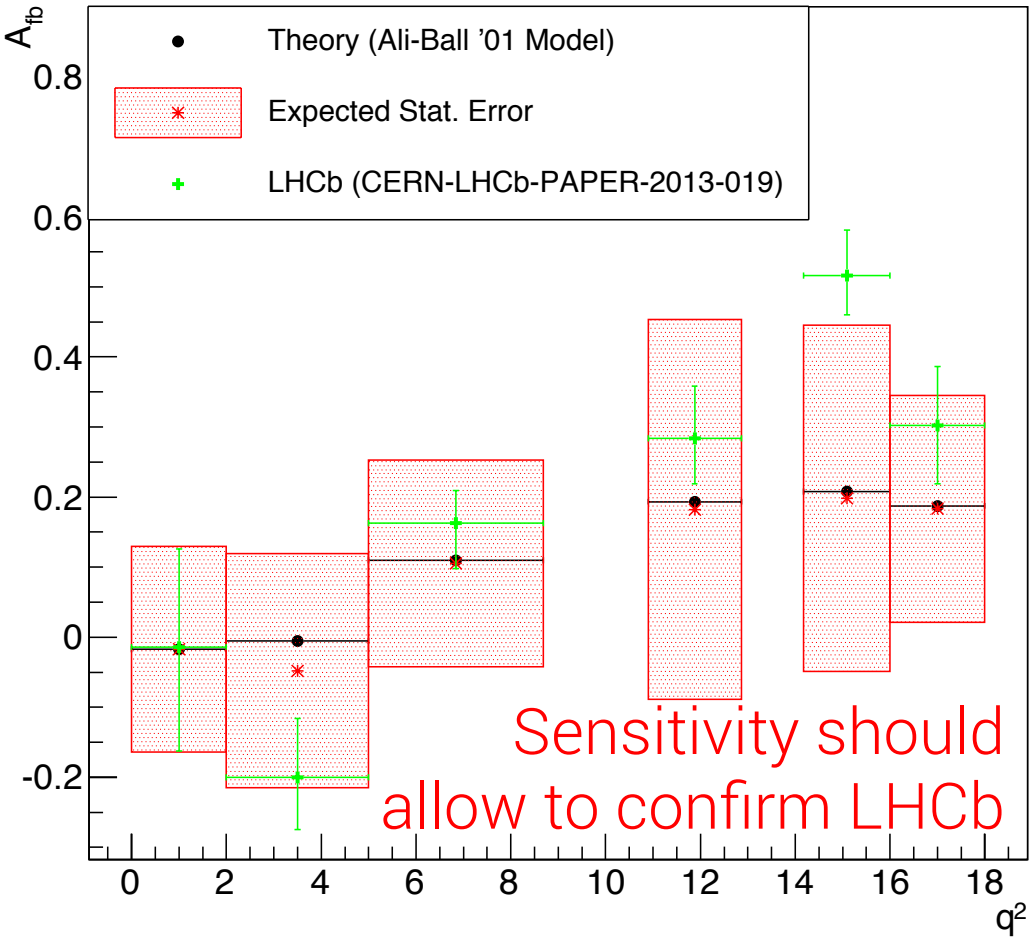


Expected Error

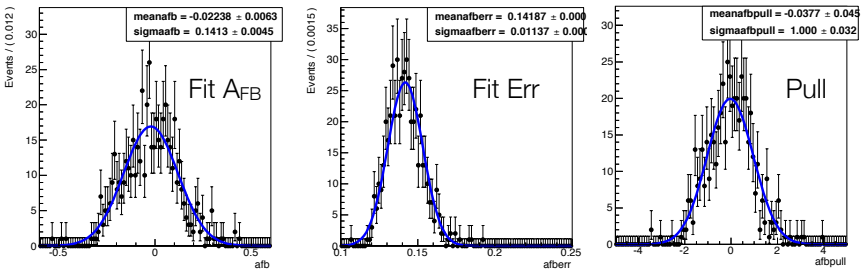
q^2 (GeV^2/c^4)	K*ll Error	Kll Error
0.0 - 2.0	0.12	0.11
2.0 - 4.3	0.14	0.07
4.3 - 8.69	0.12	0.07
10.9 - 12.86	0.14	0.10
14.18 - 16.0	0.18	0.11
> 16	0.23	0.09

Advantages of e^+e^- vs LHC:
Include e in final state
Good K^0_S reconstruction
Good π^0 reconstruction

Penguin decay: $b \rightarrow s\, l^+l^-$ ($B \rightarrow K^{(*)}\, l^+l^-$)



K*ee PSE: $0.0 < q^2 < 2.0$



- Using pseudo experiments estimate our sensitivity
- No systematics yet, but statistically limited

Conclusions

- The **FCNC B decays are a rich topic** than can be used to explore beyond the Standard Model (See Tues. Plenary)
- Tantalizing hints of new physics
- Radiative decay: $b \to s\gamma$ ($B^0 \to p\bar{\Lambda}\pi\gamma$)
  - Upper limit on $\mathcal{BR}$ **not consistent with hierarchy** seen in other modes
  - $\mathcal{BR}(B^0 \to p\bar{\Lambda}\pi^-\gamma) > 6.48 \times 10^{-7} \quad (90\% C.L.)$
- Penguin decay: $b \to s\, l^+l^-$ ($B \to X_s\, l^+l^-$)
  - Low q^2 : **Consistent with SM at 1.8σ** (6.6% C.L.)
  - High q^2 : **Exclude $C_{10}*C_9 > 0$ with 2.3σ** (97.9% C.L.)
- Penguin decay: $b \to s\, l^+l^-$ ($B \to K^{(*)}\, l^+l^-$)
  - Belle's sensitivity for **A_I should be very competitive** and complementary for A_{FB} and we will unblind soon