Isospin Asymmetry in $B \to K^{\star}\gamma$ and Hint for $B \to \mu\nu$

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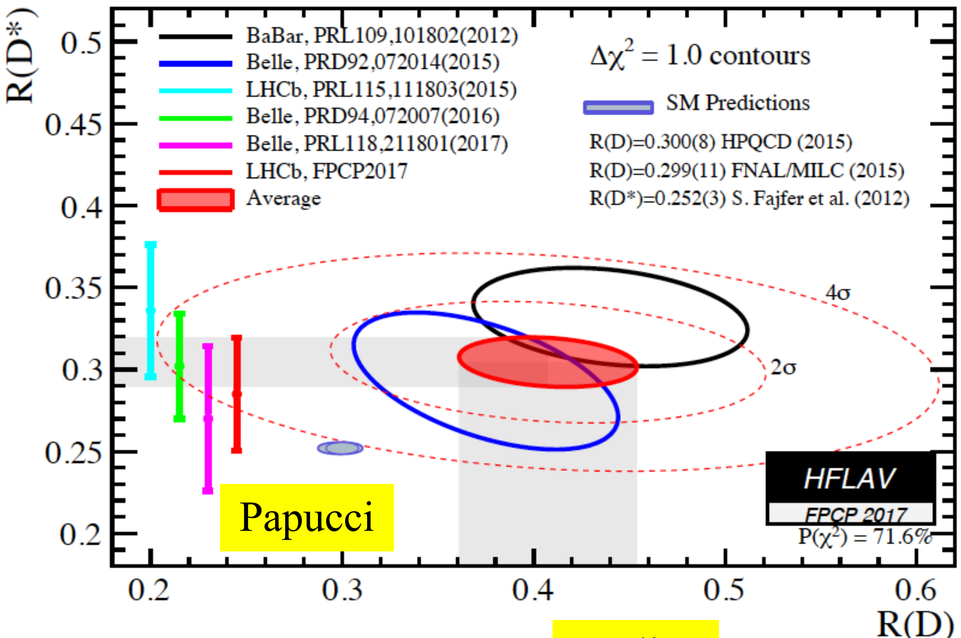
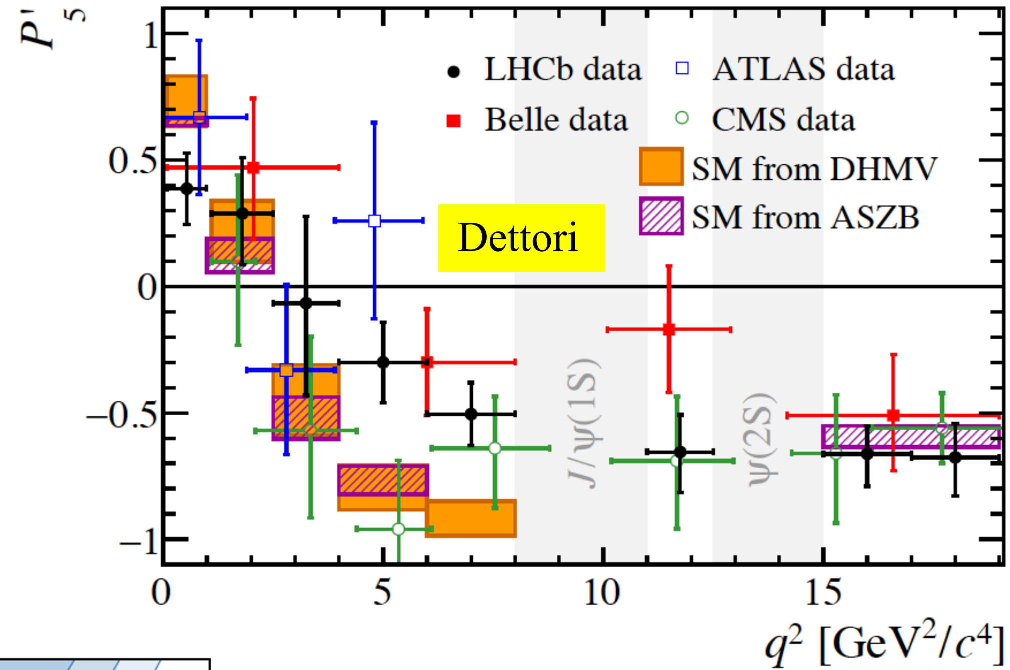
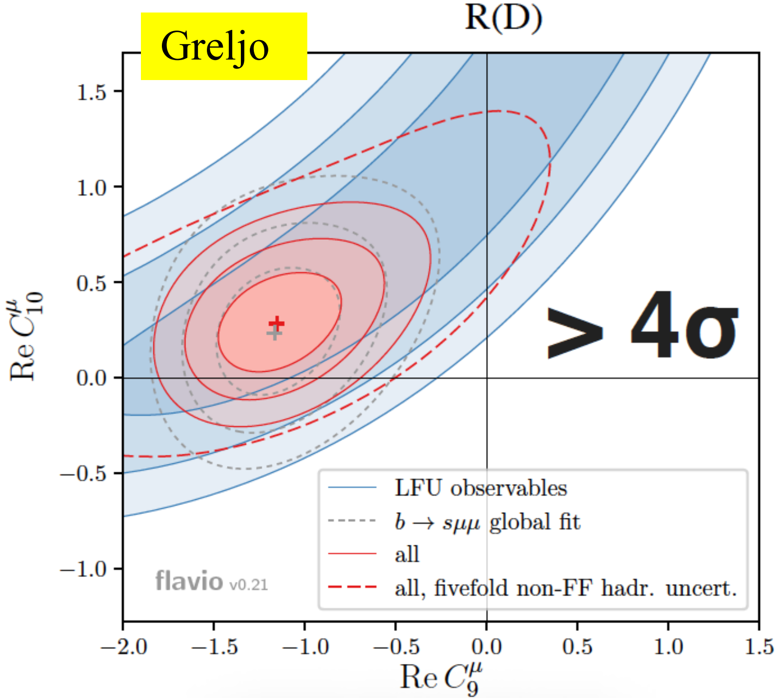
On behalf of the Belle Collaboration

Prelude

- Flavor seems to be the toast of the town

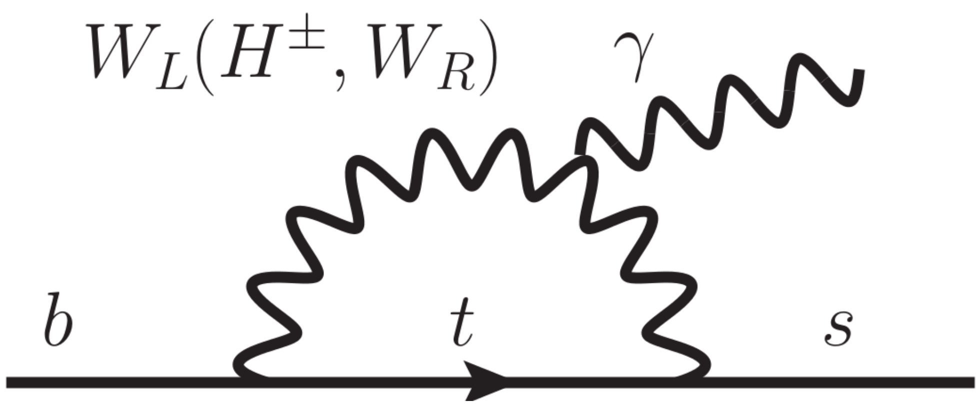






➢ Imperative to look for other places as well...

Enter $B \to K^{\star}\gamma$ Decays



- Dominantly mediated by one-loop electromagnetic penguin diagram
- Cleanest exclusive $b \to s\gamma$ decay with expected BF $\sim 4{\times}10^{-5}$

Grinstein and Pirjol, PRD62 (2000) 093002

- Calculations suffer from large uncertainties due to form factors

➢ Need theoretically clean observables...

Look for Ratios

- Isospin asymmetry:

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

- CP violation asymmetry:

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

- CP asymmetry difference between isospin channels:

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

- Ratio of branching fractions:

$$\frac{\mathcal{B}(B^0 \to K^{*0}\gamma)}{\mathcal{B}(B_s^0 \to \phi\gamma)}$$

➢ Theory uncertainties largely cancel out

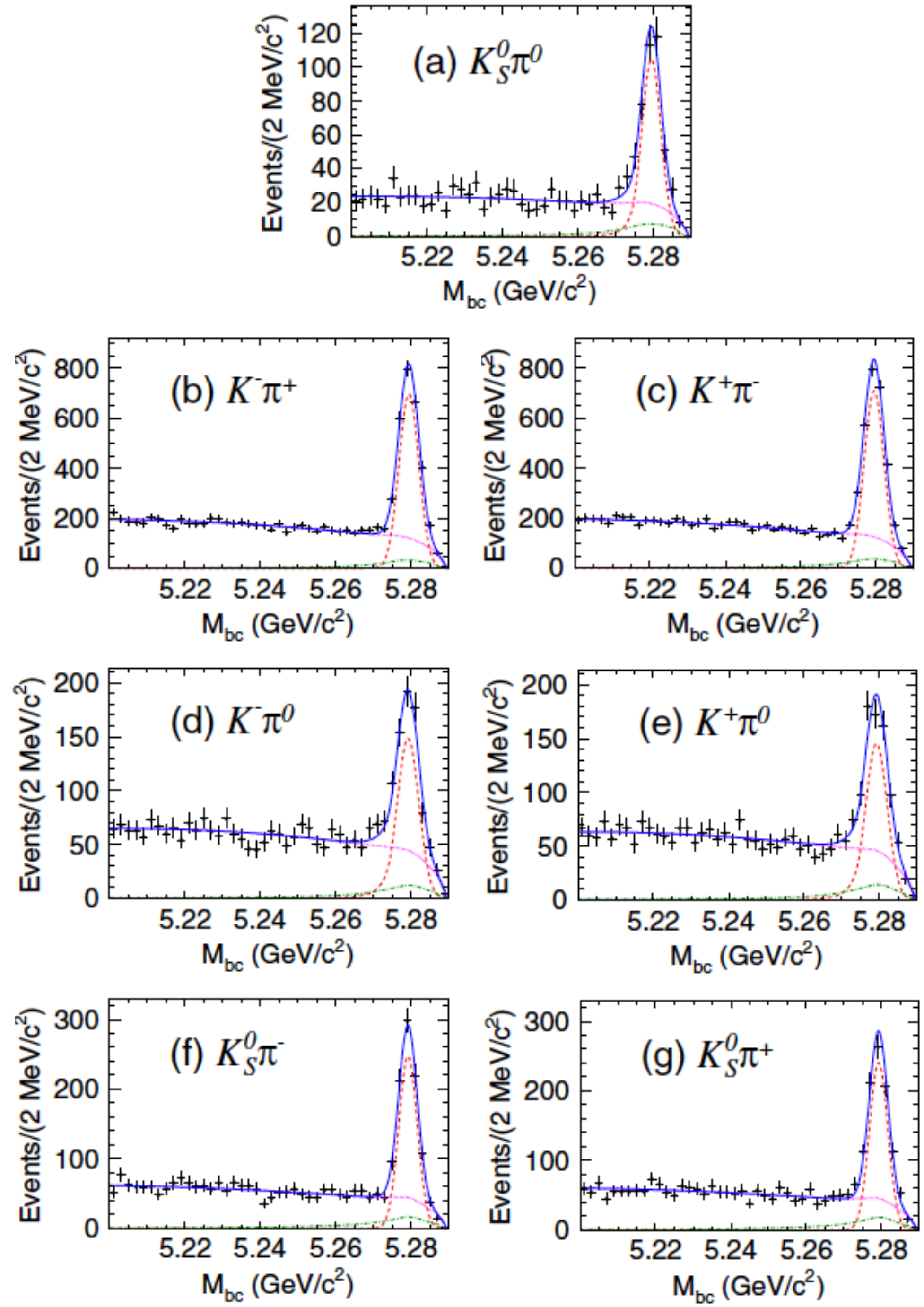
Matsumori, Sanda and Keum, PRD72 (2005) 014013

Fit Strategy

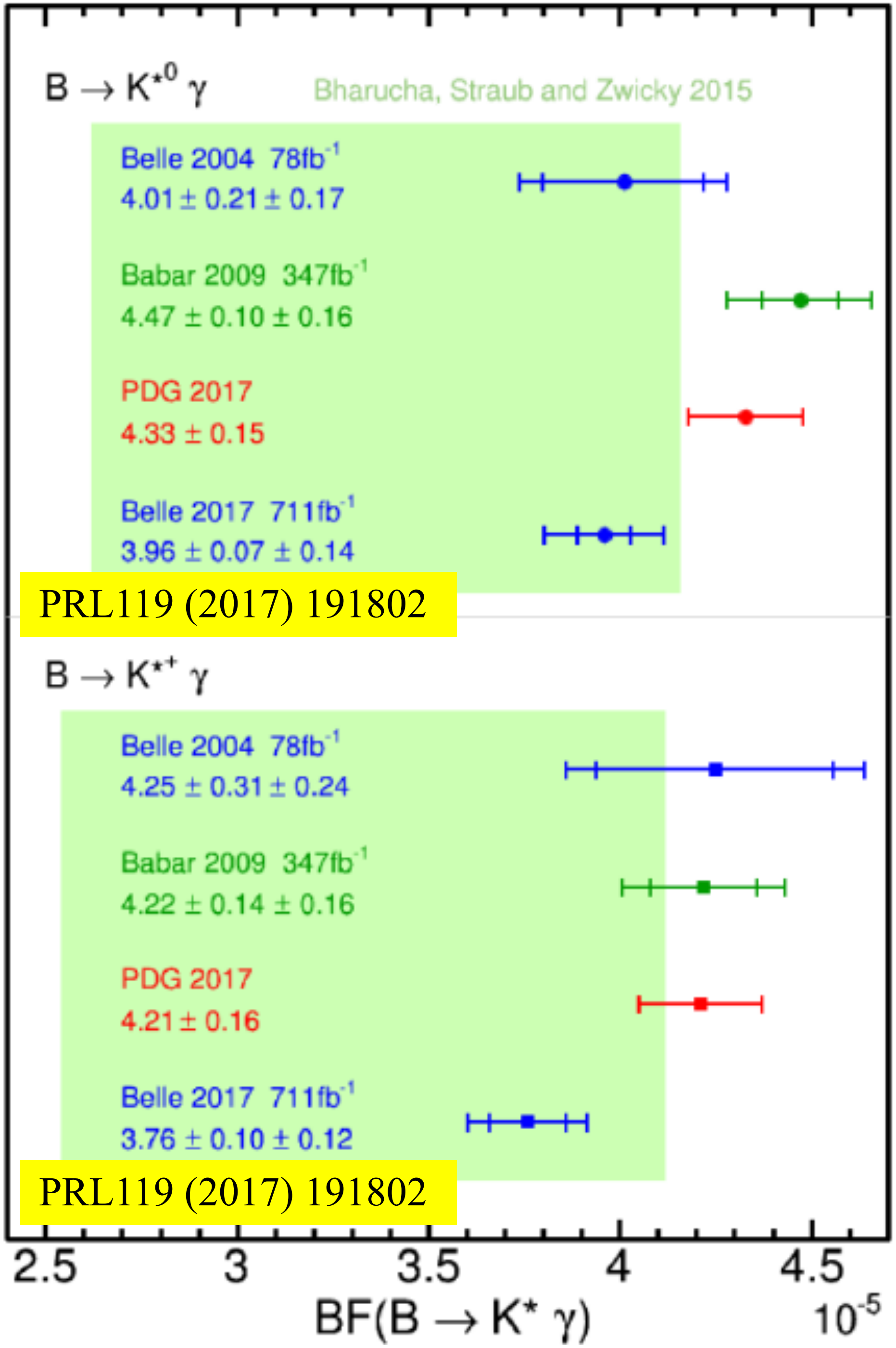
- Unbinned maximum likelihood to M_{bc} distributions in seven modes:

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

- signal (with π^0): Gaussian (Crystal Ball)
- cross-feed: ARGUS + asymmetric Gaussian with its yield proportional to that of signal
- continuum $q\bar{q}$: ARGUS
- $B\bar{B}$ bkg: ARGUS + asymmetric Gaussian



Branching Fraction

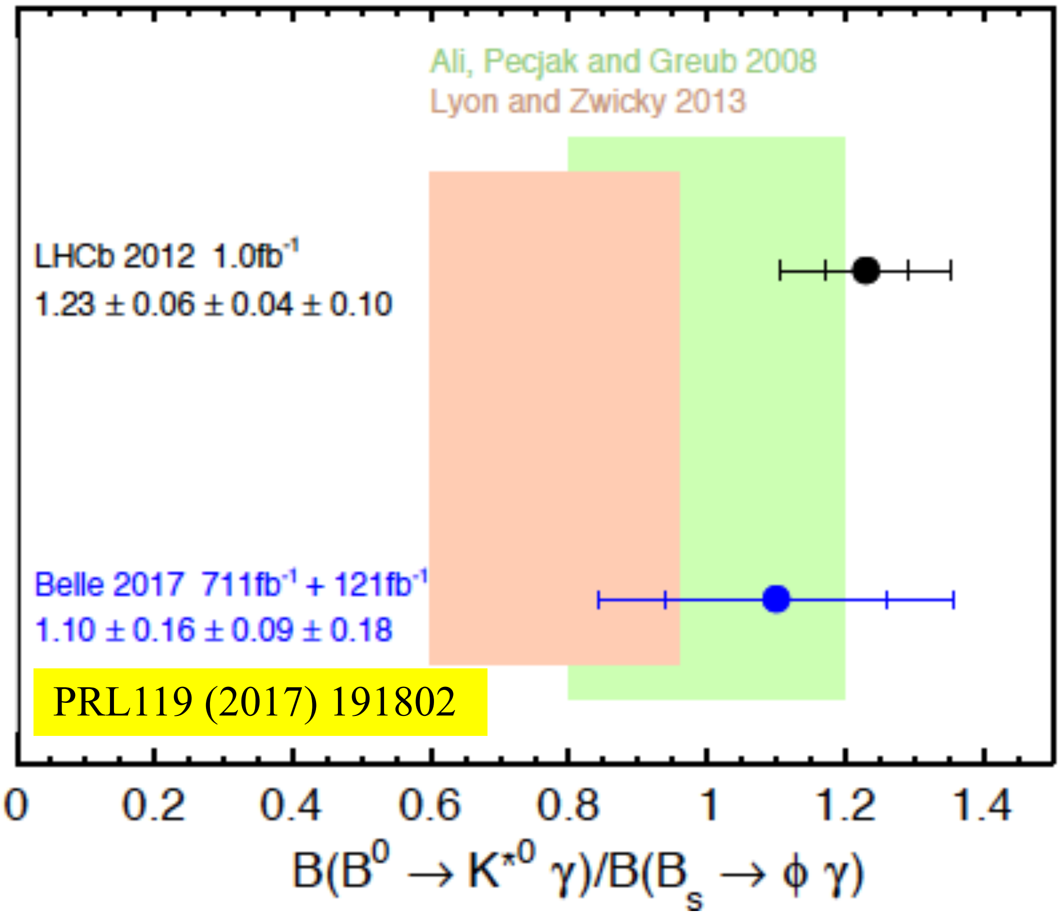


- Most precise one to date
- Consistent with theory

Bharucha, Straub and Zwicky, JHEP 08 (2016) 098

- Agree with earlier measurements

Ratio of Branching Fractions



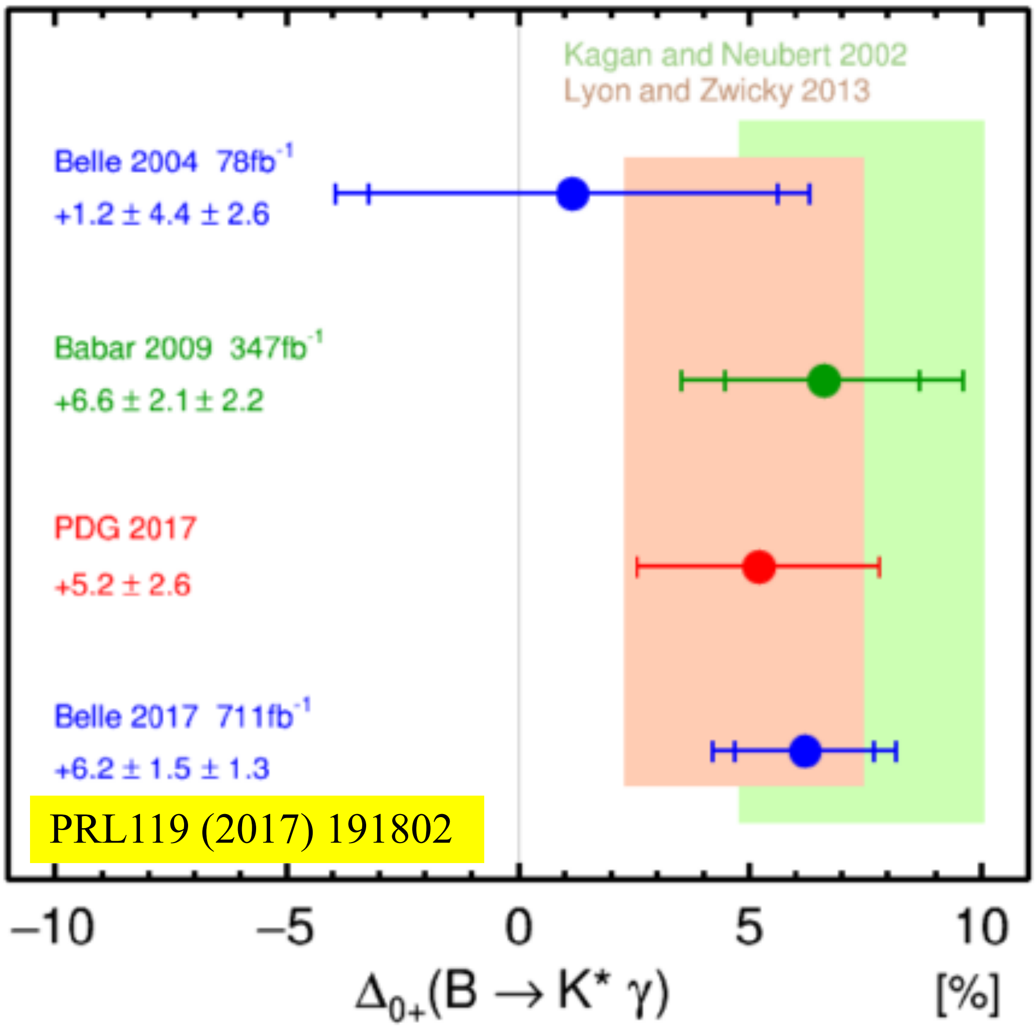
- Belle measurement of BF($B_s \to \phi\gamma$) based on 121fb^{-1} used in the calculation PRD91 (2015) 011101
- Only $K^\star \to K^+\pi^-$ used in order to cancel common systematics
- Result:

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

is consistent with theory as well as LHCb

NP B867 (2013) 1

Isospin Asymmetry



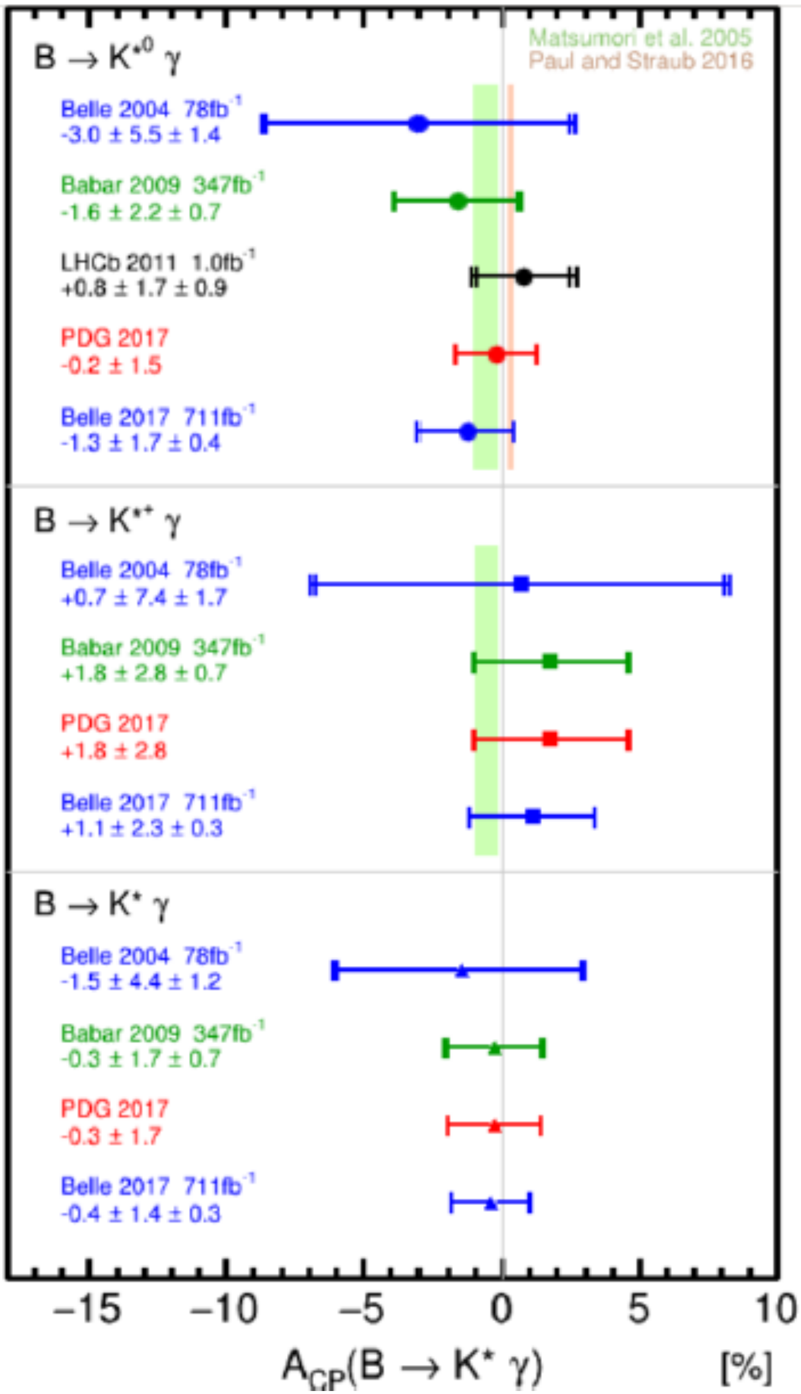
- First evidence for isospin violation in $b \to s$ transition exceeding 3σ significance
- Agree with theory predictions of

  Lyon and Zwicky PRD88 (2013) 094004

  Kagan and Neubert PLB 539 (2002) 227
- Consistent with and more precise than BaBar result

➢ To observe isospin violation with 5σ significance at Belle II, reduction of dominant systematic uncertainty due to f_{+-}/f_{00} is also essential

CP Asymmetry



- Most precise results to date

PRL119 (2017) 191802

- Consistent with theory predictions

Paul and Straub JHEP04 (2017) 027

Matsumori, Sanda and Keum, PRD72 (2005) 014013

- Agree with BaBar and LHCb (in the neutral mode)

➢ As the measurements are dominated by statistical errors, we expect substantial improvement at Belle II

Average and Difference in A_{CP}

- First measurements of:

PRL119 (2017) 191802

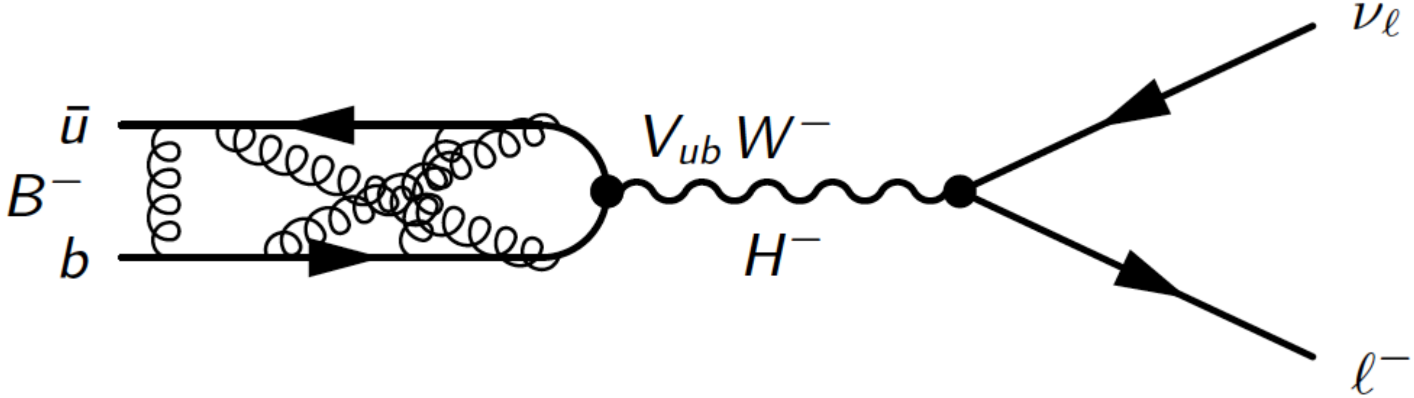
$$\Delta A_{CP} = (+2.4 \pm 2.8 \pm 0.5)\%$$

$$\bar{A}_{CP} = (-0.1 \pm 1.4 \pm 0.3)\%$$

- Results consistent with zero and dominated by statistical errors

➢ Substantial improvement expected at Belle II

Now to $B \to \mu\nu$ Decay



- Tree level diagram and strongly helicity suppressed:

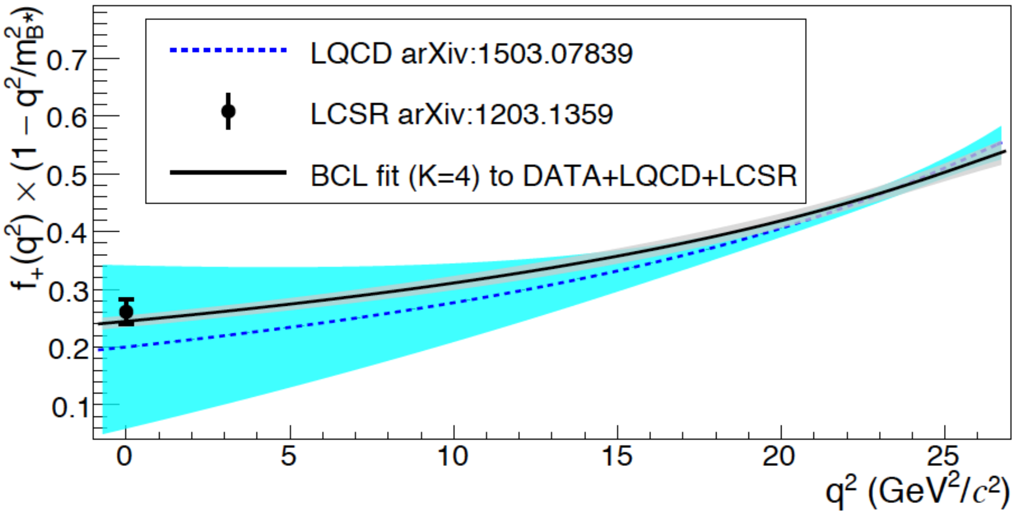
$$\mathcal{B}(B^- \to \ell^- \bar{\nu}_\ell) = \frac{G_F^2 m_B m_\ell^2}{8\pi}\left(1 - \frac{m_\ell^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

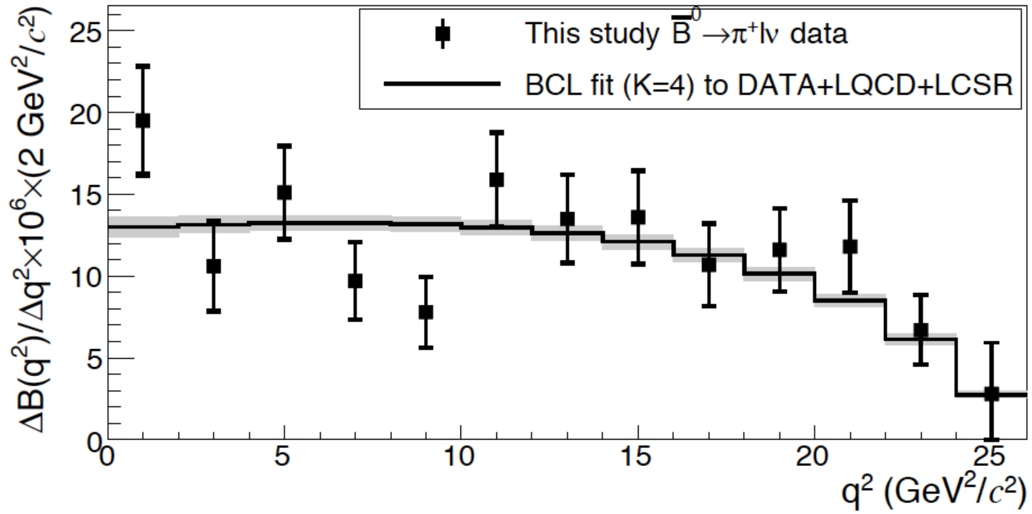
➢ Decay rate could be modified due to possible NP contribution, such as charged Higgs boson or leptoquark

Hou, PRD48 (1993) 2342

Georgi and Glashow, PRL32 (1974) 438

Our Expectation





Inputs

Value of $|V_{ub}| \times 10^3 = 3.736 \pm 0.142$ is from the exclusive $B \to \pi \ell \nu$ fit with the new LQCD input.
Value of $f_B = 185 \pm 3$ MeV is the recent result of HPQCD collaboration [arXiv:1212.0586].

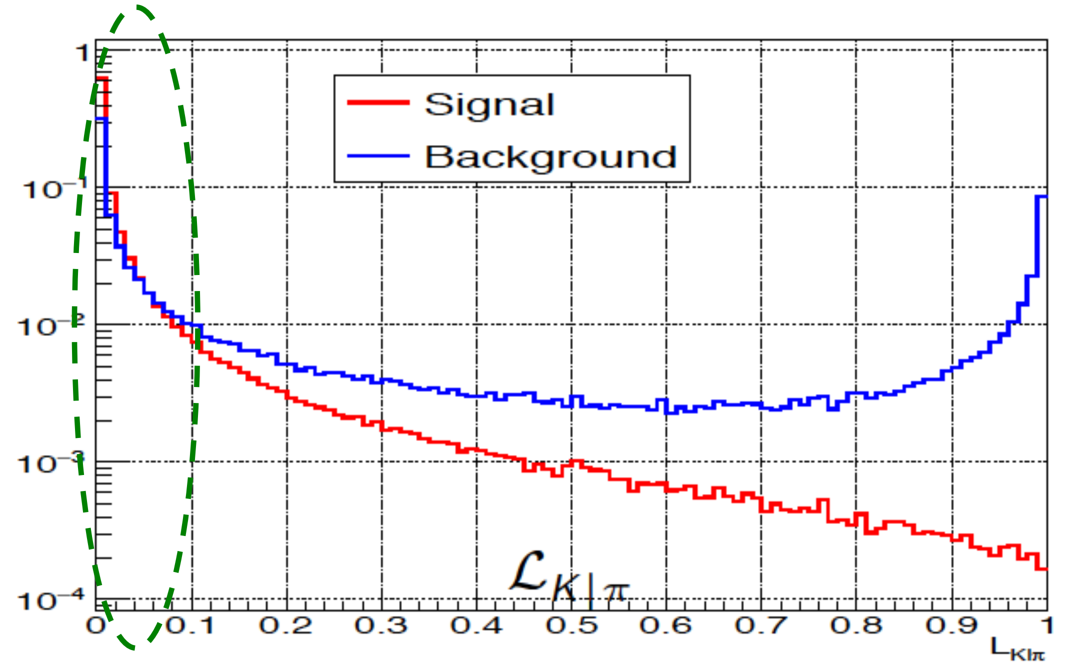
- Using these inputs, with the full Belle dataset we expect

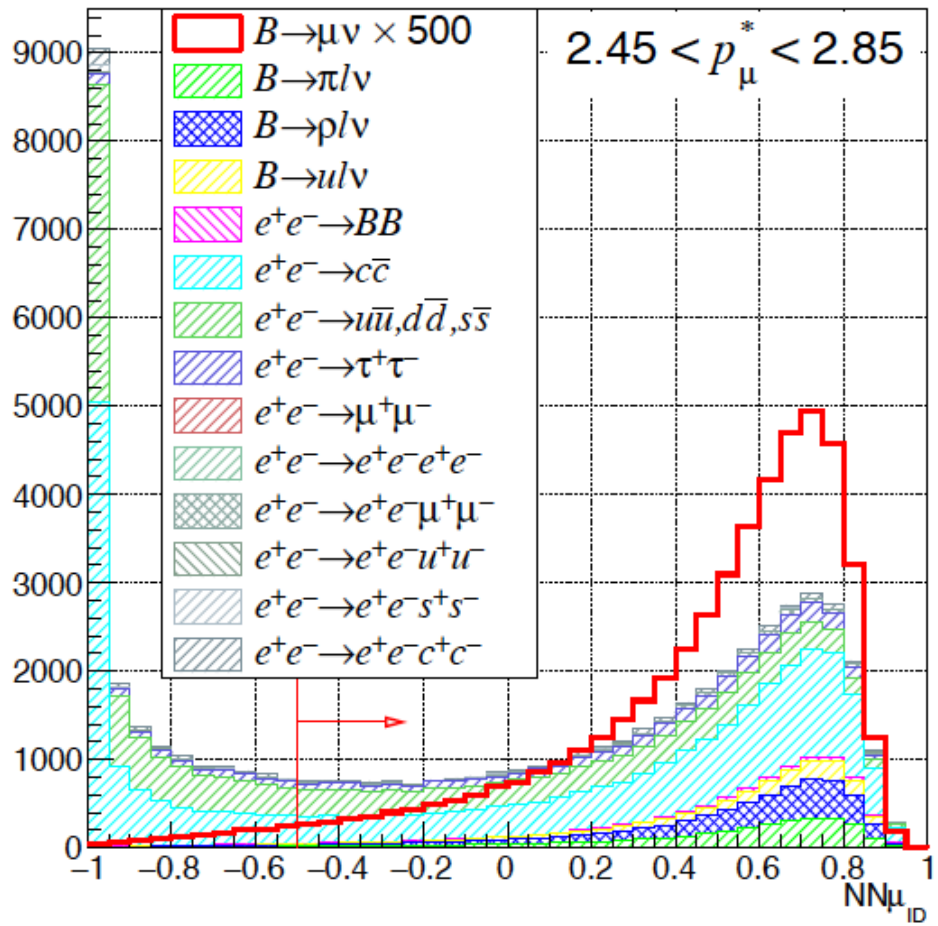
ℓ	$\mathcal{B}_{\mathrm{SM}}$	$N_{\mathrm{SM}}^{\mathrm{Belle}}$
τ	$(8.45 \pm 0.70) \times 10^{-5}$	$(670 \pm 57) \times 10^2$
μ	$(3.80 \pm 0.31) \times 10^{-7}$	301 ± 25
e	$(8.89 \pm 0.73) \times 10^{-12}$	0.0071 ± 0.0006

- $B \to \tau\nu$ is already measured by B-factories, while $B \to \mu\nu$ is potentially measurable with the full Belle dataset
- $B \to e\nu$ won't be possible even with Belle II

Improved Muon Identification

- Highest momentum muon in an event is signal candidate muon
- Although well detected by the dedicate K_L/muon system, find considerable amount of kaon contamination





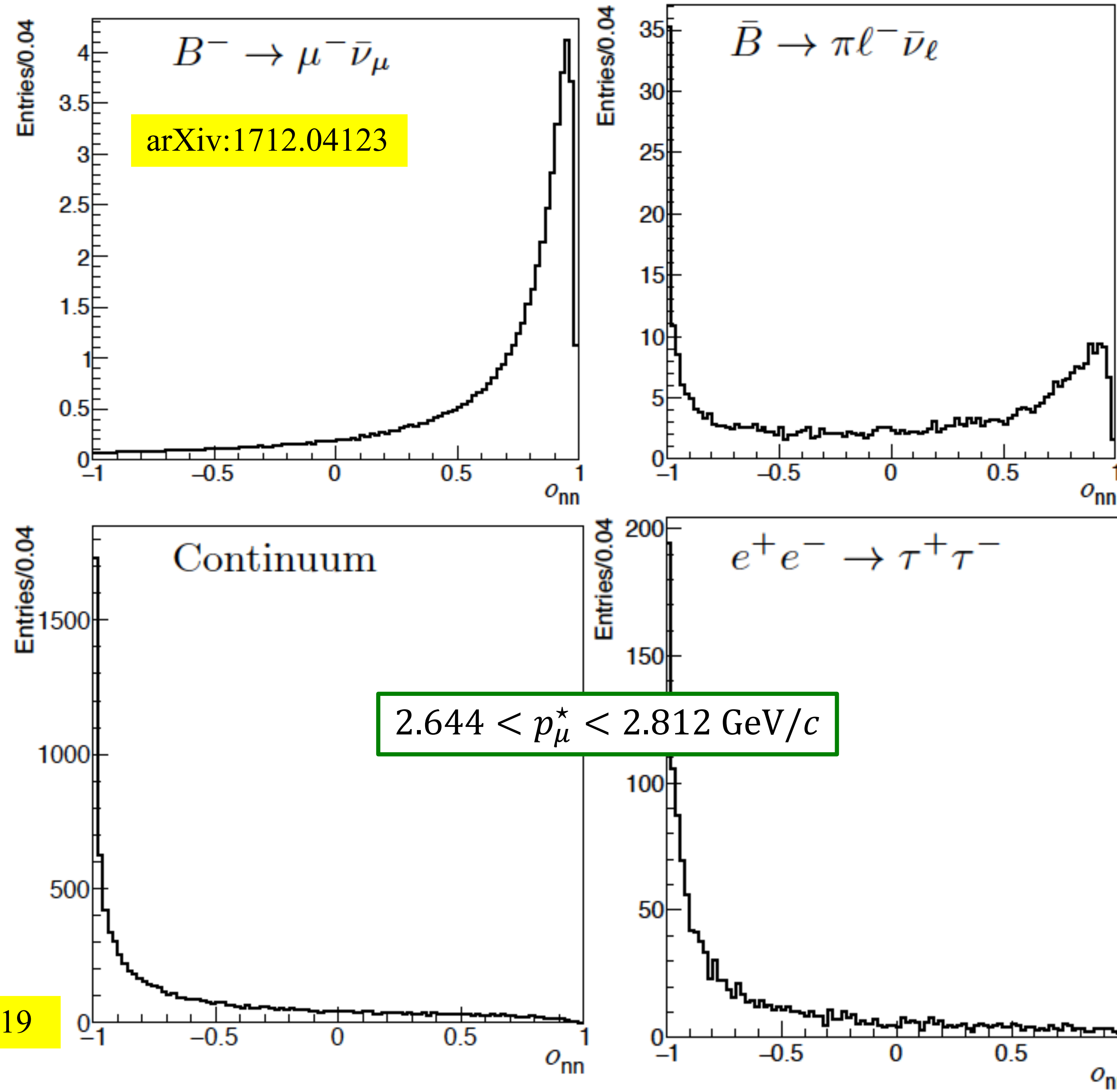
- Dedicated neural network is designed employing information from the other detectors, such as drift chamber and electromagnetic calorimeter

➢ For a signal-muon detection efficiency of 97%, a background suppression of 33% is achieved

Background Fighting is the Key!

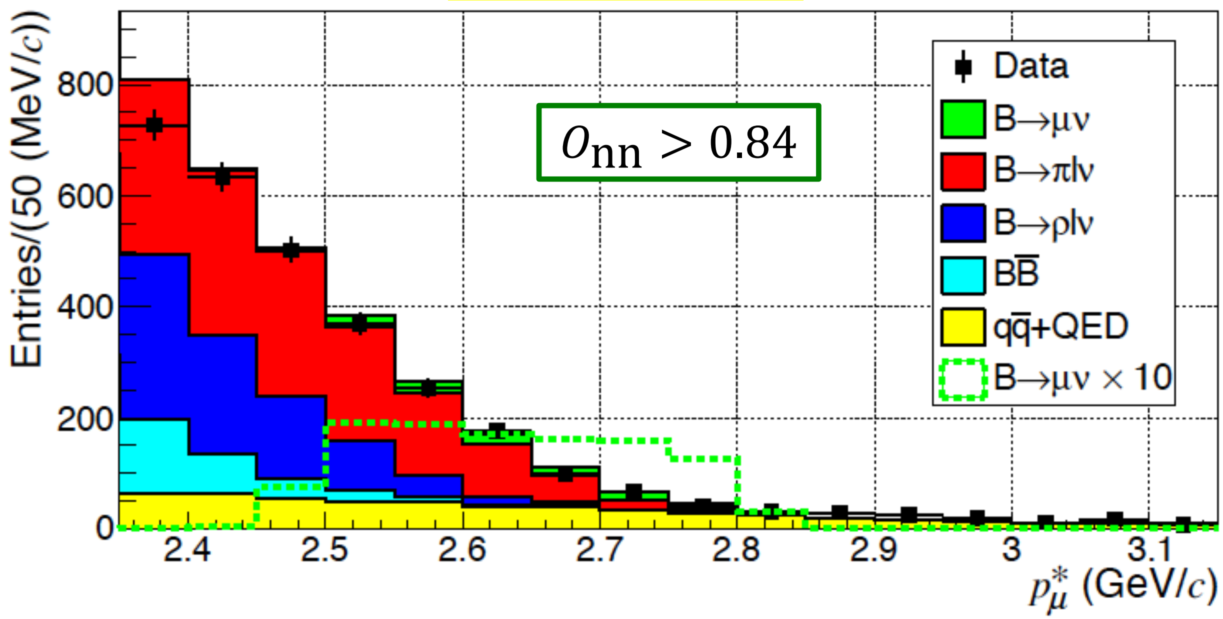
- An artificial neural network is formed out of 14 kinematic variables $\Rightarrow$ largely uncorrelated to the muon momentum
- Major background peaking in the O_{nn} signal region: $B \to \pi \ell \nu$
- Determine the signal yield with a binned maximum likelihood fit in $p_\mu^\star \sim O_{\text{nn}}$ plane using the method in:

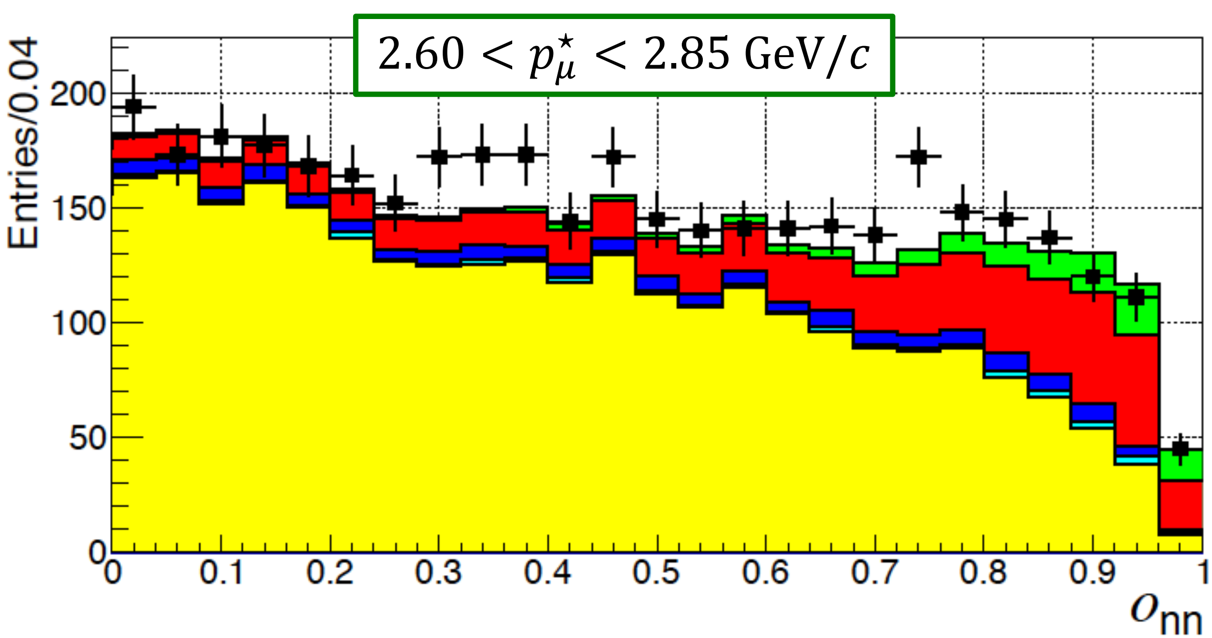
Comp. Phys. Comm. 77 (1993) 219



Results

arXiv:1712.04123





- Fit the ratio

$$R = N_{B\to\mu\bar{\nu}_\mu} / N_{B\to\pi\mu\bar{\nu}_\mu}$$

- We get $R = (1.66 \pm 0.57) \times 10^{-2}$, which is equivalent to:

$$N_{B\to\mu\bar{\nu}_\mu} = 195 \pm 67$$

Branching fraction

$$\mathcal{B}(B \to \mu\bar{\nu}_\mu) = (6.46 \pm 2.22) \times 10^{-7}$$
$$= (6.46 \pm 2.22_{\rm stat} \pm 1.6_{\rm syst}) \times 10^{-7}$$

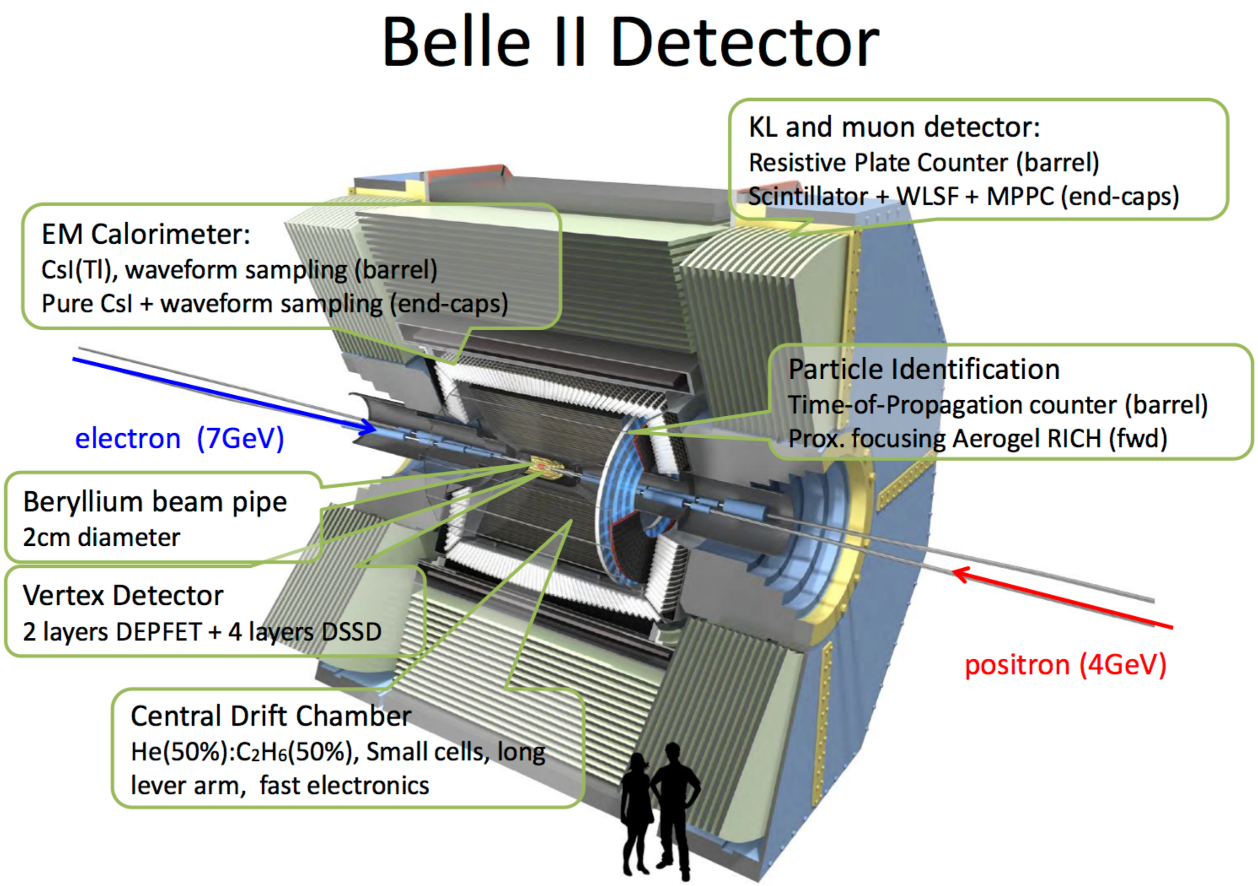
- 3.4σ statistical significance $\Rightarrow$ 2.4σ including systematic uncertainties

- 90% confidence interval for BF $\in (2.9, 10.7) \times 10^{-7}$

- Belle II will make definitive measurement

What the Future Holds?

- Seems to be bright...
  - Belle II would be soon up and running ⇒ phase 2 (without the vertex detector) starts in this summer and phase 3 (with full detector) by early 2019



- First pixel layer closer to the IP ⇒ better vertex resolution
- Larger vertex detector ⇒ ~30% better K_S coverage
- TOP and ARICH ensure at least similar or better PID performance under harsher (20× higher) background condition

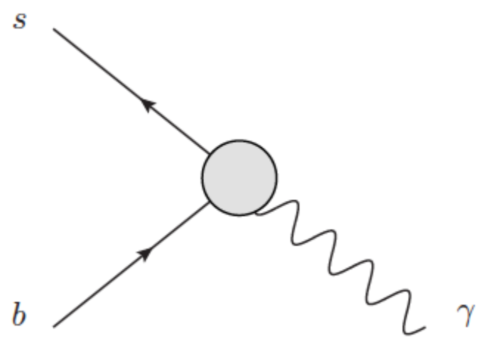
- These features make Belle II an ideal device to probe rare decays

- Along with LHCb and taking related information from CMS+ATLAS, flavor enthusiasts would likely have sunnier days ahead...

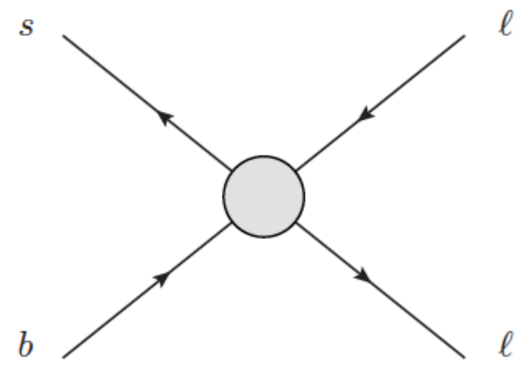
Supplementary Information

Why Rare Decays?

- Typical examples:



$\mathcal{O}_7$



$\mathcal{O}_9$ and $\mathcal{O}_{10}$

- Decay dynamics can be expressed by an effective Hamiltonian

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

- Wilson coefficients $C_{7,9,10} \Rightarrow$ short distance couplings

➢ In presence of new physics (NP), possible new coefficients can give rise to deviations from the standard model

Systematic Uncertainties for $B \to \mu\nu$

Source	Uncertainty (%)
$\bar{B} \to \pi\ell^-\bar{\nu}_\ell$ form-factor	0.9
$\bar{B} \to \rho\ell^-\bar{\nu}_\ell$ form-factor	12
$B^- \to K_L^0\pi^-$	5.5
$B^- \to \mu^-\bar{\nu}_\mu\gamma$	6
Continuum shape	15
Signal peak shape	11
Trigger	8
$\mathcal{B}(\bar{B} \to \pi\ell^-\bar{\nu}_\ell)$	3.4
Total	24.6

- $B \to \rho\ell\nu$ form-factor: several FF calculations are employed in the fit $\Rightarrow$ the resultant maximal deviation is attributed as the systematic error
- $B \to \mu\nu\gamma$: uncertainty due to this background is estimated from a fit where the former contribution is fixed to half of the best upper limit from Belle