Physics cases of rare B meson decays at Belle II

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On behalf of Belle II collaboration

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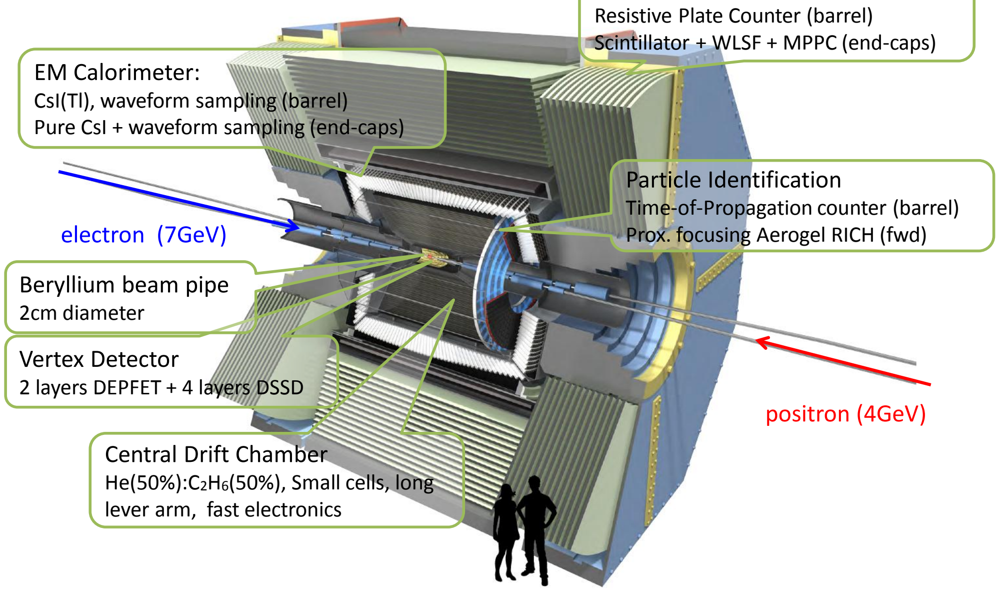
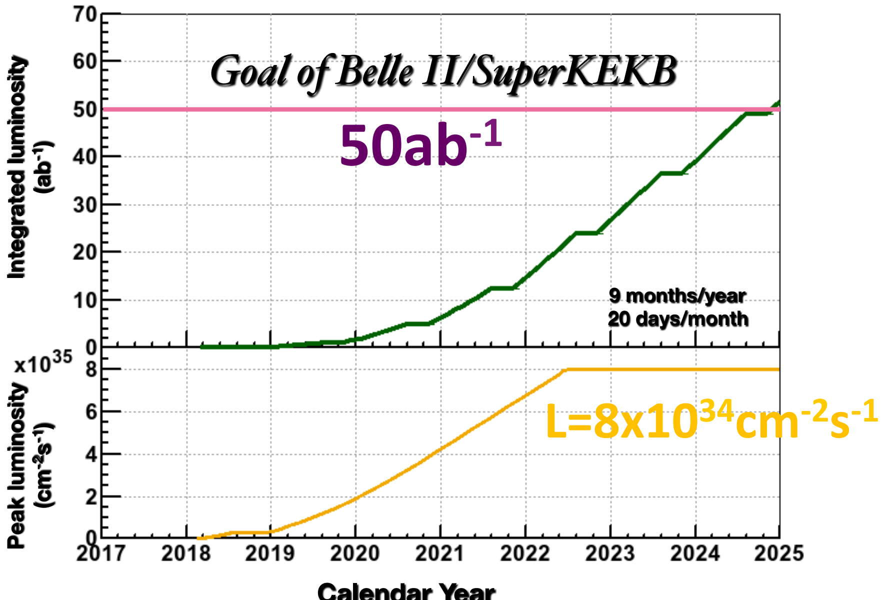
HQL2018, Yamagata

Rare B decay at Belle II

Belle II detector



SuperKEKB Luminosity prospection



- **FCNC $b \to s$ and $b \to d$ processes play important roles in the precision flavor physics. Powerful tools for BSM searches.**

Main rare B decay modes at Belle II:

- **Radiative penguin B decays**
- **Semileptonic penguin B decays**
- **Leptonic charged-B decays** (tree process, but heavy helicity suppression)

In this talk, expected precision of several interesting measurements in above decay modes will be presented.

Radiative penguin *B* decay

at Belle II experiment

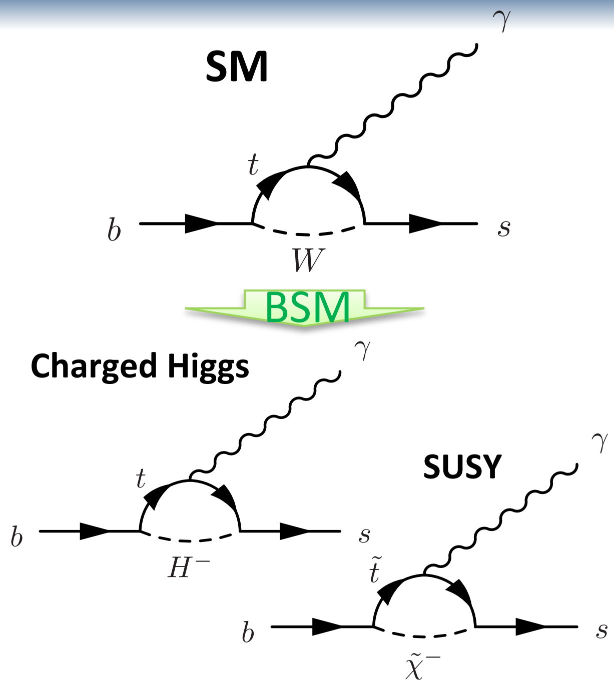
MENÜ

1. *Branching fraction*
2. *Direct CP asymmetry*
3. *Indirect CP asymmetry*

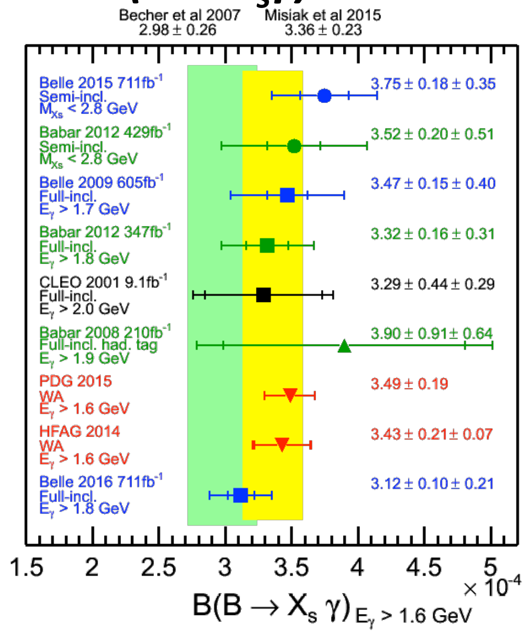
$$C_7: \; Q_7 = \frac{e}{16\pi^2} m_b (F_L(\bar{s}_L \sigma^{\mu\nu} b_R) + F_R(\bar{s}_R \sigma^{\mu\nu} b_L)) F_{\mu\nu}$$

$$C_8: \; Q_8 = \frac{g_s}{16\pi^2} m_b (\bar{s}_L \sigma^{\mu\nu} T^a b_R) G^a_{\mu\nu}$$

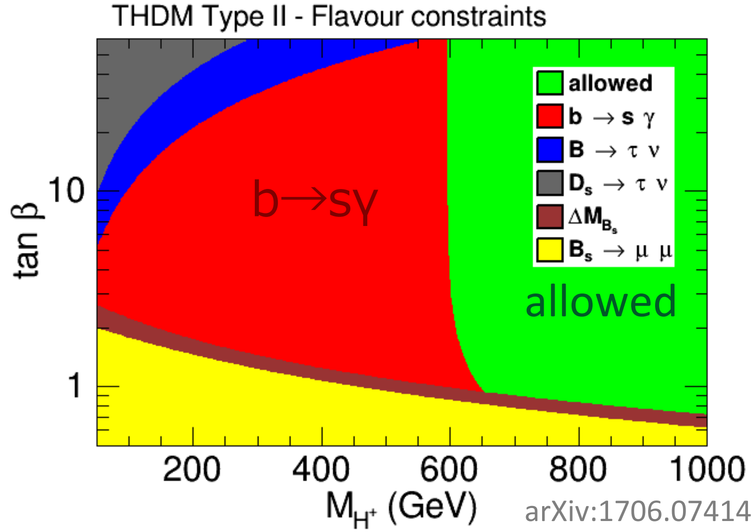
$B \to X_s \gamma$: Branching Fraction



BF($B \to X_s \gamma$) results



Constraint (95% C.L.) on Charged Higgs(2HDM type-II)



- **The inclusive $B \to X_s \gamma$ decays provide constraints on many possible BSM scenarios.**
  - e.g. Strong constraint on extended Higgs sectors (2HDM).
- **The newest Belle result with fully inclusive method: only 7.3% uncertainty (systematic dominant)** arXiv:1608.02344

$$B^{\rm exp}_{s\gamma} = (3.32 \pm 0.15) \times 10^{-4},$$ HFLAV Dec. 2017

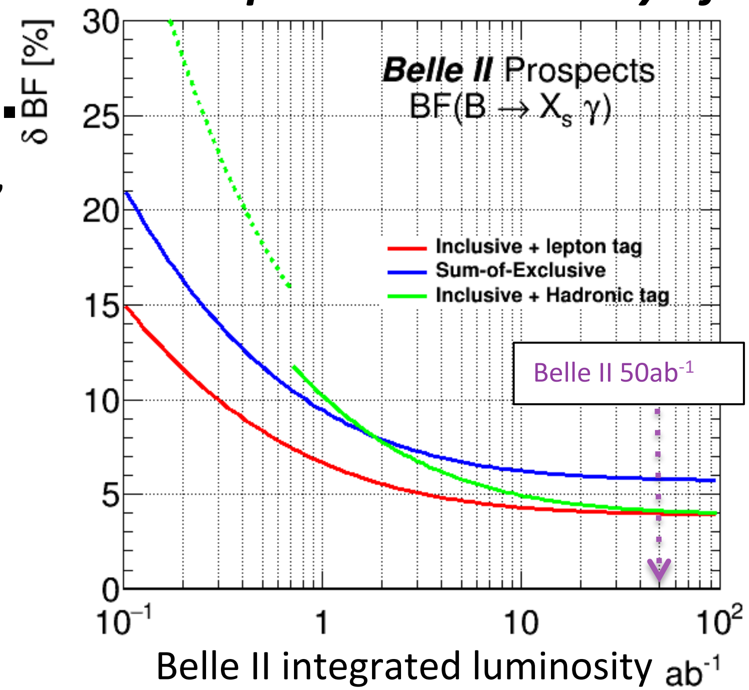
  - Charged Higgs mass (2HDM type-II) > 580GeV in 95% C.L.

$B \to X_s \gamma$: Branching Fraction

- **Mission at Belle II is to reduce the systematic uncertainties with more data.**
  - Main systematic uncertainties: BB counts, detector response, BG rejection, fragmentation model
  - BF with E_γ>1.6GeV can be measured w/o extrapolation

- **3.9% total error achievable with 50 ab^{-1}**
- **Comparable to theoretical uncertainty due to non-perturbative effect**

Belle II expected uncertainty of BF



$B \to X_{(s,d)}\gamma$: Direct CP Asymmetry

- The baryon asymmetry of the universe indicates new CP violation source with new physics.
→ CP asymmetry measurement is powerful test to search BSM contributions.
- Direct CP asymmetry (time-integral):

$$A_{CP} = \frac{\Gamma(\bar{B} \to X_s\gamma) - \Gamma(B \to X_{\bar{s}}\gamma)}{\Gamma(\bar{B} \to X_s\gamma) + \Gamma(B \to X_{\bar{s}}\gamma)}$$

arXiv:hep-ph/0312260
arXiv:1012.3167

- SM predicts the asymmetries for $B \to X_s\gamma$ and $B \to X_d\gamma$ can be non-zero due to a long-distance *c*-loop effect:

$$A_{CP}^{\mathrm{SM}}(s\gamma) = [-0.6, 2.8]\% \ , \quad A_{CP}^{\mathrm{SM}}(d\gamma) = [-62, 14]\%$$ *(has large uncertainties…)*

Two important measurements

- However, the sum of *s* and *d* ($B \to X_{s+d}\gamma$) is predicted to be zero at order of Λ_{QCD}/m_b, thanks to the CKM unitarity.

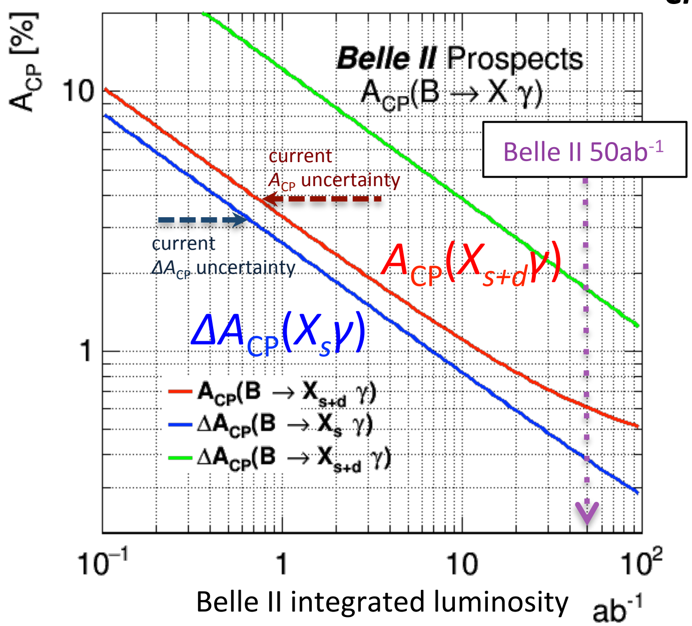
$$A_{CP}^{\mathrm{SM}}(B \to X_{s+d}\gamma) \sim 0$$

- Furthermore, difference of A_{CP} between charged and neutral B mesons is proportional to $\mathrm{Im}(C_{8g}/C_{7\gamma})$ (=zero in SM). → Sensitive to BSM.

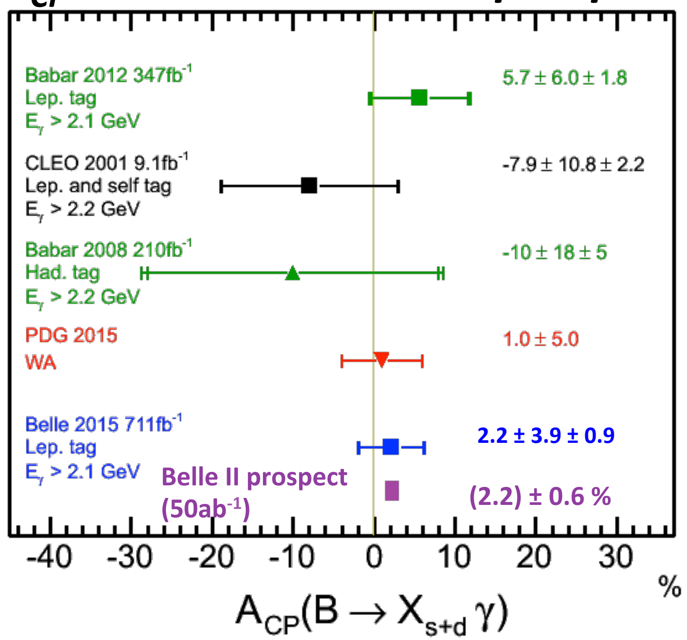
$$\Delta A_{CP}(B \to X_s\gamma) = A_{CP}(B^+ \to X_s^+\gamma) - A_{CP}(B^- \to X_s^0\gamma) \sim 0 \text{ in SM}$$

$B \to X_{(s,d)}\gamma$: Direct CP Violation

Belle II expected uncertainty of A_{CP} and ΔA_{CP}



A_{CP} results and Belle II prospect



- **The statistical error will be dominated.**
  - most of the systematic errors cancel out.
- **Uncertainty in A_{CP} to be ±0.6% with 50ab^{-1}**
  - → 3.7σ significance if the central value does not change.
- **Uncertainty in ΔA_{CP} to be ±0.4% with 50ab^{-1}**
  - Babar measurement: $\Delta A_{CP}(X_s\gamma)$ = +5.0±3.9±1.5%

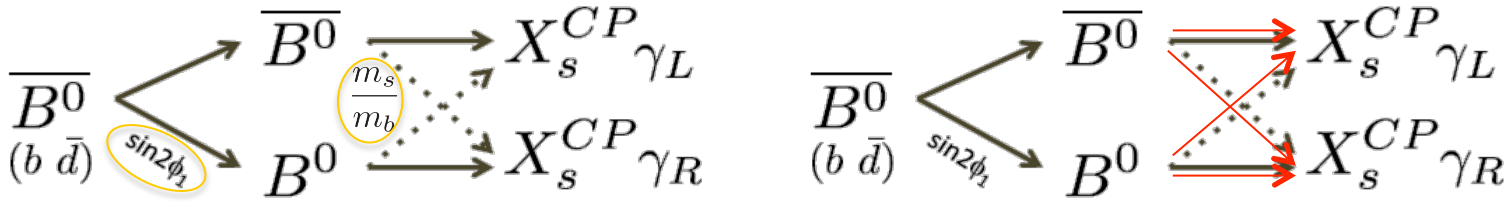
arXiv:1406.0534

$b \to s\gamma$: Time-dependent CPV

- **As well as the direct CP violation, time-dependent CP violation in exclusive $b \to s\gamma$ CP-eigenstate is also an excellent probe for BSM.**

$$\frac{\Gamma[\bar{B}^0(t) \to f\gamma] - \Gamma[B^0(t) \to f\gamma]}{\Gamma[\bar{B}^0(t) \to f\gamma] + \Gamma[B^0(t) \to f\gamma]} = S_{f\gamma}\sin(\Delta t) - C_{f\gamma}\cos(\Delta t)$$

arXiv:hep-ph/9704272 (1997)



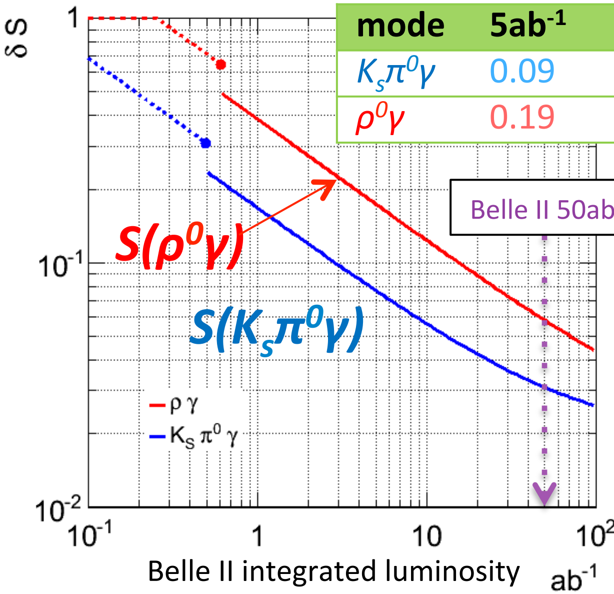
- **New physics with right-handed current changes the mixing fraction.**
- **SM predicts:** $S(K^{*0}\gamma) \sim -\frac{2m_s}{m_b}\sin(2\phi_1) \sim \text{a few }\%, \quad S(\rho^0\gamma) \sim 0$
  - the long-distance *c*-loop effect also to be taken into account

$$S^{\rm SM}_{K^*(K_S\pi^0)\gamma} = (-2.3 \pm 1.6)\%, S^{\rm SM}_{\rho^0(\pi^+\pi^-)\gamma} = (0.2 \pm 1.6)\%$$

arXiv:hep-ph/0612081 (2006)
arXiv:hep-ph/0609037 (2006)

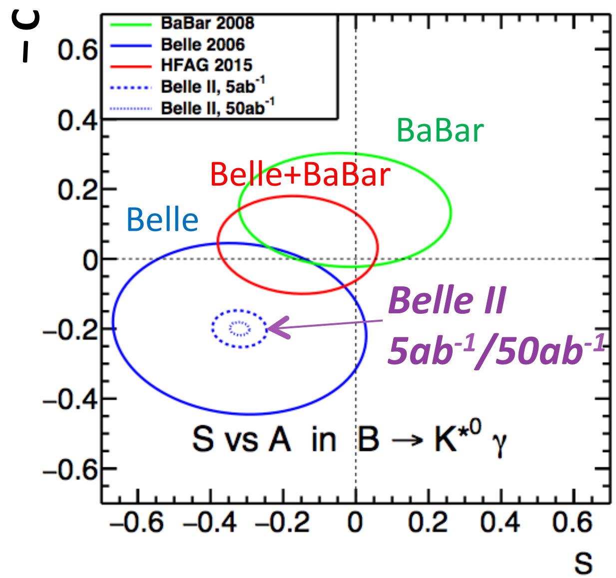
$b \to s\gamma$: Time-dependent CPV

Belle II expected uncertainty of TDCPV



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

TDCPV in Belle II $50ab^{-1}$



- **At Belle II, significant improvement from Belle in the determination of $K_s\pi^0\gamma$ TDCPV.**
  - Larger radius of VXD detector (6cm → 11.5cm) and 30% more K_s with vertex information available
  - Effective tagging efficiency is conservatively 13% better
- **Expected uncertainty for *S* measurement: $K_s\pi^0\gamma$ ~3%, $\rho^0\gamma$ ~6%.**
  - Statistical components are dominant.

Semi-leptonic penguin *B* decay at Belle II experiment

MENÜ

1. Angular analysis

- Inclusive $B \to X_s ll$ mode

2. Lepton Flavor Universality test

3. $B \to K^{(*)} \nu\nu$ analysis

$$C_7 : \ Q_7 = \frac{e}{16\pi^2} m_b (\bar{s}_L \sigma^{\mu\nu} b_R) F_{\mu\nu}$$

$$C_9^l : \ Q_9^l = (\bar{s}_L \gamma_\mu b_L)(\bar{l} \gamma^\mu l)$$

$$C_{10}^l : \ Q_{10}^l = (\bar{s}_L \gamma_\mu b_L)(\bar{l} \gamma^\mu \gamma_5 l)$$

$$C_L : \ Q_L^l = (\bar{s}_L \gamma_\mu b_L)(\bar{\nu}_{lL} \gamma^\mu \nu_{lL})$$

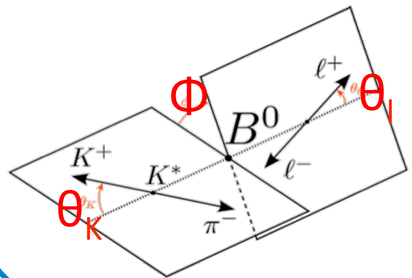
$$C_R : \ Q_R^l = (\bar{s}_R \gamma_\mu b_R)(\bar{\nu}_{lL} \gamma^\mu \nu_{lL})$$

$B \to K^* l^+ l^-$: angular analysis

LHCb(2015): LHCb-CONF-2015-002
Belle(2016): arXiv:1604.04042
CMS(2015): CMS_PAS_BPH_15_008
ATLAS(2017): ATLAS-CONF-2017-023

Full decomposition of angular distribution

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



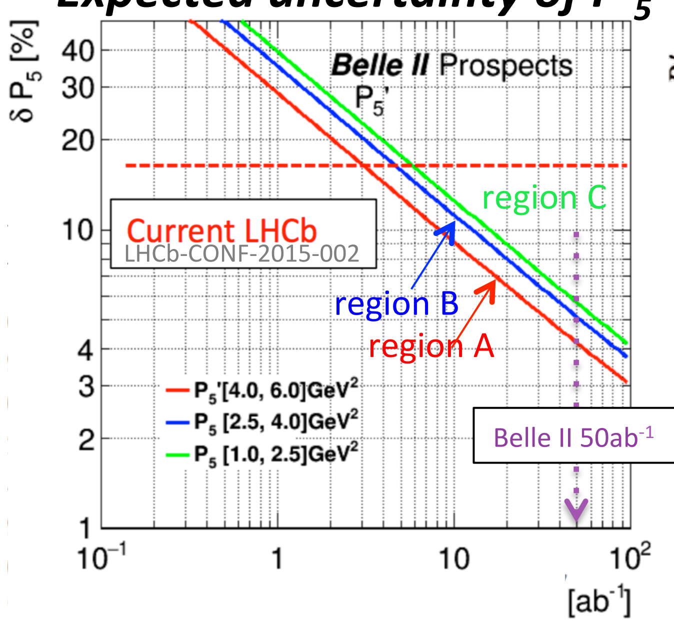
Optimized observable

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

P'_i : Cancel out uncertainties from form factor in leading order

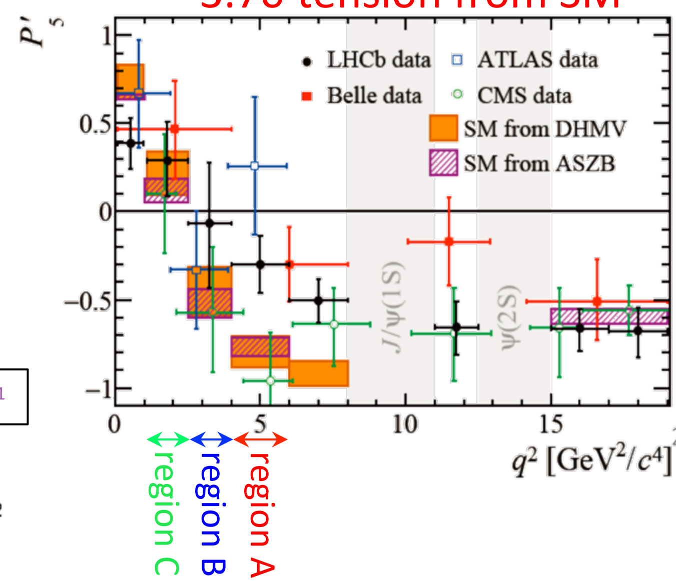
- **Sensitive to C_7, C_9 and C_{10} in Wilson Coefficients**
- **Achieve LHCb(2015) precision with $3ab^{-1}$(～2020)**
- **4% error with 50 ab^{-1}**
  - comparable with LHCb $22fb^{-1}$ result

Expected uncertainty of P'_5



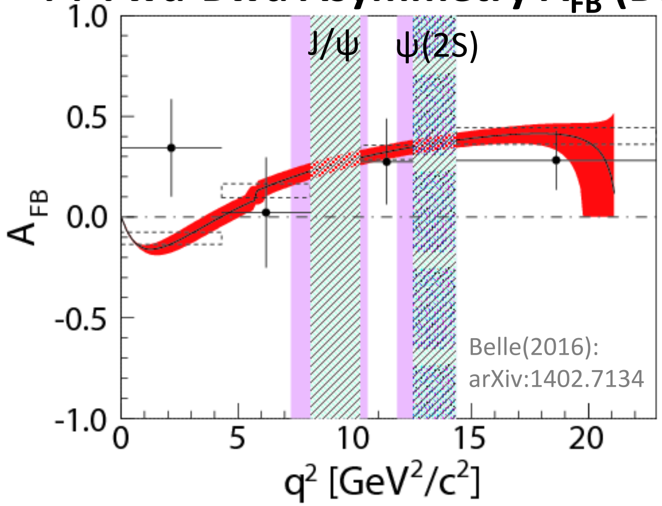
P'_5 measurement results

3.7σ tension from SM

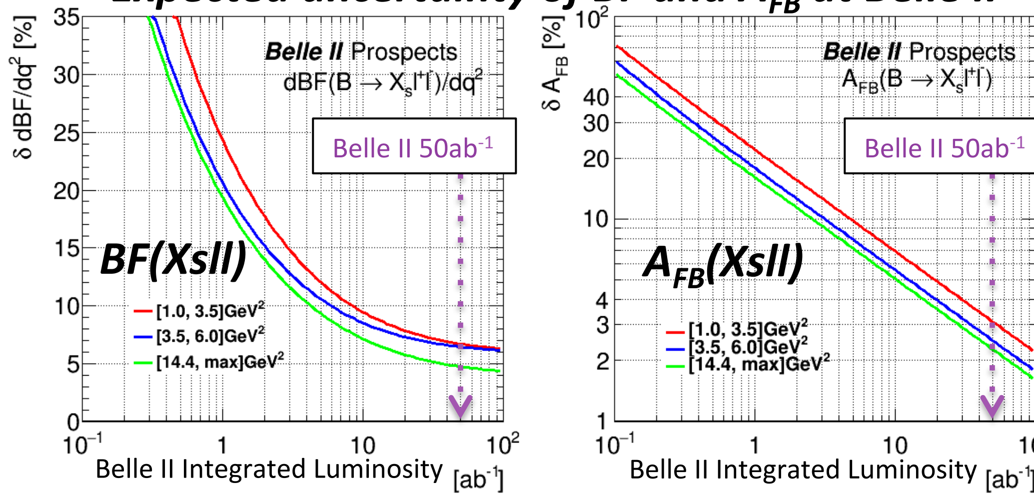


$B \to X_s l^+ l^-$: angular analysis

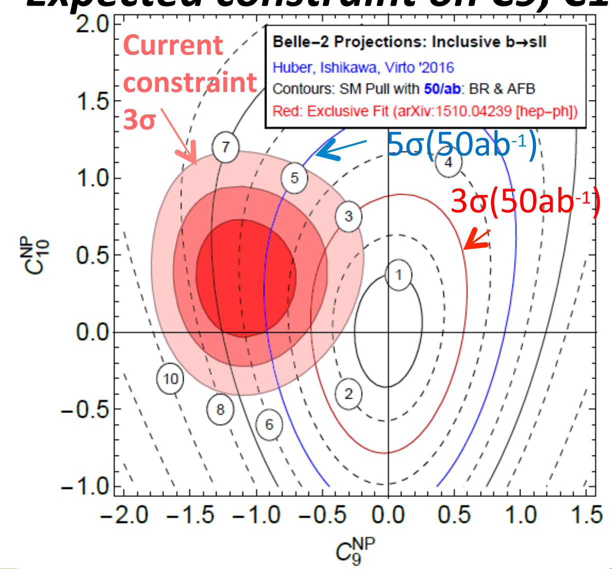
l^+l^- Fwd-Bwd Asymmetry A_{FB} (Belle)



Expected uncertainty of BF and A_{FB} at Belle II



Expected constraint on C9, C10



- **$B \to X_s l^+ l^-$: Theoretically clean channel**
  - No form factor uncertainty
  - less uncertainty on long distance *c*-loop correction
- **dBF/dq^2, A_{FB}: sensitive to C_9 and C_{10}**
  - dBF/dq^2: systematic error limits the precision at 10ab^{-1}
  - A_{FB}: statistical error dominant up to 50ab^{-1}
- **5σ discrepancy in C_9 from SM achievable only with $B \to X_s l^+ l^-$ analysis, if the central value does not change.**
  - Complementary for the exclusive channel studies

Lepton Universality Test : $R_{K(*),Xs}$

$$R_{X_s} = \frac{\mathrm{BR}(B \to X_s \mu\mu)}{\mathrm{BR}(B \to X_s ee)}$$

- $R_{K(*),Xs}$: **Sensitive to flavor-dependent $C_{9,10}$**
  - In SM, R ~ 1 ($q^2 \gg m_\mu^2$)

Advantages in Belle II:

- **Excellent momentum resolution for both *e* and *μ***
- **Both the low and high q^2 regions accessible**
- **Dominant systematic error is lepton ID ~0.4%: Very small**
- **Inclusive $B \to X_s l^+ l^-$ measurable: correlation among R_K, R_{K^*}, and R_{Xs} is an important test to validate the observed deviation from SM**

$$R_K \simeq 1 + \Delta_+ \,,$$

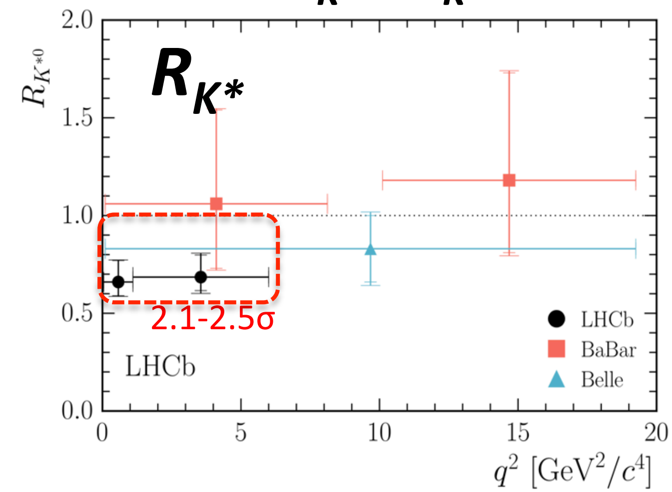
$$R_{K^*} \simeq 1 + p\,(\Delta_- - \Delta_+) + \Delta_+ \,,$$

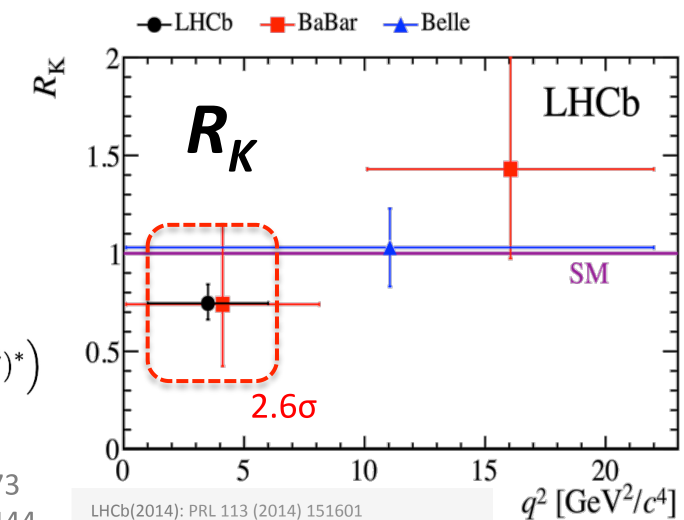
$$R_{X_s} \simeq 1 + (\Delta_+ + \Delta_-)/2 \,,$$

$$\Delta_\pm = \frac{2}{|C_9^{\mathrm{SM}}|^2 + |C_{10}^{\mathrm{SM}}|^2} \Big[\mathrm{Re}\left(C_9^{\mathrm{SM}} (C_9^{\mathrm{NP}\mu} \pm C_9'^{\mu})^* \right) + \mathrm{Re}\left(C_{10}^{\mathrm{SM}} (C_{10}^{\mathrm{NP}\mu} \pm C_{10}'^{\mu})^* \right) - (\mu \to e) \Big] \,.$$

arXiv:1411.4773
arXiv:1704.05444

Current R_{K^*}, R_K results

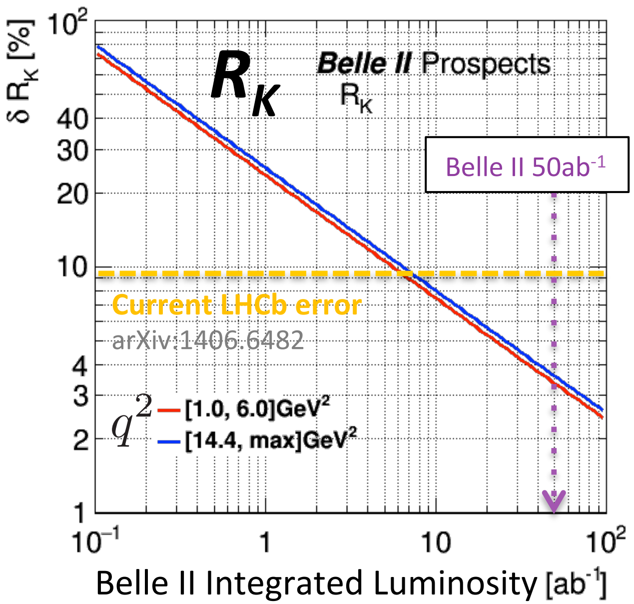


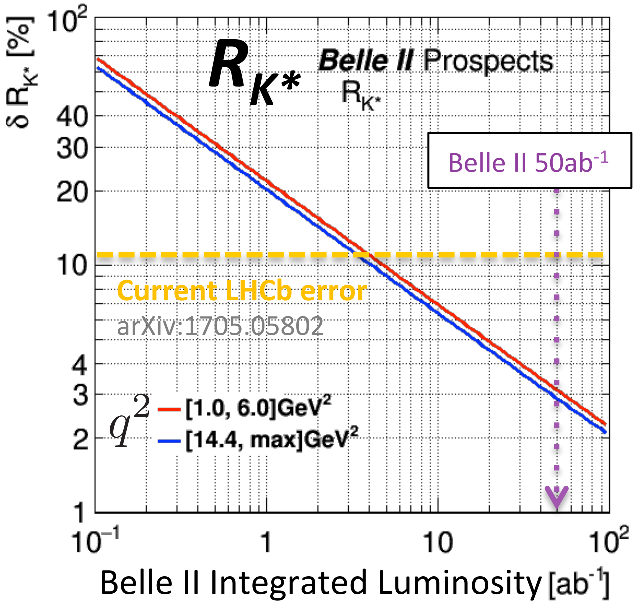


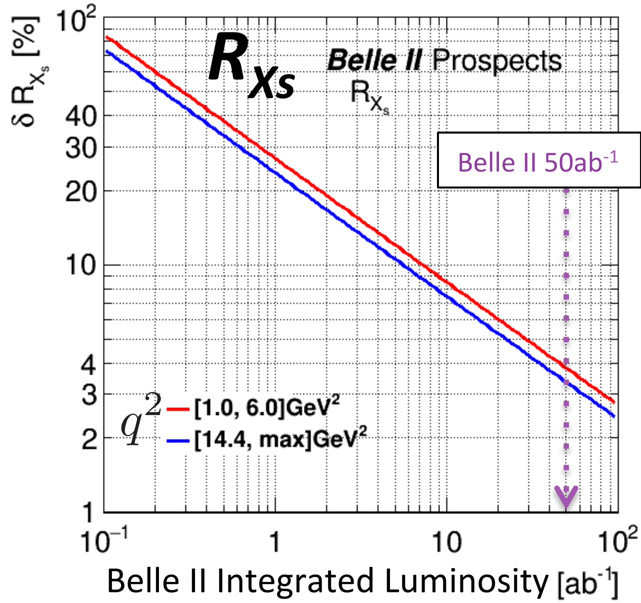
LHCb(2014): PRL 113 (2014) 151601
LHCb(2017): JHEP08(2017)055 [arXiv:1705.05802]

Lepton Universality Test : $R_{K(*),Xs}$

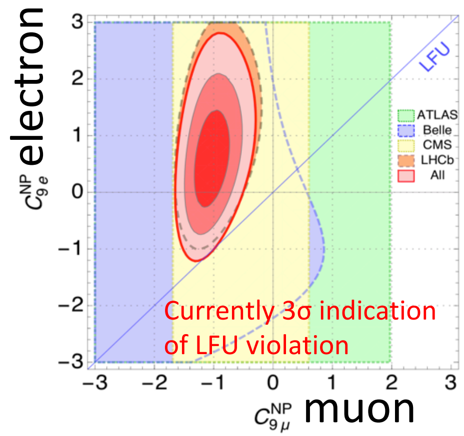
Expected uncertainty of R measurement at Belle II







- **With 20ab^{-1} Belle II data (~2022), about 5 % uncertainty achievable.**
  - the current R_K anomaly will be confirmed in a 5σ significance, if the central value does not change.
- **With 50ab^{-1}, about 3% uncertainty achievable.**
  - Still errors are statistically limited.



$B \to K^{(*)}\nu\nu$

- **Theoretically further clean: Factorization works pretty well**
  - Main uncertainties: B→K(*) form factor and knowledge of CKM elements
- **SM branching fraction is 1 order larger than b→sll (due to Weinberg angle and sum of 3 flavors)**

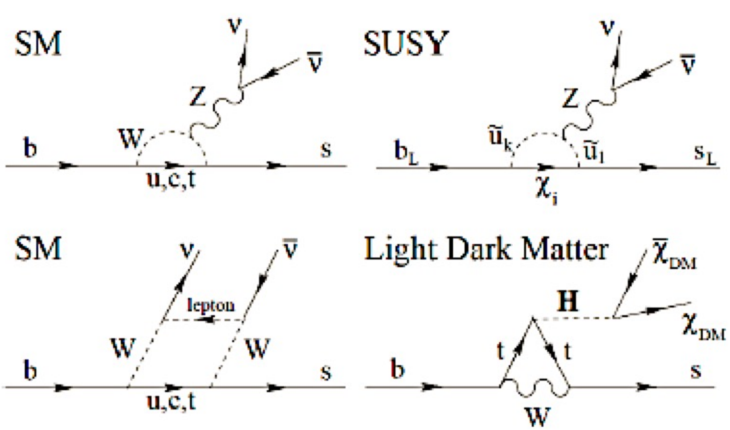
$$\mathrm{BF}(B \to K^* \nu\bar{\nu})_{\mathrm{SM}} = (9.6 \pm 0.9) \times 10^{-6}, \quad \mathrm{BF}(B^+ \to K^+ \nu\bar{\nu})_{\mathrm{SM}} = (4.6 \pm 0.5) \times 10^{-6}$$

- **Provide constraints on C_L and C_R**

$$Q_L^l = (\bar{s}_L \gamma_\mu b_L)(\bar{\nu}_{lL} \gamma^\mu \nu_{lL}), \quad Q_R^l = (\bar{s}_R \gamma_\mu b_R)(\bar{\nu}_{lL} \gamma^\mu \nu_{lL})$$

- **Effectively, this analysis works also as light invisible particle search**

- **BF($B \to K^{(*)}\nu\nu$) is measurable at Belle II with about 10% uncertainty.**
- **K* longitudinal polarization F_L also can be measured with about 8% uncertainty.**
  - Theoretical prediction: 0.48 ± 0.03 arXiv:1409.4337



Expected uncertainty at Belle II

Observables	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
$\mathrm{Br}(B^+ \to K^+\nu\bar{\nu})$	30%	11%
$\mathrm{Br}(B^0 \to K^{*0}\nu\bar{\nu})$	26%	9.6%
$\mathrm{Br}(B^+ \to K^{*+}\nu\bar{\nu})$	25%	9.3%
$F_L(B^0 \to K^{*0}\nu\bar{\nu})$	–	0.079
$F_L(B^+ \to K^{*+}\nu\bar{\nu})$	–	0.077
$\mathrm{Br}(B^0 \to \nu\bar{\nu}) \times 10^6$	< 5.0	< 1.5
$\mathrm{Br}(B_s \to \nu\bar{\nu}) \times 10^5$	< 1.1	–

Leptonic charged-*B* decay

at Belle II experiment

MENÜ

1. $B \to \tau\nu$, $B \to \mu\nu$:

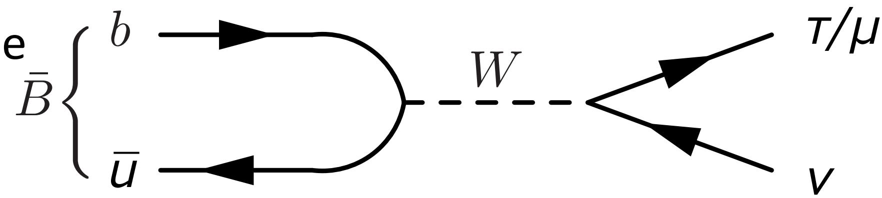
Branching fraction, ratio

New physics with different chiral structure

$B\to\tau\nu$, $B\to\mu\nu$

arXiv:1608.05207

- **Charged-B leptonic decay**
  - Tree process, but heavily suppressed due to helicity suppression
  - Only leptons in final state: Small theoretical uncertainty



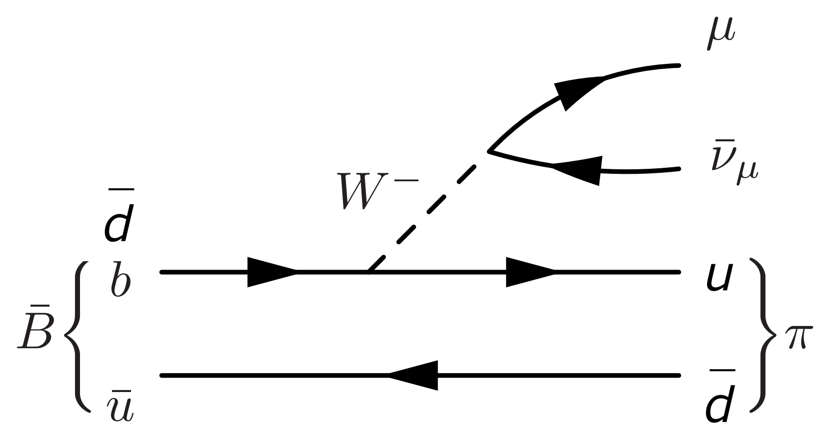
B→τν, B→μν

$$\mathrm{BR}(B\to\tau\nu_\tau)_{\mathrm{SM}} = (8.45\pm0.70)\times10^{-4} \quad \mathrm{BR}(B\to\mu\nu_\mu)_{\mathrm{SM}} = (3.80\pm0.31)\times10^{-7}$$

- ***B→μν***
  - Belle (2017): Find an excess with 2.4σ significance

$$\mathrm{BR}(B^-\to\mu\bar{\nu}_\mu) = (6.46\pm2.22(\mathrm{stat})\pm1.60(\mathrm{syst}))\times10^{-7}$$

  - Belle II will measure BF with good accuracy



B→πμν

- **Noble measurement:**

$$R_{\mathrm{ps}} = \frac{\tau_{B^0}}{\tau_{B^-}}\frac{\mathrm{BR}(B^-\to\tau\bar{\nu}_\tau)}{\mathrm{BR}(\bar{B}^0\to\pi^+\mu\bar{\nu}_\mu)}$$ SM: 0.539 ± 0.043

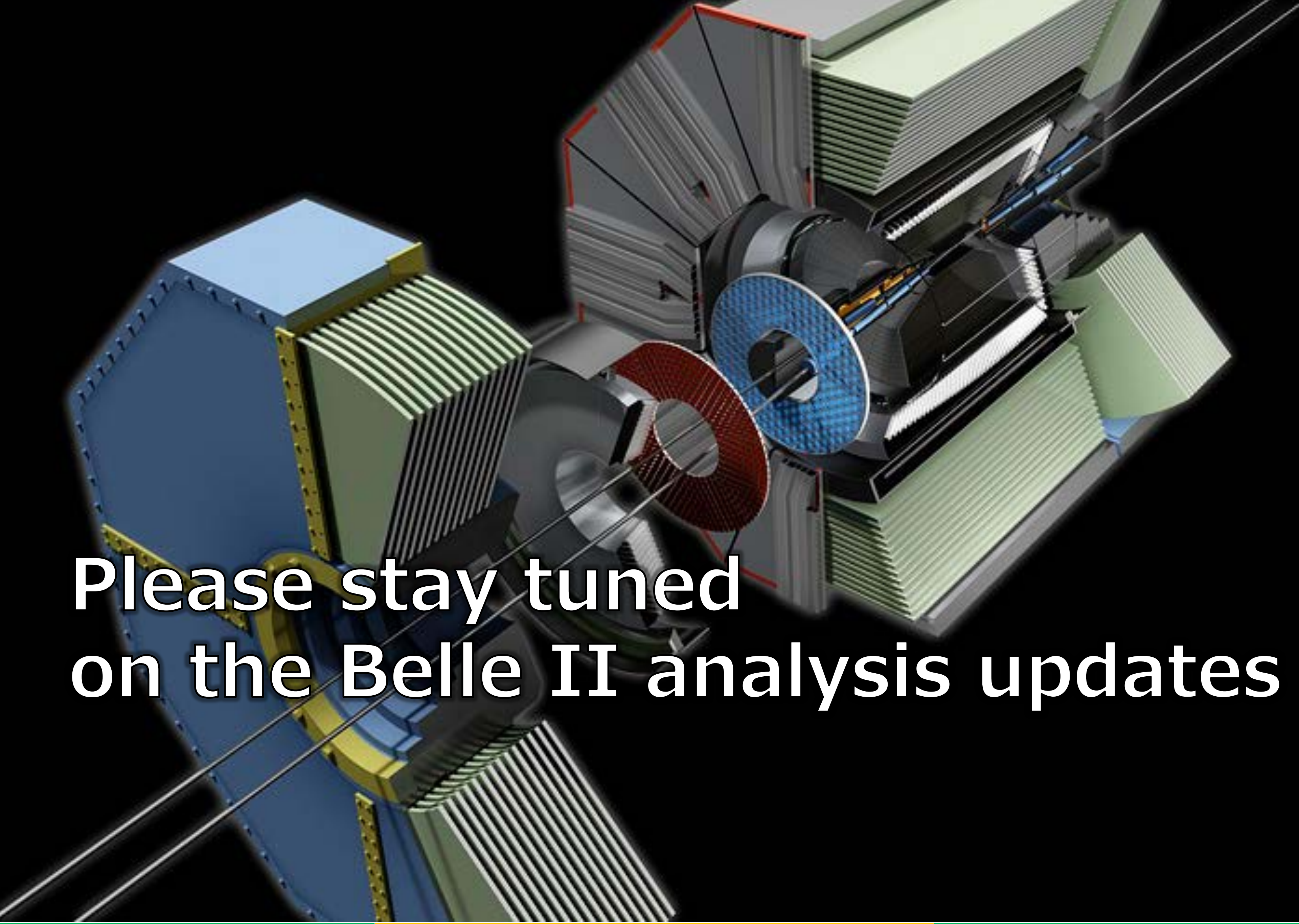
$$R_{\mathrm{pl}} = \frac{\mathrm{BR}(B^-\to\tau\bar{\nu}_\tau)}{\mathrm{BR}(B^-\to\mu\bar{\nu}_\mu)}$$ SM: 222.37

  - Cancel out uncertainties of f_B, $|V_{ub}|$
  - R_{pl}: determined only by lepton mass

Perform precise measurement at Belle II

Summary

- **Belle II experiment will contribute strongly to apply further constraint on BSM and to understand the current anomalies, with abundant rare B decay data:**
  1. Radiative penguin B decays
  2. Semileptonic penguin B decays
  3. Leptonic B decays
- **Moreover, Belle II has a sufficient ability to discover other interesting decay channels:**
  - $B \to K^{(*)}\nu\nu$, $B \to \mu\nu$
- **Now Belle II starting the physics operation without the vertex detector. The full detector operation (w/ the vertex detector) will start from Feb 2019.**



Please stay tuned on the Belle II analysis updates

$B \to X_s\gamma$ analysis methods

Semi-inclusive (= sum of exclusive)

- **The hadronic system is reconstructed from many exclusive decays containing a *K*, such as $X_s = K(n\times\pi)$, $K\eta(m\times\pi)$, or $3K(m\times\pi)$ (n≥1, m≥0)**
- **These hadronic candidates are combined with a hard photon to reconstruct B-meson candidates.**
  - Challenge: missing mode and cross-feed

Fully inclusive

- **The other B meson is fully reconstructed either in a hadronic final state (hadronic tagging) or with an energetic lepton (semi-leptonic tagging) from the B-meson decay.**
- **Select a hard photon. Subtract the background component from continuum and BB events.**
  - Challenge: background reduction

$B \to V_s \gamma$: Isospin Asymmetry

- Isospin asymmetry is sensitive to BSM, defined as :

$$a_I^{\bar{0}-} = \frac{c_V^2\,\Gamma(\bar{B}^0 \to \bar{V}^0\gamma) - \Gamma(B^- \to V^-\gamma)}{c_V^2\,\Gamma(\bar{B}^0 \to \bar{V}^0\gamma) + \Gamma(B^- \to V^-\gamma)}$$ for $c_{\rho^0}^2 = 2$ and $c_{K*}^2 = 1$

- To accumulate more statistics, CP-averaged IAs can be defined as: $\bar{a}_I = (a_I^{\bar{0}-} + a_I^{0+})/2$

$\bar{a}_I^{SM}(K^*\gamma) = (4.9 \pm 2.6)\%$

$\bar{a}_I^{SM}(\rho\gamma) = (5.2 \pm 2.8)\%$

PRD 88 (2013), 094004

$\bar{a}_I^{exp}(K^*\gamma) = (5.2 \pm 2.6)\%$

$\bar{a}_I^{exp}(\rho\gamma) = (30^{-13}_{+16})\%$

HFLAV 2017

slight tension with considerable uncertainty

- The observable with reduced uncertainty $\delta_{a_I} = 1 - \frac{\bar{a}_I(\rho\gamma)}{\bar{a}_I(K^*\gamma)} \sqrt{\frac{\bar{\Gamma}(B \to \rho\gamma)}{\bar{\Gamma}(B \to K^*\gamma)}} \left|\frac{V_{ts}}{V_{td}}\right|$

$$\delta_{aI}^{SM} = 0.10 \pm 0.11$$

$$\delta_{aI}^{exp} = -4.0 \pm 3.5$$ → **Can be improved at Belle II with more statistics.**

The sensitivity of δ_{aI} to BSM physics has been studied in PRD 88 (2013), 094004 in a model-independent fashion

S. Sandilya (SUSY17)

Double-radiative B decays

$B_q \to \gamma\gamma$:

SM prediction

$Br(B_s \to \gamma\gamma)_{SM} \in [0.5, 3.7] \times 10^{-6}$

$Br(B_d \to \gamma\gamma)_{SM} \in [1.0, 9.8] \times 10^{-8}$

Bosch and Buchalla, JHEP 08 (2002) 054

Exp. situation

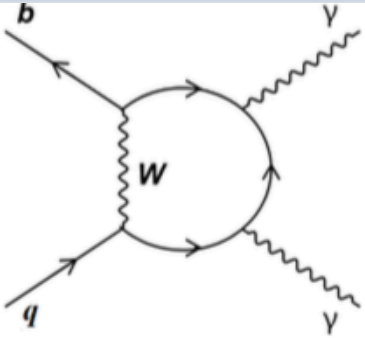
$Br(B_s \to \gamma\gamma)_{exp} < 3.1 \times 10^{-6}$

[Belle, PRD 91, 011101 (2015)]

$Br(B_d \to \gamma\gamma)_{exp} < 3.2\ \{6.2\} \times 10^{-7}$

BaBar, PRD 83, 032006 (2011)

{Belle, , PRD 73, 051107 (2006)}



- With the above comparison, Belle II will be able to discover $B_d \to \gamma\gamma$ with the anticipated 50 ab^{-1} at $\Upsilon(4S)$.
- Furthermore, in an appropriately large data at $\Upsilon(5S)$ $B_s \to \gamma\gamma$ can be observed.

$B \to X_s\gamma\gamma$:

- $B \to X_s\gamma\gamma$ decays are suppressed by $\alpha_s/4\pi$ compared to $B \to X_s\gamma$.

$$Br(B \to X_s\gamma\gamma)^{c=0.02}_{SM} = (1.7 \pm 0.7) \cdot 10^{-7}$$

Asatrian et al., PRD 93, 014037 (2016)

should be observable at Belle II.

- Measurements of the double-radiative decay mode would allow to put bounds on 1PI type corrections.
- One can study more complicated distributions like, double differential rate ($d^2\Gamma/dE_1dE_2$) and forward backward asymmetry → sensitive to BSM physics.

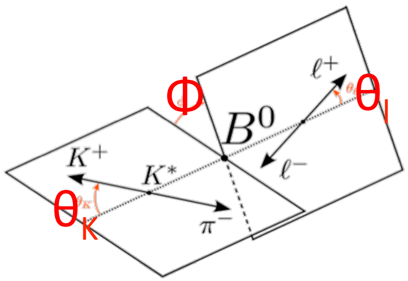
S. Sandilya (SUSY17)

$B \to K^* l^+ l^-$: angular analysis

LHCb(2015): LHCb-CONF-2015-002
Belle(2016): arXiv:1604.04042
CMS(2015): CMS_PAS_BPH_15_008
ATLAS(2017): ATLAS-CONF-2017-023

Full decomposition of angular distribution

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

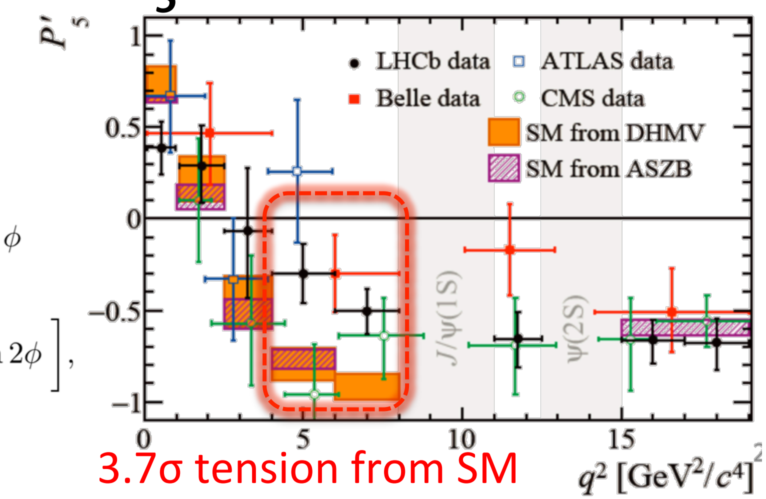


Optimized observable

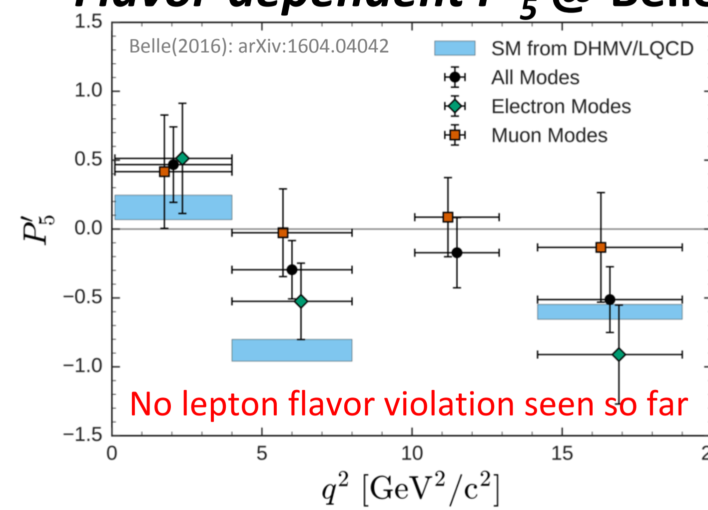
$$P'_{i=4,5,6,8} = \frac{S_{j=4,5,7,8}}{\sqrt{F_L(1-F_L)}},$$

- ***P'_i*** **: Cancel out uncertainties from form factor in leading order**
- **Sensitive to C_7, C_8 and C_9 in Wilson Coefficients**
- **P'_5 : 3.7σ tension from SM reported (LHCb)**
- **Belle I & II: Excellent PID for both muon and electron**
  → Lepton-flavor-dependent angular analysis of $B \to K^* l^+ l^-$ performed

P'_5 measurement results



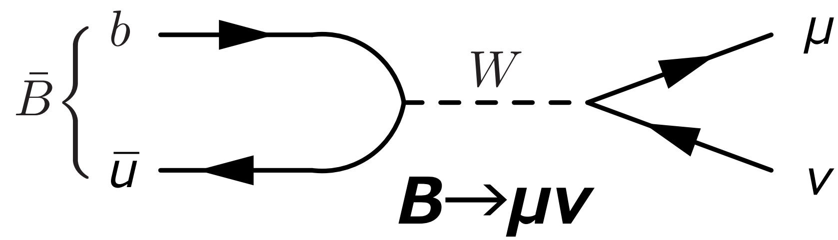
Flavor-dependent P'_5 @ Belle



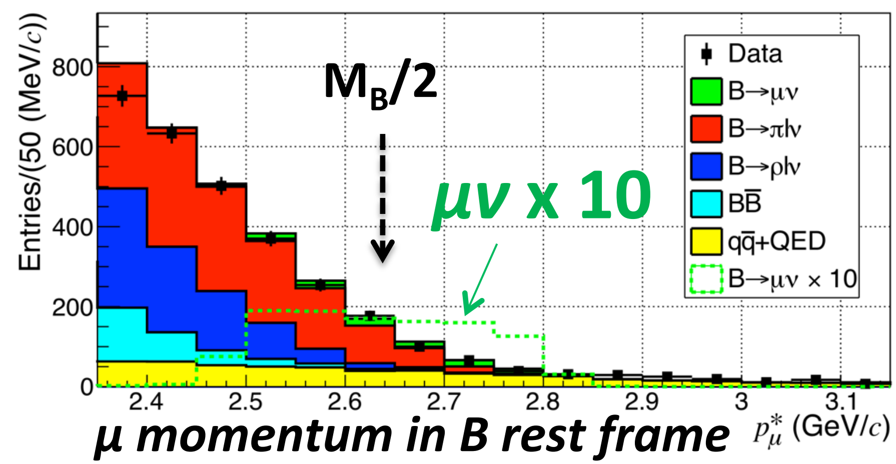
B→μν

- **B leptonic decay**
  - Tree process, but heavily suppressed due to helicity suppression
  - Only leptons in final state： Theoritical uncertainty mainly from f_B , $|V_{ub}|$

$$\mathrm{BR}(B \to \tau\nu_\tau)_{\mathrm{SM}} = (8.45 \pm 0.70) \times 10^{-4}$$
$$\mathrm{BR}(B \to \mu\nu_\mu)_{\mathrm{SM}} = (3.80 \pm 0.31) \times 10^{-7}$$



- ***B→μν***
  - Reconstruct another B, and search M_B/2 peak in μ momentum (signal B rest frame) distribution
  - Belle (2017): Find an excess with 2.4σ significance Belle(2017): arXiv:1712.04123



$$\mathrm{BR}(B^- \to \mu\bar{\nu}_\mu) = (6.46 \pm 2.22(\mathrm{stat}) \pm 1.60(\mathrm{syst})) \times 10^{-7}$$

First non-zero BF measurement!