RARE B DECAYS at *Belle II*

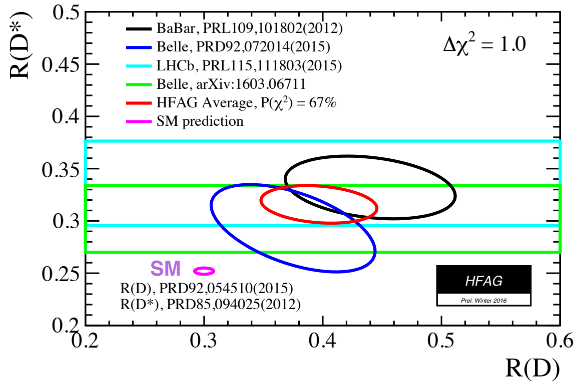
Hülya Atmacan

University of South Carolina

HINT2016

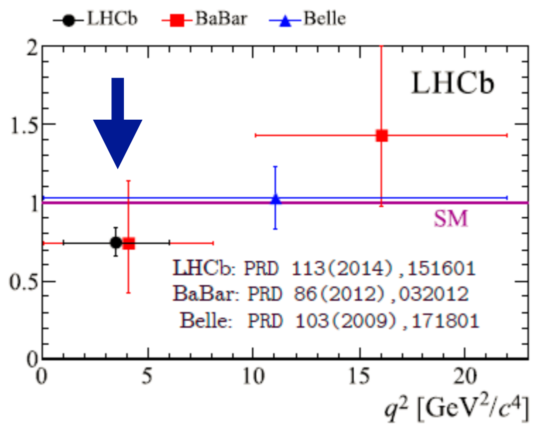
December 7, 2016

Existing Anomaly Examples in *B* Decays



- $R_{D^{(*)}} = \dfrac{Br(B \to D^{(*)}\tau\nu)}{Br(B \to D^{(*)}l\nu)}$ ~4.0σ

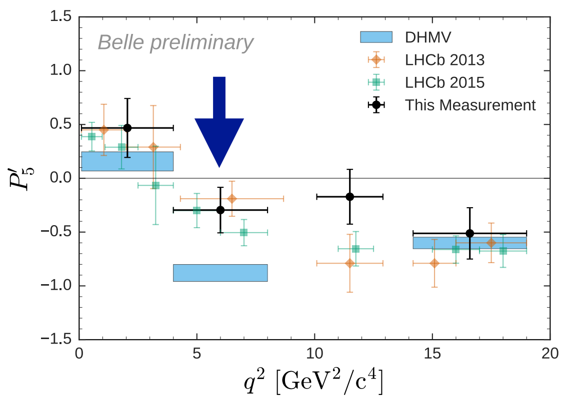
  deviation from Standard Model (SM)



- $R_K = \dfrac{Br(B \to K\mu^+\mu^-)}{Br(B \to Ke^+e^-)}$ ~2.6σ

  deviation from SM

  [PRL 113, 151601 (2014)]

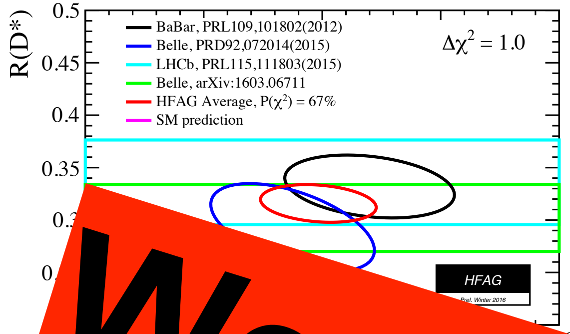


- $B \to K^*\mu^+\mu^-$

  ~3.7σ (LHCb), ~2.6σ (*Belle*)

  deviation from SM prediction in P_5' for $4<q^2<8$ GeV^2

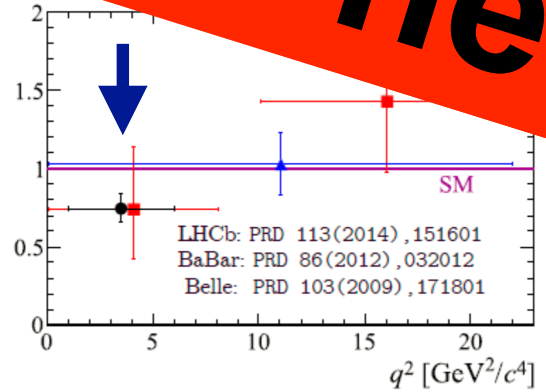
Existing Anomaly Examples in *B* Decays



- $R_{D^{(*)}} = \dfrac{Br(B \to D^{(*)}\tau\nu)}{Br(B \to D^{(*)}l\nu)}$ ~4.0σ

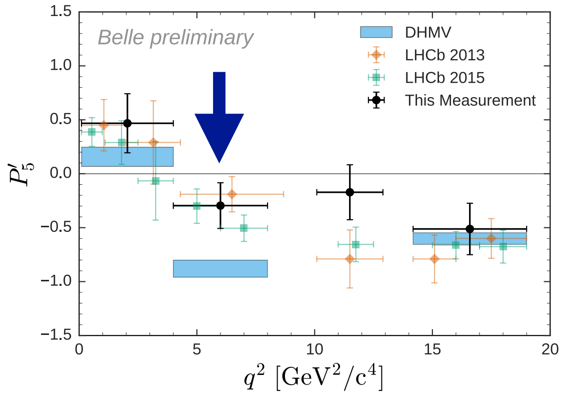
  deviation from Standard Model (SM)

We need more data!



$\dfrac{Br(B \to K\mu^+\mu^-)}{\ldots Ke^+e^-)}$ ~2.6σ

[PRL 113, 151

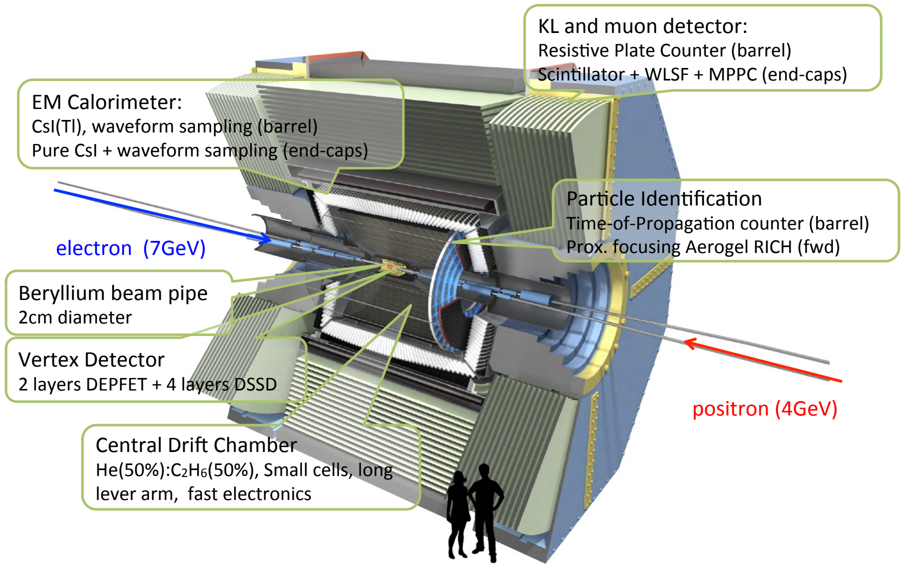


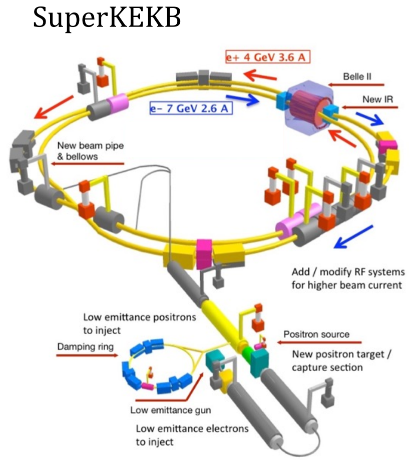
- $B \to K^*\mu^+\mu^-$

  ~3.7σ (LHCb), ~2.6σ (*Belle*)

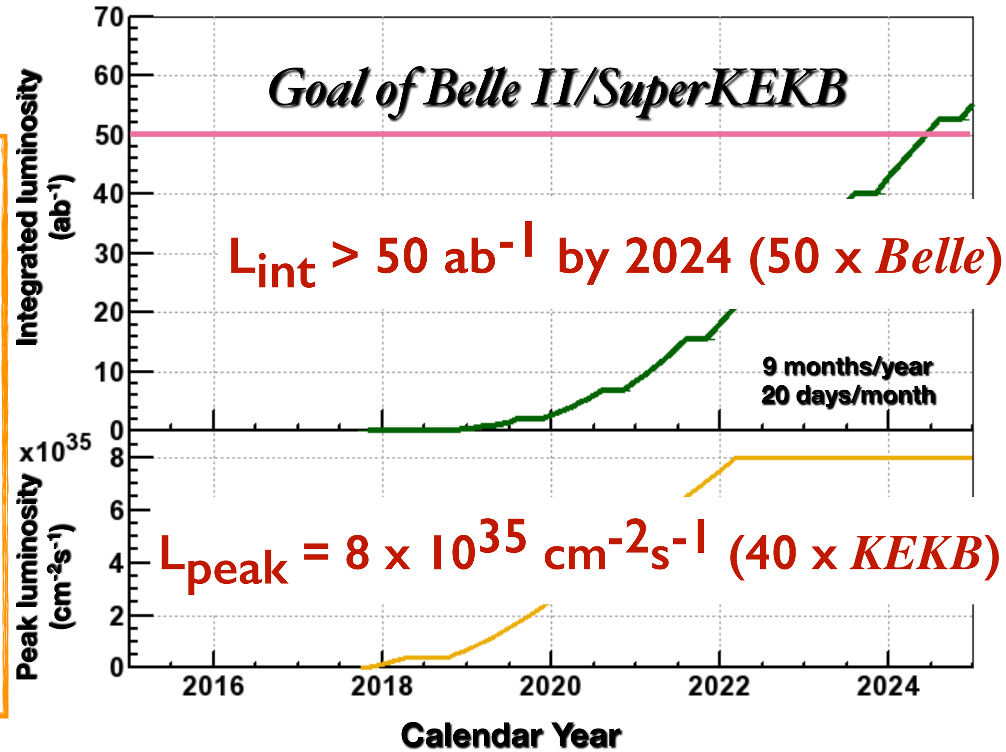
  deviation from SM prediction in P_5' for $4<q^2<8$ GeV²

Belle II Detector @ SuperKEKB





- full solid angle detector; clean event environment; well defined initial state.
- Improved detector efficiency and purity (tracking, PID, K/π separation, …).
- Good and efficient reconstruction of decays with neutrals.
- Smarter software and precise algorithms.



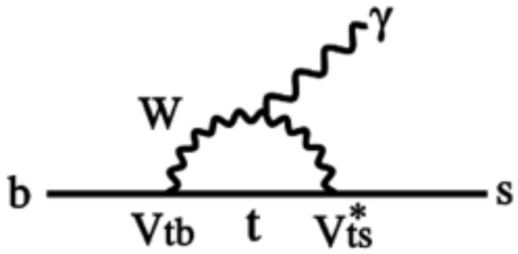
Covered by Hiroshi Kaji (SuperKEKB) and Katsuro Nakamura (Belle II) on Monday (Dec. 5 2016)

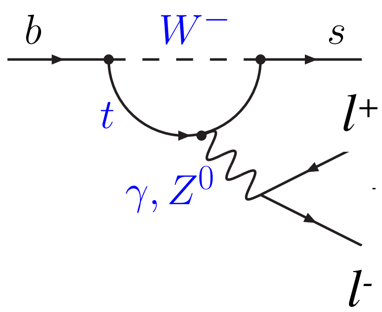
Outline

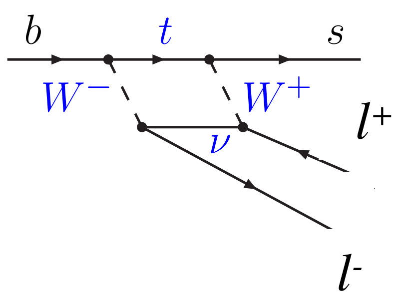
- Radiative and Electroweak Penguin *B* Decays
  - Branching Fraction of $B \to X_s \gamma$
  - Direct *CP* Asymmetry in $B \to X_{(s+d)} \gamma$
  - Time Dependent CP Violation in $B \to K^{*0} \gamma$
  - Electroweak penguin $b \to s\, l^+ l^-$
  - Missing Energy Decay $B \to K^{(*)} \nu \bar{\nu}$

Radiative and Electroweak (EW) Penguin B Decays

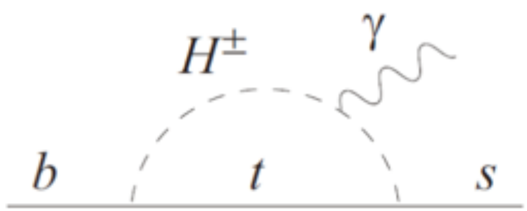
- Flavour-Changing Neutral Currents (FCNC): occur only at the loop level.

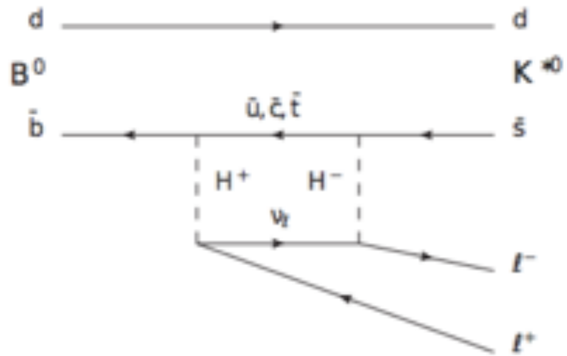






- Non-SM particles (eg. H^- in Two-Higgs-Doublet Model type II (2HDM-II)) may contribute to loop and box diagrams.





Radiative and Electroweak (EW) Penguin B Decays

- Efective Hamiltonian for b → s transition (leading contribution):

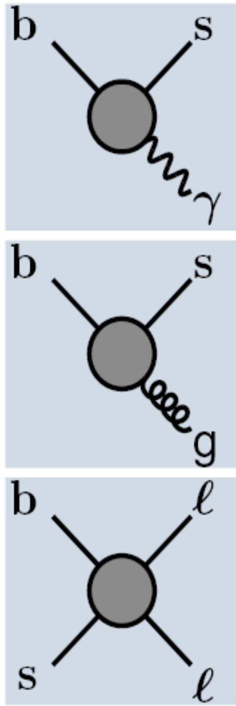
$$H_{eff} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_i C_i O_i$$

- C_i are Wilson coefficients, and O_i are the corresponding effective operators
  - $i = 1, 2$ Tree
  - $i = 3\text{-}6, 8$ Gluon penguin
  - $i = 7$ Photon penguin
  - $i = 9, 10$ Electroweak penguin
  - $i = S, P$ (Pseudo)scalar penguin

$\mathcal{O}_{7\gamma}$

$\mathcal{O}_{8g}$

$\mathcal{O}_{9\ell,10\ell}$



- Decays sensitive to different Wilson coefficients:
  - $B \to X_s \gamma$ C_7
  - $B \to X_s l^+ l^-$ C_7, C_9, C_{10}

Branching Fraction (*BF*) of $B \to X_s \gamma$

- Current SM next-to-next-to-leading order (*NNLO*) *BF* ***[PRL 114, 221801, 2015]***

$$Br(\bar{B} \to X_s\gamma)^{NNLO}_{E_\gamma>1.6GeV} = (3.36 \pm 0.23) \times 10^{-4}$$

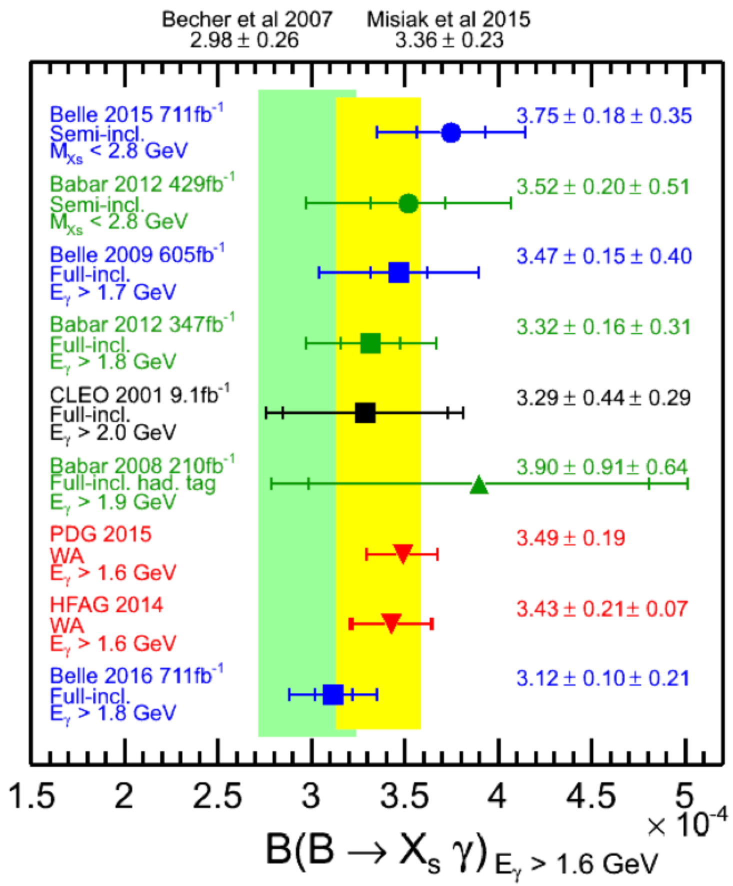
- HFAG 2016 / PDG 2015 Average

$$Br(\bar{B} \to X_s\gamma)_{E_\gamma>1.6GeV} = (3.34 \pm 0.21_{stat} \pm 0.07_{sys}) \times 10^{-4}$$

- Experiment and theory are in agreement ➛ tight constraints on NP scenarios e.g. 2HDM-II.
- The newest *Belle* result with fully inclusive method has only 7.3% uncertainty.
  - Limit on 2HDM-II:

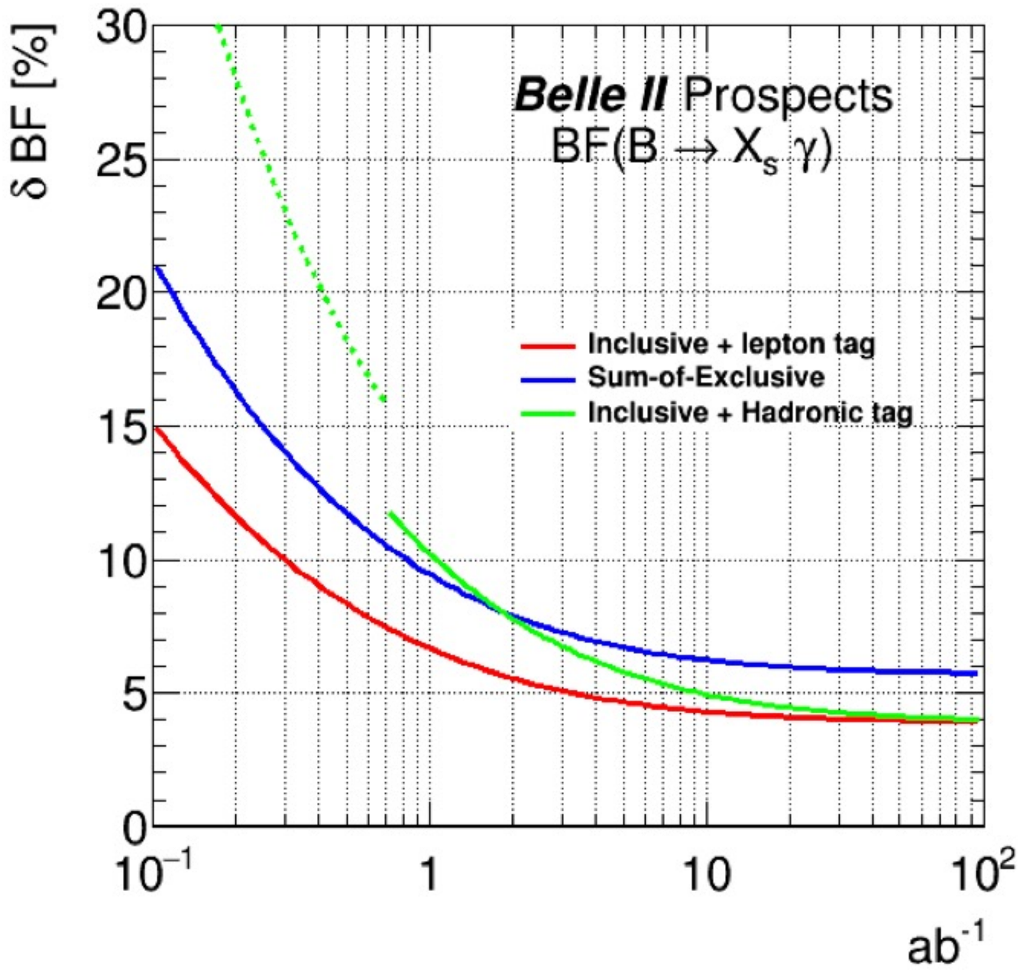
M(H⁺) > 580 GeV at 95% CL

[arXiv:1608.02344v1]



BF($B \to X_s \gamma$) at *Belle II*

- *Belle II* mission: reduce the systematic uncertainty with huge data.
- Can also measure the *BF* with $E_\gamma > 1.6\ GeV$ without extrapolation.



- 3.9 % total error will be reachable with 50 ab^{-1} (conservatively estimated).
  - comparable to uncertainty due to non-perturbative effect, very hard to reduce, in theory *[PRL 114, 221801 (2015)]*.

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

- The SM predicts quite different A_{CP} for $B \to X_s\,\gamma$ and $B \to X_d\,\gamma$

$$A_{CP}^{b \to q\gamma} \equiv \frac{\Gamma(\bar{B} \to X_q \gamma) - \Gamma(B \to X_{\bar{q}} \gamma)}{\Gamma(\bar{B} \to \bar{X}_q \gamma) + \Gamma(B \to X_{\bar{q}} \gamma)}$$

$$A_{CP}(\bar{B} \to X_s \gamma) = (+0.44^{+0.24}_{-0.14}) \times 10^{-2}$$

$$A_{CP}(\bar{B} \to X_d \gamma) = (-10.2^{+3.3}_{-5.8}) \times 10^{-2}$$

[Nucl.Phys.B704:56-74,2005]

- Thanks to U-spin relations and unitarity of the *CKM* matrix, A_{CP} for $b \to (s+d)\gamma$ is negligible (close to 0).

If $A_{CP}(B \to X_{(s+d)}\,\gamma)$ deviates from 0, it will be a clear NP signal.

Direct CP Asymmetry in $B \to X_{(s+d)}\gamma$ and $\Delta A_{CP}(B \to X_s\gamma)$

$$A_{CP}^{b\to q\gamma} \equiv \frac{\Gamma(\bar{B} \to X_q\gamma) - \Gamma(B \to X_{\bar{q}}\gamma)}{\Gamma(\bar{B} \to \bar{X}_q\gamma) + \Gamma(B \to X_{\bar{q}}\gamma)}$$

- The SM predicts quite different A_{CP} for $B \to X_s\gamma$ and $B \to X_d\gamma$

$$A_{CP}(\bar{B} \to X_s\gamma) = (+0.44^{+0.24}_{-0.14}) \times 10^{-2}$$

$$A_{CP}(\bar{B} \to X_d\gamma) = (-10.2^{+3.3}_{-5.8}) \times 10^{-2}$$

[Nucl.Phys.B704:56-74,2005]

- Thanks to U-spin relations and unitarity of the *CKM* matrix, A_{CP} for $b \to (s+d)\gamma$ is negligible (close to 0).

If $A_{CP}(B \to X_{(s+d)}\gamma)$ deviates from 0, it will be a clear NP signal.

- One more quantity, $\Delta A_{CP} = A_{CP}(B^{\pm}) - A_{CP}(B^0/\bar{B}^0)$ contains information on C_8

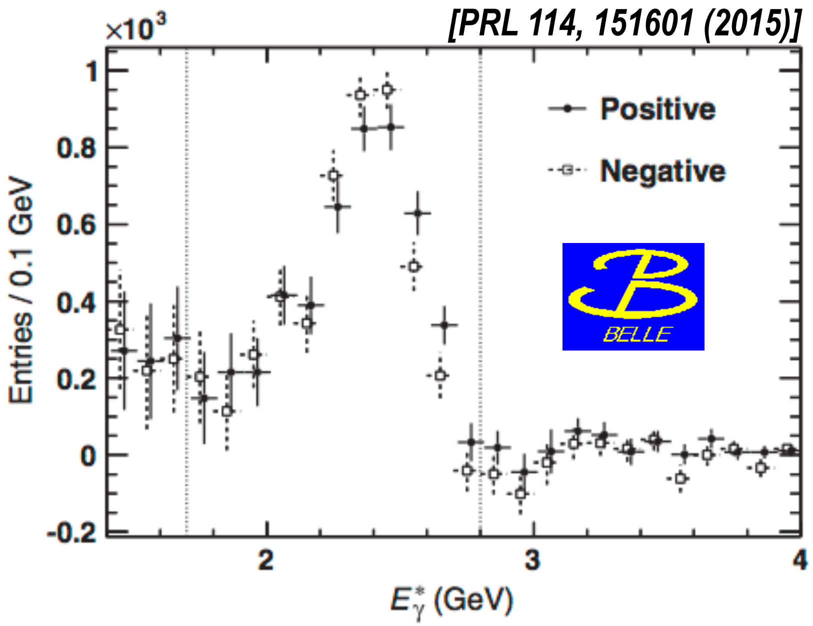
[Phys.Rev.Lett. 106 (2011) 141801]

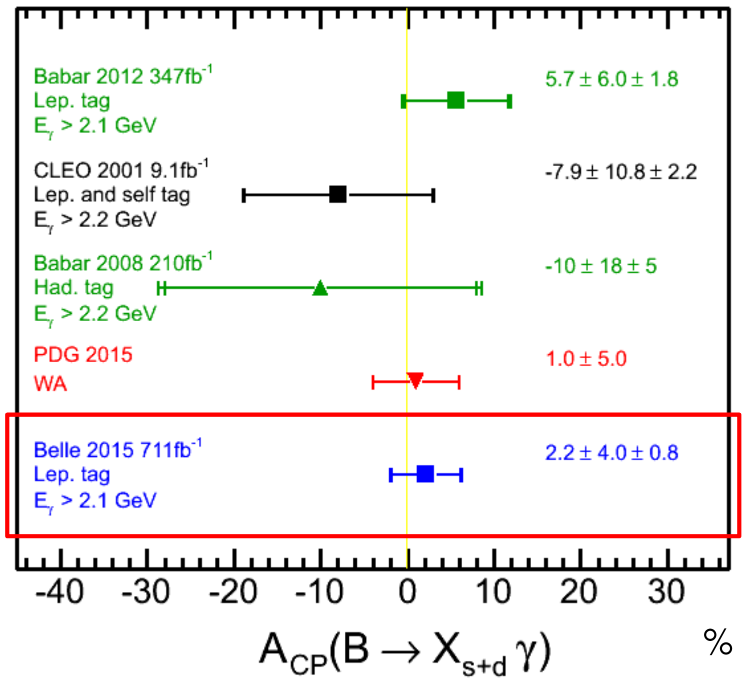
$$\Delta A_{CP} \approx 4\pi^2\alpha_s \frac{\tilde{\Lambda}_{78}}{m_b} \mathrm{Im}\left(\frac{C_8}{C_7}\right)$$

- In the SM, phases in C_7 and C_8 are zero $\Rightarrow$ **$\Delta A_{CP} = 0$**

If $\Delta A_{CP}(B \to X_s\gamma)$ deviates from 0, it will be a clear NP signal.

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





- Recently *Belle* performed world best measurement (710 fb^{-1} Υ(4S)).

$$A_{CP}(B \to X_{(s+d)}\gamma) = (2.2 \pm 3.9 \pm 0.9)\%$$

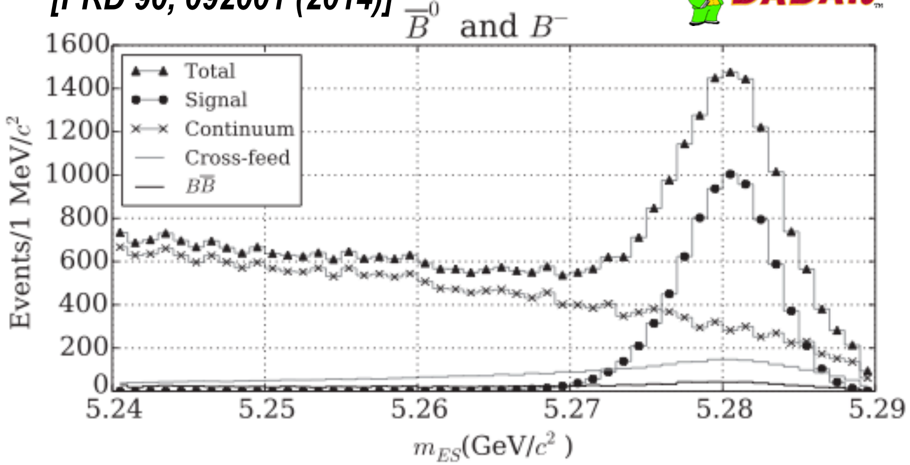
- Inclusively reconstruct photon with $1.7 < E_\gamma < 2.8$ GeV.
- High momentum lepton to tag flavor of the other B.

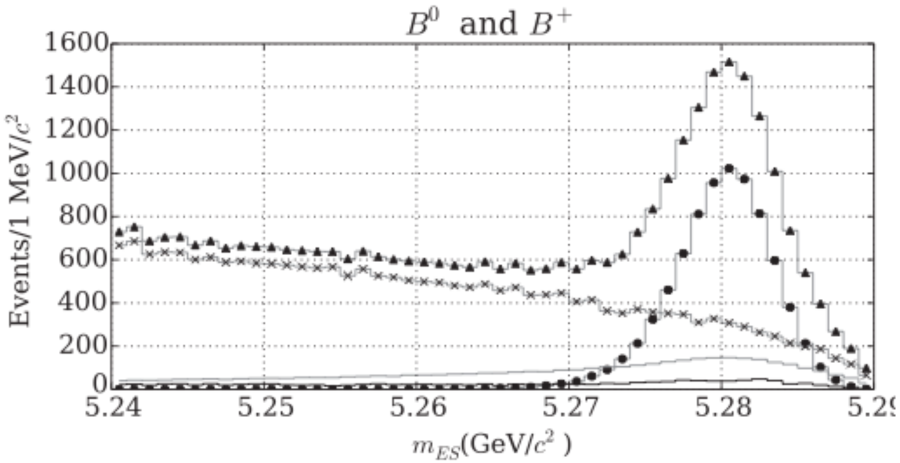
  $1.10 \leq p_l^* \leq 2.25$ GeV

$\Delta A_{CP}(B \to X_s \gamma)$

[PRD 90, 092001 (2014)]

BABAR





$$m_{bc}(m_{ES}) \equiv \sqrt{E_{Beam}^2 - |\vec{p}_B|^2}$$

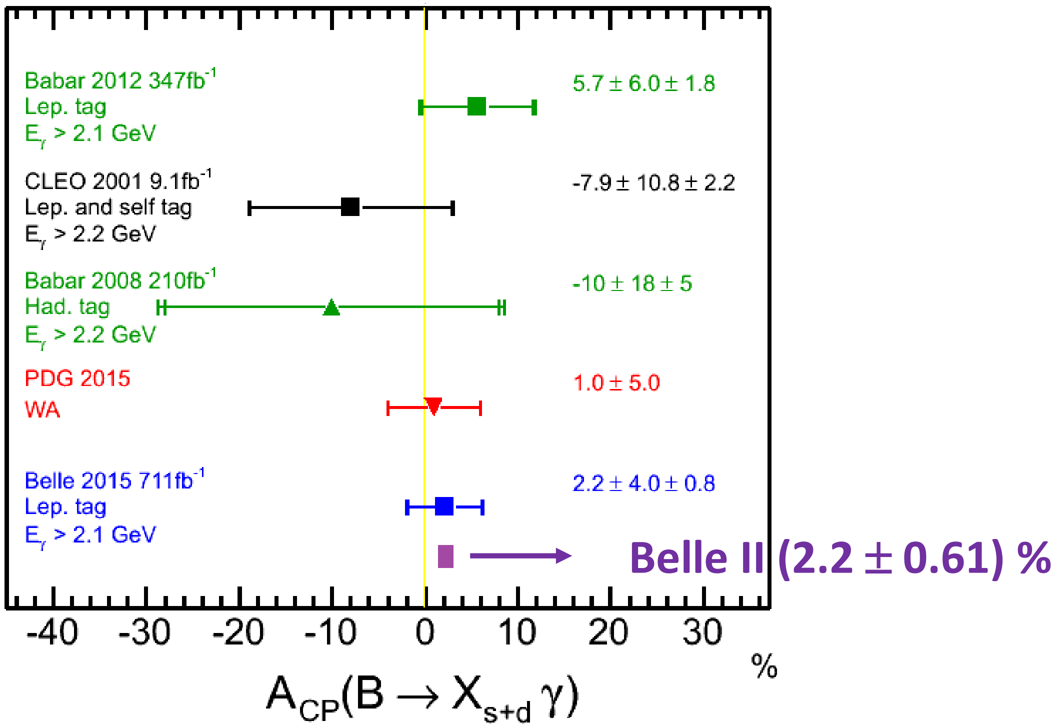
- Only measured by *BABAR* (429 fb^{-1} Υ(4S)).
- Sum-of-exclusive method with 38 exclusive B decay modes.
  - Only self-tagged modes were used.

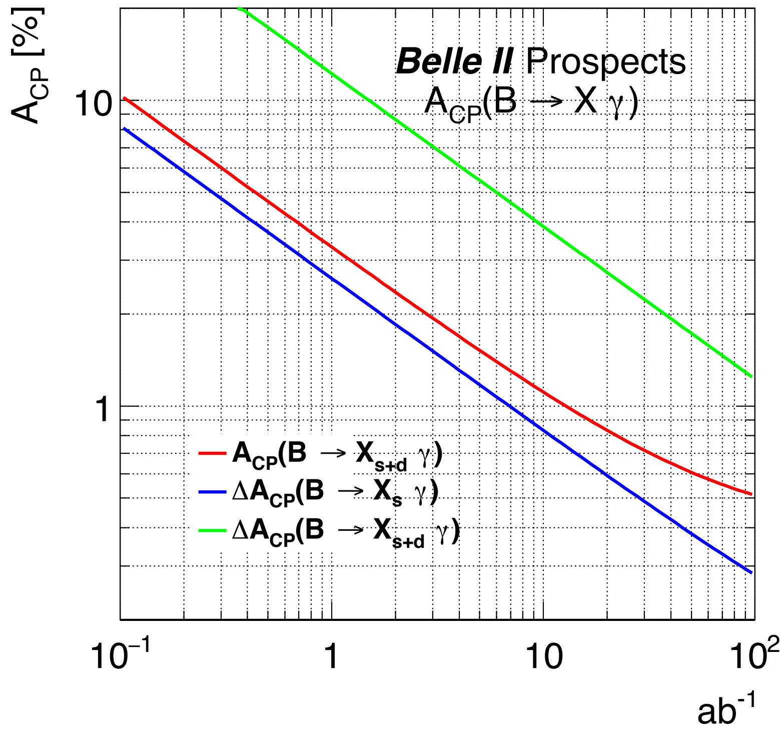
$$\Delta A_{X_s\gamma} = +(5.0 \pm 3.9 \pm 1.5)\%$$

- Quoted systematic error is *conservative*.

$A_{CP}(B \to X_{(s+d)}\,\gamma)$ and $\Delta A_{CP}(B \to X_s\,\gamma)$ at *Belle II*

- In both A_{CP} and ΔA_{CP} measurements most of systematic error cancel out.
  → both are still statistically dominated at *Belle II* with 50 ab^{-1}.





- If the central values don't change:
  - Uncertainty in A_{CP} to be **±*0.61%*** → **3.4 σ**.
  - Uncertainty in ΔA_{CP} to be **±*0.37%*** → **13.5 σ**.

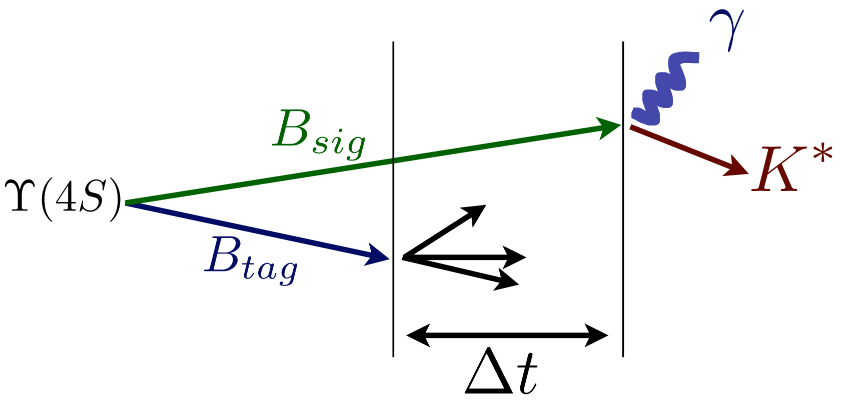
BABAR

$$\Delta A_{X_s\gamma} = +(5.0 \pm 3.9 \pm 1.5)\%$$

Belle II

$$\Delta A_{X_s\gamma} = +(5.0 \pm 0.37)\%$$

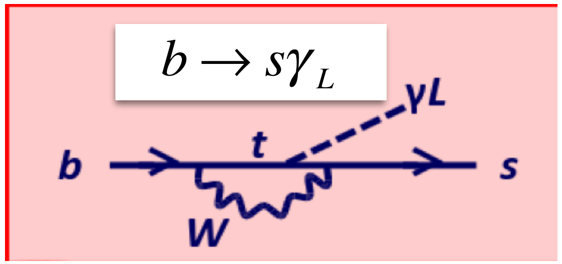
Time-Dependent CP Violation (TDCPV) in $B \to K^{*0} (K_s \pi^0)\gamma$

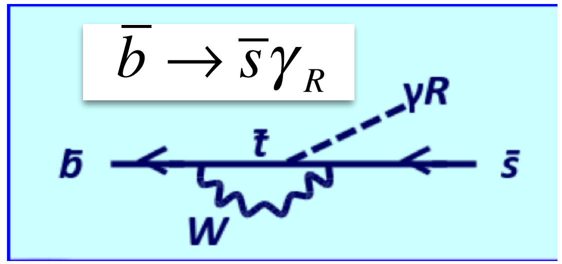


$$A_{CP}(\Delta t) = \frac{\Gamma\left(\bar{B}^0(\Delta t) \to X_s \gamma_L\right) - \Gamma\left(B^0(\Delta t) \to X_s \gamma_R\right)}{\Gamma\left(\bar{B}^0(\Delta t) \to X_s \gamma_L\right) + \Gamma\left(B^0(\Delta t) \to X_s \gamma_R\right)}$$

$$= S \sin \Delta m \Delta t - C \cos \Delta m \Delta t$$

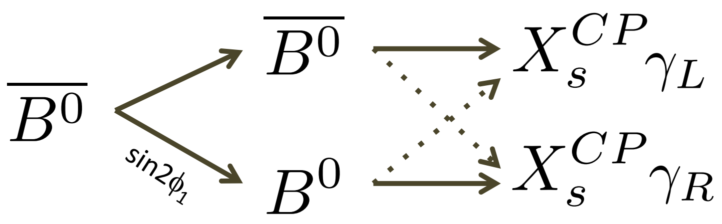
- "Flavour-Specific Decay" :





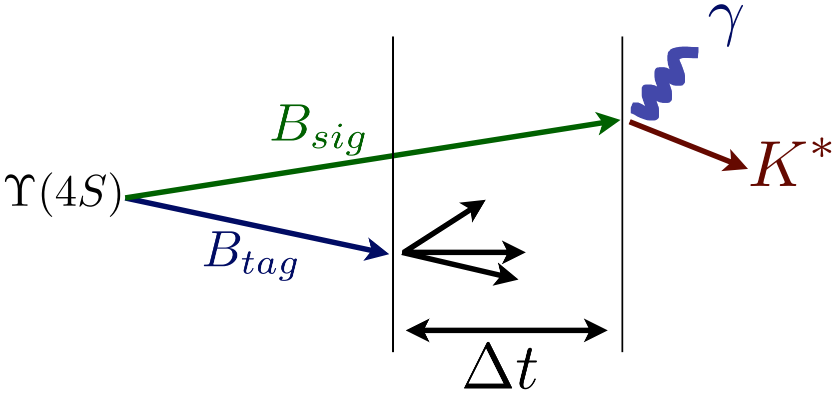
- TDCPV in $B^0 \to K^{*0}\gamma$ is small in the SM

$$|S| \approx \frac{2m_s}{m_b} \sin 2\phi_1 \quad \sim\text{a few \%}$$



dotted : helicity filip

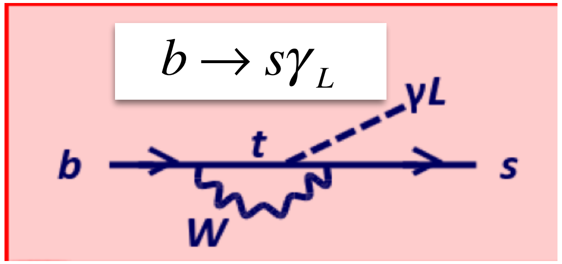
Time-Dependent CP Violation (TDCPV) in $B \to K^{*0} (K_s \pi^0)\gamma$

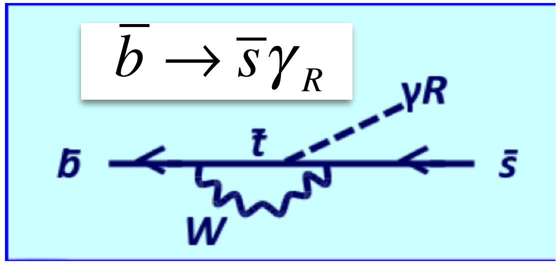


$$A_{CP}(\Delta t) = \frac{\Gamma\left(\bar{B}^0(\Delta t) \to X_s\gamma_L\right) - \Gamma\left(B^0(\Delta t) \to X_s\gamma_R\right)}{\Gamma\left(\bar{B}^0(\Delta t) \to X_s\gamma_L\right) + \Gamma\left(B^0(\Delta t) \to X_s\gamma_R\right)}$$

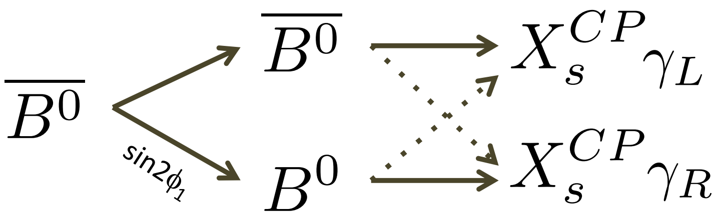
$$= S \sin \Delta m \Delta t - C \cos \Delta m \Delta t$$

- "Flavour-Specific Decay" :

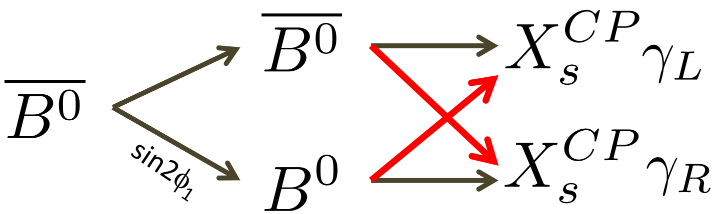




- New physics with right handed current increases the fraction of right handed photon.
    - Interfere with the SM occurs and large TDCPV possible



dotted : helicity filip



red : helicity filip +NP

S($B \to K^{*0} \gamma$) at *Belle* and *BABAR*

- ***Belle*** : 535 M BB pairs

  K^{*0} region

  $(0.8 < m(K_s \pi^0) < 1.0\ GeV/)c^2)$

  $$S_{K^*\gamma} = -0.32^{0.36}_{-0.33} \pm 0.05$$

  $$C_{K^*\gamma} = -0.20 \pm 0.24 \pm 0.05$$

- ***BABAR***: 467 M BB pairs

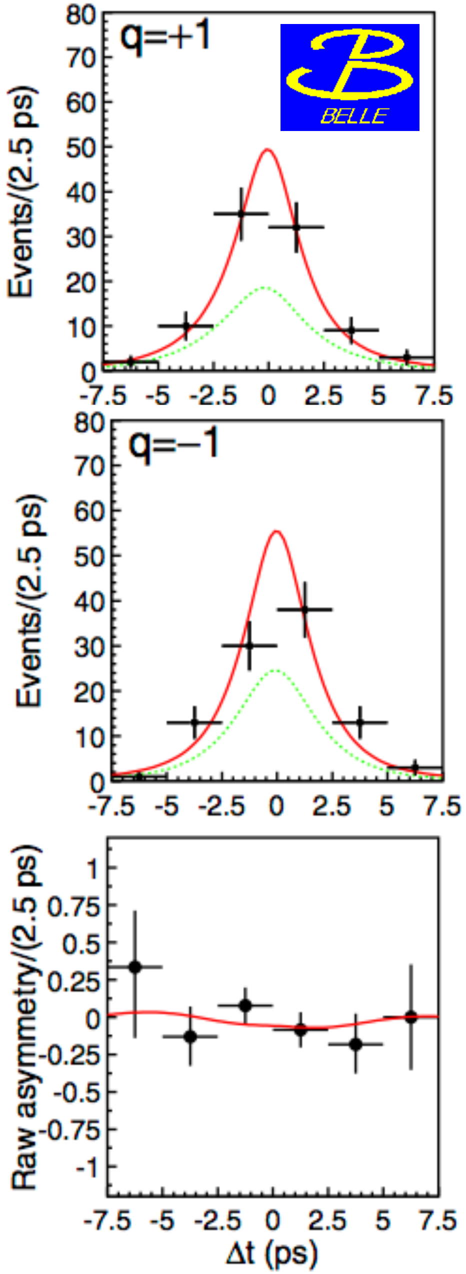
  K^{*0} region

  $(0.8 < m(K_s \pi^0) < 1.0\ GeV/)c^2)$

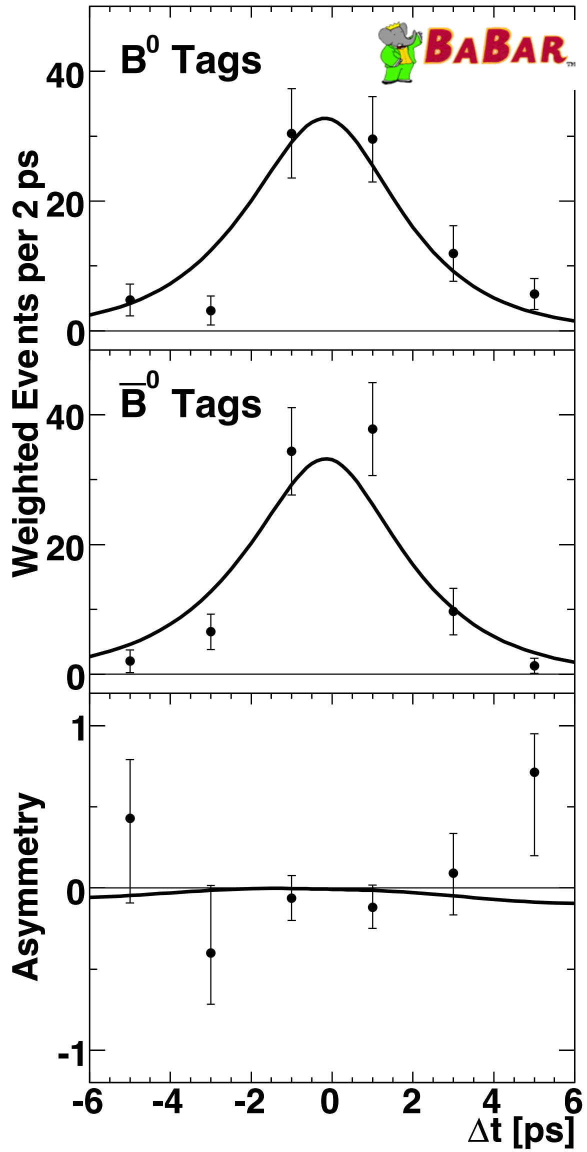
  $$S_{K^*\gamma} = -0.03 \pm 0.29 \pm 0.03$$

  $$C_{K^*\gamma} = -0.14 \pm 0.16 \pm 0.03$$

[PRD 74 111104(R) 2006]



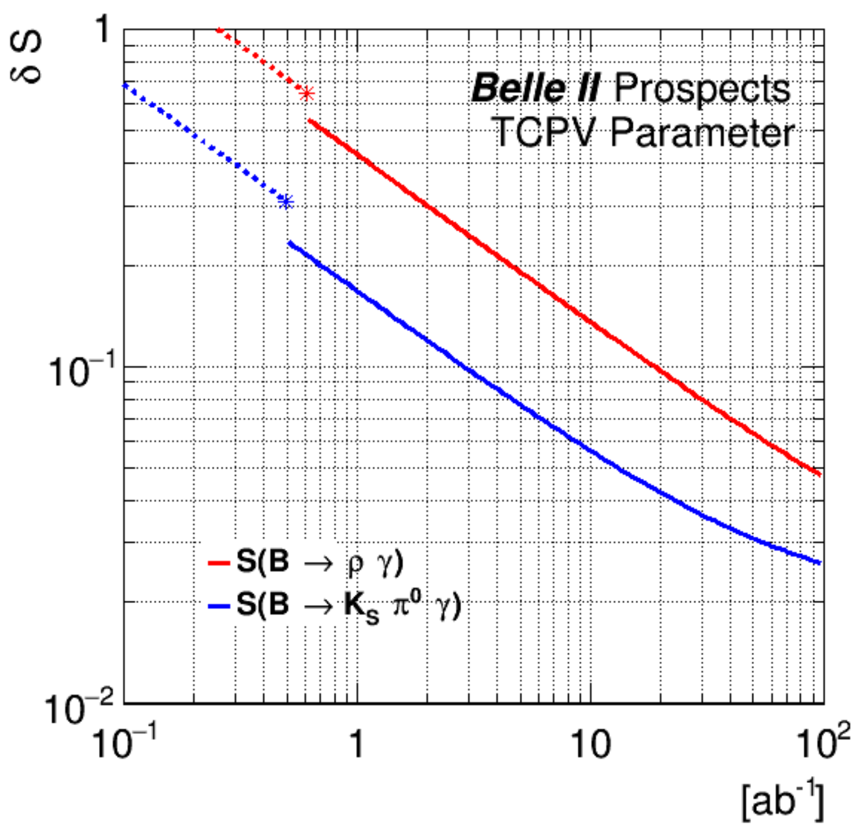
[PRD 78 071102(R) 2008]

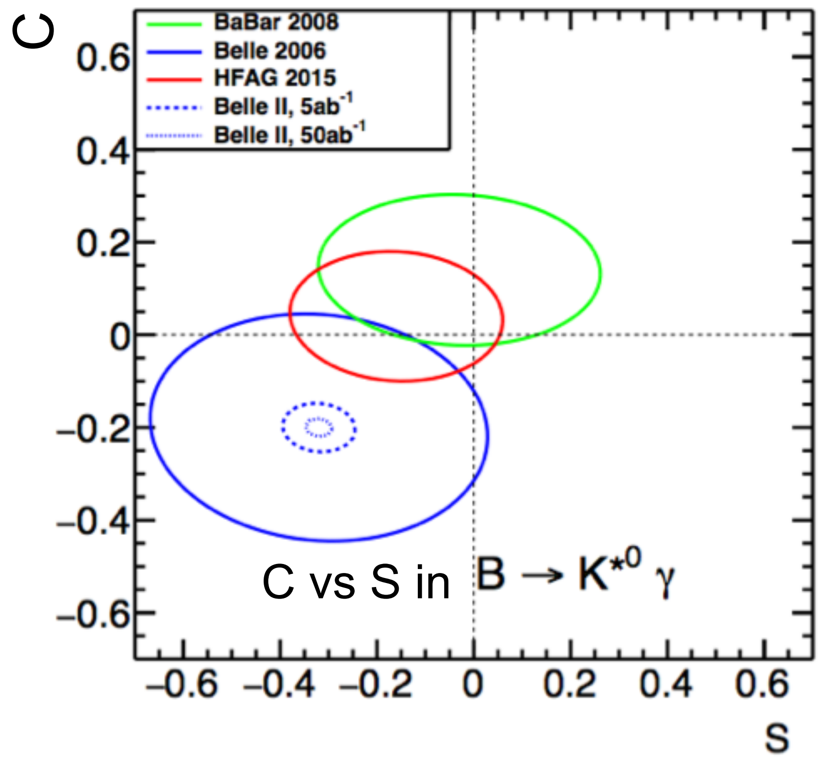


No significant CP asymmetry.

$S(B \to K^{*0} \gamma)$ at *Belle II*

- Very important decay mode for *Belle II*.
  - Belle II vertex detector is larger than Belle (6 cm → 11.5 cm)
  - 30% more K_s with vertex hits available.
  - Effective tagging efficiency is 13% better (*very conservative*).
  - Can reach 0.03 uncertainty on S.

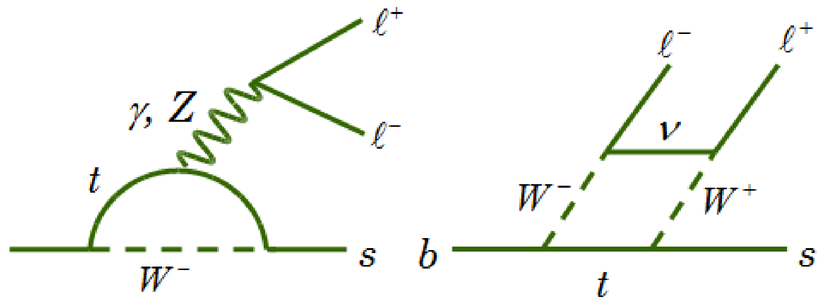




16σ deviation with 50ab⁻¹

Electroweak Penguin $b \to s\, l^+ l^-$

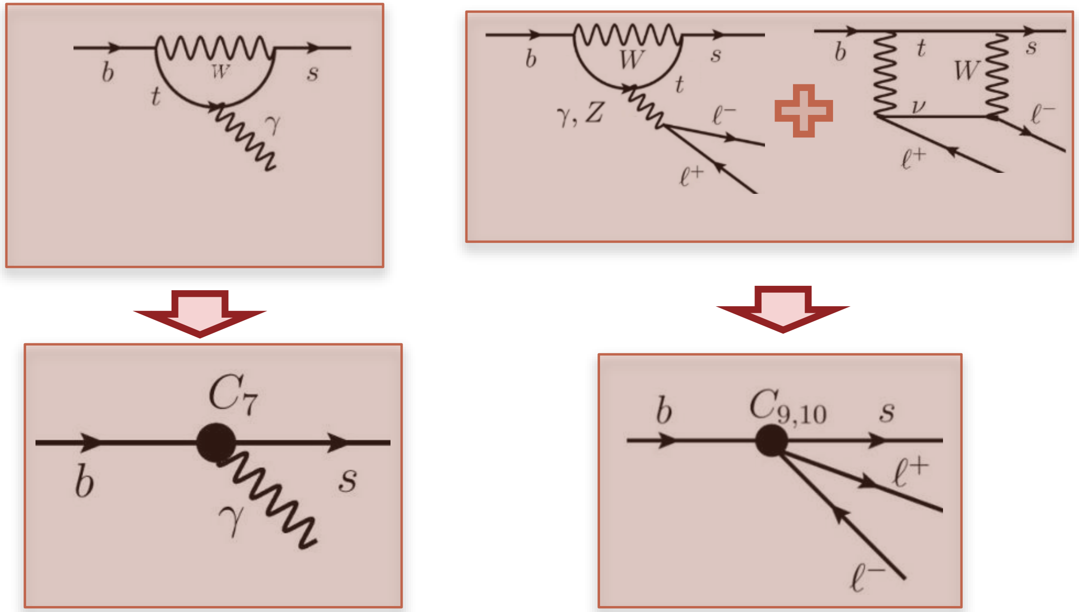
- Electroweak penguin (or box) diagram



electromagnetic dipole operator

semileptonic operators

- Sensitive to the effective Wilson coefficients for the electromagnetic penguin C_7 ,and the vector and axial-vector electroweak contributions C_9 and C_{10} .

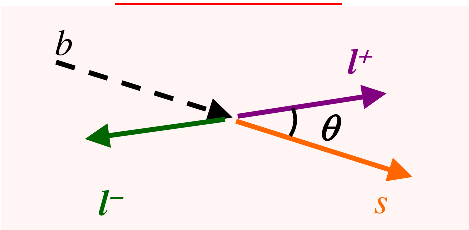


- Rich set of observables:
  - Branching fraction, *CP* Asymmetry, isospin asymmetry, $q^2=|M(l^+ l^-)|^2$, F_L, forward-backward asymmetry, ratio of μ mode and e mode.

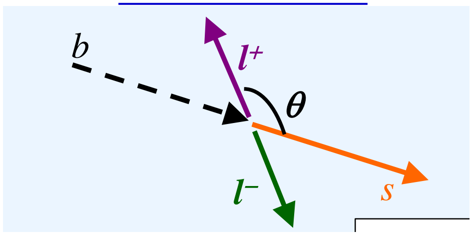
Inclusive $B \to X_s\, l^+ l^-$ at *Belle*

- A_{FB} forward-backward asymmetry $B \to X_s\, l^+ l^-$ in *Belle*

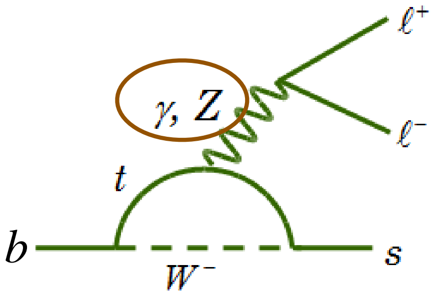
Forward event



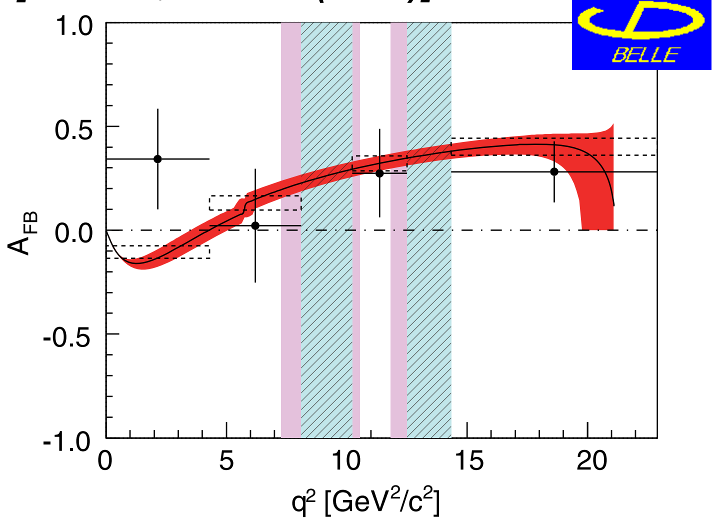
Backward event



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



[PRD 93, 032008 (2016)]

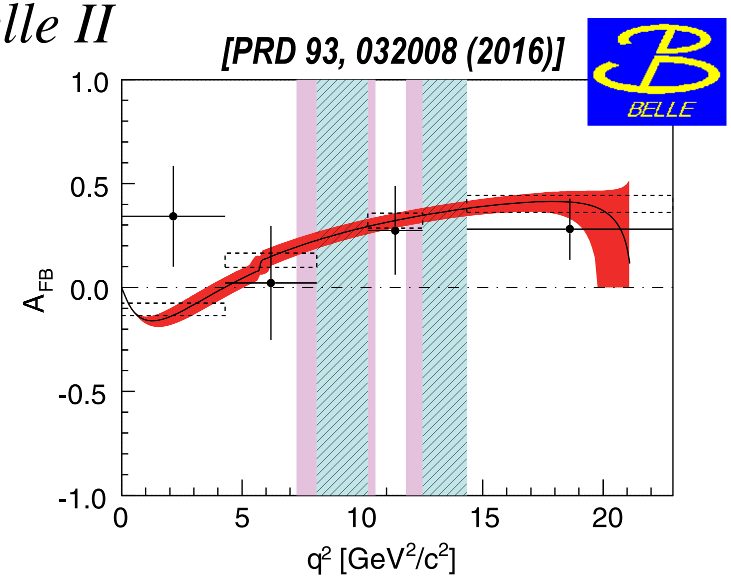


- Sum-of-exclusive method is utilized. $B \to X_s\, l^+ l^-$ is reconstructed from 36 exclusive modes.
- Tension in low q^2 (q^2 < 4.3 GeV^2)
- One of the key measurement in *Belle II*

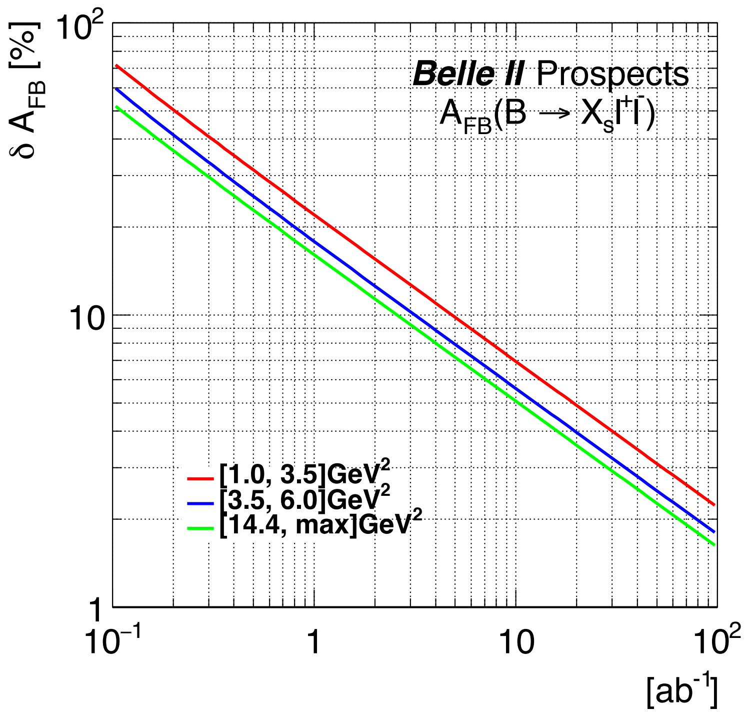
Inclusive $B \to X_s\, l^+\, l^-$ at *Belle II*

- A_{FB} forward-backward asymmetry $B \to X_s\, l^+\, l^-$ in *Belle II*

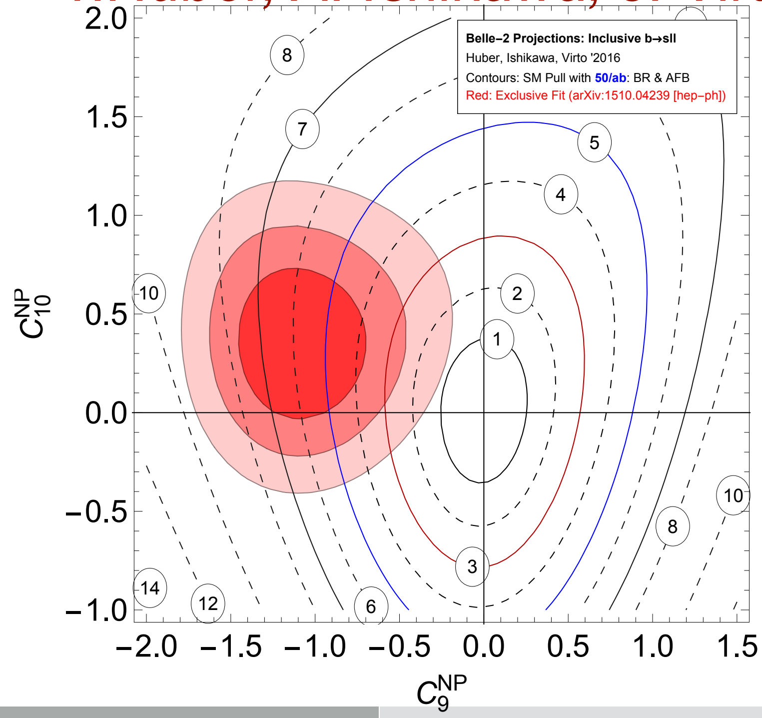
[PRD 93, 032008 (2016)]



- Naïve estimation
  - Systematic error (<1%) is smaller than statistical error with 50 ab^{-1}.
  - 3.1% for q^2 bin1 [1, 3.5] GeV^2
  - 2.9% for q^2 bin2 [3.5, 6] GeV^2



T.Huber, A. Ishikawa, J. Virto



R(K), R(K*), R(Xs)

- Ratio of $B \rightarrow K\mu^+\mu^-$ and $B \rightarrow Ke^+e^-$, R_K, is a clean observable in the SM.

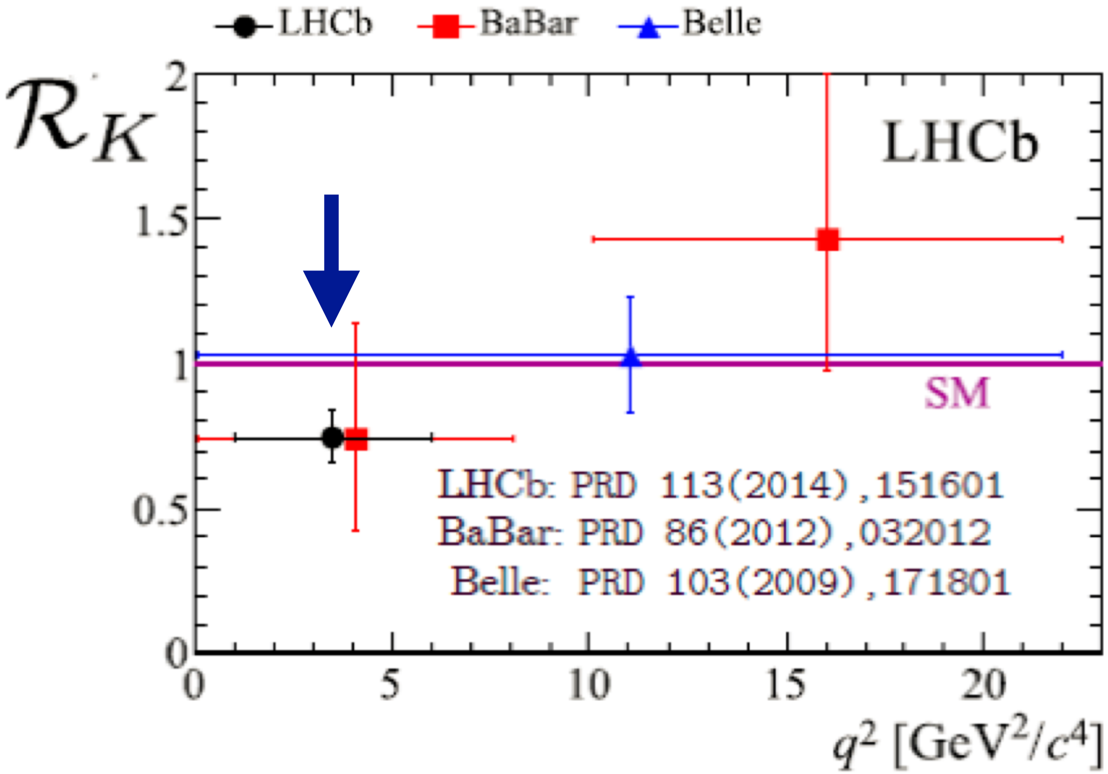
$$R_K = \frac{Br(B \rightarrow K\mu^+\mu^-)}{Br(B \rightarrow Ke^+e^-)} = 1.003 \pm 0.001$$

[JHEP 0712, 040 (2007)]

- LHCb reports 2.6 σ deviation of ratio of BFs in $1 < q^2 < 6$ GeV^2. ***[PRL 11, 151601 (2014)]***

$$R_K = 0.75^{+0.090}_{-0.074} \pm 0.036$$

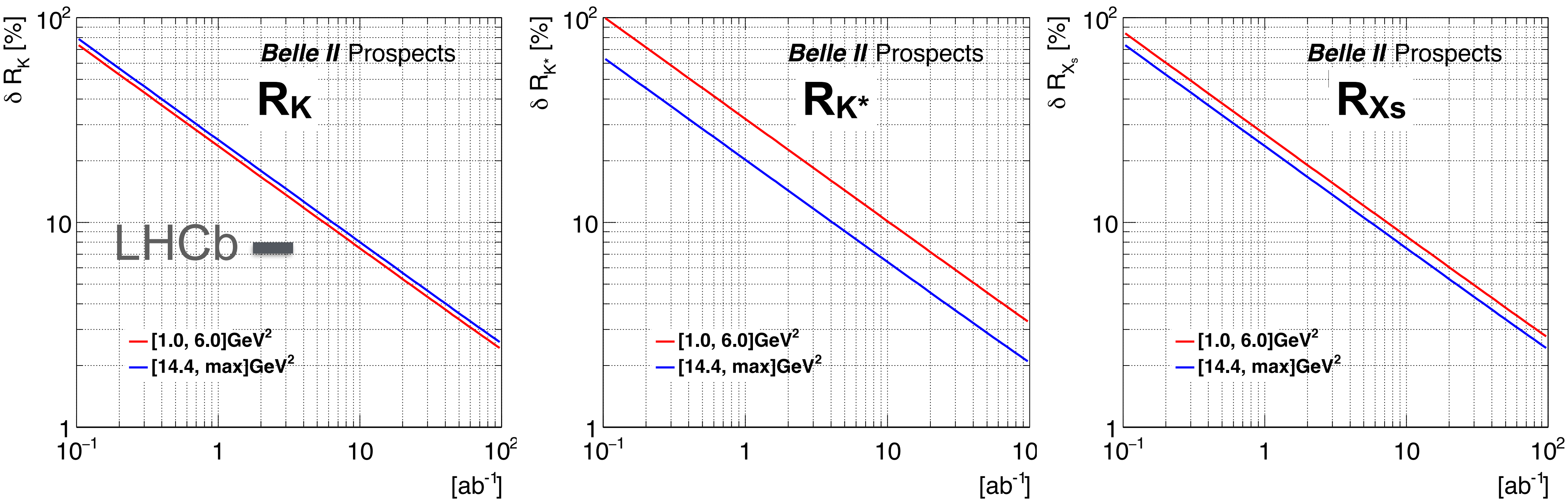
- Electron mode is challenging in LHCb, especially for high q^2



R(K), R(K*), R(Xs) at *Belle II*

- All ratios R(K), R(K*) and R(Xs) are possible
- Electron and muon modes have similar efficiency
- Sensitive to both low q^2 and high q^2 (q^2 >14.4 GeV^2)
- The errors reach to ~2% for all K, K* and Xs modes

◉ Lepton ID systematics is about ±0.4% at *Belle II*



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

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

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

8 free parameters

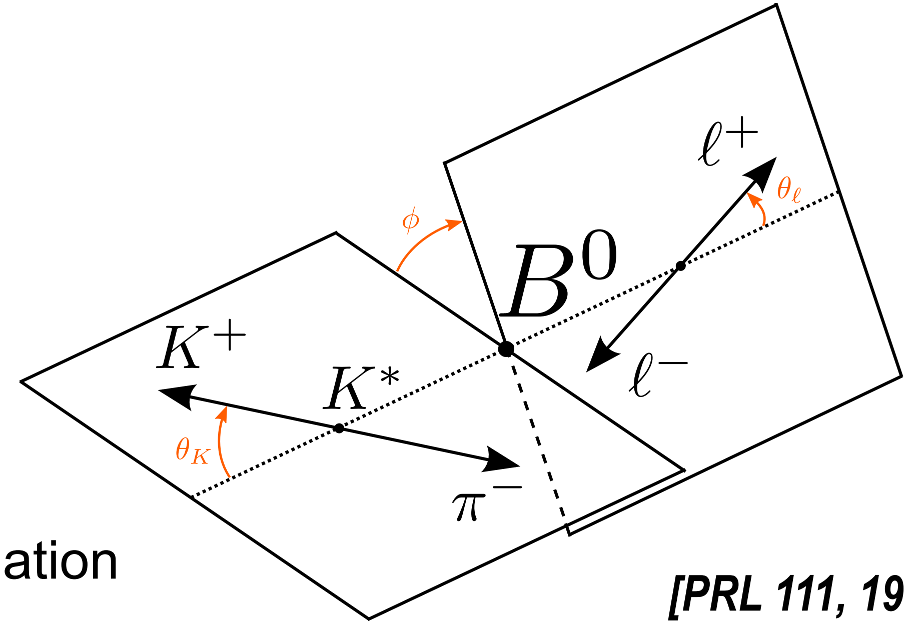
Observables

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

Transformation:

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

- Free parameters reduce to three: F_L, S_3, and the observable S_5 or P_5'
- $S_{4,7,8}$ or $P_{4,6,8}'$ have the similar transformation

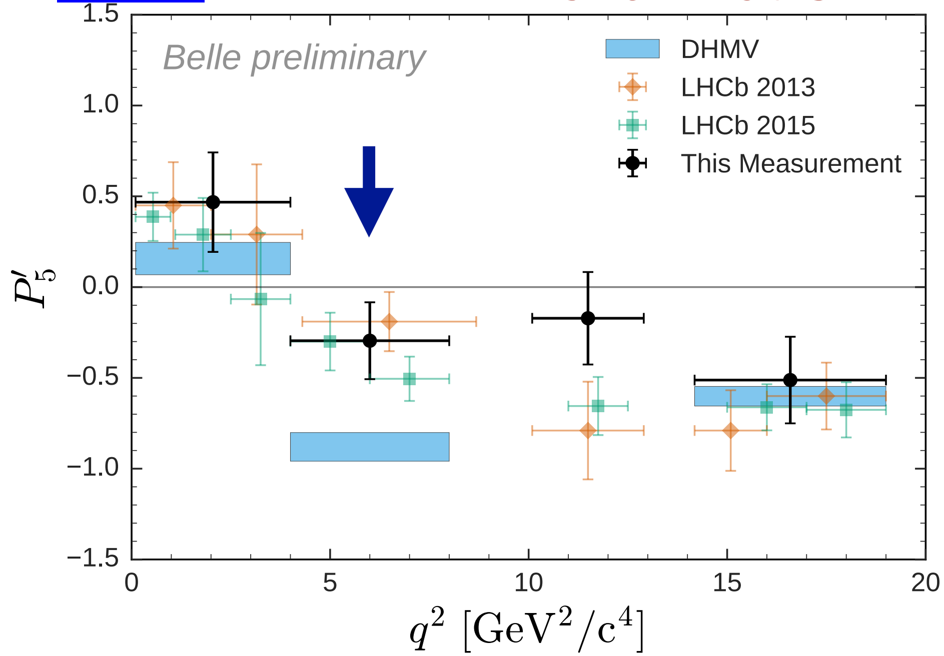


[PRL 111, 191801]

Angular Analysis of $B \to K^* l^+ l^-$ at *Belle II*

BELLE preliminary

shown at CKM 2016



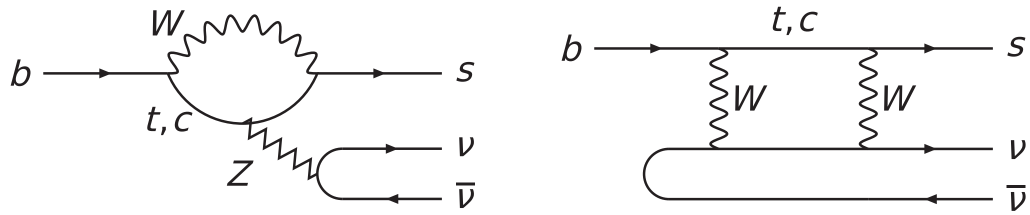
- $P'_{4,6,8}$ → overall in agreement with SM predictions.
- P'_5 → 2.6σ deviation from Standard Model prediction in the range $4.0 < q^2 < 8.0$ GeV^2

- *Belle II* and LHCb will be comparable for this process.
- *Belle II* will be able to do isospin comparison of K^{*+} and K^{*0}, or the ground states K.

Absolute error in P'_5

q^2 (GeV^2)	Belle	Belle II 50 ab^{-1}
0.1 - 4.00	0.416	0.059
4.00 - 8.00	0.277	0.04
10.09 - 12.0	0.344	0.049
14.18 - 19.0	0.248	0.033

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



- $b \to s$ flavour-changing neutral current
- golden mode of *Belle II* because theoretically very clean: free of uncertain long-distant hadronic effects.

SM $B \to K^{(*)} \nu \bar{\nu}$ branching fractions:

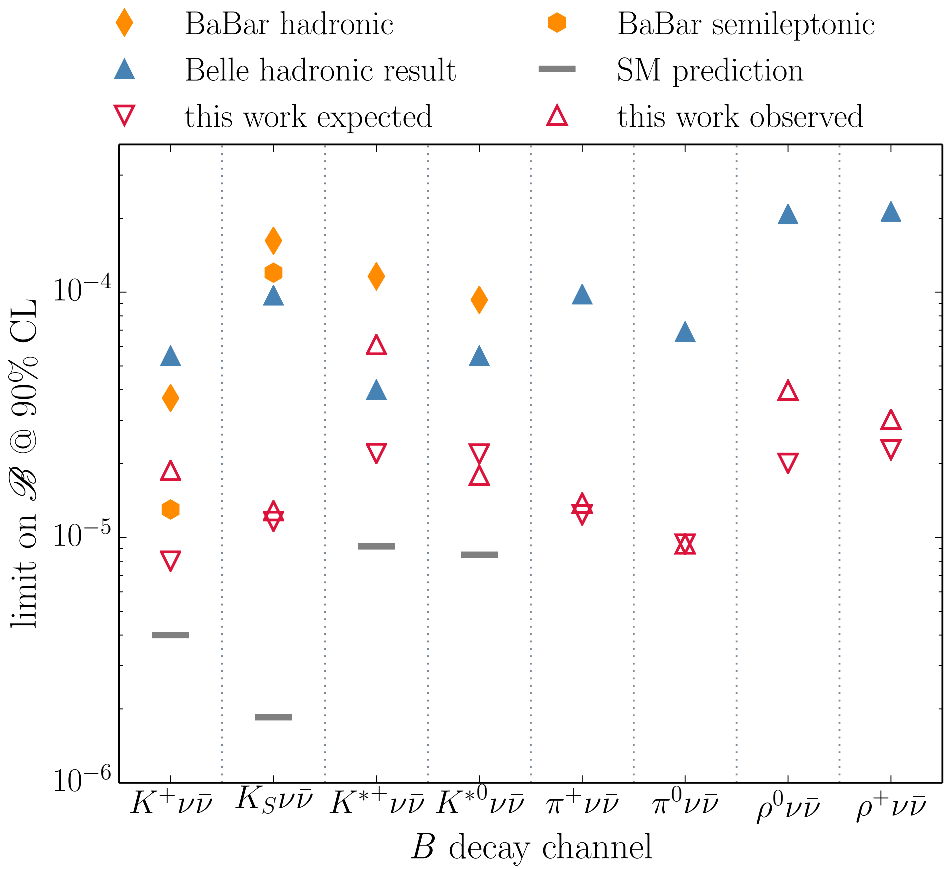
[BELLE2-MEMO-2016-007]

$$Br_{SM}(B^+ \to K^+ \nu\bar{\nu}) = (4.68 \pm 0.64) \times 10^{-6}$$
$$Br_{SM}(B^0 \to K_s^0 \nu\bar{\nu}) = (2.17 \pm 0.30) \times 10^{-6}$$
$$Br_{SM}(B^+ \to K^{*+} \nu\bar{\nu}) = (10.22 \pm 1.19) \times 10^{-6}$$
$$Br_{SM}(B^0 \to K^{*0} \nu\bar{\nu}) = (9.48 \pm 1.10) \times 10^{-6}$$

- New *Belle* measurement of $Br(B \to h^{(*)} \nu \bar{\nu})$ with the semileptonic tagging method.
- Highest significance in the $B^+ \to K^{*+} \nu \bar{\nu}$ channel, 2.3σ.
- None of the limits excludes SM predictions, leave room for new physics contributions.

preliminary

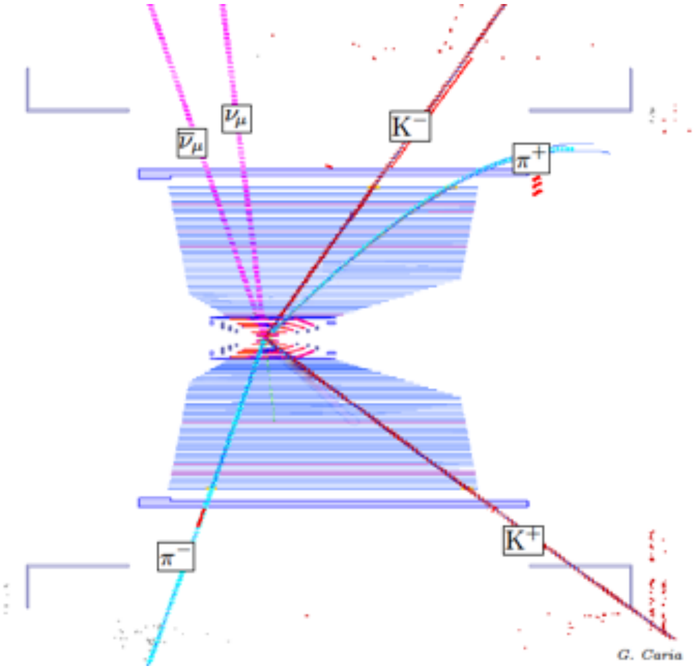
(shown at CKM 2016)



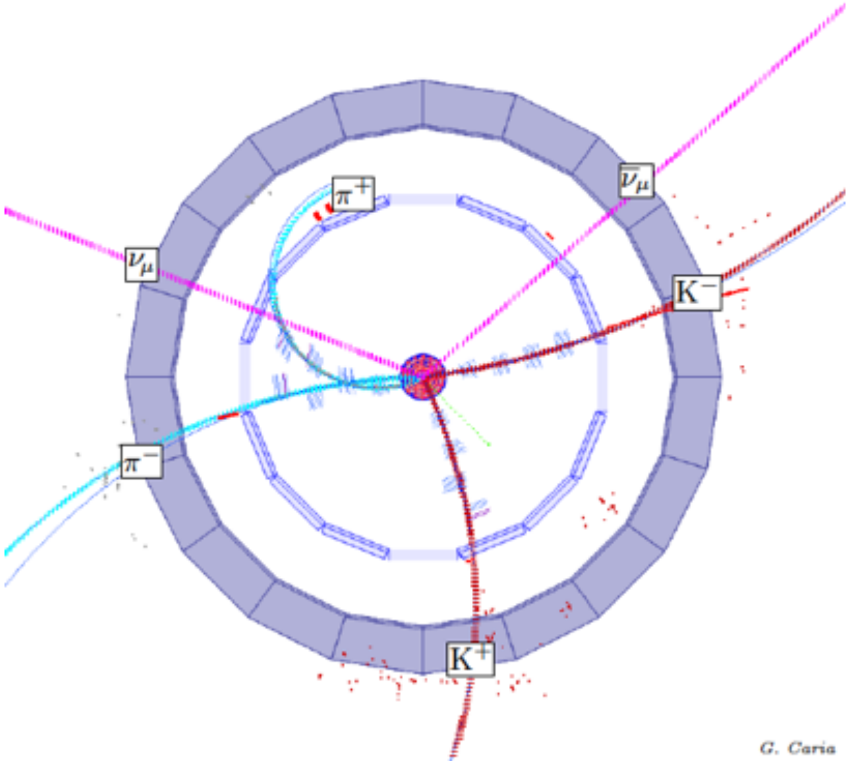
$B \to K^{(*)} \nu \bar{\nu}$ at *Belle II*

"Missing Energy Decay" in a Belle II GEANT4 MC simulation

Signal B→K ν ν tag B→Dπ; D→Kπ



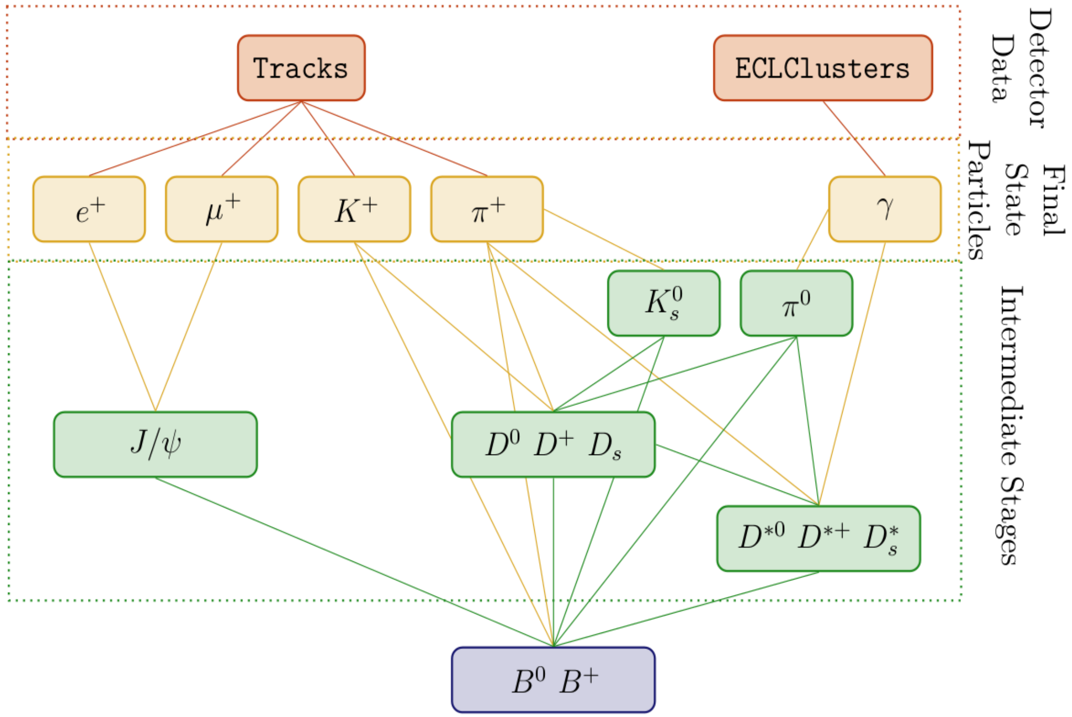
View in ***r-z***

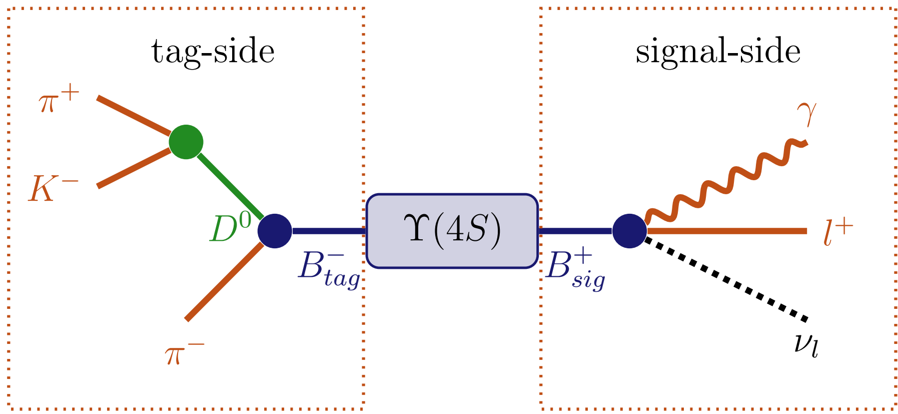


Zoomed view of the vertex region ***r-φ***

Full Event Interpretation (FEI)

- New signal specific training technique.
- Uses a multivariate technique to reconstruct the B-tag side through lots of decay modes in a Υ(4S).

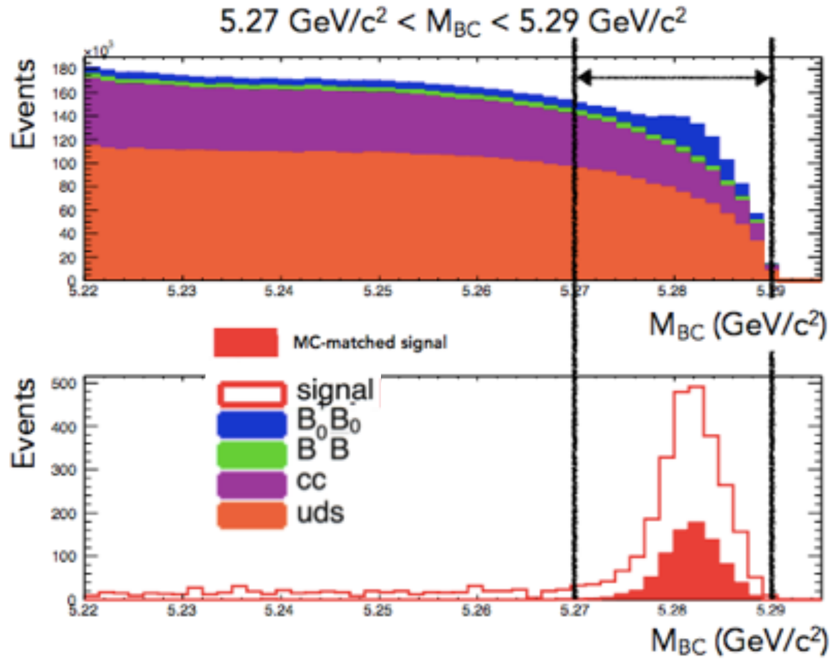




https://ekp-invenio.physik.uni-karlsruhe.de/record/48602/files/EKP-2015-00001.pdf

MC study at *Belle II*

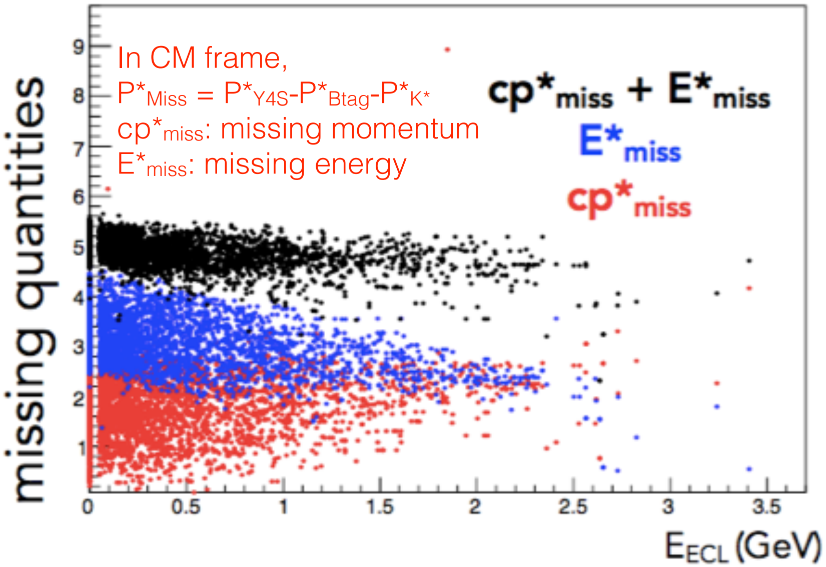
- 500 fb^{-1} $\Upsilon(4S)$ MC samples with beam background mixing.
- FEI used to reconstruct tag side B (hadronic)
- Signal and background extraction by a 2-D fit to extra neutral energy and missing quantities.



At 500 fb^{-1} :
$Br(B \to K^{*+} \nu \bar{\nu}) < 4.4 \times 10^{-4}$ at 90% C.L.

compatible with

BABAR 2008 result with 413 fb^{-1} :
$Br(B \to K^{*+} \nu \bar{\nu}) < 3.3 \times 10^{-4}$



$B \to K^{(*)} \nu \bar{\nu}$ at *Belle II*

- The Belle II sensitivity projection is based on the previous Belle measurement (hadronic tag) (***[PRD 87, 111103(R) 2013]***)
  - 50 ab^{-1} of $\Upsilon(4S)$ data.
  - The hadronic tag have 100% higher efficiency.
  - K_S^0 reconstruction has 30% higher efficiency.

Mode	$\mathcal{B}$ $[10^{-6}]$	Efficiency Belle $[10^{-4}]$	$N_{\text{Backg.}}$ 711 fb^{-1} Belle	$N_{\text{Sig-exp.}}$ 711 fb^{-1} Belle	$N_{\text{Backg.}}$ 50 ab^{-1} Belle II	$N_{\text{Sig-exp.}}$ 50 ab^{-1} Belle II	Statistical error 50 ab^{-1}	Total Error
$B^+ \to K^+ \nu\bar{\nu}$	4.68	5.68	21	3.5	2960	245	20%	22%
$B^0 \to K^0_S \nu\bar{\nu}$	2.17	0.84	4	0.24	560	22	94%	94%
$B^+ \to K^{*+} \nu\bar{\nu}$	10.22	1.47	7	2.2	985	158	21%	22%
$B^0 \to K^{*0} \nu\bar{\nu}$	9.48	1.44	5	2.0	704	143	20%	22%
$B \to K^{*} \nu\bar{\nu}$ combined							15%	17%

[BELLE2-MEMO-2016-007]

Summary

- *Belle II* has a rich physics program
  - possible to study the channels with missing energies and neutral particles in the final states.
- Electroweak penguin B decays are very sensitive to New Physics.
  - It is possible to access these decays both inclusively and exclusively at *Belle II*.
- Belle II will help to understand the deviations from SM in $B \rightarrow K^{(*)} l^{+} l^{-}$.
- $B \rightarrow K^{(*)} \nu\bar{\nu}$ could be probed at 5σ.

Extra

Summary of the Sensitivities

Observables	Belle 0.7 ab^{-1}	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
$B(B \to X_s\gamma)_{\text{incleptontag}}$	7.3%	–	3.9%
$B(B \to X_s\gamma)_{\text{sum-of-ex}}$	10.5%	–	5.7%
$A_{CP}(B \to X_{s+d}\gamma)_{\text{incleptontag}}$	4.0%	1.5%	0.61%
$\Delta A_{CP}(B \to X_s\gamma)_{\text{sum-of-ex}}$	3.1%	1.2%	0.37%
$\Delta A_{CP}(B \to X_s\gamma)_{\text{inchadtag}}$	14.5%	4.0%	1.2%
$B(B \to X_d\gamma)_{\text{sum-of-ex}}$	30%	20%	14%
$S_{CP}(B \to K^{*0}\gamma)$	0.29	0.09	0.030
$S_{CP}(B \to \rho^0\gamma)$	0.63	0.19	0.064
$B(B \to X_s\ell^+\ell^-)$ $(1 < q^2 < 6\ \text{GeV}^2)$	20%	10%	6.2%
$B(B \to X_s\ell^+\ell^-)$ $(q^2 > 14.4\ \text{GeV}^2)$	17%	8.0%	4.3%
R_{X_s} $(1 < q^2 < 6\ \text{GeV}^2)$	32%	12%	4.0%
R_{X_s} $(q^2 > 14.4\ \text{GeV}^2)$	28%	11%	3.4%
R_K $(1 < q^2 < 6\ \text{GeV}^2)$	28%	11%	3.6%
R_K $(q^2 > 14.4\ \text{GeV}^2)$	30%	12%	3.6%
R_{K^*} $(1 < q^2 < 6\ \text{GeV}^2)$	38%	15%	4.6%
R_{K^*} $(q^2 > 14.4\ \text{GeV}^2)$	24%	9.2%	3.4%
P_5' $(4 < q^2 < 8\ \text{GeV}^2)$	will be updated		
Q_5' $(4 < q^2 < 8\ \text{GeV}^2)$			
$B(B \to K\nu\bar{\nu})$	will be updated		
$B(B \to K^*\nu\bar{\nu})$			