

$b \rightarrow s/d \gamma$ at Belle/Belle II

Rahul Tiwary
On behalf of the Belle/Belle II Collaboration



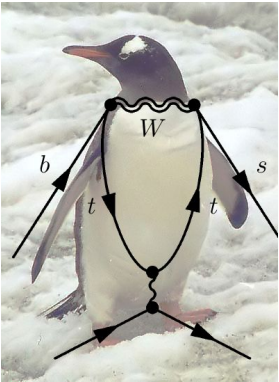
12th International Workshop on the CKM Unitarity Triangle,
September 18-22, 2023 Santiago de Compostela, Spain

Outline

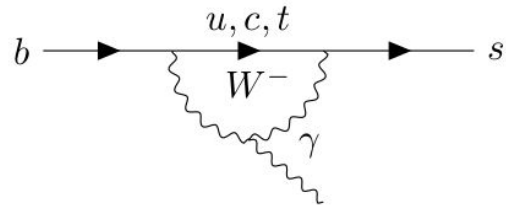
- Motivation
- Belle/Belle II overview and status
- Fully inclusive measurement of $B \rightarrow X s \gamma$ transition at Belle II
- Results for exclusive $B \rightarrow \rho \gamma$ study using Belle + Belle II data
- Summary

Motivation

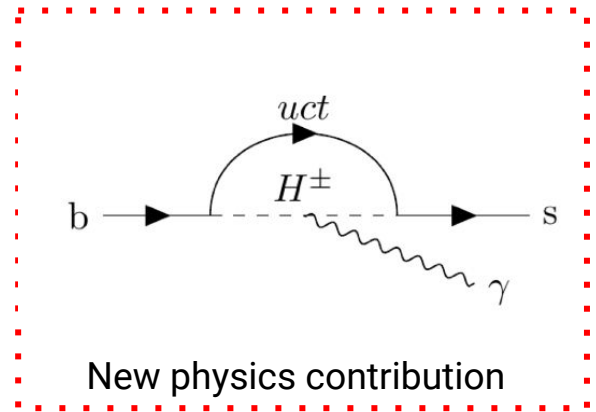
- FCNC transition $b \rightarrow s(d)$ is forbidden at tree level in the Standard Model and proceeds via electroweak loop diagrams.
- New physics effects can contribute in the loop or mediate the process at tree level.



Electroweak penguin



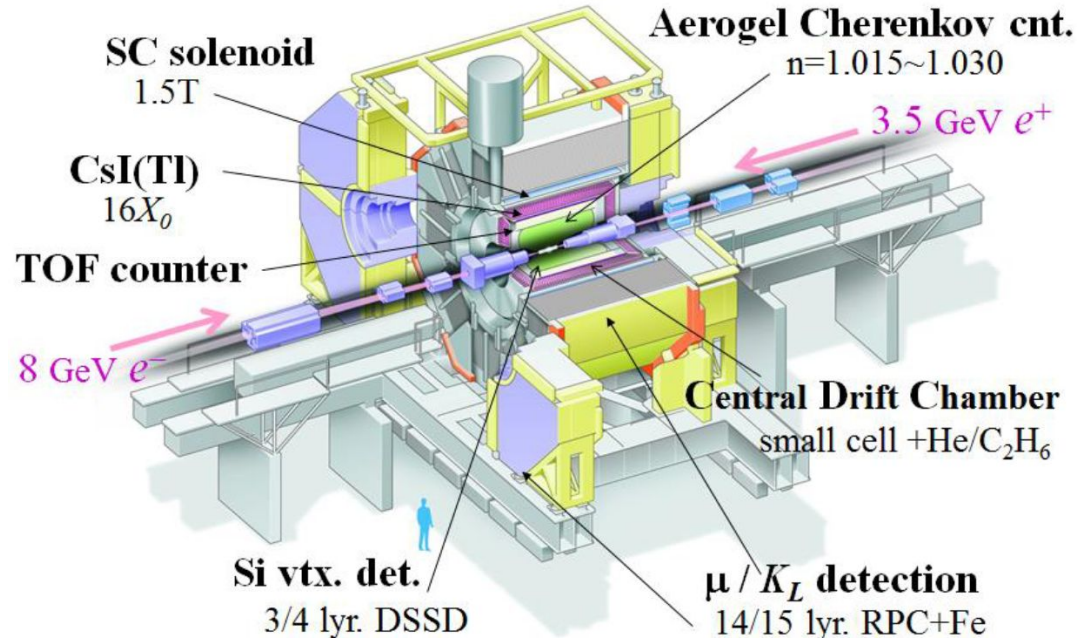
$b \rightarrow s\gamma$ loop



New physics contribution

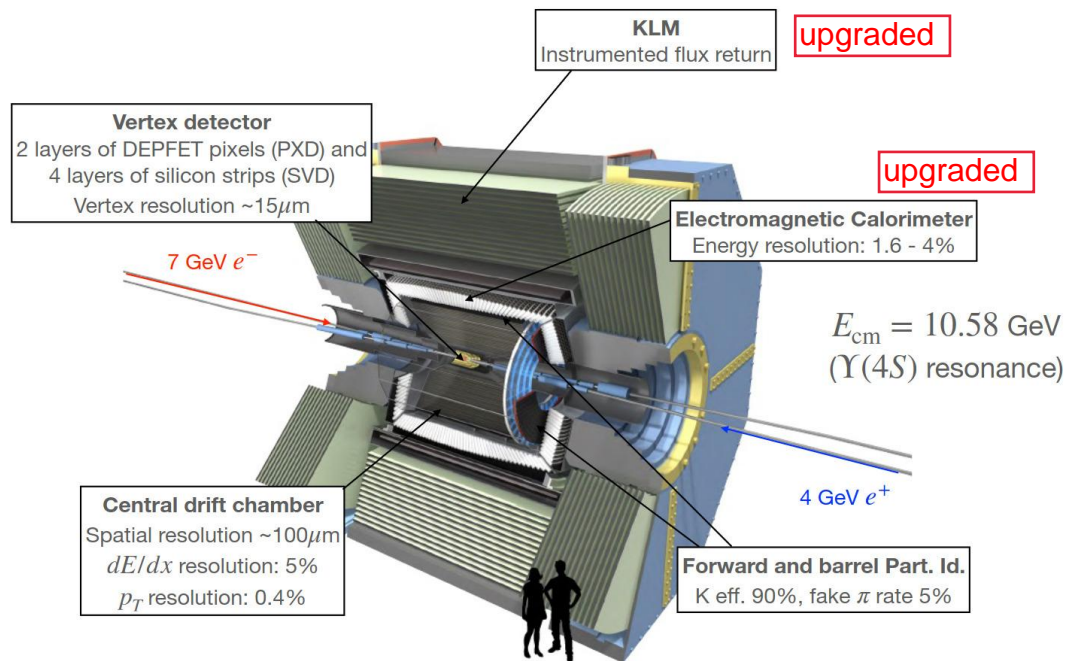
Belle

- SVD (3/4 layers) \Rightarrow Vertex Reco.
- ACC+TOF \Rightarrow Particle ID (K/π)
- ECL $\Rightarrow \gamma$ and e
- CDC \Rightarrow Tracking
- KLM \Rightarrow RPC



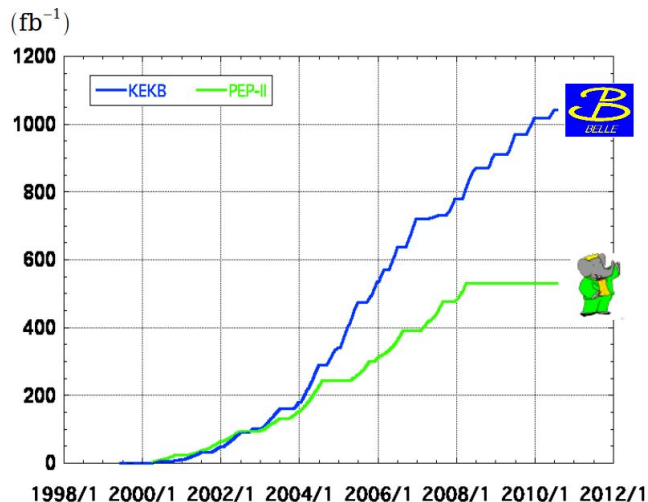
Belle/Belle II

- PXD (2 layers) + SVD (4 layers)
⇒ Vertex Reco.
- ARICH+TOP ⇒ Particle ID (K/π)
- ECL ⇒ With waveform sampling
readout electronics (γ and e)
- CDC ⇒ Small cell, long lever arm
- KLM ⇒ Scintillator + RPC



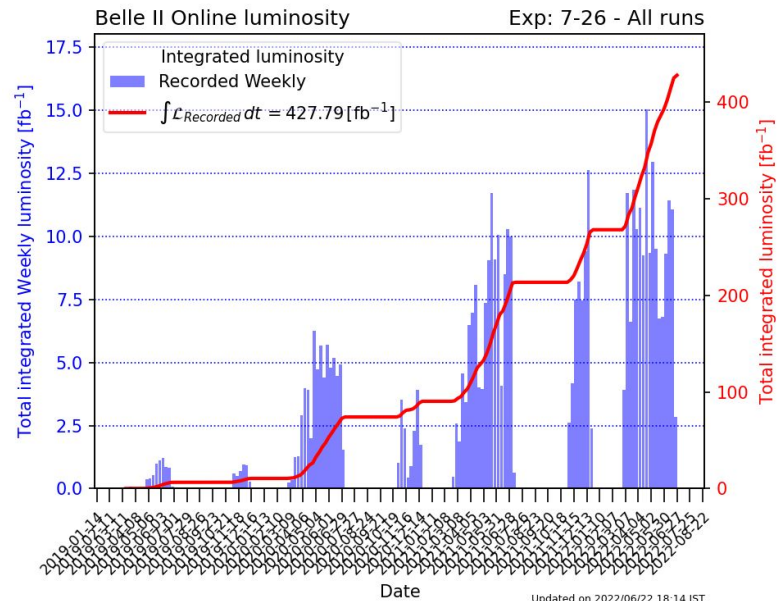
Belle/Belle II status

Integrated luminosity of B factories



> 1 ab⁻¹
On resonance:
 Y(5S): 121 fb⁻¹
 Y(4S): 711 fb⁻¹
 Y(3S): 3 fb⁻¹
 Y(2S): 25 fb⁻¹
 Y(1S): 6 fb⁻¹
Off reson./scan:
 ~ 100 fb⁻¹

~ 550 fb⁻¹
On resonance:
 Y(4S): 433 fb⁻¹
 Y(3S): 30 fb⁻¹
 Y(2S): 14 fb⁻¹
Off resonance:
 ~ 54 fb⁻¹

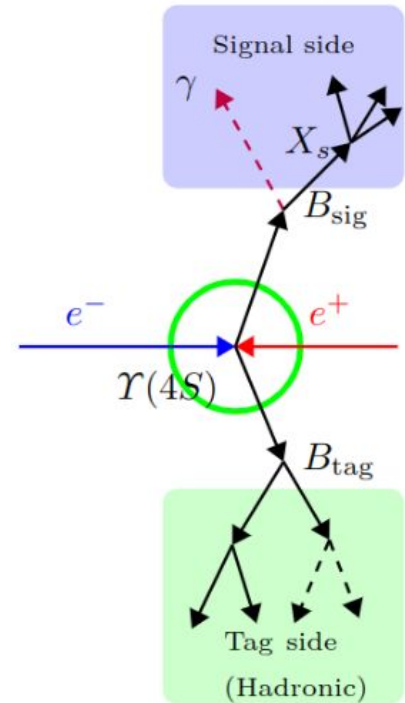


Belle II collected 362 fb⁻¹ at $\gamma(4S)$ – equivalent to BaBar and ~1/2 of Belle sample

Belle II collected 42 fb⁻¹ of off-resonance data [60 MeV below $\gamma(4S)$] compared to ~90 fb⁻¹ from Belle

Inclusive measurement of $\mathcal{B}(B \rightarrow X_s \gamma)$ at Belle II

- Fully inclusive measurement using hadronic tagging.
- Complementary to untagged and sum of exclusive measurements.
- SM parameters describe E_γ spectrum in decaying B rest frame:
 - $\rightarrow m_b$; Fermi motion of b [[Phys. Rev. L. 127, 102001](#)].
- The other side B meson is reconstructed in hadronic final states [[Comp.Sci.HEP.2019.3.6](#)]
 - Direct access to E_γ^B , photon energy in signal B meson rest frame
- Earlier hadronic tag study by BaBar [[Phys. Rev. D 77, 051103](#)].

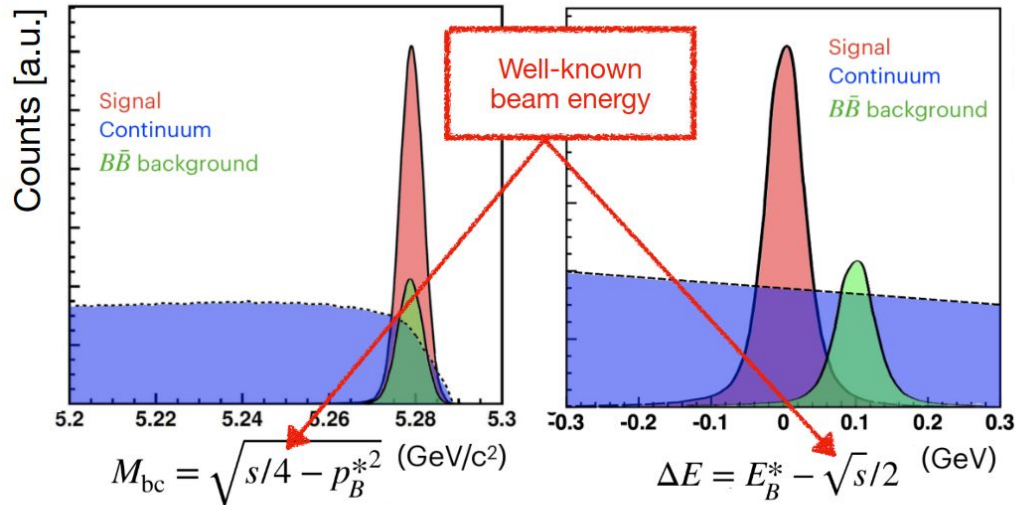


Inclusive measurement of $\mathcal{B}(B \rightarrow Xs\gamma)$ at Belle II

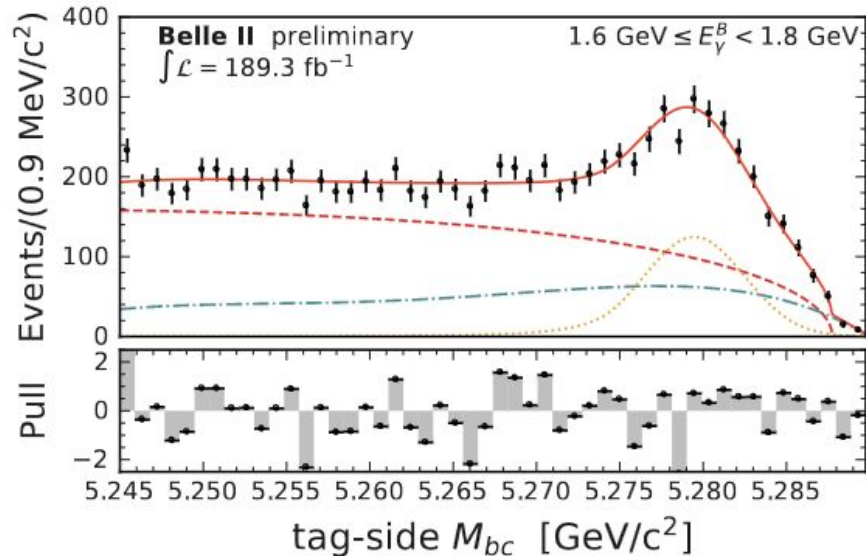
- **Signal Candidate:** Highest energy photon in event, $E_\gamma^B > 1.4$ GeV.
- **Background:**
 - Asymmetric decay of $\pi^0/\eta \rightarrow \gamma\gamma$
 - $e^+e^- \rightarrow q\bar{q}$ where $q \in (u, d, s, c)$ light-quark continuum events.
- Pair the signal side hard photon with low-energy photons in the event Veto events consistent to $\pi^0/\eta \rightarrow \gamma\gamma$ transitions using a dedicated multivariate analyser trained on kinematic feature variables such as helicity, $M_{\gamma\gamma}$ and variables related to the low-energy photon.
- Employed dedicated classifier to suppress $e^+e^- \rightarrow q\bar{q}$ events using event shape variables such as CLEO cones, thrust etc.

Inclusive measurement of $\mathcal{B}(B \rightarrow Xs\gamma)$ at Belle II

- **Signal Extraction:** Perform fit to $M_{bc} = \sqrt{(\sqrt{s}/2)^2 - p_B^{*2}}$ in bins of E_γ^B
- Subtract contribution from residual $e^+e^- \rightarrow q\bar{q}$ and combinatorial $B\bar{B}$
- Selections and fit validated on $1.4 < E_\gamma^B < 1.8$ GeV control region.
- Subtract correctly tagged non $B \rightarrow Xs\gamma$ background. (estimated from simulation)



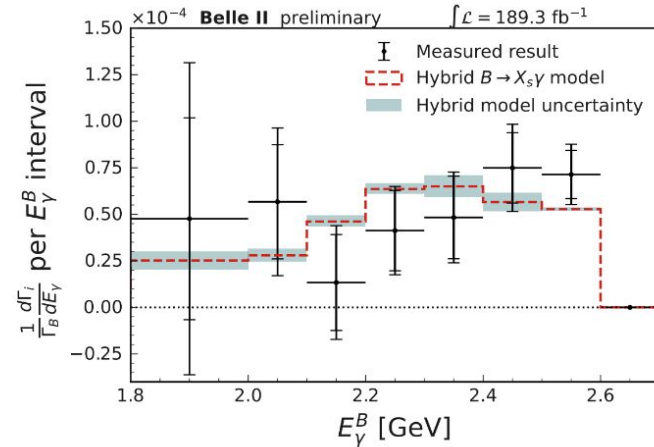
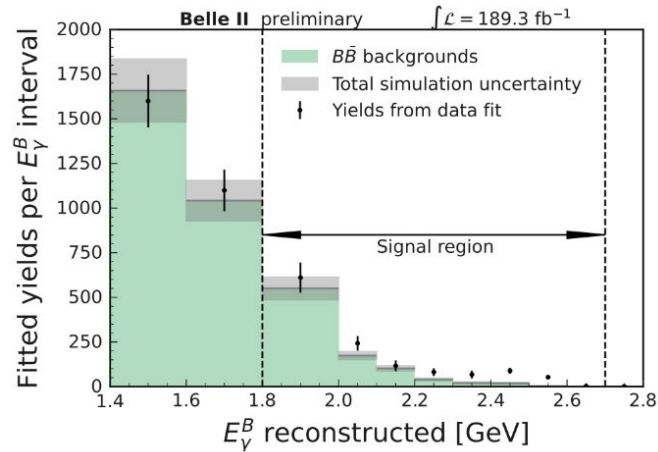
Inclusive measurement of $\mathcal{B}(B \rightarrow X_s \gamma)$ at Belle II



[arXiv:2210.10220](https://arxiv.org/abs/2210.10220) [hep-ex]

The orange dotted curve corresponds to the $B\bar{B}$ peaking tags. The dashed and dash-dotted curves correspond to the continuum and misreconstructed $B\bar{B}$ components, modelled by ARGUS and Chebyshev PDFs, respectively. The solid red curve corresponds to the total fit.

Inclusive measurement of $\mathcal{B}(B \rightarrow X_s \gamma)$ at Belle II



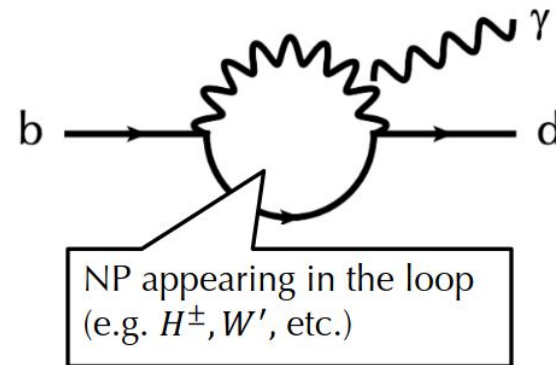
| E_γ^B threshold, GeV | Branching fraction (10^{-4}) |
|-----------------------------|--|
| 1.8 | 3.54 ± 0.78 (stat.) ± 0.83 (syst.) |
| 2.0 | 3.06 ± 0.56 (stat.) ± 0.47 (syst.) |

[arXiv:2210.10220](https://arxiv.org/abs/2210.10220) [hep-ex]

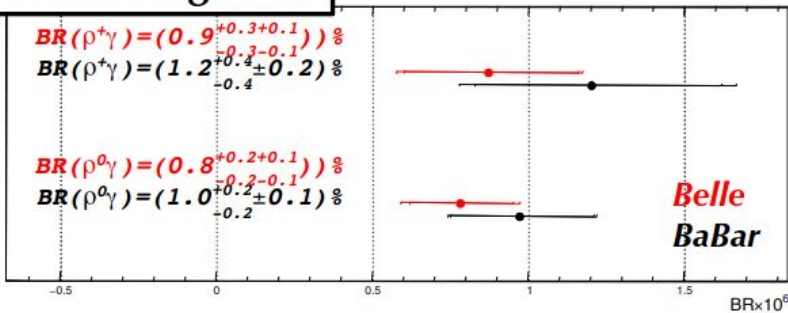
- Dominating systematic uncertainties related to data-simulation differences
- Consistent with world average (includes all tagging approaches): $(3.49 \pm 0.19) \times 10^{-4}$ [PDG]

Exclusive measurement of $B \rightarrow \rho \gamma$ at Belle and Belle II

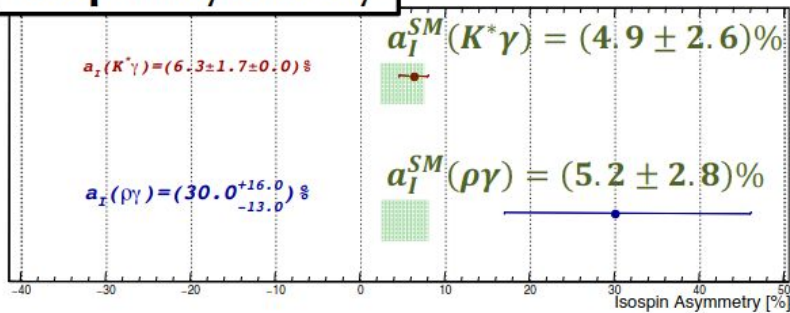
- Flavor changing neutral current with $b \rightarrow d$ transition
- Independent search for NP
- More challenging due to presence of $K^* \gamma$ background
- The first “charmless” study with Belle and Belle II joint data
- Earlier results from Belle [[Phys. Rev. Lett. 101, 111801](#)] and BaBar [[Phys. Rev. D 78, 112001](#)].



Branching ratio



Isospin asymmetry



Exclusive measurement of $B \rightarrow \rho \gamma$ at Belle and Belle II

- Select high energy photon candidate $1.8 < E_\gamma^B < 2.8$ GeV with shower shape consistent to an isolated photon.
- Reconstruct $\rho^0 \rightarrow \pi^+ \pi^-$ and $\rho^+ \rightarrow \pi^+ \pi^0$ for neutral and charged modes of B.
- Define $M_{K\pi}$ as the invariant mass calculated assuming π^+ is K^+
- The $M_{K\pi}$ helps separate $K^* \gamma$ background better compared to $M_{\pi\pi}$
- **Other backgrounds:**
 - Asymmetric decay of $\pi^0 / \eta \rightarrow \gamma \gamma$
 - $e^+ e^- \rightarrow q \bar{q}$ where $q \in (u, d, s, c)$ light-quark continuum events.
- The strategy to suppress background events is similar to the one used in $B \rightarrow X_s \gamma$

Exclusive measurement of $B \rightarrow \rho \gamma$ at Belle and Belle II

- $B^0 \rightarrow K^{*0} [K^+ \pi^-] \gamma$ taken as a control channel.
 - Calibrate the signal PDF modelling
 - Efficiency corrections due to application of multivariate analyzers.
- Simultaneous 3D fitting with $3 \times 2 = 6$ samples to determine target observables.
- $M_{bc}, \Delta E = E_B^* - \sqrt{s}/2$ and $M_{K\pi}$ for $(B^+, B^-, B^0) \times (\text{Belle, Belle II})$

– Floating parameters:

- $A_I \equiv \frac{rc_\rho^2 BR(B^0 \rightarrow \rho^0 \gamma) - BR(B^\pm \rightarrow \rho^\pm \gamma)}{rc_\rho^2 BR(B^0 \rightarrow \rho^0 \gamma) + BR(B^\pm \rightarrow \rho^\pm \gamma)}$, where $c_\rho = \sqrt{2}$ and $r \equiv \frac{f_{+-} \tau_{B^\pm}}{f_{00} \tau_{B^0}}$

- $A_{CP} \equiv \frac{BR(B^+ \rightarrow \rho^+ \gamma) - BR(B^- \rightarrow \rho^- \gamma)}{BR(B^+ \rightarrow \rho^+ \gamma) + BR(B^- \rightarrow \rho^- \gamma)}$

- $\mathbb{I} \equiv rc_\rho^2 BR(B^0 \rightarrow \rho^0 \gamma) + BR(B^\pm \rightarrow \rho^\pm \gamma)$

- $BR(B^\pm \rightarrow \rho^\pm \gamma) = \frac{\mathbb{I}}{2} (1 - A_I)$
- $BR(B^0 \rightarrow \rho^0 \gamma) = \frac{\mathbb{I}}{4r} (1 + A_I)$

Exclusive measurement of $B \rightarrow \rho \gamma$ at Belle and Belle II

- Most precise measurement of observables for $B \rightarrow \rho \gamma$ till date

Signal enriched region

$$M_{bc} > 5.27 \text{ GeV}/c^2$$

$$M_{K\pi} > 0.92 \text{ GeV}$$

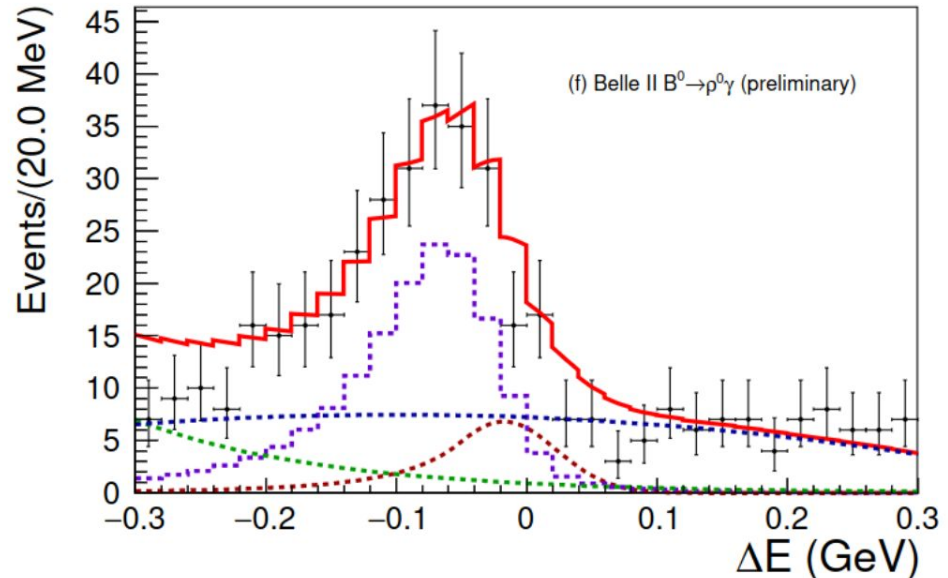
$$\mathcal{B}(B^+ \rightarrow \rho^+ \gamma) = (12.9_{-1.9}^{+2.0+1.3}) \times 10^{-7},$$

$$\mathcal{B}(B^0 \rightarrow \rho^0 \gamma) = (7.5_{-1.3}^{+1.3+1.0}) \times 10^{-7},$$

$$A_{CP}(B^+ \rightarrow \rho^+ \gamma) = (-8.4_{-15.3}^{+15.2+1.3}) \%,$$

$$A_I(B \rightarrow \rho \gamma) = (11.0_{-11.7}^{+11.2+7.1+3.8}) \%,$$

Uncertainty: stat. + sys. + f_+/f_{00} (for A_I)



The points with error bars are data, the solid red curve is the sum of signal and background PDFs, the dashed red curves are signal, the dotted blue curve is continuum background, the dashed yellow curve is $K^* \gamma$ background, and the dotted-dashed green curve shows other $B\bar{B}$ backgrounds.

Summary

- FCNC's are attractive to probe SM and physics beyond.
- Measured branching fraction of $B \rightarrow Xs\gamma$ decays using 189 fb-1 Belle II data
 - Competitive result with respect to previous experiments even with the limited data-sample size.
- World's most precise measurement of $B \rightarrow \rho\gamma$ decays using Belle (711 fb-1) and Belle II (362 fb-1) data.

