Recent Belle II results on radiative and electroweak penguin decays

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Search for New Physics in EWP and radiative decays

- Flavor-changing neutral current ***b*** $\rightarrow$ ***s*** **transitions forbidden at tree level** in the Standard Model: $\mathcal{B}_{\mathrm{SM}} \sim \mathcal{O}(10^{-7} - 10^{-4})$

- **Probes for New Physics** at much higher scales than direct searches:
  - FCNC (high energy contributions) treated as point-like, encoded in Wilson coefficients
  - Long-distance physics (low energy contributions) described by effective operators

$$H_{eff}^{b\to s} = \frac{G_F}{\sqrt{2}} \sum_i V_{ib} V_{is}^* C_i(\lambda) Q_i(\lambda)$$

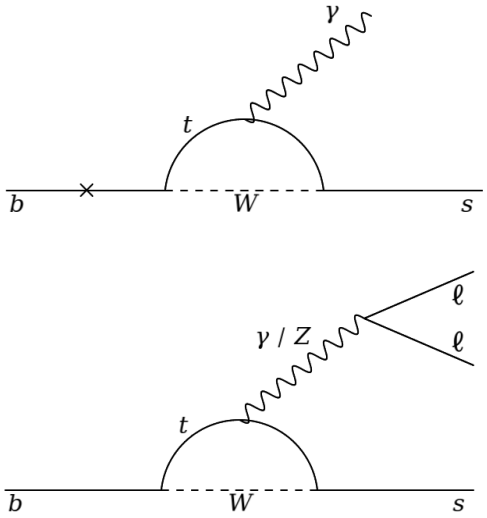
- New Physics can modify the Wilson coefficients or add new ones, thus **affecting branching ratios and angular distributions**

- Today: recent results on **radiative and electroweak penguins decays** at Belle II

  1) Fully inclusive $B \rightarrow X_s\, \gamma$

  2) $B \rightarrow J/\psi\, (l^+l^-)\, K$

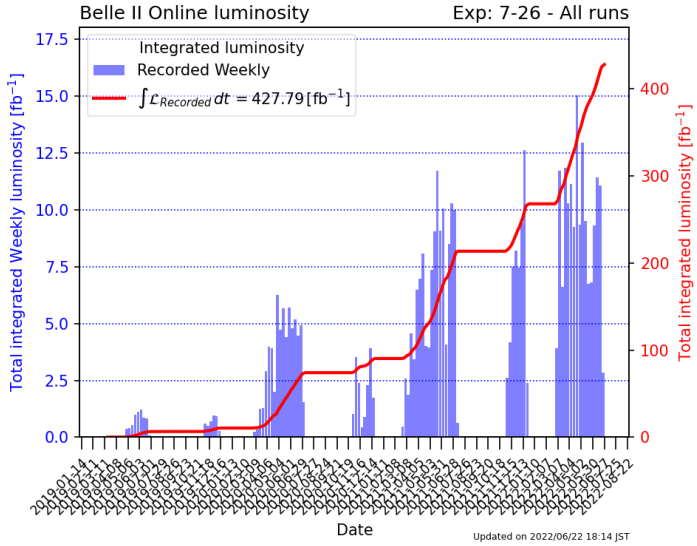
  3) $B \rightarrow K^*(892)\, l^+l^-$



Belle II at SuperKEKB [KEK Report 2010-1]

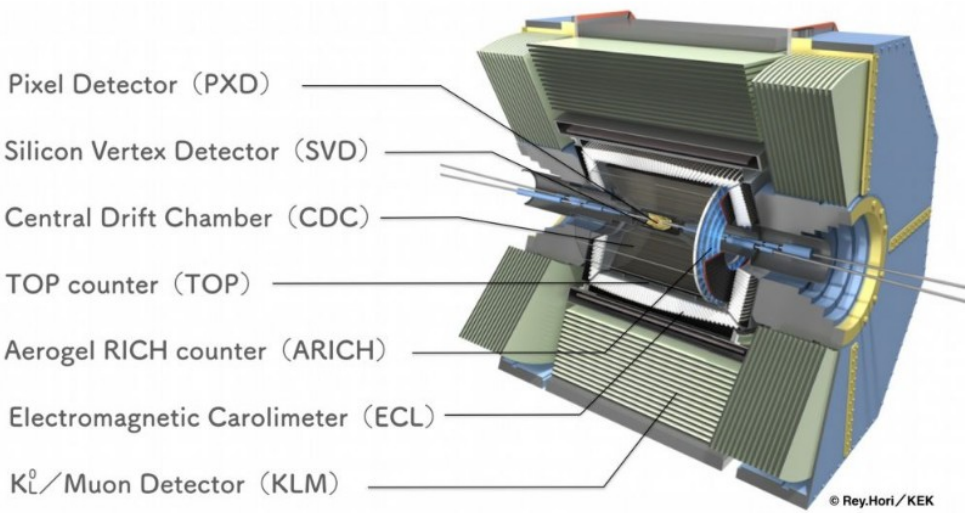
- **Multi-purpose detector @ SuperKEKB** accelerator
- Focus on *B*, charm and τ physics
- Asymmetric e^+ e^- collisions at center-of-mass energy of 10.58 GeV
  - $\sigma(e^+e^- \to \Upsilon(4S)) \sim 1$ nb
  - $\mathcal{B}(\Upsilon(4S) \to B\bar{B}) \sim 100\%$

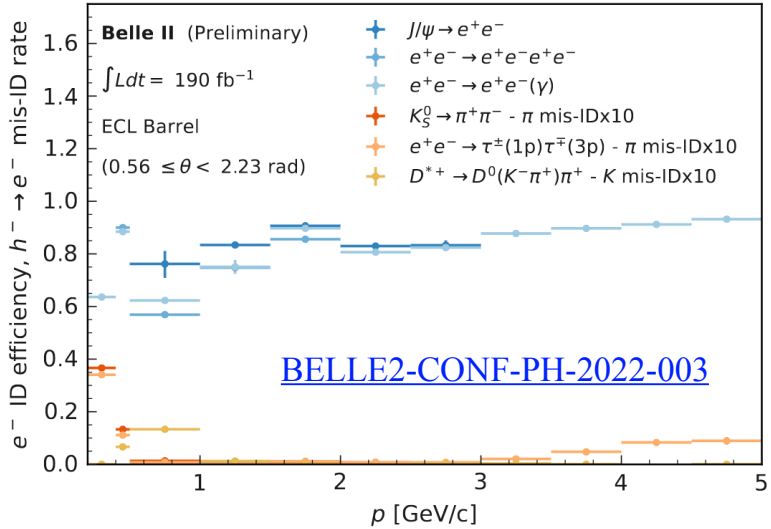
- **Collected ~ 428 fb^{-1}** (362 fb^{-1} at *Y*(4*S*) mass + 66 fb^{-1} below)
  - Today's results obtained with 189 fb^{-1}
  - Will collect 50 ab^{-1} at the end of operation
- Instantaneous luminosity world record: **4.7 x 10^{34} cm^{-2} s^{-1}** (June 2022)
  - Target instantaneous luminosity: 6 x 10^{35} cm^{-2} s^{-1}



The Belle II detector [KEK Report 2010-1]

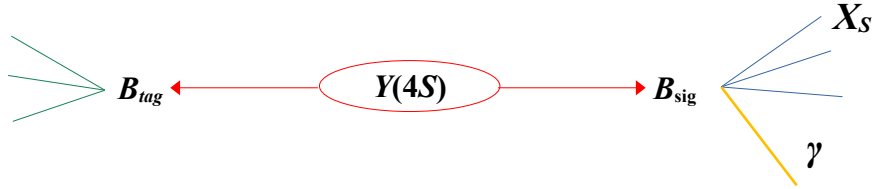
- While good with charged, suited also for measurements with **neutrals, missing energy and inclusive decays**
- ~ 4π coverage + knowledge of initial 4-momentum → Reconstruction of missing energy [Comput Softw Big Sci 3, 6 (2019)]
- High photon detection efficiency and good energy resolution (π^0 mass resolution ~ 5 MeV)
- Good and similar electrons and muons identification efficiency



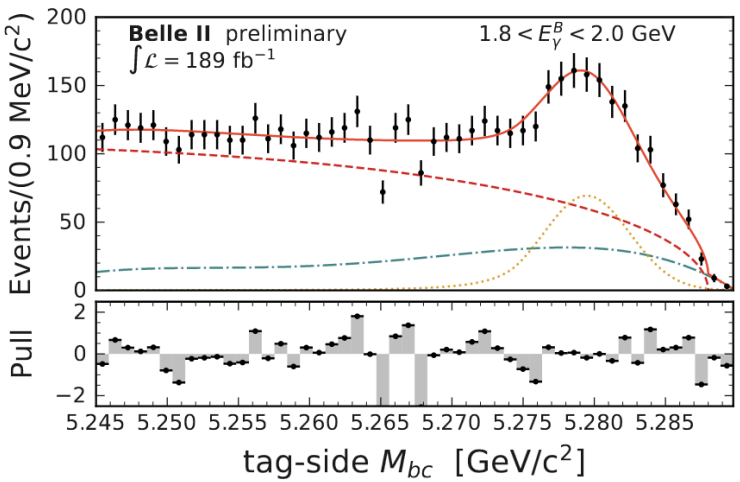


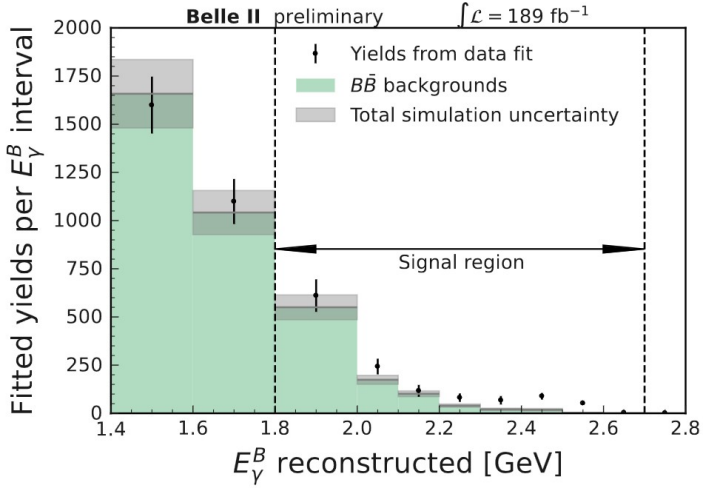
Fully inclusive $B \to X_s \gamma$ BELLE2-CONF-PH-2022-018

- Measurement of **inclusive $B \to X_s \gamma$ branching ratio in bins of photon energy** (E_γ^B)
- Hadronic tagging used to reconstruct the partner B in the event



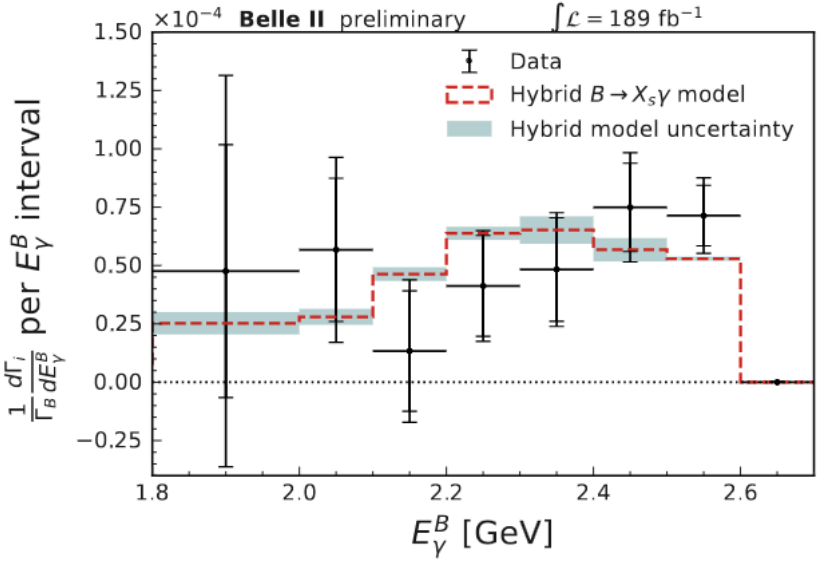
- Selection and fit strategy:
  - Hadronic **tag B candidate reconstructed and combined with highest energy photon** from the rest of the event
  - π^0, $\eta \to \gamma\gamma$ and $e^+e^- \to qq$ background suppressed with MVA techniques
  - **Simultaneous fit of tag-side M_{bc}** in bins of E_γ^B to extract number of B mesons in the dataset: $M_{bc} = \sqrt{(\sqrt{s}/2)^2 - p^*_{\mathrm{B_{tag}}}{}^2}$
  - Resulting B yield includes $B \to X_{s+d}\,\gamma$ events and other correctly tagged B decays → non-signal B subtracted using simulation





Fully inclusive $B \to X_s \gamma$ BELLE2-CONF-PH-2022-018

- Dominating systematic uncertainties coming from background modeling and fit assumptions:
  - Fit repeated by varying polynomial coefficient by their 1σ uncertainties, shift in signal yield assumed as uncertainty
  - Background uncertainties due to limited size of the simulation propagated to the final result



$$\mathcal{B}(B \to X_s\gamma) = (3.54 \pm 0.78(\text{stat.}) \pm 0.83(\text{syst.})) \cdot 10^{-4}$$

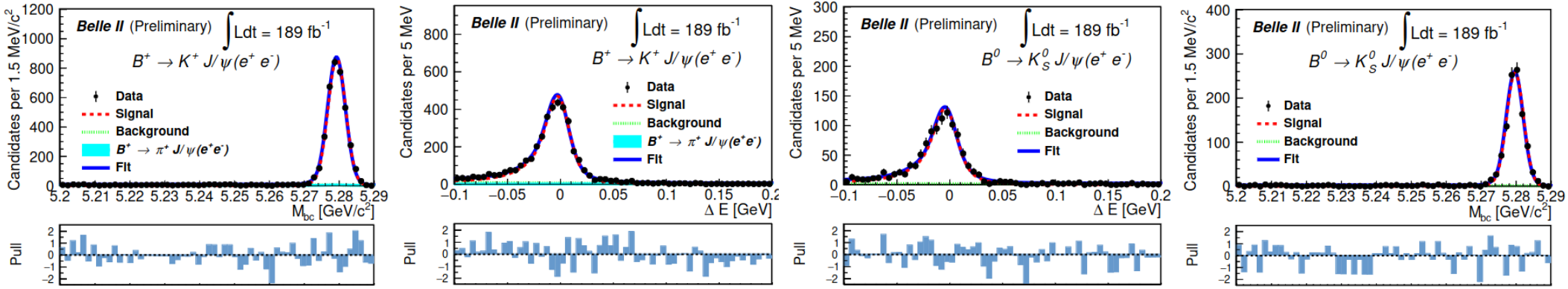
- **World average** $= (3.49 \pm 0.19) \cdot 10^{-4}$ Prog. Theor. Exp. Phys. 2022, 083C01

Measurements of $B \to J/\psi\,(l^+l^-)\,K$ arXiv:2207.11275

- Measurement of $B \to J/\psi\,(l^+l^-)\,K$ **branching fraction and isospin asymmetry, and** $R_K(J/\psi)$
  - Four channels: $B^+ \to J/\psi\,(l^+l^-)\,K^+$ and $B^0 \to J/\psi\,(l^+l^-)\,K^0_S$; $l = e, \mu$
- **Favored b → c transition**, control channel for suppressed b → s R_K ratio

$$R_K(J/\psi) = \frac{\mathcal{B}(B \to J/\psi(\mu^+\mu^-)K)}{\mathcal{B}(B \to J/\psi(e^+e^-)K)}$$

- Selection and fit strategy:
  - K^0_S and J/ψ candidates formed with oppositely charged tracks
  - J/ψ and K combined to form B candidates with $M_{bc} \in [5.20,\ 5.29]$ and $\Delta E = E^*_B - \sqrt{s}/2 \in [-0.1,\ 0.2]$
  - **Fit to M_{bc} and ΔE**: signal + background and $B^+ \to J/\psi\,\pi^+$ component for misidentified π (~90% K efficiency at ~5% π mis-ID)



Measurements of $B \to J/\psi\,(l^+l^-)\,K$ arXiv:2207.11275

- Main systematic uncertainty coming from $Y(4S)$ branching fraction to charged and neutral B pairs (2.6 %)
- Additional systematic uncertainty for K^0_S modes due to data-MC differences in K^0_S reconstruction efficiency (3 %)

$$\begin{aligned}
\mathcal{B}\left(B^+ \to J/\psi(e^+e^-)K^+\right) &= (6.00 \pm 0.10 \pm 0.19) \times 10^{-5} \\
\mathcal{B}\left(B^+ \to J/\psi(\mu^+\mu^-)K^+\right) &= (6.06 \pm 0.09 \pm 0.19) \times 10^{-5} \\
\mathcal{B}\left(B^0 \to J/\psi(e^+e^-)K^0_S\right) &= (2.67 \pm 0.08 \pm 0.12) \times 10^{-5} \\
\mathcal{B}\left(B^0 \to J/\psi(\mu^+\mu^-)K^0_S\right) &= (2.78 \pm 0.08 \pm 0.12) \times 10^{-5} \\
A_I\left(B \to J/\psi(e^+e^-)K\right) &= -0.022 \pm 0.016 \pm 0.030 \\
A_I\left(B \to J/\psi(\mu^+\mu^-)K\right) &= -0.006 \pm 0.015 \pm 0.030 \\
R_{K^+}\left(J/\psi\right) &= 1.009 \pm 0.022 \pm 0.008 \\
R_{K^0}\left(J/\psi\right) &= 1.042 \pm 0.042 \pm 0.008
\end{aligned}$$

- World averages:

$$\mathcal{B}(B^+ \to J/\psi K^+)_{\mathrm{WA}} = (10.20 \pm 0.19) \cdot 10^{-4}$$
$$\mathcal{B}(B^0 \to J/\psi K^0)_{\mathrm{WA}} = (8.91 \pm 0.21) \cdot 10^{-4}$$
$$\mathcal{B}(J/\psi \to e^+e^-)_{\mathrm{WA}} = (5.971 \pm 0.032)\%$$
$$\mathcal{B}(J/\psi \to \mu^+\mu^-)_{\mathrm{WA}} = (5.961 \pm 0.033)\%$$

Prog. Theor. Exp. Phys. 2022, 083C01

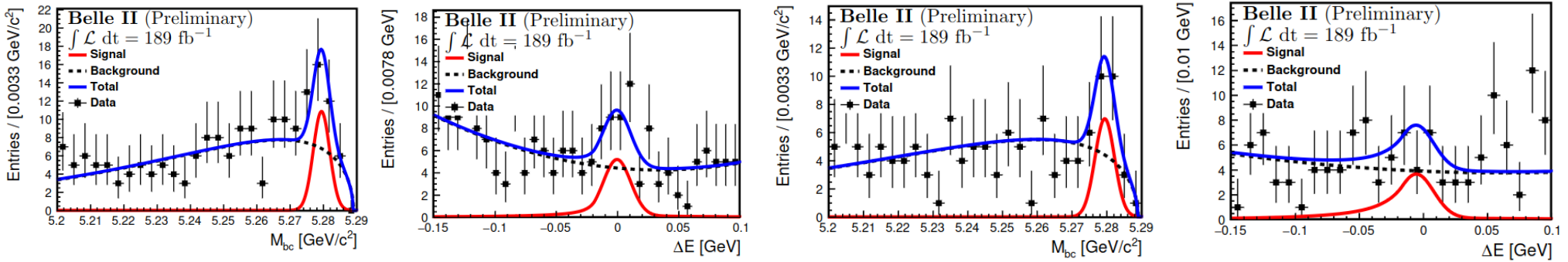
- Similar efficiencies for electron and muon modes: uncertainty on R_K equally contributed by the two flavor modes

Branching fraction of $B \to K^* l^+l^-$ BELLE2-CONF-PH-2022-009

- Measurement of $\boldsymbol{B \to K^* l^+l^-}$ **branching fraction** ($l = e, \mu$)
  - $B^+ \to K^{*+}(892)\, l^+l^-$ with $K^{*+} \to K^0_S\, \pi^+, K^+\, \pi^0$
  - $B^0 \to K^{*0}(892)\, l^+l^-$ with $K^{*0} \to K^+\, \pi^-$

- Selection and fit strategy:
  - K^0_S and π^0 candidates formed with pairs of oppositely charged tracks or photons
  - Veto di-lepton mass ranges corresponding to J/ψ and $\psi(2S)$ (and γ for electron channel only)
  - Remaining background suppressed with BDT
  - **Fit to M_{bc} and ΔE**, $B \to K^* J/\psi$ (l^+l^-) used as control channel to fix signal PDF parameters

$\boldsymbol{B \to K^* \mu^+\mu^-}$ $\qquad$ $\boldsymbol{B \to K^* e^+e^-}$



Branching fraction of $B \to K^* l^+ l^-$ BELLE2-CONF-PH-2022-009

- Main systematic uncertainties from total number of *BB* (2.9 %) and data-MC differences in π^0 reconstruction efficiency (3.4 %)

$$\mathcal{B}(B \to K^* \mu^+ \mu^-) = (1.19 \pm 0.31^{+0.08}_{-0.07}) \cdot 10^{-6}$$
$$\mathcal{B}(B \to K^* e^+ e^-) = (1.42 \pm 0.48 \pm 0.09) \cdot 10^{-6}$$

- World averages:

$$\mathcal{B}(B \to K^* \mu^+ \mu^-)_{\mathrm{WA}} = (1.06 \pm 0.09) \cdot 10^{-6}$$
$$\mathcal{B}(B \to K^* e^+ e^-)_{\mathrm{WA}} = (1.19 \pm 0.20) \cdot 10^{-6}$$

Prog. Theor. Exp. Phys. 2022, 083C01

- Similar performances between electron and muons
- Results precision limited by sample size
  - First result towards determination of R_{K^*}

Conclusions

- Recent results in the EWP and radiative sector at Belle II with 189 fb^{-1}:
  - Branching ratio of inclusive $B \to X_S \gamma$ decays
  - Branching ratio and isospin asymmetry of $B \to J/\psi\ (l^+l^-)\ K$, and $R_K(J/\psi)$ measurement
  - Branching ratio of $B \to K^*(892)\ l^+l^-$ decays

- Many more results shown during this conference (see e.g. Gaetano's talk)
- Twice the dataset already available, data-taking will restart by early 2024
- **Much more to come, stay tuned!**