Belle II status and prospects for studies of neutral currents

New Frontiers in Lepton Flavor | PISA

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on behalf of Belle II collaboration

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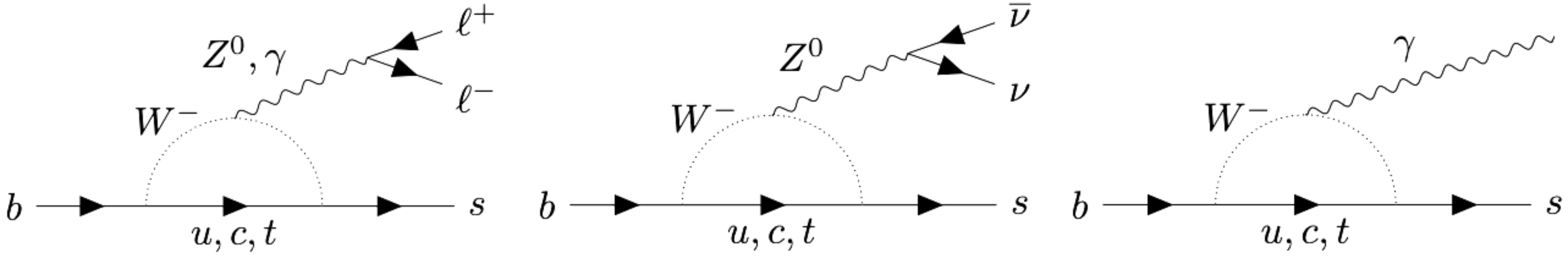
Neutral current interest

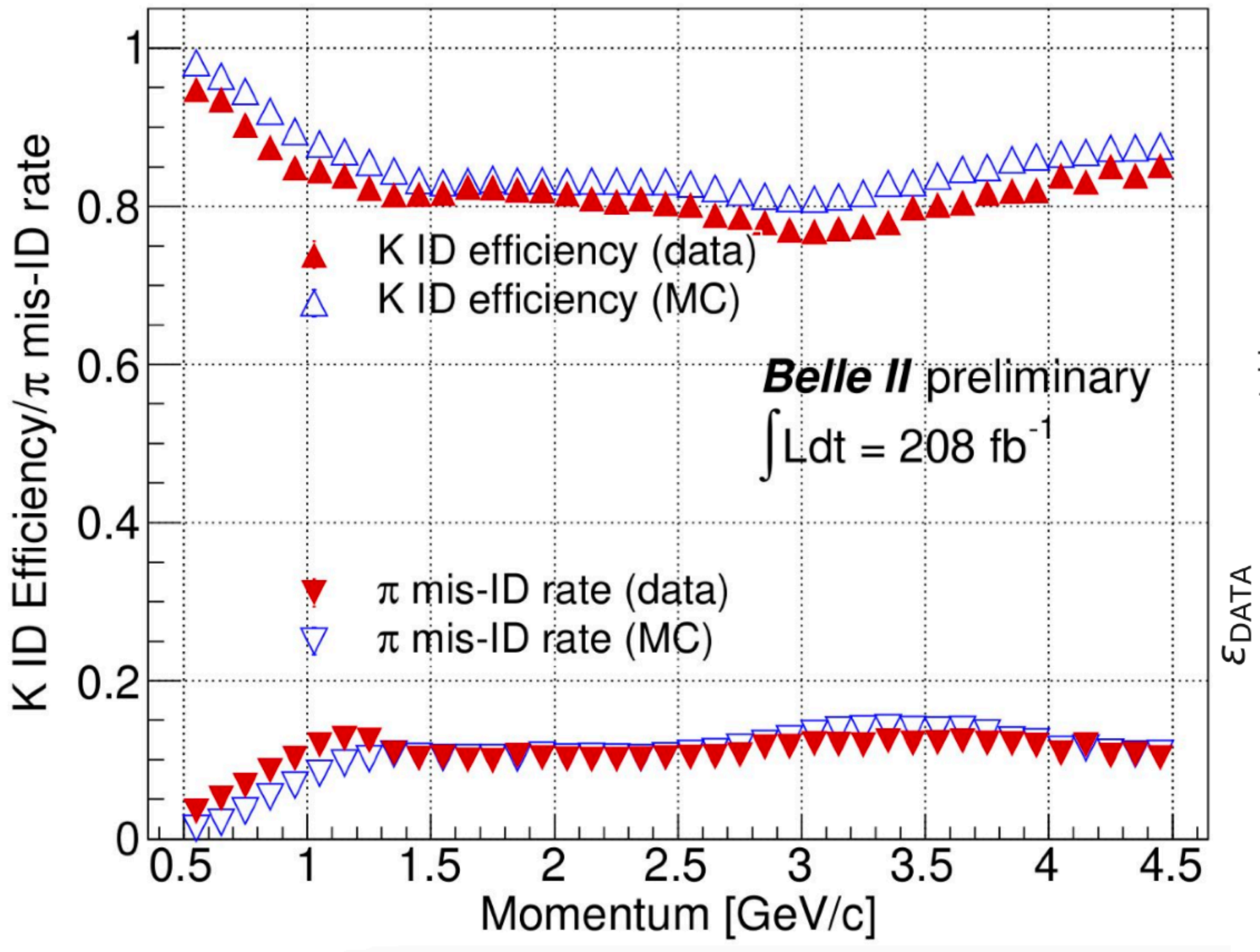
- $b \to s$ transitions are **FCNC** ⇒SM suppressed (forbidden at tree level) ⇒ sensitive to New Physics
- SM BR $\mathcal{O}(10^{-5} - 10^{-7})$ with 10-30% uncertainty
- **Ratios**, **asymmetries**, **angular distributions** can be used:
  - to improve precision
  - to access Beyond the Standard Model (BSM) coupling **properties**



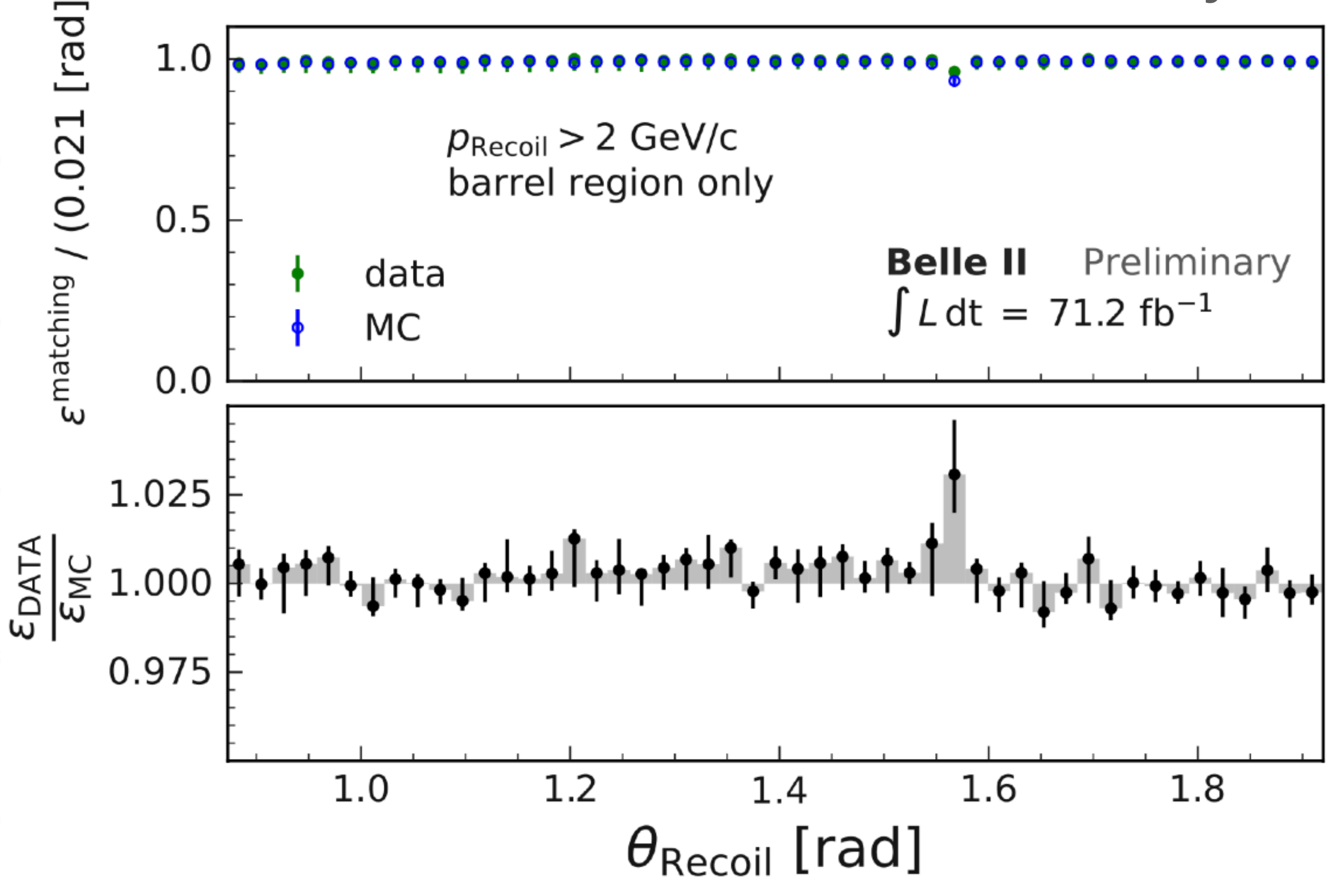
Belle II performance

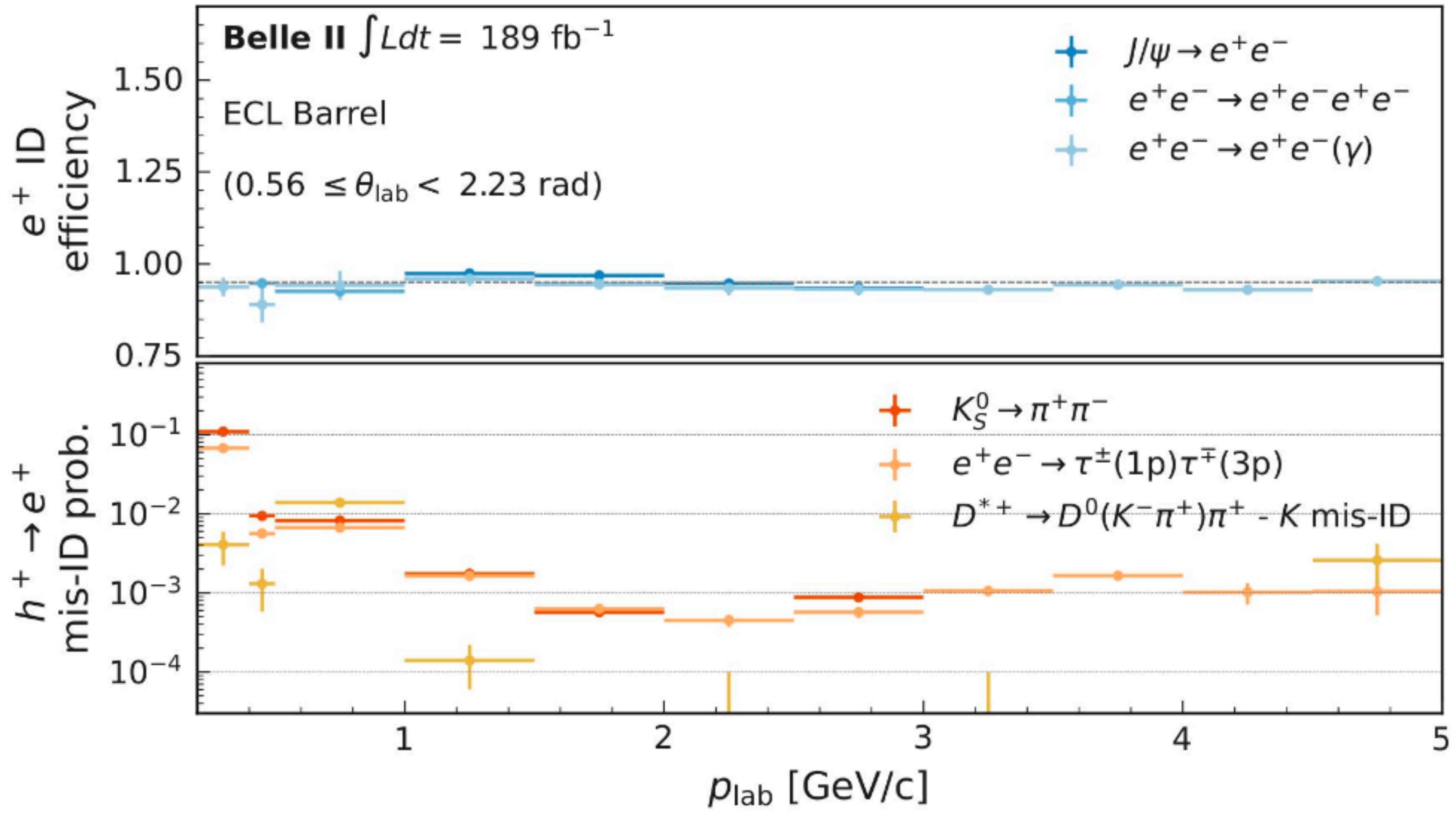
The key features in the $b \to s$ transition analysis are:

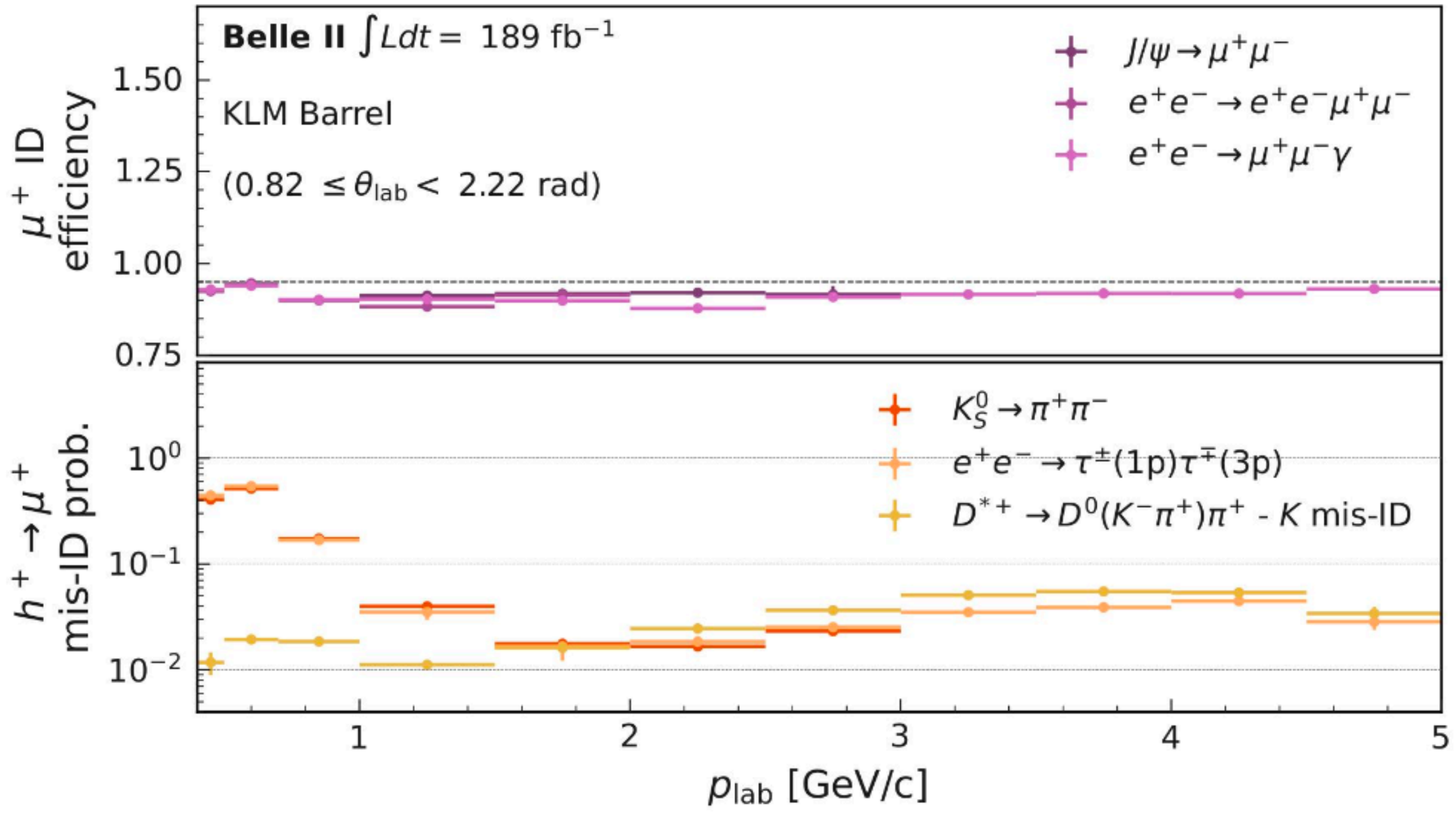
- High tracking and photon **efficiency** and low fake rate
- **Particle Identification** (e, μ, K)
- Momentum **resolution**



Photon detection efficiency



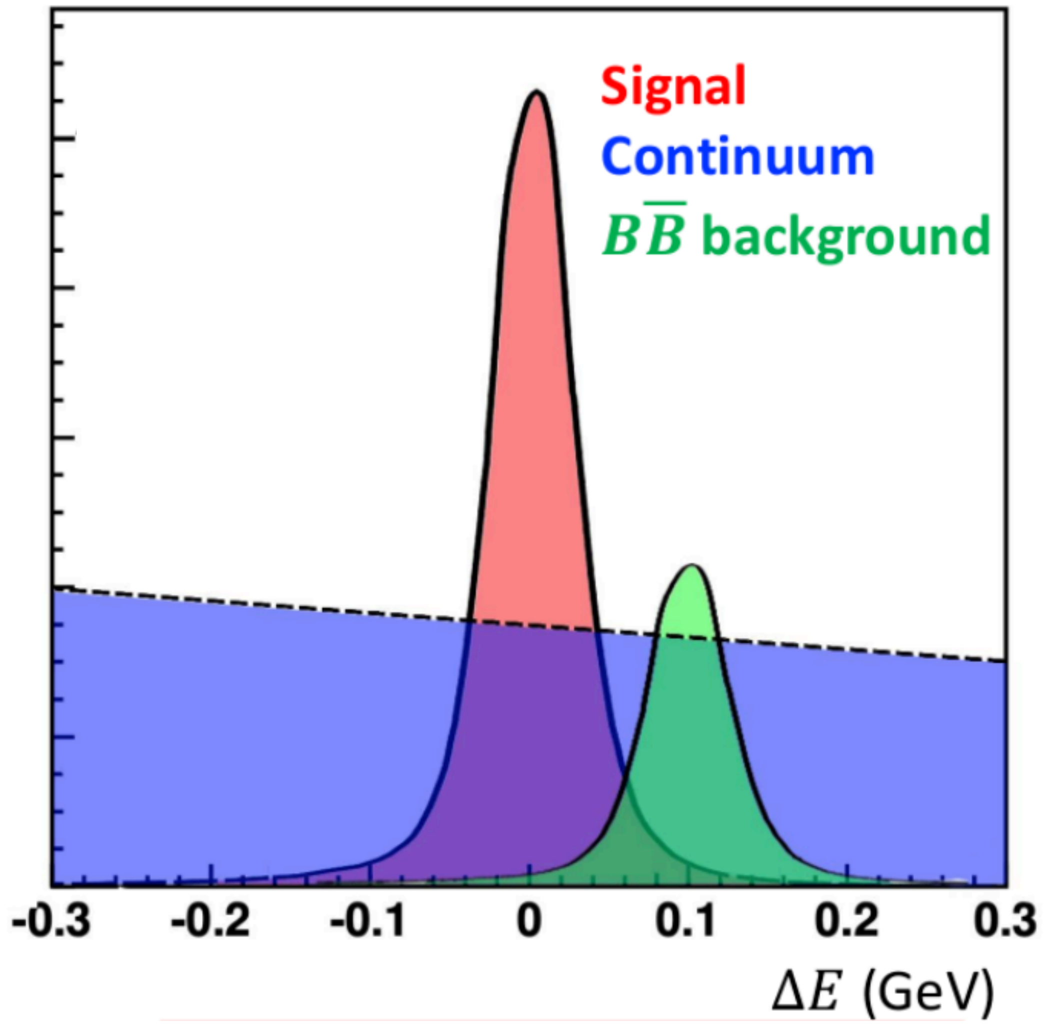




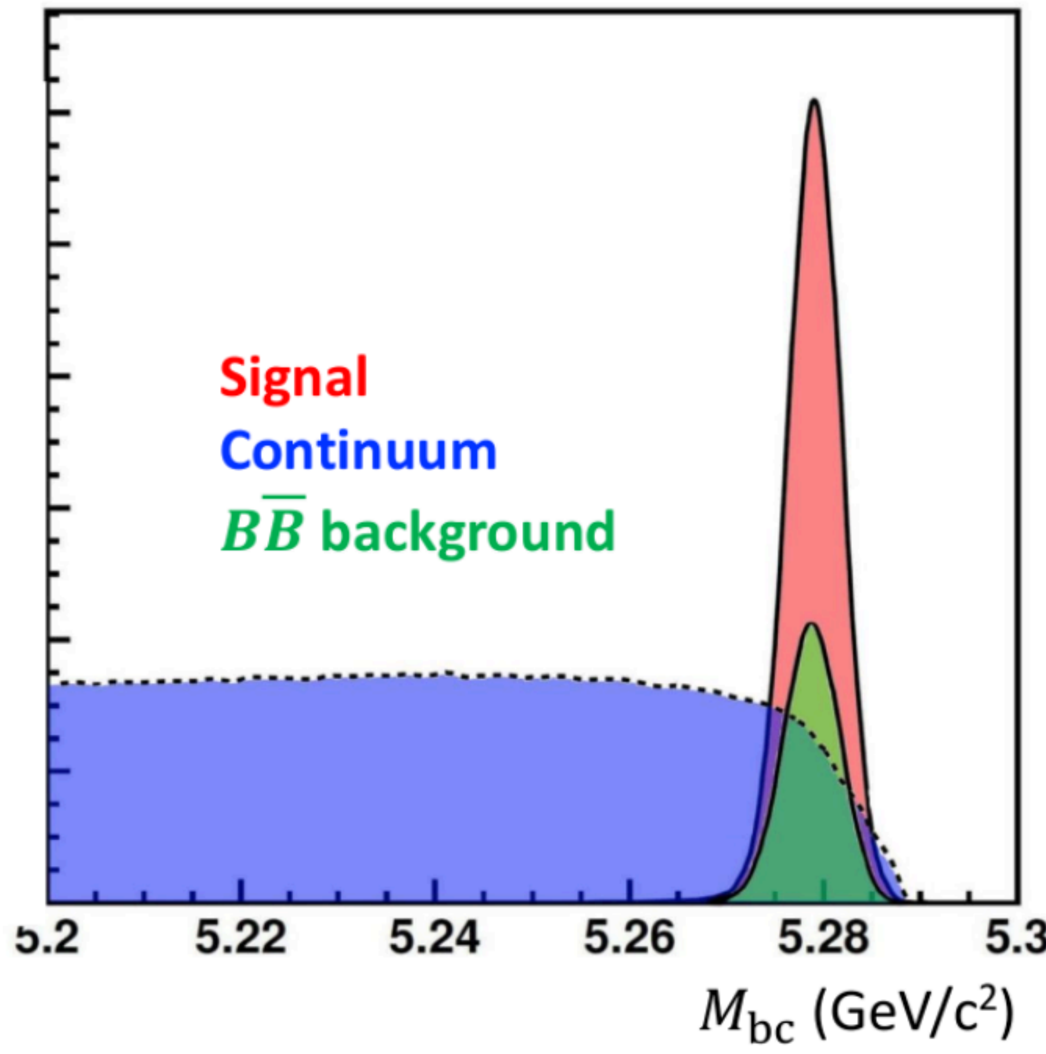
B-Factory basics

- $\sqrt{s} = m(\Upsilon(4S)) = 10.58\ \text{GeV} \simeq 2m_B \Rightarrow$ constrained kinematics
- Hermetic detector $\Rightarrow$ complete event reconstruction

$$\Delta E = E_B^* - \sqrt{s}/2 \qquad M_{bc} = \sqrt{(\sqrt{s}/2)^2 - \vec{p}_B^{*2}}$$



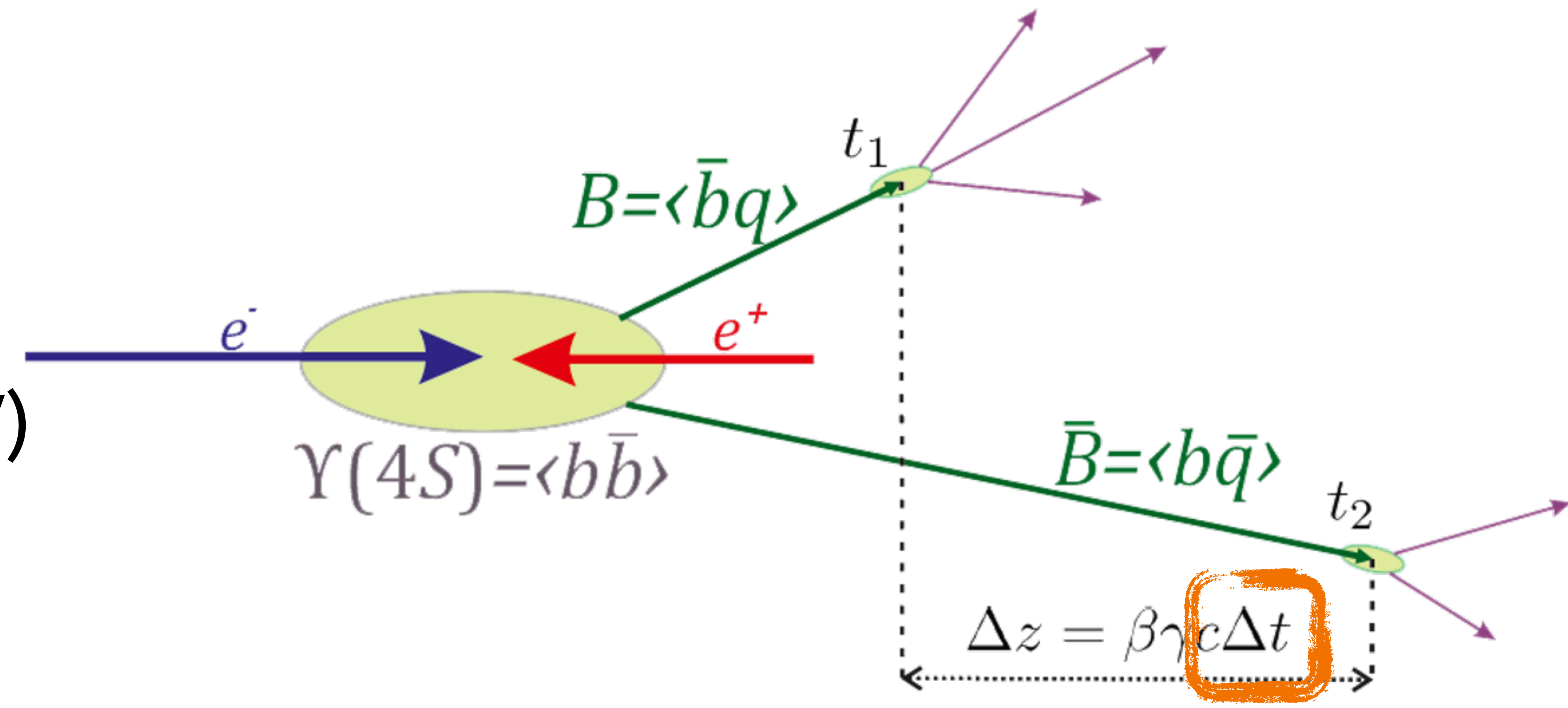
Expected $\Delta E \simeq 0$



Expected $M_{bc} \simeq m_B$

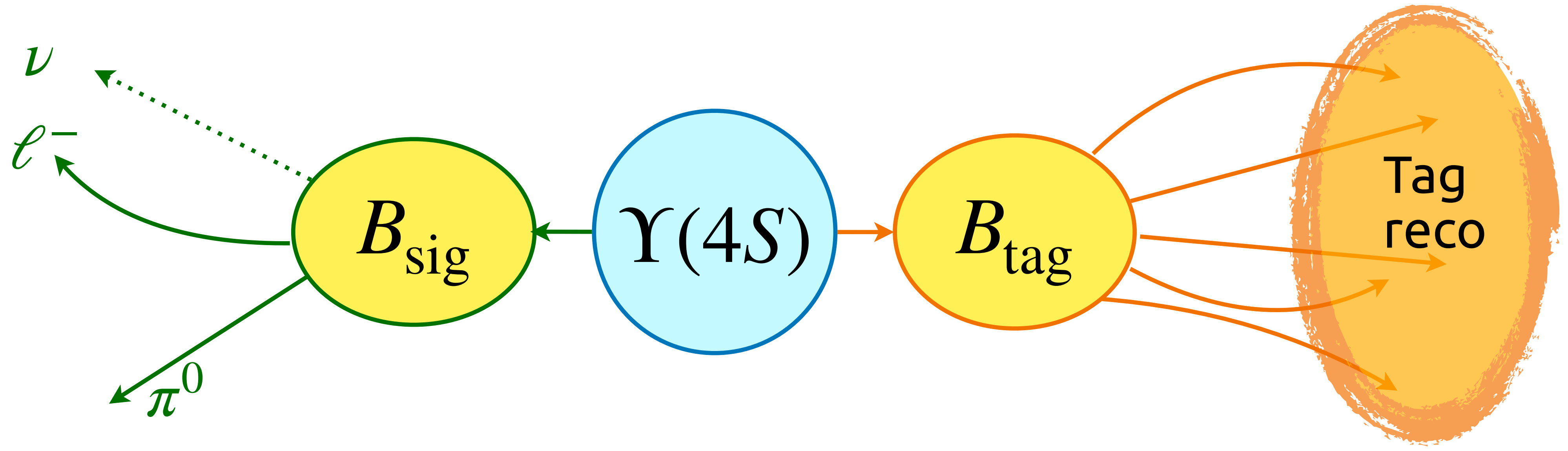
- Asymmetric collider $\Rightarrow$ Boost of center-of-mass
- Excellent vertexing performance ($\sigma \sim 15\ \mu\text{m}$)
- coherent $B\overline{B}$ pairs production
- Excellent flavour tagging performance

measurement of Δt for time dependent CP violation (TDCPV)



B-tagging for missing energy channels

In channels with **missing energy** $\Rightarrow$ use of the the **Rest of the Event (ROE)** information:



Step 1: Reconstruction of the partner B (B_{tag}) using **well-known channels**

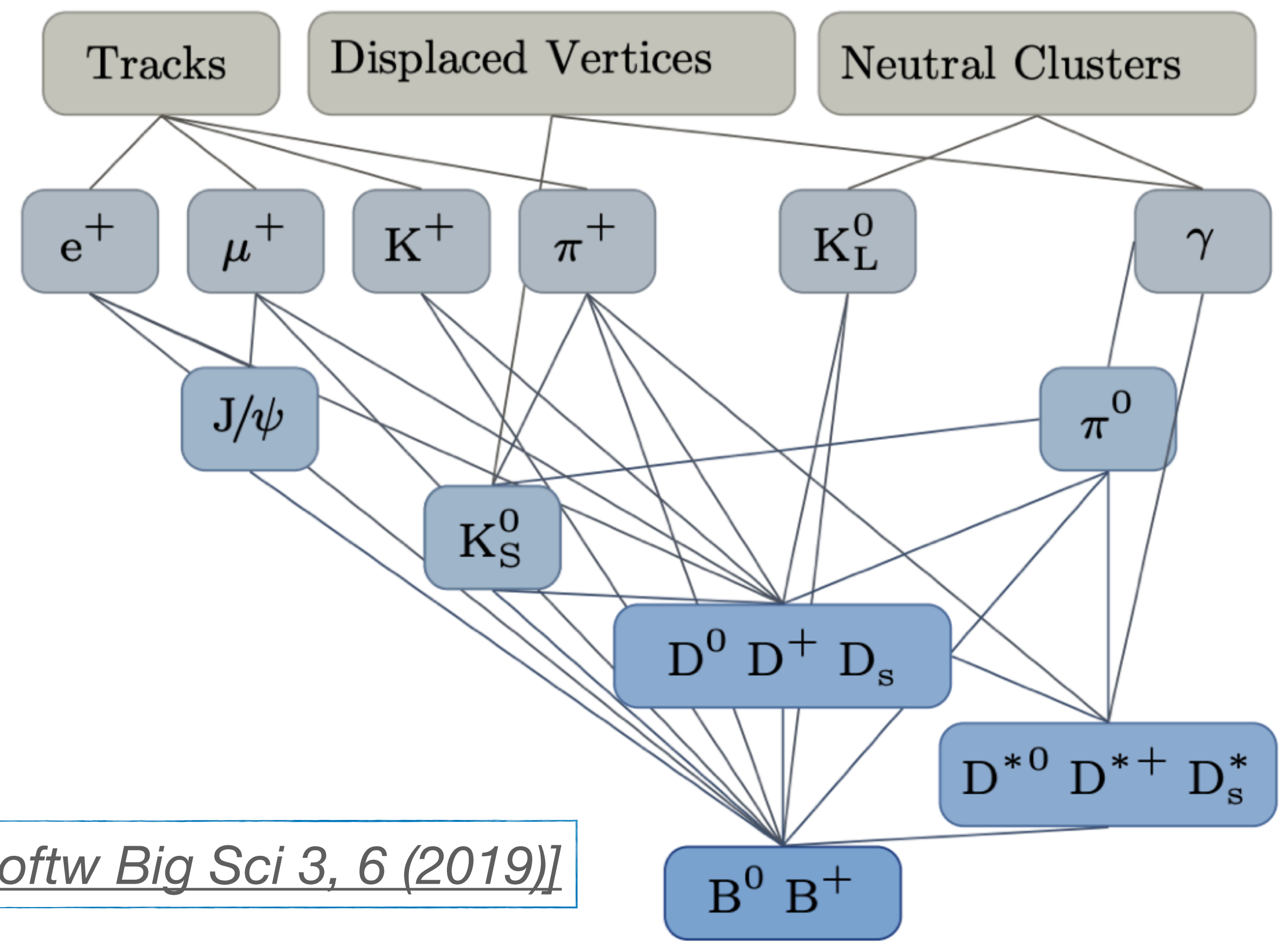
- **Hadronic tagging:** lower efficiency, but full tag reconstruction
- **Semileptonic Tagging:** higher efficiency, but lower purity

Step 2: Using the $\Upsilon(4S)$ constraint, infer the information on the second B (B_{sig}): **flavour**, **charge** and **kinematic** constraints

- **Inclusive Tagging:** signal reconstruction first, and then use of the ROE+$\Upsilon(4S)$ constraint to add information to the signal

Full Event Interpretation (FEI)

- MVA based B-tagging algorithm
- hierarchical approach to reconstruct $\mathcal{O}(10^4)$ decay chains
- $\varepsilon_{\mathbf{had}} \simeq \mathbf{0.5\,\%}$, $\varepsilon_{\mathbf{SL}} \simeq \mathbf{2\,\%}$



[T. Keck et al, Comput Softw Big Sci 3, 6 (2019)]

Neutral current opportunity

- Belle II has similar (and good!) performance **both in electron and muons**
  - Opportunity to **LFU test** and **LFV searches** (eg. $R_{K^{(*)}}$, $B \to K\ell\ell'$)
- Some of the channels in Belle II will become **competitive with few ab**$^{-1}$, so now Belle II is statistically limited ($\mathscr{L}_{\mathrm{int}}^{\mathrm{Belle\ II}} = 362$ fb^{-1} at $\Upsilon(4s)$)
- However, several unique opportunities in Belle II (**radiative**, multiple **neutrinos**) given:
  - Almost full hermetic detector
  - $\Upsilon(4S)$ constraint
  - Relatively low combinatorial background

Analyses outline

This talk will cover:

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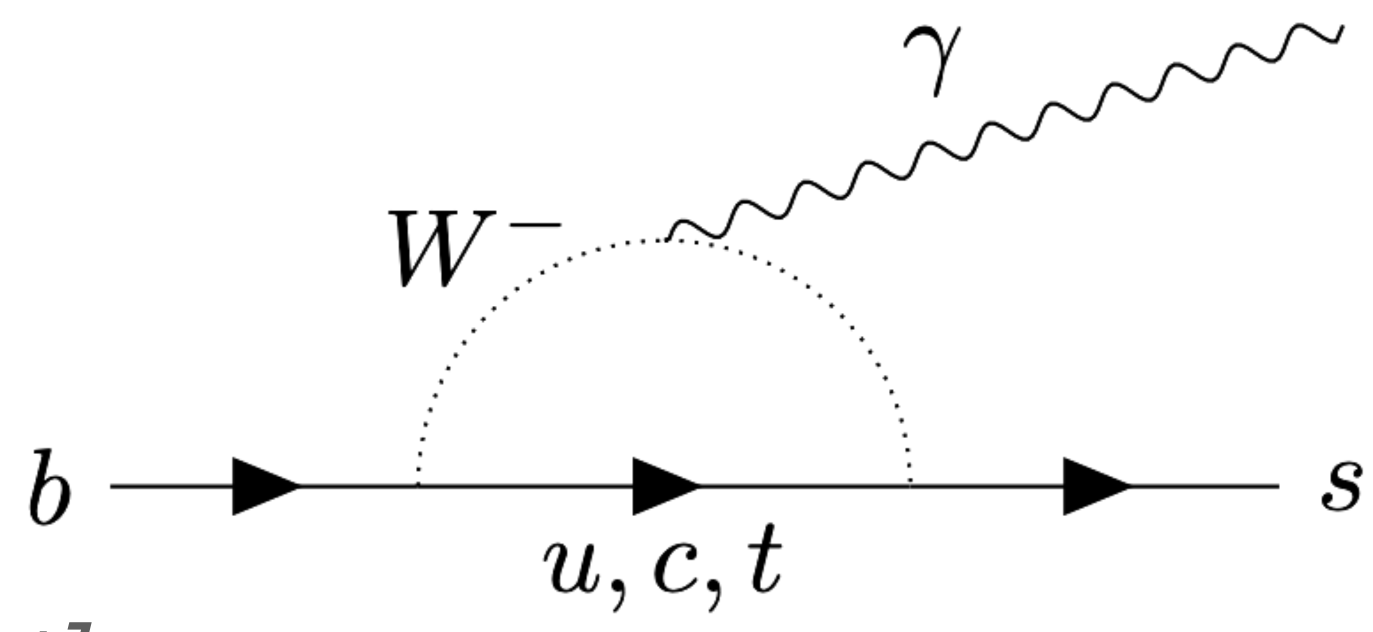
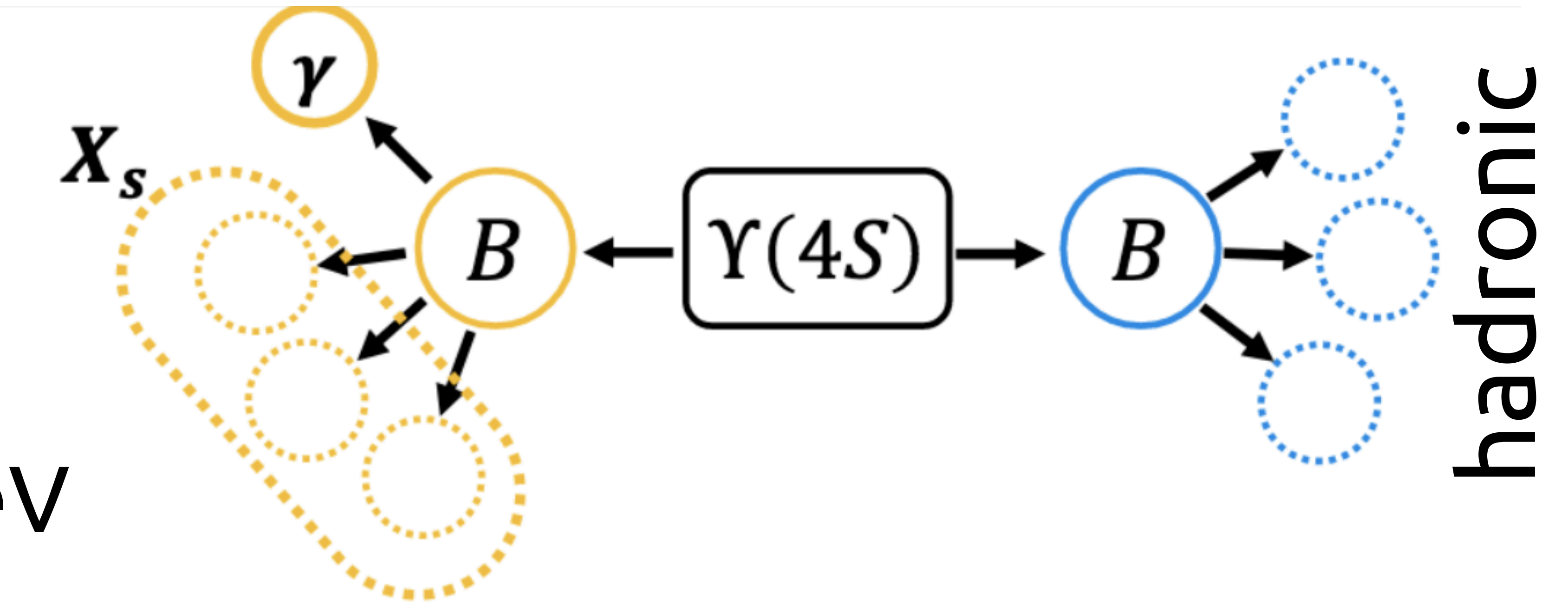
Fully inclusive $B \to X_s\gamma$

[arXiv:2210.10220] $189\ \mathrm{fb}^{-1}$

- Motivation:
  - $b \to s$ **radiative FCNC transition,** BR large ($\mathcal{O}(10^{-4})$)
  - Precise SM predictions (5% uncertainty) [JHEP, 06 (2020),175]
  - allow to give input for $|V_{ub}|$ and b-quark mass [PRL, 127 (2021), 102001]
  - Inclusive measurement: no theory uncertainty from form-factors



- Reconstruction:
  - **Hadronic B tagging**
  - Select the γ with highest energy in the signal side, with $E_\gamma > 1.4$ GeV



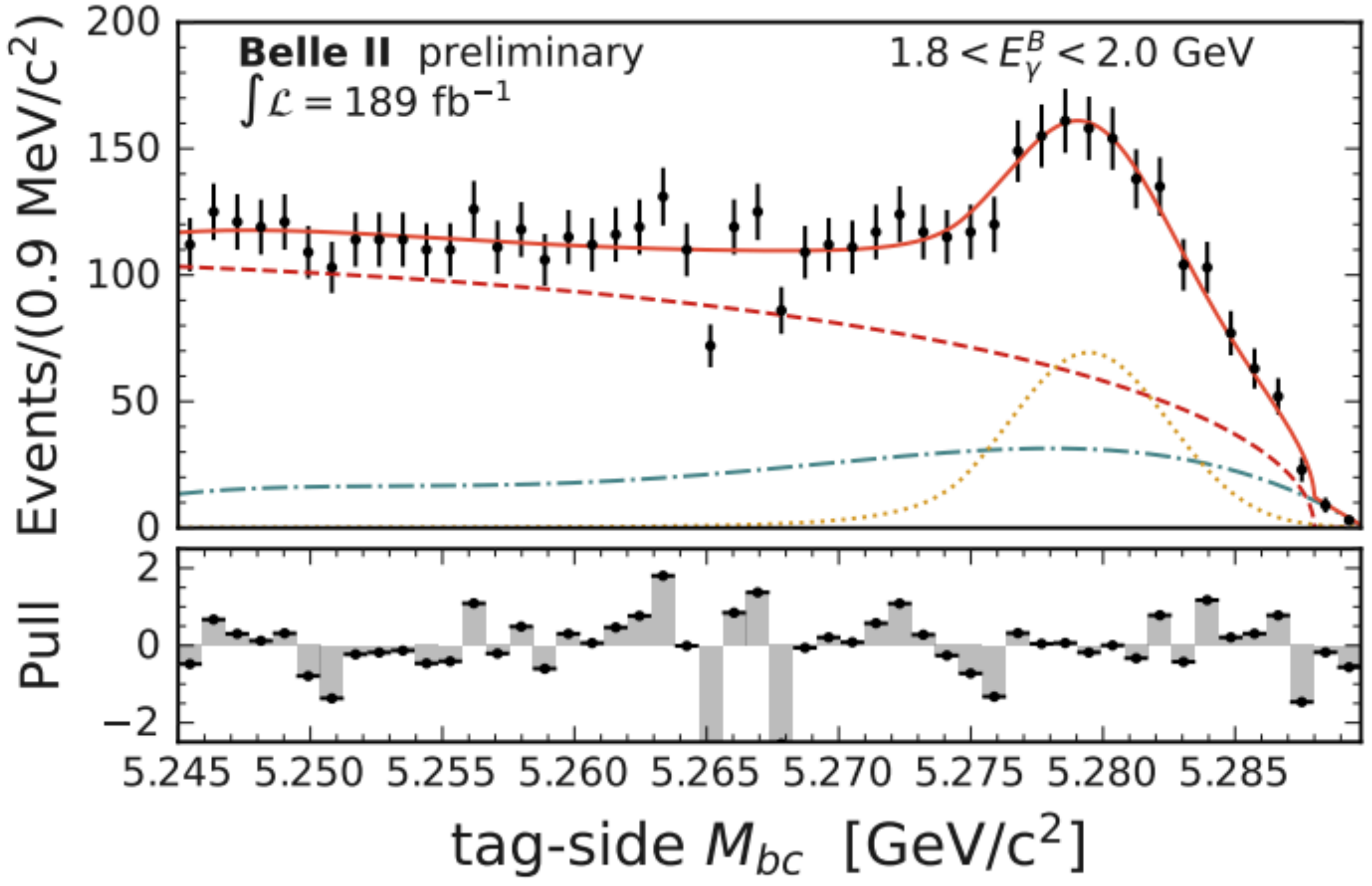
- **Background suppression:** main challenge of the analysis
  - MVA to veto photons consistent with $\pi^0 \to \gamma\gamma$ and $\eta \to \gamma\gamma$ decays
  - BDT for $e^+e^- \to q\bar{q}$ bkg with features not correlated with E_γ and M_{bc}

Fully inclusive $B \to X_s\gamma$

[arXiv:2210.10220]

$189\ \text{fb}^{-1}$

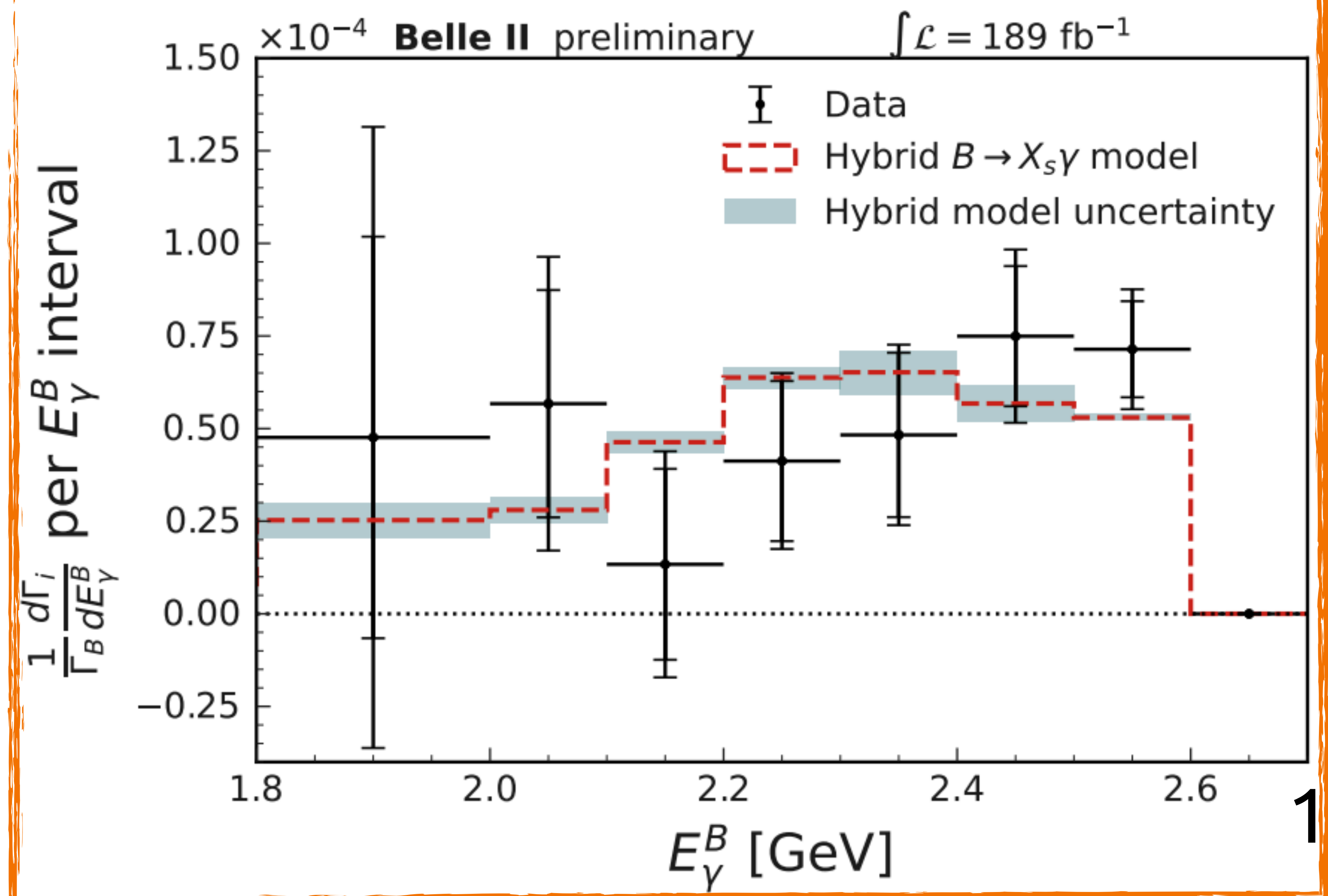
- **Fit of tag-side M_{bc}** in bins of E_γ
  - allow to remove tag-side $B\overline{B}$ bkg
- Residual background removal using **MC** information (mostly X_d)
  - 1.4 GeV $< E_\gamma < 1.8$ GeV region used to **validate** fit and selection
  - 1.8 GeV $< E_\gamma < 2.7$ GeV: signal region
- Yields integrated in multiple bins to obtain the **energy spectrum** (1.8., 2.0, 2.1 GeV threshold)
- Leading **systematics** from data/MC mismodellig in the fit and bkg suppression



E_γ^B threshold [GeV]	$\mathcal{B}(B \to X_s\gamma)$ $[10^{-4}]$	Experiment
1.8	$\mathbf{3.54 \pm 0.78 \pm 0.83}$	Belle II
2.0	$\mathbf{3.06 \pm 0.56 \pm 0.47}$	Belle II
1.9	$3.66 \pm 0.85 \pm 0.60$	BaBar

[PRD 91 (2015) 5, 052004]

Competitive with hadronic tag measurement



Inclusive $B \to X_s\gamma$: perspectives

[arXiv:2207.06307]

- Systematics trend:
  - lower threshold $\Rightarrow$ higher bkg
  - higher threshold $\Rightarrow$ higher theoretical uncertainties

  } trade off

Lower E_γ^B threshold	Statistical uncertainty				Baseline (improved)
	1 ab^{-1}	5 ab^{-1}	10 ab^{-1}	50 ab^{-1}	syst. uncertainty
1.4 GeV	10.7%	6.4%	4.7%	2.2%	10.3% (5.2%)
1.6 GeV	9.9%	6.1%	4.5%	2.1%	8.5% (4.2%)
1.8 GeV	9.3%	5.7%	4.2%	2.0%	6.5% (3.2%)
2.0 GeV	8.3%	5.1%	3.8%	1.7%	3.7% (1.8%)

- Improved scenario = improved $\pi^0 \to \gamma\gamma$ **veto** modelling
- Other possible improvements: different **tagging approaches**
- In the long term planning **crucial to use ratios/asymmetries** to cancel systematics

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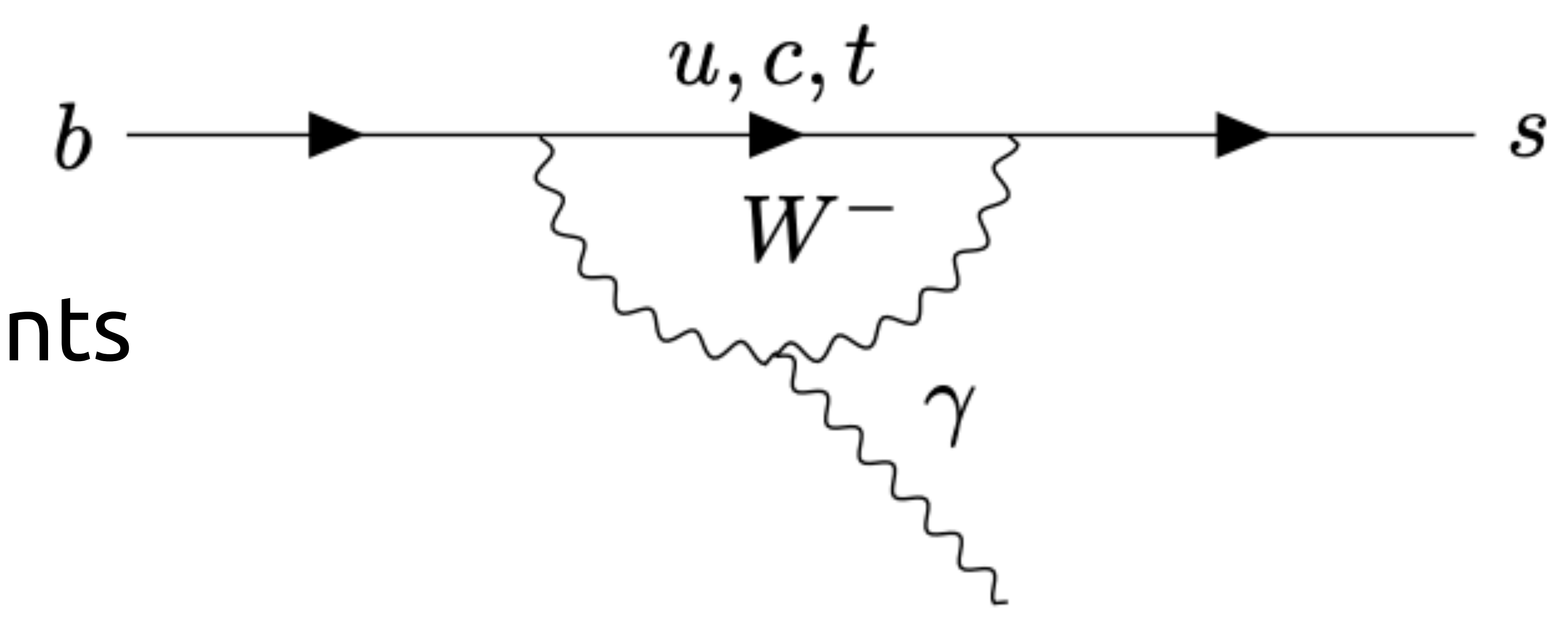
$B \to K^*\gamma$

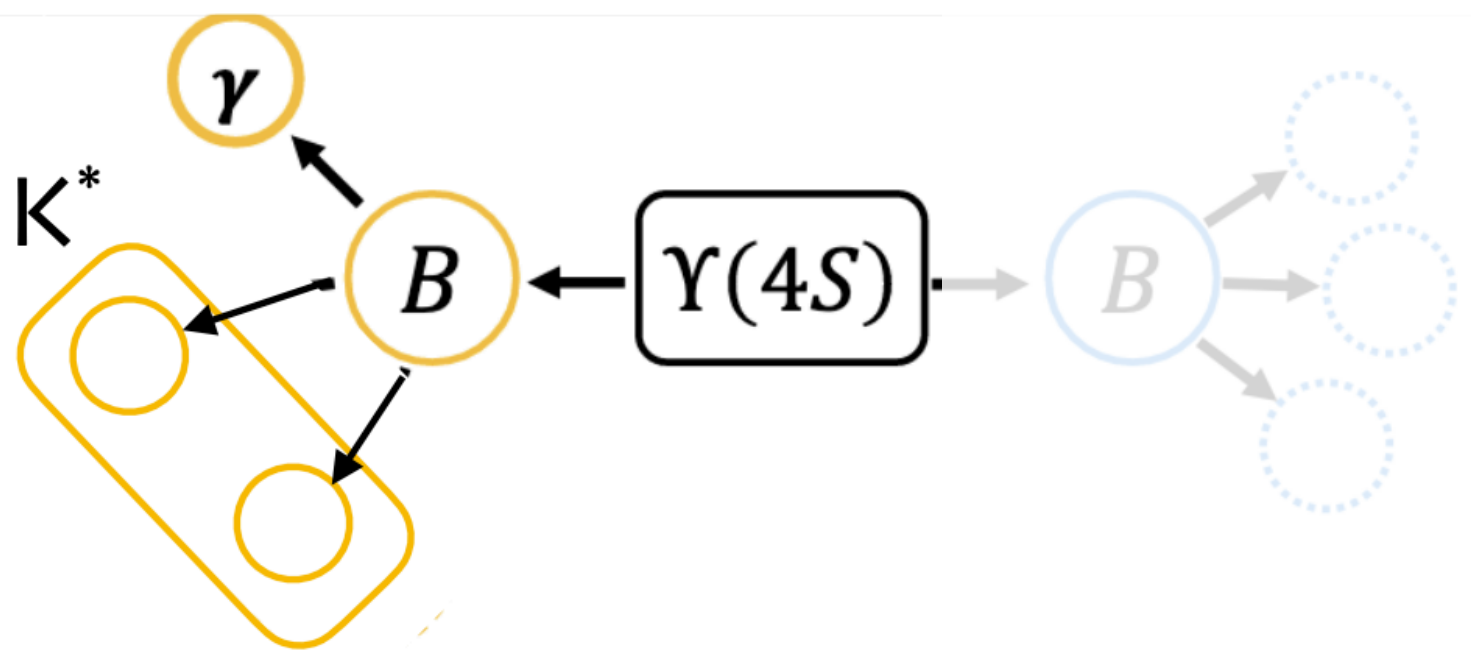
[arXiv: 2110.08219]

$63\ \mathrm{fb}^{-1}$

- Motivation:
  - Cleanest exclusive mode of the $B \to X_s\gamma$ sector
  - measurement of the BR as a first step for asymmetries measurements



- Reconstruction:
  - $K^{*+}(892) \to K^+\pi^0, K_S^0\pi^+$ and $K^{*0}(892) \to K_S^0\pi^+, K^+\pi^0$
  - reconstruct only 1 B of the event



- Photon bkg suppression:
  - **2-body decay**: $E_\gamma^* \approx m_B/2 \approx 2.5$ GeV $\Rightarrow$ cut on photon energy
  - **Veto** on γ from π^0 and η
- K^* bkg suppression
  - **Helicity angle** of the Kaon from K^* follow $\sin^2\theta_{\text{hel}}$, while misreconstructed K^* peak at $\cos\theta \approx \pm 1$
  - ΔE discriminate between signal $K^*(892)$ and **other resonance** like $K^{*+}(1410)$
- MVA to suppress $e^+e^- \to q\bar{q}$ background

$B \to K^*\gamma$

[arXiv: 2110.08219]

63 fb^{-1}

- Fit to ΔE, including peaking bkg from other resonances

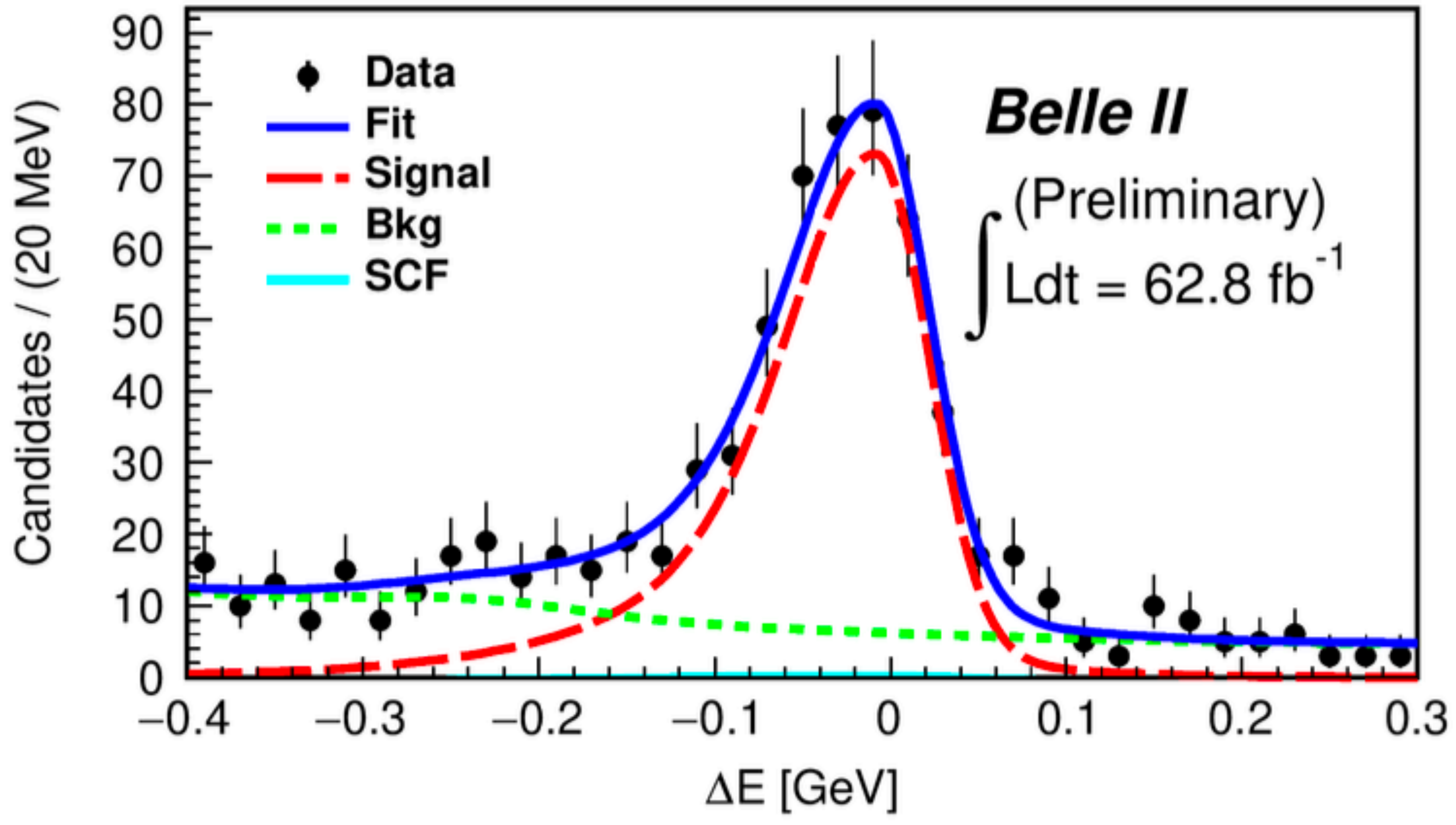
Mode	Signal yield	$\mathcal{B}_{\text{meas}}$ $[10^{-5}]$
$B^0 \to K^{*0}[K^+\pi^-]\gamma$	454 ± 28	$4.5 \pm 0.3 \pm 0.2$
$B^0 \to K^{*0}[K^0_S\pi^0]\gamma$	50 ± 10	$4.4 \pm 0.9 \pm 0.6$
$B^+ \to K^{*+}[K^+\pi^0]\gamma$	169 ± 18	$5.0 \pm 0.5 \pm 0.4$
$B^+ \to K^{*+}[K^0_S\pi^+]\gamma$	160 ± 17	$5.4 \pm 0.6 \pm 0.4$

world best by Belle with 3% precision [PRL 119 (2017), 191802]

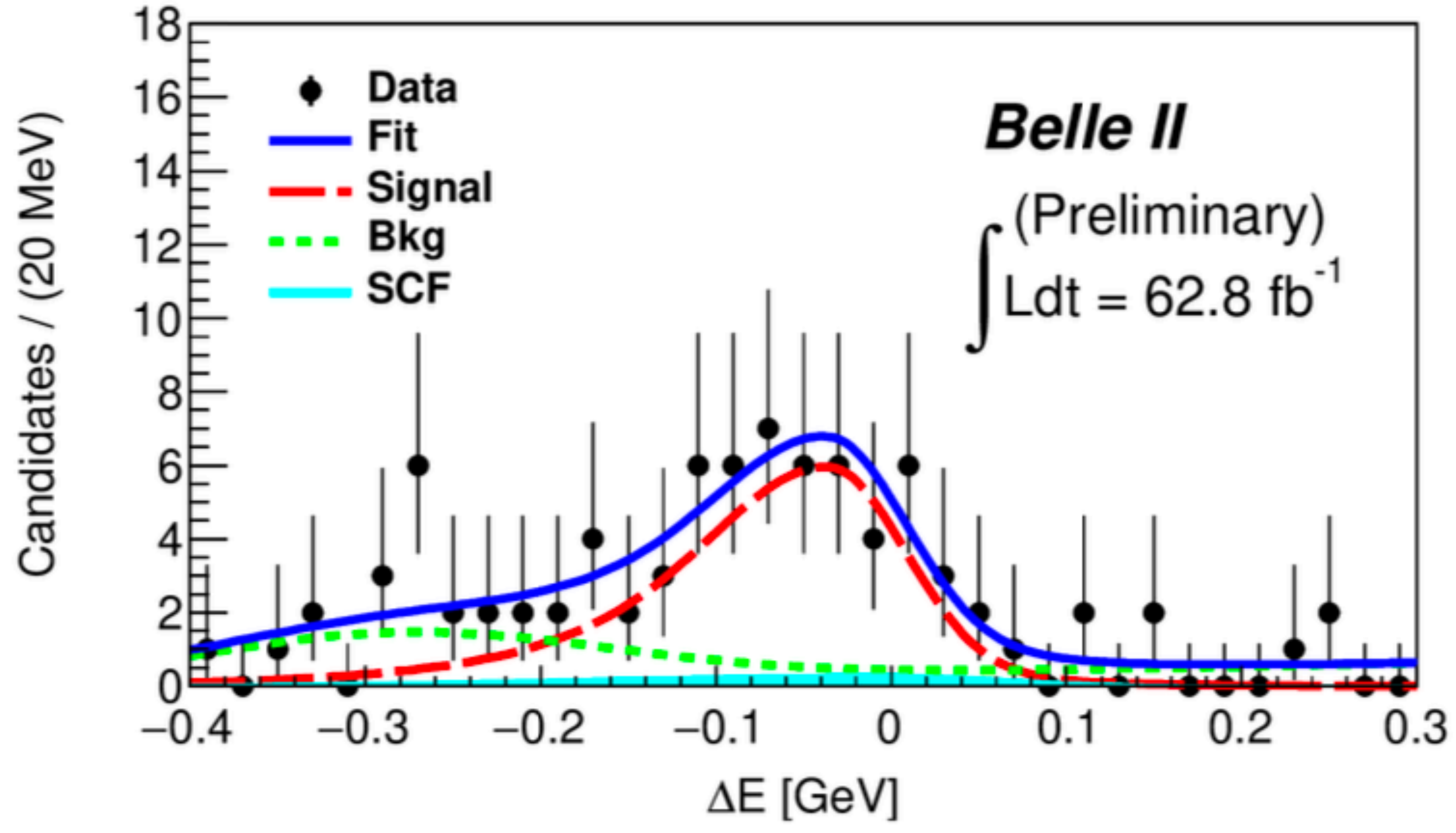
consistent with world average

- Statistically limited

- Leading systematics from π^0 **and η veto** (plus MVA bkg suppression and misreconstructed signal)



(a) $B^0 \to K^{*0}[K^+\pi^-]\gamma$



(b) $B^0 \to K^{*0}[K^0_S\pi^0]\gamma$

$B \to K^*\gamma$: perspectives

[arXiv:2207.06307]

- Measurement of BR is the first step toward the measurement of **asymmetries**:

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

3.1σ evidence of isospin violation by Belle [PRL 119 (2017), 191802]

- on contrary of the BRs, they do not suffer of form-factor related uncertainties
- Also photon **polarization** (left in SM, right in BSM) is a future target
- Extrapolation using Belle results ($O(10^{-2})$ precision)

Observable	1 ab^{-1}	5 ab^{-1}	10 ab^{-1}	50 ab^{-1}	Systematic uncertainty
$\Delta_{0+}(B \to K^*\gamma)$	1.3%	0.6%	0.4%	0.2%	1.2%
$A_{CP}(B^0 \to K^{*0}\gamma)$	1.4%	0.6%	0.5%	0.2%	0.2%
$A_{CP}(B^+ \to K^{*+}\gamma)$	1.9%	0.9%	0.6%	0.3%	0.2%
$\Delta A_{CP}(B \to K^*\gamma)$	2.4%	1.1%	0.7%	0.3%	0.3%

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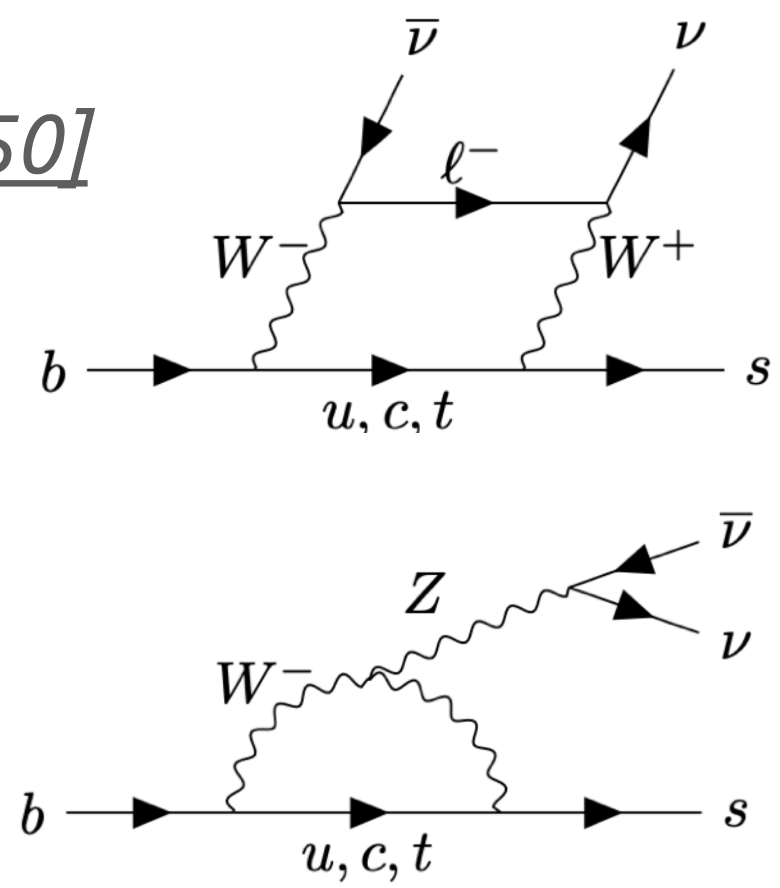
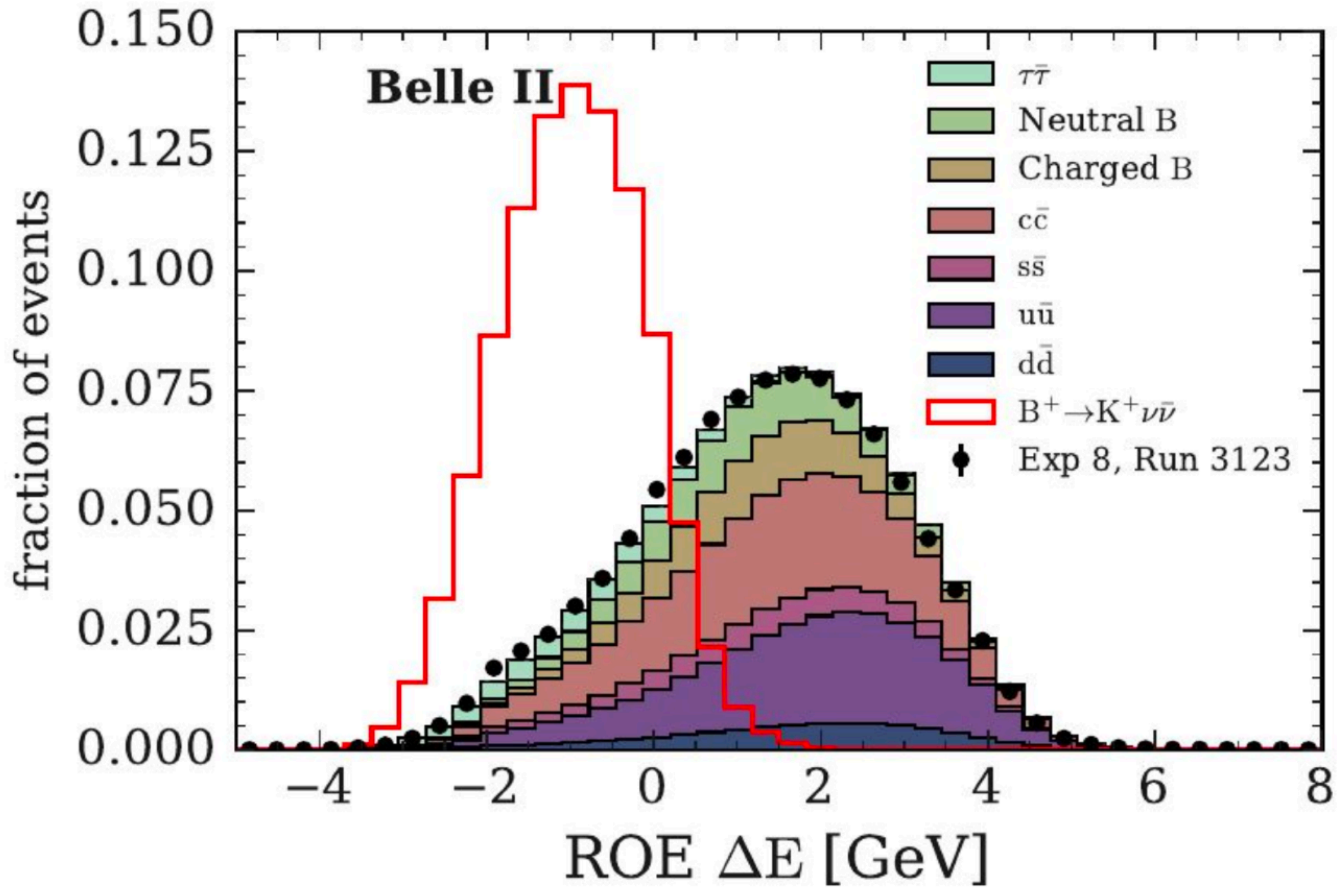
$B^+ \to K^+ \nu\bar{\nu}$

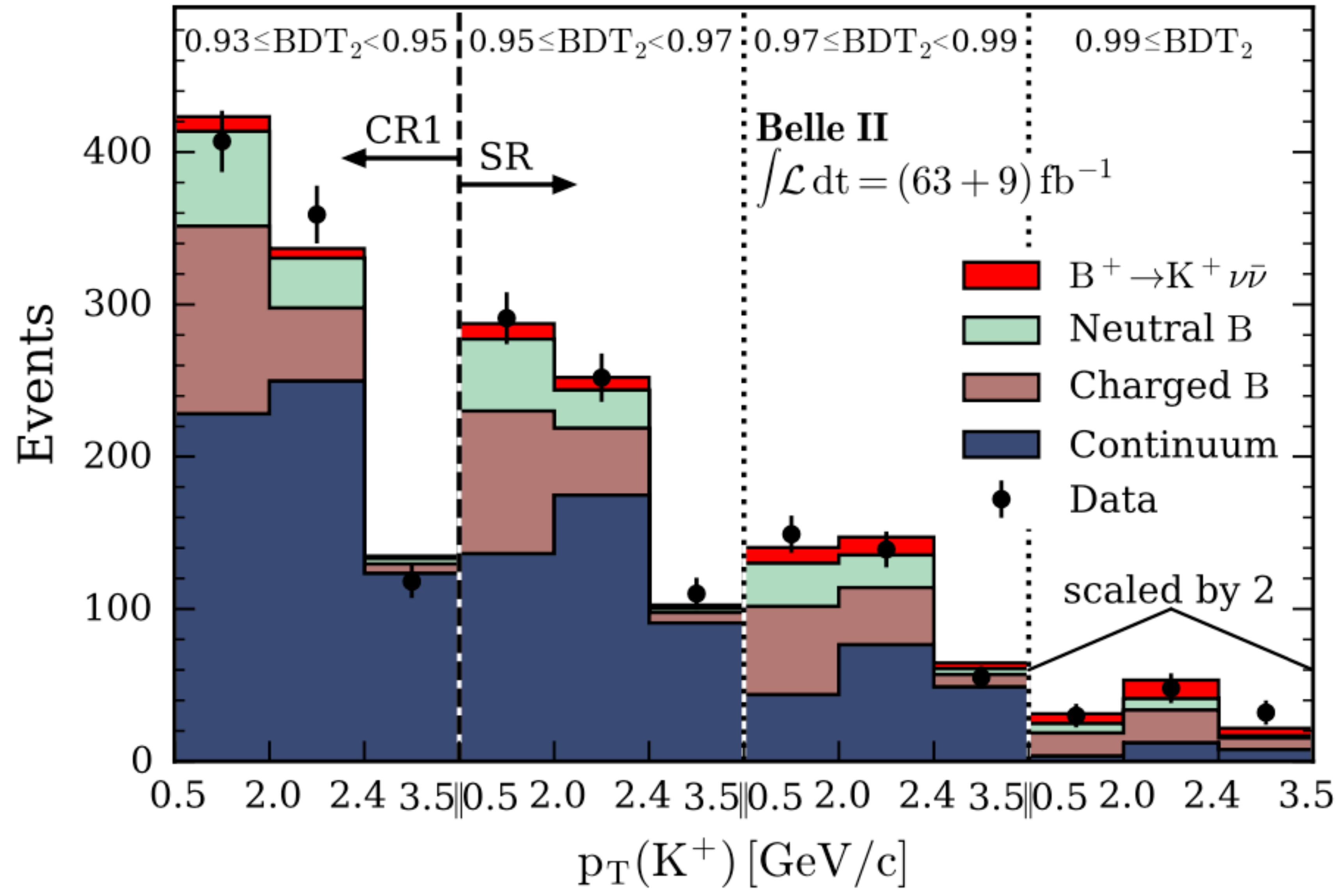
[Phys.Rev.Lett. 127 (2021) 18, 181802]

63 fb^{-1}

- Motivation:
  - BR predicted ~ 4.6×10^{-6} [Prog. Part. Nucl. Phys. 92(2017), 50]
    main uncertainty from $B \to K$ form factor
  - no charged leptons ⇒ Lower theoretical uncertainties
  - **BSM amplitudes** can increase O(50%) the BR
  - Not yet observed! **Unique** opportunity in Belle II
- Reconstruction:
  - **inclusive tagging**
  - $K^+ =$ highest p_T track, ROE information
- Bkg: **2 BDT in cascade** to exploit the event information and suppress the bkg
  - main variables: event shape, kinematics, vertexing variables
- Fit: performed in $(\boldsymbol{p_T^K}, \boldsymbol{BDT_2})$ in signal region and 3 control regions (lower BDT values)
- control sample: $B^+ \to J/\psi(\to \mu\mu)K^+$
  - ignoring muons (to mimic $\nu\bar{\nu}$) and p_K replaced from MC





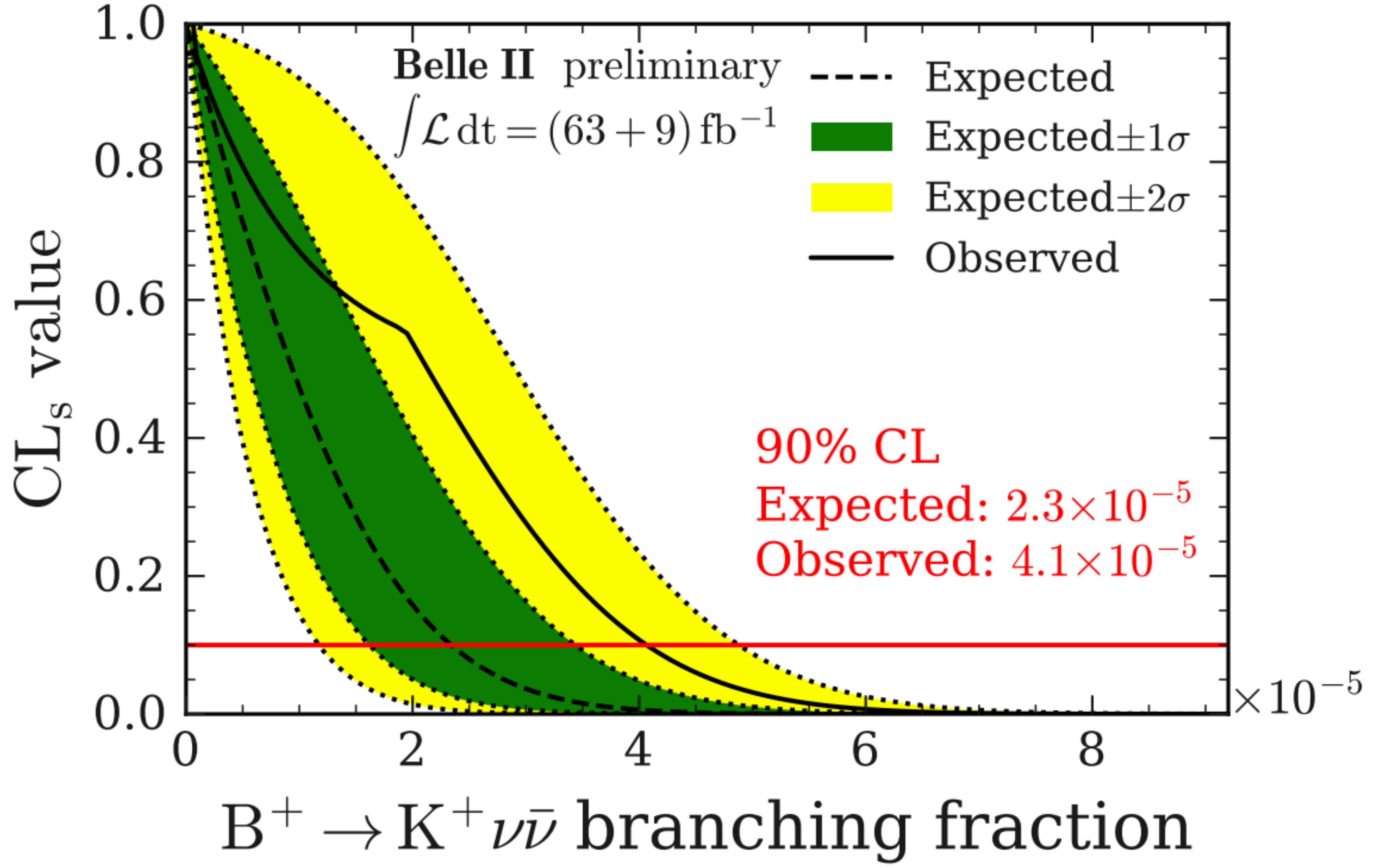


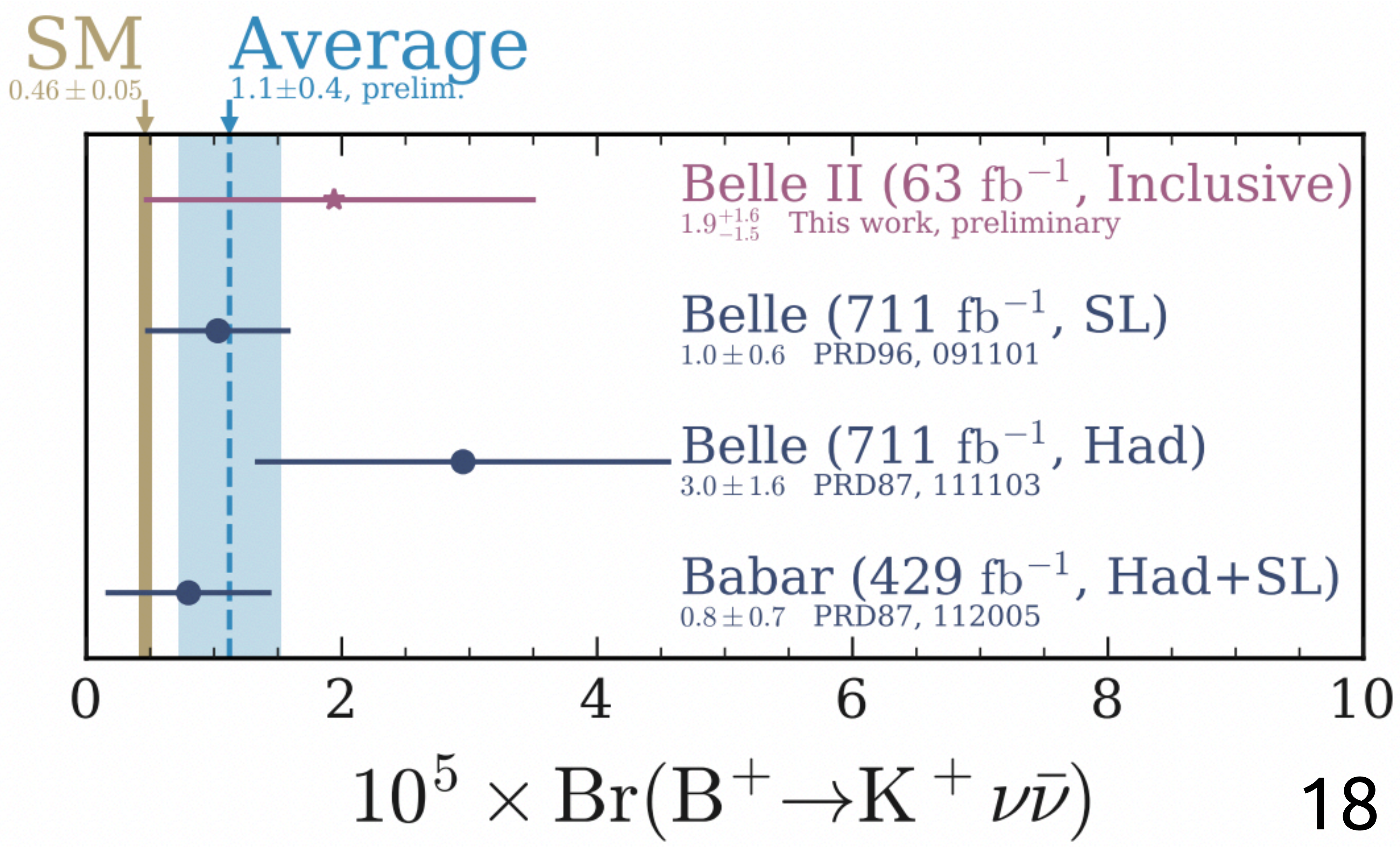
$B^+ \to K^+ \nu \bar{\nu}$

[Phys.Rev.Lett. 127 (2021) 18, 181802]

$63\ \mathrm{fb}^{-1}$

- Results:
  - No signal observed $\Rightarrow$ **Upper limit**
  - signal strength compatible with SM prediction at 1σ or bkg-only at 1.3σ
- Inclusive tagging ($\varepsilon = 4.3\ \%$)$\Rightarrow$ x3.5 better of hadronic tag, 20% better of SL tag
- Statistically limited
- Leading systematic: **bkg normalization**





$B^+ \to K^+\nu\bar{\nu}$ - perspectives

[arXiv:2207.06307]

Uncertainties on BR(meas)/BR(SM)

Decay	$1\,\text{ab}^{-1}$	$5\,\text{ab}^{-1}$	$10\,\text{ab}^{-1}$	$50\,\text{ab}^{-1}$
$B^+ \to K^+\nu\bar{\nu}$	0.55 (0.37)	0.28 (0.19)	0.21 (0.14)	0.11 (0.08)
$B^0 \to K^0_S\nu\bar{\nu}$	2.06 (1.37)	1.31 (0.87)	1.05 (0.70)	0.59 (0.40)
$B^+ \to K^{*+}\nu\bar{\nu}$	2.04 (1.45)	1.06 (0.75)	0.83 (0.59)	0.53 (0.38)
$B^0 \to K^{*0}\nu\bar{\nu}$	1.08 (0.72)	0.60 (0.40)	0.49 (0.33)	0.34 (0.23)

- Projection based on published+MC study
- baseline (improved) assume current scenario (**+50% efficiency** with same bkg)
- Improvement coming from **extra tagging** scenario (semileptonic, hadronic)
- with $5\ \text{ab}^{-1}$ we can achieve 5σ signal on $B^+ \to K^+\nu\bar{\nu}$

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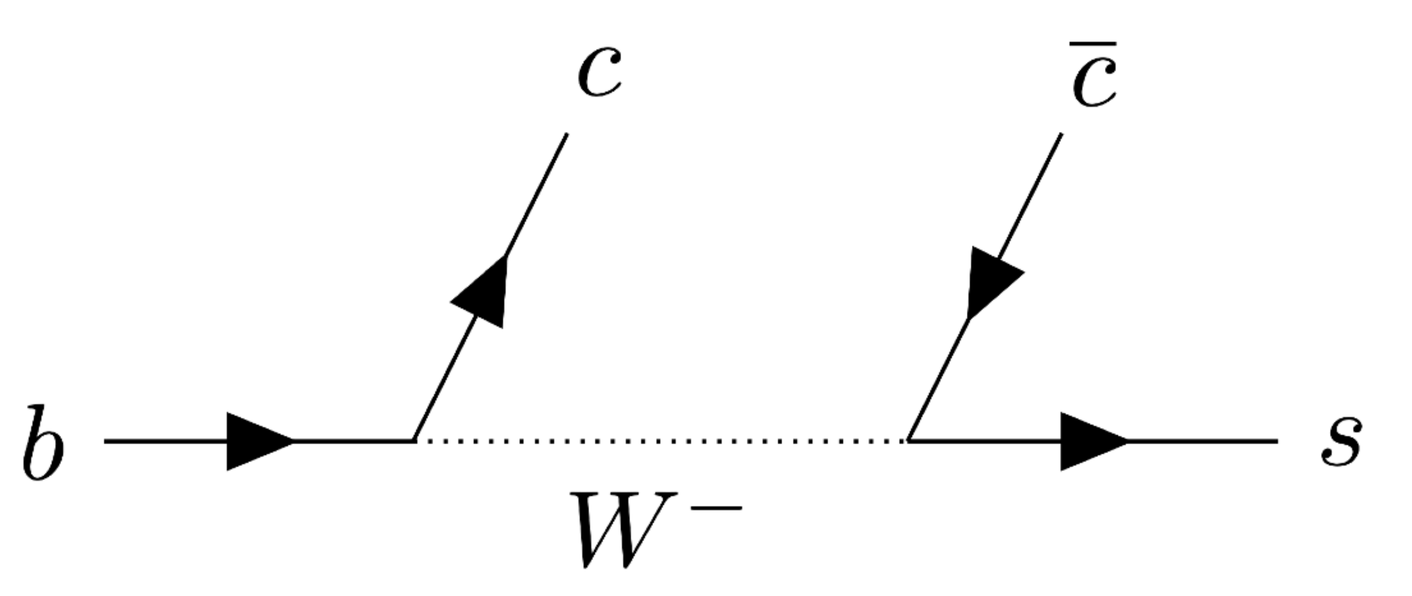
Towards LFU test: $B^{0,+} \to J/\psi(\to \ell\ell)K_S^{0,+}$

[arXiv:2207.11275] $189\ \mathrm{fb}^{-1}$

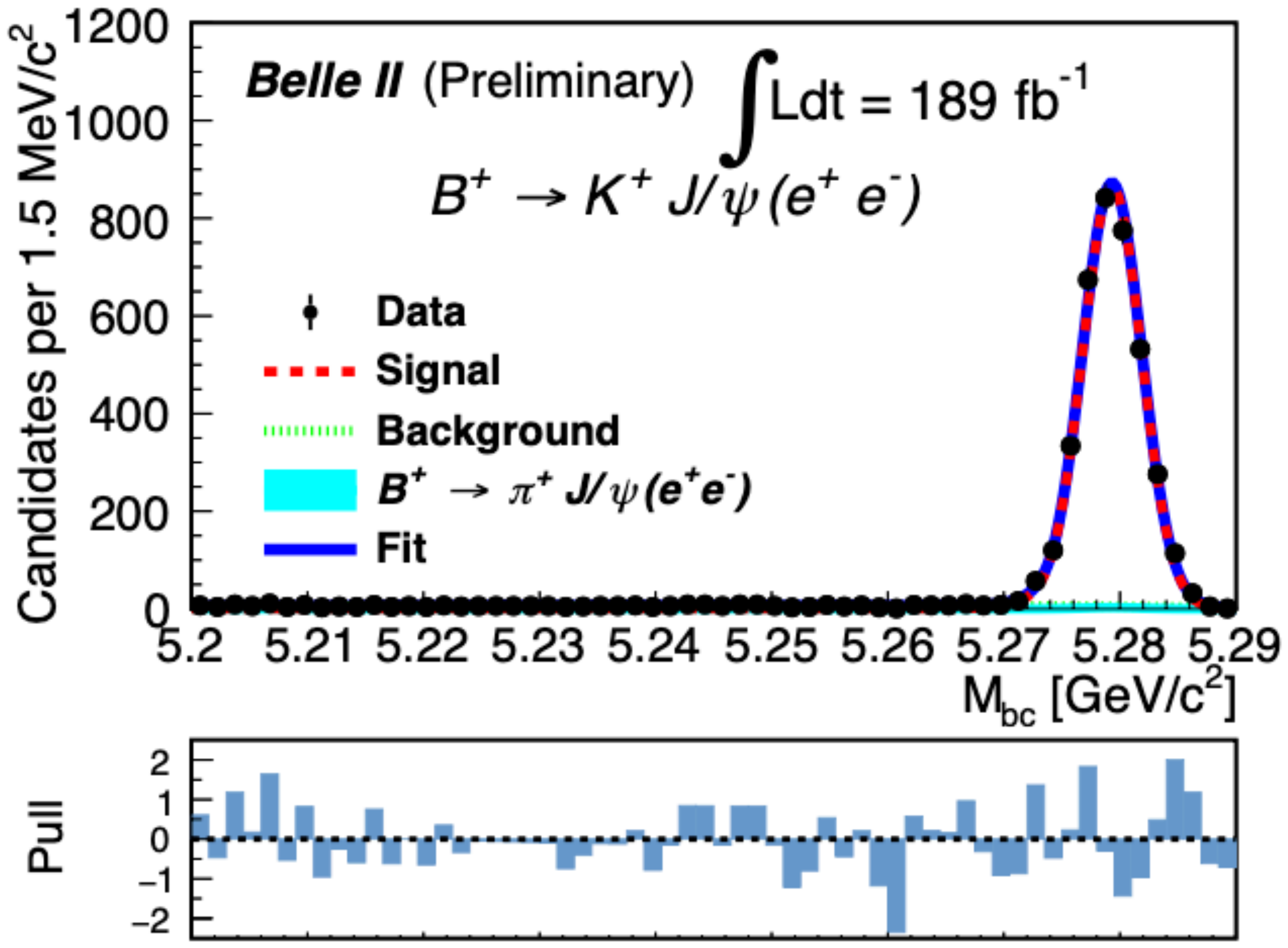
- actually $b \to c$ transition: **no sensitivity to BSM** amplitudes expected



- Expected $R_K(J/\psi) = \dfrac{\mathcal{B}(B \to J/\psi(\mu^+\mu^-)K)}{\mathcal{B}(B \to J/\psi(e^+e^-)K)} \approx 1$
- Used as a **control sample** to validate $B \to K^{(*)}\ell\ell$ analysis
- Reconstructed with $K^+, K_S^0, \ell = e, \mu$
- Fit: $(\Delta E, M_{bc})$

$$R_{K^+}(J/\psi) = 1.009 \pm 0.022 \pm 0.008,$$
$$R_{K^0}(J/\psi) = 1.042 \pm 0.042 \pm 0.008,$$

Agreement with 1, satisfactory precision



- Systematic uncertainty driven by **Lepton ID**, and below 1% (smaller than Belle)

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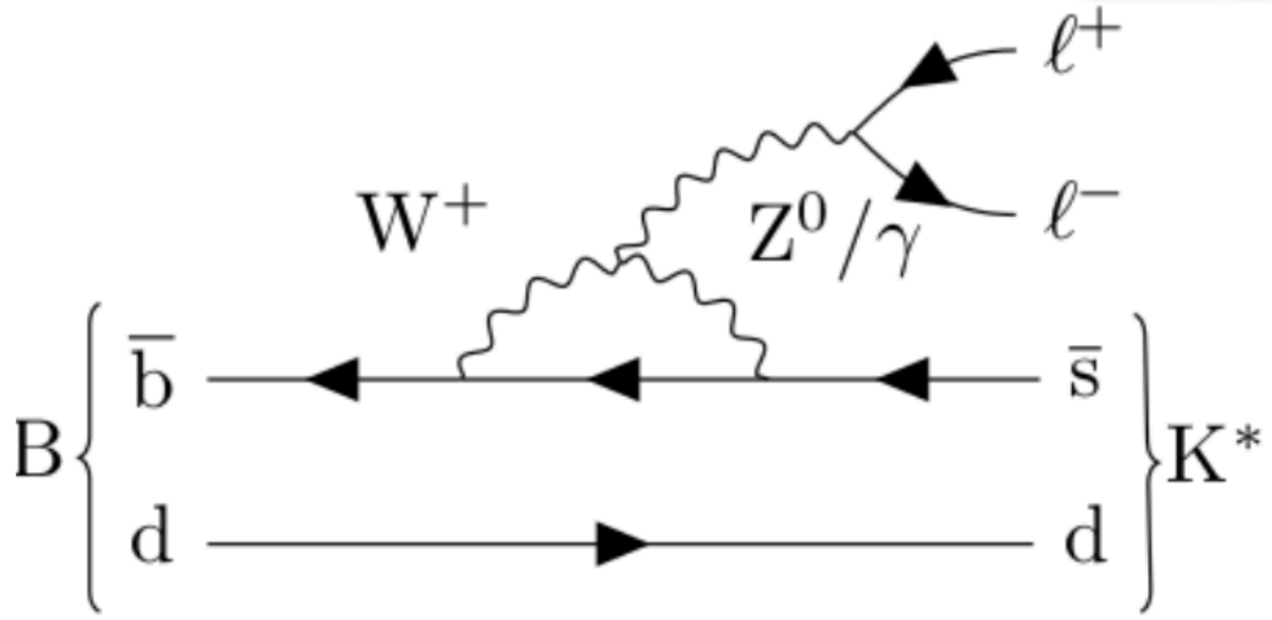
Towards LFU test: $B \to K^*\ell\ell$

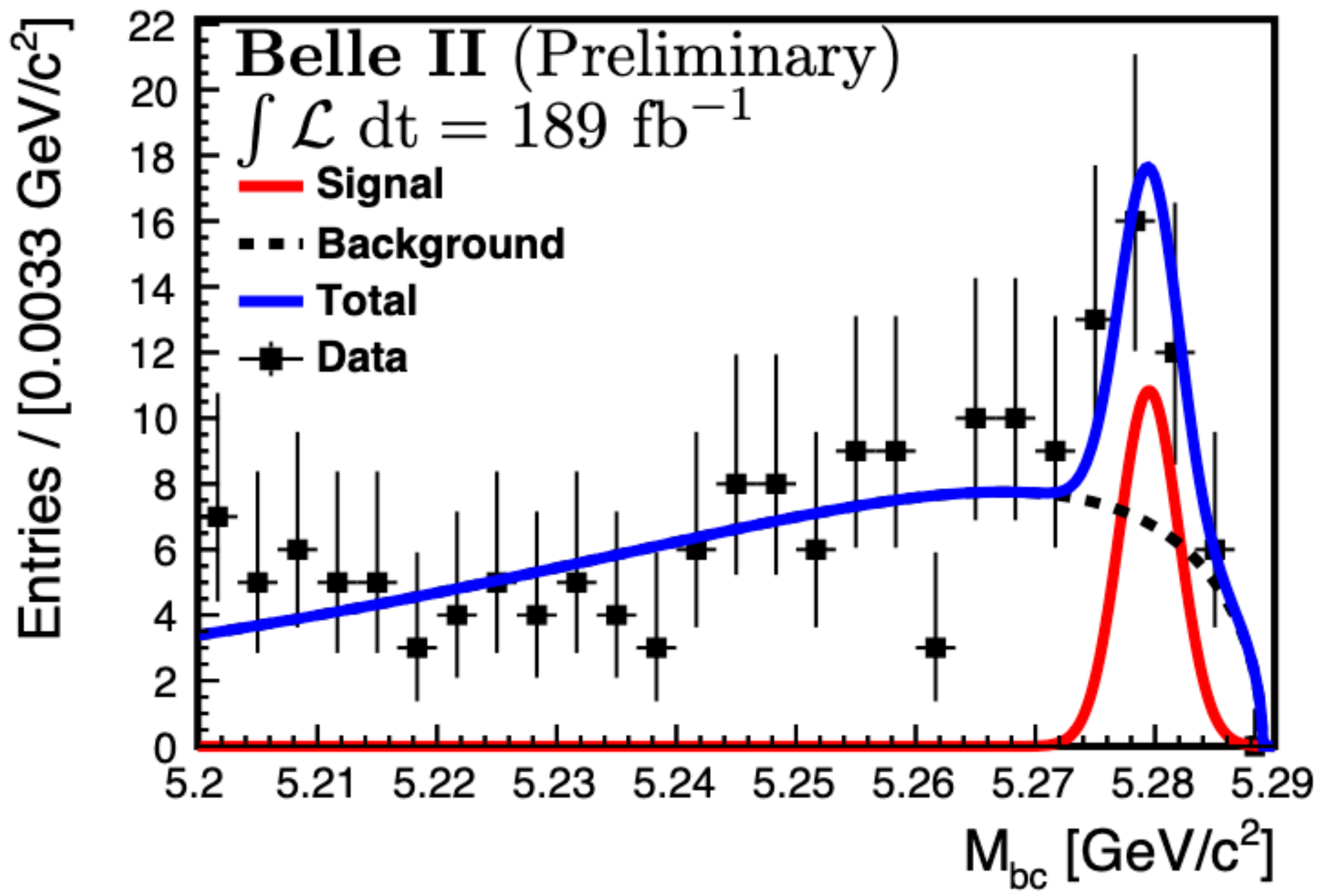
[arXiv:2206.05946]

$189\ \text{fb}^{-1}$

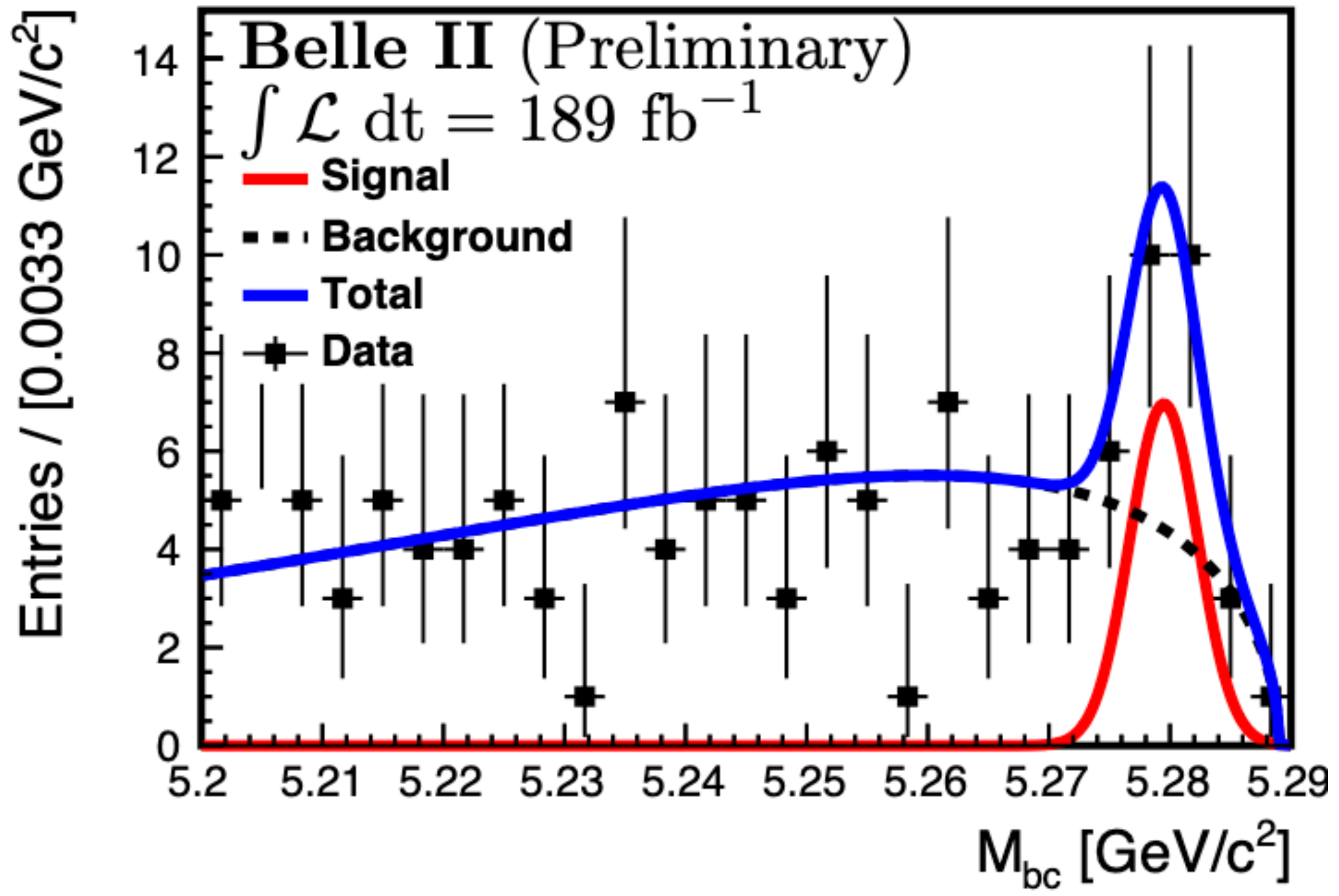


- Challenge: low BR $\Rightarrow$ **statistically limited**
- Reconstruction: $K^{*0} \to K^+\pi^-$, $K^{*+} \to K^+\pi^0$, $K^{*+} \to K_S^0\pi^+$
- **Bkg suppression:**
  - BDT (for $ee \to q\bar{q}, B\bar{B}$...)
  - veto on $M(J/\psi, \psi(2S) \to \ell\ell)$
  - veto on $B \to K^*\gamma : M(e^+e^-) > 0.14$ GeV
- **Fit to $(M_{bc}, \Delta E)$** distribution
- Similar performance for electrons and muons

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



$K^*e^+e^-$



Towards LFU test: $B \to K^*\ell\ell$

[arXiv:2206.05946]

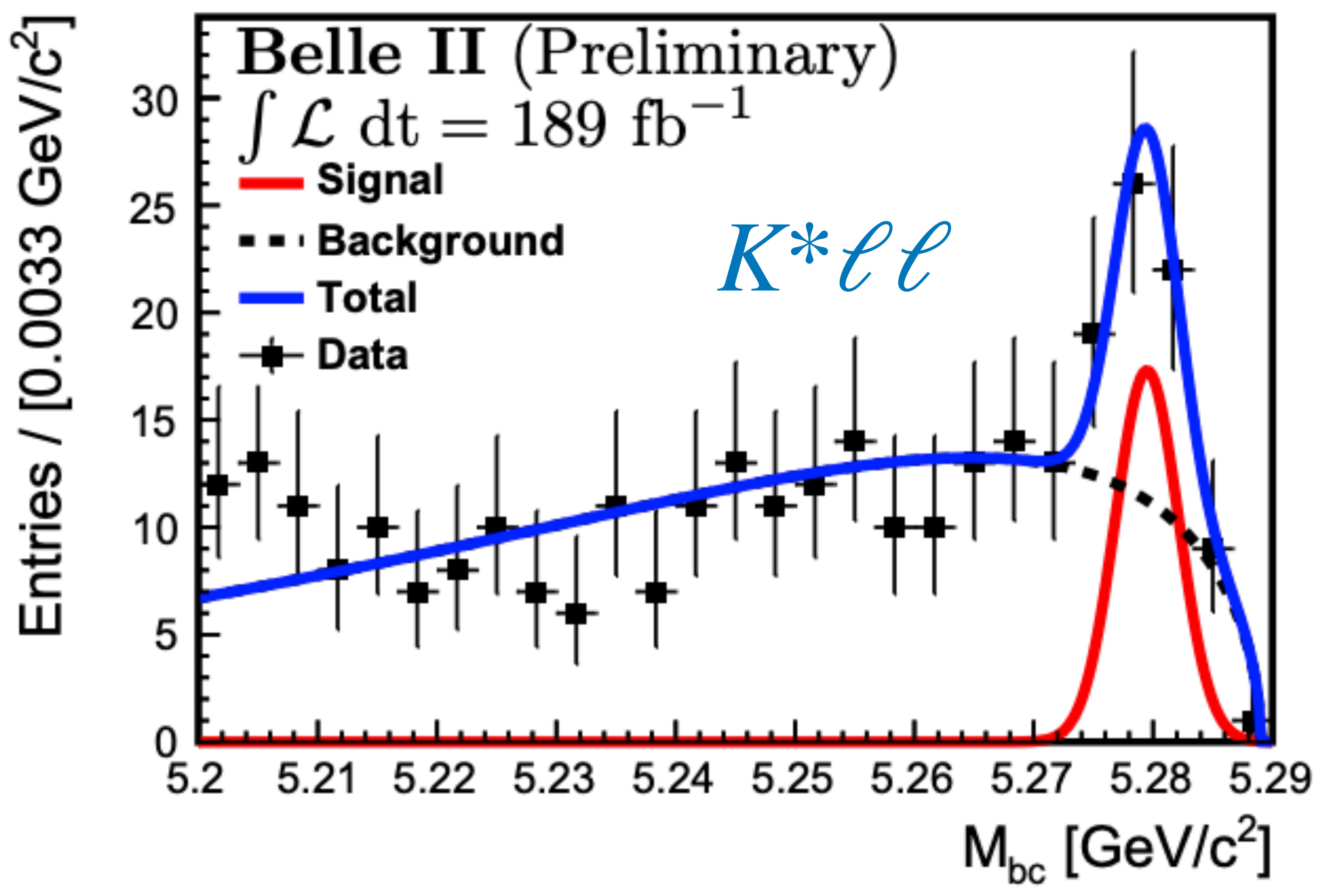
189 fb^{-1}

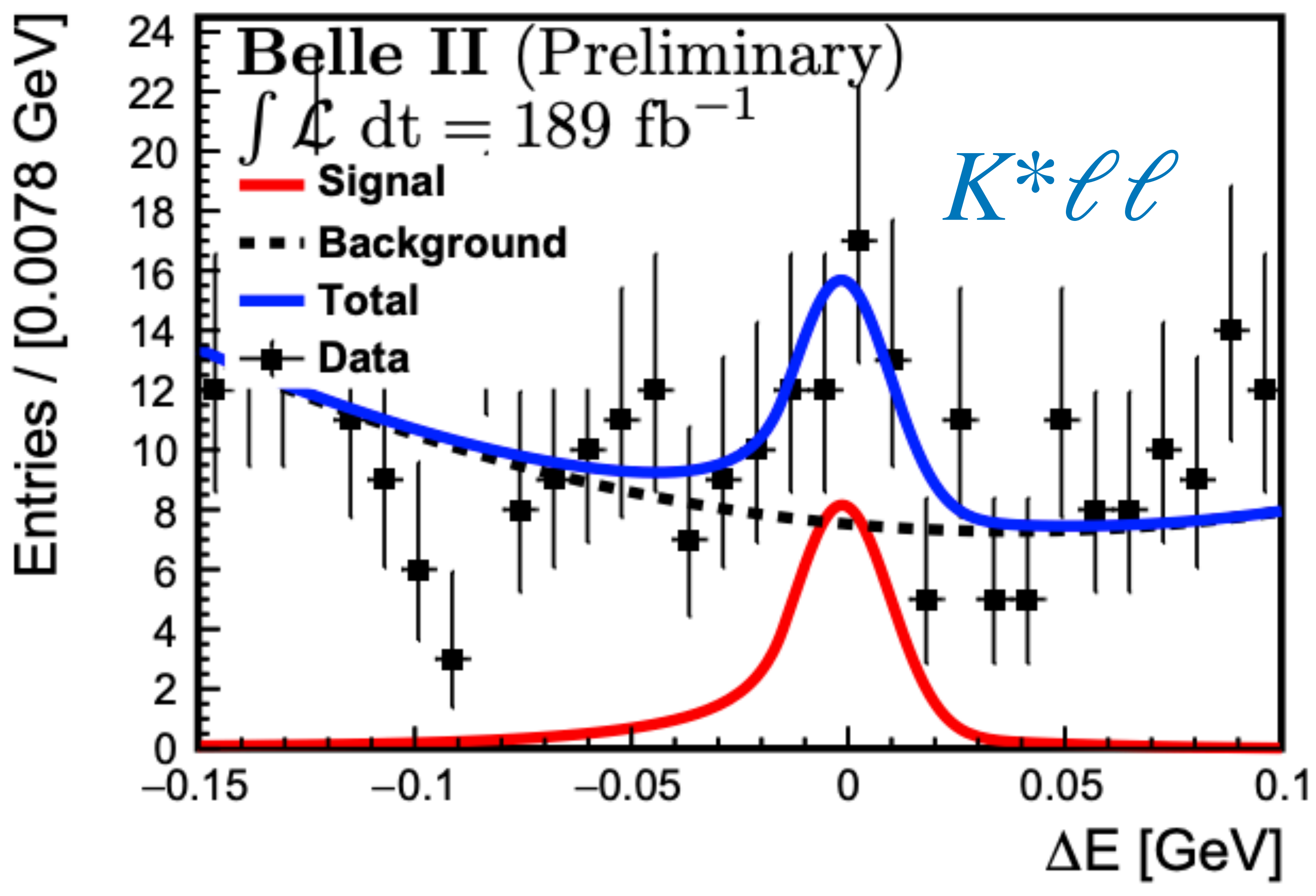
$$\mathcal{B}(B \to K^*\mu^+\mu^-) = (1.19 \pm 0.31 \pm^{+0.08}_{-0.07}) \times 10^{-6},$$
$$\mathcal{B}(B \to K^*e^+e^-) = (1.42 \pm 0.48 \pm 0.09) \times 10^{-6},$$
$$\mathcal{B}(B \to K^*\ell^+\ell^-) = (1.25 \pm 0.30 \pm^{+0.08}_{-0.07}) \times 10^{-6}.$$

Ground ready for more data for $R(K^{(*)})$ measurement

w.a.
$(1.06 \pm 0.09) \times 10^{-6}$
$(1.19 \pm 0.20) \times 10^{-6}$
$(1.05 \pm 0.10) \times 10^{-6}$

- Statistically limited
- Systematic uncertainty subleading, and driven by particle ID





Analyses outline

This talk will cover:

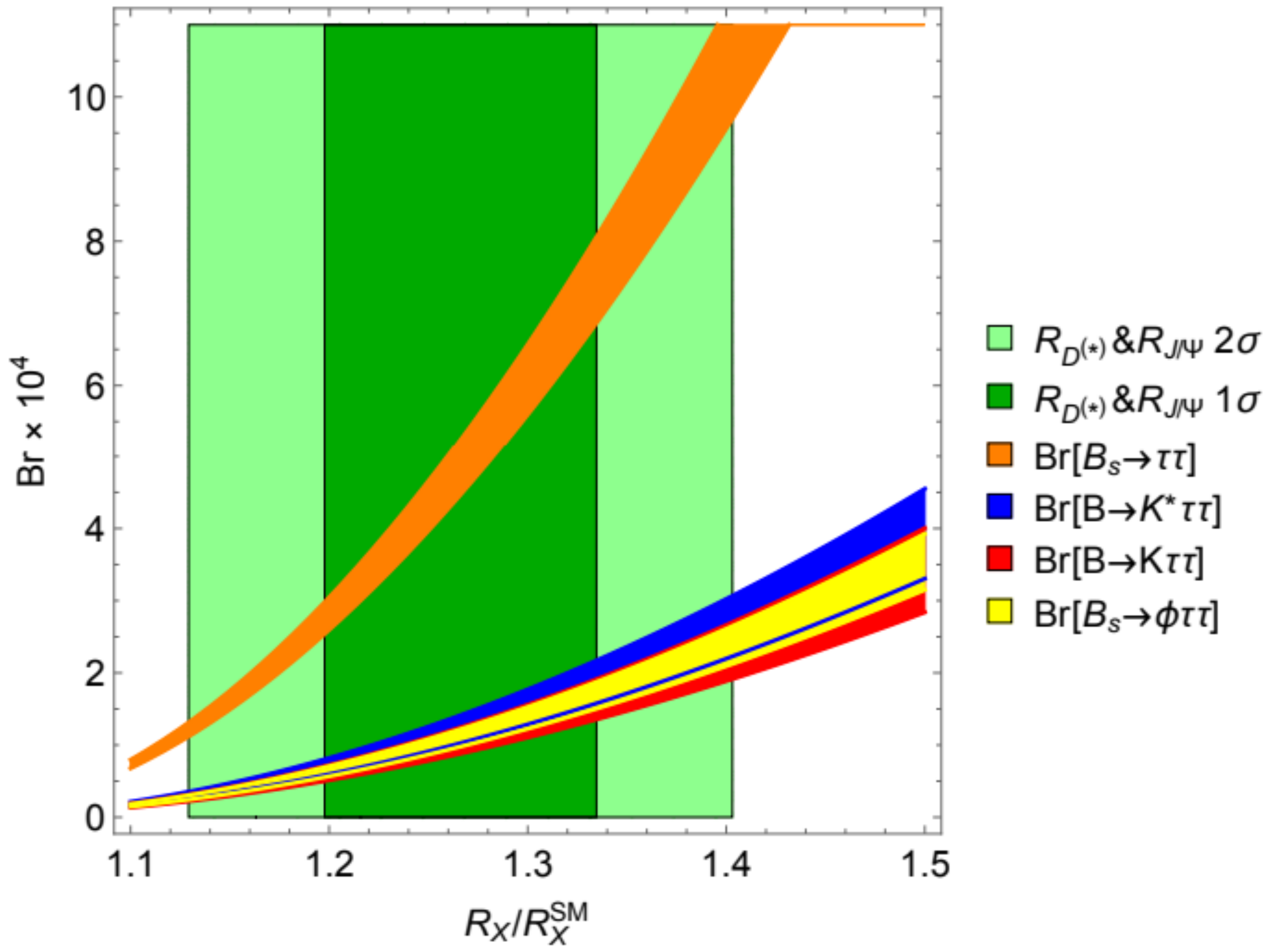
sector	channel	achieved results?
Radiative	fully inclusive $B \to X_s \gamma$	189 fb^{-1}
	$B \to K^* \gamma$	63 fb^{-1}
Multi-neutrinos	$B^+ \to K^+ \nu \bar{\nu}$	63 fb^{-1}
(Towards) LFU violation	$B \to J/\psi(\to \ell\ell)K$	189 fb^{-1}
	$B \to K^* \ell\ell$	189 fb^{-1}
	$B^0 \to K^{*0} \tau\tau$	prospects only
	$B \to K^{(*)} \ell\ell'$	experimental status only

$B^0 \to K^{*0}\tau^+\tau^-$ - perspectives

[arXiv:2207.06307]

- SM BR~$\mathcal{O}(10^{-7})$ $\Rightarrow$ extremely sensitive to New Physics: **BSM may enhance** the rate $\sim 10^3$SM BR.
- **Complementary** to $B \to K^{(*)}\ell\ell$, and experimentally UL only $\mathcal{O}(10^{-3})$ 90% CL

$\mathcal{B}(B^0 \to K^{*0}\tau\tau)$ (had tag)		
ab^{-1}	"Baseline" scenario	"Improved" scenario
1	$< 3.2 \times 10^{-3}$	$< 1.2 \times 10^{-3}$
5	$< 2.0 \times 10^{-3}$	$< 6.8 \times 10^{-4}$
10	$< 1.8 \times 10^{-3}$	$< 6.5 \times 10^{-4}$
50	$< 1.6 \times 10^{-3}$	$< 5.3 \times 10^{-4}$



[PRL 120 (2018), 181802]

- baseline: Belle analysis (hadronic tag, $\tau \to \ell\nu\nu$) [arXiv:2110.03871]
- improved: extra tag, $\tau \to \pi\nu$
- Additional improvement including $B \to K^{(*)+}\tau\tau$

Analyses outline

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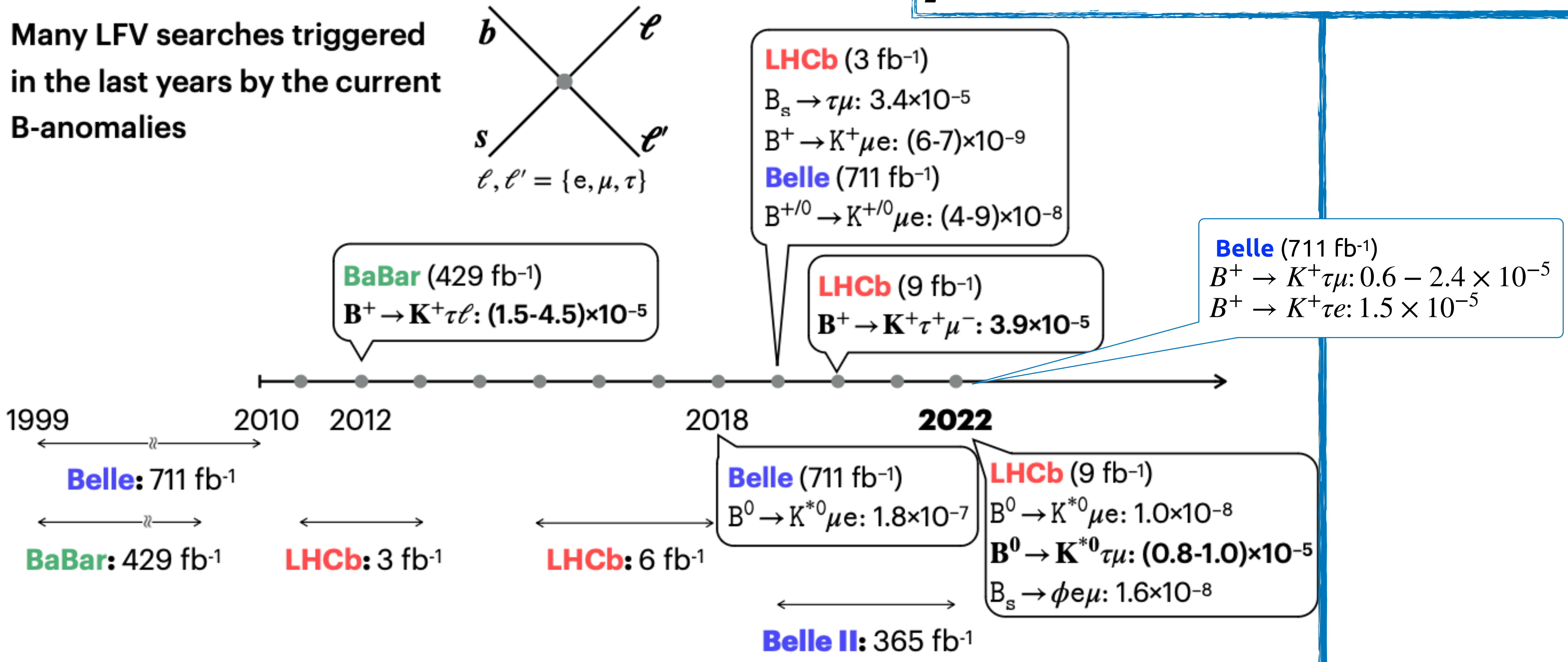
	$B^0 \to K^{*0}\tau\tau$	prospects only
	$B \to K^{(*)}\ell\ell'$	experimental status only

LFV: Experimental status of $b \to s\ell\ell', \ell = e, \mu, \tau$

[from G. De Marino thesis]

Many LFV searches triggered in the last years by the current B-anomalies



Limits on modes with τ's are not as constraining as those with μe because of the **more challenging τ reconstruction**

- **(2-5)×10^{-5} range for $B^+ \to K^+\tau\ell$ (BaBar and LHCb)**

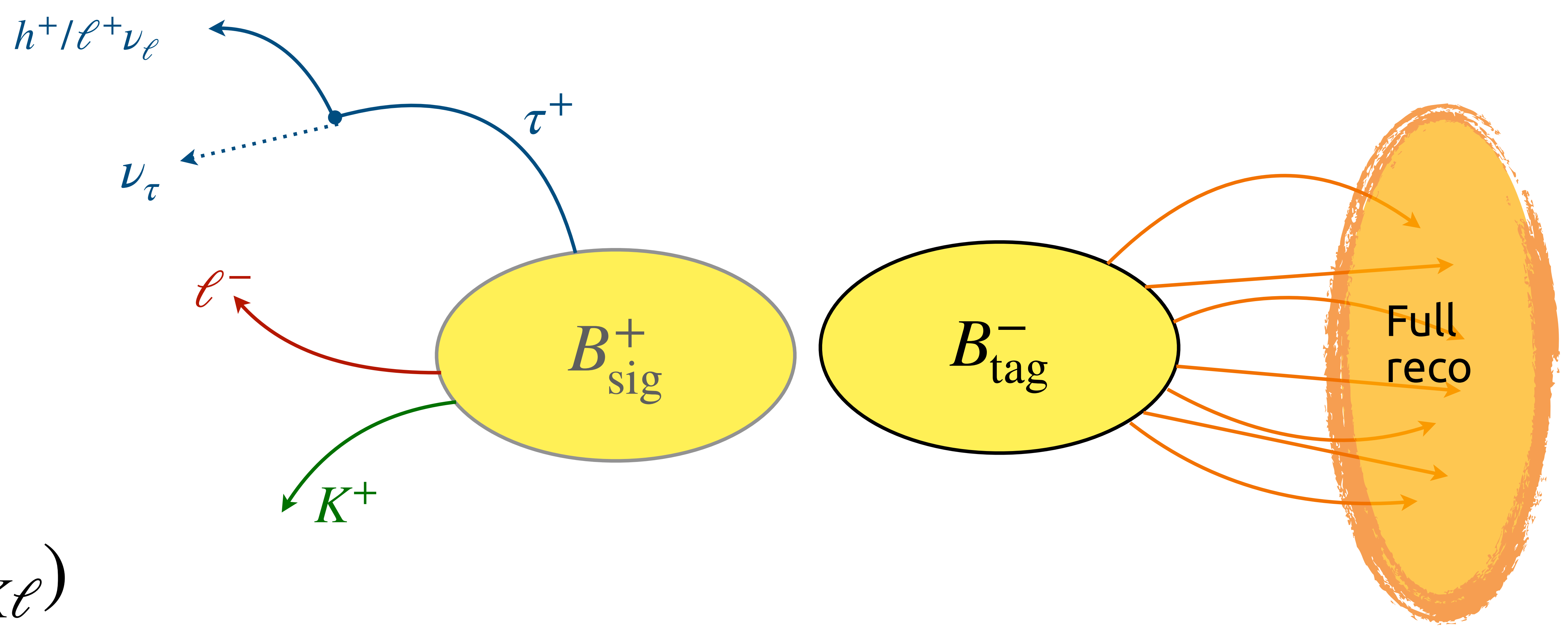
$B \to K\tau\ell$ experimental methods

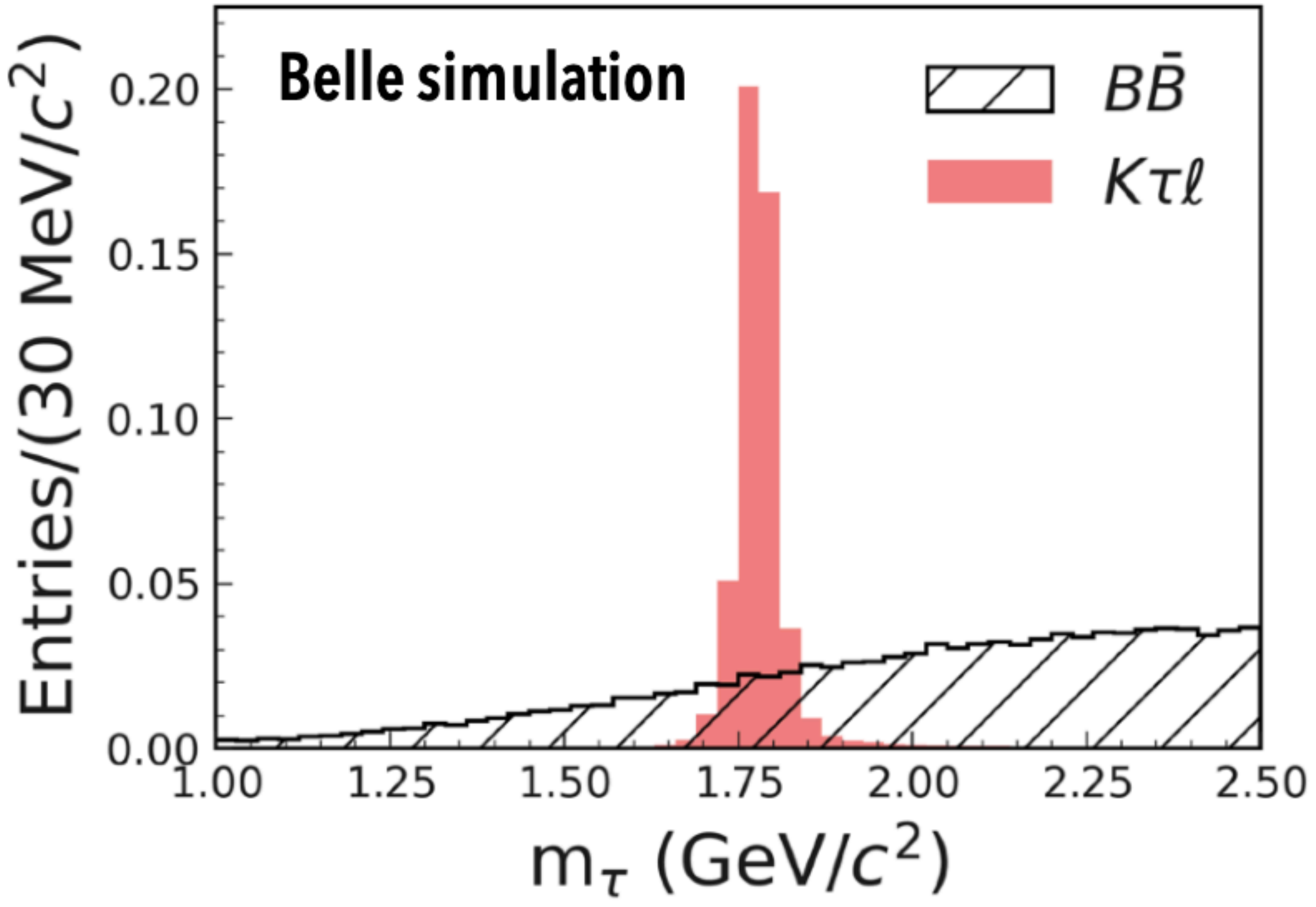
- B-tagging (hadronic or semileptonic)
- Reconstruct $B_{\rm tag}$ and K, ℓ tracks
- Missing energy only from τ decay $\Rightarrow$ recoil τ mass:

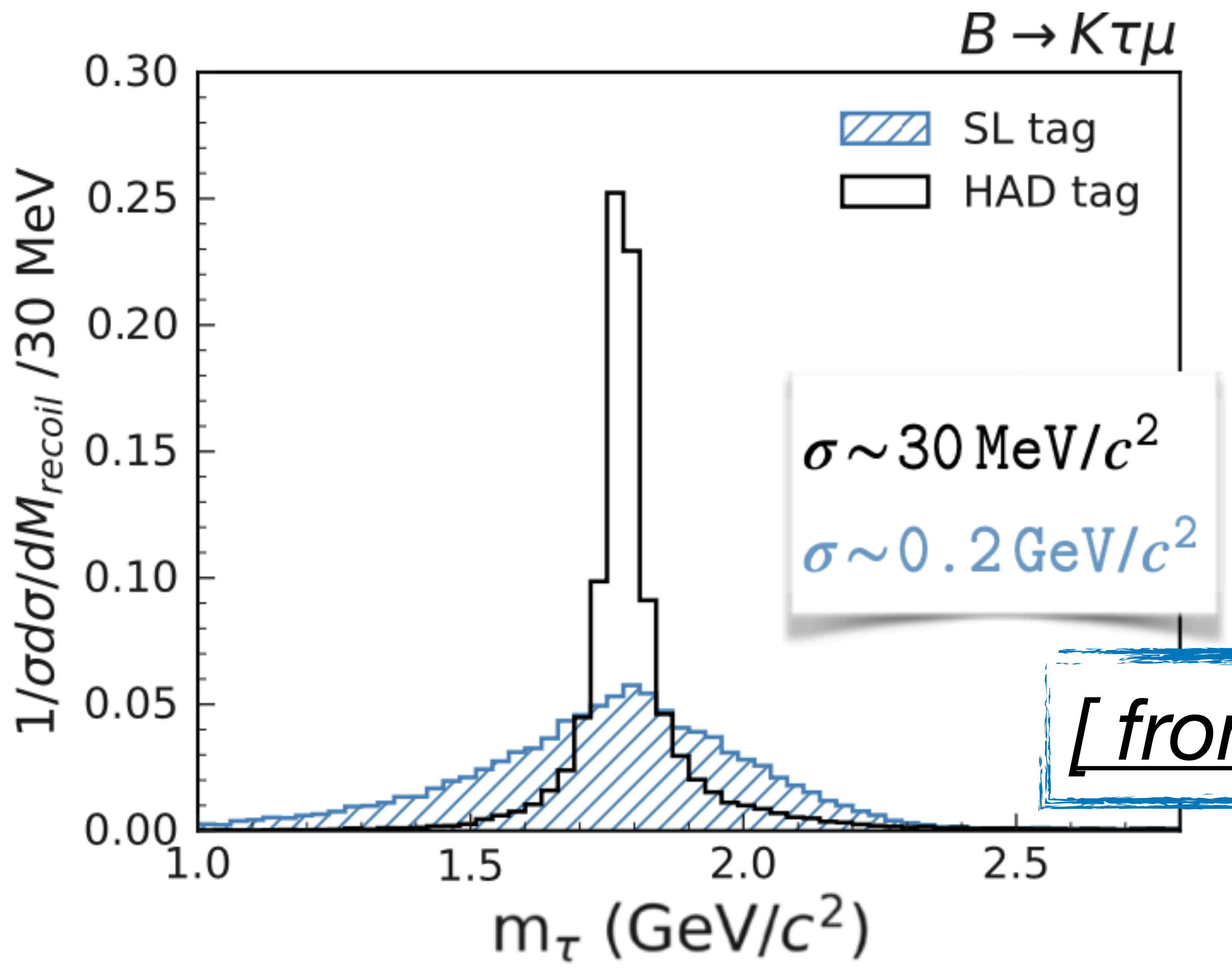
$$p_\tau = p_{e^+e^-} - (p_K + p_\ell + p_{B_{\rm tag}})$$

$$m_\tau^2 = m_B^2 + m_{K\ell}^2 - 2(E_B^* E_{K\ell} + |\vec{p}_B^*||\vec{p}_{K\ell}^*|\cos\theta_{B_{\rm tag},K\ell})$$

replacing $E_B \to E_{beam}, p_B \to p_{B_{tag}}$







[from G. De Marino thesis]

Summary

- Current BR measurements in radiative decays **are on par with world best measurements**
  - few ab^{-1} allow to explore **asymmetries** and improve the NP sensitivity
- $B \to K\nu\bar{\nu}$ is a **unique opportunity** for Belle II, few ab^{-1} allow to observe the decay or access to NP
- Despite $R(K^{(*)})$ anomaly disappeared, $B \to K^*\ell\ell$ measurements prepared the ground for **rare decay searches**:
  - strongly SM suppressed: $B \to K^{(*)}\tau\tau$
  - **LFV** decays: $B \to K^{(*)}\ell\ell'$

Data taking **will resume from winter 2023-24**, with an upgraded detector and improved collider, aiming for more luminosity!

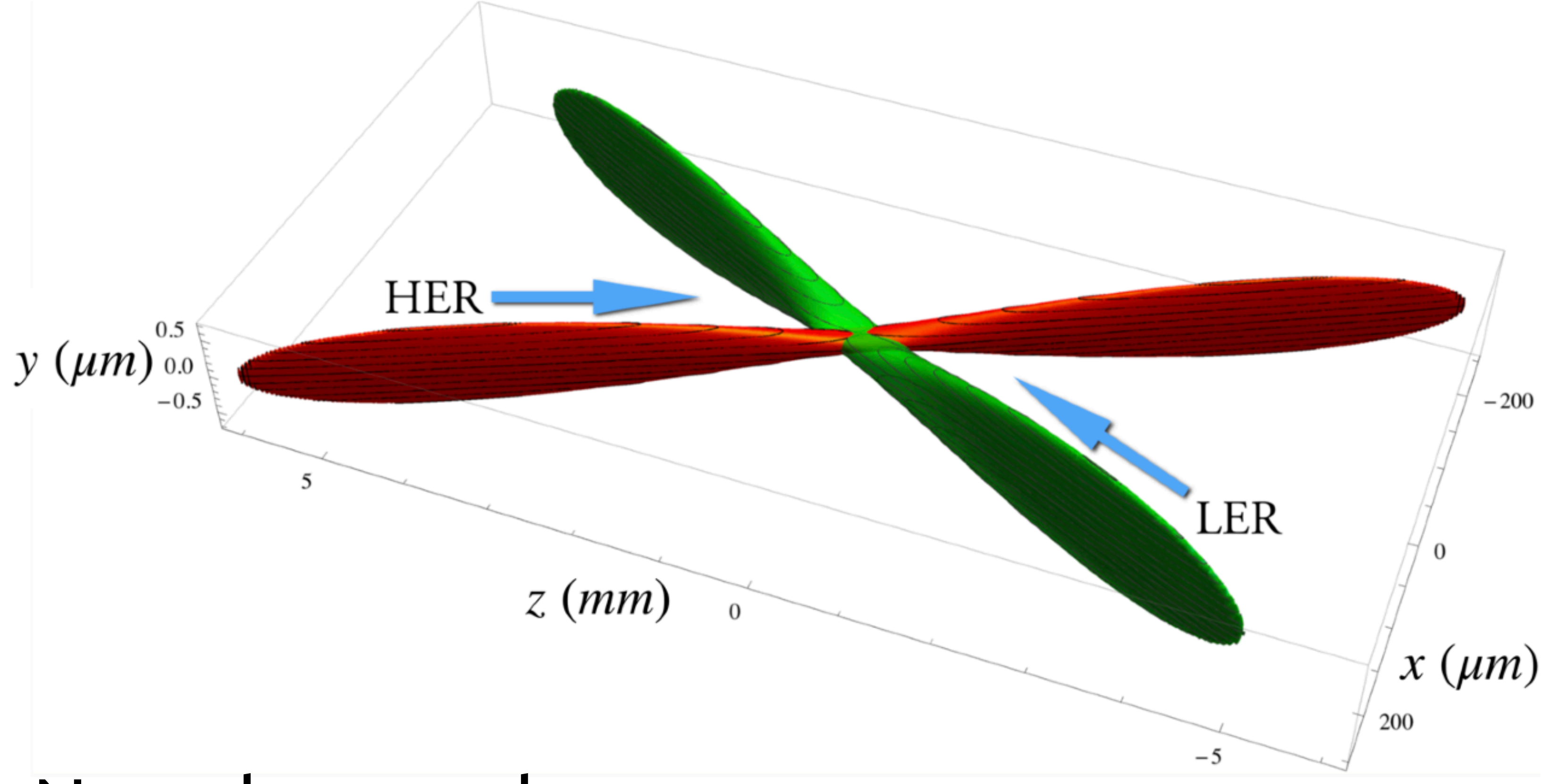
Thank you for your attention!

BACKUP SLIDES

Belle II experiment at SuperKEKB collider

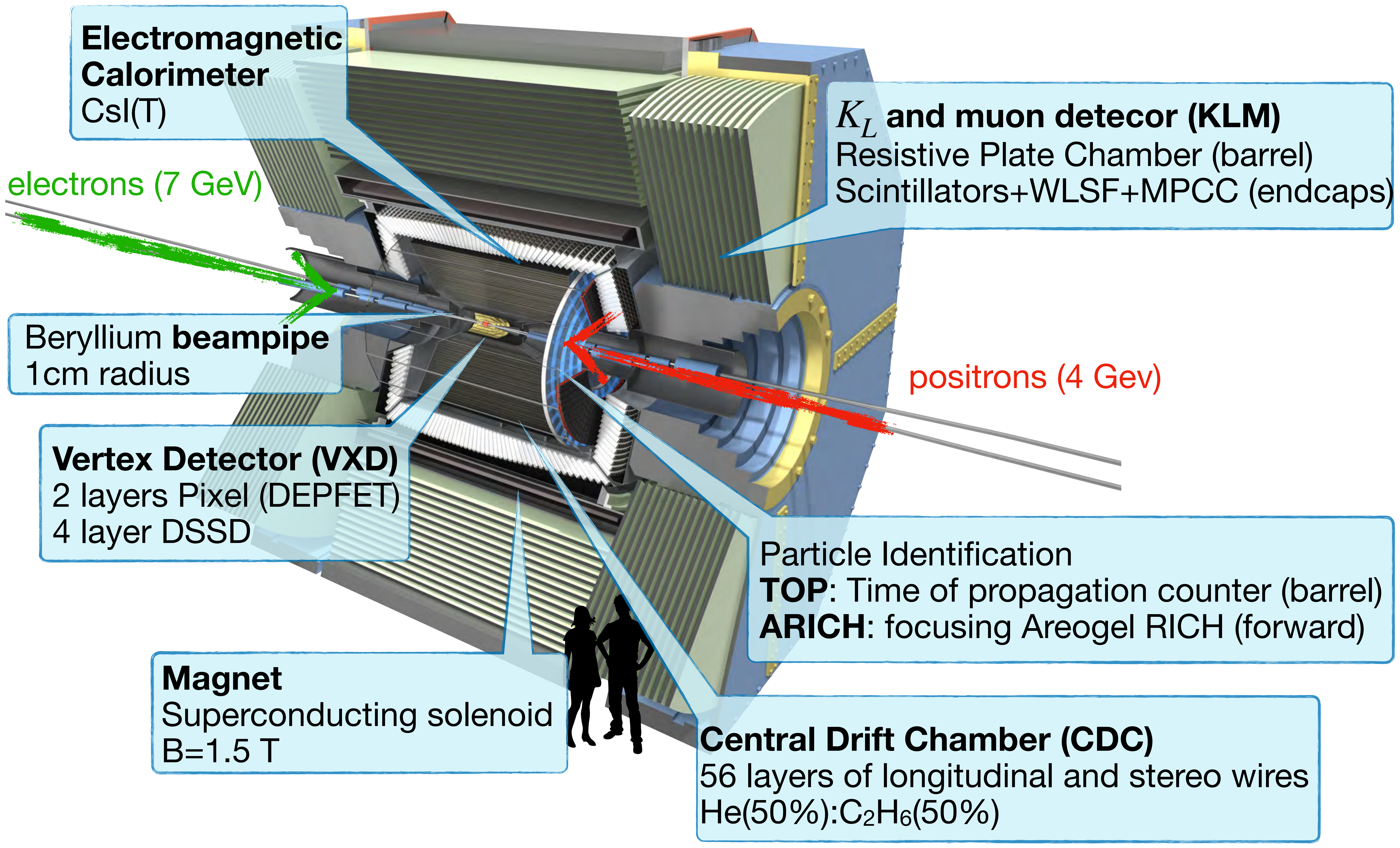
SuperKEKB

- Energy-asymmetric e^+e^- collider
- $\sqrt{s} = m(\Upsilon(4S)) = 10.58\ \text{GeV}$
- Successor of KEKB (1999-2010, KEK, Japan)
- Target peak luminosity: $6 \cdot 10^{35}\ \text{cm}^{-2}\text{s}^{-1}$ (x 30 of KEKB)



Nano-beam scheme:
$250\ \mu\text{m}\ (Z) \times 10\ \mu\text{m}\ (X) \times 50\ \text{nm}\ (Y)$

Belle II



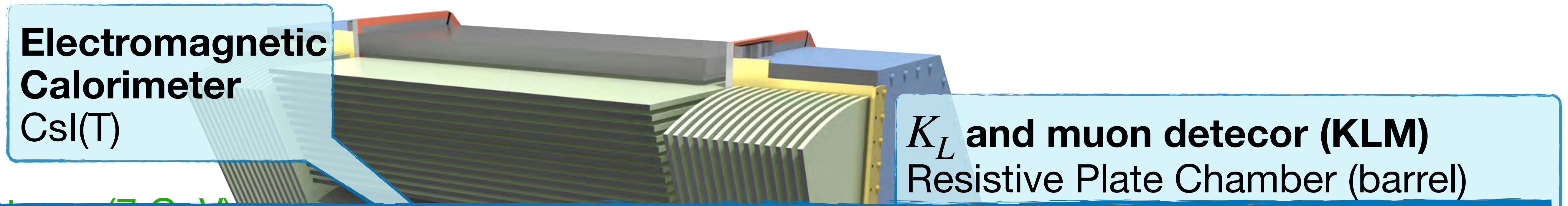
[Belle II Technical Design Report, arXiv:1011.0352]

Belle II experiment at SuperKEKB collider

SuperKEKB

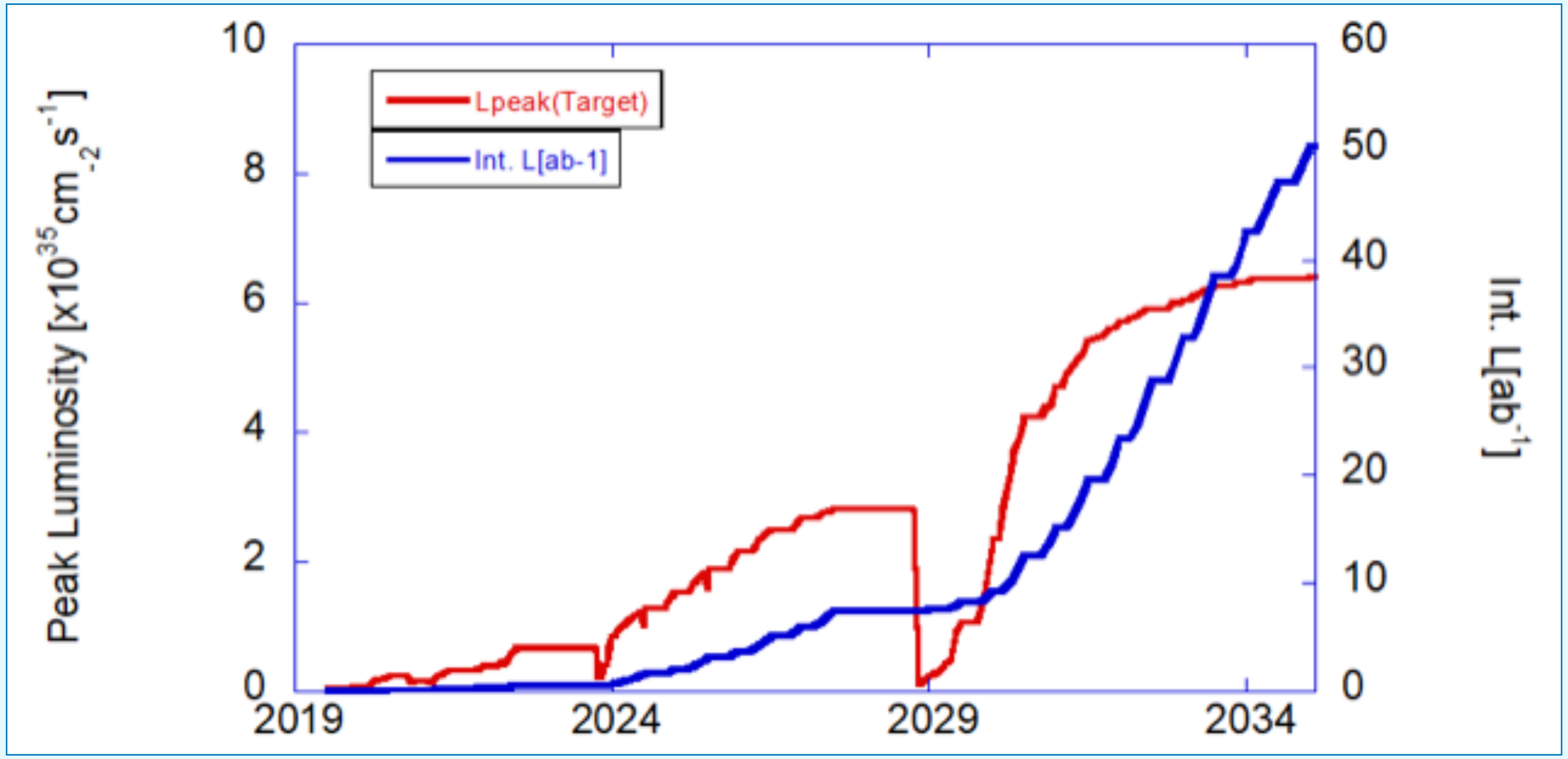
- Energy-asymmetric e^+e^- collider
- $\sqrt{s} = m(\Upsilon(4S)) = 10.58$ GeV

Belle II



Current Status

- complete detector data taking started in 2019
- Current peak luminosity $\mathbf{4.7 \cdot 10^{34}\ cm^{-2}s^{-1}}$ (reached the 22/06/2022)
- current integrated luminosity: $\sim \mathbf{424\ fb^{-1}}$ (~Babar~0.5 Belle)
  - $\sim \mathbf{362\ fb^{-1}}$ at the $\Upsilon(4S)$
- Currently in Long Shutdown 1 (LS1), restart in Winter 2023-24



Long shutdown 1 plans

Long shutdown 1 (LS1): data-taking sopped in July 2022

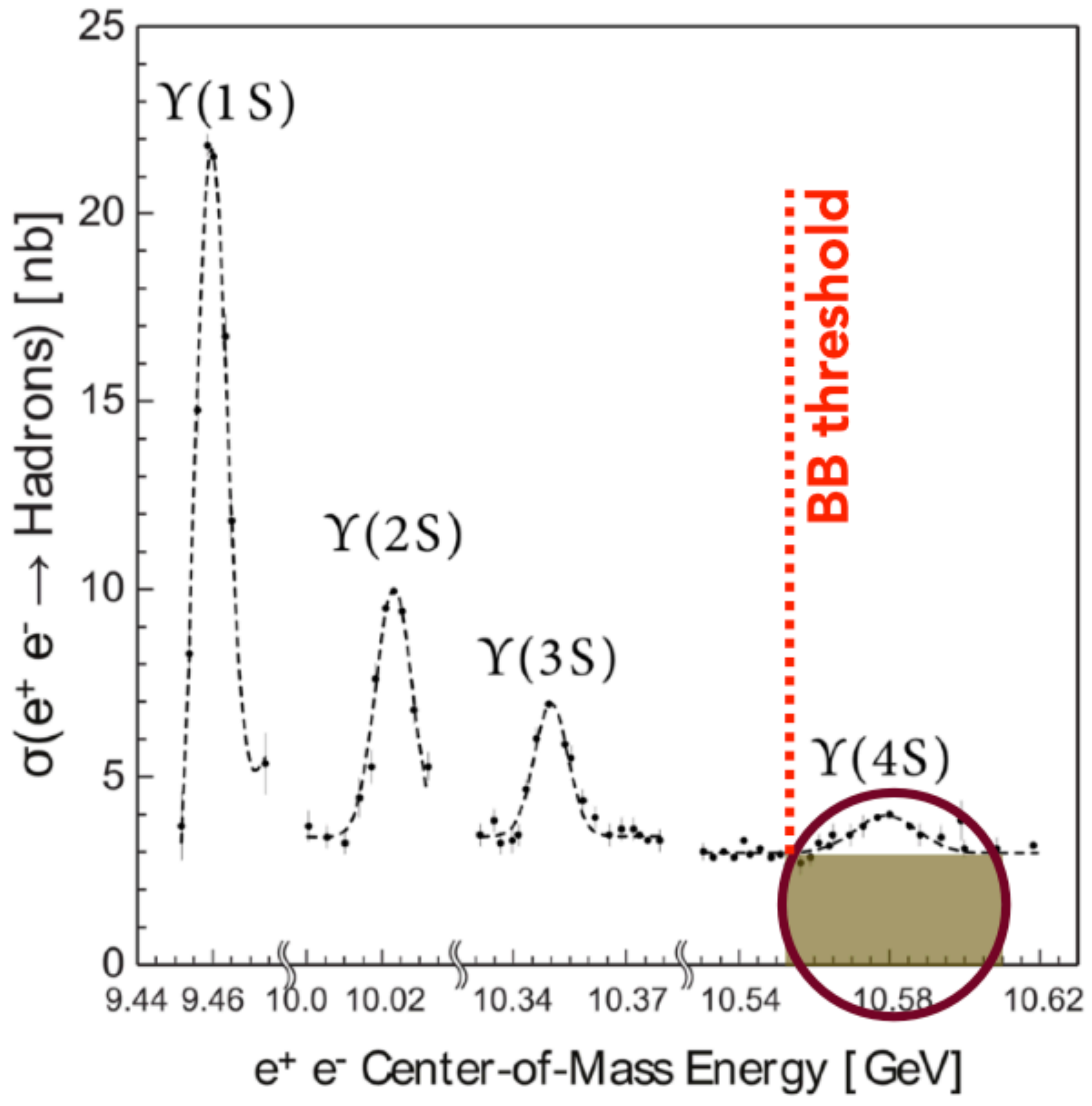
On track to resume data taking in winter!

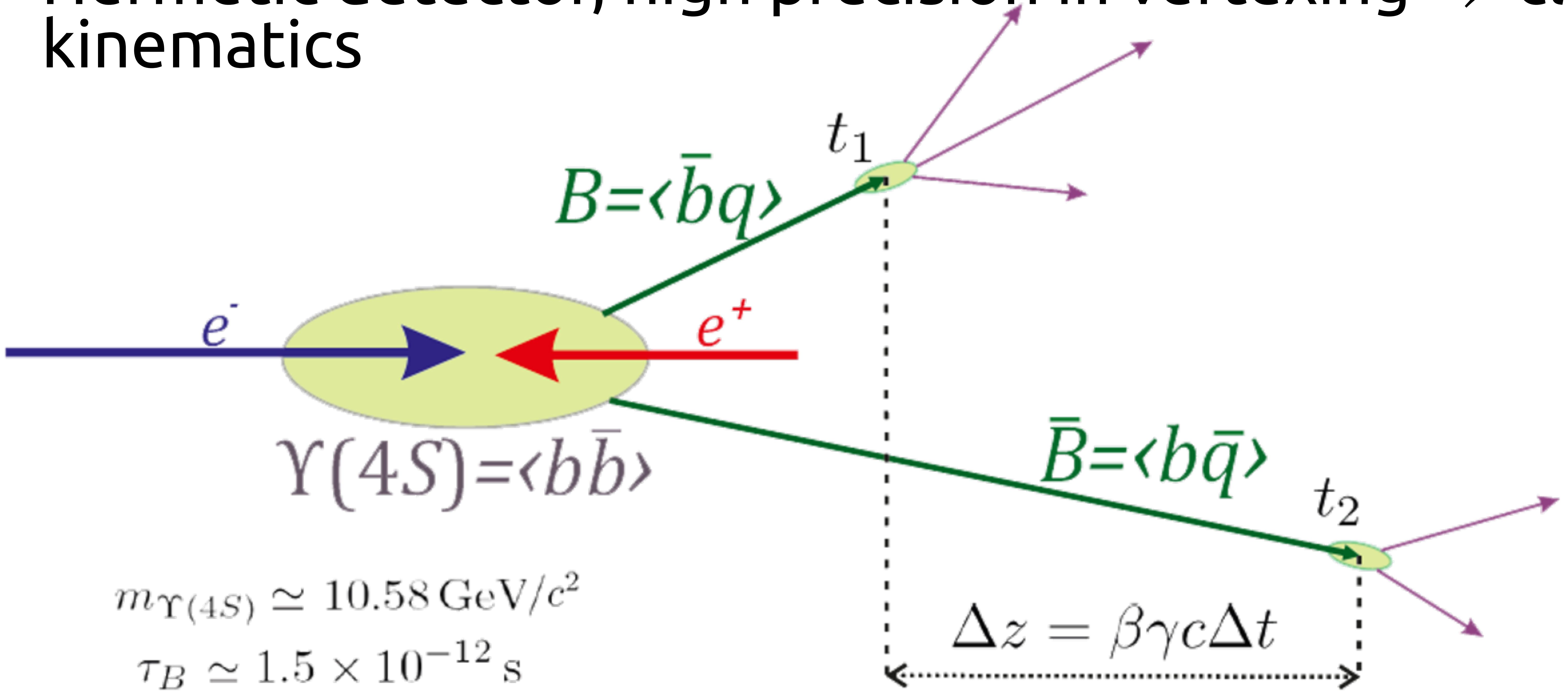
LS1 activities:

- replacement of the **beam-pipe**
- replacement of PMT of central PID detector (**TOP**)
- installation of 2-layer of **pixel detector**
  - shipped to KEK mid-March
  - final test scheduled in April
- improvement of data-quality monitoring and alarm system
- complete transition to new DAQ boards (PCle40)
- replacement of aging components
- additional shielding against beam backgrounds
- accelerator improvements: injection, non linear-collimators, monitoring

B-Factory idea

- Asymmetric collider e^+e^-, $E_{cm} = m(\Upsilon(4S)) = 10.58\ \text{GeV}$ $\Rightarrow$ coherent $B\overline{B}$ pairs
- Boost of center-of-mass ($\beta\gamma = 0.28$)$\Rightarrow$ measure of Δz
- High luminosity $\Rightarrow$ precision measurements
- Hermetic detector, high precision in vertexing $\Rightarrow$ closed kinematics





$m_{\Upsilon(4S)} \simeq 10.58\,\text{GeV}/c^2$

$\tau_B \simeq 1.5 \times 10^{-12}\ \text{s}$

$m_B \simeq 5.279\ \text{GeV}/c^2$

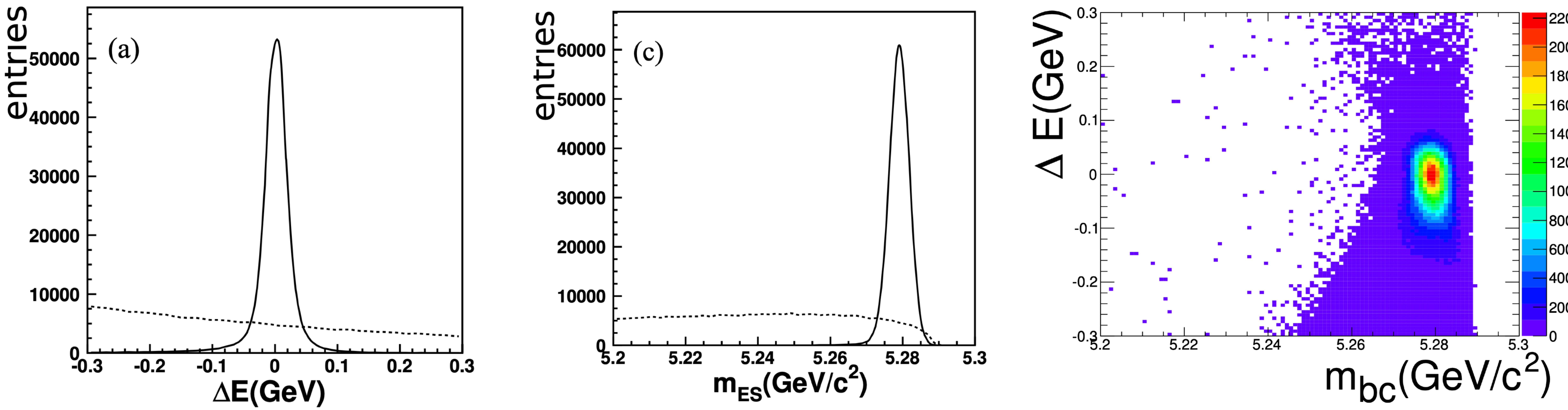
$e^+e^- \to$	Cross section [nb]
$\Upsilon(4S)$	1.05 ± 0.10
$c\bar{c}$	1.30
$s\bar{s}$	0.38
$u\bar{u}$	1.61
$d\bar{d}$	0.40
$\tau^+\tau^-(\gamma)$	0.919
$\mu^+\mu^-(\gamma)$	1.148
$e^+e^-(\gamma)$	300 ± 3

B-Factory variables

- $\Delta E = E^*_B - E^*_{\text{beam}}$
- Expected $\Delta E \simeq 0$ for properly reconstructed signal

- $m_{ES} = M_{bc} = \sqrt{E^{*2}_{\text{beam}} - \vec{p}^{*2}_B}$
- Expected $M_{bc} \simeq m_B$ for properly reconstructed signal

- 2 variable mostly uncorrelated
- tag-signal relation:
  - $E^*_{B_{\text{tag}}} = E^*_{B_{\text{sig}}} = \sqrt{s}/2,$
  - $\vec{p}^*_{B_{\text{tag}}} = -\vec{p}^*_{B_{\text{sig}}}$



Fully inclusive $B \to X_s\gamma$ - extra info

- Photon veto check the compatibility of single-γ events with π^0 and η decays using:
  - invariant mass, angular distibutions, energy, helicity...
- Unfolding: bin-by-bin multiplicative factor based on signal model (Nexp/Ngen)

$$\frac{1}{\Gamma_B}\frac{d\Gamma_i}{dE_\gamma^B} = \frac{\mathcal{U}_i \times (N_i^{\text{DATA}} - N_i^{\text{BKG, MC}} - N_i^{B\to X_d\gamma})}{\varepsilon_i \times N_B},$$

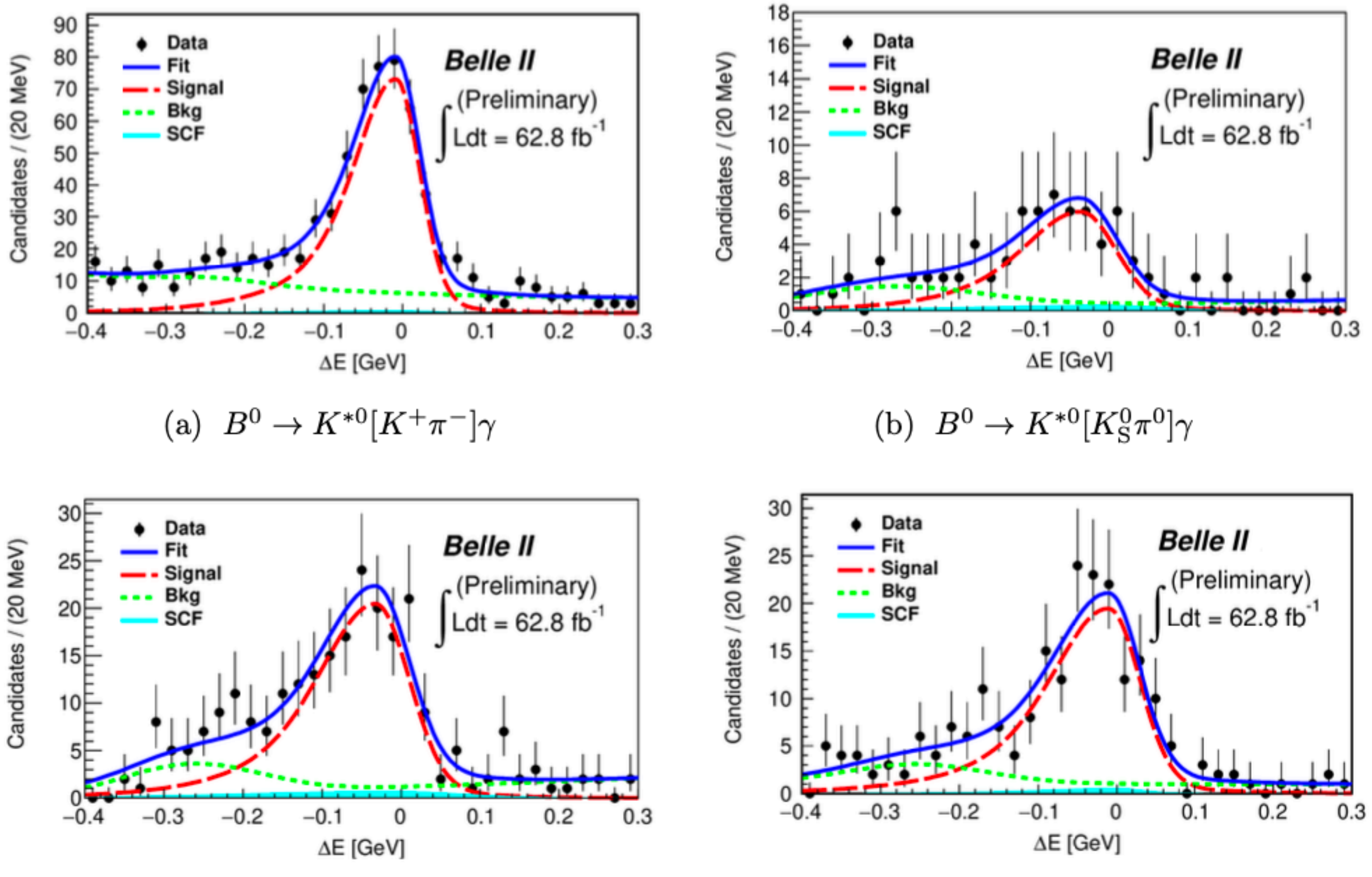
- Signal MC: BTOXGAMMA with the addition of $B \to K^*\gamma$

E_γ^B [GeV]	$\frac{1}{\Gamma_B}\frac{d\Gamma_i}{dE_\gamma^B}(10^{-4})$	Statistical	Systematic	Fit procedure	Signal efficiency	Background modelling	Other
1.8 – 2.0	0.48	0.54	0.64	0.42	0.03	0.49	0.09
2.0 – 2.1	0.57	0.31	0.25	0.17	0.06	0.17	0.07
2.1 – 2.2	0.13	0.26	0.16	0.13	0.01	0.11	0.01
2.2 – 2.3	0.41	0.22	0.10	0.07	0.05	0.04	0.02
2.3 – 2.4	0.48	0.22	0.10	0.06	0.06	0.02	0.05
2.4 – 2.5	0.75	0.19	0.14	0.04	0.09	0.02	0.09
2.5 – 2.6	0.71	0.13	0.10	0.02	0.09	0.00	0.04

$B \to K^*\gamma$ - extra info

Table III. Relative systematic uncertainties (in %) for the branching fraction measurement.

Source	$K^{*0}[K^+\pi^-]\gamma$	$K^{*0}[K^0_S\pi^0]\gamma$	$K^{*+}[K^+\pi^0]\gamma$	$K^{*+}[K^0_S\pi^+]\gamma$
No. of $B\overline{B}$ events	1.6	1.6	1.6	1.6
Photon selection	$^{+0.2}_{-0.4}$	$^{+0.2}_{-0.4}$	$^{+0.2}_{-0.4}$	$^{+0.2}_{-0.4}$
π^0/η veto	3.8	3.8	3.8	3.8
Pion identification	0.6	—	—	0.6
Kaon identification	0.8	—	0.8	—
K^0_S reconstruction	—	2.4	—	2.4
π^0 selection	—	3.4	3.4	—
Tracking efficiency	1.4	1.4	0.7	1.4
MVA selection	2.0	6.0	2.0	4.0
MC statistics	0.2	0.5	0.3	0.3
PDF shape parameters	1.0	$^{+7.4}_{-5.4}$	$^{+2.4}_{-3.1}$	$^{+0.6}_{-1.4}$
Misreconstructed signal	1.5	$^{+6.8}_{-7.2}$	$^{+4.7}_{-5.9}$	$^{+2.5}_{-3.1}$
Total	5.3	$^{+13.2}_{-12.4}$	$^{+7.9}_{-8.9}$	$^{+7.0}_{-7.3}$



(a) $B^0 \to K^{*0}[K^+\pi^-]\gamma$

(b) $B^0 \to K^{*0}[K^0_S\pi^0]\gamma$

(c) $B^+ \to K^{*+}[K^+\pi^0]\gamma$

(d) $B^+ \to K^{*+}[K^0_S\pi^+]\gamma$

helicity angle definition: angle between the K from K* and the B, in the $K\pi$ rest frame

$B \to K^* \ell\ell$ extra info

systematic uncertainties

Source	Systematic (%)
Kaon identification	0.4
Pion identification	2.5
Muon identification	$^{+1.9}_{-0.8}$
Electron identification	$^{+0.9}_{-0.5}$
K_S^0 identification	2.0
π^0 identification	3.4
Tracking	1.2 – 1.5
MVA selection	1.3 – 1.7
Simulated sample size	< 0.5
Signal cross feed	< 1%
Signal PDF shape	0.5 – 1.0%
$\mathcal{B}(\Upsilon(4S) \to B^+B^-)[(\mathcal{B}(\Upsilon(4S) \to B^0\overline{B^0}))$	1.2
Number of $B\overline{B}$ pairs	2.9
Total	$^{+6.7}_{-6.0}$

Yields:

μ : 22 ± 6

e: 18 ± 6

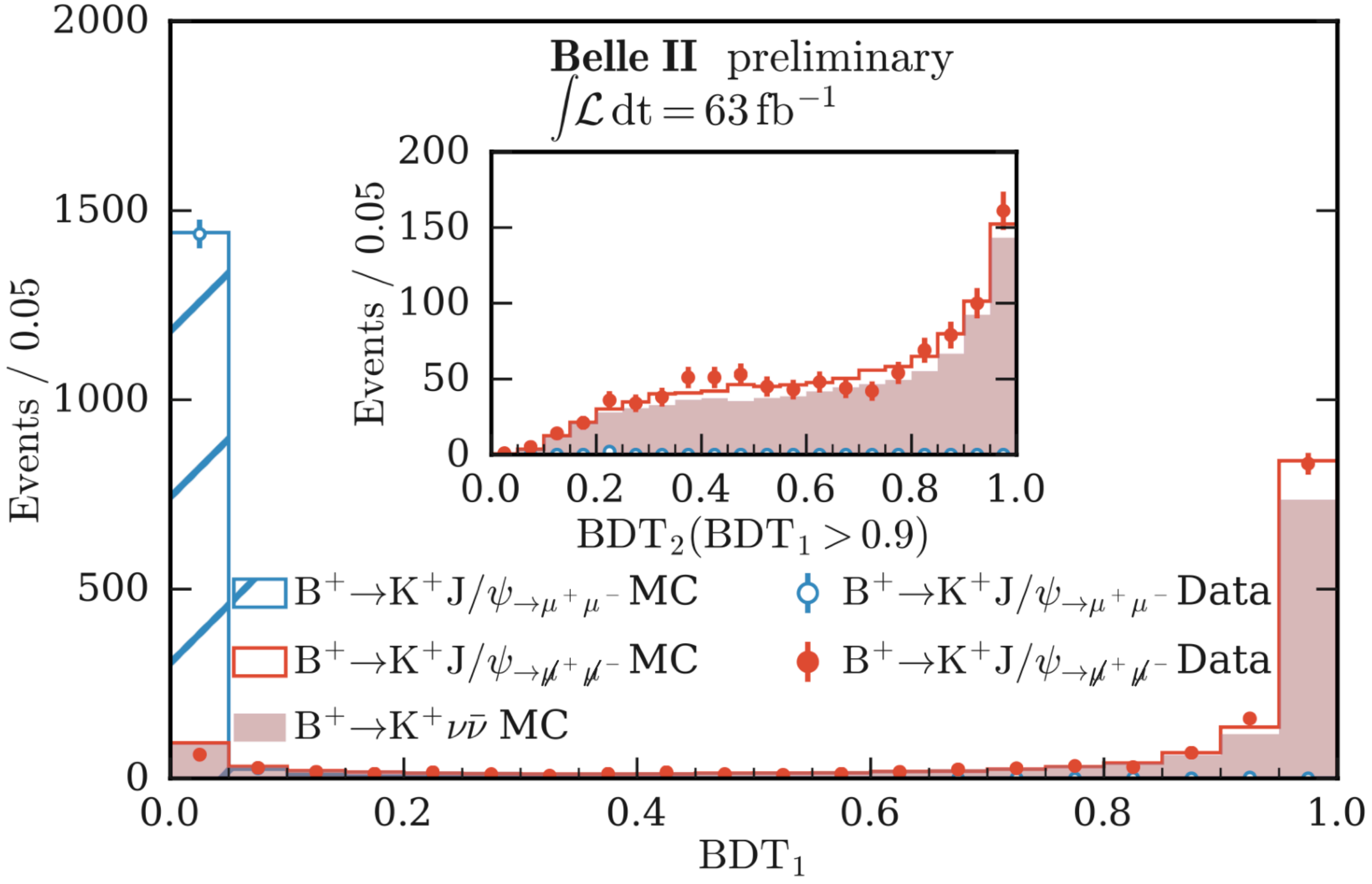
ℓ: 38 ± 9

$B^{0,+} \to J/\psi(\to \ell\ell)K_S^{0,+}$ - extra info

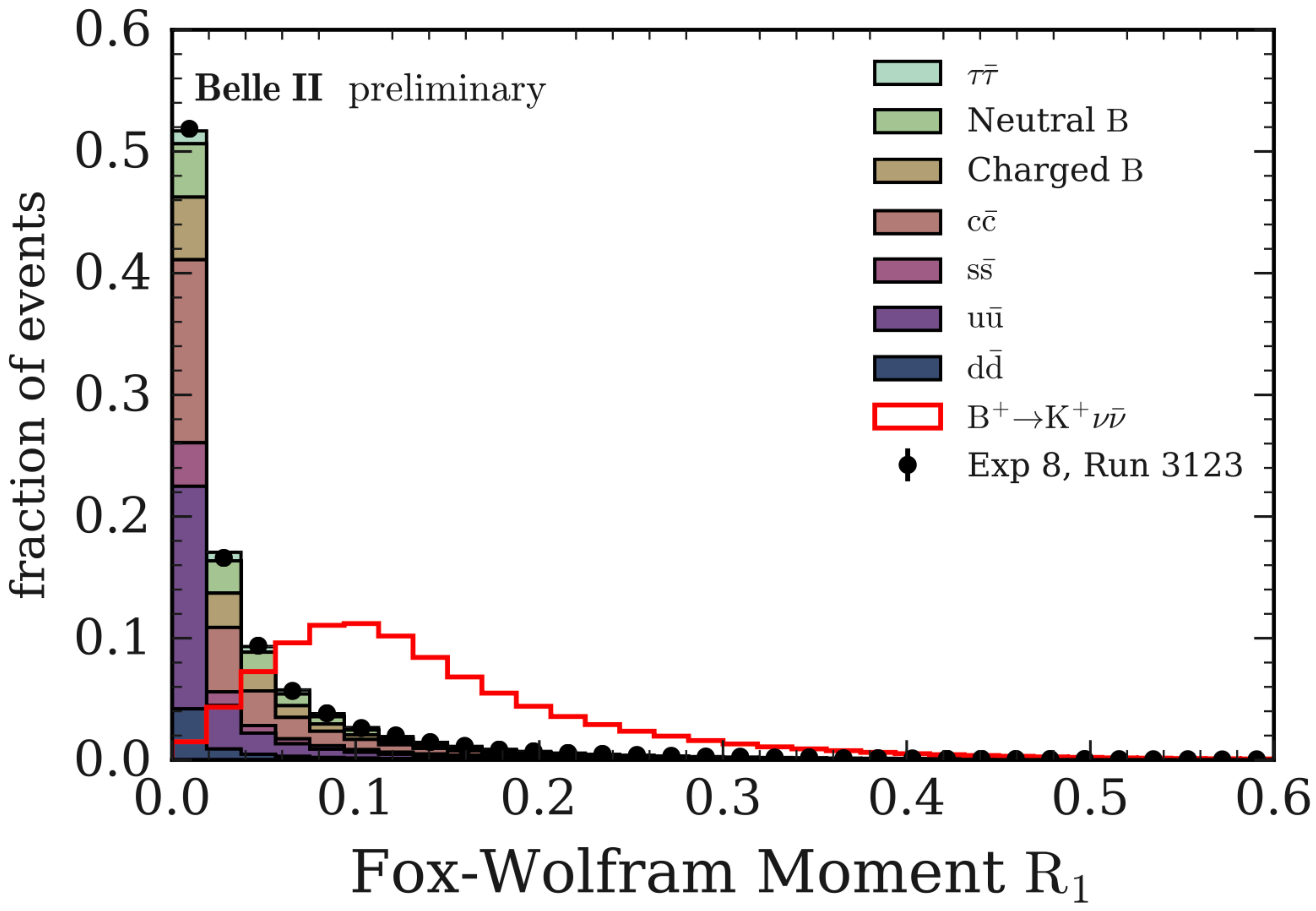
Table III. Relative systematic uncertainties (%) on $\mathcal{B}(B \to J/\psi K)$, $R_K(J/\psi)$, and absolute uncertainty on $A_I(B \to J/\psi K)$.

Source	$\mathcal{B}(B \to KJ/\psi)$				R_K		A_I	
	K^+	K^+	K_S^0	K_S^0	K^+	K^0		
	e^+e^-	$\mu^+\mu^-$	e^+e^-	$\mu^+\mu^-$			e^+e^-	$\mu^+\mu^-$
Number of $B\overline{B}$ events	1.5	1.5	1.5	1.5	–	–	–	–
PDF shape	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1
Electron identification	0.6	–	0.6	–	0.6	0.6	–	–
Muon identification	–	0.4	–	0.4	0.4	0.4	–	–
Kaon identification	0.2	0.2	–	–	–	–	0.1	0.1
K_S^0 reconstruction	–	–	3.0	3.0	–	–	1.5	1.5
Tracking efficiency	0.9	0.9	1.2	1.2	–	–	0.4	0.4
Simulation sample size	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
$\Upsilon(4S)$ branching fraction	2.6	2.6	2.6	2.6	–	–	2.6	2.6
(τ_{B^+}/τ_{B^0})	–	–	–	–	–	–	0.2	0.2
Total	3.2	3.2	4.4	4.4	0.8	0.8	3.0	3.0

$B^+ \to K^+\nu\bar{\nu}$ extra information



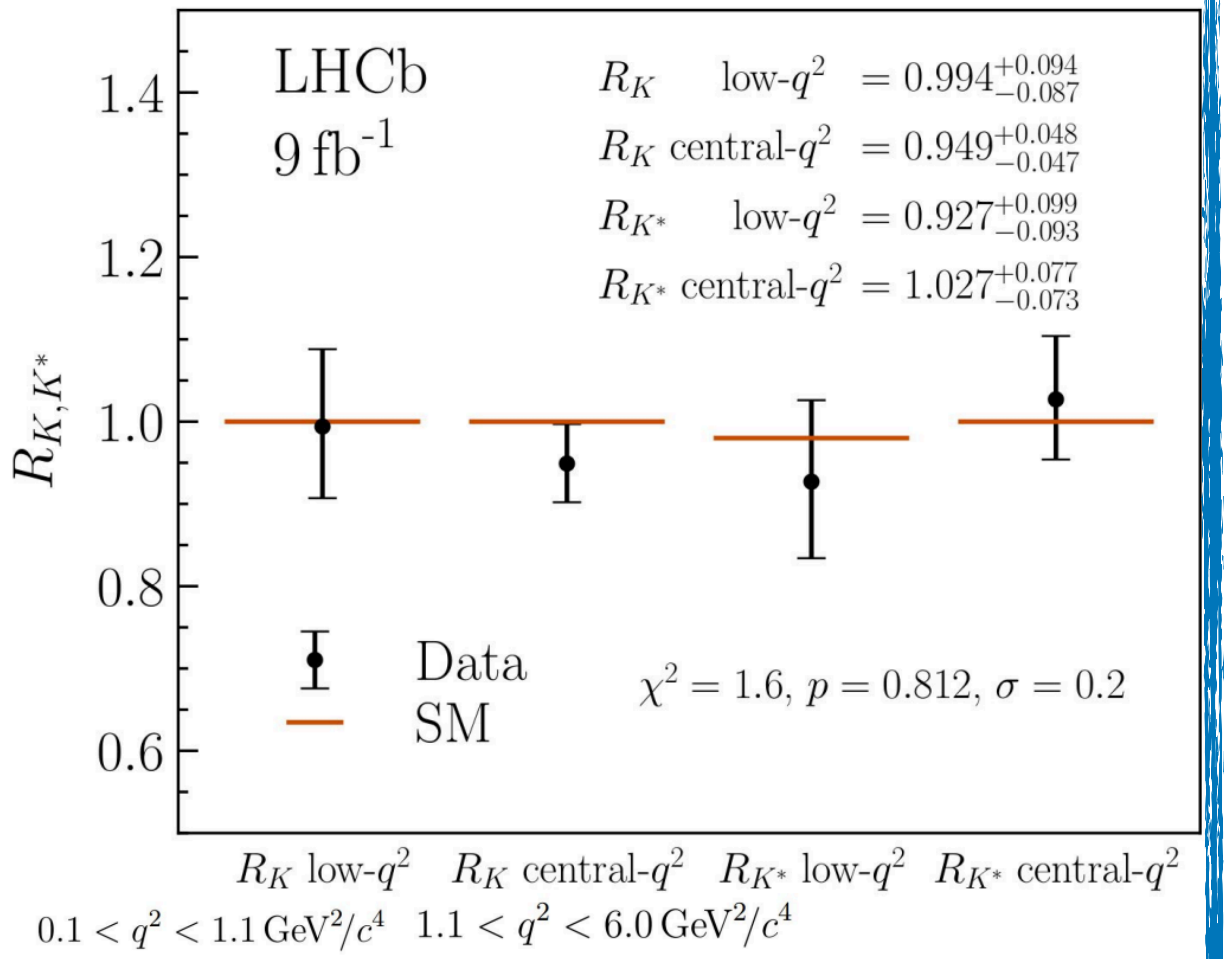
example of discrimination variable

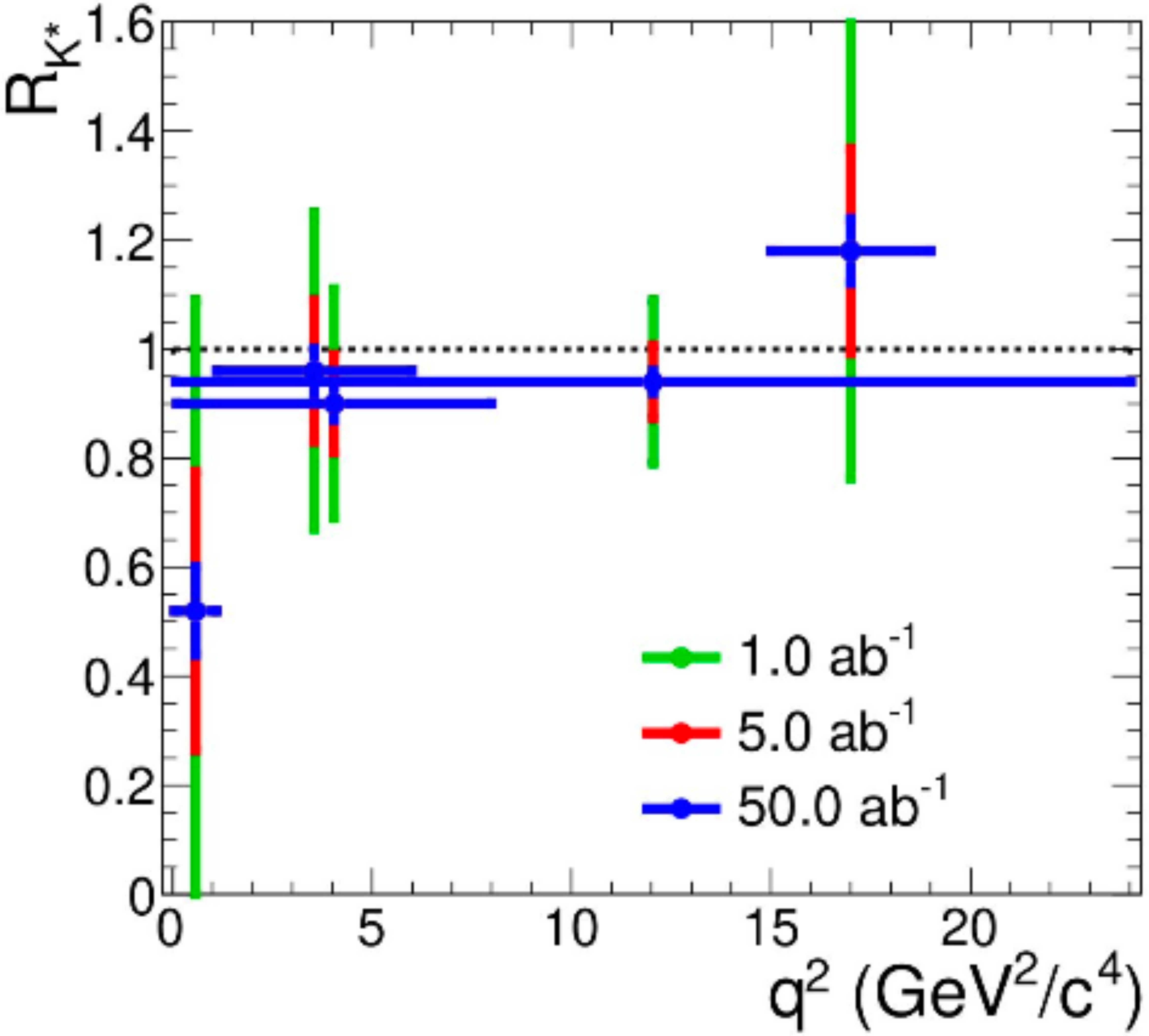


$R(K^*)$ prospects

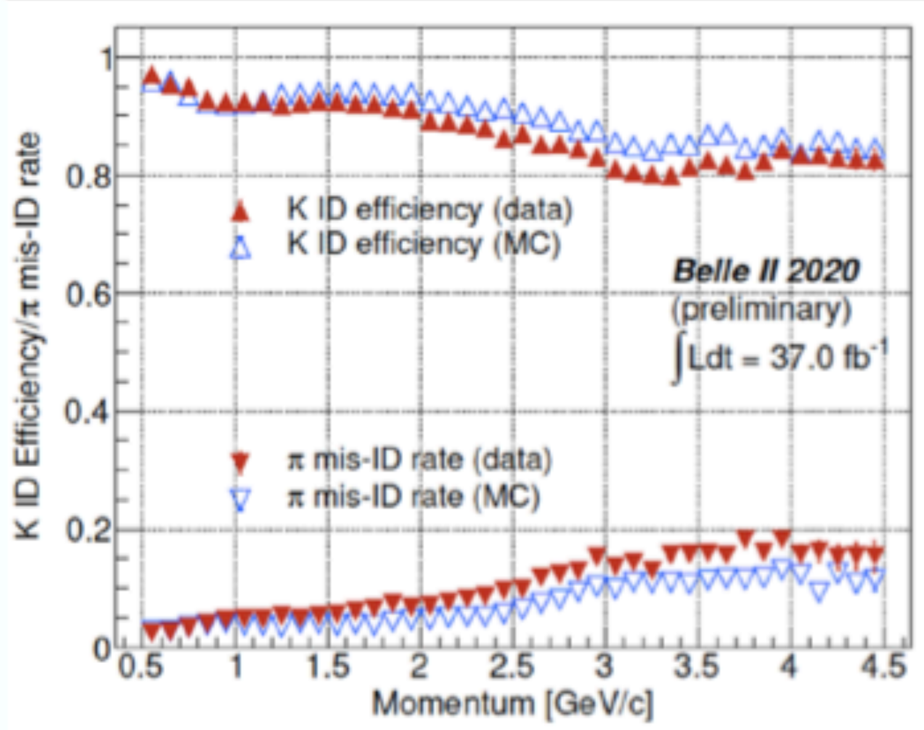
- Given recent LHCb result, there is an excellent agreement with SM
- Currently Belle II is not competitive
- Uncertainties dominated by statistics

[LHCb reference: arXiv:2212.09153]

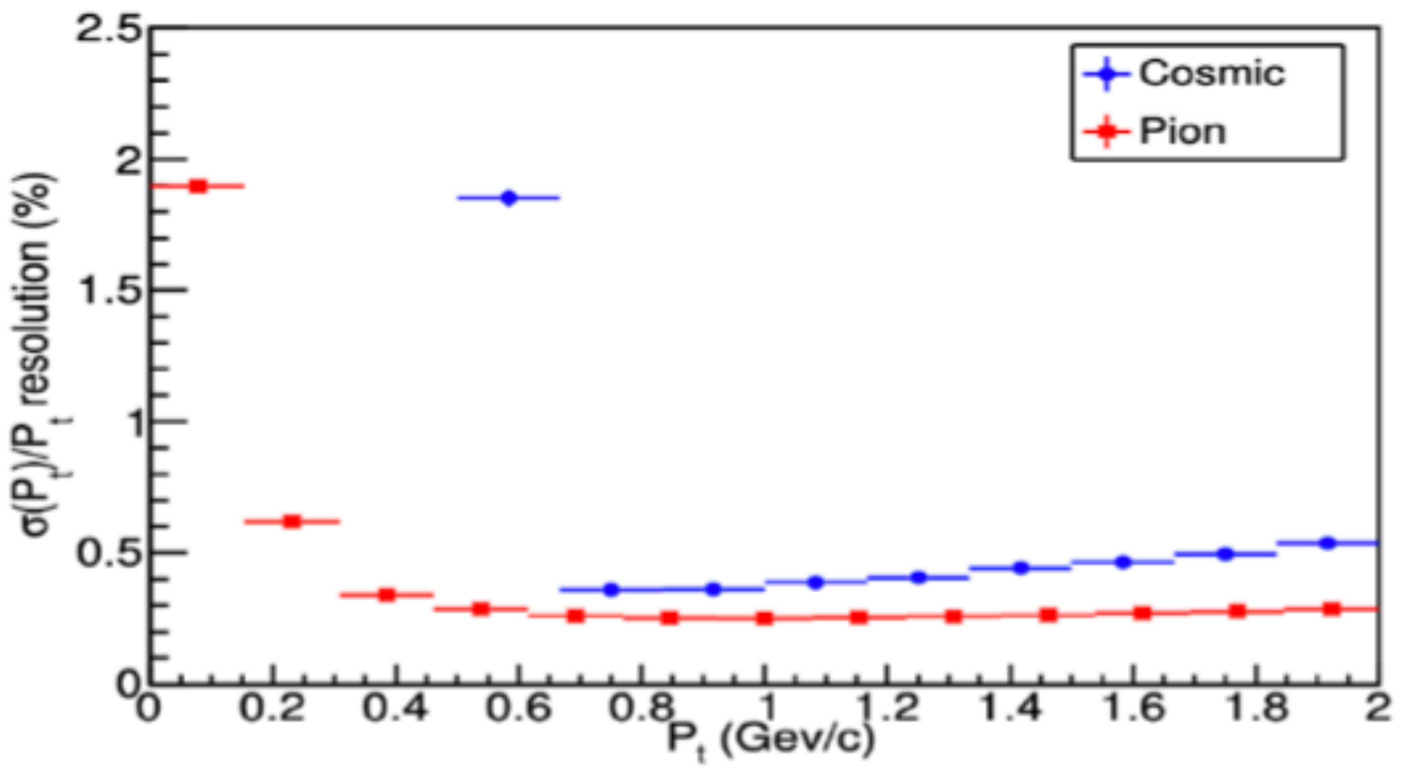




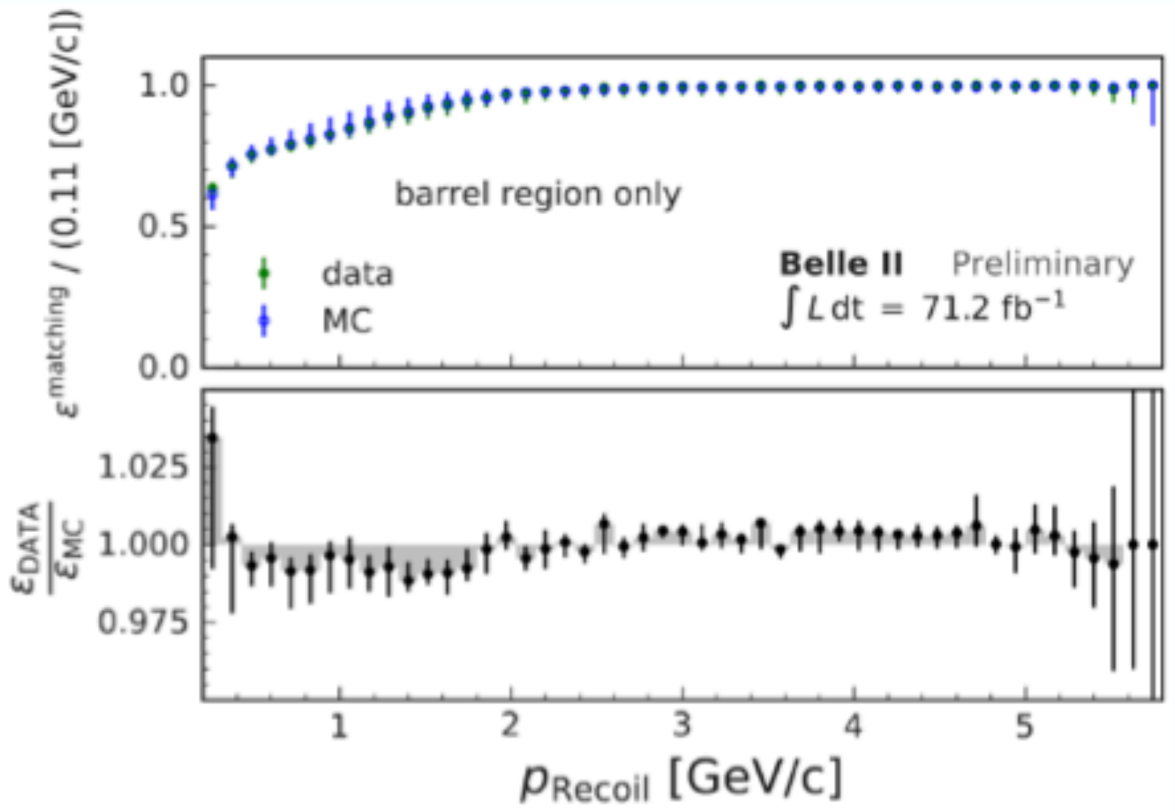
Belle II performance



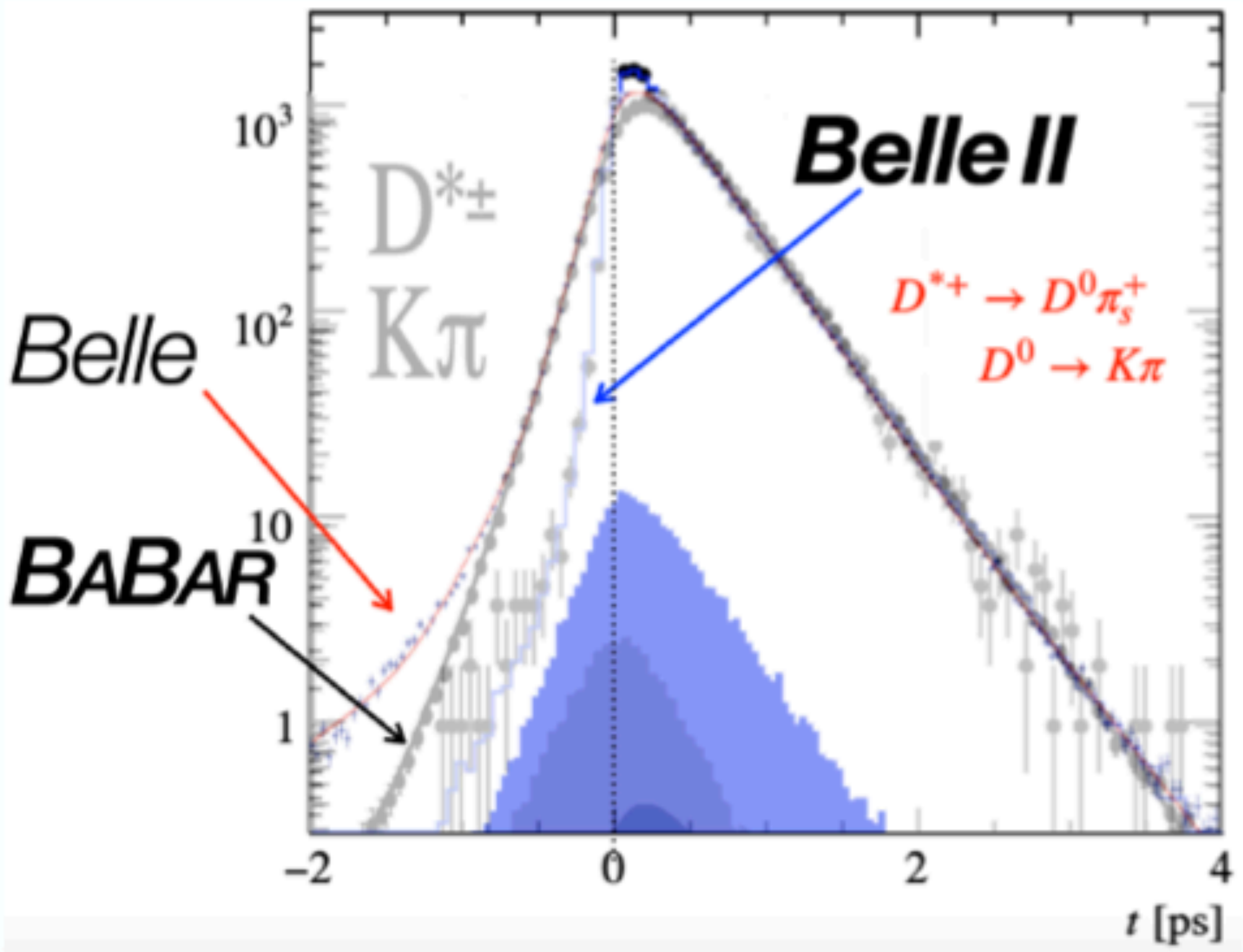
PID still 20% worse than Belle but improving



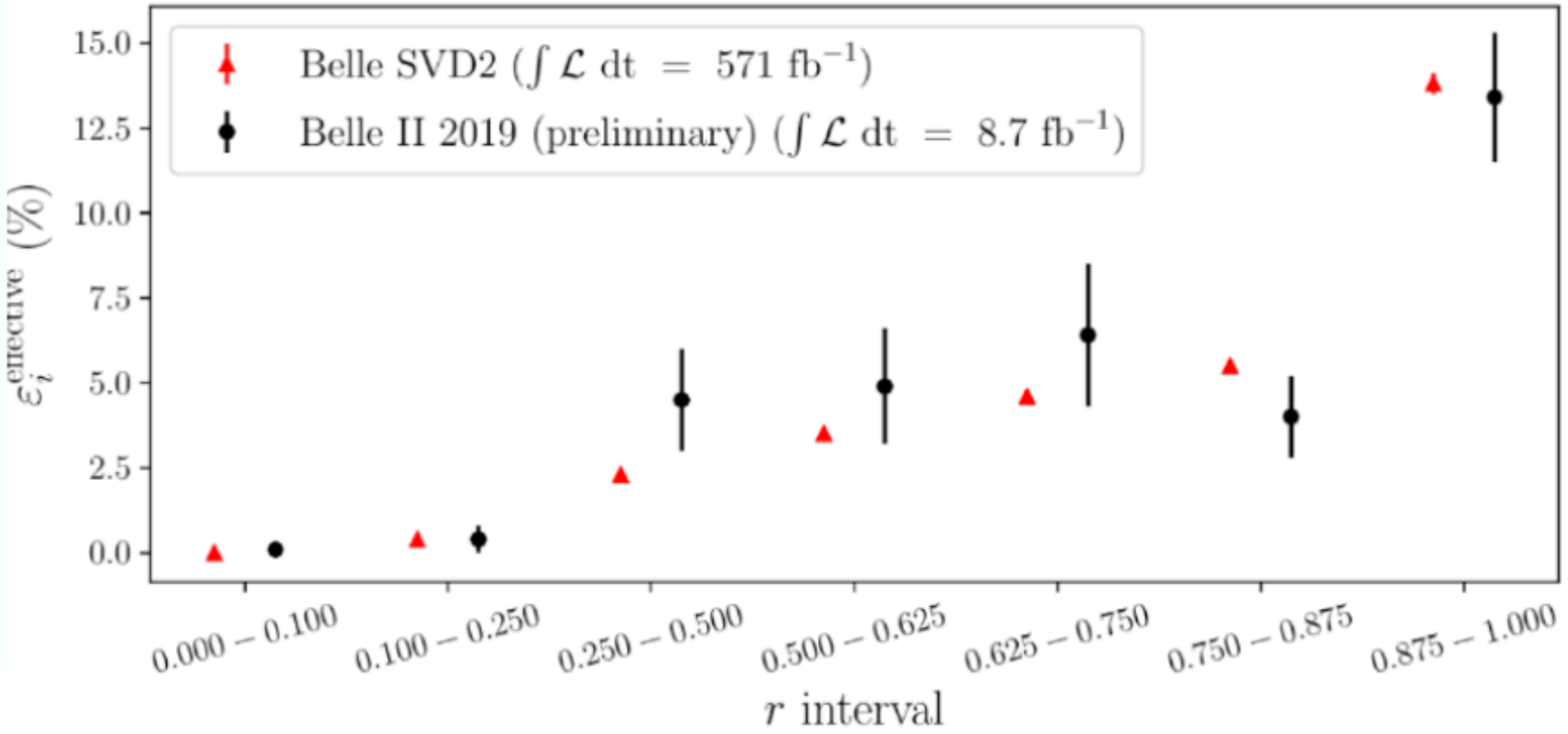
Momentum resolution 20% better than Belle



High photon efficiency,



Nearly 2x better decay-time resolution than Belle



Tagging performance similar to Belle and improving

[From D. Tonelli]