Electroweak penguins and radiative decays at Belle II

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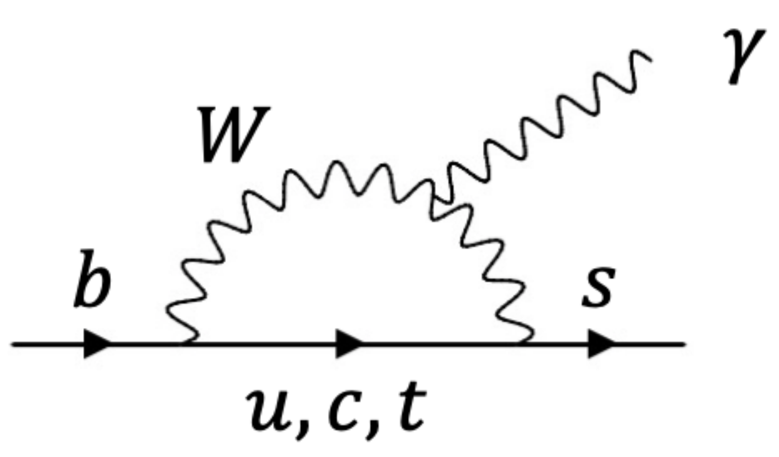
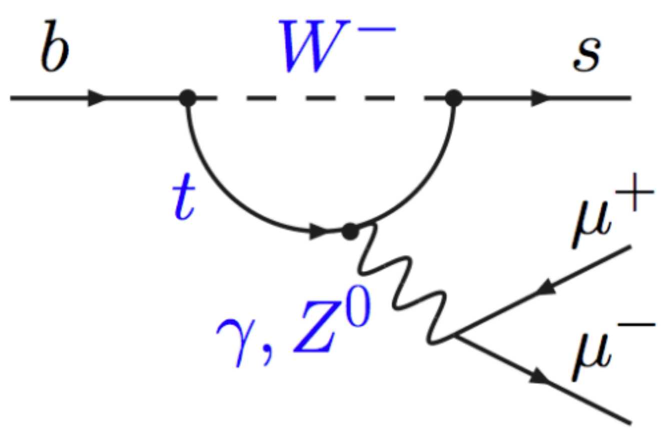
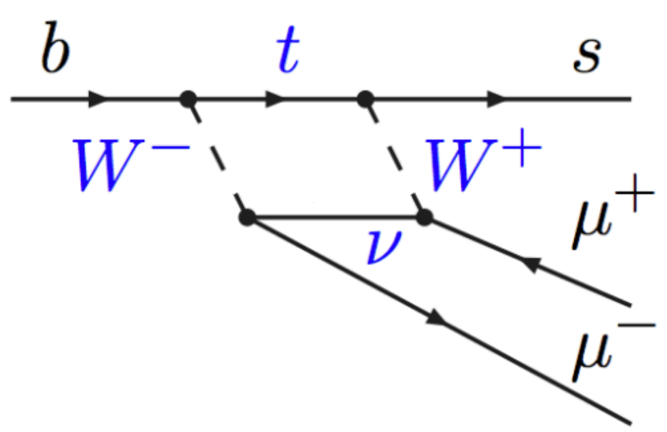
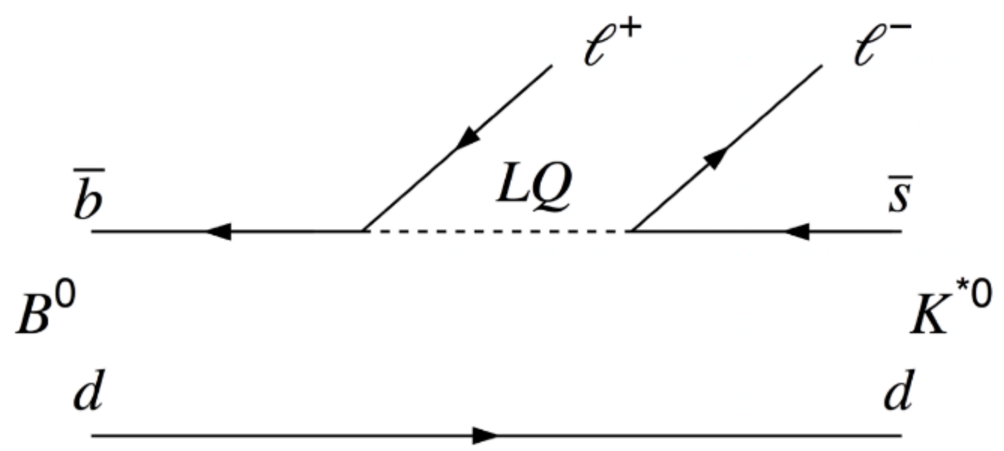
Electroweak and radiative penguins





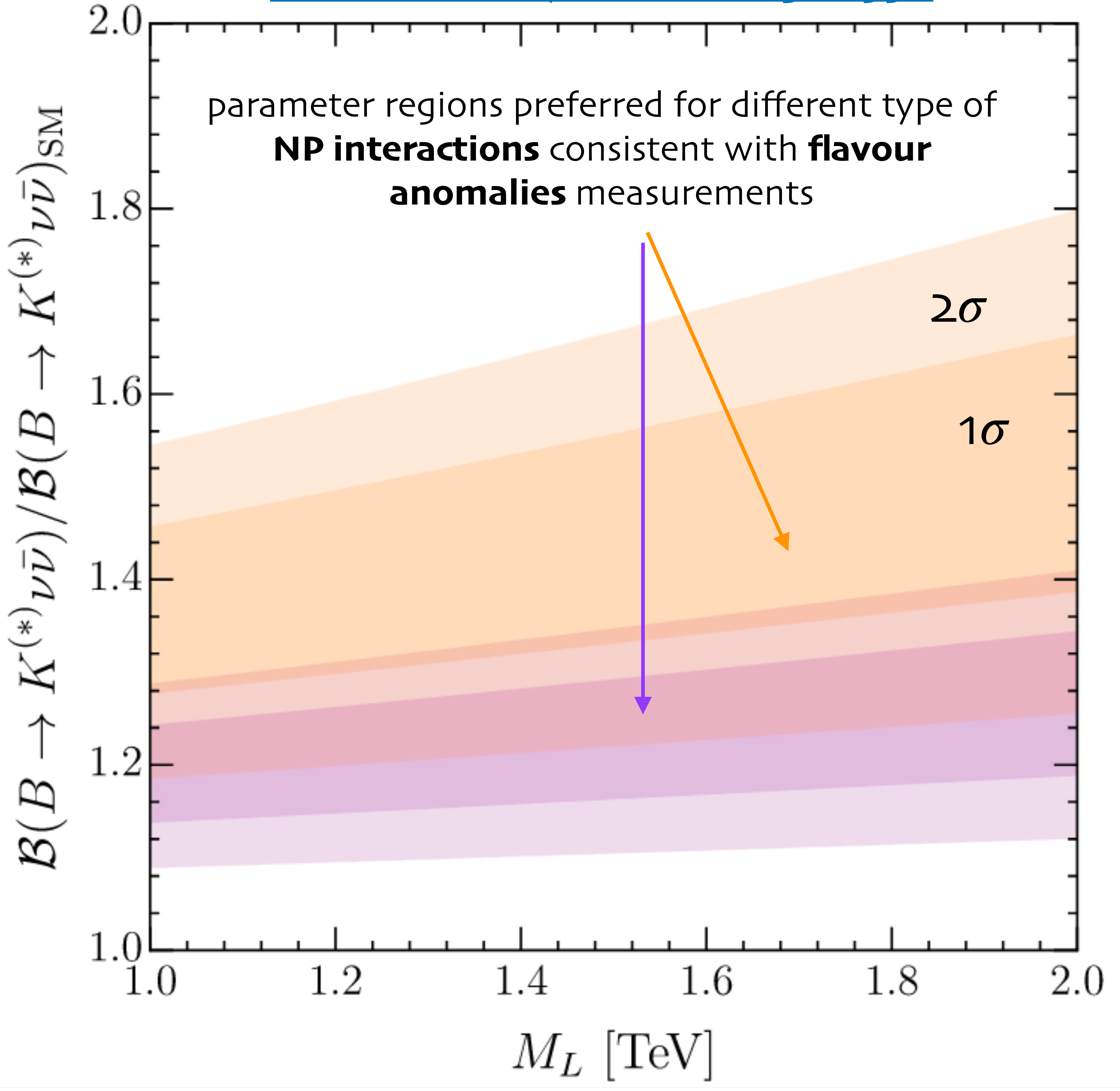


- b➝s transition: Flavour Changing Neutral Current prohibited @ tree level in the standard model (SM):
  - 10^{-7} - 10^{-5} predicted BF, with 10-30% uncertainties (dominated by soft QCD effects)
  - more accurate precisions for angular observables, asymmetries and ratios



- New Physics (NP) can enter as:
  - new mediators in loop and box or new tree level diagrams
  - new sources of missing energy (e.g. in b➝$s\nu\bar{\nu}$)
- Can modify rates, asymmetries, angular distributions ➝ variety of interesting channels and measurable

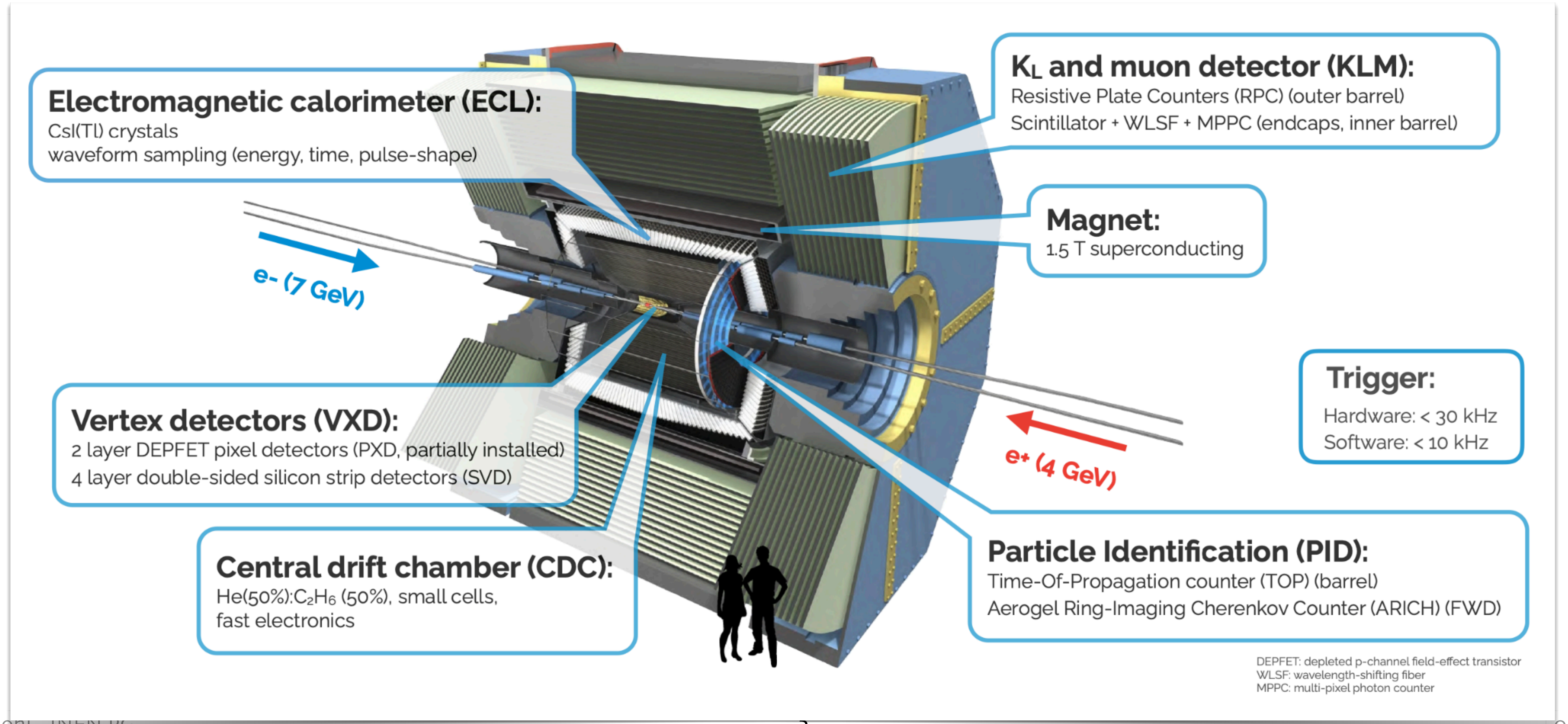
Cornella et al, arXiv:2103.16558



BelleII @ SuperKeKB (I)

- SuperKeKB and Belle II detector already described by previous Belle II speakers
- From Apr 2019 to Dec 2021:
  - 268 fb^{-1} "on-resonance data" collected at the $\Upsilon(4S)$ mass
  - 18 fb^{-1} "off-resonance" data collected 60 MeV below

Will show today results with 63 fb^{-1} or 190 fb^{-1}



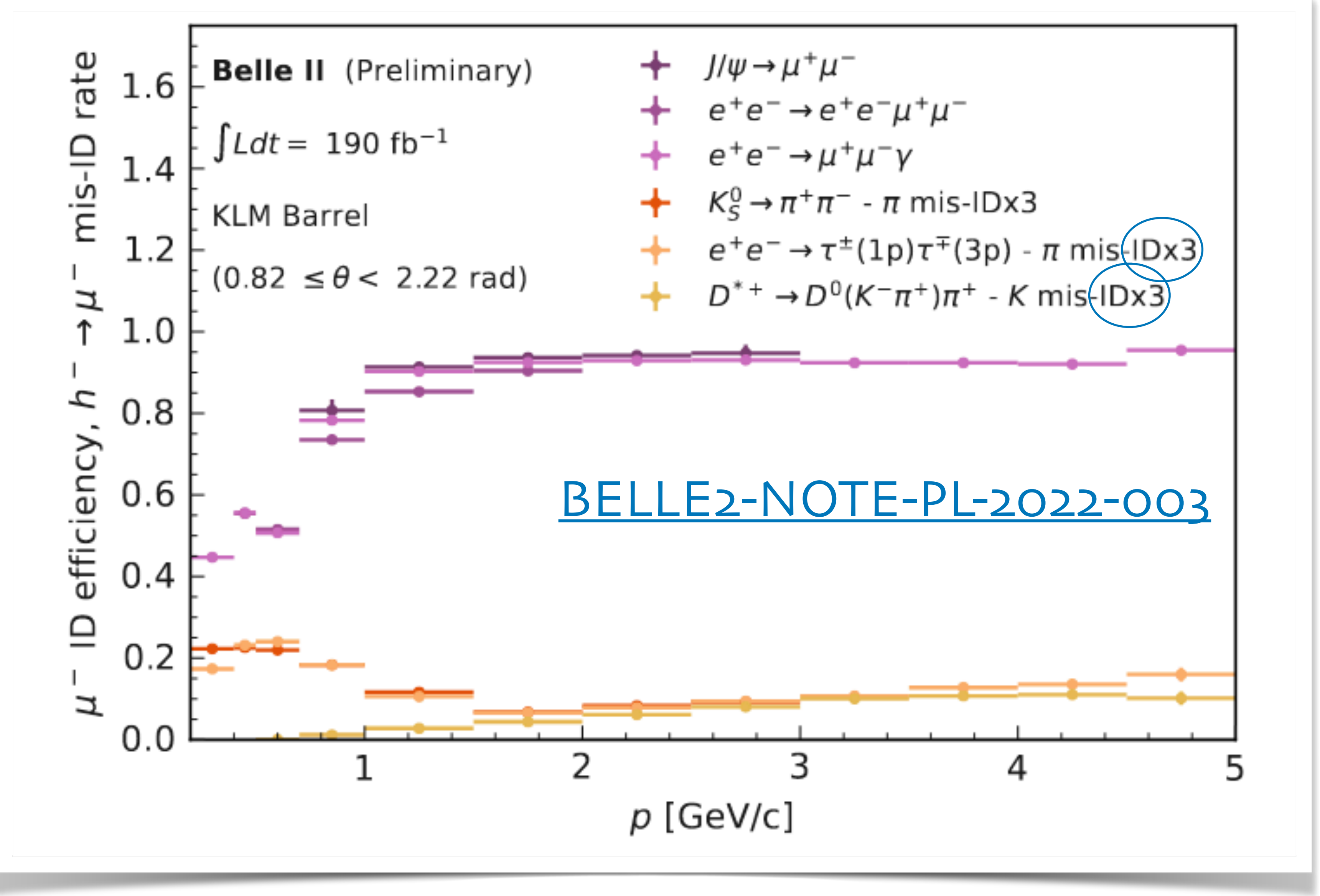
BelleII @ SuperKeKB (II)

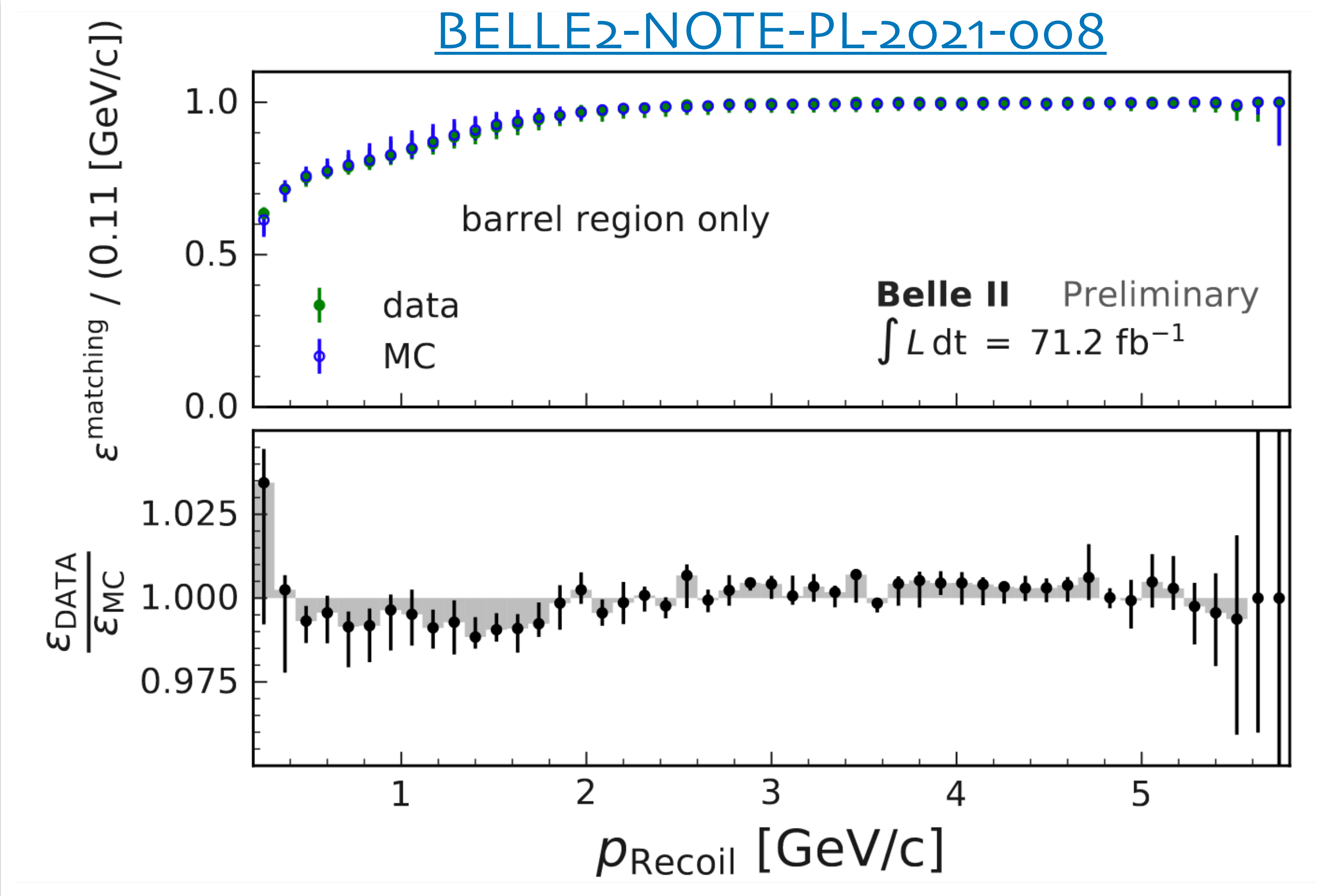
- A glance to Belle II performances relevant to analysis presented in this talk:

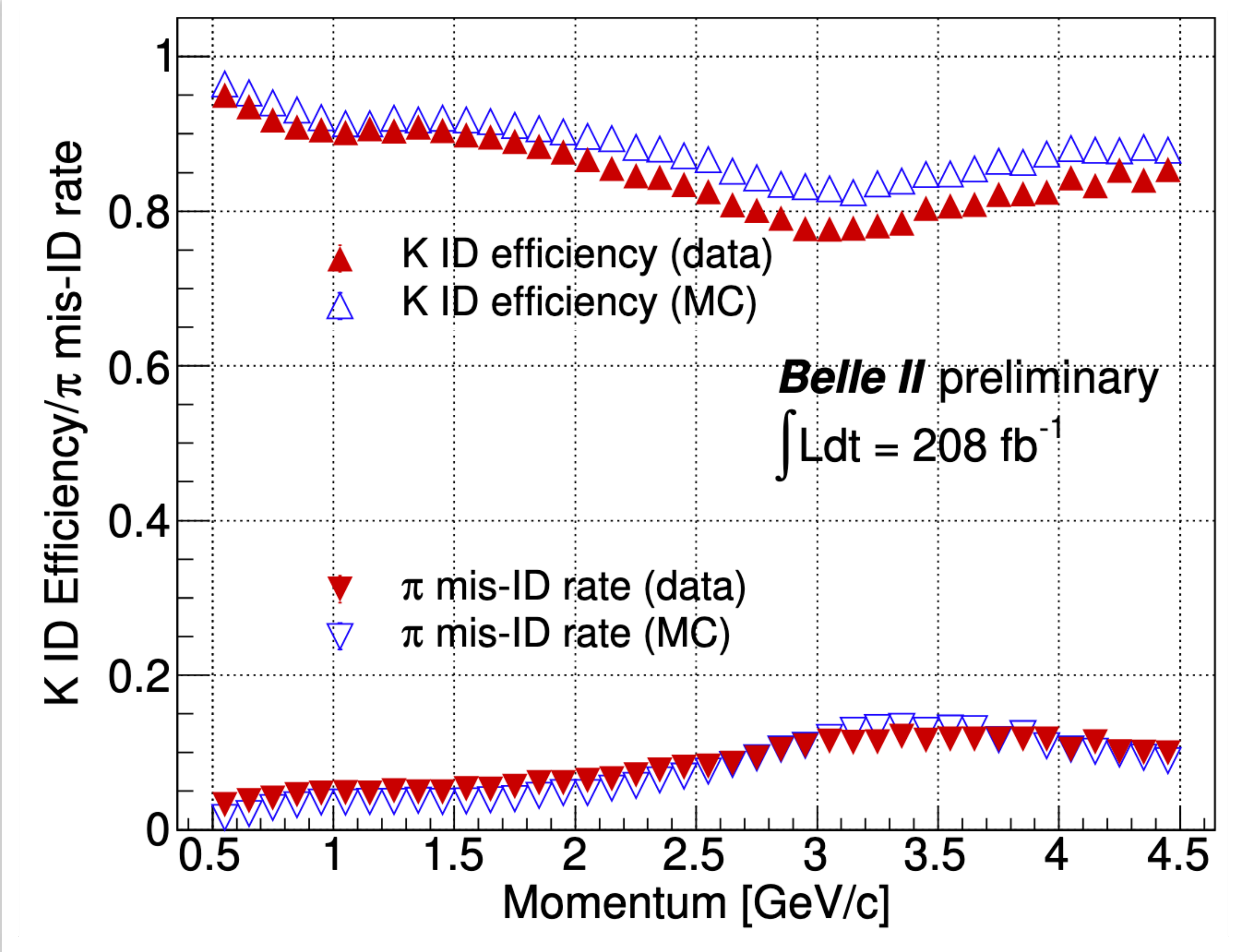
Good Lepton ID, Muon/ Electron-ID over/under performing wrt Belle, improvements in progress

High photon detection efficiency, Belle-like resolution π^0 mass

Good kaon identification, underperforming wrt Belle, improvements in progress







LFU violation in b→$s\ell\ell$ final states and Belle II contribution

- State of the art: 3.1σ evidence for LFU violation by LHCb

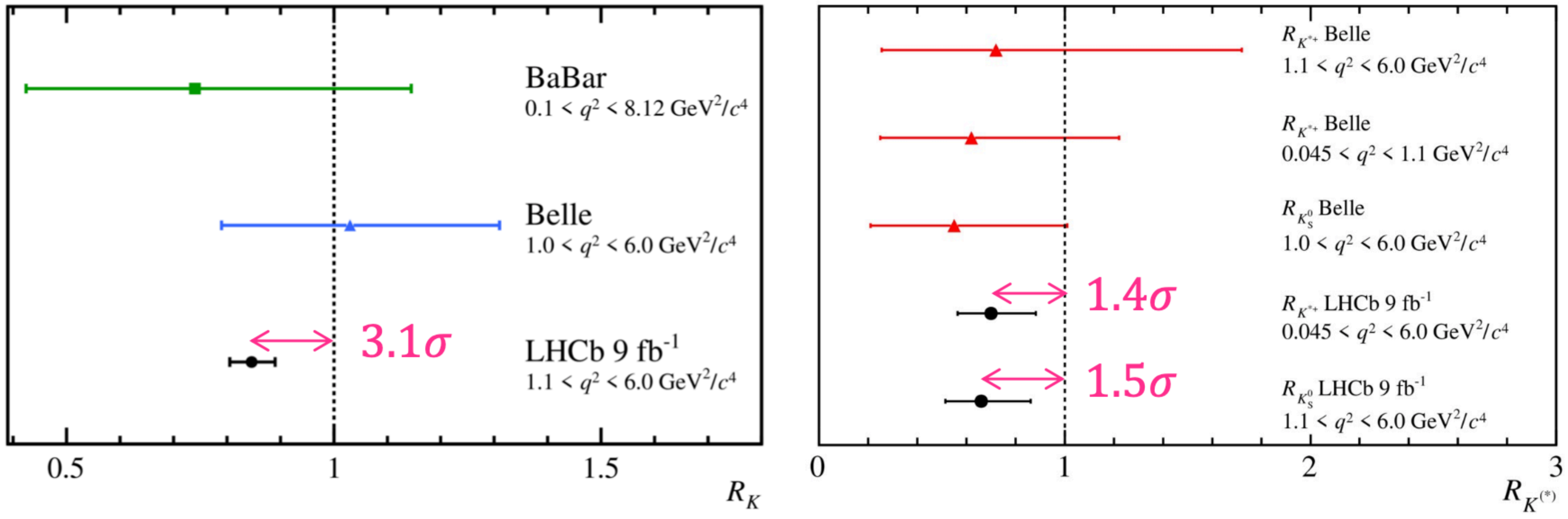
SM

$$R(K^{(*)}) = \frac{\mathcal{B}(B \to K^{(*)}\mu^+\mu^-)}{\mathcal{B}(B \to K^{(*)}e^+e^-)} = 1 \pm \mathcal{O}(10^{-2})$$

$q^2 \in [1(1.1), 6]$ for $R(K^{(*)})$

JHEP 2018, 93 (2018)

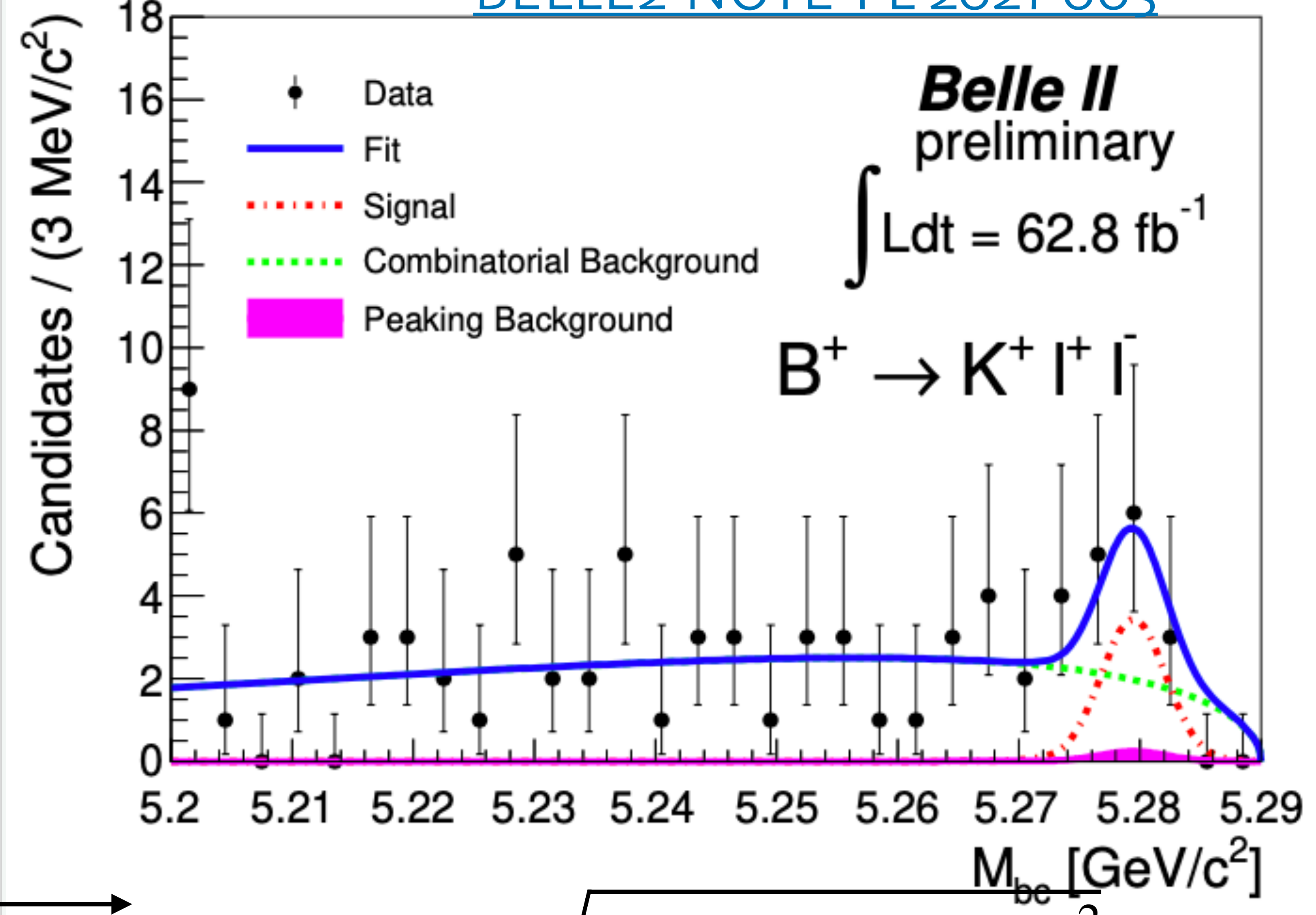
arXiv:2103.11769, arXiv:2110.09501



- Belle II, which enjoys nearly symmetric electron/muon reconstruction performance, can:
  - provide independent check of R(K$^{(*)}$) anomalies with > 5-10 ab^{-1}
  - measure R(X_s)
  - provide independent measurement of absolute BF for e and μ (e.g. constraint on C9 Wilson coefficient, separately for the two modes)

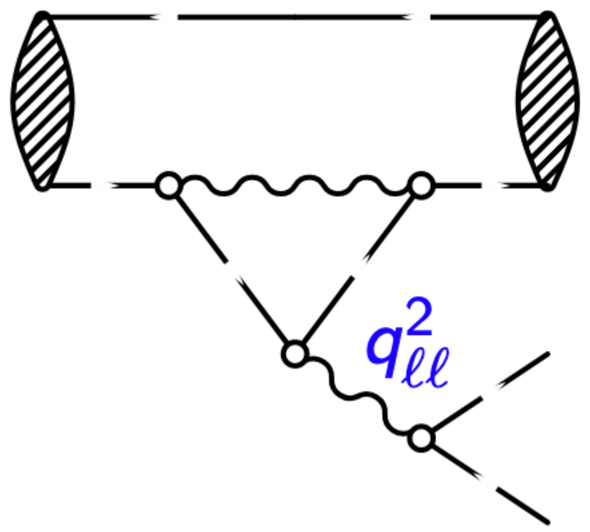
- 2021 preliminary result on for $B^+ \to K^+\ell^+\ell^-$ with 63 fb^{-1} of Belle II data: 2.7σ significance for signal

BELLE2-NOTE-PL-2021-005

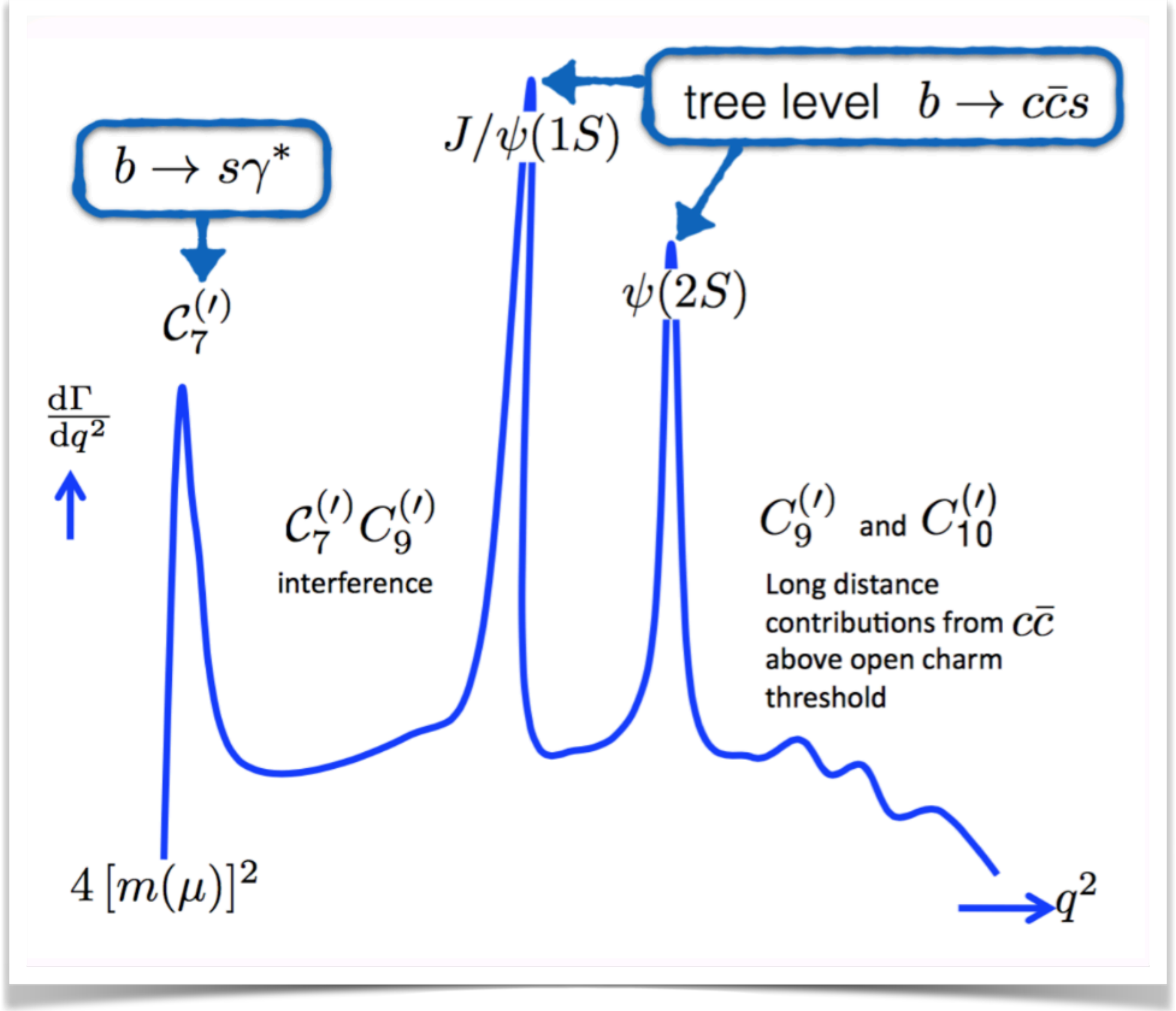


$$M_{BC} = \sqrt{s/(4c^2) - \left|\vec{p}^{\,*}_B/c\right|^2}$$

$B \to K^* \ell\ell$ branching fraction (I)

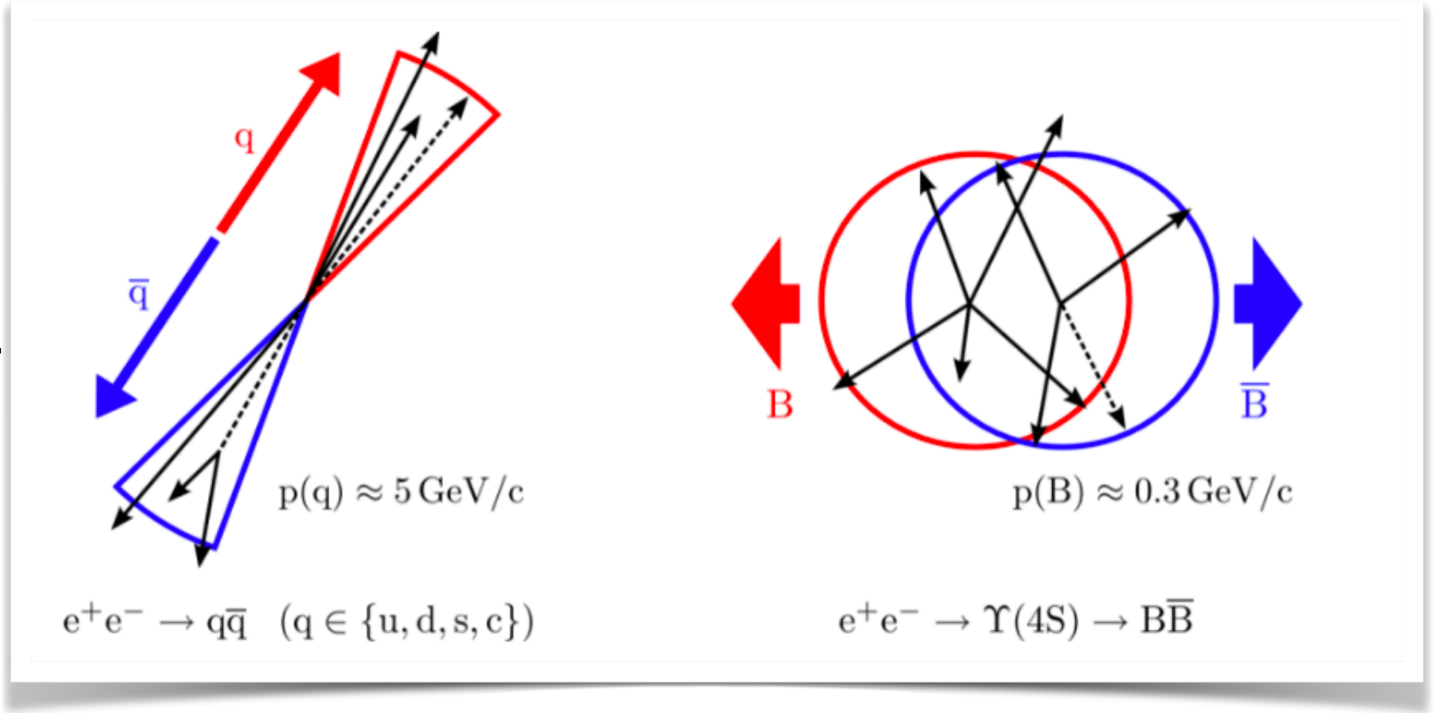


- Belle II search for $B \to K^* \ell^+ \ell^-$ (ℓ= e, μ) with 189.26 fb^{-1}
- Fully reconstructed mode, $K^* \to K^+\pi^-$, $K^+\pi^0$, $K_S\pi^+$ + 2 same-flavour leptons: ~2%-14% reconstruction efficiency depending on the mode



- Background suppression:
  - veto on $\ell\ell$ invariant mass to suppress **J/ψ, ψ(2S)** $\to \ell^+\ell^-$
  - BDT with kinematic and event shape variables to suppress

mis-reconstructed events from **$B\bar{B}$** and **$q\bar{q}$**



  - ad-hoc cuts to suppress **background peaking in M_{bc}**, e.g.

$B^+ \to \bar{D}^0 (K^+ \pi^0 \pi^-)\ \pi^+$

fake K^{*0}

both pions mis-identified as muons

events peaking in M_{bc} for $B^0 \to K^{*0}(K^+\pi^0)\mu\mu$ mode

$\Longrightarrow$ veto in $(K^+\pi^0\mu^-)$ invariant mass

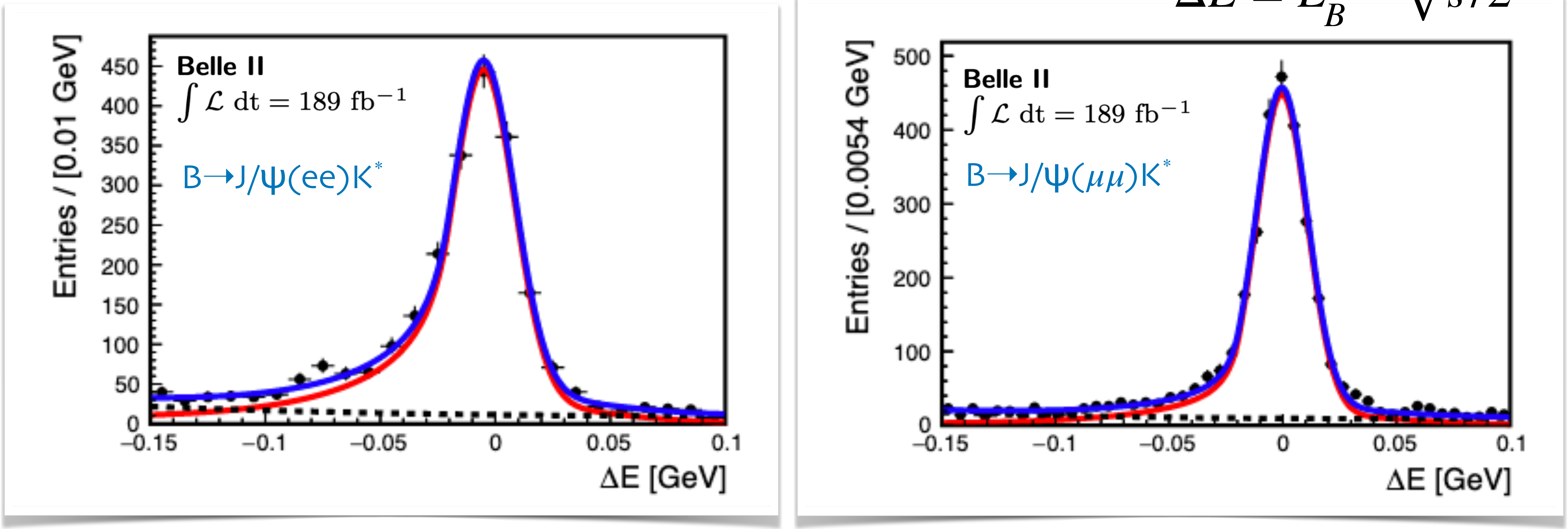
$B \to K^* \ell\ell$ branching fraction (II)

New

- $B \to J/\psi(\ell\ell)K^*$ used as control sample
  - computation of fit parameters for signal PDF
  - efficiency correction factor for residual data/MC disagreement after all selection cuts and data/MC corrections related to particle reconstruction performances are applied

$$\Delta E = E_B^* - \sqrt{s}/2$$

● data
signal PDF
background PDF
total PDF



- Systematic uncertainties: dominant contributions from data/simulation mis-modelling of particle identification and from B-counting (BF normalisation)

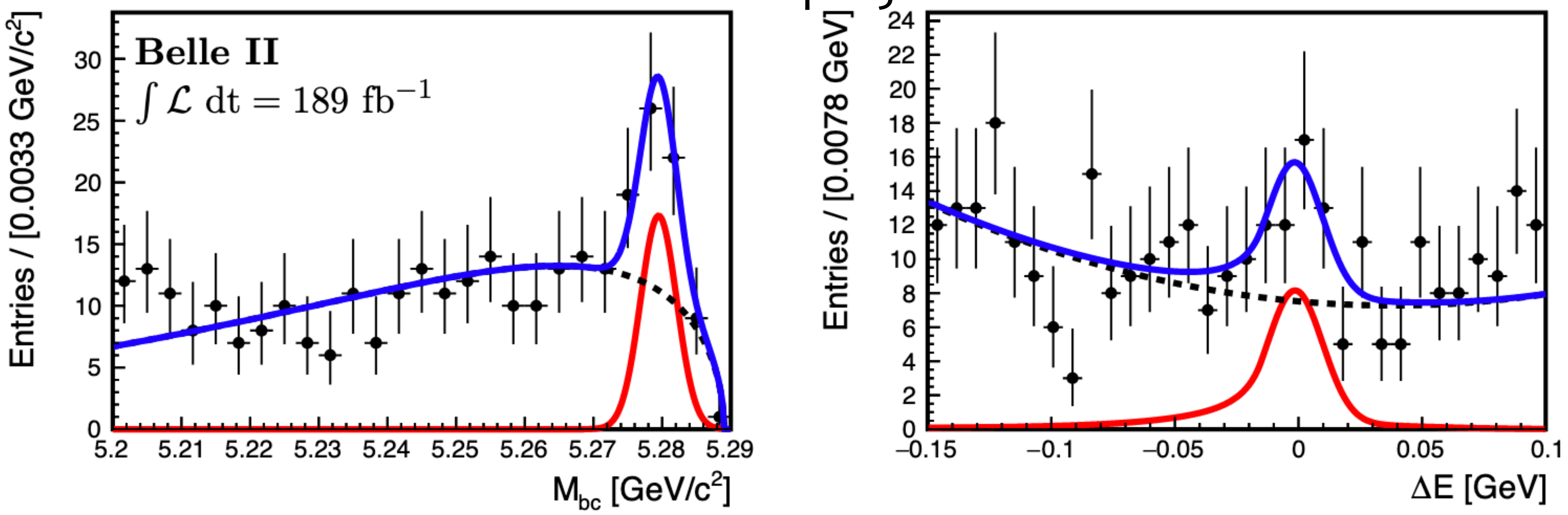
$B \to K^* \ell\ell$ branching fraction (III)

New

- Signal yield extracted from 2D fit to M_{bc} and ΔE

● data
signal PDF
background PDF
total PDF

$B \to K^* \ell\ell$ fit projections



- Branching fraction in entire q^2 range excluding J/ψ and $\psi(2S)$ resonances:

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

PDG averages

$(1.06 \pm 0.09) \times 10^{-6}$

$(1.19 \pm 0.20) \times 10^{-6}$

$(1.05 \pm 0.10) \times 10^{-6}$

- Precision for electron and muon channels in the same ballpark
- Limited by sample size
- Electron channel "only" 2.5σ worst wrt PDG, expected to became competitive with 1 ab^{-1}

- Will provide essential independent check of anomalies with few 1/ab

Radiative b→s transitions

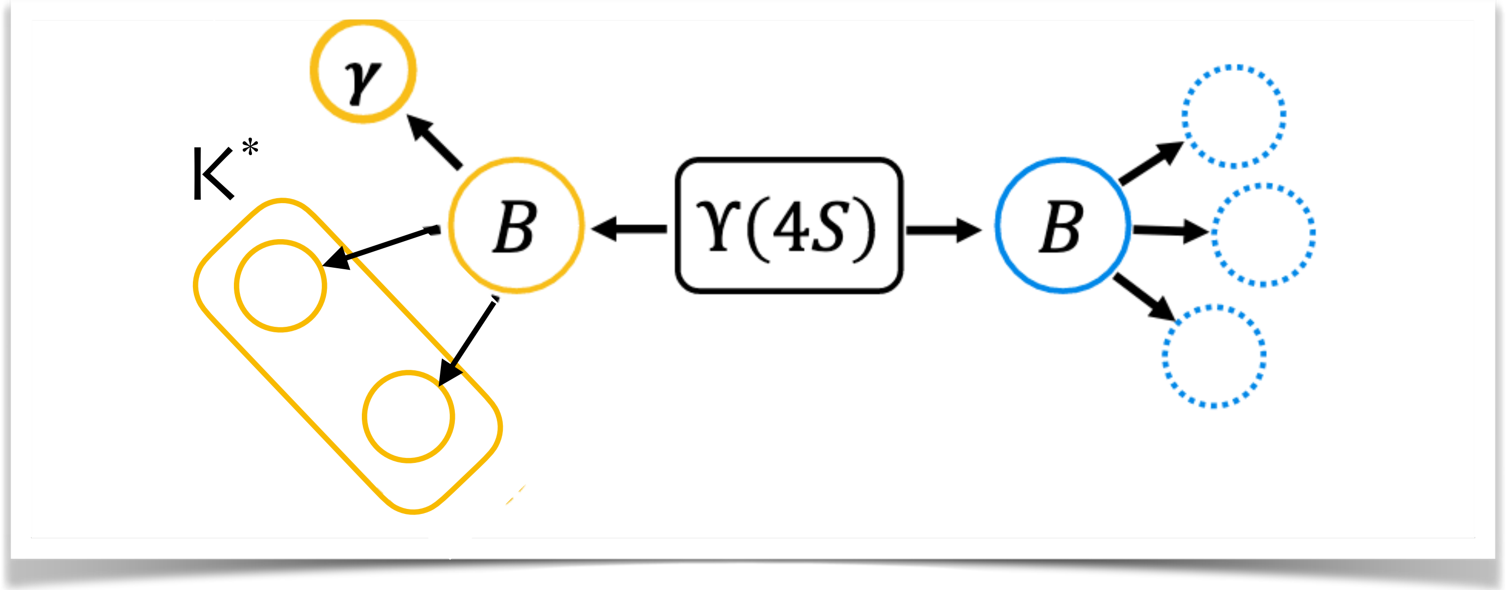
- b→sγ has higher rates wrt b→s$\ell\ell$, variety of reconstruction techniques feasible at Belle II → optimally suited/unique for Belle II
- State of the art on $B\to K^*\gamma$ and $B\to X_s\gamma$, best measurements from Belle →

[1] Phys. Rev. D 99, 032012 (2019), 711 fb^{-1}, [2] *Phys.Rev.D* 91 (2015) 5, 052004, 711 fb^{-1}, [3] Phys. Rev. Lett. 119, 191802 (2017), 711 fb^{-1}

	$B\to K^*\gamma$	$B\to X s\gamma$
BF precision	3% **[3]**	10% **[2]**
A_{CP}	consistent with zero and SM predictions **[1]** , **[3]**	
Δ_{0-}	first evidence for isospin violation @ 3.1σ **[3]**	consistent with zero **[1]**

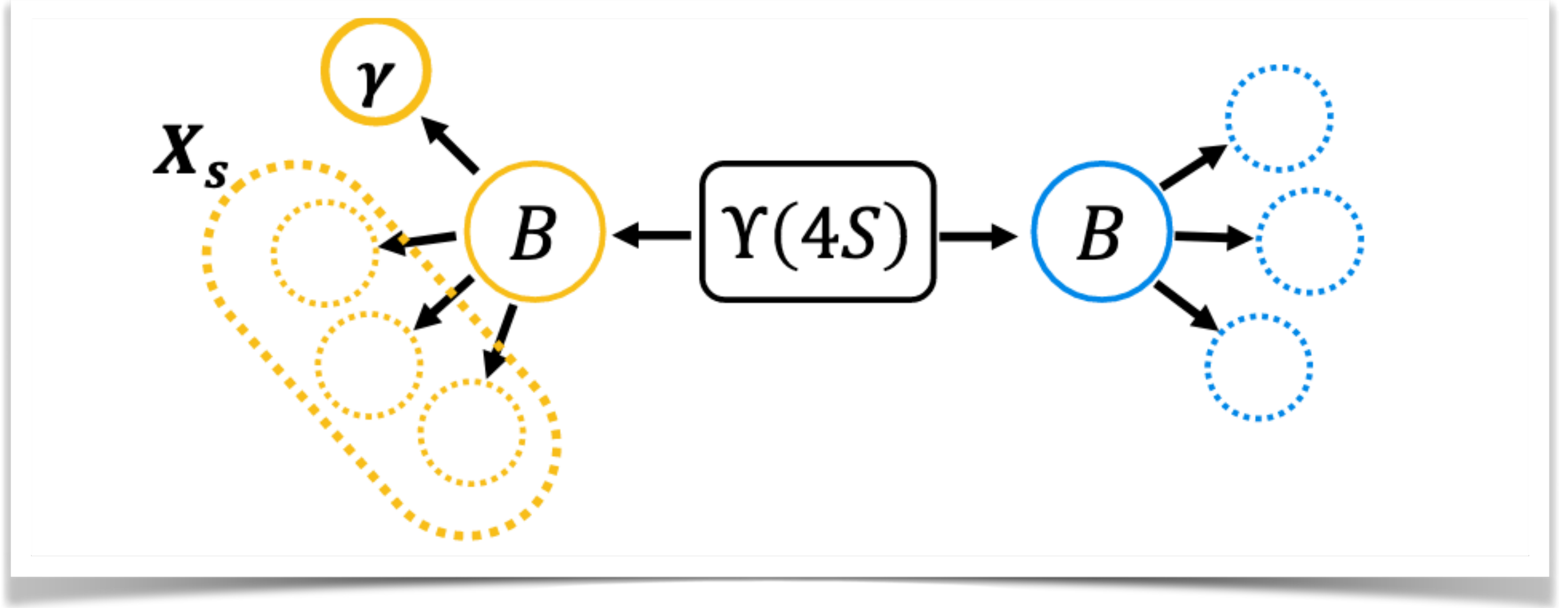
- Reconstruction strategies:

B→K$^*\gamma$



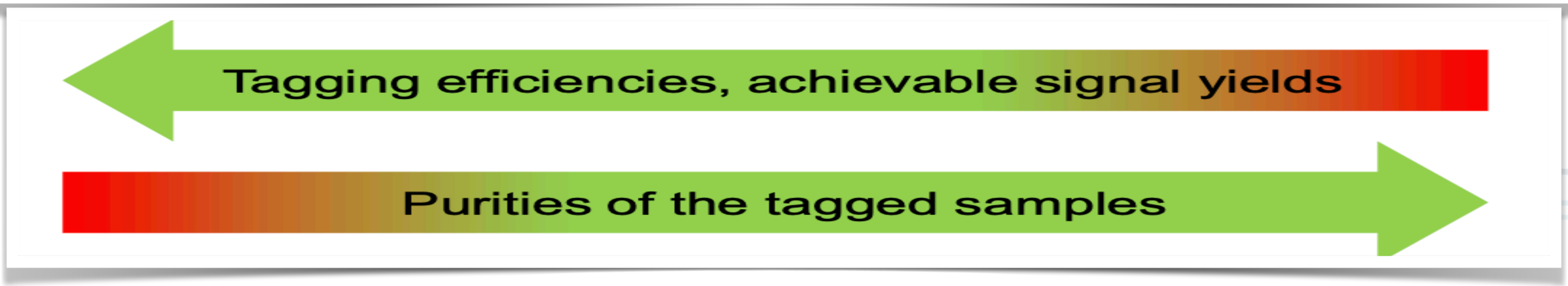
- Full reconstruction of only 1 B in the event
- Reconstruction and selection efficiency ~2-15% depending on K* mode

B→X$_s\gamma$



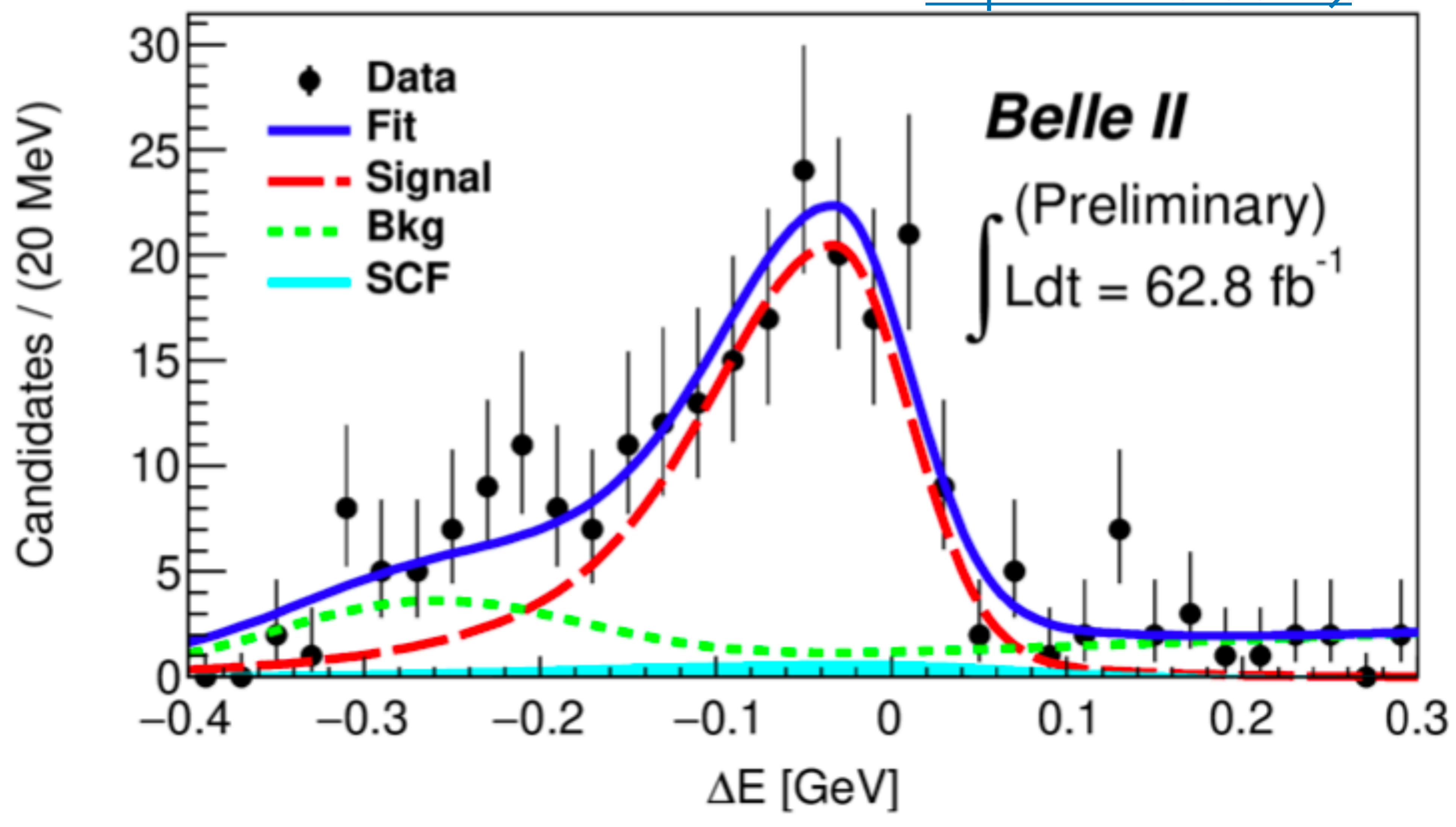
- Inclusive signal side reconstruction, require 1 high energy photon
- Different strategies for other-B reconstruction:

Fully inclusive, no tagging	Lepton tagging	Semileptonic tagging	Hadronic tagging
$B\to$ anything	$B\to lX$	$B\to \bar{D}^{(*)}l\nu n\pi$	$B\to$ hadrons, e.g. $B\to \bar{D}^{(*)} n\pi$



$B \to K^* \gamma$ branching fraction

hep-ex:2110.08219

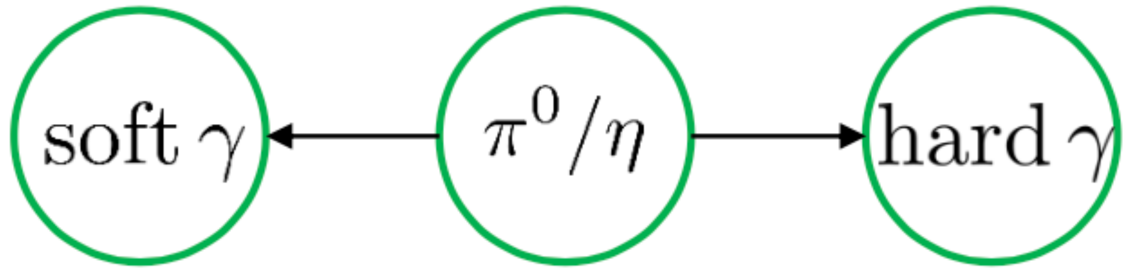


(c) $B^+ \to K^{*+}[K^+\pi^0]\gamma$

- $B \to K^* \gamma$ branching fraction measurement, with 63 fb^{-1}
- Signal yield extracted from unbinned maximum likelihood fit to ΔE
- Measured branching fractions:

Mode	$\mathcal{B}_{\rm meas}$ $[10^{-5}]$
$B^0 \to K^{*0}[K^+\pi^-]\gamma$	$4.5 \pm 0.3 \pm 0.2$
$B^0 \to K^{*0}[K^0_S\pi^0]\gamma$	$4.4 \pm 0.9 \pm 0.6$
$B^+ \to K^{*+}[K^+\pi^0]\gamma$	$5.0 \pm 0.5 \pm 0.4$
$B^+ \to K^{*+}[K^0_S\pi^+]\gamma$	$5.4 \pm 0.6 \pm 0.4$

- Main systematic contributions from fit modelling , mis-modelling of π^0/η veto and selection variables in simulation (depending on the mode)
- Analysis update with available dataset ongoing to measure BF and isospin asymmetry

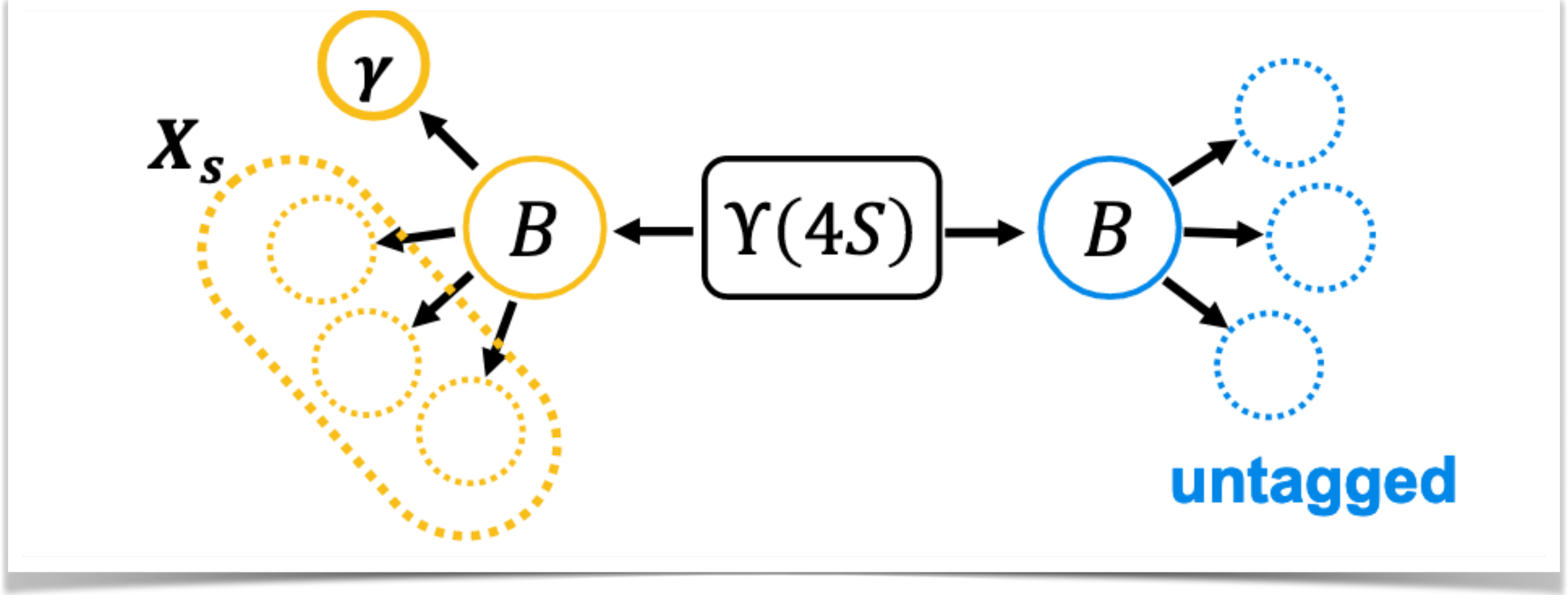


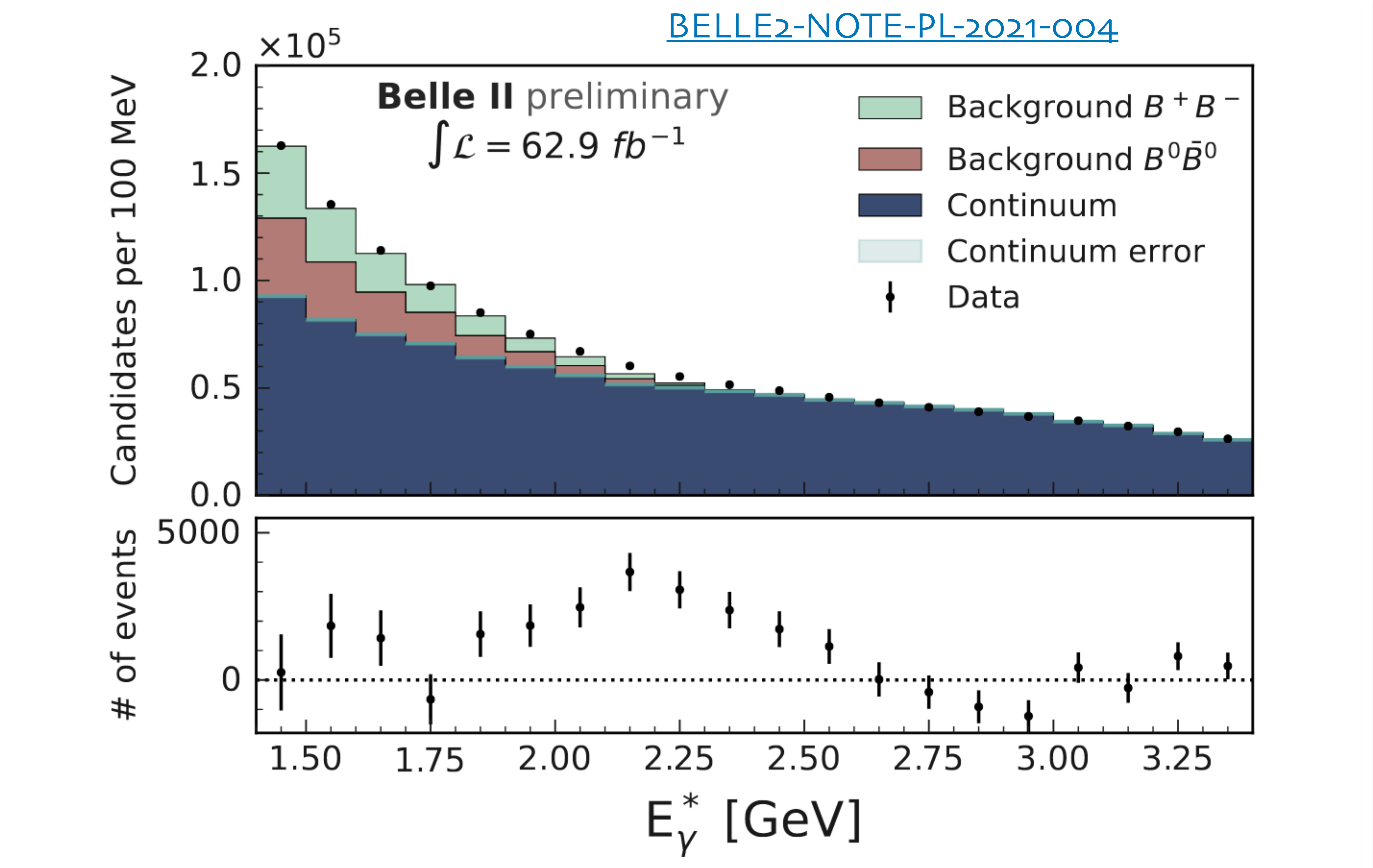
(hard photon from asymmetric π^0/η faking signal γ)

$B \to X_s\gamma$ photon spectrum with fully untagged method

- $B \to X_s\gamma$ with untagged method, with 63 fb^{-1}
- Reconstruct only high energy γ from signal side,
- Signal photon spectrum obtained by subtracting expected background from data
  - $B\bar{B}$ estimated from simulation
  - $q\bar{q}$ from off-resonance data
- Excess visible in the expected signal region

- Update of the measurements with inclusive (improved method), hadronic and semileptonic tag ongoing, BF first and asymmetries later on





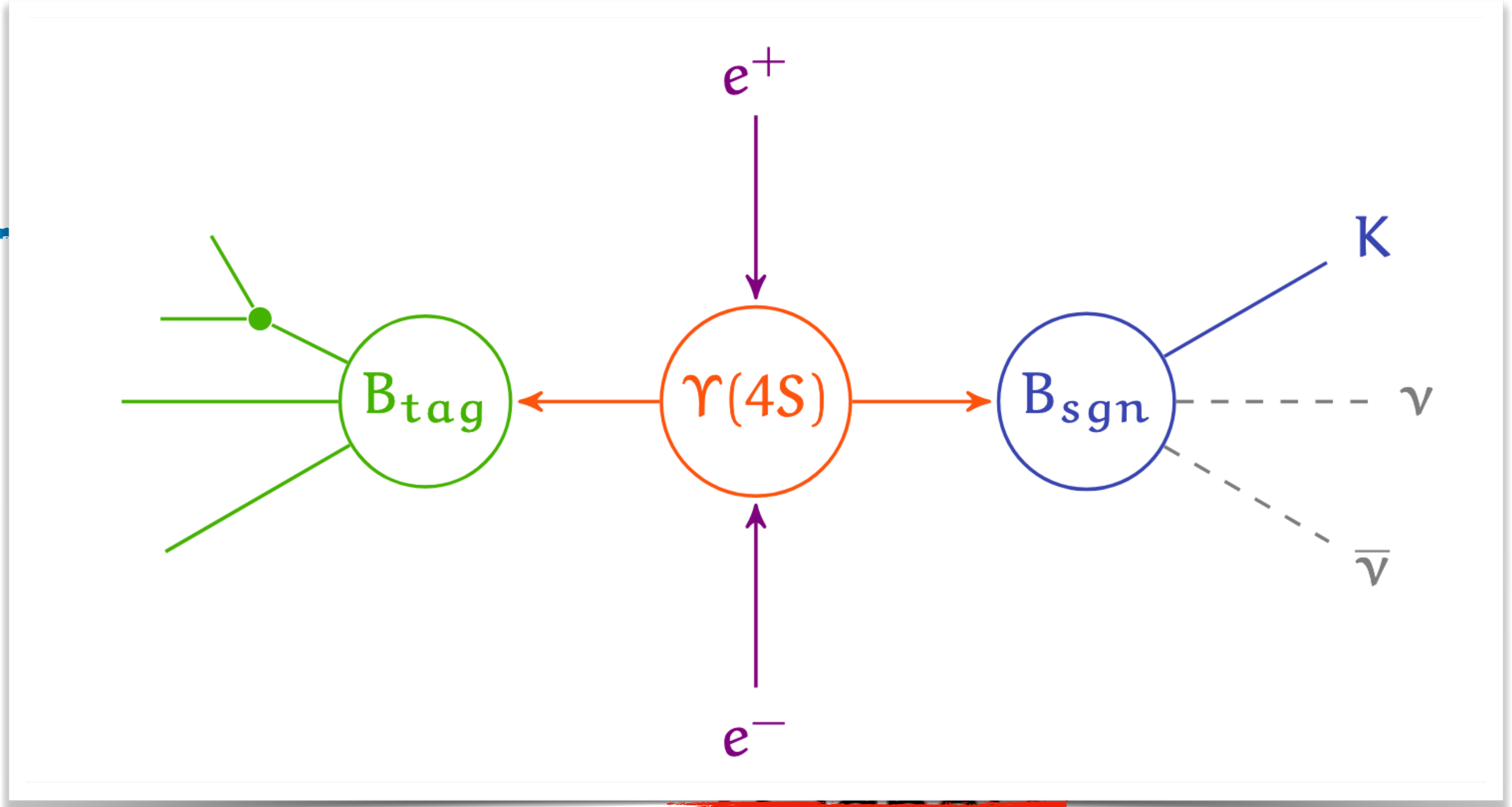
$B^+ \to K^+ \nu\bar{\nu}$ search (I) [Phys.Rev.Lett. 127 (2021) 18, 181802]

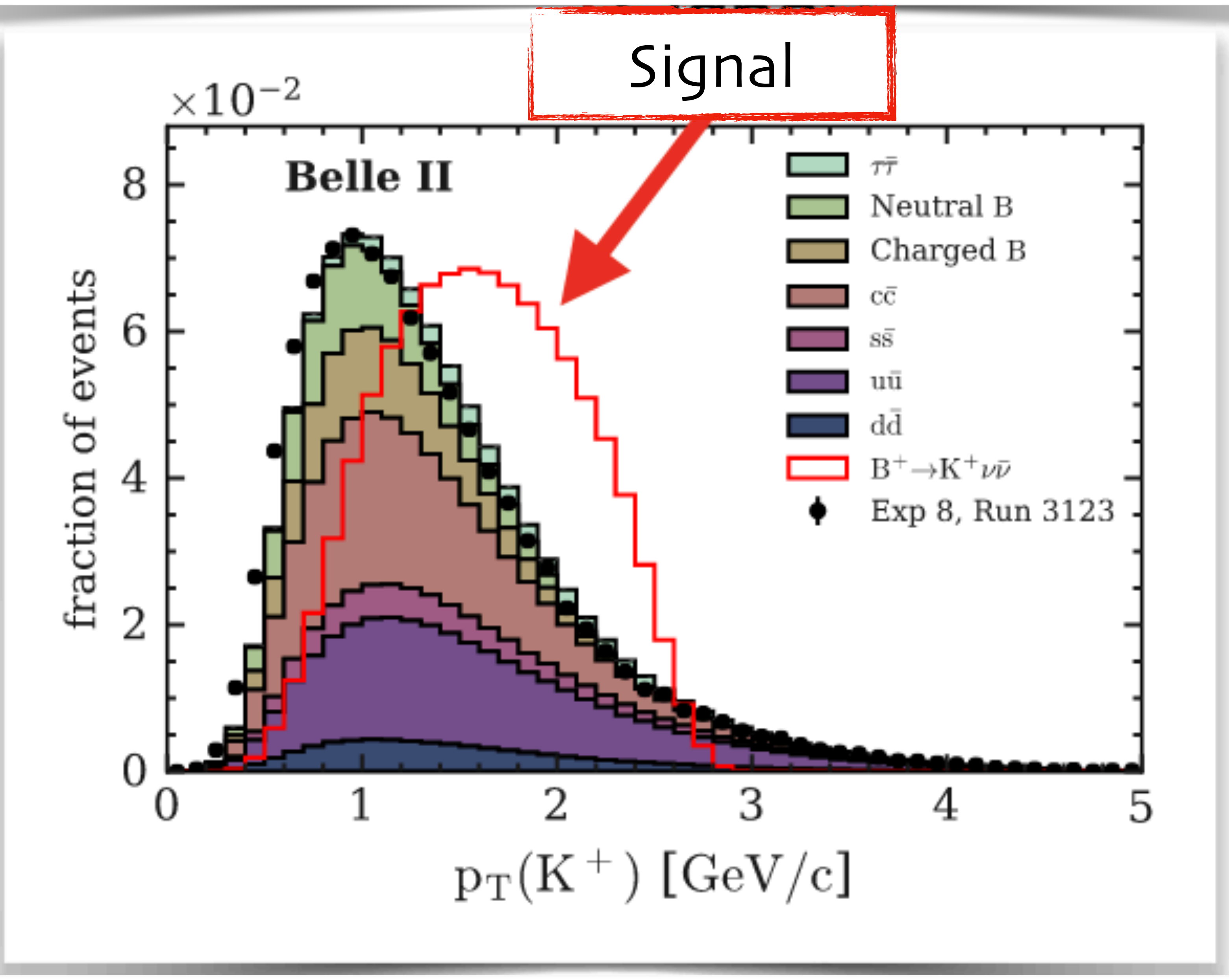
- Connected to flavour anomalies, one of the missing energy modes unique to Belle II

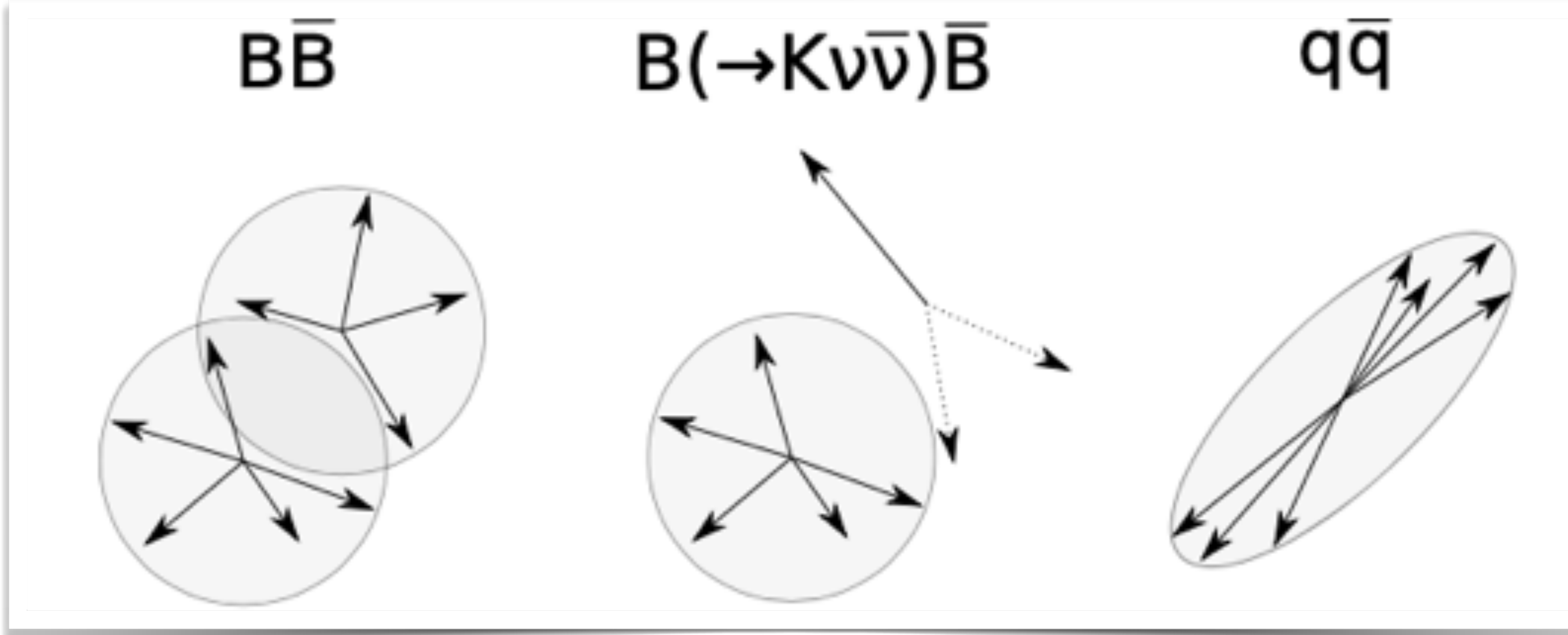
- SM expectation: $(4.6 \pm 0.5) \times 10^{-6}$ (A. J. Buras et al., High Energy Phys. 02, 184 (2015))

- Key ingredient in BaBar and Belle searches: hadronic and semileptonic tag side reconstruction, tag efficiency at per-cent/per-mille

- Novel inclusive approach on 63 fb^{-1} of Belle II data:
- Signal kaon = highest p_T track
- Associate all other tracks and clusters to other B in the event
- Use multivariate approach (2 BDTs in cascade) based on kinematics, event shape and vertexing variables to suppress background
- Signal efficiency ~ 4.3 % (SM signal)







$B^+ \to K^+ \nu\bar{\nu}$ search (II)

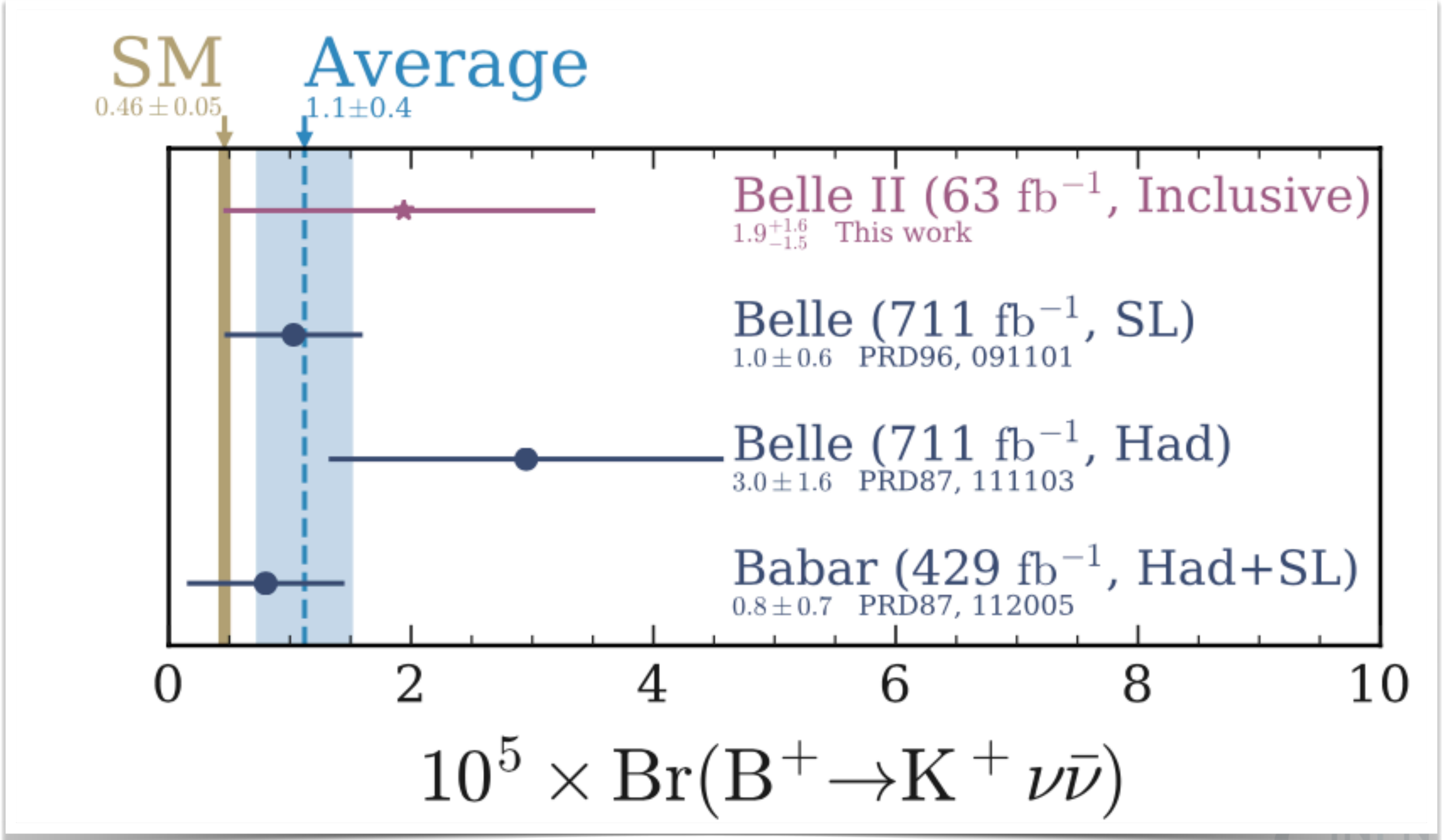
Phys.Rev.Lett. 127 (2021) 18, 181802

- Extract signal from simultaneous maximum likelihood fit to on-resonance + off- resonance data in bins of $p_T(K^+)$ and second BDT
- Results:
  - signal strength: $\mu = 4.2^{+2.9}_{-2.8} \pm^{+1.8}_{-1.6}$
  - Upper Limit @ 90% CL:

    $\mathscr{B}(B \to K\nu\bar{\nu}) < 4.1 \times 10^{-5}$
  - corresponding BF:

    $\mathscr{B}(B \to K\nu\bar{\nu}) = (1.9^{+1.6}_{-1.5}) \times 10^{-5}$
- Comparing theory and experiments:
  - Inclusive method offers 20%—350% sensitivity improvement over previous approaches

- Signal strength consistent with SM exp (μ=1) at 1 σ and with background-only hypothesis at 1.3 σ
- Leading systematics: background normalisation uncertainty, room for improvement



Conclusions

- b→s transitions are powerful probes for physics beyond SM
- Belle II is accumulating high quality data
  - healthy complementarity with LHCb on LFU violation in $b \to s\ell\ell$ modes, can perform independent BF measurement for $K^{(*)}ee$ and $K^{(*)}\mu\mu$ final states with similar performances
  - unique environment to study radiative decays and missing energy modes
- Measurements with $63 fb^{-1}$ and $190 fb^{-1}$ have been shown
  - $B \to K^{*}\ell\ell$ branching fraction measurement new for Moriond22
  - Inclusive and exclusive measurements on $b \to s\gamma$ decays
  - $B^+ \to K^+ \nu\bar{\nu}$ inclusive measurement in the same ballpark wrt Belle and BaBar ones with ~1/10 Belle statistics

Extra slides

Luminosity plans (I)

F. Forti @ VCI 2022

Path to the future

Steep path to higher luminosity

- A. Machine performance and stability
  - Beam blow up due to beam-beam effects
  - Lower than expected beam lifetime
  - Transverse mode coupling instabilities
  - Low machine stability
  - Injector capability
  - Aging infrastructure
- B. Backgrounds in the detector
  - Single beam: Beam-gas, Touchek,
  - Luminosity: Radiative Bhabha, Two photons
  - Injection backgrounds

Mitigation measures

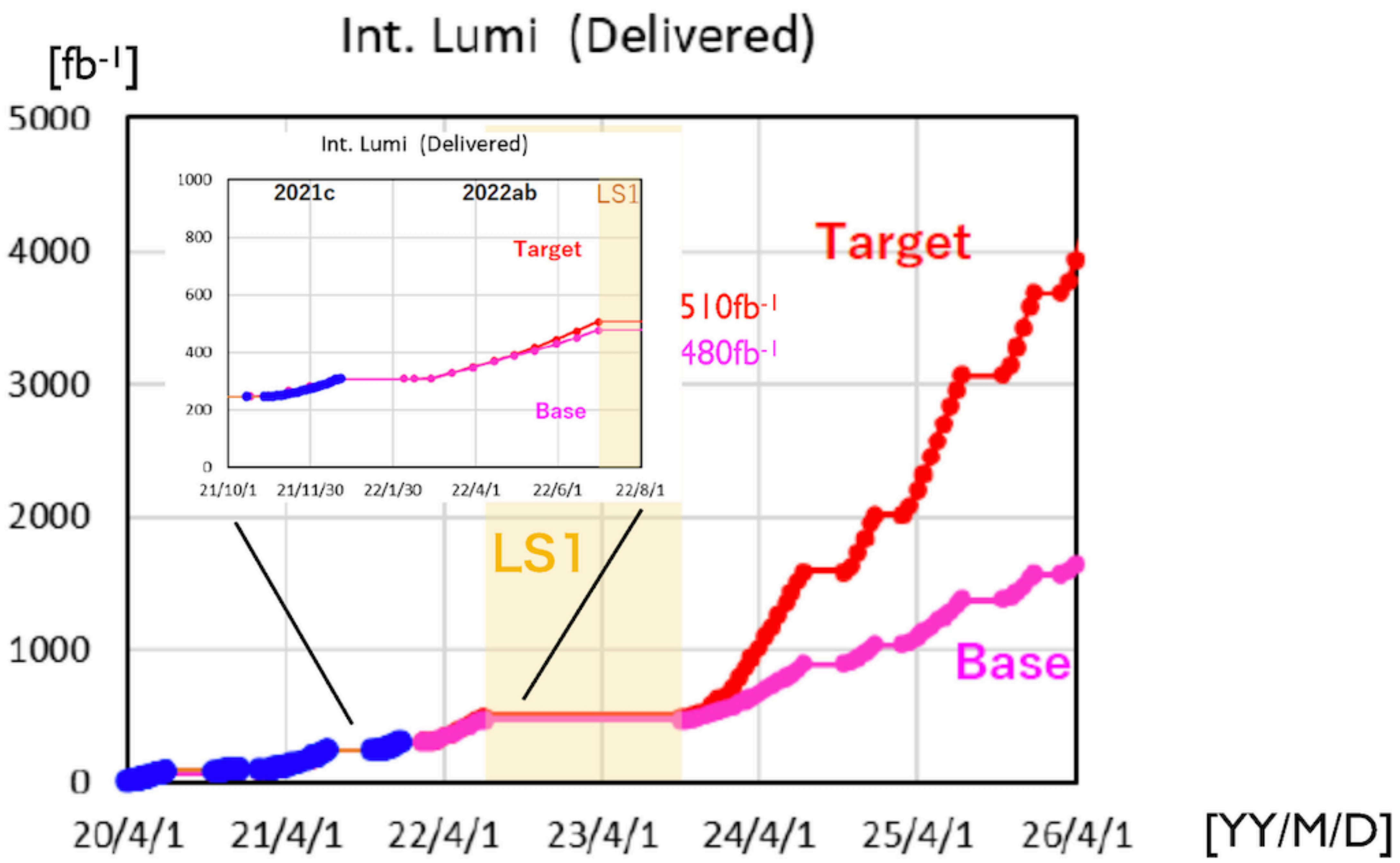
- A. Consolidate machine
  - International task force at work to help
  - Many countermeasures under development
  - A major redesign of the Interaction Region may be required to go beyond $\sim 2 \times 10^{35} cm^{-2}s^{-1}$.
- B. Consolidate the detector
  - Install a complete PXD
  - Complete installation of more robust TOP PMTs
- C. Improve detector
  - Upgrade program to make the detector more robust against backgrounds and with improved performance

Luminosity plans (II)

Projection of integrated luminosity delivered by SuperKEKB to Belle II

Target scenario: extrapolation from 2021 run including expected improvements.

Base scenario: conservative extrapolation of SuperKEKB parameters from 2021 run



- We start long shutdown 1 (LS1) from summer 2022 for 15 months to replace VXD. There will be other maintenance/improvement works of machine and detector.
- We resume physics running from Fall 2023.
- A SuperKEKB International Taskforce (aiming to conclude in summer 2022) is discussing additional improvements.
- An LS2 for machine improvements could happen on the time frame of 2026-2027

Details on systematics (I)

B→K*ℓℓ systematics table

Source	Systematic (%)
signal shape	~ 1.0
muon identification	$^{+1.9}_{-0.8}$
electron identification	$^{+0.9}_{-0.5}$
kaon identification	0.4
pion identification	2.5
K_S^0 identification	2.0
π^0 identification	3.4
FastBDT	1.3 – 1.7
limited MC statistics	< 0.5
signal cross feed	$\sim 1\%$
tracking	1.2 – 1.5
$f^{+-(00)}$	1.2
number of $B\bar{B}$ pairs	2.9
Total	$^{+6.7}_{-6.0}$

B→K*γ systematics table

Source	$K^{*0}[K^+\pi^-]\gamma$	$K^{*0}[K_S^0\pi^0]\gamma$	$K^{*+}[K^+\pi^0]\gamma$	$K^{*+}[K_S^0\pi^+]\gamma$
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_S^0 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	$^{+13.2}_{-12.4}$	$^{+7.9}_{-8.9}$	$^{+7.0}_{-7.3}$

Details on systematics (II)

TABLE VII. Systematic uncertainties (%) in each M_{X_s} mass bin.

M_{X_s} bin (GeV/c^2)	$B\overline{B}$ counting	Detector response	Background rejection	Signal PDF	Cross-feed PDF	Peaking BG PDF	$q\overline{q}$ BG PDF	Frag.	Missing proportion	Total
0.6-0.7	1.4	2.7	3.4	0.0	0.0	0.0	0.0	-	-	4.5
0.7-0.8	1.4	2.6	3.4	0.1	12.2	7.8	0.0	-	-	15.3
0.8-0.9	1.4	2.6	3.4	0.2	0.4	0.5	0.0	-	-	4.5
0.9-1.0	1.4	2.6	3.4	0.1	0.5	0.4	0.0	-	-	4.5
1.0-1.1	1.4	2.6	3.4	0.1	2.9	1.1	0.3	-	-	5.4
1.1-1.2	1.4	3.0	3.4	0.4	3.1	1.7	0.2	32.1	1.2	32.1
1.2-1.3	1.4	3.2	3.4	0.2	1.6	0.9	0.0	2.1	1.0	5.6
1.3-1.4	1.4	3.2	3.4	0.2	1.6	0.2	0.0	2.6	1.9	6.0
1.4-1.5	1.4	3.1	3.4	0.2	2.0	0.1	0.0	4.0	1.3	6.7
1.5-1.6	1.4	3.3	3.4	0.6	2.2	0.1	0.0	2.4	1.3	6.1
1.6-1.7	1.4	3.5	3.4	0.1	1.7	2.1	0.2	2.8	1.9	6.7
1.7-1.8	1.4	3.6	3.4	0.1	2.2	1.7	0.2	3.4	1.0	6.8
1.8-1.9	1.4	3.7	3.4	0.1	1.9	2.0	0.1	3.6	2.1	7.2
1.9-2.0	1.4	3.7	3.4	0.1	4.2	4.0	0.1	3.7	1.6	8.8
2.0-2.1	1.4	3.8	3.4	0.1	5.6	0.6	0.2	17.8	2.2	19.5
2.1-2.2	1.4	3.8	3.4	0.3	3.7	2.5	0.4	21.9	1.9	23.1
2.2-2.4	1.4	3.8	3.4	0.1	7.4	7.1	0.0	25.5	1.6	28.0
2.4-2.6	1.4	3.8	3.4	0.1	11.5	21.8	0.3	29.6	1.0	38.9
2.6-2.8	1.4	3.8	3.4	0.1	44.7	101.0	0.9	29.4	2.0	113.9

Belle coll, Phys.Rev.D 91 (2015) 5, 052004, untagged $X_s\gamma$ sum of exclusive, 711 fb-1

$$\mathcal{B}(\overline{B} \to X_s\gamma) = (3.51 \pm 0.17 \pm 0.33) \times 10^{-4}$$

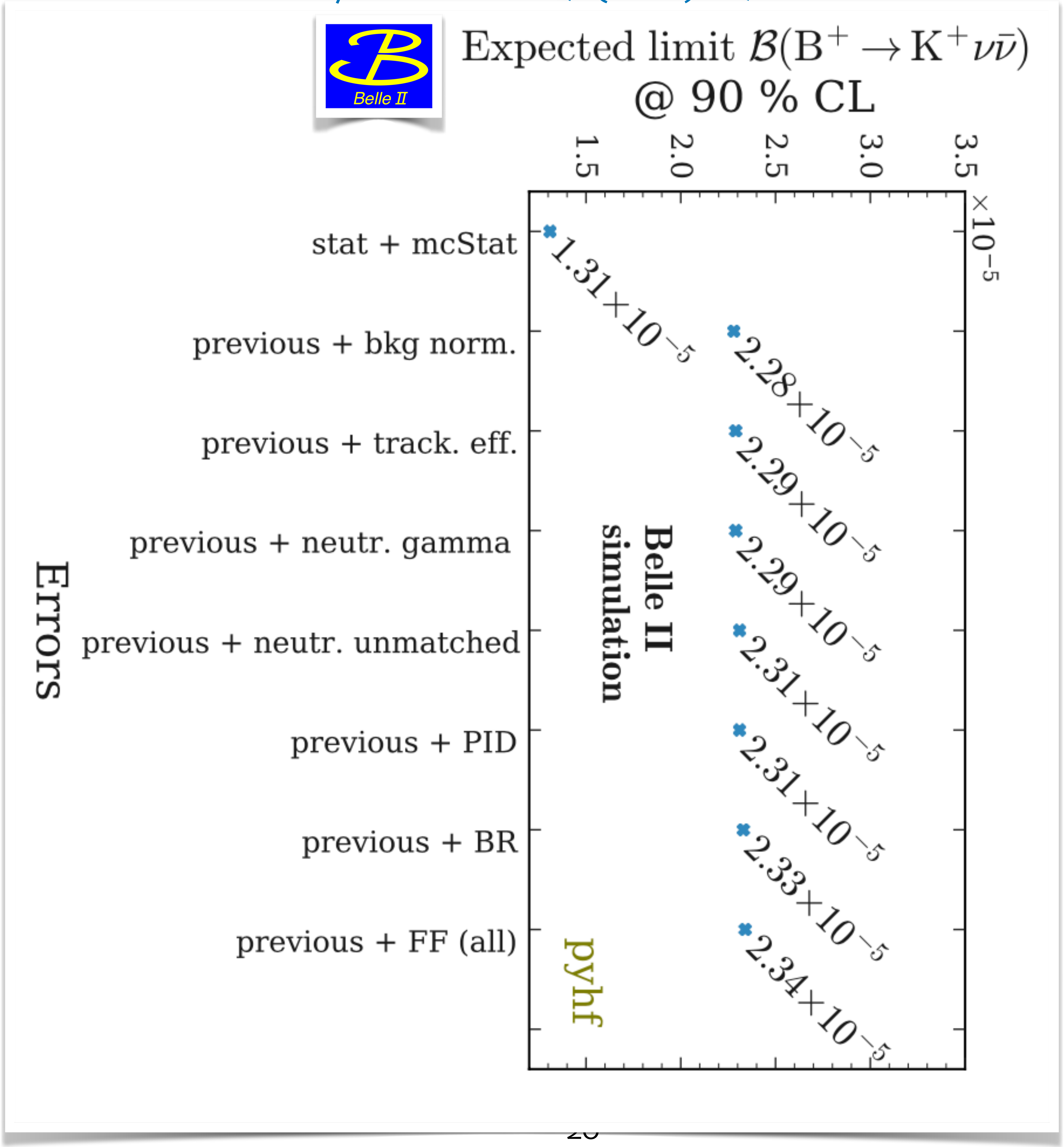
Belle coll, Phys.Rev.Lett.103:241801,2009, untagged $X_s\gamma$ inclusive, 605 fb-1

	BF$(B \to X_s\gamma)$ (10^{-4})			
$E^{B}_{\gamma-\mathrm{Low}}$ [GeV]	1.70	1.80	1.90	2.00
Value	3.45	3.36	3.21	3.02
±statistical	0.15	0.13	0.11	0.10
±systematic	0.40	0.25	0.16	0.11
				Syst
1. Continuum	0.26	0.16	0.10	0.07
2. Selection	0.15	0.12	0.10	0.08
3. π^0/η	0.07	0.05	0.04	0.02
4. Other B	0.25	0.14	0.06	0.02
5. Beam bkgd.	0.03	0.02	0.02	0.01
6. Unfolding	0.01	0.01	0.02	0.02
7. Model	0.01	0.01	0.00	0.01
8. Resolution	0.05	0.03	0.01	0.00
9. γ Detection	0.03	0.02	0.00	0.00
10. $B \to X_d\gamma$	0.01	0.01	0.01	0.01
11. Boost	0.01	0.01	0.02	0.02

$$\mathrm{BF}(B \to X_s\gamma) = (3.45 \pm 0.15 \pm 0.40) \times 10^{-4}$$

Details on systematics (III)

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



Collection of projections from physics book (I)

The Belle II Physics Book, PETP 2019, 123C01 (2019)

Observables	Belle 0.71 ab^{-1}	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
$\mathrm{Br}(B \to X_s\gamma)^{\text{lep-tag}}_{\text{inc}}$	5.3%	3.9%	3.2%
$\mathrm{Br}(B \to X_s\gamma)^{\text{had-tag}}_{\text{inc}}$	13%	7.0%	4.2%
$\mathrm{Br}(B \to X_s\gamma)_{\text{sum-of-ex}}$	10.5%	7.3%	5.7%
$\Delta_{0+}(B \to X_s\gamma)_{\text{sum-of-ex}}$	2.1%	0.81%	0.63%
$\Delta_{0+}(B \to X_{s+d}\gamma)^{\text{had-tag}}_{\text{inc}}$	9.0%	2.6%	0.85%
$A_{CP}(B \to X_s\gamma)_{\text{sum-of-ex}}$	1.3%	0.52%	0.19%
$A_{CP}(B^0 \to X_s^0\gamma)_{\text{sum-of-ex}}$	1.8%	0.72%	0.26%
$A_{CP}(B^+ \to X_s^+\gamma)_{\text{sum-of-ex}}$	1.8%	0.69%	0.25%
$A_{CP}(B \to X_{s+d}\gamma)^{\text{lep-tag}}_{\text{inc}}$	4.0%	1.5%	0.48%
$A_{CP}(B \to X_{s+d}\gamma)^{\text{had-tag}}_{\text{inc}}$	8.0%	2.2%	0.70%
$\Delta A_{CP}(B \to X_s\gamma)_{\text{sum-of-ex}}$	2.5%	0.98%	0.30%
$\Delta A_{CP}(B \to X_{s+d}\gamma)^{\text{had-tag}}_{\text{inc}}$	16%	4.3%	1.3%

Observables	Belle 0.71 ab^{-1} (0.12 ab^{-1})	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
$\Delta_{0+}(B \to K^*\gamma)$	2.0%	0.70%	0.53%
$A_{CP}(B^0 \to K^{*0}\gamma)$	1.7%	0.58%	0.21%
$A_{CP}(B^+ \to K^{*+}\gamma)$	2.4%	0.81%	0.29%
$\Delta A_{CP}(B \to K^*\gamma)$	2.9%	0.98%	0.36%
$S_{K^{*0}\gamma}$	0.29	0.090	0.030

Collection of projections from physics book (II)

The Belle II Physics Book, PETP 2019, 123C01 (2019)

Observables	Belle 0.71 ab^{-1} (0.12 ab^{-1})	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
$\mathrm{Br}(B^+ \to K^+\tau^+\tau^-) \cdot 10^5$	< 32	< 6.5	< 2.0
$\mathrm{Br}(B^+ \to K^+\tau^\pm e^\mp) \cdot 10^6$	–	–	< 2.1
$\mathrm{Br}(B^+ \to K^+\tau^\pm \mu^\mp) \cdot 10^6$	–	–	< 3.3

tagged analysis ONLY!

Observables	Belle 0.71 ab^{-1} (0.12 ab^{-1})	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
$\mathrm{Br}(B^+ \to K^+\nu\bar{\nu})$	$< 450\%$	30%	11%
$\mathrm{Br}(B^0 \to K^{*0}\nu\bar{\nu})$	$< 180\%$	26%	9.6%
$\mathrm{Br}(B^+ \to K^{*+}\nu\bar{\nu})$	$< 420\%$	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

Collection of projections from physics book (II)

The Belle II Physics Book, PETP 2019, 123C01 (2019)

Observables	Belle 0.71 ab^{-1}	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
R_K ([1.0, 6.0] GeV^2)	28%	11%	3.6%
R_K (> 14.4 GeV^2)	30%	12%	3.6%
R_{K^*} ([1.0, 6.0] GeV^2)	26%	10%	3.2%
R_{K^*} (> 14.4 GeV^2)	24%	9.2%	2.8%
R_{X_s} ([1.0, 6.0] GeV^2)	32%	12%	4.0%
R_{X_s} (> 14.4 GeV^2)	28%	11%	3.4%

Observables	Belle 0.71 ab^{-1}	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
$A_T^{(2)}$ ([0.002, 1.12] GeV^2)	–	0.21	0.066
A_T^{Im} ([0.002, 1.12] GeV^2)	–	0.20	0.064

Belle II - LHCb Comparison

+ Important contributions on B and D flavour physics from ATLAS, CMS, BESIII.

Belle II
Higher sensitivity to decays with photons and neutrinos (e.g. $B\to K\nu\nu$, $\mu\nu$), inclusive decays, time dependent CPV in B_d, τ physics.

LHCb
Higher production rates for ultra rare B, D, & K decays, access to all b-hadron flavours (e.g. Λ_b), high boost for fast B_s oscillations.

Overlap in various key areas to verify discoveries.

Upgrades
Most key channels will be stats. limited (not theory or syst.).
LHCb scheduled major upgrades during LS3 and LS4.
Belle II formulating a 250 ab^{-1} upgrade program post 2028.

Observable	Current Belle/ Babar	2019 LHCb	Belle II (5 ab^{-1})	Belle II (50 ab^{-1})	LHCb (23 fb^{-1})	Belle II Upgrade (250 ab^{-1})	LHCb upgrade II (300 fb^{-1})
CKM precision, new physics in CP Violation							
$\sin 2\beta/\varphi_1$ ($B\to J/\psi K_S$)	0.03	0.04	0.012	0.005	0.011	0.002	0.003
γ/φ_3	13°	5.4°	4.7°	1.5°	1.5°	0.4°	0.4°
α/φ_2	4°	–	2	0.6°	–	0.3°	–
$\|V_{ub}\|$ (Belle) or $\|V_{ub}\|/\|V_{cb}\|$ (LHCb)	4.5%	6%	2%	1%	3%	<1%	1%
φ_s	–	49 mrad	–	–	14 mrad	–	4 mrad
$S_{CP}(B\to\eta' K_S$, gluonic penguin)	0.08	○	0.03	0.015	○	0.007	○
$A_{CP}(B\to K_S\pi^0)$	0.15	–	0.07	0.04	–	0.02	–
New physics in radiative & EW Penguins, LFUV							
$S_{CP}(B_d\to K^*\gamma)$	0.32	○	0.11	0.035	○	0.015	○
$R(B\to K^* l^+ l^-)$ ($1<q^2<6$ GeV^2/c^2)	0.24	0.1	0.09	0.03	0.03	0.01	0.01
$R(B\to D^*\tau\nu)$	6%	10%	3%	1.5%	3%	<1%	1%
$Br(B\to\tau\nu)$, $Br(B\to K^*\nu\nu)$	24%, –	–	9%, 25%	4%, 9%	–	1.7%, 4%	–
$Br(B_d\to\mu\mu)$	–	90%	–	–	34%	–	10%
Charm and τ							
$\Delta A_{CP}(KK-\pi\pi)$	–	8.5×10^{-4}	–	5.4×10^{-4}	1.7×10^{-4}	2×10^{-4}	0.3×10^{-4}
$A_{CP}(D\to\pi^+\pi^0)$	1.2%	–	0.5%	0.2%	–	0.1%	–
$Br(\tau\to e\gamma)$	$<120\times10^{-9}$	–	$<40\times10^{-9}$	$<12\times10^{-9}$	–	$<5\times10^{-9}$	–
$Br(\tau\to\mu\mu\mu)$	$<21\times10^{-9}$	$<46\times10^{-9}$	$<3\times10^{-9}$	$<3\times10^{-9}$	$<16\times10^{-9}$	$<0.3\times10^{-9}$	$<5\times10^{-9}$

Results on other D & τ modes expected

○ *Possible in similar channels, lower precision*
– *Not competitive.*

arXiv: 1808.08865 (Physics case for LHCb upgrade II), PTEP 2019 (2019) 12, 123C01 (Belle II Physics Book)