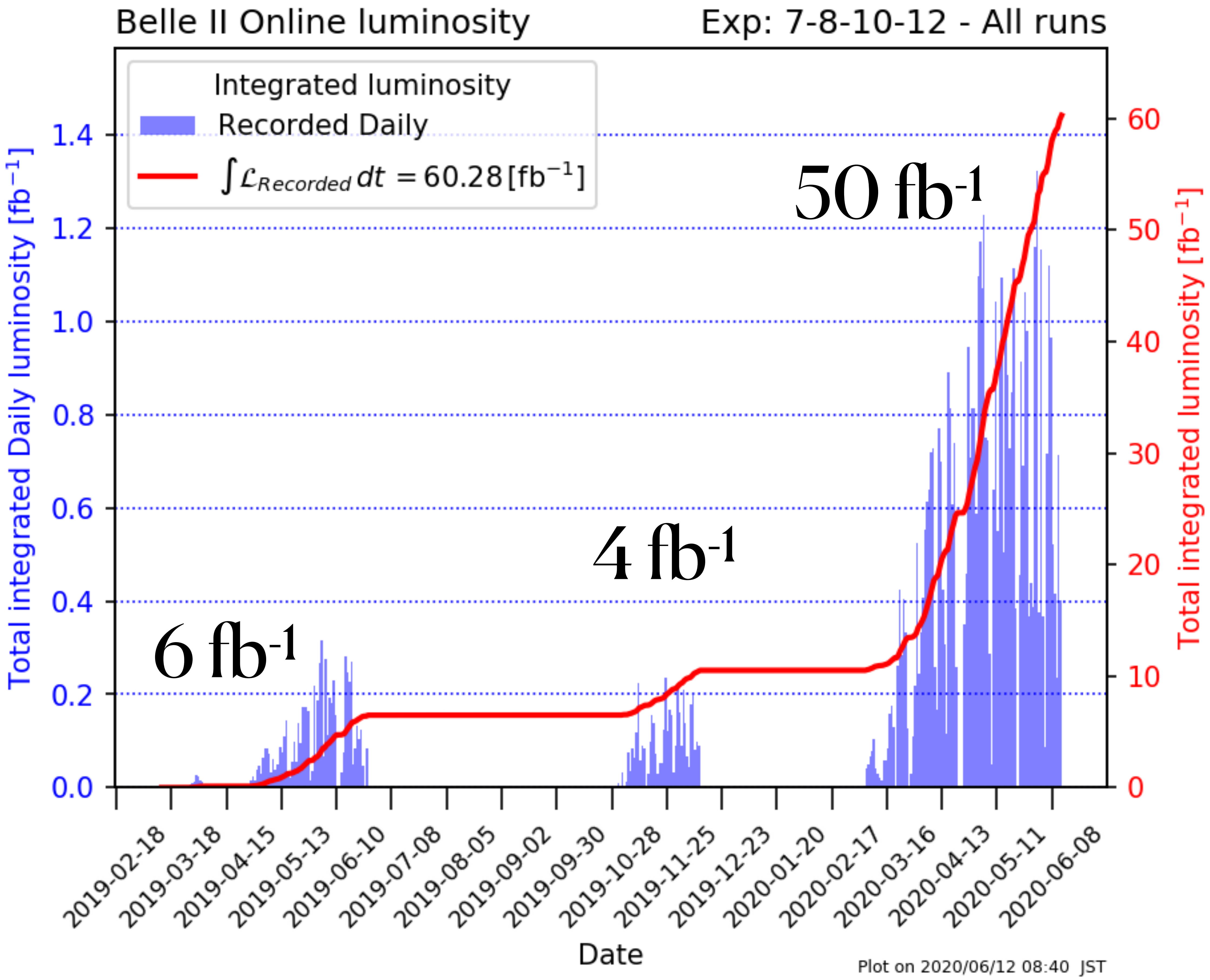
Belle II Status and Prospects



Phillip Urquijo, The University of Melbourne
Flavour Physics and CP Violation 2020

Belle II @ Super-KEKB

Intensity frontier flavour-factory experiment, Successor to Belle @KEKB (1999-2010)

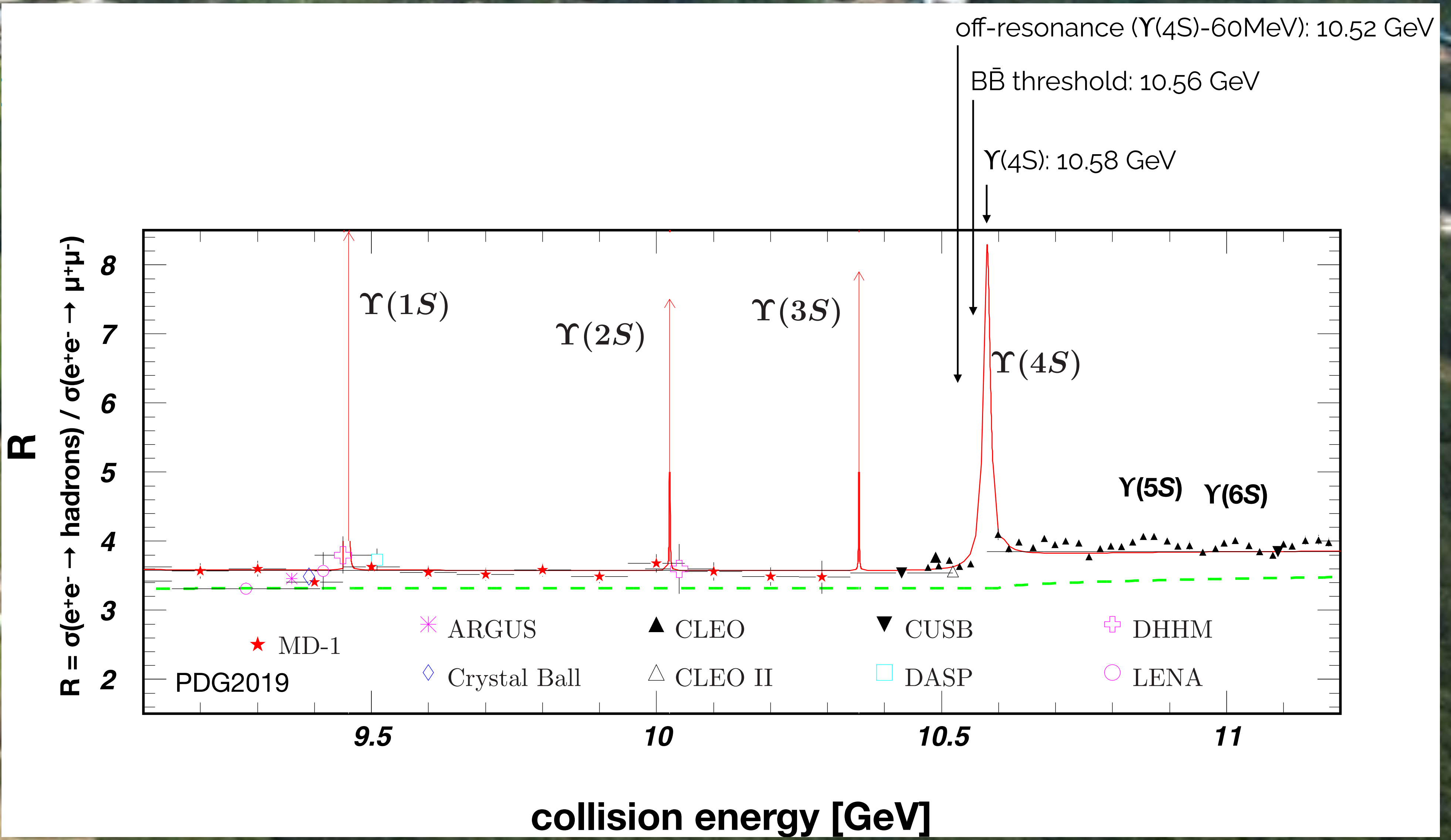
7 GeV e^-, 4 GeV e^+

E_{CM} Υ(4S) = 10.58 GeV + scans

Υ(4S) → B anti-B

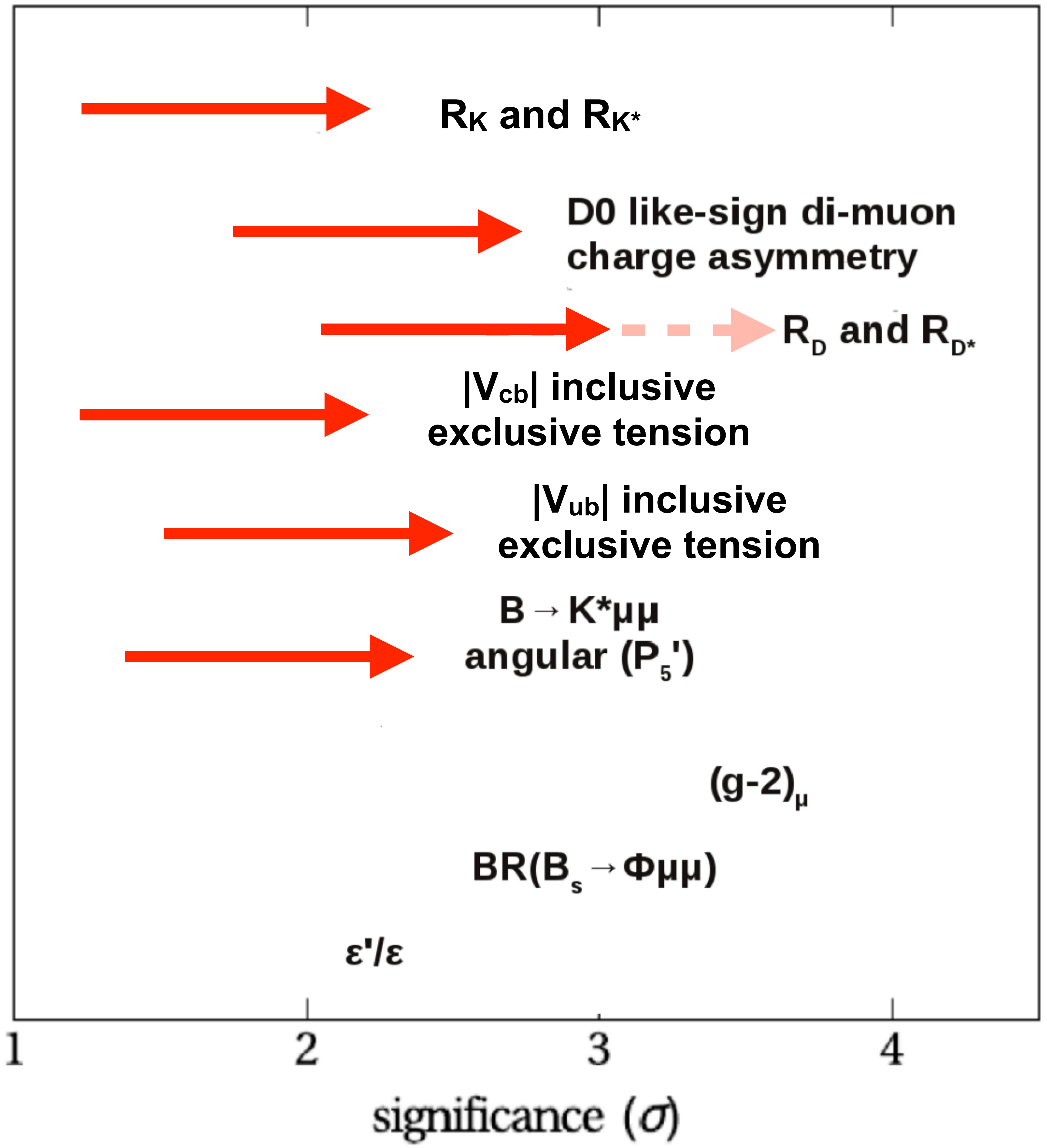
B + Charm + τ + Υ factory

~1050 researchers
(355 grad students)
from 23 countries.

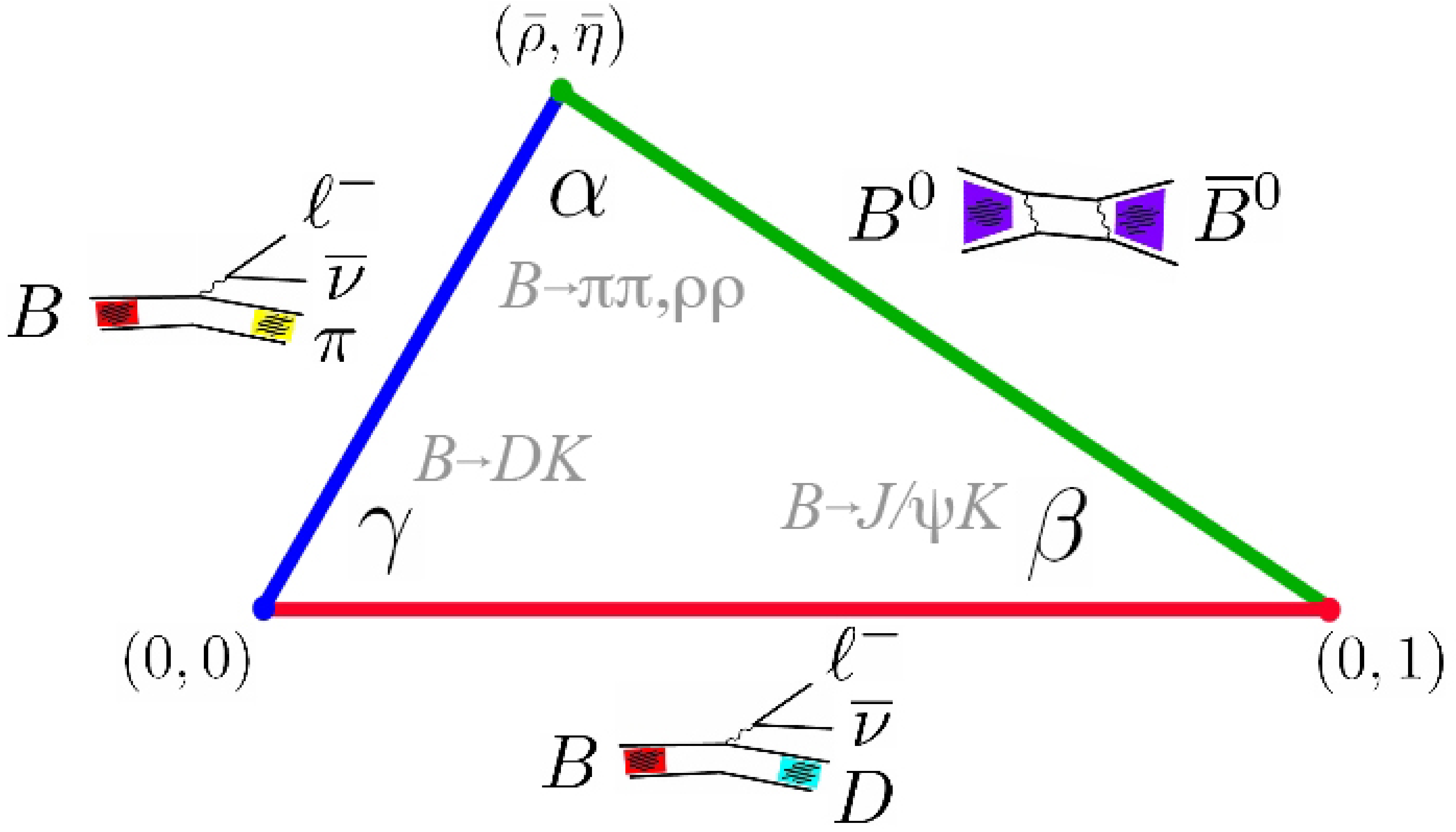


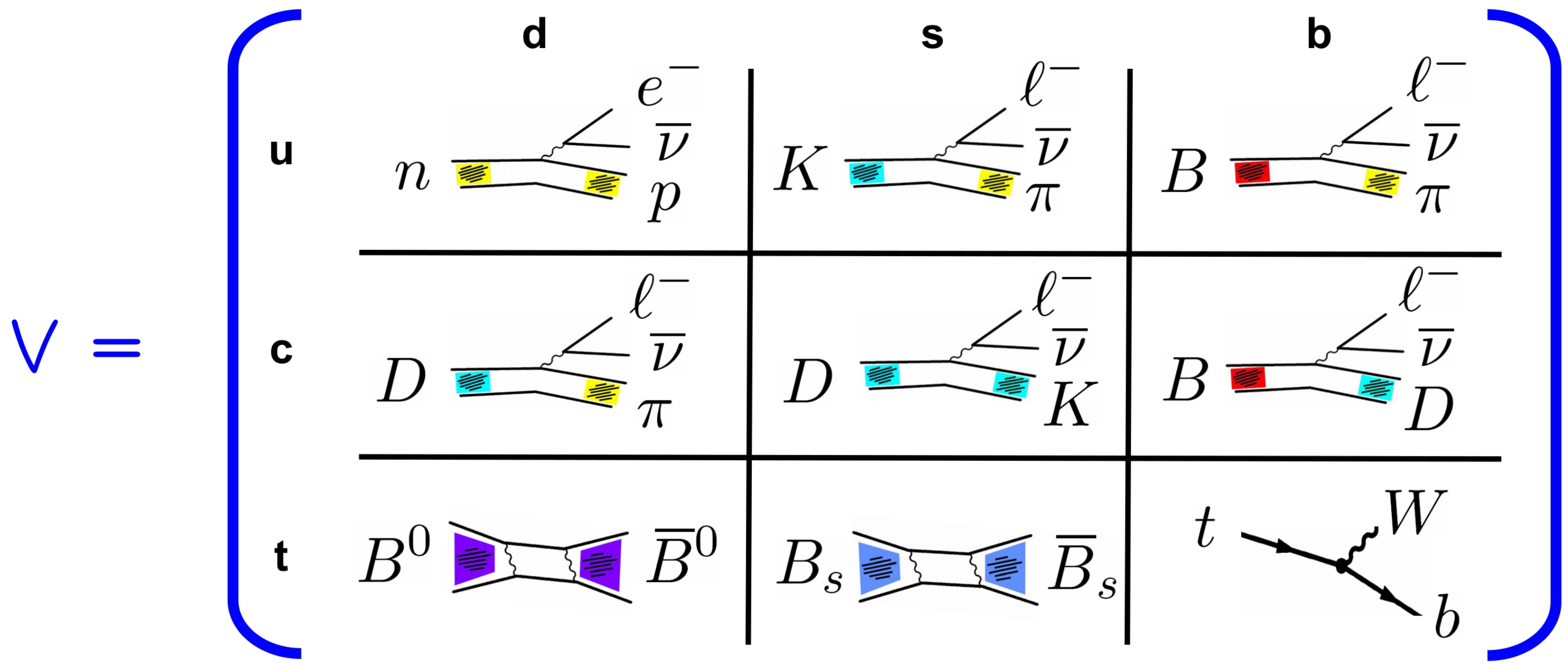
Belle II Flavour Program

- Belle II plans to collect 50 ab^{-1} of collisions near Υ(4S)
  - a (Super) B-factory (~1.1 x 10^9 BB pairs per ab^{-1})
    a (Super) charm factory (~1.3 x 10^9 cc pairs per ab^{-1})
    a (Super) τ factory (~0.9 x 10^9 ττ pairs per ab^{-1})
- *Flavour program at Belle II*
  - CKM precision metrology
  - Flavour BSM analyses with good "detection universality" (e.g. leptons). Ready to tackle "anomalies".
  - Dark, missing energy: hidden portals, axiflavons etc.
- Important, unexplained hierarchy among 10 of 19 params of SM m_ν=0
  - Mass (6 params, small ratios of scales)
  - CP violation (4 params, strong hierarchy between generations)
- With phenomenological consequences for quark flavour dynamics



CKM and CPV SM Metrology: Belle II core program





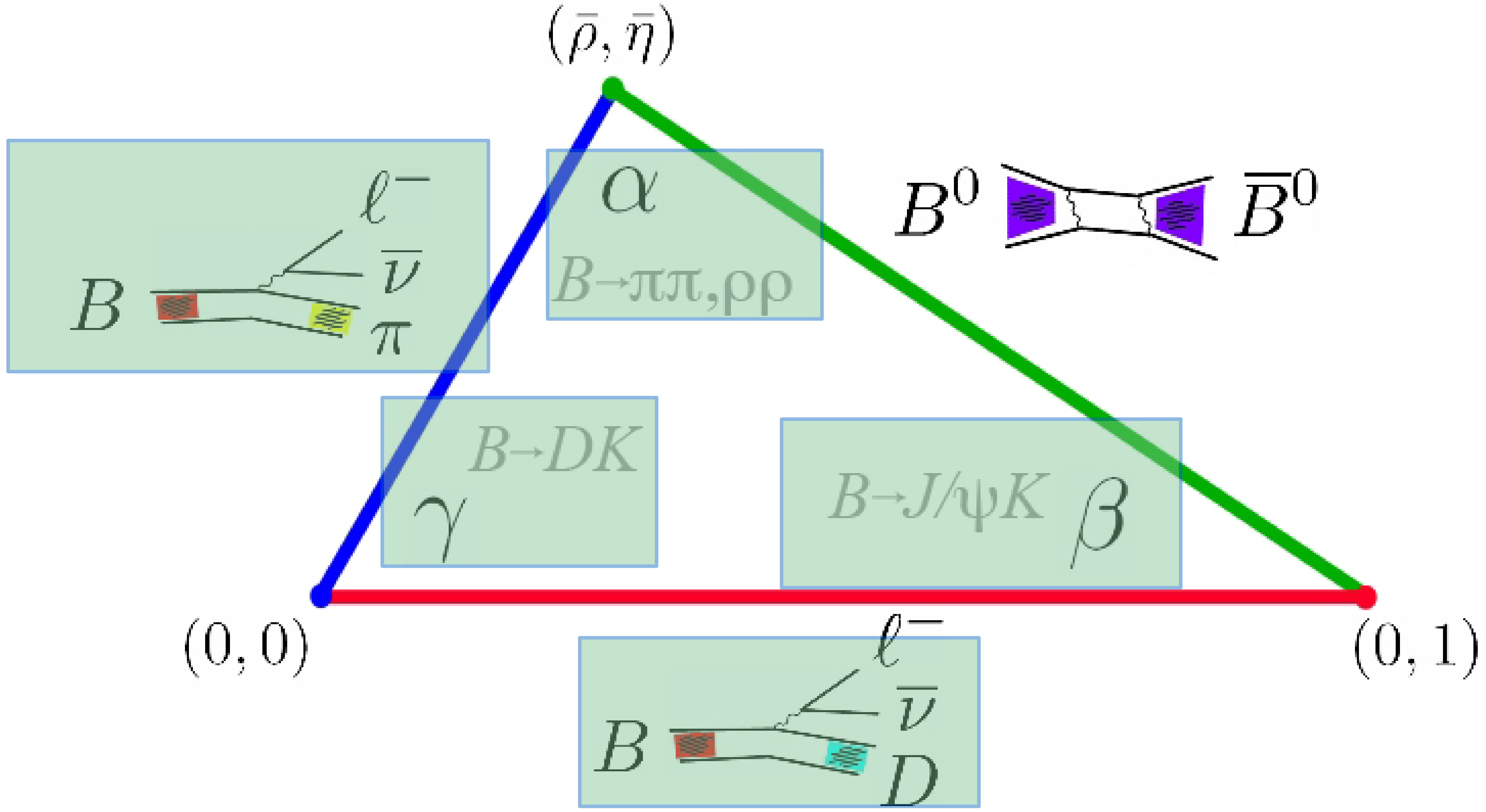
$B \to \pi\pi, \rho\rho$	Φ_2	$B \to D\, l\, \nu$ / $b \to c\, l\, \nu$	$\lvert V_{cb}\rvert$ via Form factor / OPE
$B \to D^{(*)} K^{(*)}$	Φ_3	$B \to \pi\, l\, \nu$ / $b \to u\, l\, \nu$	$\lvert V_{ub}\rvert$ via Form factor / OPE
$B \to J/\psi\, K_s$	Φ_1	$M \to l\, \nu\, (\gamma)$	$\lvert V_{UD}\rvert$ via Decay constant f_M
$B_s \to J/\psi\, \Phi$	β_s	ε_K	(ρ, η) via B_K
$K \to \pi\, \nu$ anti-ν	ρ, η	Δm_d, Δm_s	$\lvert V_{tb} V_{t\{d,s\}}\rvert$ via Bag factor B_B
		$B_{(s)} \to \mu^+ \mu^-$	$\lvert V_{t\{d,s\}}\rvert$ via Decay constant f_B

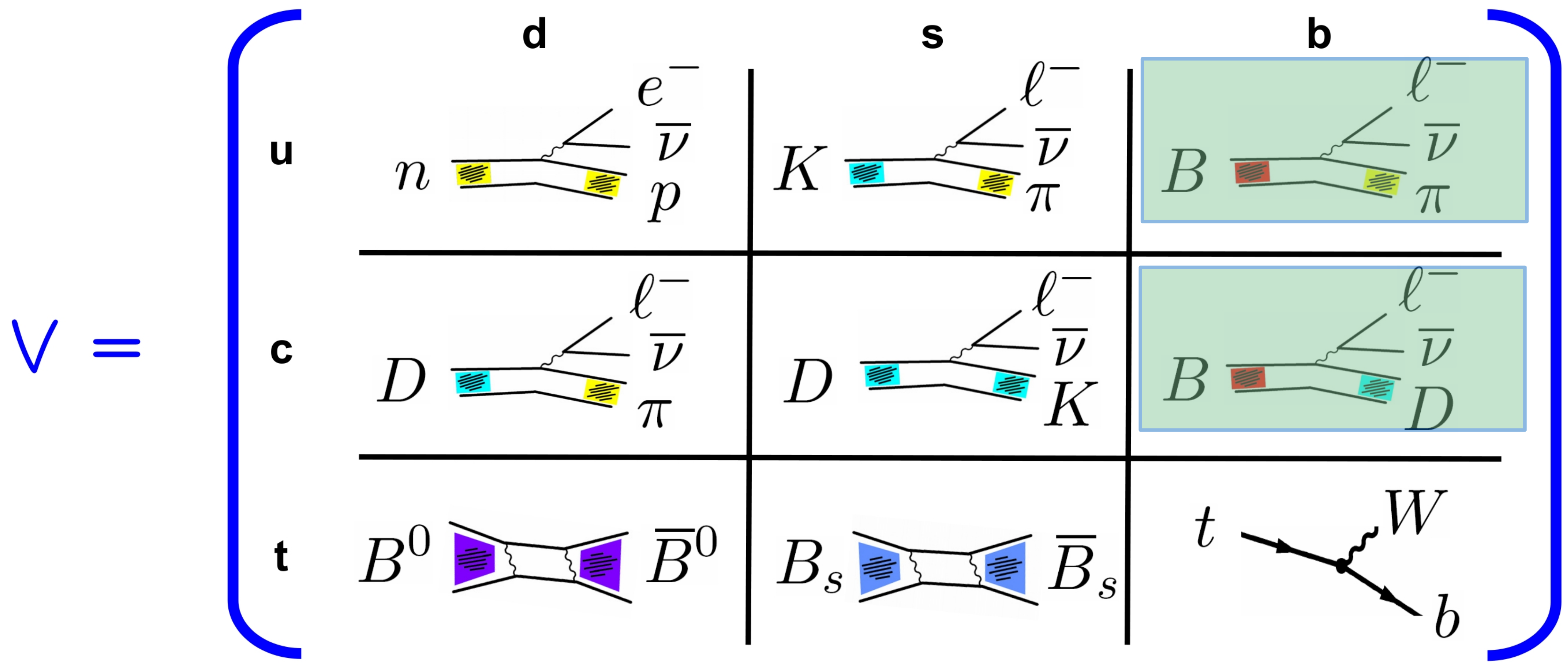
Observables with very different properties

Tree: e.g., $\lvert V_{ub}\rvert$, $\Phi 3$
Loop: e.g., Δm_d , Δm_s , ε_K , $\sin(2\beta)$
CP-conserving: e.g., $\lvert V_{ub}\rvert$, Δm_d, Δm_s
CP-violating: e.g., γ, ε_K , $\sin(2\beta)$

Exp. uncs.: e.g., α, $\sin(2\beta)$, γ
Syst. uncs.: e.g., $\lvert V_{ub}\rvert$, $\lvert V_{cb}\rvert$, ε_K, Δm_d, Δm_s

CKM and CPV SM Metrology: Belle II core program





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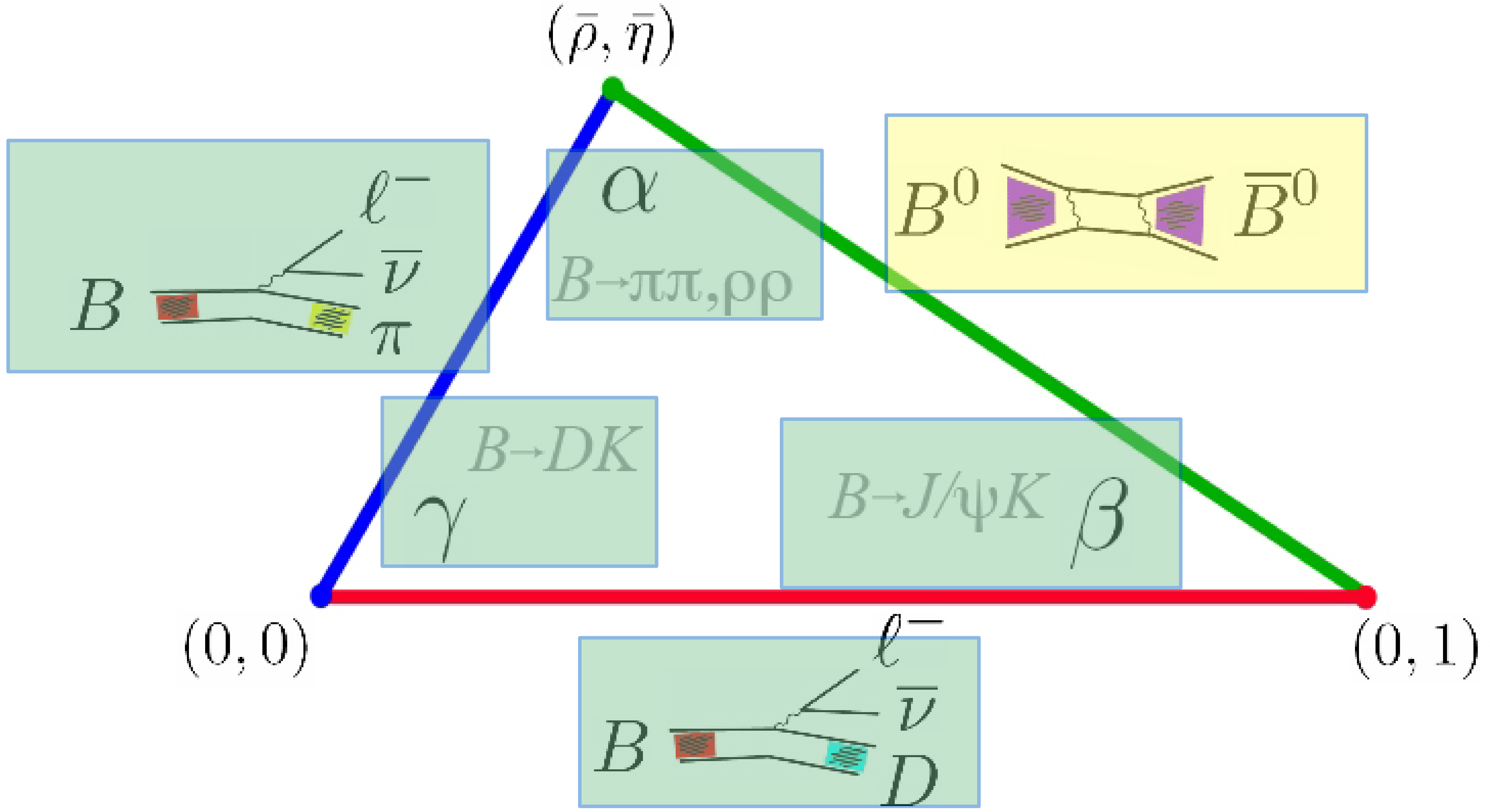

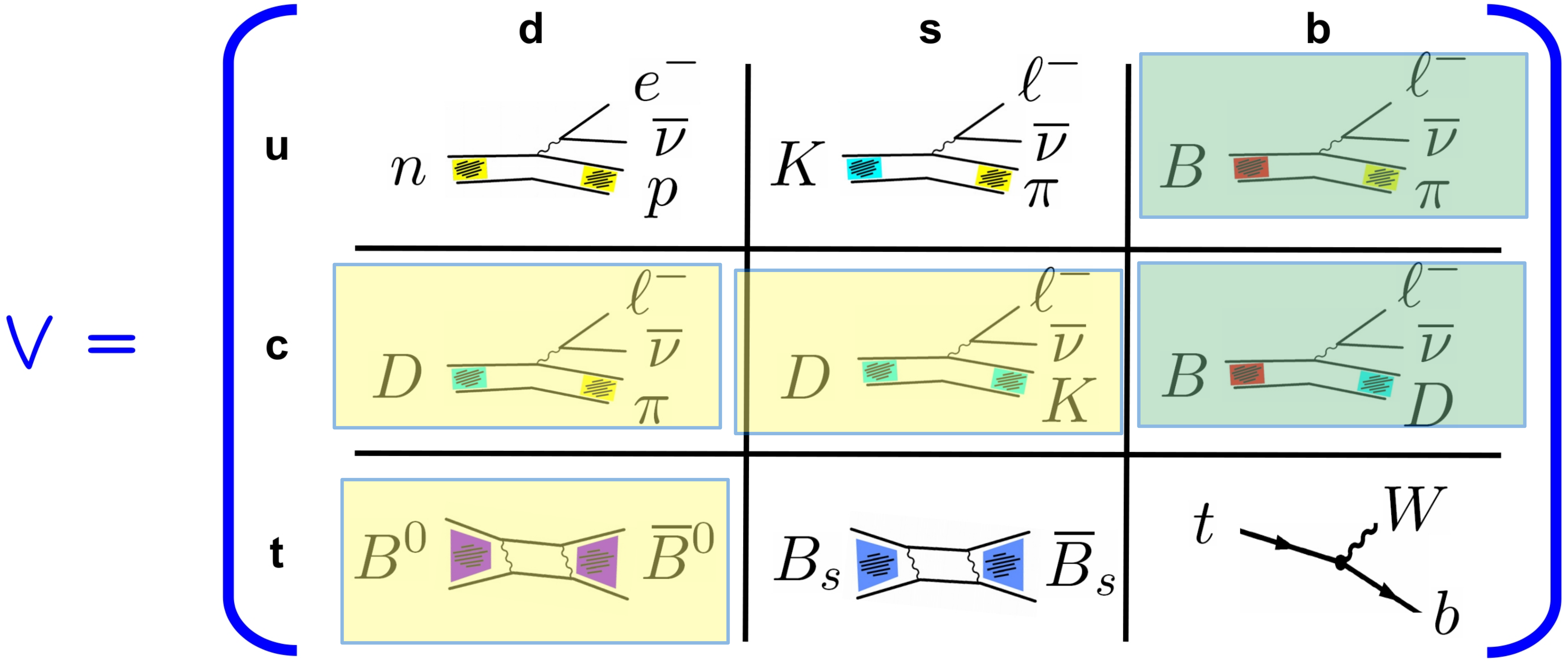

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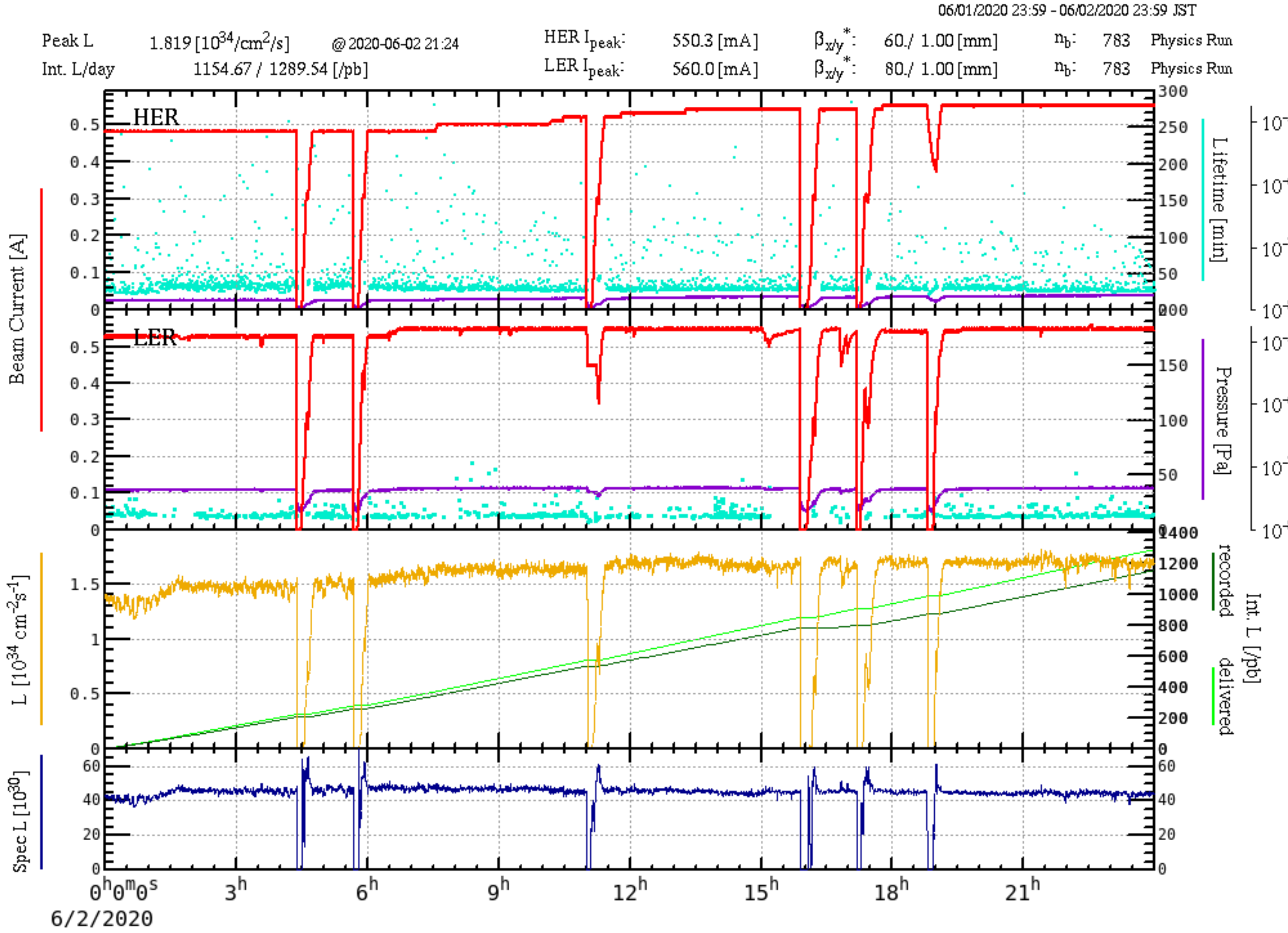
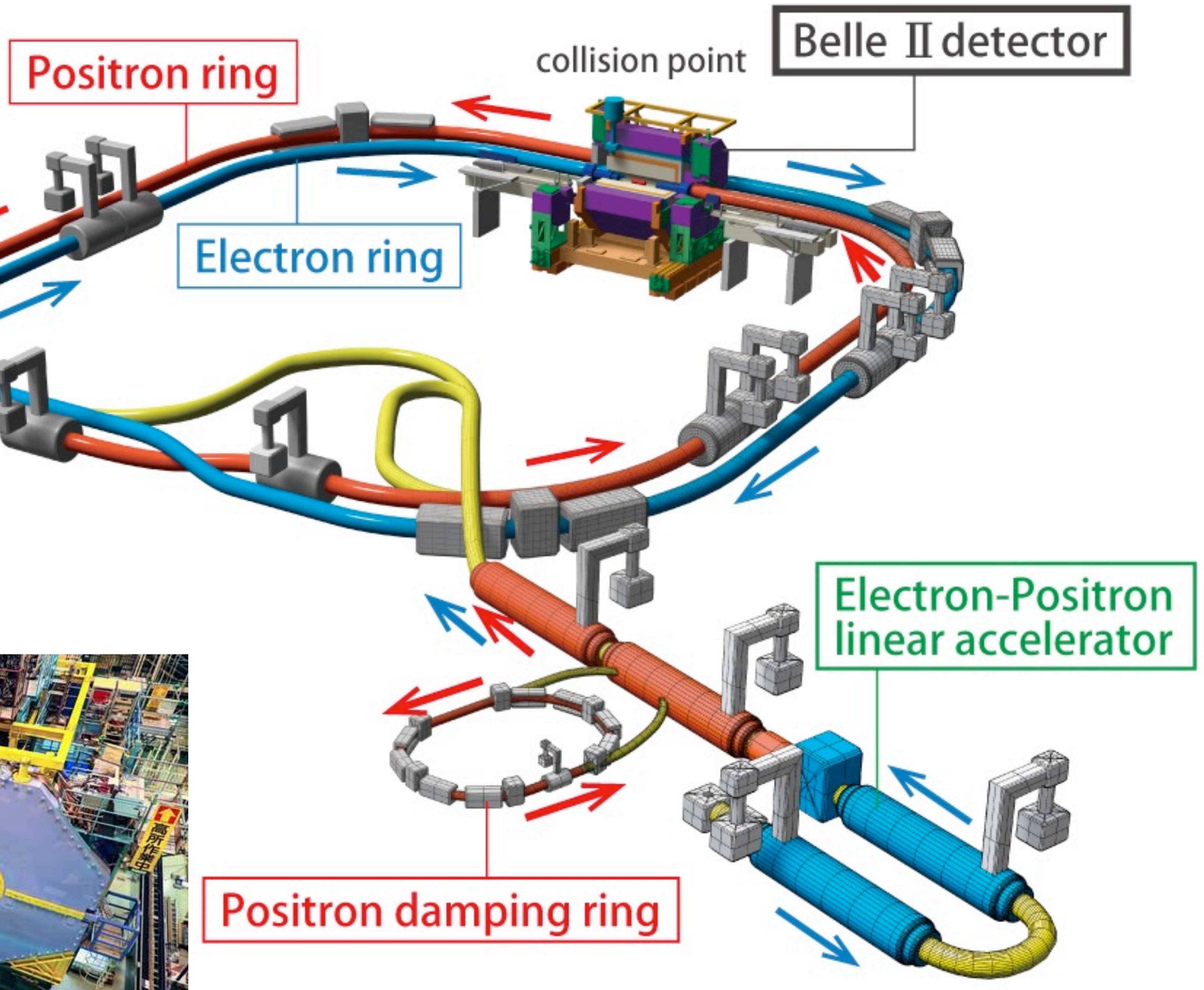
SuperKEKB

$$L = \frac{\gamma_{\pm}}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_{\pm}\xi_{\pm y}}{\beta_y^*}\frac{R_L}{R_y}$$

	KEKB	SuperKEKB	**Achievements**
β^*_y(mm)	5.9/5.9	0.3/0.27	**1/1**
I_{beam}(A)	1.19/1.65	2.6/3.6	**0.70/0.88 ****
L($cm^{-2}s^{-1}$)	2.11x10^{34}	80x10^{34}	**1.88x10^{34}**

SuperKEKB, 1/6/2020

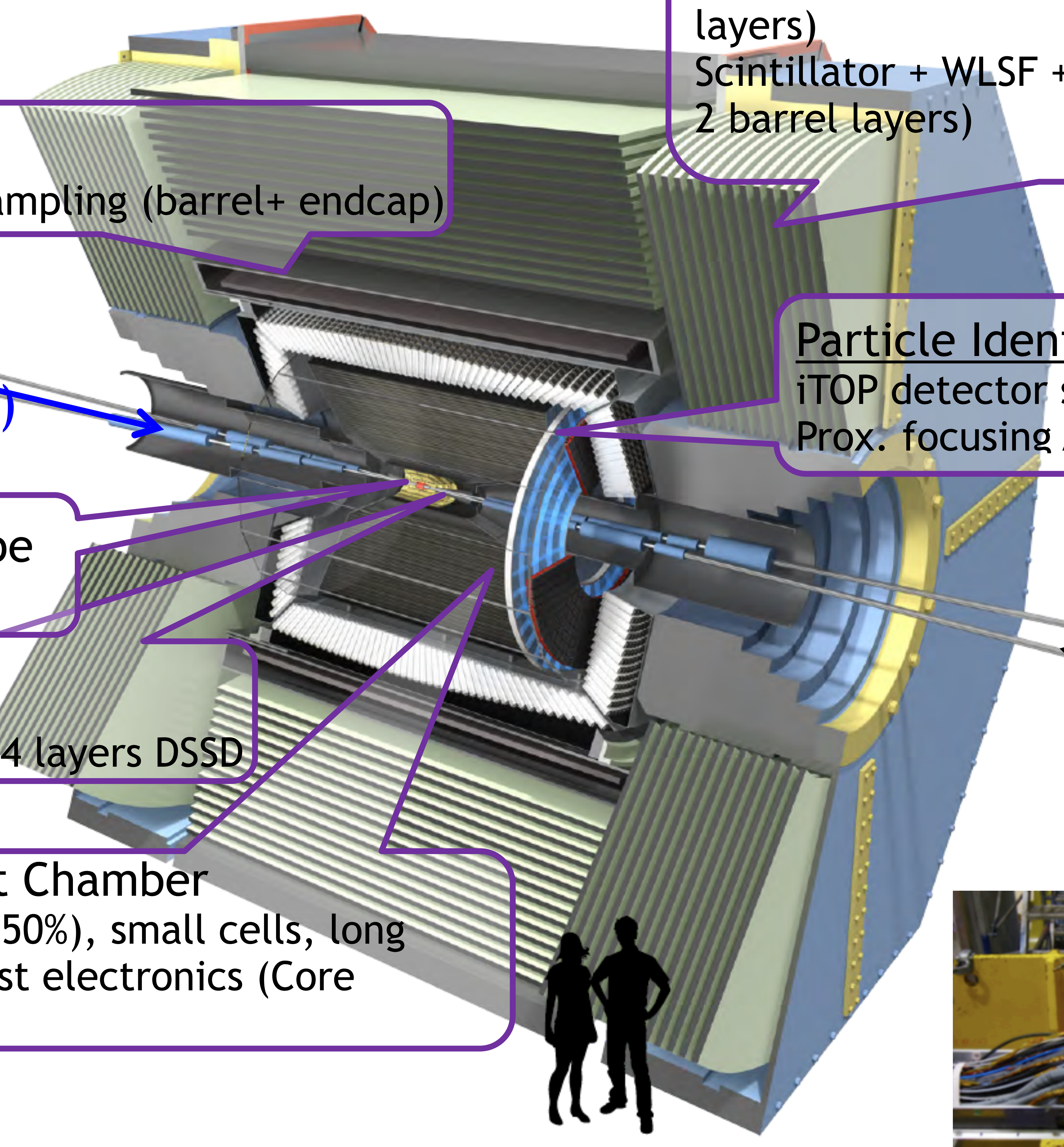




1) New e⁺ damping ring (commissioned 2018).
2) New 3 km e⁺ ring vacuum chamber (commissioned in 2016). Optics and vacuum scrubbing in 2018.
3) New superconducting final focus (commissioned 2018).

20× smaller beam spot (σ_y=50 nm) but *generally higher beam background*

Belle II Detector, 2020 Full Operations



K-Long and muon detector:
Resistive Plate Chambers (barrel outer layers)
Scintillator + WLSF + SiPM's (end-caps , inner 2 barrel layers)

EM Calorimeter:
CsI(Tl), waveform sampling (barrel+ endcap)

electrons (7 GeV)

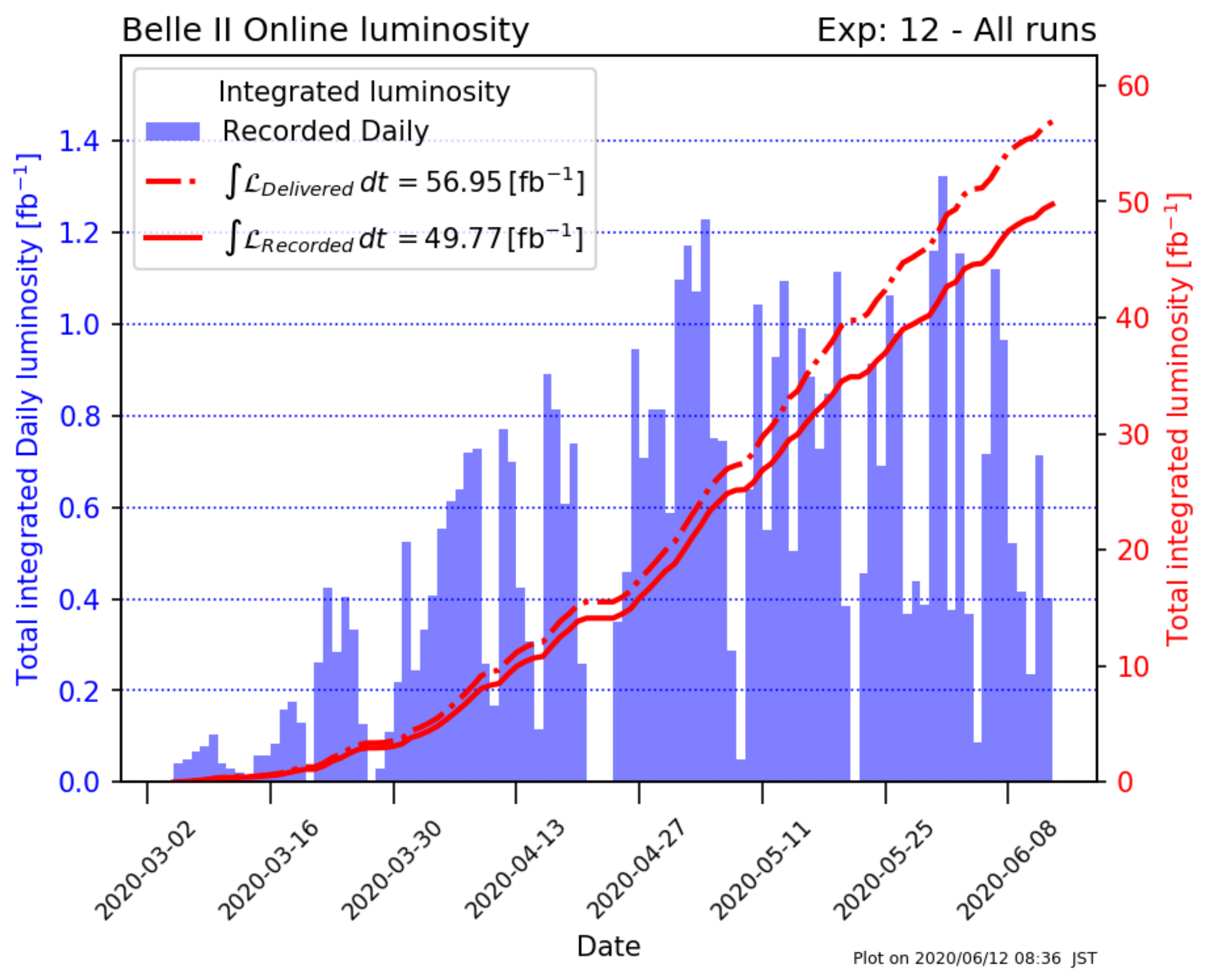
Particle Identification
iTOP detector system (barrel)
Prox. focusing Aerogel RICH (fwd)

Beryllium beam pipe
2cm diameter

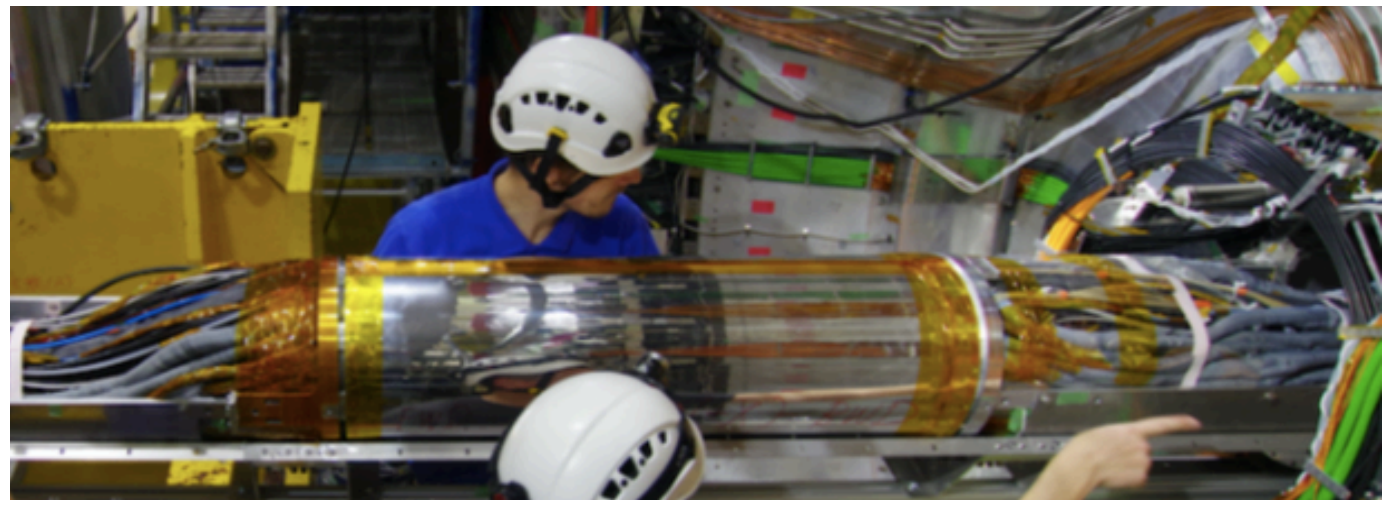
Vertex Detector
1→2 layers DEPFET + 4 layers DSSD

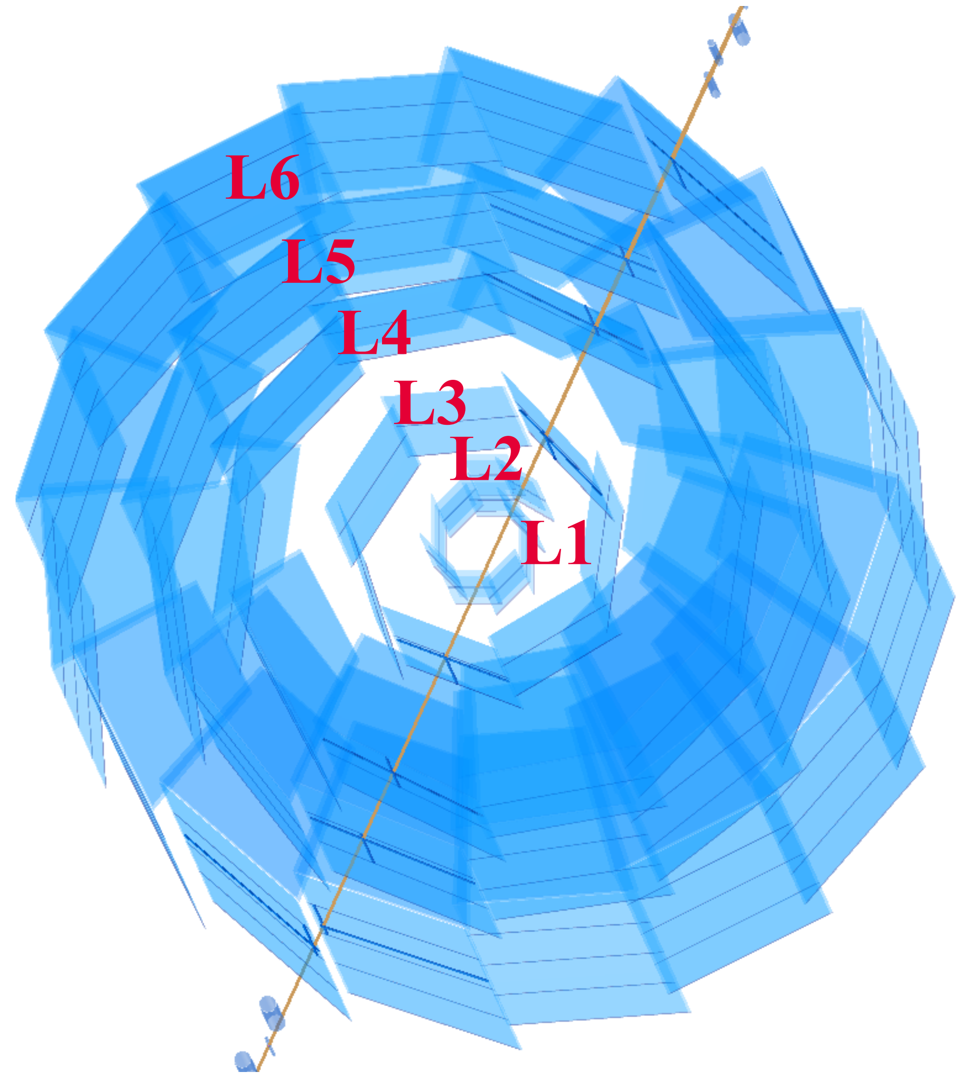
Central Drift Chamber
He(50%):C_2H_6(50%), small cells, long lever arm, fast electronics (Core element)

positrons (4 GeV)



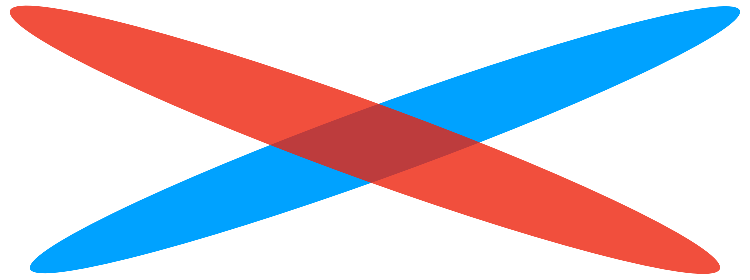
~90% data taking efficiency





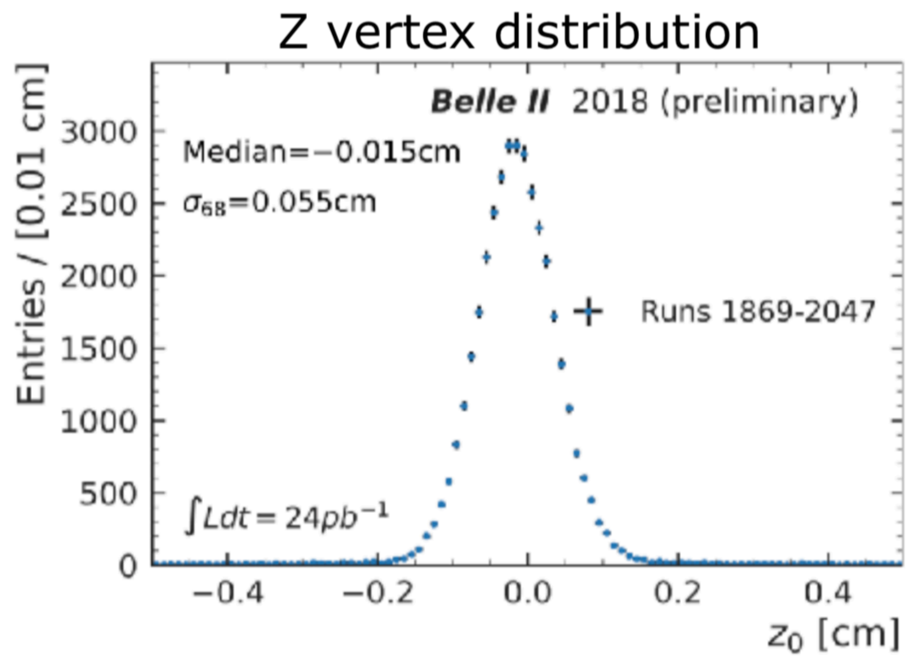
Nano-beams and the vertex detector

SuperKEKB

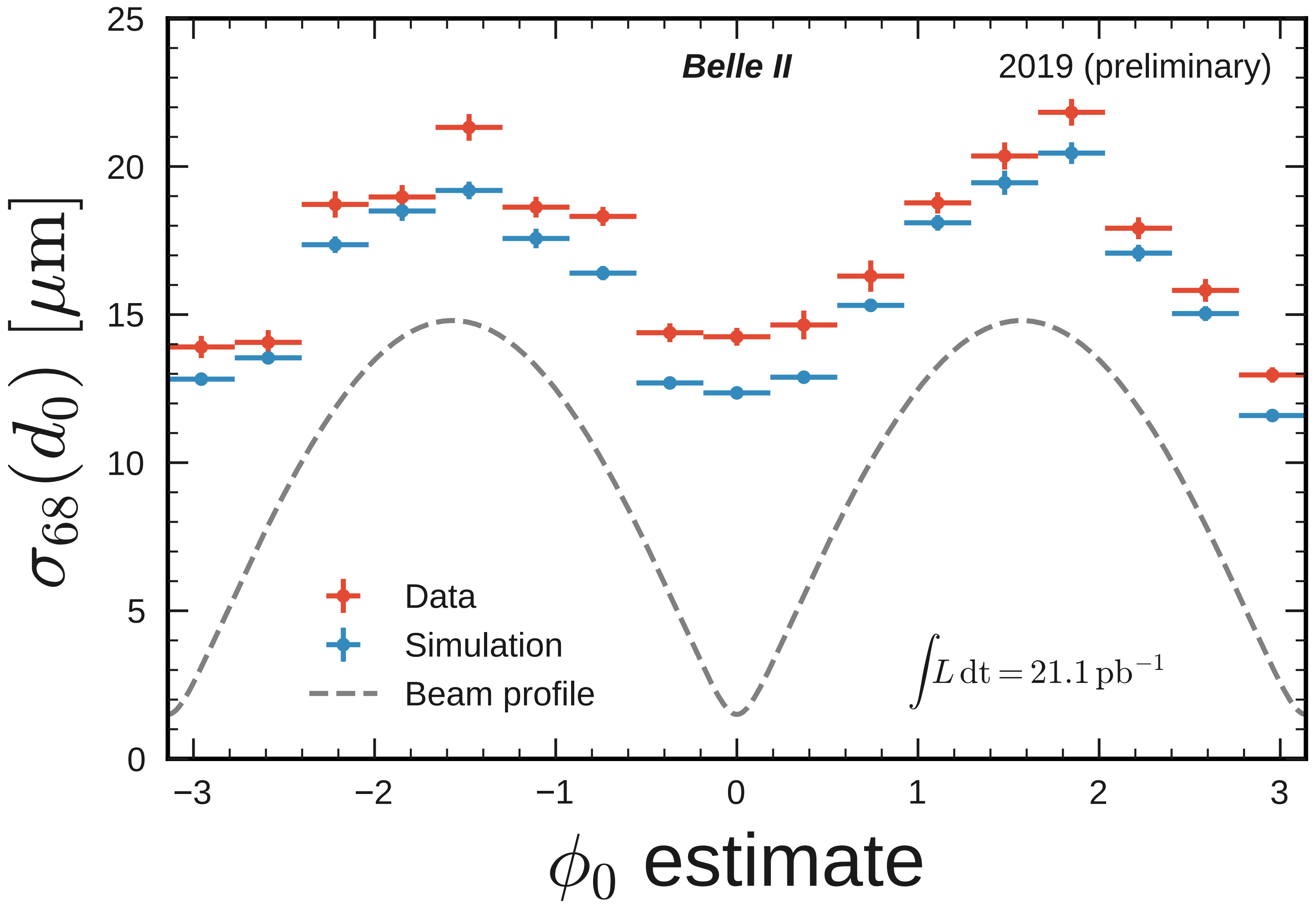


The vertex distribution is constrained in the nano-beam scheme.

Nano-Beam (SuperKEKB Phase2)



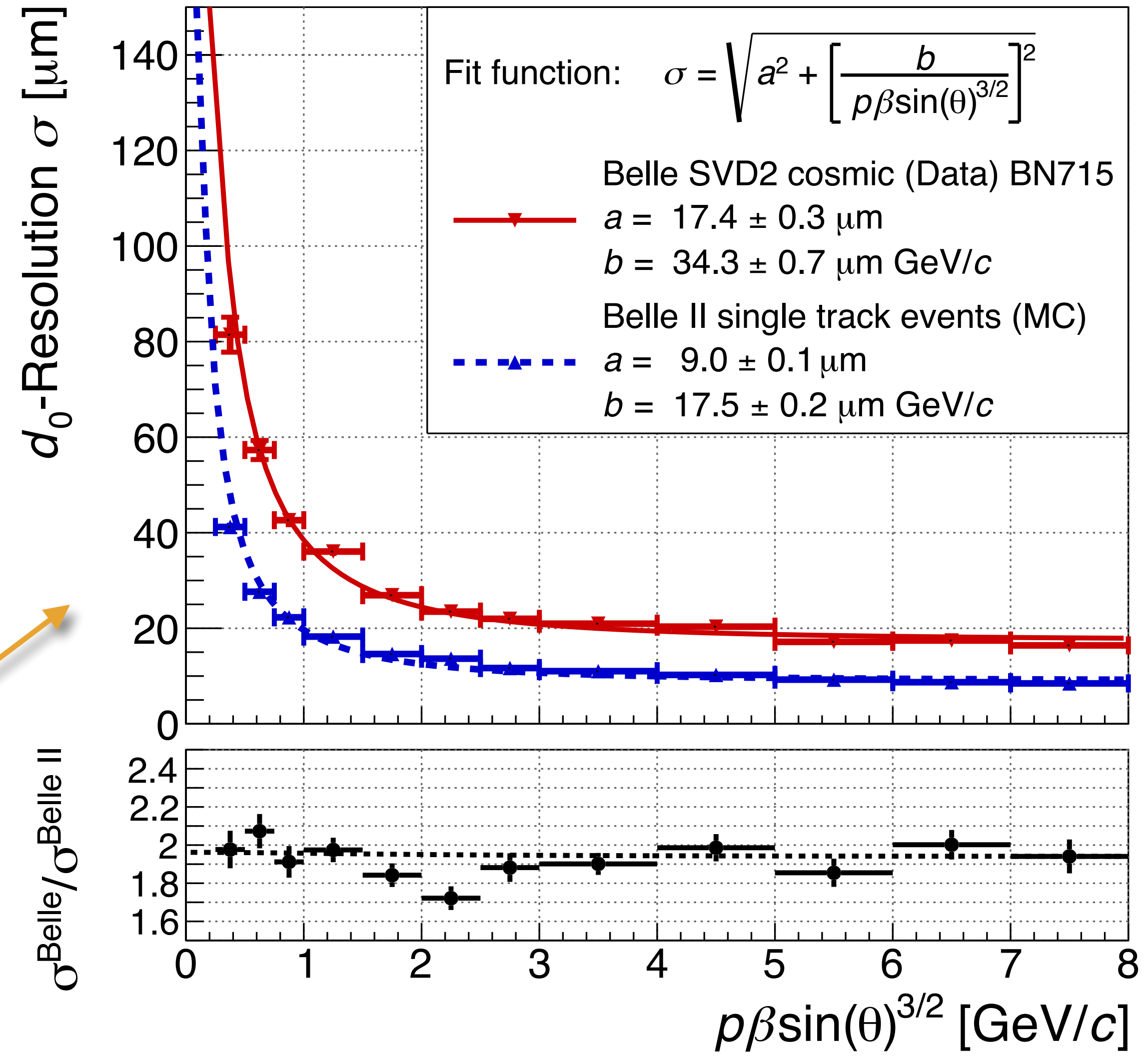
σ = 550 μm

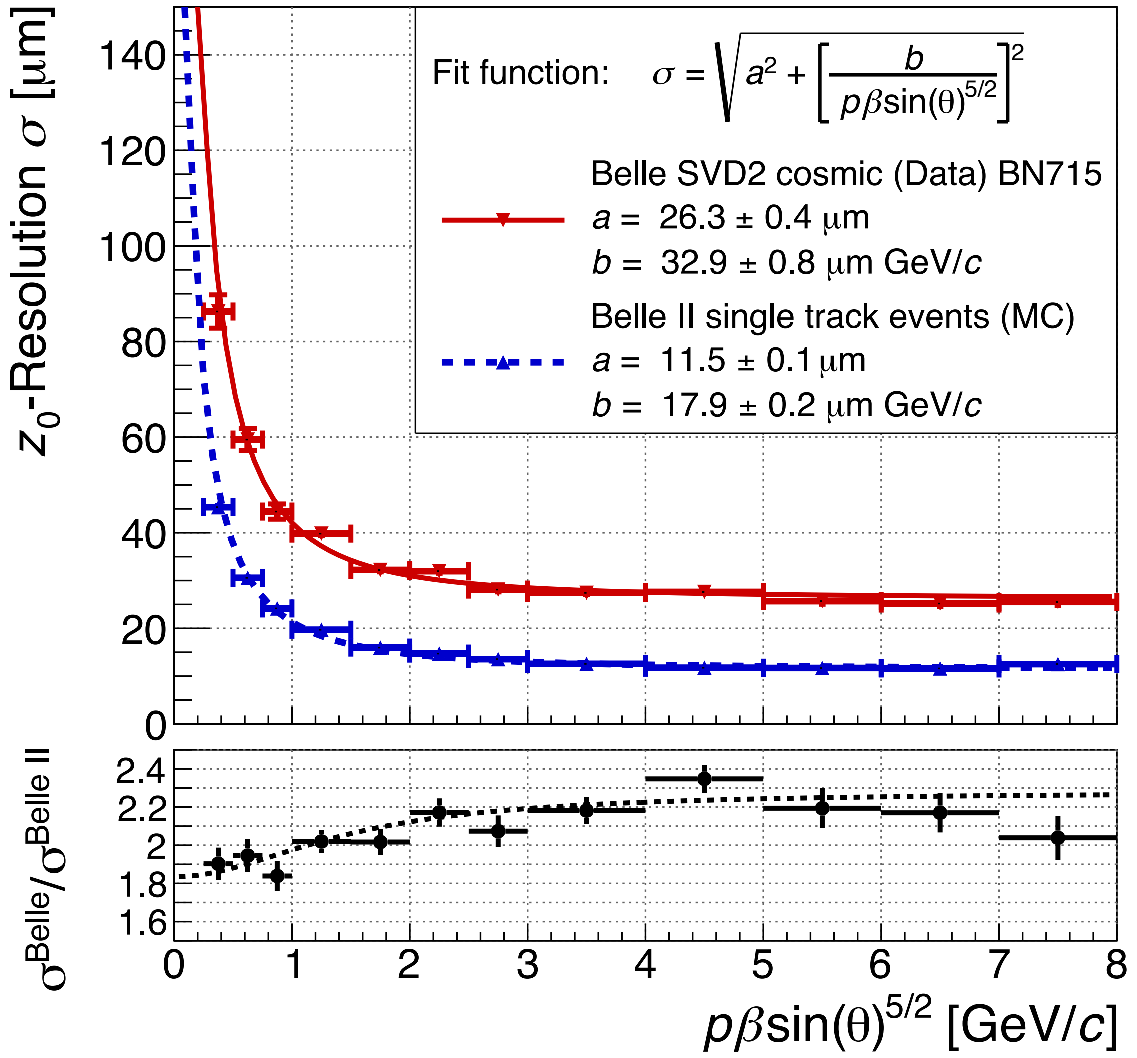


Effective bunch length *reduced x 1/10*

And vertex resolution 2x better than Belle

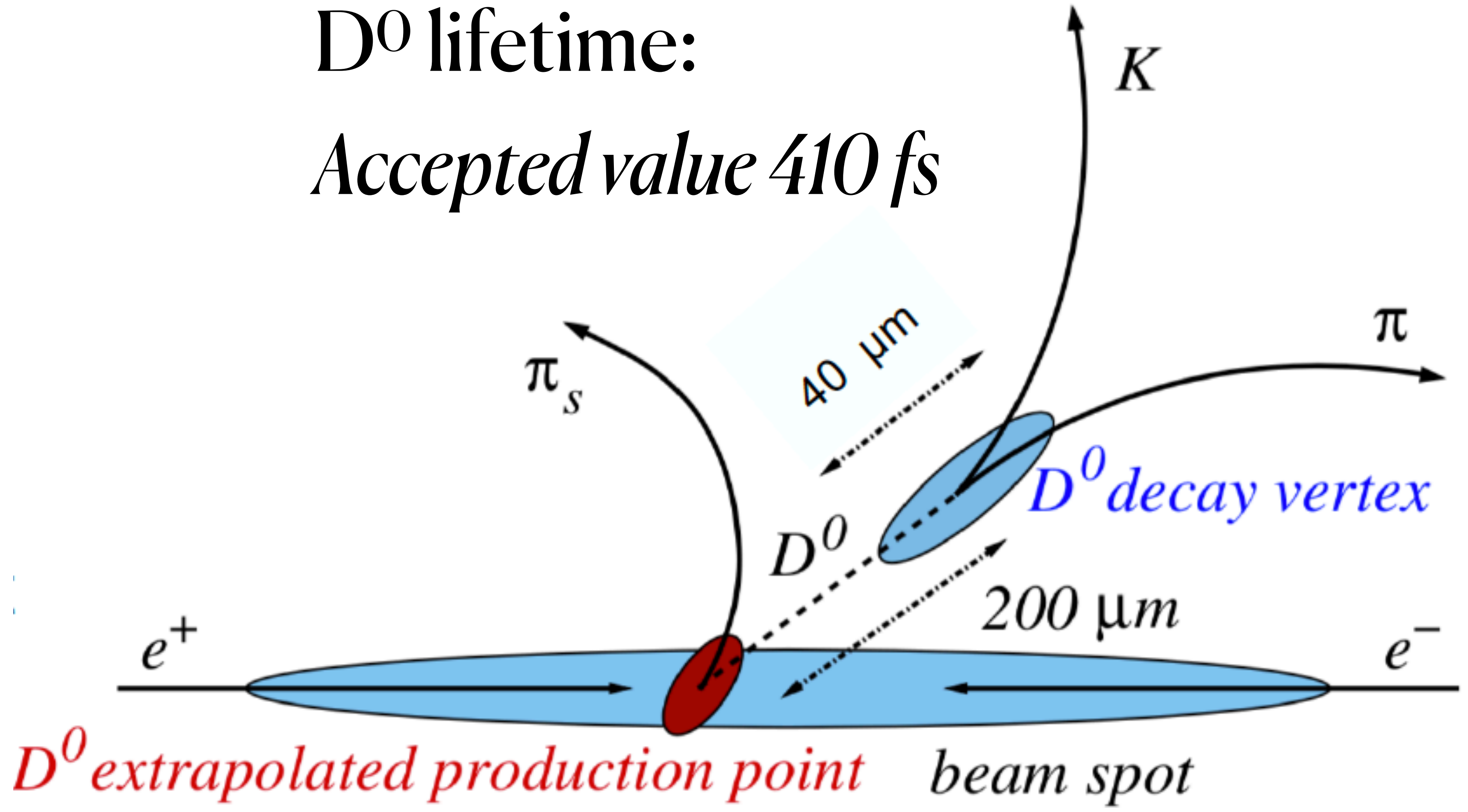
Belle II MC Vs Belle



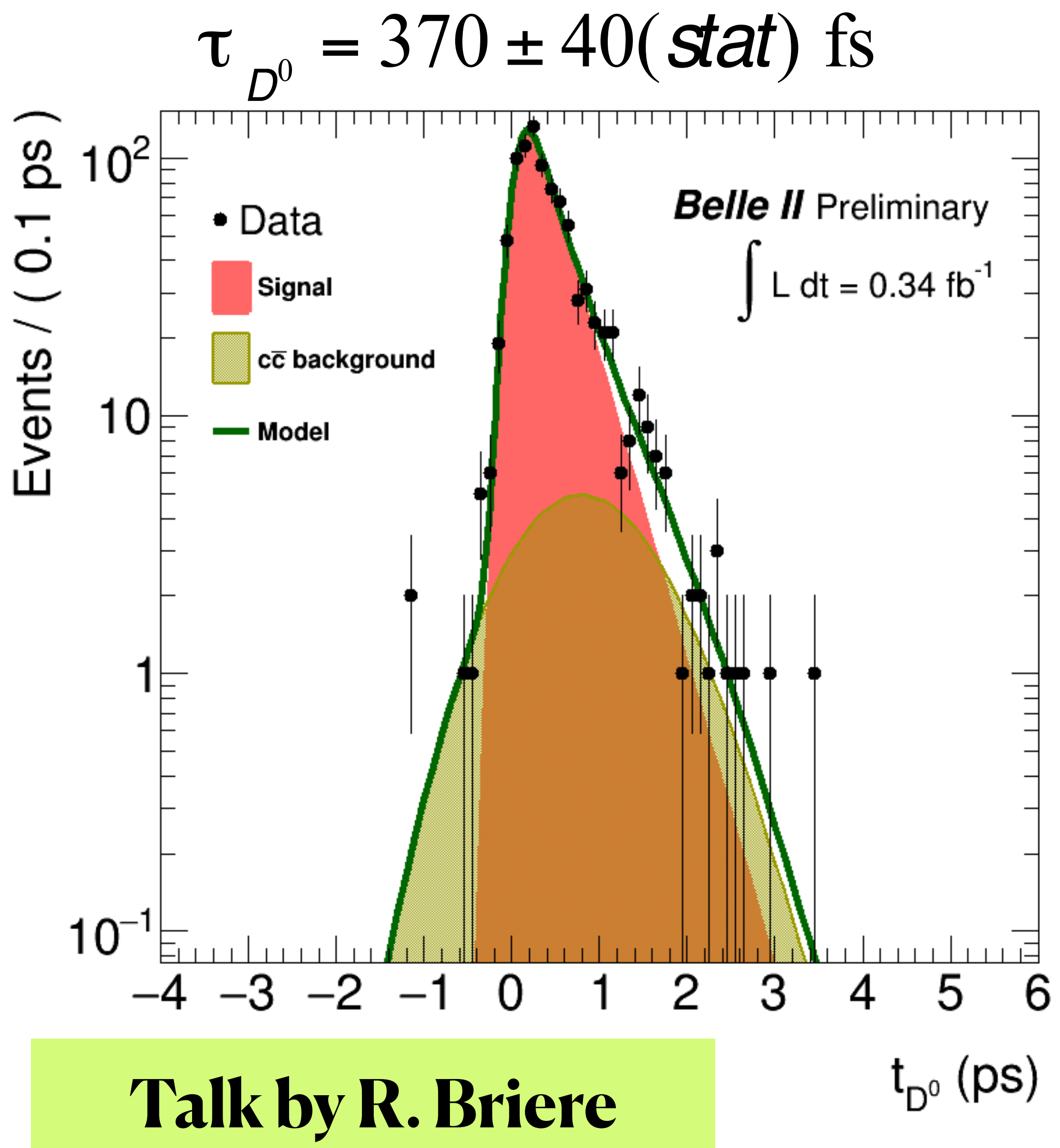


D^0 lifetime:

Accepted value 410 fs



$\tau_{D^0} = 370 \pm 40(stat)$ fs



~ 40 μm D^0 flight path resolution

Talk by R. Briere

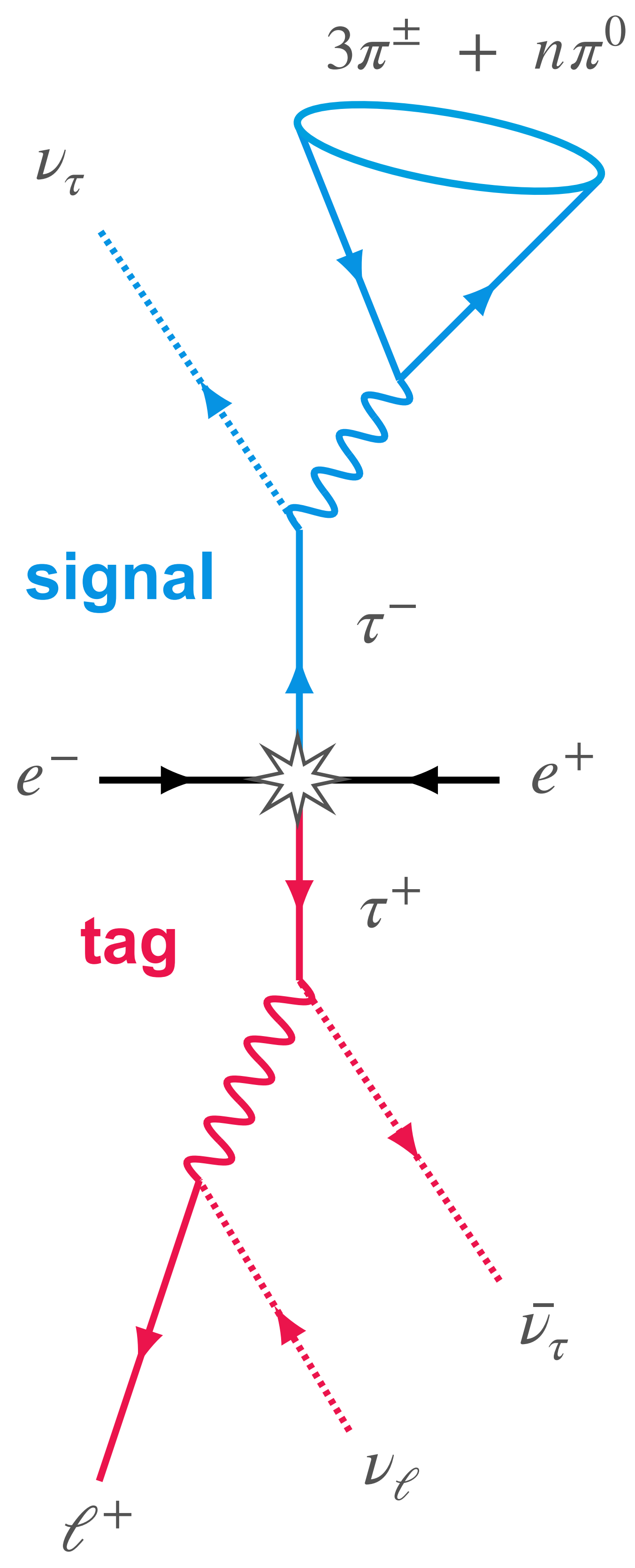
Tracking - tag and probe

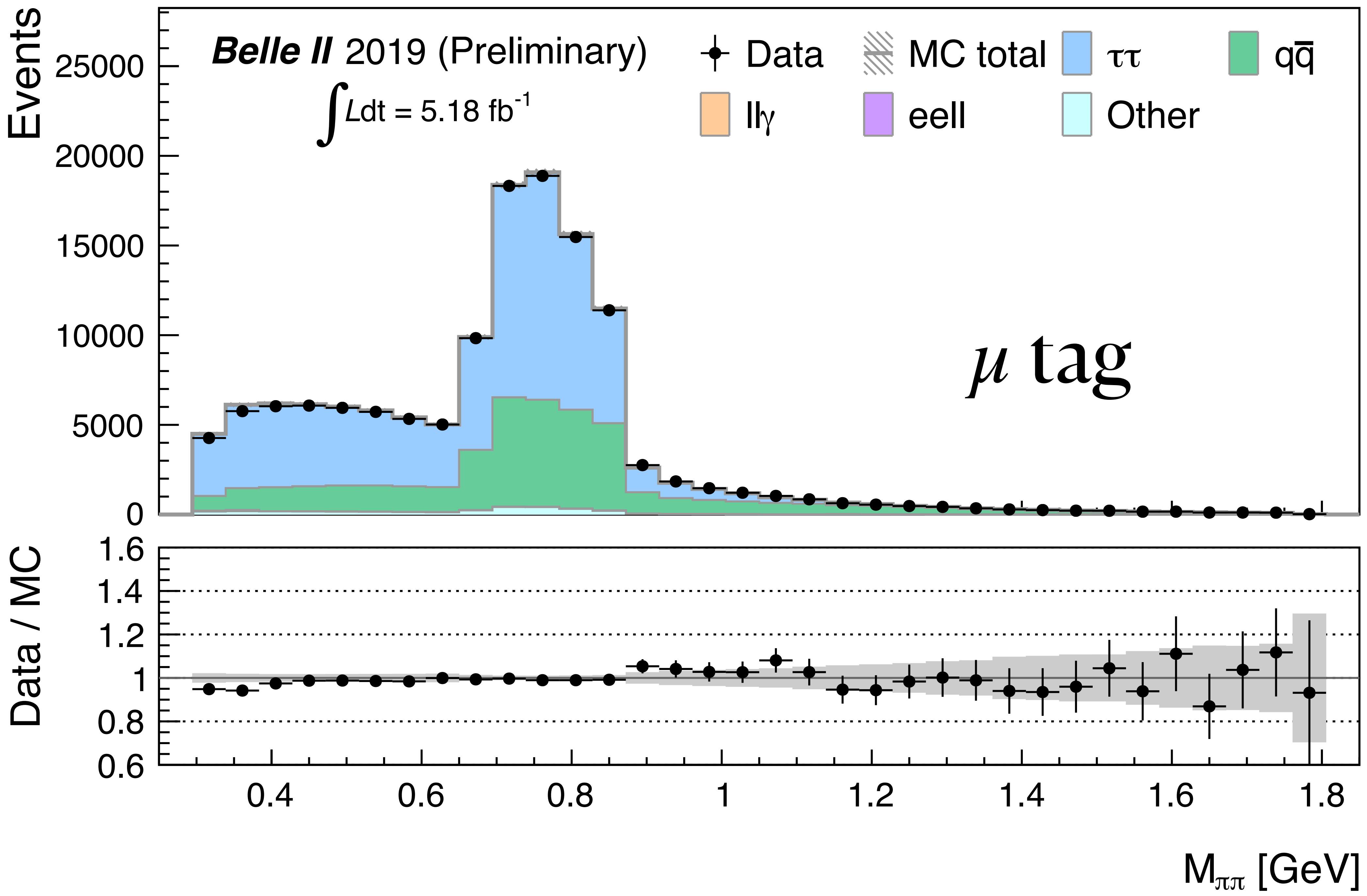
ee→ττ(γ)

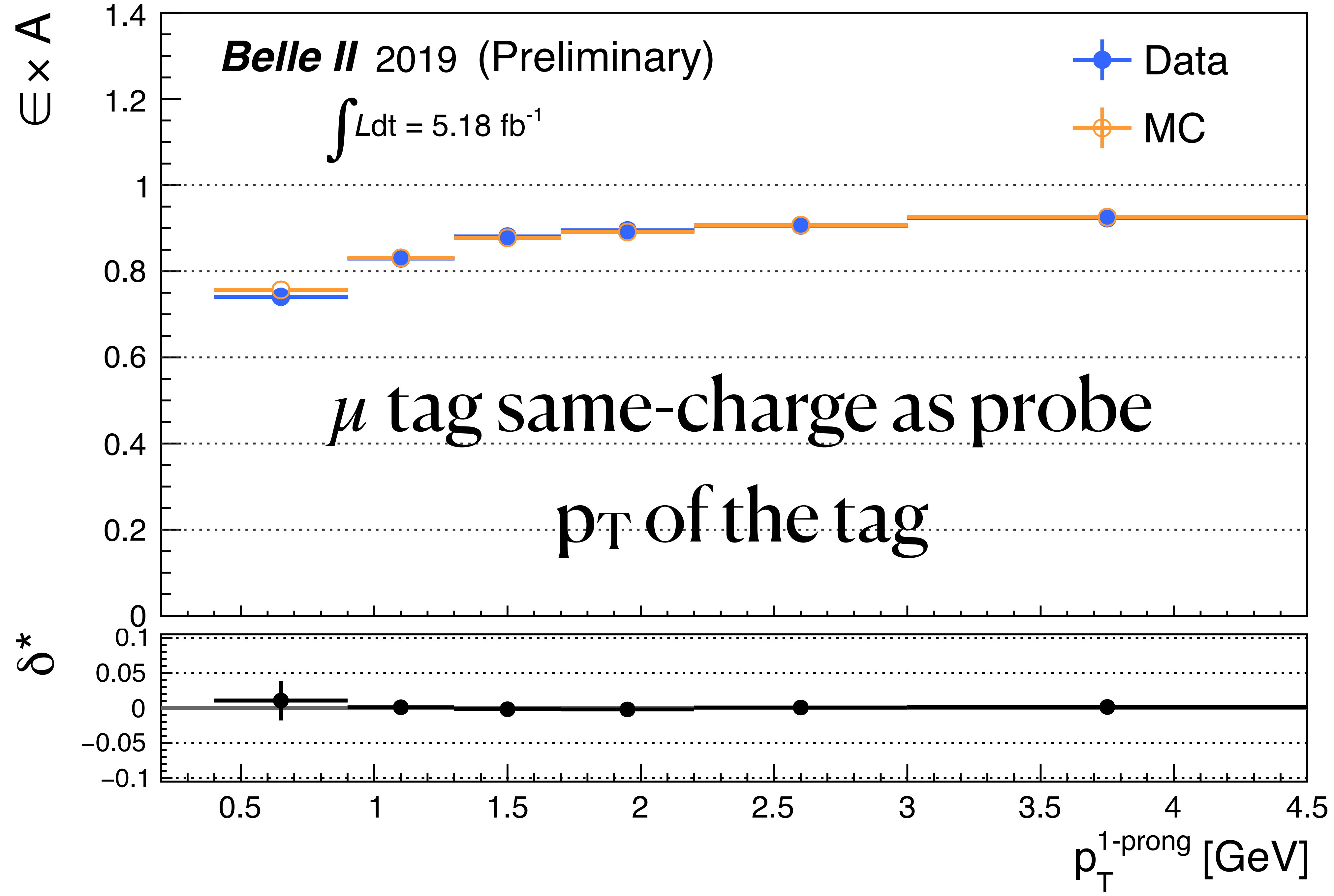
Used for early trigger & track efficiency measurements.
Ratio of 3 and 4 track events, with e or μ tag.
More techniques being explored with > 10 fb-1 datasets.

$$\epsilon_{track} \cdot A = \frac{N_4}{N_3 + N_4}$$

$$\delta = 1 - \frac{\epsilon_{Data}}{\epsilon_{MC}}$$







Talk by M. Villanueva

Systematic error on tracking based on averaging over subsets.

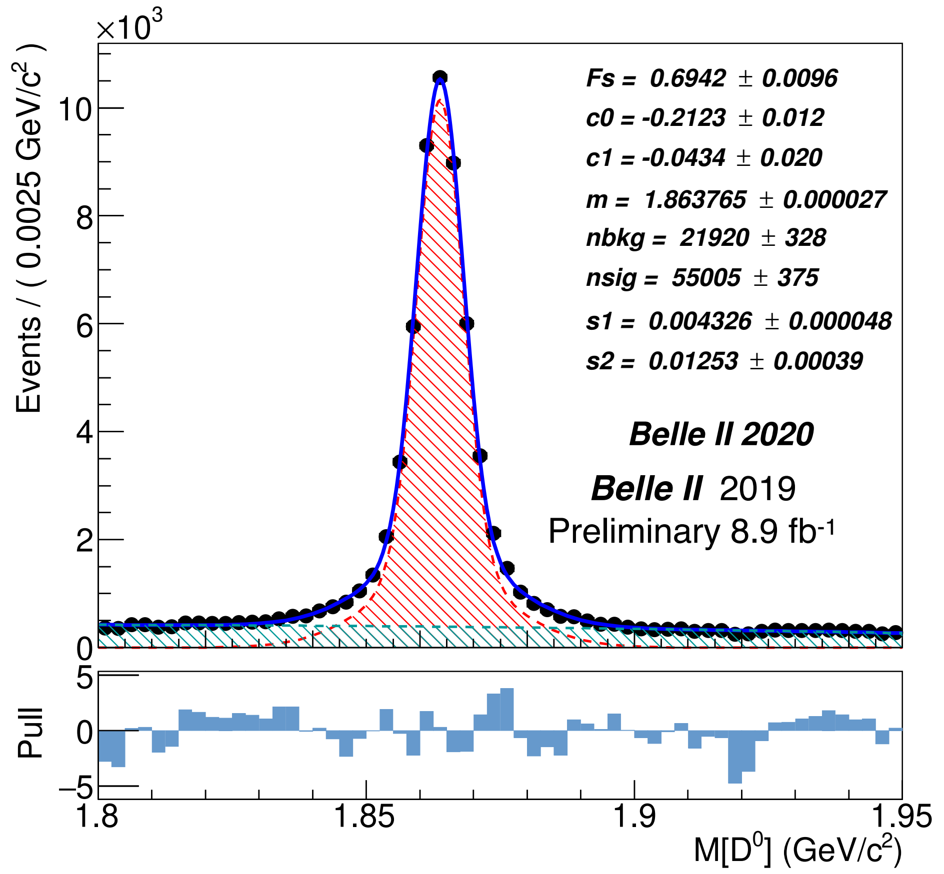
$$\delta^*_{\mathrm{overall}} = 0.19 \pm 0.14\ (\mathrm{stat})\ \%$$

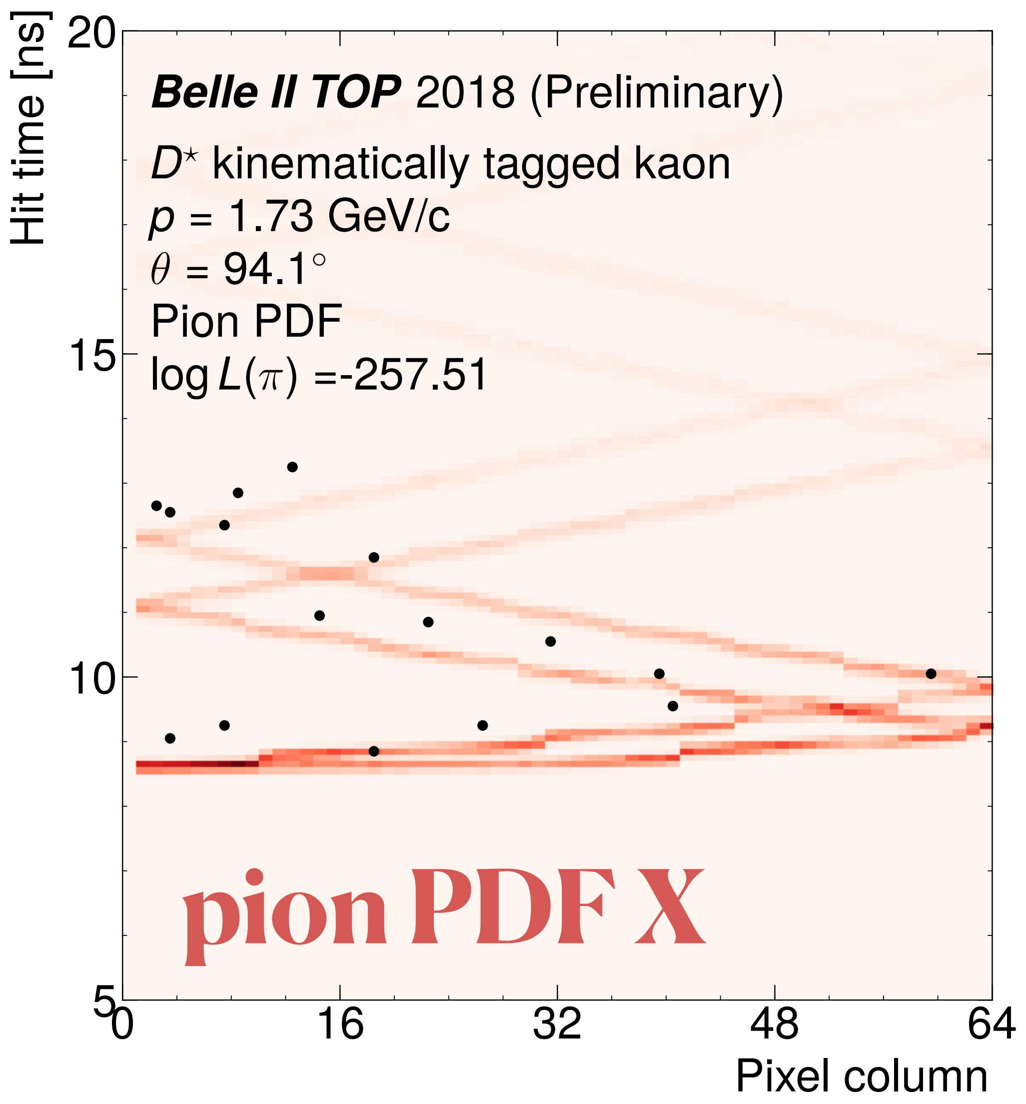
Hadron Identification

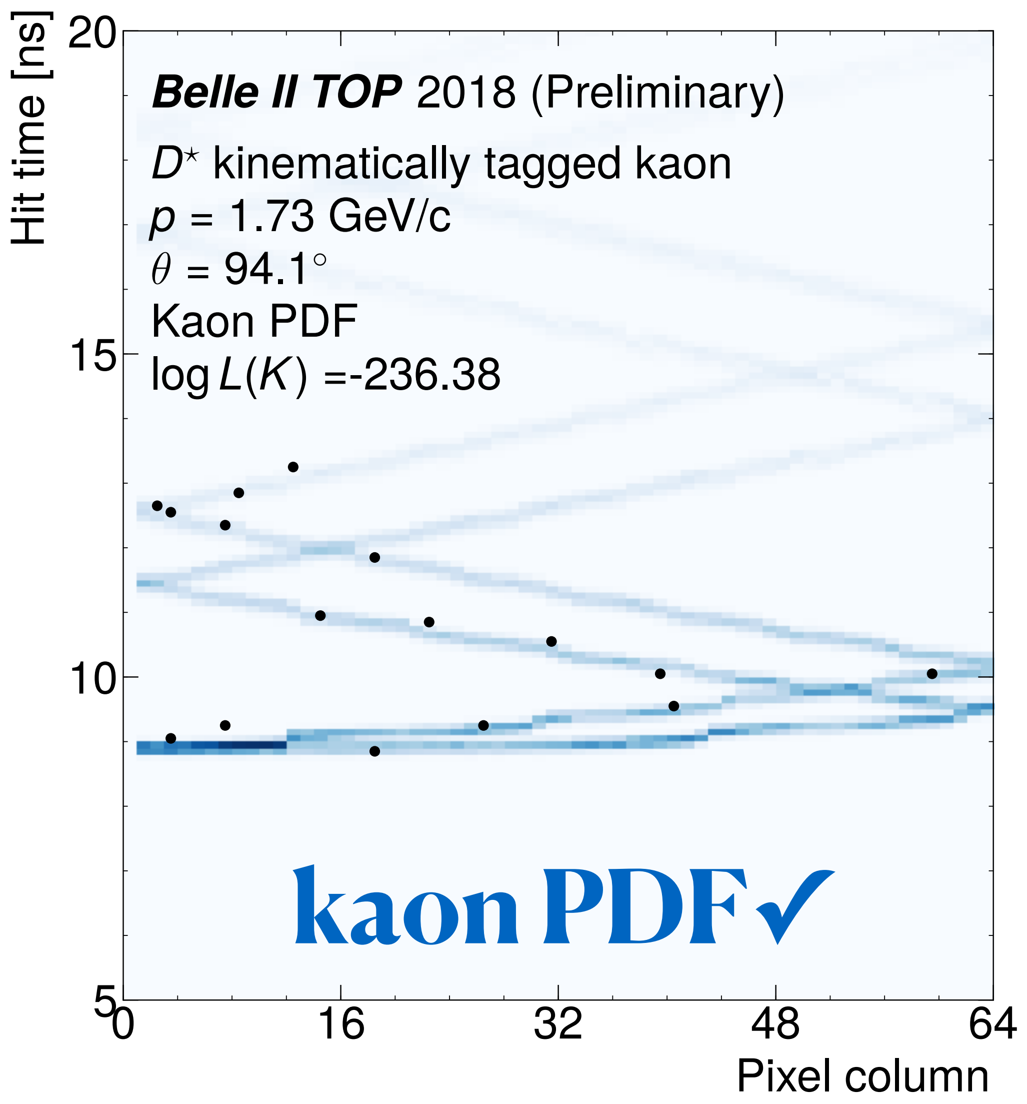
- dE/dx (CDC, SVD) & Time of propagation Cherenkov patterns (TOP), and Cherenkov rings (ARICH).
  - Performance with D* sample.
- FCNC b→d and b→s transitions are key are for flavour studies, requiring better K/π ID performance than Belle.

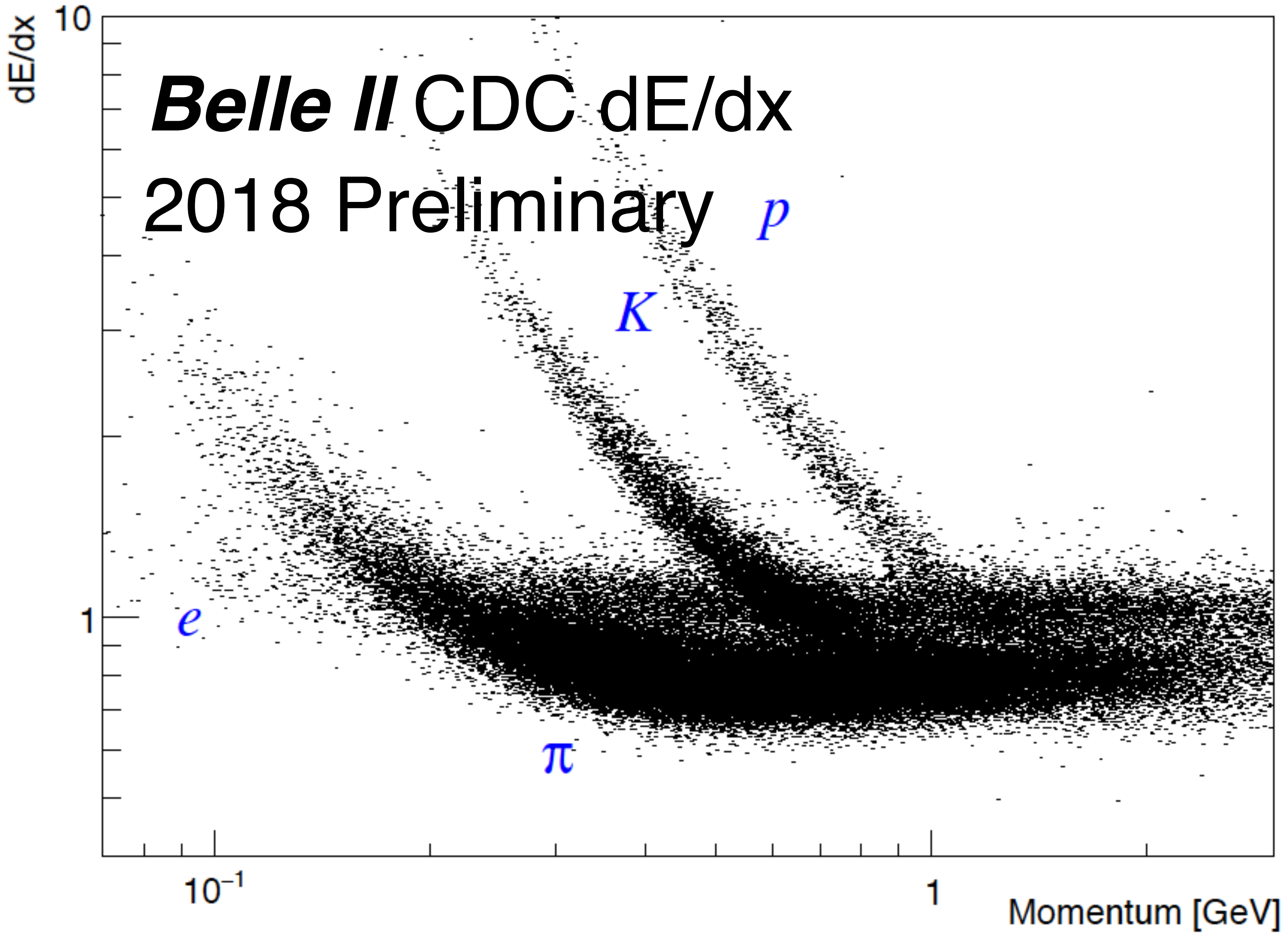
Kinematically identified kaon from D*+ in TOP; x vs t pattern (mapping of Cherenkov ring)

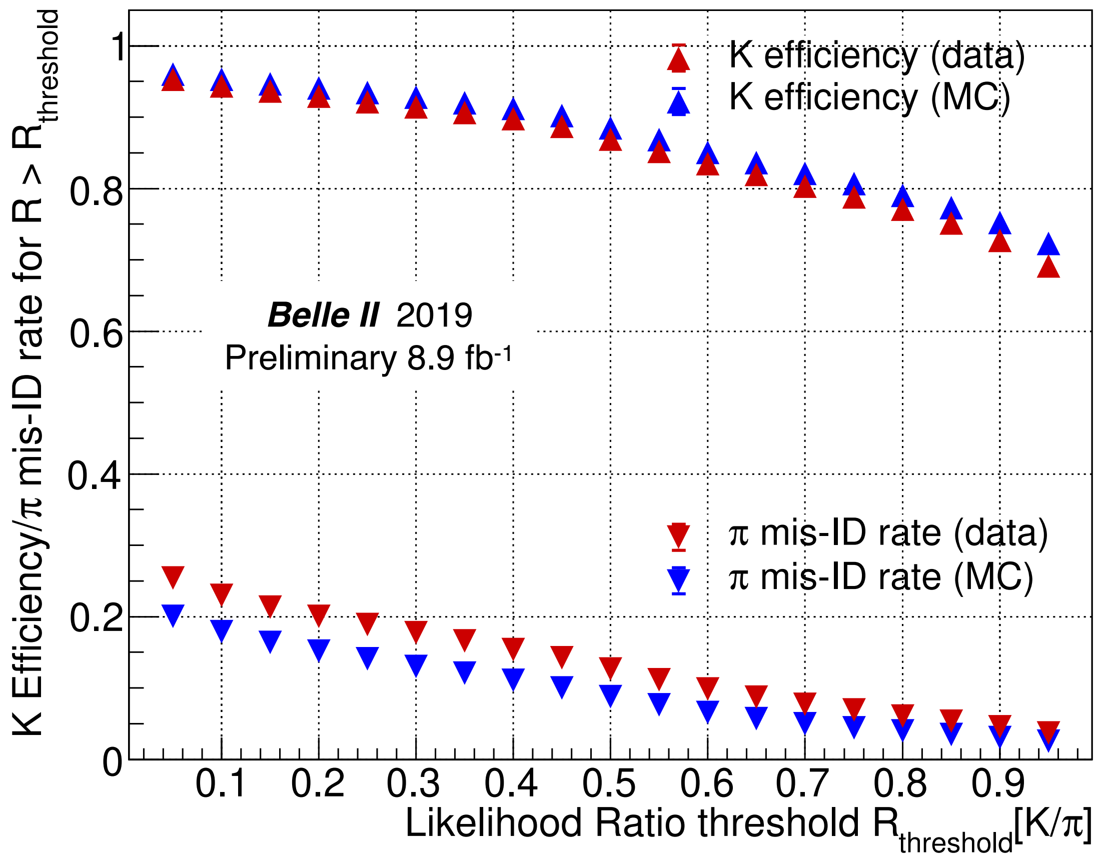
$$D^{*+} \to D^0 \pi_s^+ ; D^0 \to K^- \pi^+$$

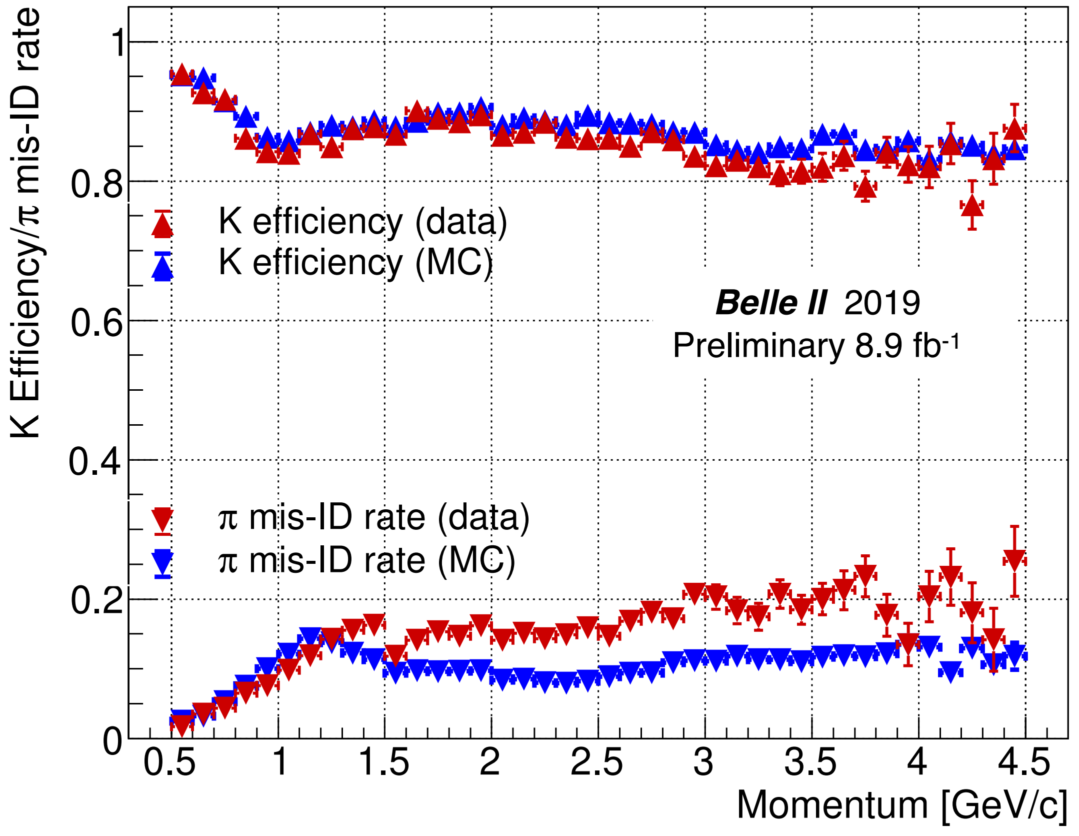


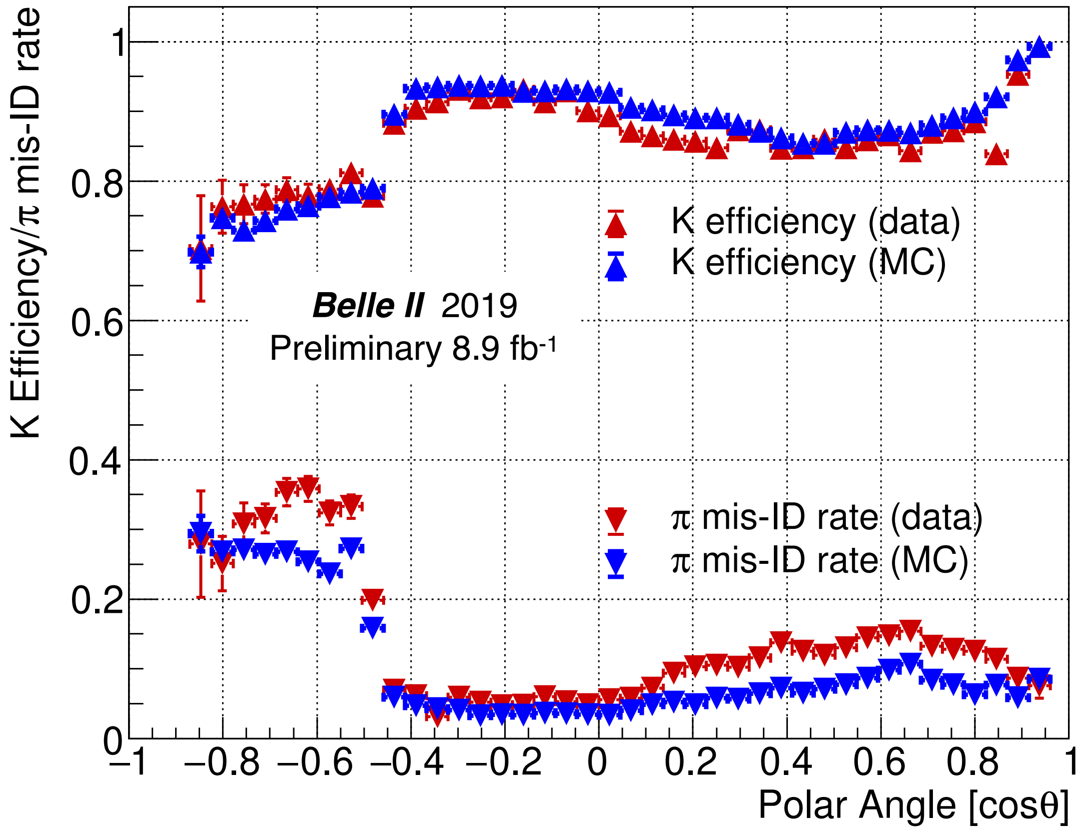






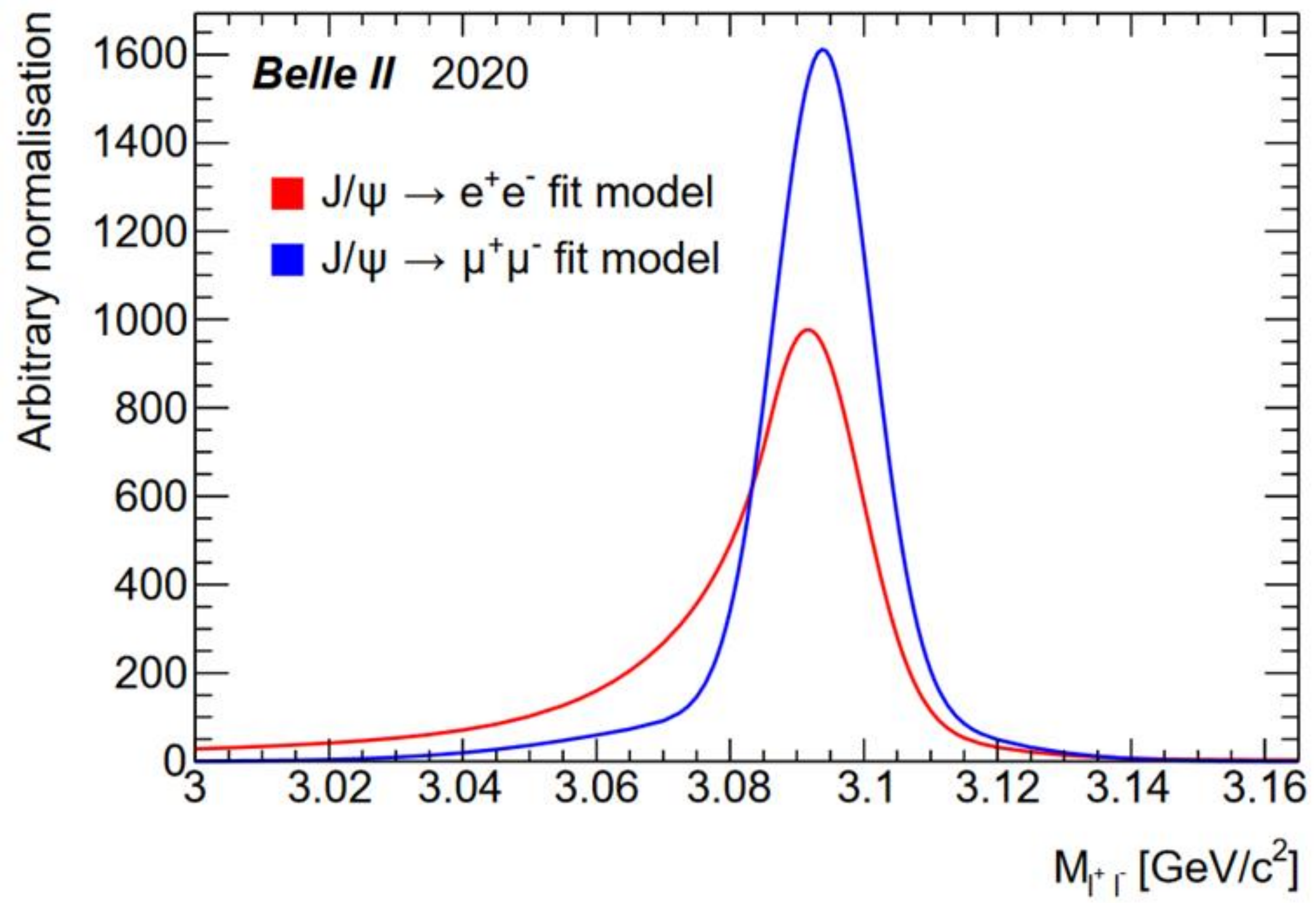


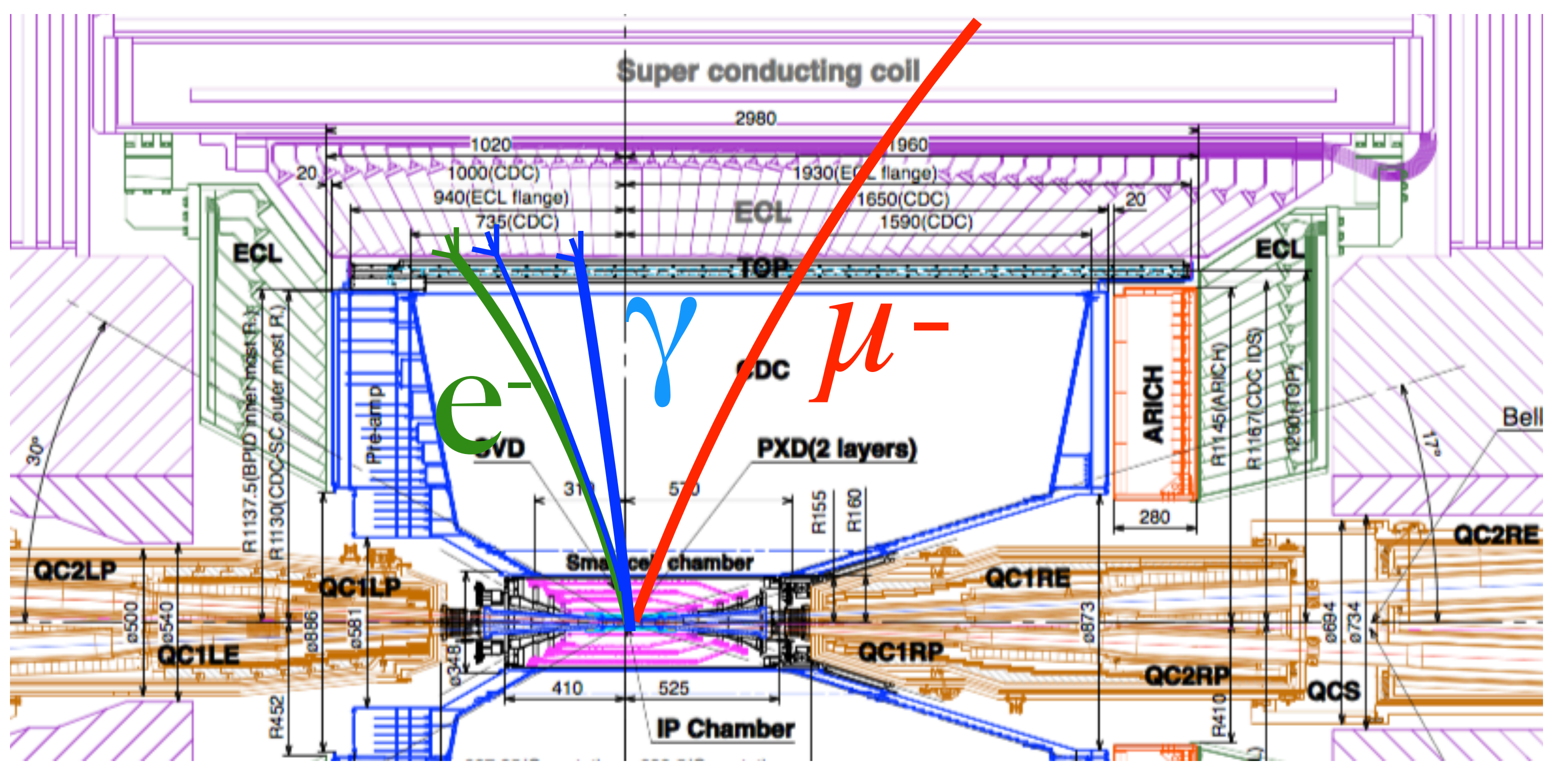


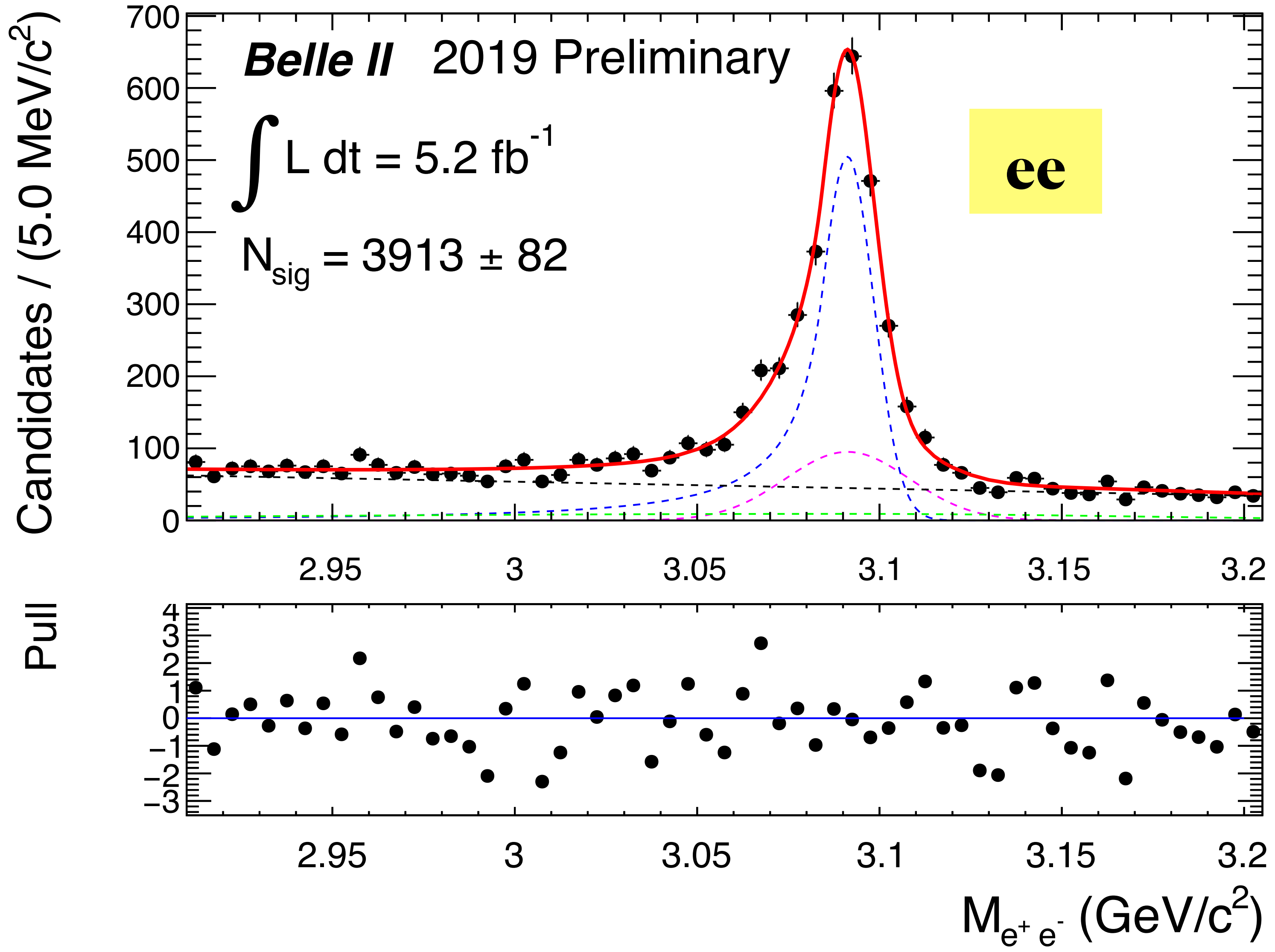


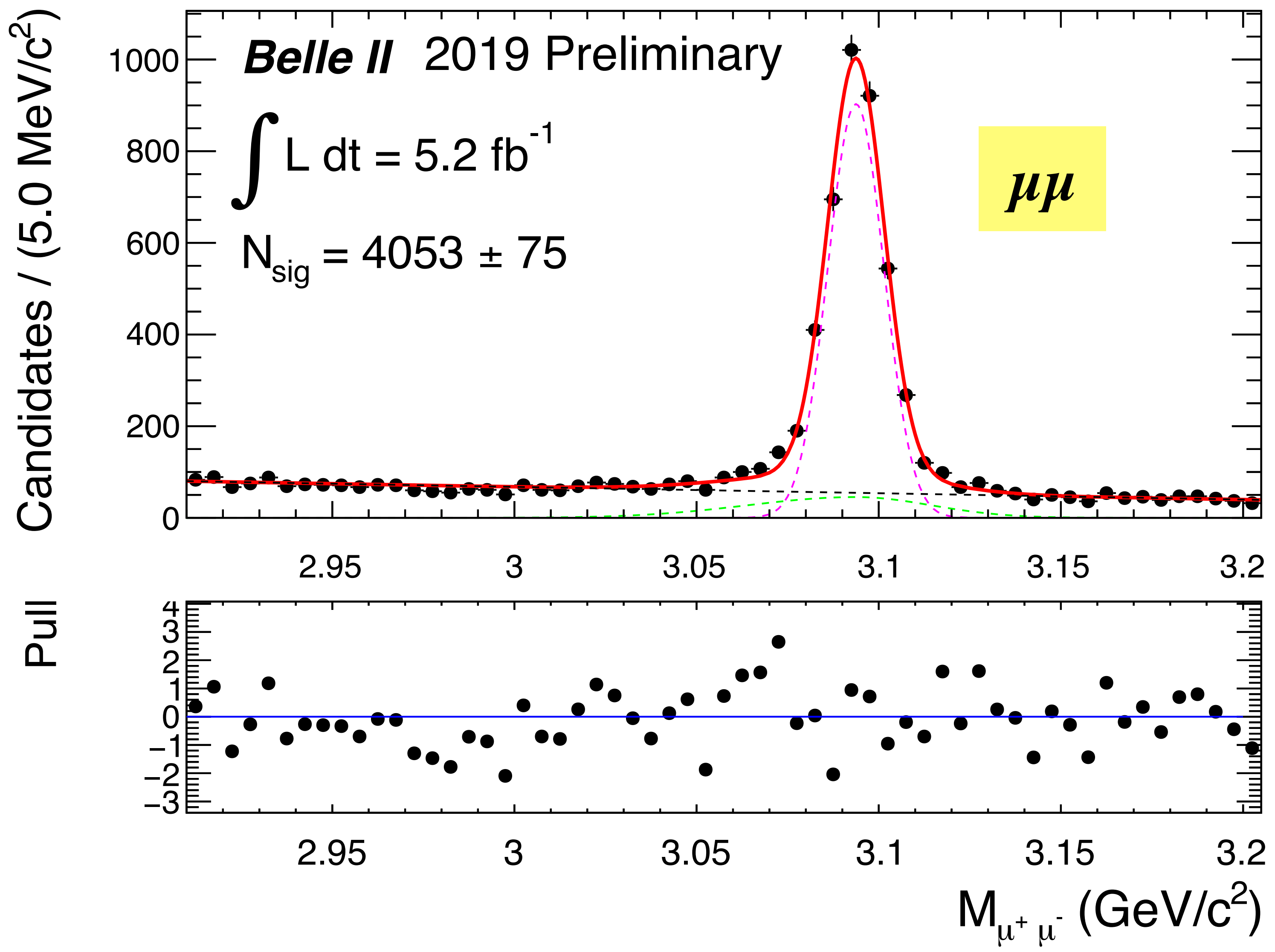
Lepton Reconstruction & Identification

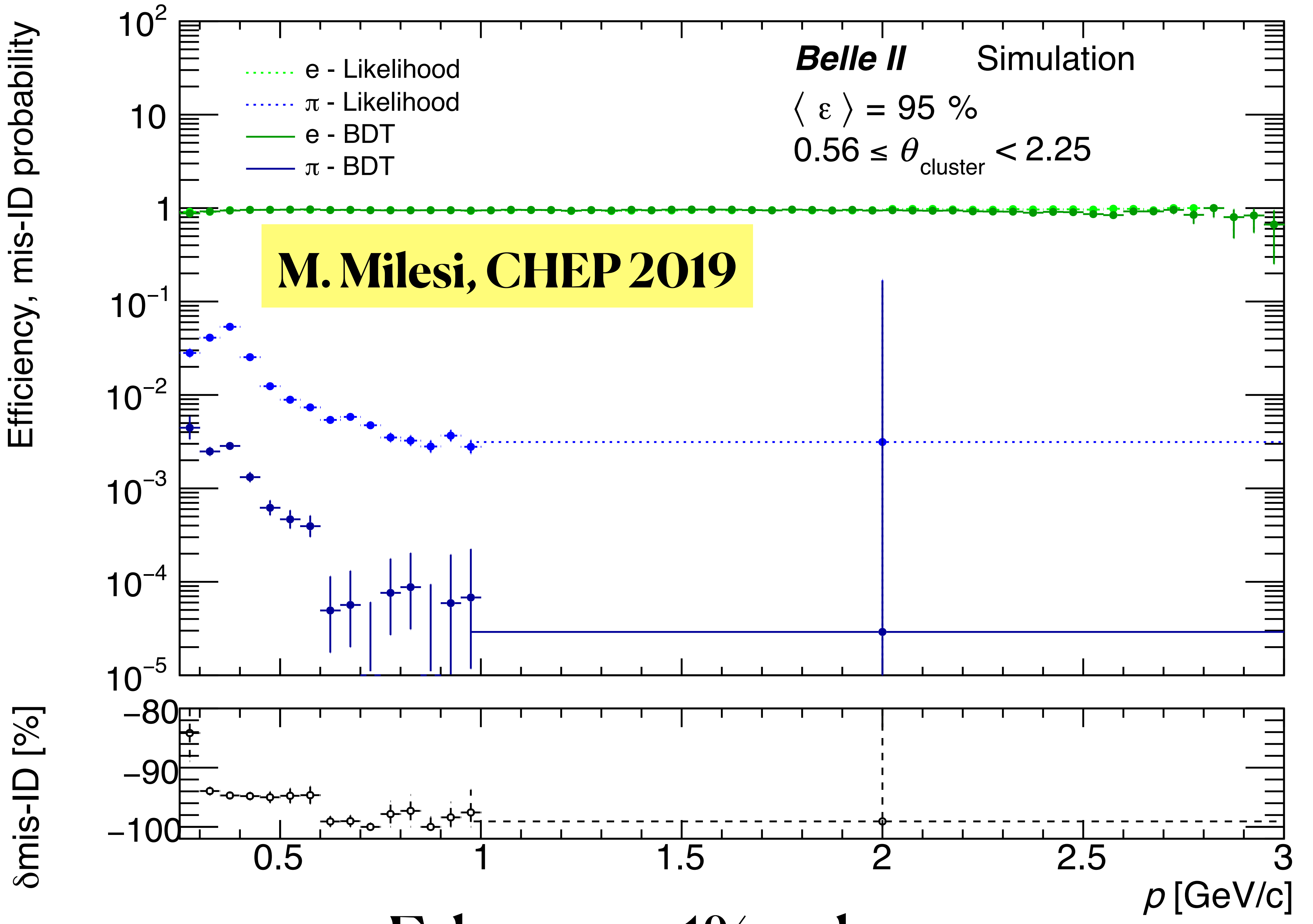
- Targeting precision in LFUV tests.
  Challenge: $B \to \tau \to l$ have <p>~500 MeV/c.
  - Driven by ECL, KLM, + dE/dx (CDC, SVD)
  - μ Little to no radiation (heavy), Stable within Belle II but need > 700 MeV/c to reach KLM.
  - **e** Final state radiation, Brems. in material (less material than LHC detectors).
  - Good universality between e and μ: efficiencies and resolution (after Brems. recovery).











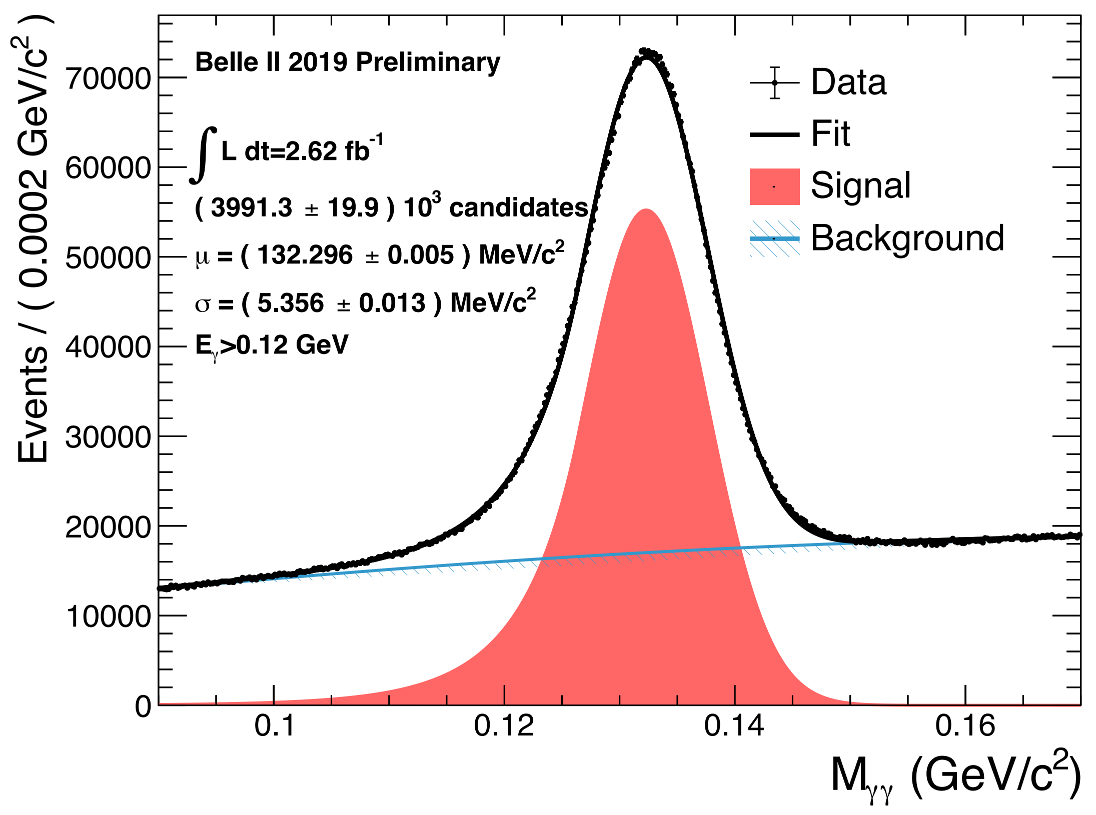
Fakes near 1% or lower.

Photons, π^0, η

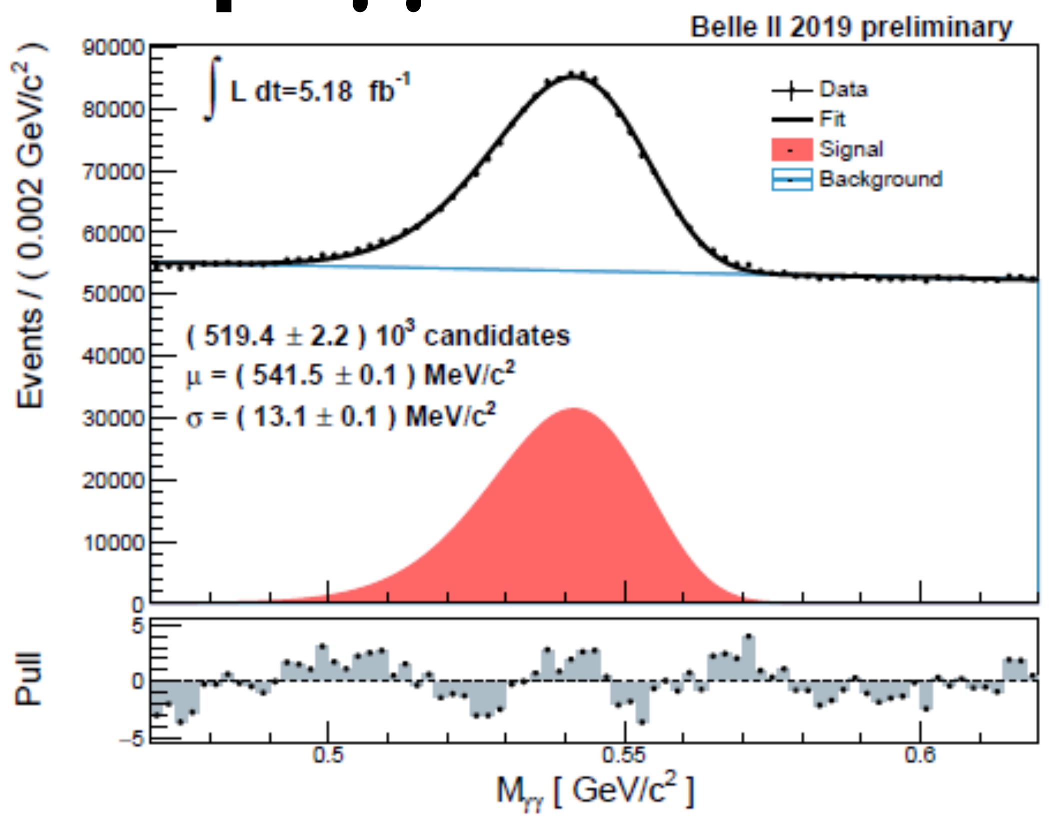
Talk by F. Abudinen

- Stable photon efficiencies, resolution and pointing information for invariant masses from the calorimeter.
  - Efficiencies: $ee \to \mu\mu\gamma$
  - Resolution: π^0, η, $\mu\mu\gamma$
- Calibration and material effects under constant development and improvement.
- K_L-ID under development too.

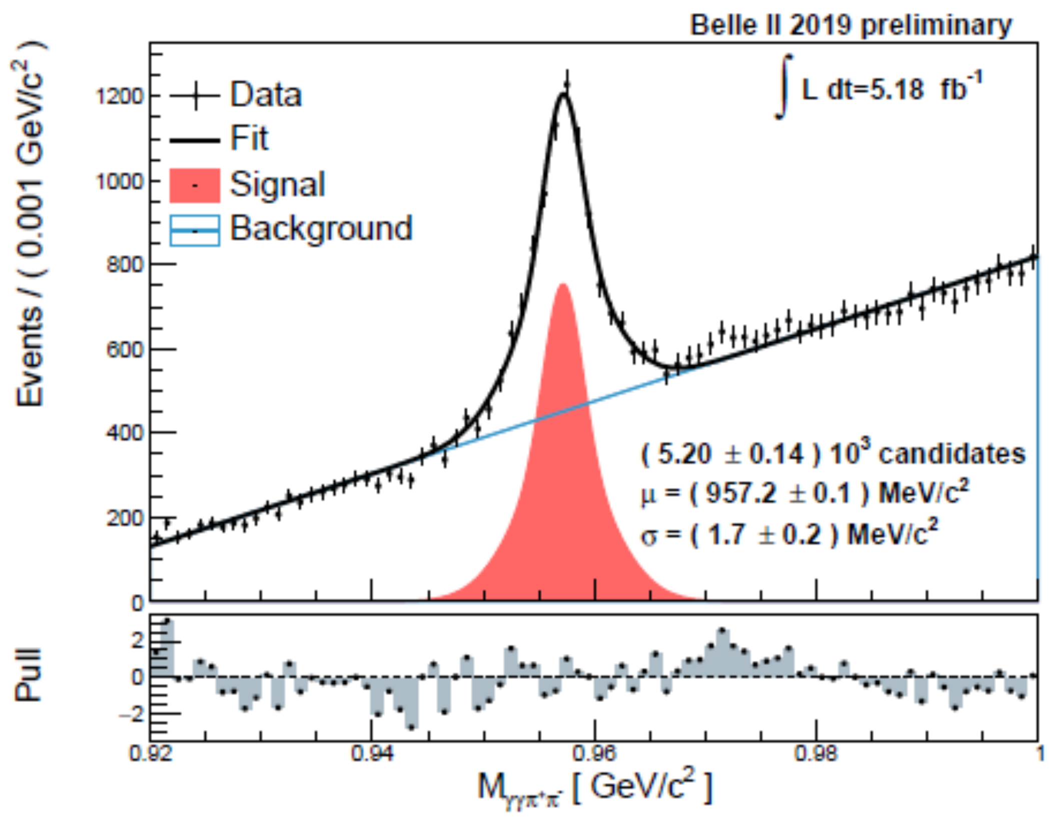
$\pi^0 \to \gamma\gamma$



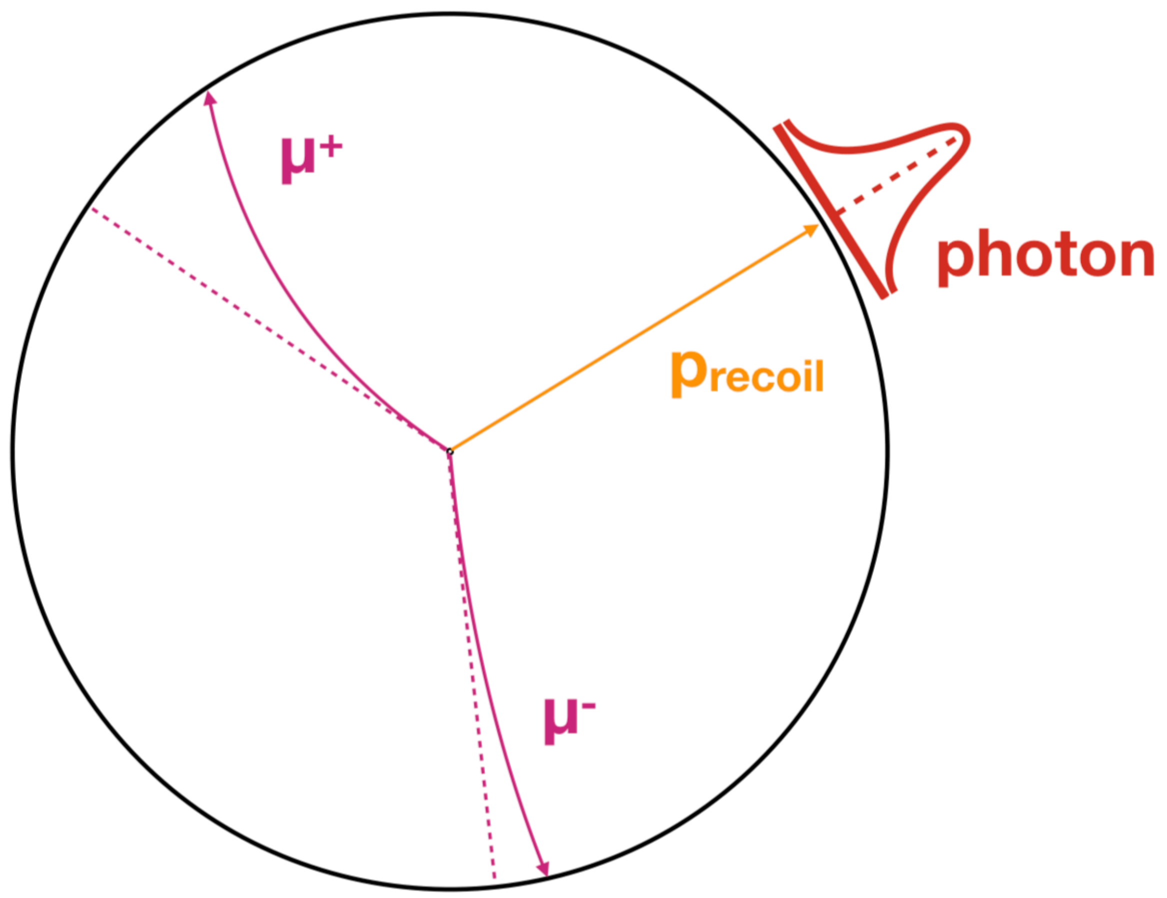
$\eta \to \gamma\gamma$



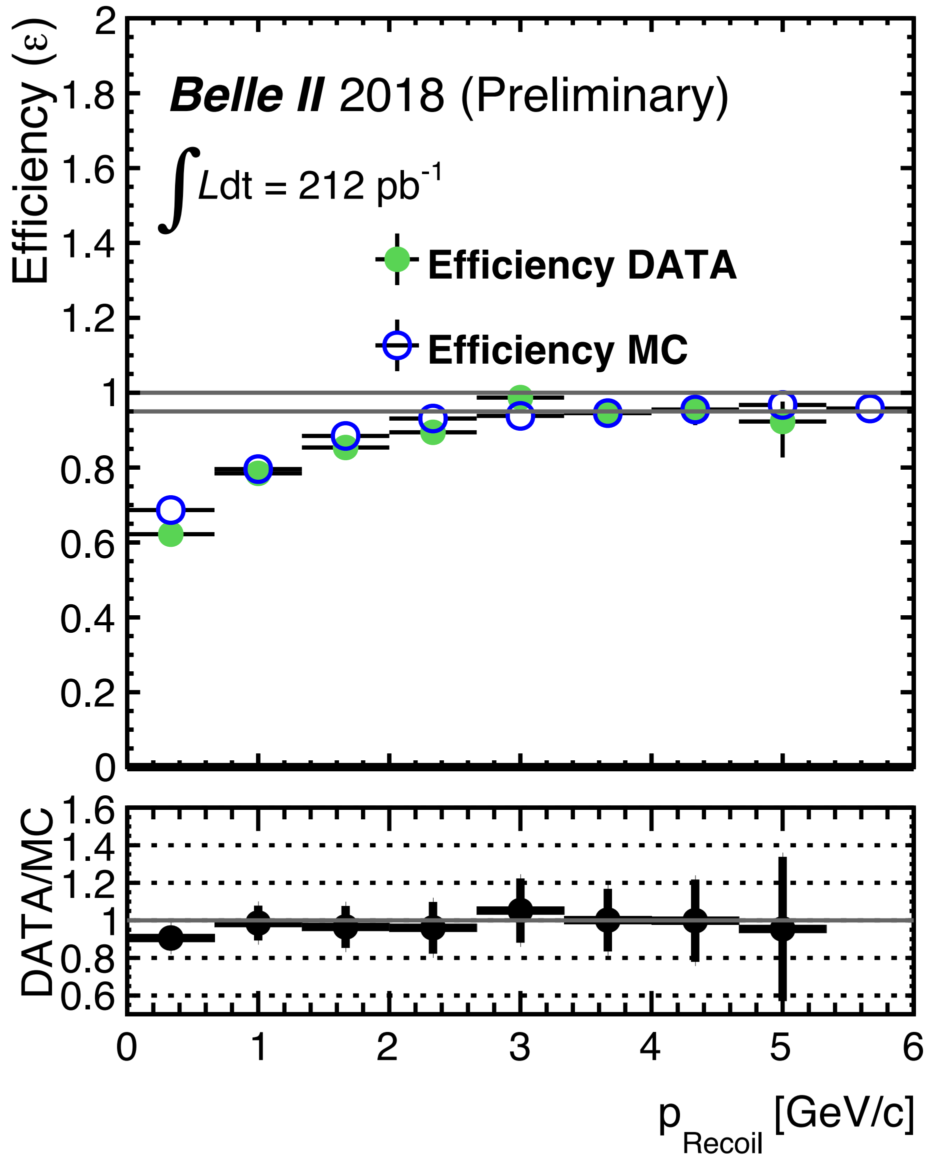
$\eta' \to \pi\pi\eta(\gamma\gamma)$



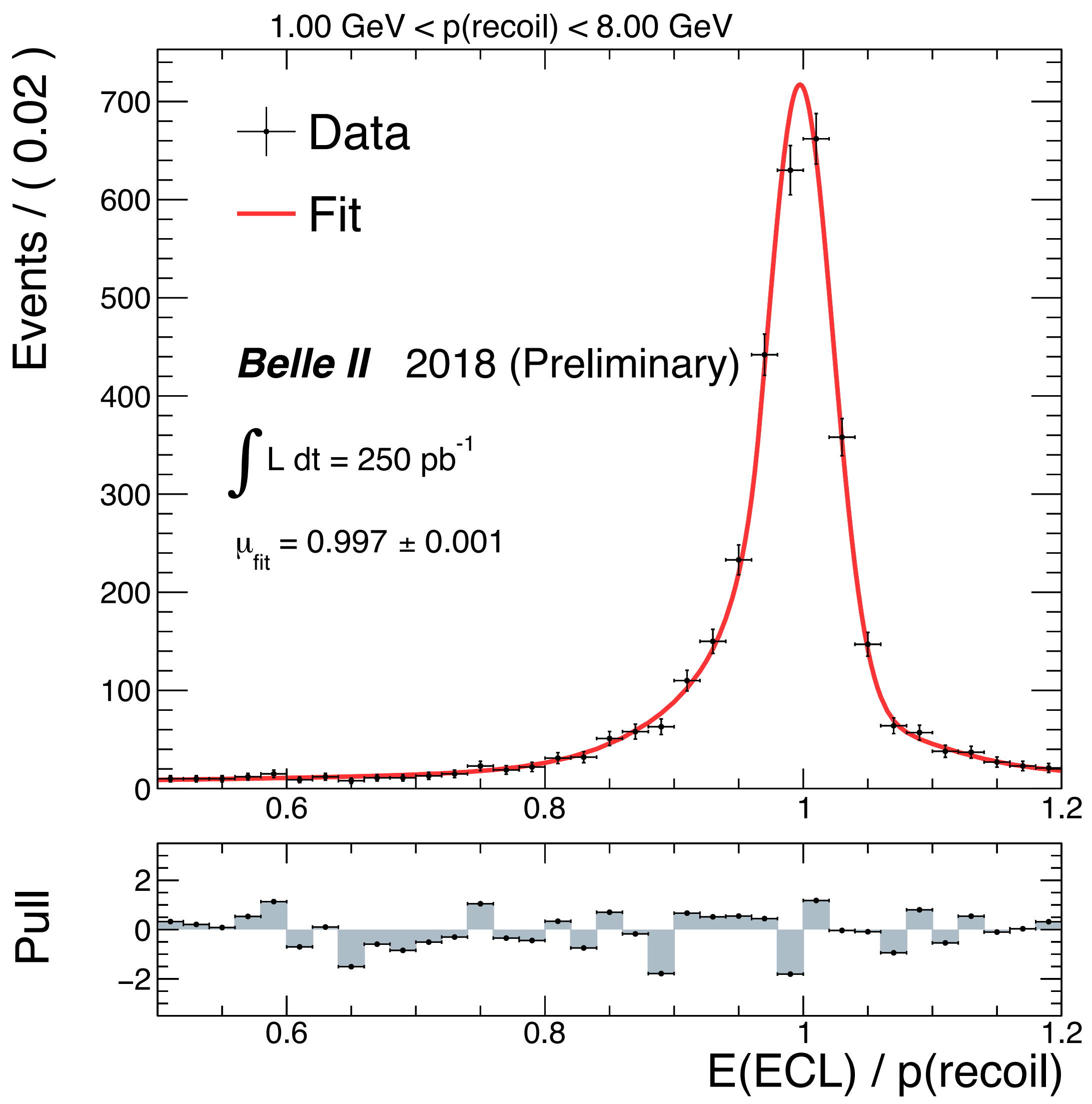
$ee \to \mu\mu\gamma$



Photon Efficiencies



Single Photon Lines



Counting

Luminosity

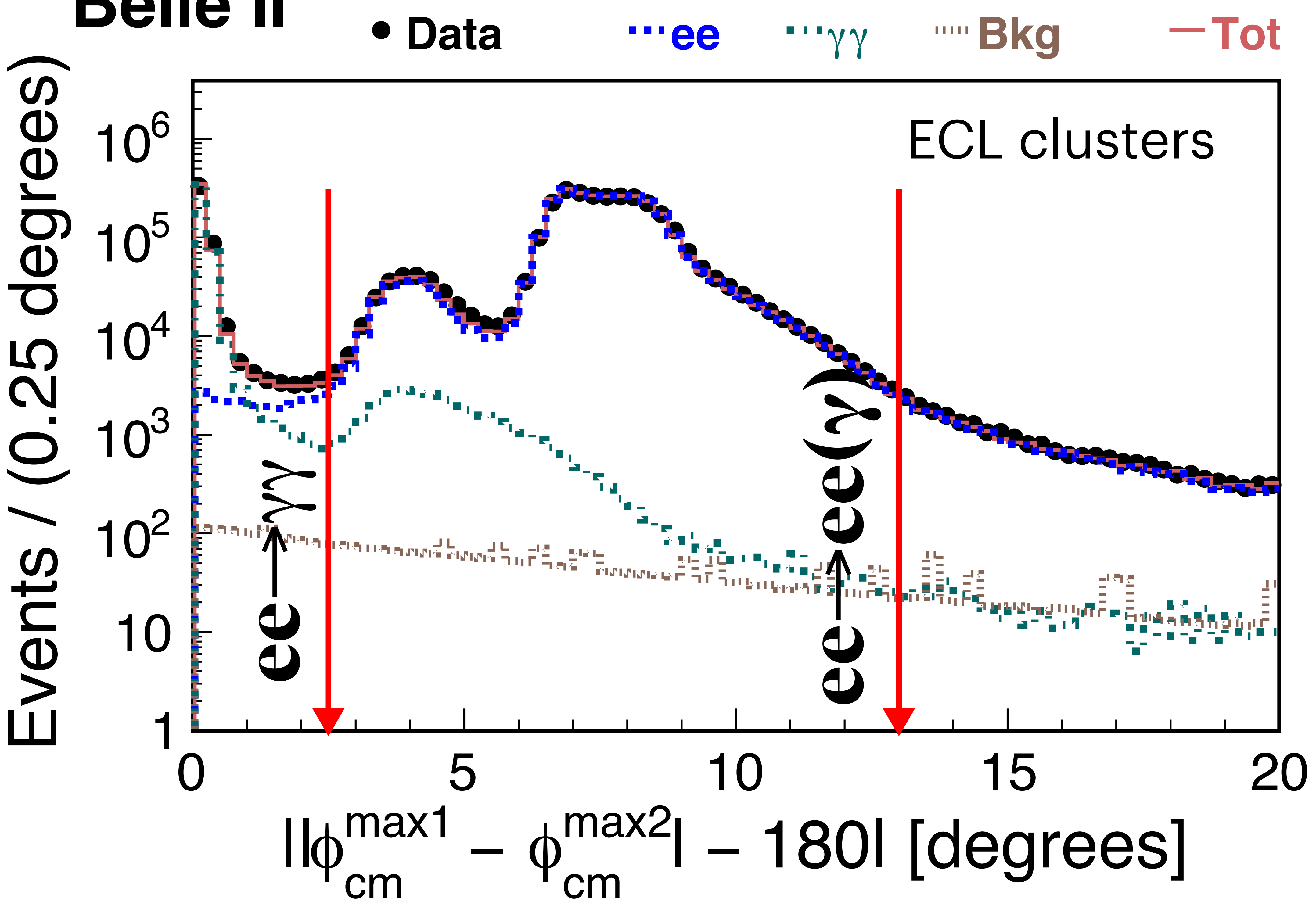
Chin.Phys.C 44 (2020) 2, 021001

Measured with ee→ ee(γ), γγ **in ECL**

Integrated luminosity in phase 2

= 496.3±0.3±3.0 pb^{-1}

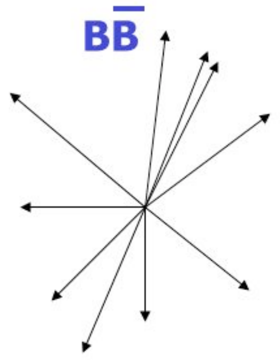
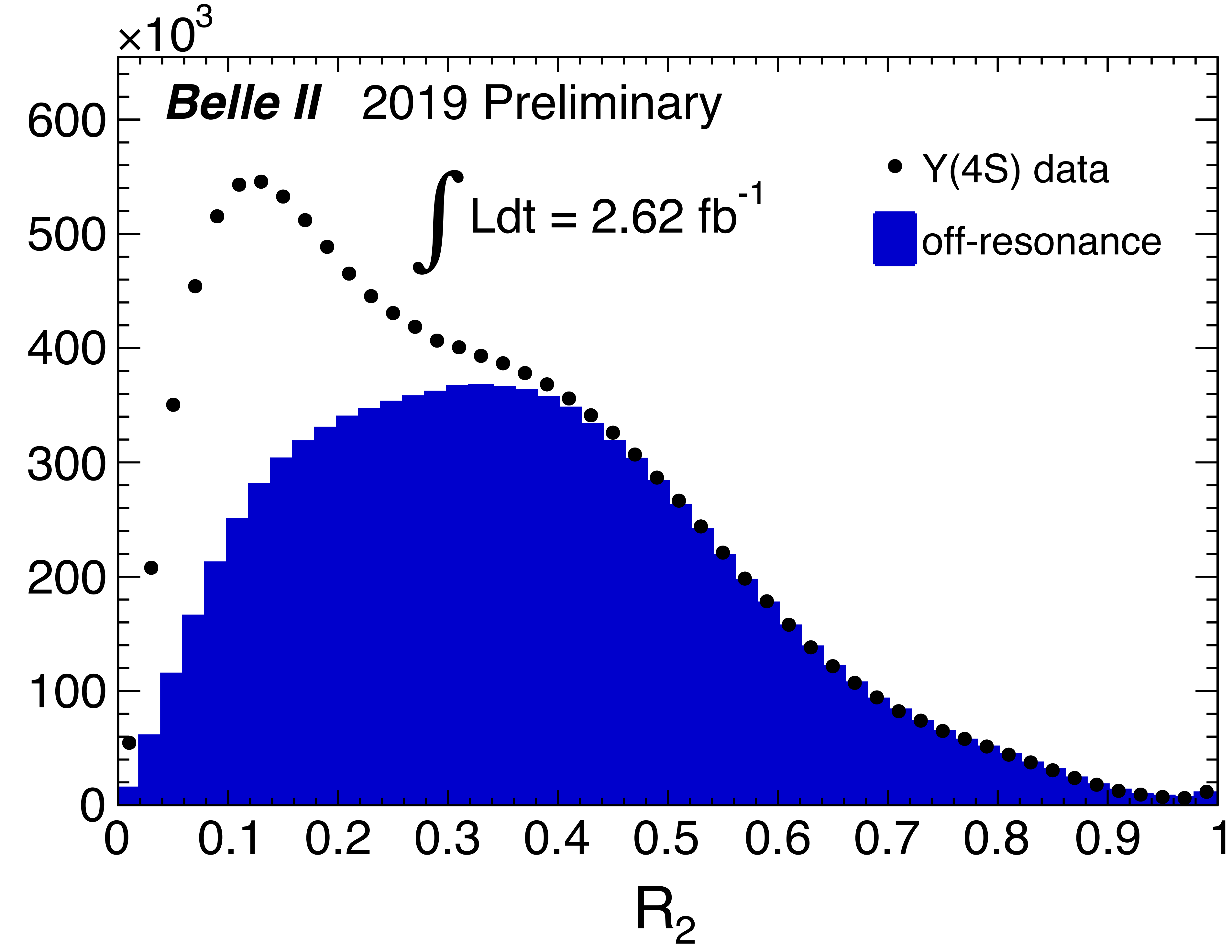
→ better than 1% precision .

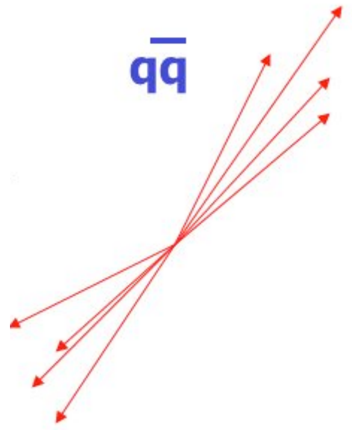


B-counting

We are on the ϒ(4S) resonance and recording B-anti B pairs with ~99% efficiency.
c.f. σ(ϒ(4S))~1.05 nb at 10.58 GeV

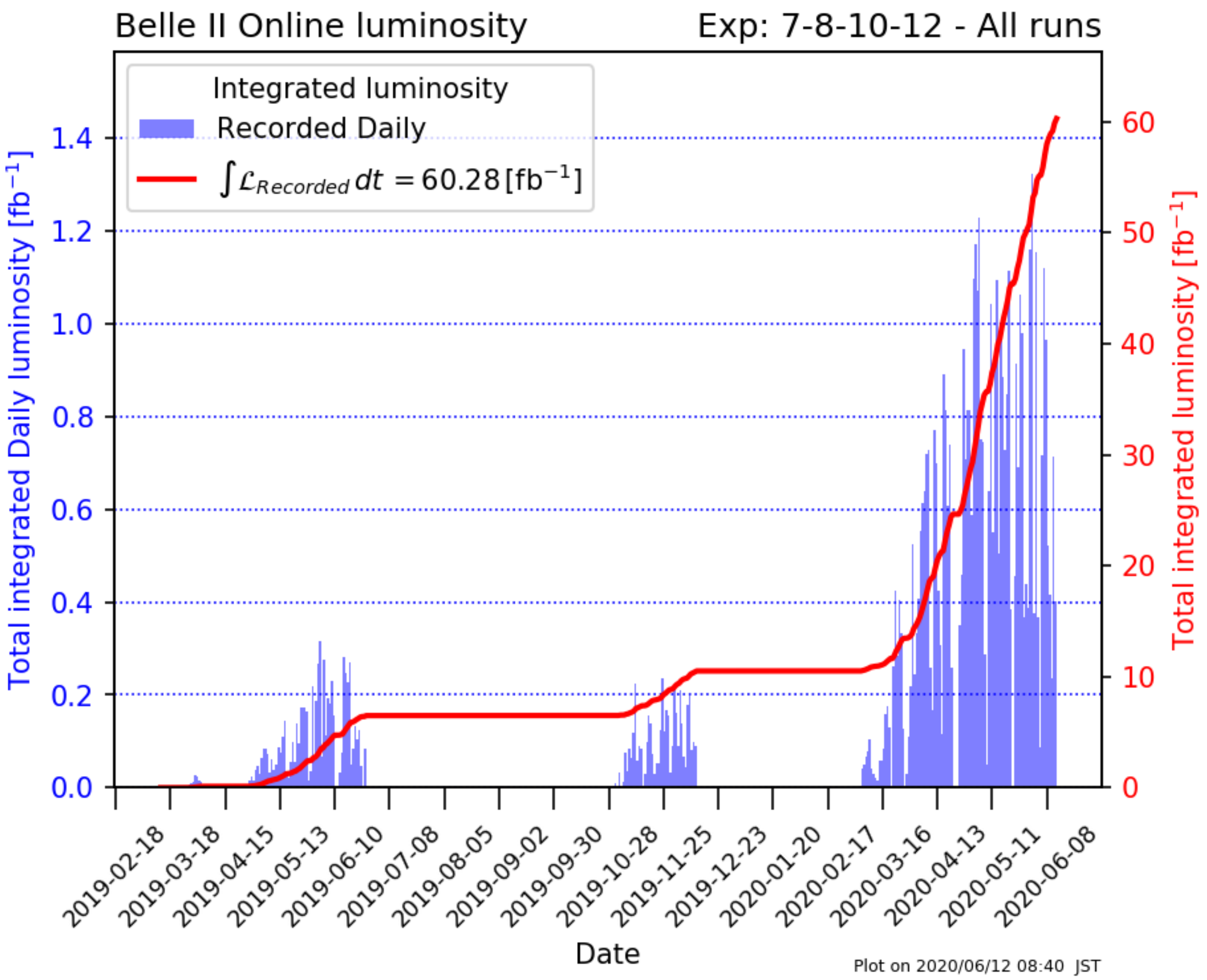
+ ~6 fb^{-1} of data taken 60 MeV below Y(4S) to date.



2020 — Towards the first flavour publications

- (59) fb^{-1} on disk, ready to reach several hundred by the end of the year.
  - Already 1 publication on dark sector searches - more soon to come.
  - Flavour publications likely to start with 2019+2020 data - **several ideas for new τ results.**



Talk by M. Villanueva

2019: 10 fb^{-1} (November)

2020: ~80 fb^{-1} (End of run in June)

2020: ~200-400 fb^{-1} (December, **Babar 500 fb^{-1}**)
Run resumes October.

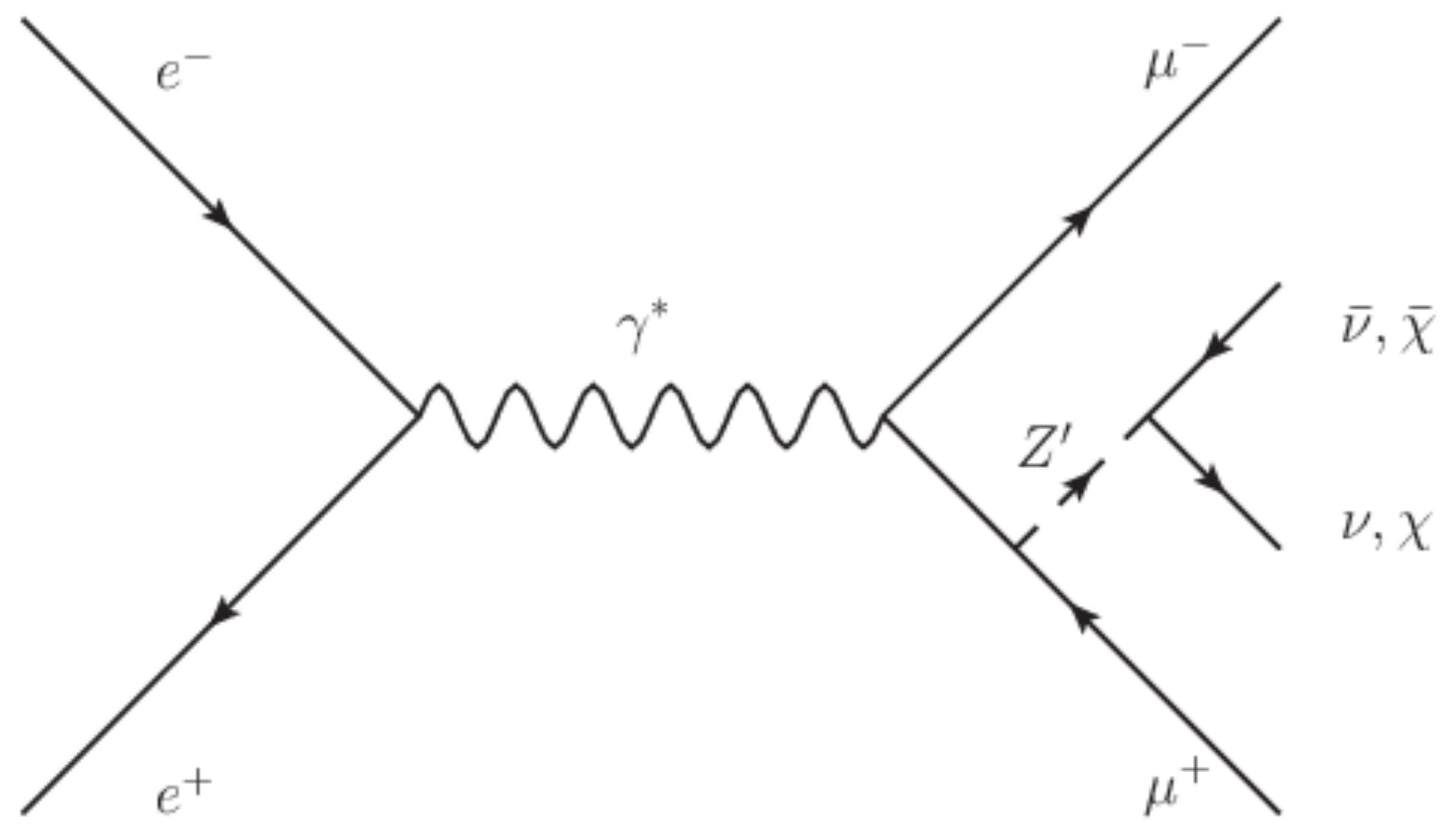
2021-2022: ~1 ab^{-1} (**Belle**)

2023 5 ab^{-1} B2TiP Milestone
arXiv: 1808.10567 / PTEP

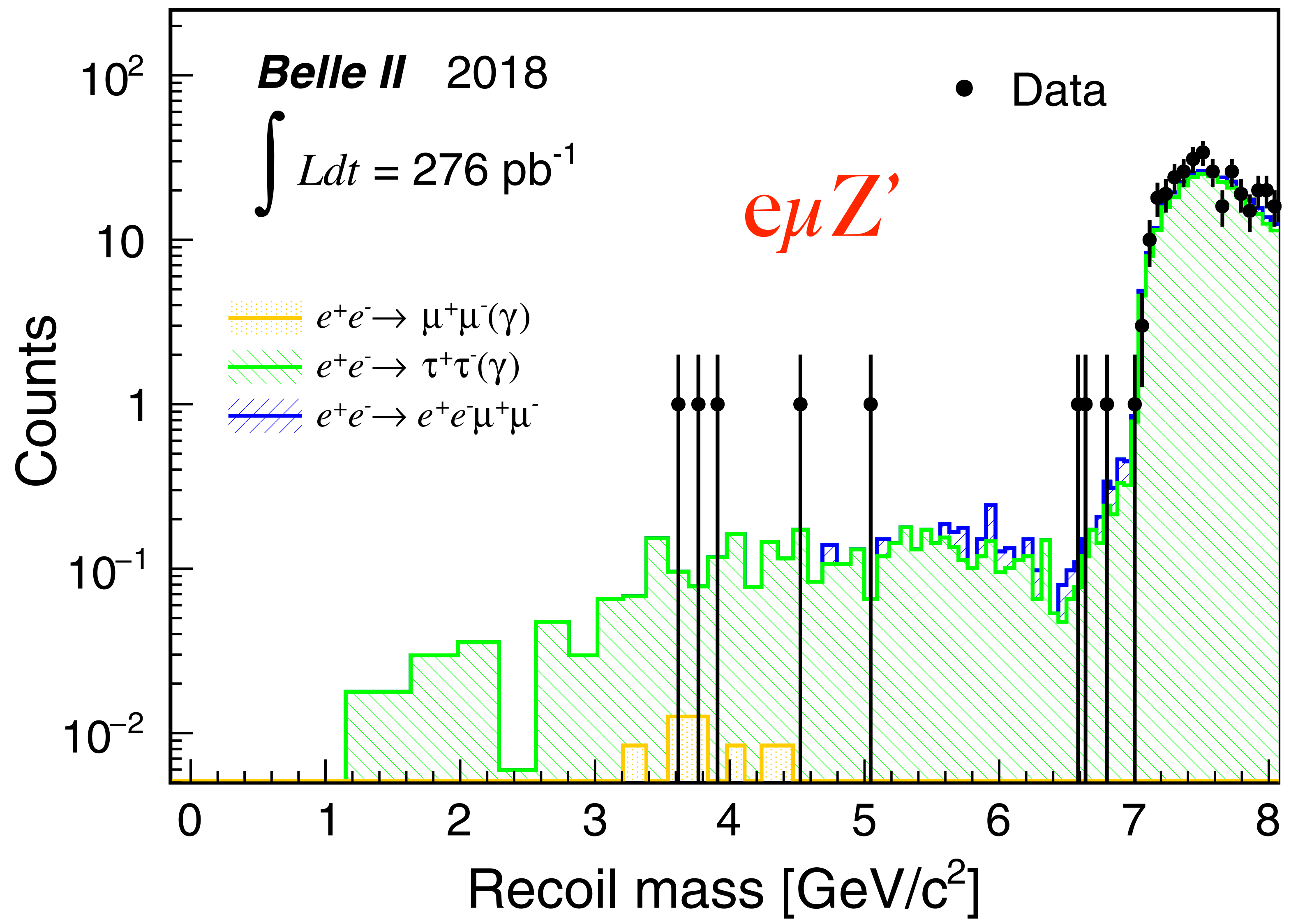
Search for an invisibly decaying Z’

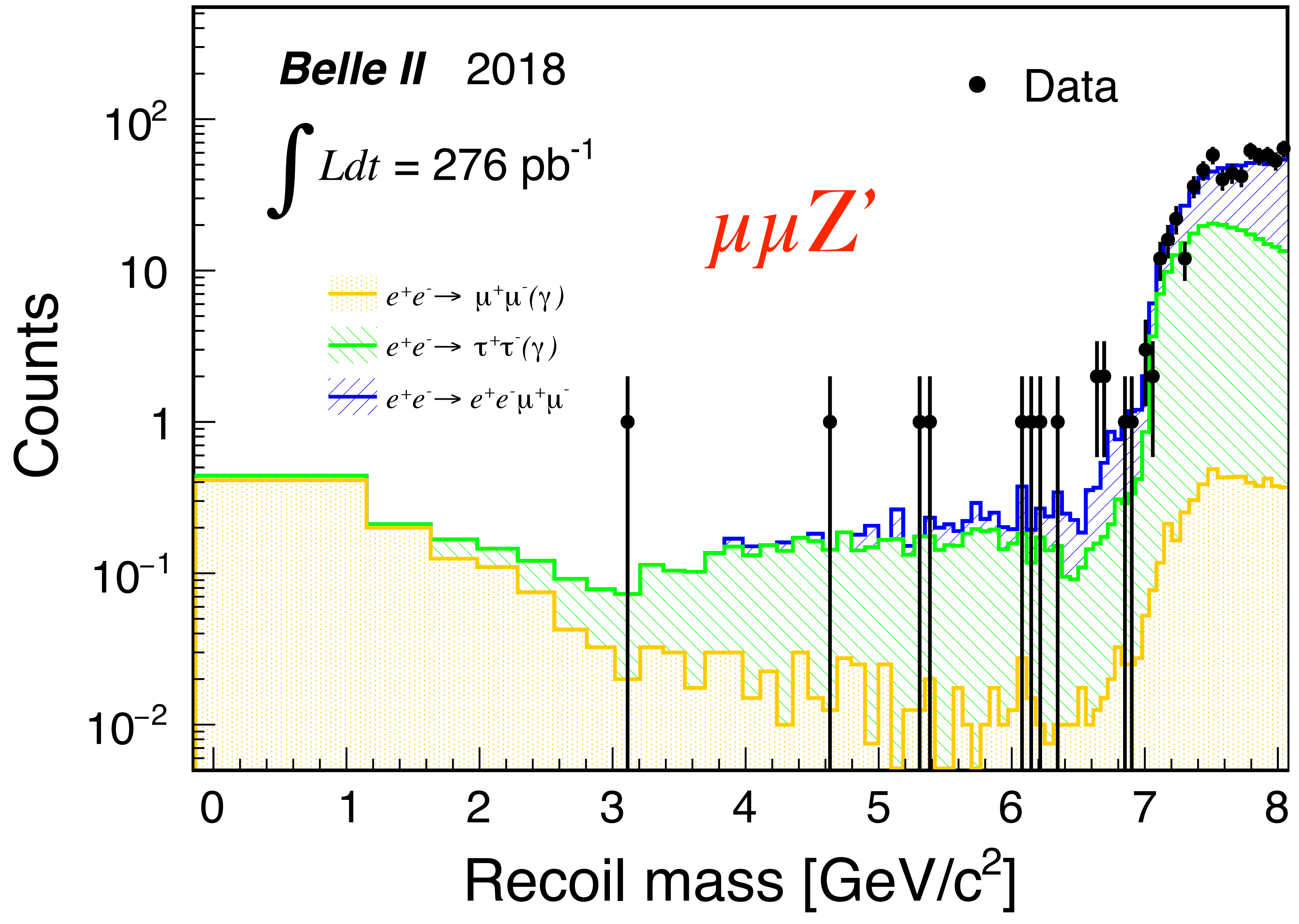
Phys. Rev. Lett. 124, 141801 (2020)

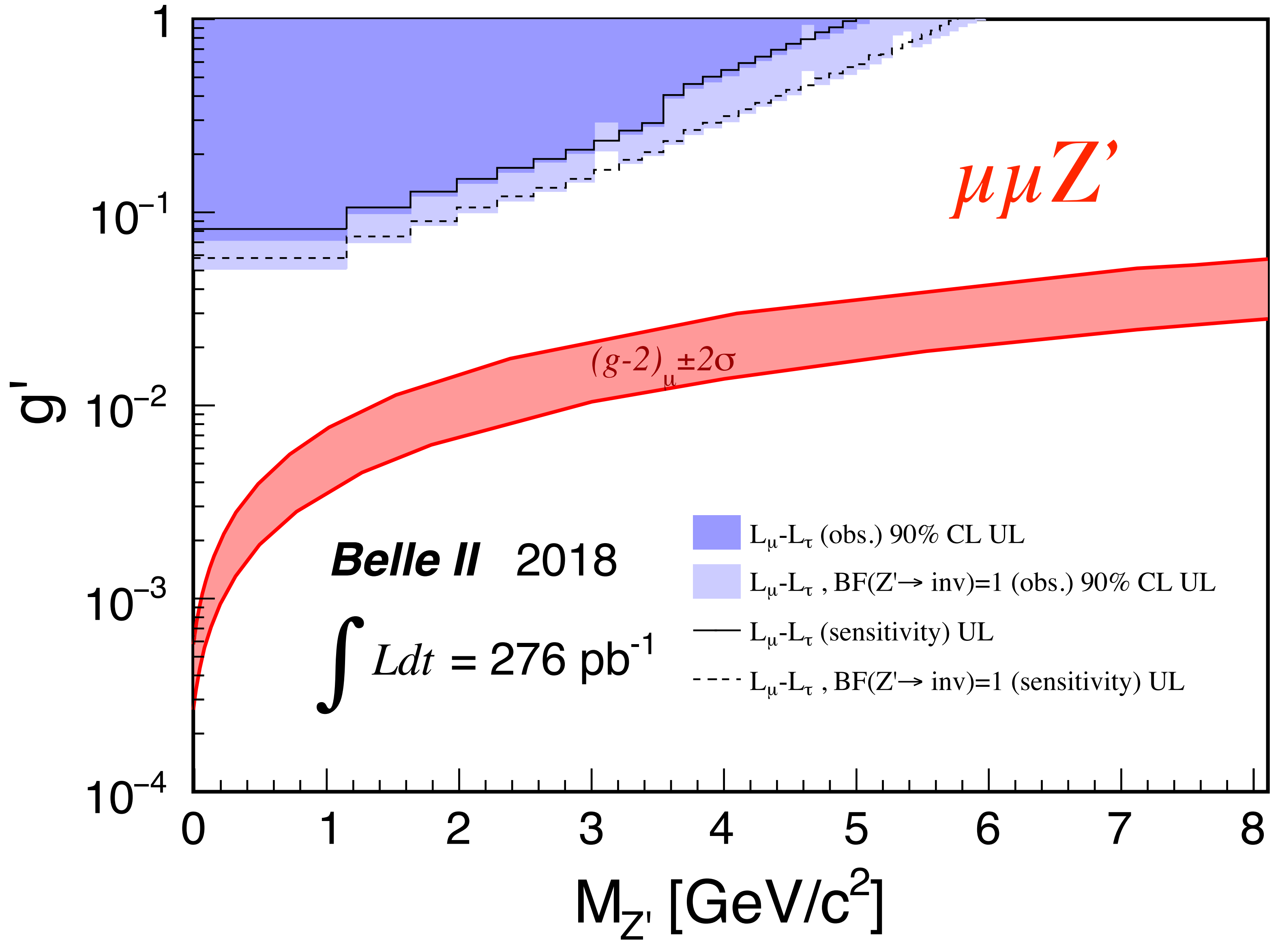
- Search for vector boson Z′ that couples to 2nd and 3rd generation only.
    - ee→μμZ′ or eμZ′
- Invisible decays to Dark Matter or neutrinos.
- Possible explanation for g-2 anomaly.
- First physics publication.



limits on the Z coupling constant at the level of 5×10 -2–1 for M(Z0) ≤ 6 GeV/c2







Dark Sector - results to come

- Vector portal $\epsilon F^{\mu\nu}_{Y} F'_{\mu\nu}$ (dark photon A'), $\sum_l \theta g' \bar{l} \gamma^{\mu} Z'_{\mu} l$ (dark Z')
- Axion portal $\frac{G_{agg}}{4} a G_{\mu\nu} \tilde{G}^{\mu\nu} + \frac{G_{a\gamma\gamma}}{4} a F_{\mu\nu} \tilde{F}^{\mu\nu}$ (axion, alps)
- Scalar portal $\lambda H^2 S^2 + \mu H^2 S$ (dark Higgs)

Fast and broadband DAQ
- Maximum operable L1 rate: 30 kHz
- Typical data size: 1 MB/ev

Trigger system
- Tracking + PID + E_e, E_γ + muon
- L1 trigger latency: 5 μs

Often with low multiplicity signatures, not explored at Belle. But the trigger/data volume is a challenge.

O(10 nb) acceptance / suppress QED events (100s nb), keeping B & D > 99% efficiency.

More to come, e.g.

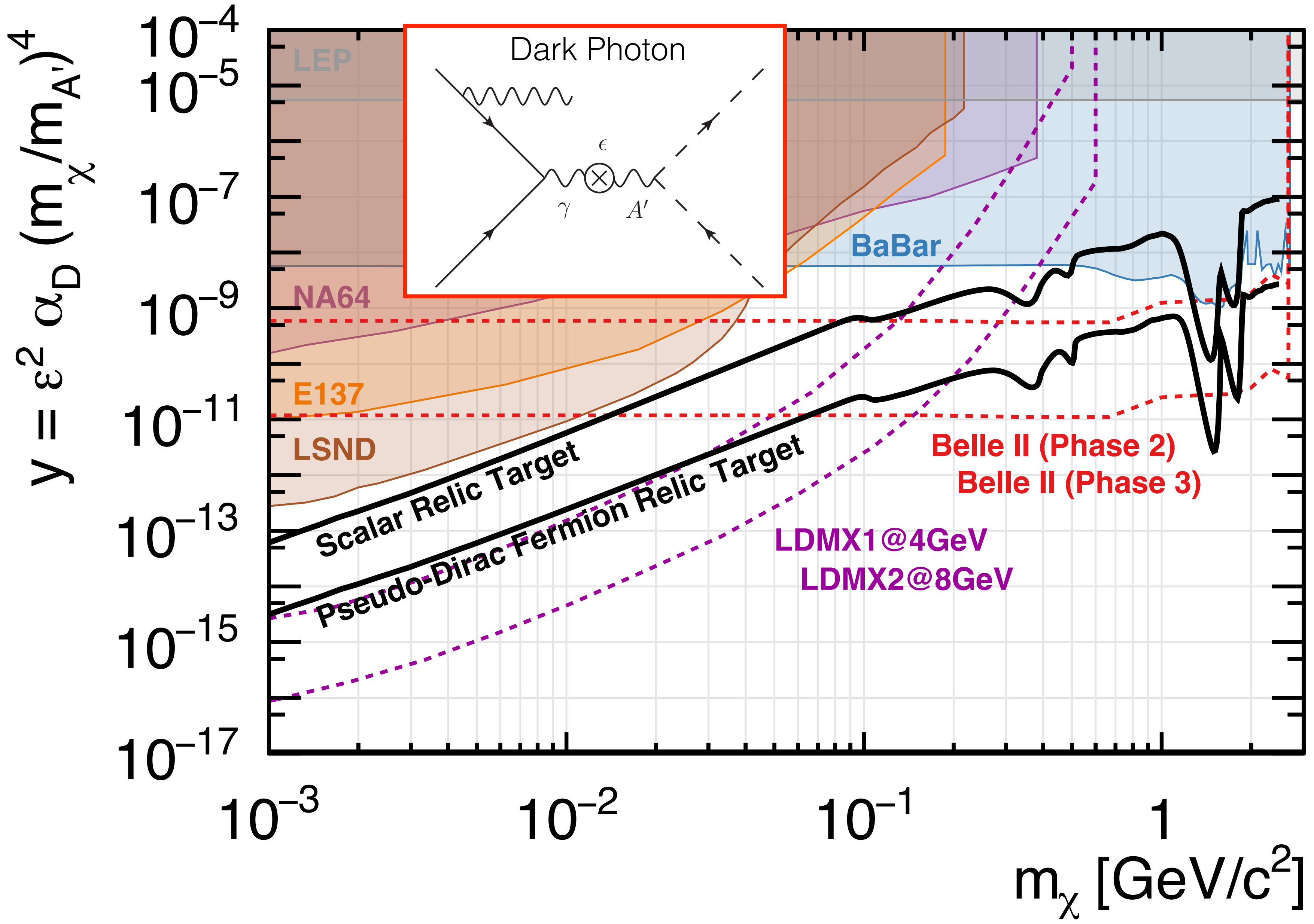
$e^+e^- \to \gamma X$

$e^+e^- \to \gamma$ ALP ($\to \gamma\gamma$)

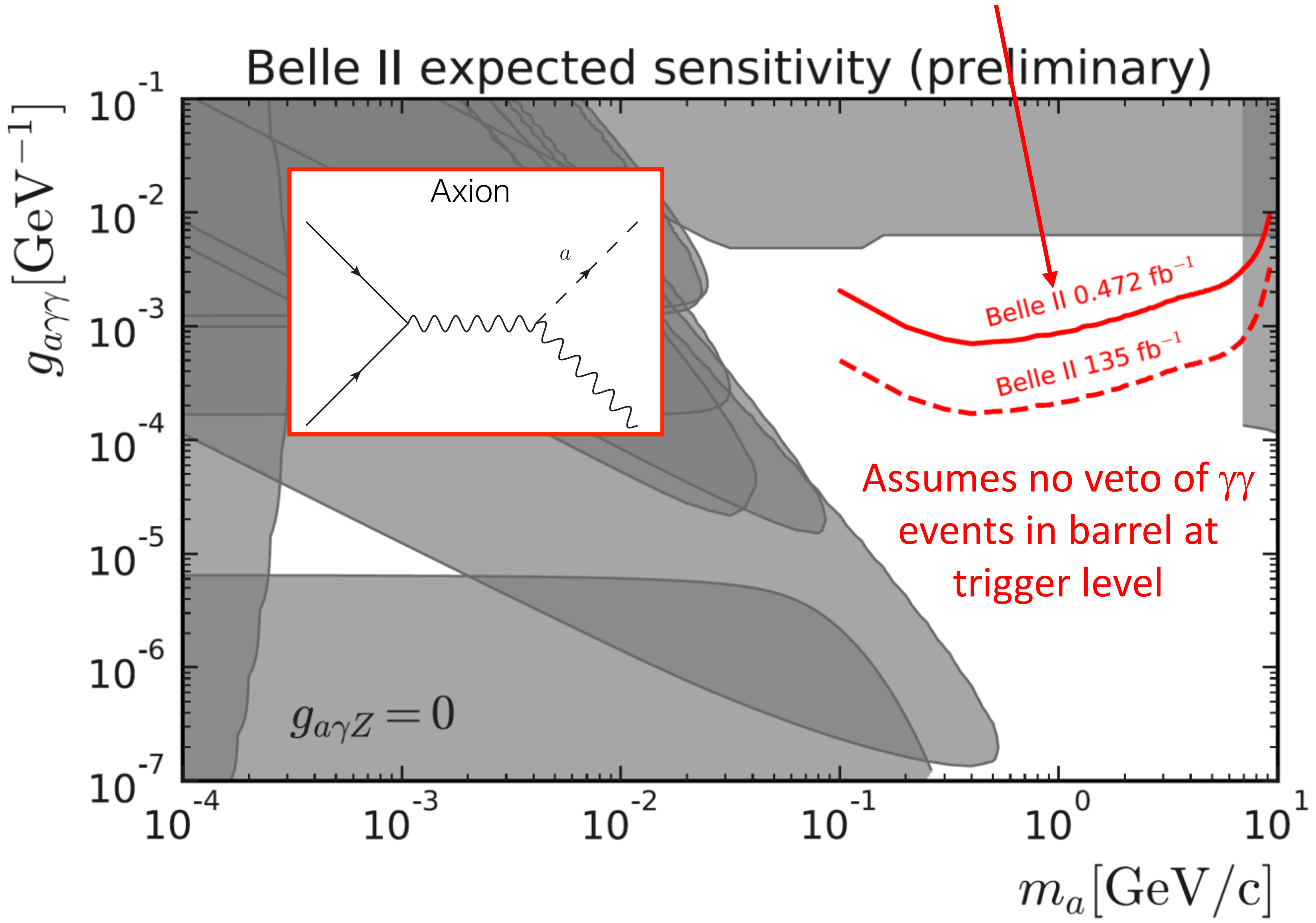
$e^+e^- \to \gamma A'$ (dark photon)

Dark Z′, Magn. Monopoles

Can also access through heavy flavour transitions.

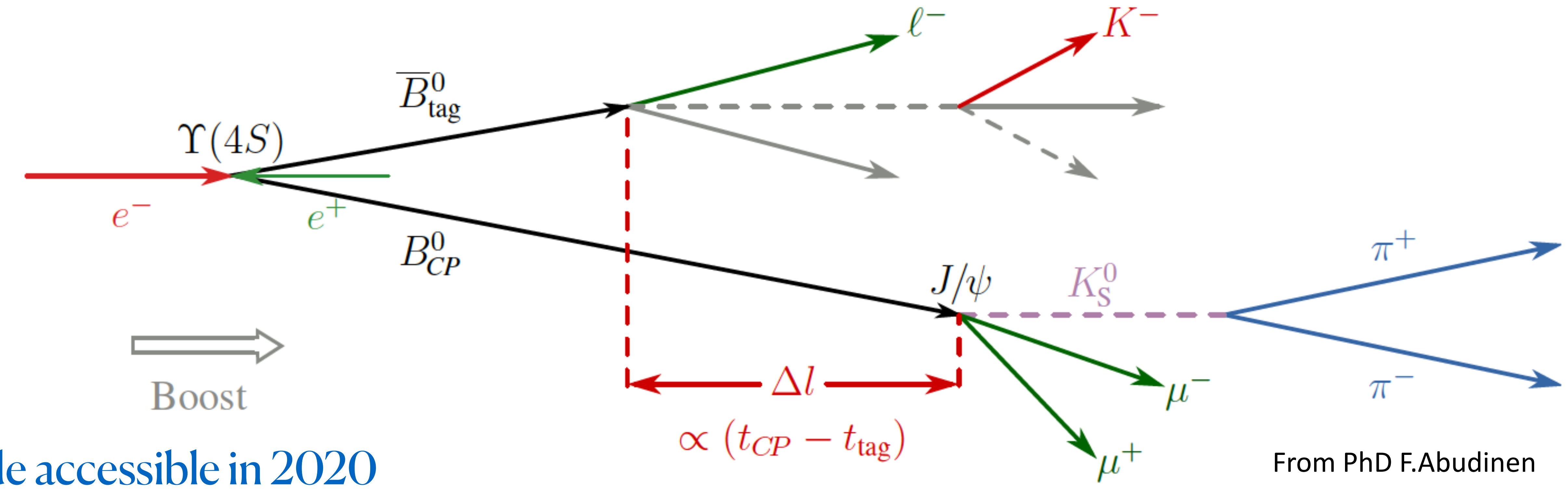


Phase2 & early Phase 3



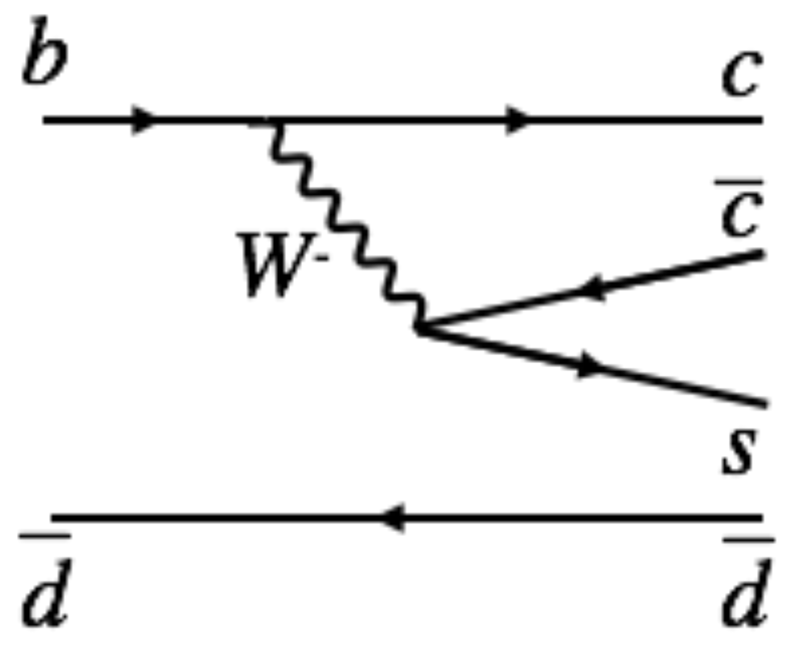
Time dependent CP Violation / Overview

- Φ_1 & New physics TDCPV in b → qqs transitions (q = u,d,s) are major targets
- Δt resolution ~0.77 ps (30% to a factor 2 better than Belle);
  - **PXD + nano-beam spot in Belle II, +30% K_S acceptance**
- Effective flavour tagging efficiency ~**36%** (MC estimate, **30%** at Belle)

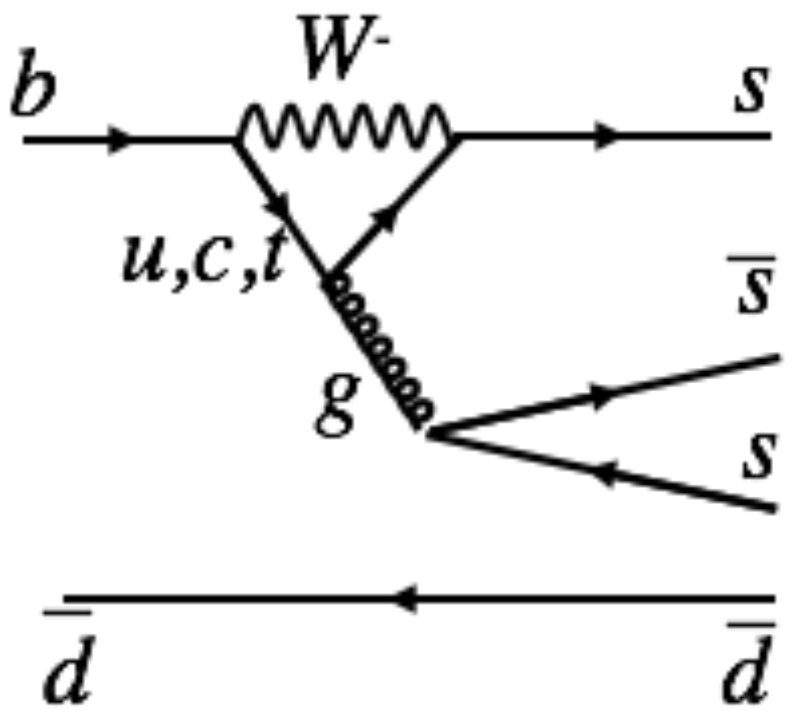


From PhD F.Abudinen

Tree (SM precision)



Gluonic Penguin (NP sensitive)



✸ Mode accessible in 2020

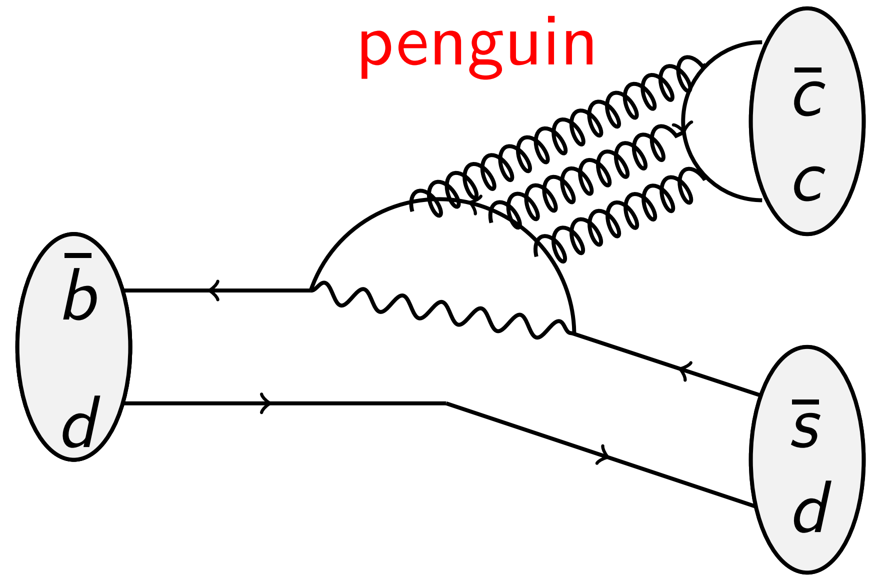
	Channel	WA (2017) $\sigma(S)$	WA (2017) $\sigma(A)$	5 ab^{-1} $\sigma(S)$	5 ab^{-1} $\sigma(A)$	50 ab^{-1} $\sigma(S)$	50 ab^{-1} $\sigma(A)$
✸	$J/\psi K^0$	0.022	0.021	0.012	0.011	0.0052	0.0090
✸	ϕK^0	0.12	0.14	0.048	0.035	0.020	0.011
✸	$\eta' K^0$	0.06	0.04	0.032	0.020	0.015	0.008
✸	ωK^0_S	0.21	0.14	0.08	0.06	0.024	0.020
✸	$K^0_S \pi^0 \gamma$	0.20	0.12	0.10	0.07	0.031	0.021
✸	$K^0_S \pi^0$	0.17	0.10	0.09	0.06	0.028	0.018

PTEP 2019 (2019) 12, 123C01

SM: $J/\psi K^0$; NP: remaining channels

Expect Belle II to dominate all these channels within 2 years

Constrains penguin pollution



B^0 lifetime

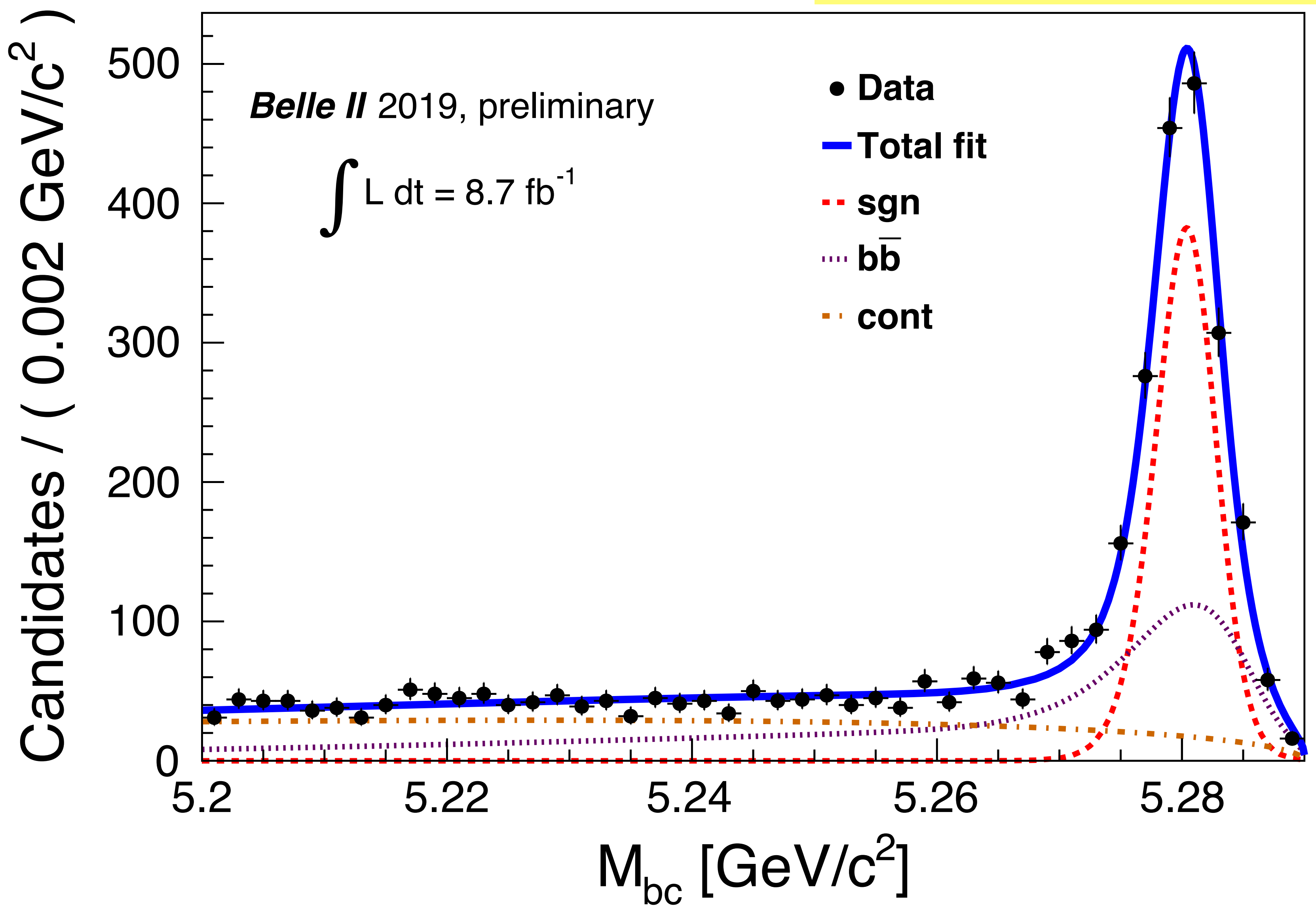
BELLE2-CONF-PH-2020-003, arXiv:2005.07507

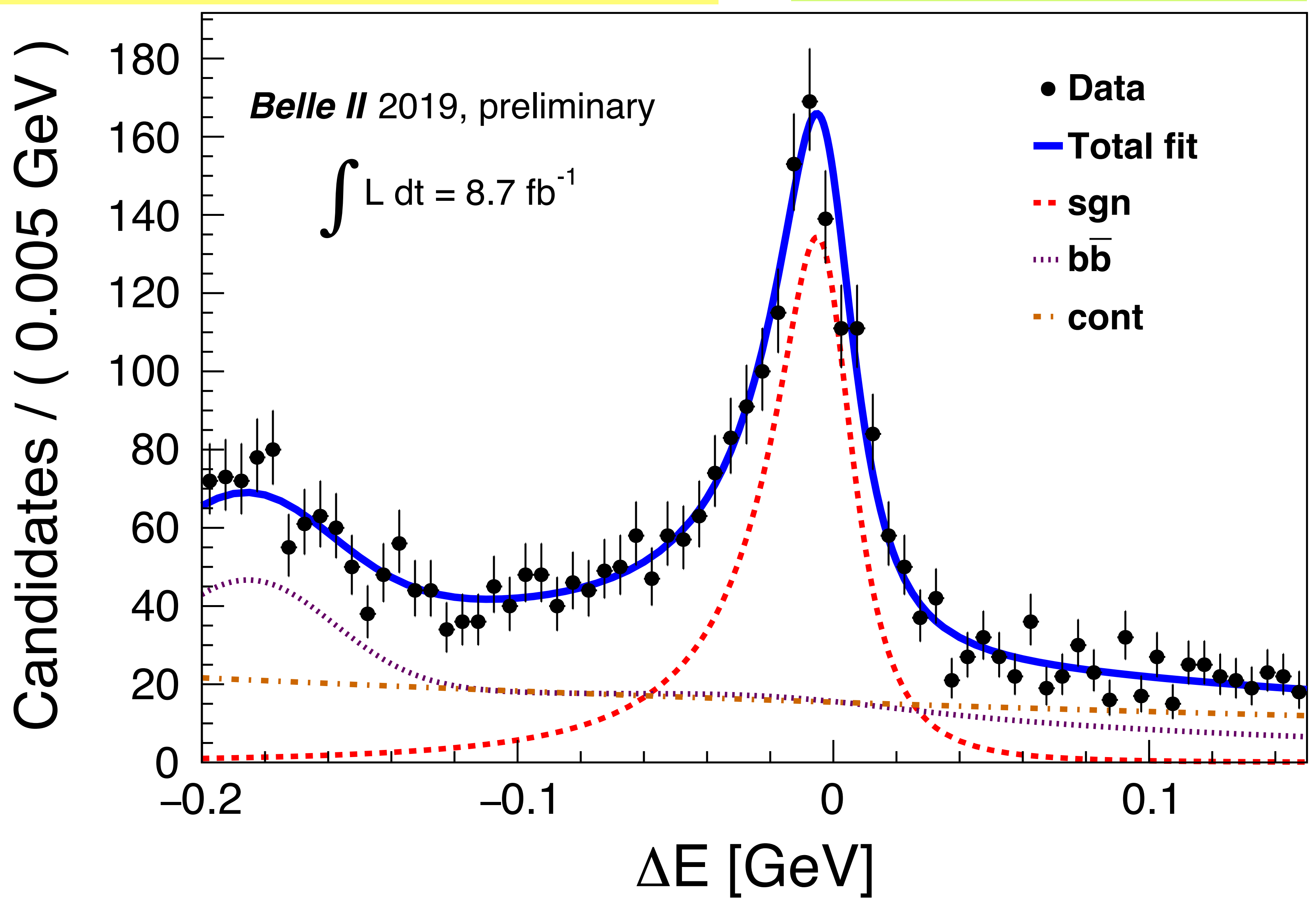
Talk by F. Abudinen

- Good understanding of basic tools and performance for TDCPV.
  - B-decay vertices reconstructed using VXD hit information.
  - ~1 ps Δt resolution achieved - dominated by tag-side.

Systematic Errors	[ps]
Fit bias	0.05
τ_{eff}	0.01
Calibration	0.03

- τ_{B0} = 1.48±0.28±0.06 ps compatible with world average 1.519 ± 0.004 ps



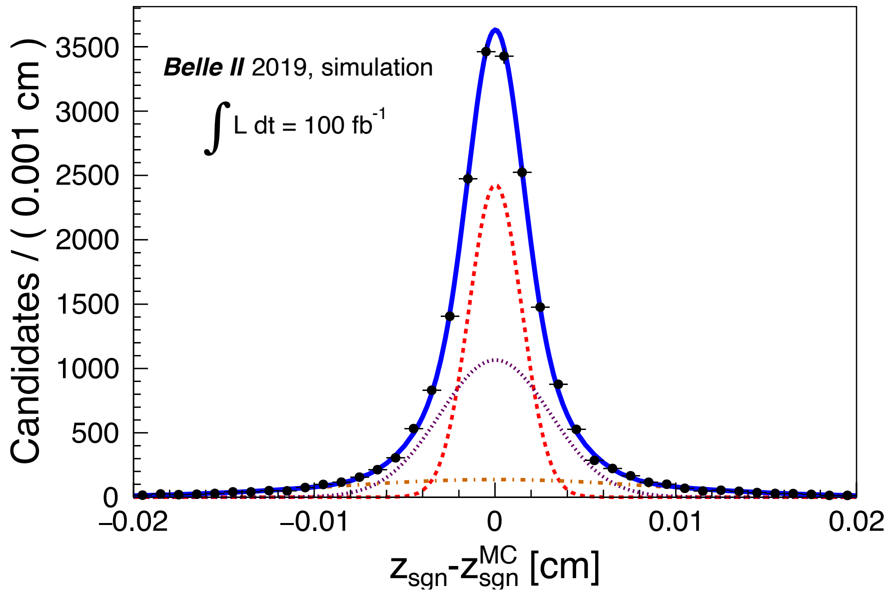


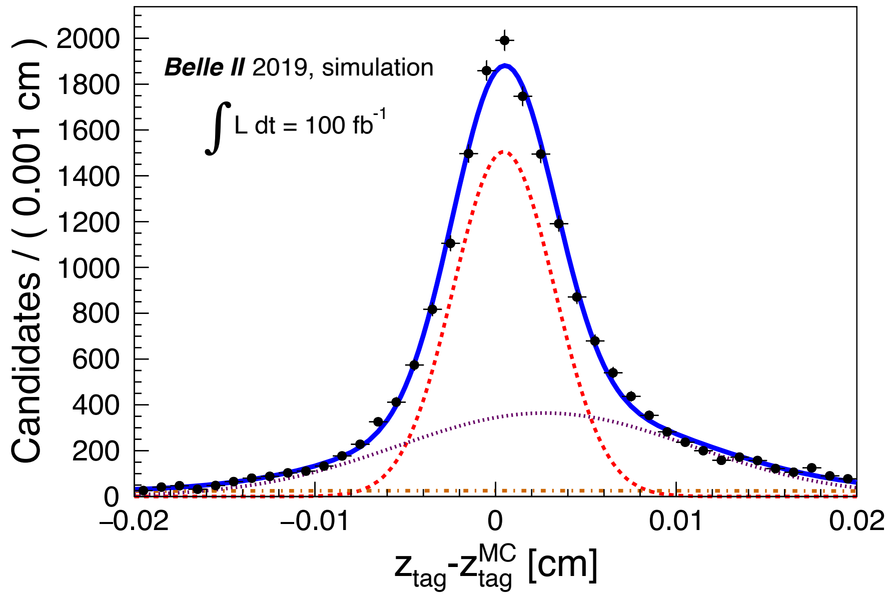
$B^0 \to D^- \pi^+$
$B^0 \to D^- \rho^+$
$B^0 \to D^{*-} \pi^+$
$B^0 \to D^{*-} \rho^+$

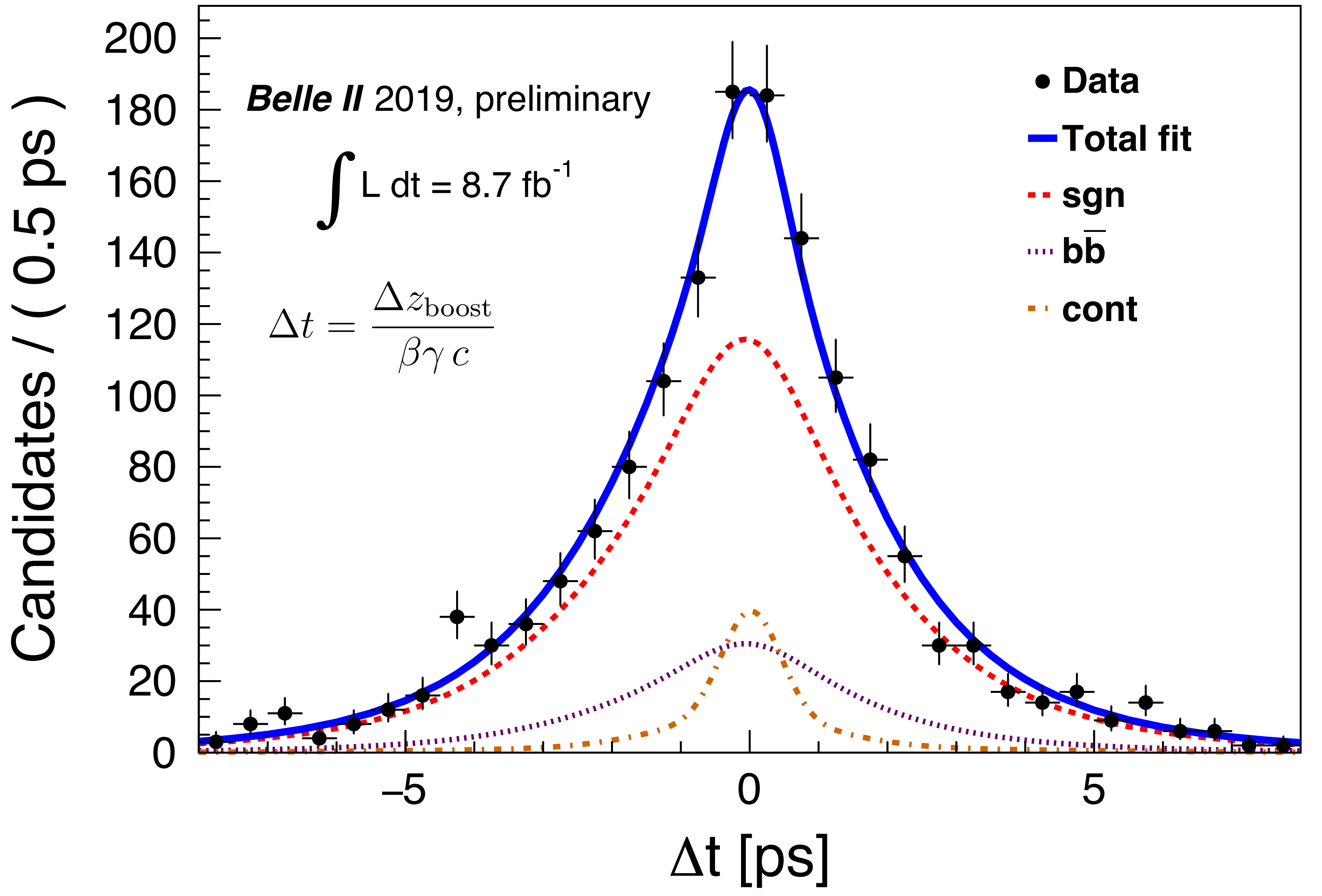
$D^{*+} \to D^0 \pi^-$

$D^- \to K^+ \pi^- \pi^-$

$D^0 \to K^- \pi^+$
$D^0 \to K^- \pi^+ \pi^0$
$D^0 \to K^- \pi^+ \pi^+ \pi^-$

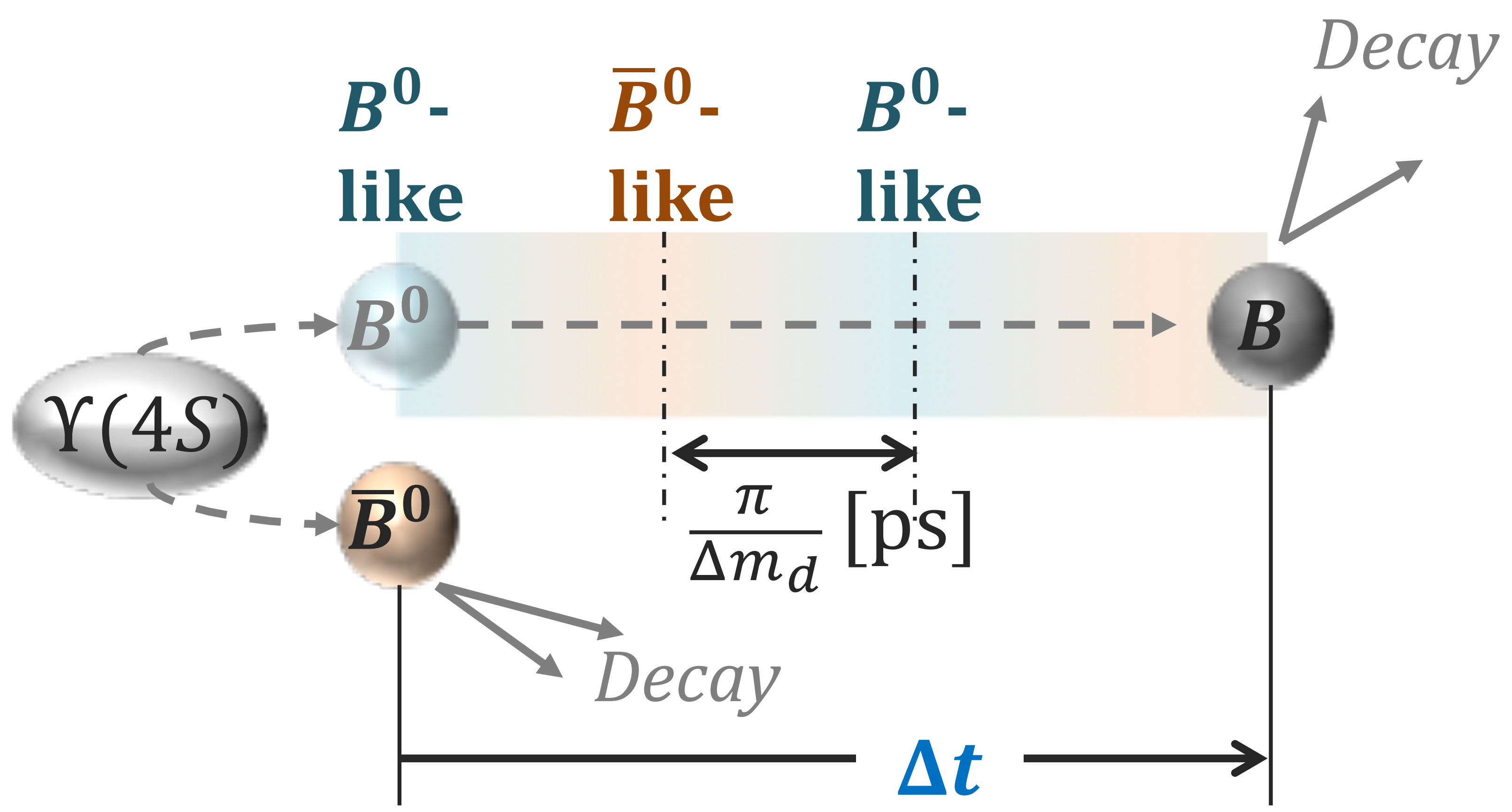


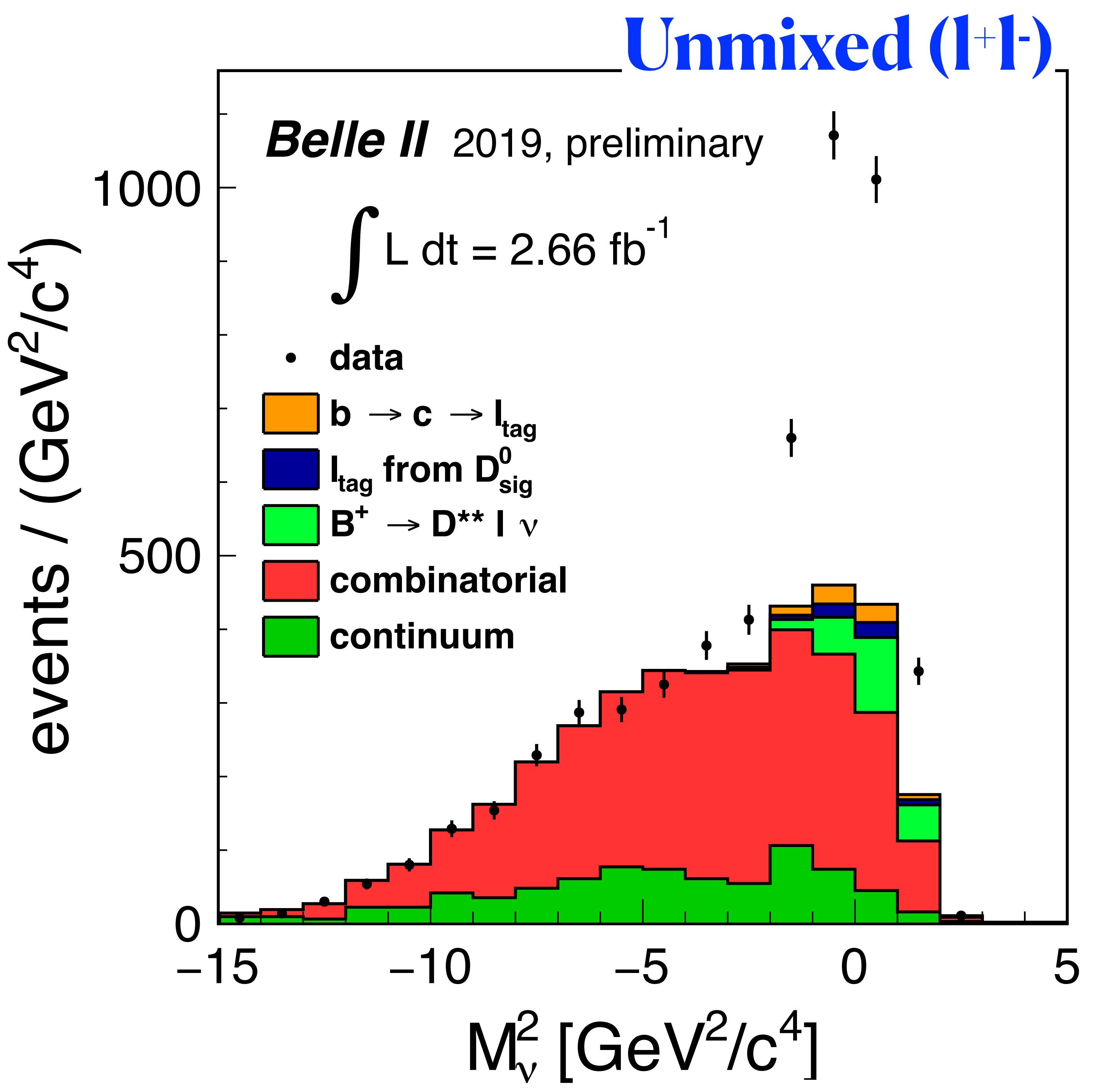


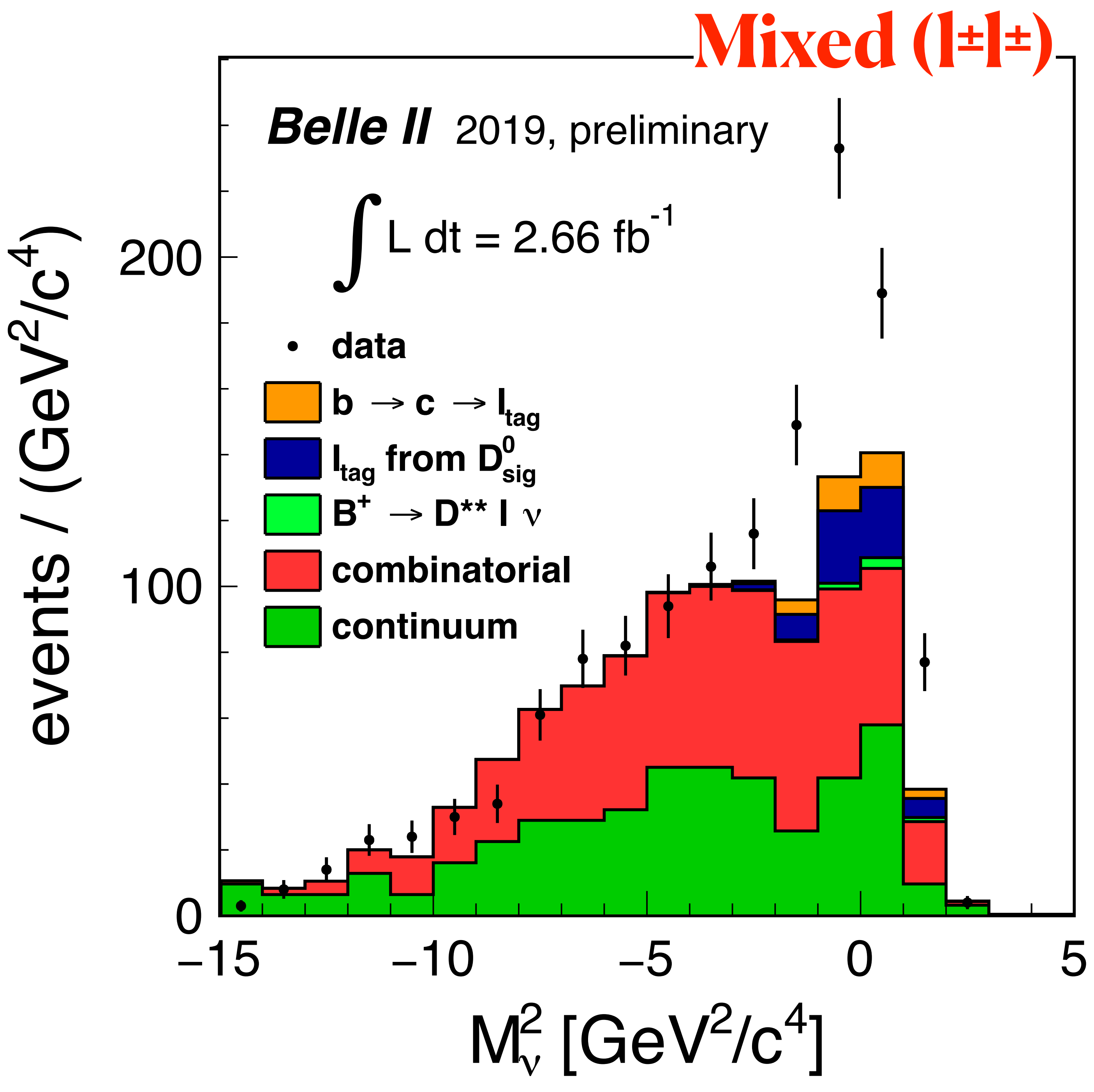


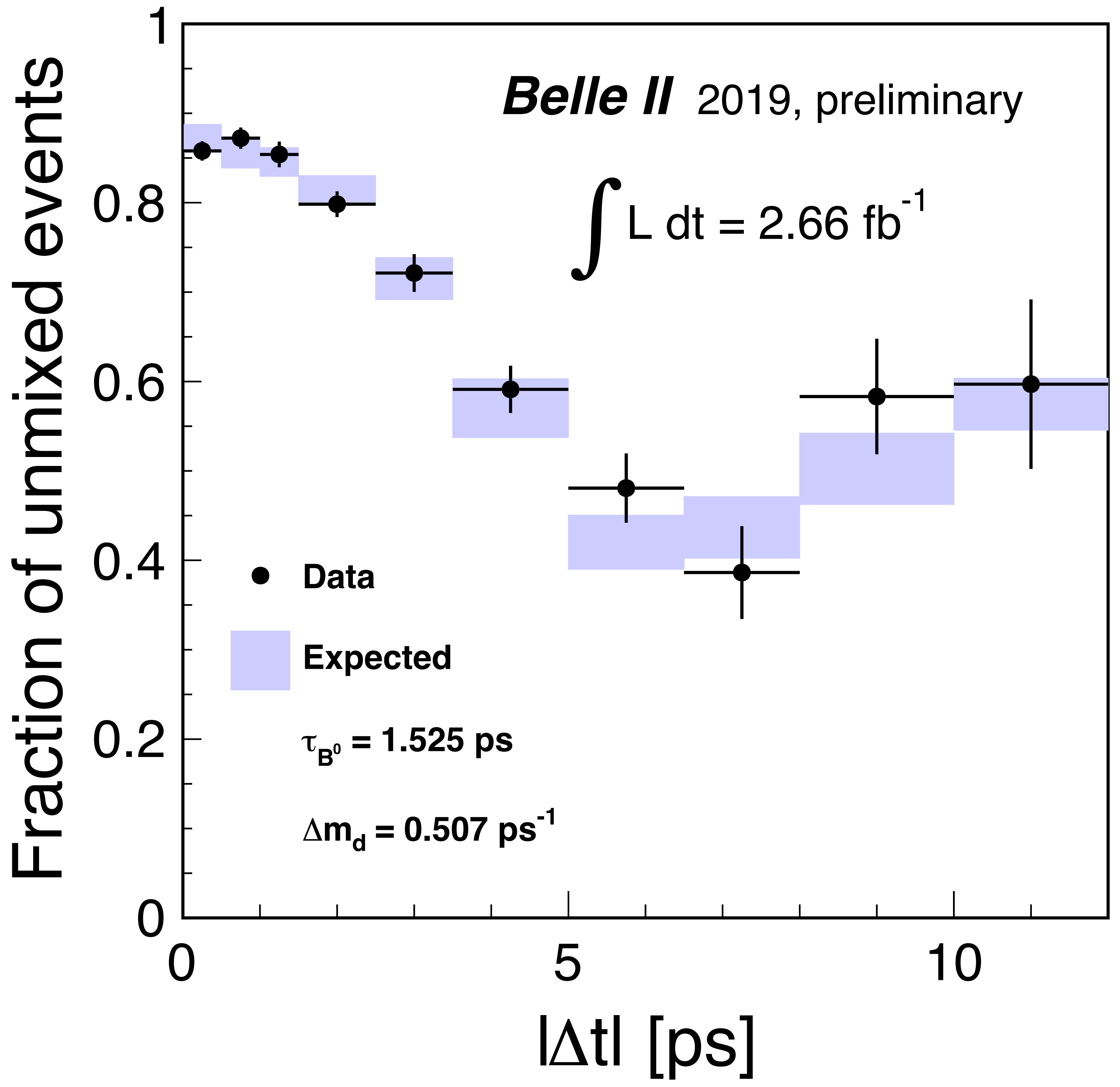
B mixing

- Fraction $N_{OF}/(N_{OF}+N_{SF})$ calculated for each Δt bin and compared with MC-expected value $P_{OF}(\Delta t)\otimes R(\Delta t)$
- $P_{OF}(\Delta t)=[1-\cos(\Delta m t)]$
- Flavour specific final states: l^+l^-, $l^\pm l^\pm$









$\chi_d = (17.2 \pm 3.6)\%$ (WA = 18.6%)

B reconstruction towards Φ_1

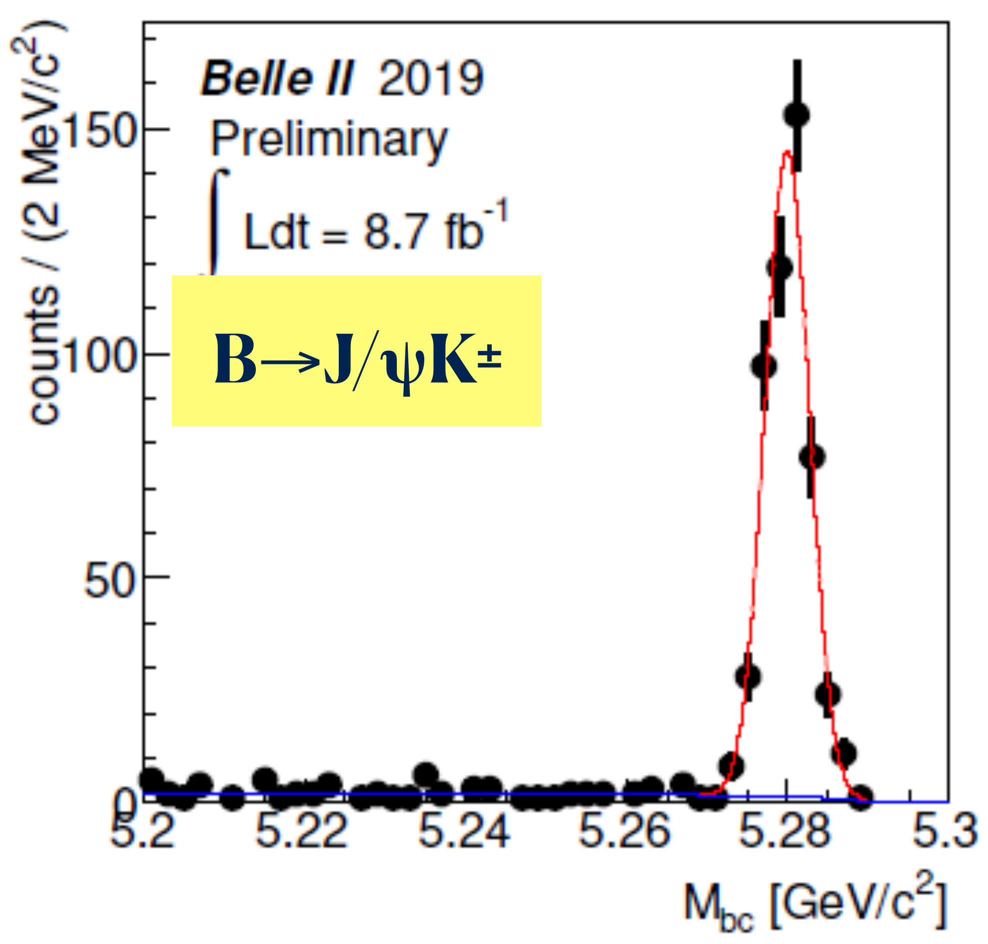
Talk by F. Abudinen

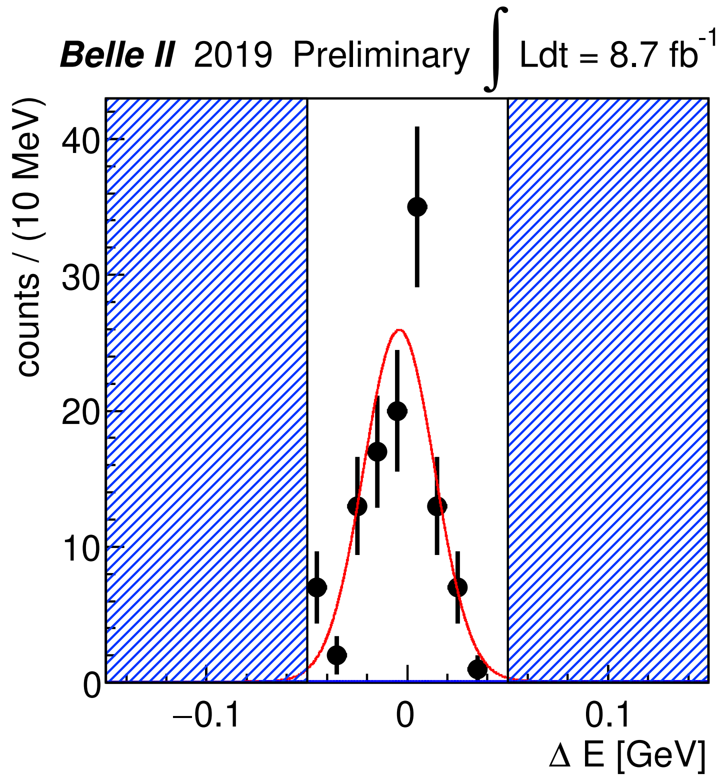
- **$\sin 2\Phi_1$** from **B → cc K^0** ~ a few x 1000 recorded by Belle II to date.
  - With the full dataset “systematic" uncertainties will be larger, but data driven. Balance stat-power with good vertex fitted events.
  - Searches for NP in B→ η′K_S etc. are stat limited through to 50 ab^{-1}.
  - For theory: often neglected the contributions from suppressed amplitudes carrying a different phase - need to work together on modes like B→J/psi π^0.

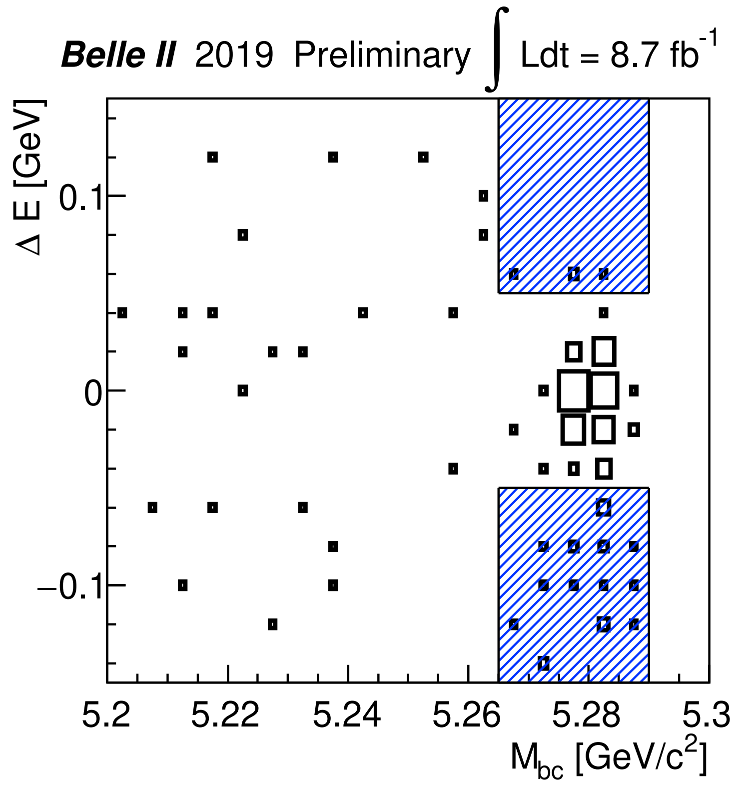
PTEP 2019 (2019) 12, 123C01

	Current	50 ab^{-1} projection
ϕ_1:		
Experimental:	0.7°	0.2°
Theoretical - QCDF & pQCD	0.1°	0.1°
Theoretical - SU(3)	1.7°	0.8°
ϕ_2:		
Experimental:	4.2°	0.6°
Theoretical:	1.2°	< 1.0°

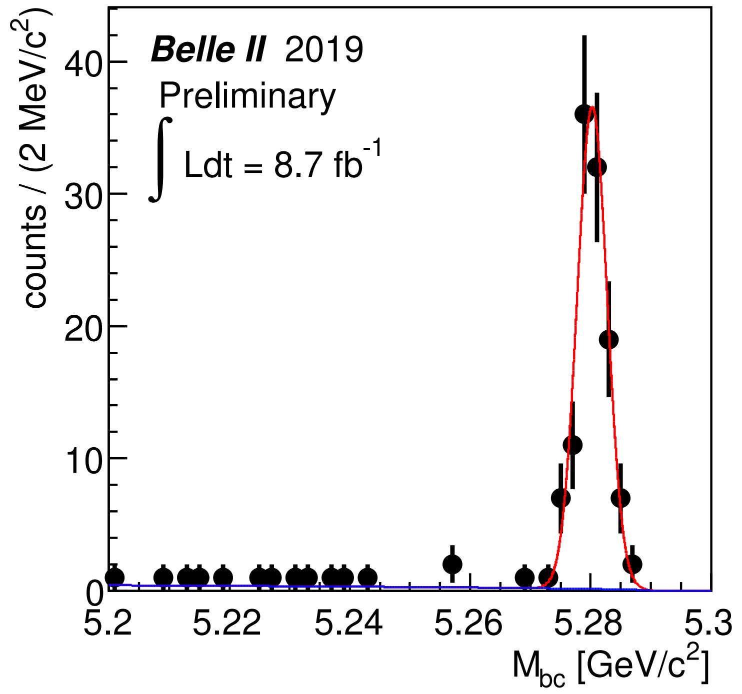
BELLE2-NOTE-PL-2020-004



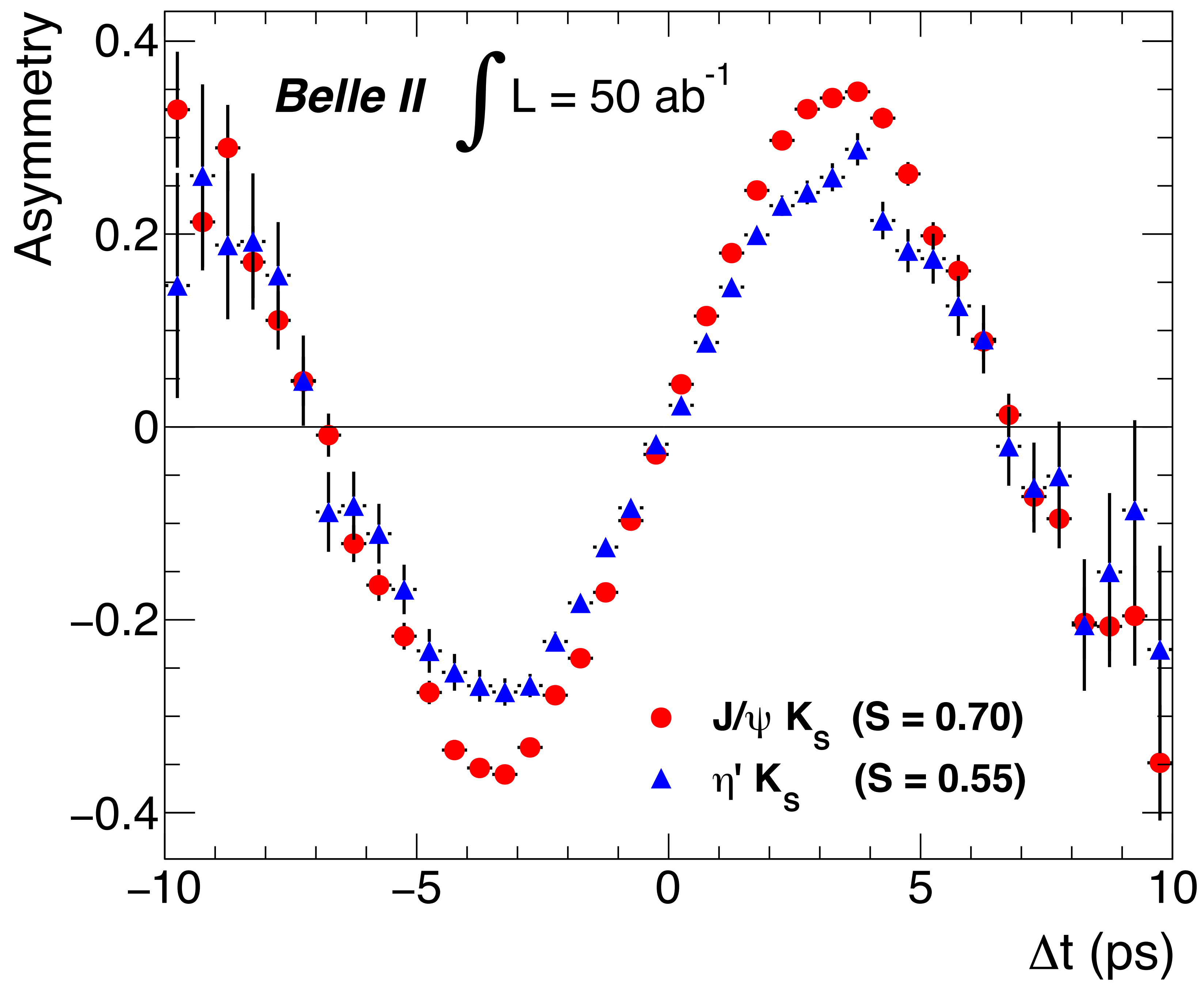




B→J/ψK$_S$



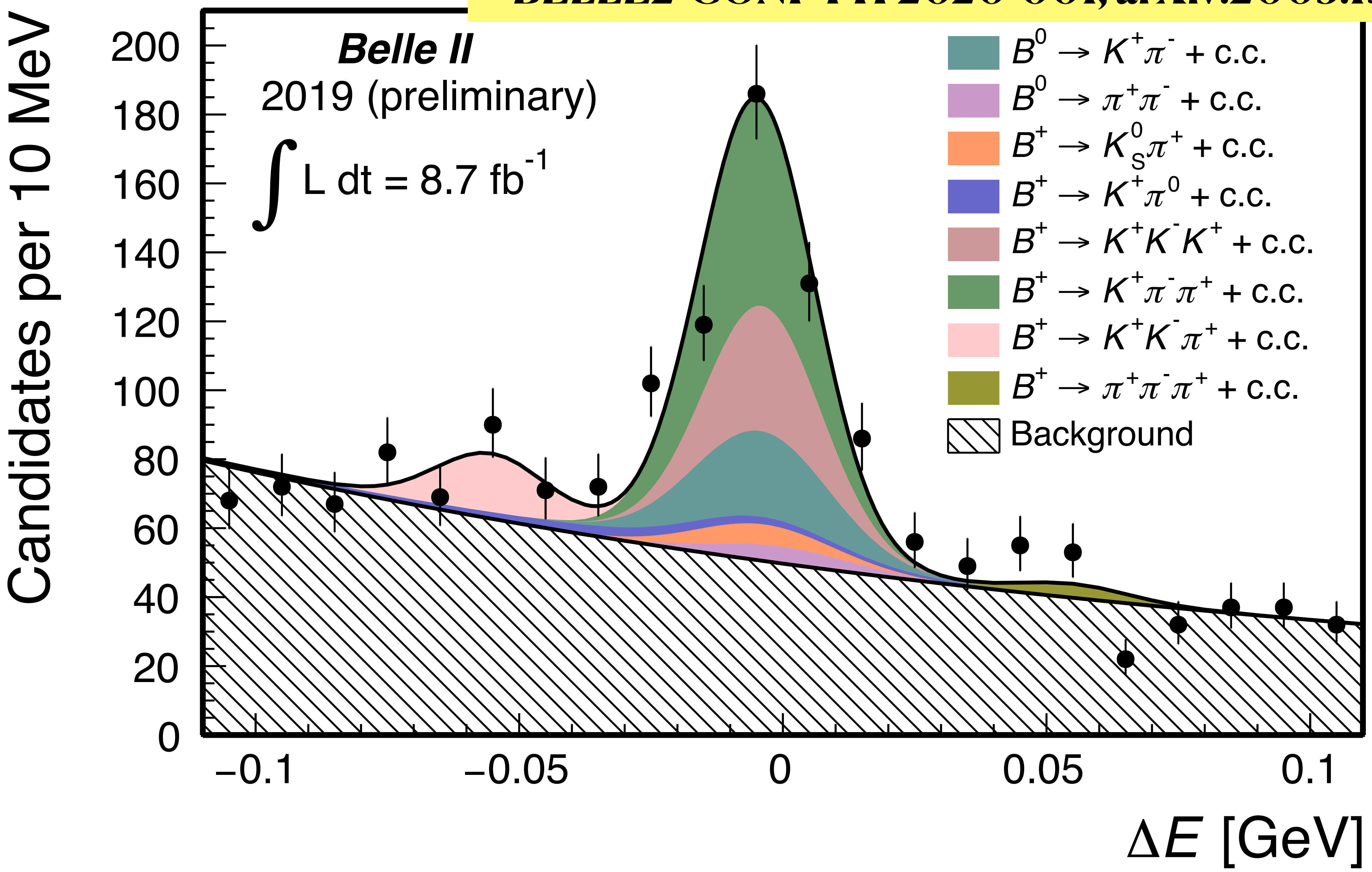
Mode	Signal	Background	Expected signal
$B^0 \to J/\psi K_S^0,\ J/\psi \to e^+e^-$	38.4 ± 6.3	1.9 ± 0.5	38.5 ± 3.1
$B^0 \to J/\psi K_S^0,\ J/\psi \to \mu^+\mu^-$	74.8 ± 8.5	0.5 ± 0.2	64.6 ± 4.5
$B^0 \to J/\psi K_S^0,\ J/\psi \to \ell^+\ell^-$	113.9 ± 11.1	1.3 ± 0.3	103.1 ± 5.5

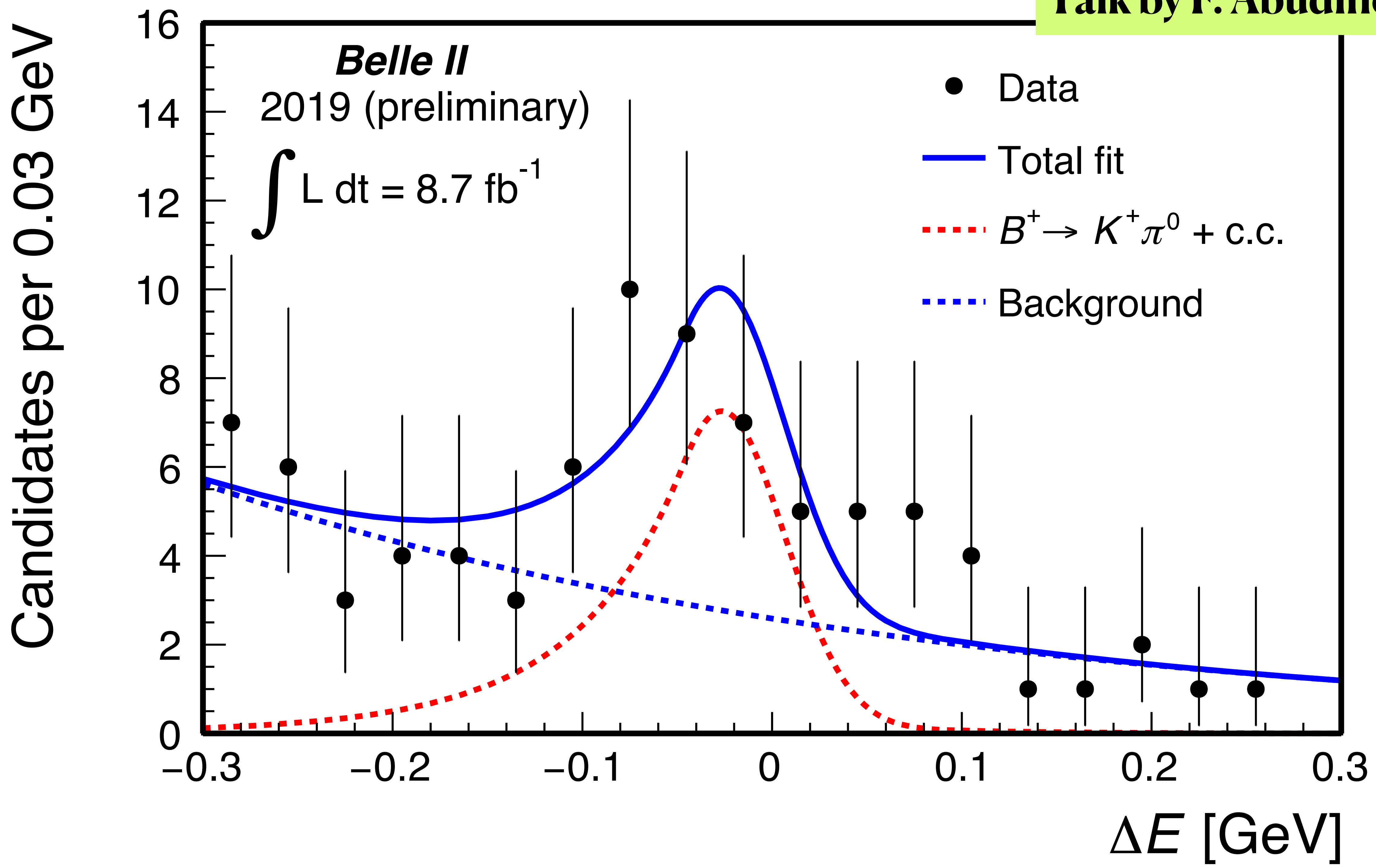


B reconstruction towards Φ_2 & Direct CPV

BELLE2-CONF-PH-2020-001, arXiv:2005.13559

Talk by F. Abudinen

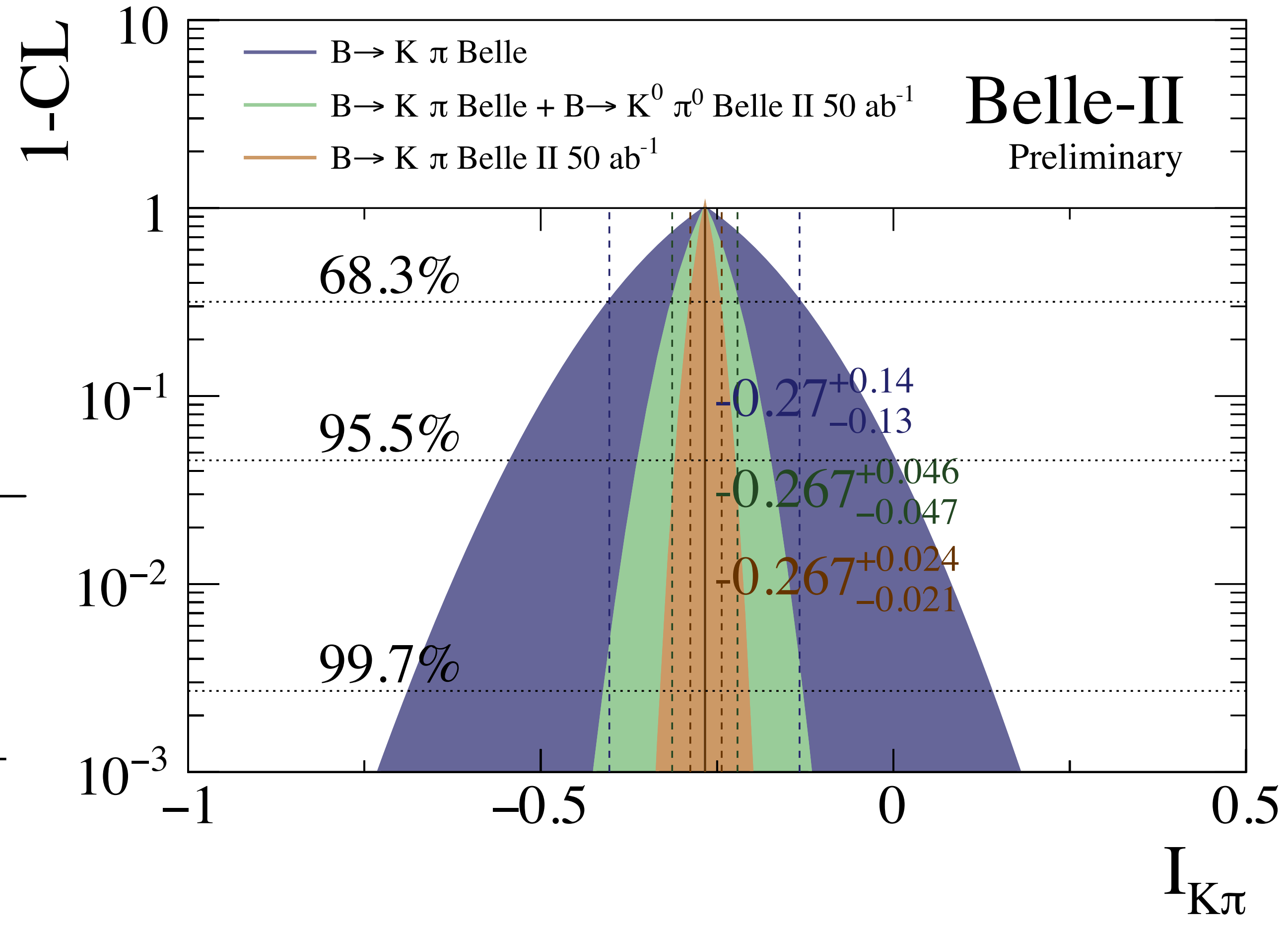




Decay	Yield MC	Yield Data	Yield/fb^{-1} MC	Yield/fb^{-1} Data
$B^0 \to K^+\pi^-$	371 ± 24	79 ± 11	7.4 ± 0.5	9.1 ± 1.3
$B^0 \to \pi^+\pi^-$	78 ± 11	16 ± 5	1.6 ± 0.2	1.8 ± 0.6
$B^+ \to K_S^0\pi^+$	83 ± 10	18 ± 5	1.7 ± 0.2	2.1 ± 0.6
$B^+ \to K^+\pi^0$	191 ± 20	27 ± 8	3.8 ± 0.4	3.1 ± 0.9
$B^+ \to K^+K^+K^-$	559 ± 28	92 ± 12	11.2 ± 0.6	10.6 ± 1.4
$B^+ \to K^+\pi^+\pi^-$	1008 ± 44	160 ± 19	20.2 ± 0.9	18.4 ± 2.2

Complement of B→Kπ isospin rotations required to test for new sources of CPV, $I_{K\pi}$ = 0 in SM

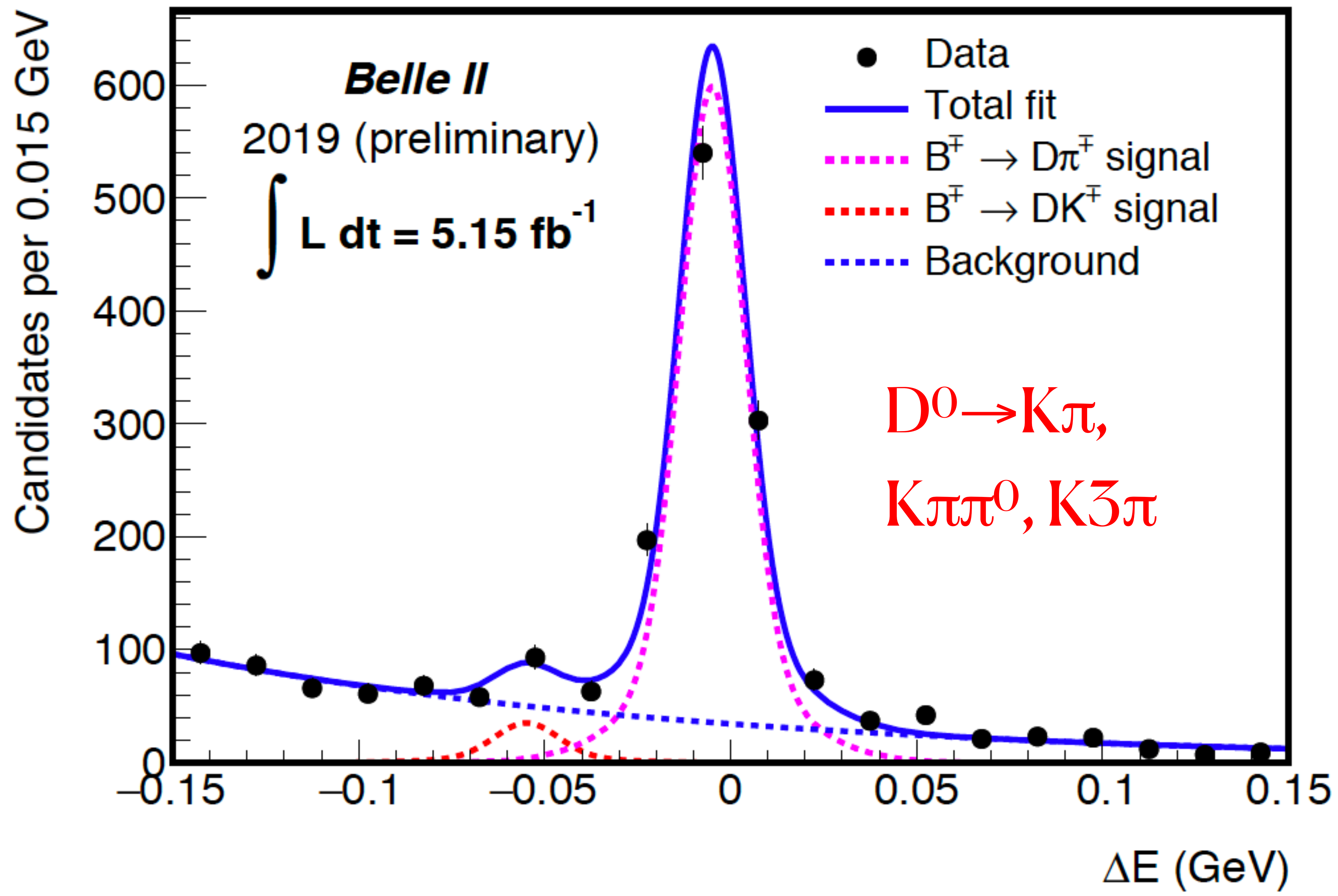
$$I_{K\pi}\cdot\mathcal{B}(B^0\to K^+\pi^-) = A_{CP}^{K^+\pi^-}\cdot\mathcal{B}(B^0\to K^+\pi^-) + A_{CP}^{K^0\pi^-}\cdot\mathcal{B}(B^+\to K^0\pi^-)\frac{\tau_{B^0}}{\tau_{B^+}} - 2A_{CP}^{K^0\pi^0}\cdot\mathcal{B}(B^0\to K^0\pi^0) + 2A_{CP}^{K^+\pi^0}\cdot\mathcal{B}(B^+\to K^+\pi^0)\frac{\tau_{B^0}}{\tau_{B^+}}$$



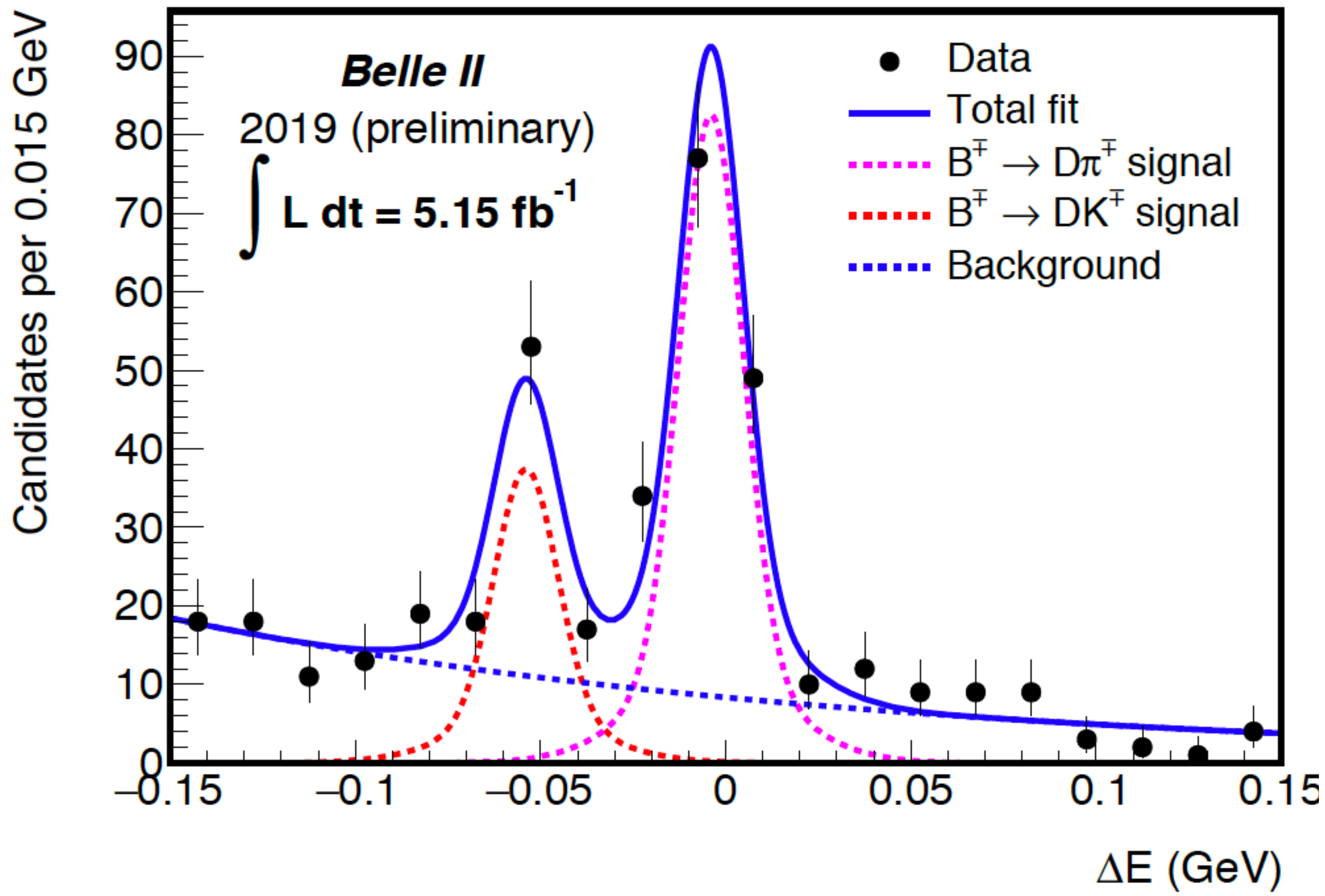
B reconstruction towards Φ_3

Talk by M. Merola

No K/π Particle ID



With Particle ID



- Demonstration of Belle II high momentum PID on a decay mode to be used for future determinations of the UT angle ϕ_3. Improved ΔE resolution in Belle II - better DK/Dπ separation than Belle.
- Ultimate reach of ~1.5° precision on Φ_3 predominantly from GGSZ $D \to K_S^0\pi^+\pi^-$.
- Requires us to use neutral modes with significant BRs:

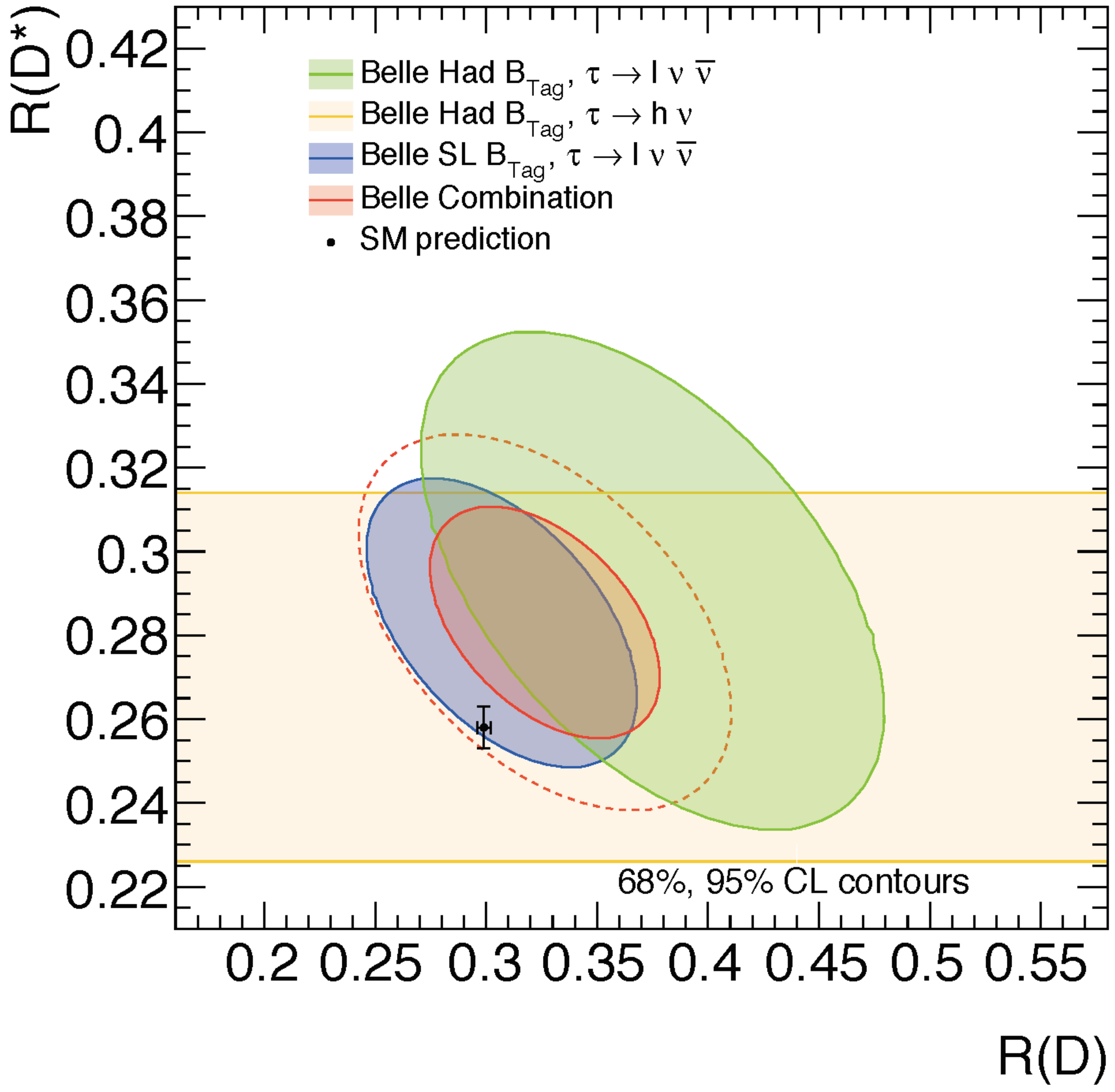
CP even ($\pi^0\pi^0$, $K_L^0\pi^0$, $K_S^0\pi^0\pi^0$...), CP odd ($K_S^0K_S^0K_L^0$, $\eta\pi^0\pi^0$, ...), Self-conjugate ($K_L\pi\pi$, K_LKK...).

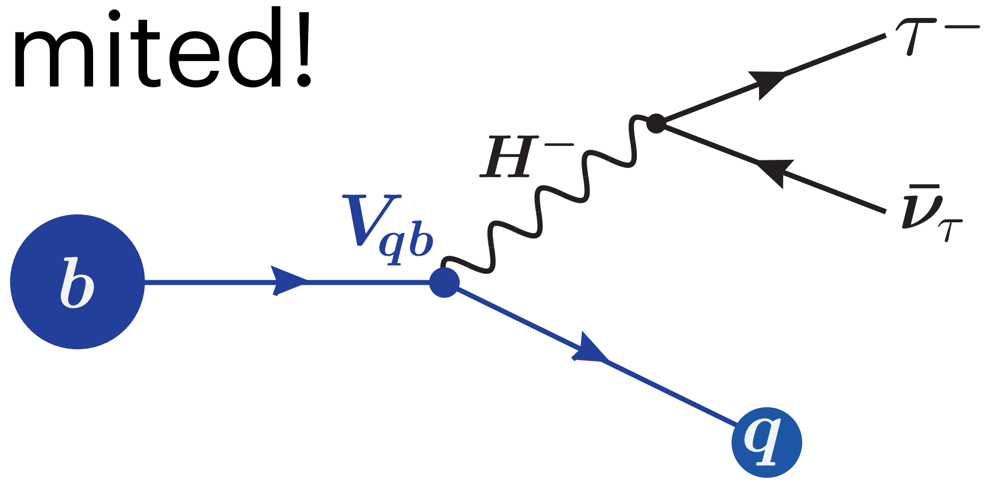
$B \to D^{(*)} \tau^- \nu$ analysis / Converted Belle→Belle II Data

Talk by S. Sandilya

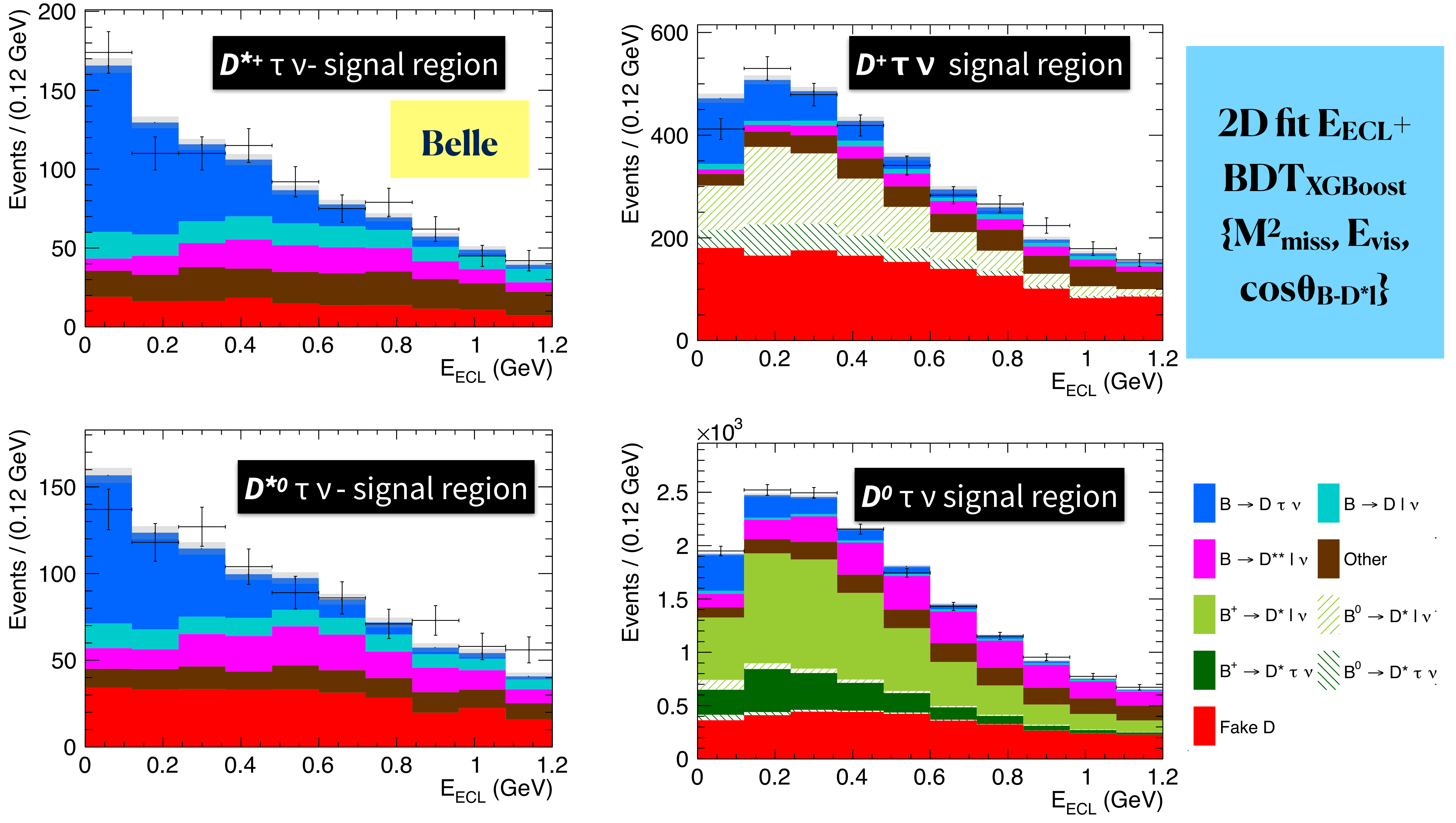
- Semileptonic tag / FEI BDT, $B \to D \tau \nu$ and $B \to D^* \tau \nu$ *Simultaneously*
- Employed Belle II analysis framework. Stat. limited!

Phys.Rev.Lett. 124 (2020) 16, 161803





$$\mathcal{R}(D) = 0.307 \pm 0.037 \pm 0.016$$
$$\mathcal{R}(D^*) = 0.283 \pm 0.018 \pm 0.014$$



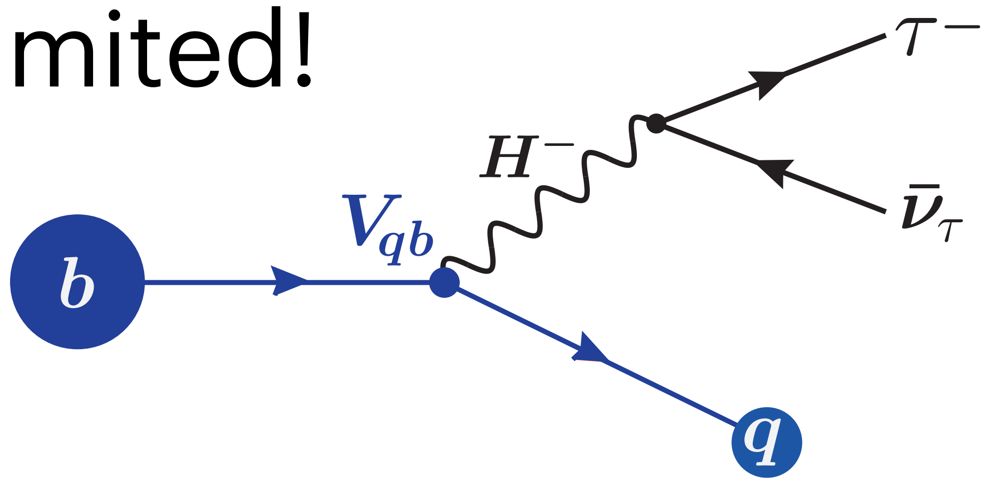
2D fit E_{ECL}+ $BDT_{XGBoost}$ {M^2_{miss}, E_{vis}, $\cos\theta_{B\text{-}D^*l}$}

$B \to D^{(*)} \tau^- \nu$ analysis / Converted Belle→Belle II Data

Talk by S. Sandilya

- Semileptonic tag / FEI BDT, B→D τ ν and B→D* τ ν *Simultaneously*
- Employed Belle II analysis framework. Stat. limited!

Phys.Rev.Lett. 124 (2020) 16, 161803



$$\mathcal{R}(D) = 0.307 \pm 0.037 \pm 0.016$$
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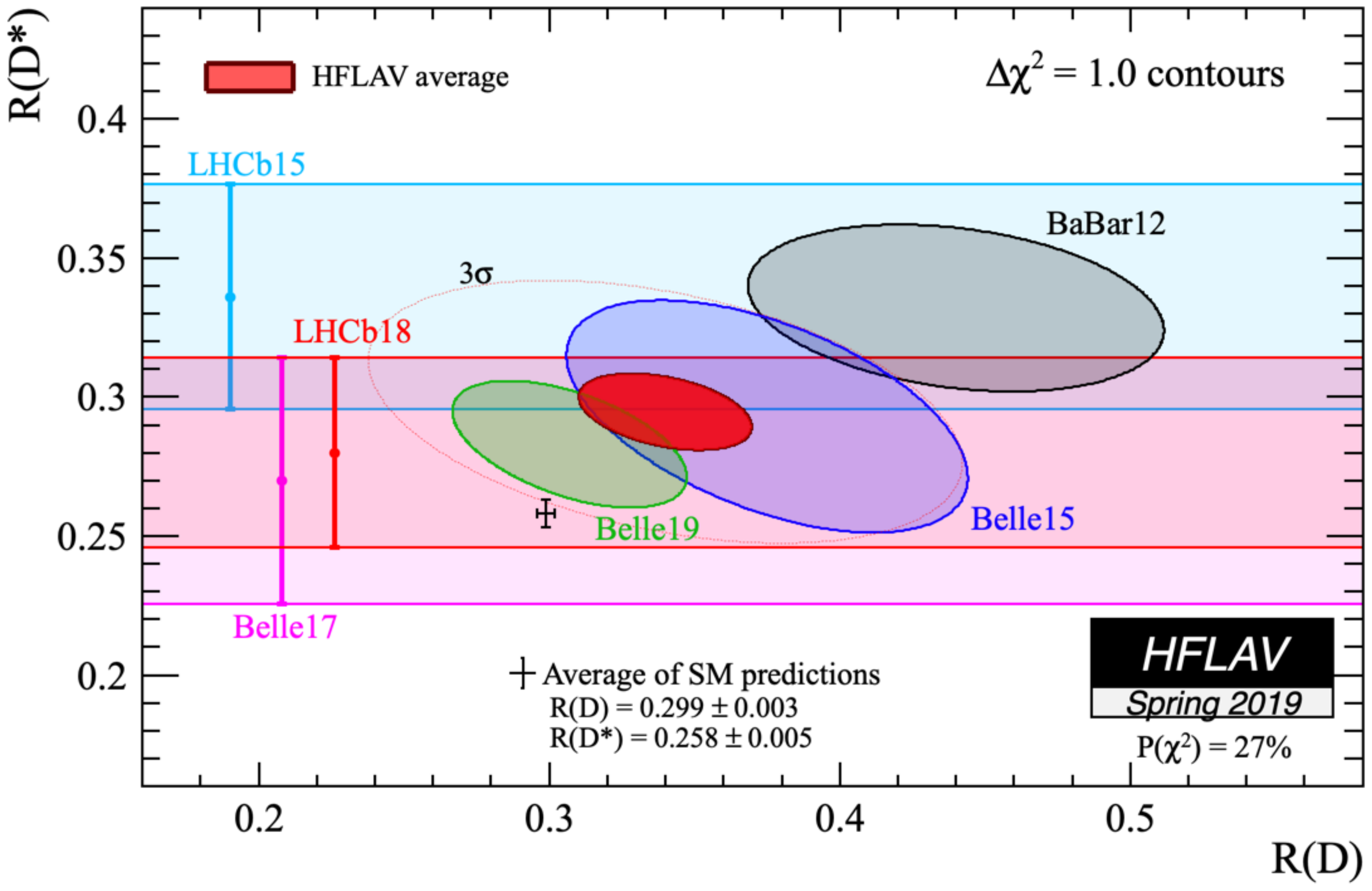
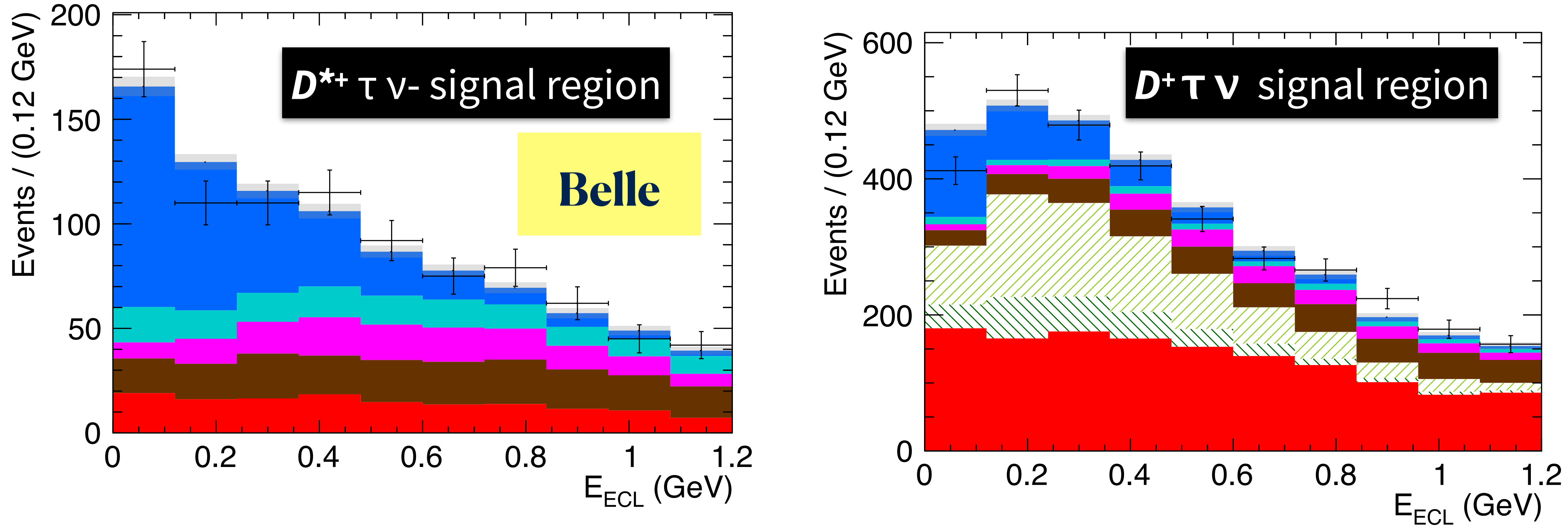
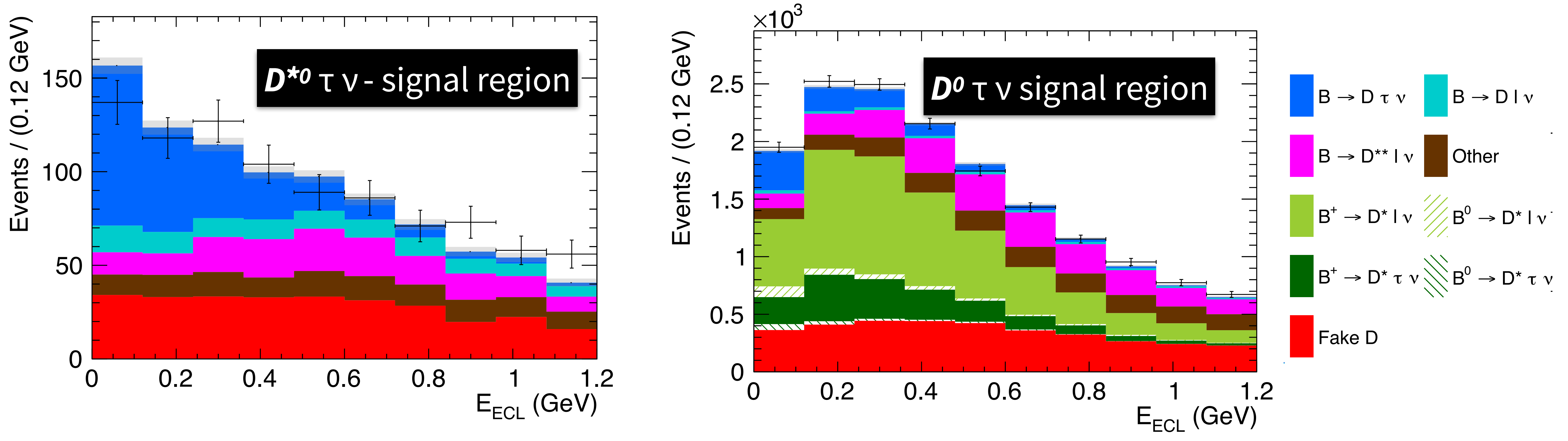


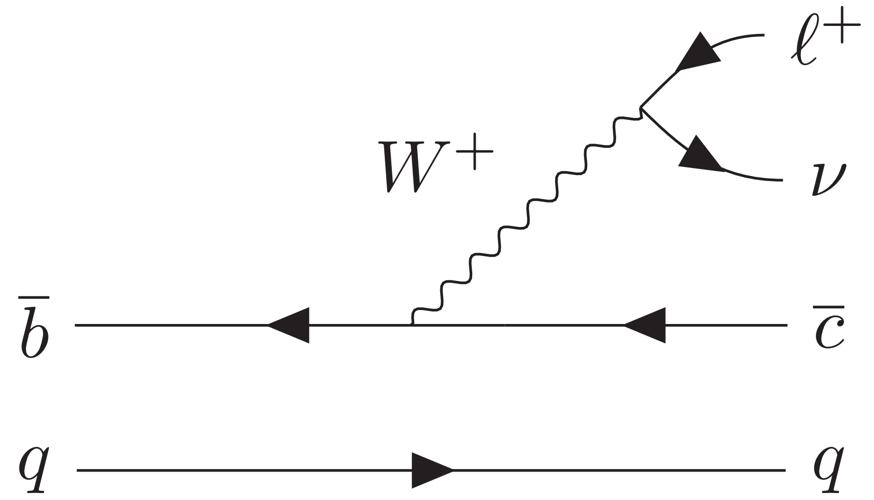


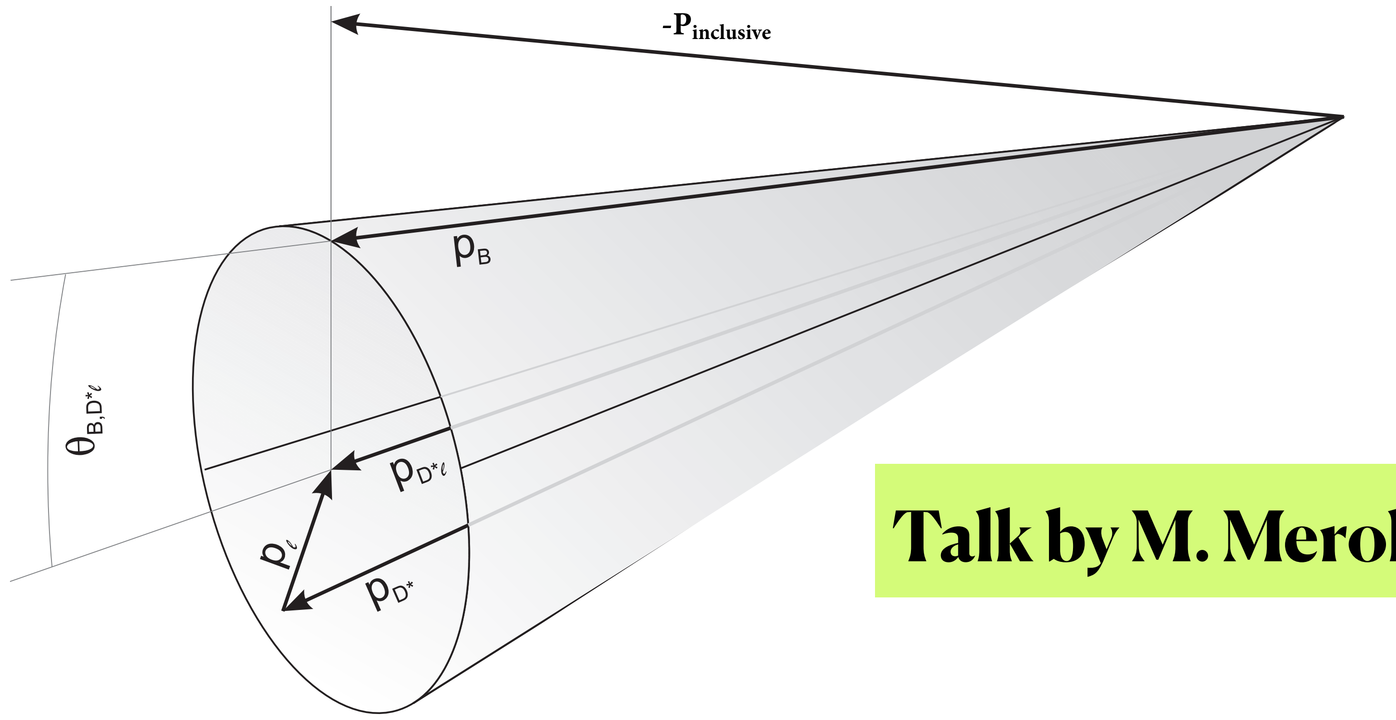
2D fit E_{ECL} + $BDT_{XGBoost}$ {M^2_{miss}, E_{vis}, $\cos\theta_{B\text{-}D^*l}$}



Untagged B→D* l ν

- Signals for $B \to D^{*+} l^- \nu$, $D^{*+} \to D^0 \pi^+$ using $\cos\theta_{BD^*l}$
- *Clear signals are found in both e and μ modes.*
- *BRs consistent with WA. Performance corrections applied.*





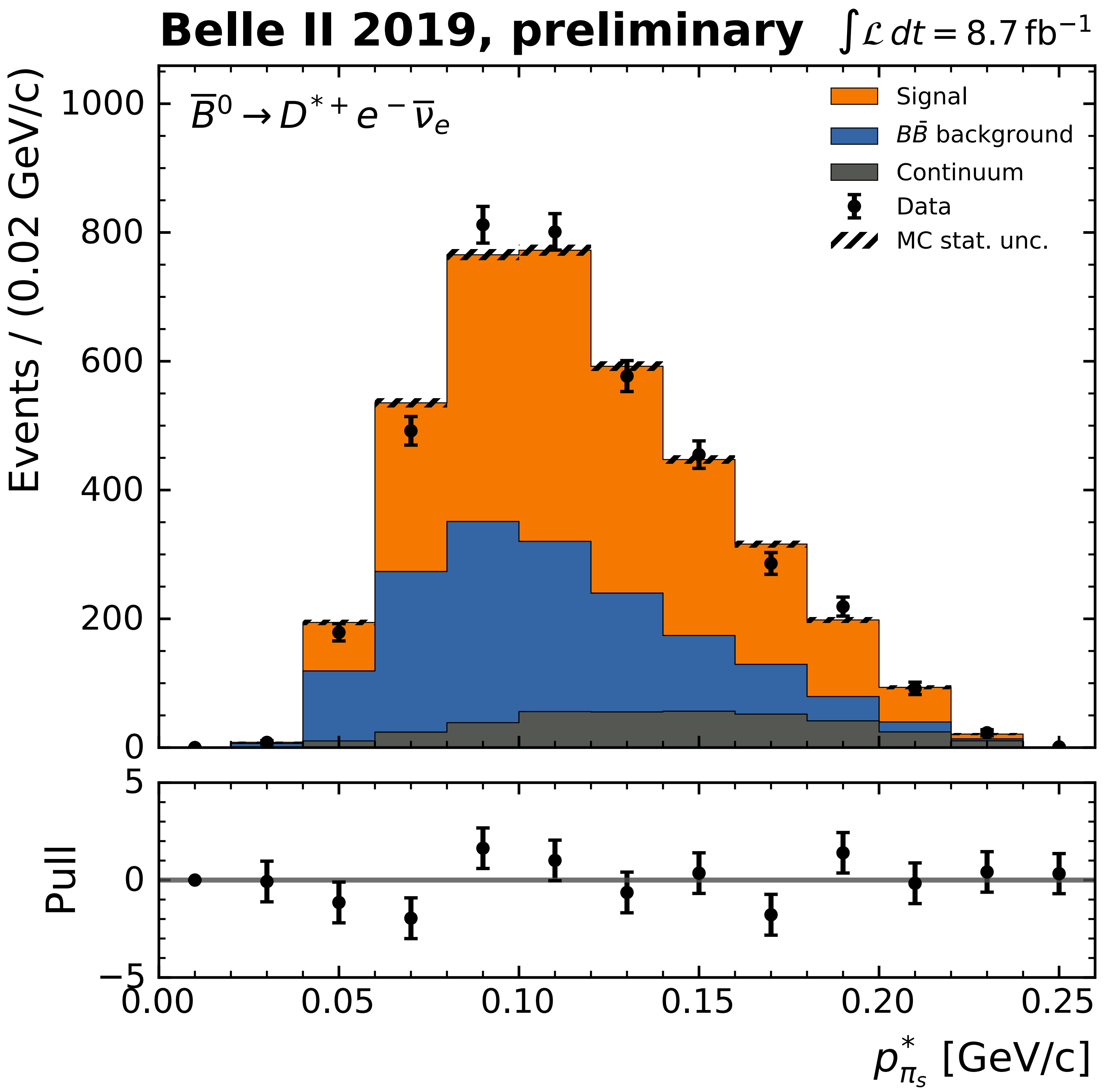
Talk by M. Merola

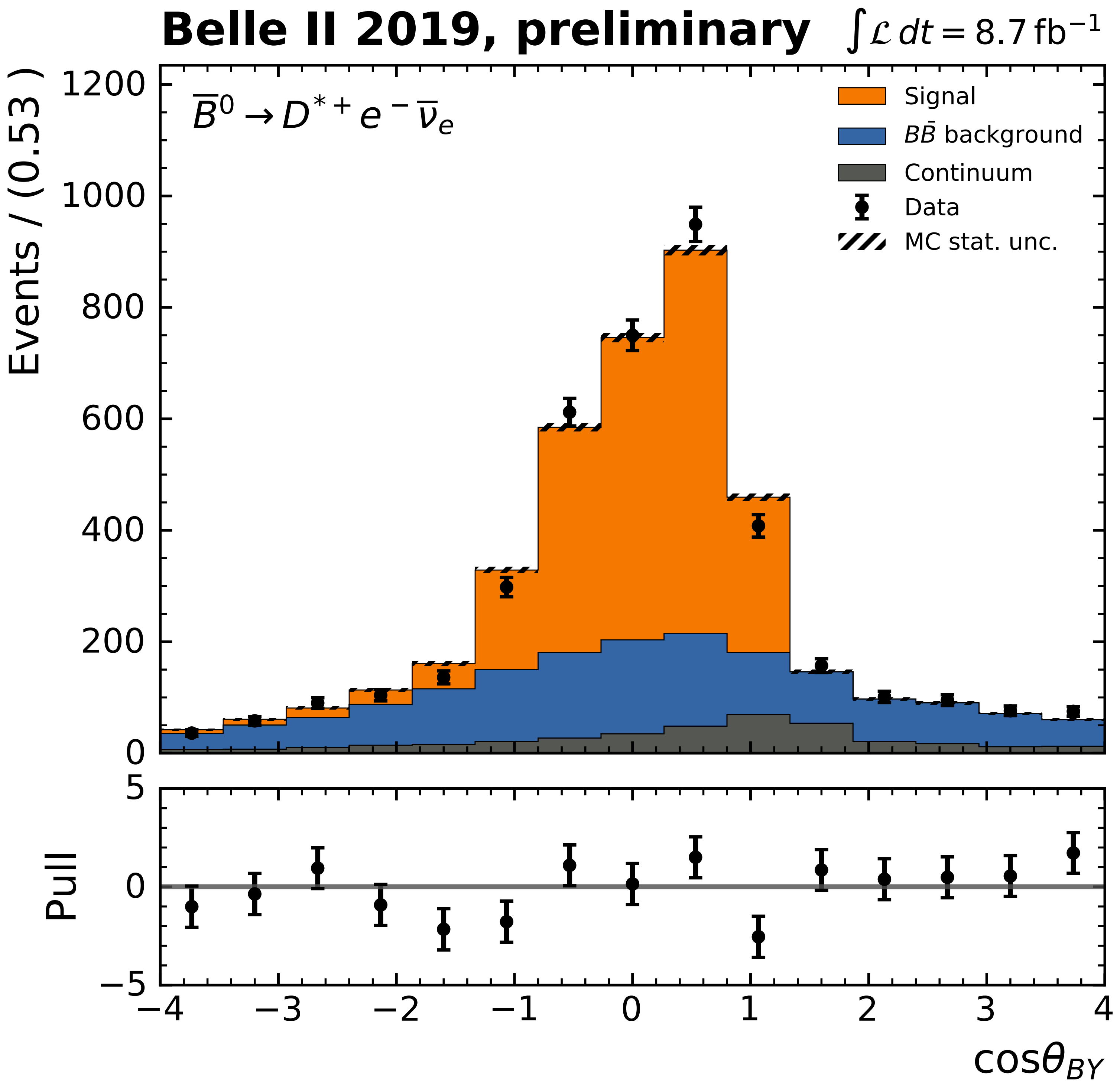
$$\mathcal{B}(\overline{B}^0 \to D^{*+} e^- \overline{\nu}_e) = (4.42 \pm 0.14(\text{stat}) \pm 0.33(\text{sys}))\%$$

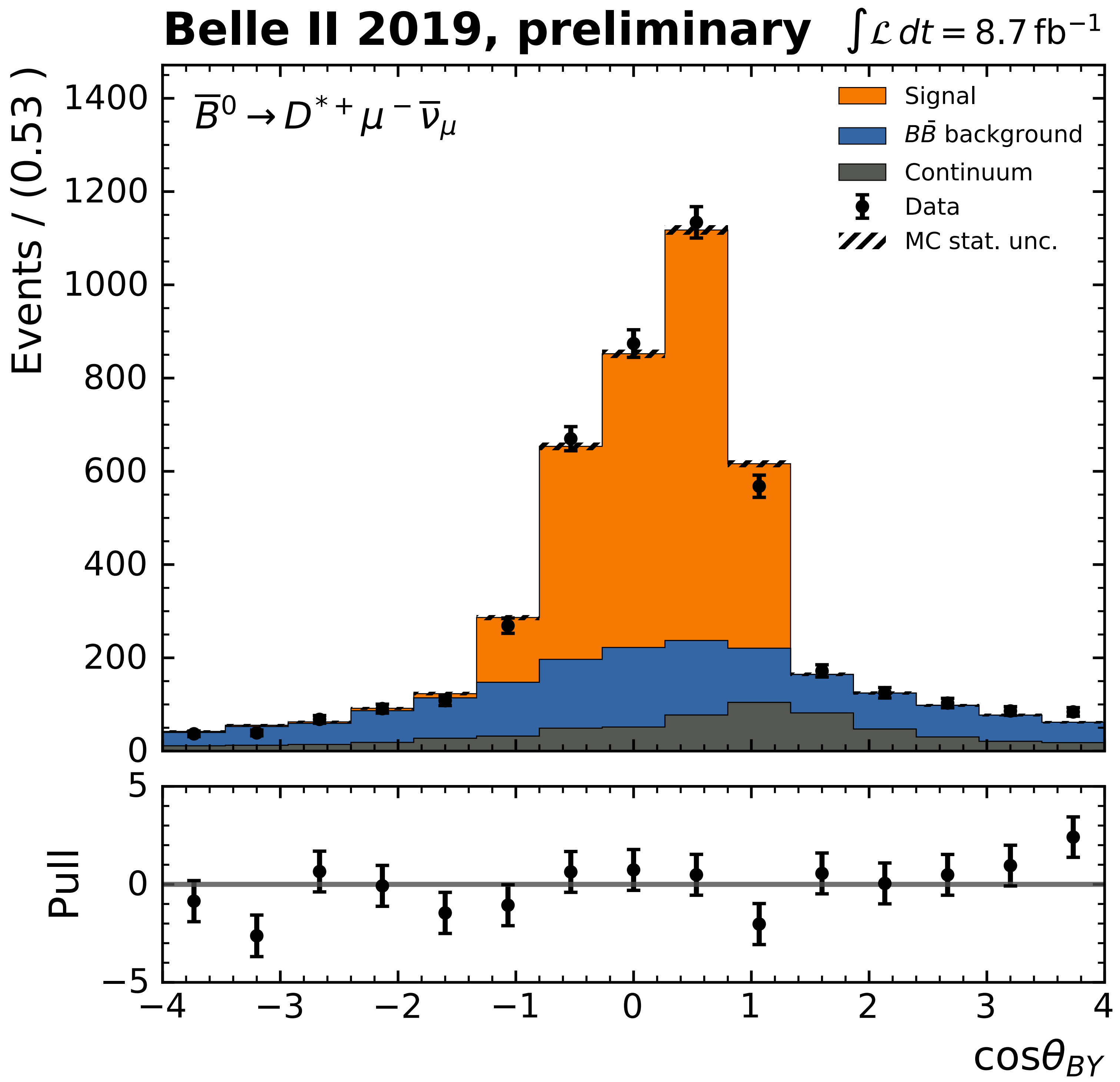
$$\mathcal{B}(\overline{B}^0 \to D^{*+} \mu^- \overline{\nu}_\mu) = (4.70 \pm 0.13(\text{stat}) \pm 0.35(\text{sys}))\%$$

$$\cos\theta_{BY} = \frac{2E_B^* E_Y^* - M_B^2 - m_Y^2}{2p_B^* p_Y^*}$$

BELLE2-CONF-PH-2020-002, arXiv:2004.09066





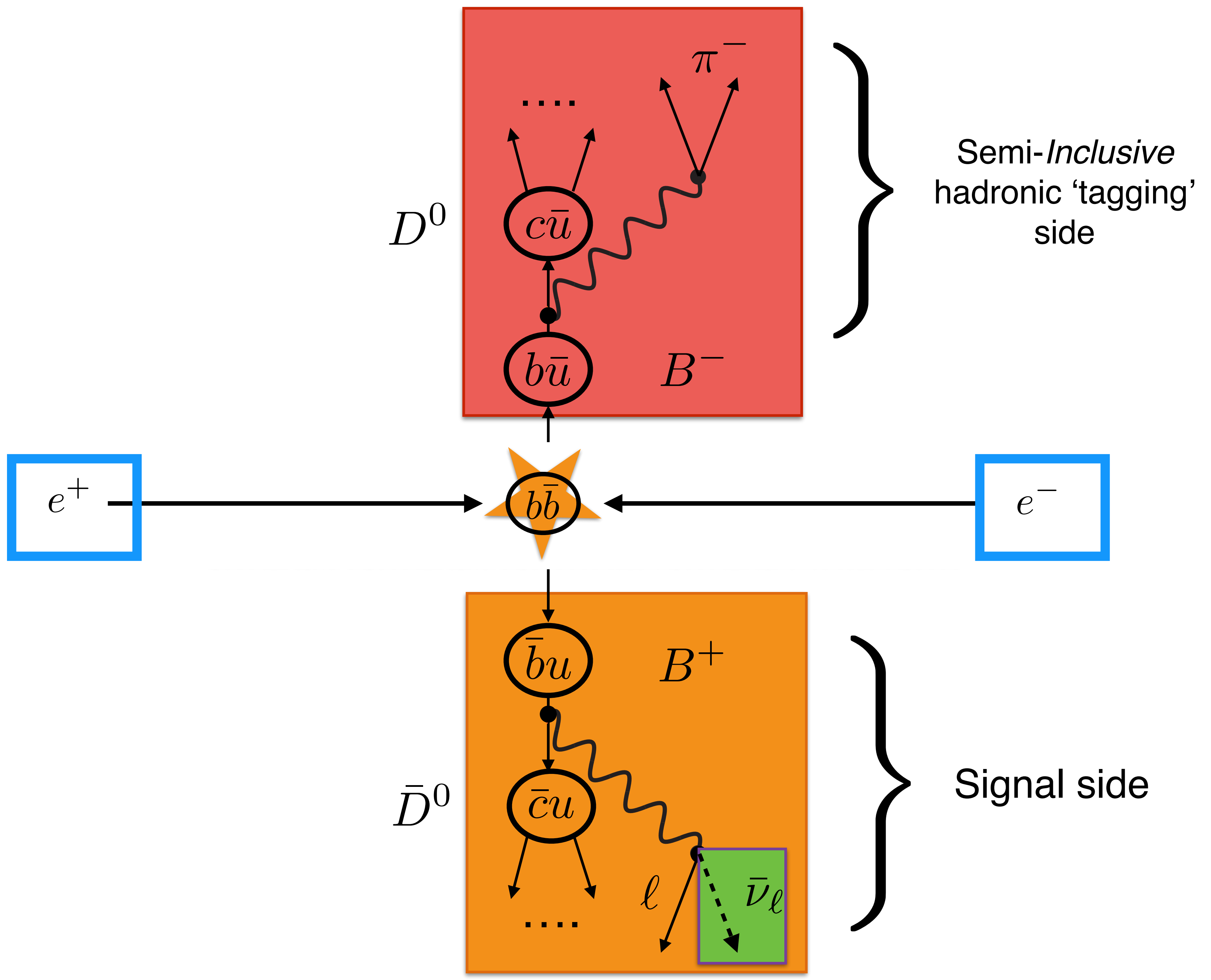


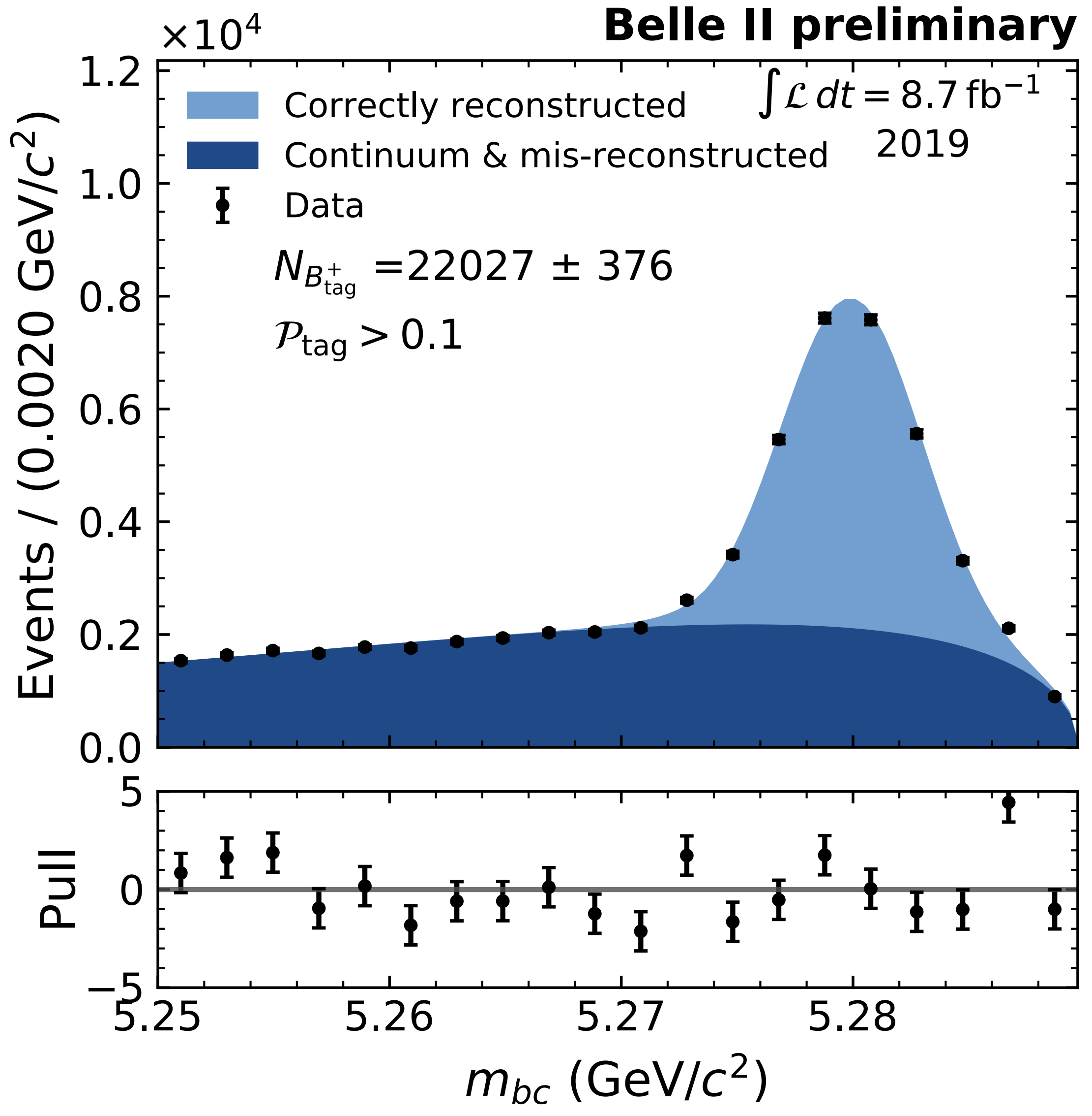
B full reconstruction algorithms

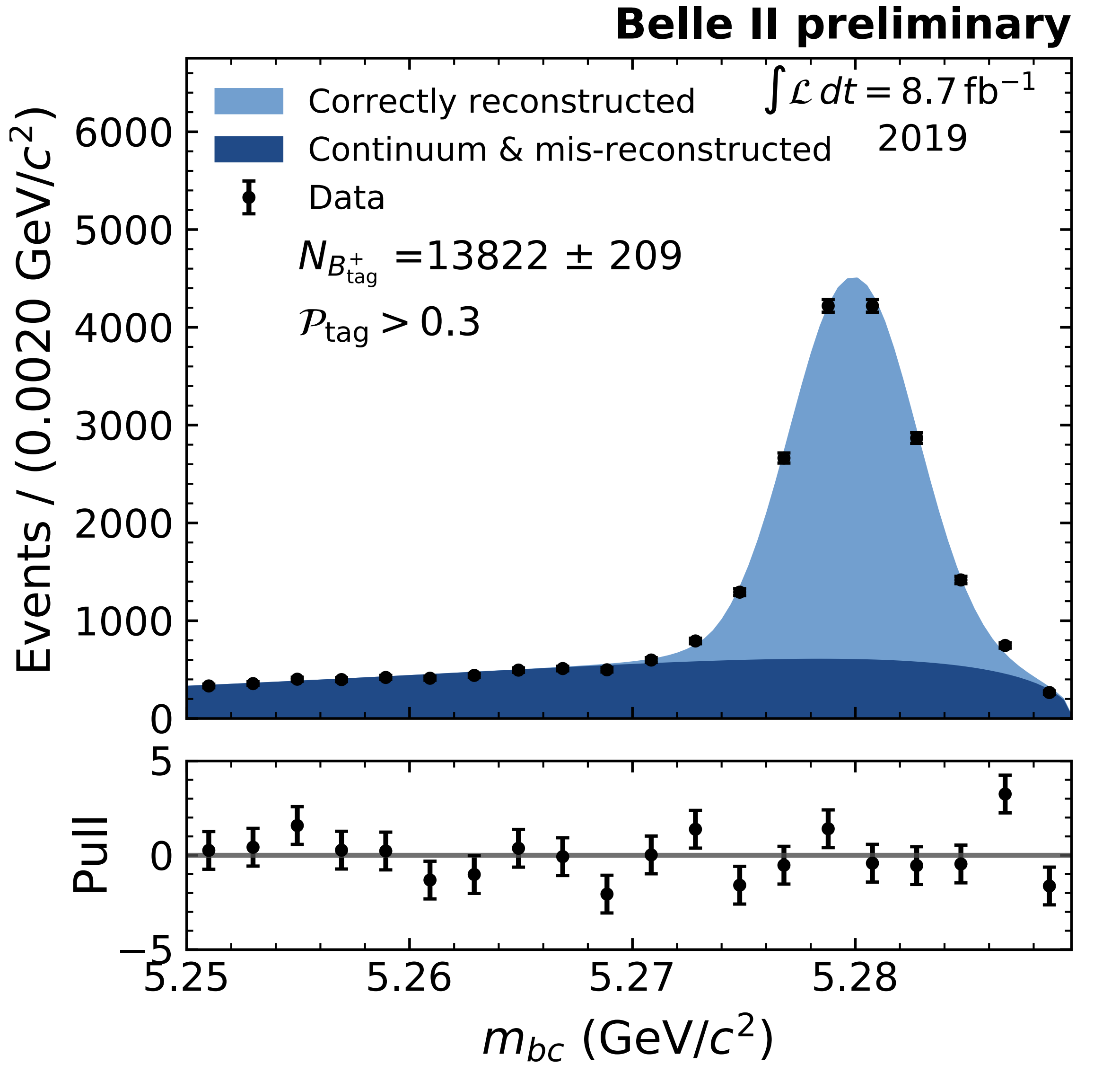
Talk by S. Stefkova

BELLE2-CONF-PL-2020-002

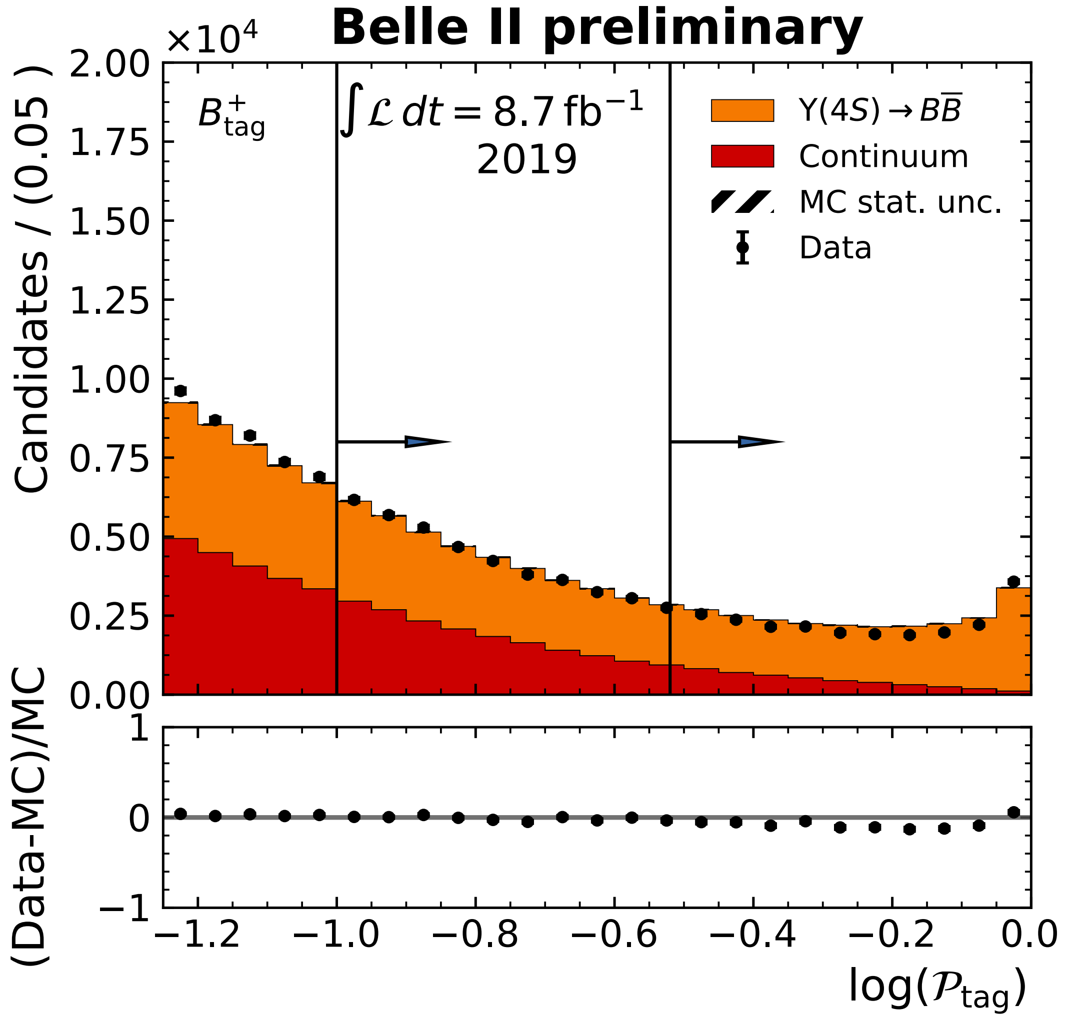
- Belle (II) analyses use semileptonic and hadronic "tagging" for flavour, charge, kinematics.

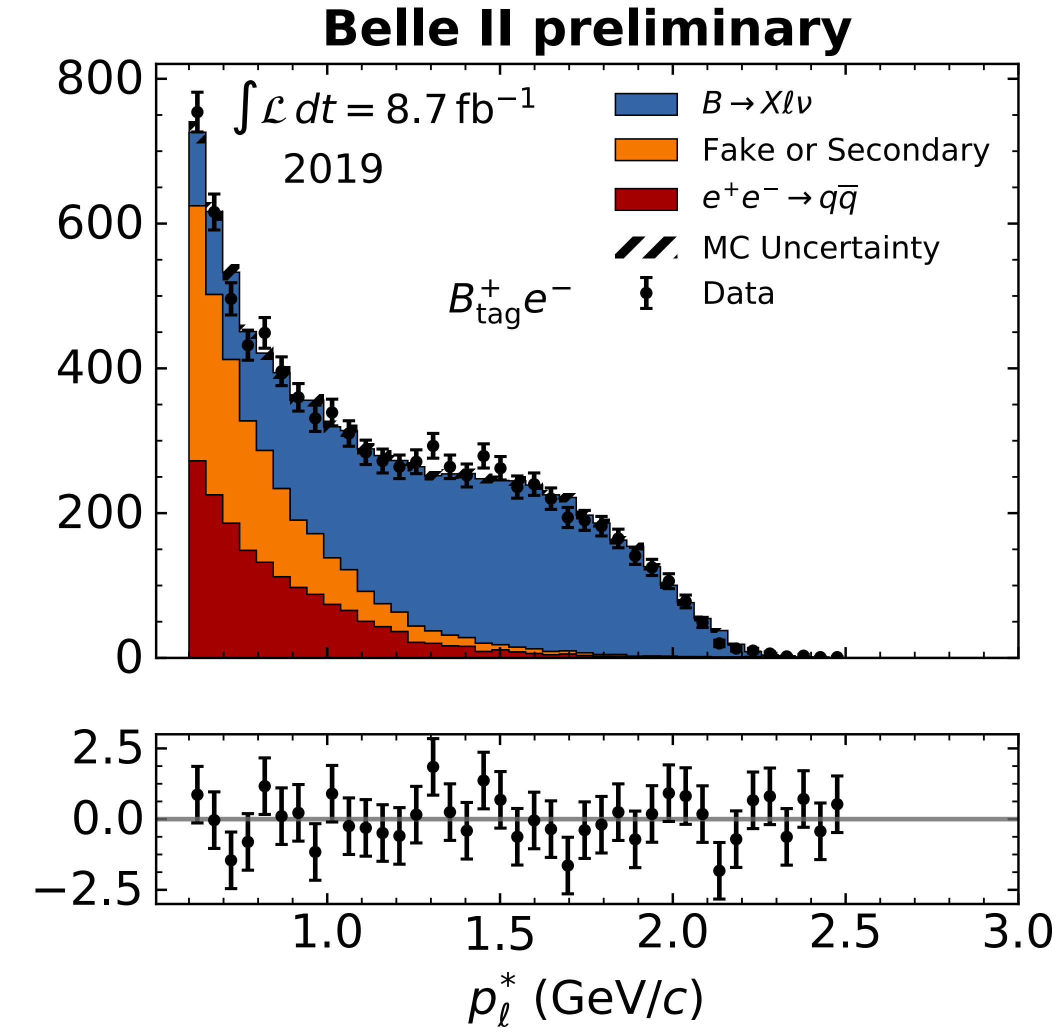






MC tag-side efficiency @10% purity	Had. B^+/B^0 [%]	SL. B^+/B^0 [%]
Full Reconstruction Belle	0.28/0.18	0.67/0.63
FEI Belle	0.76/0.46	1.80/2.04
N of correct B_{tag} per 1 fb^{-1} in Belle (FEI)	8350/5060	19800/22440



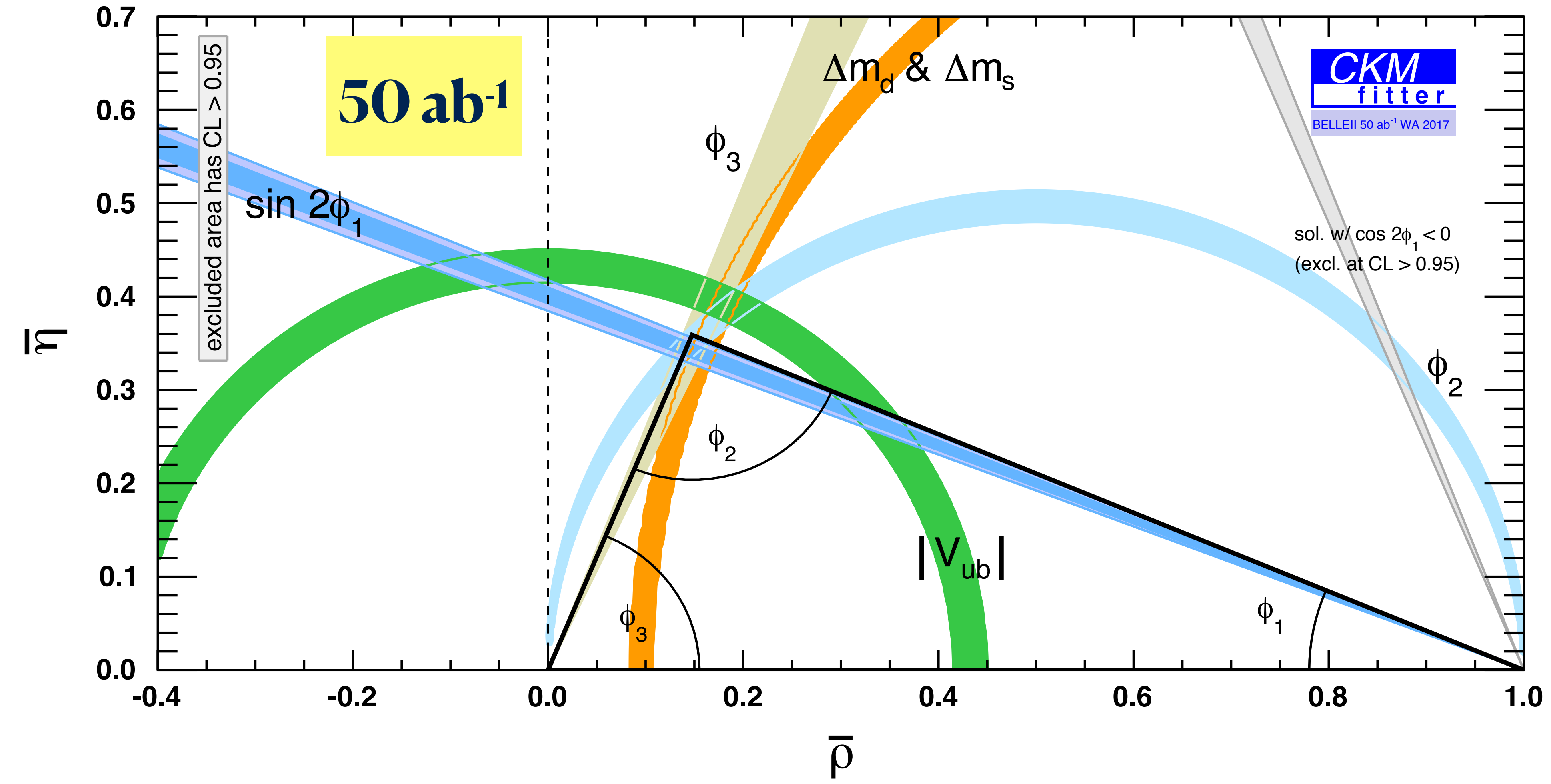


650k Hadronic B-tags for physics analysis already (50 fb^{-1})!

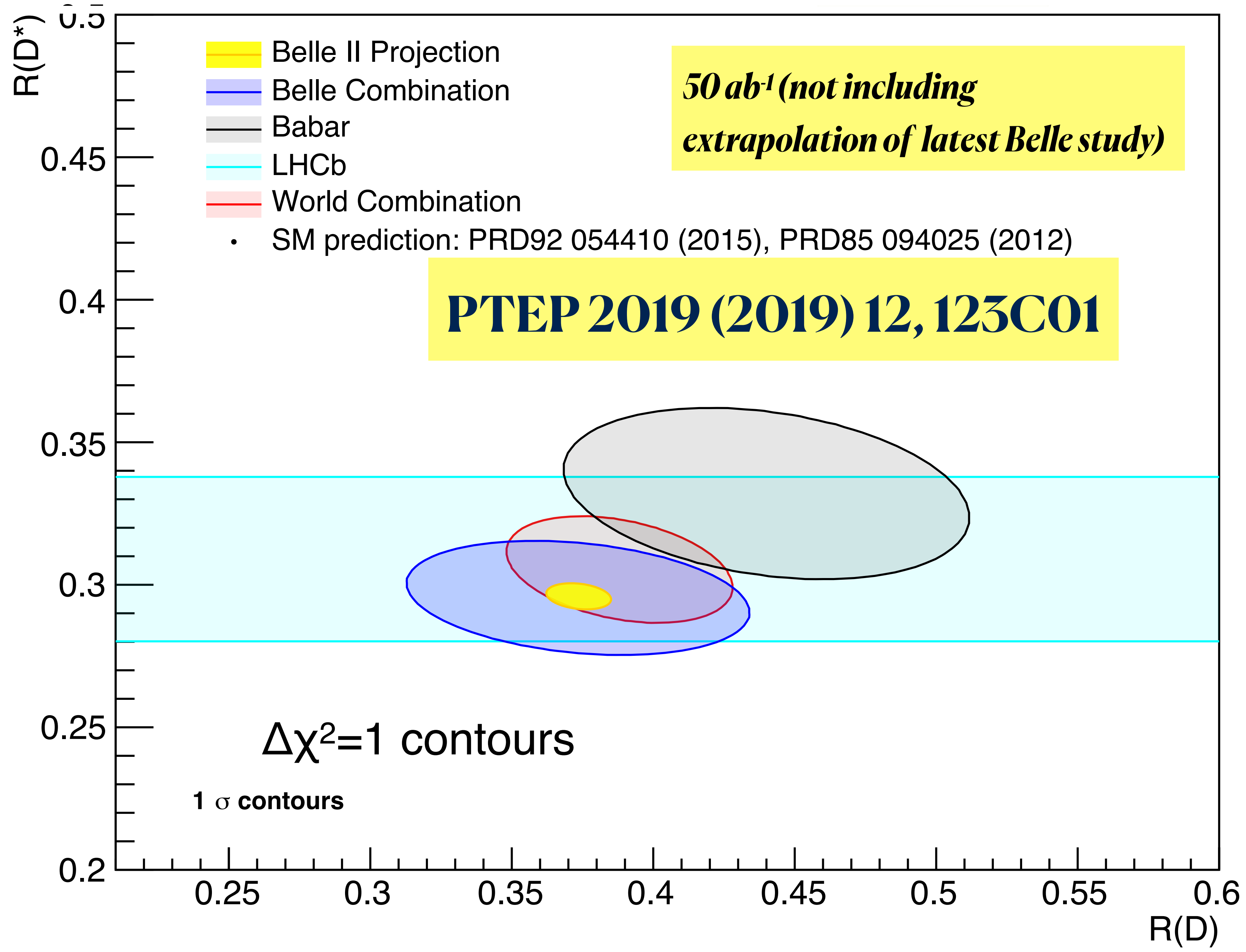
- Enough for tagged measurements of many modes.

Semileptonic and leptonic B decays / Targets

- History of anomalies in $|V_{ub}|$, $|V_{cb}|$, $B \to D^{(*)} \tau \nu$ — key to identify bias.
    - CKM precision tests are challenging, but more data will help overcome over most systematic errors.
    - Improvements to K_L reconstruction, beam background mitigation for ΣE_{ECL}, $B \to D^{**} l \nu$ background, tag efficiency, tag calibration.
    - Purely leptonic modes are a Belle II focus for > 1 ab^{-1}.



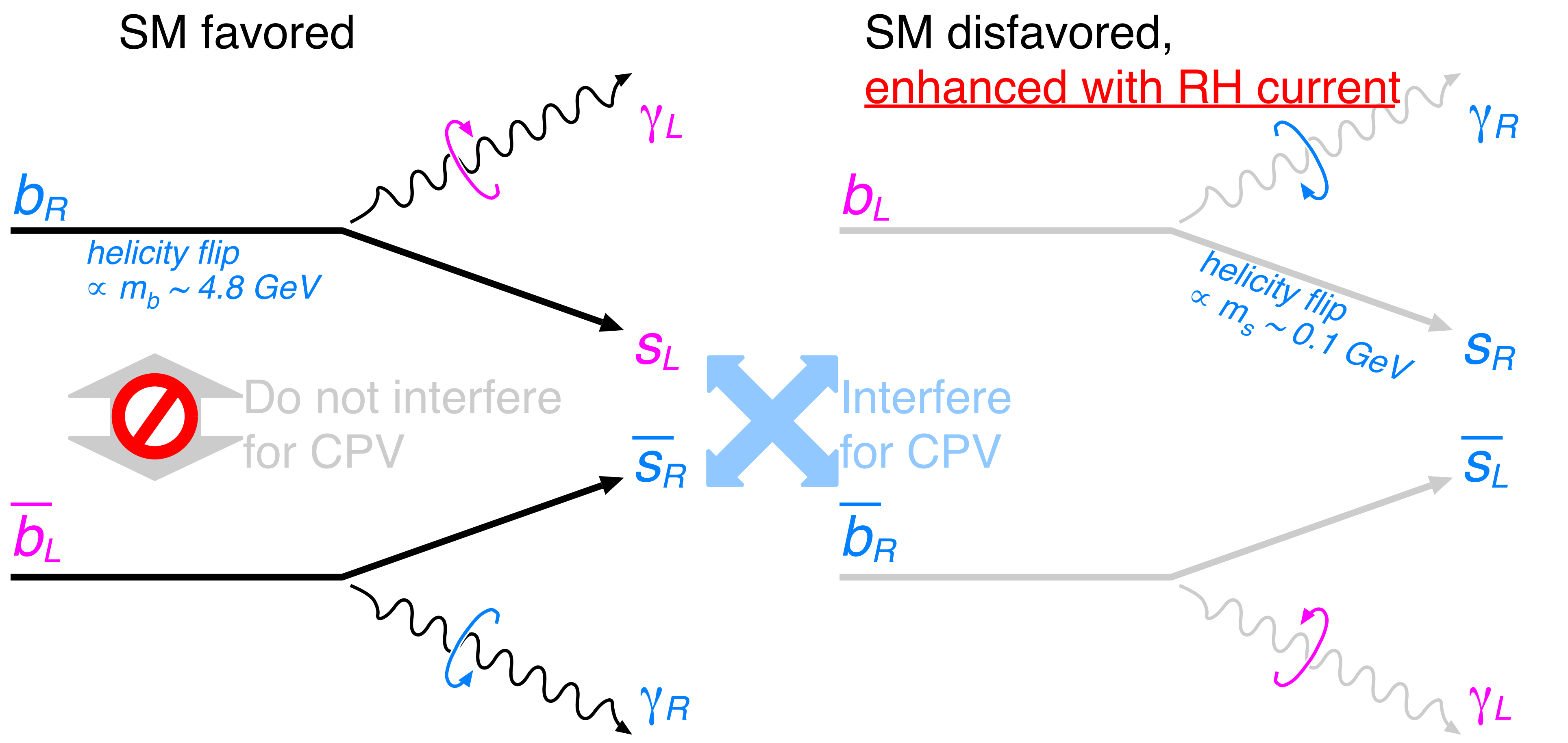
Observables	Belle (2017)	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
✸ $\lvert V_{cb}\rvert$ incl.	$42.2 \cdot 10^{-3} \cdot (1 \pm 1.8\%)$	1.2%	—
✸ $\lvert V_{cb}\rvert$ excl.	$39.0 \cdot 10^{-3} \cdot (1 \pm 3.0\%_{\rm ex.} \pm 1.4\%_{\rm th.})$	1.8%	1.4%
✸ $\lvert V_{ub}\rvert$ incl.	$4.47 \cdot 10^{-3} \cdot (1 \pm 6.0\%_{\rm ex.} \pm 2.5\%_{\rm th.})$	3.4%	3.0%
✸ $\lvert V_{ub}\rvert$ excl. (WA)	$3.65 \cdot 10^{-3} \cdot (1 \pm 2.5\%_{\rm ex.} \pm 3.0\%_{\rm th.})$	2.4%	1.2%
$\mathcal{B}(B \to \tau\nu)$ $[10^{-6}]$	$91 \cdot (1 \pm 24\%)$	9%	4%
$\mathcal{B}(B \to \mu\nu)$ $[10^{-6}]$	< 1.7	20%	7%
$R(B \to D\tau\nu)$ (Had. tag)	$0.374 \cdot (1 \pm 16.5\%)$	6%	3%
✸ $R(B \to D^*\tau\nu)$ (Had. tag)	$0.296 \cdot (1 \pm 7.4\%)$	3%	2%



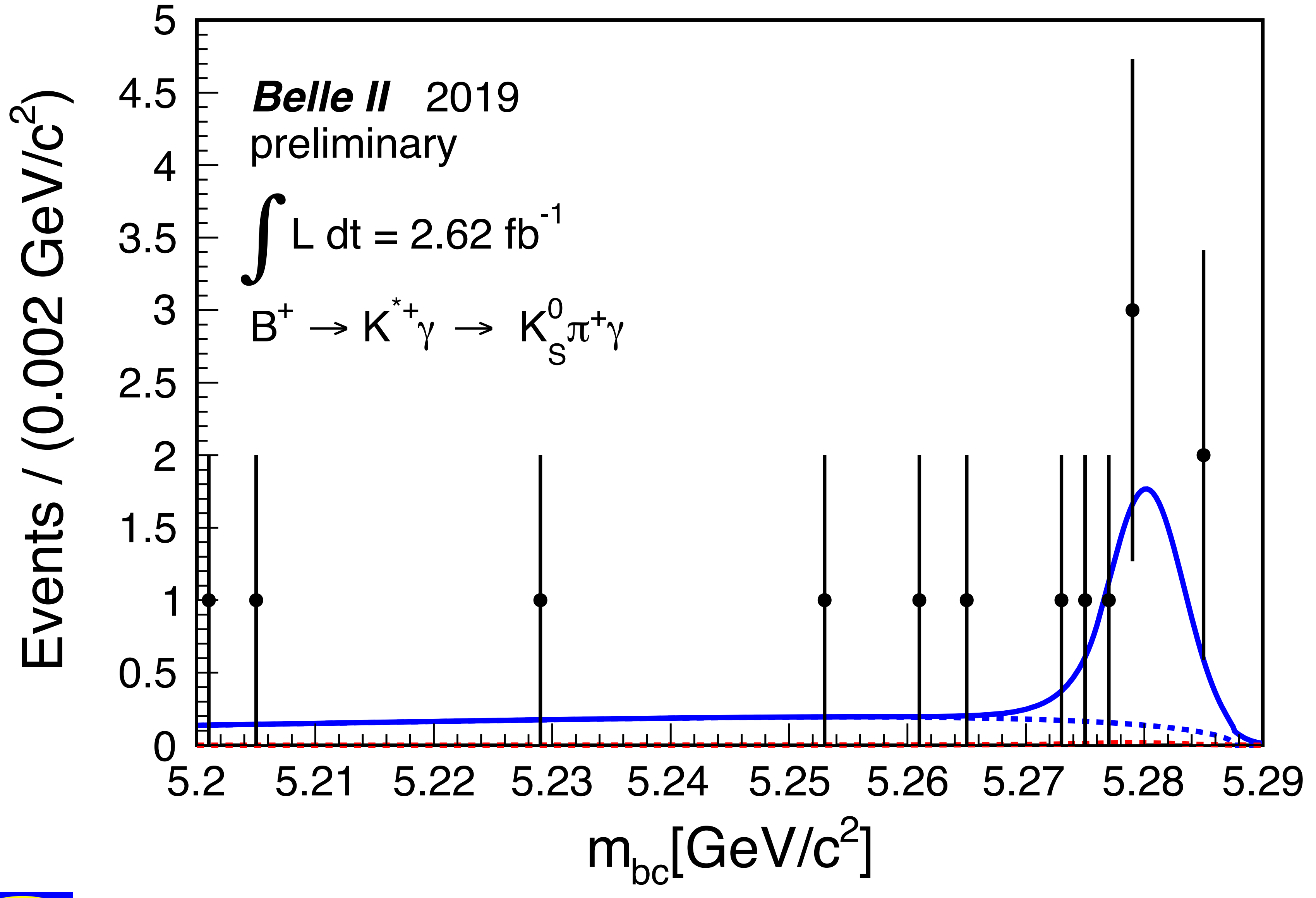
b→s γ Reconstruction

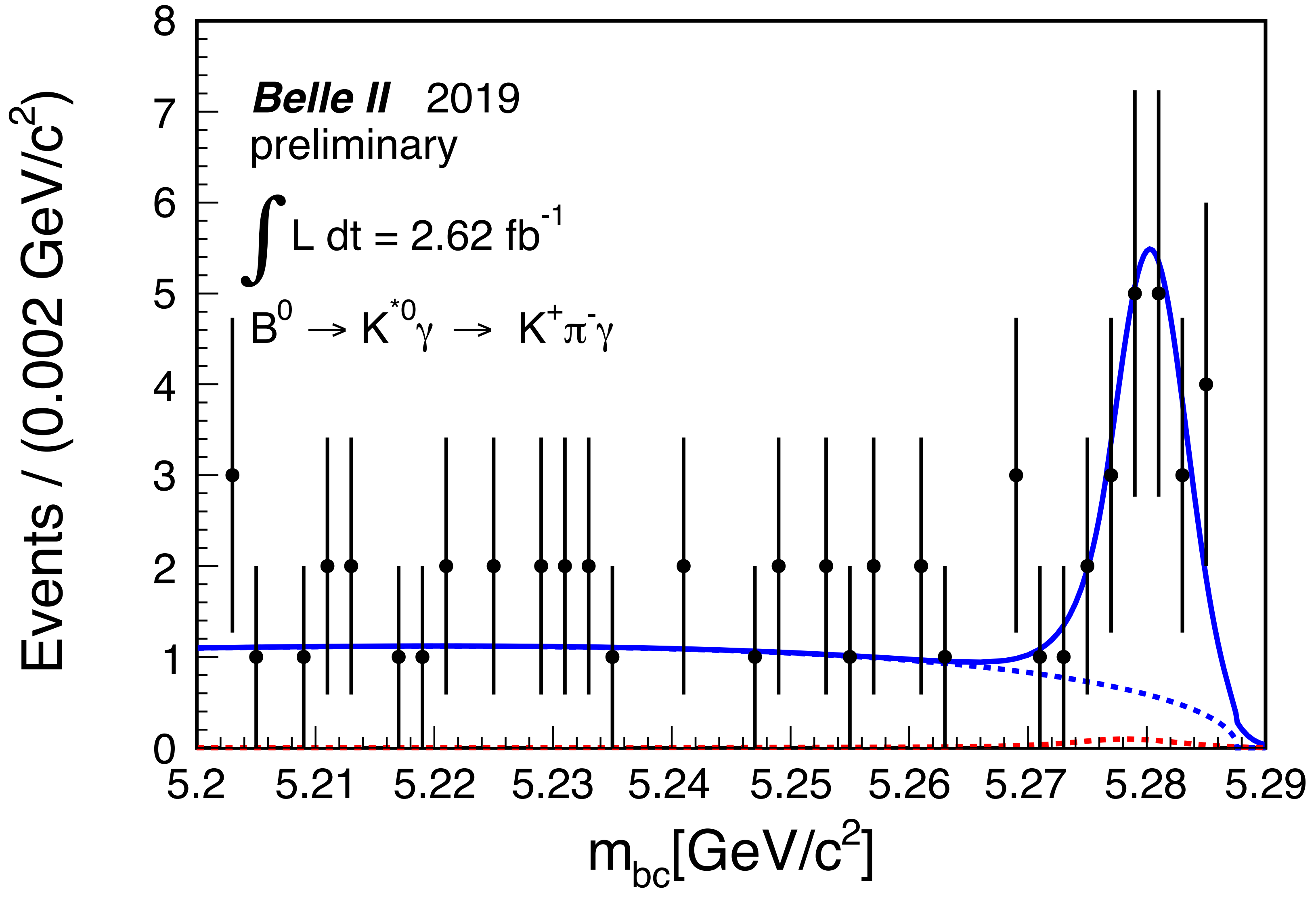
Talk by S. Halder

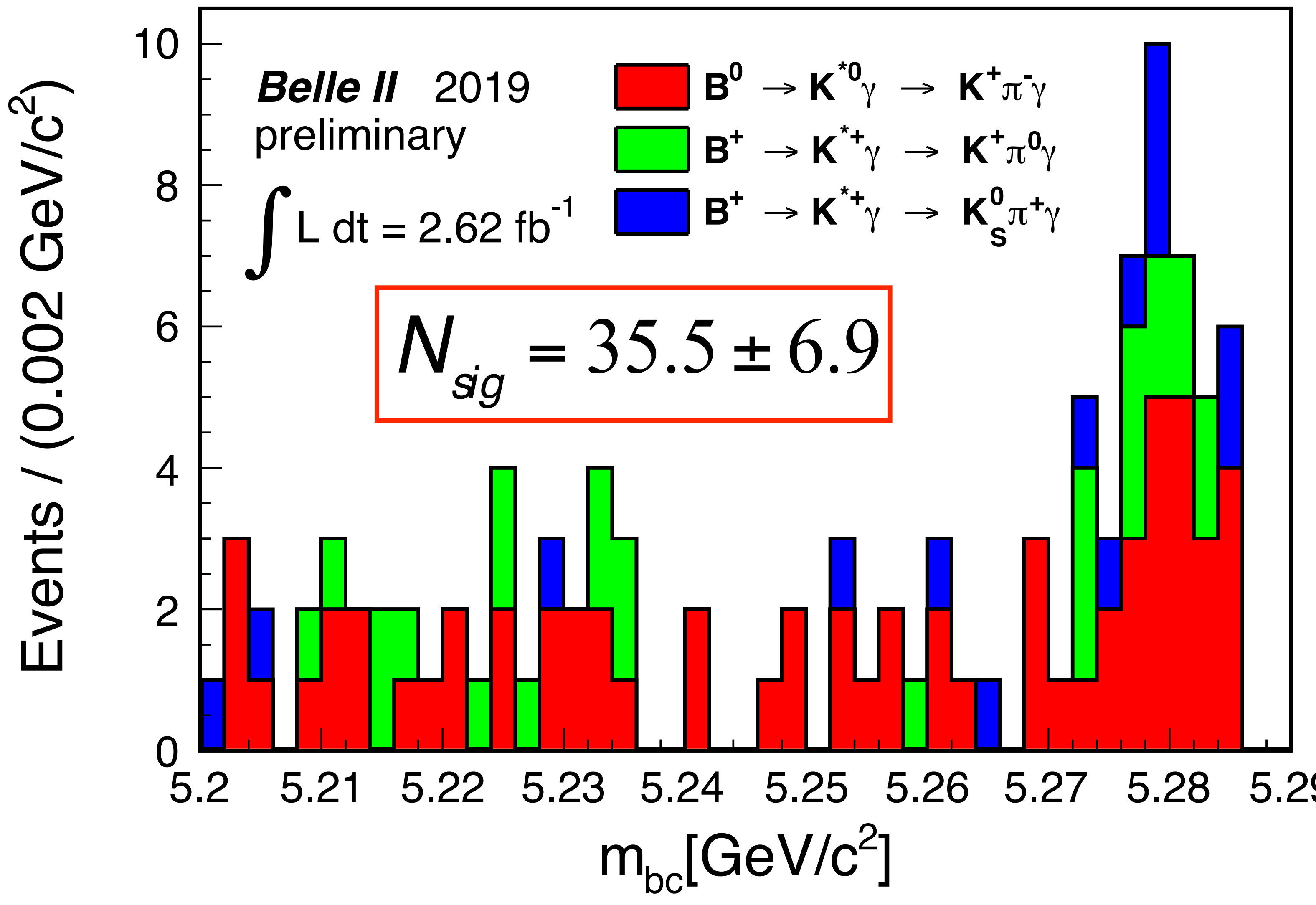
- Large program of radiative decays CP violation - New sources of CP violation in B→K*γ, ργ could reveal right handed currents.
  - B→$K_S\pi^0$ γ is a near term target for TDCPV analysis.
  - *b→d currents not well explored yet.*
- Reconstructed yields (2.6 fb^{-1}) consistent with WA branching fraction.



	signal yield ((stat. error only))	significance
$B^0 \to K^{*0}[K^+\pi^-]\gamma$	19.1 ± 5.2	4.4σ
$B^+ \to K^{*+}[K^+\pi^0]\gamma$	9.8 ± 3.4	3.7σ
$B^+ \to K^{*+}[K^0_s\pi^+]\gamma$	6.6 ± 3.1	2.1σ



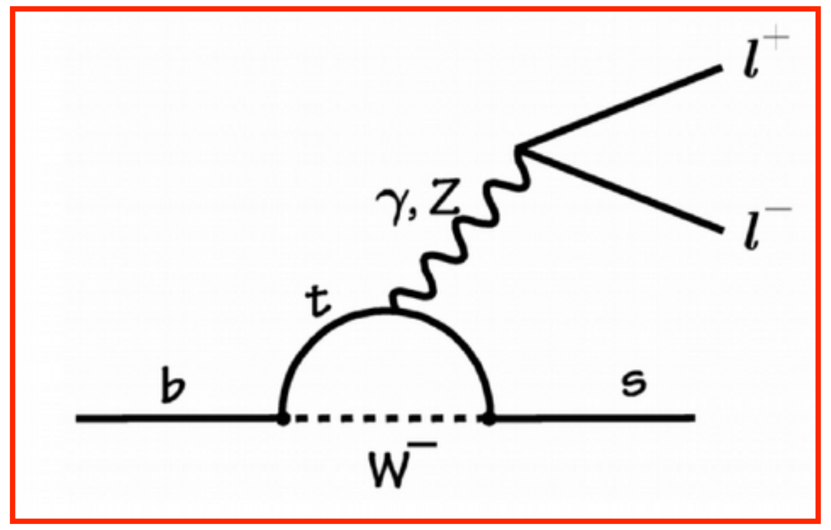


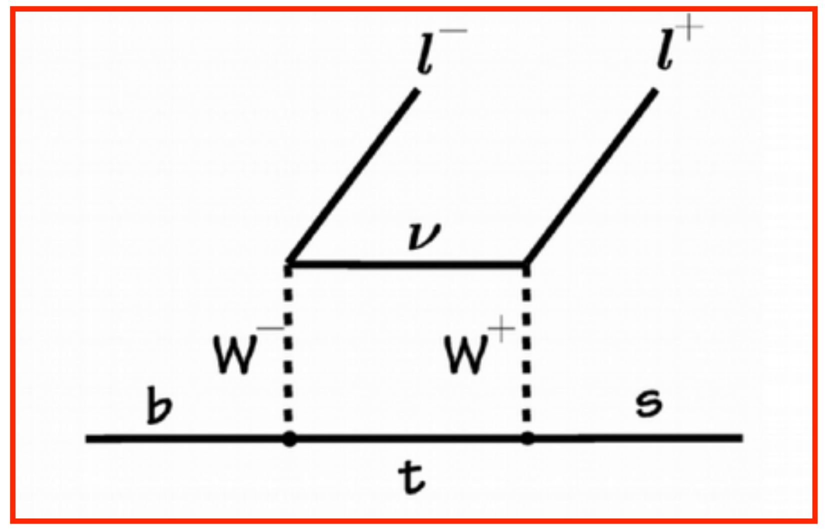


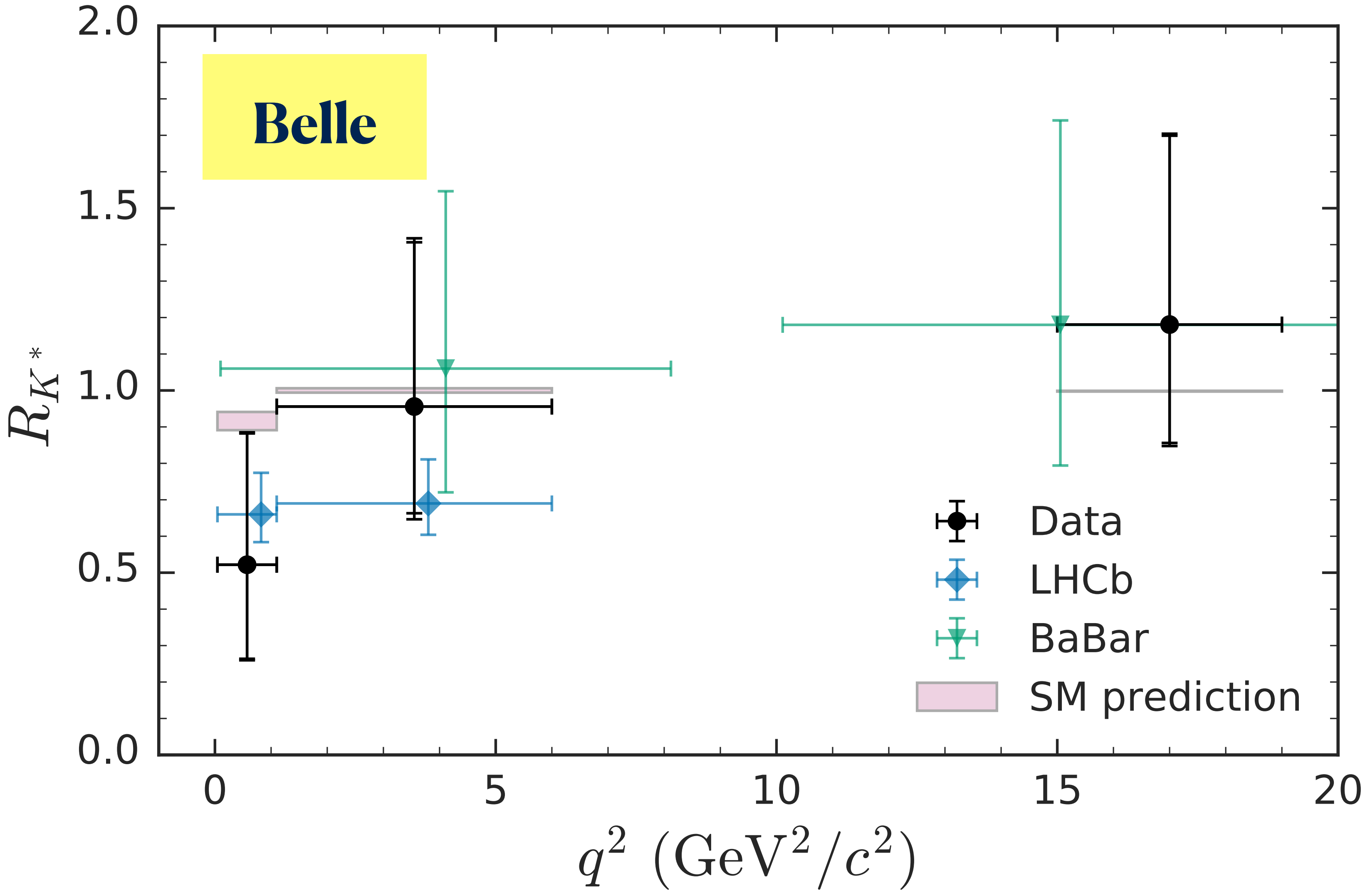
EW penguin B decay prospects

Talk by S. Halder

- Belle II should refute/confirm deviations observed by LHCb within 4 years. Expect first signals by ICHEP.
  - Electron channels (low X/X_0) good resolution & τ channels
  - Inclusive $B \to X l^+ l^-$ (initially sum over exclusives with $M(X_s) < 1.8$ GeV/c^2, eventually: explore fully inclusive recoil).

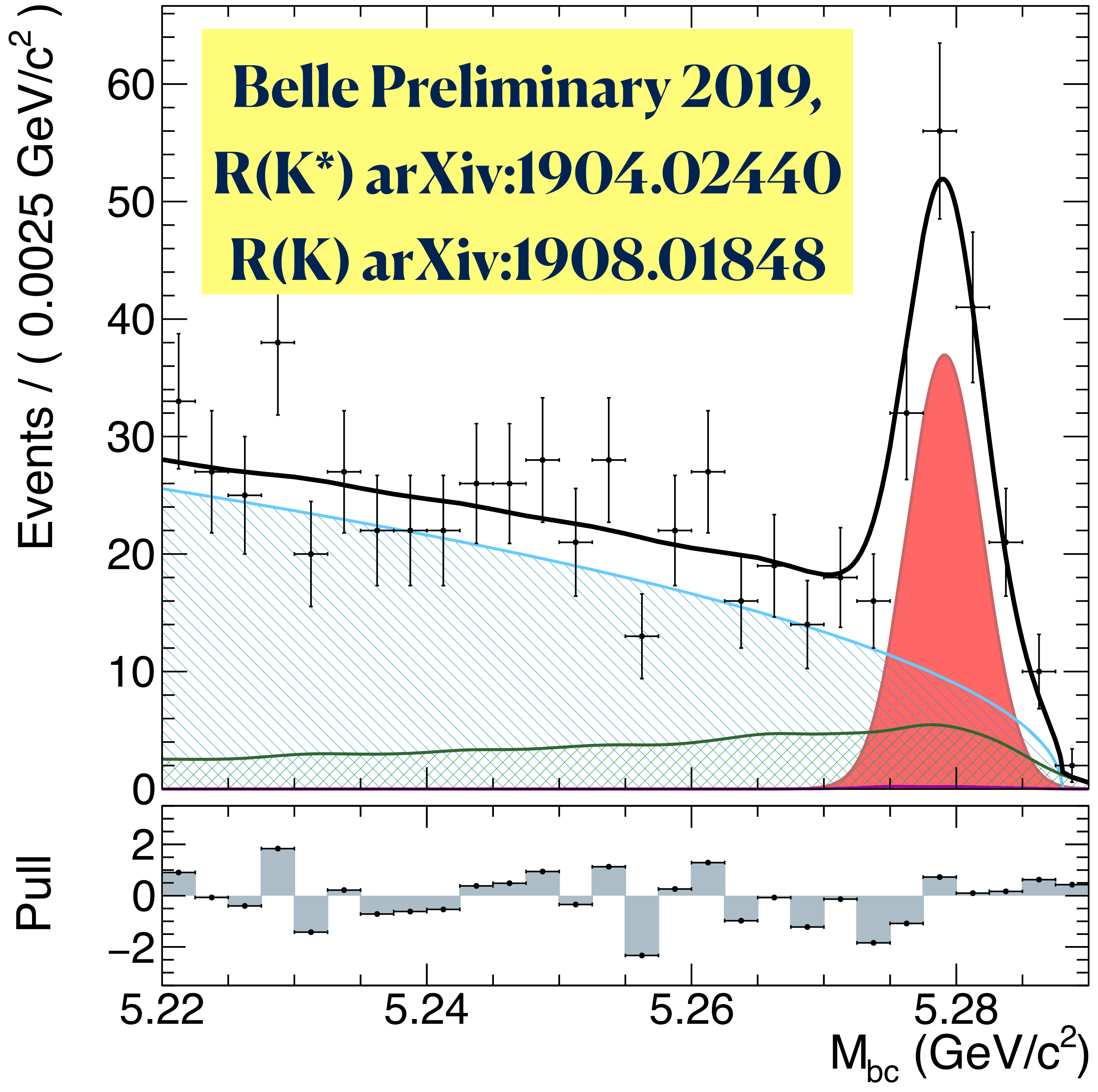


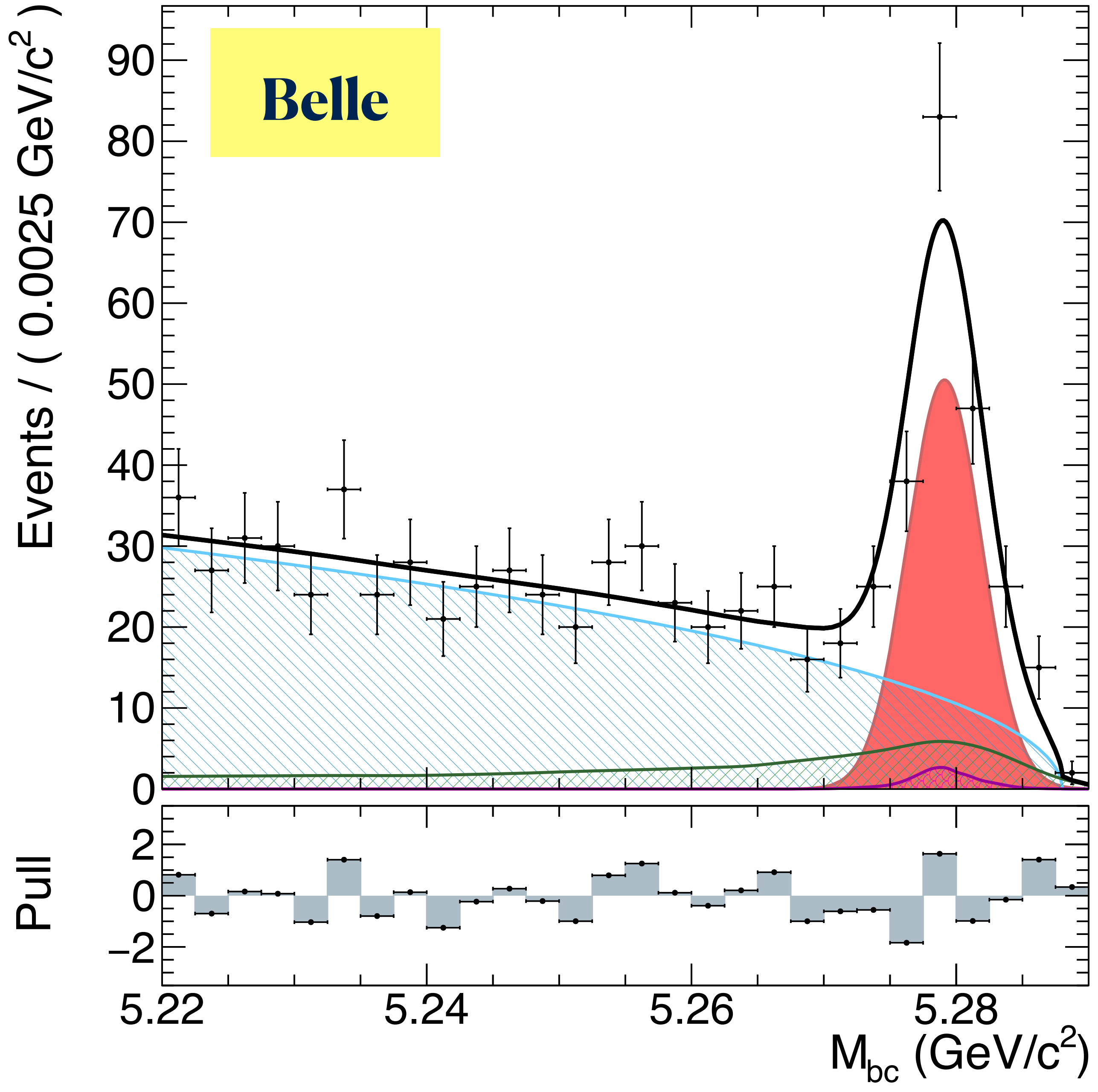


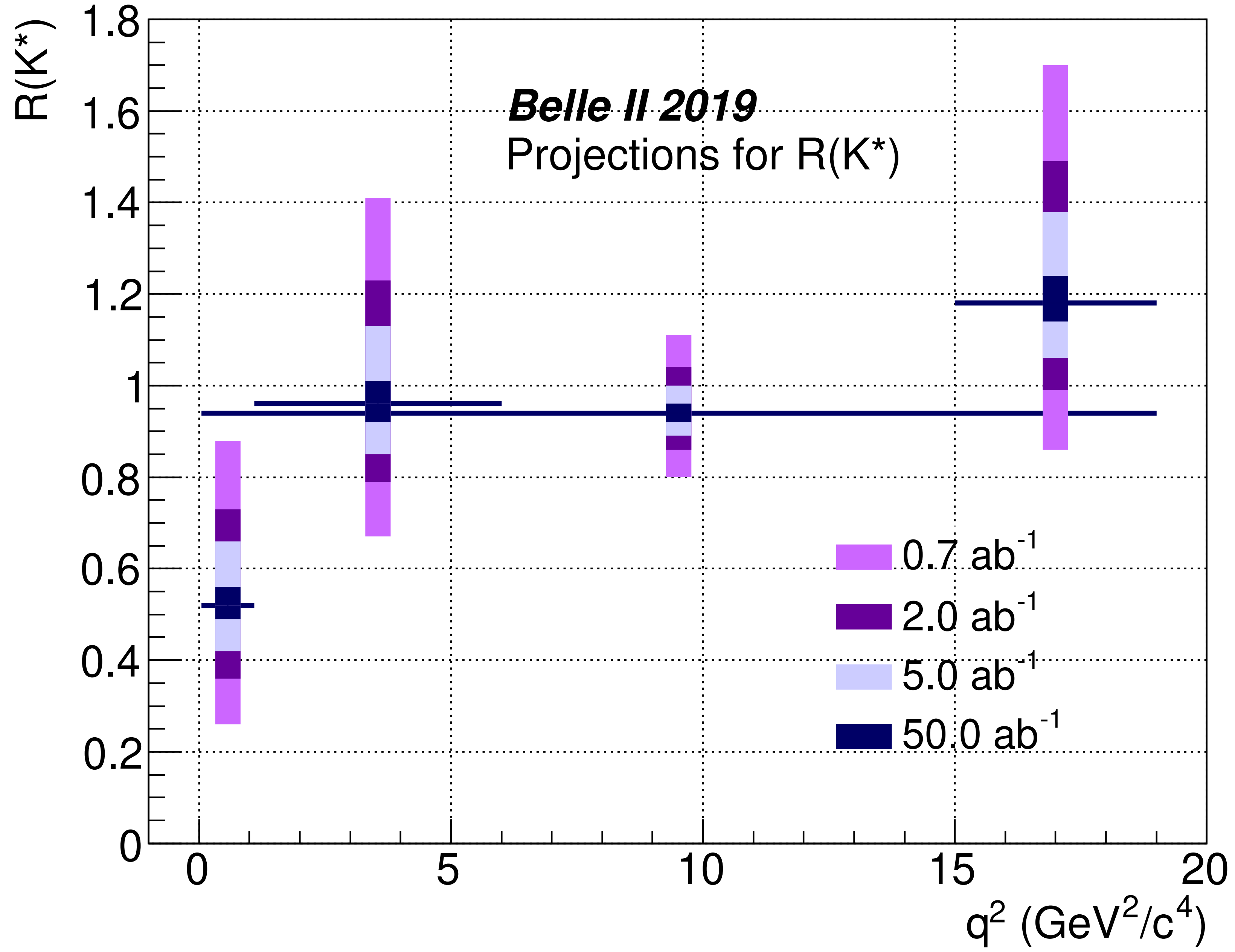


Expect to see first clear signals in data collected to date!

Rare: e.g. $BR(B^0 \to K^{*0} l^+ l^-) = (9.9 \pm 1.2) \times 10^{-7}$



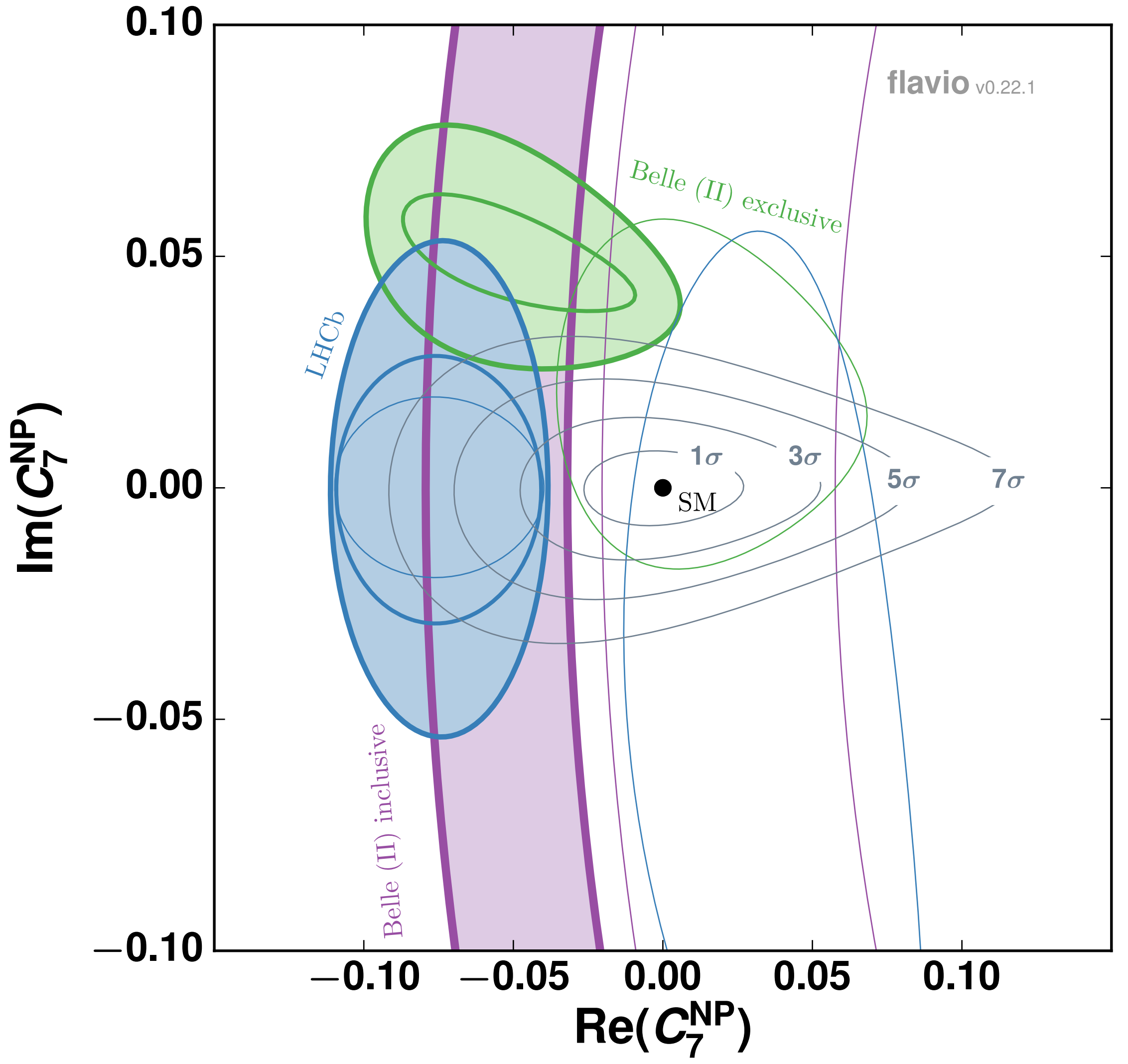


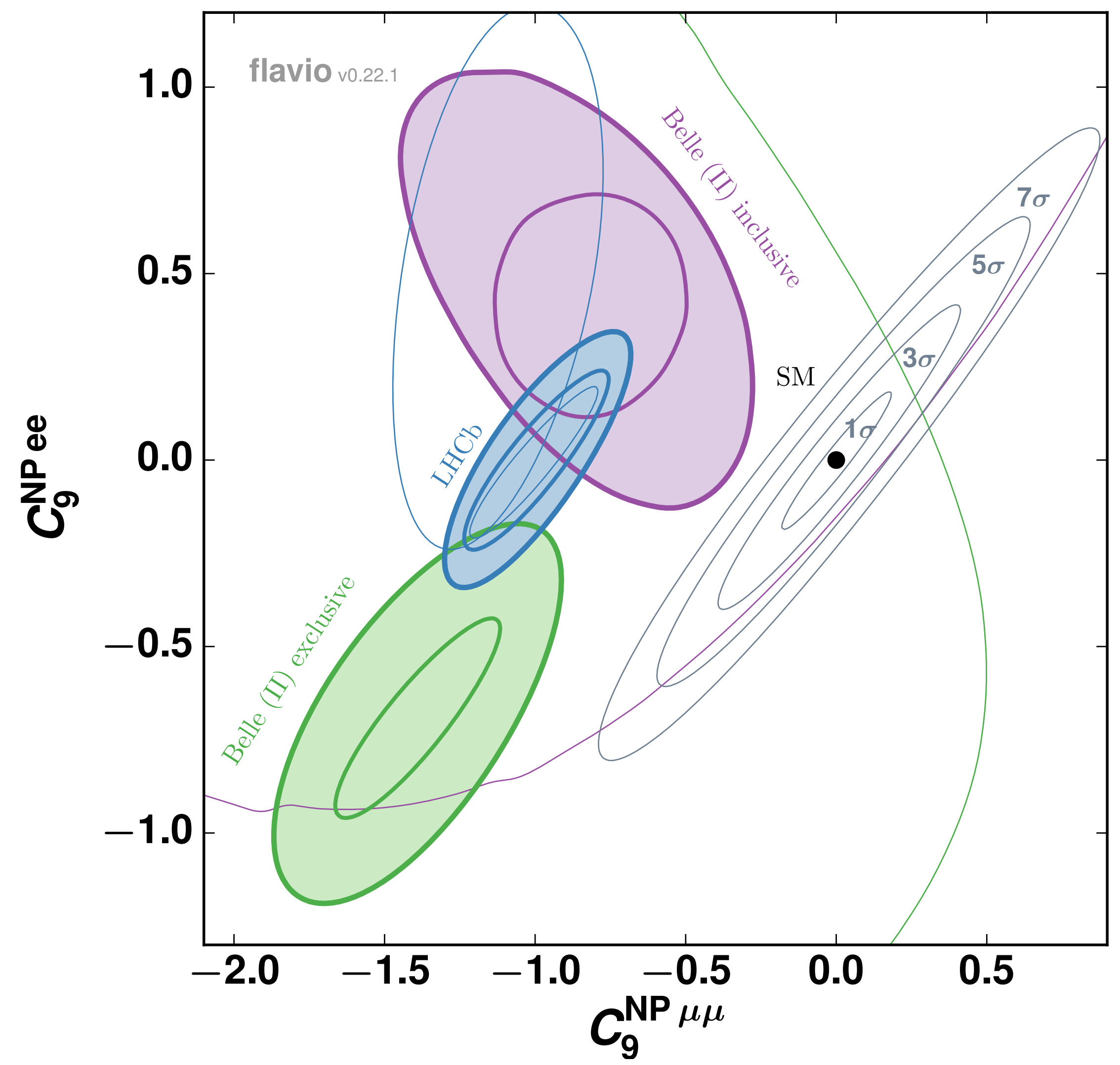


Radiative and EW penguin B decays / Targets

- Except for $B \to X_{s+d}\,\gamma$ inclusive, all channels are highly statistics limited.
  - Expect systematics to be subdominant beyond 50 ab^{-1}
  - Key to understand beam **background induced efficiency loss and E_{ECL} degradation** in $B \to K\nu\nu$.
- SM level (5 σ)in $B \to X\nu\nu$. Novel ALPs/Scalars/LLPs searches in B decays.

$$\mathcal{H}_{\text{eff}} = -\frac{4\,G_F}{\sqrt{2}} V_{tb} V_{ts}^{*} \frac{e^2}{16\pi^2} \sum_i (C_i O_i + C_i' O_i') + \text{h.c.}$$

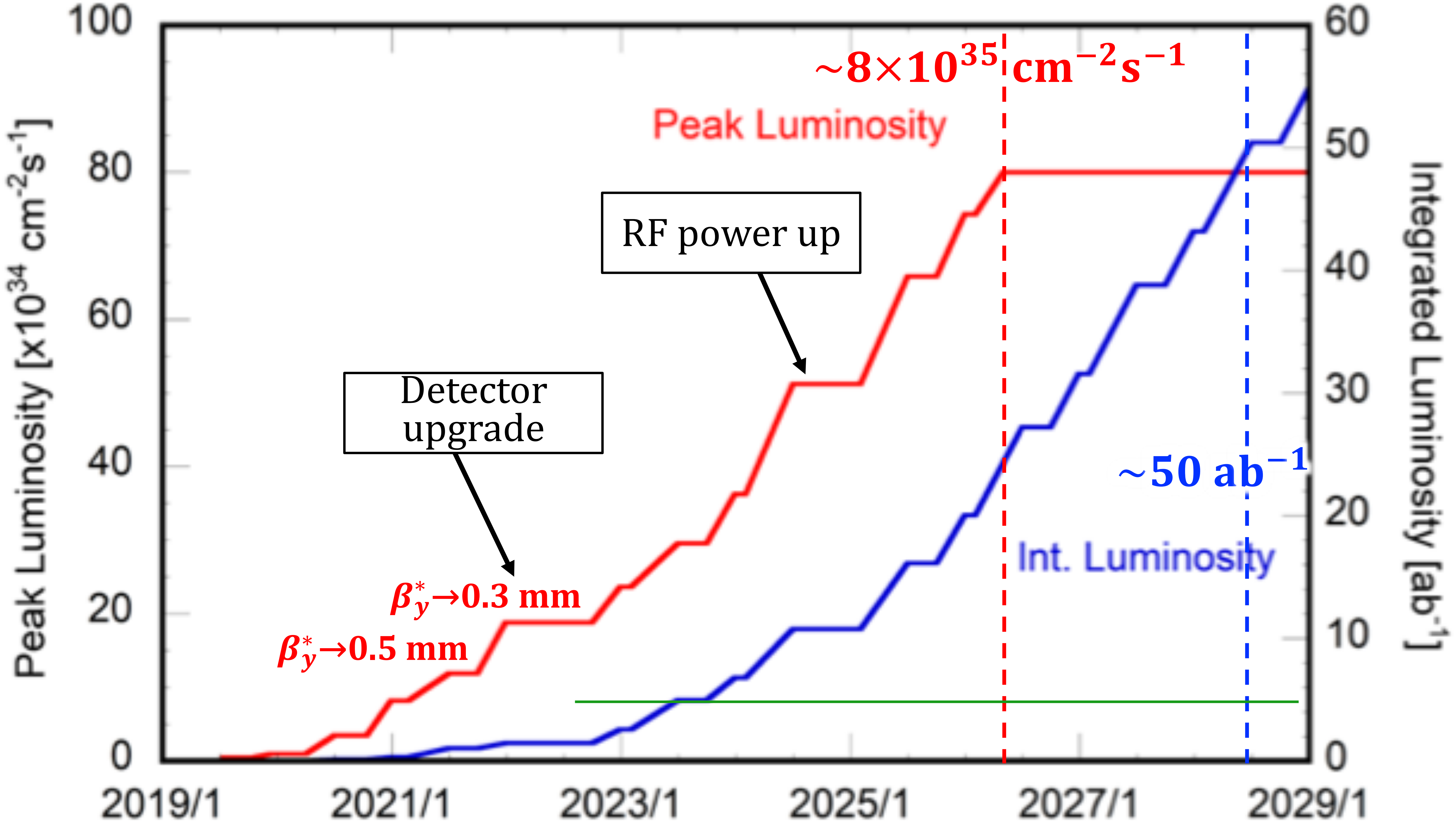




PTEP 2019 (2019) 12, 123C01

Observables	Belle (2017)	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
$\mathcal{B}(B \to K^{*+}\nu\bar{\nu})$	$< 40 \times 10^{-6}$	25%	9%
$\mathcal{B}(B \to K^{+}\nu\bar{\nu})$	$< 19 \times 10^{-6}$	30%	11%
✷ $A_{CP}(B \to X_{s+d}\gamma)$ $[10^{-2}]$	$2.2 \pm 4.0 \pm 0.8$	1.5	0.5
✷ $S(B \to K_S^0\pi^0\gamma)$	$-0.10 \pm 0.31 \pm 0.07$	0.11	0.035
✷ $S(B \to \rho\gamma)$	$-0.83 \pm 0.65 \pm 0.18$	0.23	0.07
✷ $A_{FB}(B \to X_s\ell^+\ell^-)$ $(1 < q^2 < 3.5\ \text{GeV}^2/c^4)$	26%	10%	3%
✷ $Br(B \to K^+\mu^+\mu^-)/Br(B \to K^+e^+e^-)$ $(1 < q^2 < 6\ \text{GeV}^2/c^4)$	28%	11%	4%
✷ $Br(B \to K^{*+}(892)\mu^+\mu^-)/Br(B \to K^{*+}(892)e^+e^-)$ $(1 < q^2 < 6\ \text{GeV}^2/c^4)$	24%	9%	3%
$\mathcal{B}(B_s \to \gamma\gamma)$	$< 8.7 \times 10^{-6}$	23%	–
$\mathcal{B}(B_s \to \tau\tau)$ $[10^{-3}]$	–	< 0.8	–

Expected (Integrated) Luminosity



2021	Integrated luminosity > 0.5 – 1.0 ab^{-1}
2022	β^*_y to reach 0.3 mm (design value)
2023	Integrated luminosity 5 ab^{-1}
2026	Peak luminosity to reach ~8 x 10^{35} $cm^{-2}s^{-1}$ (design value)
2028	Integrated luminosity 50 ab^{-1}

Belle II - LHCb Comparison

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							
ΔA_{CP}(KK-ππ)	–	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($\tau \to \mu\mu\mu$)	$<21\times10^{-9}$	$<46\times10^{-9}$	$<3\times10^{-9}$	$<3\times10^{-9}$	$<16\times10^{-9}$	$<0.3\times10^{-9}$	$<5\times10^{-9}$

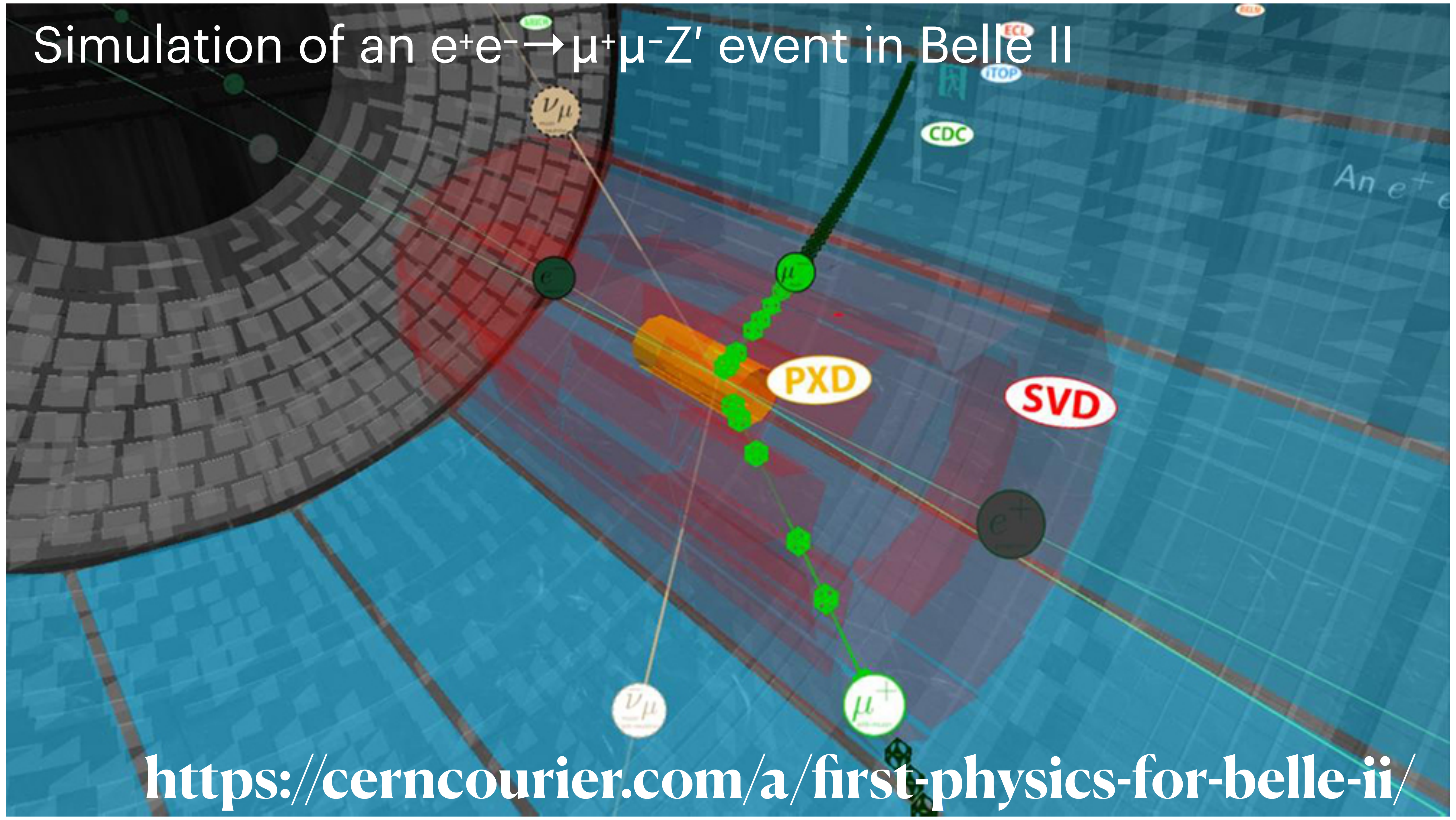
Results on other D & τ modes expected

○ *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)

Conclusion

- **60 fb^{-1} collected** (much of it during Covid19 travel restrictions): x10 or more each year since commencing in 2018.
  - Enough to explore the power of Belle II with performance control channels, **and to start the flavour physics program in earnest.**
  - Presented selected highlights with up to 10 fb^{-1} with 2018+2019 data.
- **Dark sector publication on dark Z'**, with ALPs and dark photons to come soon.
- *First competitive flavour publications within reach.*



Belle II Presentations at FPCP

F. Abudinen, Belle II Highlights on first physics results
R. Briere, Charm and Charmonium at Belle II
S. Halder, Results and Prospects of Radiative and Electroweak Penguin Decays at Belle II
M. Merola, CKM first measurements at Belle II
S. Stefkova, Status and future development of the Full Event Interpretation algorithm at Belle II
M. H. Villanueva, Tau physics highlights and prospects at Belle II