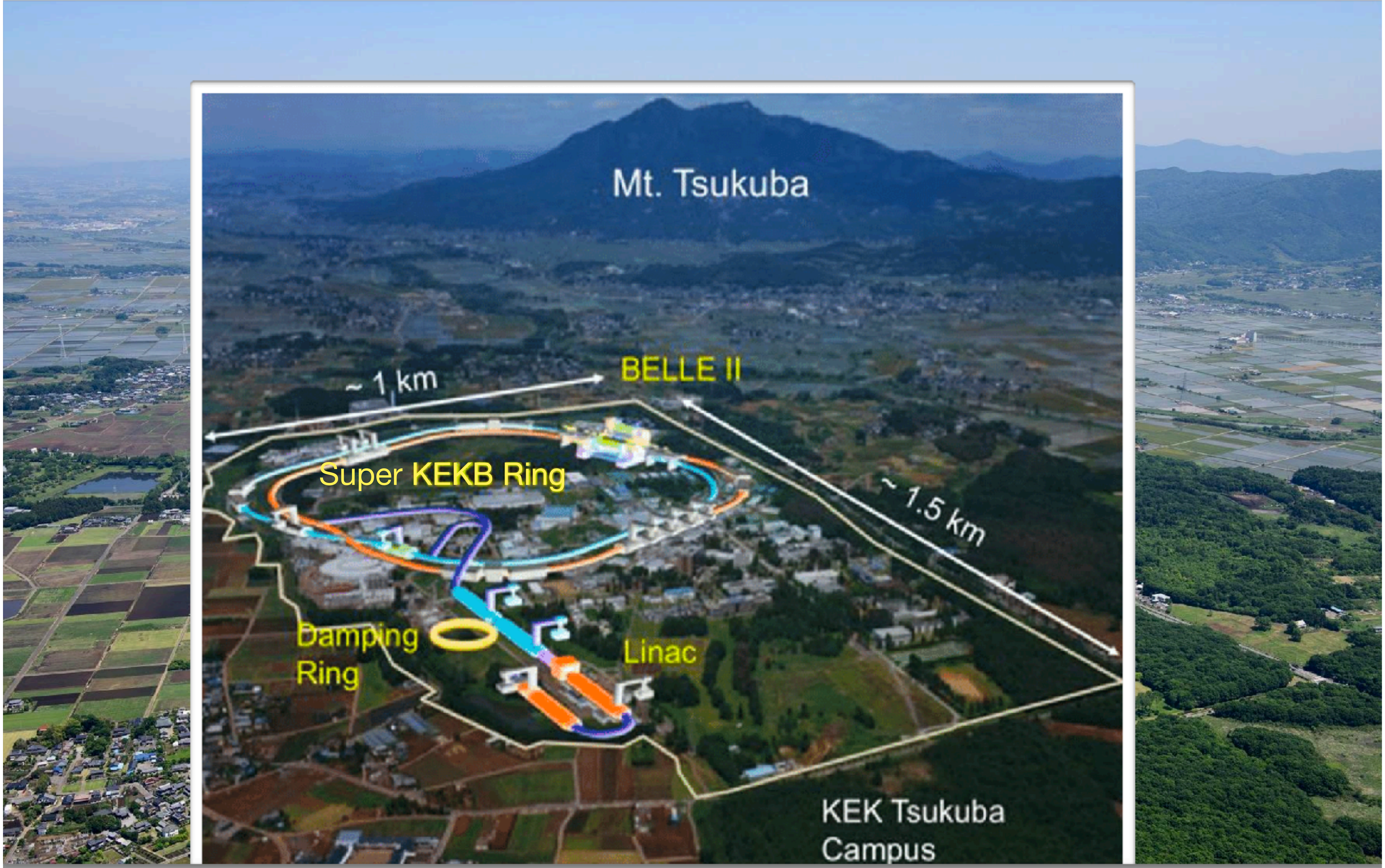
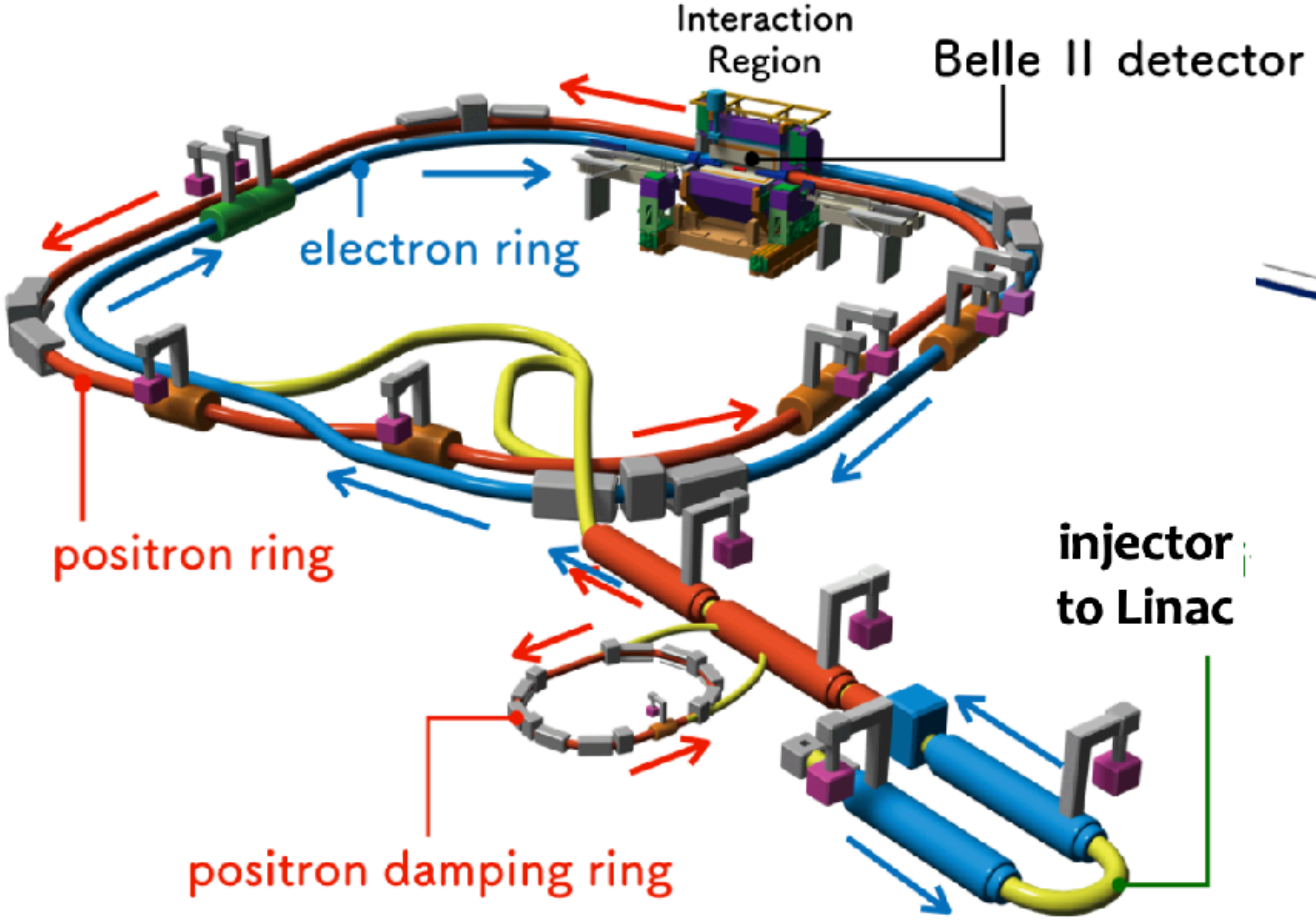
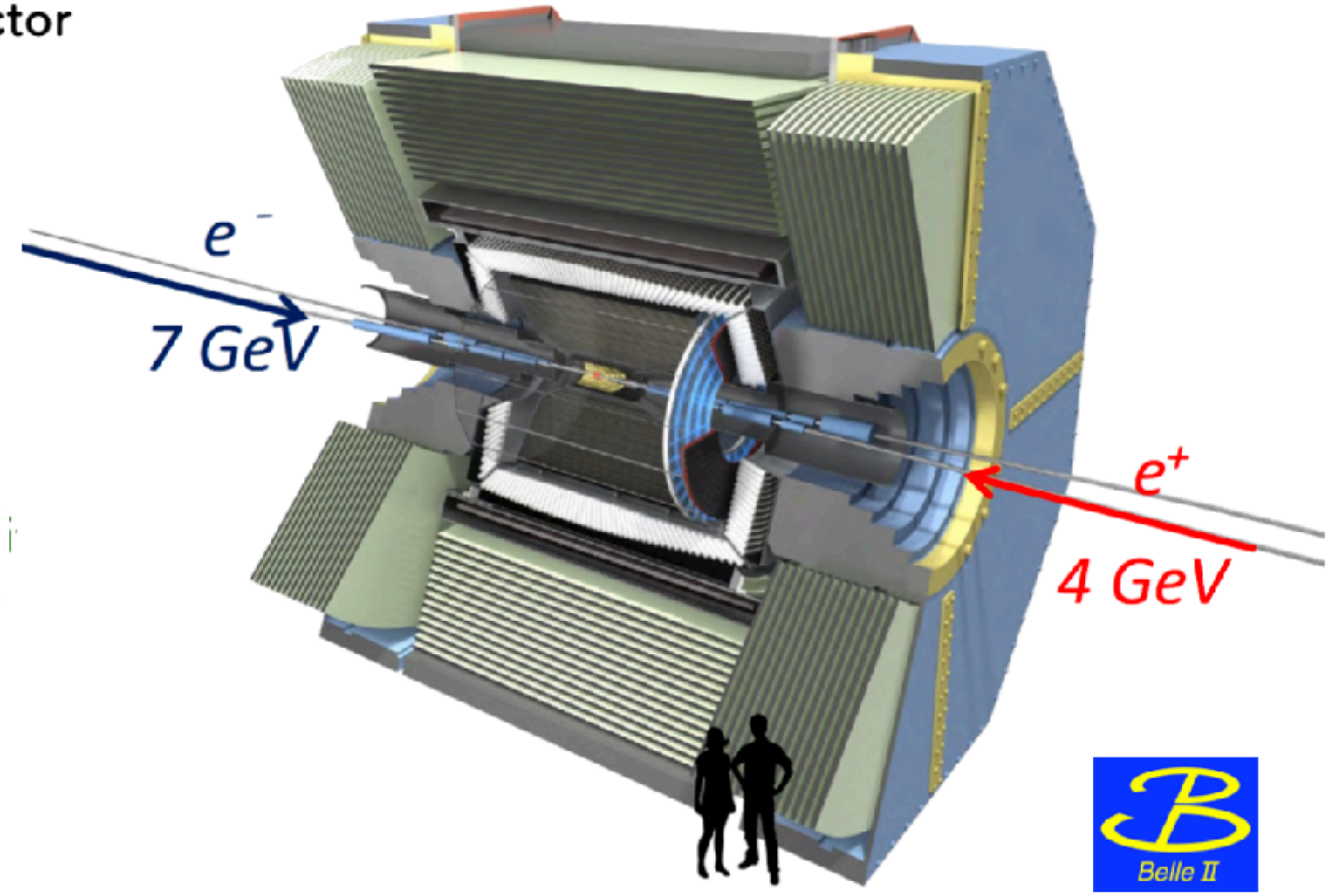
Recent results of Belle II

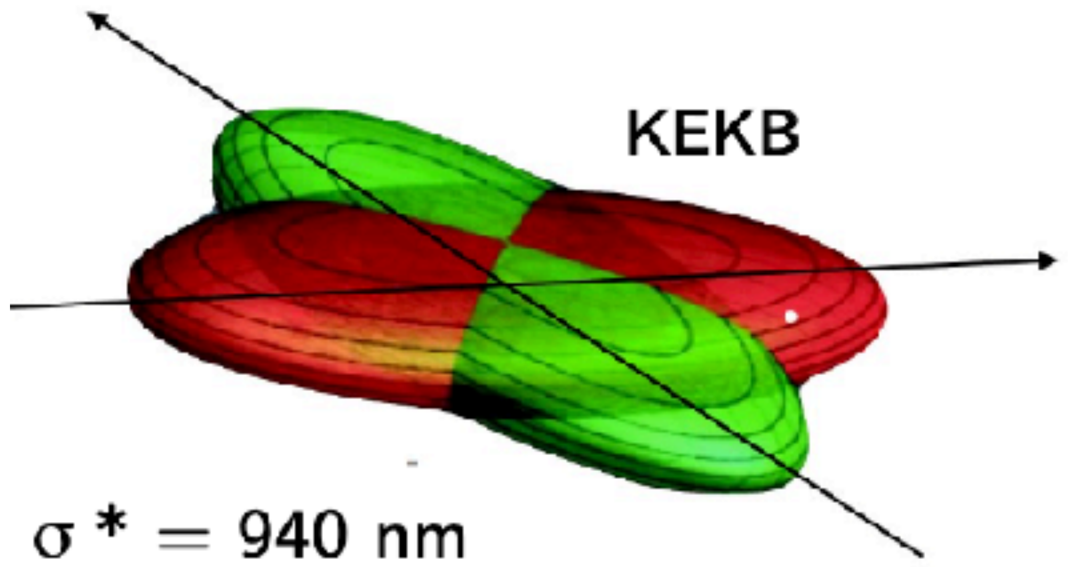
Speaker: Junhao Yin[1] (on behalf of Belle II collaborations)
[1] Korea University


Mt. Tsukuba
~ 1 km
BELLE II
Super KEKB Ring
~ 1.5 km
Damping Ring
Linac
KEK Tsukuba Campus

SuperKEKB $e^- \xrightarrow{7\text{ GeV}} (\star) \xleftarrow{4\text{ GeV}} e^+$ Belle II



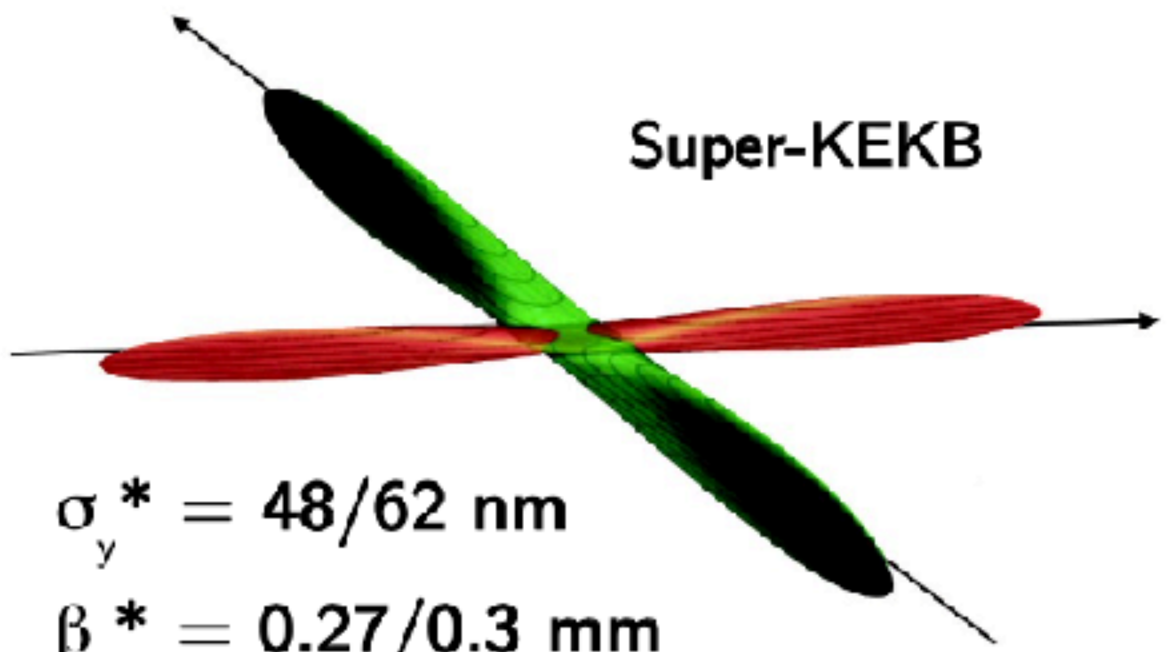




$\sigma_y^* = 940$ nm

$\beta_y^* = 5.9$ mm

$\sigma_x^* = 147/170$ μm



$\sigma_y^* = 48/62$ nm

$\beta_y^* = 0.27/0.3$ mm

$\sigma_x^* = 10.1/10.7$ μm

$$\mathcal{L}_{\rm II}^{\rm peak} \approx 30 \times \mathcal{L}_{\rm I}^{\rm peak}$$

$$\int^{\rm goal} \mathcal{L}_{\rm II}\, dt = 50\ {\rm ab}^{-1} \approx 50 \int \mathcal{L}_{\rm I}\, dt$$

Belle II Data
Upsilon(5S, 6S) runs
Bs physics
New hadron states Zb's, b bbar gluon
New Hadrons, QCD measurements
New Charmonium-Like States
New bottomonium-like states
New baryons
e+e- -->ISR, pi+ pi- cross-sections (g-2)
Spin Fragmentation Functions (-->EIC)
Linac energy upgrade
Dark Sector
Dark Photon
Axion-Like Particles (ALPs)
Invisible Z' s
Dark Higgs
Heavy tau neutrinos
LLPs (Long-Lived Particles)
Magnetic Monopoles
Gazelle (LLP search)
Tau Physics
Tau mass, lifetime
Tau Spectral Functions
Lepton Flavor Violation (LFV)
Tau Electric Dipole Moment (EDM), ...
Electroweak physics with e- polarization
sin^2 theta_W
A_LR (tau, mu, e+, b, c)
NC (Neutral Current) universality
improved tau LFV
Charm Physics
D-Dbar mixing and CPV
Charm Lifetimes
Branching Fractions, Dalitz analyses
c->u l+l-, Lepton flavor violation
Radiative charm decays
CKM Matrix Elements (Vcb, Vub)
Inclusive Measurements
Vtd/Vts from penguins
Exclusive measurements
B->D(*) tau nu, lepton universality
Time Dependent Measurements
alpha, beta, gamma
Direct T violation
New physics phases in b->s: B->phi Ks, B->eta' Ks
Rare B decays
Hadronic B Decays: B-->K pi, pi pi Direct CPV, isospin sum rules
B-->K* gamma and radiative penguins, B-->K(*) nu nubar
B-->V V: right-handed currents, triple products
Electroweak Penguins: b-->s l+l-, lepton universality, b-->s nu nubar
Hadronic b-->c decays
gamma determinations
New charmed resonances

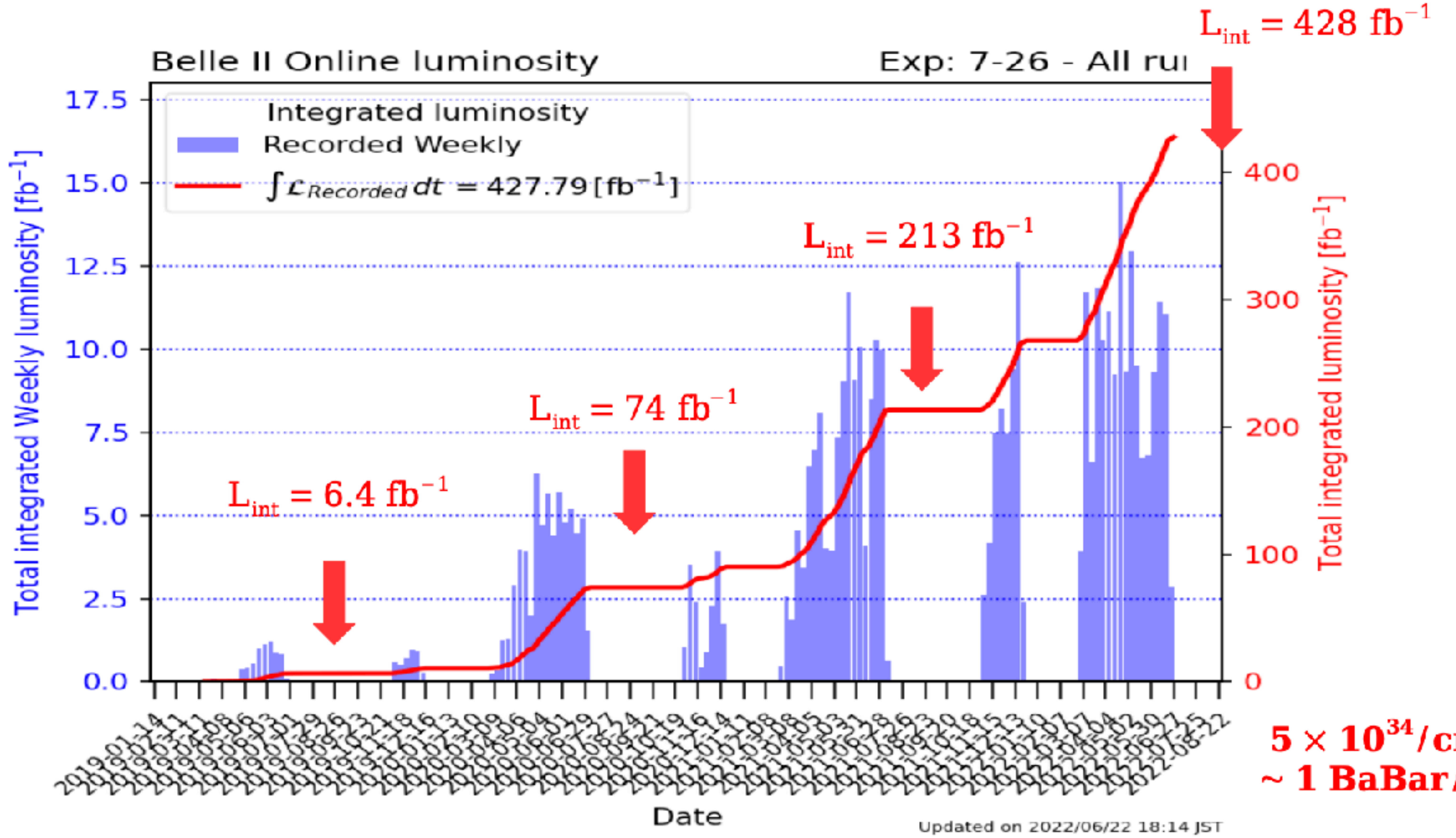
Belle II RUN-I (2019-2022)

luminosity: $4.7\times10^{34}/cm^2/s$! $>2\,fb^{-1}$ per day !

June, 2022

06/07 23:59:36 - 06/08 23:59:36, 2022 JST

$\mathcal{L}_{peak}$ 4.653 × 10^{34} $cm^{-2}s^{-1}$ @ 22:58:08 06/08	HER I_{peak} 1127 mA	n_b 2249	β^*_x / β^*_y 60 / 1 mm
int. $\mathcal{L}$/day 1253 / 1681 pb^{-1}	LER I_{peak} 1405 mA	n_b 2249	β^*_x / β^*_y 80 / 1 mm



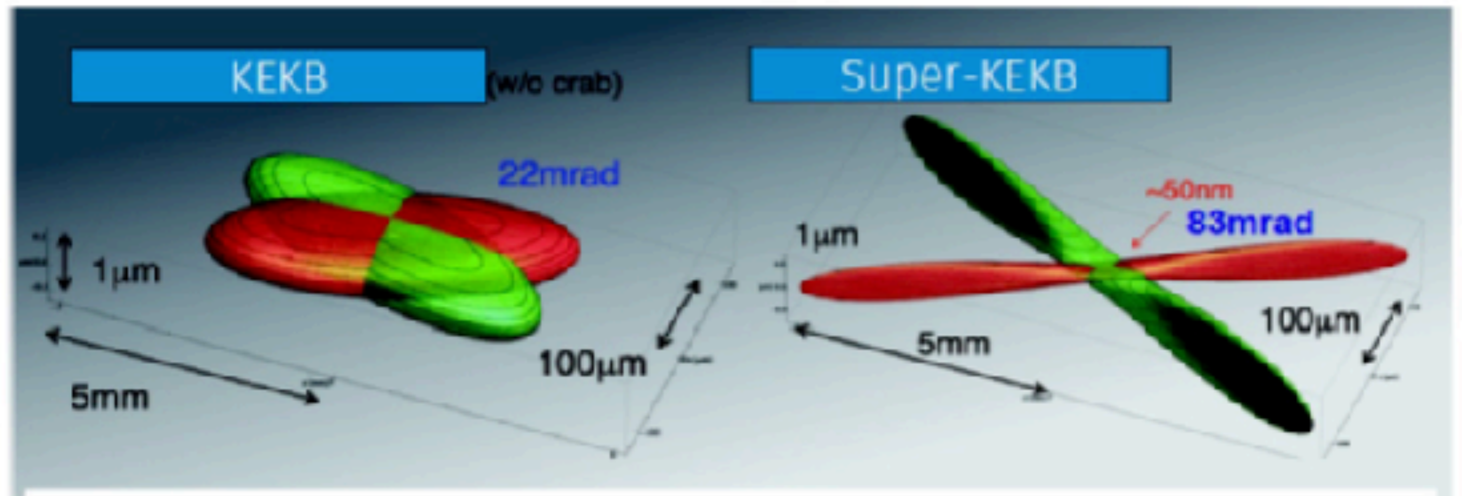
$5\times10^{34}/cm^2/s$
~ 1 BaBar/year

record of KEKB/Belle

$2\times10^{34}/cm^2/s$; currents >1 A

record of PEPII/BaBar

$1\times10^{34}/cm^2/s$; currents >2 A



	E (GeV) LER/HER	β^*_y (mm) LER/HER	β^*_x (cm) LER/HER	φ (mrad)	I (A) LER/HER	L ($cm^{-2}s^{-1}$)
KEKB	3.5/8.0	5.9/5.9	120/120	11	1.6/1.2	2.1 x 10^{34}
SuperKEKB	4.0/7.0	0.27/0.30	3.2/2.5	41.5	3.6/2.6	80 x 10^{34}

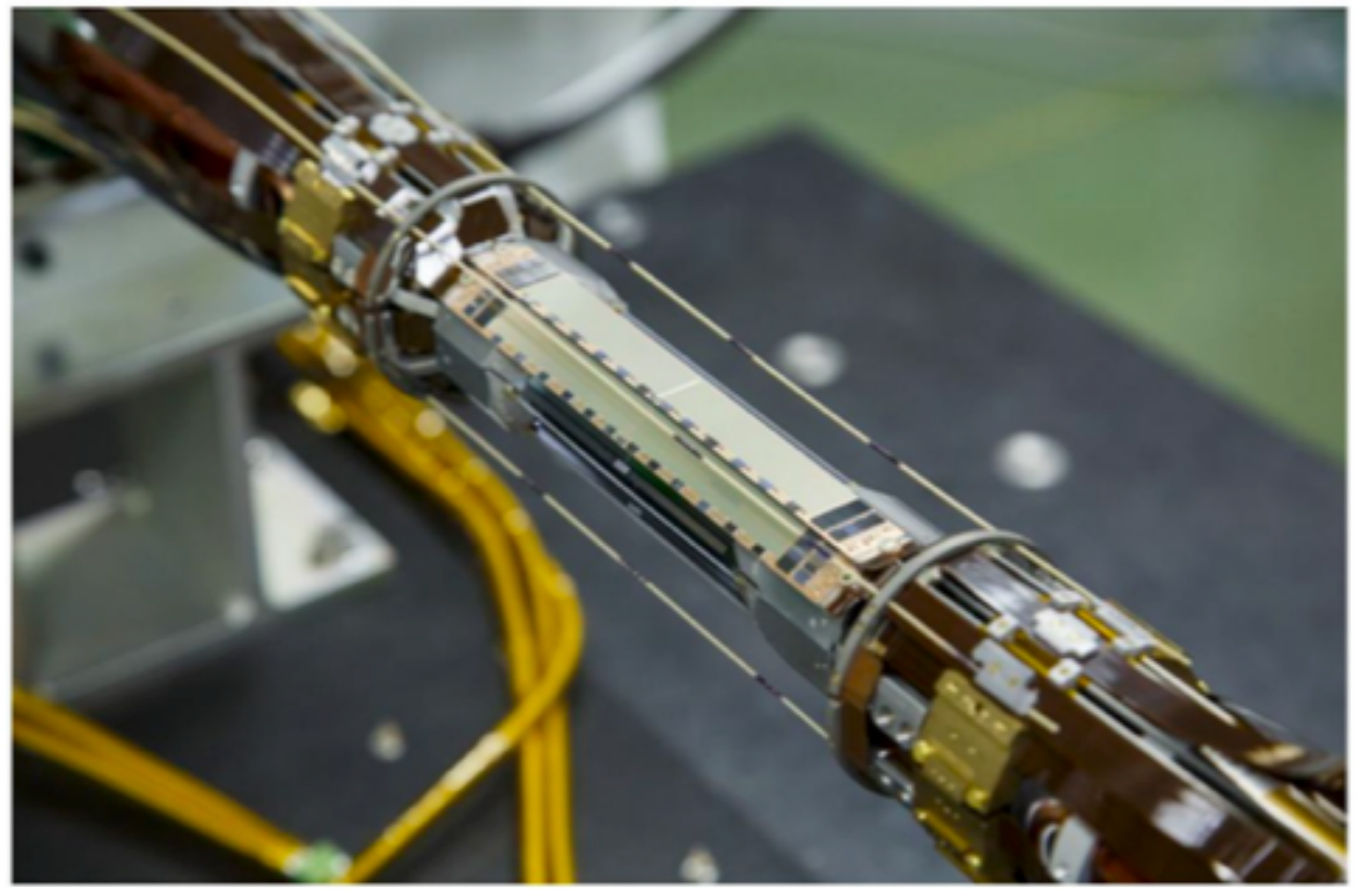
factor 20 factor 2-3

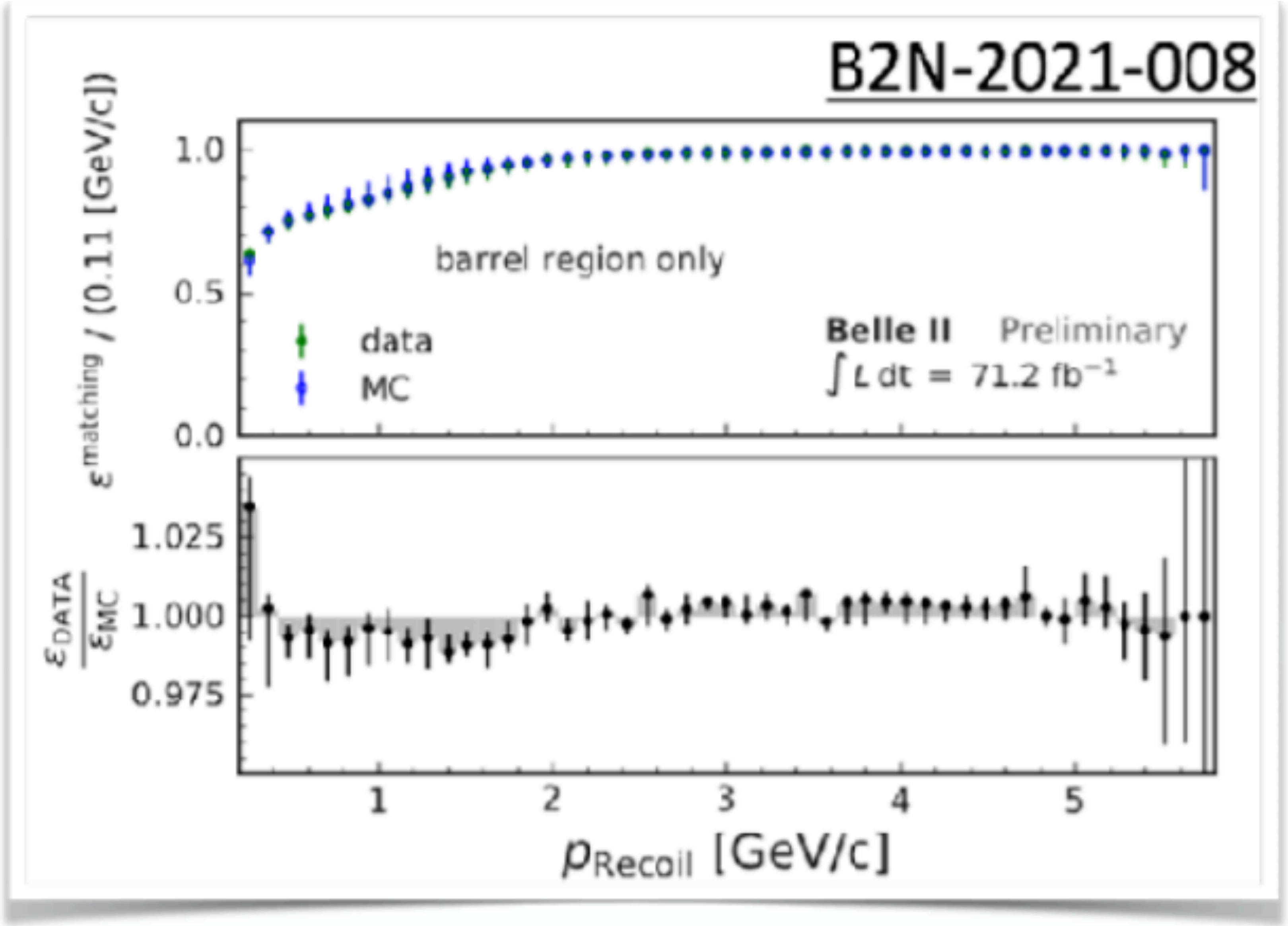
⇒ $362\ fb^{-1}$ at the $\Upsilon(4S)$ resonance (rest off resonance, and scan)

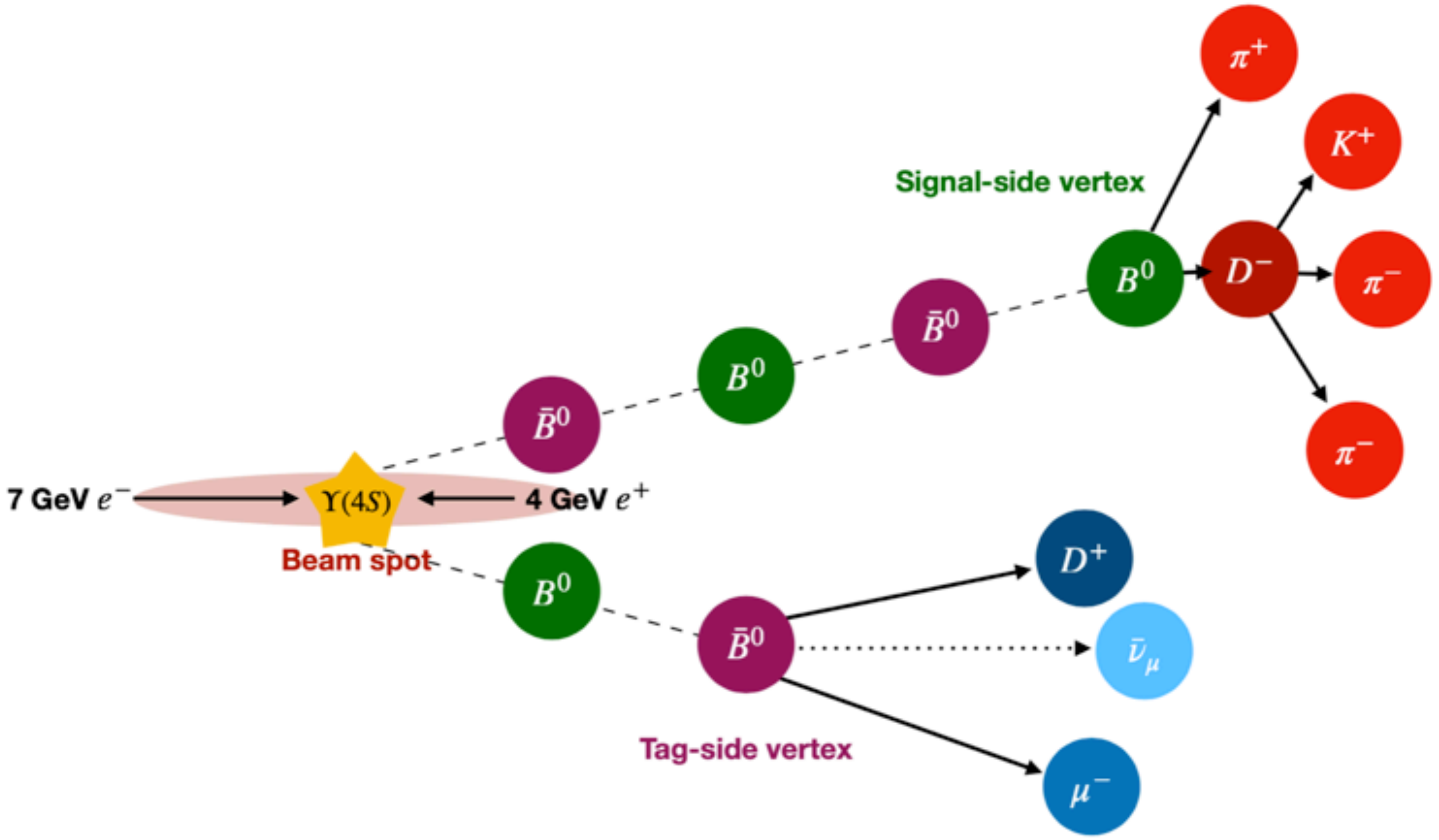
squeezing further β^*_y (→ 0.6 mm)
doubling (or more) the currents
⇒ $L > 10^{35}/cm^2/s$ after LS1

Belle II advantages

- Excellent muon and electron identification
- High photon detection efficiency
- Good hermiticity: useful for modes with missing energy
- Good vertex and momentum resolution

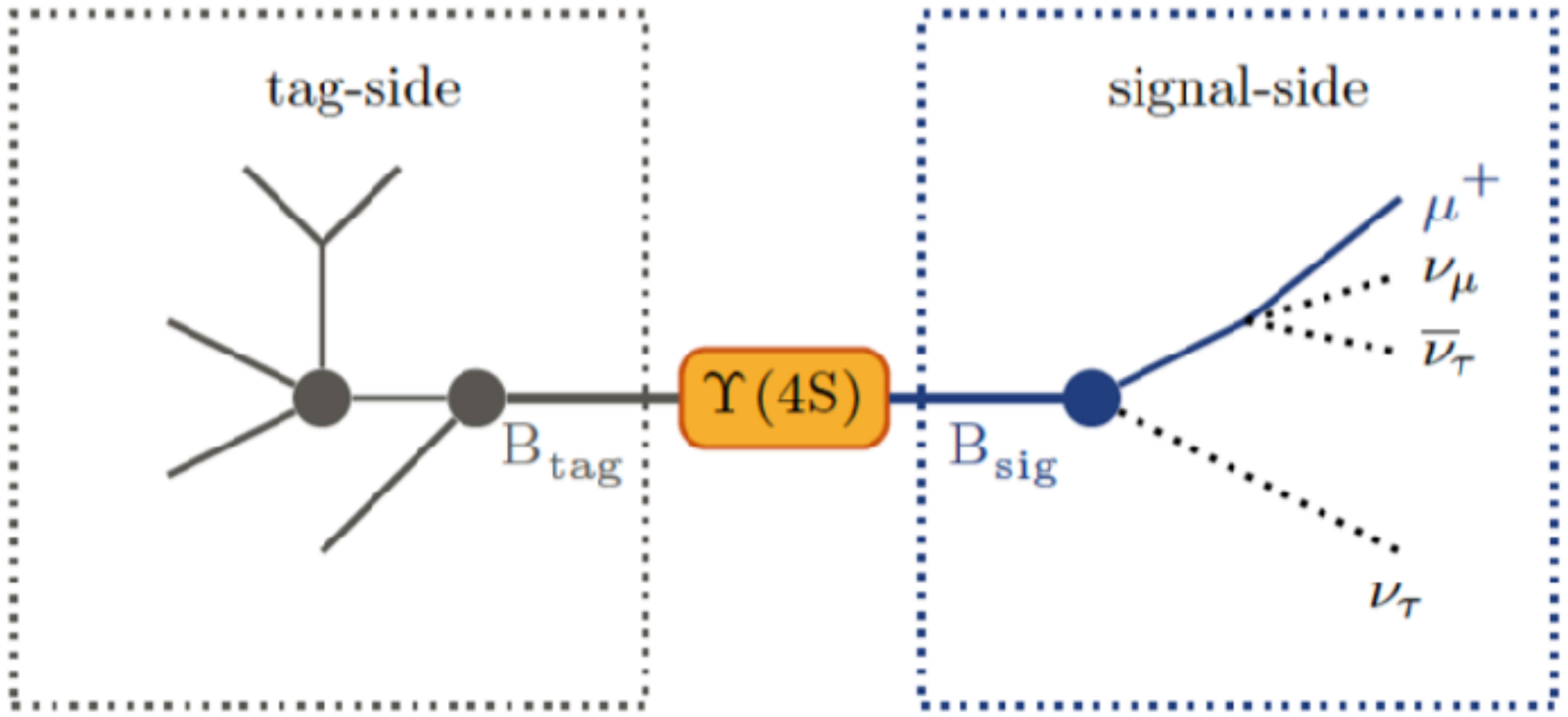


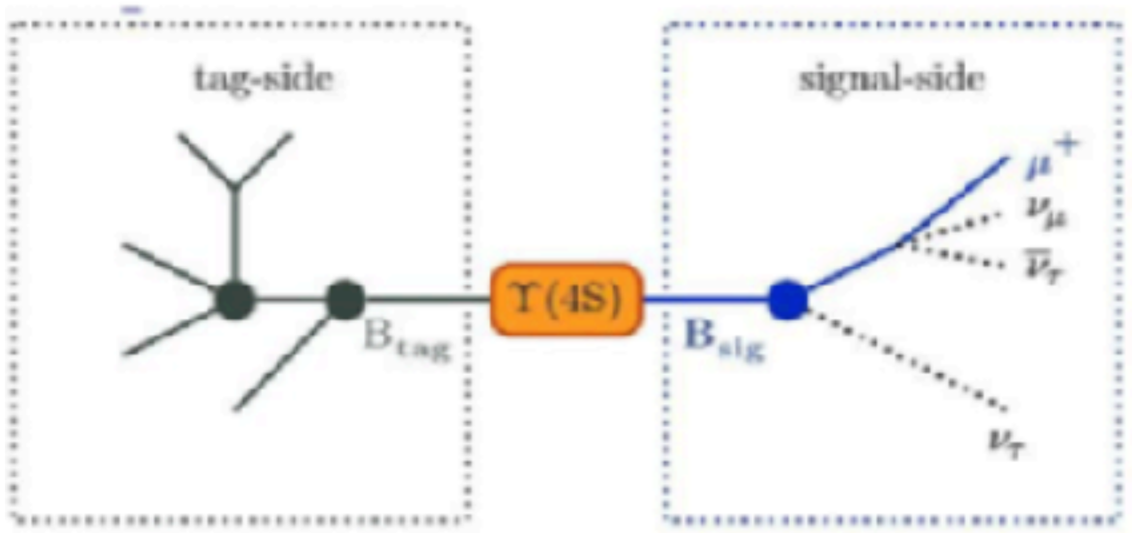




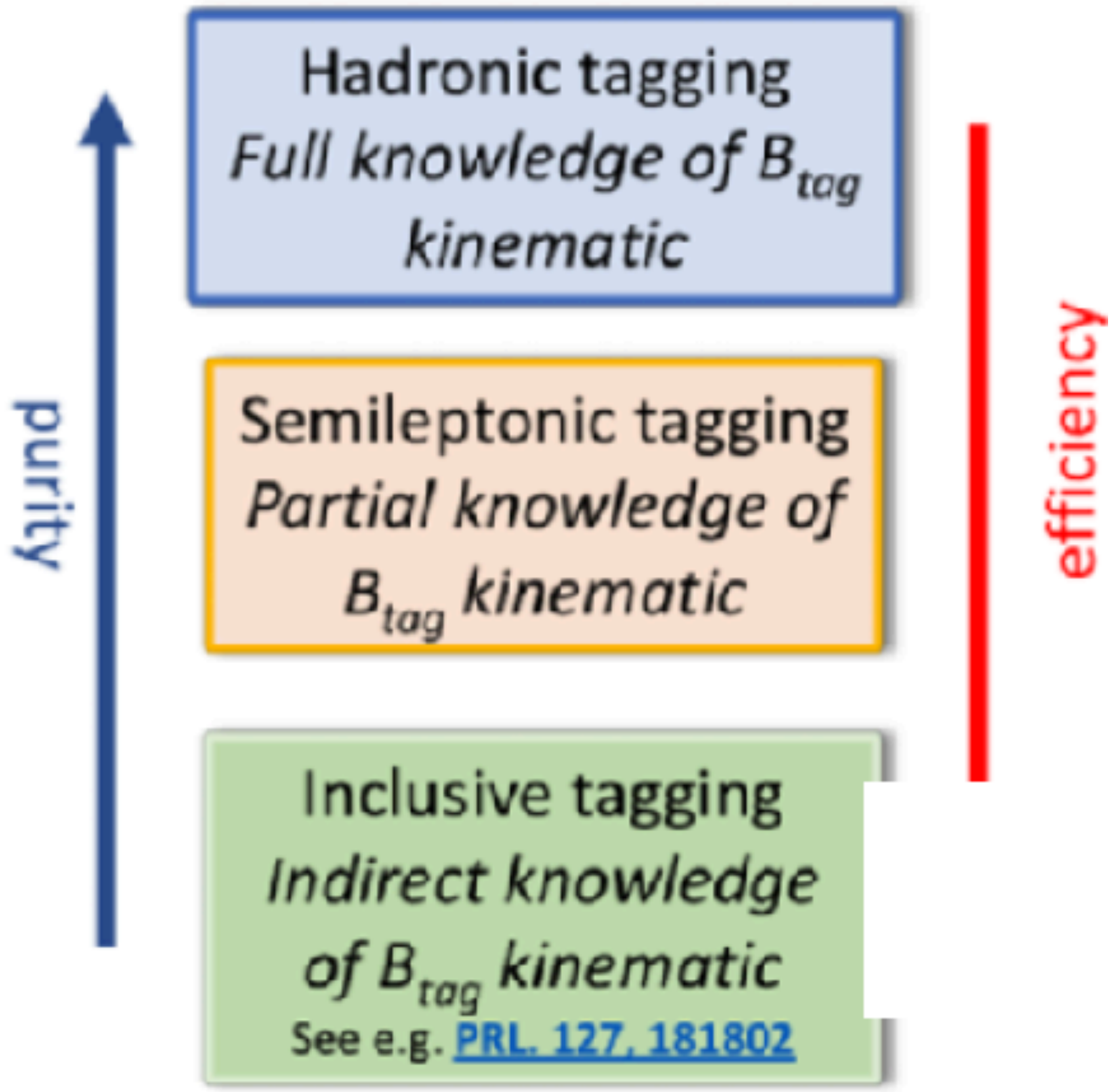
Full Event Interpretation (FEI)

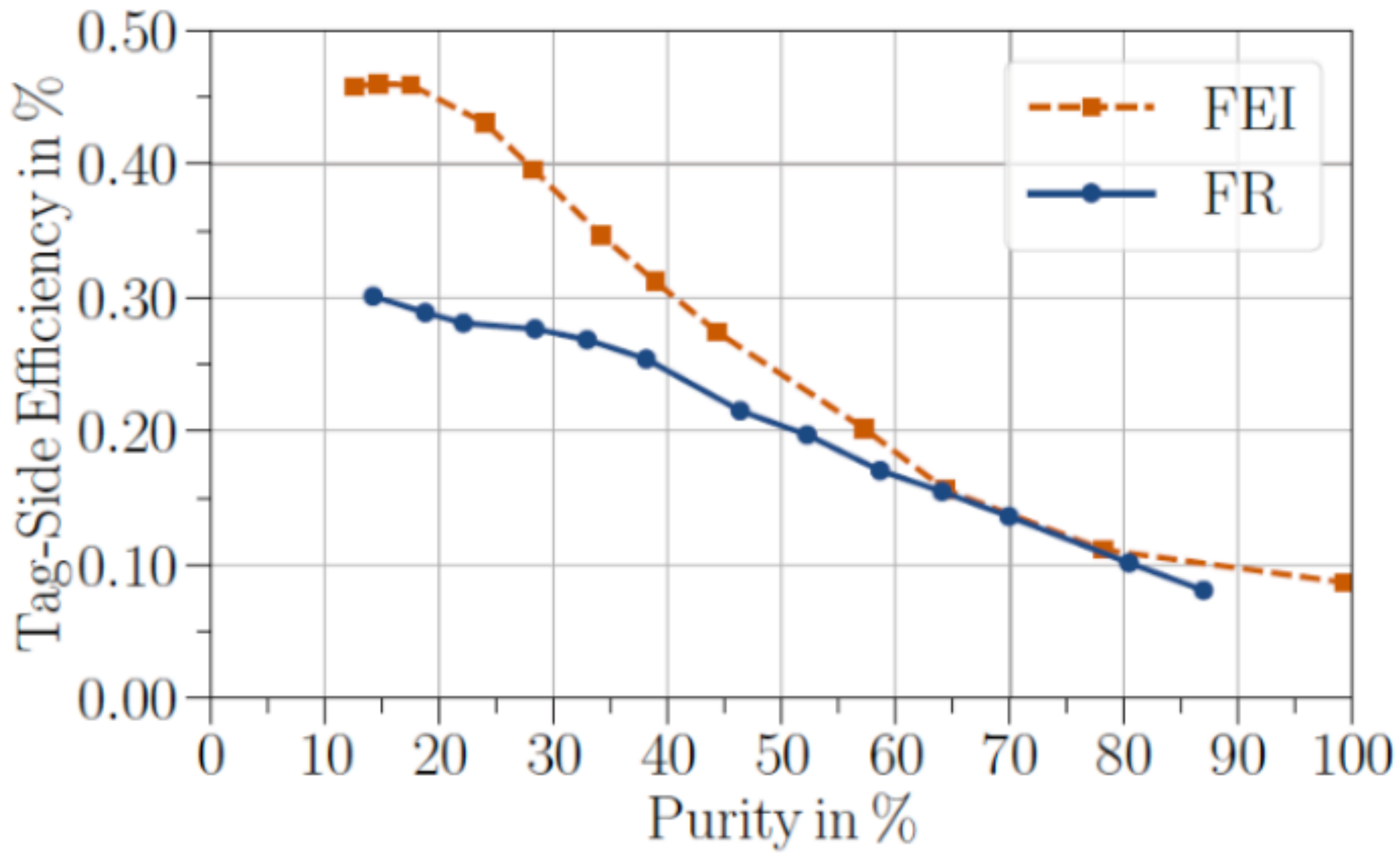
- Reconstructs this B_{tag} in roughly 10 000 channels
- First reconstructing low-level particles (K, π, . . .), then intermediate D mesons and finally B mesons.
- Most-likely particle candidates are selected using pre-trained multivariate classifiers





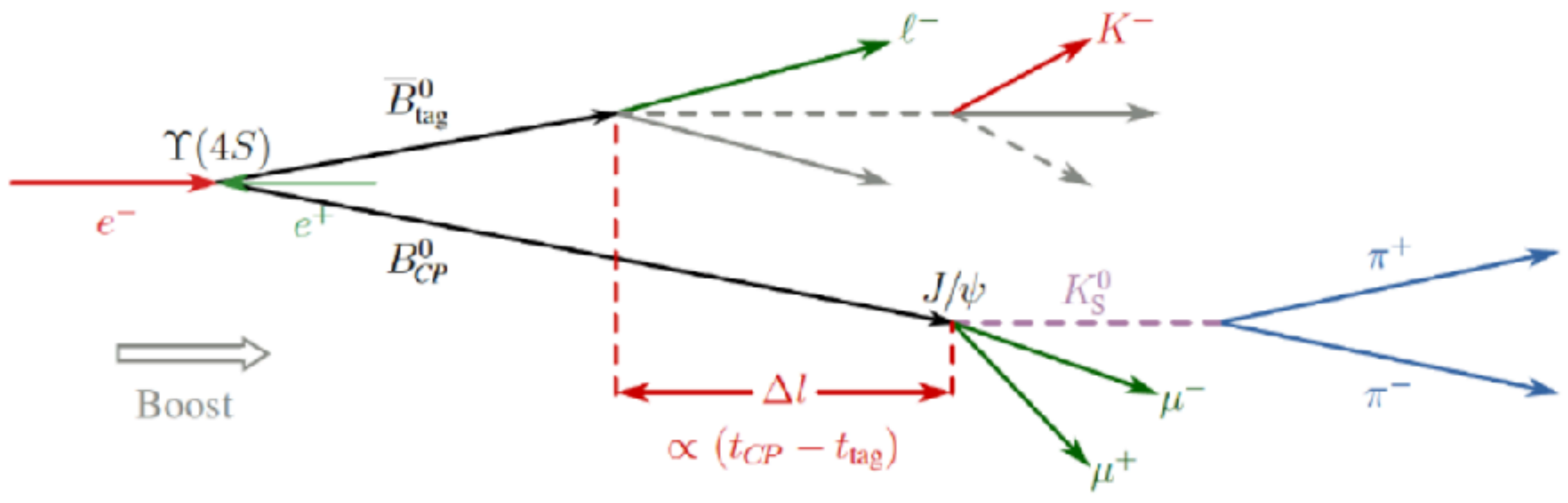
Full Event Interpretation (FEI)

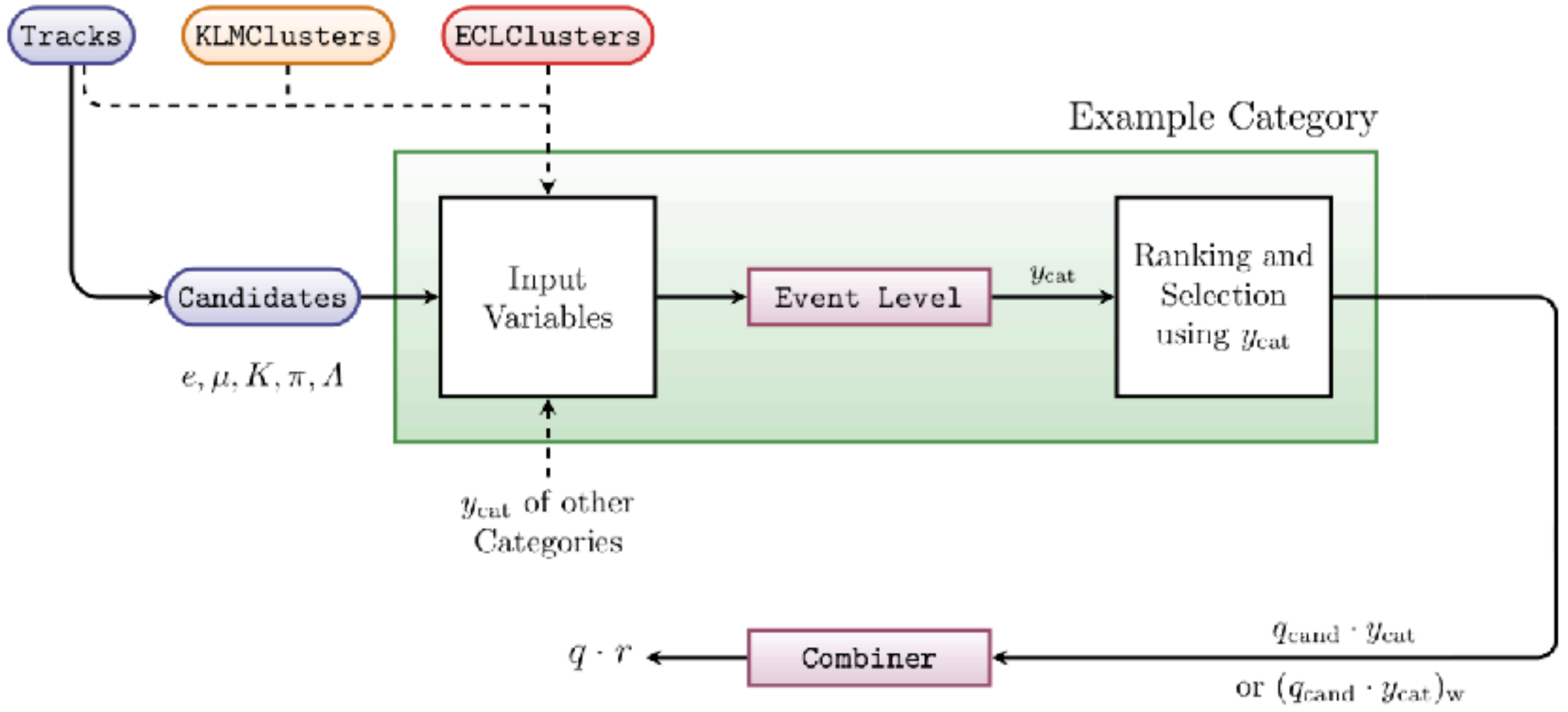




Flavor Tagger

- Identify flavor of a particle, useful in TDCPV
- Inspired by the Flavor Tagging concept developed by Belle and BaBar.
- Proceeds in 2 levels: *EventLevel* and *CombinerLevel*. Each step relies on pre-trained multivariate methods.
- High efficiency: 37% in Belle II, 30% in Belle.





Today's highlight

$\Upsilon(10753)$ study

τ physics

charm lifetime

CKM matrix element measurement

B anomalis

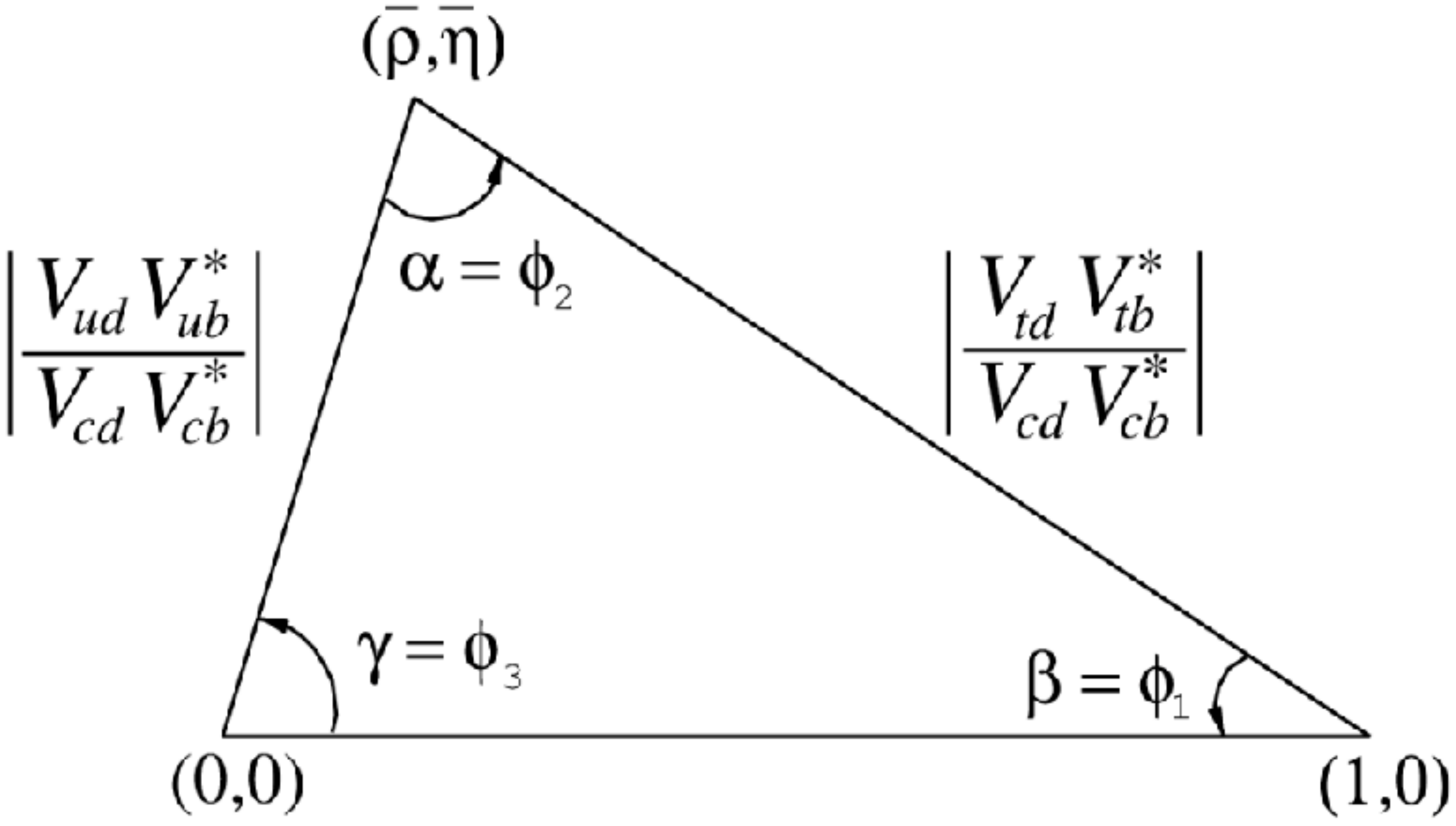
CP violation and the CKM matrix

Quark mixing via charged-current interactions

N. Cabibbo M. Kobayashi T. Maskawa

- Kobayashi and Maskawa predict three generations of quarks
  - Three mixing angles and one CP violating phase
  - Unitarity condition represented as triangles, e.g.

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$



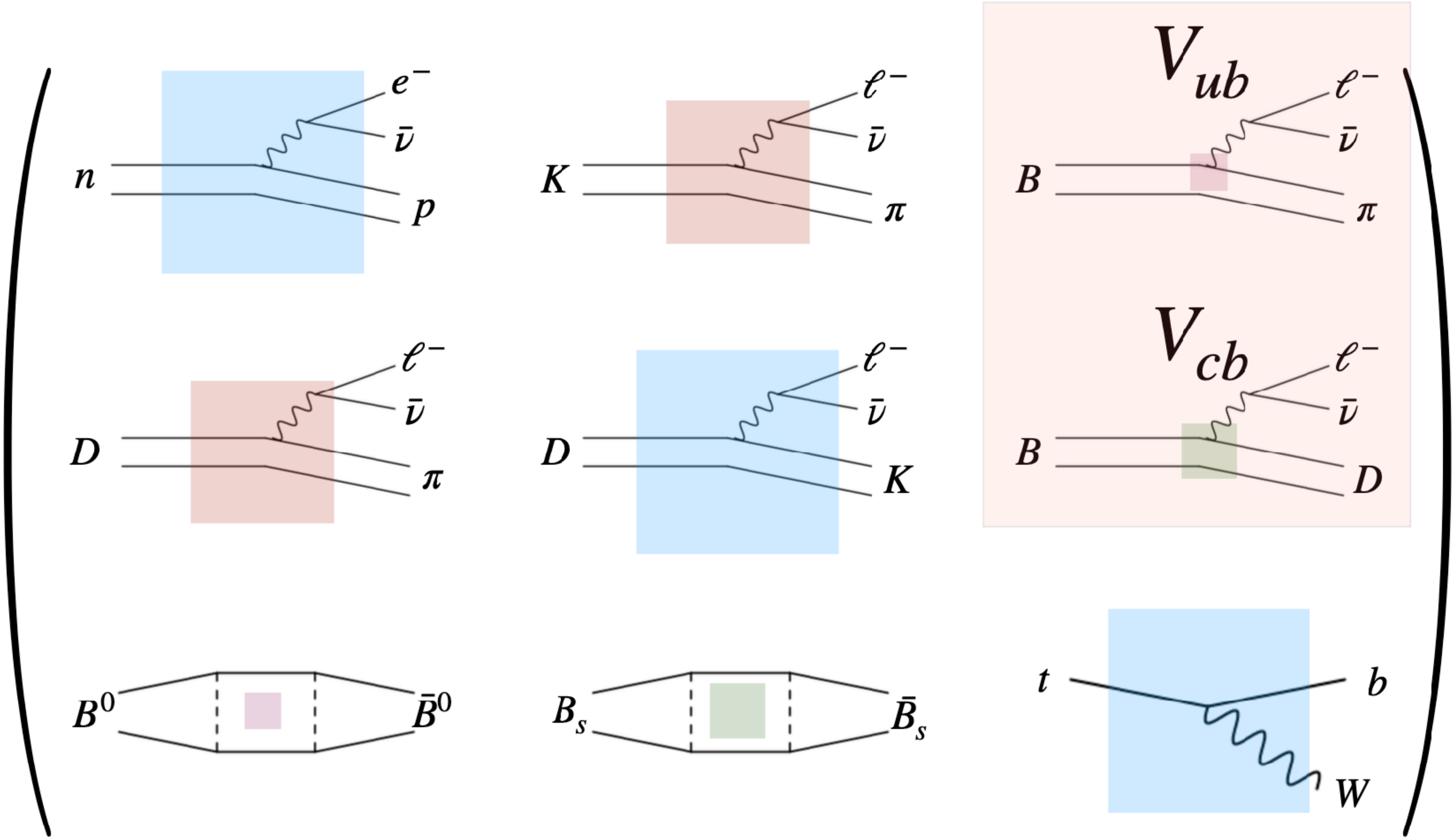
Interaction eigenstates → Mass eigenstates

$$\begin{pmatrix} d_W \\ s_W \\ b_W \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d_m \\ s_m \\ b_m \end{pmatrix}$$

- Common CKM parameterization: Wolfenstein
  - Exploit hierarchy of matrix elements

$$V_{\mathrm{CKM}} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + \mathcal{O}(\lambda^4)$$

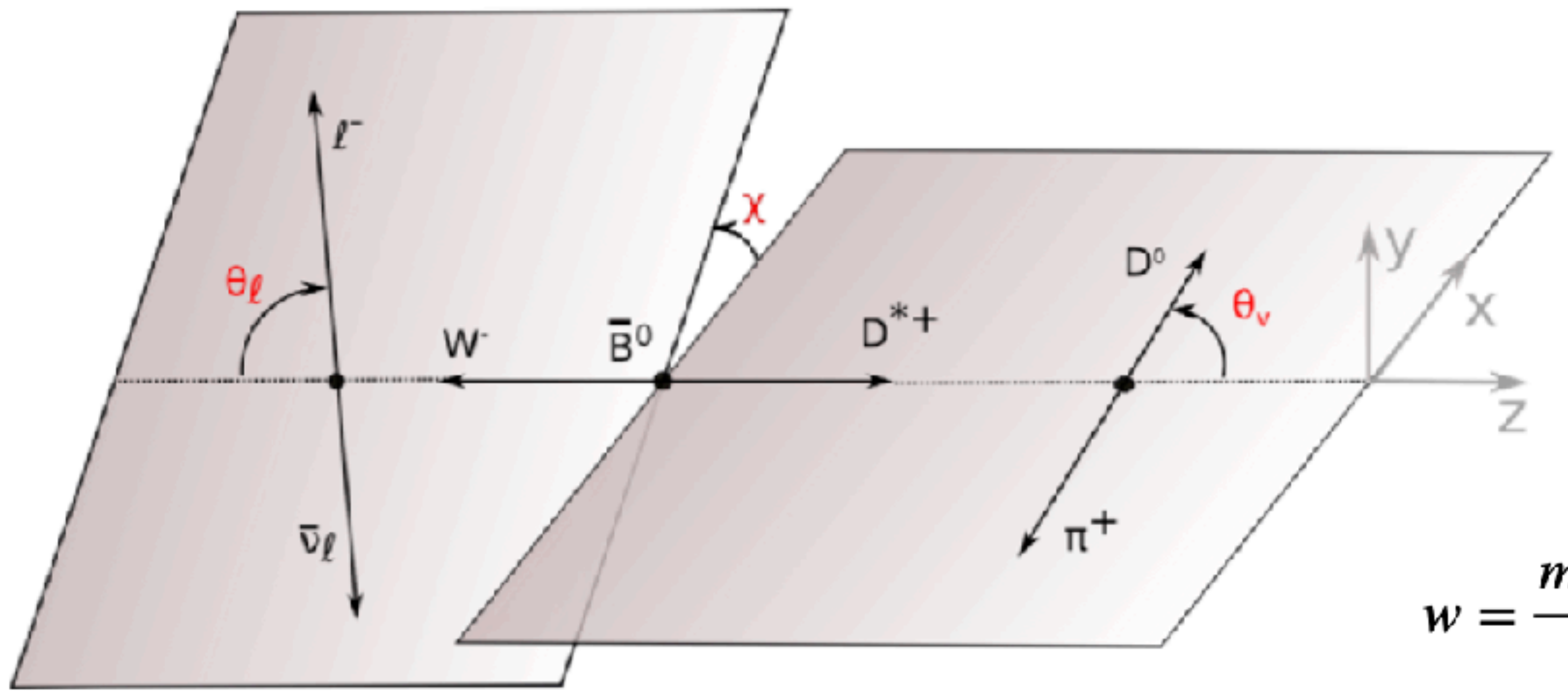
scaled apex parameters



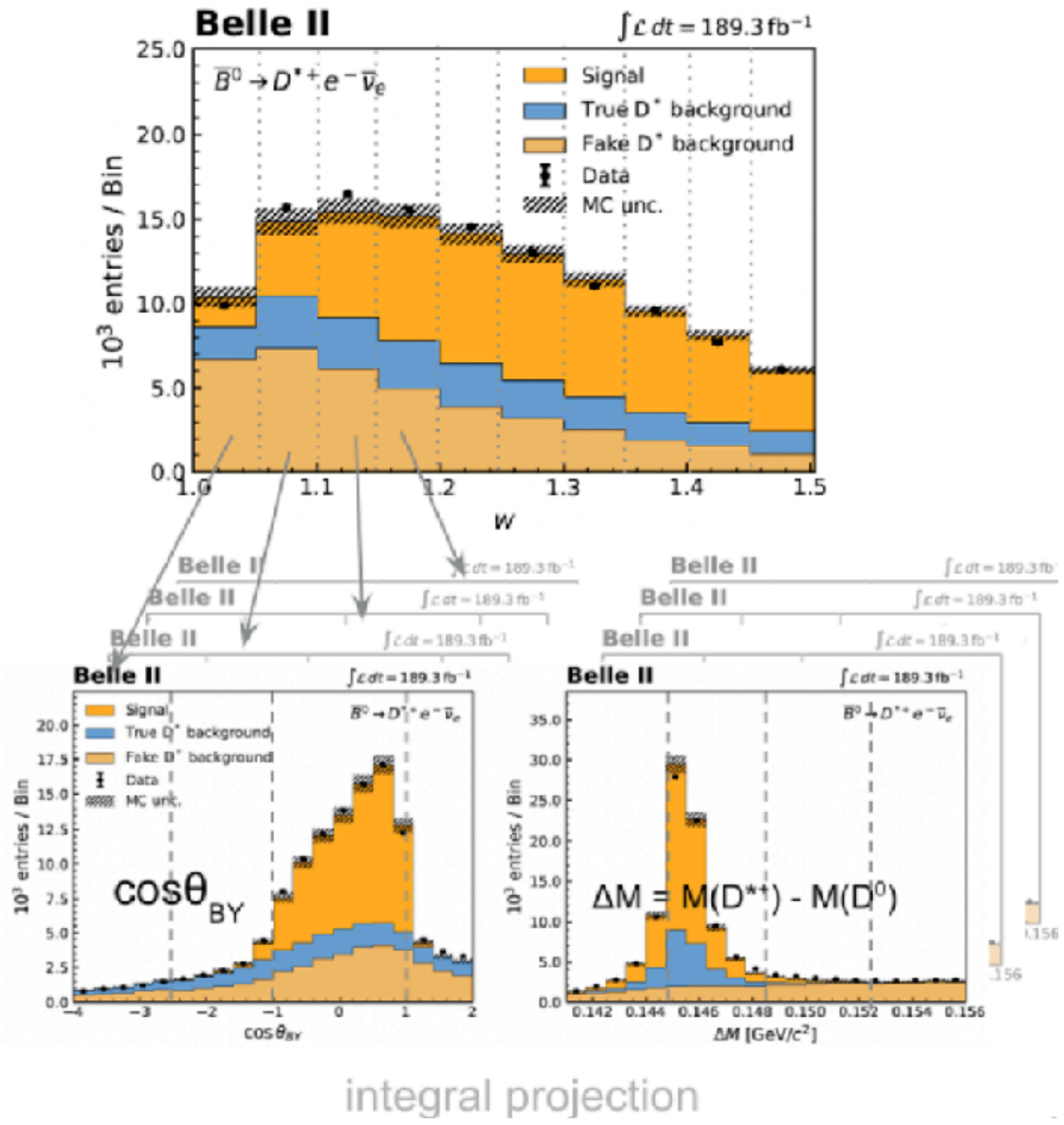
e^-
$\bar{\nu}$
n
p
ℓ^-
$\bar{\nu}$
K
π
V_{ub}
ℓ^-
$\bar{\nu}$
B
π
ℓ^-
$\bar{\nu}$
D
π
ℓ^-
$\bar{\nu}$
D
K
V_{cb}
ℓ^-
$\bar{\nu}$
B
D
B^0
$\bar{B}^0$
B_s
$\bar{B}_s$
t
b
W

$|V_{cb}|$ using $\bar{B}^0 \to D^{*+}\ell^-\bar{\nu}_\ell$

PRD 108, 092013 (2023)

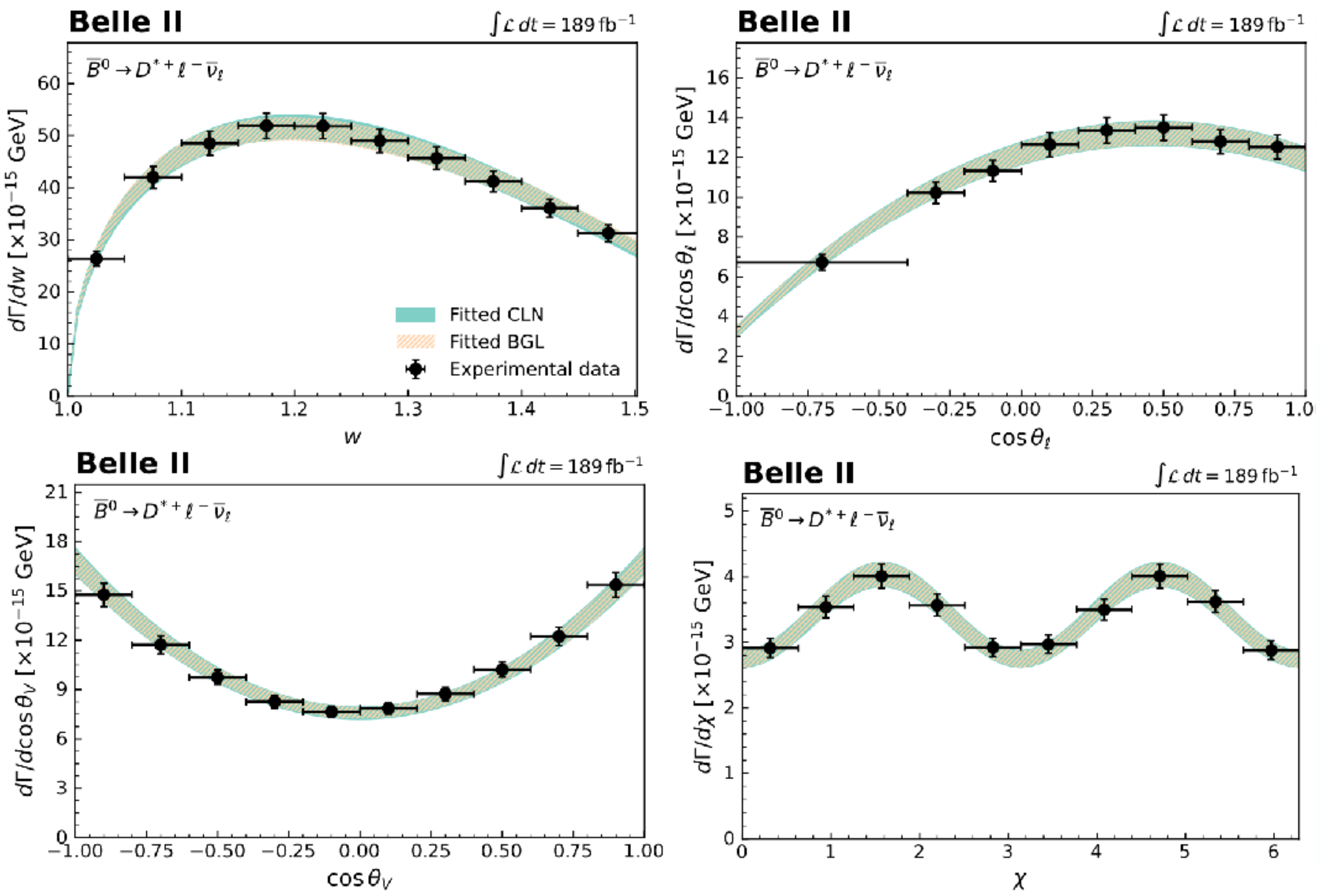


$$w = \frac{m_{\bar{B}^0}^2 + m_{D^*}^2 - q^2}{2m_{B^0}m_{D^*}}$$



- $\bar{B}^0 \to D^{*+}\ell^-\bar{\nu}_\ell$ is parameterized by the recoil parameter (w) and three decay angles (θ_l, χ, θ_V)
- 2D-binned likelihood fit to ($\cos\theta_{\mathrm{BY}}$, ΔM) for each bin of variables.
  - $\cos\theta_{\mathrm{BY}} = \dfrac{2E_B^{CM}E_Y^{CM} - m_B^2 - m_Y^2}{2|p_B^{CM}||p_Y^{CM}|}$, $\Delta M = M(D^{*+}) - M(D)$

- Systematic uncertainties incorporated and signal yields unfolded
- Full post-unfolding stat. & syst. covariance propagated into partial decay rate



reco. eff & acc. — input of PDG2022

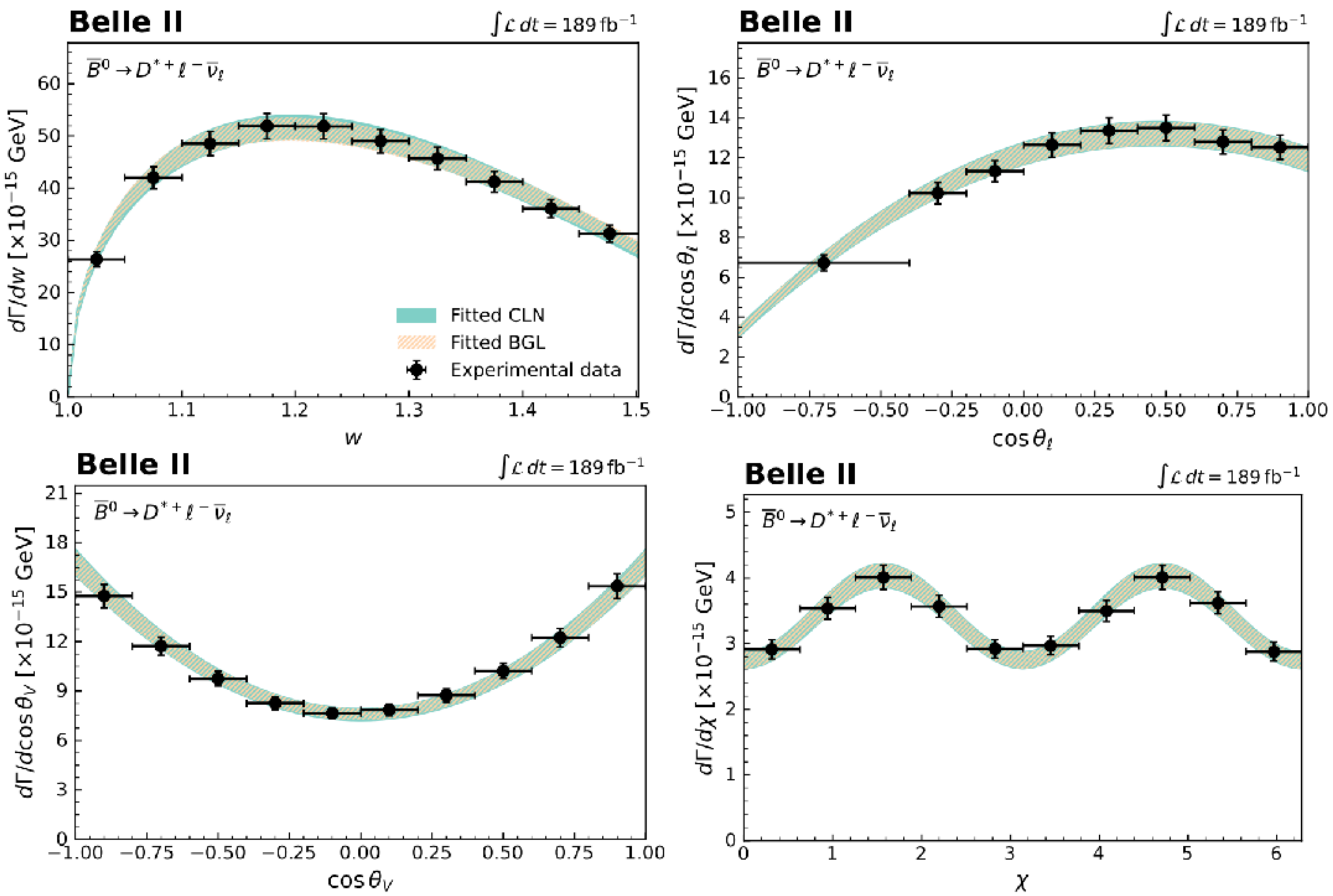
$$\Delta\Gamma_i = \frac{y_i^{\text{unfolded}}}{\epsilon_i N_{B^0} \mathcal{B}(D^{*+} \to D^0\pi^+)\mathcal{B}(D^0 \to K^-\pi^+)\tau_{B^0}}$$

$$\Gamma = \left(\sum_{i=1}^{10} \Delta\Gamma_i^w + \sum_{i=1}^{8} \Delta\Gamma_i^{\cos\theta_\ell} + \sum_{i=1}^{10} \Delta\Gamma_i^{\cos\theta_V} + \sum_{i=1}^{10} \Delta\Gamma_i^{\chi} \right) / 4$$

Branching fraction extracted by the **total rate** summing over partial decay rates and averaging all kin. variables

e mode:	$\mathcal{B}(\overline{B}^0 \to D^{*+} e^- \bar{\nu}_e) = (4.94 \pm 0.03 \pm 0.22)\%$
μ mode:	$\mathcal{B}(\overline{B}^0 \to D^{*+} \mu^- \bar{\nu}_\mu) = (4.94 \pm 0.03 \pm 0.24)\%$
Average:	$\mathcal{B}(\overline{B}^0 \to D^{*+} \ell^- \bar{\nu}_\ell) = (4.94 \pm 0.02 \pm 0.22)\%$

- Include all measured w, θ_l, χ, θ_V to extract form factor & |Vcb|
- Fit differential shapes with form factor expansion based on Caprini-Lellouch-Neubert (CLN) [Nucl. Phys. B530, 153 (1998)] & Boyd-Grinstein-Lebed (BGL) parameterisations [Phys. Rev. D56, 6895 (1997)]



$$|V_{cb}|\eta_{\mathrm{EW}}\mathcal{F}(1) = \frac{1}{\sqrt{m_B m_{D^*}}}\left(\frac{|\tilde{b}_0|}{P_f(0)\phi_f(0)}\right)$$

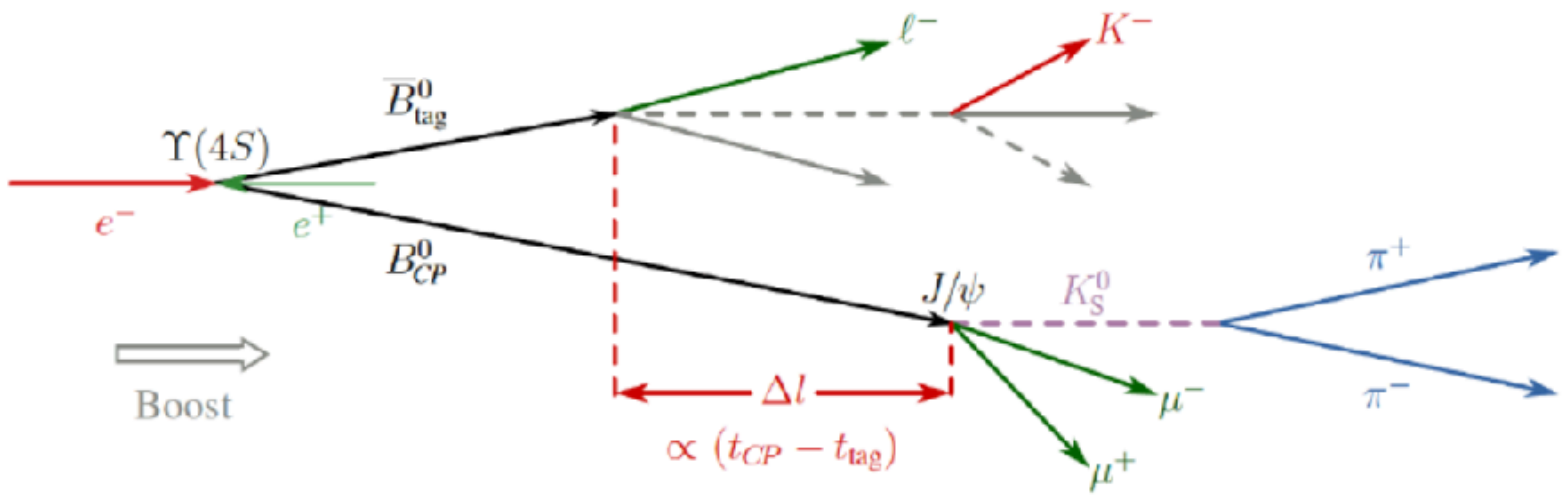
$$|V_{cb}|_{\mathrm{BGL}} = (40.9 \pm 0.3 \pm 1.0 \pm 0.6) \times 10^{-3}$$

$$|V_{cb}|_{\mathrm{CLN}} = (40.4 \pm 0.3 \pm 1.0 \pm 0.6) \times 10^{-3}$$

Slow pion eff. plays leading role in syst.

Input from LQCD at zero-recoil F(1)

$\sin 2\phi_1$ measurement

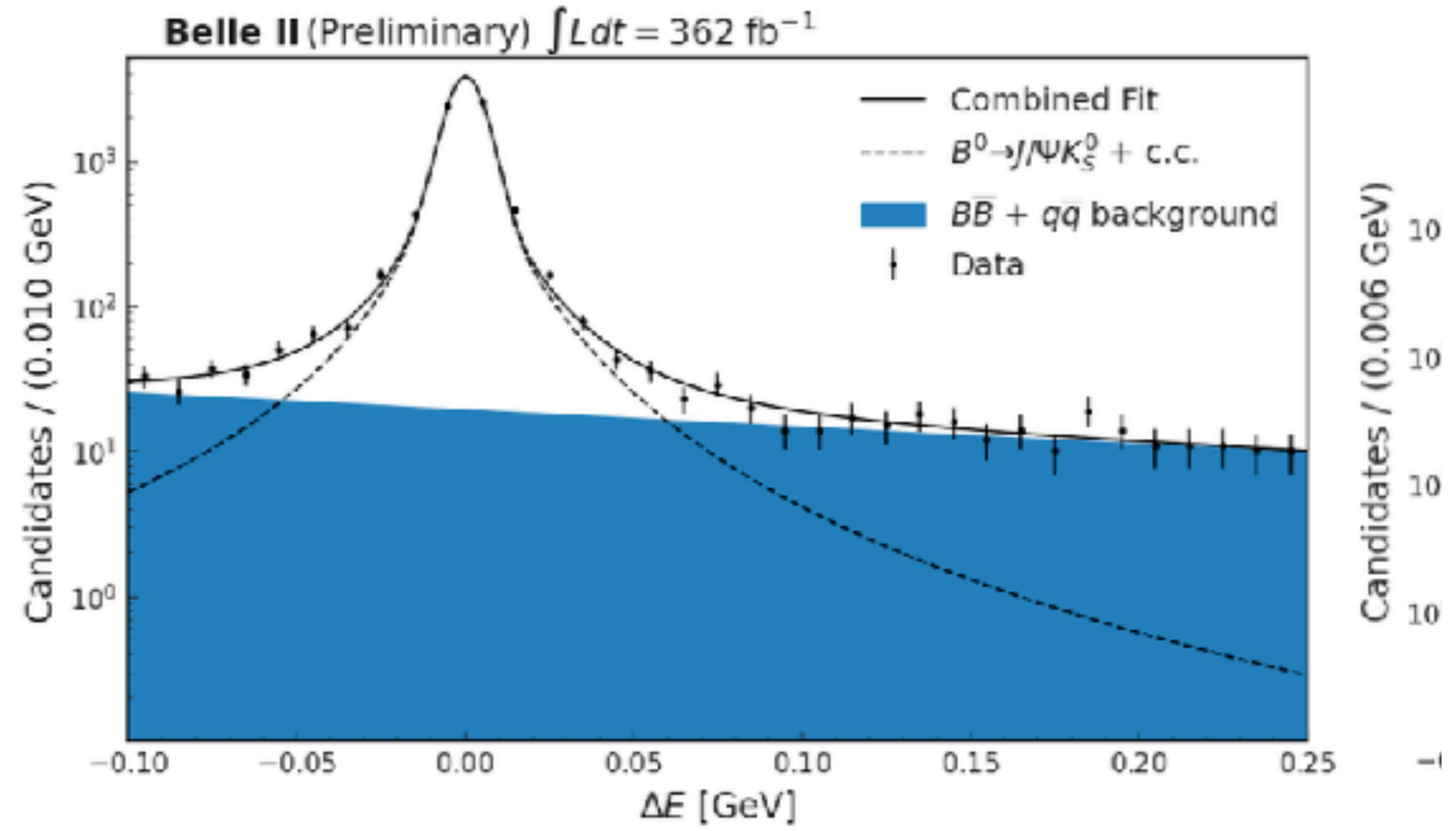


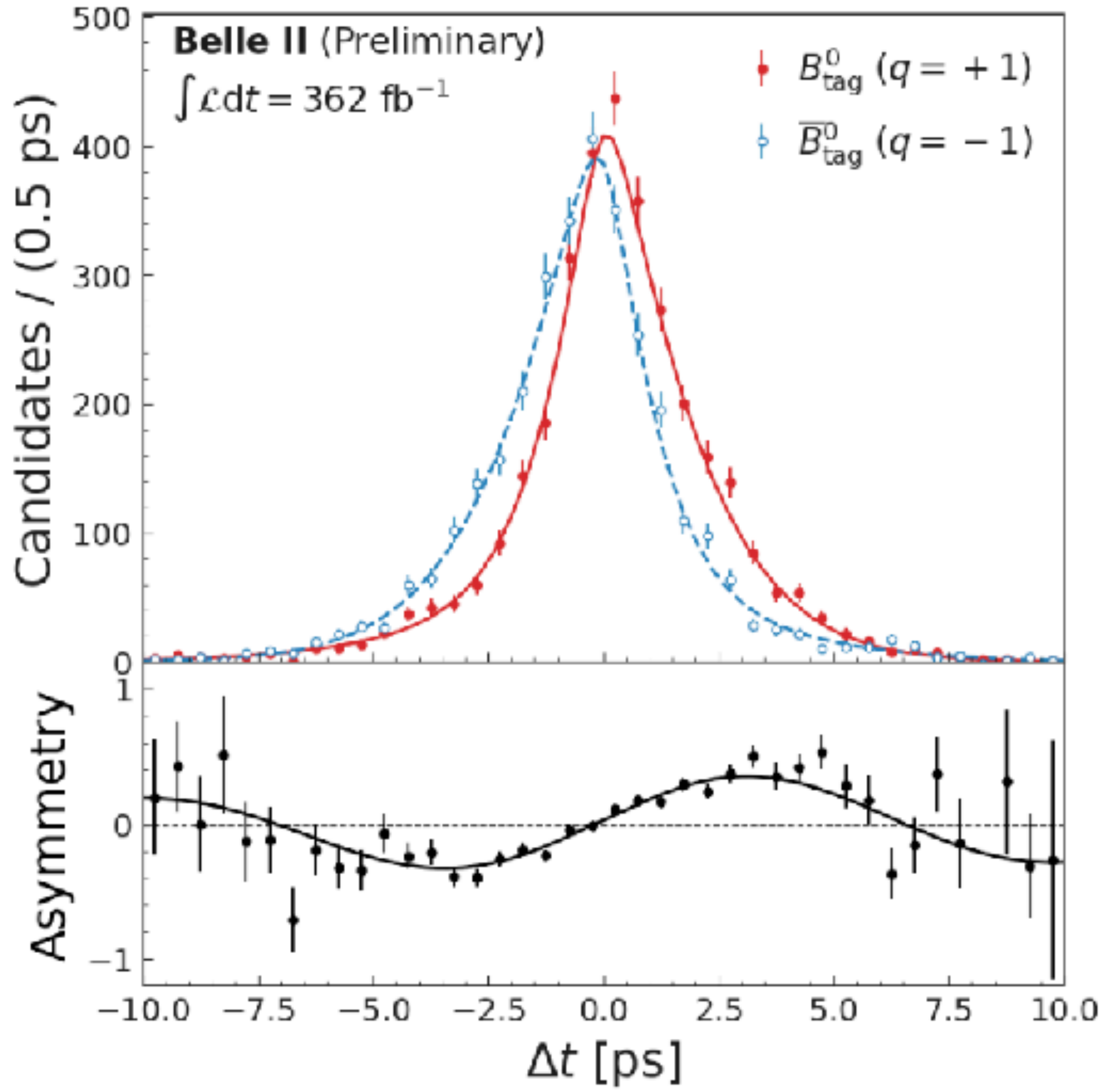
- Sensitive to BSM physics
- Fit Δt to extract S_{CP} and C_{CP}:

$$f_{CP}^{\text{true}} = \frac{1}{4\tau_B^0} e^{-|\Delta t|/\tau_B^0}(1 + q[S_{CP}\sin(\Delta m \Delta t) - C_{CP}\cos(\Delta m \Delta t)])$$

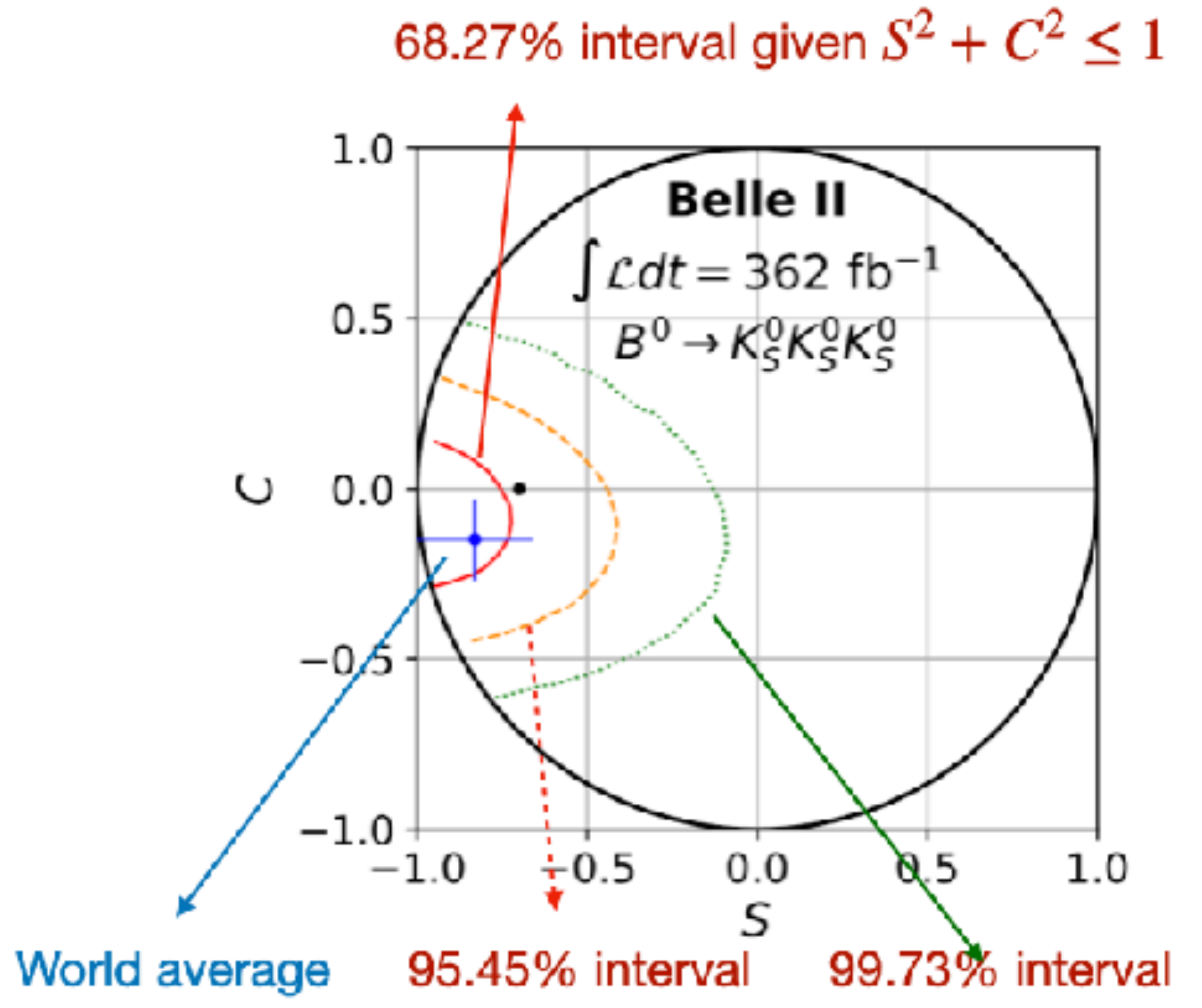
- SM expectation: $S_{CP} = \sin 2\phi_1$, and $C_{CP} = 0$
- Deviation from $\sin 2\phi_1$ would suggest BSM physics
- Sensitive to BSM physics in
  - $b \to sq\bar{q}$
  - $b \to s\gamma$

$B^0 \to K^0_S J/\psi$





channel	S_meas	C_meas	
$B^0 \to K_S^0 J/\psi$	$0.724 \pm 0.035 \pm 0.014$	$-0.035 \pm 0.026 \pm 0.012$	preliminary
$B^0 \to K_S^0 \pi^0 \gamma$	$0.04^{+0.45}_{-0.44} \pm 0.10$	$-0.06 \pm 0.25 \pm 0.07$	preliminary
$B^0 \to \eta' K_S^0$	$0.67 \pm 0.10 \pm 0.04$	$-0.19 \pm 0.08 \pm 0.03$	preliminary
$B^0 \to \pi^0 K_S^0$	$0.75^{+0.20}_{-0.23} \pm 0.04$	$-0.04^{+0.14}_{-0.15} \pm 0.05$	**PRL 131, 111803** (2023)
$B^0 \to \phi K_S^0$	$0.54 \pm 0.26^{+0.06}_{-0.08}$	$-0.31 \pm 0.20 \pm 0.05$	**PRD 108, 072012** (2023)



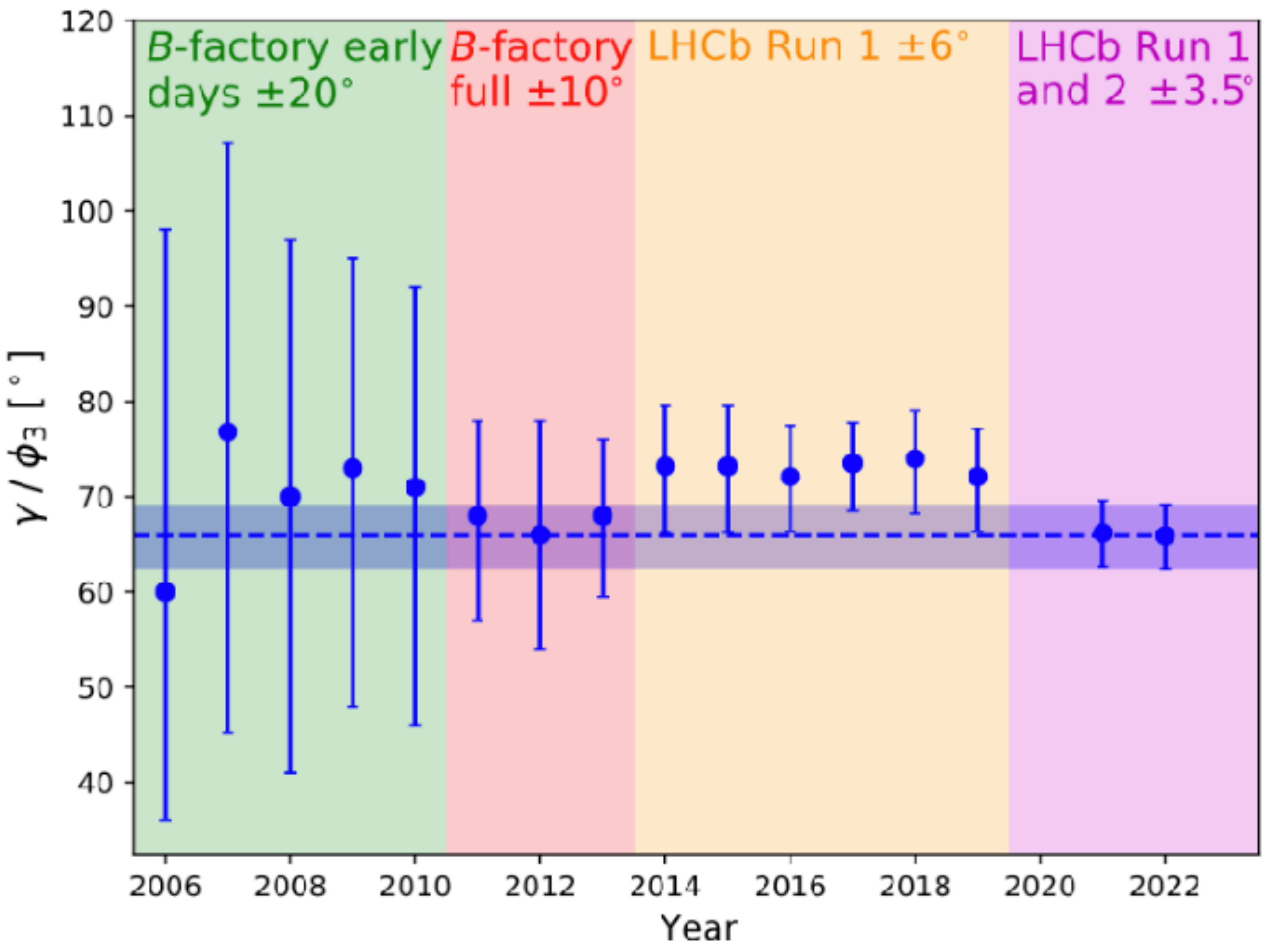
Pseudo-experiments

- $B^0 \to \eta' K_S^0$ provides the most sensitive results up to date.
- Smaller data size but equivalent uncertainties, sometimes better.
- Consistent with world average and SM expectation.

Determination of ϕ_3

- World average:

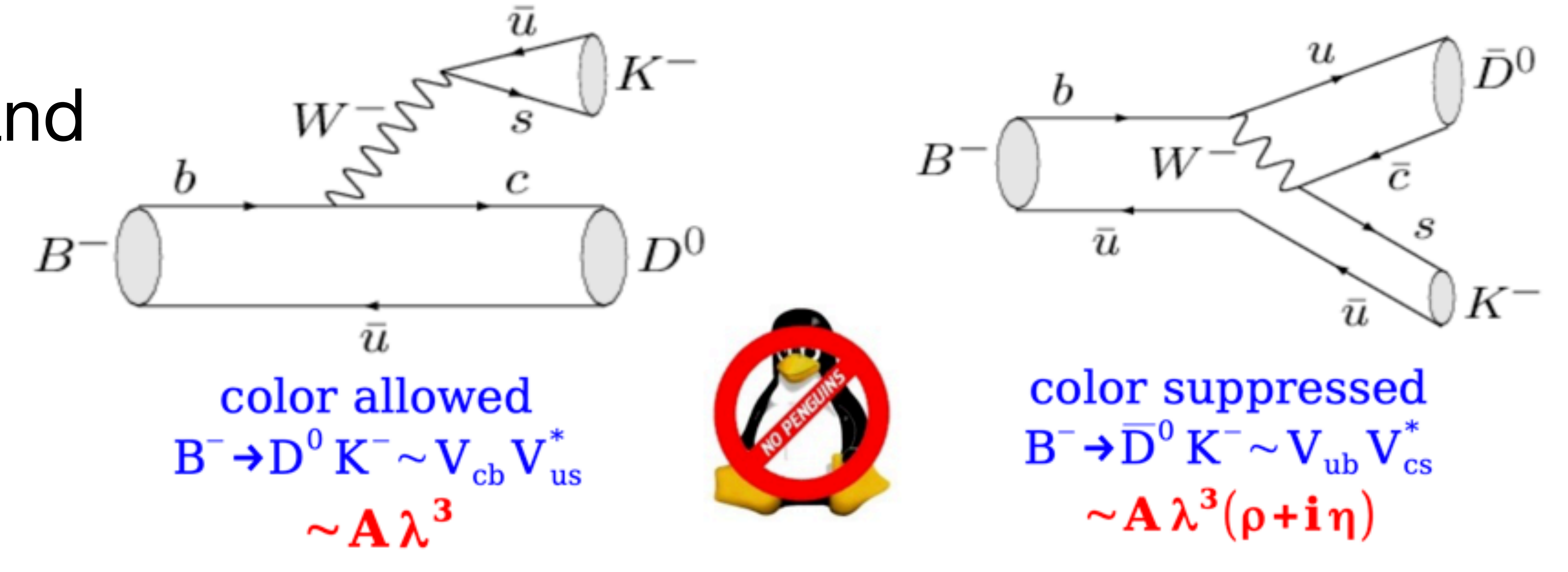
  - Direct: $(66.2^{+3.4}_{-3.6})^\circ$, PRD 107 (2023) 052008]
  - Indirect: $(66.29^{+0.72}_{-1.86})^\circ$, [JHEP03(2020)112]



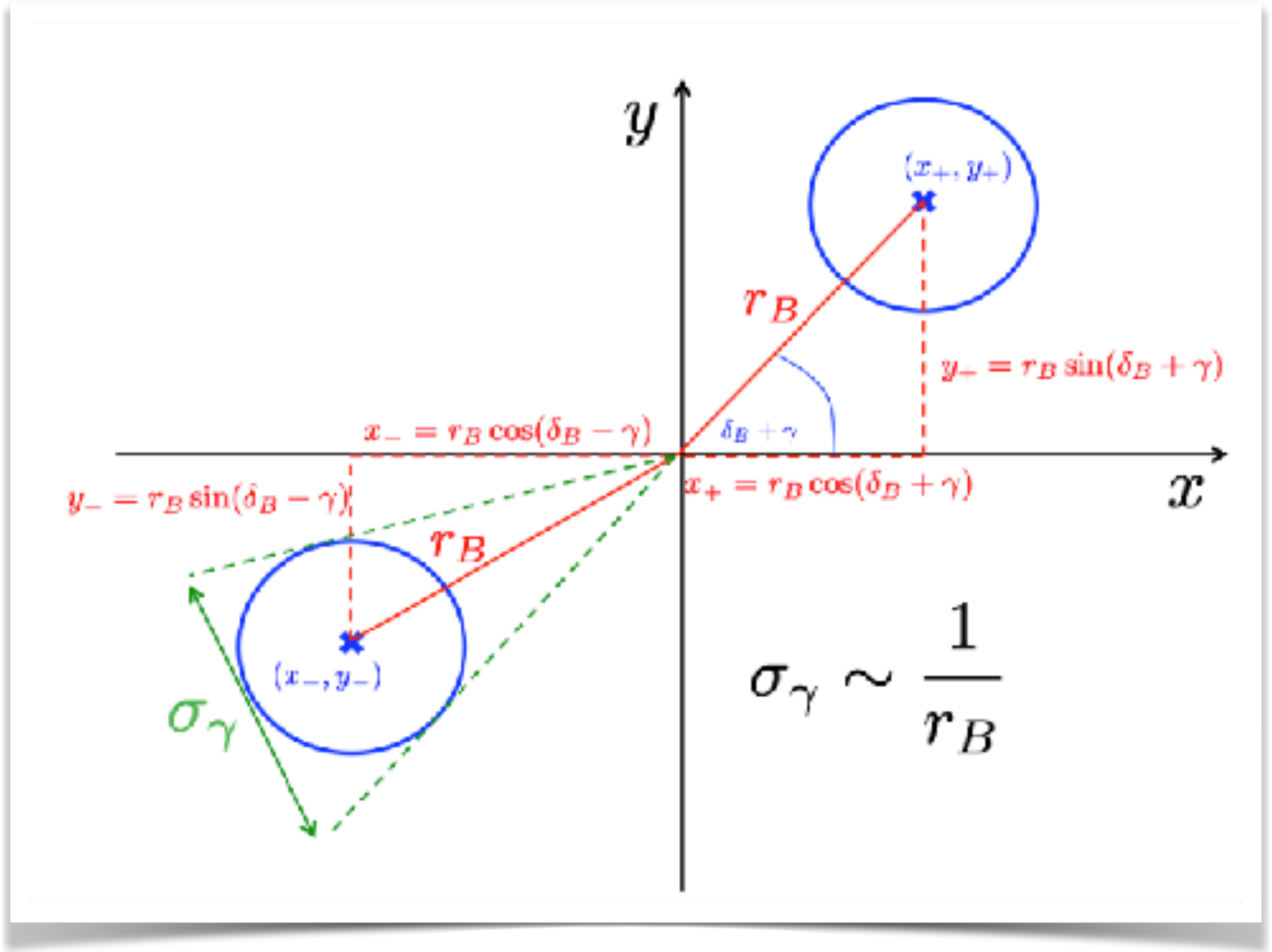
Important to improve precision from direct measurement.

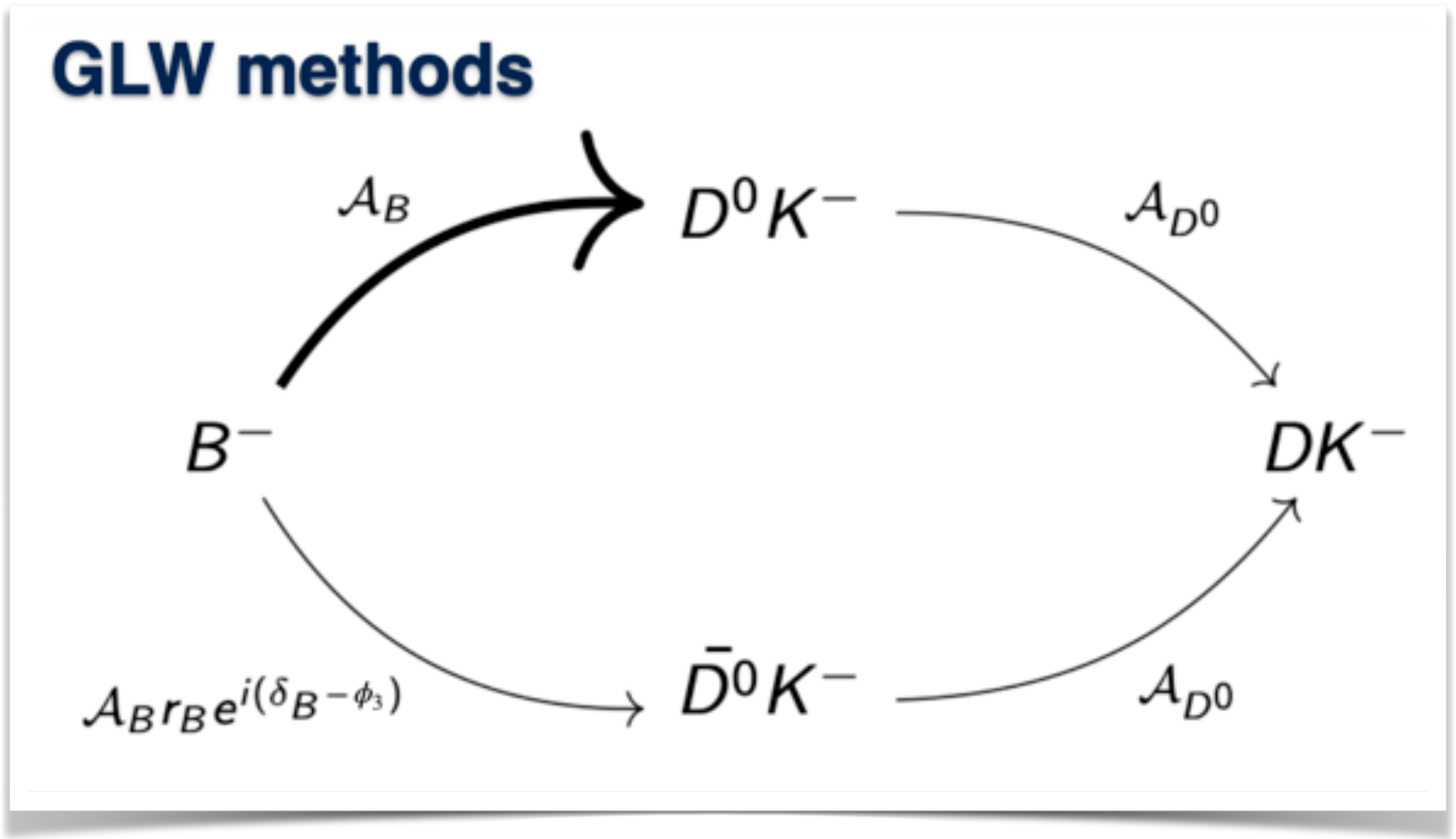
- Determined from $B^+ \to Dh^+$ decays, where D is the mixture of D^0 and $\bar{D}^0$ flavor eigenstates.

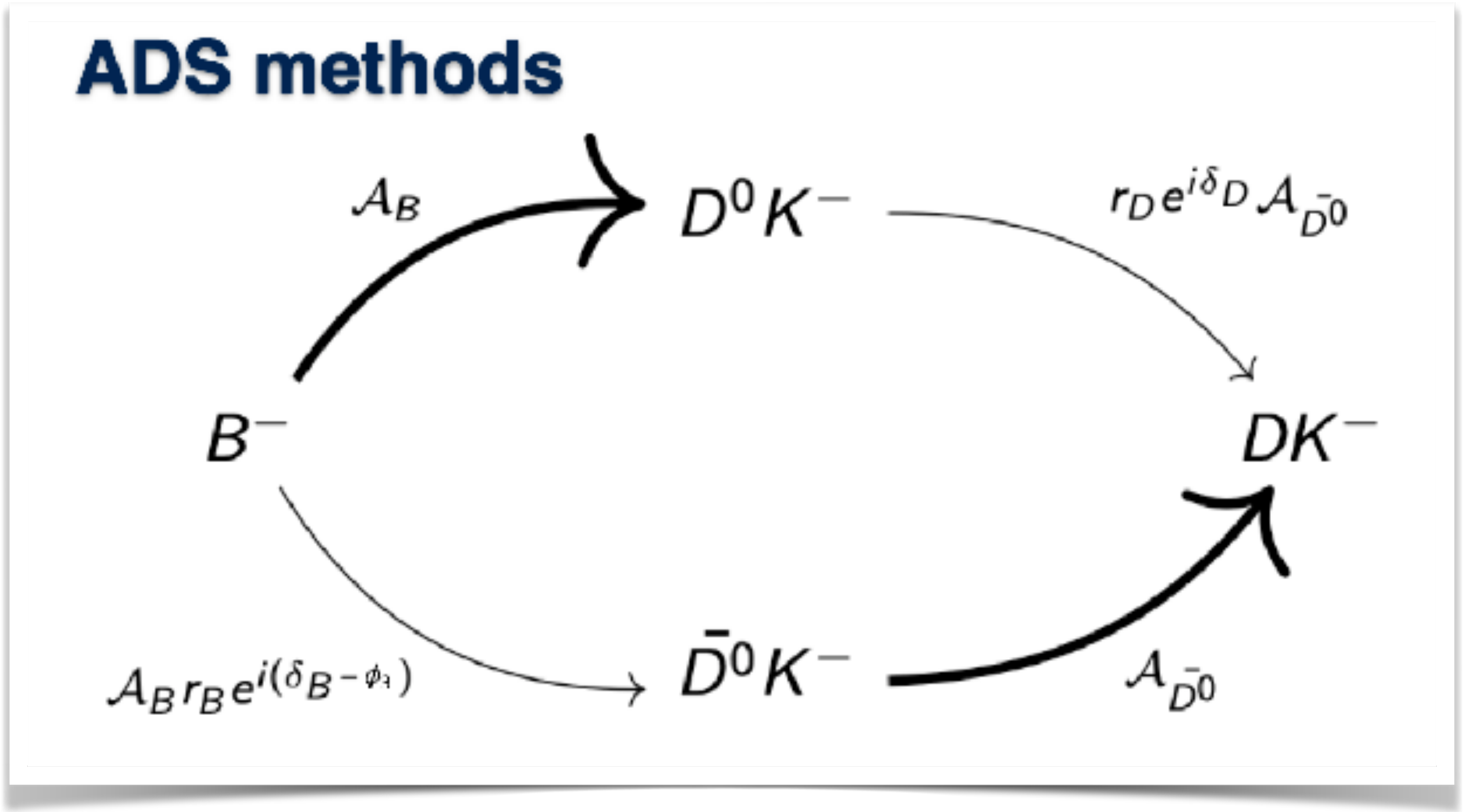
- Access ϕ_3 via interference between $B^+ \to D^0K^+$ and $B^+ \to \bar{D}^0K^+$
  - Need information of the D decays, e.g. strong-phase difference.
    - CLEO-c and BESIII provides model-independent external inputs.(**Significant contribution!**)



- Methods depending on different D final states:
  - **BPGGSZ**: self conjugated multi-body decays, e.g. $K_S^0\pi^+\pi^-$, $K_S^0\pi^+\pi^-\pi^0$, $\pi^+\pi^-\pi^+\pi^-$
  - **GLW**: CP eigenstates, e.g. $K_S^0\pi^0$, K^+K^-
  - **ADS**: CF and DCS decays, e.g. $K^-\pi^+$, $K^-\pi^+\pi^0$, $K^-\pi^+\pi^\pm\pi^\mp$
  - **GLS**: SCS decays, e.g. $K_S^0K^\mp\pi^\pm$







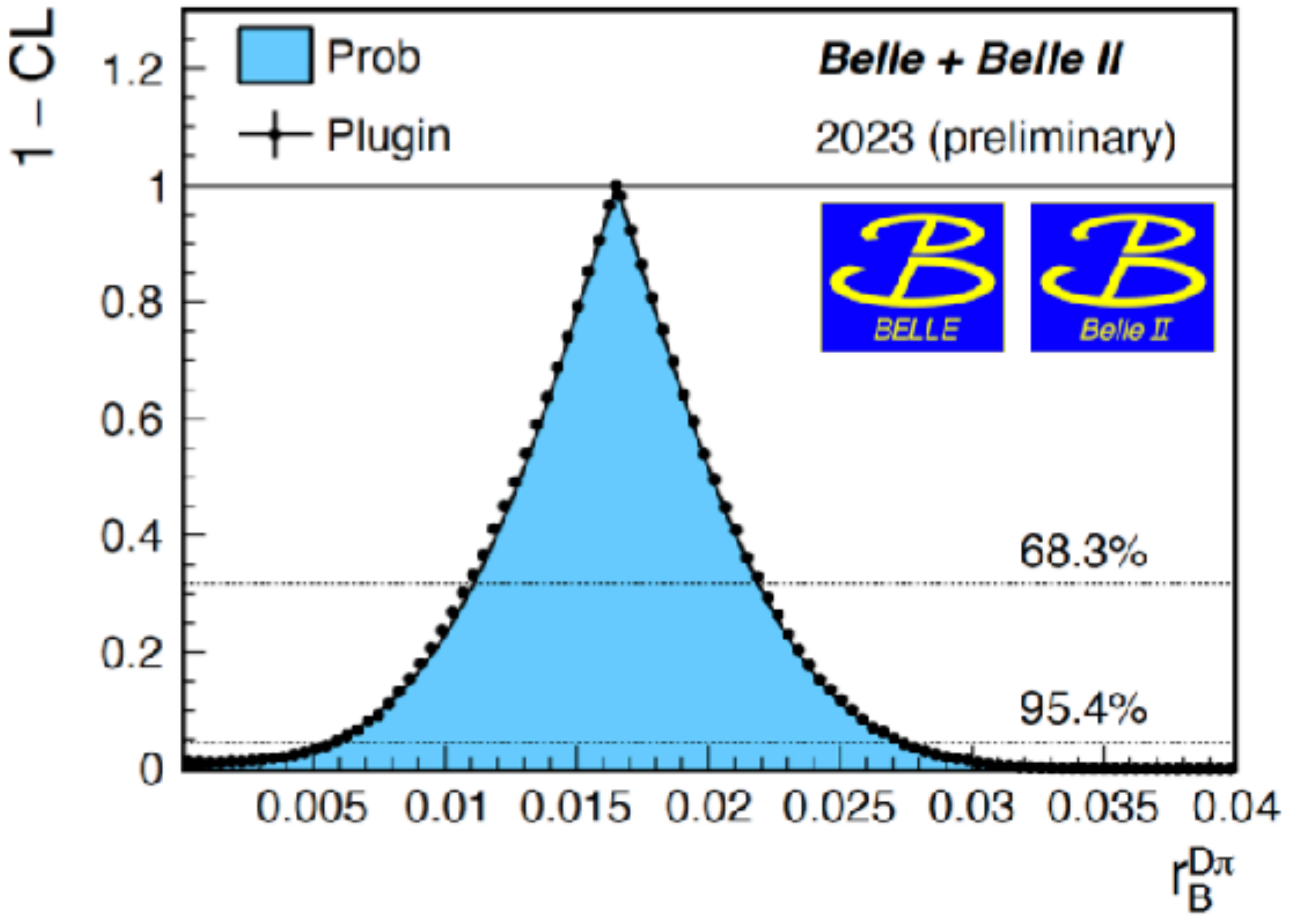
Combined measurement of ϕ_3 with Belle & Belle II

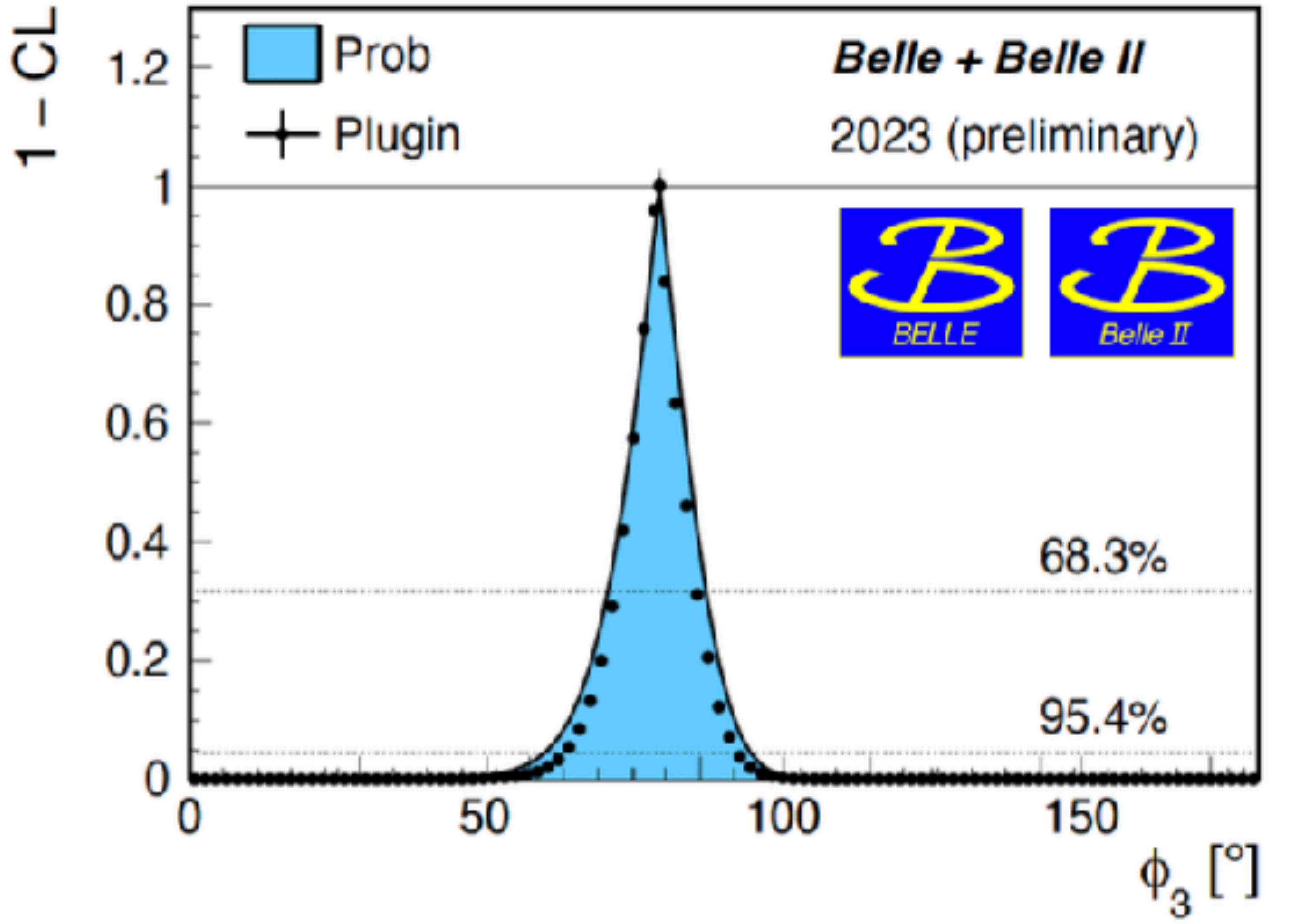
Preliminary

- Four different methods using 17 different final states
- Inputs on D decays dynamics from other experiments
  - r_D (amplitude ratio), δ_D (strong-phase difference), κ_D (coherence factor), etc.

B decay	D decay	Method	Data set (Belle + Belle II)[fb^{-1}]	
$B^+ \to Dh^+$	$D \to K_S^0 h^- h^+$	BPGGSZ	$711 + 128$	[JHEP 02 063 (2022)]
$B^+ \to Dh^+$	$D \to K_S^0 \pi^- \pi^+ \pi^0$	BPGGSZ	$711 + 0$	[JHEP 10 178 (2019)]
$B^+ \to Dh^+$	$D \to K_S^0 \pi^0, K^- K^+$	GLW	$711 + 189$	[arxiv:2308.05048]
$B^+ \to Dh^+$	$D \to K^+ \pi^-, K^+ \pi^- \pi^0$	ADS	$711 + 0$	[PRL 106 231803 (2011)]
$B^+ \to Dh^+$	$D \to K_S^0 K^- \pi^+$	GLS	$711 + 362$	[JHEP 09 (2023) 146]
$B^+ \to D^* K^+$	$D \to K_S^0 \pi^- \pi^+$	BPGGSZ	$605 + 0$	[PRD 81 112002 (2010)]
$B^+ \to D^* K^+$	$D \to K_S^0 \pi^0, K_S^0 \phi, K_S^0 \omega, K^- K^+, \pi^- \pi^+$	GLW	210+0	[PRD 73 051106 (2006)]

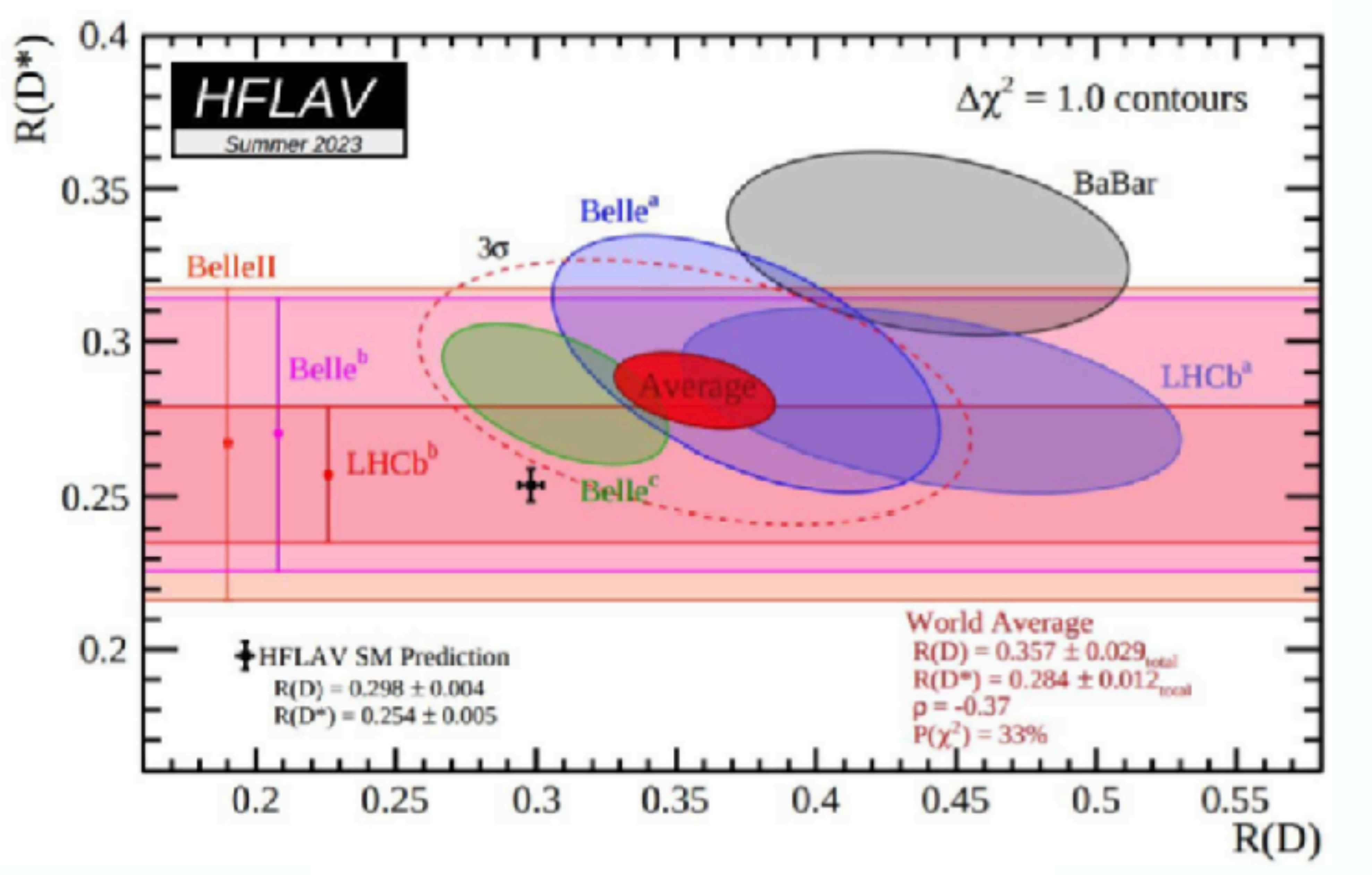
Parameters	$\phi_3(^\circ)$	r_B^{DK}	$\delta_B^{DK}(^\circ)$	$r_B^{D\pi}$	$\delta_B^{D\pi}(^\circ)$	$r_B^{D^*K}$	$\delta_B^{D^*K}(^\circ)$
			Plugin method				
Best fit value	78.6	0.117	138.4	0.0165	347.0	0.234	341
68.3% interval	[71.4, 85.4]	[0.105, 0.130]	[129.1, 146.5]	[0.0109, 0.0220]	[337.4, 355.7]	[0.165, 0.303]	[327,355]
95.5% interval	[63, 92]	[0.092, 0.141]	[118, 154]	[0.006, 0.027]	[322, 366]	[0.10, 0.37]	[307, 369]

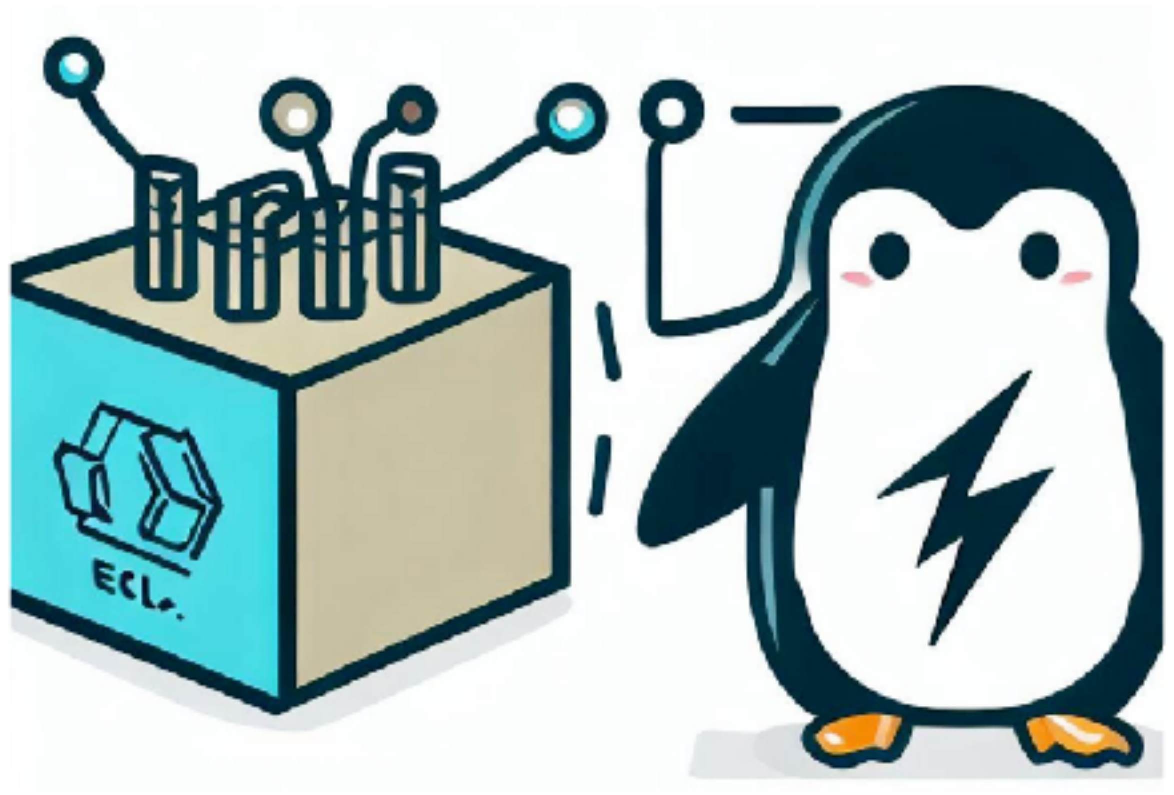


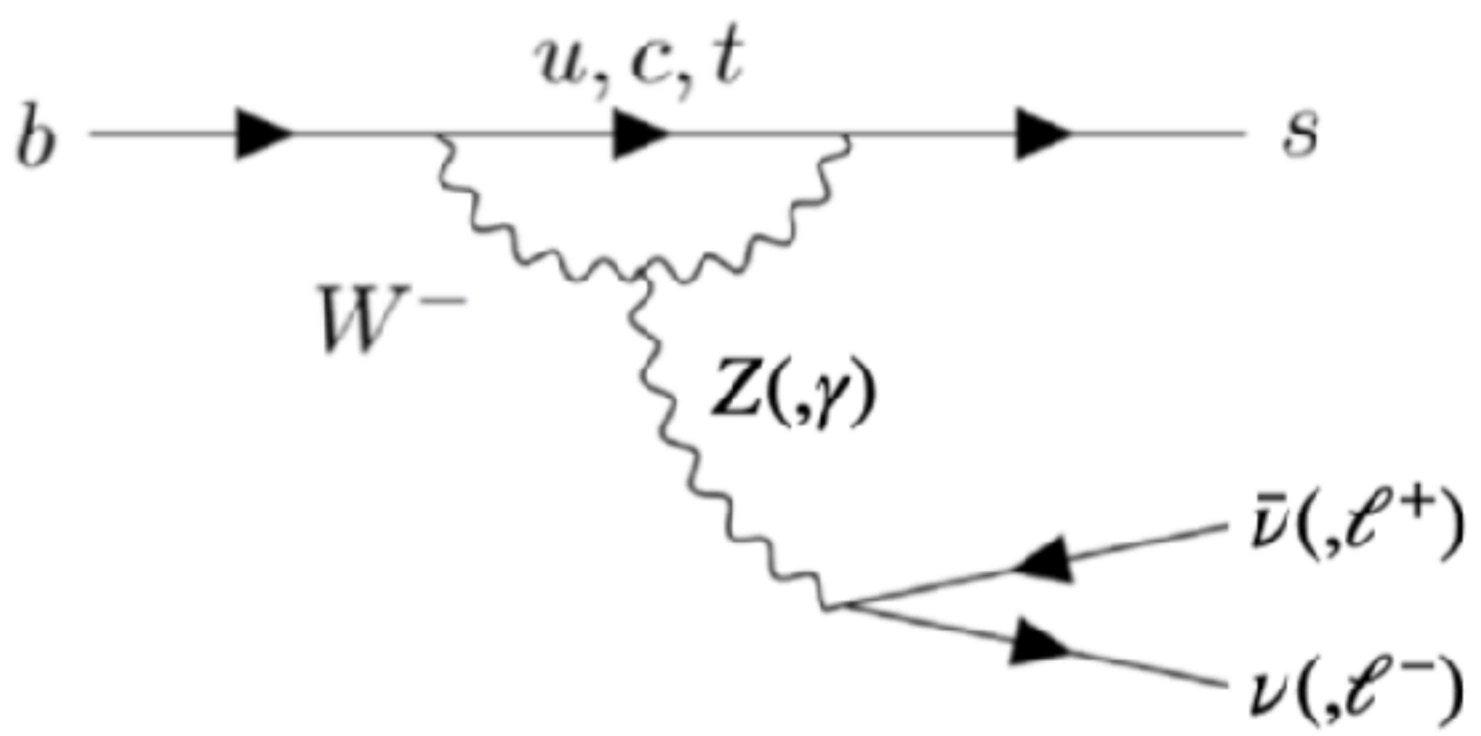


$\phi_3 = (78.6 \pm 7.3)^\circ$, consistent with WA, $\phi_3 = (66.2^{+3.2}_{-3.6})^\circ$, within 2σ

B anomalies







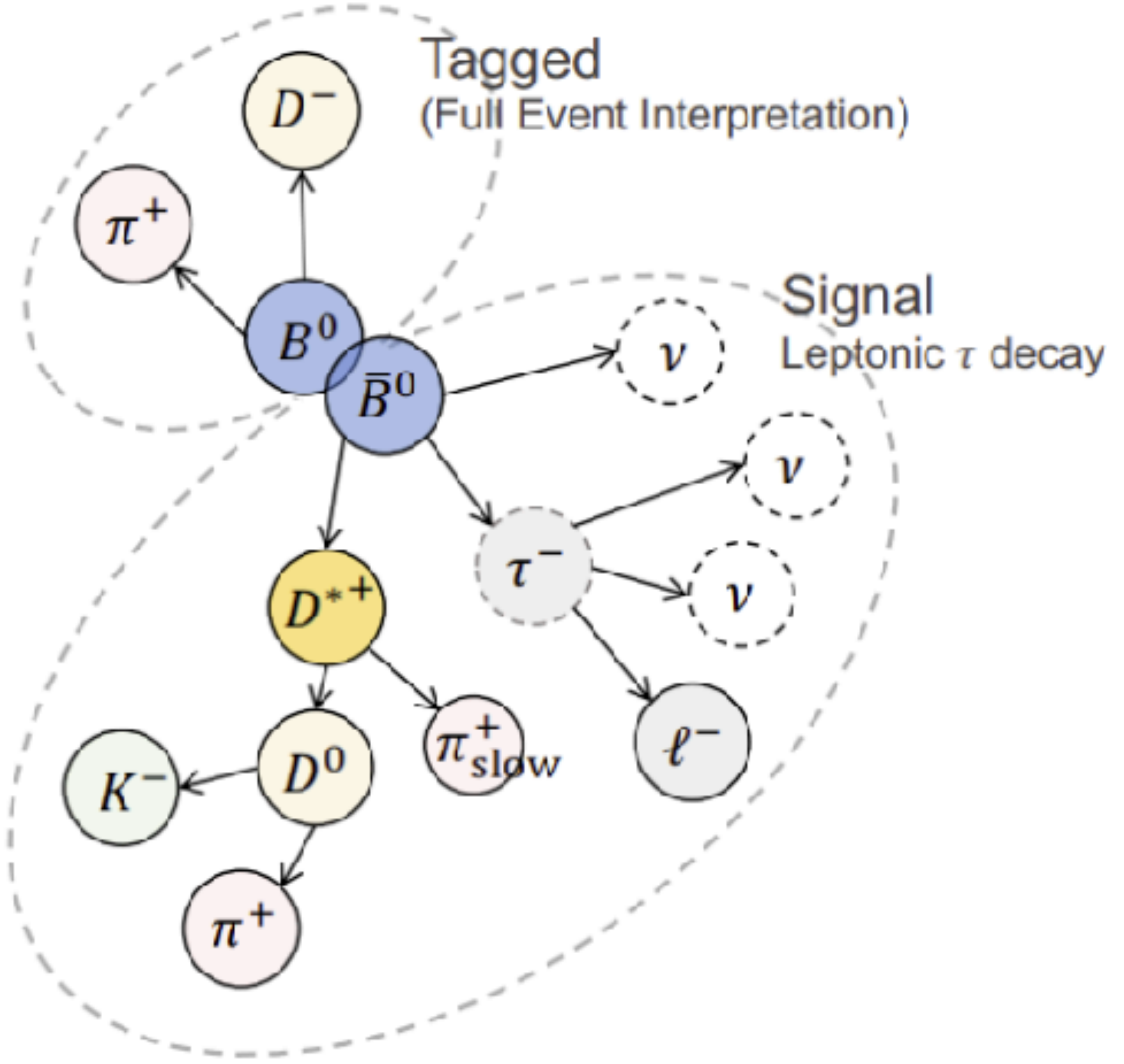
$$R(D^{(*)}) = \frac{\mathcal{B}(B \to D^{(*)}\tau\nu_\tau)}{\mathcal{B}(B \to D^{(*)}\ell\nu_\ell)},$$

$\ell = e, \mu$

- SM predictions greatly confirmed by a variety of flavor and non-flavor measurements.
- Hints for anomalies from indirect searches of NP: some are gone, some are persisting

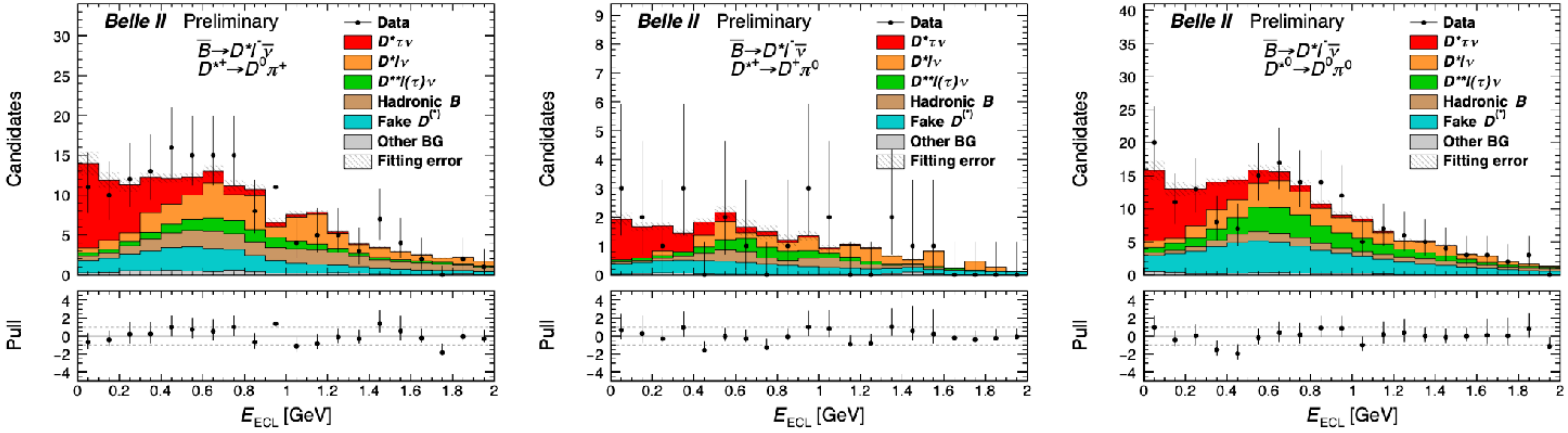
Measurement of $R(D^*)$ Preliminary

First $R(D^*)$ measurement on Belle II



$B \to D^*\tau\nu$ and $B \to D^*\ell\nu$ measured by 2D binned likelihood fit to:

- Missing mass of undetected neutrinos
- Sum of energy from extra photons in ECL (E_{ECL})



Signal enhanced region

$M^2_{\mathrm{miss}} \in [1.5,\ 6.0]\ \mathrm{GeV}^2$

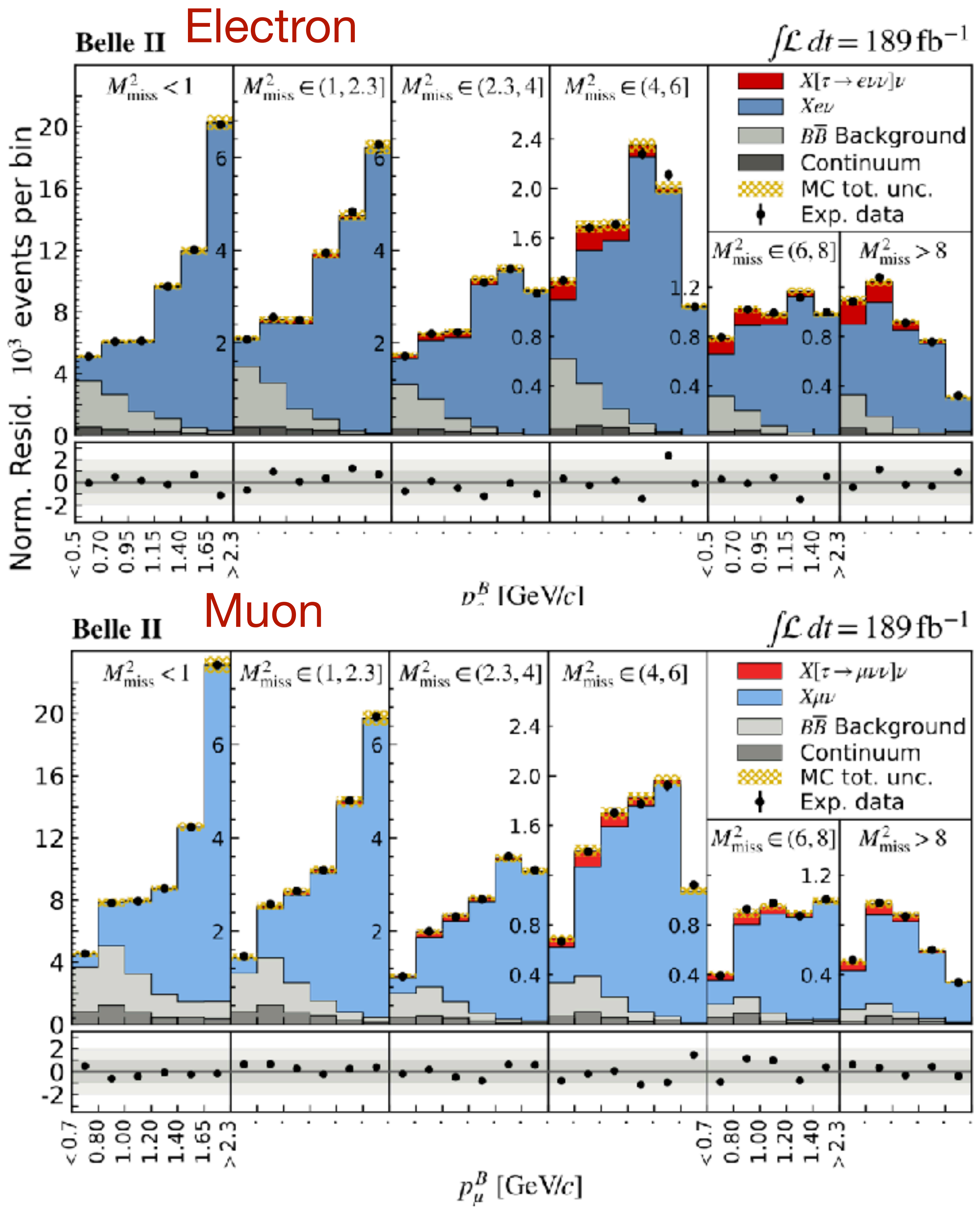
$$R(D^*) = 0.267\ ^{+0.041}_{-0.039}(\mathrm{stat.})\ ^{+0.028}_{-0.033}(\mathrm{syst.})$$

Consistent with the SM and previous measurements.

First measurement of $R(X_{\tau/\ell})$ arXiv:2311.07248

- $R(X_{\tau/\ell}) = \dfrac{\mathcal{B}(B \to X\tau\nu_\tau)}{\mathcal{B}(B \to X\ell\nu_\ell)}$, measure inclusively. First measurement at B factories
- X reconstructed from remaining tracks and neutral clusters.
- Variables for yield extraction, 2D-fit to M^2_{miss} and p^B_ℓ
- Results:
  - $R(X_{\tau/e}) = 0.232 \pm 0.020(\text{stat.}) \pm 0.037(\text{syst.})$
  - $R(X_{\tau/\mu}) = 0.222 \pm 0.027(\text{stat.}) \pm 0.050(\text{syst.})$
- Combining:
  - $R(X_{\tau/\mu}) = 0.228 \pm 0.016(\text{stat.}) \pm 0.036(\text{syst.})$

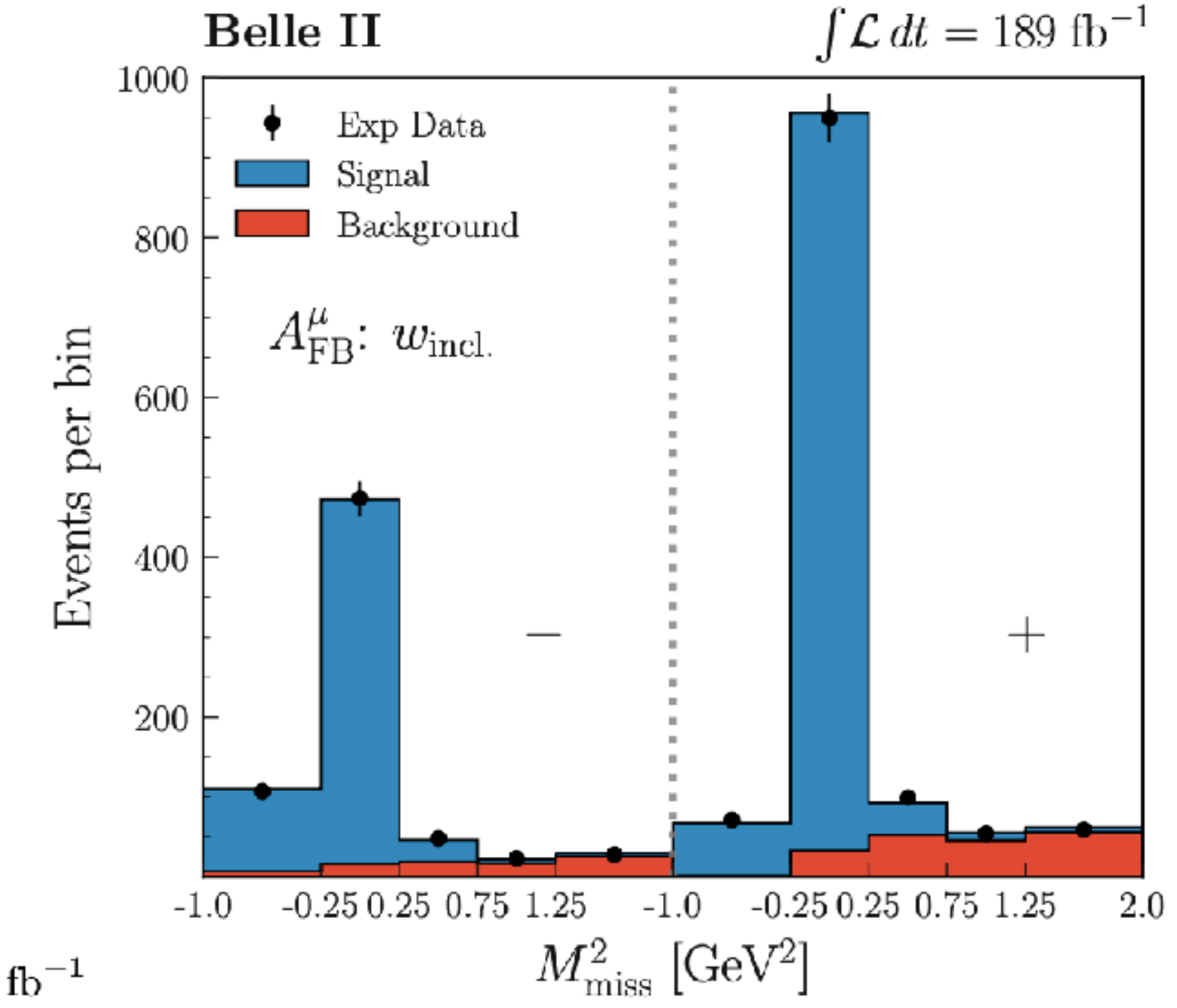
In agreement with SM prediction and $R(D^{(*)})$ measurements

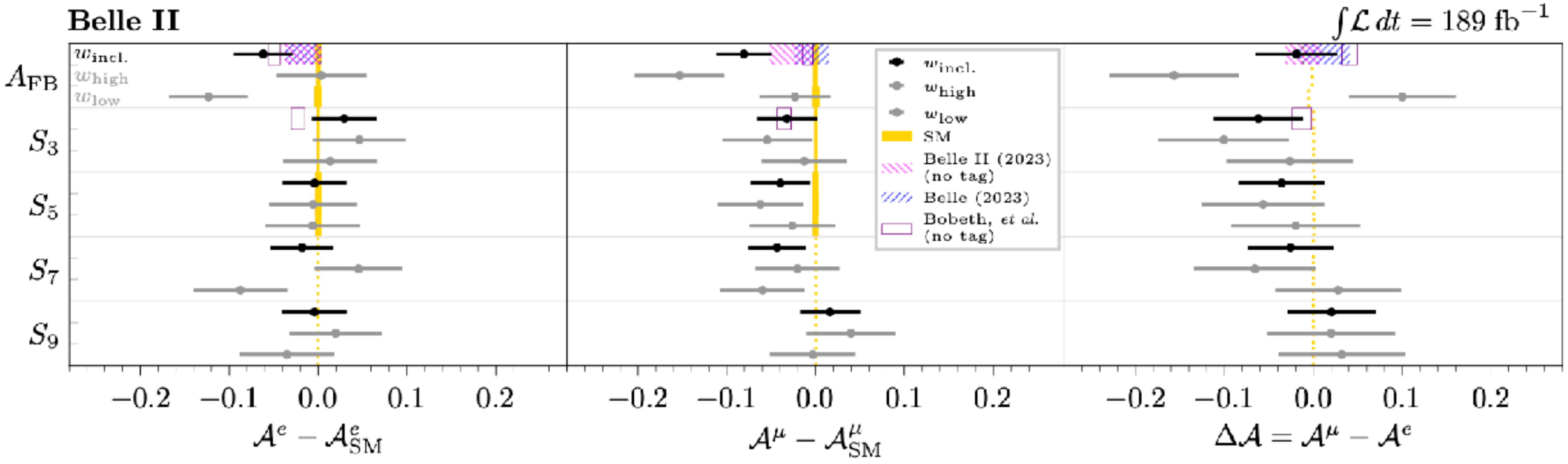


Angular asymmetries using $B^0 \to D^{*-}\ell^+\nu_\ell$

PRL 131, 181801 (2023)

- $B^0 \to D^{*-}\ell\nu$ is mediated in the SM via W-boson exchange.
- Characterized in terms of a recoil parameter and 3 helicity angles.
- Calculate the asymmetry: $\mathscr{A}_x(w) = \dfrac{N_x^+ w - N_x^-(w)}{N_x^+ w + N_x^-(w)}$
- Difference $\Delta A_x(w) = A_x^\mu(w) - A_x^e(w)$, is sensitive to LUV.
- Separate signal candidates into angular categories + and – based on the measured value of x.





First comprehensive tests of LU in the angular distributions of semileptonic B decays.

Agrees well with SM.

CP and isospin asymmetries in $B \to \rho\gamma$

Combine Belle+Belle II preliminary

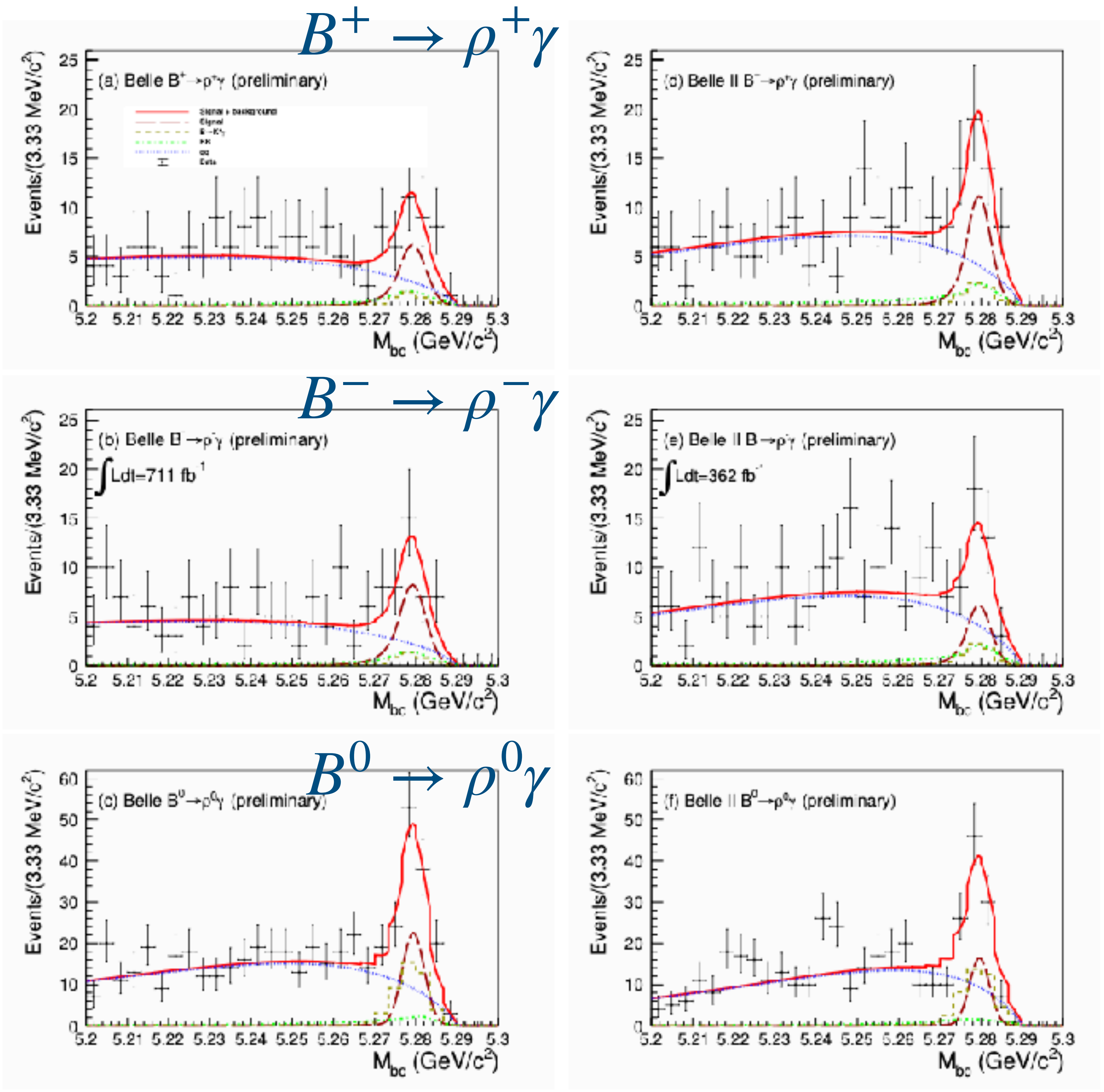
- Clean environment to search for BSM physics
- SM expect CP-average isospin asymmetry as $\bar{A}_{\mathrm{I}}^{\mathrm{SM}} = (5.2 \pm 2.8)\,\%$

$$A_{\mathrm{I}} = (A_{\mathrm{I}}^{\bar{0}-} + A_{\mathrm{I}}^{0+})/2, \text{ with } A_{\mathrm{I}}^{\bar{0}-} = \frac{c_\rho^2\Gamma(\bar{B}^0 \to \rho^0\gamma) - \Gamma(B^- \to \rho^-\gamma)}{c_\rho^2\Gamma(\bar{B}^0 \to \rho^0\gamma) + \Gamma(B^- \to \rho^-\gamma}$$

- Current world average $A_{\mathrm{I}}^{\mathrm{exp}} = (30^{+16}_{-13})\,\%$.

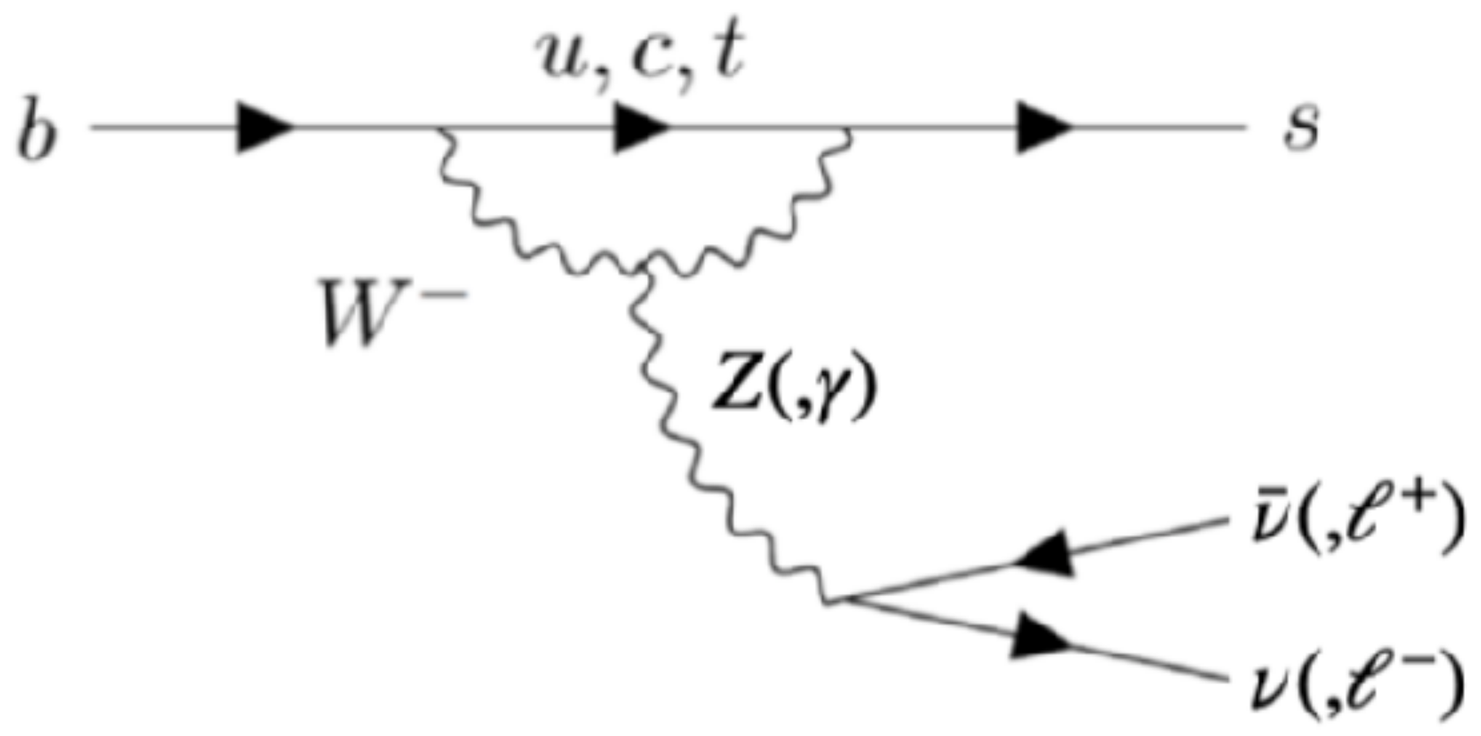
$$\mathcal{B}\left(B^+ \to \rho^+\gamma\right) = \left(12.85^{+2.02+1.38}_{-1.92-1.13}\right) \times 10^{-7},$$
$$\mathcal{B}\left(B^0 \to \rho^0\gamma\right) = \left(7.45^{+1.33+0.97}_{-1.27-0.79}\right) \times 10^{-7},$$
$$A_{\mathrm{CP}}\left(B^+ \to \rho^+\gamma\right) = \left(-7.1^{+15.3+1.4}_{-15.2-1.3}\right)\%,$$
$$A_{\mathrm{I}}\left(B \to \rho\gamma\right) = \left(14.2^{+11.0+6.6+6.0}_{-11.7-6.4-6.5}\right)\%,$$

- *Consistent with the SM prediction.*
- *Highest precision to date; supersede the previous measurements from Belle*



Measurement of branching fraction of $B^+ \to K^+\nu\bar{\nu}$

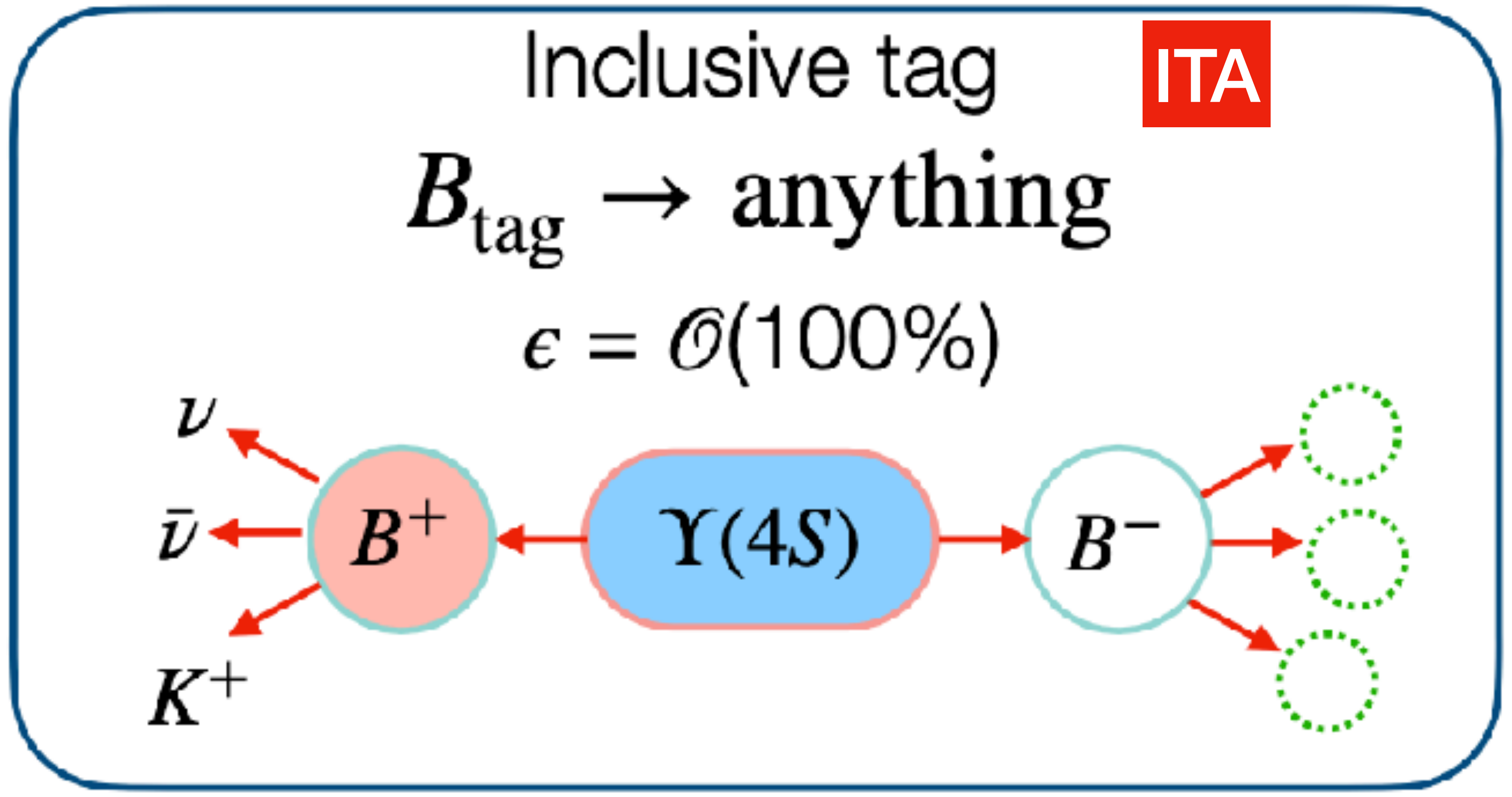
arXiv:2311.14647

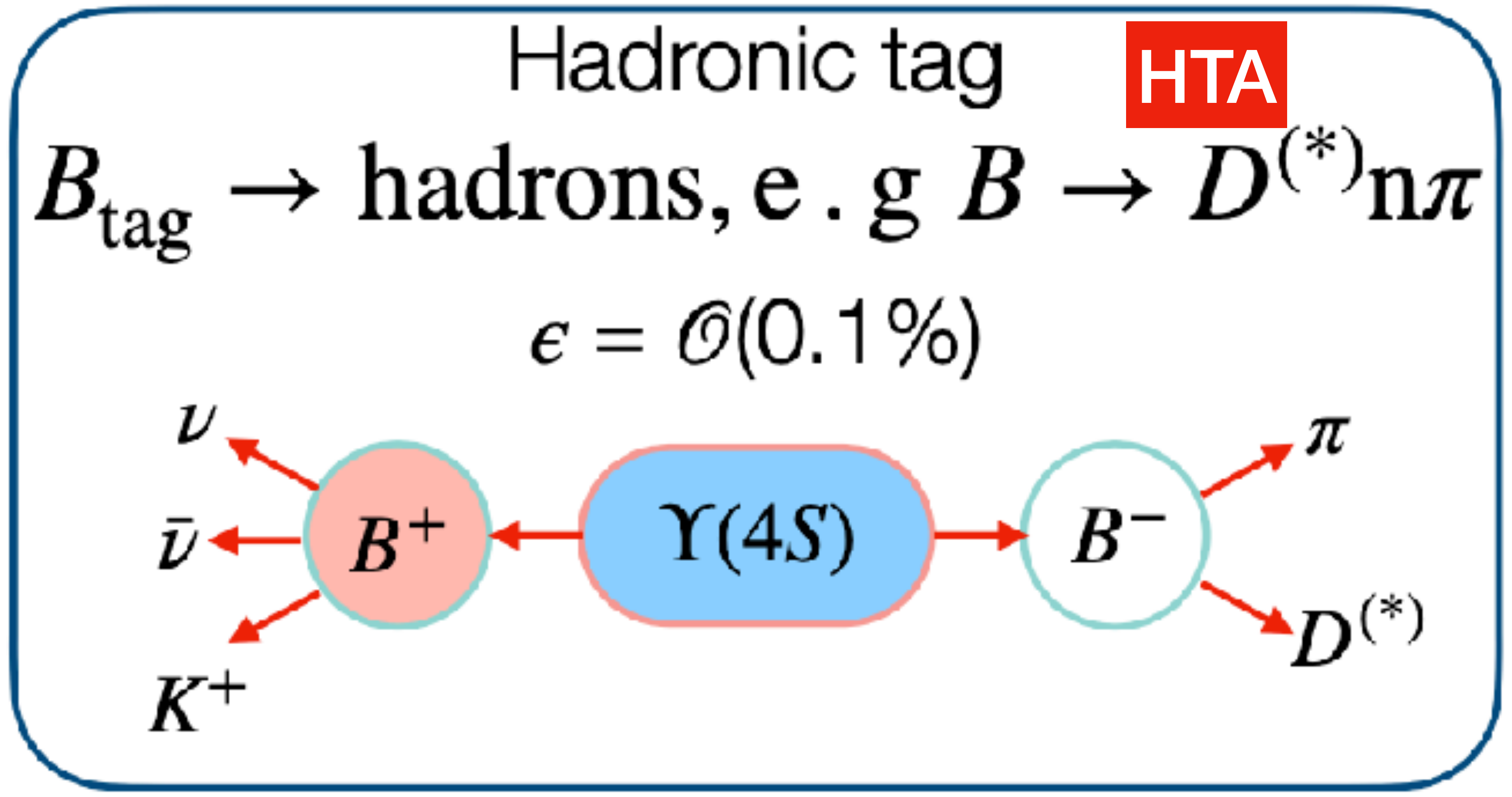


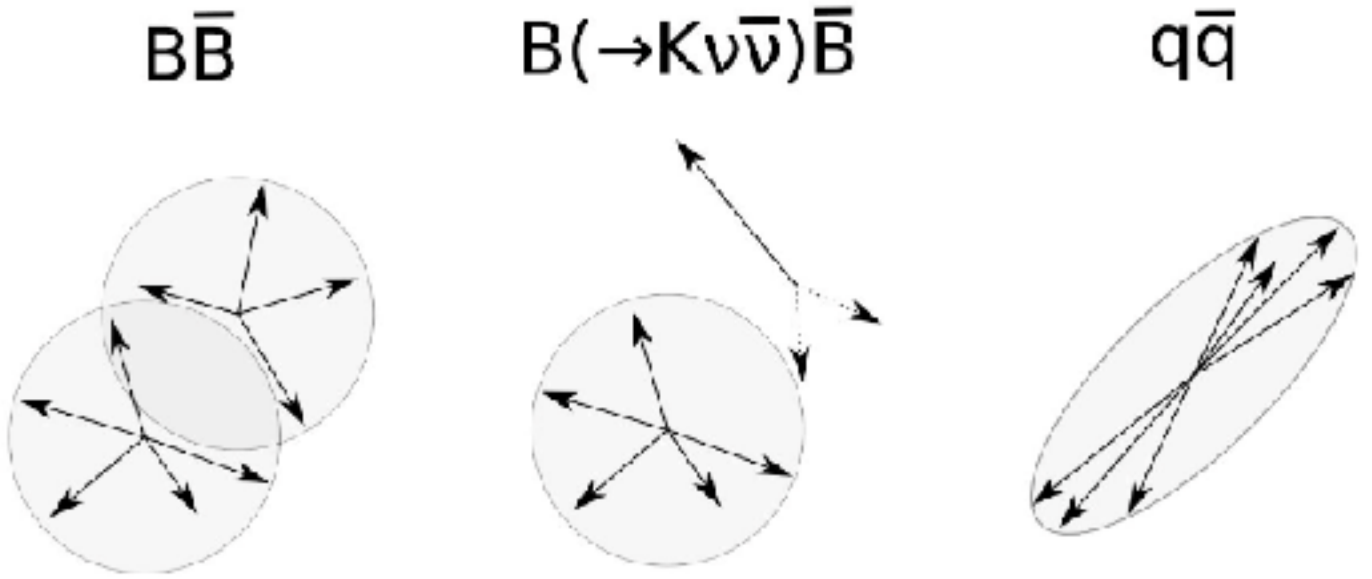
- The $B \to K\nu\nu$ process is known with high accuracy in the SM:
  - $\mathscr{B}(B^{\to}K^+\nu\nu) = (5.6 \pm 0.4) \times 10^{-6}$(arXiv:2207.13371)
  - We use 4.97×10^{-6} as a reference, after removal of $B \to \tau(K\bar{\nu})\nu$
- Extensions beyond SM may lead to significant rate increase
- Very challenging experimentally, not yet observed
  - Low branching fraction, high background contributions
  - 3-body kinematics, no good kinematic variable to fit

Analysis strategy

arXiv:2311.14647





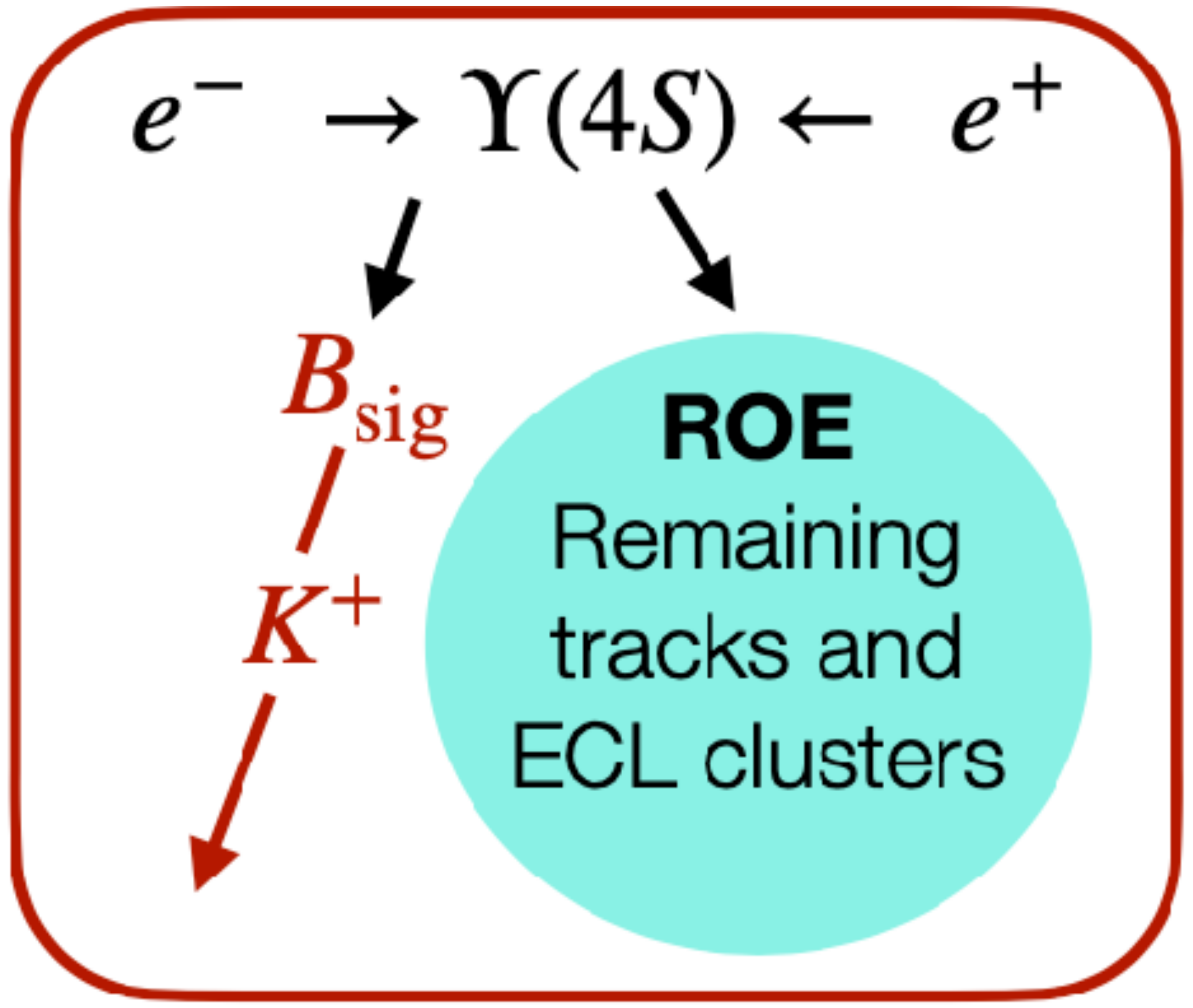


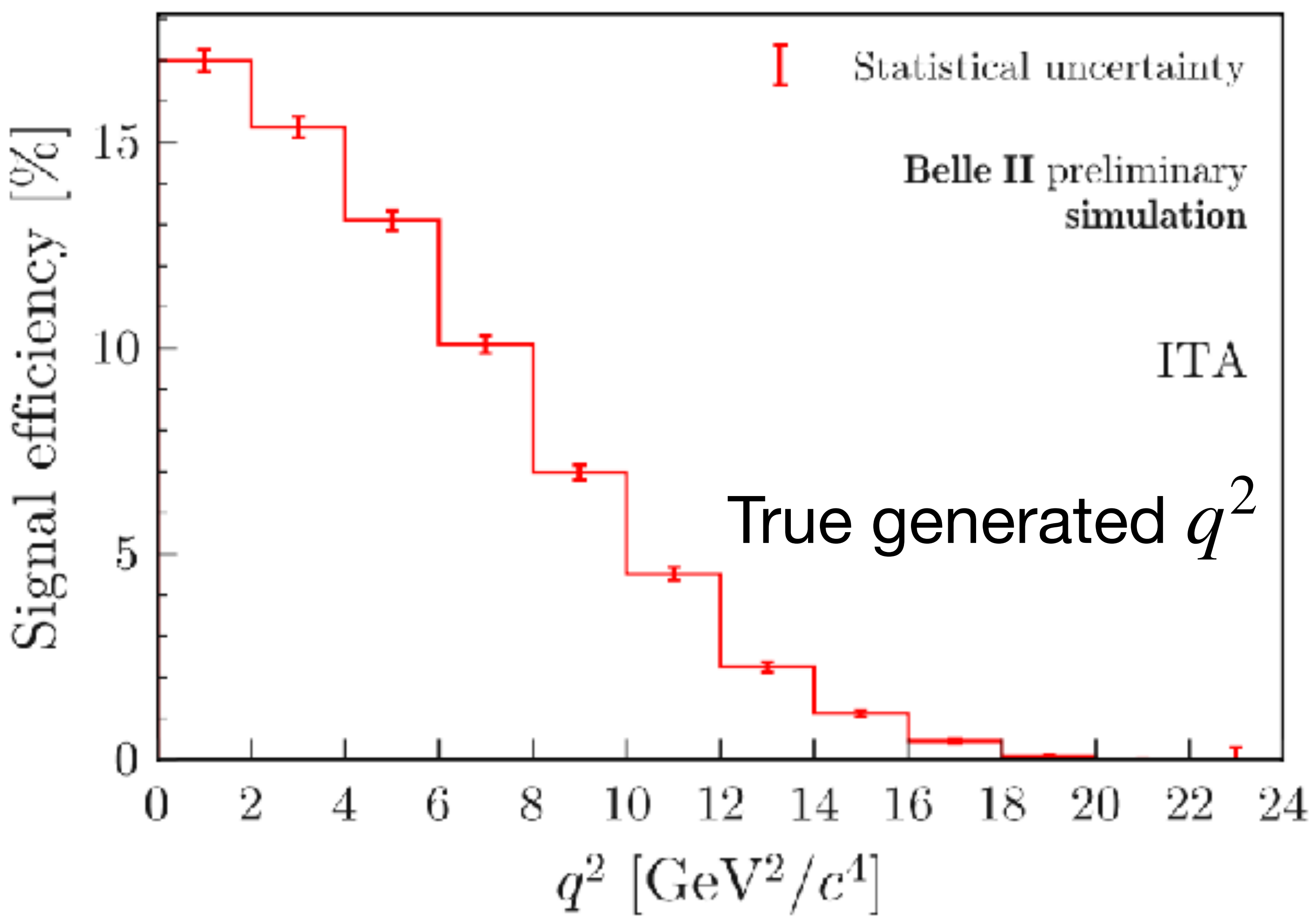
- Two analyses:
  - More sensitive inclusive tagging (ITA)
  - Conventional hadronic tagging (HTA)
- Kinematic properties to suppress background with MVA
- Use classifier output as (one of) the fit variable(s), use simulation for signal and background templates
- Use multiple control channels to validate simulation with data

arXiv:2311.14647

Inclusive-tag

- Reconstruct signal kaon candidate by applying kaon-enriching selection.
- Assign remaining tracks and ECL clusters to the rest of event (ROE)
- Three steps filter:
  - Basic event cuts: tracks, neutral, candidate, etc.
  - BDT_1: 12 variables based kinematic variables; $\mathrm{BDT}_1 > 0.9$
  - BDT_2: 35 variables using signal, event, and their correlations. Final selection.
- Use $q^2_{\mathrm{rec}} = s + M_K^2 - \sqrt{s}E_K^*$ and $\eta(\mathrm{BDT}_2) \equiv 1 - \int_{\mathrm{BDT}_2}^{1} \epsilon(b)db$ to yield signals.

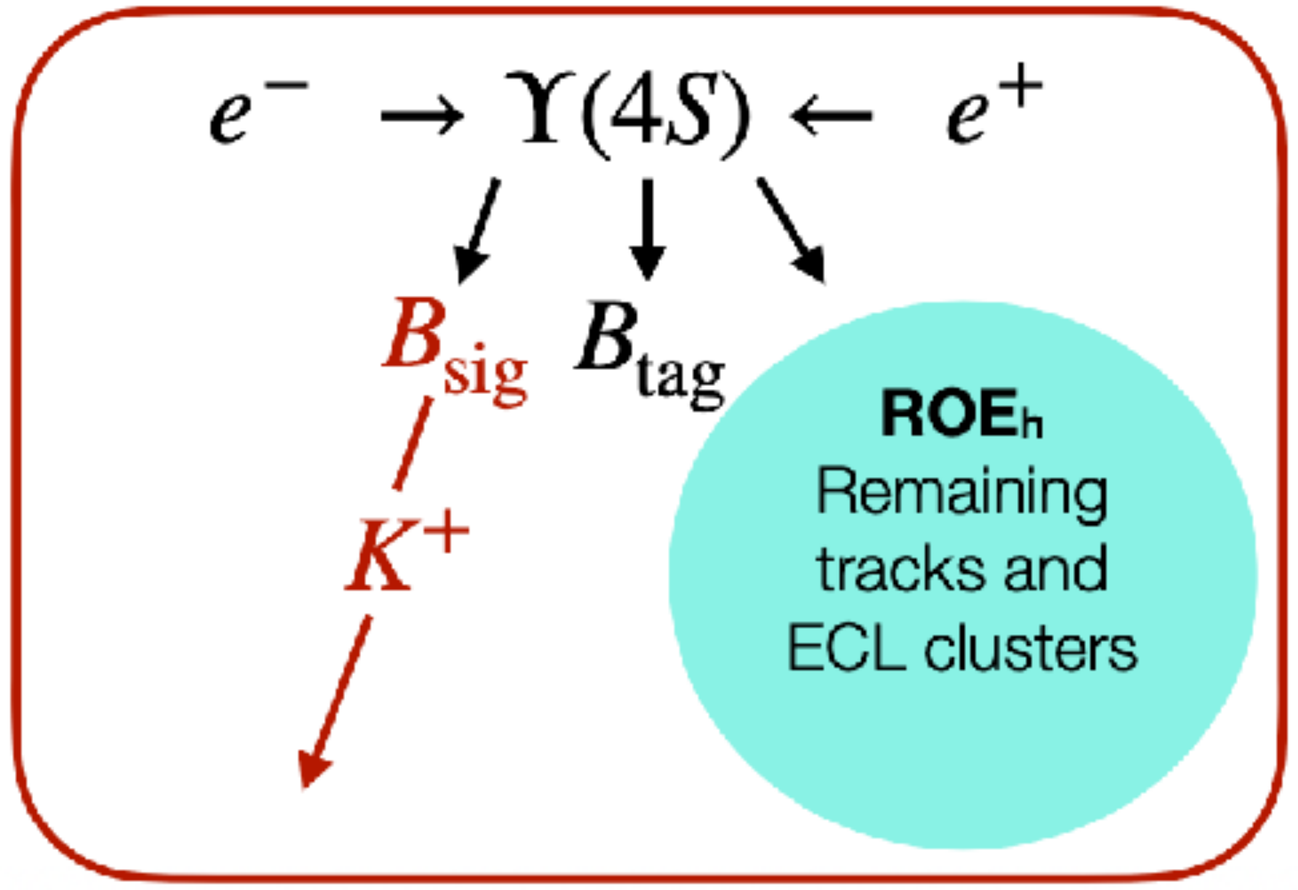


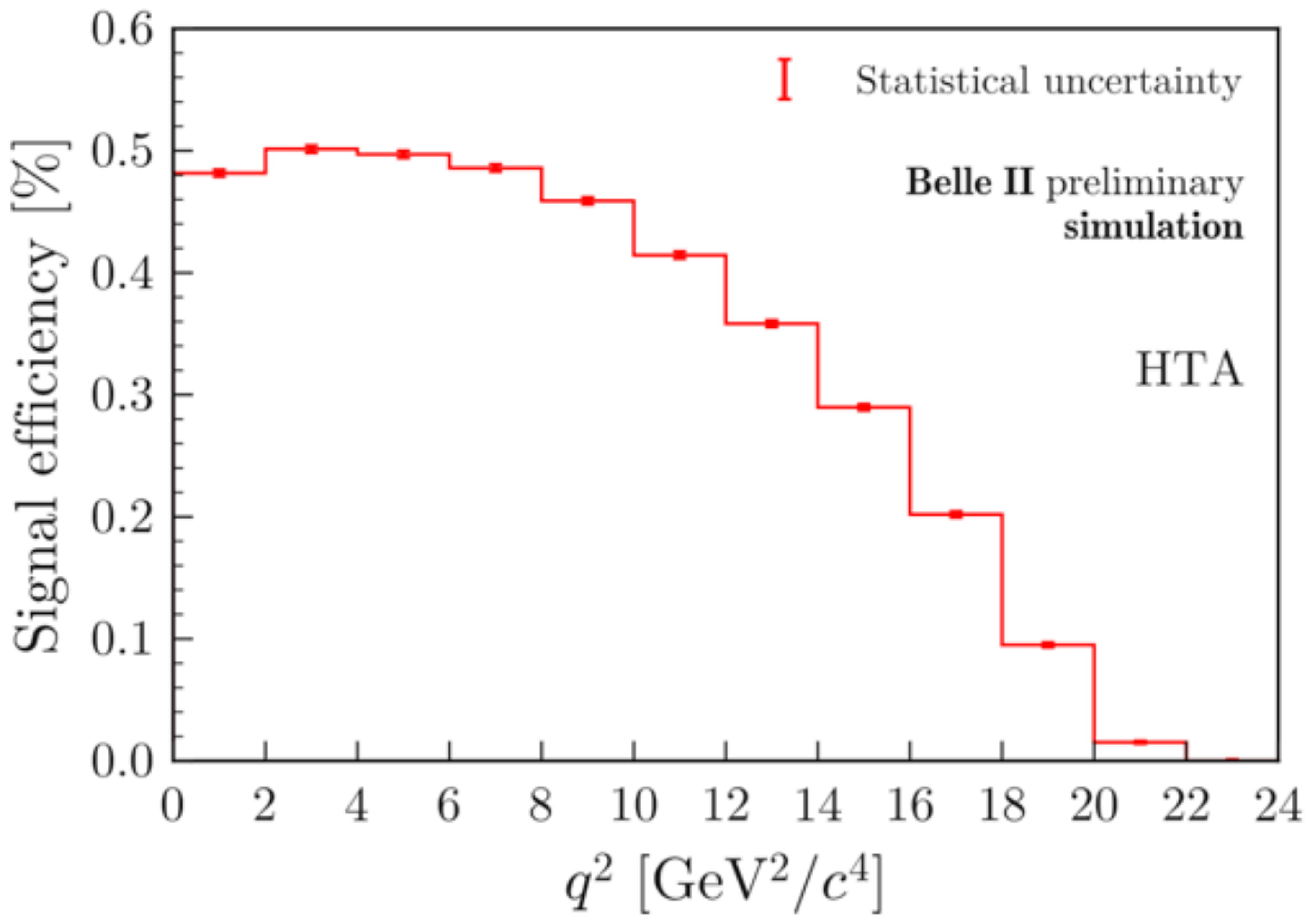


High signal efficiency

Hadronic-tag

- Reconstruct of accompanying B meson, B tag, decaying into one of 35 hadronic final states using FEI.
- Reconstruct signal kaon candidates
- Build rest-of-event (ROEh) from remaining tracks and ECL clusters.
- $Mbc > 5.27\ \mathrm{GeV},\ |\Delta E| < 300\ \mathrm{MeV}$
- Combine signal kaon, B tag, ROEh (12 variables) info in an MVA.
- Determine signal strength using $\eta(\mathrm{BDT_h})$





High purity

FIT

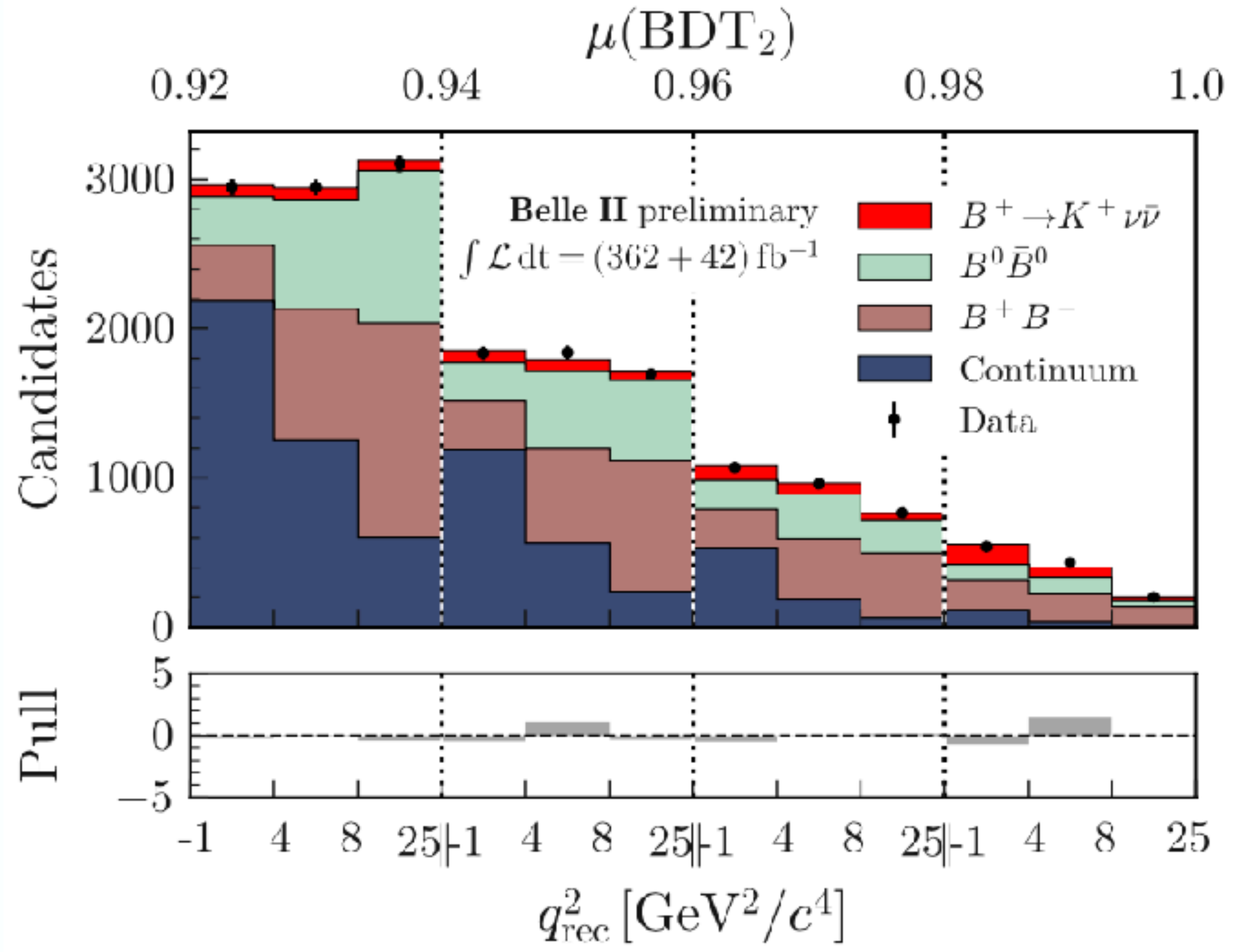
arXiv:2311.14647

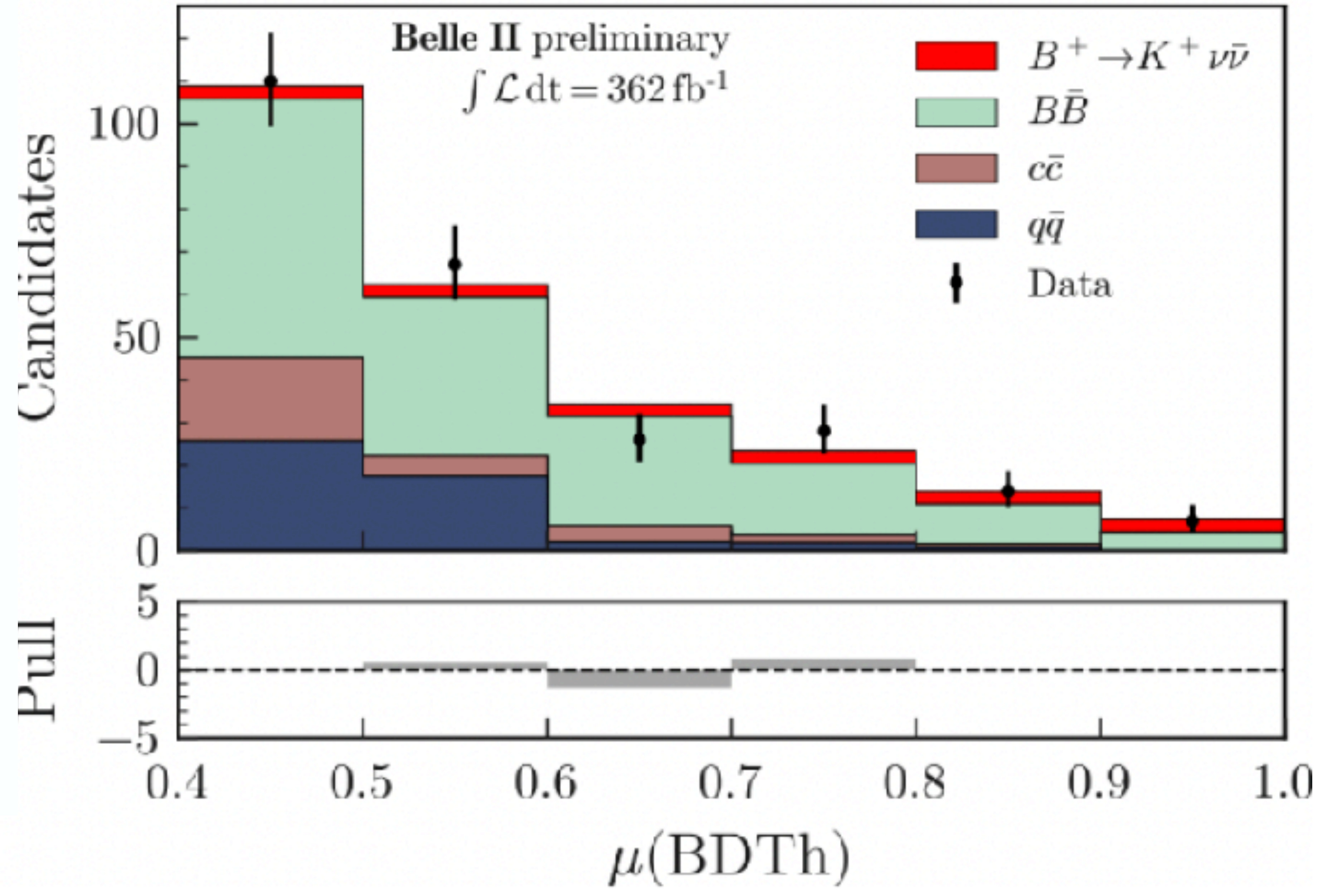
- Extract signal from maximum likelihood fit
  - Inclusive tag: in bins of q^2_{rec} and $\eta(\mathrm{BDT}_2)$
  - Hadronic tag: in bins of $\eta(\mathrm{BDT_h})$
- Signal is extracted in terms of signal strength μ

  signal relative to SM expectation

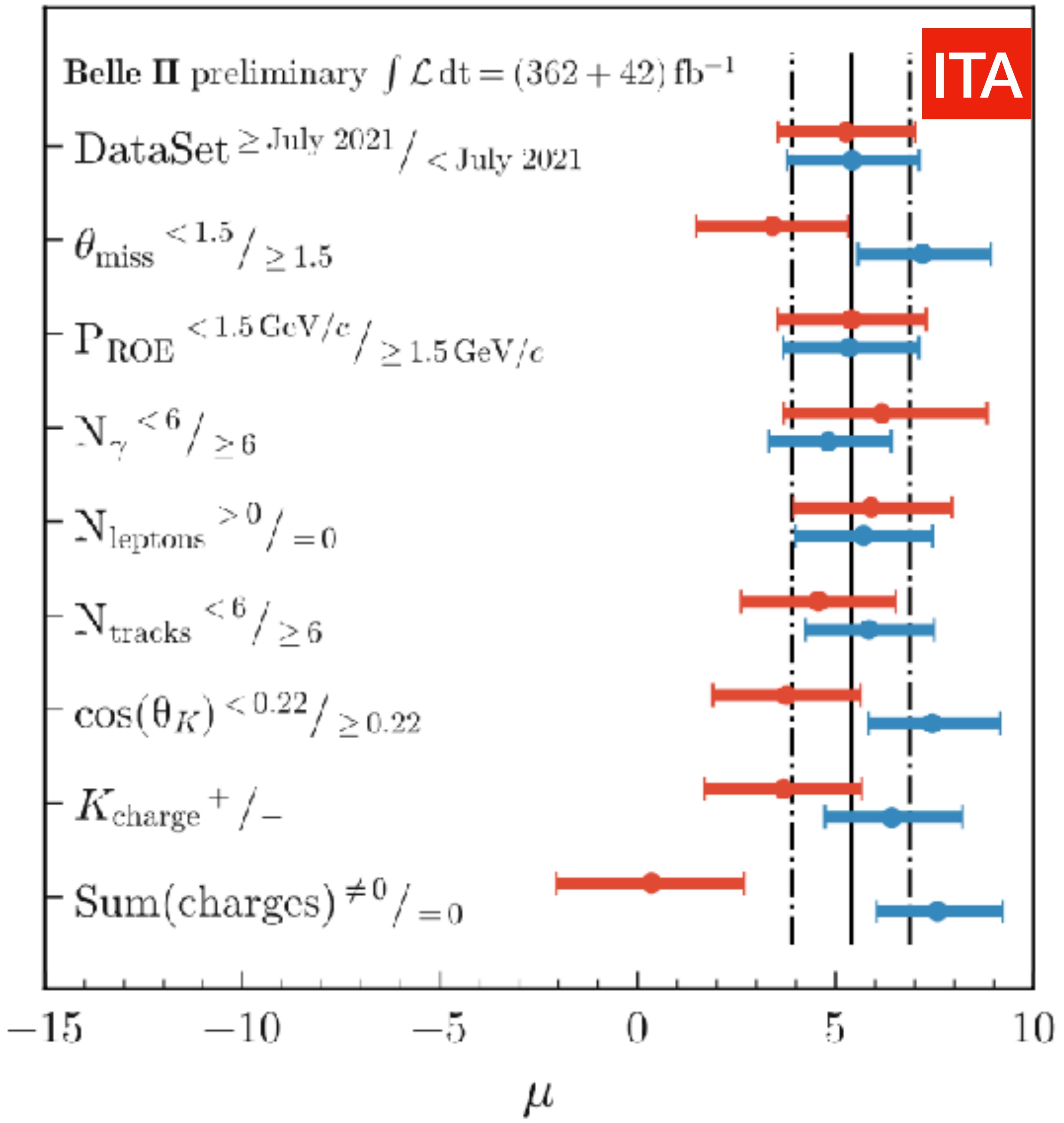
  - Inclusive tag: $\mu = 5.4 \pm 1.0(\mathrm{stat}) \pm 1.1(\mathrm{syst})$
  - Hadronic tag: $\mu = 2.2^{+1.8}_{-1.7}(\mathrm{stat})^{+1.6}_{-1.1}(\mathrm{syst})$
  - Combined: $\mu = 4.6 \pm 1.0(\mathrm{stat}) \pm 0.9(\mathrm{syst})$

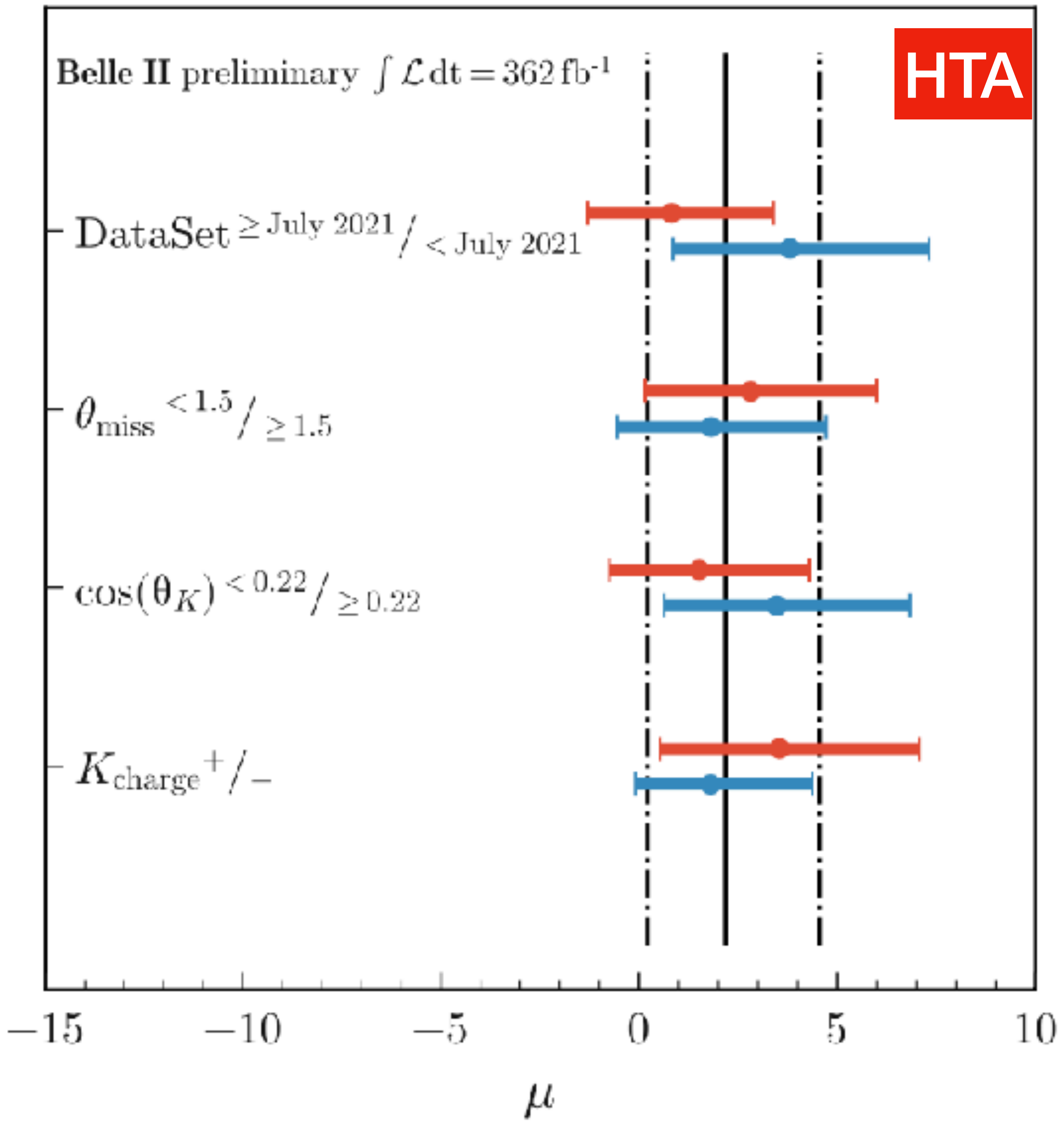
ITA and HTA results are consistent at 1.2σ level

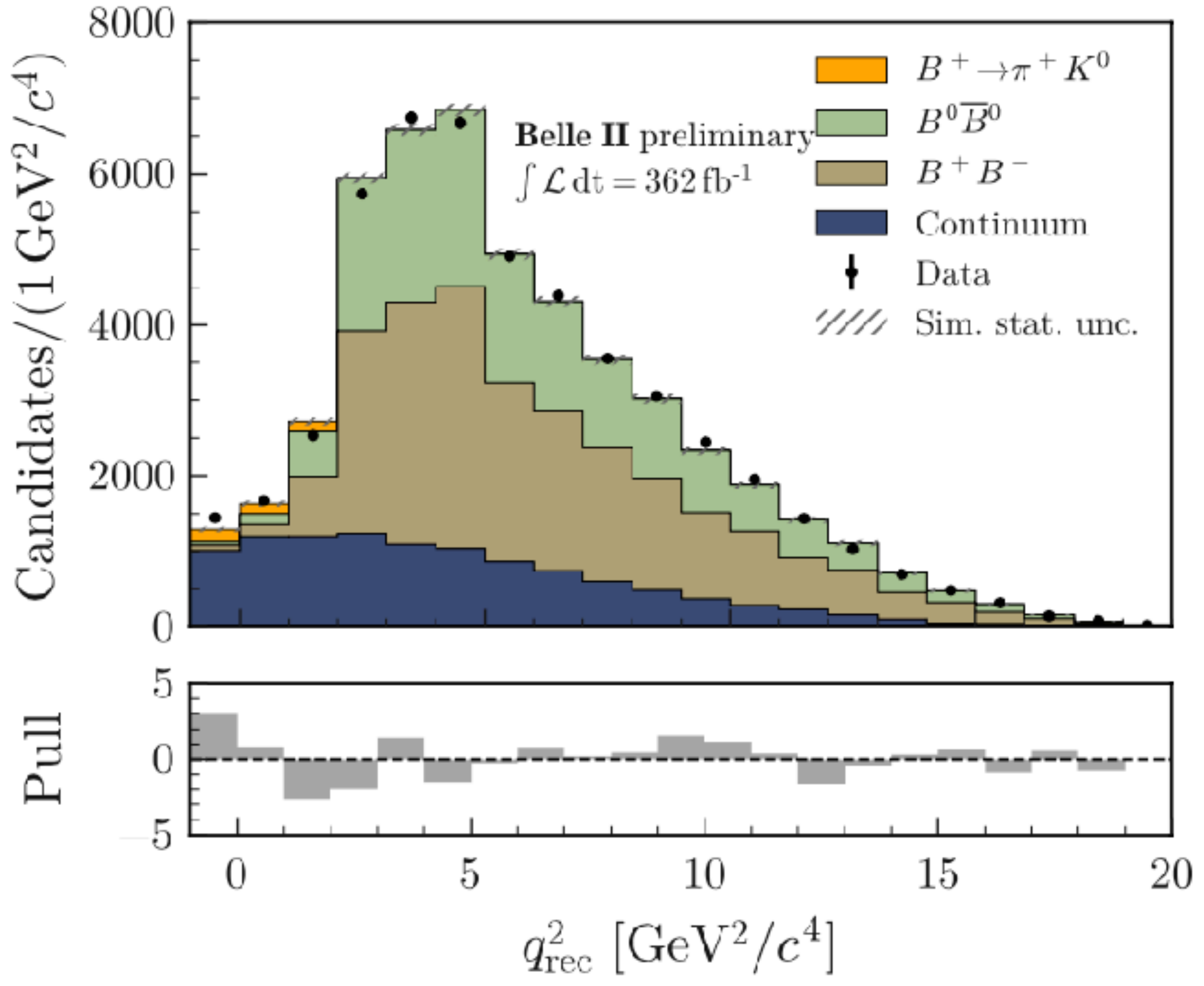




Cross check







- Multiple checks of the analyses stability, including tests dividing data into approximately equal sub-samples. Extra checks of “sum of charges” split.
- Control measurement of $B^+ \to \pi^+ K^0$decay

Inclusive tag: $\mathscr{B} = 2.7 \pm 0.5(\text{stat}) \pm 0.5(\text{syst})$

Hadronic tag: $\mathscr{B} = 1.1^{+0.9}_{-0.8}(\text{stat})^{+0.8}_{-0.5}(\text{syst})$

Combined: $\mathscr{B} = 2.3 \pm 0.5(\text{stat})^{+0.5}_{-0.4}(\text{syst})$

For the inclusive tag, significance of the result

- wrt null hypothesis is 3.5σ
- wrt SM is 2.9σ

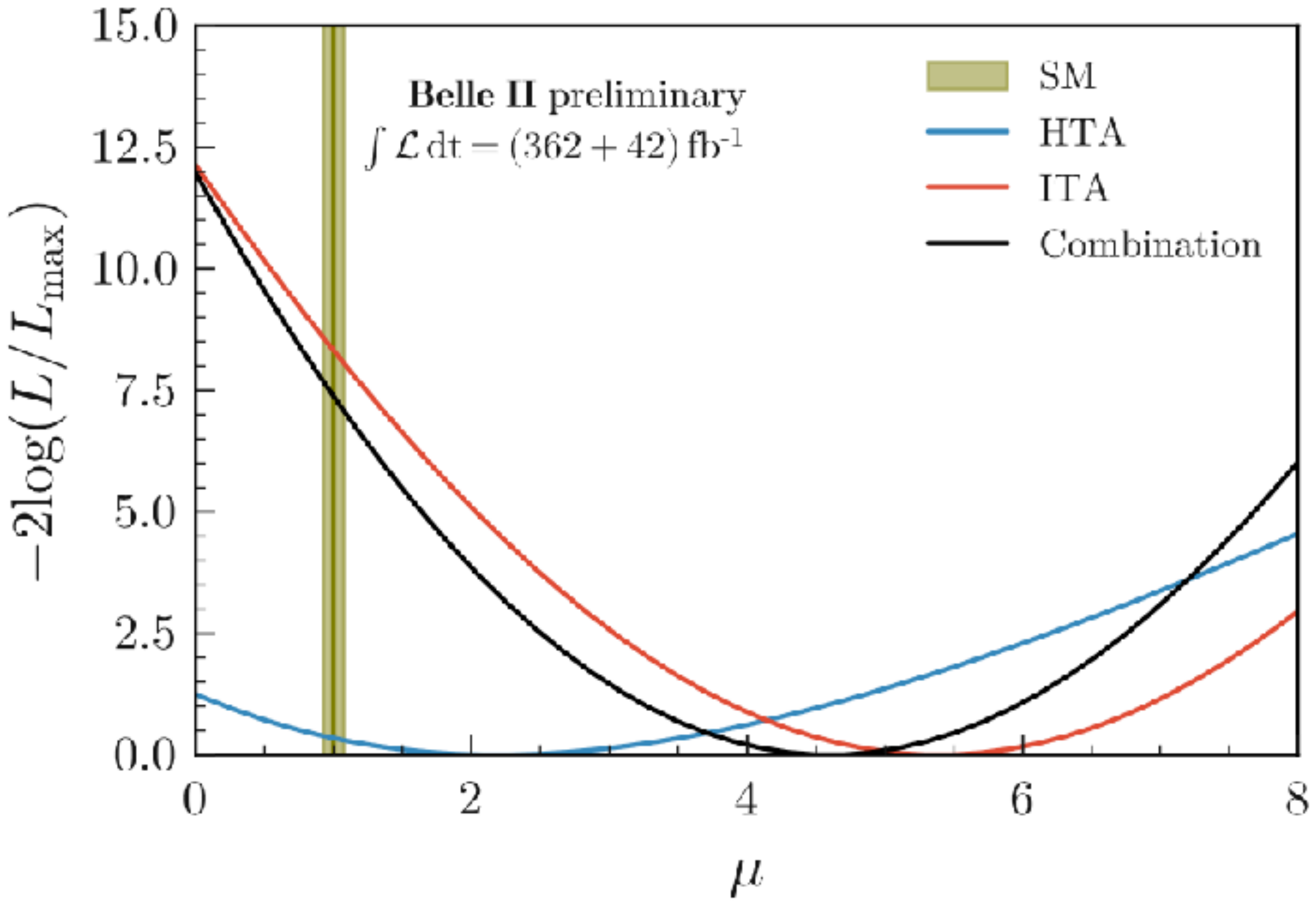
For the hadronic tag, significance of the result

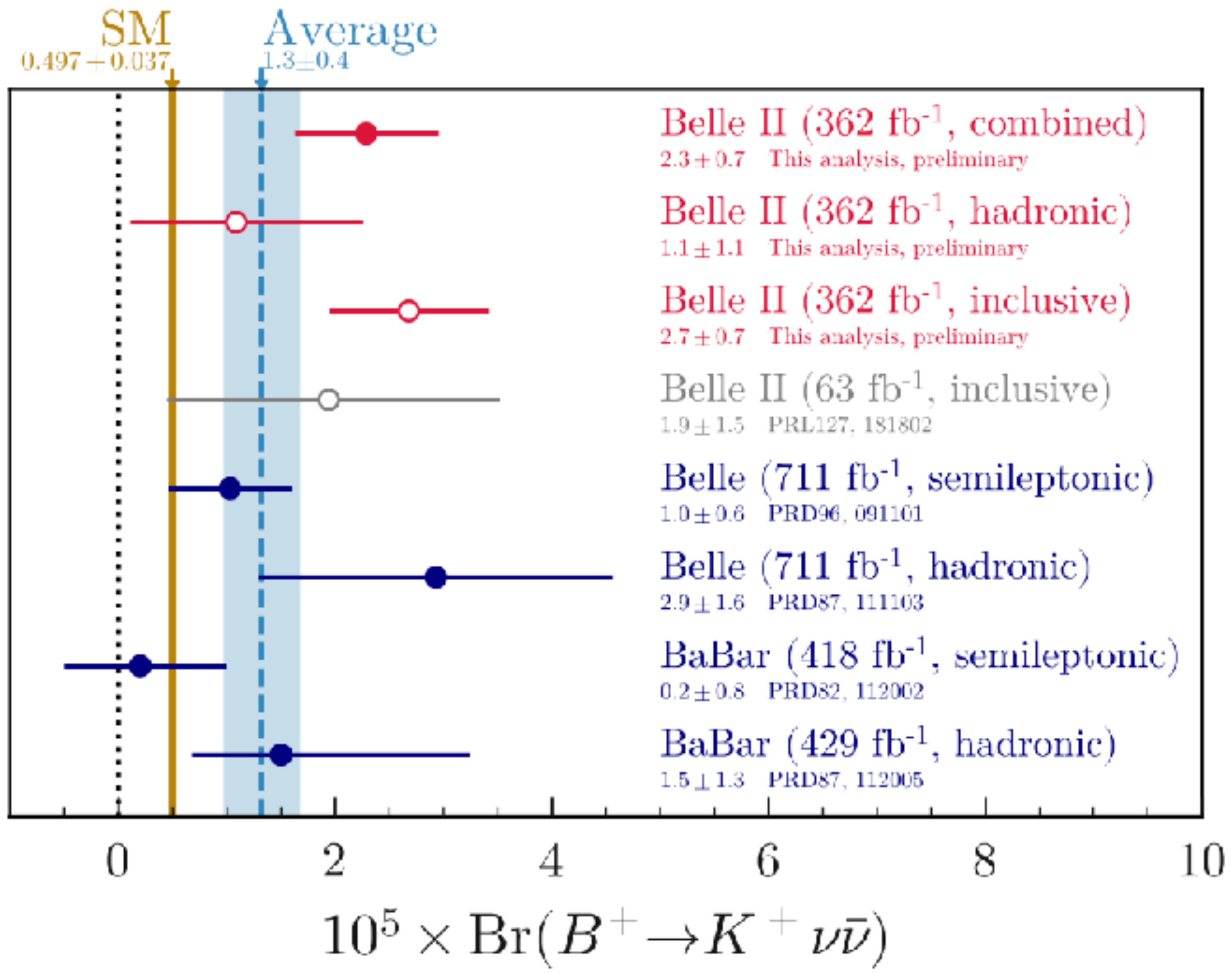
- wrt null hypothesis is 1.1σ
- wrt SM is 0.6σ

For the combination, significance of the result

- wrt null hypothesis is 3.5σ
- wrt SM is 2.7σ

First evidence of the $B^+ \to K^+\nu\bar{\nu}$ decay!





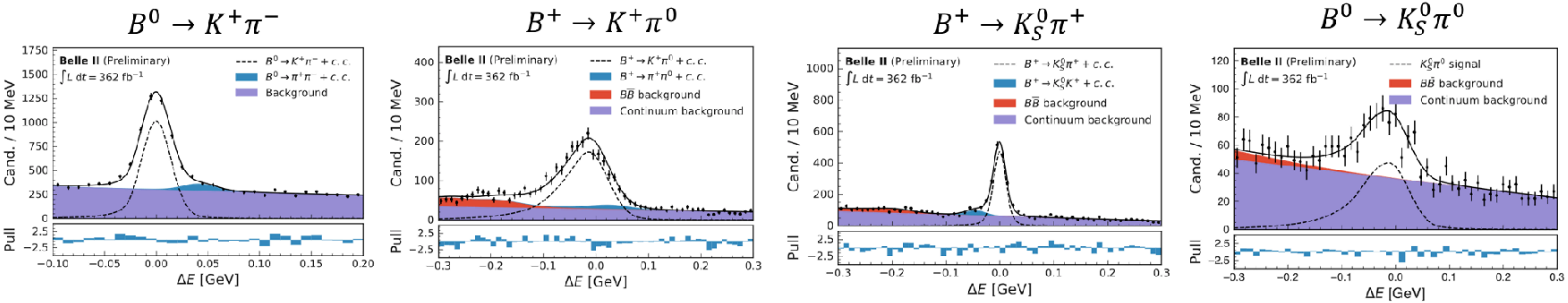
Direct CPV using $B \to K\pi$ and $B \to \pi\pi$

arXiv:2310.06381

- Charmless hadronic B meson decays feature non-negligible contributions from loop amplitudes.
- Sensitive to contributions from non-SM physics.

$$I_{K\pi} = A_{K^+\pi^-} + A_{K^0\pi^+}\frac{Br(K^0\pi^+)}{Br(K^+\pi^-)}\frac{\tau_{B^0}}{\tau_{B^+}} - 2A_{K^+\pi^0}\frac{Br(K^+\pi^0)}{Br(K^+\pi^-)}\frac{\tau_{B^0}}{\tau_{B^+}} - 2A_{K^0\pi^0}\frac{Br(K^0\pi^0)}{Br(K^+\pi^-)} \approx 0$$

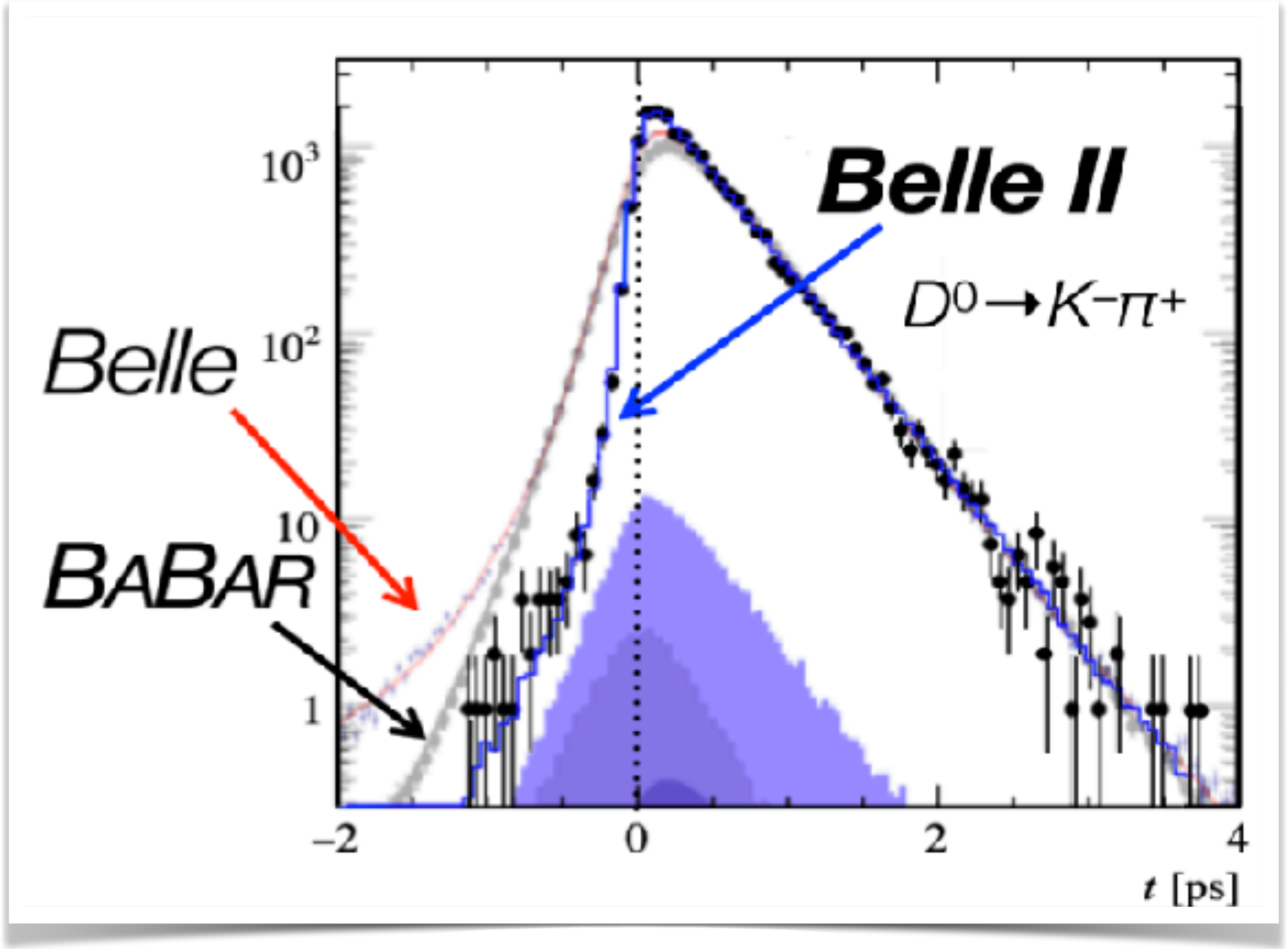
- Belle II measures all modes in coherent way with unique access to $B^0 \to K^0_S\pi^0$



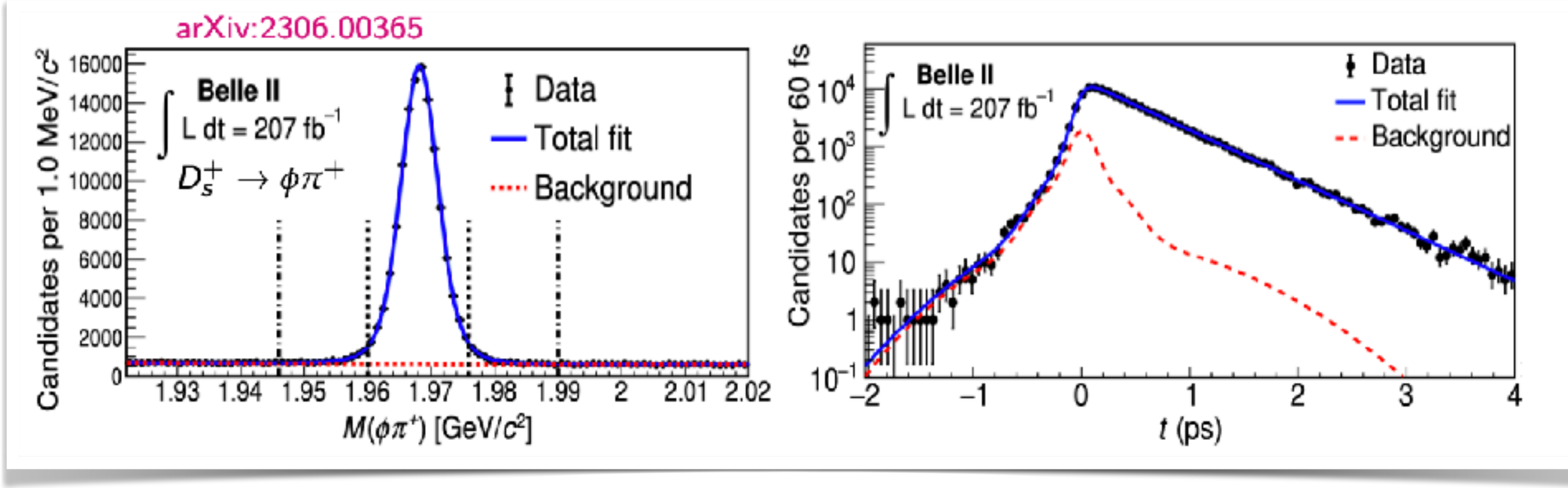
$I_{K\pi} = -0.03 \pm 0.13 \pm 0.05$ (world average: $I_{K\pi} = 0.13 \pm 0.11$)

competitive with world average with $362 fb^{-1}$

Charmed meson/baryon lifetime



- Precise lifetime measurements provide excellent tests of strong-interaction theory.
- Belle II has better (×2) time resolution than Belle/BaBar, allowing us precisely measure the lifetime, as well as the improved VXD.
- Obtain the world-best charm lifetimes:
  - $\tau(D^0) = 410.5 \pm 1.1 \pm 0.8$ fs, PRL 127, 211801 (2021)
  - $\tau(D^+) = 1030.4 \pm 4.7 \pm 3.1$ fs, PRL 127, 211801 (2021)
  - $\tau(\Lambda_c^+) = 203.20 \pm 0.89 \pm 0.77$ fs, PRL 130, 071802 (2023)
  - $\tau(D_s^+) = 499.5 \pm 1.7 \pm 0.9$ fs, PRL 131, 171803 (2023)
  - $\tau(\Omega_c^0) = 243 \pm 48 \pm 11$ fs, PRD 107, L031103 (2023)



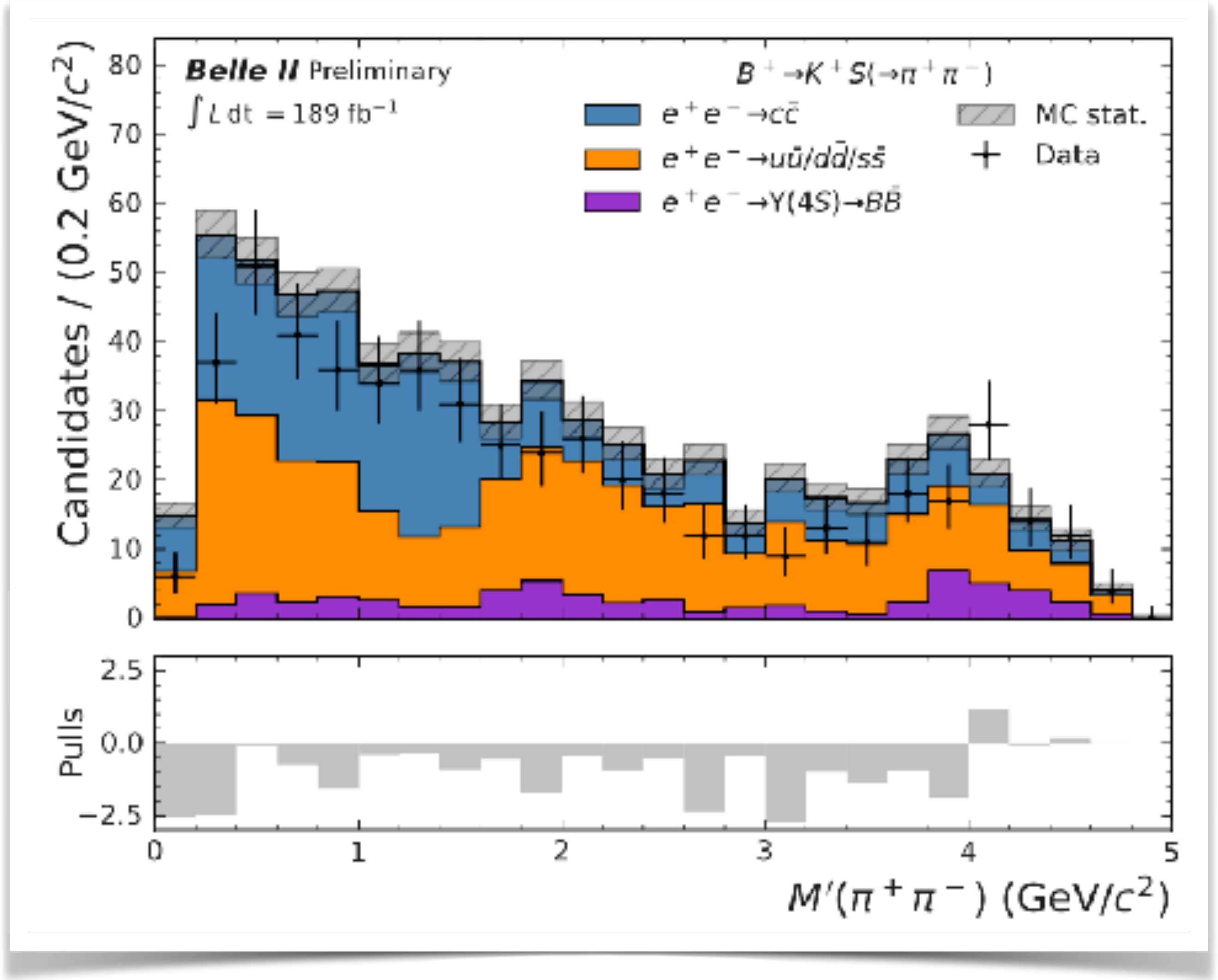
- Tiny systematic uncertainties demonstrate the excellent performance and understanding of the Belle II detector.

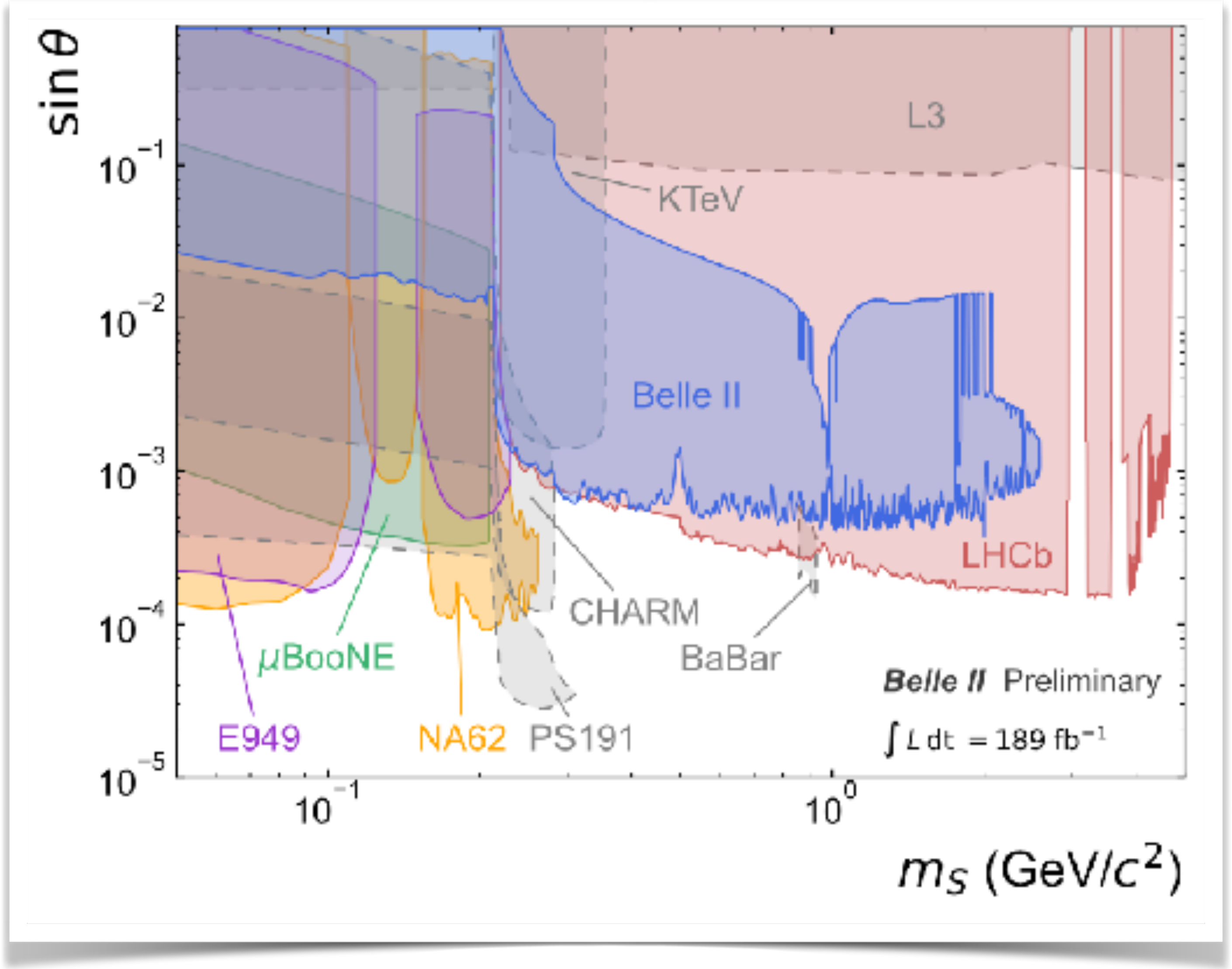
Axionlike particle

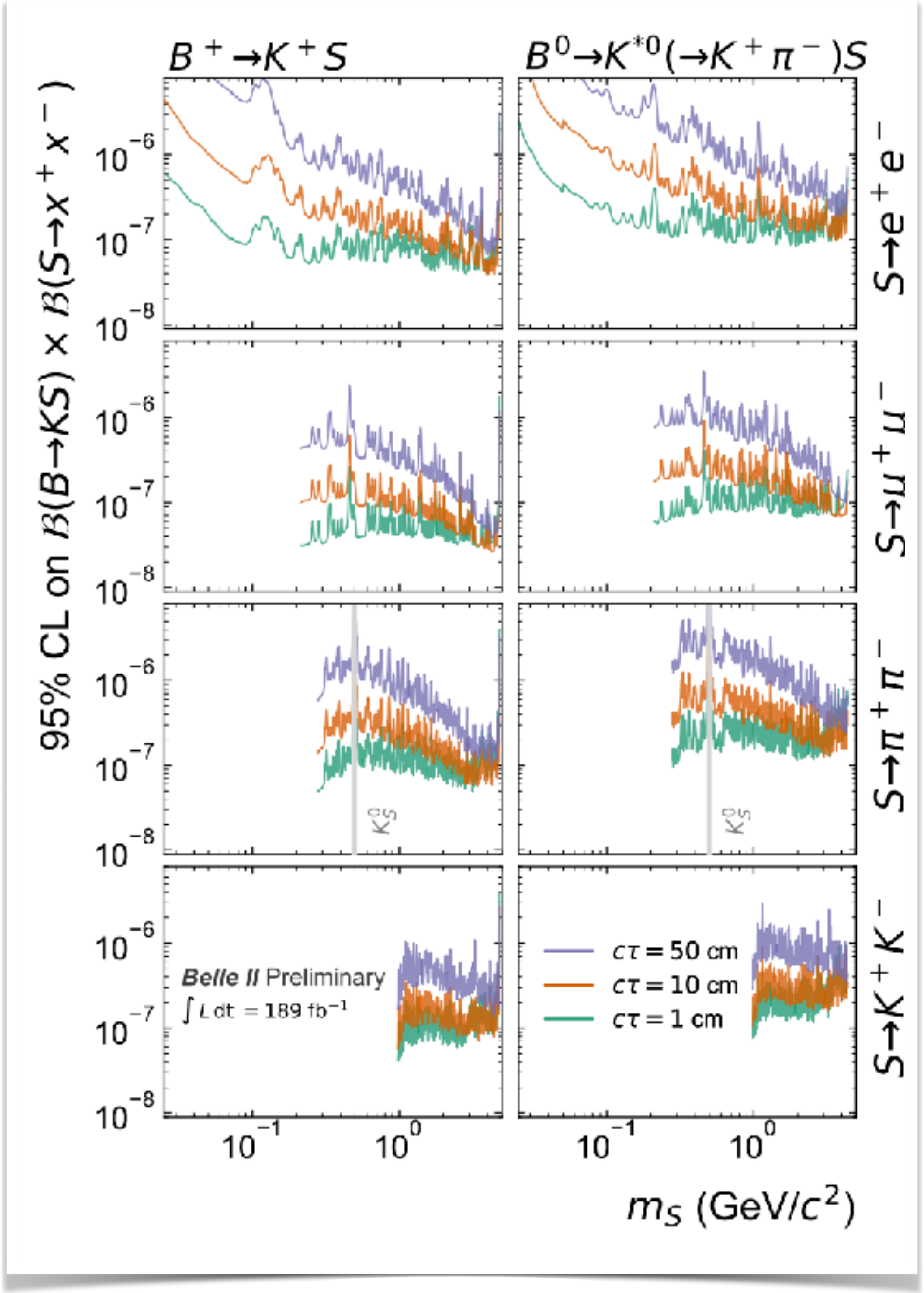
arXiv:2306.02830

Search for a long-lived spin-0 mediator in $b \to s$ transitions

- SM allow for the existence of an additional light spin-0.
- Lifetime-dependent results for different final states are needed to distinguish different theories.
- Belle II performed the first search for long-lived particles S with $s \to x^+x^-$, $x = e,\ \mu,\ \pi,\ K$ in $B^+ \to K^+S$ and $B^0 \to K^{*0}S$
- Extract signals by fitting to $M'(xx)$, and estimate upper limits in 95% C.L.

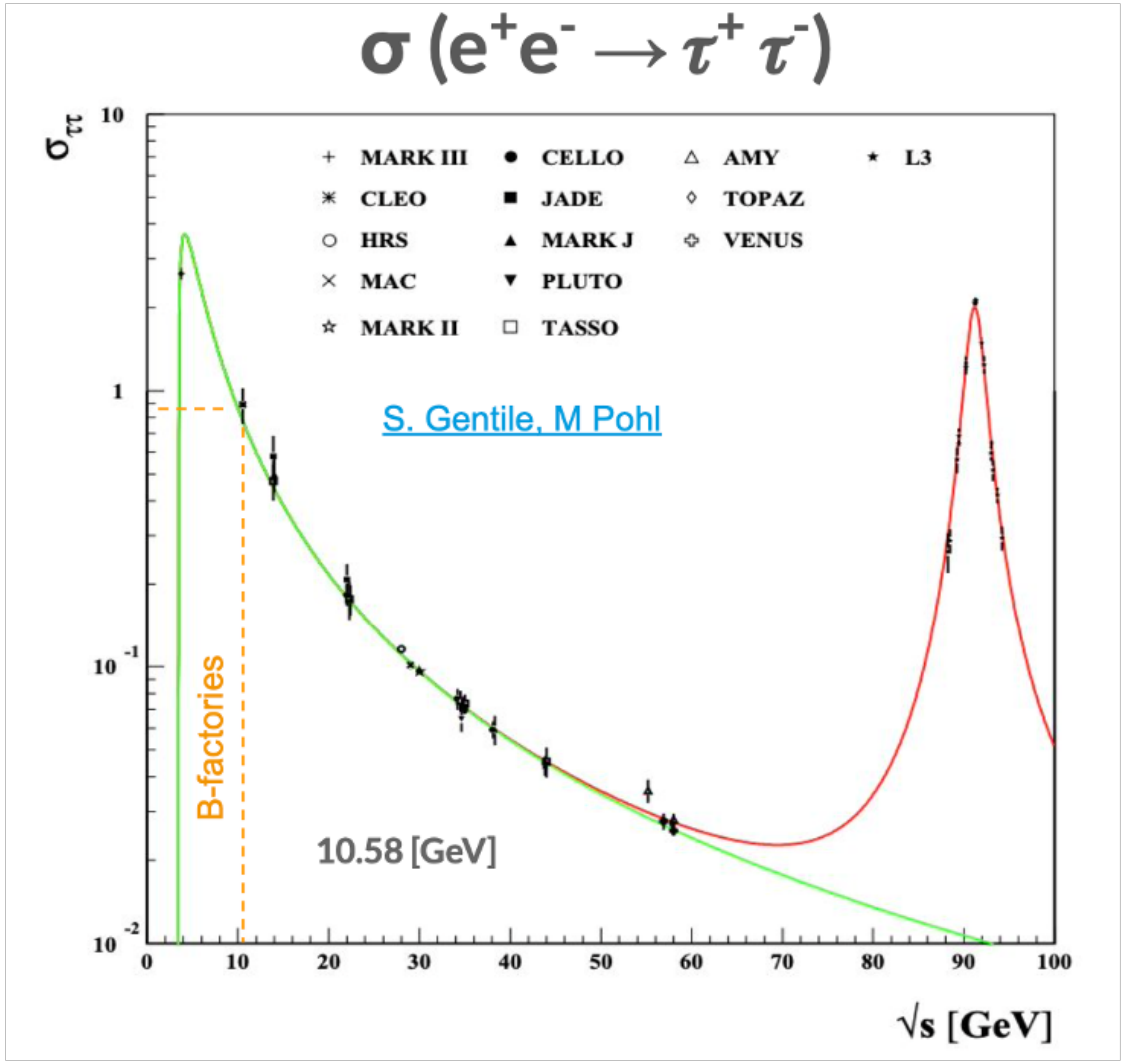






τ physics

B factory is also τ factory



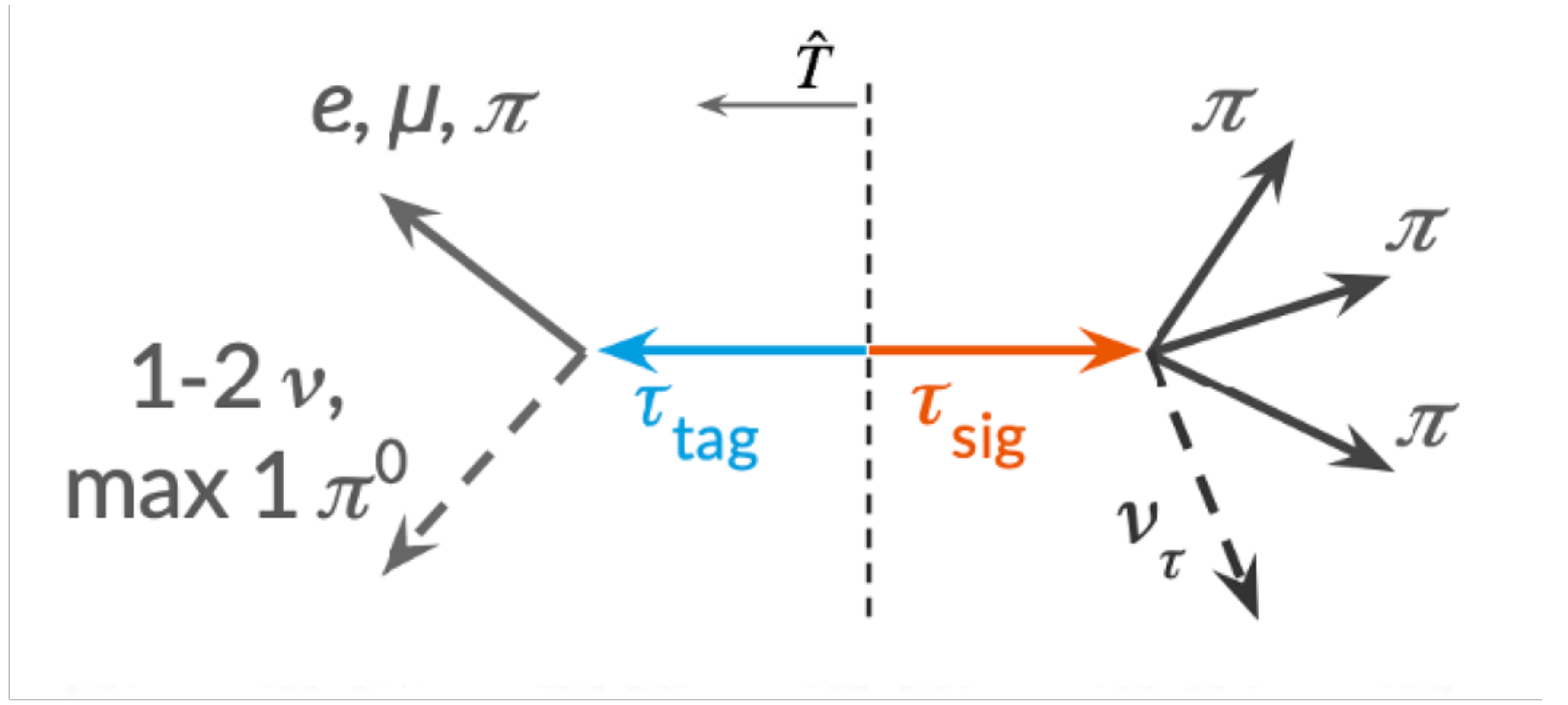
@10.58 GeV:

$$\sigma(e^+e^- \rightarrow \tau^+\tau^-) = 0.92\,nb$$
$$\sigma(e^+e^- \rightarrow \Upsilon(4S)) = 1.11\,nb$$

- High luminosity.
- Well-defined initial state.
- High vertex resolution.
- Excellent calorimetry.
- Sophisticated particle ID.
- Ability to trigger low-multiplicity event

Measurement of τ mass

PRD 108, 032006 (2023)

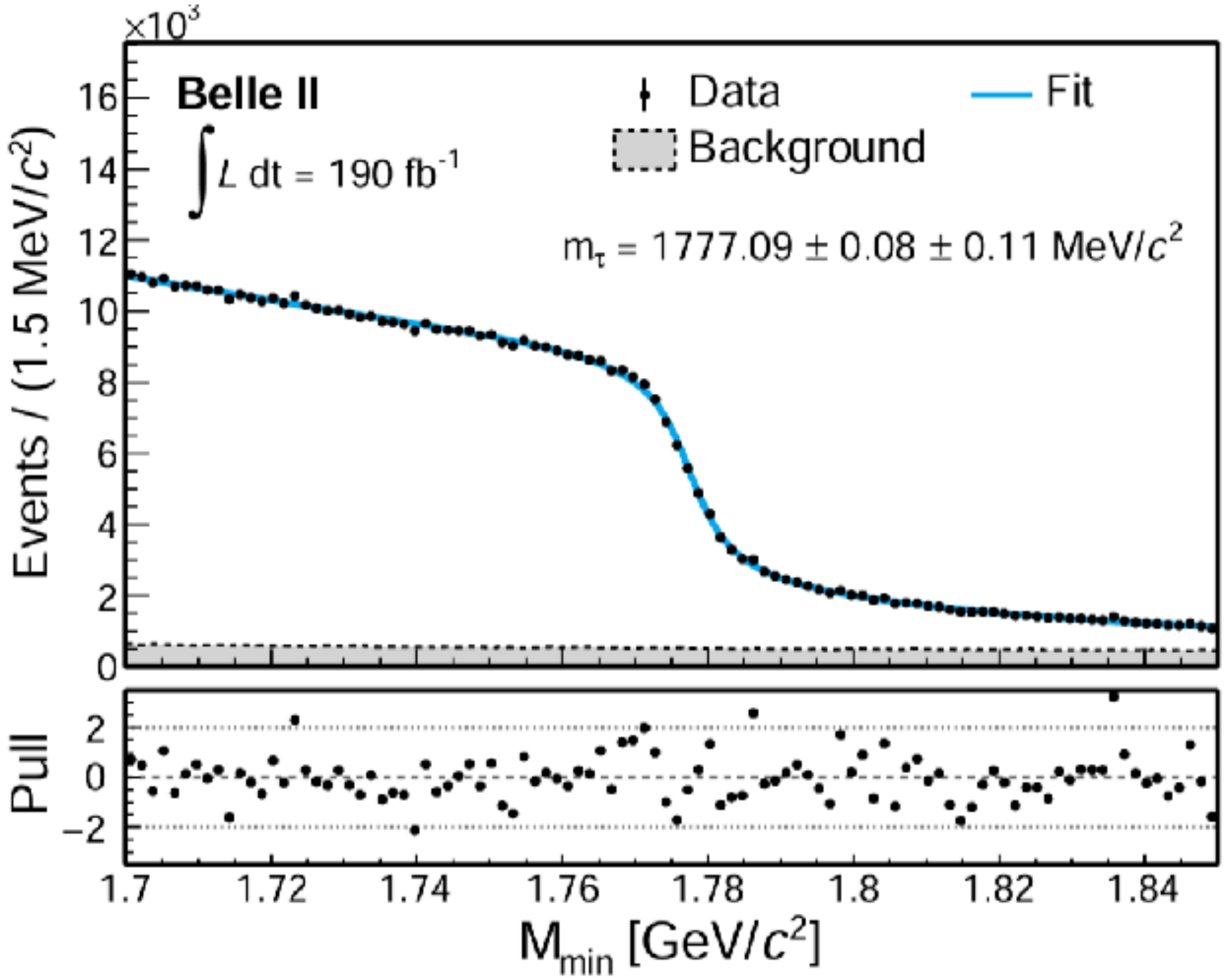


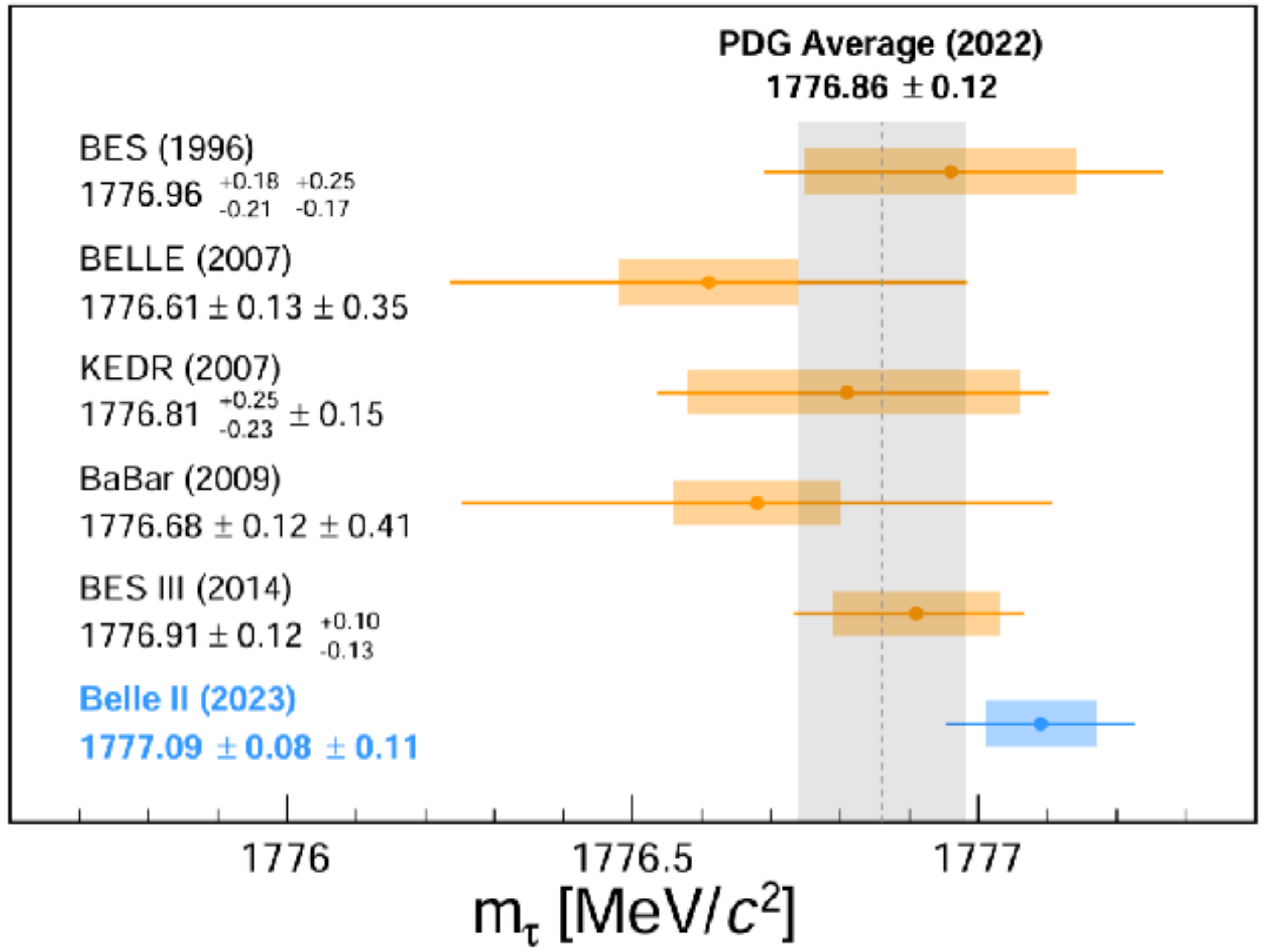
Pseudomass method:

$$m_\tau^2 = (p_h + p_\nu)^2$$
$$= 2\,E_h\,(E_\tau - E_h) + m_h^2 - 2|\vec{p}_h|(E_\tau - E_h)\cos(\vec{p}_h, \vec{p}_\nu)$$

The direction of the neutrino is not known, since $\cos(\vec{p}_h, \vec{p}_\nu) \leq 1$

Pseudomass: $M_{\min} = \sqrt{M_{3\pi}^2 + 2(\sqrt{s}/2 - E_{3\pi}^*)(E_{3\pi}^* - p_{3\pi}^*)} \leq m_\tau$





$m_\tau = 1777.09 \pm 0.08 \pm 0.11\ \text{MeV}/c^2$

World's best!

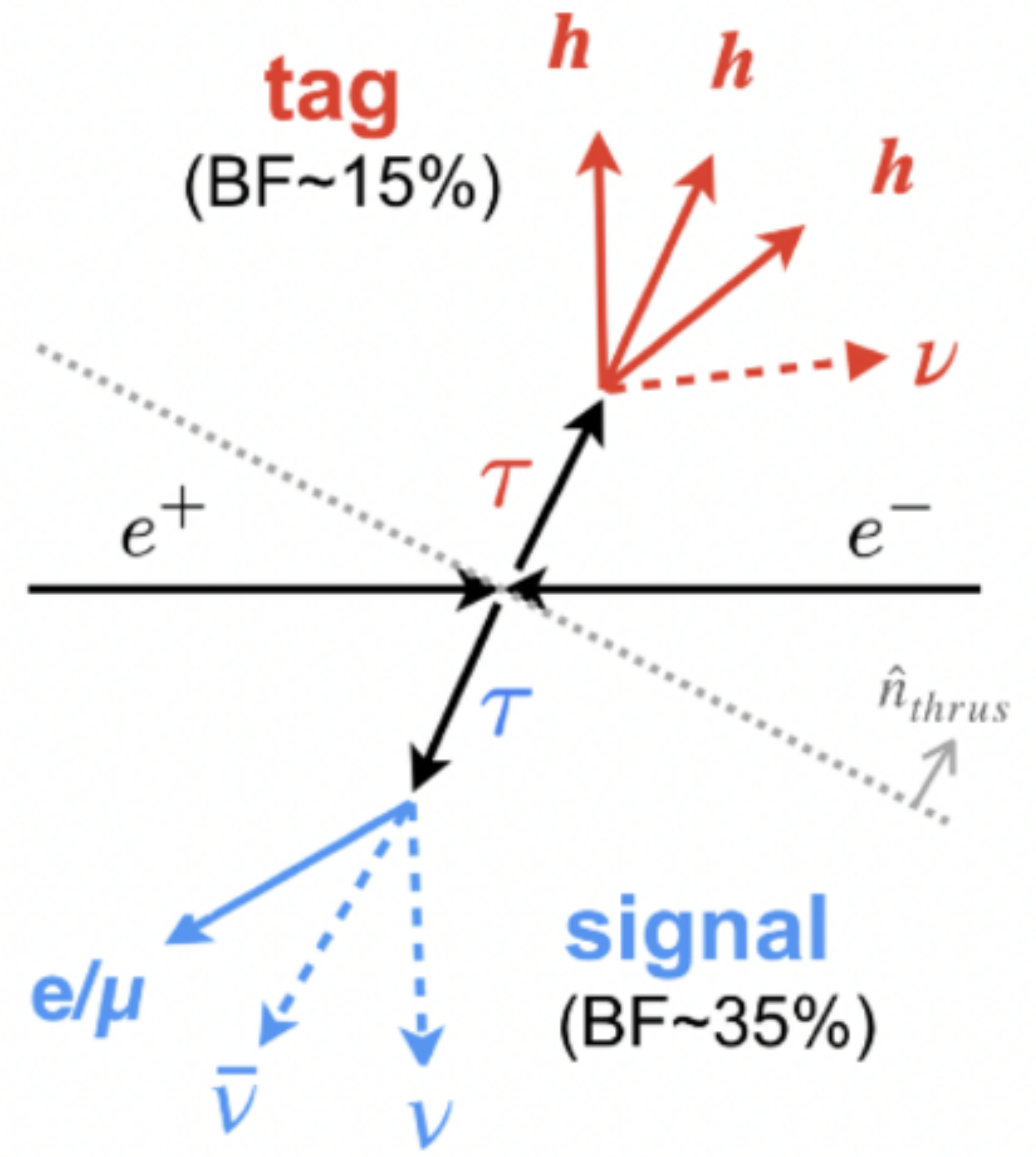
Smaller data

BUT better statistical precision!

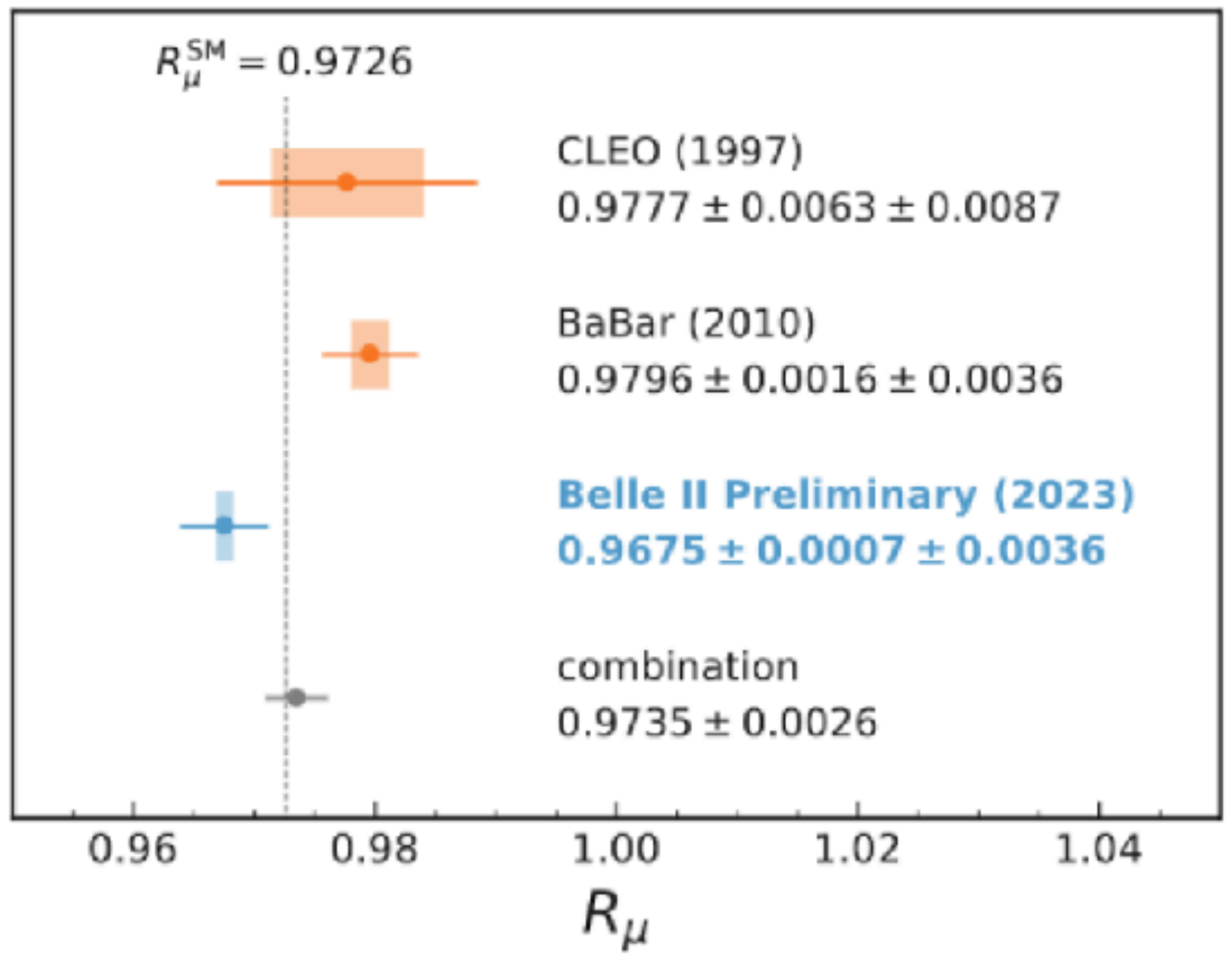
τ Lepton Flavor Universality Violation

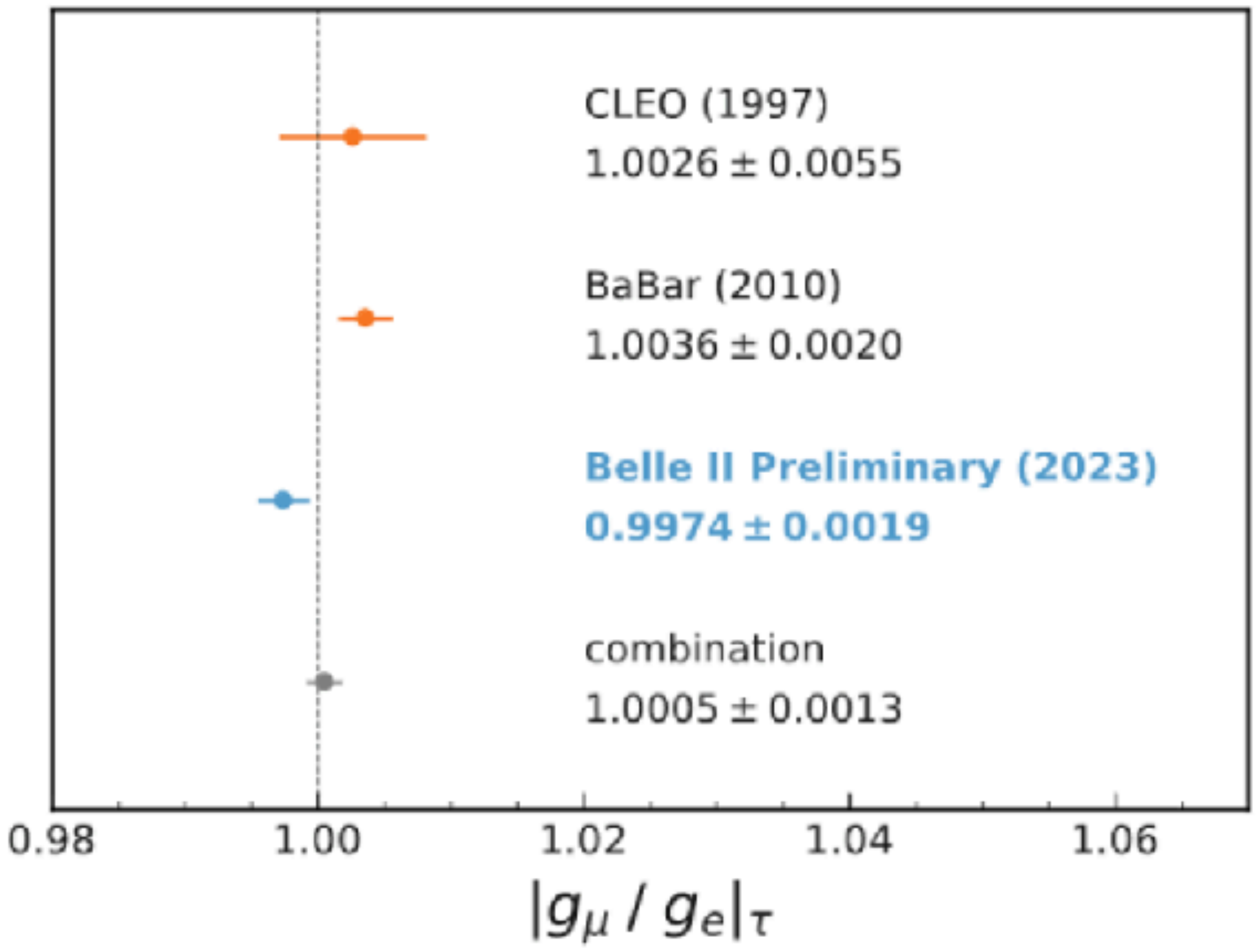
$$\left(\frac{g_\mu}{g_e}\right)_\tau = \sqrt{\frac{BF\left[\tau^- \to \mu^-\bar{\nu}_\mu\nu_\tau\right]}{BF\left[\tau^- \to e^-\bar{\nu}_e\nu_\tau\right]}\frac{f\left(m_e^2/m_\tau^2\right)}{f\left(m_\mu^2/m_\tau^2\right)}}$$

In the SM: $\left(\frac{g_\mu}{g_e}\right)_\tau = 1$



Tests with 3x1 topology: same method as Babar



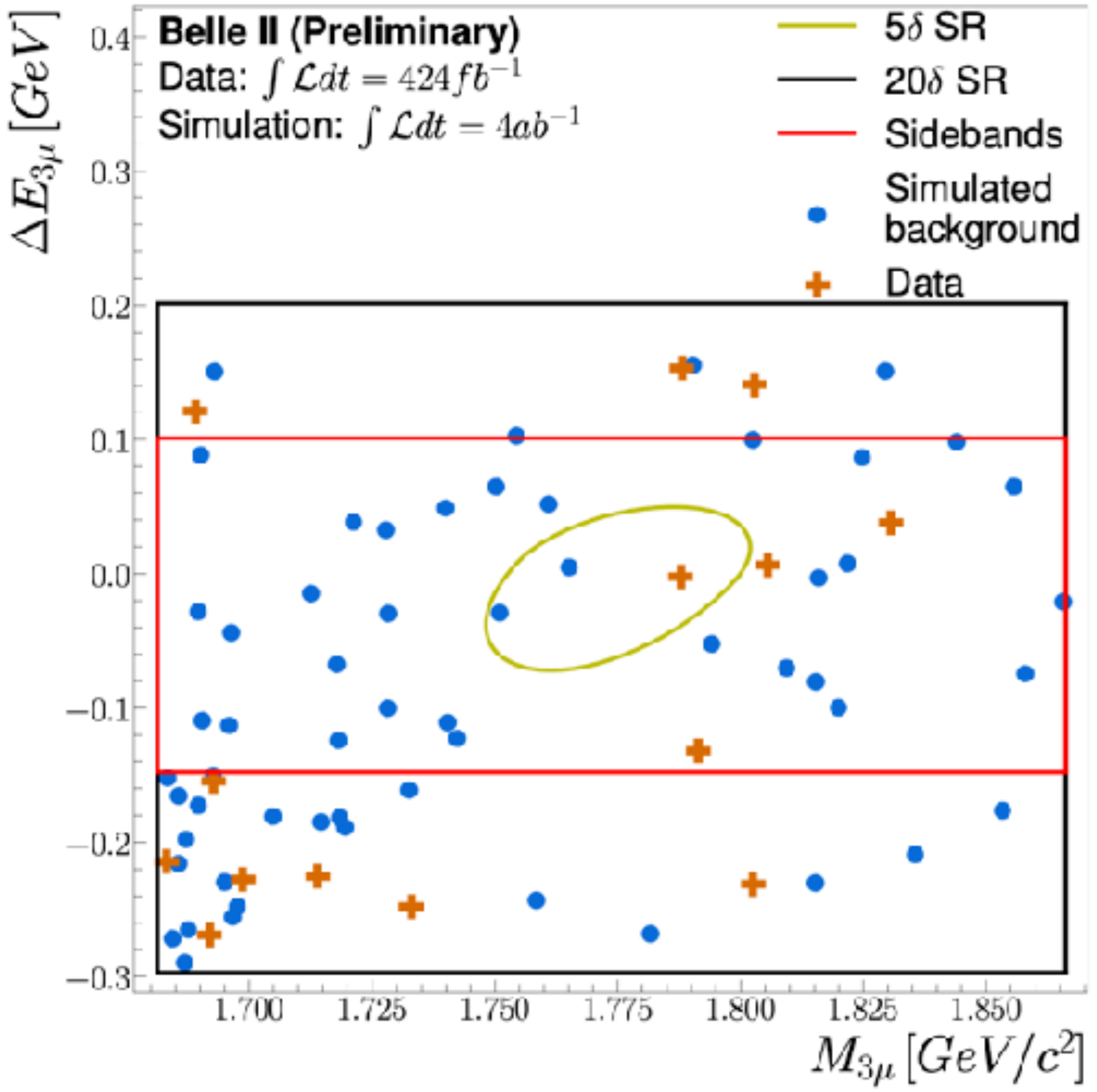


$$R_\mu = \frac{\mathcal{B}(\tau^- \to \mu^-\bar{\nu}_\mu\nu_\tau)}{\mathcal{B}(\tau^- \to e^-\bar{\nu}_e\nu_\tau)} = 0.9675 \pm 0.0007 \pm 0.0036.$$

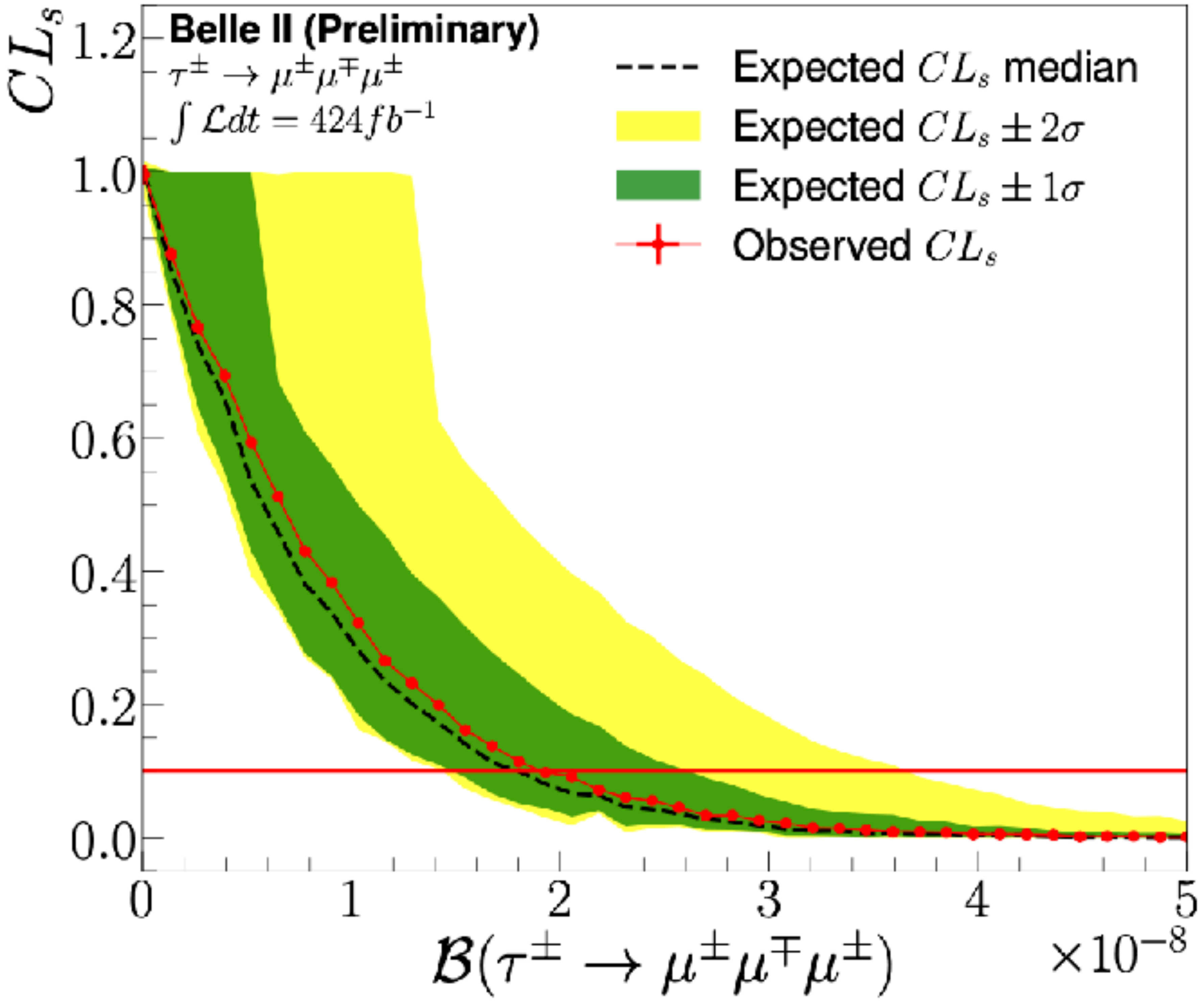
Consistent with previous measurements

Most precise to date

τ Lepton Flavor Violation

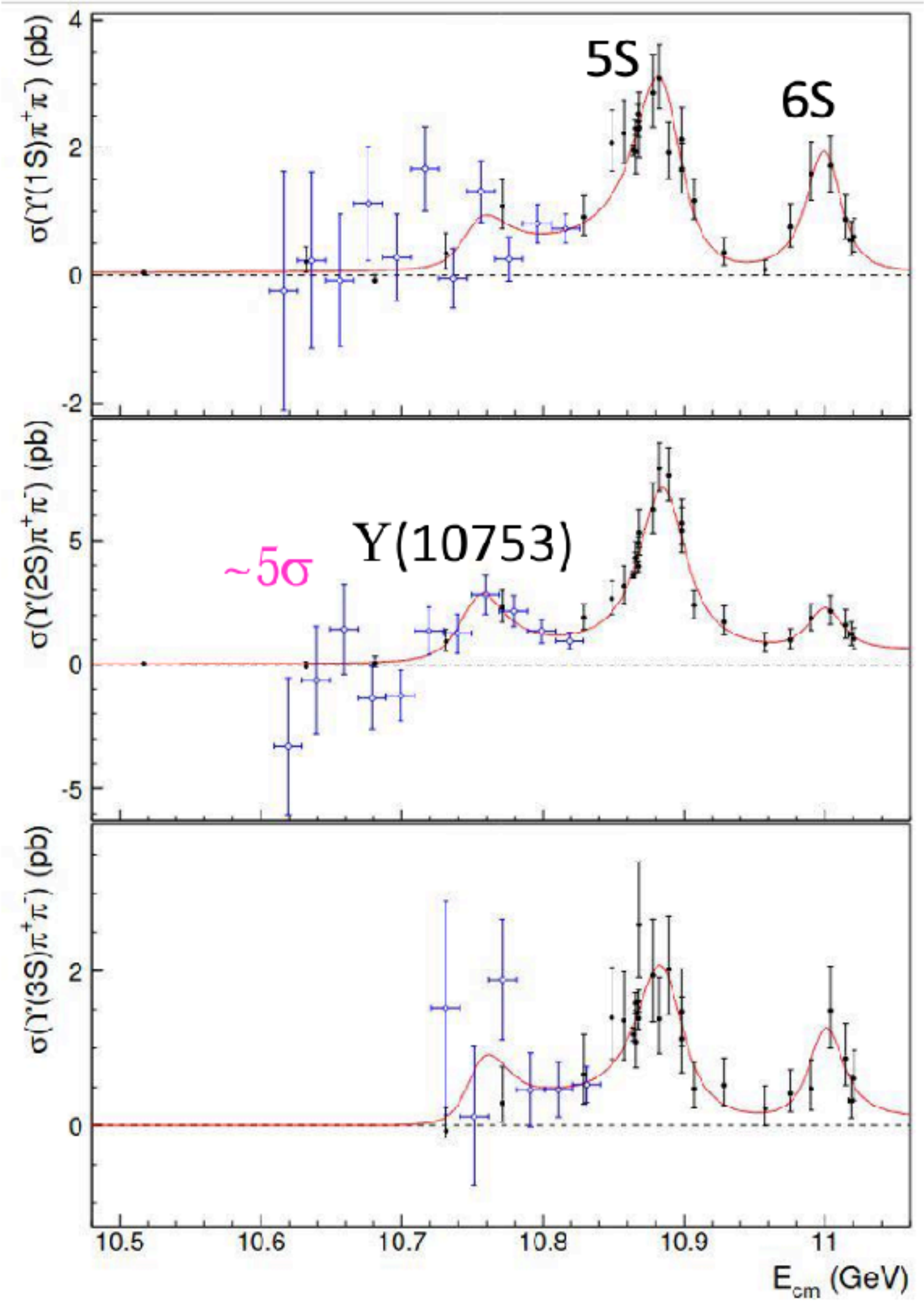


- A search for the charged-lepton-flavour violating decay $\tau \rightarrow \mu\mu\mu$
- Provide indisputable evidence of physics beyond the SM.



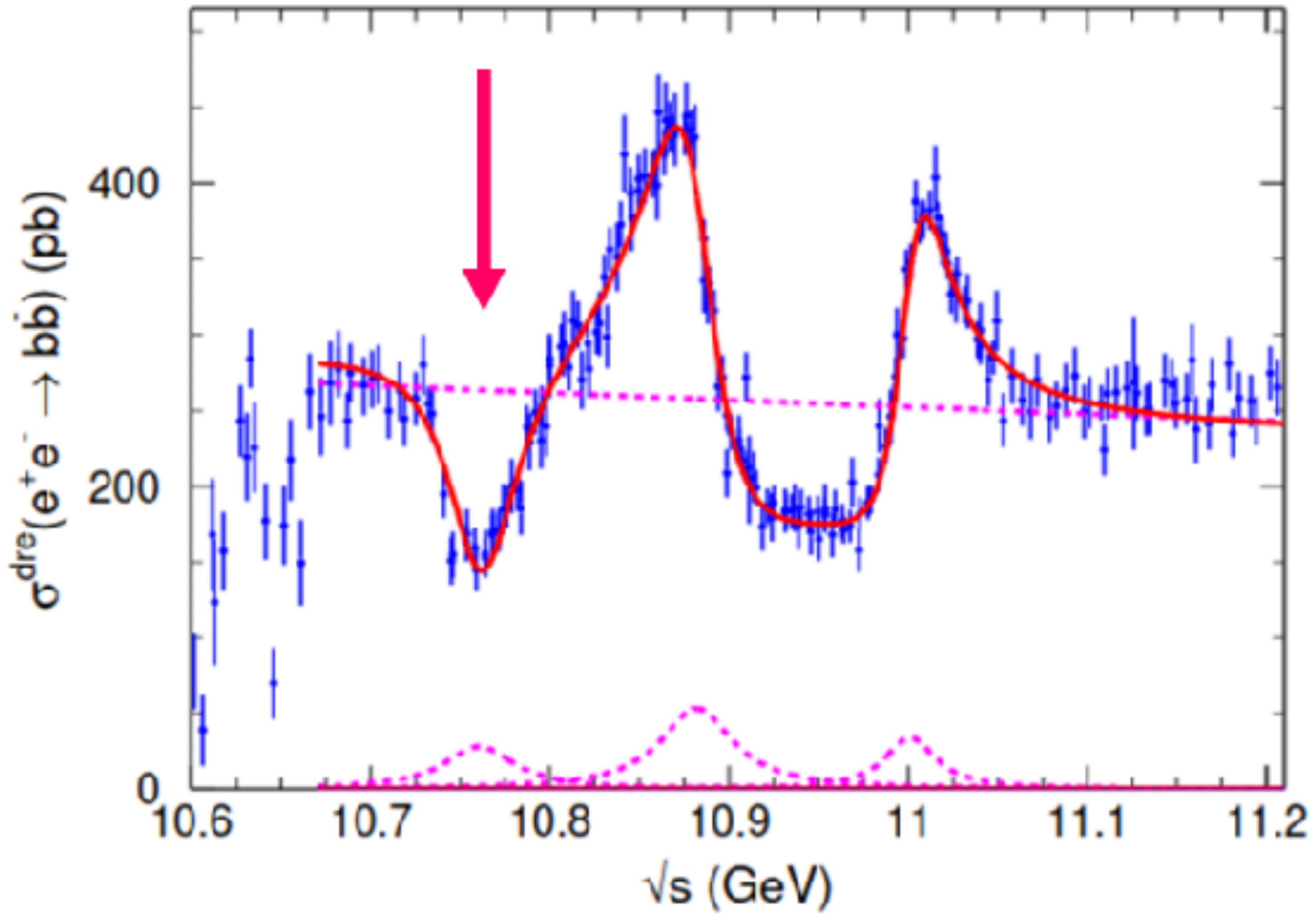
- Novel inclusive tagging followed by a BDT-based selection.
  - 2.5 times higher efficiency than Belle and 37% higher efficiency than 1-prong tagging
- One event in signal region:
  - $B(\tau^- \rightarrow \mu^-\mu^+\mu^-) = (3.1 + 8.7 \pm 0.1) \times 10^{-9}$
- $< 1.9(1.8) \times 10^{-8}$ for observed (expected) limit at 90% C.L.
- Less data, more restrictive than Belle

Exotic studies —on $\Upsilon(10753)$

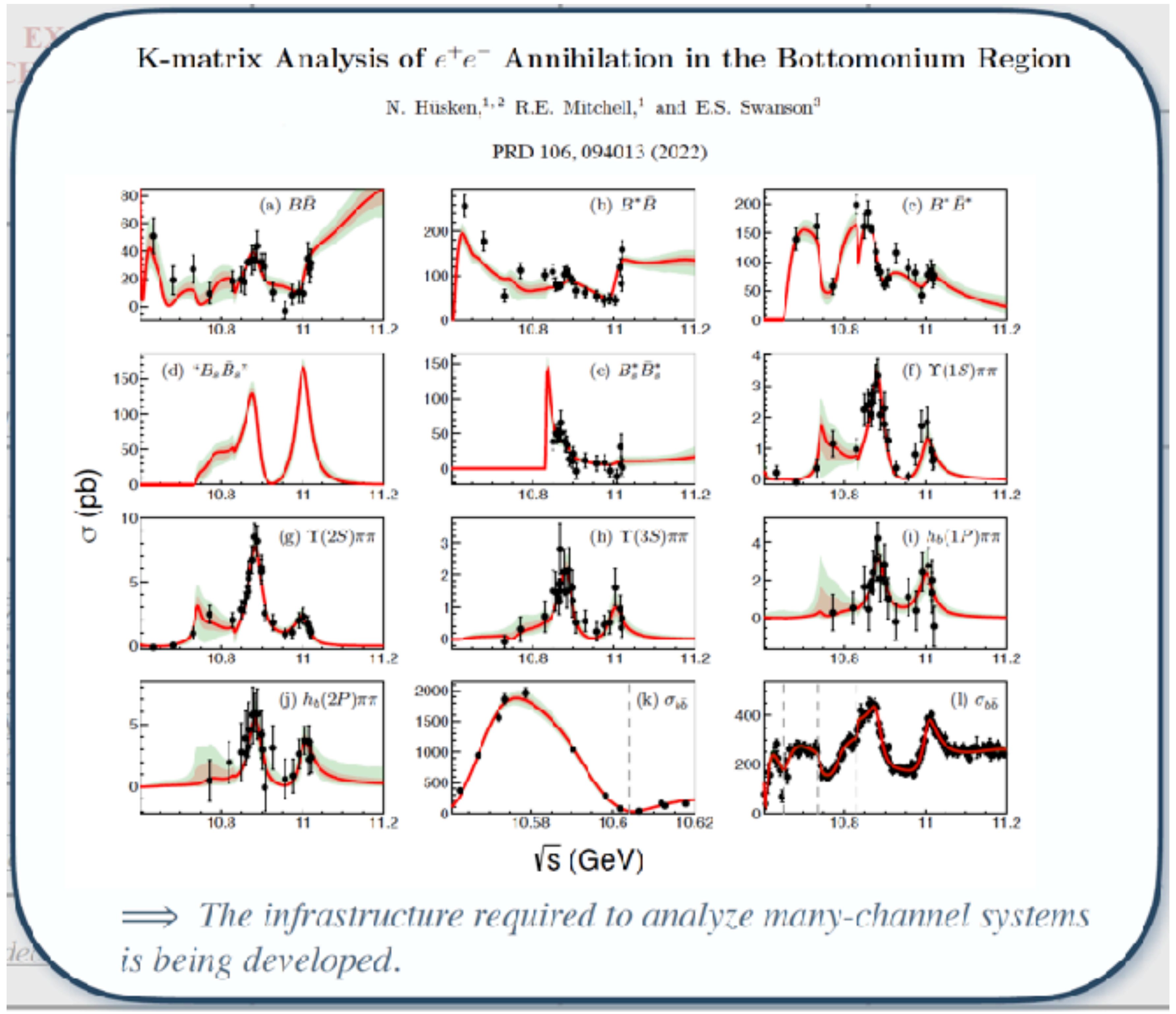


- The $\Upsilon(10753)$ was observed in the energy dependence of $e^+e^- \to \Upsilon(nS)\pi^+\pi^-(n=1,2,3)$ cross sections by Belle. [JHEP 10,220(2019)]

- Confirmed in the refit to R_b and K-matrix analysis.

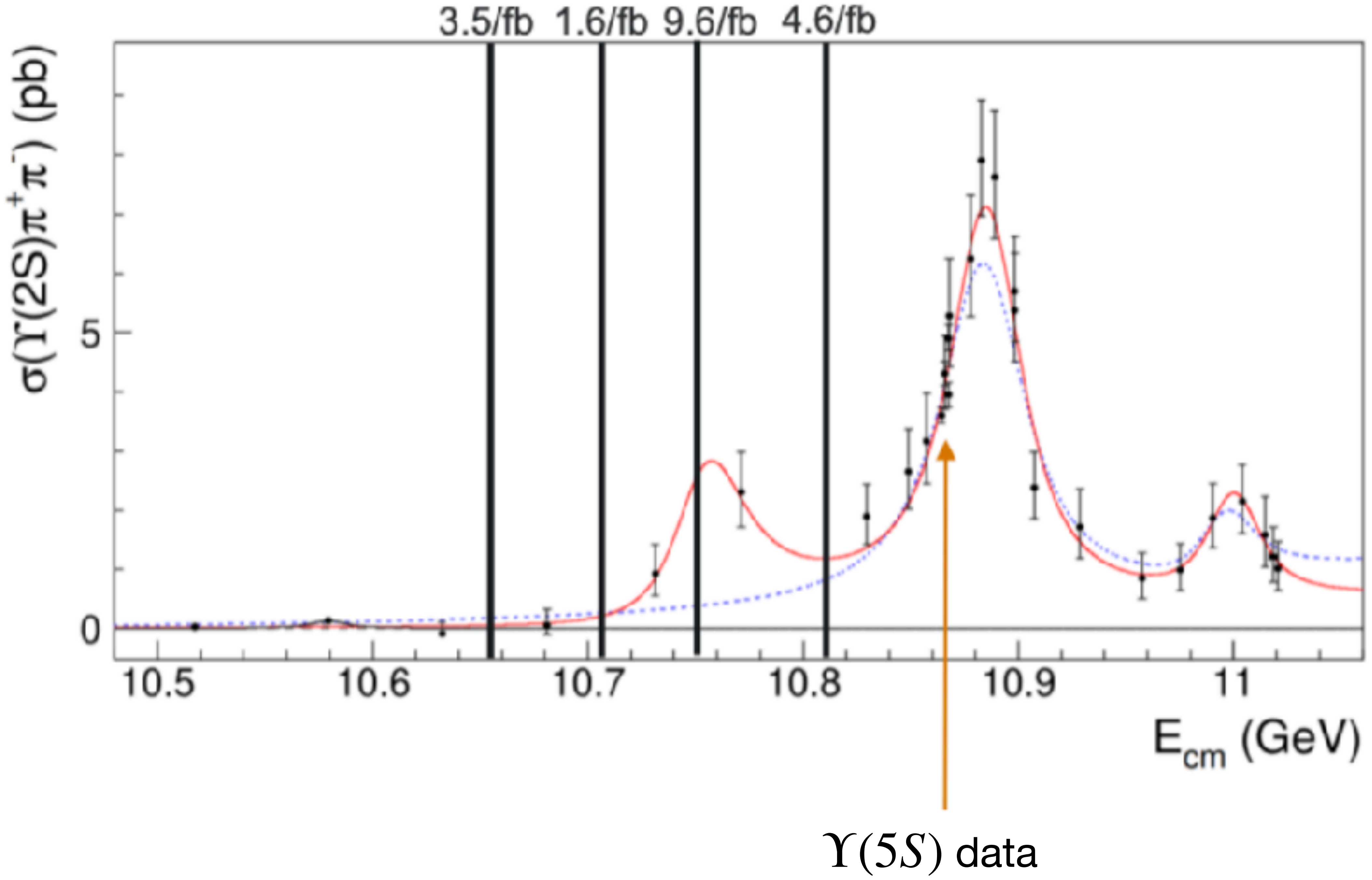


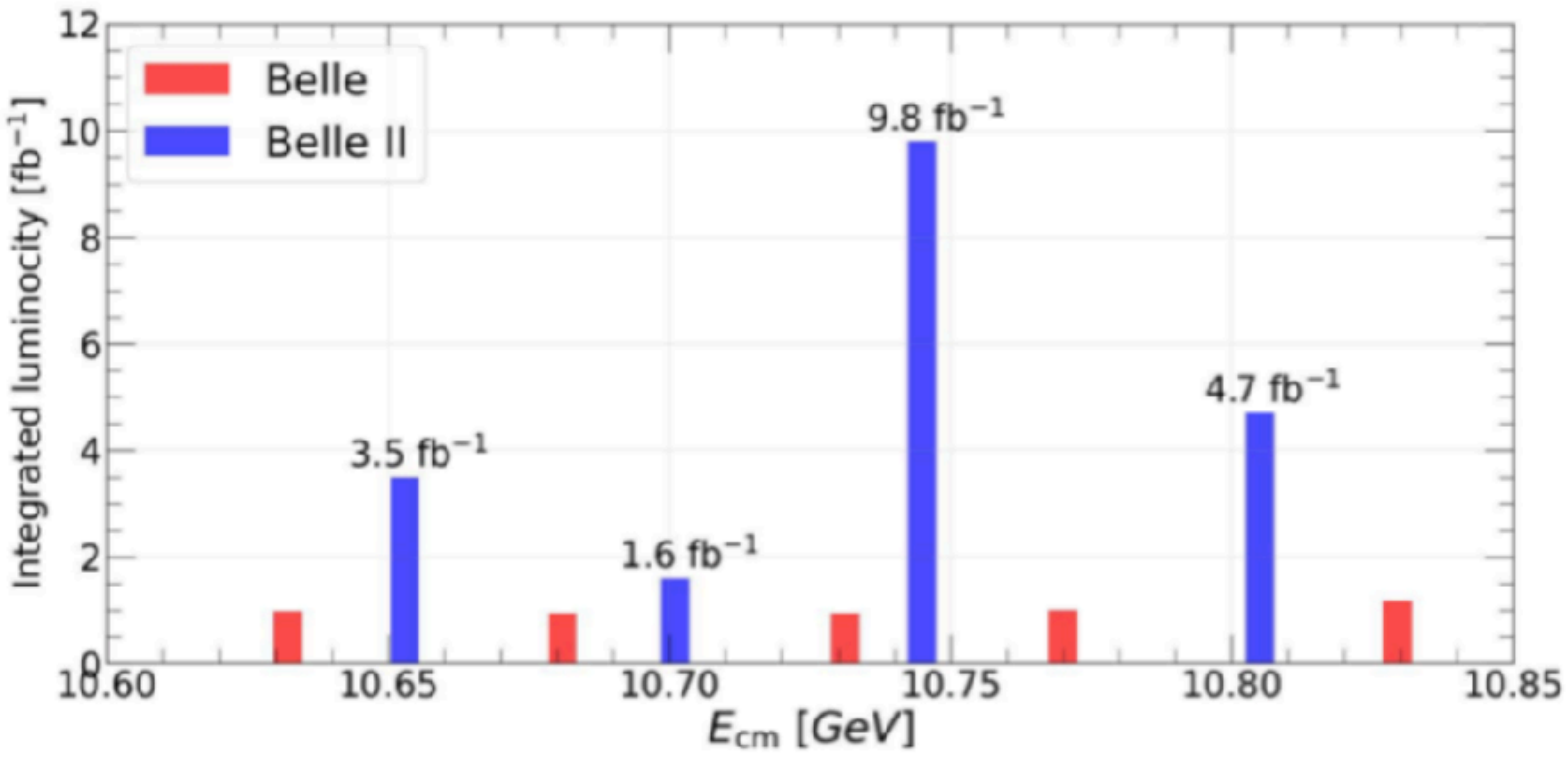
[CPC 44 (2020) 8, 083001]:



Unique energy scan data

- In Nov. 2021, Belle II collected ~20/fb of unique scan data at energies near 10.75 GeV
    - Fill the gaps in Belle Scan data
- Physics goal is to understand the nature of $\Upsilon(10753)$

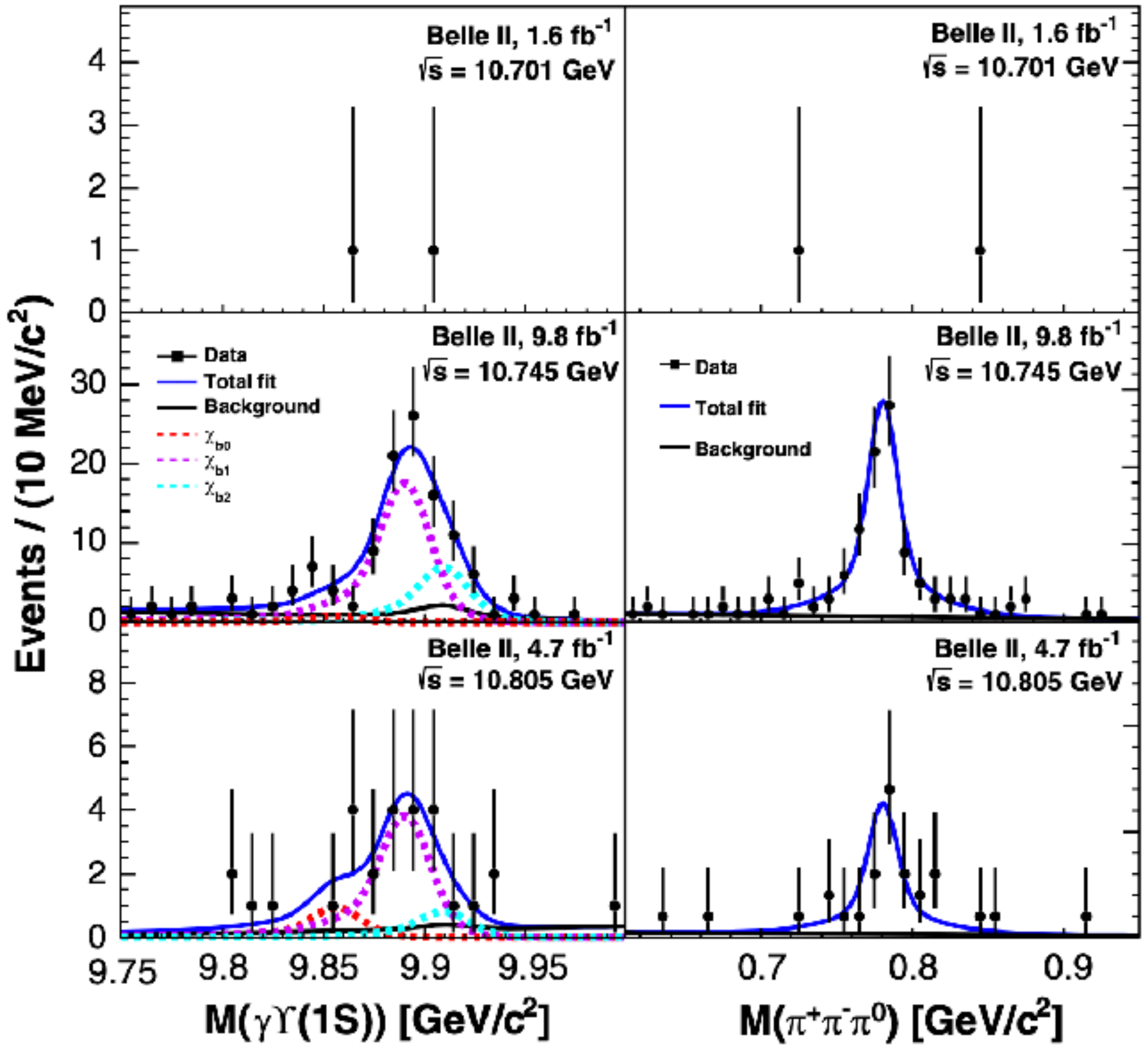


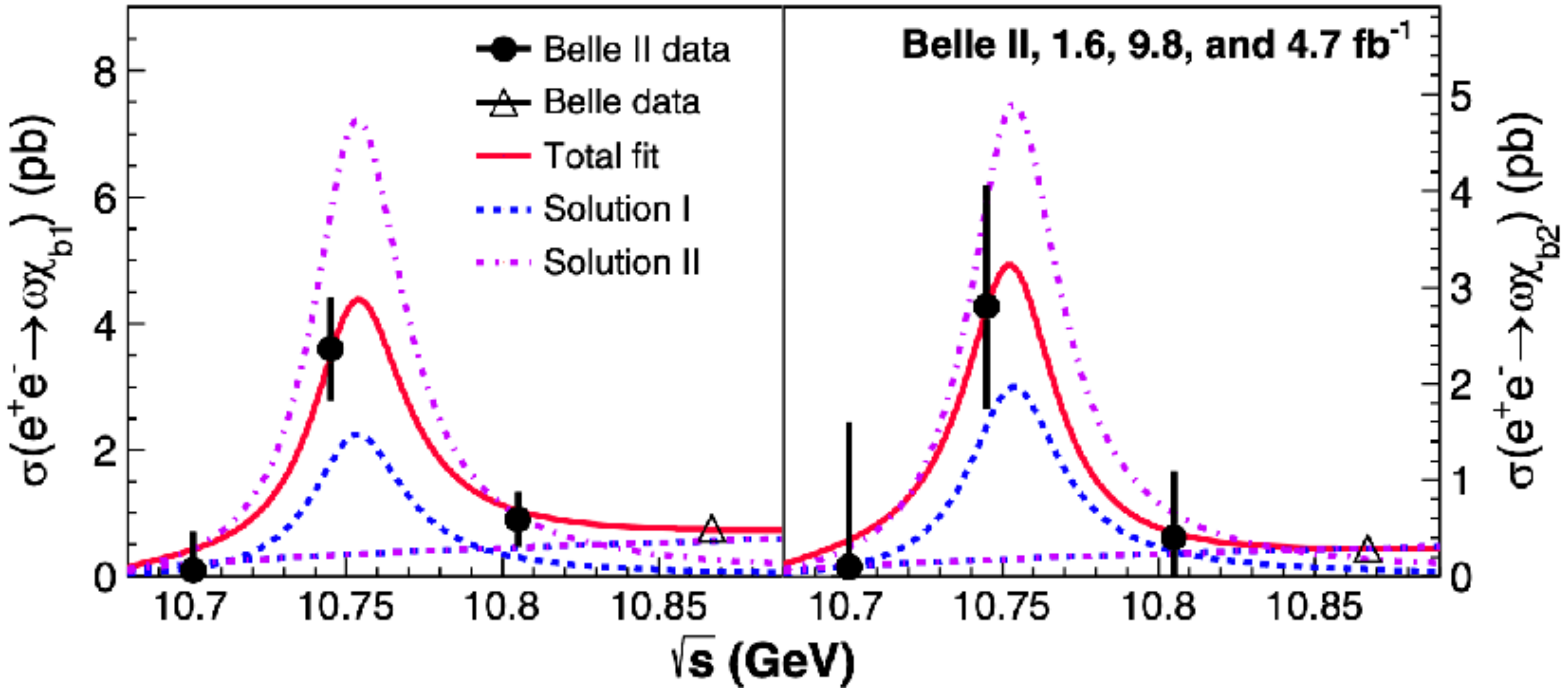


Observation of $Y(10753) \to \omega\chi_{bJ}$ in $e^+e^- \to \gamma\omega\Upsilon(1S)$

PRL 130, 091902 (2023)

Clear $\omega\chi_{bJ}$ signals at $\sqrt{s} = 10.745$ and 10.805 GeV





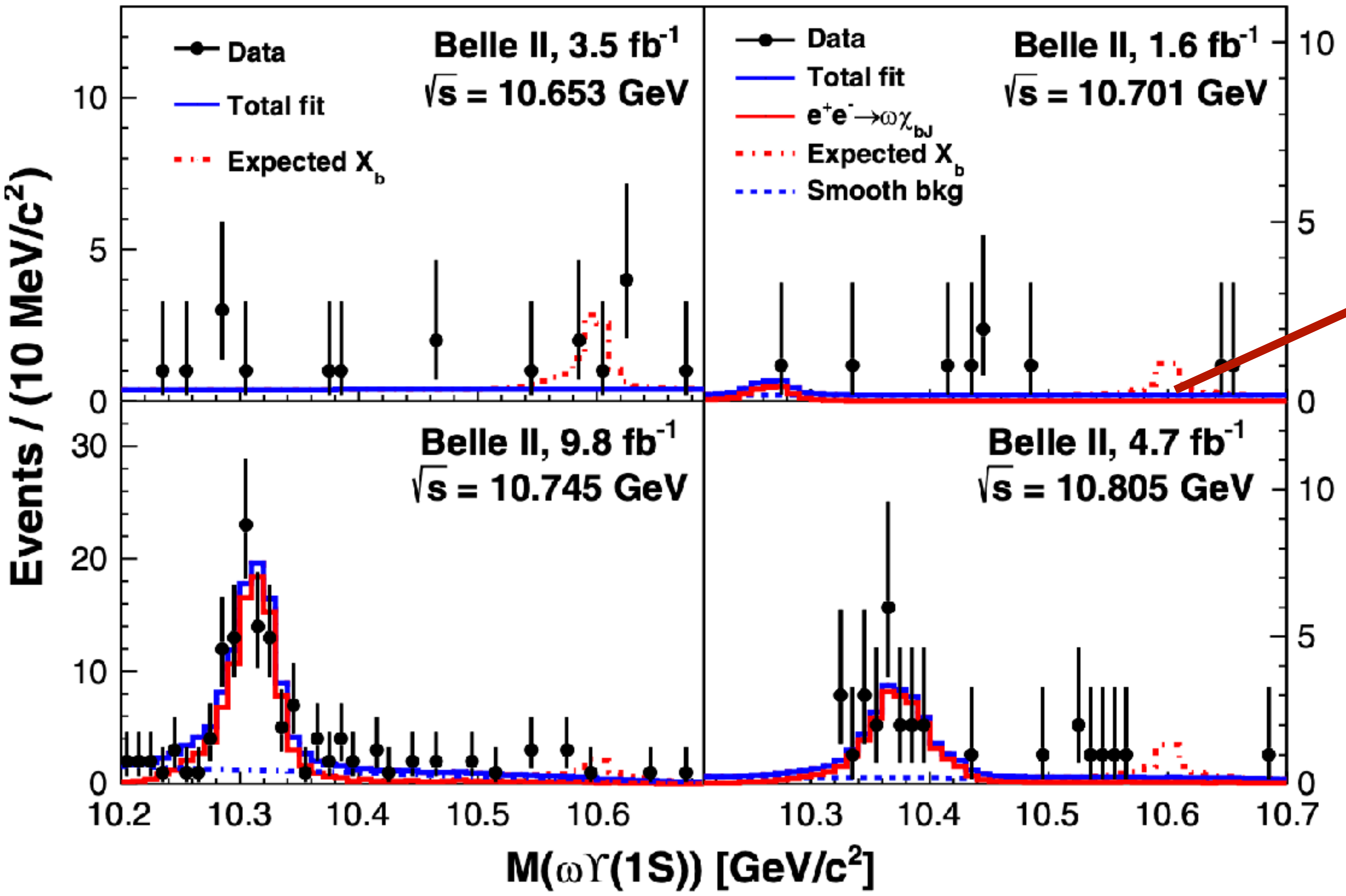
$\Gamma_{ee}\mathcal{B}_f$	Solution I	Solution II
$\Gamma_{ee}\mathcal{B}(\Upsilon(10753) \to \omega\chi_{b1})$	$(0.63 \pm 0.39 \pm 0.20)$ eV	$(2.01 \pm 0.38 \pm 0.76)$ eV
$\Gamma_{ee}\mathcal{B}(\Upsilon(10753) \to \omega\chi_{b2})$	$(0.53 \pm 0.46 \pm 0.15)$ eV	$(1.32 \pm 0.44 \pm 0.55)$ eV

- $\dfrac{\Gamma_{ee}\mathcal{B}(\Upsilon(10753) \to \omega\chi_{b1})}{\Gamma_{ee}\mathcal{B}(\Upsilon(10753) \to \omega\chi_{b2})} \sim 1.0$ agrees with the expectation for HQET[3]
- $\dfrac{\Gamma_{ee}\mathcal{B}(\omega\chi_{b1/2})}{\Gamma_{ee}\mathcal{B}(\pi^+\pi^-\Upsilon(2S))^{[2]}} \sim 1.5$ for $\Upsilon(10753)$ and ~ 0.1 for $\Upsilon(10870)$

[1]PRL 113, 142001(2014); [2]. JHEP 10, 220(2019); [3]. arXiv:hep-ph/9908366;

- Confirm the existence of $\Upsilon(10753)$.
- Large difference of $\dfrac{\mathcal{B}(\omega\chi_{bJ})}{\mathcal{B}(\pi^+\pi^-\Upsilon(nS))}$ between $\Upsilon(10753)$ and $\Upsilon(10870)$.

Search for $X_b \to \omega\Upsilon(1S)$ in $e^+e^- \to \gamma\omega\Upsilon(1S)$



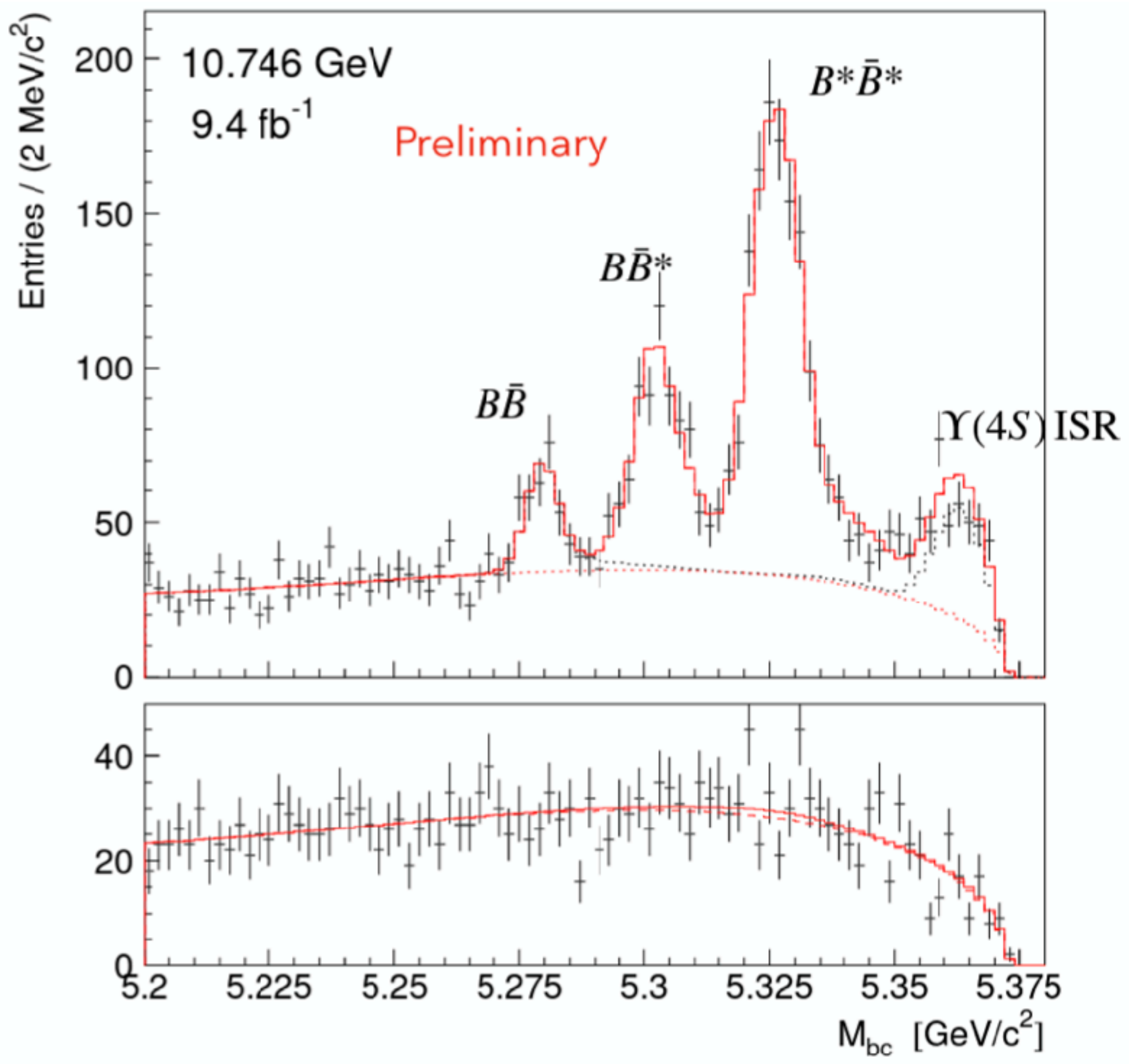
From simulated events with $M(X_b)$ = 10.6 GeV/c^2

The yield is fixed at the upper limit on 90% C.L.

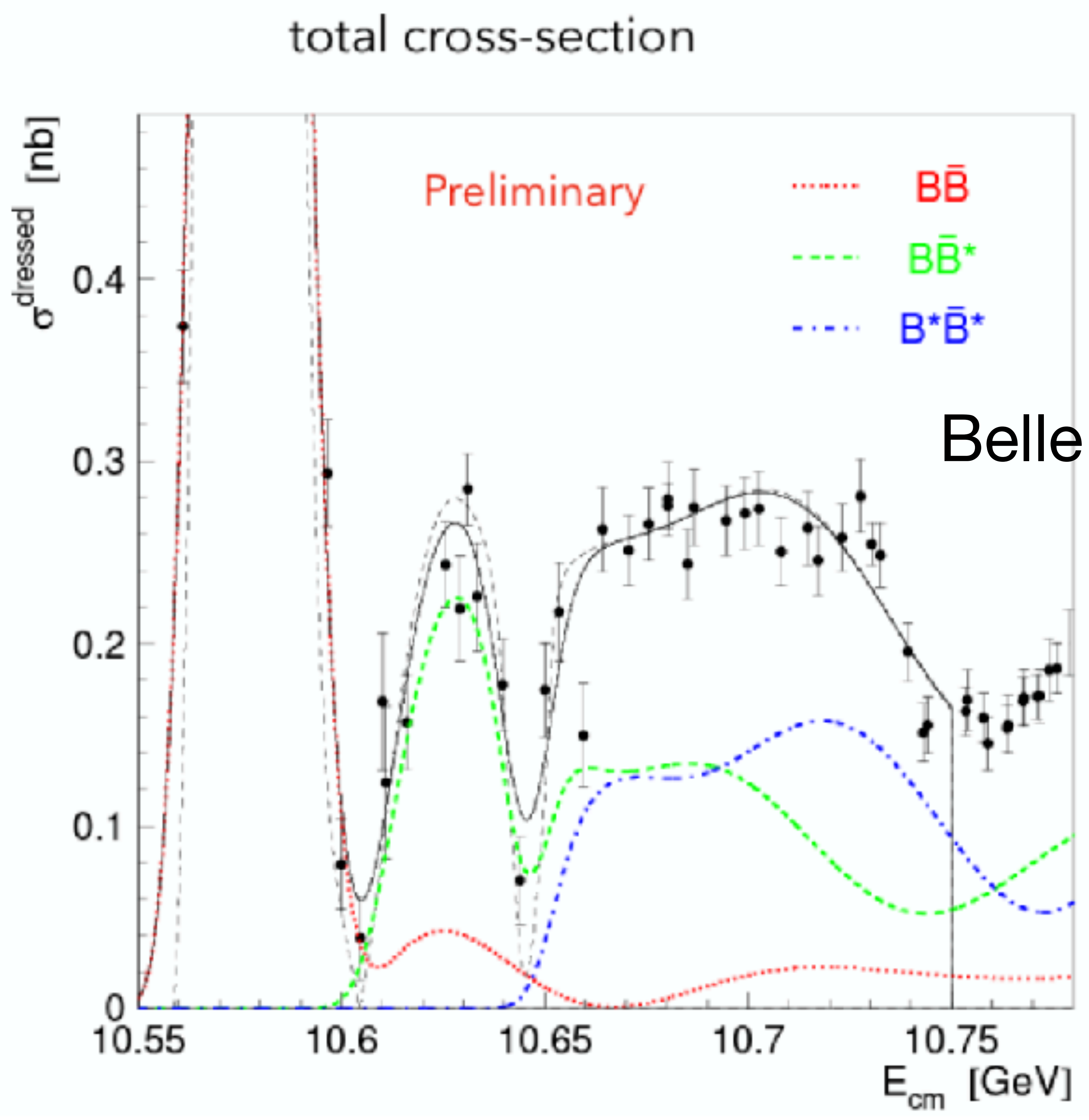
- No significant X_b signal is observed.
- The peaks are the reflections of $e^+e^- \to \omega\chi_{bJ}$

Measurement of $e^+e^- \to B^{(*)}\bar{B}^{(*)}$

Preliminary



- Reconstruct B_{tag} with FEI
- Yield signals from simultaneous fit to M_{bc} (SR and SB)



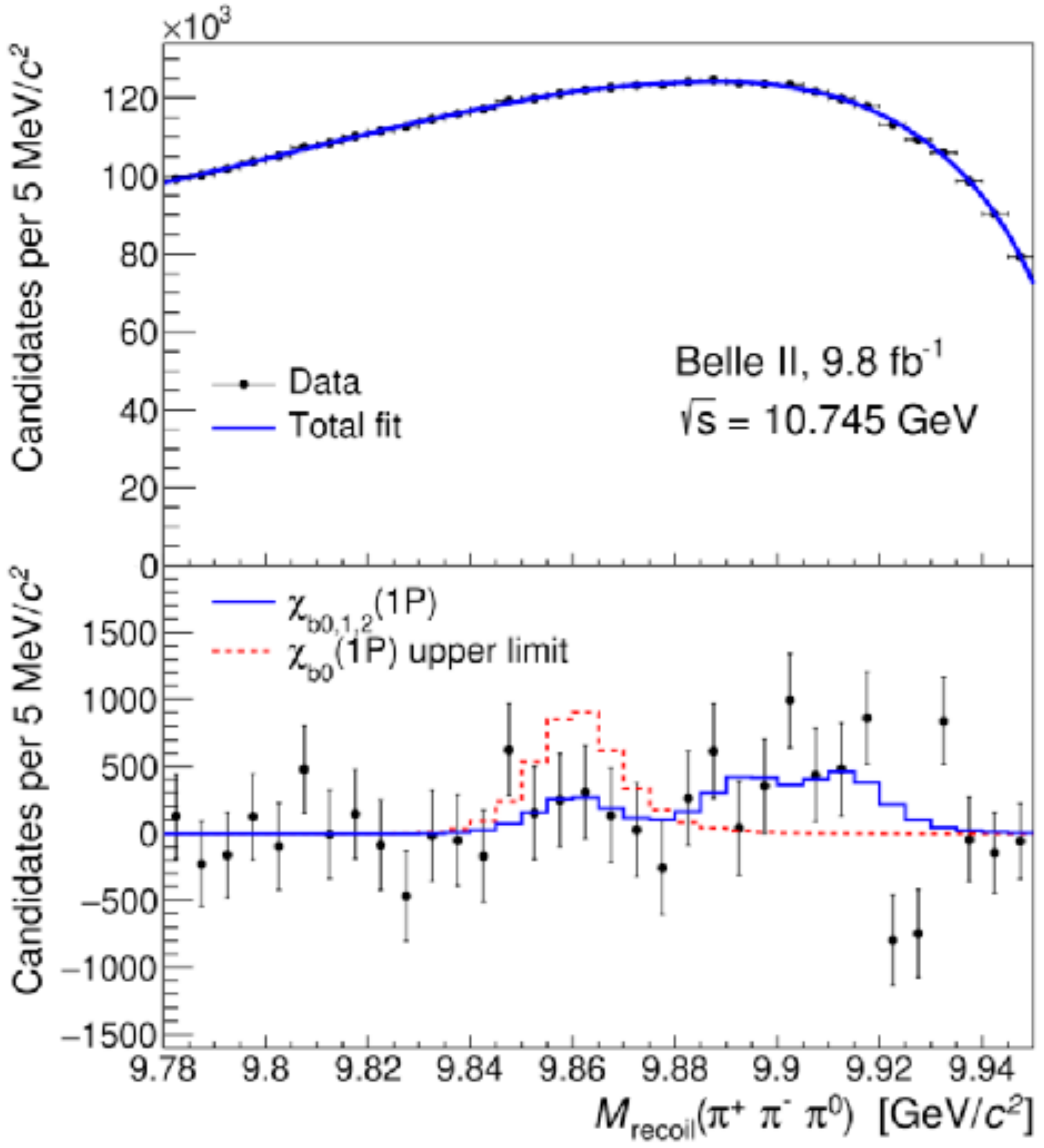
Belle + Belle II

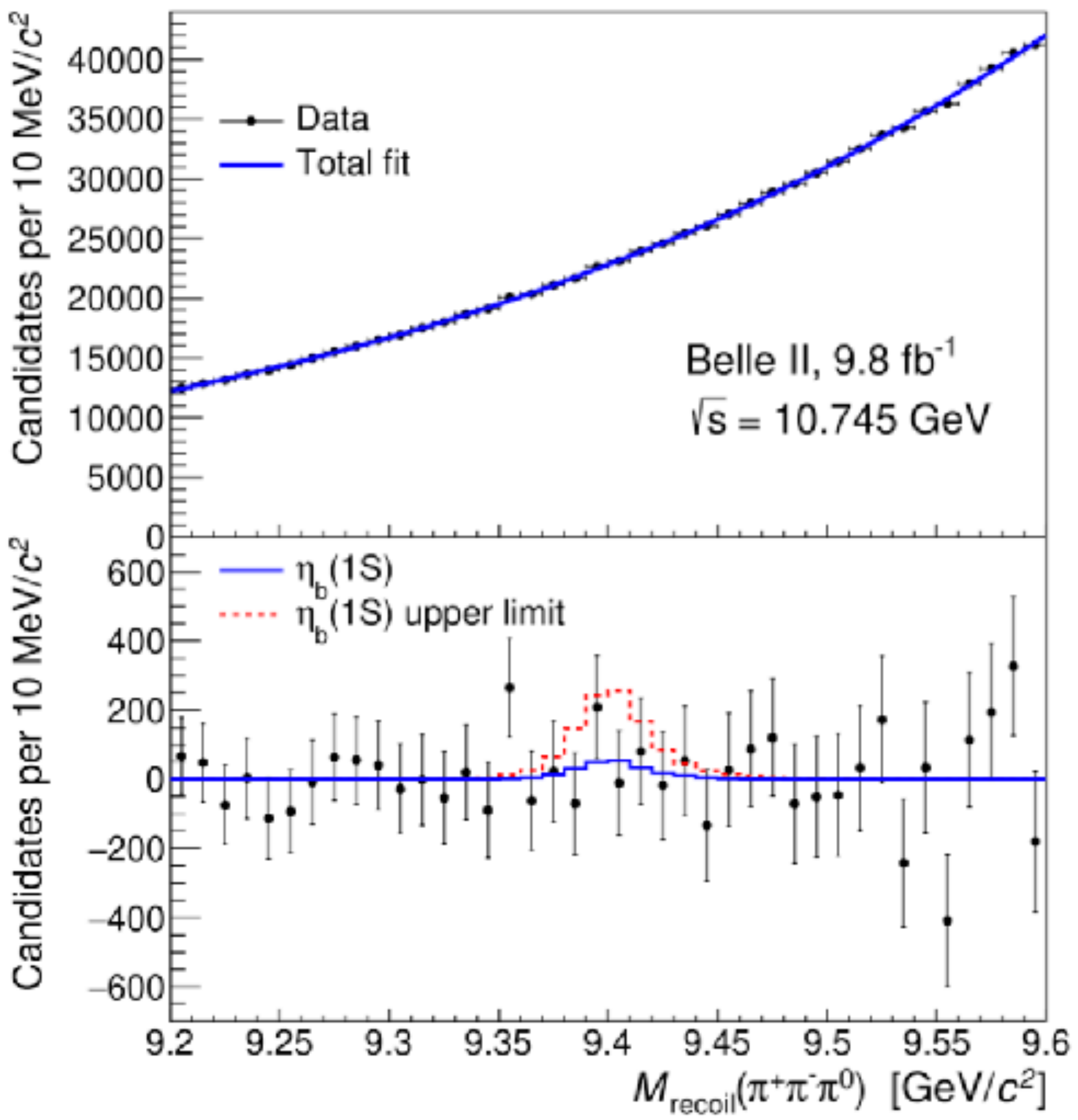
Shape increase at $B\bar{B}^*$ threshold. Suggestive of something?

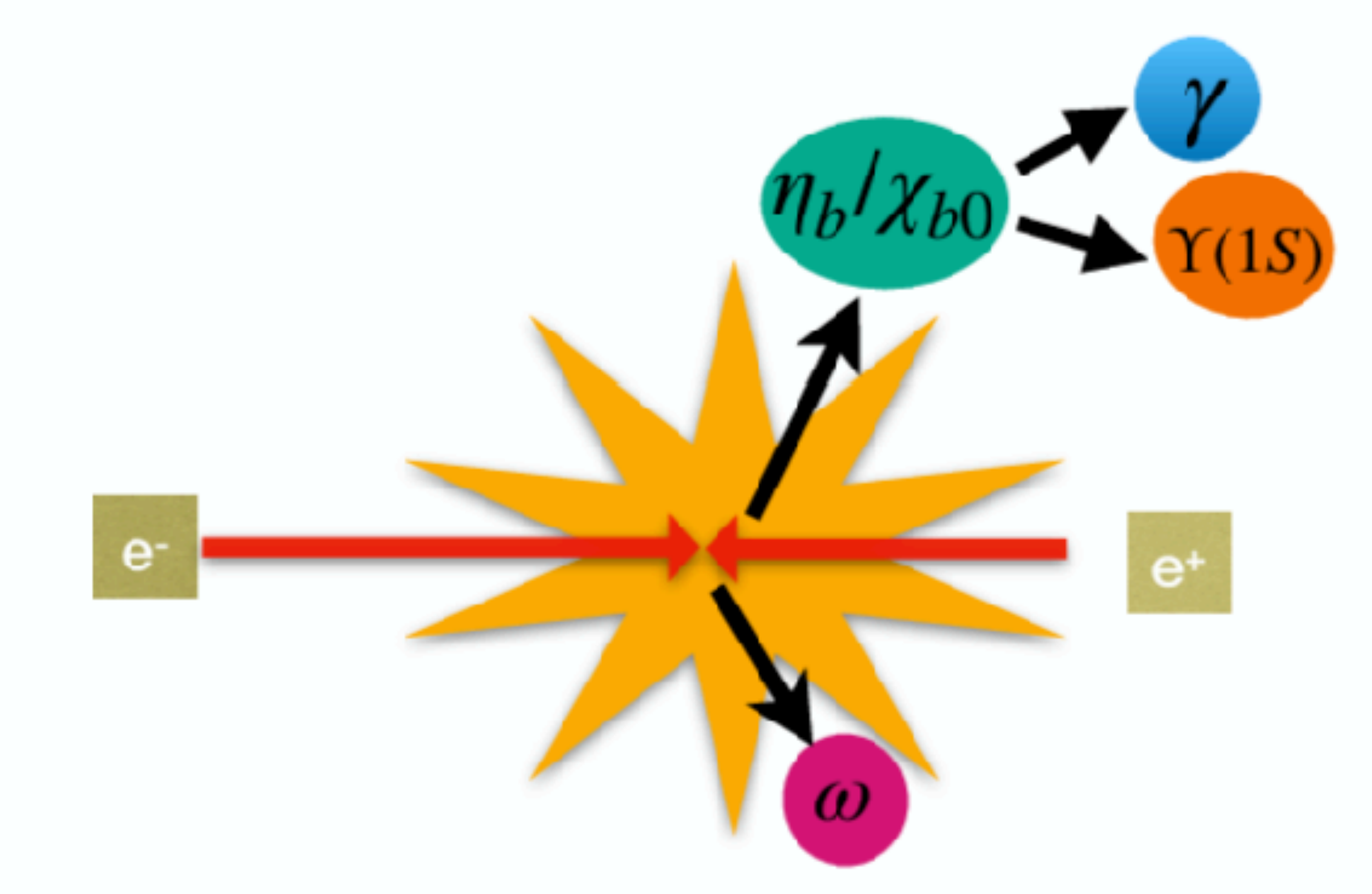
Search for $\Upsilon(10753) \to \omega\eta_b,\ \omega\chi_{b0}$

Preliminary

- $\Upsilon(10753) \to \omega\eta_b(1S)$ is strongly enhanced in tetraquark model.
- Analogy to $Y(4230) \to \omega\chi_{c0}$ in searching for $\omega\chi_{b0}$







	$\eta_b(1S)\omega$	$\chi_{b0}(1P)\omega$
Born cross section (pb)	$0.5 \pm 1.1 \pm 0.5$	$2.8 \pm 3.1 \pm 2.1$
90% C.L. UL	< 2.4	< 9.1

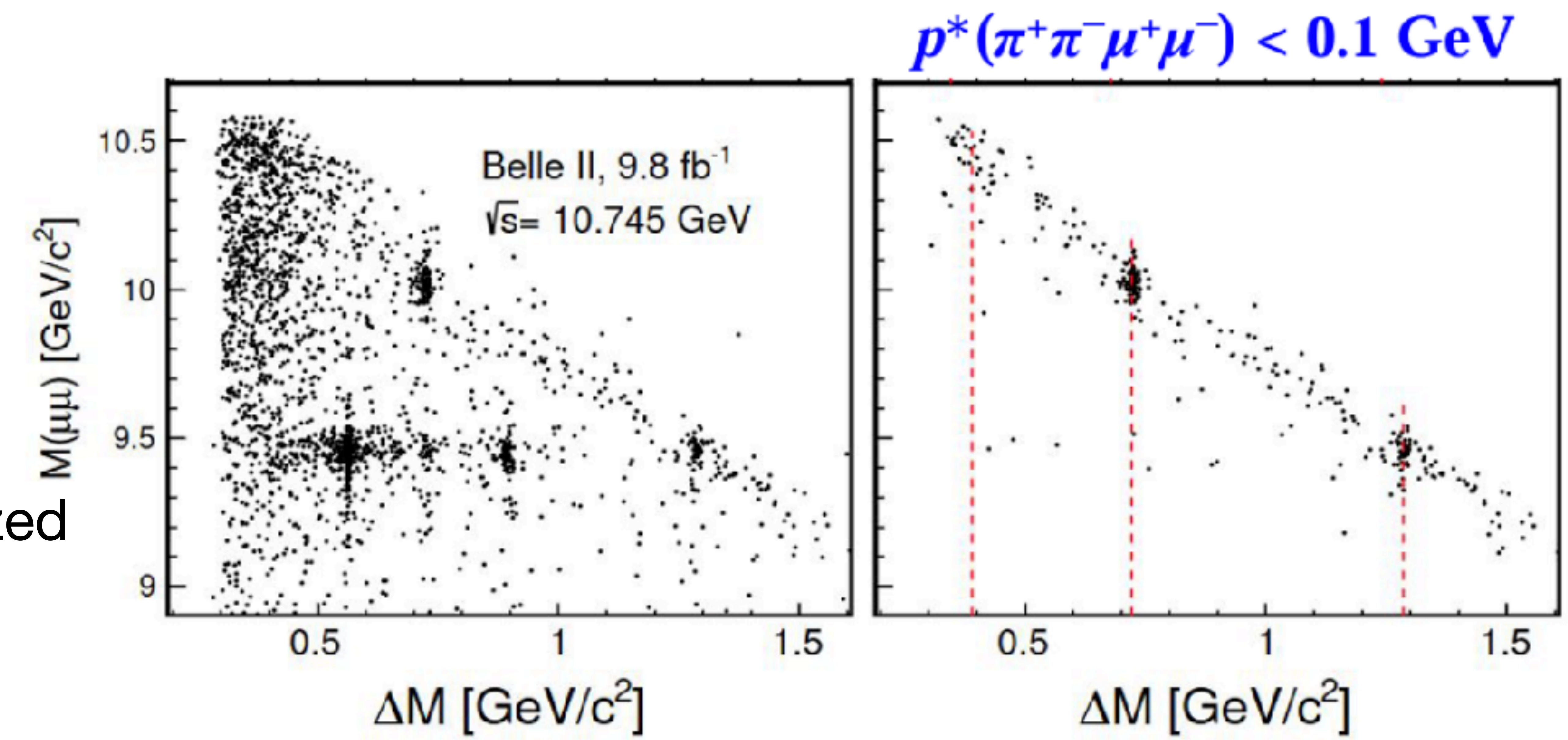
UL of $\omega\eta_b(1S)$ is similar to $\pi\pi\Upsilon(nS)$. Strongly inconsistent with one of the tetraquark model.

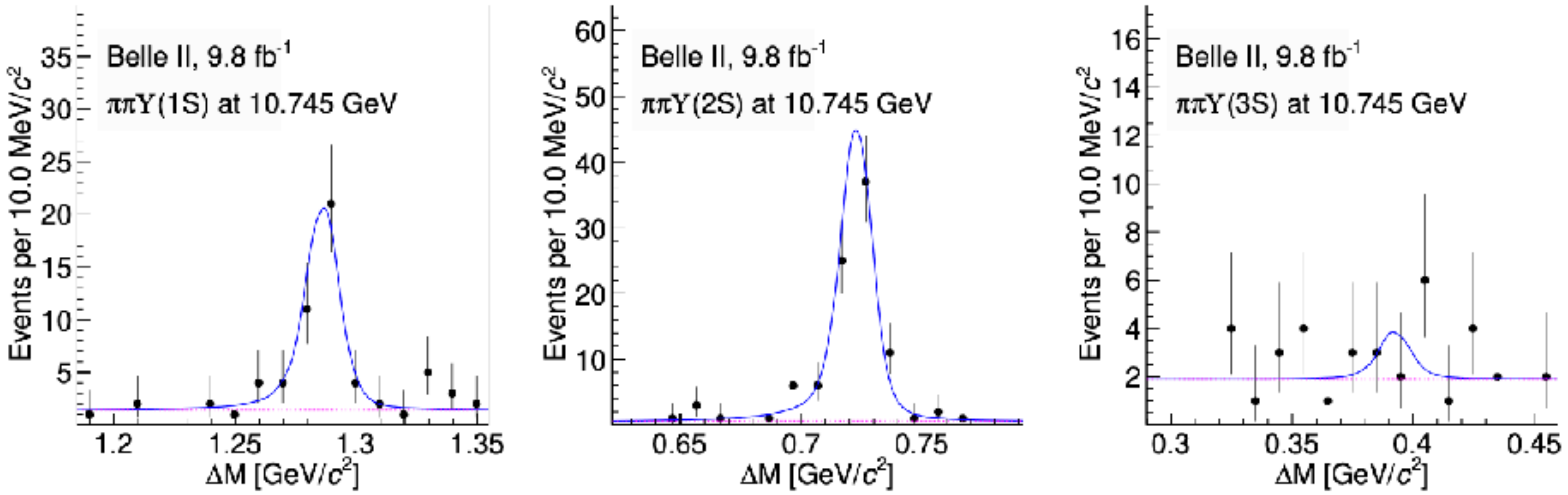
UL with full reconstruction is 11.3 fb - similar sensitivities.

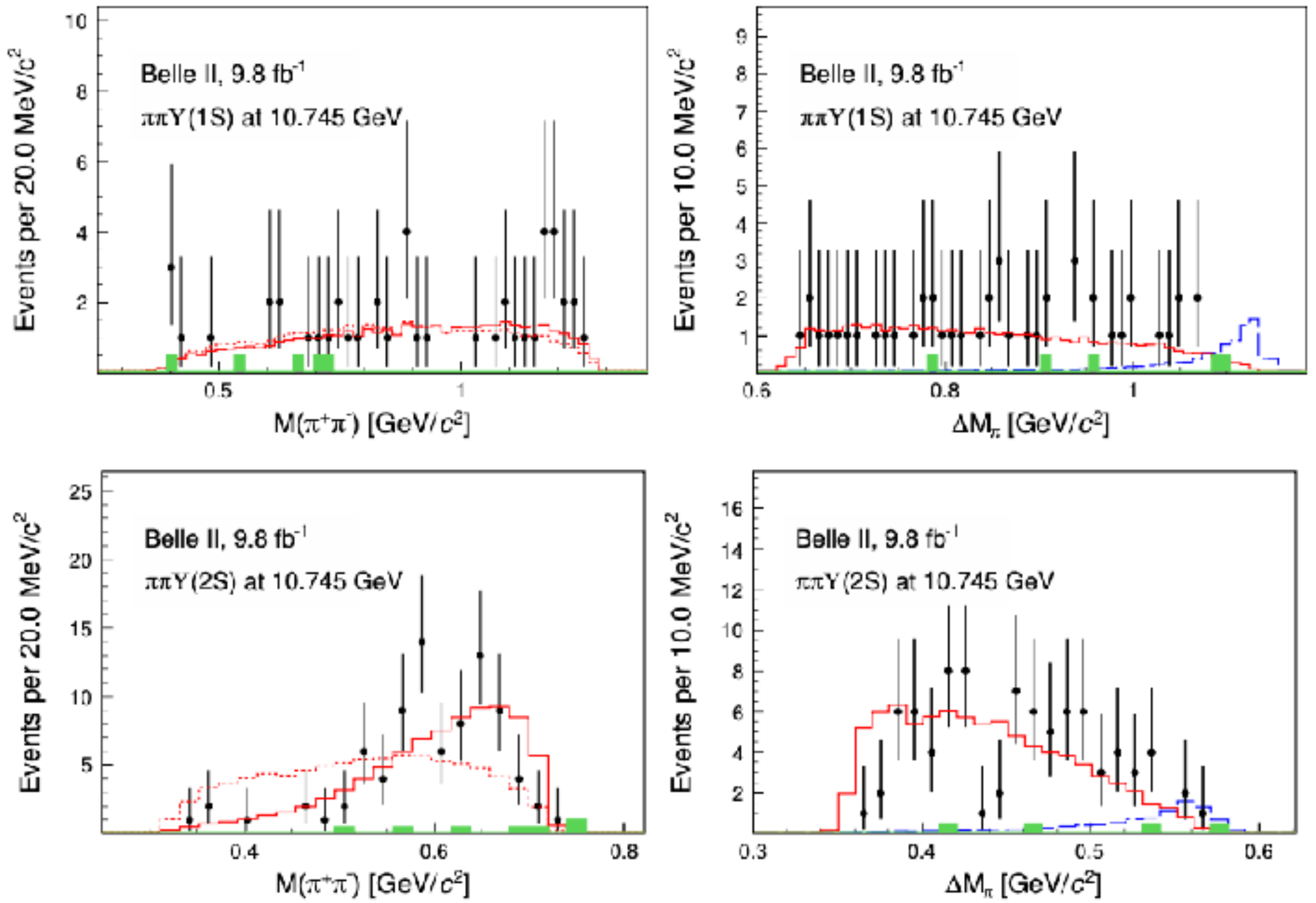
Measurement of $\Upsilon(10753) \to \pi^+\pi^-\Upsilon(nS)$, n=1,2,3

Preliminary

- Full reconstruction of $\pi^+\pi^-\mu^+\mu^-$, clear signal of $\Upsilon(10753)$ as well as other $\Upsilon(2,3S)$ signals.
- Evident signal of $\Upsilon(10753) \to \pi^+\pi^-\Upsilon(1S)$ and $\pi^+\pi^-\Upsilon(2S)$; no evidence of $\pi^+\pi^-\Upsilon(3S)$.
- No $Z_b(10610/10650)$; $M(\pi^+\pi^-)$ could be parameterized like $\Upsilon(2S) \to \pi^+\pi^-\Upsilon(1S)$







Fit with three coherent BW, convoluting a Gaussian modeling energy spread:

$$\sigma \propto \left| \sum_{i}^{3} \frac{\sqrt{12\pi\Gamma_i \mathscr{B}_i}}{s - M_i + iM_i\Gamma_i} \cdot \sqrt{\frac{f(\sqrt{s})}{f(M_i)}} e^{i\phi_i} \right|^2 \otimes G(0, \delta E)$$

All parameters are free, except $\delta E = 0.0056\ \text{GeV}$

Parameters of $\Upsilon(10753)$:

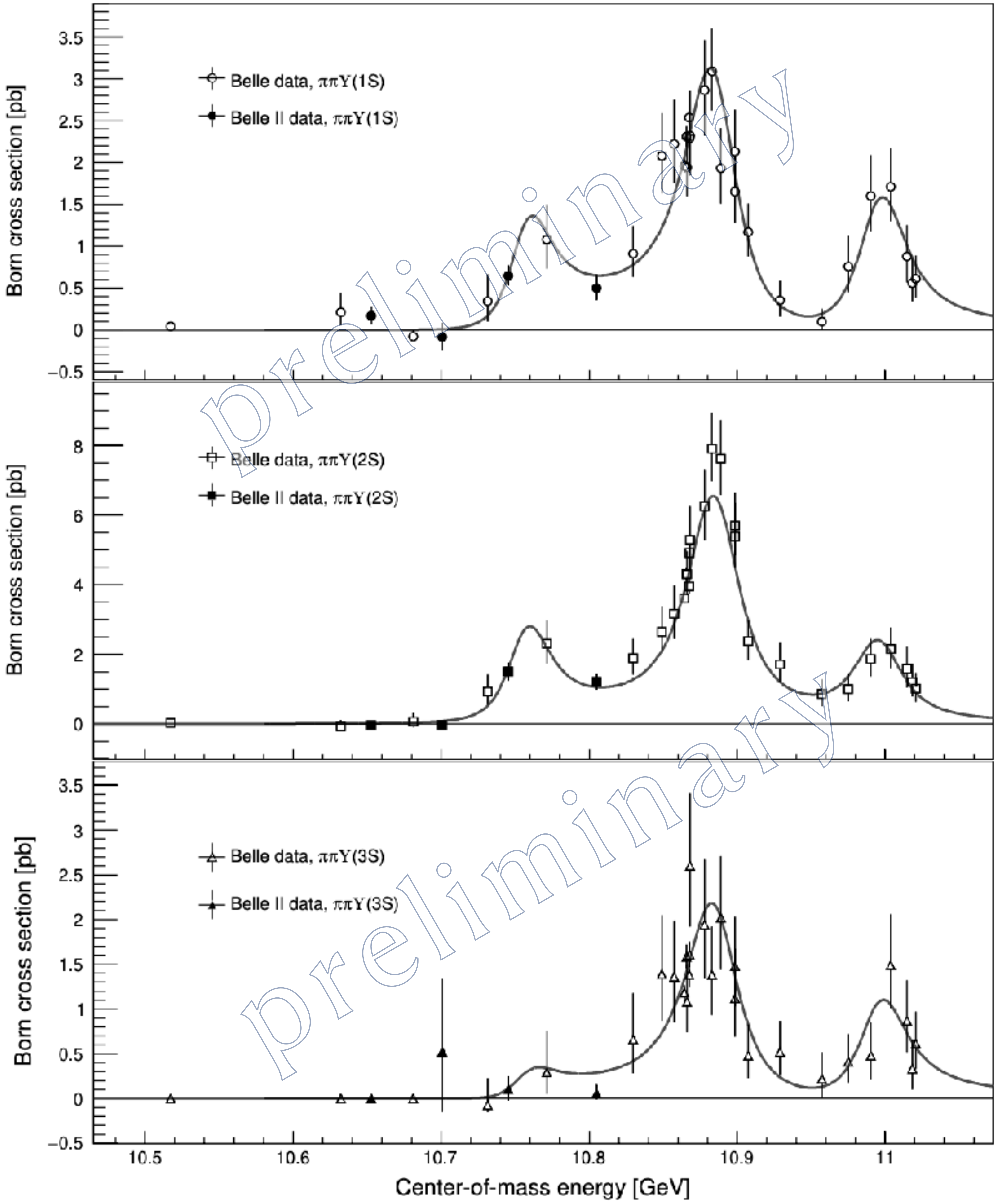
$M = 10756.3 \pm 2.7_{(stat.)} \pm 0.6_{(syst.)}\ \text{MeV}/c^2$

$\Gamma = 29.7 \pm 8.5_{(stat.)} \pm 1.1_{(syst.)}\ \text{MeV}$

Agree with previous Belle measurement.

Improve uncertainties ~2 times smaller

resonance	mass (MeV/c^2)	width (MeV)
$\Upsilon(5S)$	10884.7 ± 1.2	38.7 ± 3.7
$\Upsilon(6S)$	10995.5 ± 4.2	34.6 ± 8.6



Summary

- Belle II has collected 424/fb data.
- New data, new methods, new ideas lead to brand new results
  - First evidence of $B \to K\nu\nu$
  - Determination of ϕ_3 from Belle and Belle II
  - Most precise τ properties measurement
  - Most precise charm meson lifetime measurements
  - Properties study of $\Upsilon(10753)$, unique in Belle II
  - …
- Long shutdown 1 is finishing and new run will start from the beginning of 2024.
  - More data, more new results

BACK UP

Reconstruction and background suppression

Charged particles:
- p_t>0.1 GeV/c
- close to collision point
- in central region

Neutral particles:
- E>100 MeV
- in central region

Signal candidate:
- **charged particle**
- Kaon identification
- Minimal q^2_{rec}

Event (pre-selection):
- $4 \le N_{track} \le 10$
- E_{total}>4 GeV
- $17^o < \vartheta_{miss} < 160^o$

→

BDT$_1$ (first filter):
- 12 event-shape based kinematic variables

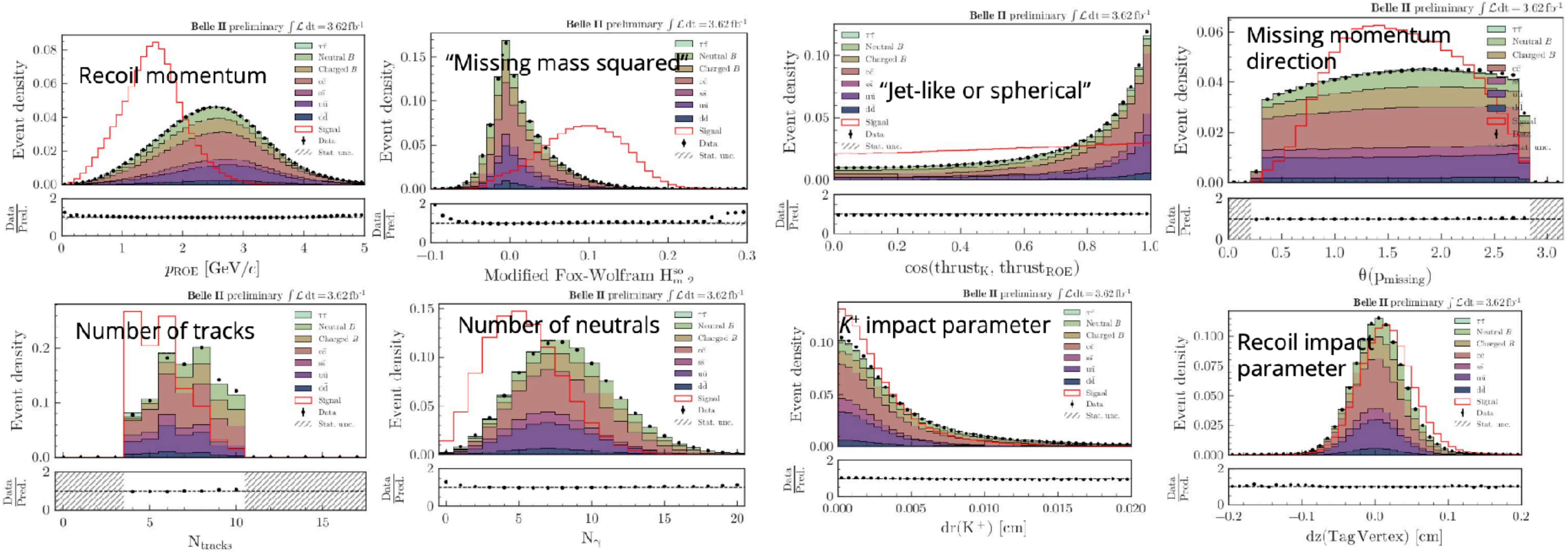
→

BDT$_2$ (final selection):
- *35 input variables*: using signal, event, and their correlations

- Selection criteria for particles to ensure high and well-measured efficiency
- Signal candidate selected using mass of the neutrino pair q^2_{rec} (computed as K^+ recoil)
- Three-step filter: basic event cuts, BDT-based filter (BDT$_1$) and final selection (BDT$_2$). BDT$_2$ improves performance in terms of s/√s+b by almost factor 3

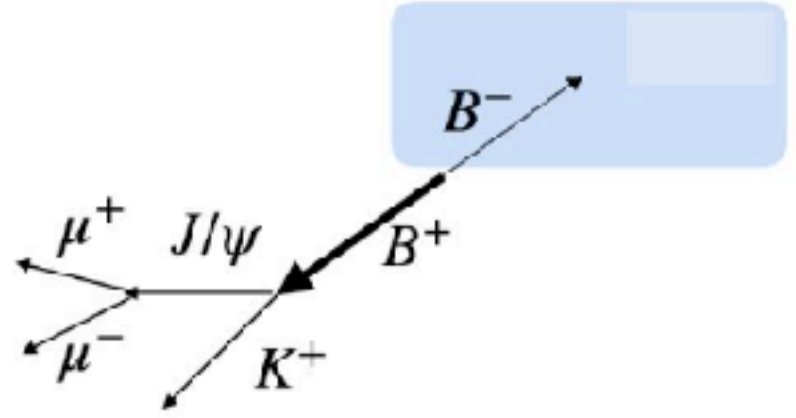
*Missing momentum is reconstructed using beam and all reconstructed particle 4-momenta

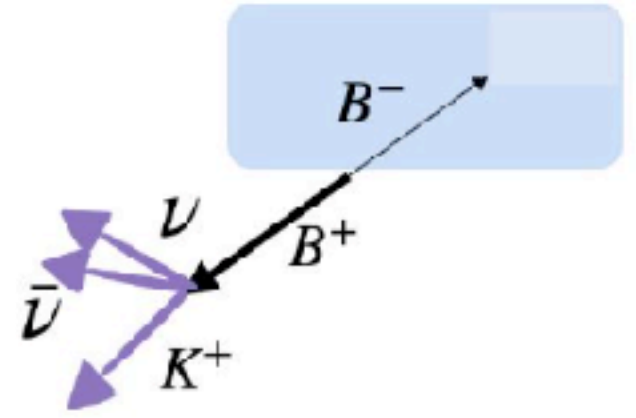
Examples of input variables for BDT_1 and BDT_2

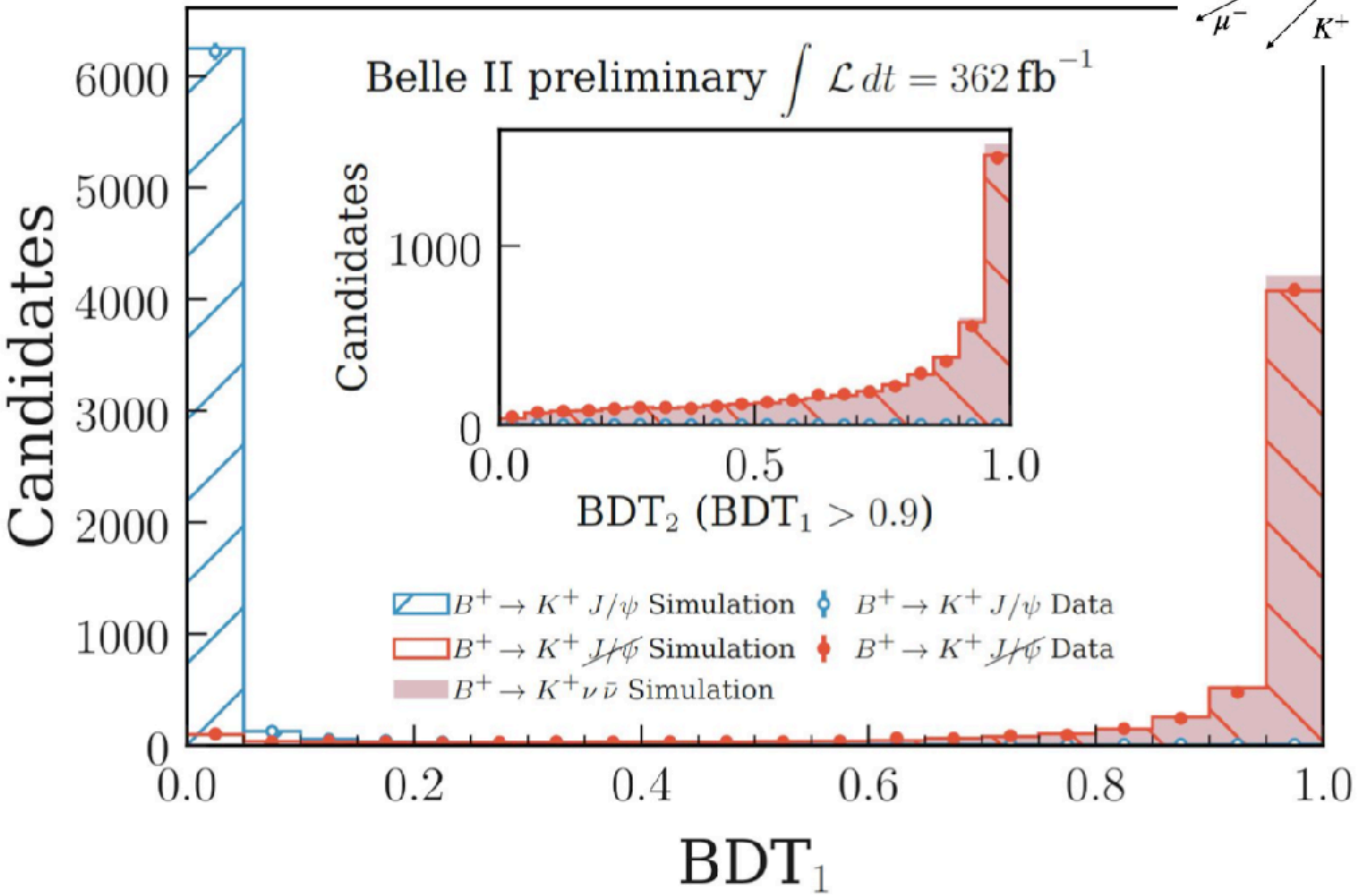


- Example of input distributions at pre-selection level, 1% of data, with detector-level corrections applied but no physics modeling corrections
- Each variable is examined to have reasonable description by simulation and significant separation power

Signal efficiency validation

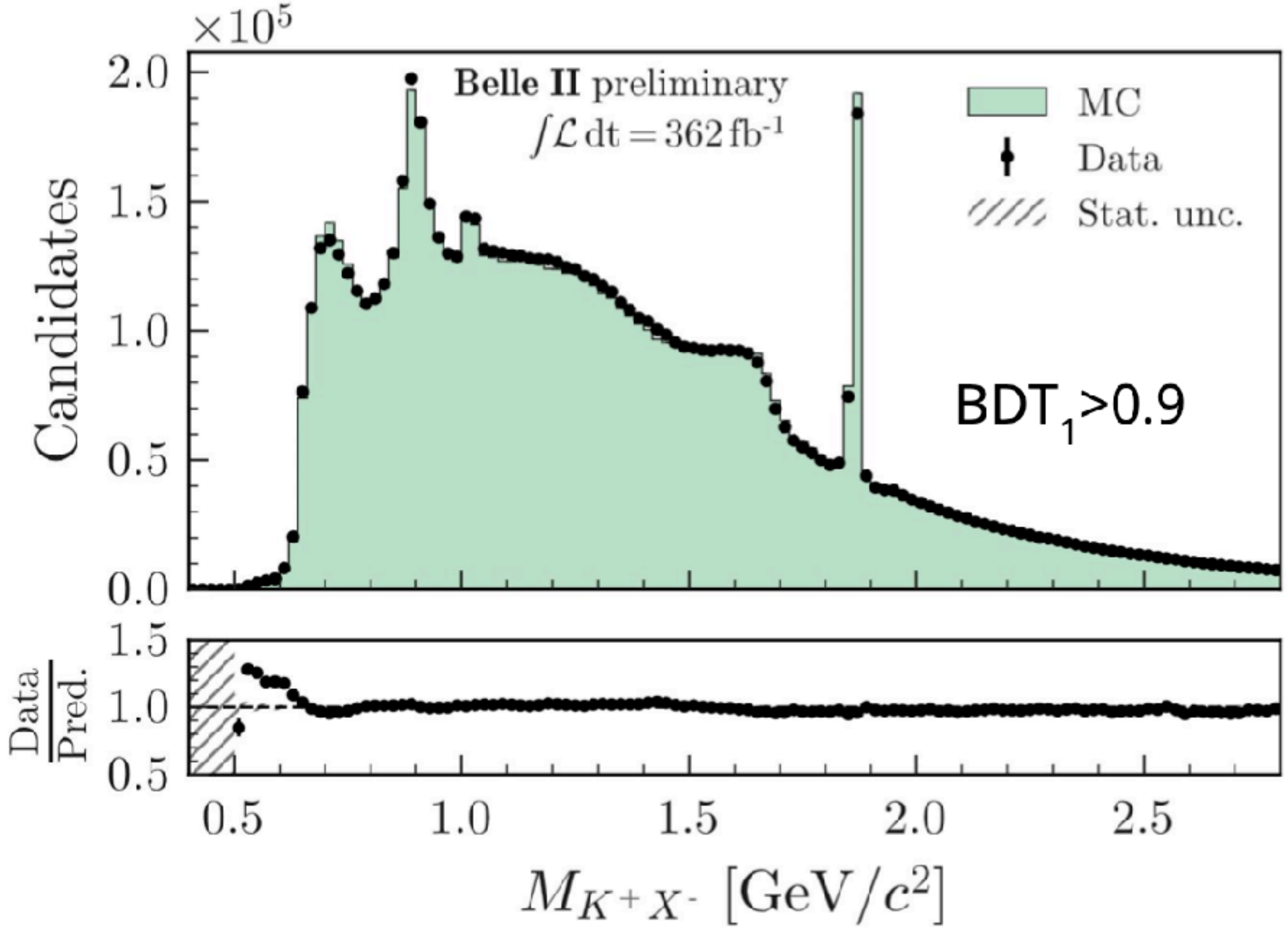


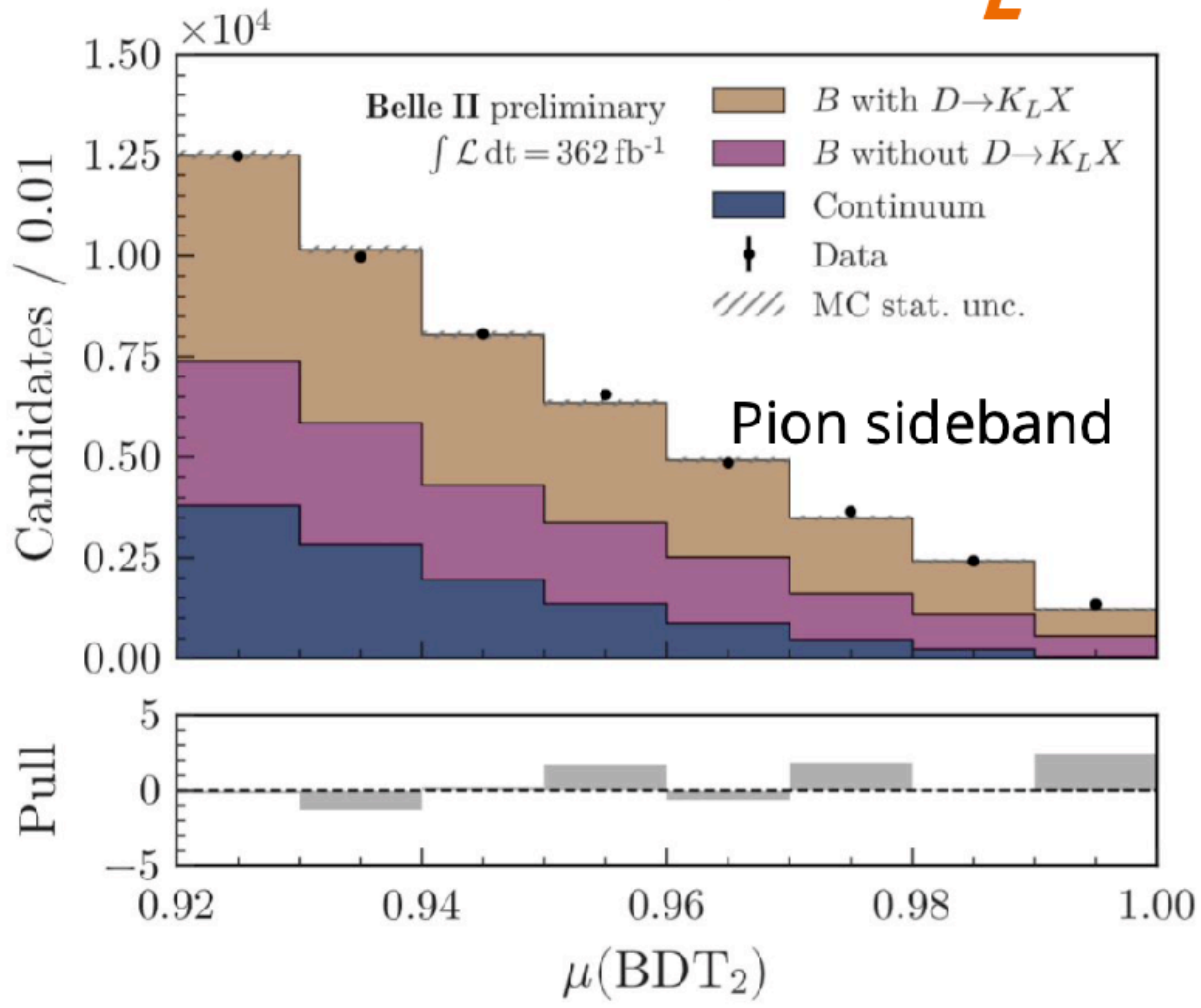




- Use cleanly reconstructed $B^+ \to K^+ J/\psi(\to \mu^+\mu^-)$ decays with $\mu^+\mu^-$ pair removed and K^+ kinematics adjusted to validate the signal efficiency in simulation. The ratio of data/simulation efficiency in the signal region is **1.00±0.03**

Background from $B \to D(\to K^+ X) l\nu$ and $B \to K^+ D(\to K_L X)$

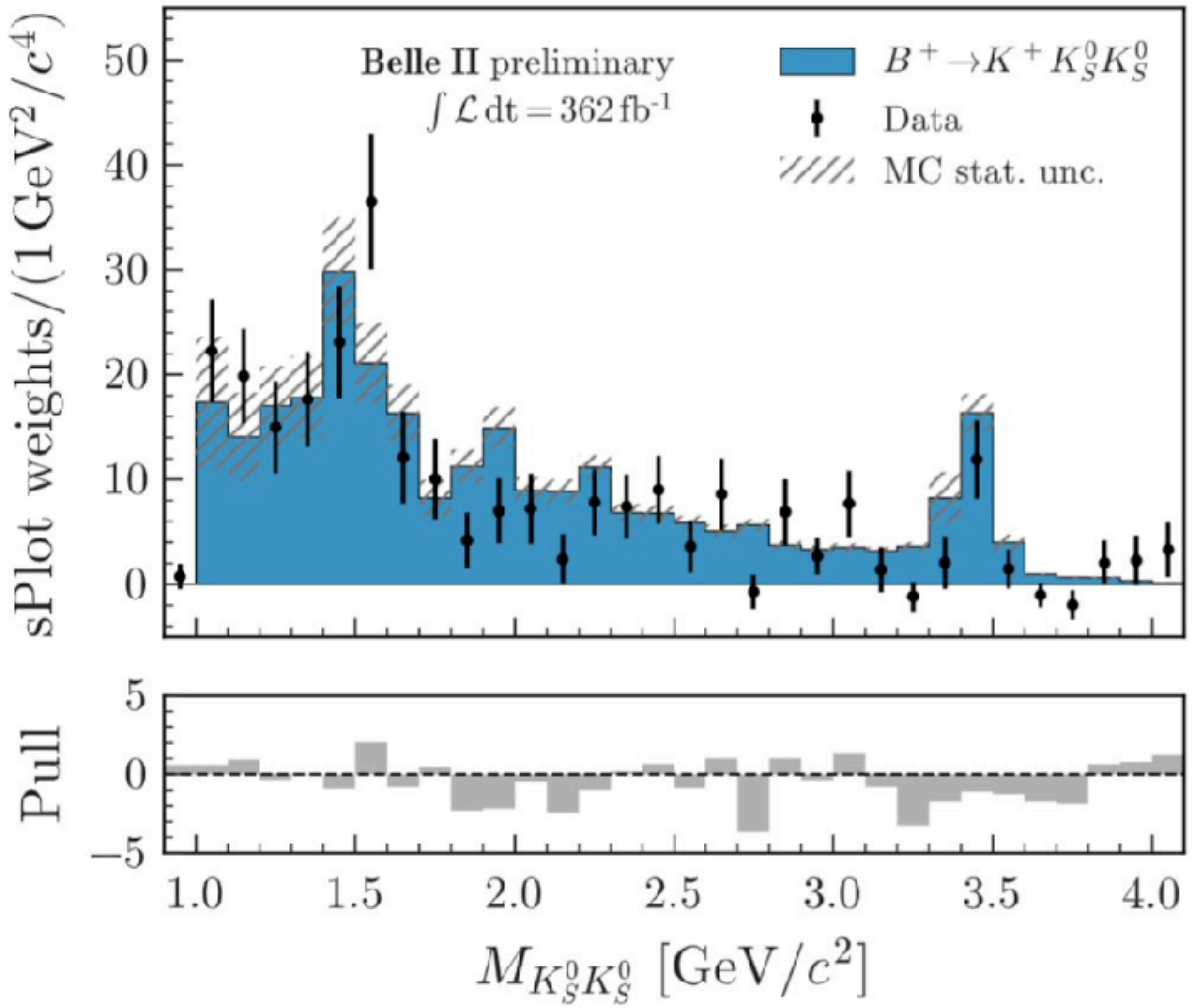




- Main backgrounds: semileptonic $B \to D(\to K^+ X) l\nu$ decays and prompt $B \to K^+ X$ production (>90%)
- Semileptonic decays suppressed by several MVA variables, checked at each selection step
- Prompt K^+ production studied using prompt π^+ from $B^+ \to \pi^+ X$ (and l^+ from $B^+ \to l^+ X$) decays
- Systematic uncertainties on decay branching fractions, enlarged for $D(\to K_L X)$ and $B \to D^{**} l\,\nu$

Background from $B^+ \to K^+ K^0 K^0$

Most signal-like backgrounds

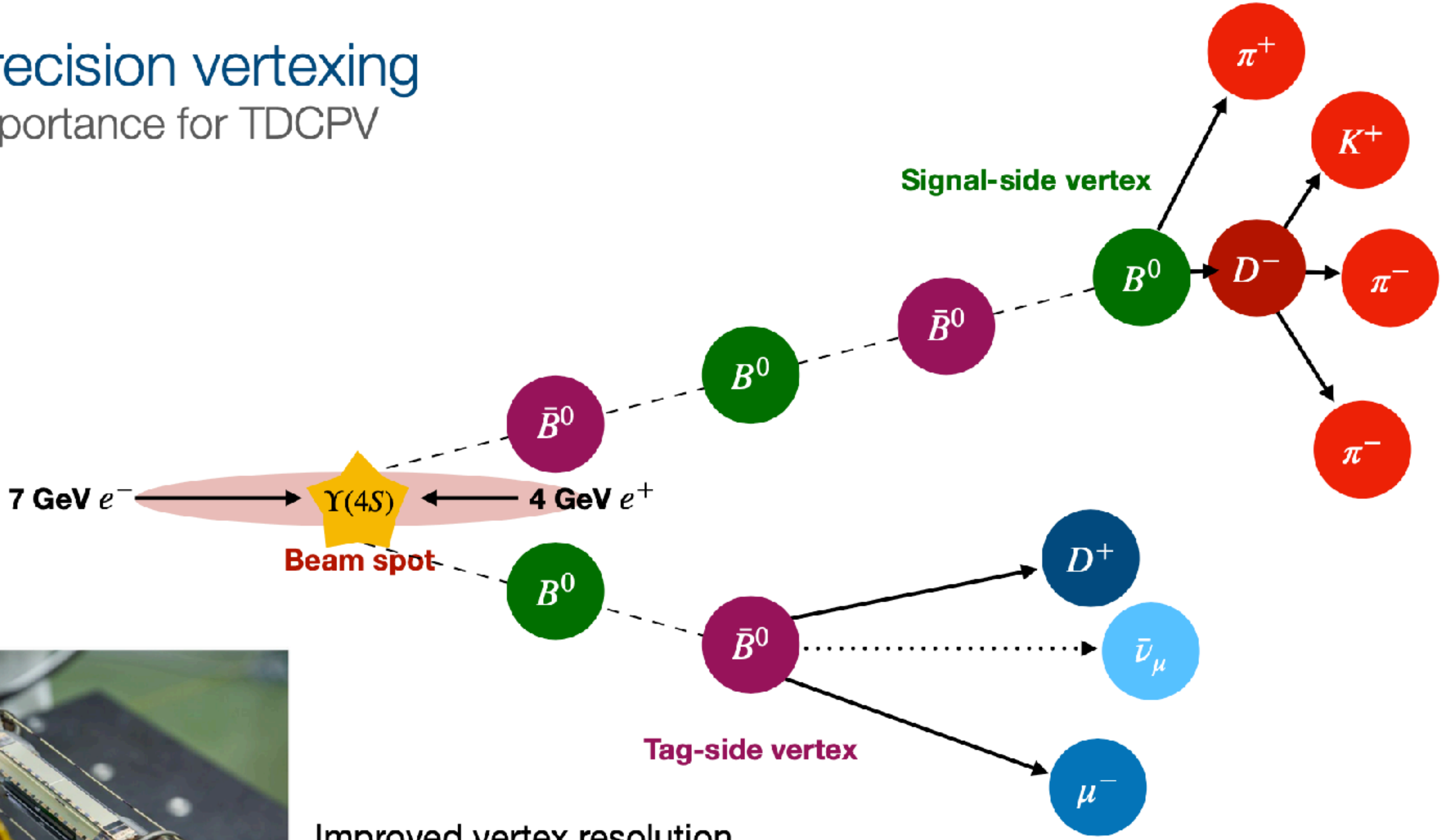


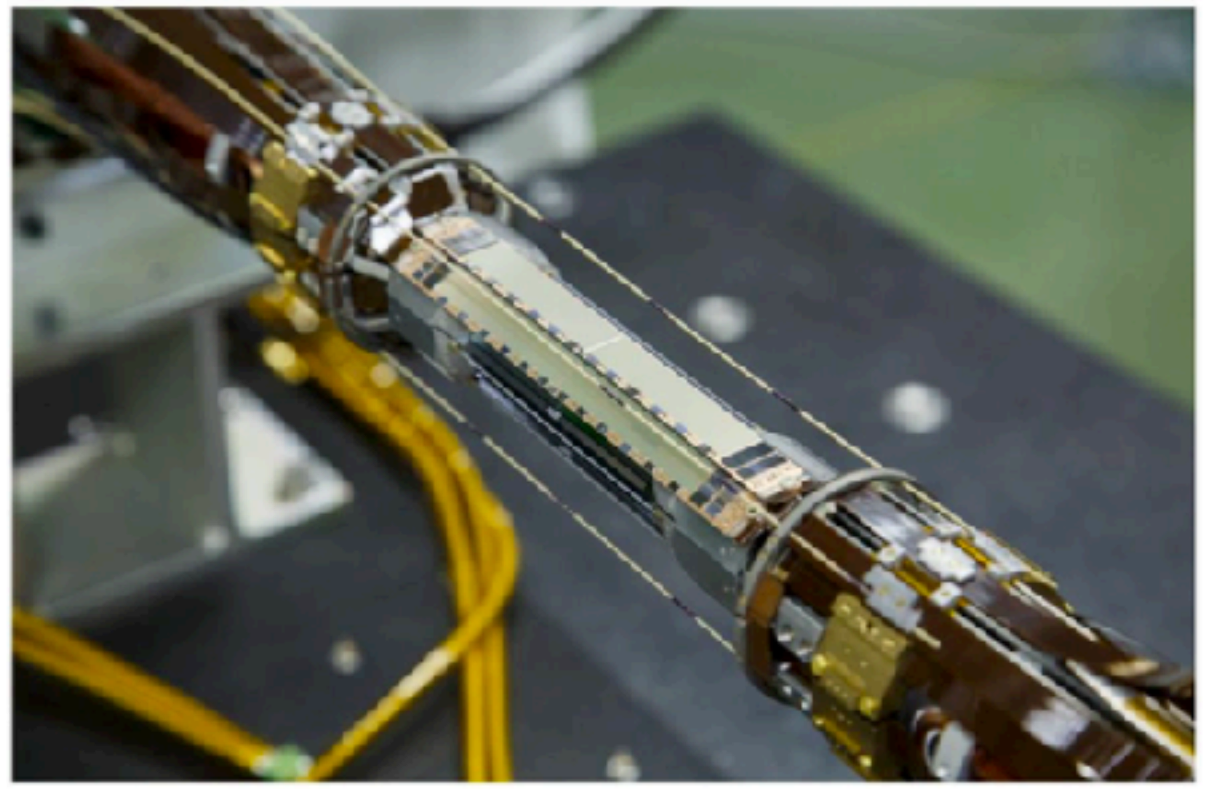
←$B^+ \to K^+ K_S K_S$ decays

- Backgrounds from $B^+ \to K^+ nn$ and $B^+ \to K^+ K^0 K^0$ have branching fractions of few x 10^{-5}, however K_L and neutrons can escape EM calorimeter
- $B^+ \to K^+ K^0 K^0$ modeled based on BaBar analysis (arXiv:1201.5897)
- Dedicated checks of K_L performance in calorimeter using radiative φ production
- Dedicated checks using $B^+ \to K^+ K_S K_S$ and $B^0 \to K_S K^+ K^-$ control channels

High-precision vertexing

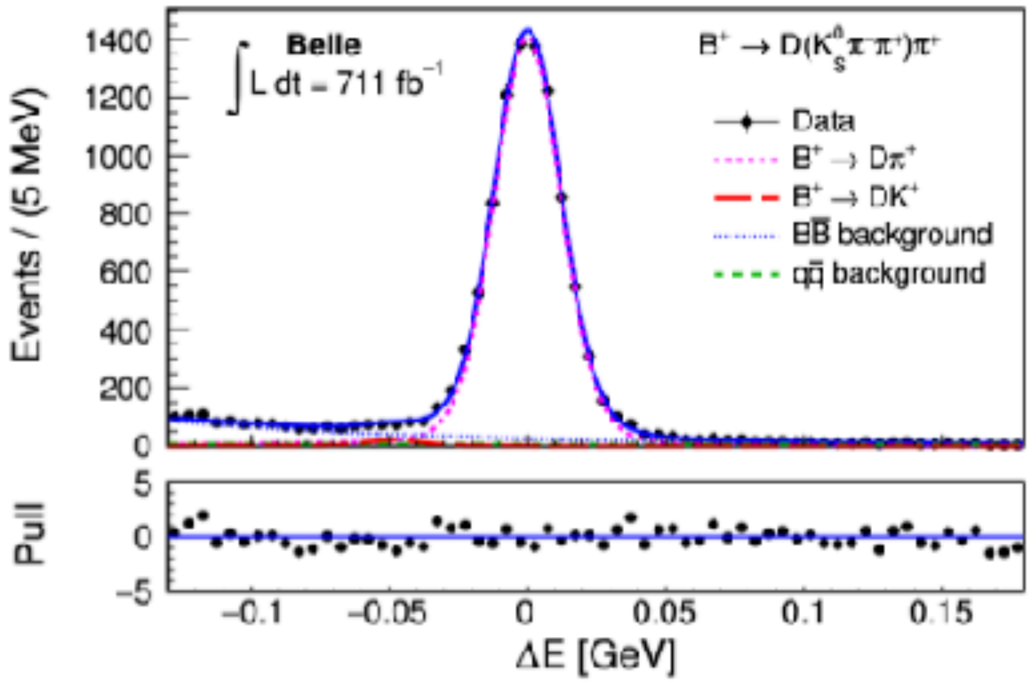
and its importance for TDCPV

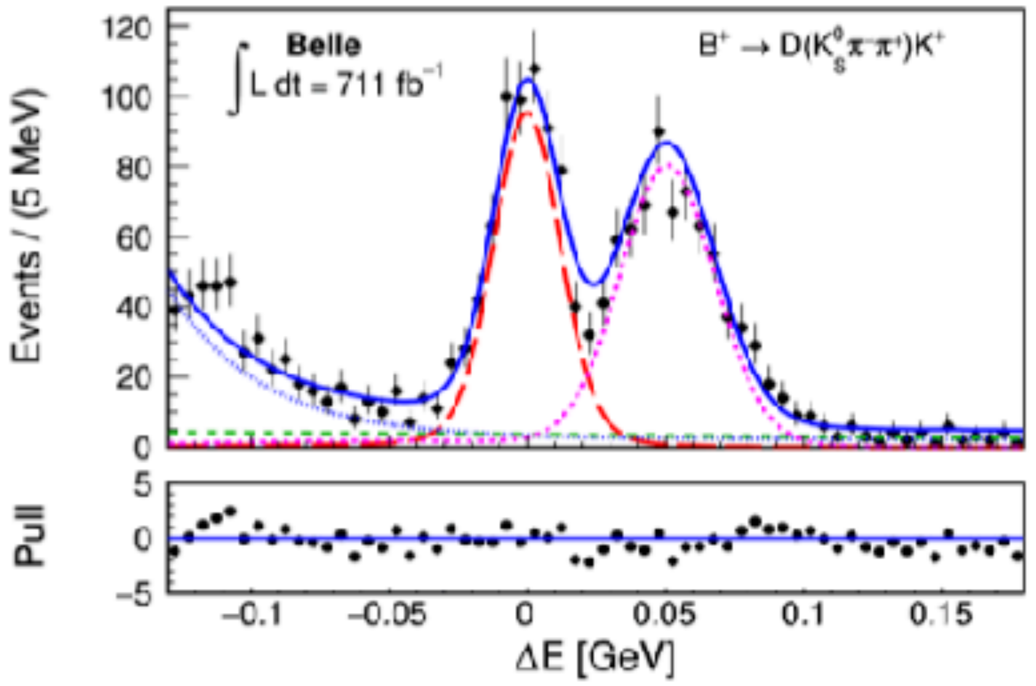


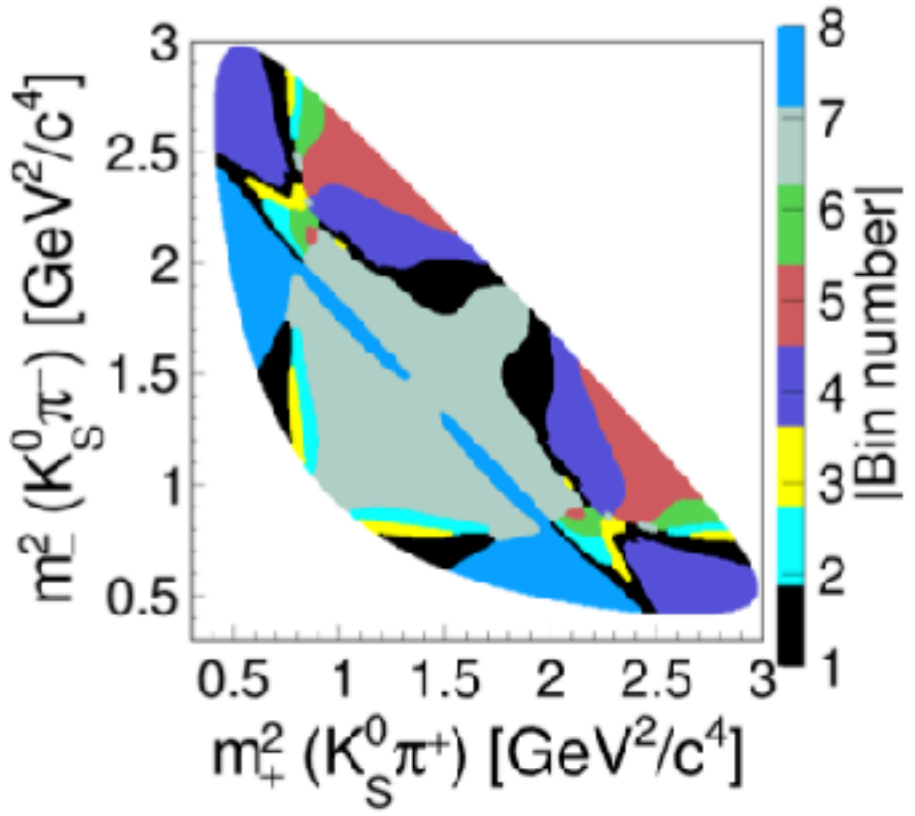


Improved vertex resolution
due to pixel detector
(despite lower boost)

γ measurement in $B^+ \to D(K_S^0 h^+ h^-)h^+$ with Belle and Belle II data



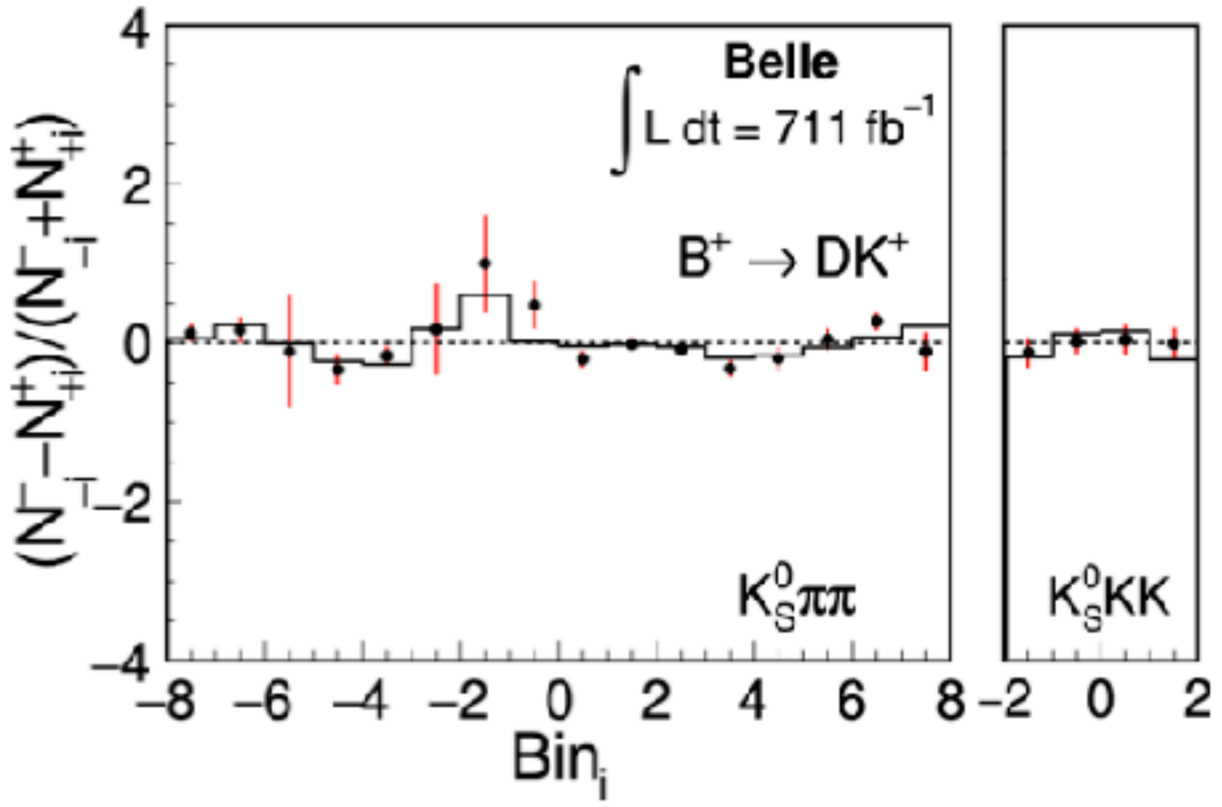


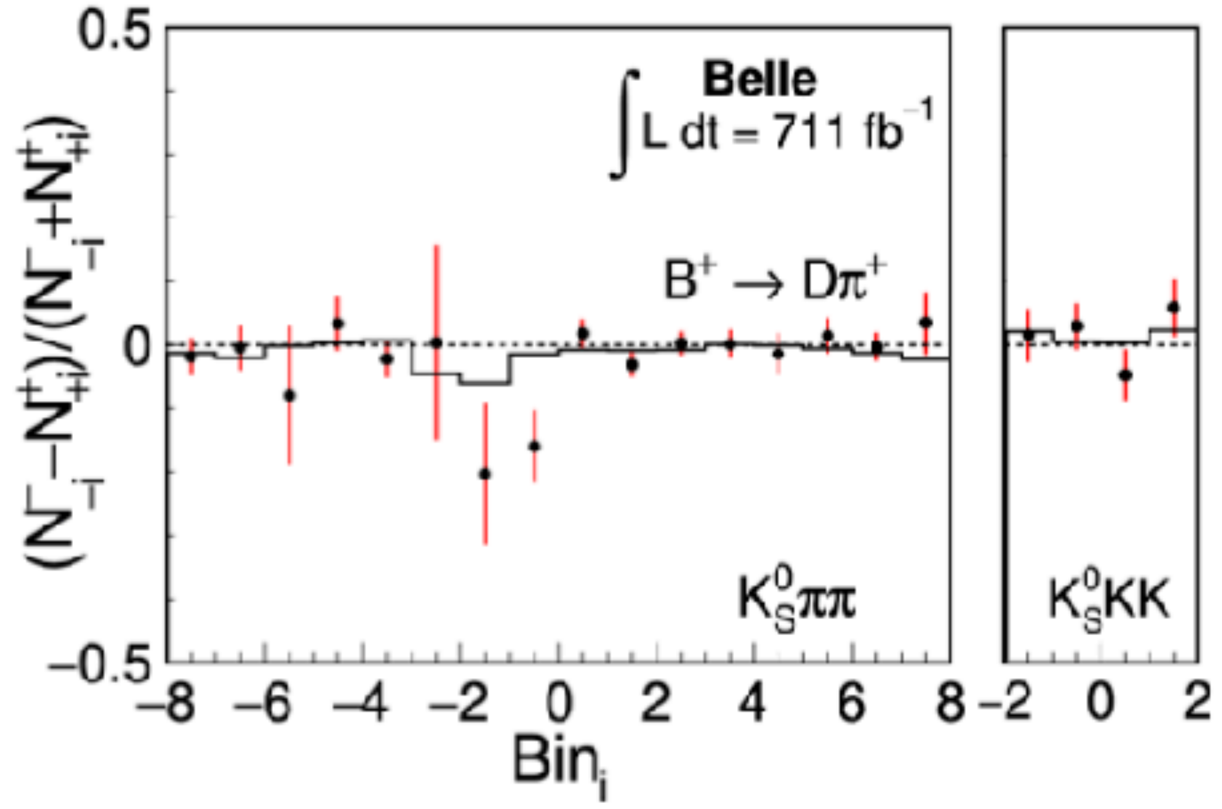


Determine bin-by-bin asymmetries

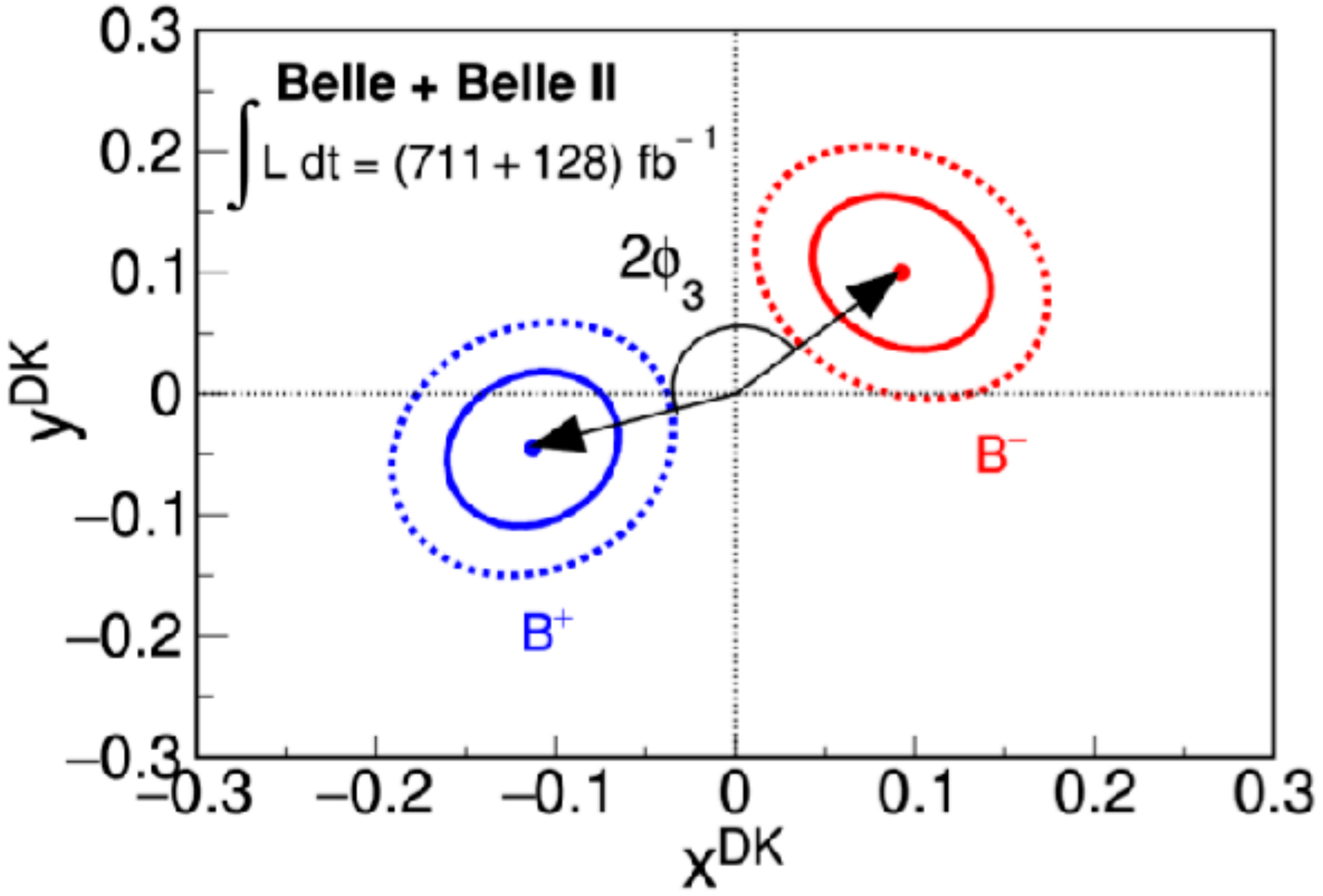
$(N_-^{-i} - N_+^{+i})/(N_-^{-i} + N_+^{+i})$

in each Dalitz plot bin i





$$x_\pm^{DK} = r_B^{DK}\cos(\delta_B^{DK} \pm \phi_3)$$
$$y_\pm^{DK} = r_B^{DK}\sin(\delta_B^{DK} \pm \phi_3)$$



$$\phi_3 = (78.4 \pm 11.4 \pm 0.5 \pm 1.0)^\circ,$$
$$r_B^{DK} = 0.129 \pm 0.024 \pm 0.001 \pm 0.002,$$
$$\delta_B^{DK} = (124.8 \pm 12.9 \pm 0.5 \pm 1.7)^\circ,$$
$$r_B^{D\pi} = 0.017 \pm 0.006 \pm 0.001 \pm 0.001,$$
$$\delta_B^{D\pi} = (341.0 \pm 17.0 \pm 1.2 \pm 2.6)^\circ.$$

Measurement of $B^{\pm} \to D_{CP\pm}K^{\pm}$ with Belle and Belle II data

- Simultaneous fit to $B^{\pm} \to DK^{\pm}$ and $B^{\pm} \to D\pi^{\pm}$ with D decays to CP eigenstates

$$\mathcal{R}_{CP\pm} \equiv \frac{\mathcal{B}(B^- \to D_{CP\pm}K^-) + \mathcal{B}(B^+ \to D_{CP\pm}K^+)}{(\mathcal{B}(B^- \to D_{\rm flav}K^-) + \mathcal{B}(B^+ \to \overline{D}_{\rm flav}K^+))/2}$$

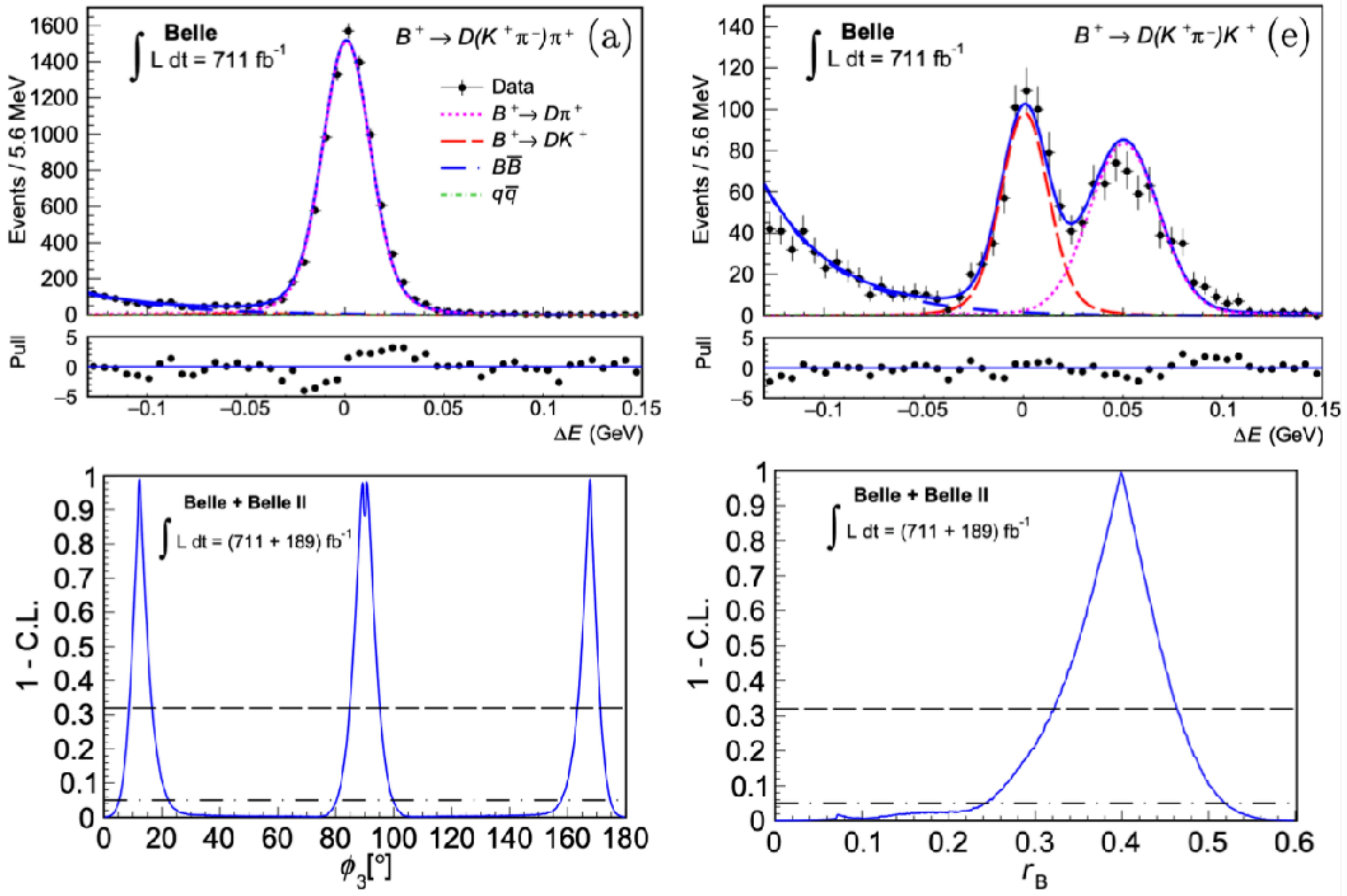
$$\mathcal{A}_{CP\pm} \equiv \frac{\mathcal{B}(B^- \to D_{CP\pm}K^-) - \mathcal{B}(B^+ \to D_{CP\pm}K^+)}{\mathcal{B}(B^- \to D_{CP\pm}K^-) + \mathcal{B}(B^+ \to D_{CP\pm}K^+)}$$

$$\mathcal{R}_{CP\pm} \approx \frac{R_{CP\pm}}{R_{\rm flav}}$$

$$\mathcal{R}_{CP\pm} = 1 + r_B^2 \pm 2r_B \cos\delta_B \cos\phi_3$$

$$\mathcal{A}_{CP\pm} = \pm 2r_B \sin\delta_B \sin\phi_3 \,/\, \mathcal{R}_{CP\pm}$$

	68.3% CL	95.4% CL
ϕ_3 (°)	[8.5, 16.5]	[5.0, 22.0]
	[84.5, 95.5]	[80.0, 100.0]
	[163.3, 171.5]	[157.5, 175.0]
r_B	[0.321, 0.465]	[0.241, 0.522]



R(X) Result

-The first results of $R(X) = \frac{\mathcal{B}(B \to X\tau\nu_\tau)}{\mathcal{B}(B \to X\ell\nu_\ell)}$ at B factory:

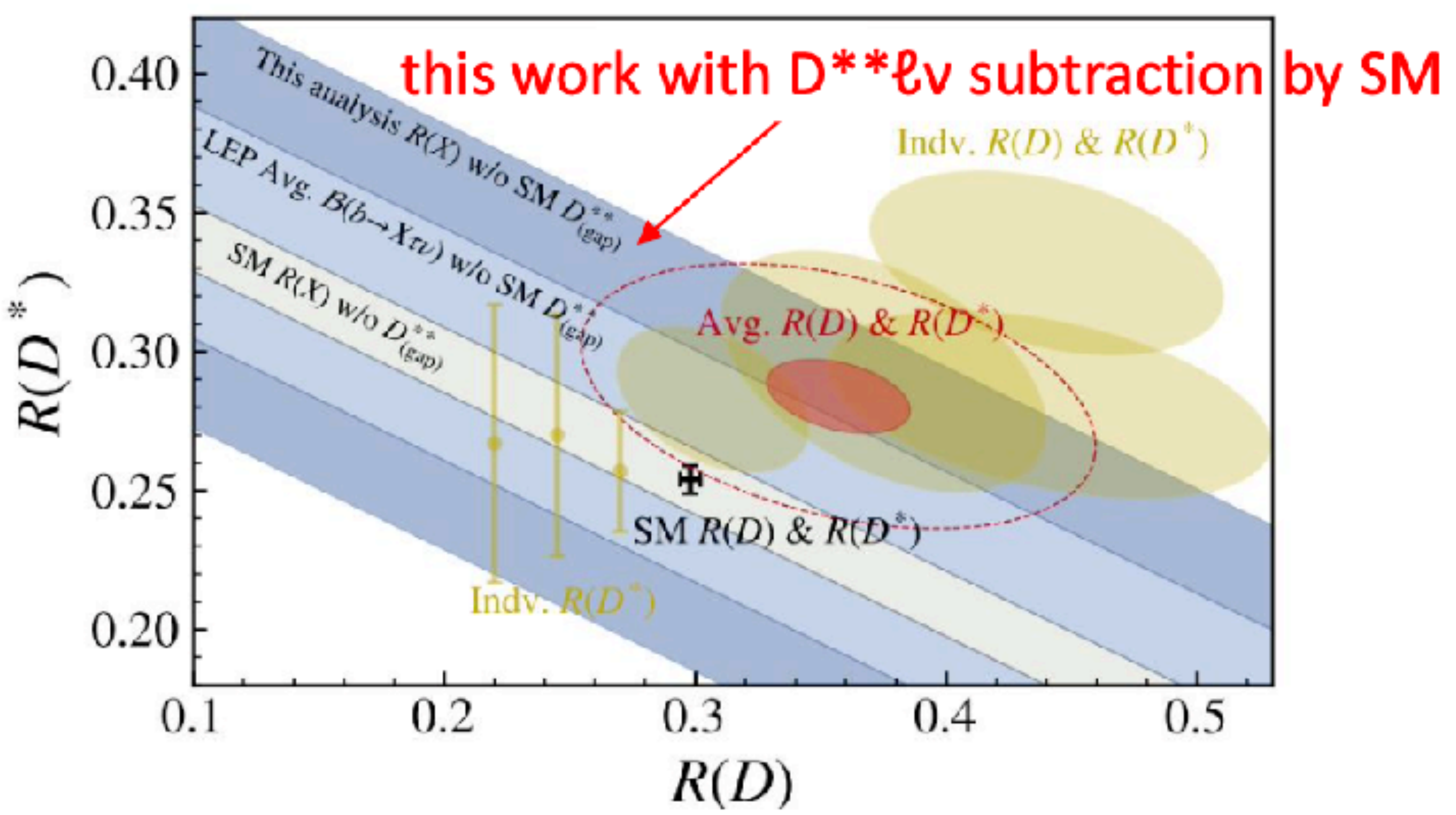
$$R(X_{\tau/e}) = 0.232 \pm 0.042, [0.020\ (\text{stat}), 0.037\ (\text{syst})]$$

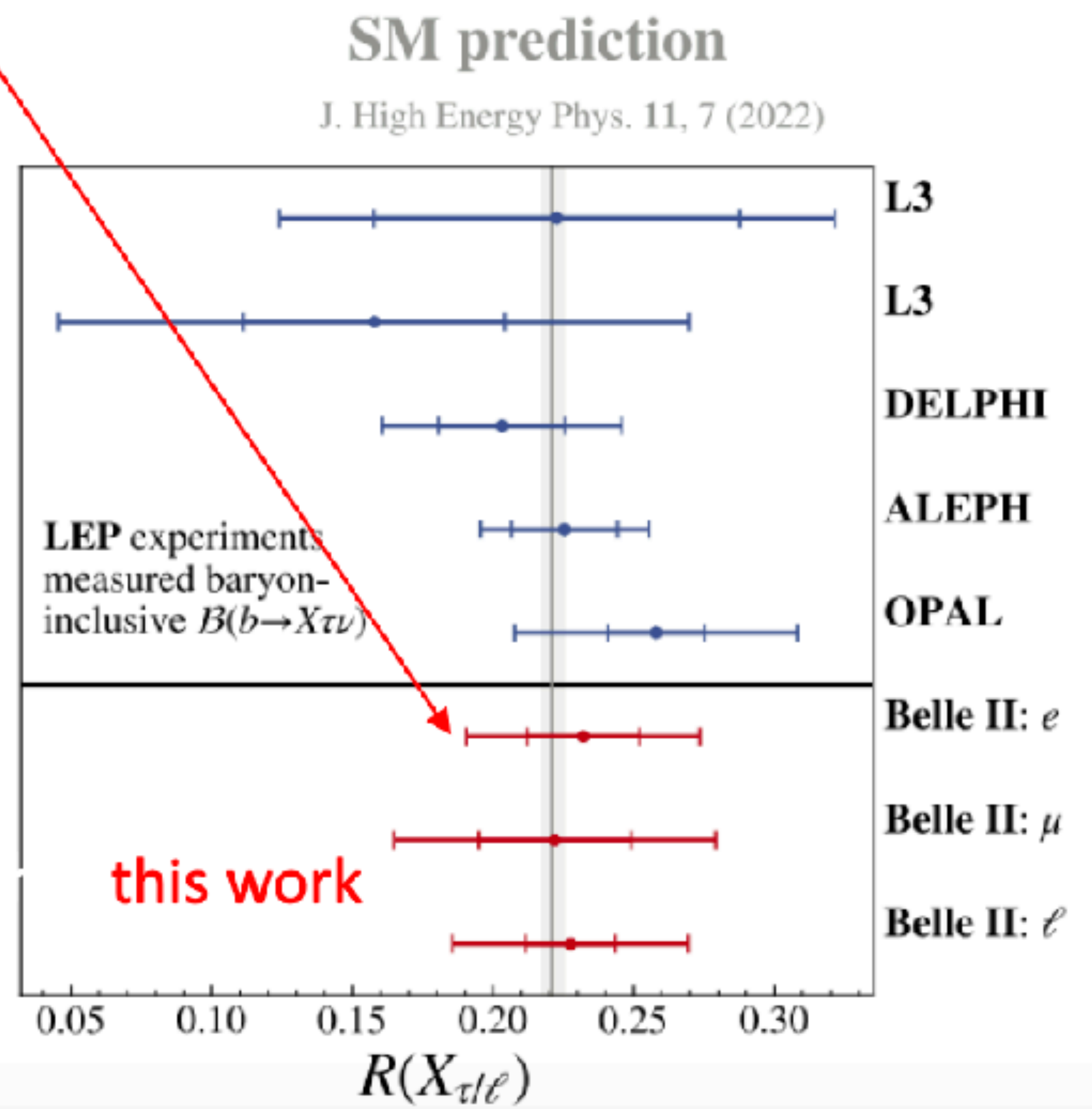
$$R(X_{\tau/\mu}) = 0.222 \pm 0.057, [0.027\ (\text{stat}), 0.050\ (\text{syst})]$$

$$R(X_{\tau/\ell}) = 0.228 \pm 0.039, [0.016\ (\text{stat}), 0.036\ (\text{syst})]$$

Major systematics: MC statistics, PDF shape, BR of B→D**ℓv

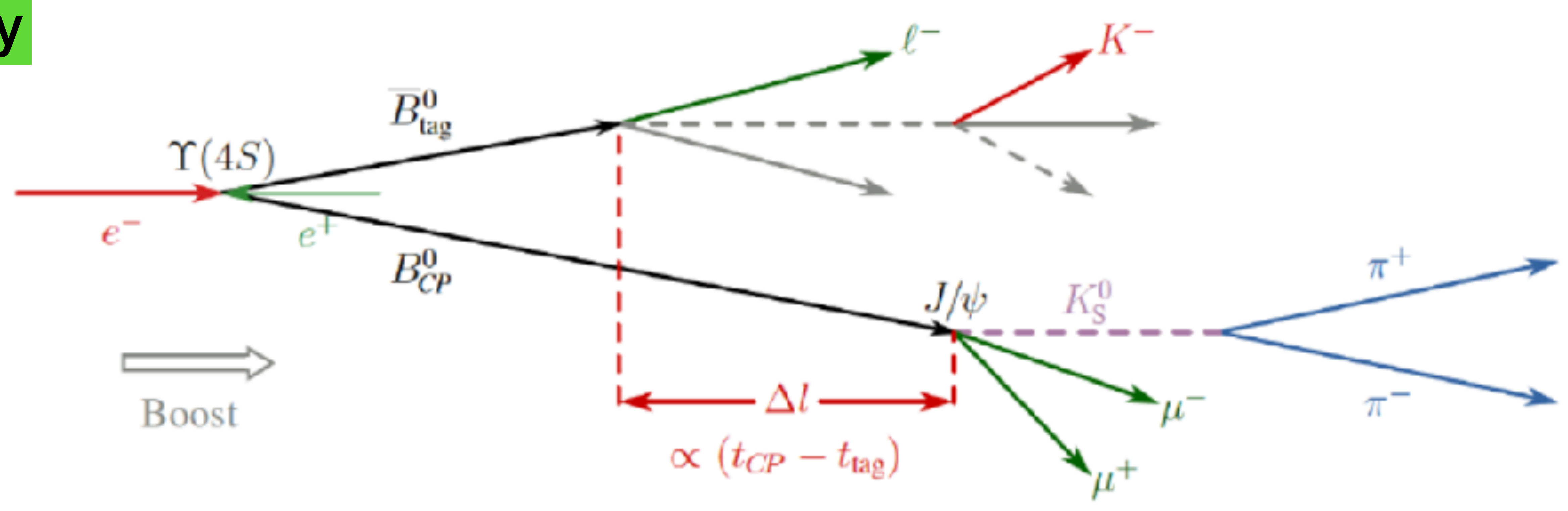
-Consistent with SM prediction





$\sin 2\phi_1$ using $B^0 \to K_S^0 J/\psi$

preliminary

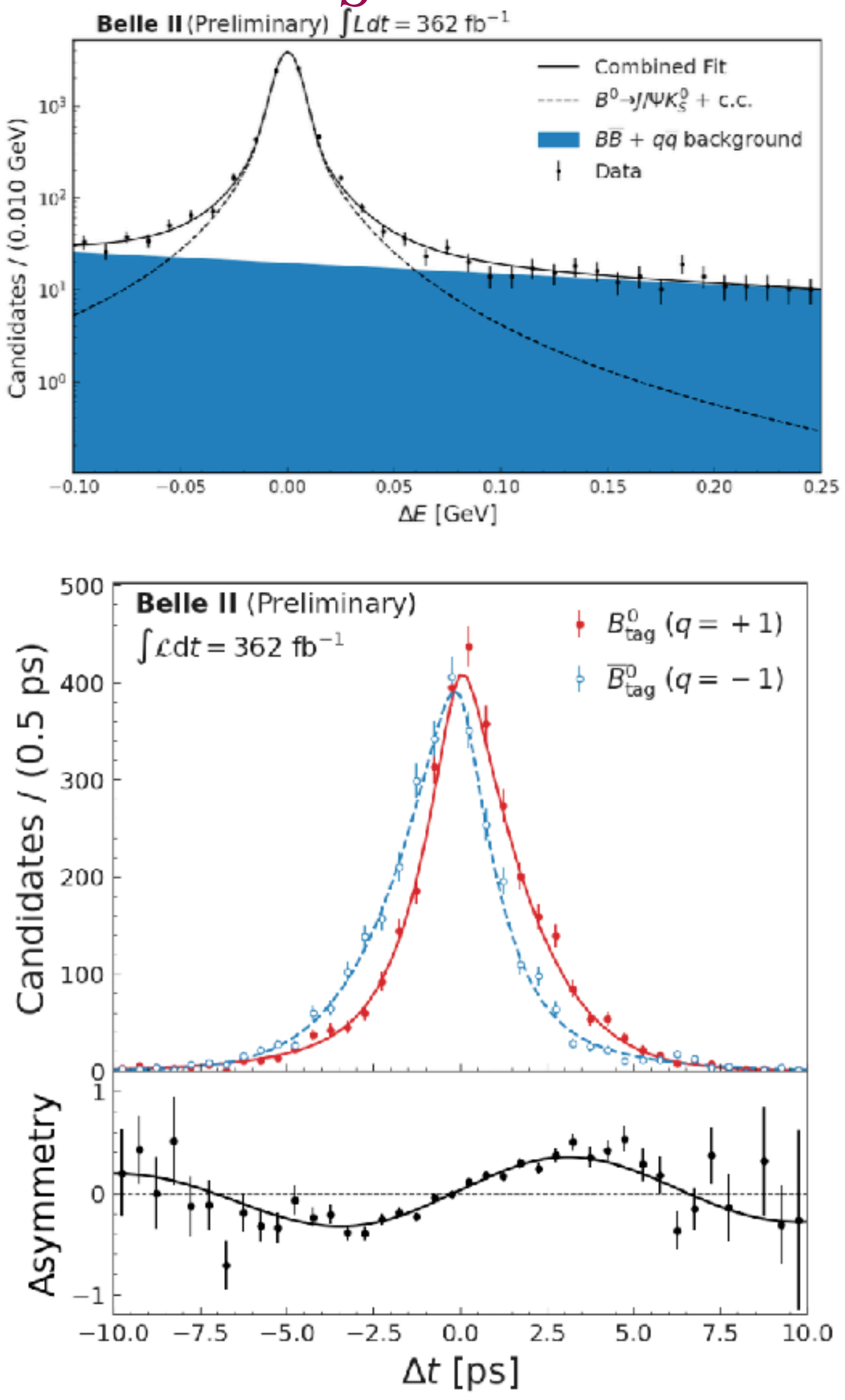


- Use $J/\psi \to e^+e^-, \mu^+\mu^-, K_S^0 \to \pi^+\pi^-$
- Analysis method:
  - Employ Graph Flavor tagger based on Dynamic Graph Convolution Neural Network (GFlaT)
  - Determine signal yields and subtract background using sWeights from ΔE fit
  - Fit Δt to extract S_{CP} and C_{CP}:

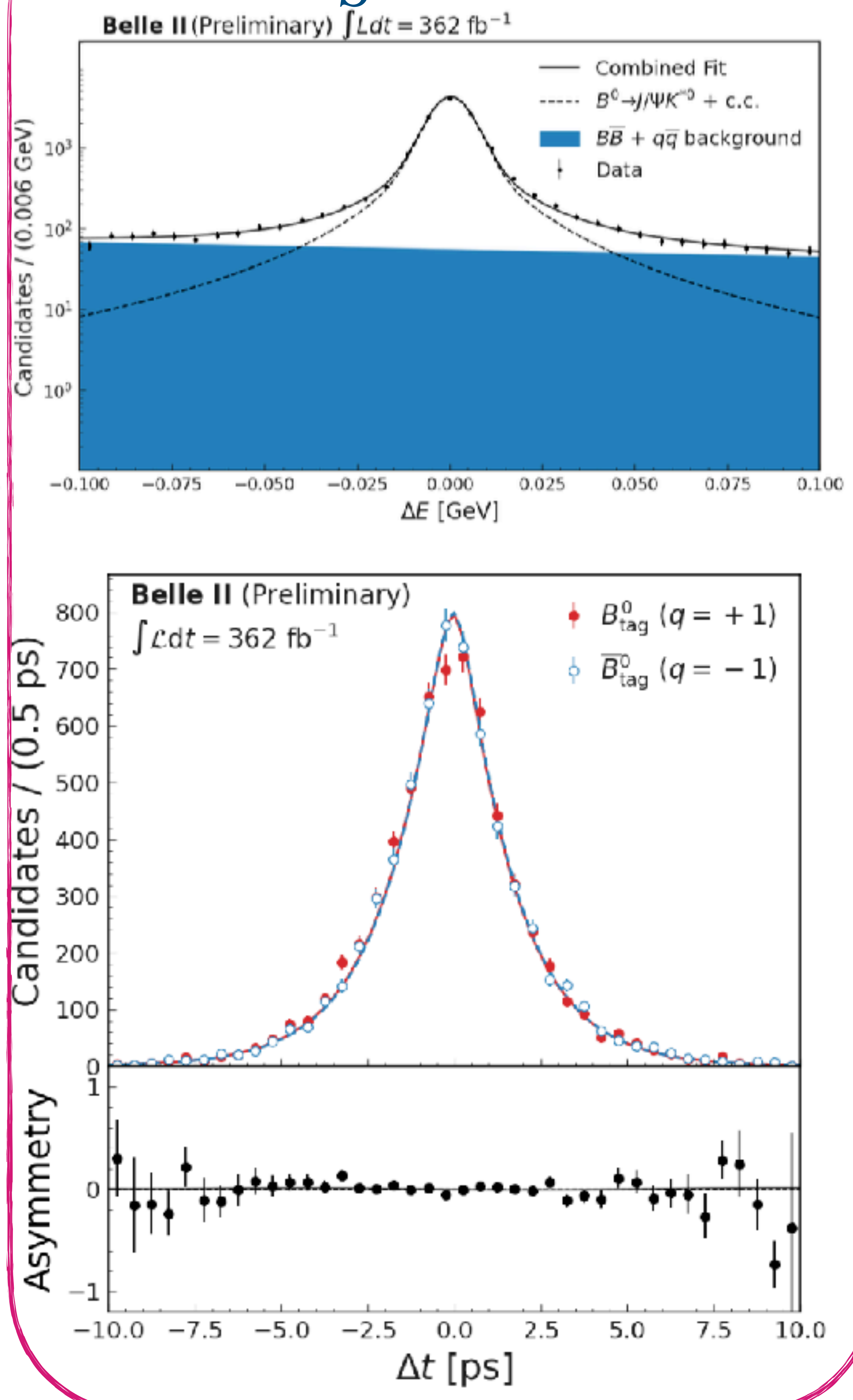
$$f_{CP}^{\text{true}} = \frac{1}{4\tau_B^0} e^{-|\Delta t|/\tau_B^0}(1 + q[S_{CP}\sin(\Delta m \Delta t) - C_{CP}\cos(\Delta m \Delta t)])$$

  - SM expectation: $S_{CP} = \sin 2\phi_1$, and $C_{CP} = 0$
  - Flavor resolution effect and resolution function taken from calibration with $B^0 \to D^{(*)+}\pi^-$

$B^0 \rightarrow K^0_S J/\psi$



$B^0 \rightarrow K^{*0}_S J/\psi$



cross check:

SM expectation: $S_{cp} = C_{CP} = 0$

$$S_{cp} = 0.008 \pm 0.019$$

$$C_{cp} = -0.018 \pm 0.026$$

$$C_{CP} = -0.035 \pm 0.026\,(\text{stat}) \pm 0.012\,(\text{syst})$$
$$S_{CP} = 0.724 \pm 0.035\,(\text{stat}) \pm 0.014\,(\text{syst})$$

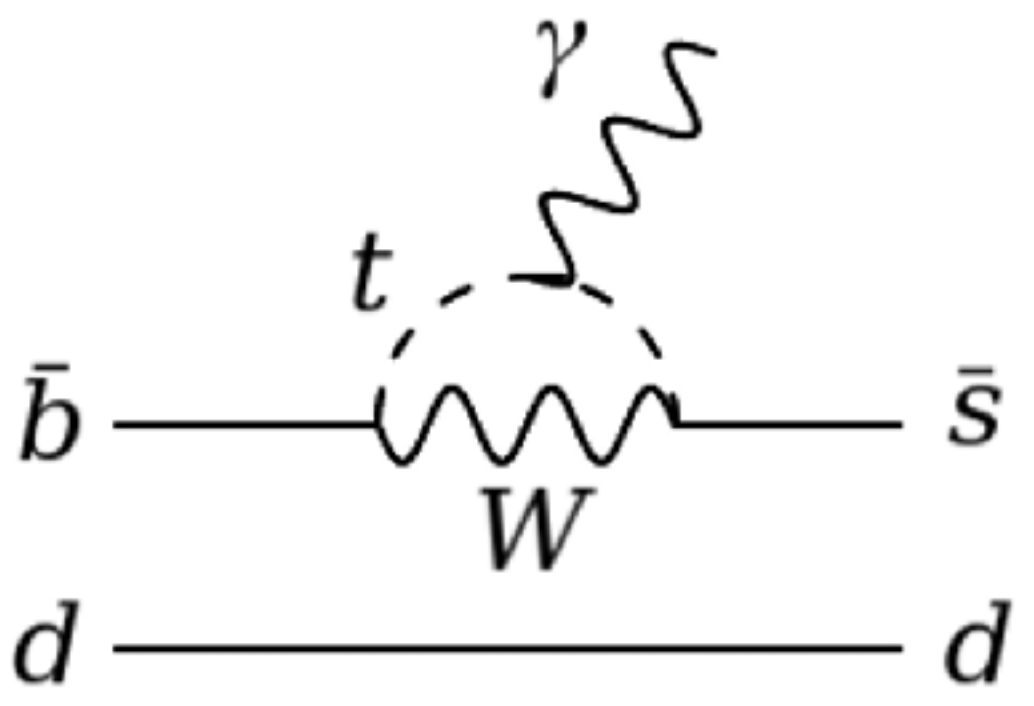
Previous stat. uncertainties:
Belle II ICHEP22: σS_{CP} =0.062 (improvement equivalent to 3.1X larger dataset)

Previous results (JPsi KS **only**):
Belle 2012: $\sigma S_{CP} = 0.029$
BaBar 2009: $\sigma S_{CP} = 0.036$
LHCb 2023: $\sigma S_{CP} = 0.015$

GFlaT established as standard tool for forthcoming TDCPV analyses

CP asymmetries in $B^0 \to K_S^0 \pi^0 \gamma$

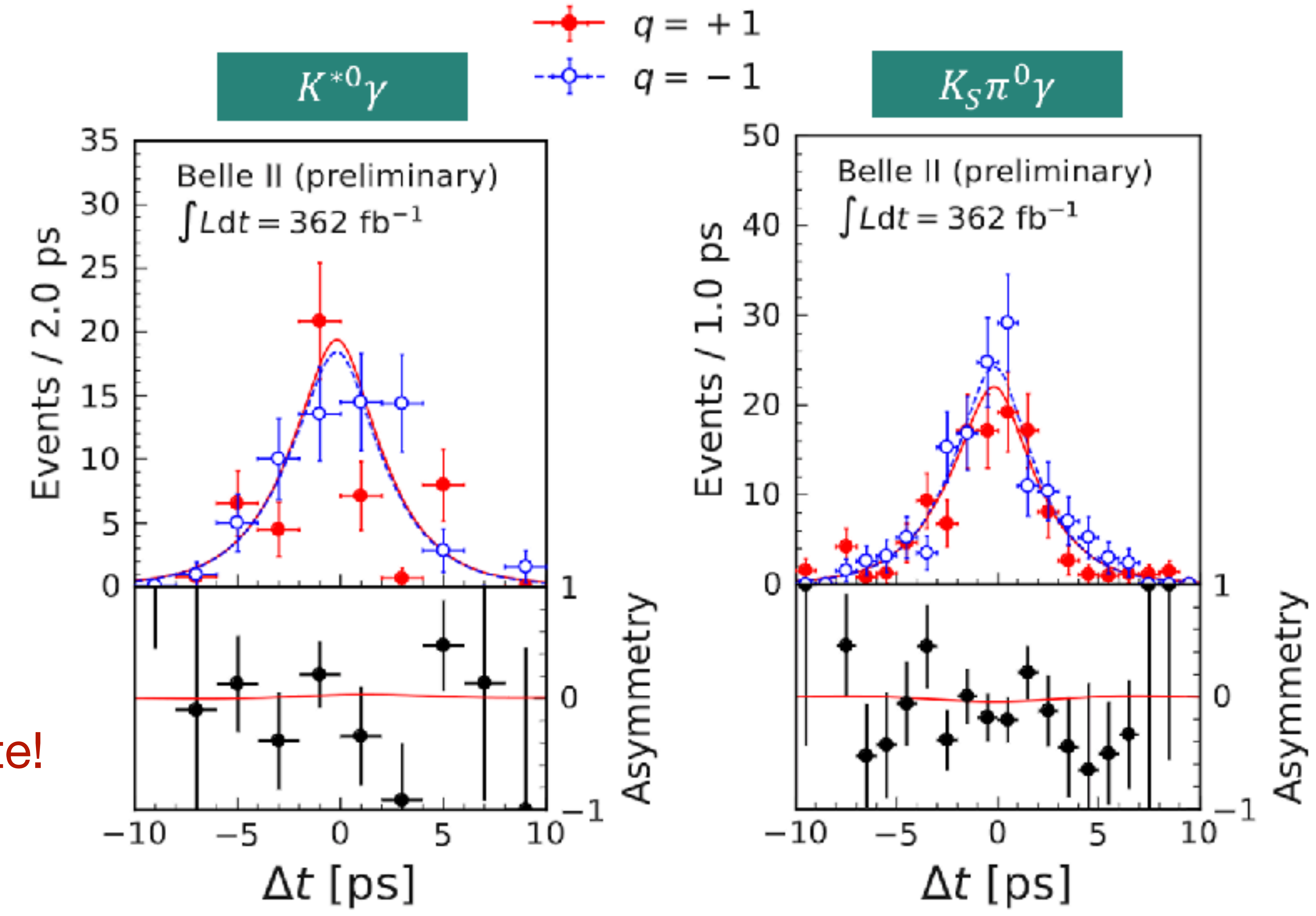
preliminary



- $b \to s\gamma$ proceeds via one-loop diagrams
  - Sensitive to BSM physics
- Mixing-induced time-dependent CP asymmetries (S) are expected to be small
  - $S_{CP} = -0.035 \pm 0.017$ (arXiv:hep-ph/0406055)

$$S(K^{*0}\gamma) = 0.00^{+0.27+0.03}_{-0.26-0.04},$$
$$C(K^{*0}\gamma) = 0.10 \pm 0.13 \pm 0.03,$$
$$S(K^0_S\pi^0\gamma) = 0.04^{+0.45}_{-0.44} \pm 0.10,$$
$$C(K^0_S\pi^0\gamma) = -0.06 \pm 0.25 \pm 0.07,$$

Most precise result up to date!

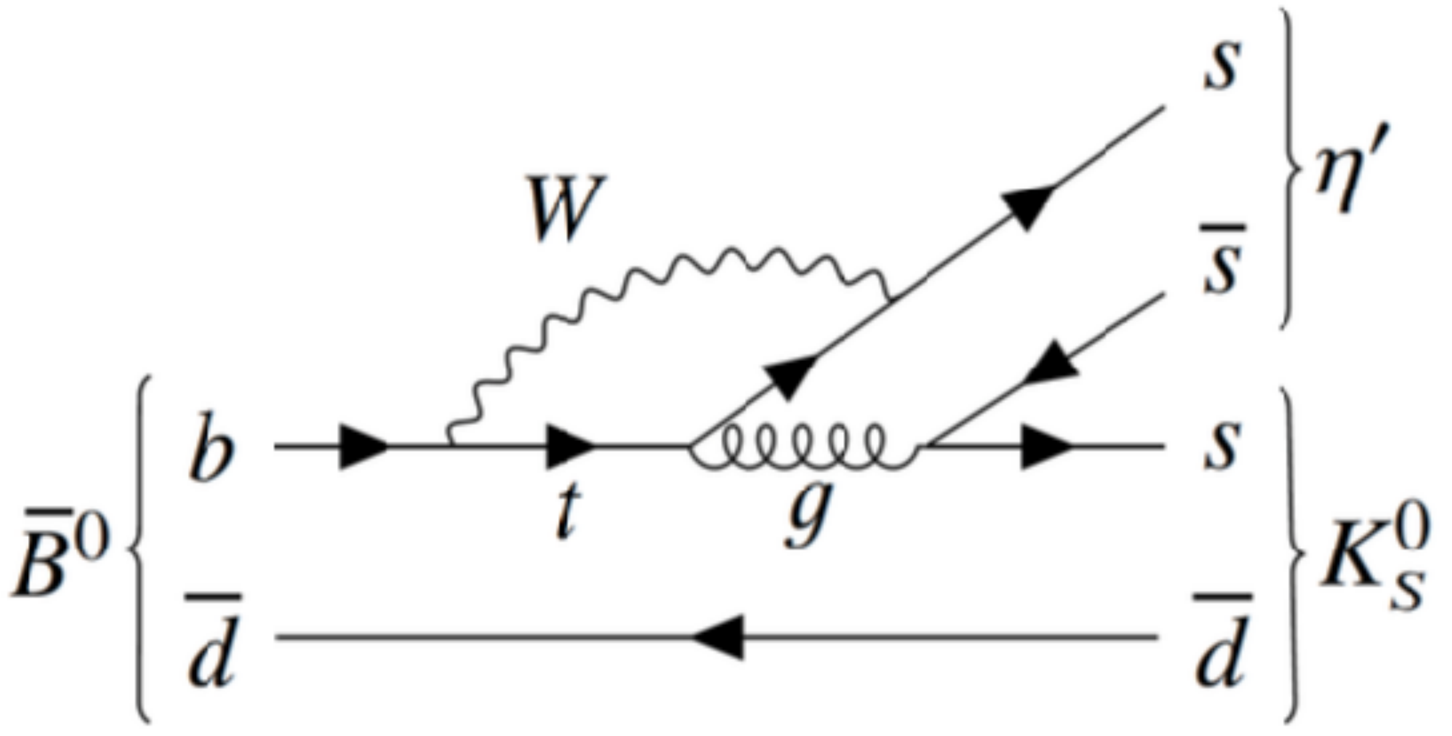


HFLAV:
$K^{*0}\gamma$: $C_{CP} = -0.04 \pm 0.14$ $S_{CP} = -0.16 \pm 0.22$
$K_S\pi^0\gamma$: $C_{CP} = -0.07 \pm 0.12$ $S_{CP} = -0.15 \pm 0.20$

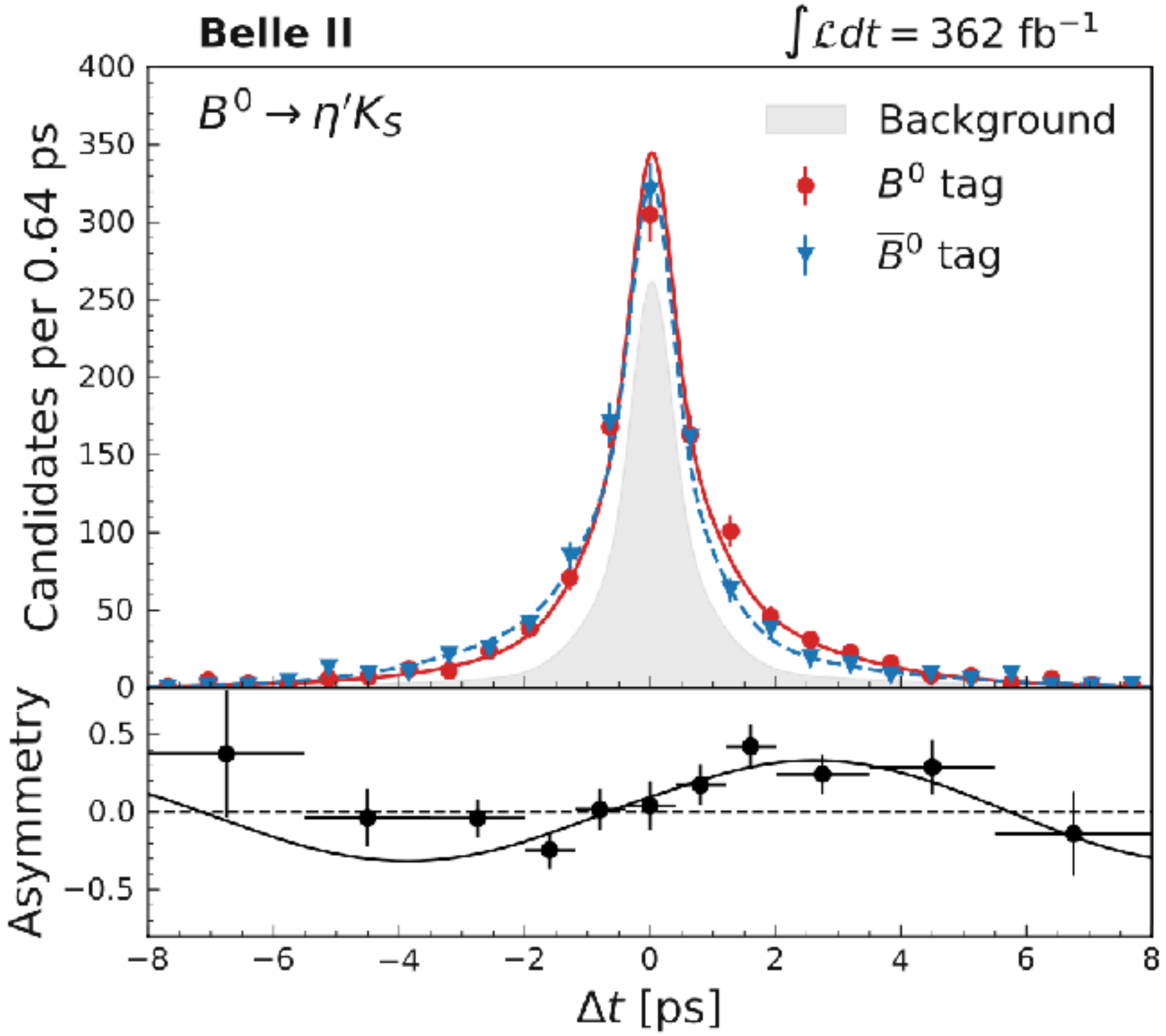
*The HFLAV $K_S\pi^0\gamma$ values include $K^{*0}\gamma$

CP asymmetries in $B^0 \to \eta' K_S^0$

preliminary



- Process $b \to sq\bar{q}$ via loop amplitude
- High transition rate relative to other gluonic penguins
- Addition source BSM could be involved
- Deviation from $\sin 2\phi_1$would suggest BSM physics
- Cross checked with $B^+ \to \eta' K^+$, where no CP asymmetry is expected



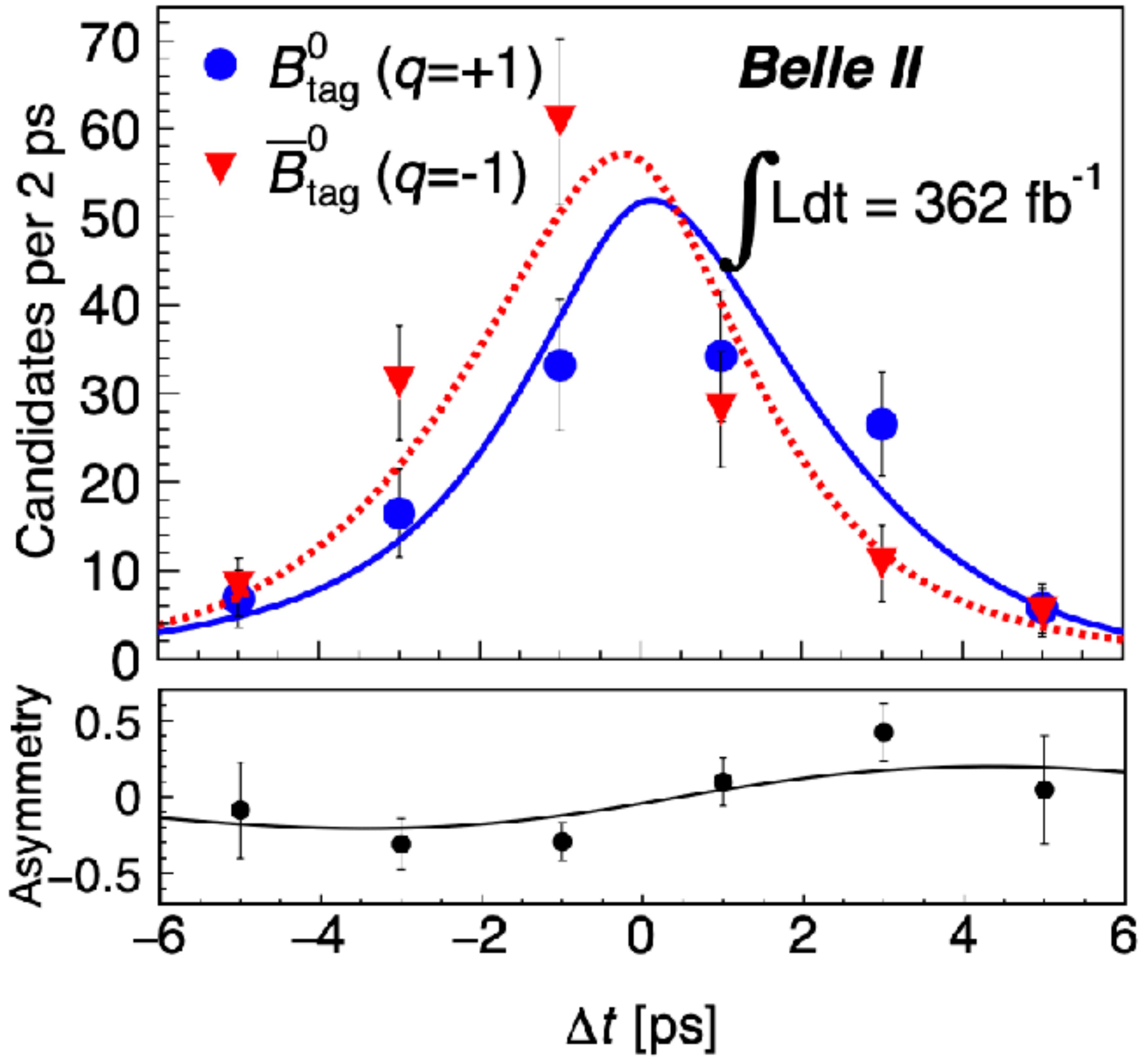
$$C_{\eta' K_S^0} = -0.19 \pm 0.08 \pm 0.03,$$
$$S_{\eta' K_S^0} = 0.67 \pm 0.10 \pm 0.04,$$

$C = -0.05 \pm 0.04$ and $S = 0.63 \pm 0.06$ from HFLAV

Measurement of CPV in $B^0 \to \pi^0 K_S^0$

PRL 131, 111803 (2023)

- Process $b \to sd\bar{d}$ via loop amplitude
- High transition rate relative to other gluonic penguins
- Addition source BSM could be involved
- Deviation from $\sin 2\phi_1$ would suggest BSM physics
- Cross checked with $B^+ \to \eta' K^+$, where no CP asymmetry is expected



Time dependent CPV using $B^0 \to K_S^0 K_S^0 K_S^0$

preliminary

- Current world average:

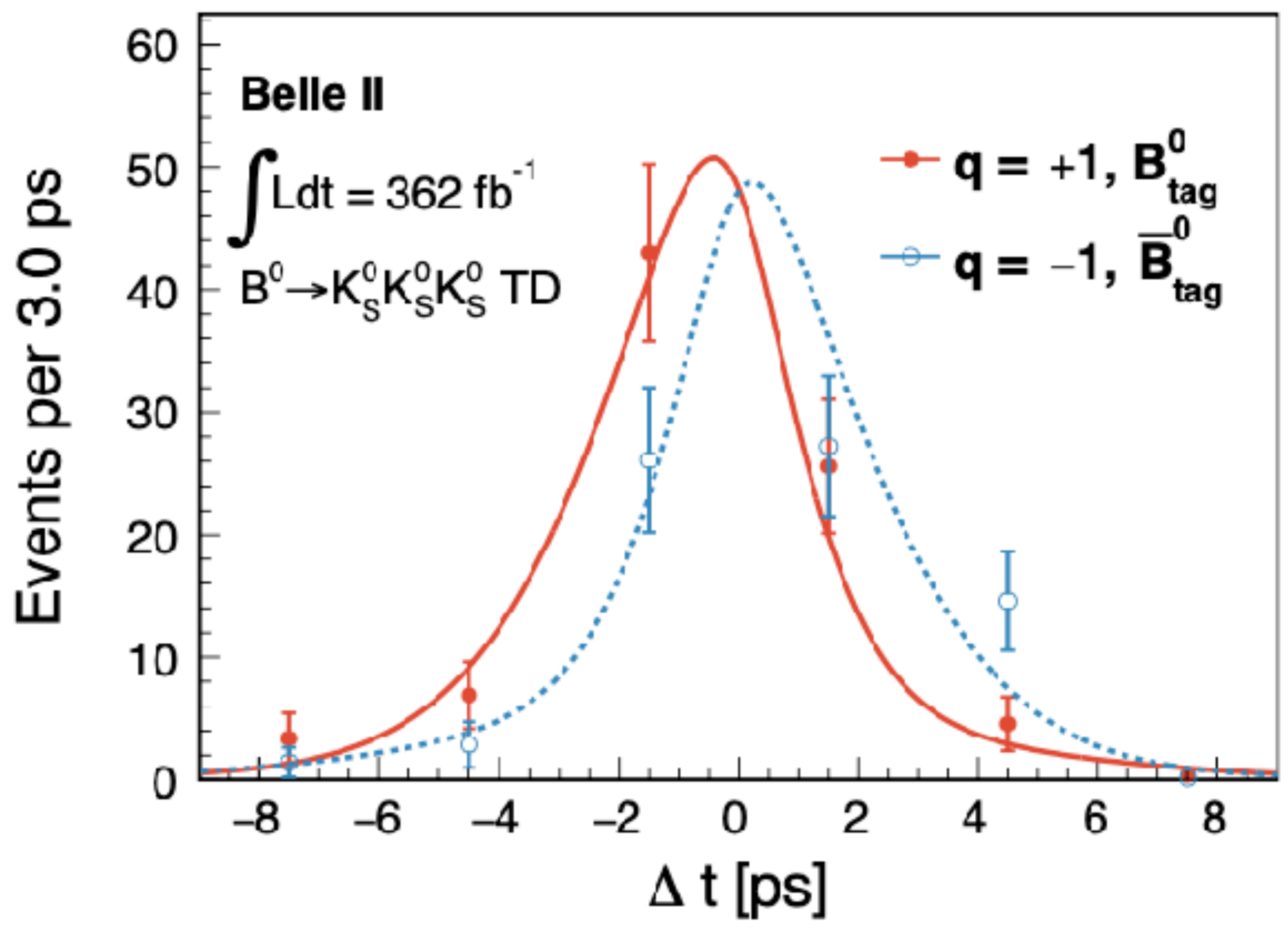
$$C = -0.15 \pm 0.12$$

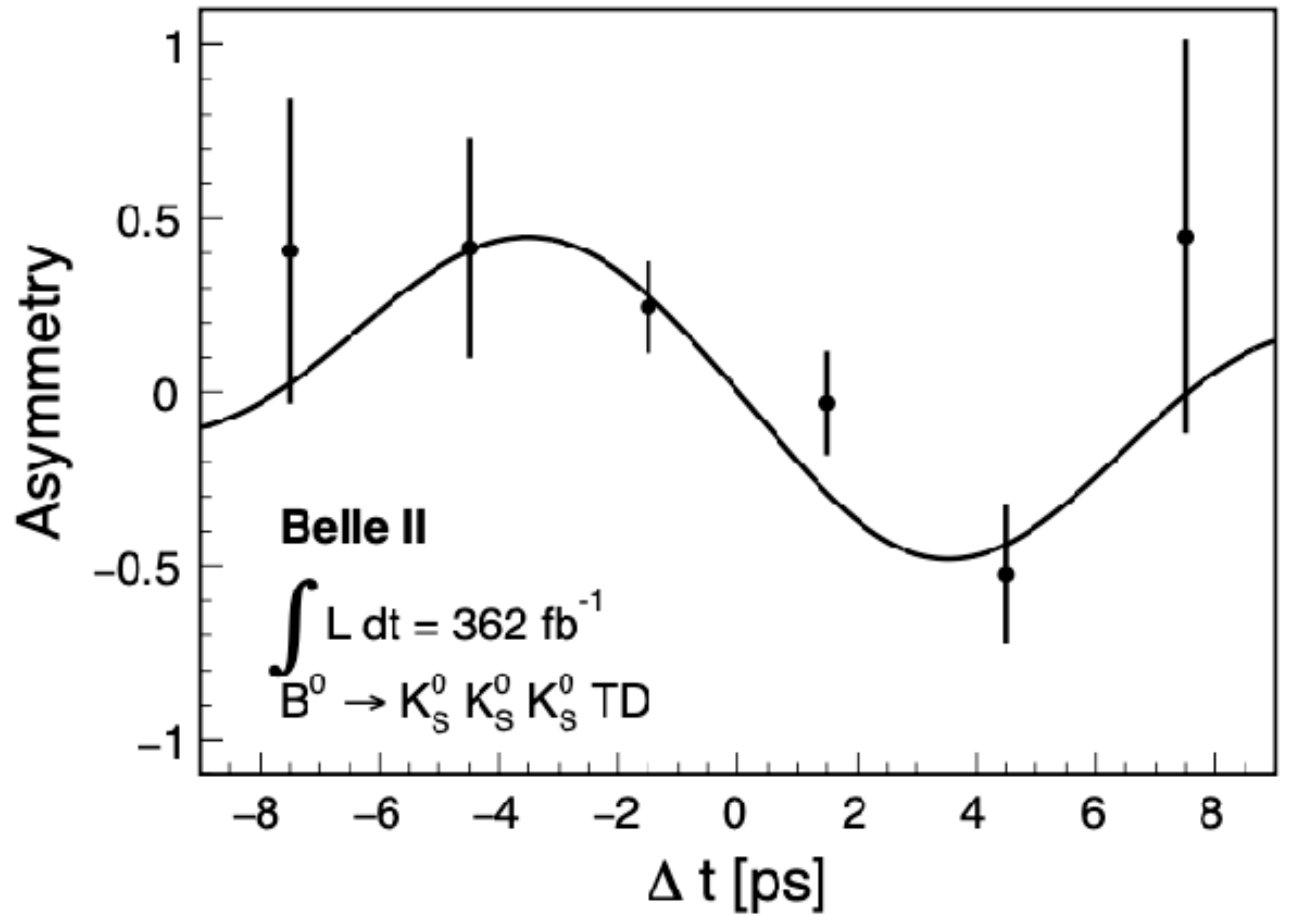
$$S = -0.83 \pm 0.17$$

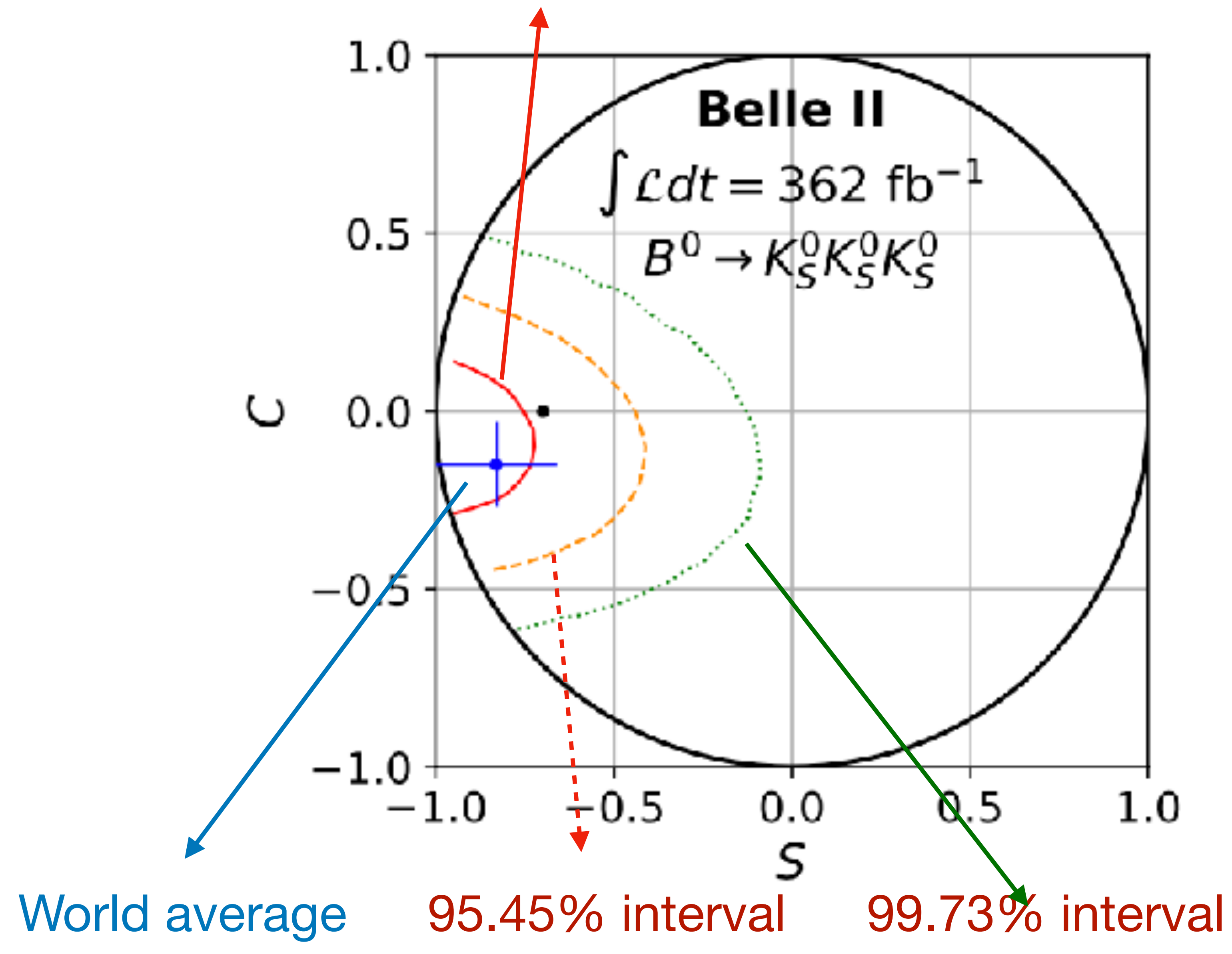
Need improvement on uncertainties.

Use the likelihood from the fit,

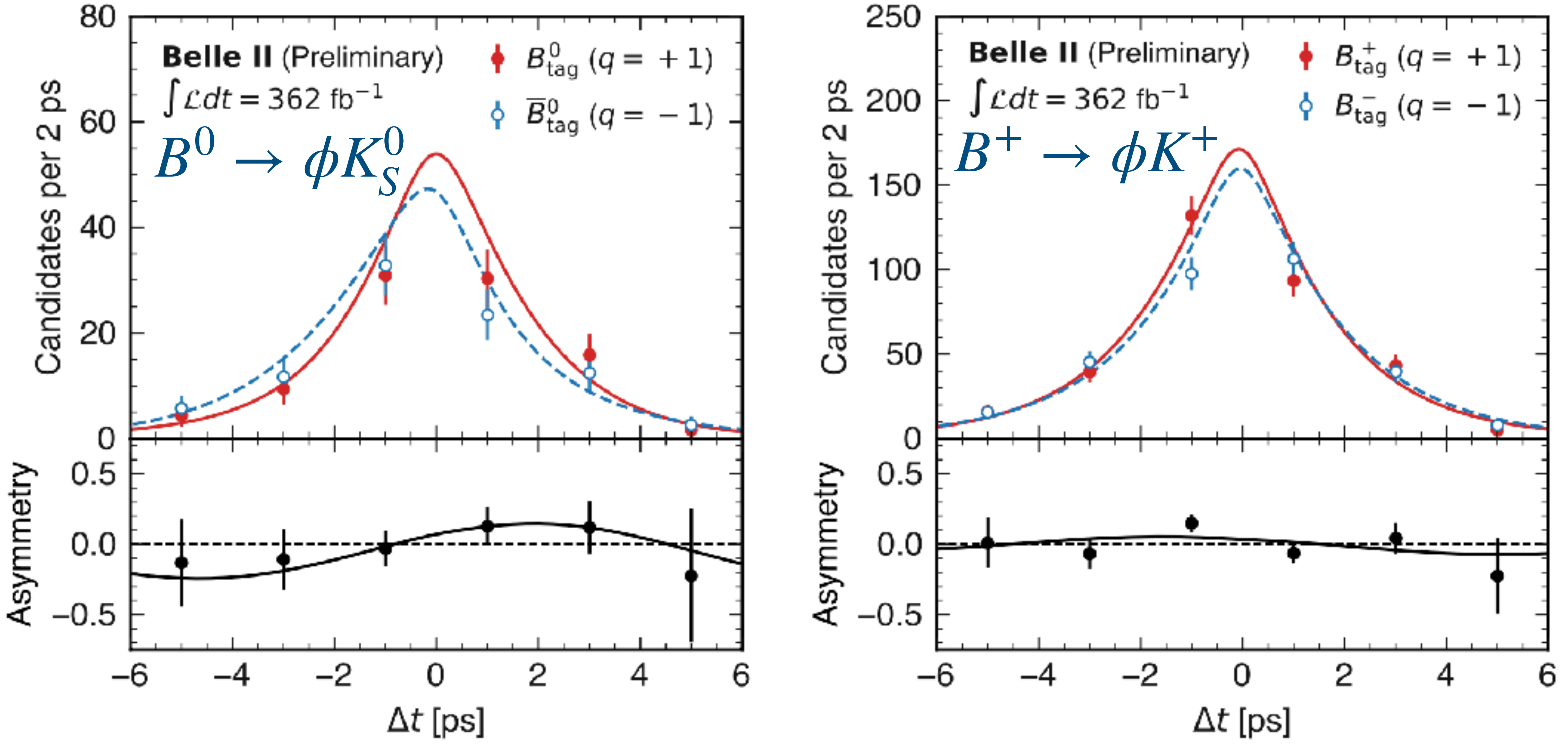
resulting 2D confidence intervals







$B^0 \to \phi K^0_S$ PRD 108, 072012 (2023)



- Current world average:

$$C = 0.01 \pm 0.14$$

$$S = 0.74^{+0.11}_{-0.13}$$

whereas C is expected to be zero in SM, with $S = 0.02 \pm 0.01$

- Cross checked with $B^+ \to \phi K^+$, resulting $C = -0.12 \pm 0.10$ and $S = -0.09 \pm 0.12$

$$C = -0.31 \pm 0.20 \pm 0.05$$

$$S = 0.54 \pm 0.26^{+0.06}_{-0.08}$$

- *Compatible with previous determinations from Belle and BABAR.*
- *Similar uncertainty on C despite of smaller data sample.*
- *Improvement on the statistical uncertainty on S for the same number of signal events.*