Recent highlights from Belle II

QCD23
26th HIGH-ENERGY PHYSICS
INTERNATIONAL CONFERENCE
IN QUANTUM CHROMODYNAMICS
MONTPELLIER
10 - 14 july 2023

Renu
(On the behalf of Belle II collaboration)
Supported by DOE funding

Carnegie
Mellon
University

Belle II

Beyond the standard model

The SM is the most successful theory that describes elementary particles and interactions.

However, there are open questions coming from observations unexplained by the SM.

- No explanation of matter-antimatter asymmetry
- No explanation dark matter or dark energy
- Hints of violation of Lepton Flavor Universality
- ……..

Physics beyond the SM (New Physics) is likely to exist

Precision measurements and high statistics needed to discover New Physics

Digging for New Physics

- Belle II belongs to the Intensity Frontier.
  - New Physics is searched for via **very high-precision measurements** to detect deviations from SM predictions.
- Probes New Physics energy scale higher than the one accessed at the Energy Frontier.
- What is needed at the intensity frontier?
  - A larger dataset to minimize statistical uncertainty.
  - Keep systematics under control.

Belle II detector

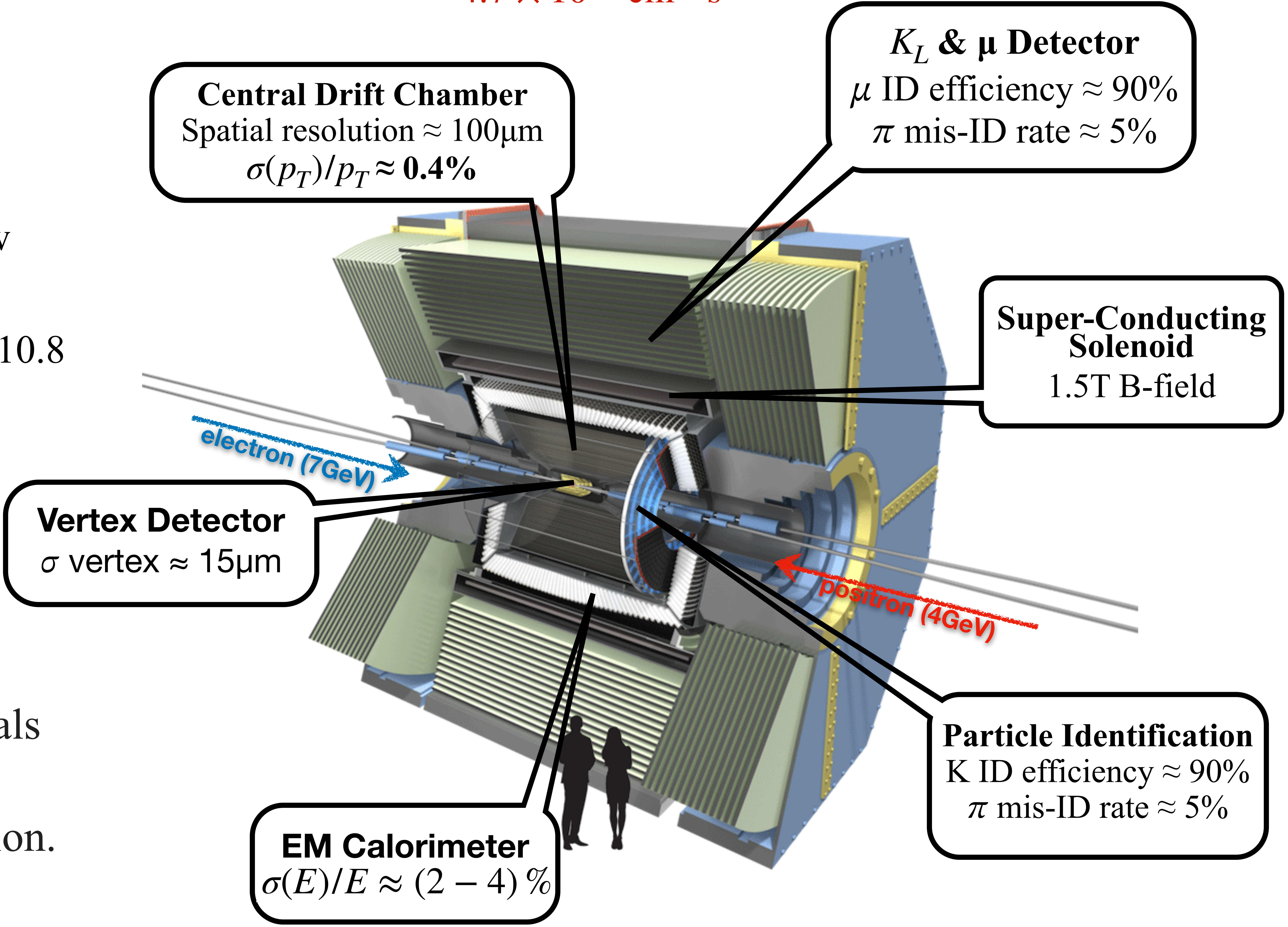
- Asymmetric e^+e^- collider
- **Collected data**
  - ~ 362 fb^{-1} at Υ(4S)
  - 42 fb^{-1} off-resonance, 60 MeV below Υ(4S).
  - 19 fb^{-1} energy scan between 10.6 to 10.8 GeV for exotic hadron studies.

Record-breaking instantaneous luminosity:

$4.7 \times 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$

Features:

- Near-hermetic detector
- Excellent vertexing and tracking
- High-efficiency detection of neutrals (γ, π^0, η, η', …)
- Good charged particle reconstruction.



Central Drift Chamber
Spatial resolution ≈ 100μm
$\sigma(p_T)/p_T \approx$ **0.4%**

K_L & μ Detector
μ ID efficiency ≈ 90%
π mis-ID rate ≈ 5%

Super-Conducting Solenoid
1.5T B-field

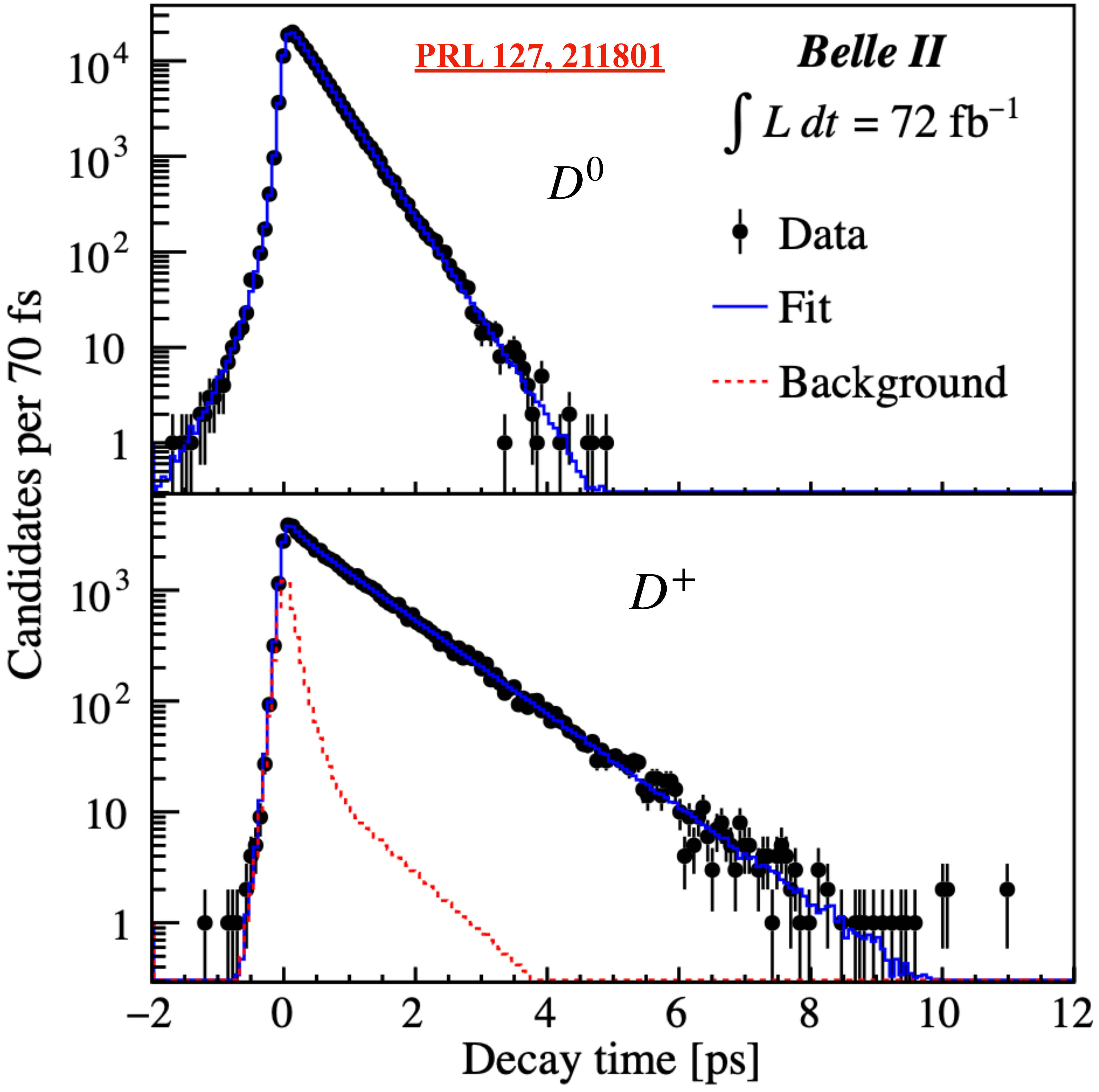
Vertex Detector
σ vertex ≈ 15μm

EM Calorimeter
$\sigma(E)/E \approx (2-4)\ \%$

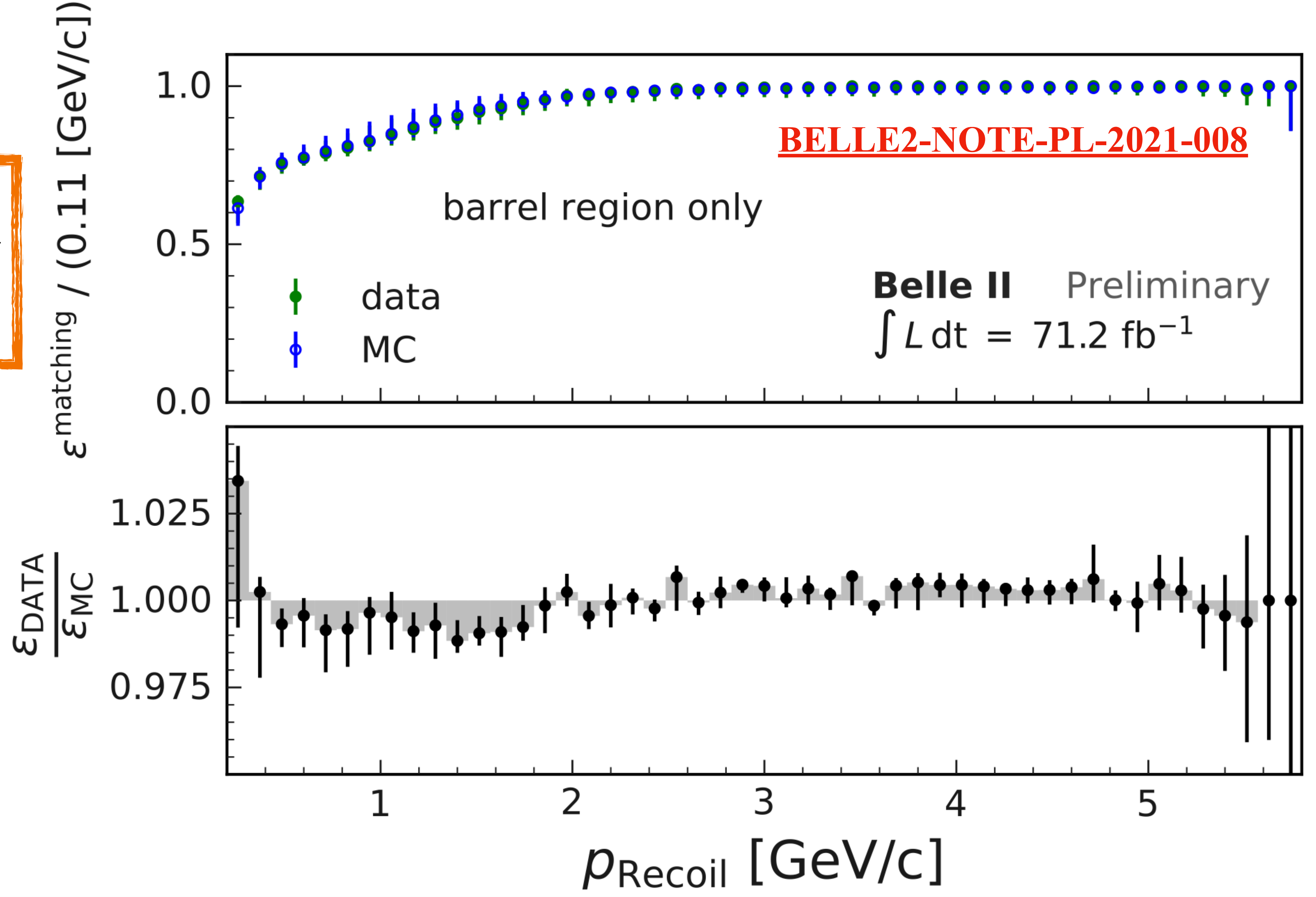
Particle Identification
K ID efficiency ≈ 90%
π mis-ID rate ≈ 5%

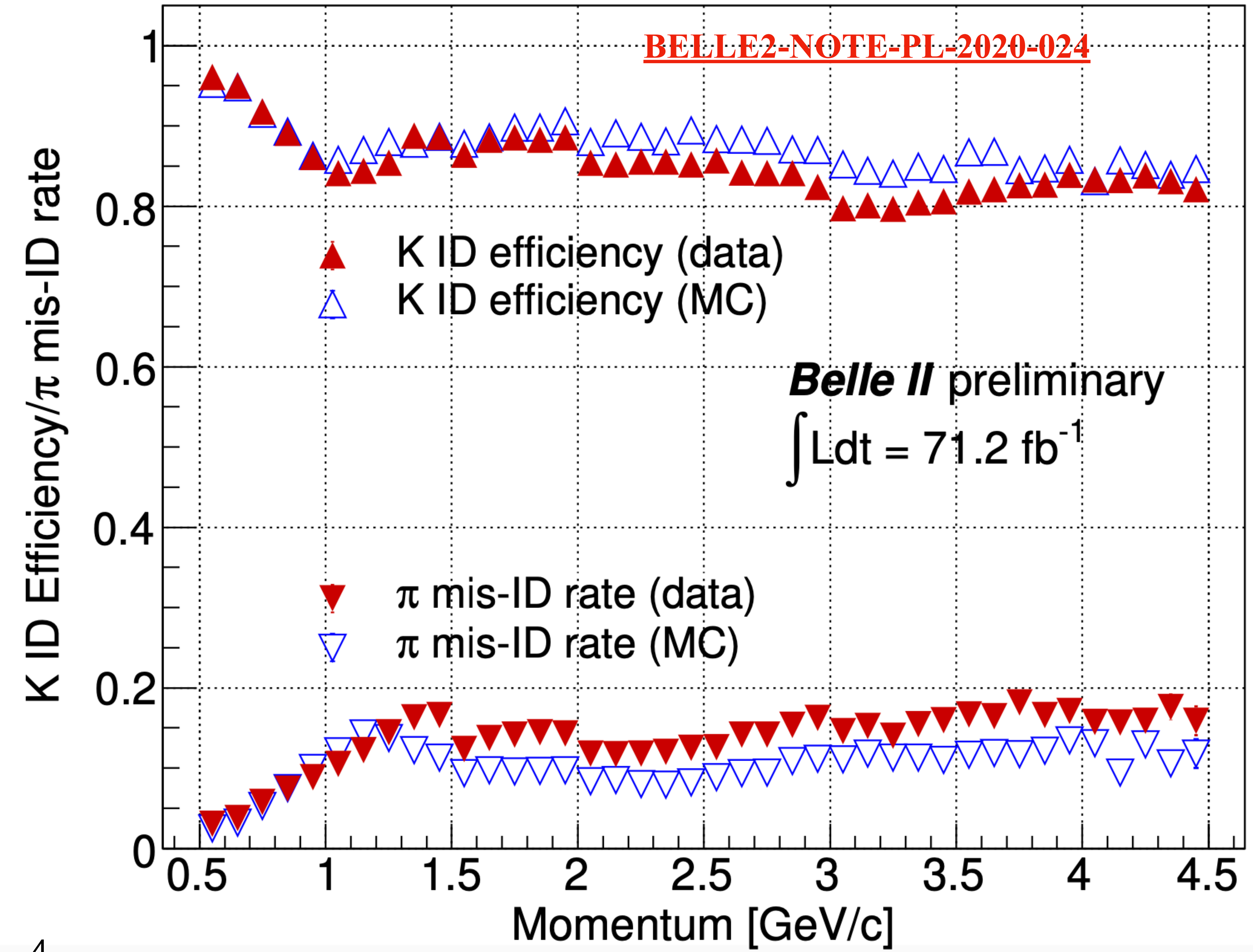
Belle II detector performance

Factor 2 improvement in proper time resolution despite lower boost



High photon reconstruction efficiency



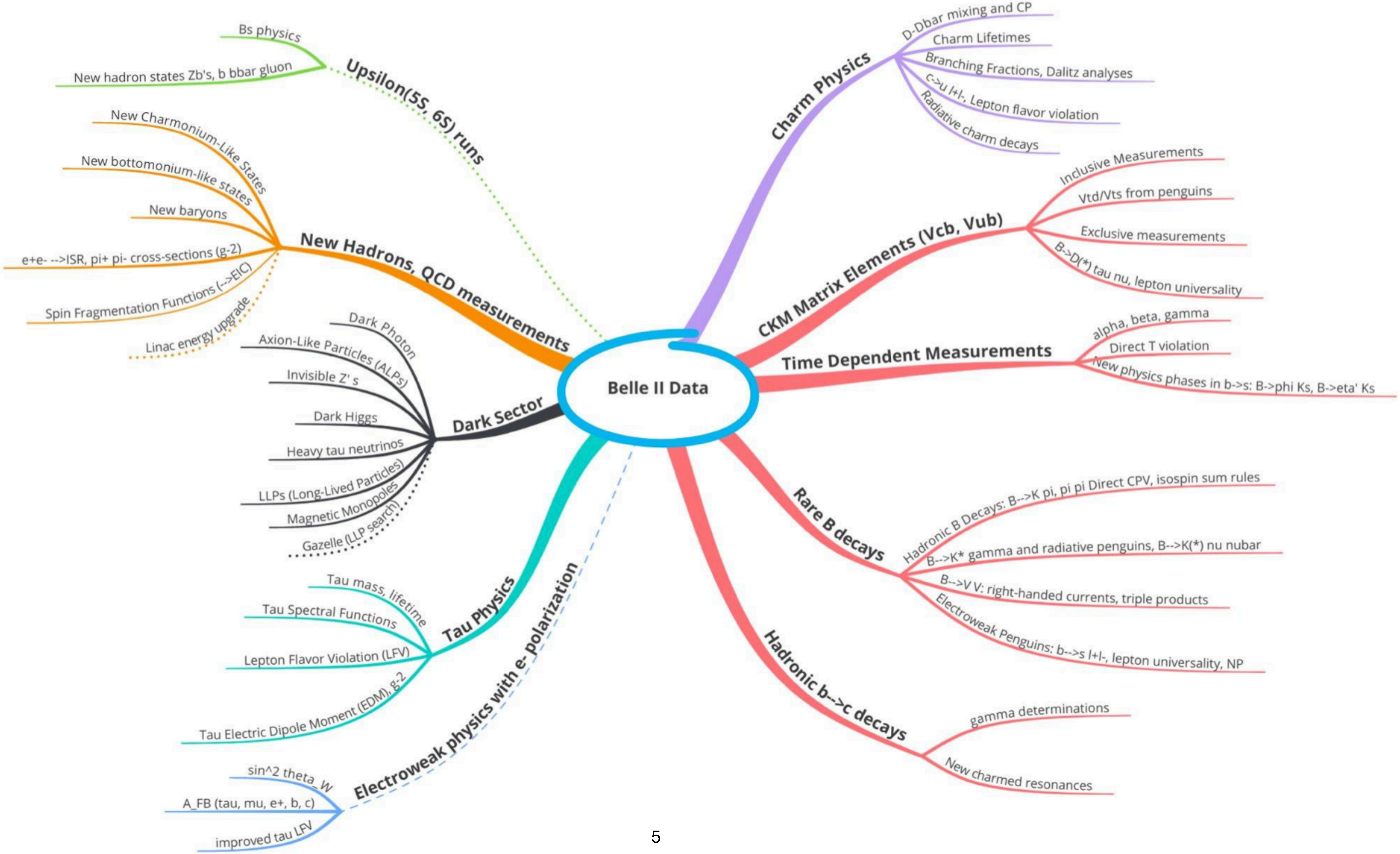


Good particle identification

Belle II physics program

[Snowmass White Paper]

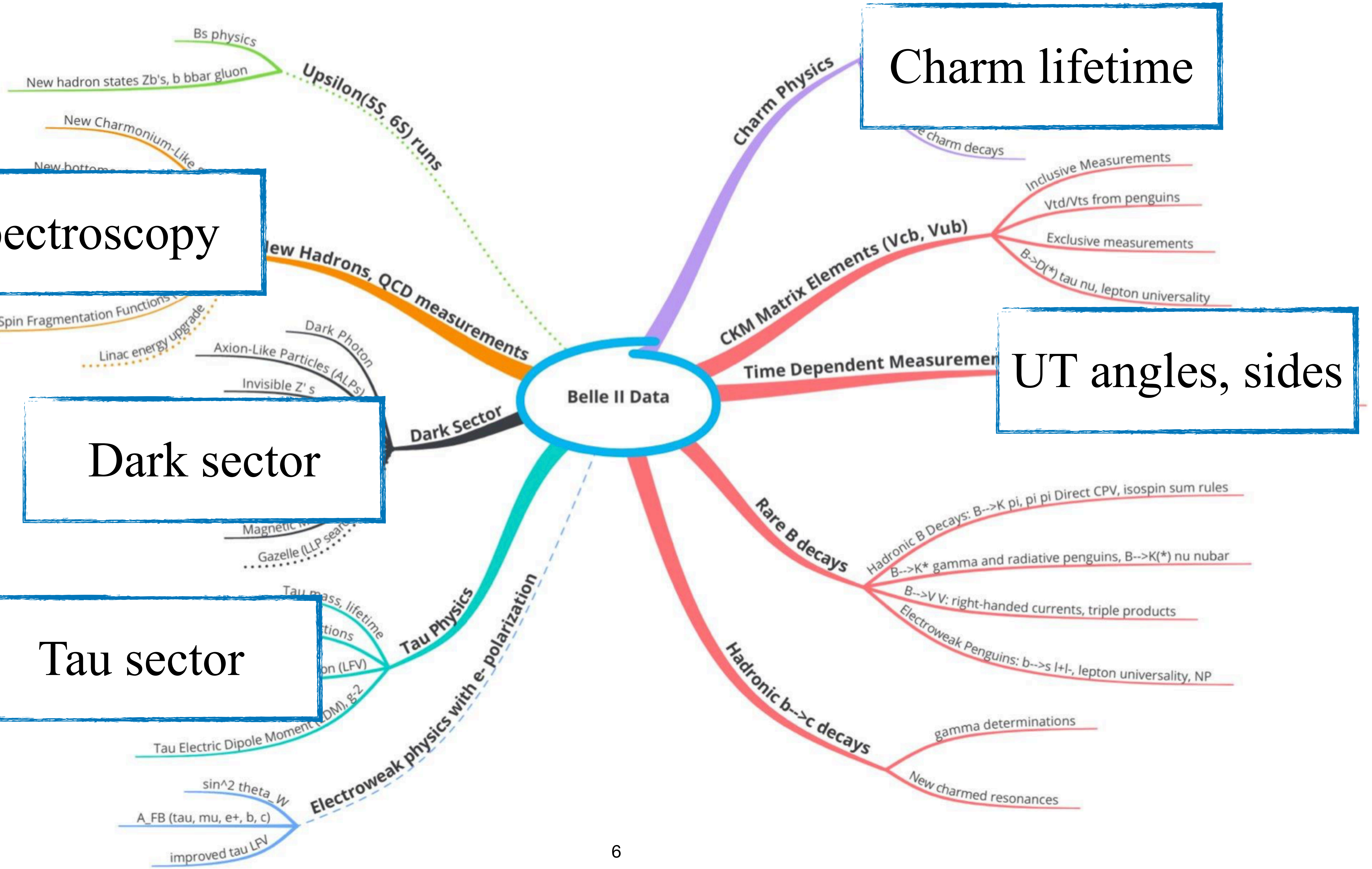
Diversified physics program



Belle II physics program

[Snowmass White Paper]

Diversified physics program



Charm lifetime

Spectroscopy

UT angles, sides

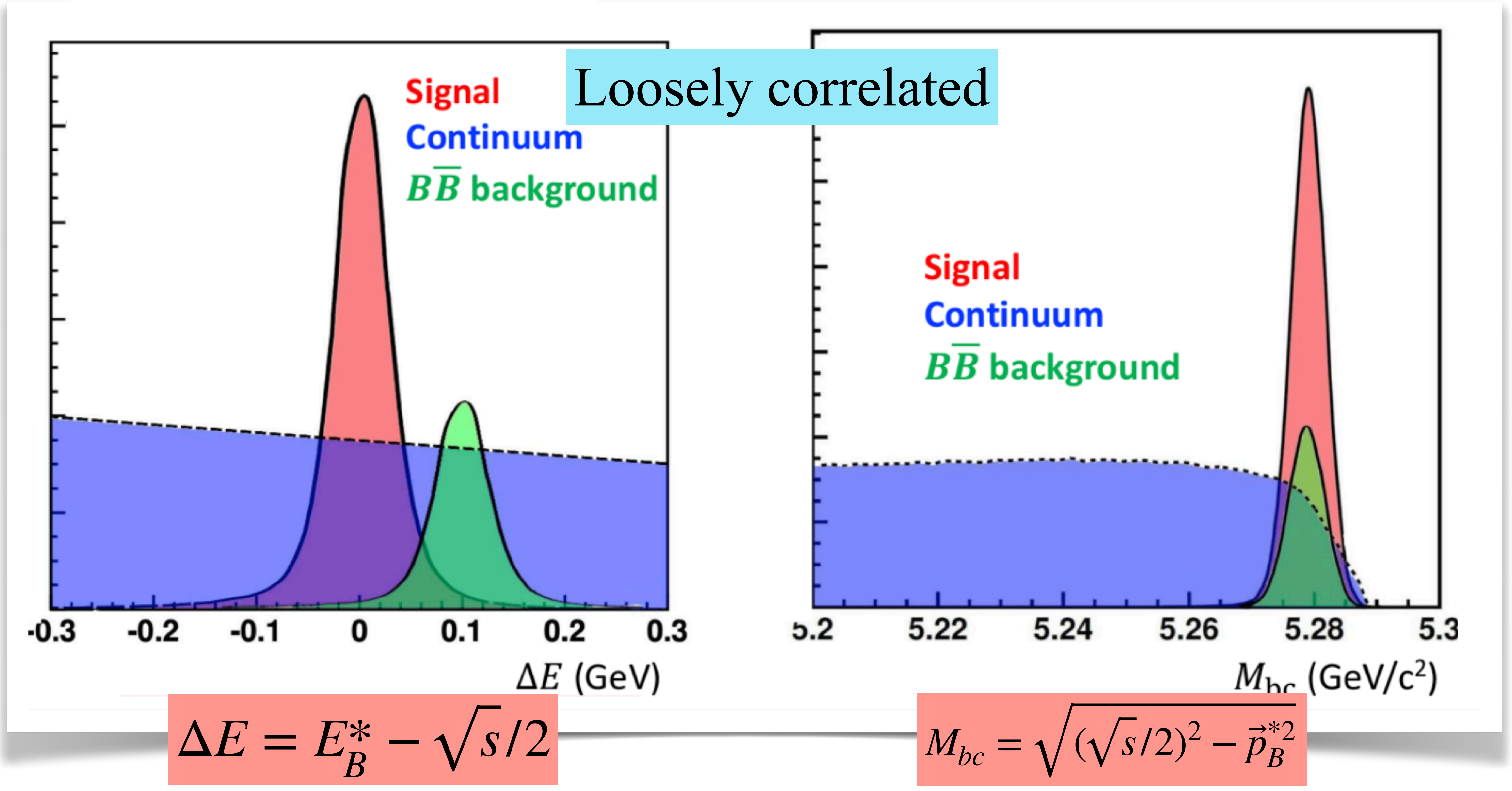
Dark sector

Tau sector

B-physics

$B\bar{B}$ basics

- **Asymmetric e^+e^- collision:**
  - Collision energy well defined
  - Constrained kinematics ⇒ $\sqrt{s} \;=\; m\,(\Upsilon(4S)) \;=\; 10.58\ GeV \;\simeq\; 2\ m_B$
- Measurement of Δt (difference between the proper decay times of the B_{sig} and B_{tag}):
  - Boost of center-of-mass
  - Excellent vertex performance
  - Excellent Flavor tagger performance


Energy difference (ΔE)

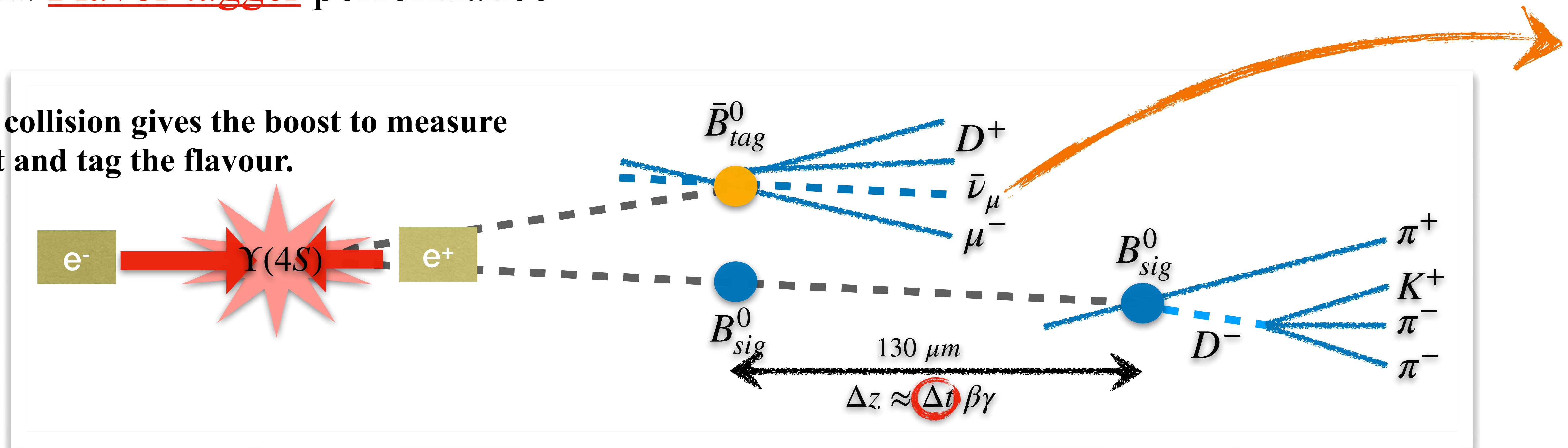
Beam-constrained mass (M_{bc})

Loosely correlated

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

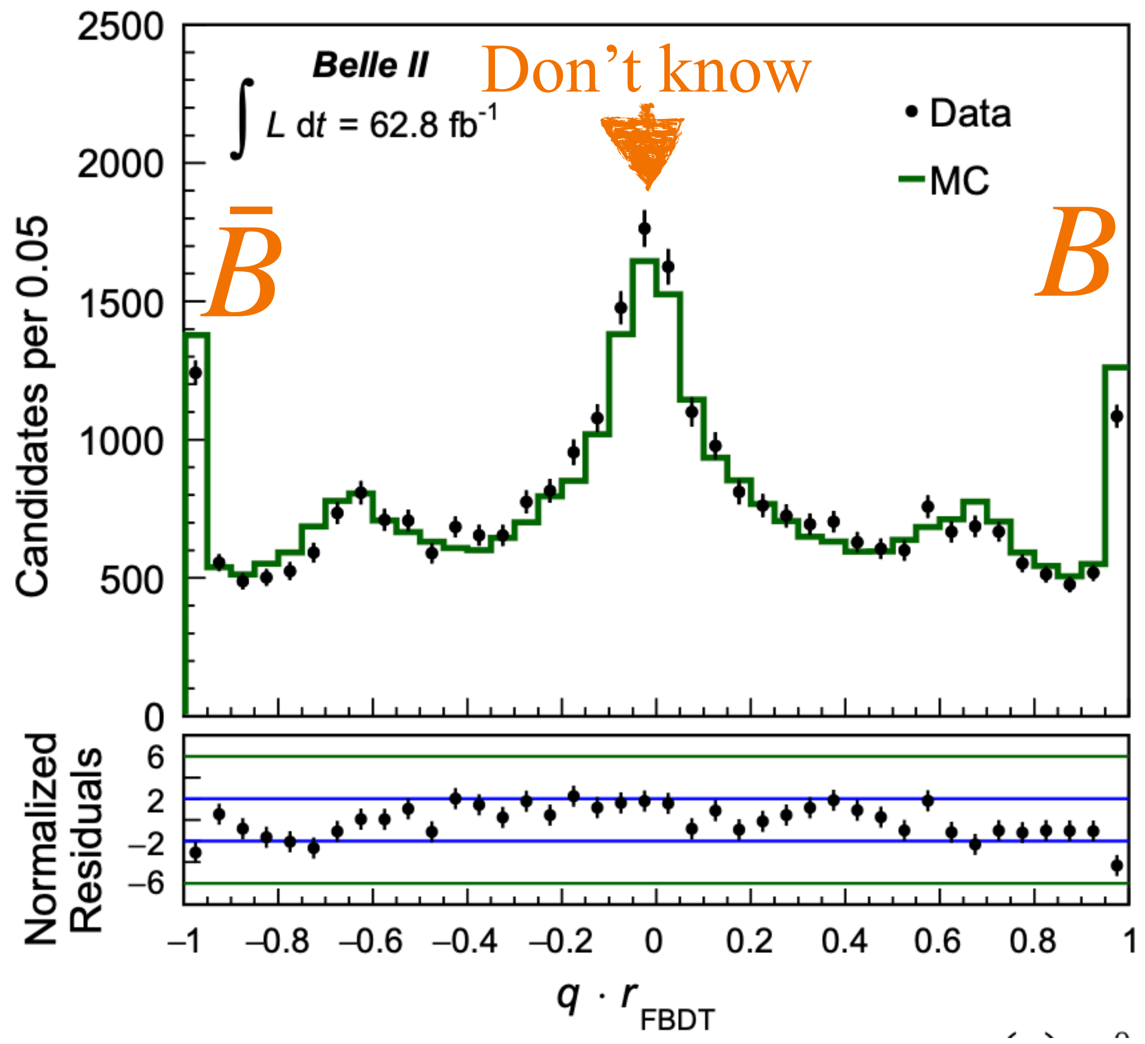
$M_{bc} = \sqrt{(\sqrt{s}/2)^2 - \vec{p}_B^{*2}}$

The asymmetric collision gives the boost to measure the displacement and tag the flavour.



Distance measurement ⟺ Time measurement

Eur. Phys. J. C 82, 283(2022)



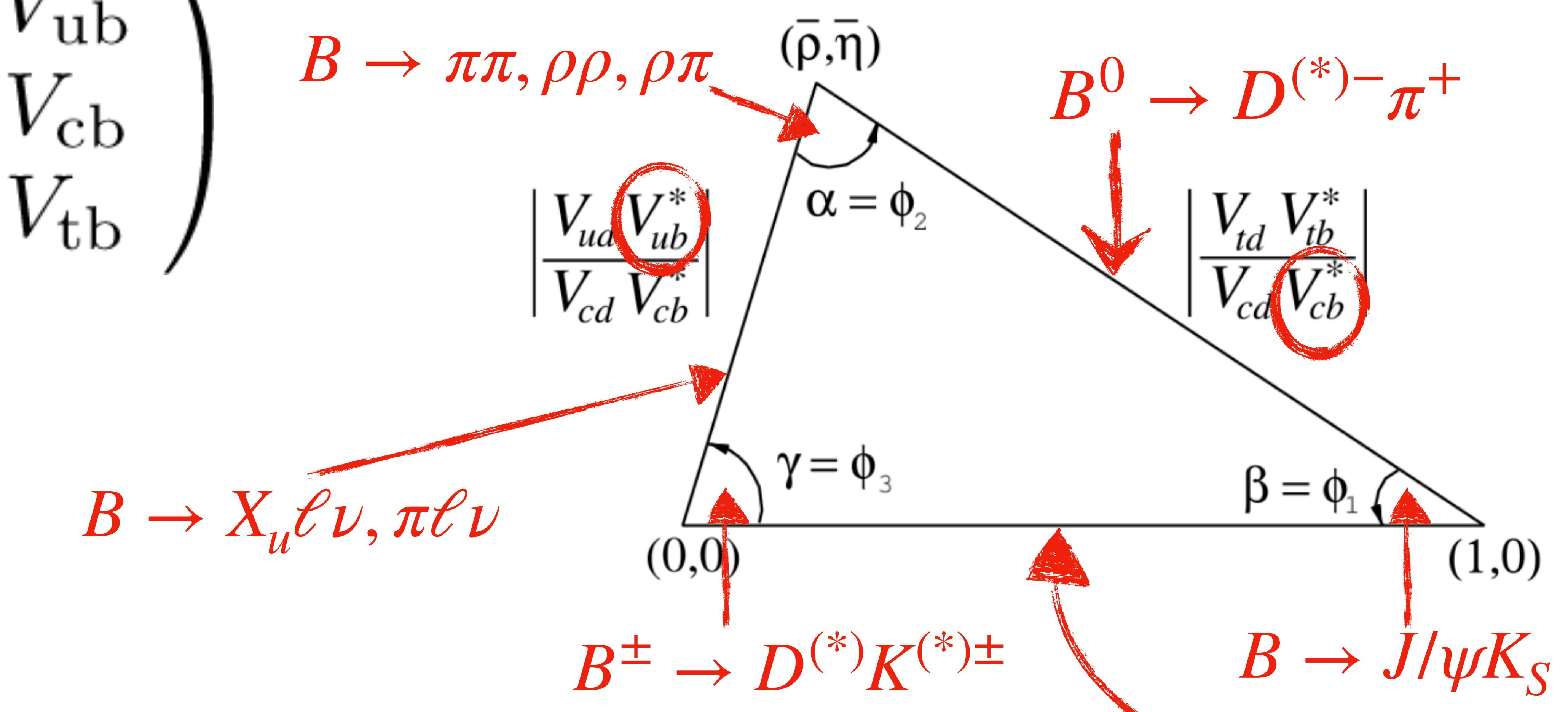
Flavour tagger classifier

A very rich program…..

Over constraining the UT is a very powerful test of the SM

- B mixing & searches for new sources of CPV
- Non-SM probes from radiative & (semi)-leptonic decays
- Tests of LFU, e.g. $\mathscr{R}(X_{e/\mu})$,..
- Measurements of CKM Unitary Triangle (UT) sides & angles for SM precision test

$$V_{\rm CKM} = \begin{pmatrix} V_{\rm ud} & V_{\rm us} & V_{\rm ub} \\ V_{\rm cd} & V_{\rm cs} & V_{\rm cb} \\ V_{\rm td} & V_{\rm ts} & V_{\rm tb} \end{pmatrix}$$



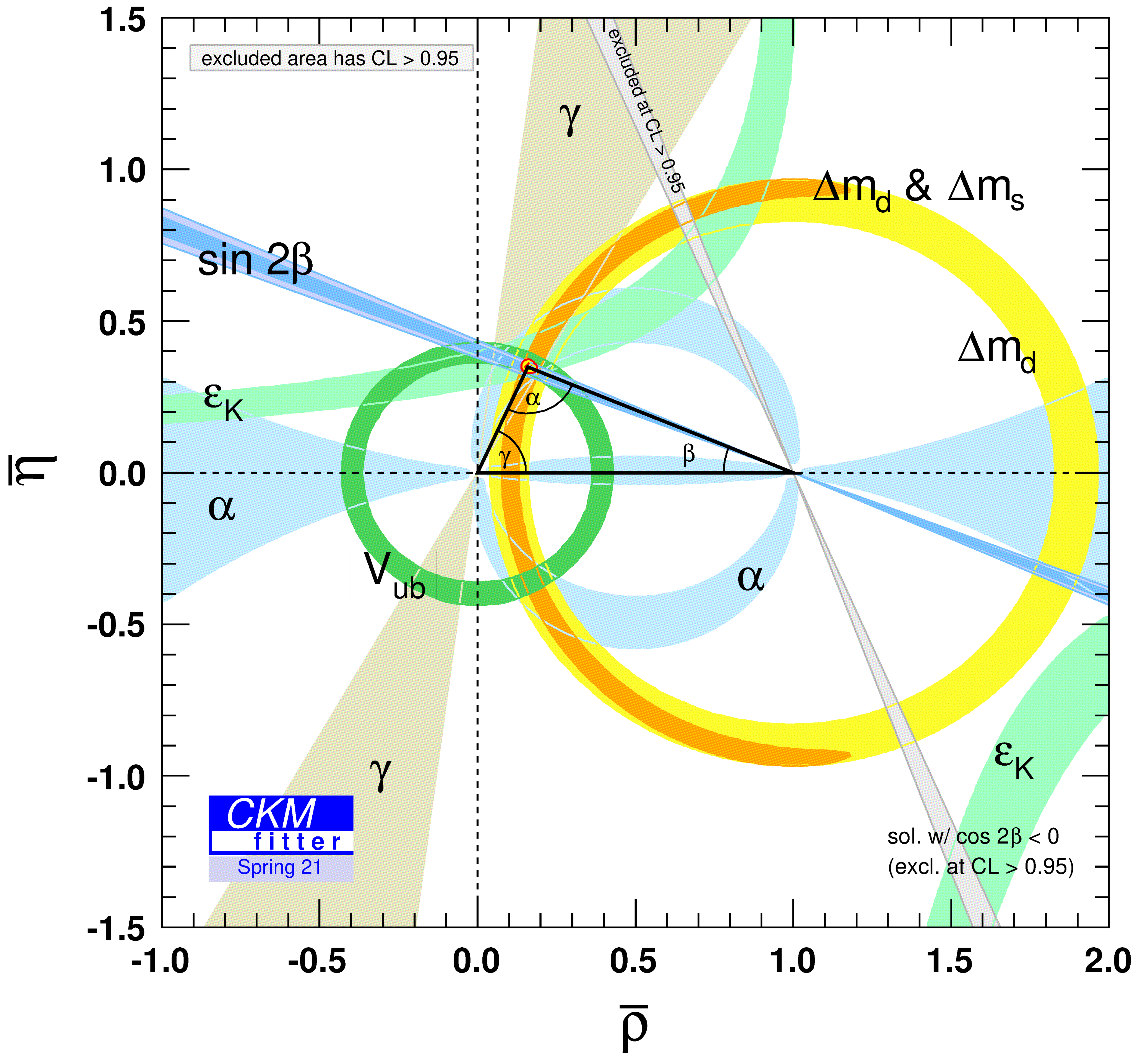
$B \to \pi\pi, \rho\rho, \rho\pi$

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

$B \to X_u \ell \nu, \pi \ell \nu$

$B^\pm \to D^{(*)}K^{(*)\pm}$

$B \to J/\psi K_S$



Normalization side

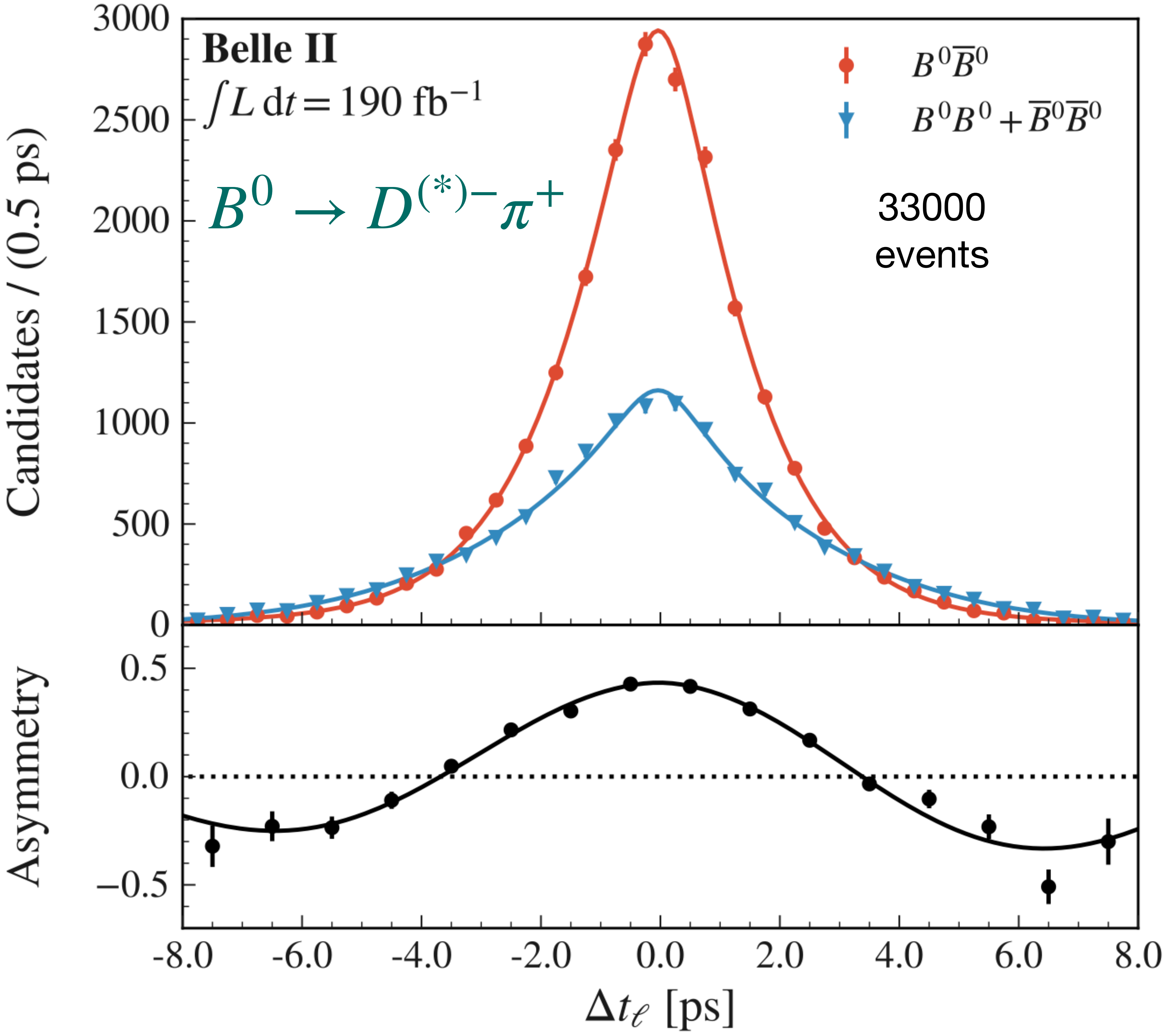
$B \to X_c \ell \nu, D^{(*)}\ell\nu$

Unitarity of $V_{\rm CKM}$ $\Rightarrow$ $V^\dagger_{\rm CKM}V_{\rm CKM} = 1 \Rightarrow V_{ud}V^*_{ub} + V_{cd}V^*_{cb} + V_{td}V^*_{tb} = 0$

$B^0 - \bar{B}^0$ mixing

PRD 107, L091102

- New beam scheme means reduced boost:
  - **Belle**: $\beta\gamma = 0.43$, $\Delta z \approx 200\mu m$ →
    Belle2: $\beta\gamma = 0.29$, $\Delta z \approx 130\mu m$
  - added a pixel detector around the beam pipe (radius ≈ 1.4 cm) to recover precision on Δt.
- Measurement of B^0, lifetime (τ_{B^0}) and flavor oscillation frequency (Δm_d):
  - Test QCD theory of strong interactions.
  - CKM theory of weak interactions.
  - Crucial for time-dependent CPV analyses.



$$\tau_{B^0} = (1.499 \pm 0.013 \pm 0.018)\ ps$$
$$\Delta m_d = (0.516 \pm 0.008 \pm 0.005)\ ps^{-1}$$

Comparable to previous measurements

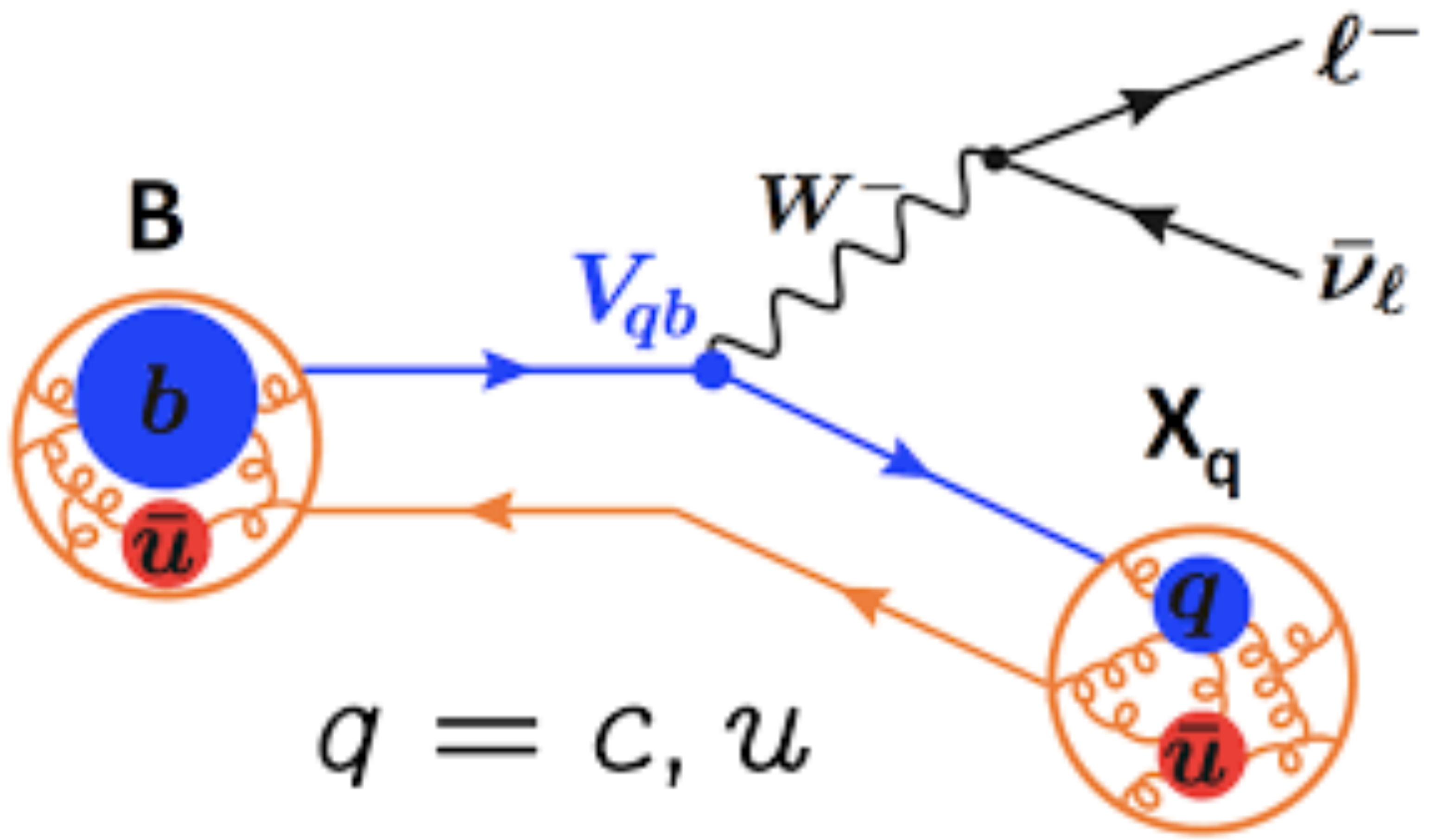
Asymmetry:

$$\mathscr{A} = \frac{N_{B^0\bar{B}^0} - N_{B^0B^0+\bar{B}^0\bar{B}^0}}{N_{B^0\bar{B}^0} + N_{B^0B^0+\bar{B}^0\bar{B}^0}}$$

Benchmark for time-dependent measurements

Semi-leptonic *B* decays

Determination of the CKM elements $|V_{cb}|$ and $|V_{ub}|$

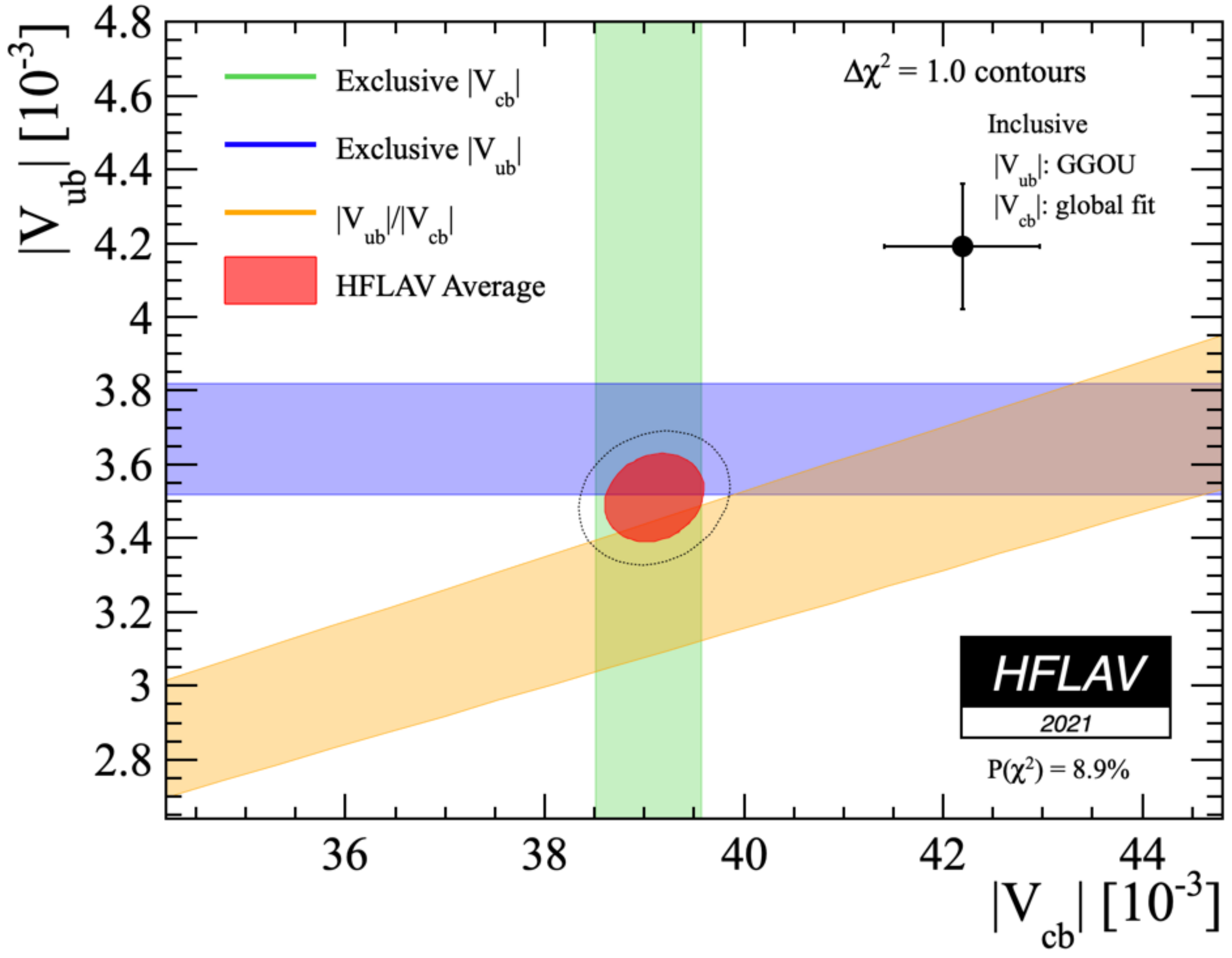


- Semi-leptonic *B* decays are studied to determine the CKM elements $|V_{cb}|$ and $|V_{ub}|$.
  - $|V_{xb}|$ are limiting the global constraining power of UT fits.
- The determination can be: **exclusive** (single final state) or **inclusive** (sensitive to all final states).

Experimentally clean
Theoretically challenging

Experimentally challenging
Theoretically clean

- **Experimental Status:**
  - Determinations of both $|V_{cb}|$ and $|V_{ub}|$ exhibit a discrepancy at the level of $\sim 3\sigma$ between **exclusive** and **inclusive.**
  - The current experimental **focus** is on understanding the origin of this discrepancy, as this inconsistency limits the power of precision flavour physics.

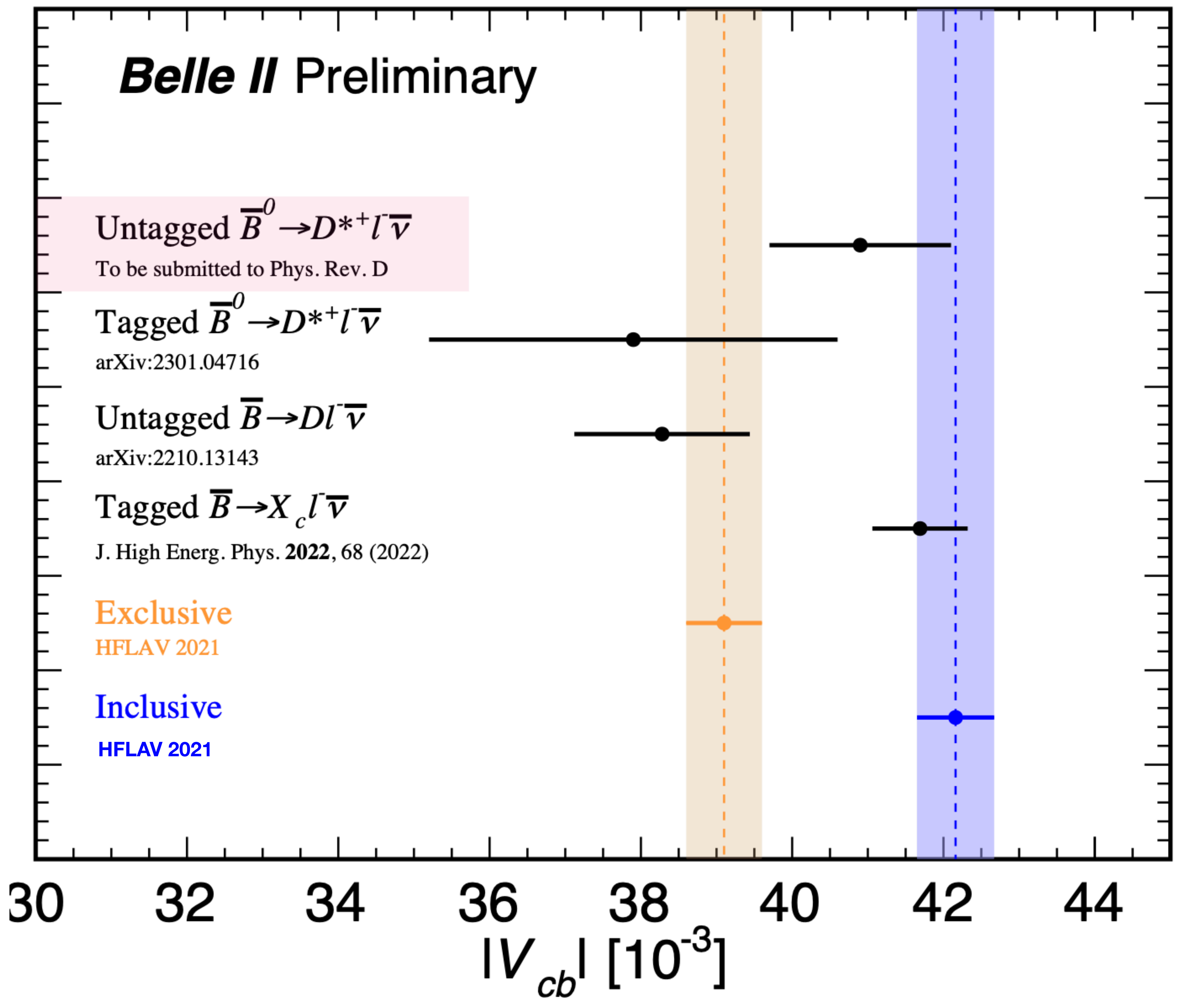


Semi-leptonic *B* decays

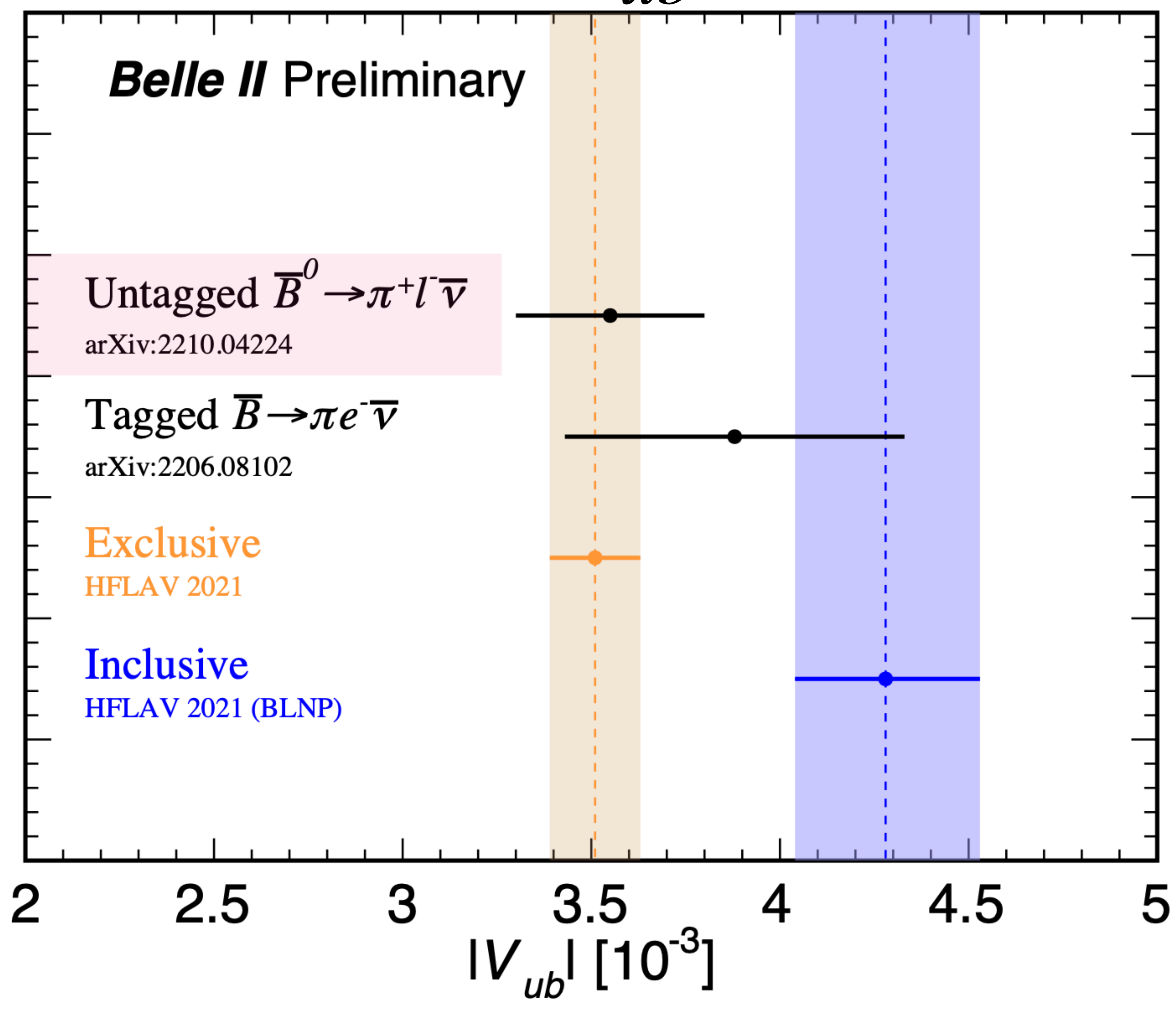
Determination of the CKM elements $|V_{cb}|$ and $|V_{ub}|$

Many new results measured will be very helpful to examine the long-standing $|V_{xb}|$ puzzle

$|V_{cb}|$



$|V_{ub}|$

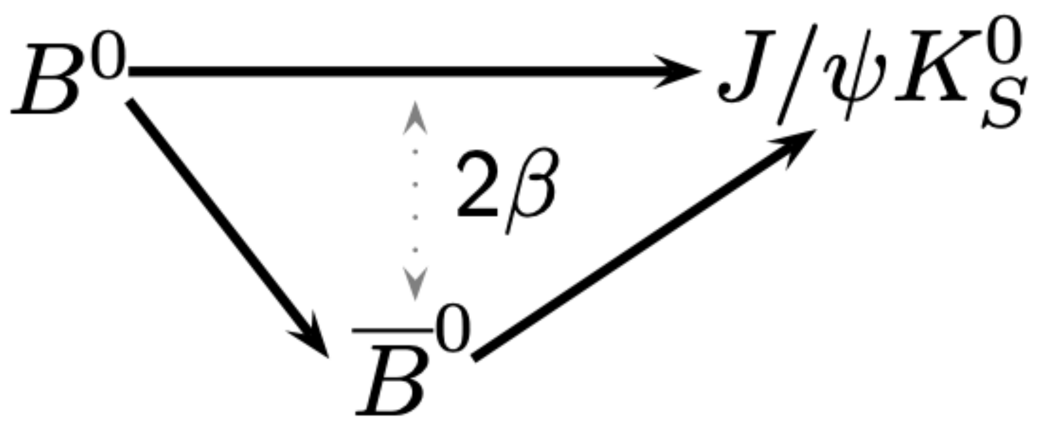


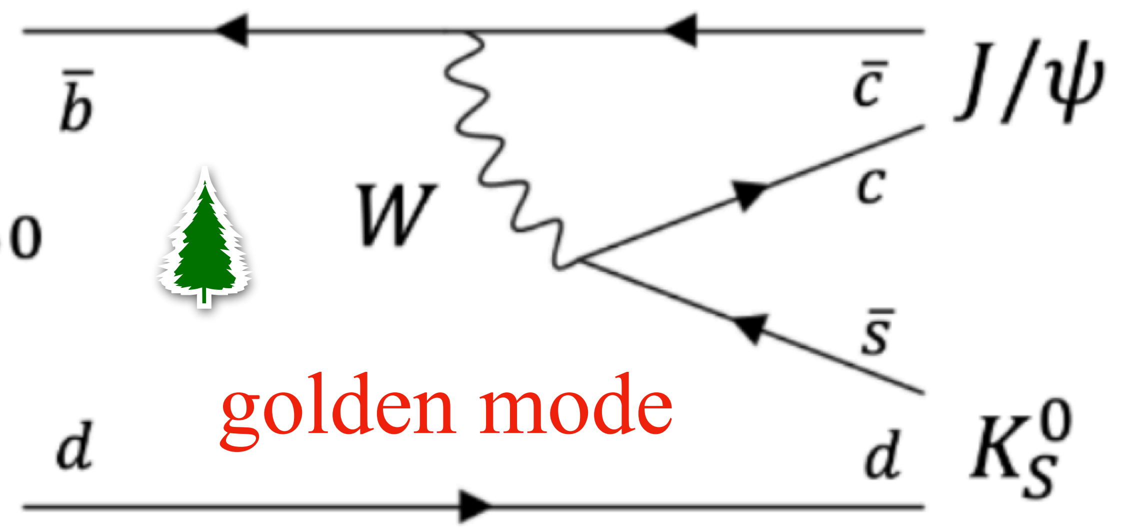
Seen discrepancies in Exp. for $B \to D^* \ell \nu$ need to be investigated.
Continuous efforts from experiment and theory are still needed.

Higher precision expected at Belle II.

ϕ_1 (β) Mixing phase

- CP-violation occurs with B^0 or $\bar{B}^0$ decays to CP eigenstate.
- ϕ_1 best-known angle of the UT with ~2.4% precision.





Reference mode for non-SM searches in gluonic penguin decays.

$$\mathscr{A}^{raw}(\Delta t) = \frac{N(\bar{B}^0 \to f_{CP}) - N(B^0 \to f_{CP})}{N(\bar{B}^0 \to f_{CP}) + N(B^0 \to f_{CP})}(\Delta t) = \mathscr{A}_{CP}\ cos(\Delta m_d \Delta t) + \mathscr{S}_{CP}\ sin(\Delta m_d \Delta t)$$

Direct CP asymmetry
$\mathscr{A}_{CP} \approx 0$ in SM

Mixing induced CP asymmetry
$\mathscr{S}_{CP} \propto sin2\phi_1$ in SM

$B^0 \to J/\psi K_S^0$

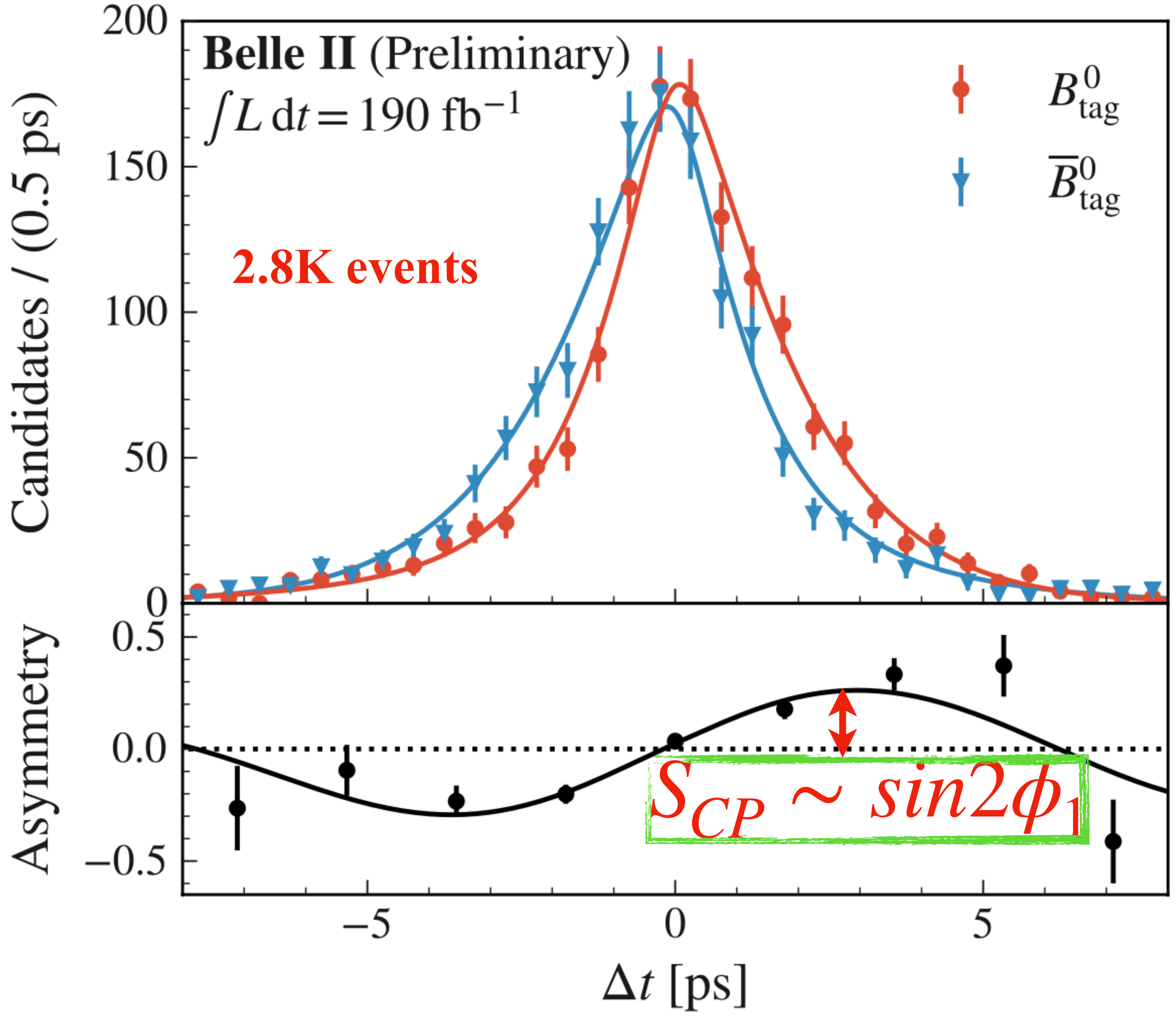
- Experimentally clean.
- High branching fraction, low background.
- Flavor tagger effective efficiency:

$$\epsilon_{eff} = \epsilon\,(1-2w) = (30.0 \pm 1.2 \pm 0.4)\,\%$$

$$\phi_1 = (23.0 \pm 2.6 \pm 0.7)^\circ$$
w.a $(21.9 \pm 0.7)^\circ$

$$\mathscr{A}_{CP} = 0.094 \pm 0.044^{+0.042}_{-0.017} \quad \text{w.a} \quad \mathscr{A}_{CP} = 0.000 \pm 0.020$$
$$\mathscr{S}_{CP} = 0.72 \pm 0.062 \pm 0.016 \quad \text{w.a} \quad \mathscr{S}_{CP} = 0.695 \pm 0.019$$

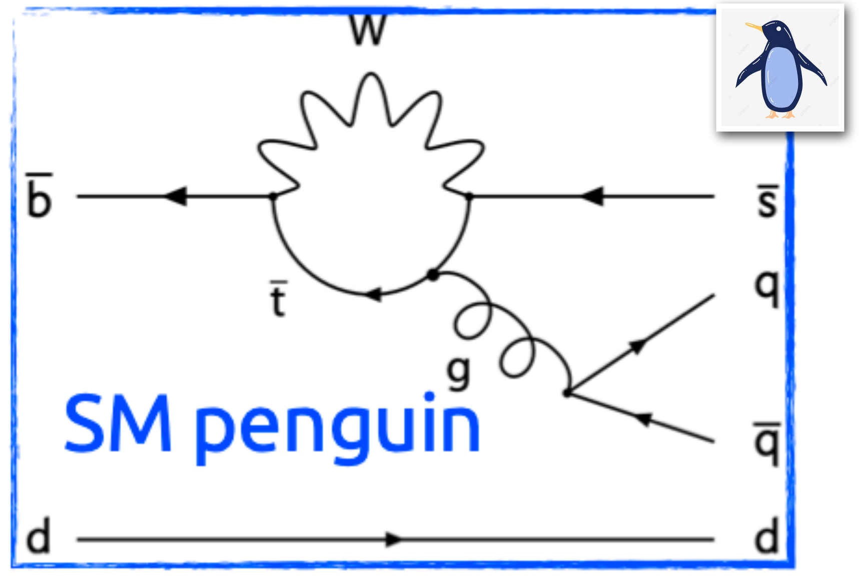
arXiv:2302.12898

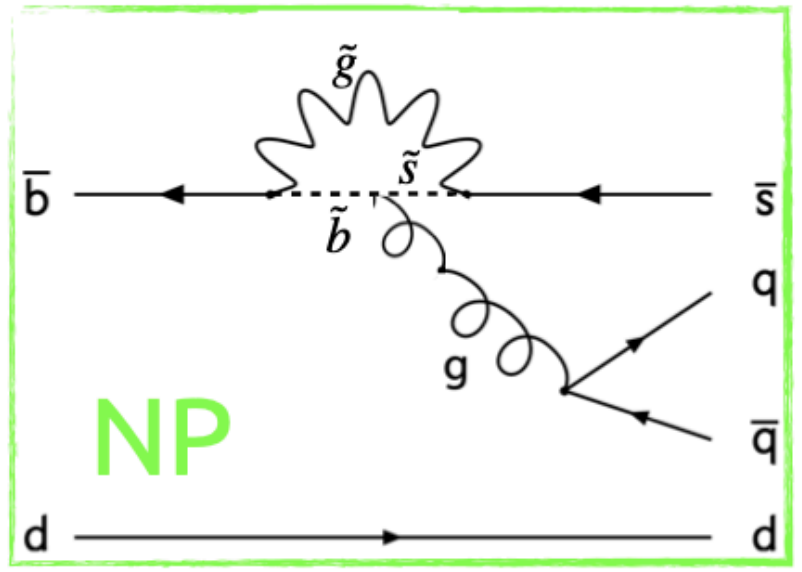


$\phi_1^{\rm eff}$ ($\beta^{\rm eff}$) from suppressed penguins

362 fb^{-1}

- **Gluonic penguin** ($b \to sq\bar{q}$) decays are suppressed in SM, BR ~ 10^{-5}-10^{-6}.
    - New Physics expected to have larger impact in these decays.
    - Check if $\mathcal{A}_{CP}$ and $\mathcal{S}_{CP}$ deviate from SM expectation in modes with clean theory prediction.
    - Important comparison of $sin2\phi_1$ with the reference favored channels to probe new amplitudes in loops.





$\mathcal{S}_{\rm penguin} \approx sin2\phi_1$ (SM) + ΔS (NP)

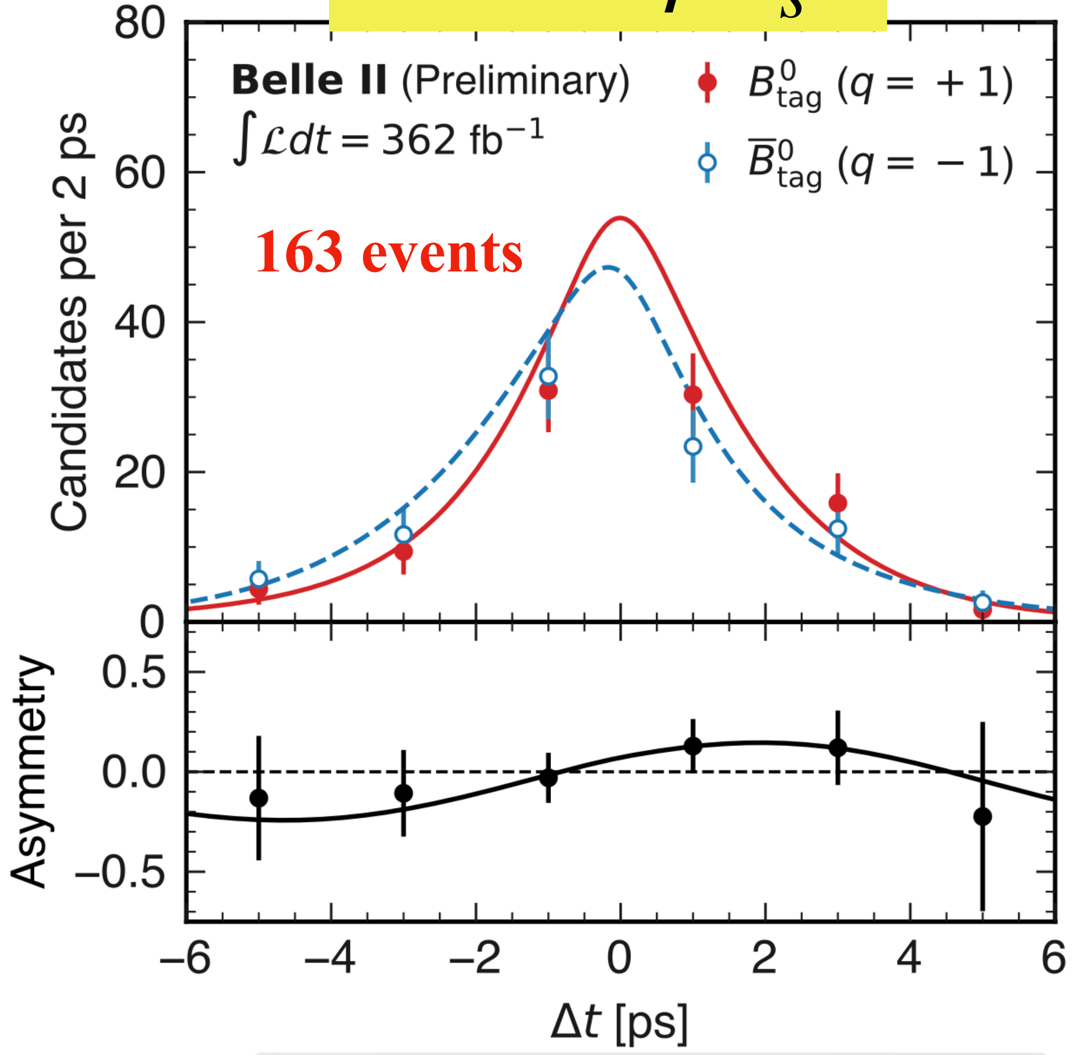
$\mathcal{A}_{\rm penguin} \approx 0$ (SM) + ΔA (NP)

- **Experimentally challenging:**
    - Fully hadronic states with neutrals (Unique to Belle II)
        - challenging B vertex reconstruction
    - Low purity ⇒ dedicated continuum suppression.

Consistent with previous determinations despite of small dataset.

arXiv:2307.02802

$B^0 \to \phi K_s^0$

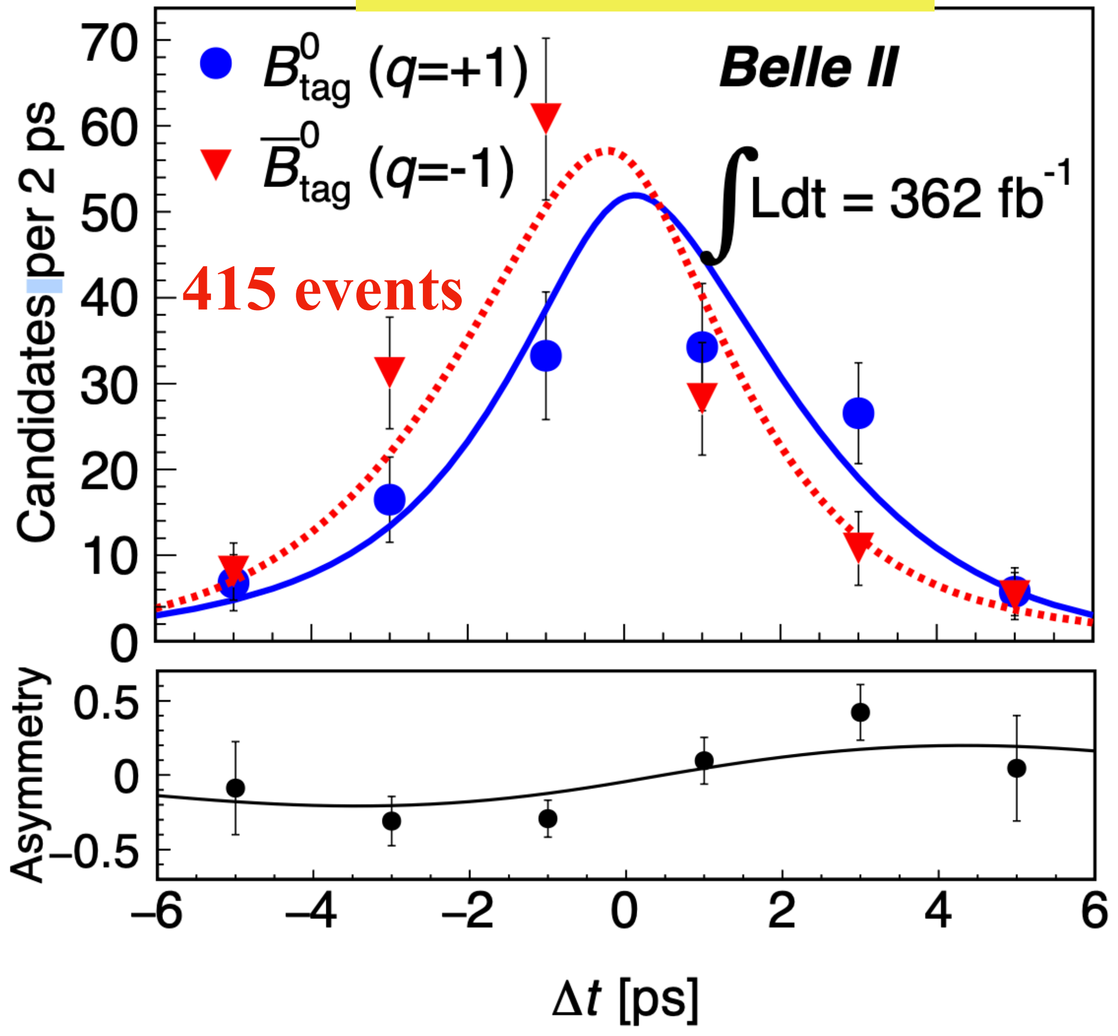


$\mathcal{A}_{CP} = 0.31 \pm 0.20 \pm 0.05$

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

arXiv:2305.07555v1

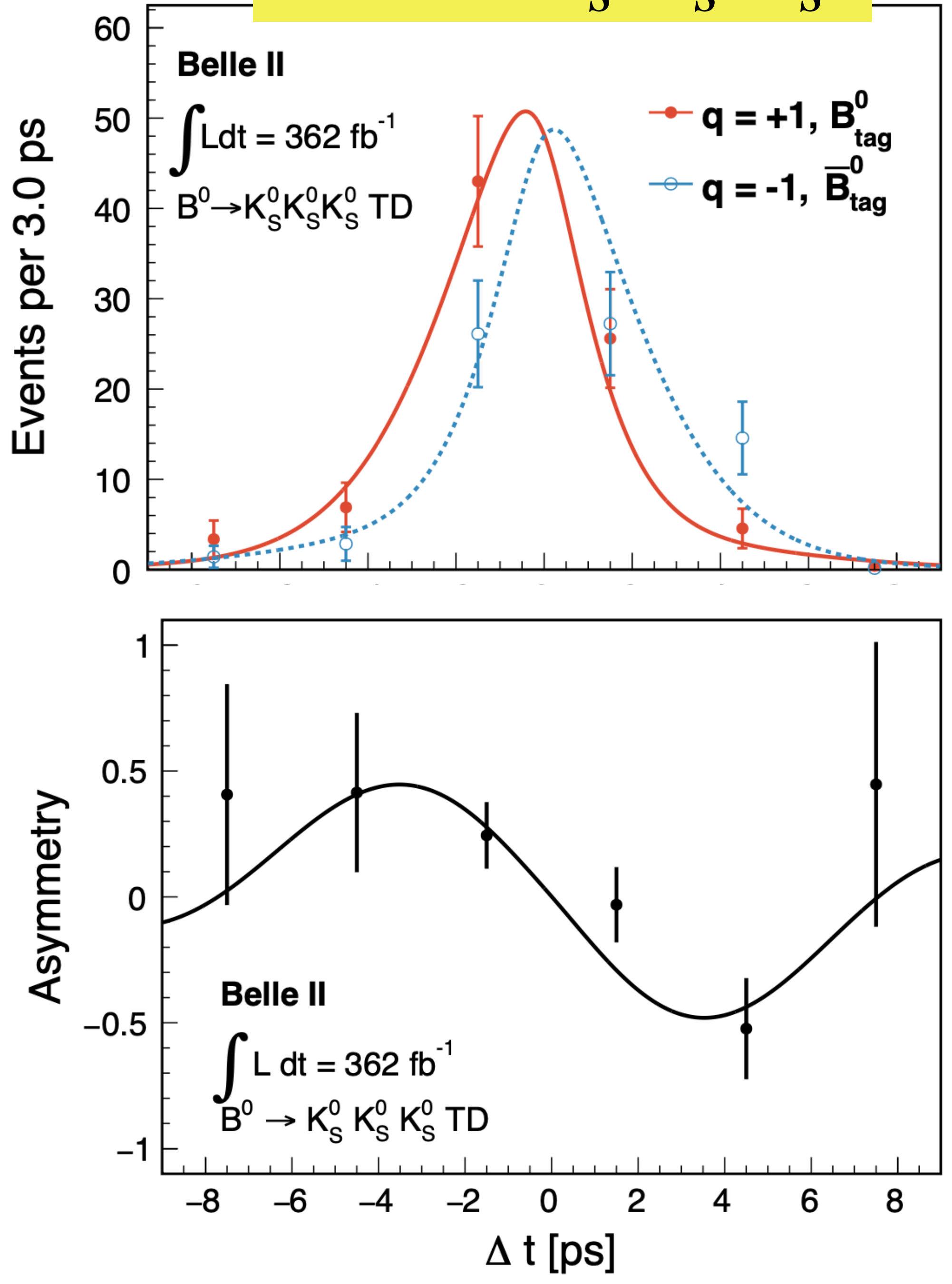
$B^0 \to K_s^0\pi^0$



$\mathcal{A}_{CP} = 0.04^{+0.15}_{-0.14} \pm 0.04$

$\mathcal{S}_{CP} = 0.74^{+0.20}_{-0.23} \pm 0.04$

$B^0 \to K_s^0K_s^0K_s^0$



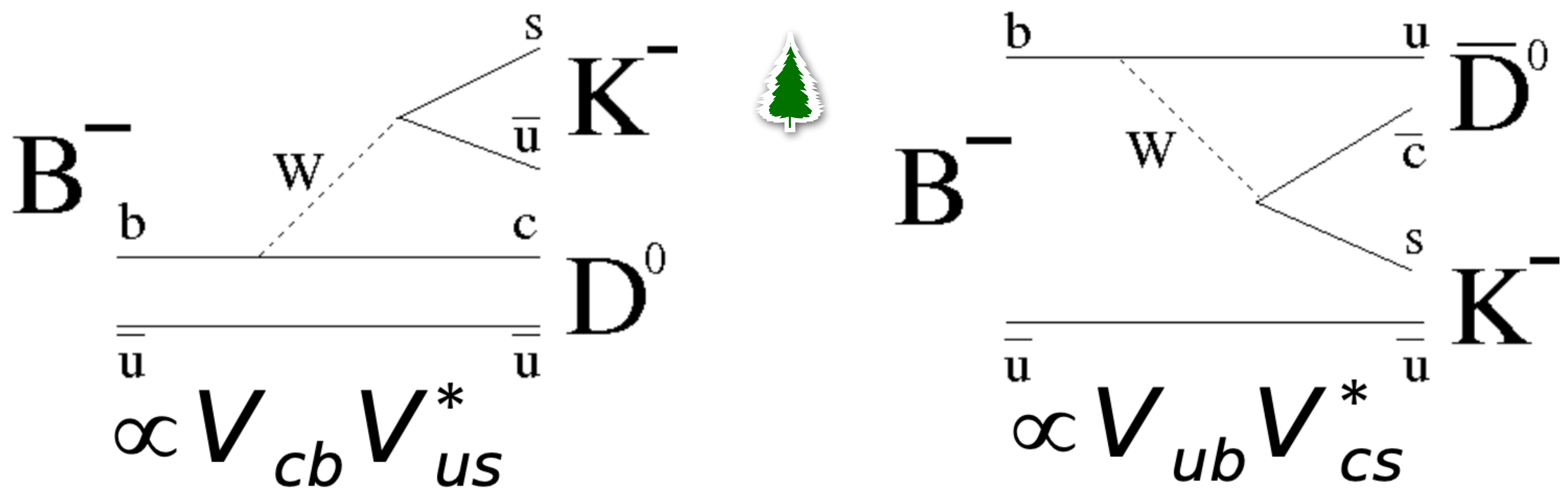
$\mathcal{A}_{CP} = 0.07^{+0.15}_{-0.20} \pm 0.02$

$\mathcal{S}_{CP} = -1.37^{+0.35}_{-0.45} \pm 0.03$

$\phi_3\ (\gamma)$

$B^+ \to D^0(K_S h^+ h^-)h^+$ **BPGGSZ method**

- Appears in $b \to c$ and $b \to u$ tree decay interference.
- $\frac{\mathscr{A}_{\text{supp}}(B^- \to \bar{D}^0 K^-)}{\mathscr{A}_{\text{fav}}(B^- \to D^0 K^-)} = r_B e^{i(\delta_B - \phi_3)} \Rightarrow \phi_3$
- Current world average precision $\Delta\phi_3 \sim 3.5°$



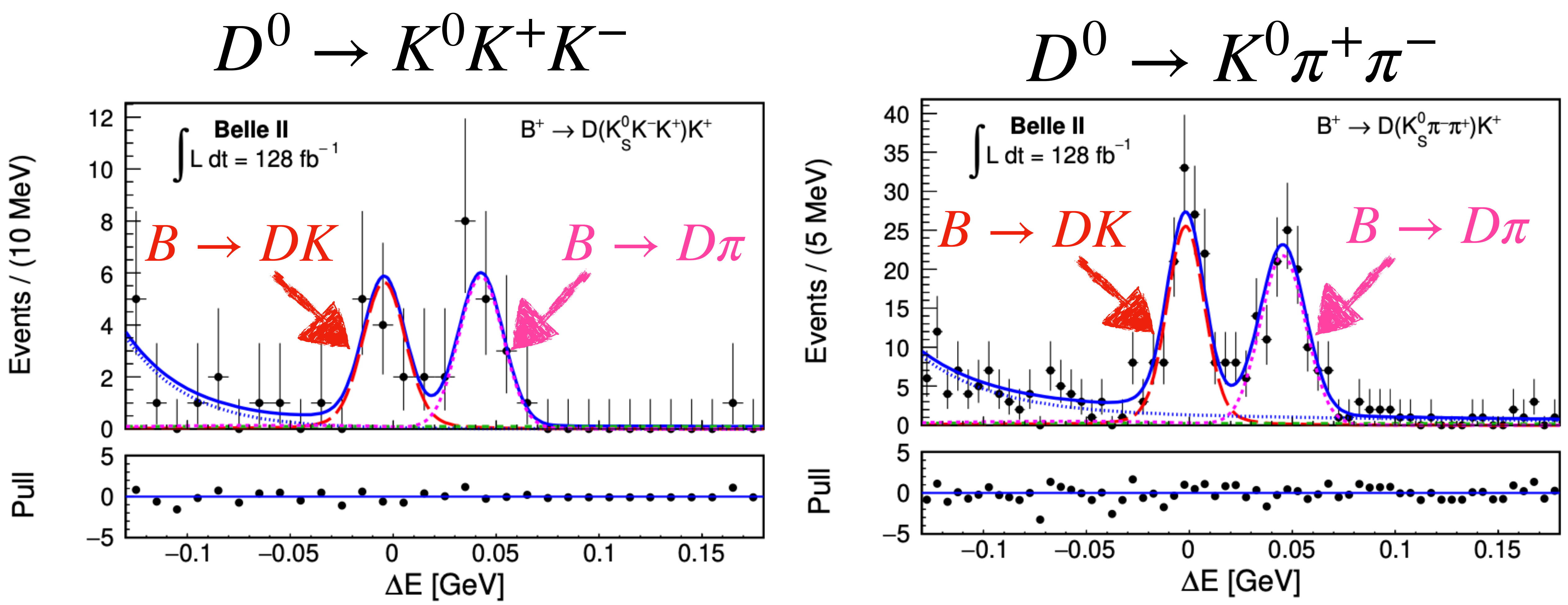
$\propto V_{cb} V_{us}^*$
colour allowed

$\propto V_{ub} V_{cs}^*$
colour suppressed

- **Multiple approaches**: according to D final state:
  - **Self-conjugate final states (BPGGSZ):** $D^0 \to K_S h^+ h^-$
  - **Singly cabibbo suppressed (GLS):** $D^0 \to K_S K^\pm \pi^\mp$
  - **CP eigenstates (GLW):** $D^0 \to K^+K^-,\ K_S^0 \pi^0$

- Combined 711/fb of **Belle** and 128/fb of **Belle II** dataset.
- **Self conjugate** modes:
  - $D^0 \to K^0\pi^+\pi^-$ and $D^0 \to K^0 K^+ K^-$.
- Simultaneous fit to $B \to DK$ and $B \to D\pi$.

JHEP 02, 063 (2022

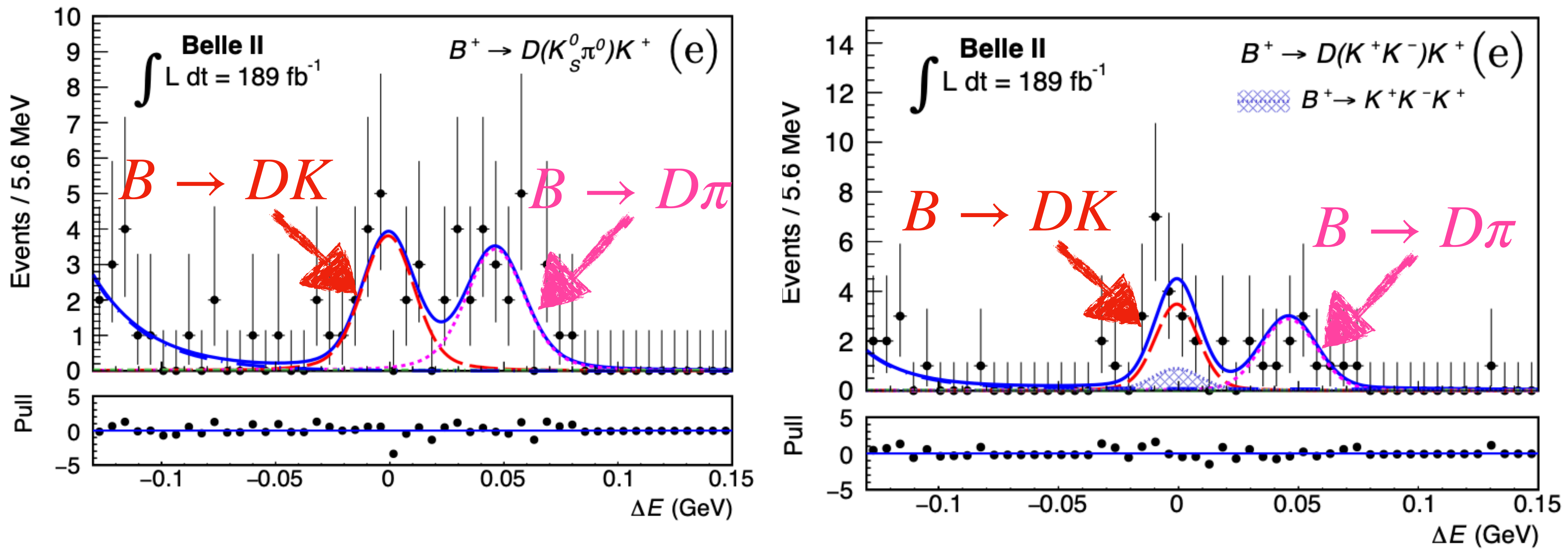

$D^0 \to K^0 K^+ K^-$ $D^0 \to K^0 \pi^+ \pi^-$

$\phi_3 = (78.4 \pm 11.4 \pm 0.5)°$
Improved compared to previous Belle analysis

ϕ_3 (γ)

$B^\pm \to D_{CP\pm}K^\pm$ **GLW** method

- Combined 711/fb of **Belle** and 189/fb of **Belle II** data
- $B^\pm \to DK^\pm$ with $D \to K^+K^-$ (CP-even) or $D \to K^0\pi^0$ (CP-odd)
- Interference between CP eigenstates:
  - $\mathscr{R}_{CP_\pm} = 1 + r_B^2 \pm 2\, r_B\, cos\delta_B\, cos\phi_3$
  - $\mathscr{A}_{CP_\pm} = \pm 2\, r_B\, sin\delta_B\, sin\phi_3 \,/\, \mathscr{R}_{CP_\pm}$



$$\mathcal{R}_{CP+} = 1.164 \pm 0.081 \pm 0.036,$$
$$\mathcal{R}_{CP-} = 1.151 \pm 0.074 \pm 0.019,$$

Large R_{CP+} compare to W.A. (~2.2 σ)

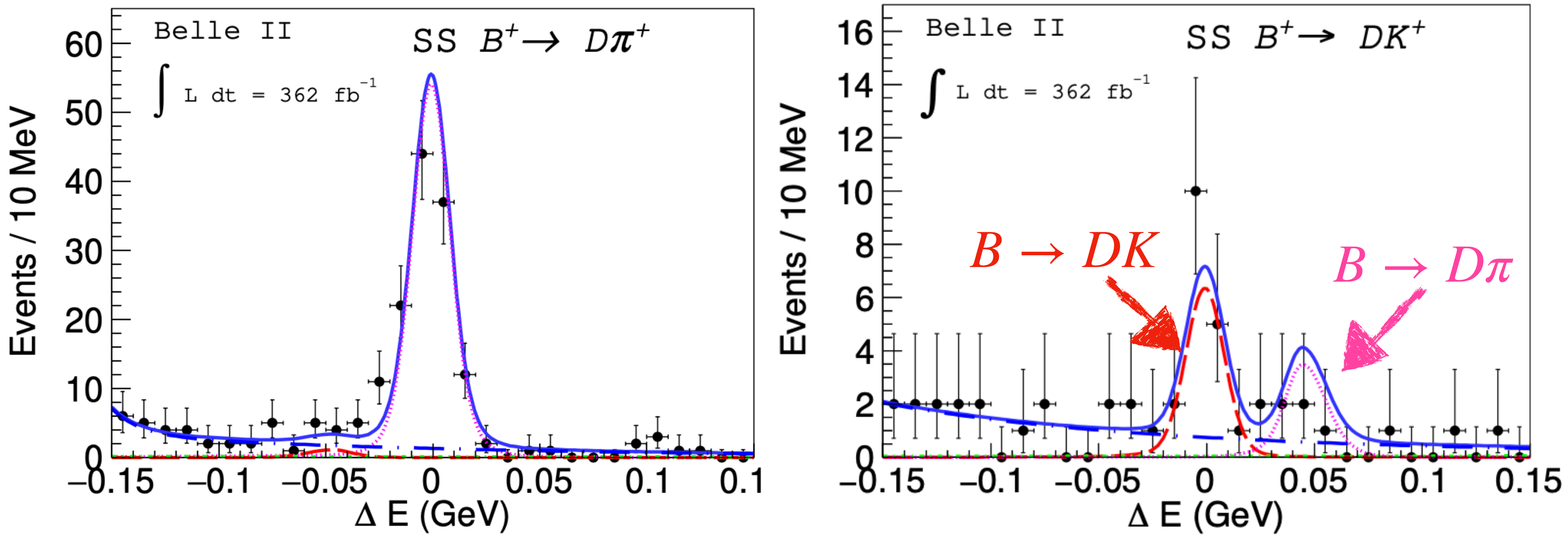
$$\mathcal{A}_{CP+} = (+12.5 \pm 5.8 \pm 1.4)\%,$$
$$\mathcal{A}_{CP-} = (-16.7 \pm 5.7 \pm 0.6)\%.$$

In agreement with SM predictions

$B^\pm \to Dh^\pm$ **GLS** method

- Combined 711/fb of **Belle** and 362/fb of **Belle II** data
- Cabibbo suppressed decay:
  $B^\pm \to DK^\pm$, $D\pi^\pm$, $D \to K^0K^\pm\pi^\mp$

arXiv:2306.02940v1



$$A_{\rm SS}^{DK} = -0.089 \pm 0.091 \pm 0.011,$$
$$A_{\rm OS}^{DK} = 0.109 \pm 0.133 \pm 0.013,$$
$$A_{\rm SS}^{D\pi} = 0.018 \pm 0.026 \pm 0.009,$$
$$A_{\rm OS}^{D\pi} = -0.028 \pm 0.031 \pm 0.009,$$

$$R_{\rm SS}^{DK/D\pi} = 0.122 \pm 0.012 \pm 0.004,$$
$$R_{\rm OS}^{DK/D\pi} = 0.093 \pm 0.013 \pm 0.003,$$
$$R_{\rm SS/OS}^{D\pi} = 1.428 \pm 0.057 \pm 0.002,$$

Results are consistent with LHCb results.

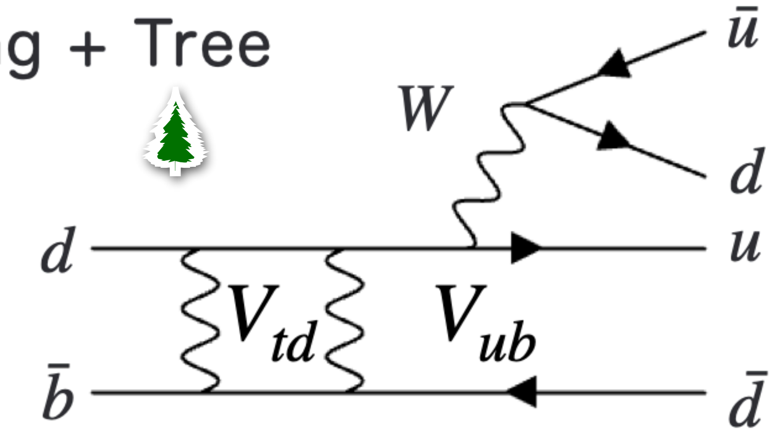
ϕ_2 (α)

190 fb^{-1}

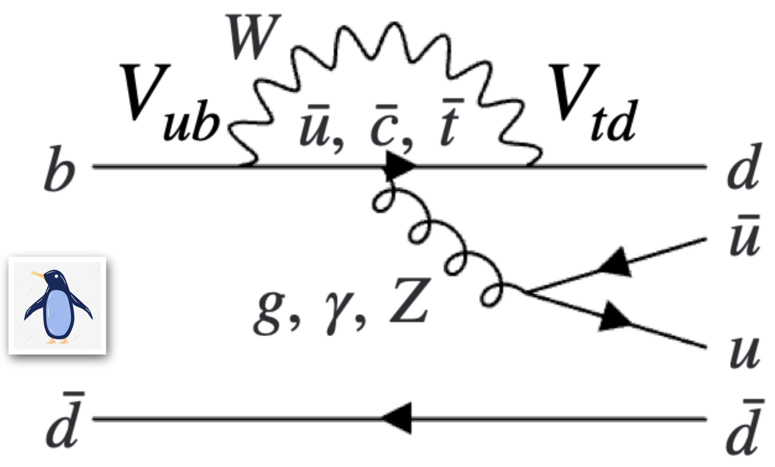
- ϕ_2 is **least known angle** in UT with 4° precision.
- $B \to \pi\pi/\rho\rho = [b \to u\bar{u}d] + [d$ or u$]$
- $b \to u\bar{u}d$: Tree and Penguin processes interfere.
- Need to eliminate the contribution of the penguin process → **Isospin analysis**

$$A^{+0} = A^{+-}/\sqrt{2} + A^{00},$$
$$\bar{A}^{-0} = \bar{A}^{+-}/\sqrt{2} + \bar{A}^{00}$$

Mixing + Tree

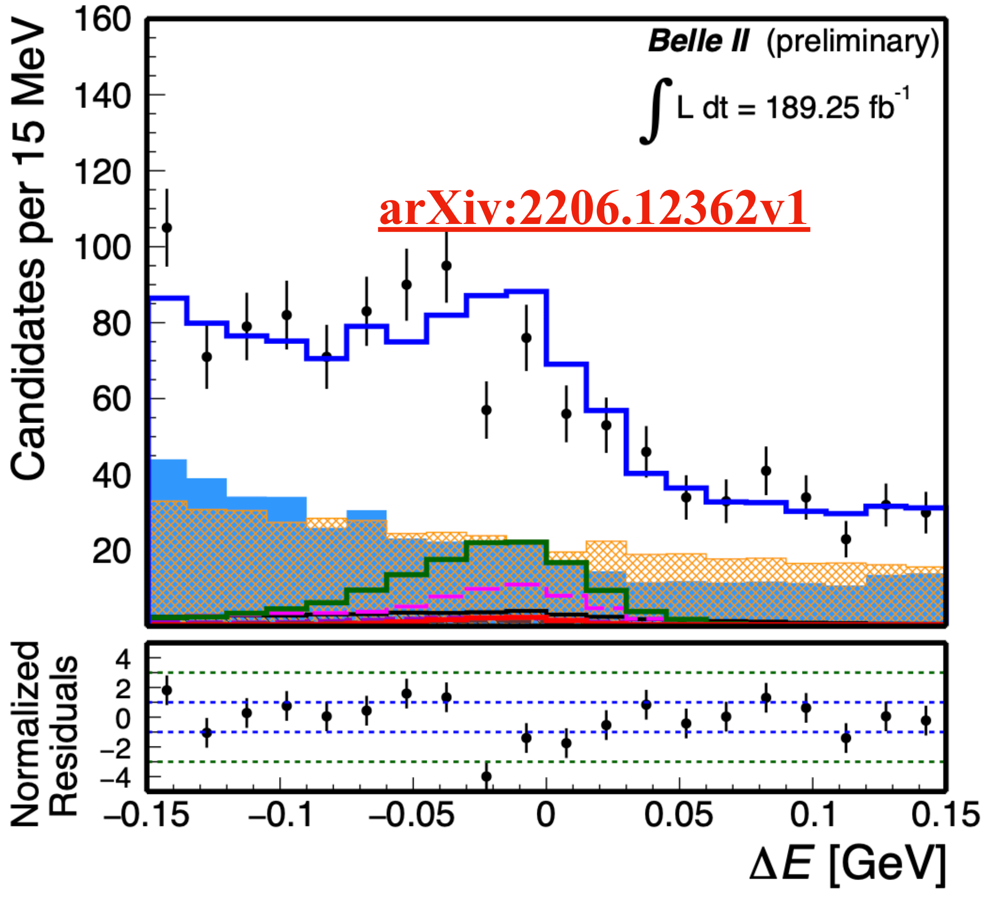


Penguin (new-physics sensitive)



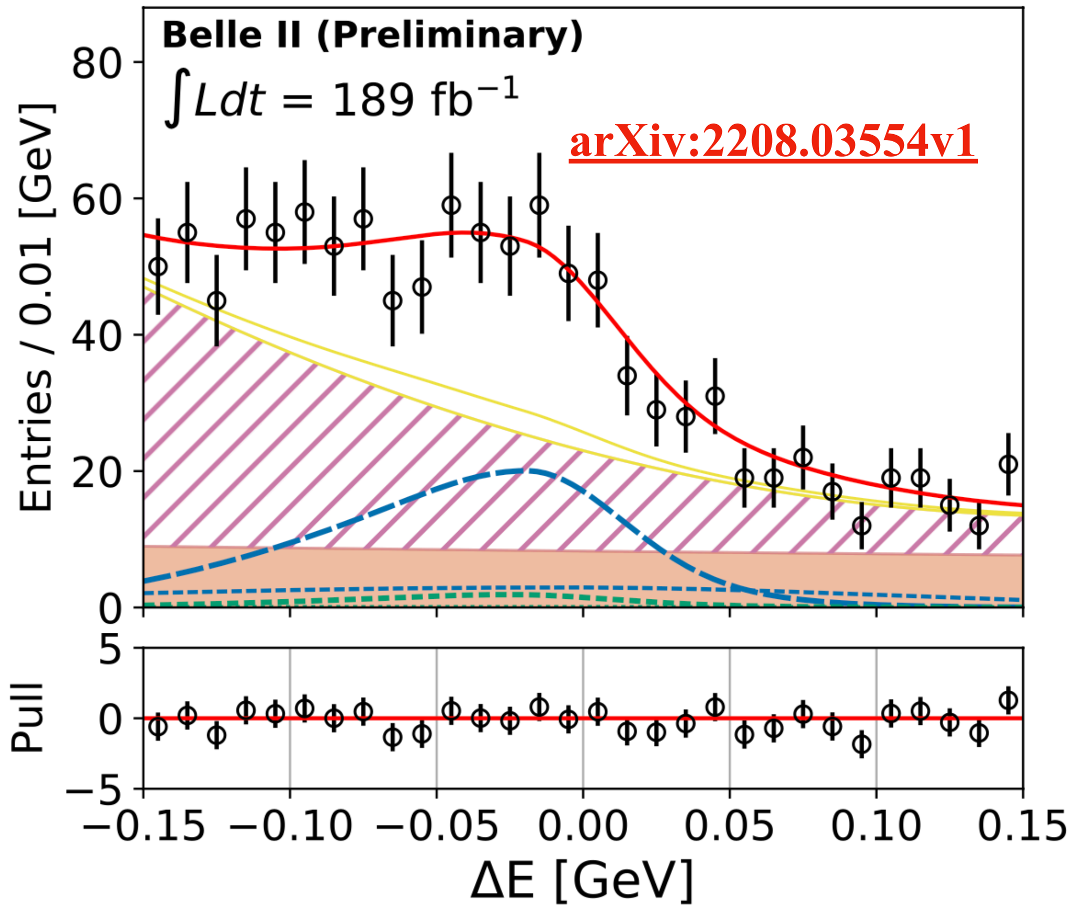
	$B^+ \to \rho^+\rho^0$	$B^0 \to \rho^+\rho^-$	$B^0 \to \pi^0\pi^0$	$B^+ \to \pi^+\pi^0$
$\mathscr{B} \times 10^{-6}$	$23.2 \pm 2.2 \pm 2.7$	$26.7 \pm 2.8 \pm 2.8$	$1.38 \pm 0.27 \pm 0.22$	$6.12 \pm 0.53 \pm 0.53$
$\mathscr{A}_{CP}(\%)$	$-6.9 \pm 6.8 \pm 6.0$		$14 \pm 46 \pm 7$	$-8.5 \pm 8.5 \pm 1.9$
	WA			
$\mathscr{B} \times 10^{-6}$	24.0 ± 1.9	27.7 ± 1.9	1.59 ± 0.26	5.5 ± 0.4
$\mathscr{A}_{CP}(\%)$	-5.0 ± 5.0		33 ± 22	3.0 ± 4.0

$B^+ \to \rho^+\rho^0$



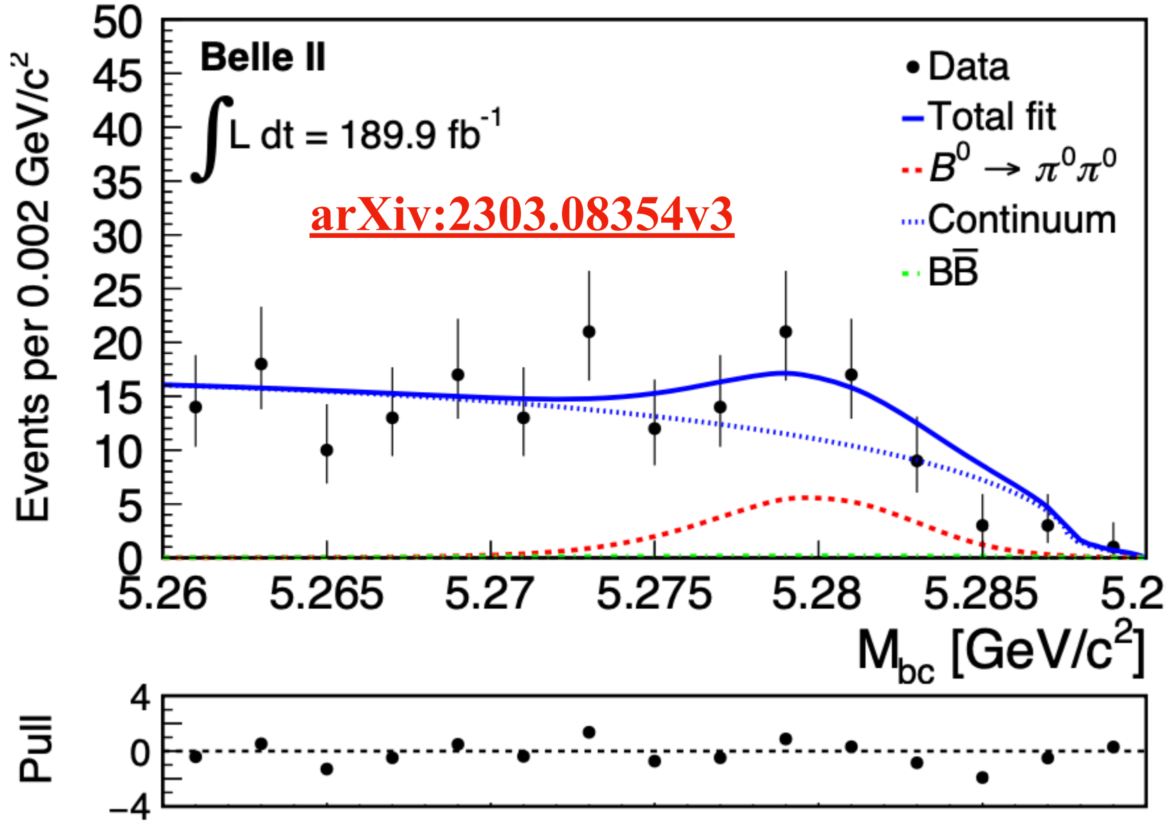
arXiv:2206.12362v1

$B^0 \to \rho^+\rho^-$



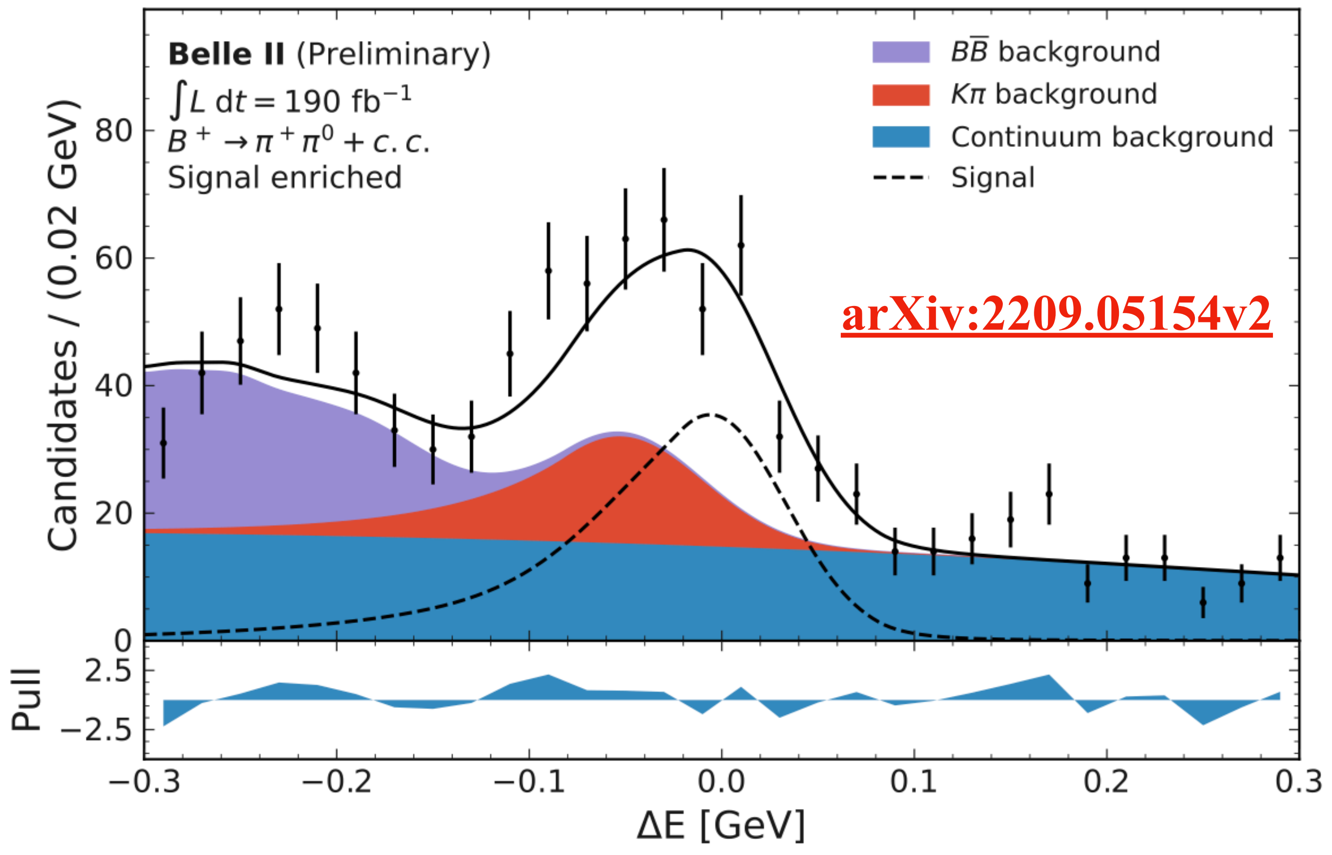
arXiv:2208.03554v1

$B^0 \to \pi^0\pi^0$



arXiv:2303.08354v3

$B^+ \to \pi^+\pi^0$



arXiv:2209.05154v2

The measured results are in good agreement with world averages

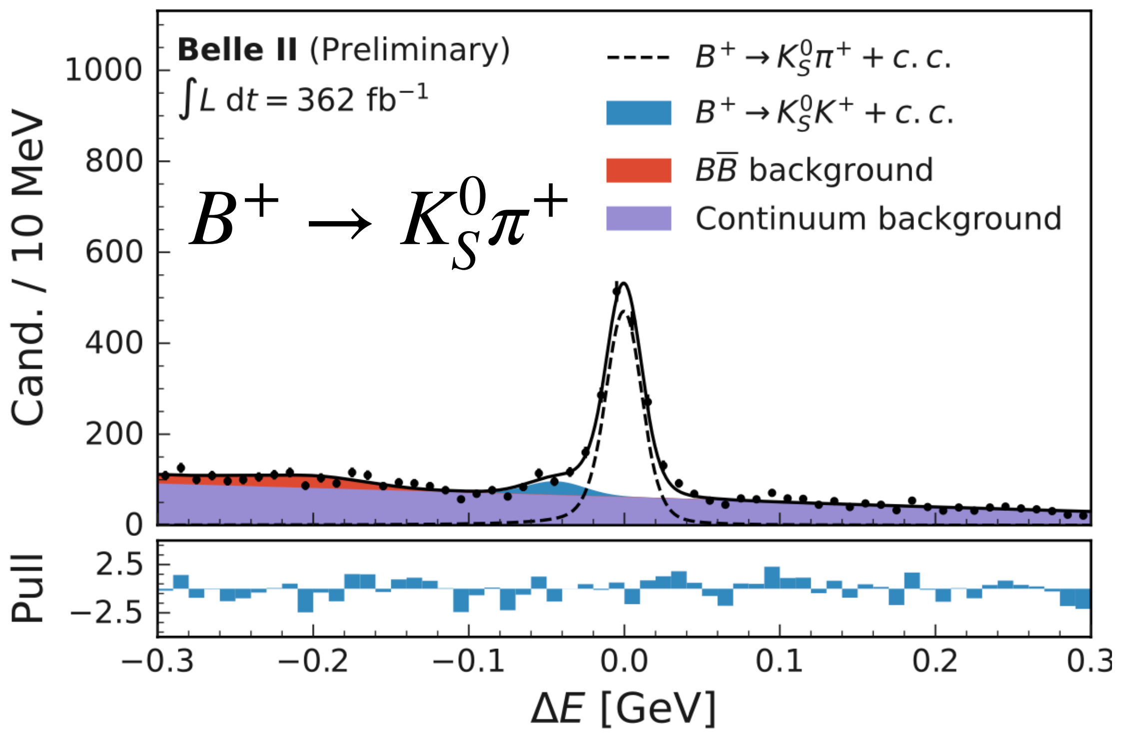
Direct CP violation: $B \to K\pi$

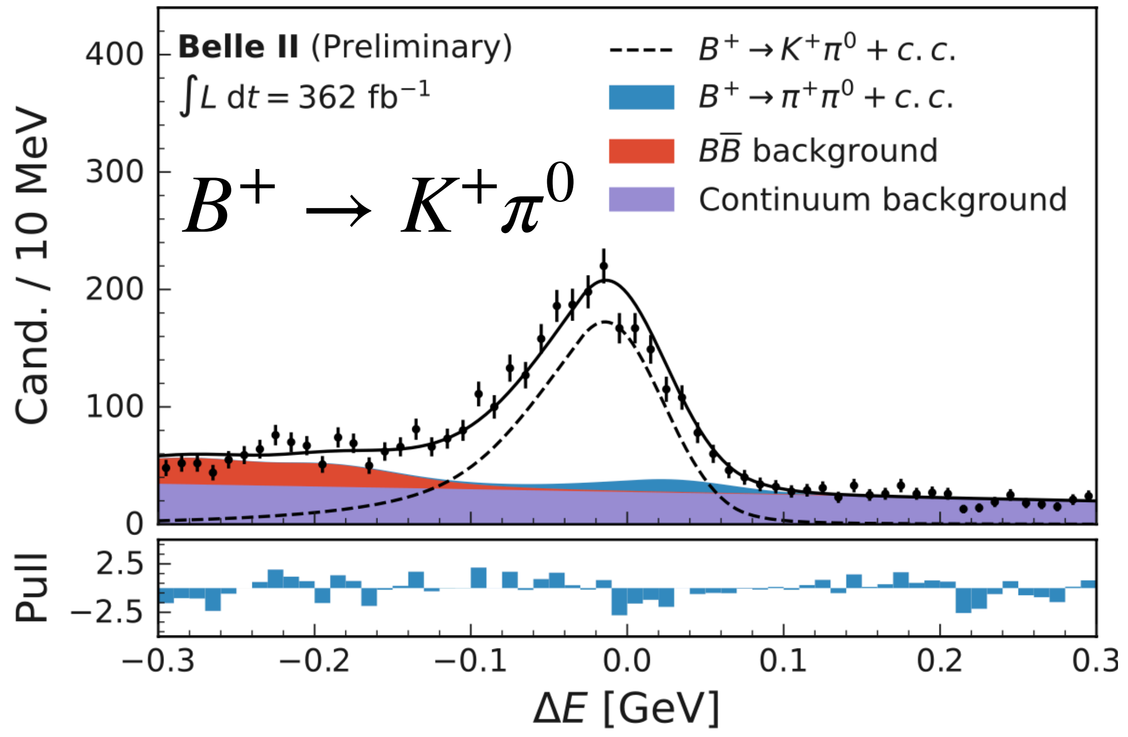
- Isospin sum rule: $I_{K\pi} = \mathscr{A}^{K^+\pi^-} + \mathscr{A}^{K^0\pi^+}\frac{\mathscr{B}_{K^0\pi^+}}{\mathscr{B}_{K^+\pi^-}}\frac{\tau_{B^0}}{\tau_{B^+}} - 2\mathscr{A}^{K^+\pi^0}\frac{\mathscr{B}_{K^+\pi^0}}{\mathscr{B}_{K^+\pi^-}}\frac{\tau_{B^0}}{\tau_{B^+}} - 2\mathscr{A}^{K^0\pi^0}\frac{\mathscr{B}_{K^0\pi^0}}{\mathscr{B}_{K^+\pi^-}}$
  - Exactly zero with isospin symmetry and no EW penguins.
  - Theoretical precision $\mathscr{O}(1\%)$, experimental precision $\mathscr{O}(10\%)$, driven by $\mathscr{A}^{K^0\pi^0}$.

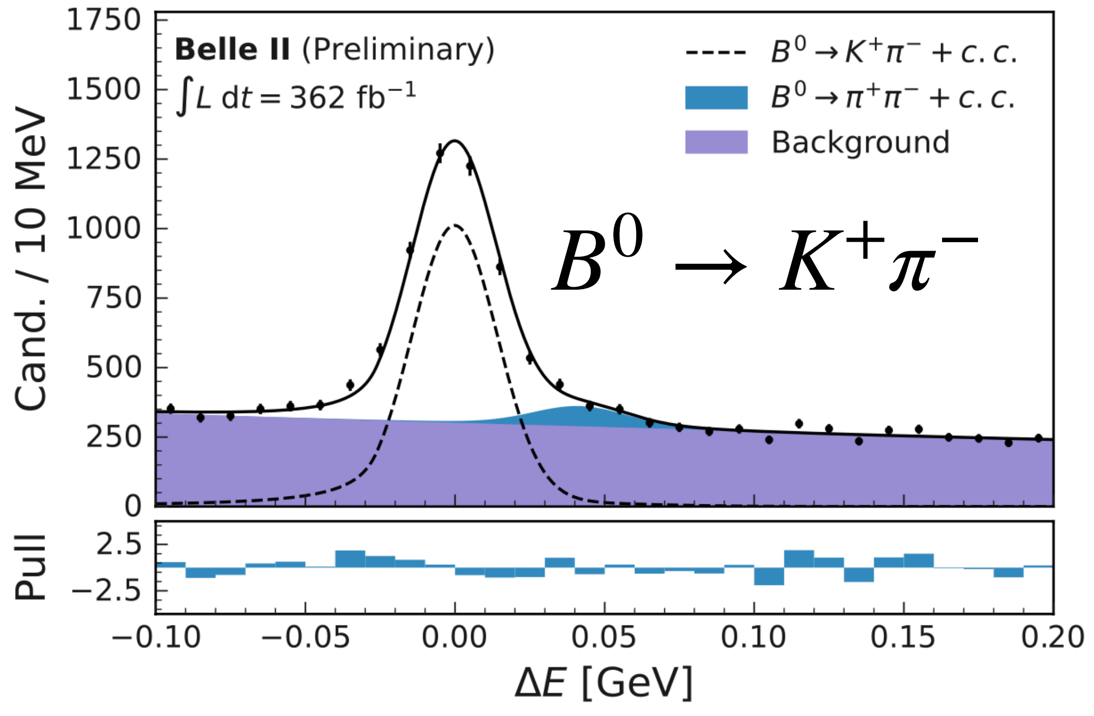
Measured all final states: $B^0 \to K^+\pi^-$, $B^+ \to K_S^0\pi^+$, $B^+ \to K^+\pi^0$, $B^0 \to K_S^0\pi^0$

	$B^+ \to K_S^0\pi^+$	$B^+ \to K^+\pi^0$	$B^0 \to K^+\pi^-$
$\mathscr{B} \times 10^{-6}$	$24.4 \pm 0.71 \pm 0.86$	$13.93 \pm 0.38 \pm 0.84$	$20.67 \pm 0.37 \pm 0.62$
$\mathscr{A}(\%)$	$4.6 \pm 2.9 \pm 0.7$	$1.3 \pm 2.7 \pm 0.5$	$-7.2 \pm 1.9 \pm 0.7$

$\mathscr{B}$ and $\mathscr{A}_{CP}$ results in agreements with world averages and competitive with world best

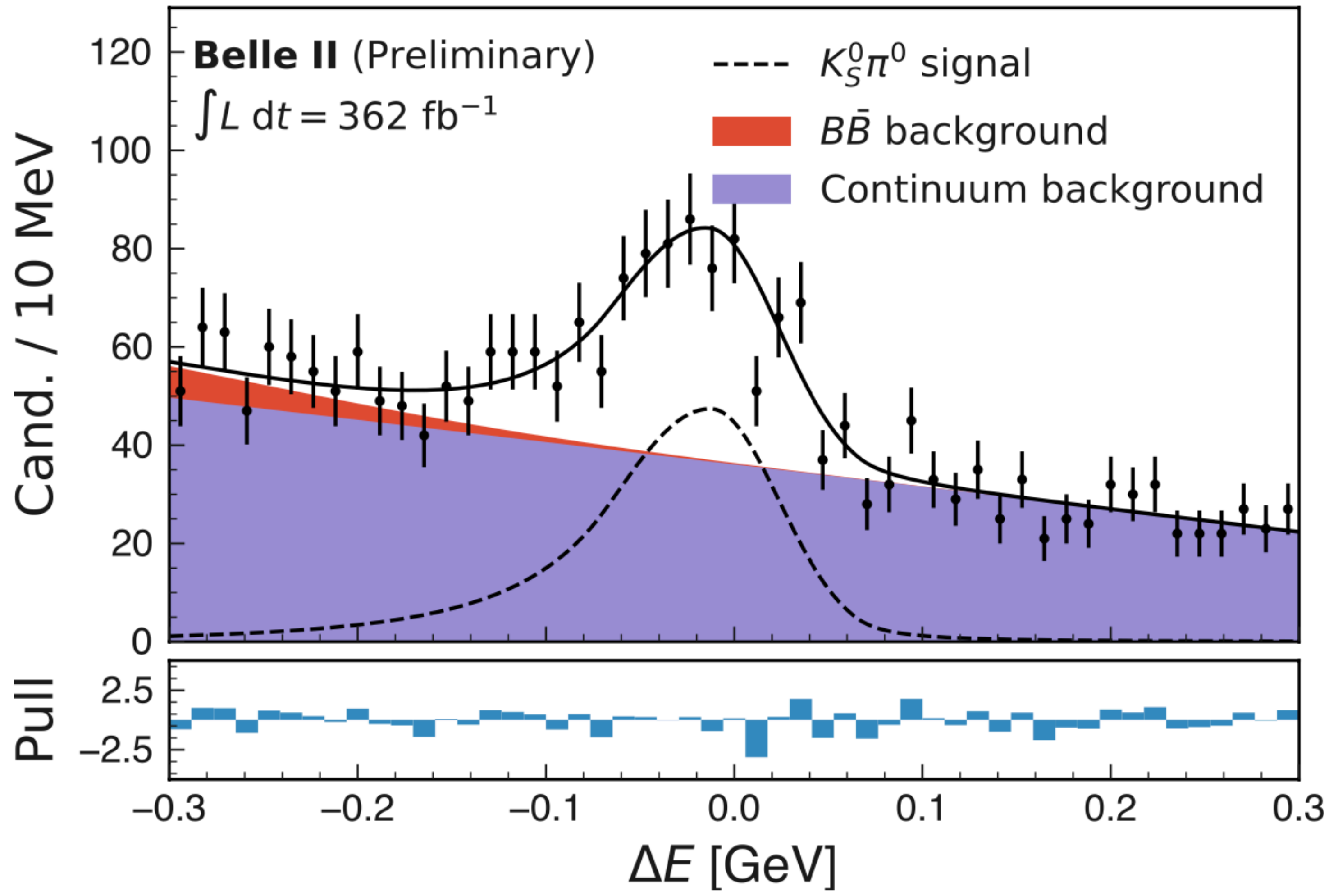






$B^0 \to K_S^0\pi^0$

- Independent decay-time integrated analysis.
- Combine with time-dependent analysis.



$$\mathscr{B} = (10.50 \pm 0.62 \pm 0.69) \times 10^{-6}$$

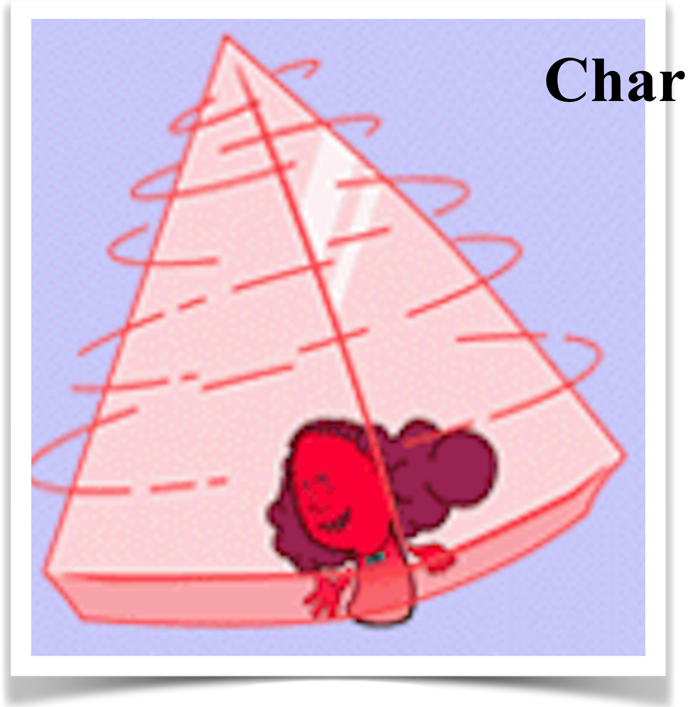
$$\mathscr{A}_{CP} = -0.01 \pm 0.12 \pm 0.05$$

Combining all the $B \to K\pi$ final states measured by Belle II

$$I_{K\pi} = -0.03 \pm 0.13 \pm 0.05$$

Agree with SM, competitive with world average (0.13 ± 0.11)

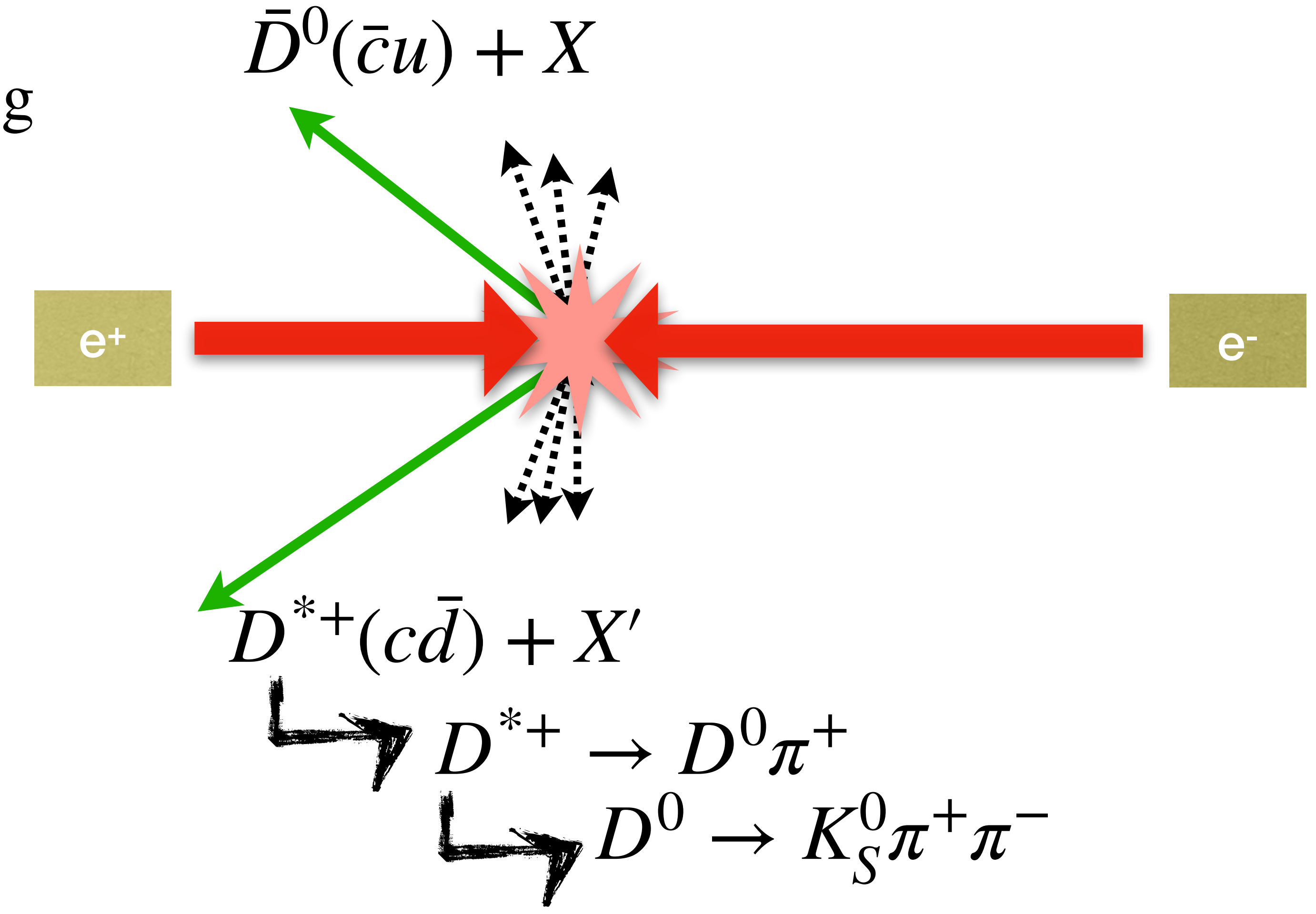
Charm-physics



Charm

Charm physics

$$e^+e^- \rightarrow c\bar{c} \rightarrow D_{\text{tag}}\ X_{\text{frag}}\ D_{\text{sig}}$$



A brief picture

- $e^+e^- \longrightarrow$ two charm hadrons + **fragmentation**
- Main ingredient of CPV/mixing measurement is flavor tagging:
  - exclusive reconstruction of strong decay $D^{*+} \rightarrow D^0\pi^+$.
  - inclusive charm mesons & baryons samples to study.
    (semi-)leptonic decays (missing energy), or to invisible final states.

Charm lifetime

- **Lifetime measurements**:
  - test non-perturbative QCD and provide guidance to describe strong interactions.
  - HQE used to determine heavy-quark hadron lifetime as expansion in $1/m_q$.
  - charm mass is not so heavy ⇒ the spectator quark contribution can't be neglected.
- Hierarchy of hadron lifetimes:

D^0, D^+, D_s^+, and Λ_c lifetime measurement ⇒ world best

PRL, 121, 092003 (2018)

Hierarchy changed by LHCb Ω_c results

LHCb

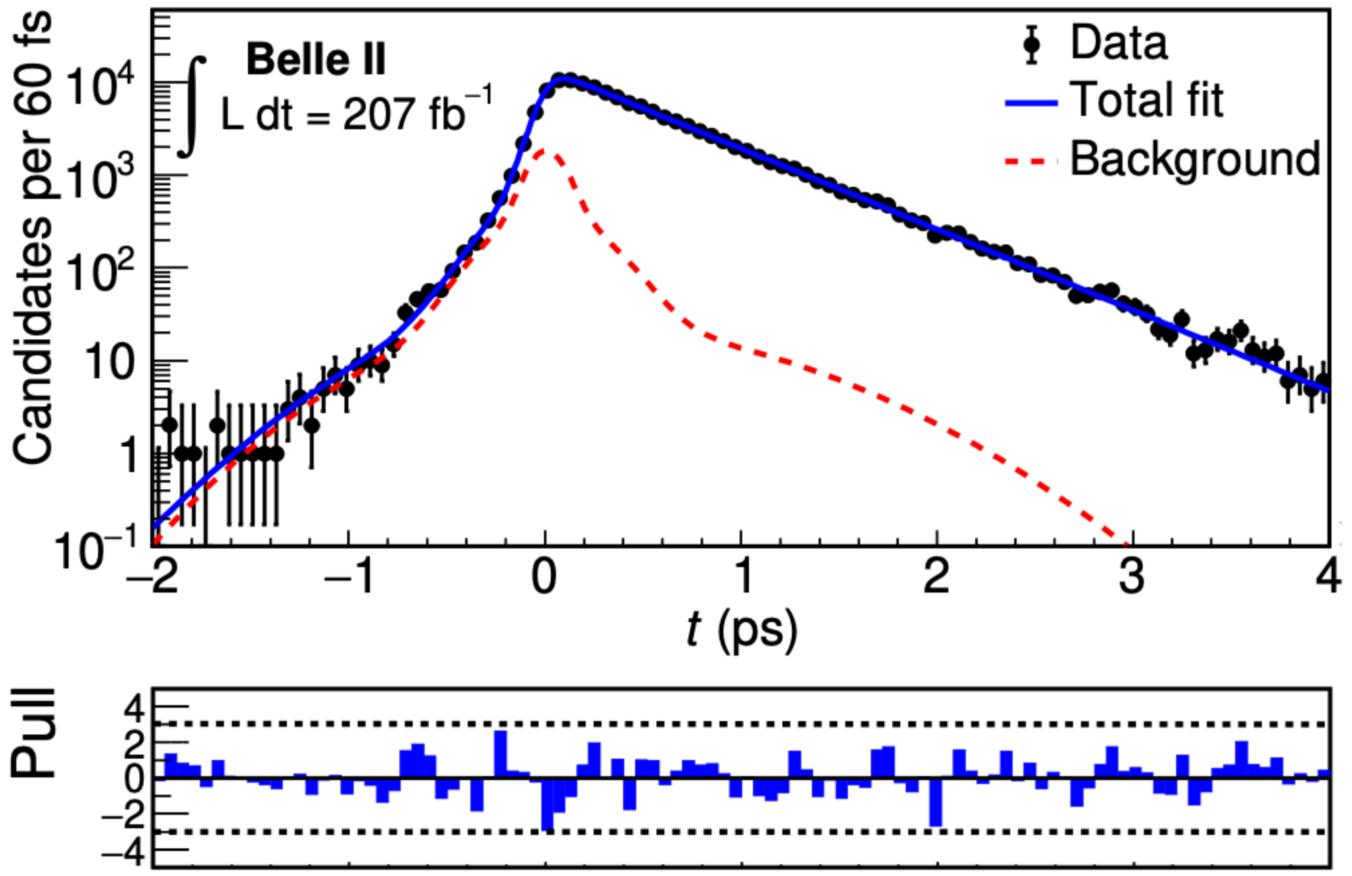
$$\tau(\Xi_c^+) > \tau(\Lambda_c^+) > \tau(\Xi_c^0) > \tau(\Omega_c^0)$$

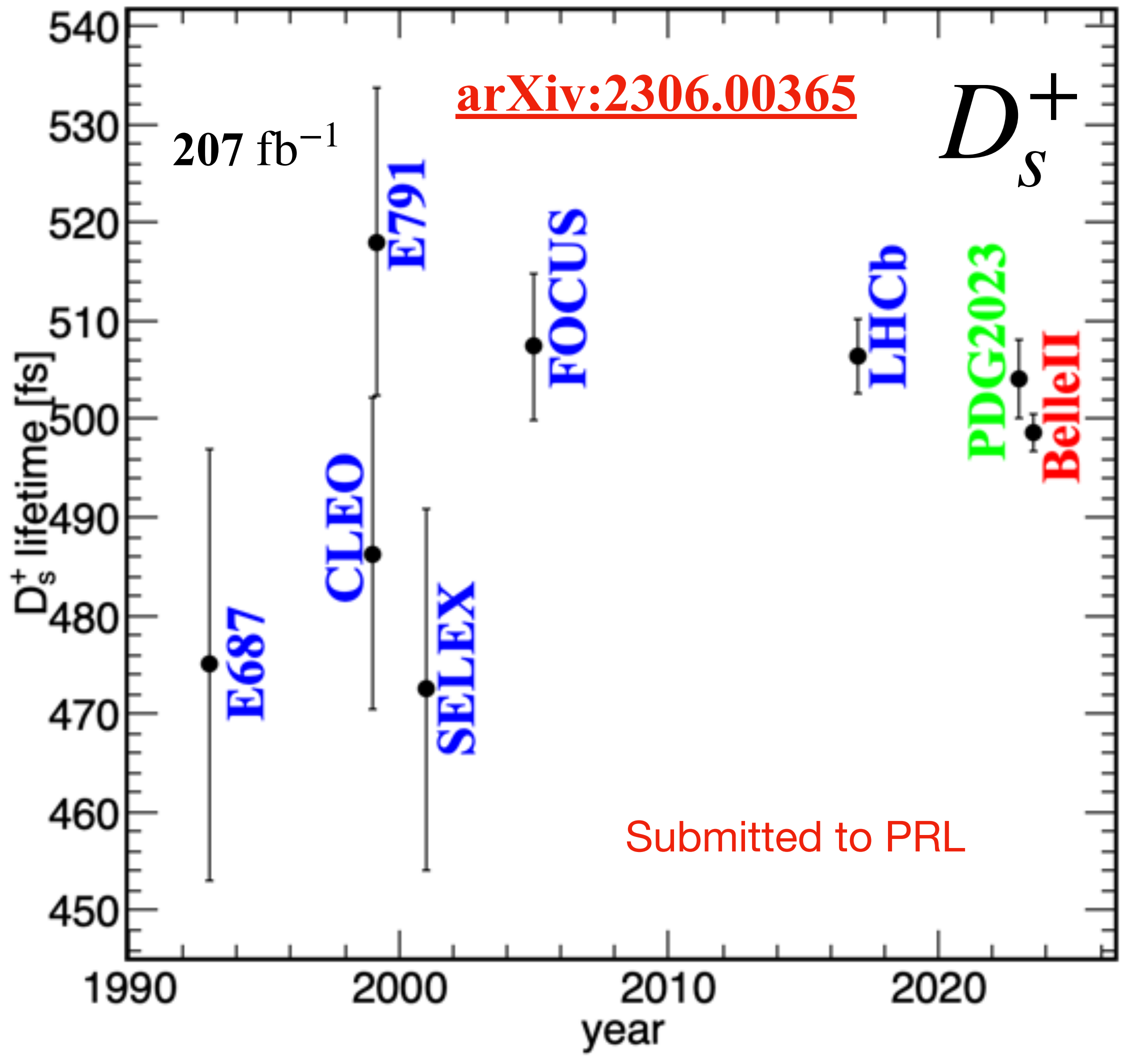
Belle II confirmed the new picture

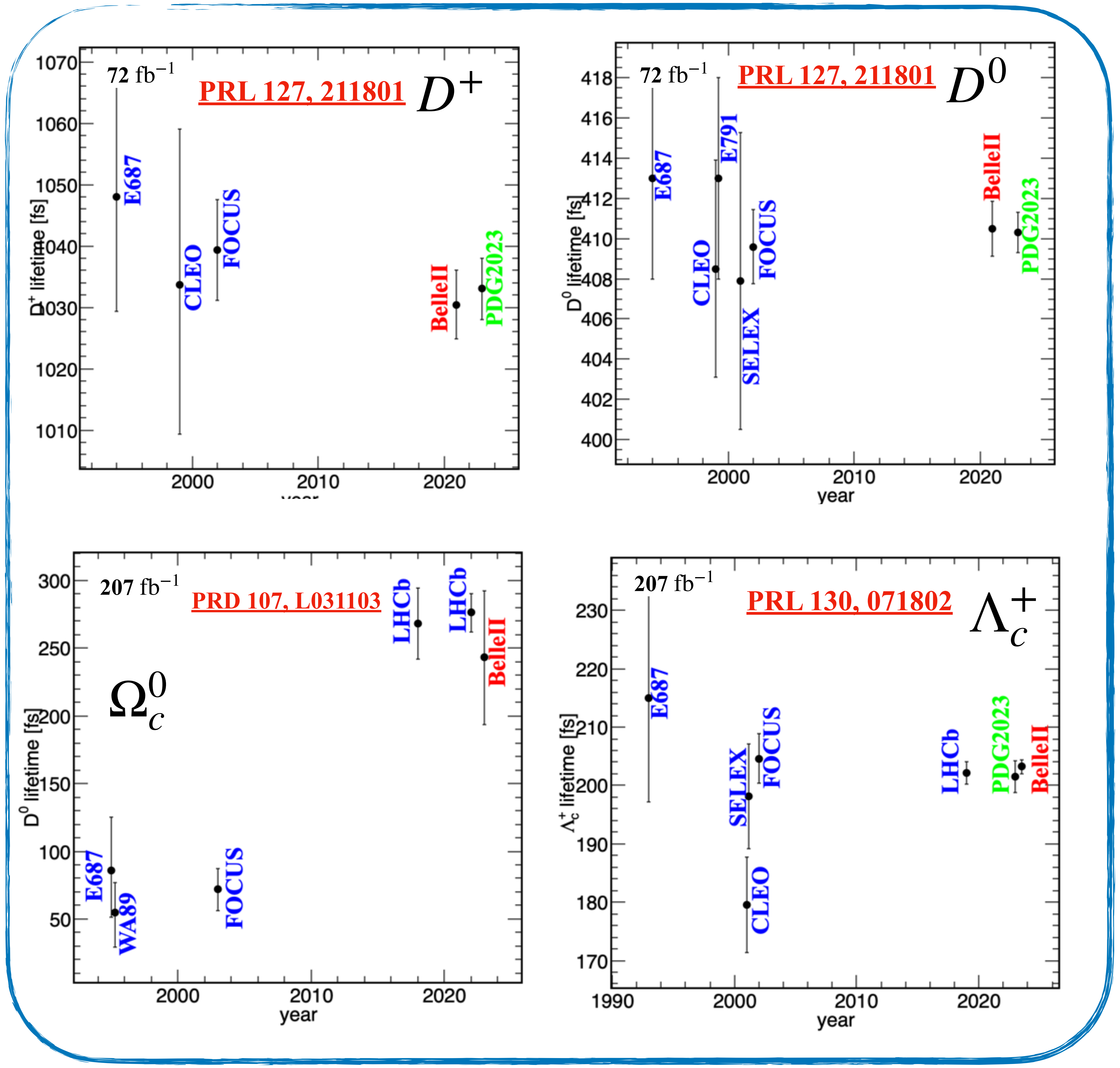
Interest in improving the precision on these SM measurements

Results

- Lifetimes consistent with world averages . (Λ_c, D^0, D^+, and D_s^+) and with LHCb value (Ω_c).
- First lifetime measurements done at experiments at B-Factories
  - **Belle II** can do more than what Belle & BABAR have done.







- **World's most precise measurements of the Λ_c, D^0, D^+, and D_s^+ lifetimes.**
- **New lifetime hierarchy by LHCb :**

$$\tau(\Xi_c^+) > \tau(\Omega_c^0) > \tau(\Lambda_c^+) > \tau(\Xi_c^0)$$

Confirmed by Belle II

τ-physics

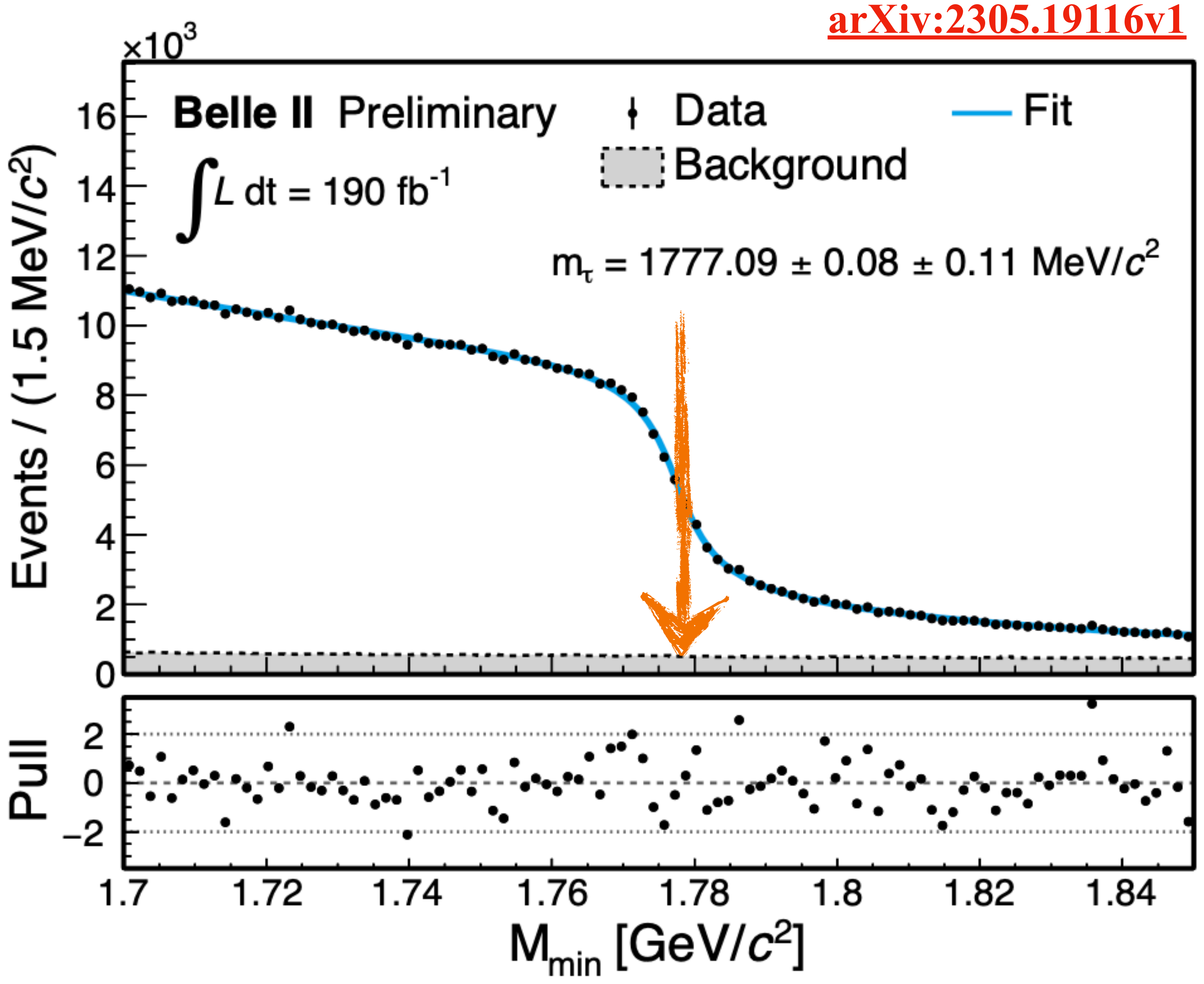
τ physics

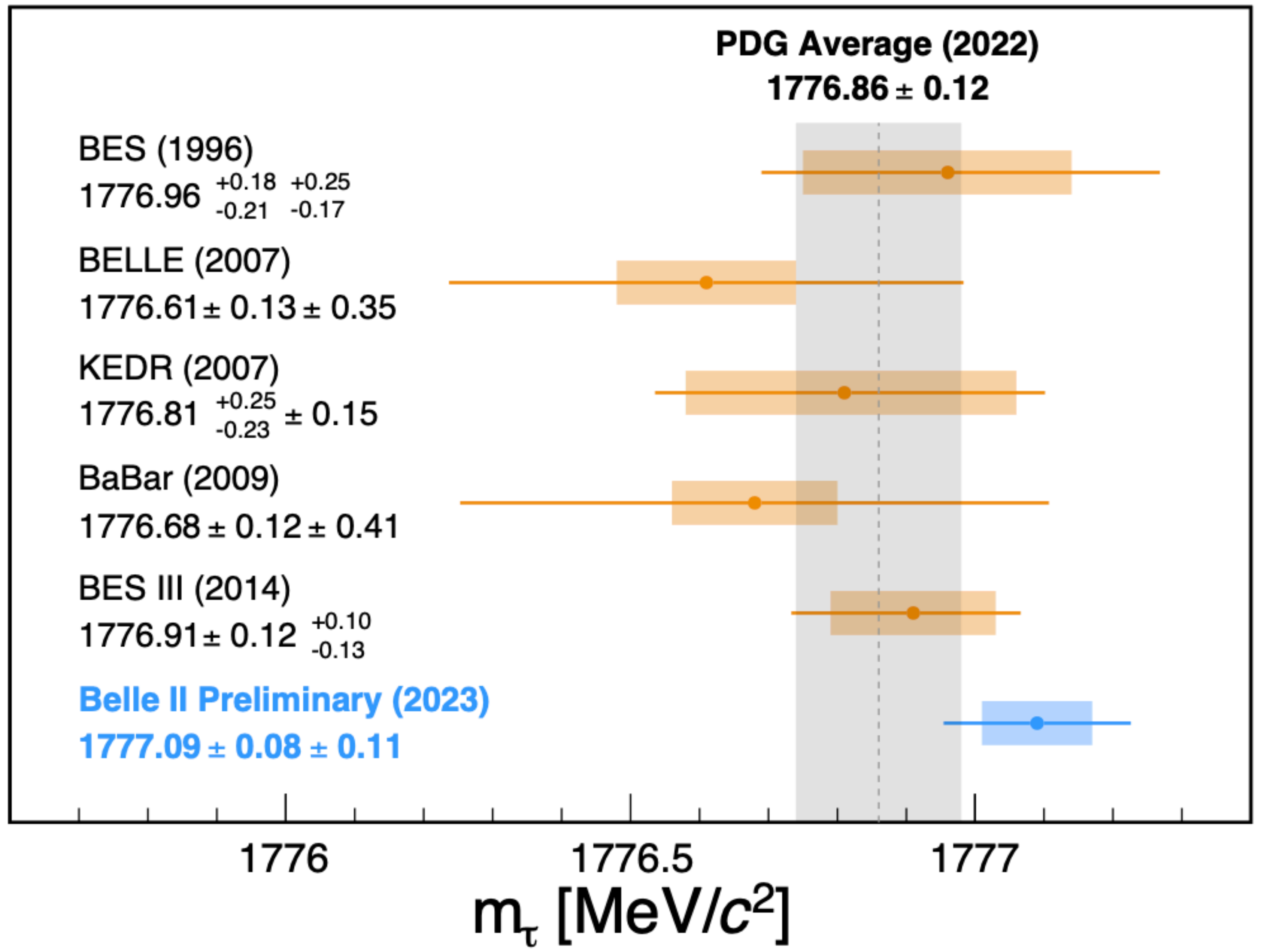
arXiv:2305.19116v1

- High production rate of $e^+e^- \to \tau^+\tau^-$ events allow:
  - High-precision measurements of τ properties (mass, lifetime, …)
  - Search for LFV decays.

Precise measurement of τ mass

- τ mass uncertainty enters in precision test of LFU, predictions of τ branching fractions and α_s measurement at τ-mass scale.
- Analysis performed on $e^+e^- \to \tau^+\tau^-$ events with $\tau^+ \to \pi^+\pi^-\pi^+\nu$ decays.
- $M_{\text{min}} = \sqrt{M_{3\pi}^2 + 2\left(\sqrt{s}/2 - E_{3\pi}^*\right)\left(E_{3\pi}^* - p_{3\pi}^*\right)} \leq m_\tau$
- τ mass is extracted from threshold of this distribution measured using empirical function fit.
- Knowledge of beam energy and its resolution is crucial.





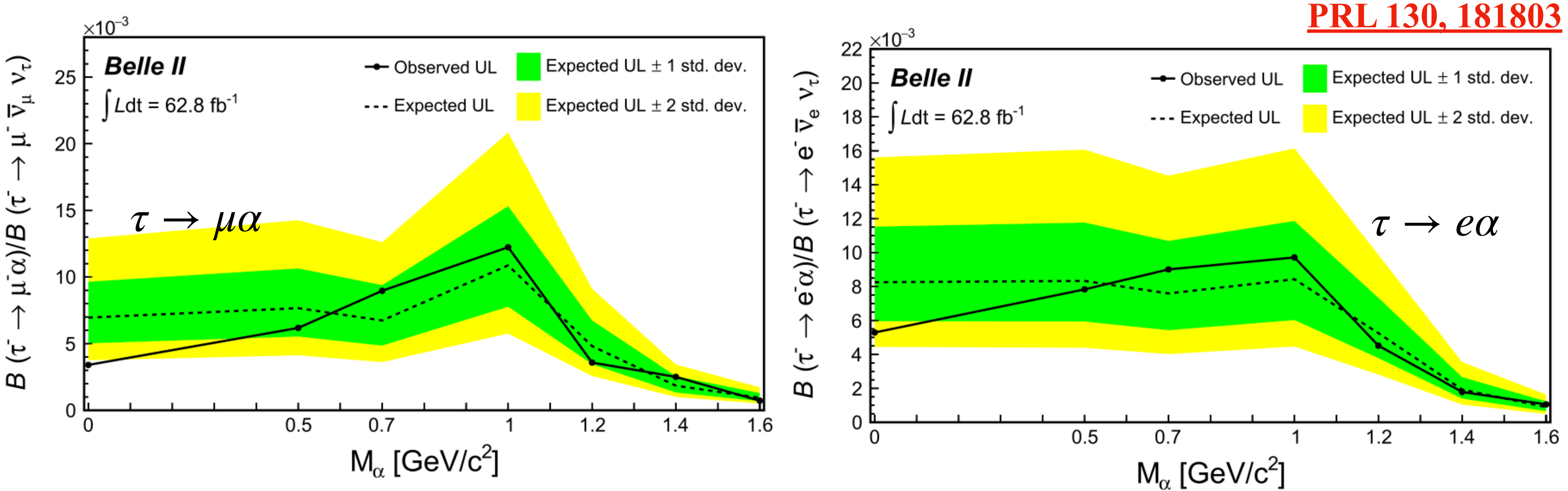
World best τ mass measurement

τ physics

Search for $\tau \to \ell\alpha$ (invisible)

- Search for invisible boson with τ coupling.
- $\tau \to \ell^{\pm}\alpha, \qquad \ell = e, \mu, \qquad \alpha = \text{invisible}$
- No significant excess found.
- Set upper limit at 95% CL on $\dfrac{\mathscr{B}(\tau^- \to \ell^-\alpha)}{\mathscr{B}(\tau^- \to \ell^-\nu\bar{\nu})}$

PRL 130, 181803



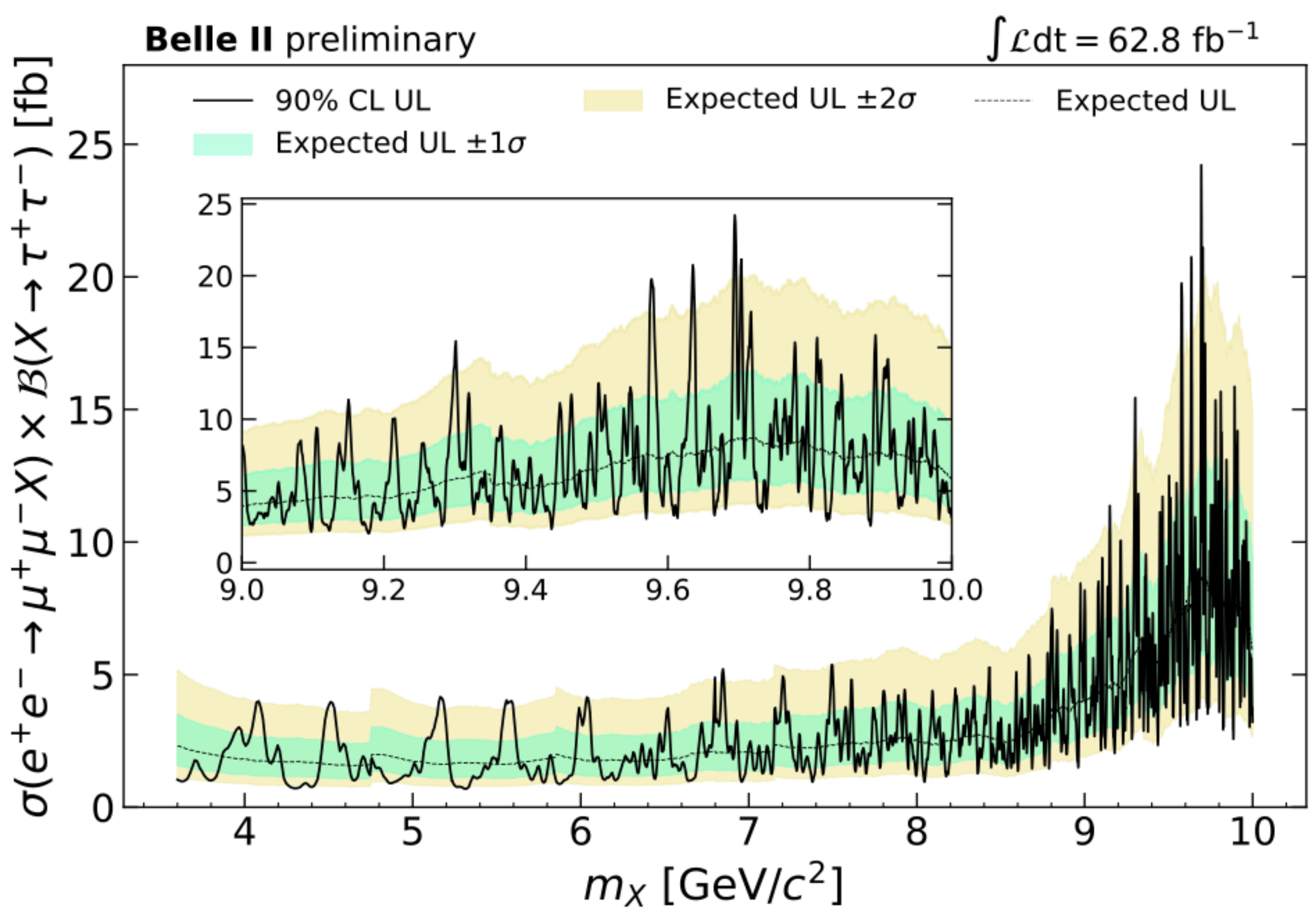
$$\frac{\mathscr{B}(\tau^- \to \mu^-\alpha)}{\mathscr{B}(\tau^- \to \mu^-\nu\bar{\nu})} \in (0.7 - 12.2) \times 10^{-3} \qquad \frac{\mathscr{B}(\tau^- \to e^-\alpha)}{\mathscr{B}(\tau^- \to e^-\nu\bar{\nu})} \in (1.1 - 9.7) \times 10^{-3}$$

$$m_\alpha \in (0 - 1.6)\ \mathrm{GeV/c^2}$$

Search for $\tau\tau$ resonance in $e^+e^- \to \mu^+\mu^-\tau^+\tau^-$

- Selects τ decays via $\tau^- \to \ell^-\nu\nu$ or $\tau^- \to \pi^-\nu n\pi^0$
- Muons used to compute recoil mass that peaks for signal.
- No significant excess found.
- Set upper limit at 90% CL on $\sigma(e^+e^- \to \mu^+\mu^- X) \times \mathscr{B}(X \to \tau^+\tau^-)$

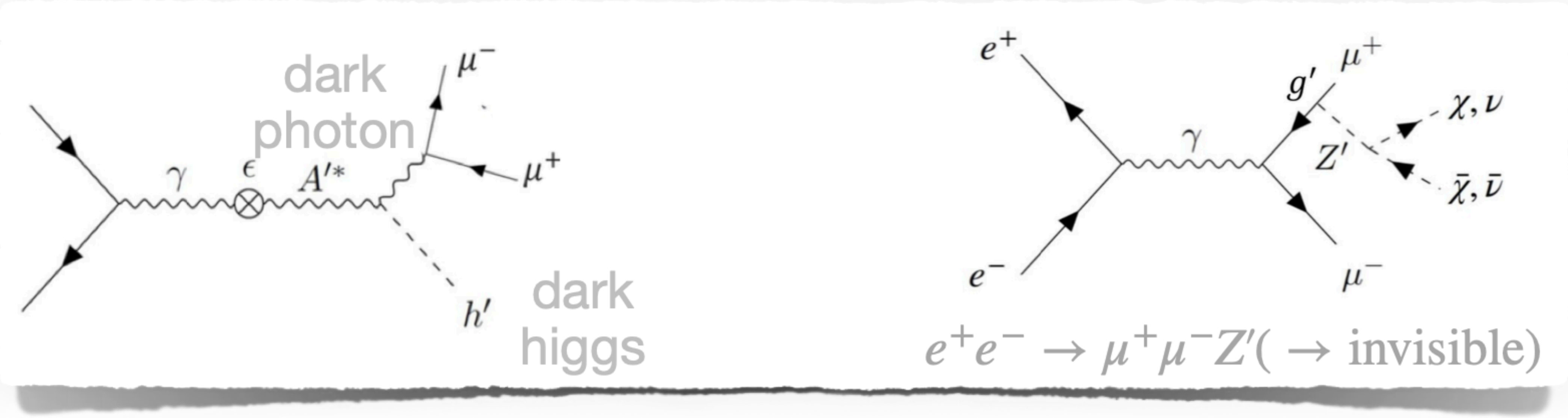
arXiv:2306.12294v1



Most stringent limits in these channels to date

Dark sector

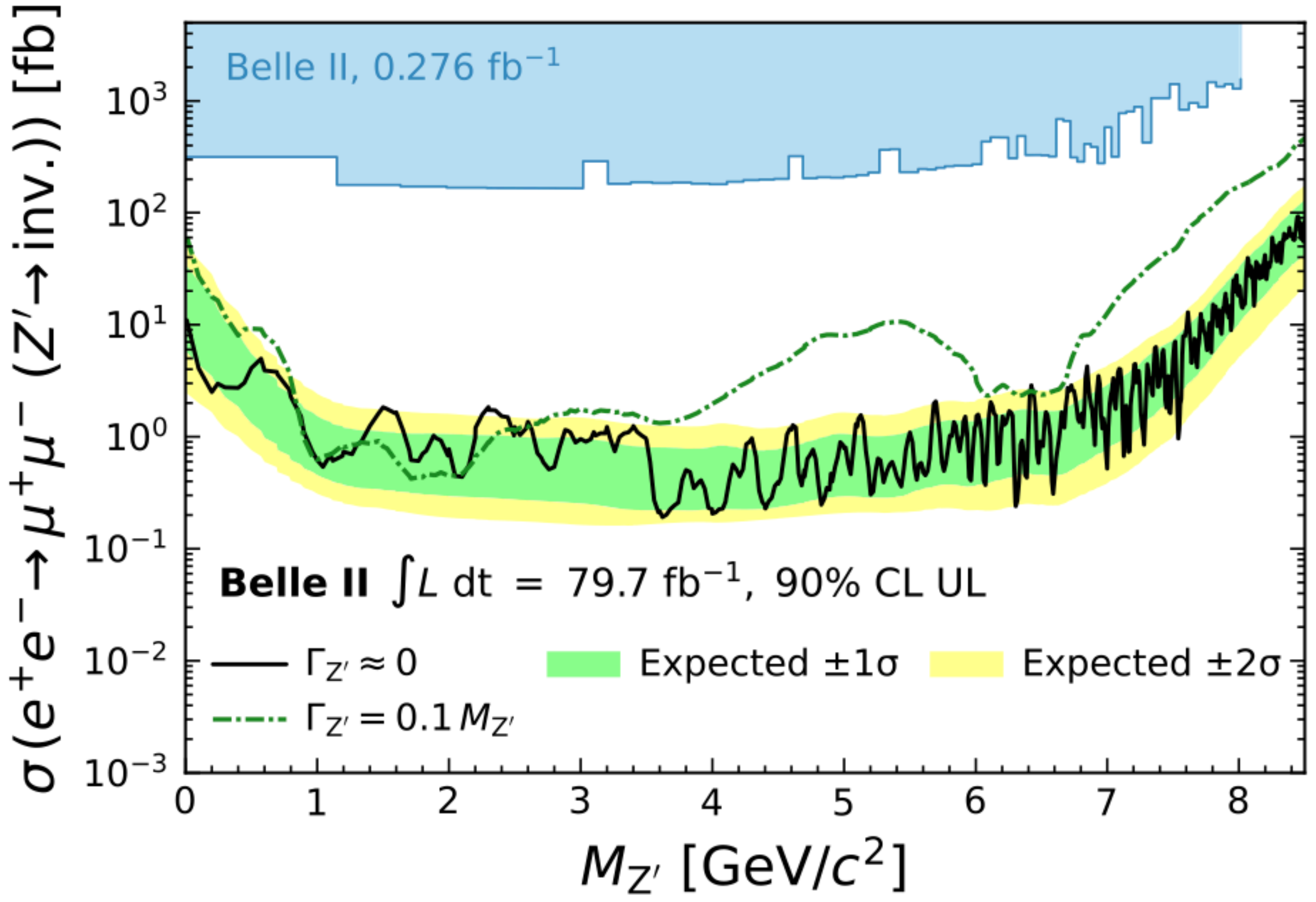
- Dark matter is likely to exist.
- Dark sectors solve expt./pheno. puzzles (e.g. strong CP).
- Belle II enjoys sensitivity in the light part of the spectrum (MeV-GeV masses).
- A main challenges is to suppress the large SM background.
  - Need dedicated low-multiplicity triggers.



Search for $Z' \to$ invisible

- $L_\mu - L_\tau$ gauge boson Z' couples 2nd and 3rd generation leptons.
  - could explain $(g-2)_\mu$ and other flavor anomalies.
- Search performed by $e^+e^- \to \mu^+\mu^-$ + missing energy.
  - Z' searched in the recoil mass of the di-muon system.
  - high-suppression of SM backgrounds.

arXiv:2212.03066

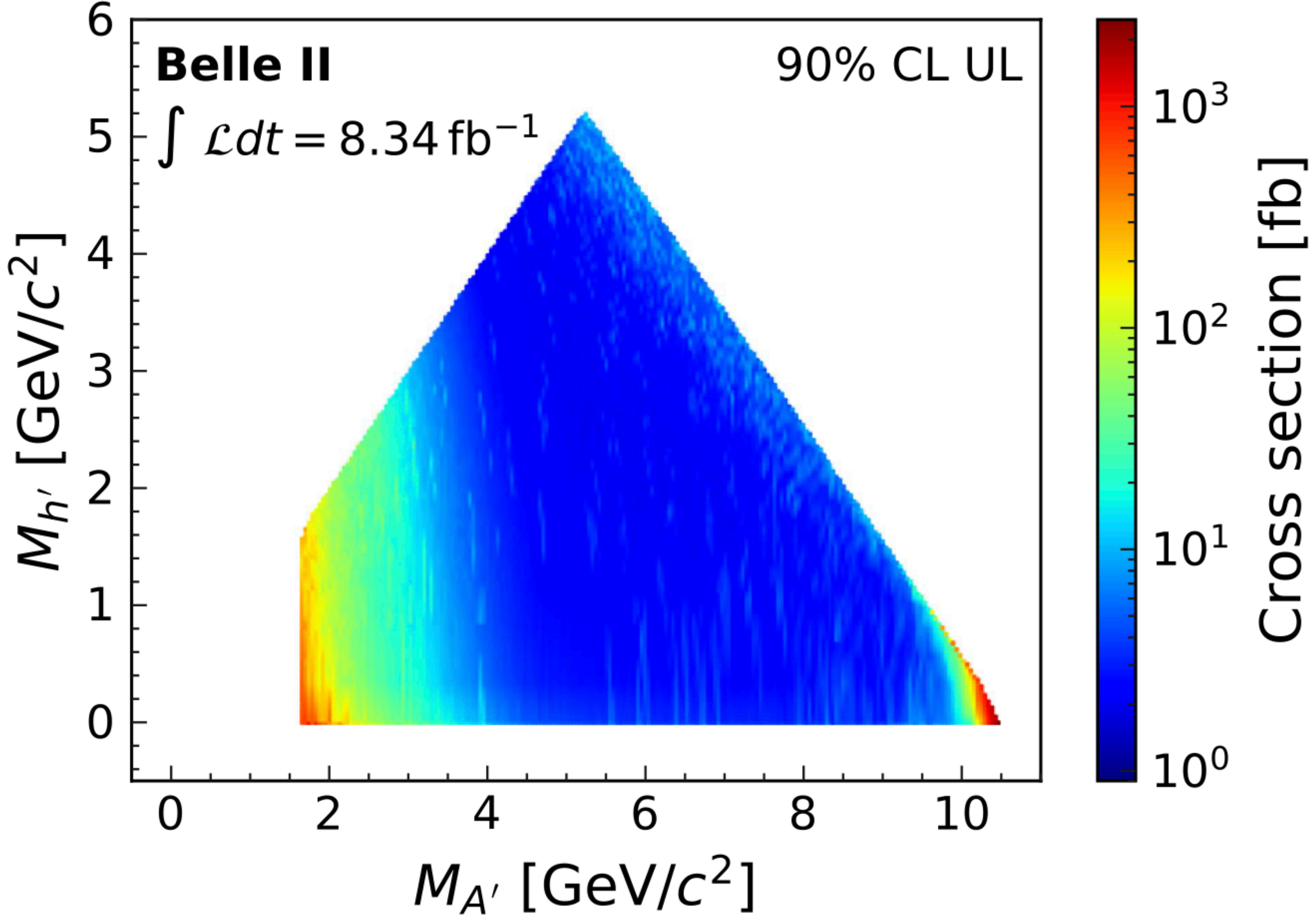


No excess was found and set 90% CL limits
Most stringent limits to date

invisible h' + A'

- Dark sector Higgs h' can give mass to dark photon A' through usual SSB mechanism.
  - No mixing of h' with SM Higgs.

PRL **130, 071804**



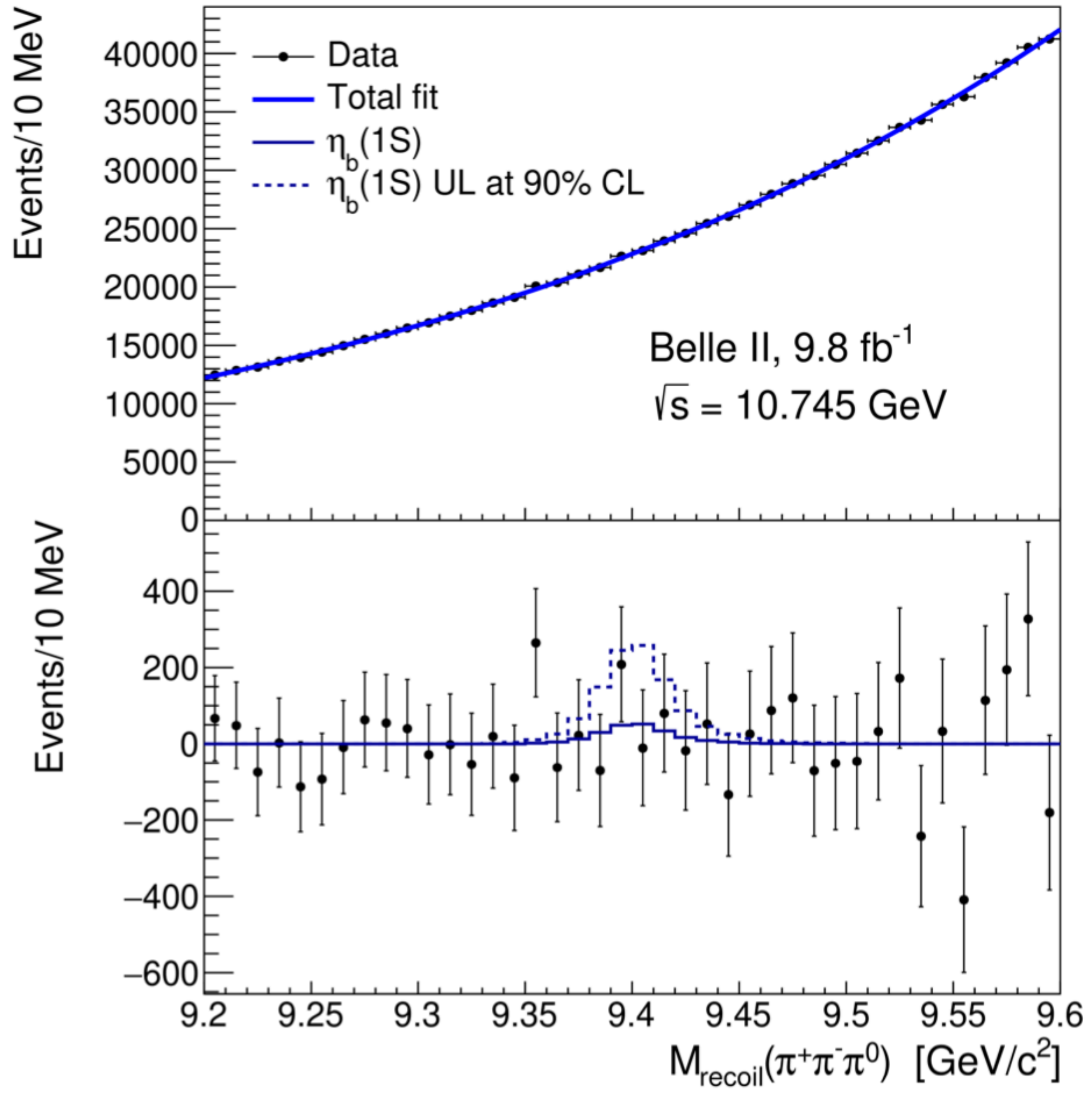
Quarkonium

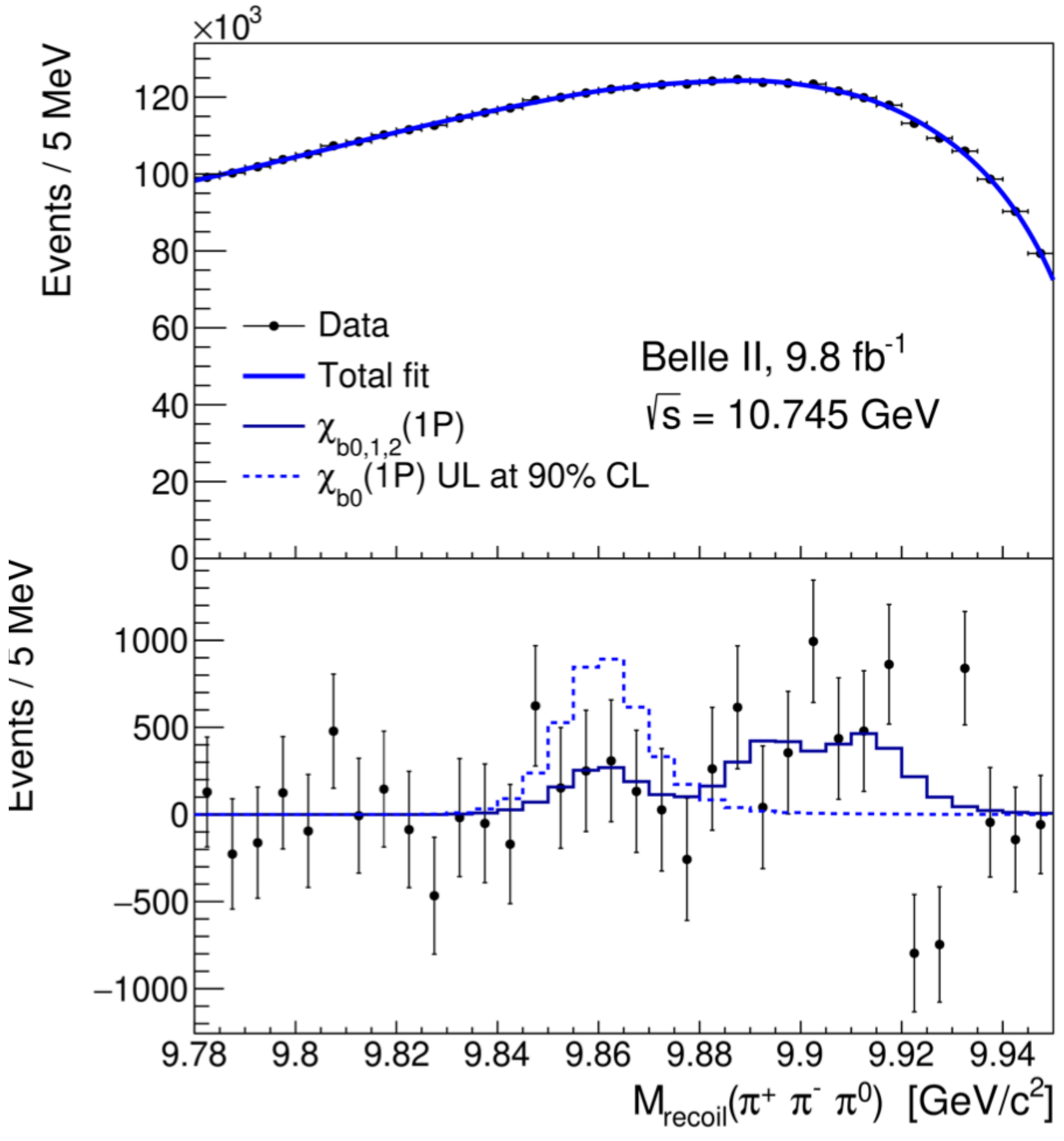
See Sen Jia's talk

- In 2021, collected data at four different E$_{\mathrm{CM}}$ to investigate uncharted regions of $b\bar{b}$ exotic states.
- Expand on earlier studies from Belle.

Search for the $e^+e^- \to \eta_b(1S)\omega$ and $e^+e^- \to \chi_{b0}(1P)\omega$ decays

No significant signals are observed

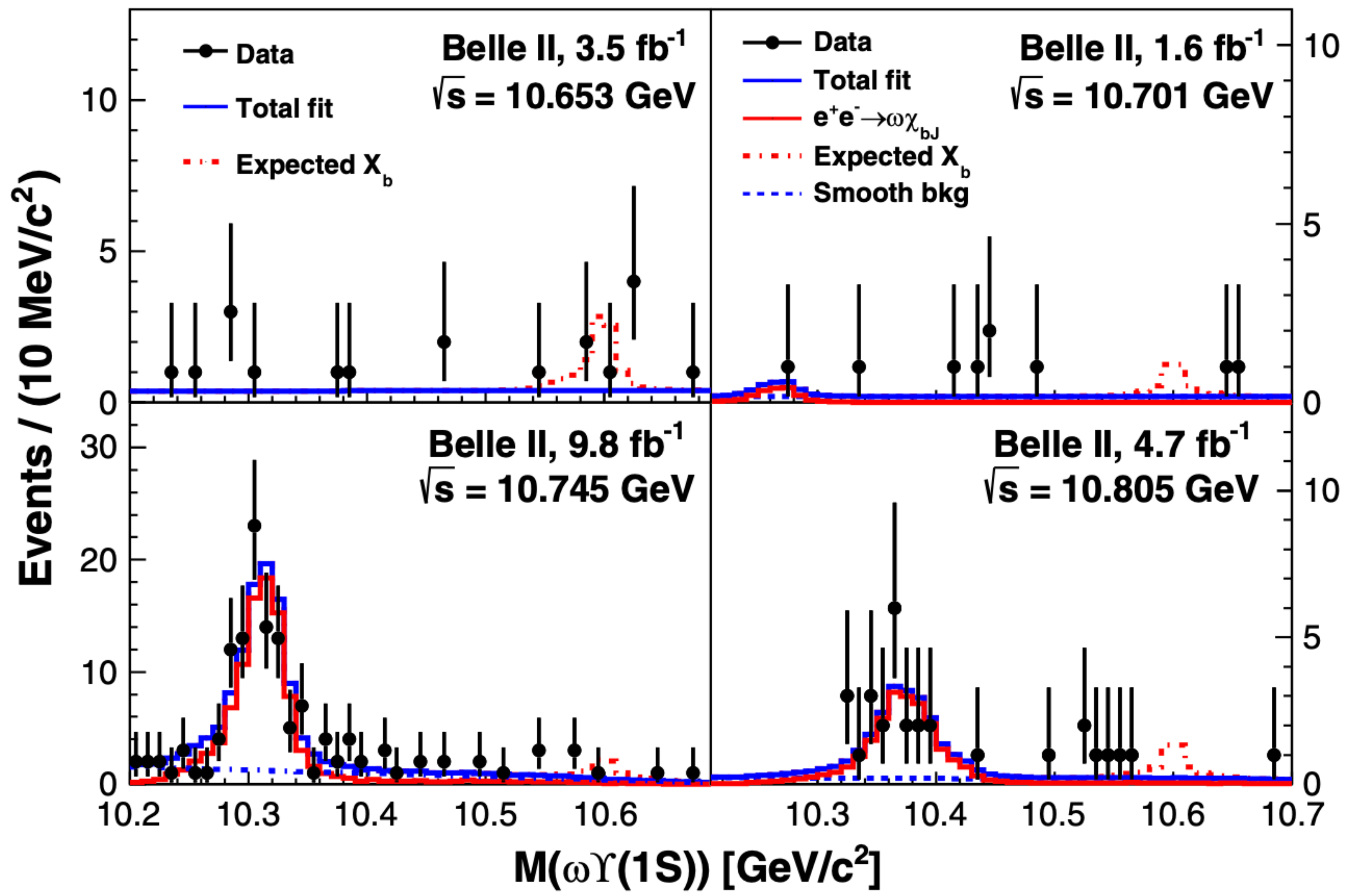




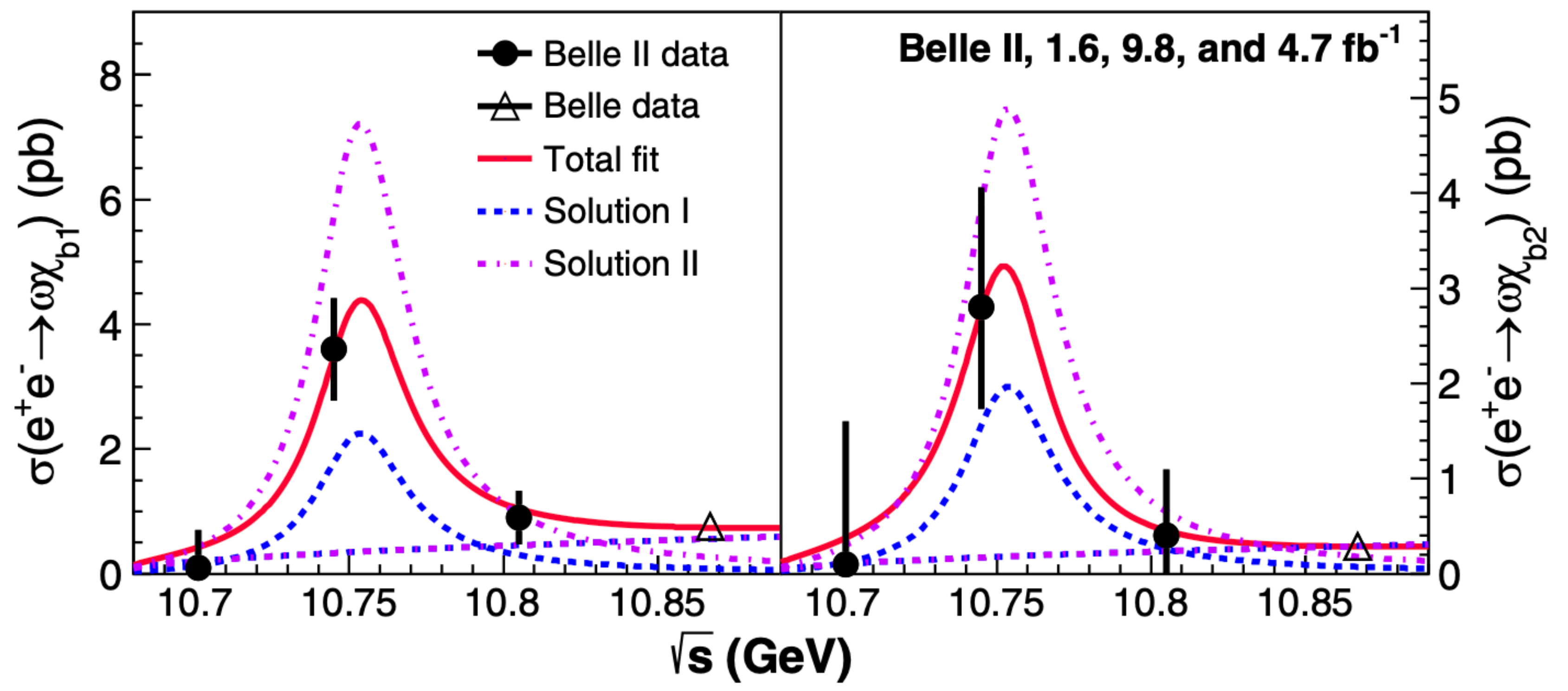
$$\sigma_B[e^+e^- \to \eta_b(1S)\omega] < 2.5 \text{ pb}$$
$$\sigma_B[e^+e^- \to \chi_{b0}(1P)\omega] < 8.6 \text{ pb}$$

Observation of $\Upsilon(10753) \to \omega\chi_{b1,2}(1P)$

PRL130 091902 (2023)



Measurement of cross-section, peaks at Y(10753)



First observation of $\omega\chi_{b1,2}(1P)$ signal at $s = 10.745$ GeV

Summary

- Collected data sample equivalent to that of BABAR or half of Belle.
- Belle II physics program is very broad.
  - B, charm, τ, dark sector, quarkonium ... physics.
- First results confirm the very good detector performance and status of our tools:
  - Precise measurement of τ mass: $m_\tau = 1777.0 \pm 0.08 \pm 0.11\ \mathrm{MeV/c^2}$
  - Most precise charm lifetime measurement till date.
  - Most stringent limits on dark matter searches.
- Ready for the New Physics search!
- Will resume data-taking in early 2024.

Stay tuned for more exciting results!

Backup

Luminosity

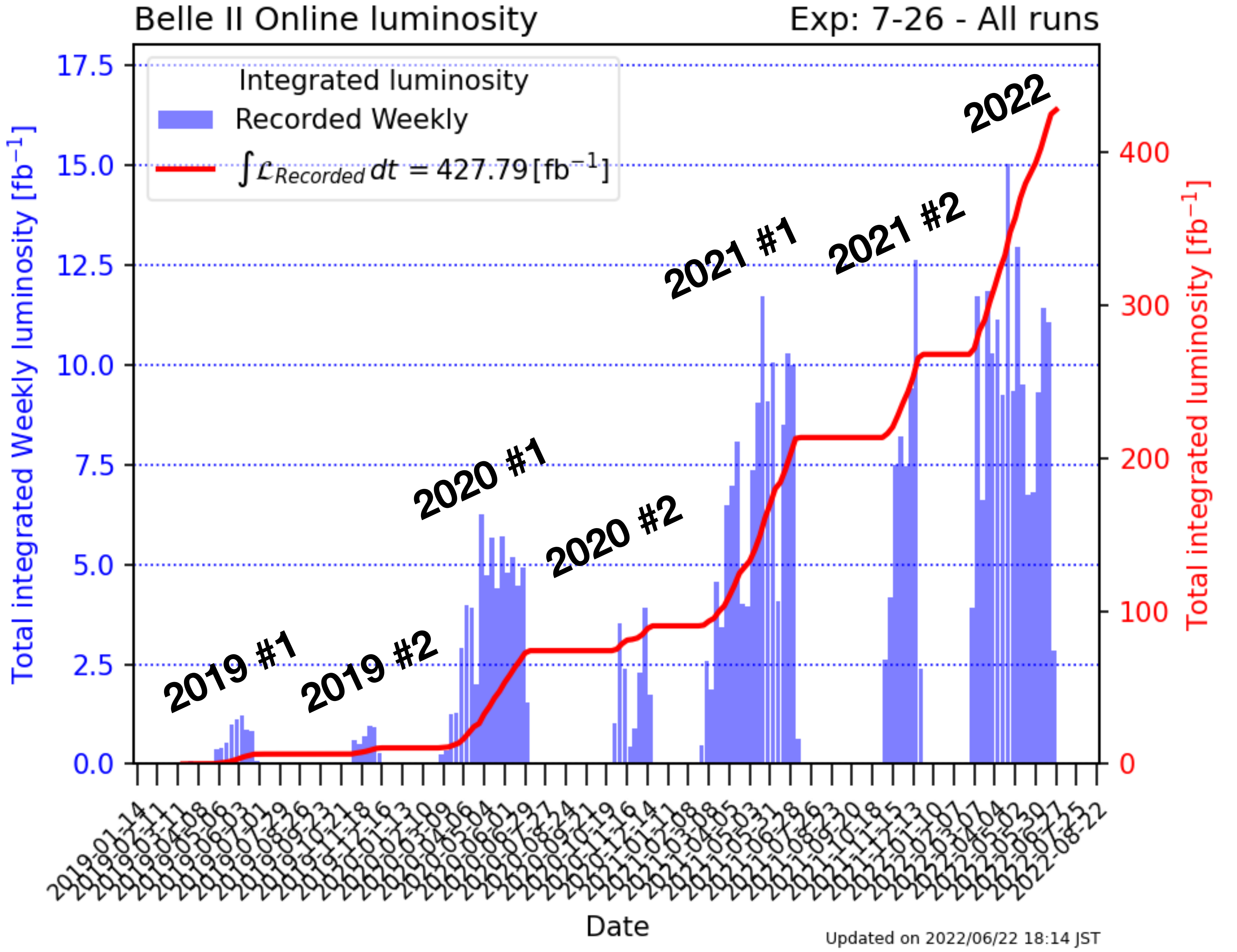
Status

- First data recorded in April 2019.
- **Collected data**
  - ~ 362 fb^{-1} at Υ(4S).
  - 42 fb^{-1} off-resonance, 60 MeV below Υ(4S).
  - 19 fb^{-1} energy scan between 10.6 to 10.8 GeV for exotic hadron studies.
- **Record-breaking instantaneous luminosity:**

  $4.7 \times 10^{34} cm^{-2}s^{-1}$ **(last: LHC** $2.14 \times 10^{34} cm^{-2}s^{-1}$**).**
- Ramping up toward the target luminosity.

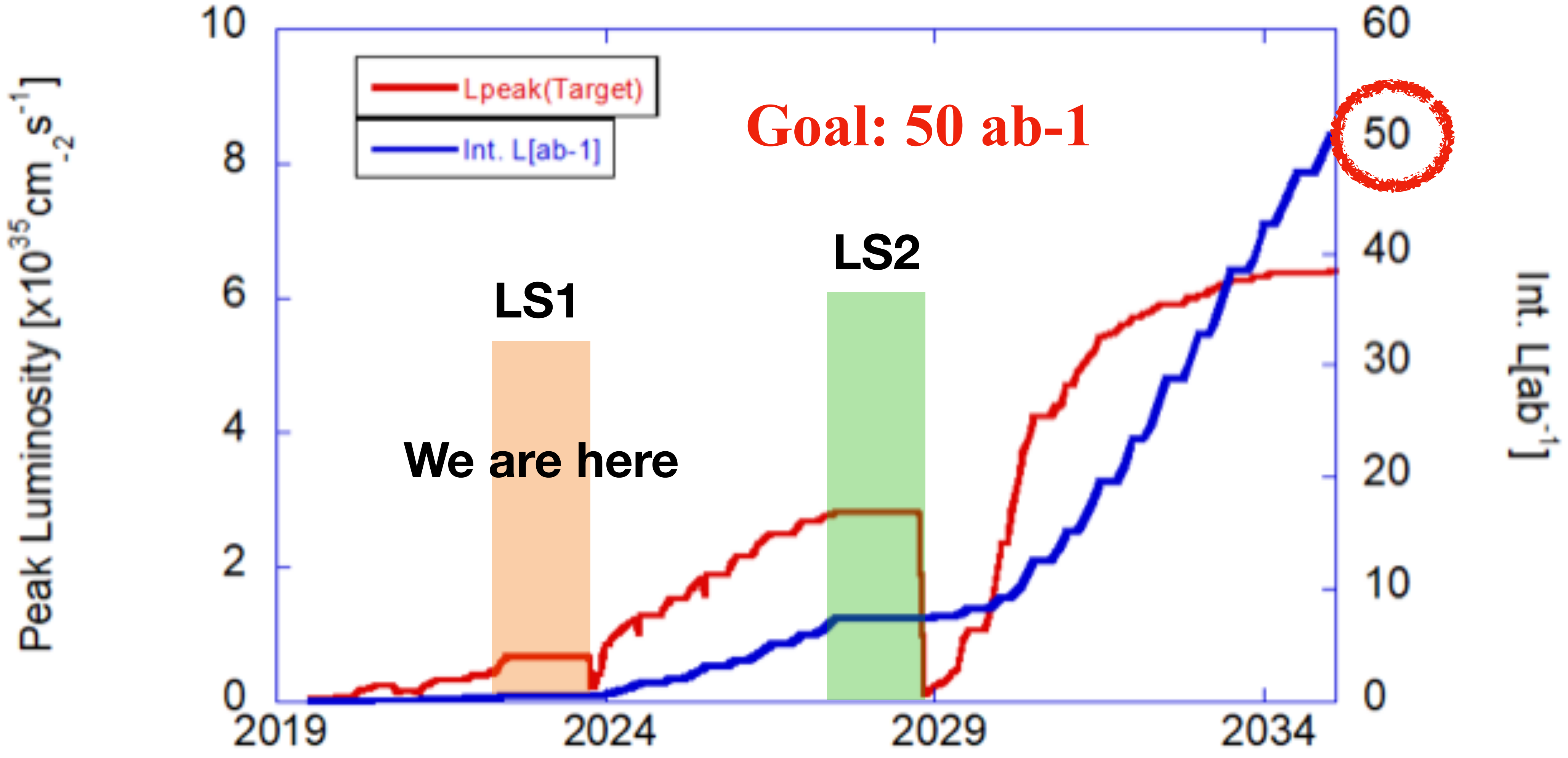
Previous B-factories luminosity

L (fb^{-1})	Belle	BaBar	Total
Υ(5S)	121	-	121
Υ(4S)	711	433	1144
Υ(3S)	3	30	33
Υ(2S)	25	14	39
Υ(1S)	6	-	6
Off-reso	100	54	154



... and roadmap to 50ab^{-1}

- Long Shutdown 1 (LS1).
  - ongoing, ends in late 2023.
  - maintenance/upgrade of machine & sub-detectors.
- Long Shutdown 2 (LS2).
  - to be confirmed (2026 - 2027).
  - upgrade of the SuperKEKB Interaction Region.



$|V_{ub}|$: exclusive

Untagged $B^0 \to \pi^- \ell \nu$ arXiv:2210.04224

- Large background suppressed using BDTs.

$$\Delta E = E_{\mathrm{B}} - E_{\mathrm{beam}}, \qquad M_{\mathrm{bc}} = \sqrt{E_{\mathrm{beam}}^2 - |\vec{p}_{\mathrm{B}}|^2}$$

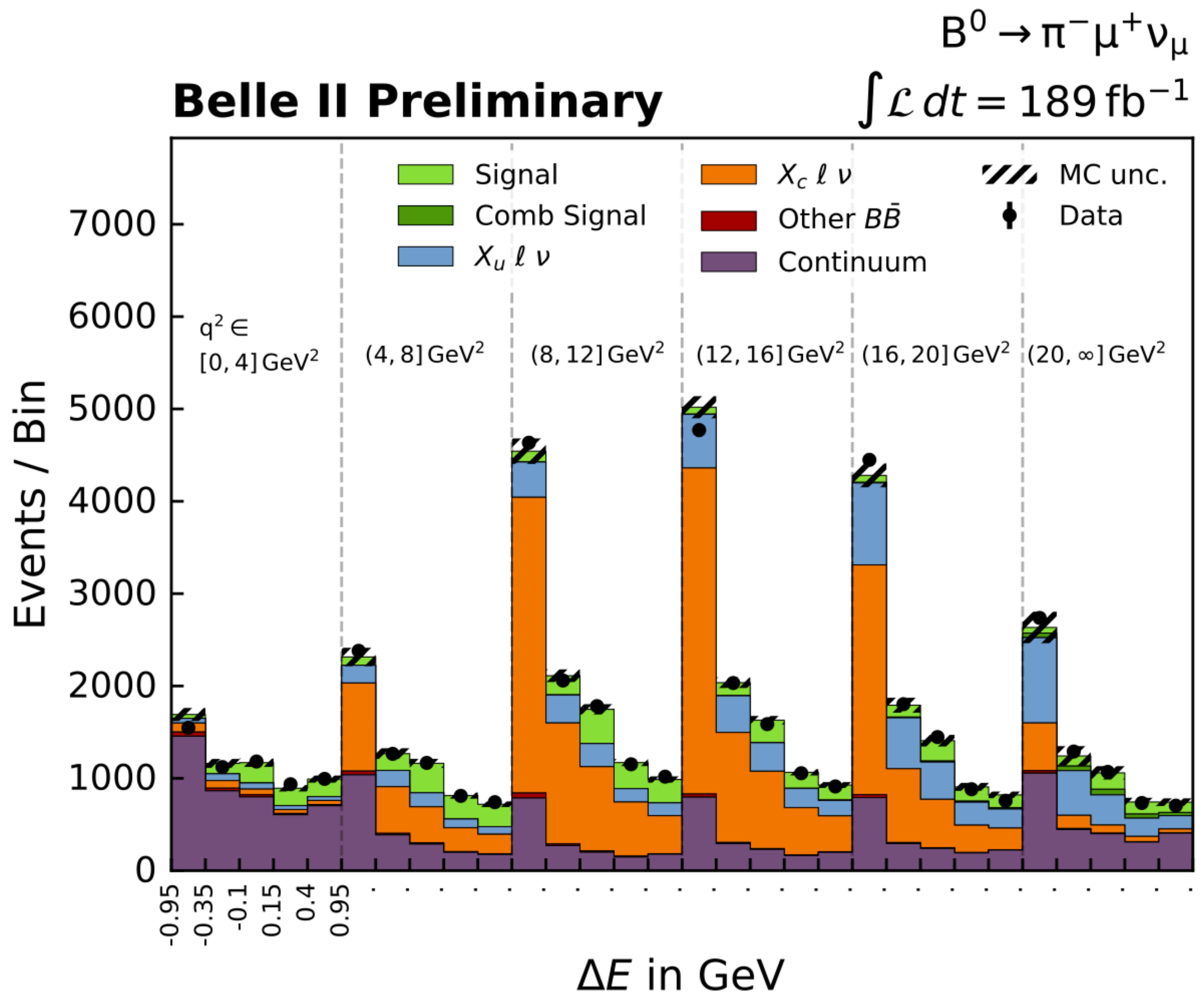
- Binned fit of ΔE and M_{bc} in six q^2 bins.

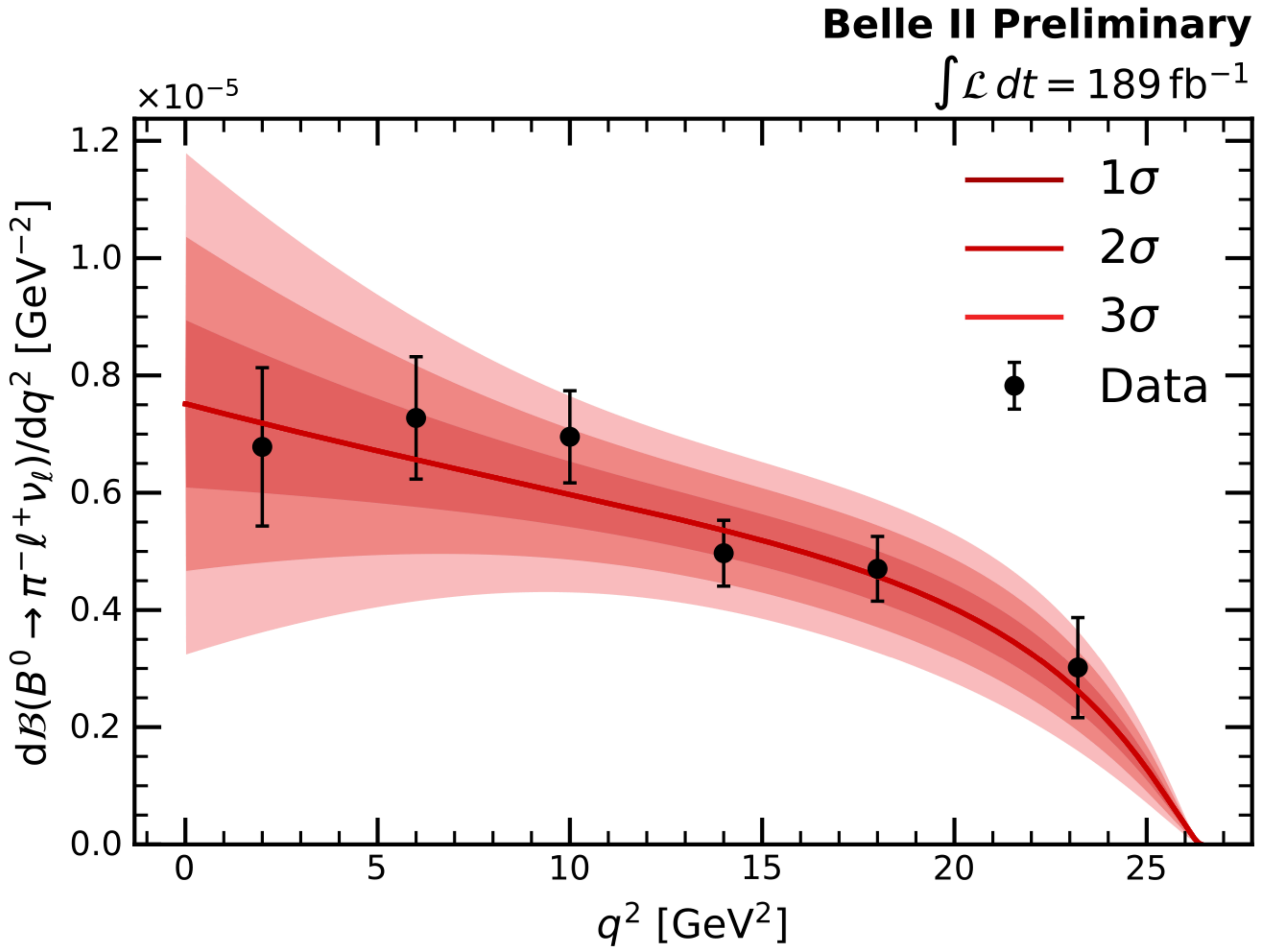
Tagged $B \to \pi e \nu$ arXiv:2206.08102

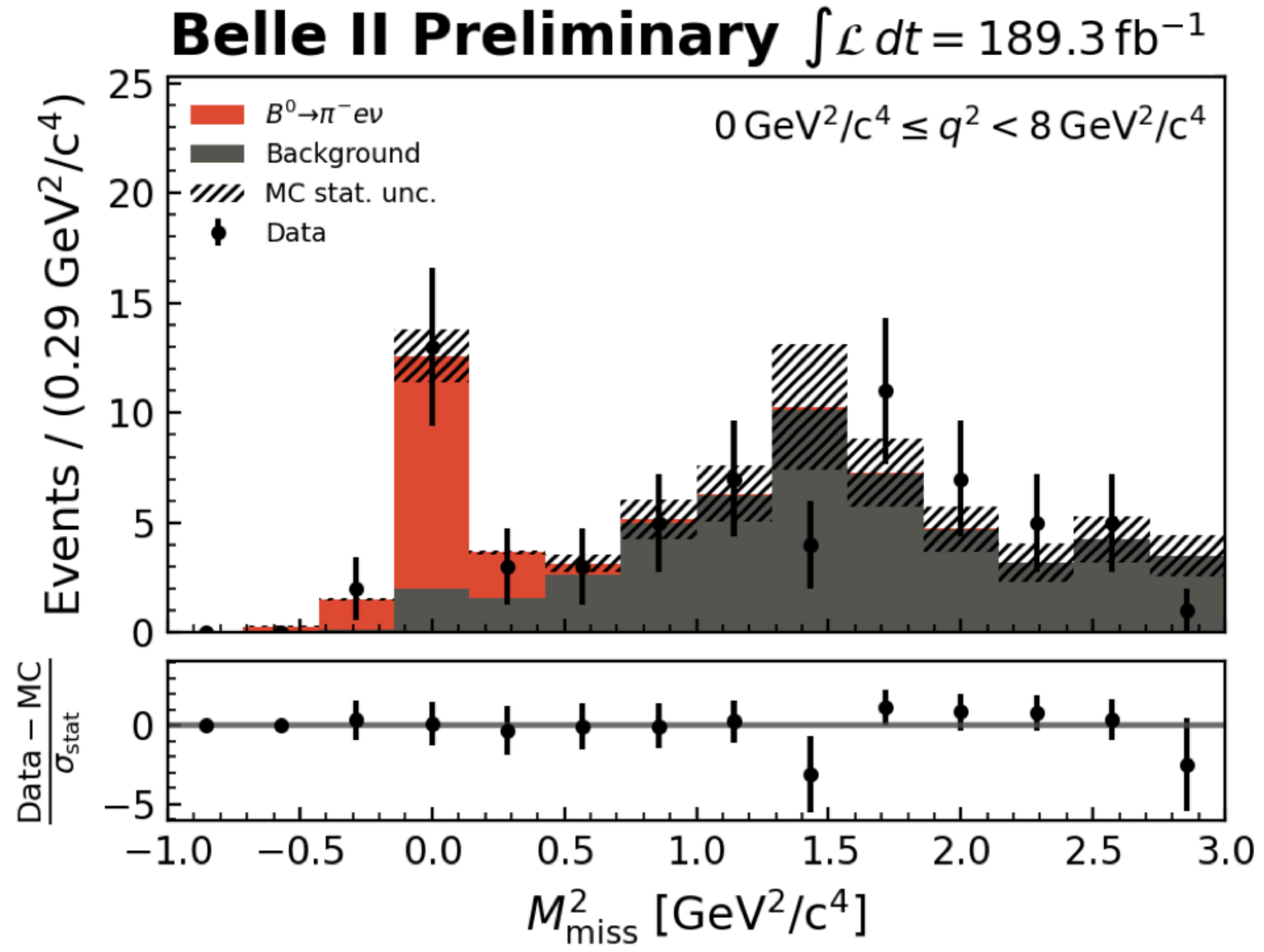
$$M_{\mathrm{miss}}^2 = p_{e^+e^-} - p_{B_{\mathrm{tag}}} - p_\pi - p_e$$

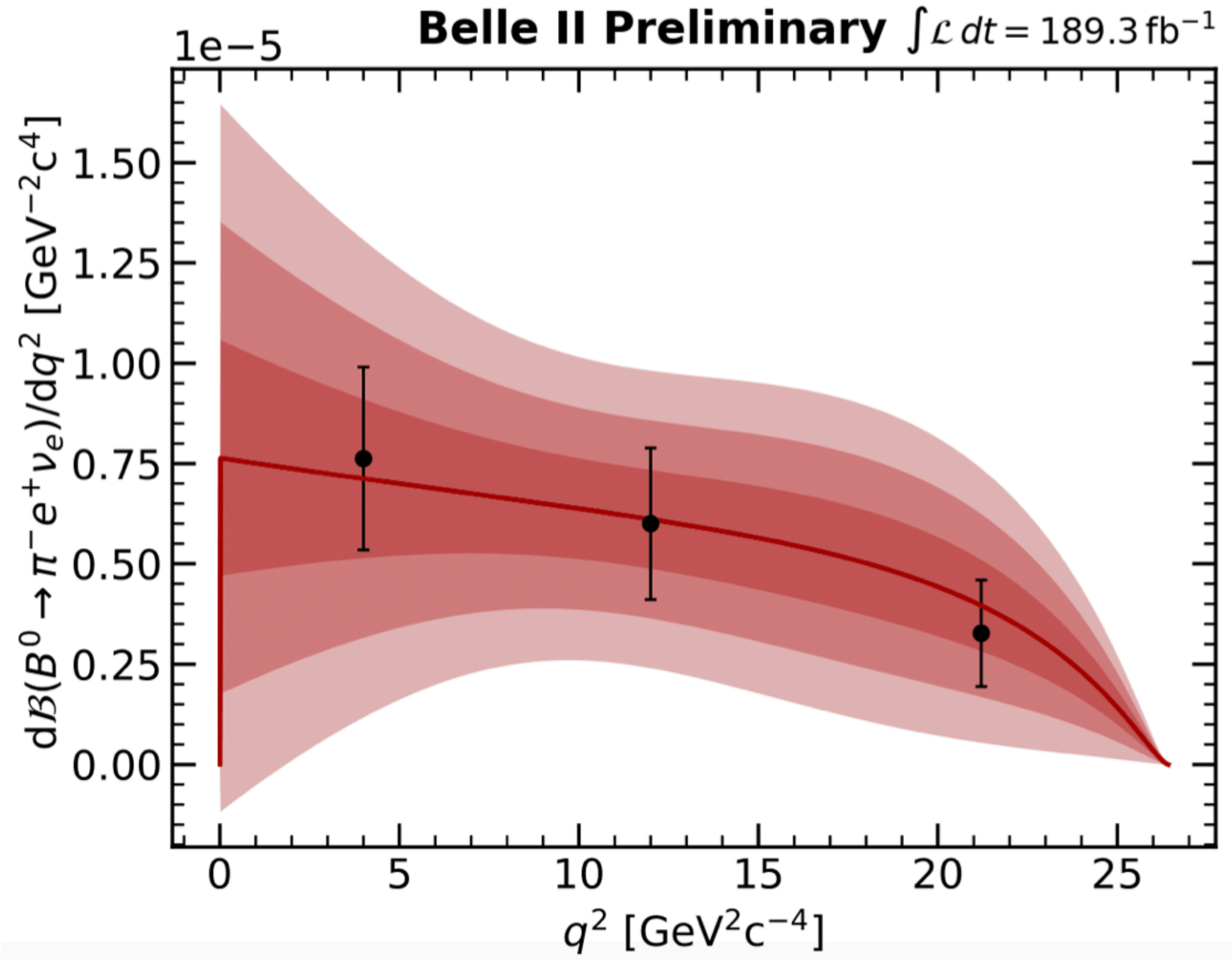
- Binned fit of M_{miss}^2 in three q^2 bins.

- Combined fit to BCL expansion and form factor LQCD constraints.









$$|V_{ub}| = (3.55 \pm 0.12 \pm 0.13 \pm 0.17) \times 10^{-3}$$

$$|V_{ub}| = (3.88 \pm 0.45) \times 10^{-3}$$

$|V_{cb}|$: exclusive

Untagged $B \to D\ell\nu$

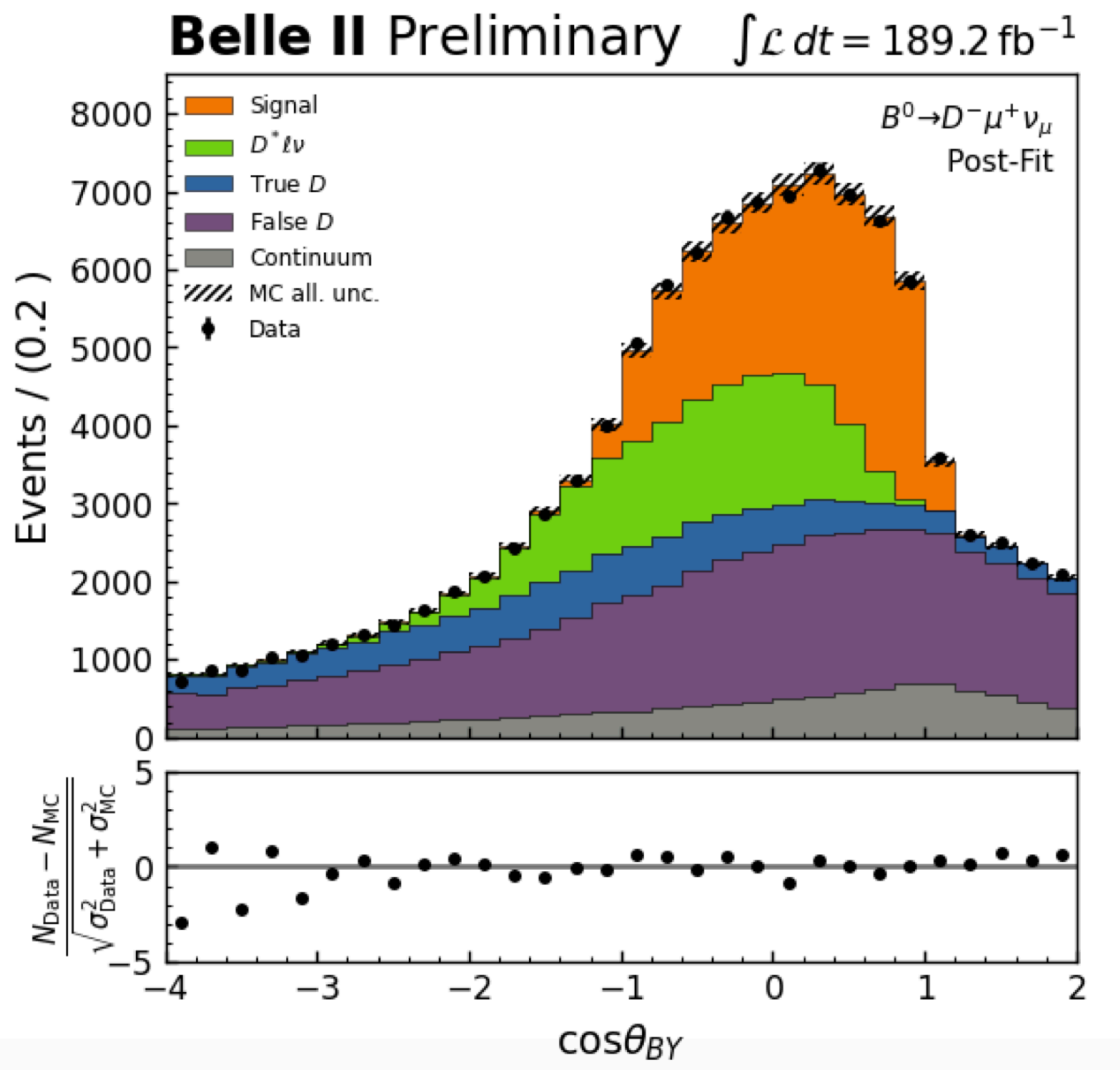
arXiv:2210.13143

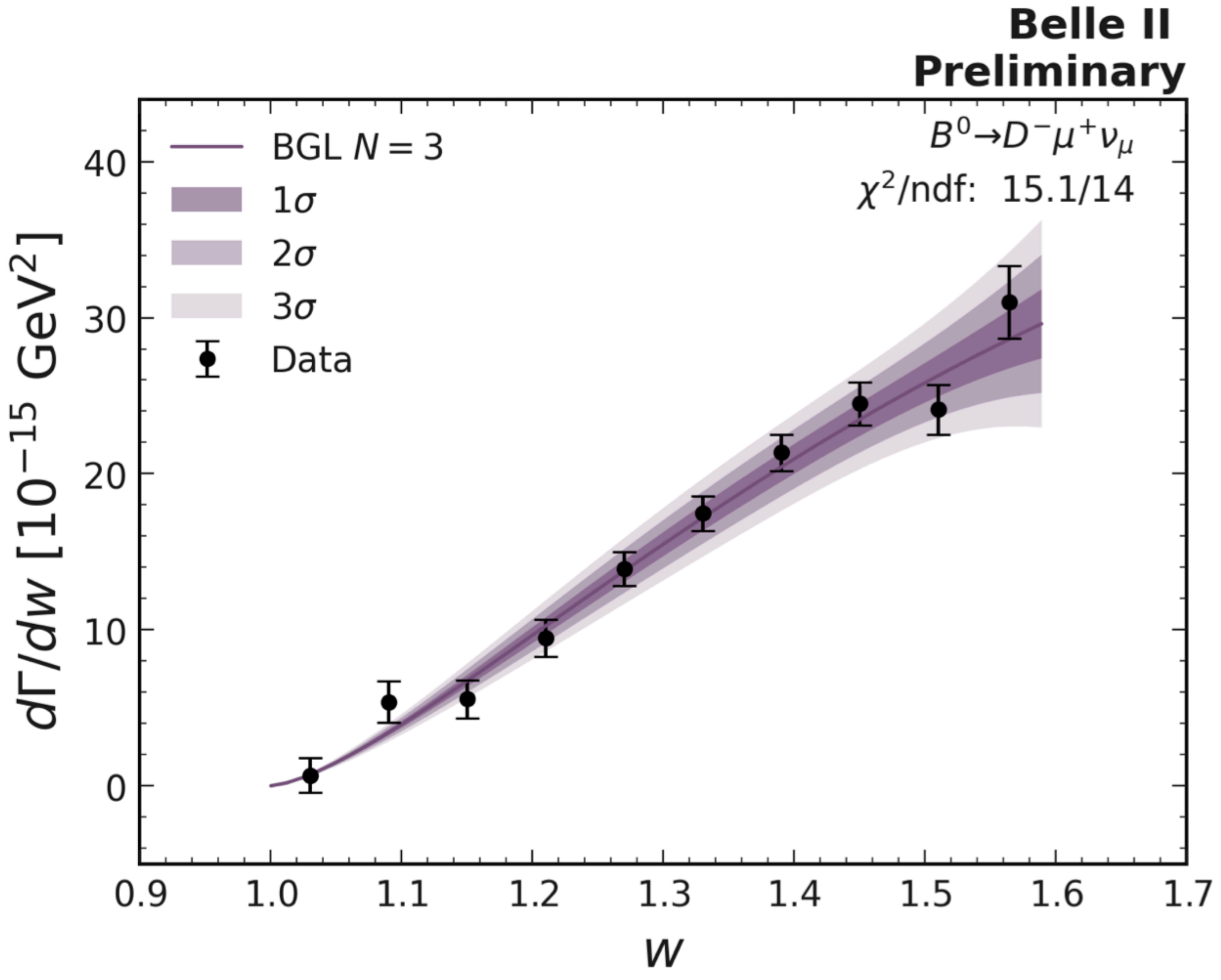
- Large background from $B \to D^*\ell\nu$
- $cos\theta_{\mathrm{BY}} = \dfrac{2E_BE_Y - m_B^2 - m_Y^2}{2p_Bp_Y}, Y = D\ell$
- Binned fit of $cos\theta_{\mathrm{BY}}$ in ten w bins.
- Combined fit to BGL expansion and form factor LQCD constraints.

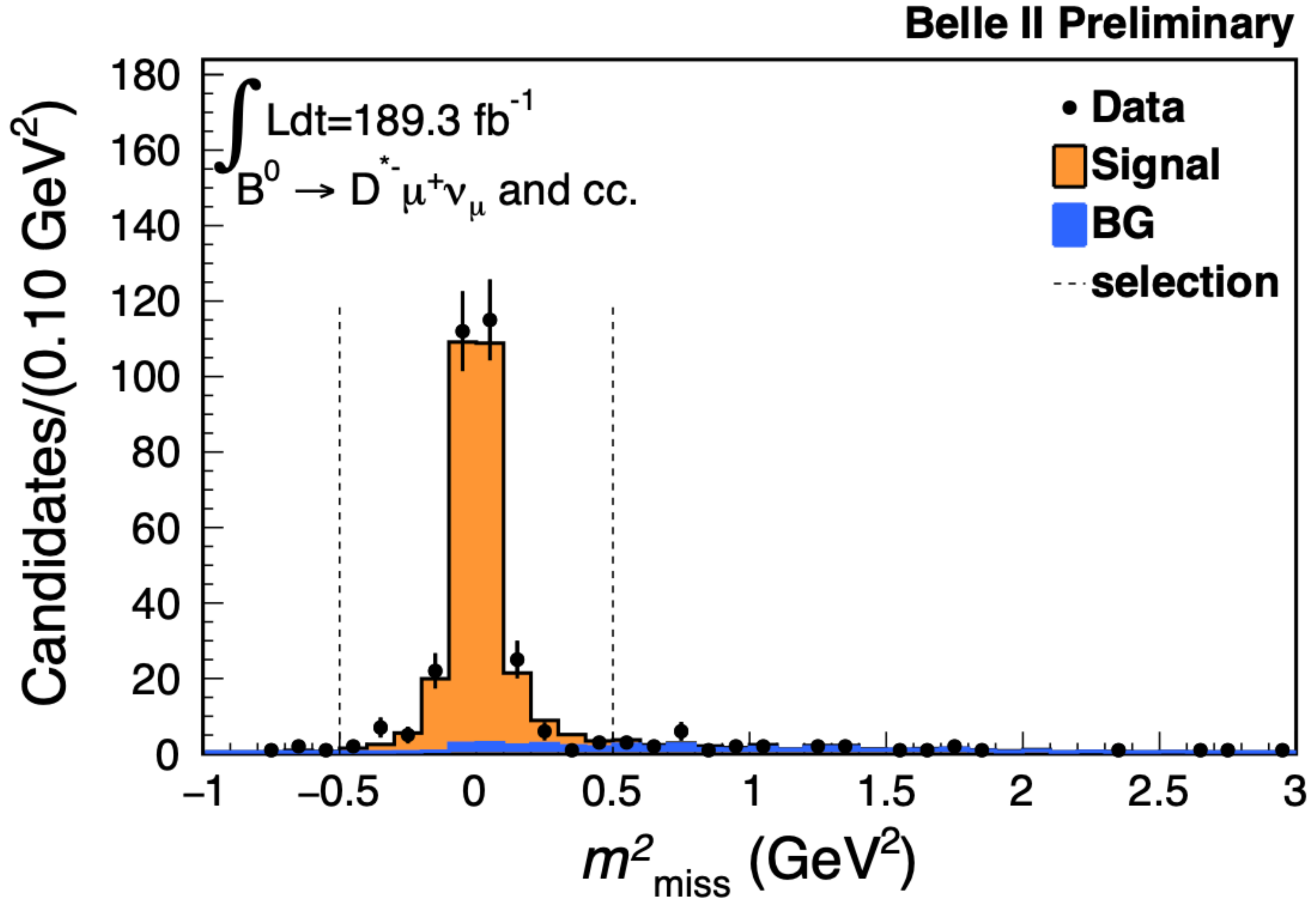
Tagged $B \to D^*\ell\nu$

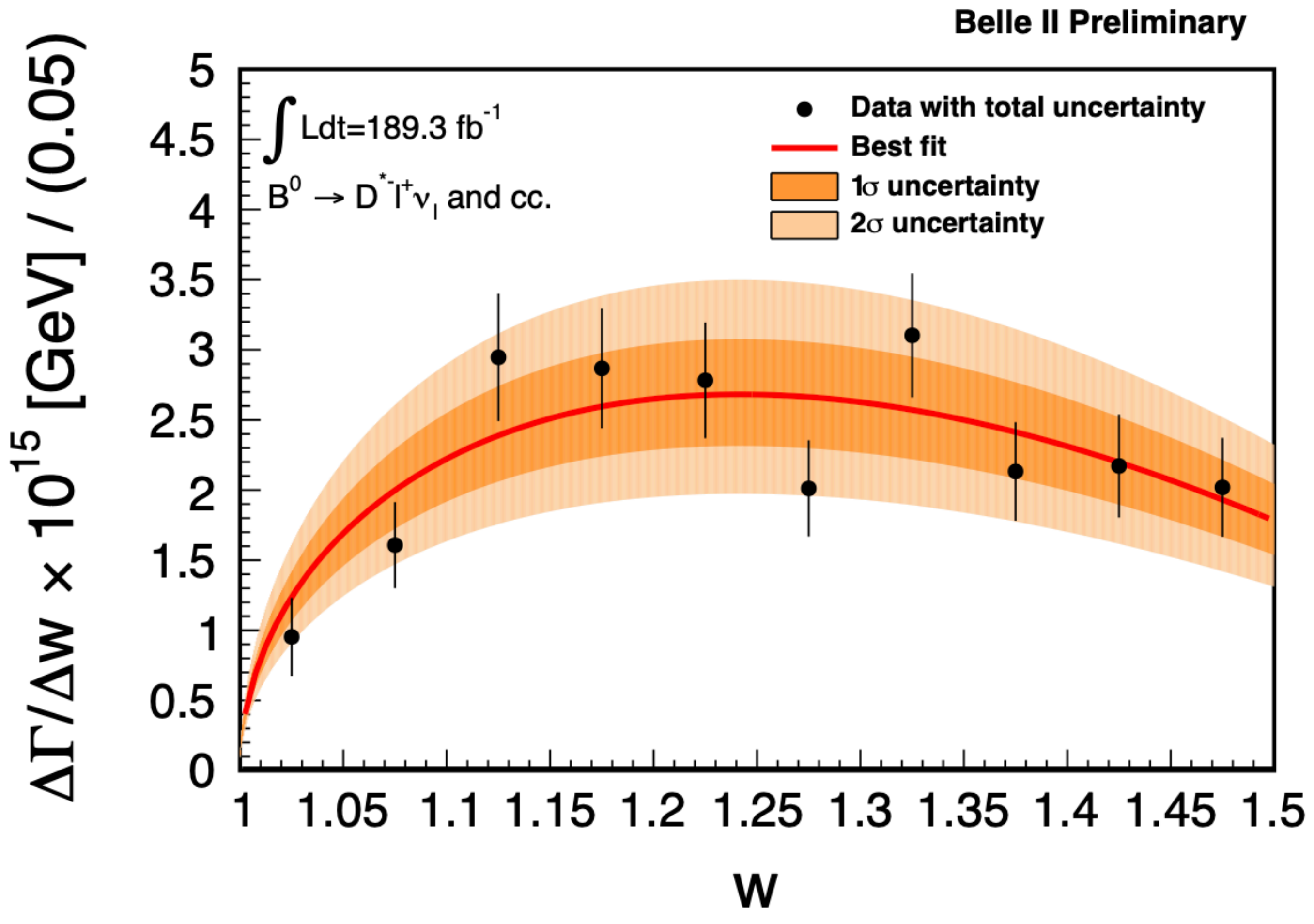
arXiv:2301.04716

- Binned fit of M^2_{miss} in ten w bins.
- Fit CLN parameterized form factor to differential decay rates.









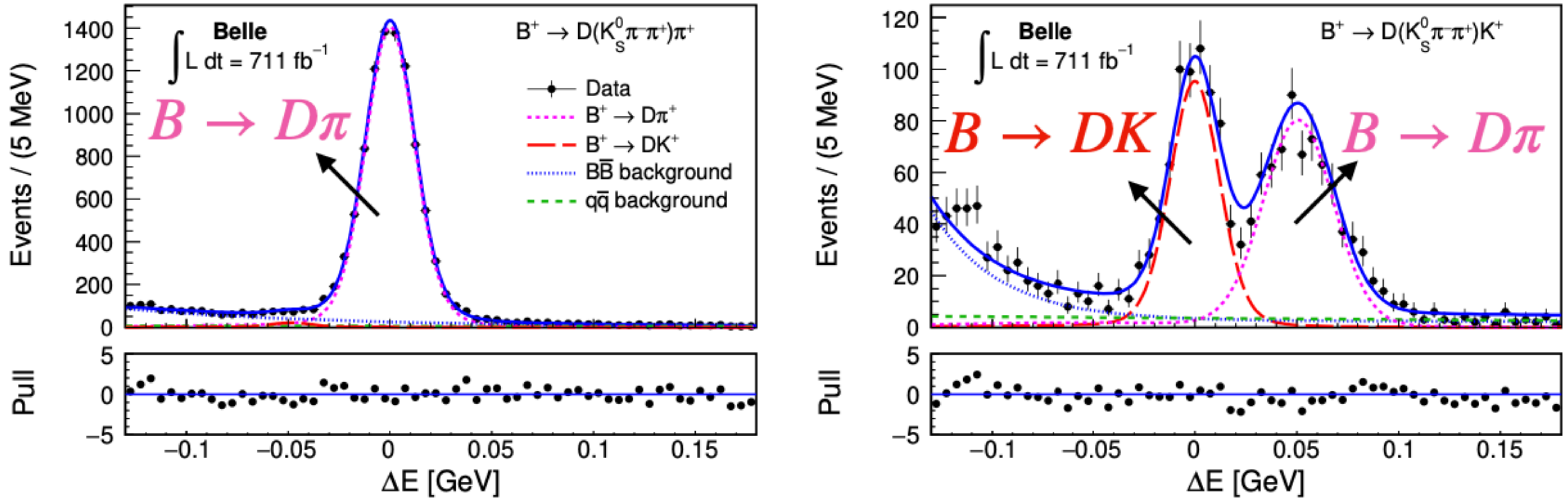
$$|V_{cb}| = (38.3 \pm 1.2_{\mathrm{tot}}) \times 10^{-3}$$

$$|V_{cb}| = (37.9 \pm 2.7_{\mathrm{tot}}) \times 10^{-3}$$

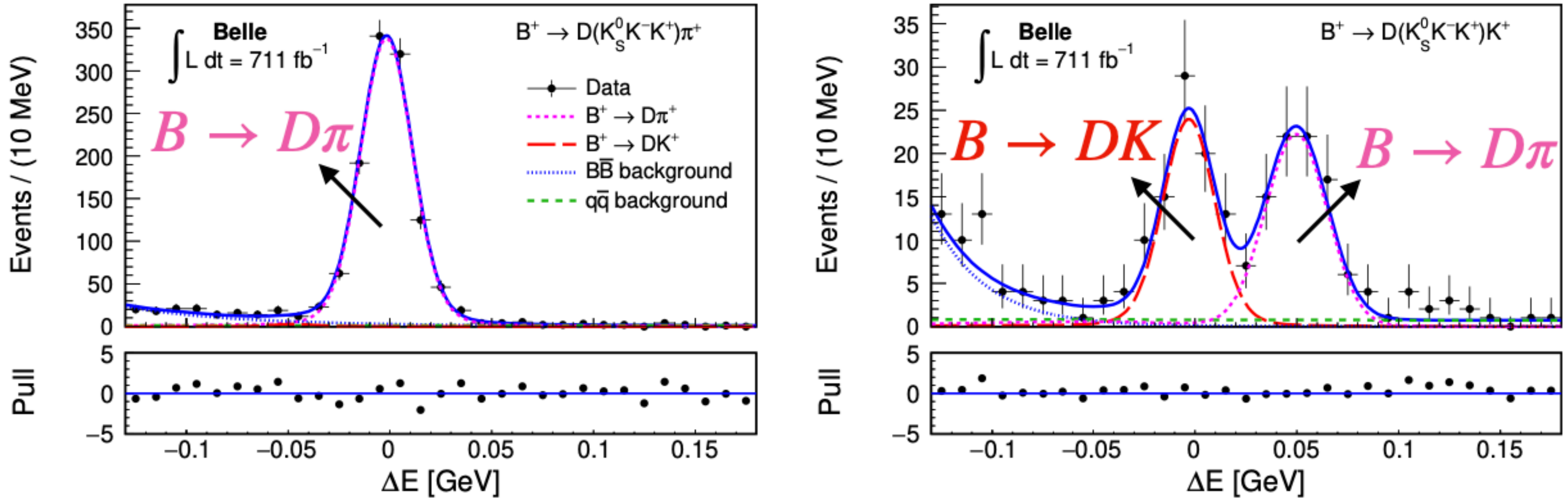
ϕ_3 (γ)

- $B^+ \to D^0(K_S h^+ h^-) h^+$ **BPGGSZ method**
- Fit plots of Belle data

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



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



Belle II prospect:

- $\delta\phi_3\ (50\ \mathrm{ab}^{-1}) = 3^\circ$ using GGSZ method