Flavour Physics in Belle II

65th ICFA Advanced Beam Dynamics Workshop on High Luminosity Circular e+e- Colliders - Frascati, 13.09.2022

Francesco Tenchini
on behalf of the Belle II collaboration

The Flavour Frontier

- The Standard Model has been tremendously successful at describing phenomena recorded at collider experiments.
- However there are several that the SM does not explain, such as:
  - The larger than expected matter-antimatter asymmetry;
  - Neutrino masses;
  - The hierarchy of CKM matrix elements and fermion masses;
  - ...and more.
- Tensions and anomalies e.g. in Lepton Flavour Universality point at the SM being an incomplete picture.

What can an e+e- collider contribute?

- High luminosity colliders can provide unique insight in these problems by providing a clean environment with closed event kinematics.
- Several interesting channels are unique to B-factories:
  - Channels rich in neutral particles (π^0, KL, η...) or neutrinos.
  - Modes with hard-to-suppress backgrounds where full knowledge of kinematics is required.
- Independent confirmation of physics results e.g. from LHCb.
  - Especially important in case of future discovery claims.

Talk Outline

- SuperKEKB and Belle II
- Dataset and Timeline

- Charm lifetimes
- CKM: Vub/Vcb puzzle
- Unitarity triangle
- First tests of LFUV
- Tau physics and LFV in tau.

→ Mainly new results from ICHEP + projections for the future.

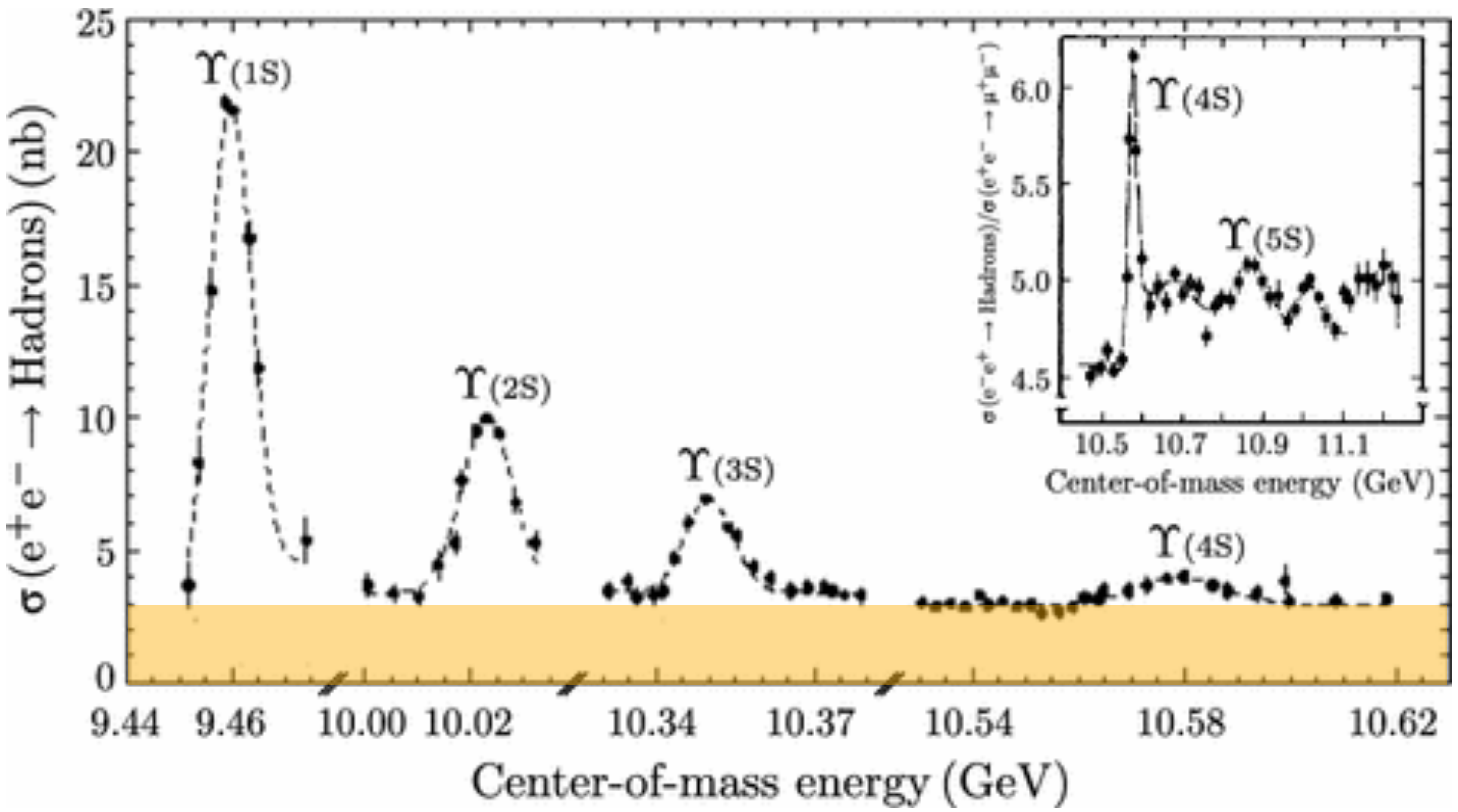
The Setup for a B-Factory

- Collide e^+e^- at center of mass energy slightly above **~2x B-meson mass**:

$$\sqrt{s} = 10.58 \text{ GeV}$$

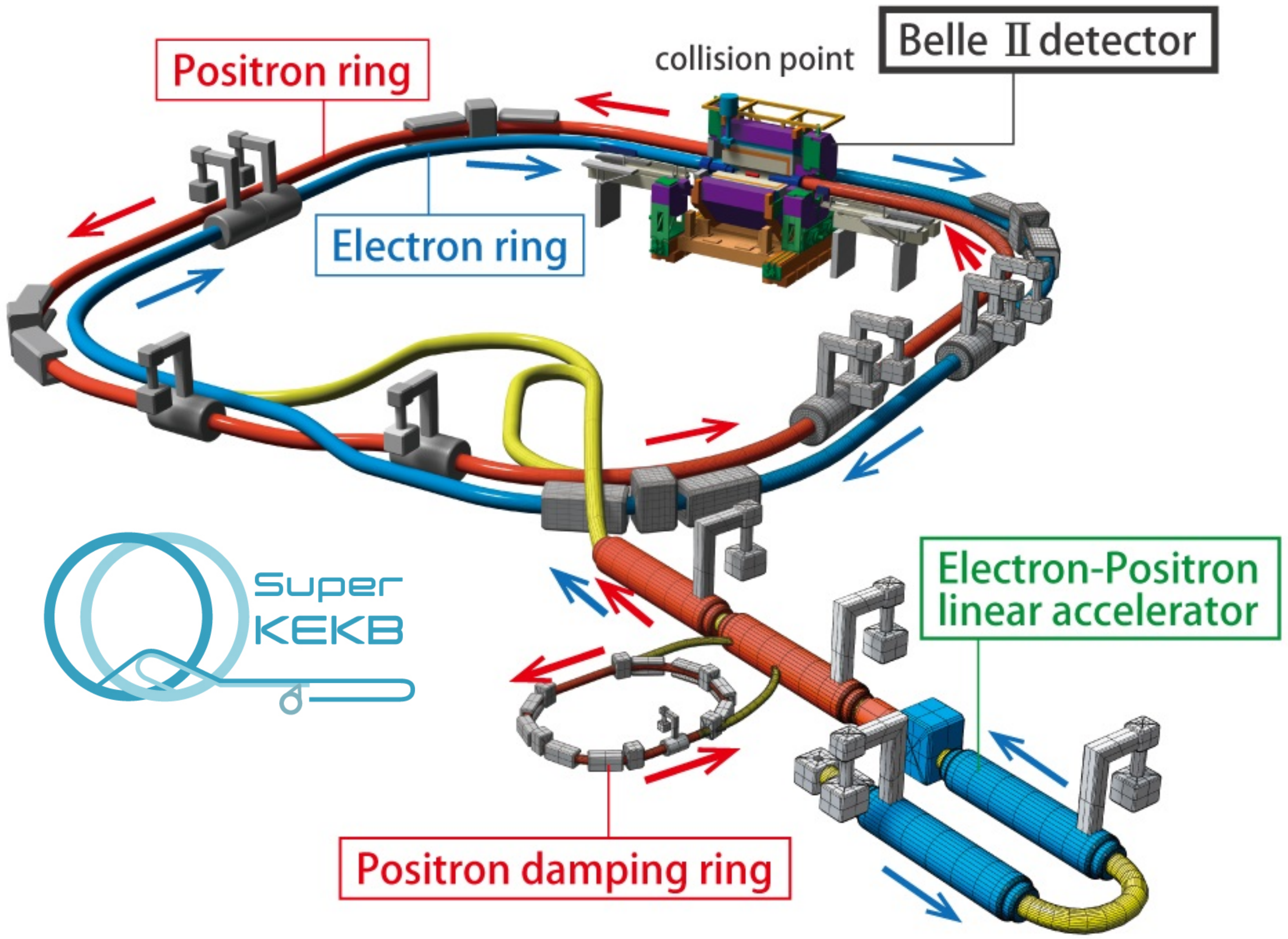
$$e^+ \longrightarrow \Upsilon(4S)\ \langle b\bar{b} \rangle \longleftarrow e^-$$

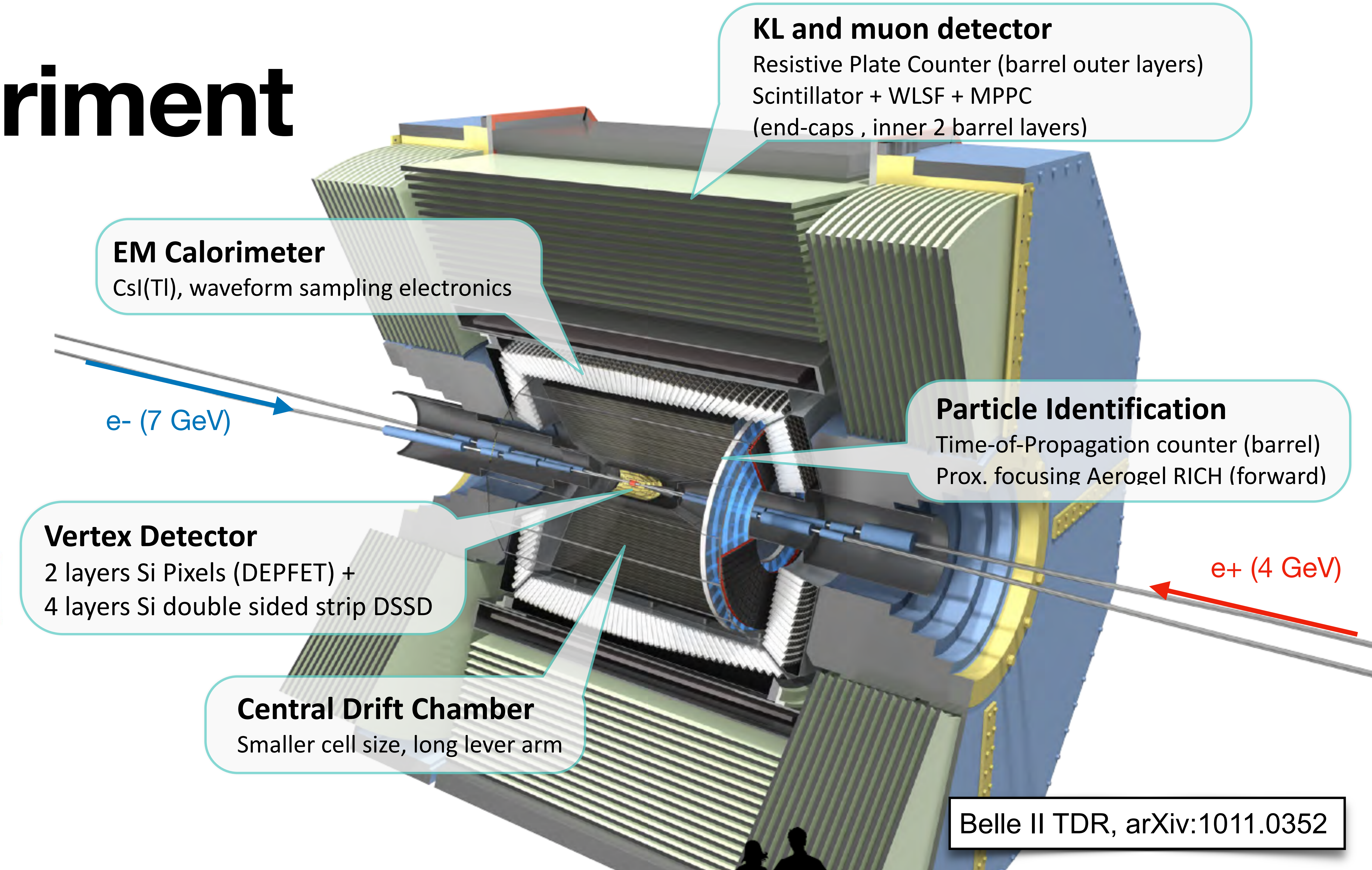
$\sigma(e^+e^- \to \Upsilon(4S))$	**1.05 nb**
$\sigma(e^+e^- \to \tau^+\tau^-)$	0.92 nb
$\sigma(e^+e^- \to c\bar{c})$	1.33 nb



- Large, relatively clean samples of **B-mesons**, **D-mesons** and **τ-leptons**.
- Well known initial state + Large solid angle coverage (>90%) → **Well constrained decay kinematics**
- Advantage in studies with neutral or missing particles.

The Belle II Experiment

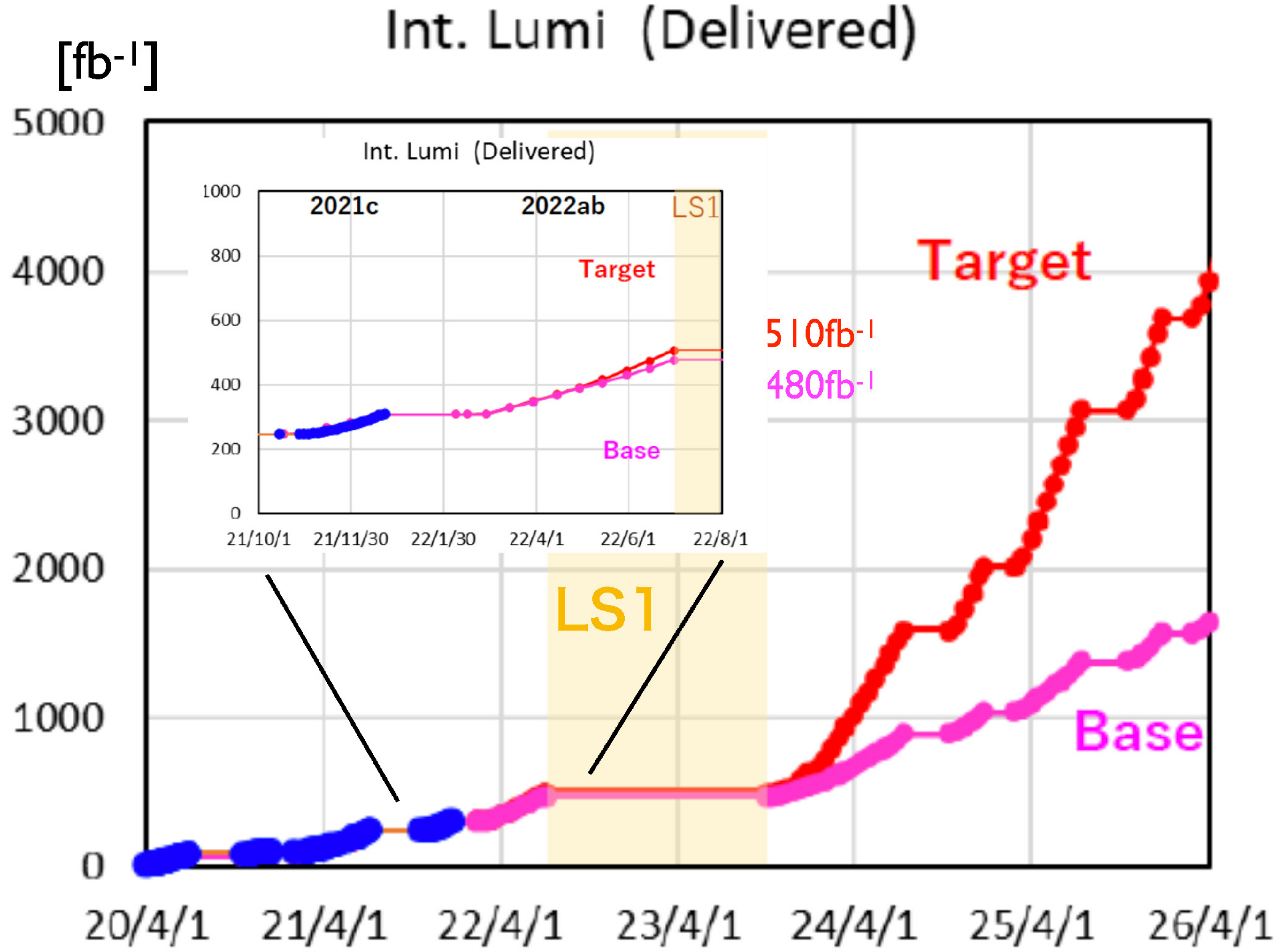




- **Belle II/SuperKEKB** succeed Belle detector and KEKB collider.
- **SuperKEKB:** Nano-beam scheme to achieve high luminosity.
- **Belle II:** new detector with improved vertex reconstruction and particle identification.

Belle II Timeline

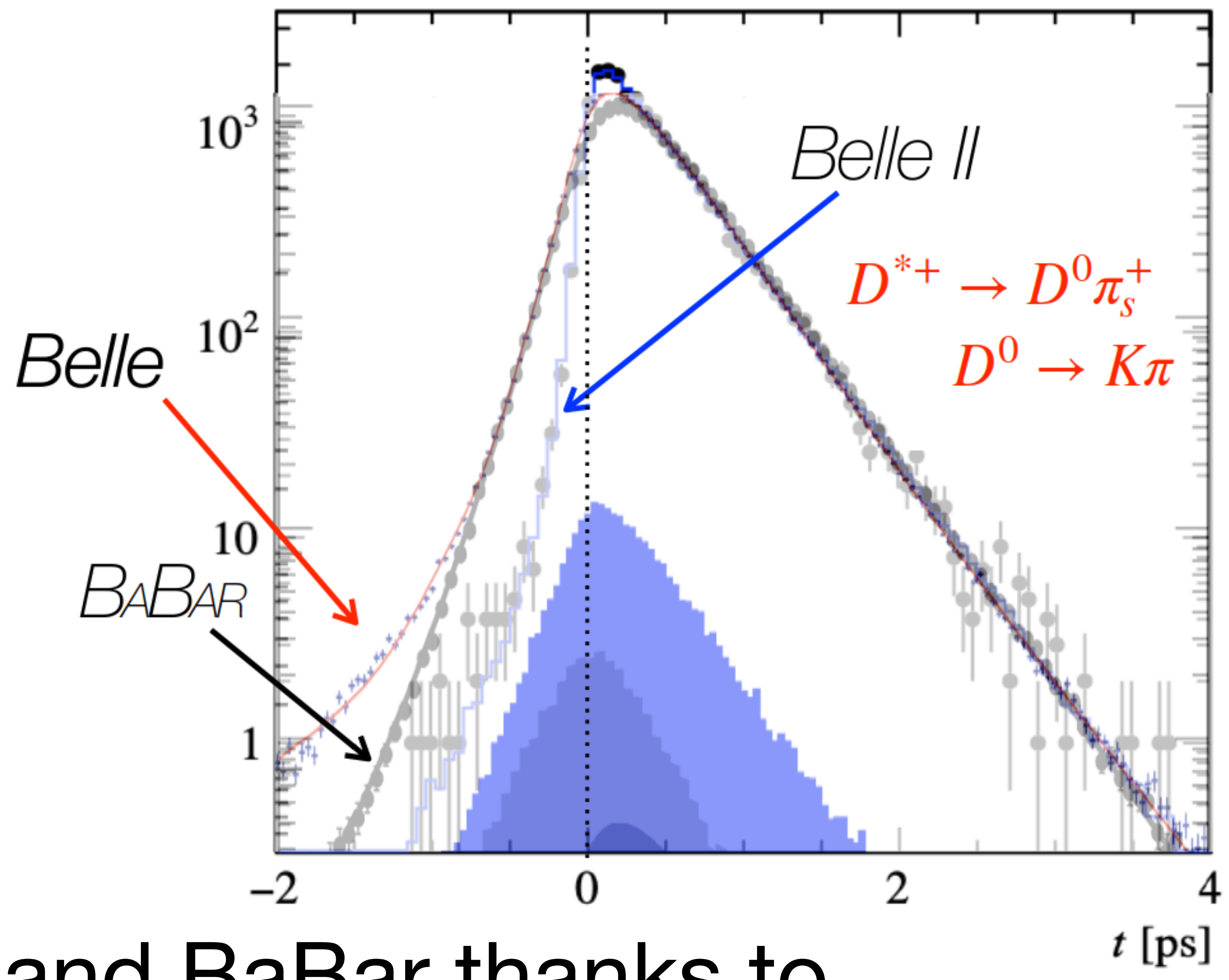
- Roll-in in 2017 followed by commissioning.
- **Full detector operation started in 2019.**
- Achieved **world record** luminosity of **4.65x10^{34} cm^{-2} s^{-1}** (June 8th, 2022)
  - **x2** Belle instantaneous luminosity
  - **Aiming one order higher**
- Long Shutdown 1 (LS1) started this summer to replace PXD + detector maintenance and improvement.



Base: Conservative extrapolation from 2021 run parameters
Target: Extrapolation from 2021 with expected improvements

- **424 fb^{-1} at LS1** (~190 fb^{-1} analyzed so far) can already match BaBar **(~550 fb^{-1})** and challenge Belle **(~1 ab^{-1})** thanks to improved reconstruction performance.

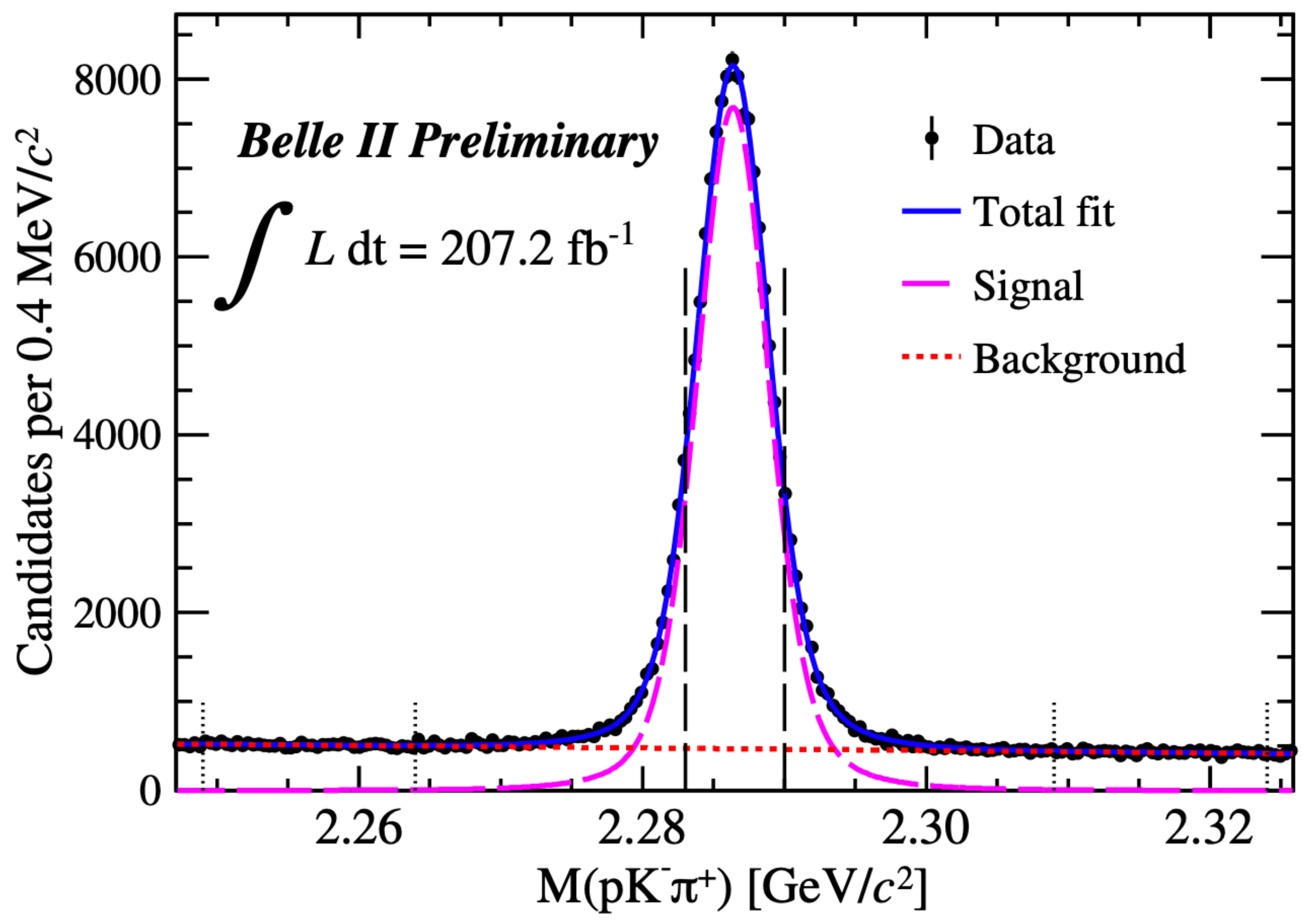
Charm Lifetimes @Belle II

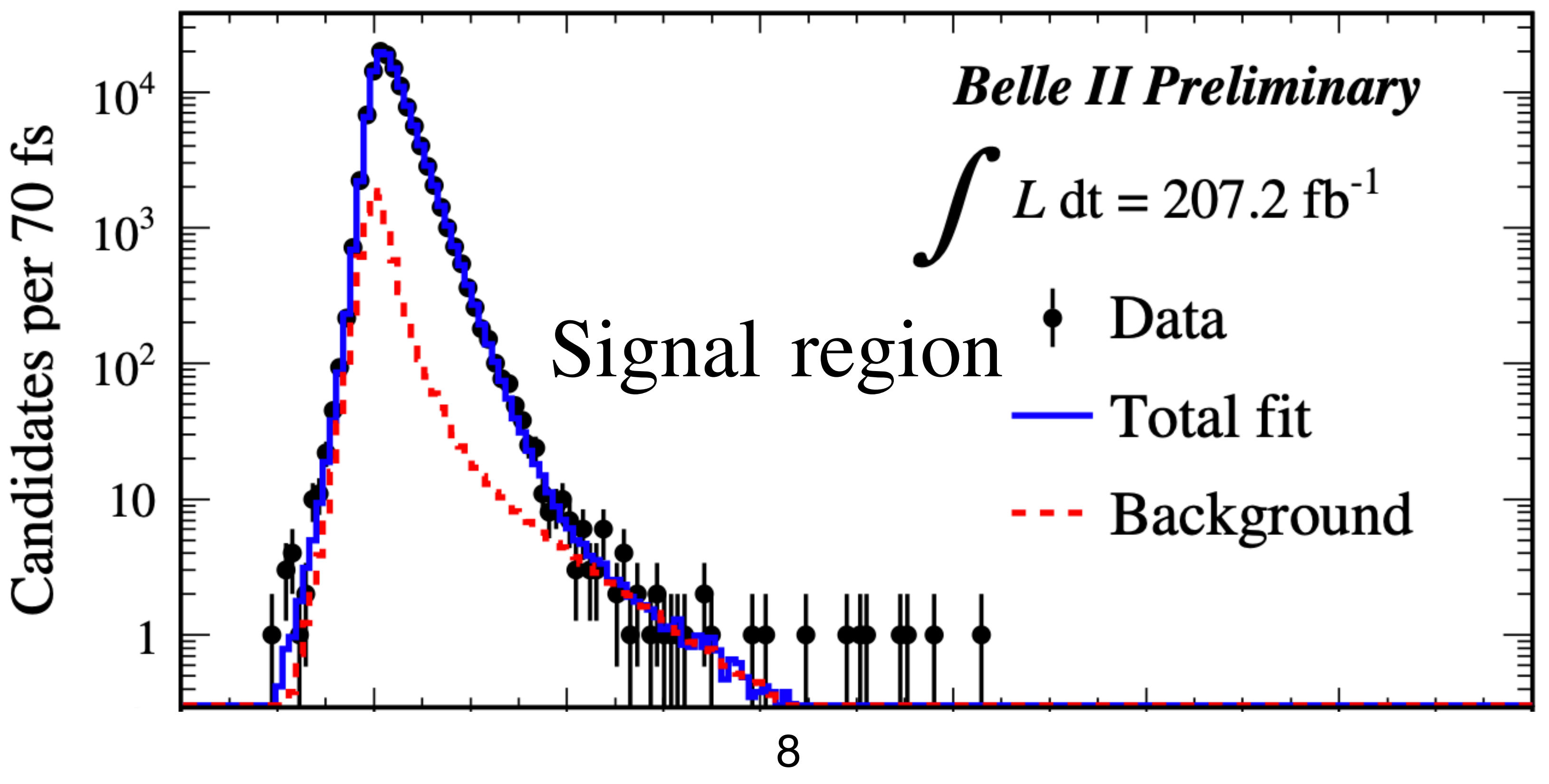


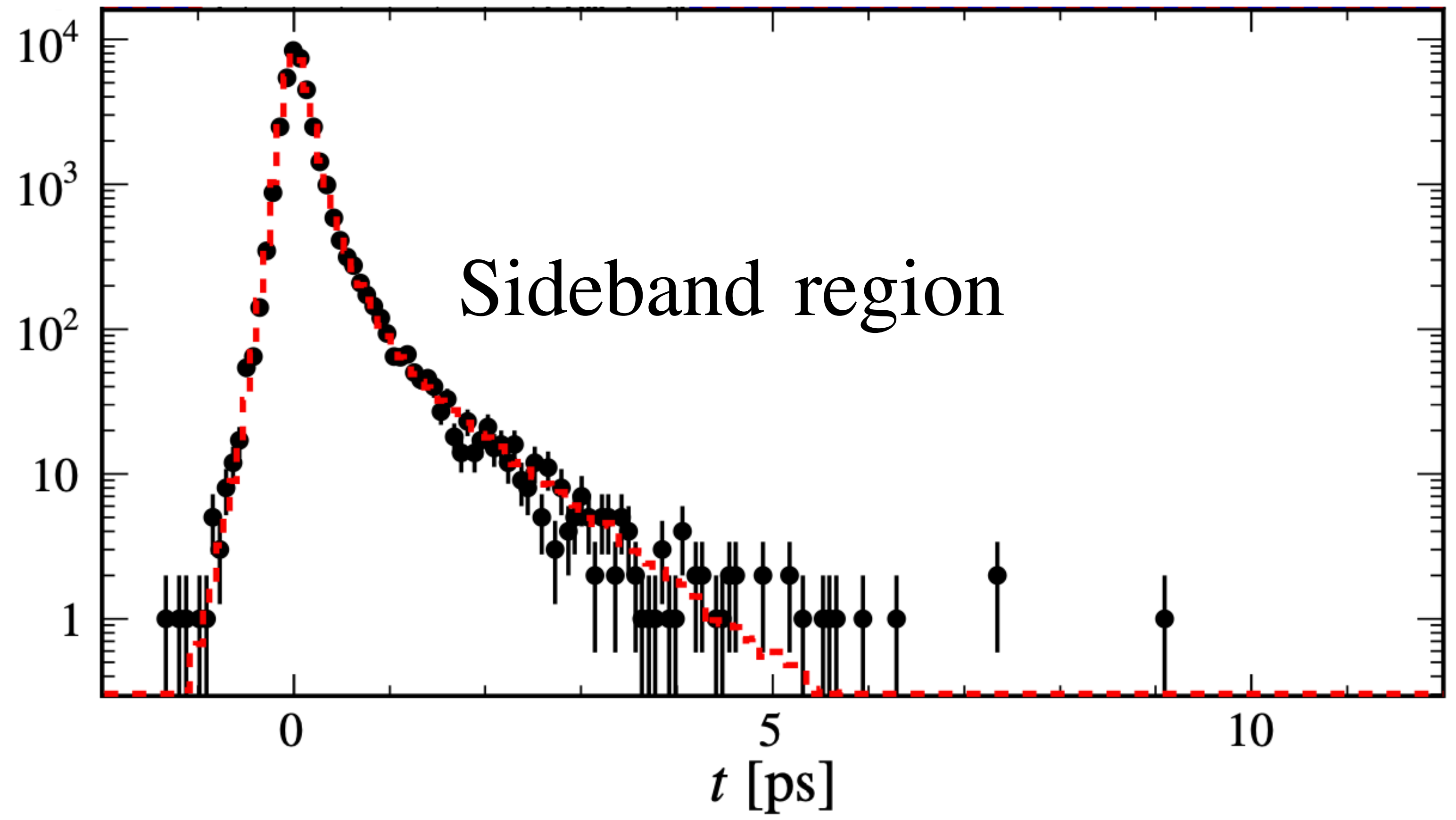
- Important test of effective theory models e.g. strong corrections to weak decays at low energy
- Requires high resolution, carefully controlled systematics
  - New detector offers **2x decay time resolution of** Belle and BaBar thanks to smaller interaction region and vertex detector located closer to the IP.
- 2D fit to signal and sideband regions with BG fraction constrained by mass fit.

Example: Λ_c^+ lifetime

arXiv: 2206.15227

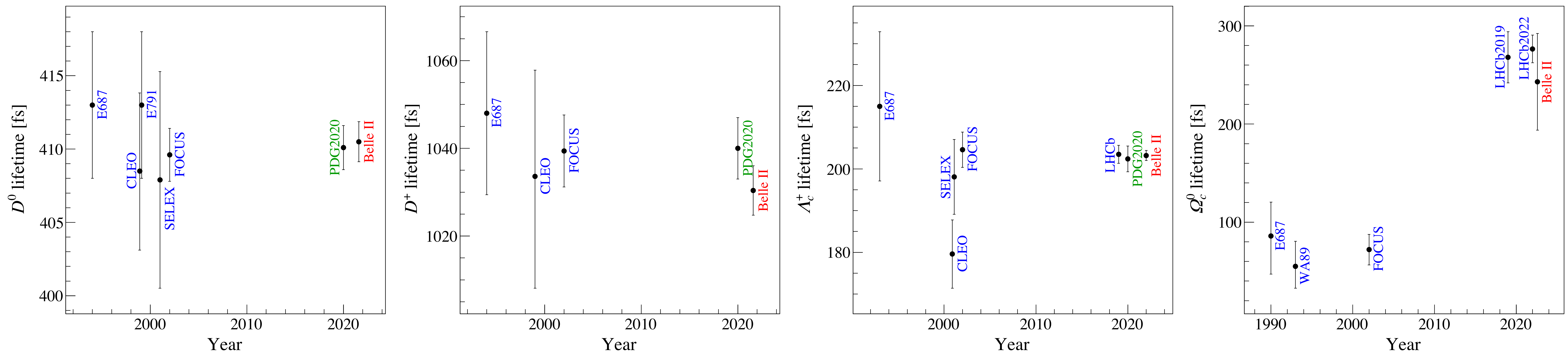






Charm Lifetimes @Belle II

Nisar Nellikunnummel
@ICHEP 2022



- Absolute lifetime measurements of charm hadrons from Belle II:
  - Improved knowledge of D lifetimes, with world-best measurements, after ~20 years

$$\tau(D^0) = 410.5 \pm 1.1 \pm 0.8 \text{ fs}$$
$$\tau(D^+) = 1030.4 \pm 4.7 \pm 3.1 \text{ fs}$$

Phys. Rev. Lett. **127** 21801(2021)

  - World's best Λ_c^+ lifetime measurement

$$\tau(\Lambda_c^+) = 203.2 \pm 0.9 \pm 0.8 \text{ fs}$$

Belle II preliminary, arXiv: 2206.15227[hep-ex]

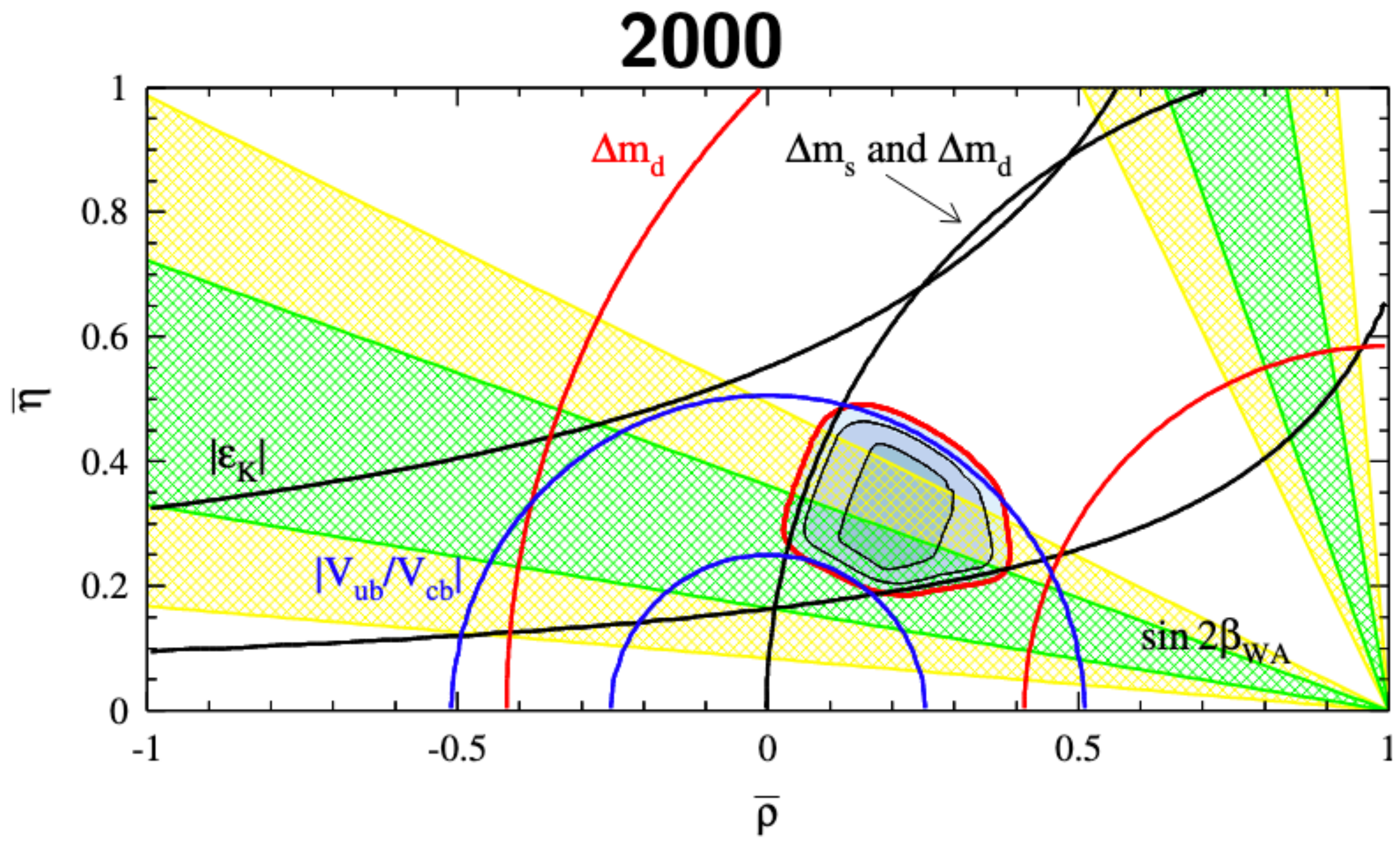
  - Independent confirmation of LHCb's finding that Ω_c^0 is not the shortest-lived weakly decaying charm baryon

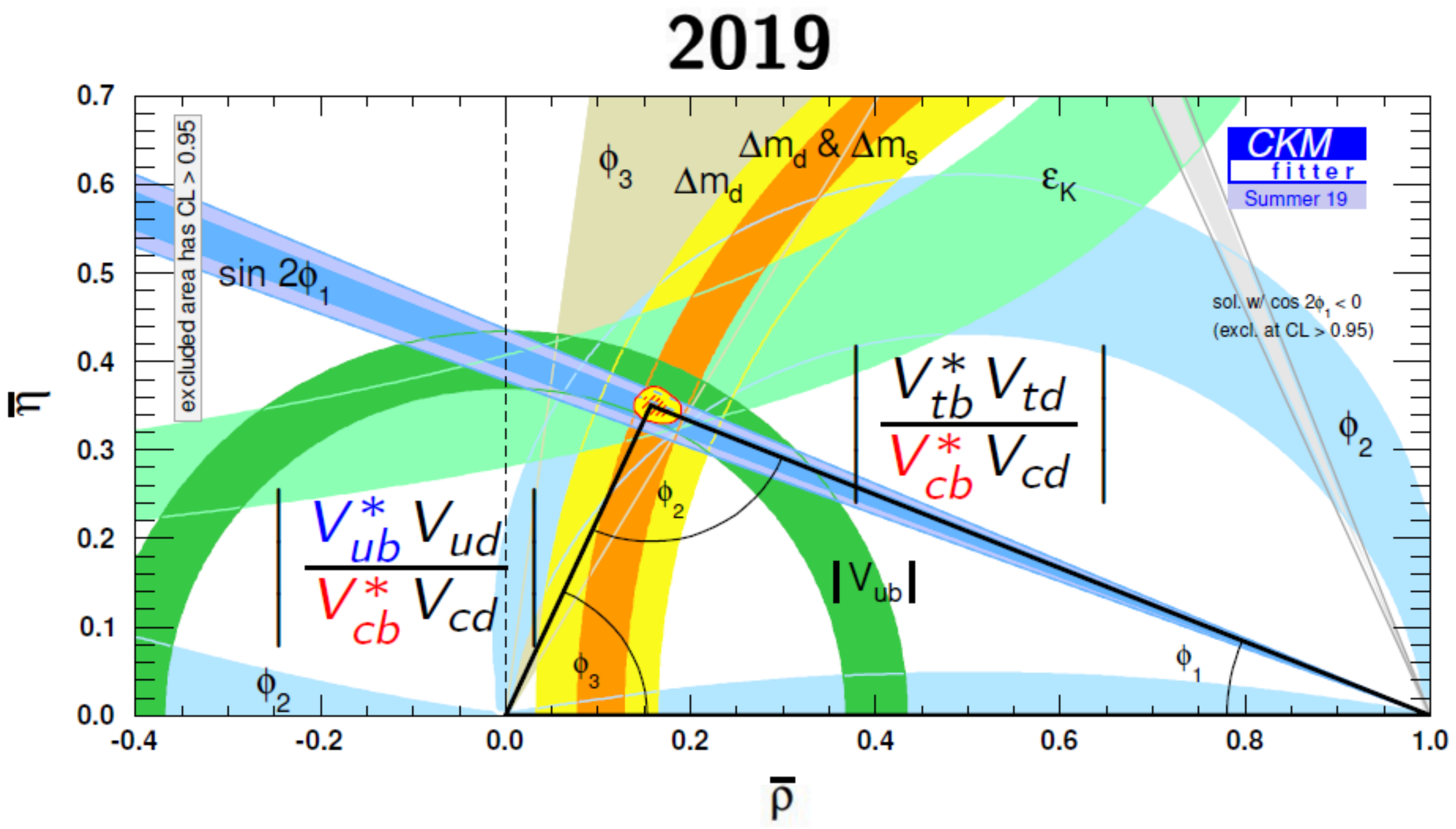
$$\tau(\Omega_c^0) = 243 \pm 48 \pm 11 \text{ fs}$$

Belle II preliminary, new at ICHEP2022

The CKM Triangle

$$\begin{bmatrix} d' \\ s' \\ b' \end{bmatrix} = \begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix} \begin{bmatrix} d \\ s \\ b \end{bmatrix}$$

- Tremendous progress in the last 20 years in understanding quark flavour dynamics thanks to BaBar, Belle, LHCb and theory advances.
- 

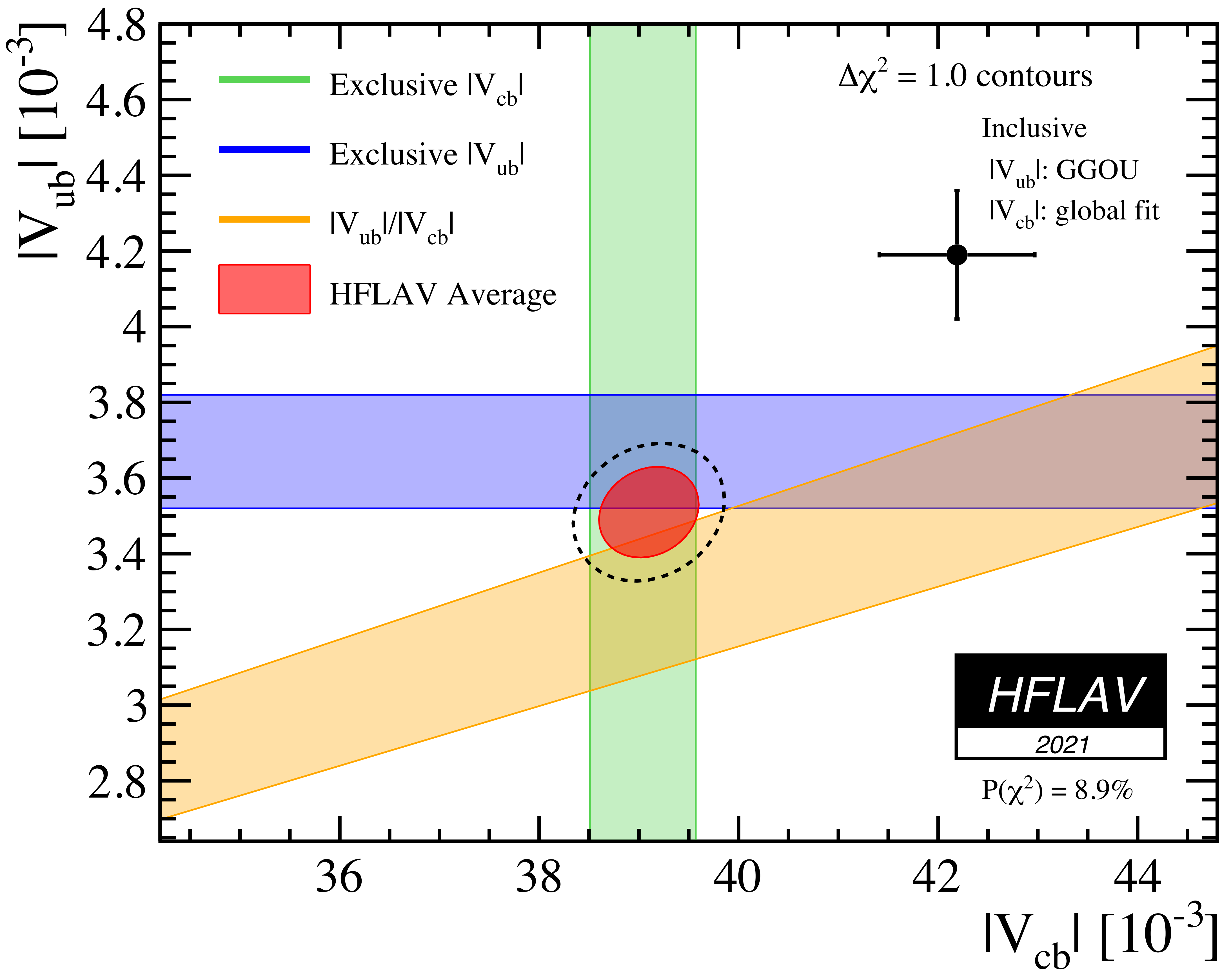


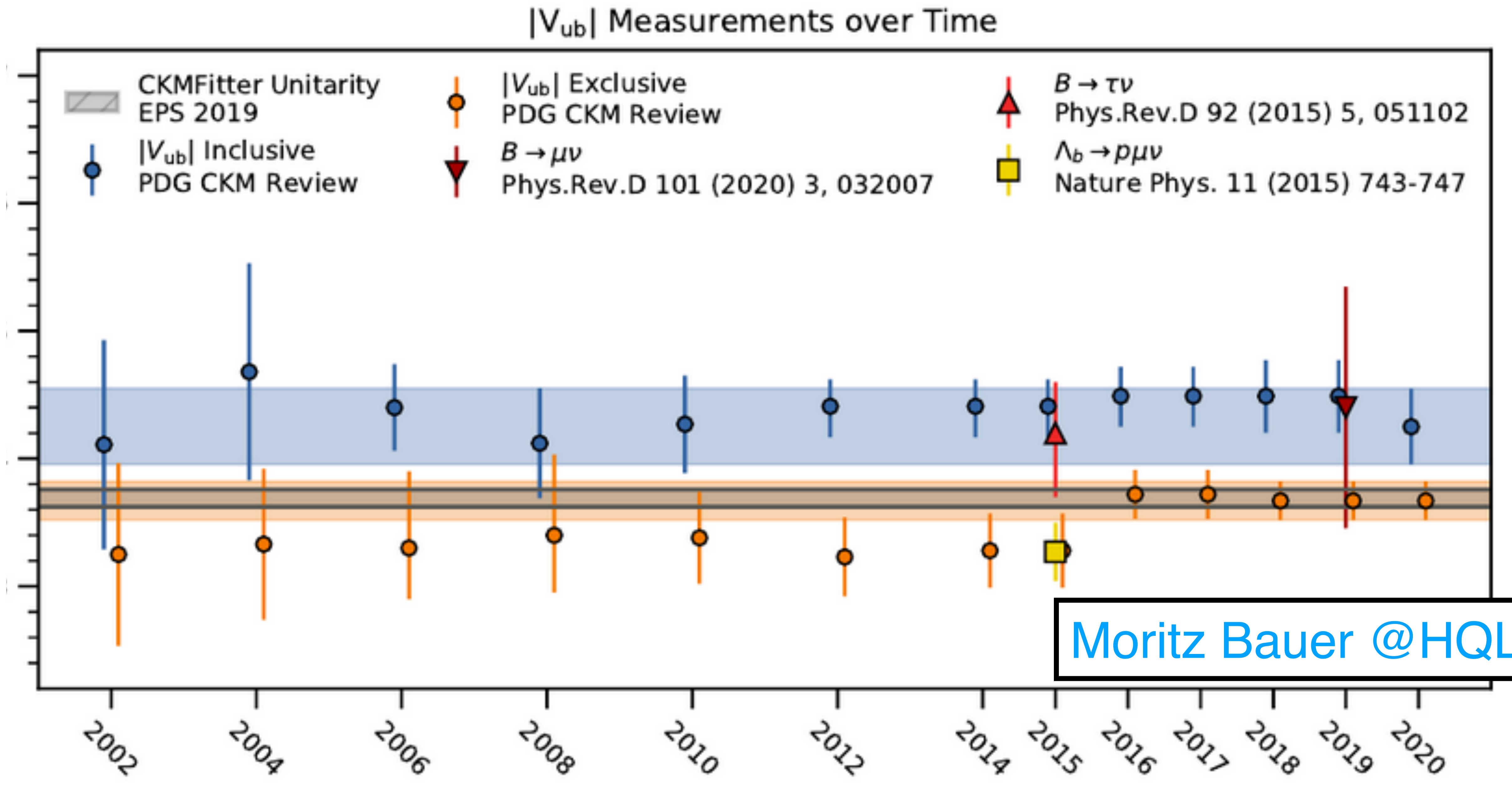
$\left|\frac{V_{tb}^* V_{td}}{V_{cb}^* V_{cd}}\right|$, $\left|\frac{V_{ub}^* V_{ud}}{V_{cb}^* V_{cd}}\right|$

- Potential for Belle II to go even further by combining unprecedented data set with well controlled kinematics and backgrounds.

|Vub| and |Vcb| Puzzles

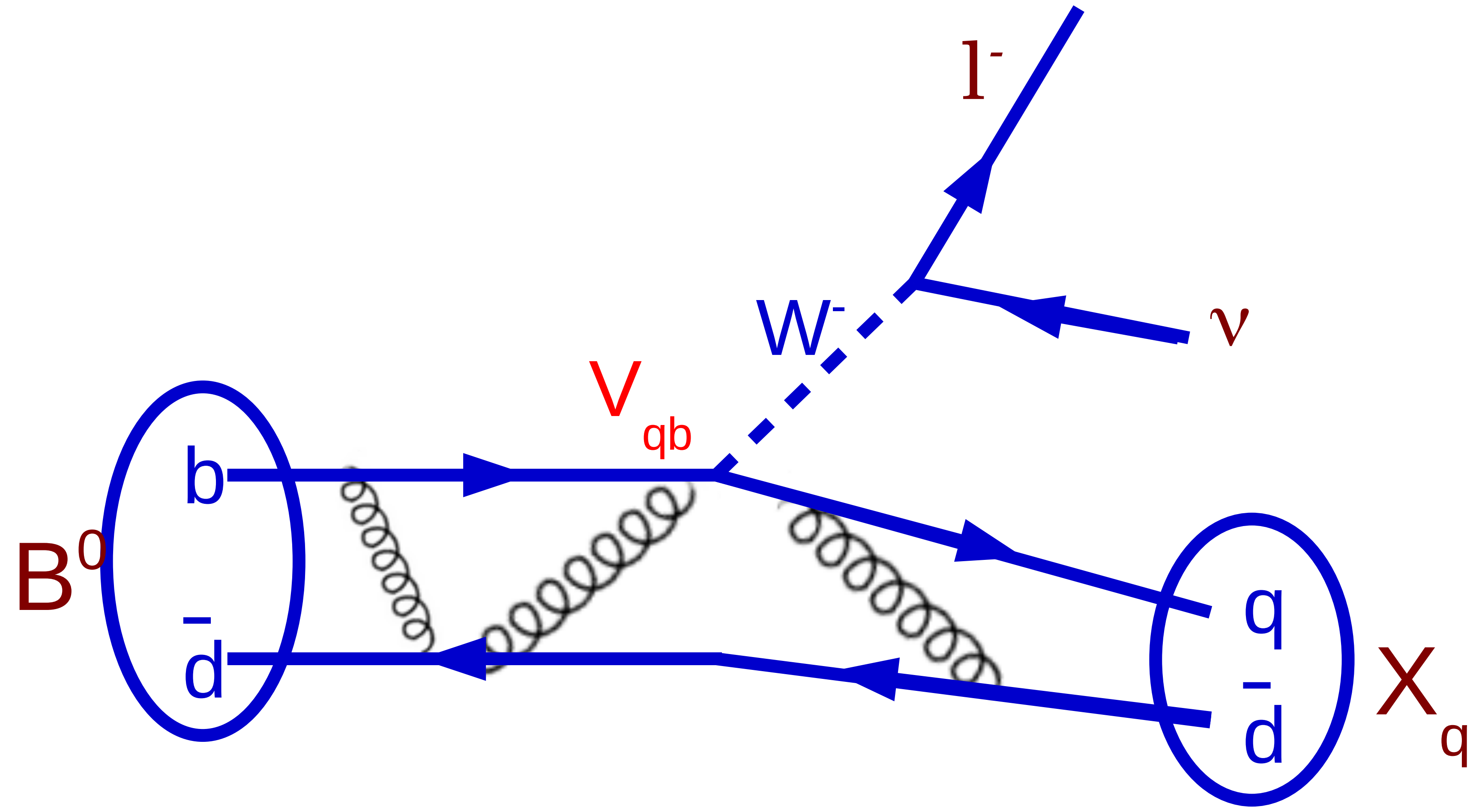
- Longstanding tension (~3σ) between inclusive and exclusive measurements
- Crucial input for SM rare decay BF, limits power of CKM unitarity tests



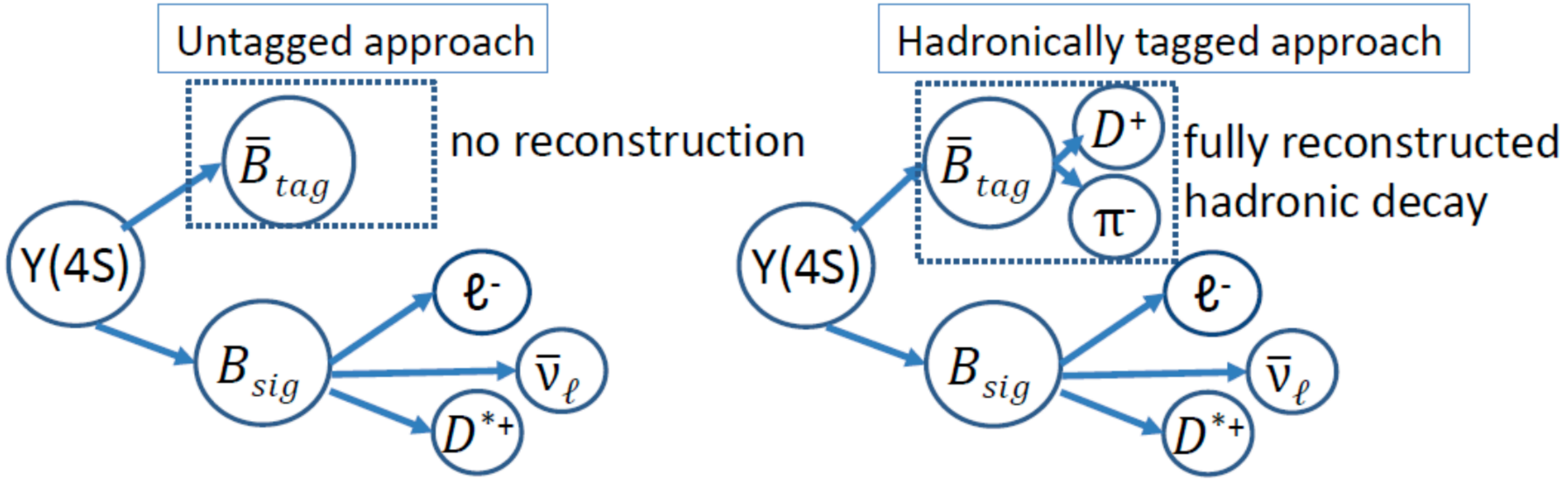


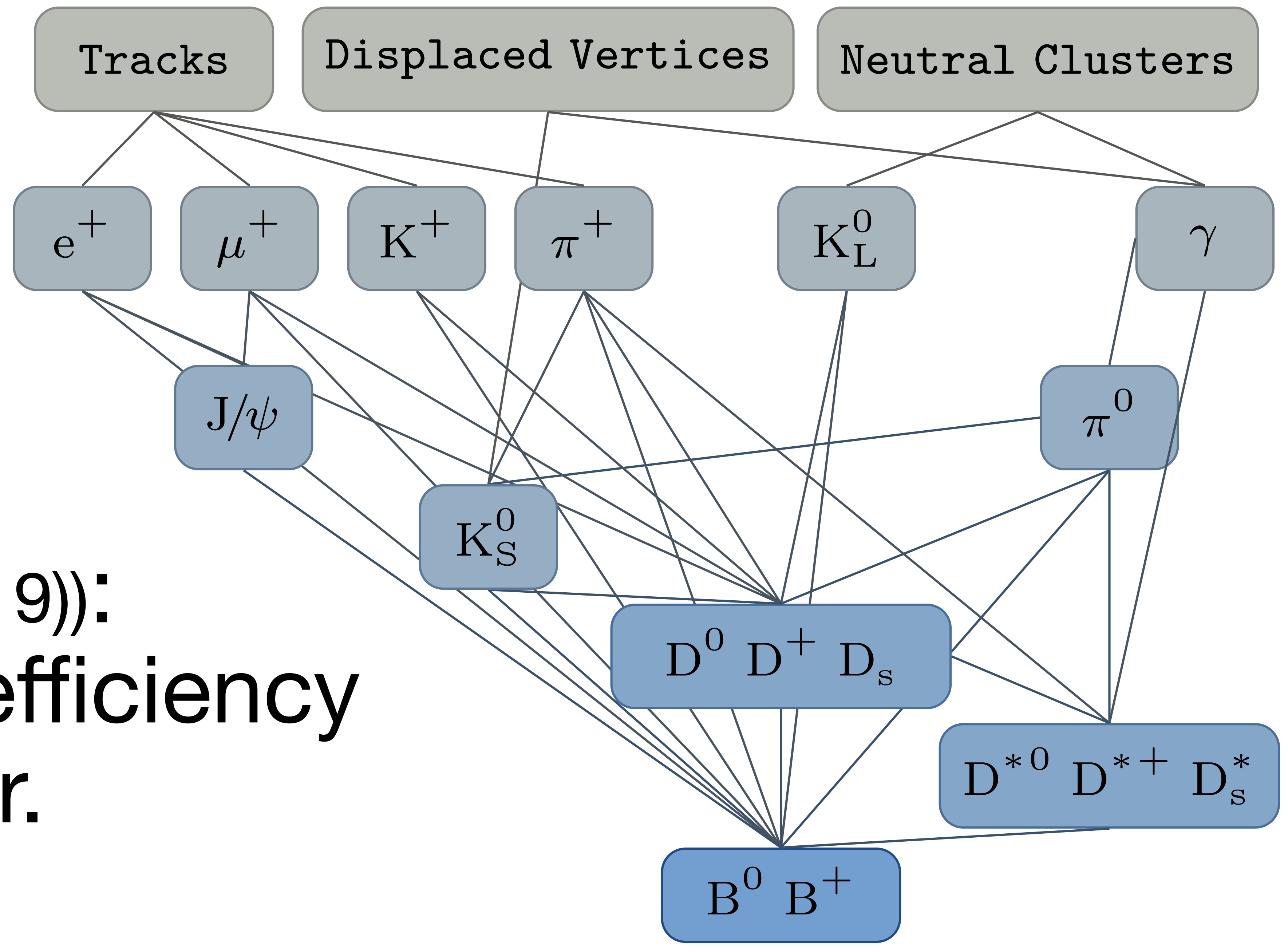
Moritz Bauer @HQL 2021

|Vxb| Determination at Belle II



- Measured from tree level semileptonic decays assumed to be free of NP.
- **Belle II** can measure |Vxb| in multiple ways:
  inclusive and **exclusive**, **tagged** (high purity) and **untagged** (high statistics)
  → unique advantage





- **Full Event Interpretation** (Comput Softw Big Sci **3,** 6 (2019)):
  New tool for B-tag reconstruction with increased efficiency (0.5 (0.3)% for $B^+(B^0)$) using a multivariate classifier.

W. Sutcliffe @Moriond EW 2022

T. Koga @ICHEP 2022

Tagged |Vcb|

$$\frac{d\Gamma}{dw} \propto \mathcal{F}^2(w)|V_{cb}|^2\eta_{\mathrm{EW}}^2$$

$$w = \frac{(m_B^2 + m_{D^{(*)}}^2 - q^2)}{2m_B m_{D^{(*)}}}$$

Normalised momentum transfer

$\eta_{EW} = 1.00662 \pm 0.00016$

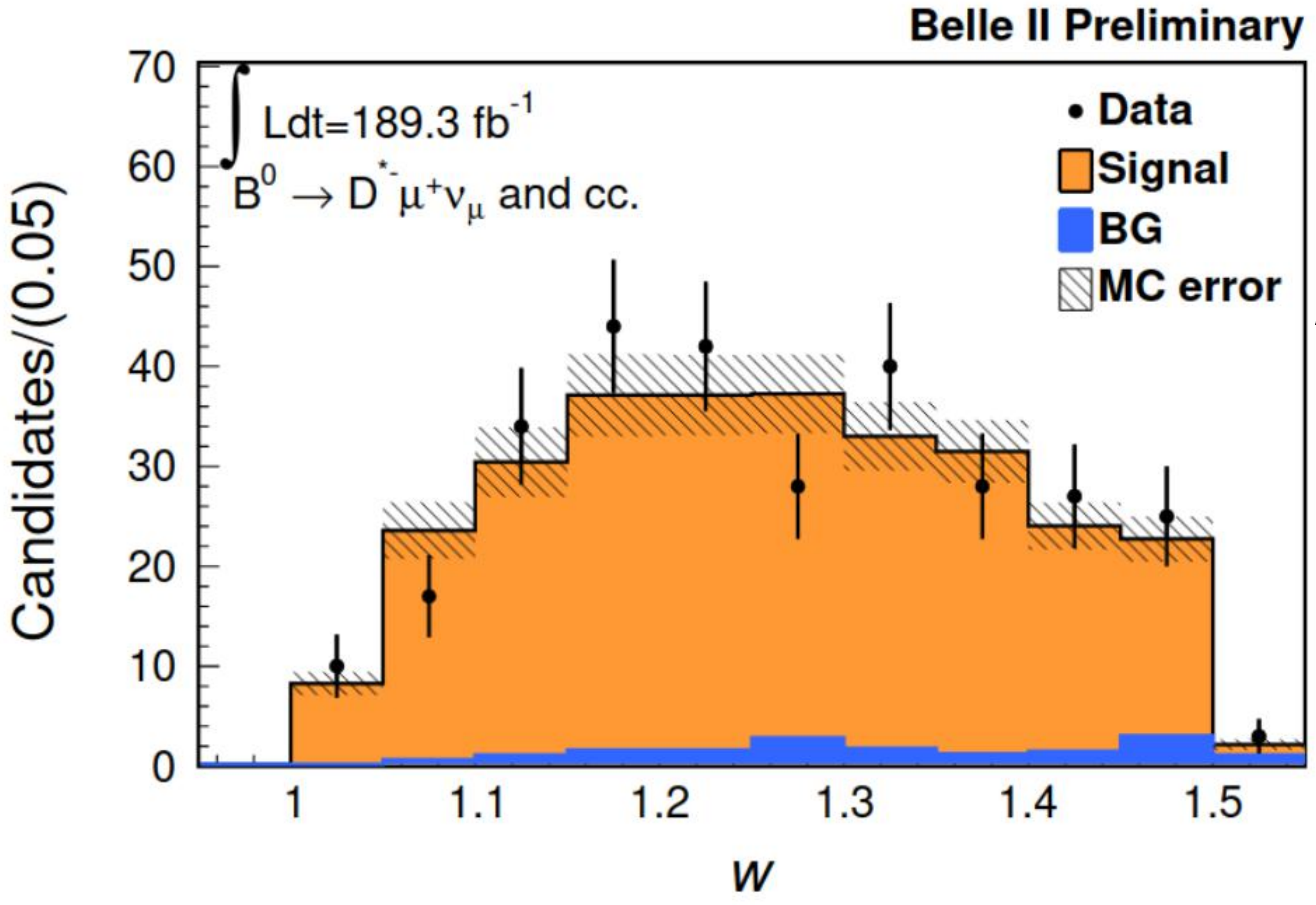
Untagged |Vcb|

- **$B^0 \to D^{*-} l^+ \nu$**
  $D^{*-} \to \bar{D}^0 \pi^+$, $\bar{D}^0 \to K^+\pi^-$
  with **$\bar{B}^0$-tag→hadronic**

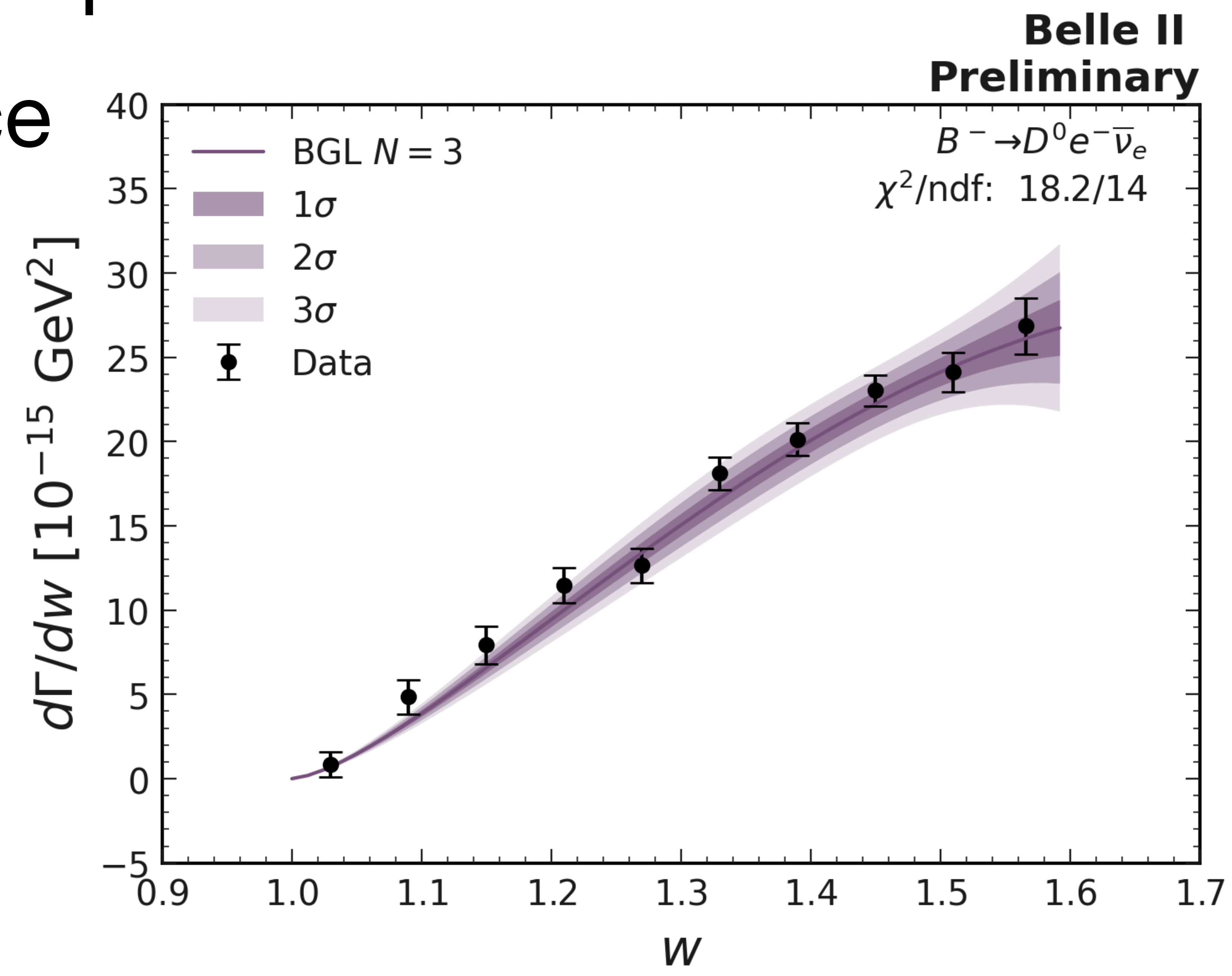
- **$B^0 \to D^- l^+ \nu$**, $D^- \to K^+\pi^-\pi^-$
  $B^+ \to \bar{D}^0 l^+ \nu$, $\bar{D}^0 \to K^+\pi^-$

- **|Vcb|** from fit of the differential decay width with a given parametrization:

CLN



BGL+lattice



$\eta_{EW}|Vcb| \times 10^3 = 38.2 \pm 2.8$ (stat+syst)

$\eta_{EW}|Vcb| \times 10^3 = 38.53 \pm 1.15$ (stat+syst)

Untagged |Vub|

T. Koga
@ICHEP 2022

- **$B^0 \to \pi^- l^+ \nu$:** challenging due to large background from continuum and B decays → rejected with MVA.
- ν momentum is inferred from visible rest-of-event.
- Signal extracted with fit to $q^2 = (p_e + p_\nu)^2$,

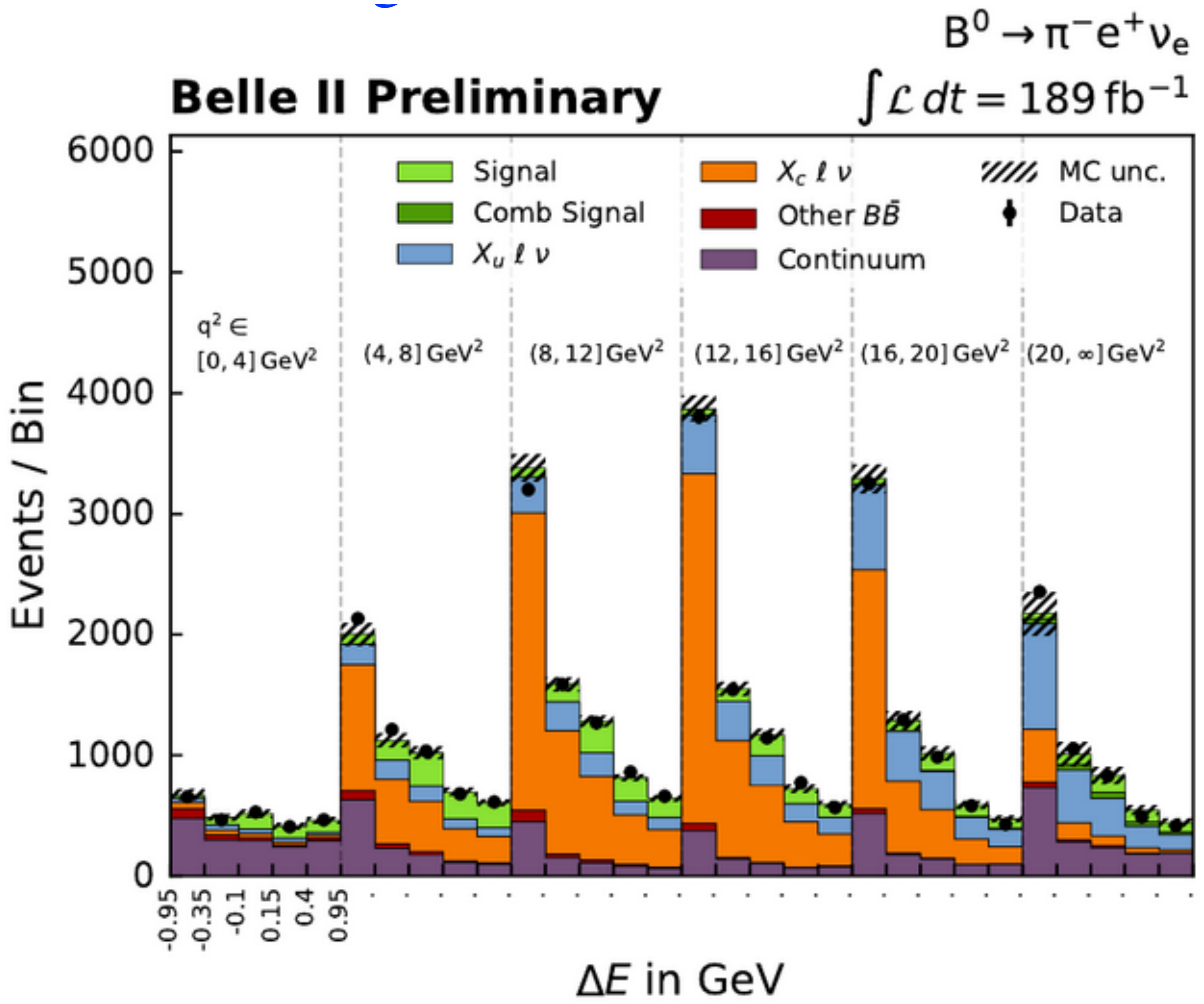
$$M_{BC} = \sqrt{\frac{s}{4} - p_B^{*2}} \text{ and } \Delta E = E_B^* - \frac{\sqrt{s}}{2}$$

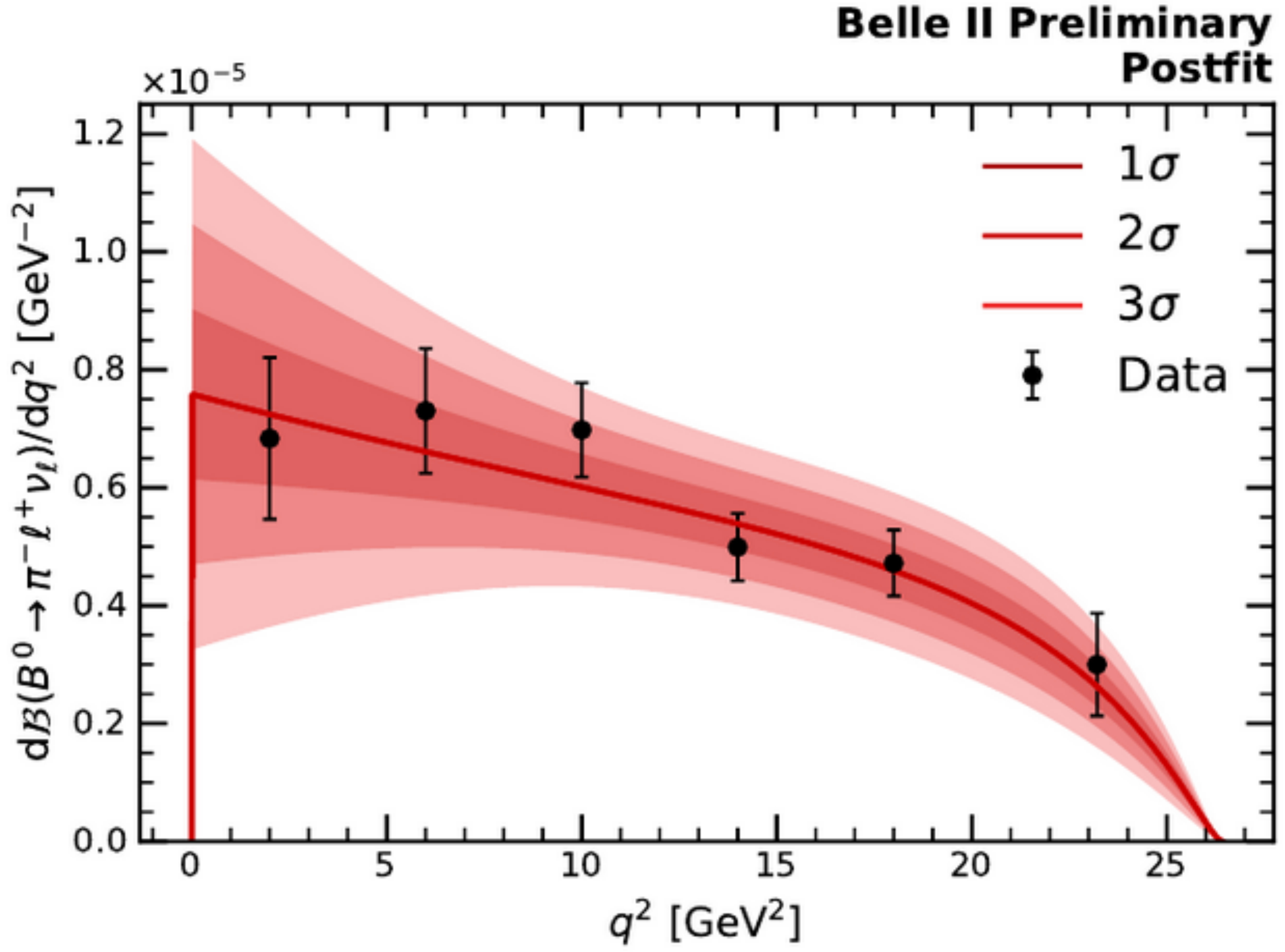
- Branching fraction measurement

$$\mathcal{B}_{B^0 \to \pi^- \ell^+ \nu_\ell} = (1.421 \pm 0.056 \pm 0.126) \times 10^{-4}$$

- Which after input from BCL+lattice QCD becomes

$$|V_{ub}|_{B^0 \to \pi^- \ell^+ \nu_\ell} = \\ = (3.54 \pm 0.12_{\text{stat}} \pm 0.15_{\text{sys}} \pm 0.16_{\text{theo}}) \times 10^{-3}$$





Tagged |Vub|

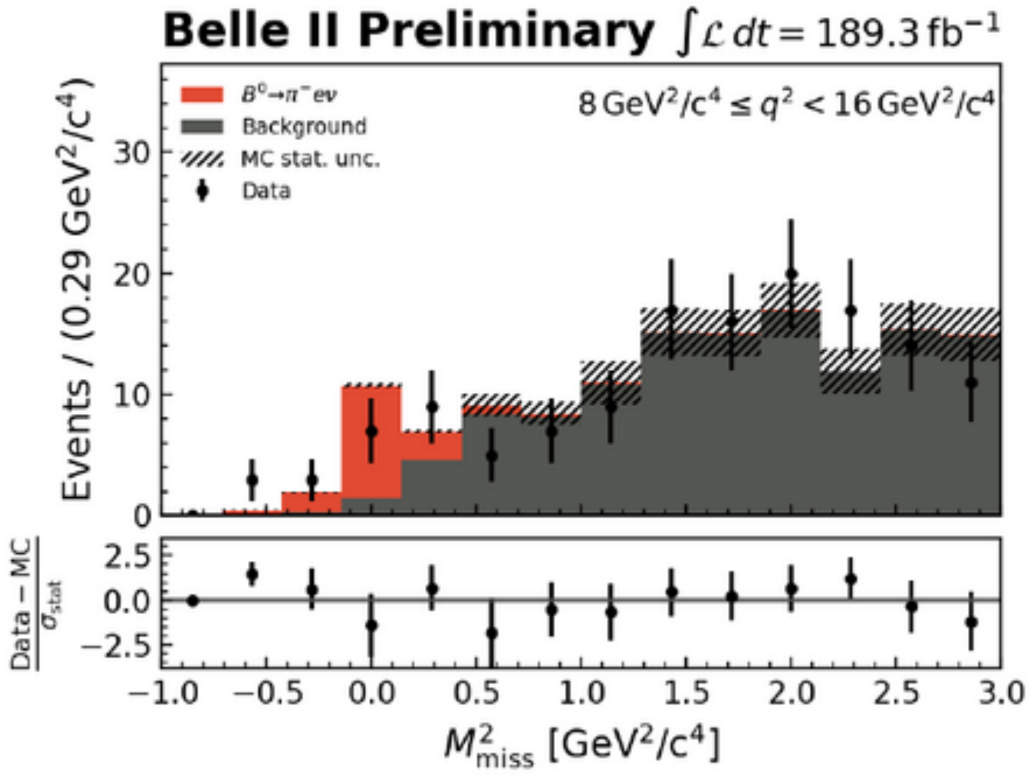
- With a tagged approach the background component can be reduced and it becomes possible to study the more challenging B→ρlν modes.

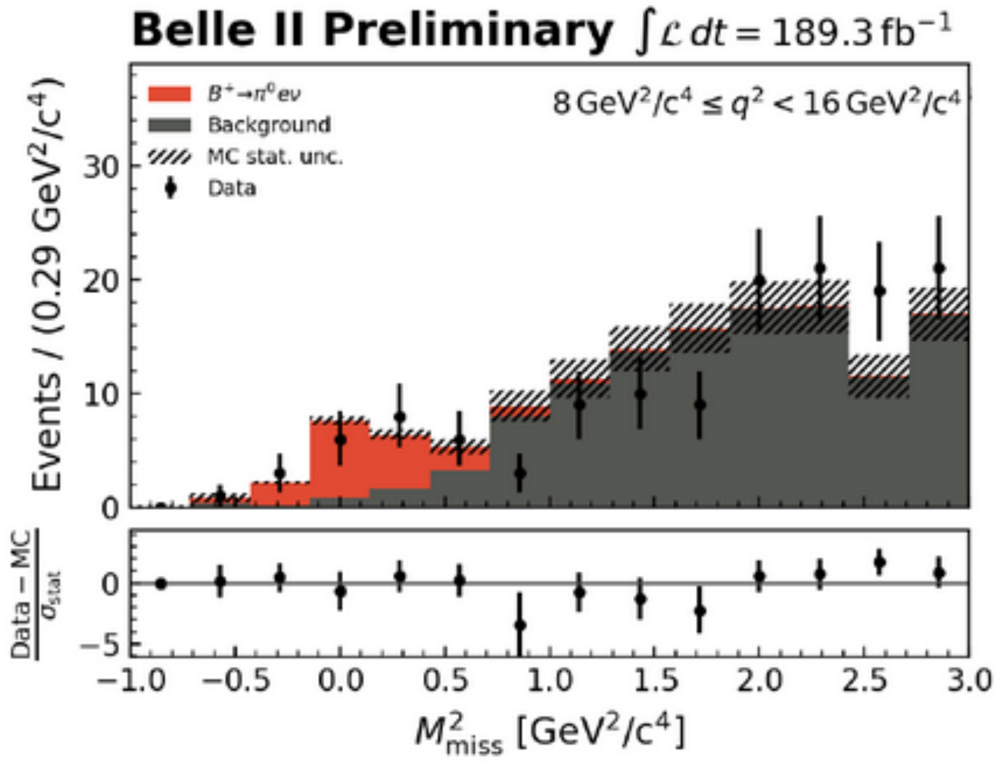
arXiv:2206.08102

$$\mathcal{B}(B^0 \to \pi^- e^+ \nu_e) = (1.43 \pm 0.27(\text{stat}) \pm 0.07(\text{syst})) \times 10^{-4}$$

$$\mathcal{B}(B^+ \to \pi^0 e^+ \nu_e) = (8.33 \pm 1.67(\text{stat}) \pm 0.55(\text{syst})) \times 10^{-5}$$

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





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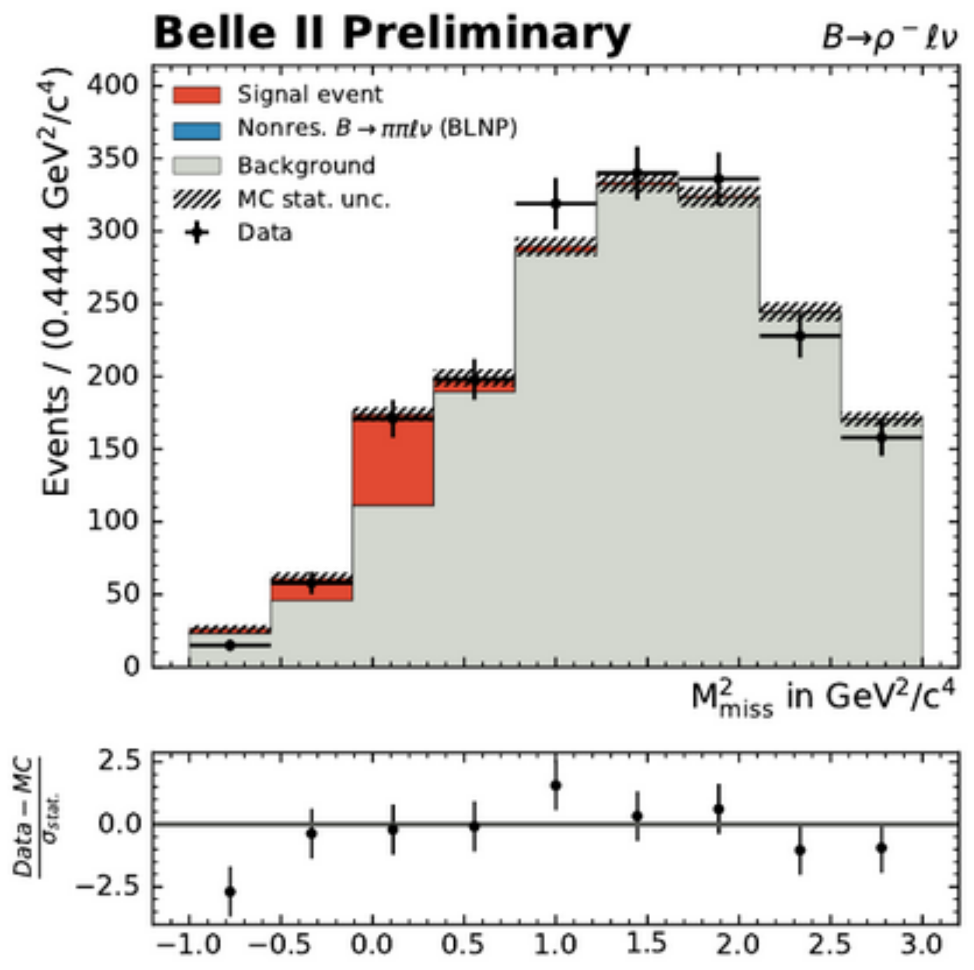
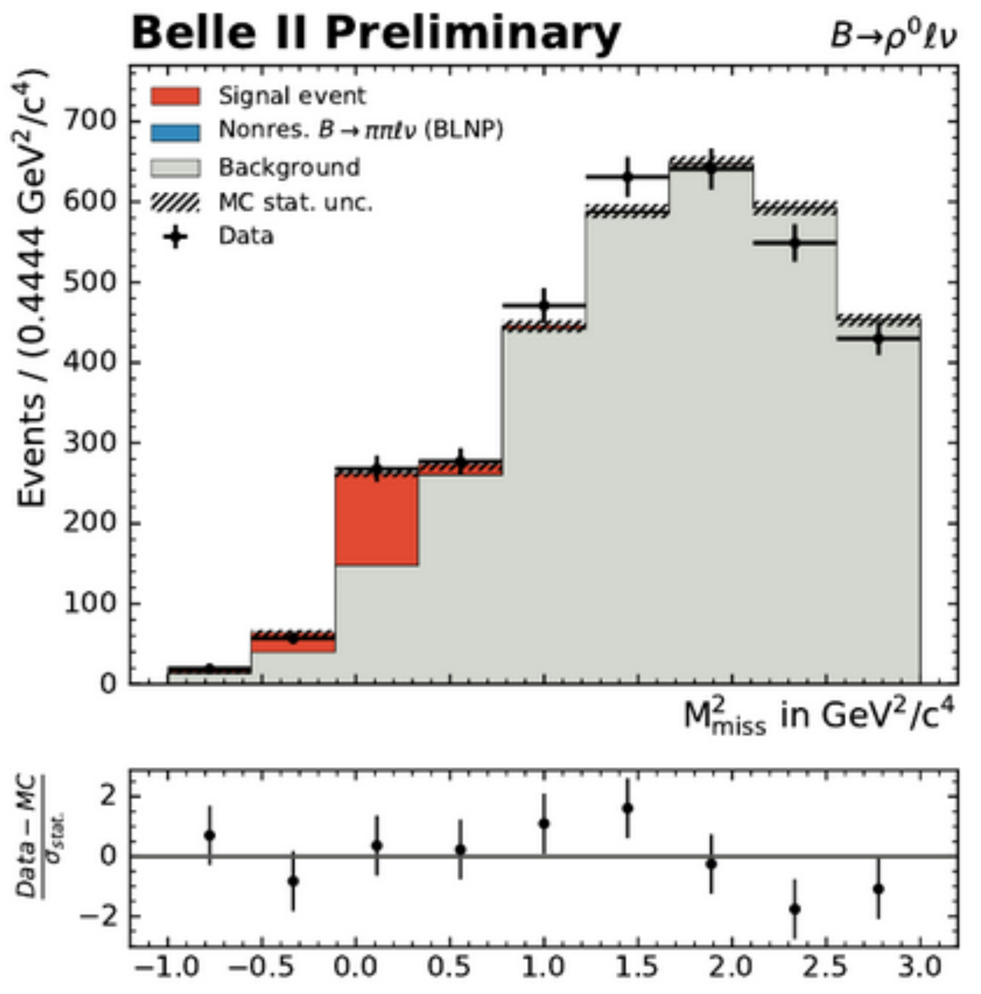
@ICHEP 2022

$$\mathcal{B}(B^0 \to \rho^- \ell^+ \nu_\ell) = (4.12 \pm 0.64_{\text{stat}} \pm 1.16_{\text{sys}}) \times 10^{-4}$$

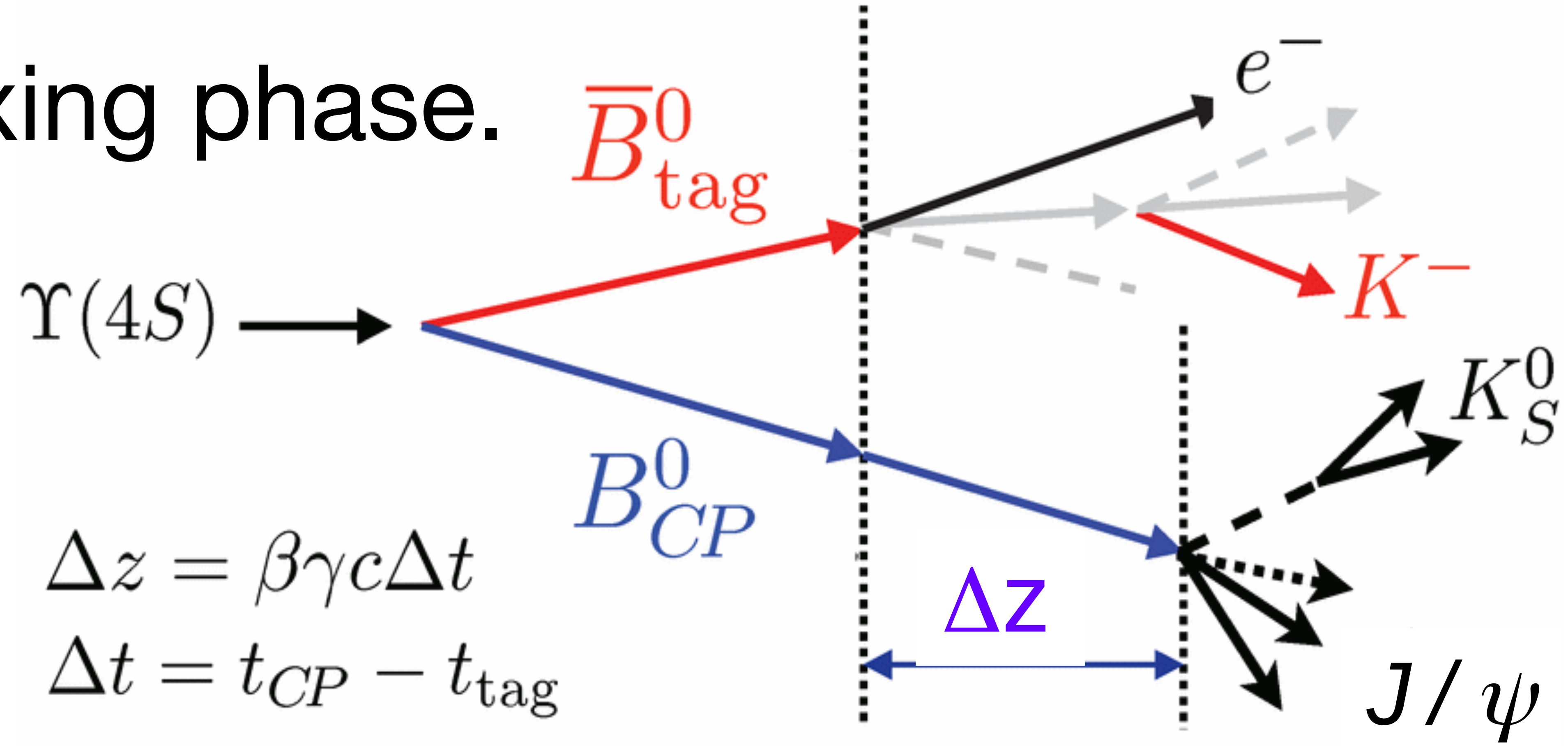
$$\mathcal{B}(B^+ \to \rho^0 \ell^+ \nu_\ell) = (1.77 \pm 0.23_{\text{stat}} \pm 0.36_{\text{sys}}) \times 10^{-4}$$





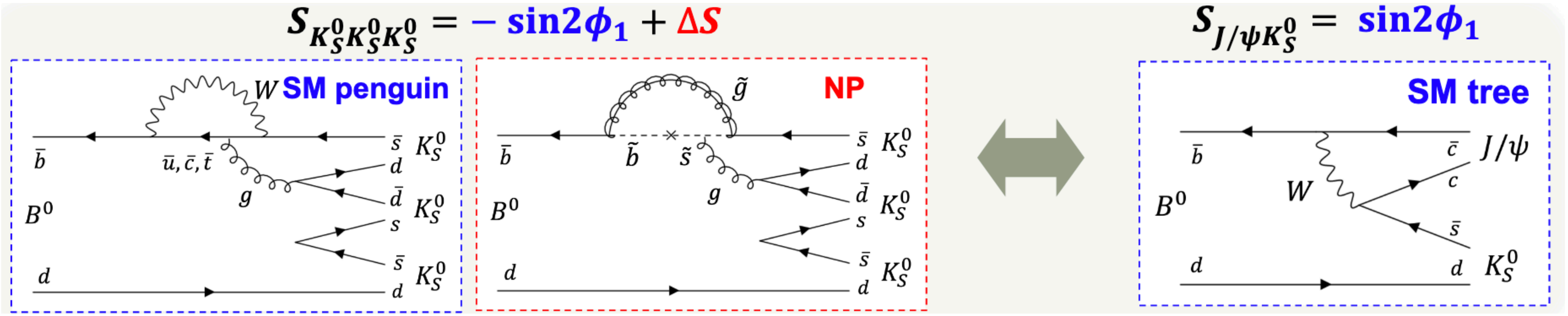
Measuring sin2ϕ_1: Time Dependent Analyses

- Flagship B-Factory measurement of the B^0-mixing phase.
- B^0-tag flavour must be accurately identified
  → dedicated **flavour tagging** algorithm
  (Eur. Phys. J. C 82, 283(2022))
- Needs precise B-decay vertex reconstruction



<Δz> ~ 130 μm at Belle II

- Comparison between tree and penguin modes could reveal NP:



Chiara La Licata
@ICHEP2022

- **$B^0 \to J/\psi$ Ks:** Fit of ΔE with resolution function parameters calibrated with $B^0 \to D^{(*)-}\pi^+$ events

$$S_{CP} = 0.720 \pm 0.062\,(\text{stat.}) \pm 0.016\,(\text{syst.})$$
$$A_{CP} = 0.094 \pm 0.044\,(\text{stat.})\,^{+0.042}_{-0.017}\,(\text{syst.})$$

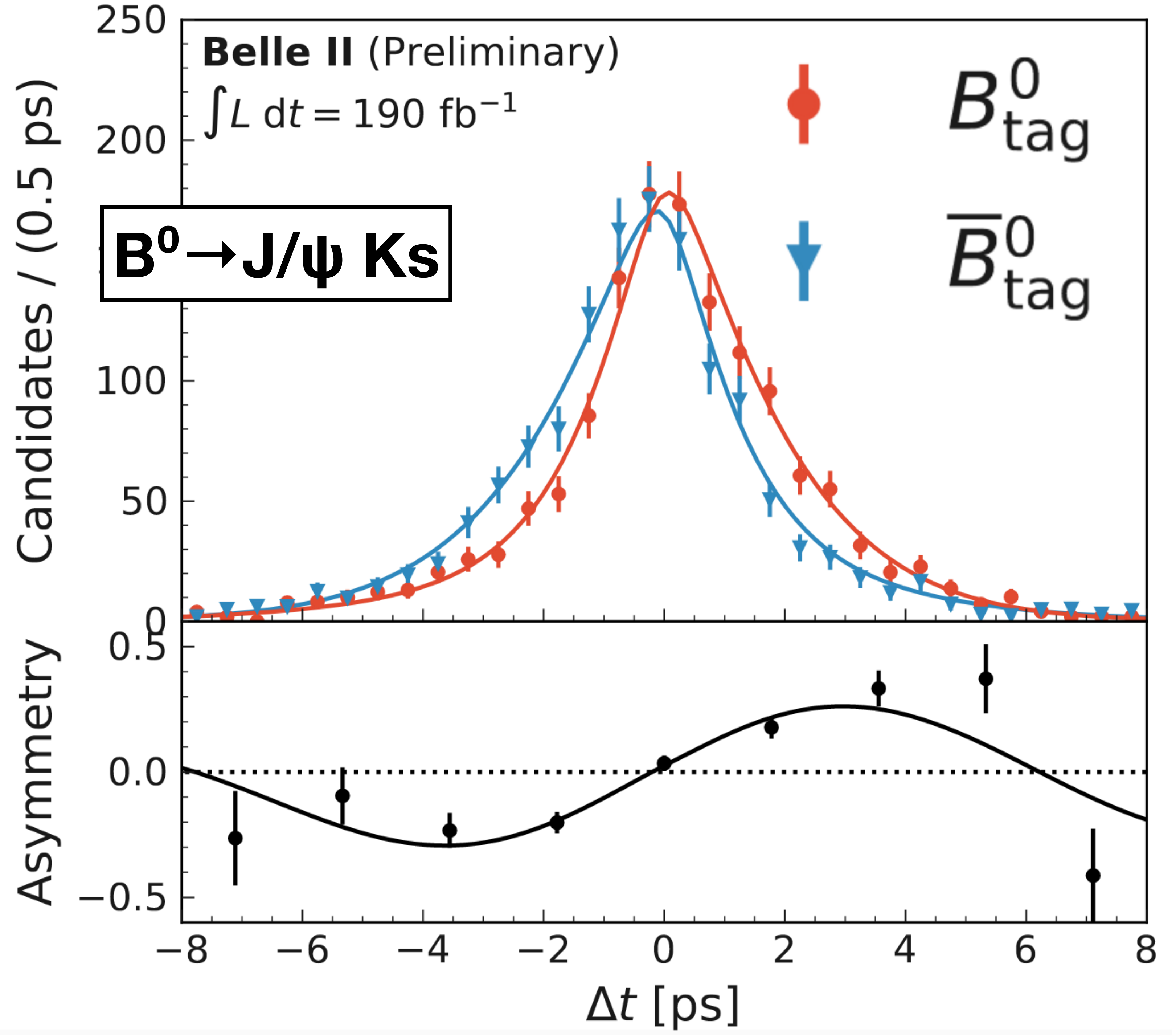
- Other channels e.g. KL, ψ(2S), ... can be added in the future.

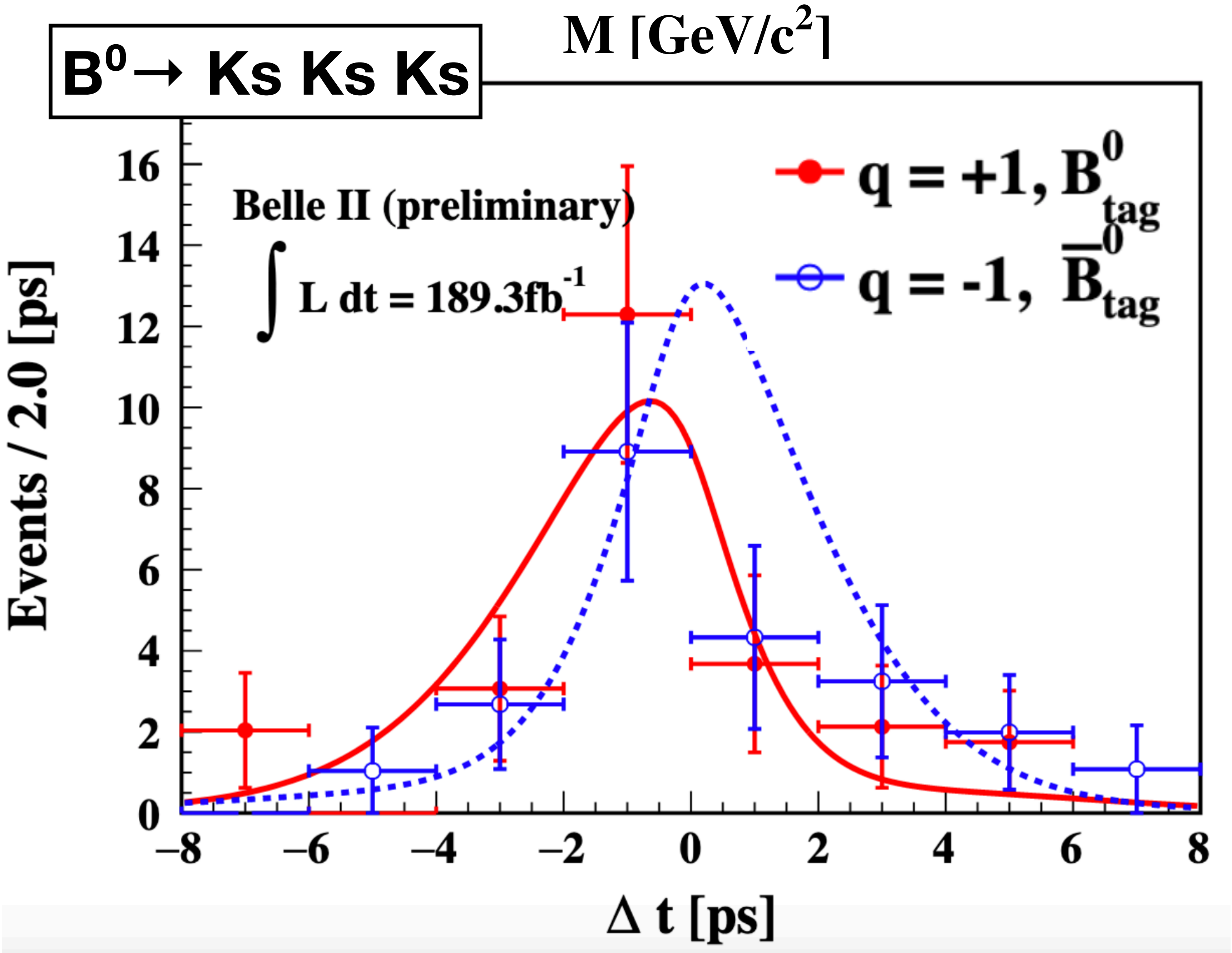
- **$B^0 \to$ Ks Ks Ks:** Unique Belle II sensitivity.
Challenging vertexing with no prompt tracks.

- Validated using $B^+ \to K^+$ Ks Ks

$$S_{CP} = -1.86\,^{+0.91}_{-0.46}\,(\text{stat.}) \pm 0.09\,(\text{syst.})$$
$$A_{CP} = -0.22\,^{+0.30}_{-0.27}\,(\text{stat.}) \pm 0.04\,(\text{syst.})$$

- Both analyses still **dominated by statistical uncertainties.**





CKM angle ϕ_2 : $B^0 \to \pi^0\pi^0$

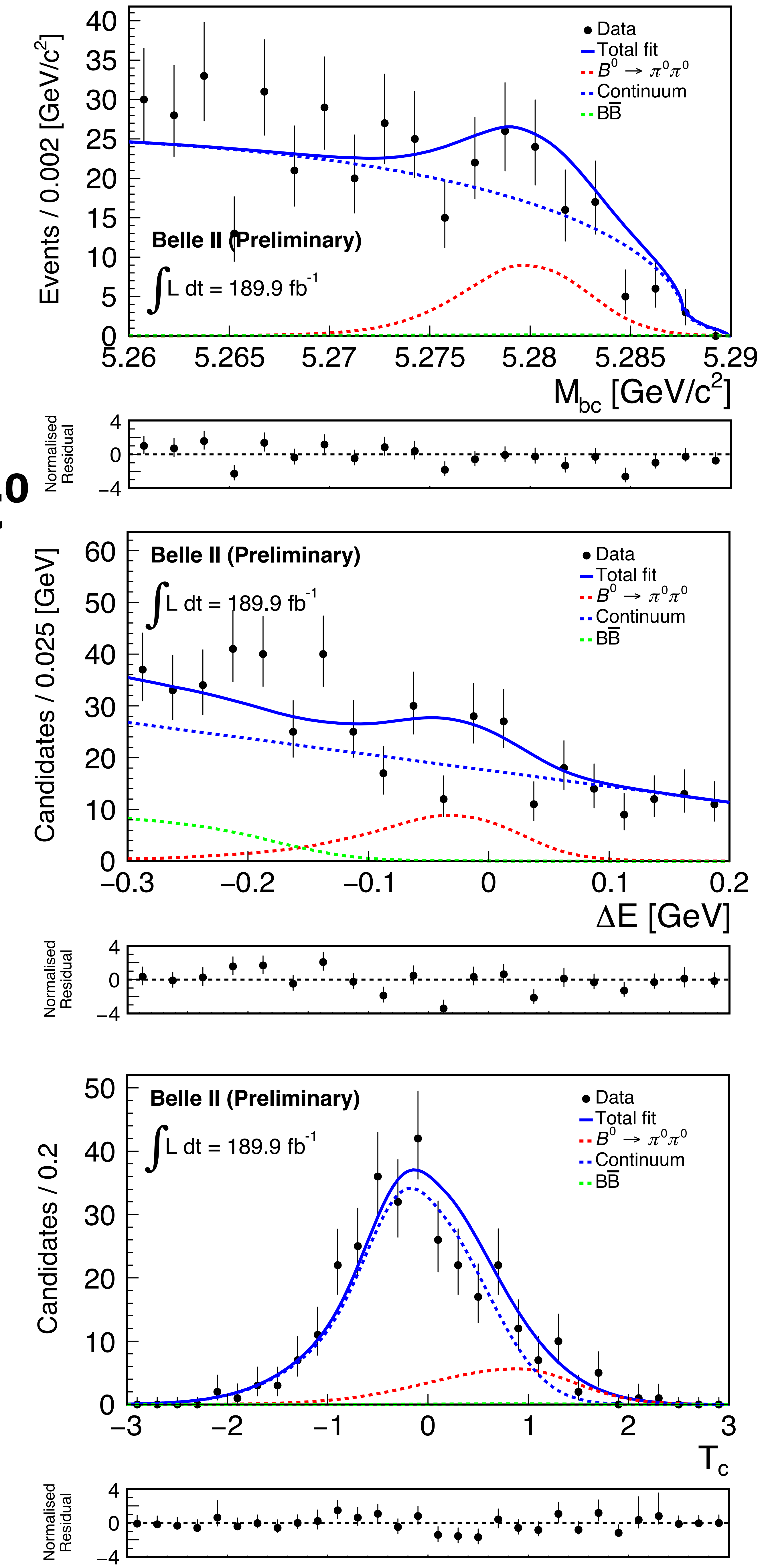
- ϕ_2 can be measured from isospin analysis of $\mathbf{B \to \pi\pi}$ (or $B \to \rho\rho$)
- Belle II can access all channels, including neutrals e.g. $\mathbf{B^0 \to \pi^0\pi^0}$
    - Requires dedicated MVA to suppress photon background.
    - Flavour tagging is required to determine A_{CP}
    - Calibration factors from $B^0 \to D^0(\to K^-\pi^+\pi^0)\pi^0$
    - Signal yields from maximum likelihood fit of ΔE, M_{bc}, and continuum-suppression BDT output.

Justin Skorupa @ICHEP2022

Results competitive with Belle with a data set of less than one third!

$$\mathcal{A}^{CP} = 0.14 \pm 0.46\ (\text{stat}) \pm 0.07\ (\text{syst})$$
$$\mathcal{B} = (1.27 \pm 0.25\ (\text{stat}) \pm 0.17\ (\text{syst})) \cdot 10^{-6}$$

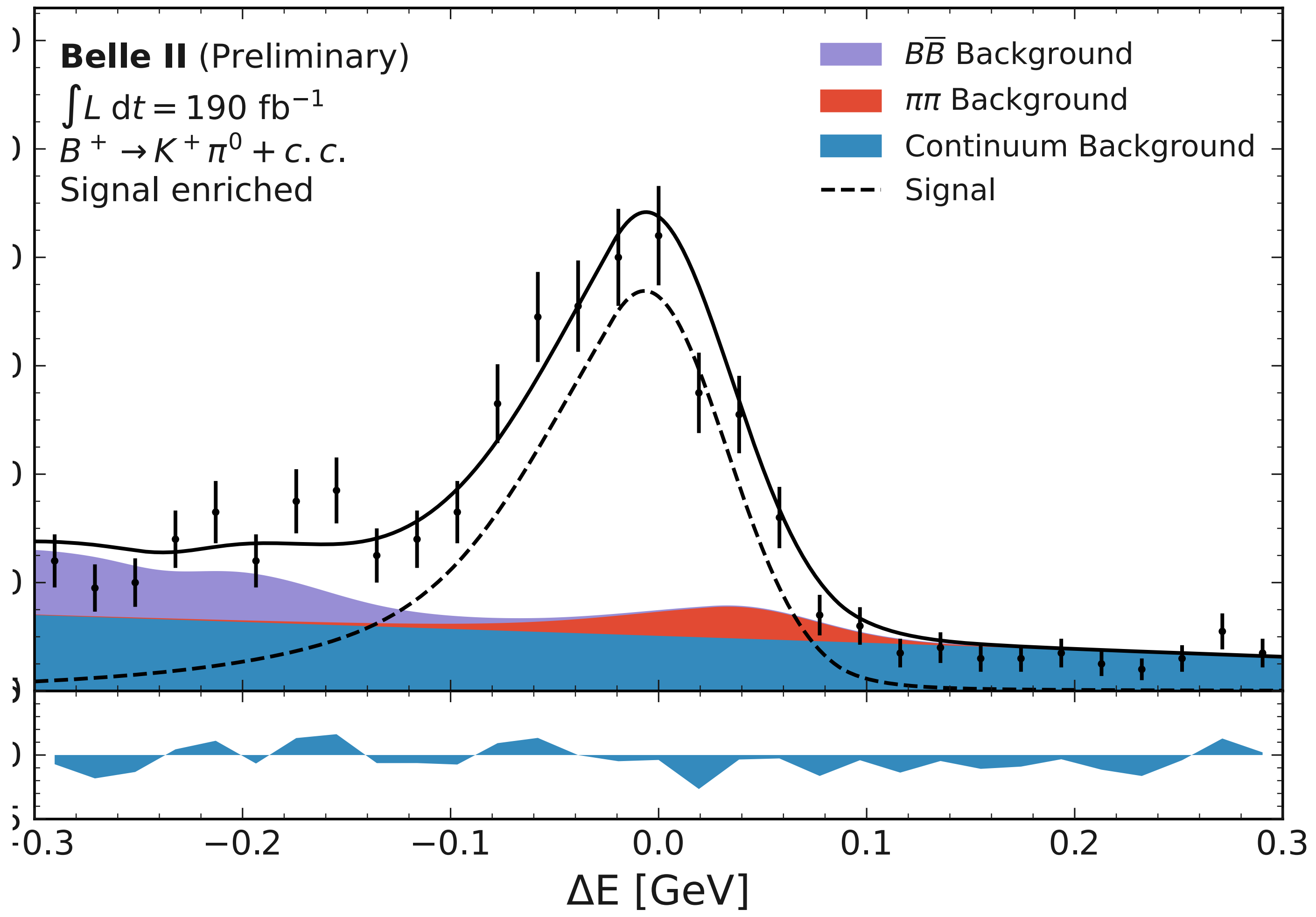
WA: $\mathcal{A}^{CP} = 0.33 \pm 0.22$, $\mathcal{B} = (1.59 \pm 0.26) \cdot 10^{-6}$



Justin Skorupa
@ICHEP2022

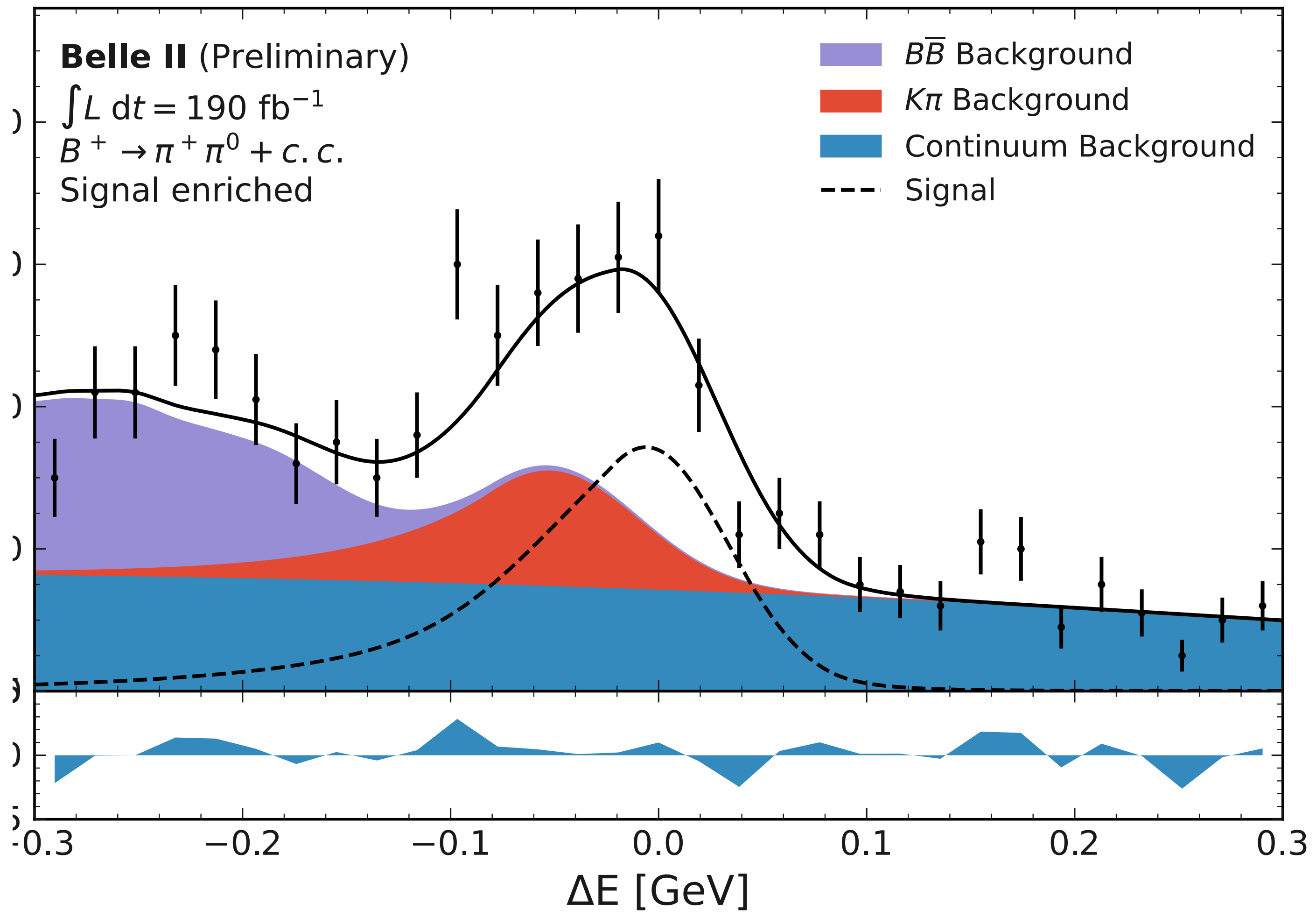
CKM angle ϕ_2 : $B^+ \to h^+\pi^0$

- $B^+ \to K^+\pi^0$ and $B^+ \to \pi^+\pi^0$ reconstructed using common selection.
  - $B^+ \to K^+\pi^0$ is an input for the "Kπ puzzle", large isospin violation in $B \to K\pi$ (see backup)
- ML fit of ΔE, M_{bc}, and continuum-suppression BDT output.
- Fit shapes controlled from off-resonance data and $B \to D(K\pi)\pi$ decays → leading systematic uncertainty from size of control samples.



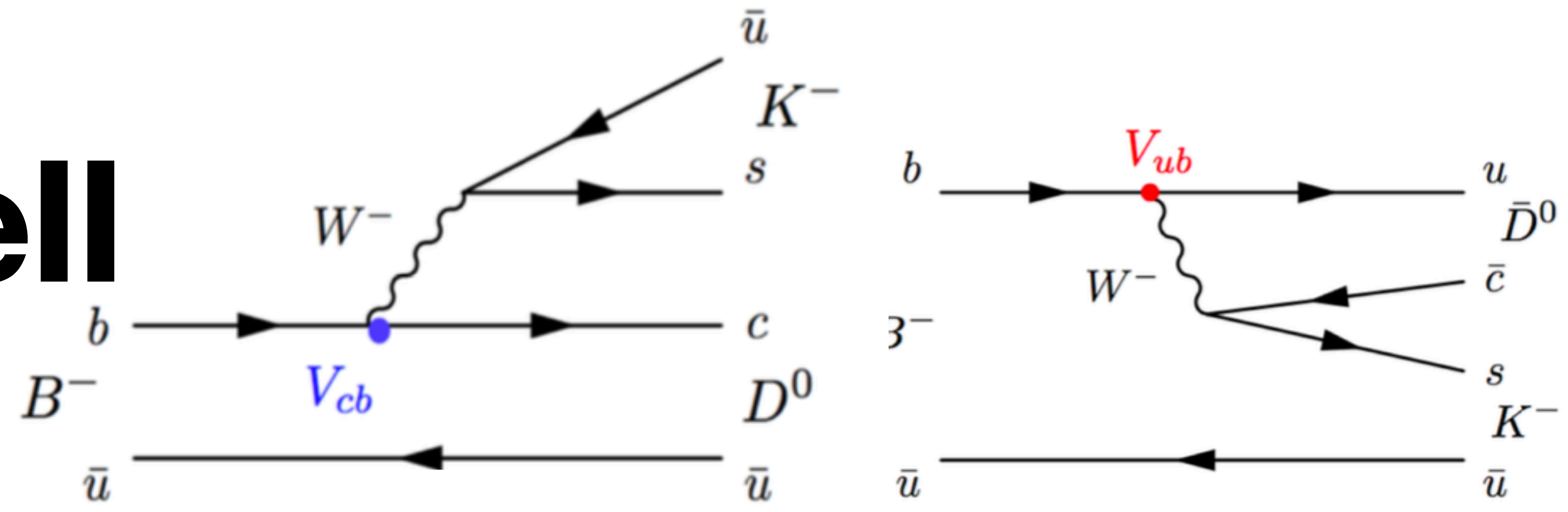
$$\mathcal{A}^{CP}_{K^+\pi^0} = 0.014 \pm 0.047\ (\text{stat}) \pm 0.010\ (\text{syst})$$
$$\mathcal{B}_{K^+\pi^0} = (14.30 \pm 0.69\ (\text{stat}) \pm 0.79\ (\text{syst}))\cdot 10^{-6}$$
$$\mathcal{A}^{CP}_{\pi^+\pi^0} = -0.085 \pm 0.085\ (\text{stat}) \pm 0.019\ (\text{syst})$$
$$\mathcal{B}_{\pi^+\pi^0} = (6.12 \pm 0.53\ (\text{stat}) \pm 0.53\ (\text{syst}))\cdot 10^{-6}$$

WA: $\mathcal{A}^{CP}_{K^+\pi^0} = 0.030 \pm 0.013$, $\mathcal{A}^{CP}_{\pi^+\pi^0} = 0.03 \pm 0.04$

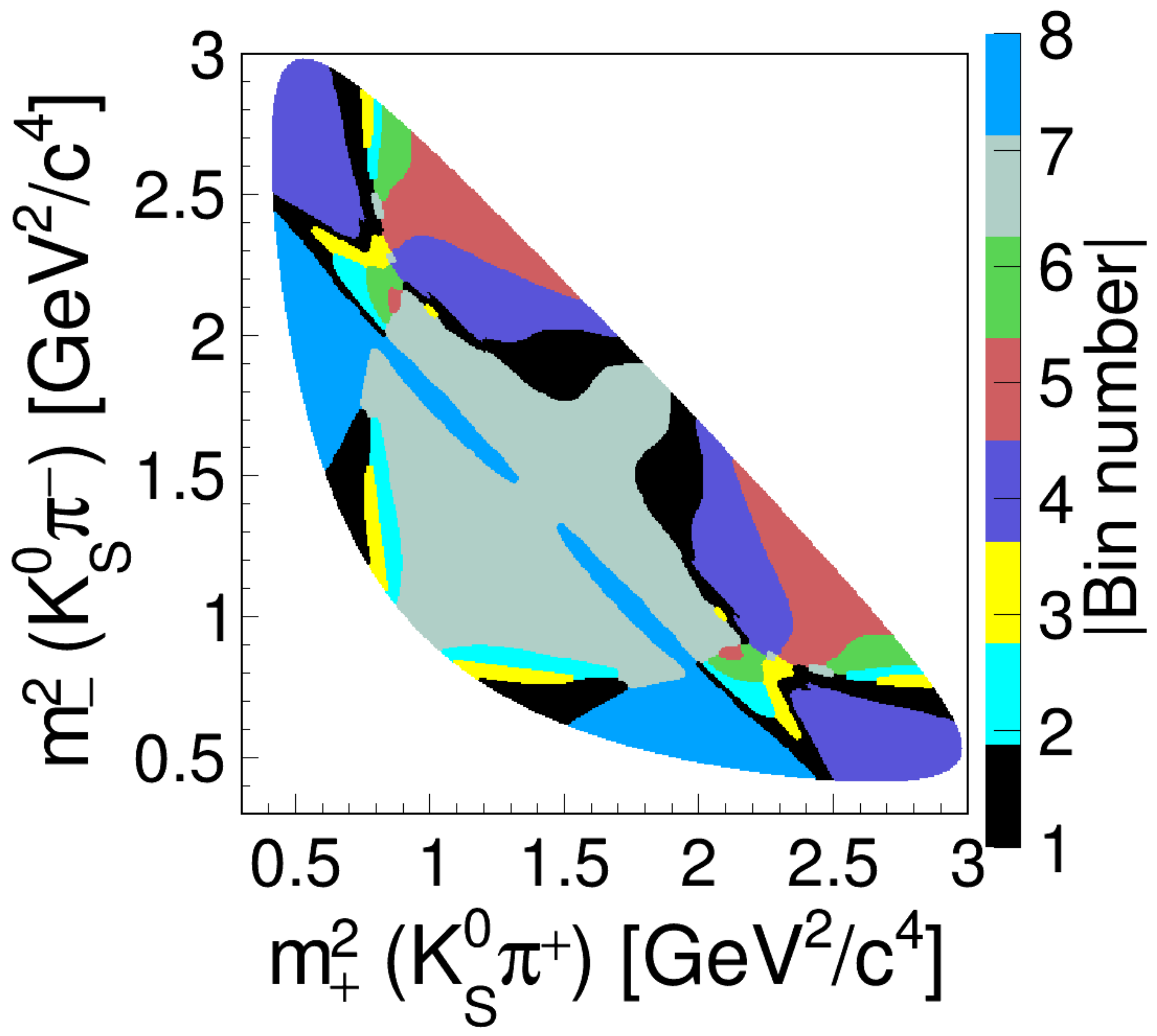


JHEP 02, 063 (2022)

CKM angle ϕ_3@Belle+BelleII

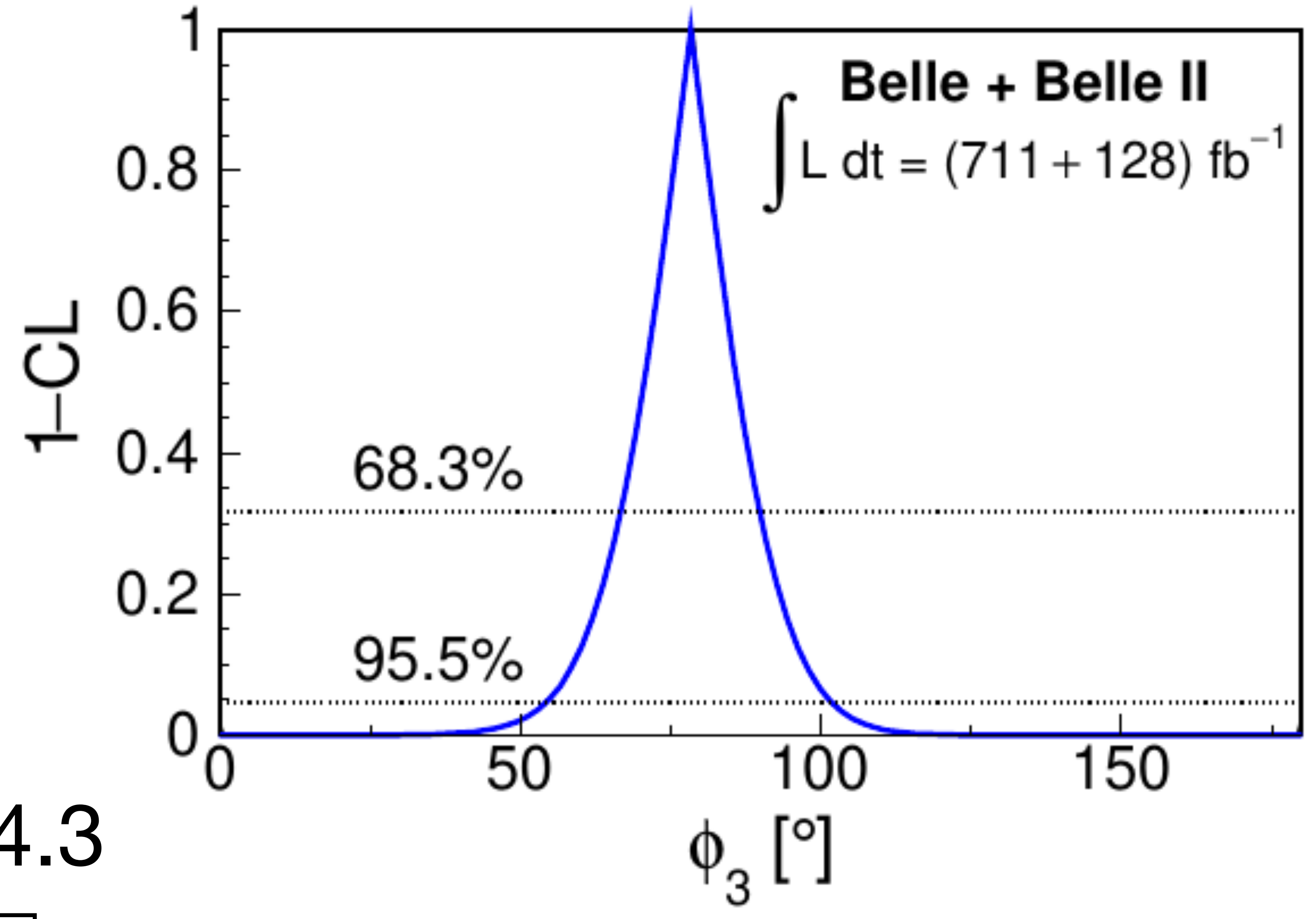


- Measured from interference of b→c$\bar{u}$s (**favored**) and b→u$\bar{c}$s (**suppressed**)
- Tree level process → SM benchmark mode, input for CKM fit. ⟶ *current status:* $(66.2^{+3.4}_{-3.6})^\circ$
- Competing with LHCb in this channel is difficult but still very important.
- Several techniques to extract the weak phase exist.
- **First combined Belle (711 fb^{-1}) and Belle II (128 fb^{-1}) analysis**
  - Using the BPGGSZ technique: model independent Dalitz plot.
  - Most sensitive single analysis, dominates at Belle/Belle II.



JHEP 02, 063 (2022)

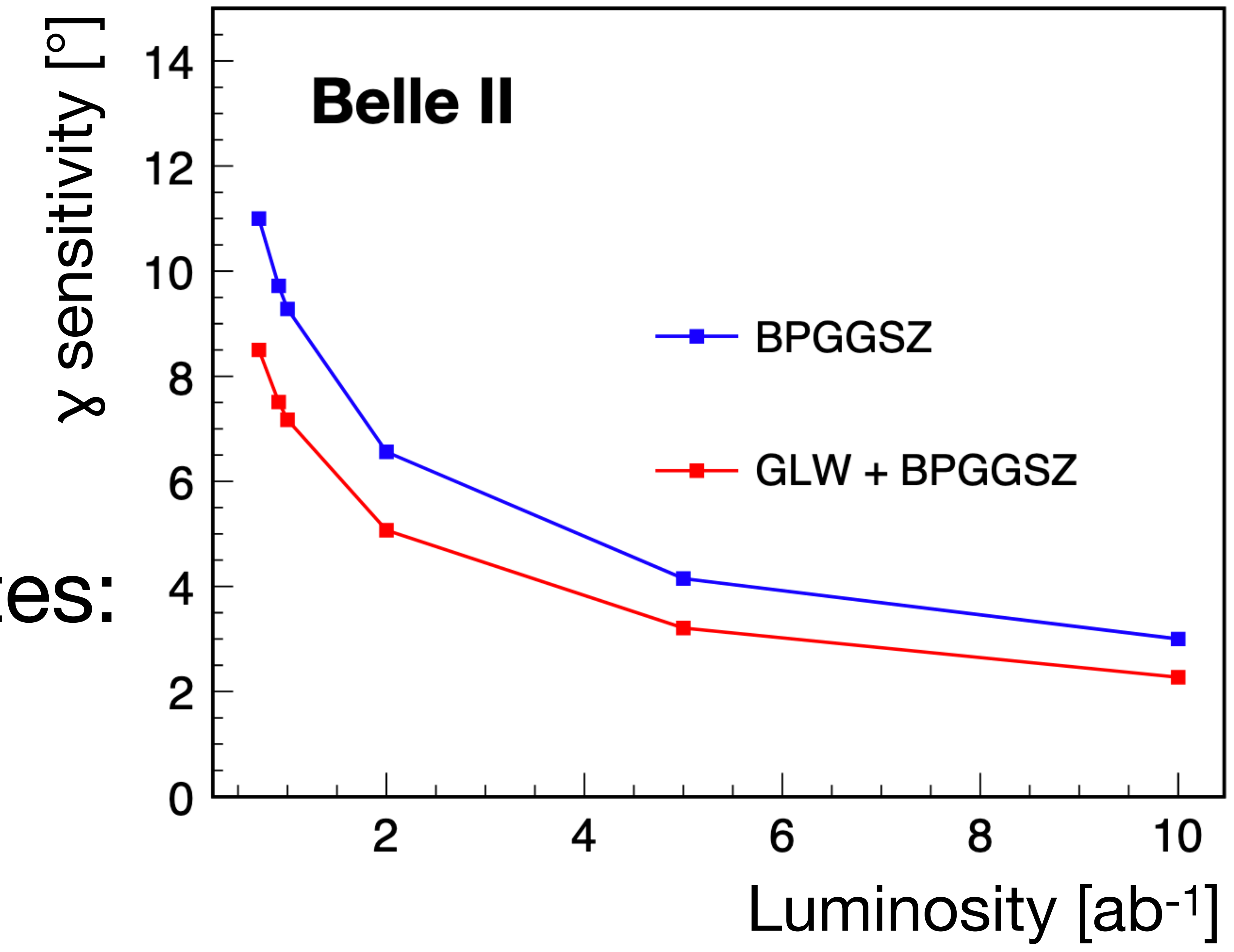
CKM angle ϕ_3@Belle+BelleII



- $\delta_B[°]$ = 124.8 ± 12.9 (stat) ± 0.5 (syst) ± 1.7 (ext)
  r_B = 0.129 ± 0.024 (stat) ± 0.001 (syst) ± 0.002 (ext)
  $\phi_3[°]$ = 78.4 ± 11.4 (stat) ± 0.5 (syst) ± 1.0 (ext)
- Previous Belle (711 fb^{-1}) result: $\phi_3[°] = 77.3^{+15.1}_{-14.9} \pm 4.1 \pm 4.3$

Phys. Rev. D 85, 112014 (2012)

- Total improvements equivalent to **doubling statistics.**
  - **Better** K_S selection, bkg suppression, analysis strategy.
  - **Improved systematics** from BES III external input.
- Expect <3° uncert. at 10 ab^{-1} by including more D final states:
- Measurement is still **statistically dominated.**

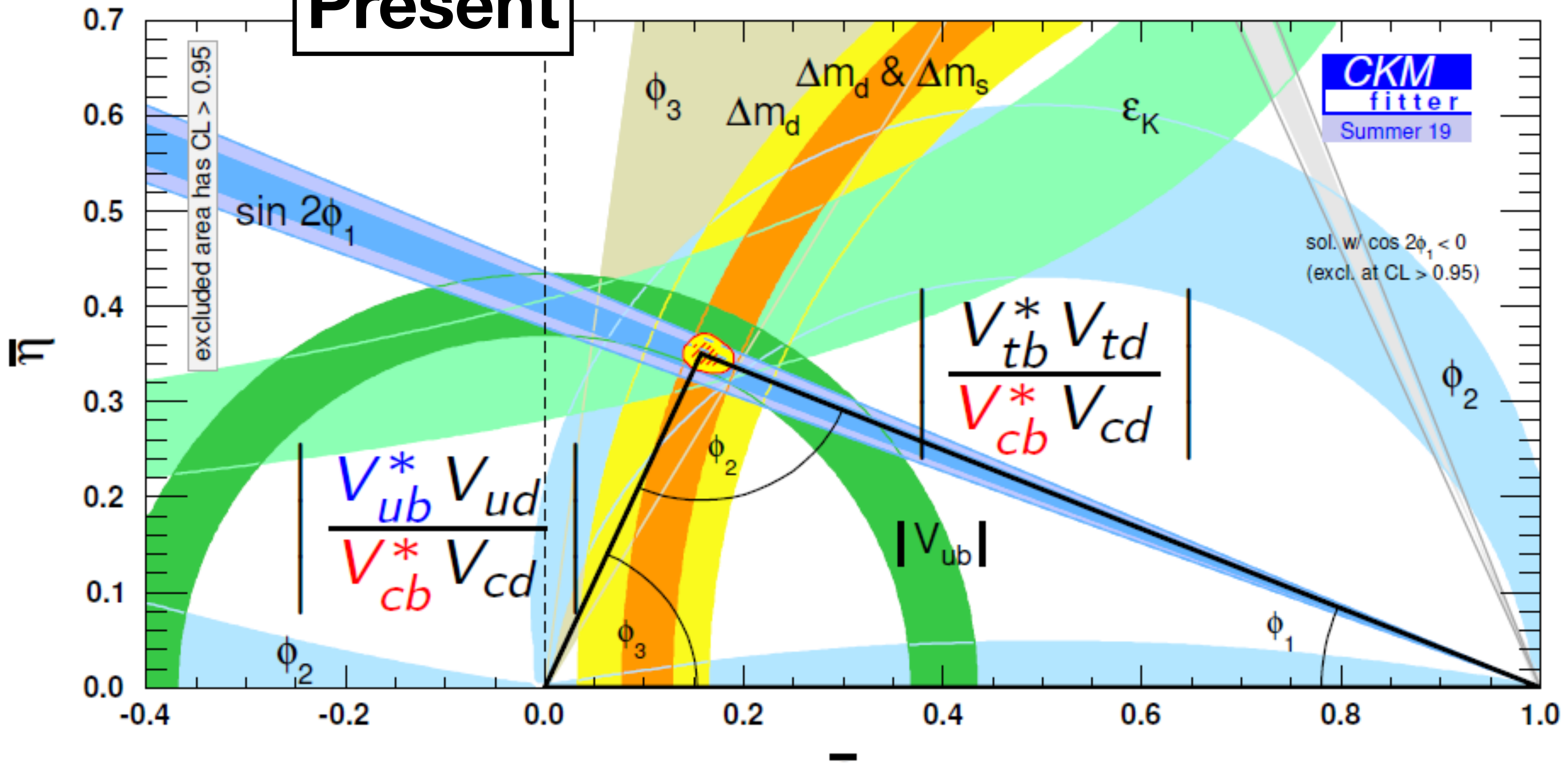


High luminosity prospects

Uncertainties from arXiv: 2203.11349

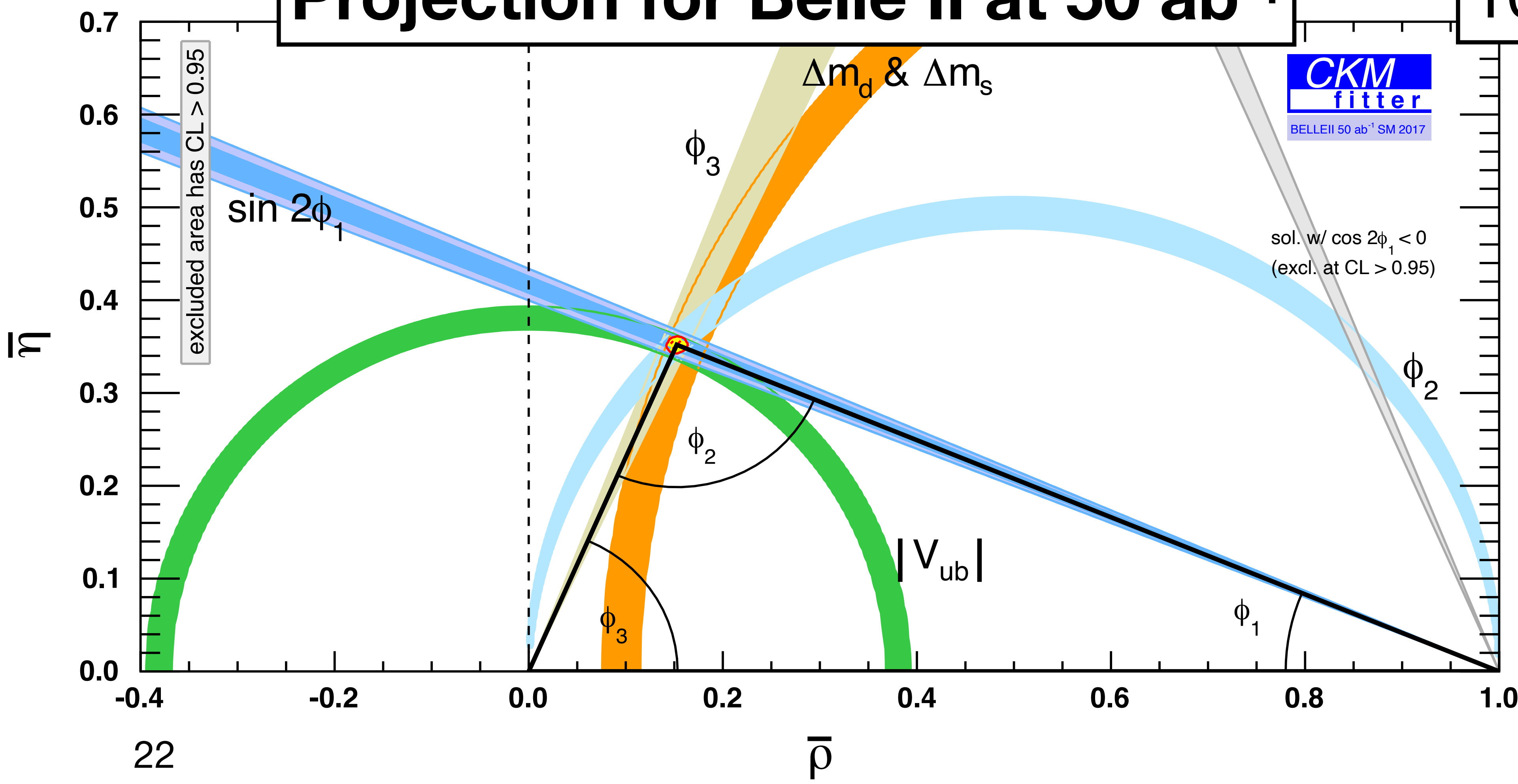
Observable	2022 Belle(II), BaBar	Belle-II $5\ ab^{-1}$	Belle-II $50\ ab^{-1}$	Belle-II $250\ ab^{-1}$
$\sin 2\beta/\phi_1$	0.03	0.012	0.005	0.002
γ/ϕ_3 (Belle+BelleII)	11°	4.7°	1.5°	0.8°
α/ϕ_2 (WA)	4°	2°	0.6°	0.3°
$\lvert V_{ub}\rvert$ (Exclusive)	4.5%	2%	1%	$< 1\%$

Present



Projection for Belle II at 50 ab^{-1}

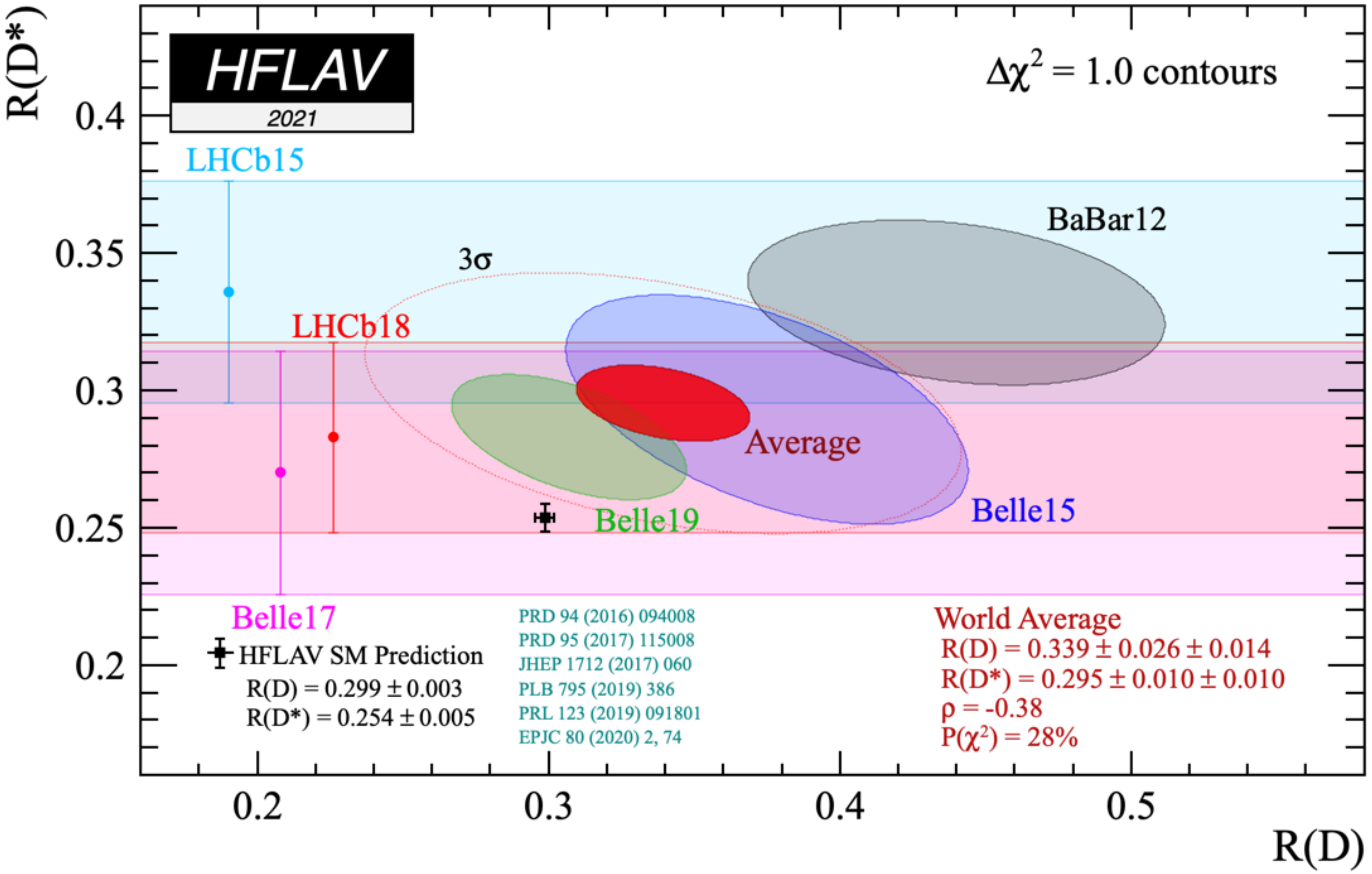
10.1093/ptep/ptz106



Lepton Flavour Universality

- EW coupling of gauge bosons is expected to be lepton-flavour-independent.
- Hints of LFU violation in charged current decays, e.g.:

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



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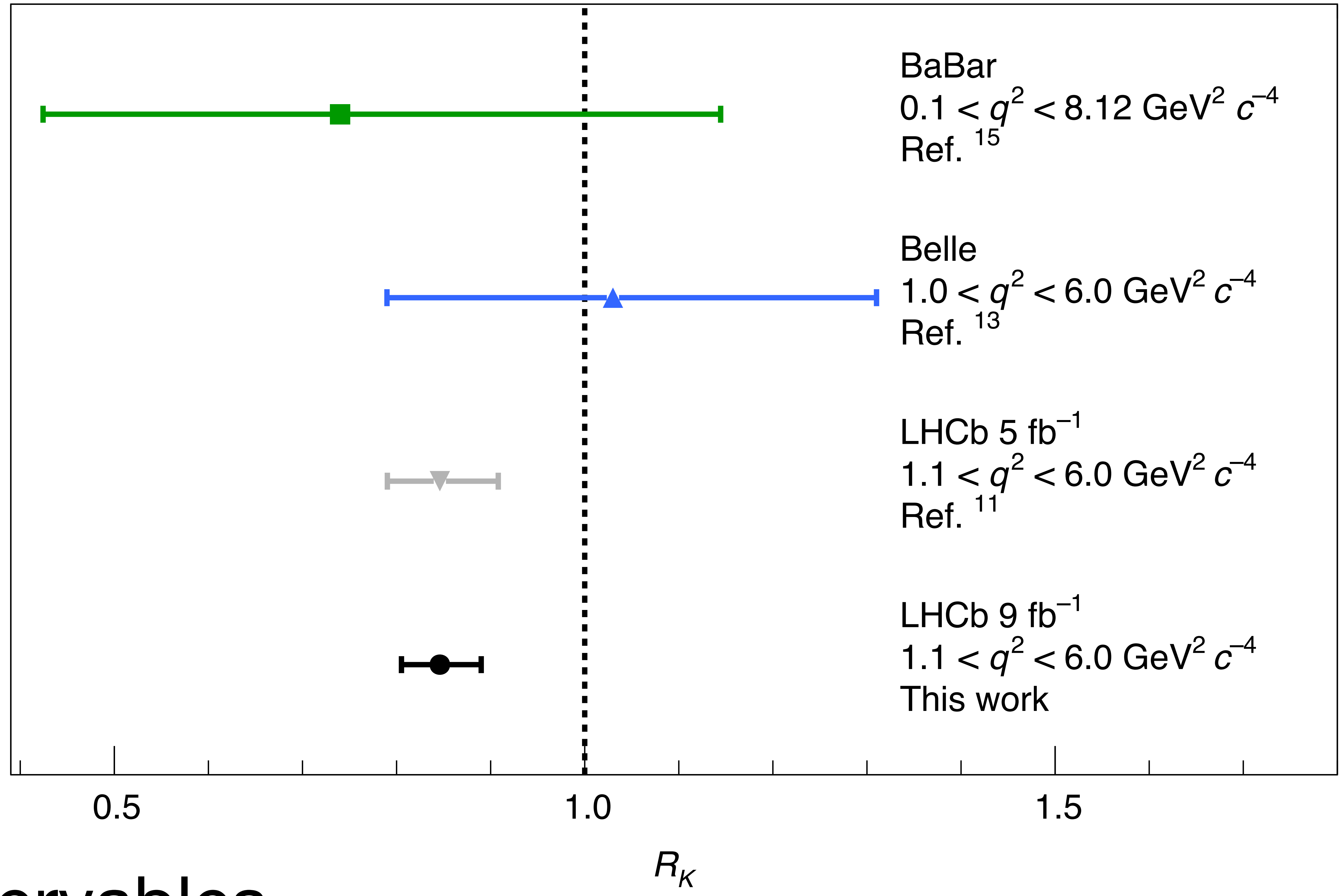
$$R(D^{(*)}) = \frac{BF(B \to D^{(*)}\tau\nu_\tau)}{BF(B \to D^{(*)}\ell\nu_\ell)}$$

$$R_K = \frac{BF(B \to K\mu^+\mu^-)}{BF(B \to Ke^+e^-)}$$



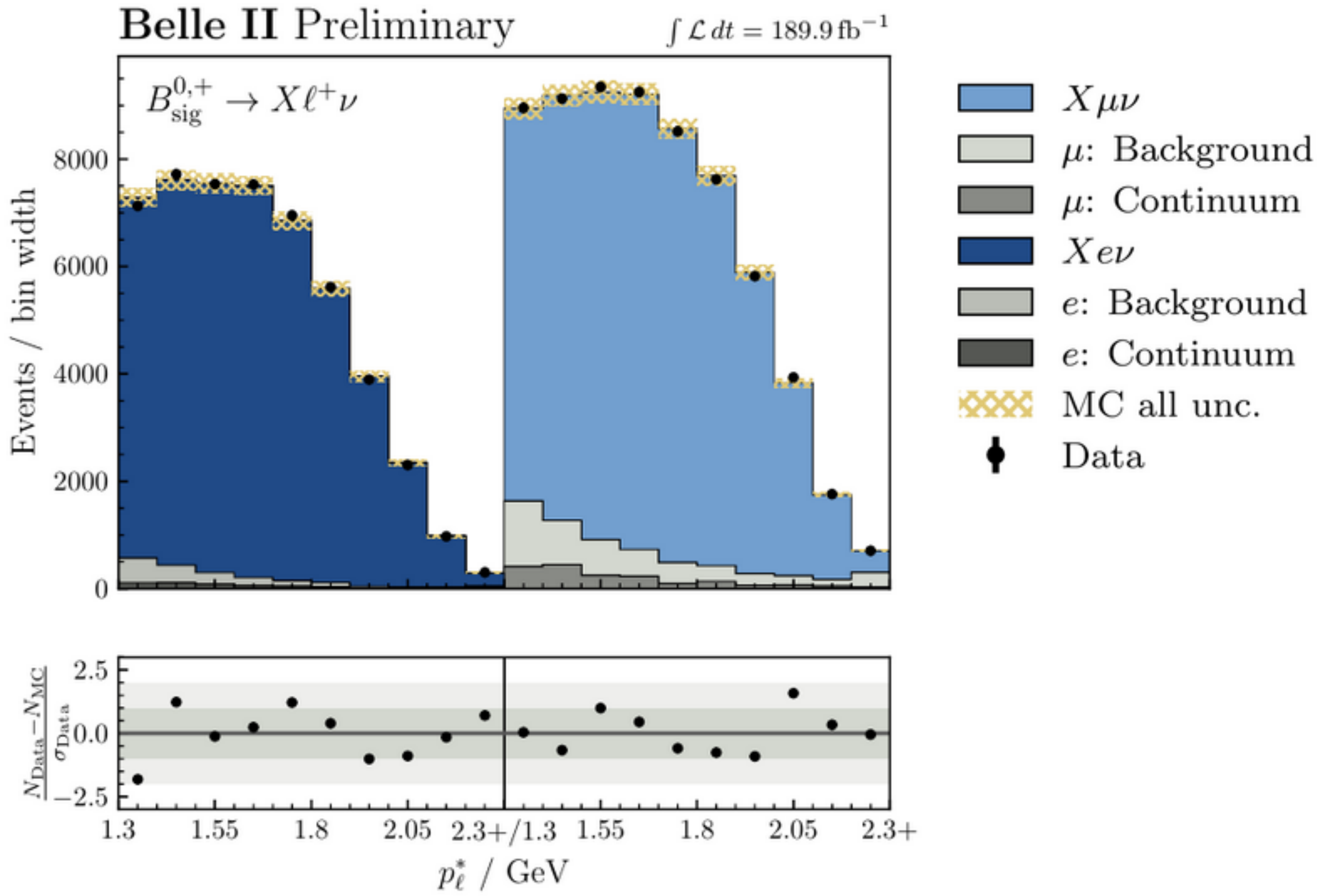
Nature Physics vol. 18, p. 277–282 (2022)

- ...and b→sll anomalies in angular observables.

Henrik Junkerkalefeld
@ICHEP2022

Independent test of LFU: R($X_{e/\mu}$)

- $R(X_{e/\mu}) = \dfrac{BF(B \to Xe\nu)}{BF(B \to X\mu\nu)}$ with hadronic tag.
- Binned template fit on CM lepton momentum.
- Backgrounds fixed from off-resonance data and sidebands while Xlv floats freely.
- Result: $R(X_{e/\mu})^{p_\ell^* > 1.3\,\mathrm{GeV}} = \mathbf{1.033 \pm 0.010^{stat} \pm 0.020^{syst}}$



- Most precise measurement, in agreement with SM and previous Belle measurement.
- Systematically dominated → can be improved with better lepton ID
- Paves the way for a measurement of $R(X_{\tau/\ell}) = BF(B \to X\tau\nu)/BF(B \to X\ell\nu)$

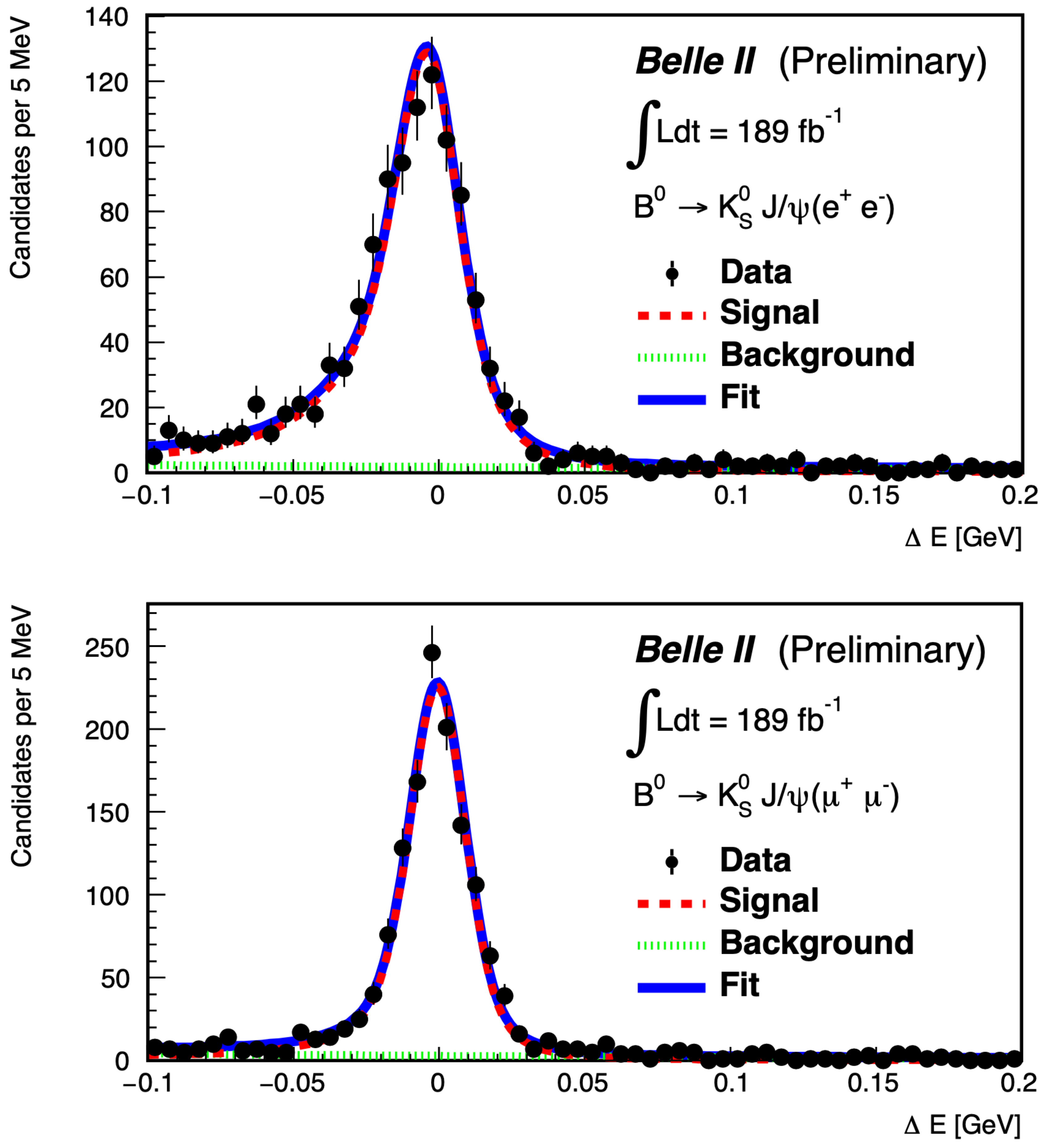
Eldar Ganiev
@ICHEP2022

Preparing to measure R(K*)

- Intermediate step: measure $R_K(J/\psi) = \dfrac{\mathcal{B}(B \to J/\psi(\mu^+\mu^-)K)}{\mathcal{B}(B \to J/\psi(e^+e^-)K)}$
- Tree level, process, so no violation expected.
- Validates R_K measurement and lepton identification.
- Simultaneous fit of M_{bc} and ΔE.

Observable	Belle II	Belle (2021)
$R_{K^+}(J/\psi)$	$1.009 \pm 0.022 \pm 0.008$	$0.994 \pm 0.011 \pm 0.010$
$R_{K^0_S}(J/\psi)$	$1.042 \pm 0.042 \pm 0.008$	$0.993 \pm 0.015 \pm 0.010$

- Systematics (dom. by Lepton ID) improved w.r.t. Belle
- Belle II can provide independent check with a few ab^{-1}.

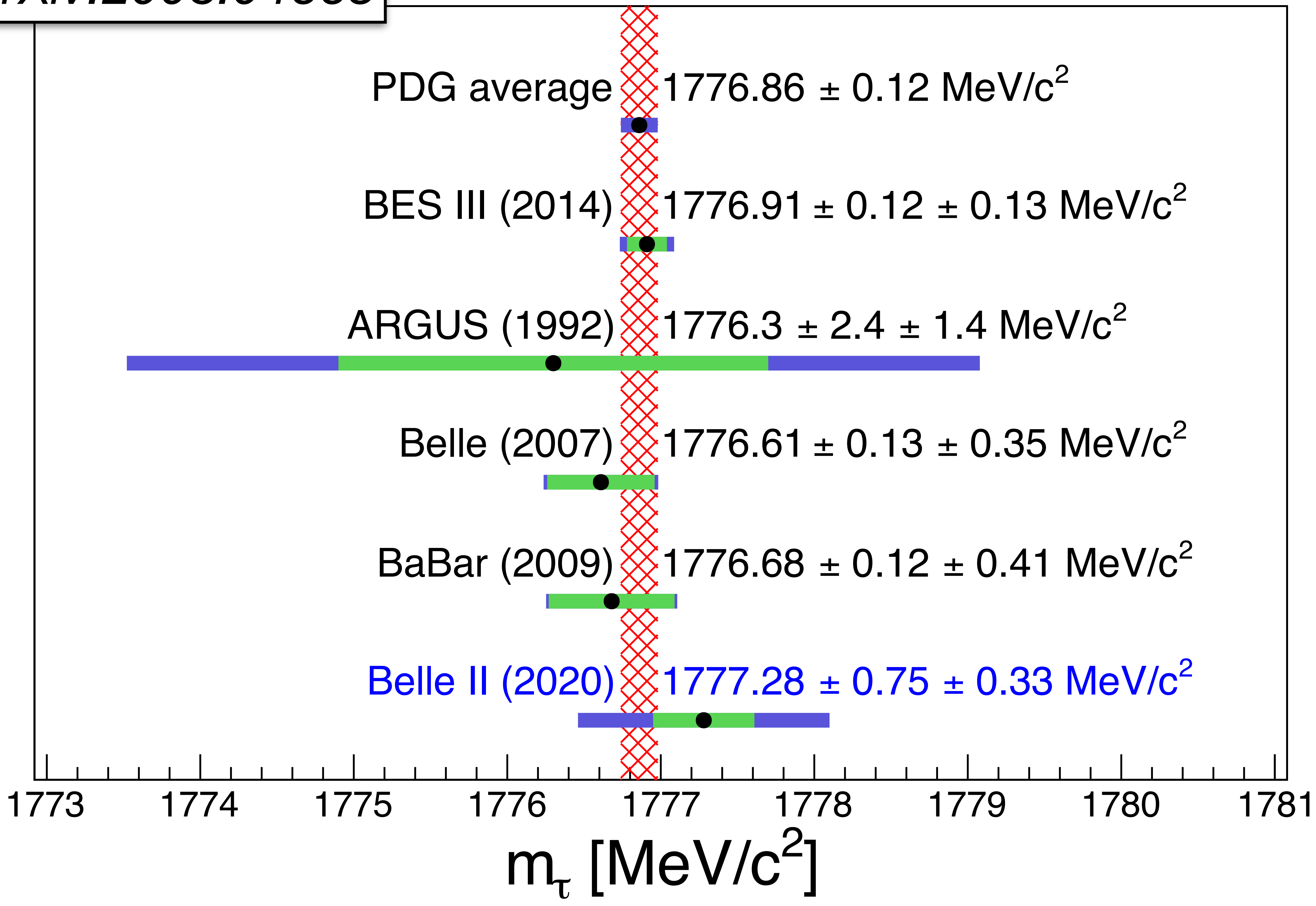


τ physics @ Belle II

$\sigma(e^+e^- \to \Upsilon(4S))$	**1.05 nb**
$\sigma(e^+e^- \to \tau^+\tau^-)$	0.92 nb

- **τ mass and lifetime** → crucial inputs for lepton flavour universality tests.

arXiv:2008.04665



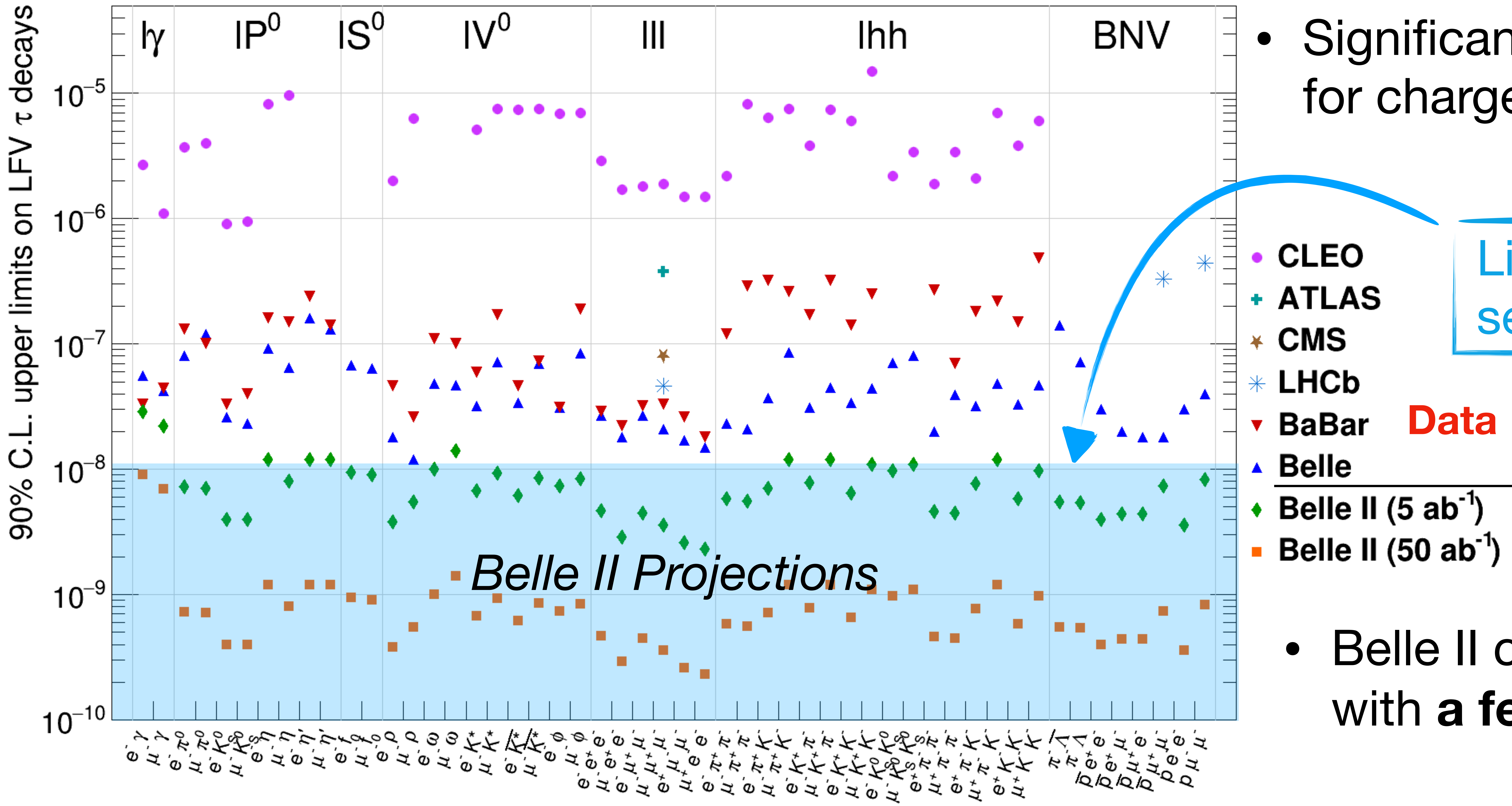
- **Mass** systematics already comparable to Belle/BaBar in preliminary studies.

  → Improve statistics with 2022 luminosity.

- Similarly to charm, improved vertex reconstruction (**x2** of Belle) allows precise **lifetime** measurements and study of **CP violation** in $\tau \to K_S \pi \nu$.

- Wide range of other observables e.g. lepton universality, V_{us} from hadronic decays, anomalous moments, etc.

Lepton Flavour Violation in the τ Sector



- Significant progress in the search for charged LFV from Belle/BaBar

Limits approach the region sensitive to NP.

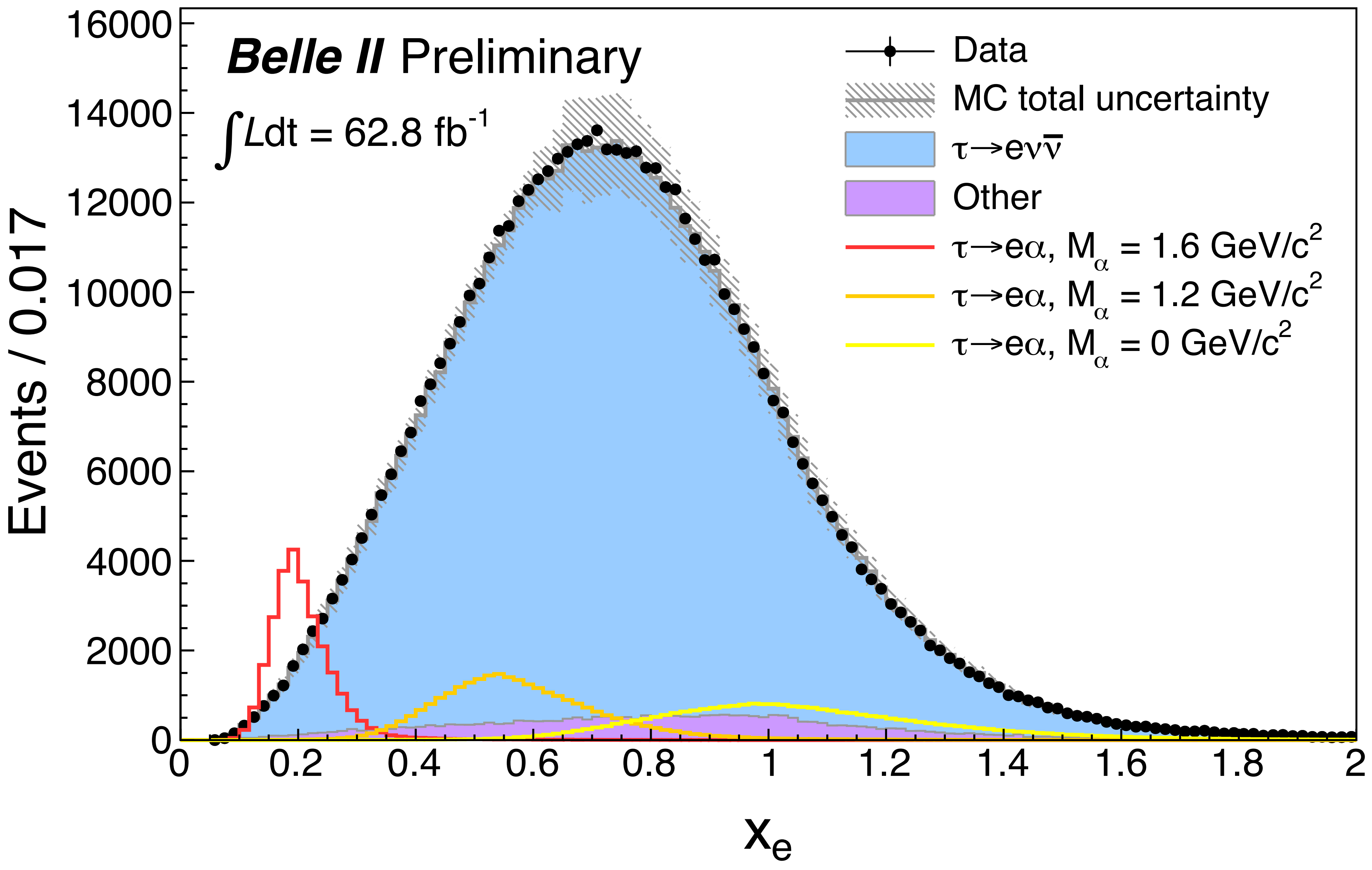
- Belle II can probe this region with **a few ab^{-1}**

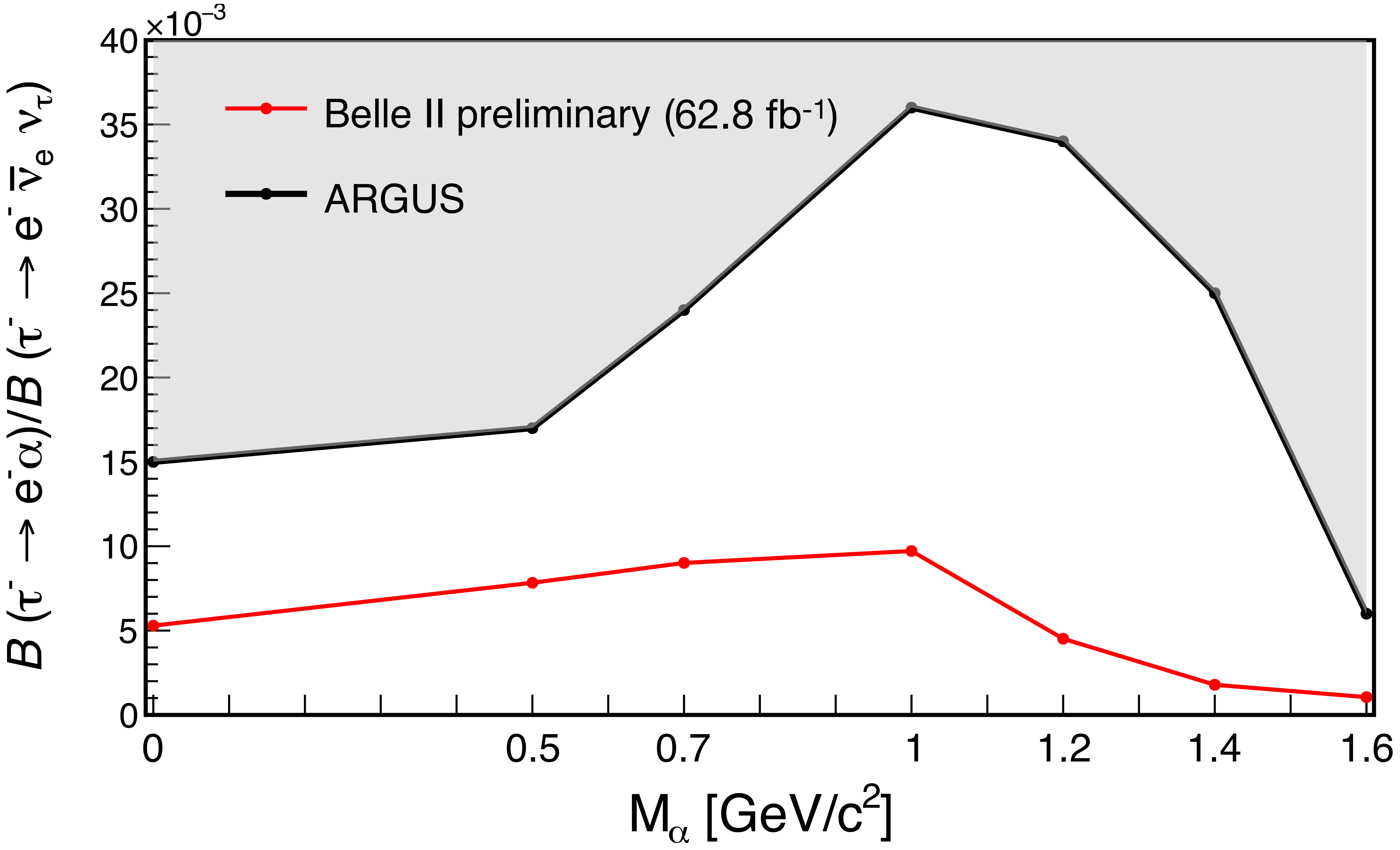
arXiv:2203.14919

Preliminary
@ICHEP2022

$\tau \to \ell + \alpha$ (invisible)

- Invisible LFV particles can emerge from new physics models e.g. light ALP (*JHEP 09 (2021) 173*)
- Not searched since ARGUS.
- Tag $e^+e^- \to \tau^+\tau^-$ using $\tau \to 3\pi\nu$, then search for excess above the $\tau \to \ell\nu\nu$ spectrum.
- Requires careful control of lepton ID → measure ratio $B(\tau \to \ell\alpha)/B(\tau \to \ell\nu\nu)$ to allow partial systematics cancellation.
- 95% CL UL is the **most stringent** to date.





ARGUS: *Z. Phys. C 68 (1995) 25*

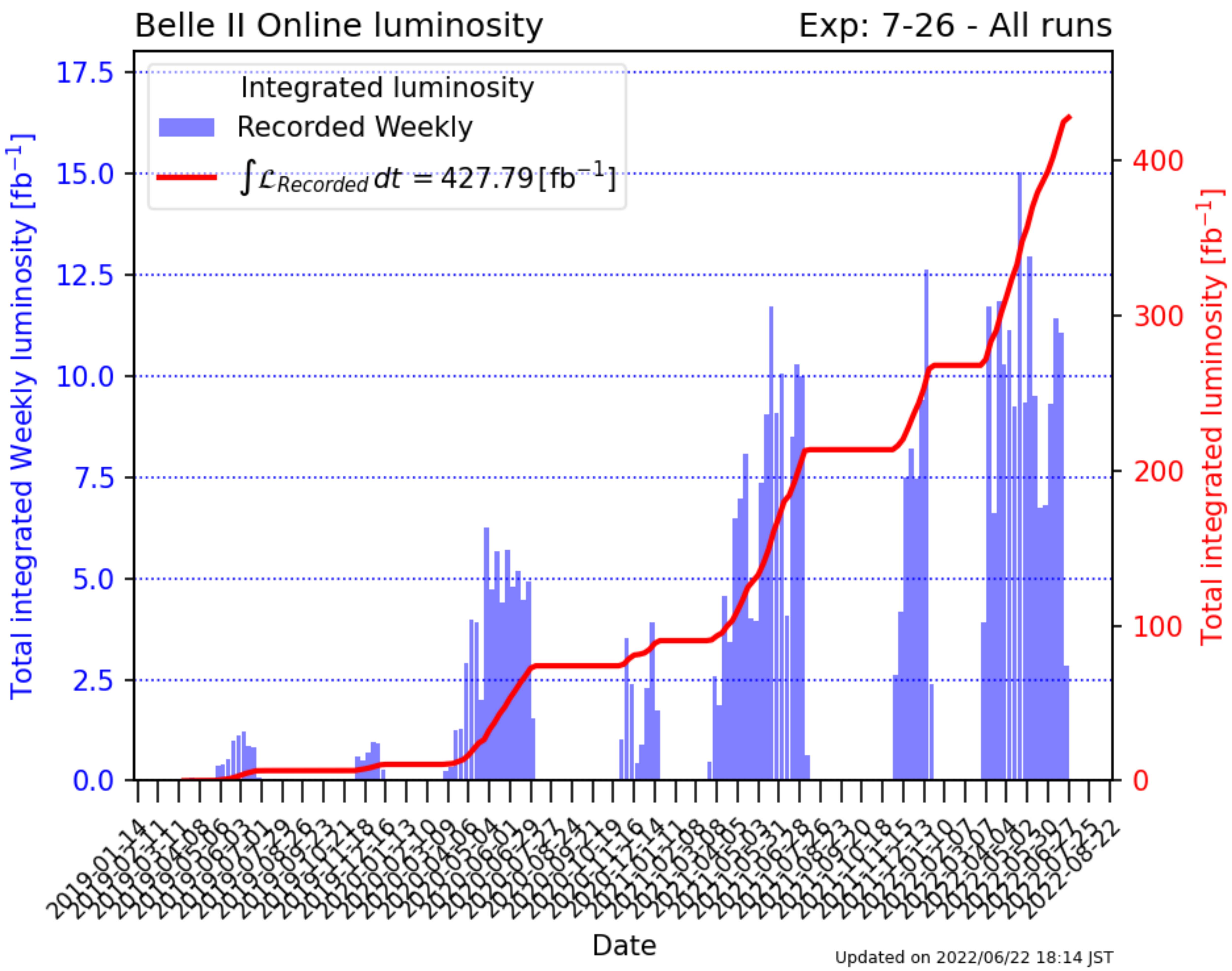
Summary

- Belle II started its journey and offers a unique and fertile environment for flavour physics.
- With 424 fb^{-1} LS1 data Belle II can already provide physics output on the level of its predecessors, as well as joint results with Belle.
- We have started producing high quality analyses and will soon see the impact on world averages.

- **Many more topics** I wasn't able to cover:
  - FCNC (e.g. $B \to K^{(*)}\nu\nu$);
  - Hadron spectroscopy at energies above $\Upsilon(4S)$;
  - B^0 lifetime and mixing measurement;
  - $B \to \rho\rho$, etc.

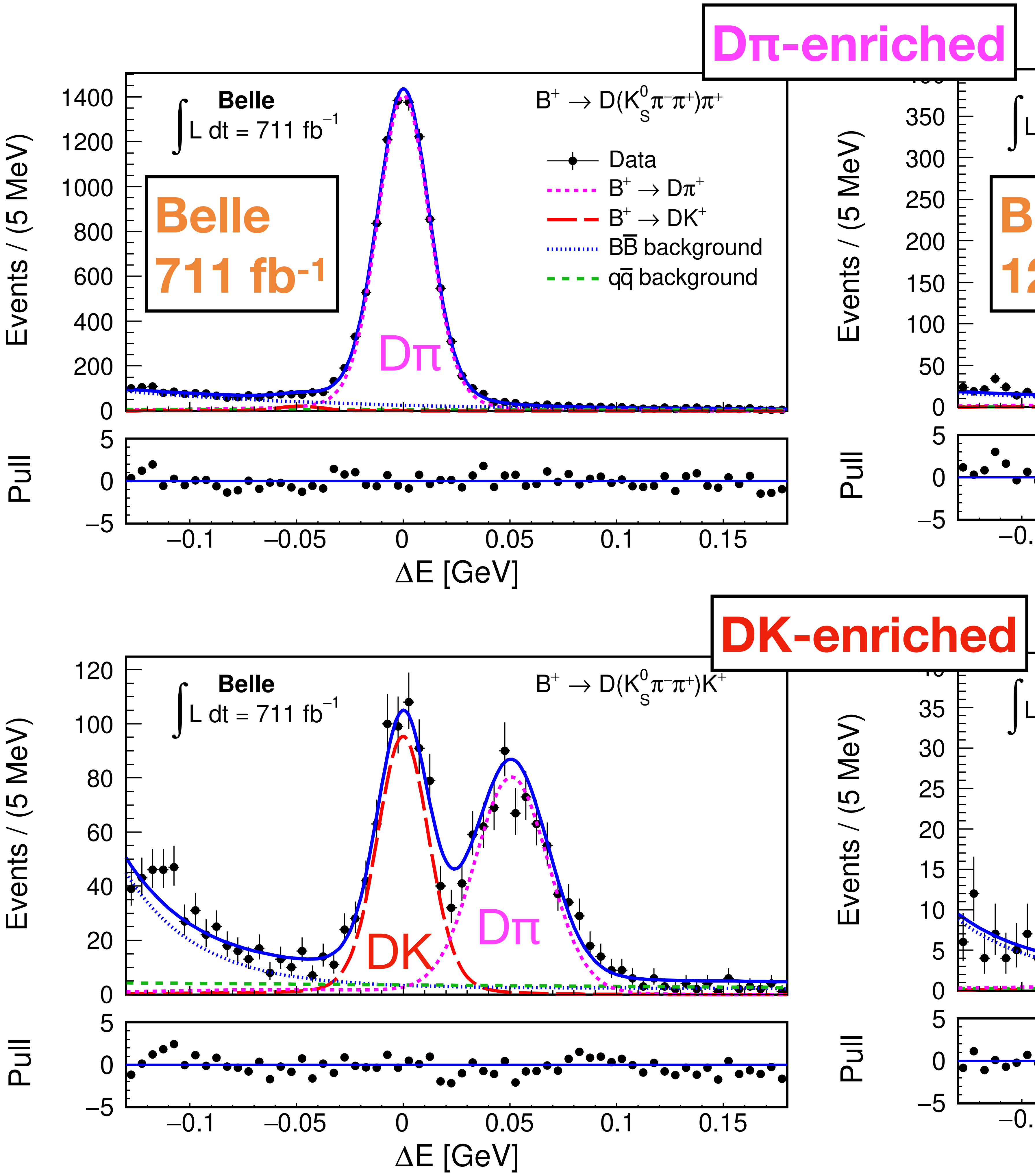
BACKUP

Belle II Luminosity



- Total integrated luminosity: **424 fb^{-1}**
  - At the Y(4S) resonance: **363 fb^{-1}**
  - Below Y(4S) resonance: **42 fb^{-1}**
  - Above Y(4S) resonance: **19 fb^{-1}**

CKM angle ϕ_3@Belle+BelleII



- Simultaneous fit of B→Dπ, B→DK to extract K-π efficiencies and misidentification rates from data.

$$\Delta E = \sum_i E_i^* - E_{\text{beam}}^*$$ + BDT output

Belle:
$K_S{}^0\pi\pi$: 1467 ± 53
$K_S{}^0KK$: 194 ± 17

Belle II :
$K_S{}^0\pi\pi$: 280 ± 21
$K_S{}^0KK$: 34 ± 7

@Moriond 2022

The Kπ Puzzle

- Model independent test of new physics.
- Null sum in SM from isospin rule:

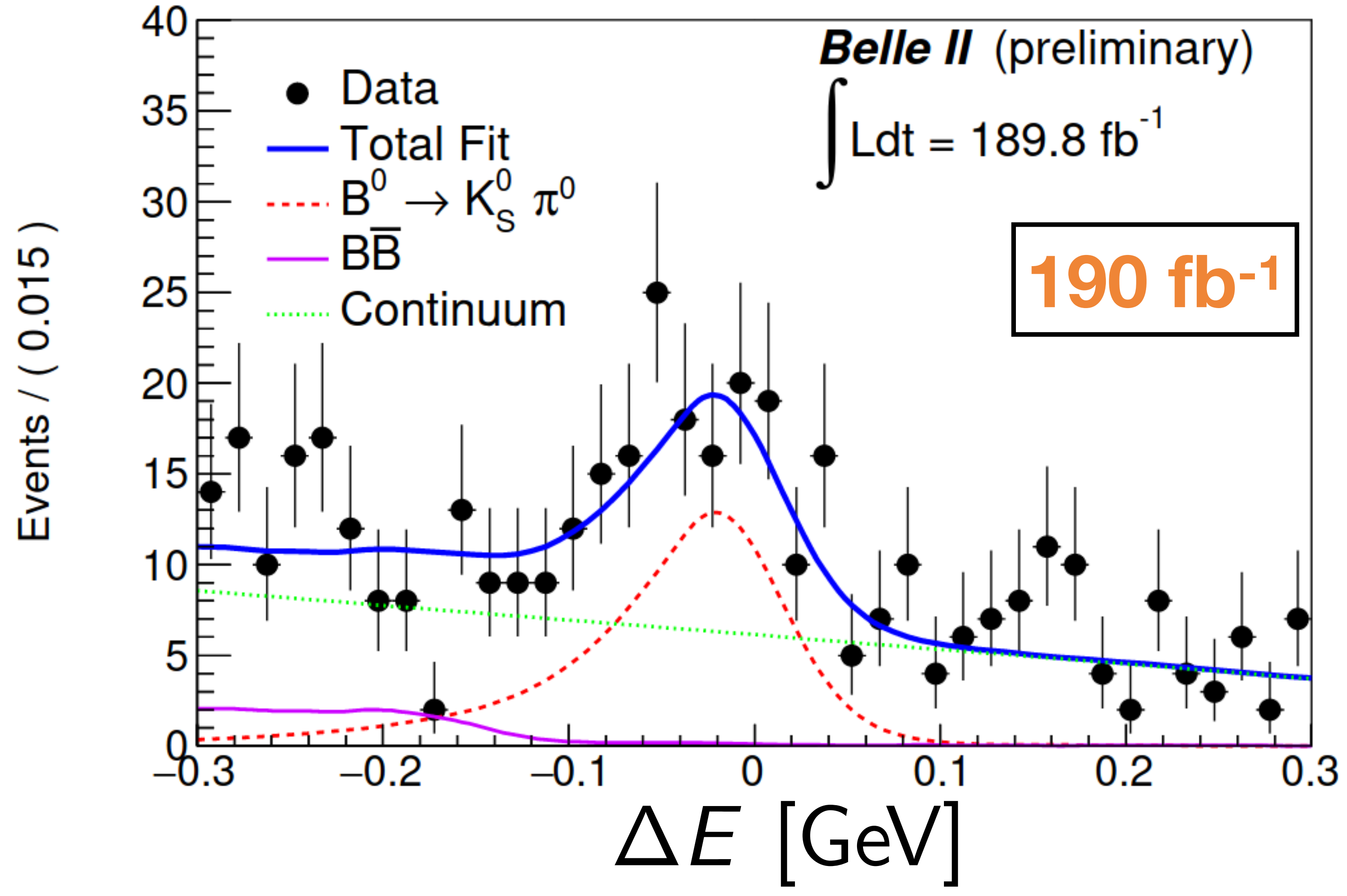
$$2A_{CP}(B^0 \to K^+\pi^-) + 1.3A_{CP}(B^+ \to K_S\pi^+)$$
$$- 1.2A_{CP}(B^+ \to K^+\pi^0) - A_{CP}(B^0 \to K_S\pi^0) \approx 0$$

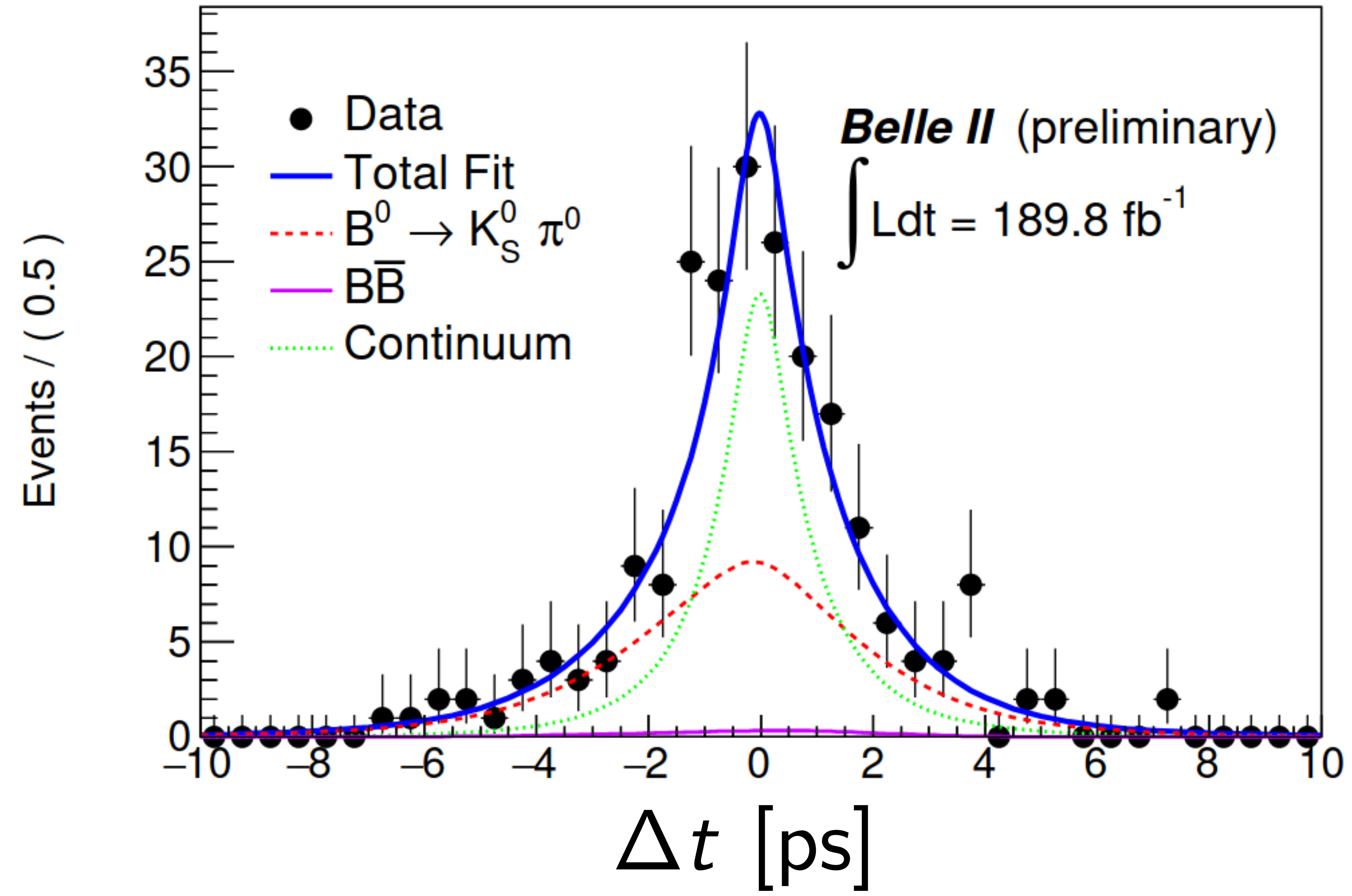
dominant uncertainty

- Challenge: need good neutral reconstruction, precise beam spot knowledge to reconstruct Ks decay → **unique to B-Factories.**
- 4D unbinned maximum likelihood fit in ΔE, Δt, M_{bc}, BDT out

$$A_{CP} = -0.41^{+0.30}_{-0.32}\,(\text{stat.}) \pm 0.09\,(\text{syst.})$$
$$\mathcal{B} = (11.0 \pm 1.2\,(\text{stat.}) \pm 1.0\,(\text{syst.})) \times 10^{-6}$$

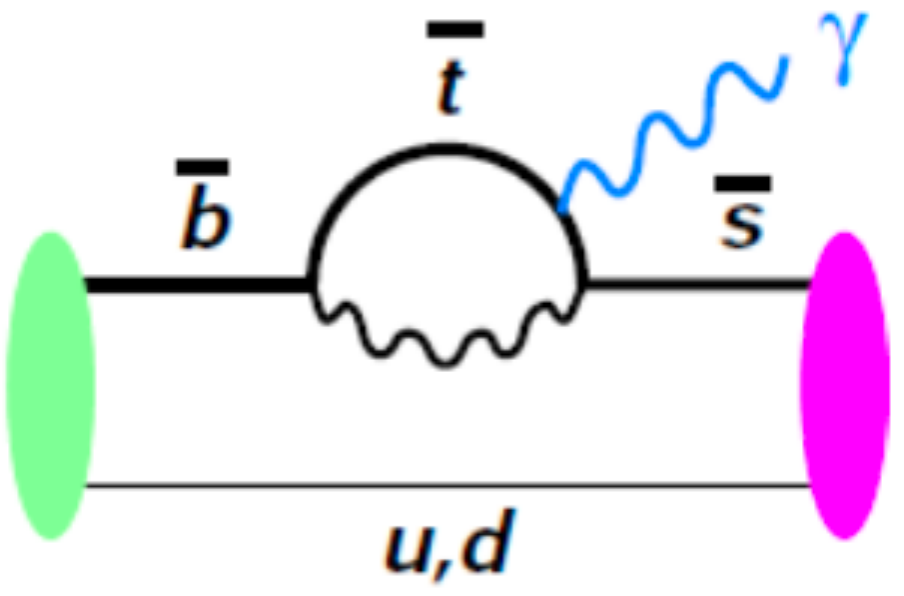
World average: $A_{CP} = 0.00 \pm 0.13.$





$$m_{bc} = c^{-2}\sqrt{E^{*2}_{beam} - \left|\sum_i \vec{\mathbf{p}}^*_i\right|^2 c^2},$$

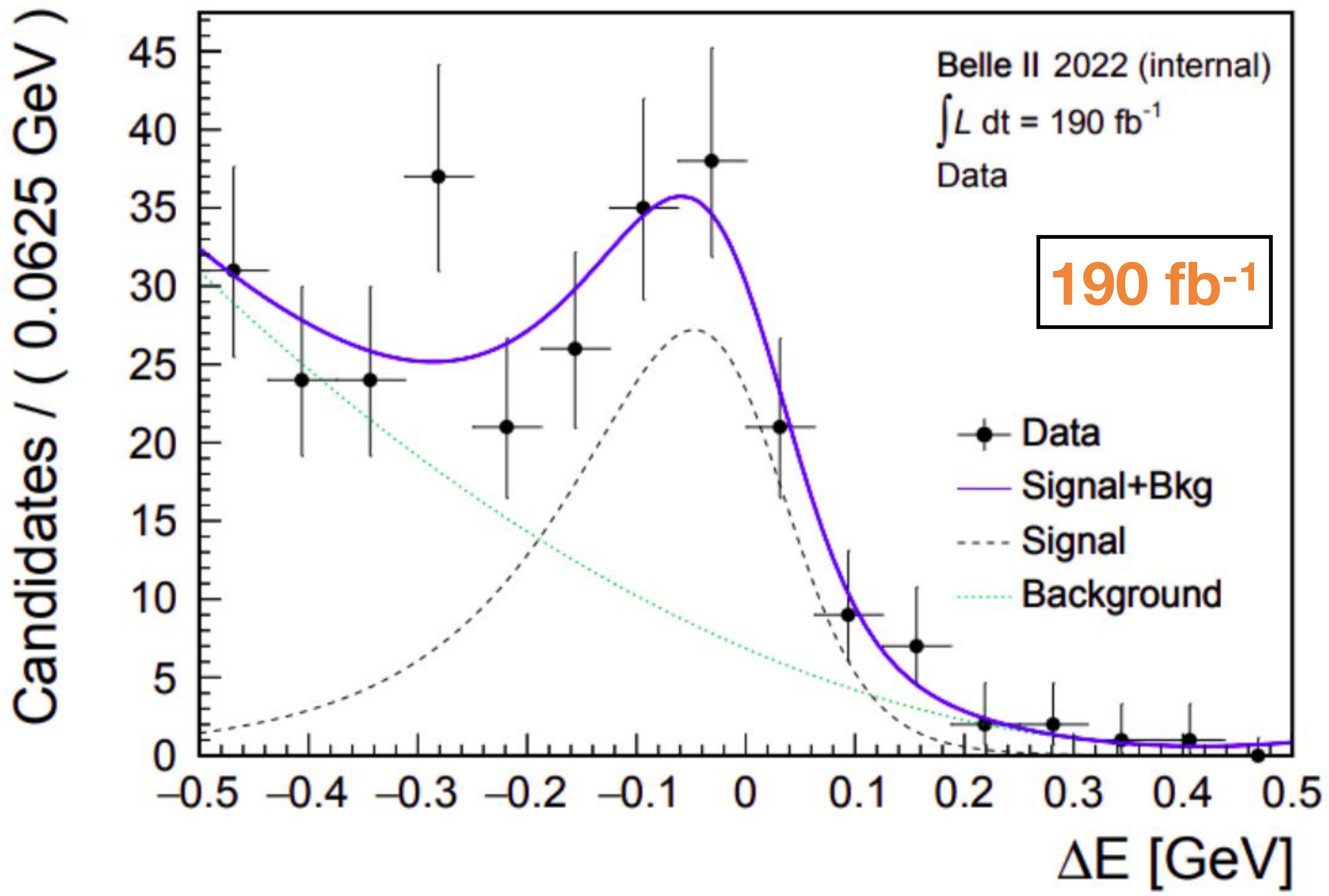
Branching Fraction of $B^0 \to K_S \pi^0 \gamma$ @Belle II



- $b \to s\gamma$ is only possible at loop level in SM.
- **Flavour-specific** polarization: $B^0 \to K_S \pi^0 \gamma$(RH) and $\bar{B}^0 \to K_S \pi^0 \gamma$(LH)
  - we do not expect time-dependent asymmetry in SM
  - possible in NP with different chiral structure
- **$B^0 \to K_S \pi^0 \gamma$ is only measurable at B-Factories**
- In preparation of a time-dependent analysis, we measure the BF:

$$\mathcal{B} = (7.3 \pm 1.8\ (\text{stat.}) \pm 1.0\ \text{syst}) \times 10^{-6}$$

Compatible with world average
$\mathcal{B} = (7.0 \pm 0.4) \times 10^{-6}$



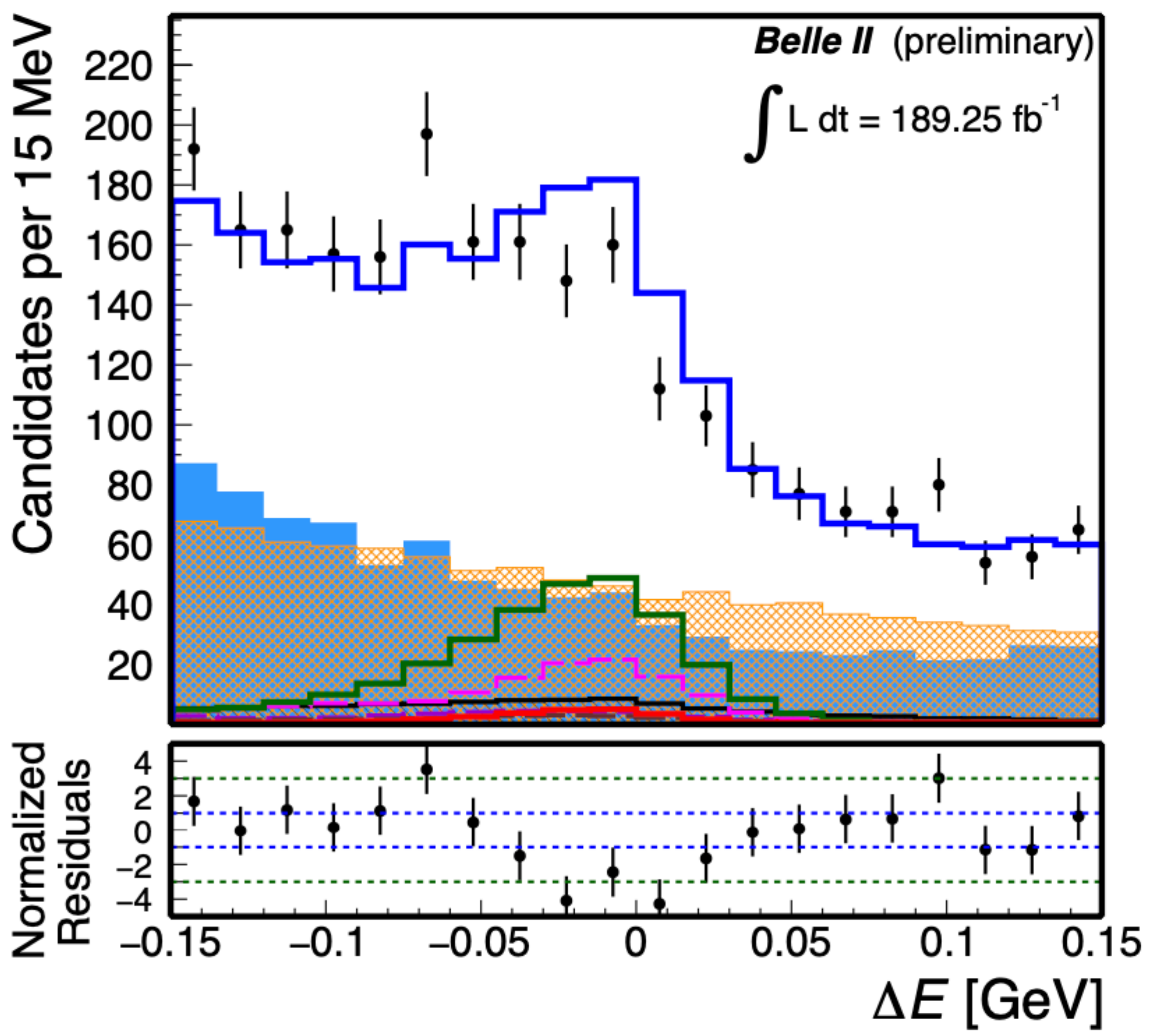
$B^+ \to \rho^+\rho^0$ @ Belle II

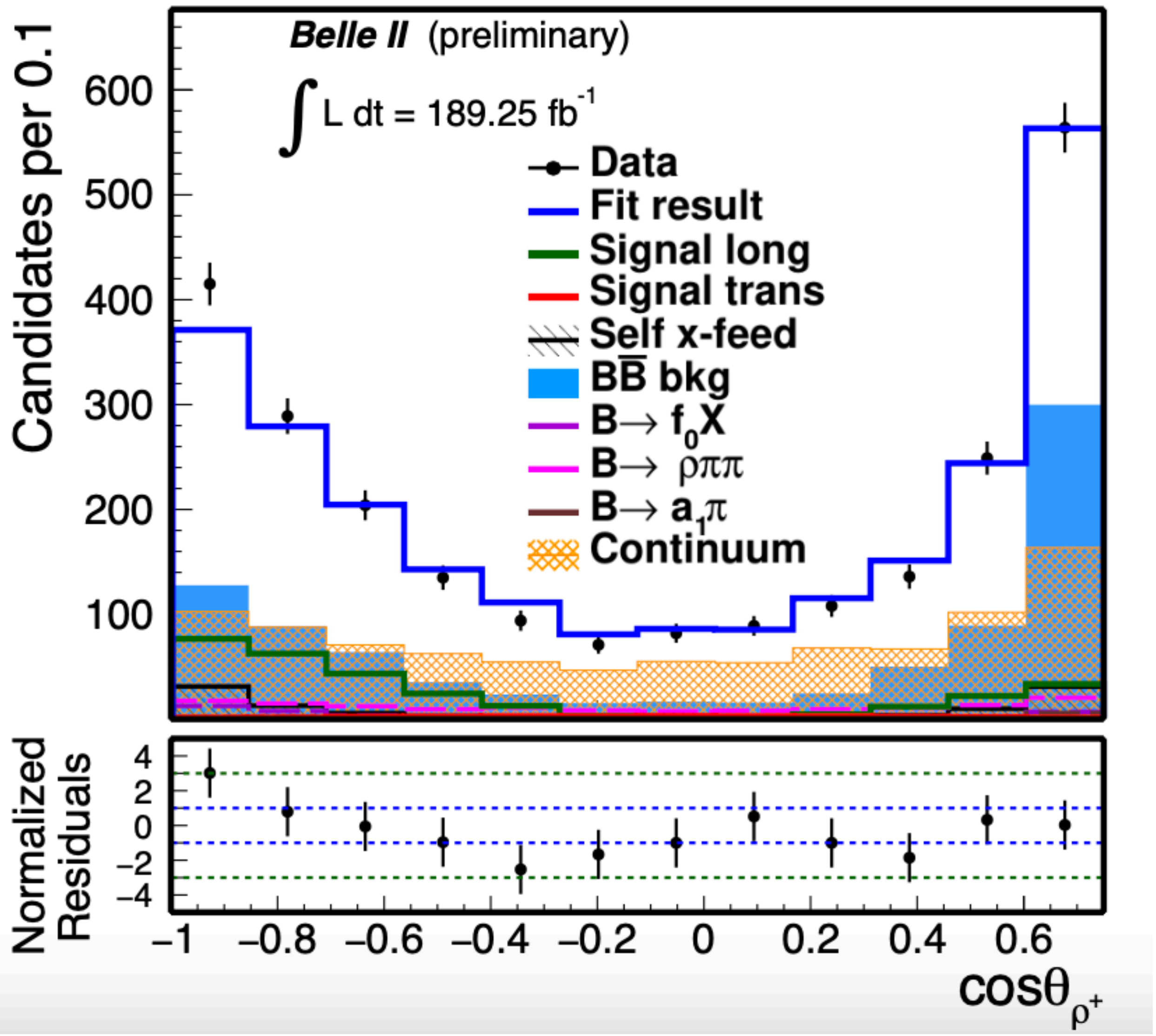
Preliminary @Moriond

- Can access CKM angle ϕ_2 by combining measurements of $\mathbf{B^+ \to \rho^+\rho^0}$, $B^0 \to \rho^0\rho^0$, $B^0 \to \rho^+\rho^-$
- Direct CPV measurement only possible at B-factories

$$A_{CP} = -0.069 \pm 0.068\,(\text{stat.}) \pm 0.060\,(\text{syst.})$$
$$\mathcal{B}(B^+ \to \rho^+\rho^0) = \left(23.2^{+2.2}_{-2.1}\,(\text{stat.}) \pm 2.7\,(\text{syst.})\right) \times 10^{-6}$$
$$f_L = 0.943^{+0.035}_{-0.033}\,(\text{stat.}) \pm 0.027\,(\text{syst.})$$

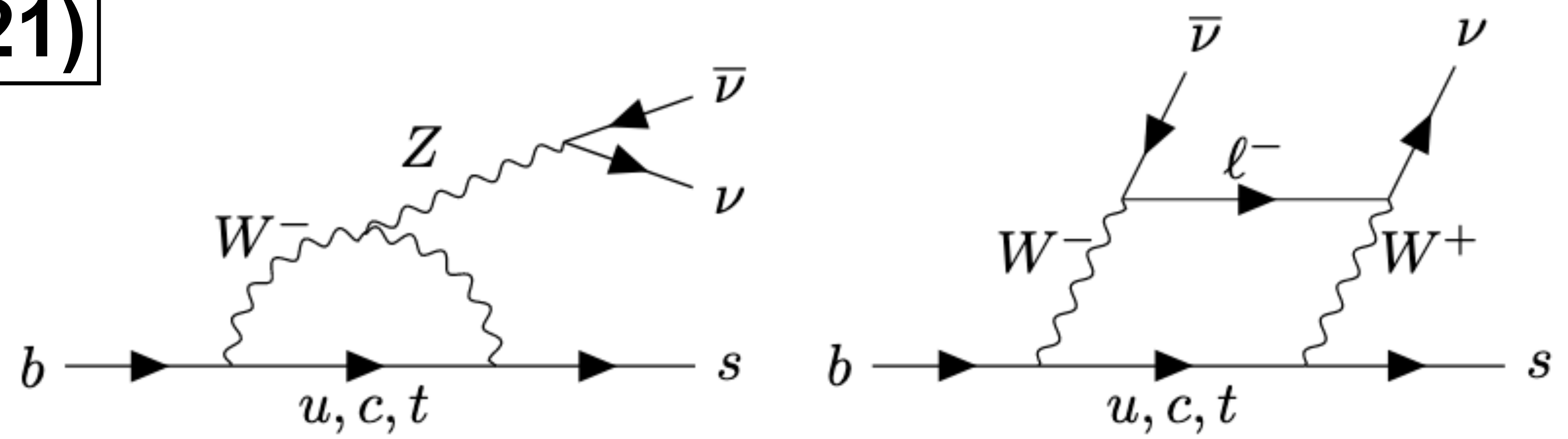
World average: $A_{CP} = -0.05 \pm 0.05$





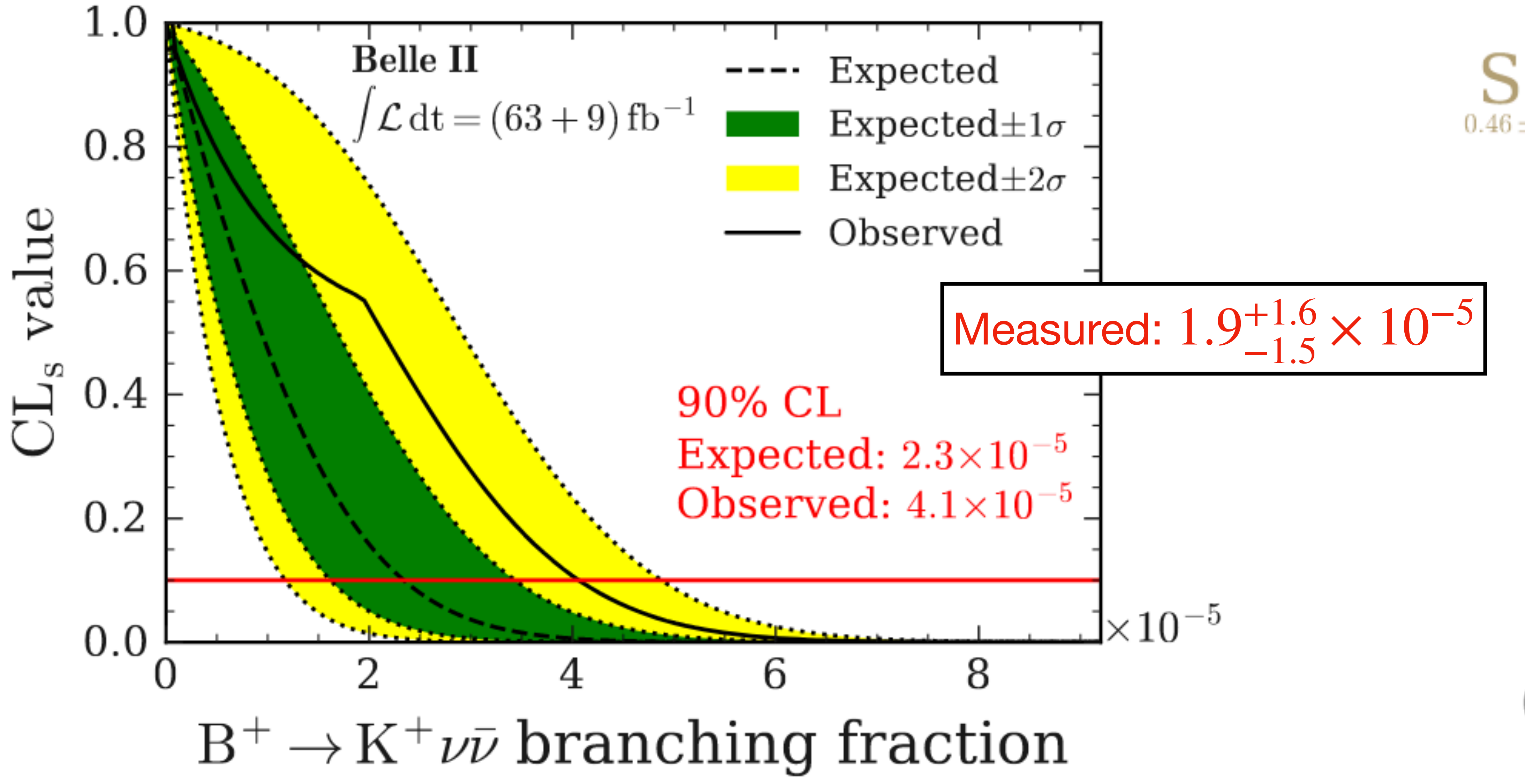
PRL 127, 181802 (2021)

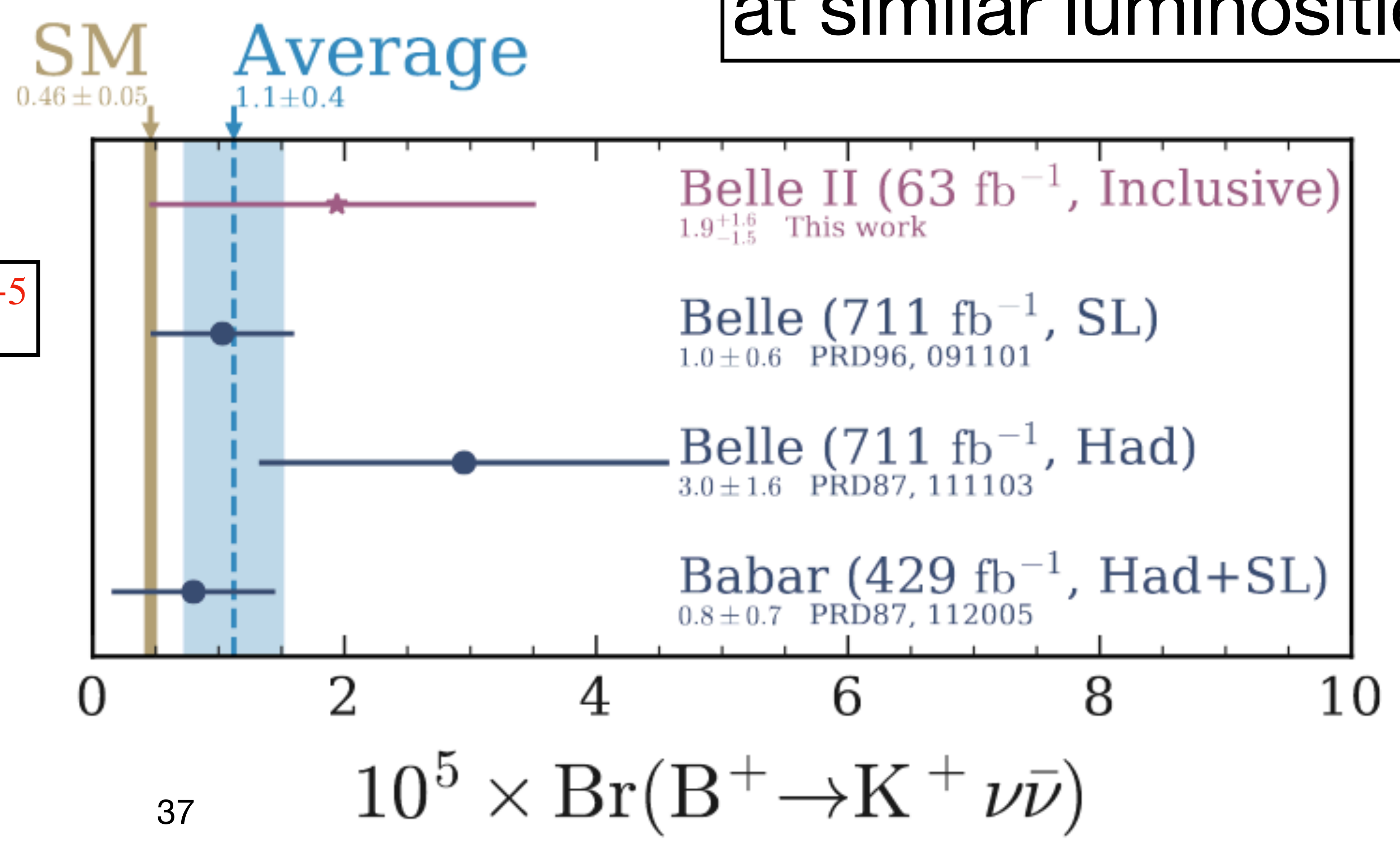
B→Kνν @Belle II



- Hermetic detector offers unique opportunity to study this channel
- FCNC strongly suppressed - SM expectation: **(4.6±0.5)x10^{-6}**
- New inclusive tagging approach with heavy usage of machine learning.
- Validated using $B^+ \to J/\psi(\to \mu\mu)K^+$
- Soon: more statistics and remaining K(*)νν modes

>3.5x better than hadronic tag, ~20% better than semileptonic tag at similar luminosities.

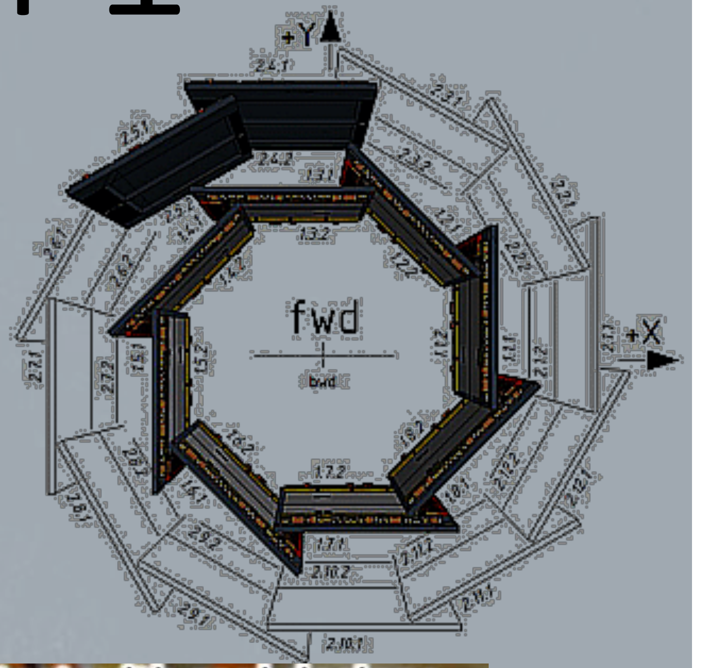




Kodai Matsuoka

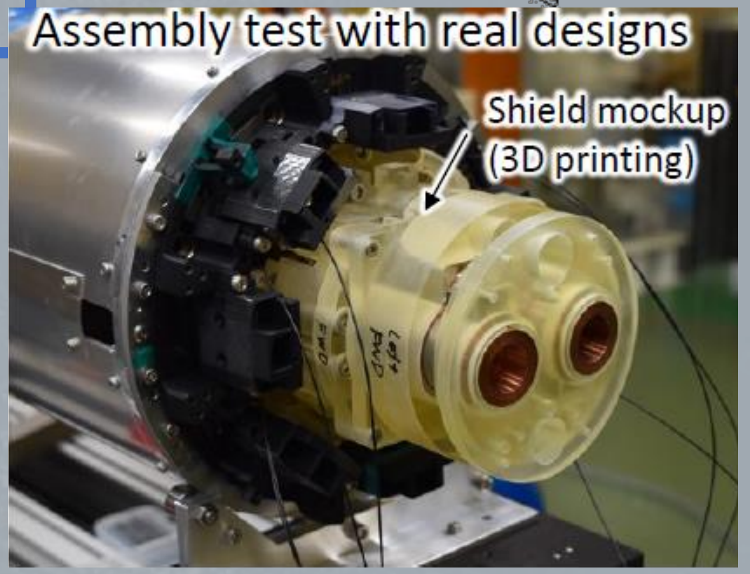
(from July 2022 until October 2023)

Major upgrade in Long Shutdown 1



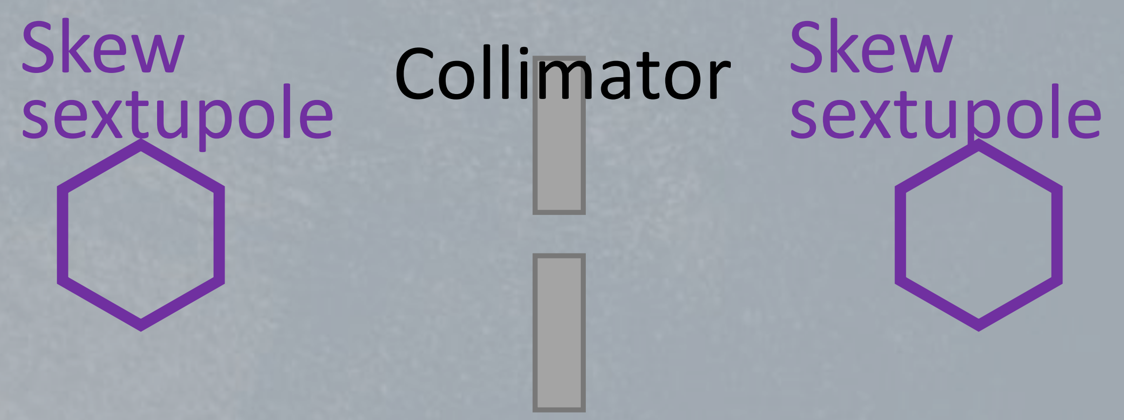
Belle II detector upgrade

- Exchange of PXD (pixel detector) with the full 2nd layer
- TOP conventional MCP-PMT replacement (TBD)
- Migration to new back-end readout (COPPER → PCIe40)



Beam background mitigation

- Additional shield on the QCS(*) bellows
- Additional shield for neutron background
- Installation of a non-linear collimator



Protection of machine and Belle II

- Collimator heads of more robust material
- Faster beam abort system

Beam kick by skew sextupole:

$$\Delta p_y = \frac{SK_2}{2}(y^2 - x^2),\ \Delta p_x = SK_2 xy$$

Improvement of beam injection

- Enlarged beam pipe at the HER injection
- Pulse-by-pulse beam control for Linac

Beam channel for injection

QCS: Final focusing system