# Review of recent Belle and Belle II results

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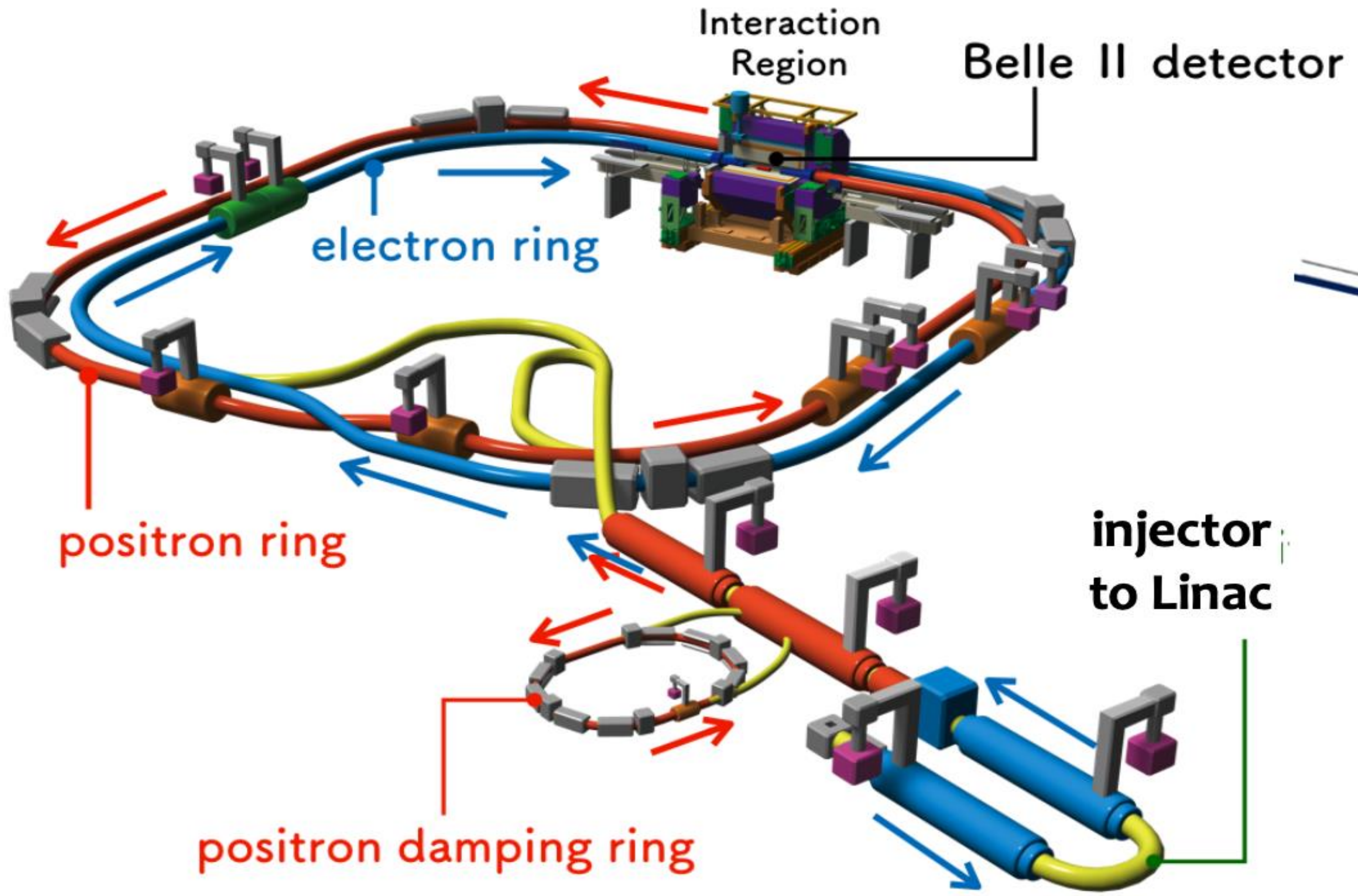
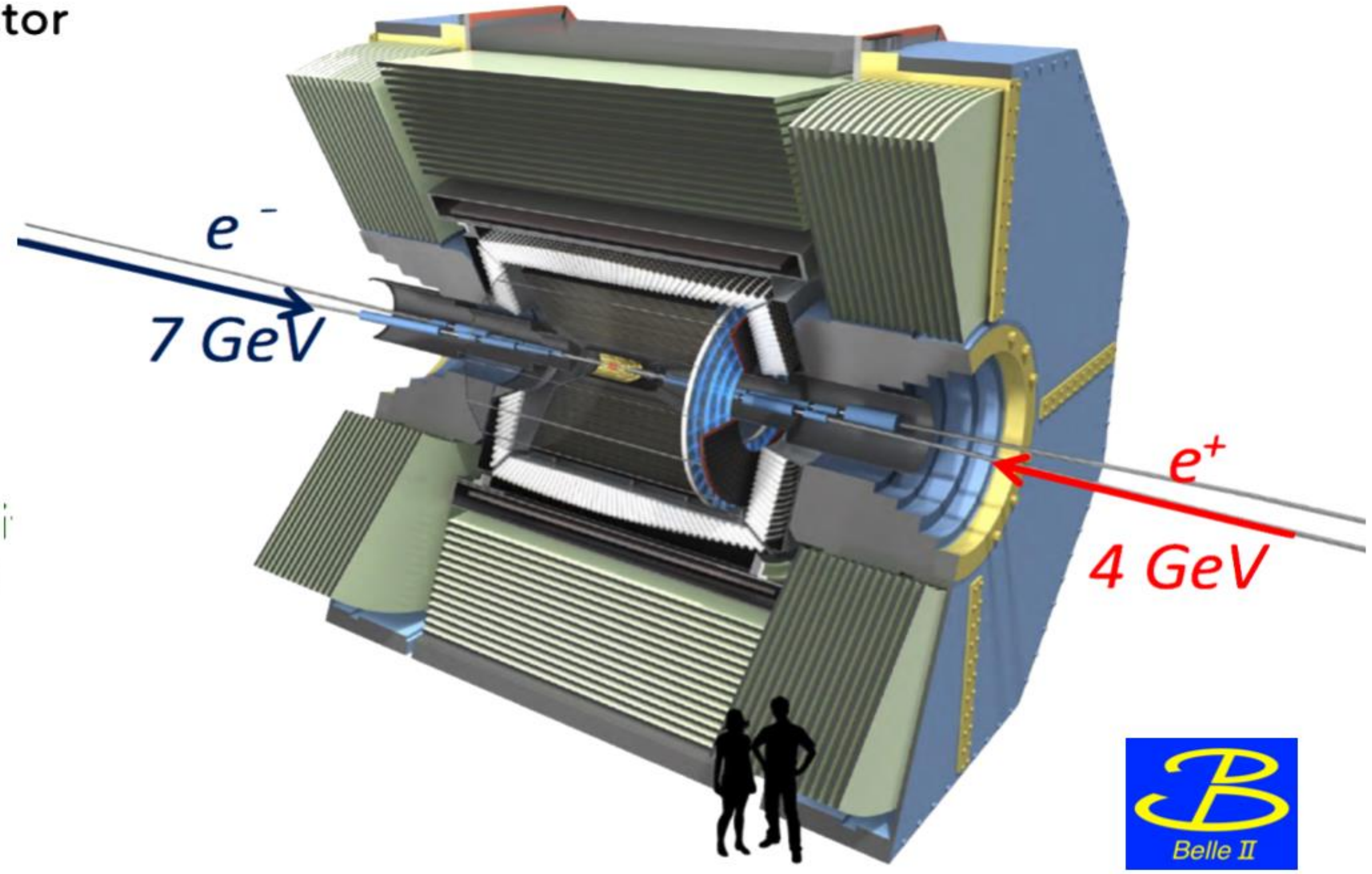
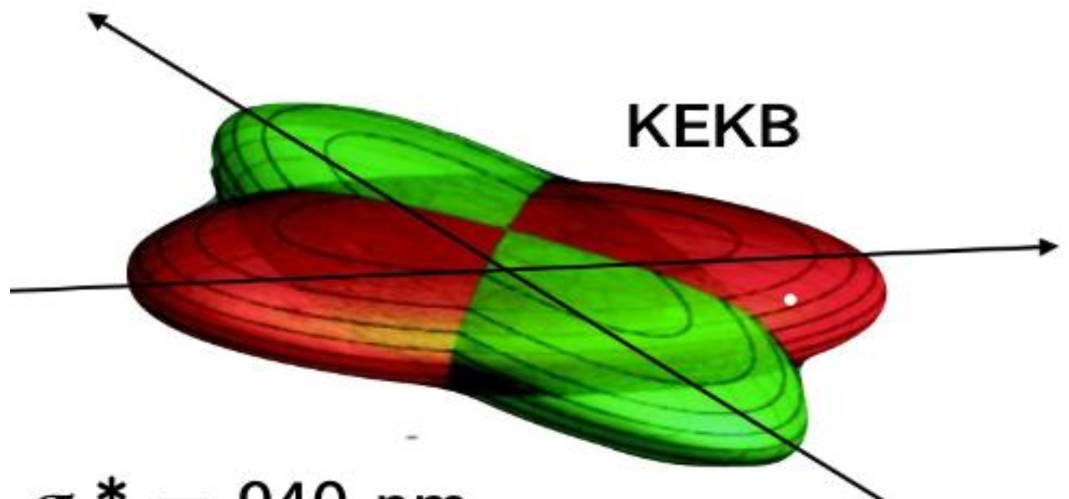
第五届强子与重味物理理论与实验联合研讨会

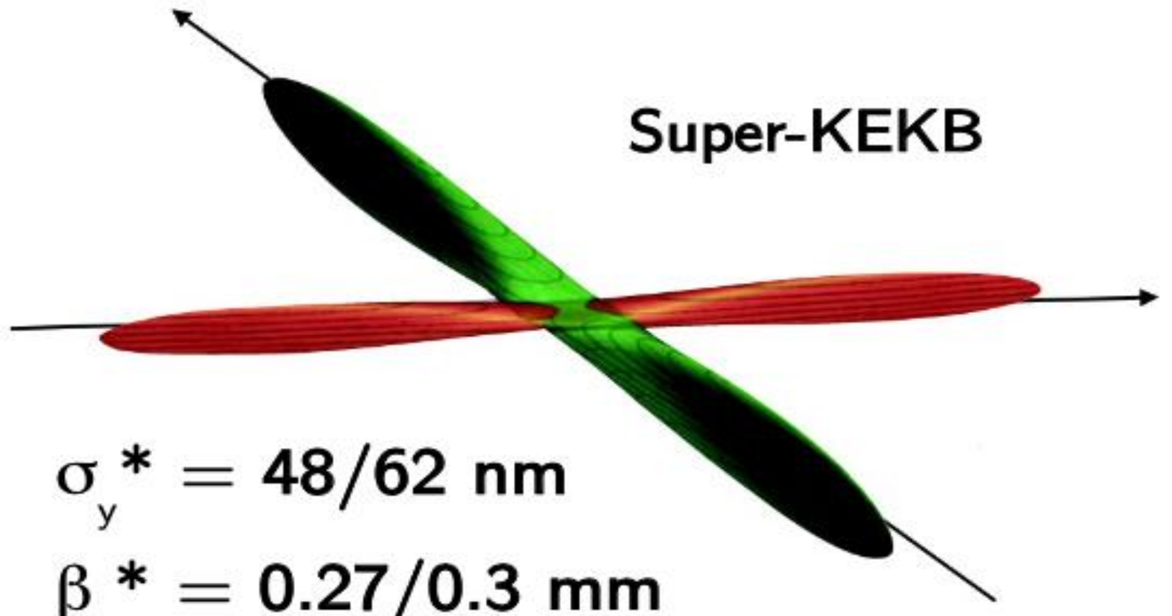
# SuperKEKB $e^- \xrightarrow{7\text{ GeV}} (\star) \xleftarrow{4\text{ GeV}} e^+$ Belle II







$\sigma_y{}^* = 940$ nm
$\beta_y{}^* = 5.9$ mm
$\sigma_x{}^* = 147/170$ μm



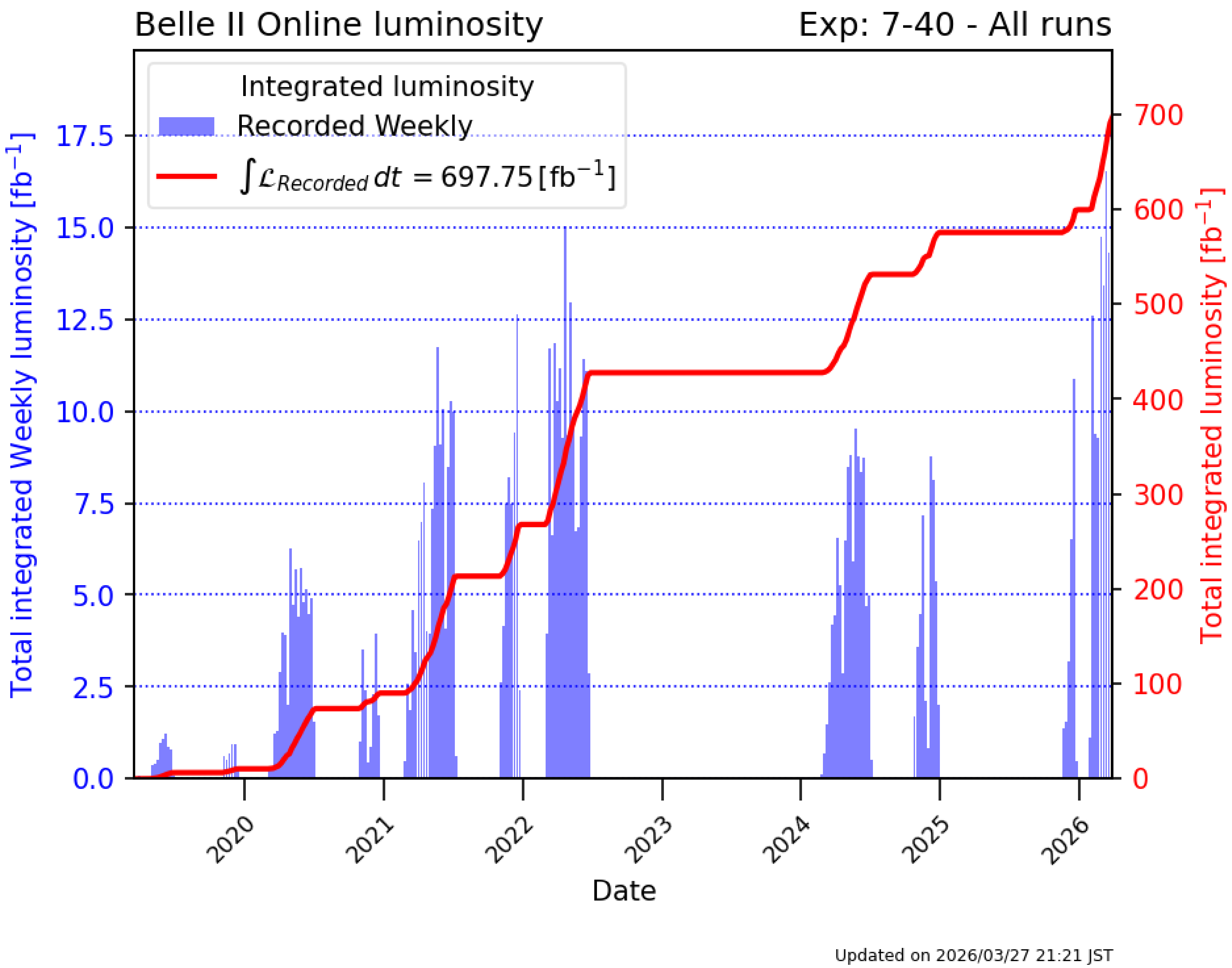
$\sigma_y{}^* = 48/62$ nm
$\beta_y{}^* = 0.27/0.3$ mm
$\sigma_x{}^* = 10.1/10.7$ μm

Beam current: KEKB x ~1.5

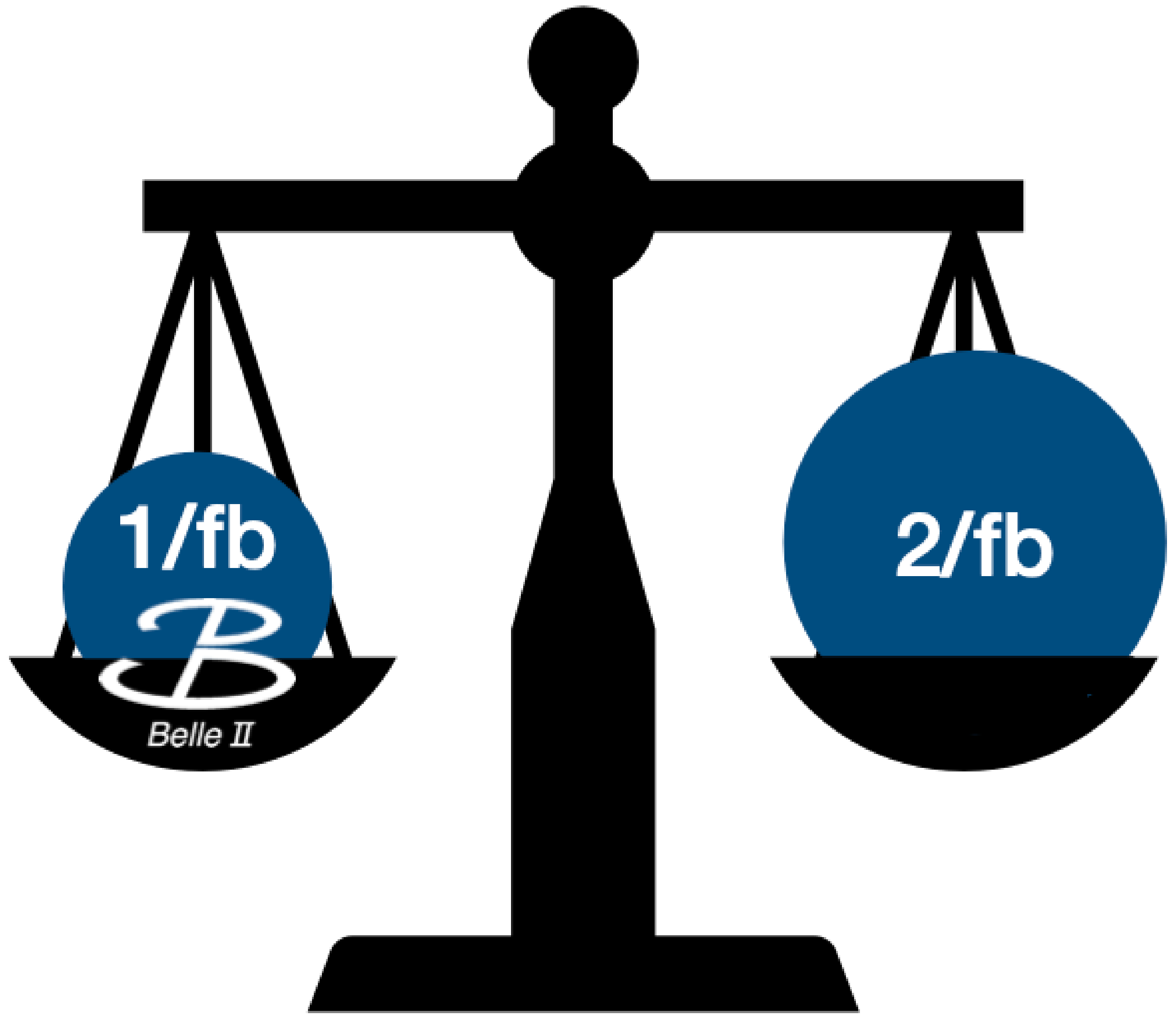
$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\left(\frac{R_L}{R_y}\right)$$

Beam squeeze: KEKB / ~20

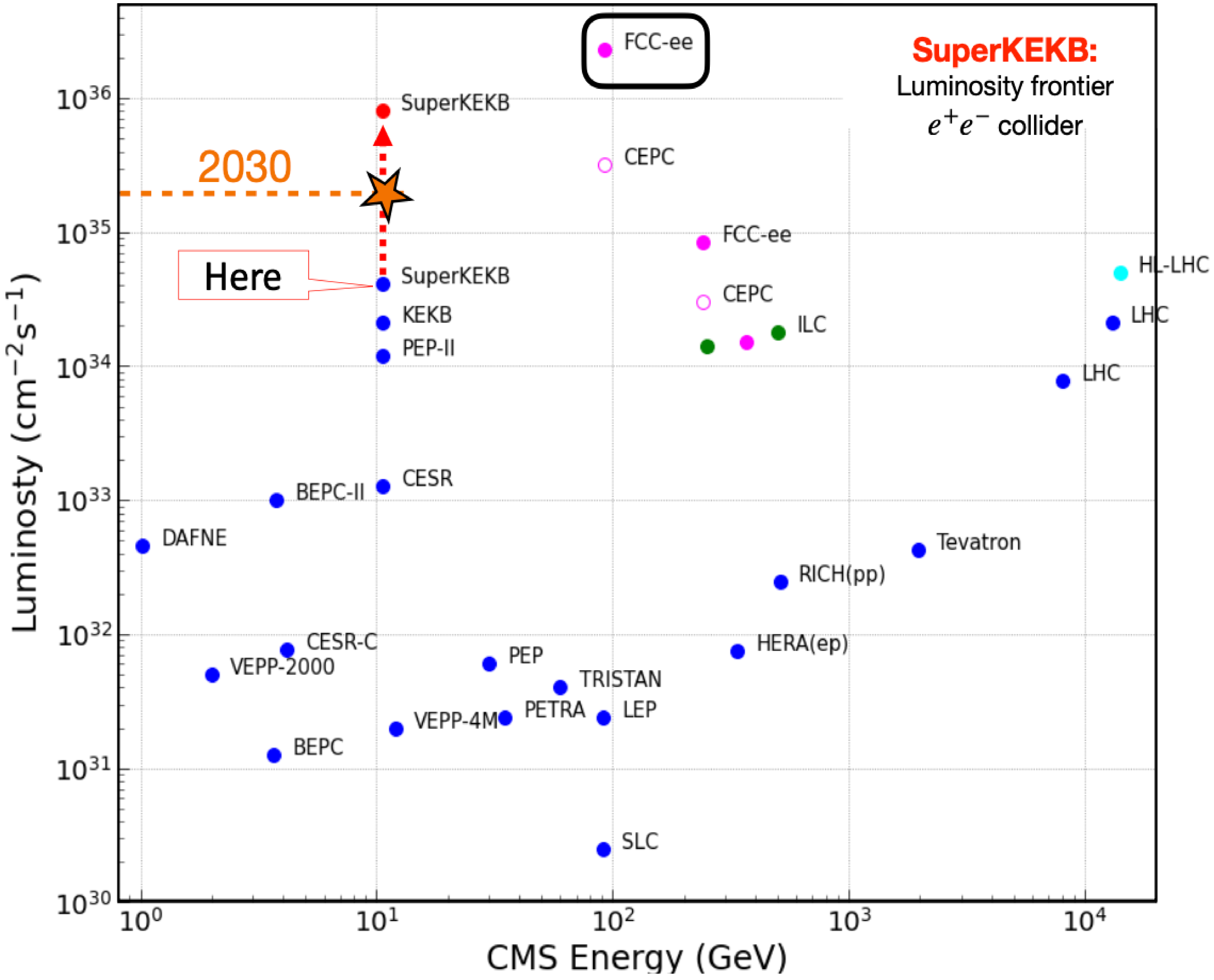
# RUN-I & II (2019-2025)



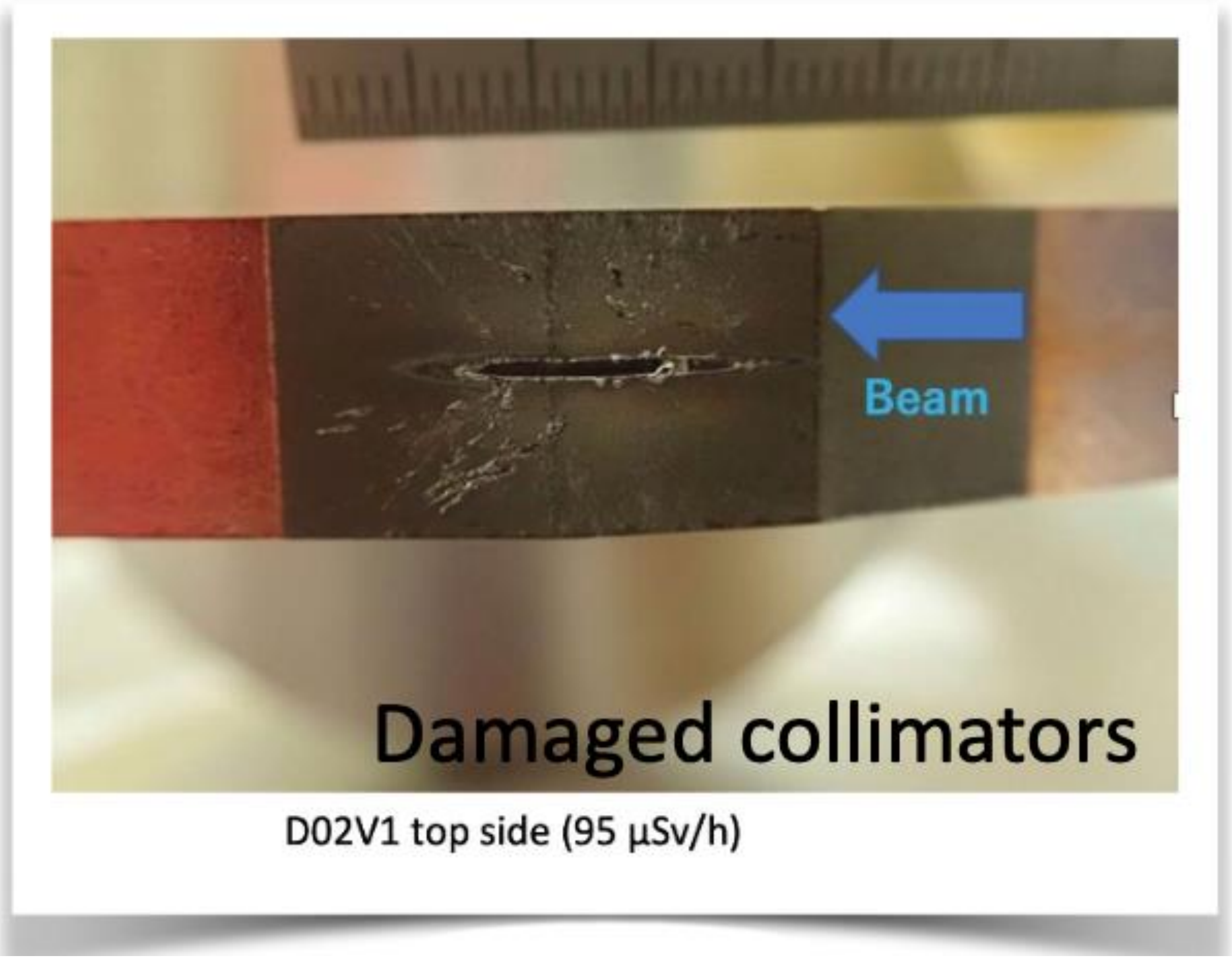
**Run 2** of experiment started Jan 29th 2024



- **Belle II** achieves **higher statistical power** than Belle & BaBar due to improved detector & modern analysis techniques.
- **1/fb of Belle II** data is **worth 2/fb of BaBar** or **Belle** data*.
- Much effort ongoing to shift this fraction even further with new triggers, better reconstruction, novel ideas etc.



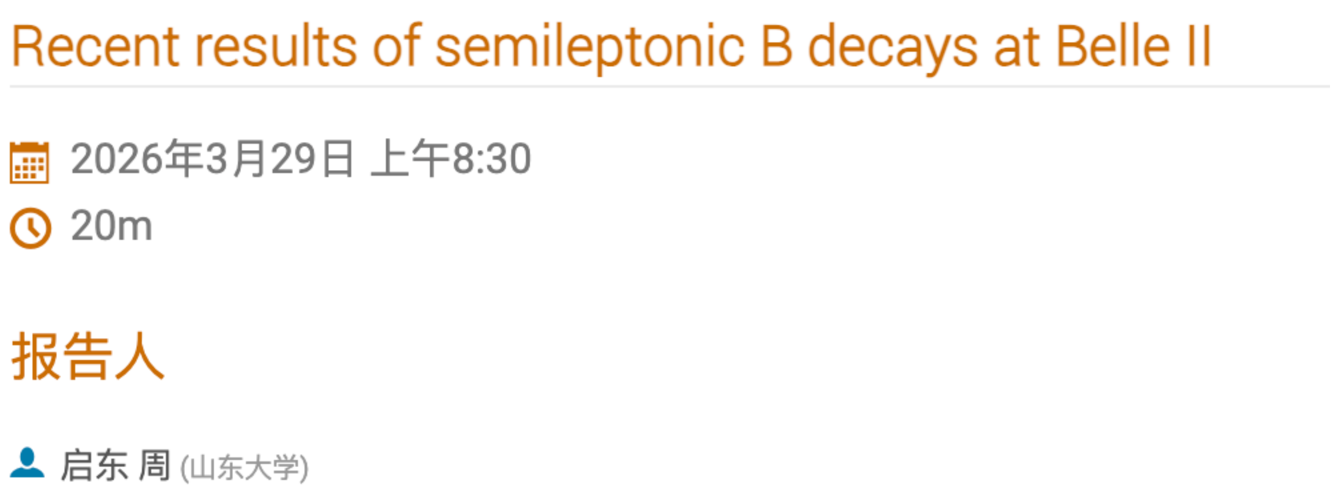
- Devoted significant fraction of running time for machine studies to understand instabilities.
- Sudden beam loss leads not only low lumi. but also detector damage



vacuum sealant

Target instantaneous luminosity: $\mathcal{L} = 6 \times 10^{35} cm^{-2} s^{-1}$ ) 30 x KEKB) until 2032

Max instantaneous luminosity: $\mathcal{L} = 5.24 \times 10^{34} cm^{-2} s^{-1}$ )15 Mar. 2026)

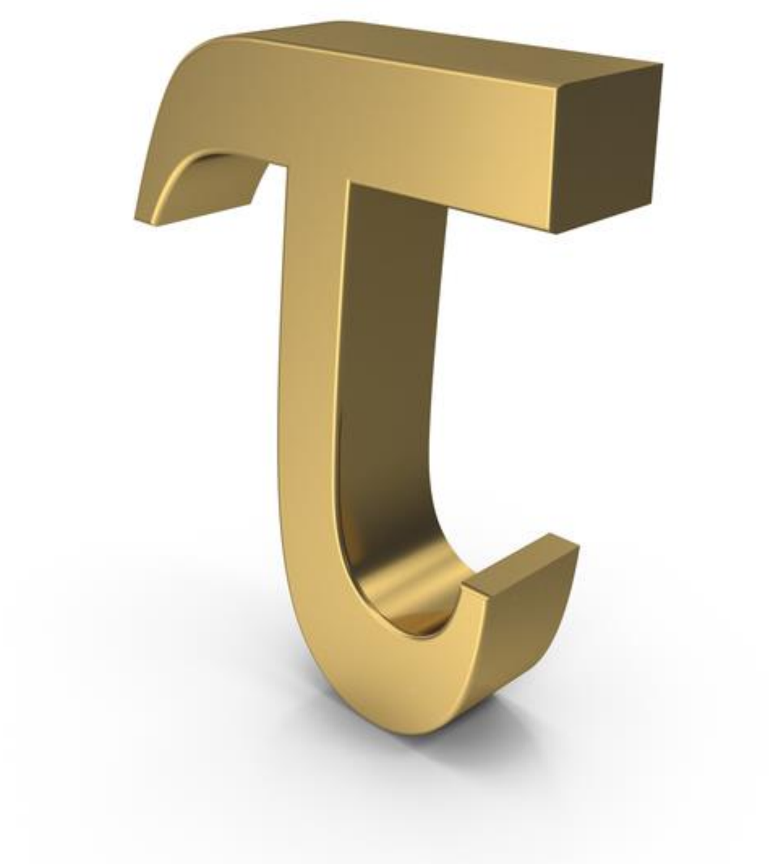

Recent results of semileptonic B decays at Belle II

2026年3月29日 上午8:30

20m

报告人

启东 周 (山东大学)

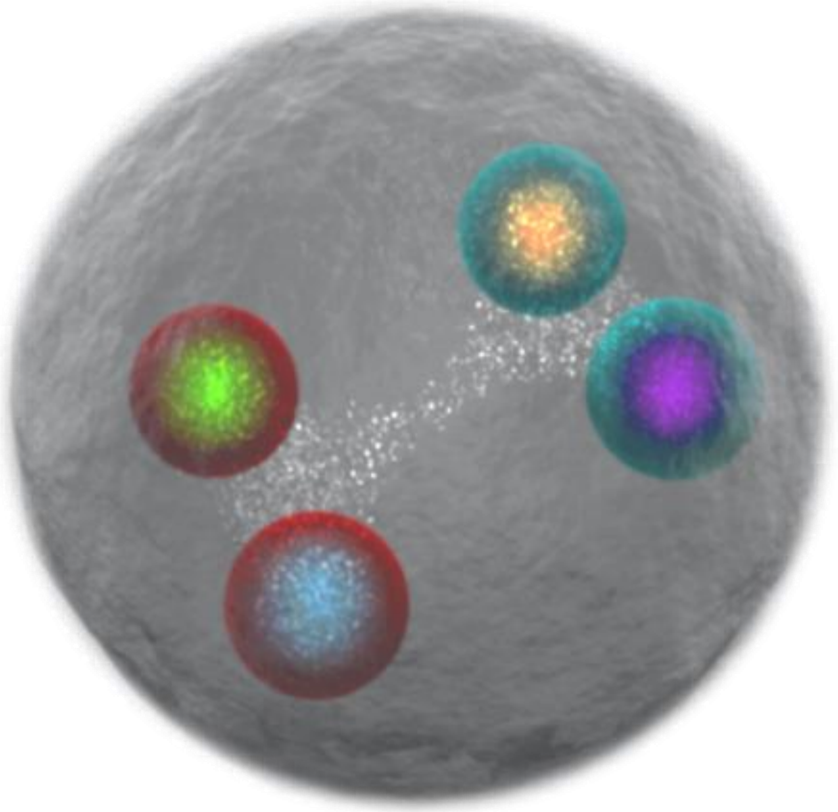


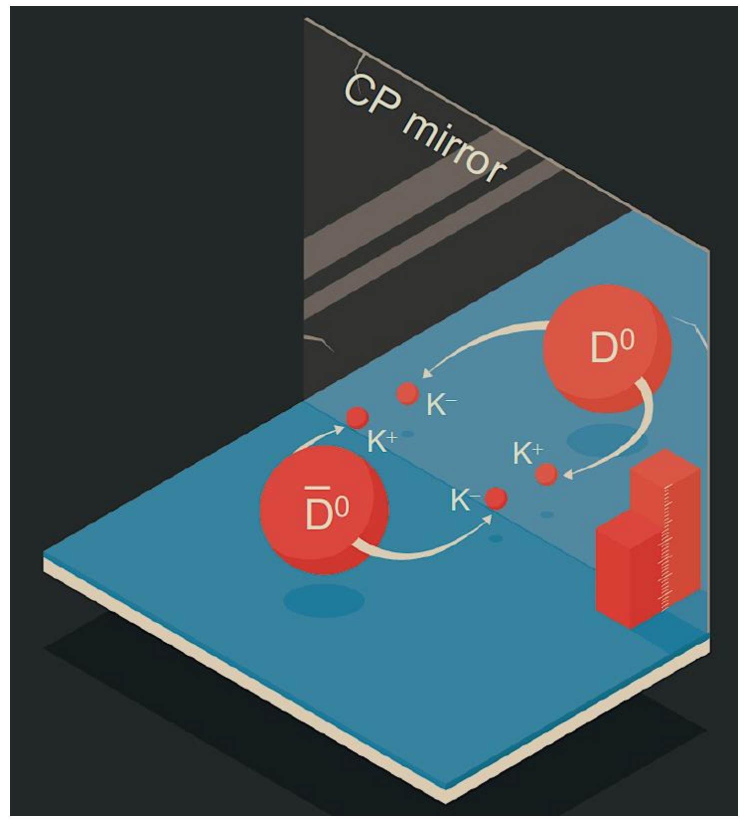
## τ physics

- CPV: $\tau \to \pi K_S^0 \nu_\tau$
- LFV: $\tau \to \mu\gamma$

## XYZ physics

- $ee \to \eta\Upsilon(1S)$
- $\sigma(ee \to BB)$
- $D_{s0}(2317) \to D_s^*\gamma$





## Charm physics (CPV):

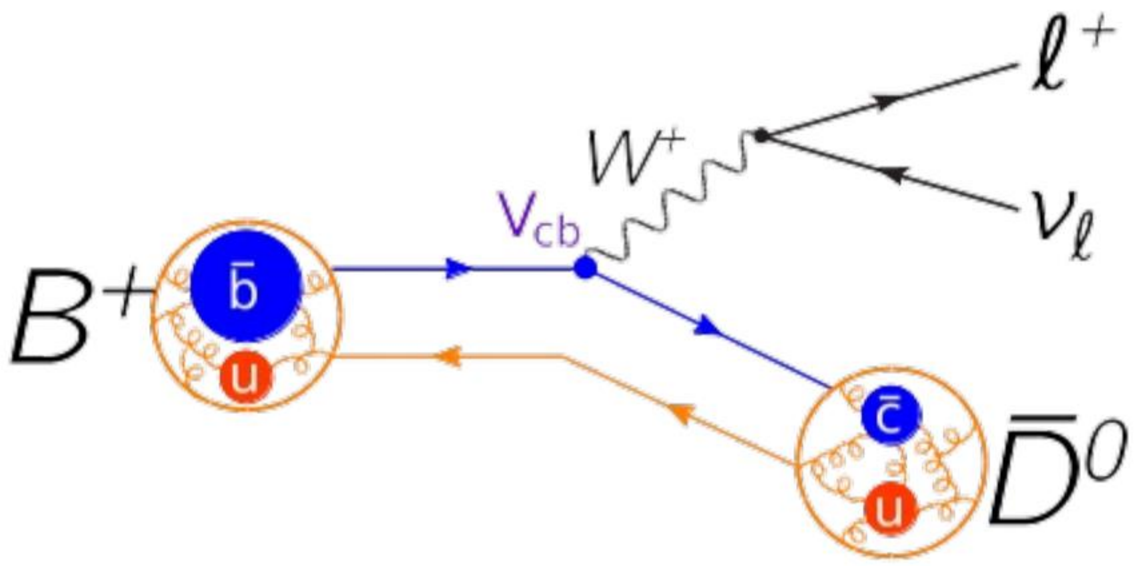
- $D^0 \to \pi^0\pi^0$
- $D^0 \to \pi^+\pi^-\pi^0$
- $D^+ \to \pi^+\pi^0$

11:00 - 11:20

李洋( 复旦大学 )
Charm physics at Belle II

## B physics (semiletopnic decay ):

- $B \to K\tau\tau$
- $B \to X_s ll$
- $B \to \pi^0\pi^0$
- $B \to D^*\eta\pi$



08:50 - 09:10

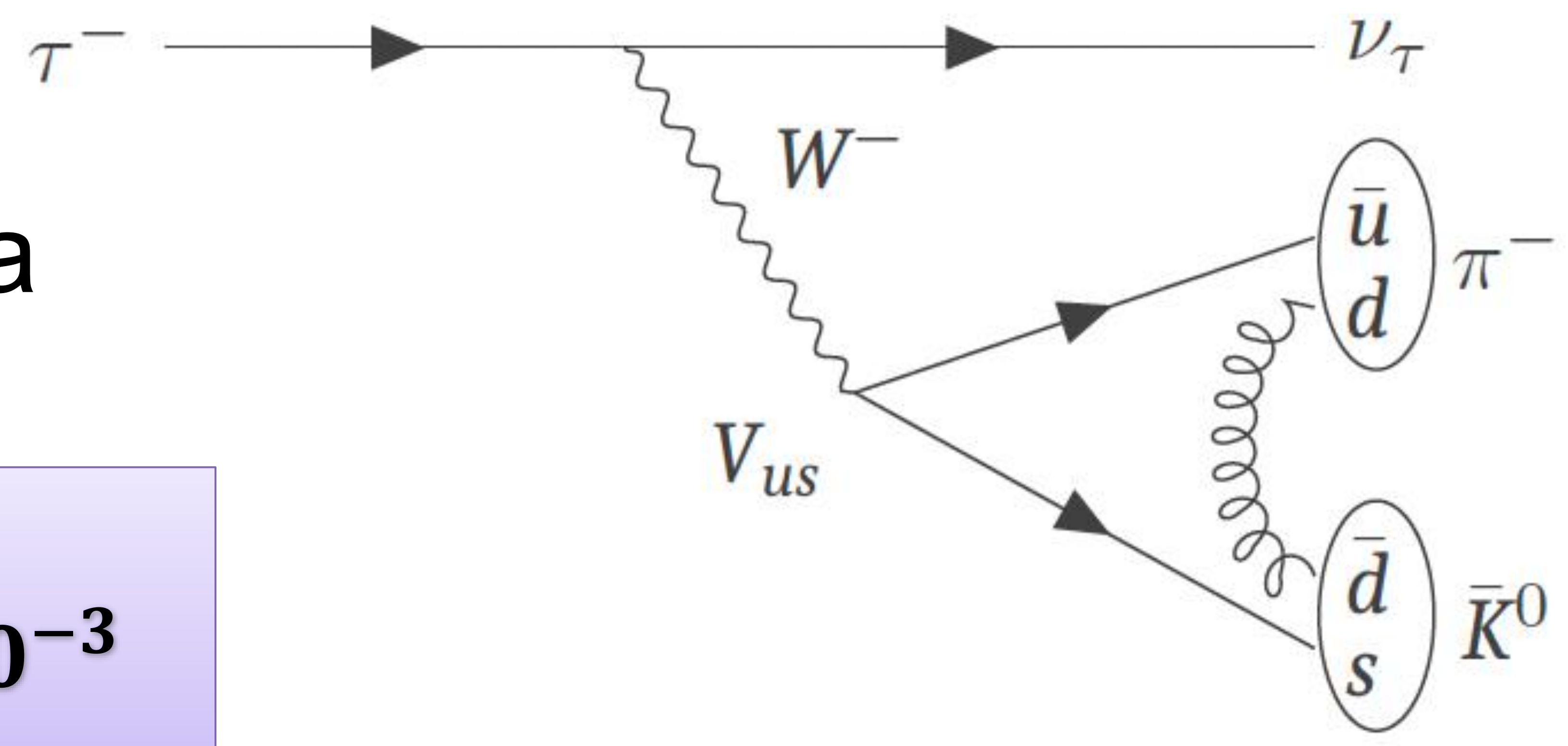
师晓东(中科院高能物理所)
Recent results of B decays at Belle II

**Preliminary**

# Search for direct CP violation in the decay: $\tau \to \pi K_s^0 \nu_\tau$

◆ Clean experimental signature.

◆ Experimentally we observe $K_s$ and $K_L$, and SM predicts a **CP violation** value in the kaon sector of

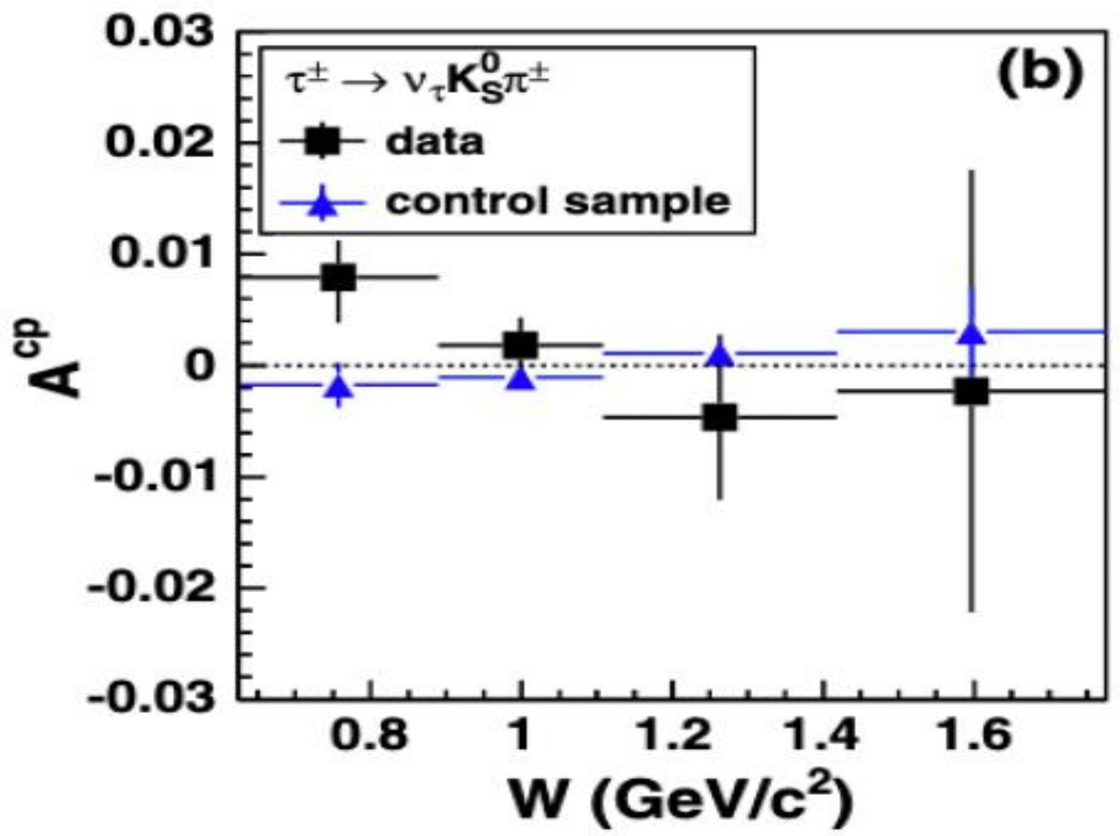


$$A_{CP}^{SM} \equiv A_1 = \frac{\Gamma\left(\tau^+ \to \pi^+ K_S^0 \bar{\nu}_\tau\right) - \Gamma\left(\tau^- \to \pi^- K_S^0 \nu_\tau\right)}{\Gamma\left(\tau^+ \to \pi^+ K_S^0 \bar{\nu}_\tau\right) + \Gamma\left(\tau^- \to \pi^- K_S^0 \nu_\tau\right)} \simeq (3.3 \pm 0.1) \times 10^{-3}$$

**Belle**

Phys. Rev. Lett. 107, 131801 (2011)

[$\mathcal{L}^{\text{int}}$ = 699 fb$^{-1}$]



$A_{CP}$ using angular observables.

*No asymmetry at $10^{-2}$ level*

**BaBar**

Phys. Rev. D 85, 031102 (2012)

[$\mathcal{L}^{\text{int}}$ = 476 fb$^{-1}$]

$$A_\tau = \frac{\Gamma\left(\tau^+ \to \pi^+ K_S^0 \bar{\nu}_\tau\right) - \Gamma\left(\tau^- \to \pi^- K_S^0 \nu_\tau\right)}{\Gamma\left(\tau^+ \to \pi^+ K_S^0 \bar{\nu}_\tau\right) + \Gamma\left(\tau^- \to \pi^- K_S^0 \nu_\tau\right)}$$

$$\boxed{A_{CP}^{BaBar} = (-0.36 \pm 0.23 \pm 0.11)\%}$$

▯ **2.8 σ** deviation from the SM expectation

**Preliminary**

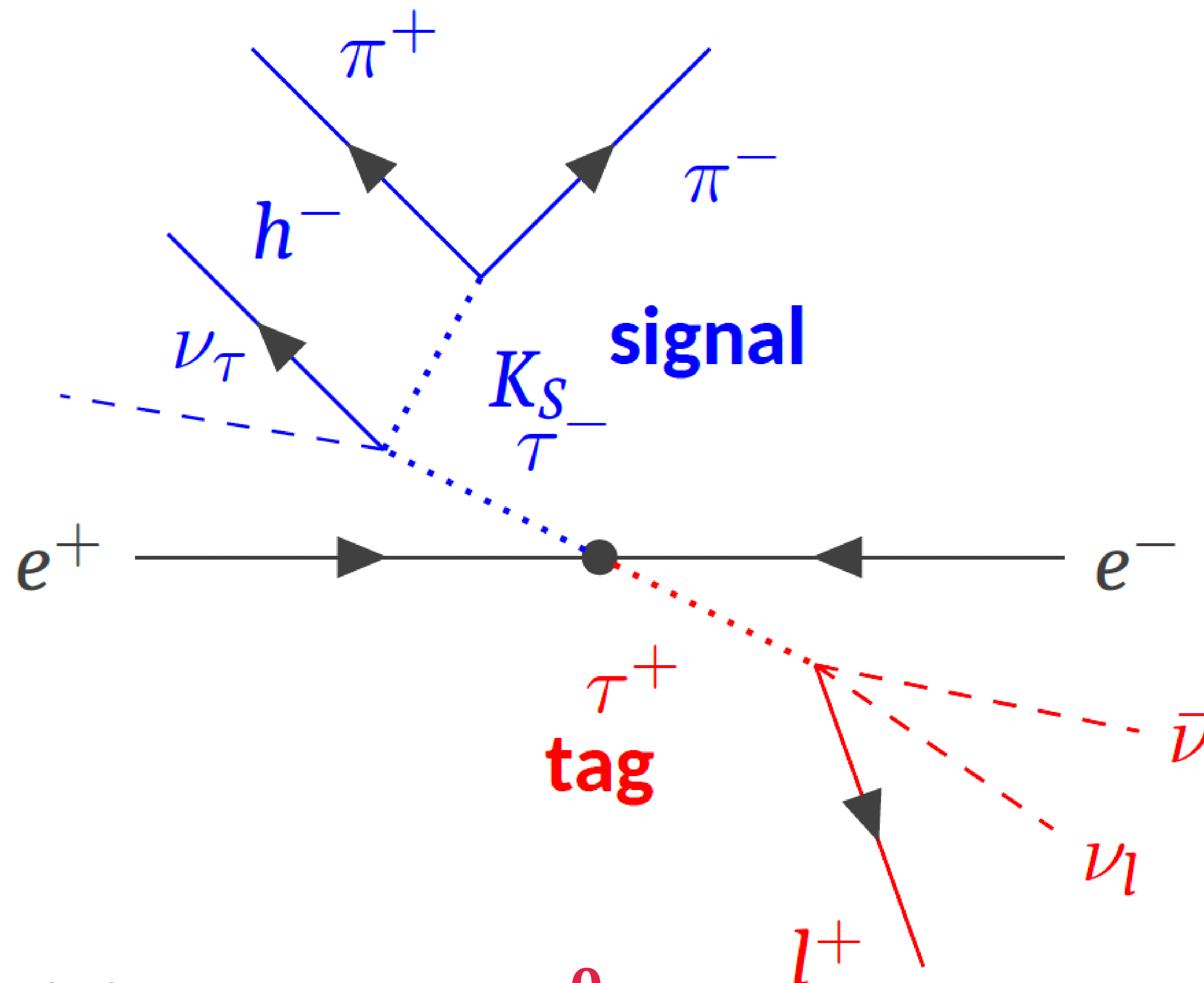
# Search for direct CP violation in the decay: $\tau \rightarrow \pi K_s^0 \nu_\tau$

| Signal decay modes considered | | |
|---|---|---|
| $\tau^- \to \pi^- K_S^0(\geq 0\pi^0)\nu_\tau,$ | $\tau^- \to K^- K_S^0(\geq 0\pi^0)\nu_\tau,$ | $\tau^- \to \pi^- K^0 \bar{K}^0 \nu_\tau$ |
| $A_1$ | $A_2$ | $A_3$ |

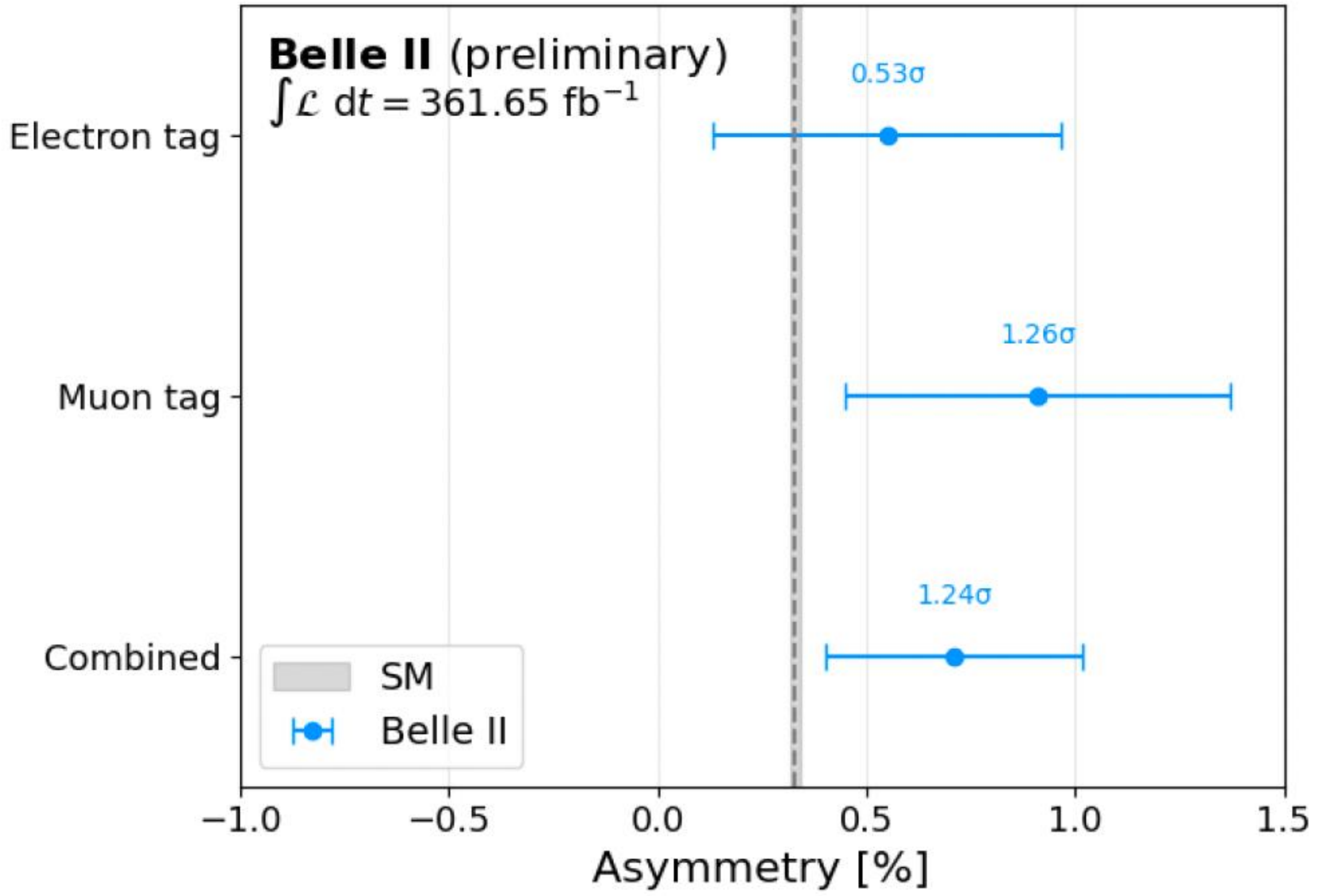
$$\mathcal{A}_{\rm CP} = \frac{f_1 A_1 + f_2 A_2 + f_3 A_3}{f_1 + f_2 + f_3} = \left(\frac{f_1 - f_2}{f_1 + f_2 + f_3}\right) A_1$$

Branching fraction

Asymmetry



- $f_1 = -f_2$: $\boldsymbol{\tau^- \to \pi^- \bar{K}^0 \nu_\tau}$, while $\boldsymbol{\tau^- \to K^- K^0 \nu_\tau}$
- $f_3 = 0$



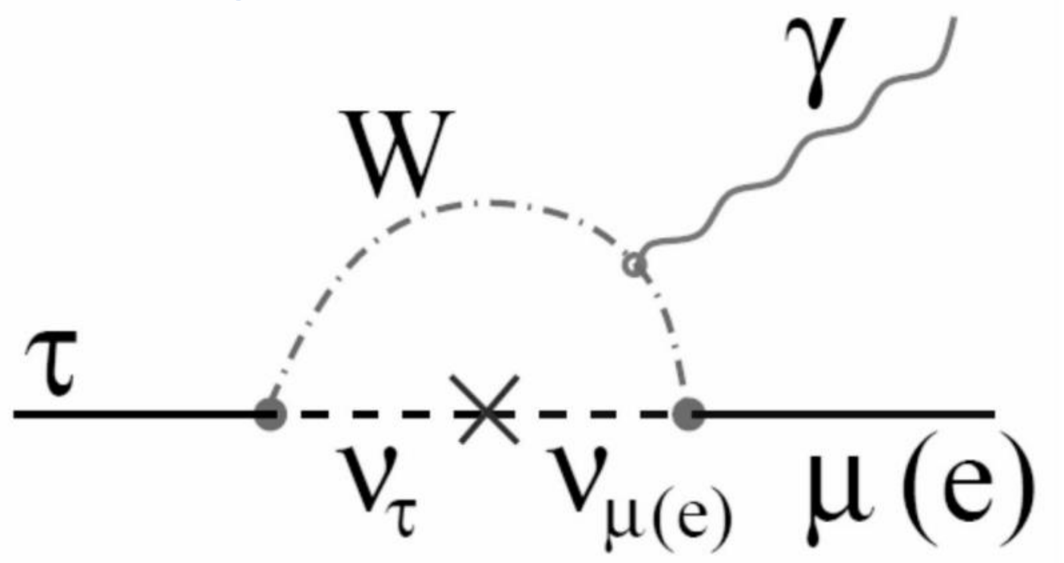
$$\boldsymbol{A_{CP}(\text{combined}) = 0.71 \pm 0.26_{\text{stat.}} \pm 0.06_{\text{sys.}} \pm 0.15_{\text{unf.}}}$$

$A_{cp}$ based on angular observables is ongoing.

**Preliminary**

# Search for LFV in the decay: $\tau \to \mu\gamma$

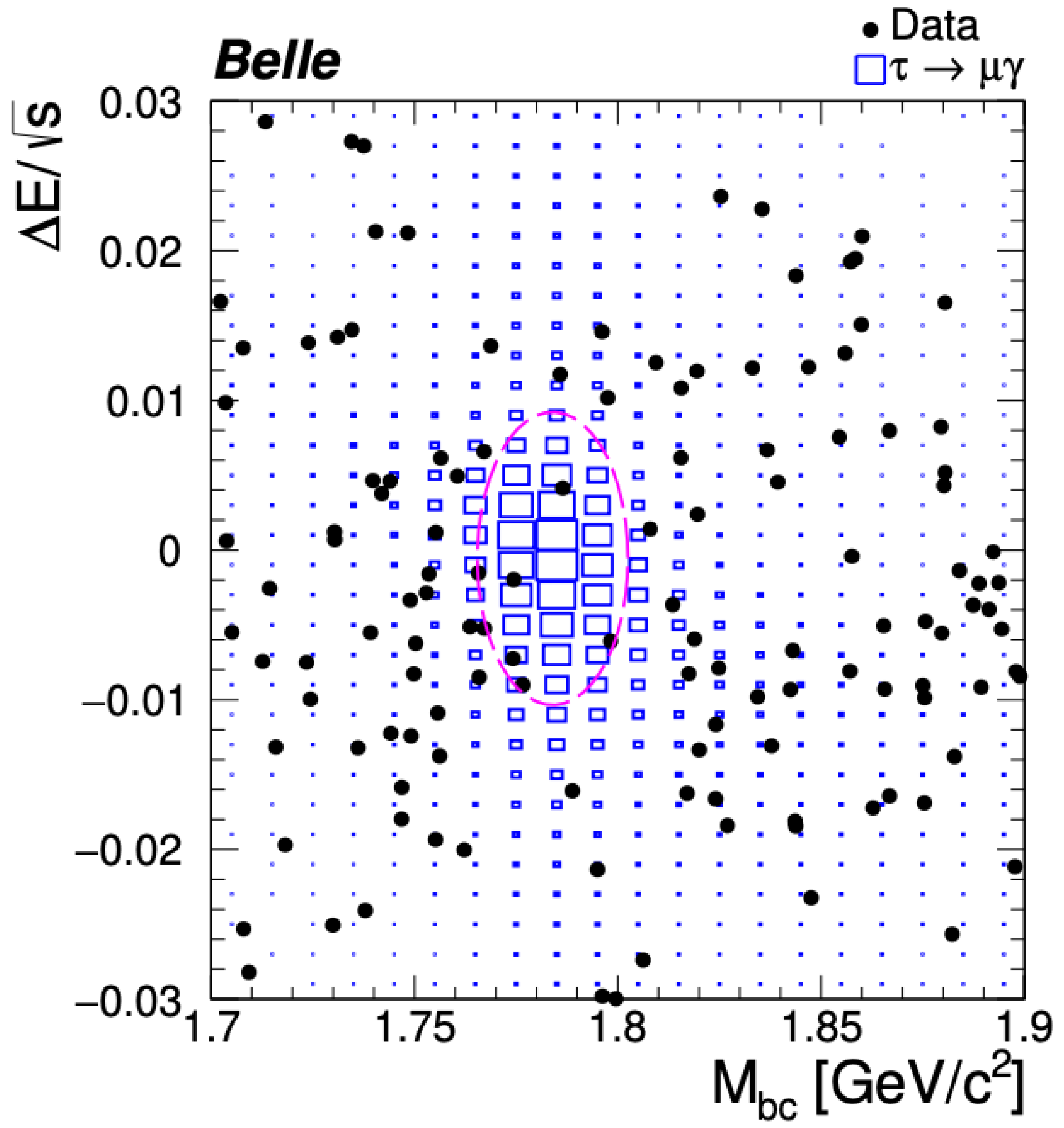
| $\tau^\pm \to \mu^\pm + \gamma$ | | |
|---|---|---|
| SUSY Higgs | $10^{-10}$ | [Phys.Lett.B566:217-225,2003] |
| Little Higgs | $10^{-10}$ | [JHEP 0705:013,2007] |
| SM + seesaw | $10^{-9}$ | Phys.Rev.D66:034008,2002 |
| Non-Universal Z’ | $10^{-9}$ | [ Phys.Lett. B547 (2002) 252-256] |
| SUSY SO(10) | $10^{-8}$ | [Phys.Rev.D68:033012,2003] |



In SM: $\mathcal{B}(\tau^\pm \to \ell^\pm\gamma) = \frac{3\alpha}{32\pi}\left|U^*_{\tau i}U_{\ell i}\frac{\Delta m^2_{3i}}{m^2_H}\right|^2 \sim 10^{-54}$

- favored by most of the beyond the SM theories.

JHEP 10 (2021) 019



Babar 515.5 fb$^{-1}$:$B(\boldsymbol{\tau} \to \boldsymbol{\mu\gamma}) < 4.4 \times 10^{-8}$ PRL104, 021802 (2010)

Belle 988 fb$^{-1}$:$B(\boldsymbol{\tau} \to \boldsymbol{\mu\gamma}) < 4.2 \times 10^{-8}$ JHEP 10 (2021) 019

Previously, Signal is identified by:

$$\Delta E/\sqrt{s} = (E^{c.m.}_{\ell\gamma} - E^{c.m.}_{beam})/\sqrt{s} \sim 0$$

$$M_{bc} = \sqrt{(E^{c.m.}_{beam})^2 - (\vec{P}^{c.m.}_{\ell\gamma})^2} \sim m_\tau$$

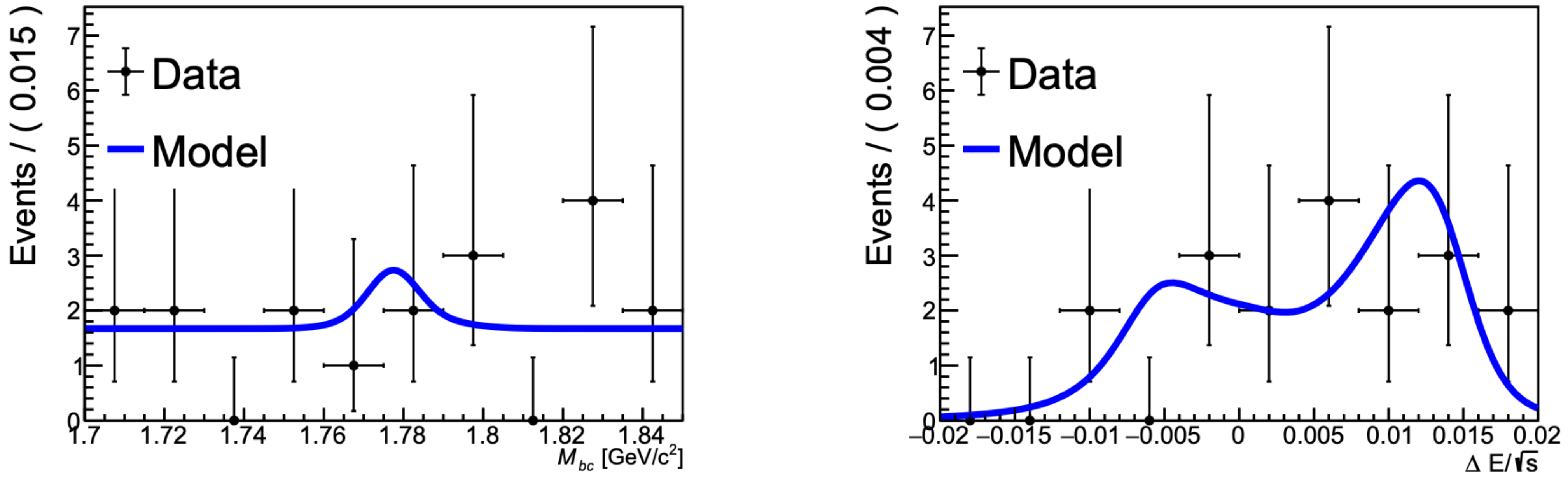
**Preliminary**

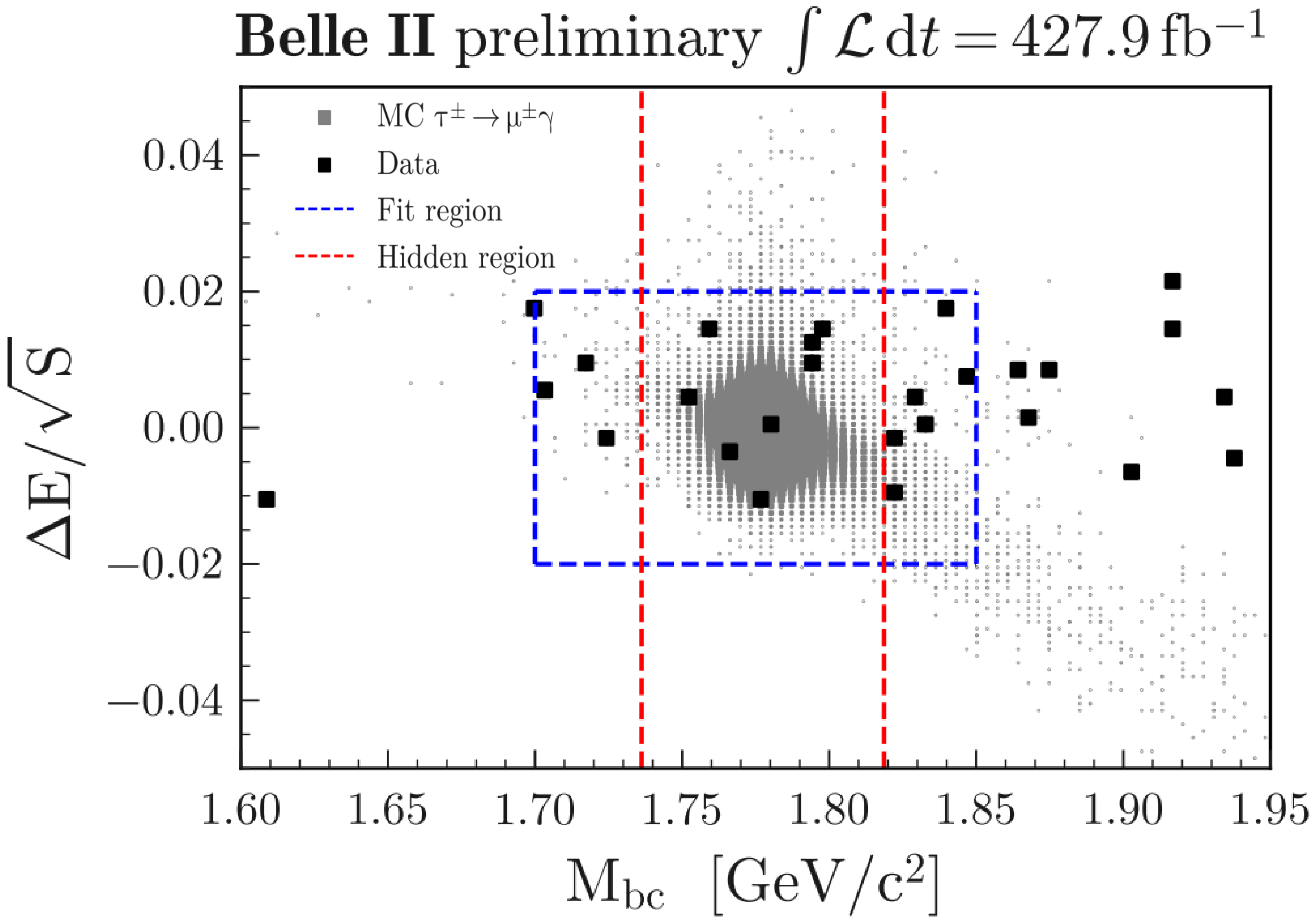
# Search for LFV in the decay: $\tau \rightarrow \mu\gamma$

Assume: $E_{\gamma}^{c.m.} = E_{beam}^{c.m.} - E_{\mu}^{c.m.}$, use new $M_{bc}$:

$$M_{bc} = \sqrt{-\left(\vec{P}_{\ell}^{c.m.}\right)^2 + \left(\sqrt{s} \cdot E_{\ell}^{c.m.}\right) - \left(E_{\ell}^{c.m.}\right)^2 - \left(2\left|\vec{P}_{\ell}^{c.m.}\right| \cdot \left(\sqrt{s}/2 - E_{\ell}^{c.m}\right) \cdot cos\theta_{\ell\gamma}\right)}$$

- Resolution of improved by **50%**
- Correlation between ($M_{bc}$, $\Delta E/\sqrt{s}$ ) is negligible





**Fit Result**

**Consistent with zero.**

$\mathcal{B}(\tau^- \rightarrow \mu^- \gamma) = (2.8^{+4.4}_{-2.6}) \times 10^{-8}$

Equivalent to $\begin{cases} \tilde{s} = 1.3^{+2.0}_{-1.2} \\ \tilde{b} = 16.7^{+4.6}_{-3.9} \end{cases}$

$\boxed{B^{UL}(\boldsymbol{\tau \rightarrow \mu\gamma}) < 9.5 \times 10^{-8}}$

$\epsilon_{sig} = 5.21 \pm 0.01\%$
$b^{exp} = 1.1 \pm 0.02$

Previous Belle (988 fb$^{-1}$) result:

$B(\boldsymbol{\tau \rightarrow \mu\gamma}) < 4.2 \times 10^{-8}$

$\epsilon_{sig} = 3.4\ \%$
$b^{exp} = 5.8 \pm 0.04$

# Observation of $D_s(2317)^+ \to D_s^{*+}\gamma$

arXiv:2510.27174

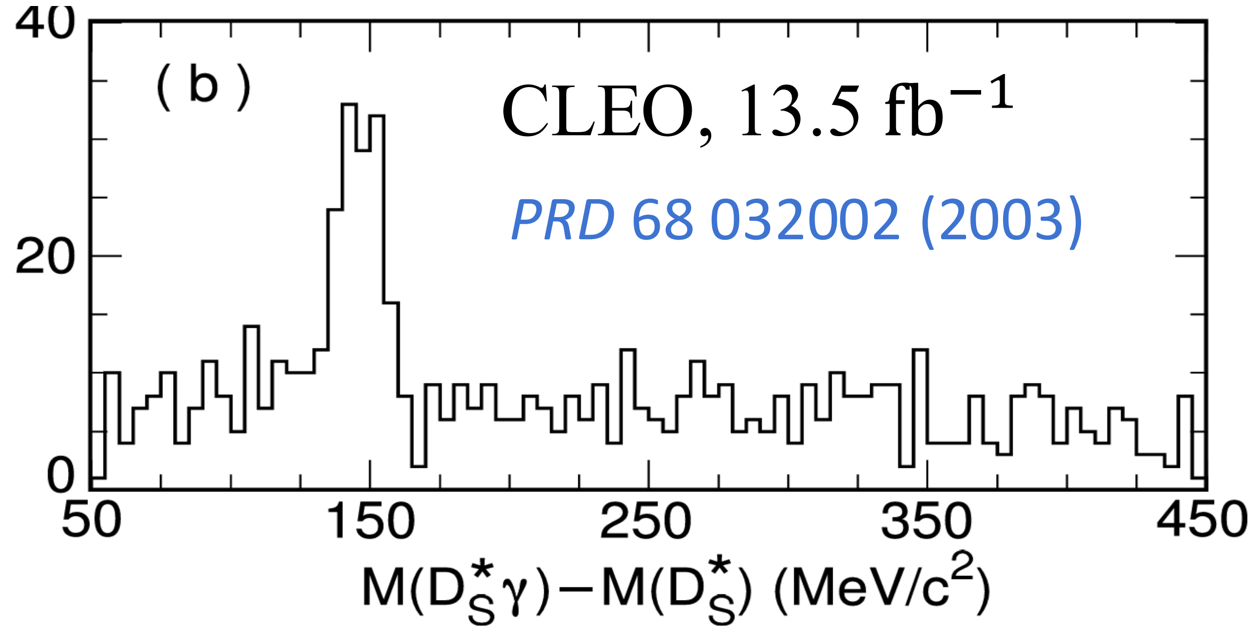
- $D_{s0}(2317)^+$ : possible exotic state ?

**Partial decay widths:**

**unique in discriminating between various models**

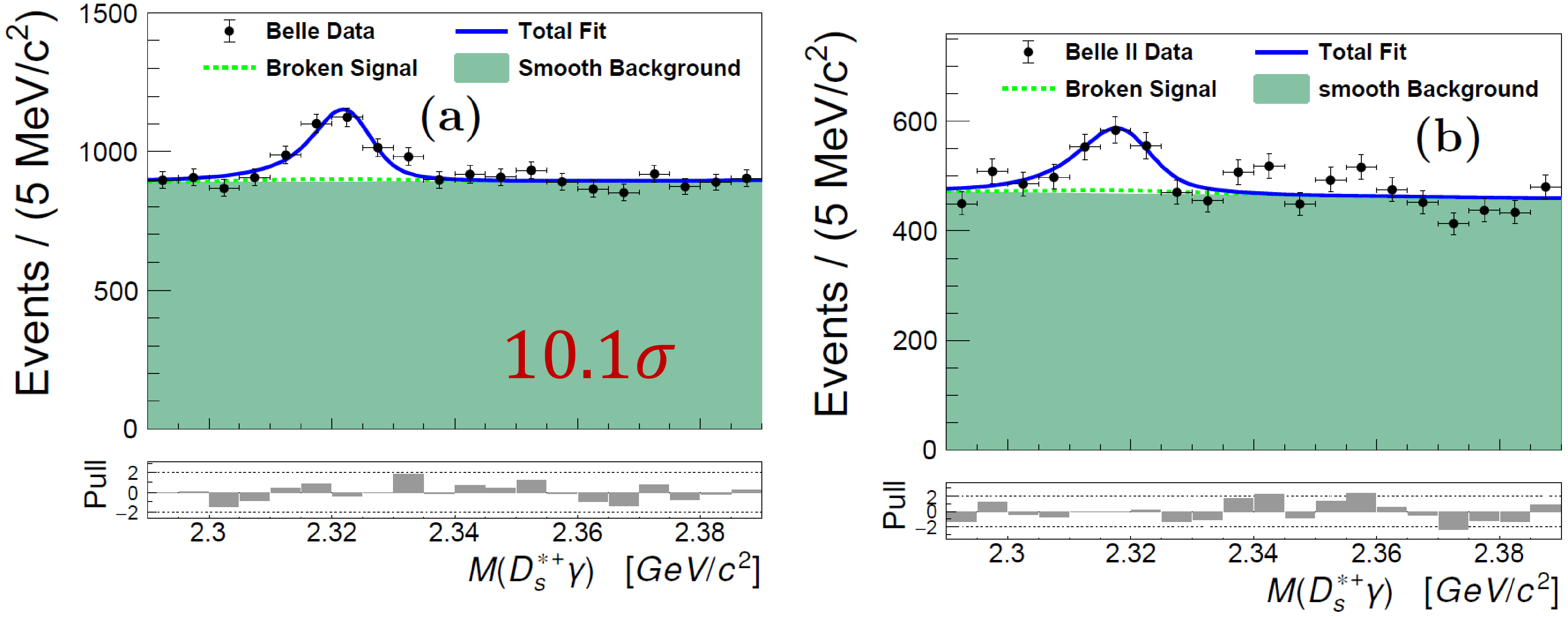
| $D_{s0}(2317)^+$ Decay mode | $J^P$ transition | Possible wave |
|---|---|---|
| $D_s^+\gamma$ | $0^+ \to 0^-1^-$ | Forbidden |
| $D_s^{*+}\gamma$ | $0^+ \to 1^-1^-$ | $L = 0, 2$ |

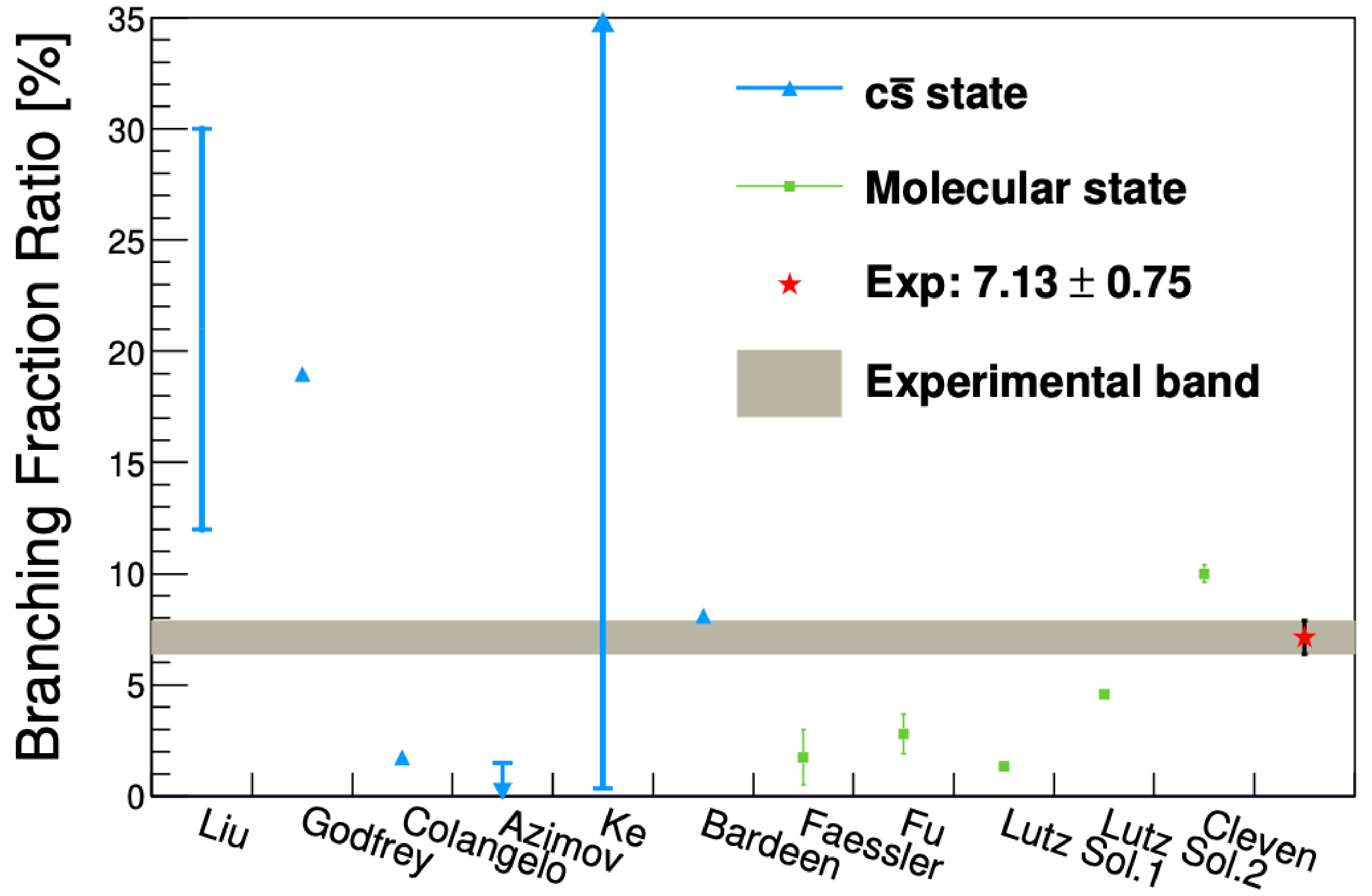
- The radiative decay of $D_{s0}(2317)^+$ has not been founded.
  - $\mathcal{R} = \frac{\mathcal{B}(D_s(2317)^+ \to D_s^{*+}\gamma)}{\mathcal{B}(D_s(2317)^+ \to D_s^+\pi^0)} < 0.059$ @ 90% CL from CLEO
  - $\mathrm{N}(\mathrm{D_s}(2317)^+ \to \mathrm{D}_s^{*+}\gamma) = -6.5 \pm 5.2$



PRD 68 032002 (2003)

- $\mathcal{R} = [7.14 \pm 0.70(stat.) \pm 0.26(syst.)]\%$





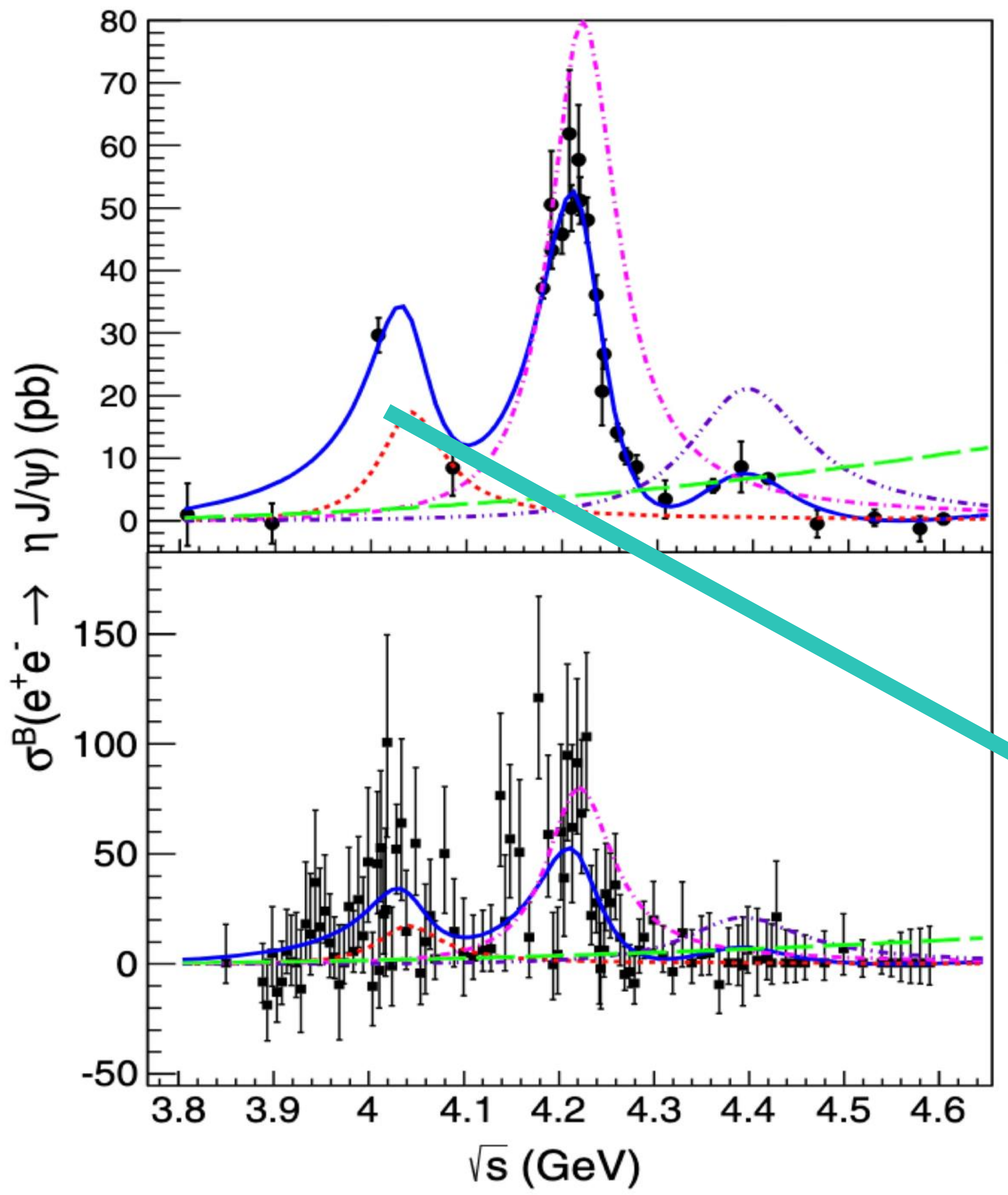
# Observation of $\Upsilon(10753) \rightarrow \eta\Upsilon(2S)$

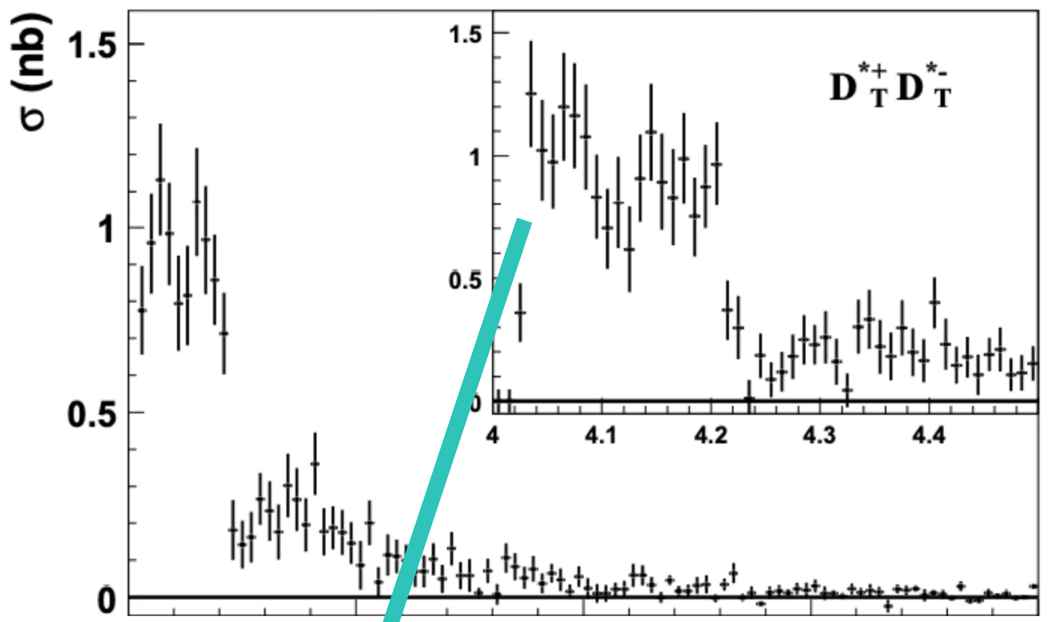
arXiv:2509.01017

Has observed in:

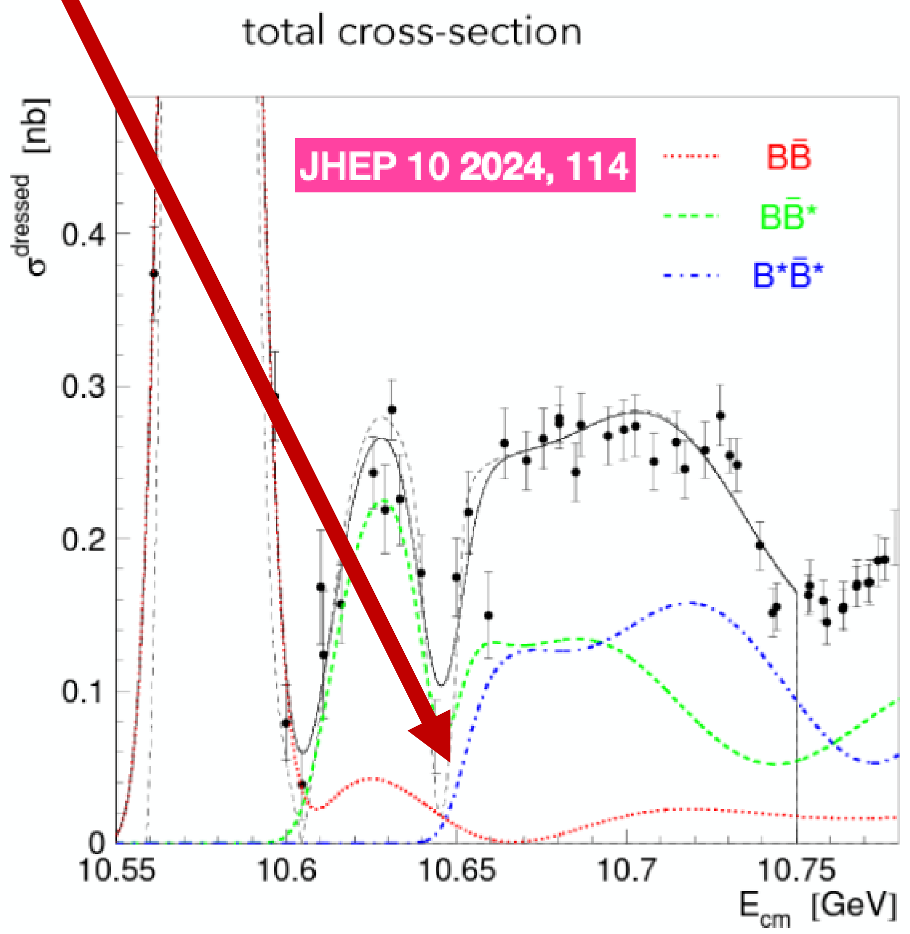
$$\Upsilon(10753) \rightarrow \pi^+\pi^-\Upsilon(1,2,3S)\omega\chi_{bJ}, B^{(*)}\bar{B}^{(*)}$$

- A relatively large $B(\Upsilon(10753) \rightarrow \eta\Upsilon(nS))$, would support a 4S–3D interpretation of ;
  - ➢ i.e. $(0.46{\sim}5.46)\ \times\ 10^{-3}$ $(\sim \omega\chi_{bJ})$
- similarly to how $\psi(4040)$ observed at $D^*\bar{D}^*$ threshold decays into $\eta J/\psi$, an enhancement near $B^*\bar{B}^*$ can decay into $\eta\Upsilon(1,2S)$ ;

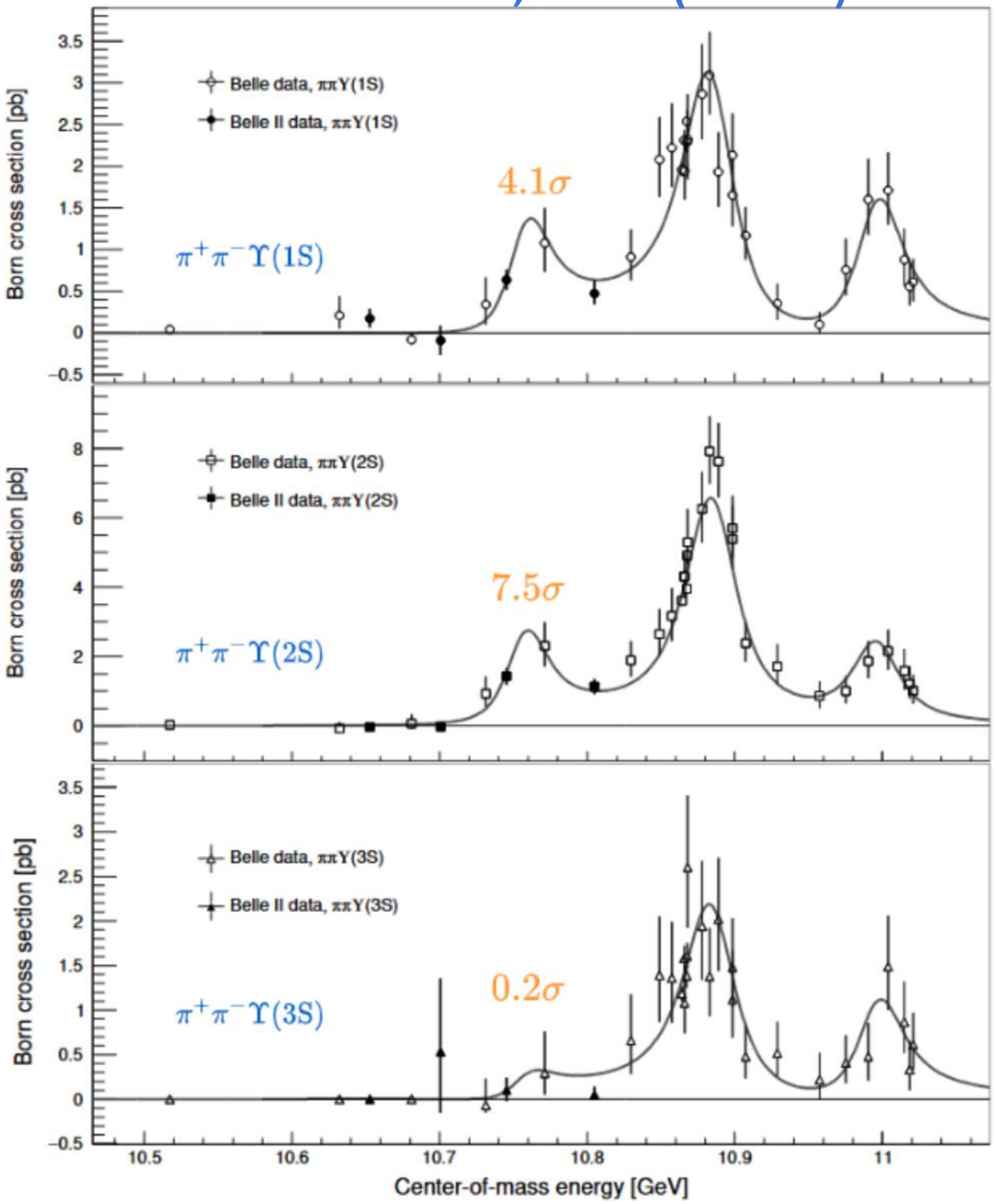




$\psi(4040)$



JHEP 07, 116 (2024)



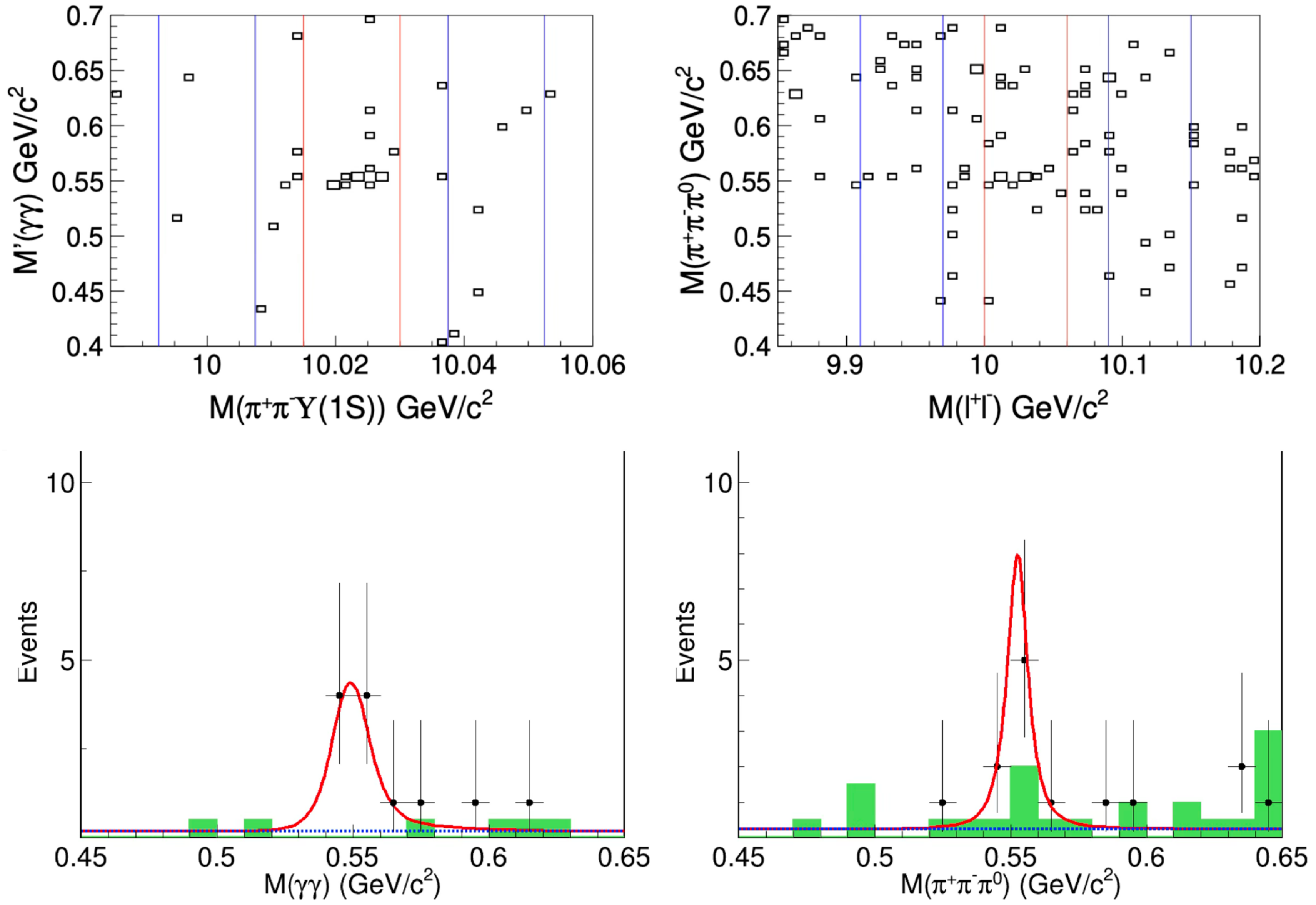
# Observation of $\Upsilon(10753) \to \eta\Upsilon(2S)$

**arXiv:2509.01017**

1. $e^+e^- \to \eta[\to \pi^+\pi^-\pi^0]\Upsilon(1S)[\to \ell^+\ell^-]$ → only 2 events
2. $e^+e^- \to \eta[\to \pi^+\pi^-\pi^0]\Upsilon(2S)[\to \ell^+\ell^-]$
3. $e^+e^- \to \eta[\to \gamma\gamma]\Upsilon(2S)[\to \pi^+\pi^-\Upsilon(1S)[\to \ell^+\ell^-]]$

**6.4σ** (items 2 and 3)

4. $e^+e^- \to \gamma X_b\left[\to \pi^+\pi^-\chi_{bJ}[\to \gamma\Upsilon(1S)[\to \ell^+\ell^-]]\right]$ → nosignal



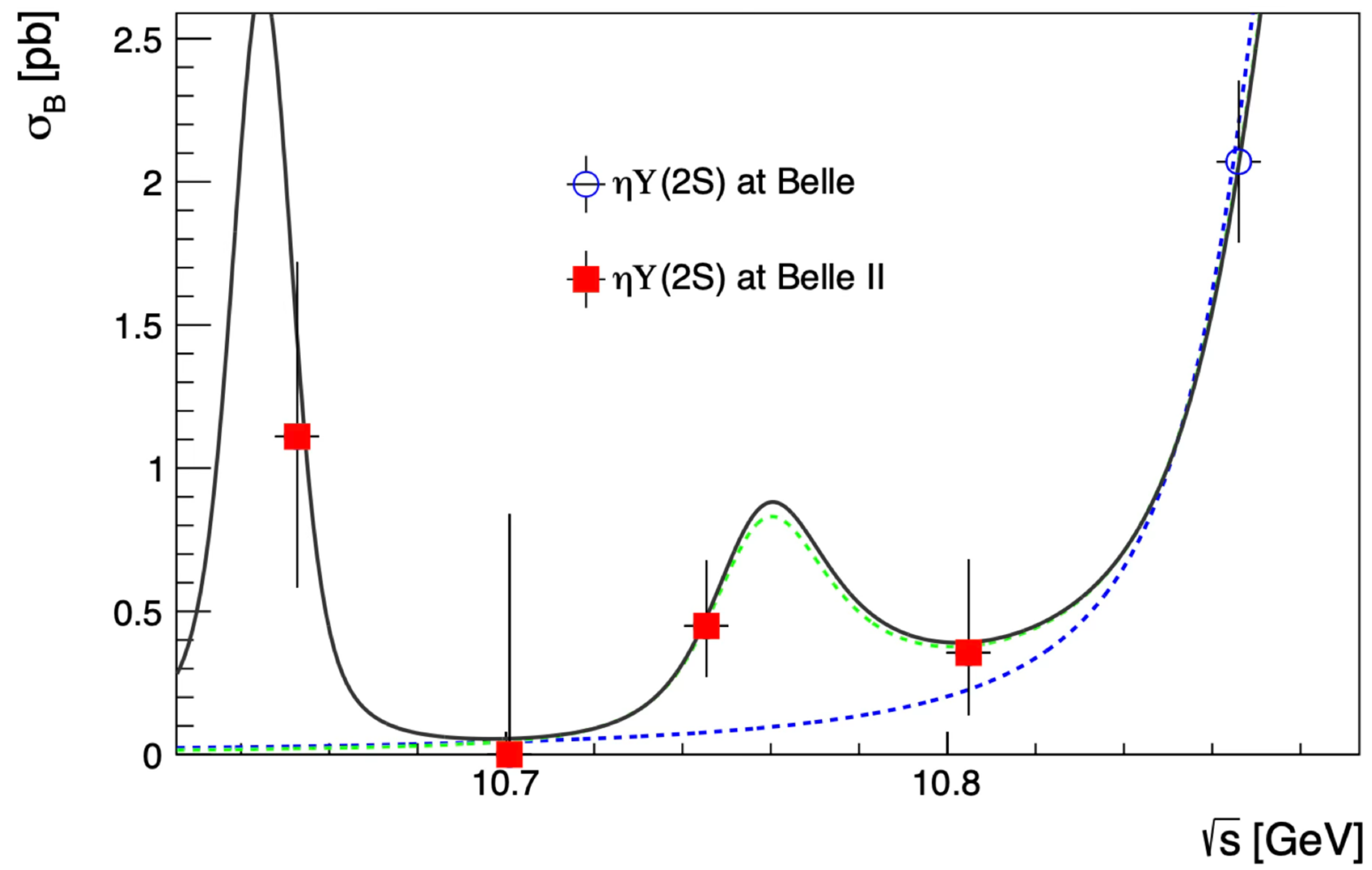
Fit hypotheses:

H1: only $\Upsilon(5S)$ (blue curve)

H2: $\Upsilon(5S)$ and $\Upsilon(10753)$ (green curve)

H3: A default fit with all 3 components (black curve)

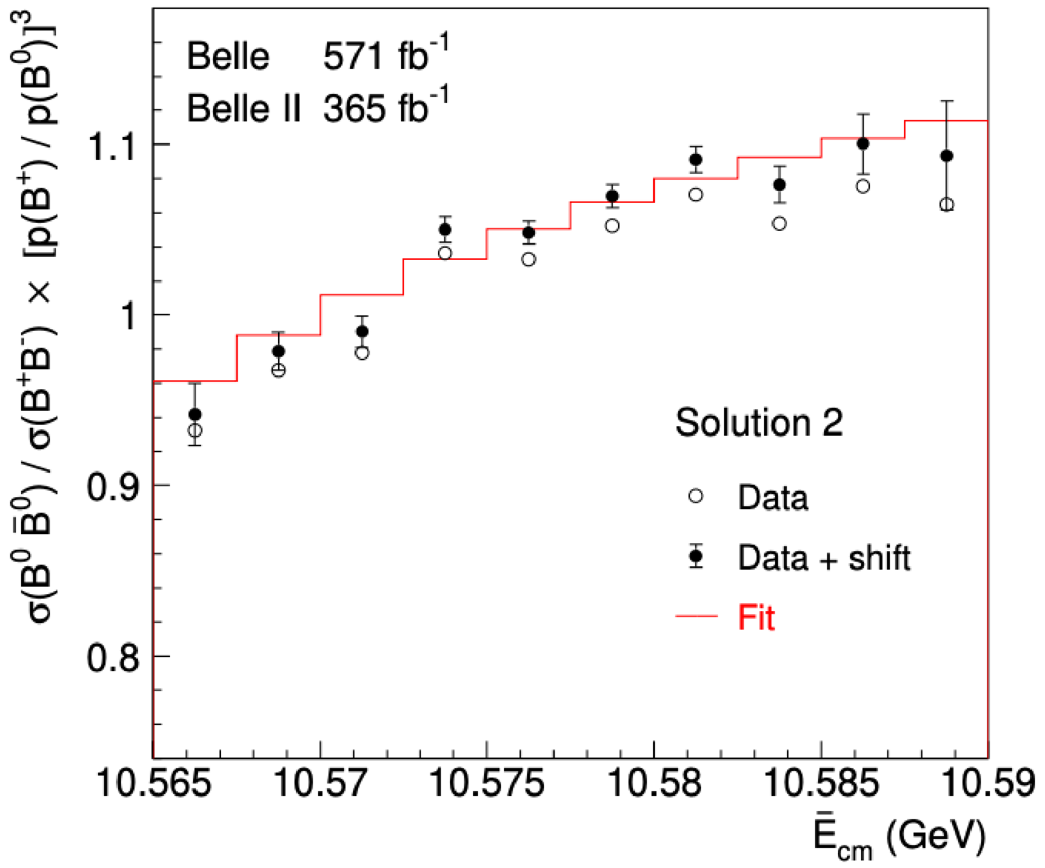
- the significance of $\Upsilon(10753)$ is < 2σ
- An extra resonance near $B^*\bar{B}^*$ threshold is favored by ~3.8σ, but with parameters fixed



JHEP 10, 114 (2024)

# Measurement of mass difference $m(B^0)-m(B^+)$ and $\sigma(B^0\bar{B}^0)/\sigma(B^+B^-)$ vs. energy at Belle and Belle II

arXiv:2511.15926



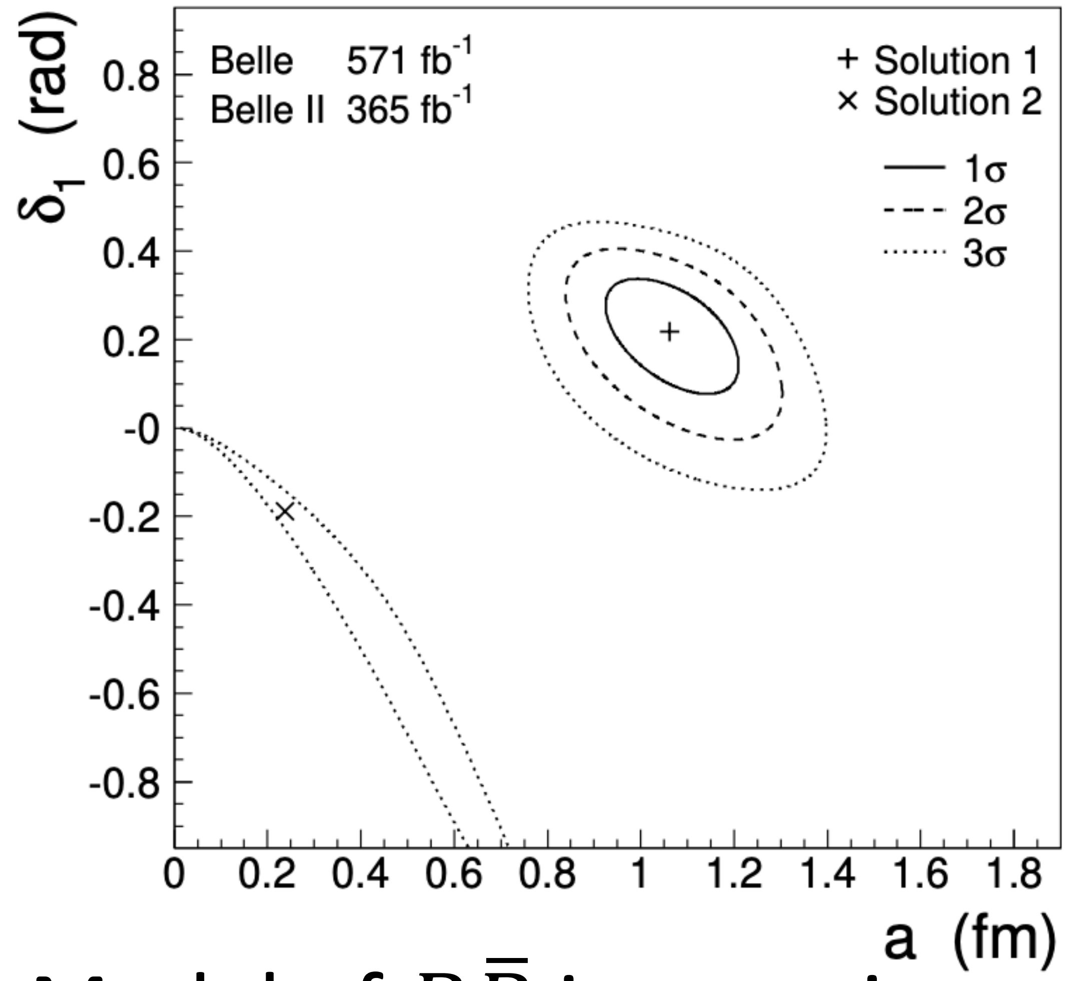
- $\Delta m = m_{B^0} - m_{B^+}$ is a basic property of B-meson system;
  - ➢important input for quark models;
  - ➢contains information on $m_d - m_u$.
- $R = \sigma(B^0\bar{B}^0)/\sigma(B^+B^-)$ vs. $E$ : strong isovector potential in $B\bar{B}$ system.
  - ➢Important for understanding of molecular states.

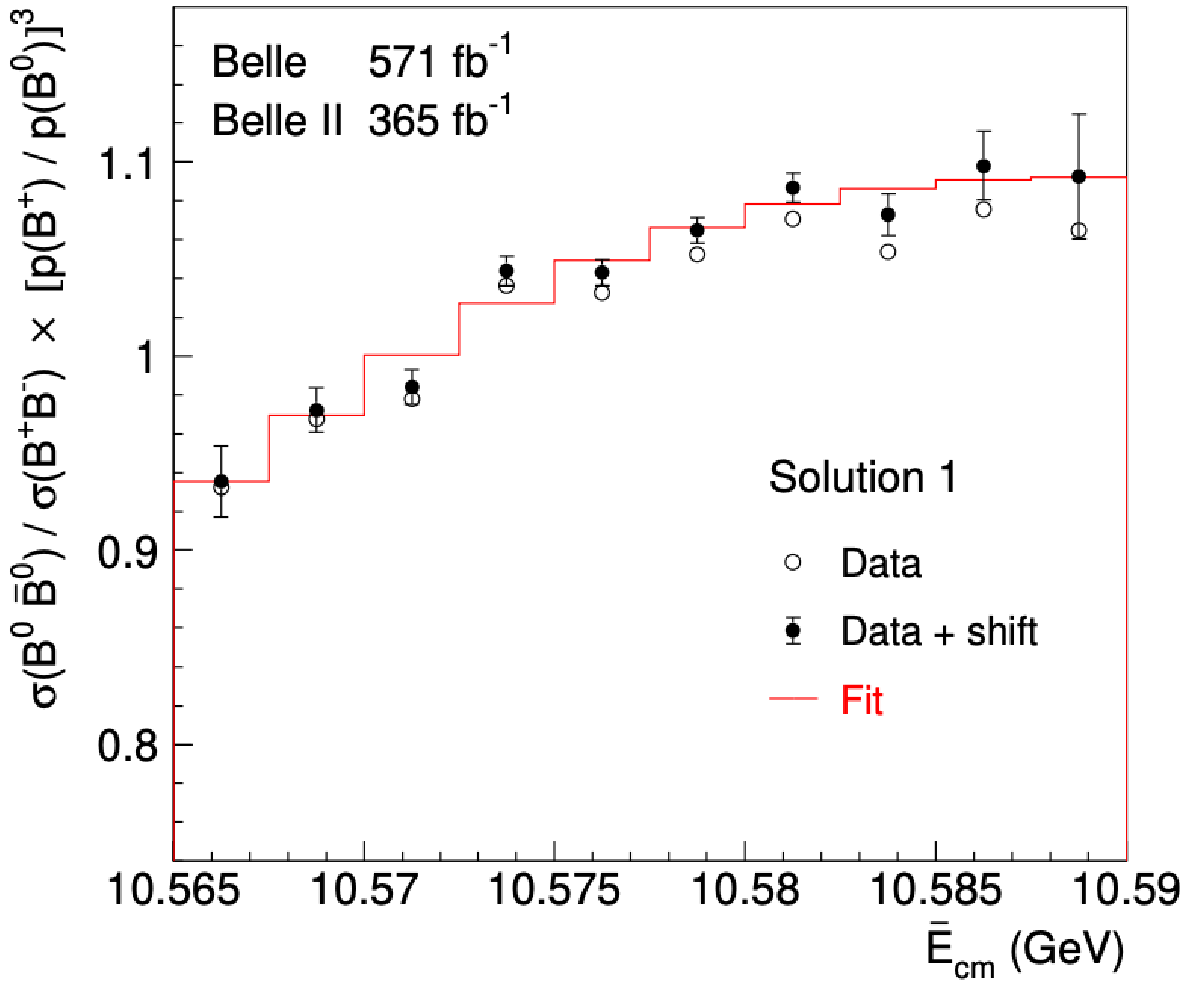
| | $\Delta m$, MeV/$c^2$ |
|---|---|
| Belle + Belle II | $0.495 \pm 0.024 \pm 0.005$ |
| BaBar PRD78, 011103 (2008) | $0.33 \pm 0.05 \pm 0.03$ |

BaBar used PHSP hypothesis:

$$R = \left(\frac{p_{B^0}}{p_{B^+}}\right)^3$$

PHSP hypothesis: excluded at 10σ level



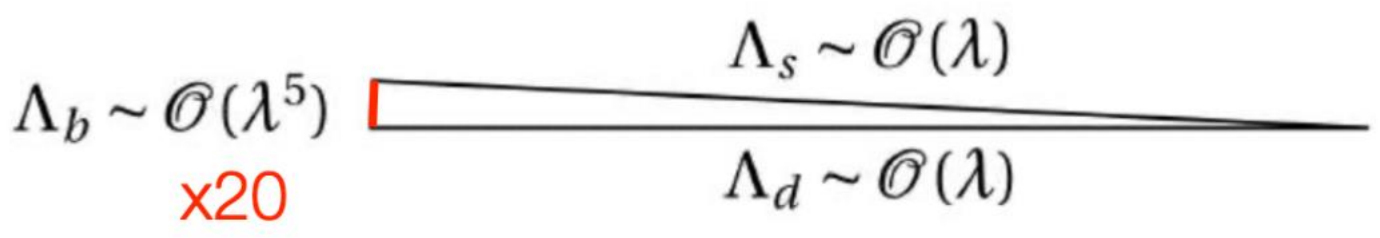


Model of $B\bar{B}$ interaction: PRD97, 114023 (2018)

- Constant potential inside radius a
- scattering phase in isovector channel $\delta_1$
  - ➢ >0 for attractive potential

# CP violation in charm meson

Charm Unitarity Triangle:



- **CP violation is smaller in charm than in beauty sector**
  - ▸ from relative phase between tree and penguin diagrams
  - ▸ Max $O(10^{-3})$ in the standard model, but may be enhanced by new physics
- **CPV only observed in one channel**

$$A_{cp}(D \to f) = \frac{\Gamma(D \to f) - \Gamma(\bar{D} \to \bar{f})}{\Gamma(D \to f) + \Gamma(\bar{D} \to \bar{f})}$$

  - ▸ LHCb in $\Delta A_{CP}(D^0 \to K^+K^-, \pi^+\pi^-) = (-1.5 \pm 0.3) \times 10^{-3}$

& $A_{CP}(D^0 \to K^+K^-) = (0.7 \pm 0.6) \times 10^{-3}$

⇒ $A_{CP}(D^0 \to \pi^+\pi^-) = (2.3 \pm 0.6) \times 10^{-3}$

**Break U-spin symmetry**

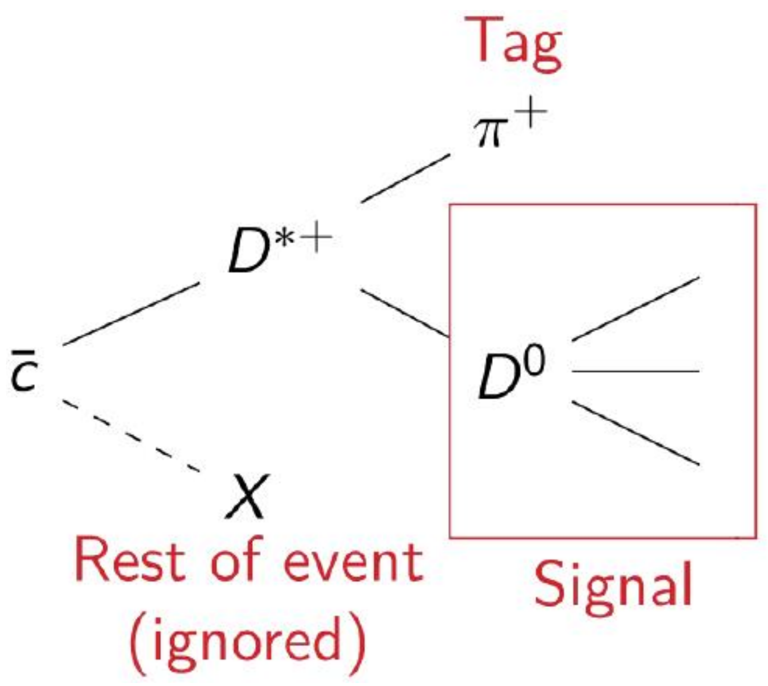
  - ▸ Not yet clear if compatible with SM:

    non-perturbative QCD may affect predictions

- ▸ **Need for measurements in different decay channels & by other experiments**
- ▸ **May sensitive to new physics contributions**

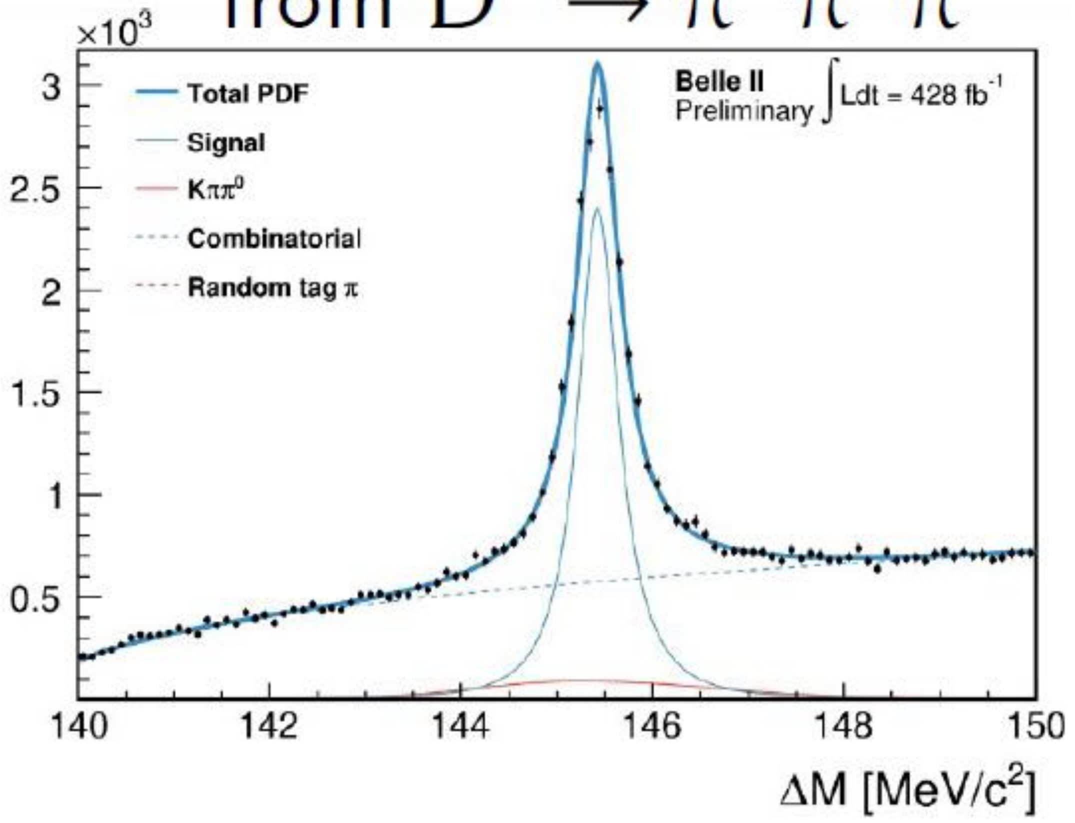
# Flavor tag method

- **$D^*$ tagging:**
  - When $D^0$ and $\overline{D}^0$ have common final state, use $D^{*+} \to D^0\pi^+$

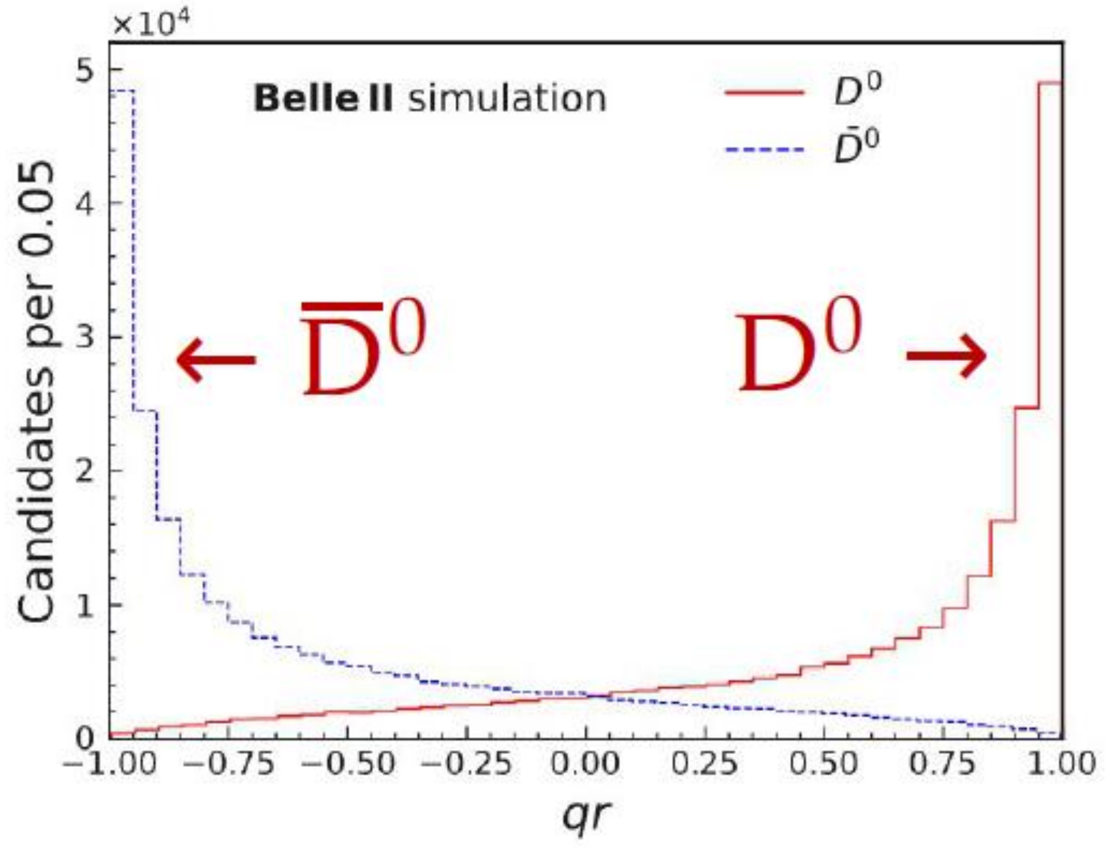


  - Slow $\pi^{\pm}$ indicate the flavor of $D$
  - Most common method:
    - ⇒Powerful background discrimination
    - ⇒Efficiency $\sim$25%, but very small mistag rate

Example $\Delta$M from $D^0 \to \pi^+\pi^-\pi^0$



- **Charm Flavor Tagger (CFT)**
  - New method developed at Belle II [PRD 107, 112010]
  - BDT using rest-of-event particles, from the other charmed hadron & fragmentation
  - ⇒ Trained based on simulation, calibrated using data



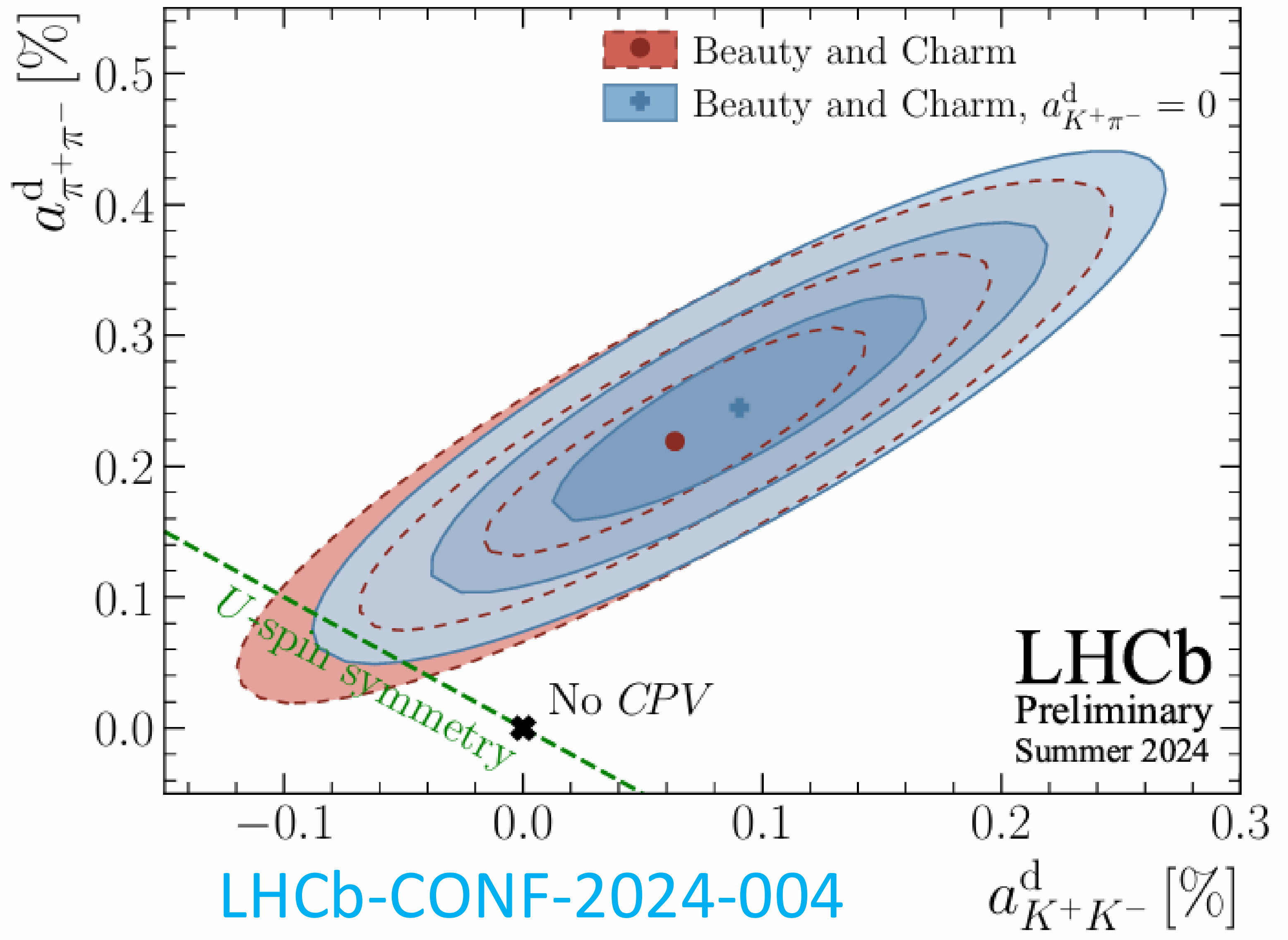
- LHCb is good at charged tracks
- Belle II better for cluster

# CP asymmetry in $D^0 \to \pi^0\pi^0$, $D^+ \to \pi^+\pi^0$

The following sum-rule for CPV in $D \to \pi\pi$ decays; it helps to determine the source of CPV

$$R = \frac{A_{CP}^{\rm dir}(D^0 \to \pi^+\pi^-)}{1 + \frac{\tau_{D^0}}{\mathcal{B}_{+-}}\left(\frac{\mathcal{B}_{00}}{\tau_{D^0}} - \frac{2}{3}\frac{\mathcal{B}_{+0}}{\tau_{D^+}}\right)} + \frac{A_{CP}^{\rm dir}(D^0 \to \pi^0\pi^0)}{1 + \frac{\tau_{D^0}}{\mathcal{B}_{00}}\left(\frac{\mathcal{B}_{+-}}{\tau_{D^0}} - \frac{2}{3}\frac{\mathcal{B}_{+0}}{\tau_{D^+}}\right)} + \frac{A_{CP}^{\rm dir}(D^+ \to \pi^+\pi^0)}{1 - \frac{3}{2}\frac{\tau_{D^+}}{\mathcal{B}_{+0}}\left(\frac{\mathcal{B}_{00}}{\tau_{D^0}} + \frac{\mathcal{B}_{+-}}{\tau_{D^0}}\right)}$$

- ◆ The $B$ and $\tau$ have been well-measured (by BESIII/BelleII/etc.)
- ◆ If $R \neq 0$, CPV from $\Delta I = 1/2$ amplitude ($D^0 \to \pi^+\pi^-$);
- ◆ if $R = 0$ and at least one $A_{CP}^{dir} \neq 0$, CPV from a beyond-SM $\Delta I = 3/2$ amplitude.



LHCb-CONF-2024-004

- ◆ $R = (0.9 \pm 3.1) \times 10^{-3}$, err. dominated by $\pi^0\pi^0$
- ◆ $A_{CP}^{dir}(D^0 \to \pi^+\pi^-) = (2.3 \pm 0.6) \times 10^{-3}$
- ◆ Belle (II) have advantage on the $\pi^0$ decay modes

**Measurement of *R* helps to figure out the amplitudes of *D* meson CPV**

# CP asymmetry in $D^0 \to \pi^0\pi^0$

PRD 112, 012006

Raw asymmetry of $D^0 \to \pi^0\pi^0$ from the $D^{*+} \to D^0\pi_s^+$ sample

$$A_{raw}(D^0 \to \pi^0\pi^0) = A_{cp}(D^0 \to \pi^0\pi^0) + A_{prod}^{D^*} + A_{\varepsilon}^{\pi_s} .$$

$A_{prod}^{D^*}$: odd function of $cos\theta^*$ due to $\gamma - Z^0$ interference and higher-order effects, suppressed by:

$$A'^f = \frac{A^f(\cos\theta_{cms}<0) + A^f(\cos\theta_{cms}>0)}{2}$$

Using $D^0 \to K^-\pi^+$ as control sample (tagged or untagged), i.e.:

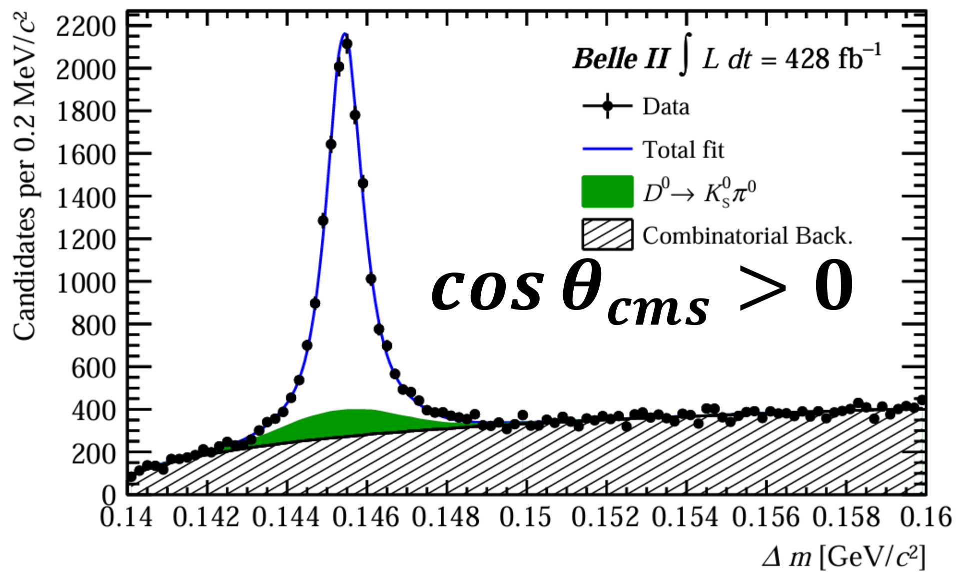
$$\begin{cases} A^{K\pi} = A_{prod}^{D^*} + A_{\varepsilon}^{\pi_s} + A_{\varepsilon}^{K\pi} \ (tag) \\ A^{K\pi} = A_{prod}^{D^0} + A_{\varepsilon}^{K\pi} \qquad (untag) \end{cases}$$

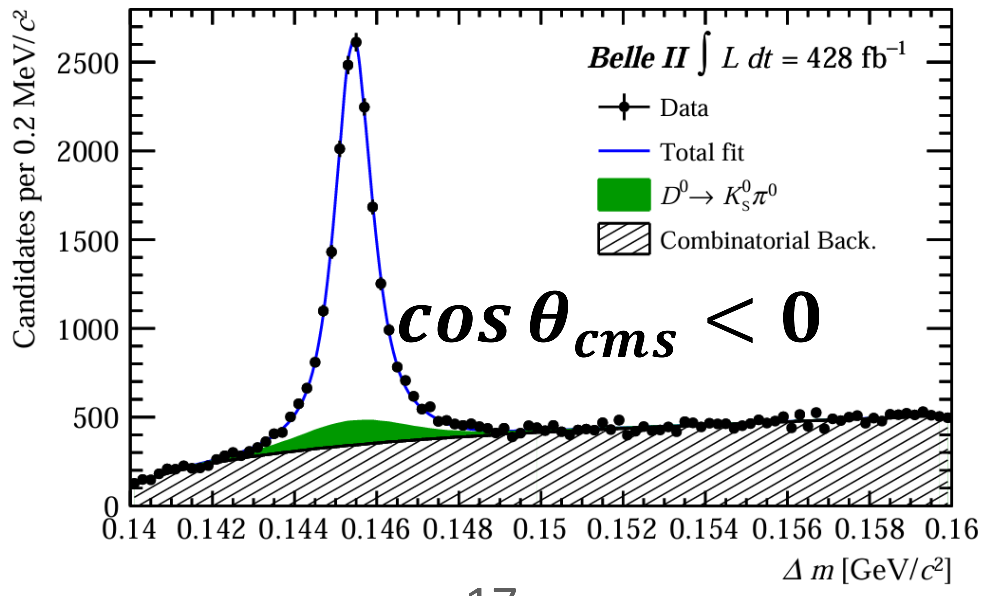
Belle II (428 fb$^{-1}$): $$A_{cp}(D^0 \to \pi^0\pi^0) = A'^{\pi^0\pi^0} - A'^{K\pi} + A'^{K\pi,untag} = (0.30 \pm 0.72 \pm 0.20)\%$$

- Belle (980 fb$^{-1}$): $A_{cp}(D^0 \to \pi^0\pi^0) = (-0.03 \pm 0.64 \pm 0.10)\%$ [PRL 112 211601 (2014)]

- 15% less precision than Belle; BUT improved precision per luminosity.
- $R = (1.5 \pm 2.5) \times 10^{-3}$,

  precision improved by ~ 20% w.r.t current HFLAV result [PRD 107 (2023) 052008]



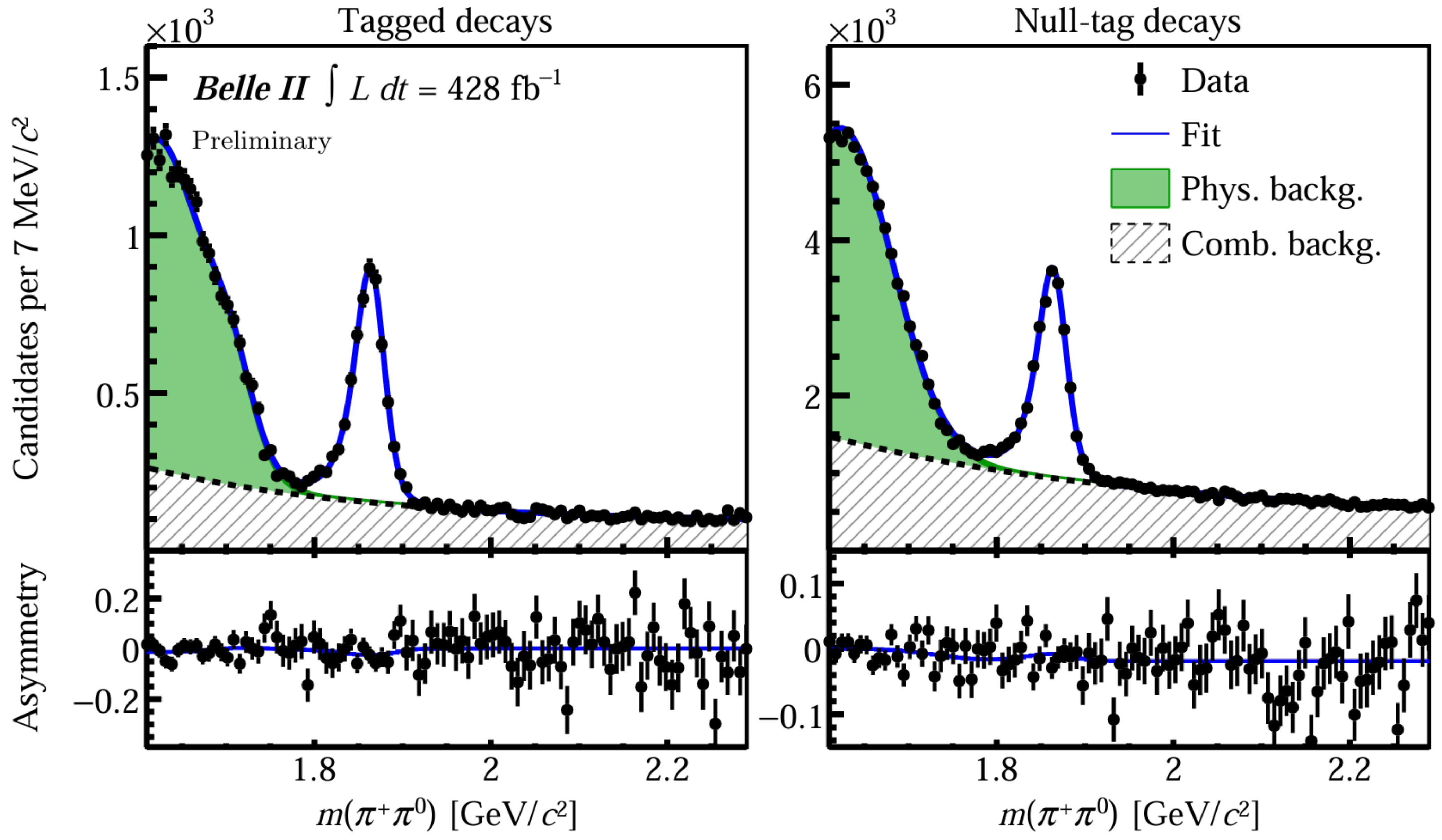


# CP asymmetry in $D^+ \to \pi^+\pi^0$

PRD 112, L031101

**Split sample:**

**$D^+$ from $D^{*+} \to D^+\pi^0$ decay or not**



$N_{\text{sig}}^{\text{tag}} = 5\,130 \pm 110$ $\quad N_{\text{sig}}^{\text{null}} = 18\,510 \pm 240$

$A_{CP}^{\text{tag}} = (-3.9 \pm 1.8 \pm 0.2)\%$ $\quad A_{CP}^{\text{null}} = (-1.1 \pm 1.0 \pm 0.1)\%$

Combined:

$$A_{cp}(D^+ \to \pi^+\pi^0) = (-1.8 \pm 0.9 \pm 0.1)\%$$

- A 3.8σ CPV in the pionic mode $D^0 \to \pi^+\pi^-$.
  - ➢ Unclear if observed CP violation can be described by the SM or not, due to large hadronic uncertainties

PRL 131, 051802 (2023) PRD 108, 036026 (2023) PRD 109, 033011 (2024)

- Isospin-related modes $D^+ \to \pi^+\pi^0$ can reduce hadronic uncertainty.
- In addition, $D^+ \to \pi^+\pi^0$ $(\Delta I = 3/2)$ is expected to have no CPV in SM
  - ➢ since it does not receive QCD penguin $(\Delta I = 1/2)$ contribution

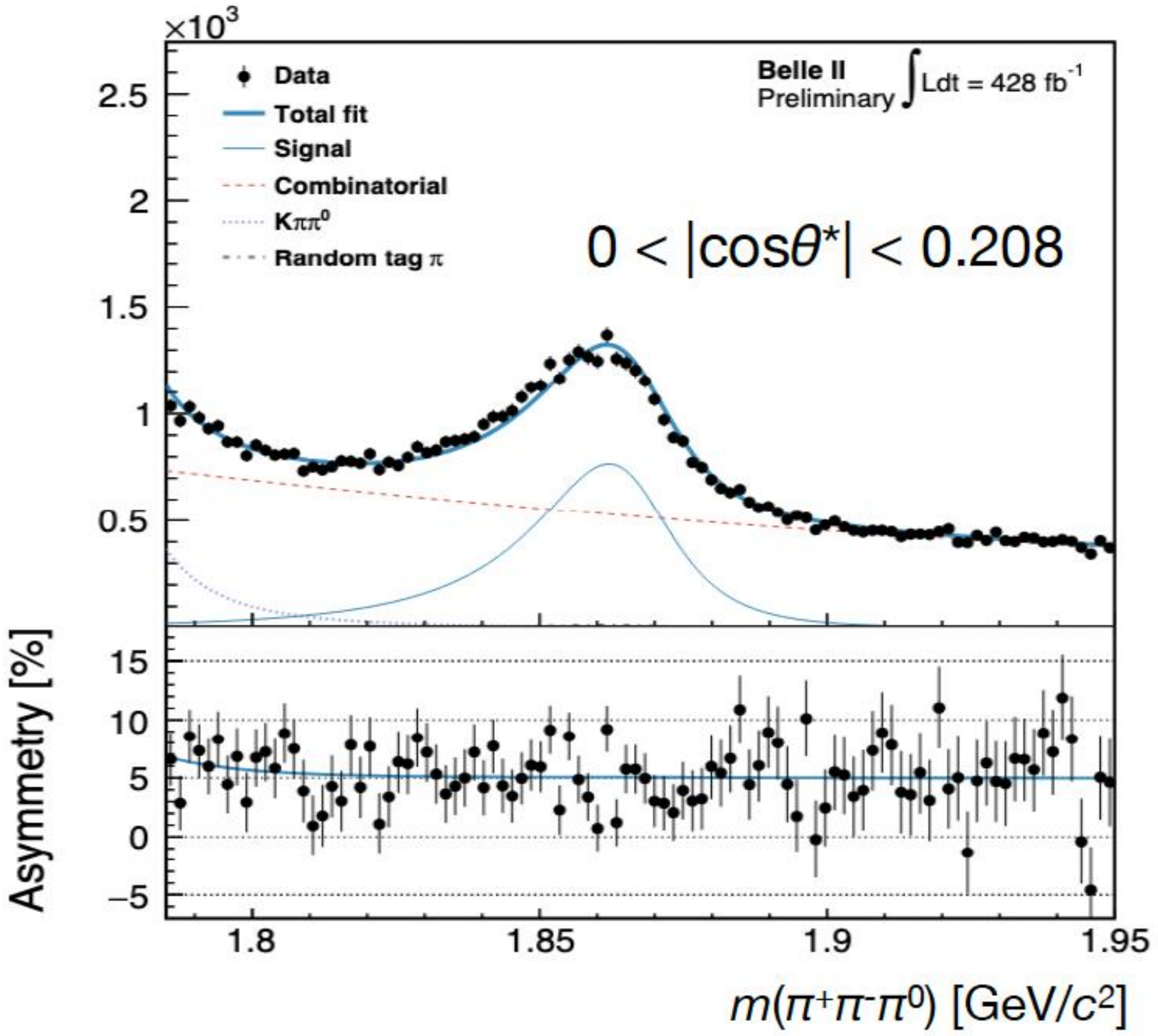
Belle: $A_{cp}(D^+ \to \pi^+\pi^0) = (2.31 \pm 1.24 \pm 0.23)\%$ PRD 97, 011101(2018)

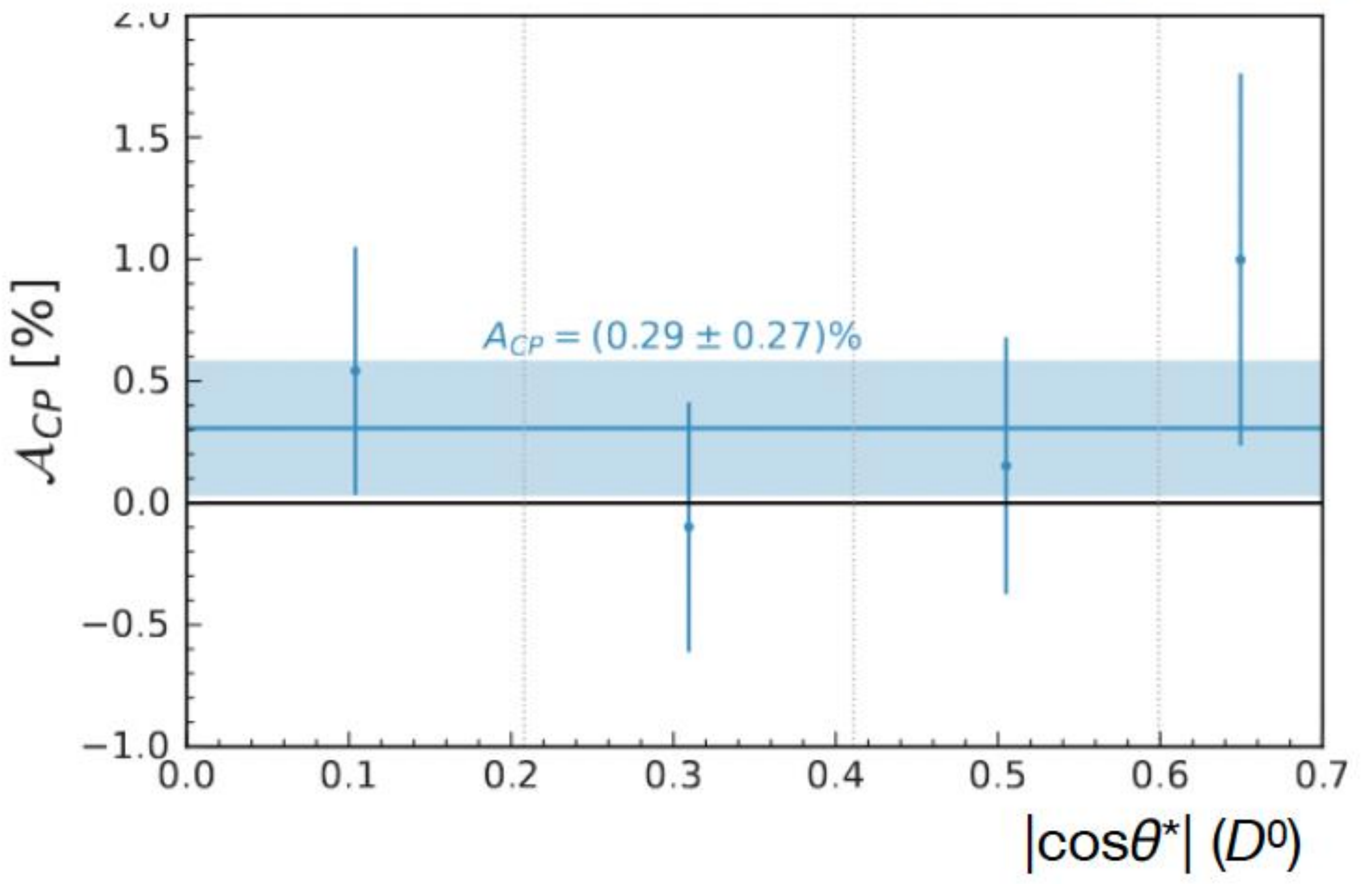
LHCb: $A_{cp}(D^+ \to \pi^+\pi^0) = (-1.3 \pm 0.9 \pm 0.6)\%$ JHEP 06, 019 (2021)

- **Agree with previous measurements**
- **Agree with CP symmetry**

# CP asymmetry in $D^0 \to \pi^+\pi^-\pi^0$

PRD 113, 052006





- Largest CPV expected in singly Cabibbo-supressed D decays (in SM)
- Due to interference between tree and loop diagrams
- Also, SCS decays are uniquely sensitive to new physics through penguin diagram

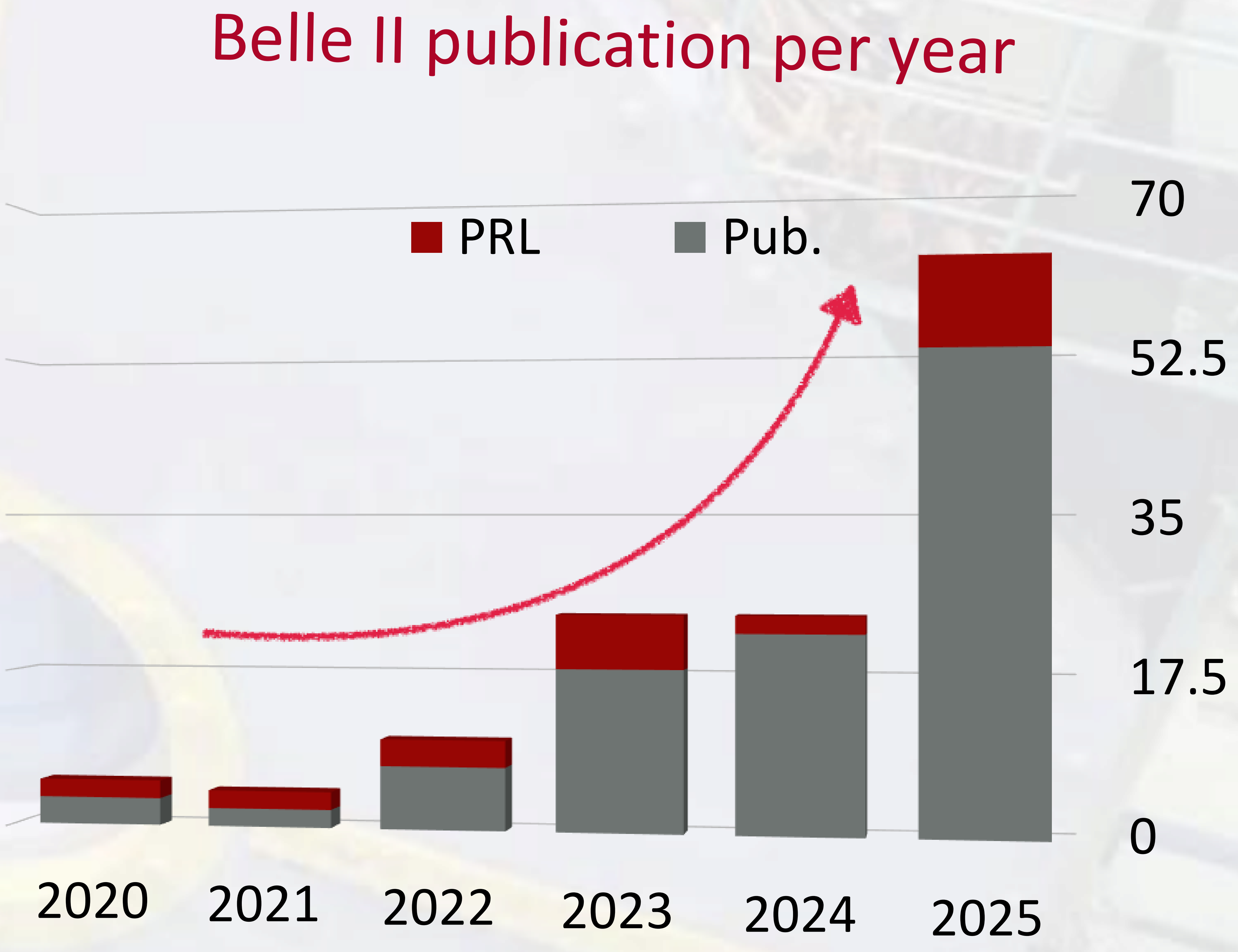
1) BaBar with 385 $\text{fb}^{-1}$ (82k candidates) PRD 78, 051102 (2008)
    - $A_{CP} = (0.31 \pm 0.41 \pm 0.17)\,\%$ (most precise $A_{CP}$ determination so far)
2) Belle with 532 $\text{fb}^{-1}$ (123k candidates) PLB 662, 102 (2008)
    - $A_{CP} = (0.43 \pm 0.41 \pm 1.23)\,\%$
3) LHCb with 6 $\text{fb}^{-1}$ (2.5M candidates) JHEP 2023, 129 (2023)
    - Energy test (unbinned comparison of Dalitz plot distributions): $p = 0.62$
4) LHCb with 7.7 $\text{fb}^{-1}$ (3.8M candidates) PRL 133, 101803 (2024)
    - Time-dependent CPV parameter $\Delta Y = (-1.3 \pm 6.3 \pm 2.4) \times 10^{-4}$

$$A_{CP} = (0.29 \pm 0.27 \pm 0.13)\,\%$$

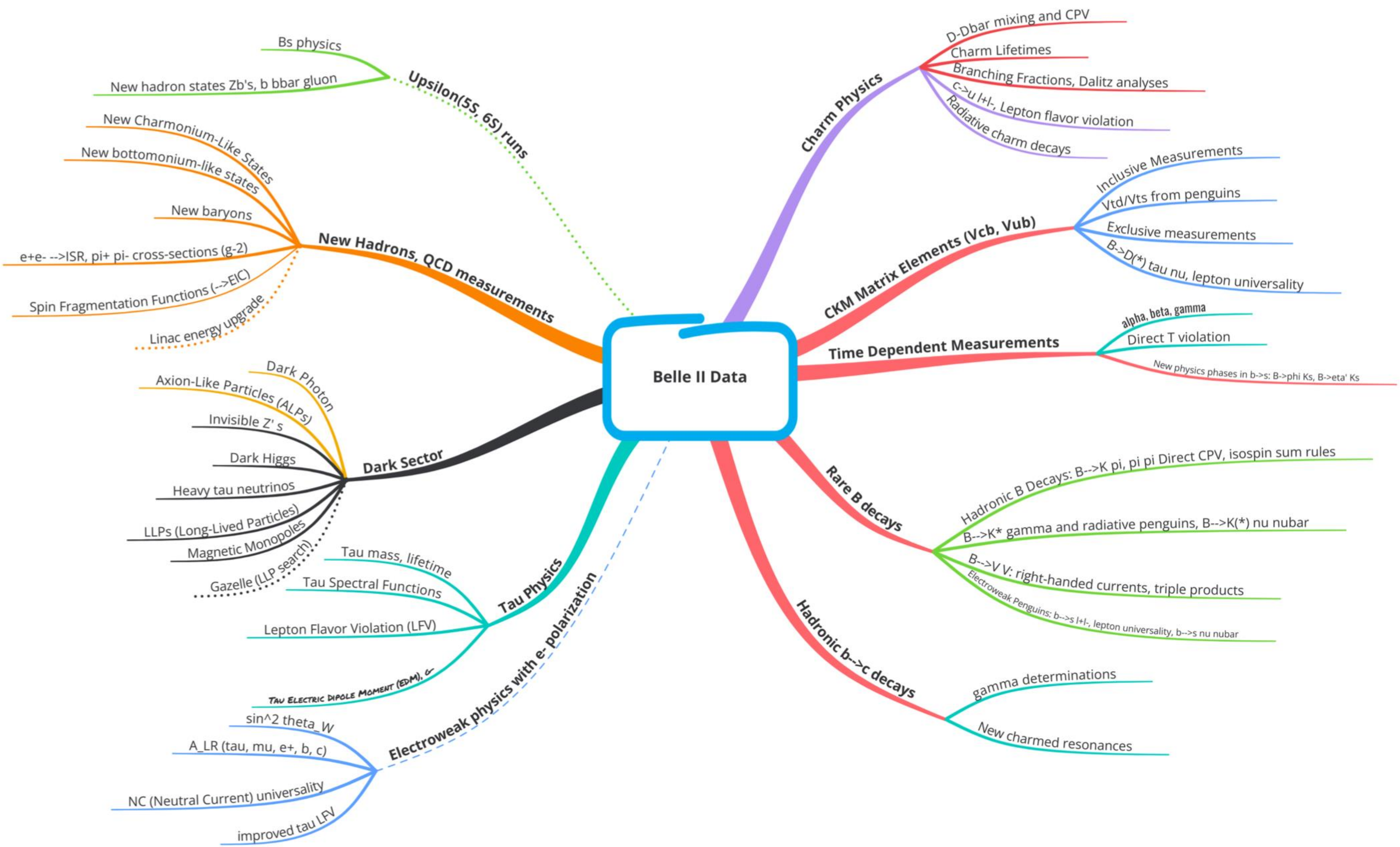
**34% better than current best**
**with only 10% more data**

# Summary

- Experienced many challenges: operation, rising cost…
- But, still lots of achievement! >50 publication in 2025.
- Make good use of Belle II unique advantages.
- Now ~600/fb data, push to 1/ab before July. 5-10/ab till 2032



Thanks!



**Belle II Data**

- **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
- **Electroweak physics with e- polarization**
  - sin^2 theta_W
  - A_LR (tau, mu, e+, b, c)
  - NC (Neutral Current) universality
  - improved tau LFV
- **Tau Physics**
  - Tau mass, lifetime
  - Tau Spectral Functions
  - Lepton Flavor Violation (LFV)
  - TAU ELECTRIC DIPOLE MOMENT (EDM), G
- **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)
- **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
- **Upsilon(5S, 6S) runs**
  - Bs physics
  - New hadron states Zb's, b bbar gluon

# Systematic Effects and Corrections

| Type | % MC |
|---|---|
| $\tau^- \to \pi^- K^0_S \nu_\tau (\geq 0\pi^0)$ | $77.8 \pm 0.2$ |
| $\tau^- \to K^- K^0_S \nu_\tau (\geq 0\pi^0)$ | $2.7 \pm 0.1$ |
| $\tau^- \to \pi^- K^0 \bar{K}^0 \nu_\tau (\geq 0\pi^0)$ | $18.2 \pm 0.1$ |
| Background | $1.3 \pm 0.1$ |

1. Background subtracted using fractions on MC and validated using low BDT regions

$$A^{raw} = \boxed{A^{det}(\pi^+/\pi^-) + A^{trigger} + A^{det}(tag) + A_{FB}} + \boxed{A(K^0/\bar{K}^0)} + \boxed{A_{CP}}$$

2. Detection asymmetry correction extracted from data control samples.
3. Neutral kaon asymmetry from absorption and interference corrected from theoretical predictions.
4. Remaining $\tau$ contribution removed through a dilution factor using SM assumptions.

$$\boxed{\mathcal{A} = \frac{f_1 A_1 + f_2 A_2 + f_3 A_3}{f_1 + f_2 + f_3} = \left(\frac{f_1 - f_2}{f_1 + f_2 + f_3}\right) A_1 = D \times A_1}$$

# CP violation and the CKM matrix

## Quark mixing via charged-current interactions

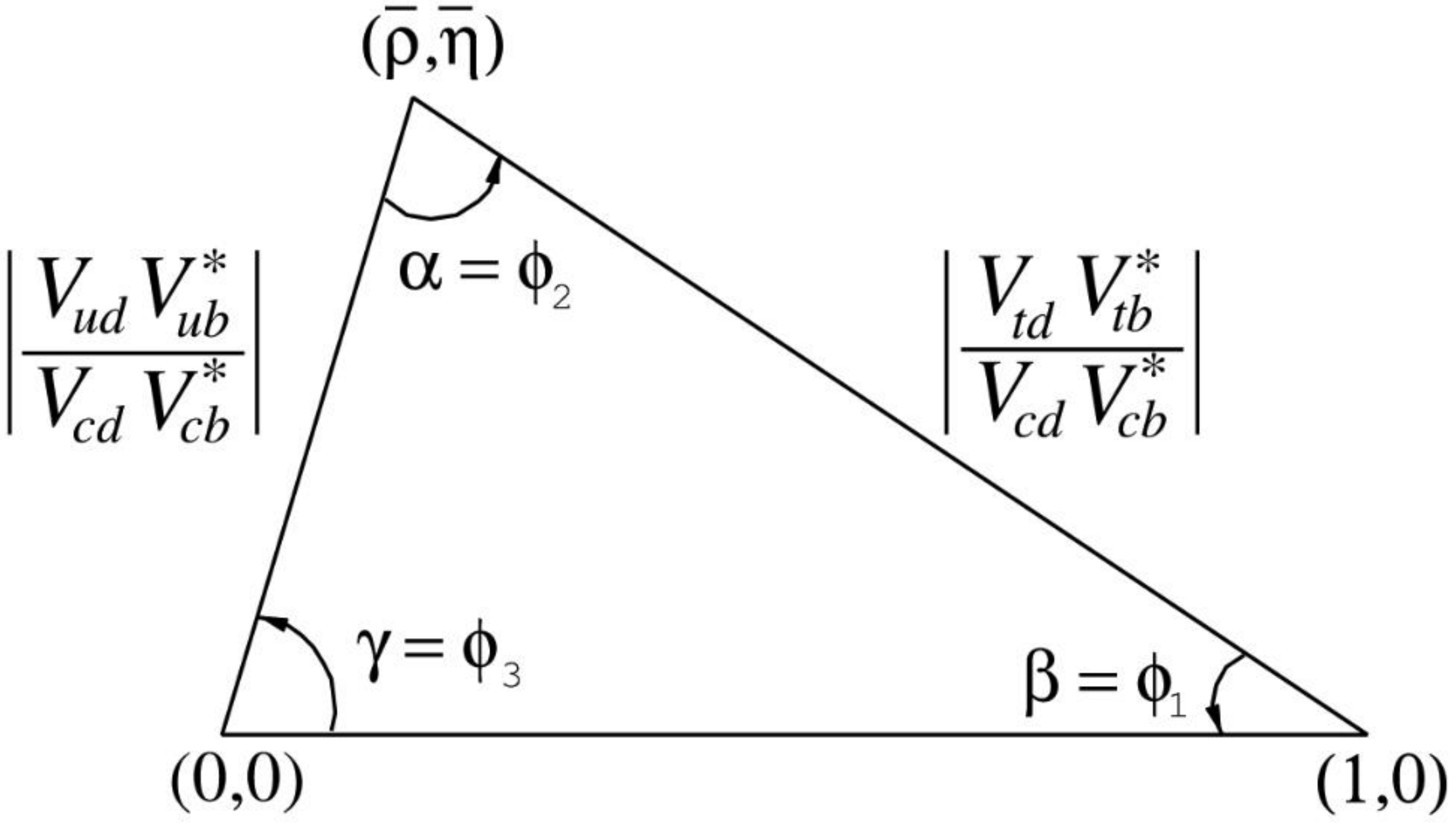
N. Cabibbo

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 ↓

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

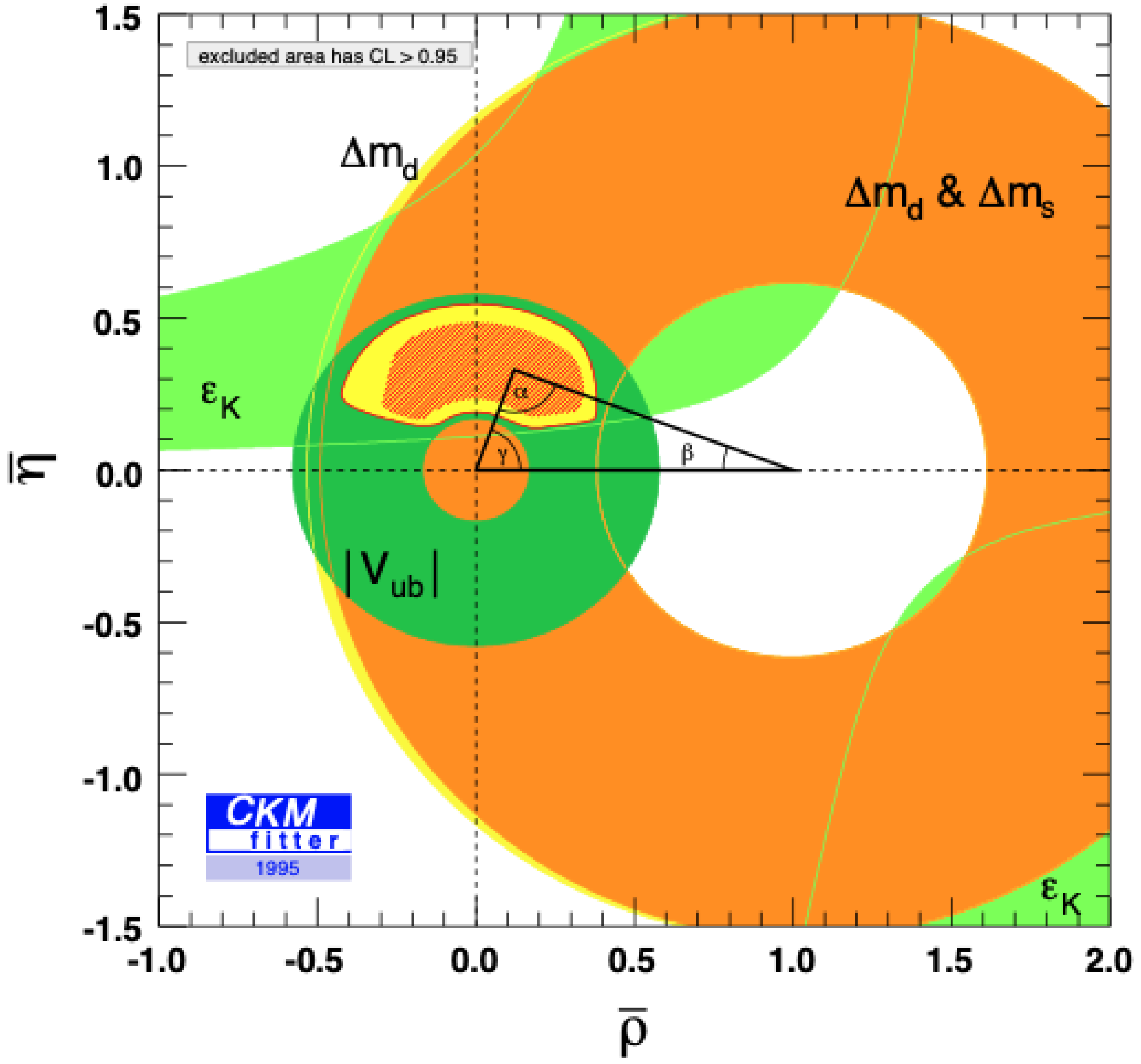
- Common CKM parameterization: Wolfenstein
  - Exploit hierarchy of matrix elements

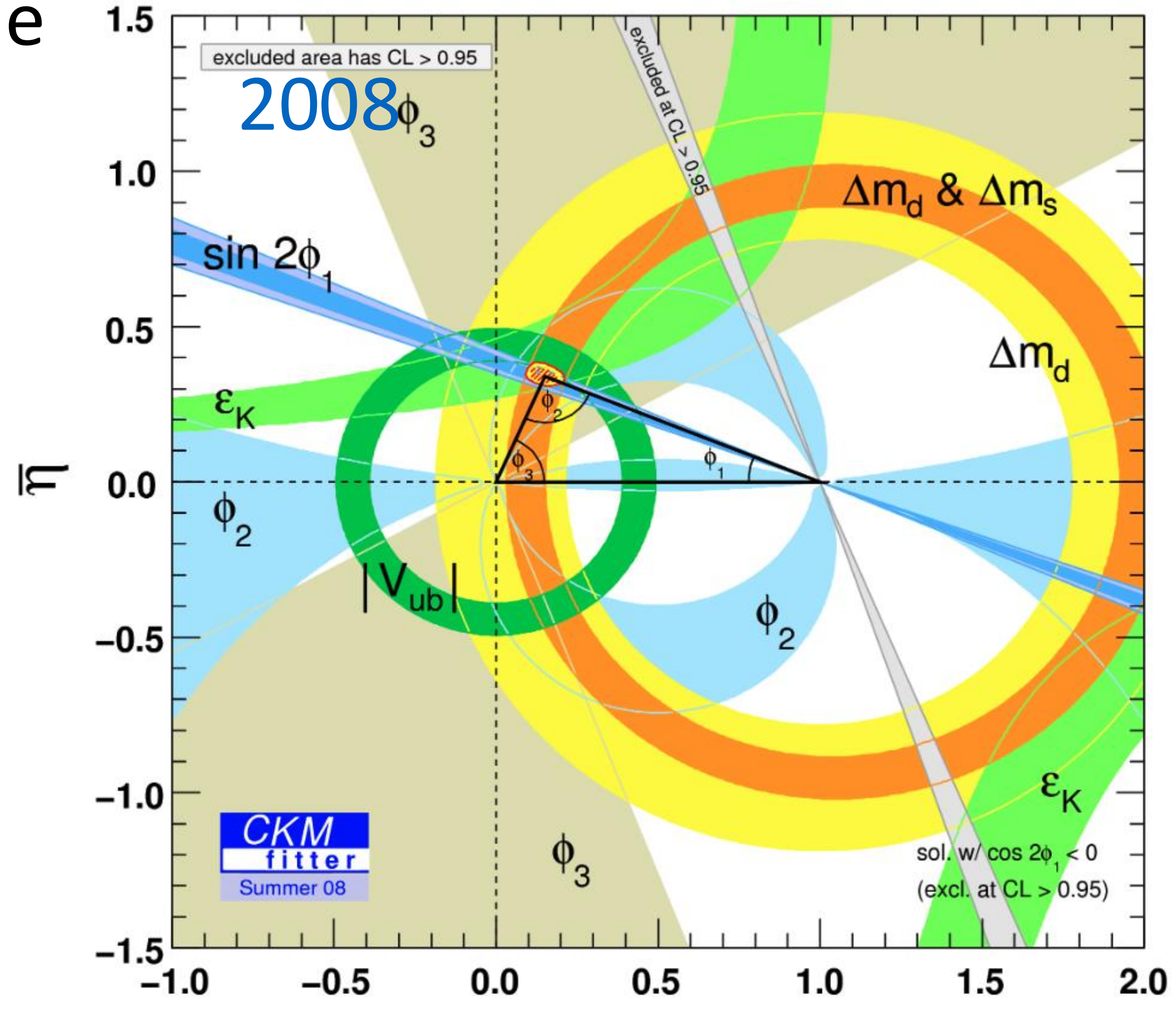
$$V_{\text{CKM}} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\underset{\uparrow}{\rho} - i\underset{\uparrow}{\eta}) & -A\lambda^2 & 1 \end{pmatrix} + \mathcal{O}(\lambda^4)$$

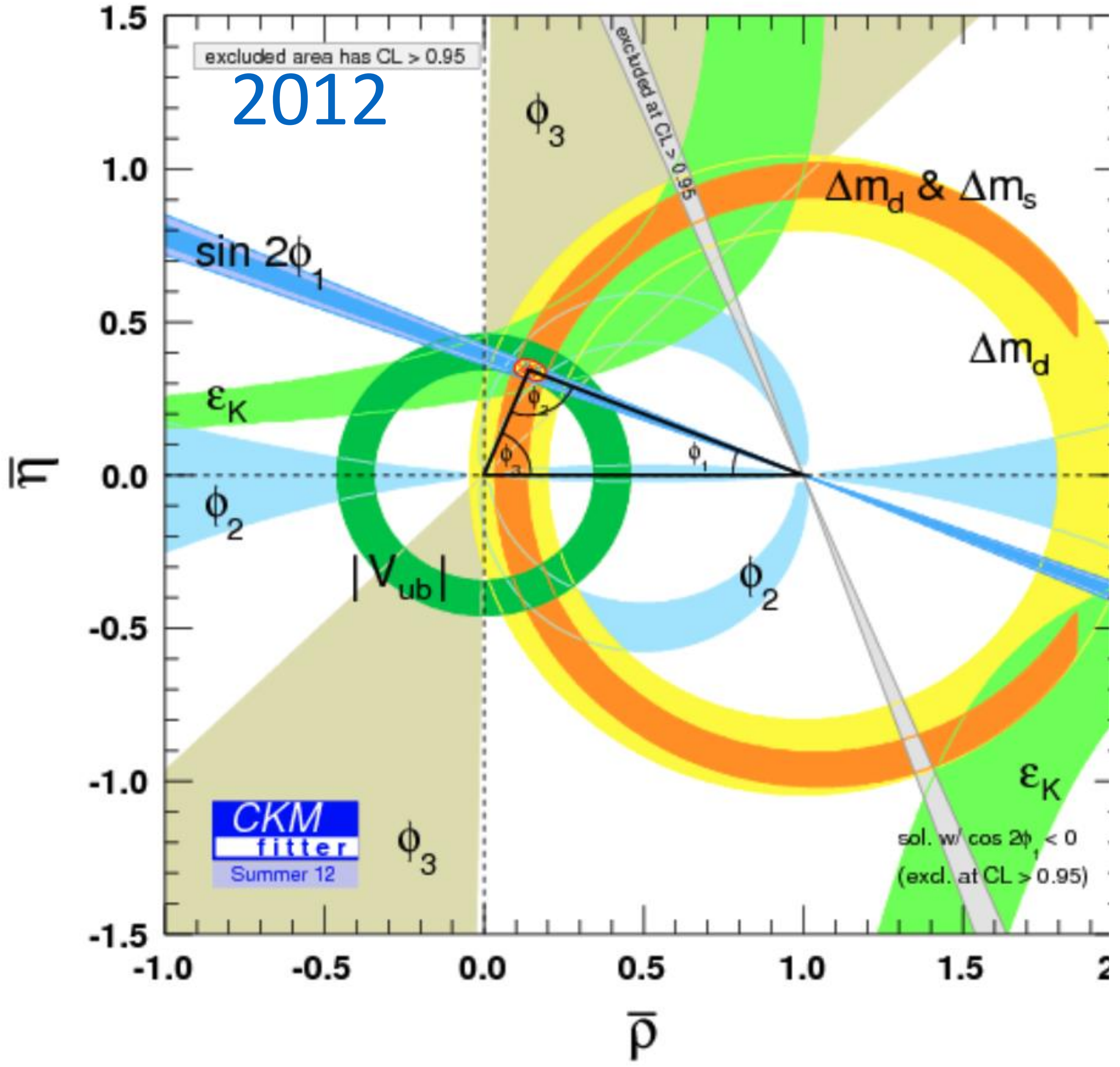
scaled apex parameters

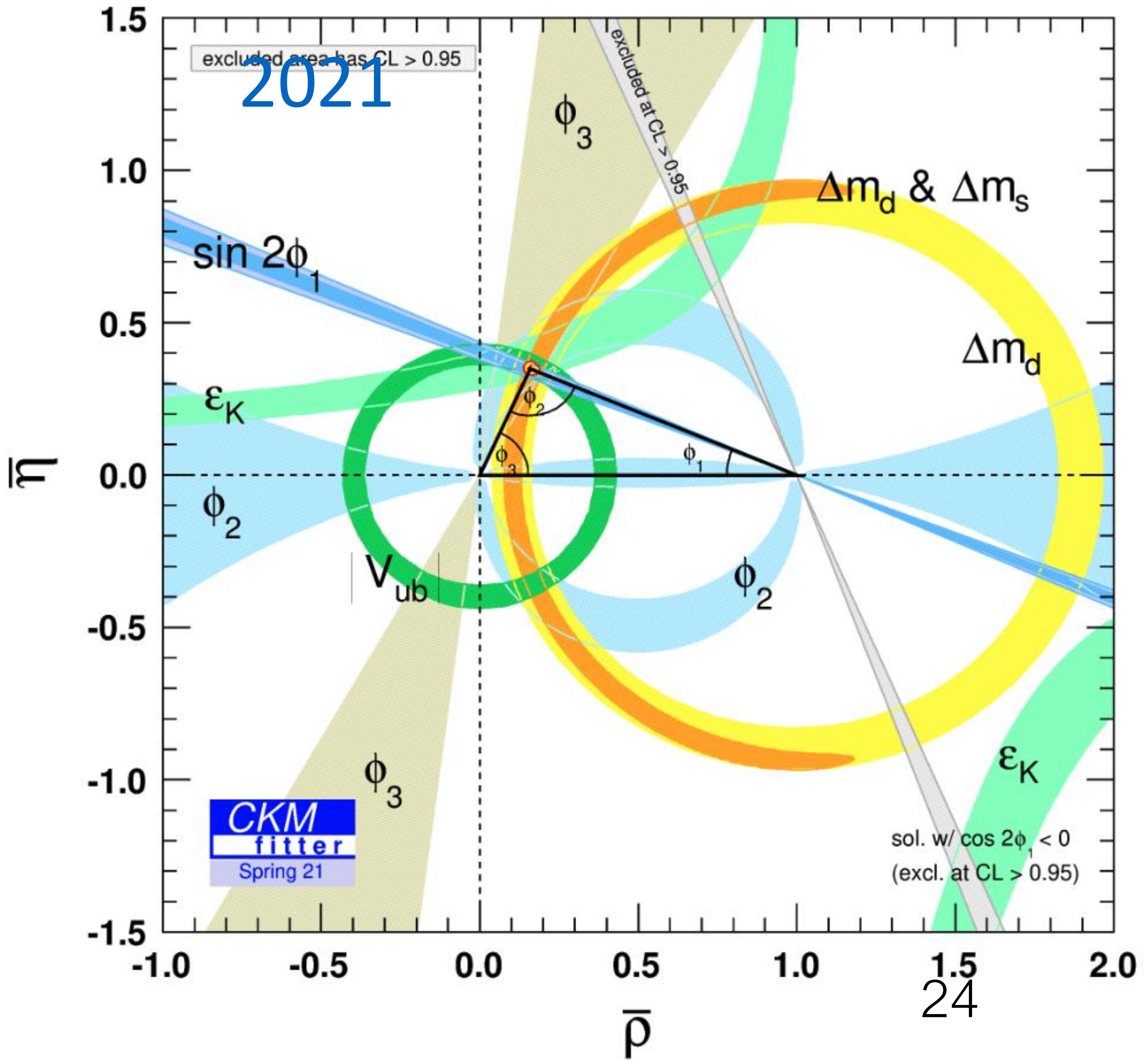
# Is the triangle closed? (Hint of New Physics?)

1995 Before BaBar and Belle







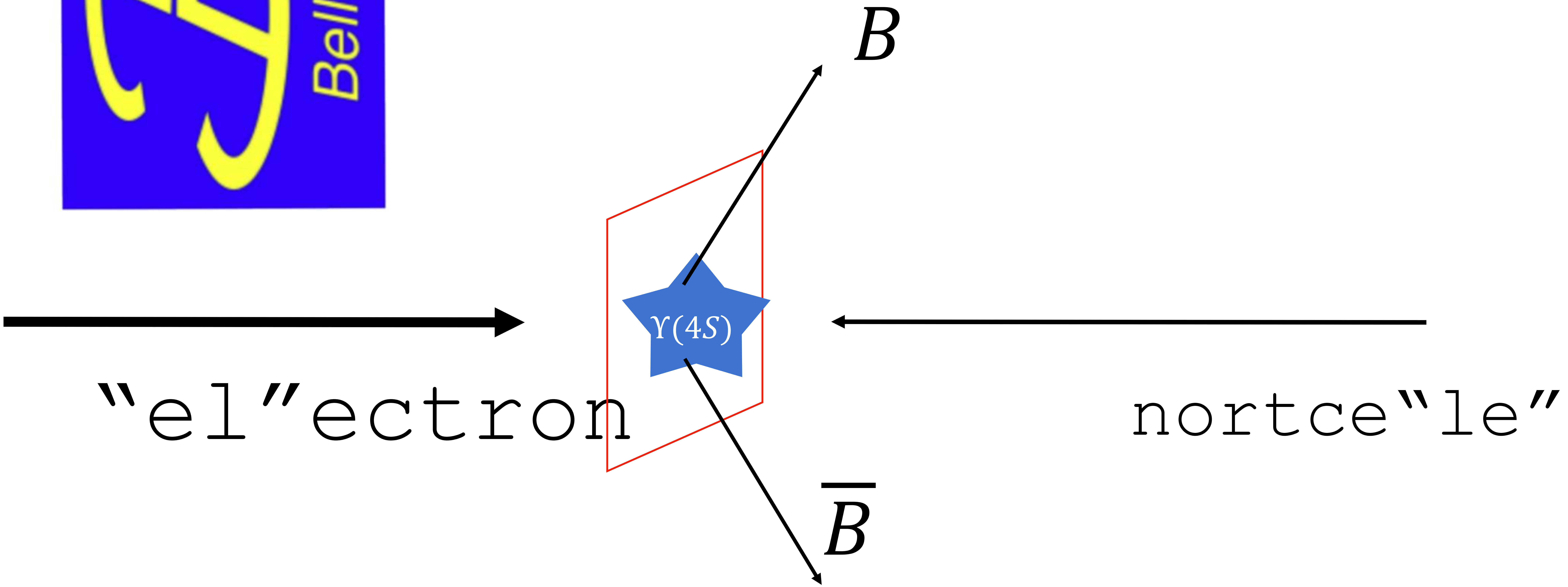


- With results from BaBar, Belle, and LHCb's Run1,2 data, the triangle is still closed.
- $\phi_1 = \beta = arg(-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}), (22.2 \pm 0.7)^\circ$
- $\phi_2 = \alpha = arg(-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}),(85.2^{+4.8}_{-4.3})^\circ$
- $\phi_3 = \gamma = arg(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}),(66.2^{+3.4}_{-3.6})^\circ$

HFLAV

- With much more data from LHCb and Belle II, we could shrink the uncertainty, test this triangle and look for hints from new physics.

# B el le



$B$

$\Upsilon(4S)$

“el”ectron

nortce“le”

$\overline{B}$