Review of recent Belle and Belle II results

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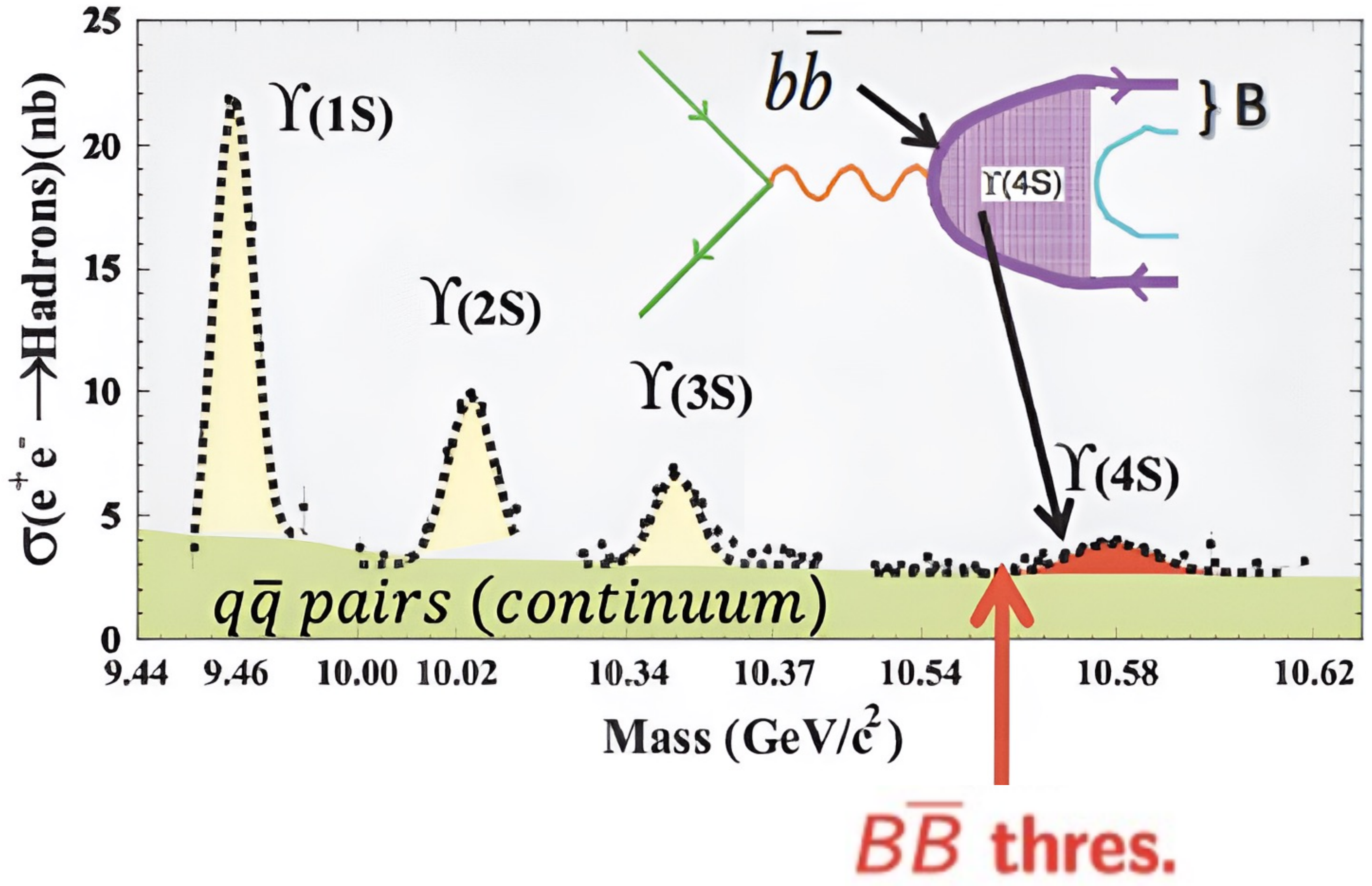
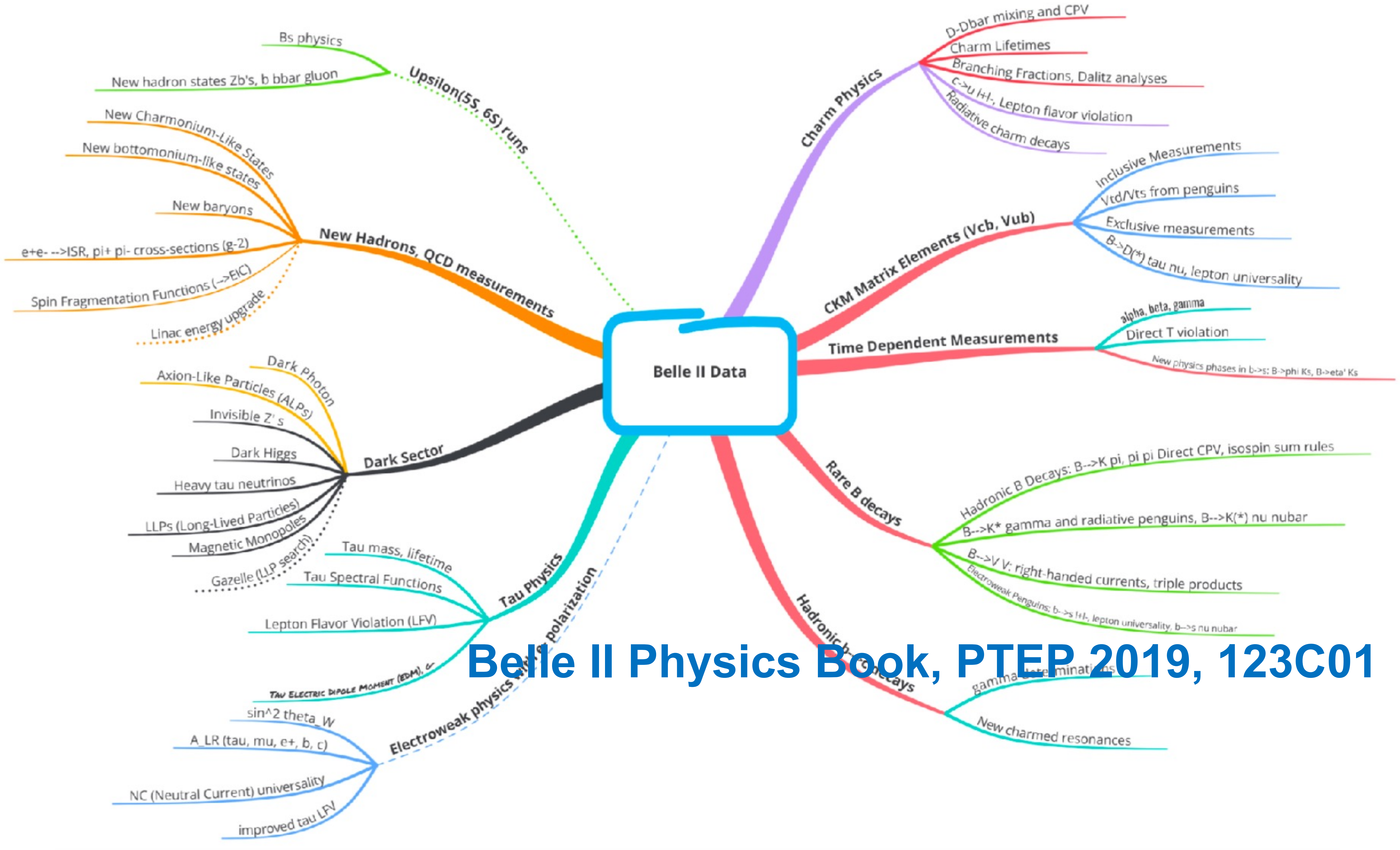
Belle II physics

The Belle II Physics Book: [PTEP 2019 (2019) 12, 123C01]



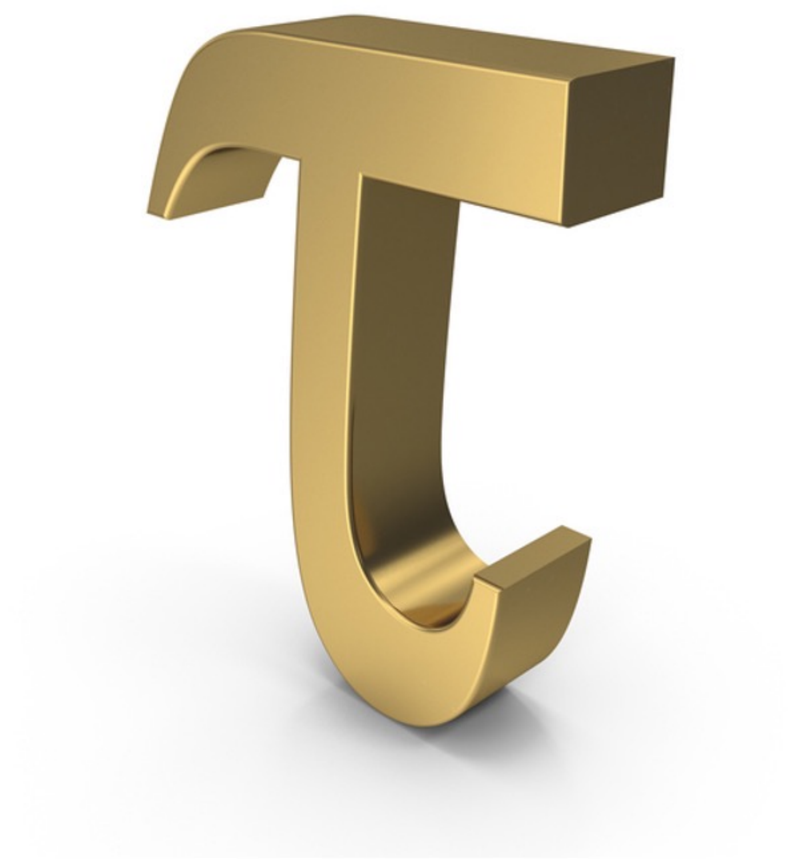


Belle II Physics Book, PTEP 2019, 123C01

$e^+e^- \to$	Cross section [nb]
$\Upsilon(4S)$	1.05 ± 0.10
$c\bar{c}$	1.30
$s\bar{s}$	0.38
$u\bar{u}$	1.61
$d\bar{d}$	0.40
$\tau^+\tau^-(\gamma)$	0.919
$\mu^+\mu^-(\gamma)$	1.148
$e^+e^-(\gamma)$	300 ± 3

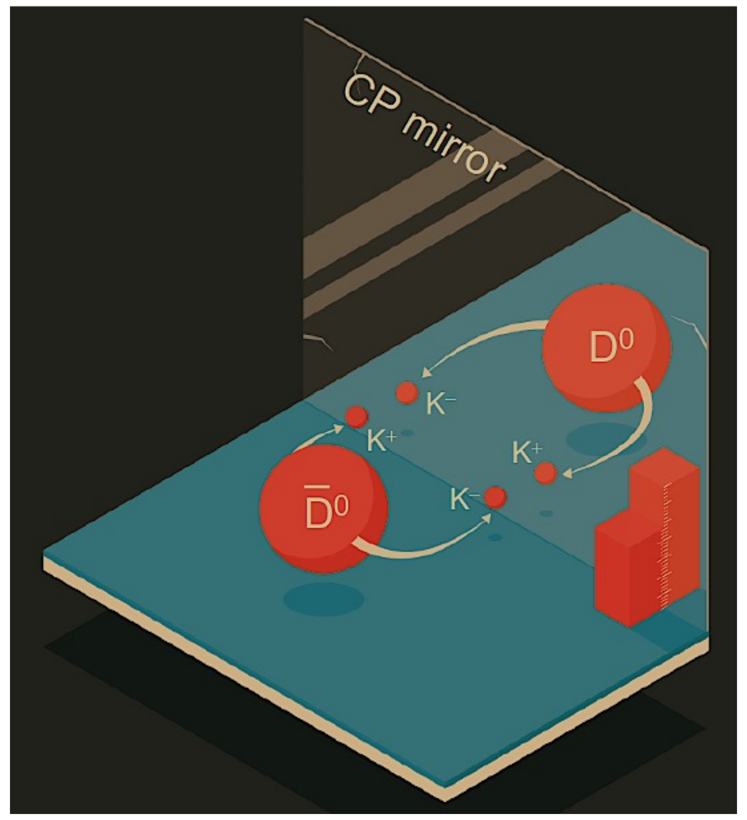
Primarily a **B factory;** But not only B physics!

Also τ, charm factories



τ physics

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



Charm physics (CPV):

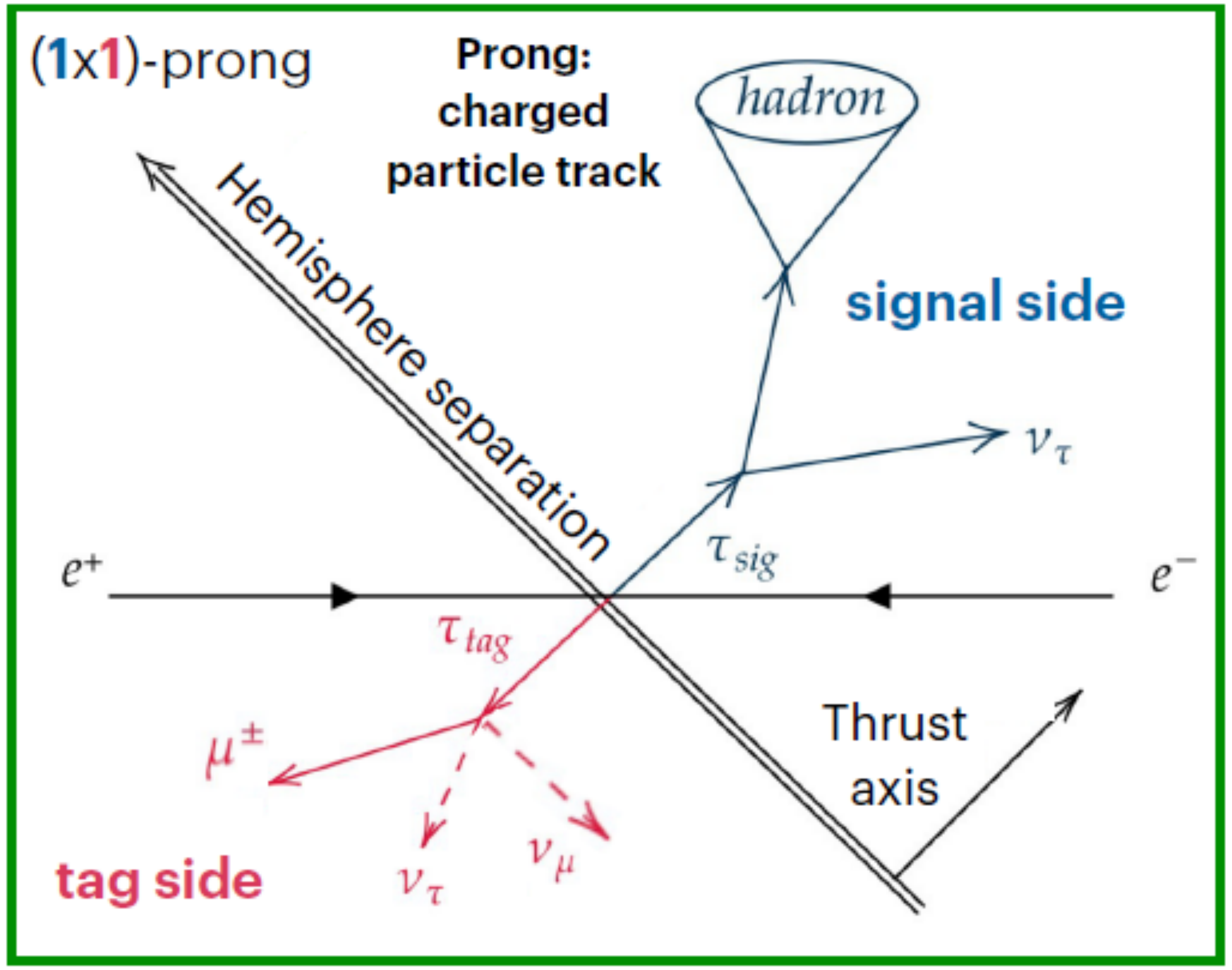
- $D^0 \to \pi^0\pi^0$
- $D^0 \to \pi^+\pi^-\pi^0$
- $D^+ \to \pi^+\pi^0$
- $D_{s0}(2317) \to D_s^*\gamma$

τ topologies and signatures

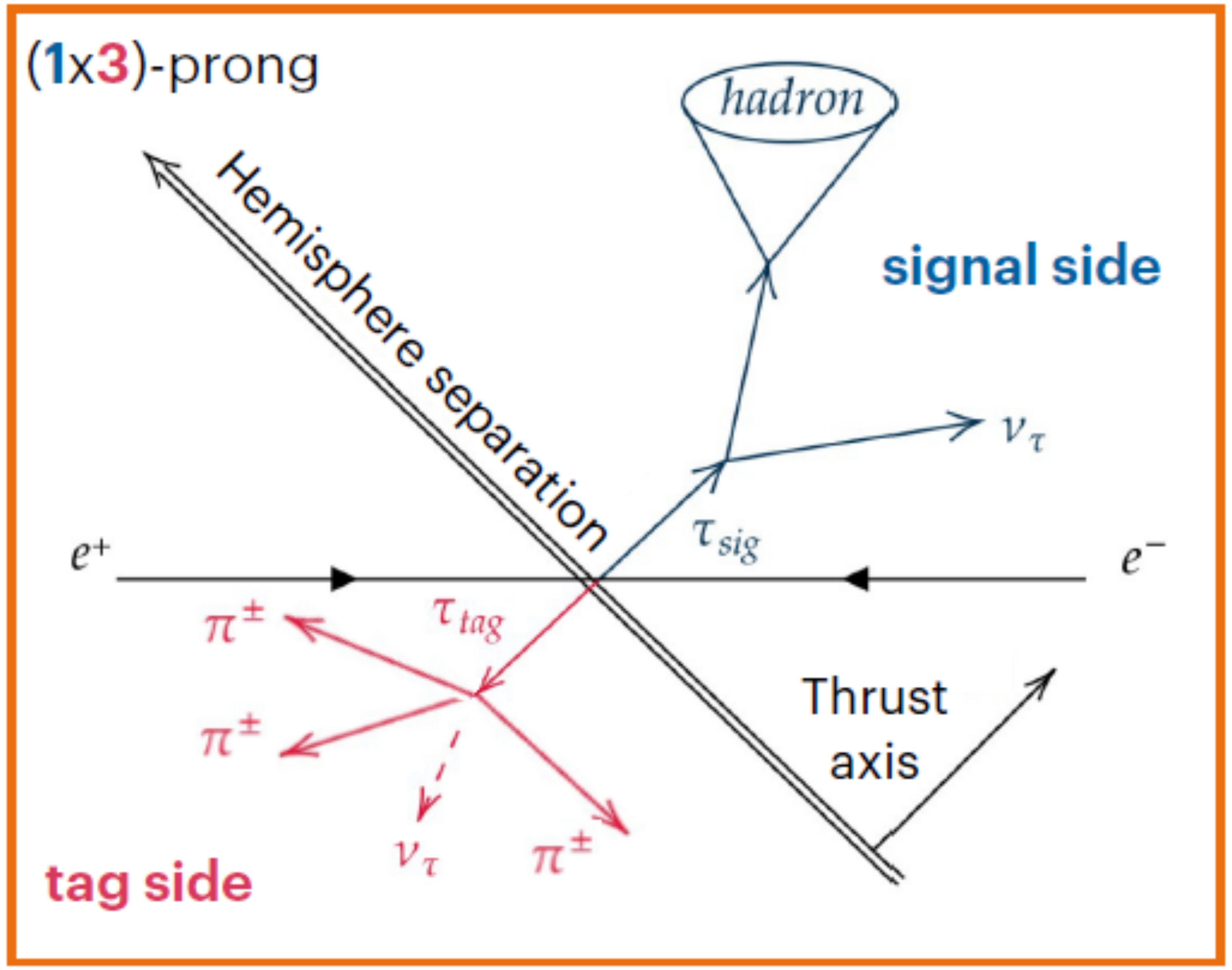
- Large cross section for $e^+e^- \rightarrow \tau^+\tau^-$. SM τ cannot be fully reconstructed due to the missing neutrino
- Identify $e^+e^- \rightarrow \tau^+\tau^-$ events using the thrust direction of the event (thrust axis)

$\sigma(e^+e^- \rightarrow b\bar{b}) = 1.05\,nb$
$\sigma(e^+e^- \rightarrow \tau^+\tau^-) = 0.92\,nb$

- Two hemispheres defined in the centre-of mass system by a plane perpendicular to the thrust axis



Higher efficiency, larger QED background

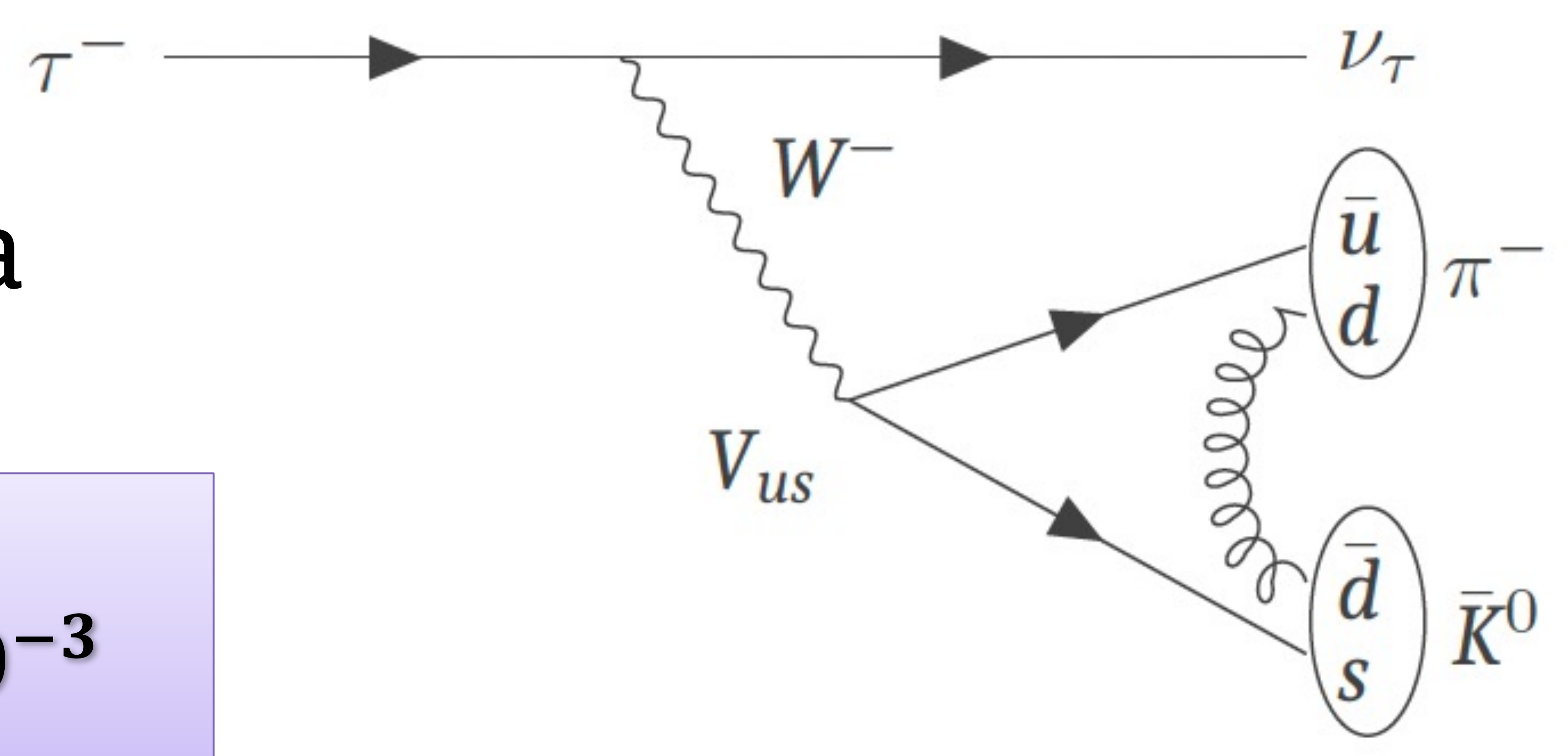


Lower efficiency, more continuum background

Preliminary

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

- Clean experimental signature.
- Experimentally we observe K_S and K_L, and SM predicts a **CP violation** value in the kaon sector of

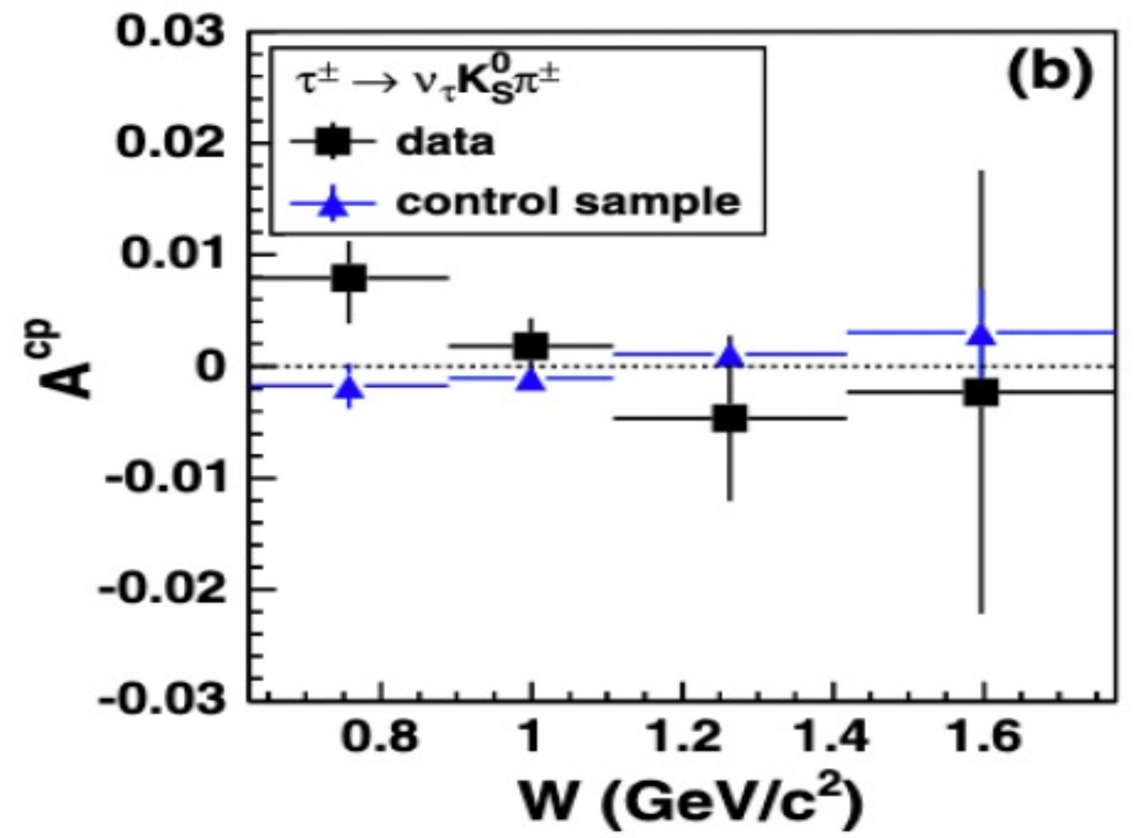


$$A_{CP}^{SM} \equiv A_1 = \frac{\Gamma(\tau^+ \rightarrow \pi^+ K_S^0 \bar{\nu}_\tau) - \Gamma(\tau^- \rightarrow \pi^- K_S^0 \nu_\tau)}{\Gamma(\tau^+ \rightarrow \pi^+ K_S^0 \bar{\nu}_\tau) + \Gamma(\tau^- \rightarrow \pi^- K_S^0 \nu_\tau)} \simeq (3.3 \pm 0.1) \times 10^{-3}$$

Belle

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

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



A_{CP} using angular observables.

No asymmetry at 10^{-2} level

BaBar

Phys. Rev. D 85, 031102 (2012)

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

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

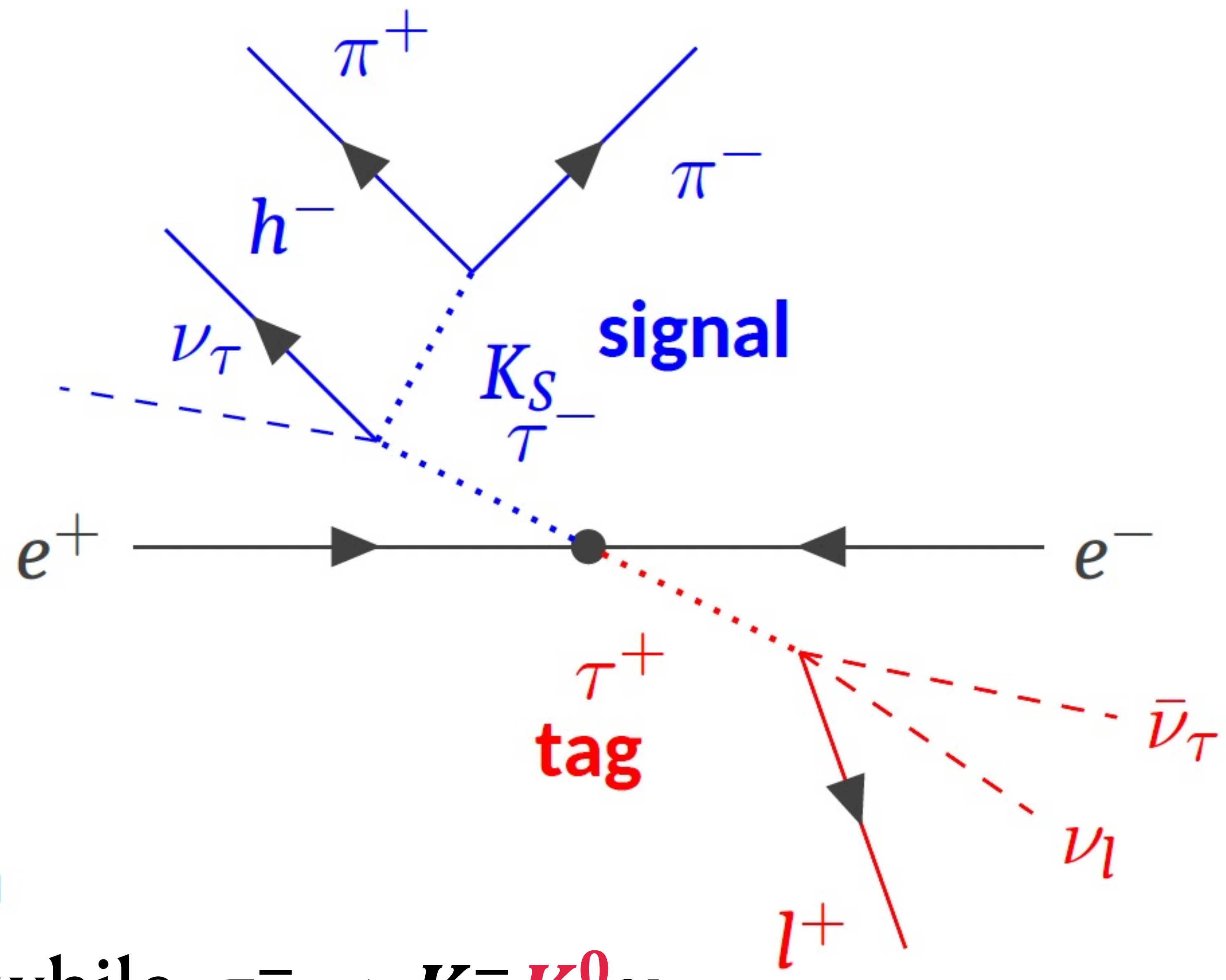
$$A_{CP}^{BaBar} = (-0.36 \pm 0.23 \pm 0.11)\%$$

2.8 σ deviation from the SM expectation

Preliminary

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

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

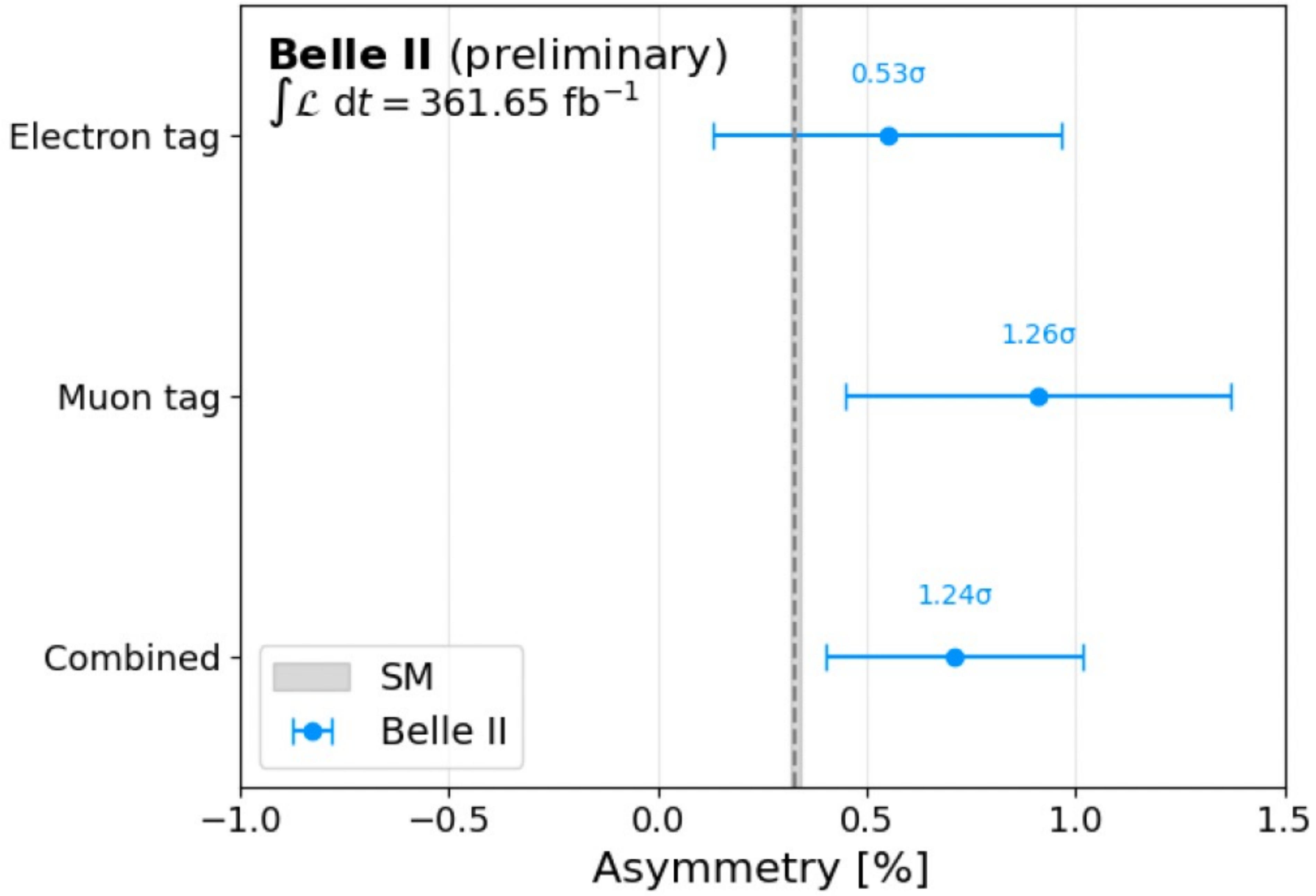


$$\mathcal{A}_{CP} = \frac{f_1 A_1 + f_2 A_2 + f_3 A_3}{f_1 + f_2 + f_3} = \left(\frac{f_1 - f_2}{f_1 + f_2 + f_3}\right) A_1$$

Branching fraction (f_1)

Asymmetry (A_1)

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



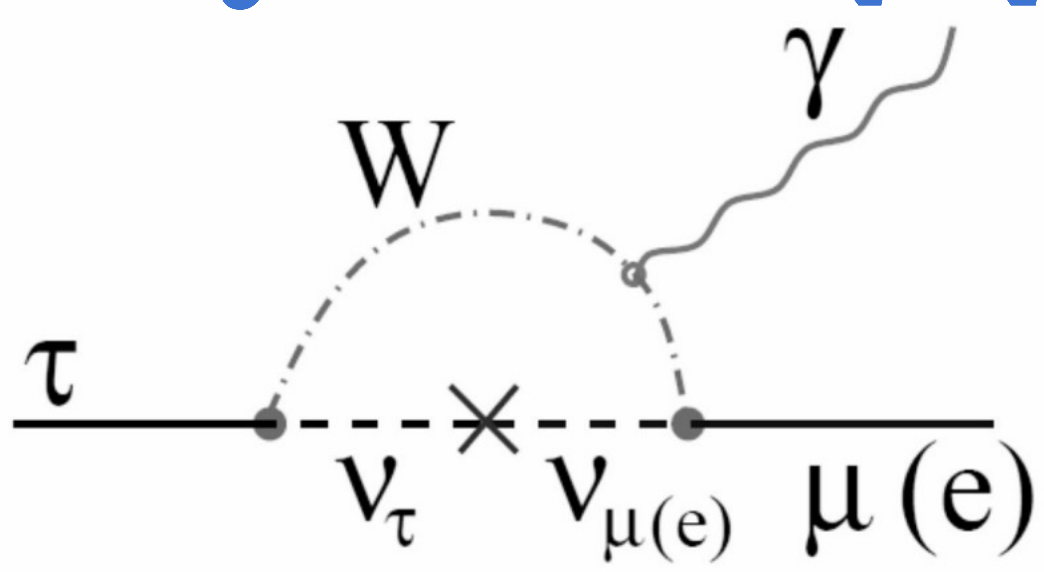
$$\boldsymbol{A_{CP}(\text{combined}) = 0.71 \pm 0.26_{\text{stat.}} \pm 0.06_{\text{sys.}} \pm 0.15_{\text{unf.}}}$$

A_{cp} based on angular observables is ongoing.

Preliminary

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

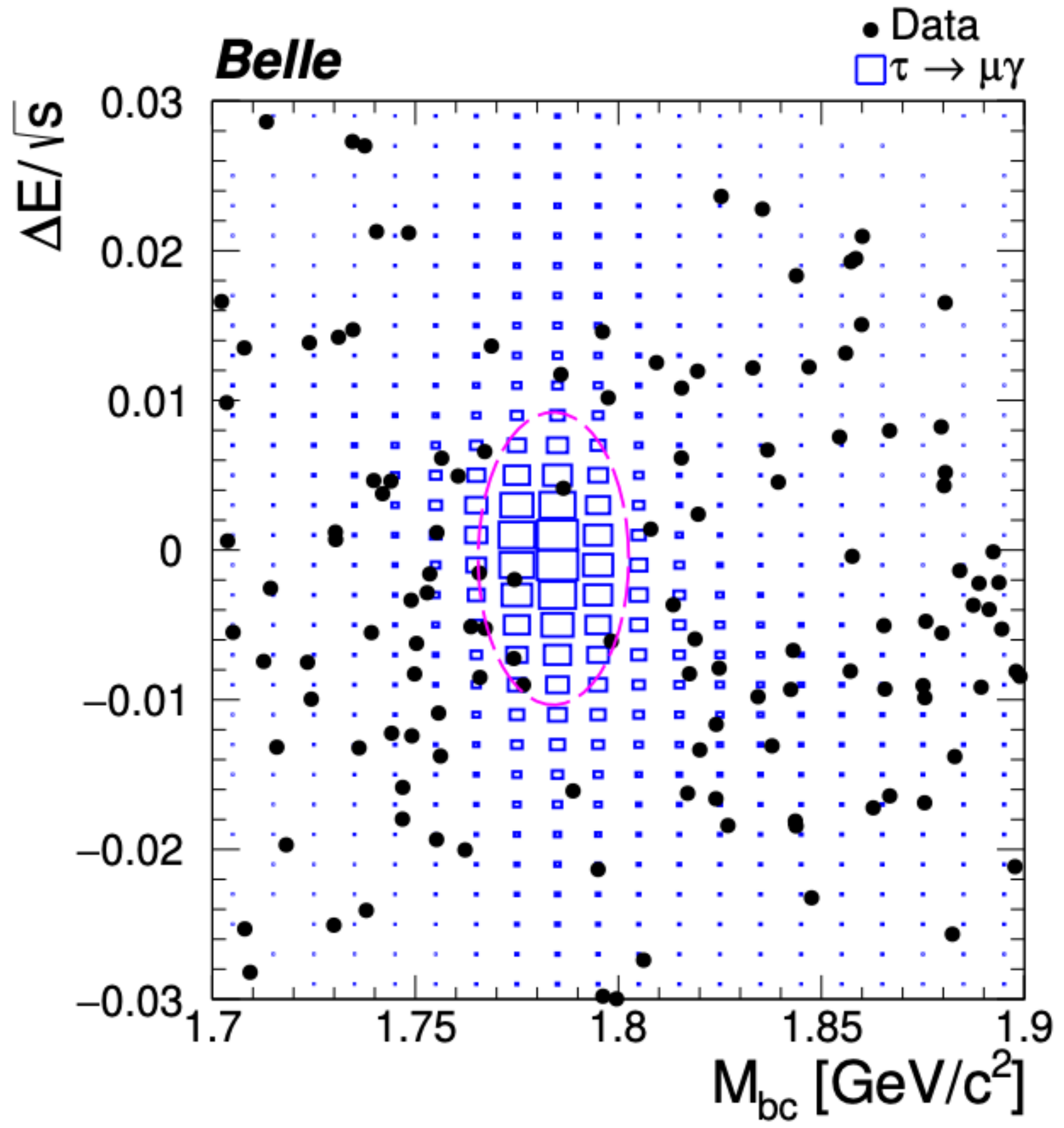
$\tau^{\pm} \to \mu^{\pm} + \gamma$		
SUSY Higgs	10^{-10}	[Phys.Lett.B566:217-225,2003]
Little Higgs	10^{-10}	[JHEP 0705:013,2007]
SM + seesaw	10^{-9}	Phys.Rev.D66:034008,2002
Non-Universal Z'	10^{-9}	[Phys.Lett. B547 (2002) 252-256]
SUSY SO(10)	10^{-8}	[Phys.Rev.D68:033012,2003]



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:

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

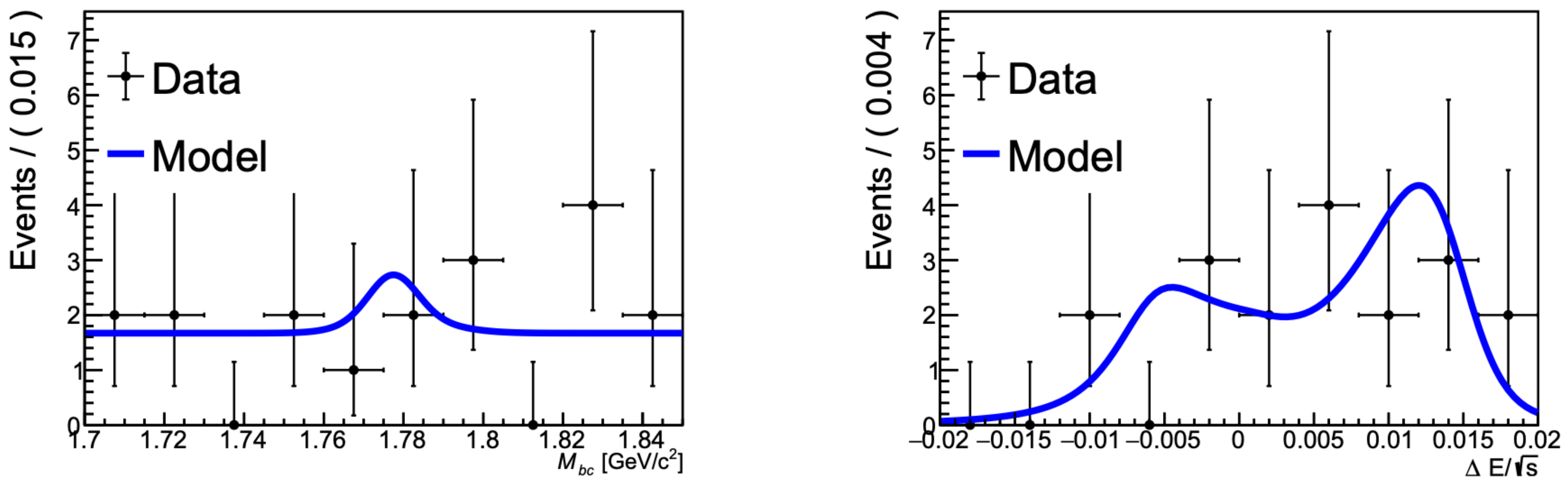
$$M_{bc} = \sqrt{(E^{c.m.}_{beam})^2 - (\vec{P}^{c.m.}_{\ell\gamma})^2} \sim m_{\tau}$$

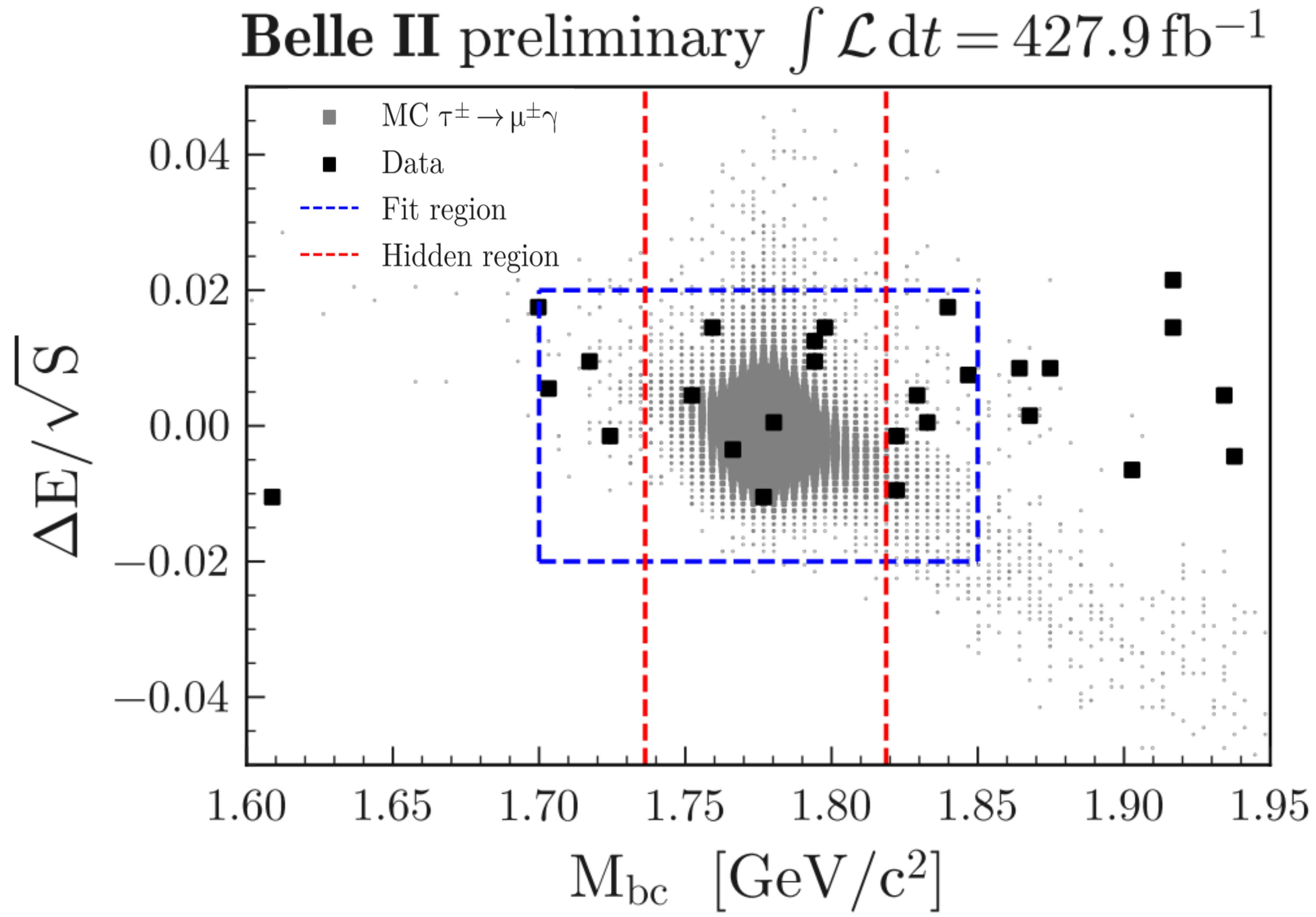
Search for LFV in the decay: $\tau \rightarrow \mu\gamma$

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

$\epsilon_{sig} = 5.21 \pm 0.01\%$

$b^{exp} = 1.1 \pm 0.02$

Belle II

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

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

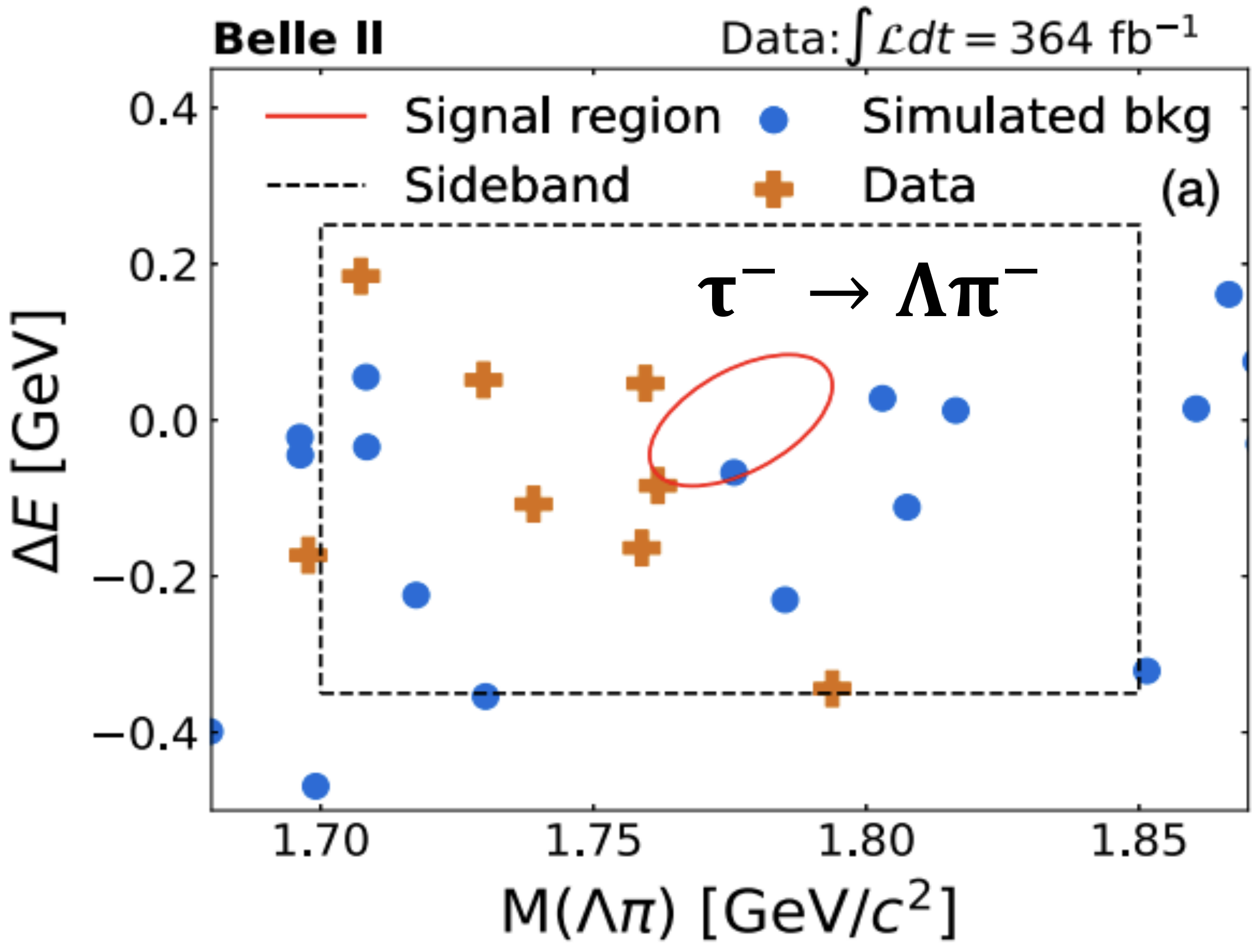
$B(\tau \rightarrow \mu\gamma) < 4.2 \times 10^{-8}$

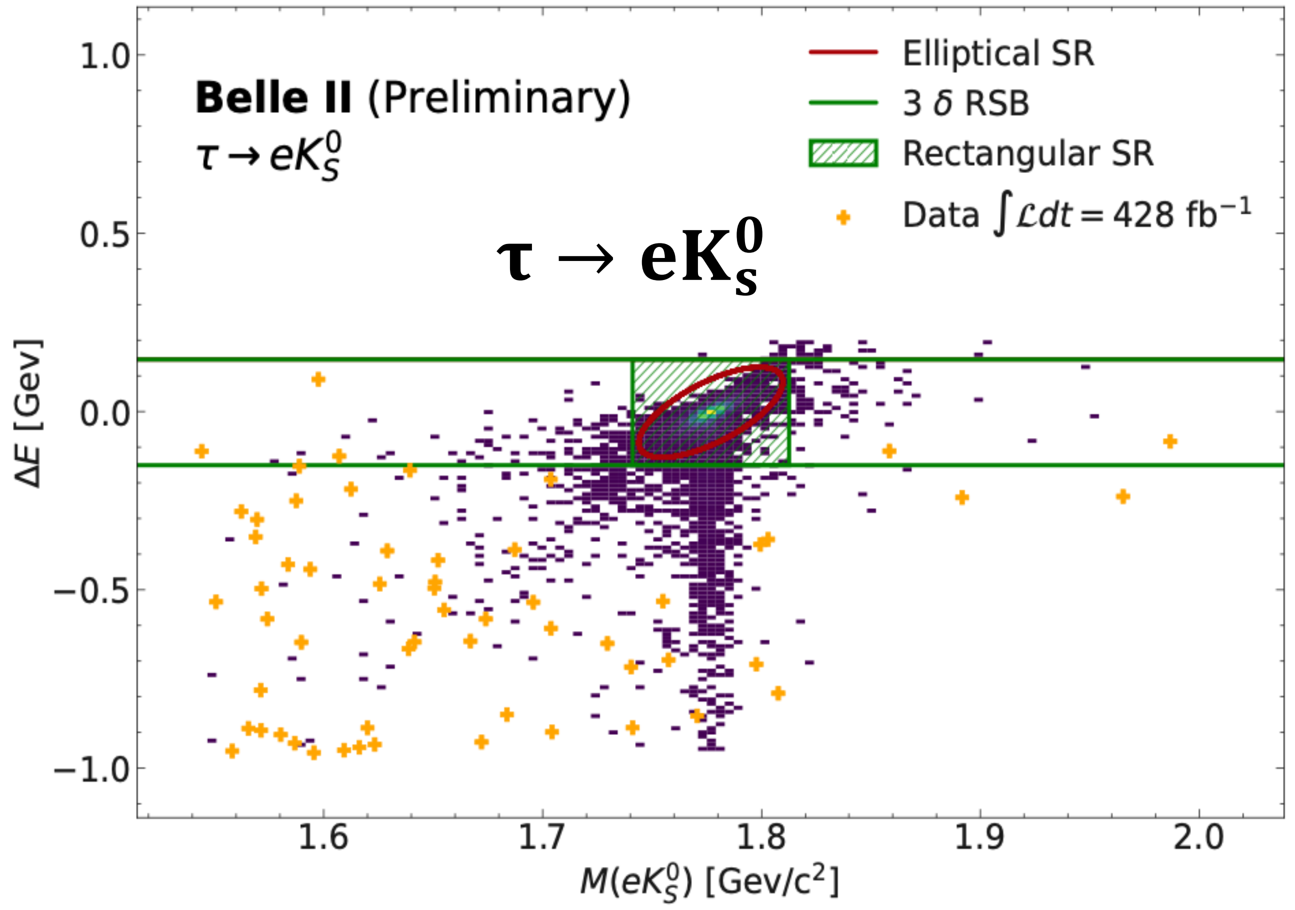
$\epsilon_{sig} = 3.4\ \%$

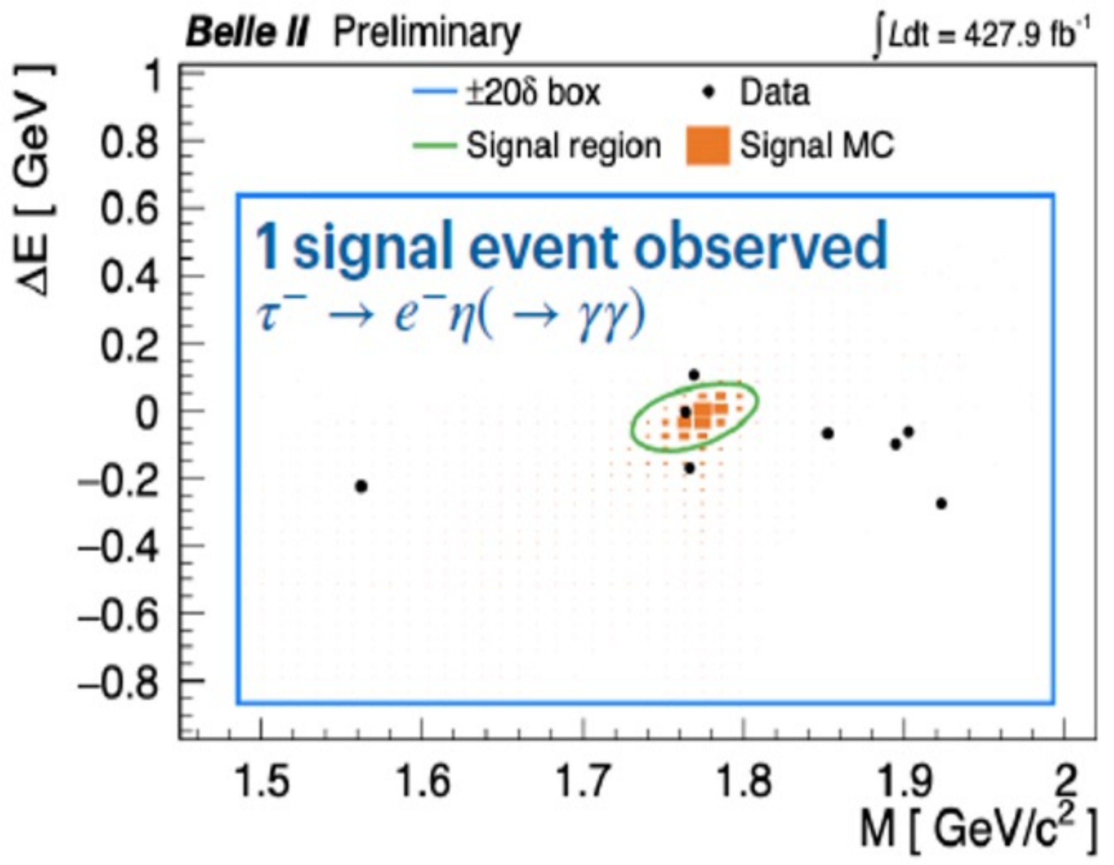
$b^{exp} = 5.8 \pm 0.04$

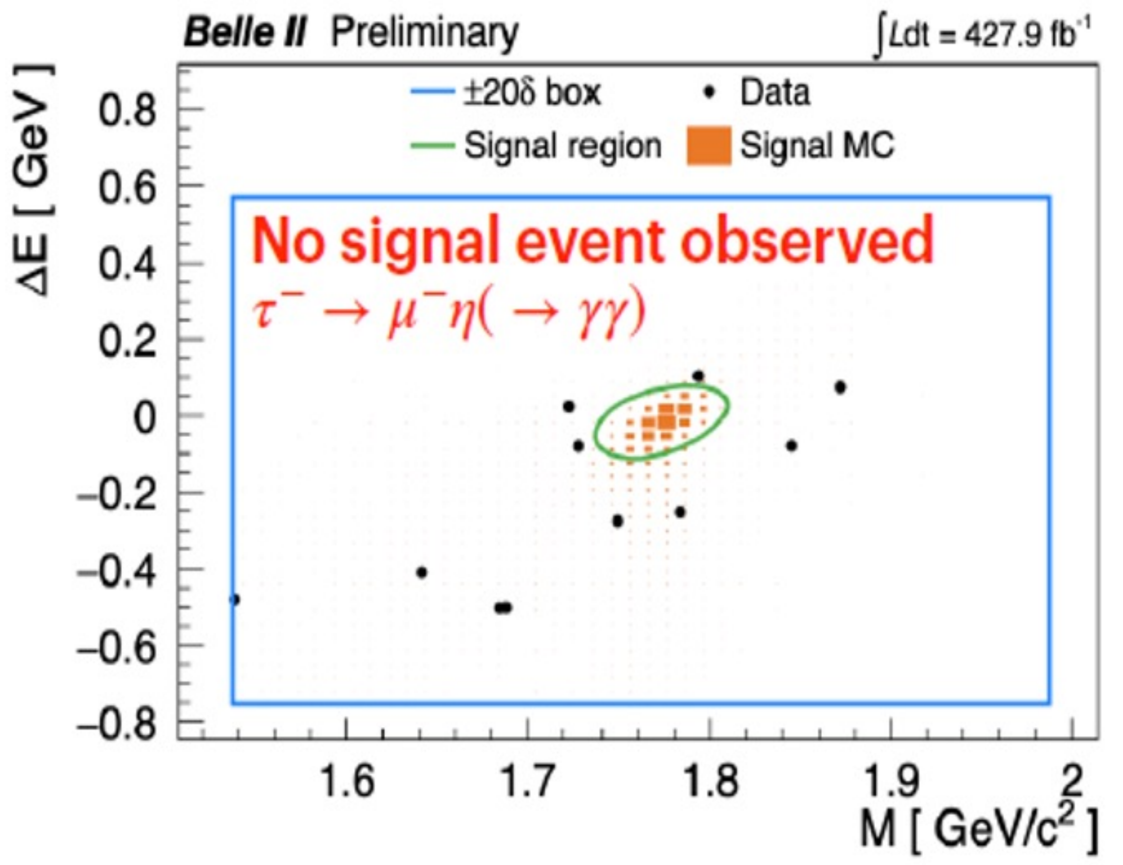
BELLE

Other LFV in τ decay



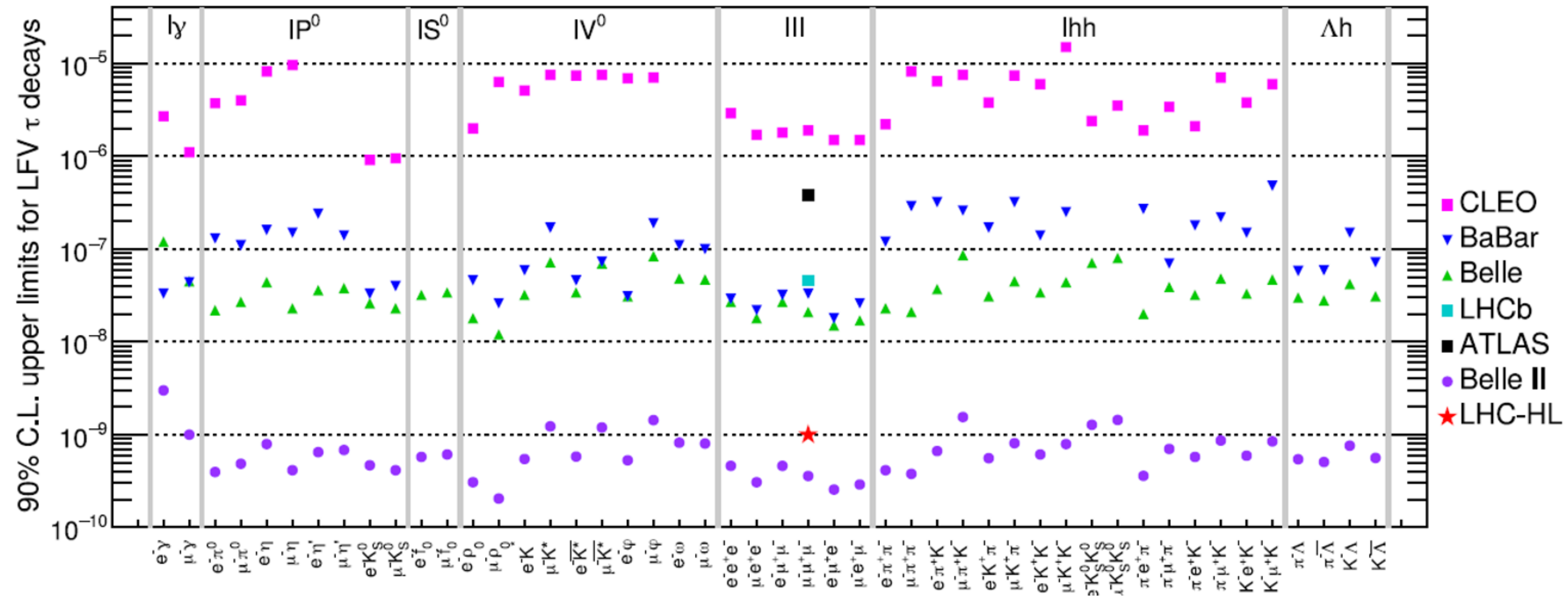






	$\mathcal{B}^{UL}_{obs} \times 10^{-8}$	$\mathcal{B}^{UL}_{Belle} \times 10^{-8}$	ϵ_{sig}	ϵ_{Belle}
$e^- e^+ e^-$	★ 2.5	2.7	15.0%	6.0%
$e^- e^+ \mu^-$	★ 1.6	1.8	20.4%	9.3%
$e^- \mu^+ e^-$	1.6	1.5	23.5%	11.5%
$\mu^- \mu^+ e^-$	★ 2.4	2.7	20.1%	6.1%
$\mu^- e^+ \mu^-$	★ 1.3	1.5	24.1%	10.1%
	@ 428 fb^{-1}	@ 782 fb^{-1}		

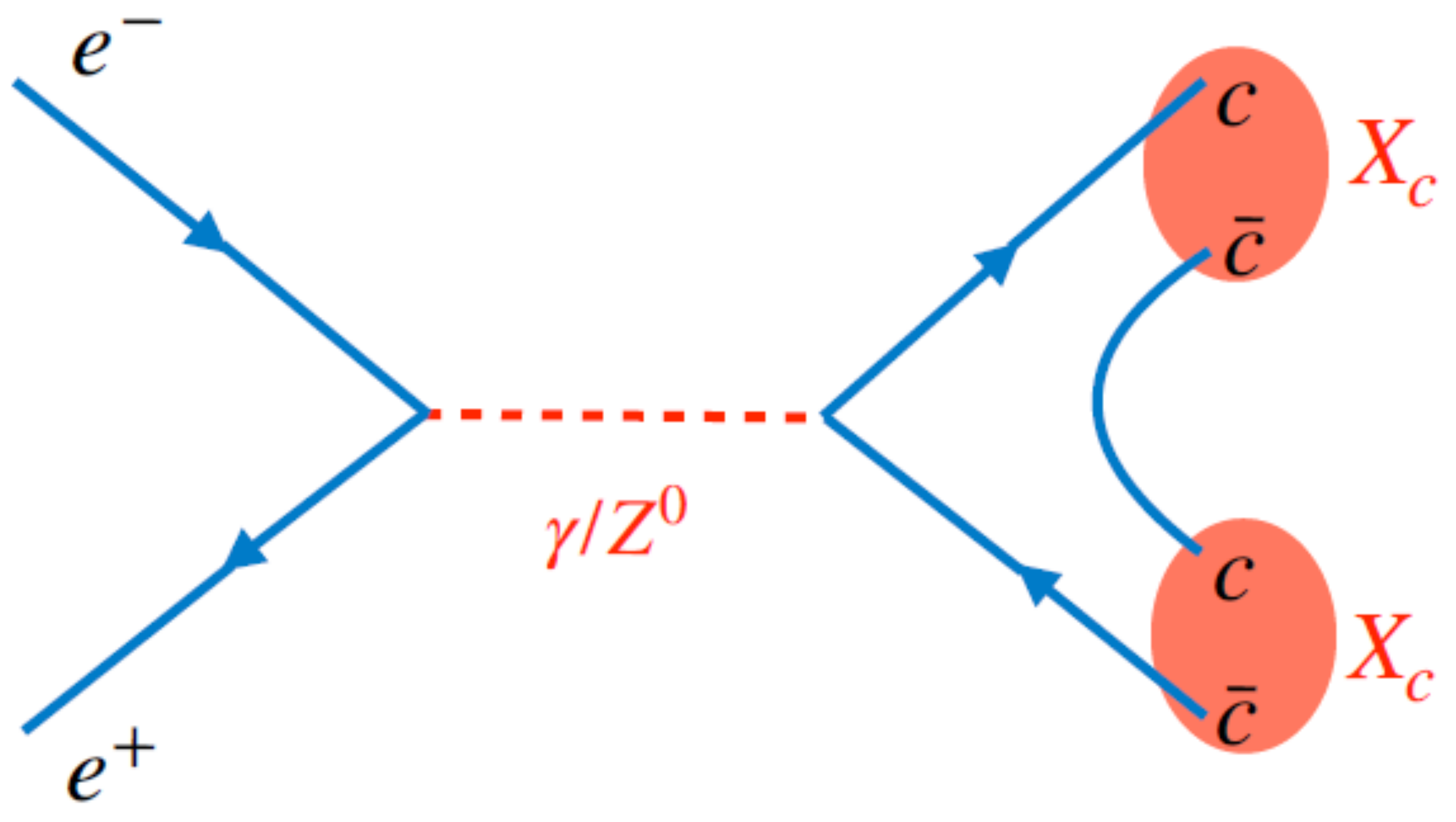
$\mathcal{B}^{UL}(\tau \to e(\mu)K_s^0) < 0.8(1.2)\times10^{-8}$ [JHEP 08 092]	The most stringent constraints
$\mathcal{B}^{UL}(\tau^- \to \Lambda\pi^-(\bar{\Lambda}\pi^-)) < 4.7(4.3)\times10^{-8}$ [PRD 110, 112003]	The most stringent constraints
$\mathcal{B}^{UL}(\tau^\pm \to \mu^\pm\gamma) < 9.5\times10^{-8}$ [Preliminary]	Best: 4.2x10^{-8} (Belle: JHEP 10 (2021)019)
$\mathcal{B}^{UL}(\tau^\pm \to e^\pm\eta) < 9.8\times10^{-8}$ $\mathcal{B}^{UL}(\tau^\pm \to \mu^\pm\eta) < 9.8\times10^{-8}$ [Preliminary]	The most stringent constraints



Charm production at Belle II

- At Belle II, e^+e^- mainly collide at 10.58 GeV to make $\Upsilon(4S)$ resonance mainly decaying into $B\bar{B}$.
- Meanwhile, **continuum processes $e^+e^- \to q\bar{q}$ ($q = u, d, s, c$) have large cross sections**.
- Two ways to produce charm samples: **1) $e^+e^- \to c\bar{c}$, and 2) $B \to$ charm decays**.

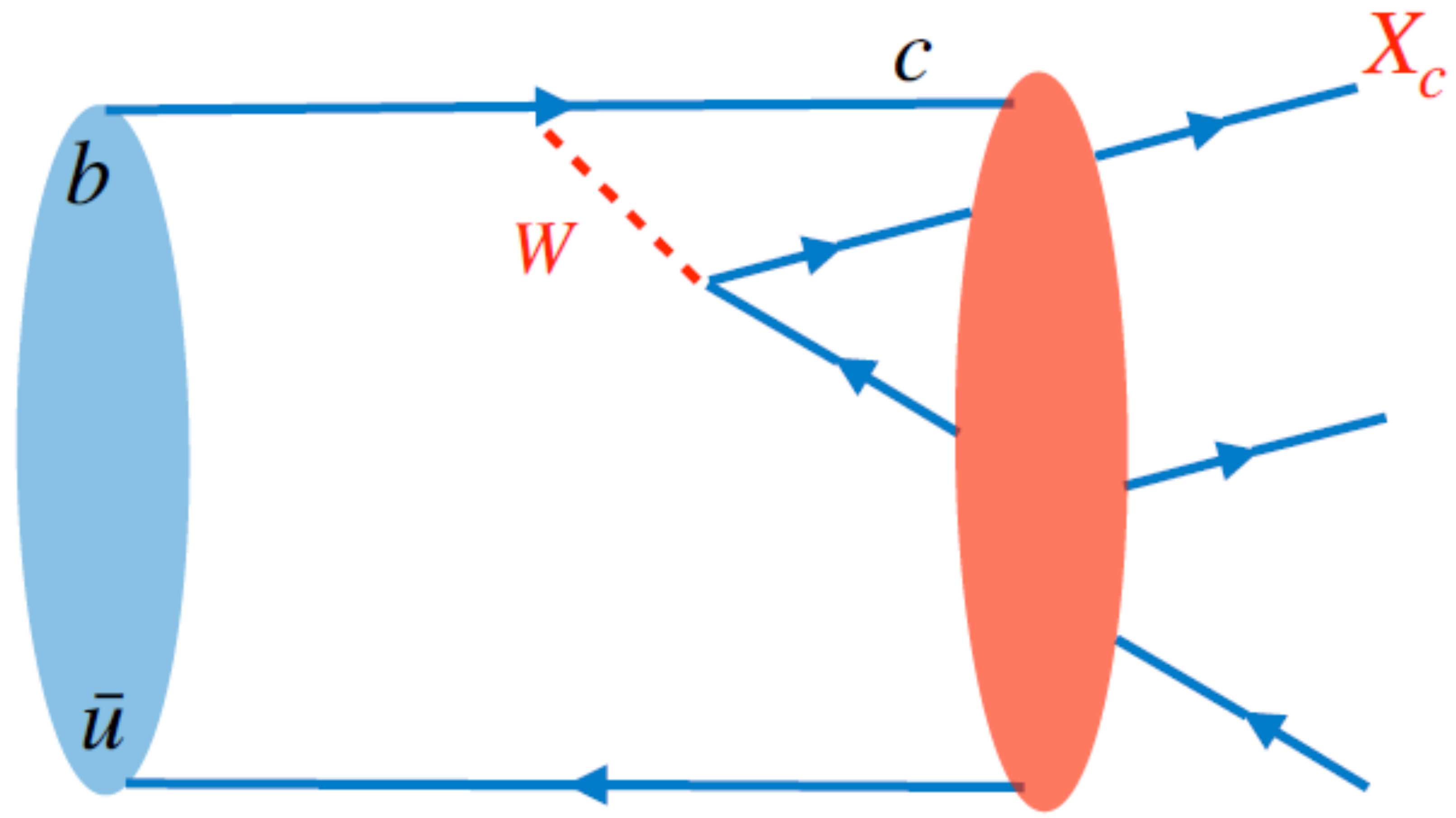
Two charmed hadrons produced from continuum



Large statistics but high level background

Only relative branching fractions can be measured
Absolute values obtained using external inputs

One or more charmed hadrons produced in B decays



Low statistics but very clean sample

Absolute branching fractions can be obtained:
cross section of $B\bar{B}$ precisely measured

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

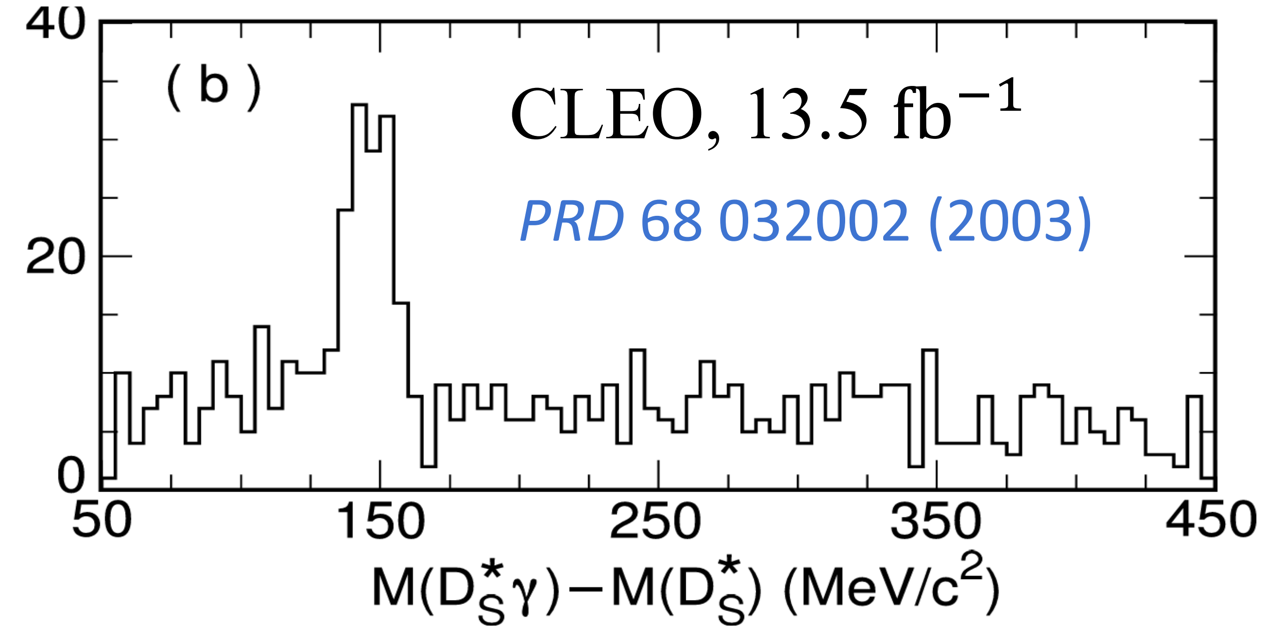
arXiv:2510.27174

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

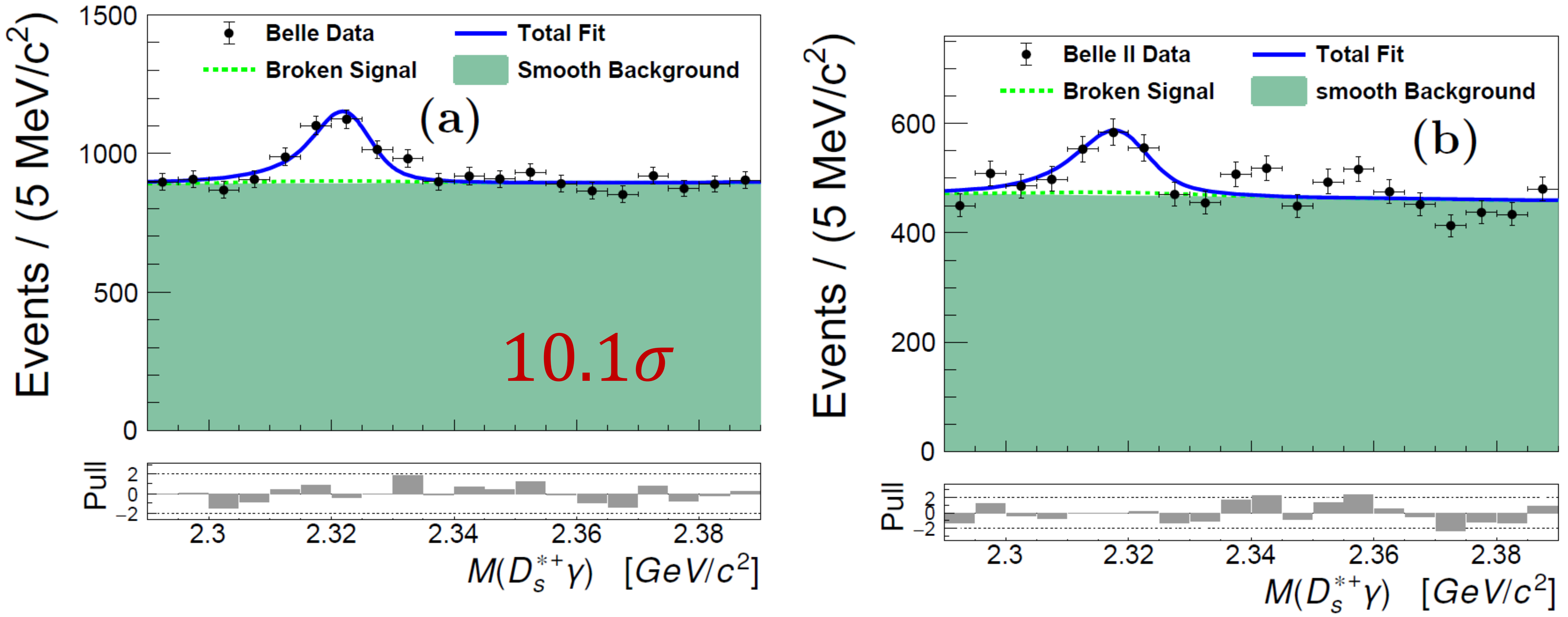
Partial decay widths: unique in discriminating between various models

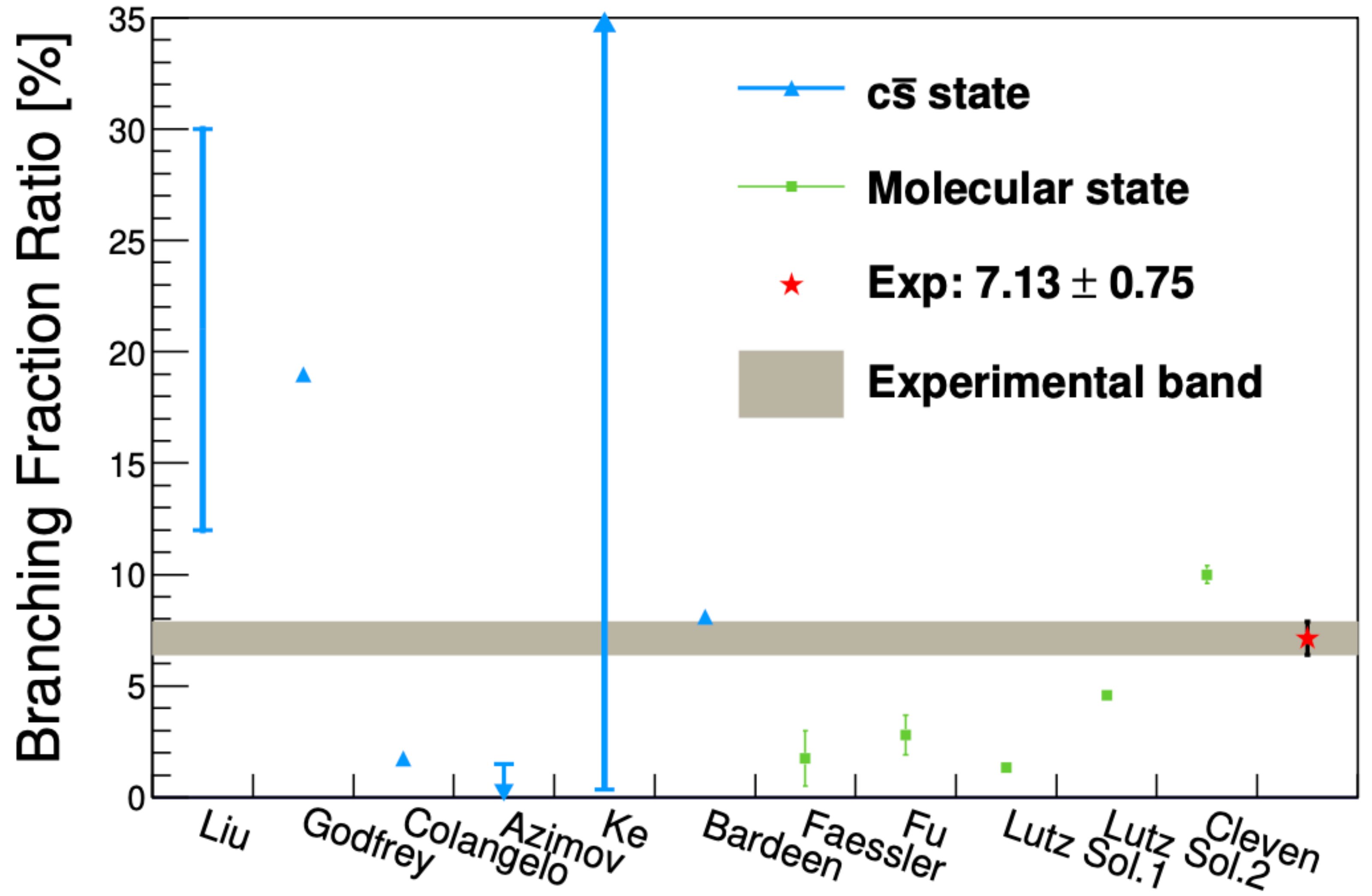
$D_{s0}(2317)^+$ Decay mode	J^P transition	Possible wave
$D_s^+\gamma$	$0^+ \to 0^- 1^-$	Forbidden
$D_s^{*+}\gamma$	$0^+ \to 1^- 1^-$	$L = 0, 2$

- 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
  - $N(D_s(2317)^+ \to D_s^{*+}\gamma) = -6.5 \pm 5.2$



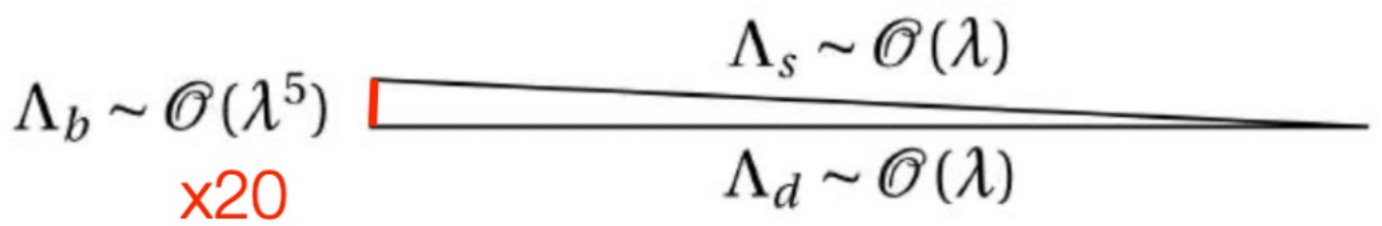
- $\mathcal{R} = [7.14 \pm 0.70(stat.) \pm 0.26(syst.)]\%$





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

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

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

} **Break U-spin symmetry**

  - Not yet clear if compatible with SM:

    non-perturbative QCD may affect predictions

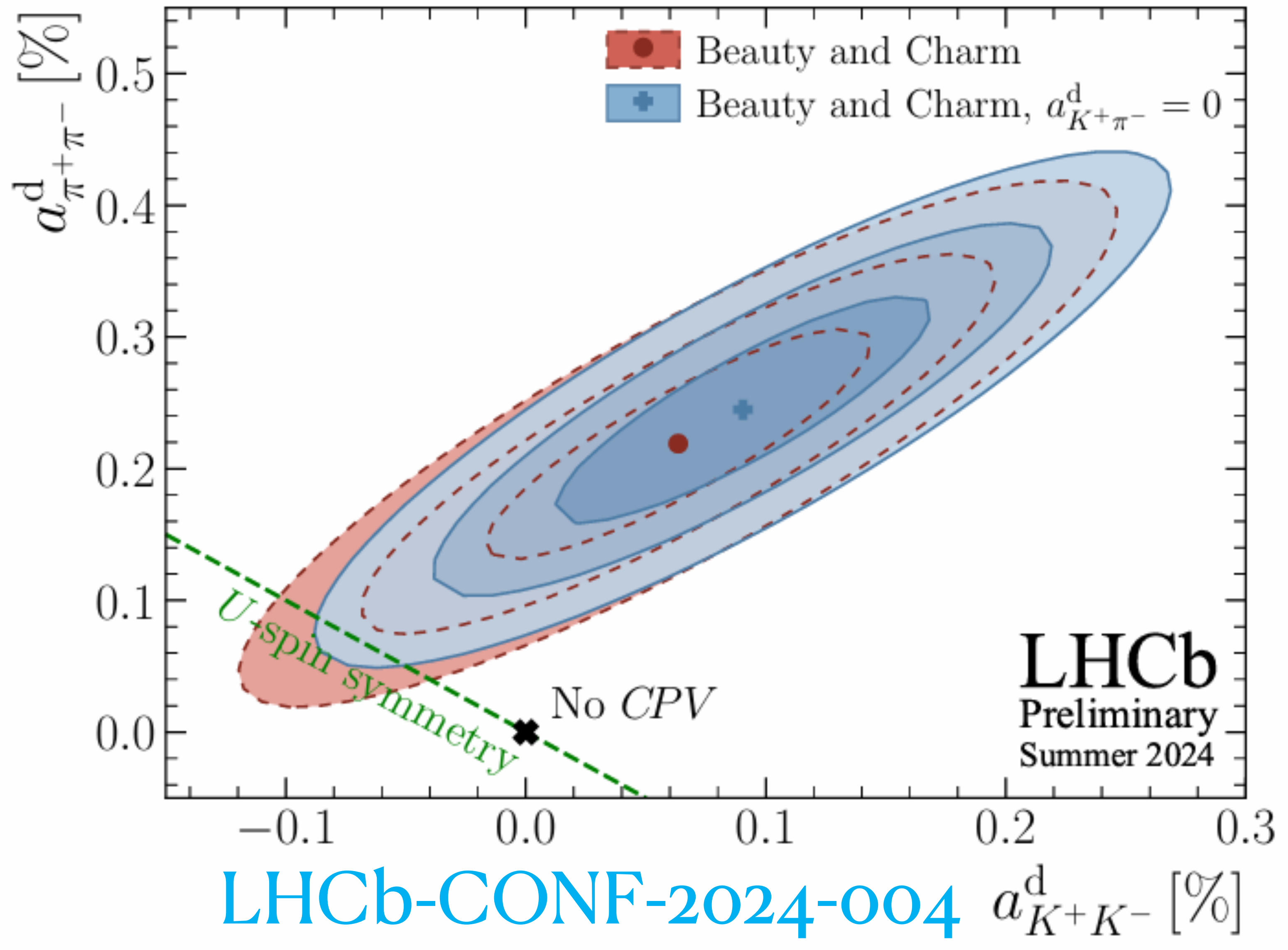
- **Need for measurements in different decay channels & by other experiments**
- **May sensitive to new physics contributions**

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 τ 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 π^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:

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

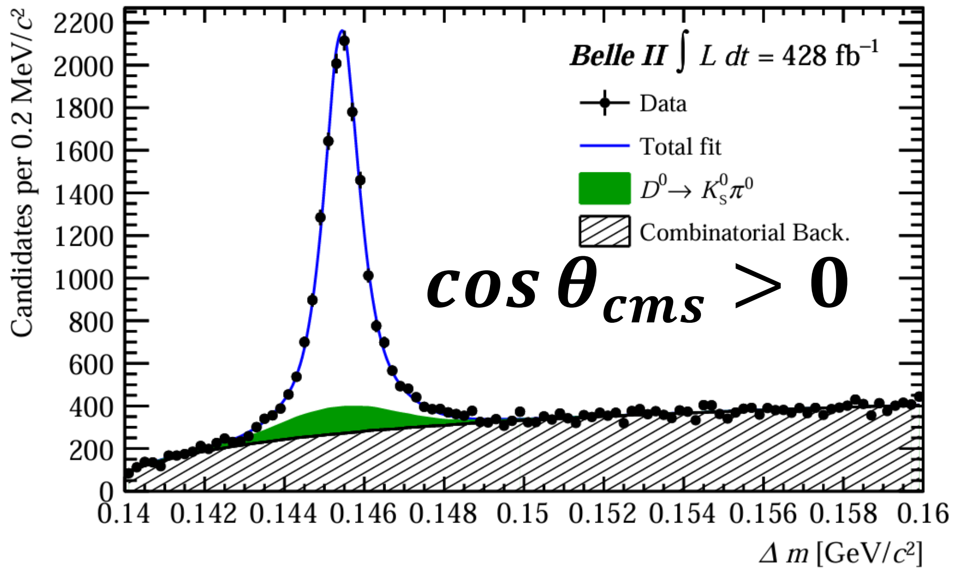
Using $D^0 \to K^-\pi^+$ as control sample (tagged or untagged), i.e.:

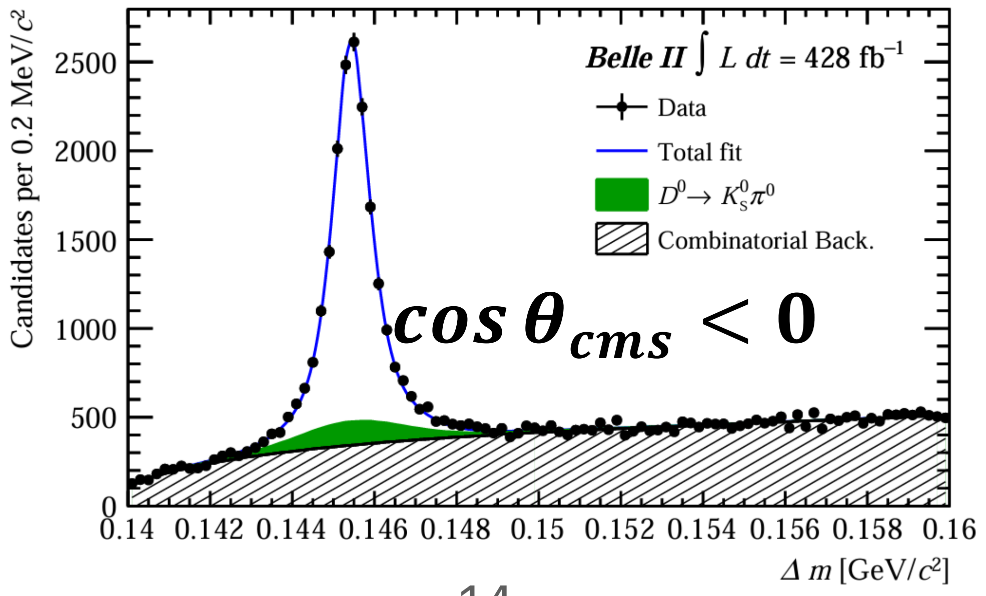
$$\begin{cases} A^{K\pi} = A_{prod}^{D^*} + A_{\varepsilon}^{\pi_s} + A_{\varepsilon}^{K\pi}\ (tag) \\ A^{K\pi} = A_{prod}^{D^0} + A_{\varepsilon}^{K\pi}\quad (untag) \end{cases}$$

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]



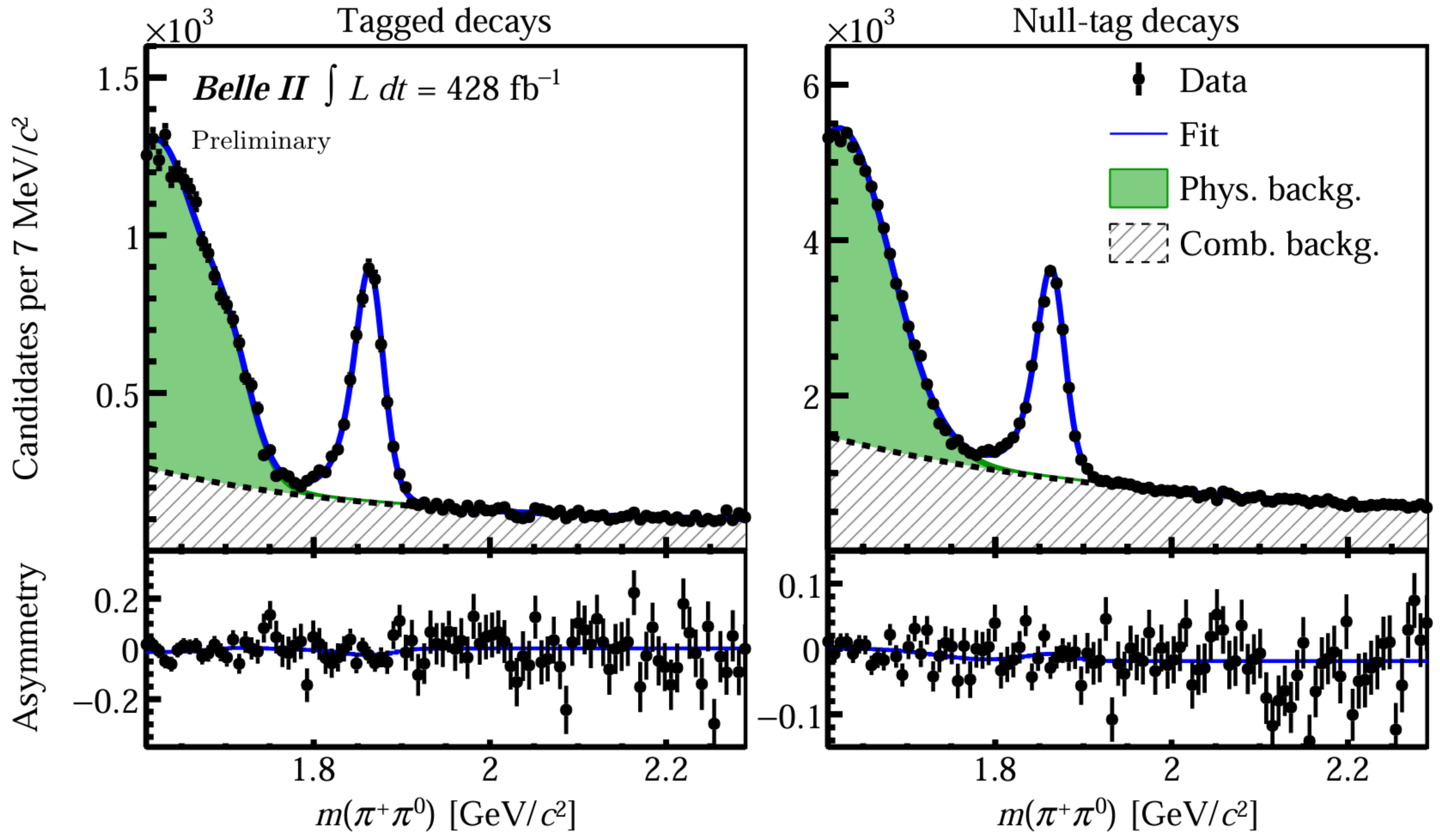


CP asymmetry in $D^+ \to \pi^+\pi^0$

PRD 112, L031101

Split sample:

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



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

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

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**

Charm CPV

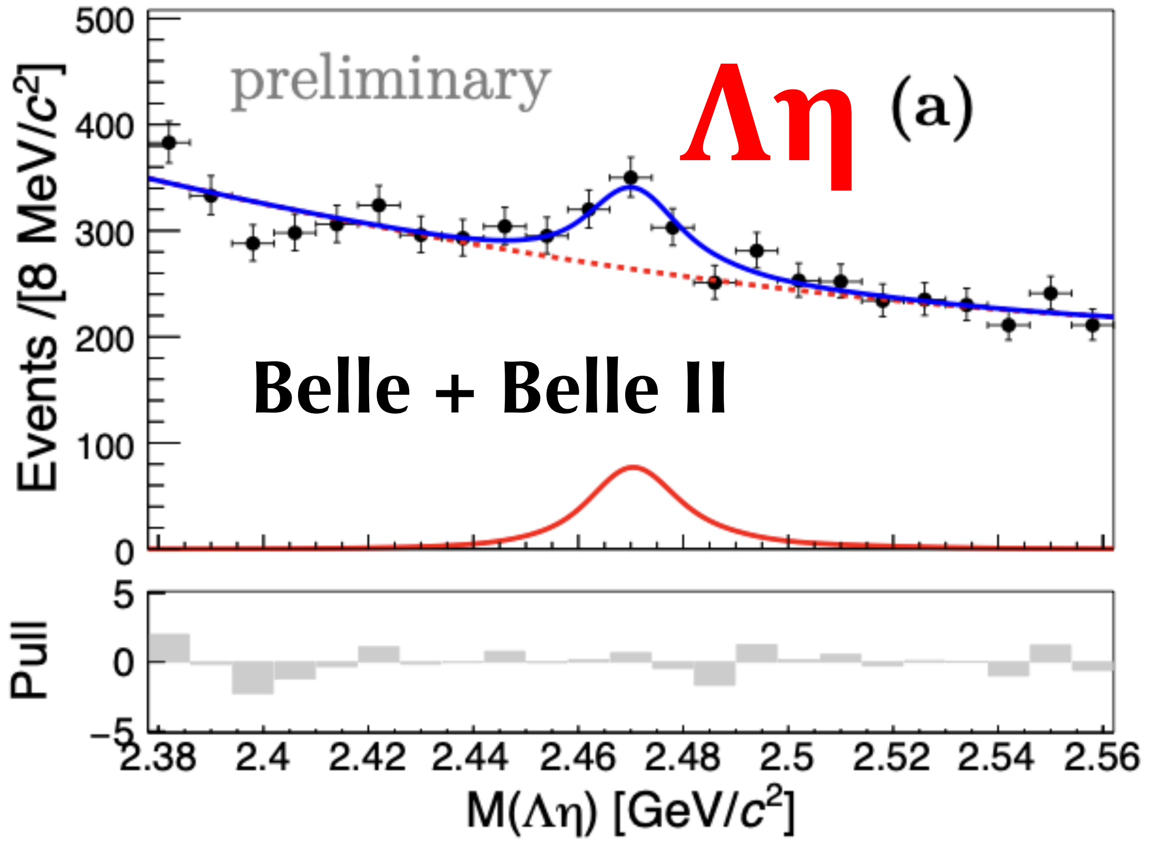
Channel	A_{CP}	References
$D^0 \to \pi^0\pi^0$	$(+0.3\pm0.7\pm0.2)\%$	PRD 112, 012006 (2025)
$D^+ \to \pi^+\pi^0$	$(-1.8\pm0.9\pm0.1)\%$	PRD 112, L031101 (2025)
$D^0 \to \pi^+\pi^-\pi^0$	$(0.3\pm0.3\pm0.1)\%$	PRD 113, 052006 (2026)
$D^0 \to K_S^0K_S^0$	$(-0.6\pm1.1\pm0.1)\%$	PRD 111, 012015 (2025), PRD 112, 012017 (2025)
$D^+, D_s^+ \to K_S^0K^-\pi^+\pi^+$	$(+3.9\pm4.5\pm1.1)\%$, $(-0.2\pm2.5\pm1.1)\%$	JHEP 04 (2025) 036
$\Lambda_c^+ \to \Lambda K^+, \Sigma^0K^+$	$(+2.1\pm2.6\pm0.1)\%$, $(+2.5\pm5.4\pm0.4)\%$	Sci. Bull. 68 (2023) 583
$\Lambda_c^+ \to pK^+K^-, p\pi^+\pi^-$	$(+3.9\pm1.7\pm0.7)\%$, $(+0.3\pm1.0\pm0.2)\%$	PRD 113,032017 (2026)
$\Xi_c^+ \to \Sigma^+K^+K^-, \Sigma^+\pi^+\pi^-$	$(+3.7\pm6.6\pm0.6)\%$, $(+9.5\pm6.8\pm0.5)\%$	PRD 113, 032017 (2026)

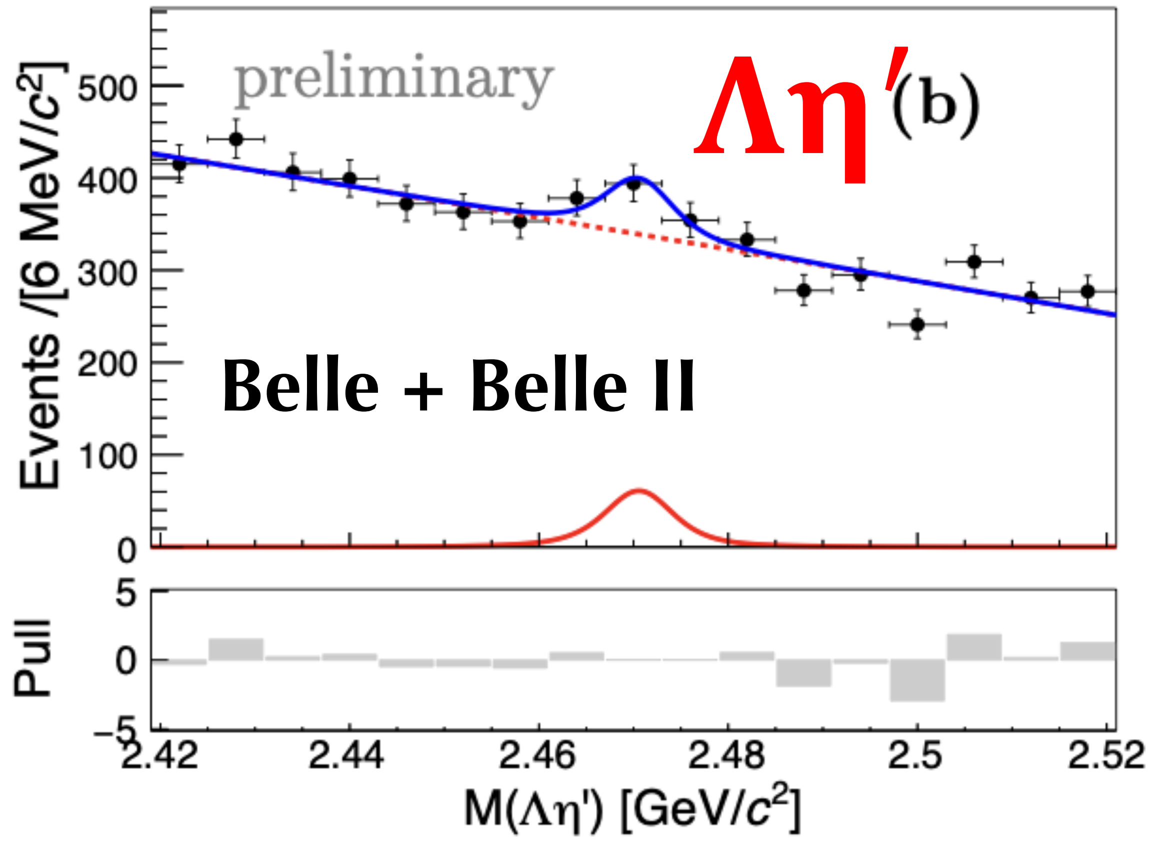
Ξ_c^+ and Ξ_c^0 decays

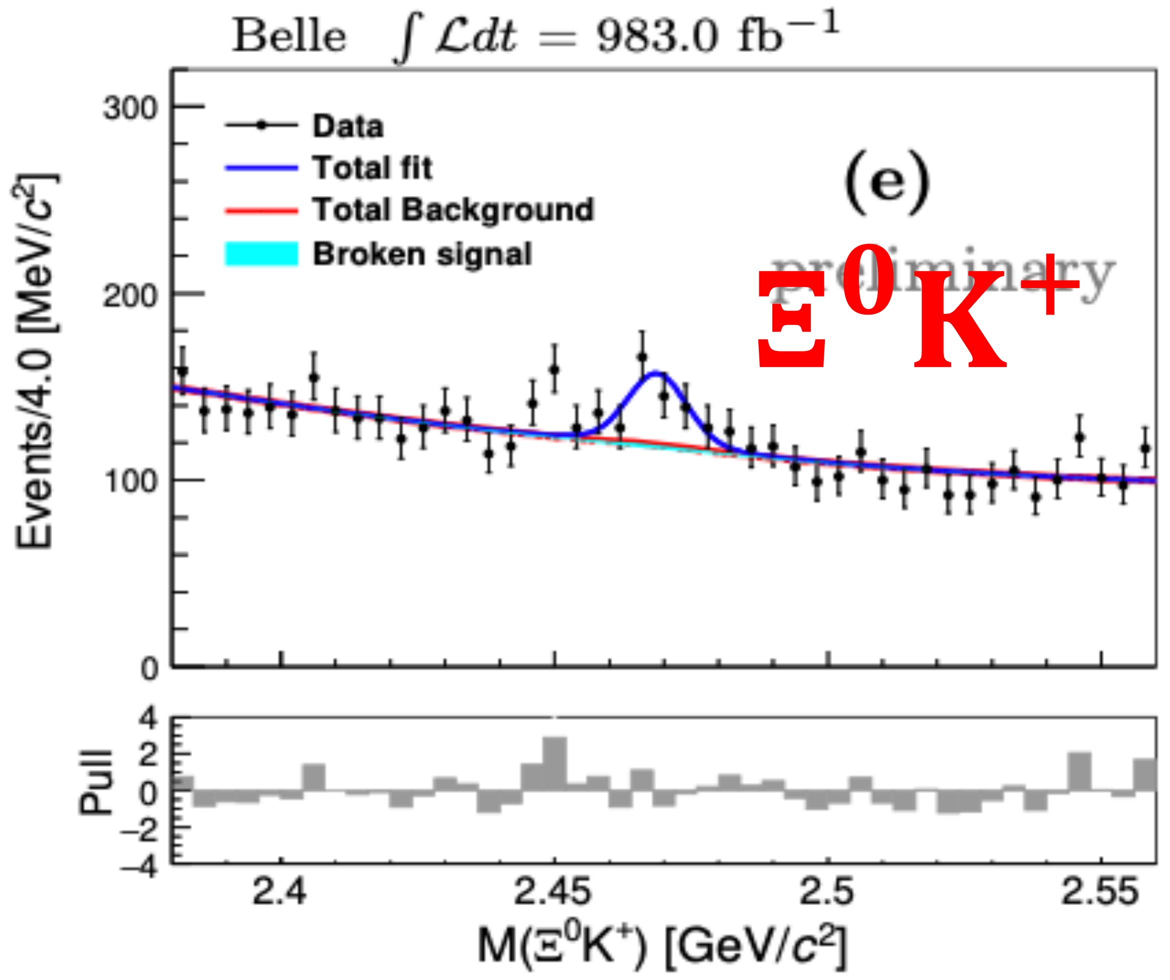
$e^+e^- \rightarrow \Xi_c^+/\Xi_c^0 + \text{anything}$

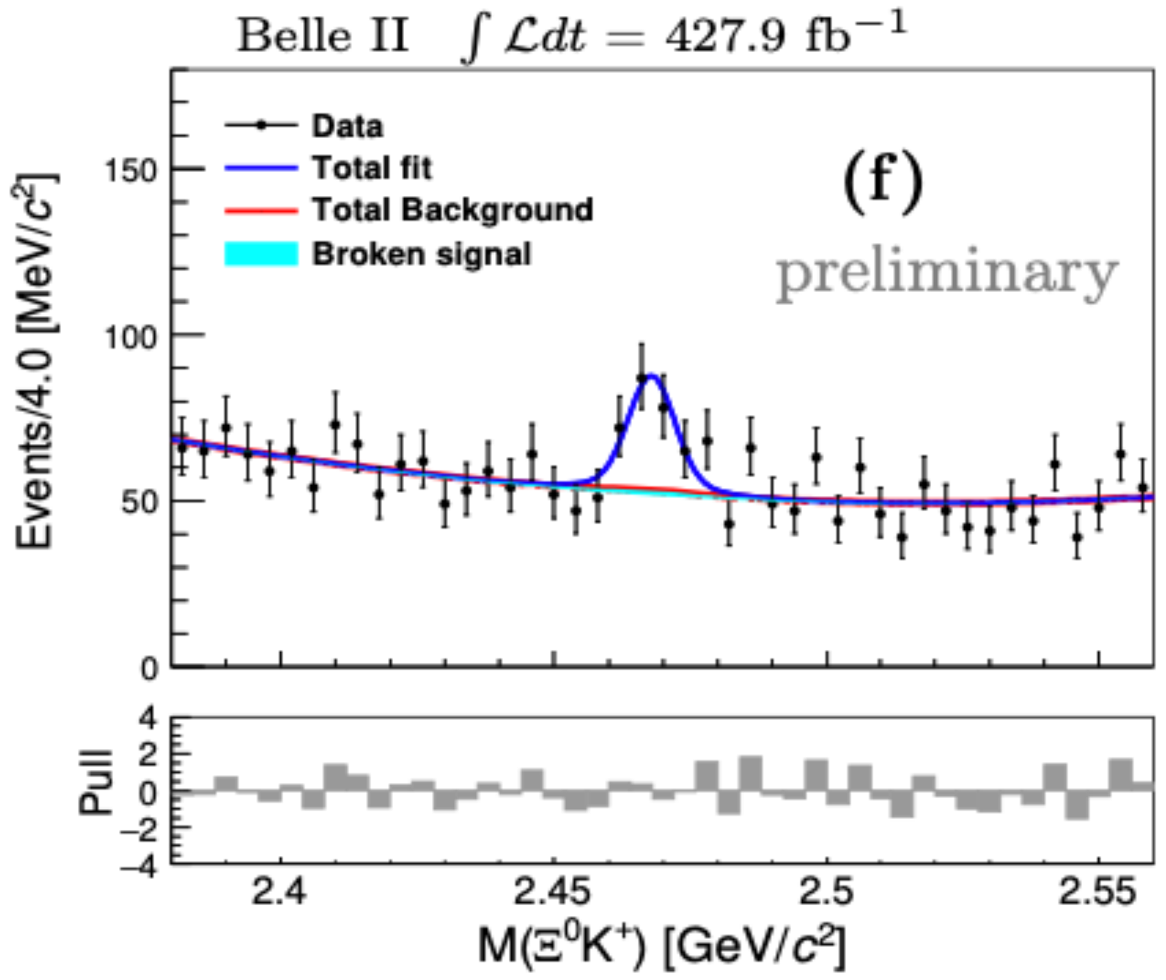
Reconstruct:

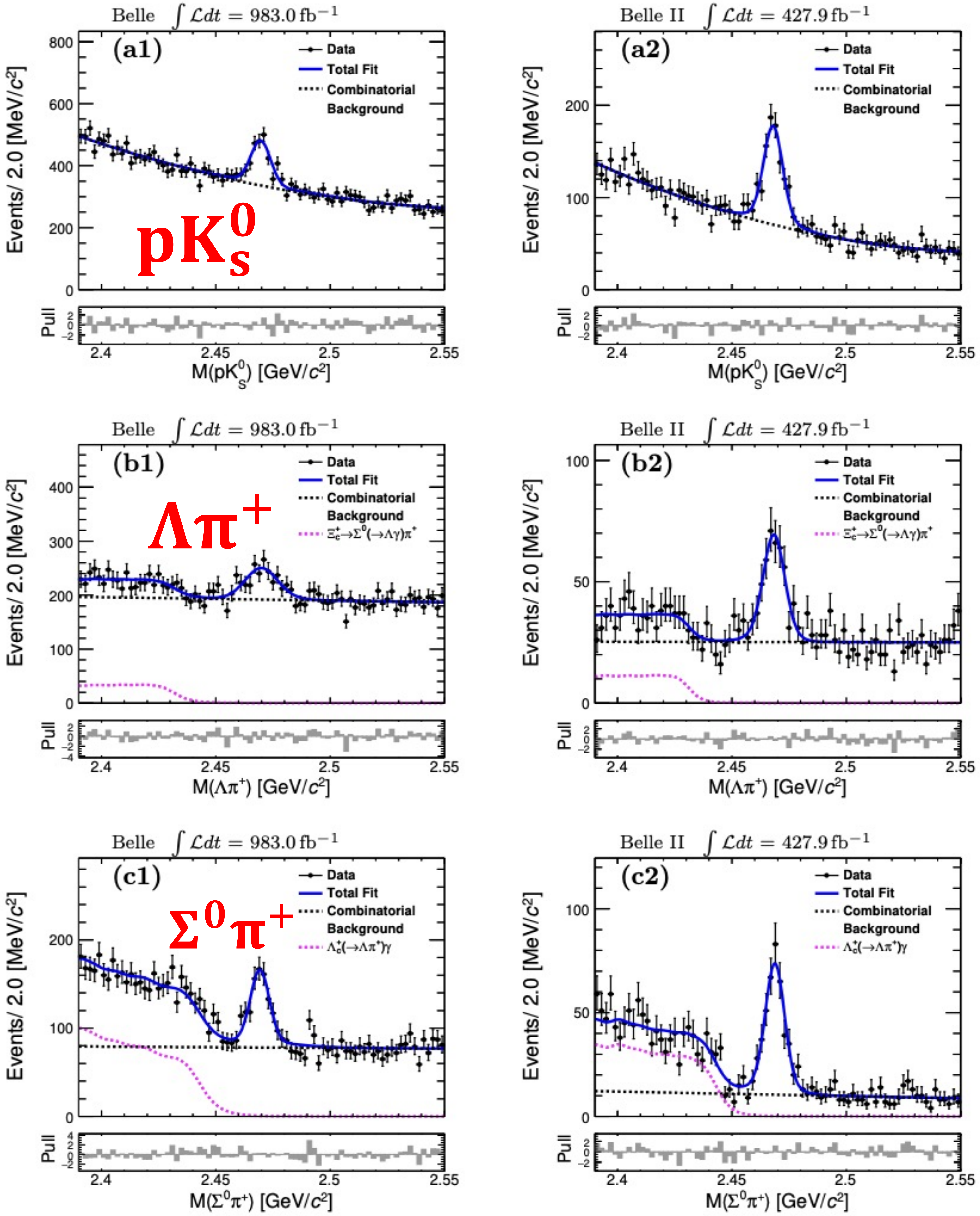
- $\Xi_c^0 \rightarrow \Lambda\eta$, $\Xi_c^0 \rightarrow \Lambda\eta'$ (singly Cabibbo-suppressed (SCS))
- $\Xi_c^+ \rightarrow \Xi^0 K^+$, $\Xi_c^+ \rightarrow pK_s^0$, $\Xi_c^+ \rightarrow \Lambda\pi^+$, $\Xi_c^+ \rightarrow \Sigma^0\pi^+$ (SCS)







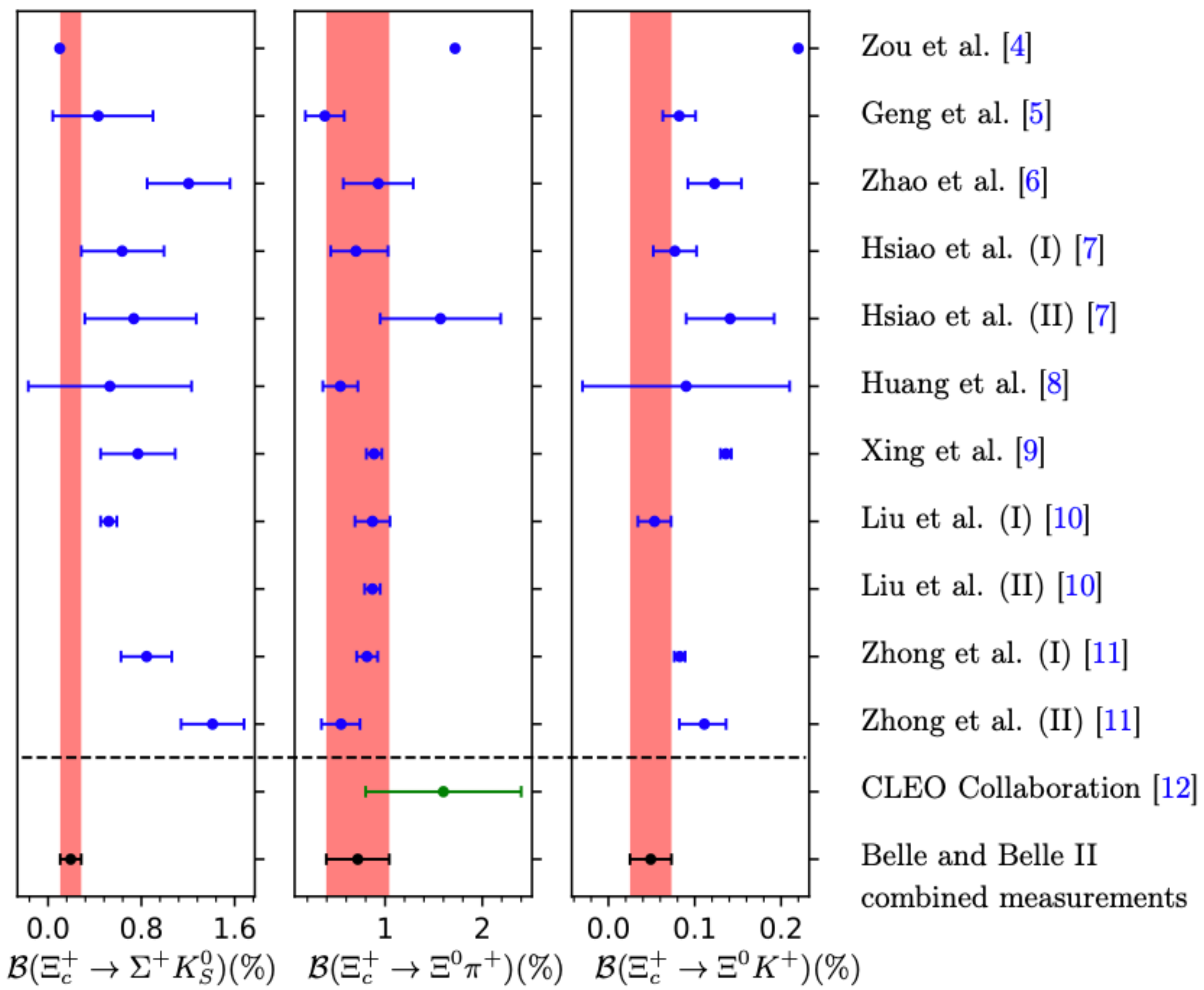




Branching fractions

First or most precise measurements!

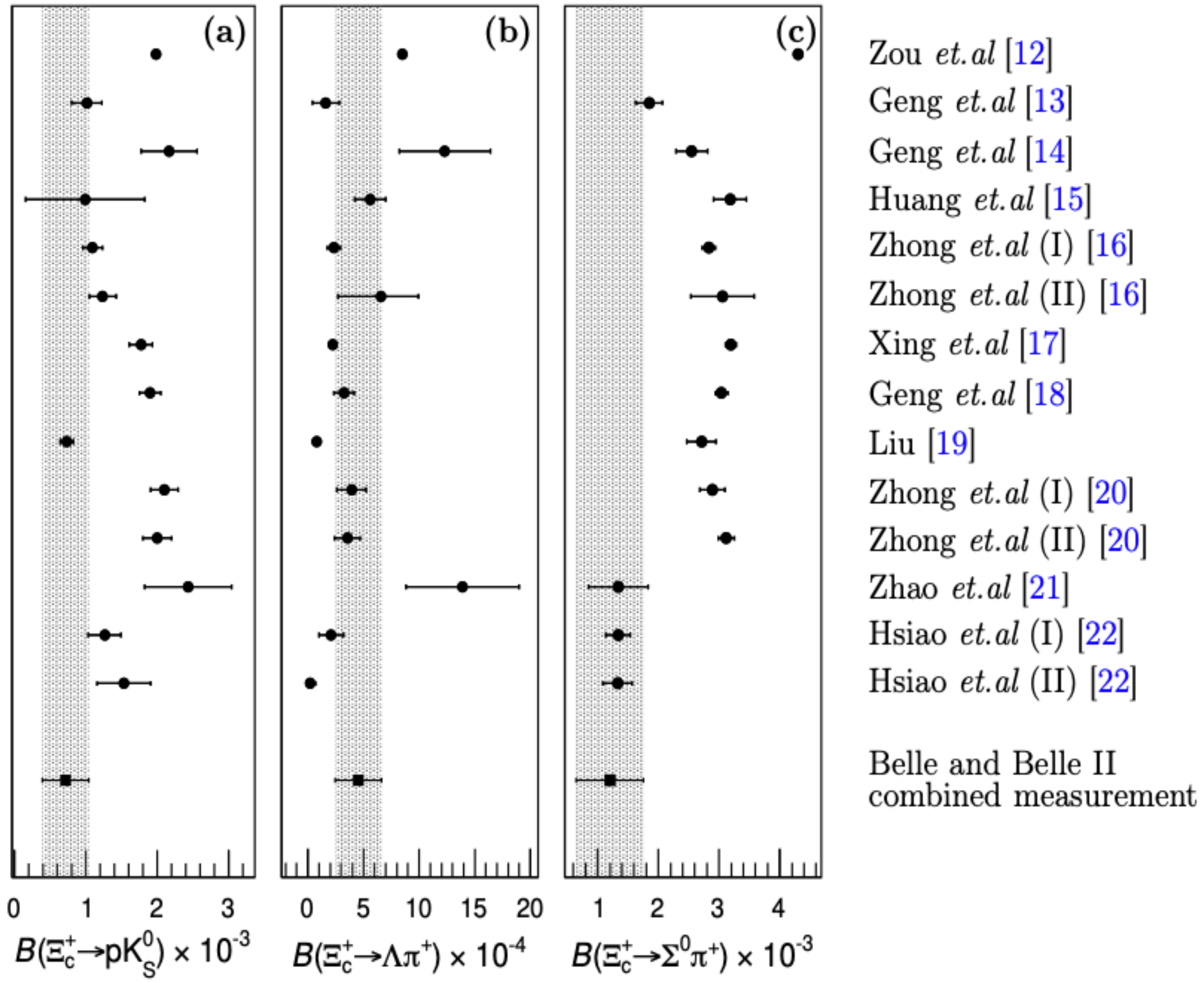
[JHEP 08 (2025) 195]



[4] the pole model (Pole), current algebra (CA)

[5-11] $SU(3)_F$ flavor symmetry

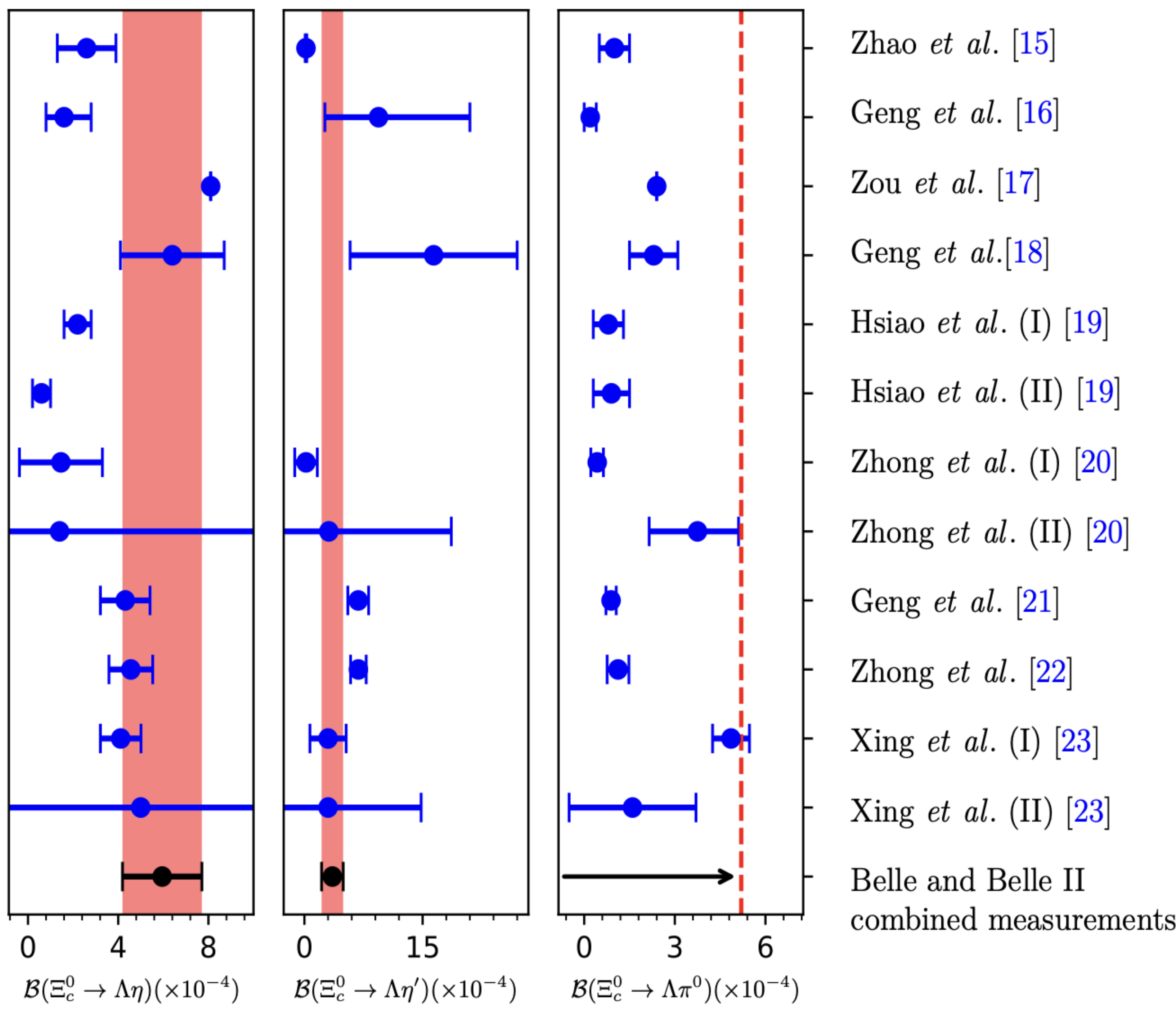
[JHEP 03 (2025) 061]



[12] Pole and CA

[13-22] $SU(3)_F$ flavor symmetry

[PRD 113, 032015 (2026)]



[15, 17-23] $SU(3)_F$ flavor symmetry

[16] Pole and CA

[22] Topological diagrammatic approach

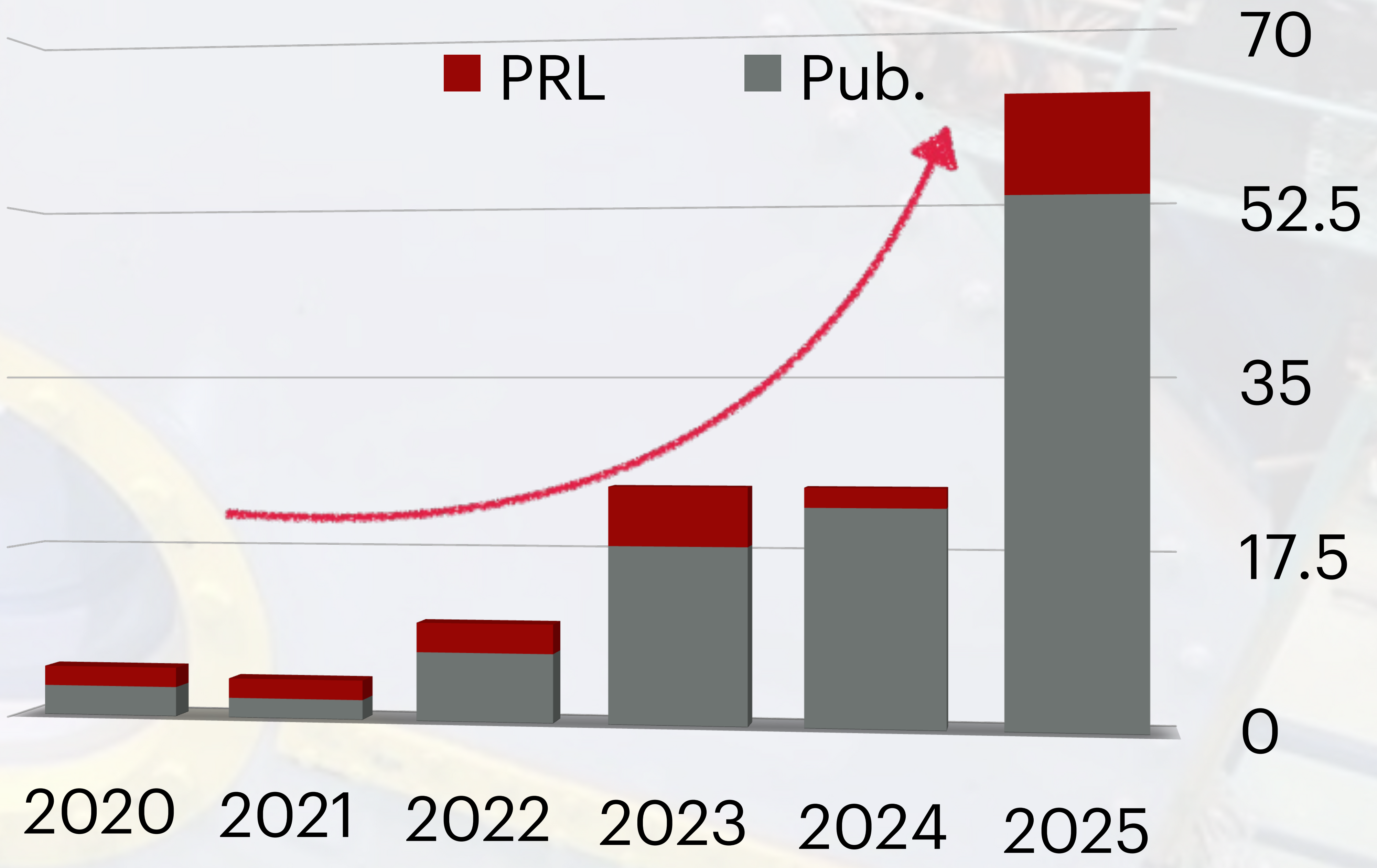
Next steps: 1. Explore three-body decays;

2. Amplitude analyses to search for new intedimediate states and identify J^P.

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

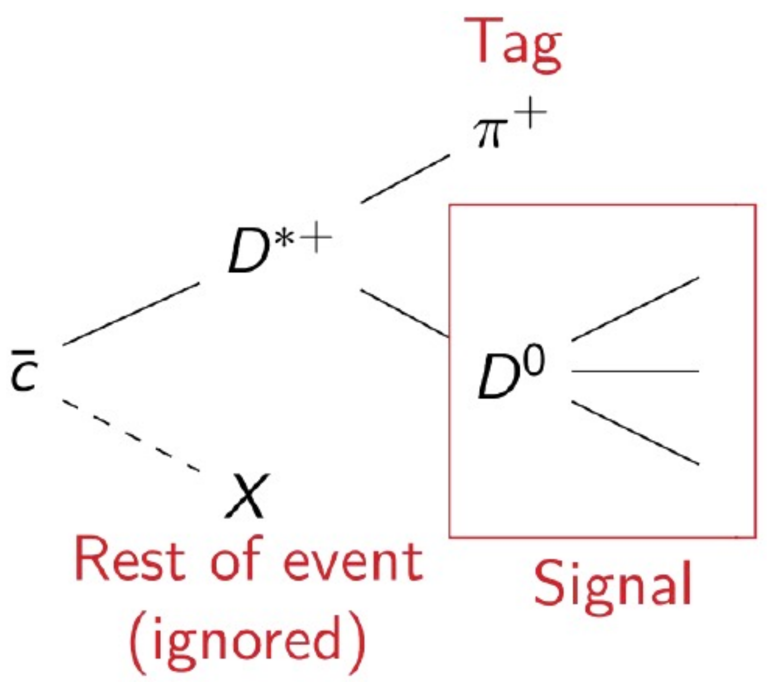
Belle II publication per year



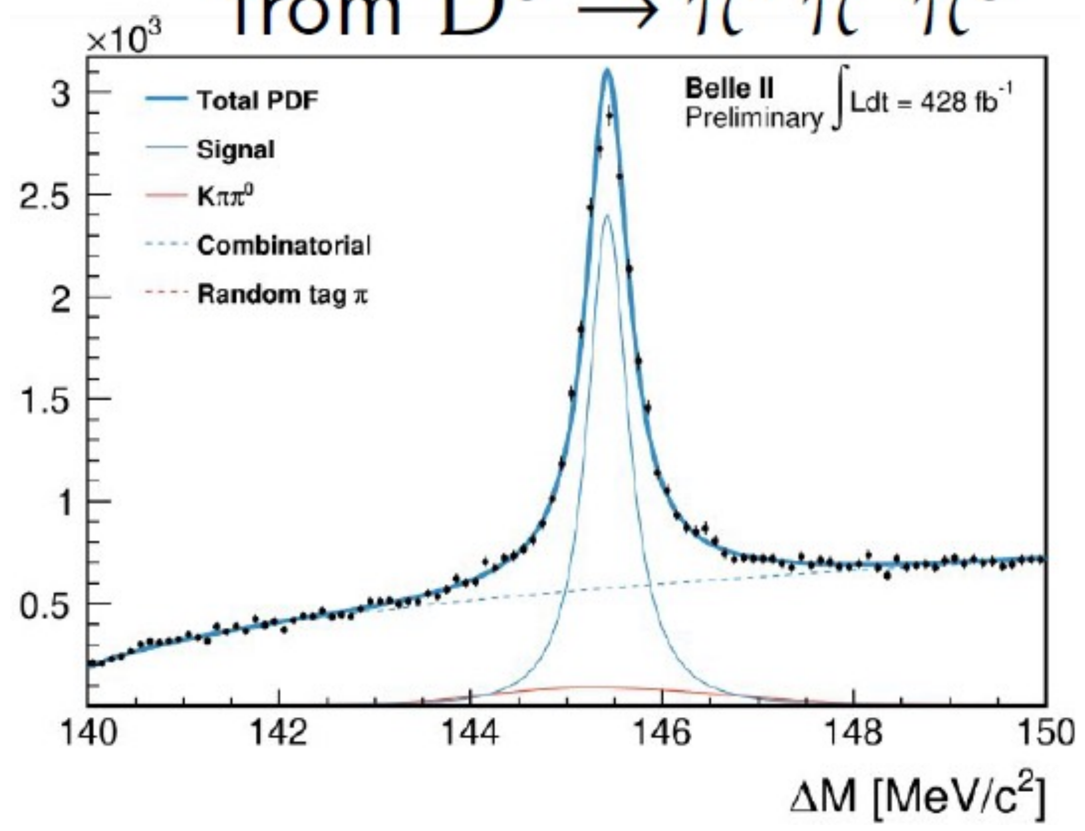
Thanks!

Flavor tag method

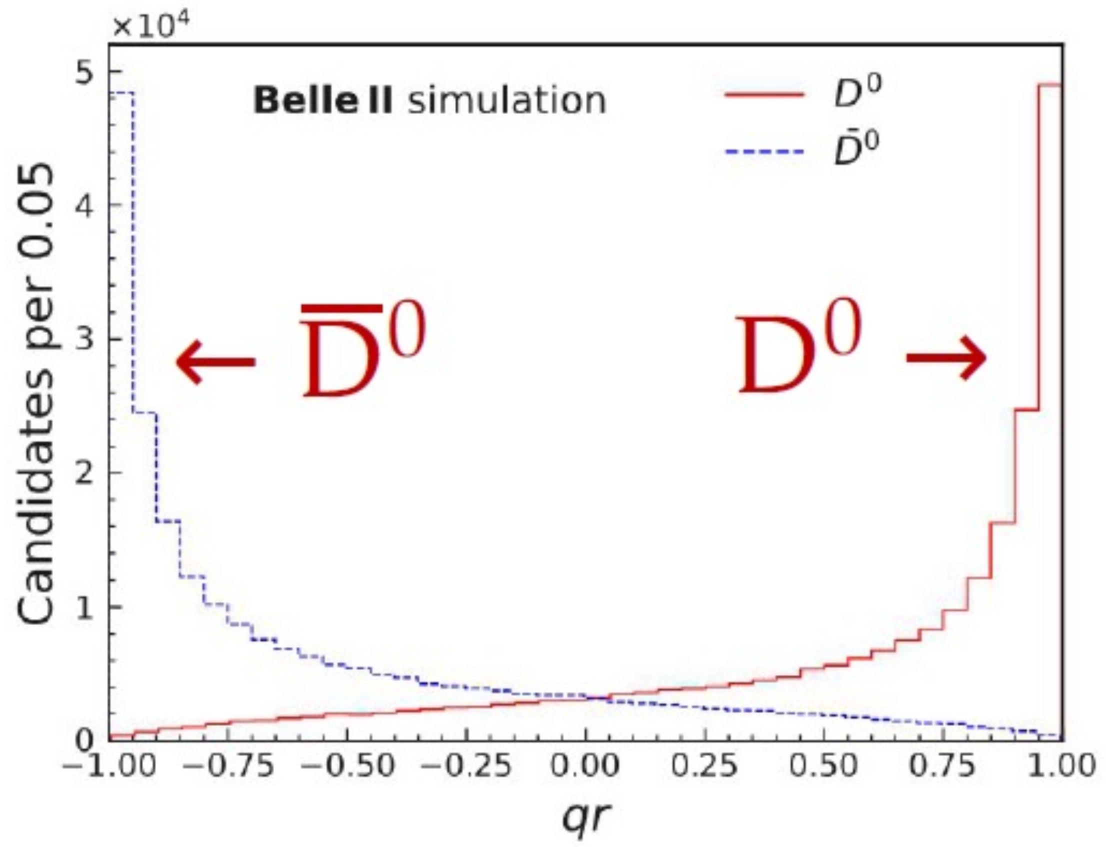
- **D^* tagging:**
  - When D^0 and $\overline{D}^0$ have common final state, use $D^{*+} \rightarrow D^0\pi^+$
  - Slow $\pi^{\pm}$ indicate the flavor of D
  - Most common method:
    - ⇒Powerful background discrimination
    - ⇒Efficiency ~25%, but very small mistag rate



Example ΔM from $D^0 \rightarrow \pi^+\pi^-\pi^0$



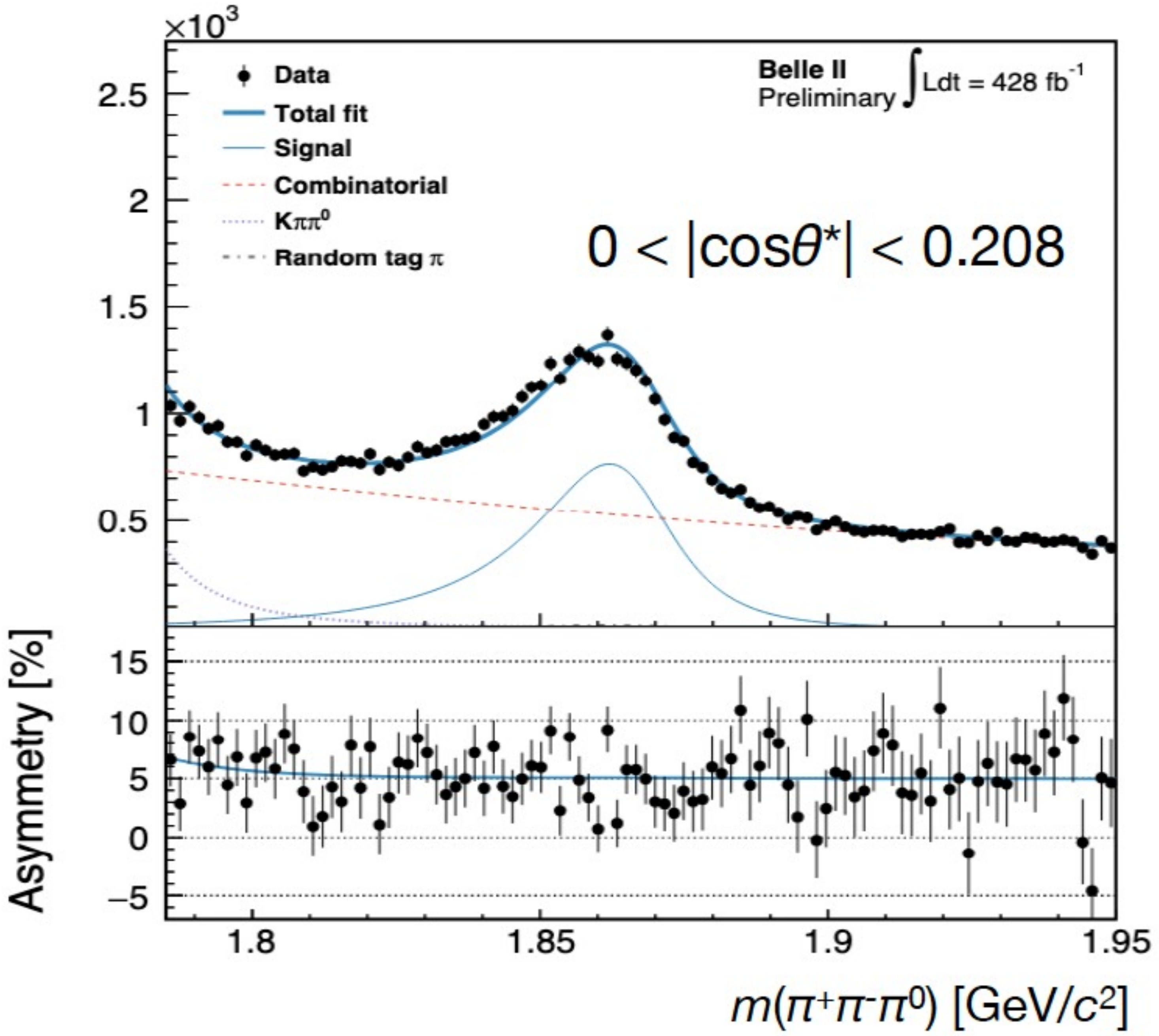
- **Charm Flavor Tagger (CFT)**
  - New method developed at Belle II [PRD 107, 112010]
  - BDT using rest-of-event particles, from the other charmed hadron & fragmentation
  - ⇒ Trained based on simulation, calibrated using data

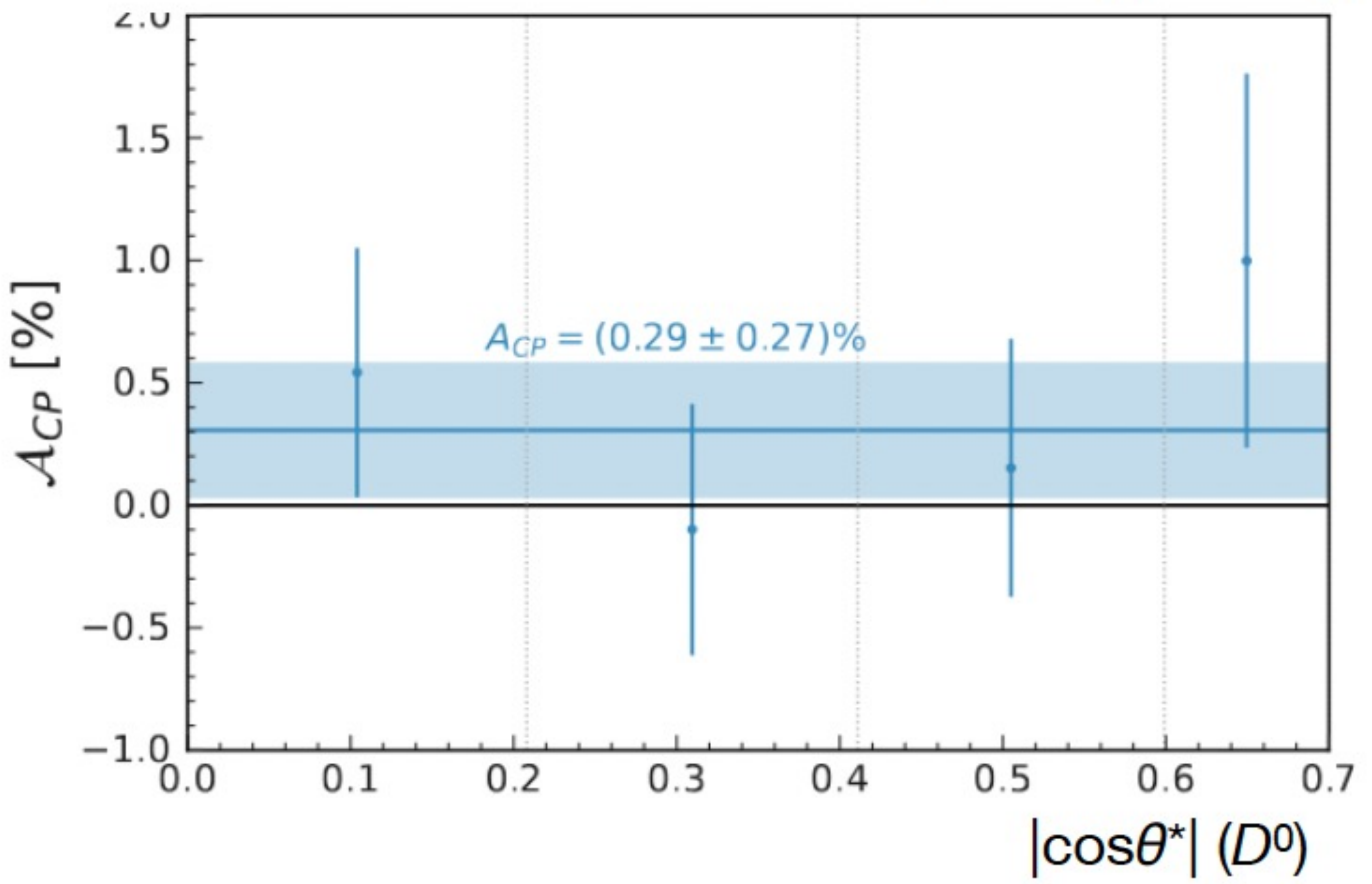


- LHCb is good at charged tracks
- Belle II better for cluster

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

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 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 fb^{-1} (123k candidates) PLB 662, 102 (2008)
   - $A_{CP} = (0.43 \pm 0.41 \pm 1.23)\,\%$
3) LHCb with 6 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 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

Systematic Effects and Corrections

Type	% MC
$\tau^- \to \pi^- K^0_S \nu_\tau (\geq 0\pi^0)$	77.8 ± 0.2
$\tau^- \to K^- K^0_S \nu_\tau (\geq 0\pi^0)$	2.7 ± 0.1
$\tau^- \to \pi^- K^0 \bar{K}^0 \nu_\tau (\geq 0\pi^0)$	18.2 ± 0.1
Background	1.3 ± 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 τ contribution removed through a dilution factor using SM assumptions.

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

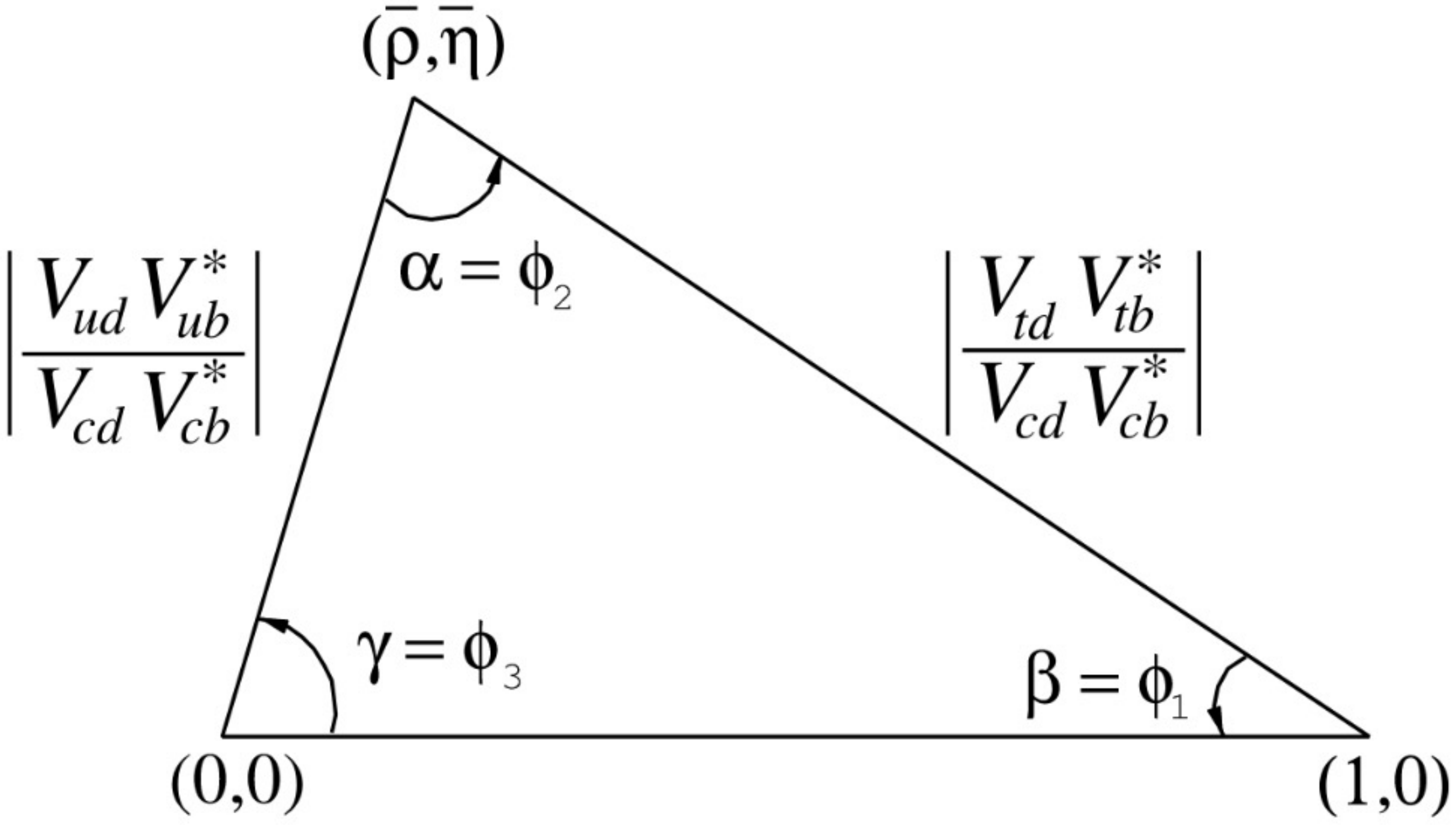
CP violation and the CKM matrix

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

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

scaled apex parameters