Charm decays and τ physics at Belle and Belle II

60th Rencontres de Moriond 2026, Electroweak Interactions & Unified Theories

17th March, La Thuile, Valle D'Aosta, Italy
Michele Mantovano on behalf of the Belle and Belle II Collaborations

HELMHOLTZ

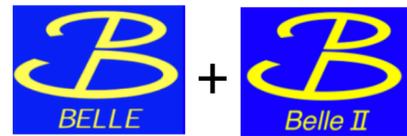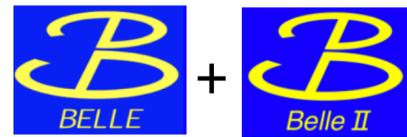michele.mantovano@desy.de

Overview

Charm and τ physics play a central role in the Belle (II) physics program

selected results (today)

charm physics

First measurements of $\mathscr{B}(\Xi_c^0 \to \Lambda h^0)$
PRD 113, 032015 (2026)

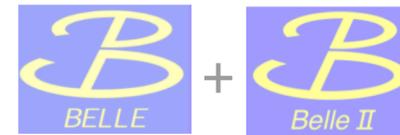First observation of $D_{s0}^*(2317)^+ \to D_s^{*+}\gamma$
arXiv:2510.27174 [submitted to PRL]

charm physics

First measurements of $A_{CP}(\Xi_c^+ \to \Sigma^+ h^+ h^-)$ and $A_{CP}(\Lambda_c^+ \to p h^+ h^-)$
PRD 113, 032017 (2026)

Measurements of $\mathscr{B}(\Xi_c^+ \to \Sigma^+ K_S, \Xi^0\pi^+, \Xi^0 K^+)$
JHEP 08, 195 (2025)

τ physics

New result for Moriond EW

Search for CPV in the $\tau \to \pi K_s^0 \nu_\tau$ decays
To be submitted to JHEP

Search for LFV $\tau \to \ell\eta$ decays
To be submitted to PRD

τ physics

Search for LFV in $\tau \to \mu\gamma$ decays
To be submitted to JHEP **[see Devender's talk]**

Search for $\tau \to \ell\alpha$ decays
JHEP 08, 155 (2025) **[see Devender's talk]**

Search for LFV in $\tau \to e\ell\ell$ decays
JHEP 12, 169 (2025)

.... and many others
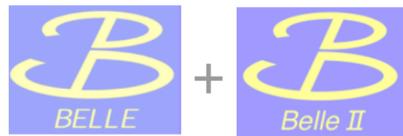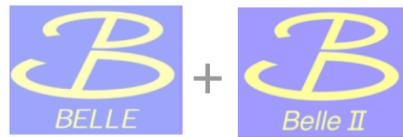
DESY.

Overview

Charm and τ physics play a central role in the Belle (II) physics program

additional results

charm physics

First measurements of $\mathcal{B}(\Xi_c^0 \to \Lambda h^0)$
PRD 113, 032015 (2026)

First observation of $D_{s0}^*(2317)^+ \to D_s^{*+}\gamma$
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charm physics

First measurements of
$A_{CP}(\Xi_c^+ \to \Sigma^+ h^+ h^-)$ and $A_{CP}(\Lambda_c^+ \to p h^+ h^-)$
PRD 113, 032017 (2026)

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.... and many others

SuperKEKB and Belle (II) experiments

More than just B-factories

- Mostly operating at the $\Upsilon(4S)$ resonance ($\sqrt{s} = 10.58\,\mathrm{GeV}$)

- Clean experimental environment

- Well-known initial state kinematics → **strong in searches with missing energy**

- Collected $1\,\mathrm{ab}^{-1}$ @Belle and $0.66\,\mathrm{ab}^{-1}$ @Belle II (so far)

- **World record instantaneous luminosity of** $5.1 \times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
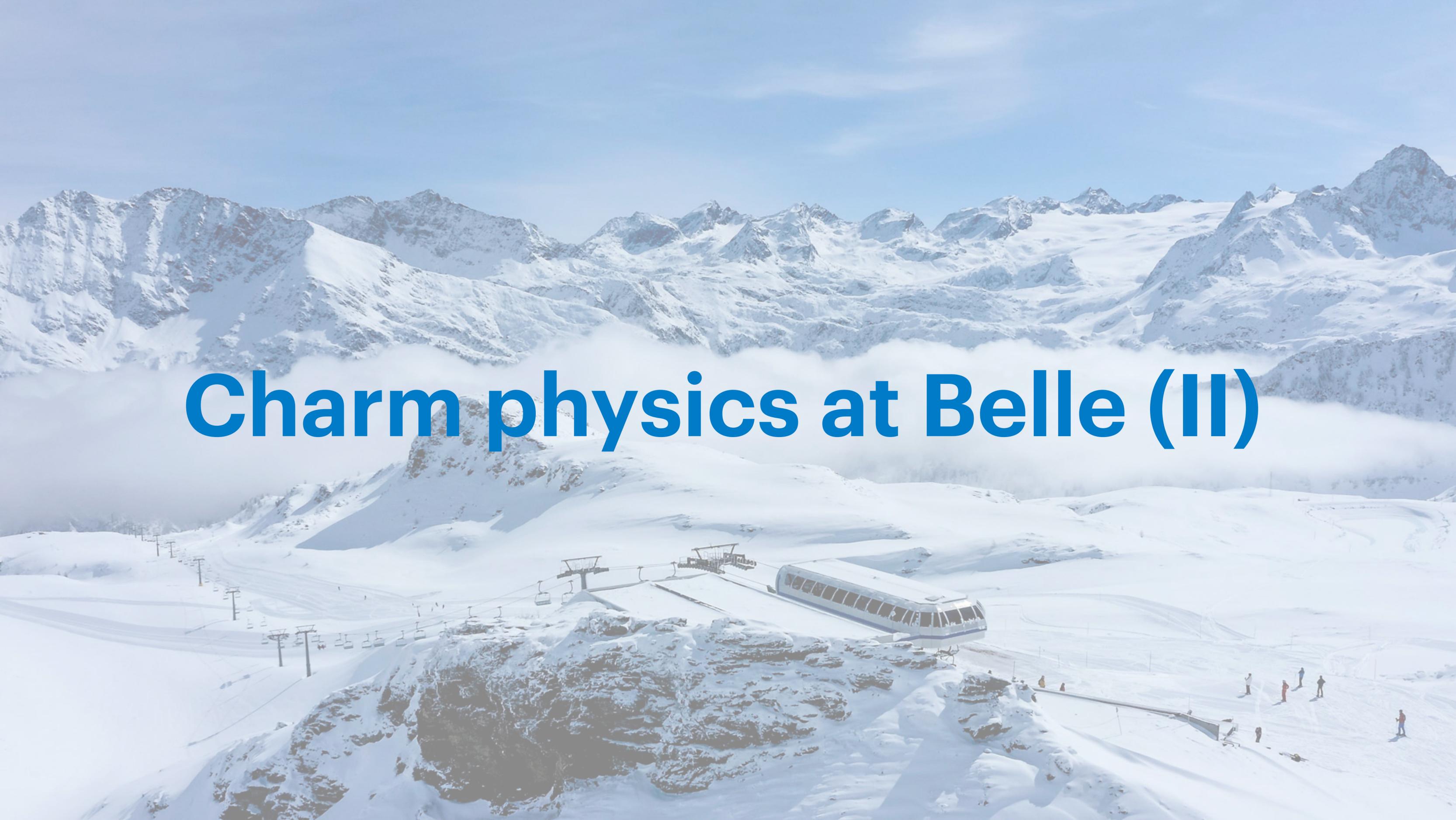
charm physics

- Extensive studies involving baryons to verify models from theoretical predictions
- High-precision in CPV and mixing measurements

τ physics

- High-precision of SM properties (mass, lifetime, LFU, V_{us} ...)
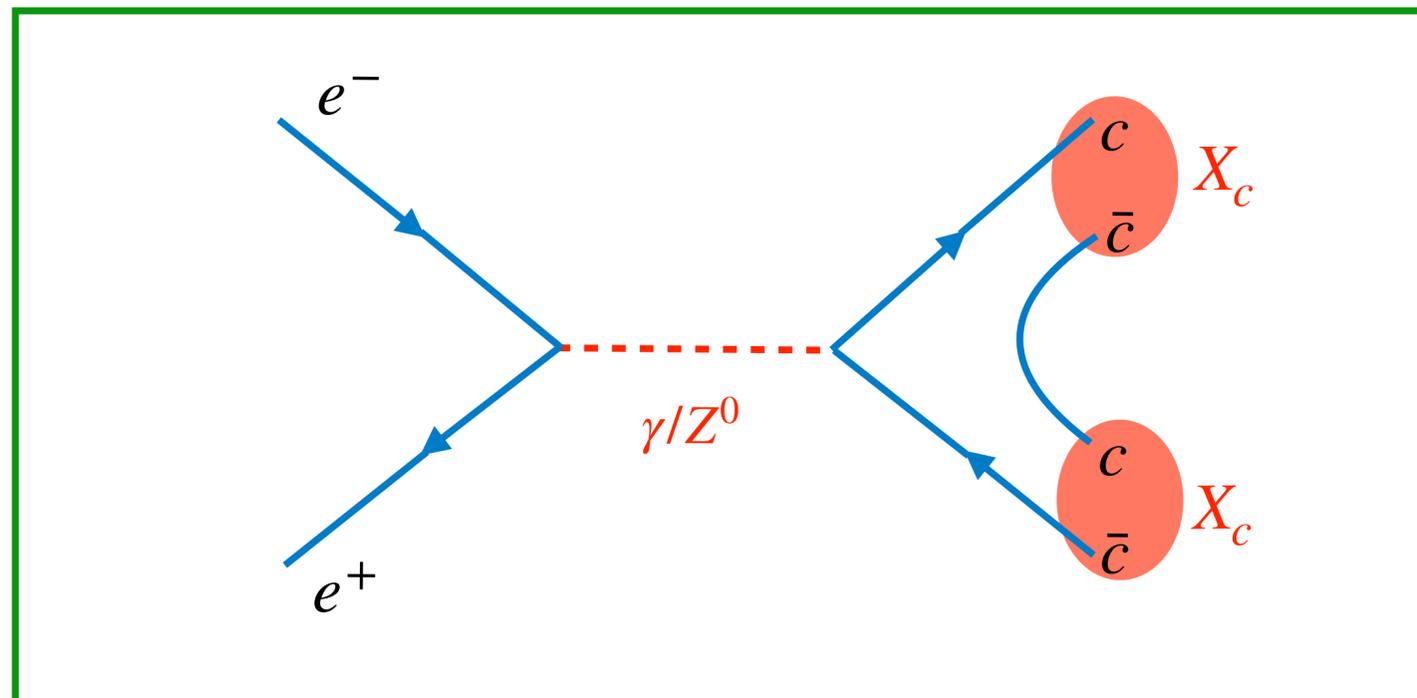- World-leading sensitivities in direct searches for rare and forbidden processes
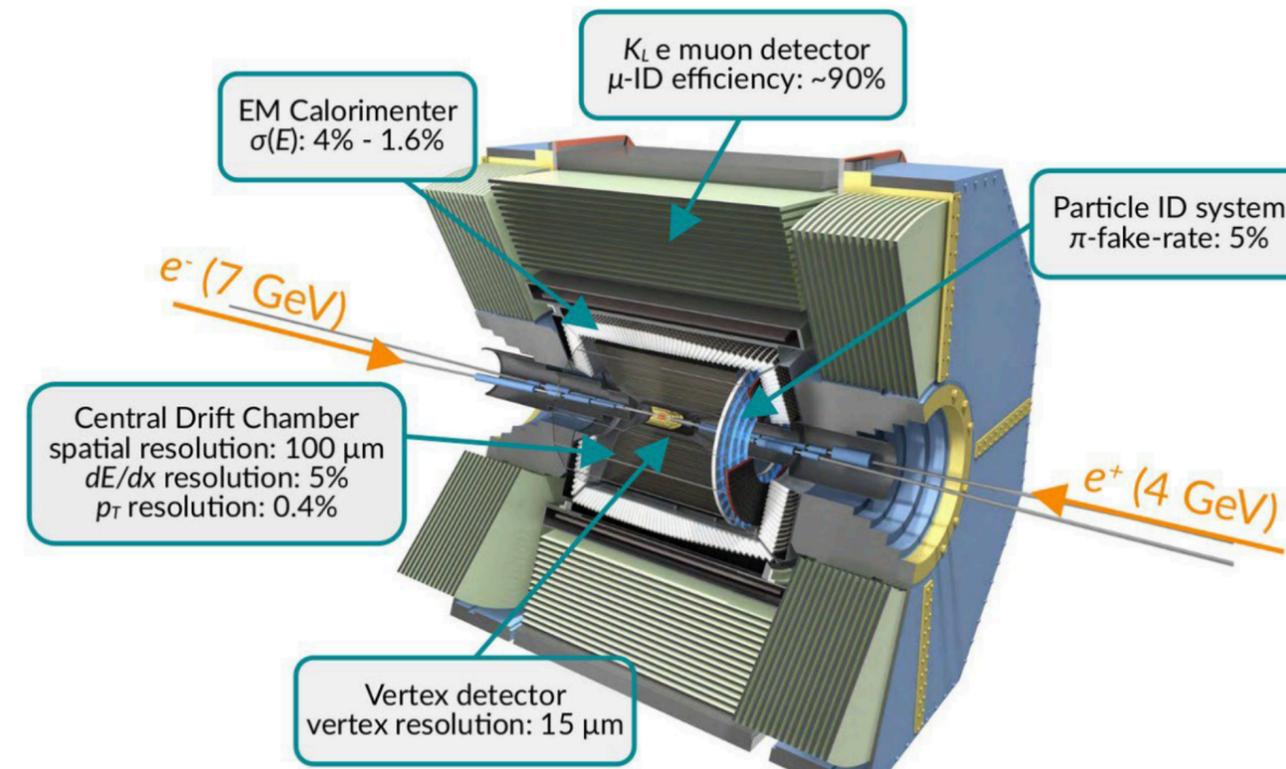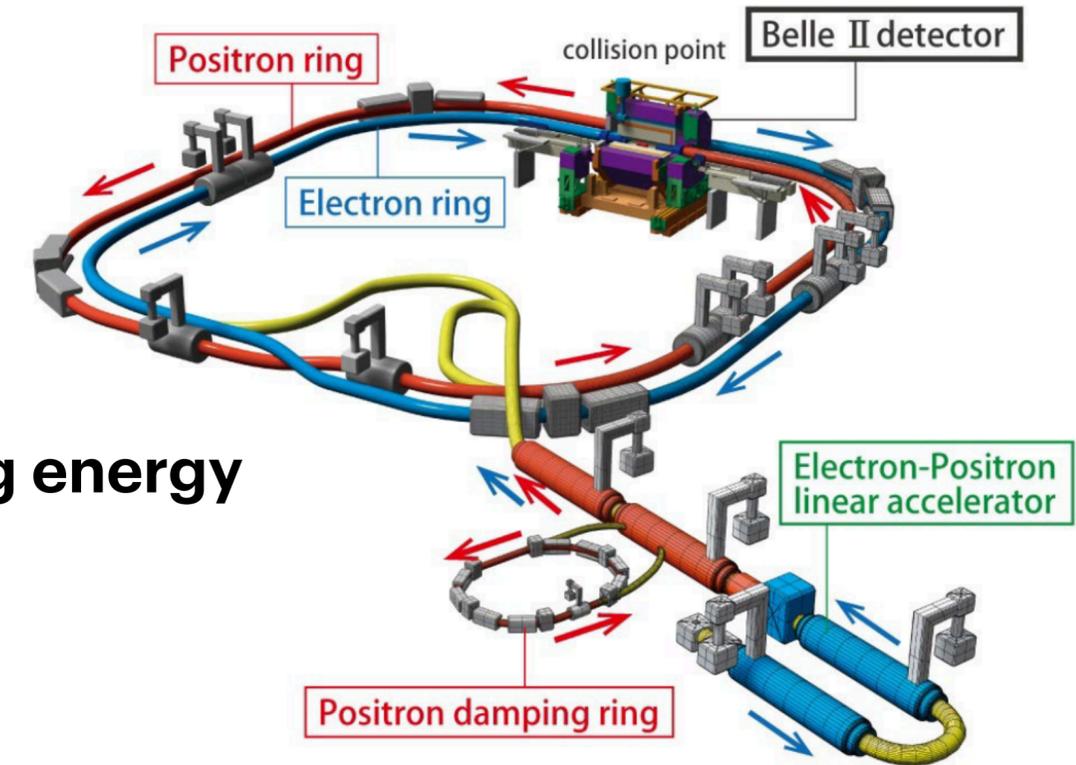
DESY.

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Charm physics at Belle (II)

Charm production

Two ways of producing charm at B-factories

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
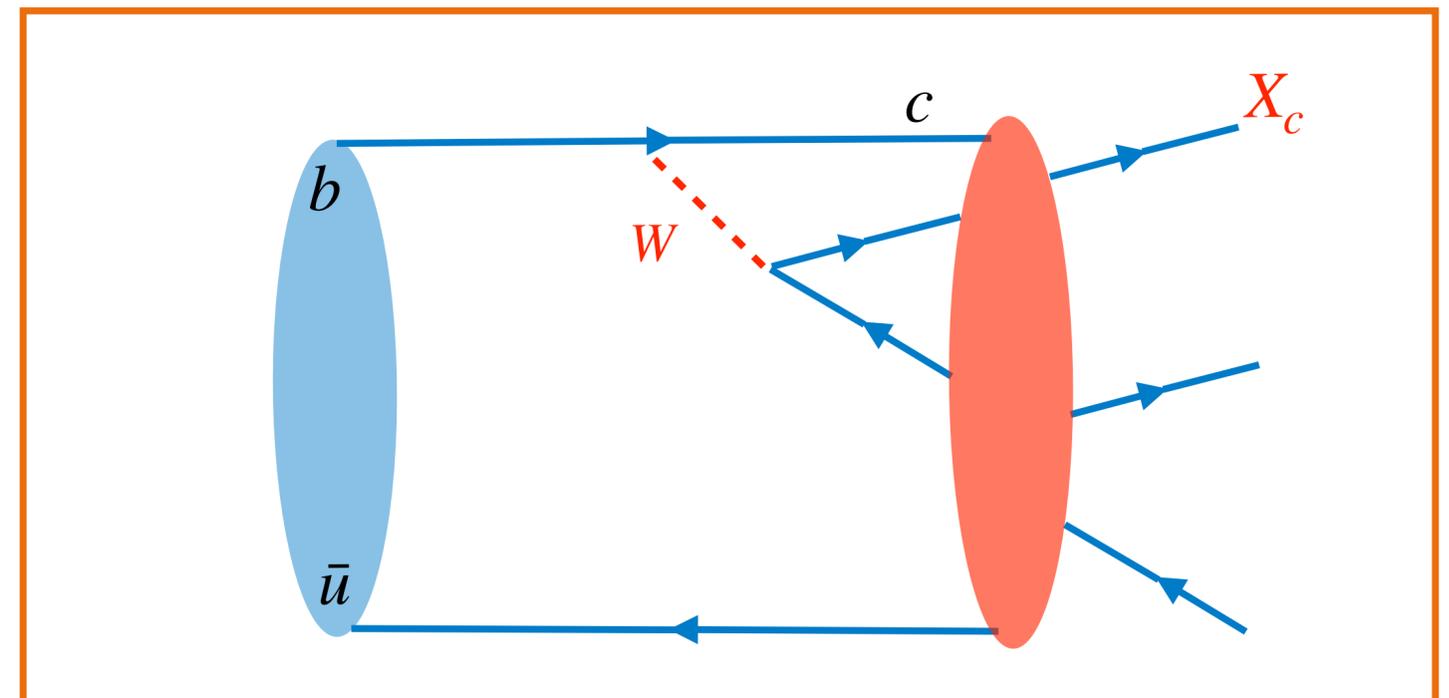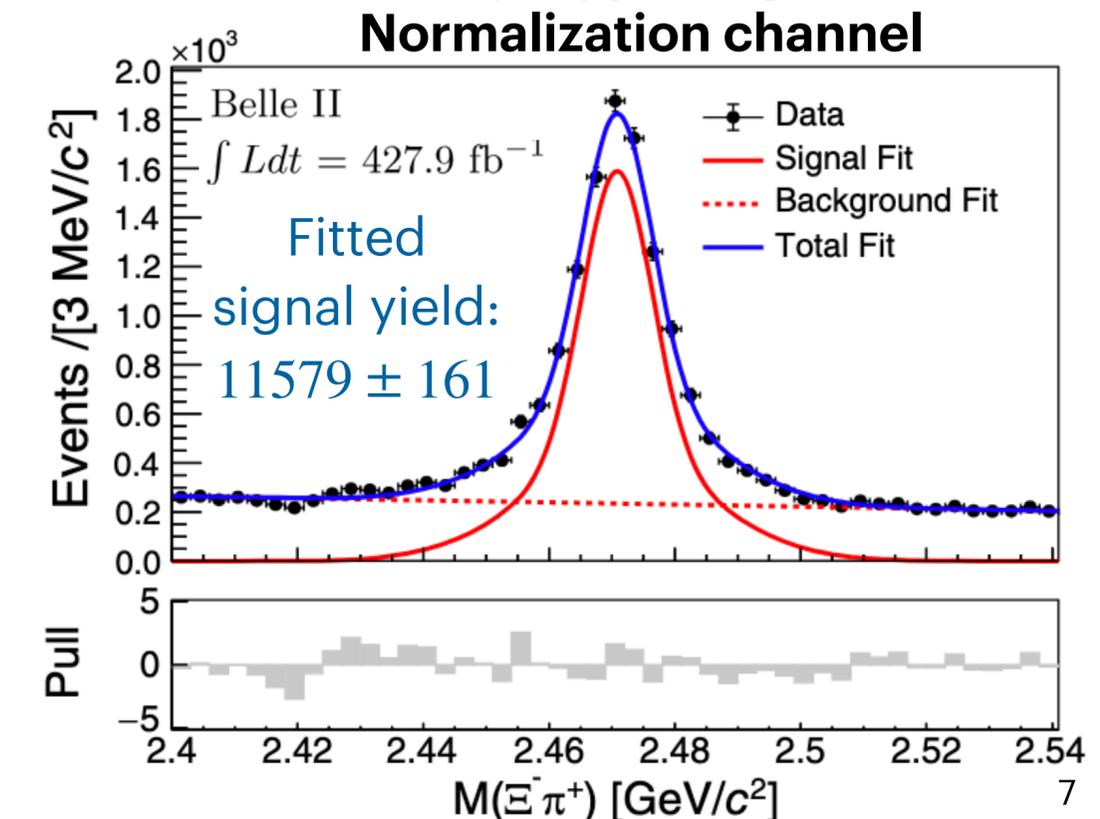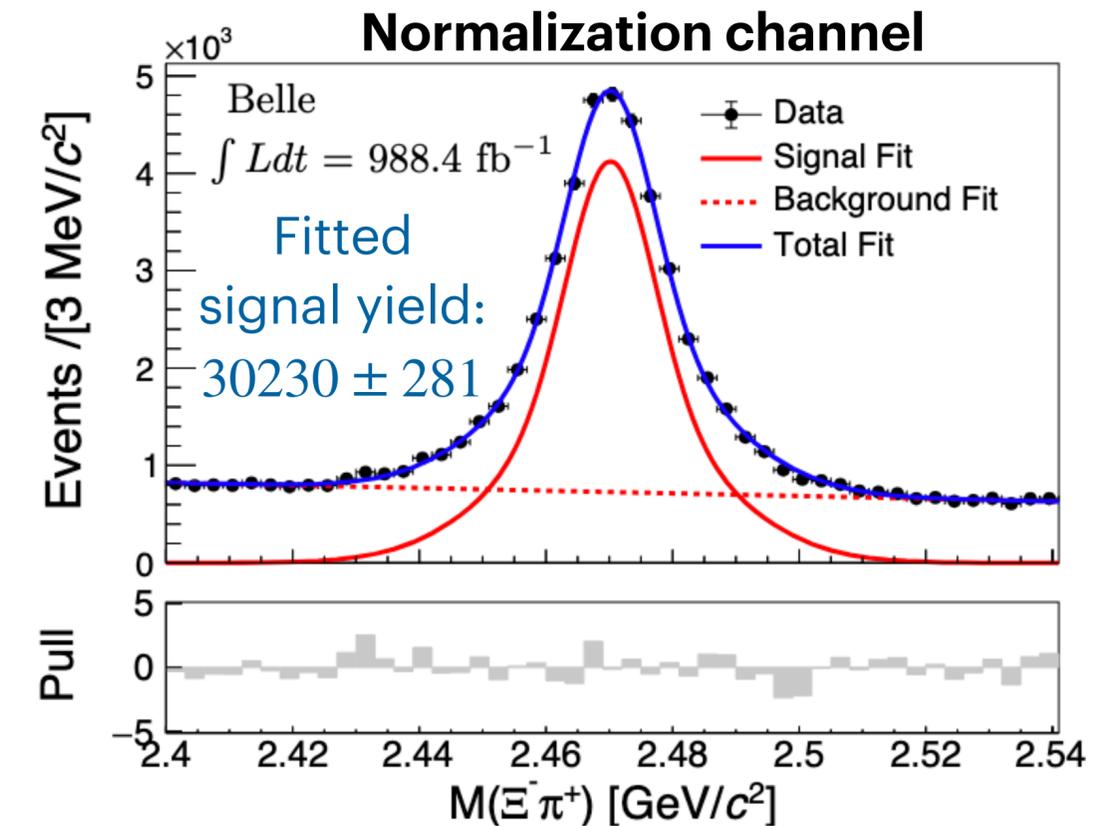

Low statistics but very clean sample

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

All the results presented today are derived from continuum processes

First measurements of $\mathscr{B}(\Xi_c^0 \to \Lambda h^0)$ at Belle and Belle II

Motivation and analysis strategy

- Singly Cabibbo-suppressed $\Xi_c^0 \to \Lambda h^0$ decays ($h = \eta, \eta', \pi^0$):

  first measurements of the branching fraction relative to $\Xi_c^0 \to \Xi^- \pi^+$

- Precise measurements of these modes:

  - Improve understanding of decay dynamics

  - Clarify the theoretical picture

- Reconstruct $\Lambda \to p\pi^-, \eta' \to 2\pi\eta, \eta' \to 2\pi\gamma, \eta \to \gamma\gamma, \eta \to 2\pi\pi^0$ and $\pi^0 \to \gamma\gamma$

- Normalization mode $\Xi_c^0 \to \Xi^- \pi^+$ cancels common input $\mathscr{B}(\Lambda \to p\pi^-)$

- Normalization yield extracted from an unbinned extended maximum-

  likelihood fit to the $M(\Xi^- \pi^+)$ spectra

Normalization channel

Belle
$\int L dt = 988.4 \text{ fb}^{-1}$

Fitted signal yield: 30230 ± 281

Data · Signal Fit · Background Fit · Total Fit

$M(\Xi^- \pi^+)$ [GeV/c^2]

Normalization channel

Belle II
$\int L dt = 427.9 \text{ fb}^{-1}$

Fitted signal yield: 11579 ± 161

Data · Signal Fit · Background Fit · Total Fit

$M(\Xi^- \pi^+)$ [GeV/c^2]

First measurements of $\mathcal{B}(\Xi_c^0 \to \Lambda h^0)$ at Belle and Belle II

Results

$\mathcal{B}(\Xi_c^0 \to \Lambda h^0)/\mathcal{B}(\Xi_c^0 \to \Xi^-\pi^+)$ using a simultaneous unbinned extended maximum-likelihood fit to $M(\Lambda h^0)$

$\mathcal{B}(\Xi_c^0 \to \Lambda\eta)/\mathcal{B}(\Xi_c^0 \to \Xi^-\pi^+) = (4.16 \pm 0.91 \pm 0.23)\,\%$

$\mathcal{B}(\Xi_c^0 \to \Lambda\eta')/\mathcal{B}(\Xi_c^0 \to \Xi^-\pi^+) = (2.48 \pm 0.82 \pm 0.12)\,\%$

$\mathcal{B}(\Xi_c^0 \to \Lambda\pi^0)/\mathcal{B}(\Xi_c^0 \to \Xi^-\pi^+) < 3.5\,\%$ at @90% CL

Multiplying by the world-average

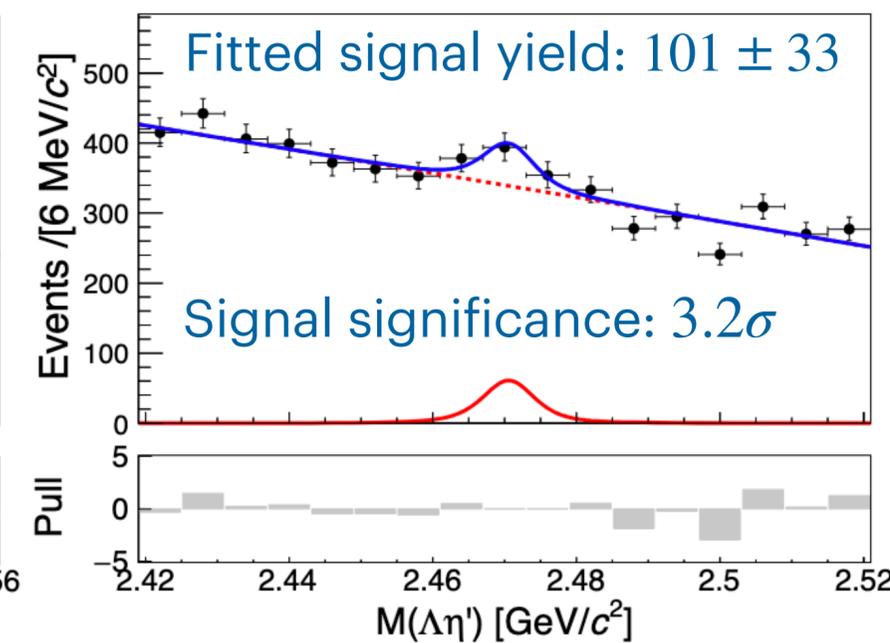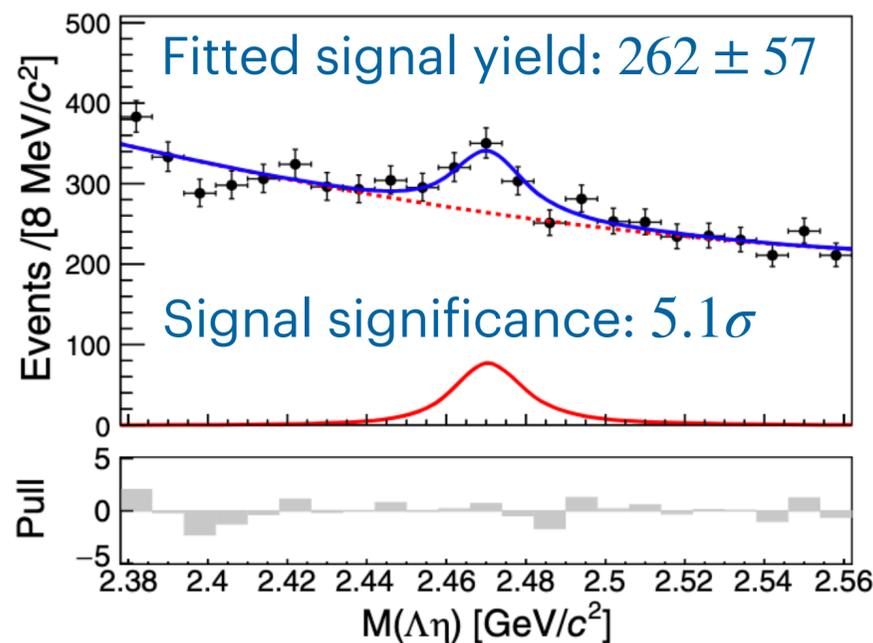$\mathcal{B}(\Xi_c^0 \to \Xi^-\pi^+)_{th} = (1.43 \pm 0.27)\,\%$ we get

$\mathcal{B}(\Xi_c^0 \to \Lambda\eta) = (5.95 \pm 1.30_{stat} \pm 0.32_{syst} \pm 1.13_{th}) \times 10^{-4}$

$\mathcal{B}(\Xi_c^0 \to \Lambda\eta') = (3.55 \pm 1.17_{stat} \pm 0.17_{syst} \pm 0.68_{th}) \times 10^{-4}$

$\mathcal{B}(\Xi_c^0 \to \Lambda\pi^0) < 5.2 \times 10^{-4}$ at @90% CL

First-ever measurements; statistically limited

Consistent with theoretical predictions

Fitted signal yield: 262 ± 57

Signal significance: 5.1σ

Fitted signal yield: 101 ± 33

Signal significance: 3.2σ

Belle $\quad \int Ldt = 988.4$ fb^{-1}

Belle II $\quad \int Ldt = 427.9$ fb^{-1}
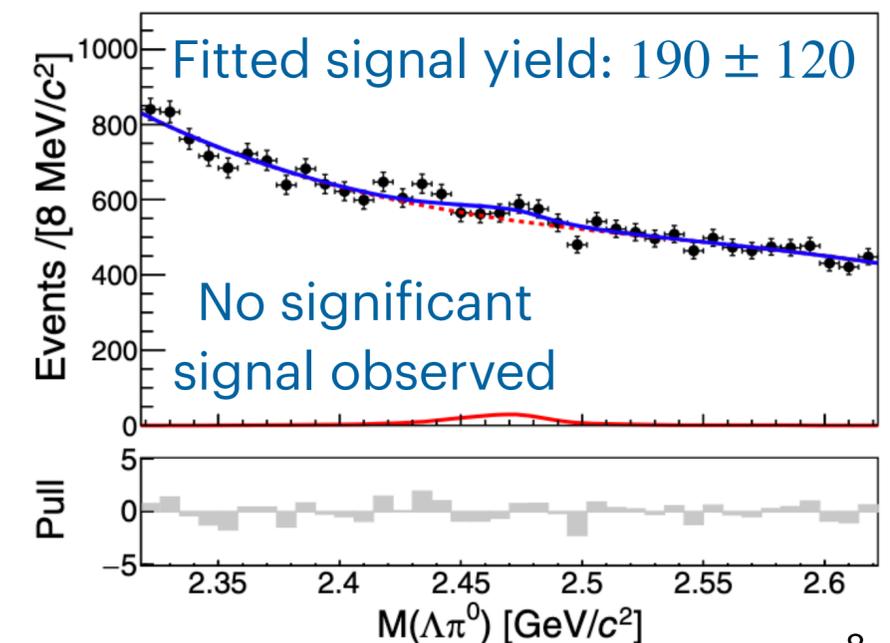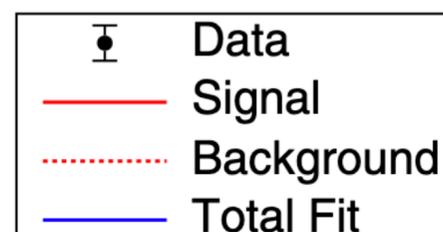
	Data
—	Signal
····	Background
—	Total Fit

Fitted signal yield: 190 ± 120

No significant
signal observed

First observation of the radiative decay $D_{s0}^*(2317)^+ \to D_s^* \gamma$ at Belle and Belle II

Motivation and analysis strategy

- Nature of $D_{s0}^*(2317)^+$ and $D_{s1}(2460)^+$ unclear: $c\bar{s}$ states, hadronic molecules, mixed configs, tetraquarks → motivate further studies

- Reconstruct $D_s^+ \to \phi[\to K^+K^-]\pi^+$ and $D_s^+ \to \bar{K}^{*0}[\to K^-\pi^+]K^+$ decays $D_{s0}^*(2317)^+$ candidates from $D_s^{*+}\gamma$ or $D_s^+\pi^0$ combinations

- $D_{s0}^*(2317)^+ \to D_s^+\pi^0$ as normalization channel: yield obtained from an unbinned maximum-likelihood fit to $M(D_s^+\pi^0)$ spectra

- Detailed study of background sources: use D_s and π^0 sidebands Peaking background from a missing γ in $D_{s1}(2460)^+ \to D_s^{*+}\pi^0$ decays Shape and yield obtained from fits to signal Monte Carlo samples

Fitted signal yield: 10820 ± 230

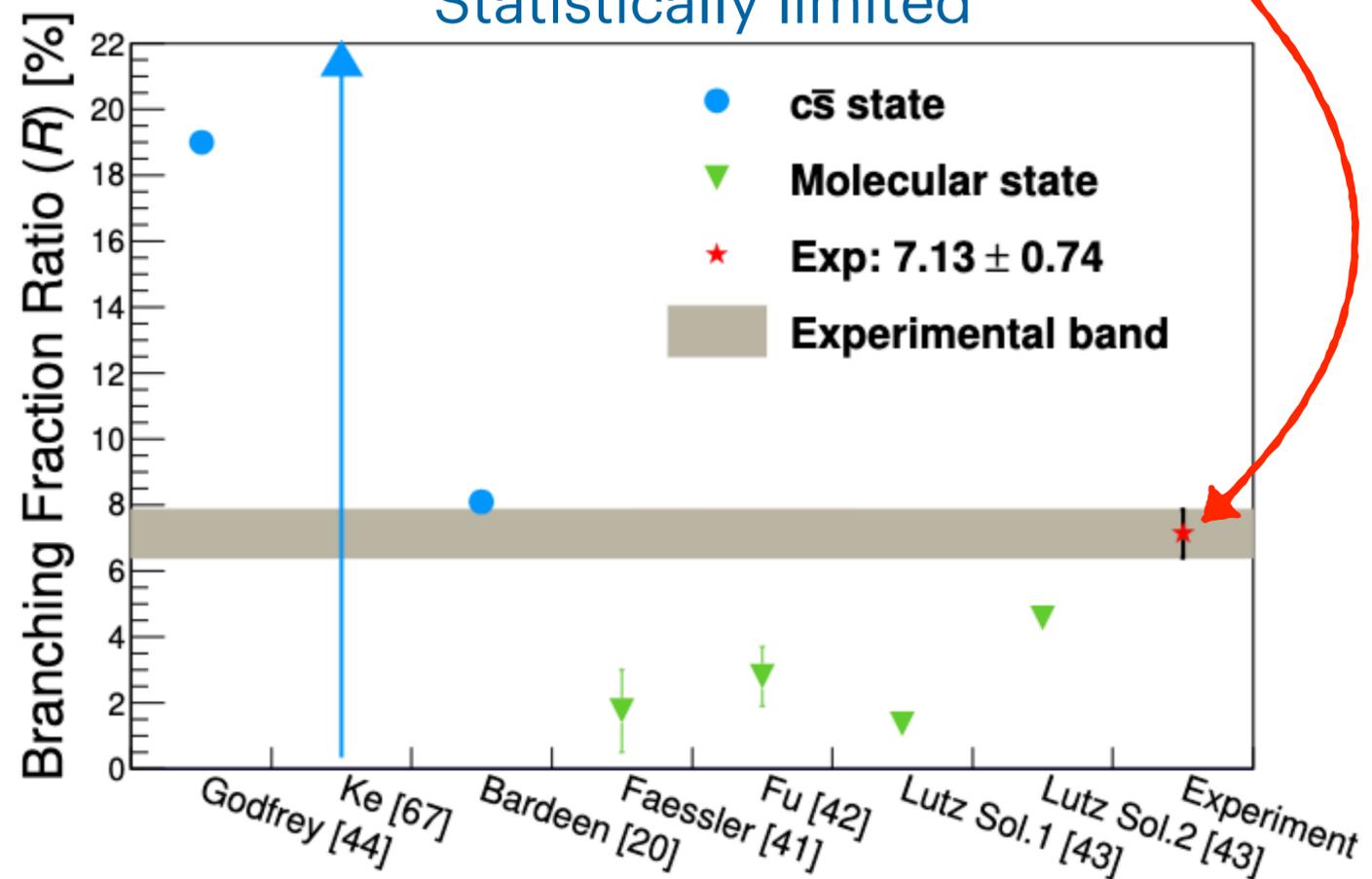Fitted signal yield: 6108 ± 163
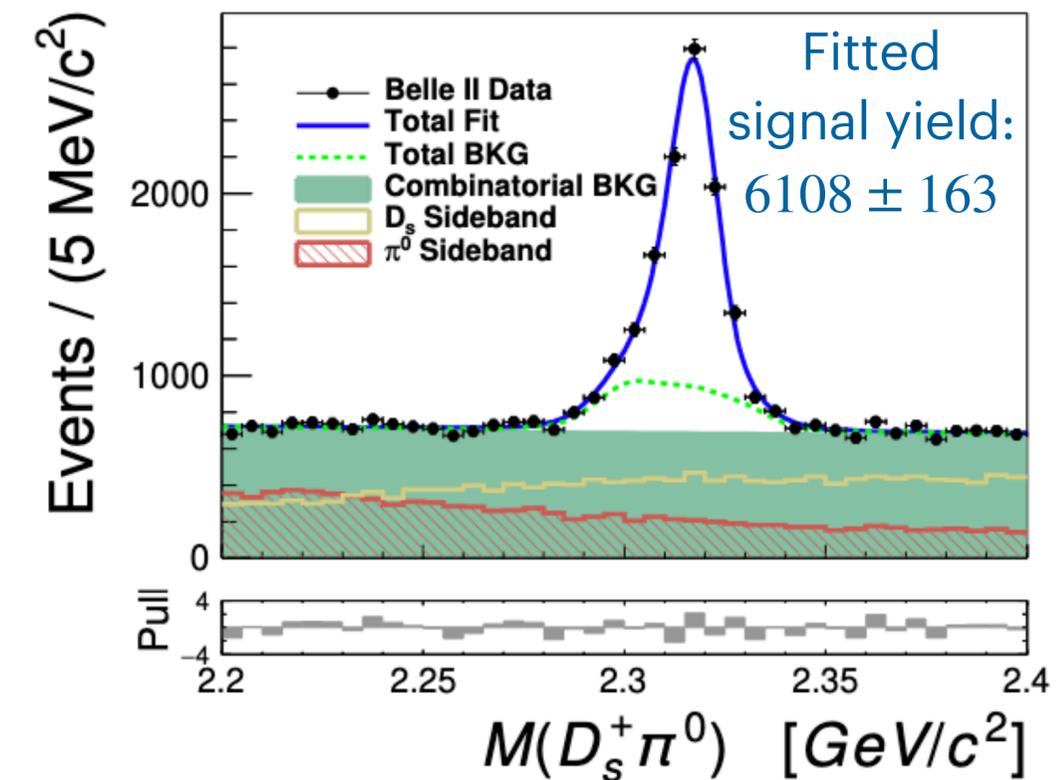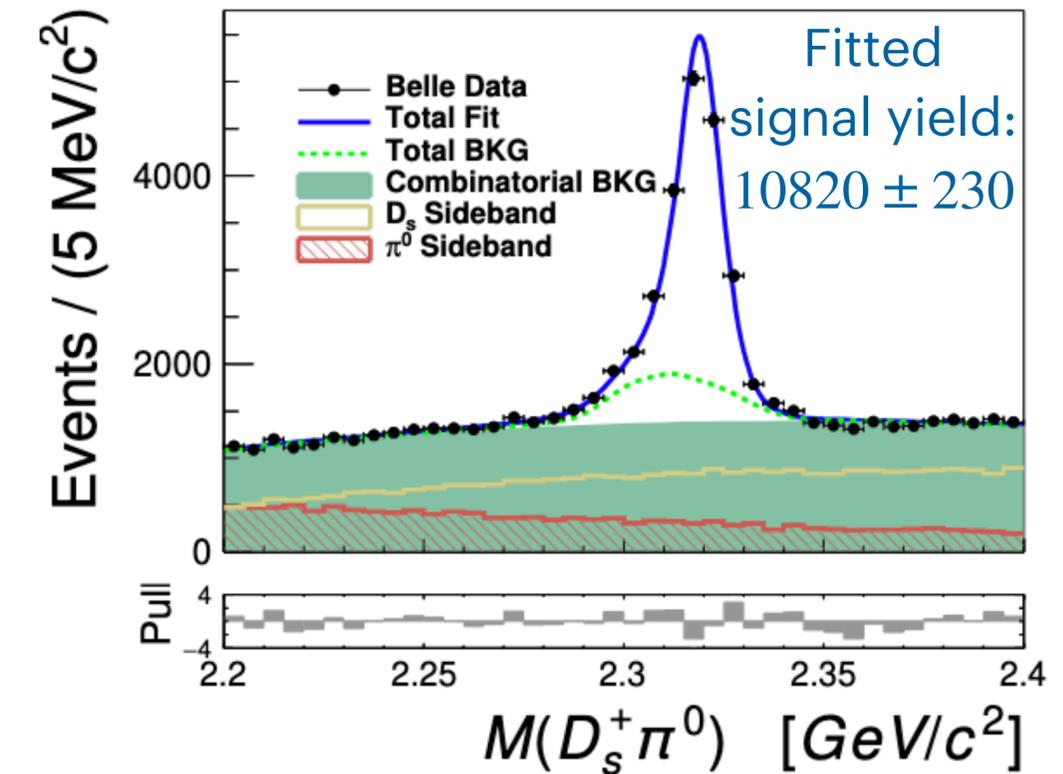
First observation of the radiative decay $D_{s0}^*(2317)^+ \to D_s^*\gamma$ at Belle and Belle II

Results

First measurement of $R = \mathscr{B}(D_{s0}^{*+} \to D_s^{*+}\gamma)/\mathscr{B}(D_{s0}^{*+} \to D_s^+\pi^0)$ using a simultaneous unbinned maximum-likelihood fit to $M(D_s^{*+}\gamma)$ spectra

$$R = (7.14 \pm 0.70_{stat} \pm 0.23_{syst}) \%$$

Statistically limited

Above molecular predictions, below quark-model expectations: could be a mixed configuration
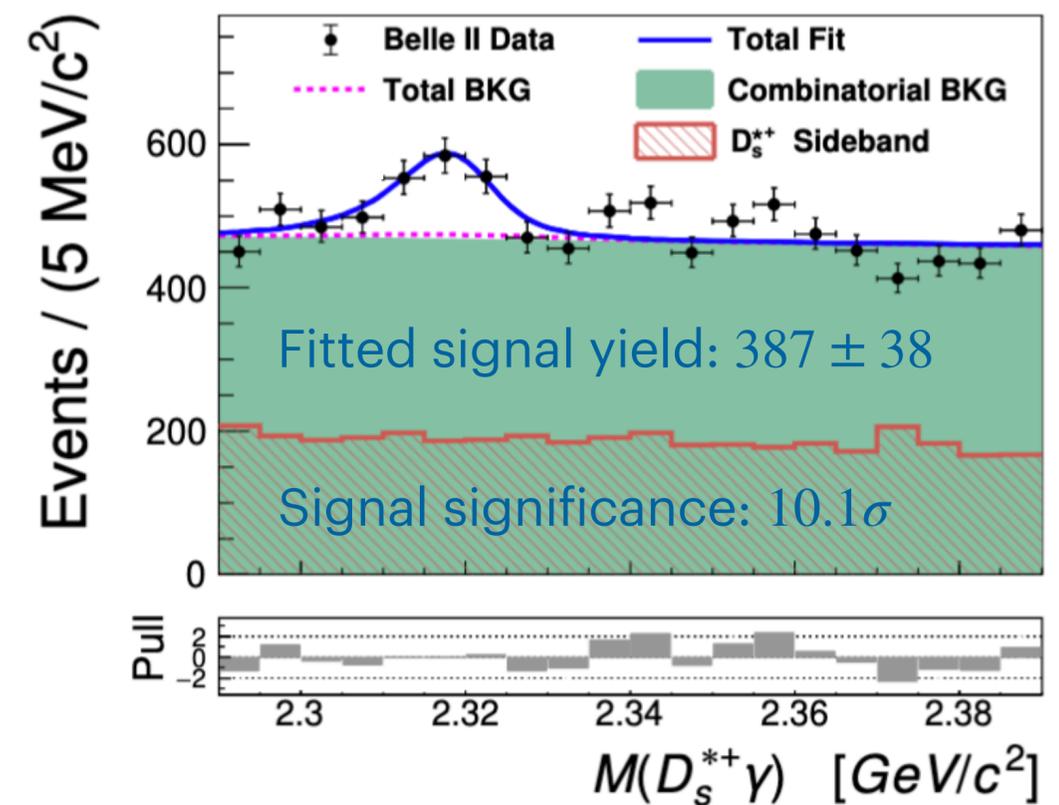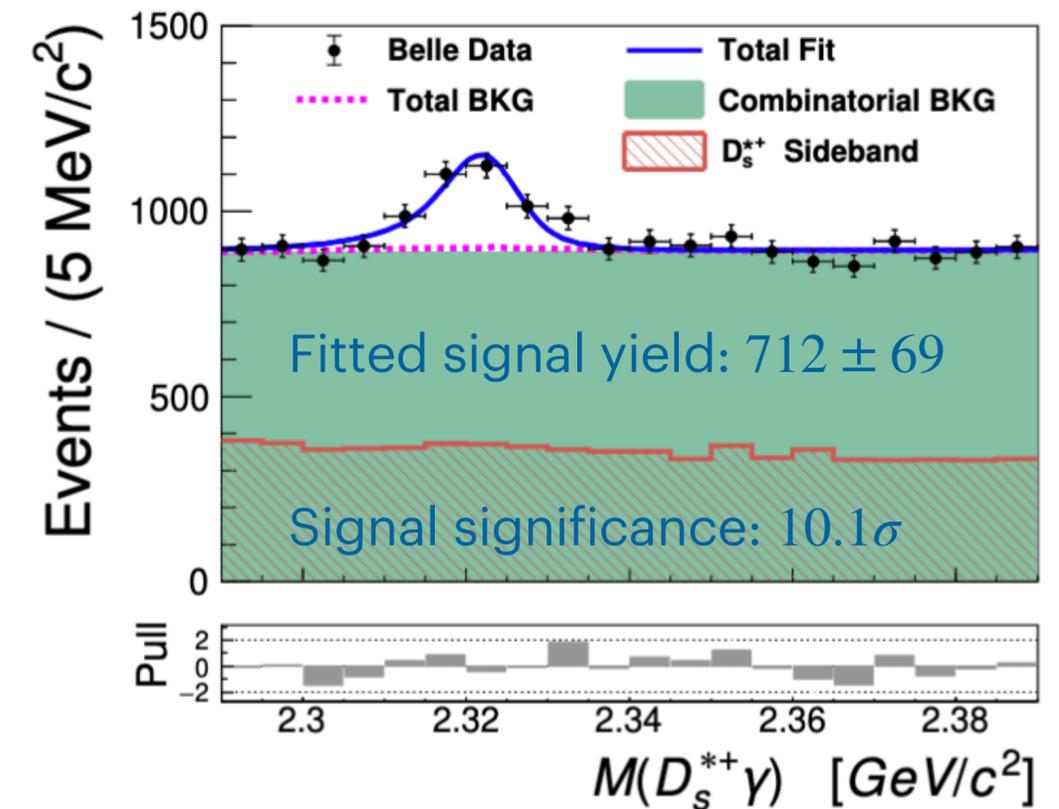
Fitted signal yield: 712 ± 69

Signal significance: 10.1σ

Fitted signal yield: 387 ± 38

Signal significance: 10.1σ

τ physics at Belle (II)

τ topologies and signatures

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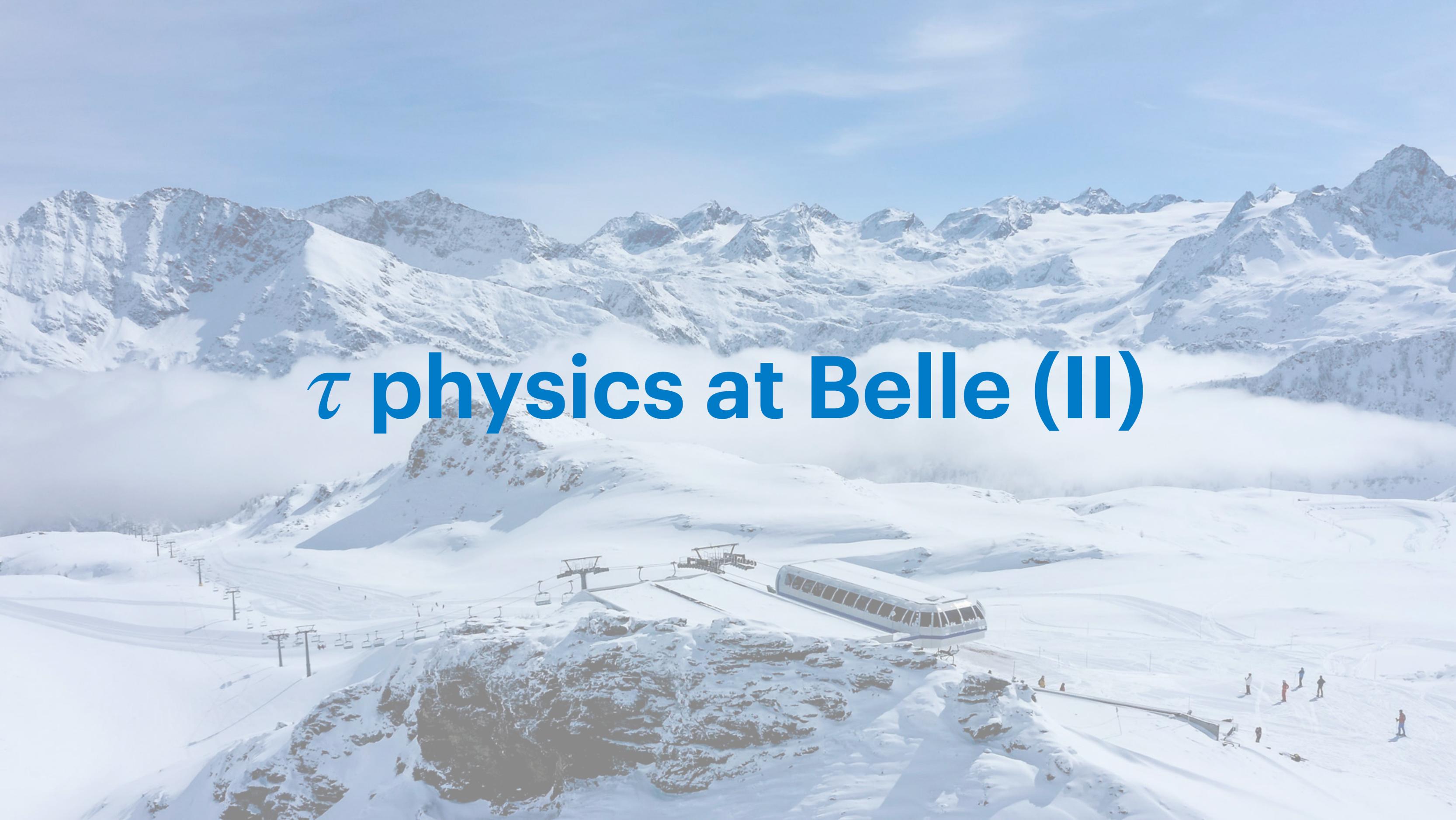
- Identify $e^+e^- \to \tau^+\tau^-$ events using the thrust direction of the event (thrust axis)

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

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

(**1**x**1**)-prong

Prong: charged particle track
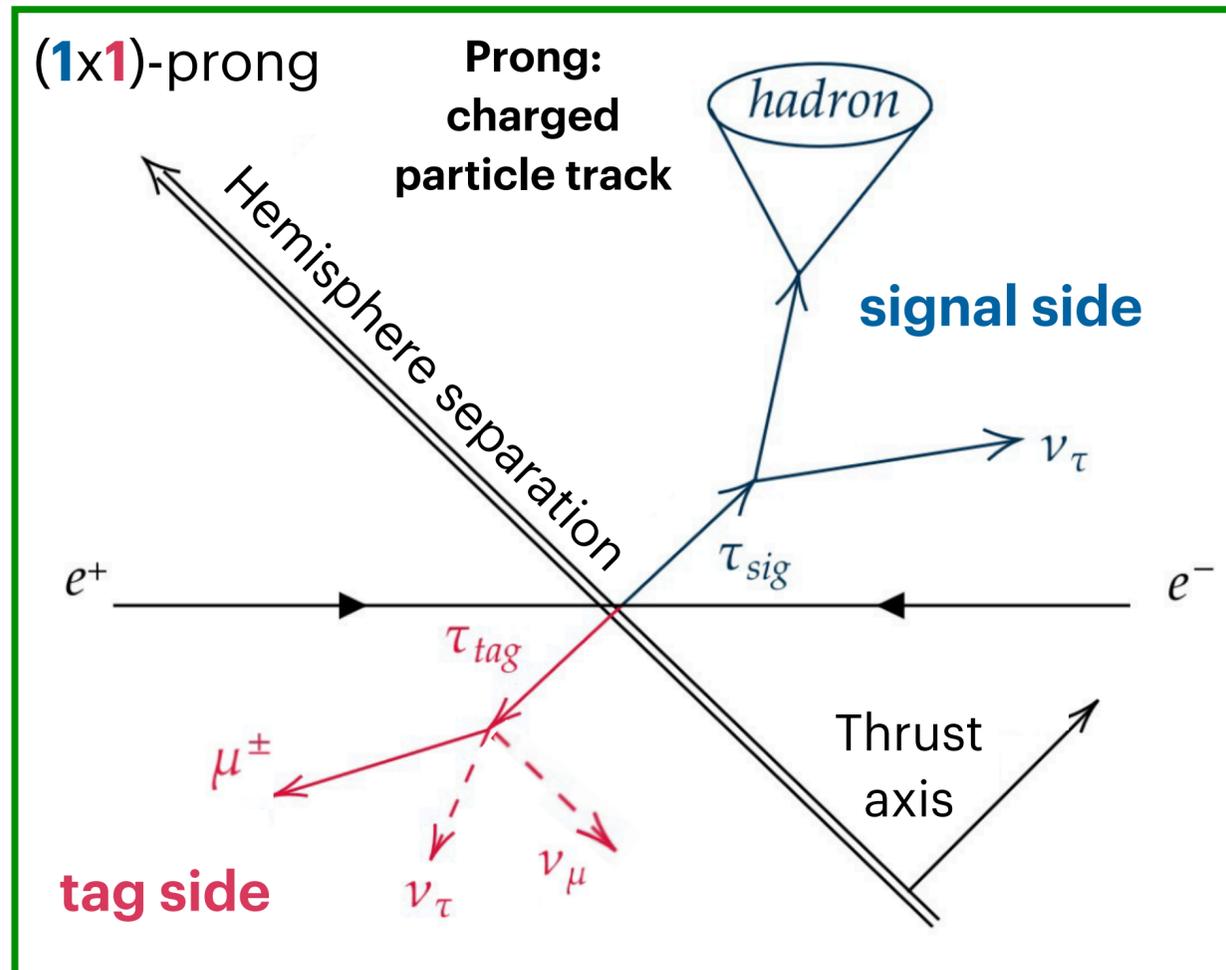
Large QED background
Small continuum background

(**1**x**3**)-prong
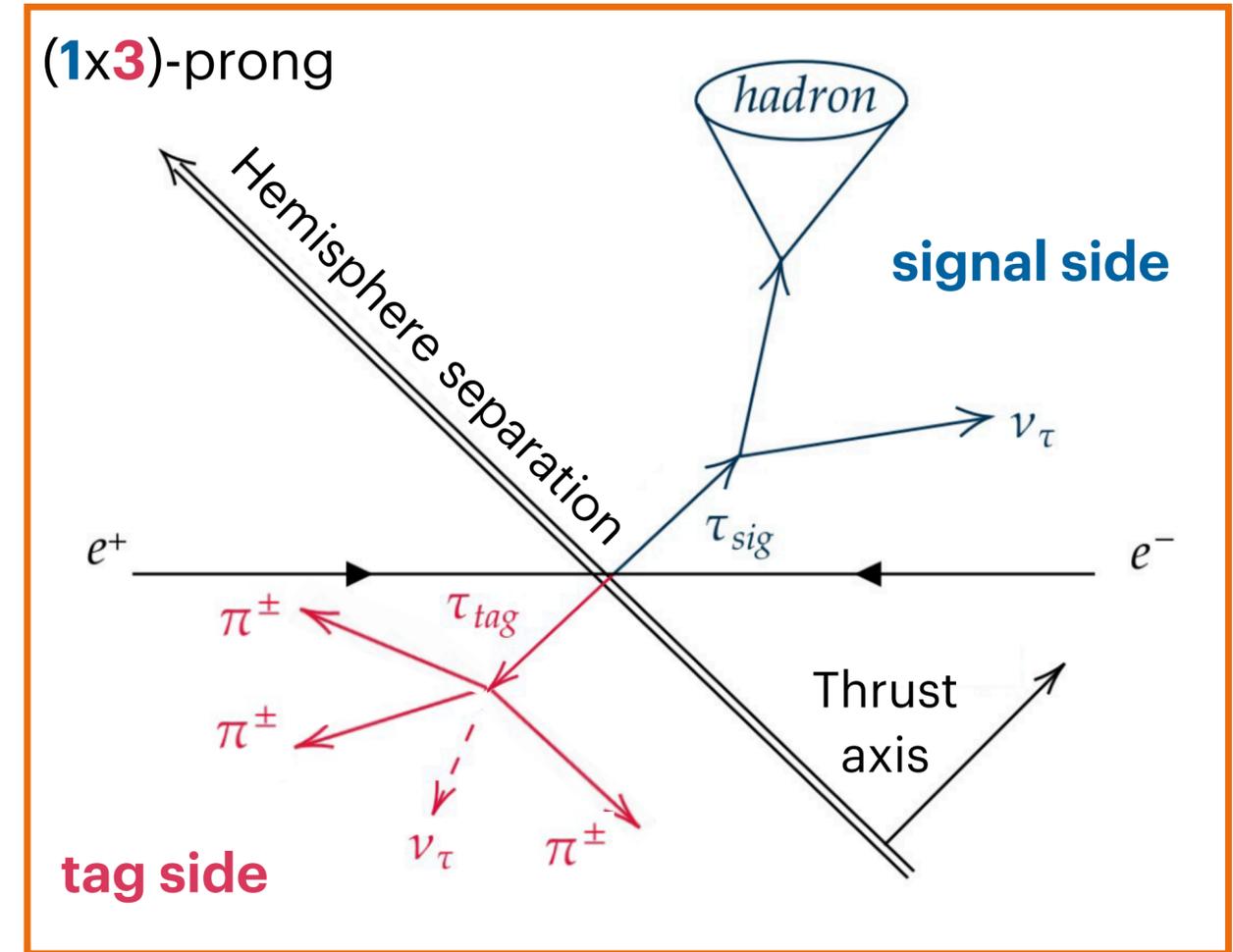
Small QED background
Large continuum background

Search for CPV in the $\tau^- \to \pi^- K_S^0 \nu_\tau$ decays at Belle II

Motivation

- CPV in τ decays is largely unexplored experimentally:

  1. Complementary to CPV in mesons → provides insight in the leptonic sector

  2. Sensitive probe for new CP-violating phases

- Search for the direct CPV in the $\tau^- \to \pi^- K_S^0 \nu_\tau$ decays

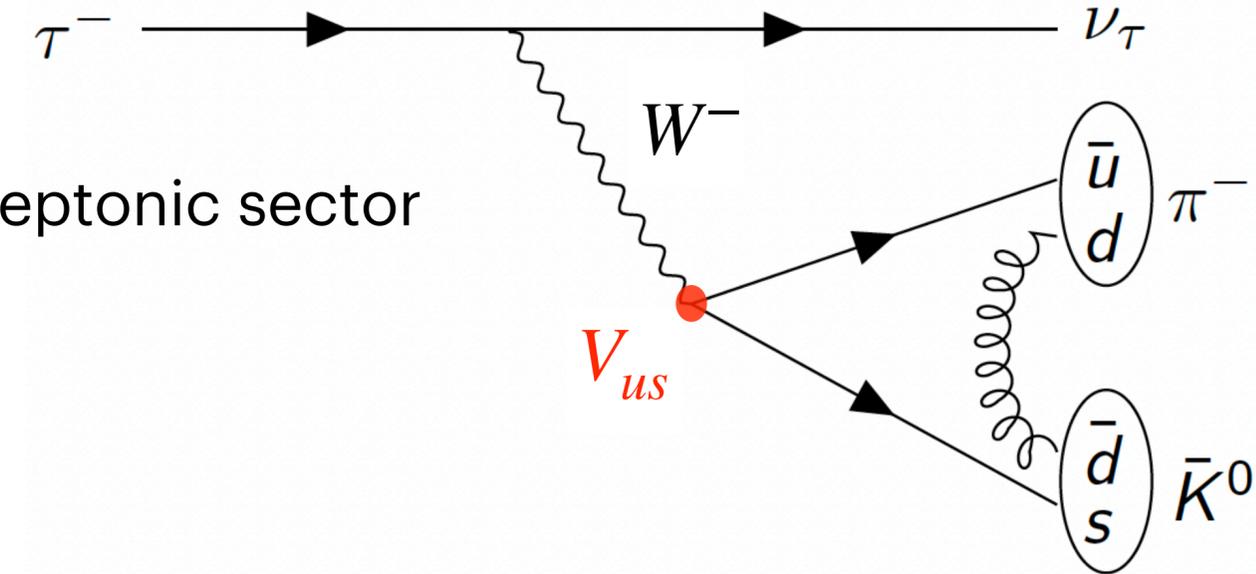$$A_{CP}^{SM} = \frac{\Gamma(\tau^+ \to \pi^+ K_S^0 \bar{\nu}_\tau) - \Gamma(\tau^- \to \pi^- K_S^0 \nu_\tau)}{\Gamma(\tau^+ \to \pi^+ K_S^0 \bar{\nu}_\tau) + \Gamma(\tau^- \to \pi^- K_S^0 \nu_\tau)} \simeq (0.33 \pm 0.01)\,\%$$

any deviation from the SM value would be evidence of new physics

- Two existing measurements:

PRL 107, 131801 (2011)

A_{CP} using angular analysis
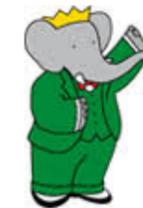
No significant A_{CP} has been observed

$699\,\text{fb}^{-1}$ UL CPV parameter @90% CL: $|\text{Im}(\eta_S)| < 0.026$

PRD 85, 031102(R) (2012)

A_{CP} using charge asymmetry

$A_{CP} = (-0.36 \pm 0.23(\text{stat}) \pm 0.11(\text{syst}))\,\%$

$476\,\text{fb}^{-1}$ 2.8σ deviation from SM expectation

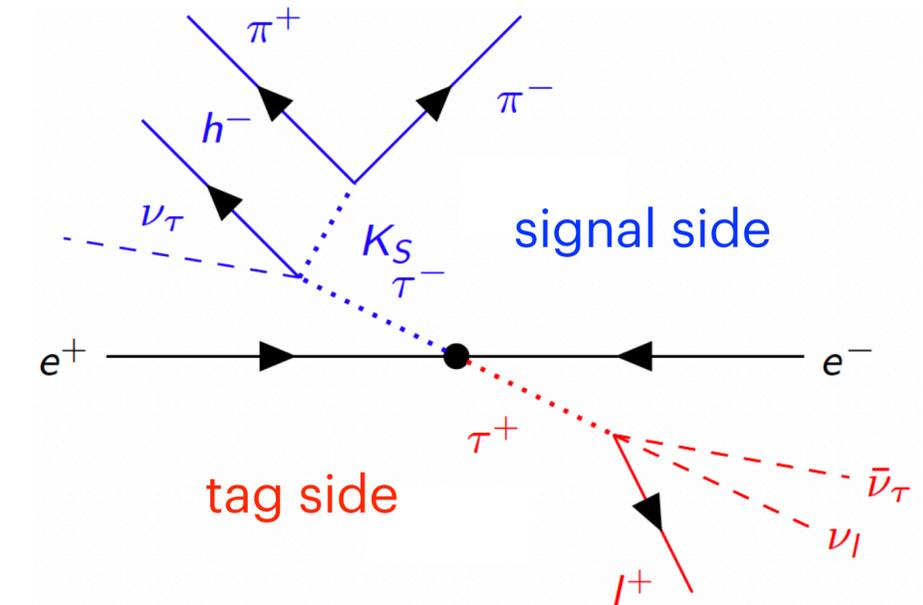Belle II provides excellent sensitivity to this decay

DESY.

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Search for CPV in the $\tau^- \to \pi^- K_S^0 \nu_\tau$ decays at Belle II

Analysis strategy

- (3x1)-prong topology: $\tau_{sig}^- \to \pi^- K_S[\to \pi^+\pi^-]\nu_\tau(\geq 0\pi^0)$ and $\tau_{tag}^+ \to \ell^+\nu_\ell\nu_\tau$

- Obtained ~98% of signal purity using a two Boosted Decision Tree (BDT) to suppress continuum and τ backgrounds

- Raw asymmetry in data (A_{raw}^{data}) should be corrected for different factors

signal side

tag side

$$A_{raw}^{data} = \underset{\mathcal{O}((-0.3/-1.3)\,\%)}{A_{det/trig/FB}} + \underset{\mathcal{O}(0.1\%)}{A_{abs/int}} + A_{CP}$$

what we measure

detection, trigger and forward-backward asymmetries. Extracted using the $\tau \to 3\pi\nu$ control channel

absorption due to different $K^0/\bar{K}^0$ cross sections in the detector material + interference between absorption and CP mixing. Evaluated from th. predictions

goal of the measurement

Employ a more sophisticated strategy than the earlier BaBar measurement
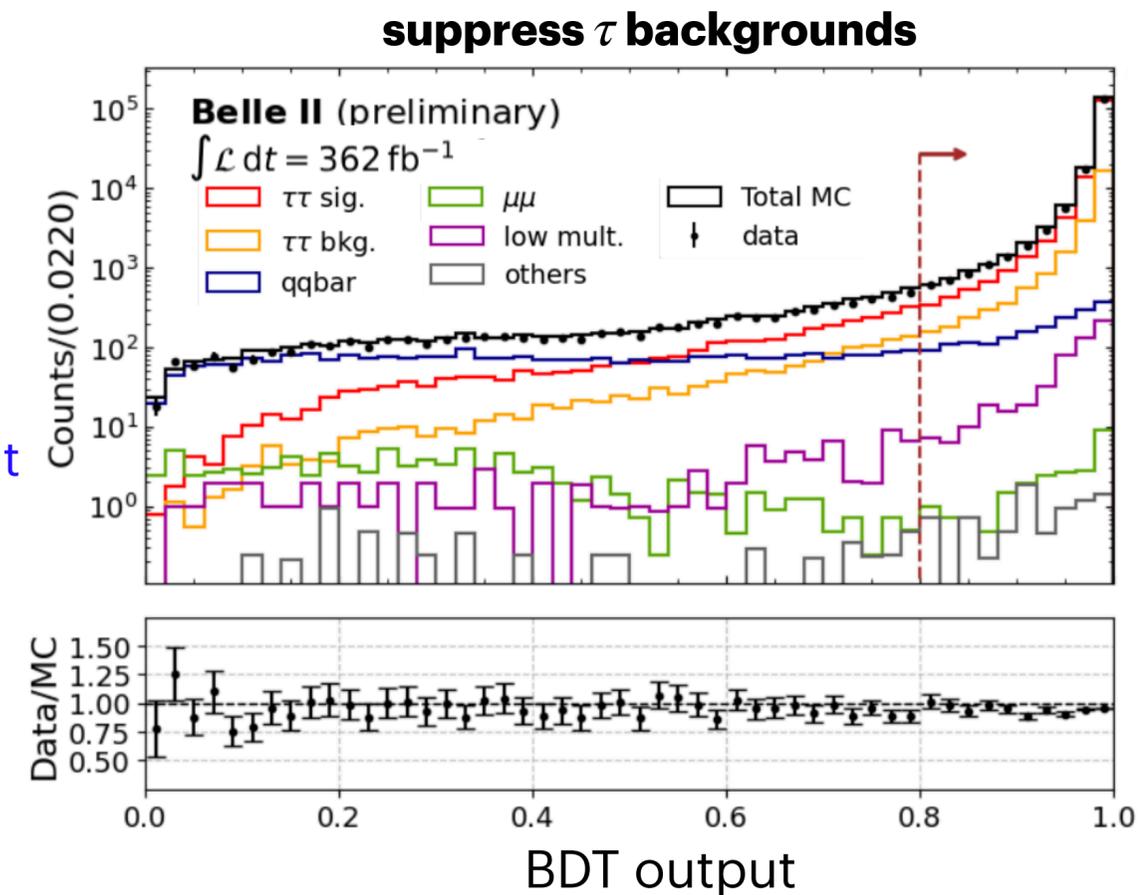
suppress τ backgrounds

BDT output

Search for CPV in the $\tau^- \to \pi^- K_s^0 \nu_\tau$ decays at Belle II

Results

A_{CP} depends on the K_s^0 decay-time efficiency: a non-uniform proper-time acceptance modifies the relative contributions of the $K^0/\bar{K}^0$ components. A_{SM} prediction is affected as well $\to$ correction required.

Belle II results corrected for the K_s^0 decay-time efficiency $\to$ direct comparison with the SM

An additional uncertainty (*unf*) is assigned to this correction
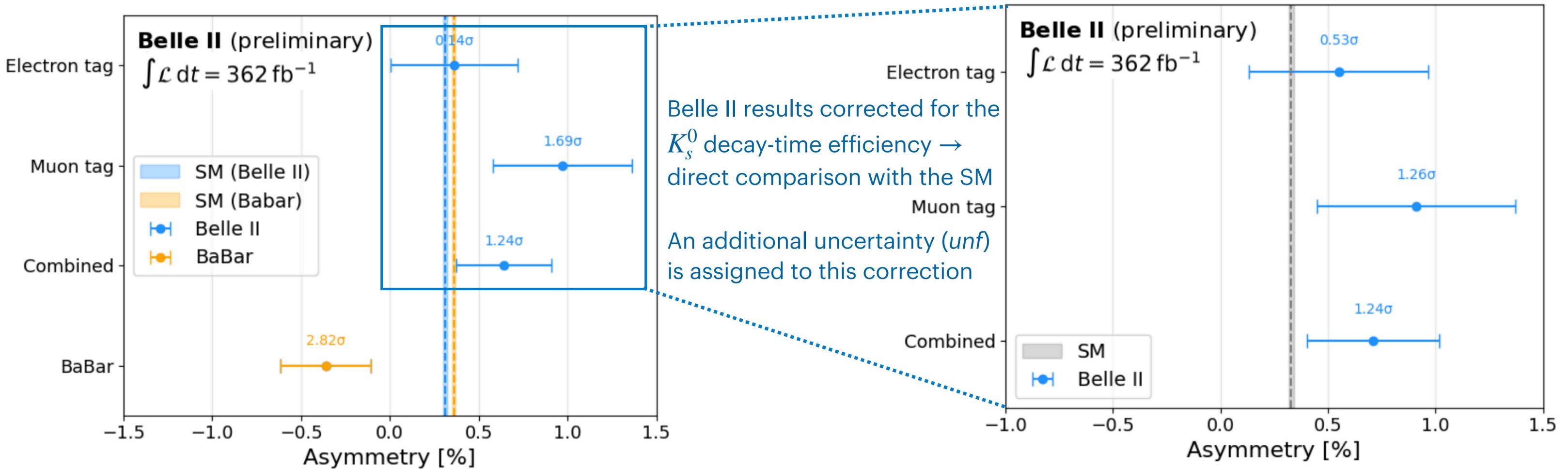
$$A_{CP}^{Belle\,II} = (0.71 \pm 0.26_{stat} \pm 0.06_{syst} \pm 0.15_{unf})\,\%$$

Measurement statistically limited, consistent with SM expectation within 1.24σ

Search for LFV $\tau \to \ell\eta$ decays at Belle II

Motivation

- Lepton flavor violation (LFV) is not allowed in the Standard Model (SM)

- LFV through neutrino mixing < $\mathcal{O}(10^{-50})$

- Non SM-contributions (H^+, leptoquarks, SUSY...) can generally allow LFV

- 52 LFV τ decays have been searched for so far: no significant evidence of a signal observed

- $\tau \to \ell\eta$ benchmark LFV channel with several beyond SM models predicting BR at the $\mathcal{O}(10^{-8})$

  Previous best limits from Belle:

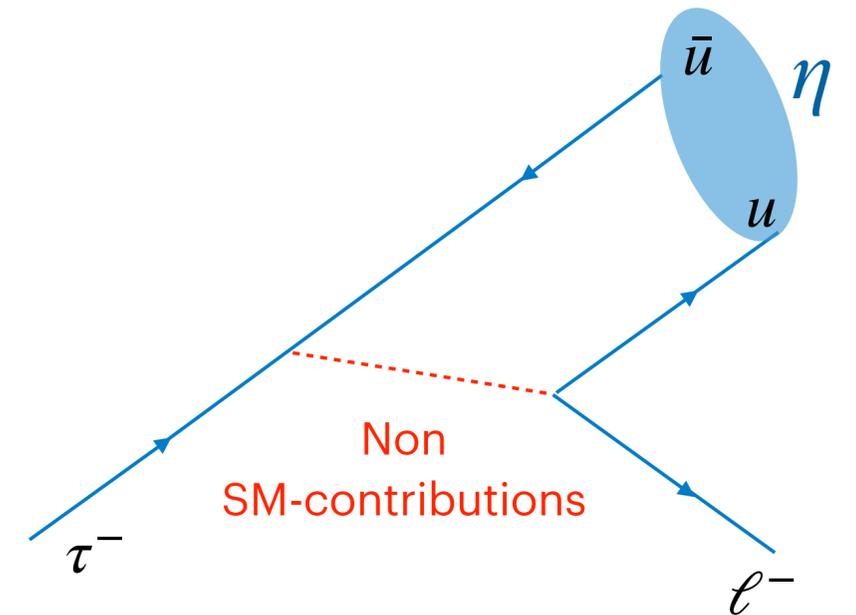[PLB 648, 341 (2007)](#)

$$\mathcal{B}(\tau^- \to e^-\eta) < 9.2 \cdot 10^{-8} \text{ @90\% CL}$$

$$\mathcal{B}(\tau^- \to \mu^-\eta) < 6.5 \cdot 10^{-8} \text{ @90\% CL}$$

401fb^{-1}

Belle II has the potential to significantly improve the current upper limits

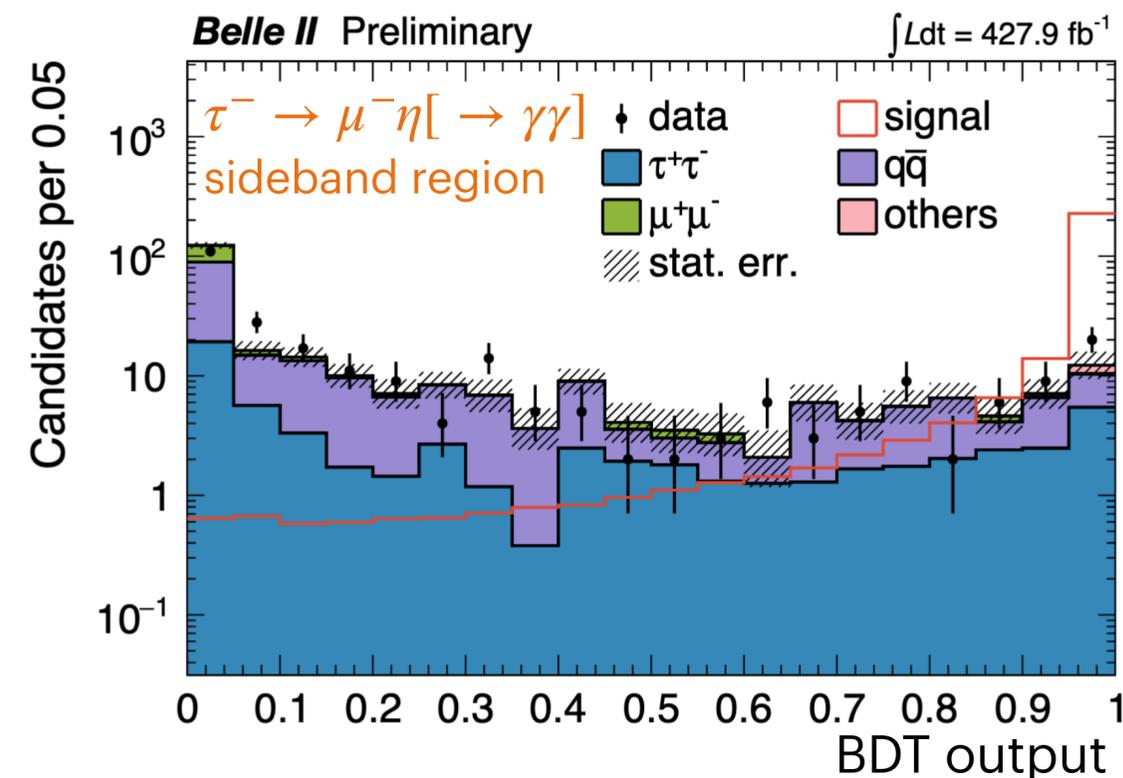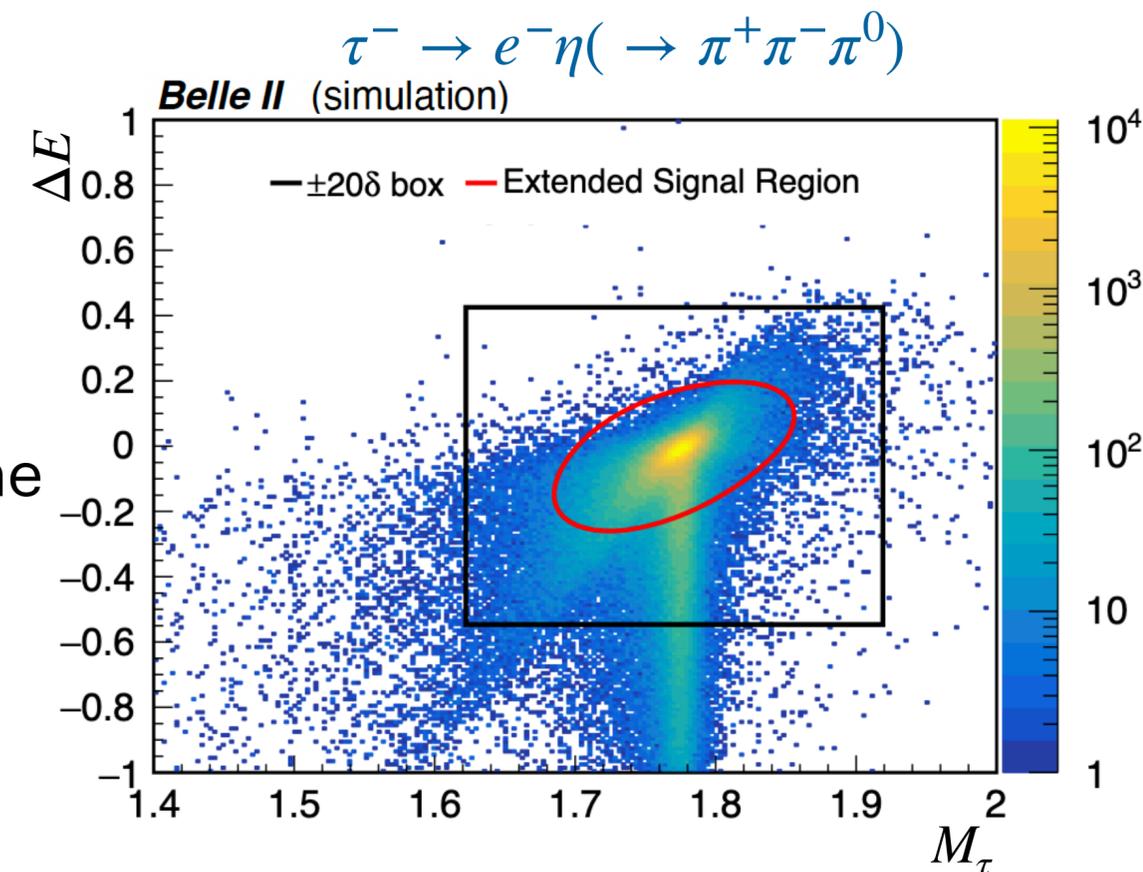# Search for LFV $\tau \to \ell\eta$ decays at Belle II

Analysis strategy

- 1x1 (3x1)-prong topology with 4 orthogonal searches:

  (e, μ) x $\eta \to \gamma\gamma$ and $\eta \to \pi^+\pi^-\pi^0$ + 1 track from tag side

- Define signal and sideband regions using $(M_\tau, \Delta E = E_\tau^{CM} - \sqrt{s}/2)$ plane

  Expected signal peak at $M_\tau \sim 1.777$ GeV and $\Delta E \sim 0$ GeV

- Background estimation using sideband data

$\eta \to \gamma\gamma$

> Background dominated by BhaBha events
> Suppression through a Boosted Decision Tree (BDT)
> Background estimation by counting based method

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

> Lower background respect to the $\eta \to \gamma\gamma$
> Suppression through a dedicated cut-based selection
> Background estimation by 2D unbinned fit in $(M_\tau, \Delta E)$

$\tau^- \to e^-\eta(\to \pi^+\pi^-\pi^0)$

Belle II (simulation)
— $\pm 20\delta$ box — Extended Signal Region

$\tau^- \to \mu^-\eta[\to \gamma\gamma]$
sideband region

Belle II Preliminary $\int Ldt = 427.9$ fb^{-1}

data, signal, $\tau^+\tau^-$, $q\bar{q}$, $\mu^+\mu^-$, others, stat. err.

Search for LFV $\tau \to \ell\eta$ decays at Belle II

Results

From the observed events and expected background, we extract

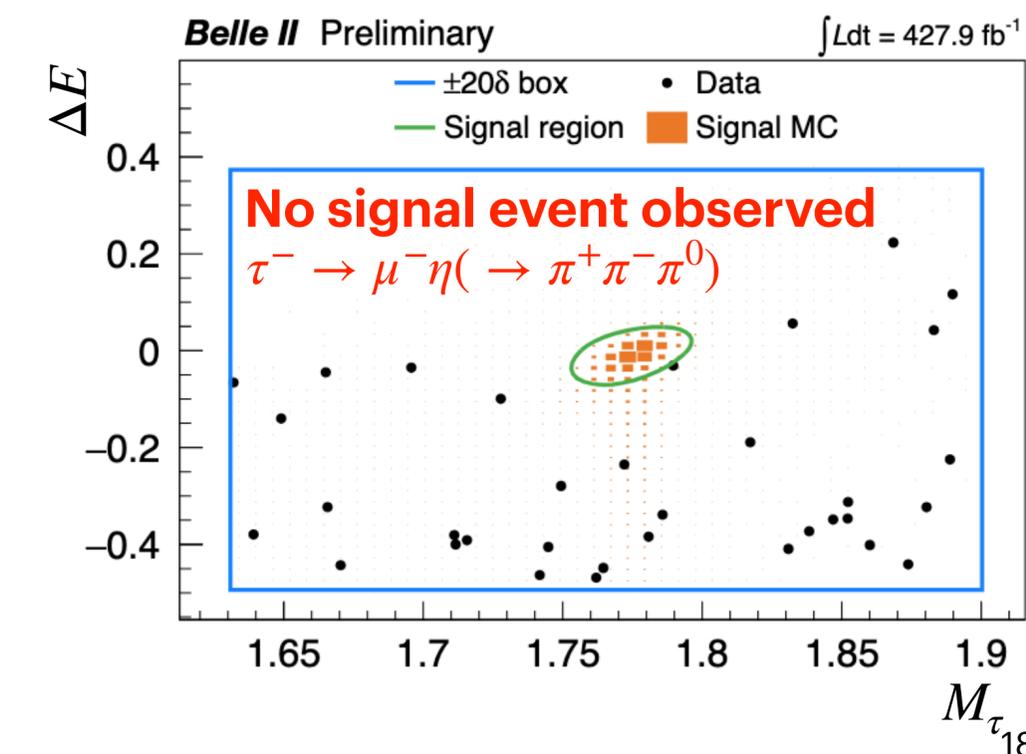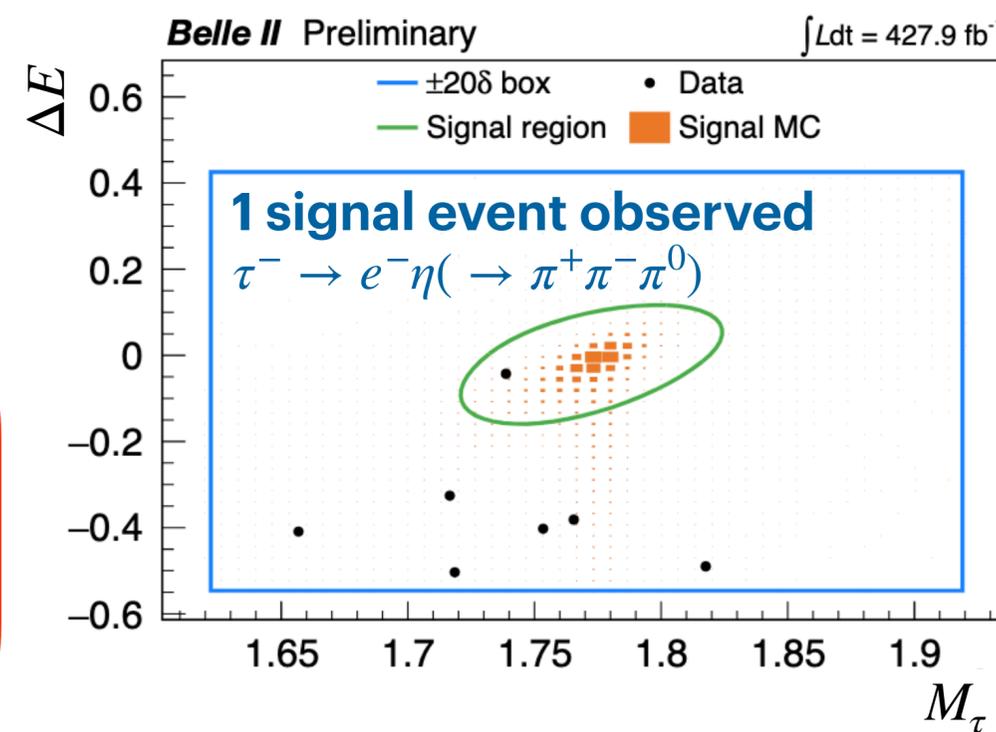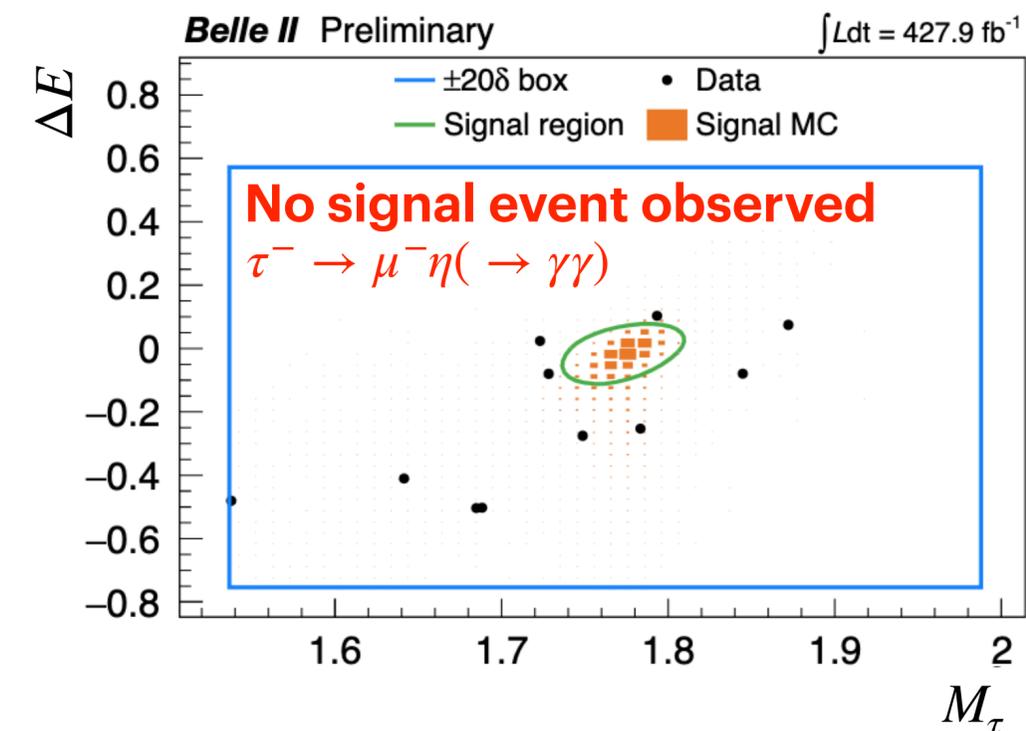$$\mathcal{B}(\tau^- \to e^-\eta) = (3.54^{+5.55}_{-2.68}) \cdot 10^{-8}$$
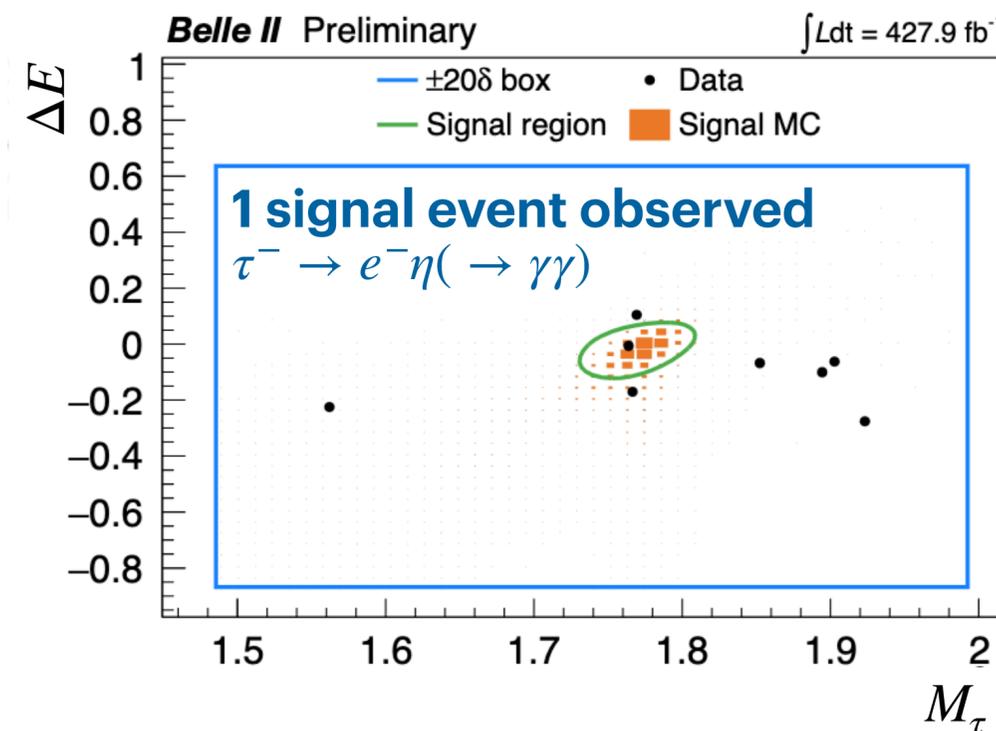
$$\mathcal{B}(\tau^- \to \mu^-\eta) = (-1.23^{+3.88}_{-0.56}) \cdot 10^{-8}$$

No significant signal observed

Upper limits are set on BRs

$\mathcal{B}(\tau^- \to e^-\eta) < 9.21 \cdot 10^{-8}$ @90% CL

compatible with previous Belle result

$\mathcal{B}(\tau^- \to \mu^-\eta) < 4.23 \cdot 10^{-8}$ @90% CL

Most stringent constraint to date

Conclusion

Belle & Belle II: an excellent environment for precision studies of τ and charm physics

Unique determination of baryon decay branching fractions

High-precision studies of CP violation and mixing in charm decays

Competitive sensitivity in τ CP-violation searches

World-leading limits in searches for lepton-flavour violation

Backup

Search for CPV in the $\tau^- \to \pi^- K_s^0 \nu_\tau$ decays at Belle II

Corrections

Type	% MC
$\tau^- \to \pi^- K_S^0 \nu_\tau (\geq 0\pi^0)$	77.8 ± 0.2
$\tau^- \to K^- K_S^0 \nu_\tau (\geq 0\pi^0)$	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

Background subtracted using fractions on Monte Carlo and validated using low BDT regions

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

Detection asymmetry correction extracted from data control samples

Neutral kaon asymmetry from absorption and interference corrected from theoretical predictions

Remaining τ contribution removed through a dilution factor using SM assumptions

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

DESY.

Search for CPV in the $\tau^- \to \pi^- K_S^0 \nu_\tau$ decays at Belle II

$A_{det/trig/FB}$ **estimation**

- Correction extracted from data using $\tau \to h^+ h^- h^+ \nu_\tau$ control channels

- Same reconstruction, selection and triggers as for the signal channel

$$A_{MC/data}^{raw}(control) = \frac{(\tau^+ \to \pi^+ \pi^- \pi^+ \nu) - (\tau^- \to \pi^- \pi^+ \pi^- \nu)}{(\tau^+ \to \pi^+ \pi^- \pi^+ \nu) + (\tau^- \to \pi^- \pi^+ \pi^- \nu)}$$

$$A_{MC/data}^{raw}(control) = A^{det}(\pi^+/\pi^-) + A^{trigger} + A^{det}(tag) + A_{FB}$$

$$+ \cancel{A^{det}(\pi^-/\pi^+)} + \cancel{A^{det}(\pi^+/\pi^-)}$$

It can be neglected, assuming the same kinematics

- Correction weights for each channel are obtained from the ratio of

  the kinematic distributions (p, θ) between the signal and the

  corresponding control channel

$$w(p, \theta) = \sum_i w_i(p, \theta) \cdot f_i$$

signal side

tag side
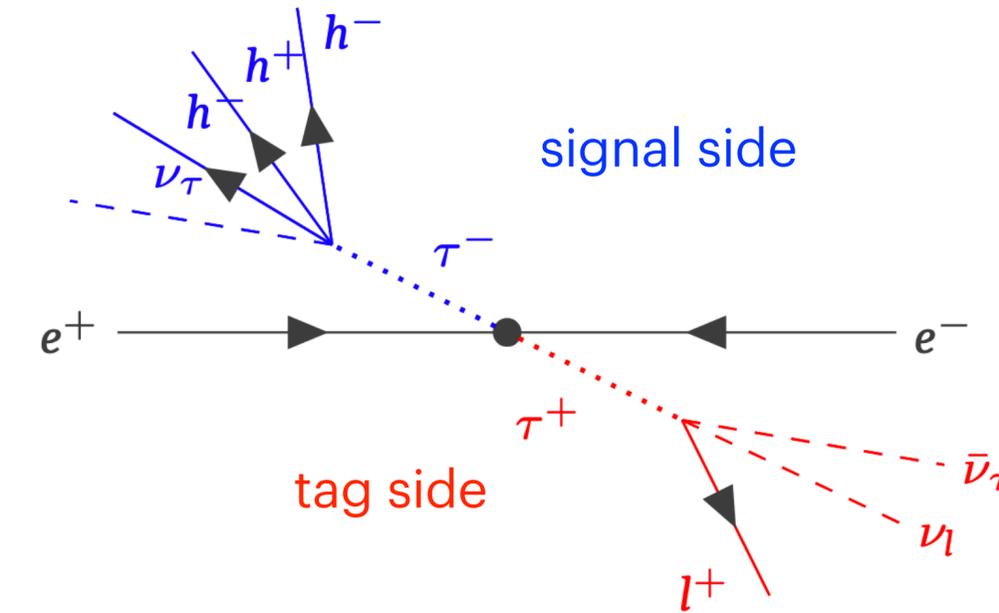
Signal Type	Control type
$\tau^\pm \to \pi^\pm K_S^0 \nu_\tau$ $\tau^\pm \to \pi^\pm K_S^0 \nu_\tau \pi^0$ $\tau^\pm \to \pi^\pm K_S^0 \nu_\tau \pi^0 \pi^0$	$\tau^\pm \to 3\pi\nu$ $\tau^\pm \to 3\pi\nu\pi^0$ $\tau^\pm \to 3\pi\nu\pi^0\pi^0$
$\tau^\pm \to K^\pm K_S^0 \nu_\tau$ $\tau^\pm \to K^\pm K_S^0 \nu_\tau \pi^0$	$\tau^\pm \to K^\pm \pi\pi\nu$ $\tau^\pm \to K^\pm \pi\pi\nu\pi^0$
$\tau^\pm \to \pi^\pm K_S^0 K_L^0 \nu_\tau$ $\tau^\pm \to \pi^\pm K^0 K_L^0 \nu_\tau \pi^0$ $\tau^\pm \to \pi^\pm K_S^0 K_S^0 \nu_\tau$ $\tau^\pm \to \pi^\pm K^0 K_S^0 \nu_\tau \pi^0$	$\tau^\pm \to 3\pi\nu$ $\tau^\pm \to 3\pi\nu\pi^0$ $\tau^\pm \to 3\pi\nu$ $\tau^\pm \to 3\pi\nu\pi^0$

Search for CPV in the $\tau^- \to \pi^- K_s^0 \nu_\tau$ decays at Belle II
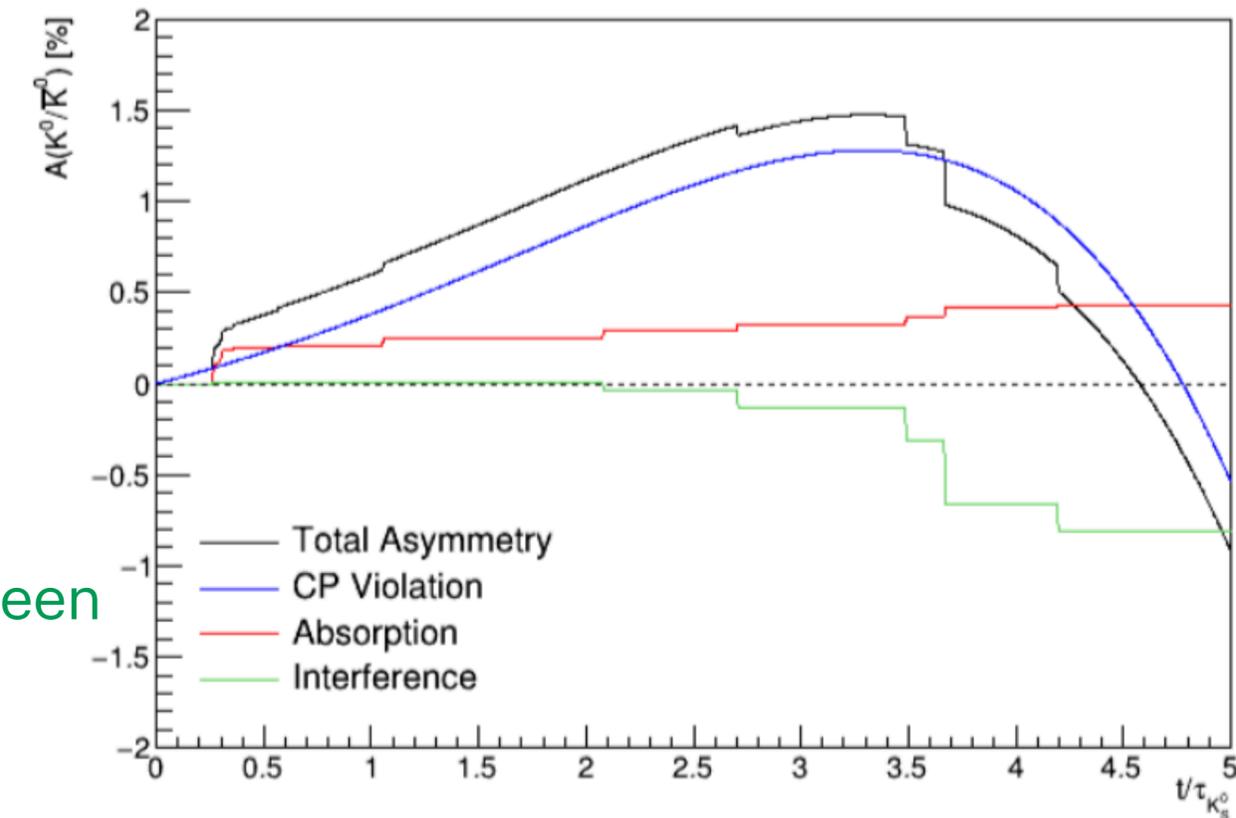
$A_{abs/int}$ **estimation**

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

$A^{absorption}(K^0/\bar{K}^0)$

Different $K^0/\bar{K}^0$ cross
sections with detector
material

$A^{interference}(K^0/\bar{K}^0)$

Interference effect between
the absorption
and the CP term

- Evaluated from theoretical predictions that depend on the detector geometry and the K^0 kinematic distributions. Detector properties are extracted using GEANT to scan the detector event by event

- Time-dependent values for the CP, absorption and interference asymmetries extracted event by event

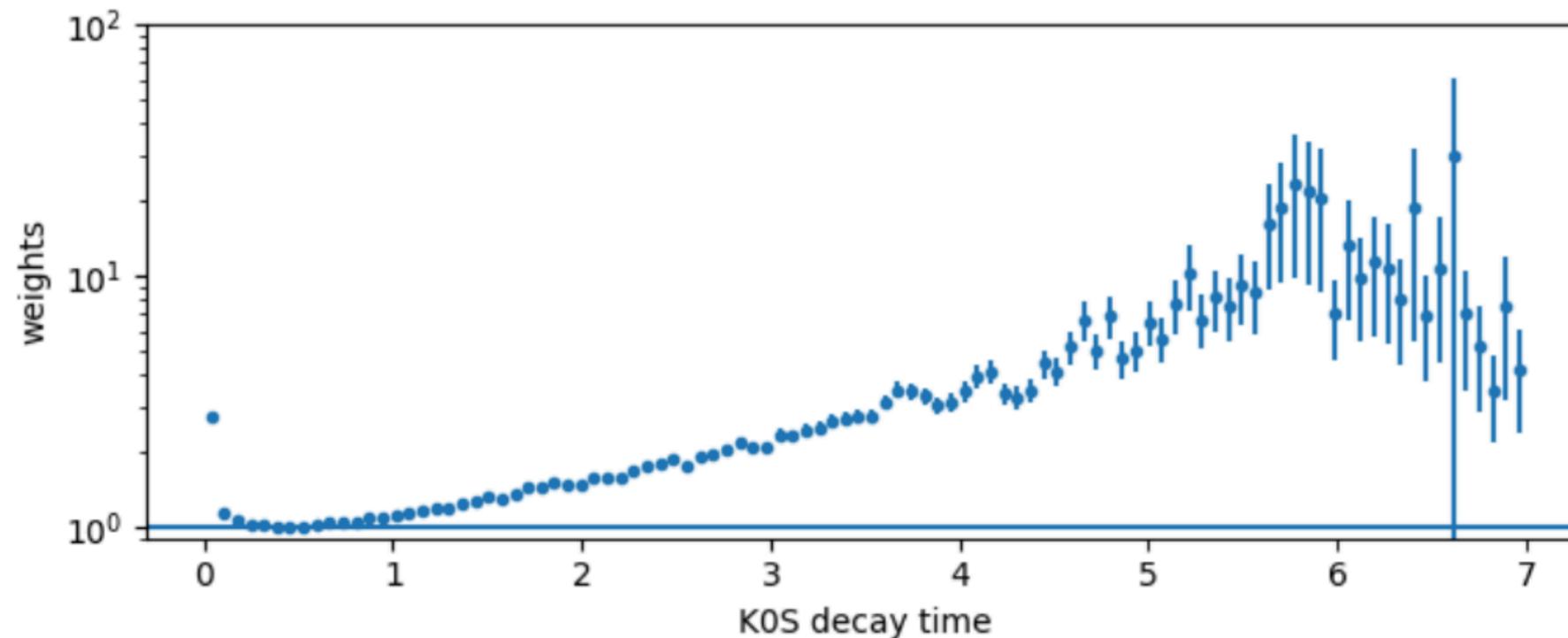- Time integrated correction obtained by averaging over the full sample

DESY.

Search for CPV in the $\tau^- \to \pi^- K^0_S \nu_\tau$ decays at Belle II

K^0_S decay-time efficiency correction

$$A_{CP} = \frac{\int_0^\infty \epsilon(t) \left[\Gamma(K^0_{t=0} \to \pi^+\pi^-)(t) - \Gamma(\bar{K}^0_{t=0} \to \pi^+\pi^-)(t)\right] dt}{\int_0^\infty \epsilon(t) \left[\Gamma(K^0_{t=0} \to \pi^+\pi^-)(t) + \Gamma(\bar{K}^0_{t=0} \to \pi^+\pi^-)(t)\right] dt}$$

Decay-time dependence of the K^0_S reconstruction efficiency is removed by applying a weight $w_i = \dfrac{1}{\epsilon_i(t)}$

Weights obtained from the ratio of the K^0_S proper decay-time distribution to an ideal exponential distribution

Additional results

First measurement of $A_{CP}(\Xi_c^+ \to \Sigma^+ h^+ h^-)$ and $A_{CP}(\Lambda_c^+ \to ph^+h^-)$ at Belle II

Motivation and analysis strategy

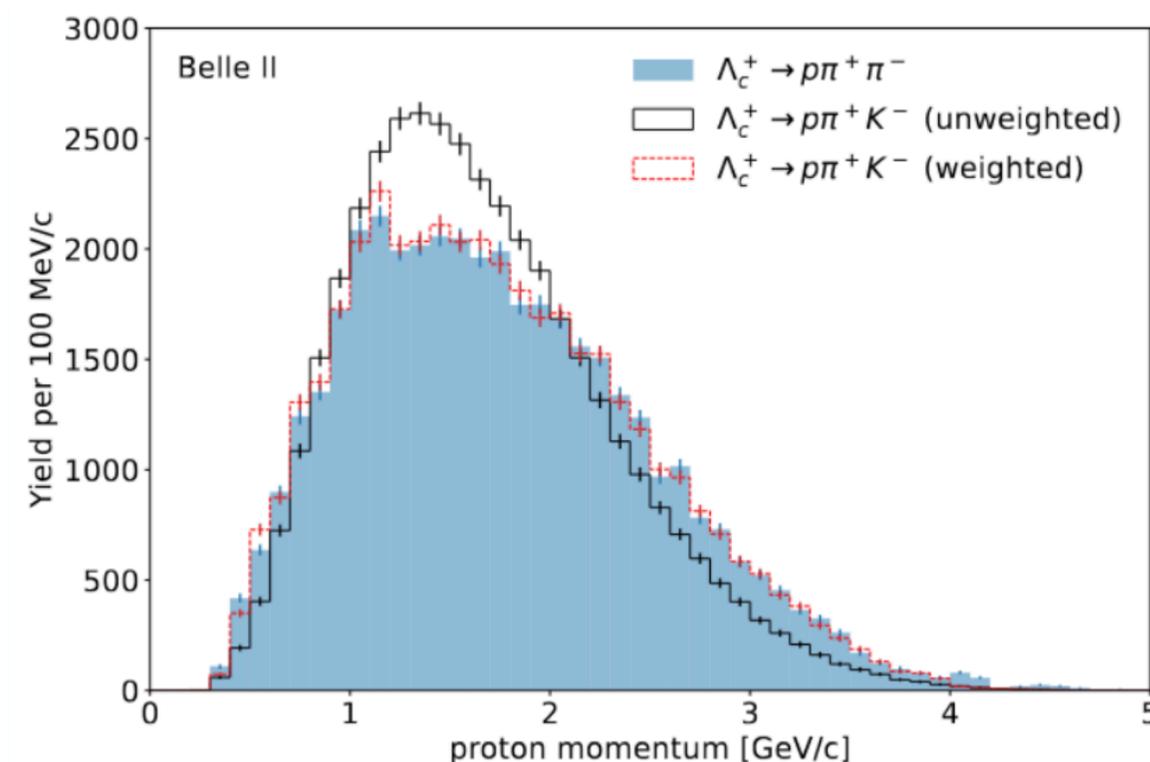- $\Xi_c^+ \to \Sigma^+ h^+ h^-$, $\Lambda_c^+ \to ph^+h^-$ $(h = \pi, K)$: first-ever measurements
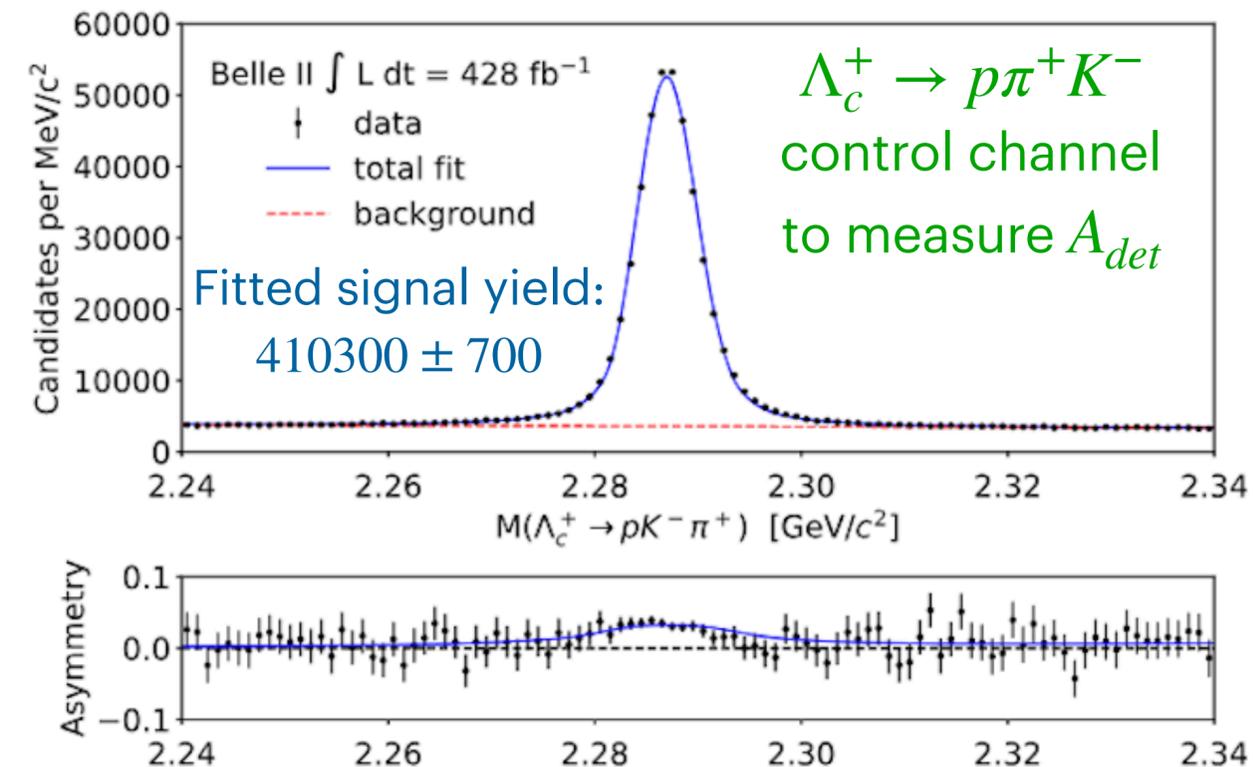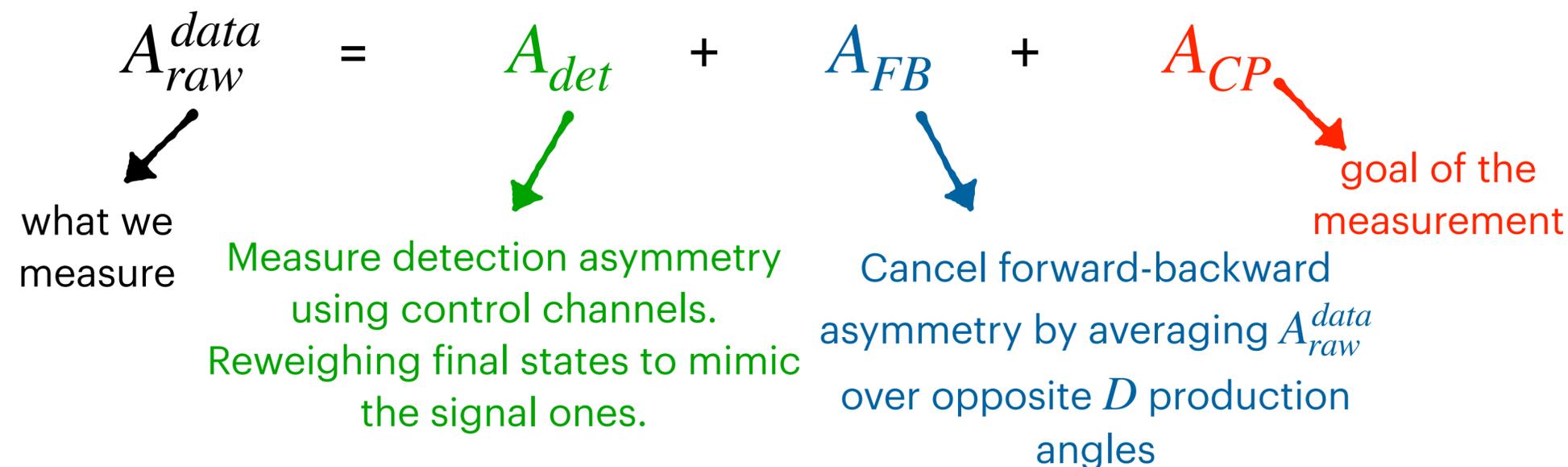
  A_{CP} in 3-body baryon decays. Test U-spin symmetry

SM expectations

$$A_{CP}(\Xi_c^+ \to \Sigma^+\pi^+\pi^-) + A_{CP}(\Lambda_c^+ \to pK^+K^-) = 0$$

$$A_{CP}(\Xi_c^+ \to \Sigma^+K^+K^-) + A_{CP}(\Lambda_c^+ \to p\pi^+\pi^-) = 0$$

$\Lambda_c^+ \to p\pi^+K^-$
control channel
to measure A_{det}

Fitted signal yield:
410300 ± 700

Get A_{CP} from

$$A_{raw}^{data} \quad = \quad A_{det} \quad + \quad A_{FB} \quad + \quad A_{CP}$$

what we measure

Measure detection asymmetry using control channels. Reweighing final states to mimic the signal ones.

Cancel forward-backward asymmetry by averaging A_{raw}^{data} over opposite D production angles

goal of the measurement

DESY.

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First measurement of $A_{CP}(\Xi_c^+ \to \Sigma^+ h^+ h^-)$ and $A_{CP}(\Lambda_c^+ \to p h^+ h^-)$ at Belle II

Results

Signal yield extracted via unbinned maximum-likelihood fits to

$M(\Xi_c^+)$ and $M(\Lambda_c^+)$; instrumental effects subtracted afterward

$$A_{CP}(\Xi_c^+ \to \Sigma^+ K^+ K^-) = (3.7 \pm 6.6 \pm 0.6)\,\%$$

$$A_{CP}(\Xi_c^+ \to \Sigma^+ \pi^+ \pi^-) = (9.5 \pm 6.8 \pm 0.5)\,\%$$

$$A_{CP}(\Lambda_c^+ \to p K^+ K^-) = (3.9 \pm 1.7 \pm 0.7)\,\%$$
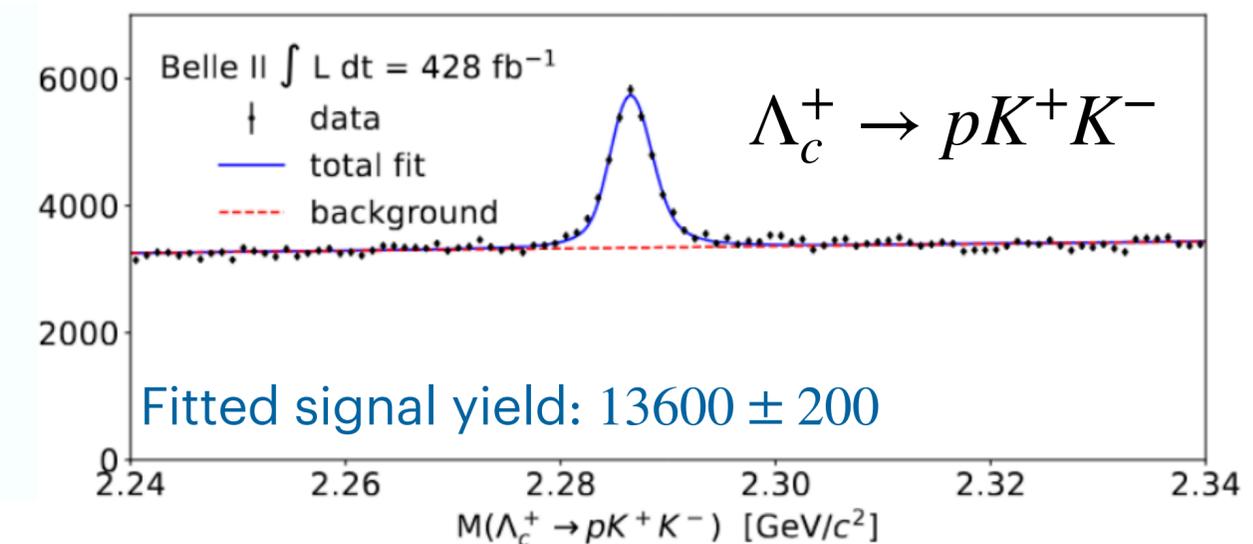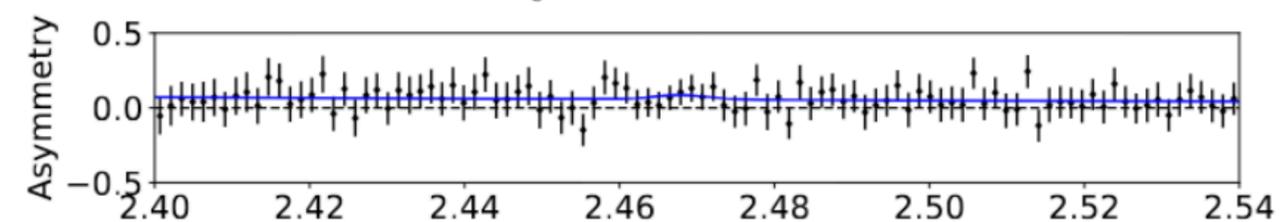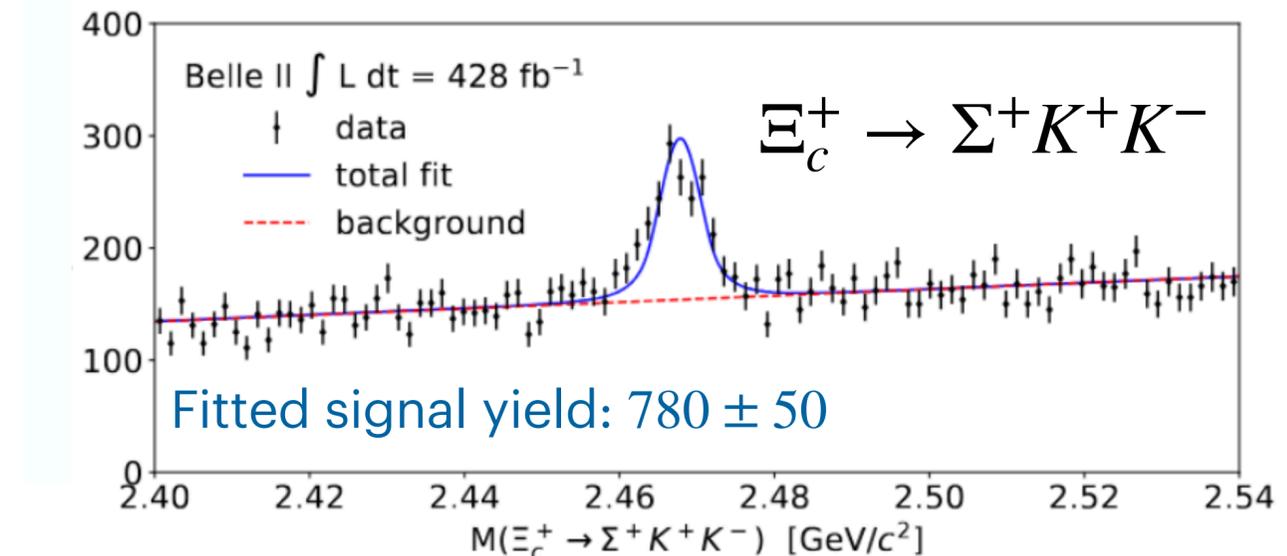
$$A_{CP}(\Lambda_c^+ \to p \pi^+ \pi^-) = (0.3 \pm 1.0 \pm 0.2)\,\%$$

from which we get

$$A_{CP}(\Xi_c^+ \to \Sigma^+ \pi^+ \pi^-) + A_{CP}(\Lambda_c^+ \to p K^+ K^-) = (13.4 \pm 7.0_{stat} \pm 0.9_{syst})\,\%$$

$$A_{CP}(\Xi_c^+ \to \Sigma^+ K^+ K^-) + A_{CP}(\Lambda_c^+ \to p \pi^+ \pi^-) = (4.0 \pm 6.6_{stat} \pm 0.7_{syst})\,\%$$

Statistically limited

Compatible with SM predictions

Belle II $\int L\,dt = 428\ \mathrm{fb}^{-1}$

$\Xi_c^+ \to \Sigma^+ K^+ K^-$

- data
- total fit
- background

Fitted signal yield: 780 ± 50

$M(\Xi_c^+ \to \Sigma^+ K^+ K^-)$ [GeV/c^2]

Belle II $\int L\,dt = 428\ \mathrm{fb}^{-1}$

$\Lambda_c^+ \to p K^+ K^-$

- data
- total fit
- background

Fitted signal yield: 13600 ± 200

$M(\Lambda_c^+ \to p K^+ K^-)$ [GeV/c^2]

DESY.
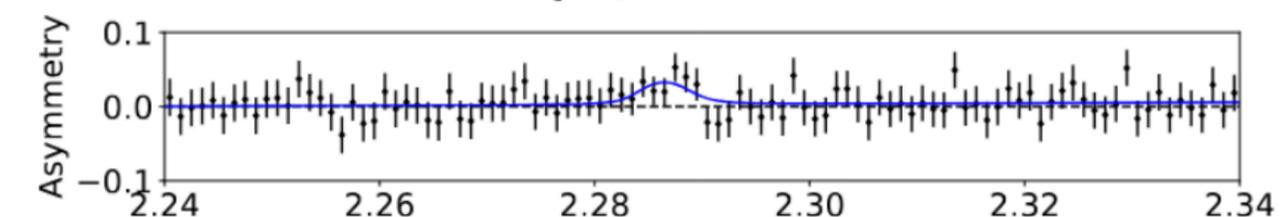
Measurements of $\mathscr{B}(\Xi_c^+ \to \Sigma^+ K_S, \Xi^0 \pi^+, \Xi^0 K^+)$ at Belle and Belle II

Motivation, analysis strategy and results

- Branching fractions measurements are indispensable of charmed baryons to solve theoretical tensions

- Measure the ratio $\mathscr{B}(\Xi_c^+ \to \Sigma^+ K_S, \Xi^0 \pi^+, \Xi^0 K^+)/\mathscr{B}(\Xi_c^+ \to \Xi^- \pi^+ \pi^+)$ using an extended maximum-likelihood fit to the invariant masses

- Multiplying the results by the $\mathscr{B}(\Xi_c^+ \to \Xi^- \pi^+ \pi^+)_{th} = (2.9 \pm 1.3)\,\%$ we obtain

$$\mathscr{B}(\Xi_c^+ \to \Sigma^+ K_S^0) = (0.194 \pm 0.021_{stat} \pm 0.009_{syst} \pm 0.087_{th})\,\%$$

$$\mathscr{B}(\Xi_c^+ \to \Xi^0 \pi^+) = (0.728 \pm 0.014_{stat} \pm 0.027_{syst} \pm 0.326_{th})\,\%$$

First measurements of these decays

$$\mathscr{B}(\Xi_c^+ \to \Xi^0 K^+) = (0.049 \pm 0.007_{stat} \pm 0.003_{syst} \pm 0.022_{th})\,\%$$

World's best measurement

Belle II $\int \mathcal{L}dt = 427.9\,\mathrm{fb}^{-1}$

Fitted signal yield: 288 ± 41

Signal significance: 6.2σ

Belle II $\int \mathcal{L}dt = 427.9\,\mathrm{fb}^{-1}$

Fitted signal yield: 2782 ± 74

Signal significance $> 10\sigma$
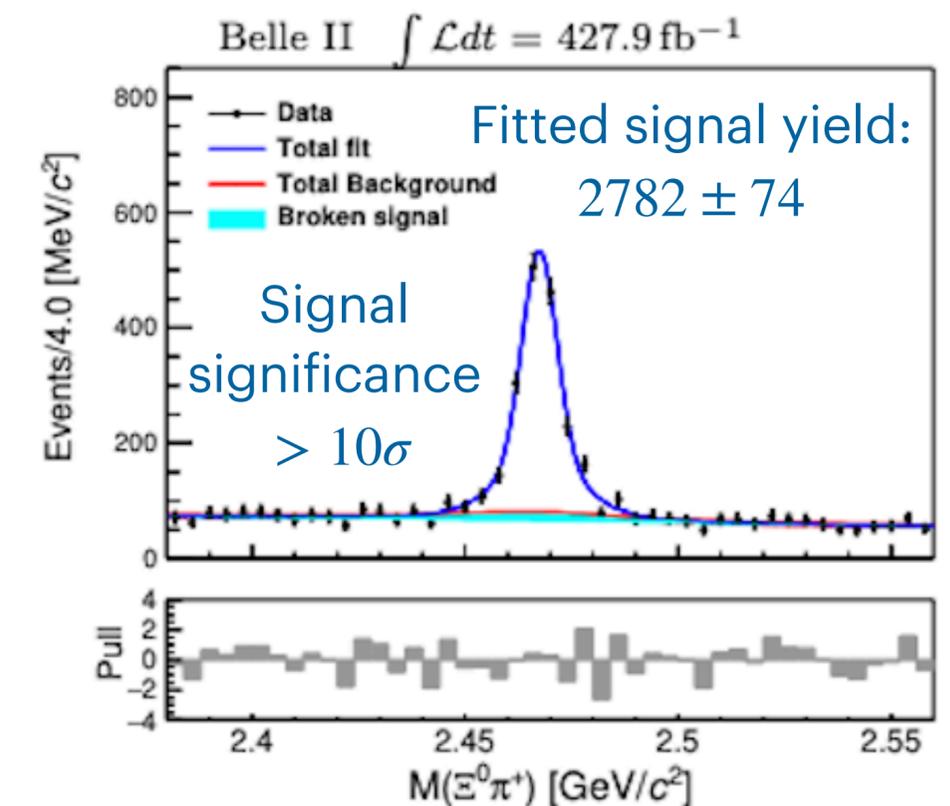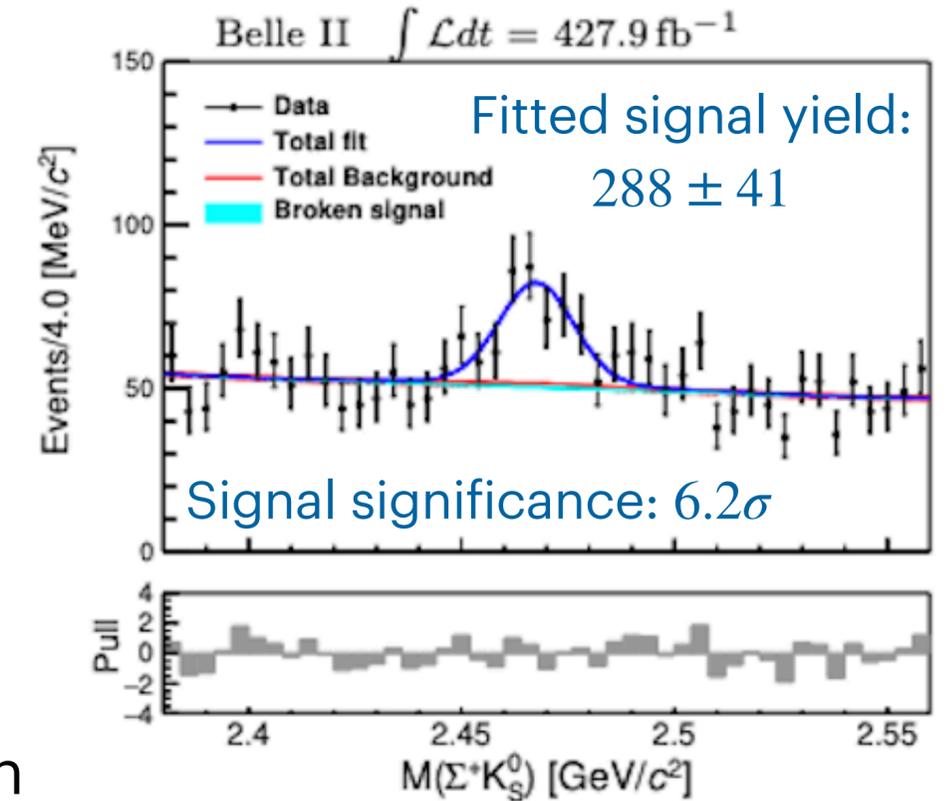
Search for LFV in the $\tau \to \mu\gamma$ decays at Belle II

Motivation and analysis strategy

- Suppressed within the SM: any observation of LFV is an indication of physics beyond SM

- World's best upper limit from Belle: $\mathscr{B}(\tau \to \mu\gamma) < 4.2 \times 10^{-8}$ [JHEP 10, 019 (2021)]

- 1x1 prong topology: signal side ($\mu\gamma$), tag side (e, π, ρ)

- Background suppression with Gradient Boost Decision Tree (GBDT):

  50% increase in the signal efficiency, 80% decrease in background

- Sidebands: derive expected background yields in the signal region

- Search using 2D plane in

$$M_{bc} = \sqrt{(E^*_{\text{beam}})^2 - (\vec{p}^*_{\mu\gamma})^2} \quad \text{and} \quad \Delta E' = \frac{\Delta E}{\sqrt{s}} = \frac{E^*_{\mu\gamma} - E^*_{\text{beam}}}{\sqrt{s}}$$

DESY.
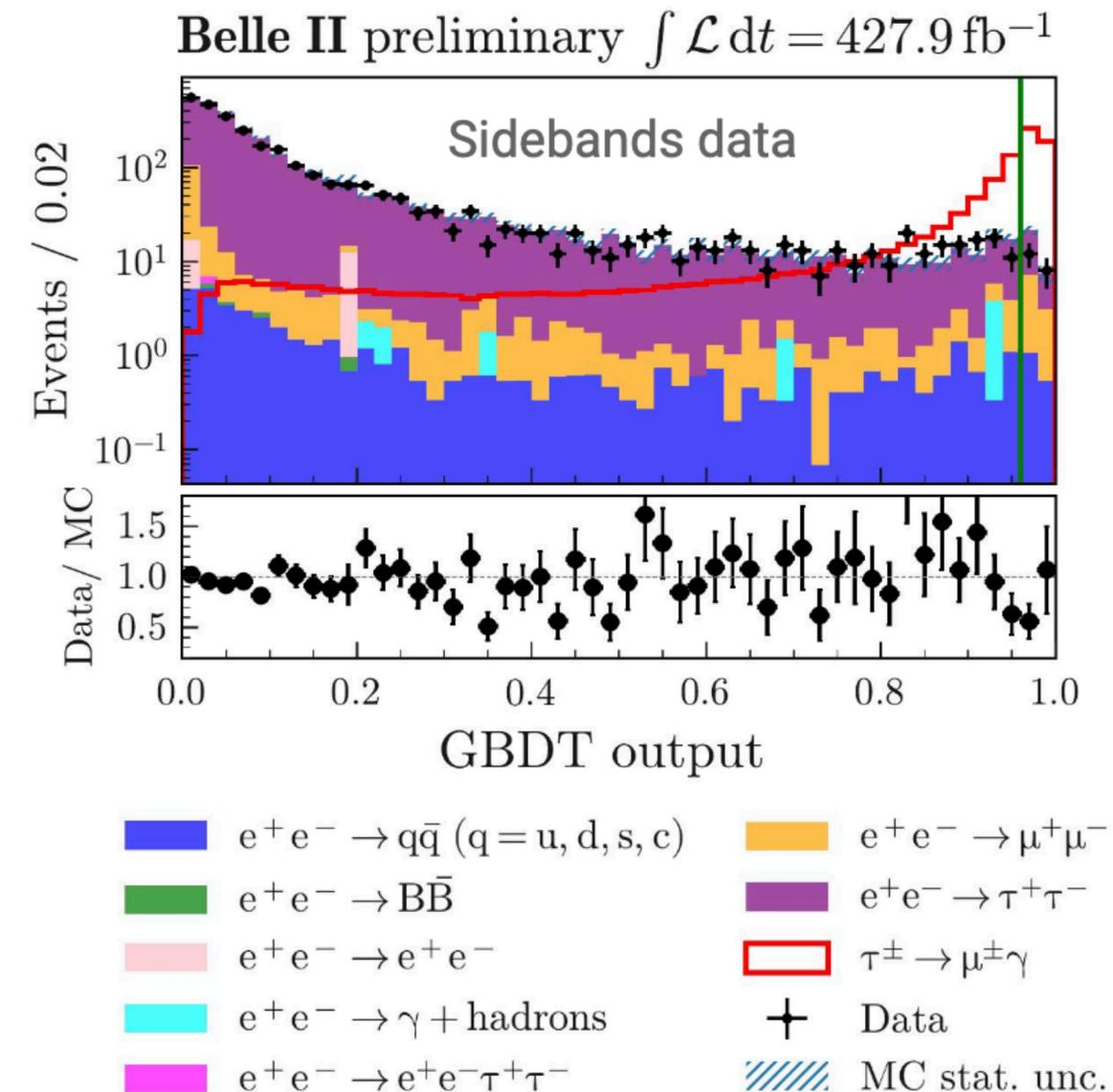
Search for LFV in the $\tau \to \mu\gamma$ decays at Belle II

Results

Signal extraction: unbinned maximum likelihood fits in (M_{bc}, $\Delta E'$)

Expected events from sidebands data 15.7 ± 3.4
compared to 18 observed events

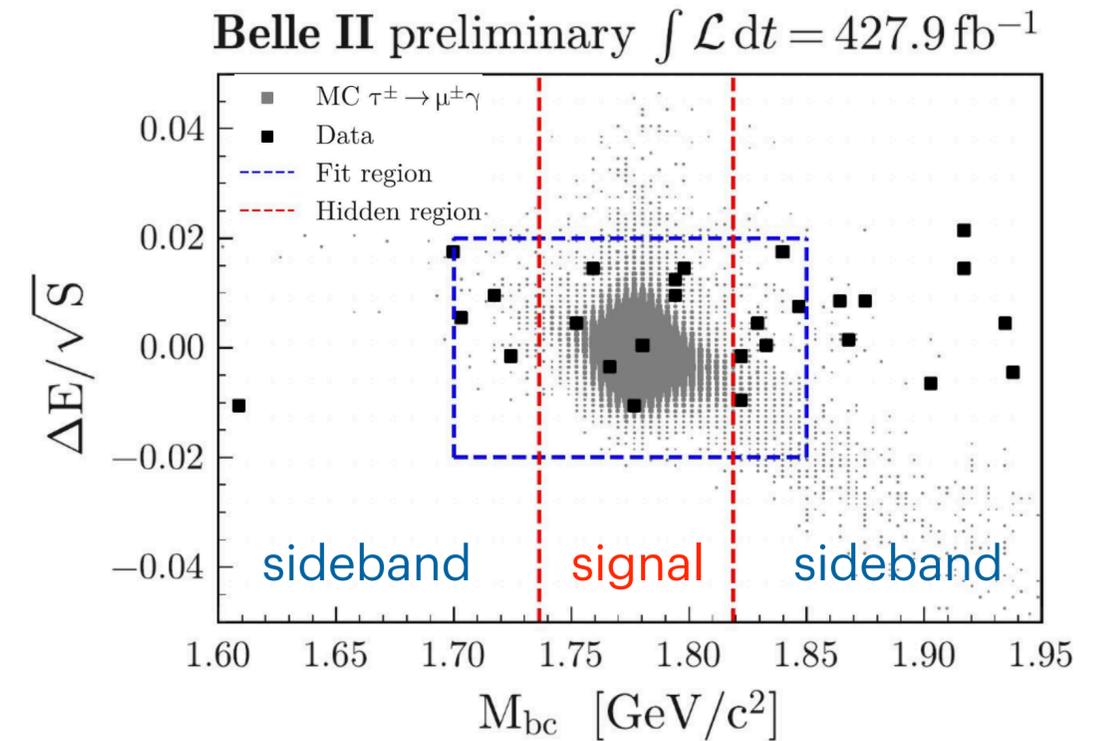Fit result for signal is consistent with zero: set an upper limit

$$\mathscr{B}(\tau \to \mu\gamma)^{exp} < 5.8 \times 10^{-8}$$

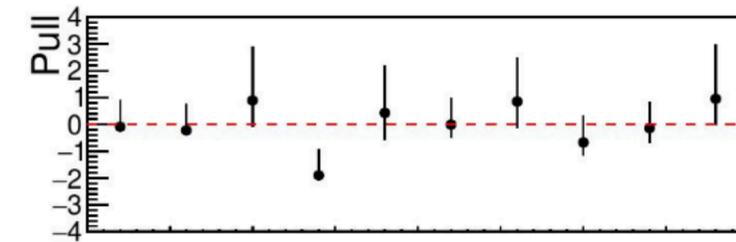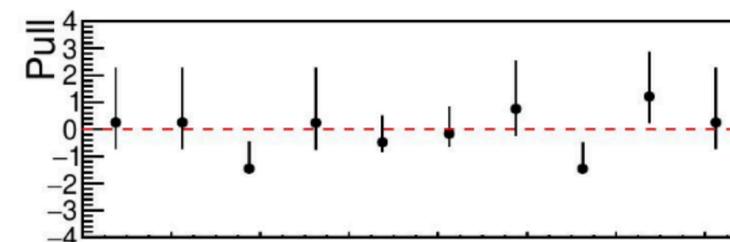$$\mathscr{B}(\tau \to \mu\gamma)^{obs} < 9.5 \times 10^{-8}$$

consistent with the previous Belle result

Belle II sensitivity with $1\,\mathrm{ab}^{-1}$ is expected
to be better than Belle.
Higher efficiency and lower background

Belle II preliminary $\int \mathcal{L}\,dt = 427.9\,\mathrm{fb}^{-1}$

- MC $\tau^{\pm} \to \mu^{\pm}\gamma$
- Data
- Fit region
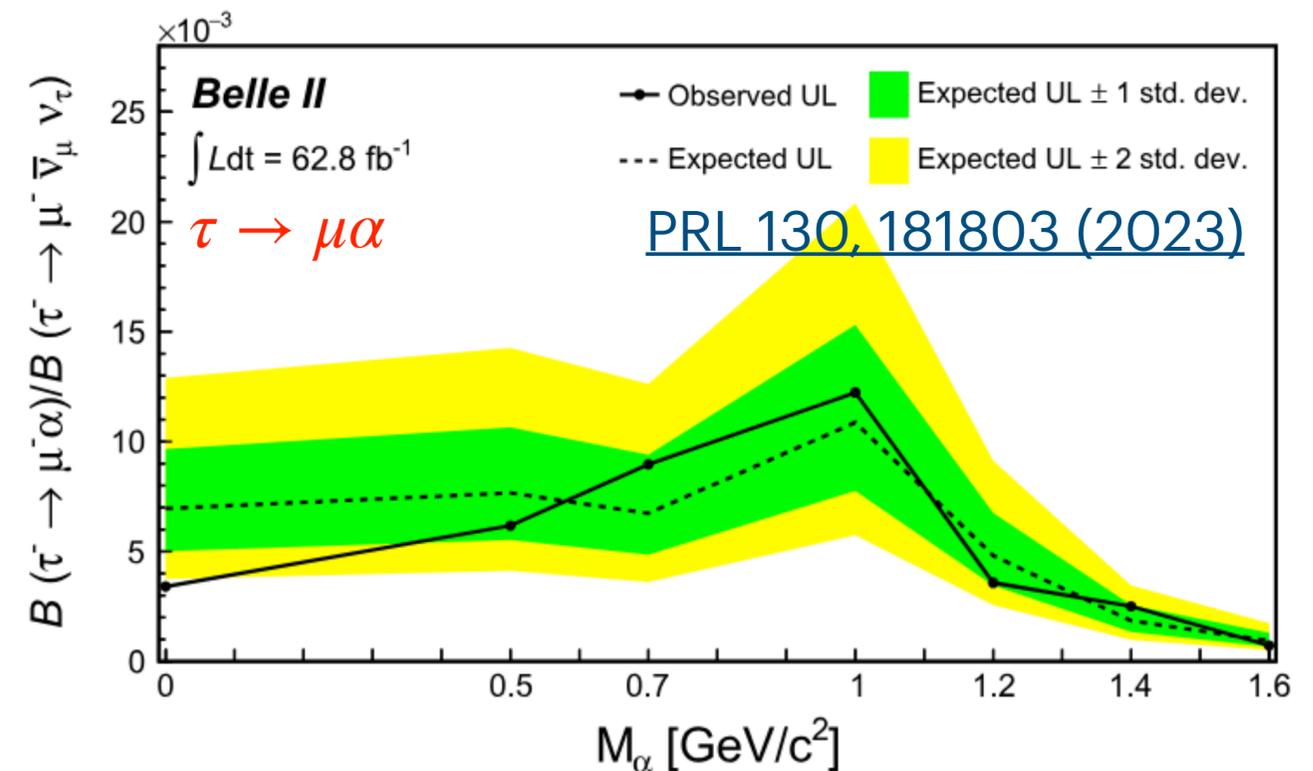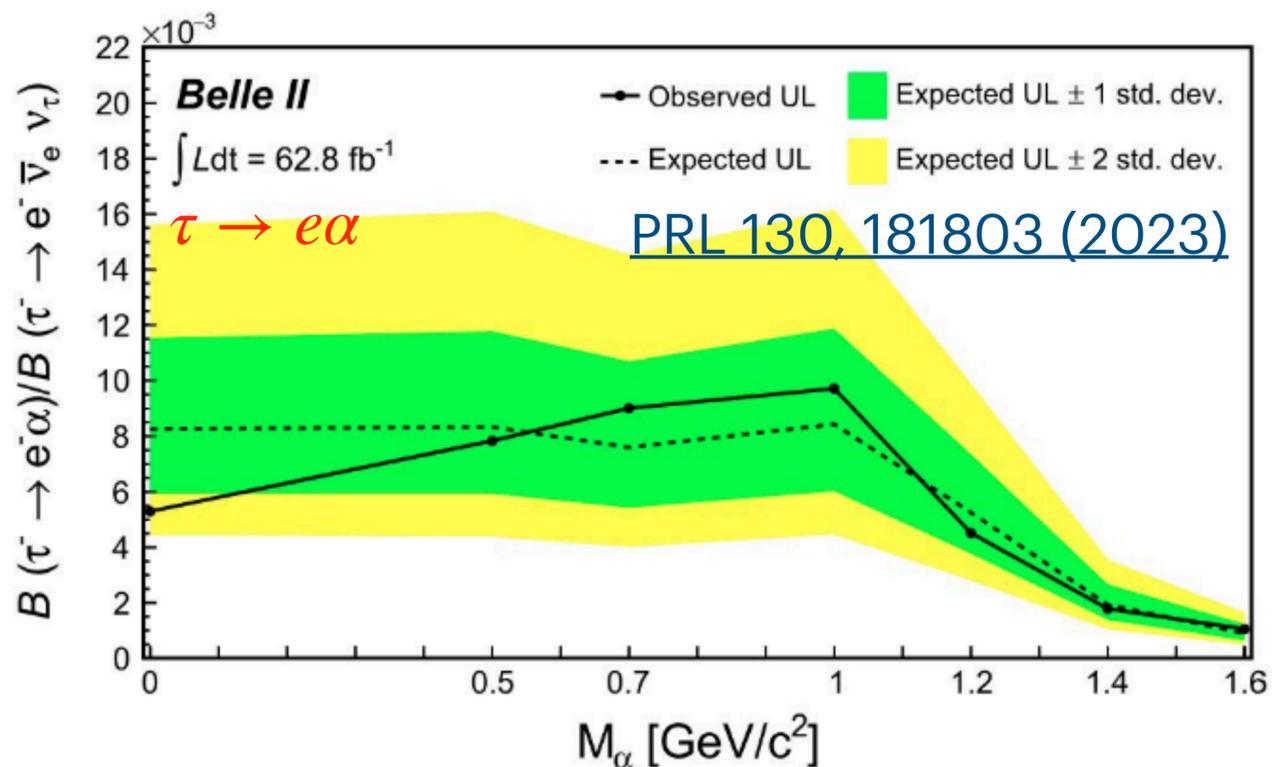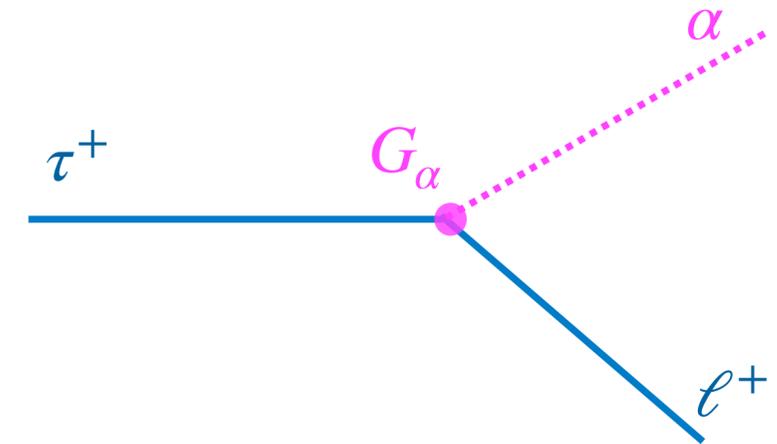- Hidden region

sideband   signal   sideband

M_{bc} [GeV/c^2]

1D projections
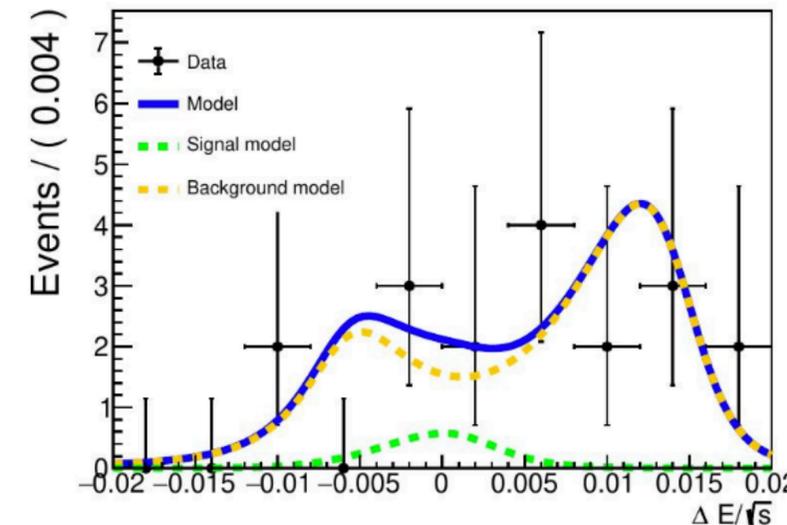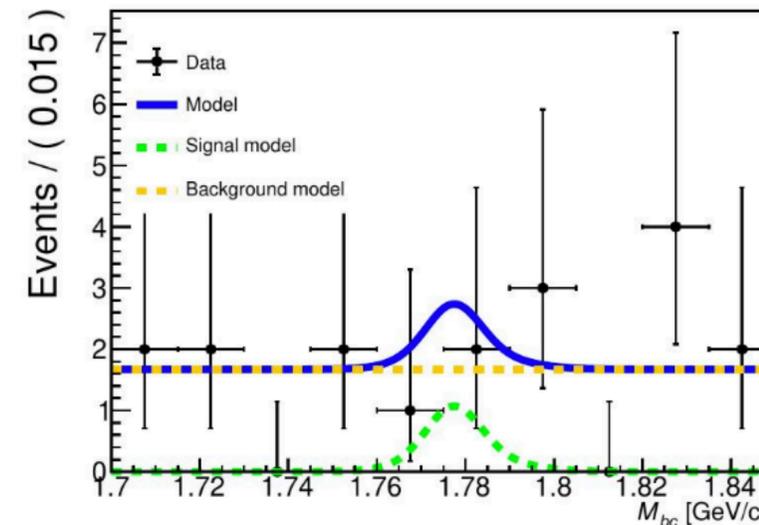
Search for $\tau \to \ell\alpha$ decays at Belle (II)

Motivation

- Beyond SM particle postulated to address the mass hierarchy problem

- DM candidate: invisible ALPs — wide mass reach at Belle II

- First search at Belle II using 1x3-prong topology [$62.8 \mathrm{fb}^{-1}$]

$\tau^+ \quad G_\alpha \quad \alpha \quad \ell^+$

$\tau \to e\alpha$ PRL 130, 181803 (2023)

$\tau \to \mu\alpha$ PRL 130, 181803 (2023)

$$\mathscr{B}(\tau^- \to \mu^-\alpha)/\mathscr{B}(\tau^- \to \mu^-\bar{\nu}_\mu\nu_\tau) < (0.7 - 12.2) \cdot 10^{-3} \text{ @95\% CL}$$

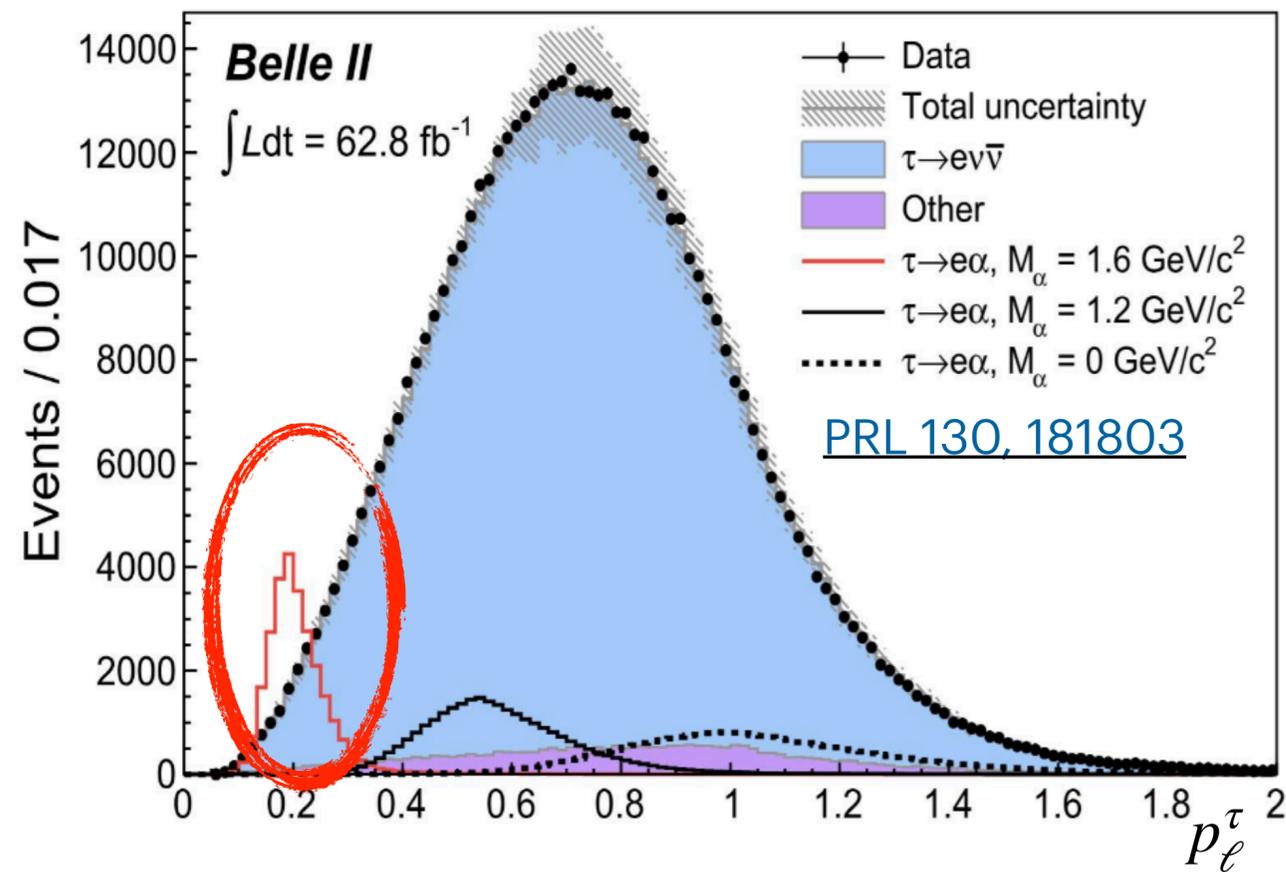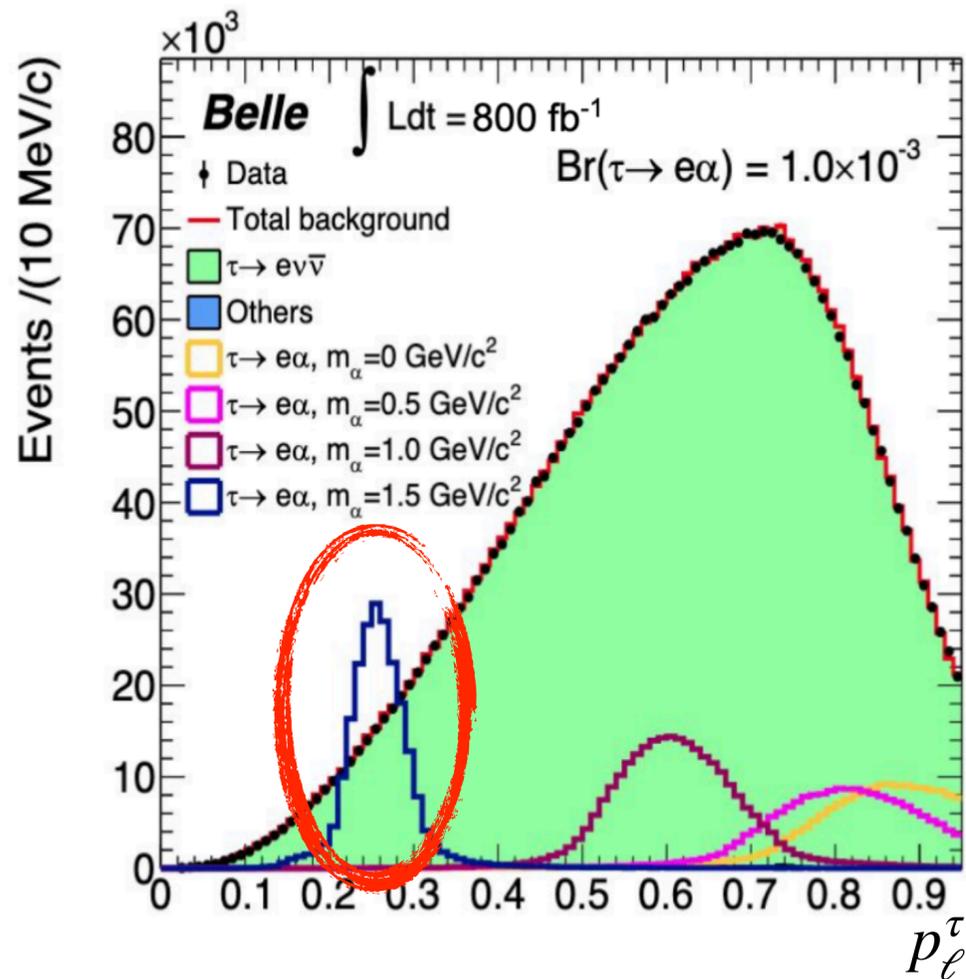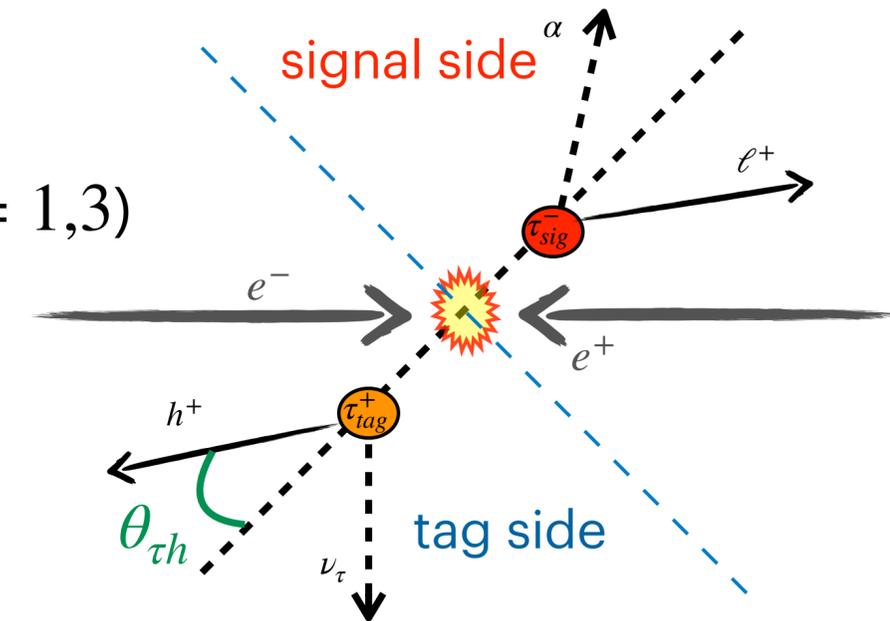$$\mathscr{B}(\tau^- \to e^-\alpha)/\mathscr{B}(\tau^- \to e^-\bar{\nu}_e\nu_\tau) < (1.1 - 9.7) \cdot 10^{-3} \text{ @95\% CL}$$

Could you further improve these upper limits?

Search for $\tau \to \ell\alpha$ decays at Belle

Analysis strategy

- 1x1 + 1x3-prong topology: $\tau^-_{sig} \to \ell^-\alpha$ and $\tau^+_{tag} \to \ell^+\nu_\ell\bar{\nu}_\tau$, $\tau^+_{tag} \to nh^+\bar{\nu}_\tau$ ($h = K, \pi; n = 1,3$)

- Discriminate signal/background using the lepton momentum in the τ rest frame

- Kinematic constraint on $\theta_{\tau h}$ to enhance p^τ_ℓ resolution → better signal sensitivity

PRL 130, 181803

Better signal sensitivity across all α mass points compared to the previous Belle II measurement

Search for $\tau \to \ell\alpha$ decays at Belle

Results

- Search for narrow peaks in the p_ℓ^τ distributions by performing a binned extended maximum-likelihood fits

- Performed the fits for each 17 M_α point: no significant excess is observed

- Determine 95% CL upper limits on the $\mathscr{B}(\tau \to \ell\alpha)$ based on the frequentist approach
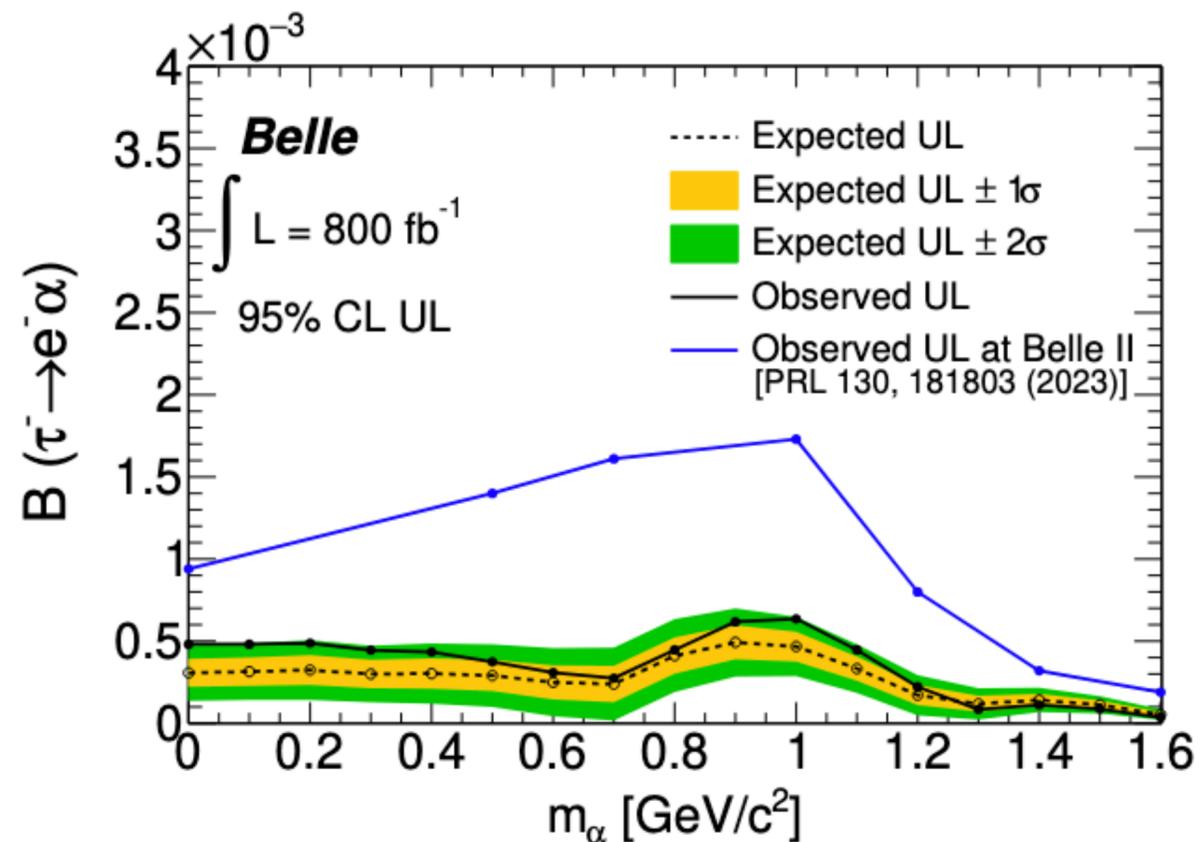
$$\mathscr{B}(\tau^- \to e^-\alpha) < (0.4 - 6.4) \cdot 10^{-4} \,\text{@95% CL}$$
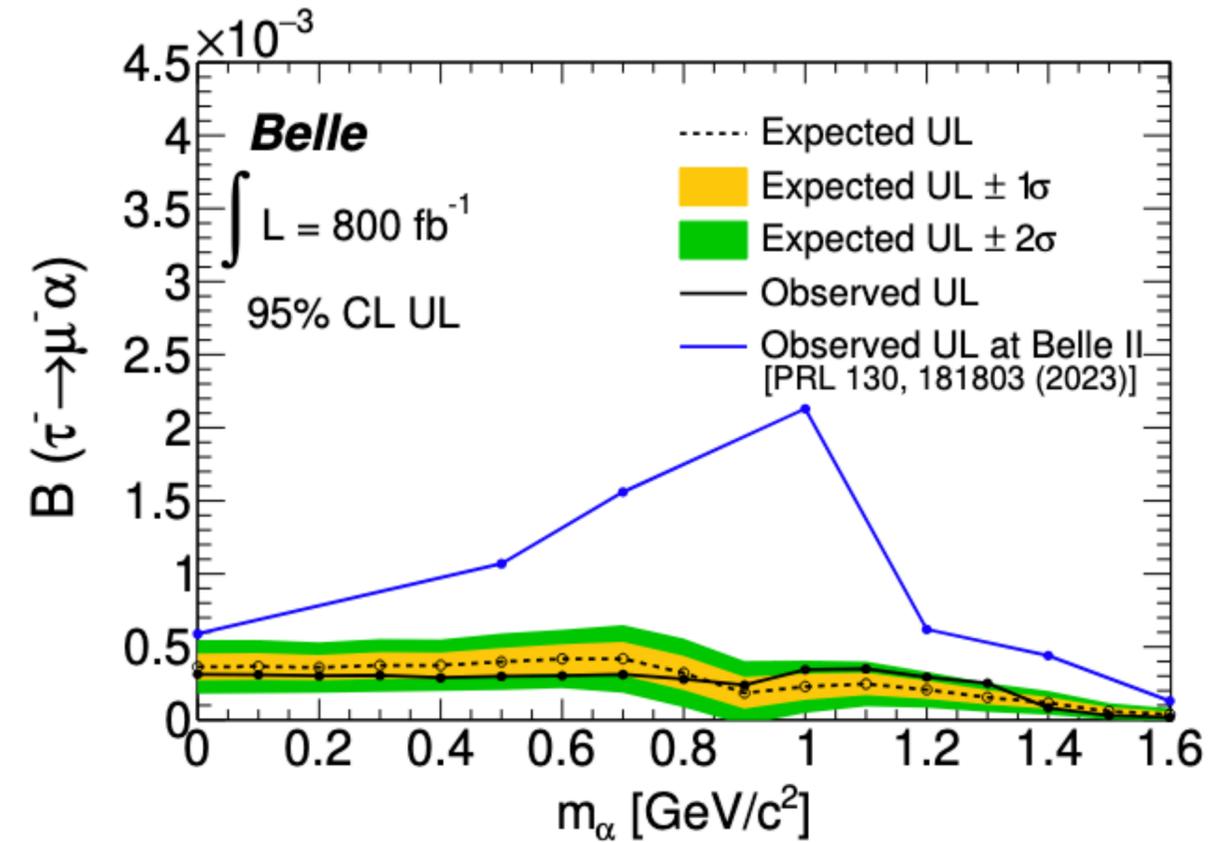
$$\mathscr{B}(\tau^- \to \mu^-\alpha) < (0.2 - 3.5) \cdot 10^{-4} \,\text{@95% CL}$$

Most stringent upper bounds to date

Search for an invisible axion-like particle in $\tau \to \ell\alpha$ decays at Belle II

New Belle II strategy and sensitivity using 1x1 decays

- 1x1-prong topology: $\tau^-_{sig} \to \ell^-\alpha$ and $\tau^+_{tag} \to \pi^+\nu_\tau$

- Binned ML fit for signal extraction using two new discriminants:

  M^2_{min} and M^2_{max} values kinematically allowed for the M^2_α

- First Belle II application of this method is coming soon

Signal 2D distribution ($M_\alpha = 0\,\text{GeV}$)

Bkg 2D distribution
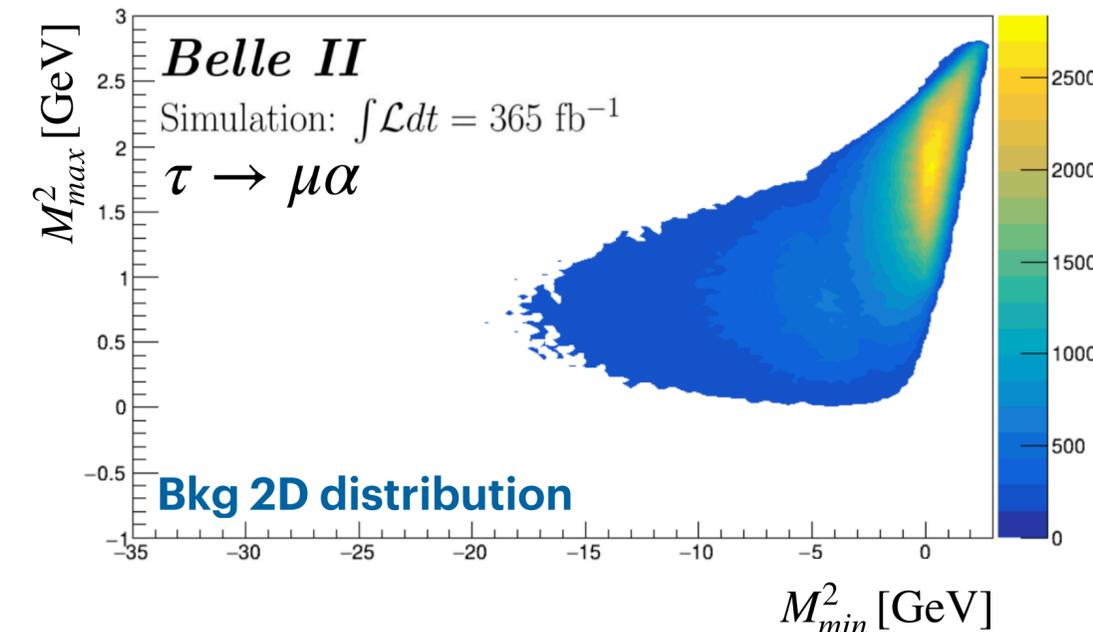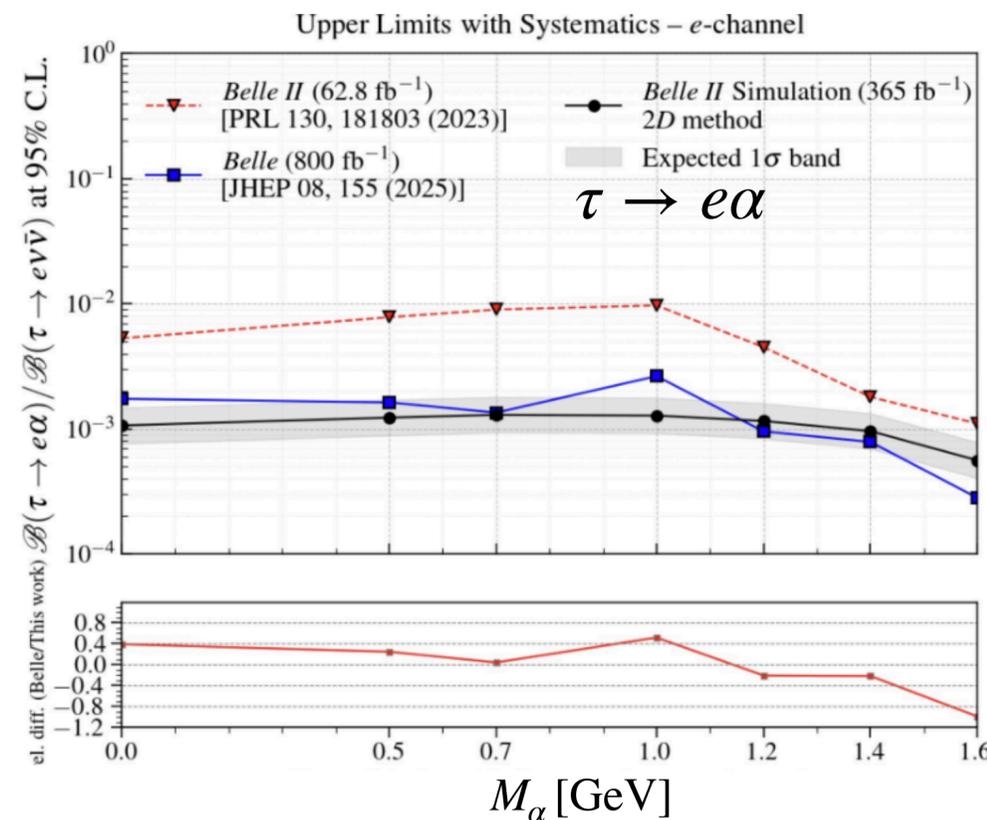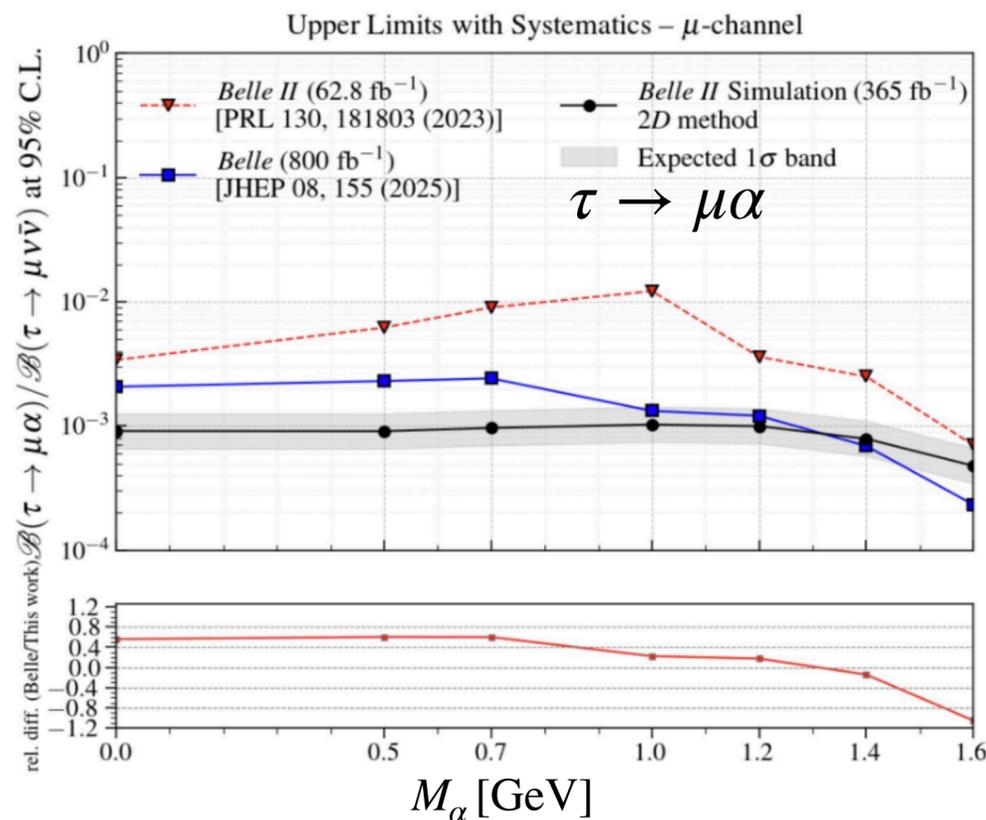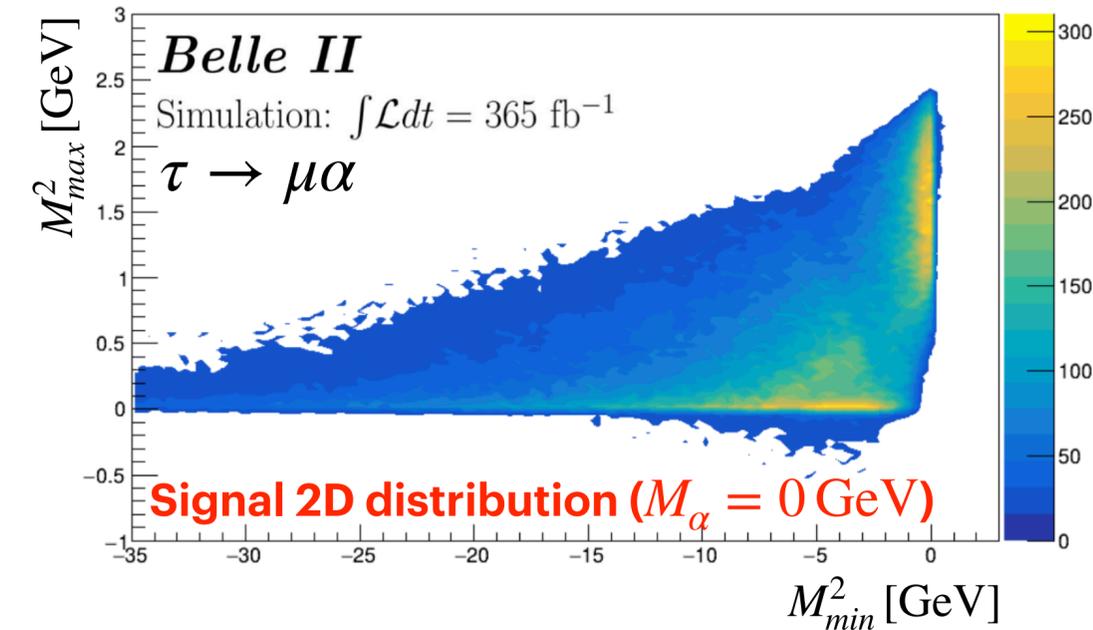
Belle II is expected to set world-leading upper limits for M_α< 1.2 GeV with only ~50% of the Belle data sample

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