DISCRETE 2026

Recent results from Belle and Belle II

Peter Križan

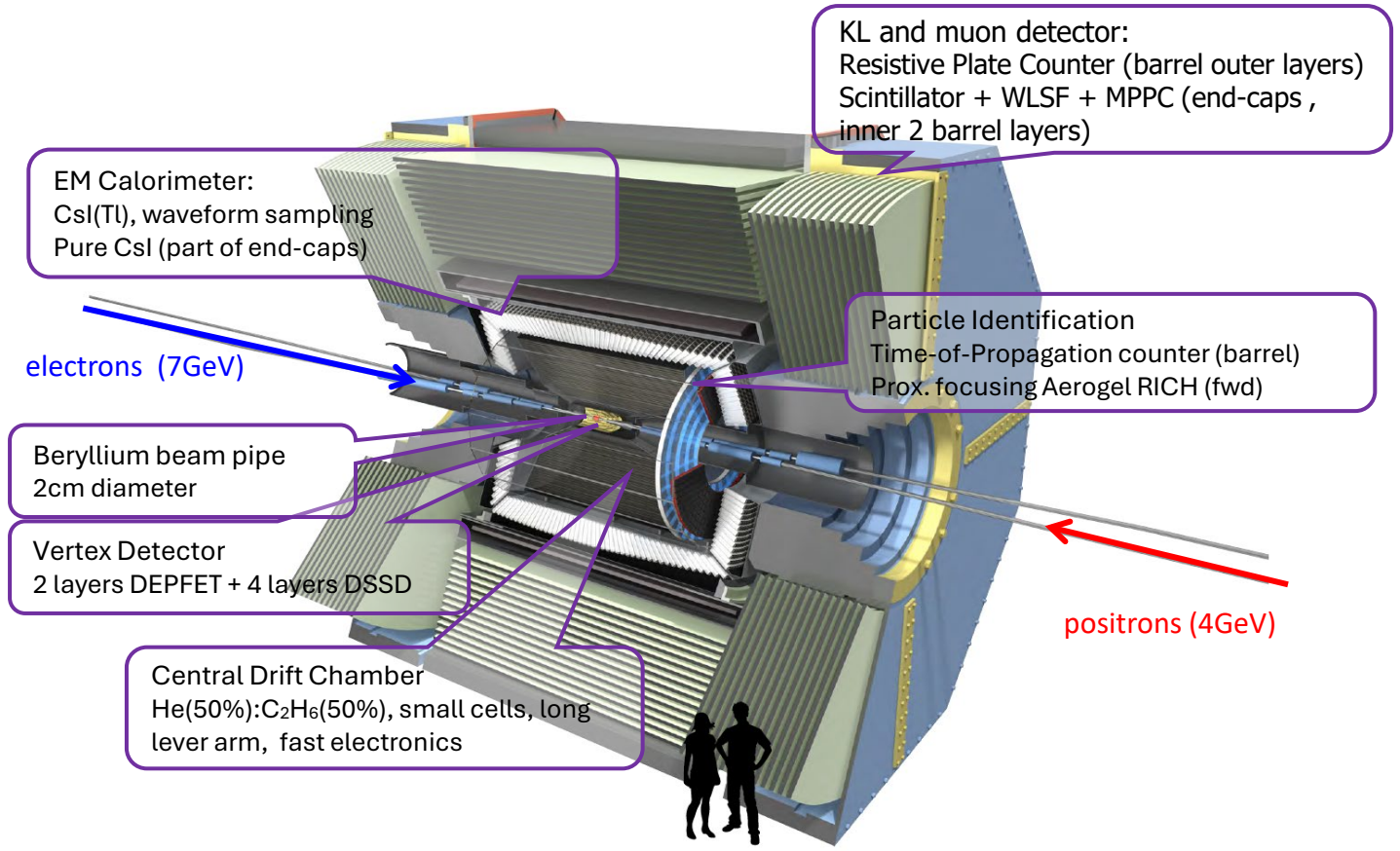
University of Ljubljana and J. Stefan Institute

UNIVERZA V LJUBLJANI

BELLE Belle II

Recent results from Belle and Belle II

- Introduction
- Time-dependent CP violation in
  $B^0 \to \pi^0\pi^0$, $\rho^+\rho^-$, $K^0\pi^0\gamma$, $K^0\pi^+\pi^-\gamma$
- CP violation in $D_s^+ \to \eta\, K/\pi$
- $D^+ \to \pi^+ e^+ e^-$
- $B \to X_s \nu\bar{\nu}$, $B \to X_s \ell^+\ell^-$ and $B \to K^0_S \tau^+\tau^-$
- Summary and outlook



Data samples:

Belle (full dataset) 1040 fb^{-1} (711 fb^{-1} at Y(4S))

Belle II Run 1 (2019–2022) 428 fb^{-1} (365 fb^{-1} at Y(4S))

Belle II total (summer 2026) 914 fb^{-1} (757 fb^{-1} at Y(4S))

The Belle II Detector Status and Plans→ talk by Steven Robertson

Flavour physics: window to physics beyond SM

Flavour physics has a central role in searches for deviations from the Standard Model (SM).

This talk: two directions

- *CP* violation
- Rare $b \to s$ transitions

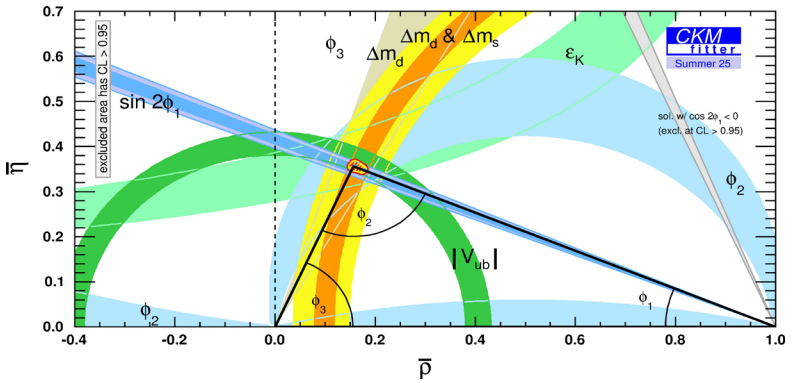
CP violation: cornerstone of flavour physics, originates from the complex phase in the CKM matrix.

Angles in the Unitarity triangle: related to the time-dependent *CP* violation in *B* meson decays.

- angle β/ϕ_1 : $B \to J/\psi\, K_S$, $\eta'\, K_S$
- angle α/ϕ_2 : $B \to \rho\rho$, $\rho\pi$, $\pi\pi$

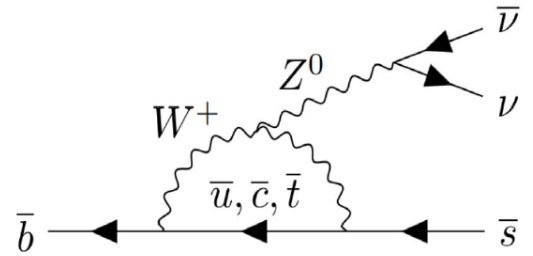
Precision measurements over-constrain the CKM picture.

A mismatch could hint at physics beyond the SM (BSM).



Rare $b \to s$ transitions: proceed only via loops and box diagrams in SM.

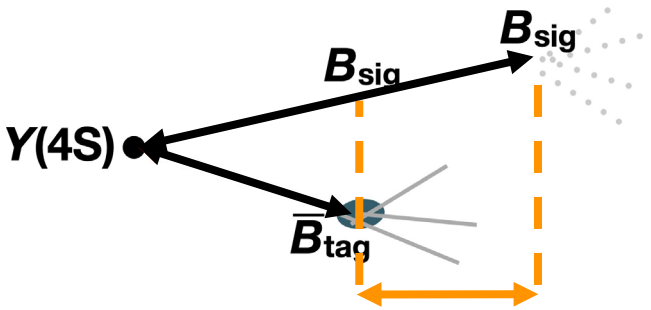
Sensitive probe of the possible presence of new particles in the loops.



Time-dependent *CP* violation (TDCPV) analyses at Belle II

Two *CP*-violation parameters: *C* (direct) and *S* (mixing-induced).

$$A_{CP} = \frac{\Gamma(\bar{B}^0(\Delta t) \to f_{CP}) - \Gamma(B^0(\Delta t) \to f_{CP})}{\Gamma(\bar{B}^0(\Delta t) \to f_{CP}) + \Gamma(B^0(\Delta t) \to f_{CP})} = S_{CP} \sin(\Delta m \Delta t) - C_{CP} \cos(\Delta m \Delta t)$$

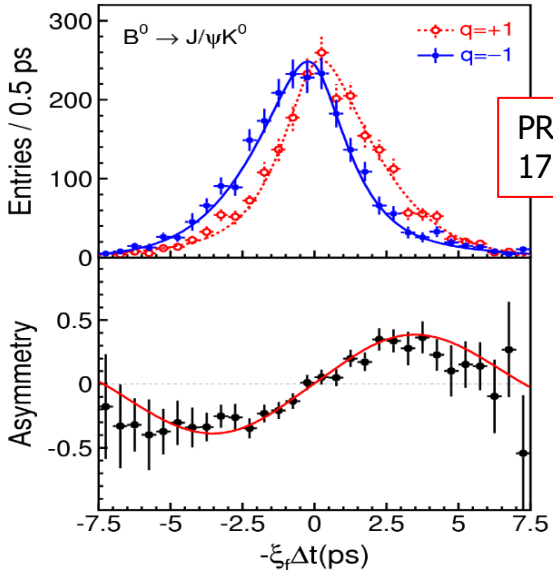


In *Y(4S)* decays, exactly two *B* mesons are produced in a coherent state.

To measure *S*, exploit quantum entanglement:

flavour of B_{tag} from the flavour tagger algorithm determines flavour B_{sig} (CP eigenstate).

Get $\Delta t = t_{sig} - t_{tag}$ from spatial separation of B_{sig} and B_{tag} decay vertices.

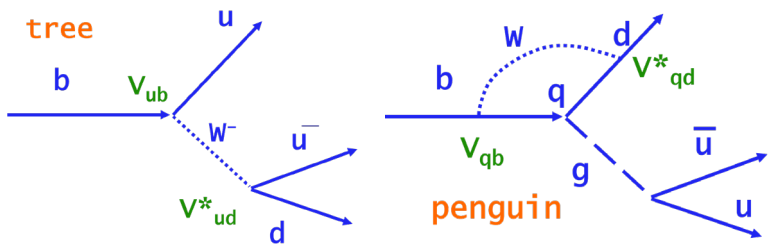


PRL 108 (2012) 171802

Very successful program, in particular for channels with neutrals in the final state.

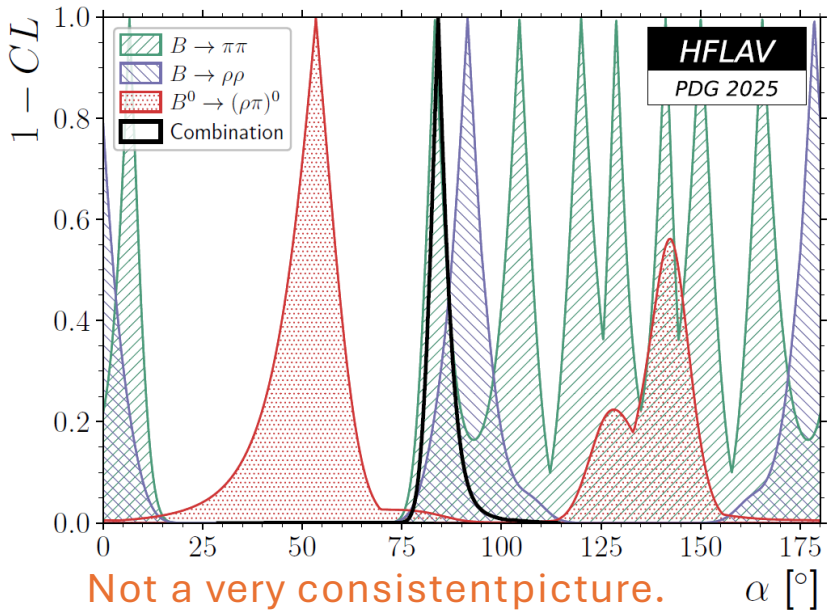
CKM angle α/ϕ_2

Angle α/ϕ_2 : from $B \to \rho\rho$, $\rho\pi$, $\pi\pi$ decays. However, these decays proceed through tree and penguin processes; to extract the value of α/ϕ_2 , the penguin contribution has to be accounted for.



Determine α/ϕ_2 from isospin analysis: combine branching ratios (*BR*) and *CP* asymmetries of isospin-related channels to separate tree and penguin topologies and suppress hadronic uncertainties.

$$\phi_2/\alpha = \arg\left(-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right) = (84.1^{+3.7}_{-3.0})^\circ$$



- $B \to \rho\rho$: smallest penguin contribution, but experimentally difficult
- $B \to \rho\pi$: golden mode, but difficult time-dependent Dalitz analysis (note also the interpretation issue, mentioned by Luiz Vale Silva in his talk; R. Žlebčik, arXiv:2609.31828, more in backup slides)
- $B \to \pi\pi$: simple two-body system, but
  - $B^0 \to \pi^0\pi^0$ time-dependent *CP* asymmetry was missing (final state with 4 photons).

Not a very consistentpicture.

$S(\rho^+\rho^-)$: Belle II run1 analysis

Phys. Rev. D 111, 092001

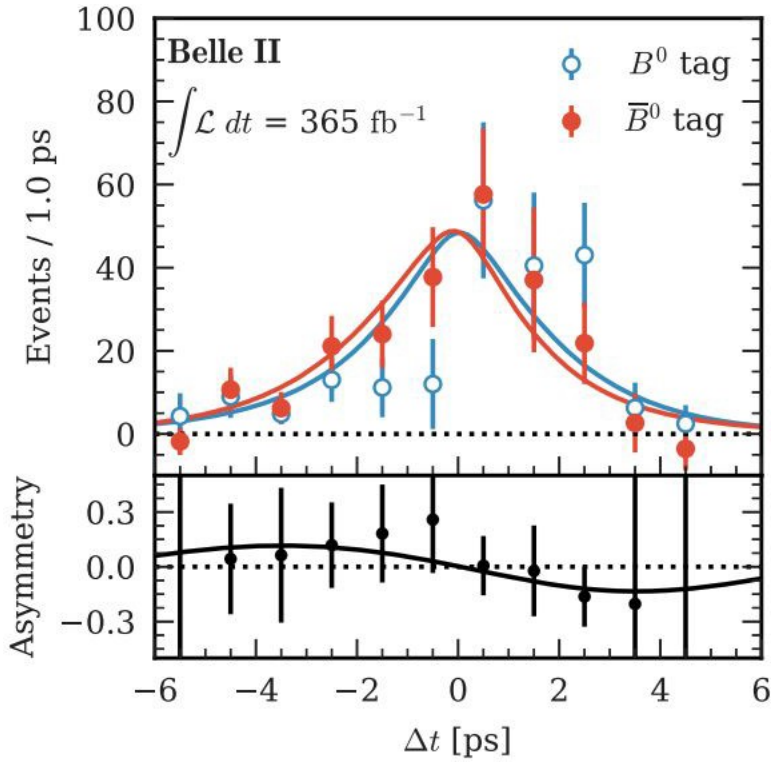
The main channel for $B \to \rho\rho$

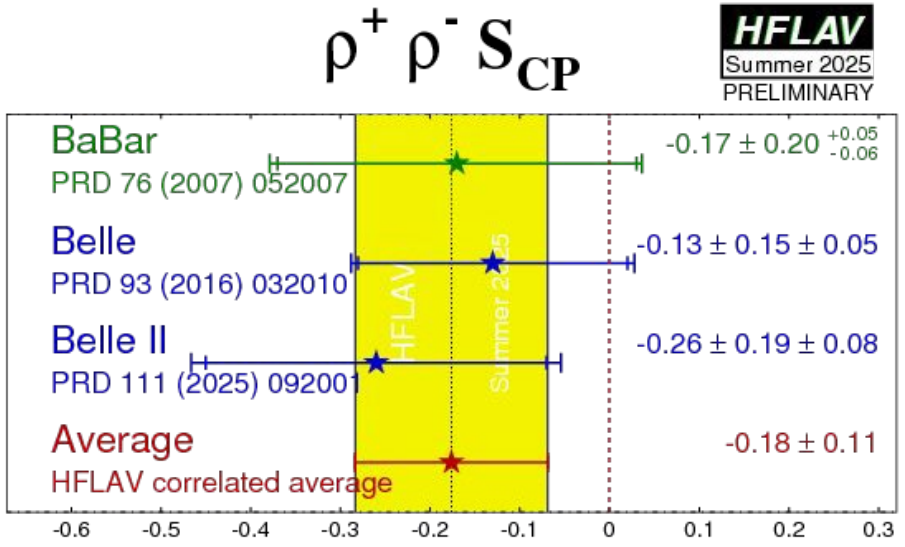
$B^0 \to (\rho^+ \to \pi^+\pi^0)(\rho^- \to \pi^-\pi^0)$

$$\mathcal{B}(B^0 \to \rho^+\rho^-) = (2.89^{+0.23\ +0.29}_{-0.22\ -0.27}) \times 10^{-5}$$

$$S = -0.26 \pm 0.19 \pm 0.08$$
$$C = -0.02 \pm 0.12^{+0.06}_{-0.05}$$

$$f_L = 0.921^{+0.024\ +0.017}_{-0.025\ -0.015}$$





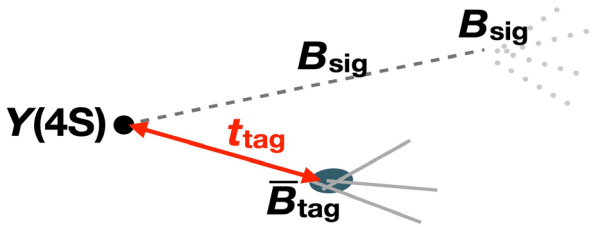
sin 2α is close to the value of *S* - small penguin contribution

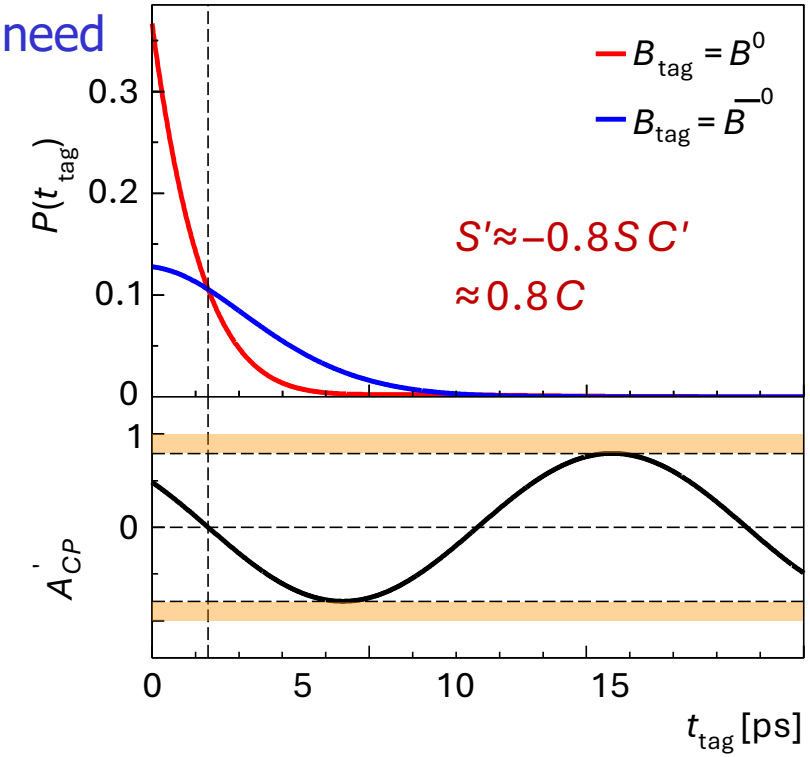
TDCPV in $B \to \pi^0\pi^0$ - a new method

How measure TDCPV in $B \to \pi^0\pi^0$?
Traditional method: need two vertices to measure $\Delta t = t_{sig} - t_{tag}$
But with the dominant π^0 decay there would be 4γ in the final state
In $B \to \pi^0\pi^0$ this would require using $\pi^0 \to e^+e^-\gamma$ decays – would need a sample of about $10 ab^{-1}$.

Idea: M. Dorigo, S. Raiz, D. Tonelli, and R. Žlebčik, PRD 112 (2025) 032011

However, if $B\bar{B}$ production point is precisely known, one can determine B_{tag} decay time t_{tag}.





Do not measure Δt, only t_{tag}, and integrate over t_{sig}.

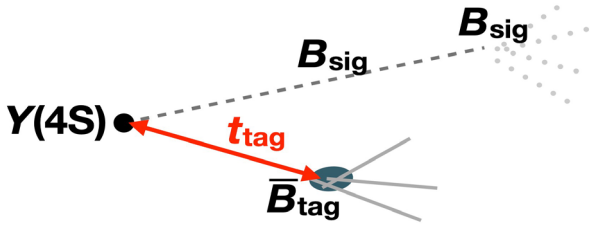
Use t_{tag} to determine signal *CP* asymmetry. Works thanks to quantum entanglement, even if with reduced amplitude.

Signal vertex **not** required to measure TDCPV —but the t_{tag} resolution is crucial.

TDCPV in $B \to \pi^0\pi^0$ - a new method

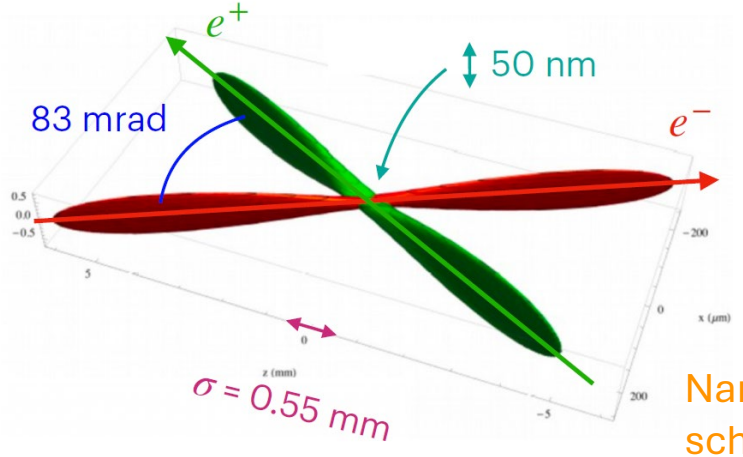
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However, if $B\bar{B}$ production point is precisely known, one can determine B_{tag} decay time t_{tag}.

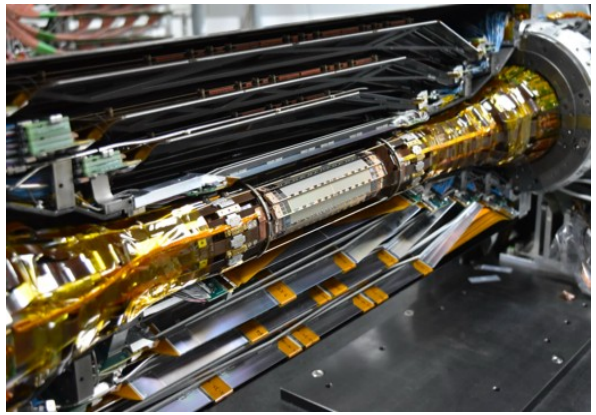


Do not measure Δt, only t_{tag}, and integrate over t_{sig}.

Use t_{tag} to determine signal *CP* asymmetry. Works thanks to quantum entanglement, even if with reduced amplitude.



Nano-beam scheme



Vertex detector

Signal vertex **not** required to measure TDCPV —but the t_{tag} resolution is crucial.

TDCPV in $B \to \pi^0\pi^0$ - Measuring t_{tag}

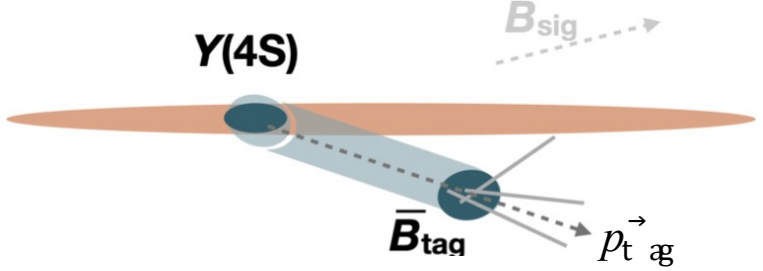
From B_{tag} vertex and $B\bar{B}$ production point.

Constraints:

– B_{tag} vertex (measured),

– B_{tag} momentum (deduced from the measured B_{sig}),

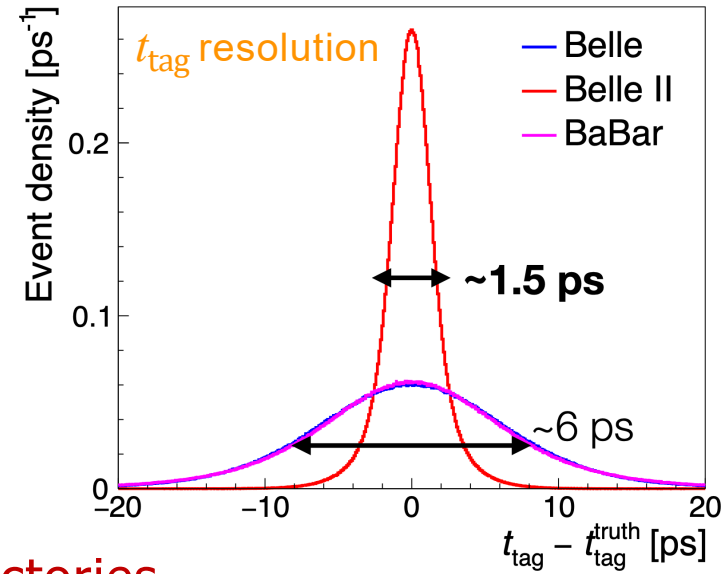
– interaction region (determined from $e^+e^- \to \mu^+\mu^-$ events).



	Belle	BaBar	Belle II
Crossing angle [mrad]	22	0	83
Interaction region x width [μm]	70	148	13
Interaction region y width [μm]	1.0	6.9	0.2
Interaction region z width [μm]	6000	15150	350
B_{tag} vertex x-y resolution [μm]	80	80	30
B_{tag} vertex z resolution [μm]	100	125	30

SuperKEKB

PXD



Belle II outperforms previous B factories.

Validation with $B^0 \to D^- \pi^+$ and $B^0 \to J/\psi K^0$

Validate in Belle II data by measuring B^0B^0 mixing and B^0 lifetime with the new t_{tag} method.
Use 36k $B^0 \to D^- \pi^+$ signal candidates. Measure
$\Delta m = 0.512 \pm 0.011\ \text{ps}^{-1}$; $\tau = 1.509 \pm 0.026$ ps
Both agree with PDG.

Validation in Belle II data from measurement of $\sin 2\phi_1$ with t_{tag} using 6k $B^0 \to J/\psi K^0$ signal candidates

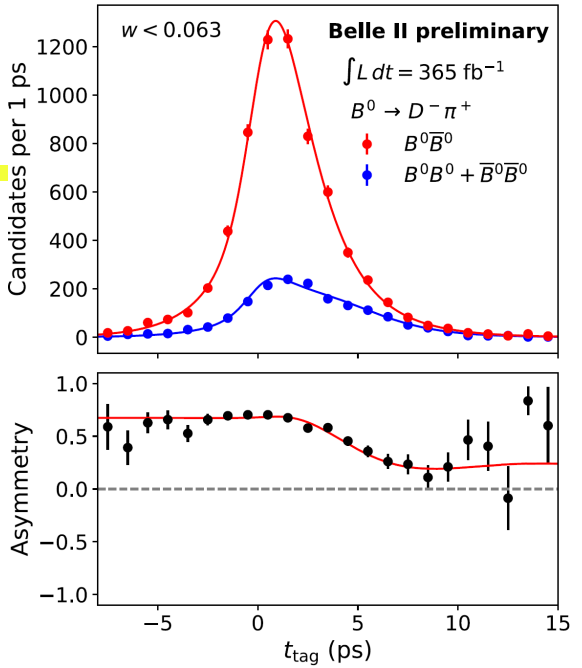
Measure $S = \sin 2\phi_1$

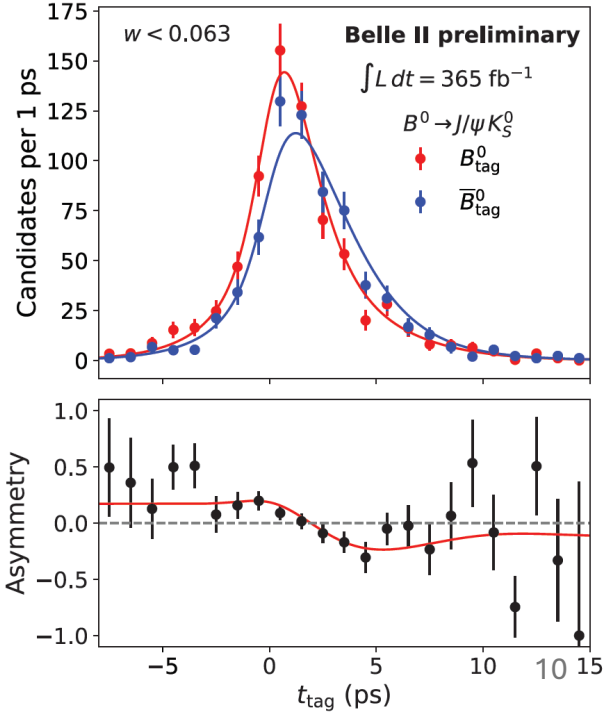
$\sin 2\phi_1 = 0.84 \pm 0.10$

Agrees with the Δt-based measurement $\sin 2\phi_1 = 0.710 \pm 0.011$

→ See flavor oscillations and CP violation.

→ The method works!





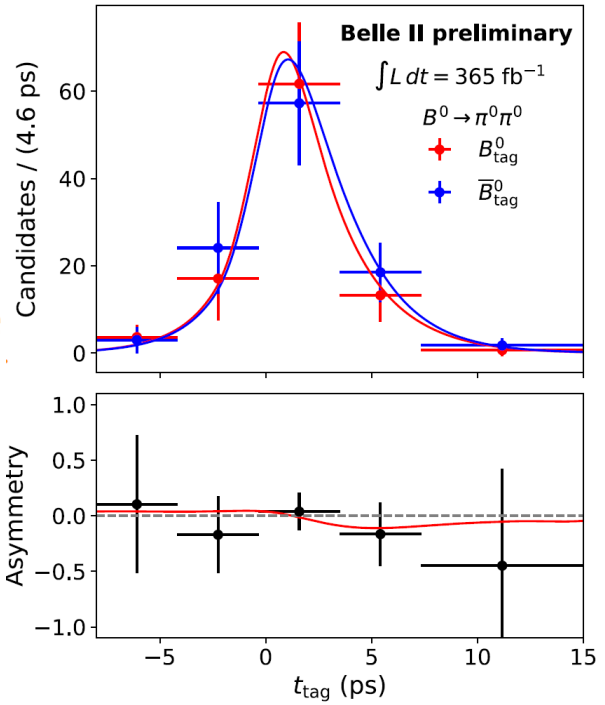
TDCPV in $B \to \pi^0\pi^0$ - the result and impact

https://arxiv.org/abs/2606.20797

Measured mixing-induced *CP* violation parameter

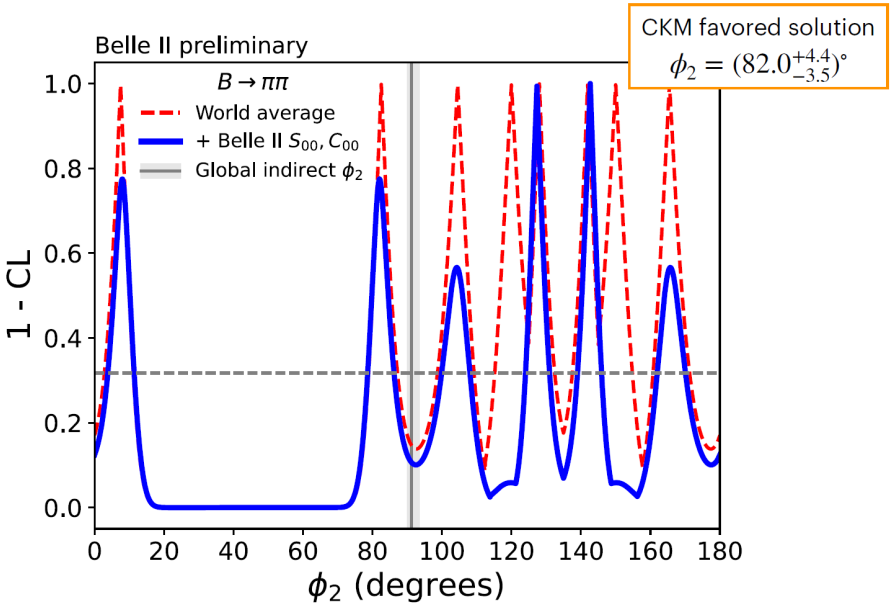
$$S_{\pi^0\pi^0} = 0.61^{+0.75}_{-0.79} \pm 0.11$$

To reach this sensitivity, the Δt-based measurement would need a 20x larger sample



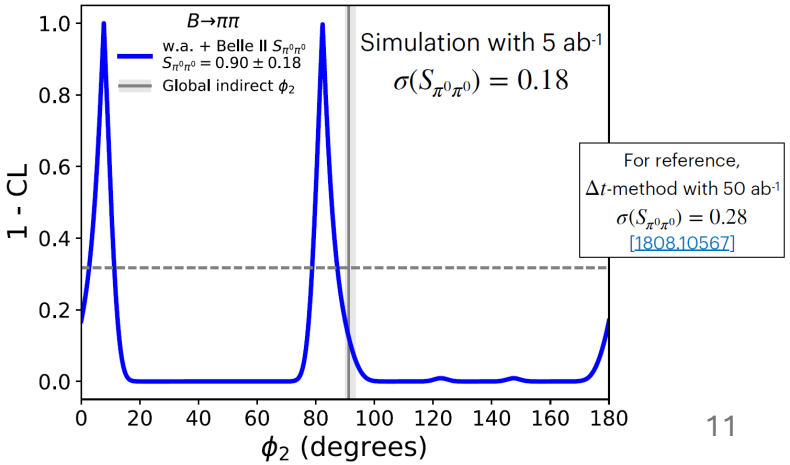
Also improved precision on the direct CPV parameter:

$C_{\pi^0\pi^0} = 0.05 \pm 0.28 \pm 0.07$



Impact

Projection to 5 ab^{-1}



TDCPV in radiative decays: $B^0 \to K^0 \pi^0 \gamma$

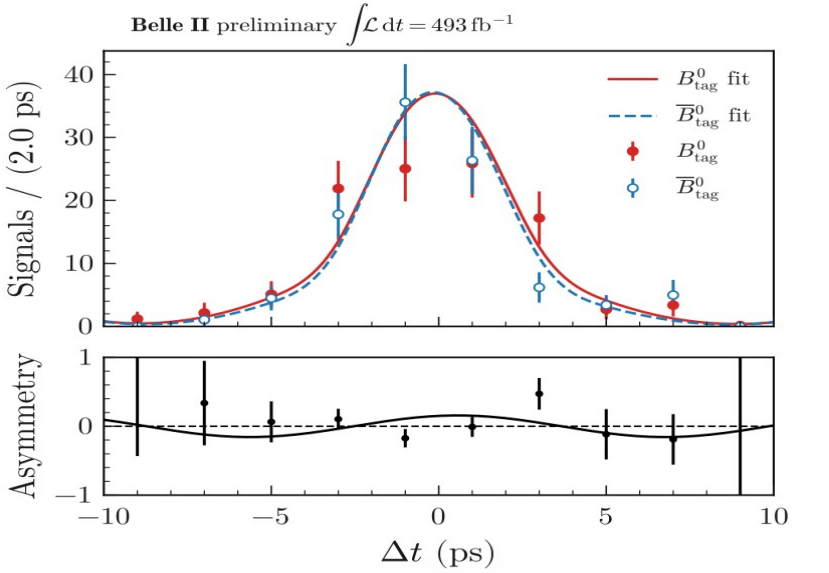
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Photon predominantly left-handed in SM; S ~ a few %

BSM can increase the right-handed contribution, amplifying mixing-induced CPV.

Use Belle+Belle II data with improved AI-based flavour tagging.

Phys. Rev. D 110 (2024) 012001



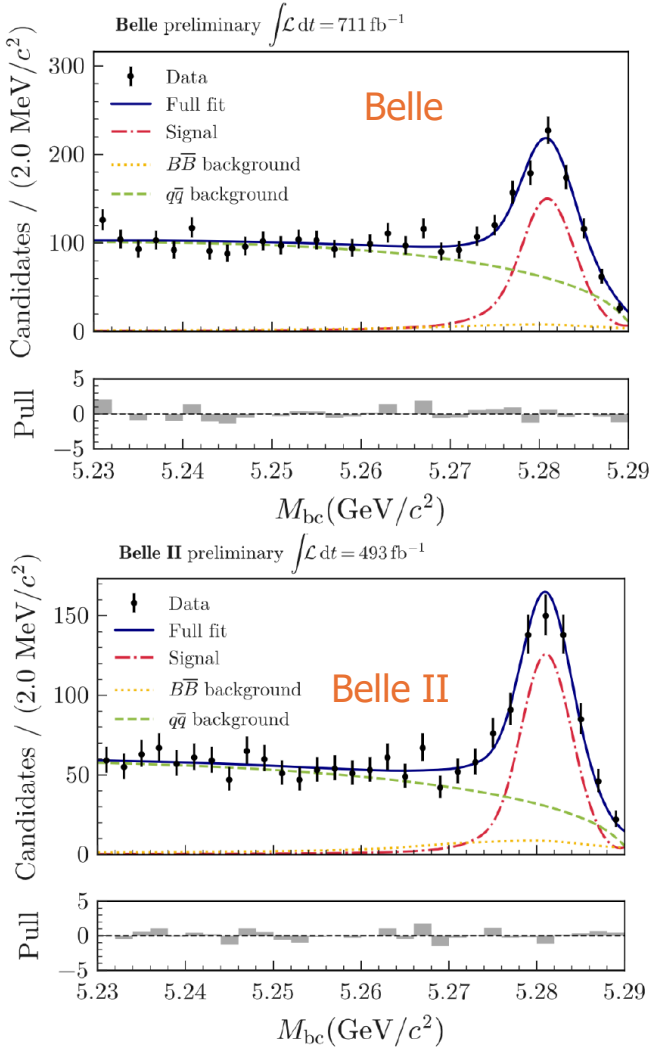
$N_{sig} = 558 \pm 29$ (Belle), 452 ± 24 (Belle II)

in the K*(892) mass region

For two mass regions: for the $K^*(892)$ contribution with $K^0\pi^0$ mass in [0.8,1.0 GeV/c^2] and for the non-$K^*(892)$ contribution [1.0,1.8 GeV/c^2]

$$S_{K^*\gamma} = 0.09 \pm 0.16 \pm 0.02,$$
$$C_{K^*\gamma} = -0.09 \pm 0.08 \pm 0.04,$$
$$C_{\text{non } K^*\gamma} = -0.07 \pm 0.17 \pm 0.08$$
$$S_{\text{non } K^*\gamma} = -0.32 \pm 0.33 \pm 0.09$$

World-best result



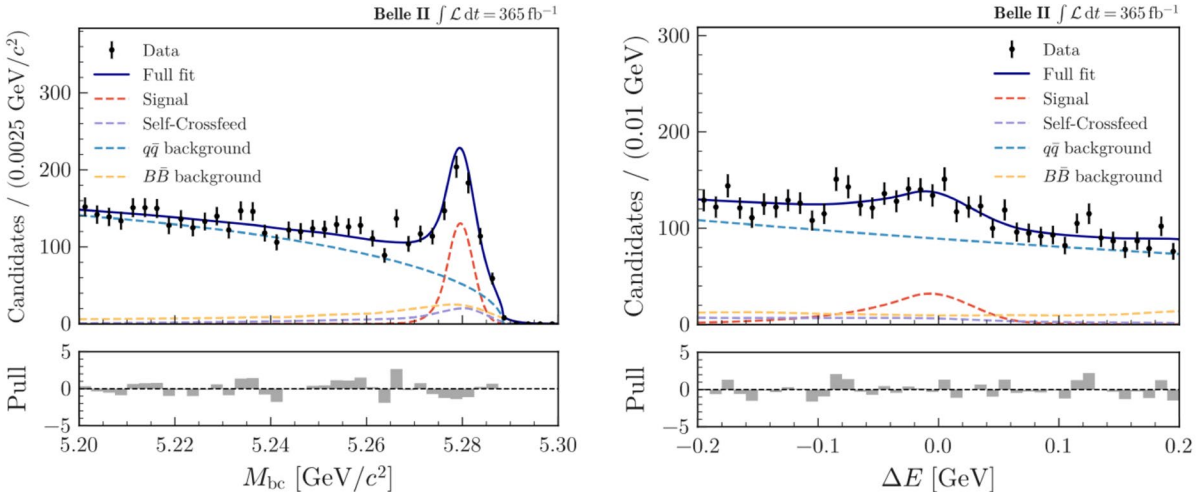
M_{bc} = beam-constrained mass

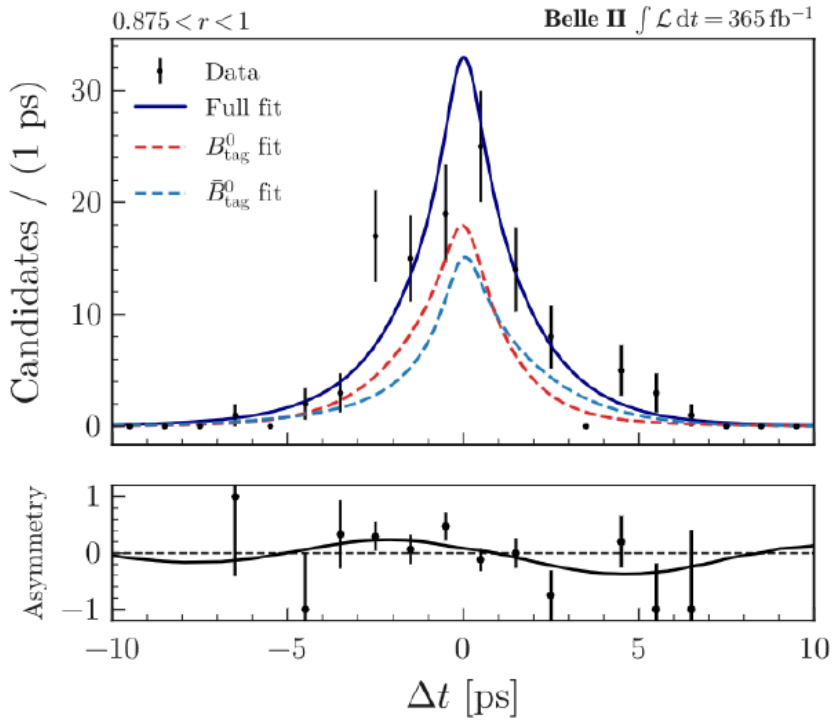
TDCPV in radiative decays : $B^0 \to K^0 \pi^+ \pi^- \gamma$

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Same motivation as for $B^0 \to K^0 \pi^0 \gamma$

Use Belle+Belle II data with improved AI-based flavour tagging and K_S reconstruction





$N_{sig} = 475 \pm 31$ (Belle), 350 ± 23 (Belle II)

$C = -0.17 \pm 0.09 \pm 0.04,\ S = -0.29 \pm 0.11 \pm 0.05$

Most precise measurement of S in $b \to s\gamma$ transitions. Improvement by at least a factor of 2 vs. Belle and Babar measurements [PhysRevLett.101.251601, PhysRevD.93.052013]

CP violation in charm decays: $D^+_{(s)} \to \eta h^+$ ($h = \pi, K$) at Belle II

Since charm transitions probe the up-type sector, they allow us to search for CP-violating interactions that do not appear in kaon or B-meson decays

Probing direct CP violation across CF, SCS, and DCS $D_{(s)}$ decays

$D^+ \to \eta\pi^+$ Singly Cabibbo-Suppressed (SCS)

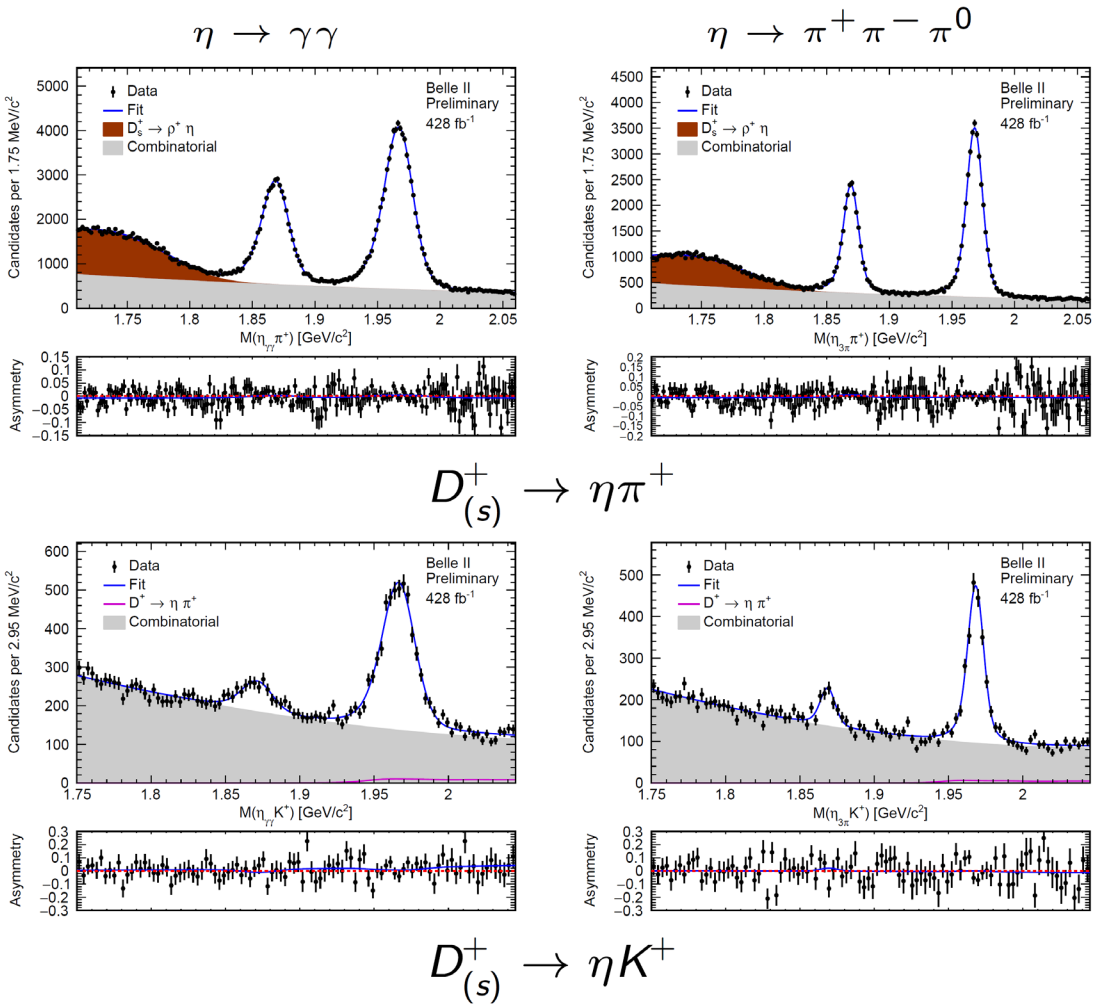
$D^+_s \to \eta\pi^+$ Cabibbo-Favored (CF)

$D^+ \to \eta K^+$ Doubly Cabibbo-Suppressed (DCS)

$D^+_s \to \eta K^+$ Singly Cabibbo-Suppressed (SCS)

Reconstruct both $\eta \to \gamma\gamma$ and $\eta \to \pi^+\pi^-\pi^0$.

Correct charged-track detection asymmetries using CF control modes: $D^+ \to K^0_S \pi^+$, $D^+_s \to K^0_S K^+$.



CP violation in charm decays: $D^+_{(s)} \to \eta h^+$ ($h = \pi, K$) at Belle II

Measure *CP* asymmetry

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

Preliminary branching fractions: the best statistical precision

$$\mathcal{B}(D^+ \to \eta K^+) = (1.086 \pm 0.078 \pm 0.018 \pm 0.026_{\rm PDG}) \times 10^{-4},$$
$$\mathcal{B}(D_s^+ \to \eta K^+) = (1.500 \pm 0.032 \pm 0.024 \pm 0.024_{\rm PDG}) \times 10^{-3}.$$

Preliminary A_{CP} results

$$A_{CP}(D^+ \to \eta\pi^+) = (-0.70 \pm 5.15 \pm 0.18) \times 10^{-3},$$
$$A_{CP}(D_s^+ \to \eta\pi^+) = (-3.23 \pm 3.80 \pm 0.18) \times 10^{-3},$$
$$A_{CP}(D^+ \to \eta K^+) = (-1.63 \pm 6.51 \pm 0.26)\%,$$
$$A_{CP}(D_s^+ \to \eta K^+) = (-0.37 \pm 1.96 \pm 0.10)\%.$$

$\eta\pi^+$: statistical precision comparable to LHCb.

D^+ : 0.50%; D^+_s : 0.42% (2021,2023 combined).

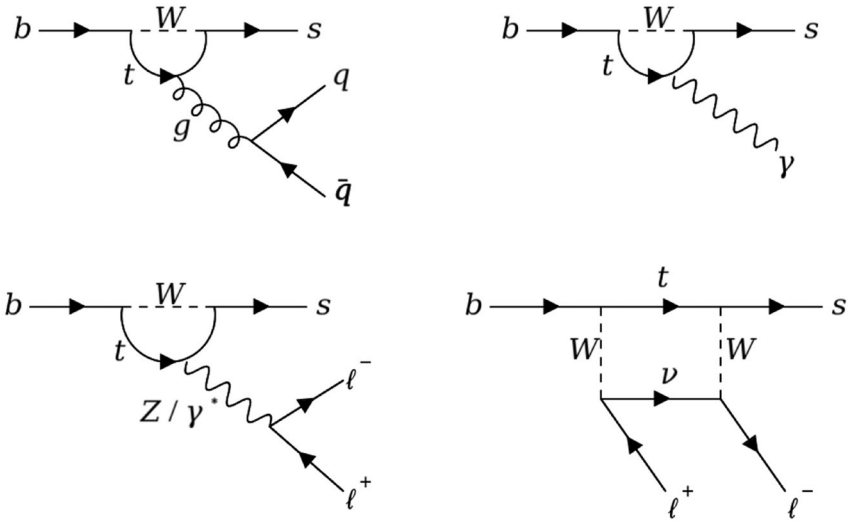
ηK^+ : best statistical precision to date.

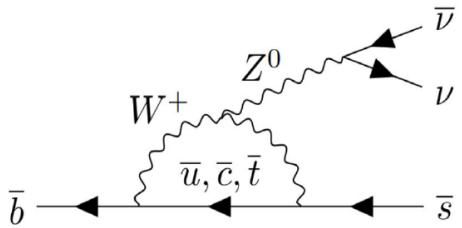
D^+ : 10%(LHCb 2021) → 6.51%

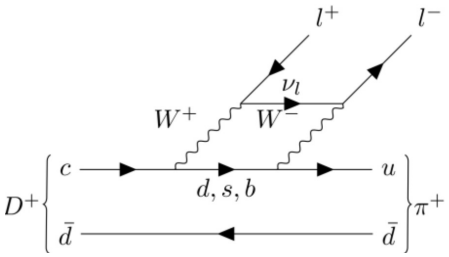
D^+_s : 2.1%(Belle 2021) → 1.96%.

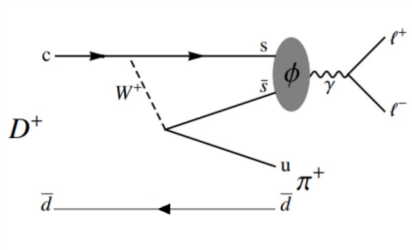
N.B. The SCS modes can receive interfering amplitudes with different weak phases ($V_{cd}V^*_{ud}$, $V_{cs}V^*_{us}$): $A_{CP}^{SM} \sim$ O(10^{-4}–10^{-3}).

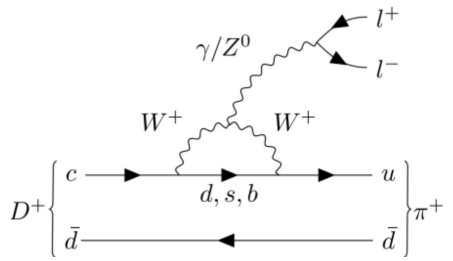
Part 2 – rare decays











Search for $D^+ \to \pi^+ e^+ e^-$

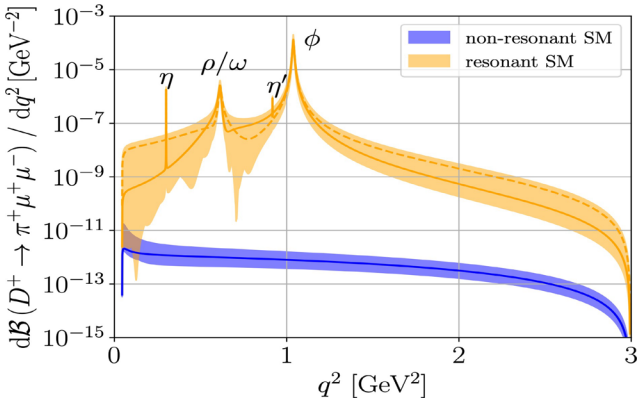
Paper in preparation

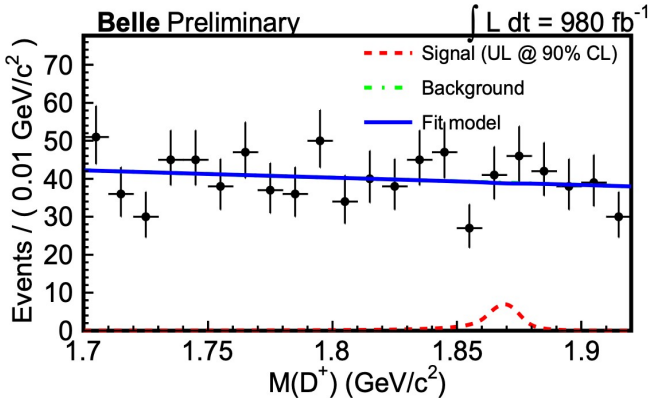
Rare FCNC charm decay, potentially sensitive to BSM physics

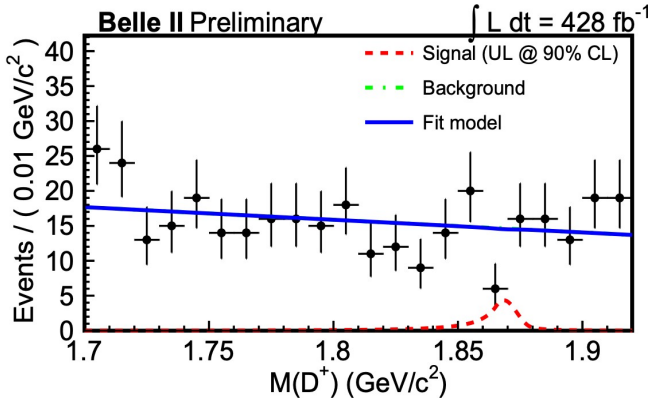
- Search for signal events in q^2 bins, separated from intermediate vector resonances

428 fb^{-1} of Belle II, 980 fb^{-1} of Belle

Dielectron invariant mass



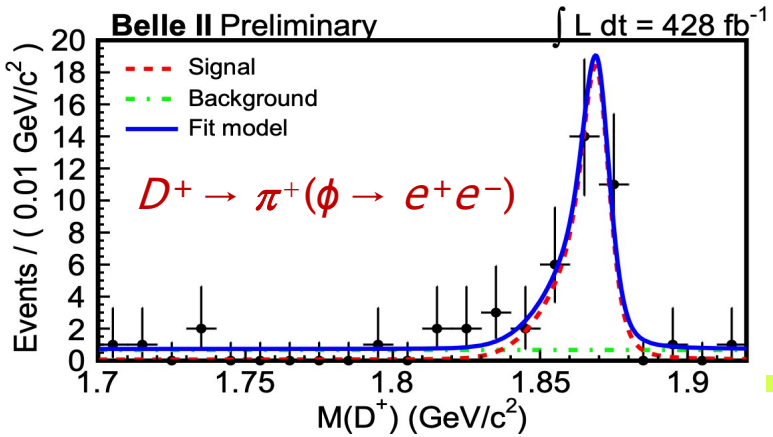




Extract signal yield with simultaneous fit to $M(\pi^+e^+e^-)$

Determine branching fraction relative to $D^+ \to \pi^+(\phi \to K^+K^-)$

Validate analysis with $D^+ \to \pi^+(\phi \to e^+e^-)$



$$I_1 = (0.20, 0.50)$$
$$I_2 = (0.56, 0.95)$$
$$I_3 = (1.05, 1.75)$$
$$I_{\text{full}} = I_1 \cup I_2 \cup I_3$$
$$I_\phi^{\text{Valid.}} = (0.995, 1.035)$$

No significant signal

Upper limits determined for q^2 bins and full mass range

Improved precision by a factor of >2

90% CL

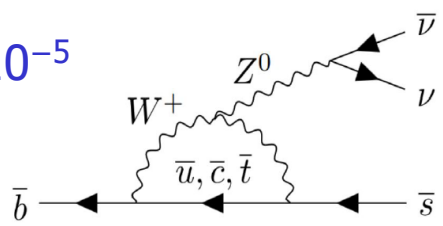
$M(e^+e^-)$ interval	Efficiency (%) Belle	Efficiency (%) Belle II	N_{sig} Belle	N_{sig} Belle II	$\mathcal{B}$ ($\times 10^{-7}$)	UL ($\times 10^{-7}$)
I_1	3.82 ± 0.04	4.73 ± 0.04	-1.7 ± 5.8	-1.0 ± 3.4	-0.6 ± 2.0	< 3.0
I_2	5.03 ± 0.03	6.14 ± 0.03	0.0 ± 6.0	0.0 ± 3.6	0.0 ± 2.1	< 3.3
I_3	5.94 ± 0.03	7.42 ± 0.03	-2.0 ± 5.8	-1.2 ± 3.4	-0.7 ± 2.0	< 2.9
I_{full}	5.29 ± 0.02	6.57 ± 0.02	-0.3 ± 9.6	-0.2 ± 5.7	-0.1 ± 3.3	< 4.7
$I_\phi^{\text{Valid.}}$	4.75 ± 0.02	6.13 ± 0.02	$51 \pm 6 \pm 3$	$30 \pm 4 \pm 2$	$17.5 \pm 2.2 \pm 1.2$	-

$B \to X_s \nu\bar{\nu}$ decay: inclusive branching fraction

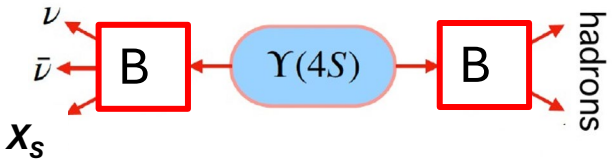
PRL136(2026) 23, 231801

- Standard model prediction BR = (2.9 ±0.3) $\times 10^{-5}$
- Previous results: Upper limit at 90% CL

from ALEPH, $BR < 6.4 \times 10^{-4}$



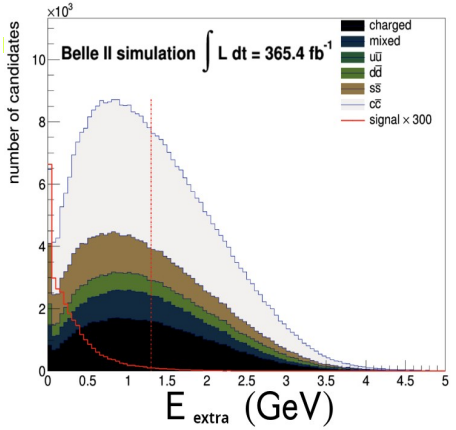
Analysis:

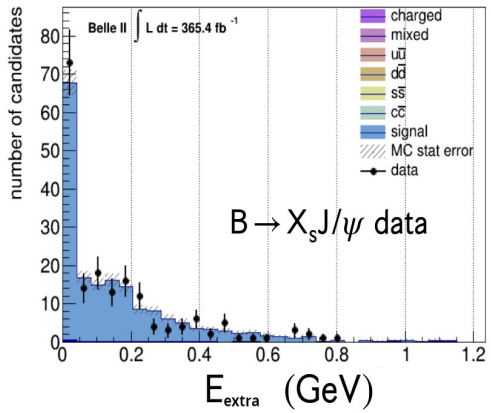


- Dataset Belle II run 1
- Hadronic tagging (full reconstruction of the decay of the other B in the event → see talk by Steve Robertson)
- X_s reconstructed from $Kn\pi$ ($n \leq 4$) and $3K(\pi)$ (30 modes)
- Background suppression via training of a classifier
- Extended binned maximum likelihood fit on the classifier output

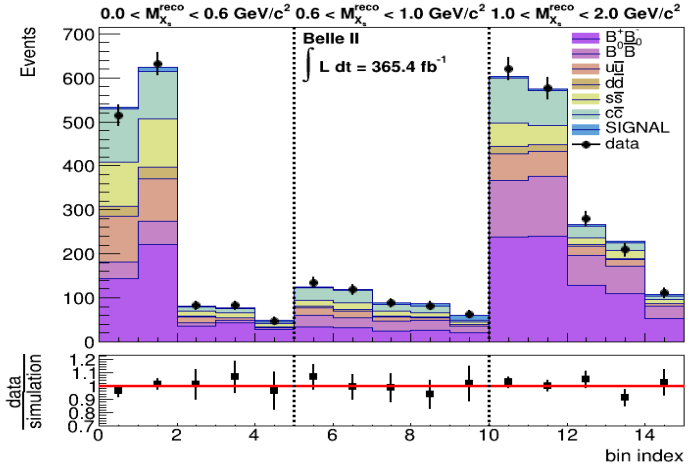
Region	$\mathcal{B}(B \to X_s \nu\bar{\nu}) \times 10^5$	Upper limit $\times 10^5$
$0 < M(X_s) < 0.6$	$0.3 \pm 0.8^{+0.8}_{-0.7}$	2.2
$0.6 < M(X_s) < 1.0$	$3.5^{+2.7+3.1}_{-2.5-2.6}$	9.3
$1.0 < M(X_s) < m_B$	$5.1^{+9.2+12.9}_{-8.8-11.0}$	30.9
Full range	$8.8^{+8.5+12.6}_{-8.2-10.7}$	32.7

The limits are consistent with the 2023 $B \to K^+ \nu\bar{\nu}$ result.





E_{extra} = extra energy in the calorimeter



→ The inclusive measurement has different sensitivity to NP than the exclusive measurements, and the improved limit serves as constraint for the exclusive searches

$B \to X_s \ell^+ \ell^-$ decay: inclusive branching fraction

Paper in preparation

- Measure inclusive $B \to X_s \ell^+ \ell^-$ branching fraction ($\ell \in \{e, \mu\}$)
- First test of lepton flavour universality with $R_{X_s} = \frac{\mathcal{B}(B \to X_s \mu^+ \mu^-)}{\mathcal{B}(B \to X_s e^+ e^-)}$
  - Dataset: Belle II run 1

Analysis

- X_s reconstructed from $K n\pi$ ($n \leq 4$) and $3K$ (20 modes)
- Background suppression via training of 8 classifiers; improved X_s modelling
- Extended unbinned maximum likelihood fit on M_{bc}

$$\mathcal{B}(B \to X_s e^+ e^-) = \left(4.49 \pm 0.73^{+0.41}_{-0.31}\right) \times 10^{-6}$$

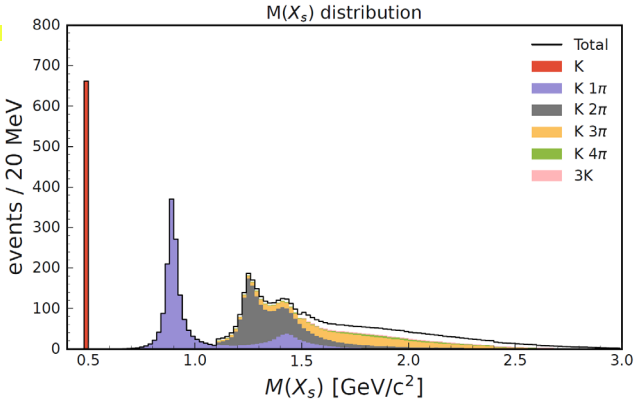
$$\mathcal{B}(B \to X_s \mu^+ \mu^-) = \left(3.33 \pm 0.64^{+0.30}_{-0.24}\right) \times 10^{-6}$$

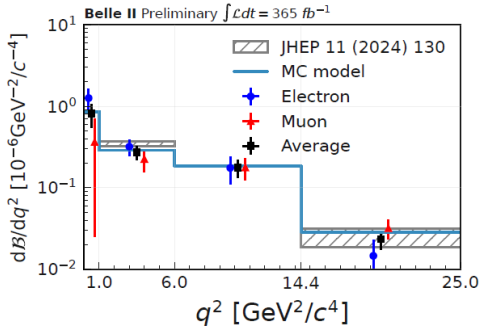
$$\mathcal{B}(B \to X_s \ell^+ \ell^-) = \left(3.91 \pm 0.49^{+0.34}_{-0.26}\right) \times 10^{-6}$$

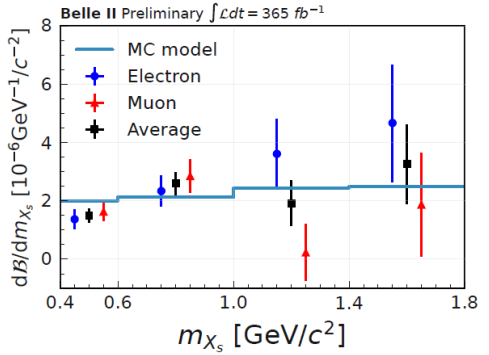
→ Improved the precision by 2 compared to the previous measurement

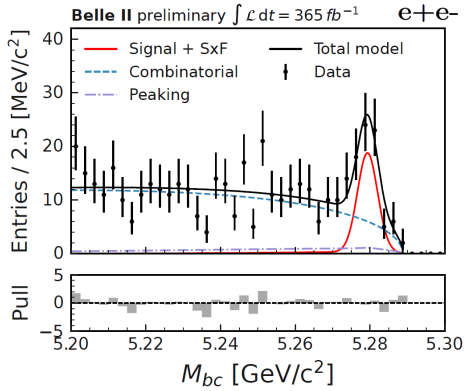
Lepton flavour universality test ratio $R_{X_s} = 0.74 \pm 0.19 \pm 0.04$

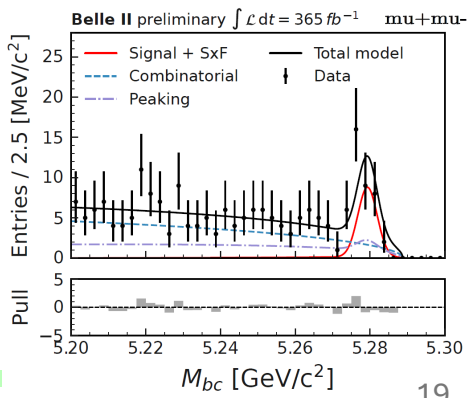
→ Results are compatible with the Standard Model predictions









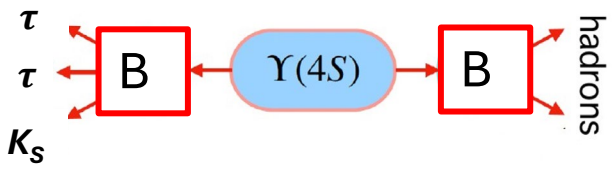


Search for $B^0 \to K_S^0 \tau^+ \tau^-$

arxiv:2607.25607, submitted to JHEP

Motivation: $b \to s\tau\tau$ transitions occur only at the loop level as flavour-changing neutral currents that provide precision tests of the SM, and excellent sensitivity to BSM.

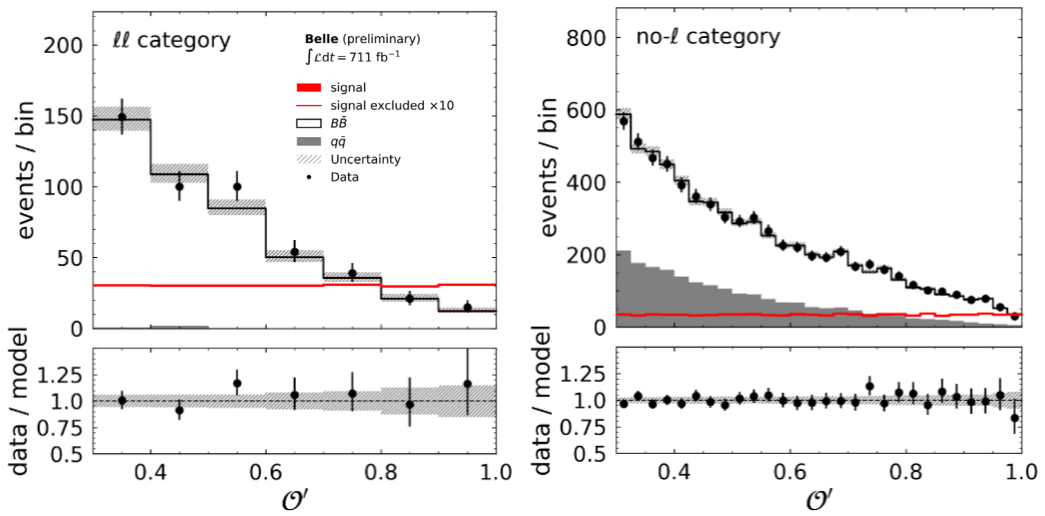
Observed flavor anomalies + BSM scenarios suggest large enhancements ($\mathcal{B}^{\mathrm{BSM}} \sim 10^{-5} - 10^{-4}$) to SM branching fraction ($\mathcal{B}^{\mathrm{SM}} \sim 10^{-7}$)



Analysis:

- Hadronic B-tagging (full reconstruction of the decay of the other B in the event → see talk by Steve Robertson)
- Reconstruct $\tau \to \ell\nu\bar{\nu}, \pi\nu, \rho\nu$ decays; group by $\tau\tau$ final state.
- Multivariate classification based on missing energy, residual energy in calorimeter, kinematics etc.
- Simultaneous fit to classifier output $\mathcal{O}'$ in five $\tau\tau$ categories in both datasets for signal extraction.

365 fb^{-1} of Belle II, 711 fb^{-1} of Belle



- Combined Belle + Belle II result:
  $\mathcal{B}(B^0 \to K_S^0 \tau^+ \tau^-) < 8.3 \times 10^{-4}$ (90% CL)

  → First search!

PRL137(2026)5,051805

- Isospin average with $B^+ \to K^+ \tau^+ \tau^-$:
  $\mathcal{B}(B \to K \tau^+ \tau^-) < 5.4 \times 10^{-4}$ (90% CL)

  → most stringent constraint to date on $b \to s\tau\tau$ transitions with a pseudoscalar kaon in the final state.

Summary and Outlook — Belle & Belle II

$B^0 \to \pi^0\pi^0$ time-dependent *CP* violation

Tag-side timing accesses $S(\pi^0\pi^0)$ without a signal vertex.

The conventional Δt method would need ≈20× more data for the same sensitivity.

CKM angle α/ϕ_2

New $B \to \rho\rho$ TDCPV results strengthen the isospin inputs.

Radiative $b \to s\,\gamma$ *CP* violation

World-leading Belle + Belle II measurements probe right-handed photons.

$K^0\,\pi^+\pi\,\gamma$ improves the precision on S by at least a factor of two.

Charm CPV: $D^+_{(s)} \to \eta h^+$ ($h = \pi, K$)

Preliminary A_{CP}: $\eta\pi^+$ statistical precision is comparable to LHCb, ηK^+: best statistical precision to date.

Search for $D^+ \to \pi^+ e^+ e^-$

Upper limits determined for q^2 bins and full mass range, improved by a factor of >2

Inclusive $B \to X_s \ell^+\ell^-$ and $B \to X_s \nu\bar{\nu}$

$\ell^+\ell^-$: ≈2× better precision, R_{Xs} = 0.74 ± 0.19 ± 0.04, compatible with the SM.

$\nu\bar{\nu}$: ≈2× stronger upper limits constrain possible new physics.

Search for $B^0 \to K^0_S \tau^+\tau^-$

First search for $B^0 \to K^0_S \tau^+\tau^-$ and a combined upper limit on isospin average, most stringent constraint to date on $b \to s\tau\tau$ transitions with a pseudoscalar kaon in the final state.

Outlook —Belle II

Belle II strengthens CKM tests and new-physics searches with improved precision

There is more to come ☺

- Collected ~0.9 ab^{-1} (+1 ab^{-1} Belle)
- By 2032: ~ 10 ab^{-1}
- By 2043: ~30-50 ab^{-1}

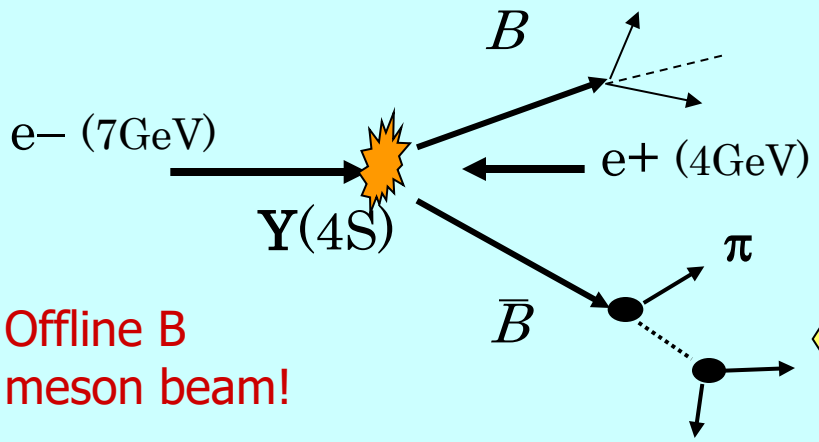
Stay tuned…

More slides...

Full Event Interpretation (FEI)

Idea: reconstruct one of the B's to tag B flavor/charge, determine its momentum, and exclude decay products of this B from further analysis

(exactly two B's produced in $\Upsilon(4S)$ decays)



Offline B meson beam!

Decays of interest
- B → X_u l ν, π l ν
- B → K ν ν
- B → Dτν, τν

full reconstruction:
- hadronic tagging, B→Dπ etc.

partial reconstruction:
- semileptonic tagging

Powerful tool for B decays with neutrinos

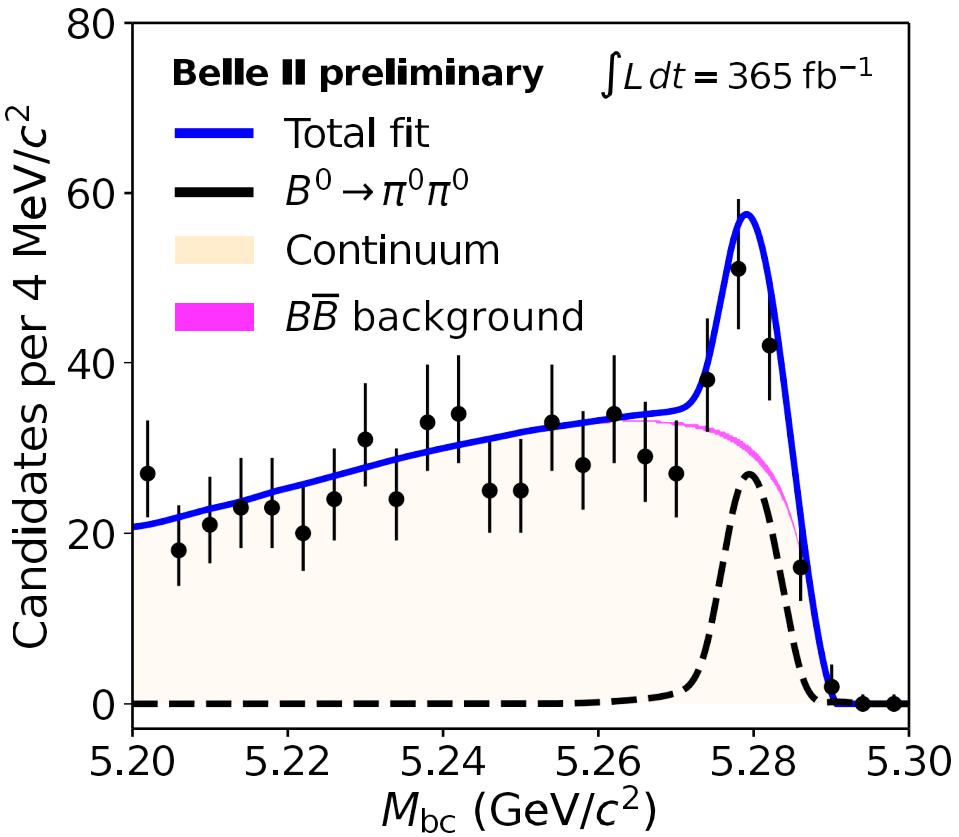
→unique feature at B factories

Selection of $B^0 \to \pi^0\pi^0$ events

Build upon recent measurement of *BR* and time-integrated *CP* violation [PRD 11(2025) L071102].

Extend to include t_{tag} and optimize signal selection to enhance sensitivity to time-dependent *CP* violation.

Use ~175 signal candidates from Run I data.



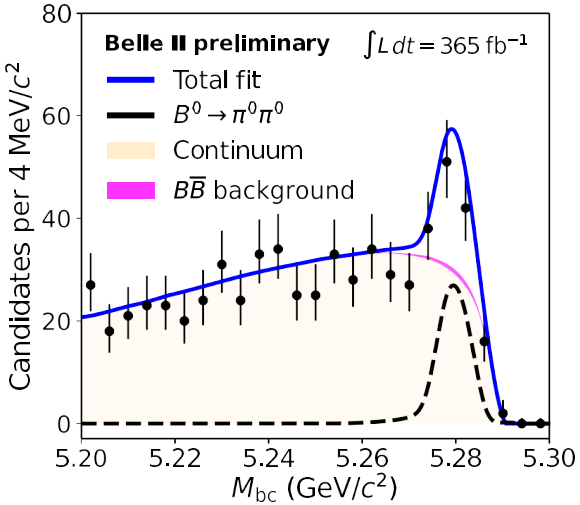
Beam-constrained mass (similar to invariant mass, uses more precise beam information)

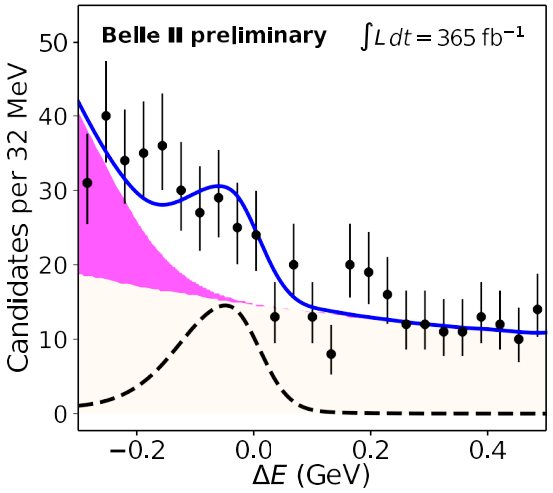
$B^0 \to \pi^0\pi^0$: Multidimensional fit

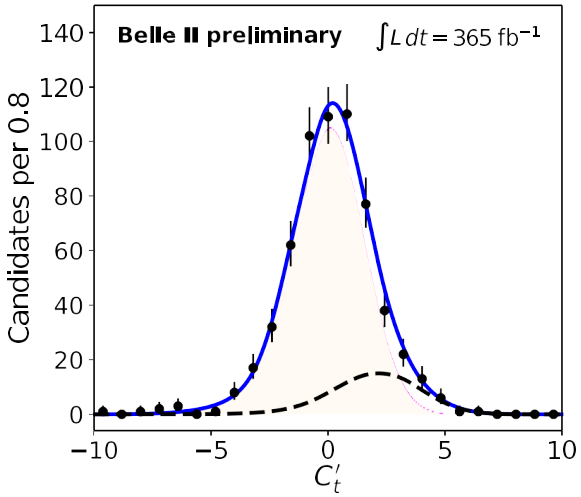
Difference between observed and expected energy

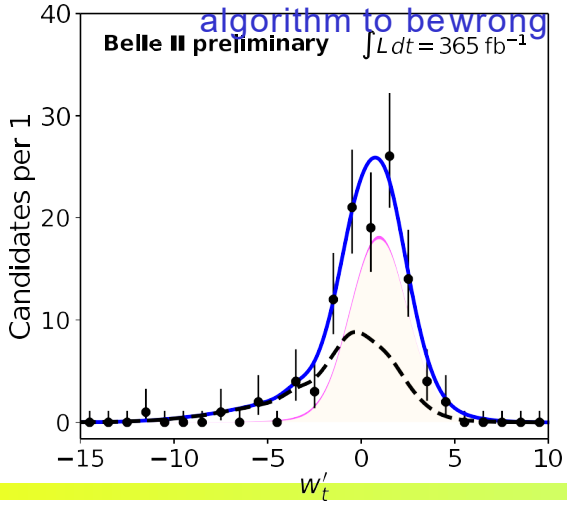
Multivariate variable to suppress bkg from $e^+e^- \to q\bar{q}$

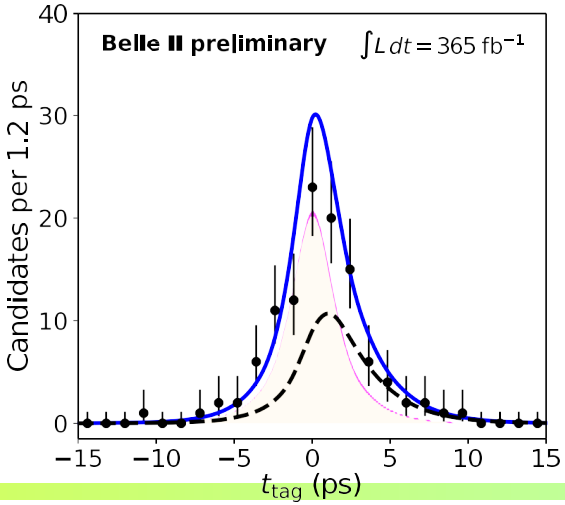
Probability of flavor tagger algorithm to be wrong

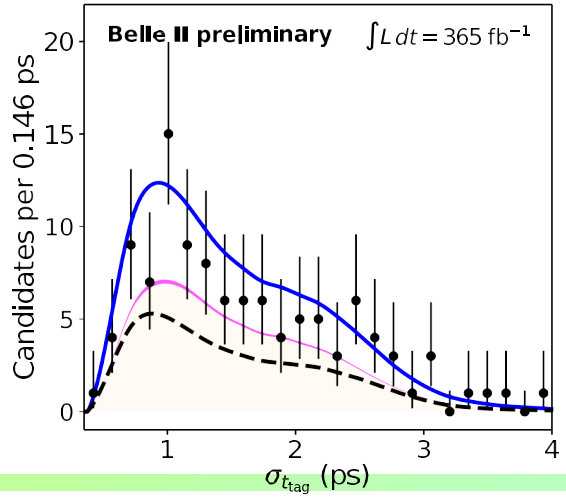








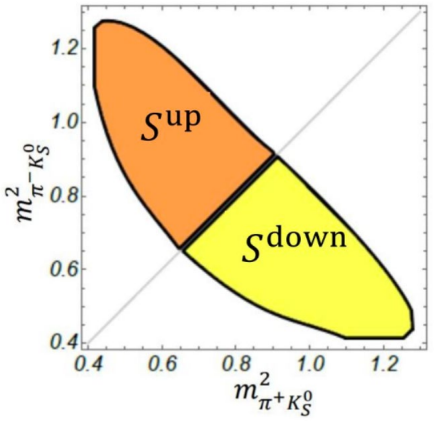




More TDCPV analyses at Belle II: $B^0 \to K^0 \pi^+\pi^-\gamma$

Same motivation as for $B^0 \to K^0 \pi^0 \gamma$

Use Belle+Belle II data with improved AI-based flavour tagging and a K_S reconstruction.

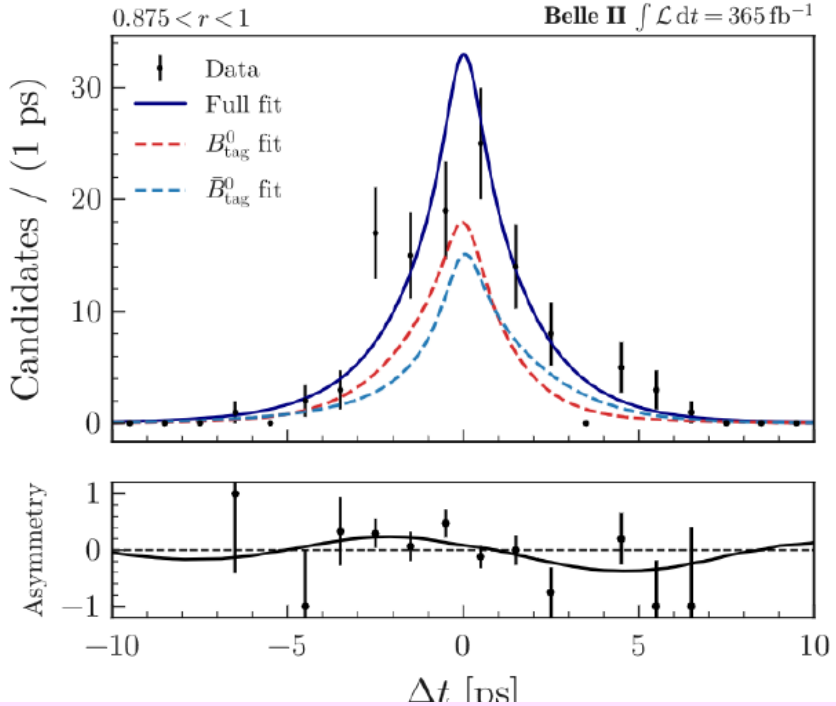


Divide the sample into 2 regions;

- $m^2(K^0_S\pi^+) > m^2(K^0_S\pi^-)$ (up)
- $m^2(K^0_S\pi^+) < m^2(K^0_S\pi^-)$ (down)

Two additional observables provide further constrains on the photon polarization

$$S^+ = S^{up} + S^{down}$$
$$S^- = S^{up} - S^{down}$$



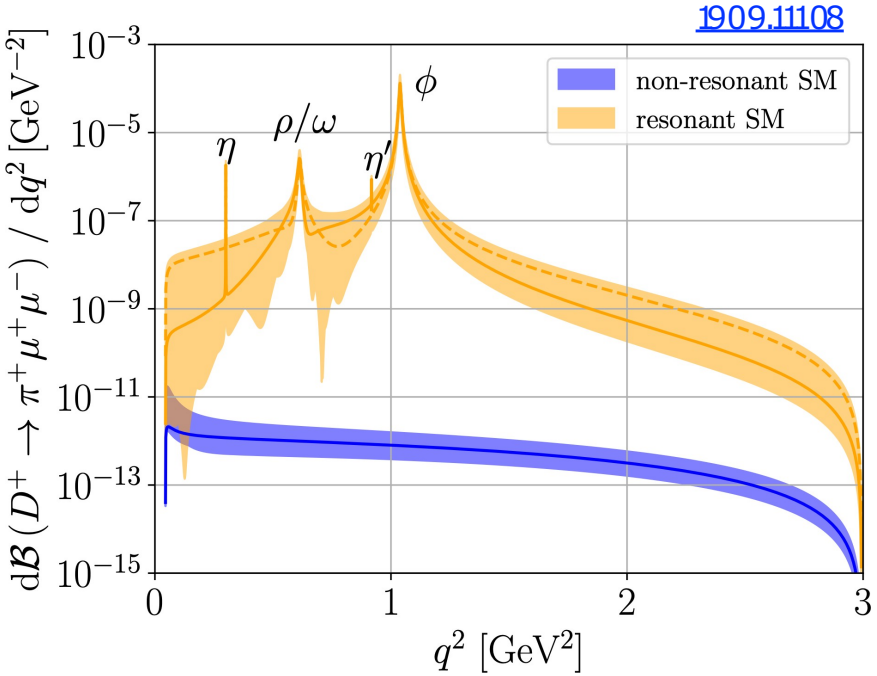
$$C = -0.17 \pm 0.09 \pm 0.04,\ S = -0.29 \pm 0.11 \pm 0.05$$
$$S^+ = -0.57 \pm 0.23 \pm 0.10,\ S^- = 0.31 \pm 0.24 \pm 0.05$$

Most precise measurement of S in b → s γ transitions
Improvement by at least a factor of 2 vs. Belle and Babar measurements [PhysRevLett.101.251601, PhysRevD.93.052013]

Search for rare flavor-changing neutral currents (FCNC)

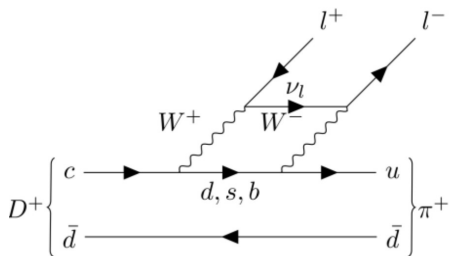
Decay rates may be enhanced due to physics Beyond the Standard Model

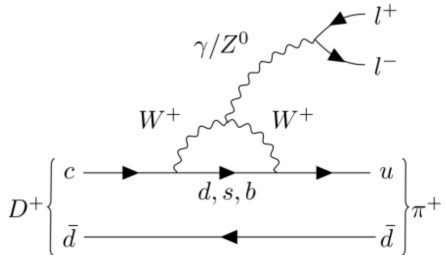
- FCNC decay $c \to u\ell^+\ell^-$ suppressed in SM; proceeds via loop or box diagrams
  - SM long-distance contributions dominate near resonances: $\mathcal{B}(SM) \sim \mathcal{O}(10^{-6})$
  - BSM contributions may be comparable far from resonances: $\mathcal{B}(SM) \sim \mathcal{O}(10^{-12})$

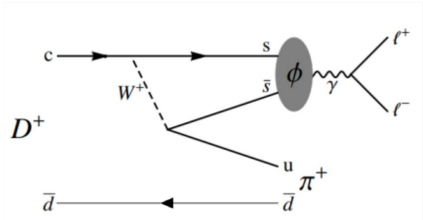


Dielectron invariant mass

- Belle II has strong potential for final states with electrons, e.g. $D^+ \to \pi^+e^+e^-$







90% CLs

BaBar (2011), 384/fb, arxiv:1107.4465	LHCb (2021), 1.6/fb arxiv:2011.00217
$\mathcal{B}(D^+ \to \pi^+e^+e^-) < 1.1 \times 10^{-6}$	$\mathcal{B}(D^+ \to \pi^+e^+e^-) < 1.6 \times 10^{-6}$
$\mathcal{B}(D^+ \to \pi^+\mu^+\mu^-) < 6.5 \times 10^{-6}$	$\mathcal{B}(D^+ \to \pi^+\mu^+\mu^-) < 6.7 \times 10^{-8}$

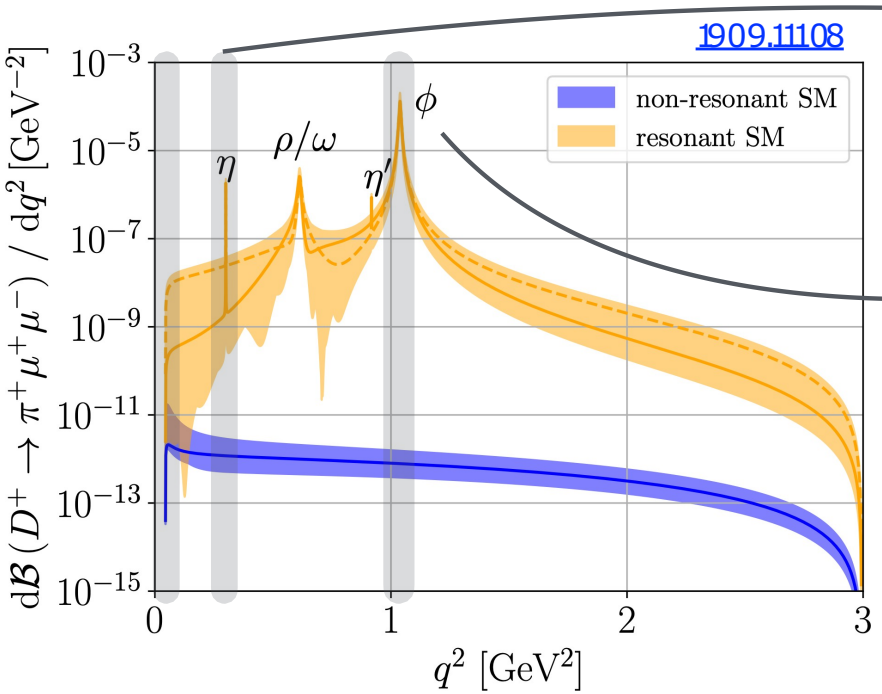
Search for $D^+ \to \pi^+ e^+ e^-$

Belle + Belle II 980+428 fb

Paper in preparation

Rare FCNC charm decay, potentially sensitive to BSM physics

- Search for signal events in q^2 bins, separated from intermediate vector resonances
  - Extract signal yield with simultaneous, unbinned maximum-likelihood fit to $M(\pi^+ e^+ e^-)$
  - Determine branching fraction relative to $D^+ \to \pi^+(\phi \to K^+ K^-)$



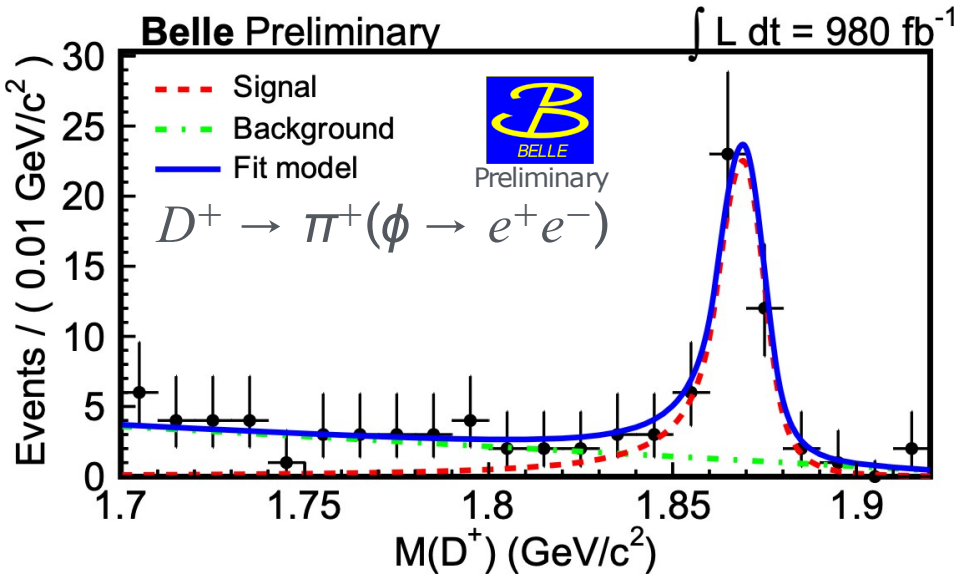
Dielectron invariant mass

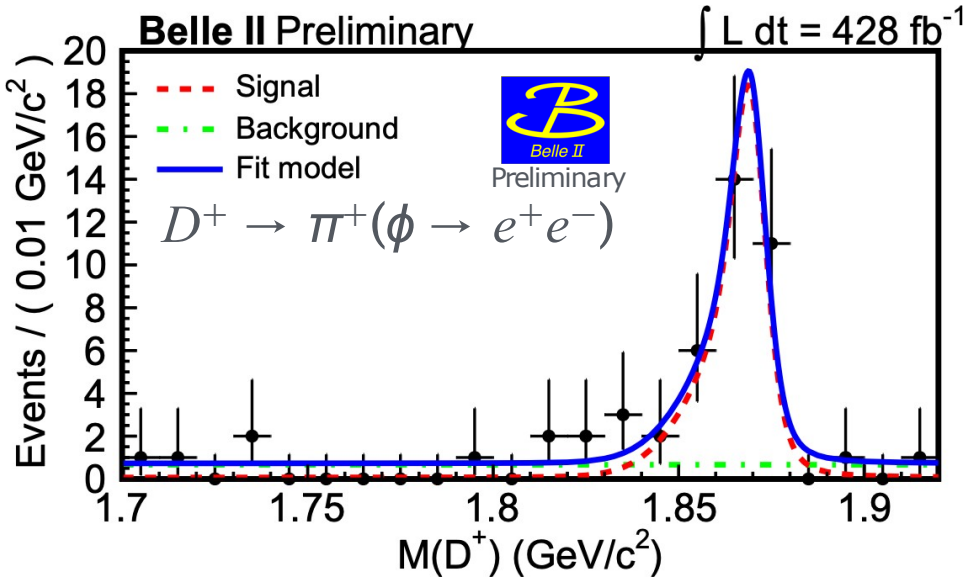
- Exclude contributions from $D^+ \to \pi^+(\eta \to \gamma e^+ e^-)$, $D^+ \to \pi^+(\phi \to e^+ e^-)$ and low-mass di-leptons
- Suppress backgrounds with random forest classifier (optimized separately for Belle and Belle II)

Search for $D^+ \to \pi^+ e^+ e^-$

Rare FCNC charm decay, potentially sensitive to BSM physics

- Search for signal events in q^2 bins, separated from intermediate vector resonances
  - Extract signal yield with simultaneous, unbinned maximum-likelihood fit to $M(\pi^+ e^+ e^-)$
  - Determine branching fraction relative to $D^+ \to \pi^+(\phi \to K^+ K^-)$





- Validate analysis with measurement near vector state:

$$\mathcal{B}(D^+ \to \pi^+(\phi \to e^+e^-)) = (1.75 \pm 0.22 \pm 0.12) \times 10^{-6}$$

c.f. CLEO 2010 measurement [1009.1606]

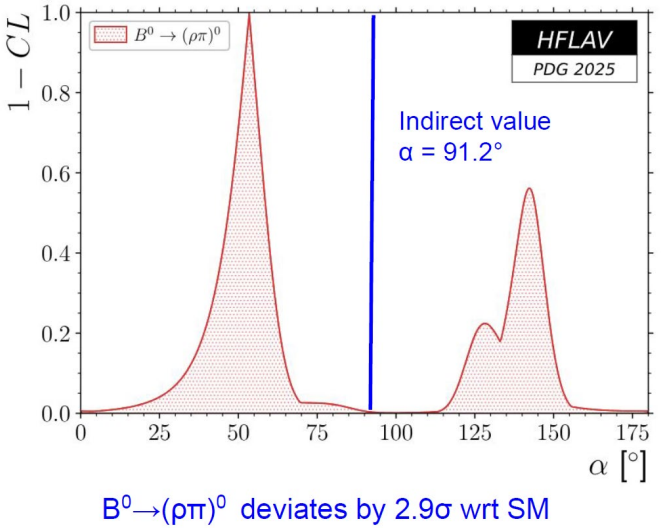
$$(1.7^{+1.4}_{-0.9} \pm 0.1) \times 10^{-6}$$

Possible issue with the $(\rho\pi)^0$ sign convention issue

Radek Žlebčik, arXiv:2609.31828, subm. to PRD

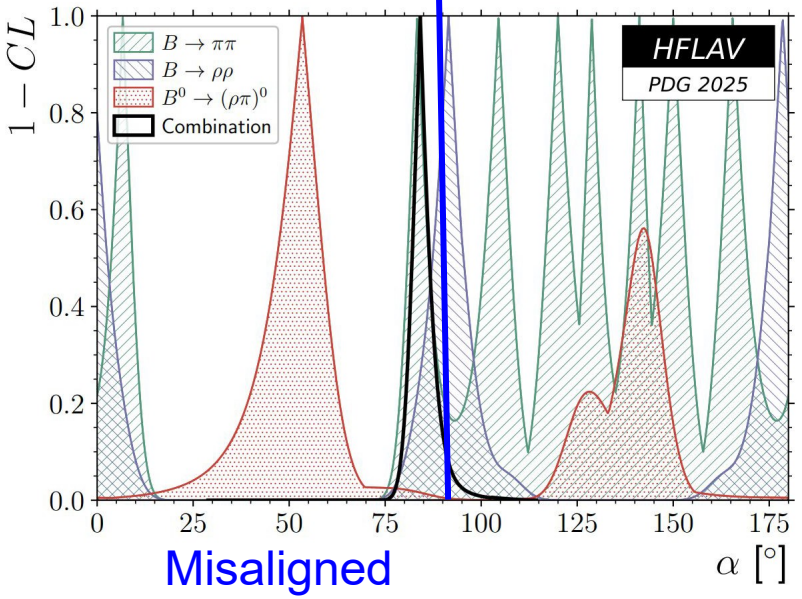
Impact of Helicity Isospin Convention Matching on the Extraction of α from $B^0 \to (\rho\pi)^0$

We show that the $\rho \to \pi\pi$ helicity convention used in the time-dependent Dalitz-plot measurements of $B^0 \to (\rho\pi)^0$ decays does not match the convention assumed in the subsequent isospin analysis. Once corrected, the tension between the direct determination of the unitarity-triangle angle α from these decays and its indirect determination from global fits decreases from 2.9σ to 2.1σ. Combined with the $B \to \pi\pi$ and $B \to \rho\rho$ modes, the direct determination becomes $\alpha = (87.0^{+11.8}_{-4.7})^\circ$, compared with the original world average $(84.1^{+3.7}_{-3.0})^\circ$.



$B^0 \to (\rho\pi)^0$ deviates by 2.9σ wrt SM

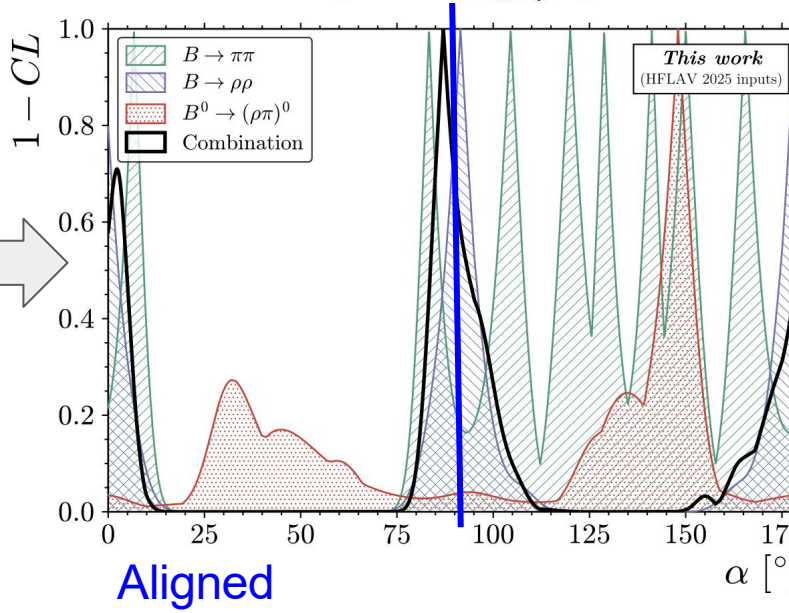
$(84.1^{+3.7}_{-3.0})^\circ$



Misaligned

Once this mismatch in conventions is corrected

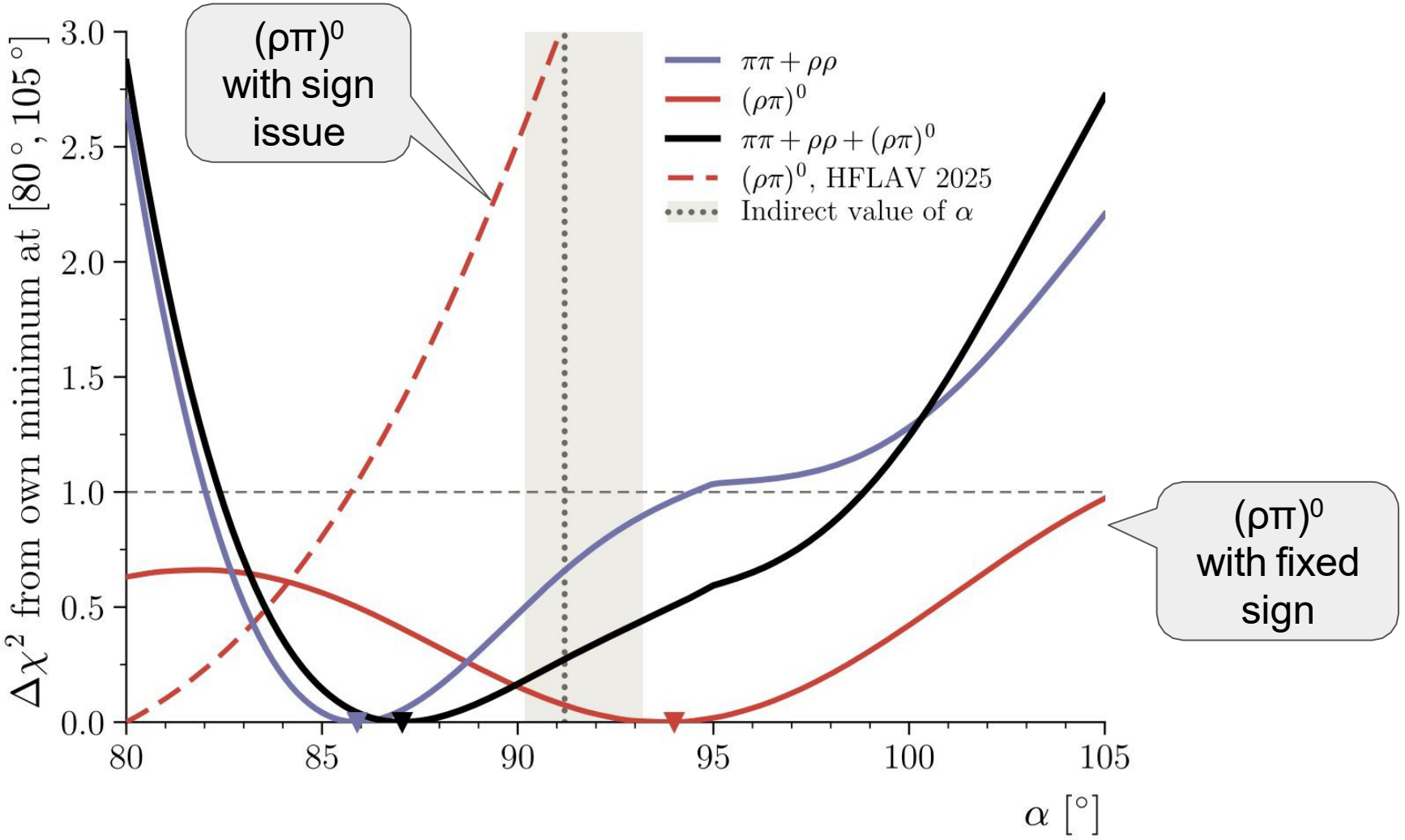
$(87.0^{+11.8}_{-4.7})^\circ$



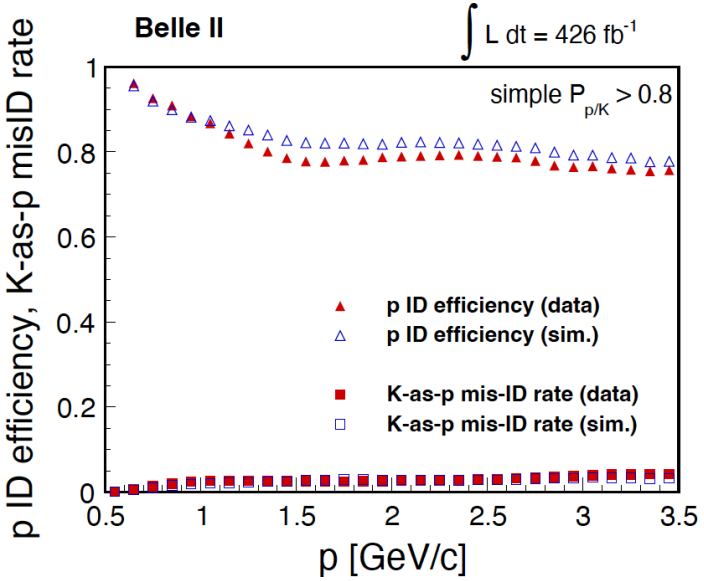
Aligned

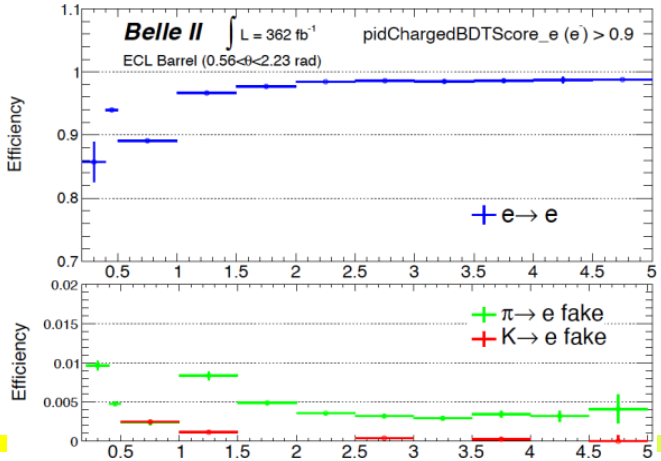
The α/ϕ_2 errors are highly non-Gaussian

Radek Žlebčik, arXiv:2609.31828, subm. to PRD



Belle II performance

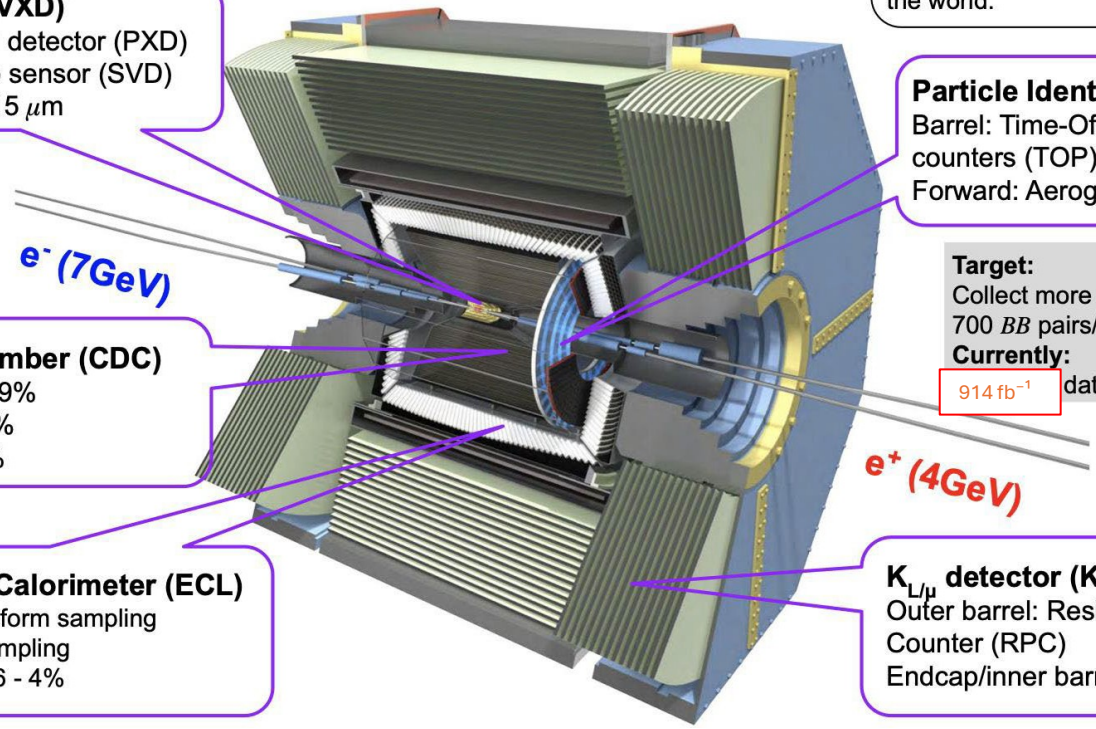




Features:
Energy-asymmetric e^+e^- collider →low background.
Highest luminosity 5.3×10^{34} cm^{-2}s^{-1} in the world.

Vertex detector (VXD)
Inner 2 layers: pixel detector (PXD)
Outer 4 layers: strip sensor (SVD)
Vertex resolution : 15 μm

Particle Identification
Barrel: Time-Of-Propagation counters (TOP)
Forward: Aerogel RICH (ARICH)



Target:
Collect more than 50 ab^{-1} data;
700 BB pairs/second
Currently:
914 fb^{-1} data are collected.

Central Drift Chamber (CDC)
Track efficiency ~ 99%
dE/dx resolution : 5%
p_T resolution : 0.4 %

ElectroMagnetic Calorimeter (ECL)
Barrel: CsI(Tl) + waveform sampling
Endcap: waveform sampling
Energy resolution : 1.6 - 4%

$K_{L/\mu}$ detector (KLM)
Outer barrel: Resistive Plate Counter (RPC)
Endcap/inner barrel: Scintillator

Particle ID and separation
- K/π: ε ~86% @ 5% fake (0.5 – 4.5 GeV/c)
- μ/π: ε~90% @ 3% fake (0.2 – 5.0 GeV/c)
- e/π: ε ~98% @ 0.5% fake (0.2 – 5.0 GeV/c)

arXiv:2606.26274, EPJ-C85, 1237 (2025)

