Flavor Physics with Belle and Belle II

Takeo Higuchi on behalf of the Belle and Belle II collaborations
Kavli IPMU (WPI), the University of Tokyo

Flavor Physics

Needs for new physics beyond the Standard Model of particle physics

- What made the matter-antimatter asymmetry of the Universe?
- What is dark matter?
- What gave masses to the neutrinos?
- What makes the Higgs boson so light? …

Approach to the NP of flavor physics

- Study particle behaviors associated with the quark and/or lepton **flavor change**, and compare the measured parameters with the SM prediction → **discrepancy = discovery of the NP.**
- Measure **as many physics observables** as possible, develop a collection of discrepancies in the observables (right table), and infer the true model of the new physics from the collection.

"DNA" of flavor physics effects

★★★ large effects, ★★ visible but small

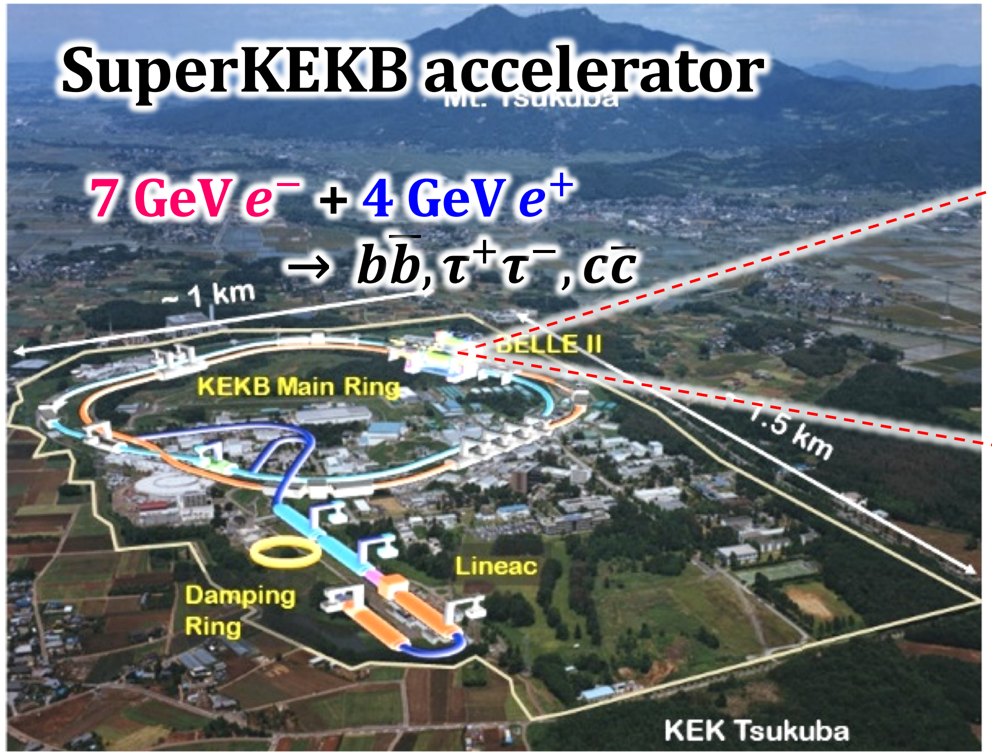
W. Altmannshofer *et al.*, Nucl. Phys. B **830**, 17 (2010).

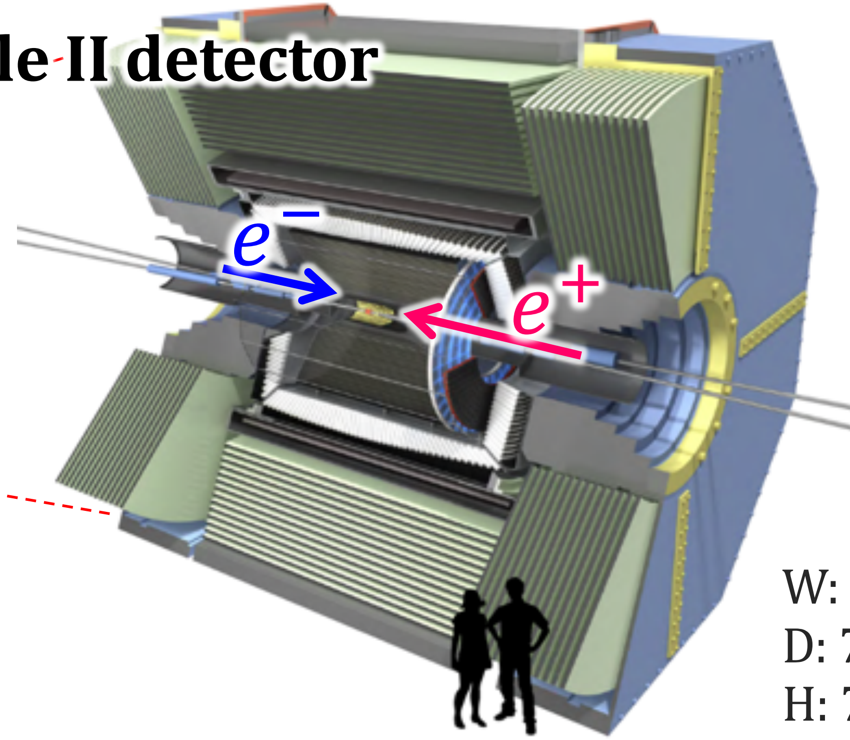
	AC	RVV2	AKM	δLL	FBMSSM	LHT	RS
D^0-$\bar{D}^0$	★★★	★	★	★	★	★★★	?
ϵ_K	★	★★★	★★★	★	★	★★	★★★
$S_{\psi\phi}$	★★★	★★★	★★★	★	★	★★★	★★★
$S_{\phi K_S^0}$	★★★	★★	★	★★★	★★★	★	?
$A_{CP}(B \to X_s\gamma)$	★	★	★	★★★	★★★	★	?
$A_{7,8}(B \to K^*\mu^+\mu^-)$	★	★	★	★★★	★★★	★★	?
$A_9(B \to K^*\mu^+\mu^-)$	★	★	★	★	★	★	?
$B \to K^{(*)}\nu\bar{\nu}$	★	★	★	★	★	★	★
$B_s \to \mu^+\mu^-$	★★★	★★★	★★★	★★★	★★★	★	★
$K^+ \to \pi^+\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★
$K_L^0 \to \pi^0\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★
$\mu \to e\gamma$	★★★	★★★	★★★	★★★	★★★	★★★	★★★
$\tau \to e\gamma$	★★★	★★★	★	★★★	★★★	★★★	★★★
$\mu + N \to e + N$	★★★	★★★	★★★	★★★	★★★	★★★	★★★

New physics models

Belle II Experiment

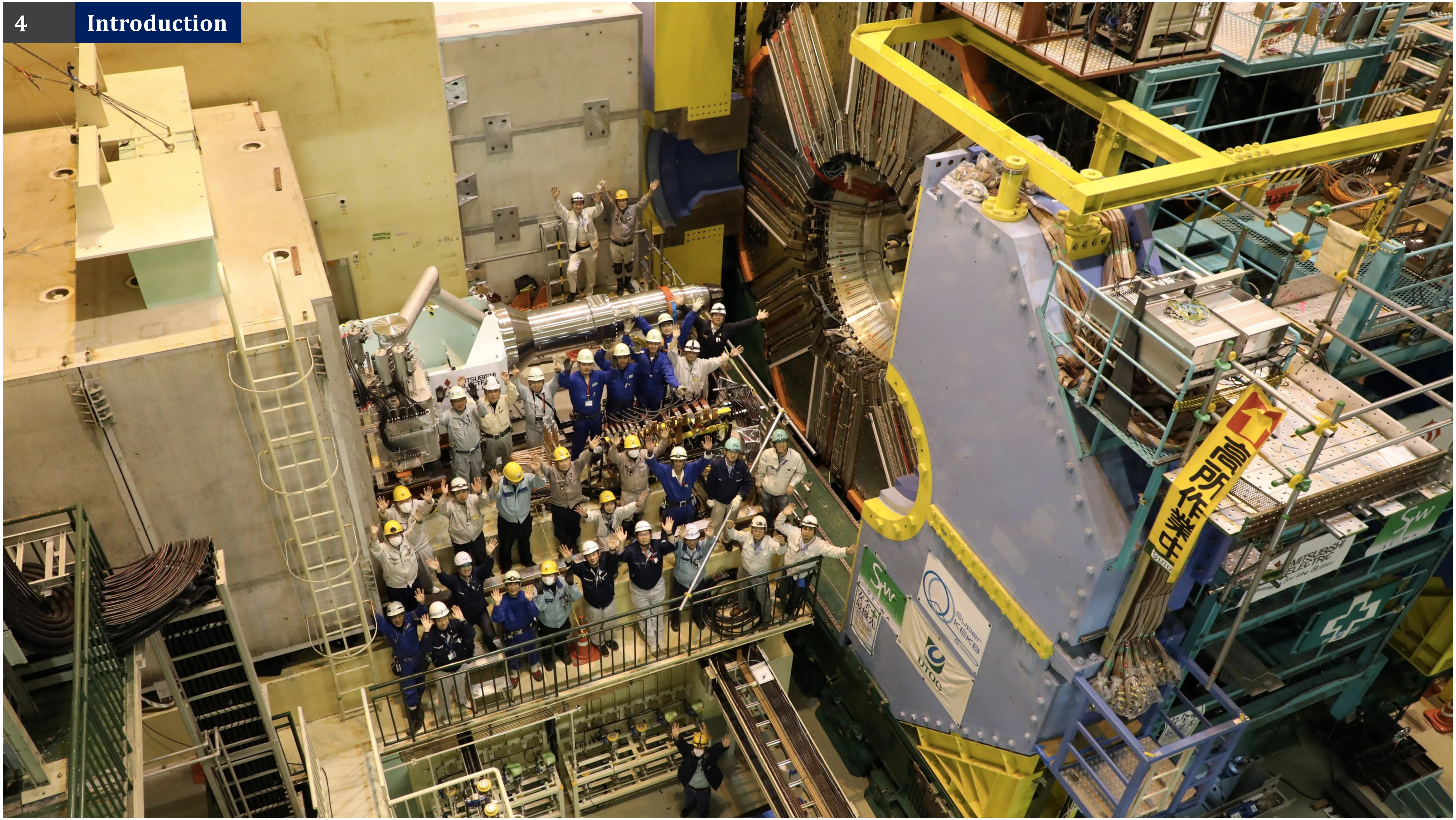
In the quest for the new physics, we started an e^+-e^- collider experiment Belle II in Japan in March 2019.





	Current record	Target / design
$\int \mathcal{L}dt$	424 fb^{-1}	50 ab^{-1}
$\mathcal{L}_{\text{peak}}$ [$\text{cm}^{-2}\text{s}^{-1}$]	4.7×10^{34} (WR)	60×10^{34}

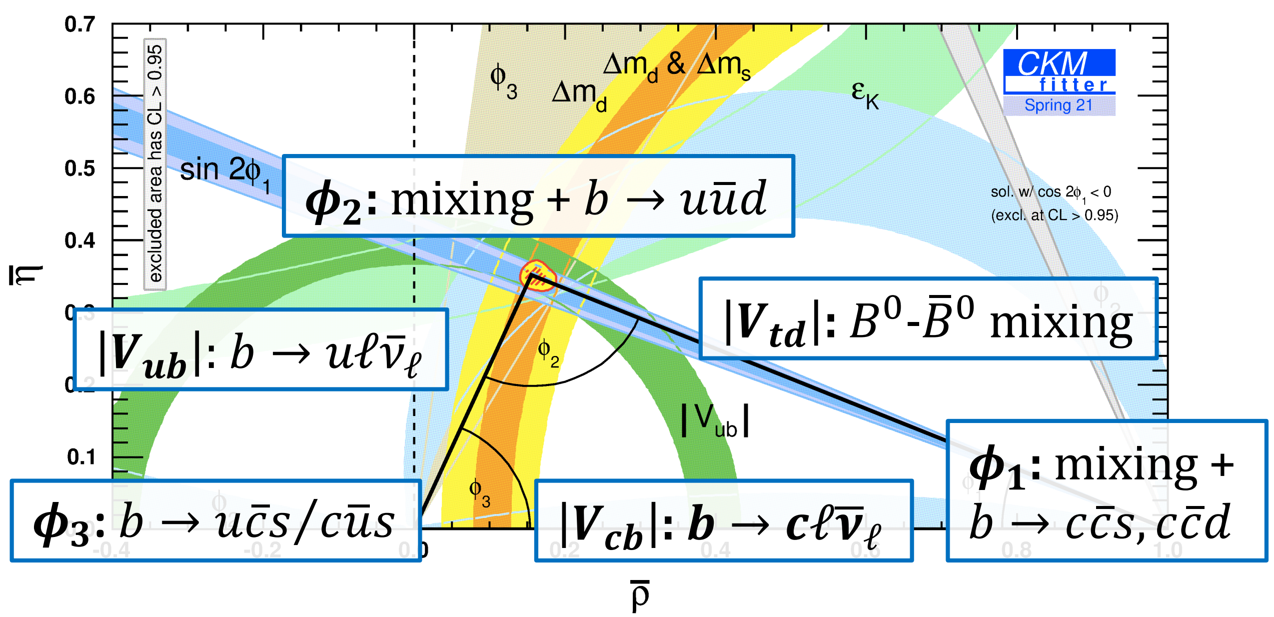
- **Silicon detectors** for particle position measurement
- **Drift chamber** for p_t and dE/dx measurement
- **TOP counters** and **ARICH counters** for PID
- **CsI(Tl) crystals** for $e^\pm$ and γ calorimetry
- **Iron/RPC sandwiches** for K_L and μ detection


Super KEKB
MITSUBISHI ELECTRIC

Test of the CKM Unitarity

CKM triangle

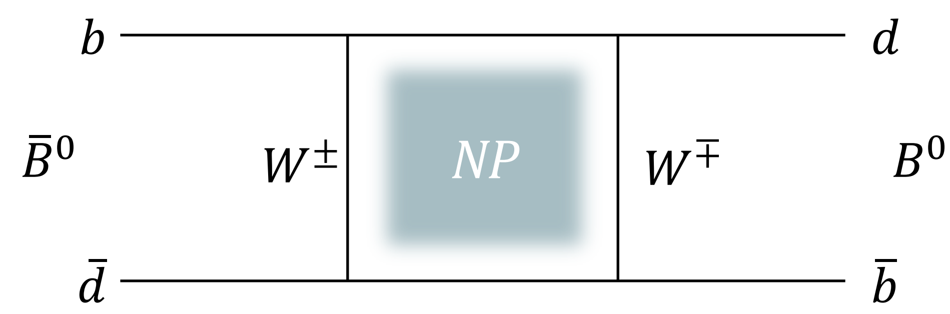
- The 9 elements of the quark mixing matrix a.k.a CKM matrix form a triangle, CKM triangle, for their unitarity condition.



- The CKM unitarity is tested by measuring the interior angles and sides of the CKM triangle.

CKM unitarity and new physics

- The new-physics particle propagated in the box diagram of the B^0-$\bar{B}^0$ mixing may violate the CKM-matrix unitarity.



- By precisely testing the CKM unitarity, Belle II can search for the new physics in an energy scale of **up to ~200 TeV** (when the new physics does not have a generation hierarchy).

➡ **Motivation for the CKM unitarity test at Belle II**

arXiv:2302.12898

Belle II 190 fb^{-1}

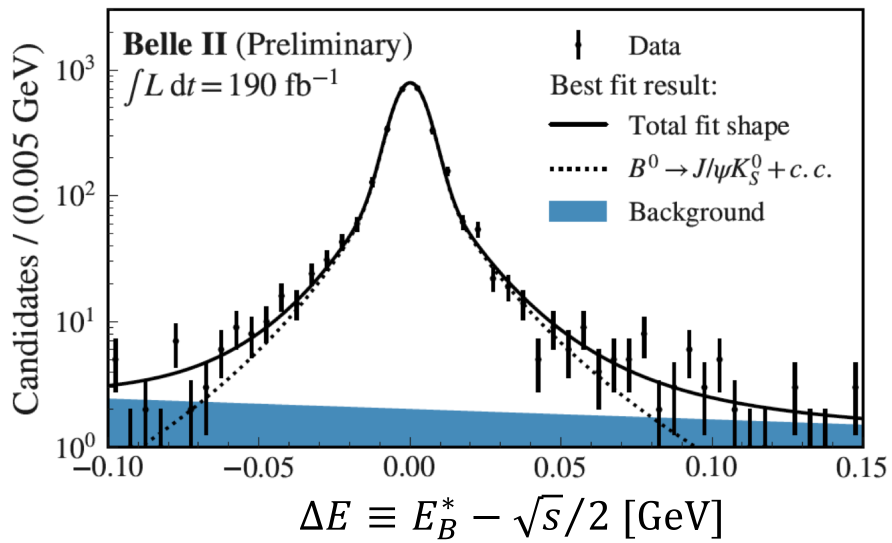
CKM Triangle Angle ϕ_1

- The *CP* asymmetry of the proper time difference distribution Δt of the two B mesons:

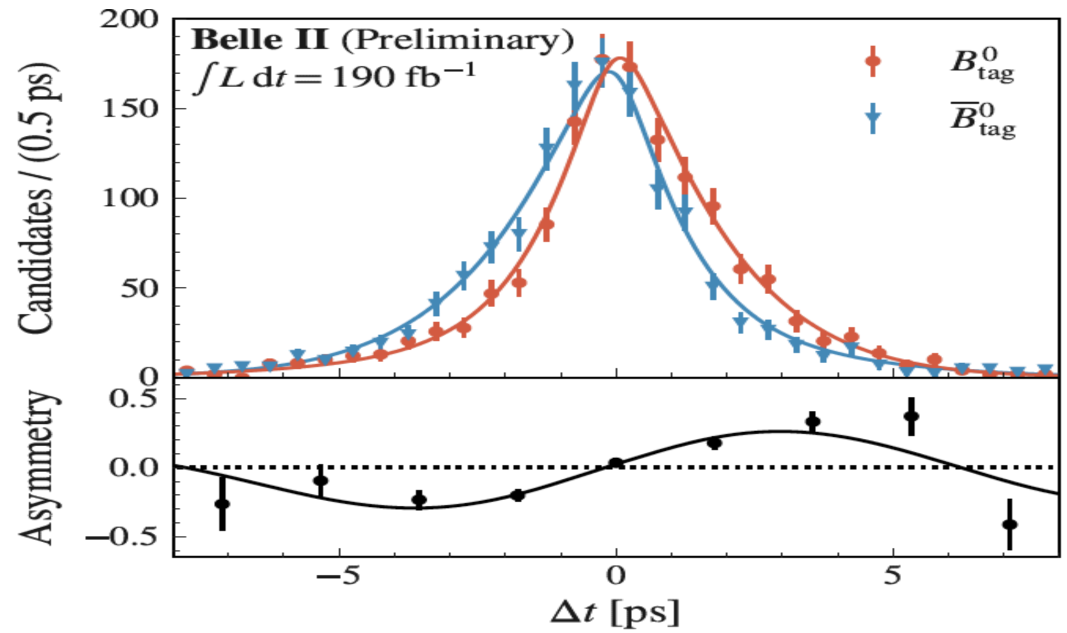
$$\frac{\mathcal{P}_{B^0}(\Delta t) - \mathcal{P}_{\bar{B}^0}(\Delta t)}{\mathcal{P}_{B^0}(\Delta t) + \mathcal{P}_{\bar{B}^0}(\Delta t)} \equiv \mathcal{A}(\Delta t)$$

$\mathcal{A}(\Delta t)$ for $B^0 \to J/\psi\, K_S^0$ $(b \to c\bar{c}s)$

- $\mathcal{A}(\Delta t) = S_{J/\psi K_S^0} \sin(\Delta m_d \Delta t) + A_{J/\psi K_S^0} \cos(\Delta m_d \Delta t)$
  - $S_{J/\psi K_S^0} \approx \sin 2\phi_1$



$S_{J/\psi K_S^0}$ and $A_{J/\psi K_S^0}$ results



$$S_{J/\psi K_S^0} = 0.720 \pm 0.062_{\rm (stat)} \pm 0.016_{\rm (syst)}$$

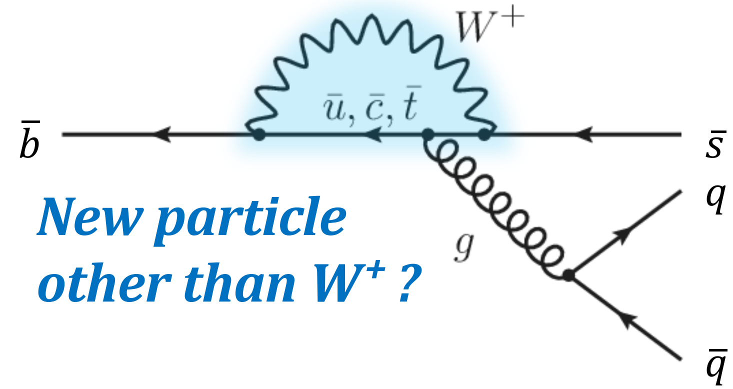
$$A_{J/\psi K_S^0} = 0.094 \pm 0.044^{+0.04}_{-0.017}$$

- $\sigma_{\rm syst}^{\rm Belle\ II} < \sigma_{\rm syst}^{\rm Belle}$ for Belle 140 fb^{-1} $(c\bar{c})K^0$ analysis thanks to improved Δt resolution.

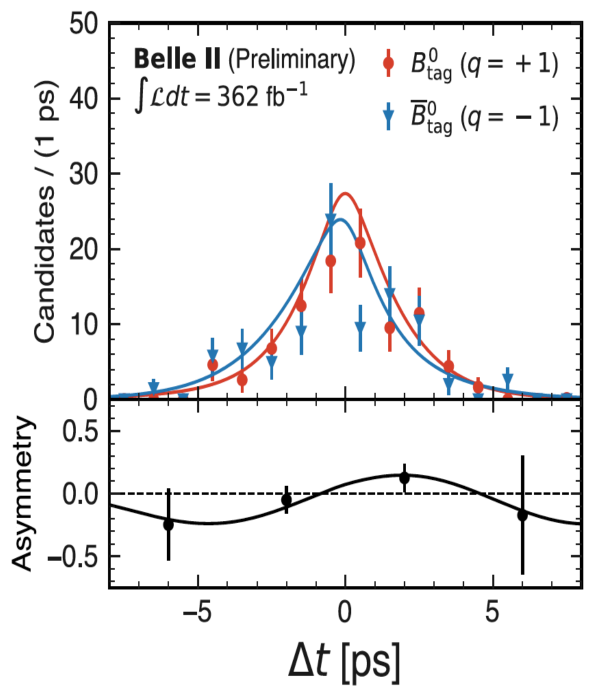
New for 2023
Belle II 362 fb^{-1}

Effective ϕ_1 for $b \to s q\bar{q}$

- $\mathcal{A}(\Delta t) = S_{sq\bar{q}} \sin(\Delta m_d \Delta t) + A_{sq\bar{q}} \cos(\Delta m_d \Delta t)$
- $S_{sq\bar{q}} \approx -\eta_{CP} S_{J/\psi K_S^0}$ in the SM since no CP-violating phase in the least-order $b \to s q\bar{q}$ diagram; $S_{sq\bar{q}} \neq -\eta_{CP} S_{J/\psi K_S^0}$ may happen if a NP particle propagated in the $b \to s q\bar{q}$ loop affects the decay.



$S_{sq\bar{q}}$ and $A_{sq\bar{q}}$ results for ϕK_S^0 (η_{CP}=−1) and $K_S^0 K_S^0 K_S^0$ (η_{CP}=+1)

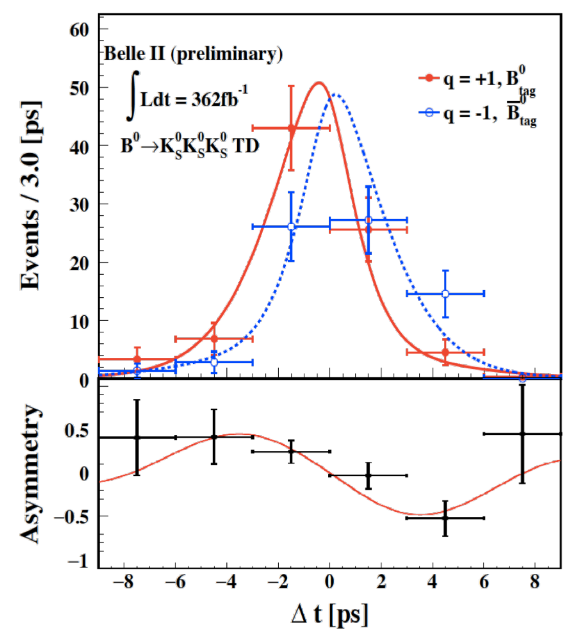


$S_{\phi K_S^0} = +0.54 \pm 0.2^{+0.06}_{-0.08}$

... consistent with $-\eta_{CP} S_{J/\psi K_S^0}$

$A_{\phi K_S^0} = +0.31 \pm 0.20^{+0.05}_{-0.06}$

- On par with the most precise result for $A_{\phi K_S^0}$.
- Improvement on S by 10-20% for the same signal yield w.r.t. Belle/BaBar.



- Challenge: no prompt tracks from B decay → uniquely possible at Belle II.

$S_{3K_S^0} = -1.37^{+0.35}_{-0.45} \pm 0.03$

... consistent with $-\eta_{CP} S_{J/\psi K_S^0}$

$A_{3K_S^0} = +0.07^{+0.15}_{-0.20} \pm 0.02$

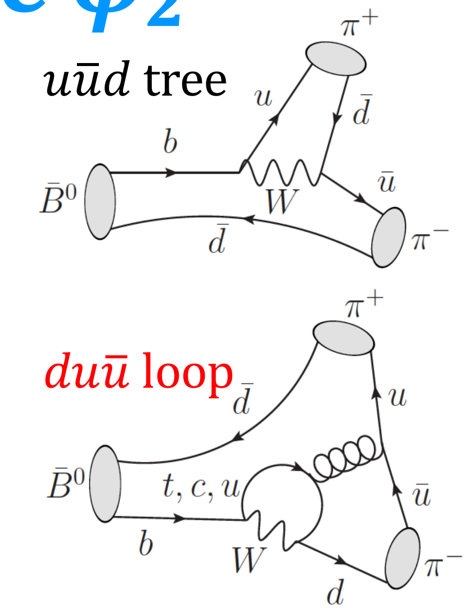
- On par with the most precise result for $A_{3K_S^0}$.

New for 2023

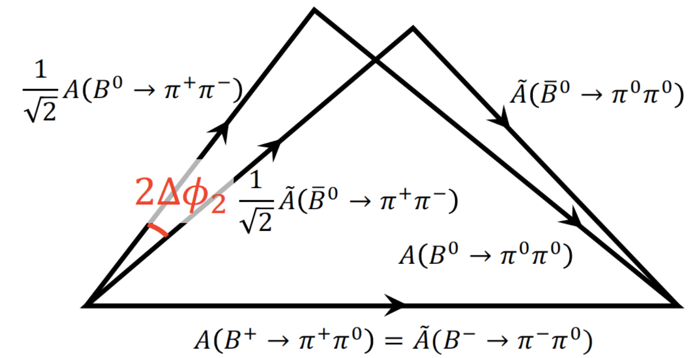
Belle II 362 fb^{-1}

Toward CKM Triangle Angle ϕ_2

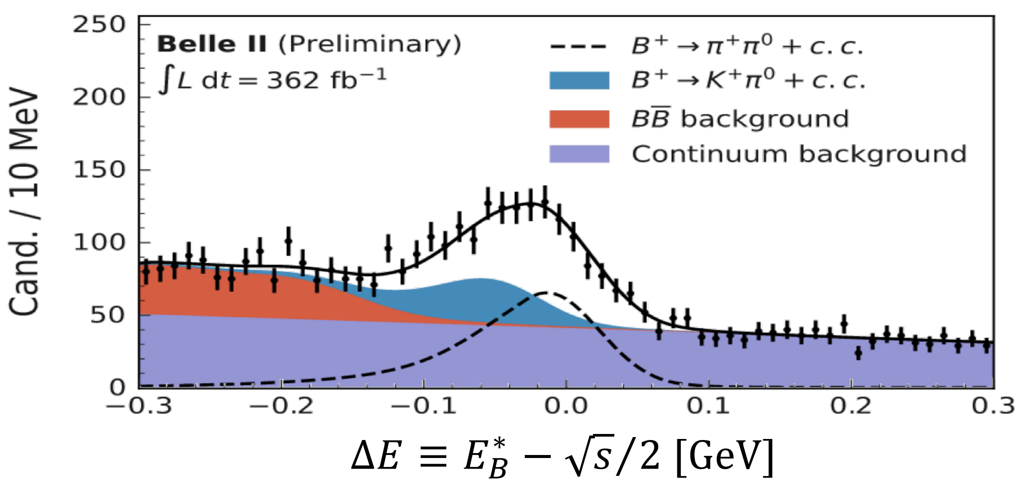
- $\mathcal{A}(\Delta t) = S_{\pi\pi} \sin(\Delta m_d \Delta t) + A_{\pi\pi} \cos(\Delta m_d \Delta t)$
  - $B \to \pi\pi$ is mediated by $b \to u\bar{u}d$ and $d\bar{u}\bar{u}$.
- $S_{\pi\pi}$ and $A_{\pi\pi}$ are related to ϕ_2 with
  $S_{\pi\pi} = -\eta_{CP}\sqrt{1 - A_{\pi\pi}^2} \sin(2\phi_2 + 2\Delta\phi_2)$.
  $d\bar{u}\bar{u}$ loop effect

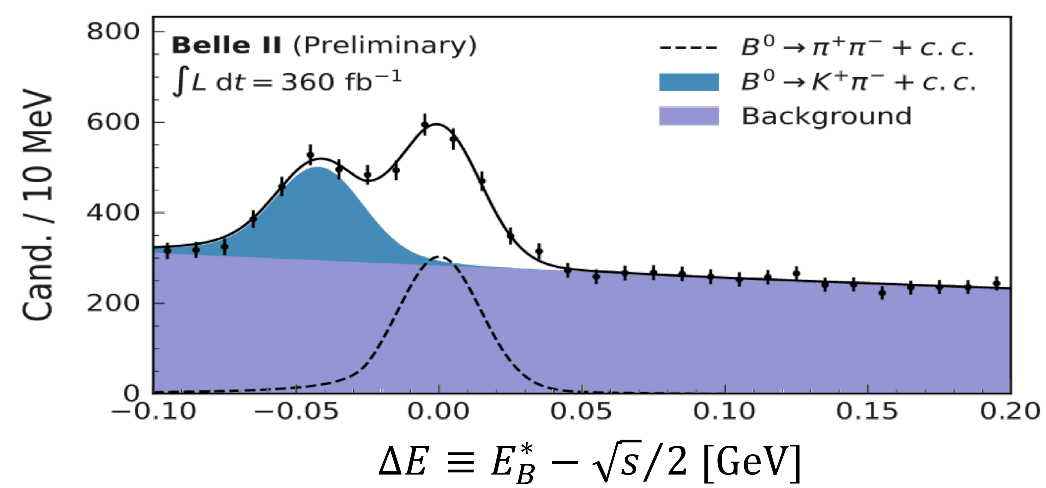


M. Gronau and D. London, Phys Rev. Lett. **65**, 3381 (1990).



$\mathcal{B}r$ and $A_{\pi\pi}$ results





$\mathcal{B}r(B^+ \to \pi^+\pi^0) = (5.02 \pm 0.28 \pm 0.32)\times 10^{-6}$
$A_{\pi^+\pi^0} = -0.08 \pm 0.05 \pm 0.01$

$\mathcal{B}r(B^0 \to \pi^+\pi^-) = (5.83 \pm 0.22 \pm 0.17)\times 10^{-6}$

New for 2023

B1 711 + B2 189 fb^{-1}

CKM Triangle Angle ϕ_3

- ϕ_3 can be measured through the interference between the $b \to c$ and $b \to u$ transitions.
- The absence of the loop contribution allows extremely clean theoretical prediction of ϕ_3 $\to$ good probe of the NP.

$B^{\pm} \to D_{CP\pm}K^{\pm}$ results ($D_{CP+} \to K^+K^-, D_{CP-} \to K_S^0\pi^0$)

- $$\mathcal{R}_{CP\pm} = \frac{\mathcal{B}r(B^- \to D_{CP\pm}K^-) + \mathcal{B}r(B^+ \to D_{CP\pm}K^+)}{\mathcal{B}r(B^- \to D_{\text{flav}}K^-) + \mathcal{B}r(B^+ \to D_{\text{flav}}K^+)}$$
$$= 1 + r_B^2 + 2r_B \cos\delta_B \cos\phi_3$$

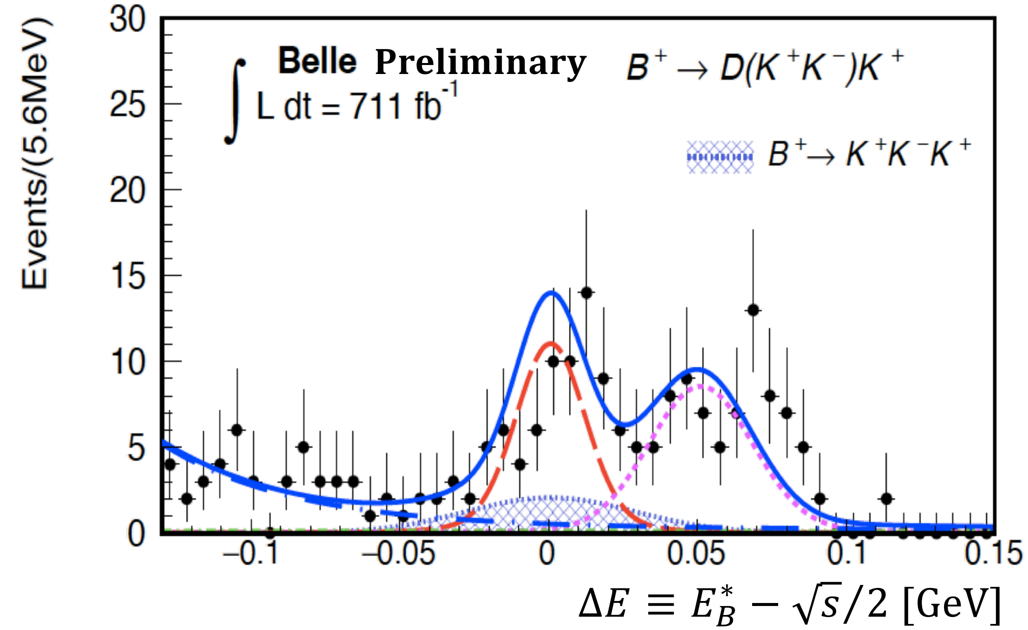
- $$\mathcal{A}_{CP\pm} \equiv \frac{\Gamma(B^- \to D_{CP\pm}K^-) - \Gamma(B^+ \to D_{CP\pm}K^+)}{\Gamma(B^- \to D_{CP\pm}K^-) + \Gamma(B^+ \to D_{CP\pm}K^+)}$$
$$= \pm 2r_B \sin\delta_B \sin\phi_3/\mathcal{R}_{CP\pm}$$

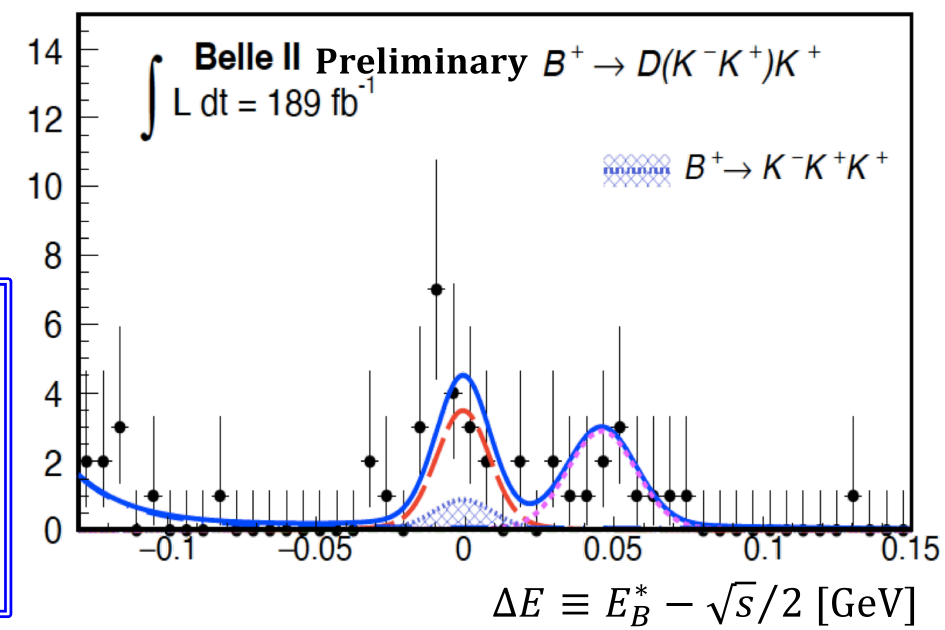
$\mathcal{R}_{CP+} = 1.164 \pm 0.081 \pm 0.036$ $\mathcal{R}_{CP-} = 1.151 \pm 0.074 \pm 0.019$

$\mathcal{A}_{CP+} = (+12.5 \pm 5.8 \pm 1.4)\%$ $\mathcal{A}_{CP-} = (-16.7 \pm 5.7 \pm 0.6)\%$

... best $\mathcal{A}_{CP-}$ measurement

$4.7^\circ < \phi_3 < 175.8^\circ$, $0.069 < r_B < 0.560$ ... @ 95.4% CL





New for 2023

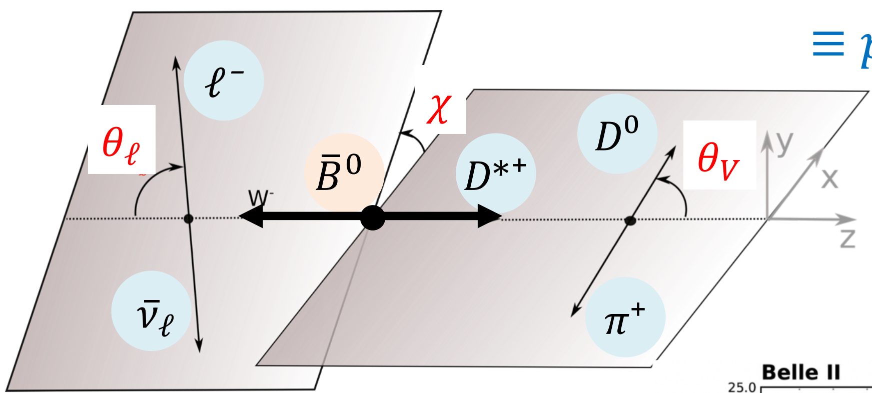
Belle II 189 fb^{-1}

CKM Triangle Side $|V_{cb}|$

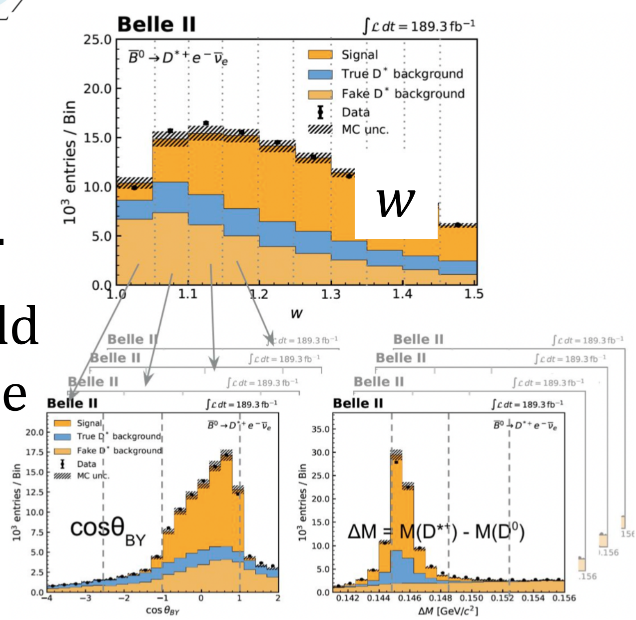
$B^0 \to D^{*-}\ell^+\nu_\ell$ differential cross section

$$\frac{d\Gamma}{dw\, d\cos\theta_\ell\, d\cos\theta_V\, d\chi} \propto |V_{cb}|^2 F^2(w, \cos\theta_\ell, \cos\theta_V, \chi)$$

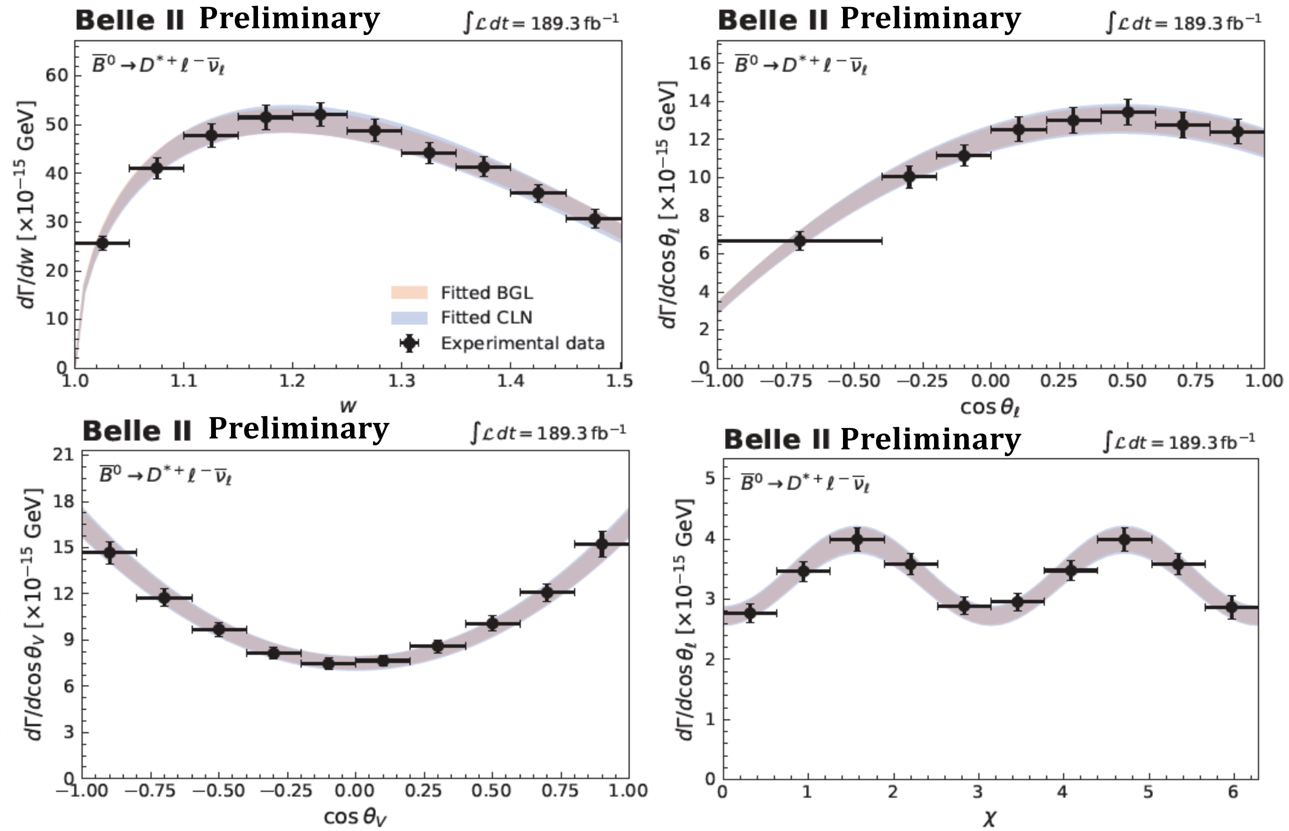
Recoil parameter $w \equiv p_B \cdot p_{D^*}/m_B m_{D^*}$



- Split $w, \chi, \cos\theta_V$ distributions into 10 and $\cos\theta_\ell$ into 8 slices.
- Estimate the signal yield from kinematic variable distributions for each slice.



$|V_{cb}|$ result



$$|V_{cb}|_{\mathrm{BGL}} = (40.9 \pm 0.3 \pm 1.0 \pm 0.6)\times 10^{-3}$$

(QCD input)

$$|V_{cb}|_{\mathrm{CLN}} = (40.4 \pm 0.3 \pm 1.0 \pm 0.6)\times 10^{-3}$$

BGL, CLN … options for the form-factor bases

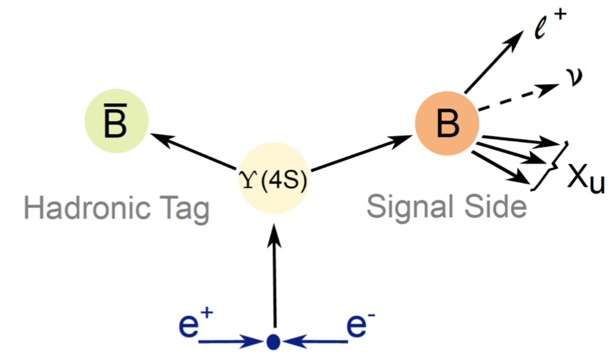
arXiv:2303.17309

CKM Triangle Side $|V_{ub}|$

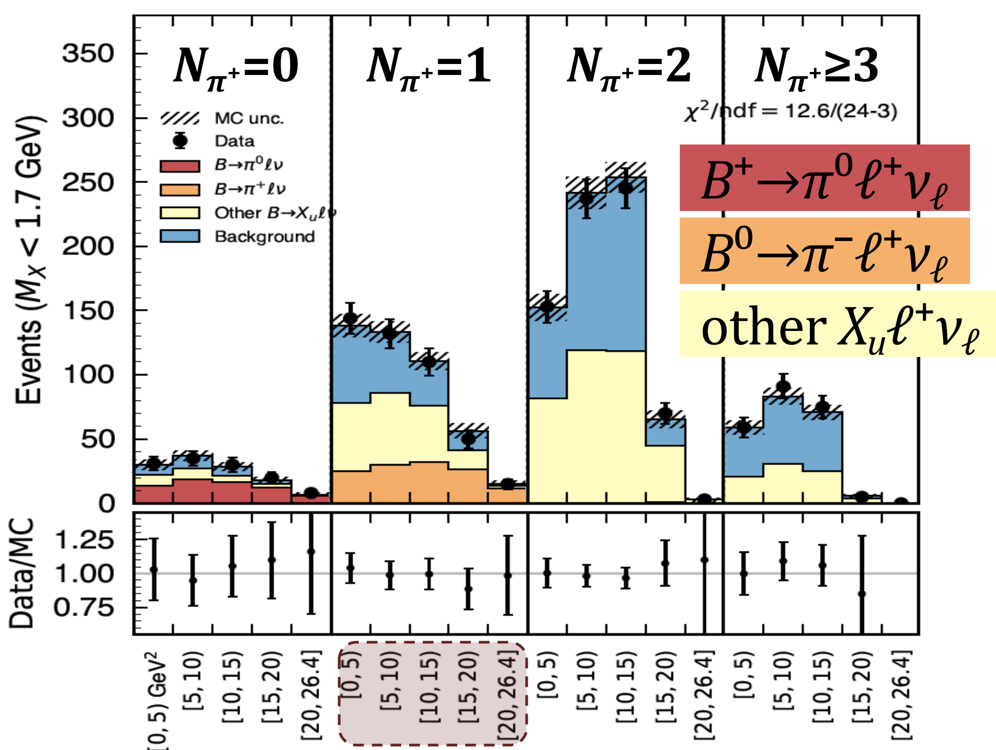
Belle 711 fb^{-1}

$B \to X_u \ell^+ \nu_\ell$ reconstruction

- Hadronic tagging with neural networks (efficiency ~ 0.2-0.3%).
- Background suppressed in the hadronic mass M_X.
- The signal probability is calculated on the momentum transfer q^2.

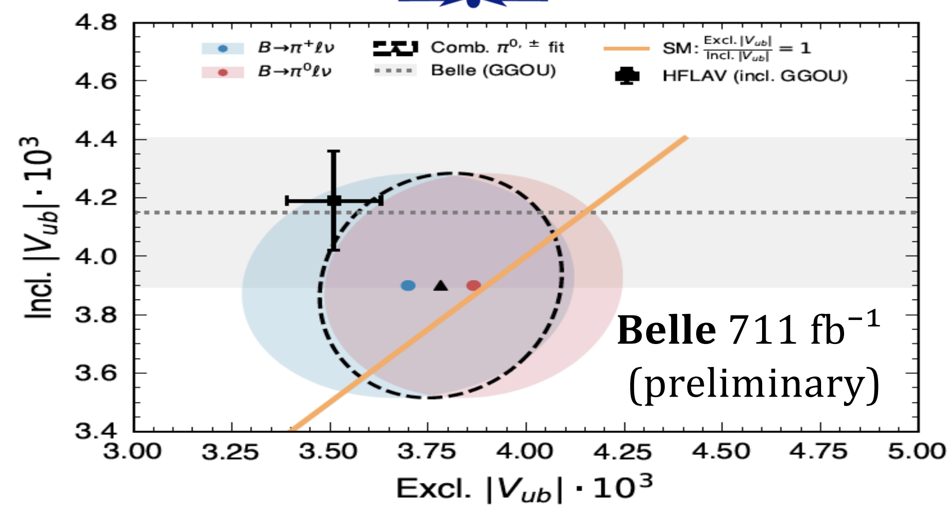


Belle 711 fb^{-1} (preliminary)



×5 q^2 bins
for each N_π variation

Simultaneous determination of exclusive $|V_{ub}|$ and inclusive $|V_{ub}|$



Exclusive: $|V_{ub}|_{\text{excl}} = (3.78 \pm 0.23 \pm 0.16 \pm 0.14) \times 10^{-3}$
(theory)

Inclusive: $|V_{ub}|_{\text{incl}} = (3.90 \pm 0.20 \pm 0.32 \pm 0.09) \times 10^{-3}$

$|V_{ub}|_{\text{excl}} / |V_{ub}|_{\text{incl}} = 0.97 \pm 0.12$

The weighted average of $|V_{ub}|_{\text{excl}}$ and $|V_{ub}|_{\text{incl}}$ is consistent with the global fit of the CKM triangle within 0.8σ.

New for 2023

Belle II 362 fb^{-1}

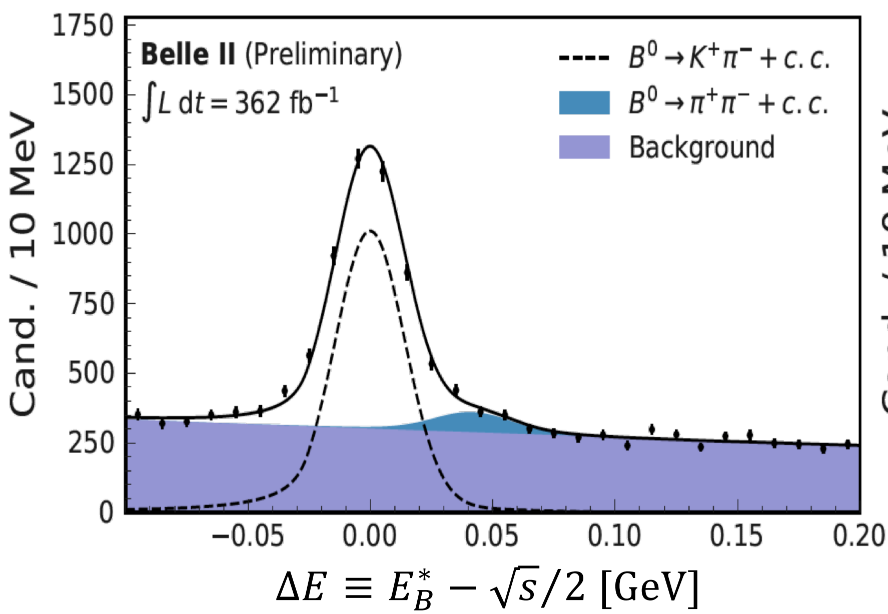
Isospin Sum-Rule

Isospin sum-rule: relation among the products of $\mathcal{B}r$ and $\mathcal{A}_{CP}$ for $B \to K\pi$

$$I_{K\pi} = \mathcal{B}r(K^+\pi^-)\mathcal{A}_{K^+\pi^-} + \mathcal{A}_{K^0\pi^+}\mathcal{B}r(K^0\pi^+)\frac{\tau_{B^0}}{\tau_{B^+}} - 2\mathcal{A}_{K^+\pi^0}\mathcal{B}r(K^+\pi^0)\frac{\tau_{B^0}}{\tau_{B^+}} - 2\mathcal{A}_{K^0\pi^0}\mathcal{B}r(K^0\pi^0); \quad I_{K\pi}^{SM} = 0$$

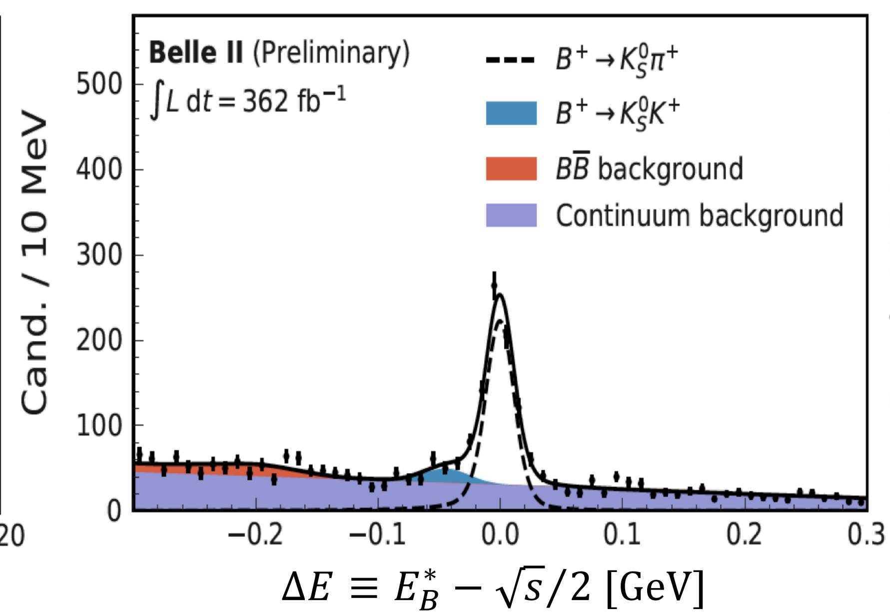
M. Gronau, Phys. Lett. B **627**, 82(2005).

$B^0 \to K^+\pi^-$ results



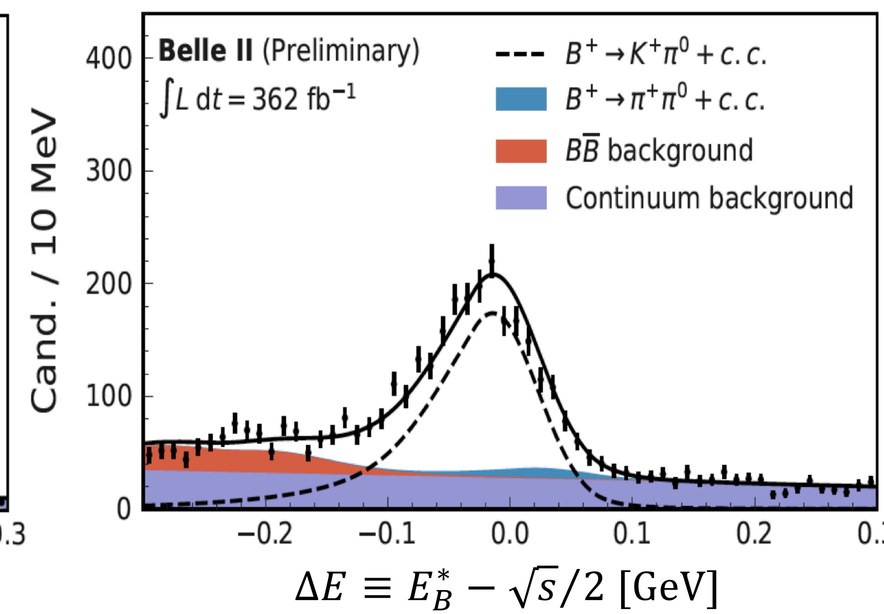
$$\mathcal{B}r = (20.7 \pm 0.4 \pm 0.6)\times 10^{-6}$$
$$\mathcal{A}_{CP} = -0.07 \pm 0.02 \pm 0.01$$

$B^+ \to K_S^0\pi^+$ results



$$\mathcal{B}r = (24.4 \pm 0.7 \pm 0.9)\times 10^{-6}$$
$$\mathcal{A}_{CP} = -0.05 \pm 0.03 \pm 0.01$$

$B^+ \to K^+\pi^0$ results



$$\mathcal{B}r = (14.2 \pm 0.4 \pm 0.9)\times 10^{-6}$$
$$\mathcal{A}_{CP} = +0.01 \pm 0.03 \pm 0.01$$

New for 2023

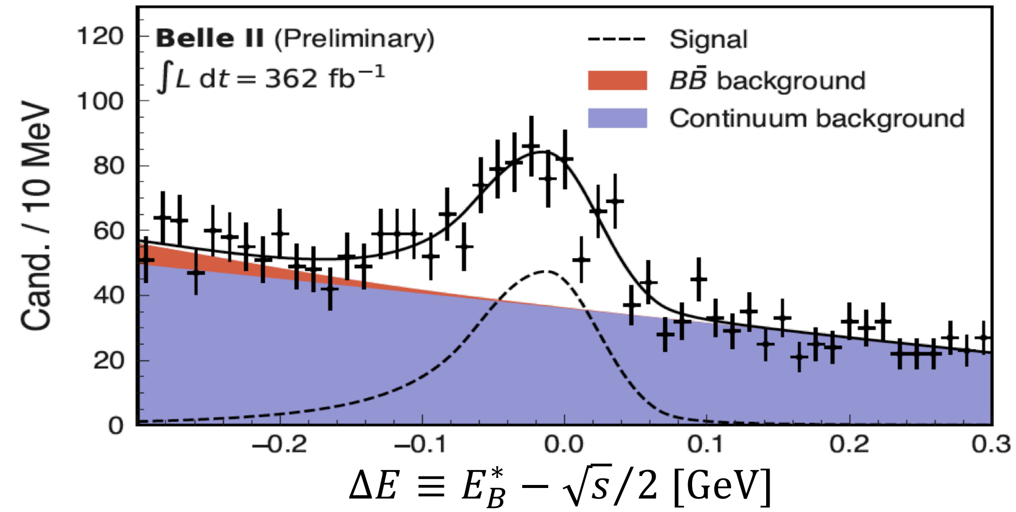
Belle II 362 fb^{-1}

Isospin Sum-Rule – Cont'd

$B^0 \to K_S^0\pi^0$ time-integrated results

- Challenge: only long lived particle + neutral particle in the signal-side final state $\to$ uniquely possible at Belle II.

$$\mathcal{B}r = (10.2 \pm 0.6 \pm 0.6)\times 10^{-6}$$
$$\mathcal{A}_{CP} = -0.06 \pm 0.15 \pm 0.05$$

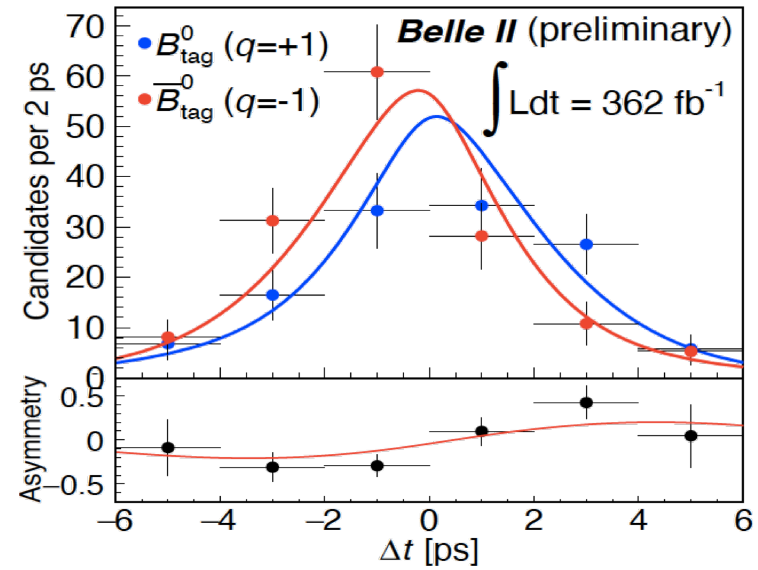


$B^0 \to K_S^0\pi^0$ (η_{CP}=−1) time-differential results

- $K_S^0\pi^0$ is a CP eigenstate and the effective ϕ_1 is defined for $K_S^0\pi^0 \to \mathcal{A}(\Delta t) = S_{K_S^0\pi^0}\sin(\Delta m_d \Delta t) + A_{K_S^0\pi^0}\cos(\Delta m_d \Delta t)$

$$S_{K_S^0\pi^0} = +0.75^{+0.20}_{-0.23} \pm 0.04$$ … consistent with $-\eta_{CP} S_{J/\psi K_S^0}$

$$A_{K_S^0\pi^0} = +0.04 \pm 0.15 \pm 0.05$$



TI + TD combination and constraint to $I_{K\pi}$

$$\mathcal{B}r = (10.5 \pm 0.6 \pm 0.7)\times 10^{-6}$$
$$\mathcal{A}_{CP} = -0.01 \pm 0.12 \pm 0.05$$

$\Rightarrow$ $I_{K\pi} = -0.03 \pm 0.13 \pm 0.05$ … consistent with the SM

arXiv:2301.08266

Test of the LFU $(b \to x\ell\nu_\ell)$

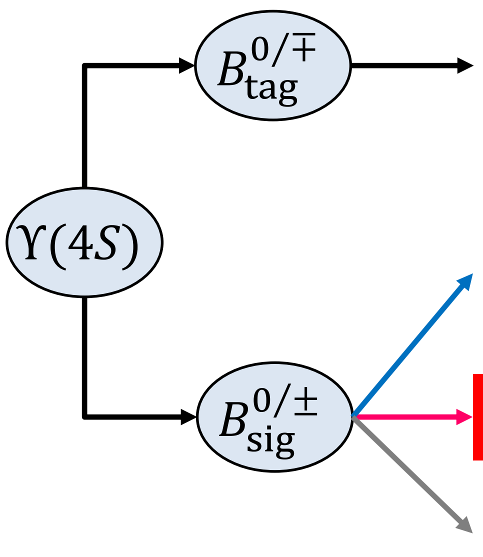
Belle II 189 fb^{-1}

$R(X_{e/\mu}) \equiv \mathcal{B}r(B \to Xe\nu_\mu)/\mathcal{B}r(B \to X\mu\nu_e)$

- The $R(X_{e/\mu})$ measurement complements the LFU tests made with $\mathcal{B}r(B \to D^{(*)}\tau\nu)/\mathcal{B}r(B \to D^{(*)}\ell\nu)$.
  - The inclusive approach reduces the systematic uncertainty.
  - The SM predicts $R(X_{e/\mu}) = 1 + \mathcal{O}(10^{-3})$.

C. Bobeth et al., Eur. Phys. J. C **81**, 984 (2021)

Event reconstruction



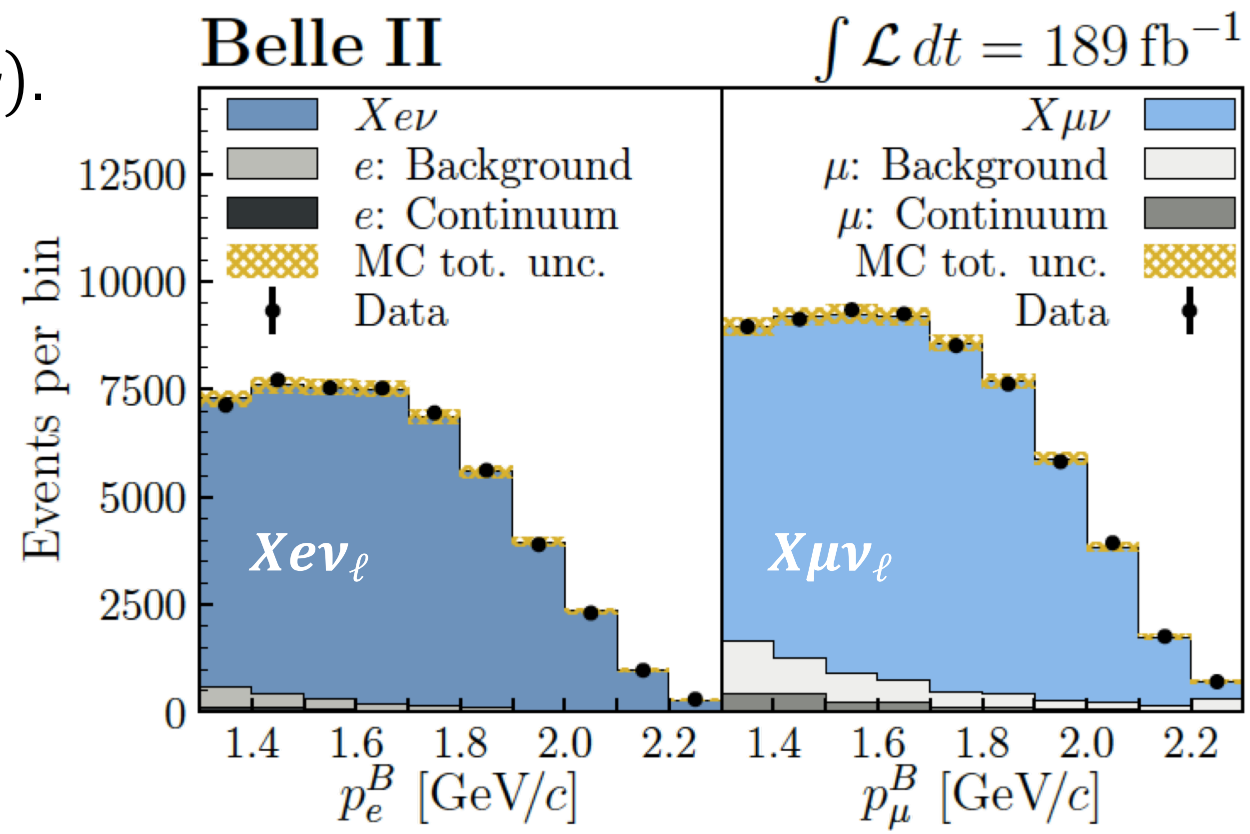
Reconstruct B_{tag} with multivariate technique through $\mathcal{O}(10^3)$ modes.

X (inclusive)

Loose cuts on tracking detector and calorimeter signals.

high momentum ℓ ($p_\ell^* > 1.3$ GeV/c)

Signal extraction with p_ℓ^*



$$R(X_{e/\mu}) = 1.0333 \pm 0.010 \pm 0.019$$

… first inclusive test of (e/μ) LFU in $B \to X\ell\nu_\ell$.

New for 2023

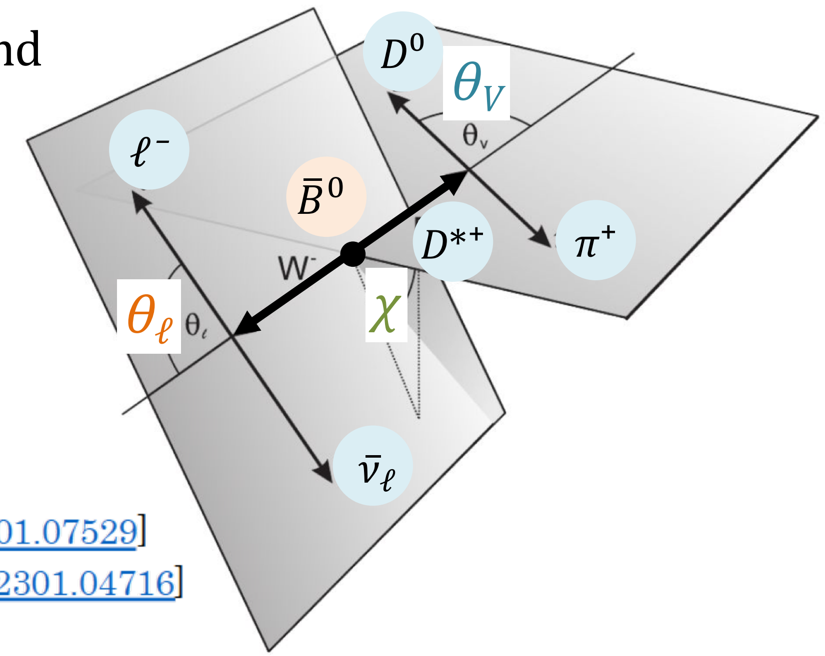
Belle II 189 fb^{-1}

Test of the LFU (angular asymmetries)

Angular asymmetries A_x in $B^0 \to D^{*-}\ell^+\nu_\ell$

$$A_x \equiv \left(\frac{d\Gamma}{dw}\right)^{-1} \left[\int_0^1 - \int_{-1}^0\right] dx \frac{d^2\Gamma}{dwdx}$$

- A_x^ℓ values are measured for 3+2 angles x and for $\ell^+=e^+$ and $\ell^+=\mu^+$.
- The SM predicts $\Delta A_x \equiv A_x^\mu - A_x^e = 0$ while the NP may modify ΔA_x to $\neq 0$.
  - A_x^ℓ values are separately measured for zero D^{*-} recoil samples (low w) and maximum D^{*-} recoil samples (high w).



ΔA_x results

A_{FB}: $dx \to d(\cos\theta_\ell)$

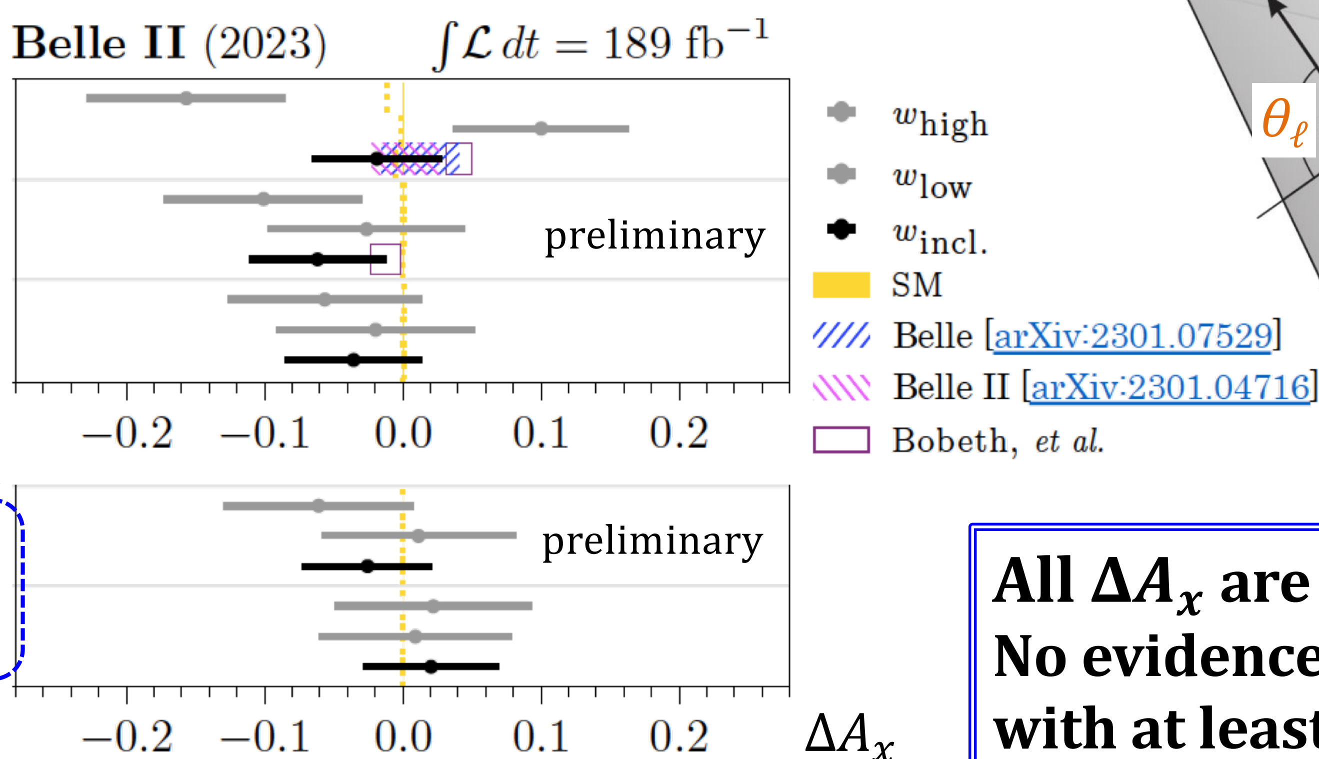
S_3: $dx \to d(\cos 2\chi)$

S_5: $dx \to d(\cos\chi \cos\theta_V)$

Control channels to confirm no experimental biases in ΔA_x

S_7: $dx \to d(\sin\chi \cos\theta_V)$

S_9: $dx \to d(\sin 2\chi)$

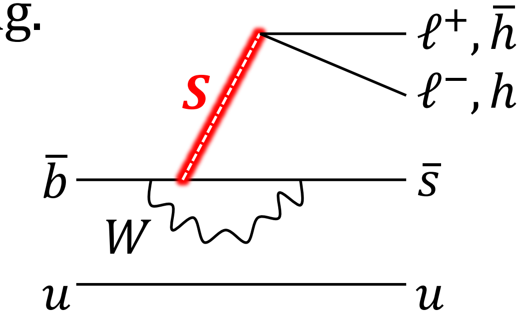


All ΔA_x are consistent with zero. No evidence of the LFU violation with at least the p-value of 0.12.

New for 2023
Belle II 189 fb^{-1}

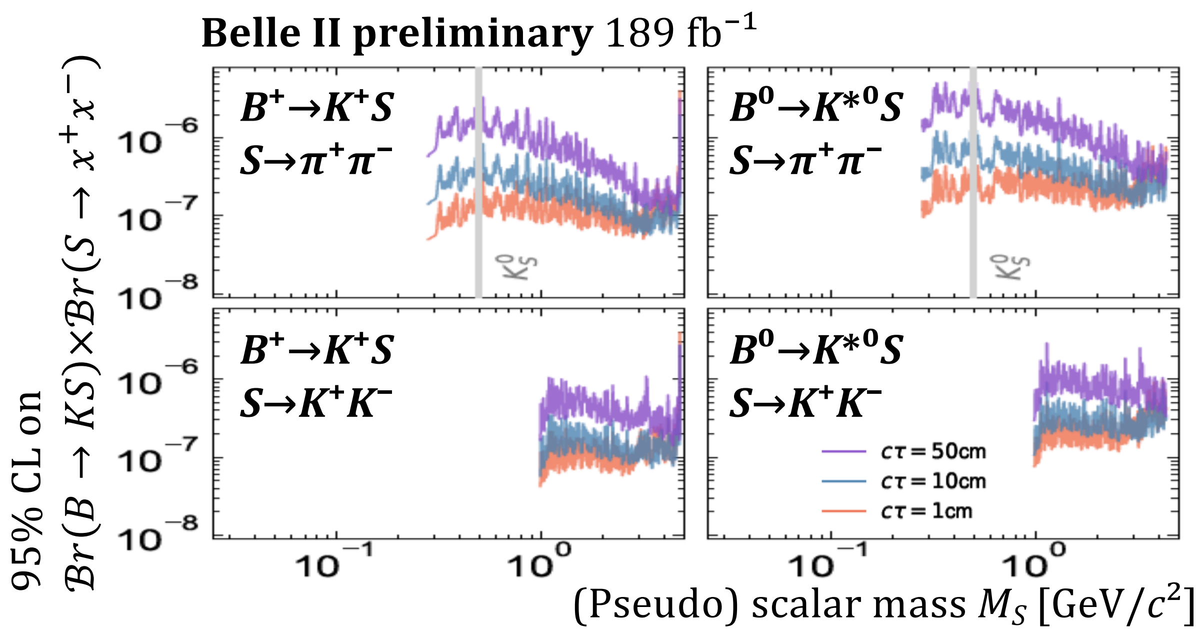
Long-Lived Scalar Particle: $B \to K^{(*)}S$

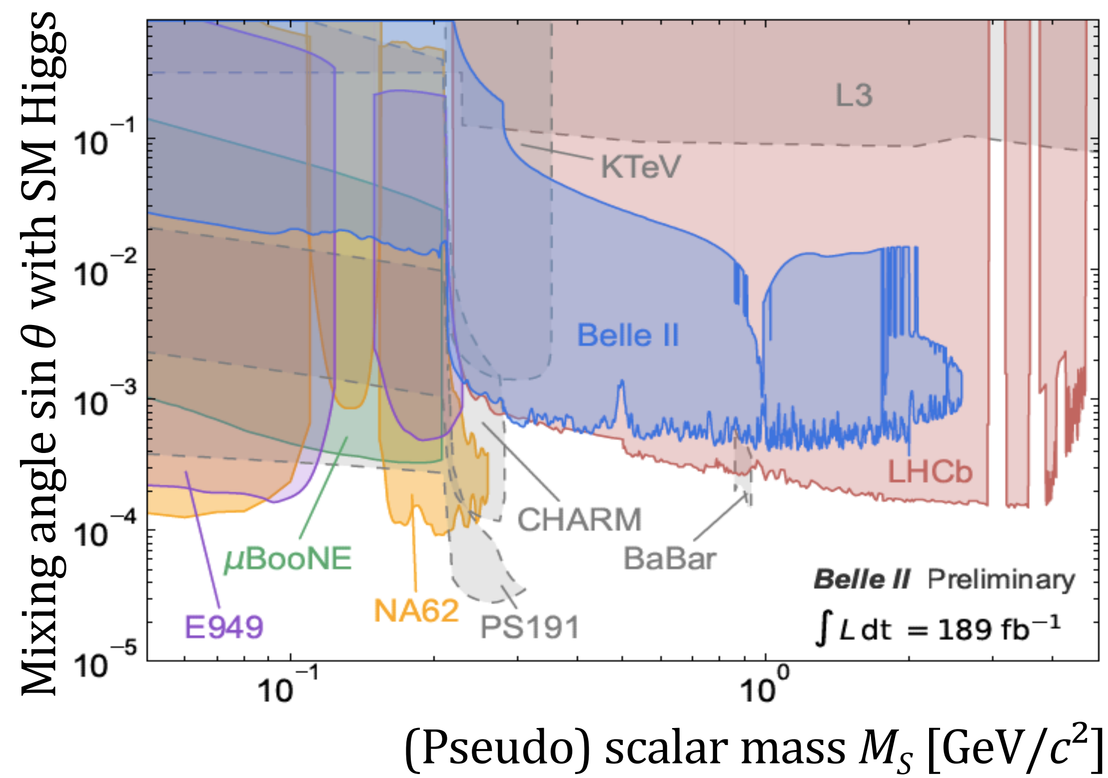
- A new (pseudo) scalar particle ***S*** mediating between SM ↔ DM only weakly interacts with the SM particles → the ***S*** lifetime tends to be long.
- Fully reconstruct a signal B in $B^+ \to K^+S$ and $B^0 \to K^{*0}(K^+\pi^-)S$ with a subsequent ***S*** decay to $\ell^+\ell^-$, $\pi^+\pi^-$, and K^+K^-.



- Search for ***S*** with $0 \le c\tau \le 400$ cm in M_S distribution.

No evidence of a new (pseudo) scalar, but the first limits on *S* decaying to hadrons.

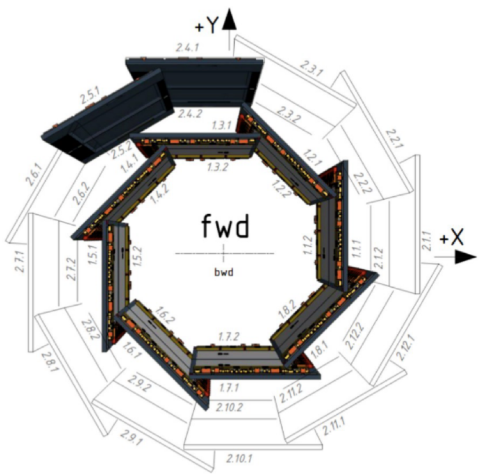


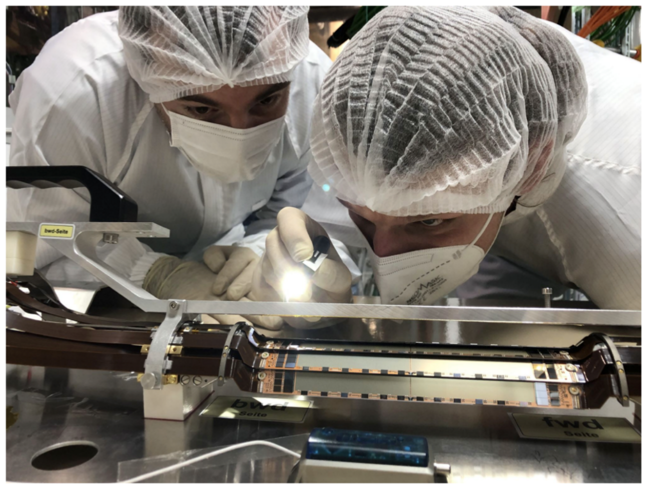


Long Shutdown

- Belle II stopped data taking in summer 2022 for the rise of the electricity rate.

Installation of the pixel detector

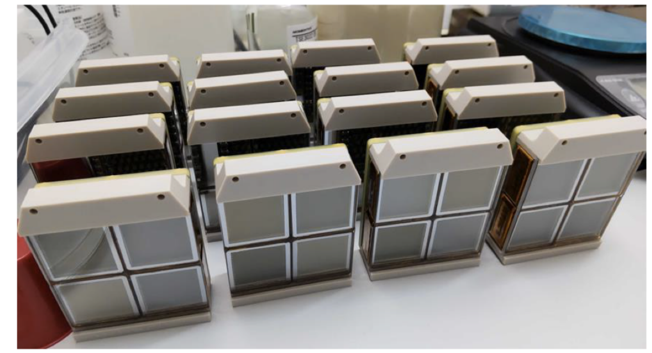




- The current pixel detector is only partially instrumented → the installation of the fully instrumented pixel detector is ongoing.

Replacement of PMTs for the PID detector

- MCP-PMTs for the PID detector are replaced before their quantum efficiency gets deteriorated.



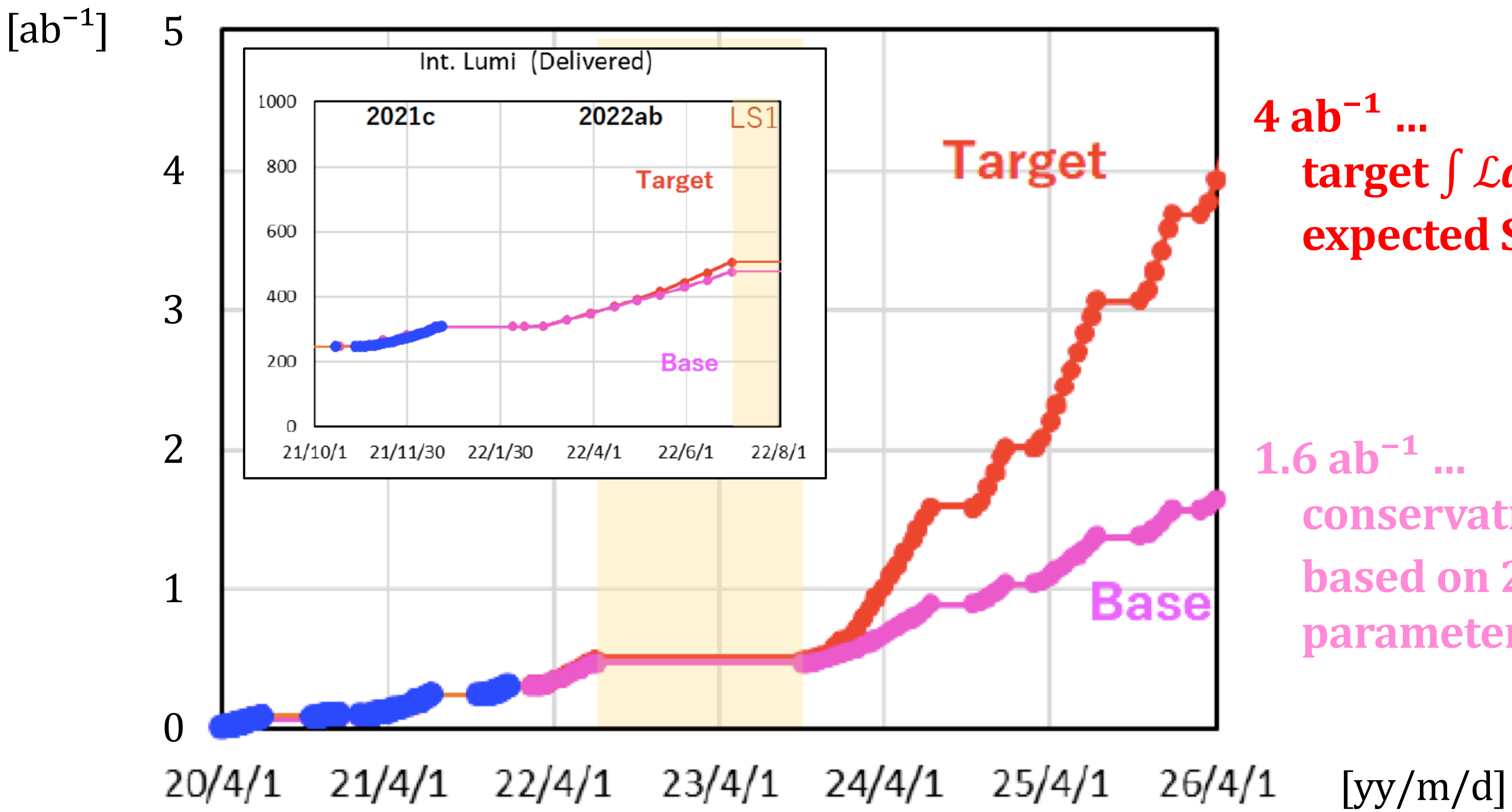
Countermeasures to a sudden beam loss

- The frequency of a sudden beam loss was increasing along with the increase of the SuperKEKB currents → may damage accelerator/detector components.
- A new beam-loss monitor and a fast beam-abort system are being developed.

On track to resume the data taking coming winter

Integrated Luminosity Prospects

50 ab^{-1} in the next decade



4 ab^{-1} ...
target $\int \mathcal{L}dt$ including expected SuperKEKB improvement

1.6 ab^{-1} ...
conservative $\int \mathcal{L}dt$ estimate based on 2021 SuperKEKB parameters

We aim for achieving $\mathcal{L}_{\mathrm{peak}} = 24\times10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ by 2026.

Summary

Plentiful physics results have been produced by the Belle II (and Belle) data analyses. Several of them are already world leading. Highlights of the new and recent results have been presented today, which include:

- Test of the CKM unitarity,
- Test of the isospin sum-rule,
- Test of the lepton flavor universality, and
- Search for dark-sector particles.

Backup Slides

arXiv:2302.12791

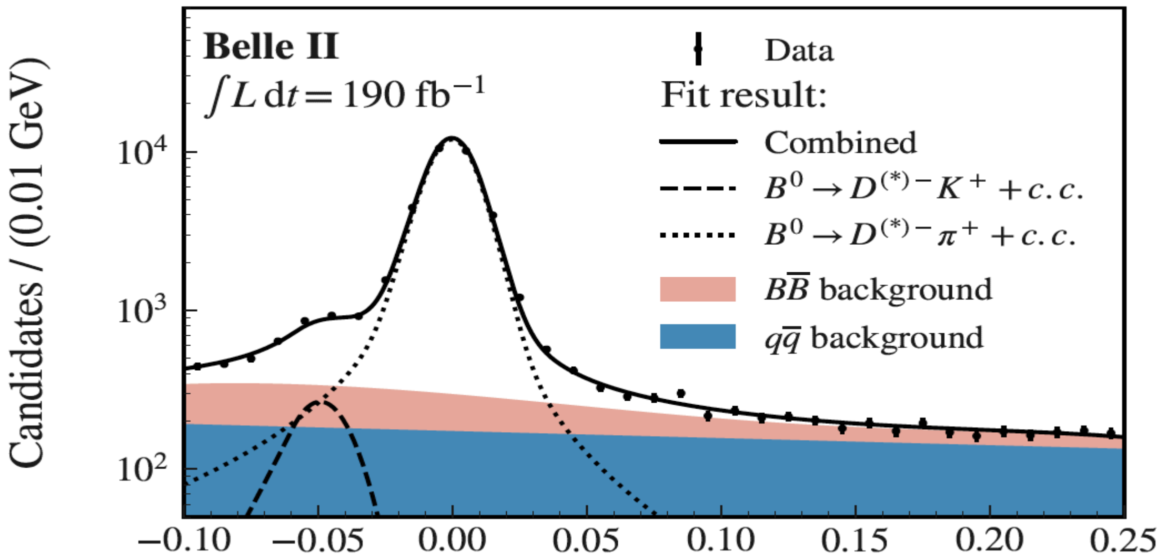
B-Meson Lifetime τ_{B^0} and Mixing Δm_d

Belle II 190 fb^{-1}

- Test of the machinery readiness for the following CPV measurements based on the *B*-flavor and Δt information.

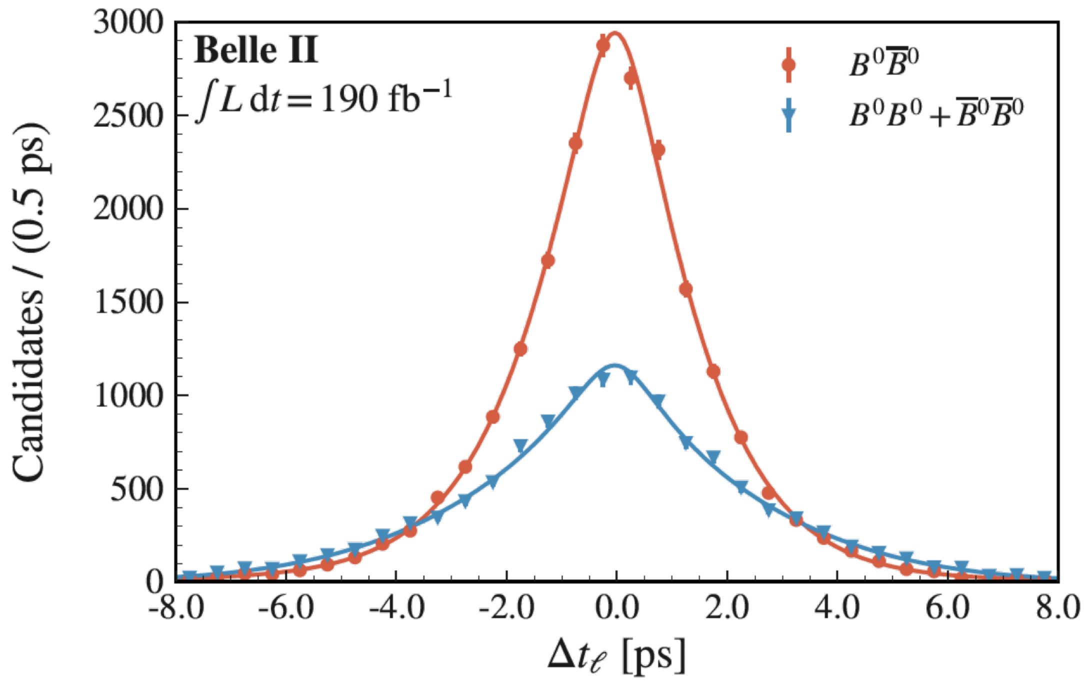
Event reconstruction

- $B^0 \to D^{*-}(\bar{D}^0\pi^-)\pi^+, D^-\pi^+$
  - $\bar{D}^0 \to K^+\pi^-n\pi, D^- \to K^+\pi^-\pi^-$



The *B* energy is expected to peak at the half of the collision energy.

τ_{B^0} and Δm_d results



$$\tau_{B^0} = 1.499 \pm 0.03 \pm 0.008 \text{ ps}$$
$$\Delta m_d = 0.516 \pm 0.008 \pm 0.005 \text{ ps}^{-1}$$

... consistent with the WA

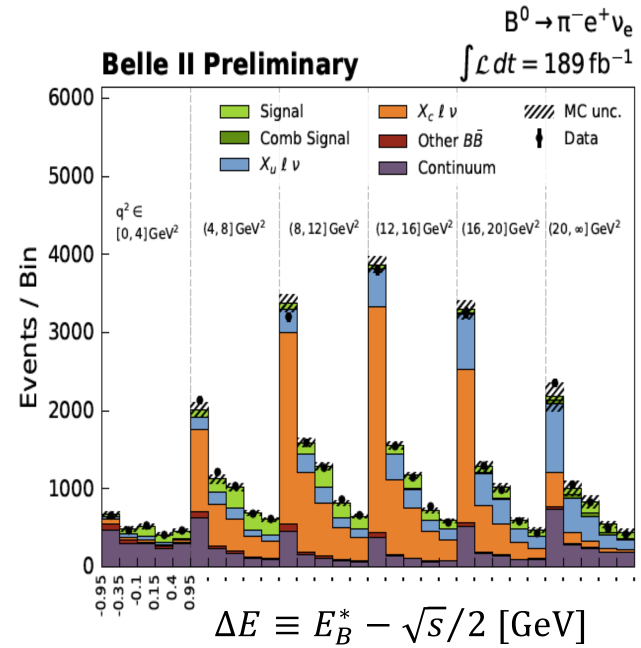
arXiv:2210.04224

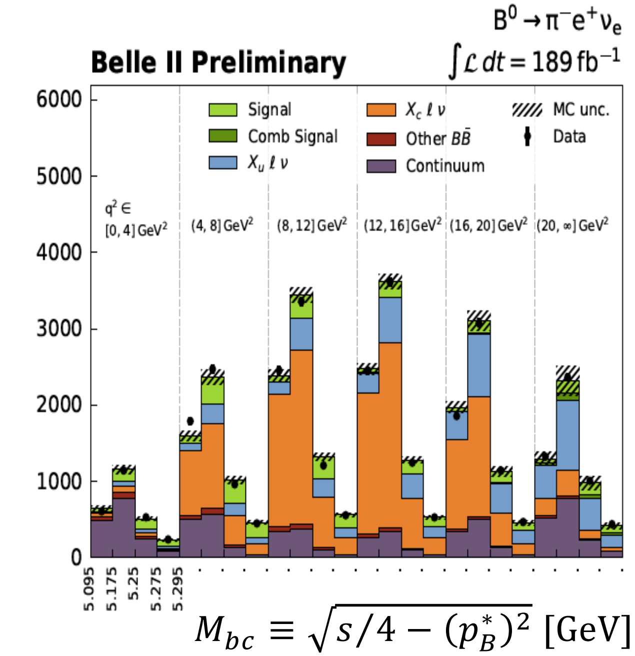
Belle II 189 fb^{-1}

CKM Triangle Side $|V_{ub}|$

$B^0 \to \pi^- \ell^+ \nu_\ell$ reconstruction

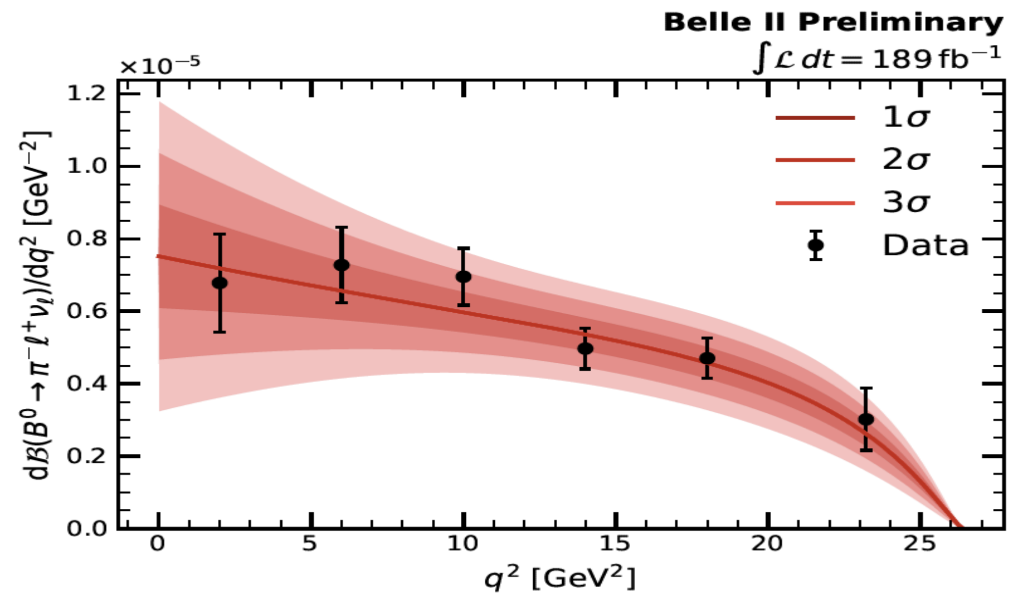
- Challenges: large background (low BR) and lack of clean kinematic signatures
- $q\bar{q}$ and combinatorial BG rejection with a BDT.





$|V_{ub}|$ exclusive result: $\dfrac{d\Gamma(q^2)}{dq^2} \propto |V_{ub}|^2$

- Calculate the recoil momentum q^2 by inferring the $\vec{p}_B$ with a modified *diamond-frame* approach.
- Obtain the differential cross sections in 6 q^2 bins.



$$|V_{ub}|_{\pi^- \ell^+ \nu_\ell} = (3.55 \pm 0.12 \pm 0.13 \pm 0.17) \times 10^{-3}$$

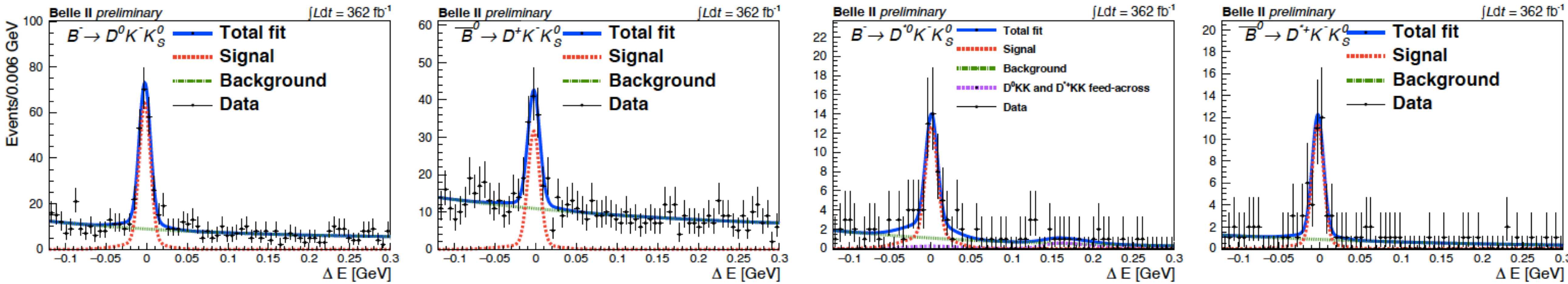
... consistent with the WAs

New for 2023

Belle II 362 fb^{-1}

$B \to D^{(*)} K^- K_S^0$

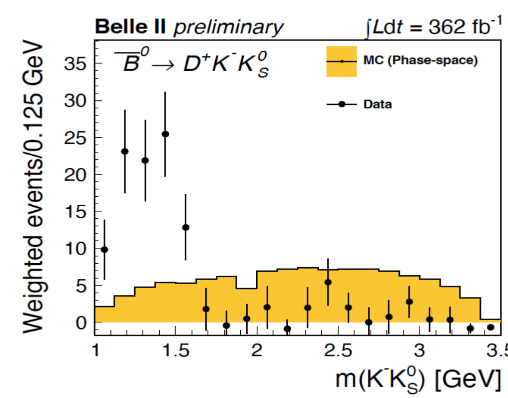
- The $D^{(*)}KK$ sector is mostly unexplored; a few % $\mathcal{B}r$ is expected while only 0.28% is measured.
- Better knowledge of this sector is useful to extend the b-tagging modes.

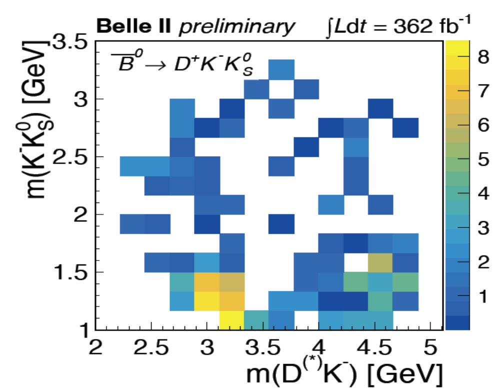


$$\mathcal{B}r(D^+K^-K_S^0) = (0.85 \pm 0.11 \pm 0.05)\times 10^{-4}$$
$$\mathcal{B}r(D^{*0}K^-K_S^0) = (1.57 \pm 0.27 \pm 0.12)\times 10^{-4}$$
$$\mathcal{B}r(D^{*+}K^-K_S^0) = (0.96 \pm 0.18 \pm 0.06)\times 10^{-4}$$
$$\mathcal{B}r(D^0K^-K_S^0) = (1.89 \pm 0.16 \pm 0.10)\times 10^{-4}$$

- First $\mathcal{B}r$ measurement for D^+, D^{*0}, and D^{*+}.
- ×3 precision of the last $\mathcal{B}r$ measurement for D^0 [Phys. Lett. B 542 (2002)].

- Some structures are seen in m_{KK} and Dalitz distributions.



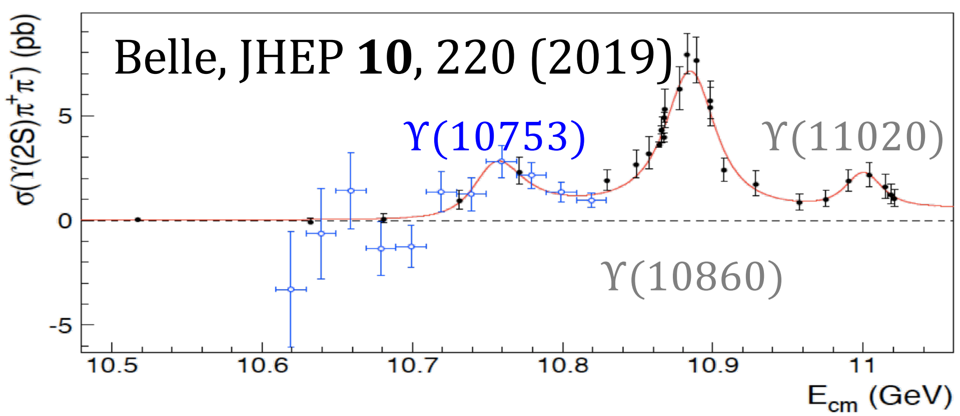


Phys. Rev. Lett. **130**, 091902 (2023).

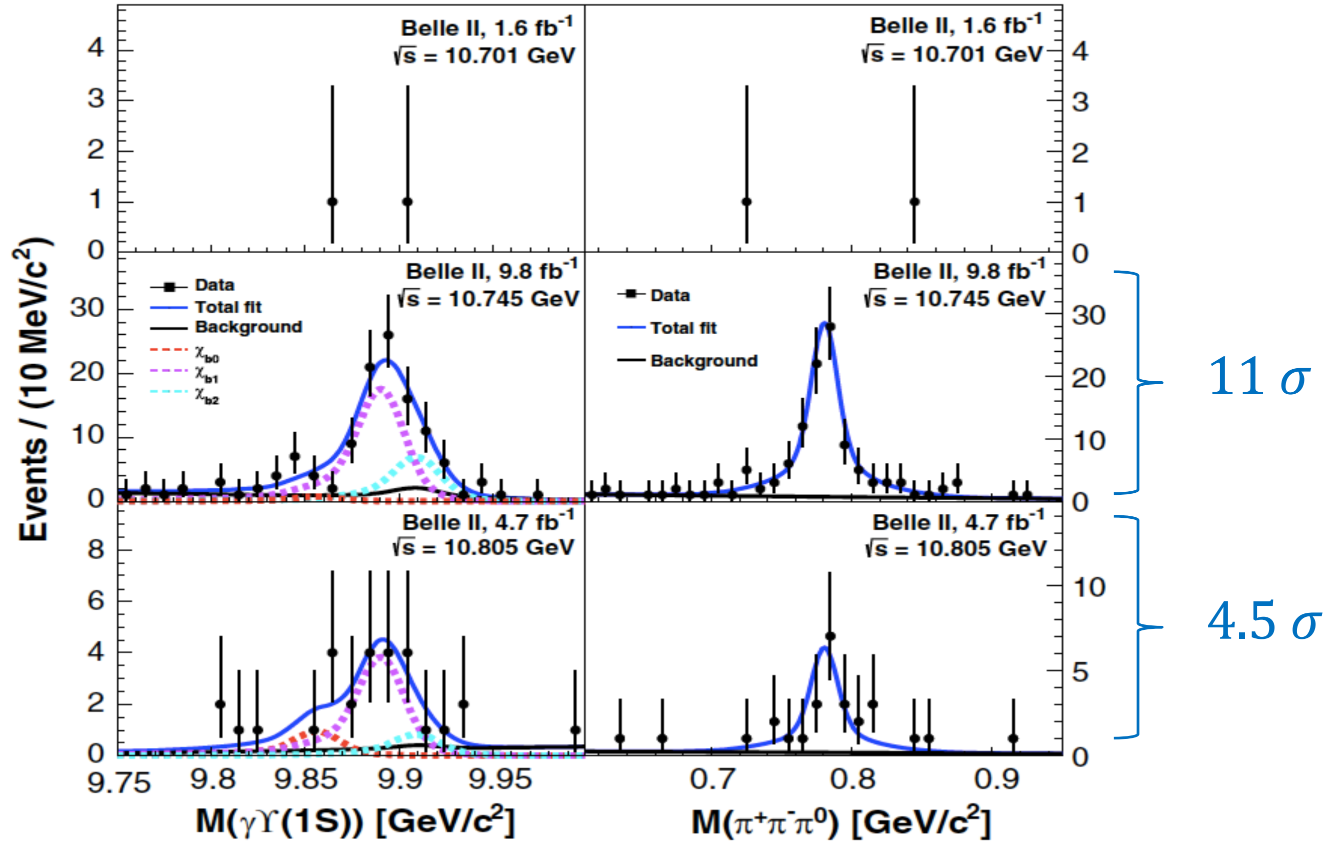
Belle II

Search for $\Upsilon(10753)$ in $e^+e^- \rightarrow \omega\chi_{bJ}$

- $\Upsilon(10753)$: a resonance-like structure discovered in the energy dependence of cross sections for $e^+e^- \rightarrow \Upsilon(nS)\pi^+\pi^-$.



- $\mathcal{B}r\left(\Upsilon(10753) \rightarrow \omega\chi_{bJ}\right) \sim \mathcal{O}(10^{-3})$ if the $\Upsilon(10753)$ is a mixing state of conventional bottomonia (3D and 4S),
- $\Upsilon(10753)$ state is searched for in $e^+e^- \rightarrow \omega\chi_{bJ}$ at $\sqrt{s}$ = 10701, 10745, 10805 GeV.
  - $\omega \rightarrow \pi^+\pi^-\pi^0$
  - $\chi_{bJ} \rightarrow \gamma\Upsilon(1S)$; $\Upsilon(1S) \rightarrow \mu^+\mu^-, e^+e^-$



2D fit on the $M_{\gamma\Upsilon(1S)}$-$M_{\pi^+\pi^-\pi^0}$ distribution
→ first observation of $e^+e^- \rightarrow \omega\chi_{bJ}$ signal

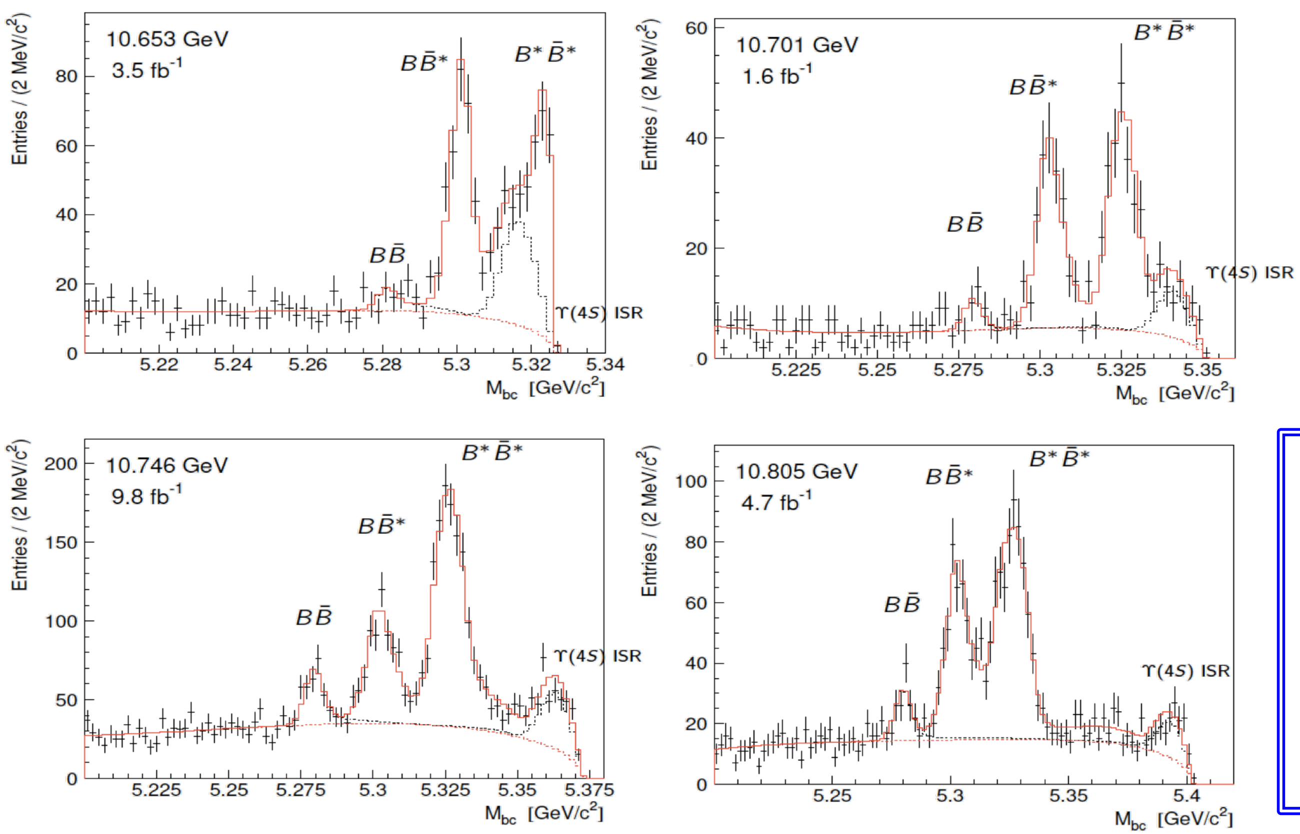
- $\Gamma_{ee}\mathcal{B}r(e^+e^- \rightarrow \omega\chi_{b1}$ and $\chi_{b2})$ is found in the range of 0.20–2.9 and 0.05–2.0 eV.

New for 2023

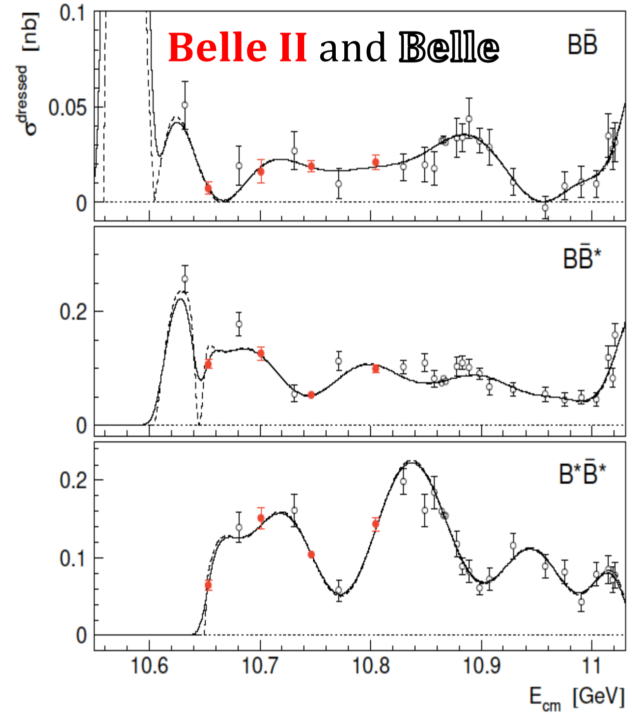
Belle II

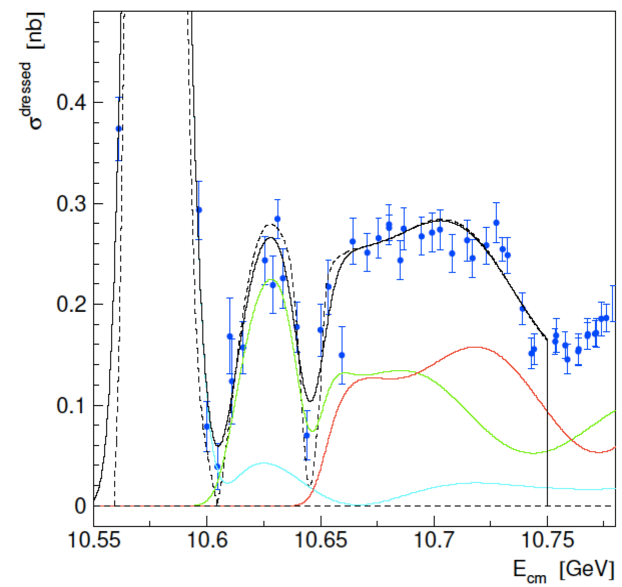
BB, *BB**, and *B*B** Cross-Sections

- A new $b\bar{b}$-resonant structure, $\Upsilon(10750)$, observed by Belle in 2019 needs confirmation → Belle II collected e^+e^- data at $\sqrt{s} = 10.653$, 10.701, 10.746 and 10.805 GeV and measure the $B^{(*)}B^{(*)}$ cross-sections for better understanding of $\Upsilon(10750)$.



Individual and total cross-sections



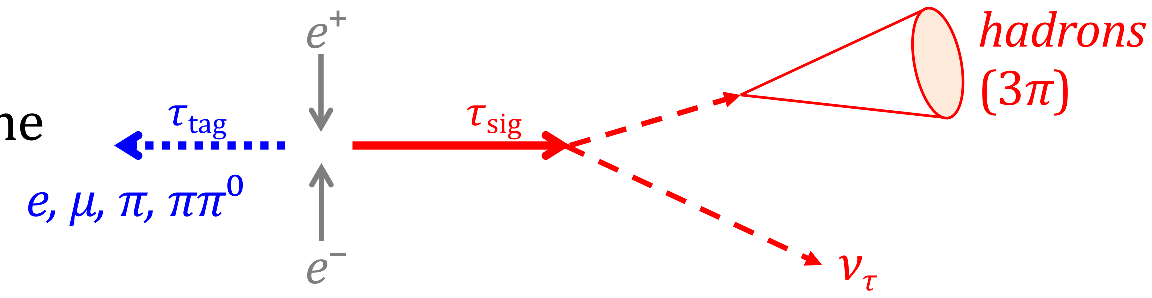


- **The $e^+e^- \to B^*B^*$ cross-section increases very rapidly just above the threshold** (10.64852 GeV for $B^{*+}B^{*-}$ and 10.65034 GeV for $B^{*0}\bar{B}^{*0}$).
- **The fact suggests the existence of a B^*B^* bound state near the B^*B^* threshold.**

τ Mass

New for 2023
Belle II 190 fb^{-1}

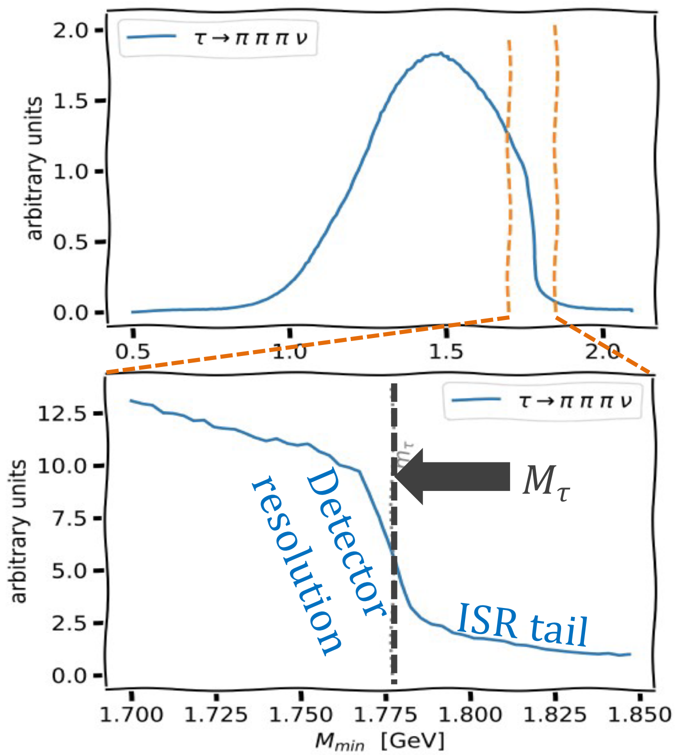
- Particle masses are fundamental parameters of the SM, and need to be measured with the highest precision. The precise determination of M_τ is important for LFU tests.



Pseudo-endpoint $M_{\min}$ method*

- $M_{\min} \equiv [M_{3\pi}^2 + 2(\sqrt{s}/2 - E_{3\pi}^*)(E_{3\pi}^* - P_{3\pi}^*)]^{1/2} \leq M_\tau$

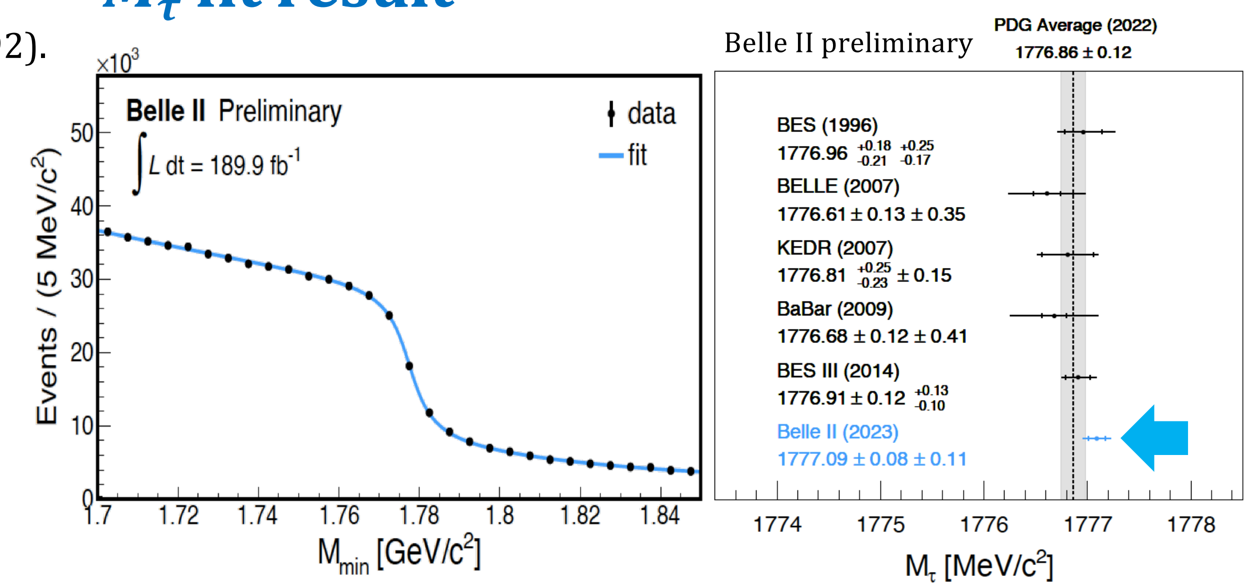
* ARGUS, Phys. Lett. B **292**, 221 (1992).



- Perform an unbinned-maximum-likelihood fit of empirical distribution parameters including M_τ to the $M_{\min}$ distribution.

$$F(M_{\min}) = 1 - P_2 \tan^{-1}\left(\frac{M_{\min} - M_\tau}{P_1}\right) + P_3(M_{\min} - M_\tau) + P_4(M_{\min} - M_\tau)^2$$

M_τ fit result



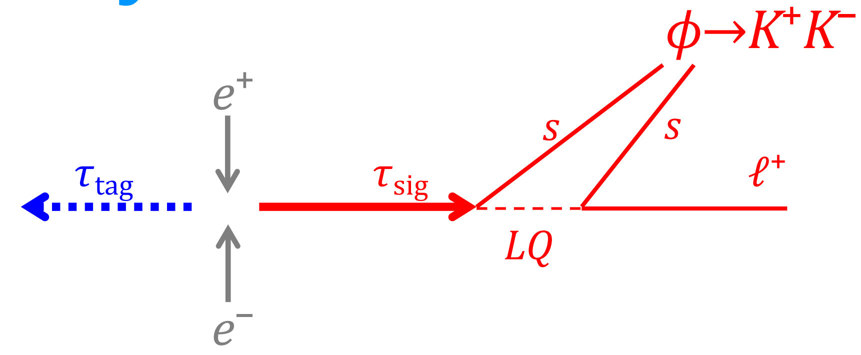
$$M_\tau = 1777.09 \pm 0.08 \pm 0.11\ \text{MeV}/c^2$$

... worlds' most precise measurement.

New for 2023
Belle II 190 fb^{-1}

Lepton Flavor Violating $\tau^- \to \ell^- \phi$ Decay

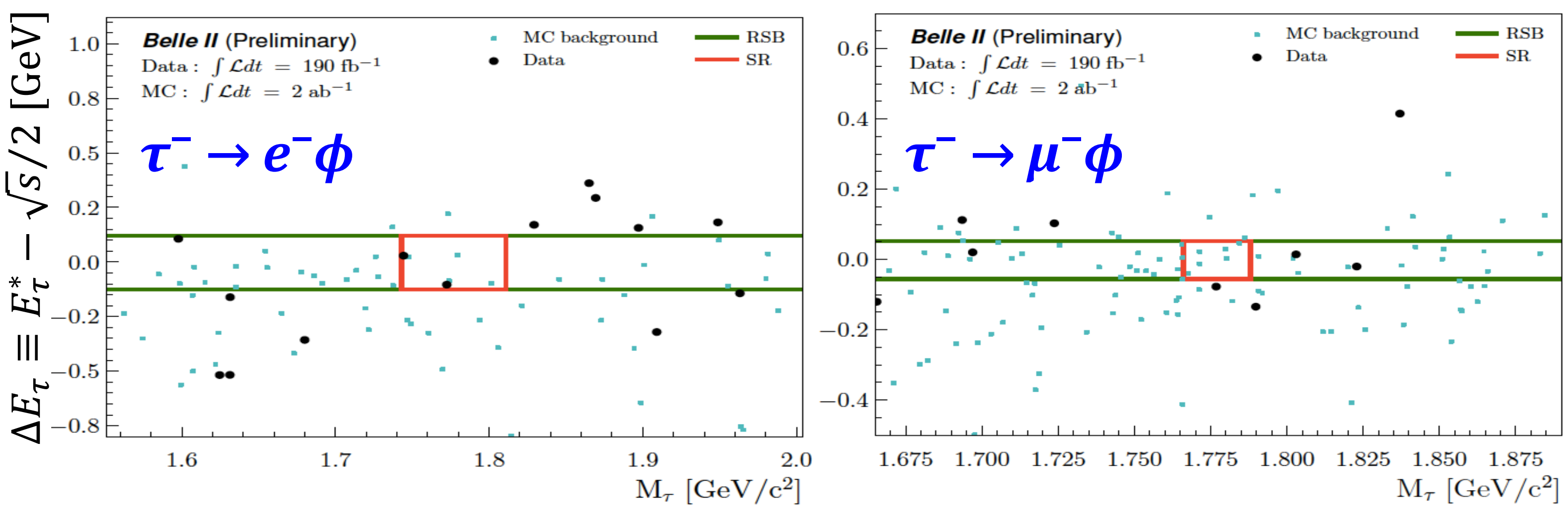
- A vector leptoquark, which can accommodate for the LFU anomaly may enhance the $\mathcal{B}r$ of the LFV $\tau^- \to e^- \phi(K^+K^-)$ and $\mu^- \phi(K^+K^-)$ decays to a level of 10^{-11}-10^{-8}.



Event "reconstruction"

- Previous searches at Belle were conducted with tagged approach ($\tau_{tag} \to$ one charged track + ν).
- Increase the signal efficiency by dropping any requirement on τ_{tag} and exploiting signal ($\ell^- K^+ K^-$) and event kinematic features to BDT classifiers to suppress background $\to$ $\epsilon_{sig}^{\mu\phi} = 6.5\% \sim 2 \times$ **Belle**.

Poisson counting of signal events on the M_τ-ΔE_τ plane



$\mathcal{B}r(\tau^- \to e^- \phi) < 23 \times 10^{-8}$
$\mathcal{B}r(\tau^- \to \mu^- \phi) < 9.7 \times 10^{-8}$
@ 90% CL

Successful first application of untagged approach in τ-pair analysis at Belle II

Phys. Rev. D **107**, L031103 (2023).

Belle II 207 fb^{-1}

Charmed-Hadron Lifetimes

Debate on the charmed-baryon lifetimes

- The hierarchy of the charmed-baryon lifetimes, recently measured by LHCb, is different from old measurements. It suggests a revision of the higher order correction of the HQE.

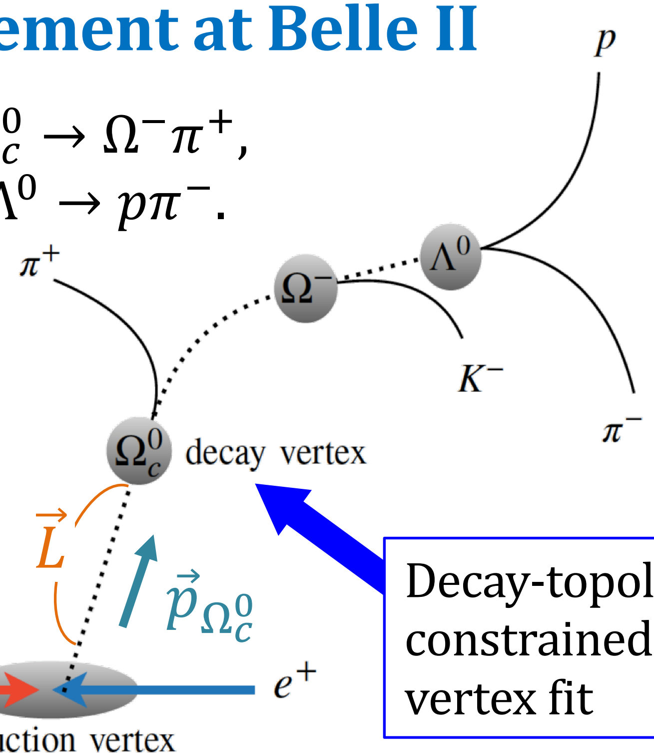
Pre-LHCb		From LHCb results
$\tau_{\Omega_c^0} < \tau_{\Xi_c^0} < \tau_{\Lambda_c^+} < \tau_{\Xi_c^+}$	$\neq$	$\tau_{\Xi_c^0} < \tau_{\Lambda_c^+} < \tau_{\Omega_c^0} < \tau_{\Xi_c^+}$

$\tau_{\Omega_c^0}$ measurement at Belle II

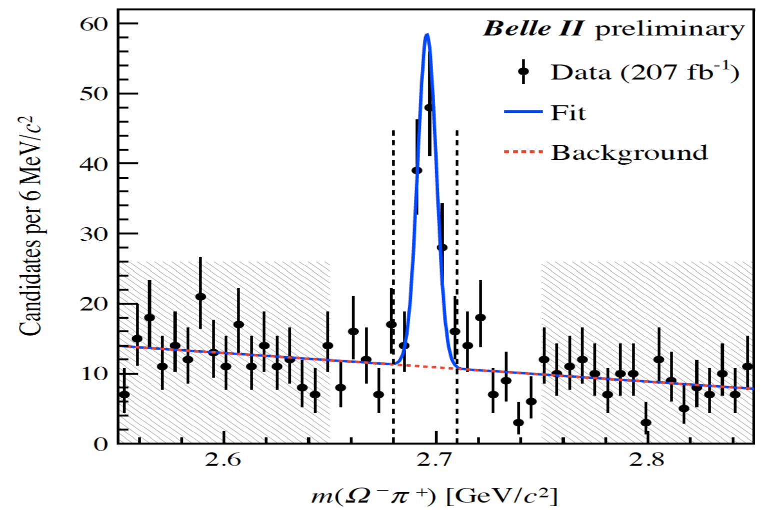
- $e^+e^- \to c\bar{c}, \Omega_c^0 \to \Omega^-\pi^+,$
  $\Omega^- \to \Lambda^0 K^-, \Lambda^0 \to p\pi^-.$

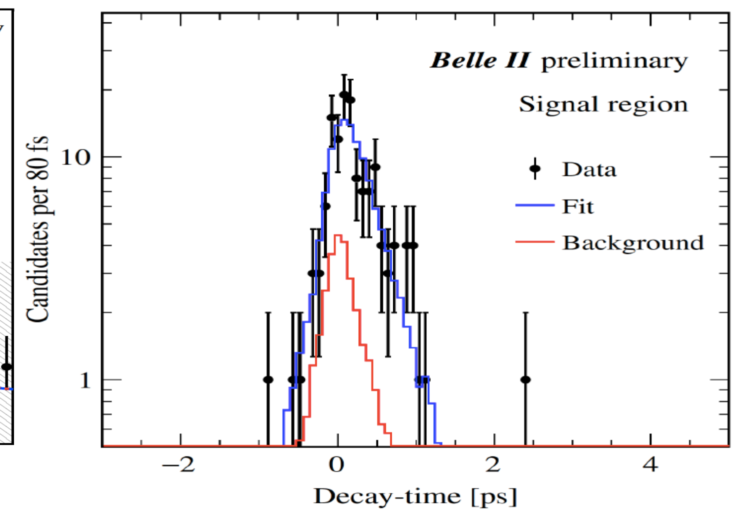
Decay time:

$$t = \frac{m_{\Omega_c^0} \vec{L} \cdot \vec{p}_{\Omega_c^0}}{\left|\vec{p}_{\Omega_c^0}\right|^2}$$



Decay-topology constrained vertex fit





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

... Belle II confirms the LHCb results

$\tau_{D_s^+}$ result will come up soon.