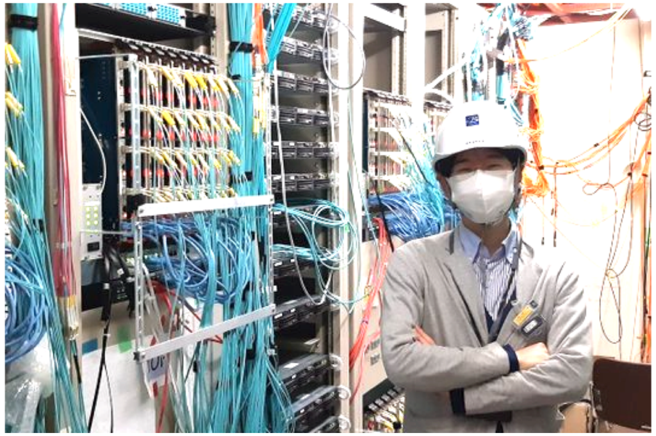
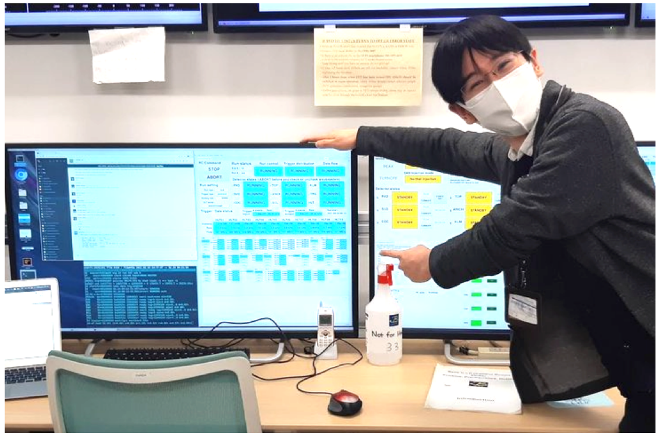




Belle II is excellently operating under the COVID-19 crisis.

Belle II: Status and Prospects

Takeo Higuchi

Kavli IPMU (WPI), the University of Tokyo

September 7th, 2021

PANIC 2021

Belle II Experiment

Mysteries in the Universe

- What made the matter-antimatter asymmetry in the Universe?
- What gave masses to the neutrinos?
- What is dark matter, and what is dark energy?
- What makes the Higgs boson so light? …

New physics beyond the SM?

In the quest for physics beyond the Standard Model, we started **the Belle II experiment** in KEK, Japan, in 2019.

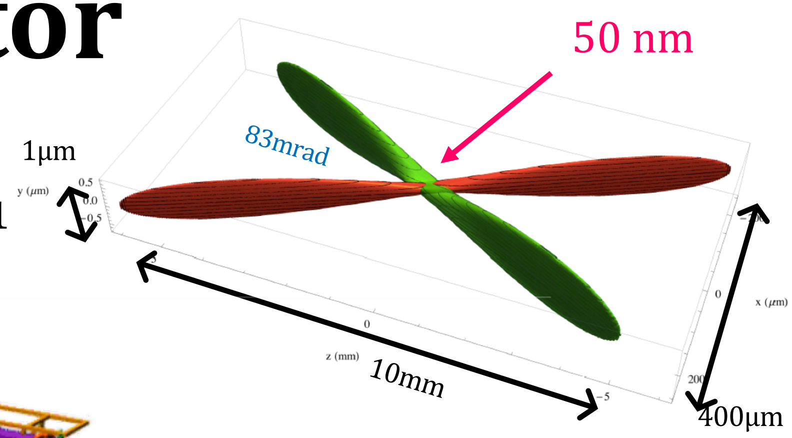
Start of the full data-taking (2019)

Belle II collaboration

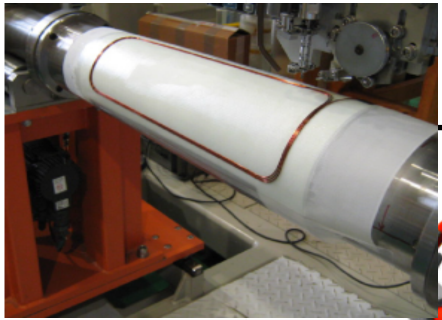
- **1,000+** collaborators at
- **110+** institutes in
- **26** countries/regions.

SuperKEKB Accelerator

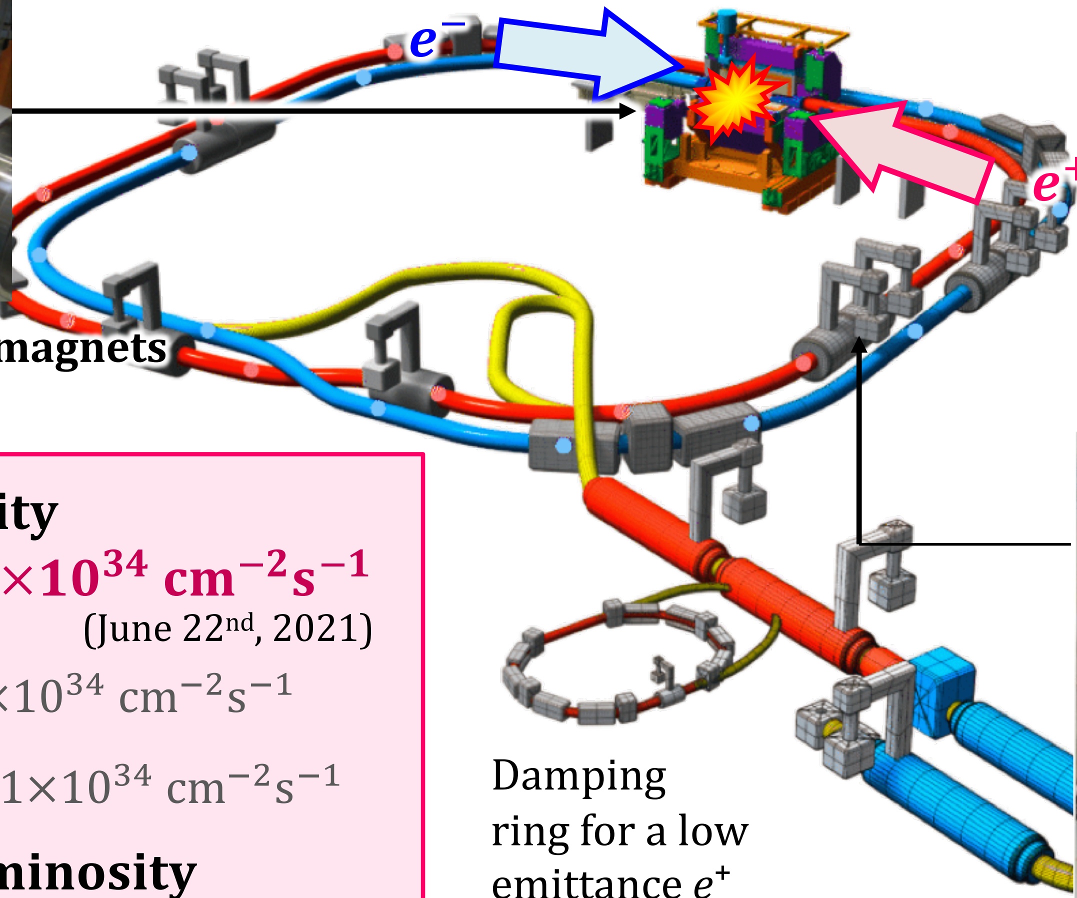
- 7 GeV e^- + 4 GeV e^+ $\rightarrow$ $b\bar{b}, \tau^+\tau^-, c\bar{c}, \ldots$
- Ultimate luminosity: 6.5×10^{35} cm^{-2}s^{-1}
- Target integrated luminosity: 50 ab^{-1}



Nano-beam scheme



New final focusing magnets



More RF cavities to increase the beam currents

Damping ring for a low emittance e^+ beam

- **Peak luminosity**
  $\mathcal{L}_{\text{peak}}^{\text{SKEKB}} = 3.1\times10^{34}$ cm^{-2}s^{-1} (June 22nd, 2021)
  $\mathcal{L}_{\text{peak}}^{\text{KEKB}} = 2.1\times10^{34}$ cm^{-2}s^{-1}
  $\mathcal{L}_{\text{peak}}^{\text{PEP-II}} = 1.21\times10^{34}$ cm^{-2}s^{-1}
- **Integrated luminosity**
  213 fb^{-1}

K. R. Nakamura, talk at TIPP2021 (2021);
BELLE2-NOTE-PL-2020-014;
BELLE2-NOTE-PL-2020-027.

Belle II Detector

Strip and pixel vertex detector
- Inner 2 layers: Pixel detector
- Outer 4 layers: Strip detectors

$\sigma_{\mathrm{min}}^{\mathrm{SVD}} \approx$ 10-25μm

Drift chamber (p, PID)
- Longer lever arm than Belle
- Smaller cell size than Belle

eff. × accept. ≥ 0.8 (for $p_T > 1$ GeV/c)

PID detectors (K/π separation)
- Barrel: Time-Of-Propagation counters
- Endcap: Aerogel RICH
- Wrong PID: x0.5 smaller than Belle

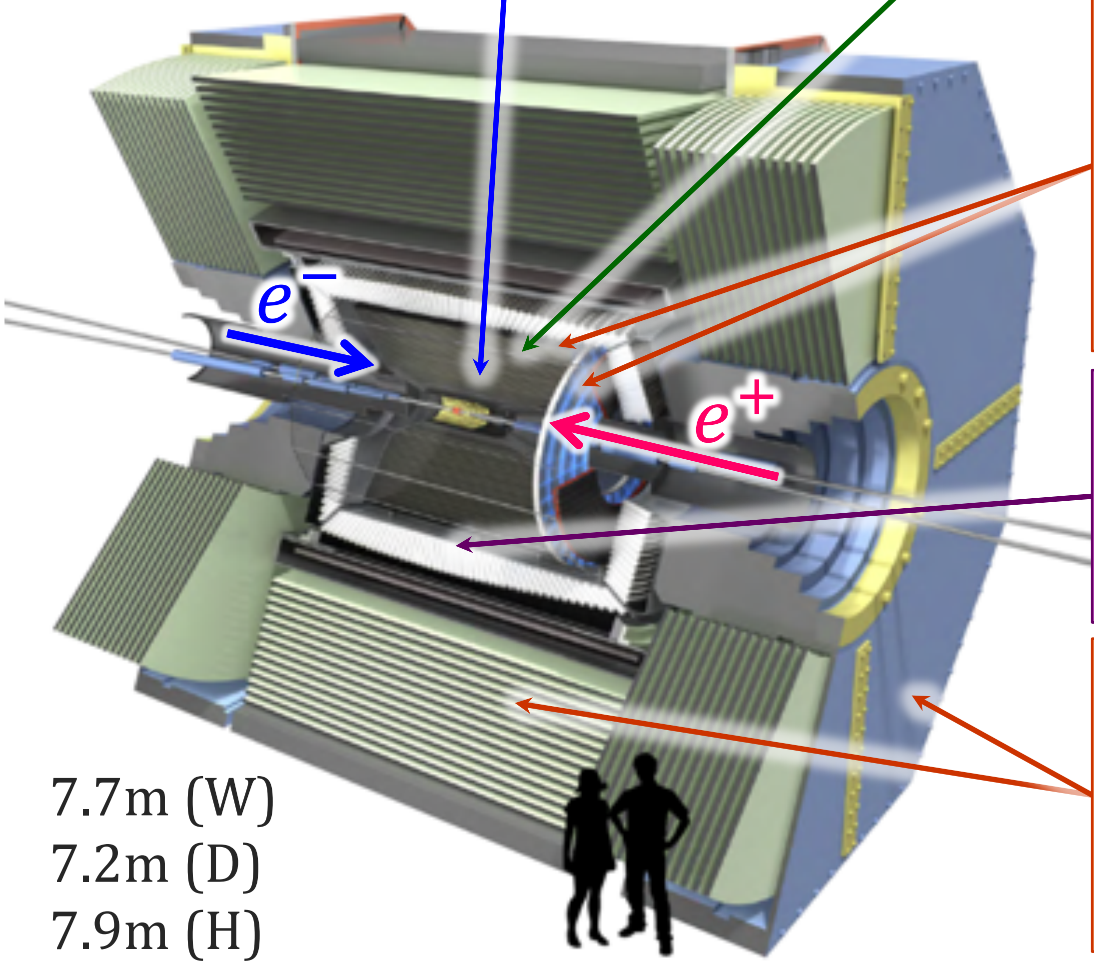
$\epsilon_K^{\mathrm{average}} \gtrsim 0.8$ (for all p region)

EM calorimeter (E_e, E_γ)
- CsI(Tl) + wave-form sampler

$\epsilon_{e^\pm} \approx 94\%$, wrong $h^\pm \to e^\pm$ ID $\approx 2\%$

K_L^0/μ detector
- Outer barrel: RPC (streamer mode)
- Endcap, inner barrel: Sci. + WL shifter

$\epsilon_{\mu^\pm} \approx 90\%$, wrong $h^\pm \to \mu^\pm$ ID $\approx 4\%$



7.7m (W)
7.2m (D)
7.9m (H)

New Physics Search at Belle II

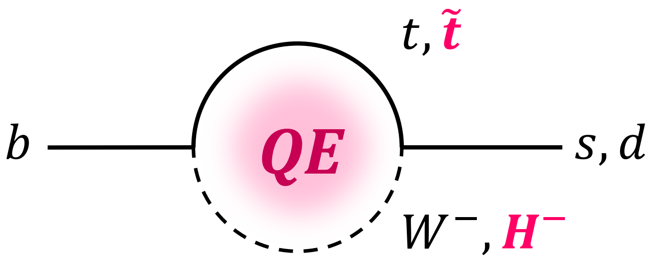
New physics search at Belle II

$$\Gamma_{\mathrm{SM}}(B \to f) = |A_{\mathrm{SM}}(B \to f)|^2 \xrightarrow[\text{contribution}]{\text{NP}} \Gamma_{\mathrm{obs}}(B \to f) = |A_{\mathrm{SM}}(B \to f) + A_{\mathrm{NP}}(B \to f)|^2$$

$$\Delta \equiv \Gamma_{\mathrm{obs}} - \Gamma_{\mathrm{SM}}$$

- Discovery of $\Delta \neq 0$ → discovery of a **new physics**
- Development of a list of Δ_i, collation of the list with the predictions by NP models → pinning down the most appropriate **NP model**

Quantum effect



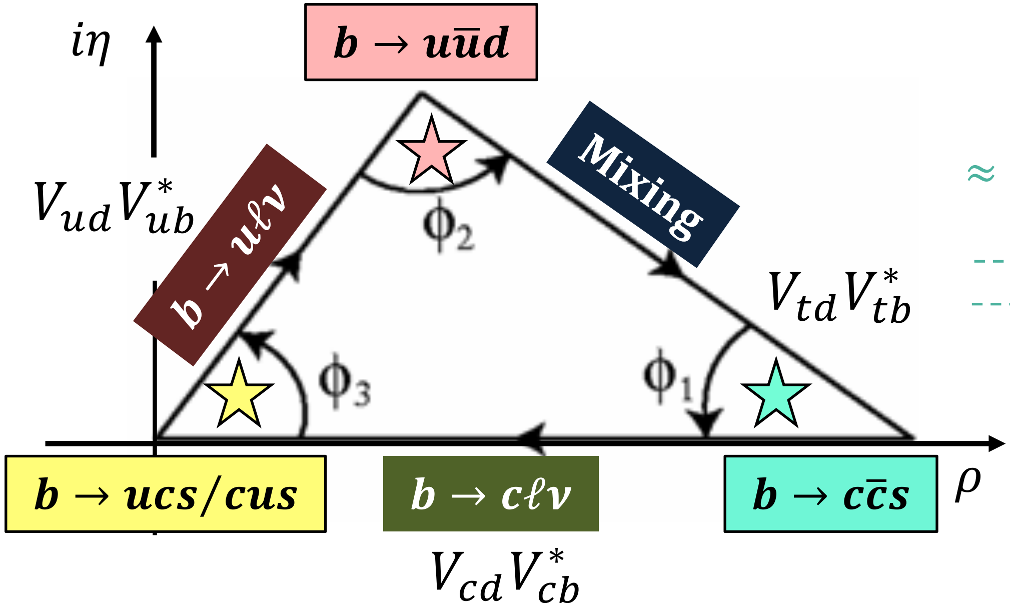
The quantum effect allows a NP particle that is much heavier than our $\sqrt{s} = 10.58$ GeV to appear in a loop. The NP particle intervene in the process mediated by the SM loop diagram.

Belle II is able to explore a NP-energy scale of $\gtrsim$ 100 TeV.

E. Kou, P. Urquijo *et al.*, Prog. Theor. Exp. Phys. 2019, 123C01 (2019).

UT Angle ϕ_1

Unitarity triangle ($V_{\mathrm{CKM}} V_{\mathrm{CKM}}^{\dagger}$)



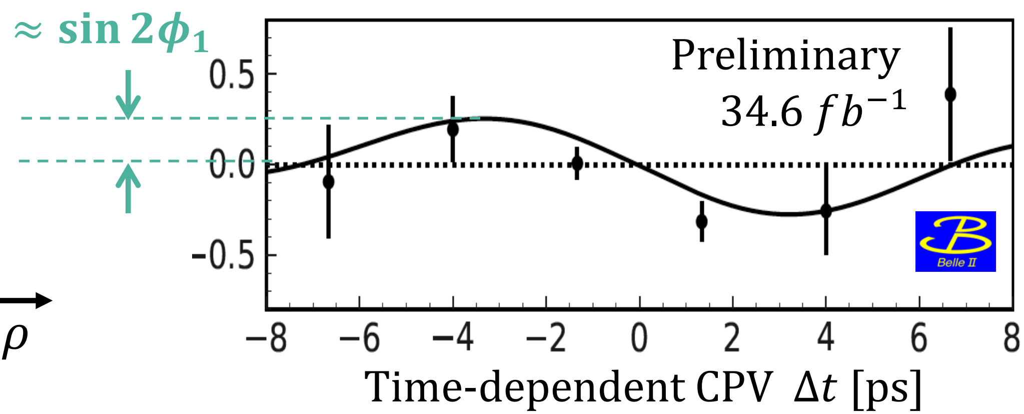
ϕ_1 measurement in $B^0 \to J/\psi\, K_S^0$

$\mathcal{S}_{c\bar{c}s} = \sin 2\phi_1$

Preliminary, BELLE2-NOTE-PL-2020-011

$$\mathcal{S}_{J/\psi K^0} = \mathbf{0.55 \pm 0.21 \pm 0.04}$$

$(\mathcal{S}_{\mathrm{WA}} = +0.699 \pm 0.017)$



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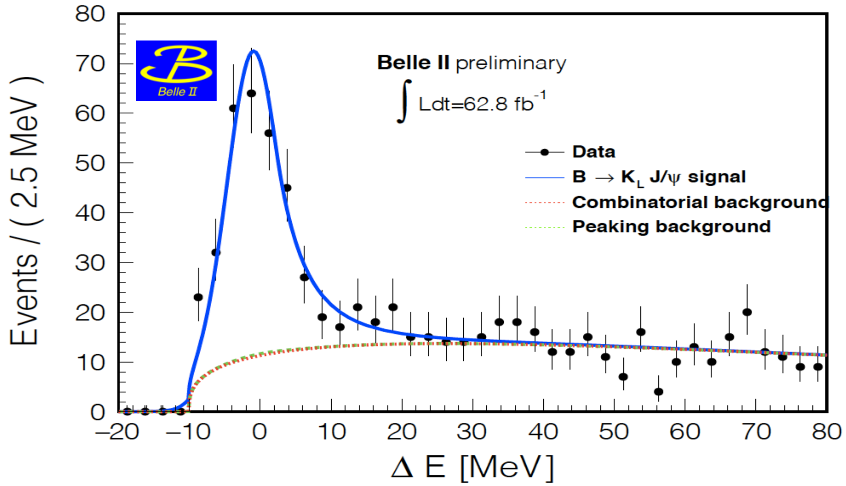
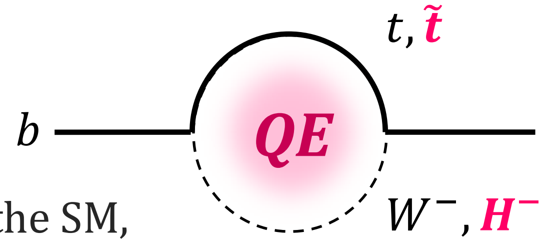
arXiv:2106.13547

$B^0 \to J/\psi\, K_L^0$ reconstruction for ϕ_1

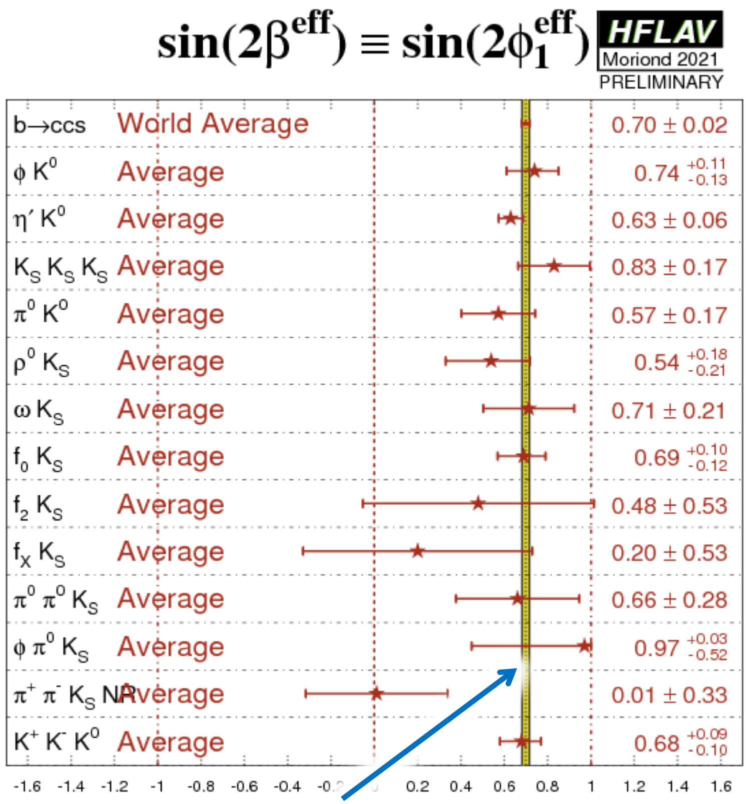
- The K_L^0 is identified by a hadron shower in the KLM (K_L^0 and muon detector).
- Only the direction of the $p_{K_L^0}$ is measured → only the E_B is measured instead of M_{bc}.



$\phi_1^{sq\bar{q}}$: Effective ϕ_1 in $b \to sq\bar{q}$ $(q = u, d, s)$



In the SM,
$S_{sq\bar{q}} = \sin 2\phi_1$.

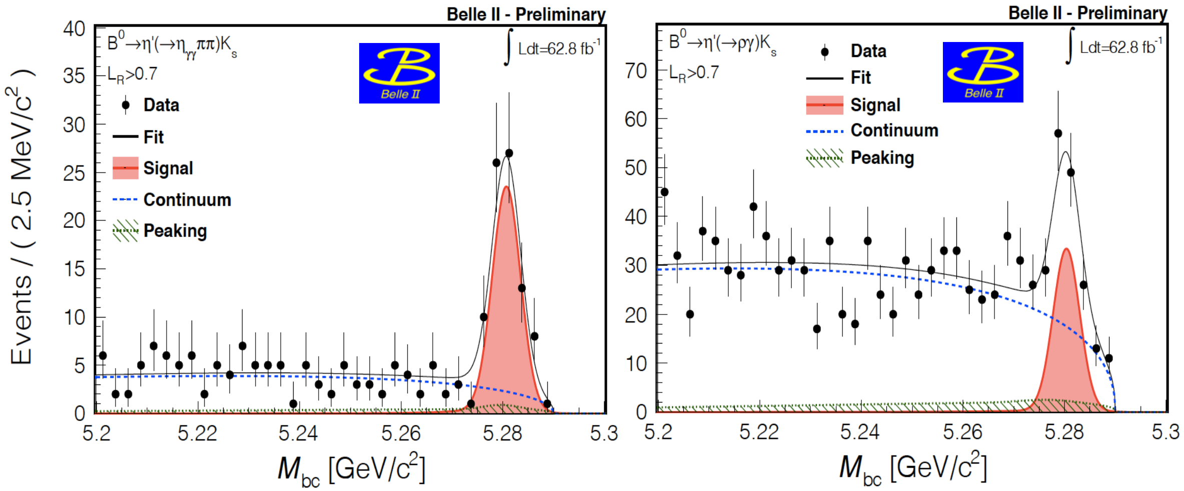


$(\sin 2\phi_1)_{c\bar{c}s} = 0.699 \pm 0.017$

$B^0 \to \eta' K_S^0$ reconstruction: an exciting NP probe for its small theoretical ambiguity.

BELLE2-CONF-PH-2021-005

$\eta' K_S^0$ $(\eta' \to \eta_{\gamma\gamma}\pi^+\pi^-)$ $\eta' K_S^0$ $(\eta' \to \rho^0(\pi^+\pi^-)\gamma)$



Preliminary

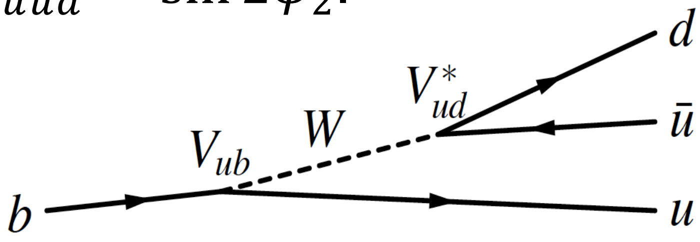
$$\mathcal{B}(B^0 \to \eta' K^0) = [59.9^{+5.8}_{-5.5} \pm 2.7] \times 10^{-6}$$

$(\mathcal{B}^{\text{PDG-Live}} = [66 \pm 4] \times 10^{-6})$

Used data size: $62.8\ \text{fb}^{-1} < 9\%$ of Belle

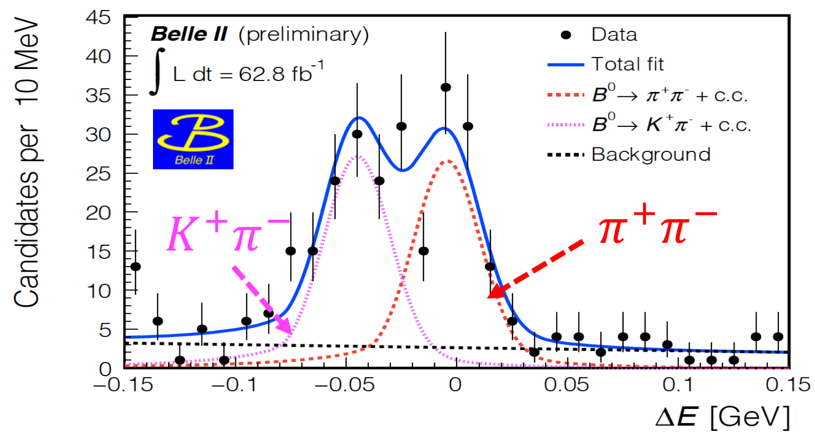
UT Angle ϕ_2

- The ϕ_2 can be measured with the $b \to u\bar{u}d$ transition.
- $\mathcal{S}_{u\bar{u}d} = \sin 2\phi_2$.



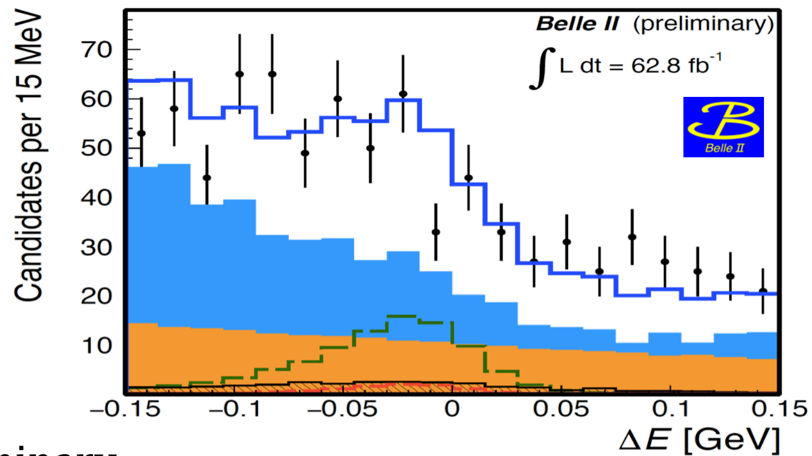
$B^0 \to \pi^+\pi^-$ reconstruction

arXiv:2106.03766



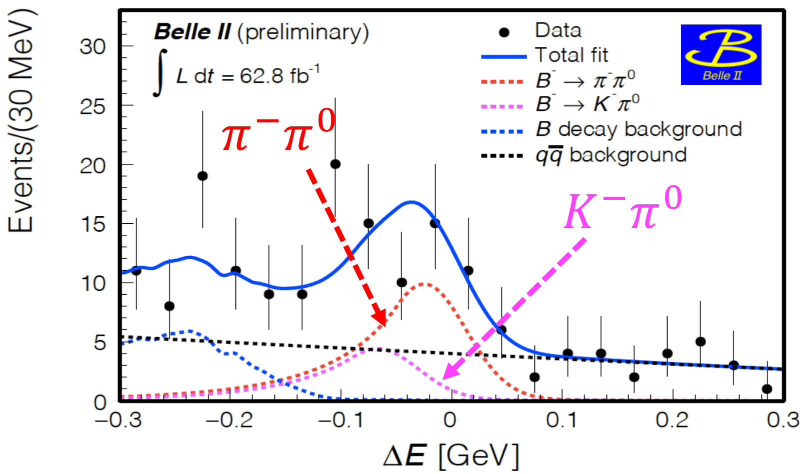
$B^\pm \to \rho^\pm\rho^0$ reconstruction

BELLE2-TALK-CONF-2021-013



$B^\pm \to \pi^\pm\pi^0$ reconstruction

arXiv:2105.04111



Preliminary

$$\mathcal{B}(B^0 \to \pi^+\pi^-) = [5.8 \pm 0.7 \pm 0.3]\times 10^{-6}$$
$$\mathcal{B}(B^+ \to \pi^+\pi^0) = [5.5^{+1.0}_{-0.9} \pm 0.7]\times 10^{-6}$$
$$\mathcal{B}(B^+ \to \rho^+\rho^0) = [20.6 \pm 3.2 \pm 4.0]\times 10^{-6}$$

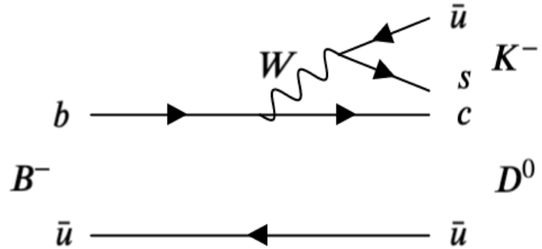
$B \to D^{(*)}h$ Study $(h = K, \pi)$

- The ϕ_3 can be measured with interference between CF (D^0K^-) and CS ($\bar{D}^0K^-$) decays.

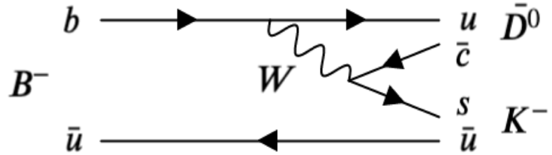
$$\frac{A_{\mathrm{CS}}(B^- \to \bar{D}^0K^-)}{A_{\mathrm{CF}}(B^- \to D^0K^-)} = r_B \exp(i\delta_B - i\phi_3)$$

r_B: amplitude ratio, δ_B: strong phase difference

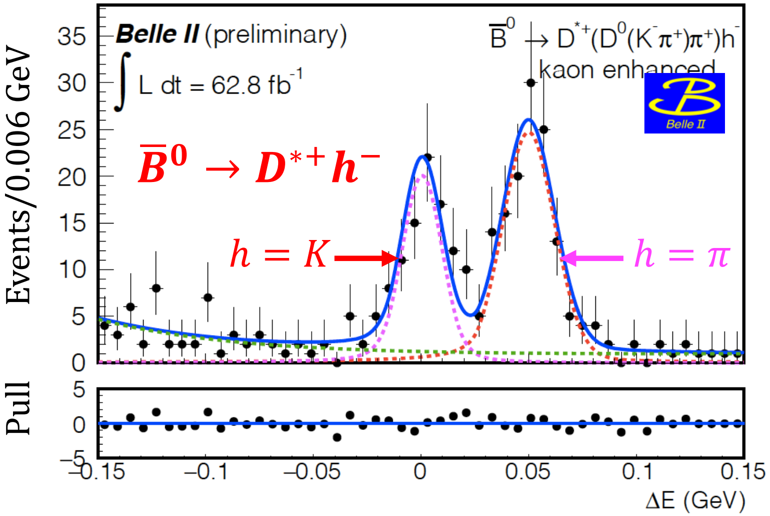
CF



CS



arXiv:2104.03628



$$\frac{\mathcal{B}(B^- \to D^0K^-)}{\mathcal{B}(B^- \to D^0\pi^-)} = (7.66 \pm 0.55^{+0.11}_{-0.08})\times 10^{-2} \quad (D^0 \to K^-\pi^+)$$

$$\frac{\mathcal{B}(B^- \to D^0K^-)}{\mathcal{B}(B^- \to D^0\pi^-)} = (6.32 \pm 0.81^{+0.09}_{-0.11})\times 10^{-2} \quad (D^0 \to K_S^0\pi^+\pi^-)$$

$$\frac{\mathcal{B}(B^- \to D^{*0}K^-)}{\mathcal{B}(B^- \to D^{*0}\pi^-)} = (6.80 \pm 1.01 \pm 0.07)\times 10^{-2}$$

$$\frac{\mathcal{B}(\bar{B}^0 \to D^+K^-)}{\mathcal{B}(\bar{B}^0 \to D^+\pi^-)} = (9.22 \pm 0.58 \pm 0.09)\times 10^{-2}$$

Preliminary

$$\frac{\mathcal{B}(\bar{B}^0 \to D^{*+}K^-)}{\mathcal{B}(\bar{B}^0 \to D^{*+}\pi^-)} = (5.99 \pm 0.82^{+0.17}_{-0.08})\times 10^{-2}$$

$K\pi$ Puzzle

- Belle reported a difference in the direct CPV parameter values:

$$A_{CP}^{K^+\pi^-} \equiv \frac{(N_{\bar{B}^0\to K^-\pi^+} - N_{B^0\to K^-\pi^+})}{(N_{\bar{B}^0\to K^-\pi^+} + N_{B^0\to K^-\pi^+})} = -0.069 \pm 0.014 \pm 0.014$$

$$A_{CP}^{K^+\pi^0} \equiv \frac{(N_{B^-\to K^-\pi^0} - N_{B^+\to K^+\pi^0})}{(N_{B^-\to K^-\pi^0} + N_{B^+\to K^+\pi^0})} = +0.043 \pm 0.024 \pm 0.002$$

$$\boldsymbol{A_{CP}^{K^+\pi^0} - A_{CP}^{K^+\pi^-} = +0.112 \pm 0.027 \pm 0.007}$$

- Isospin sum-rule:

Dominant ambiguities in $I_{K\pi}$

$$I_{K\pi} \equiv A_{CP}^{K^+\pi^-} + A_{CP}^{K^0\pi^-}\frac{\mathcal{B}(K^0\pi^+)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_{B^0}}{\tau_{B^+}} - 2A_{CP}^{K^+\pi^0}\frac{\mathcal{B}(K^+\pi^0)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_{B^0}}{\tau_{B^+}} - 2A_{CP}^{K^0\pi^0}\frac{\mathcal{B}(K^0\pi^0)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_{B^0}}{\tau_{B^+}}$$

$I_{K\pi} \neq 0 \implies$ NP.

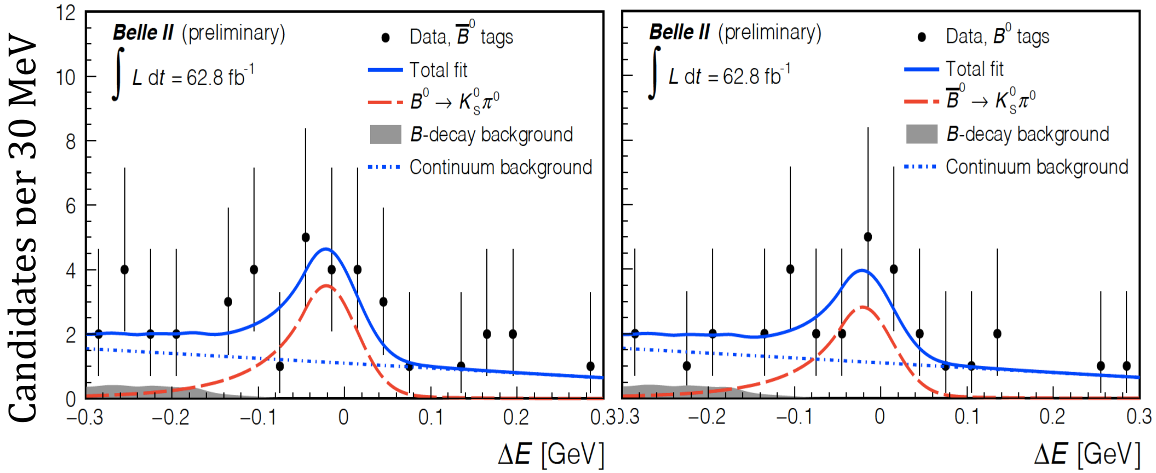
M. Gronau, Phys. Lett. B 627, 82 (2005).

$B^0 \to K_S^0\pi^0$ reconstruction

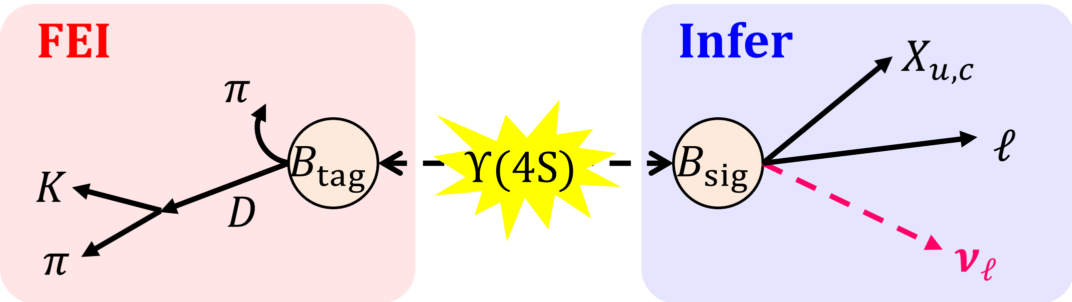
$$\boldsymbol{\mathcal{B}(B^0 \to K_S^0\pi^0) = [8.5^{+1.7}_{-1.6} \pm 1.2]\times 10^{-6}}$$

$$\boldsymbol{A_{CP}^{K^0\pi^0} = -0.40^{+0.46}_{-0.44} \pm 0.04}$$

Preliminary, arXiv:2104.14871



Full Event Interpretation (FEI)



- Essential technique to study B decay modes containing ν_ℓ(s).
- Reconstruct the B_{tag} momentum with multivariate technique through $\mathcal{O}(10^3)$ B_{tag} decay modes.
- Infer the the B_{sig} momentum and determine the $\vec{p}_{\text{miss}}$ of the event.

Tagging eff. (evaluated on Belle MC) of FEI

ϵ_{tag} **for had**:	$0.78\%(B^+)$, $0.46\%(B^0)$
ϵ_{tag} **for SL**:	$1.80\%(B^+)$, $2.04\%(B^0)$

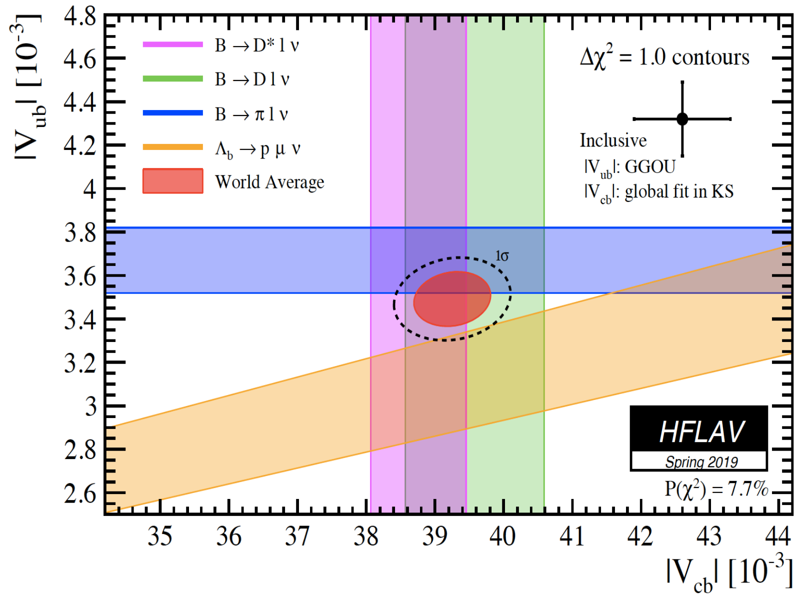
T. Keck *et al.* Comp. Soft. Big Sci. (2019) 3:6.

Motivation for FEI, motivation study of $b \to u/c\, \ell \nu_\ell$

- There is a $\sim 3\sigma$ tension between incl. and excl. determinations for both $|V_{ub}|$, $|V_{cb}|$.
- $X_c \ell \nu_\ell$ is used to test the lepton flavor universality (sensitive to LQ, H^+, ...).

We focus on $|V_{ub}|$ today.

HFLAV, Eur. Phys. J., C **81**, 226 (2021)

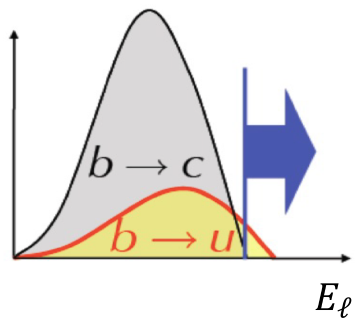


arXiv:2103.02629

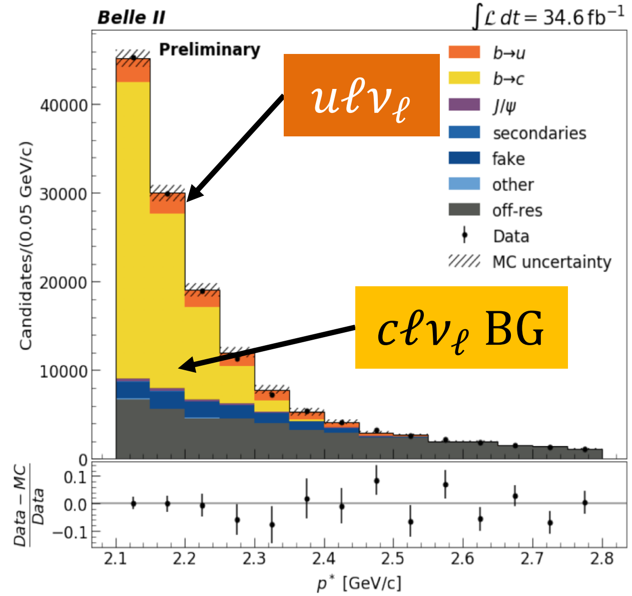
CKM Matrix Element $|V_{ub}|$ $(b \to u\ell\nu_\ell)$

Inclusive $b \to u\ell\nu_\ell$

- E_ℓ from $b \to u\ell\nu_\ell$ tends to be larger than that from $b \to c\ell\nu_\ell$ because $m_c > m_u$.
- Select events in the E_ℓ endpoint region: $2.1 < E_\ell < 2.8$ GeV.



Preliminary

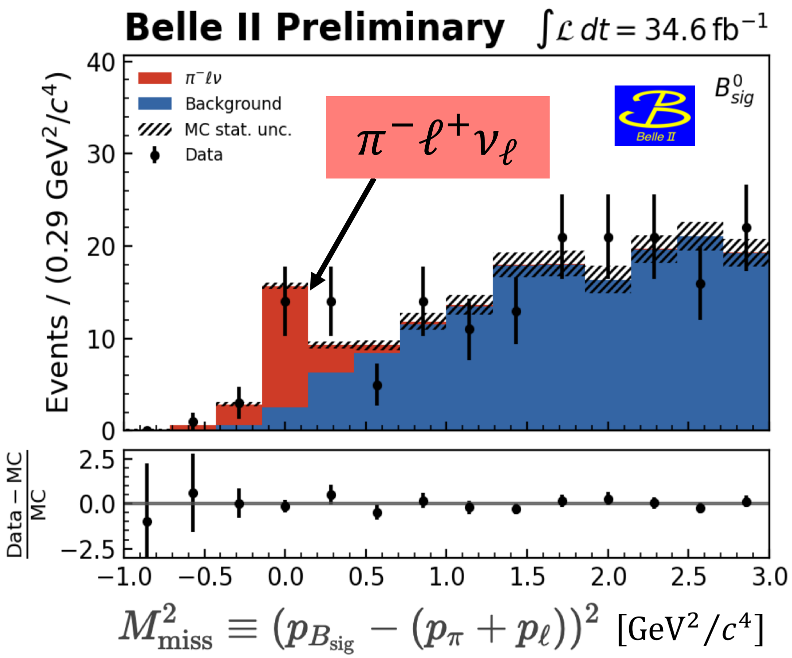


Observed $b \to u\ell\nu_\ell$ excess in data ($> 3\sigma$).

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

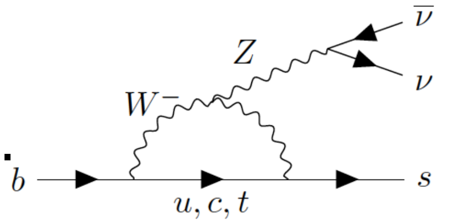
- Infer the B_{sig} momentum $p_{B_{sig}}$ with FEI.
- Identify $\ell^\pm, \pi^\mp$ and determine the signal yield by fitting the M_{miss}^2 distribution to the MC-estimated distribution.

Preliminary

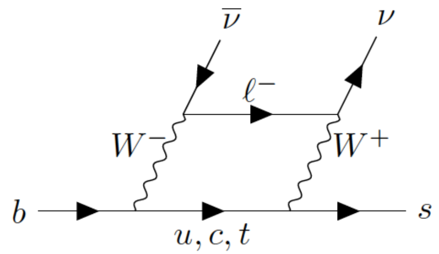


$$\mathcal{B}(B^0 \to \pi^-\ell^+\nu_\ell) = [1.58 \pm 0.43 \pm 0.07] \times 10^{-4}\ (5.69\sigma)$$

$B^+ \to K^+ \nu\bar{\nu}$



- The SM prediction of $\mathcal{B}(B^+ \to K^+\nu\bar{\nu})$ is $(4.6 \pm 0.5)\times 10^{-6}$.
- No evidence for signal was observed so far, but the NP could potentially enhance $\mathcal{B}(B^+ \to K^+\nu\bar{\nu})$.



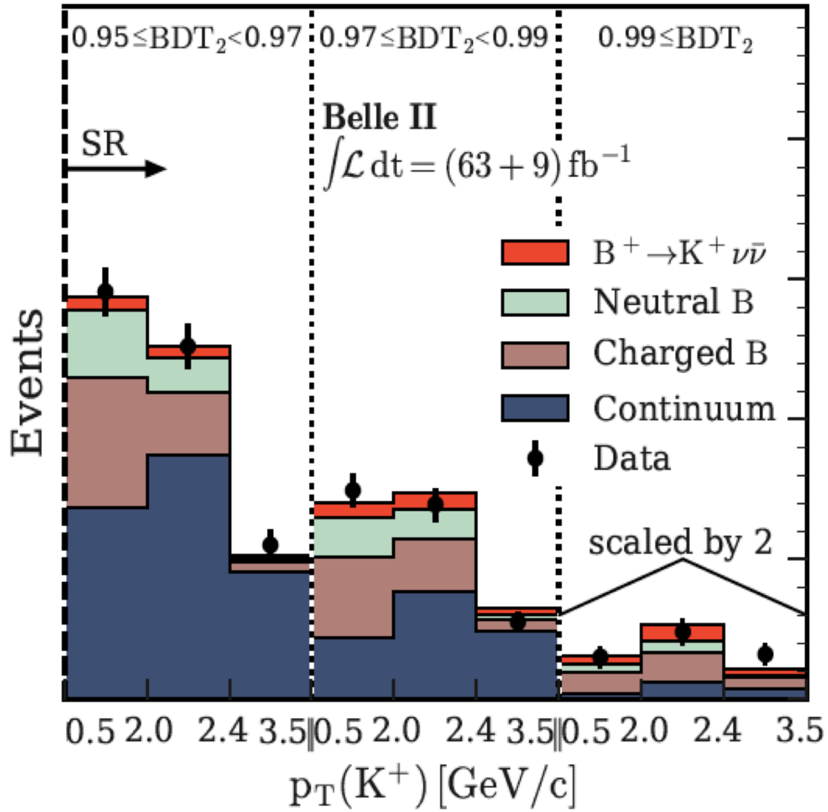
$B^+ \to K^+\nu\bar{\nu}$ reconstruction

- The signal candidate K^+ is required to have **the largest p_T in the event**, ≥1 vertex detector hit(s), good kaon ID.
- The FastBDT algorithm is employed to extract signal events. Two BDTs are used:
  - BDT_1 for the event selection (BDT_1>0.9).
  - BDT_2 for background suppression (see →)
- No signal excess above the expected BG.

Preliminary, arXiv:2104.12624

$$\mathcal{B}(B^+ \to K^+\nu\bar{\nu}) = (1.9^{+1.3+0.8}_{-1.3-0.7}) \times 10^{-5}$$

4.1×10^{-5} @90% CL



Tau Physics

A B-factory is also a τ-factory because $\sigma_{b\bar{b}} \approx \sigma_{\tau\tau}$ at $\sqrt{s} = 10.58$ GeV.

Measurement of the τ mass

- In the SM, $\mathcal{B}(\tau^- \to \ell^- \bar{\nu}_\ell \nu_\tau) \equiv \mathcal{B}_{\tau\ell}$ is related to m_τ, τ_τ by $\mathcal{B}_{\tau\ell}^{\rm SM} \propto \mathcal{B}_{\mu e} \dfrac{\tau_\tau}{\tau_\mu} \dfrac{m_\tau^5}{m_\mu^5}$ which motivates their precise measurements.
- τ reconstruction: $\tau^- \to \pi^-\pi^-\pi^+\nu_\tau$.
- $M_{\rm min} \equiv \sqrt{M_{3\pi}^2 + 2(E_{\rm beam} - E_{3\pi})(E_{3\pi} - p_{3\pi})}$

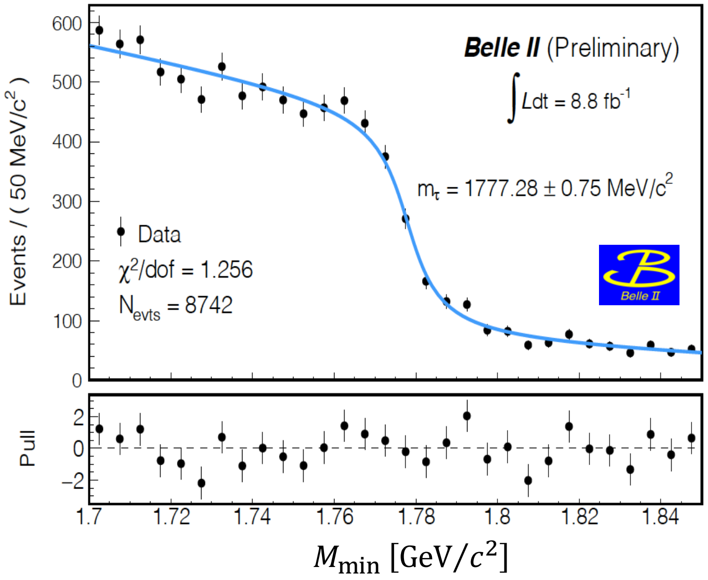
$$F(M_{\rm min}; m_\tau, P_2 \dots P_5) = (P_3 + P_4 M_{\rm min}) \cdot \tan^{-1}\left[\frac{M_{\rm min} - m_\tau}{P_2}\right] + P_5 M_{\rm min} + 1$$

Preliminary

$$m_\tau = 1777.28 \pm 0.75 \pm 0.33 \ \ \mathrm{MeV}/c^2$$

(PDG: $m_\tau = 1776.86 \pm 0.12 \ \ \mathrm{MeV}/c^2$)

arXiv:2008.04665

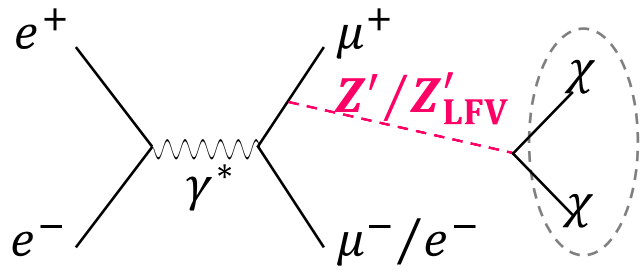


- Preparation for the τ lifetime measurement is ongoing.

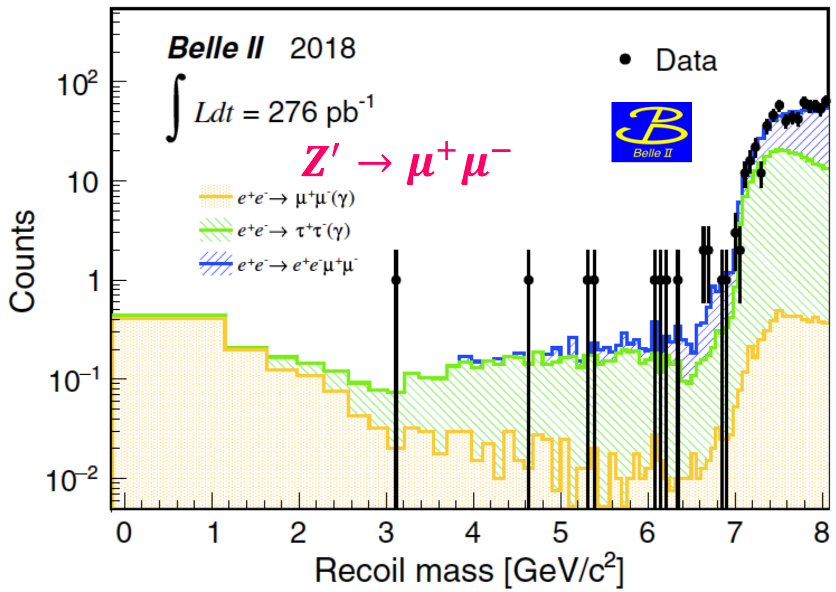
Invisible Particle Search

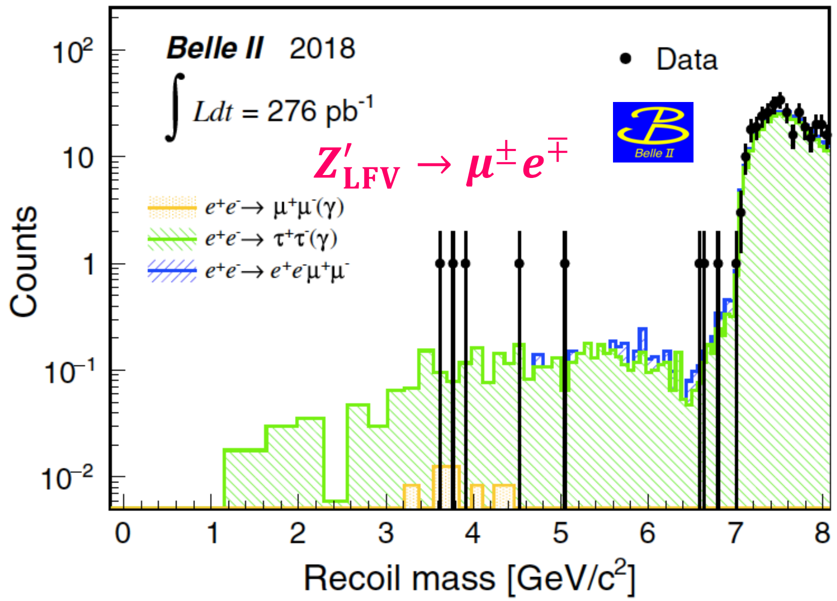
Search for a new gauge boson Z' that couples only with $\mu, \tau, \nu_\mu, \nu_\tau$

- The Z' can answer to the g-2 problem, $R_{K^{(*)}}$ issue, *etc.*
- Signal: $e^+e^- \to \mu^+\mu^- Z' \to \mu^+\mu^- + (\chi\chi)$
  Dominant BG: $e^+e^- \to \tau^+\tau^- \to \mu^+\mu^- + 4\nu$



Invisible

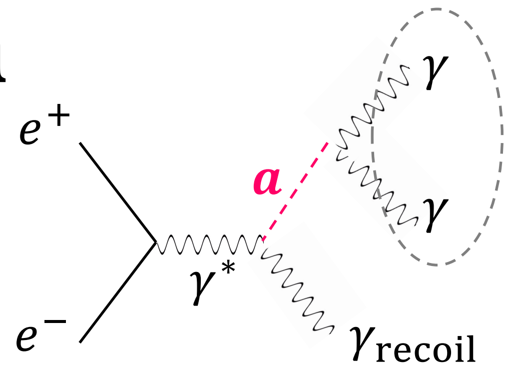




No evidence for Z'
$g_{Z'\ell\ell} < 5\times10^{-2}\ldots1$ for $m_{Z'} \le 6\ \mathrm{GeV}/c^2$

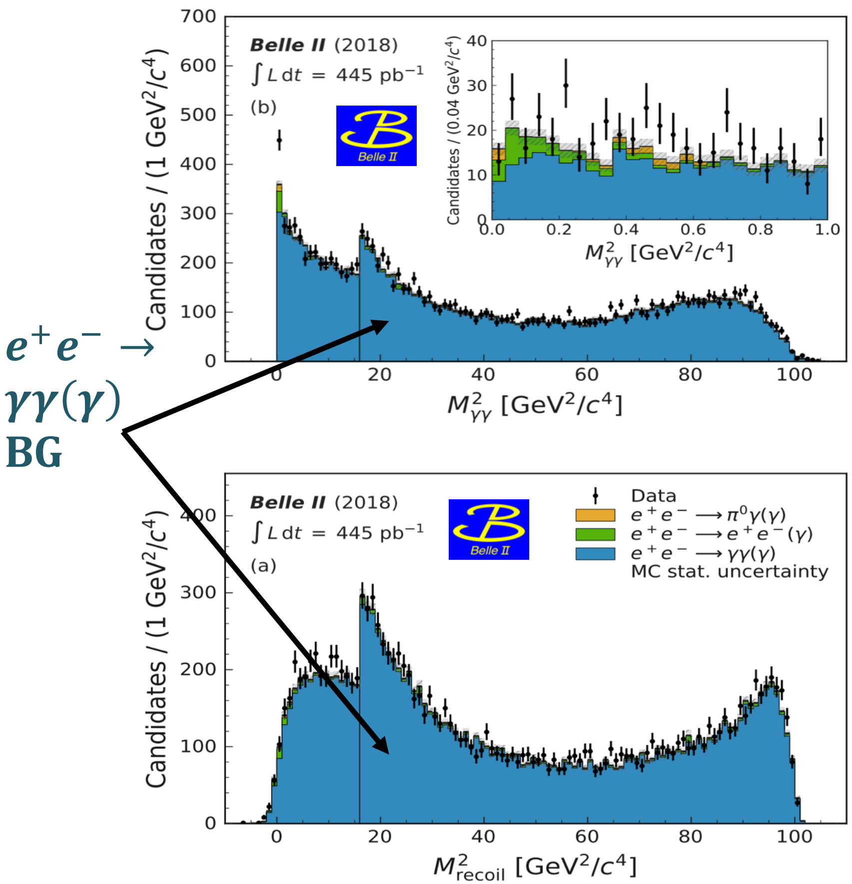
I. Adachi *et al.* (Belle II), Phys. Rev. Lett. **124**, 141801 (2020)

Axion-Like Particle Search



Search for an axion like particle (ALP)

- A GeV-scale ALP (a) is a pseudoscalar portal mediator between Dark Sector and Standard Model.
- Signal: $e^+e^- \to \gamma_{\text{recoil}} + a \to \gamma_{\text{recoil}} + (\gamma\gamma)$; $\sqrt{s}^2 = p^2_{\text{recoil}} + p^2_{\gamma\gamma}$.



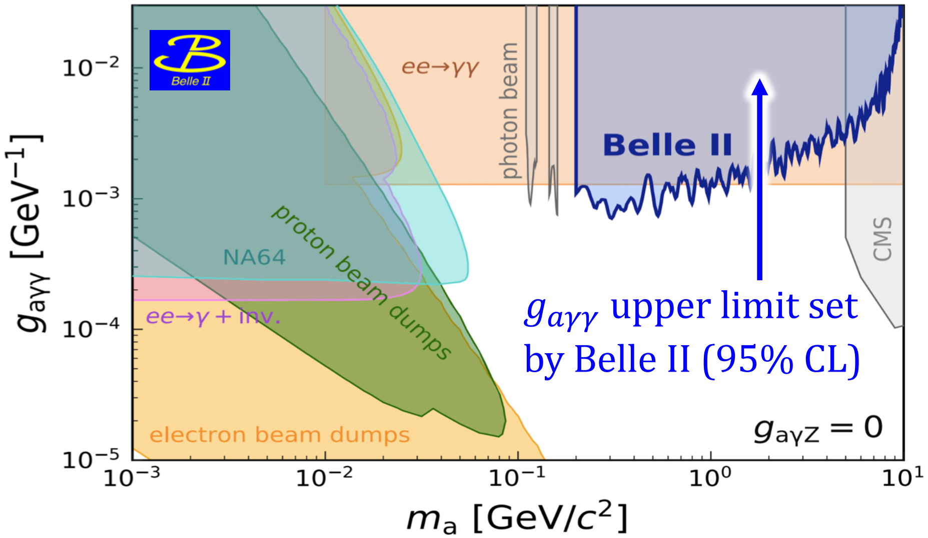
F. Abudinén *et al.* (Belle II), Phys. Rev. Lett. **125**, 161806 (2020)

No evidence for ALP

$$g_{a\gamma\gamma} \lesssim 10^{-3}\,(\text{GeV}/c^2)^{-1}$$

$$\text{for } 0.2 < m_a \leq 1\ \text{GeV}/c^2$$

Most restrictive to date for $0.2 < m_a < 1\ \text{GeV}/c^2$.



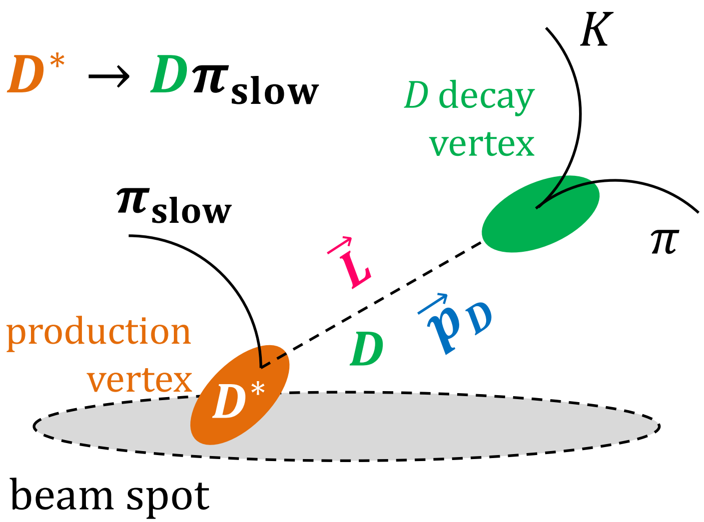
Charm Physics (D^0, D^+ lifetimes)

- τ_D (and τ_B) provides with useful input for testing the “effective models”, along which low-energy QCD interaction is computed.

τ_{D^0} and τ_{D^+} measurement

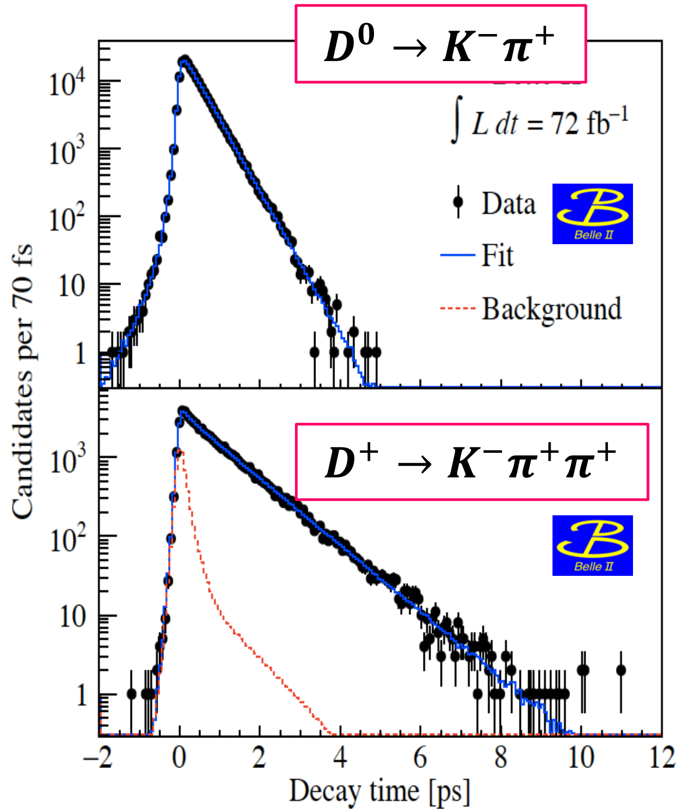
- τ_{D^0} and τ_{D^+} are obtained from the D momentum $\vec{p}_D$ and the distance $\vec{L}$ from the production to the decay vertices of the D.

arXiv:2108.03216



$$\delta t = m_D \vec{L} \cdot \vec{p}_D / (|\vec{p}_D|^2 c).$$

VXD resolution = 60-70 fs



Preliminary

τ_{D^0} = **$410.5 \pm 1.1 \pm 0.8$ fs**

($\tau_{D^0}^{PDG-Live} = 410.1 \pm 1.5$ fs)

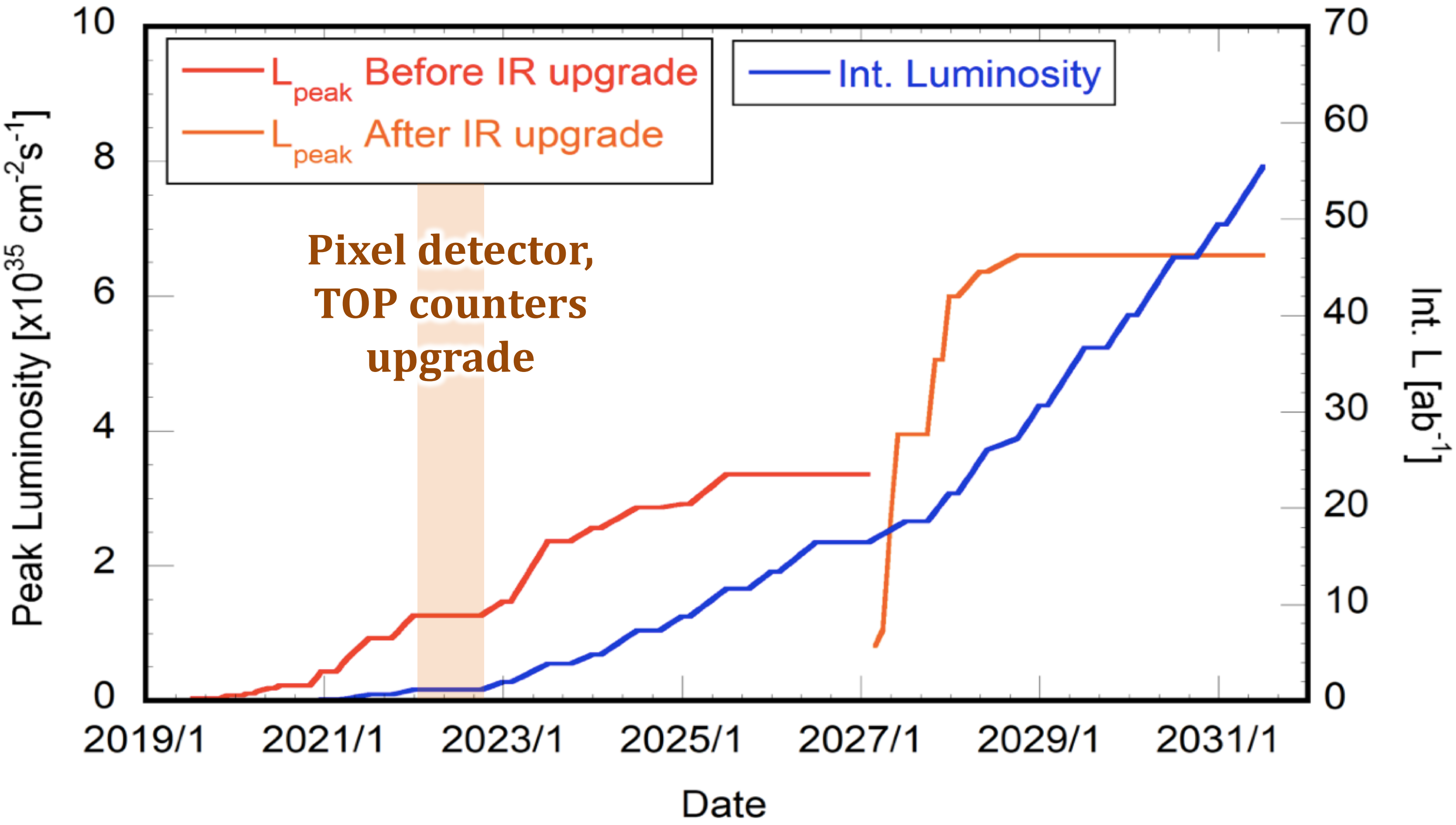
Preliminary

τ_{D^+} = **$1030.4 \pm 4.7 \pm 3.1$ fs**

($\tau_{D^+}^{PDG-Live} = 1040 \pm 7$ fs)

They are the most precise single measurements.

Belle II Prospect



We will collect 50 ab^{-1} data in the next ~10 years.

Summary

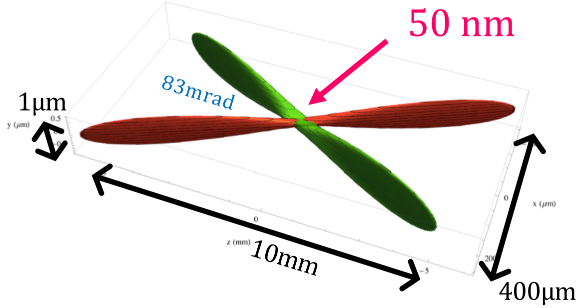
- In quest for a new physics beyond the SM, we had kicked off the operation of Belle II in 2019.
- We are operating Belle II very nicely coping with COVID-19 difficulties. We have collected 213 fb^{-1} data.
- We are actively working on Belle II data analyses. Several cutting-edge results in data analyses have been presented.
- Plenty of exciting physics results are coming in the next few years.

Backup Slides

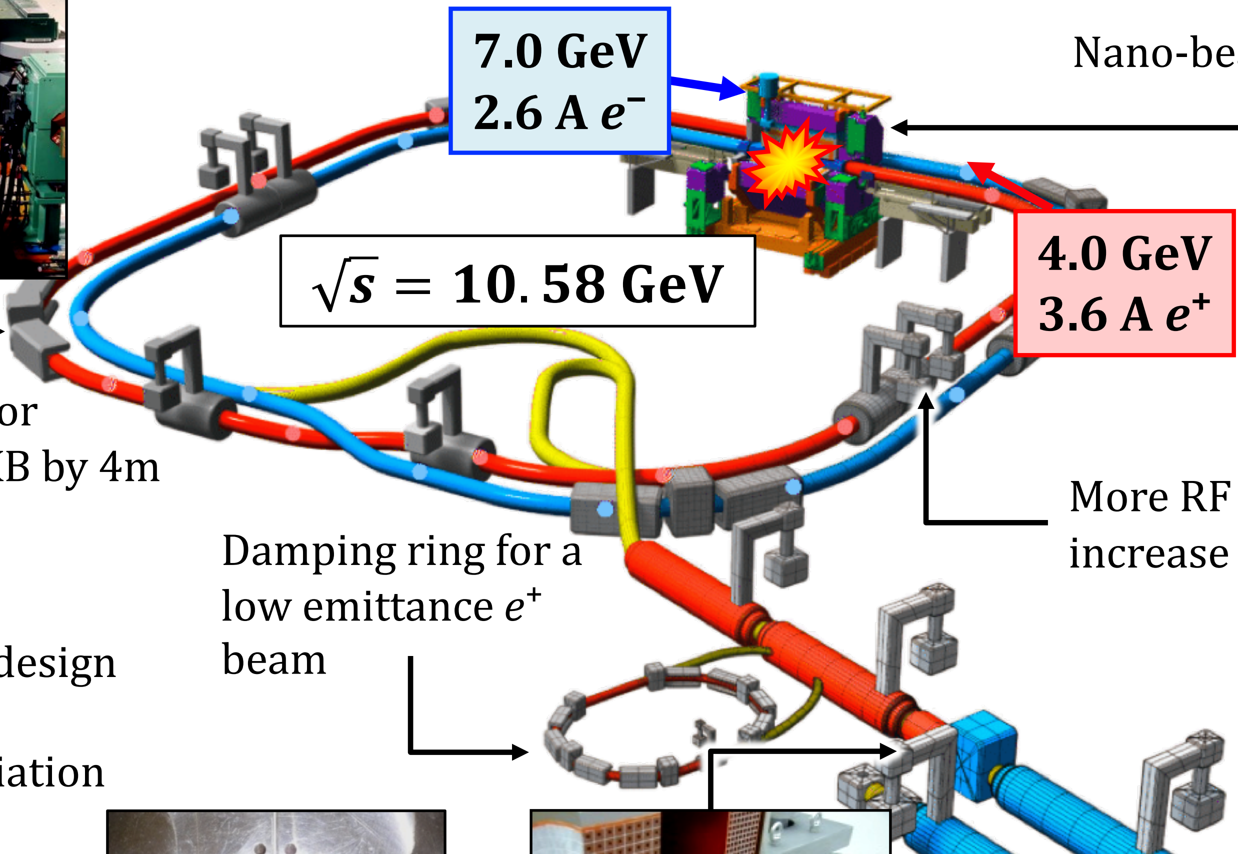
SuperKEKB Accelerator

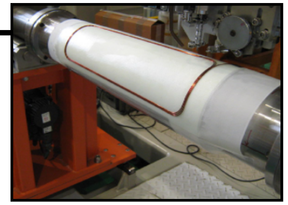
$$\mathcal{L}_{\mathbf{design}} = 6.5\times10^{35}\ \mathrm{cm^{-2}s^{-1}}$$
$$\int \mathcal{L}dt = 50\ \mathrm{ab^{-1}}$$

Longer magnets for the LER than KEKB by 4m



Nano-beam scheme



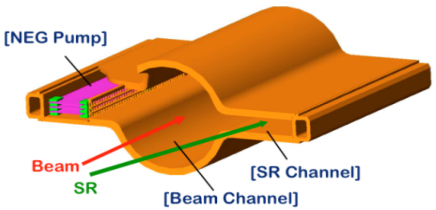


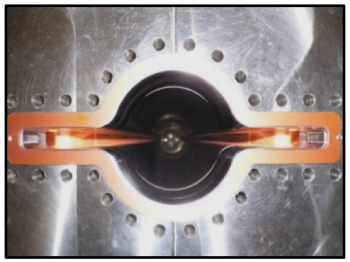
New final focusing magnets

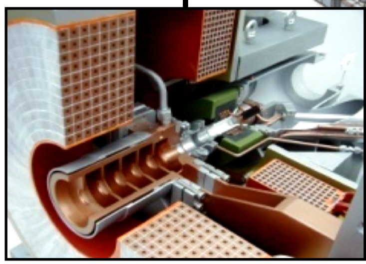
More RF cavities to increase the beam currents

Damping ring for a low emittance e^+ beam

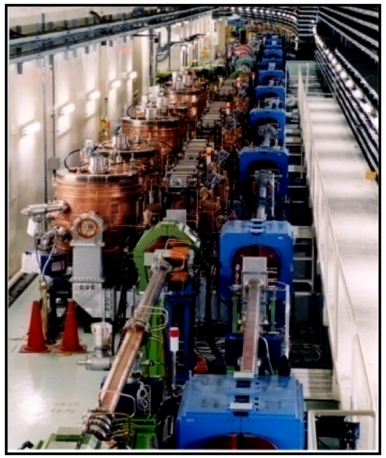
New beam pipe design to reduce the synchrotron radiation







Positron source

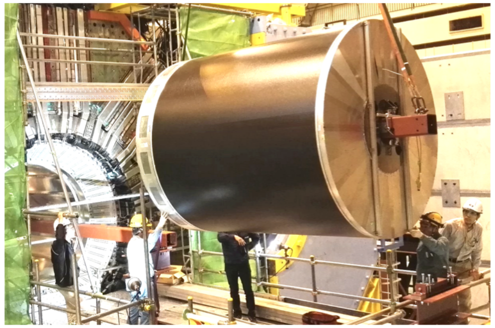


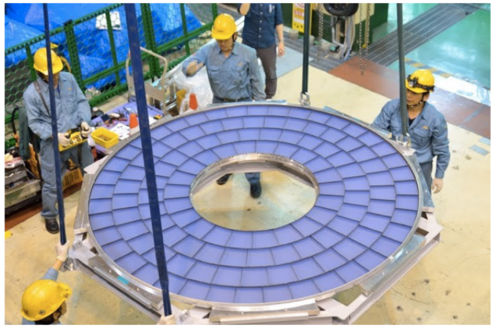
Belle II Operation History

2016
2017
2018
2019
2020
2021

Phase 1 — **Accelerator commissioning with no collisions**

Outer detector and reduced-scale VXD installation





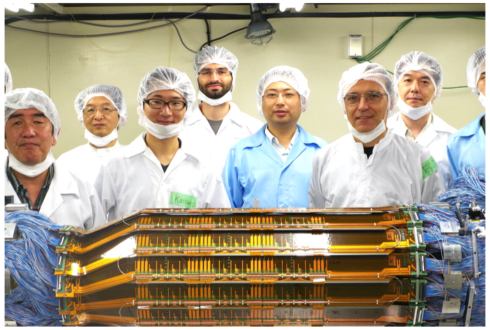
Cosmic ray run

Phase 2 — **Accelerator + outer detector commissioning**
collected **$472\ \mathrm{pb}^{-1}$ data**

Belle II physics results

- Dark gauge boson Z' search
- Axion like particle search

VXD installation and commissioning



Phase 3

Full data taking

SuperKEKB

- $\int \mathcal{L} dt = 213\ \mathrm{fb}^{-1}$
- $\mathcal{L}_{\max} = 2.96\times10^{34}/\mathrm{cm}^2\mathrm{s}$
- $\sqrt{I_{e^+} I_{e^-}}_{\max} = 0.83\ \mathrm{A}$

Belle II physics results

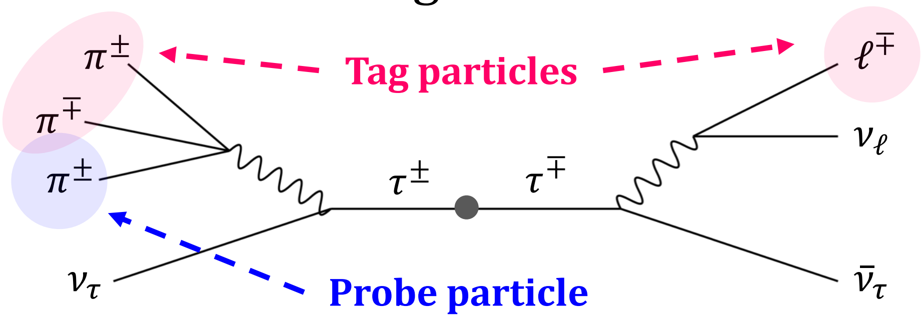
- $B \to K\nu\bar{\nu}$ search
- D-meson lifetime
- Preparation for the CP-violation meas …

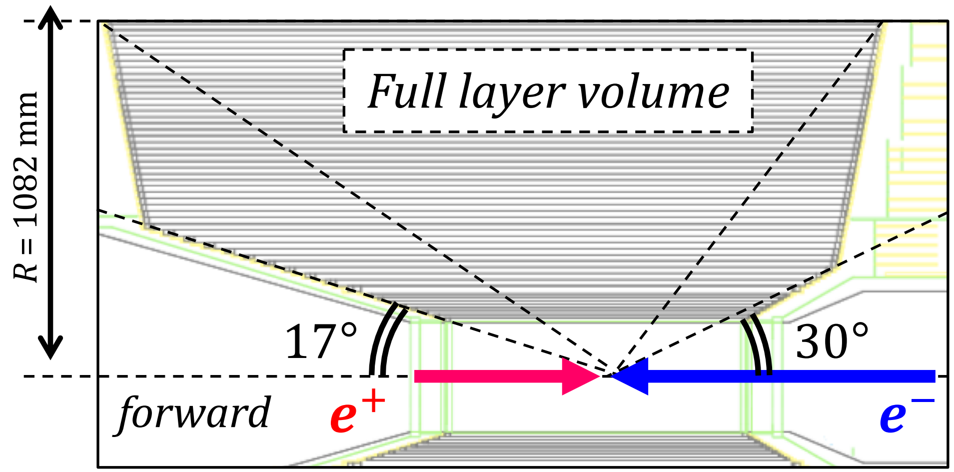
Tracking Detector Performance

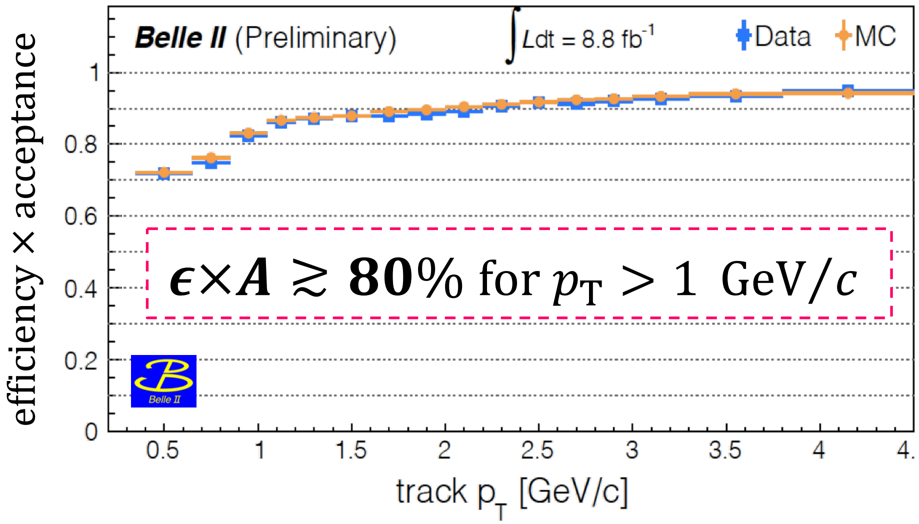
BELLE2-NOTE-PL-2020-014

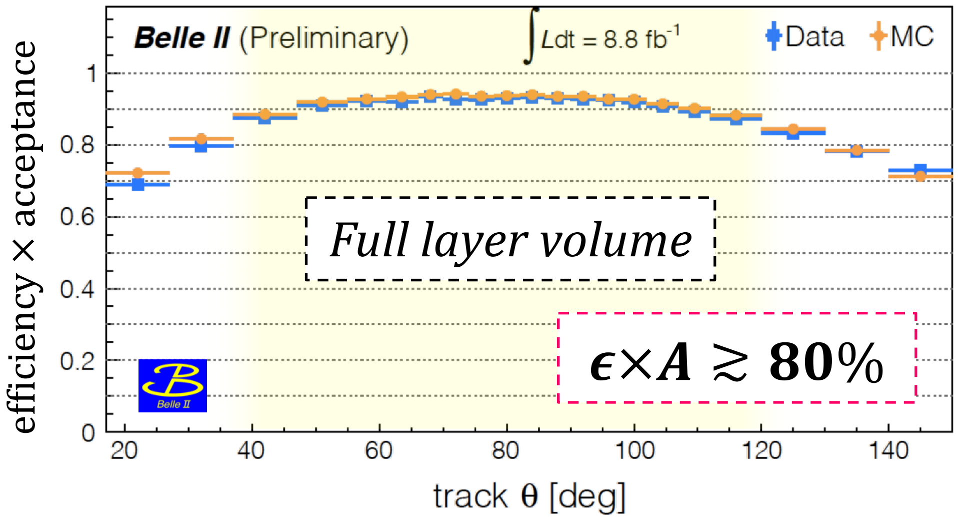
Track finding efficiency ϵ

Estimated using $e^+e^- \to \tau^+\tau^-$.









Momentum resolution δ_{p_T}

Estimated using cosmic rays.

(preliminary)

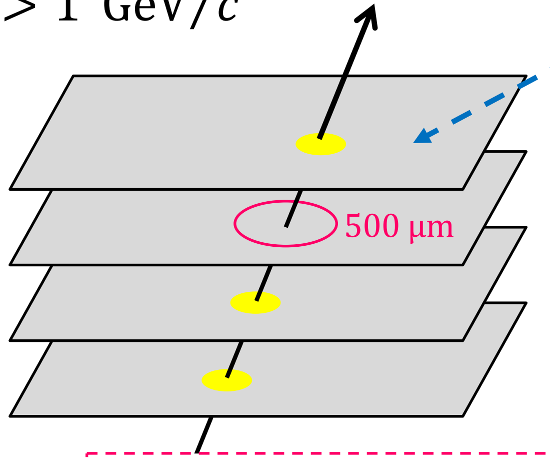
$$\delta_{p_T} = \left(0.127 p_T \left(\mathrm{GeV}/c^2\right) \oplus 0.321\right)\%$$

Vertex Detector Performance

VXD hit efficiency ϵ for tracks with $p_T > 1$ GeV/c

4-layers of the silicon strip detector

Layer	ϵ [%] (P-side)	ϵ [%] (N-side)
6	99.31 ± 0.08	99.58 ± 0.06
5	99.66 ± 0.03	99.77 ± 0.04
4	99.69 ± 0.03	99.68 ± 0.03
3	99.83 ± 0.01	99.48 ± 0.03

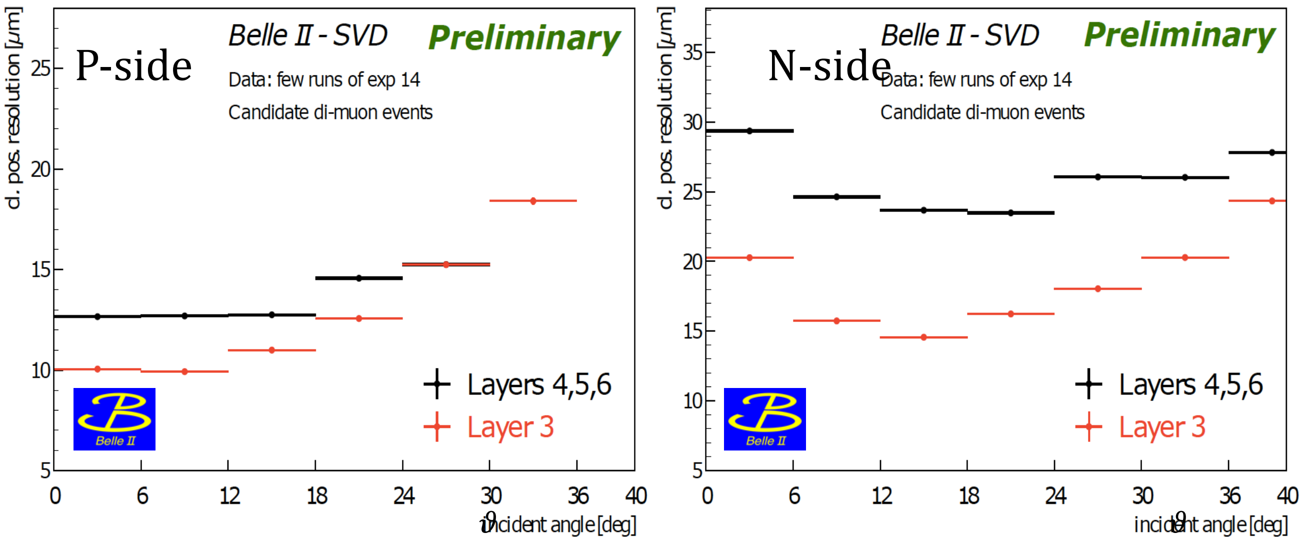


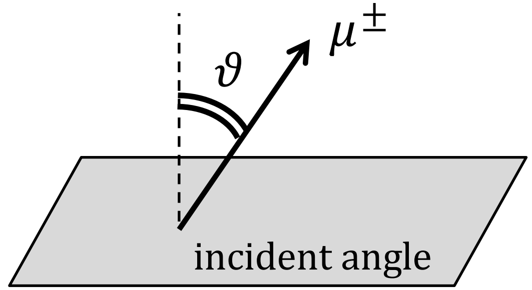
A cluster within a 500 μm window with respect to the expected intercept position on the sensor is counted.

Excellent efficiency $\epsilon > 99\%$ for both sides for all layers

Cluster position resolution σ

The σ is estimated $e^+e^- \to \mu^+\mu^-$ events.



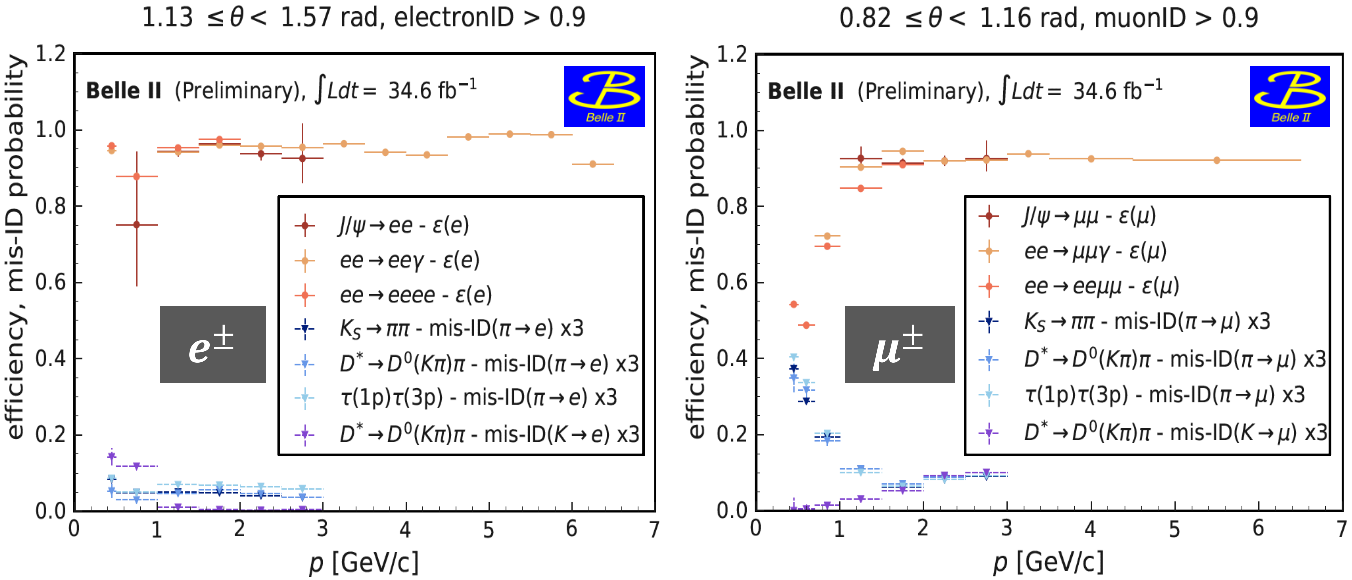


Excellent resolution σ_P^{L3} = 10-20 μm and σ_N^{L3} = 15-25 μm for $\vartheta < 40^\circ$ in L3 ladders

Lepton Identification

BELLE2-NOTE-PL-2020-027

$e^{\pm}$-ID and $\mu^{\pm}$-ID efficiencies ϵ_{ℓ} and mis-ID rate $w_{h\to\ell}$



$\epsilon_e \approx 94\%, \epsilon_{\mu} \approx 90\%$

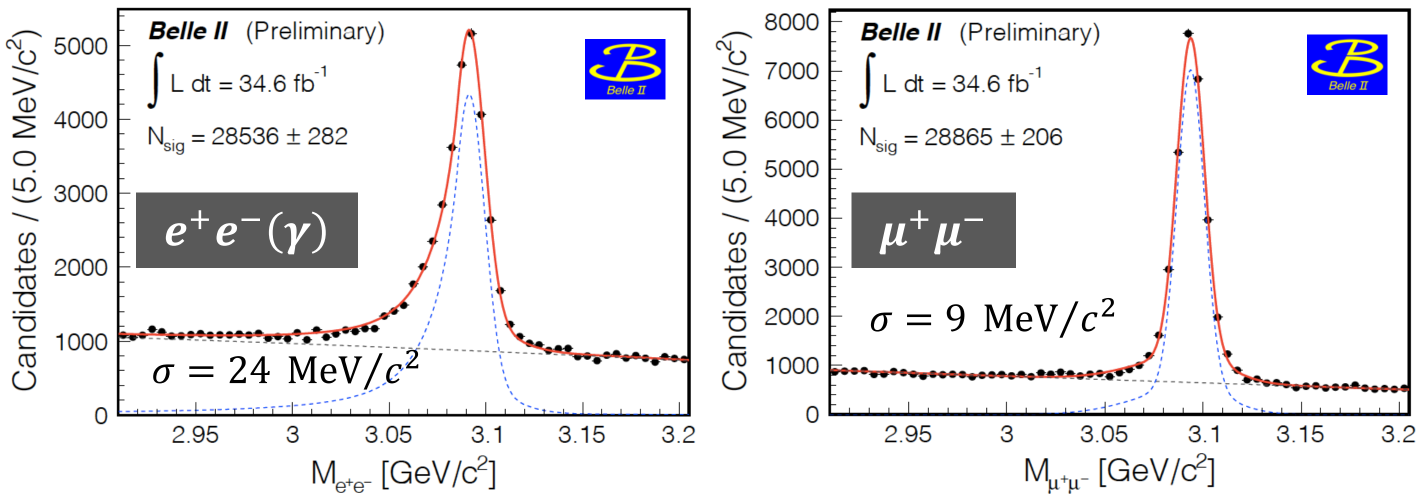
with analyses of $J/\psi \to \ell^+\ell^-$, $e^+e^- \to \ell^+\ell^-(\gamma)$, and $e^+e^- \to e^+e^-\ell^+\ell^-(\gamma)$

$w_{h\to e} \approx 2\%, w_{h\to\mu} \approx 4\%$

with analyses of $K_S^0 \to \pi^+\pi^-$, $\tau \to 3\pi(nh^0)\nu_{\tau}$, and $D^{*+} \to D^0(K^-\pi^+)\pi^+$

The mis-ID rates are inflated by ×3 for the illustration purpose.

Demonstration: $J/\psi \to e^+e^-(\gamma), \mu^+\mu^-$ reconstruction



A clear peak is observed at the $m_{J/\psi}$ position.

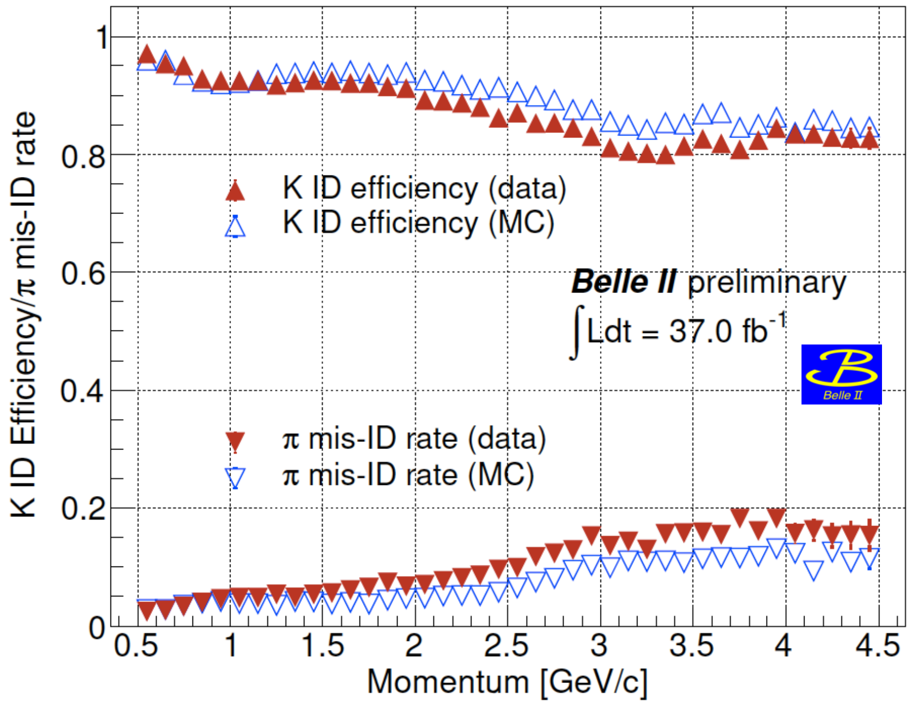
K/π Separation

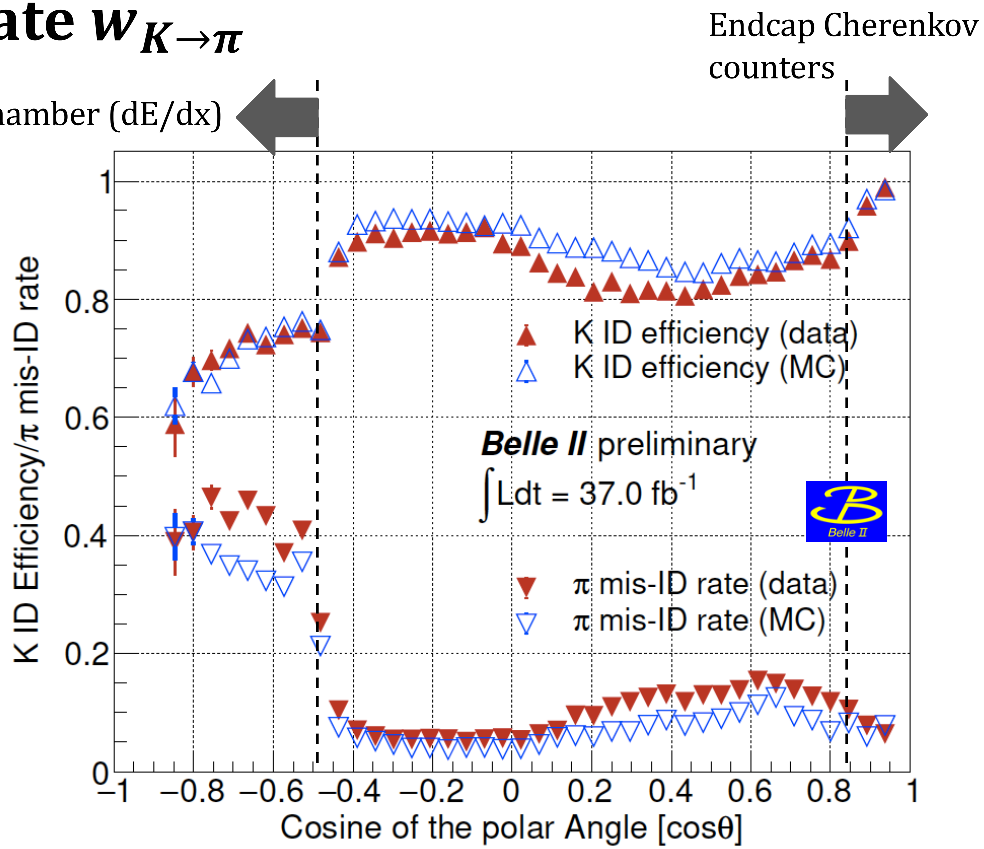
Quasi K/π tagging

BELLE2-NOTE-PL-2020-024

1. Reconstruct $\pi_{\mathrm{slow}} + (h_1^+ + h_2^-)$
2. When $\pi_{\mathrm{slow}} = \pi_{\mathrm{slow}}^+$, $[\pi_{\mathrm{slow}} + (h_1^+ + h_2^-)] = D^{*+}$, $[h_1^+ + h_2^-] = D^0$, and $h_1^+ = \pi^+$ and $h_2^- = K^-$.
3. When $\pi_{\mathrm{slow}} = \pi_{\mathrm{slow}}^-$, $h_1^+ = K^+$ and $h_2^- = \pi^-$.

Kaon efficiency ϵ_K and mis-ID rate $w_{K\to\pi}$



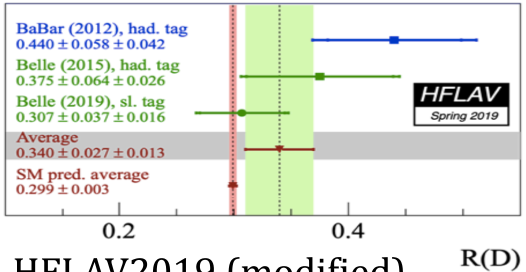


Good kaon efficiency and K/π separation power are confirmed.

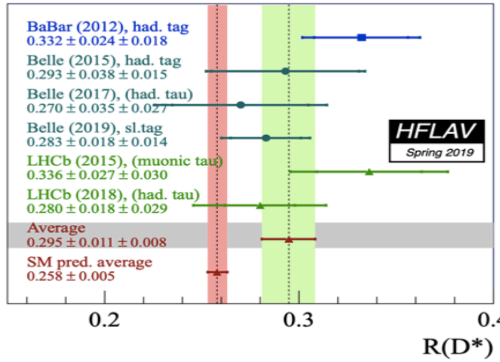
CKM Matrix Element $|V_{cb}|$ $(b \to c\ell\nu_\ell)$

Potential anomaly in $R_{D^{(*)}} \equiv \mathcal{B}(B \to D^{(*)}\tau^-\overline{\nu}_\tau)/\mathcal{B}(B \to D^{(*)}\ell^-\overline{\nu}_\ell)$

- The $(R_D, R_{D^*}) = (R_D^{\mathrm{SM}}, R_{D^*}^{\mathrm{SM}})$ is disfavored at a 3.08σ level.

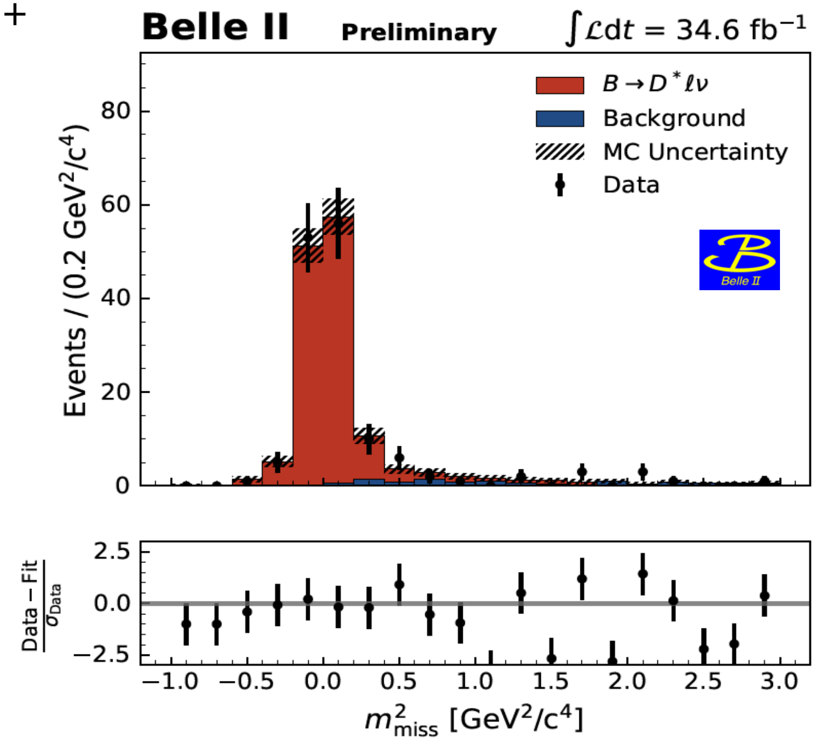


HFLAV2019 (modified)



Exclusive $B^0 \to D^{*-}\ell^+\nu_\ell$

- Use the EFI tagging method and infer the signal-B momentum $p_{B_{\mathrm{sig}}}$.
- Reconstruct D^0 from $K^-\pi^+$ and reconstruct D^{*+} from $D^0\pi_s^+$ (π_s^+: slow pion).
- Determine the signal yield by fitting the M_{miss}^2 distribution where $M_{\mathrm{miss}} = (p_{B_{\mathrm{sig}}} - (p_{D^*} + p_\ell))$.



Preliminary, arXiv:2008.10299

$$\mathcal{B}(B^0 \to D^{*-}\ell^+\nu_\ell) = (4.51 \pm 0.41 \pm 0.27 \pm 0.45)\times 10^{-4}$$

The first and second errors are statistical and systematic uncertainties, respectively. The third error is an uncertainty in the slow pion efficiency.

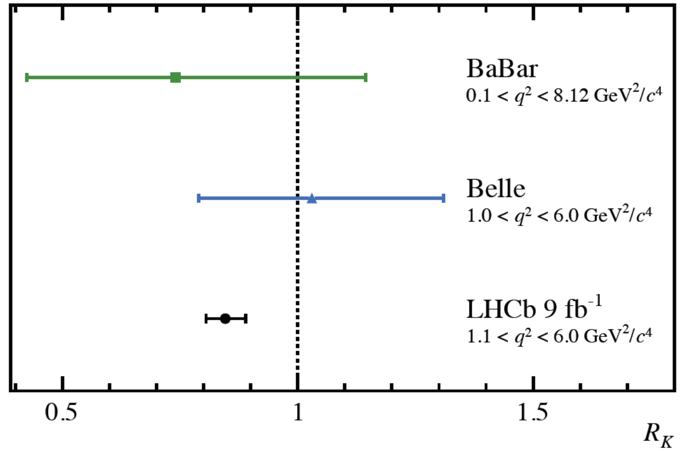
Electroweak Penguin $(b \to s\ell\ell)$

Motivation for a study of $b \to s\ell^+\ell^-$

- $b \to s\ell^+\ell^-$ is sensitive to a NP effect to Wilson coefficients C_7, C_9, C_{10}
- LHCb reported a 3.1σ tension between the observation and the SM-predicted values R_K which suggests a lepton universality violation.

$$R_K \equiv \mathcal{B}(B^+ \to K^+\mu^+\mu^-)/\mathcal{B}(B^+ \to K^+e^+e^-)$$

arXiv:2103.11769

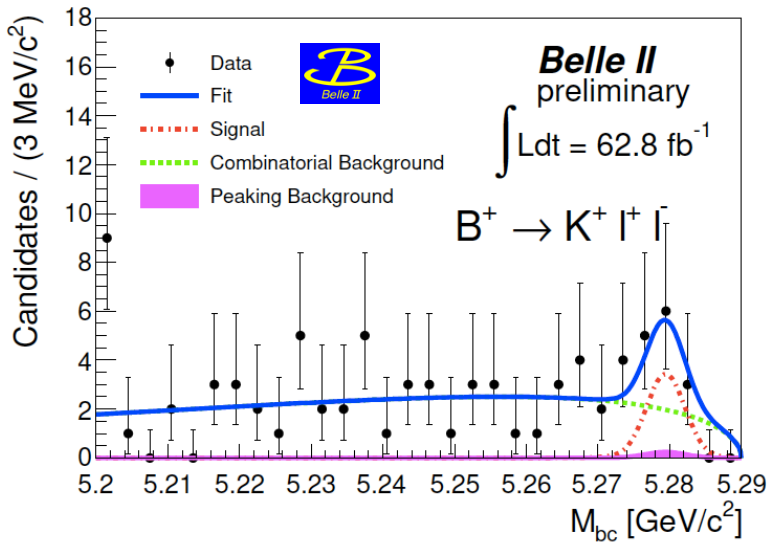


$B^+ \to K^+\ell^+\ell^-$ reconstruction

Preliminary

Signal yield: $N = 8.6^{+4.3}_{-3.9} \pm 0.4$
Signal significance: 2.7σ

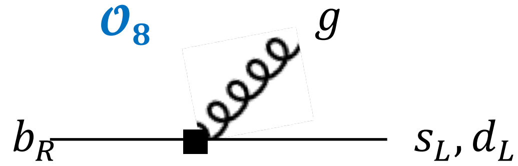
BELLE2-NOTE-PL-2021-005



Radiative Penguin $(b \to s\gamma)$

Motivation for a study of $b \to s\gamma$

$$A_{CP}^{X_{s+d}\gamma} \equiv \frac{\Gamma(\bar{B} \to X_{s+d}\gamma) - \Gamma(B \to X_{s+d}\gamma)}{\Gamma(\bar{B} \to X_{s+d}\gamma) - \Gamma(B \to X_{s+d}\gamma)} \approx \mathcal{O}(\Lambda_{\mathrm{QCD}}/m_b)$$

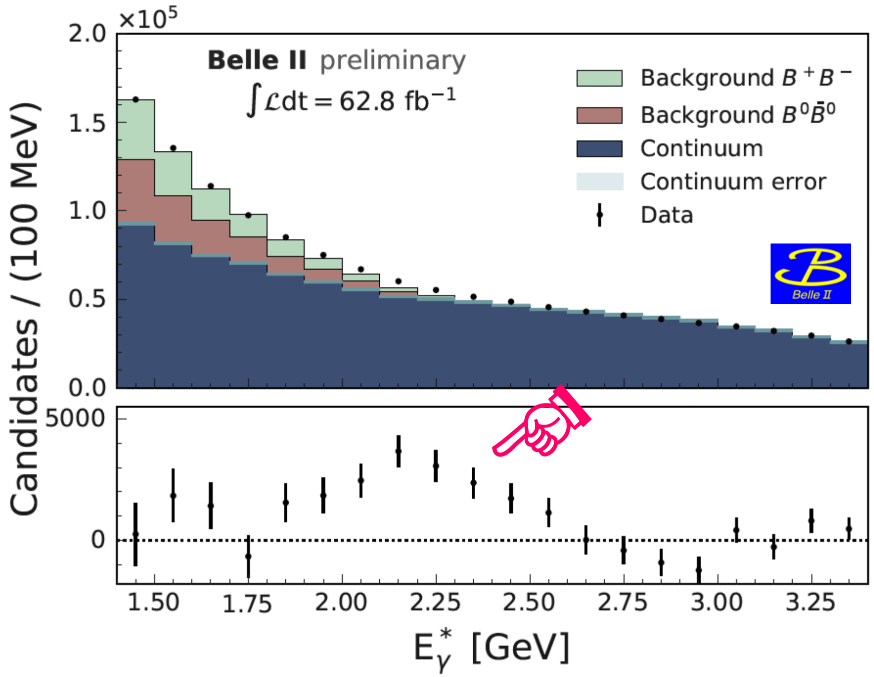


$$\Delta A_{CP}^{X_s\gamma} \equiv A_{CP}^{X_s^+\gamma}(B^+ \to X_s^+\gamma) - A_{CP}^{X_s^0\gamma}(B^0 \to X_s^0\gamma) \propto \mathcal{Im}(C_8/C_7) = 0 \text{ in the SM.}$$

Belle II will make a vital contribution to the inclusive measurement.

Reconstruction of inclusive $B \to X_{s,d}\gamma$

BELLE2-NOTE-PL-2021-004



The bottom plot shows a difference between the observed number of candidates and the sum of expected numbers of background candidates.

The bump in the bottom plot indicates an evidence for $B \to X_{s,d}$ events at Belle II (shown uncertainties are statistical only).

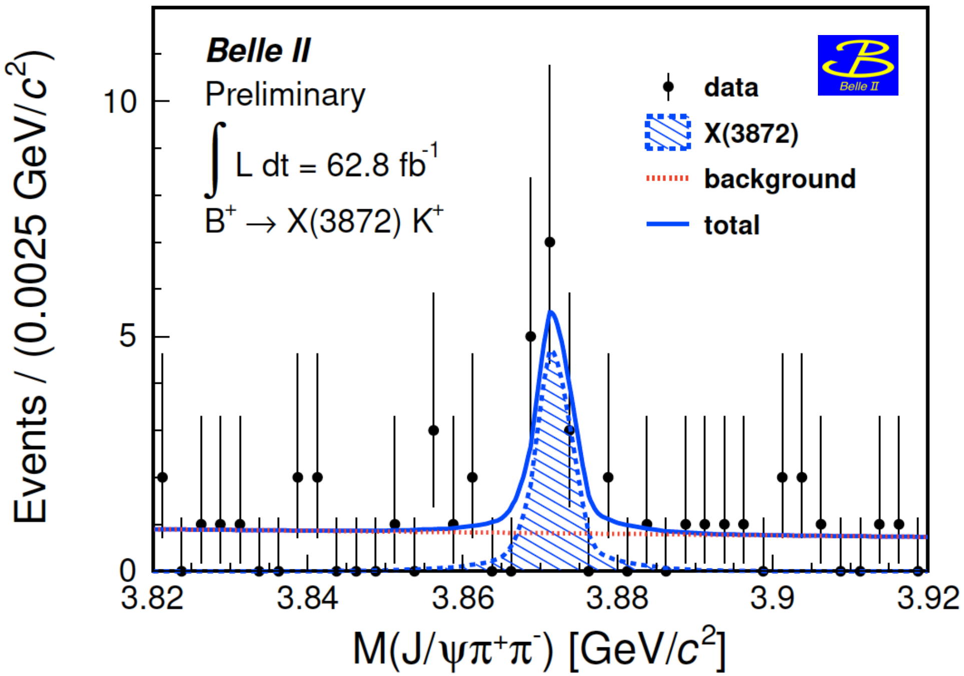
Exotic Hadrons

Reconstruction of $B \to X(3872)(J/\psi\,\pi^+\pi^-)K$

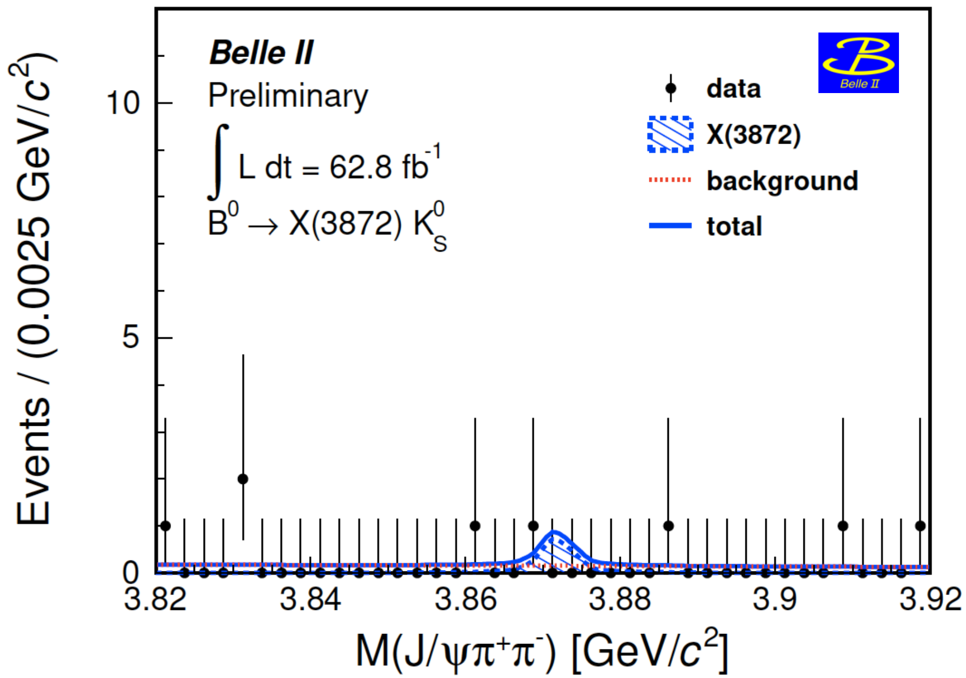
S.-K. Choi *et al.* (Belle), Phys. Rev. Lett. 91, 262001 (2003)

- A new resonance $X(3872)$ was first reported by Belle in 2003 by reconstructing $B^+ \to J/\psi\,\pi^+\pi^- K^+$ decay.
- We reconfirmed evidence for $X(3872)$ in Belle II data with 4.6σ significance.

BELLE2-NOTE-PL-2021-002



$B^+ \to X(3872)(J/\psi\,\pi^+\pi^-)K^+$



$B^0 \to X(3872)(J/\psi\,\pi^+\pi^-)K_S^0$