



SuperKEKB/Belle II status and prospect

Kenta Uno (KEK IPNS)

KMI2026

November 9, 2026

Belle II

KEK

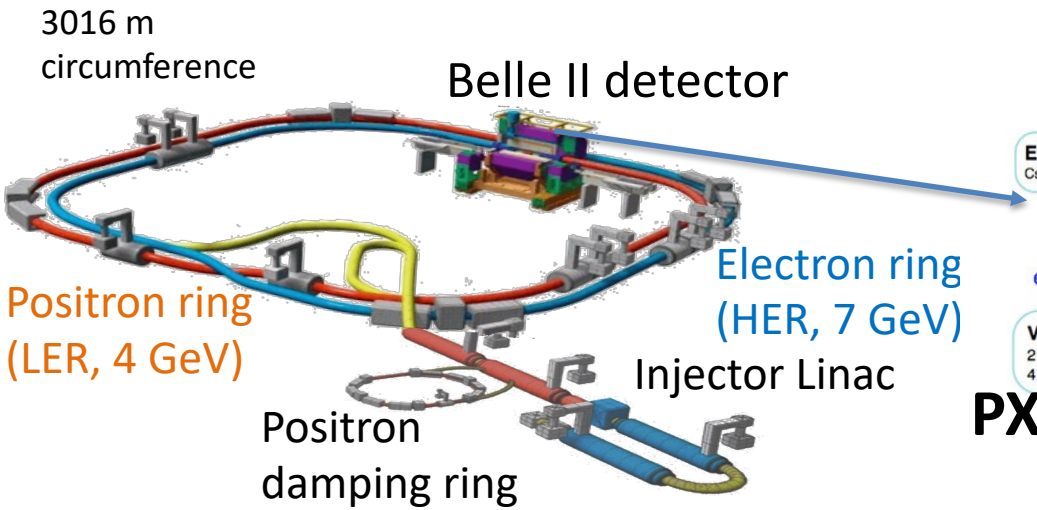
Unravelling the mysteries of matter, life and the universe.

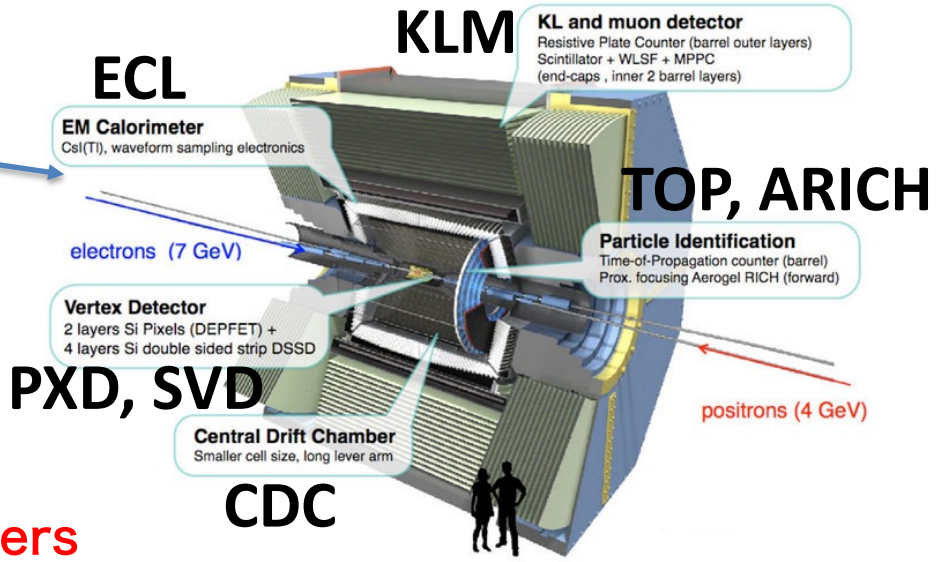
SuperKEKB

SuperKEKB/Belle II

Main goal: Search for new physics in various decays such as B, D, τ

- Asymmetric e^+e^- collider operating manily at $\Upsilon(4S)$ resonance: 10.58 GeV
- **World's highest peak luminosity of 5.3×10^{34} cm^{-2} s^{-1}** (KEKB × 2.5)
- 914 fb^{-1} dataset including 808 fb^{-1} $\Upsilon(4S)$ dataset is recorded
  - Suparssed Belle $\Upsilon(4S)$ dataset → **World's largest dataset**



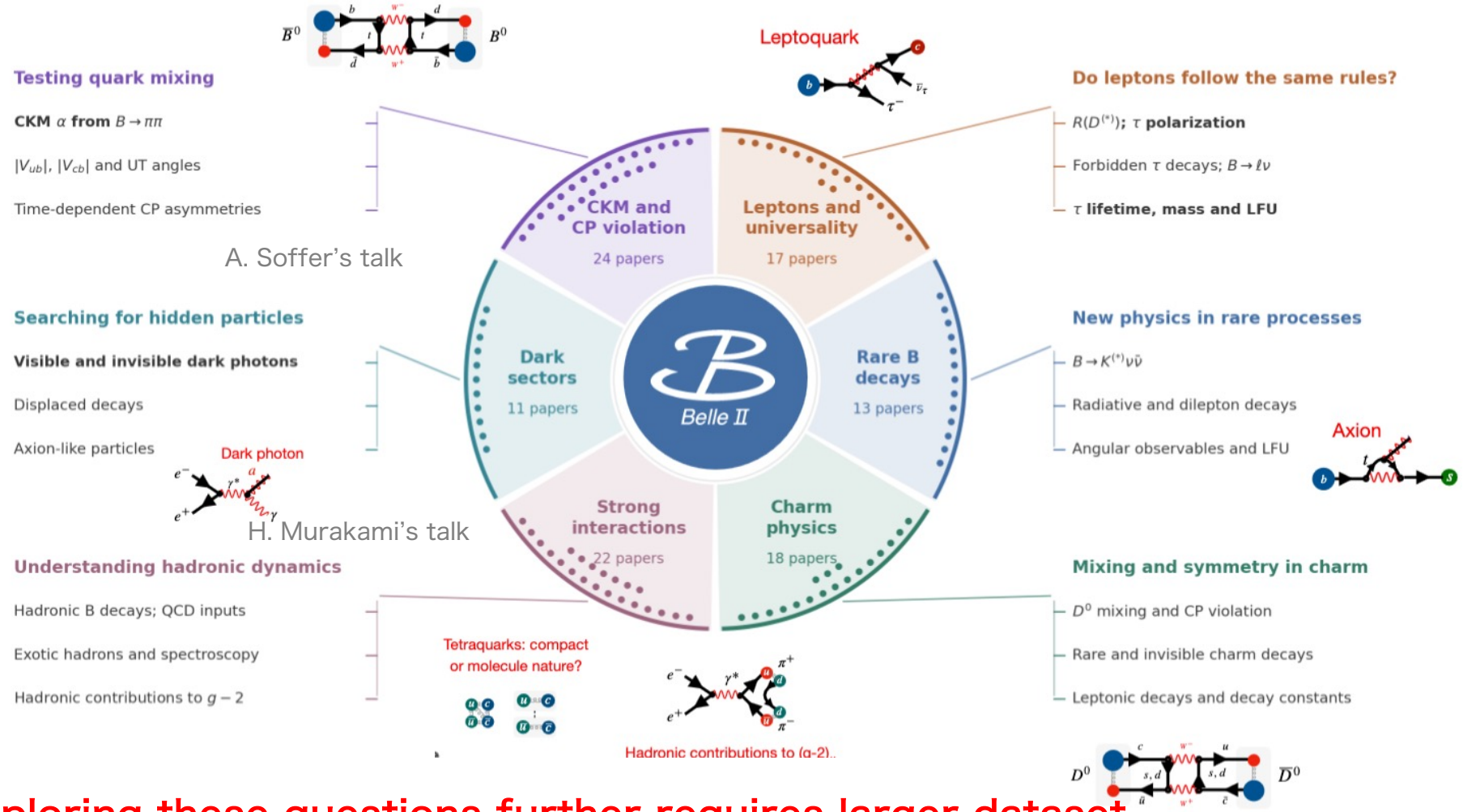


SuperKEKB is a pioneer of e^+e^- colliders

- The technologies developed here will be the basis of the future Higgs factories
  - Collaboration with FCC-ee is ongoing

Broad physics program

Complementary approaches to exploring new physics



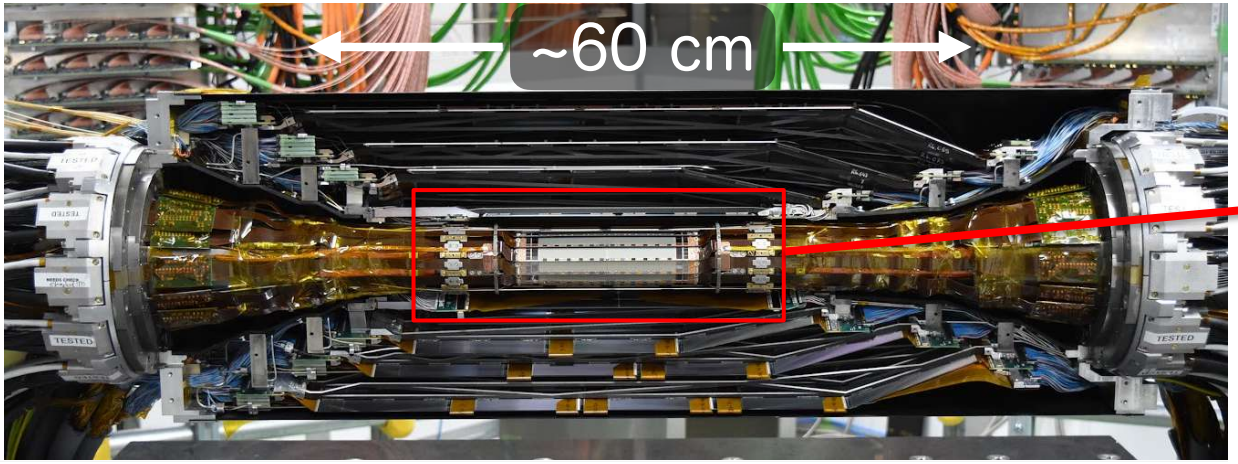
Exploring these questions further requires larger dataset

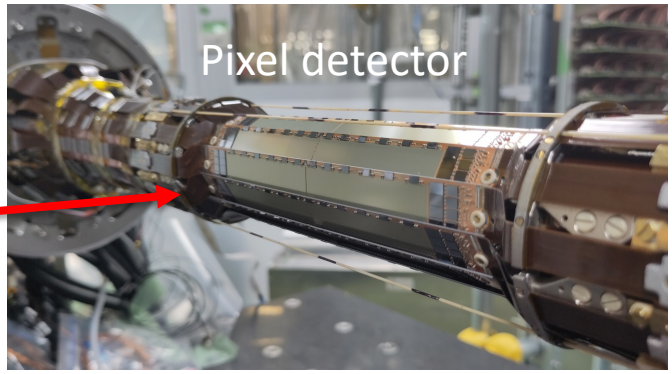
- $N = \epsilon \times \sigma \int \mathcal{L}\, dt$ → Higher detection efficiency, Higher Luminosity are crucial

Improved detector peformance

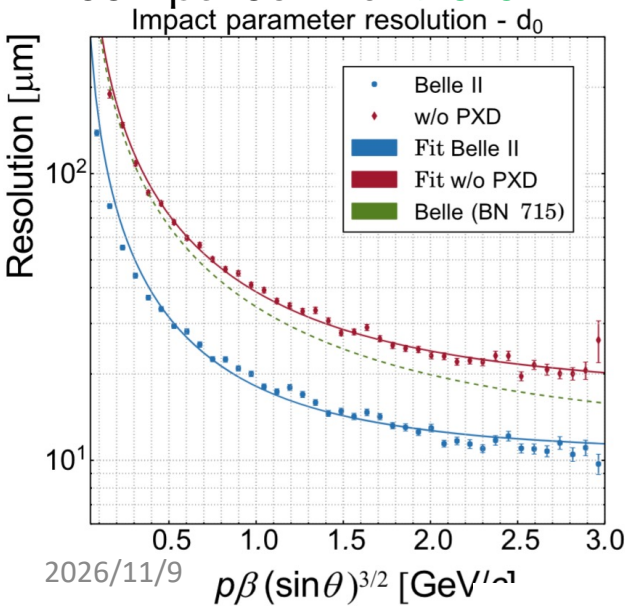
E.g. introduction of Pixel detector (PXD)

Size: 55 μm × 50 μm
About 7.6 M pixel in total

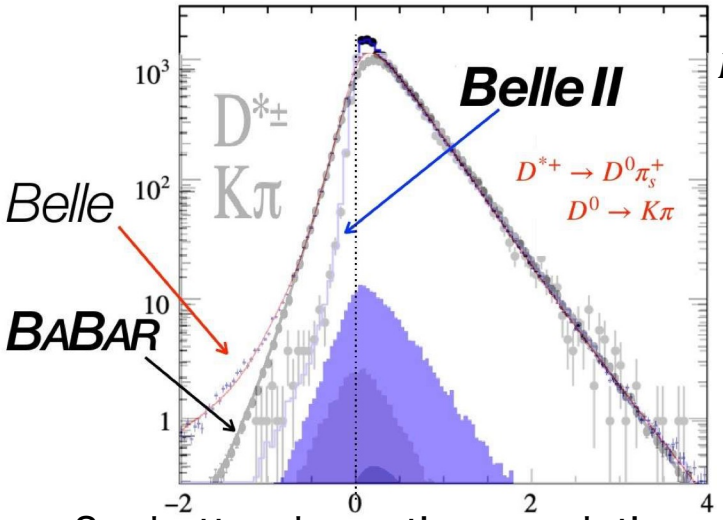




Improves by about a factor two compared with Belle



Enables precise CPV studies and measurements of short-lived particles



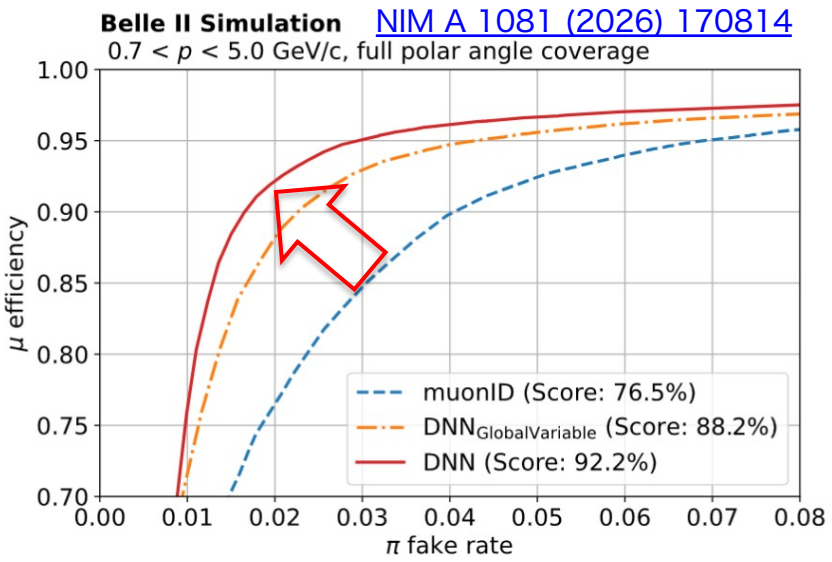
D^0 Lifetime

~2 × better decay-time resolution
→ World leading result with 72 fb^{-1}

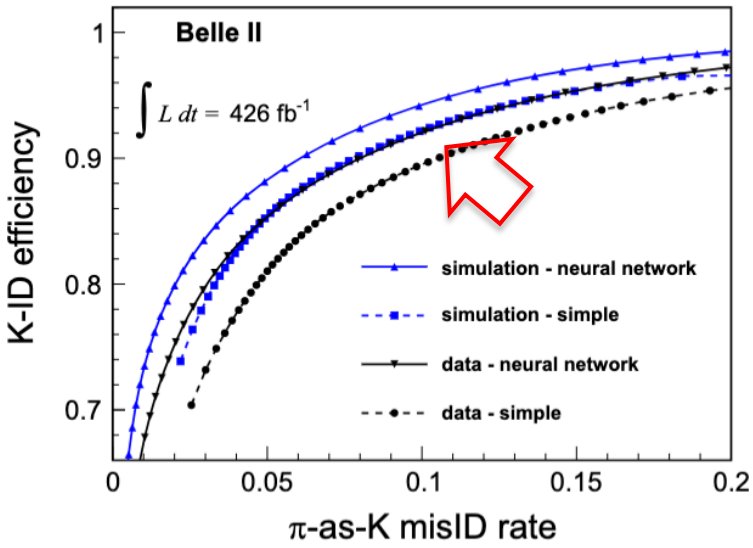
Advances in analysis techniques

Machine learning enables more efficient reconstruction and analysis

- Particle Identification (e, μ, π, KID), Tagging to determine of neutral B mesons



NIM A 1081 (2026) 170814



Eur. Phys. J. C 85 (2025) 1237

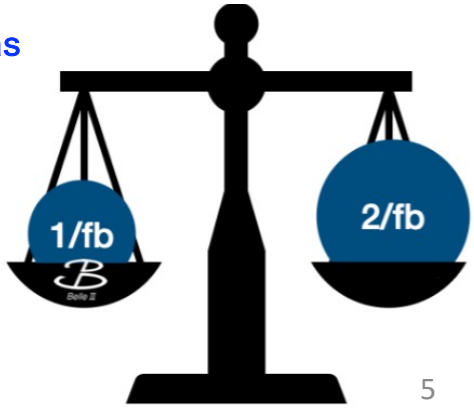
New analysis techniques also deliver sensitivity gain

beyond initial expectations

Rough rule of thumb:

1/fb of Belle II data is **worth 2/fb of BaBar** or **Belle** data*

* exceptions of course do exist



We can obtain meaningful physics results with less data than originally expected

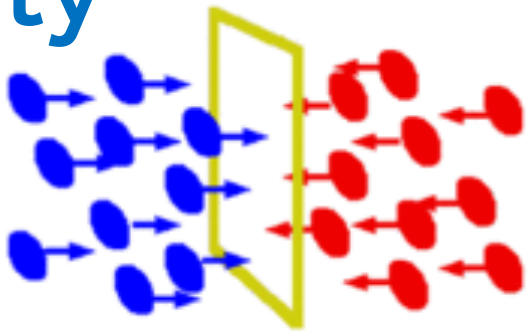
Key challenge: Luminosity

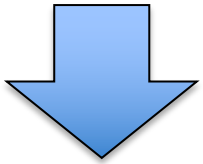
A measure of collider performance

$$\mathcal{L} \propto \frac{I_{e^+} I_{e^-}}{\sigma_x \sigma_y}$$

$I_{e^+(e^-)}$: beam current of e^+ (e^-)

$\sigma_{x(y)}$: horizontal (vertical) beam size



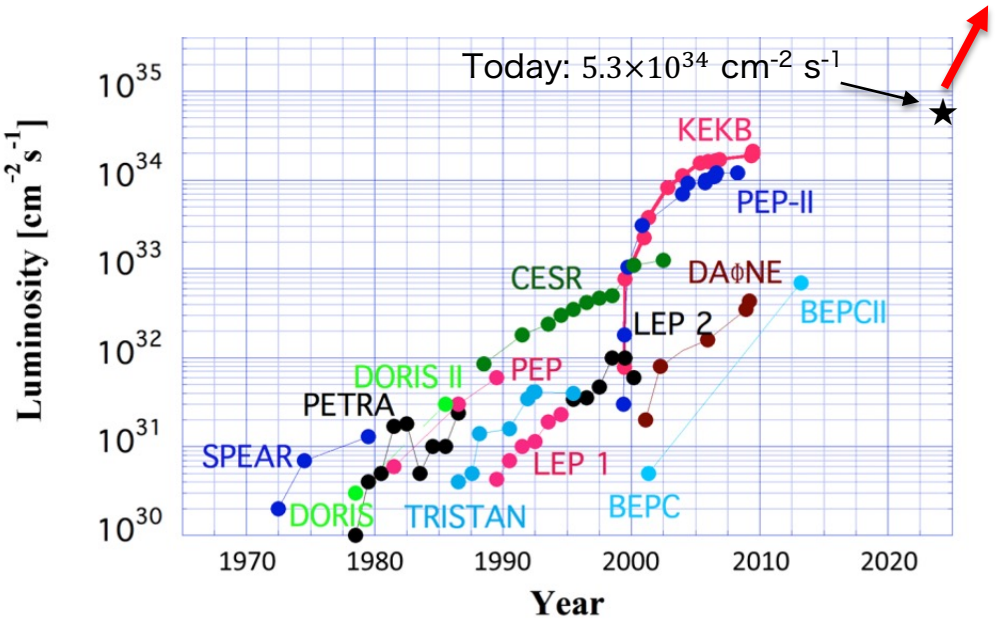


<u>Key for higher peak luminosity</u>

- Increase beam currents (KEKB × 2)
- Squeeze both beams at the IP
  - σ_y ~ 50 nm (KEKB × 1/20)

interaction point

($\beta_y^* = 0.3$ mm, ϵ_y~8 pm)



KEKB: 2.1×10^{34} cm^{-2} s^{-1} → SuperKEKB's final target: 6×10^{35} cm^{-2} s^{-1}

~30 times the luminosity of KEKB → most challenging part for SuperKEKB/Belle II

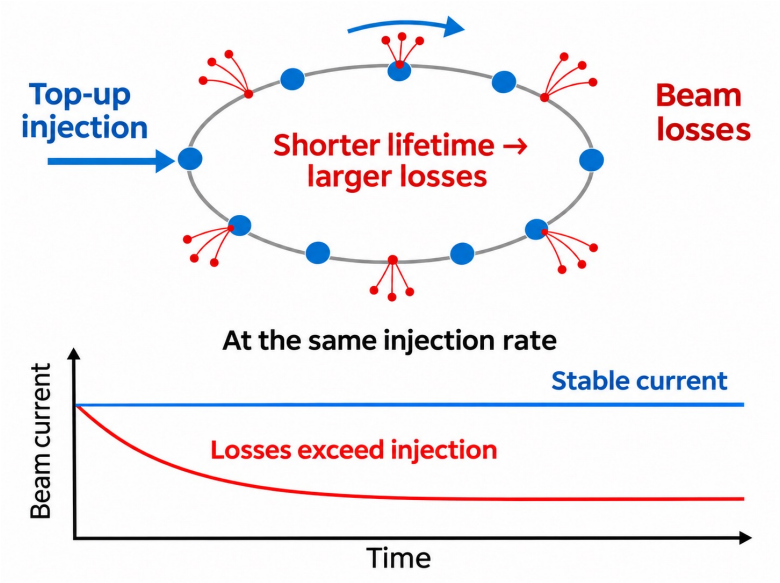
Major challenges of SuperKEKB

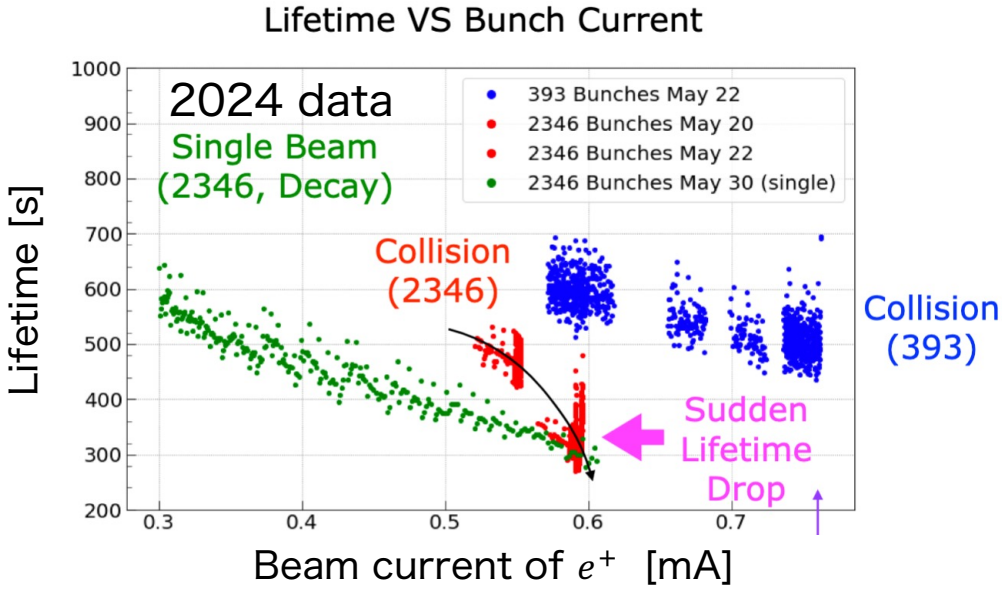
Several challenges for higher luminosity → Cutting-edge research topics

E.g. key item for higher beam currents:

- Shorter beam lifetime
- Lower injection efficiency
  - Reduce the injection beam emittance
- Beam background
- Sudden Beam Loss (SBL)

Major progress in addressing these challenges in 2026 operation

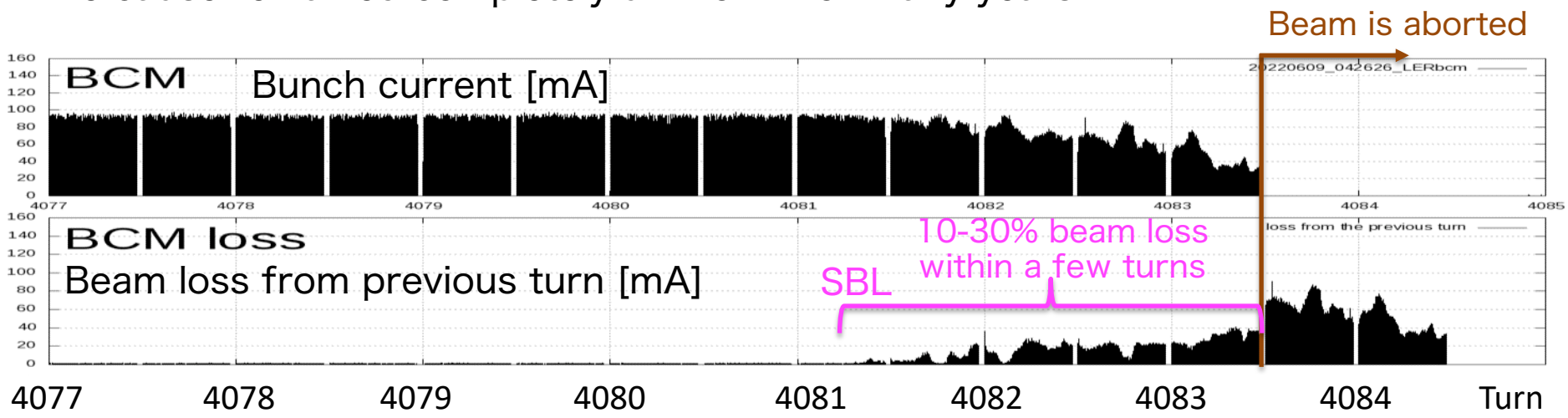




Sudden Beam Loss (SBL)

The beam is suddenly lost without clear precursors

- The cause remained completely unknown for many years



- Damage the detector and accelerator components
  - PXD temporarily off since May 7, 2024
- SBL frequency increases with beam currents

→ Limits beam currents and luminosity



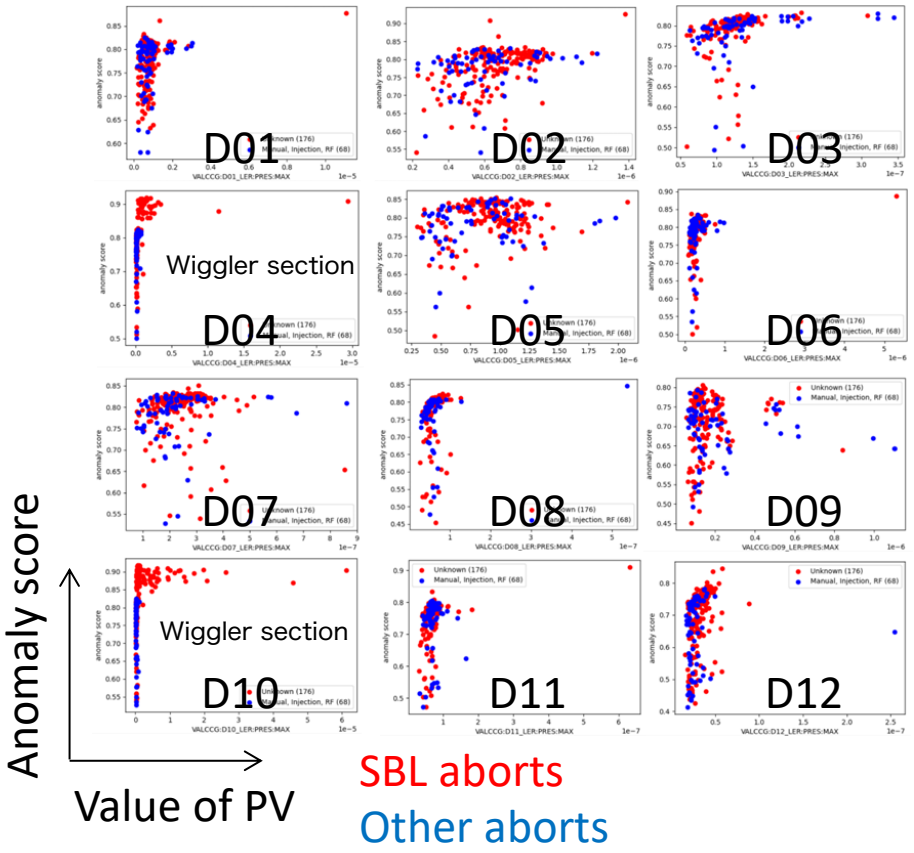
Understanding and suppressing SBL became a top priority for stable/high-luminosity operation

Hunting the sources of SBLs

Identified some parameters by anomaly detection algorithm in 2024

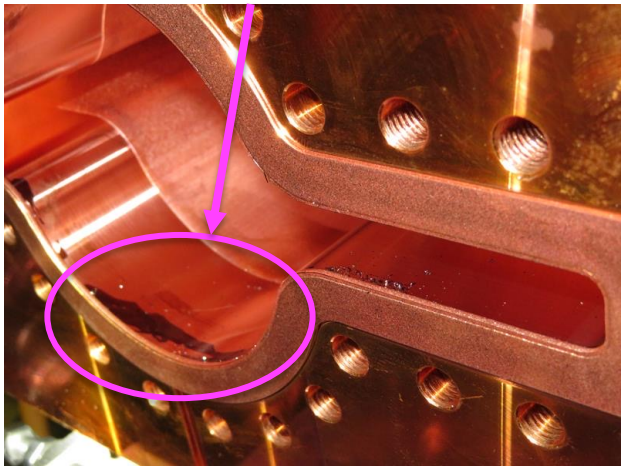
- Abnormal pressure bursts frequently observed at specific locations during SBL
  - Opened the beam pipe for inspection in November, 2024 → Found black stains (dusts)

D01…D12: location of MR

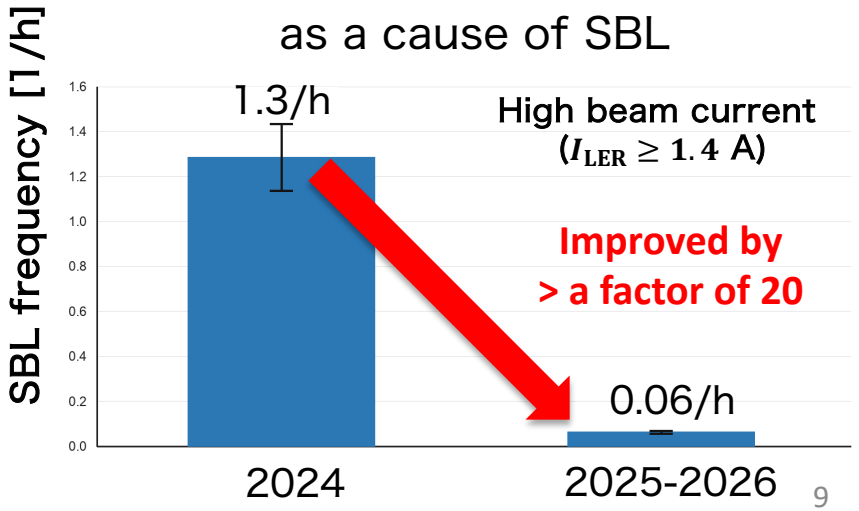


SBL aborts

Other aborts



Vacuum sealant was identified as a cause of SBL



Joint efforts by SuperKEKB and Belle II

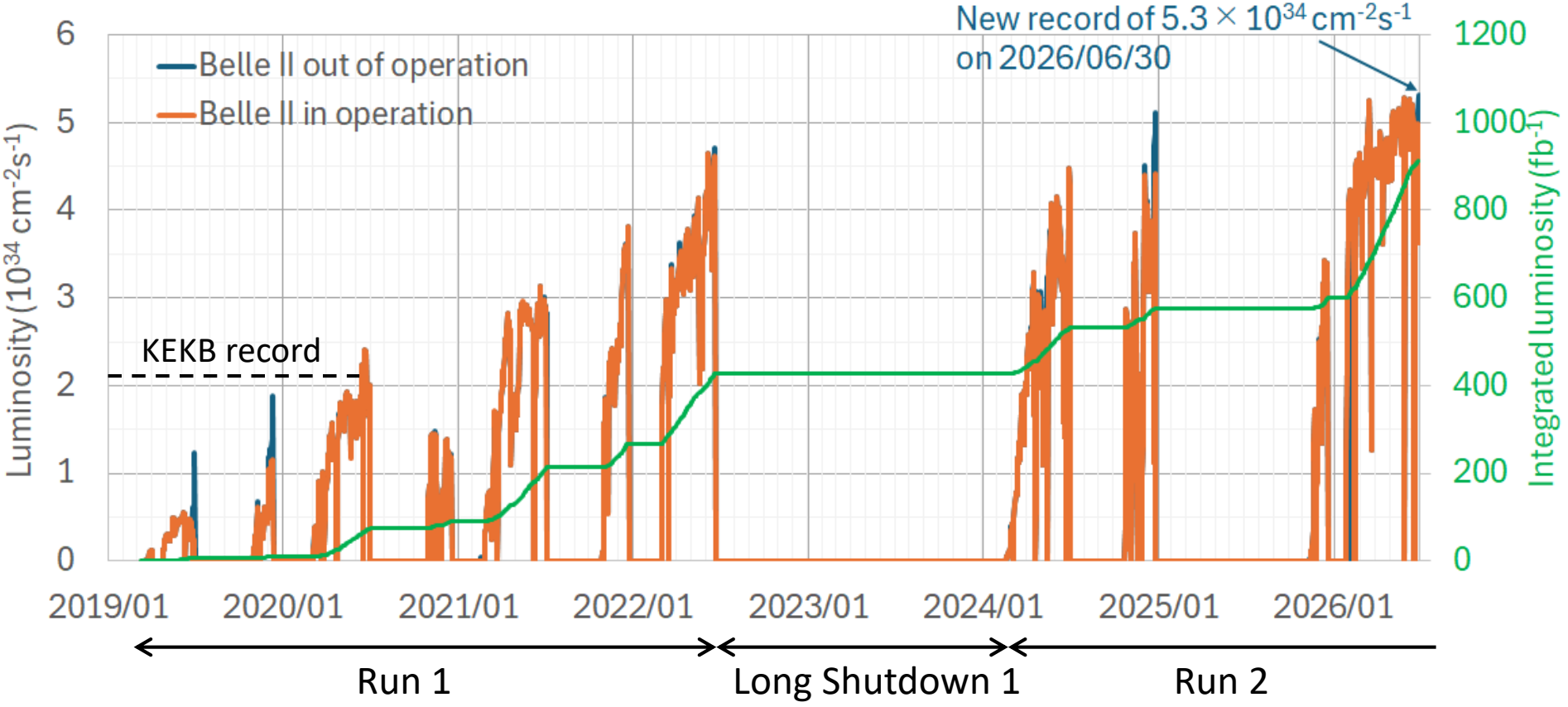
SuperKEKB/Belle II operation

Drastic reduction in SBL frequency enabled operation at higher luminosity

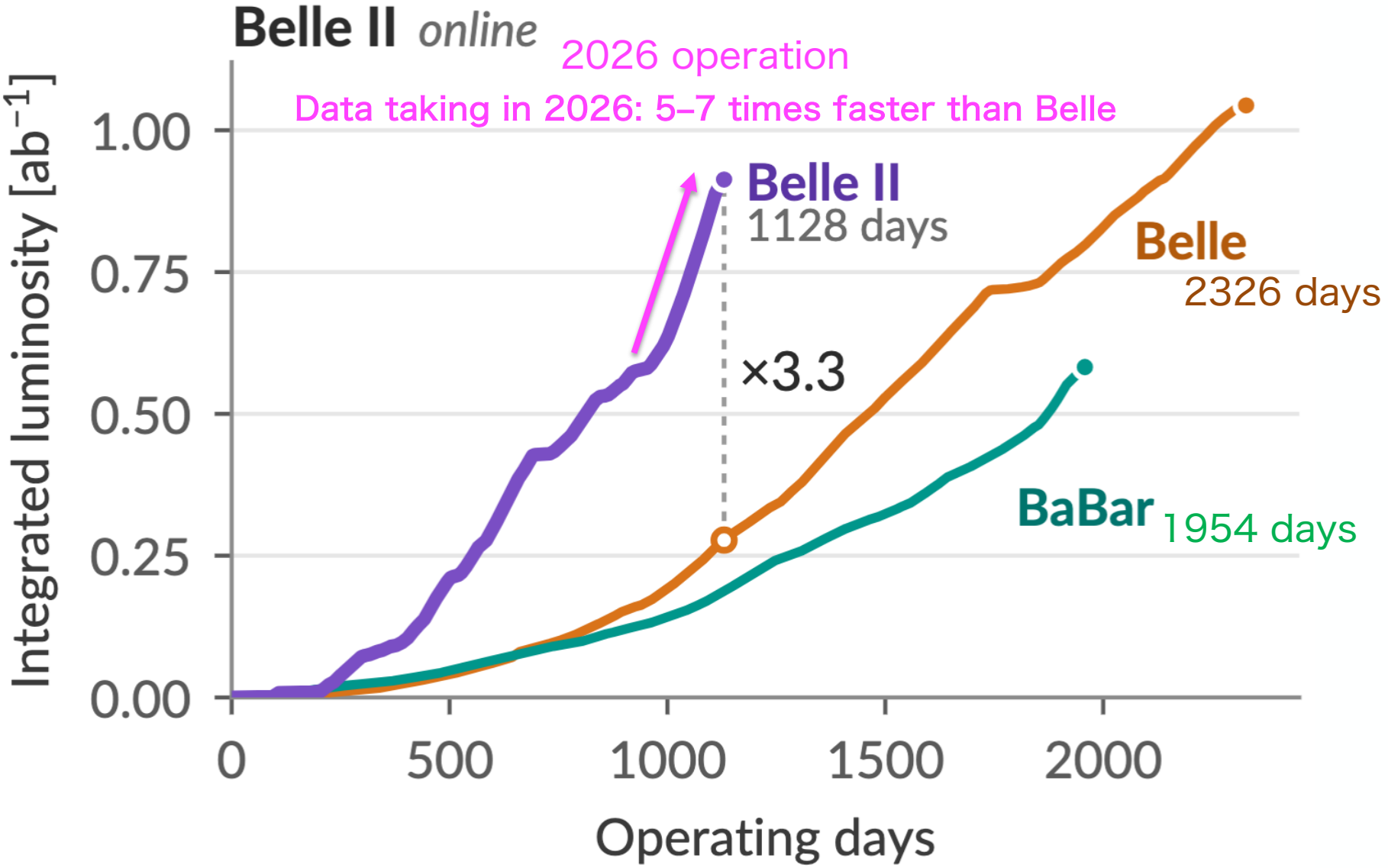
- Established stable operation at 5.0×10^{34} cm^{-2} s^{-1} in 2026
  - With $\beta_y^* = 0.9$ mm 1.6 A (e^+), 1.2 A (e^-)

→ 0.5 ab^{-1}/year achievable with 7 months of operation

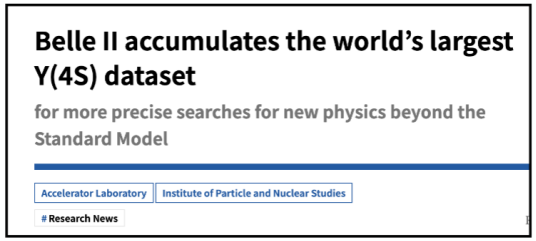
Assuming the operating and data-taking efficiencies achieved in 2026

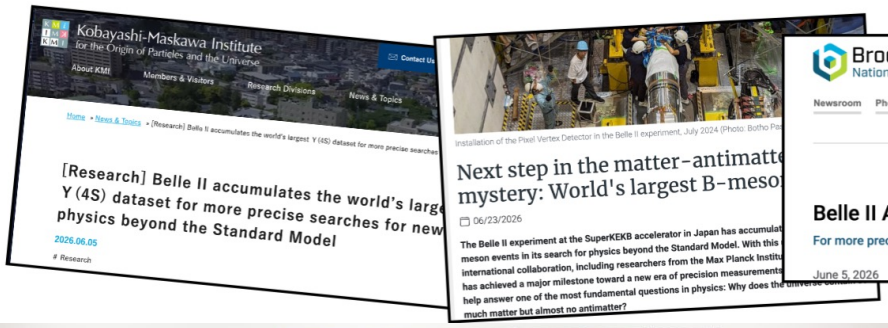


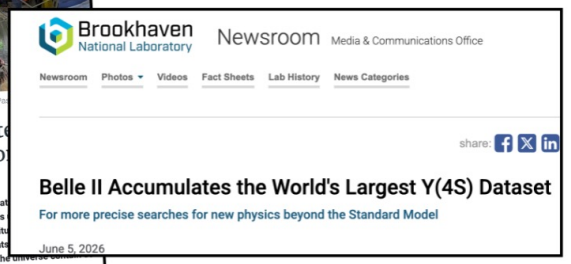
Integrated Luminosity

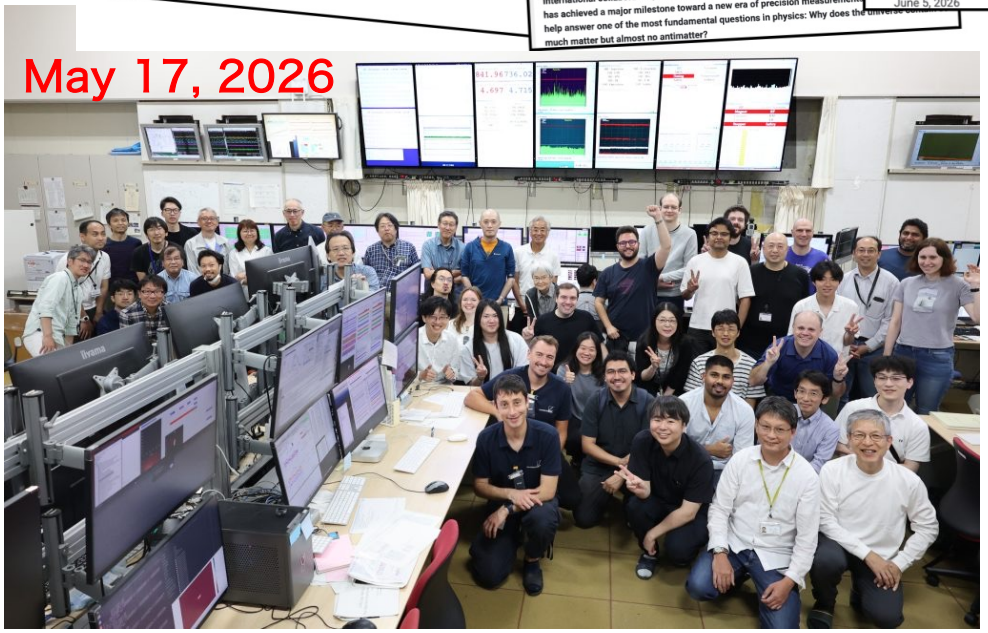


Recorded 808 fb^{-1} at $\Upsilon(4S)$ (> Belle), and 914 fb^{-1} in total









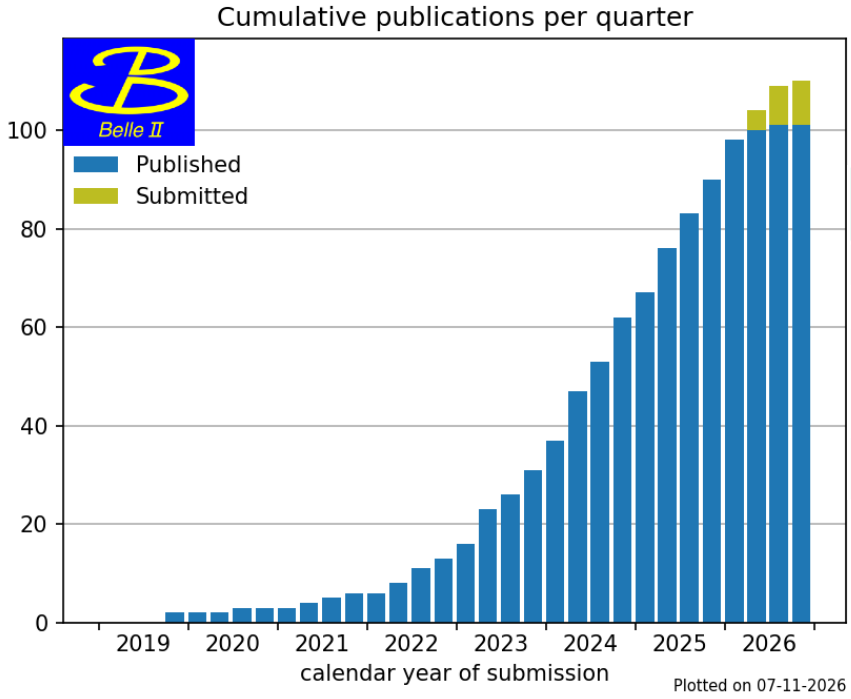
2026: New records in daily and weekly integrated luminosity

- 8-hour record: 1.25 fb^{-1}
- Daily record: 3.5 fb^{-1} previous record: 2.5 fb^{-1}
- Weekly record: 21.8 fb^{-1}

Routinely achieved > 3.0 fb^{-1}/day

Steadily growing number of results

110 papers and 101 accepted



Rank	Title	Year	Citation count
1	Evidence for $B^+ \to K^+ \nu \bar{\nu}$ decays	2024	295
2	Search for Axion-Like Particles produced in e^+e^- collisions at Belle II	2020	204
3	Search for $B^+ \to K^+ \nu\nu$ decays using an inclusive tagging method at Belle II	2021	111
4	Search for an Invisibly Decaying Z' Boson at Belle II in $e^+e^- \to \mu^+\mu^-(e^\pm\mu^\mp)$ Plus Missing Energy Final States	2020	97
5	Test of lepton flavor universality with a measurement of $R(D^*)$ using hadronic B tagging at the Belle II experiment	2024	82

Most results use data collected through 2022 (365 fb^{-1} at $\Upsilon(4S)$)

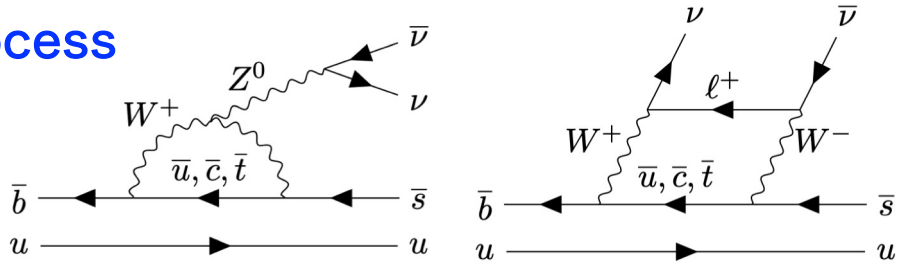
- Now, more than 2 × the previous dataset

→ More results with larger datasets come soon! (from winter conference?)

Rare decays: $B \to K\nu\nu$

The decay occurs through a FCNC process

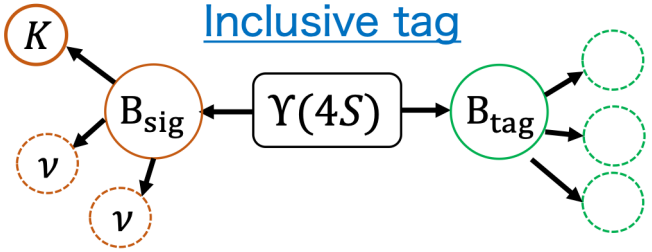
→ A promising probe of new physics



New approach: inclusive B-tagging

- Only reconstruct $B_{\rm sig}$, no request on the other B
  - Higher signal efficiency, but lower purity

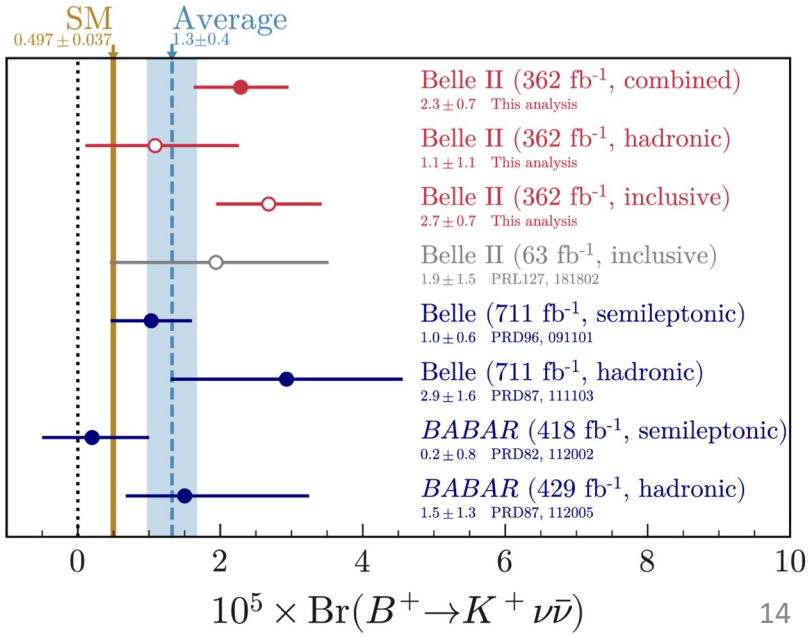
→ Utilize ML techniques to suppress backgrounds



First evidence for $B \to K\nu\nu$ decays

- $\mathcal{B}(B \to K\nu\nu) = \left[2.3 \pm 0.5\ (\text{stat})^{+0.5}_{-0.4}\ (\text{syst})\right] \times 10^{-5}$
  - 2.7σ above the SM prediction

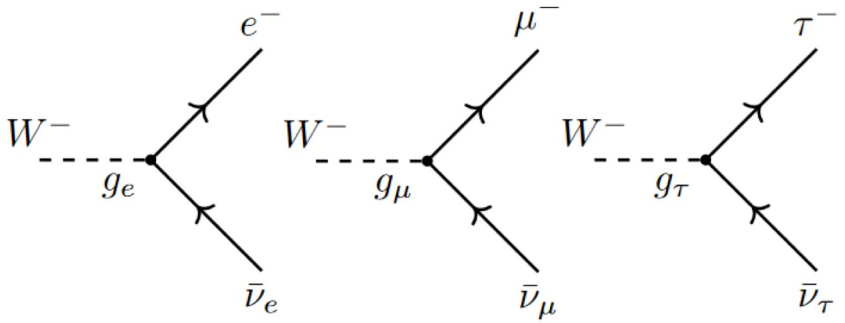
→ Further results will come soon

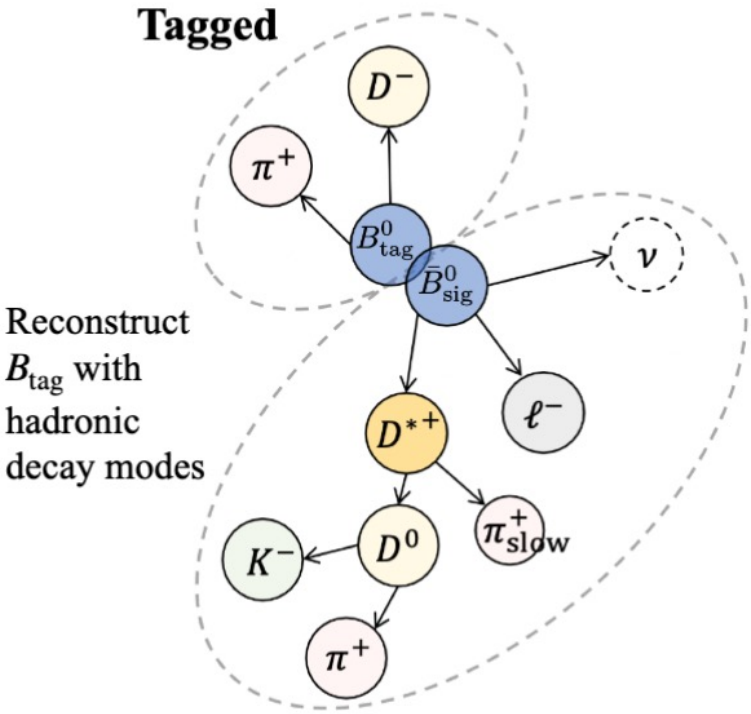


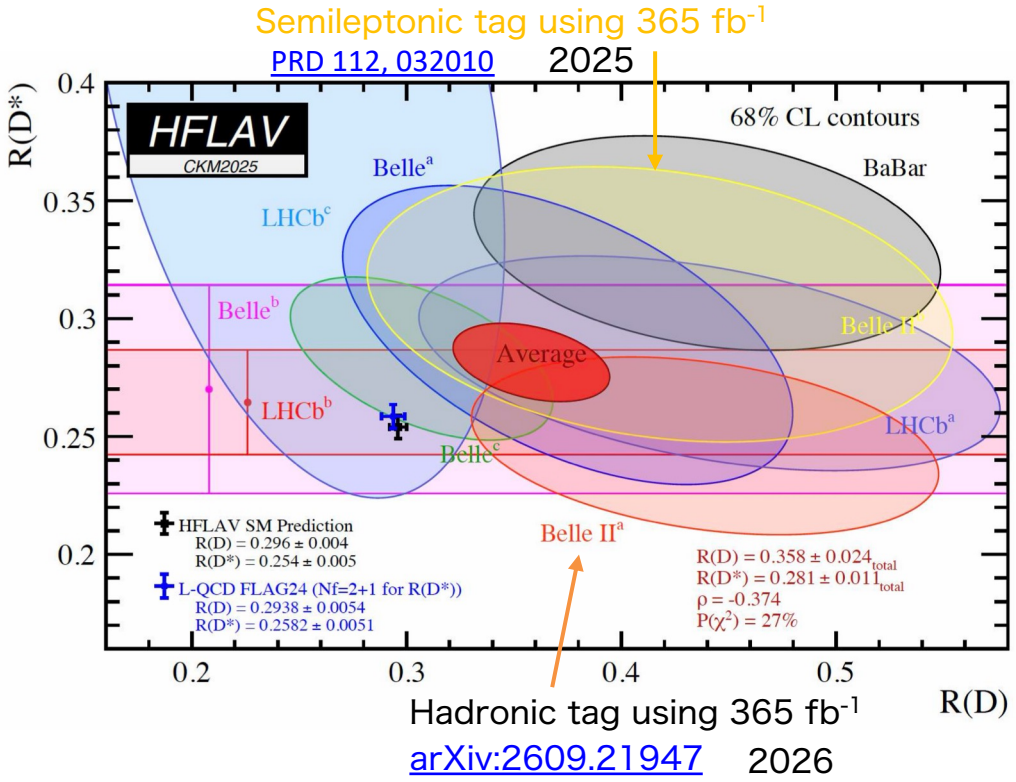
LFU tests: $b \to c\ell\nu$

Lepton Flavor Universality (LFU)

$$R(D^{(*)}) = \frac{\mathcal{B}(B \to D^{(*)}\tau\nu_\tau)}{\mathcal{B}(B \to D^{(*)}\ell\nu_\ell)}, \ell = e, \mu$$







~3.8σ deviation above the SM prediction (w/o BABAR preliminary result)

The analysis is still statistically dominant.. We will update the result with ~1 ab^{-1} data

Tau LFV searches at Belle II

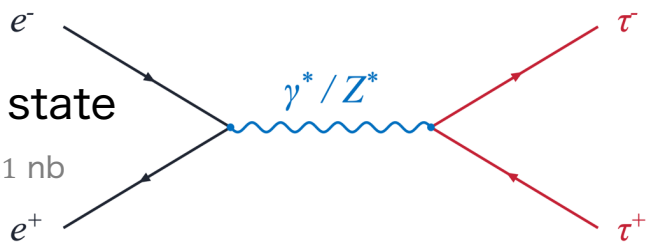
Major contributions from KMI

Tau LFV searches at Belle II

$e^+e^- \to \tau^+\tau^-$:

- Clean production of $\tau\tau$ pairs with a well-defined initial state
- $\sigma(e^+e^- \to \tau^+\tau^-)$~0.92 nb at $\sqrt{s} = 10.58$ GeV

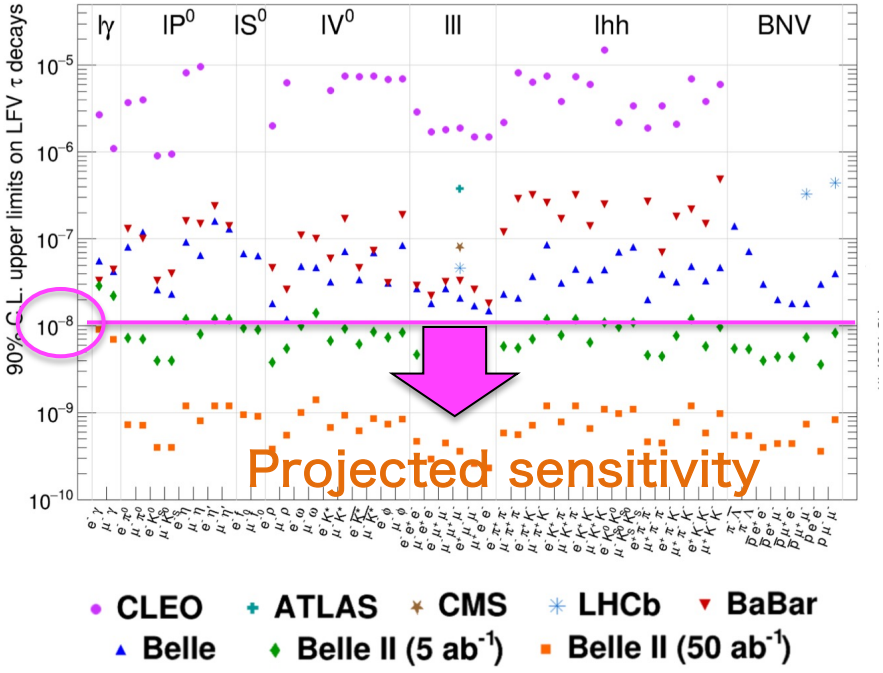
c.f. $\sigma(e^+e^- \to b\bar{b})$~1.1 nb



	Luminosity	$N_{\tau\tau}$
Belle	~1 ab^{-1}	9.1×10^8
BABAR	516 fb^{-1}	4.8×10^8
Belle II	914 fb^{-1}	8.4×10^8

Belle II has ~10^9 τ pairs are produced

Tau Factories!



In addition to more data,

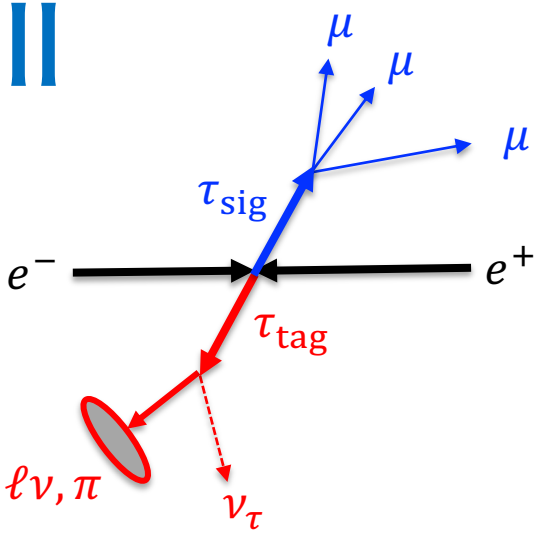
better event selection is essential to maximize the sensitivities

$\tau \to \ell\ell\ell$ search at Belle II

Golden channel

- Potentially sizeable branching fractions in NP models
- Experimentally clean environment
  - Fewer background sources

→ High signal detection efficiency is crucial



Belle: Require 1-prong tau decays in the tag side

NEW

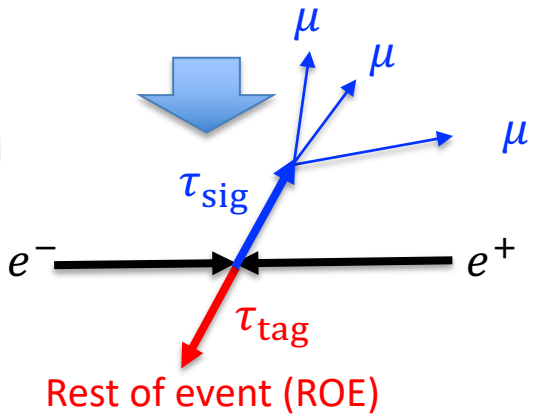
↓ ※ No specific tag-side decay mode required

Belle II: Allow at most 3 tracks in the tag side

- Consider 3-prong decays, $\mathcal{B}\sim 15\%$
- Consider 1-prong events with additional tracks

→ Signal detection efficiency increases!

  - Reduce backgrounds by using BDT (XGBoost)



Signal detection efficiency is 20.4%

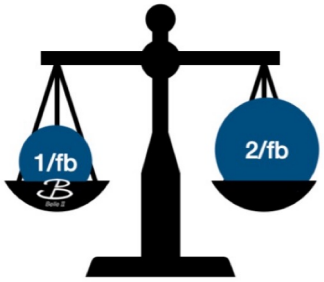
7.6% at Belle

$\tau \to \ell\ell\ell$ search at Belle II

Belle II, JHEP 09 (2024) 062

No significant excess..

→ $\mathcal{B}(\tau \to \mu\mu\mu) < 1.9\times10^{-8}$ with 424 fb^{-1}



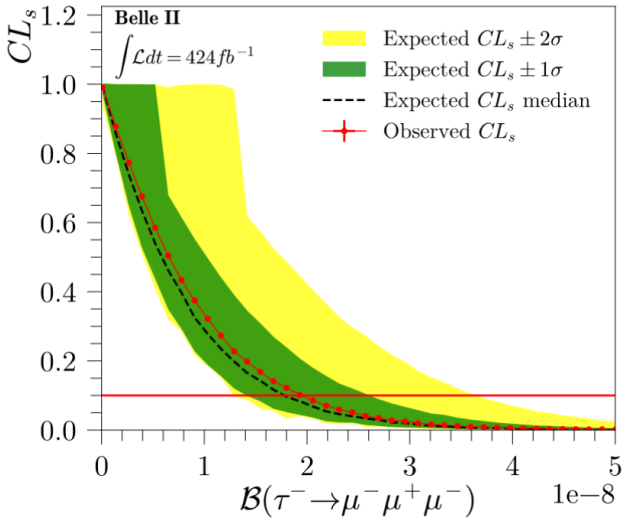
c.f. Belle: 2.1×10^{-8} with 782 fb^{-1}

→ A stronger limit with ~half the Belle dataset

Search for other decay modes: $\mathcal{B} < (1.6 - 2.5)\times10^{-8}$ at 90% CL

→ Possible to probe the 10^{-9} range in the next round

Milestone is to reach sensitivity at the 10^{-10} level

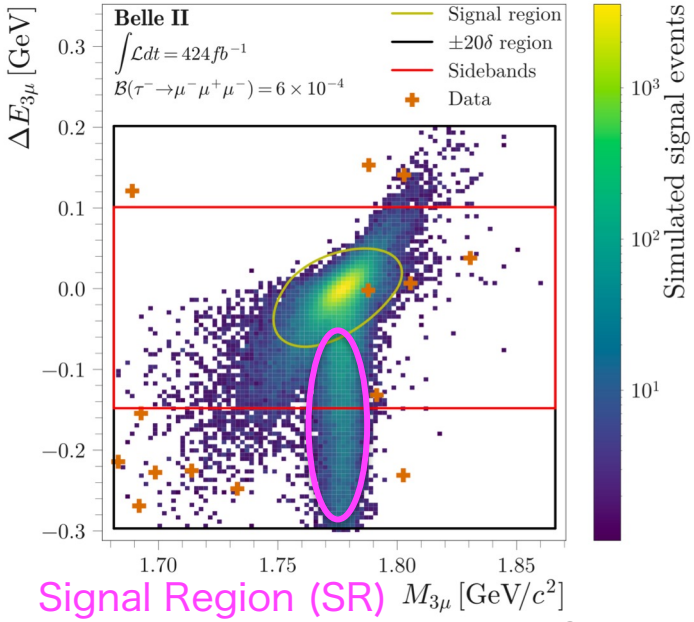


Idea to improve the sensitivity

- Add a dedicated SR targeting ISR-induced events
  - Optimize a dedicated ML-based selection

→ Achieved a 10% relative increase in signal eff and ~7% improvement in sensitivity

J. Park, 2026 JPS, 23aT1-4



Signal Region (SR)

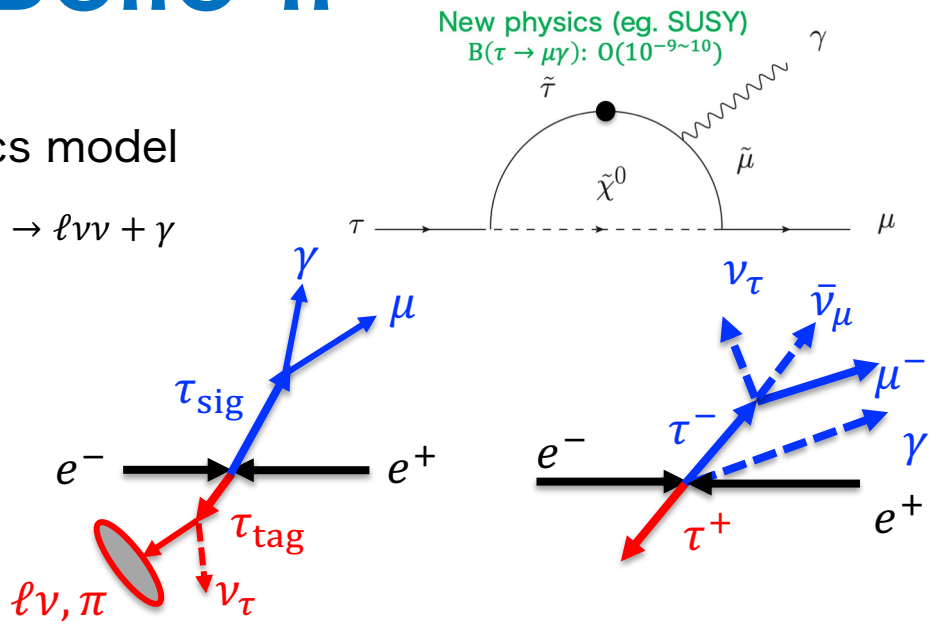
$\tau \to \ell\gamma$ search at Belle II

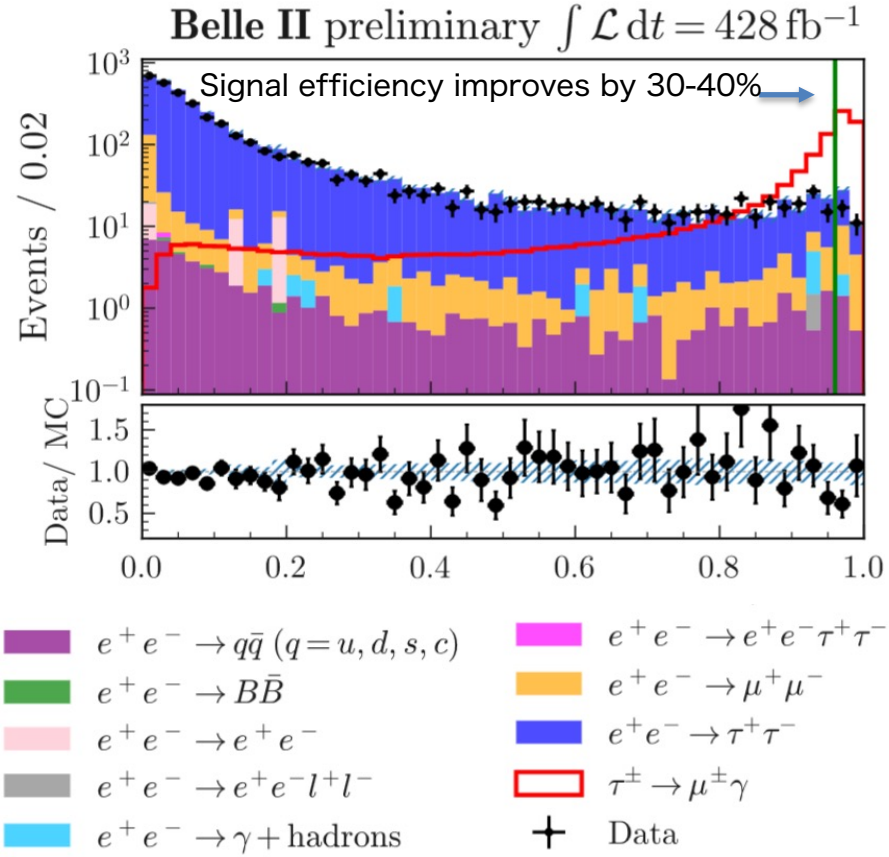
arXiv:2608.23009 (2026)

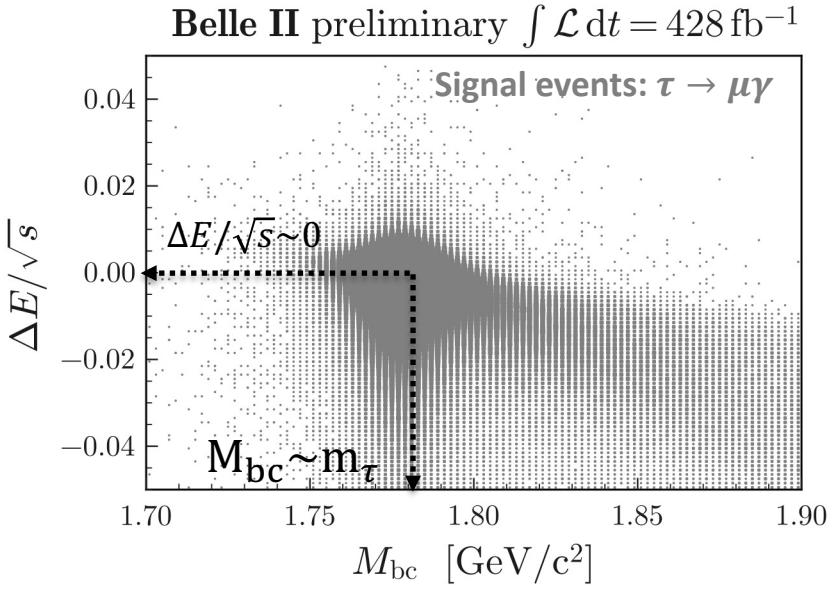
Golden channel

- Sizeable probability in several new physics model
- Background suppression is challenging: $\tau \to \ell\nu\nu + \gamma$

→ Utilize MVA to maximize sensitivity

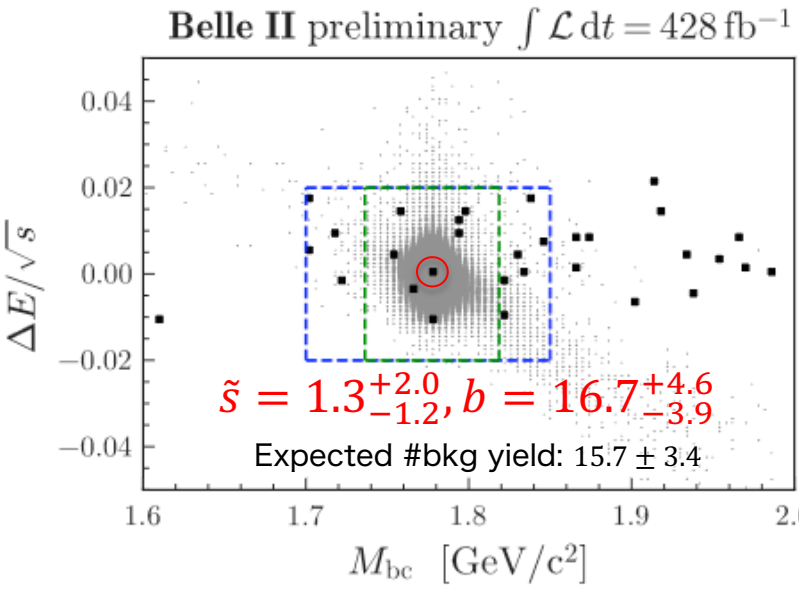




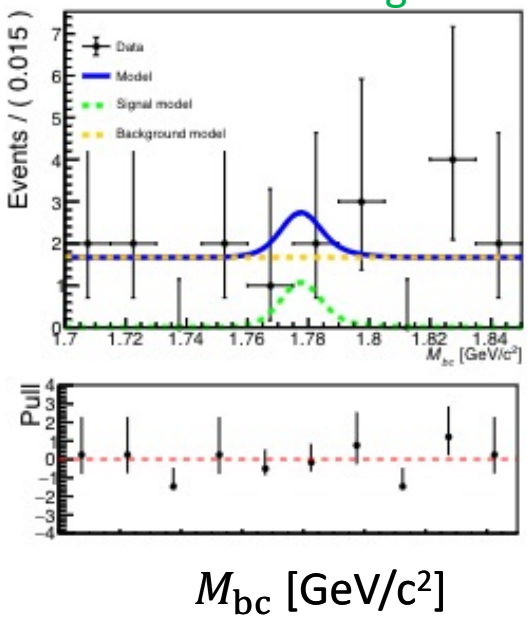


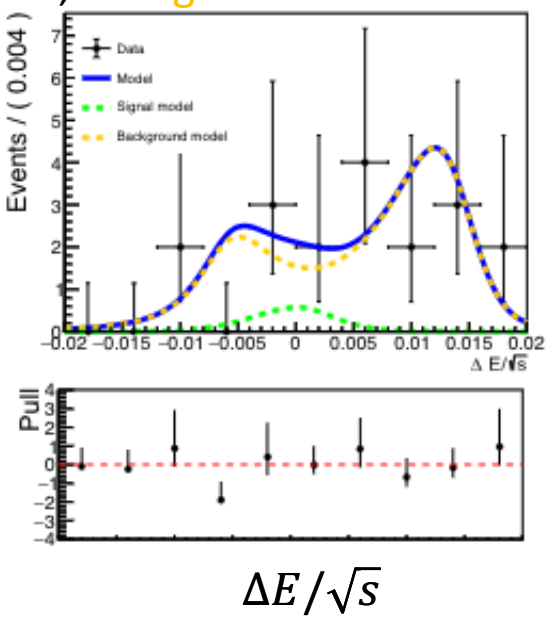
$$M_{bc} = \sqrt{(E_{beam}^{c.m.})^2 - (p_{\mu\gamma}^{c.m.})^2}$$

$\tau \to \ell\gamma$ search at Belle II



Data, Fit result
Signal Model, Background Model





M_{bc} [GeV/c²] $\Delta E/\sqrt{s}$

Comparable expected sensitivity to Belle after scaling to the same $N_{\tau\tau}$

- $\mathcal{B}^{\mathrm{obs}}(\tau \to \mu\gamma) < 9.5\times10^{-8}$ with 428 fb^{-1} at 90% CLs

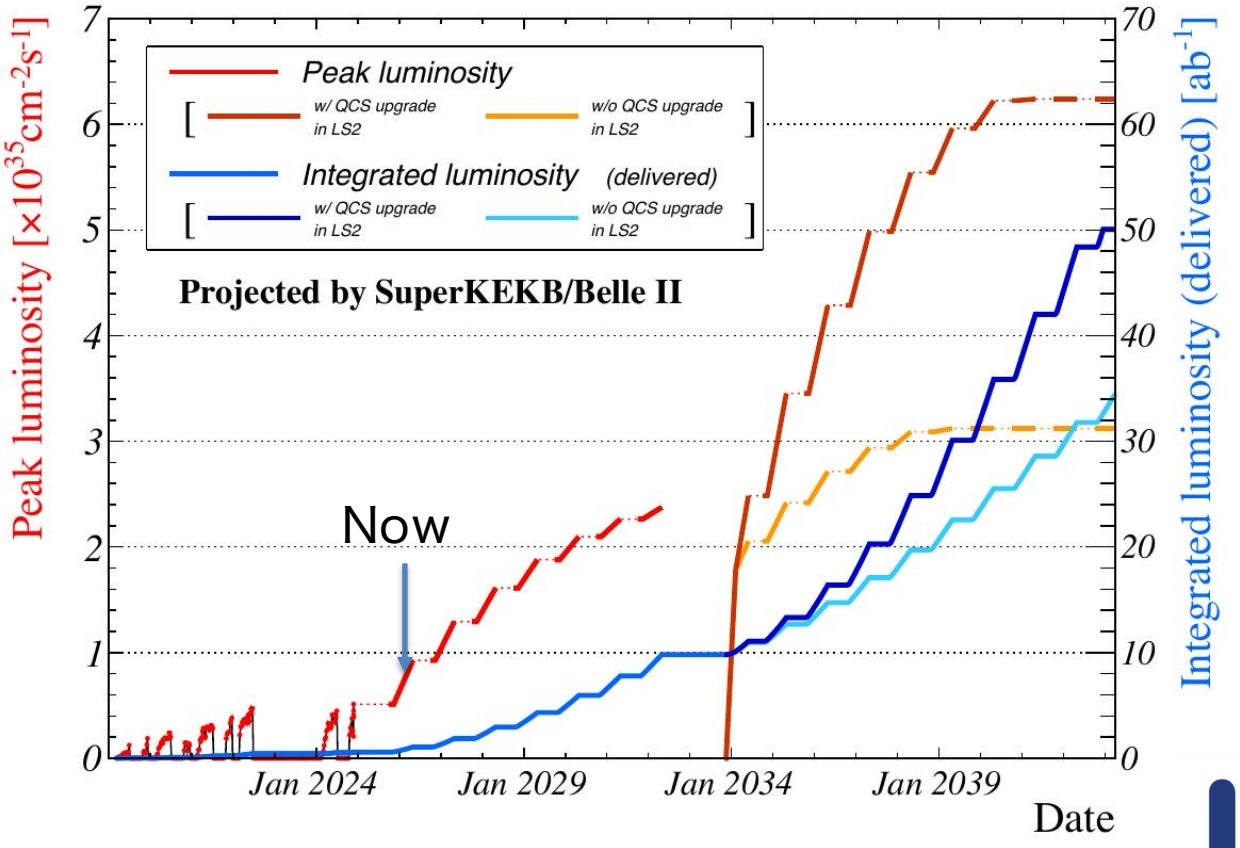
Next steps:

- Combine with Belle and update the analysis with 1 ab^{-1}
- Further sensitivity improvements: Include 3-prong decay in the tag side

S. Kato, 2026 JPS, 23aT1-2

→ Aim to reach the 10^{-9} level

Prospect



50 ab^{-1} remains a long-term goal; a few ab^{-1} is within reach

- The next target is to achieve a peak luminosity of 1×10^{35} cm^{-2} s^{-1}
  - Aim to re-turn on PXD as soon as possible

0.914 ab^{-1}→ 1.3 ab^{-1} → 2.0 ab^{-1} in a few years?

Summary

SuperKEKB/Belle II: search for new physics in various decays

- Recorded dataset: 914 fb^{-1}, including 808 fb^{-1} $\Upsilon(4S)$ dataset (> Belle)
- Established stable operation at a peak luminosity 5×10^{34} cm^{-2} s^{-1}
  - Thanks to several improvements in accelerator; reduction of SBL frequency

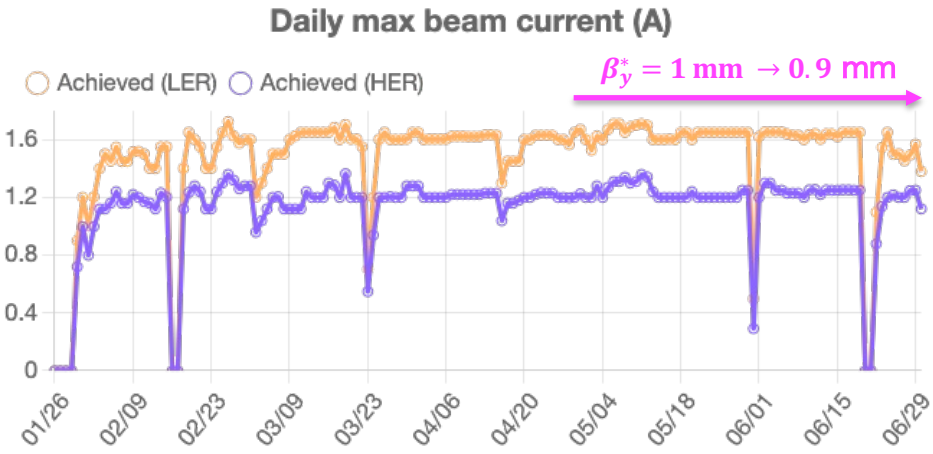
Physics with 914 fb^{-1} and beyond

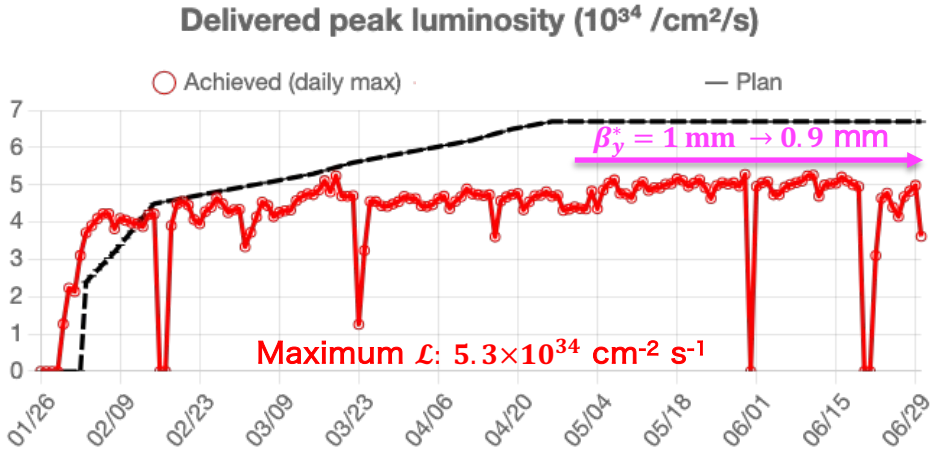
- Update of several physics analyzes will come soon

The next few ab^{-1} offer exciting opportunities to test new physics

Backup

Beam current, luminosity

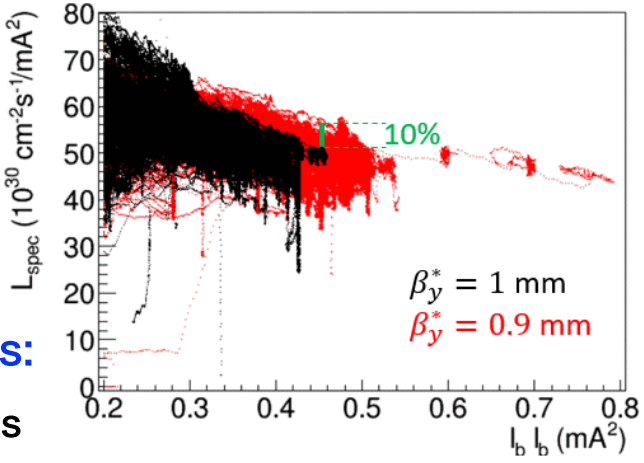




- **Established stable operation at $I_{\mathrm{LER}} = 1.6 - 1.7$ A, $I_{HER} = 1.2 - 1.3$ A at $\beta_y^* = 0.9$ mm**
  - Stable operation at $4.5 - 5.2\times10^{34}$ cm^{-2} s^{-1} was achieved

→ <u>Squeezing β_y^* improved the specific luminosity by 10%</u>

  - Also achieved the same beam currents as at $\beta_y^* = 1.0$ mm



- **Further current increase was limited by several issues:**
  - **SBLs and frequent QCS quenches at high beam currents**
  - Short LER beam lifetime, low HER injection efficiency, higher beam background

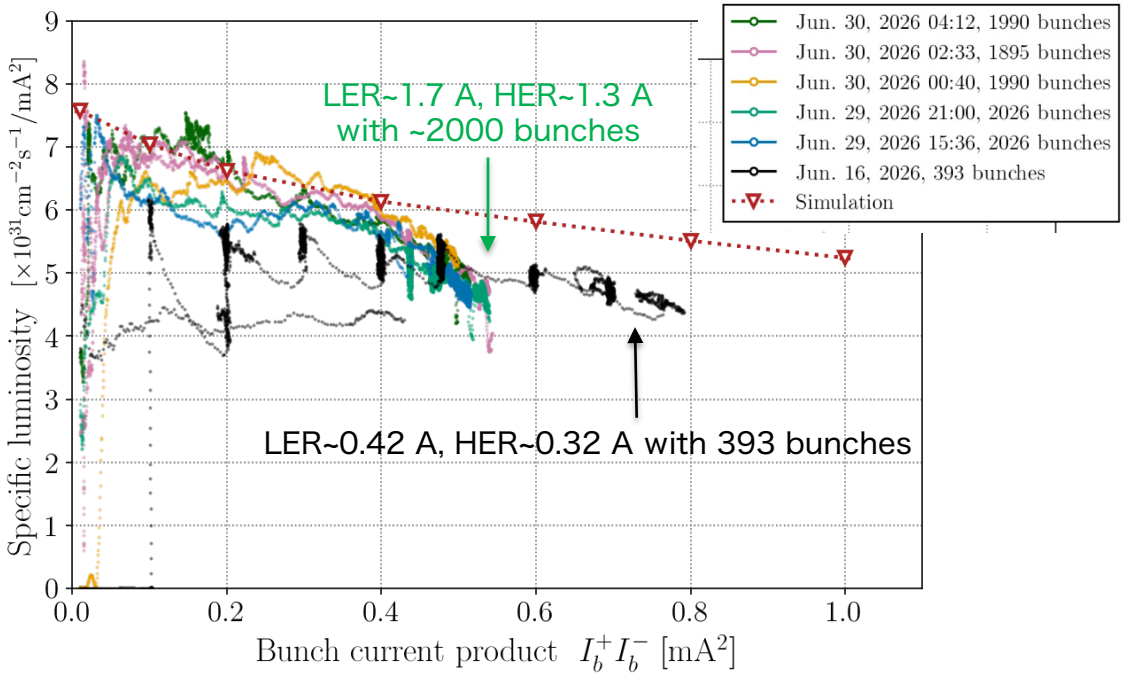
→ <u>Stable operation at the target luminosity of ~6×10^{34} cm^{-2} s^{-1} was not reached</u>

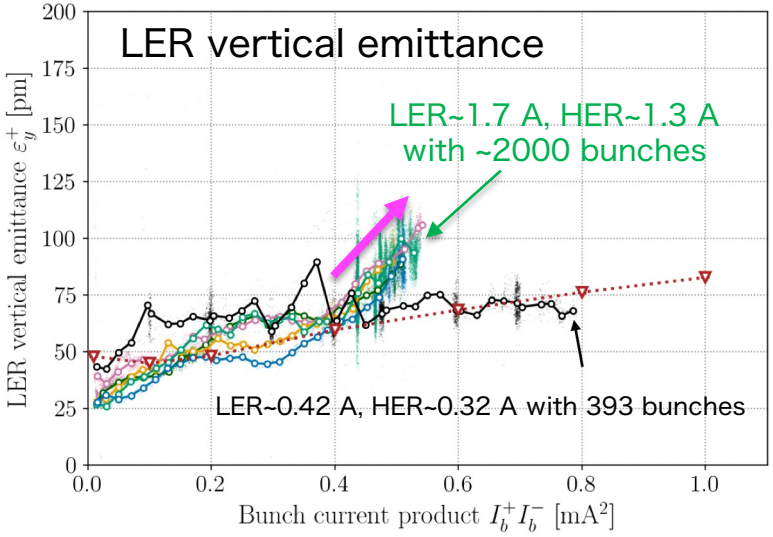
Luminosity Performance

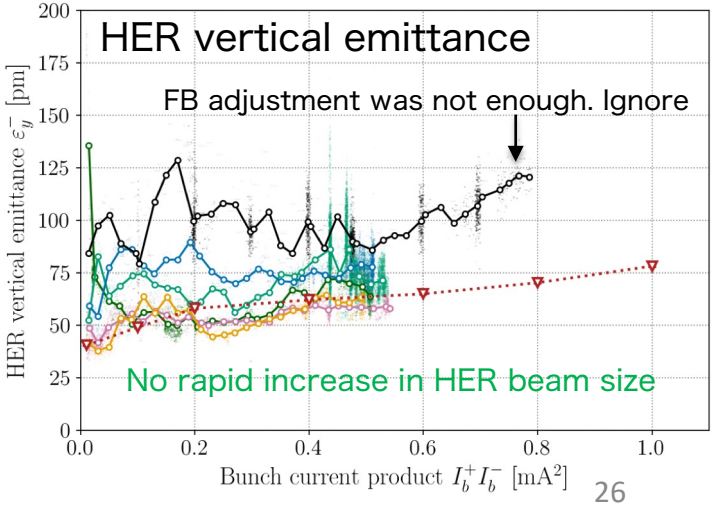
Significant degradation in the specific luminosity is observed at > 0.4 mA^2

- Blow-up in the LER beam size at > 0.4 mA^2 during physics runs
  - The tendency with 393-bunches is different

  → Total current-dependent effects?







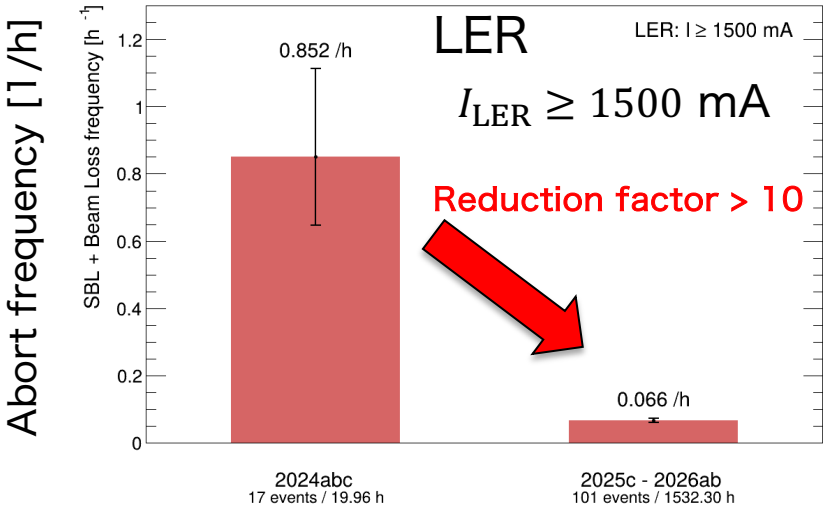
Need more studies and measurements

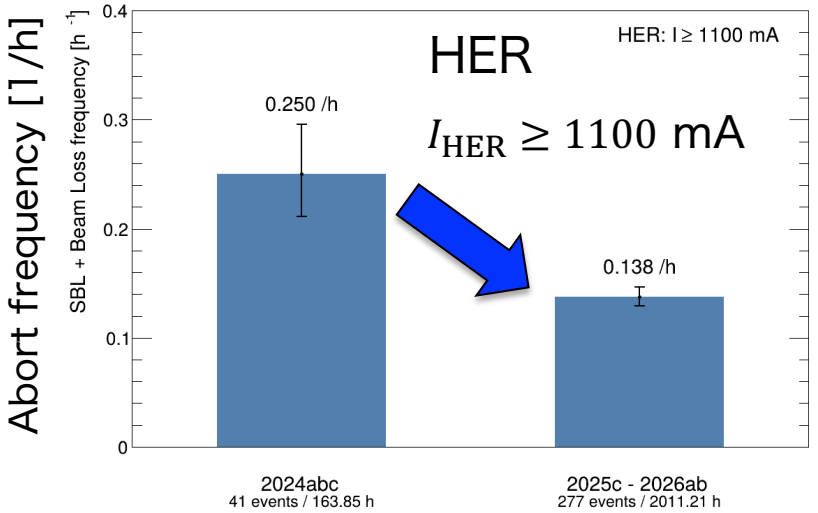
- Bunch-by-bunch FB, chromatic X-Y coupling
- Collimator aperture ..

Action items for the 2027ab

2026ab situation

Cleaning beam pipes works well → Significant reduction of beam abort rates





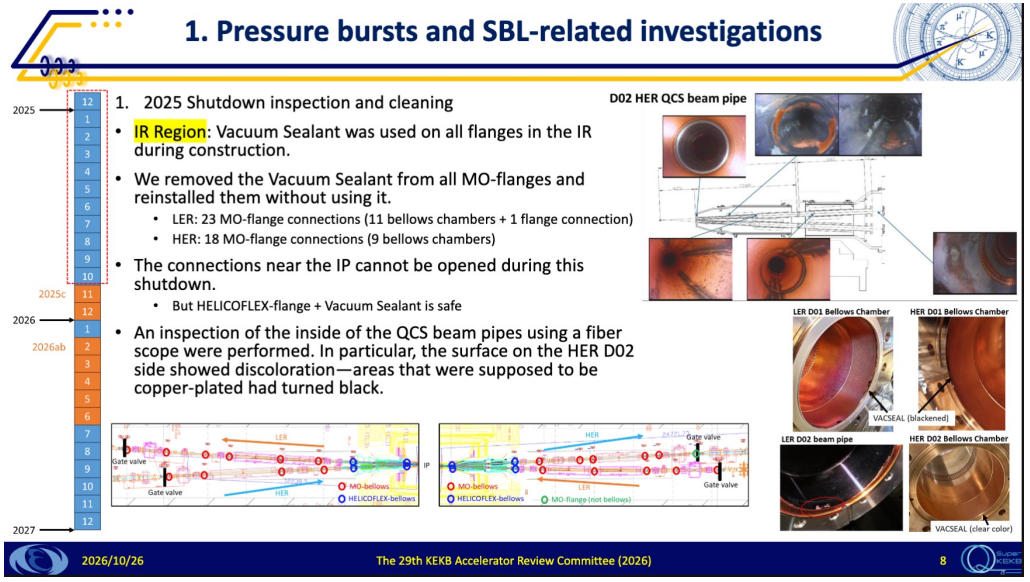
Operation time at $I > 1.5$ A

- 20 h → 1532 h

  2024 2025-2026

Enabled stable operation at higher beam current ☺

Focused on investigating the remaining abort events in detail

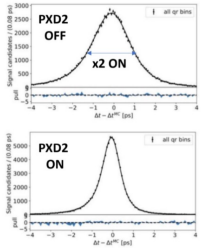


Strategy to turn on PXD

Jim Libby @ September 2024 BPAC meeting

Studies with PXD2 off

- Given 2024c data taking likely to be without PXD2 the time-dependent WG has investigated the impact on lifetime resolution and sin 2β
- B-lifetime resolution ~40% worse
  - Two different beam background scenarios tested – similar results
- For sin 2β from B→J/ψK$_S$ the preliminary studies show a ~20% degradation
  - Study with sample with comparable size to current data



sin 2β value and uncertainty with and without PXD

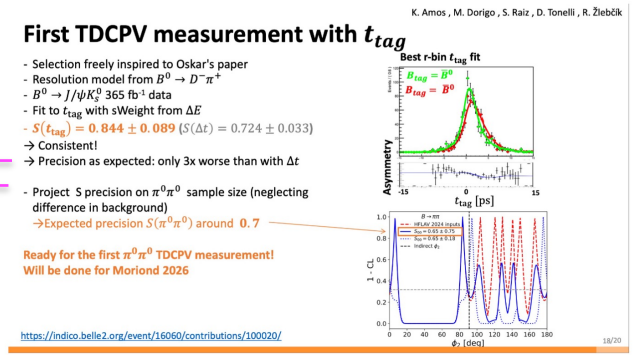
Exp 0	PXD ON	PXD OFF
mean	0.715 ± 0.003	0.713 ± 0.003
width	0.035 ± 0.002	0.042 ± 0.002

Physics September 2024 BPAC 15

Based on study in TDCPV WG

Also … novel tag-side decay time CPV measurements

- ϕ_2 measurement from $S_{\pi^0\pi^0}$
  - Uses only B_{tag} decay vertex and nano beam spot
  - 20x better sensitivity than method in Belle II Physics Book
  - Resolves discrete ambiguities
- Vertex resolution from PXD is crucial !



R. Okubo, October 2025 B2GM TDCPV WG summary

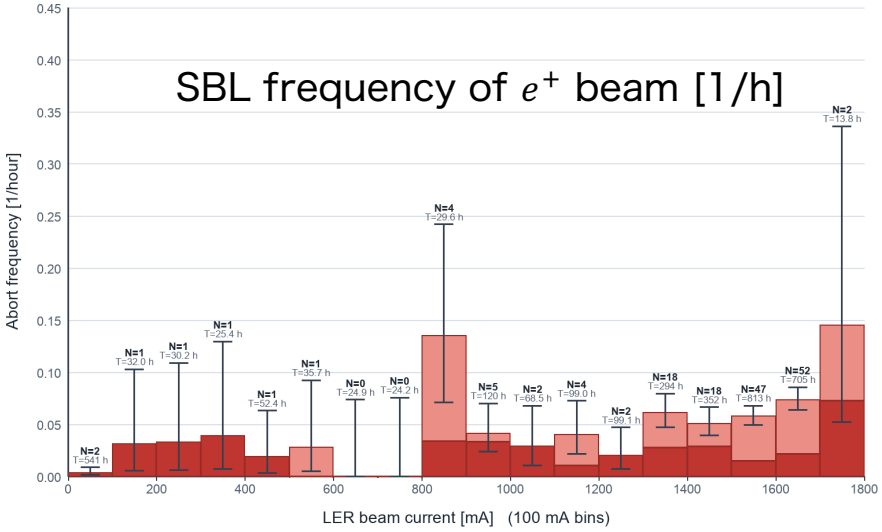
PXD can be considered safe only with following conditions

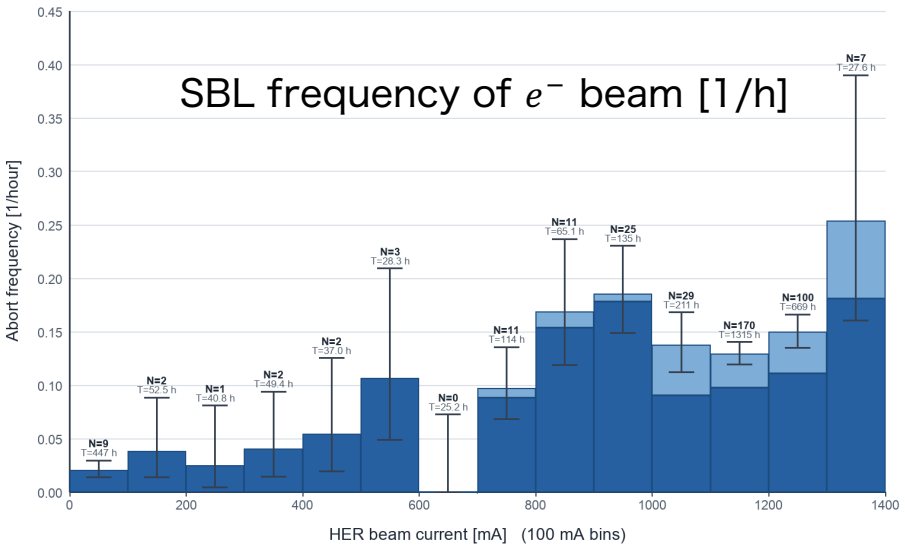
- Acceptable SBL rates (with smaller IR loss)
- Fast hardware shutdown

No conclusion yet. Need more discussion to determine the criteria

SBL

The SBL frequency was reduced, but not enough





SBLもまだ残っている。ダストを取り除きれていない？他の原因？

電子ビームでのSBLの原因が完全に理解できていない

- アボート頻度も高電流で非常に高い。安定運転を阻害している
  - バンチの振動データに特徴あり. Ion trapping? 詳細調査中。頻度を減らせる可能性十分にある

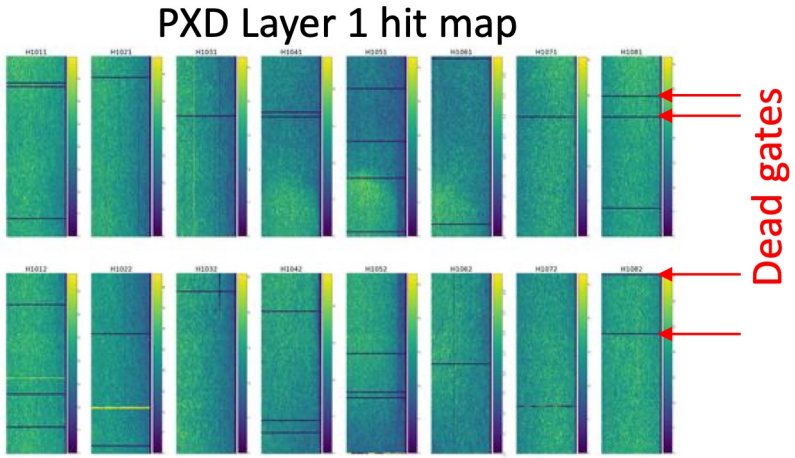
SBL TFを立ち上げ、来期運転までに解決できるように取り組んでいる

リーダーは私

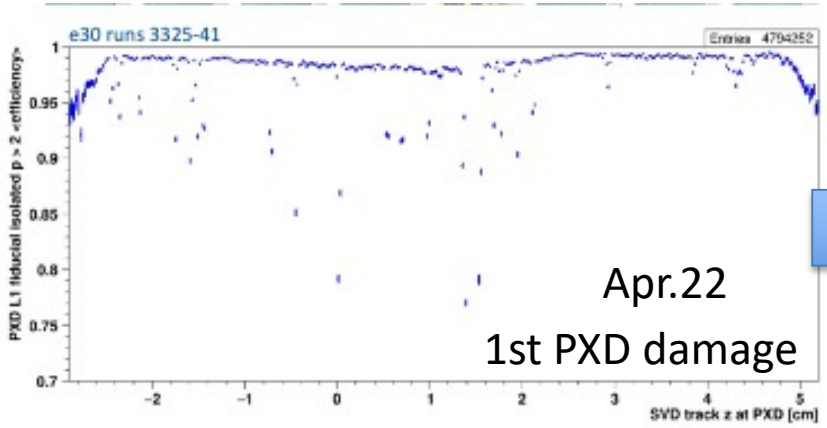
PXD..

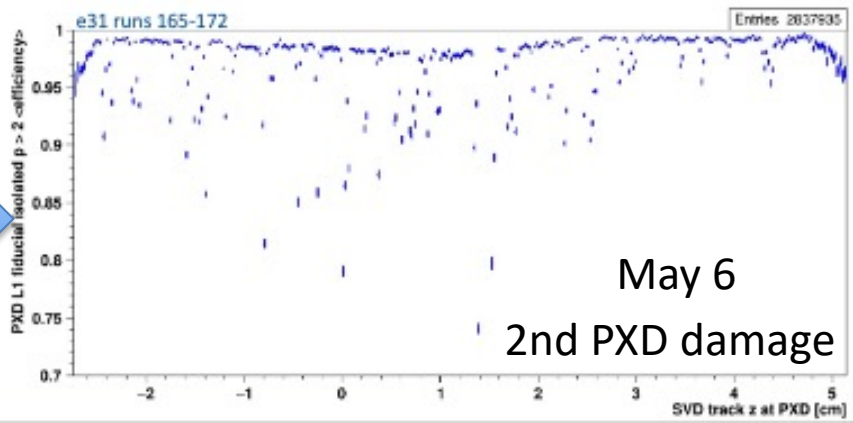
2024

- Only 2% gates damaged
- Increase dark current of some ASIC sensors
  - Risk of deformation



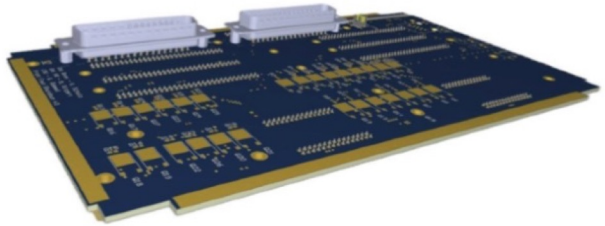
Hit efficiency of PXD modules





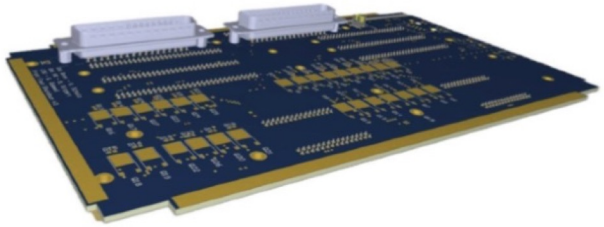
Development of PXD fastdown module

- Turning off PXD: 200 us → ~15 us



PXD fast shutdown

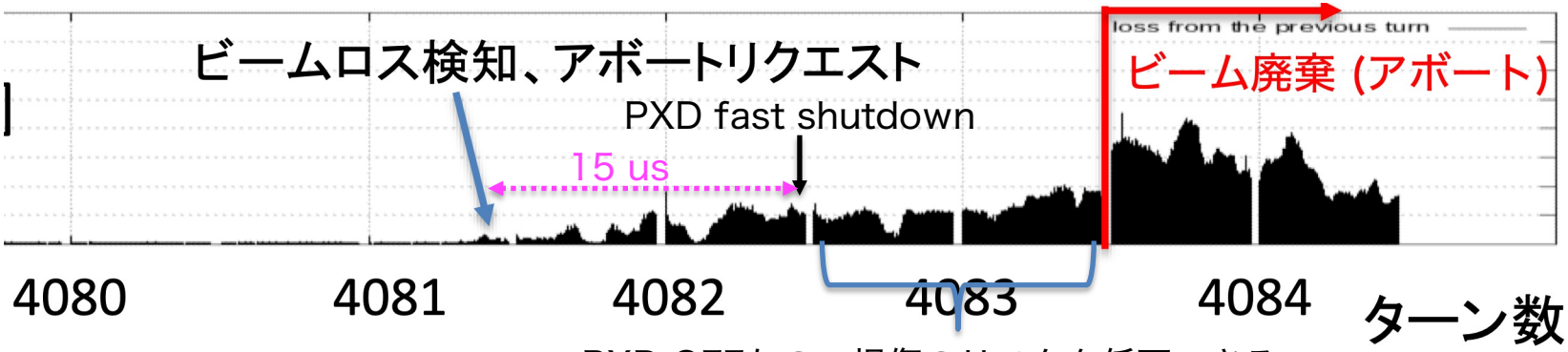
Turn off PXD: 200 us → ~15 us



- **No problem if PXD is OFF**
- Develop dedicated modules
  - ASICにかかっている制御電圧をハードウェアで強制的に落とす

200 us (リング20周分) → ビーム異常を早く検知しても、電源落ちる頃には大量の放射線浴びる

15 us → 現状でもある程度の放射線をPXD ONで浴びずに済む



PXD OFFなので損傷のリスクを低下できる

SBLから完全にPXDを守るためには、
大きなビーム損失が発生する~15 us前に異常を検知する必要あり

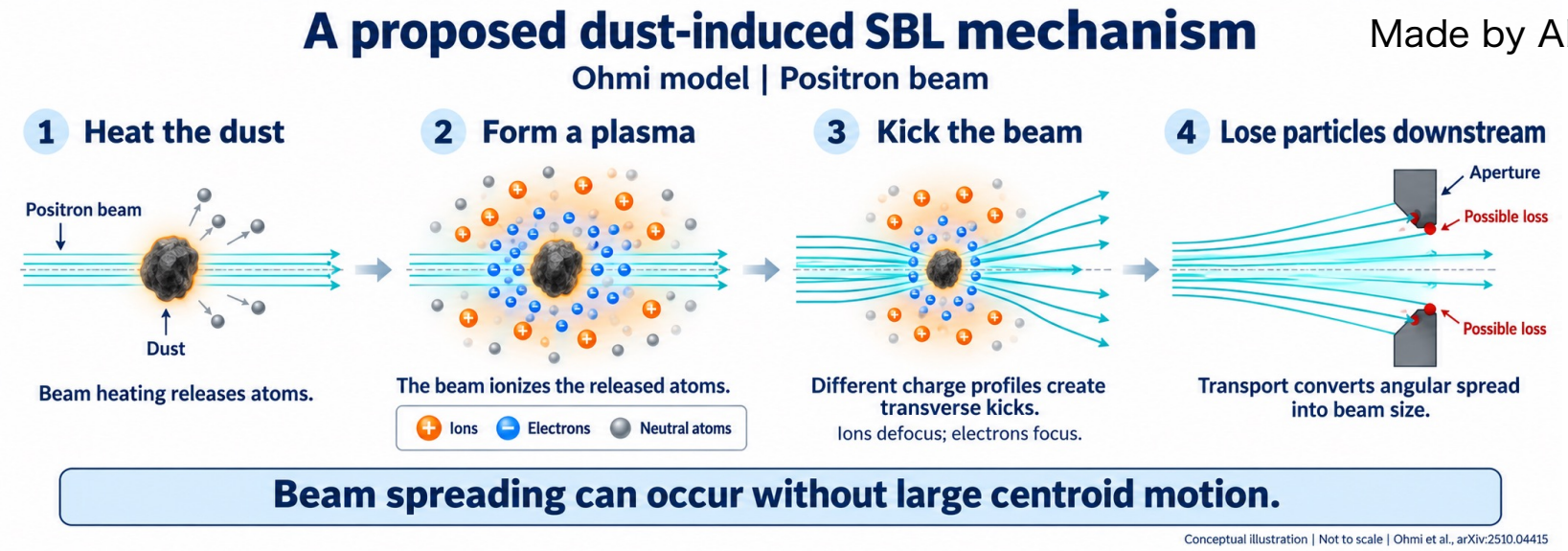
SuperKEKB/Belle IIで、予兆の信号を探索中
→ いくつか候補はあり、評価中

2027運転でPXDを復活させ、Belle II本来の性能を出したい

https://journals.aps.org/prab/abstract/10.1103/pyl3-rfjg
https://indico.jacow.org/event/75/contributions/7097/attachments/801/3282/Beam-dust_Interaction_ohmi.pdf

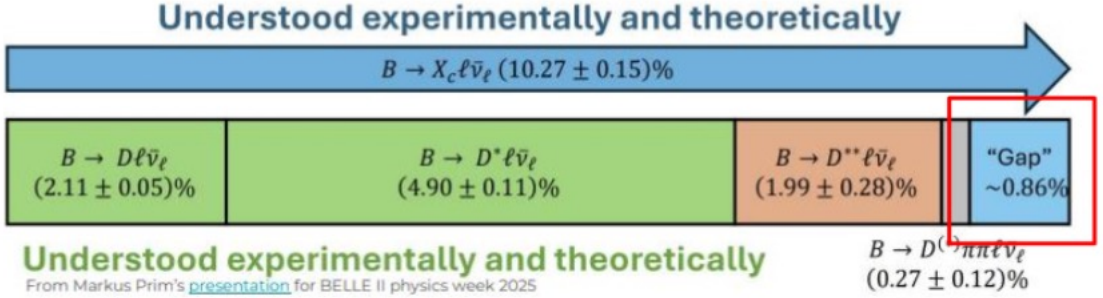
In Ohmi's model,

- a dust particle overlapping the beam is heated and releases atoms.
- The beam ionizes these atoms, creating a localized plasma.
- The plasma's electric field acts like a strong, nonlinear lens, giving the beam particles transverse kicks.
- As the beam travels around the ring, the increased angular spread turns into a larger beam size, potentially causing sudden beam loss.
- The key point is that the beam can spread without a large oscillation of its center.
- So this mechanism does not necessarily require a clear precursor in the beam-centroid motion



new measurement: $B \to D^{(*)} \eta \ell \nu$

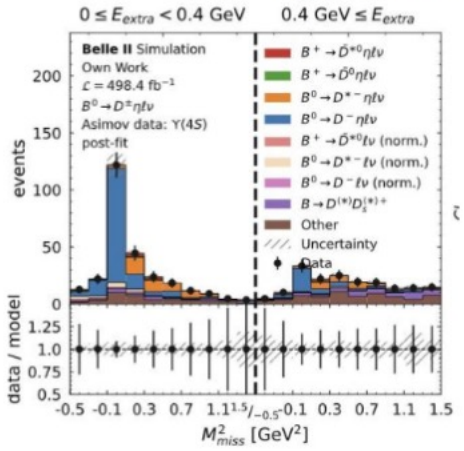
- Next leading systematics is modeling of gap mode in $B \to X \ell \nu$
  - ~0.86% unmeasured decay
  - for now, we are using $B \to D^{(*)} \eta \ell \nu$ to model it



- We are measuring BR($B \to D^{(*)} \eta \ell \nu$)
  - targeting winter 2026
  - expected Asimov sensitivity is ~0.1%

$$\mathcal{B}(B^0 \to D^{\pm} \eta \ell \nu) = (0.88 \pm 0.10_{\text{stat.}})\%$$
$$\mathcal{B}(B^0 \to D^{*\pm} \eta \ell \nu) = (0.88 \pm 0.11_{\text{stat.}})\%$$
$$\mathcal{B}(B^{\pm} \to D^{0} \eta \ell \nu) = (0.92 \pm 0.08_{\text{stat.}})\%$$
$$\mathcal{B}(B^{\pm} \to D^{*0} \eta \ell \nu) = (0.92 \pm 0.09_{\text{stat.}})\%$$

Full Gap slide at last JPS

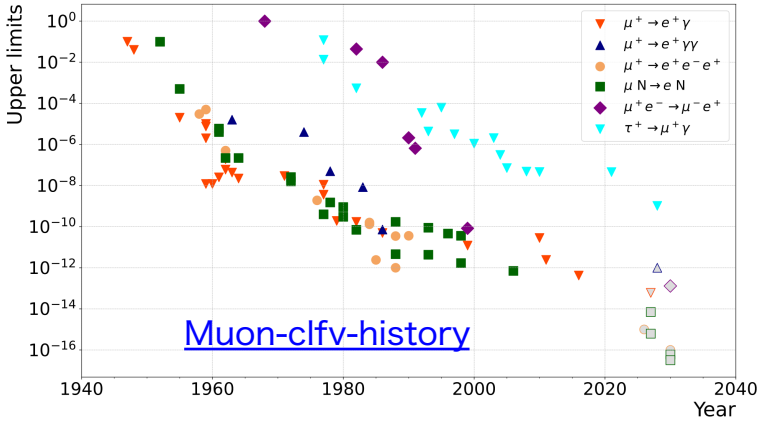


LFV searches at colliders

Strong constraints from muon LFV searches

- $\mathcal{B}(\mu \to e\gamma) < 1.5\times10^{-13}$ at 90% C.L [arXiv:2504.15711]
- $R_{\mu e}(\mathrm{Au}) < 7.0\times10^{-13}$ at 90% C.L. [EPJC 47 (2006) 337]

→ No CLFV observed so far… ;(



Searches beyond $\mu - e$ are essential to explore other flavors and interactions

- Even if $\mu - e$ is observed, other channels are needed to reveal the flavor structure of NP

Colliders produce τ-leptons and heavy particles

- τ: $\tau \to \mu\gamma, \tau \to e\gamma, \tau \to \mu\mu\mu, \ldots$
- H/Z: $H/Z \to \mu\tau, \ldots$
- t/b: $t/b \to q\mu\tau, \ldots$

Colliders offer unique opportunities to search for LFV in a wide range of channels



https://higgstan.com/standerd-model/

NP couple more strongly to τ?

LFV branching fractions probe the flavor structure of NP

- $r = \frac{\mathcal{B}(\tau \to \mu\gamma)}{\mathcal{B}(\mu \to e\gamma)} \propto \left| \frac{(m^2_{\tilde{L}})_{\mu\tau}}{(m^2_{\tilde{L}})_{e\mu}} \right|^2$ Left-handed slepton mixing

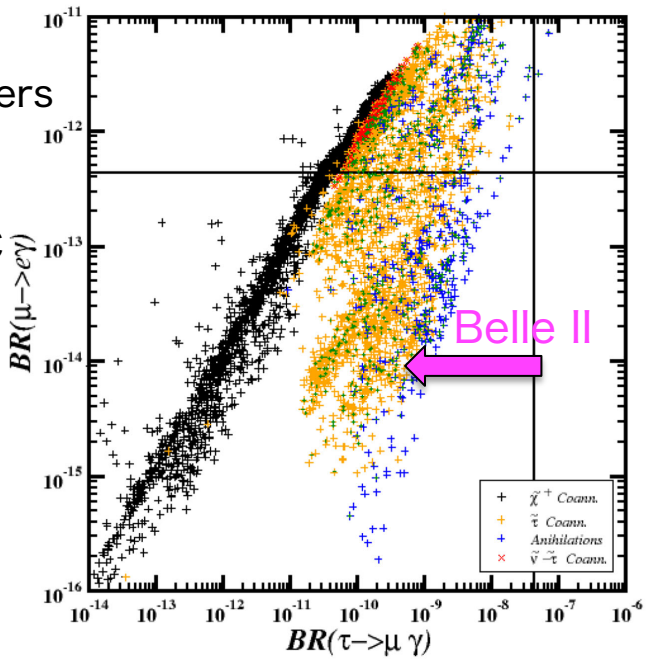
  M.E. Gomez et. al. Phys. Rev. D 110, 095003 (2024)

  - Illustrative SUSY-seesaw scenarios: $r \sim 1 - 10^4$ CKM-like: $O(10^{3\sim4})$
  - MEG II limits tightly constrain many scenarios..
    - **Enhanced 2-3 mixing relative to 1-2 mixing can make $\tau \to \mu\gamma$ a valuable probe**

E.g. SUSY with a U(1) flavor symmetry

- $\tau \to \mu\gamma$ can be more promising, depending on the parameters
  - $\tilde{B} - \tilde{\tau}$ coannihilation can reproduce the DM relic density
  - Compressed spectra are challenging to probe at the LHC

Phys.Rev.D 110 095003 (2024)



In addition, B-anomalies → NP couples to the 3rd gen?

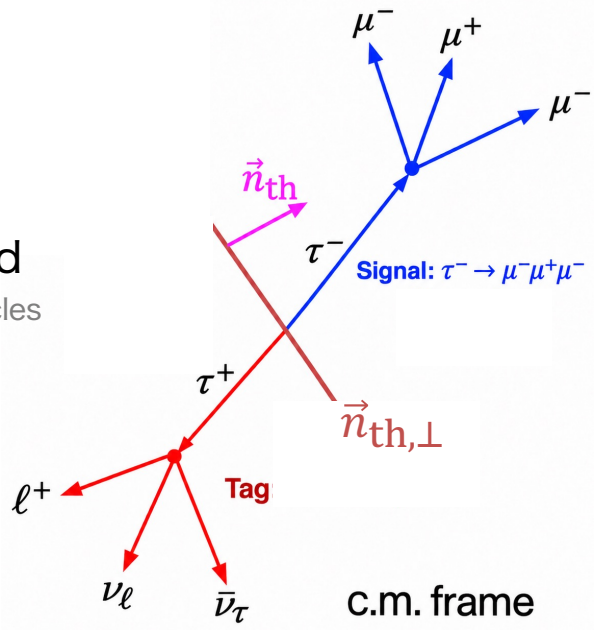
- If these interactions violate lepton flavor, complementary signals may appear in τ, b, t decays
  - For example, $\tau \to \mu\mu\mu$ via a flavor-violating Z'.

τ LFV search at Belle II

Identify τ-pair events using thrust axis, $\vec{n}_{\rm th}$

- $\vec{n}_{\rm th}$ is defined so that $V_{\rm th} = \Sigma_i |\vec{p}_i^{\rm c.m.} \cdot \vec{n}_{\rm th}| / |\Sigma_i |\vec{p}_i^{c.m.}|$ is maximized

All the reconstructed particles



τ-pair event is divided into two hemispheres

- Signal-side: Target τ LFV decay: e.g. $\tau \to \ell\gamma, \ell\ell\ell$ ..
- Tag-side: τ decay in the SM

Signal region (SR) definition

- Invariant mass of signal-side tau ($\tau_{\rm sig}$): $M_{\rm inv}$
- $\Delta E = E^{c.m.}_{\tau_{\rm sig}} - \sqrt{s}/2$

