Belle II status in 2024
(ARC review January 2025)

with lot of inputs from:
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ex-run coordinator: K.Matsuoka
physics coordinator: J.Libby

K. Trabelsi
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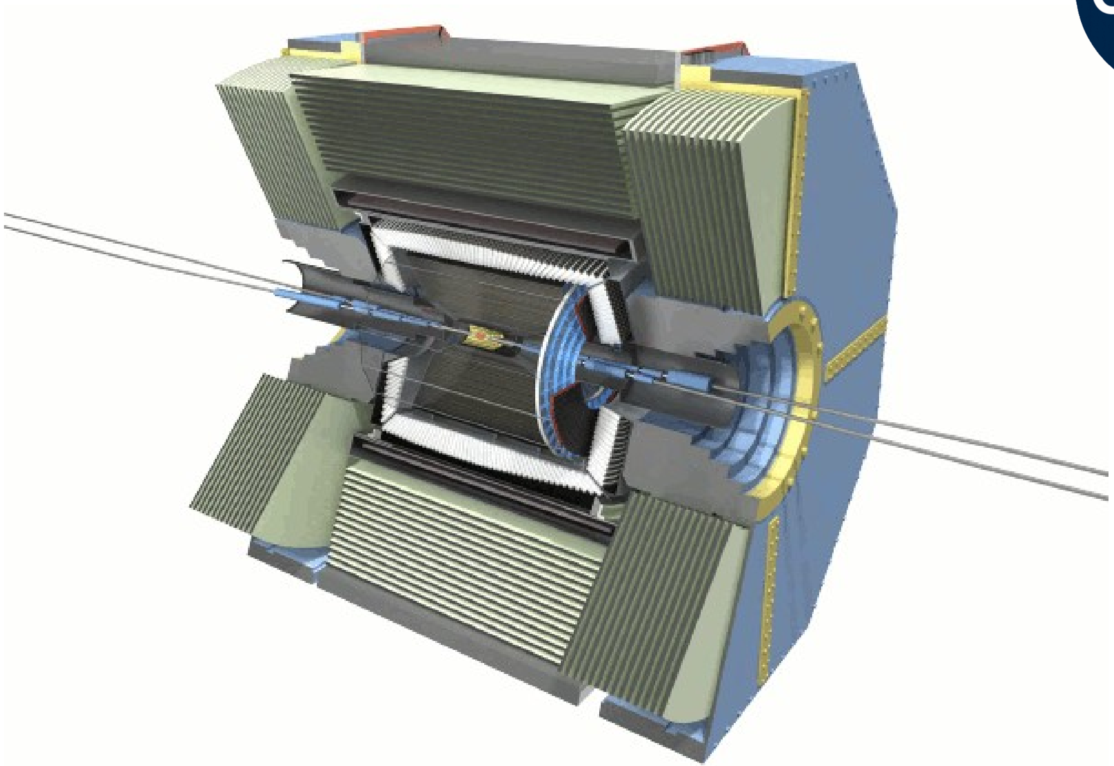
(TYL/IN2P3)



Belle II is...

Staff : 311, Post-docs: 125, PhD students : 257 ~ **700 collaborators**
and undergraduate/master students, technical members

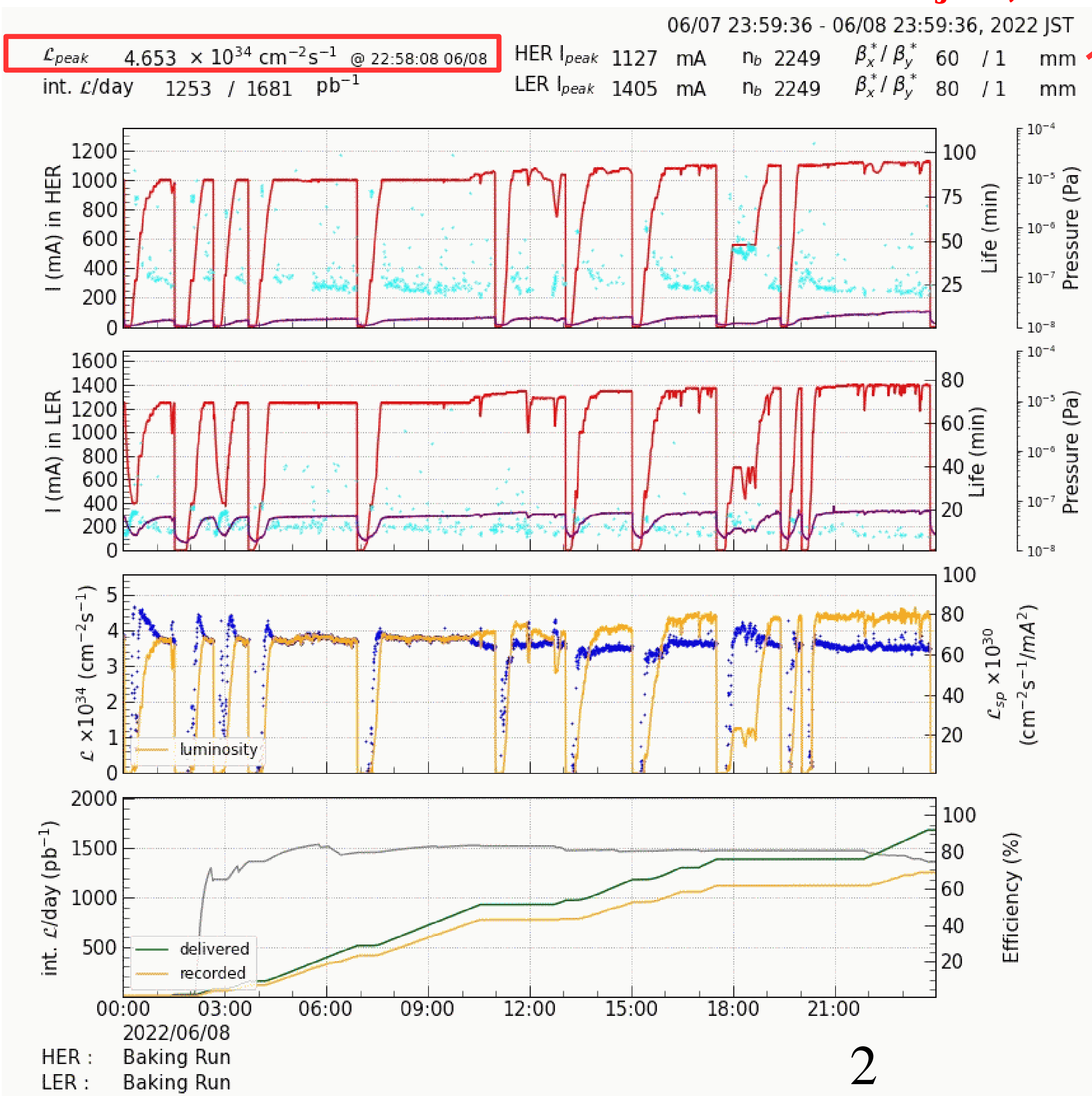
Belle II run 1 (2019 - 2022)

data taking from March 2019 to June 2022

→ despite difficult conditions since March 2020 (Covid, war in Ukraine, energy cost...)

luminosity: 4.7×10^{34}/cm^2/s ! > 2 fb^{-1} per day !

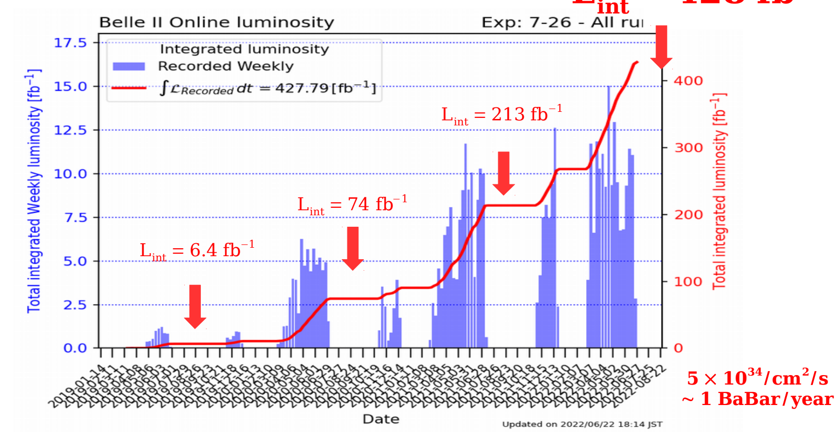
June, 2022



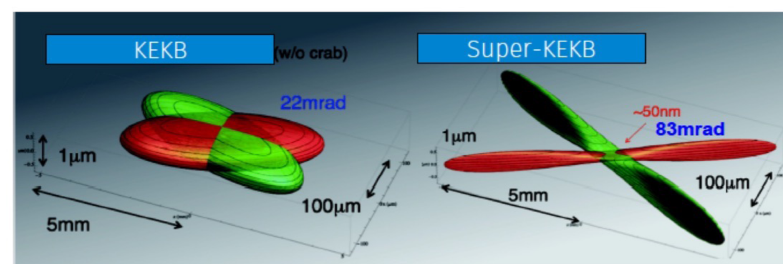
β^*_y = 1 mm, $I_{LER/HER}$ = 1.4/1.2 A

record of KEKB/Belle
2×10^{34}/cm^2/s currents > 1 A
record of PEPII/BaBar
1×10^{34}/cm^2/s currents > 2 A

L_{int} = 428 fb^{-1}



5×10^{34}/cm^2/s ~ 1 BaBar/year



	E (GeV) LER/HER	β*y (mm) LER/HER	β*x (cm) LER/HER	φ (mrad)	I (A) LER/HER	L (cm⁻²s⁻¹)
KEKB	3.5/8.0	5.9/5.9	120/120	11	1.6/1.2	2.1 x 10^{34}
SuperKEKB	4.0/7.0	0.27/0.30	3.2/2.5	41.5	3.6/2.6	80 x 10^{34}

factor 20 factor 2-3

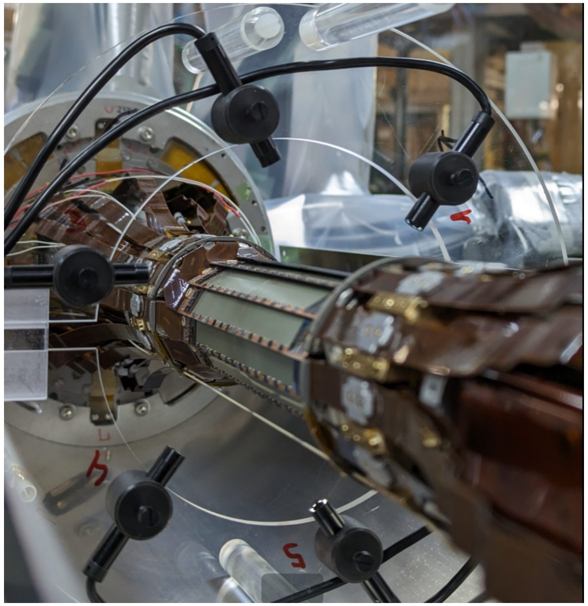
squeezing further β^*_y (→ 0.6 mm)
doubling (or more) the currents
⇒ L > 10^{35}/cm^2/s after LS 1

Long-shutdown (LS1) activity and plans

Belle II stopped taking data in Summer 2022 for a long shutdown (1.5 yr)

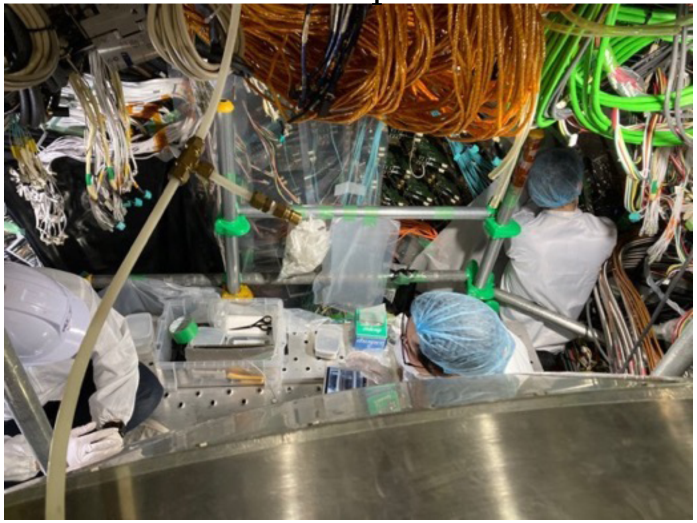
- accelerator improvements:
  injection, **copper coated collimators heads, non-linear collimators**...
  monitoring (BOR, loss monitor for timing measurement, acoustic emission sensors)
- additional shielding and increased resilience against beam bckg
- **replacement of beam-pipe**
- **installation of 2-layered pixel vertex detector**
- replacement of photomultipliers of the central PID detector (TOP)
- completed transition to new DAQ boards (PCIe40)
- work on other detectors such as CDC, KLM...
- improved data-quality monitoring and alarm system

PXD2 at KEK since March 2023



VXD extraction in May 2023

TOP MCP-PMT replacement work

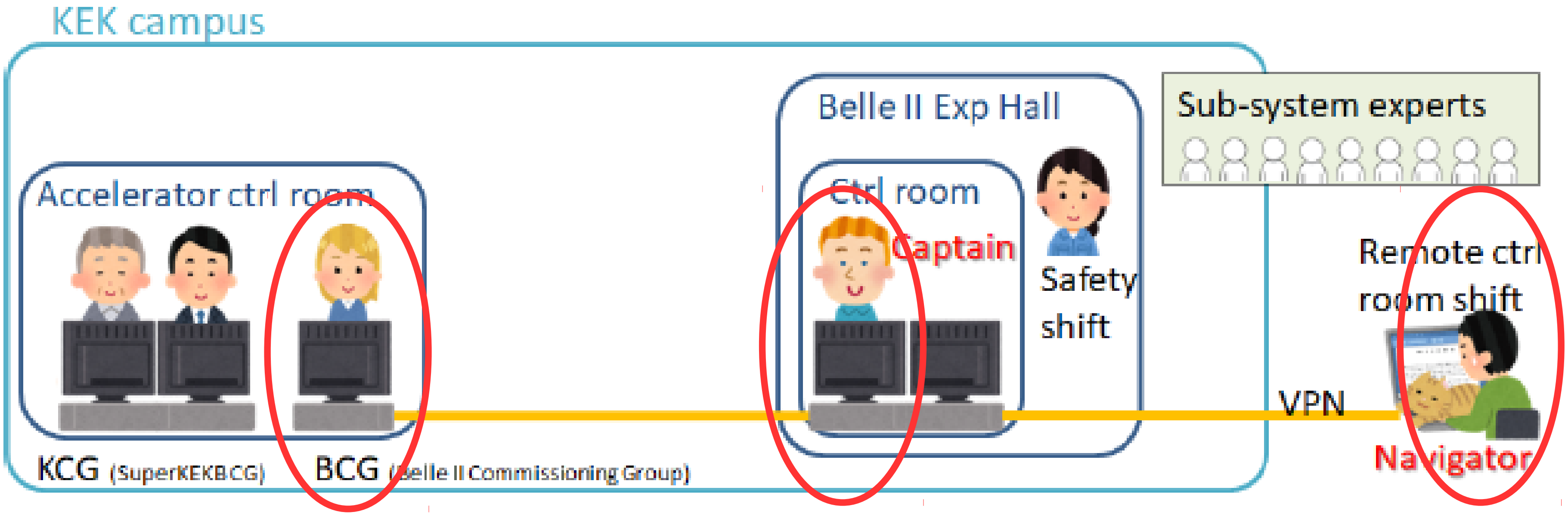


CDC FE reinstallation work

first collisions of run 2 in February 2024

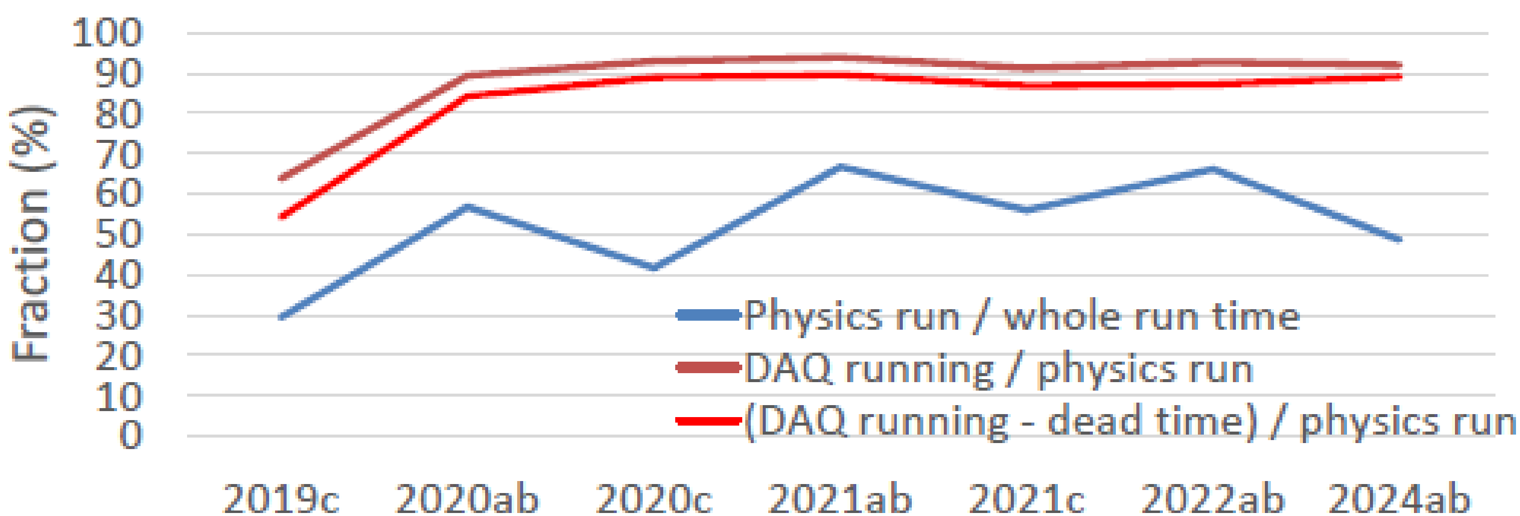
2024 a/b (Feb to June) + 2024 c (Oct to Dec) → 8 months

Belle II operation shifts in run 2



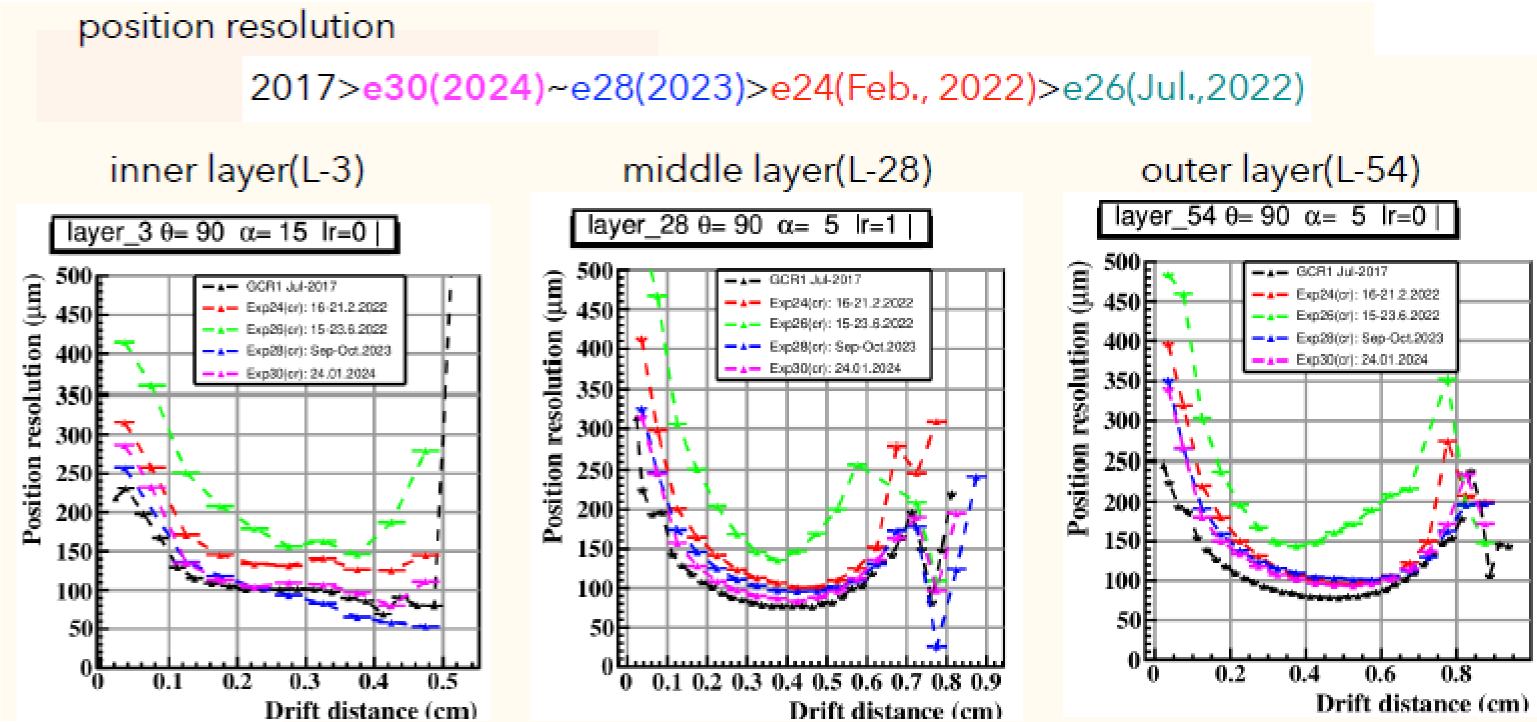
During 2024a/b, Fraction of physics run time < 50%

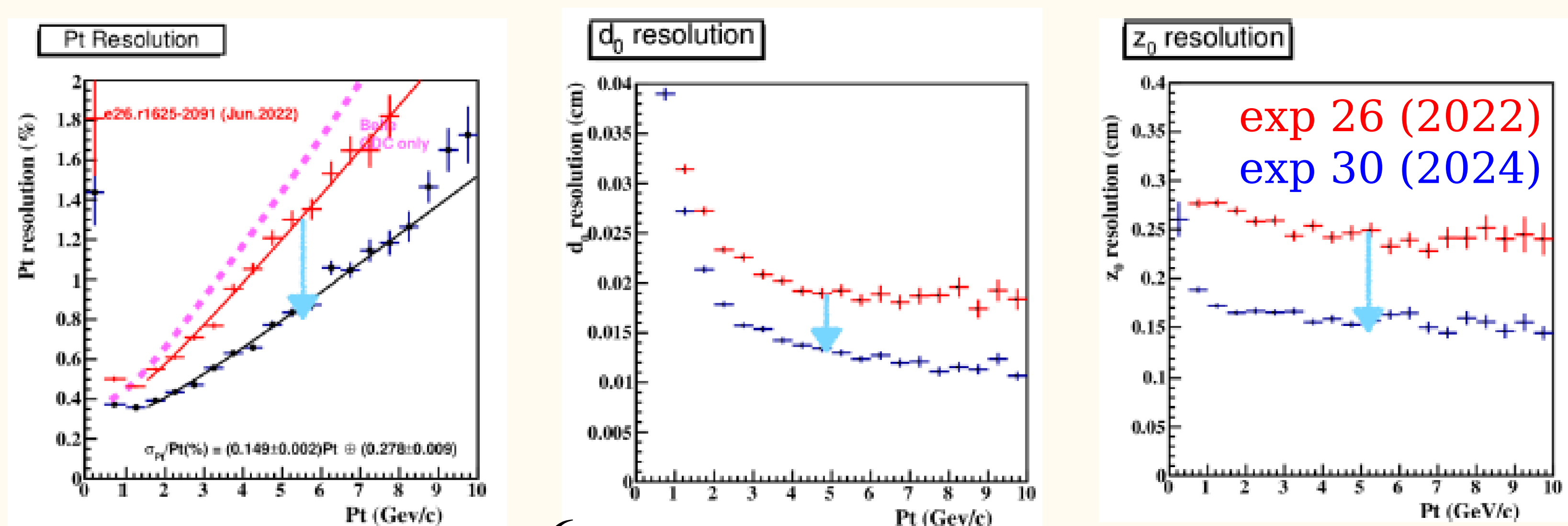
Data taking efficiency: 89.1% (target 90%)



Among the first results of run 2, as an illustration

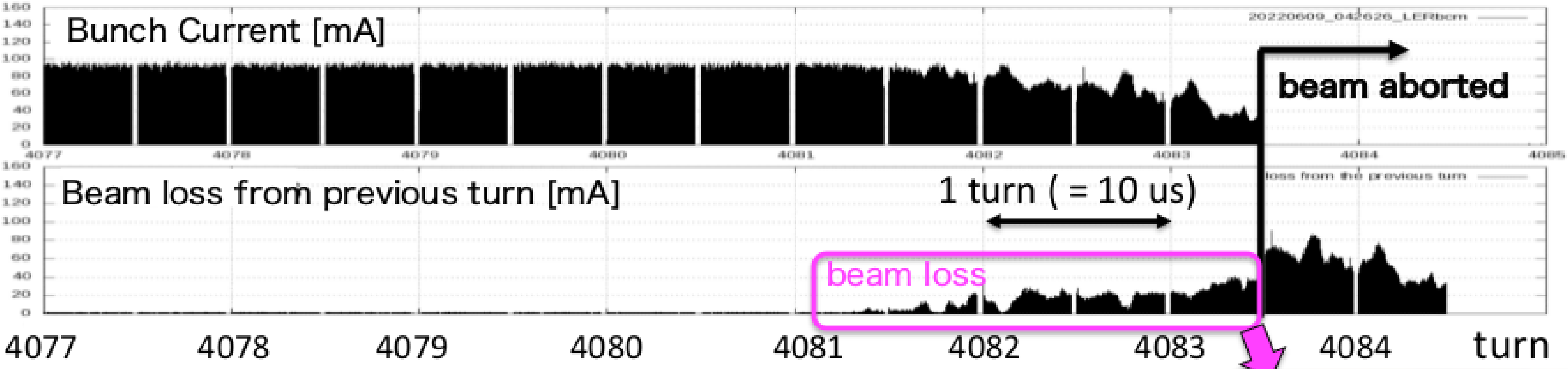
CDC performance on cosmic 2024 (better gas/water control and monitoring)
⇒ performance much improved compared to end of run 1



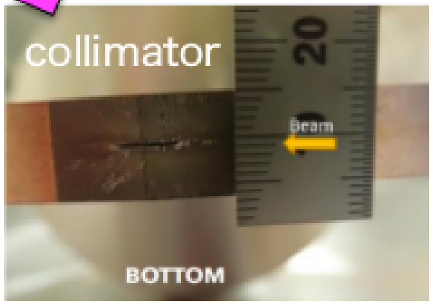


Sudden Beam Loss (SBL)

Cause the beam to lose most of its particles within a few turns



In few cases, damaged Belle II detector and accelerator equipment (collimator heads), or caused QCS quenches



⇒ Temporary PXD2 off since May 7, 2024 to avoid further damage

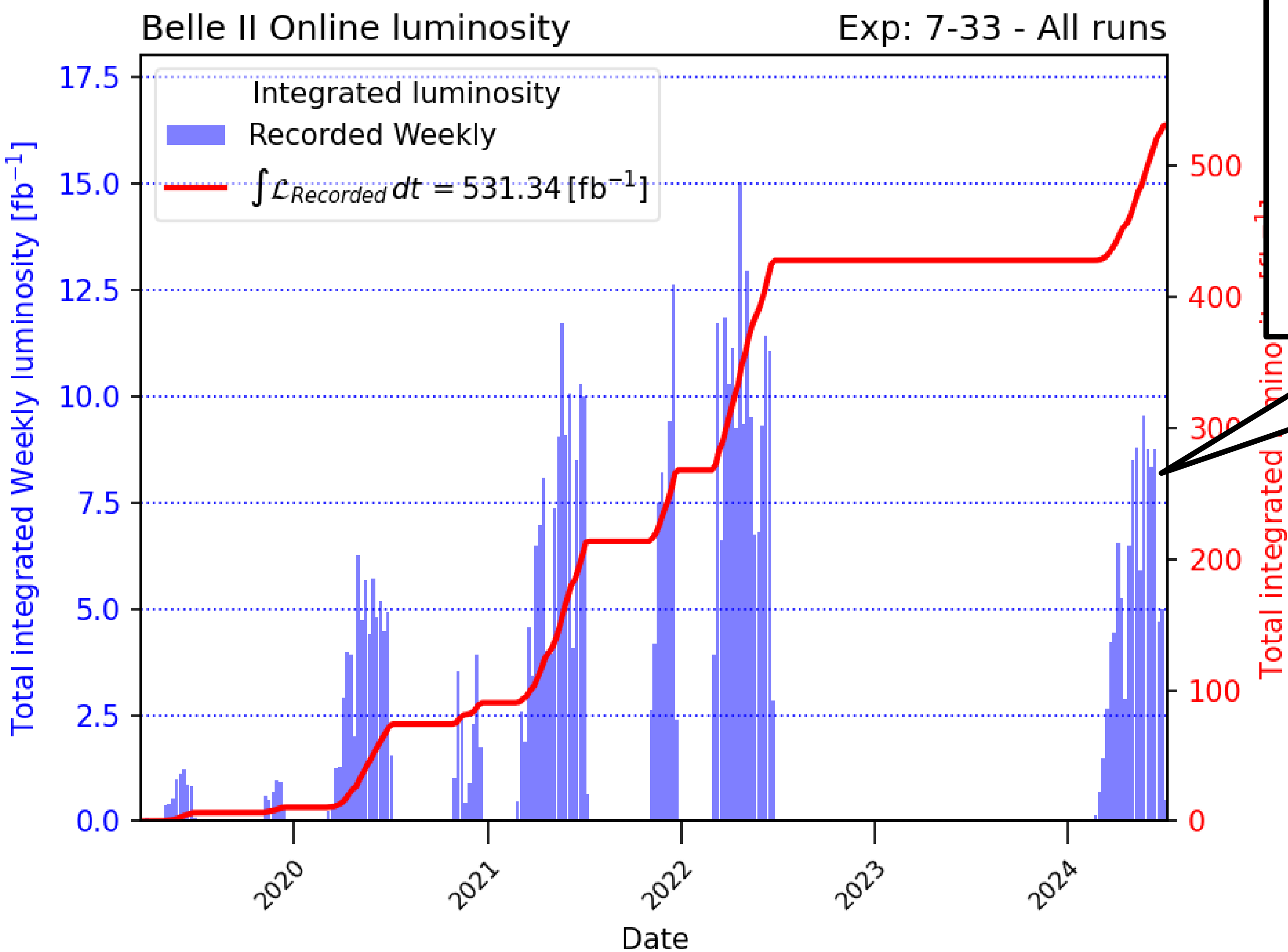
Radiation dose and frequency seem to be proportional to beam current

→ have to be cautious when increasing currents

Understanding SBL events and implementing countermeasures crucial to achieve high luminosity

(see Ikeda-san's talk)

Situation in 2024a/b



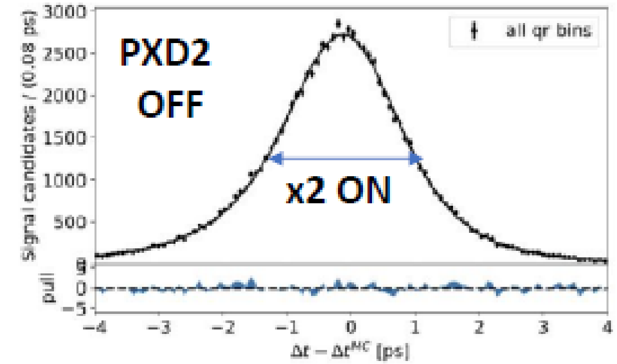
Jan 29 th - July 1 st
$I_{LER} = 1.47\,A\,,\ I_{HER} = 1.21\,A$
$\beta_y^* = 0.9$ mm
$L = 4.47 \times 10^{34}\,cm^{-2}s^{-1}$
$\Rightarrow\ \int L = 100\ fb^{-1}$

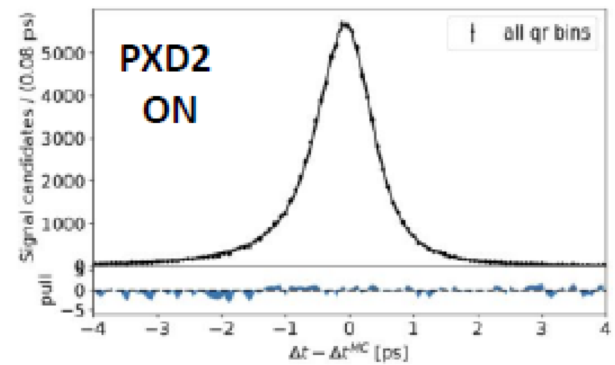
- **Sudden Beam Loss** **(PXD2 turned off since May)**
  clearing electrodes in the wiggler sections could be the major cause of SBL in LER
- Beam size blowup due to beam-beam effects
- Injection Efficiency
  Challenges in two bunch injection
- Small physical and dynamic aperture
- Vertical beam size blowup

(from BPAC 09/2024)

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 $B \to J/\psi K_S$ the preliminary studies show a ~20% degradation
  - Study with sample with comparable size to current data



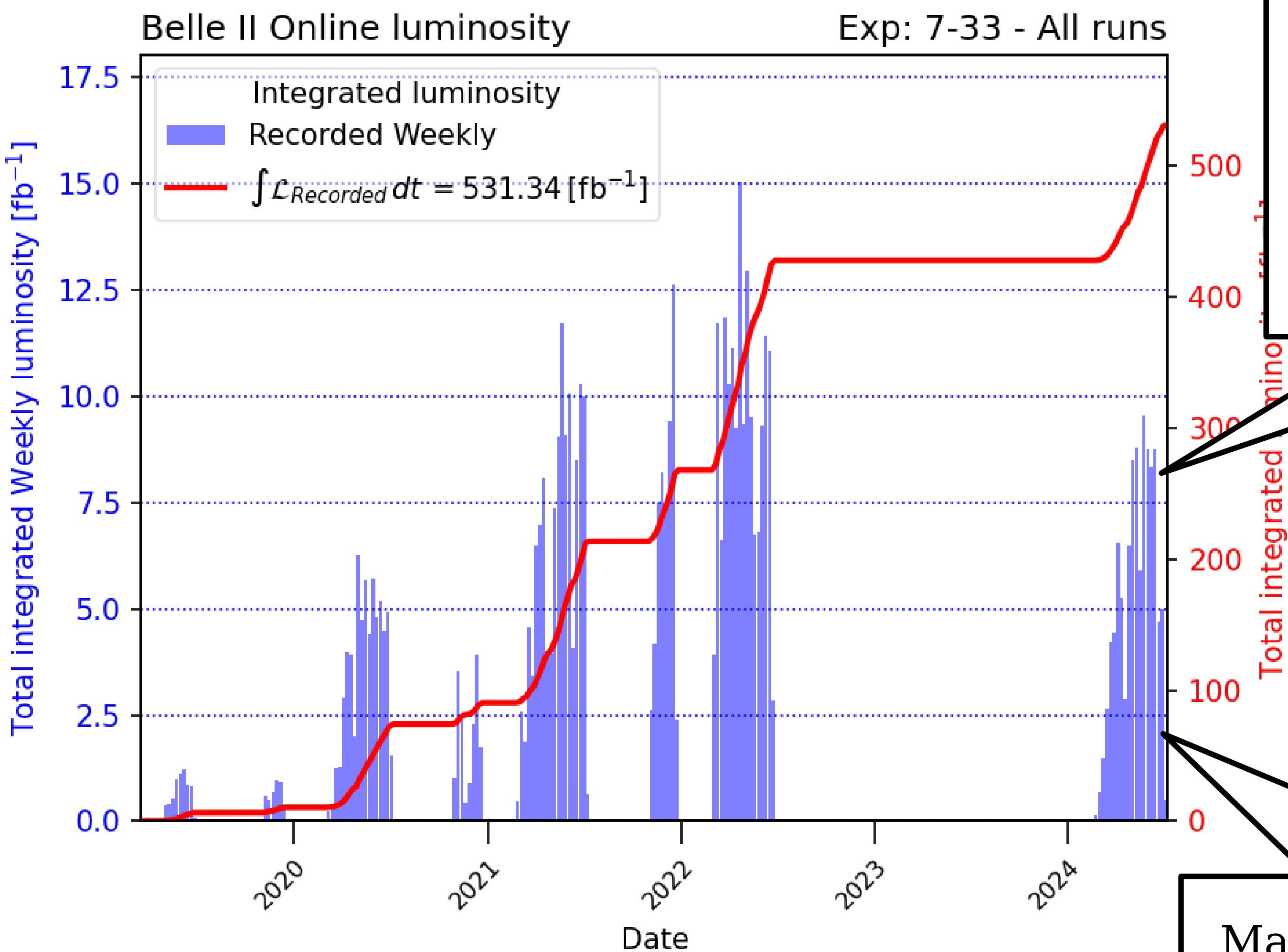


sin 2β value and uncertainty with and without PXD

Exp 0	PXD ON	PXD OFF
mean	0.715 ± 0.003	0.713 ± 0.003
width	$\boxed{0.035} \pm 0.002$	$\boxed{0.042} \pm 0.002$

Physics September 2024 BPAC

Situation in 2024a/b

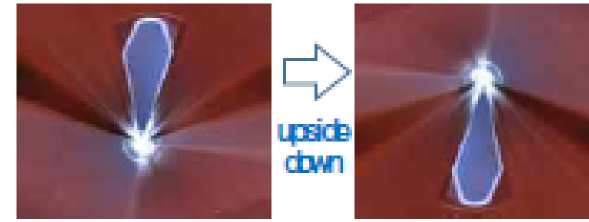


Jan 29th - July 1st
$I_{LER} = 1.47\,A$, $I_{HER} = 1.21\,A$
$\beta_y^* = 0.9$ mm
$L = 4.47 \times 10^{34}\,cm^{-2}s^{-1}$
$\Rightarrow \int L = 100\ fb^{-1}$

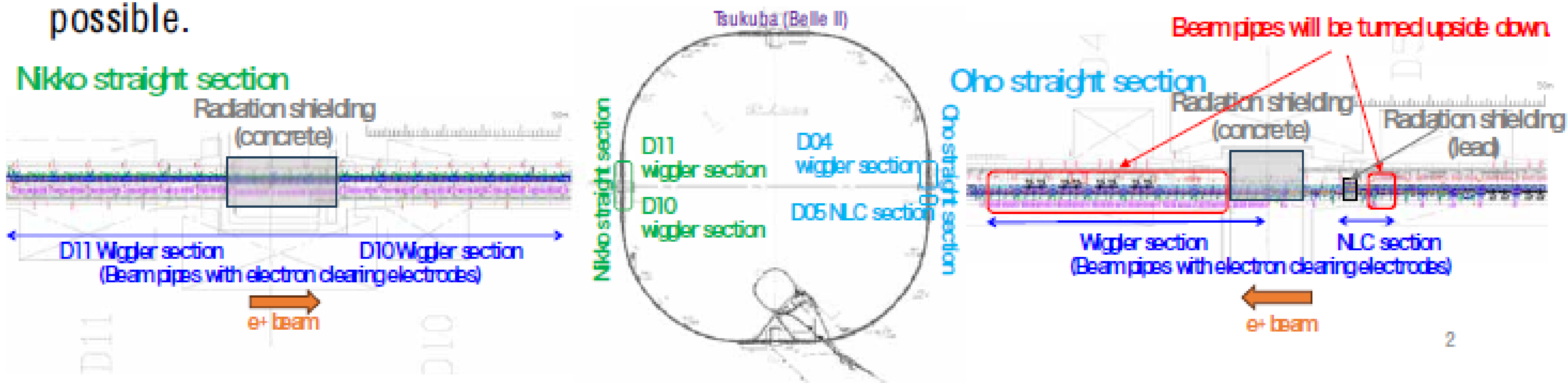
- Sudden Beam Loss
  The clearing electrodes in the wiggler sections could
- Beam size blowup due to beam-beam effec
- Injection Efficiency
  Challenges in two bunch injection
- Small physical and dynamic aperture
- Vertical beam size blowup

Machine-learning approach for operating electron beam at KEK electron/positron injector linac
"Optuna" framework for black-box optimization (https://optuna.org)
S.Kato (U.Tokyo), G.Mitsuka (KEK)

Countermeasures against SBL (summer 2024)



- Turning beam pipes with electron clearing electrode upside down
  - 15/50 beam pipes will be turned upside down. (56 m / 185 m = 30 %)
  - Oho straight section : 13/16 beam pipes (D04 wiggler section) and 2/4 beam pipes (D05 NLC section) will be turned upside down.
    - D05 NLC section (2/4) : Done
    - D04 wiggler section (13/16) : In progress now (until the end of September)
  - Nikko straight section : 30 beam pipes at Nikko wiggler section will not be turned upside down.
- Visual check and dust cleaning of beam pipes which will not be turned upside down.
- Knocking as many beam pipes (with electron clearing electron or groove structure) as possible.



⇒ if we confirm that it works, we will consider to flip the remaining pipes
(5 beam pipes at D04/D05 + 30 beam pipes at D10/D11)

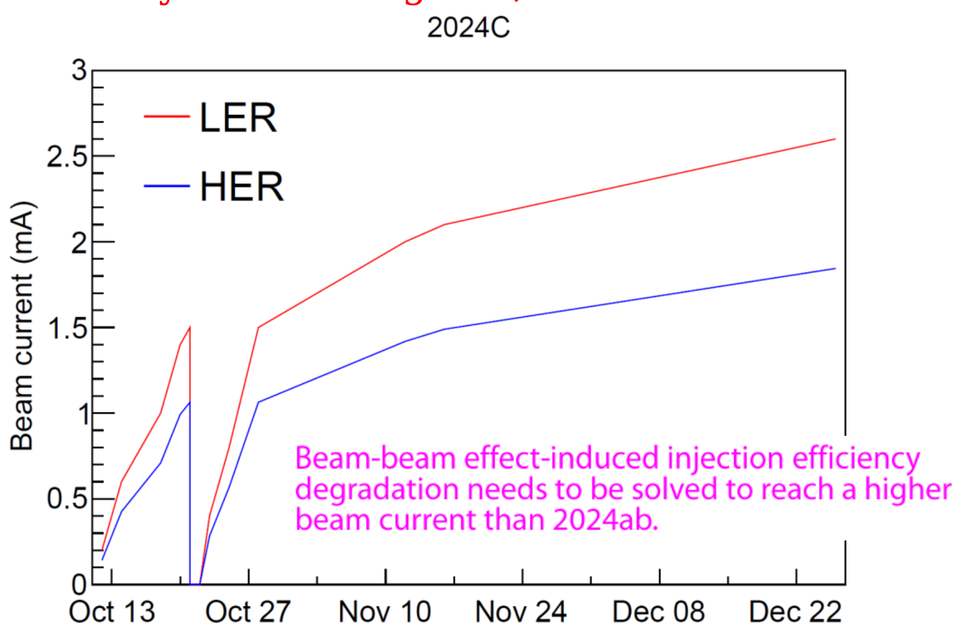
(see Ikeda-san's talk)

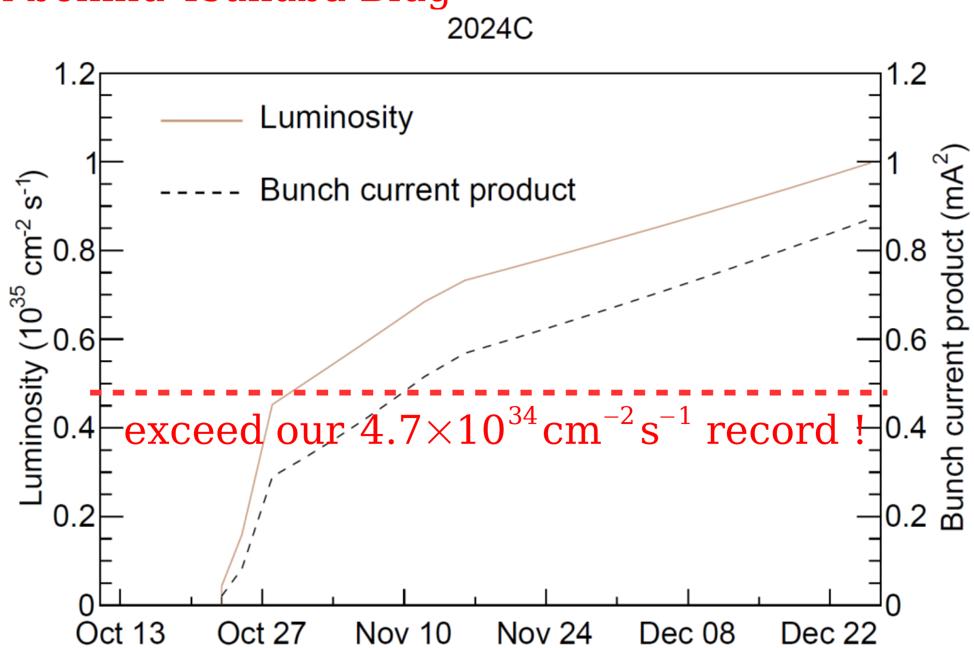
SuperKEKB resumes operations in October

Project budget runs out by operating till Nov. 2024

⇒ Possible extra budget: discretionary budget to operate in Dec. 2024

(1) new high-voltage power receiving and substation facility, to replace the very old existing one, is under construction behind Tsukuba Bldg

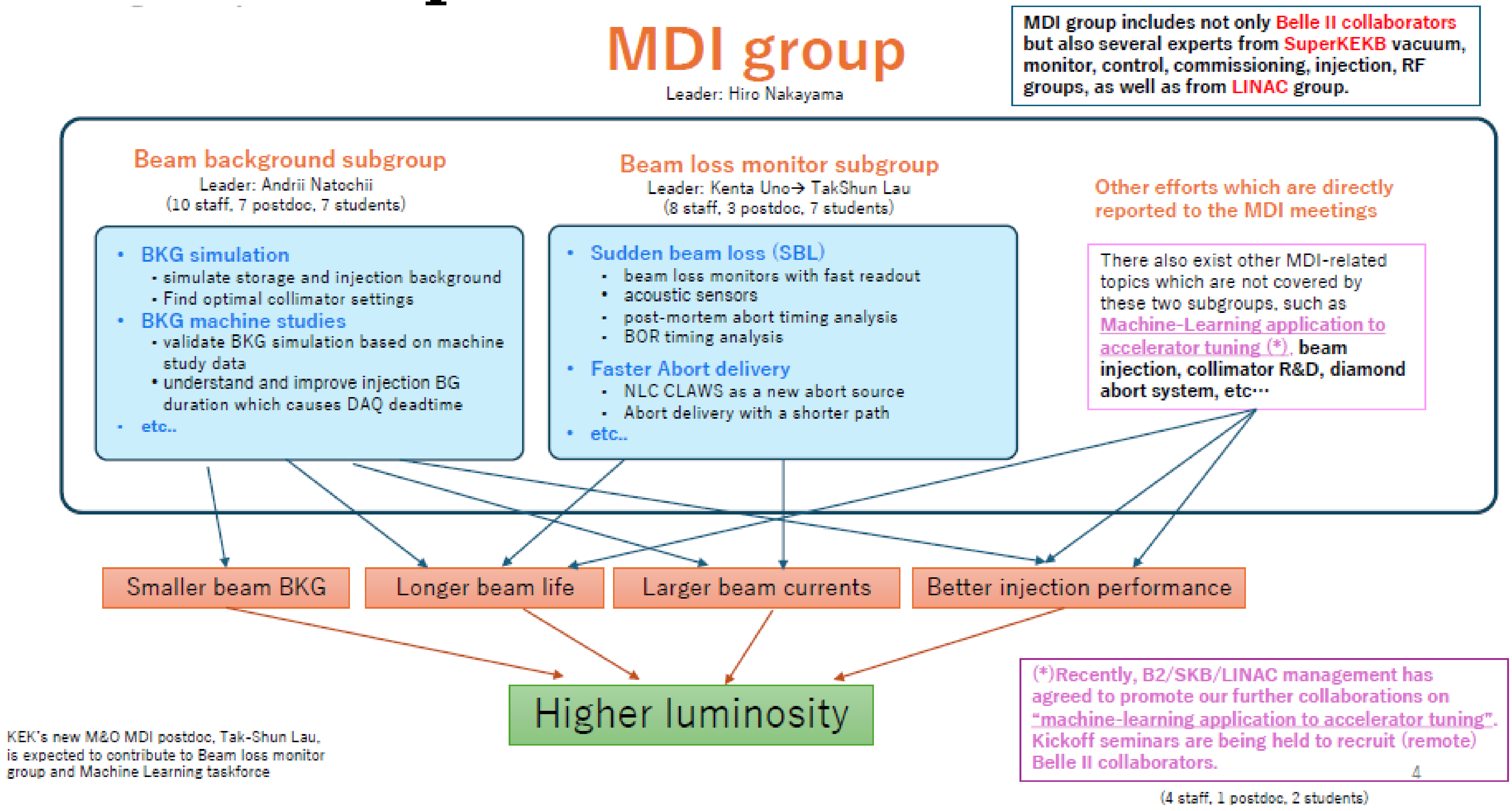




⇒ and expect reduced SBL frequency

⇒ essential for planning of 2025 runs

SuperKEKB - Belle II



SuperKEKB - Belle II

MDI group

Leader: Hiro Nakayama

MDI group includes not only Belle II collaborators but also several experts from SuperKEKB vacuum, monitor, control, commissioning, injection, RF groups, as well as from LINAC group.

Beam background subgroup
Leader: Andrii Natochii
(10 staff, 7 postdoc, 7 students)

- BKG simulation
  - simulate storage and injection background
  - Find optimal collimator settings
- BKG machine studies
  - validate BKG simulation based on machine

Beam loss monitor subgroup
Leader: Kenta Uno → TakShun Lau
(8 staff, 3 postdoc, 7 students)

- Sudden beam loss (SBL)
  - beam loss monitors with fast readout
  - acoustic sensors
  - post-mortem abort timing analysis
  - BOR timing analysis

Other efforts which are directly reported to the MDI meetings

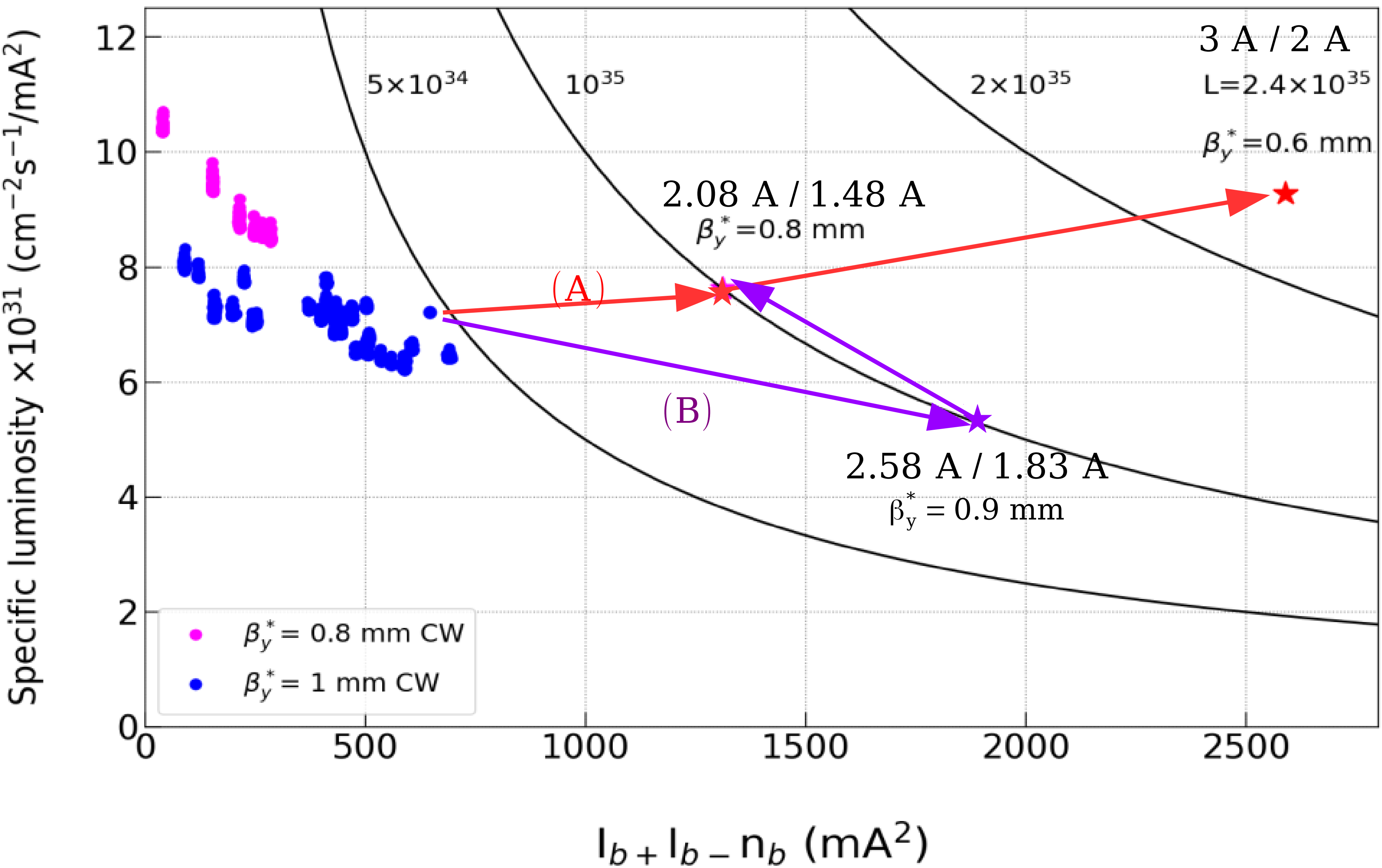
There also exist other MDI-related topics which are not covered by these two subgroups, such as Machine-Learning application to

help to improve SuperKEKB performance

- faster beam aborts (CLAWs):
  → 5-10μs shortening of the beam abort response realized this summer
- keep improving monitoring (LM, BOR: more information on SBLs)
- anomaly detection, correlation studies:
  → better understanding of the cause of SBLs, injection aborts
- improve diamonds, collimators, understanding beam background (inc BGnet)
  → protect our detector, reduce beam aborts
- implement ML for injection, accelerator tuning, collimators…
- improve SuperKEKB simulation
  → GPU resources, help from international collaborators (CERN/IHEP/US)

Strategy toward > 10^{35} $cm^{-2}s^{-1}$

- Countermeasure against SBL during summer 2024
  Turning beam pipes with electron clearing electrodes upside down
- Path toward increasing the luminosity

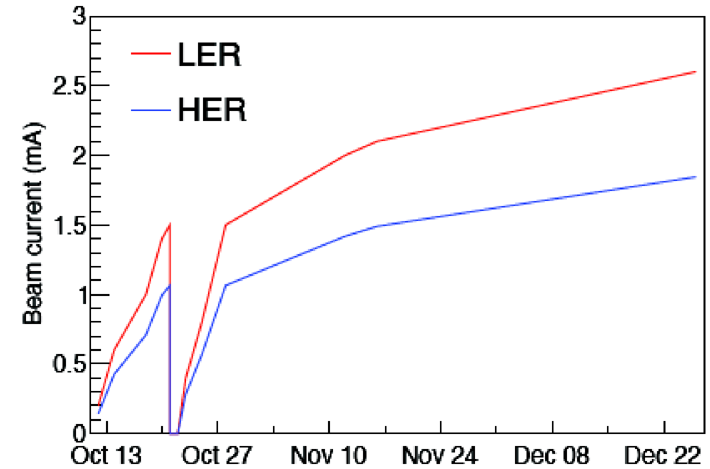


Objectives for 2024c

- **Confirm that countermeasure against SBL works**

  - Flipped beam pipes at D04, D05 during this summer
  - Check the frequency of SBL

- **Achieve higher peak luminosity**



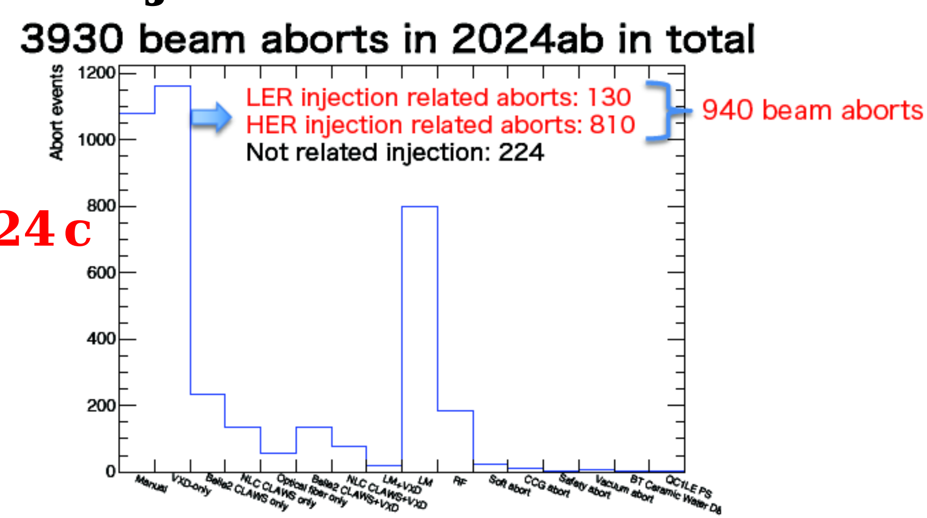
  - pursue our milestone is $L_{peak} = 1.0 \times 10^{35}\ cm^{-2}\ s^{-1}$
  - by aggressively increase beam currents
  - to reach $I_{LER} = 2.6$ A, $I_{HER} = 1.8$ A at $\beta_y^* = 0.9$ mm

    (while 1.5 A at LER and 1.2 A at HER during 2024a/b)
    - 2-bunch injection, injection tuning by ML
    - understand beam-beam interaction effect

(larger β_x at injection point, smaller β_x at IP, tune scan to improve injection efficiency)

⇒ **give enough machine time**

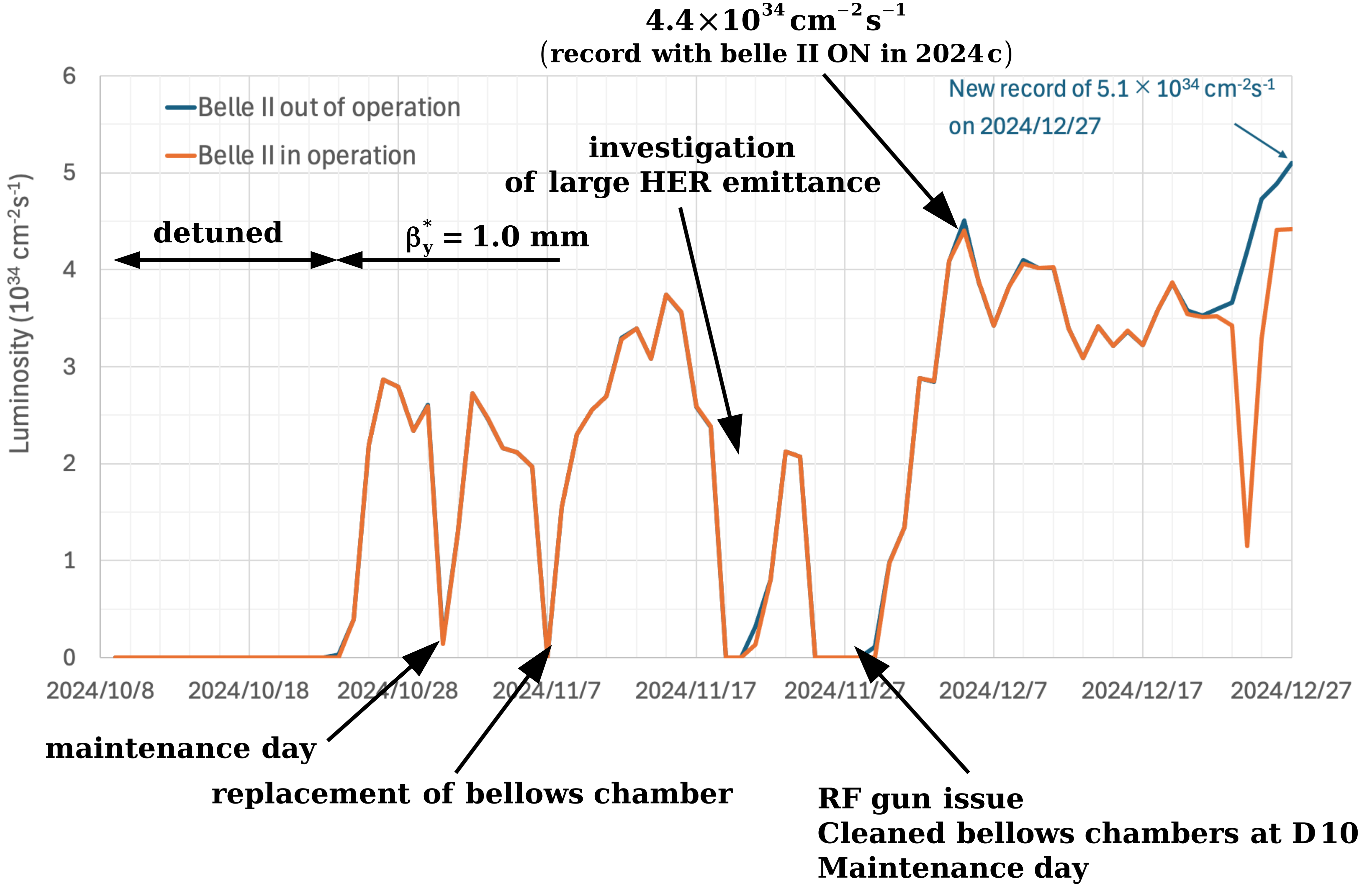
- **New diamond threshold: outside/inside injection**

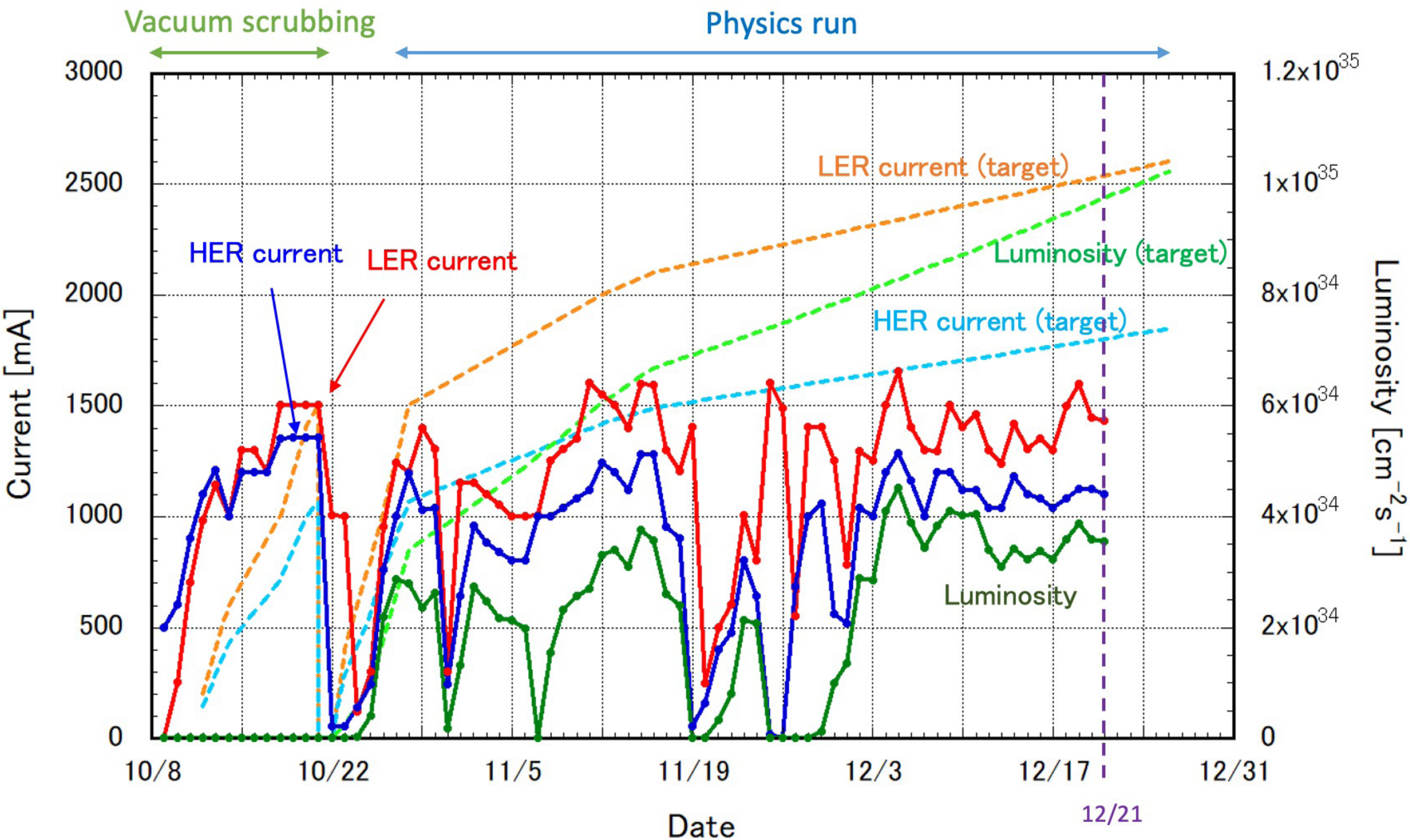


  - Low threshold: 8/8/8/8 mRad outside inj
  - High threshold: 50/40/12/12 mRad during inj

⇒ **suppress harmless inj. aborts during 2024c**

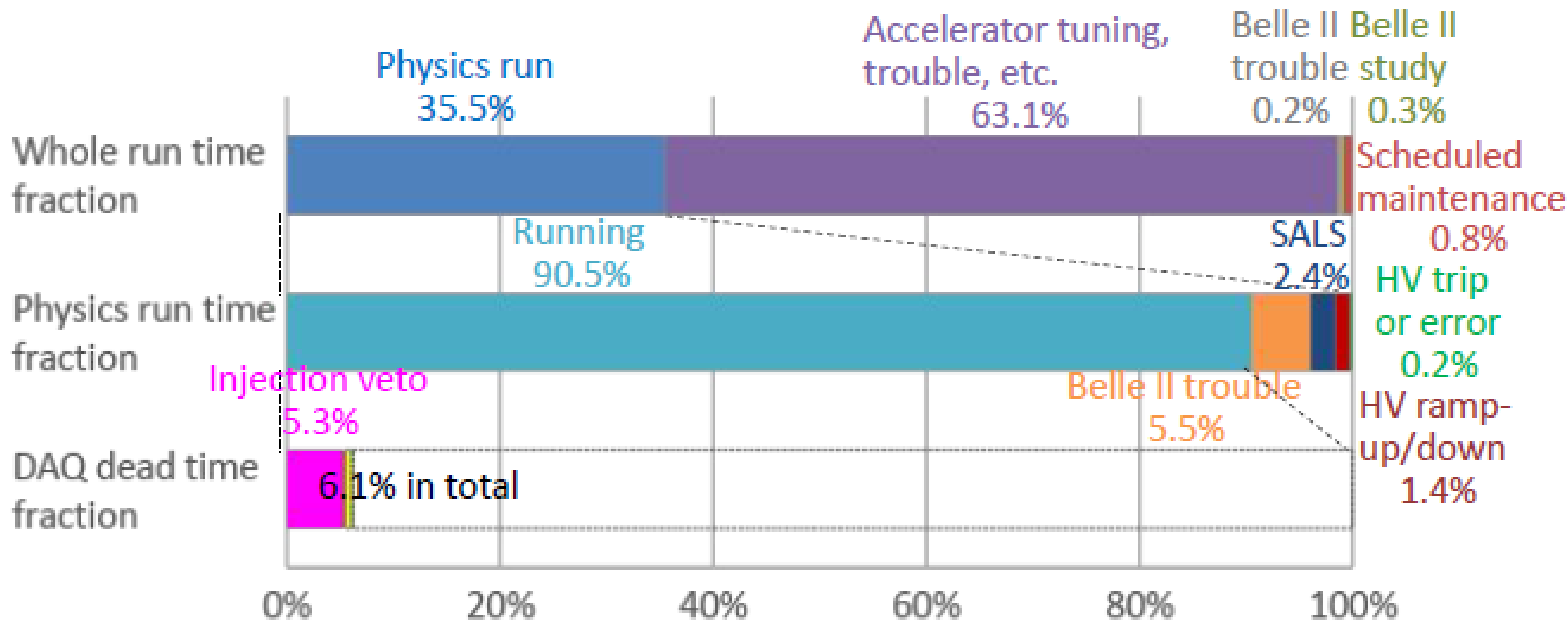
Situation in 2024c

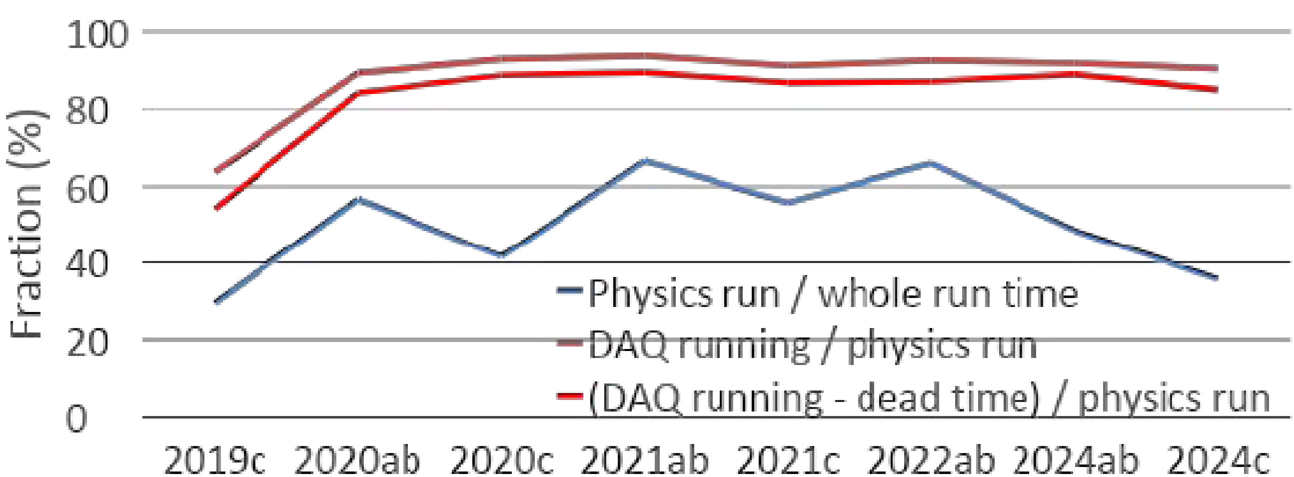




⇒ quickly increased beam current up to LER 1.5A and HER 1.3A
⇒ but didn't get much higher until the end of 2024c

Data taking efficiency in 2024c





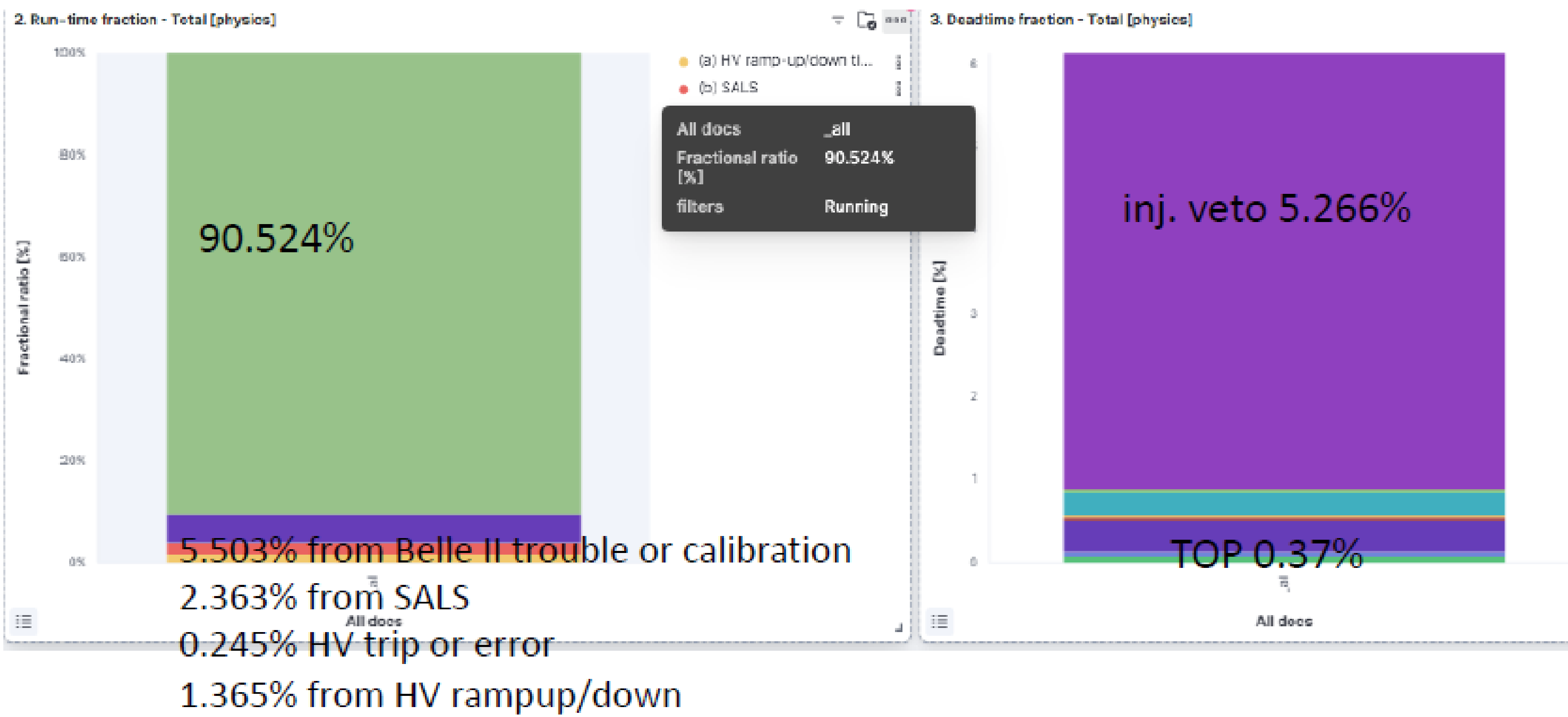
Overall data taking efficiency = 85%

(target 90%)

During 2024c: we always suffered from high background

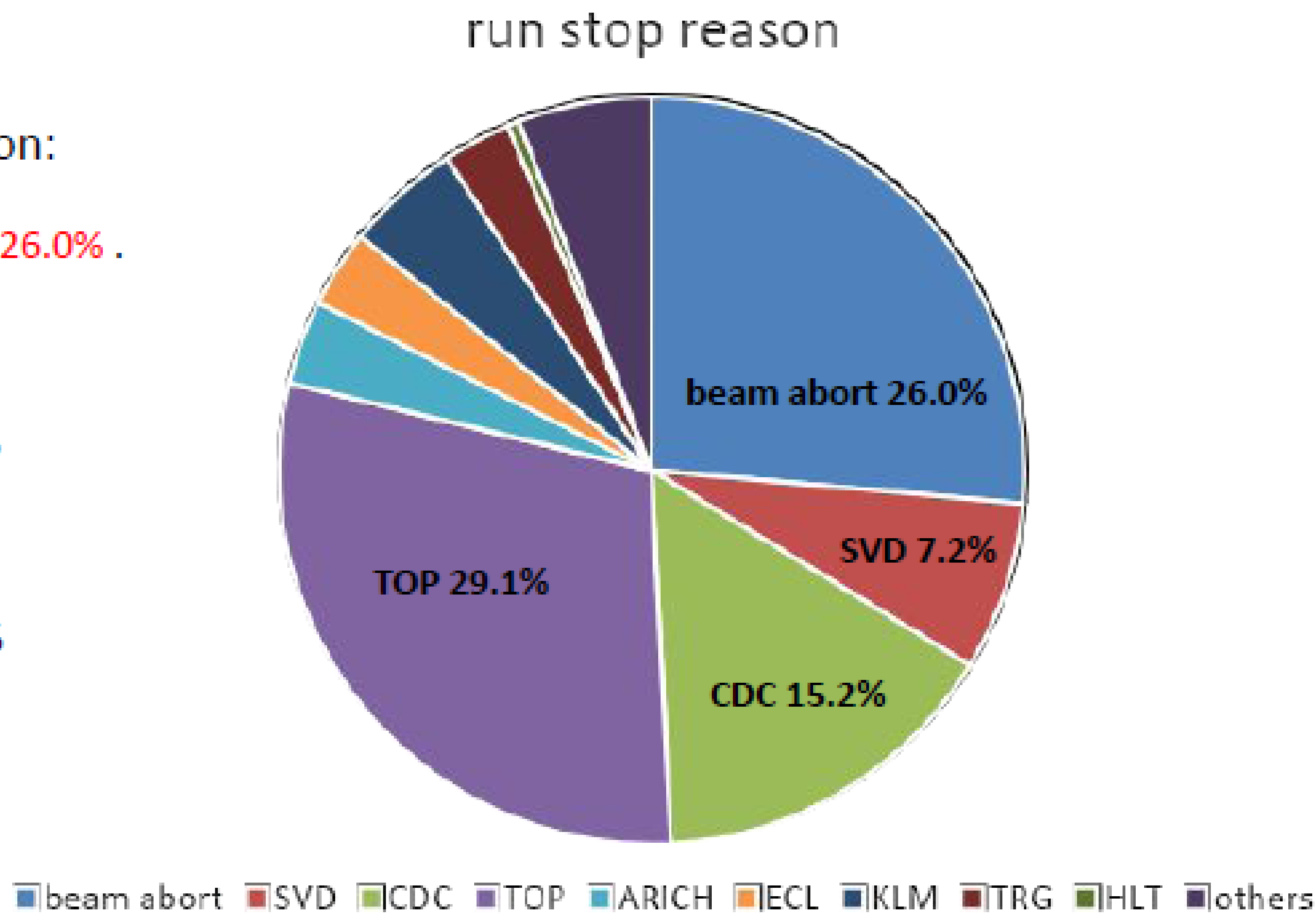
Data taking efficiency in 2024c

In 2024c, during "physics run" mode, Belle II DAQ running time: 90.5%,
DAQ dead time: 6.1% (5.3% from injection veto)
Belle II data taking efficiency: 90.5% x (100-6.1)% = 85.0%



Run stop reason in 2024c

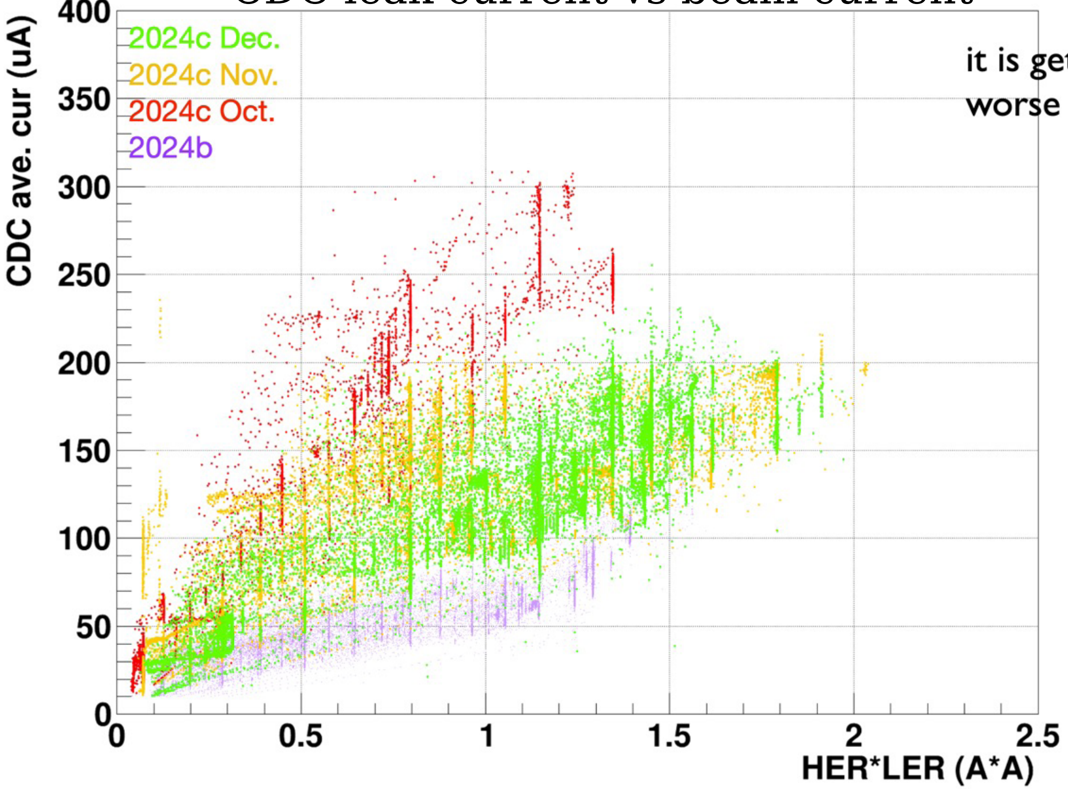
- Run stop reason:
  - TOP: 29.1%
  - beam abort 26.0% .
  - CDC: 15.2%.
  - SVD: 7.2%
  - KLM: 4.9%
  - ARICH: 3.6%
  - ECL: 3.3%
  - TRG: 2.9%.
  - HLT: 0.5%
  - others: 5.7%



Frequent DAQ error from TOP occurred, because of high inj background
⇒ need to contiue to improve our detector robustness against high background

Status of CDC

CDC leak current vs beam current

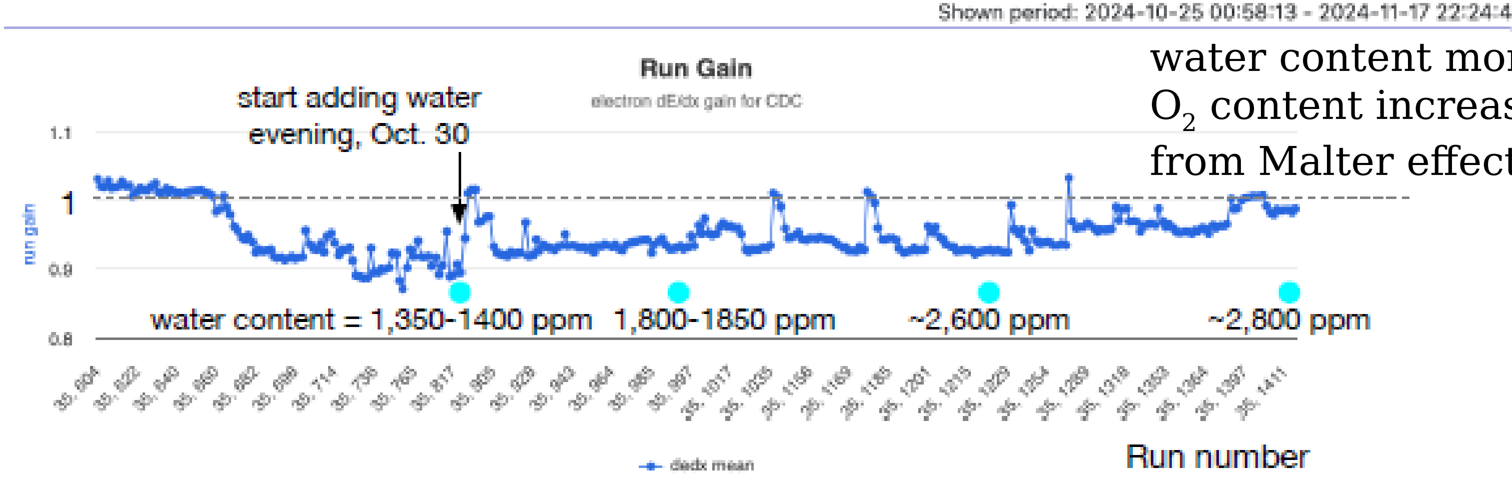


it is getting better though it is still worse than 2024b

condition better thanks to machine and collimator tuning

CDC leak current blow-up in end of Oct for innermost layers in sector 3

Shown period: 2024-10-25 00:58:13 - 2024-11-17 22:24:44

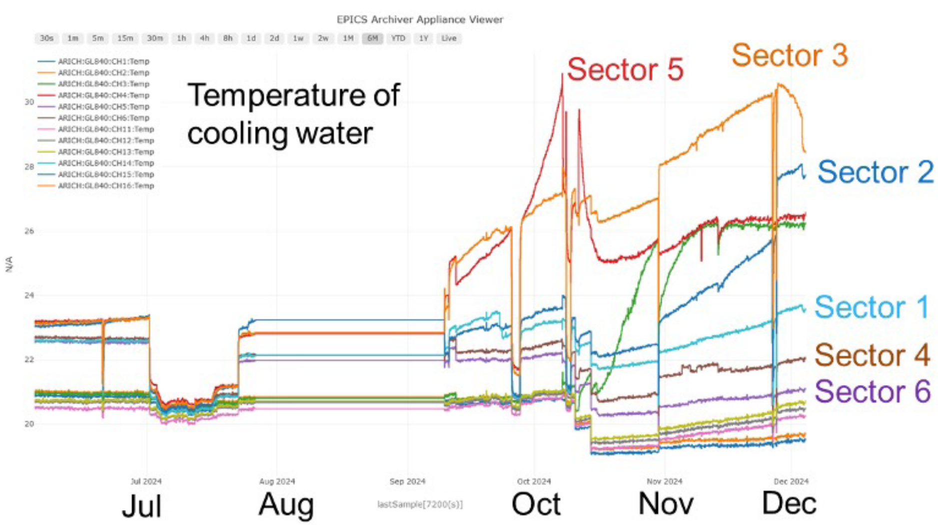


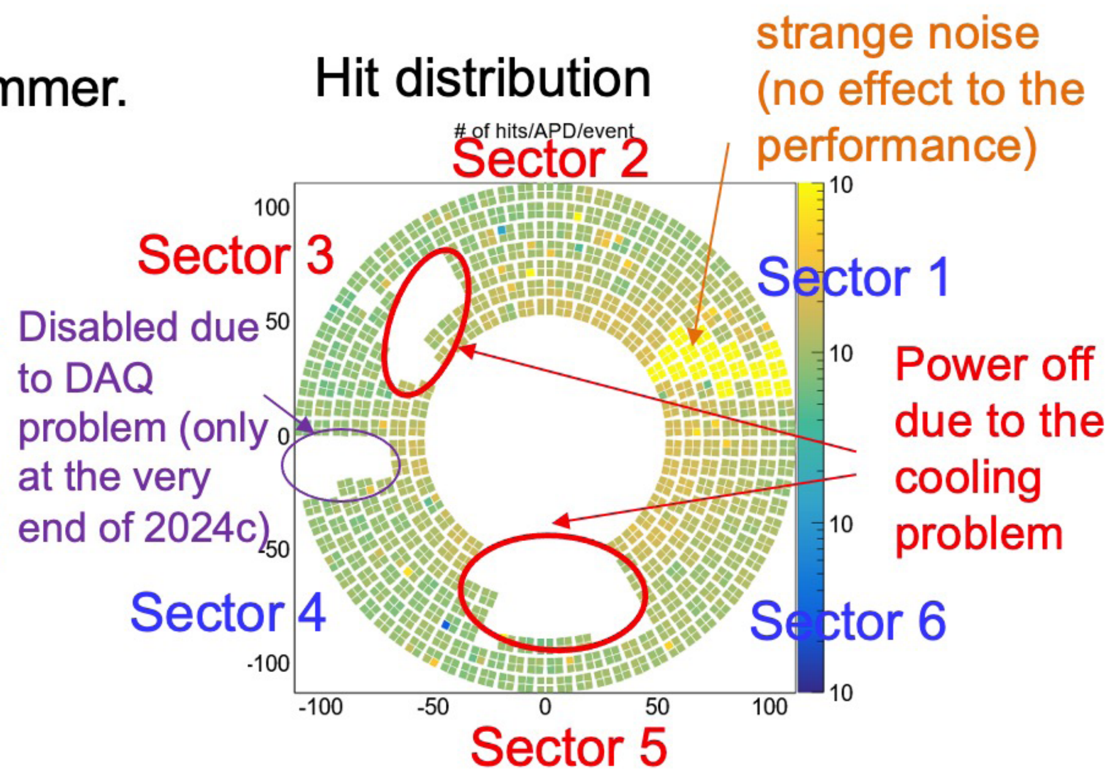
water content monitored and tuned

O_2 content increased to recover from Malter effect

ARICH Cooling Water Problem

- In 2024c, ARICH suffered a serious problem of the cooling water flow.
  - ✓ No flow in Sector 5. Flow gradually decreased in Sector 2 and 3.
- We turned off a part of ARICH so that the temperature of the front-end boards is kept below ~50 deg.
- Investigation will be done in 2025 summer.





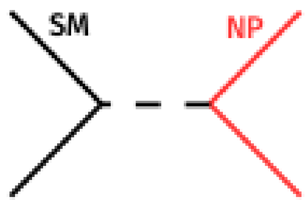
Nov 6-: 3/4 of Sector 5 OFF
Nov 8-: 1/2 of Sector 5 OFF
Dec 3-: 1/2 of S5 &1/4 of S3 OFF
Dec 25-: 1/2 of S5 &1/2 of S3 OFF

Around 8-13% of channels were kept off due to ARICH cooling problem.
(With 13% off, PID efficiency decreases by 5-10% for tracks in ARICH acceptance)

Rare B decays

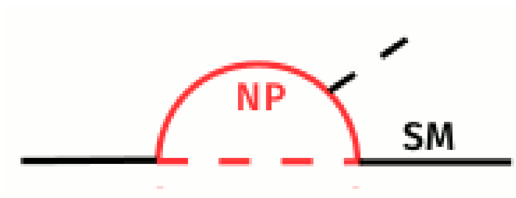
- FCNC are strongly suppressed in the SM: only loops + GIM mechanism
- Any new particle generating new diagrams can change the amplitudes

energy frontier



limited by beam energy

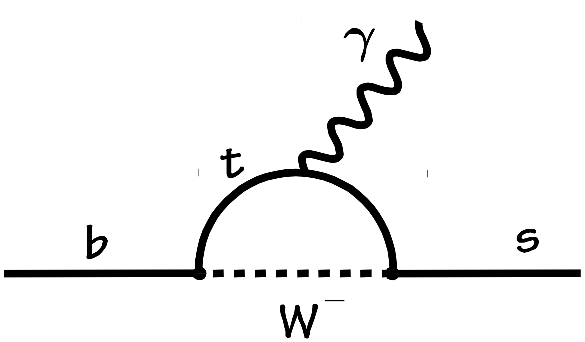
intensity frontier

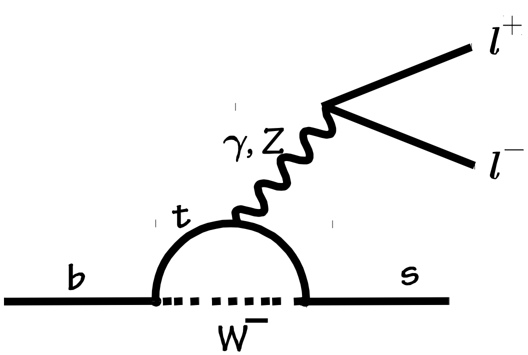


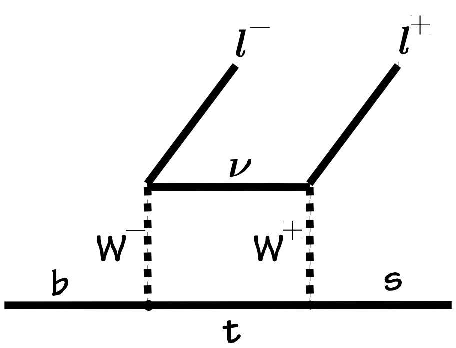
limited by statistics

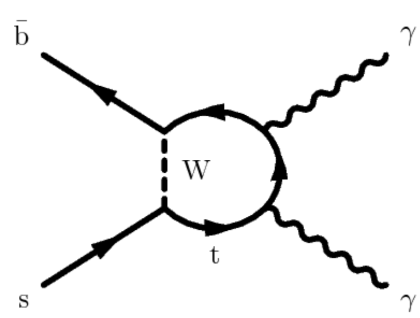
→ **NP beyond the <u>direct</u> reach of the LHC**

New particles can for example contribute to loop or tree level diagrams **by enhancing/suppressing decay rates, introducing new sources of CP violation or modifying the angular distribution of the final-state particles**





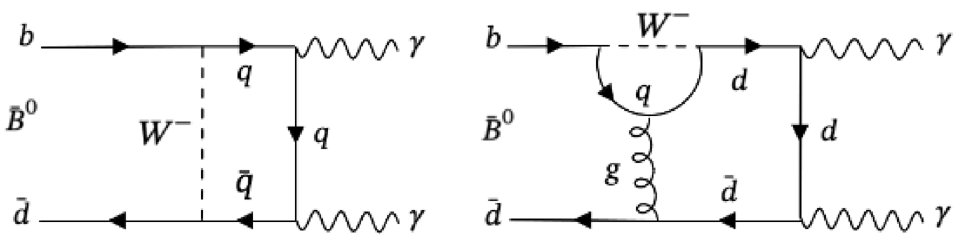




Search for B→γγ using Belle and Belle II

[arXiv:2405.19734], PRD 110, L031106 (2024)

Very rare decay: $B_{SM} = (1.4\,^{+1.4}_{-0.8}) \times 10^{-8}$ [JHEP 12, 169 (2020)]



Experiment	Integrated Luminosity ($\int \mathcal{L}\, dt$)	Limit @ 90 C.L.
L3	73 pb^{-1}	3.9×10^{-5}
Belle	104 fb^{-1}	6.2×10^{-7}
Babar	426 fb^{-1}	3.2×10^{-7}

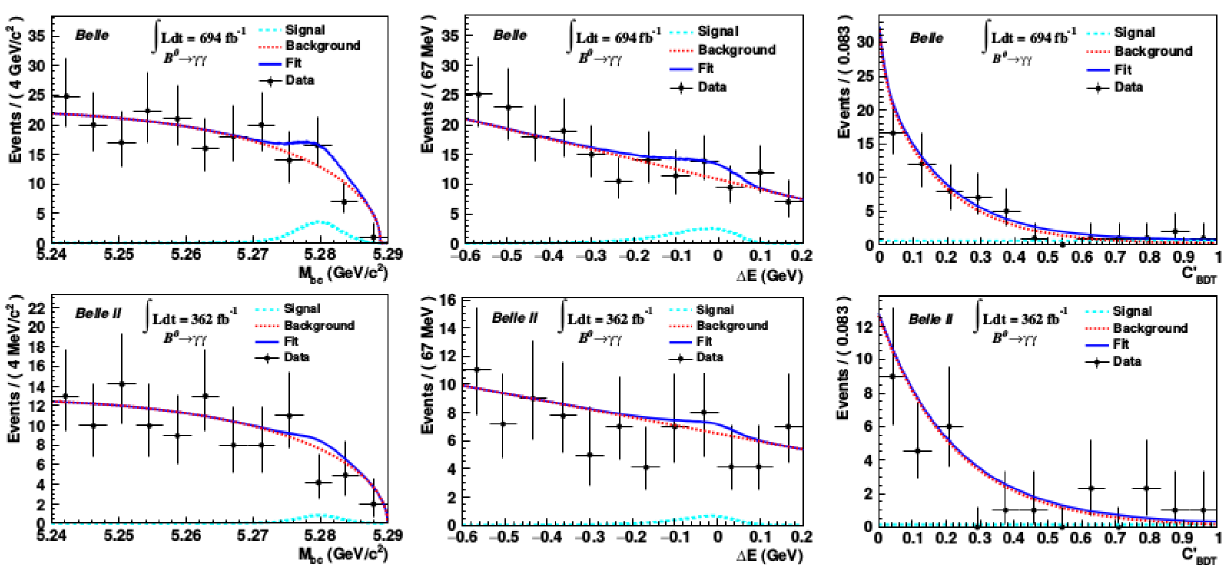
- Reconstruct signal from two prompt photons
- Peaking background in M_{bc} due to back-to-back off time photons

⇒ Suppressed using photon timing cuts

- 3D fit to ΔE, M_{bc} and transformed continuum BDT output

- Combined signal yield $= 11.0^{+6.5}_{-5.5}$
- no significant signal

	$\mathcal{B}(B^0 \to \gamma\gamma)$	UL on $\mathcal{B}(B^0 \to \gamma\gamma)$
Belle	$(5.4^{+3.3}_{-2.6} \pm 0.5) \times 10^{-8}$	$< 9.9 \times 10^{-8}$
Belle II	$(1.7^{+3.7}_{-2.4} \pm 0.3) \times 10^{-8}$	$< 7.4 \times 10^{-8}$
Combined	$(3.7^{+2.2}_{-1.8} \pm 0.5) \times 10^{-8}$	$\boxed{< 6.4 \times 10^{-8}}$

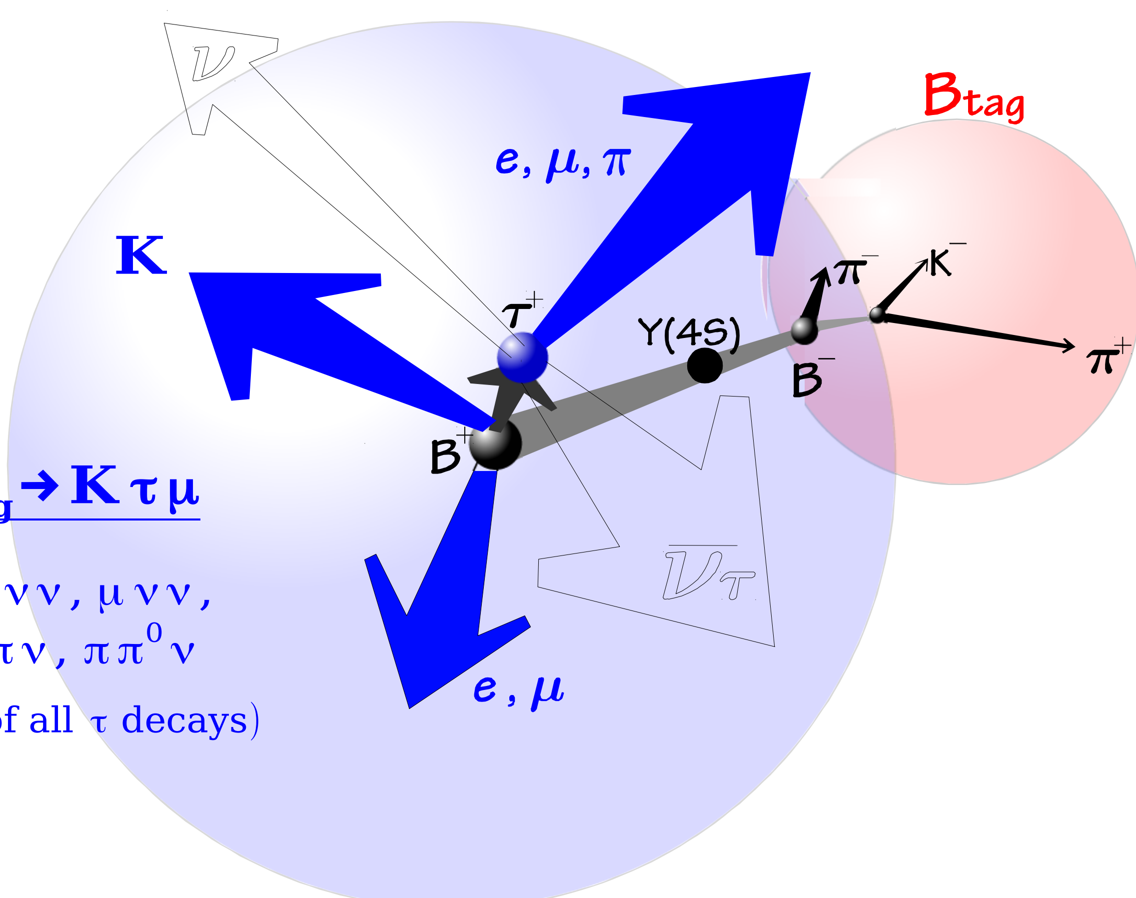


- Sensitivity approaching SM prediction
- 5x improvement over previous best UL

Missing energy modes and B-tagging

Many interesting B-physics studies involved missing energy

- $D^{(*)}\tau\nu$, $D^{(*)}l\nu$ (e.g. $|V_{cb}|$)
- $\pi l\nu$, $b\to ul\nu$...
- $\tau\nu$, $\mu\nu$
- **$K^{(*)}\tau\tau$, $K^{(*)}\nu\nu$, $K^{(*)}\tau l$...**
- $\tau\tau$, τl....



$B_{sig}\to K\tau\mu$

$\tau\to e\nu\nu$, $\mu\nu\nu$,
$\tau\to\pi\nu$, $\pi\pi^0\nu$
(70 % of all τ decays)

B_{tag}

hadronic tag

$B\to D^{(*)}\pi$, $D^{(*)}\rho$...
$\epsilon < 1\%$

semileptonic tag

$B\to D^{(*)}l\nu X$
$\epsilon \sim 2\%$

Search for $B \to K^{*0} \tau \tau$ decays

- FCNC processes are suppressed in SM at tree level

$$BF_{SM} = (1.0 \pm 0.1) \times 10^{-7}$$

[PRD 53, 4964 (1996)]

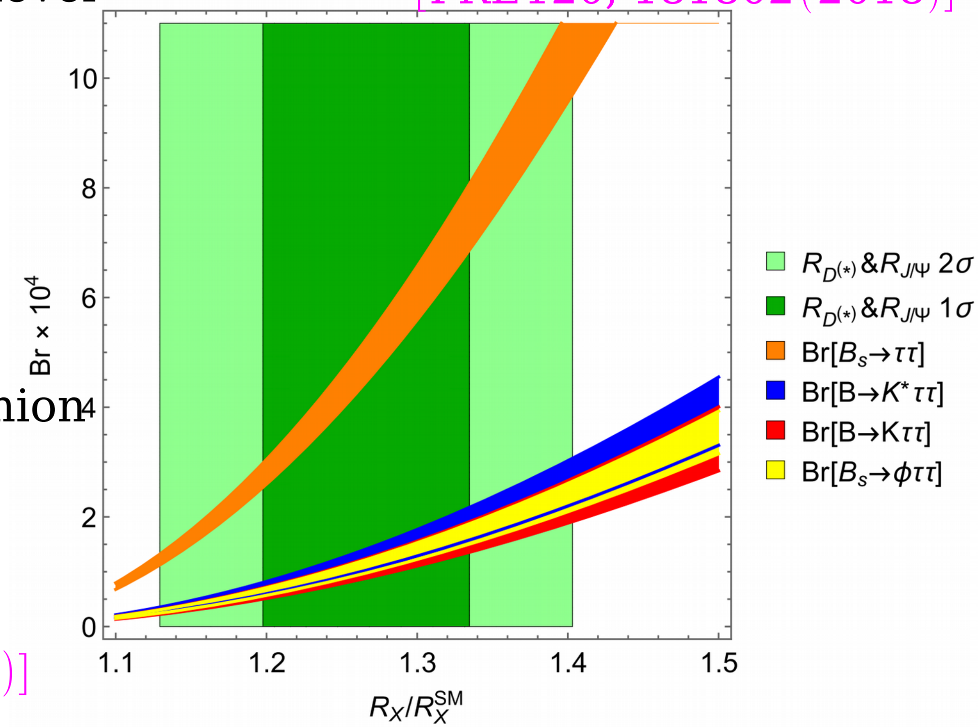
- NP models that accommodate the $b \to c \tau \nu$ anomalies predict an enhancement of several orders of magnitude with $\tau\tau$ pair in final state

NP couplings are those involving the third-fermion generation

Belle ($711\ fb^{-1}$) $BF < 3.1 \times 10^{-3}$ @ 90%C.L.

[PRD 108, L011102 (2023)]

[PRL 120, 181802 (2018)]

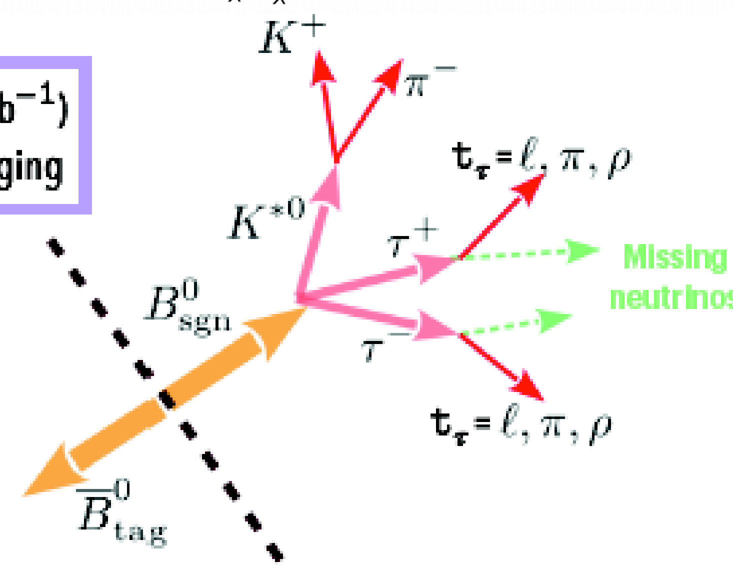


Challenges

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

- Low BF
- No signal peaking kinematic observable
- Large backgrounds+more than 3 prompt track
- Up to **4 neutrinos** orignating from τ
- K^{*0} has **low momentum** due to the phase space

Belle II ($364\ fb^{-1}$)
hadronic B-tagging

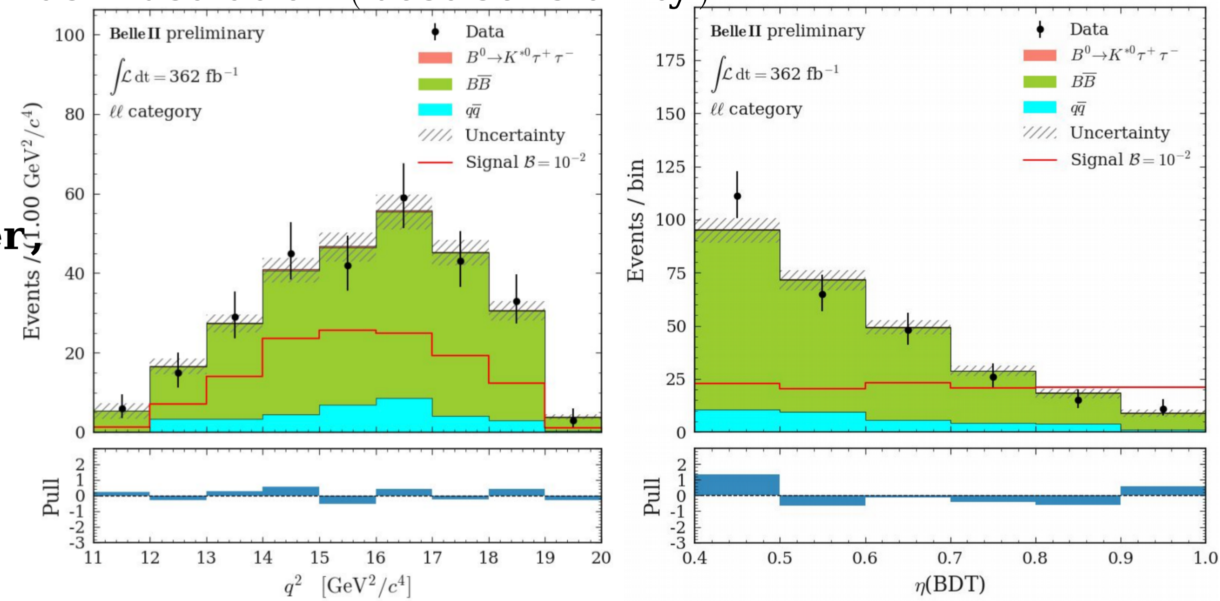


Search for $B \to K^{*0} \tau\tau$ decays

[PRELIMINARY] shown last summer

- Combinations of 4 categories: l^+l^-, $l\pi$, $\pi\pi$, ρX
- **BDT trained using missing energy, extra cluster energy in EM calorimeter, $M(K^{*0} t_\tau)$, q^2, ...**
- BDT output $\eta(\text{BDT})$ is used to extract signal yield with a simultaneous fit to 4 categories

l^+l^- as illustration (best sensitivity)



Validation

- total efficiency and peaking $B^0 \overline{B^0}$: $B \to J/\psi K^{*0}$ sample, replace $J/\psi K^{*0}$ with $K^{*0} \tau^+ \tau^-$ (14% uncertainty)
- Non-peaking $B\bar{B}$: sample with B_{sig} and B_{tag} having same flavor
- $q\bar{q}$ background is scaled by off-resonance data

Belle II (364 fb^{-1}) BF $(B \to K^{*0}\tau\tau) < 1.8\times10^{-3}$ @ 90%C.L.

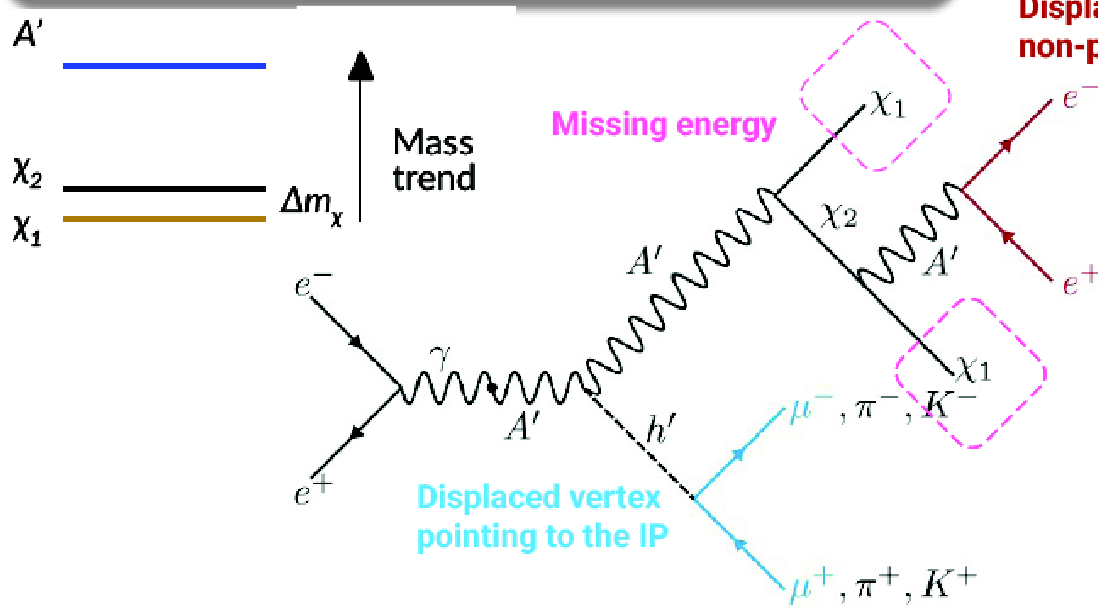
The most stringent limit among the results for $b \to s\tau\tau$ transition

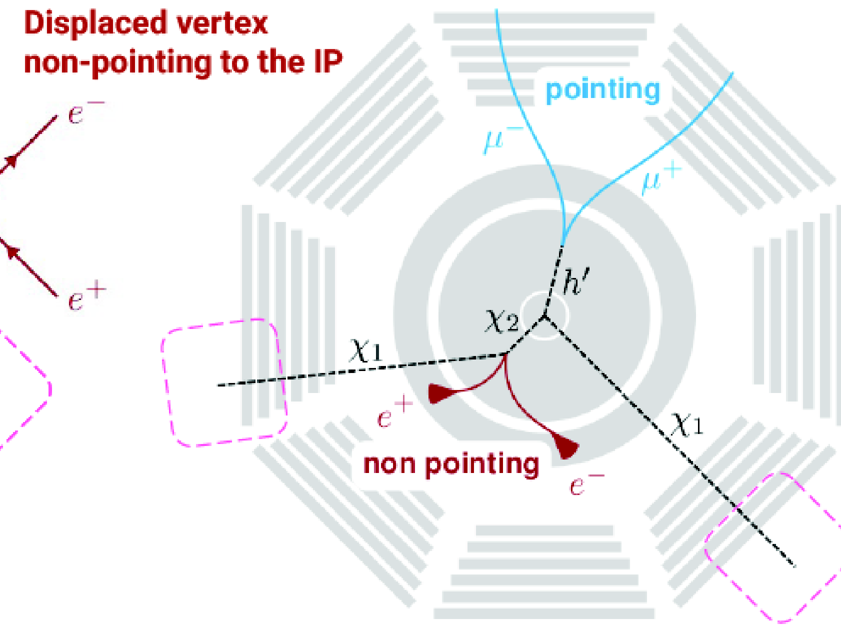
Twice better with only half sample wrt Belle !
Better tagging + more categories + BDT classifer...

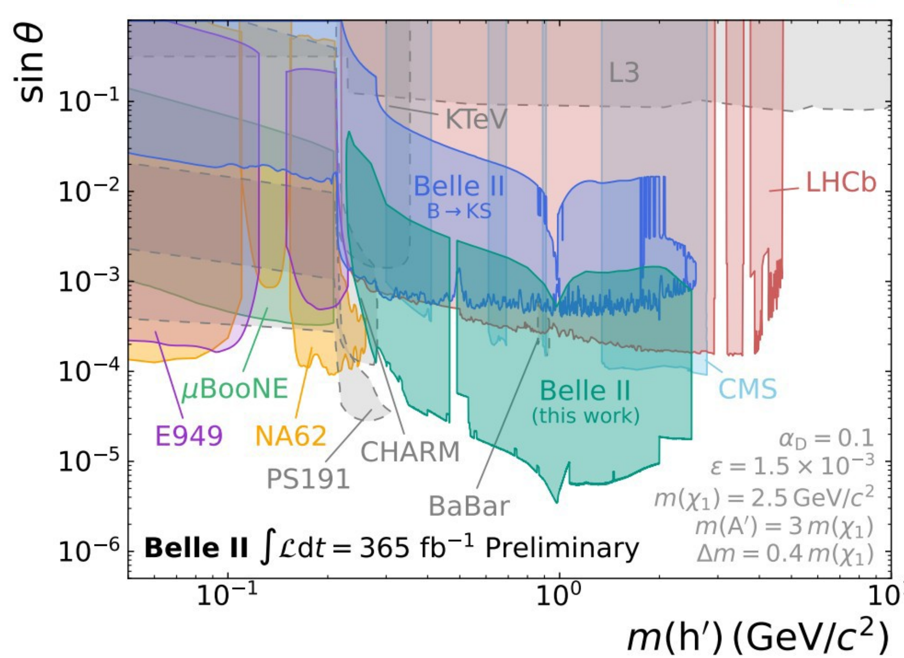
Inelastic dark matter with a dark Higgs

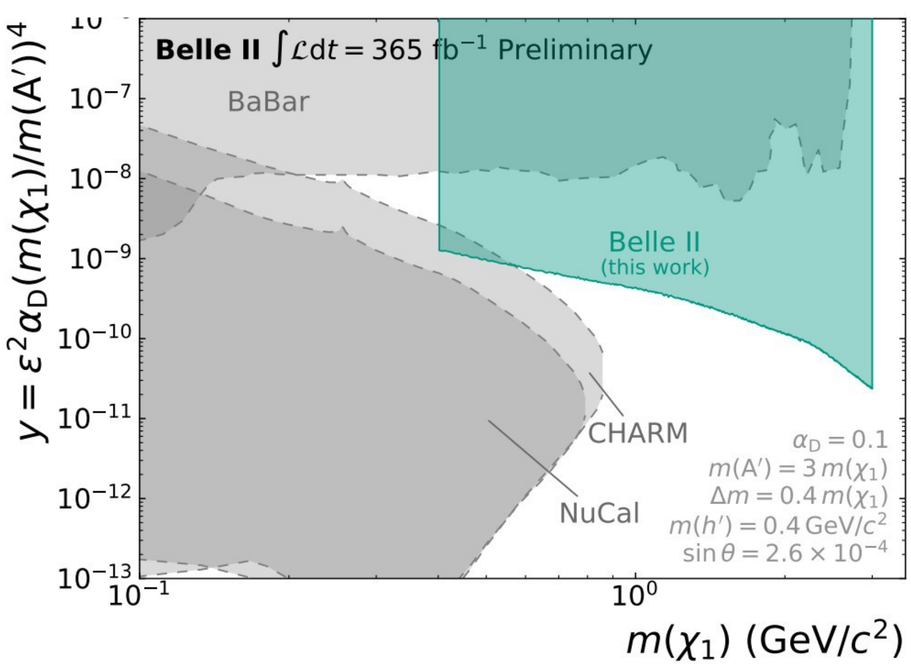
- We have 4 dark sector particles: A', h', χ_1 and χ_2
- We have 7 parameters: $m_{A'}$, $m_{h'}$, $m_{\chi 1}$, Δm_{χ}, θ, ε, α_D

- Challenging for tracking and trigger
- Almost zero background analysis









Physics week (Oct 14-18)

2024 Belle II Physics Week

14–18 Oct 2024
KEK
Asia/Tokyo timezone

https://indico.belle2.org/event/12273/

97 participants (2021, Rome)
93 participants (2022, Valencia)
123 participants (2023, KEK, + KEK theory)
151 participants (2024, KEK, + KEK theory)

The **2024 Belle II Physics Week** will be in-pe
experimentalists and theory experts.

All collaborators are invited to join KEK for in-person attendance.

The week will consist of two parts:

- **Mornings: a school for PhD students and early postdocs** with general pedagogical lectures about aspects of Belle II and flavour physics. It will include plenary sessions on phenomenology, detectors, and benchmark analyses along with in-person hands-on work. Plenary lectures will be recorded. In-person hands-on will be conducted on-site. Online participation will be also possible.

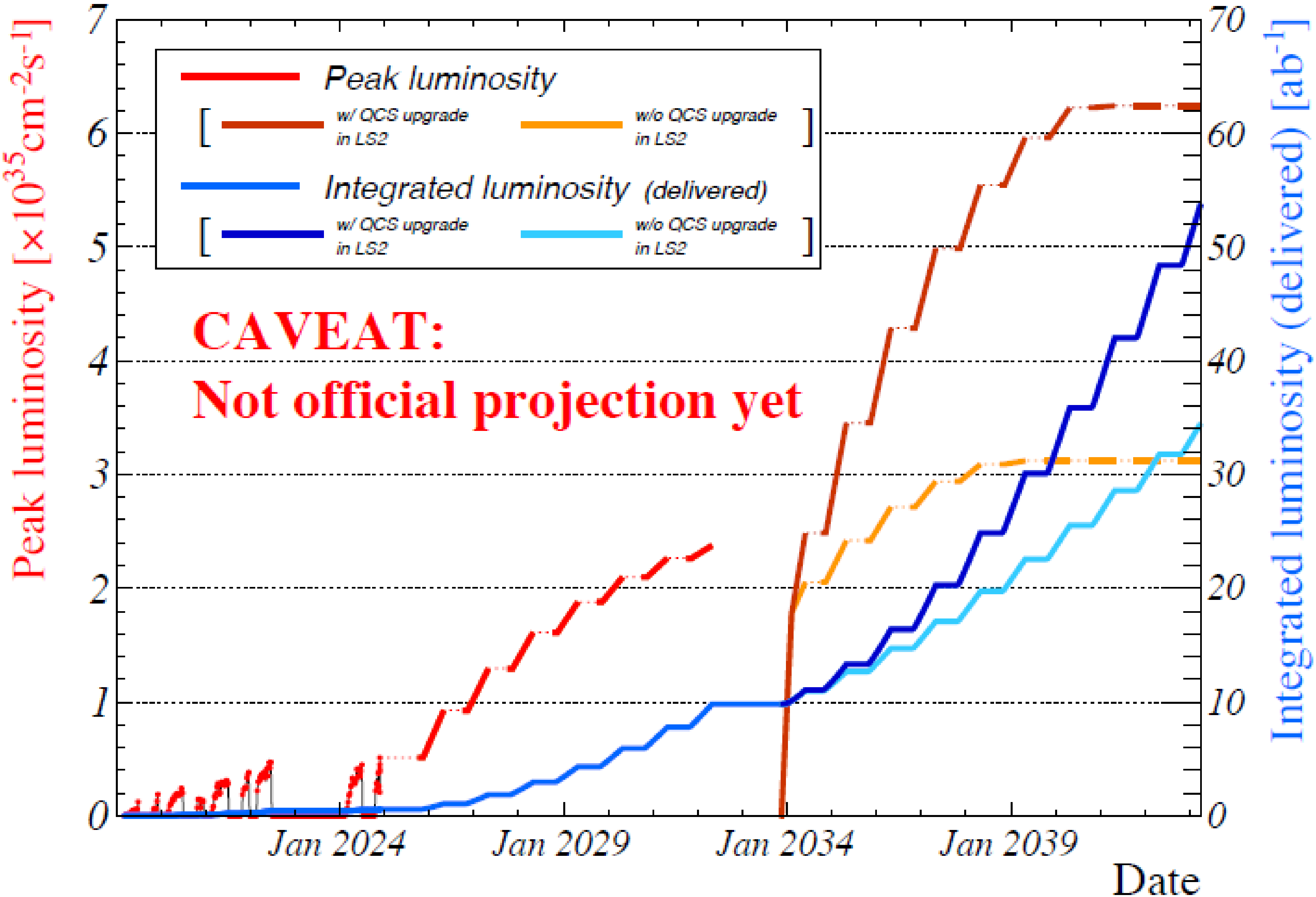
- **Afternoons: a workshop**, this is the second in a seri
theory and experiment that are priorities for the Bel

This year the workshop is on tau and dark sector a

invited speakers include:
Marco Ardu, Anke Biekoetter, Mattia Bruno, Lorenzo Calibbi, Pablo Roig Garcés, Stefania Gori, Martin Hoferichter, Nazila Mahmoudi, Giordon Stark, Olcyr Sumensari, Jure Zupan, Gilly Elor, Tobioka Kohsaku, Robert McGehee, Tomasz Procter, Lorenz Gaertner, Adrian Casais Vidal, ...

sponsored by TYL, KMI, KEK-LBL

Luminosity projection

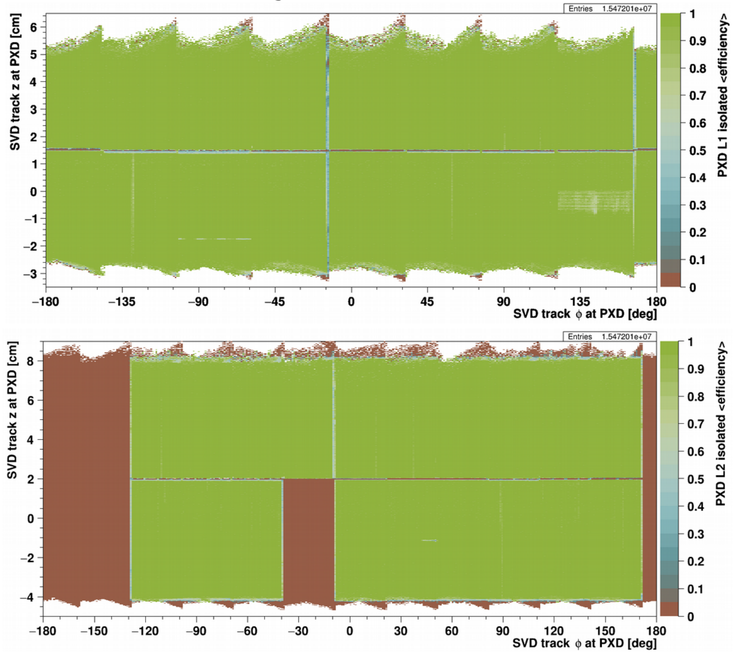


Summary

- Run 1 sample is providing competitive results…
  - in B physics with missing energy (e.g. $B \to K \nu \bar{\nu}$, $K^* \tau \tau$)
  - in τ sector, dark sector (5-6 PRLs), measurements that improve hadronic vacuum polarization estimate muon g-2 …
- A lot of improvements in Belle II during LS1…
  - for better detector performance
  - for more efficient data taking
- Run 2 is crucial to…
  - understand the behaviour of the machine in order to identify the remaining causes of luminosity limitation
  - cumulate o(5 ab^{-1}) in ~5 years and impact the flavor/DS sector
- Upgrade:
  - understanding the IR envelope and design as soon as possible is of primary importance

Among the first results of run 2, as an illustration

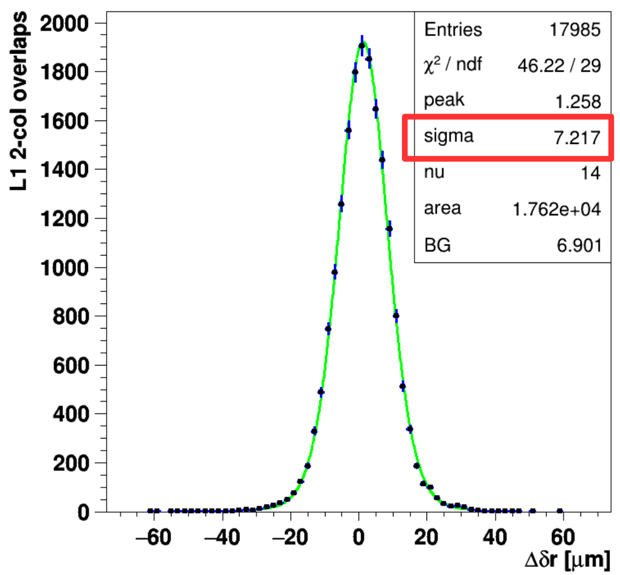
Efficiency map for PXD2



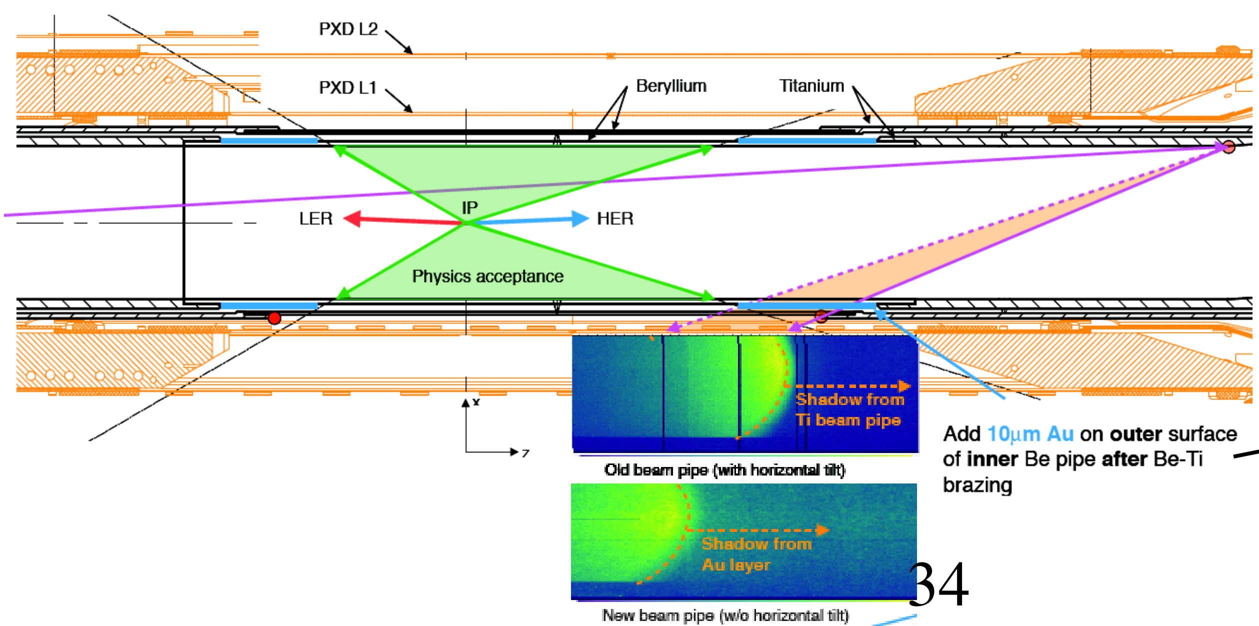
PXD2 efficiency
above 97% for active modules
reaching 99.7% in forward regions:
the maximum limited by Readout and Clear

- PXD L1 overlap rφ residuals
- **both hits with 2 pixels in *u*:**
  - width 7.2 μm
  - (Student's *t* fit)
- single hit:
  - **σ = res / $\sqrt{2}$ = 5.1 μm**
  - (pixel size 50 μm in *u*)

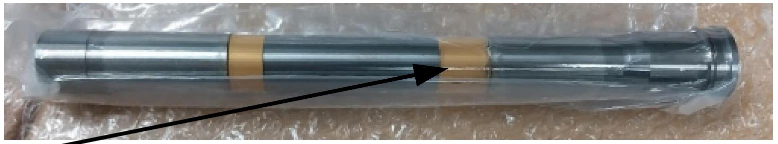
Resolution from overlaps



Run 1 → Run 2



Add 10μm Au on **outer** surface of **inner** Be pipe **after** Be-Ti brazing



2024ab operation: SBL

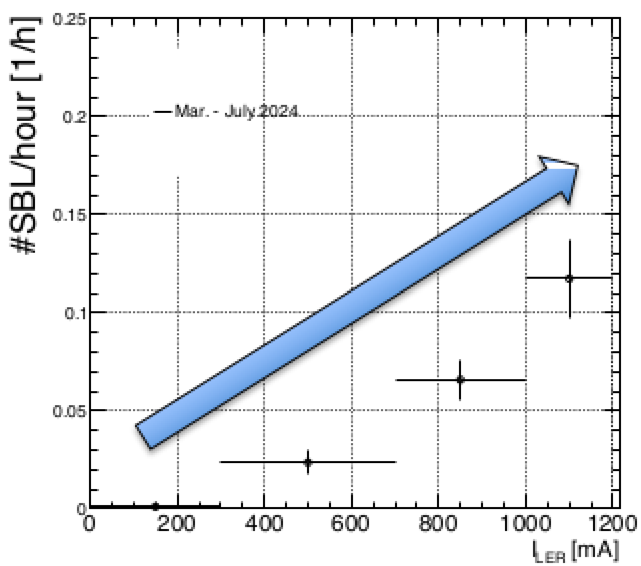
suffered from SBLs: HER 20 times, LER 140 times

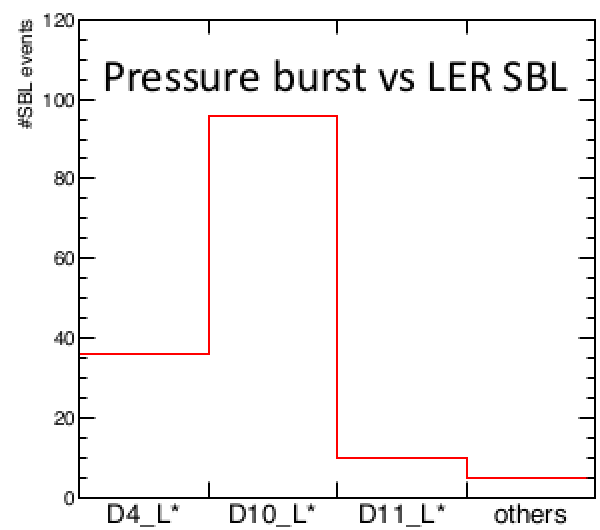
- LER SBL frequently occurred. Collision and optics (β_y^*) do not matter
- Excluded some hypothesis. Obtained a good knowledge by monitors

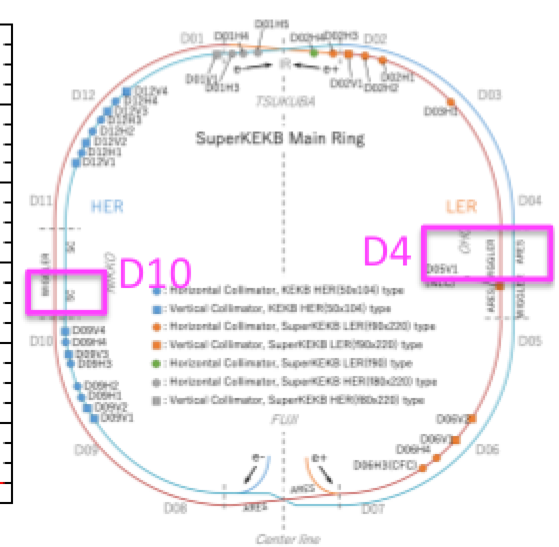
Belle II/SuperKEKB analyzed SBL events and found some features

- Frequency (#SBL/hour) strongly depends on beam current
- Pressure burst is mostly observed in LER SBL: D04/D10 wiggler section
- Vertical beam size blow-up is observed for some SBL events

The source of LER SBL is dust in D04 or D10 wiggler section ?

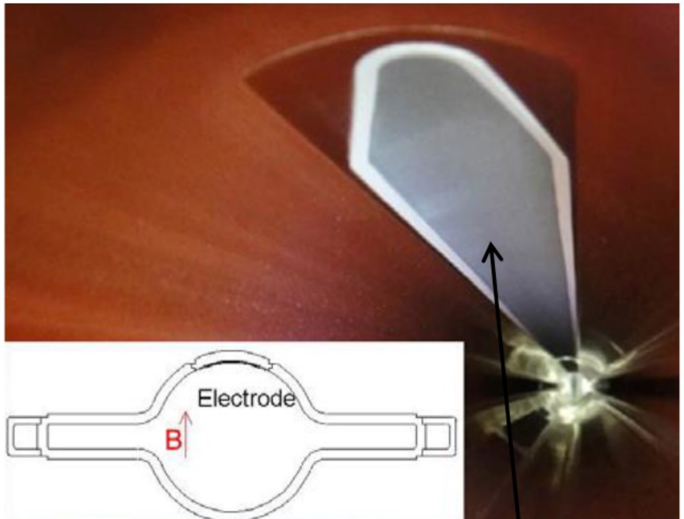


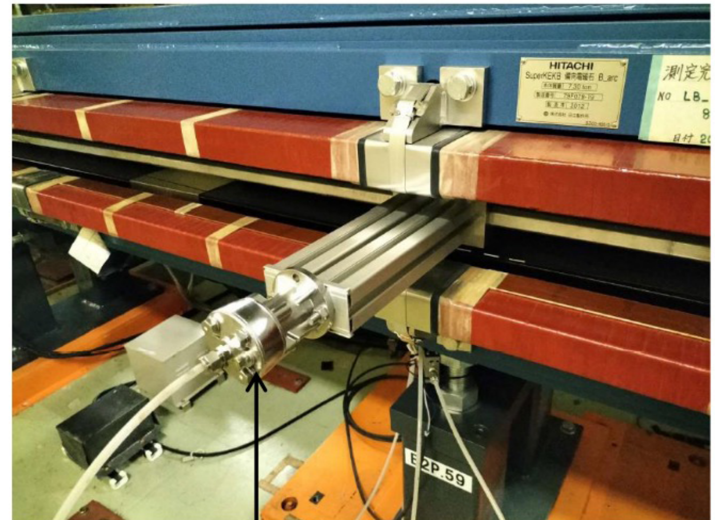




Knocker studies

◦ knocked beam pipes on D10 wiggler with clearing electrodes (with beams at 600-1000 mA)

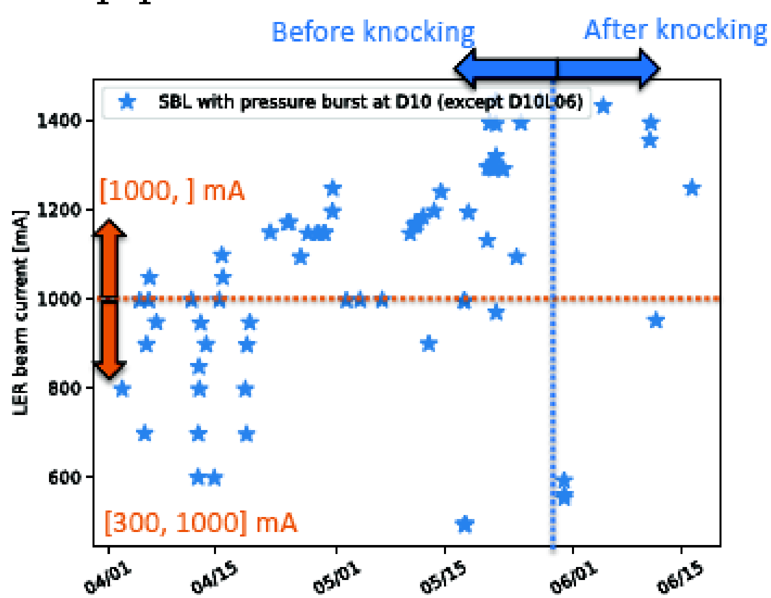




clearing electrode Knocker machine

⇒ SBL events can be artificially produced by knocking beam pipes !!

◦ knocked beam pipes at D10 several times without beams



I_{LER} [mA]		[300, 1000]	[1000,]
Before knocking	#SBL	24	42
	Operation-time [h]	633.77	350.32
	#SBL/time [1/h]	0.038 ± 0.008	0.12 ± 0.02
After knocking	#SBL	4	4
	Operation-time [h]	98.5	162.3
	#SBL/time [1/h]	0.041 ± 0.020	0.025 ± 0.012

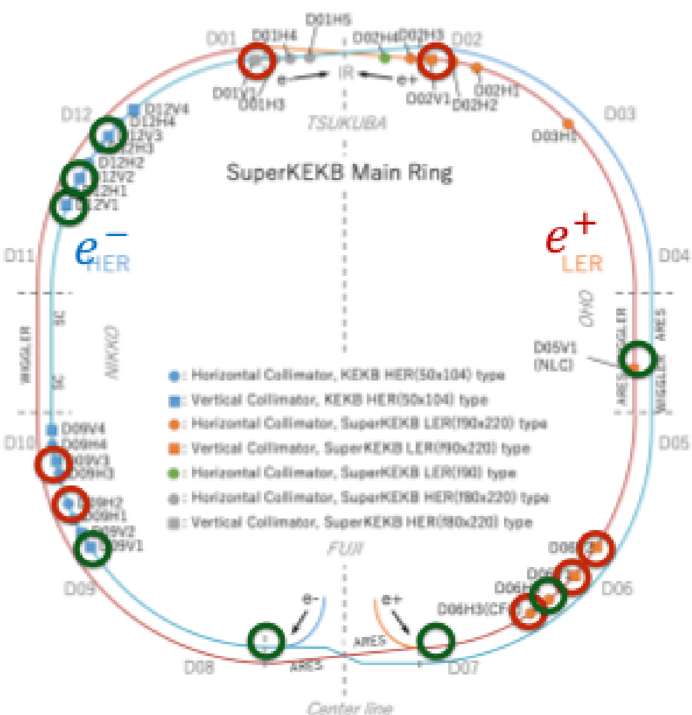
⇒ frequency at $I_{LER} \geq 1$ A is reduced: $0.12 \pm 0.02 \rightarrow 0.025 \pm 0.012$!! (''knocking effect'')

Timing analysis using Loss Monitor

Where beam loss starts?

- Install fast loss monitors to record precise beam loss timing of SBLs
  - Provide chronological order of beam loss along the rings

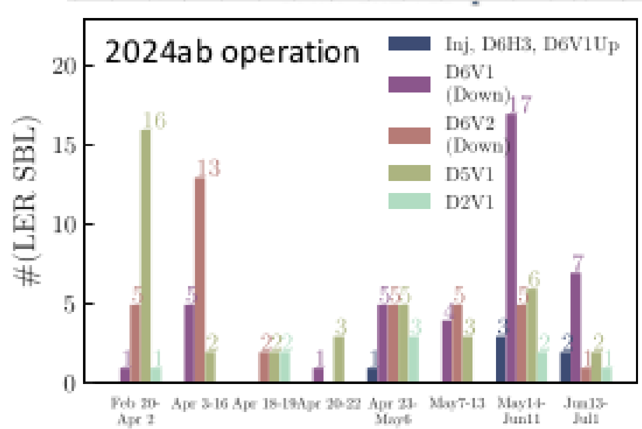
White Rabbit developed by CERN has been introduced as time sync system

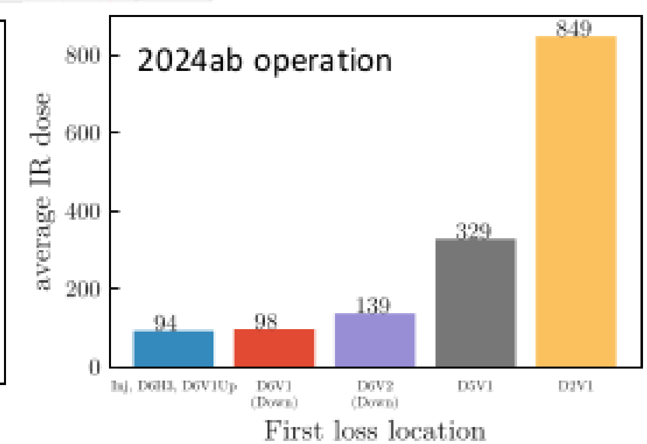


Installation in LS1
Installation before LS1

SBL on March 24th

First beam loss is D05V1





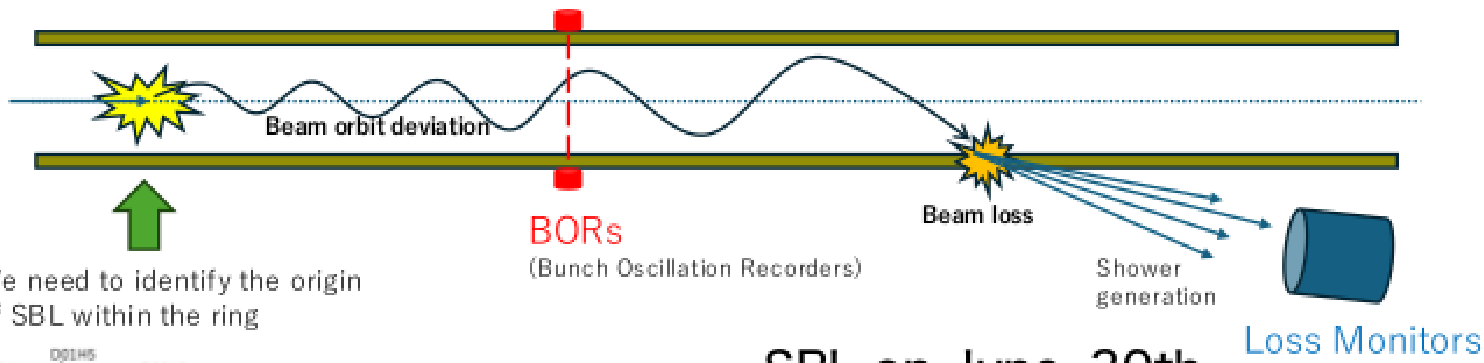
The initial loss mostly appeared on D05V1 or D06V1
IR dose tends to be high in case the first loss location is D2V1

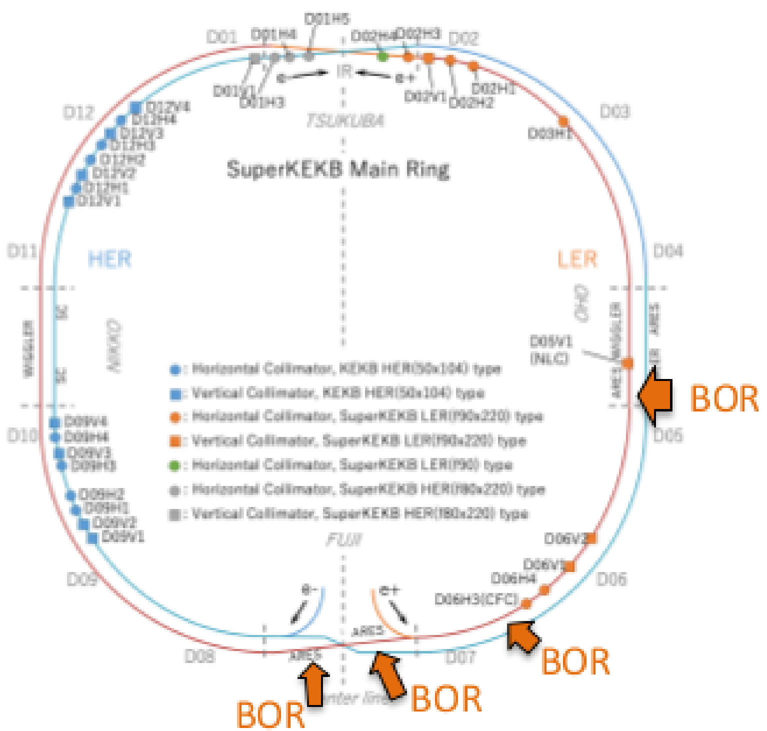
Bunch Oscillation Recorder (BOR)

Is there any abnormal behavior of beam orbit?

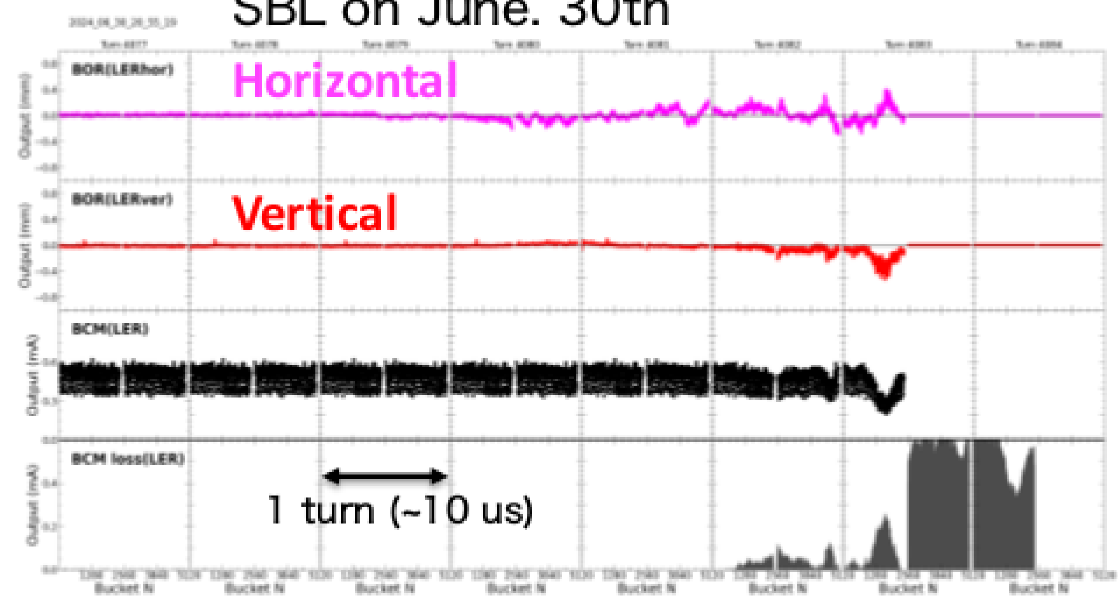
(prior to the beam loss)

- Installed BORs to observe earlier stage of beam orbit deviation





SBL on June. 30th

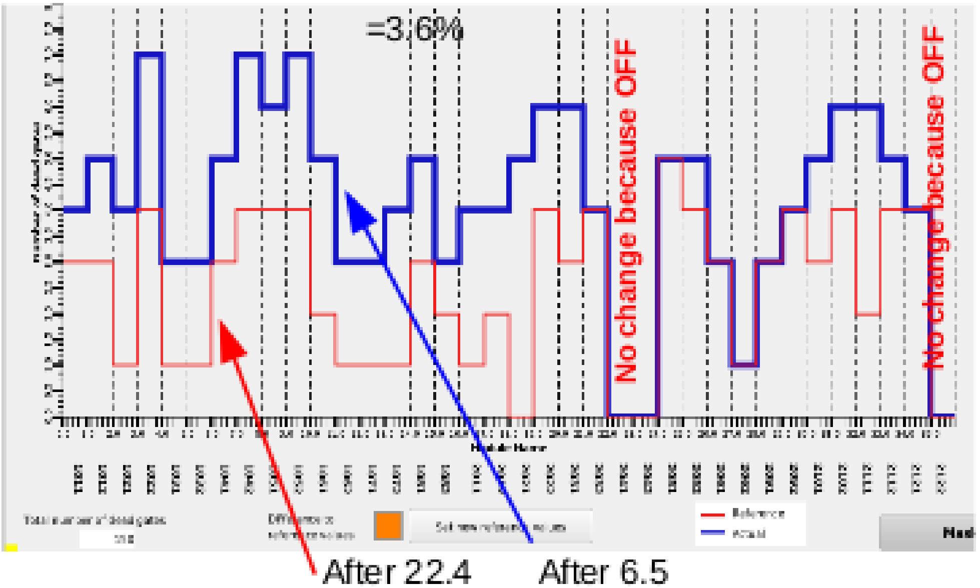


More study is ongoing

In most cases, beam orbit deviations were observed,
but the source was not identified..

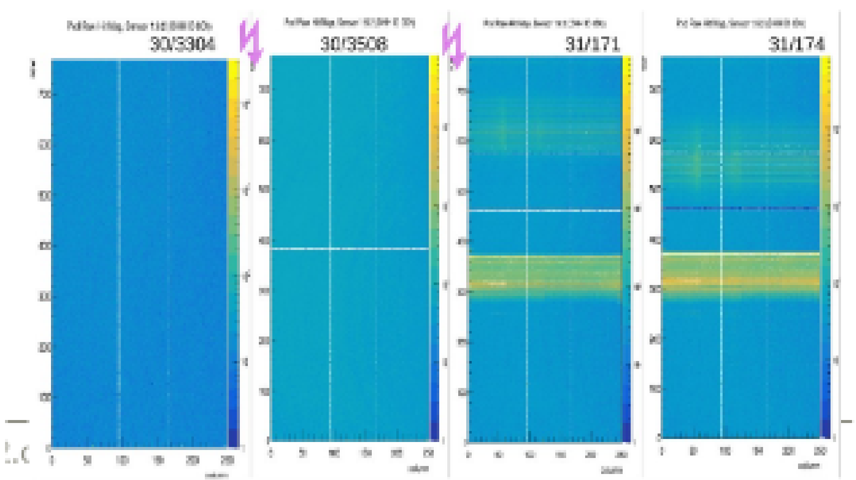
Result of Beam Losses: PXD Damages

- Two beam loss with damages on PXD on 22.4 and 6.5
- Dose unknown, as all four Diamonds went into saturation
- Nearly all PXD modules have damaged switcher channels!
  - 4 dead gates → 84 dead gates → 150 dead gates
  - 3-4 gates/module = ~1.5-2% of the pixels
- Clear currents increased
  - → Temperature increased!
  - Several modules in Layer 2 turned off to reduce temperature
- "unstable" regions/operation (similar in PXD1)



One switcher channel (gate) affects 4 rows → 1000 pixels per dead channel

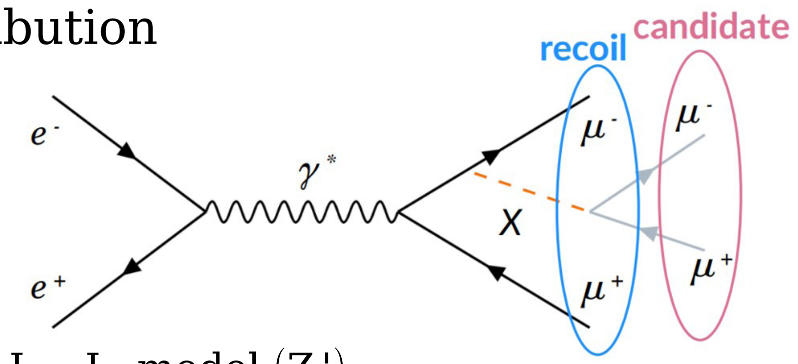
PXD1 before exchange in 2022:
~150 dead channels (but in 19 modules)



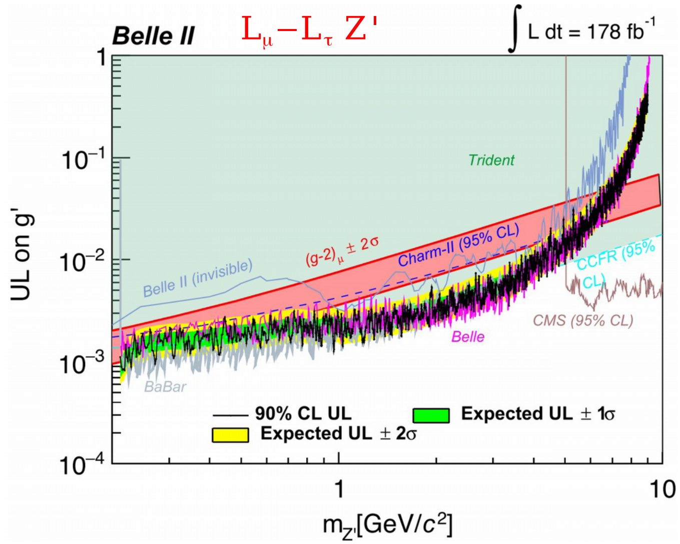
Searches for dark sector particles at Belle II

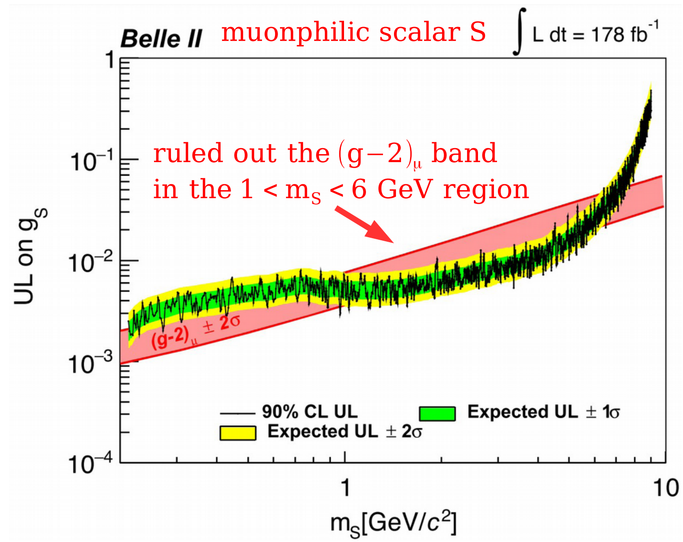
[arXiv:2403.02841, PRD 109, 112015 (2024)]

- Search for the process $e^+e^- \to \mu^+\mu^- X$ with $X \to \mu^+\mu^-$
  - look for a narrow peak in the $\mu^+\mu^-$ mass distribution



- Probing two different models:
  - $L_\mu - L_\tau$ vector mediator (Z')
  - Muonphilic dark scalar (S)
- No significant excess found in 178 fb^{-1}
  - Competitive 90% CL upper limits for g' coupling of the $L_\mu - L_\tau$ model (Z') with BaBar (> 500 fb^{-1}) and Belle (> 600 fb^{-1}) results
  - First 90% CL upper limits for the muonphilic dark scalar (S) model from a dedicated search





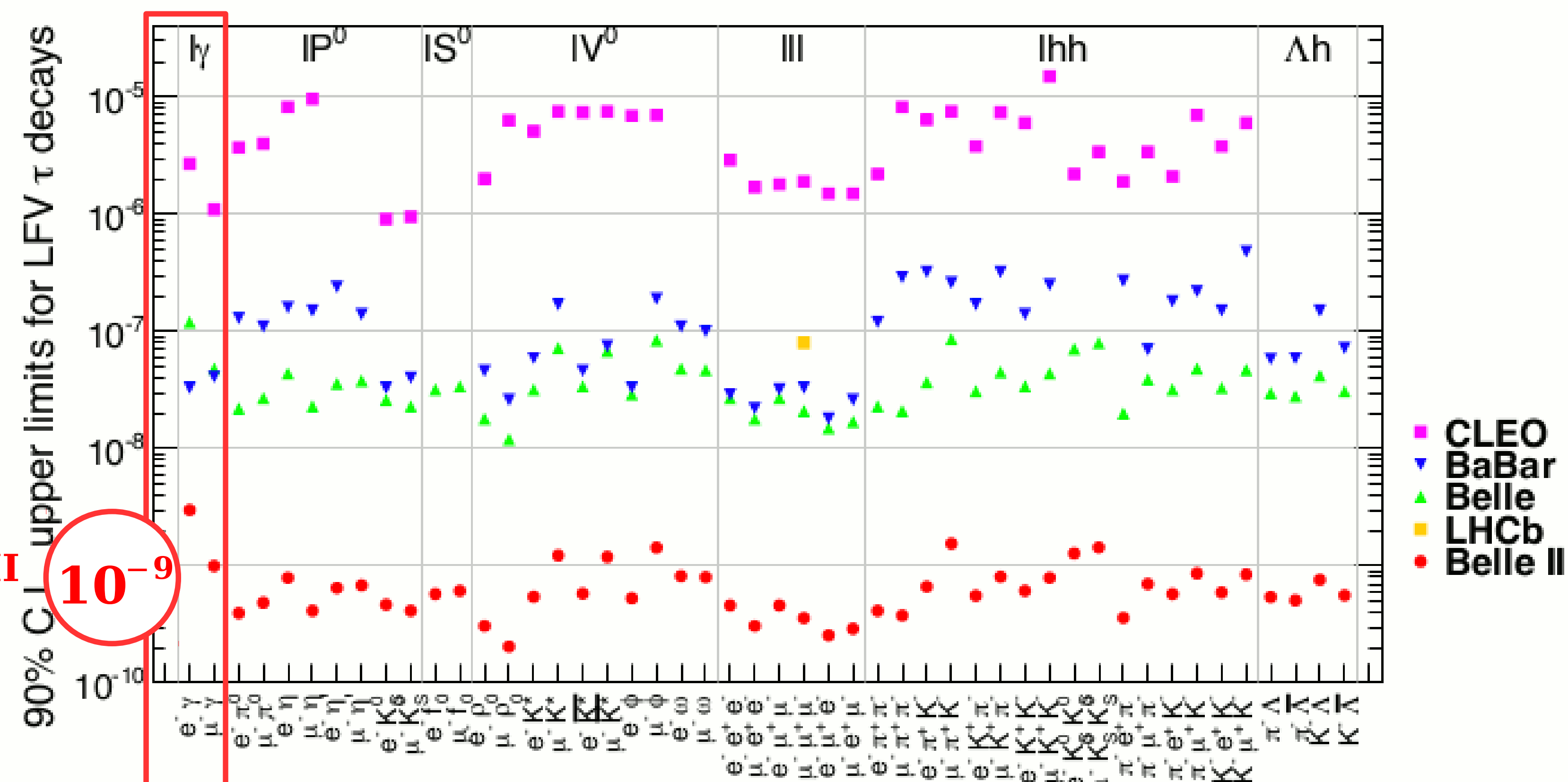
- Special triggers for low multiplicity at Belle II (much improved than Belle !!)
  - single photon trigger, single muon trigger, single track using neural networks
- Lot of developments in trigger (including displaced vertices for LLP searches)

"τ – factory"

- **SuperKEKB/Belle II is also a τ-factory !**
- **lepton flavour violating decays of the τ as NP probe**

$\Rightarrow$ LFV accidental symmetry of SM, many NP models can naturally break this symmetry

Model	Reference	$\tau\to\mu\gamma$	$\tau\to\mu\mu\mu$
SM+ ν oscillations	EPJ C8 (1999) 513	10^{-40}	10^{-40}
SM+ heavy Maj ν_R	PRD 66 (2002) 034008	10^{-9}	10^{-10}
Non-universal Z'	PLB 547 (2002) 252	10^{-9}	10^{-8}
SUSY SO(10)	PRD 68 (2003) 033012	10^{-8}	10^{-10}
mSUGRA+seesaw	PRD 66 (2002) 115013	10^{-7}	10^{-9}
SUSY Higgs	PLB 566 (2003) 217	10^{-10}	10^{-7}

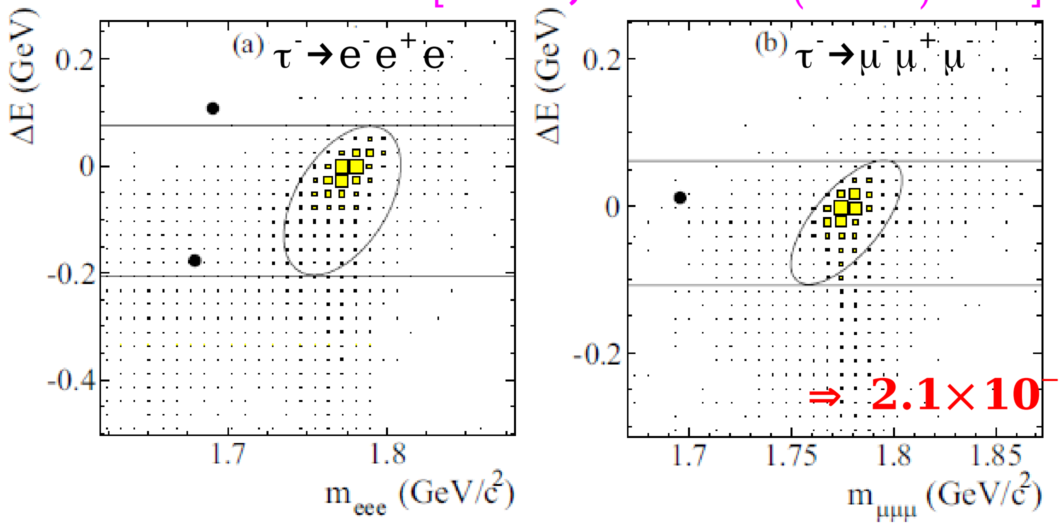


expected Belle II sensitivity 10^{-9}

cLFV : beyond the Standard Model

τ LFV searches at Belle II will be extremely clean with very little background (if any), thanks to pair production and double-tag analysis technique.

[Belle, PLB 687 (2010) 139]

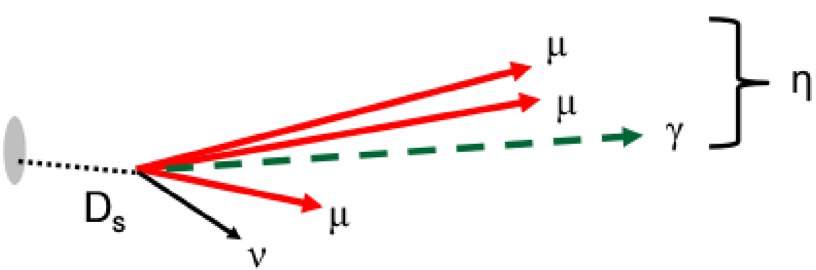


⇒ 2.1×10^{-8} at 90% CL

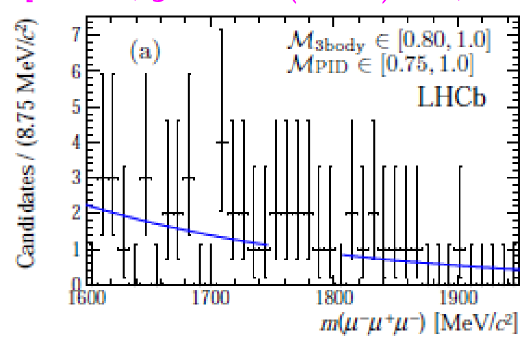
how to improve further ?

…considering $\tau \to \mu/e\, h^+ h^-$
in function of one prong tag categories
…for $\tau \to 3$ muons,
improve μ-ID at low mom (ECL info)

In contrast, hadron collider experiments must contend with larger combinatorial and specific backgrounds



[LHCb, JHEP02(2015)121, 2 fb^{-1}]



⇒ 4.6×10^{-8} at 90% CL

Background modes normalised to $D_s \to \eta(\mu\mu\gamma)\mu\nu$ (BR ~ 10^{-5})

Decay channel	Relative abundance
$D_s \to \eta(\mu\mu\gamma)\mu\nu$	1
$D_s \to \varphi(\mu\mu)\mu\nu$	0.87
$D_s \to \eta'(\mu\mu\gamma)\mu\nu$	0.13
$D \to \eta(\mu\mu\gamma)\mu\nu$	0.13
$D \to \omega(\mu\mu)\mu\nu$	0.06
$D \to \rho(\mu\mu)\mu\nu$	0.05

CMS, full Run 2 dataset: 2.9×10^{-8} at 90% CL

Most improvement in coming decade is expected from Belle II, which can reach 1×10^{-9} [arXiv:1011.0352] and will do even better if can achieve ~ zero bckgd

$\tau \to 3\mu$ at Belle II

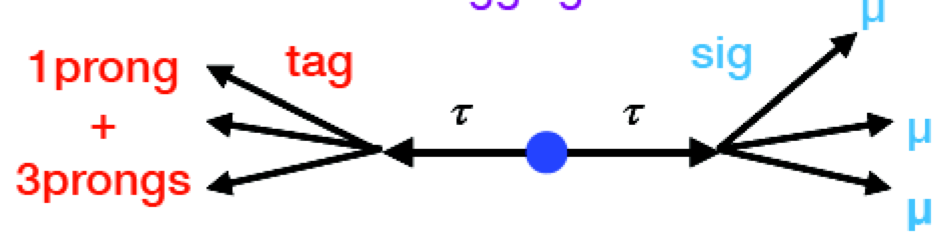
arXiv:2405.07386
JHEP 09 (2024) 062

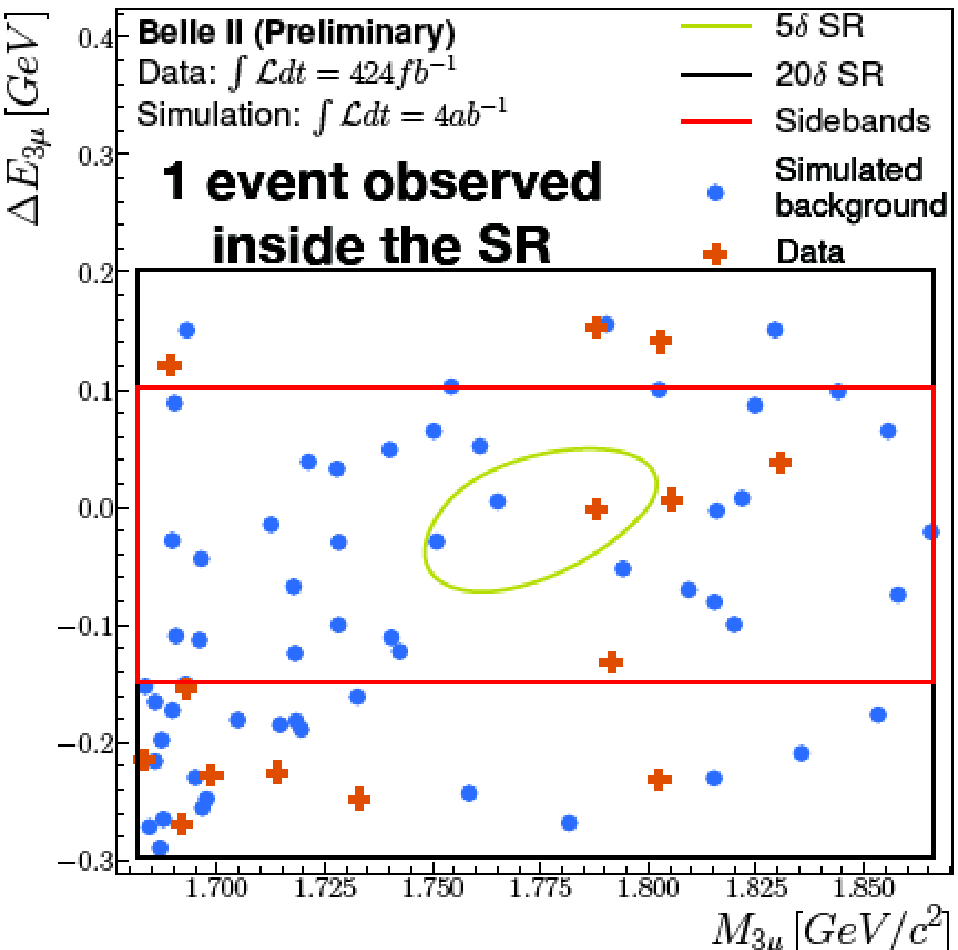
Analysis selection and results: inclusive approach

BDT trained on 32 variables:
inputs from signal τ^-, event tag side, event shape and kinematics

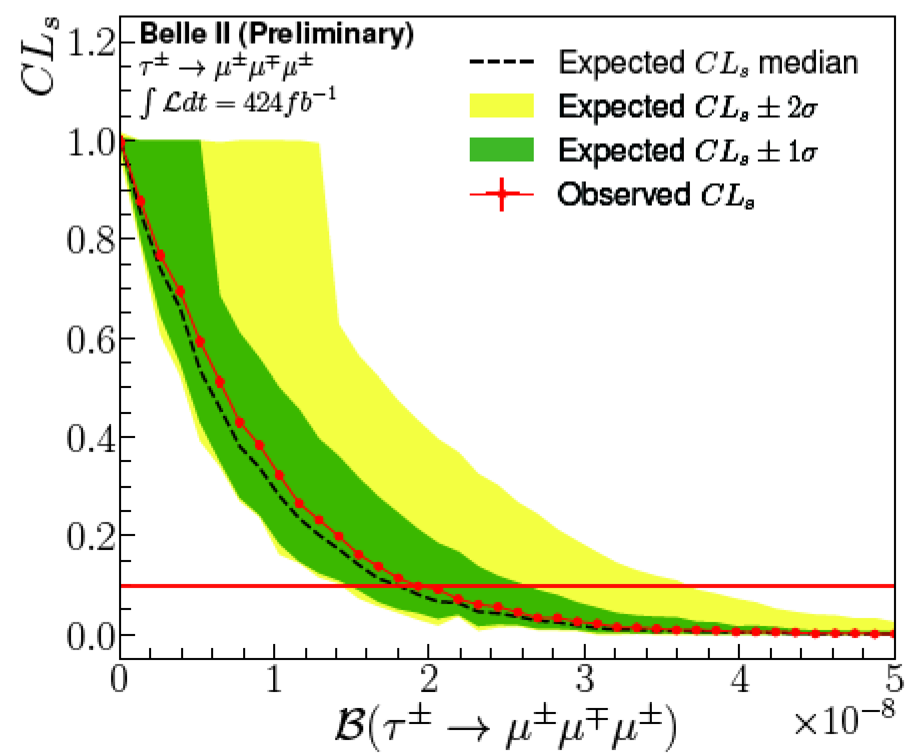
$\epsilon_{sig} = (20.42 \pm 0.06)\%$ ($3 \times$ larger than Belle)
Expected BKG: $0.5^{+1.4}_{-0.5}$ evts

Inclusive tagging schema





No significant excess in 424 fb^{-1} of data



Obtained most stringent limit
1.9×10^{-8}

more results coming: $\tau \to \Lambda\pi$ (arXiv:2407.05117), and soon $\tau \to e l^+ l^-$ modes