Belle II status
(ARC review March 2024)

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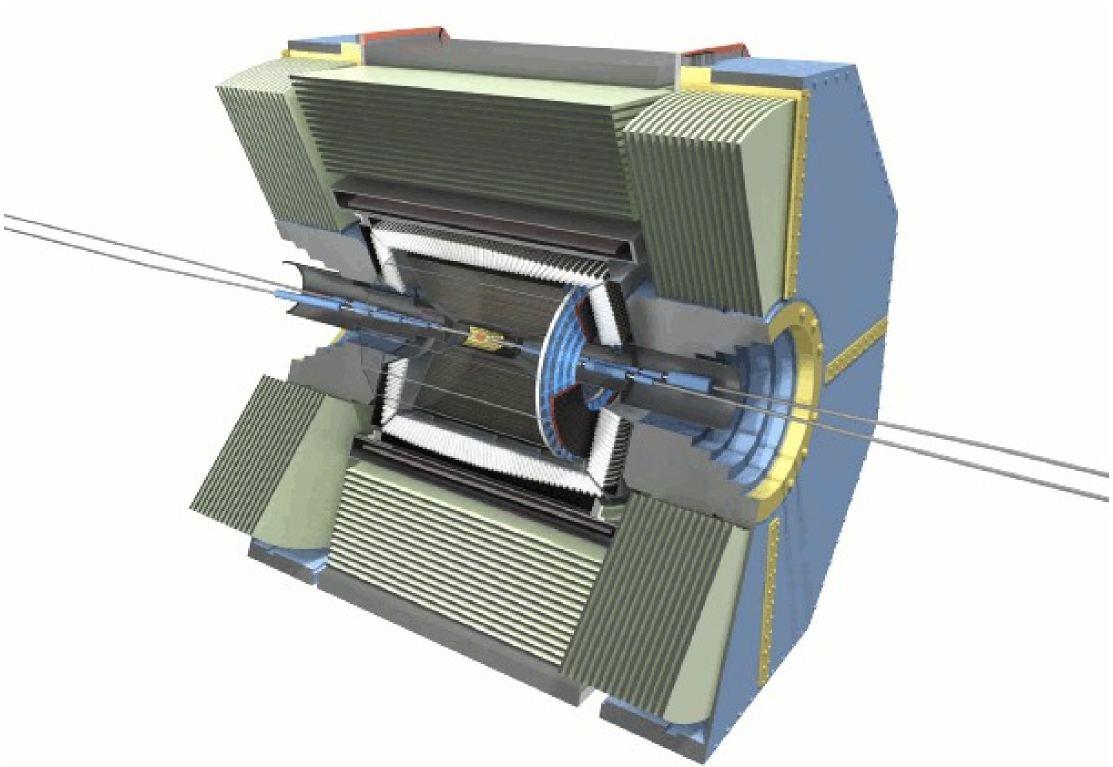


Belle II is...

Staff: 305, Post-docs: 131, PhD students: 264 = **700 collaborators**
and undergraduate/master students, technical members

SuperKEKB + Belle II, a flavour-factory,

(Belle ~ 1 ab^{-1})

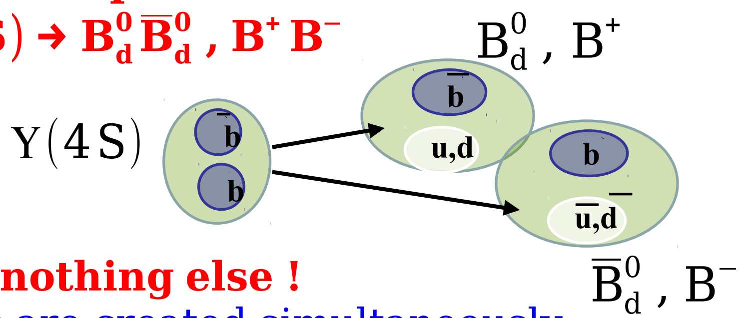
a rich physics program...

- We plan to collect (**at least**) 50 ab^{-1} of e^+e^- collisions at (or close to) the $\Upsilon(4S)$ resonance, so that we have:

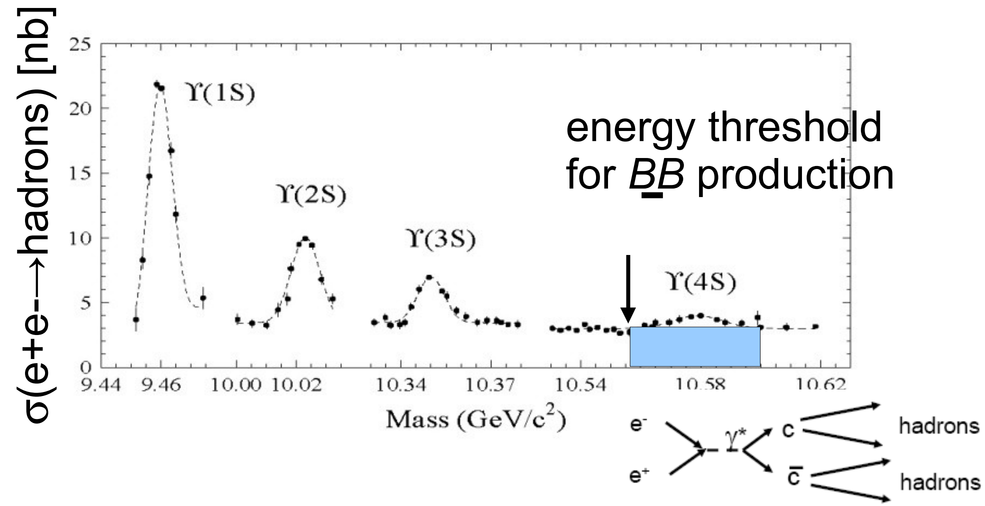
– a (Super) B-factory ($\sim 1.1 \times 10^9$ $B\bar{B}$ pairs per ab^{-1})

"on resonance" production

$e^+e^- \to \Upsilon(4S) \to B_d^0\bar{B}_d^0$, B^+B^-



- **2 B's and nothing else !**
- 2 B mesons are created simultaneously in a L=1 coherent state



– a (Super) charm factory ($\sim 1.3 \times 10^9$ $c\bar{c}$ pairs per ab^{-1})

(but also charmonium, X, Y, Z, pentaquarks, tetraquarks, bottomonium...)

– a (Super) τ factory ($\sim 0.9 \times 10^9$ $\tau^+\tau^-$ pairs per ab^{-1})

– exploit the clean e^+e^- environment to probe the existence of exotic hadrons, dark photons/Higgs, light Dark Matter particles, ALPs, LLPs ...

⇒ to reach $6 \times 10^{35}\ cm^{-2}s^{-1}$

⇒ cumulate 50 ab^{-1} by ~2035

Belle II run 1 (2019 - 2022)

data taking from March 2019 to June 2022

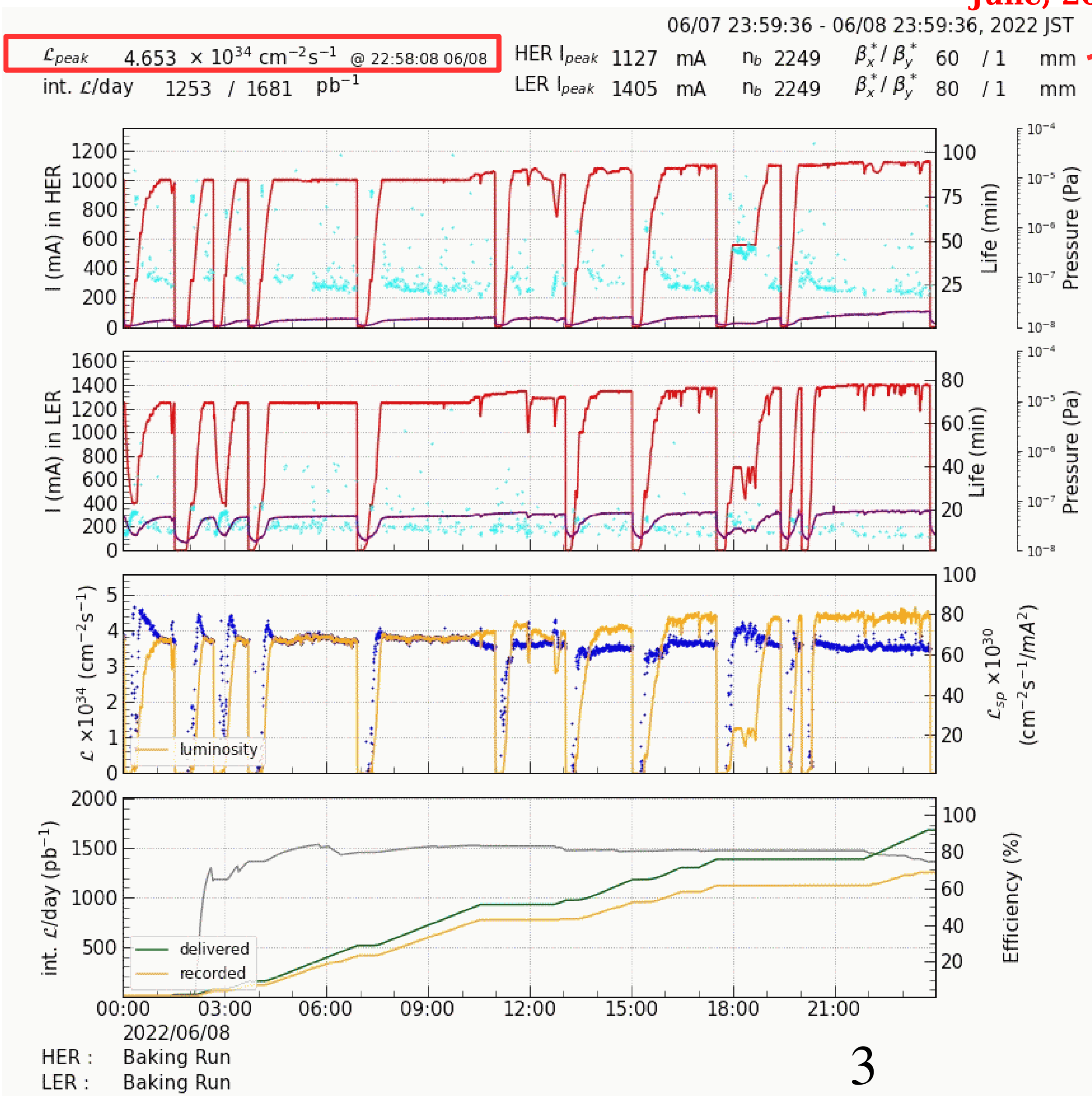
→ despite difficult conditions since March 2020 (Covid, war in Ukraine, energy cost…)

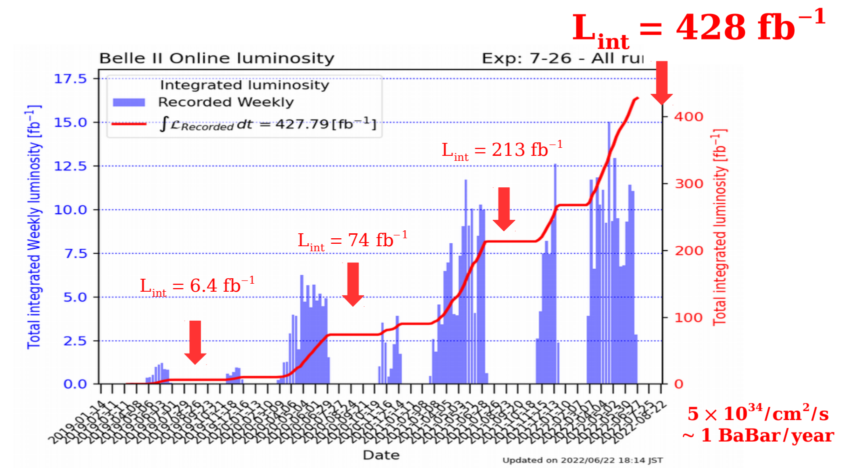
luminosity: $4.7\times10^{34}/cm^2/s$! > $2\,fb^{-1}$ per day!

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

June, 2022

record of KEKB/Belle
$2\times10^{34}/cm^2/s$ currents > 1 A
record of PEPII/BaBar
$1\times10^{34}/cm^2/s$ currents > 2 A





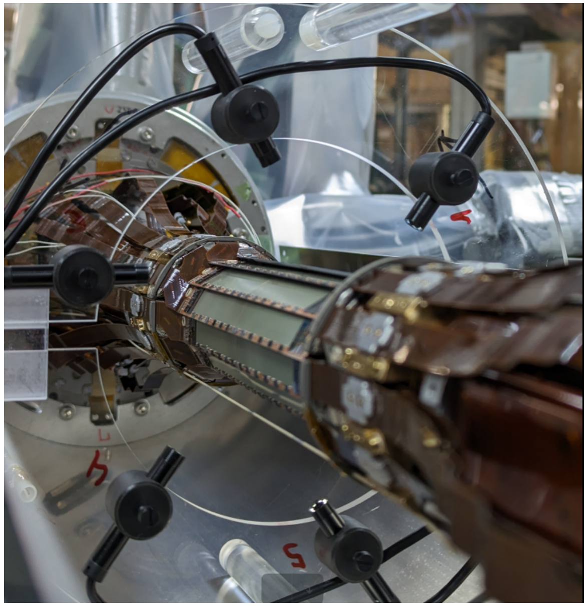
Long-shutdown (LS1) activity and plans

Belle II stopped taking data in Summer 2022 for a long shutdown

- accelerator improvements: injection, non-linear collimators, monitoring...
- additional shielding (e.g. neutron) and increased resilience against beam bckg
- installation of additional loss monitors and speed-up of abort signal

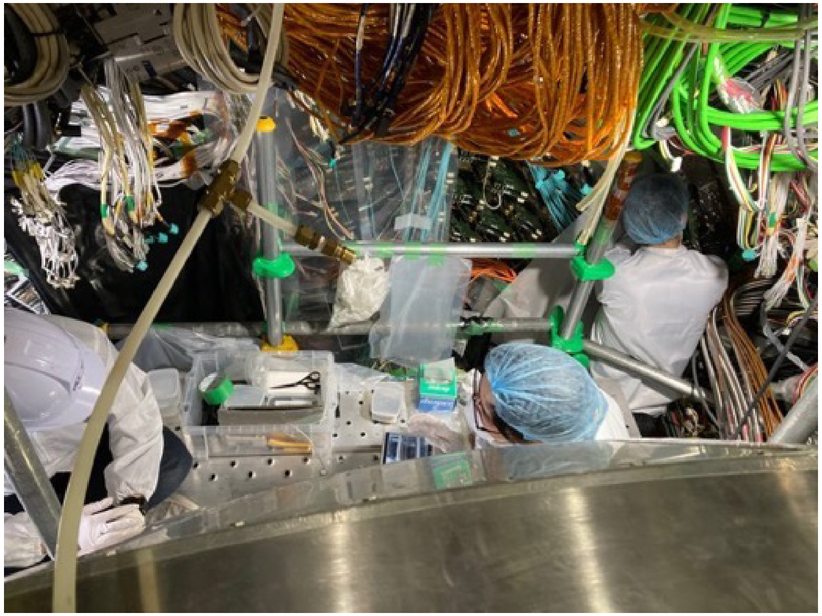
- replacement of beam-pipe
- installation of 2-layered pixel vertex detector (PXD2)
- replacement of photomultipliers (MCP-PMT) of the central PID detector (TOP)
- improvement in CDC gas circulation and monitoring
- completed transition to new DAQ boards (PCIe40)
- work on other detectors as KLM, ECL...
- improved data-quality monitoring and alarm system

PXD2 at KEK since March



VXD extraction in May

TOP MCP-PMT replacement work



CDC FE reinstallation work

PXD2

Issue in **gliding mechanism** and damage of two L1 ladders in 1st half-shell: August 2022

Improve ladder gliding functionality

PXD2 was delivered to KEK: in March 2023

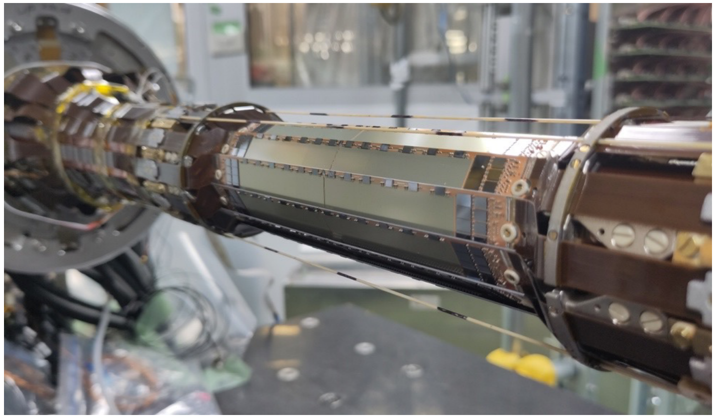
PXD2 mount completed on April 5th. After basic functionality checks (thermomechanical and electrical) evaluated from internal review committee
➜ EB+TB gave green light for installation April 21st.

VXD uninstallation work during May

SVD attachment during June

Installation VXD in Belle II end of July

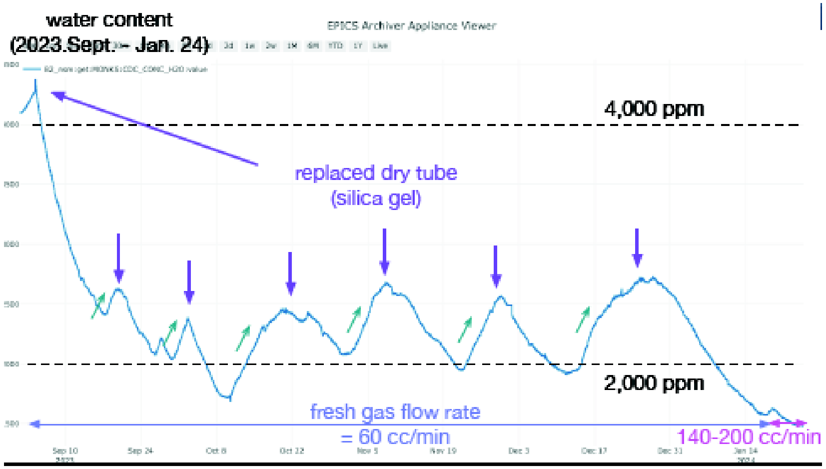
Commissioned with cosmic data in Fall (stand alone with SVD)
⇒ All 40 modules can be powered and deliver data
⇒ temperature, basic module functions

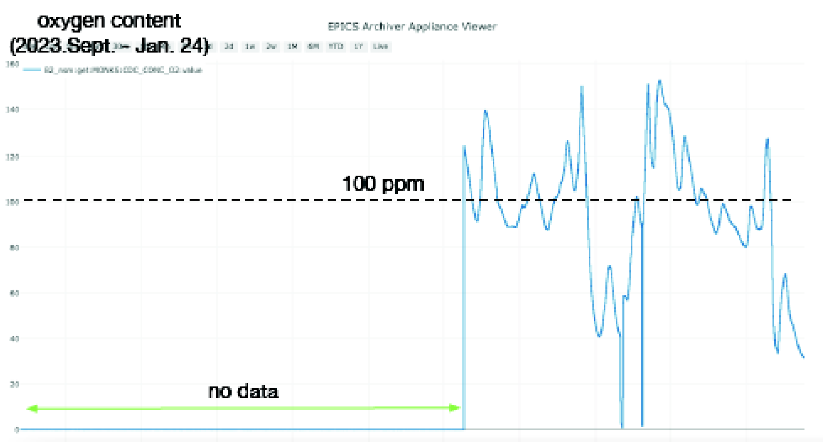


CDC

- Resistance replacement of HV divider to decrease voltage drop due to high injection background
- Hardware repair to fix HV trip in a few sectors
- Improved CDC gas system and monitoring

  - Origin of $H_2 0$ increase is now understood and under control with silica-gel dryer tubes
  - Redundant $H_2 0$ and O_2 sensors: to detect drift of calibration and improve reliability of monitor system





TOP PMT replacement work

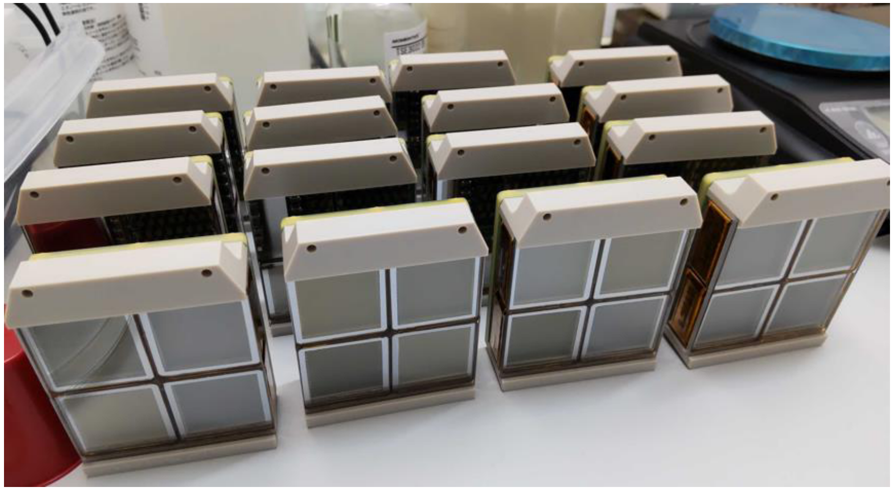
Performed PMT/electronics replacement

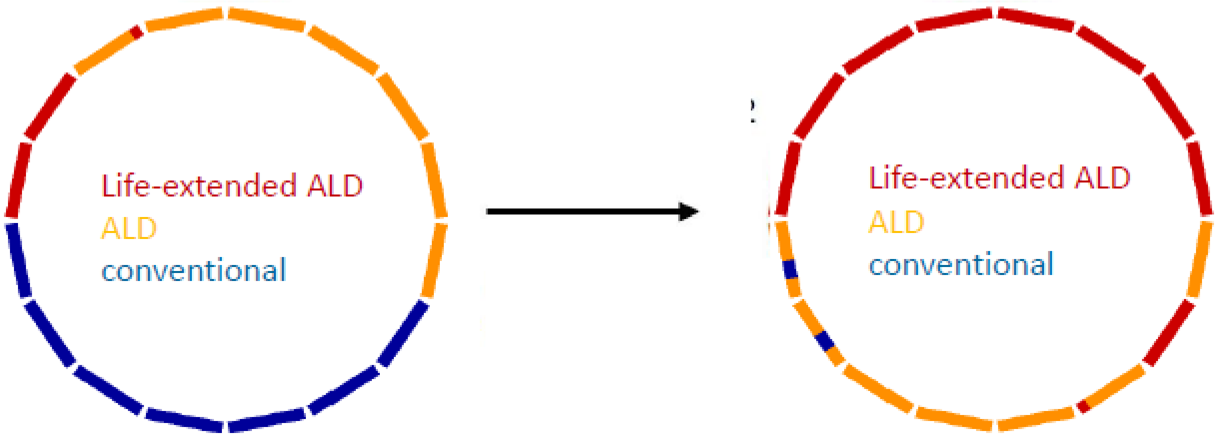
Allocated 2.5 months for TOP work (completed end of April 2023)

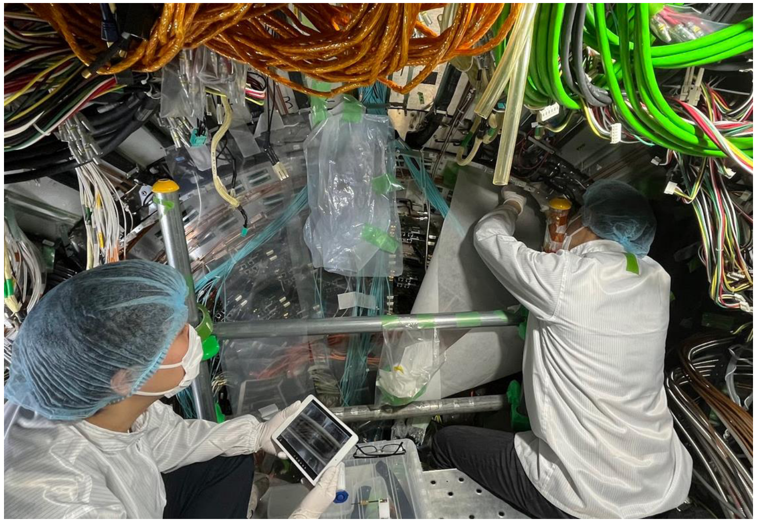
Replace degraded PMTs with new life-extended ALD PMTs (upper half)

Replace degraded PMTs with best PMTs available (lower half)

Replace problematic electronic boards
⇒ > 99.5% channels operational



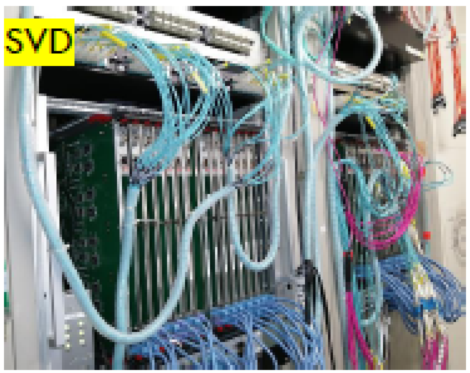


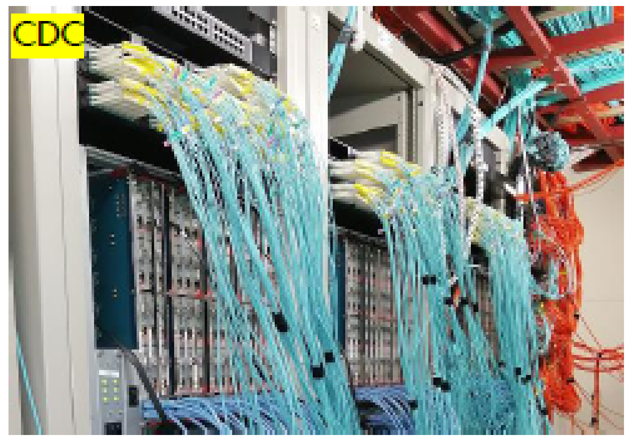


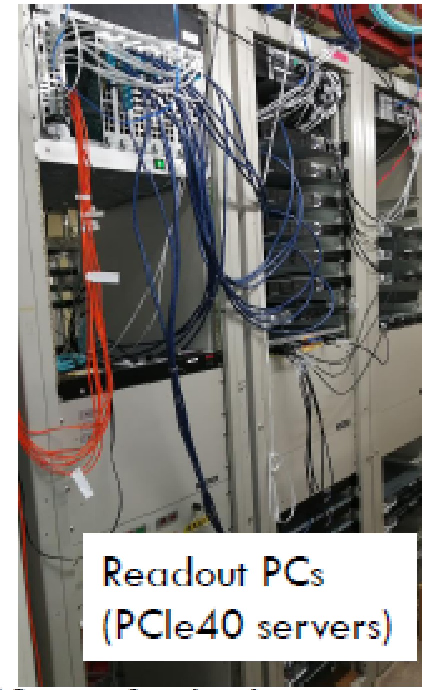
DAQ

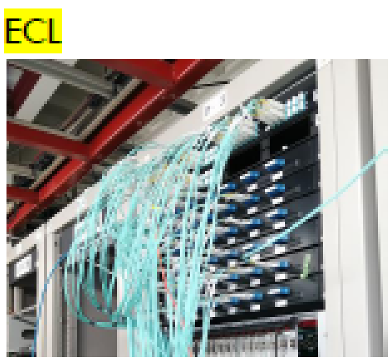
- upgrade of the readout system (COPPER to PCIe40), performance improvements

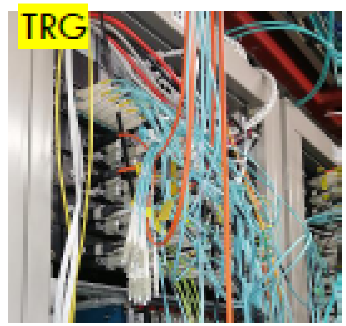
  - TOP, KLM : 2021 summer
  - ARICH : 2021/22 winter
  - SVD, CDC, ECL and TRG : LS1











  - Switching fibers to PCIe40 was finished in 2022
  - COPPER system for all sub systems(but PXD) will be kept as backup so that we can roll back quickly in case of a serious trouble.

- Reduction of time for SALS (stop-abort-load-start)
- HLT reinforcement (+3 units) and new framework
- Direct ROOT file recording

2 DAQ core members rehired with M&O

Other consolidation activities

- **ECL**

  Implementation new pedestal correction algorithm

- **KLM**

  Development and integration of bubbler flow monitor readout
  Investigation NH_3 flushing with RPC test chambers

- **Environmental monitor and alarm system**

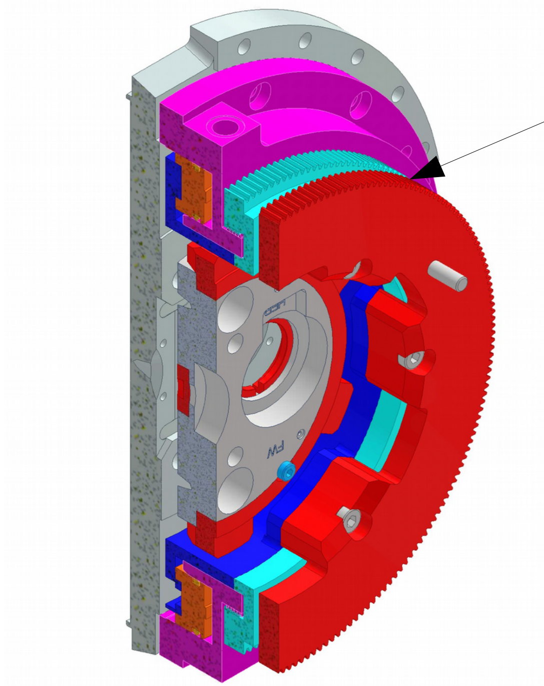
  EPIC-based framework alarm system

- **More shielding**

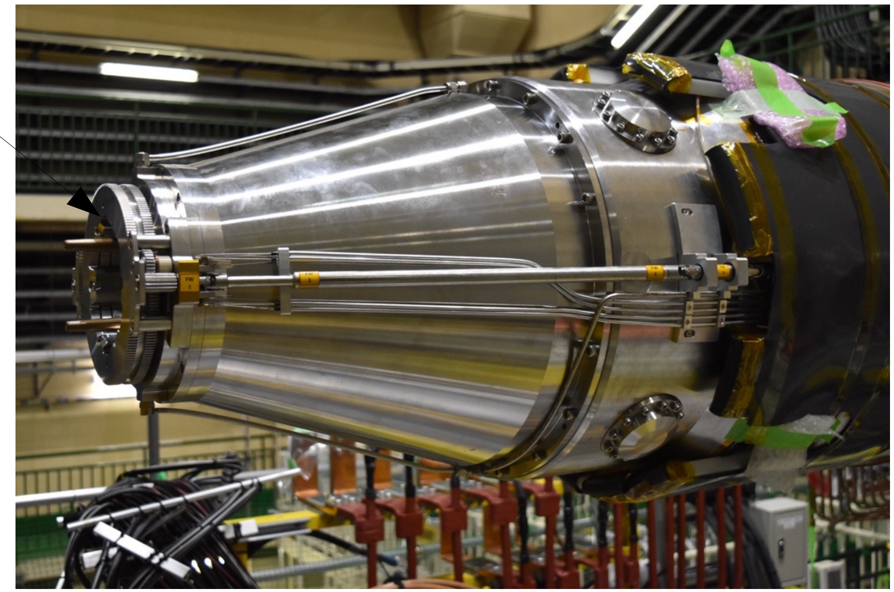
  PE shield for QCS neutron shield
  PE+SWX238 on QCS
  against charged background (i.e. bellows shield)

In Oct 2023, LS1 schedule delay: incident in FWD QCSR insertion

After QCS insertion, beam pipe vacuum sealing between pipes in QCS and is established by RVC (Remote Vacuum Connection)

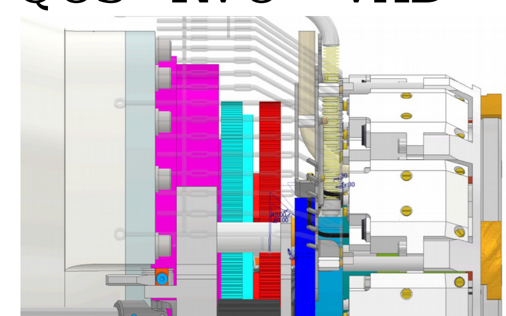


RVC



QCS could reach final position but RVC hit the cable cage and consequently couldn't get locked at this final position
large displacements of the cable cage ➜ large interference
possible that RVC gets stuck during its operation

QCS RVC VXD



- **modifications of RVC/cable cage**
  ➜ allowed to get back the needed clearance
- **LS1 schedule revised and start of run 2 at the end of Jan 2024**

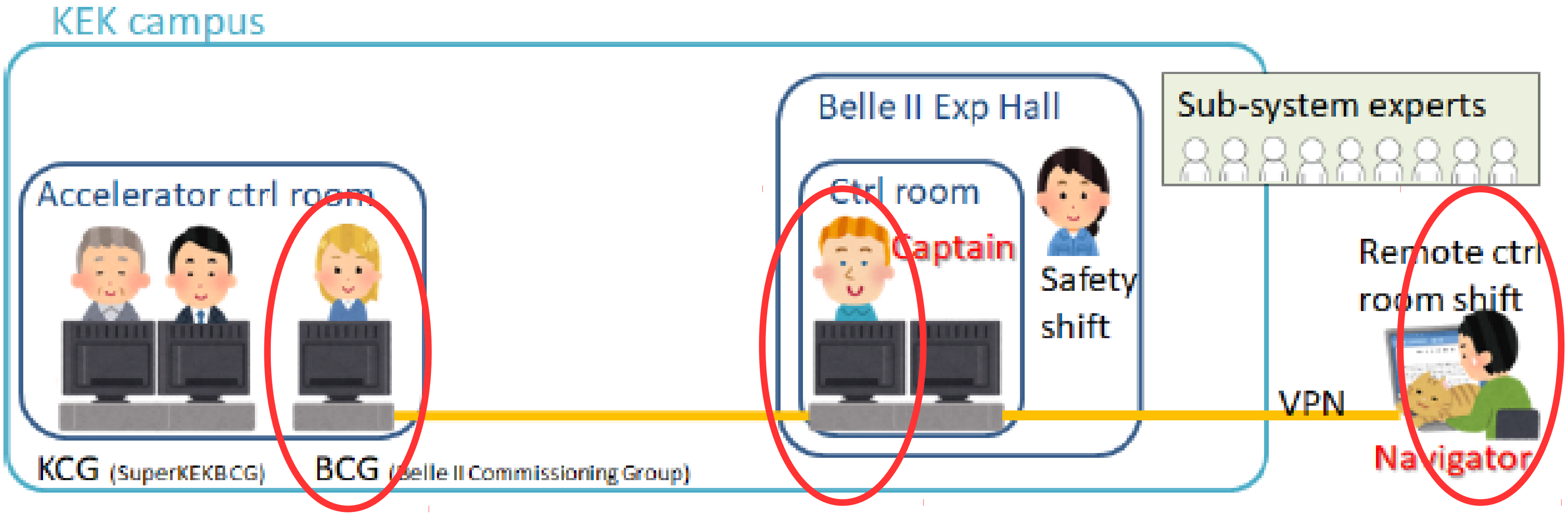
thank the machine group for modifying cryostat and make VXD installation possible !

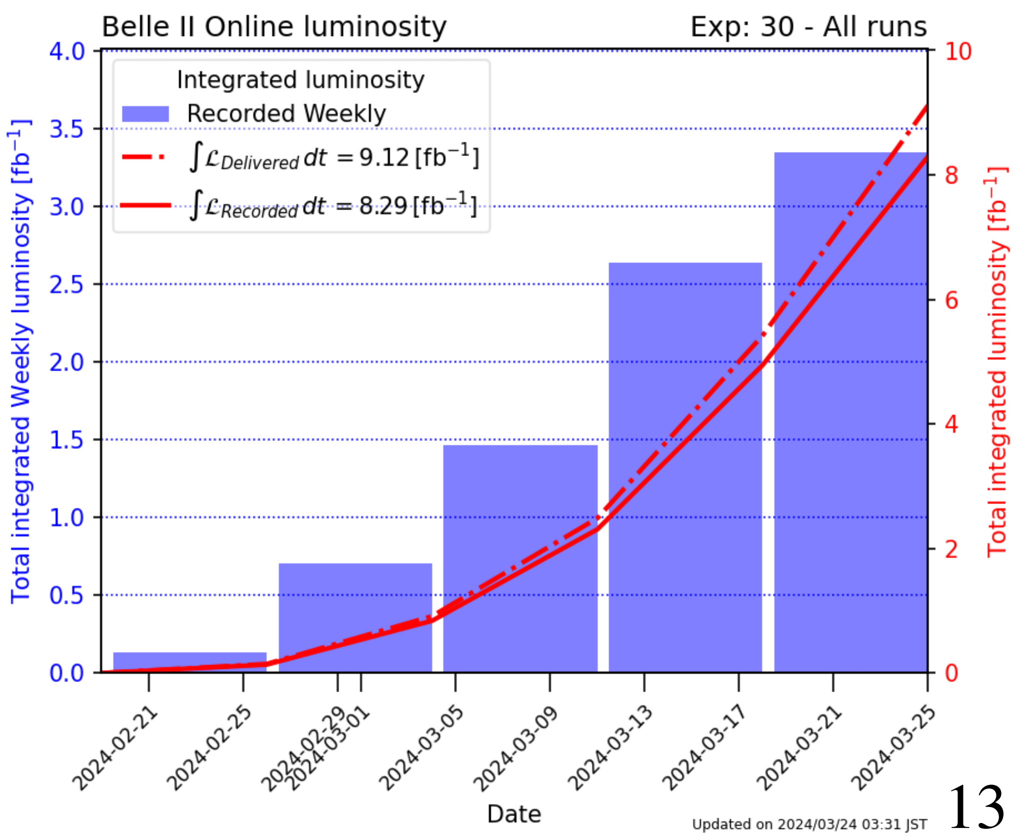
LS1 chapter is closed

Run 1 is with us, run 2 has started

first collisions of run 2 in February 2024

Belle II operation shifts in run 2





Fraction of physics run time: 32.4%

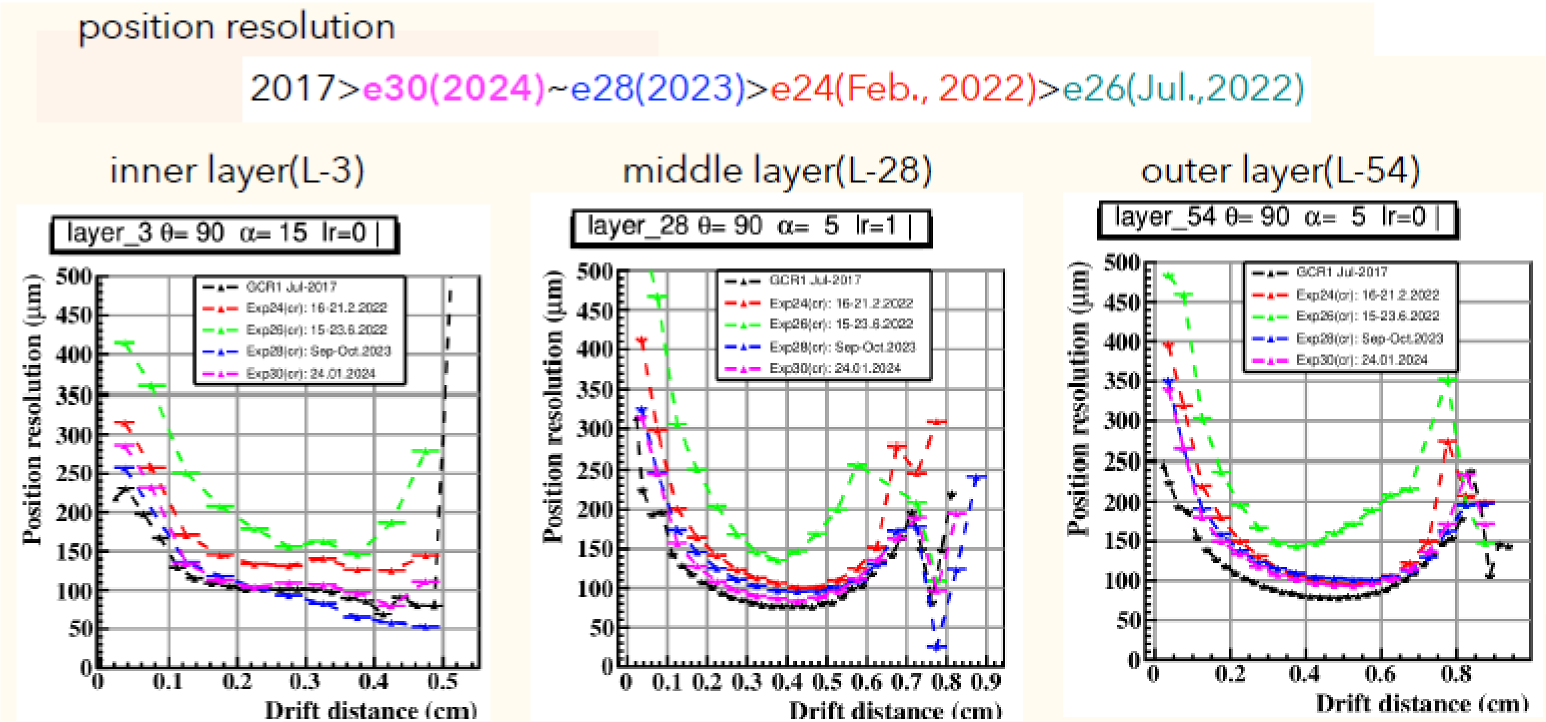
Fraction of DAQ running time in physics run time: 92.0%
Fraction of dead time in DAQ running time: 2.0%

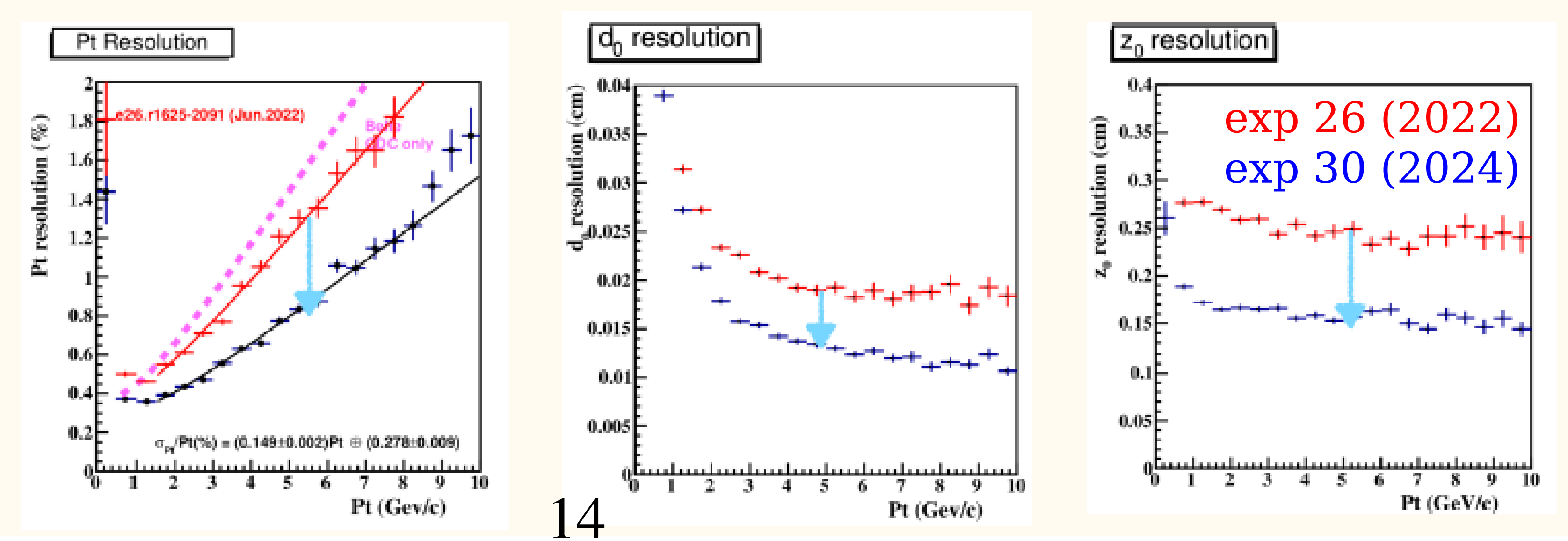
Data taking efficiency: 90.2%

Among the first results of run 2, as an illustration

CDC performance on cosmic 2024 (better gas/water control and monitoring)

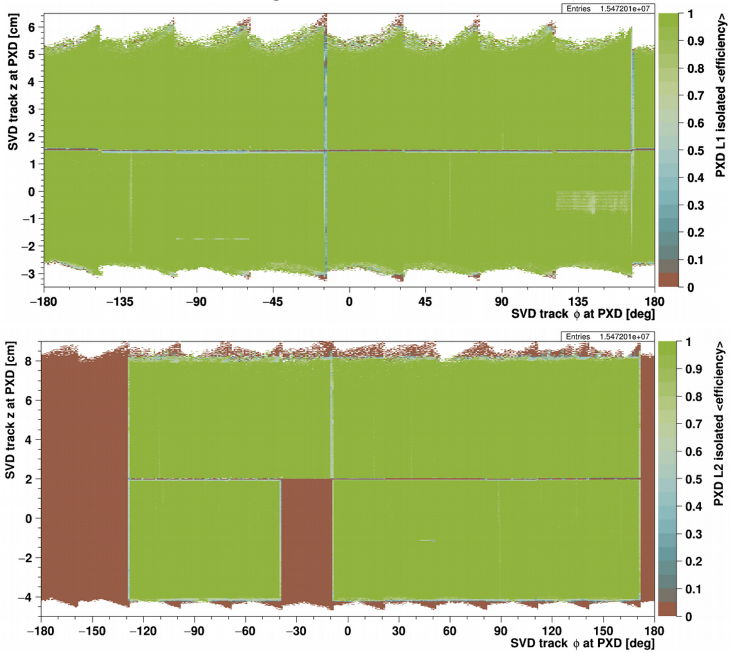
⇒ performance much improved compared to end of run 1





Among the first results of run 2, as an illustration

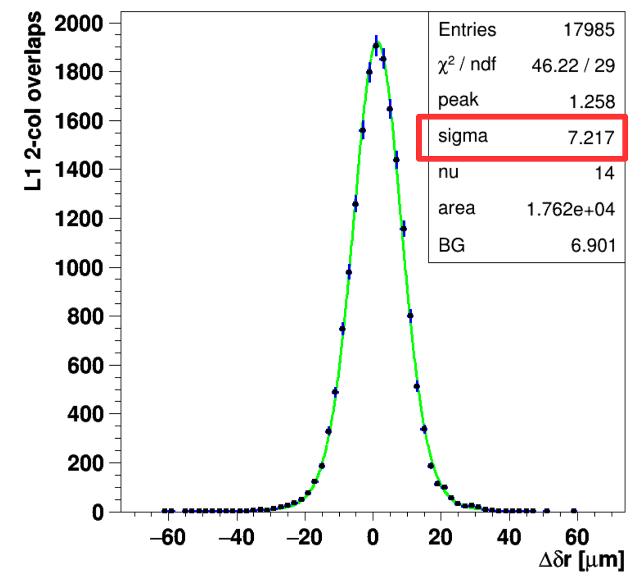
Efficiency map for PXD2



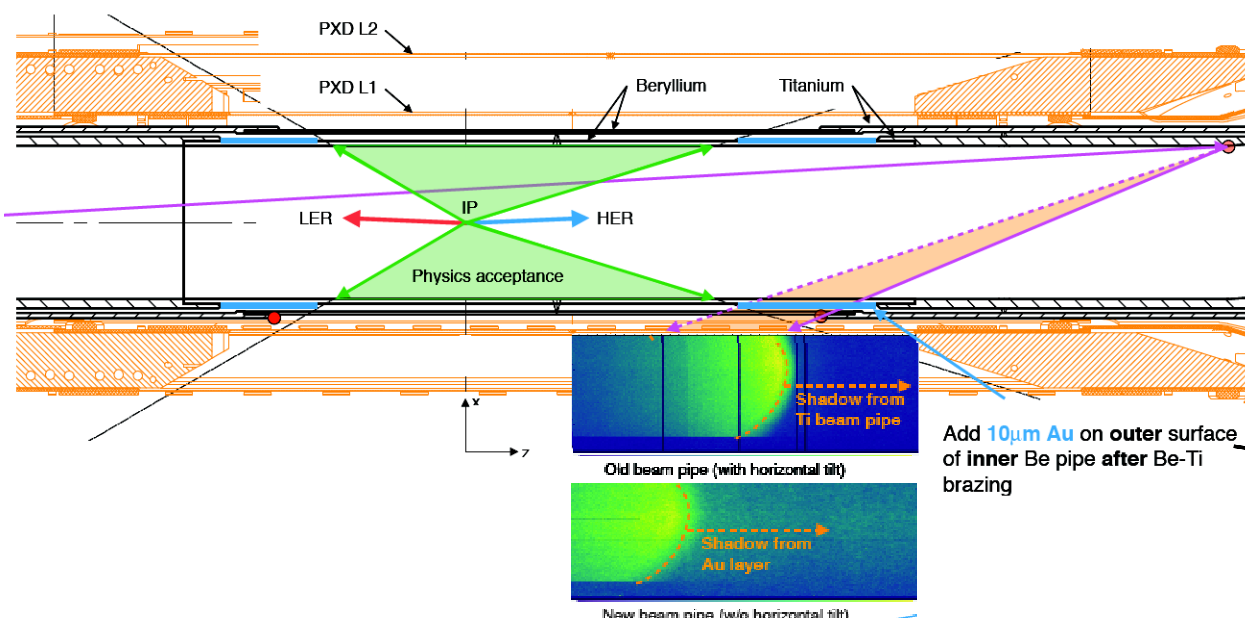
PXD2 efficiency
above 97% for active modules
reaching 99.7% in forward regions:
the maximum limited by Readout and Clear

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

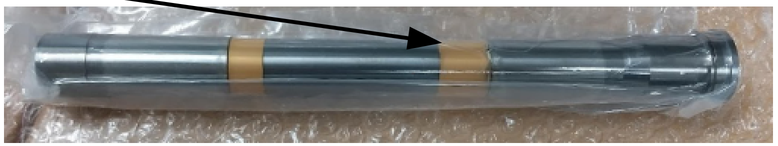
Resolution from overlaps



Run 1 → Run 2



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



Belle(II), LHCb side by side

Belle (II)

$e^+e^- \to \Upsilon(4S) \to b\bar{b}$

at $\Upsilon(4S)$: 2 B's (B^0 or B^+) and nothing else ⇒ clean events

(flavour tagging, B tagging, missing energy)

⇒ **initial conditions are precisely known**

$\sigma_{b\bar{b}} \sim 1\,\text{nb} \Rightarrow 1\ \text{fb}^{-1}$ produces $10^6\ B\bar{B}$

$\sigma_{b\bar{b}}/\sigma_{total} \sim 1/4$

LHCb

$pp \to b\bar{b}X$

production of B^+, B^0, B_s, B_c, Λ_b...
but also a lot of other particles in the event

⇒ lower reconstruction efficiencies

$\sigma_{b\bar{b}}$ much higher than at the $\Upsilon(4S)$

	$\sqrt{s}$ [GeV]	$\sigma_{b\bar{b}}$ [nb]	$\sigma_{b\bar{b}}/\sigma_{tot}$
HERA pA	42 GeV	~30	~10^{-6}
Tevatron	2 TeV	5000	~10^{-3}
LHC	8 TeV	~3×10^5	~ 5×10^{-3}
	14 TeV	~6×10^5	~10^{-2}

$b\bar{b}$ production cross-section at LHCb ~ 500,000 × BaBar/Belle !!

higher luminosity

$\sigma_{b\bar{b}}/\sigma_{total}$ much lower than at the $\Upsilon(4S)$

⇒ lower trigger and acceptance efficiencies

B mesons live relatively long

mean decay length $\beta\gamma c\tau \sim 200\ \mu m$

mean decay length $\beta\gamma c\tau \sim 7$ mm
(displaced vertices)

data taking period(s)

[1999-2010] = 1 ab^{-1}
[2019-...] = ...

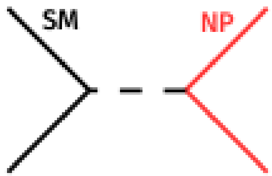
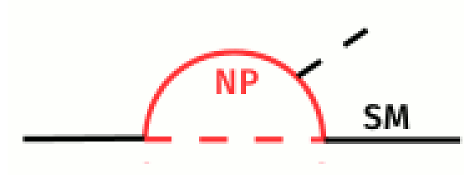
[run I: 2010-2012] = 3 fb^{-1}
[run II: 2015-2018] = 6 fb^{-1}

(near) future

[Belle II from 2019] → 50 ab^{-1}

[LHCb upgrade from 2022] → 50 fb^{-1}

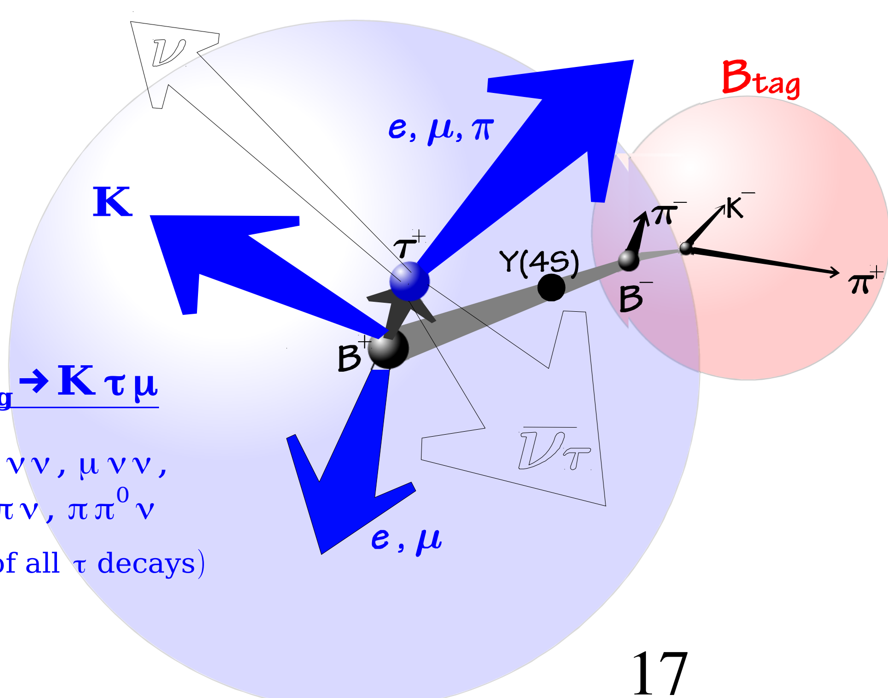
Rare/Forbidden B decays

energy frontier	intensity frontier
	
limited by beam energy	limited by statistics

→ **NP beyond the direct 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**

Many interesting B-physics studies involve missing energy
$D^{(*)}\tau\nu$, $K^{(*)}\tau l$, $K^{(*)}\tau\tau$, $K^{(*)}\nu\nu$, $\pi l\nu$, τl, $\tau\tau$, $\tau\nu$, $\mu\nu$....



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

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

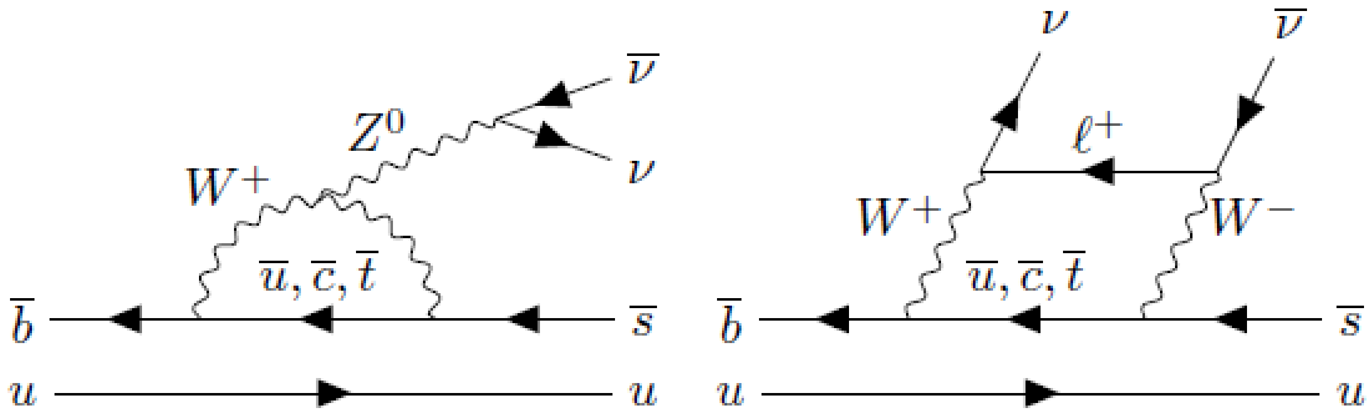
B_{tag}

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

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

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

[arXiv:2311.14647]
accepted by PRD

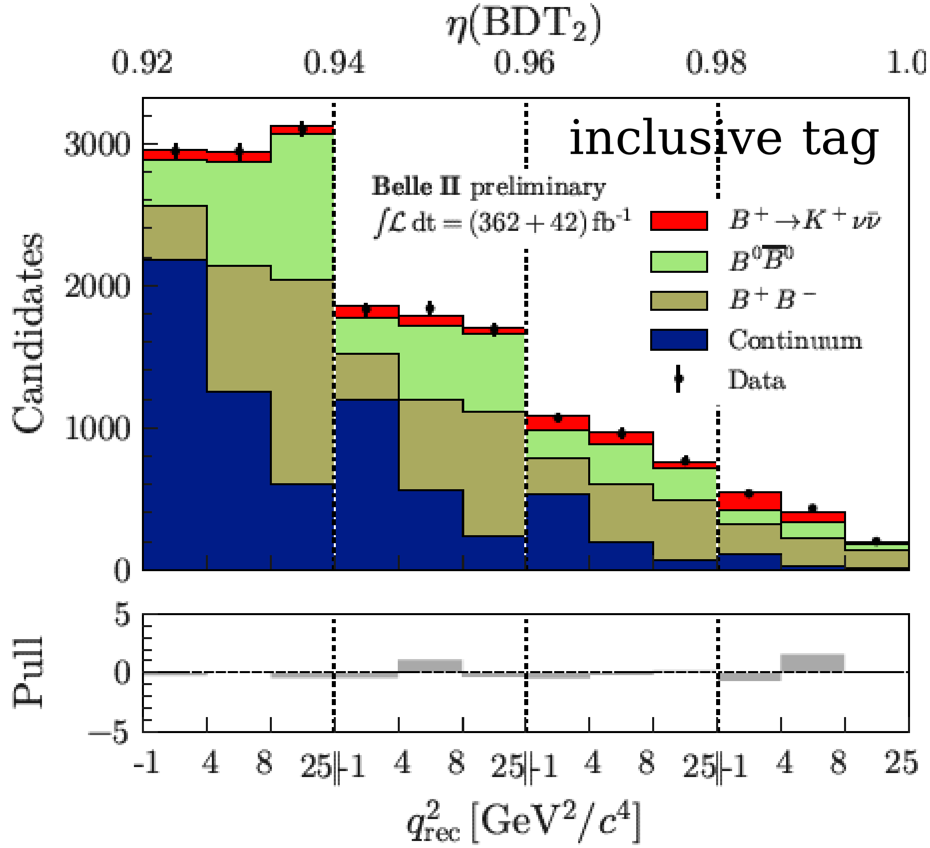


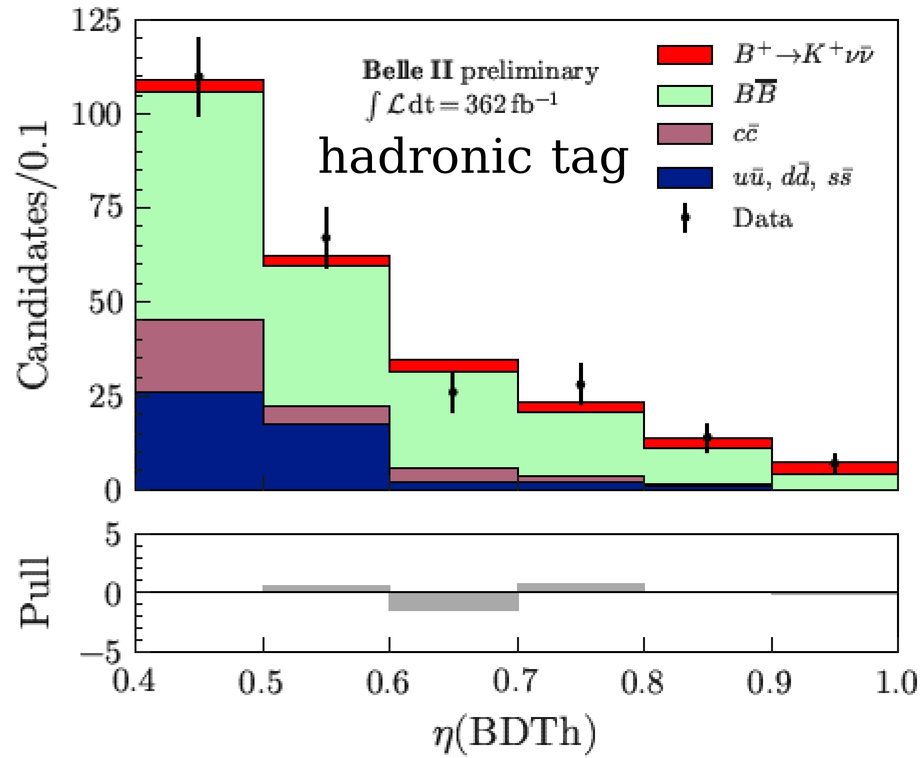
- $B \to K \nu \nu$ is known with high accuracy
  $B(B \to K \nu \nu) = (5.6 \pm 0.4) \times 10^{-6}$ [arXiv:2207.13371]
- Extensions beyond SM may lead to significant rate increase
- Very challenging experimentally, not yet observed
  - Low branching fraction, high background contributions
  - 3-body kinematics, no good kinematics
- Unique for Belle II

- Two analyses:
  more sensitive **inclusive** (eff = 8%), conventional **hadronic** tagging (eff = 0.4%)
- Use event properties to suppress background with multiple variables combined
- Use classifier output as (one of) the fit variables, use simulation for signal and background templates
- Use multiple control channels to validate simulation with data

Evidence of B→K ν ν̄

[arXiv:2311.14647]
accepted by PRD





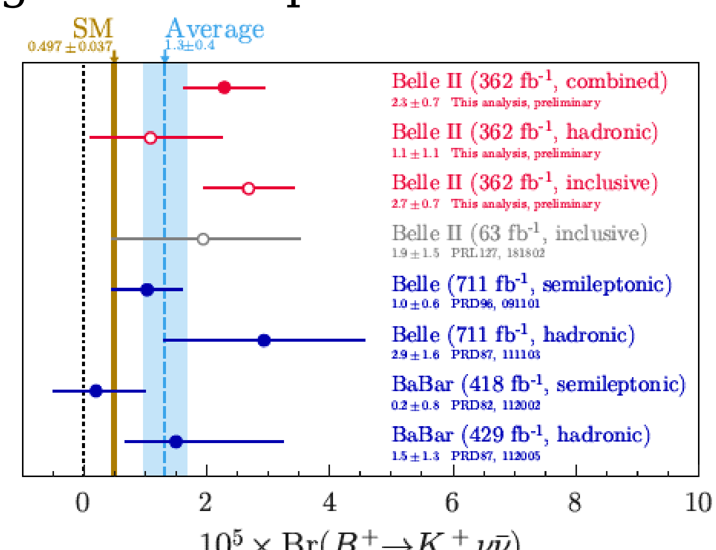
- Maximum likelihood fit to data using signal and background templates

$$\mathbf{B_{incl} = (2.7 \pm 0.5\,(stat) \pm 0.5\,(syst)) \times 10^{-5}}$$

$$\mathbf{B_{had} = (1.1\,^{+0.9}_{-0.8}\,(stat)\,^{+0.8}_{-0.5}\,(syst)) \times 10^{-5}}$$

- For inclusive analysis, evidence for B→K ν ν̄ at 3.5σ branching fraction within **3σ** of SM
- For hadronic tag, the result is consistent with null hypothesis and SM at 1.1σ and 0.6σ

⇒ Combination of two analyses provides first evidence of the decay at 2.7σ from SM

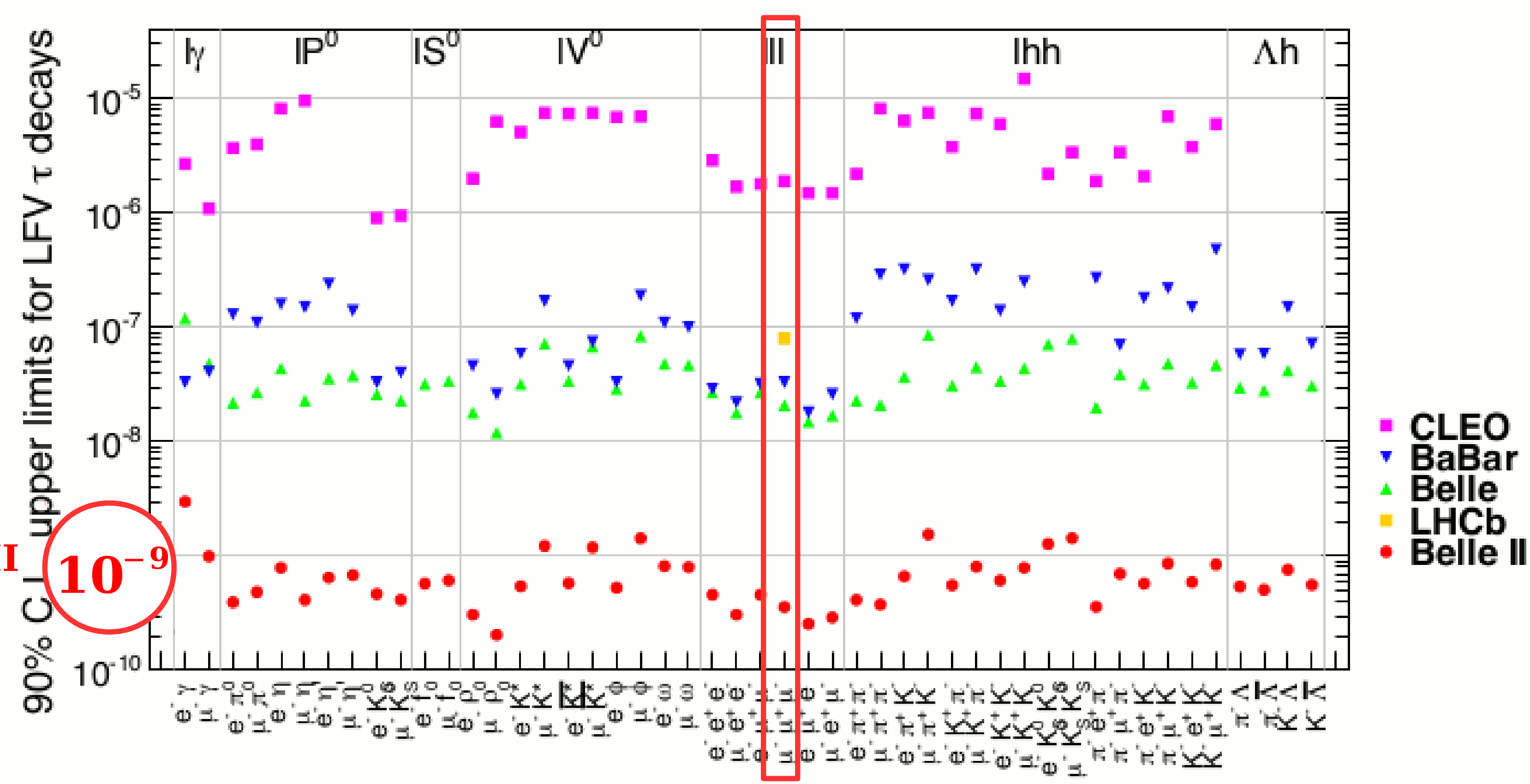


"τ factory"

- **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}

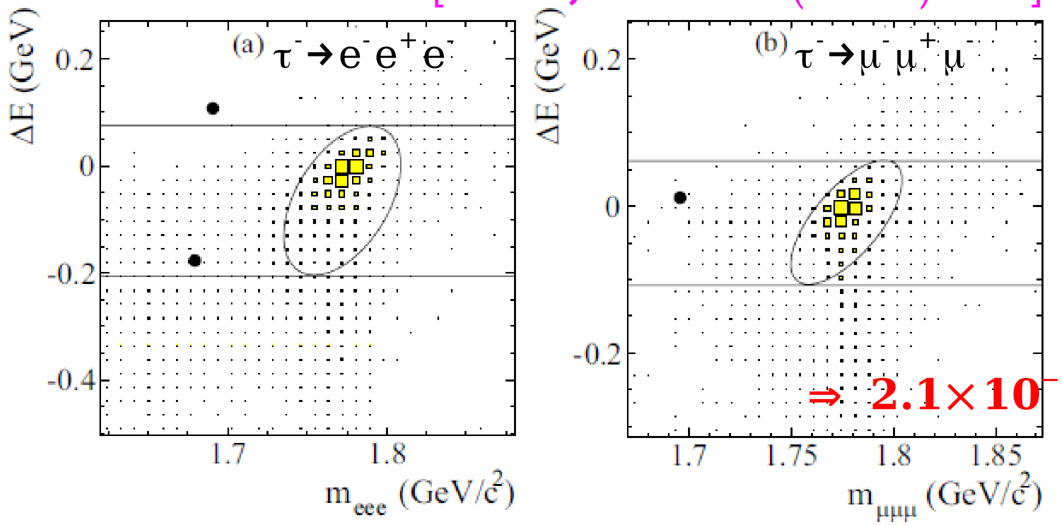


expected Belle II sensitivity

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]

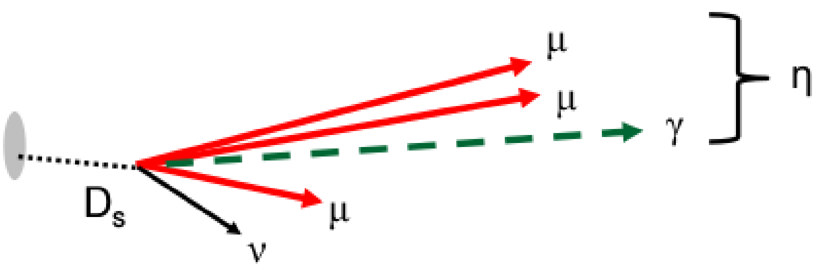


⇒ 2.1×10^{-8} at 90% CL

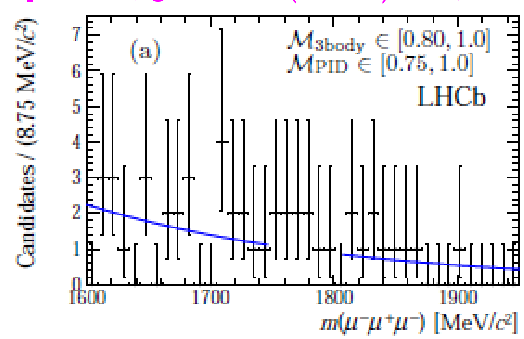
how to improve further ?

…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

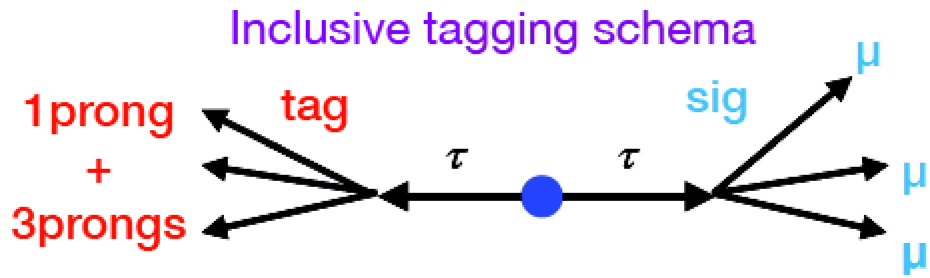
CMS, full Run 2 dataset: 2.9×10^{-8} at 90% CL

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

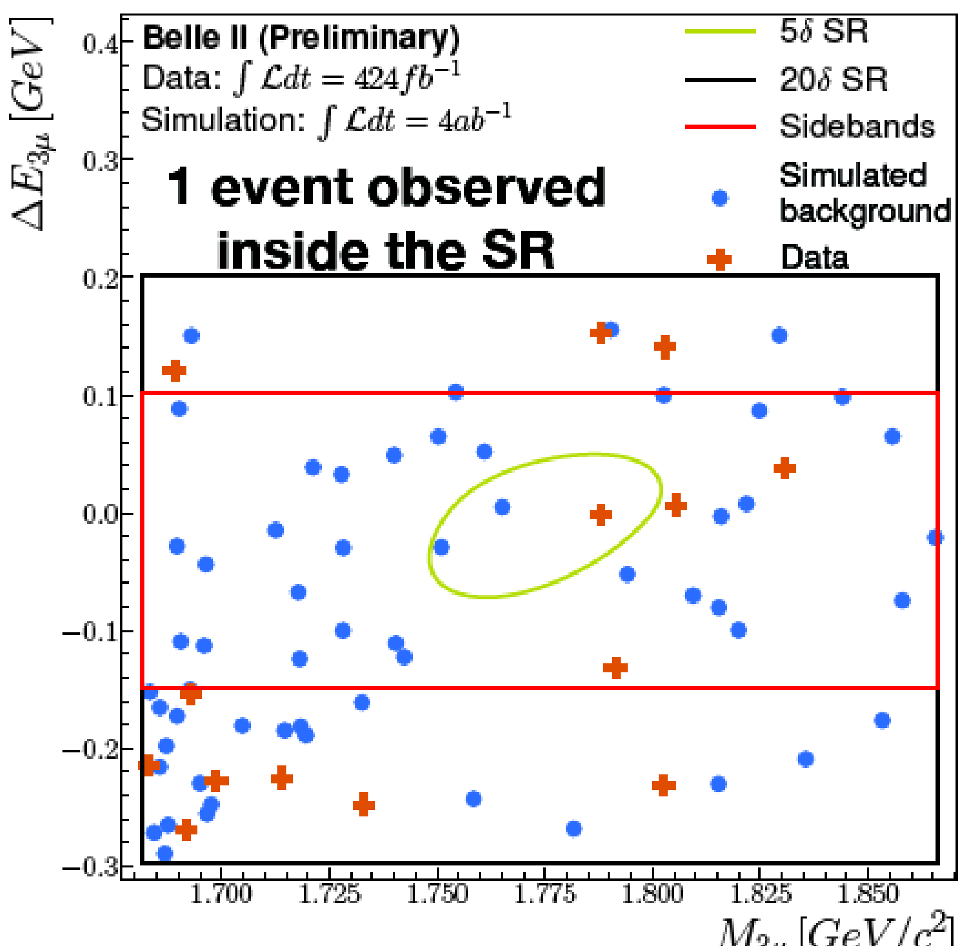
Analysis selection and results: inclusive approach

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

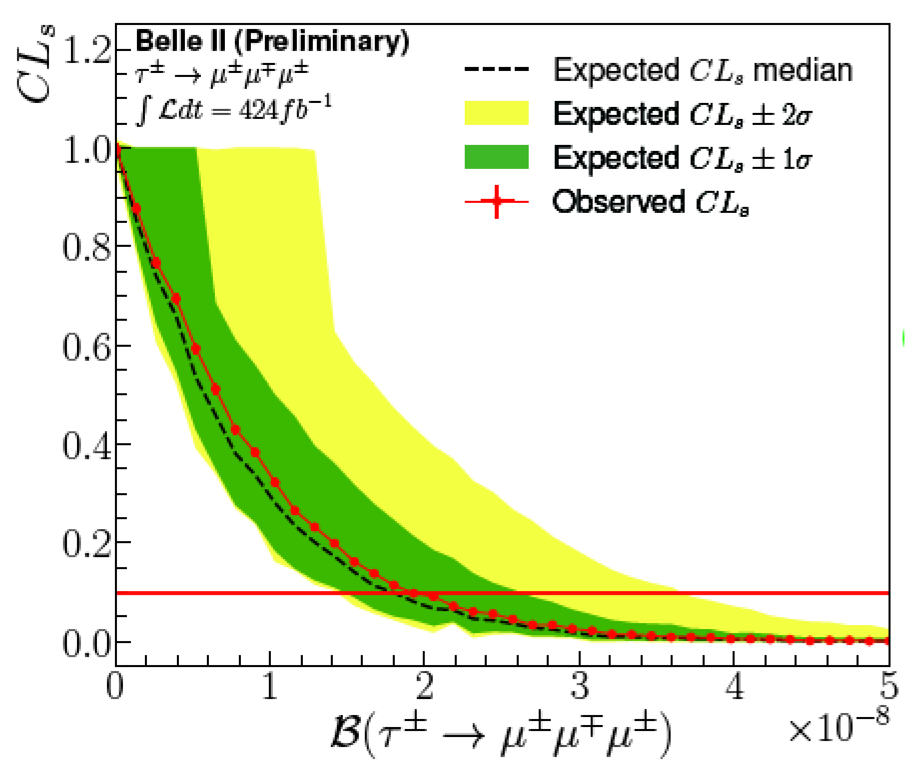


$\epsilon_{sig} = (20.42 \pm 0.06)\%$ ($3 \times$ larger than Belle)

Expected BKG: $0.5^{+1.4}_{-0.5}$ evts



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



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

Lepton universality tests at Belle II

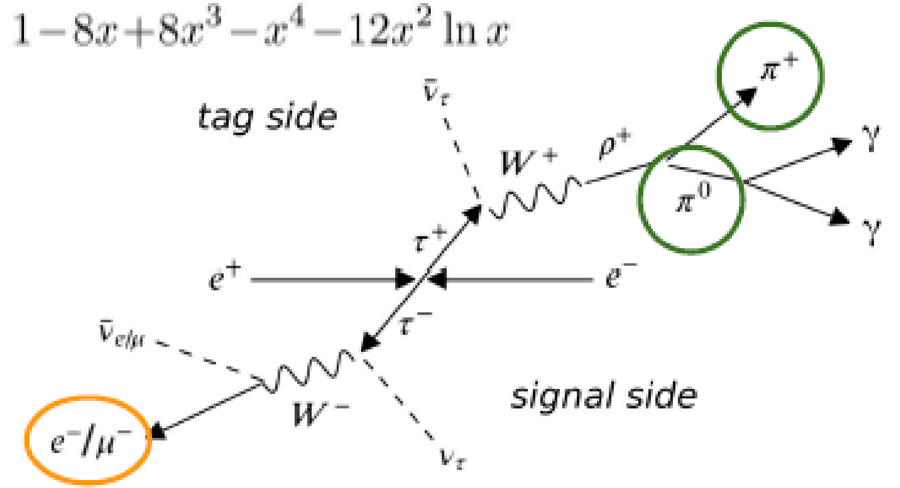
precise test of μ-e universality by measuring

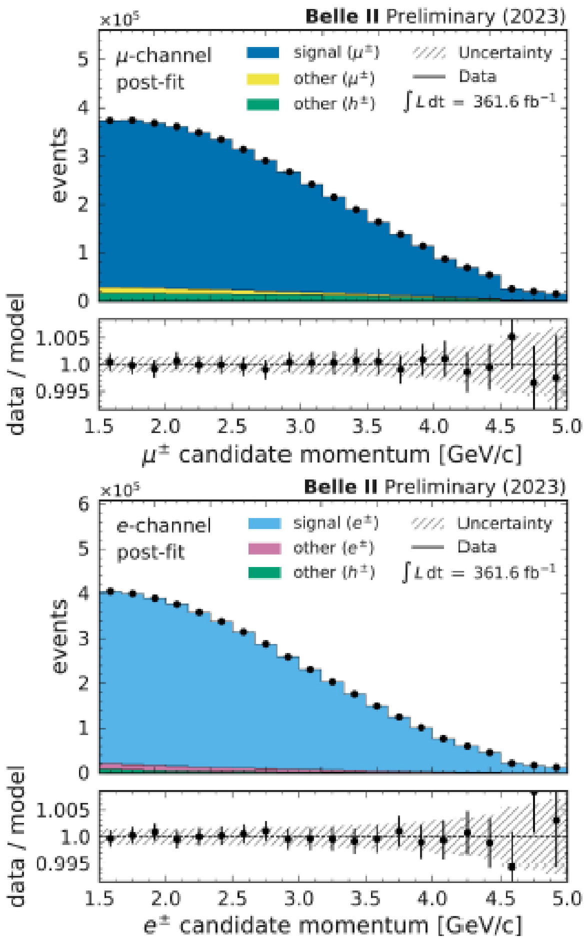
$$\left(\frac{g_\mu}{g_e}\right)_\tau = \sqrt{\frac{\mathcal{B}(\tau^- \to \nu_\tau \mu^- \overline{\nu}_\mu(\gamma))}{\mathcal{B}(\tau^- \to \nu_\tau e^- \overline{\nu}_e(\gamma))} \frac{f(m_e^2/m_\tau^2)}{f(m_\mu^2/m_\tau^2)}}$$

$$f(x) = 1 - 8x + 8x^3 - x^4 - 12x^2 \ln x$$

ratio of leptonic branching fractions

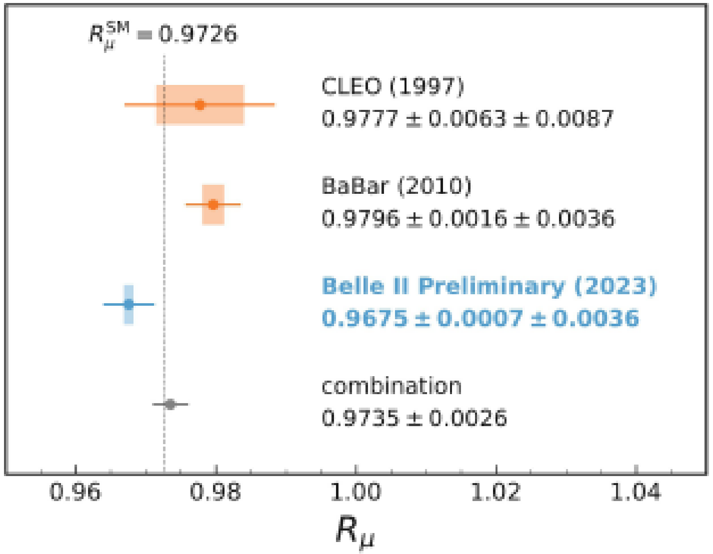
$$R_\mu \equiv \frac{\mathcal{B}(\tau^- \to \nu_\tau \mu^- \overline{\nu}_\mu(\gamma))}{\mathcal{B}(\tau^- \to \nu_\tau e^- \overline{\nu}_e(\gamma))} \stackrel{\text{SM}}{=} 0.9726$$





Source	Uncertainty [%]
Charged-particle identification:	
Electron identification	0.22
Muon misidentification	0.19
Electron misidentification	0.12
Muon identification	0.05
Trigger	0.10
Imperfections of the simulation:	
Modelling of FSR	0.08
Normalisation of individual processes	0.07
Modelling of the momentum distribution	0.06
Tag side modelling	0.05
π^0 efficiency	0.02
Modelling of ISR	0.01
Photon efficiency	< 0.01
Photon energy	< 0.01
Size of the samples	
Simulated samples	0.06
Luminosity	0.01
Charged-particle reconstruction:	
Particle decay-in-flight	0.02
Tracking efficiency	0.01
Detector misalignment	< 0.01
Momentum correction	< 0.01
Total	0.37

$R_\mu = 0.9675 \pm 0.0037$



What are our goals for 2024 ?

(please a clear and sound message)

Run stably at $10^{35}/cm^2/s$

reach 150 fb^{-1} per month

exceed 1 ab^{-1}

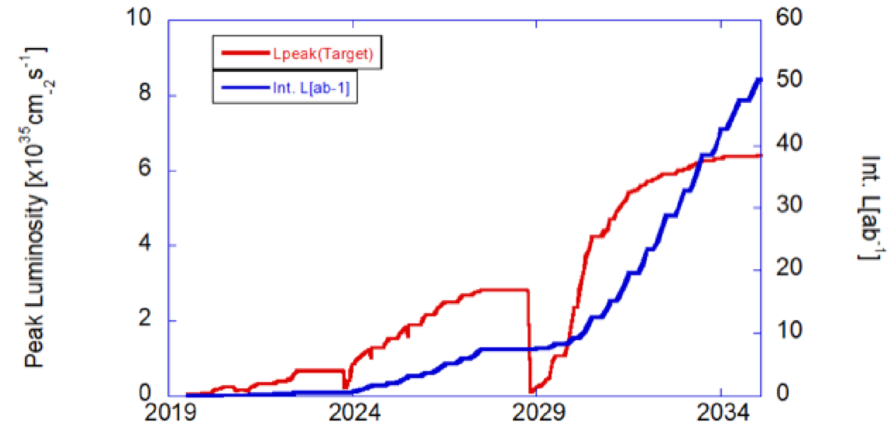
(setting the pace for run 2)
(while doing good physics and working for the upgrade)

...**'This was their finest hour.'**

Upgrade: Conceptual Design Report

(in the perspective of a LS2)

- 2018-09 Group established
- 2019-02 First presentation at BPAC
- 2020-11 Upgrade Advisory Committee established
- 2021-02 Expressions of Interest submission
- 2021-06 UAC report on EOIs/Technology downselection
- 2022-03 Snowmass White Paper Submission
- 2023-12 Upgrades Conceptual Design Report to BPAC



upgrade session at BPAC Feb 5th, 2024

11:00 AM → 11:20 AM **SKB Limitations and upgrade path**
Speaker: Mika MASUZAWA (KEK ACCL)

11:30 AM → 11:50 AM **Introduction to detector upgrade, CDR Overview, Next steps**
Speaker: Francesco FORTI (Univ and INFN, Pisa)

12:00 PM → 12:20 PM **Physics performance motivations for the upgrade**
Speaker: Alessandro GAZ (University of Padova and INFN)

12:30 PM → 1:30 PM

1:30 PM → 1:50 PM **Upgrade of tracking detectors**
Speaker: Carlos MARINAS (IFIC - Valencia)

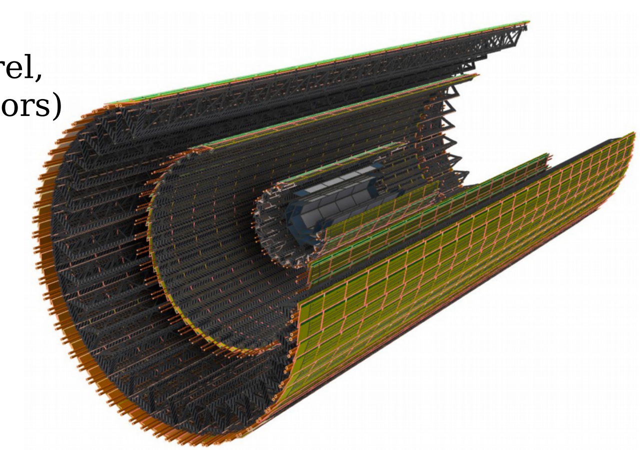
2:00 PM → 2:20 PM **KLM upgrade** ¶
Speaker: Haruki KINDO (KEK IPNS)

2:30 PM → 2:50 PM **Chiral Belle**
Speaker: John Michael RONEY (University of Victoria)

CDR presents several possible detector improvements on different time scales.

Main goal of the CDR is to have a document describing the different proposals discussed in Belle II collaboration and make it public in a timely manner (spring 2024) to allow the organization of the next steps on the path: R&D and engineering activities, preparation of TDRs for the most promising proposals, submittal of funding requests to funding agencies etc...

VTX - DMAPS
(5 straight layers barrel, using CMOS pixel sensors)



Upgrade: Conceptual Design Report

Belle II's request to BPAC (Feb 2024)

- We would greatly appreciate feedback from the committee to help us understand:
  - whether we have a reasonable concept for what the Belle II upgrade could be, especially on short and medium (LS2) term;
  - what are the weak points which must be fixed in the next phase;
  - **what proposals are worth further investigation** pushing them in the next phase, including a complete physics motivation and a detailed technical design forming the base for a future approval.

BPAC short report (March 2024)

The CDR for the LS2 upgrade plans, presented during this meeting, described various ideas for how to increase the machine luminosities, enhance the detector performance and the tolerance against beam backgrounds and radiation damage. Some of them are well advanced, in particular the new vertex detector system (VTX), which is envisioned to replace the current vertex detector, for which the committee recommends that the group should advance towards the engineering level of studies, including the aspects of system integration and operation.

The machine group presented an upgrade path with a new set of final focusing magnets. Since they have just started machine operations after the Long Shutdown 1 with a lot of changes and improvements having been made, they need first to understand the behaviour of the machine in order to identify the remaining causes of luminosity limitation and to provide a definite scheme for the upgrade.

Upgrade: Conceptual Design Report

Belle II's request to BPAC (Feb 2024)

- We would greatly appreciate feedback from the committee to help us understand:
  - whether we have a reasonable concept for what the Belle II upgrade could be, especially on short and medium (LS2) term;
  - what are the weak points which must be fixed in the next phase;
  - **what proposals are worth further investigation** pushing them in the next phase, including a complete physics motivation and a detailed technical design forming the base for a future approval.

BPAC short report (March 2024)

While the CDR provides an excellent initial framework to continue the development of the plans for the upgrade, the BPAC is not yet in a position to judge the validity of the plan described in the CDR. While the committee recommends further R&D work to continue, it also thinks that a new document providing a coherent and integrated description of the accelerator and detector upgrade plan with a quantitative demonstration of expected physics performance should be submitted for making a decision on the project.

Summary

- Run 1 sample is providing competitive results…
  - in B physics with missing energy (e.g. $B \to K \nu \bar{\nu}$)
  - 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 4-5 years and impact the flavor/DS sector
- Upgrade:
  - understanding the IR envelope and design as soon as possible is of primary importance
  - more details about the linac and RF upgrades
  - scope and timeline to flesh out and write up

Background mitigation expert (M&O)

OPENED DATE (YYYY/MM/DD)	2023/12/11
NO.	IPNS23-13
INST./LAB.	Institute of Particle and Nuclear Studies
TITLE	Assistant Professor
TERM	three years with the contract renewal every fiscal year
NUMBER	1 person
DEADLINE (YYYY/MM/DD, TIME)	2024/02/14 noon(JST)*(To reach KEK by) noon , Wednesday, February 14, 2024 (JST)
INTERVIEW DATE	Tuesday, March 5th, 2024 (Only the applicants who passed our documentary screening will be informed of the details of the interview.)
GUIDELINES FOR APPLICATION	IPNS23-13

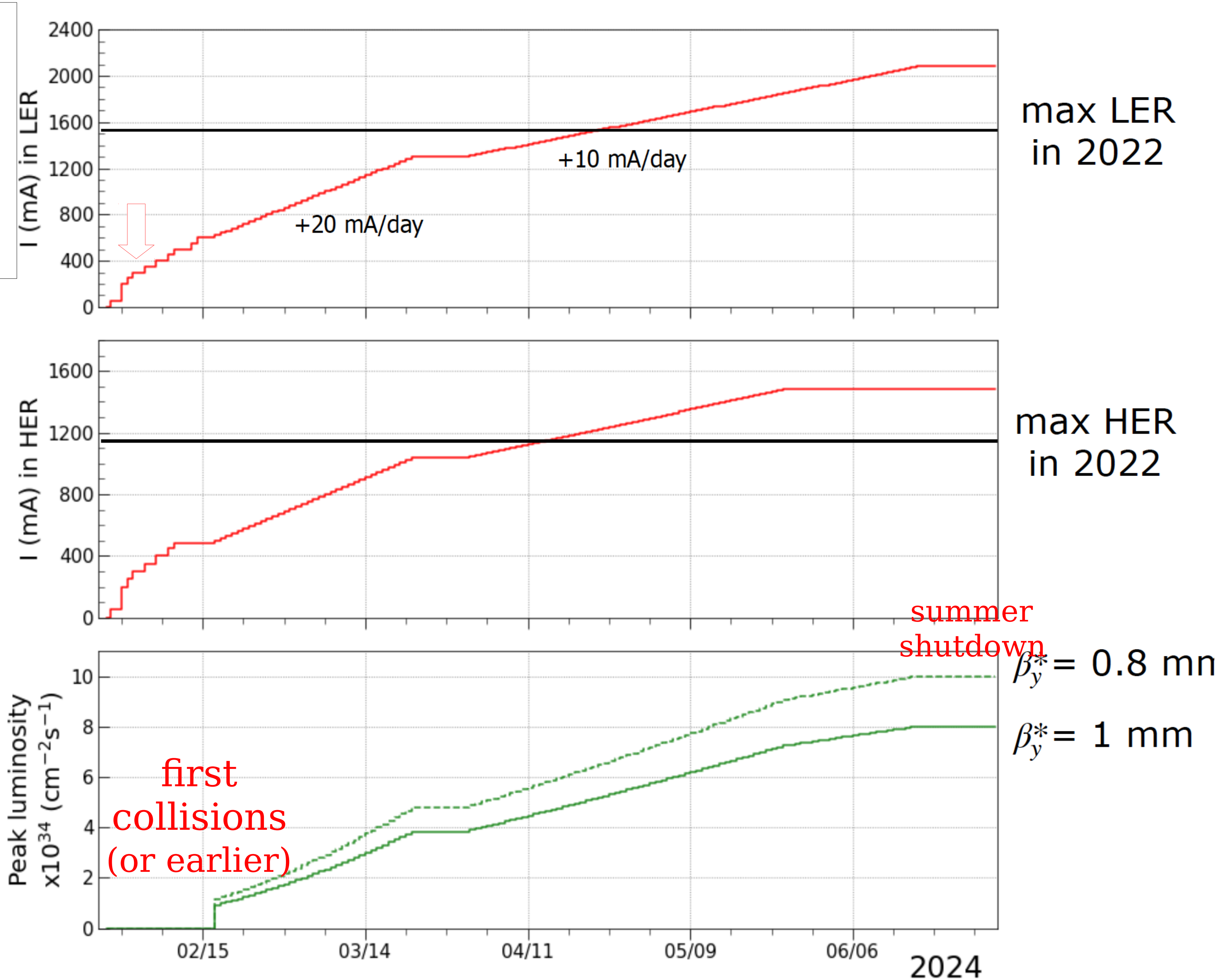
Job Description

Institute of Particle and Nuclear Studies is seeking to fill a term-limited assistant professor position. The successful candidate will belong to the Institute of Particle and Nuclear Studies as an expert on the Machine Detector Interface between the Belle II experiment and the SuperKEKB accelerator, and carry out researches such as to mitigate the beam induced background from the SuperKEKB accelerator, and to maximize the physics output from the Belle II detector. The workplace is the Tsukuba campus.

Qualification

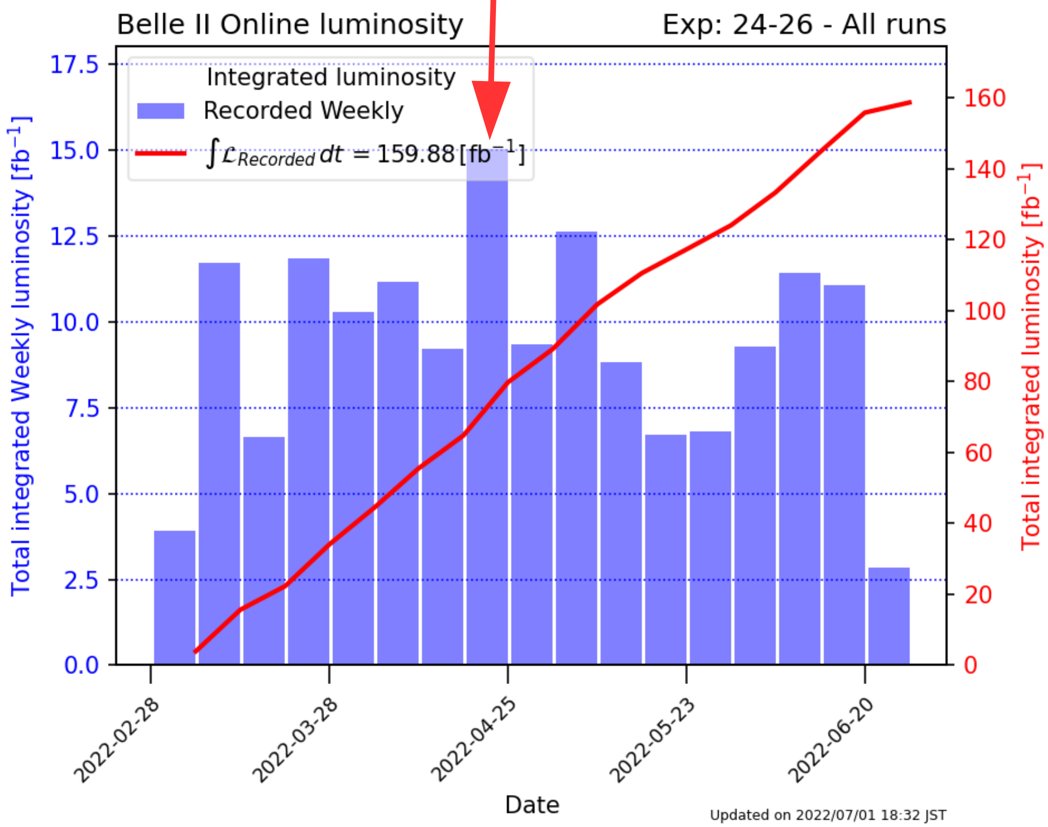
Applicants must have good skills in research and education, and must demonstrate capabilities to carrying out the described jobs.

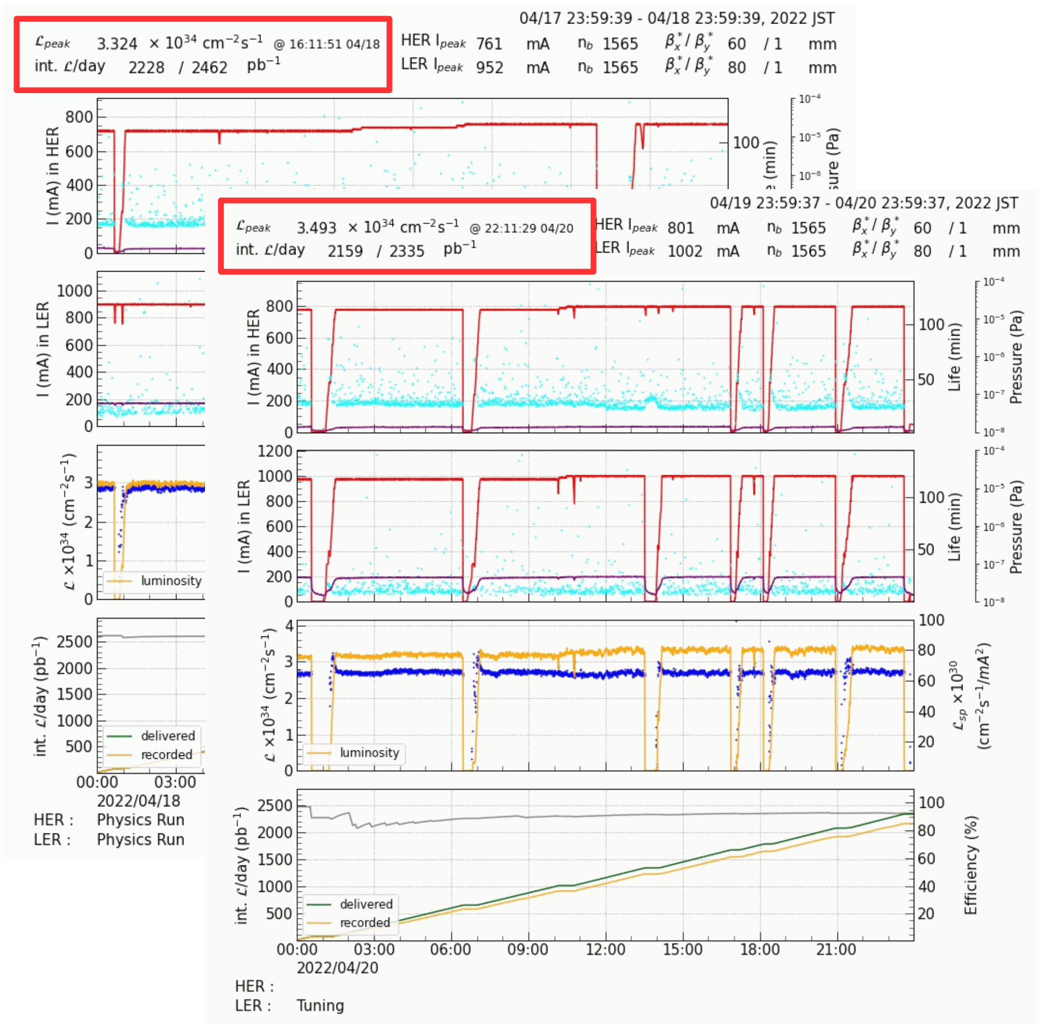
Reaching and running stably at $10^{35}/cm^2/s$



Reaching 150 fb^{-1} per month

In end of April 2022, 15/fb per week could be reached when instantaneous luminosity was $\sim 3.5 \times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$

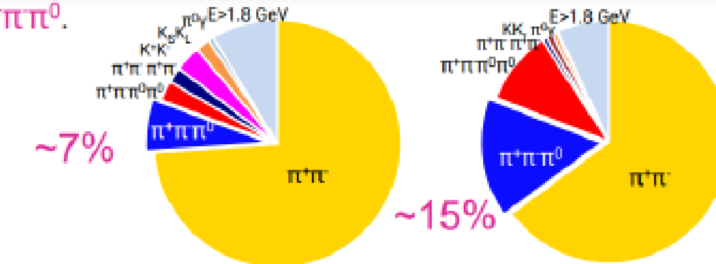




$$\Rightarrow\ 15\times4\times2.5 = 150\,\mathrm{fb}^{-1}/\mathrm{month}\ \text{at}\ \mathrm{L} = 10^{35}\mathrm{cm}^{-2}\mathrm{s}^{-1}$$

$\sigma(e^+e^- \to \pi^+\pi^-\pi^0)$

- We aim to measure the cross section of $e^+e^- \to \pi^+\pi^-\pi^0$.
  - The second largest contribution to HVP



Muon anomalous magnetic moment

$$a_\mu = \frac{g-2}{2} = a_\mu^{\mathrm{QED}} + a_\mu^{\mathrm{EW}} + a_\mu^{\mathrm{QCD}}$$

Hadron contribution term

$$a_\mu^{\mathrm{QCD}} = a_\mu^{\mathrm{HVP}} + a_\mu^{\mathrm{HLbL}}$$

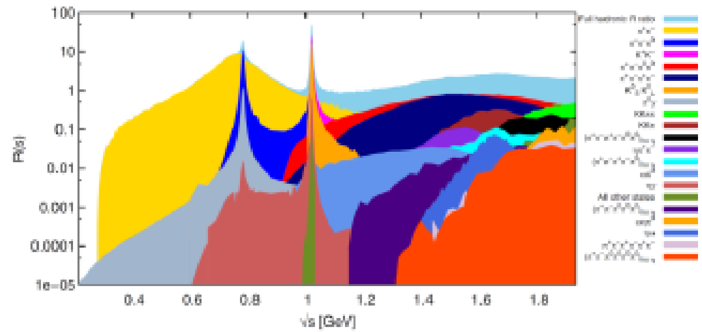
Leading-order HVP rerm

$$a_\mu^{\mathrm{HVP,LO}} = \frac{\alpha^2}{3\pi^2}\int_{m_\pi^2}^{\infty} \frac{ds}{s} R(s)K(s)$$

Hadronic R-ratio

$$R(s) = \frac{\sigma(e^+e^- \to hadrons)}{\sigma(e^+e^- \to \mu^+\mu^-)}$$

Measured R-ratio



(a) The hadronic R-ratio.

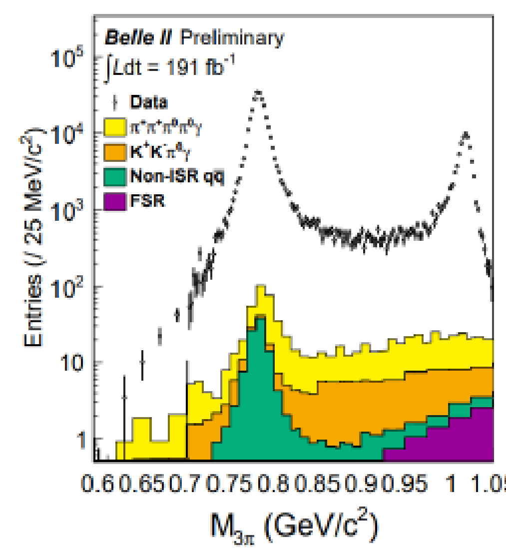
$\sigma(e^+e^- \to \pi^+\pi^-\pi^0)$

Signal process : $e^+e^- \to \gamma_{\mathrm{ISR}}\pi^+\pi^-\pi^0(\to\gamma\gamma)$

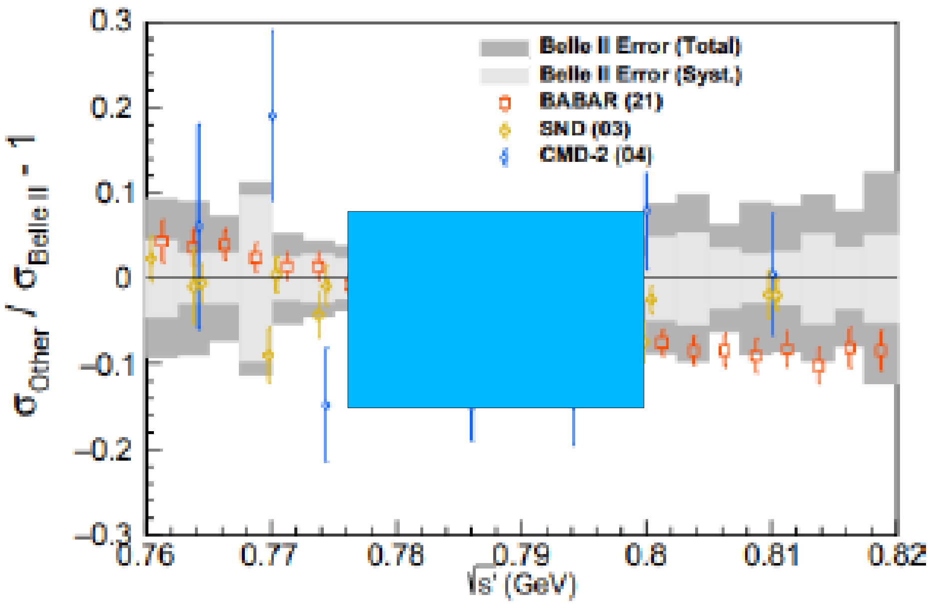
$$\frac{dN_{\mathrm{signal}}}{dm} = \sigma_{ee\to3\pi} \cdot \varepsilon \cdot \frac{d\mathcal{L}_{\mathrm{eff}}}{dm}$$

Signal spectrum — **3π mass** — **Cross section** — **Efficiency** — **Effective luminosity**

- Initial-state radiation technique – wide invariant mass range
- Partial Run 1 data set – 191 fb^{-1}
- Selection via kinematic fits
- Key challenge is π^0 efficiency
  - Custom determination using ω decay
- Background control samples for $e^+e^- \to \pi^+\pi^-\pi^0\pi^0\gamma_{ISR}$, $e^+e^- \to q\bar{q}\gamma_{ISR}$ and $e^+e^- \to K^+K^-\pi^0\gamma_{ISR}$



$\sigma(e^+e^- \to \pi^+\pi^-\pi^0)$



$$a_\mu^{3\pi} = ([redacted] \pm 0.23 \pm 1.07) \times 10^{-10},$$

[redacted] σ tension with BaBar

Source	0.62–1.05 GeV/c^2	
Trigger	0.1	(−0.09)
ISR photon detection	0.7	(+0.15)
Tracking	0.8	(−1.35)
π^0 detection	1.0	(−1.43)
Kinematic fit (χ^2)	0.6	(+0.0)
Event selection	0.2	(−1.90)
Generator	1.2	
Integrated luminosity	0.6	
Radiative corrections	0.5	
MC statistics	0.2	
Background subtraction	0.3–0.5	
Unfolding	0.7–15	
Total uncertainty	2.2-15	
(Total correction $\varepsilon/\varepsilon_{MC} - 1$)		(−4.61)

Next the largest contribution

$$\sigma(e^+e^- \to \pi^+\pi^-)$$

- Few parts per mille measurement required
- Team assembled
- Fits and tracking systematics studies ongoing
- Particle ID, trigger, backgrounds, unfolding to be studied
- 1-1.5 years