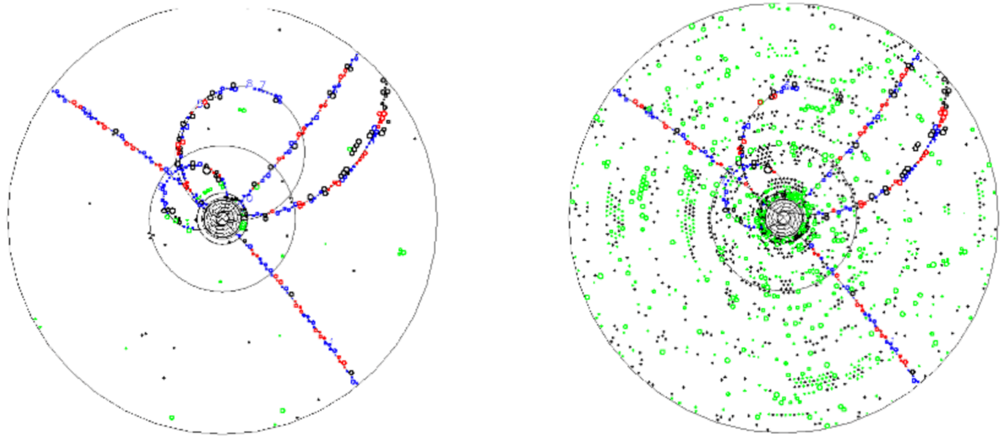
Belle II and LHCb Upgrade I Performance

Petar Rados (HEPHY)
July 20 2023
on behalf of the Belle II and LHCb Collaborations

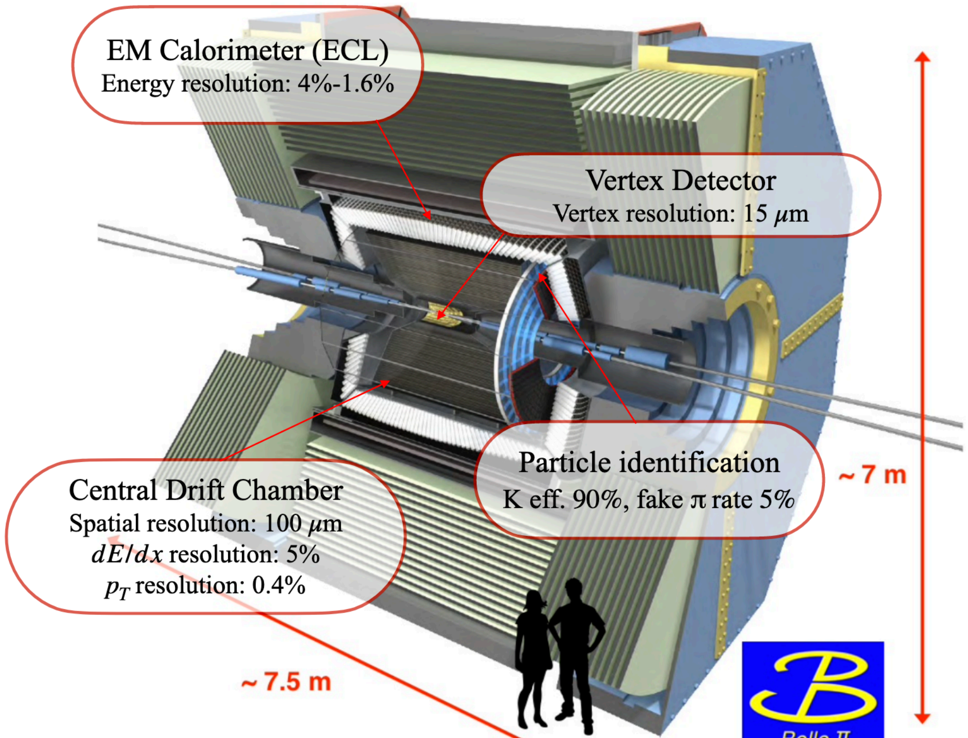
Belle II Detector at SuperKEKB

- Next generation B-factory: $e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\bar{B}$, $\sqrt{s} = 10.58GeV$ + rich program of low-multiplicity physics.
- **KEKB → SuperKEKB accelerator**
  - 2x beam currents, 50nm vertical beam spot size (“nano beam”).
  - design peak luminosity 2.1×10^{34} → $\mathbf{6.0\times10^{35}}$ **$cm^{-2}s^{-1}$**.
  - SuperKEKB currently holds world record ($4.7\text{x}10^{34}$ $cm^{-2}s^{-1}$).

KEKB SuperKEKB



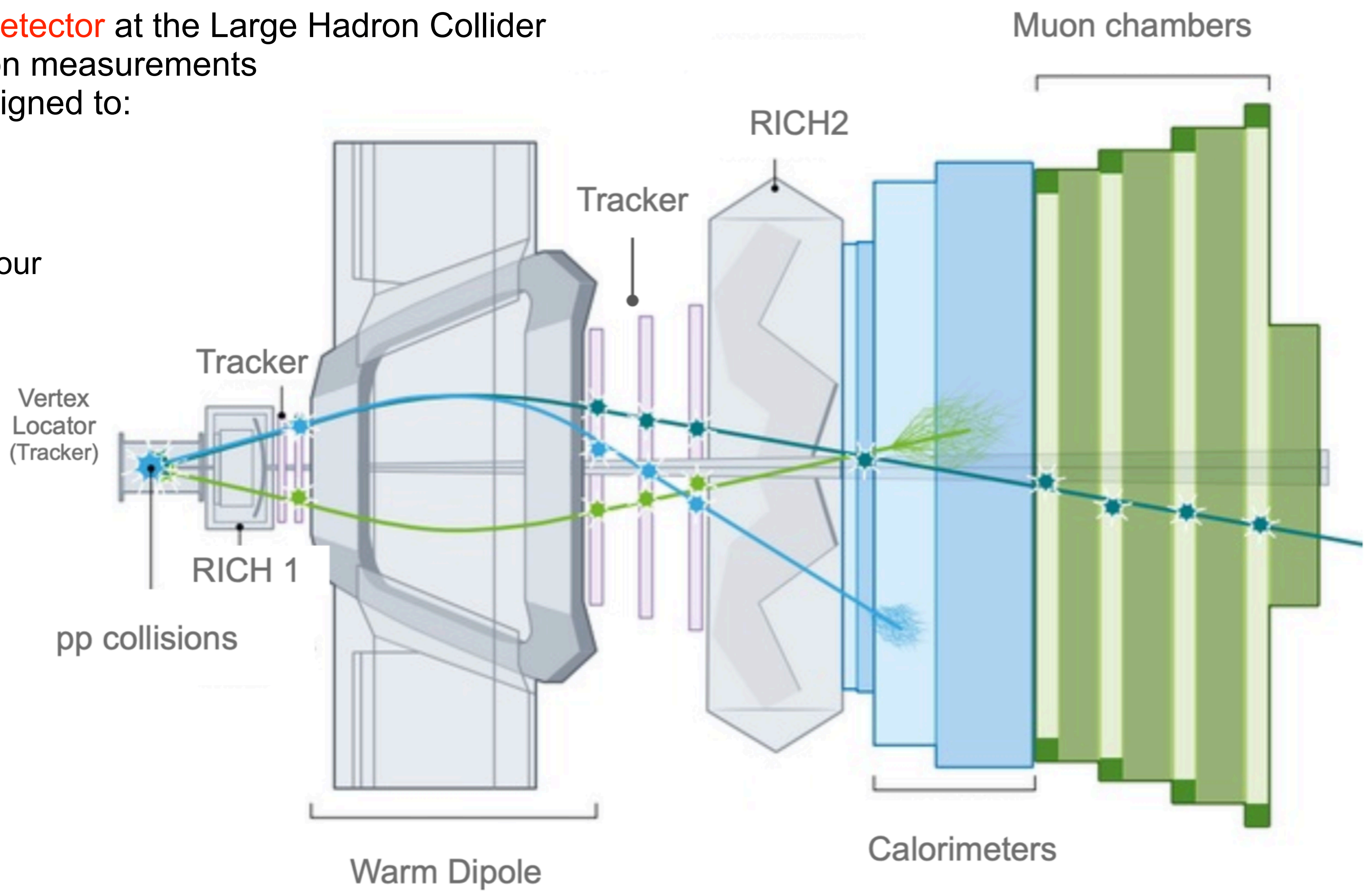
- Consequently, SuperKEKB has higher beam background conditions and event rates.



Belle II TDR: arXiv:1011.0352

- **Belle → Belle II detector**
  - New 2-layer Pixel Detector (PXD) with first layer at 1.4cm, significantly improves vertexing (full inner + partial outer layer).
  - 4-layer Silicon Vertex Detector (SVD) with larger acceptance.
  - Central Drift Chamber (CDC) with larger outer radius.
  - Improved particle ID: TOP + new ARICH (K/π separation).
  - Improved trigger, and faster electronics in general.

- LHCb is a general-purpose forward detector at the Large Hadron Collider which is particularly suited to precision measurements in the beauty and charm sectors, designed to:
  - Capture forward production
  - trigger on low p_T
  - provide particle identification for flavour tagging and distinguishing topologically similar decays e.g. $B \to \pi\pi$, $B \to K\pi$



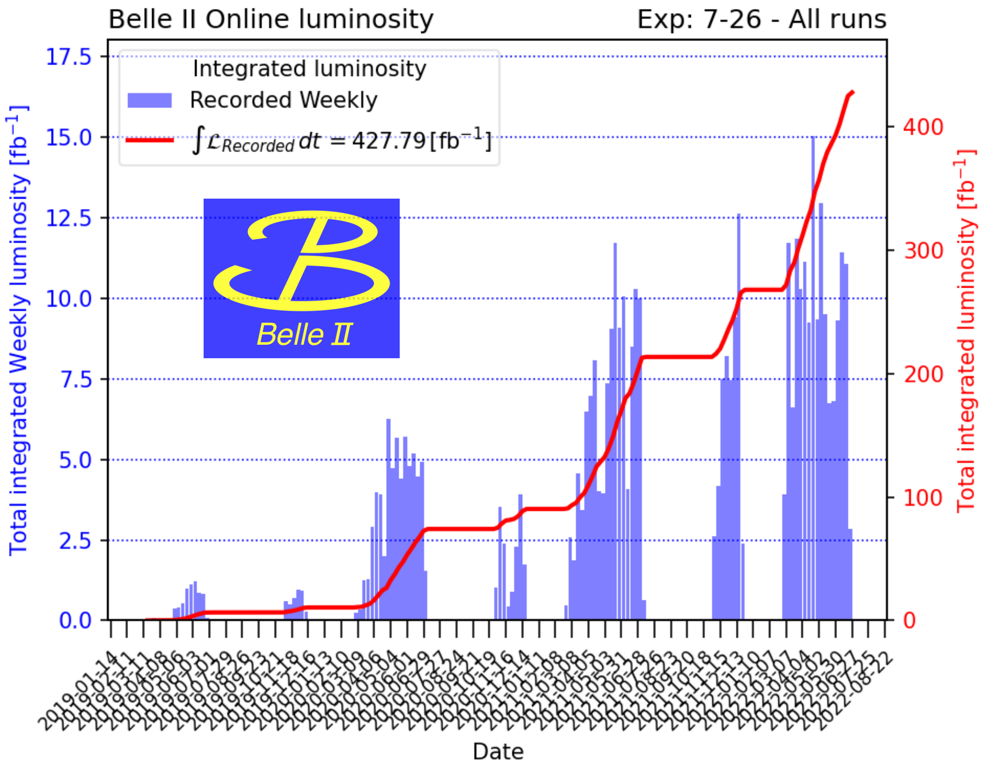
Working outward:

VELO
RICH1
TT
Magnet
OT+IT (T-stations)
RICH2
Muon station 1
SPD/PS
ECAL
HCAL
Muon stations 2-5

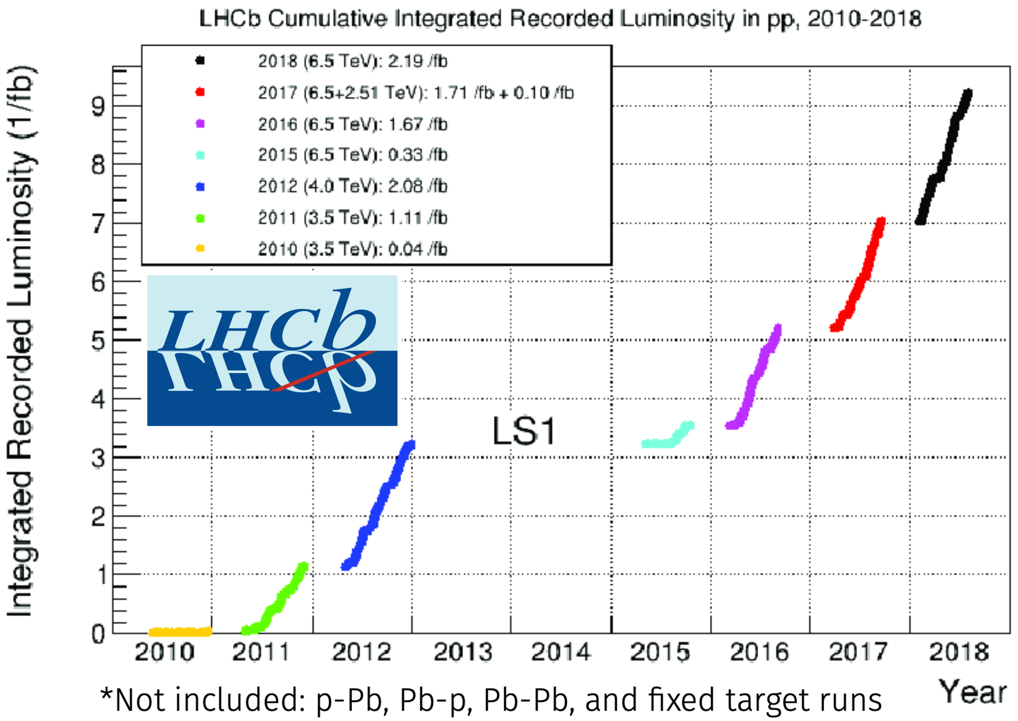
Tracking
Particle ID
Both

Luminosity Status and Outline

Run1 of **Belle II** (2019 - 2022): 428 fb^{-1}



Run1+2 of **LHCb** (2011 - 2018): 9 fb^{-1}



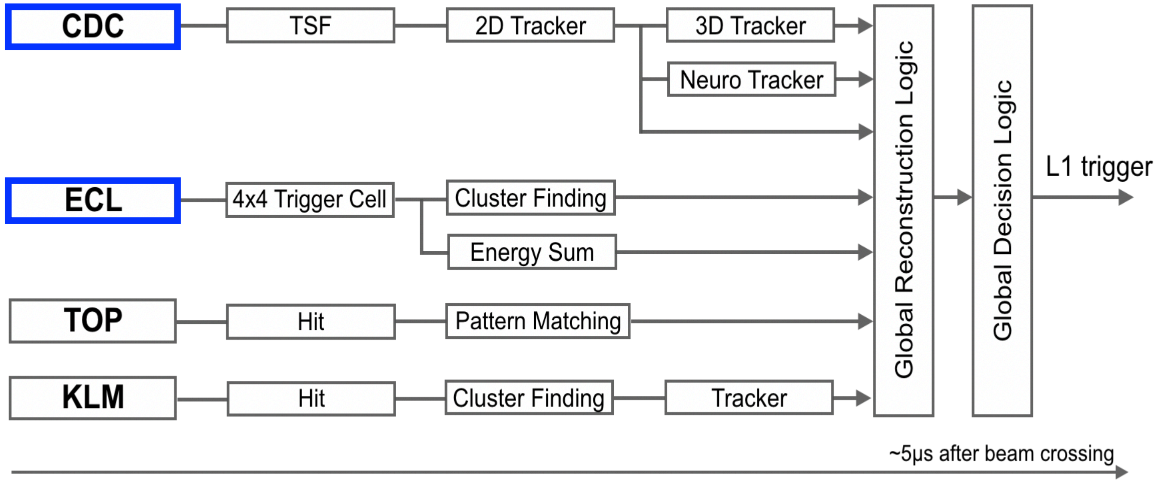
*Not included: p-Pb, Pb-p, Pb-Pb, and fixed target runs

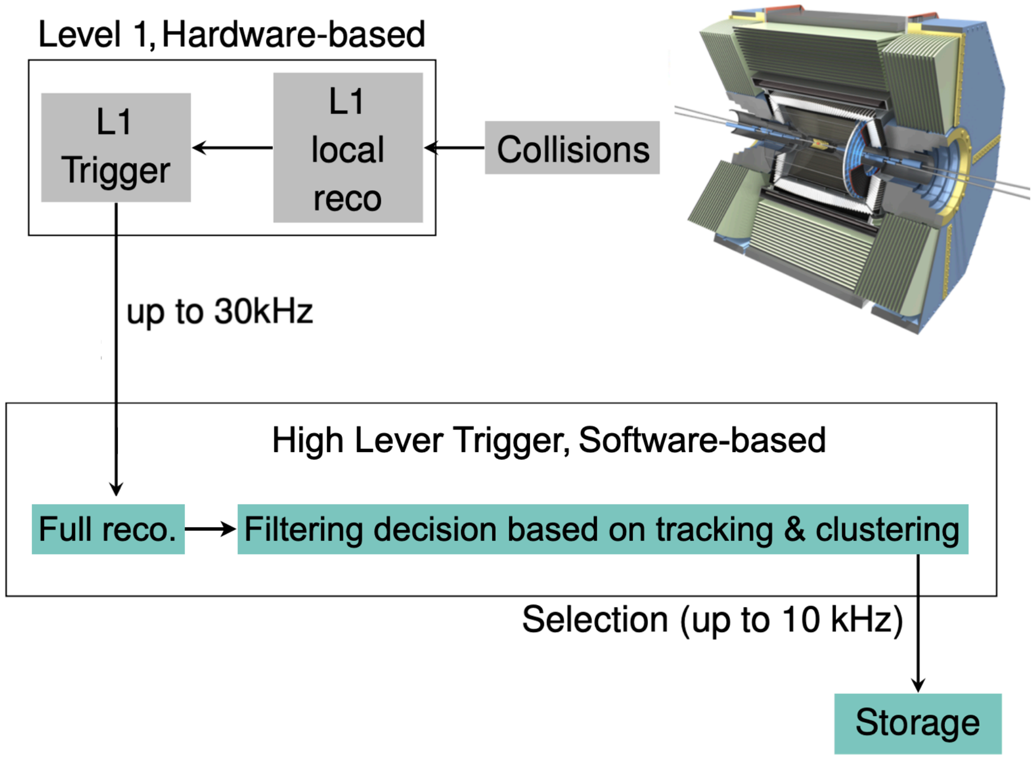
- The first part of this talk will be on **Belle II performance during Run1**.
- After Run2 LHCb underwent a major upgrade → "Upgrade I". Run3 with the upgraded detector started last year. The second part of this talk will be on **LHCb Upgrade I performance**.

Belle II Performance

- Hardware-based **Level 1 trigger** must reduce total rate to a maximum of 30 kHz. Requirements:
  - high efficiency for both low and high multiplicity physics
  - latency ~5μs, timing precision ≤ 10 ns, two event separation ≥ 200 ns

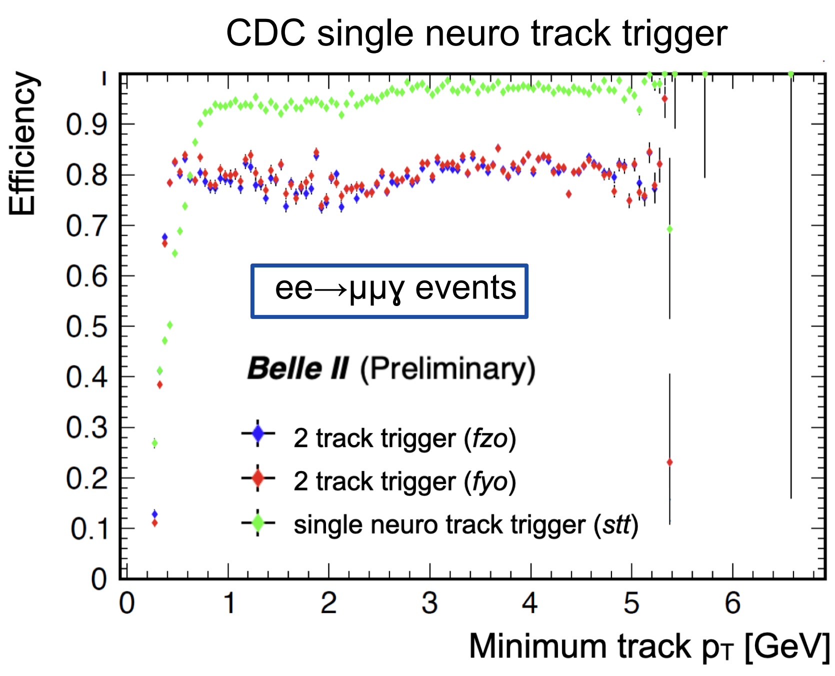
- Two primary components: Central Drift Chamber and Electromagnetic Calorimeter based triggers.
  - CDC 2D (r-ϕ space), 3D & neural network track finding
  - ECL total energy and cluster finding, low-multiplicity cluster topology, Bhabha veto.

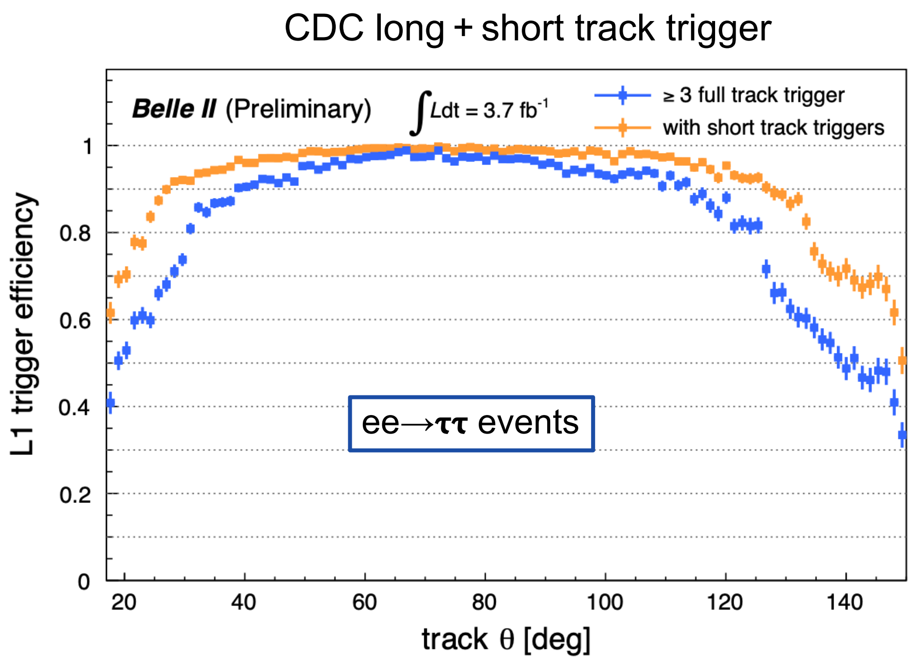


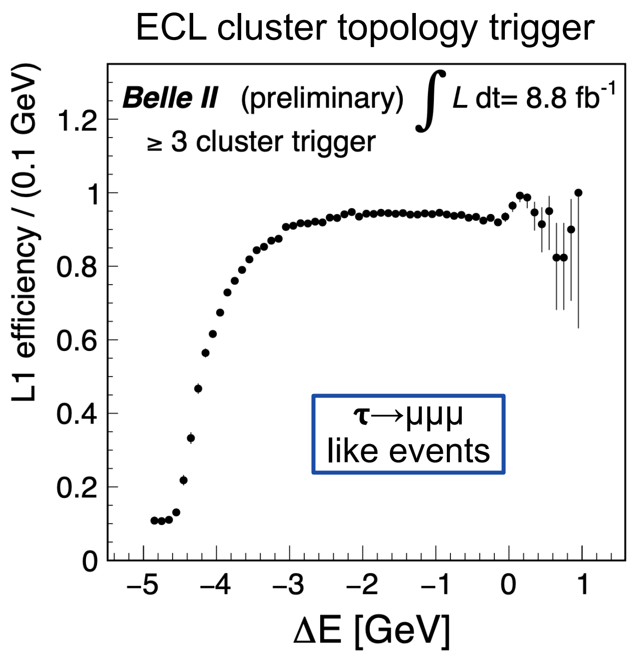


- Software-based **High Level Trigger** then reduces rate to manageable level, at most 10 kHz.
  - Discards background events with selections based on full event reconstruction, very similar to offline.
  - Menu of trigger lines carefully designed to cover the compete Belle II physics program.

Trigger Performance







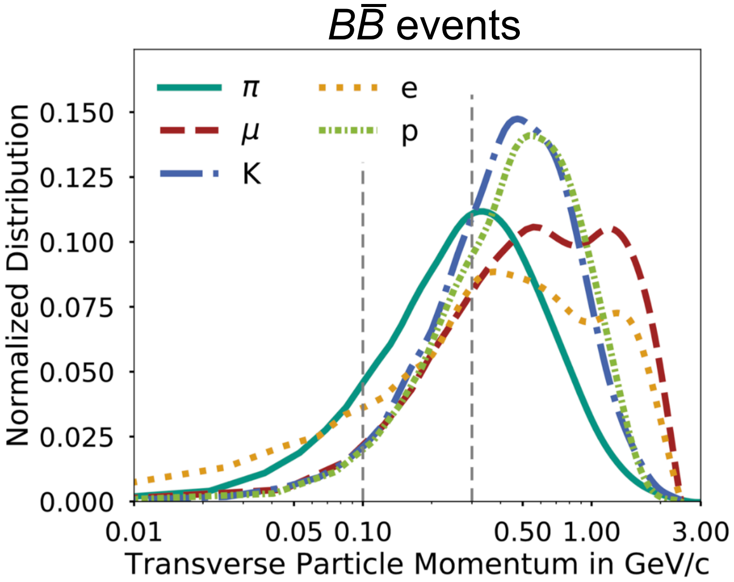
- Several triggers are unique to Belle II and not previously available at Belle
  - e.g. neural network single track trigger, track pair with small opening angle, short tracks, ECL cluster topology.

- We observe major gains in efficiency
  - **Opens up new Dark Sector & Tau Physics opportunities at Belle II**, even with less data.
  - See talk by *Savino Longo* on Tuesday.

- Challenges of tracking at Belle II:
  - Many tracks at low momentum (multiple scattering, curling tracks).
  - Larger machine backgrounds and high occupancy. Typical Υ(4S) event has 11 tracks $\Rightarrow O(10^2)$ signal vs $O(10^4)$ bkg hits.

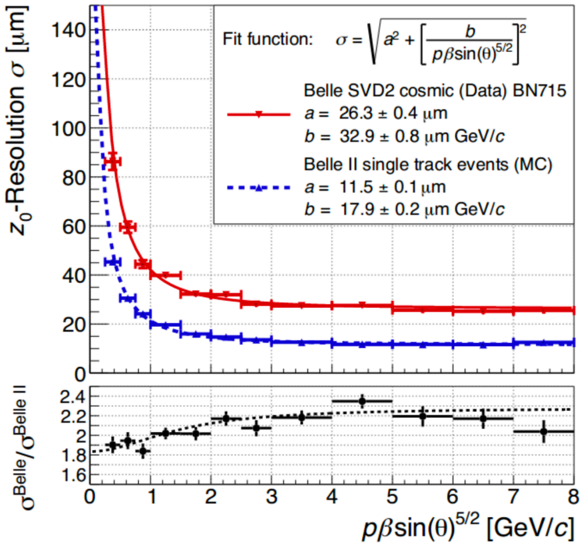
- Belle II has state-of-the-art tracking detectors *and software*.

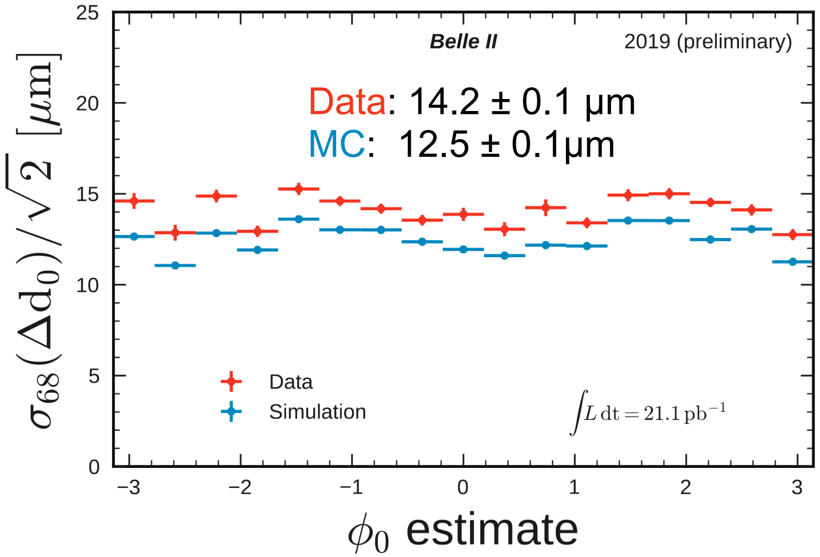
- Modular code structure, with flexibility for reconstruction sequence. See:
  - Belle II software and tracking algorithms papers.
  - Belle II Analysis Software Framework (basf2) repository.



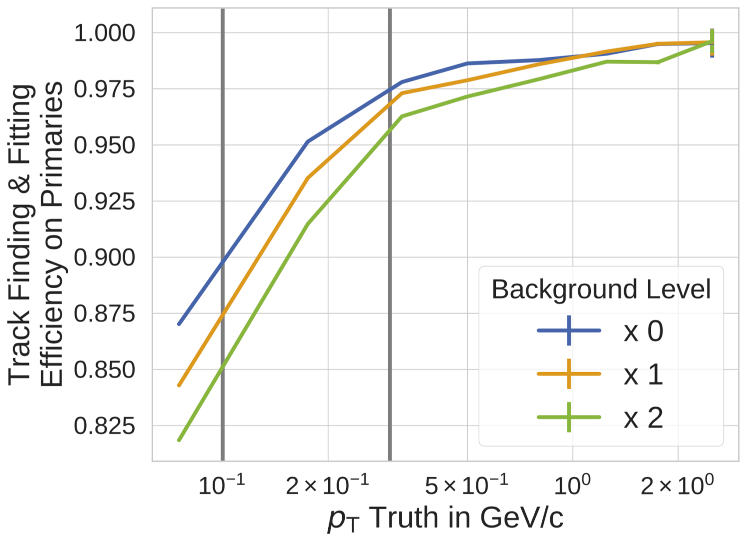
- Excellent tracking performance is critical to achieving our physics goals (e.g measurement of time dependent CP violation).

PXD provides ~2x better single vertex resolution wrt Belle.

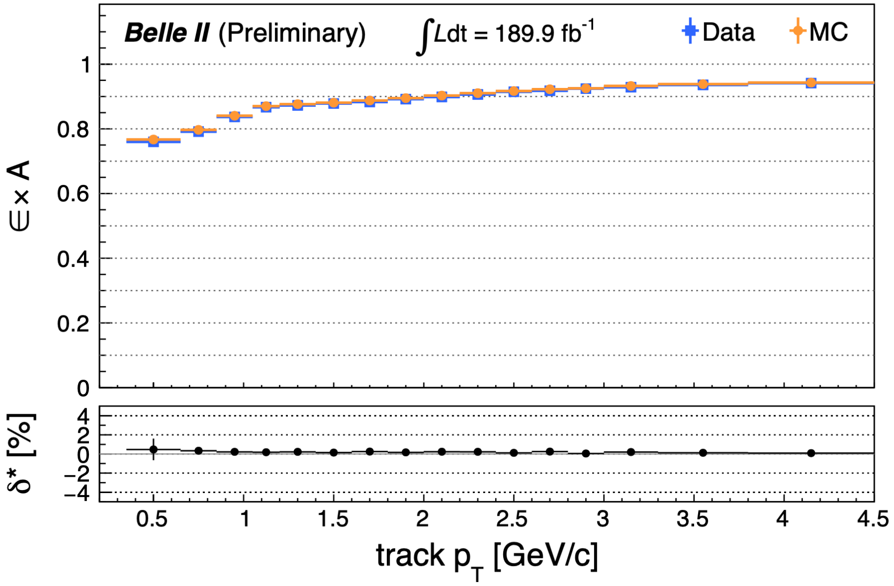




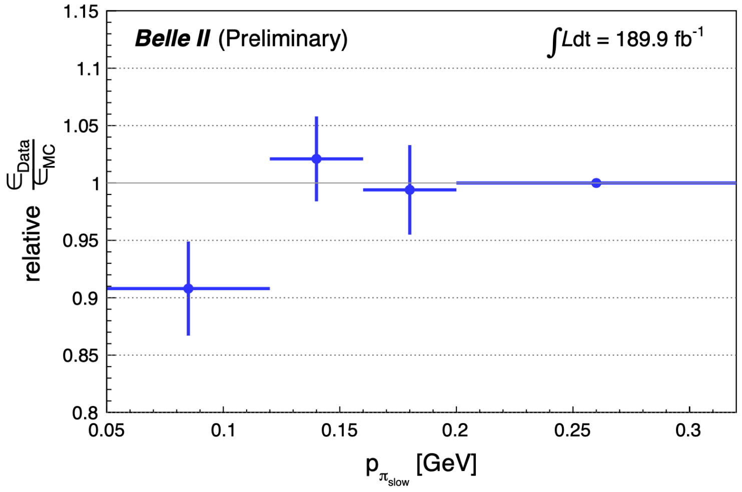
MC efficiency @ nominal background



Fast-track efficiency: data vs MC

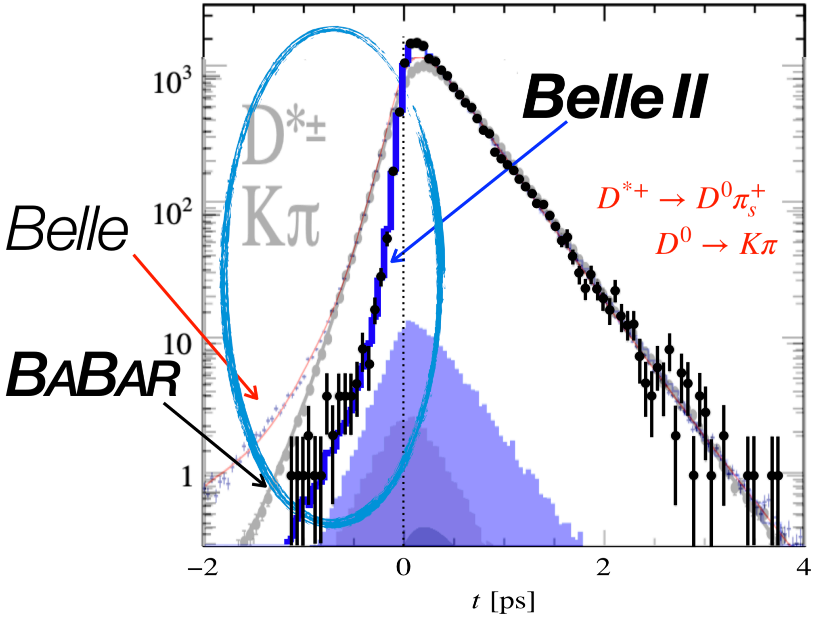


Slow pion efficiency: data/MC

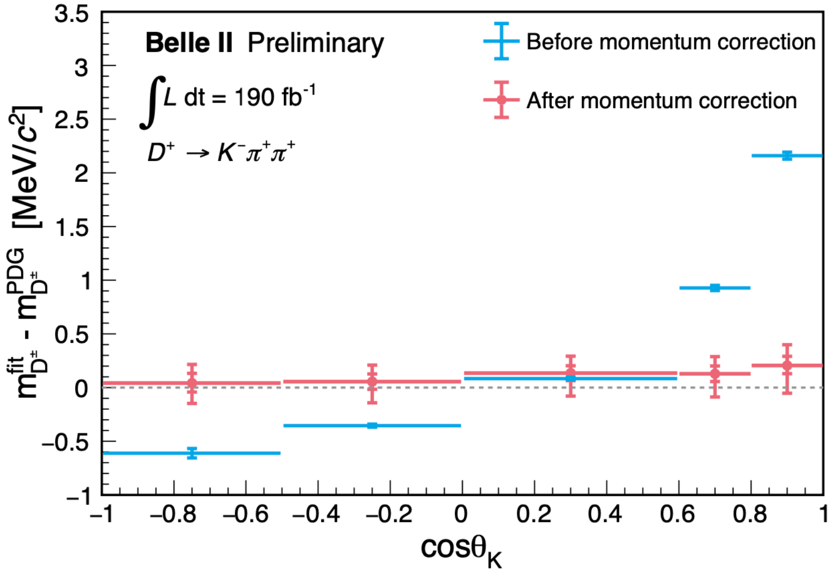


- **Fast track** finding ($0.2 < p_T < 4.5$ GeV):
  - Excellent agreement b/w data and MC, very stable with time.
    - ⇒ **0.3%** per-track uncertainty (0.35% at Belle)
- **Slow pions** (50-200 MeV):
  - Overall systematic uncertainty is **2.1%** on 190 fb^{-1} of data (1.3% at Belle).
  - Statistically limited measurement and will improve with more data.

- World's best D lifetime measurement (Phys. Rev. Lett.127,211801) with only 72 fb^{-1} of data, enabled by:
  - Decay time resolution 2x better than Belle & BABAR.
    (mainly due to PXD first layer being only 1.4 cm from IP, but also excellent VXD reco, track finding and vertex fitting)
  - Accurate alignment of the vertex-detector, resulting in much smaller systematics (EPJ Web Conf. 245, 02023, 2020).
  - See Tuesday talk by *Michele Veronesi* for the full story on charm-hadron lifetime measurements (D^0, D^+, Λ_c^+, Ω_c^0, D_s^+).



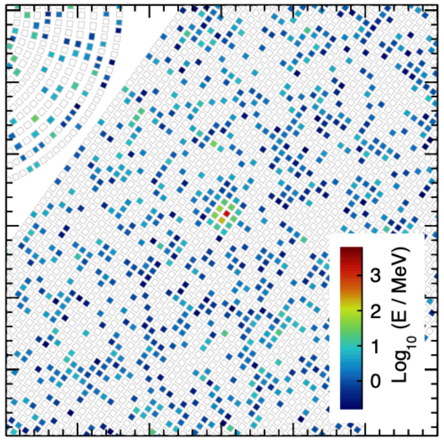
- World's best tau mass measurement (arXiv:2305.19116) with only 190 fb^{-1} of data, enabled by:
  - Many systematic sources being under control, in particular having a precise and cos(θ) dependent calibration of the track momentum scale.
  - More details in talk from *Savino Longo* on Tuesday.



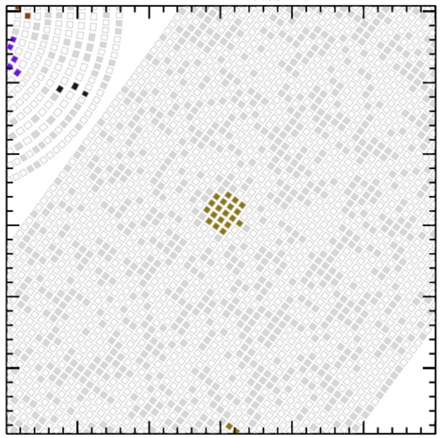
Photon performance

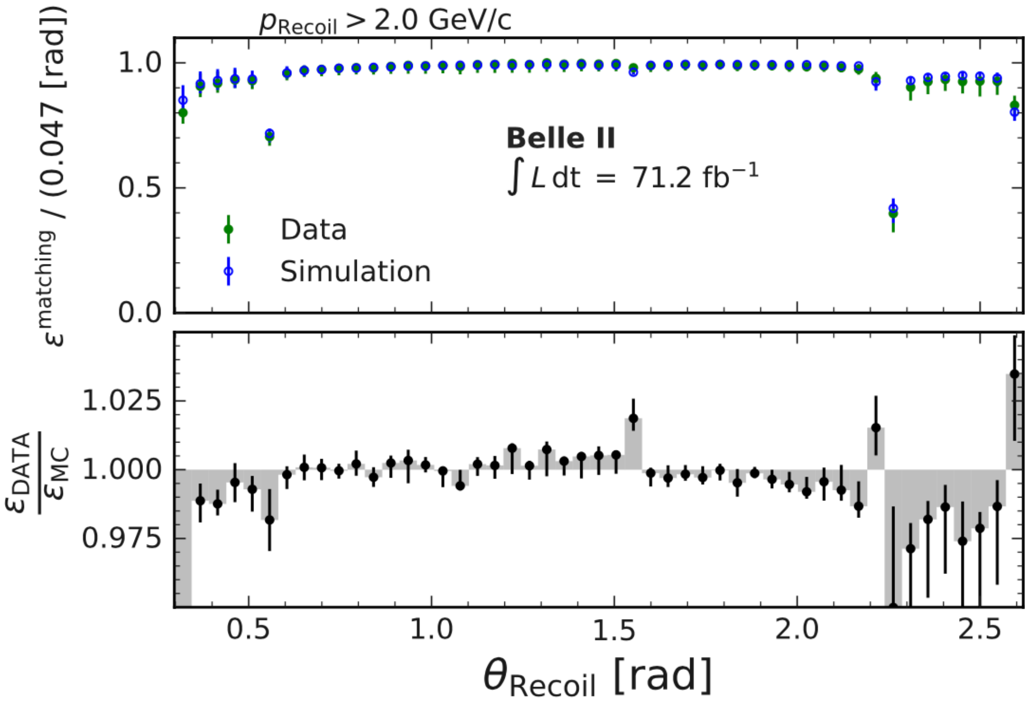
- The raw crystal-level information of Belle II ECL is translated into photon objects via state-of-the-art clustering and identification algorithms.
- Photons can be mimicked by:
  - Neutral hadrons
  - Charged hadrons → "secondary" clusters w/o matching track due to hadronic splitoffs.
- Identification mostly relies on variables describing the lateral shower shape development → isolation (E1/E9), Zernike moments.

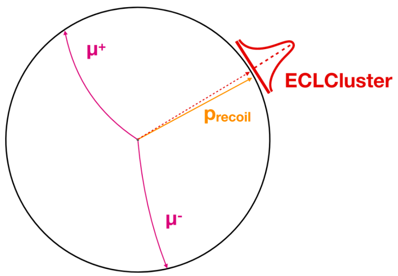
input to clustering algorithm



output



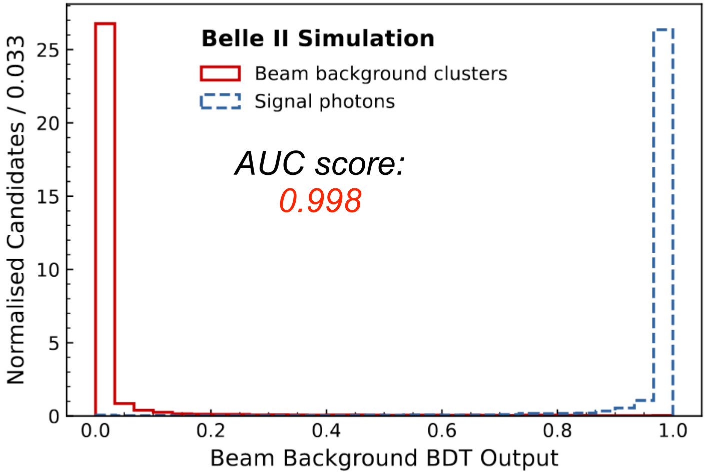




High efficiency with systematics at **0.3%** in barrel.

(was 2% at Belle)

- Novel BDT-based classifiers recently developed to provide a final suppression of both beam bkg and fake photons.

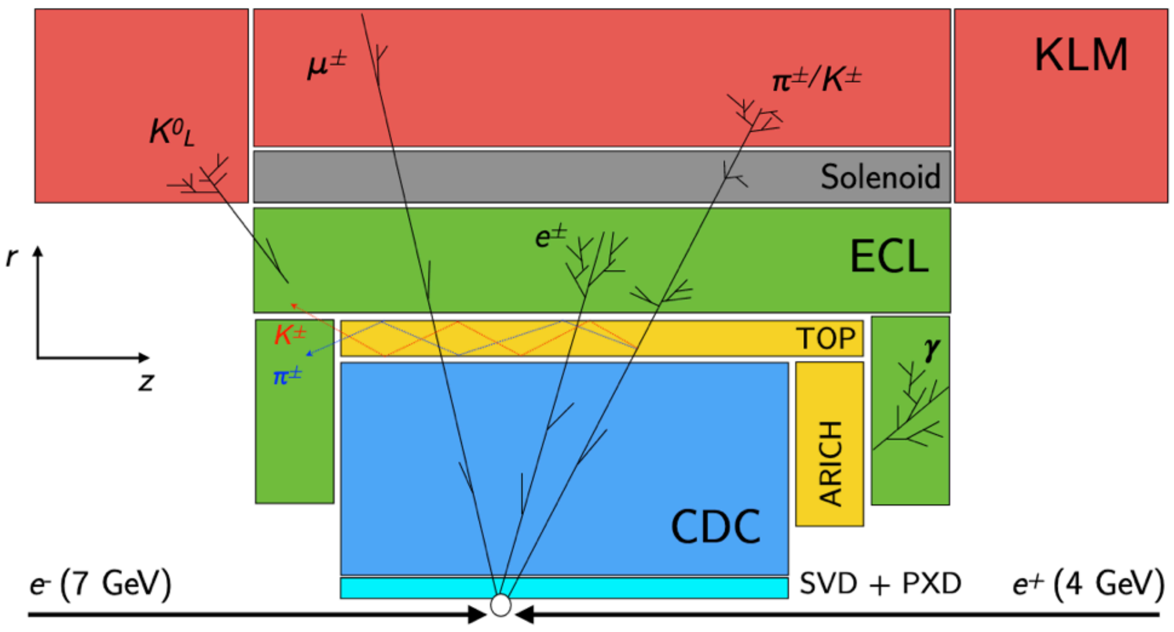


- Particle Identification (PID): identify "long lived" particles passing through the detector by means of their interaction with matter.

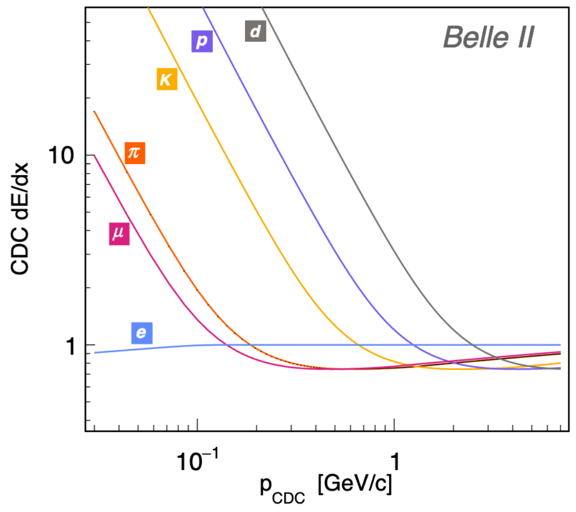
(In *Belle II*) "standard charged": $\{e^\pm, \mu^\pm, \pi^\pm, K^\pm, p^\pm, d^\pm\}$

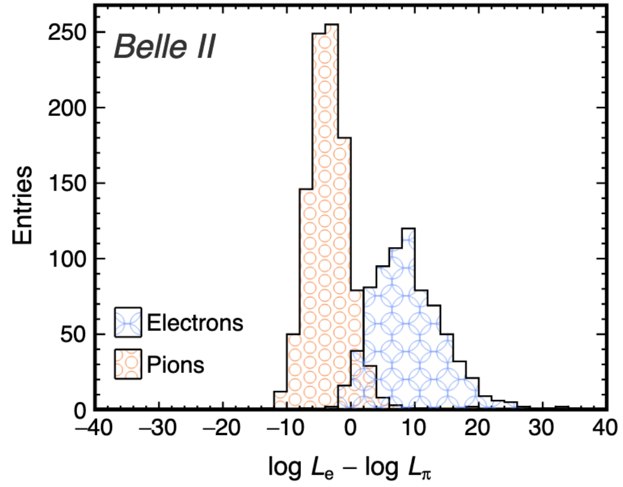
- Often one of the most crucial factors determining sensitivity/precision of a physics measurement.
- PID algorithm works by encoding measurements from different sub-detectors into a likelihood ratio

(Sub-detectors not to scale)



Example of **CDC** measurements





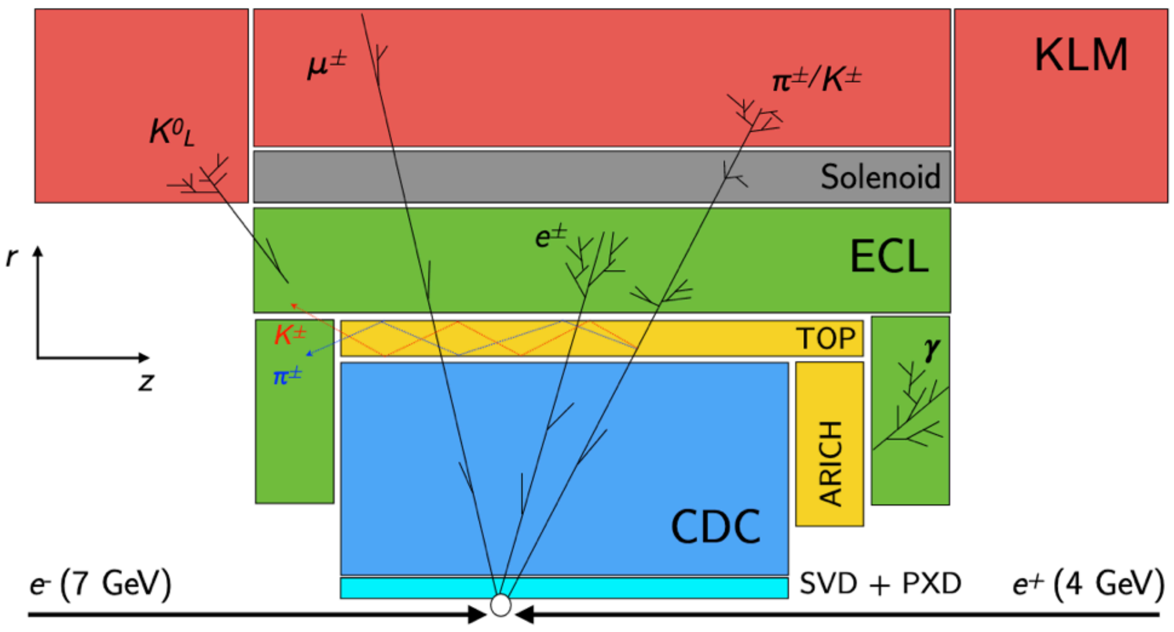
Charged PID

- Particle Identification (PID): identify "long lived" particles passing through the detector by means of their interaction with matter.

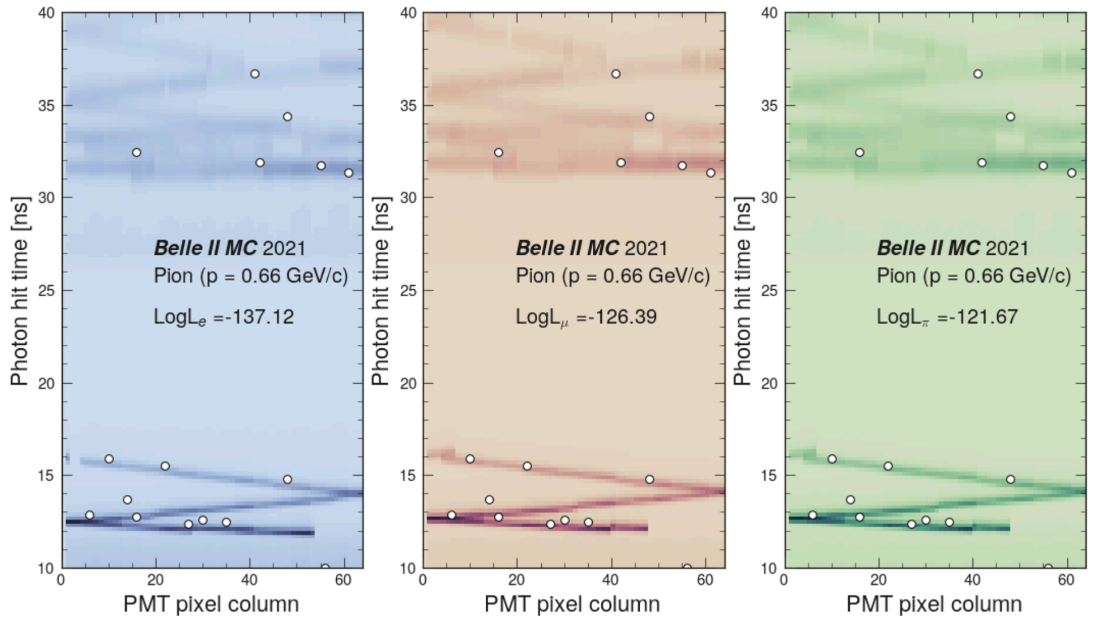
  (In *Belle II*) "standard charged": $\{e^{\pm}, \mu^{\pm}, \pi^{\pm}, K^{\pm}, p^{\pm}, d^{\pm}\}$

- Often one of the most crucial factors determining sensitivity/precision of a physics measurement.
- PID algorithm works by encoding measurements from different sub-detectors into a likelihood ratio

(Sub-detectors not to scale)



Example of **TOP** measurements



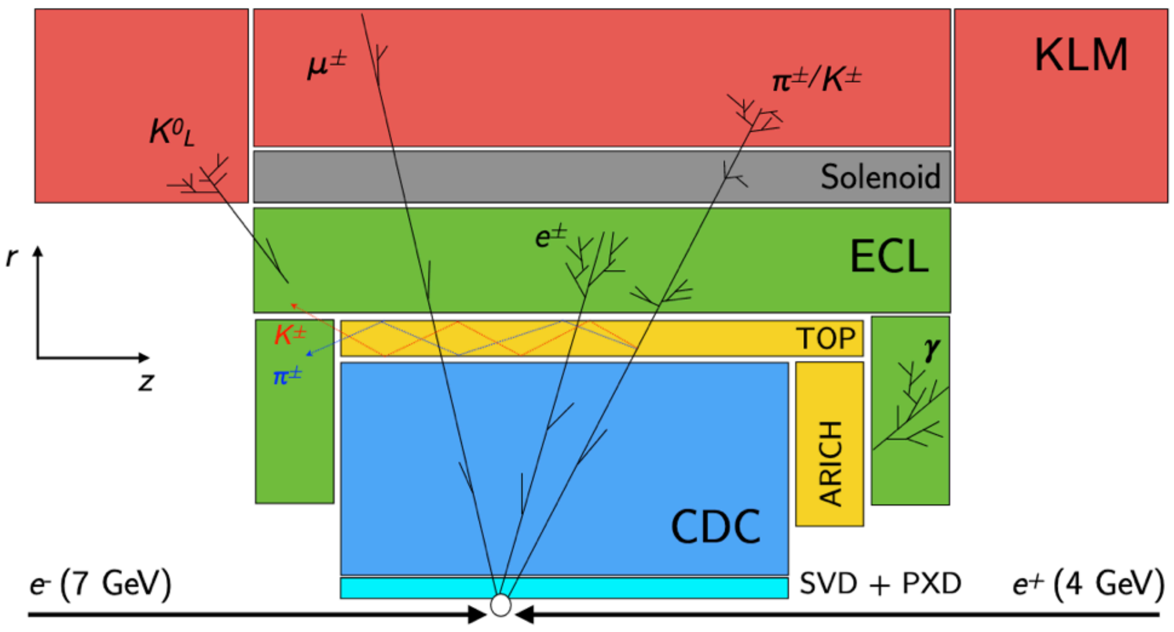
Charged PID

- Particle Identification (PID): identify "long lived" particles passing through the detector by means of their interaction with matter.

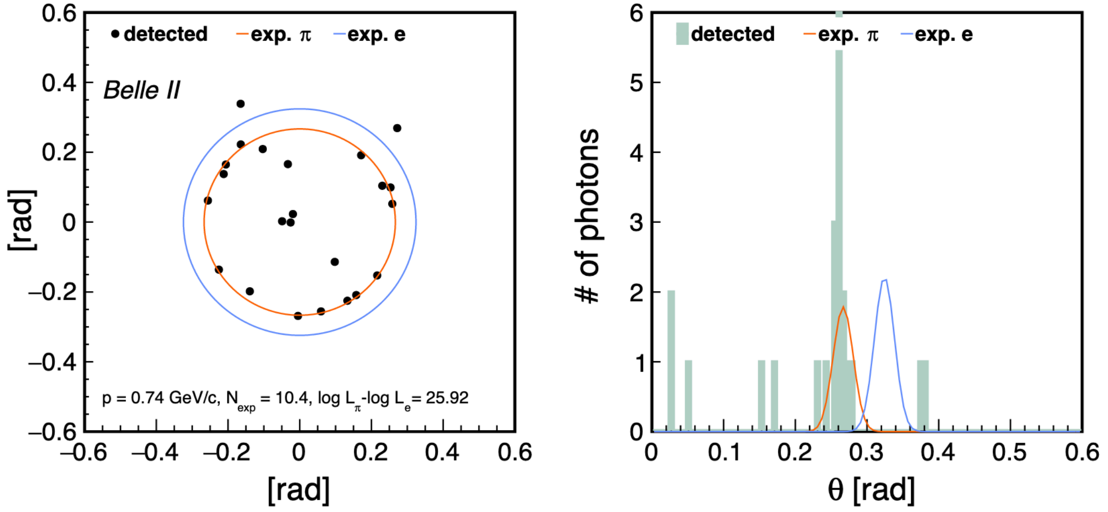
(In *Belle II*) "standard charged": $\{e^\pm, \mu^\pm, \pi^\pm, K^\pm, p^\pm, d^\pm\}$

- Often one of the most crucial factors determining sensitivity/precision of a physics measurement.
- PID algorithm works by encoding measurements from different sub-detectors into a likelihood ratio

(Sub-detectors not to scale)



Example of ARICH measurements

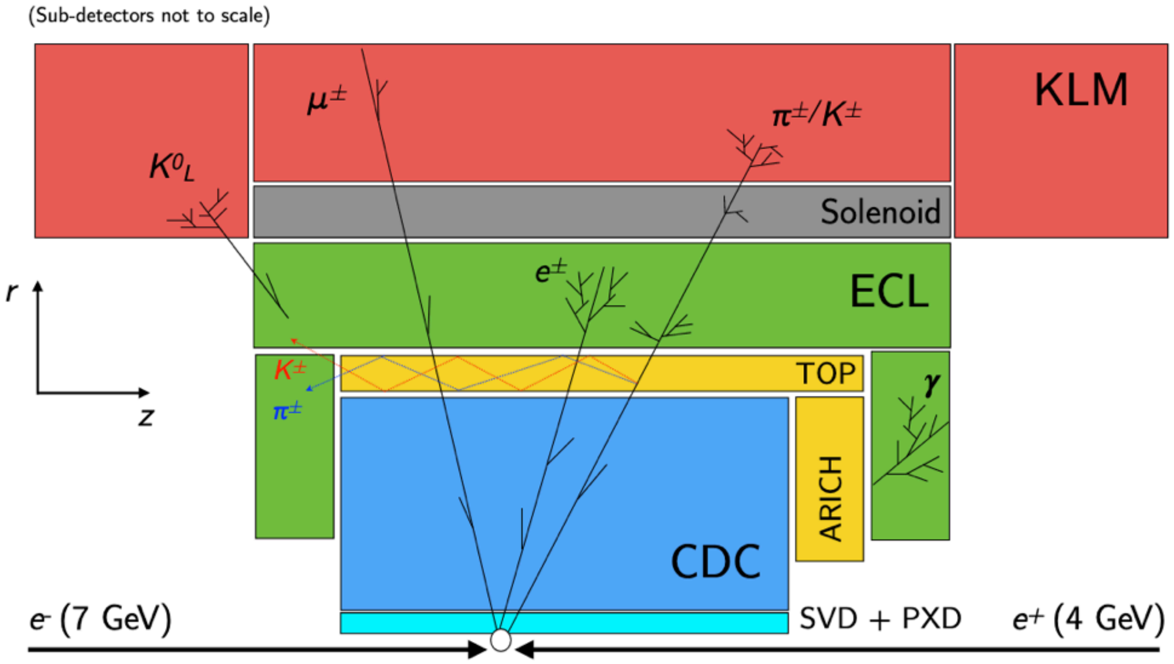


Charged PID

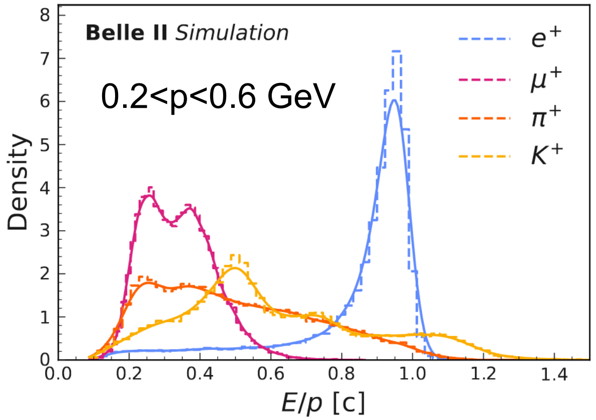
- Particle Identification (PID): identify "long lived" particles passing through the detector by means of their interaction with matter.

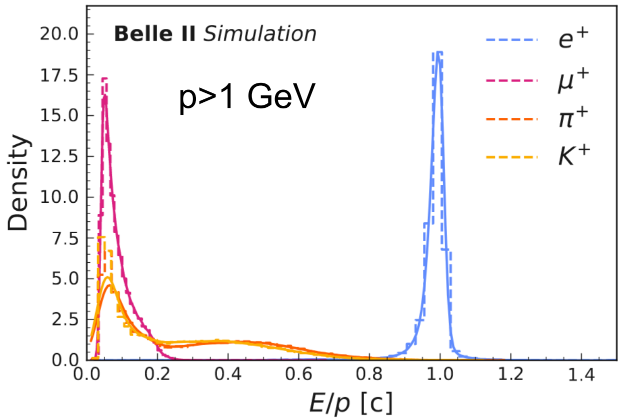
  (In *Belle II*) "standard charged": $\{e^\pm, \mu^\pm, \pi^\pm, K^\pm, p^\pm, d^\pm\}$

- Often one of the most crucial factors determining sensitivity/precision of a physics measurement.
- PID algorithm works by encoding measurements from different sub-detectors into a likelihood ratio



Example of **ECL** measurements



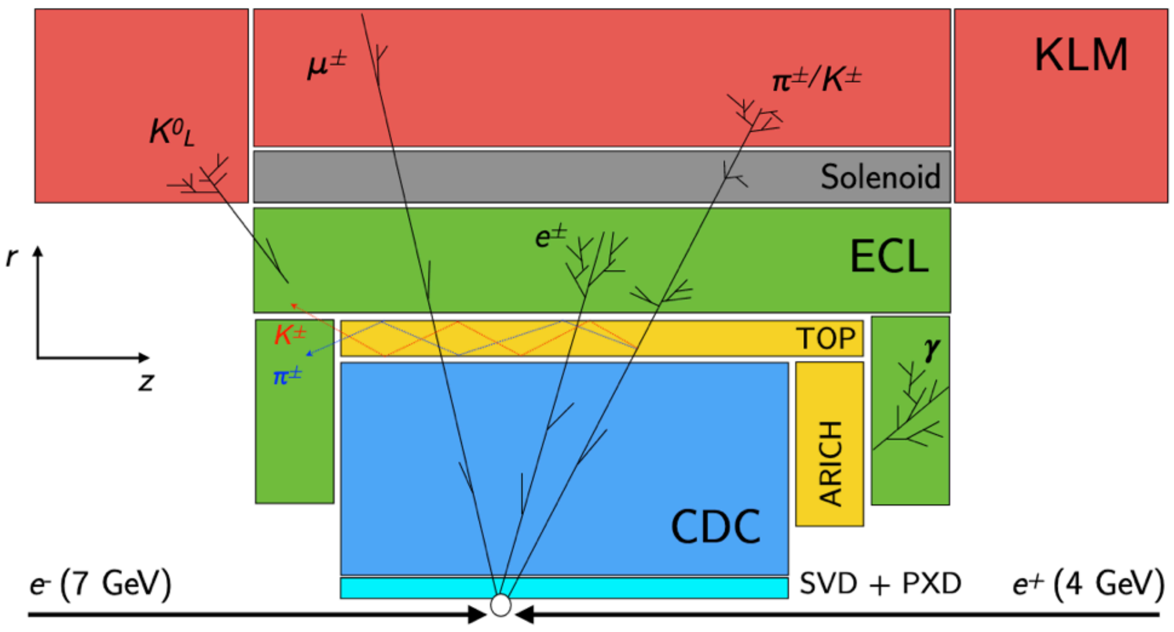


- Particle Identification (PID): identify "long lived" particles passing through the detector by means of their interaction with matter.

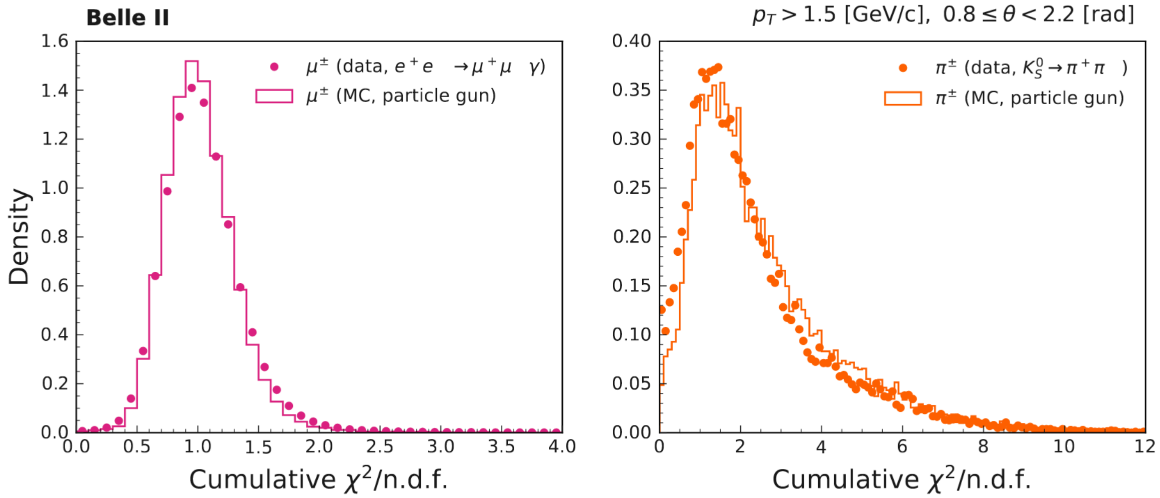
(In *Belle II*) "standard charged": $\{e^{\pm}, \mu^{\pm}, \pi^{\pm}, K^{\pm}, p^{\pm}, d^{\pm}\}$

- Often one of the most crucial factors determining sensitivity/precision of a physics measurement.
- PID algorithm works by encoding measurements from different sub-detectors into a likelihood ratio

(Sub-detectors not to scale)



Example of **KLM** measurements

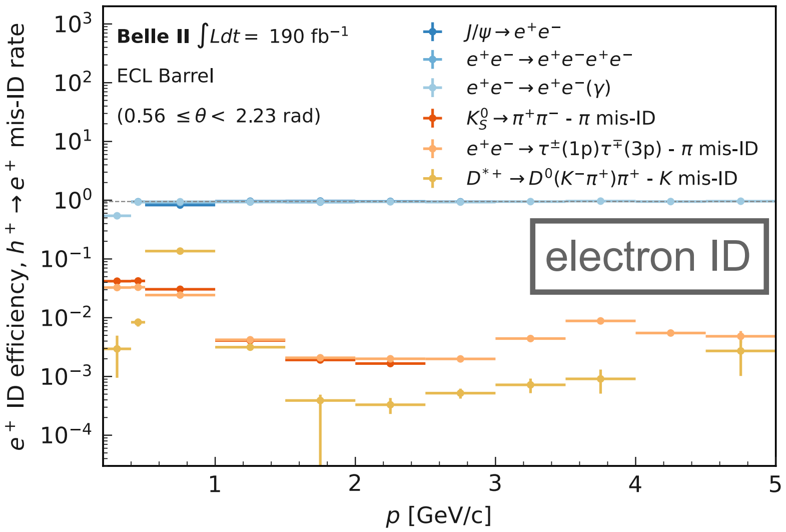


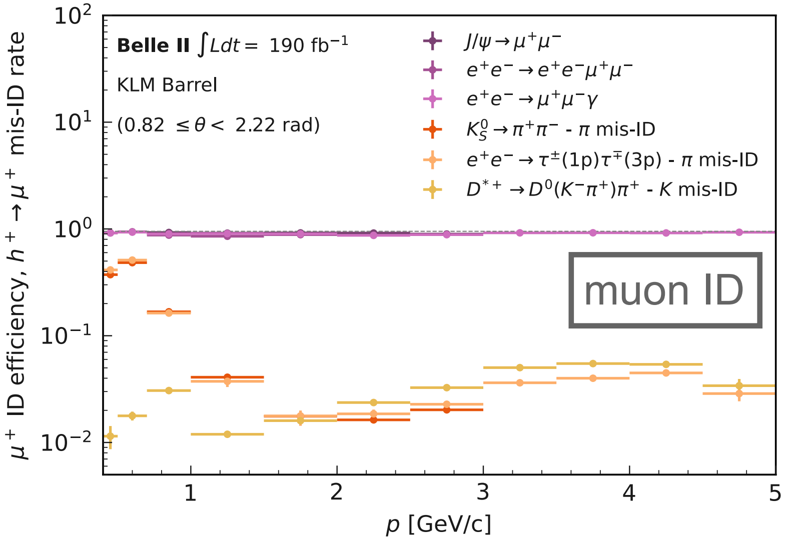
Lepton ID Performance

- Overall good lepton ID performance.
- BDT has superior performance across the whole momentum spectrum, especially below 0.6 GeV where the fake rate is reduced by up to a factor of 10.

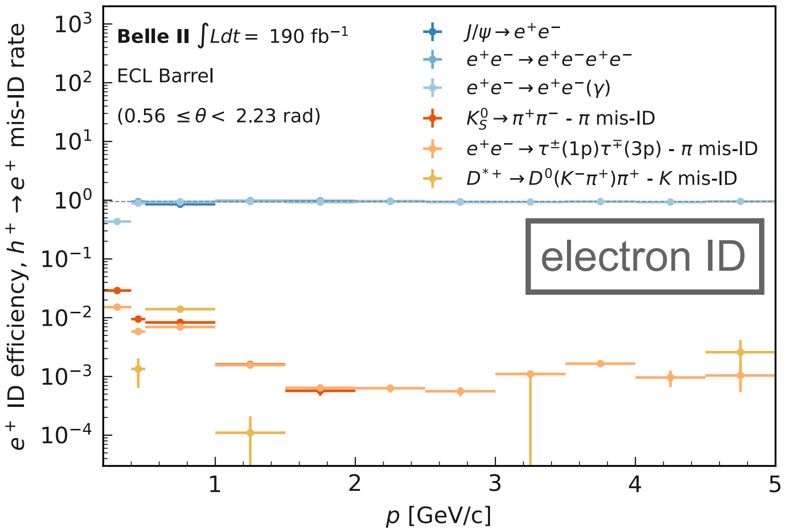
- Data/MC correction factors have associated systematics for the efficiency at the 0.5-1.5% level (1.0-1.5% at Belle).
- Precision continues to improve as we better understand remaining tensions b/w control channels.

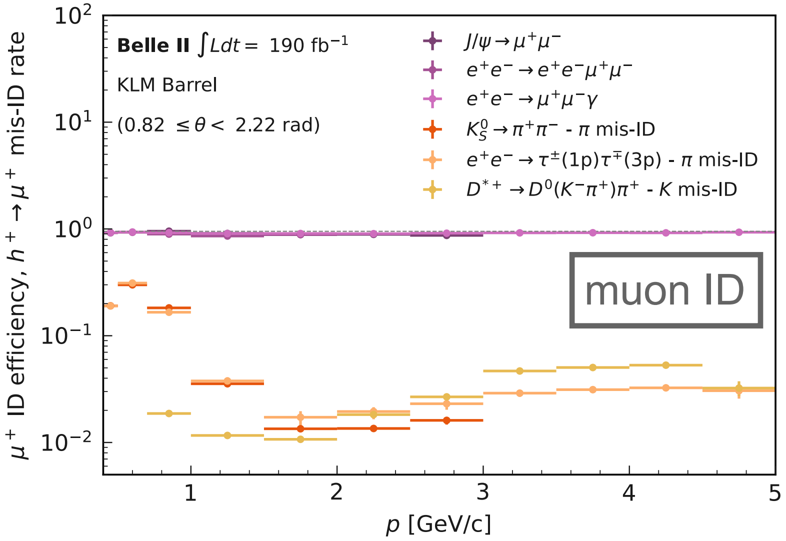
Likelihood-based



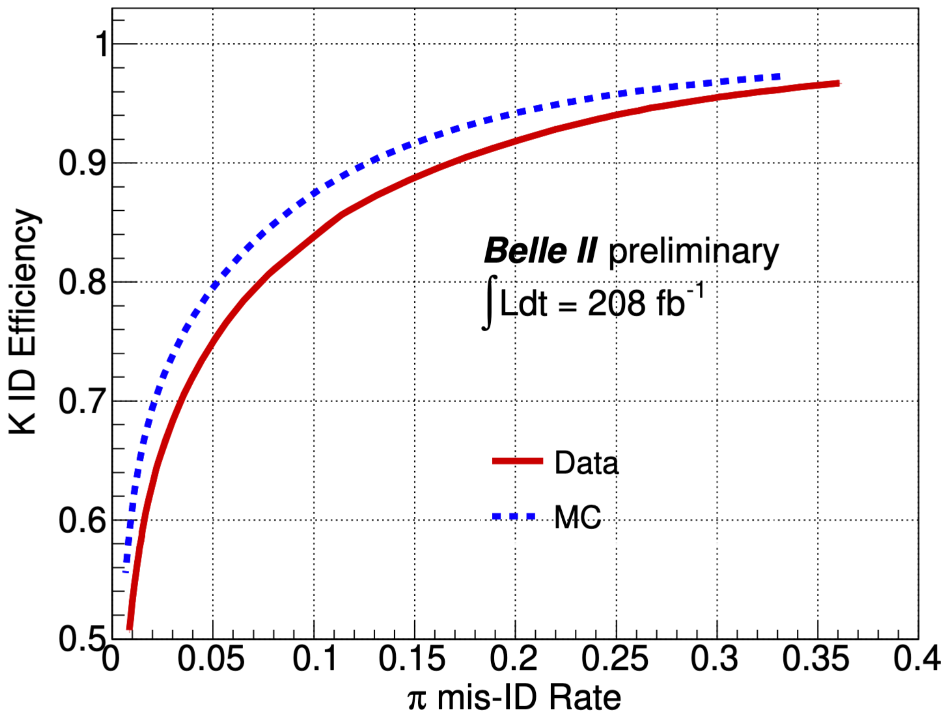


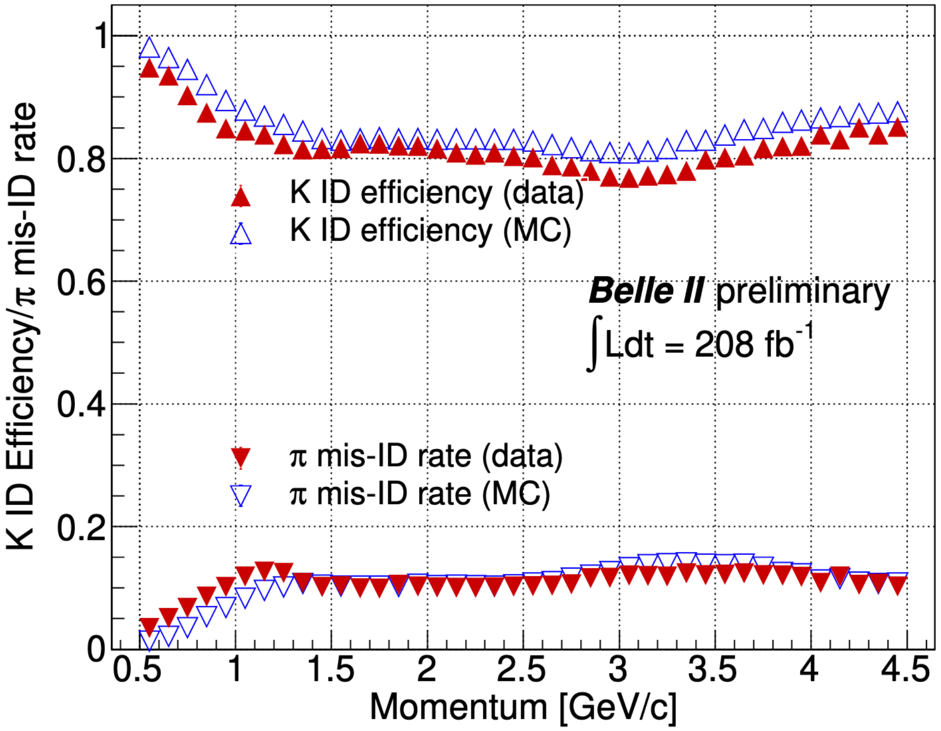
BDT-based





Hadron ID Performance





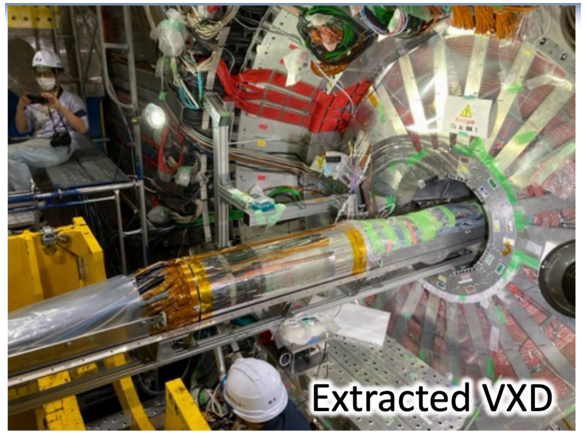
- Good kaon identification, slightly underperforming wrt Belle albeit under much harsher background conditions.
- Big efforts underway that will improve this (e.g. TOP software, Neural Network based ID).

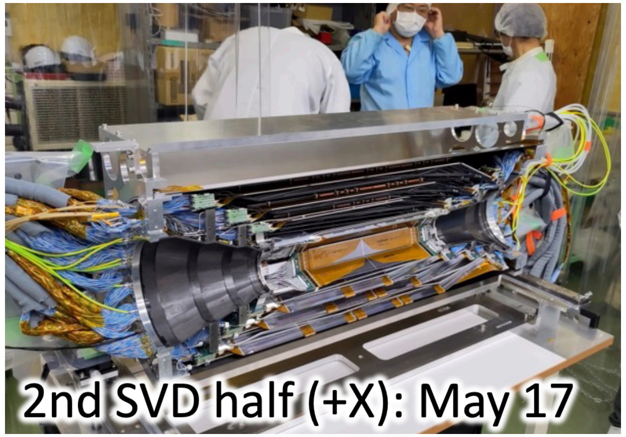
- Systematics associated to Data/MC correction factors currently at 0.8-1% level (0.8% at Belle).

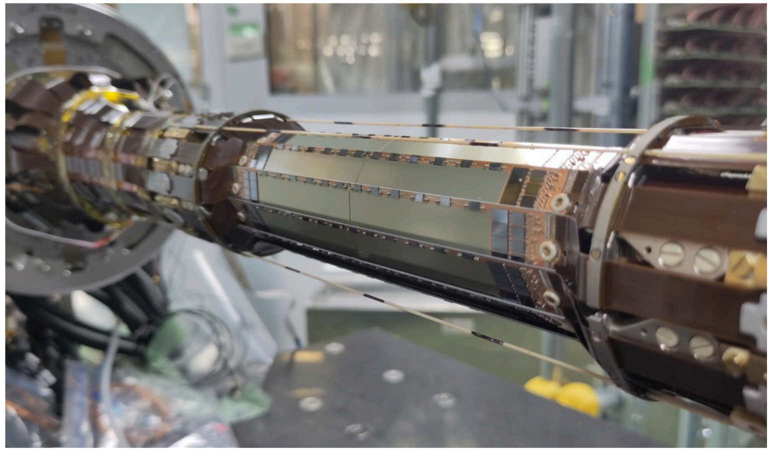
Getting ready for Run2

- **Long shutdown 1 (LS1)**: Belle II data-taking stopped in July 2022 and is on track to resume in December 2023.

- LS1 activities:
  - installation of full 2-layer **pixel detector** (PXD2)
  - replacement of PMT of central PID detector (**TOP**)
  - replacement of the **beam-pipe**
  - + more:
    - improvement of data-quality monitoring and alarm system
    - complete transition to new DAQ boards
    - replacement of aging components
    - additional shielding against beam bkgs
    - accelerator improvements: injection, non linear- collimators, monitoring.







- **PXD2 is ready to be installed!**

LHCb Upgrade I Performance

LHCb Upgrade I Challenge

- The LHCb *Upgrade I* has transformed the detector to cope with new challenges at Run 3 and Run 4.
  - **Raise operational luminosity to $2x10^{33}$ $cm^{-2}s^{-1}$**
  - **Move to full 40 MHz software trigger.**

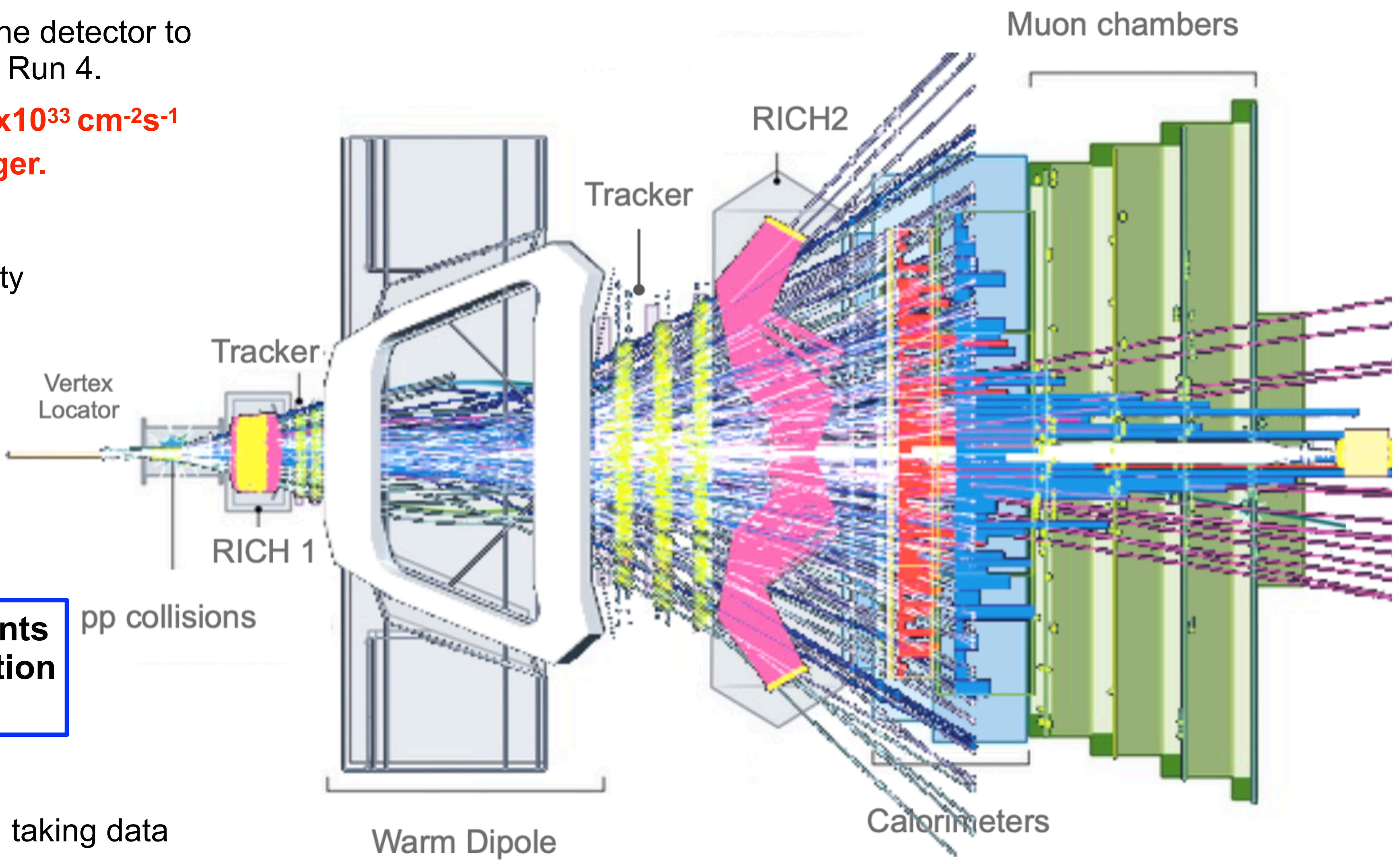
- Large increase in precision and the ability to perform studies beyond the reach of the current detector.

- Flexible trigger & unique acceptance opens up opportunities in topics apart from flavour.

Only possible with vast improvements in granularity, readout speed, radiation hardness, and trigger innovations.

2019: removal of detector.

2022/2023: upgraded detector complete, taking data and in commissioning stage.



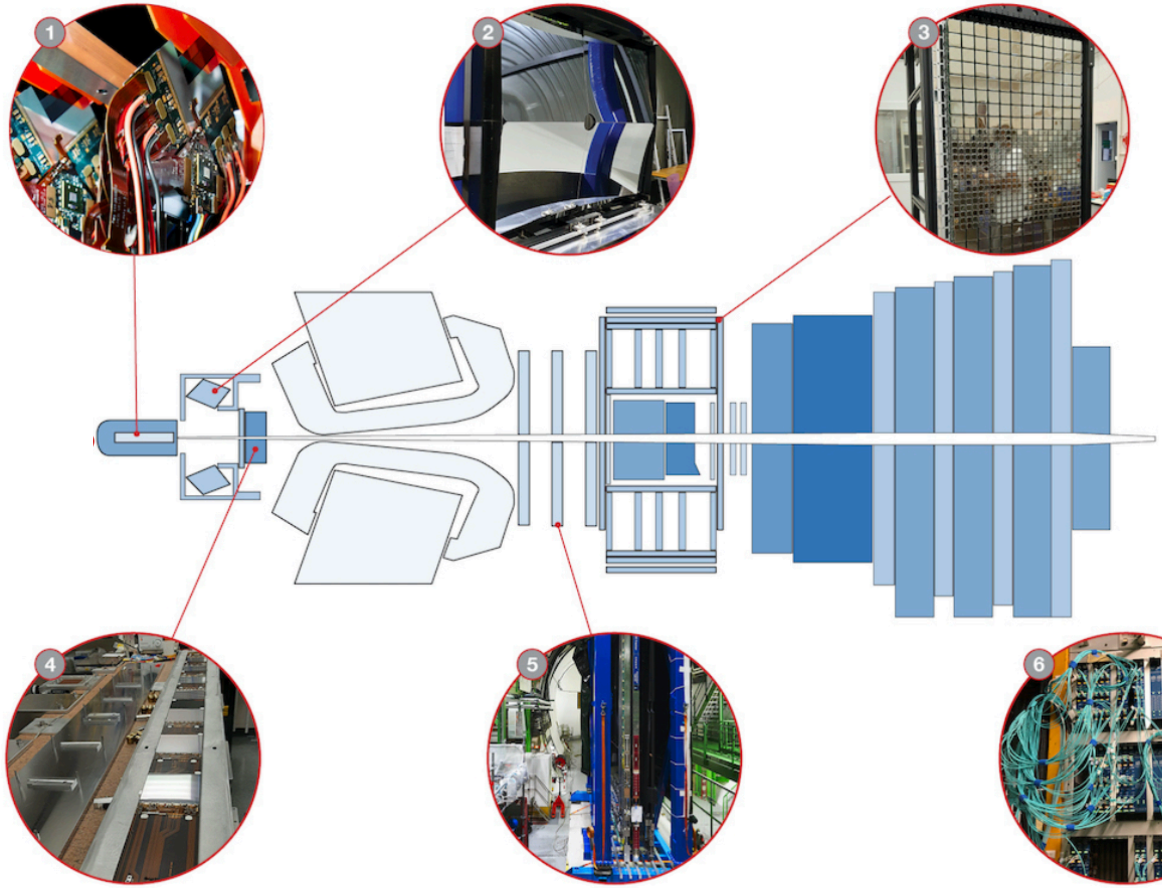
Upgrading the LHCb hardware

VELO Installation

VELO: NEW SILICON PIXEL DETECTOR
Vertex Locator (VELO) replaced by a new silicon pixel detector, installed as close as 5.1 mm to the proton beams.

RICH1
New optics of RICH1 mirrors, with larger curvature radius.

RICH2
New multi-anode photomultipliers replaced the hybrid photon detectors (HPD) in RICH1 and RICH2.



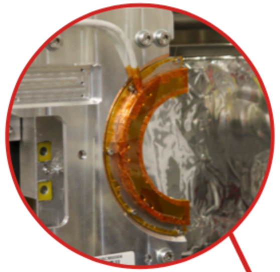
TRACKER: New UT
New high granularity silicon microstrip upstream tracker (UT).

TRACKER: SCI-FI
Three new scintillating fibre tracker (Sci-Fi) stations.

FRONT-END ELECTRONICS
All front-end electronics (i.e. those connected directly to the detectors) have been modified.

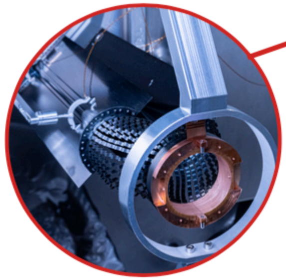
Upgrading the LHCb hardware

RADIATION SAFETY AT LHCb
Replaced Beam Conditions Monitors from Run1+2 and added new Radiation Monitoring System



PLUME: NEW LUMINOMETER
Cherenkov quartz detector. Delivers online and offline luminosity, measures radiation background.

SMOG2
New gas cell upstream of the VELO. Gives up to 100x increase in gas pressure for fixed target mode

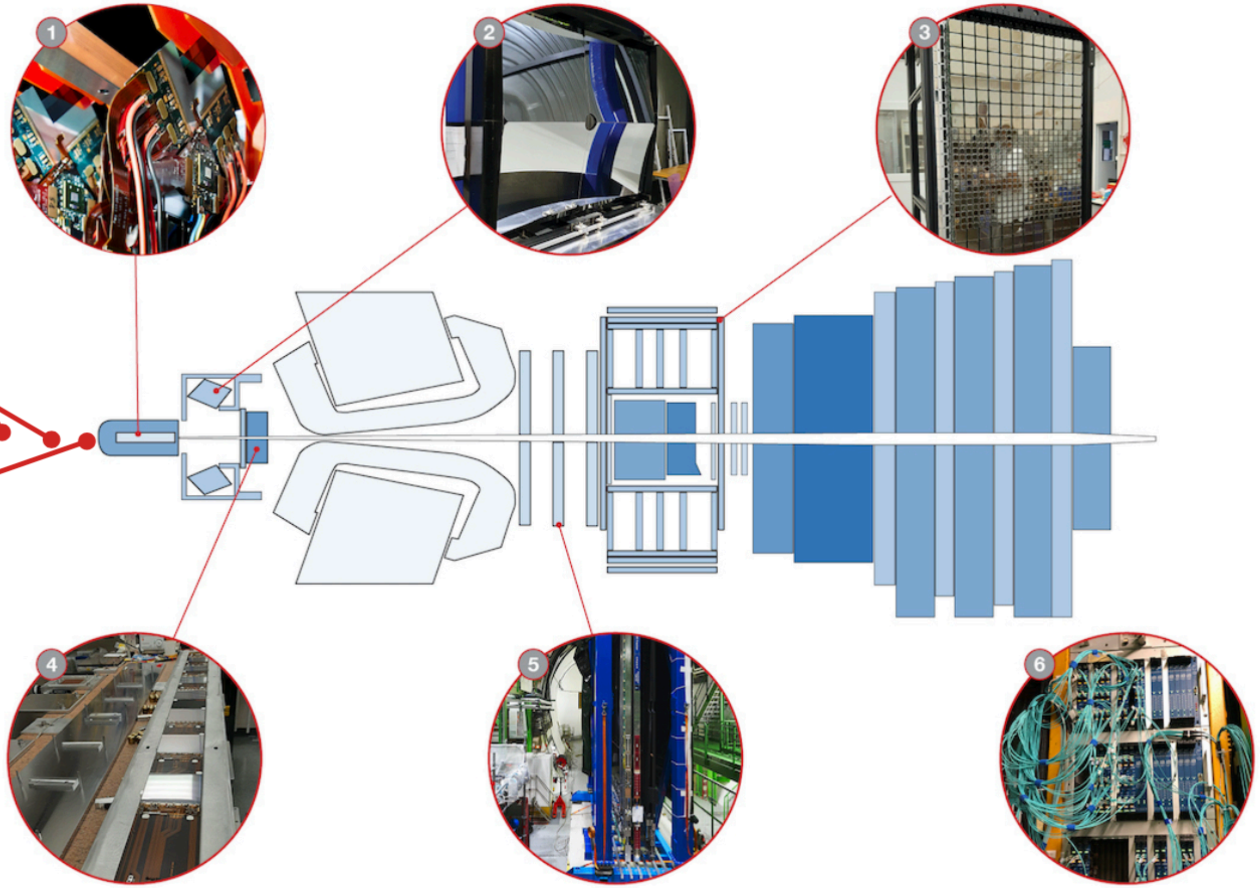


ON-SITE DATA CENTRE
Processing readout from front-end electronics and running event reconstruction for full software trigger

VELO: NEW SILICON PIXEL DETECTOR
Vertex Locator (VELO) replaced by a new silicon pixel detector, installed as close as 5.1 mm to the proton beams.

RICH1
New optics of RICH1 mirrors, with larger curvature radius.

RICH2
New multi-anode photomultipliers replaced the hybrid photon detectors (HPD) in RICH1 and RICH2.

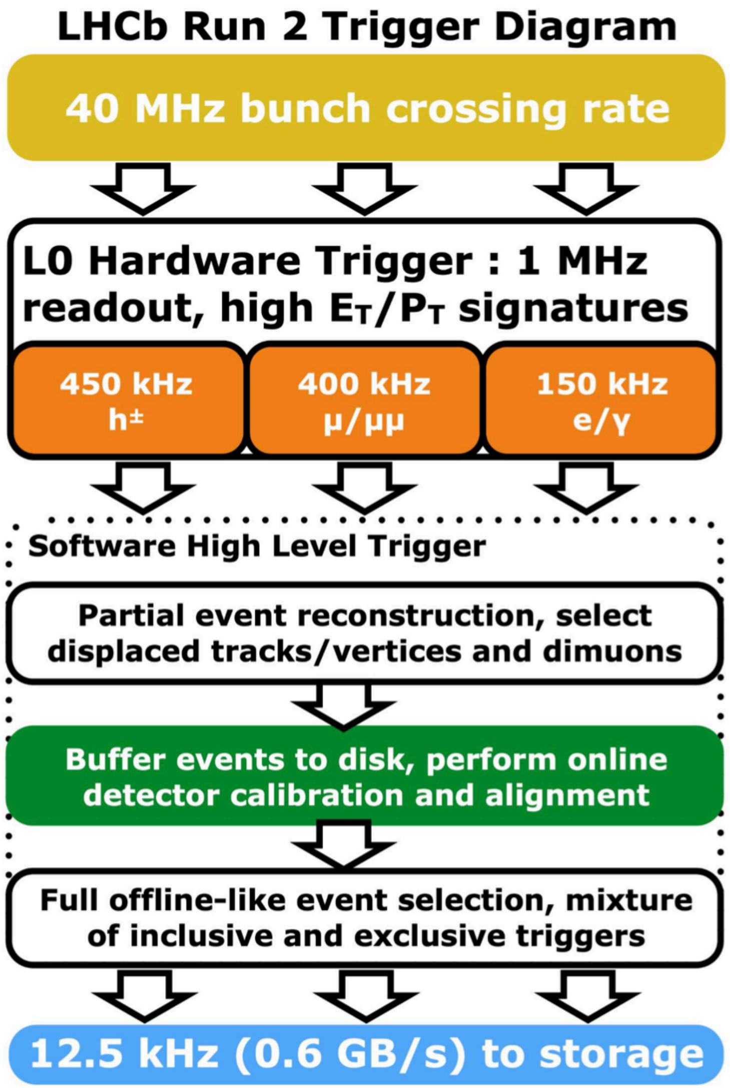


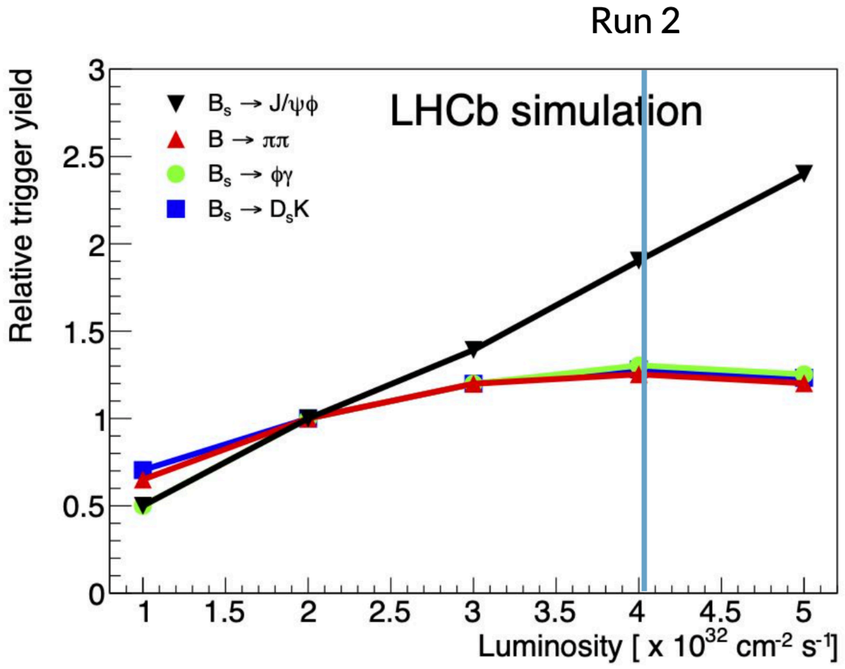
TRACKER: New UT
New high granularity silicon microstrip upstream tracker (UT).

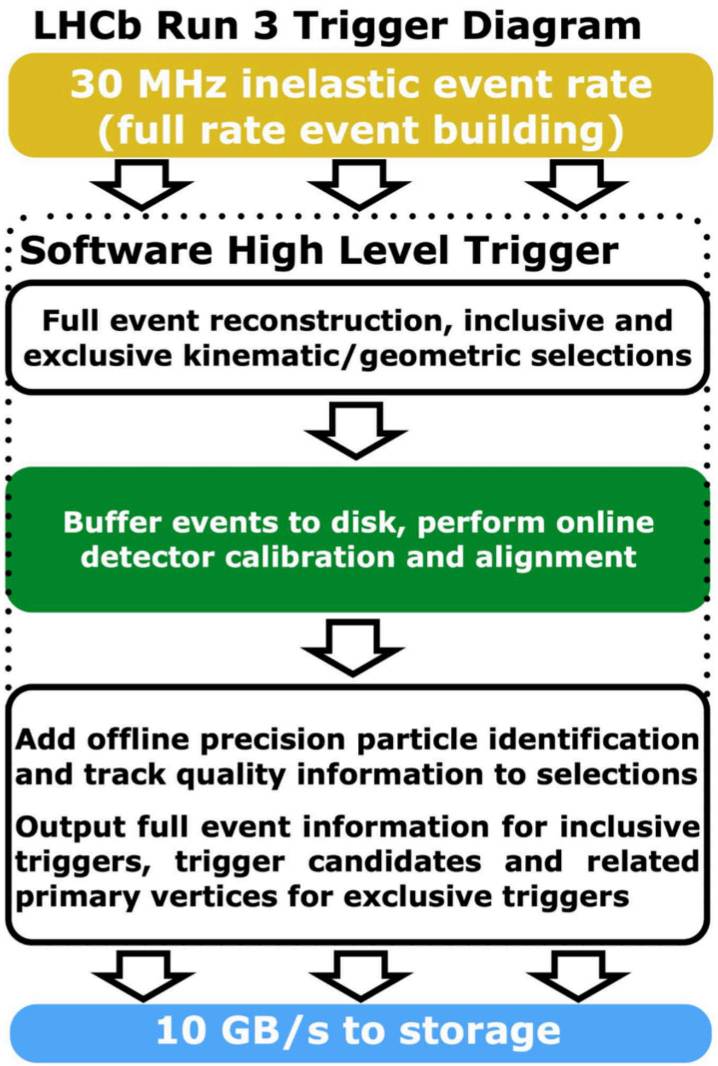
TRACKER: SCI-FI
Three new scintillating fibre tracker (Sci-Fi) stations.

FRONT-END ELECTRONICS
All front-end electronics (i.e. those connected directly to the detectors) have been modified.

Trigger Scheme for Upgrade I

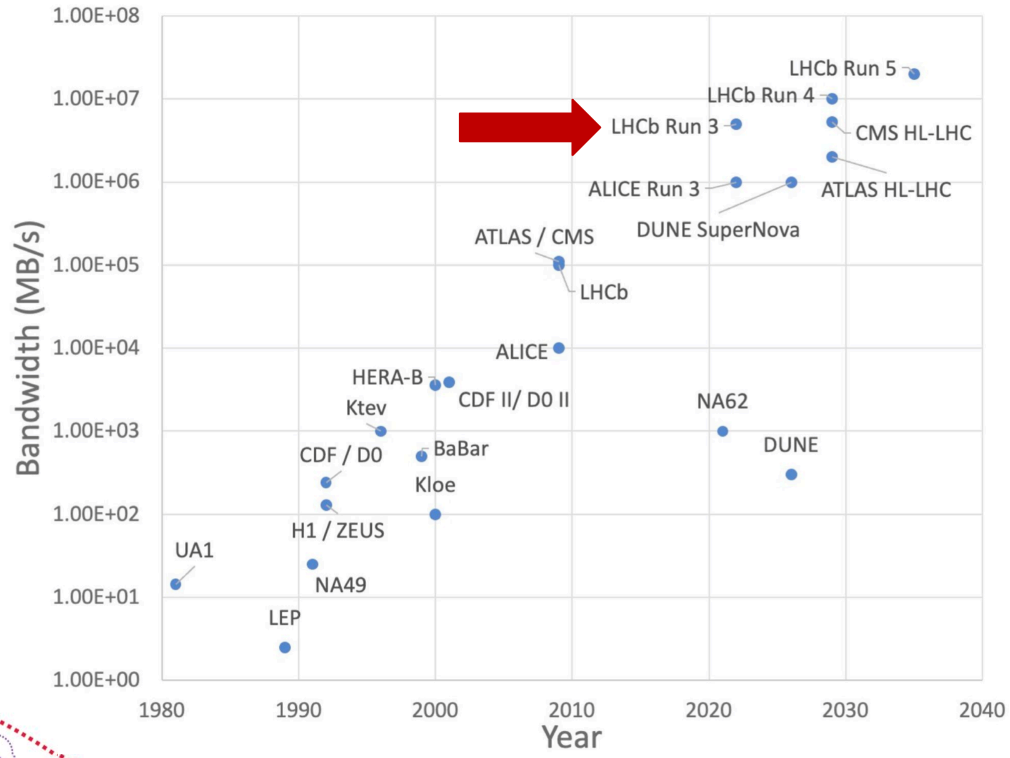


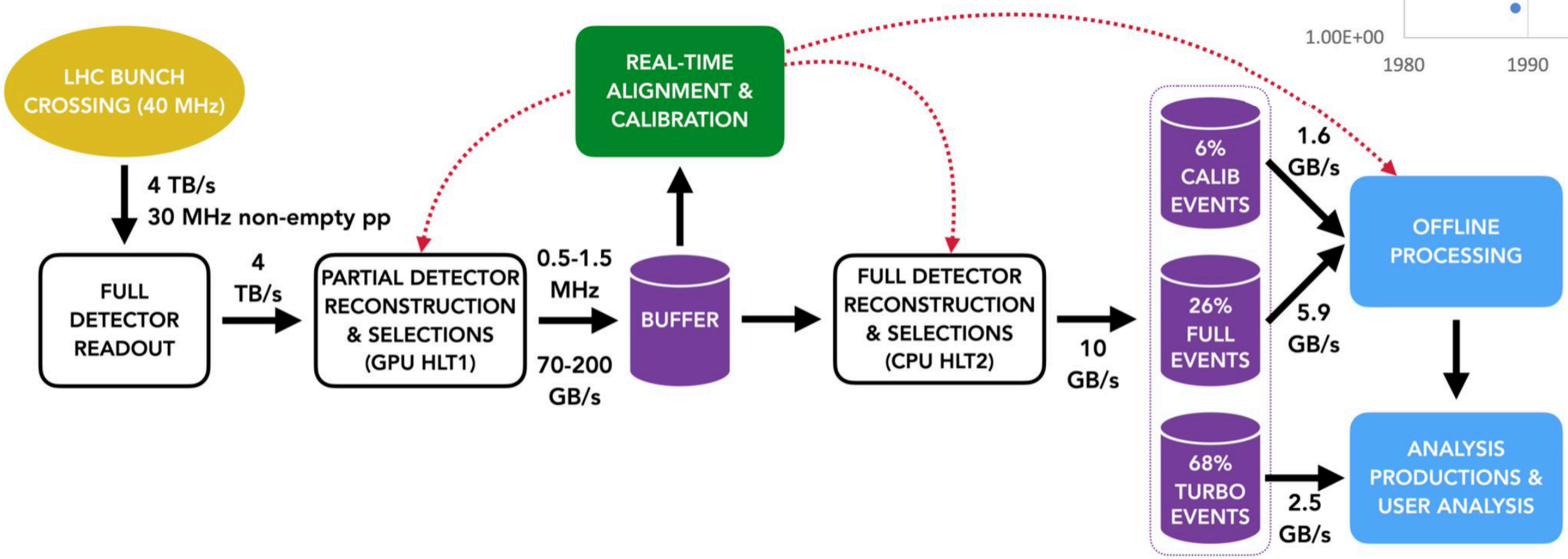




Upgrading the LHCb trigger & software

- Run 2 hadronic trigger with hardware first stage was saturated.
- LHCb is facing now the challenges that other experiments will face in > 5 years from now.
- Data flood requires novel approaches…
- **First GPU trigger in a HEP experiment!**





All numbers related to the dataflow are taken from the LHCb

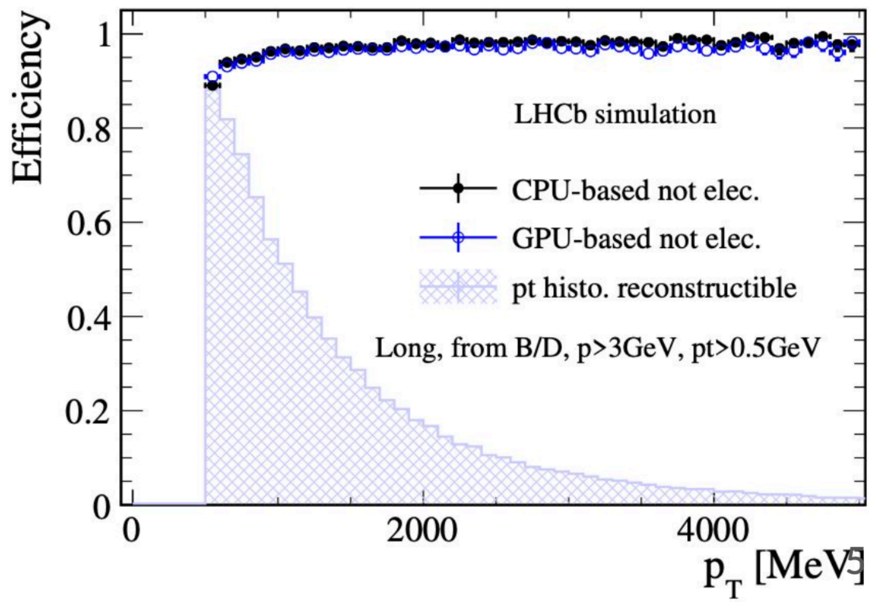
Upgrade Trigger and Online TDR

Upgrade Computing Model TDR

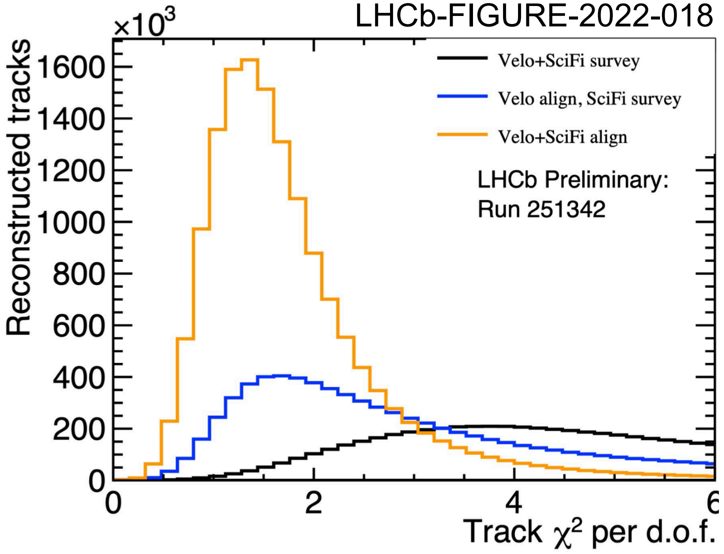
HLT1, alignment and calibration

- First software trigger stage:
  - Run full HLT1 on ~340 GPUs (Nvidia RTA A5000), since 2023.
  - Perform partial event reconstruction (tracking + MuonID + simplified Calo).
  - Run O(50) trigger lines, most of physics programme covered by 1- and 2-track topological lines.
- Performed extensive comparisons with HLT1 implementation on CPU to verify performance.
- Buffer has two purposes: (1) Run HLT2 out-of-sync
  (2) Perform alignment & calibration automatically

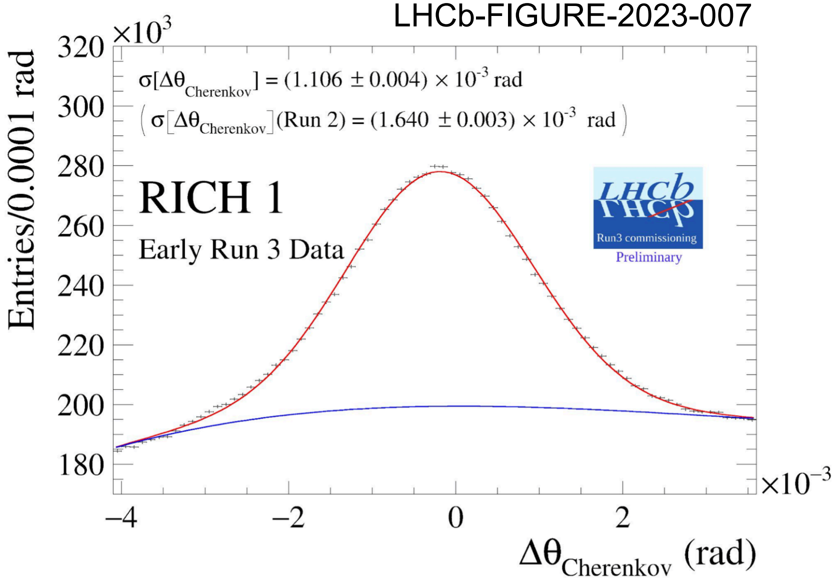
arXiv:2305.10515



LHCb-FIGURE-2022-018



LHCb-FIGURE-2023-007



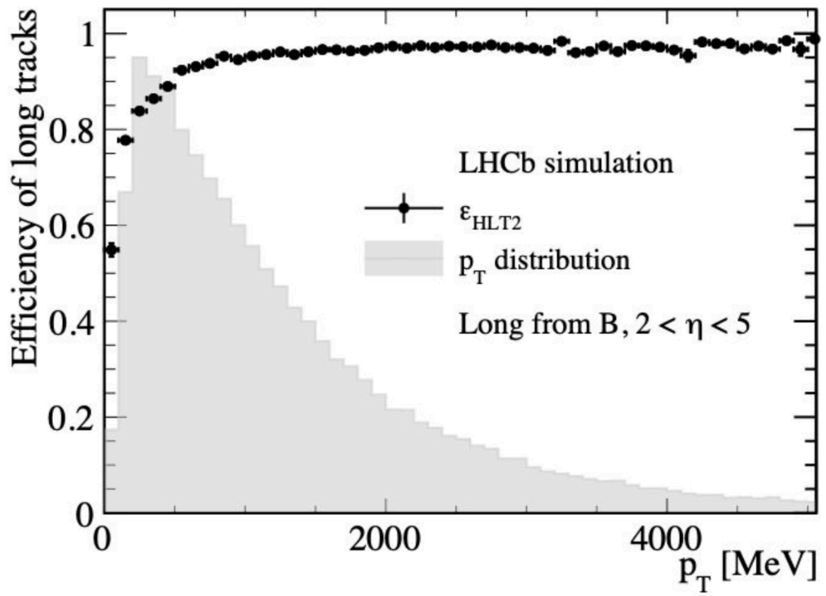
- Alignment: spatial position of trackers / Muon and RICH elements.
- Calibration: PMT gain calibrations of ECAL and RICH gas refractive index calibrations.

⇒ Full offline performance in HLT2, and using output of trigger directly for physics analyses.

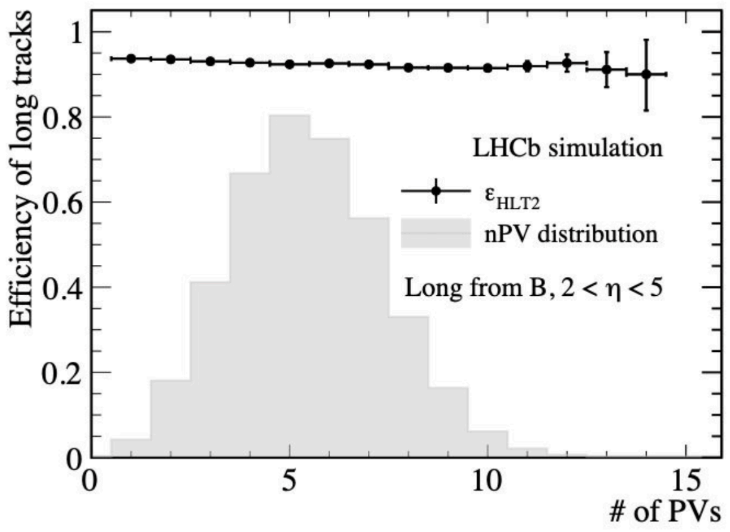
HLT2

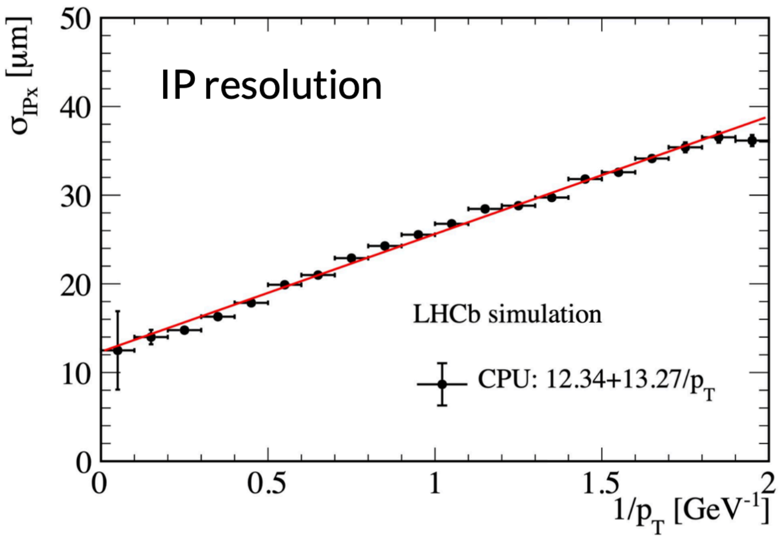
arXiv:2305.10515

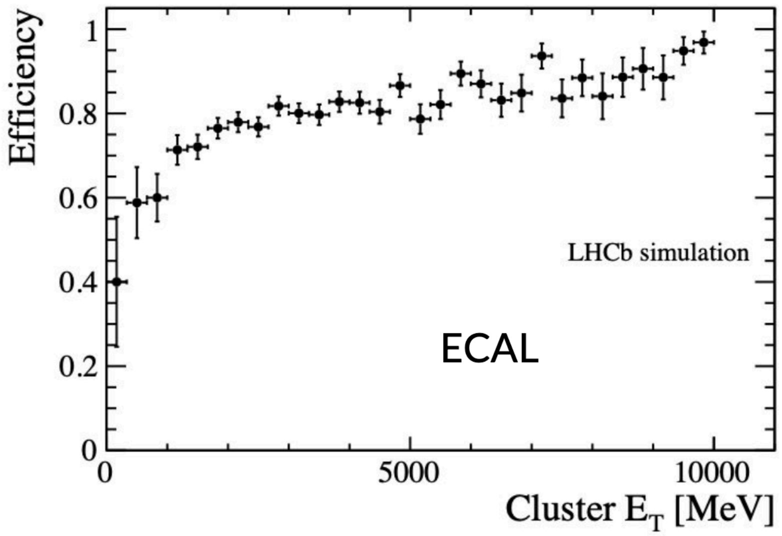
- Second software trigger stage:
  - Performs the full event reconstruction on O(4000) CPU servers
  - Run O(1500) trigger lines, covering the full spectrum from strange and charm physics to electroweak physics, including fixed-target (SMOG) programme.
  - HLT2 performs the final event reconstruction.



- Split selected data into several streams:
  - Signal candidates only directly to disk (TURBO).
  - Full events to further offline processing.



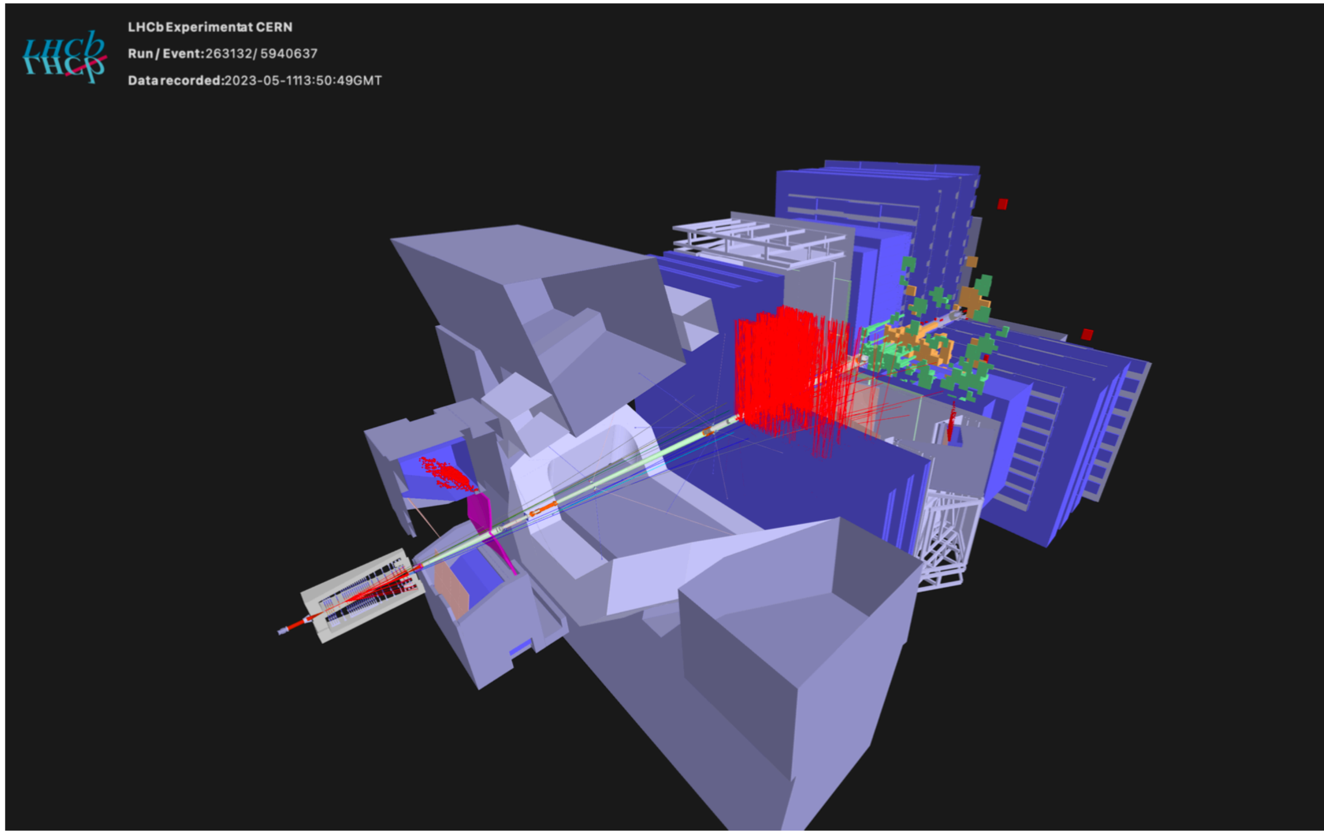




First collisions

LHCb control room July 5 2022

Event display with first full machine configuration in 2023

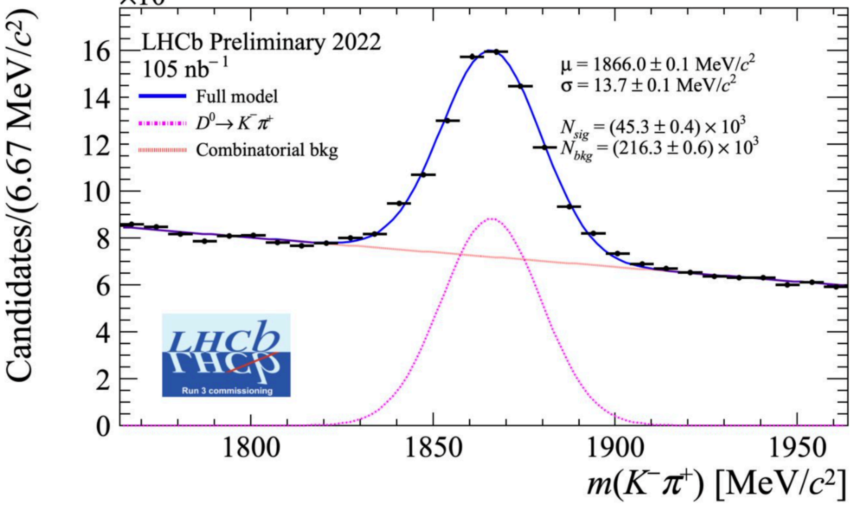


- 2022 has been a commissioning year for the LHCb experiment as a whole.
- At end of the year managed to take data at a doubled instantaneous luminosity with respect to Run 2.

First Run3 Results

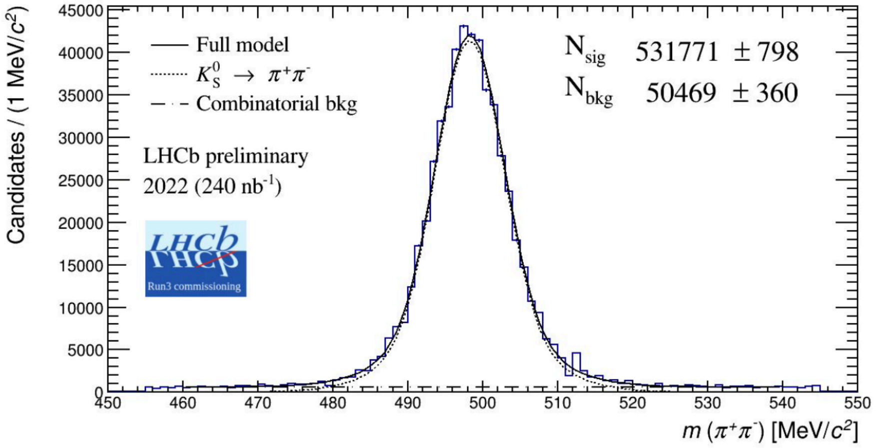
- Huge collaboration-wide efforts in the study of the first data from the new detector!
- Crucial to optimise the performance in view of 2023 and for Run 3 in general.

LHCb-FIGURE-2023-009

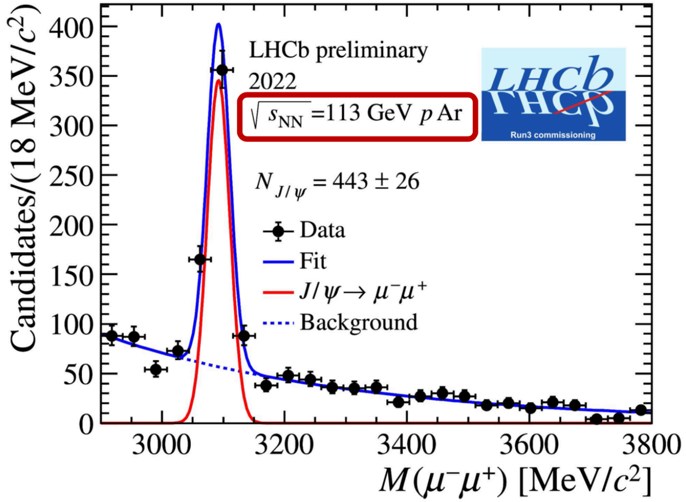


HLT1

LHCb-FIGURE-2023-005

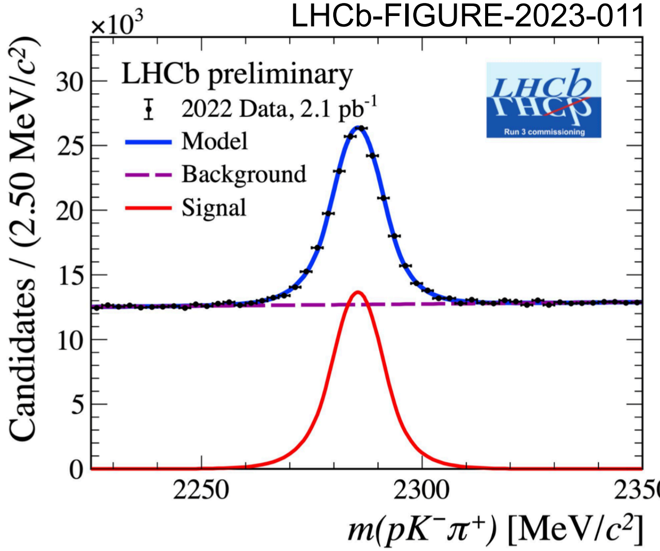


LHCb-FIGURE-2023-008

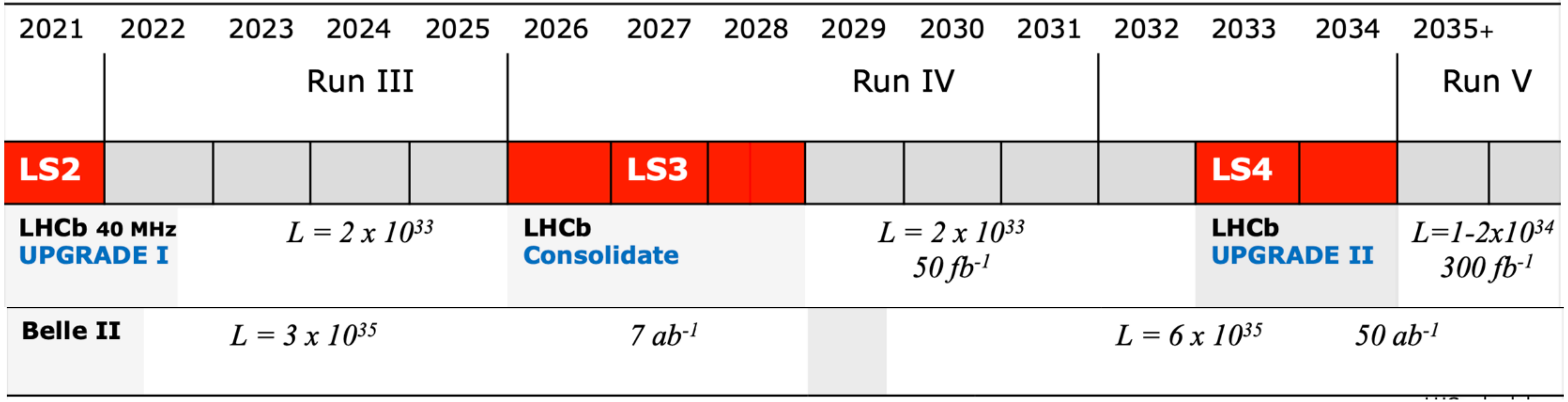


HLT2

LHCb-FIGURE-2023-011



Future upgrades



arXiv:2203.11349

Snowmass Whitepaper:
The Belle II Detector Upgrade Program

Belle II Collaboration

March 23, 2022

Abstract

We describe the planned near-term and potential longer-term upgrades of the Belle II detector at the SuperKEKB electron-positron collider in Tsukuba, Japan. These upgrades will allow increasingly sensitive searches for possible new physics beyond the Standard Model in flavor, tau, electroweak and dark sector physics that are both complementary to and competitive with the LHC and other experiments. We encourage the instrumentation-frontier community to contribute and study upgrade ideas as part of the Snowmass process.

LHCb-TDR-023

Framework TDR for the LHCb Upgrade II

Opportunities in flavour physics, and beyond, in the HL-LHC era

The LHCb collaboration

Abstract

This document is the Framework Technical Design Report for the Upgrade II of the LHCb experiment, which is proposed for the long shutdown 4 of the LHC. The upgraded detector will operate at a maximum luminosity of $1.5 \times 10^{34}\,\mathrm{cm^{-2}s^{-1}}$, with the aim of integrating $\sim 300\,\mathrm{fb^{-1}}$ through the lifetime of the high-luminosity LHC (HL-LHC). The collected data will allow to fully exploit the flavour-physics opportunities of the HL-LHC, probing a wide range of physics observables with unprecedented accuracy. In particular, the new physics mass scale probed, for fixed couplings, will almost double as compared with the pre-HL-LHC era.

- See dedicated talks by *Didier Contardo* (LHCb),

  also *Tetsuo Abe* and *Francesco Forti* (Belle II).

Summary

Belle II:

- Completed Run1 in 2022 collecting 428 fb^{-1} of data and setting the world record for instantaneous luminosity.
- The performance of the trigger, tracking, neutrals and particle ID has been extensively studied, with good performance overall enabling many world-leading physics results (many shown at this conference).
- On track to resume data taking in Dec 2023 with PXD2 installed.

LHCb Upgrade I:

- Detector transformed to cope with new challenges at Run3 and beyond.
- 2022 was a commissioning year for the experiment as a whole. First figures of merit already indicate good performance of all subsystems.
- The goal is to have the detector at the best of its performance and running at Run3 nominal instantaneous luminosity in 2024 and 2025.

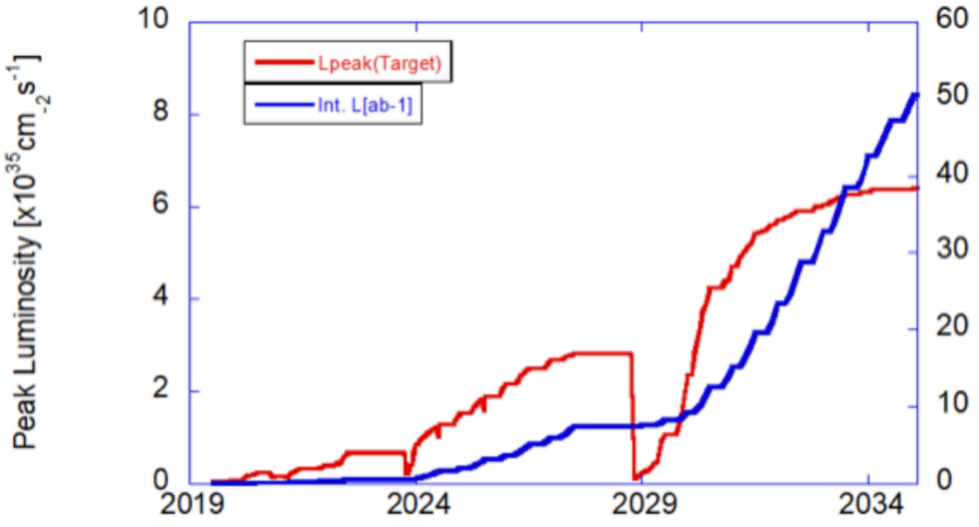
⇒ Belle II and LHCb are performing well, enabling both to deliver on their complementary physics programs.
Exciting times ahead!

BACKUP

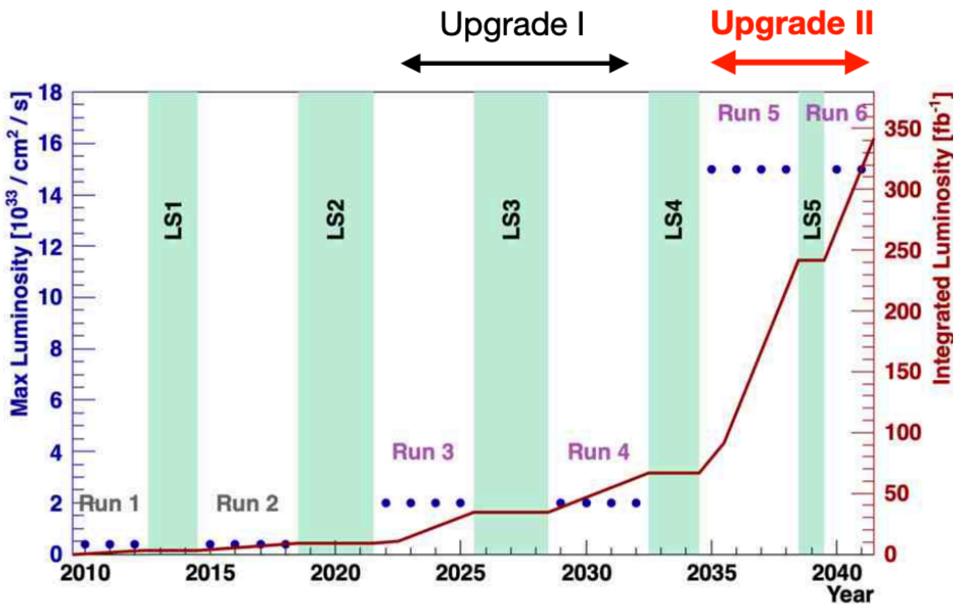
Luminosity prospects for Belle II and LHCb

- 2027:
  - Belle II: ~7 ab^{-1}
  - LHCb: ~30 fb^{-1}
- 2035:
  - Belle II: ~50 ab^{-1}
  - LHCb: ~60 fb^{-1}

Similar sensitivity



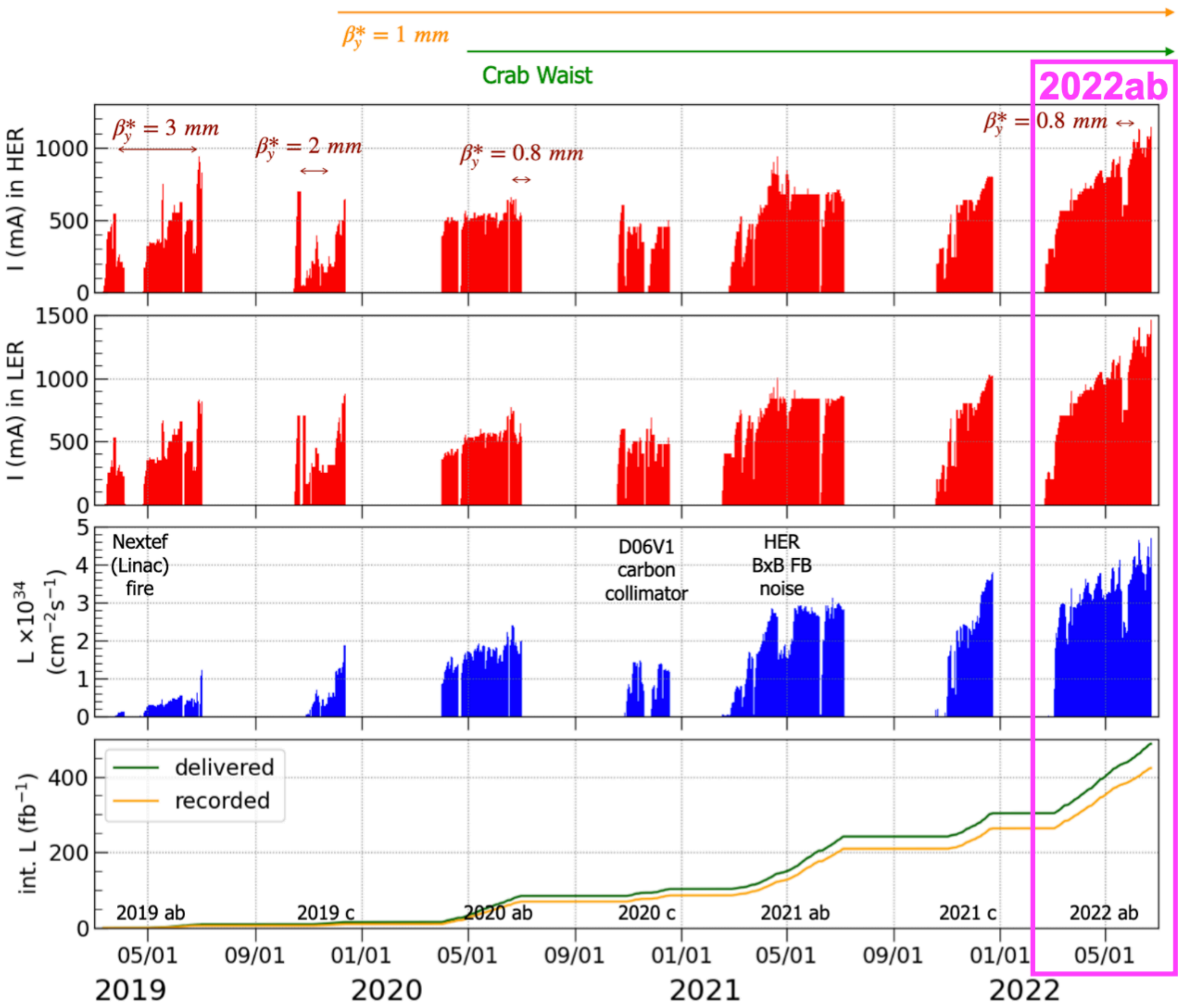
SuperKEKB plan, updated June 2022



From M.Palutan, LHCP2022

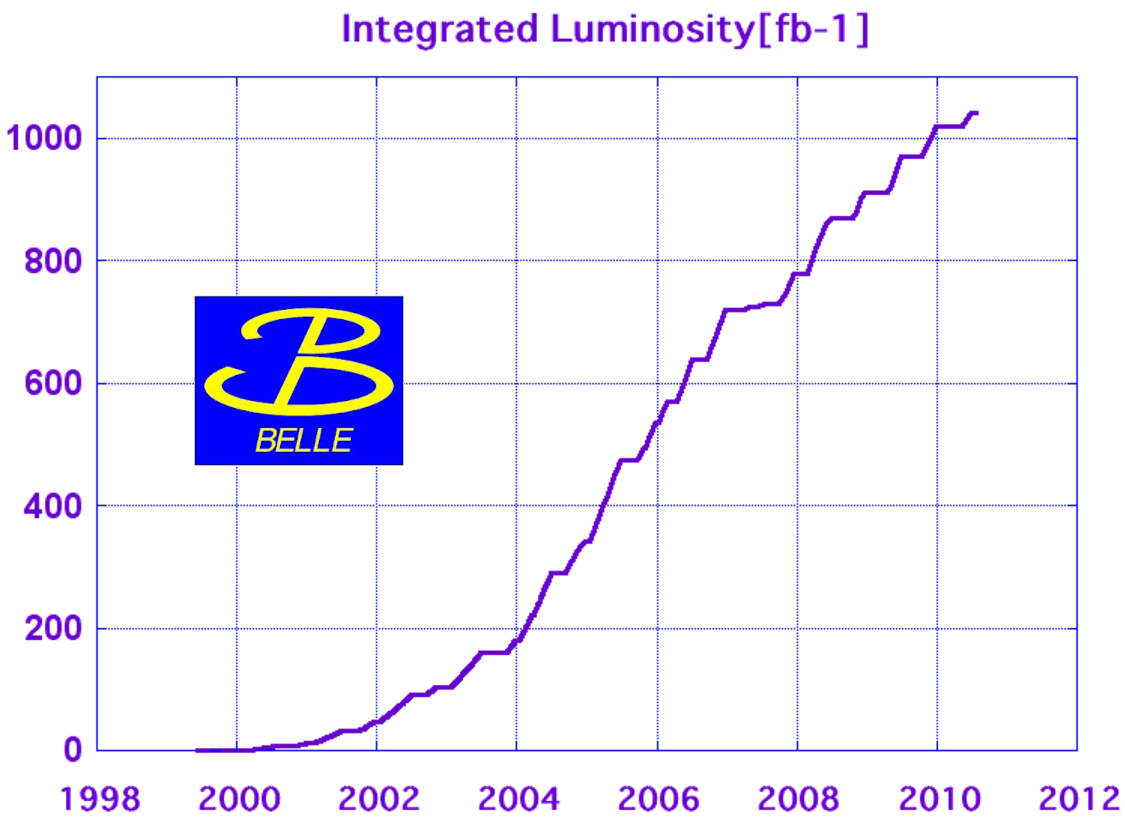
- SuperKEKB achievements until 2022:
  - β_y^*: 1mm (0.8 mm) << bunch length ~6mm
  - Peak currents
    - 1.46 A in LER
    - 1.14 A in HER
  - Peak luminosity (with Belle II data taking): 4.65 x 10^{34} $cm^{-2}s^{-1}$
  - Integrated luminosity (delivered): 424 fb^{-1}

- Toward end of **2022ab** the lumi/currents ramped up and we lost collimators, resulting in relatively high beam background conditions.

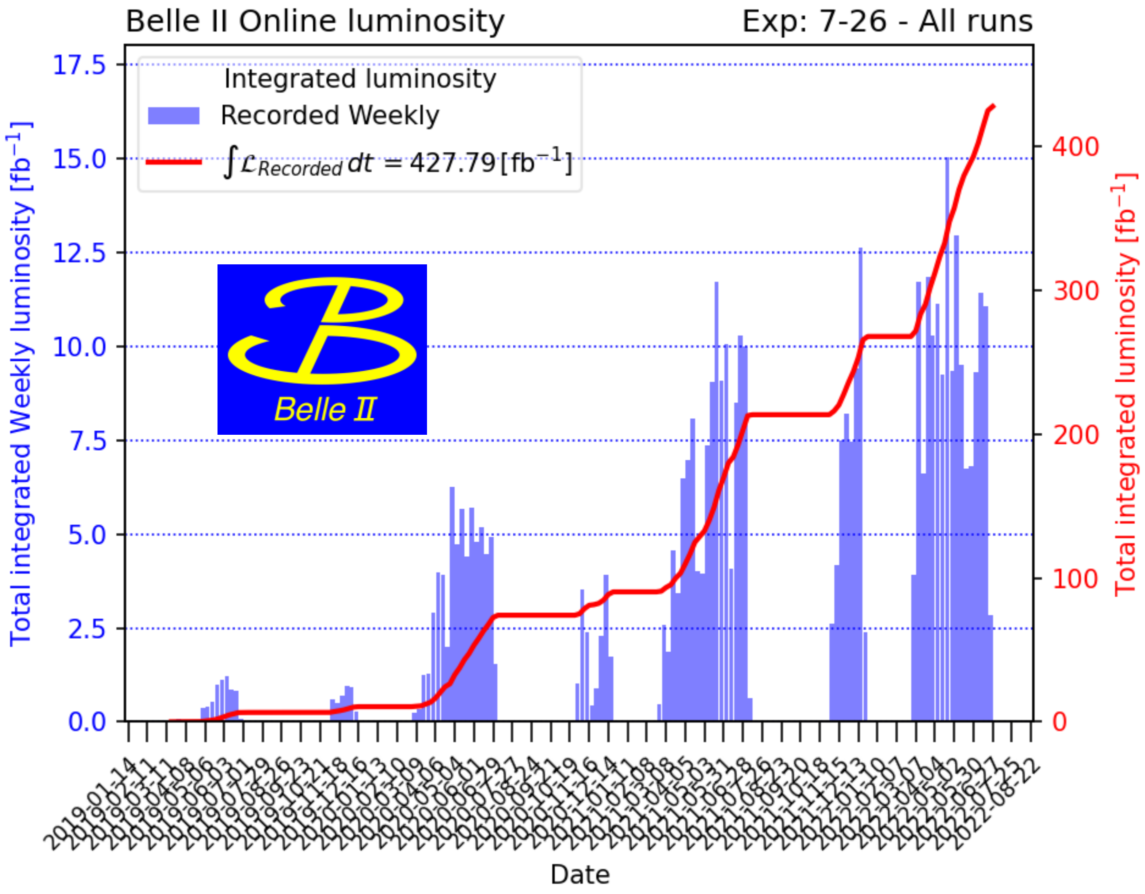


Luminosity Status

Belle from 1999 to 2010: ~**1 ab^{-1}**
710 fb^{-1} at the ϒ(4S) mass.



Belle II so far (2019 to 2022): **428 fb^{-1}**
362 fb^{-1} at the ϒ(4S) mass.
~BABAR and ~50% of Belle.



Summary

- **SuperKEKB has achieved and been updating world records in the luminosity and vertical emittance / beam size among the colliders.**
  - Luminosity record: $4.65 \times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
  - Integrated so far: $424\ \mathrm{fb}^{-1}$ (at SuperKEKB)
- **The progress in the luminosity improvement is very slow, despite the expectations, due to the various obstacles; especially serious are:**
  - Sudden Beam Loss in MR
    - The biggest obstacle in increasing the beam (bunch) currents
    - The fireball hypothesis being studied theoretically and experimentally
  - Poor injection efficiency
    - Without solving this problem, difficult to squeeze β_y^* or increasing the beam (bunch) currents
    - Emittance blowup at the end of the beam transport line (BT) to be fully understood and suppressed
      - Most likely cause is CSR and ISR, but only partially reproduced by the current simulation
        - More advanced models to be implemented in the simulation.
      - Other possibilities being investigated
    - Wider MR dynamic apertures during collision needed
- **There are many other problems and challenges:**
  - **Linac**: 2nd bunch orbit stabilization, influence of the ambient temperature change on RF phase, etc.
  - **Injection**: auto tuning, better optics matching between BT and MR, new BT line, etc.
  - **MR**: auto luminosity / collimator tunings, tot. beam current dependent optics deformation, better beam-beam performance, etc.
- **During LS1, many modifications and improvements have been done.**

24

Future Prospects

The first milestone after LS1 is 10^{35} cm^{-2}s^{-1}.

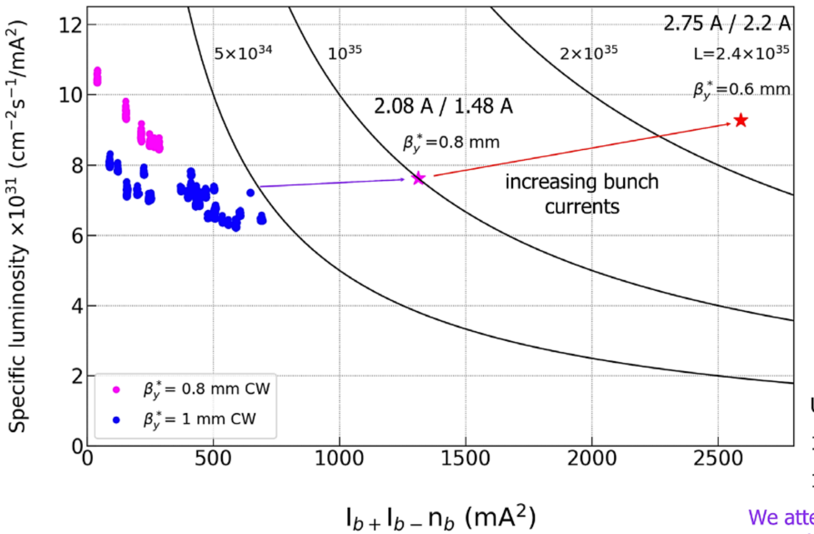
(Shown in IPAC'23 by Yukiyoshi OHNISHI)

■ The performance target after LS1

- Luminosity: $(1.0, 2.4) \times 10^{35} \mathrm{cm}^{-2}\mathrm{s}^{-1}$
- To be integrated for 10 years: 15 ab^{-1}
- Depending on how the obstacles will be overcome

Table 2: Machine Parameters in the Two-stage Improvement

Parameters	LER	HER	LER	HER
I (A)	2.08	1.48	2.75	2.20
n_b	2345		2345	
I_b (mA)	0.89	0.63	1.17	0.938
β_y^* (mm)	0.8		0.6	
ξ_y	0.0444	0.0356	0.0604	0.0431
ε_y (pm)	30		21	
Σ_y^* (μm)	0.218		0.160	
σ_z (mm)	6.49	6.35	7.23	7.05
L (cm^{-2}s^{-1})	10^{35}		2.4×10^{35}	



$$L_{sp} = \frac{L}{I_{b+} I_{b-} n_b}$$

Unit of luminosity:

10^{34} cm^{-2}s^{-1} = 1 KEKB

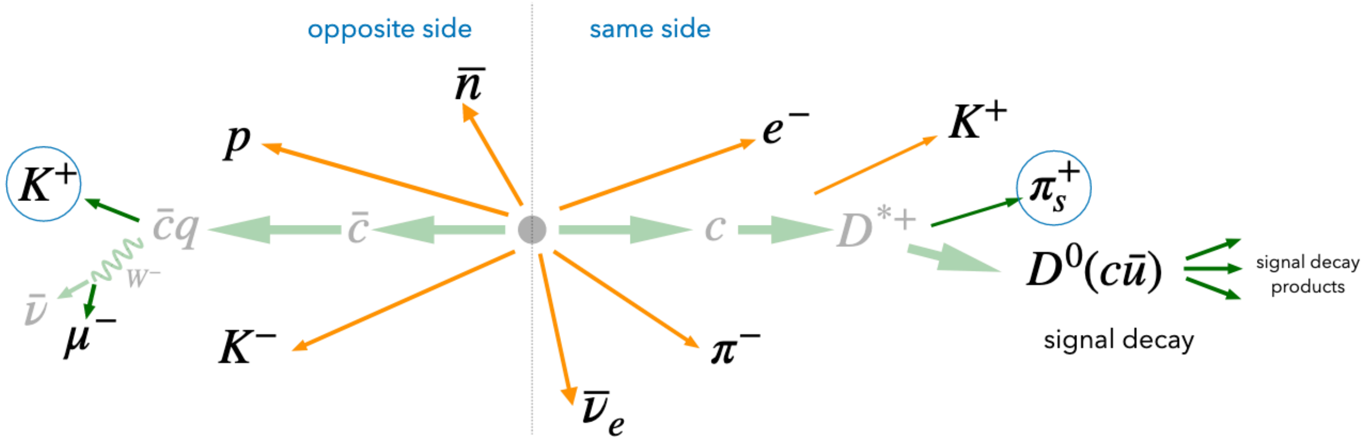
10^{35} cm^{-2}s^{-1} = 1 SuperKEKB

We attempt to improve luminosity toward a new luminosity unit.

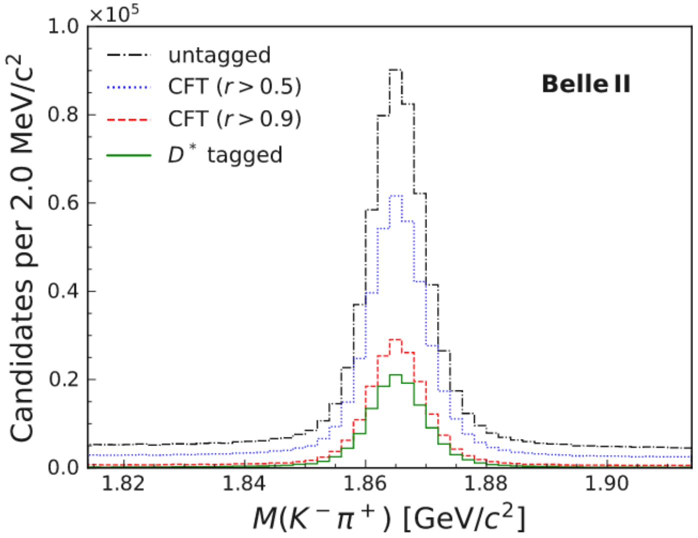
■ Discussion just started for further luminosity improvements beyond the above target

- LS2 needed with 3 possible scenarios:
  1. Moderate scale modification sometime after 2028 (> 1 year shutdown)
     - With the machine-detector interface (MDI) unchanged
  2. Larger scale modification, in addition to 1
     - With options of anti-solenoid re-configuration and MDI modification
  3. Much larger scale modification in 203X
- Final target luminosity : $6 \times 10^{35} \mathrm{cm}^{-2}\mathrm{s}^{-1}$
- To be integrated by the final end : 50 ab^{-1}
- Depending on results and achievements after LS1

Charm flavor tagger



Phys. Rev. D 107, 112010



- Novel flavor-tagging algorithm recovering D^0 candidates not tagged by traditional approach of reconstructing the $D^{*+} \rightarrow D^0\pi^+$ decay chain
- Exploiting charm pair production and charge correlation between signal D flavor and the tracks in the rest of the event
- Effective tagging efficiency calibrated in data with flavor-specific decays, roughly doubling the size of tagged D^0 sample: $\varepsilon_{eff} = 47.91 \pm 0.07$ (stat) ± 0.51 (syst) %

Vacuum incident

On 10th January 2023, during a VELO warm up in neon, there was a loss of control of the protection system

A pressure differential of 200 mbar built up between the two volumes, whereas the foils are designed to withstand 10 mbar only

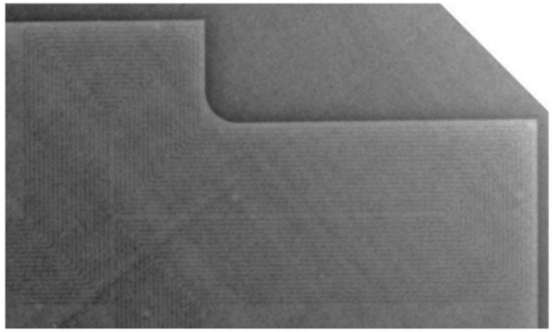
There was no damage to the VELO modules which have performed well throughout this year.

However, the RF boxes have suffered plastic deformation of about 17 mm and have to be replaced. This is a major intervention, postponed to the end of the year.

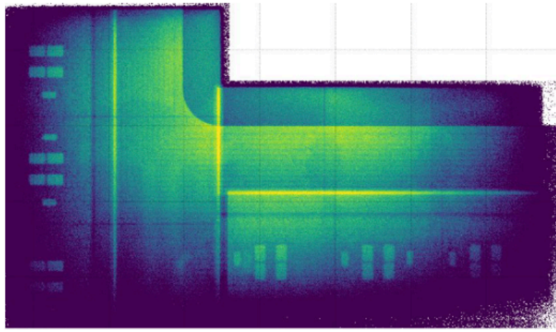
In the meantime, this year the VELO will not be fully closed

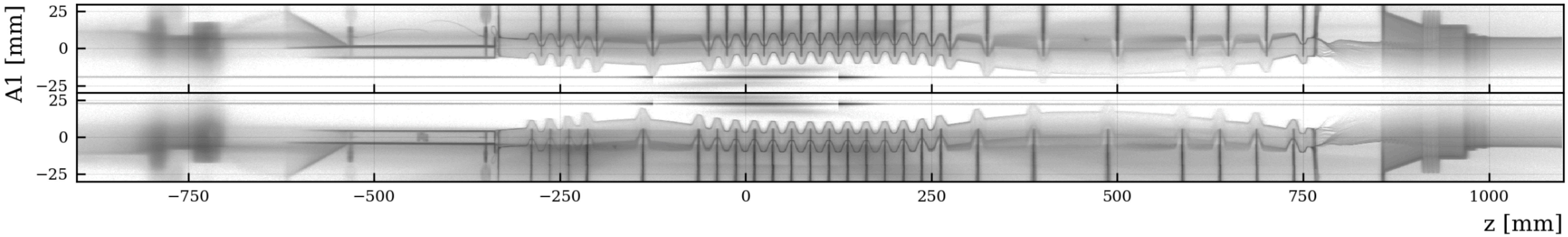
Thanks to the flexible 40 MHz trigger detailed tomography "pictures" of VELO elements can be quickly obtained

Microchannels seen with X-ray of the cooling plate



Microchannels seen with tomography of the modules





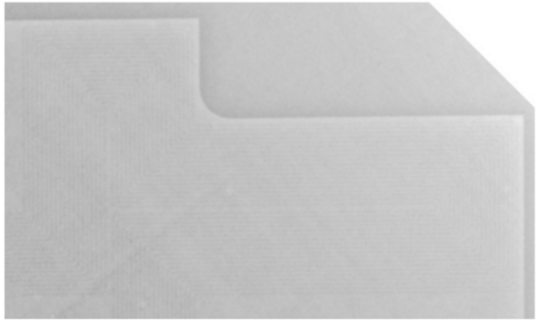
Vacuum incident

On 10th January 2023, during a VELO warm up in neon, there was a loss of control of the protection system

A pressure differential of 200 mbar built up between the two volumes, whereas the foils are designed to withstand 10 mbar only

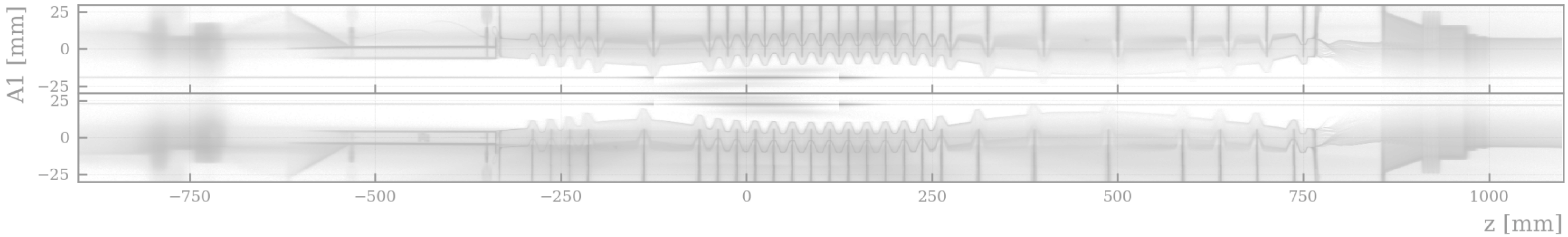
There was no damage to the VELO modules which have performed well throughout this year.

Microchannels seen with X-ray of the cooling plate



Microchannels seen with tomography of the modules

- LHC vacuum incident will have an impact on the VELO aperture on 2023, but **the LHCb commissioning, including now the Upstream tracker installed at the beginning of the year, can continue**



Likelihood-based PID

In each subdetector $d \in D = \{\text{SVD, CDC, TOP, ARICH, ECL, KLM}\}$, a likelihood $\mathcal{L}^d(\mathbf{x}|i)$ is defined for each charged particle hypothesis as a joint probability density function (PDF) of a given set of observables, $\mathbf{x}$. The PDFs are either predicted from simulation, extracted from data control samples with high purity, or determined analytically. Assuming that the subdetectors' measurements of each of the identifying observables are independent, a *global* likelihood for each particle hypothesis i is defined by:

$$\mathcal{L}(\mathbf{x}|i) = \prod_{d}^{d\in D} \mathcal{L}^d(\mathbf{x}|i) \quad \text{or equivalently,} \quad \log\mathcal{L}(\mathbf{x}|i) = \sum_{d}^{d\in D} \log\mathcal{L}^d(\mathbf{x}|i).$$

Given all possible, mutually exclusive outcomes of identification for a reconstructed particle candidate, the *global* likelihood ratio serves as a proxy for identifying such candidate:

$$P(A_i|\mathbf{x}) = \frac{P(\mathbf{x}|A_i) \cdot P(A_i)}{\sum_j P(\mathbf{x}|A_j)P(A_j)} \quad \Rightarrow P(i|\mathbf{x}) = \frac{\mathcal{L}_i}{\sum_j \mathcal{L}_j}.$$

Through knowledge of the individual hypotheses' prior probabilities for a given class of events, $P(A_j)$, the likelihood ratio can be interpreted as an actual *probability* of identifying the i-th particle species in that event subset. Currently, we assume that the prior probabilities are always identical for any j.

From the individual likelihoods, it is also possible to build *binary* likelihood ratio discriminators between two hypotheses i and j:

$$R(i/j|\mathbf{x}) = \frac{\mathcal{L}_i}{\mathcal{L}_i + \mathcal{L}_j}.$$