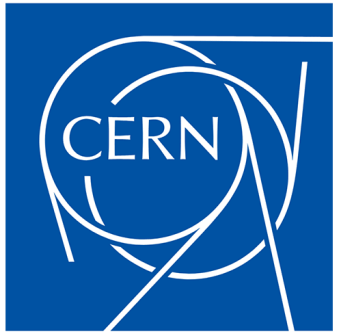
CERN-RRB-2024-041 (slides)

Status of LHCb Upgrade I

Vincenzo Vagnoni (INFN Bologna, CERN)

for the LHCb collaboration

23rd April 2024, CERN RRB meeting



LHCb's hard skin

- As you remember from last RRB meeting, the situation wasn't easy, and we needed an extraordinary effort over the winter to be in good shape for the 2024 *pp* run
- The effort has been done, and we are now in much better conditions
  - VELO restored
  - UT progressing fast
  - Electronics instabilities tamed
  - Detector in good shape

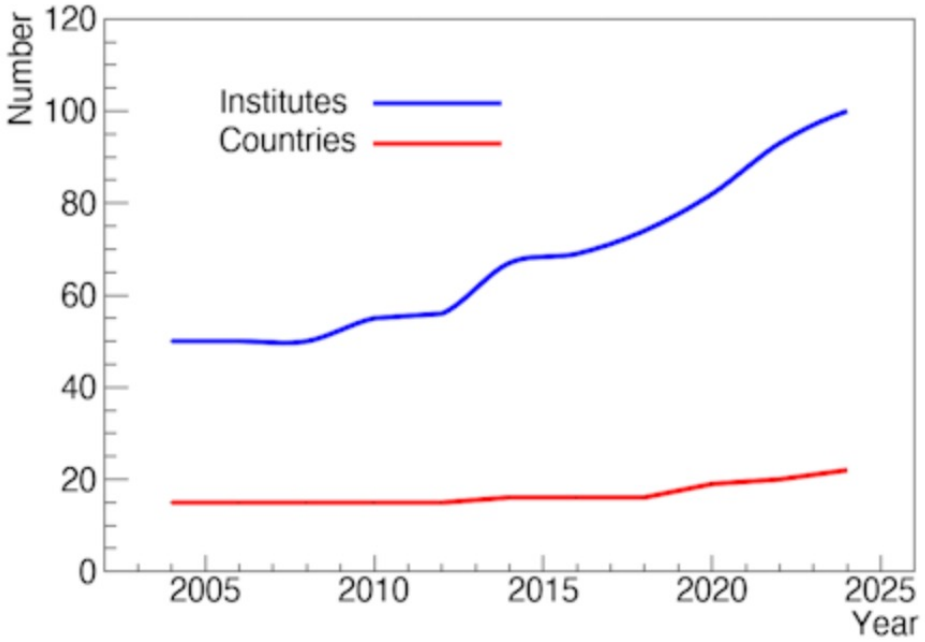
Closing remarks *from last RRB meeting*

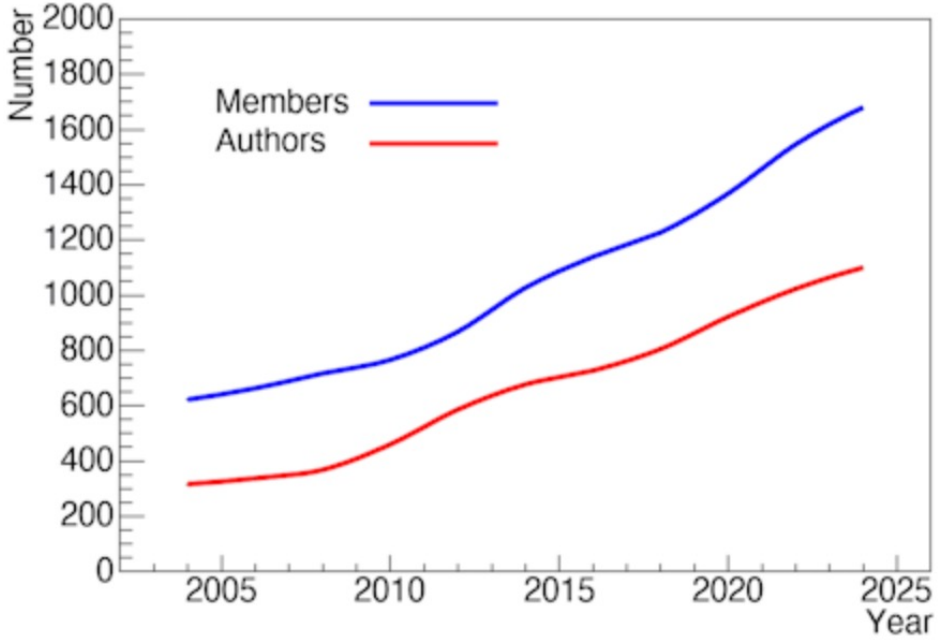
- 2023 was a difficult year for LHCb, in particular due to the LHC vacuum incident in the VELO
- However, the collaboration reacted in the proper way and is ready to fully recover the damage during the upcoming Winter shutdown
- The stop of the LHC during Summer was also impacting, but the detector is now taking good data in the Heavy Ion run, also injecting Argon into the beam pipe to collect a unique sample of Pb-Ar collision data
- Despite the adversities, the LHCb collaboration is well alive and always fighting

We'll sell our skin dearly!

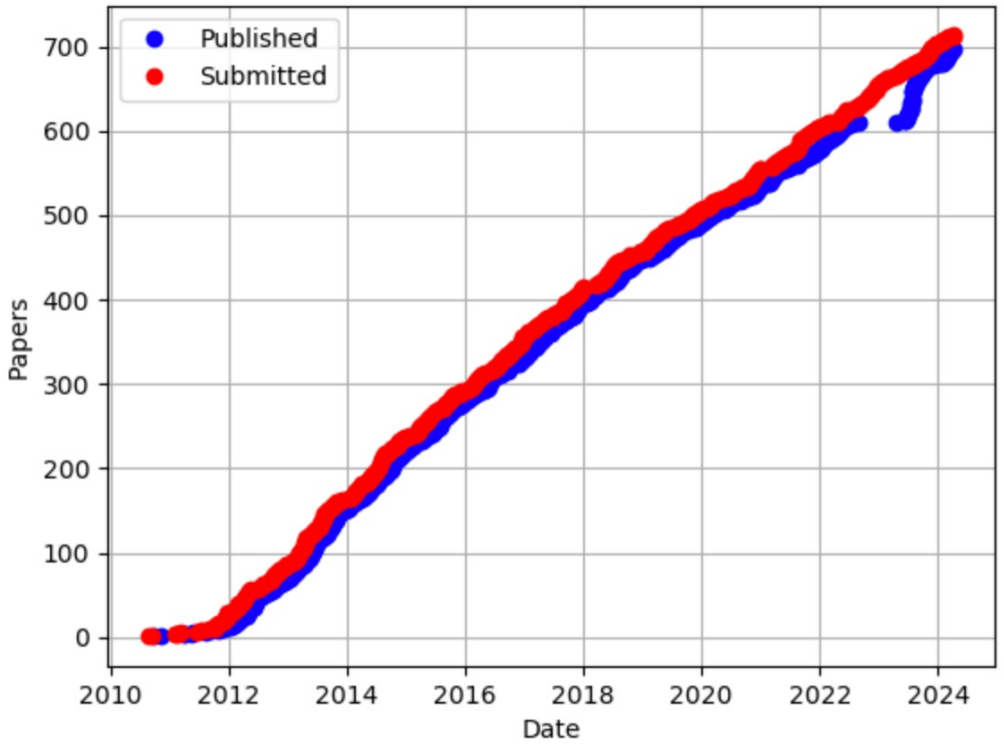
LHCb collaboration

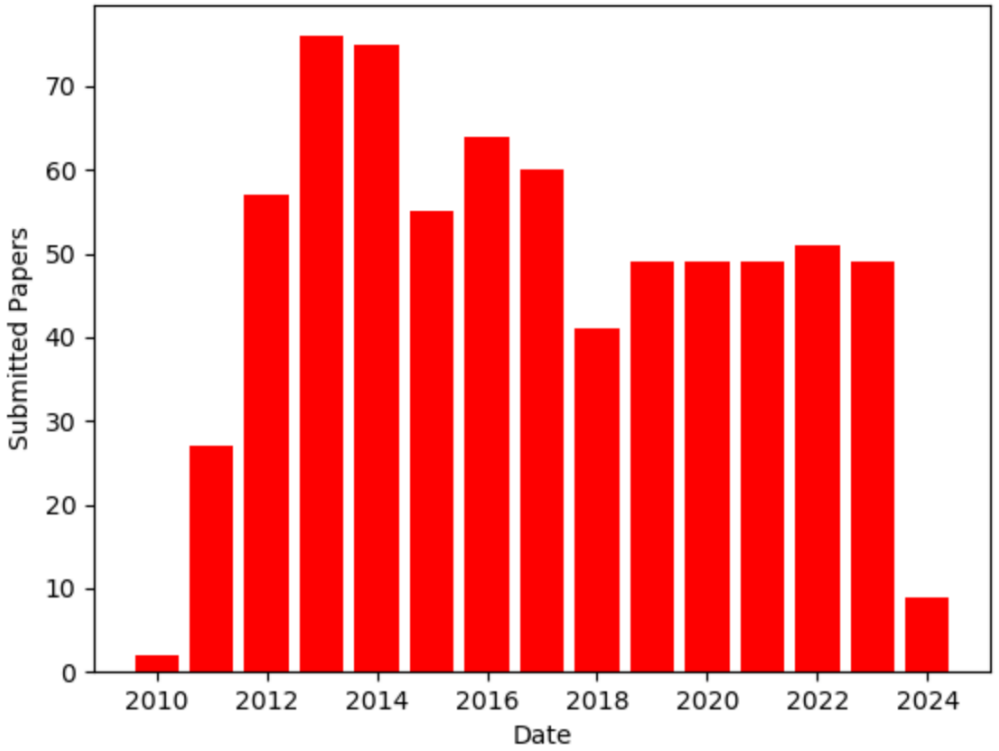
- As of today, 1710 members from 100 institutes in 22 countries
  - 1622 at last RRB meeting → 5% increase
- The collaboration keeps growing at high rate, although we will have a discrete drop later this year due to the end of the ICA with the Russian Federation
- Expect more significant growth with the Upgrade II process going ahead





Status of publications





- From October 2023 the LHCb collaboration submitted 27 new physics publications, for a grand total of 713
- There are 14 further papers being processed by the Editorial Board and 32 analyses under review

Today's three physics highlights

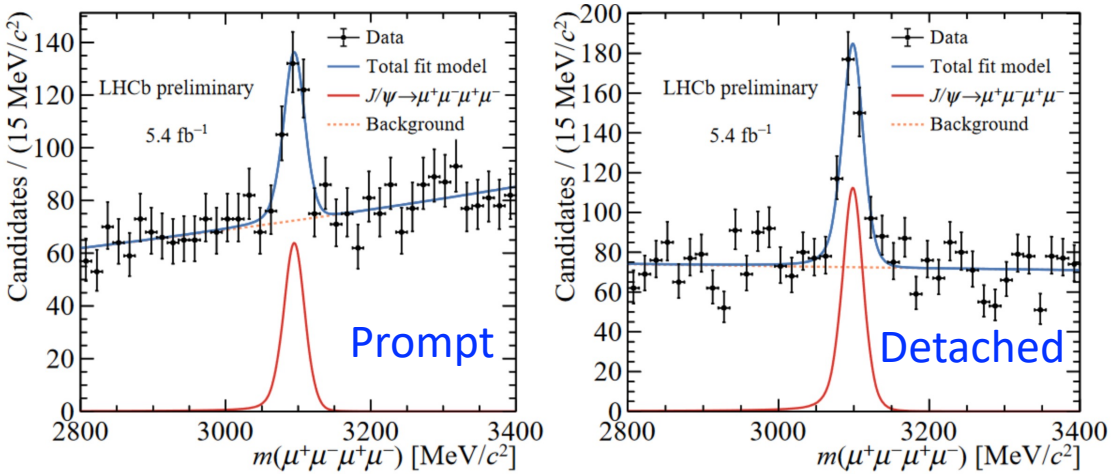
- World's best measurement of J/Ψ →4μ
- World's best measurement of charm mixing and search for *CP* violation in charm mixing
- New Lepton Universality test R(D^{*+})

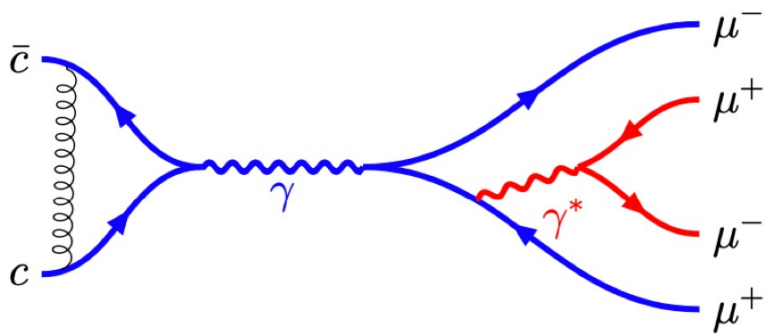
	Title	arXiv
1.	Measurement of the CKM angle γ using the B→ D*h channels	2310.04277
2.	Enhanced production of Λ_b^0 baryons in high-multiplicity pp collisions at $\sqrt{s} = 13$TeV	2310.12278
3.	A measurement of $\Delta\Gamma_s$	2310.12649
4.	Observation of $\Xi_b^0 \to \Xi_c^+ D_s^-$ and $\Xi_b^- \to \Xi_c^0 D_s^-$ decays	2310.13546
5.	Search for *CP* violation in the phase-space of $D^0 \to K_S^0 K^\pm \pi^\mp$ decays with the energy test	2310.19397
6.	Studies of η and η' production in pp and pPb collisions	2310.17326
7.	Fraction of χ_c decays in prompt J/ψ production measured in pPb collisions at $\sqrt{s_{NN}} = 8.16$ TeV	2311.01562
8.	Measurement of the D^* longitudinal polarisation in $B^0 \to D^{*-}\tau^+\nu_\tau$ decays	2311.05224
9.	Observation of strangeness enhancement with charm mesons in high-multiplicity pPb collisions at $\sqrt{s_{NN}} = 8.16$ TeV	2311.08490
10.	Measurement of forward charged hadron flow harmonics in peripheral PbPb collisions at $\sqrt{s_{NN}} = 5$ TeV with the LHCb detector	2311.09985
11.	A model-independent measurement of the CKM angle γ in partially reconstructed $B^\pm \to D^* h^\pm$ decays with $D \to K_S^0 h^+ h^-$ ($h = \pi, K$)	2311.10434
12.	Measurement of J/ψ-pair production in pp collisions at $\sqrt{s} = 13$ TeV and study of gluon transverse-momentum dependent PDFs	2311.14085
13.	Observation of $\Lambda_b^0 \to \Lambda_c^+ \bar{D}^{(*)0} K^-$ and $\Lambda_b^0 \to \Lambda_c^+ D_s^{*-}$ decays	2311.14088
14.	Measurement of associated $J/\psi - \psi(2S)$ production cross-section in pp collisions at $\sqrt{s} = 13$ TeV	2311.15921
15.	Determination of short- and long-distance contributions in $B^0 \to K^{*0}\mu^+\mu^-$ decays	2312.09102
16.	Amplitude analysis of the $B^0 \to K^{*0}\mu^+\mu^-$ decay	2312.09115
17.	Search for $B_c^+ \to \pi^+\mu^+\mu^-$ decays and measurement of the branching fraction ratio $\mathcal{B}(B_c^+ \to \psi(2S)\pi^+)/\mathcal{B}(B_c^+ \to J/\psi\pi^+)$	2312.12228
18.	Study of $B_c^+ \to \chi_c \pi^+$ decays	2312.12987
19.	Multiplicity dependence of $\sigma_{\psi(2S)}/\sigma_{J/\psi}$ in pp collisions at $\sqrt{s} = 13$ TeV	2312.15201
20.	Prompt and nonprompt $\psi(2S)$ production in pPb collisions at $\sqrt{s_{NN}} = 8.16$ TeV	2401.11342
21.	Study of *CP* violation in $B_{(s)}^0 \to DK^*(892)^0$ decays with $D \to K\pi(\pi\pi)$, $\pi\pi(\pi\pi)$, and KK final states	2401.17934
22.	Measurements of the branching fraction ratio $\mathcal{B}(\phi \to \mu^+\mu^-)/\mathcal{B}(\phi \to e^+e^-)$ with charm meson decays	2402.01336
23.	Observation of the $B_c^+ \to J/\psi\pi^+\pi^0$ decay	2402.05523
24.	Measurement of the branching fraction of $B^0 \to J/\psi\pi^0$ decays	2402.05528
25.	Modification of $\chi_{c1}(3872)$ and $\psi(2S)$ production in pPb collisions at $\sqrt{s_{NN}} = 8.16$ TeV	2402.14975
26.	First observation of the $\Lambda_b^0 \to D^+ D^- \Lambda$ decay	2403.03586
27.	Amplitude analysis of the $\Lambda_b^0 \to pK^-\gamma$ decay	2403.03710
	Performance papers	
28.	Tracking of charged particles with nanosecond lifetimes at LHCb	2403.09483
29.	Momentum scale calibration of the LHCb spectrometer	2312.01772
30.	Helium identification with LHCb	2310.05864

World's best measurement of J/Ψ →4μ

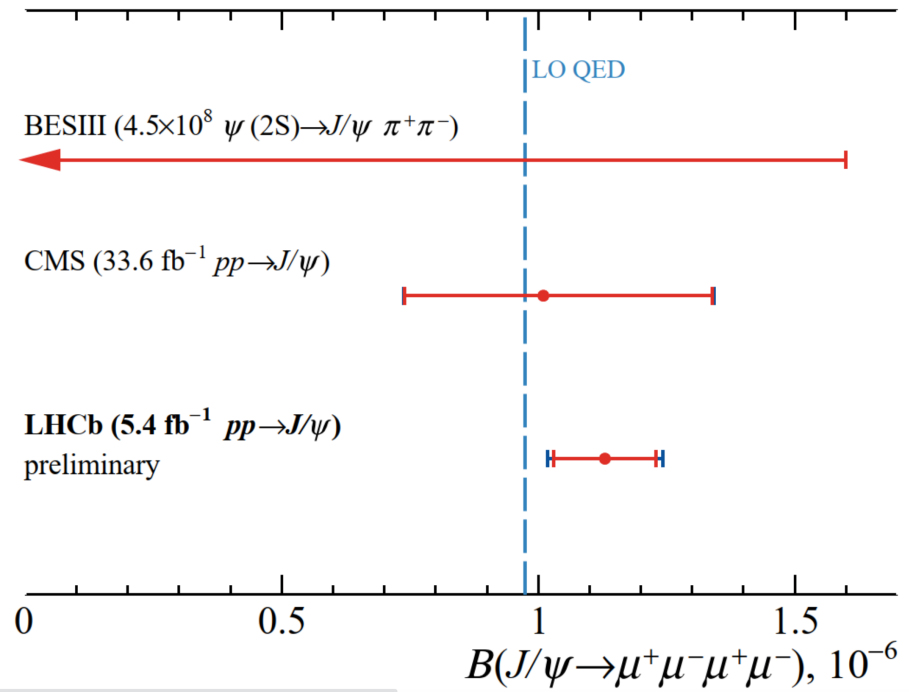
- Rare electromagnetic decay proceeding dominantly through the final-state radiation of a virtual photon

LHCb-CONF-2024-001





- Experimentally there is only a limit from BES-III and measurement from CMS with few events
- LHCb result consistent with SM at 1.4σ



$$\mathcal{B}(J/\psi \to \mu^+\mu^-\mu^+\mu^-) = (1.13 \pm 0.10 \pm 0.05 \pm 0.01) \times 10^{-6}$$

World's best measurement of charm mixing and search for *CP* violation in charm mixing

- LHCb full Run-2 measurement of mixing and *CP*-violating parameters in prompt $D^0 \to K^+\pi^-$ → total uncertainties improved by 1.6x
- LHCb plans now to collect two-body D^0 decays with 2x efficiency with respect to Run-2 → uncertainties to be halved by the end of Run-3
- LHCb is the only active facility with the potential to observe *CP* violation in charm mixing down to Standard Model values in the forthcoming future → unique prospects

Highlighted as CERN news

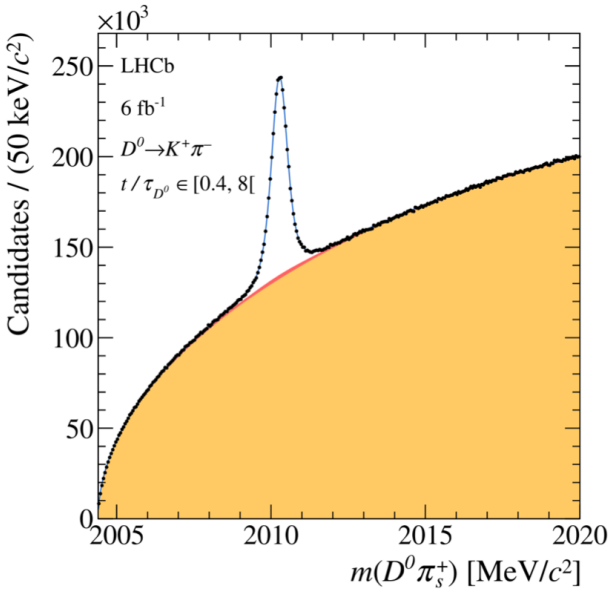
Voir en français

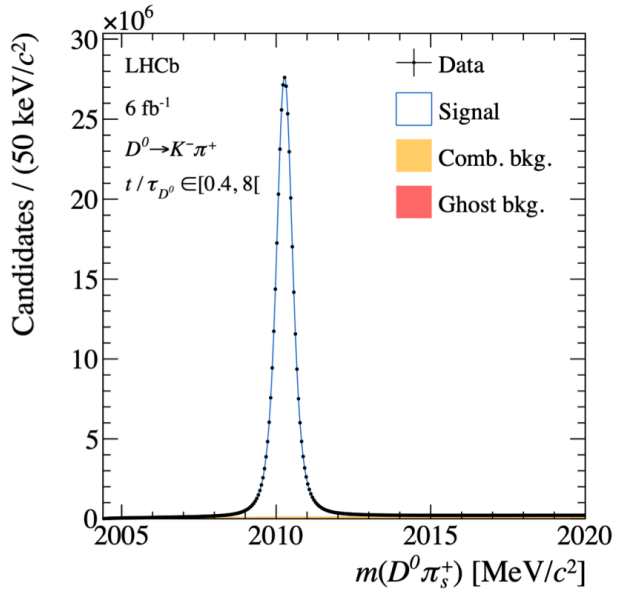
Searching for new asymmetry between matter and antimatter

LHCb has conducted a new search for matter–antimatter asymmetry using its full data sets from the first and second runs of the LHC

11 APRIL, 2024 | By Ana Lopes

LHCb-PAPER-2024-008

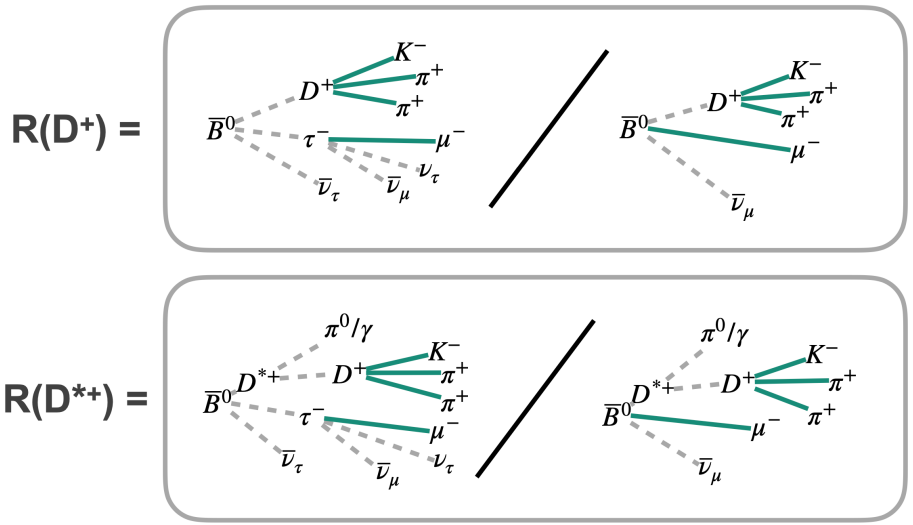


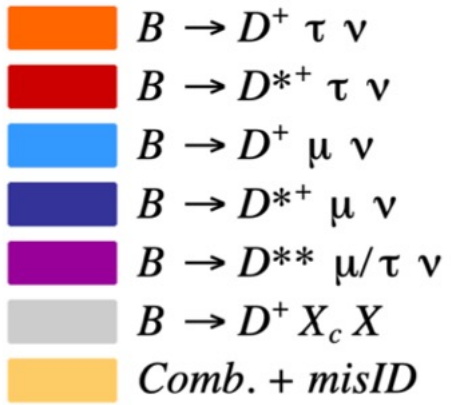


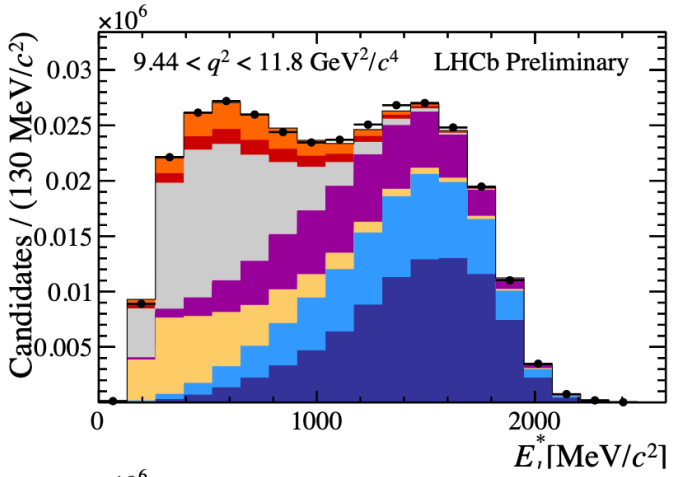
New Lepton Universality test R(D*+)

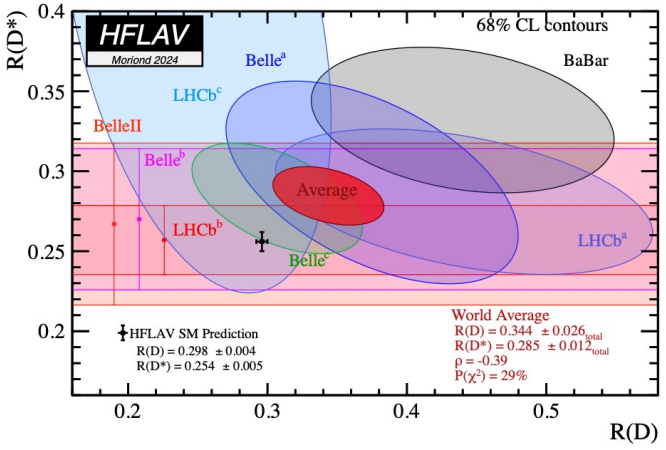
LHCb-PAPER-2024-007

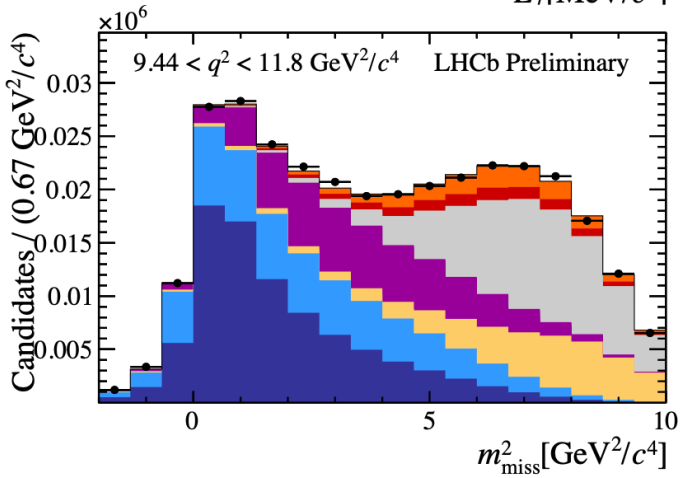
- First LHCb measurement using the D^+ ground state, with $D^+ \to K^-\pi^+\pi^+$ and muonic tau decay → primary goal is to measure $R(D^+)$











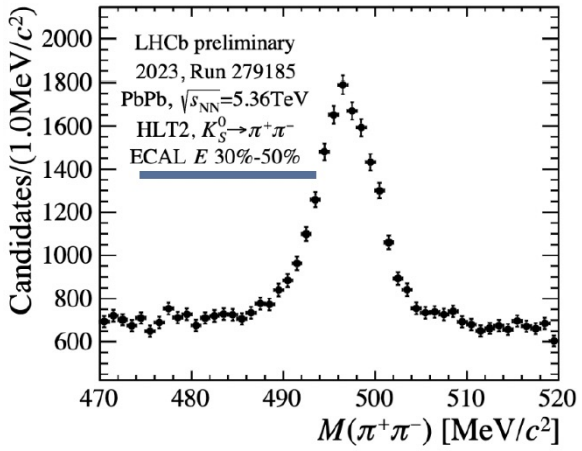
- Very complex multidimensional analysis due to large backgrounds from other decay channels
- World Average: tension with SM at 3.2σ

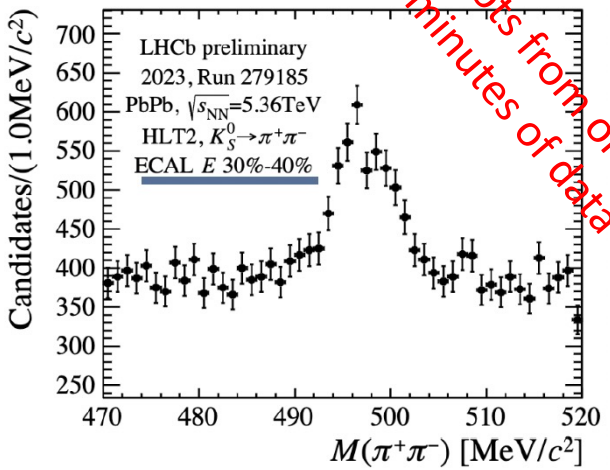
$$R(D+) = 0.249 \pm 0.043 \pm 0.047$$

$$R(D^{*+}) = 0.402 \pm 0.081 \pm 0.085$$

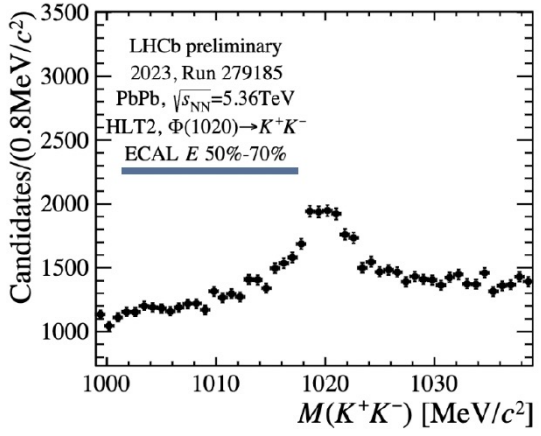
Heavy Ion run in 2023

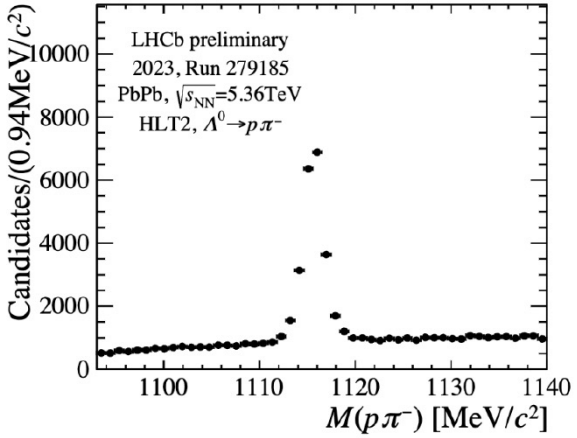
- Successful Pb-Pb run → routine data taking with 90-95% efficiency in 2nd half

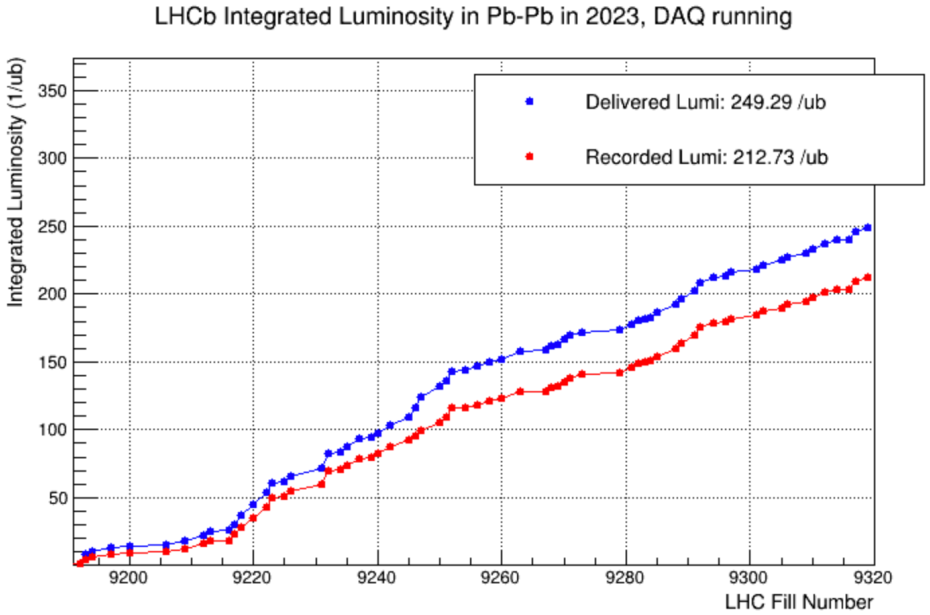


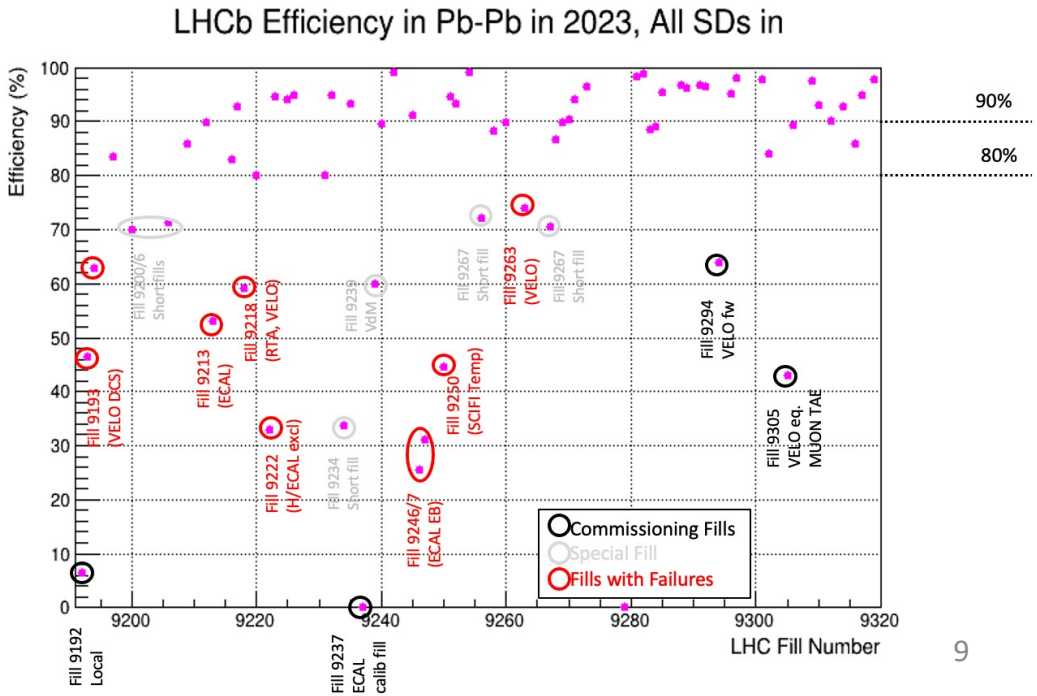


Plots from only 40 minutes of data taking









First PbPb data reconstructed down to 30% centrality by LHCb

YETS 2023/24

Improvement of the calibration system

Maintenance, stability improvements and performance studies

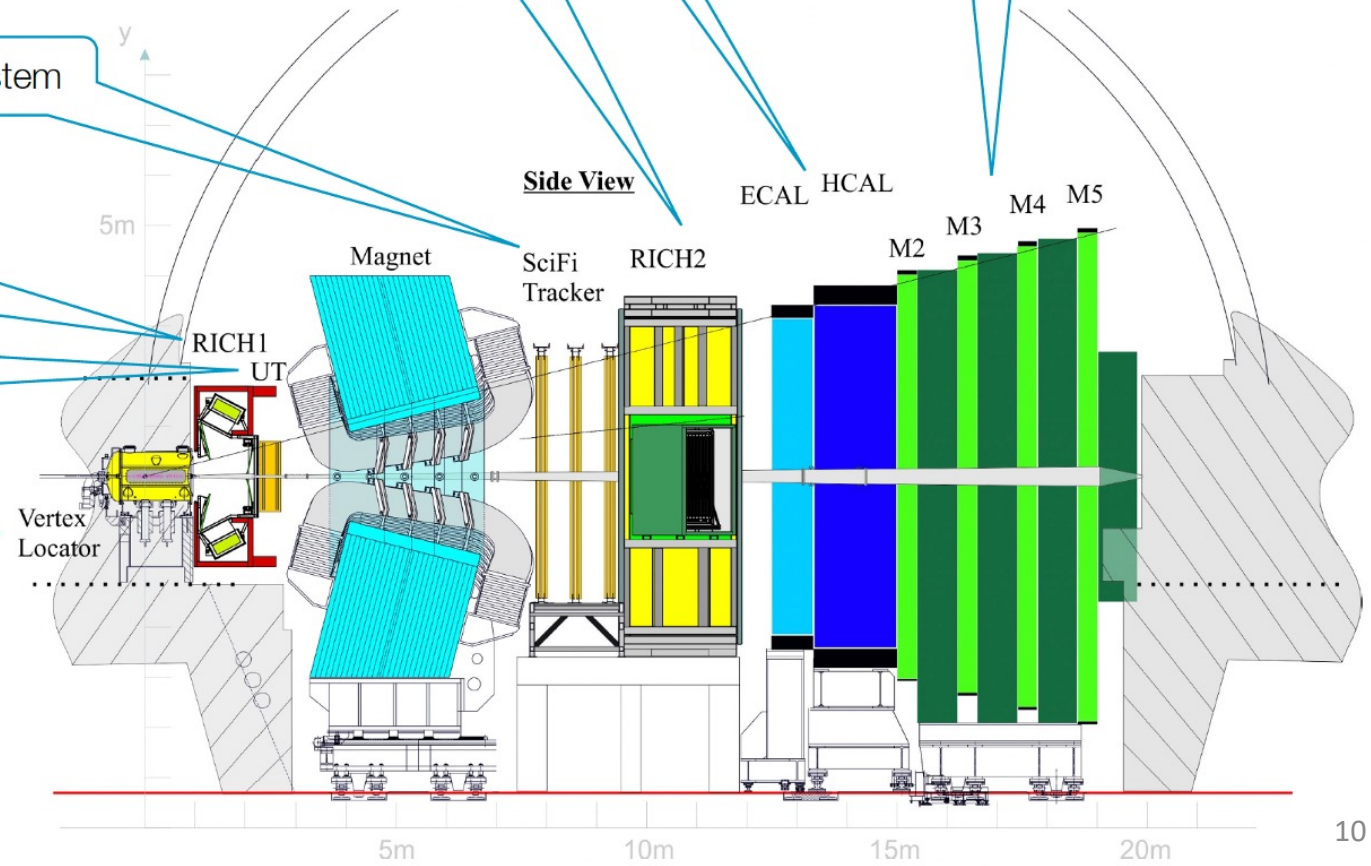
Chamber replacement, calibration and performance studies

Calibration, improved cooling system

Maintenance, stability improvements and performance studies

Hardware interventions, DAQ improvements, first tests

RF-foil replacement, re-installation and re-commissioning

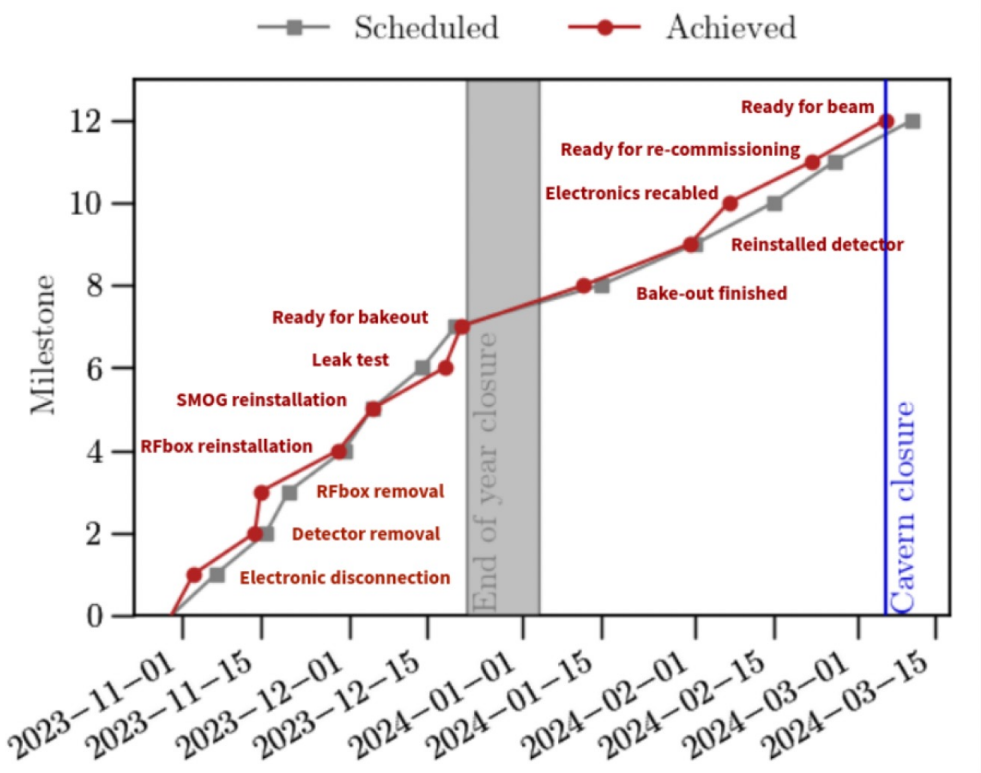


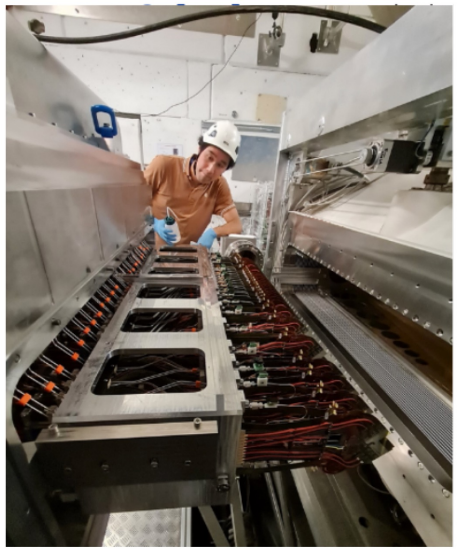
New coordinating structures in place

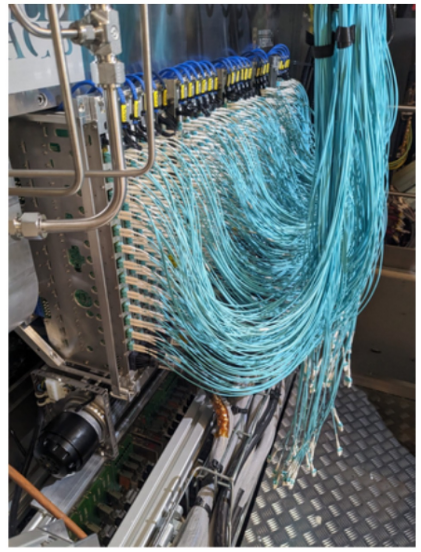
- Technical Board sub-committee (TBSC)
  - Focusing on issues related to online software components of common interest to Real Time Analysis and subsystems
- Detector Electronics Commissioning Task Force (DECTF)
  - Focusing on issues related to detector electronics
- Software and Computing Board (SCB)
  - Focusing on the mid- and long-term strategies of software and computing
  - The SCB coordinator is part of the LHCb management

VELO restoration

- During the YETS, the VELO was completely dismounted to allow for the replacement of the RF box, that was deformed in the LHC vacuum incident of January 2023
- Very complex and delicate intervention: work schedule spanning over 17 weeks and involved about 40 people from 13 institutes
  - Milestones during the intervention were strictly respected
- Long story short: the VELO was fully restored, recommissioned and is now routinely operated as by design

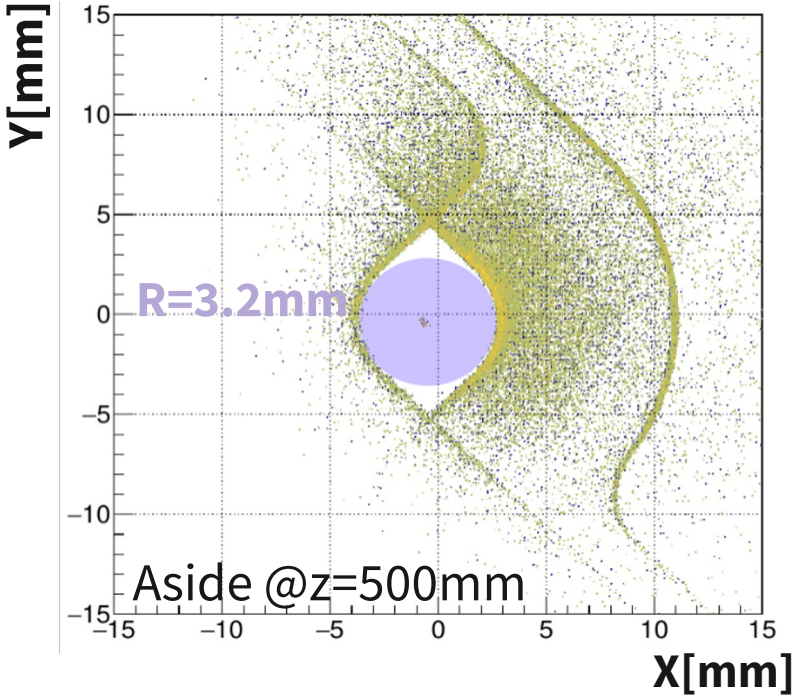


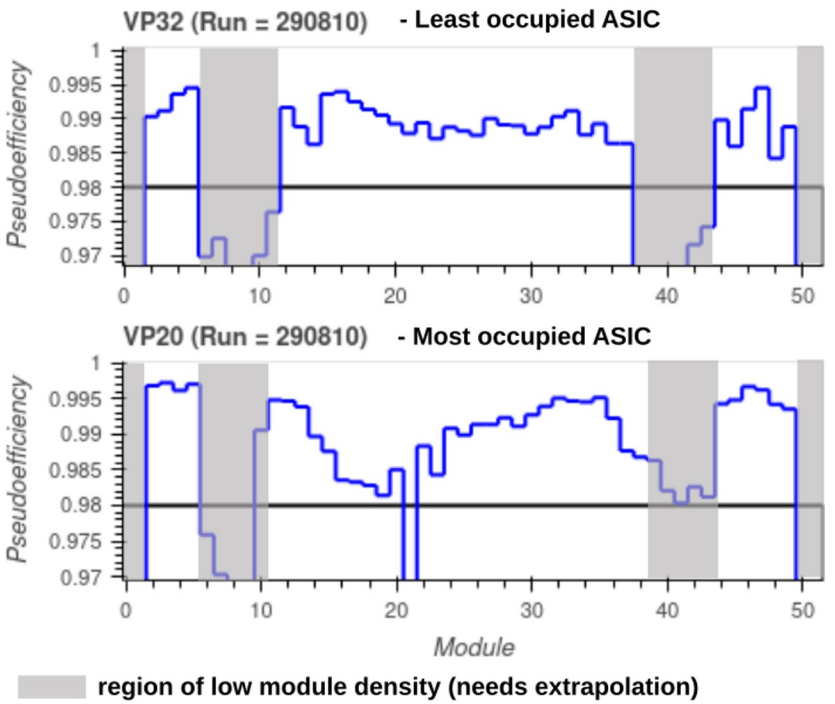




Status of VELO

- Closing procedure re-commissioned
  - Closed routinely since the first 6.8 TeV fill
- Estimated the aperture from tomography, reconstructing secondary interaction vertices in the RF-foil
  - Safe aperture between 2.9 and 3.2 mm
- Checked operation parameters (thresholds, timing) of the detector to maximise hit efficiency
  - Hit efficiency > 98% for most of the ASICs
- Improved readout firmware
- Tested procedure to control evolution of radiation damage
- On-going: operation with fully commissioned detector at high pile-up, now working to reach ultimate stability

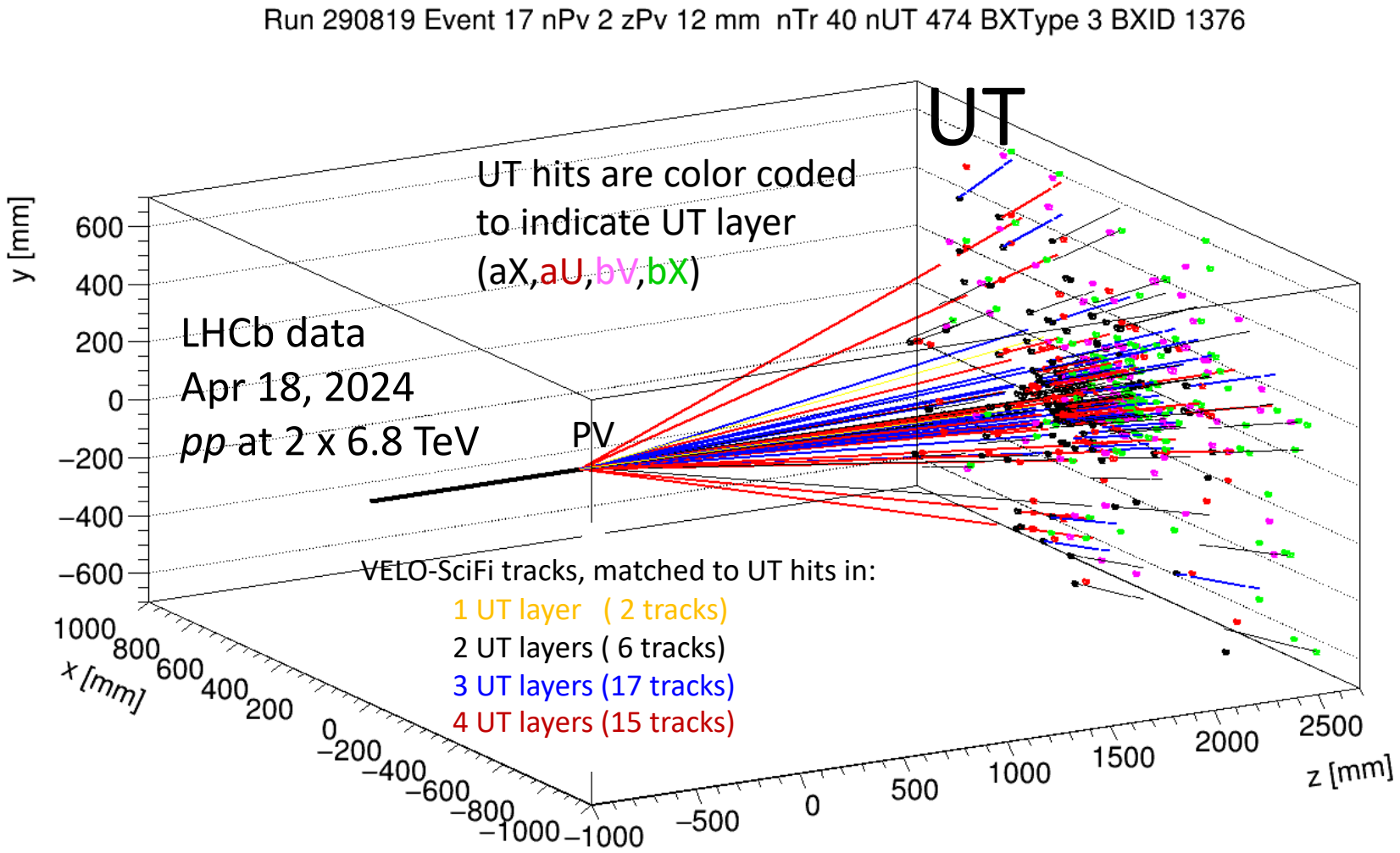




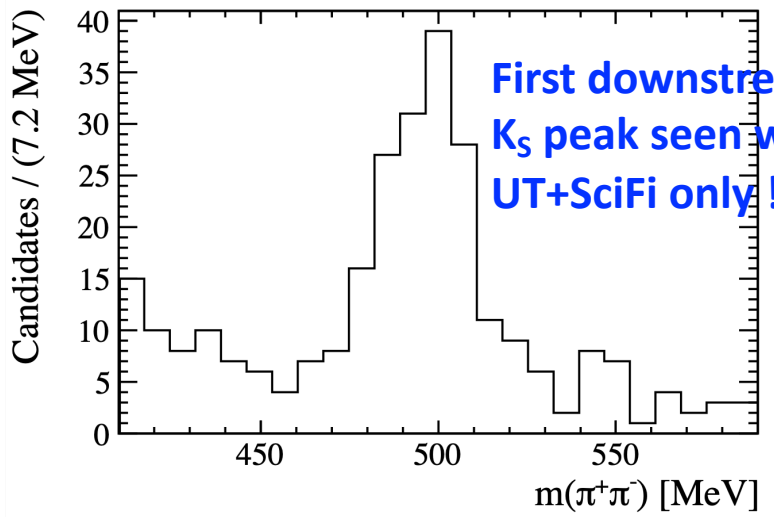
Status of UT

- Rapid progress in commissioning since beam became available in April
  - Coarse time alignment completed: 90% of ASICs peak at the right bunch crossing
  - Data for fine time alignment was collected and is being analysed
  - The UT detector successfully ran for hours on April 18 along with the other subdetectors
  - Despite space alignment is not completed, detector performances look good
  - Precise space alignment using recorded data is in progress
- Remaining commissioning work
  - Fine tune TELL40 firmware and FE ASICs
  - Automate electronic calibrations and space alignment
  - Test/optimise inclusion of UT in HLT1 and HLT2 triggers, first in off-line mode then in real time
- Targeting to start using UT in triggers for physics after the technical stop mid-June

UT event display

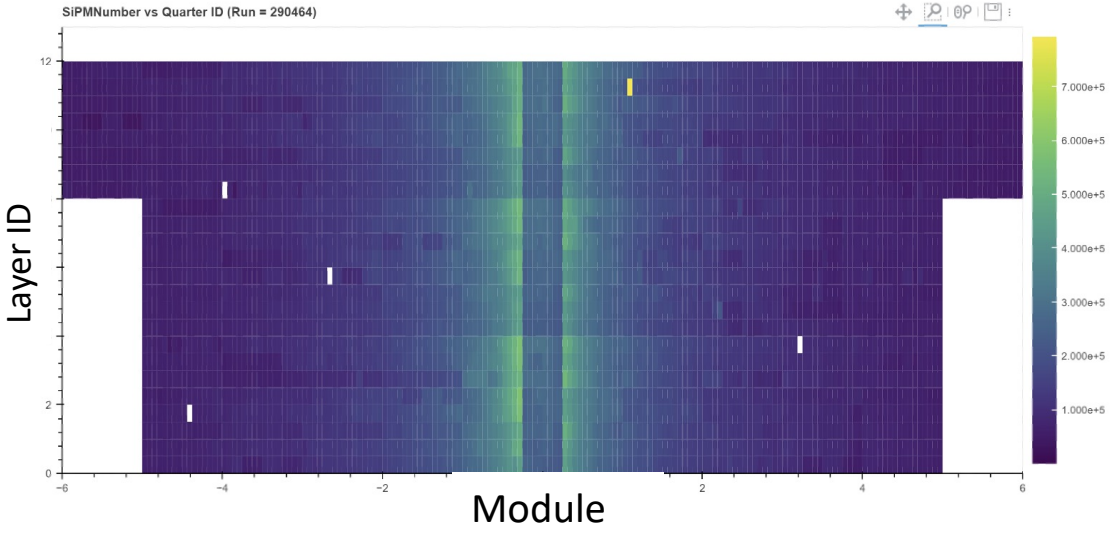


- One of the first events recorded on April 18, illustrating that the detector works with high efficiency and low noise together with the other tracking subdetectors

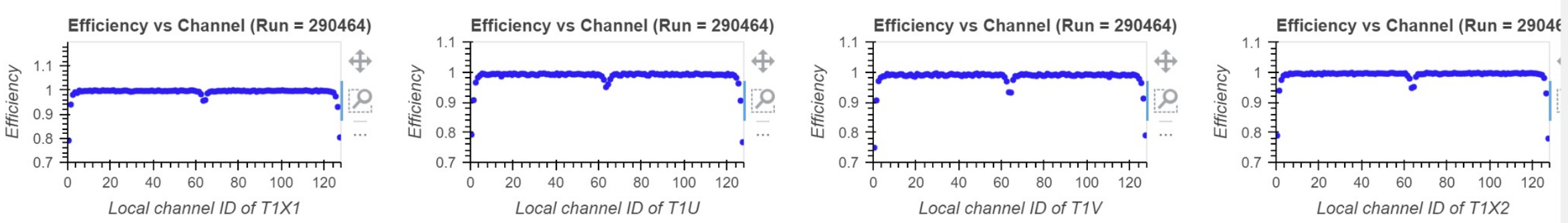


Status of SciFi

- Full detector running at nominal operation conditions with great stability
  - All FEBs calibrated: calibration of clustering thresholds for 520k channels → necessary to achieve ultimate efficiency
  - Coarse and fine time alignment done with first data
  - SiPM temperature stable at -50 ^{o}C
  - DAQ running smoothly at various pileup values, with only 4 excluded data links + 1 noisy data link out of a total of 4096
  - Key detector parameters monitored during data taking: coarse time alignment, hit efficiency, hit resolution, stability

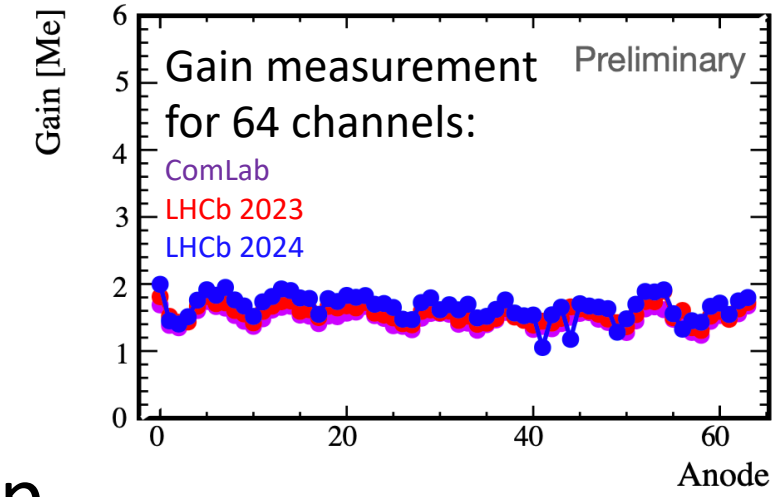


Detector efficiency very well behaved

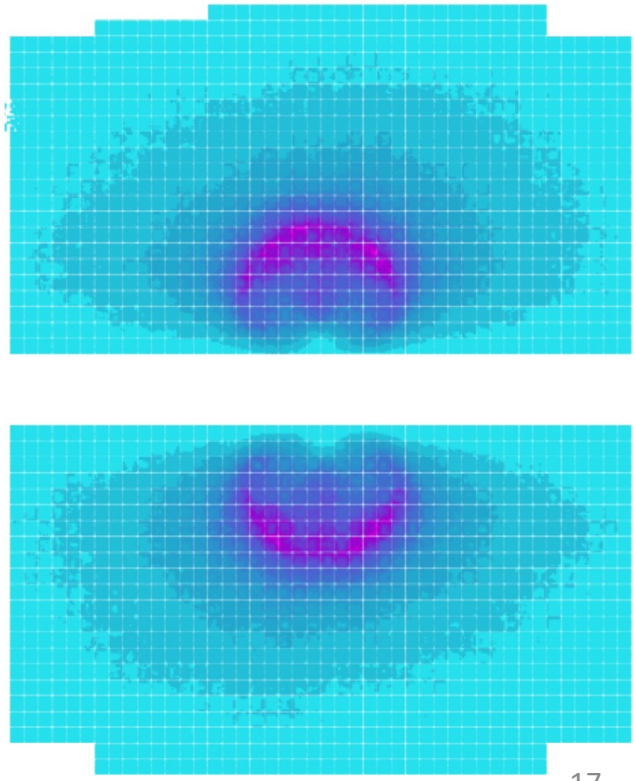


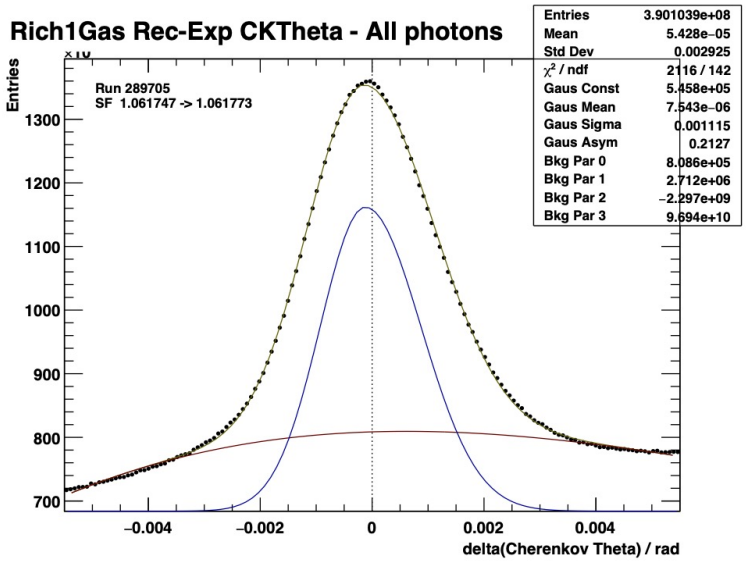
Status of RICH

- Local calibration completed with threshold scans over 200k channels, background runs and occupancy studies
- Detailed linearity checks with increased pile-up
- Monitoring further improved with online determination of detected photons per track and hadron identification efficiency and purity
- Ready for performance tuning and for physics production



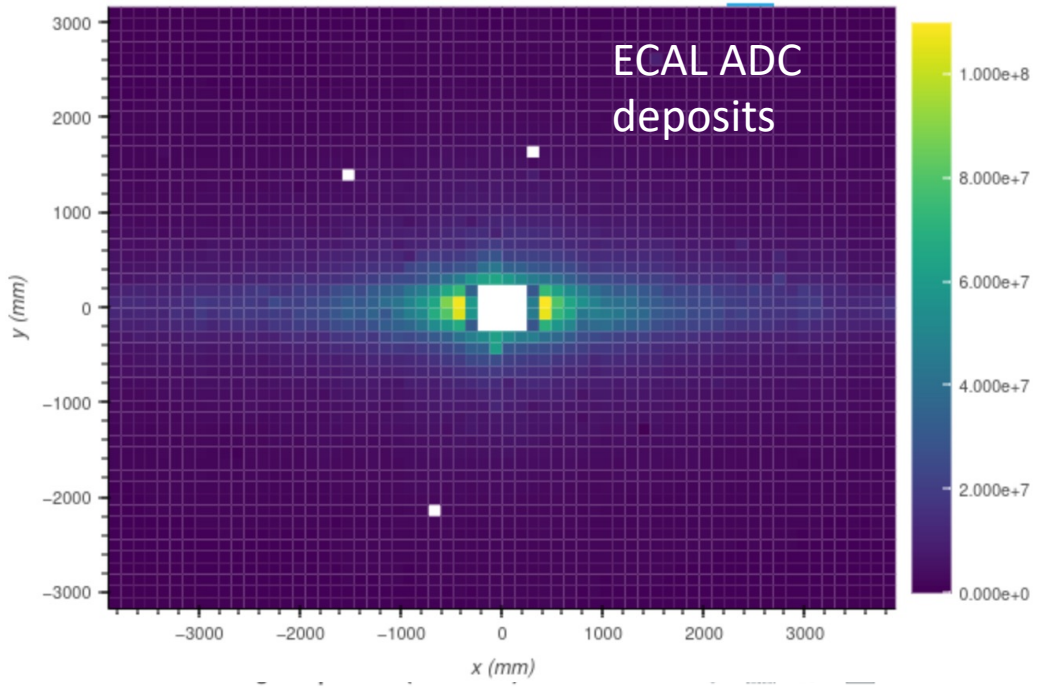
RICH 1 hit map

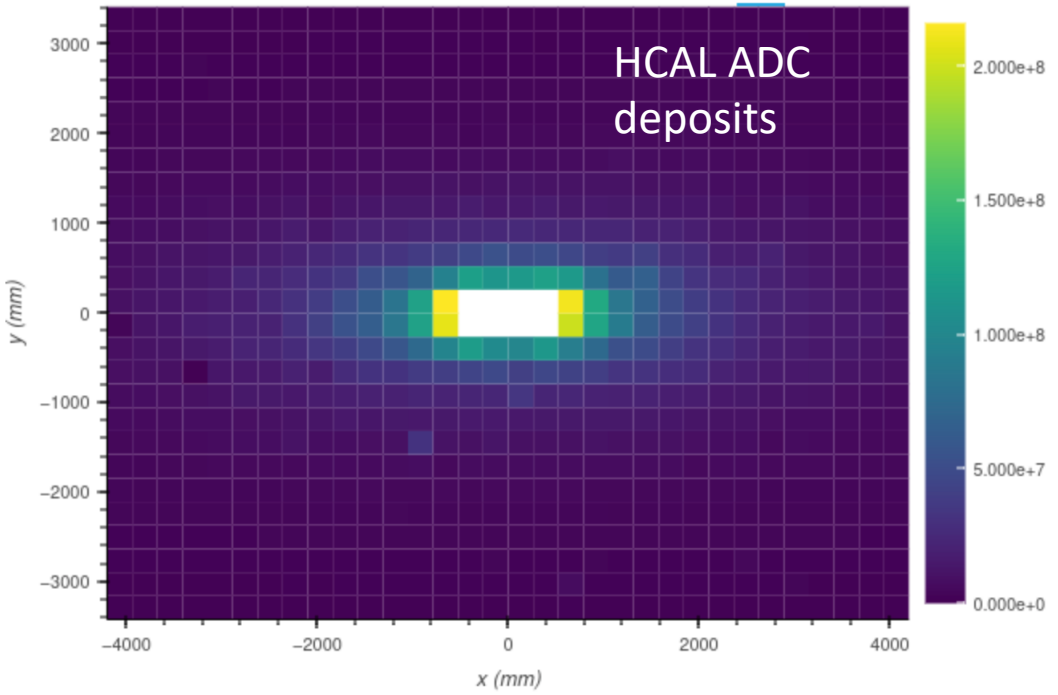




Status of CALO

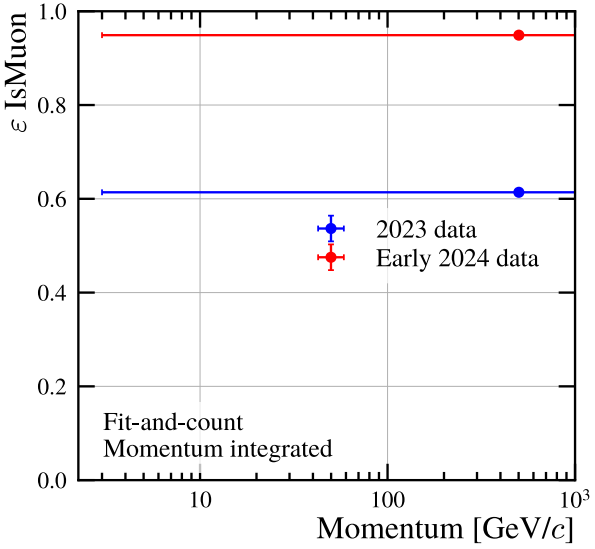
- Smooth running of the calorimeter system
- Improvements since the beginning of stable beams
  - Recovery of some faulty channels
  - HCAL energy calibrated with Cs source
  - Time alignment of the individual channels with particles → all channels properly time aligned except for a few noisy / dead ones
  - Improvements in pedestal subtraction method
- Current work
  - Tuning of the amplitude of LED pulses for monitoring
  - A large π^0 sample has been taken with stable beams
    - 90% of the channels can be satisfactorily calibrated
    - Still working on the remaining 10% (mass reconstruction fit to be improved)

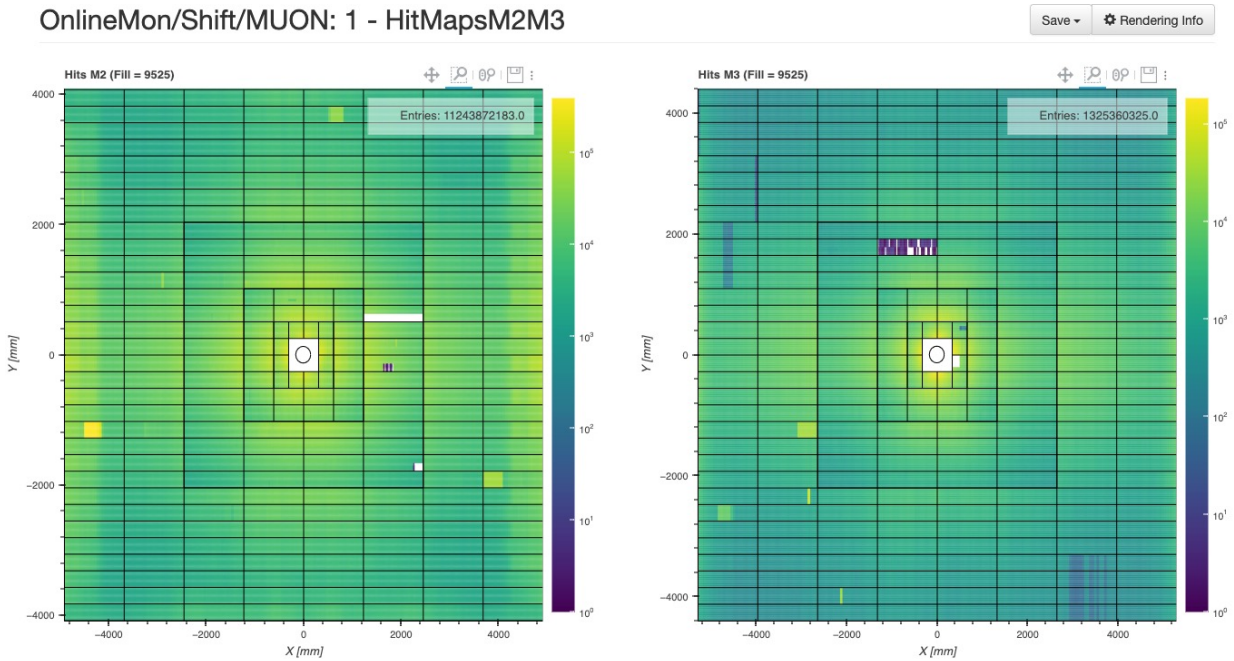


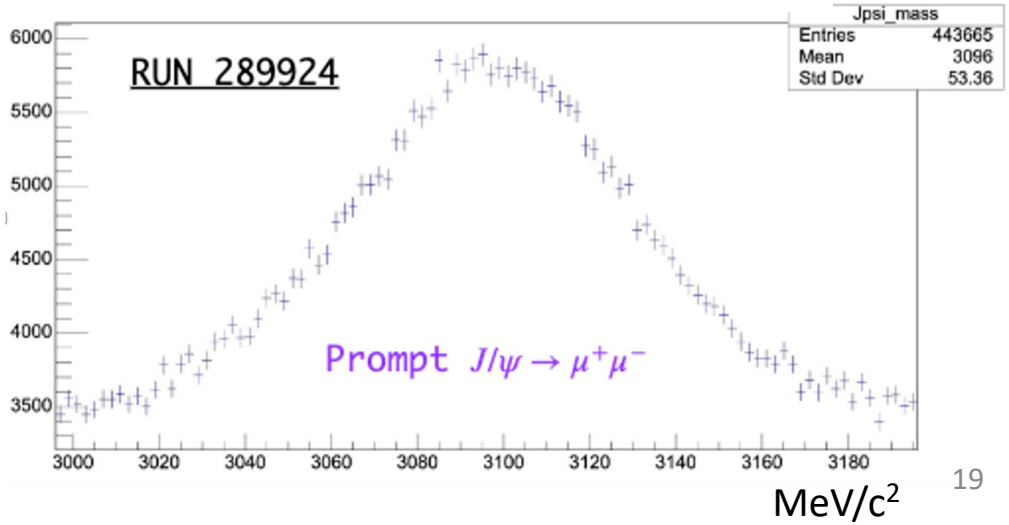


Status of MUON

- New coarse and fine time corrections using hits matched to muon tracks
- Improvements in performance are evident from illumination maps and clear $J/\psi \to \mu^+\mu^-$ mass peak at HLT1
- From a preliminary study, muon ID performance is greatly improved with respect to 2023, reaching 95% in 2024 (was as low as 61% in 2023)







Status of ONLINE

- Online system in production since 2022: constant support for subdetector activities, as firmware, ECS and software (monitoring)
- Work focusing now more on rare issues and more automation
- Still a large amount of *ad-hoc* work being done to accommodate various late requirements (higher rates, compression, dumping of raw-data at various stages, ...)
- Large batch of new farm-nodes for HLT2 acquired, awaiting delivery, followed by installation (probably June)
- Main worry (not a major one for the time being): hardware issues on EB servers creating a constant background work-load (unusual amount of failures of memory modules, CPUs, etc...,) → Can all be recovered locally, but requires work and money for spare parts, clear sign that a full replacement of EB nodes will be needed for Run-4

Status of Real-Time Analysis (RTA)

HLT1

- GPU-based HLT1 trigger ran smoothly at all intensities so far → Throughput high enough for nominal data taking
- Improved ghost rejection without UT in reconstruction
- Automated bandwidth division and deployment
- Improvements in monitoring

Align & Calib

- Automatically running VELO and SciFi alignments. First RICH alignment deployed. CALO calibrations in progress
- Real-time measurement of beamline position
- New monitoring framework for high-level quantities running online

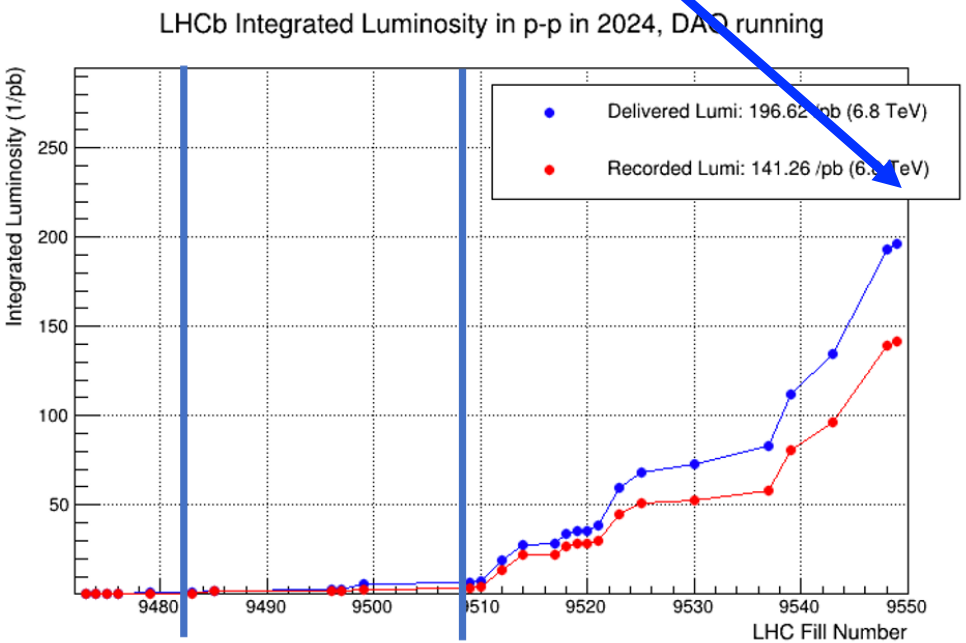
HLT2

- New neural net for ghost rejection, optimised reconstruction configuration
- Implementation of material corrections in full geometry description
- Detailed optimization of bandwidth for the full physics programme

2024 run status and plans

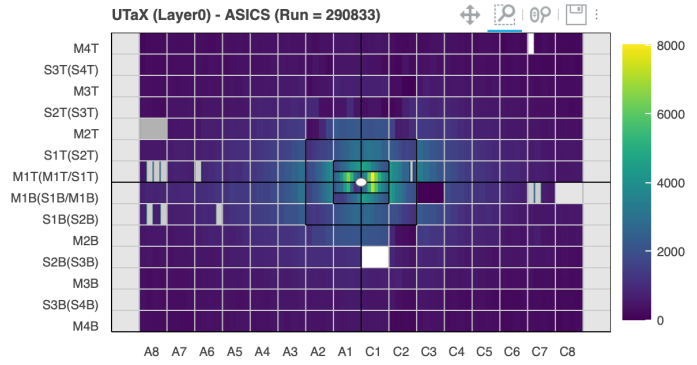
- Local phase completed with all subdetectors time aligned and calibrated
- Global phase started as planned
  - VELO routinely closed
  - Running with nominal HLT1 bandwidth and deployed versions of alignment for VELO, SciFi and RICH
  - Regularly increasing the pile-up to nominal
- UT included in global for limited periods of time and running at nominal pile-up but reduced readout rate
  - Useful to progress in parallel with reconstruction studies while solving the remaining issues
- Now working towards stable running at nominal luminosity with all subdetectors included

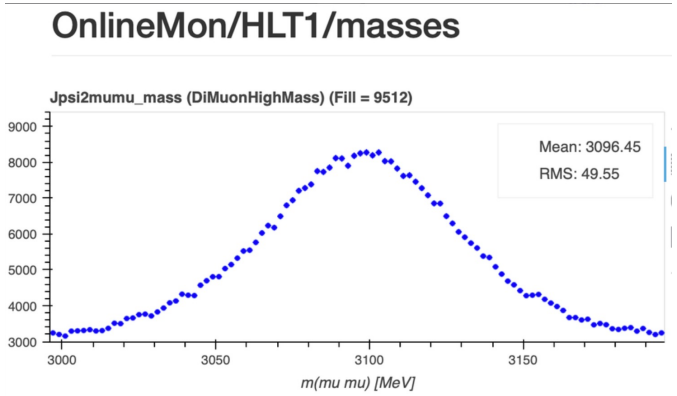
Towards end of commissioning



Start of global DAQ phase

Start of VELO closing

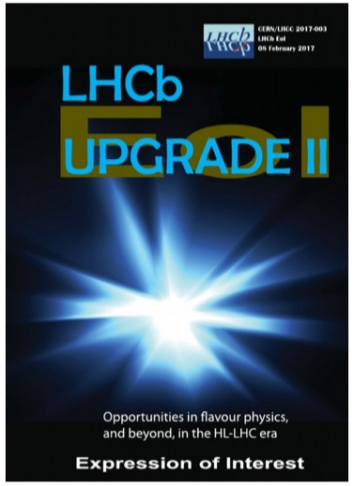




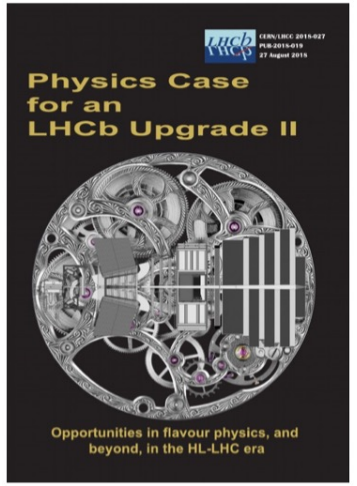
LHCb Upgrade II: towards the Scoping Document

	LHC era			HL-LHC era	
	Run 1	Run 2	Run 3	Run 4	Run 5/6
LHCb $\int \mathcal{L} dt$	3 fb^{-1}	9 fb^{-1}	23 fb^{-1}	50 fb^{-1}	300 fb^{-1}

- Upgrade proposed to increase the luminosity by another order of magnitude (up to 1.5 x 10^{34} $cm^{-2}s^{-1}$) in Run-5 and Run-6, to integrate 50 fb^{-1}/year
- Work on Scoping Document ongoing, with preliminary results, including detailed costs in various scenarios, to be discussed at tomorrow's session
- The Scoping Document will be delivered to the LHCC in September as planned



CERN-LHCC-2017-003

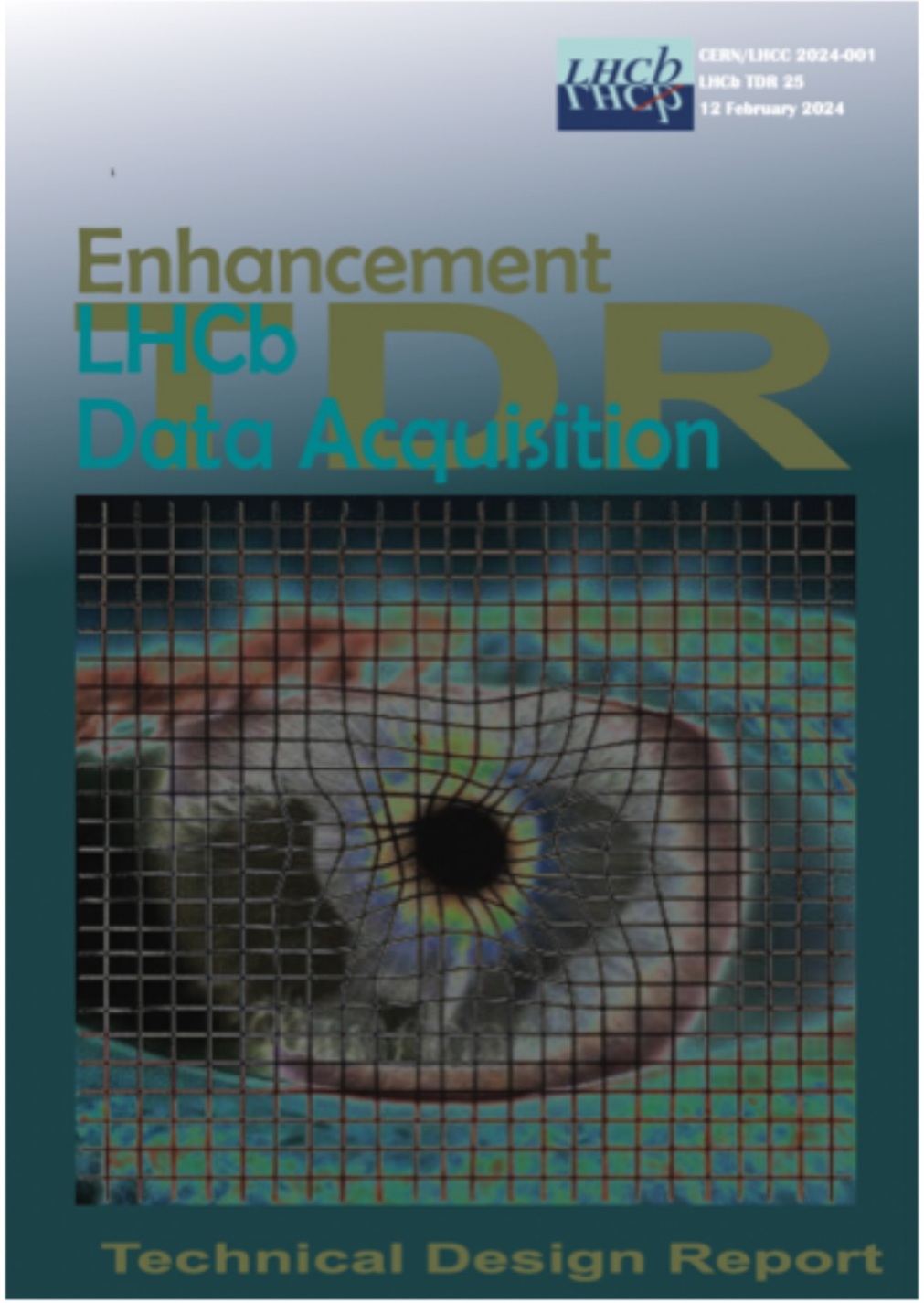


CERN-LHCC-2018-027
arXiv:1808.08865

CERN-LHCC-2021-012

Enhancements of ECAL, RICH and Online during LS3

- Technical Design Report for enhancements to the ECAL and RICH detectors during LS3 has been recommended for approval by the LHCC in February and approved by the CERN RB in March
- New TDR on data acquisition enhancements in LS3 submitted to LHCC in February and now under review
- Two mostly independent main topics
  - Development of the next generation PCIe400 DAQ board
  - Development of a new FPGA-based tracking system for downstream particle
- Review expected to go on until September



Closing remarks

- Physics productivity as high as usual
- Succesful Heavy Ion run → demonstrated with preliminary analysis that 30% centrality can be reached with the Upgrade I detector
- Successful YETS 2023/24 → no relevant issues
- VELO fully restored as by design → routinely closed to nominal position
- UT progressing fast towards full integration in recostruction and trigger
- Electronics instabilities tamed → in particular, solved annoying problem with GBTx link instabilities, that were also impacting ATLAS NSW
- 2024 run ramping up to nominal instantaneous luminosity
- The target for the remainder of Run-3 is to integrate 14 fb^{-1} of luminosity to triple available statistics (and even more for hadronic channels)

Hard Work Pays Off