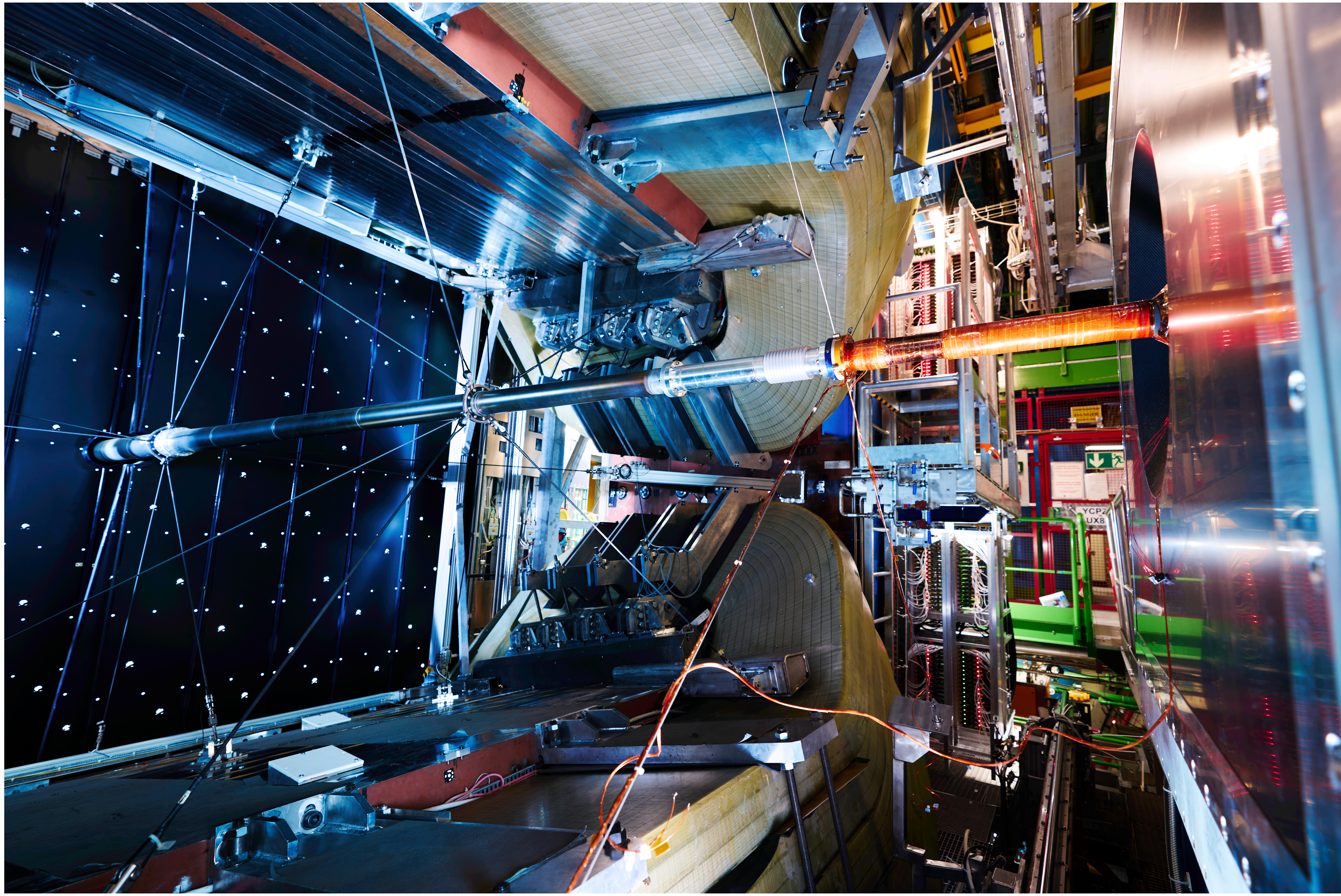
LHCC Open Session
LHCb status report

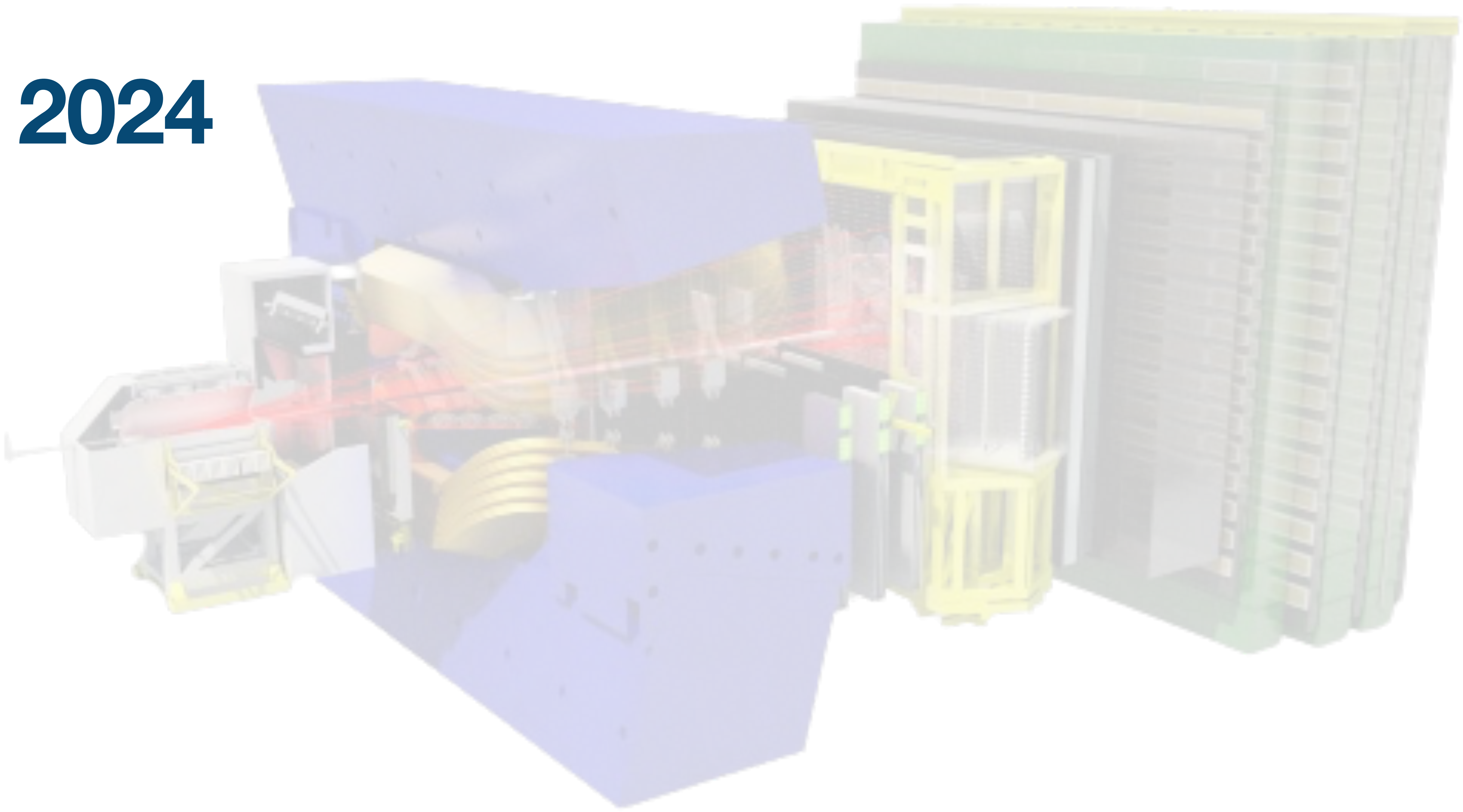
11th September 2024

Irene Bachiller
on behalf of the LHCb Collaboration



Overview

1. Physics highlights using Run 1 and Run 2 datasets
2. 2024 data-taking and LHCb performance
3. Plans for heavy ions run - 2024
4. Upgrade II



1. Physics highlights using Run 1 and Run 2 datasets

LHCb publications

Submitted 33 publications in 2024, as of September. In total, 750 publications since 2010.

Since last LHCC week: 17 new papers submitted + 9 preliminary results:

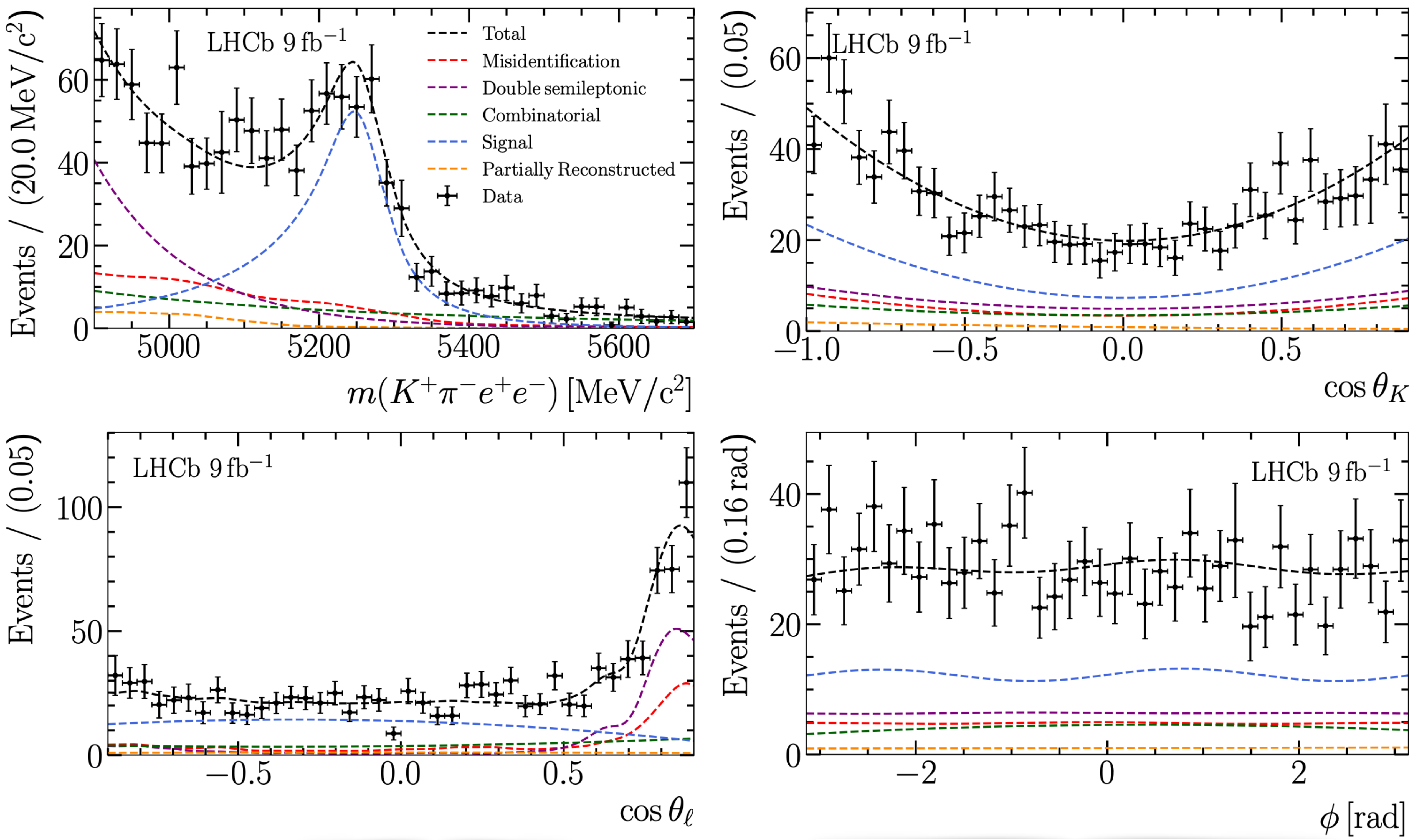
Highlighted today: (arrows point to LHCb-PAPER-2024-025, LHCb-PAPER-2024-022, LHCb-PAPER-2024-023 and LHCb-PAPER-2024-028)

Paper	Title	Arxiv Number
	Papers submitted since May LHCC week	
LHCb-PAPER-2023-043	Observation of exotic $J/\\psi \\phi$ resonances in diffractive processes in proton-proton collisions\n	2407.14301
LHCb-PAPER-2023-047	Observation of new charmonium(-like) states in $B^+\\to D^{*\\pm} D^{\\mp} K^+$ decays	2406.03156
LHCb-PAPER-2024-002	Amplitude analsysis of the $B_s^0\\to K^+K^-\\gamma$ decay	2406.00235
LHCb-PAPER-2024-004	Study of charmonium production via the decay to $p\\bar p$ at $\\sqrt{s} = 13$ TeV	2407.14261
LHCb-PAPER-2024-005	Search for the rare $\\Lambda_c^+ \\to p \\mu^+\\mu^-$ decay	2407.11474
LHCb-PAPER-2024-007	Measurement of the branching fraction ratios $R(D^+)$ and $R(D^{*+})$ using muonic $\\tau$ decays	2406.03387
LHCb-PAPER-2024-008	Measurement of $D^0-\\bar D^0$ mixing and search for CP violation with $D^0\\to K^+\\pi^-$ decays	2407.18001
LHCb-PAPER-2024-010	Precision measurement of the $\\Xi_b^{-}$ baryon lifetime	2406.12111
LHCb-PAPER-2024-012	Measurement of exclusive J/ψ and $\psi(2S)$ production at $\sqrt{s}$ = 13 TeV	2409.03496
LHCb-PAPER-2024-013	Study of $b-$hadron decays to $\\Lambda_c^+h^-h^{\\prime -}$ final states	2405.12688
LHCb-PAPER-2024-014	Amplitude analysis of $B^+\\to \\psi(2S) K^+ \\pi^+\\pi^-$ decays	2407.12475
LHCb-PAPER-2024-015	Probing the nature of the $\\chi_{c1}(3872)$ state using radiative decays	2406.17006
LHCb-PAPER-2024-016	Study of the rare decay $J/\\psi \\to \\mu^+\\mu^-\\mu^+\\mu^-$	2408.16646
LHCb-PAPER-2024-017	Measurement of Λ_b^0, Λ_c^+ and Λ decay parameters using $\Lambda_b^0 \to \Lambda_c^+h^-$ decays	2409.02759
LHCb-PAPER-2024-019	Measurement of CP violation observables in $D^+\to K^-K^+\pi^+$ decays	2409.01414
LHCb-PAPER-2024-025	Observation of muonic Dalitz decays of $\\chi_b$ mesons and precise spectroscopy of hidden beauty	2408.05134
LHCb-PAPER-2024-027	Measurement of CP violation in $B^0 \to D^+D^-$ and $B_s^0 \to D_s^+D_s^-$ decays	2409.03009
	Preliminary results since May LHCC week	
LHCb-PAPER-2024-018	First determination of the spin-parity of the $\\Xi_c(3055)^{+(0)}$ baryons	
LHCb-PAPER-2024-020	Measurement of CP asymmetry in $B_s\\to D_s K$ decays	
LHCb-PAPER-2024-021	Measurements of $\\psi(2S)$ and $\\chi_{c1}(3872)$ within fully reconstructed jets	
LHCb-PAPER-2024-022	Angular analysis of $B^0 \to K^{*0} e^+e^-$ decays	
LHCb-PAPER-2024-023	Measurement of the CKM angle $\\gamma$ in $B^\\pm\\to DK^{*\\pm}$ decays	
LHCb-PAPER-2024-024	Analysis of $\\Lambda_b \\to pK^-\\mu^+\\mu^-$ decays	
LHCb-PAPER-2024-026	Search for $B_{(s)}^{*0}\\to \\mu^+\\mu^-$ in $B_c^+ \\to \\pi^+ \\mu^+\\mu^-$ decays	
LHCb-PAPER-2024-028	Measurement of the effective leptonic weak mixing angle	
LHCb-PAPER-2024-029	Improved branching fraction measurements of $B^0_{(s)} \to K_{\rm S}^0 h^+ h^{\prime -}$ decays and first observation of $B_s^0 \to K_{\rm S}^0 K^+ K^-$	

Angular analysis of $B^0 \to K^{*0}e^+e^-$

LHCb-PAPER-2024-022

4D unbinned weighted fit to the mass and angular distributions



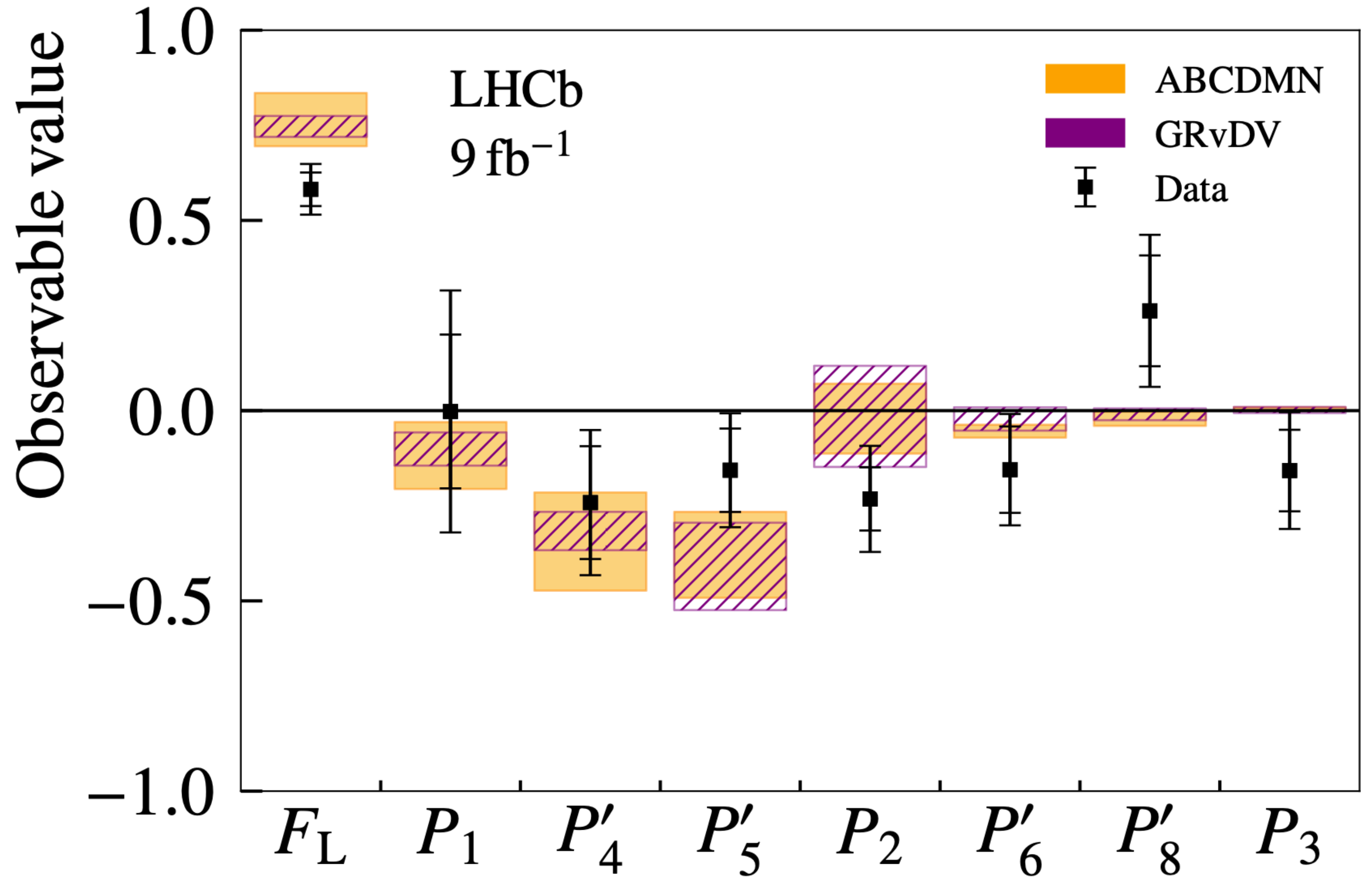
$q^2 \equiv m^2(e^+e^-)$

$q^2_{\text{central}} \equiv [1.1 - 6.0]\ \text{GeV}^2/c^4$

Allows the extraction in the central q² region

Most precise determination of angular observables and consistent with SM predictions.

Angular observables:



SM predictions:

ABCDMN

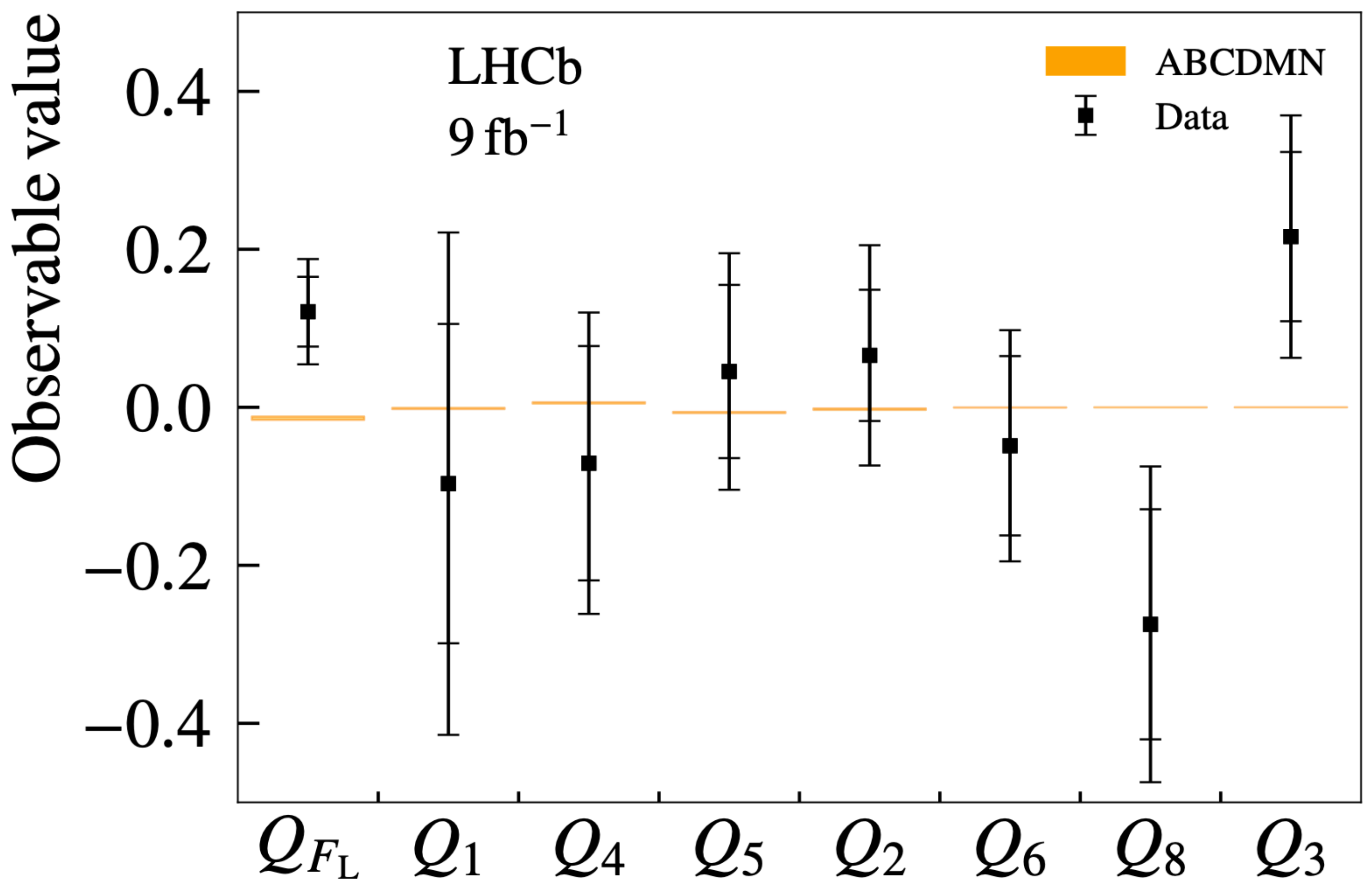
Eur.Phys.J.C.**83**(2023)648

GRvDV

JHEP **09** (2022)133

Eur.Phys.J.C.**82**(2022)569

Compared with the $B \to K^*\mu^+\mu^-$ decay:



LFU observables Q_i

$Q_i = P_i^{(\mu)} - P_i^{(e)}$

Simultaneous determination of the CKM angle γ

LHCb-CONF-2024-004

ICHEP 2024

The γ measurements has very low theory uncertainties → excellent SM benchmark parameter.

$$V_{CKM} \sim \begin{pmatrix} |V_{ud}| & |V_{us}| & |V_{ub}|e^{-i\gamma} \\ -|V_{cd}| & |V_{cs}| & |V_{cb}| \\ |V_{td}|e^{-i\beta} & -|V_{ts}|e^{i\beta_s} & |V_{tb}| \end{pmatrix}$$

Using new and improved methods, more channels:

- $B^0 \to DK^{*0}$, $D \to h^+h'^+(\pi^+\pi^-)$ with 3 simultaneous D final states.
- $B^0 \to DK^{*0}$, $D \to K^0_s h^+h^+$, binned D decay Dalitz plane analysis.
- $B^\pm \to DK^{*\pm}$, 4 simultaneous D decays, and first time $D \to K^0_s h^+h^+$ decay.

LHCb-PAPER-2023-009 LHCb-PAPER-2023-040 LHCb-PAPER-2024-023

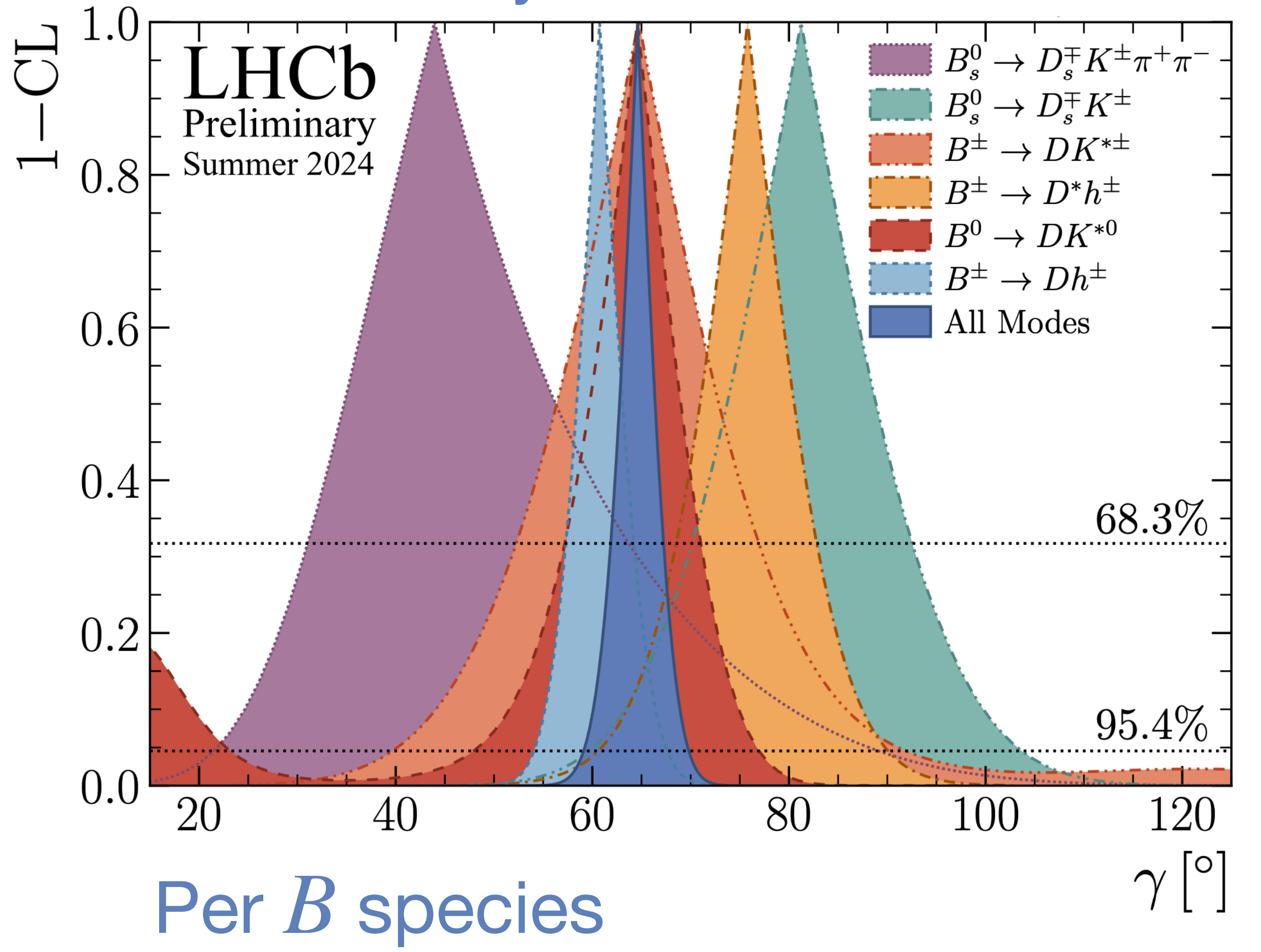
$$\gamma = (64.6 \pm 2.8)^o$$

Decreased uncertainty by 0.7^o since 2022

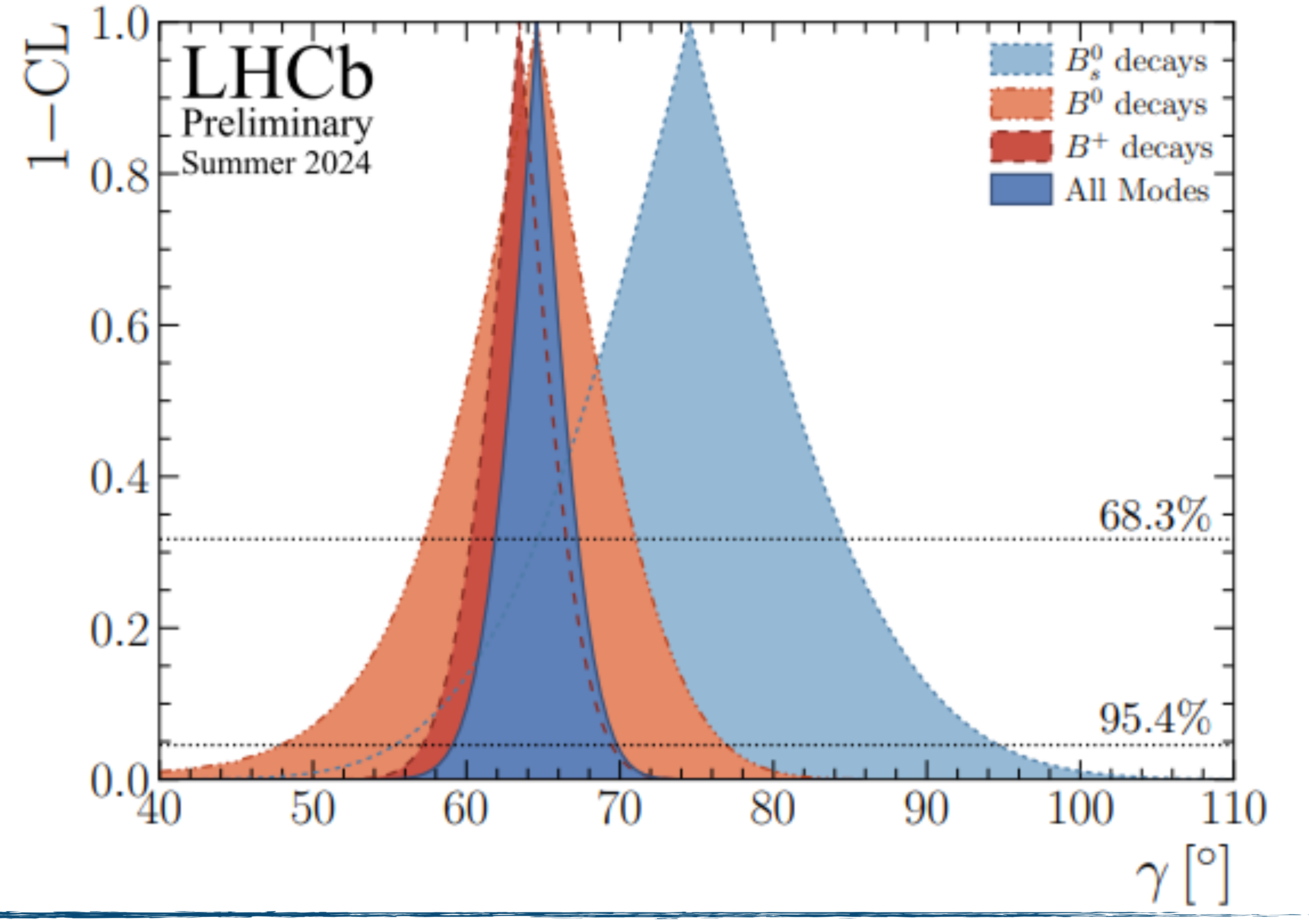
At the moment, the measurement is statistically limited.

Run 3 results will have big impact!

Per B decay

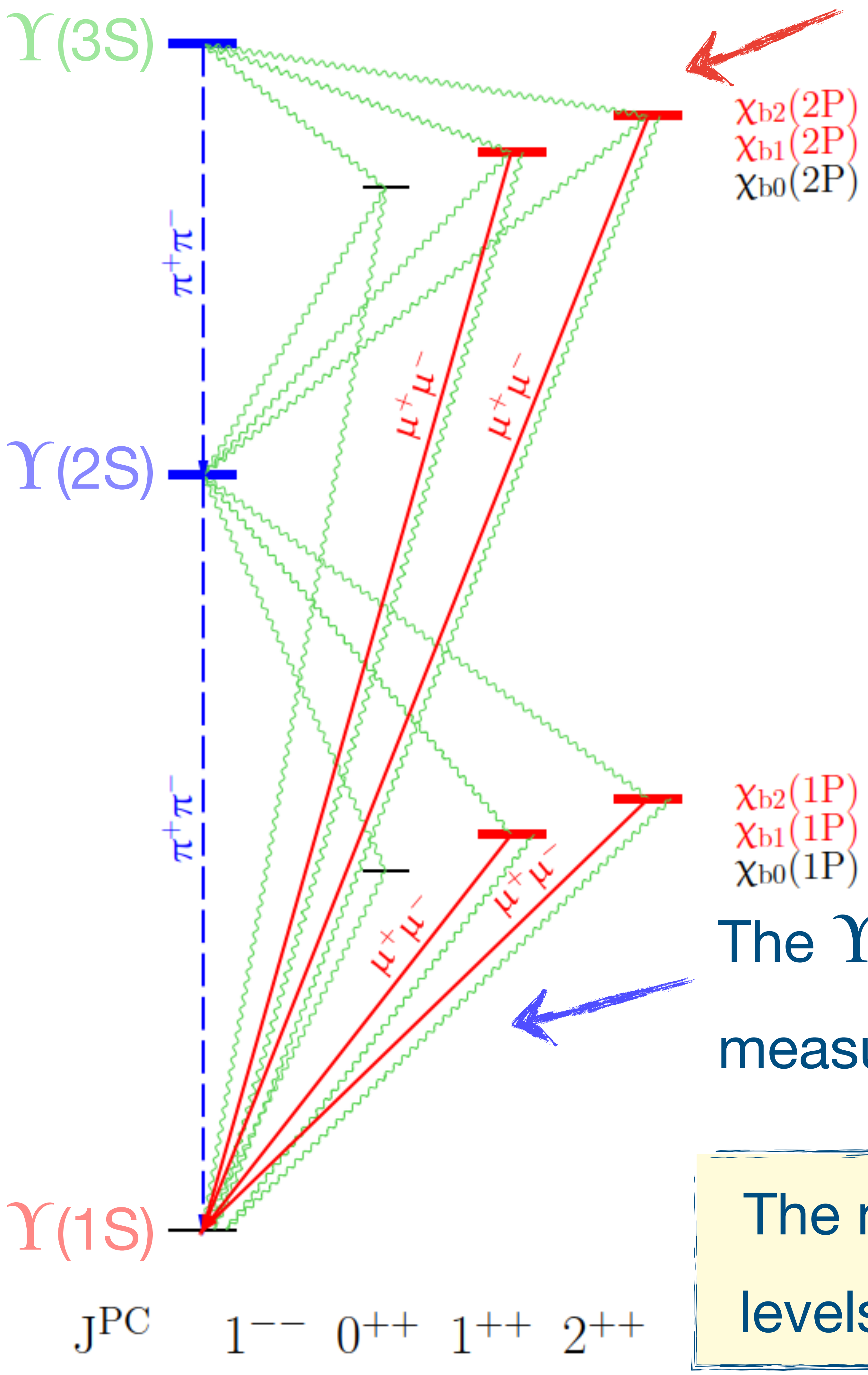


Per B species

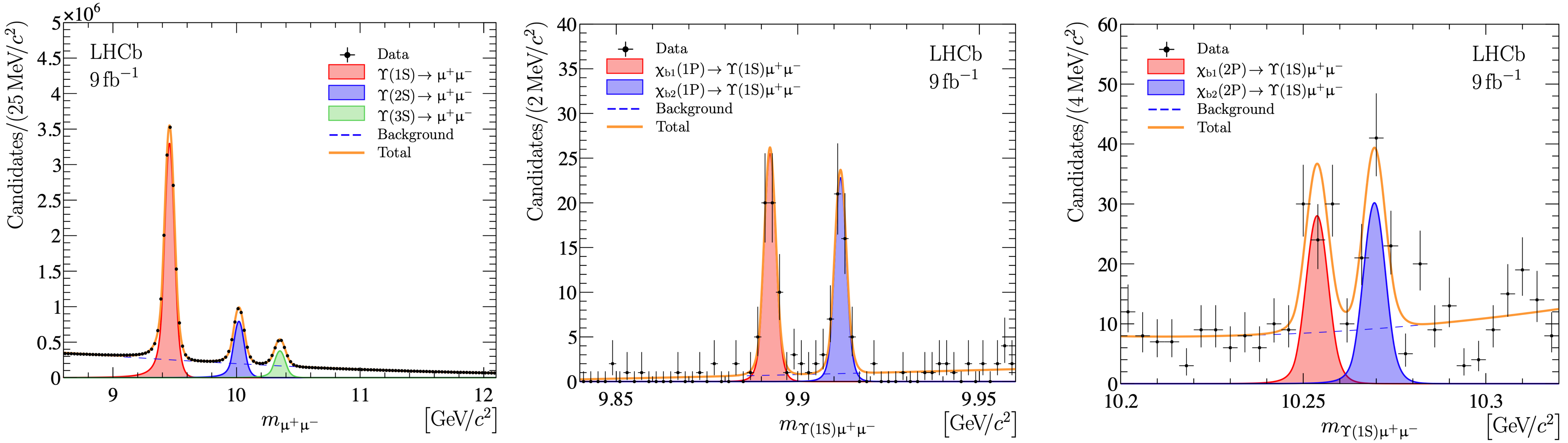


First observation of $\chi_b \to \Upsilon(1S)\mu^+\mu^-$ decays

LHCb-PAPER-2024-025
arXiv:24080.5134



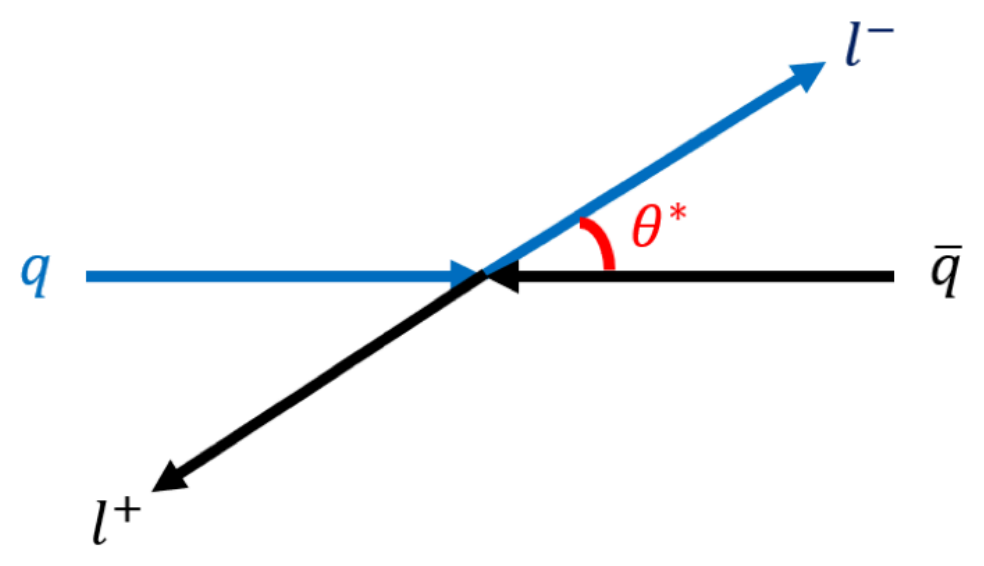
The muonic Dalitz decays of the χ_{b1}(1P), χ_{b2}(1P), χ_{b1}(2P), and χ_{b2}(2P) mesons to the Υ(1S) state ($b\bar{b}$ quark bound) are observed and used to measure the masses of these states.



The $\Upsilon(2S) \to \Upsilon(1S)\pi^+\pi^-$and $\Upsilon(3S) \to \Upsilon(2S)\pi^+\pi^-$ decay modes are used for precision measurements of the mass and mass splittings for the hidden-beauty states.

The measured Υ(2S) and Υ(3S) masses and mass difference between different $b\bar{b}$ energy levels are competitive - world best for χ_{b1}(1P) - and in agreement with the world averages.

Measurement of the effective leptonic weak mixing angle



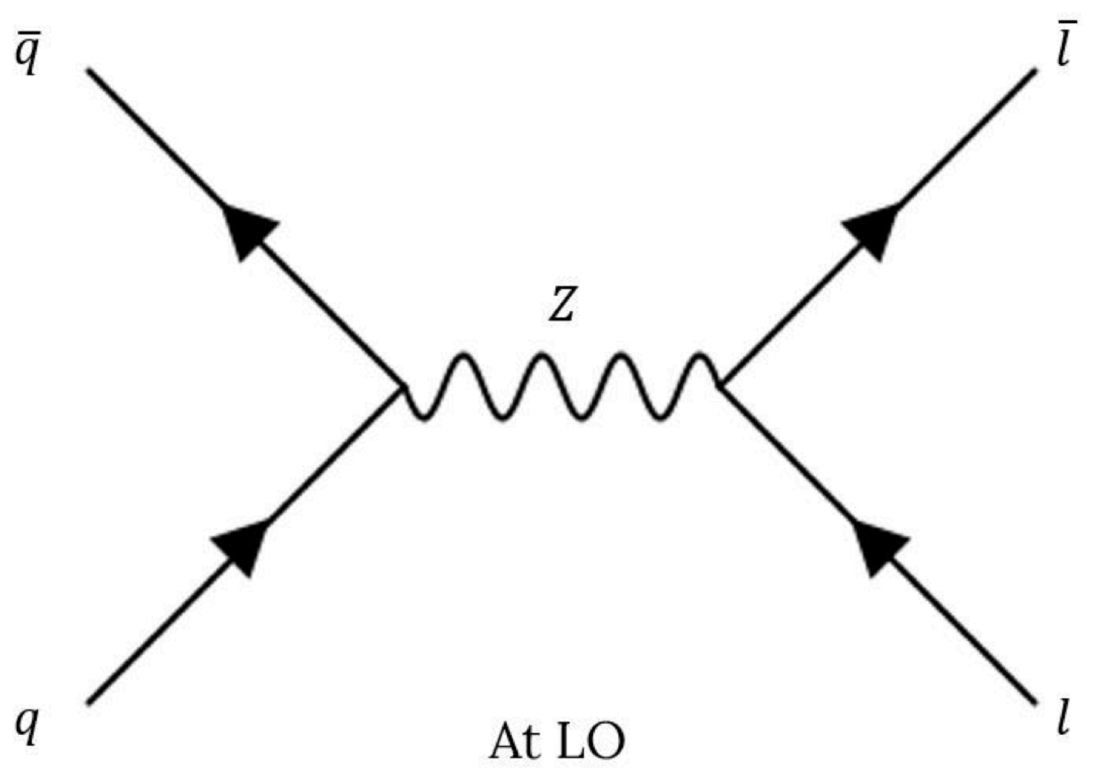
LHCb-PAPER-2024-028

CERN Courier - Sept.

CERN Seminar

The weak mixing angle is a **key parameter of the SM**:

The presence of vector and axial-vector couplings that depend on θ_W introduces a **forward-backward asymmetry** of angular distribution of lepton pairs in DY events.



$$\frac{d\sigma}{d\cos\theta^*} \propto \left(1 + \cos^2\theta^* + \frac{8}{3} A_{FB}^{4\pi} \cos\theta^*\right)$$

Forward: $0 < \cos\theta^* < 1$

Backward: $-1 < \cos\theta^* < 0$

At tree level: $\sin^2\theta_W = 1 - \frac{m_W^2}{m_Z^2}$

$\sin^2\theta^l_{eff}$ accounts for higher-order corrections

Measurement of the effective leptonic weak mixing angle

LHCb-PAPER-2024-028

CERN Courier - Sept.

CERN Seminar

$|\Delta\eta|$ = absolute difference between the pseudorapidities of the two muons produced in the Z boson decay

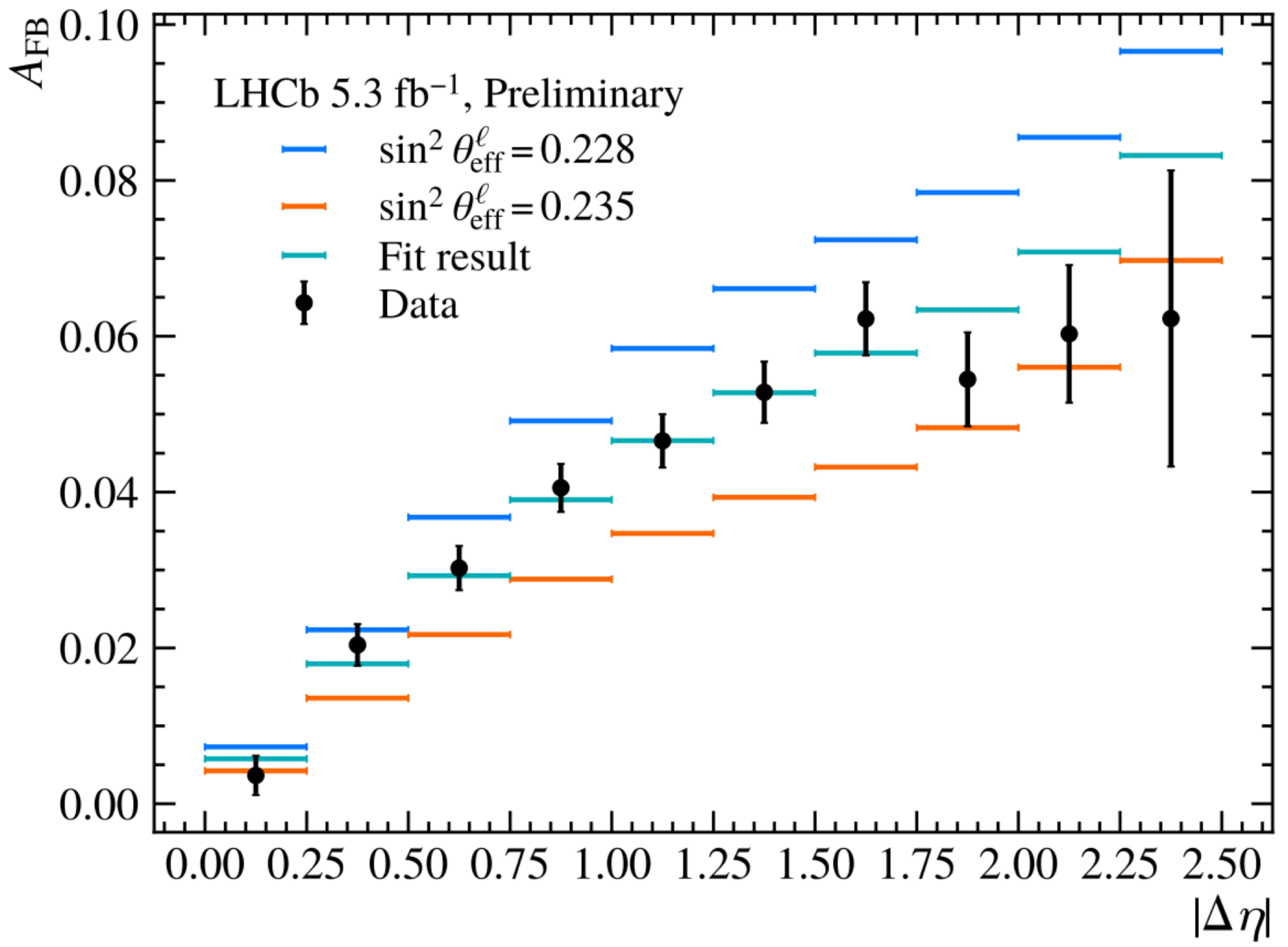
A_{FB} is measured in bins of $|\Delta\eta|$, improving the sensitivity to the weak mixing angle:

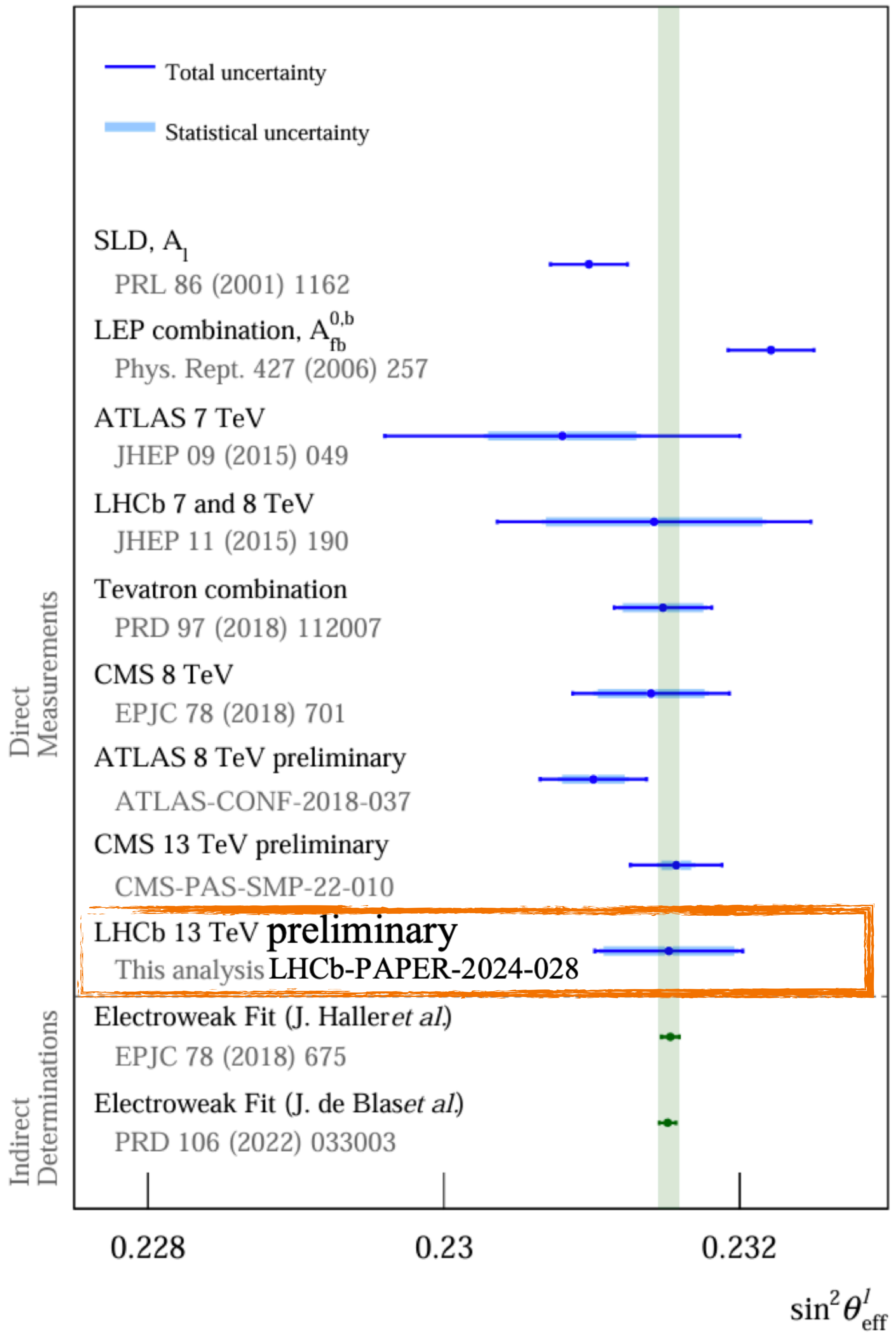
Forward-backward asymmetry:

$$A_{FB} \equiv \frac{N(\eta^- > \eta^+) - N(\eta^- < \eta^+)}{N(\eta^- > \eta^+) + N(\eta^- < \eta^+)}$$

N = yields

η = pseudo rapidity





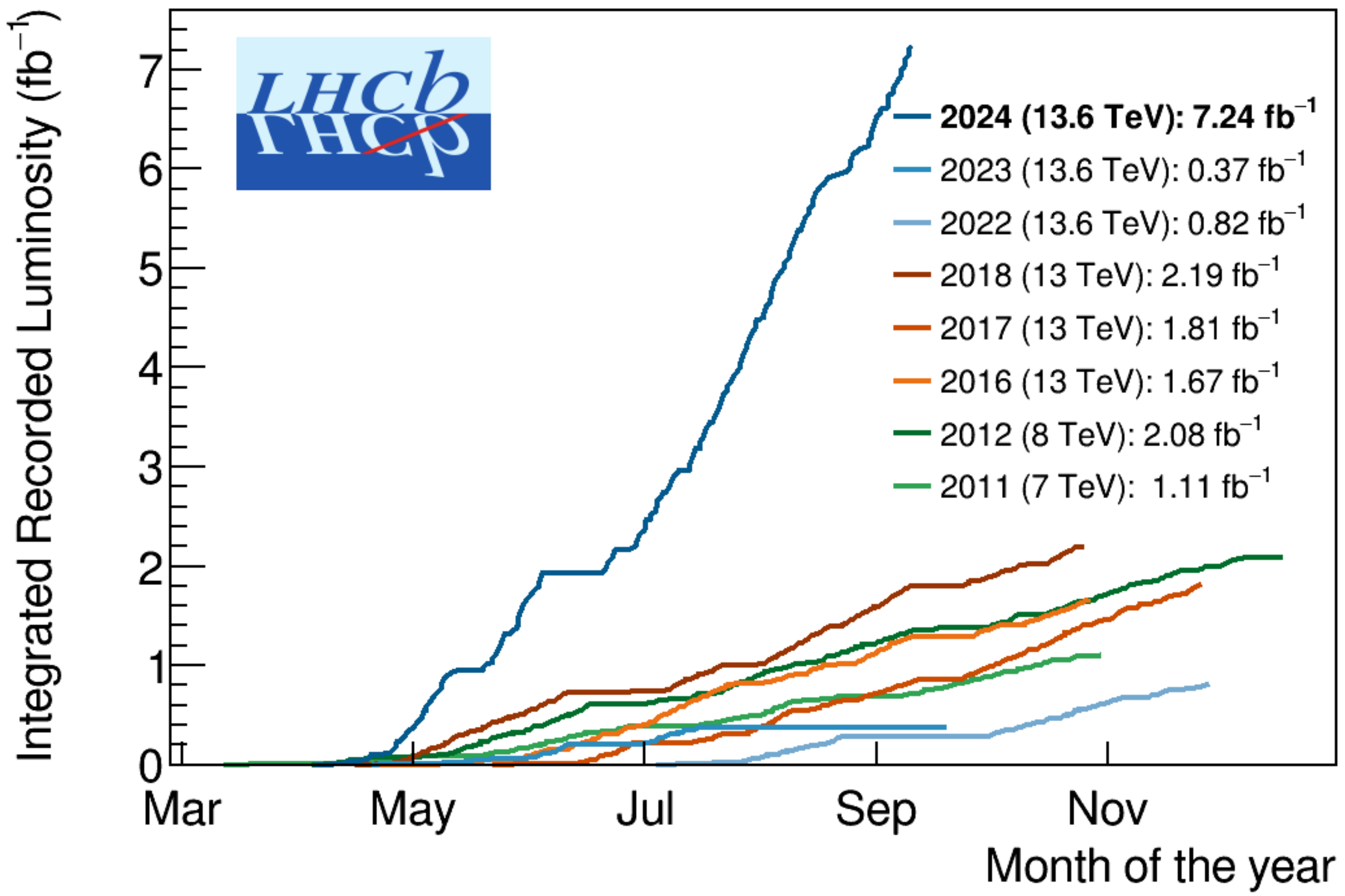
A_{FB} is compared with predictions to NLO in strong and EW couplings to derive:

$$\sin^2\theta^l_{eff} = 0.23152 \pm 0.00044\,(stat.) \pm 0.00005\,(exp.) \pm 0.00022\,(theo.)$$

2. 2024 data-taking and LHCb performance

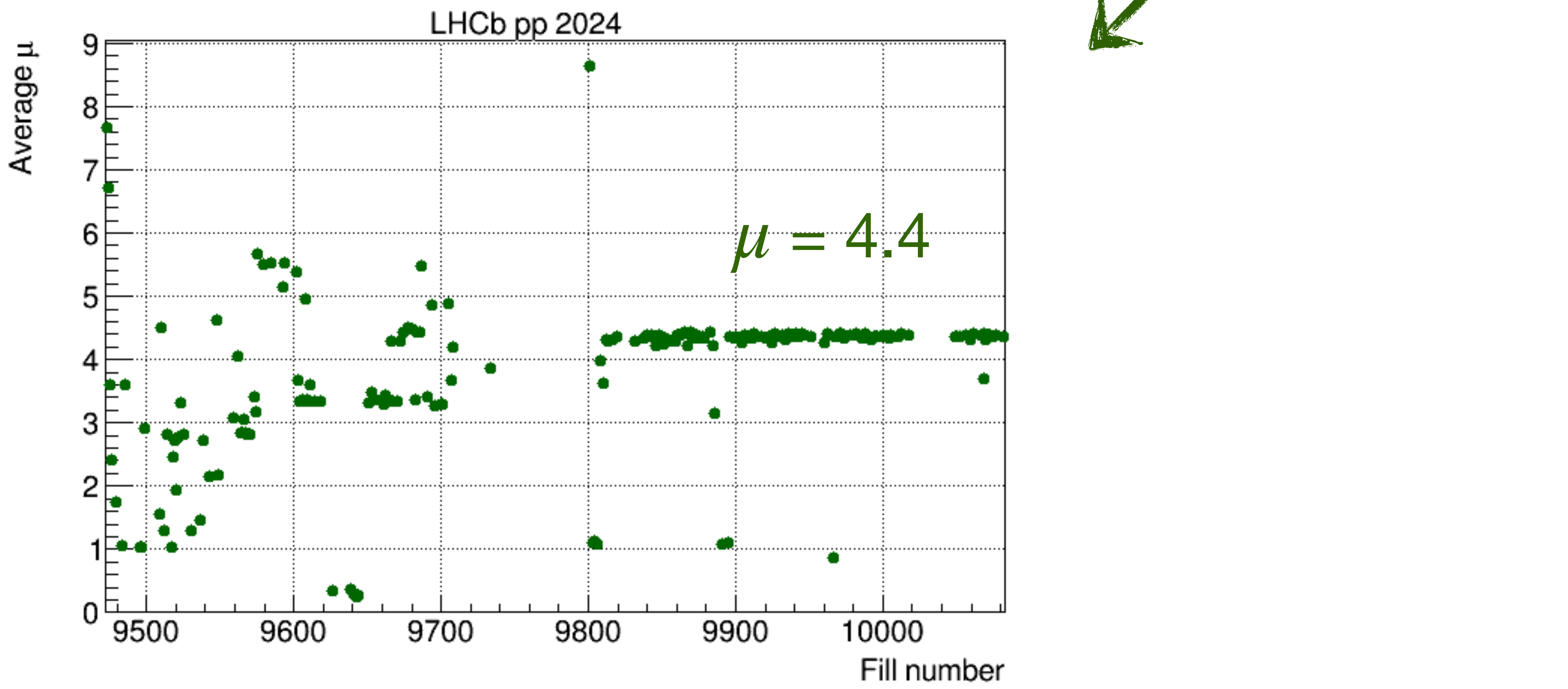
2024 data taking

Recorded luminosity of 7.24 fb^{-1} in 2024
(as of beginning of September)
More than in the whole of Run 2!



The LHCb Upgrade I final realisation:

- First opportunity for LHCb to run at nominal conditions.
- VELO sub-detector fully closed.
- The UT sub-detector now part of the data taking chain.
- Increased processing capacity with a 3rd GPU/event builder.
- Rich physics program and different beam conditions (SMOG2).
- Highest stable number of visible interactions per bunch crossing (μ).
- Good data taking efficiency ~95%.
- Good data quality efficiency for physics.



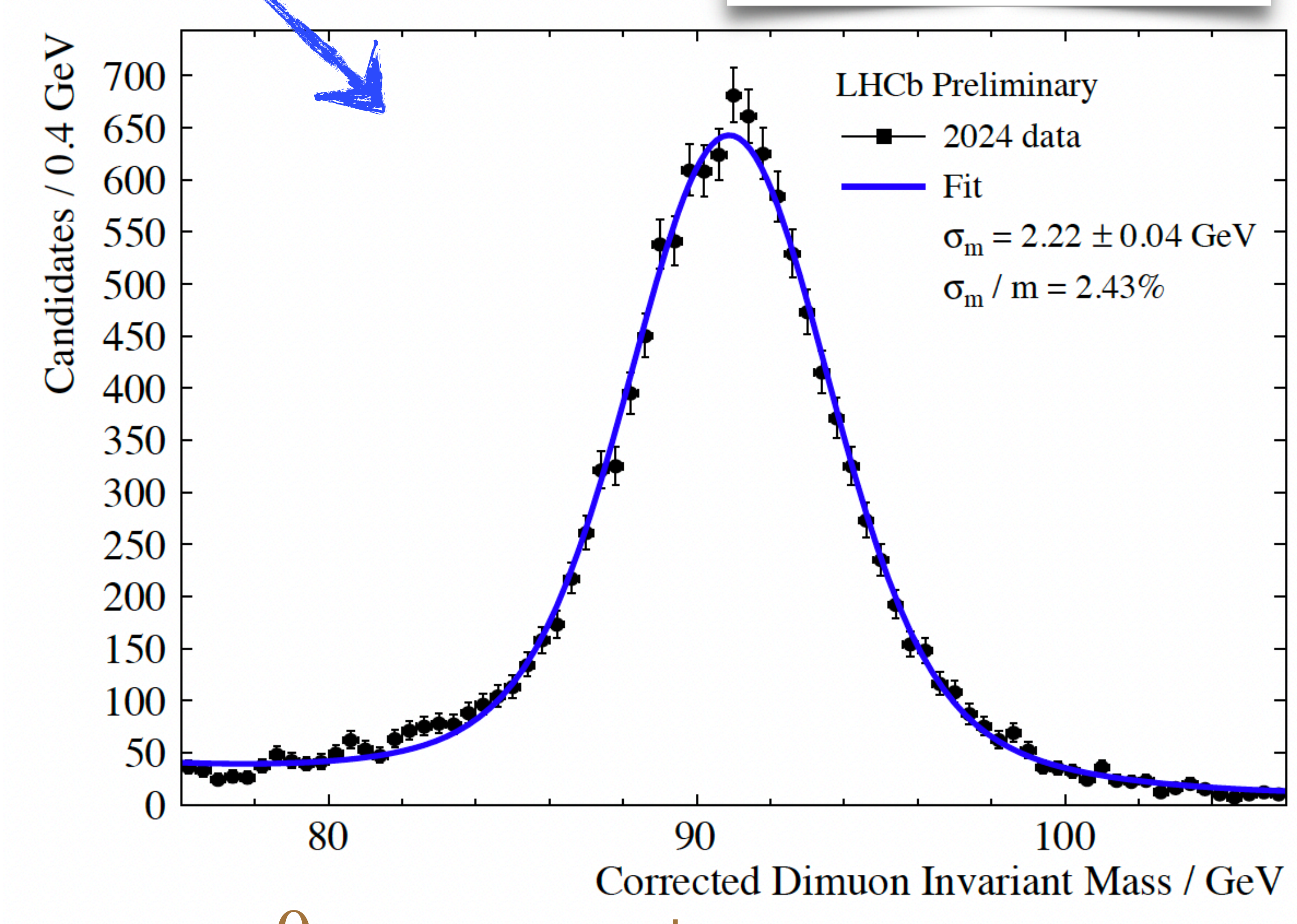
2024 data analysis

Partial datasets:

The analysis of the large 2024 data sample is already ongoing.

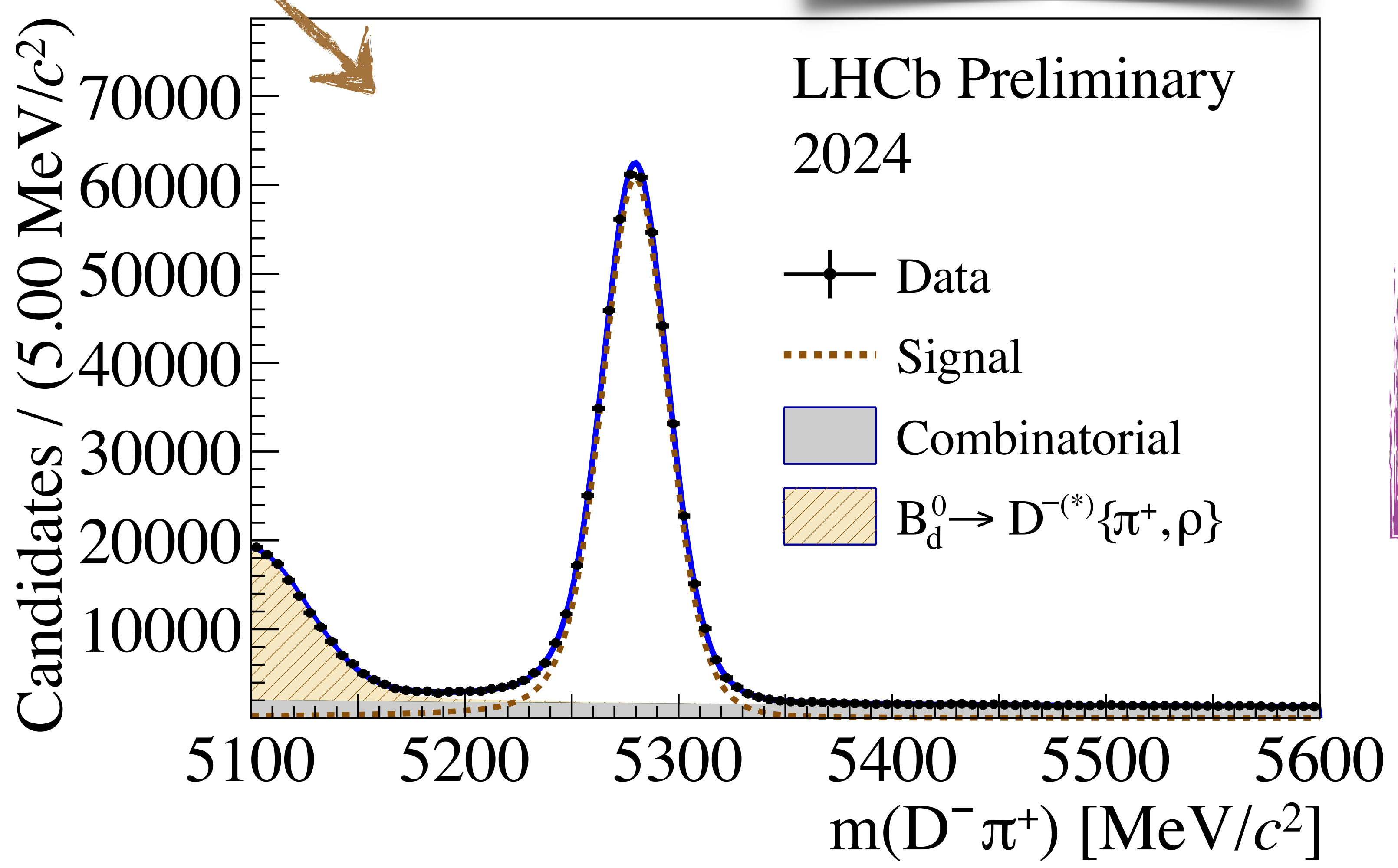
$Z^0 \to \mu^+\mu^-$

LHCb-Figure-2024-020



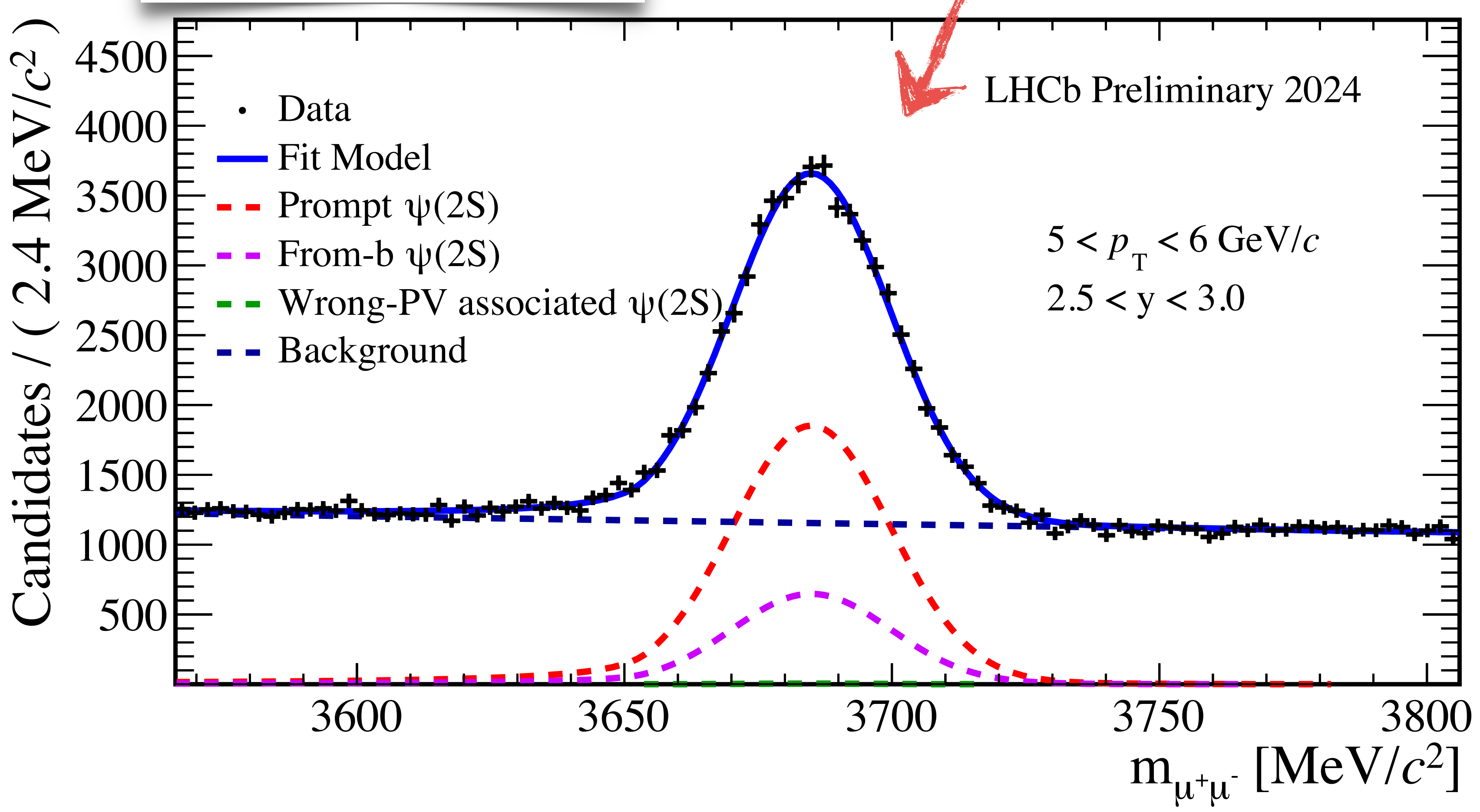
$B^0 \to D^-\pi^+$

LHCb-Figure-2024-021



$\psi(2S) \to \mu^+\mu^-$

LHCb-Figure-2024-024



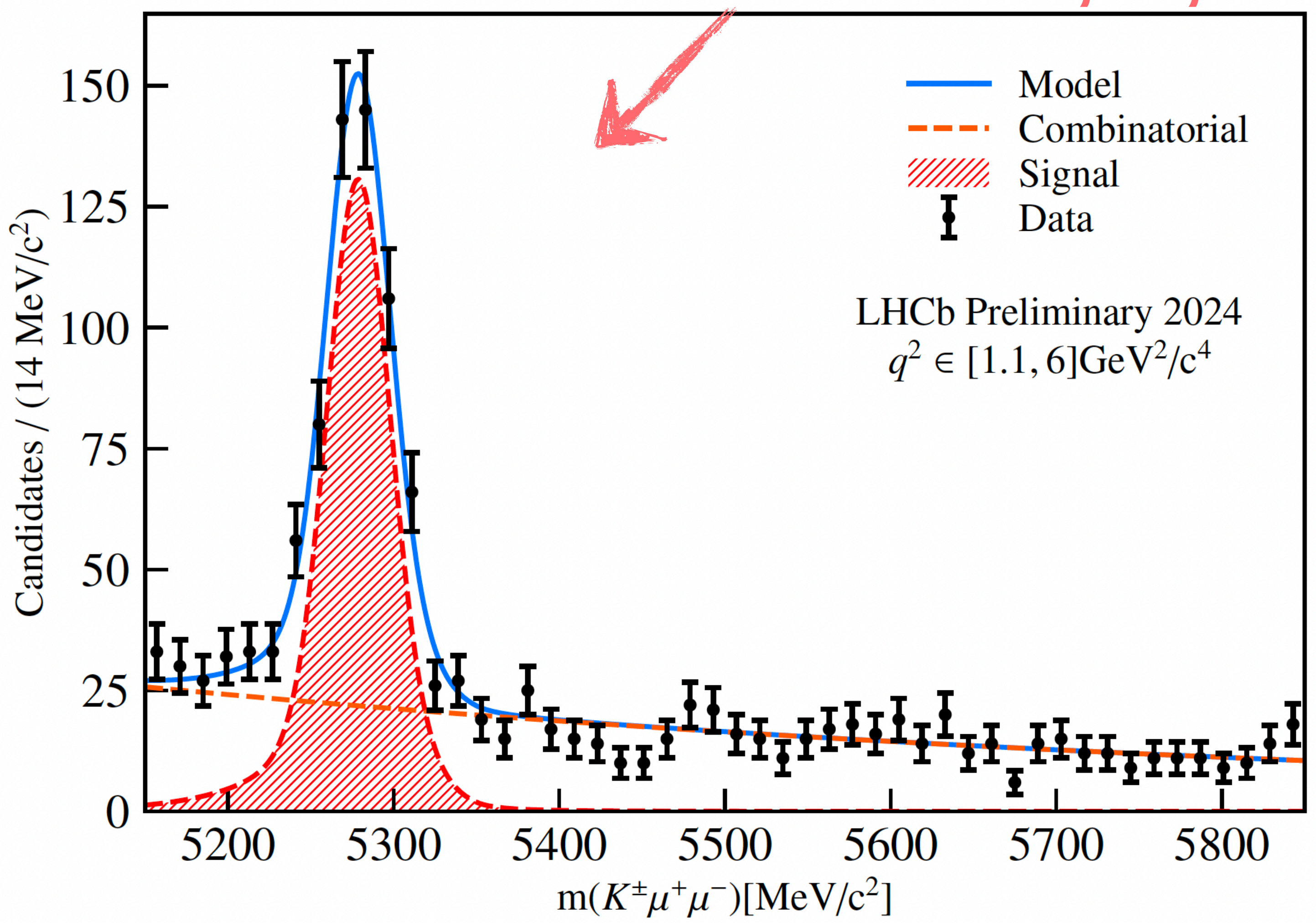
Total yields in 2024 ~[1-2] × Run 1 and 2

[channel dependent]

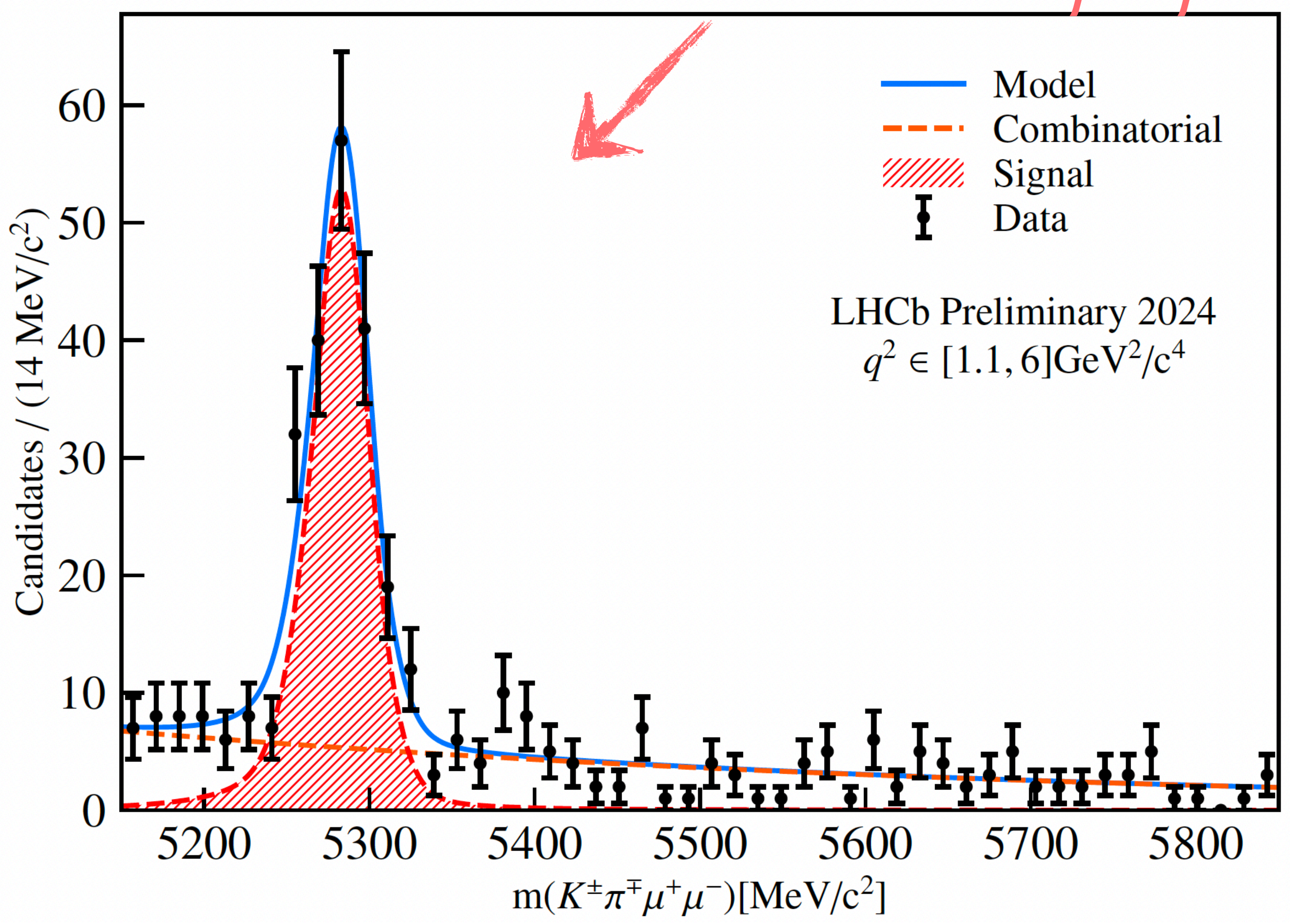
And many others…

LHCb-Figure-2024-022

$B^+ \to K^+\mu^+\mu^-$

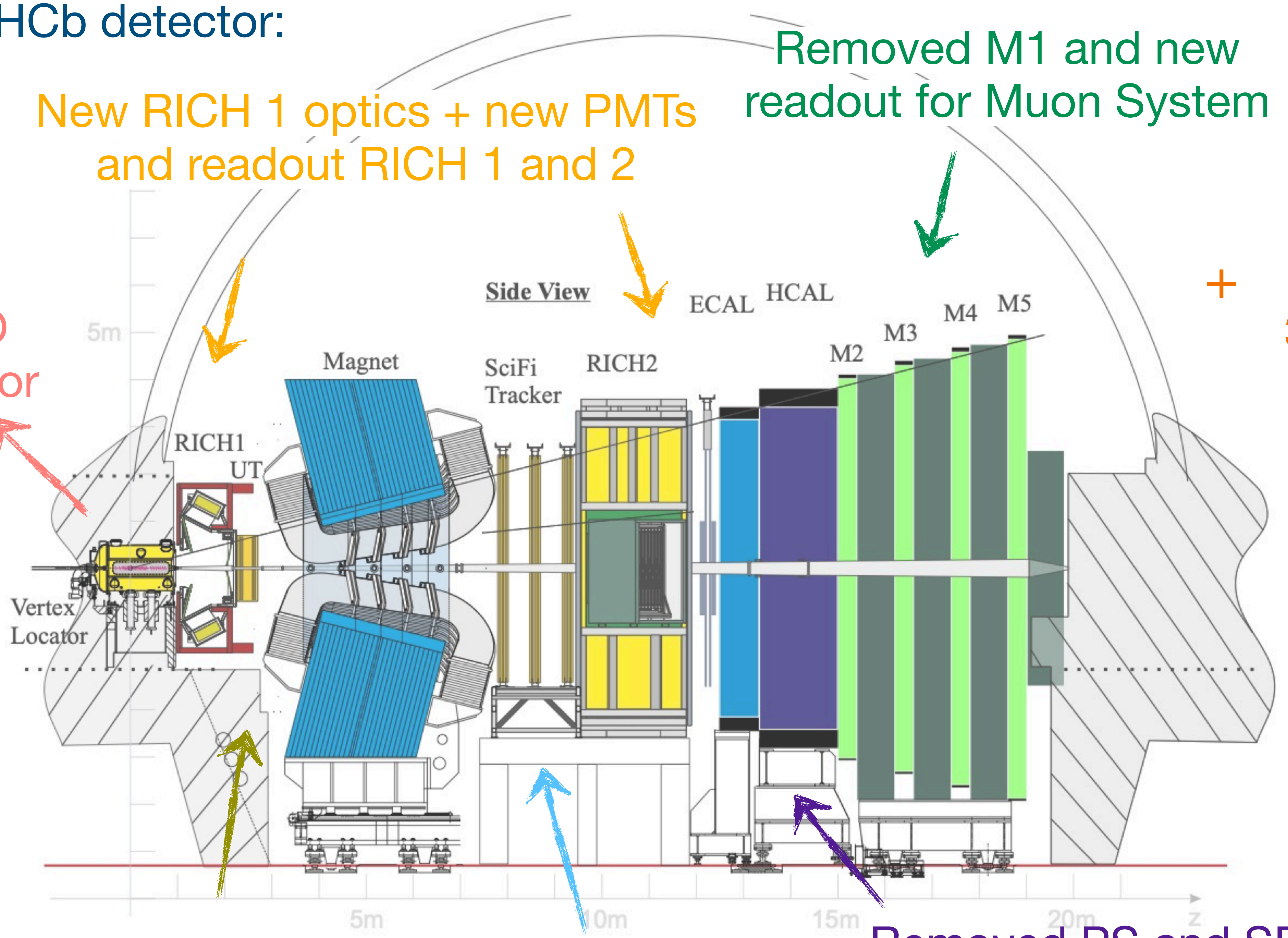


$B^0 \to K^*\mu^+\mu^-$



LHCb Upgrade I: major upgrade in all sub-detectors and readout

Current LHCb detector:



Improved physics performance, despite the more challenging environment.

+ Full software Trigger
30 MHz processing

All sub-detectors are showing excellent performance. Two milestones in 2024:

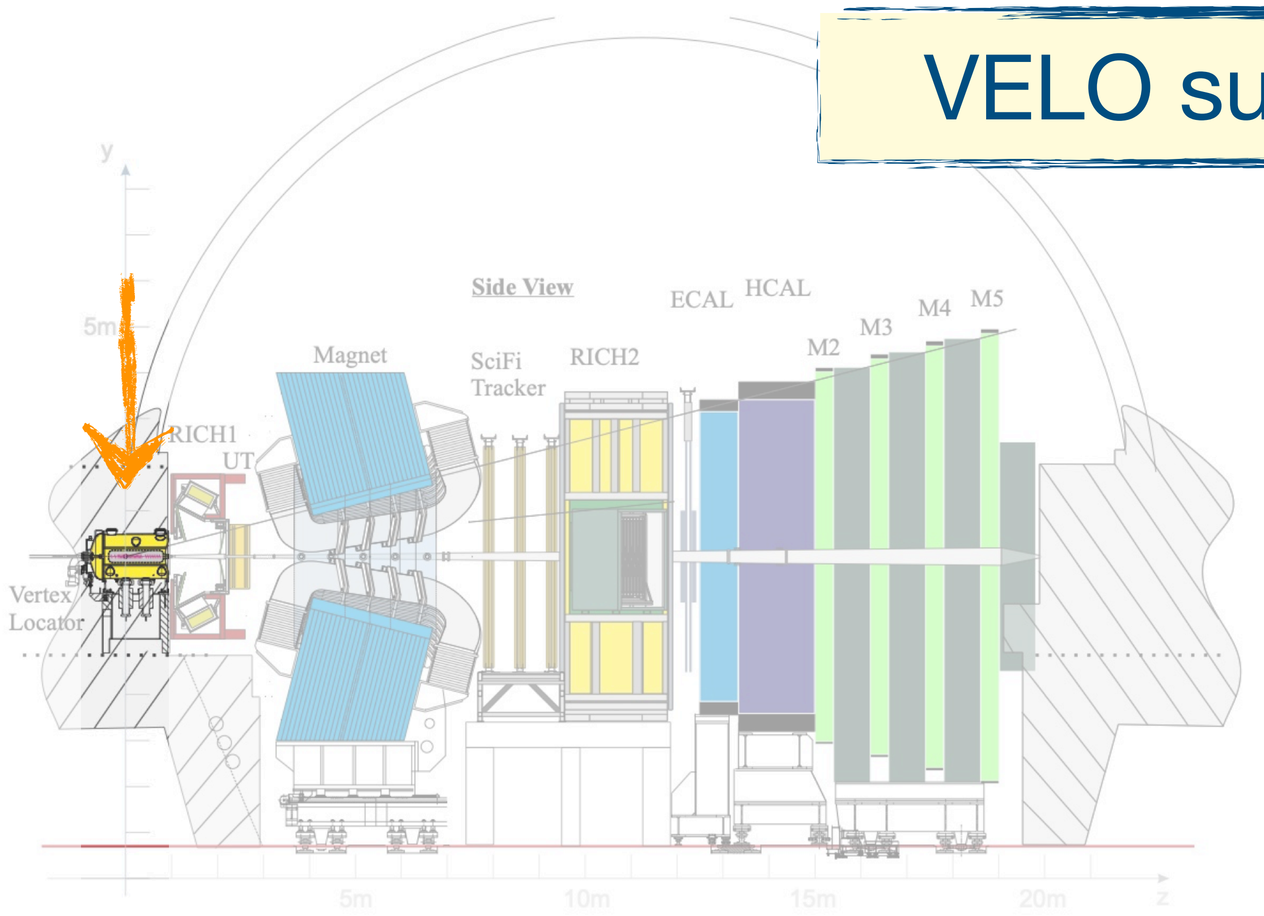
- VELO at nominal closed position
- UT stable running in global

(next slides)

The LHCb Upgrade I arXiv:2305.10515 | JINST 19P05065

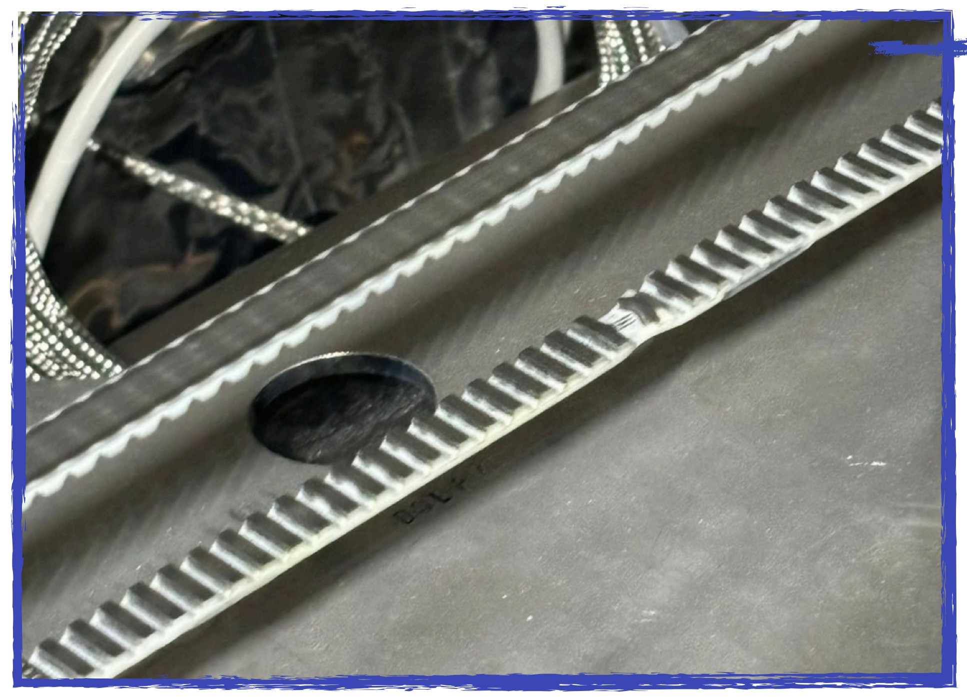
Vertex Locator (VELO)

VELO sub-detector in nominal closed position during 2024 data taking

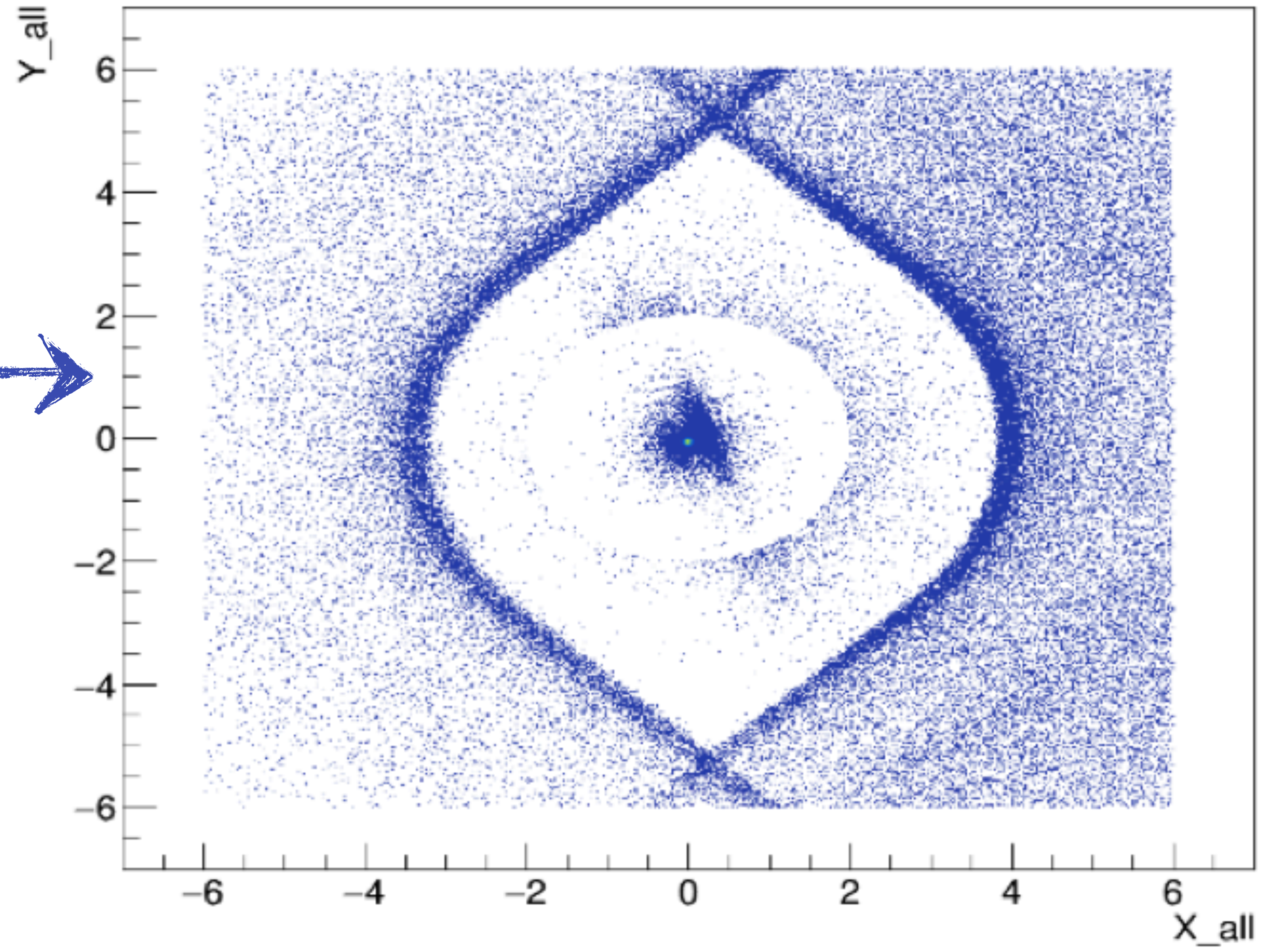


Very high overall efficiency:

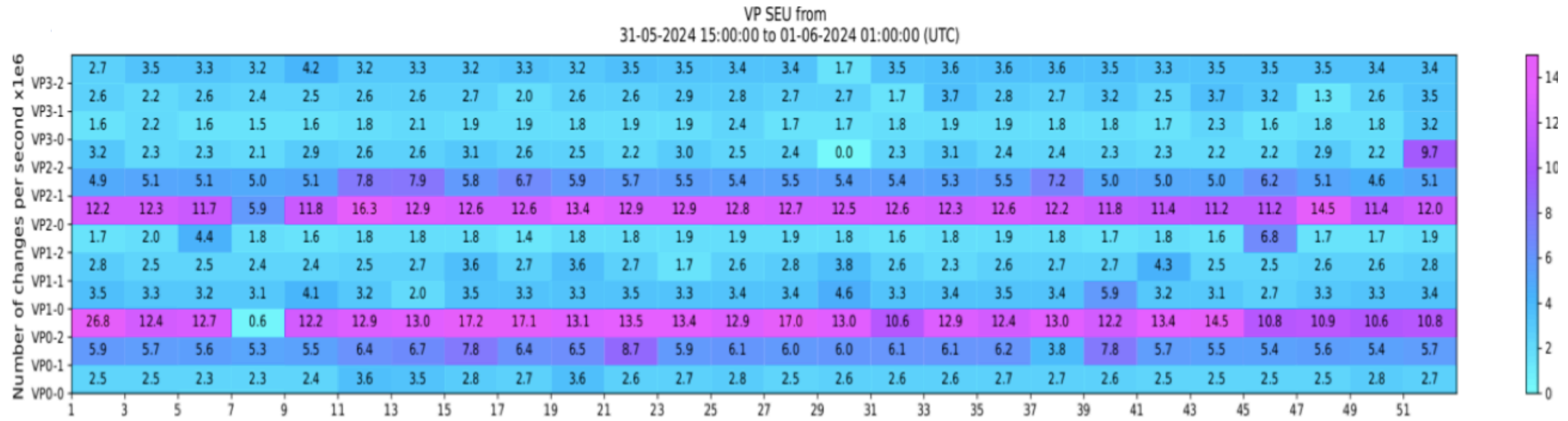
- VELO closing time ~6 minutes.
- VELO DAQ inefficiency < 2.5%.



Quick recovery from incident: the VELO belt needed to be exchanged due to a damaged teeth. Validation and alignment efficiently performed.



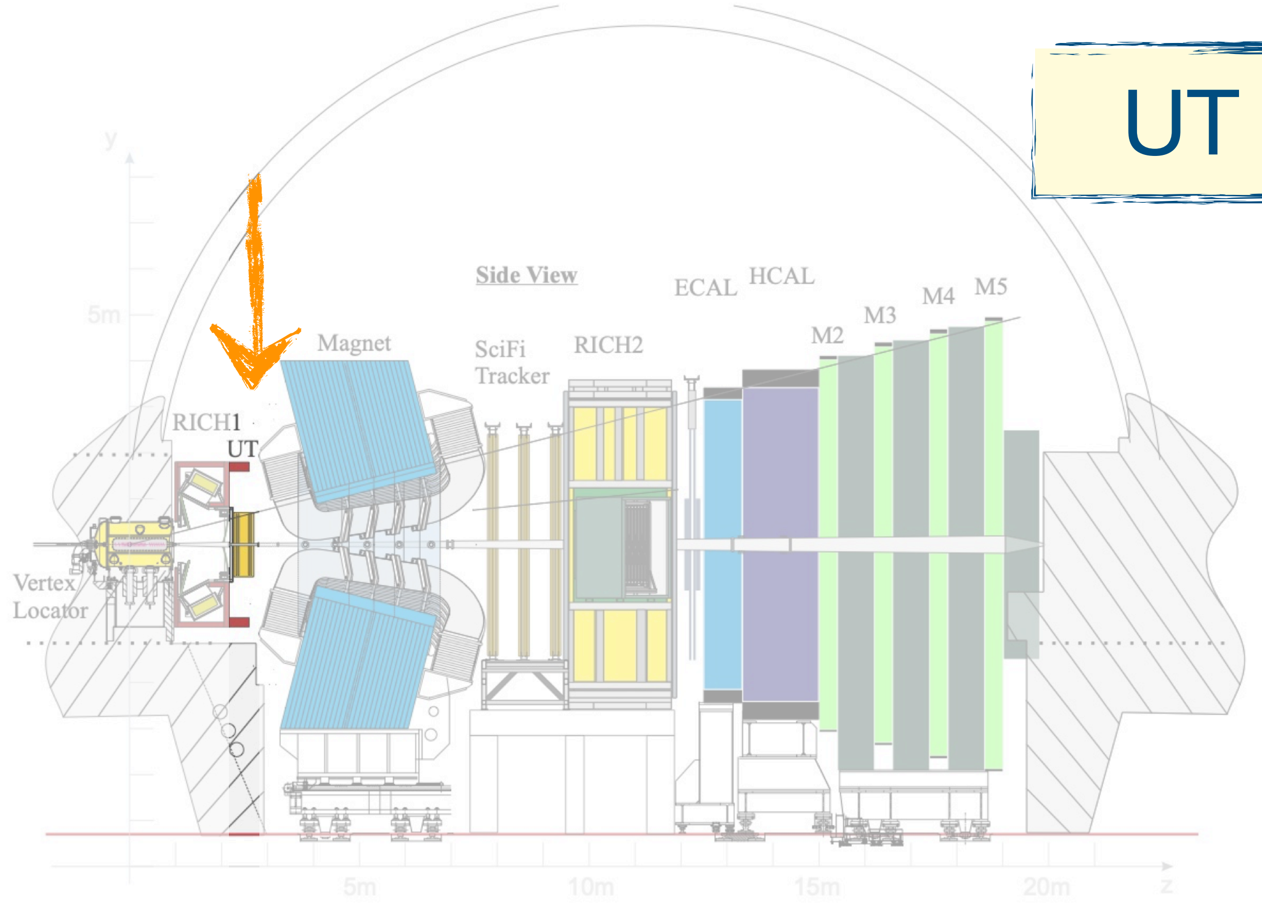
Thanks to the LHC for the 400b fill needed for tomography!



VeloPix SEU counter and automatic recovery implemented

Upstream Tracker (UT)

UT sub-detector stable running in global, in 2024 data taking



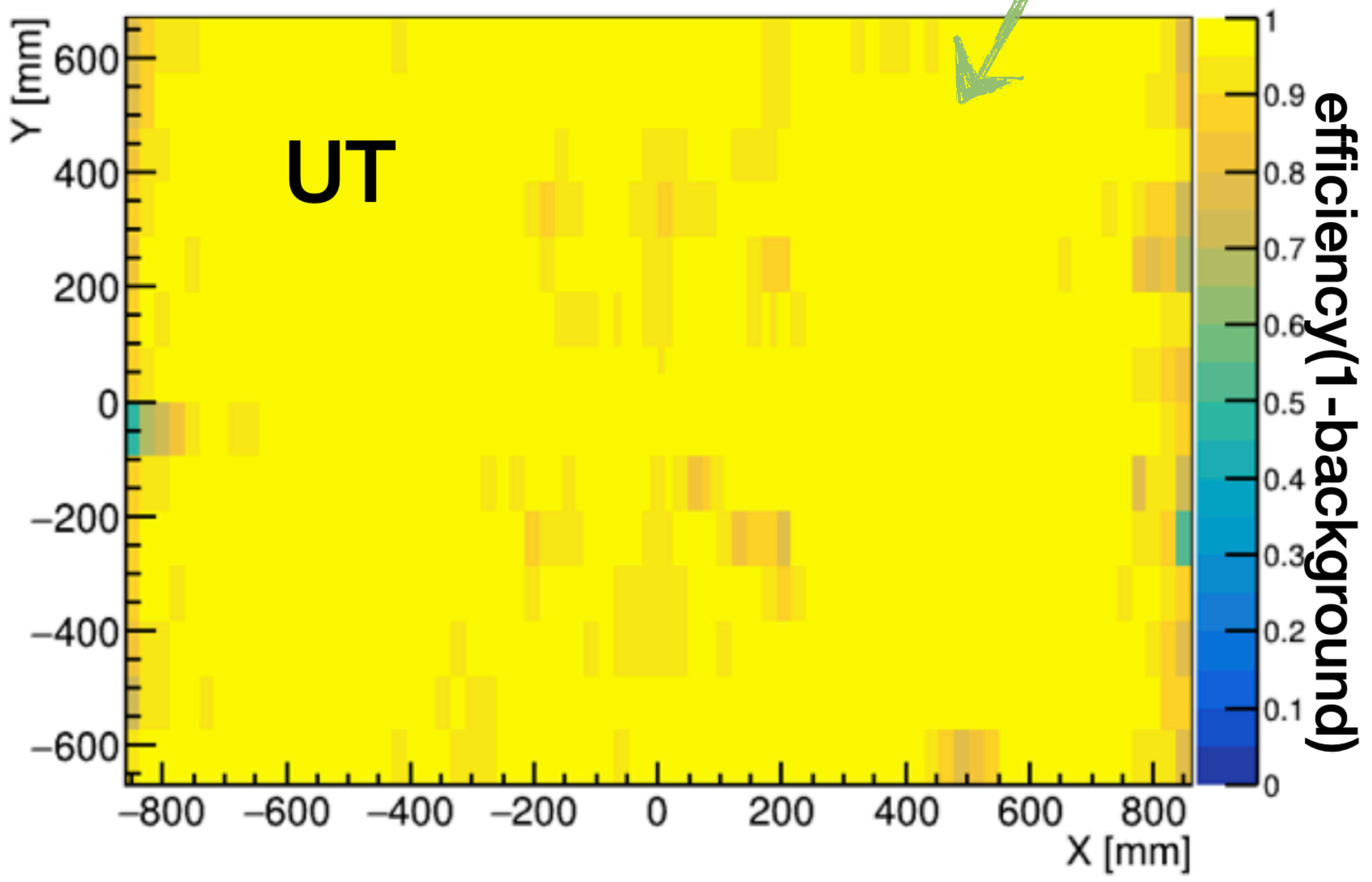
UT provides track reconstruction for:

- Decay products of long-lived particles
- Low-momentum particles

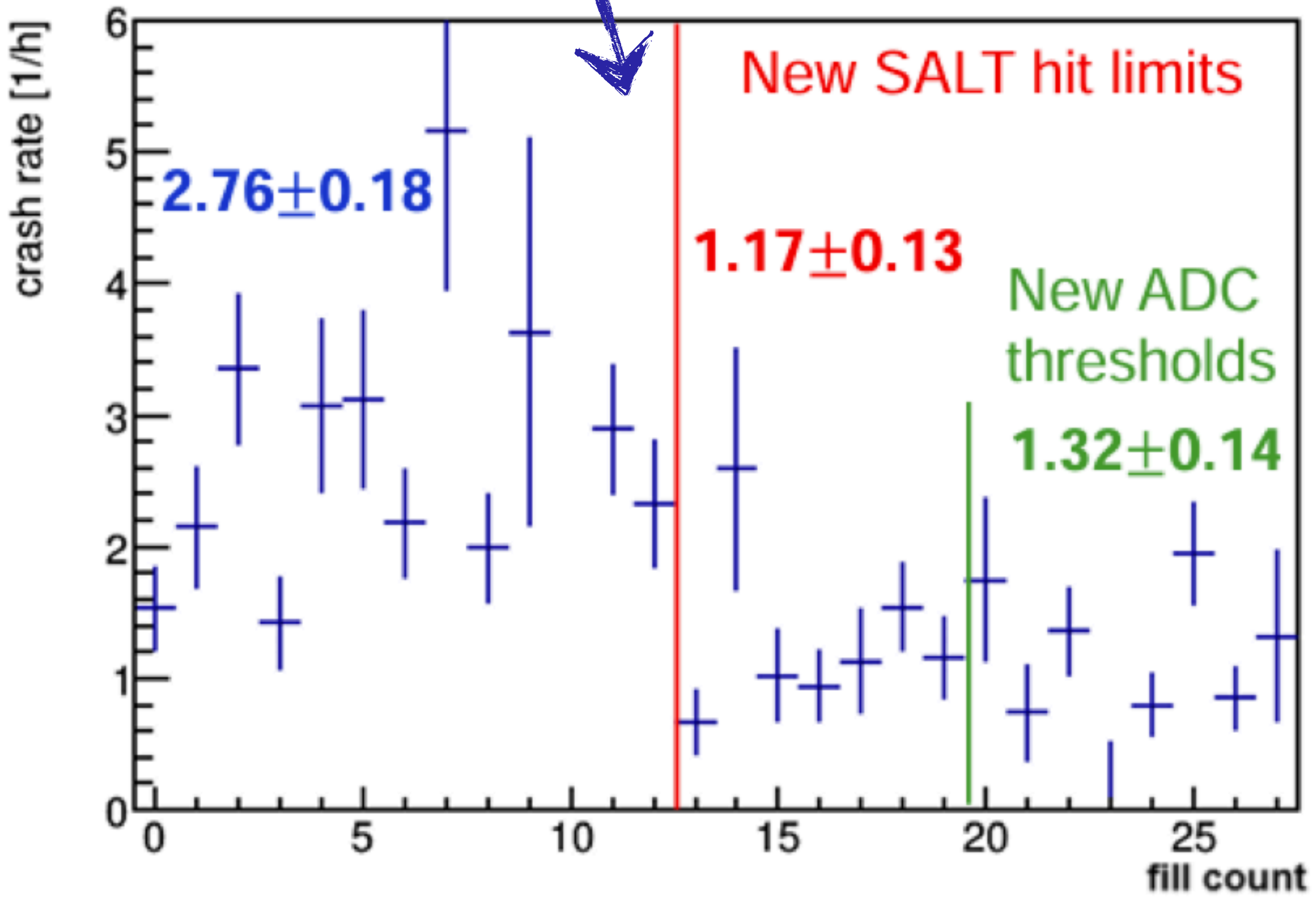
UT included in reconstruction:

- HLT2 since June-TS
- HLT1 since August-MD

UT with high efficiency

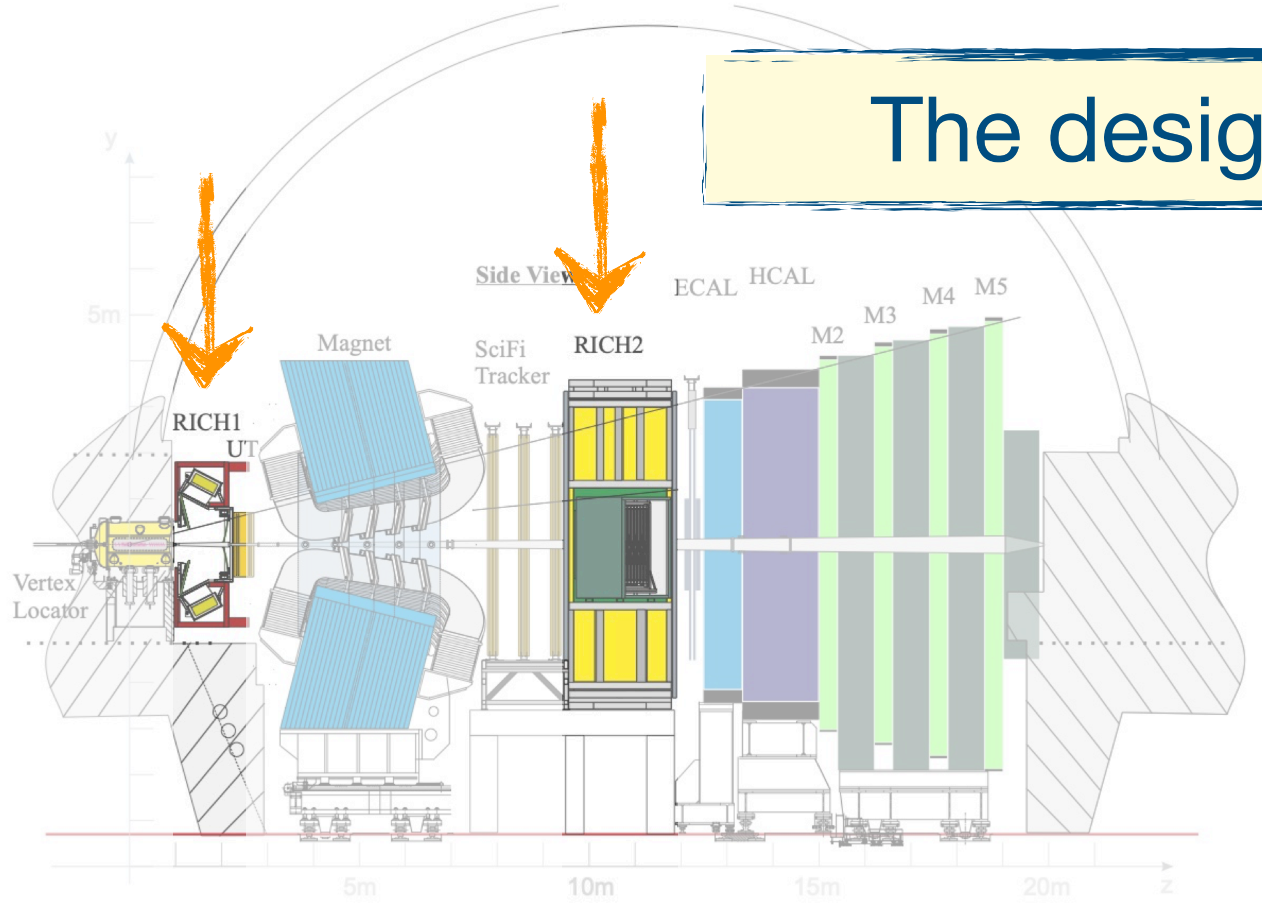


FE setting optimised to improve the DAQ stability



Preparations and tests for running at nominal pileup ongoing. (20% more than currently: $\mu = 5.3$)

Particle reconstruction performance



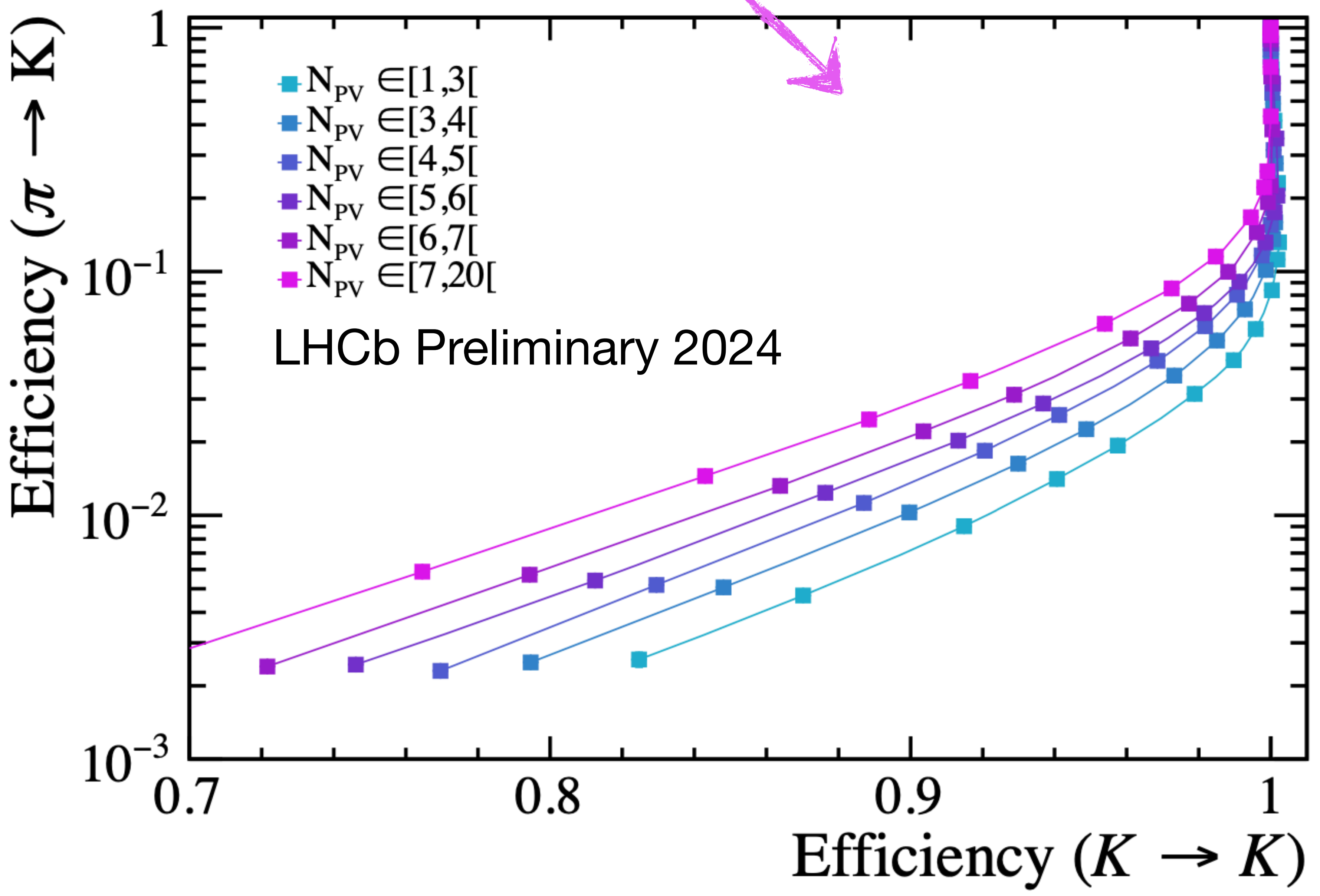
The design particle identification performance reached at high luminosity.

LHCb is at Upgrade I design level:

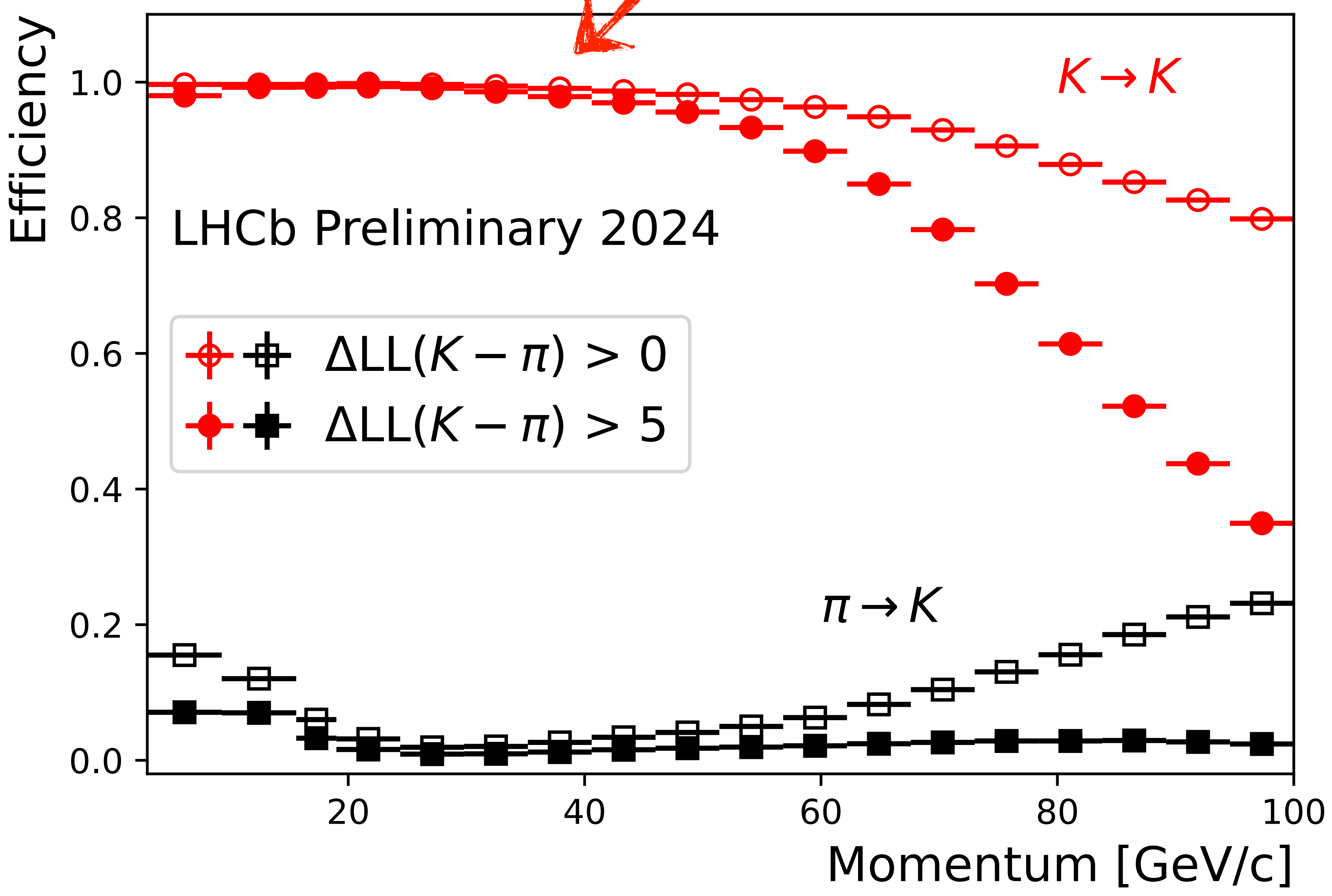
Ring-Imaging Cherenkov (RICH) sub-detector is showing better particle identification than in Run 2, while operating in harsher conditions.

Kaon - pion separation:

Primary vertex dependence



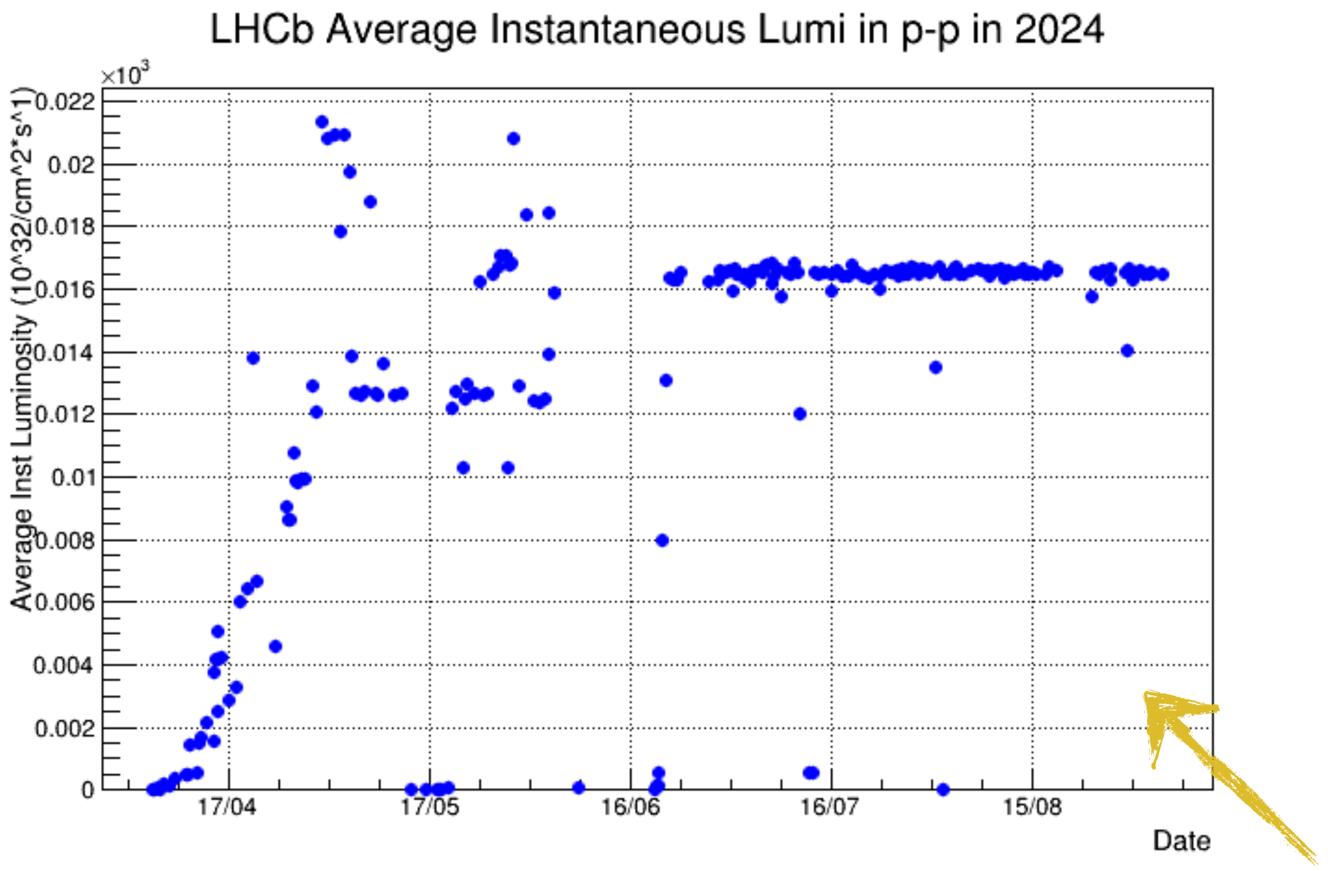
Momentum dependence



Online data processing

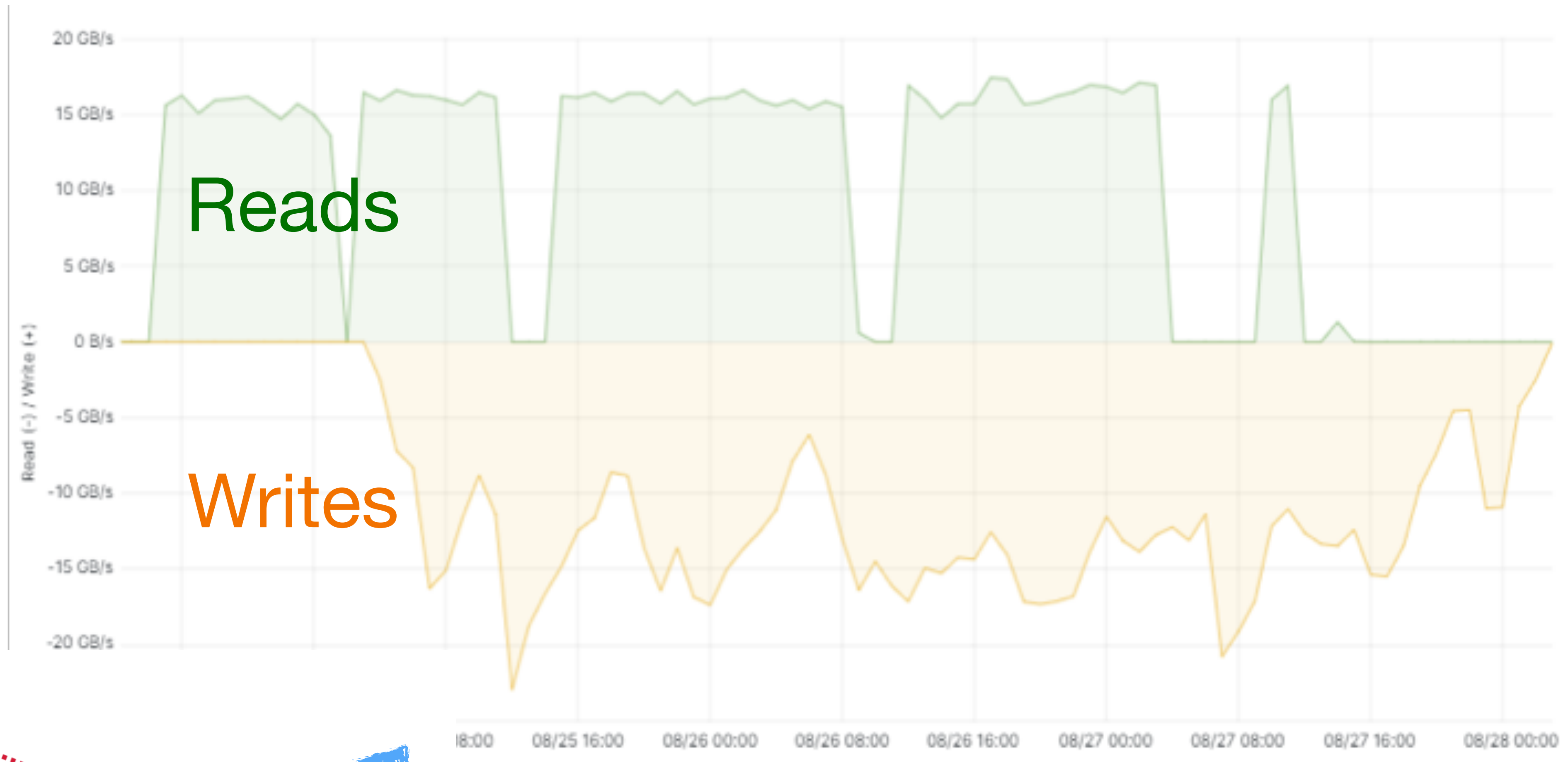
Upgrade Trigger and Online TDR

Upgrade Computing Model TDR

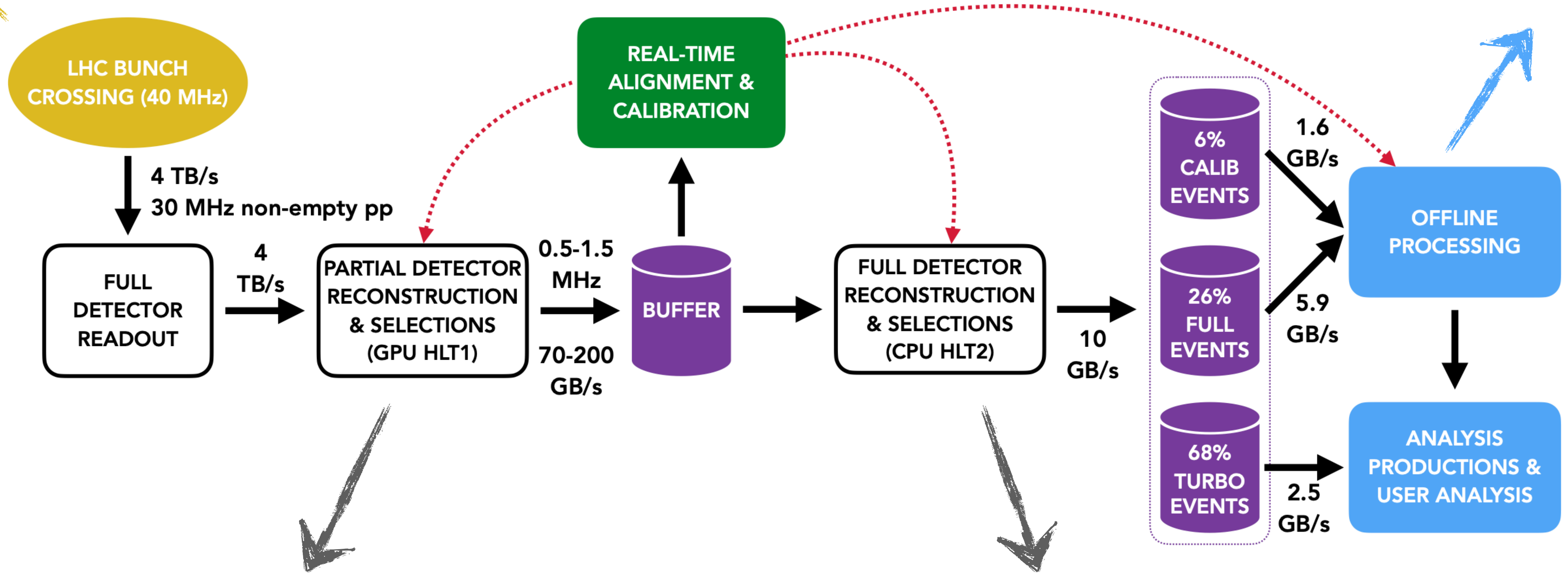


New challenging conditions

New alignment version deployed (next slide)



Constant flow of data to offline



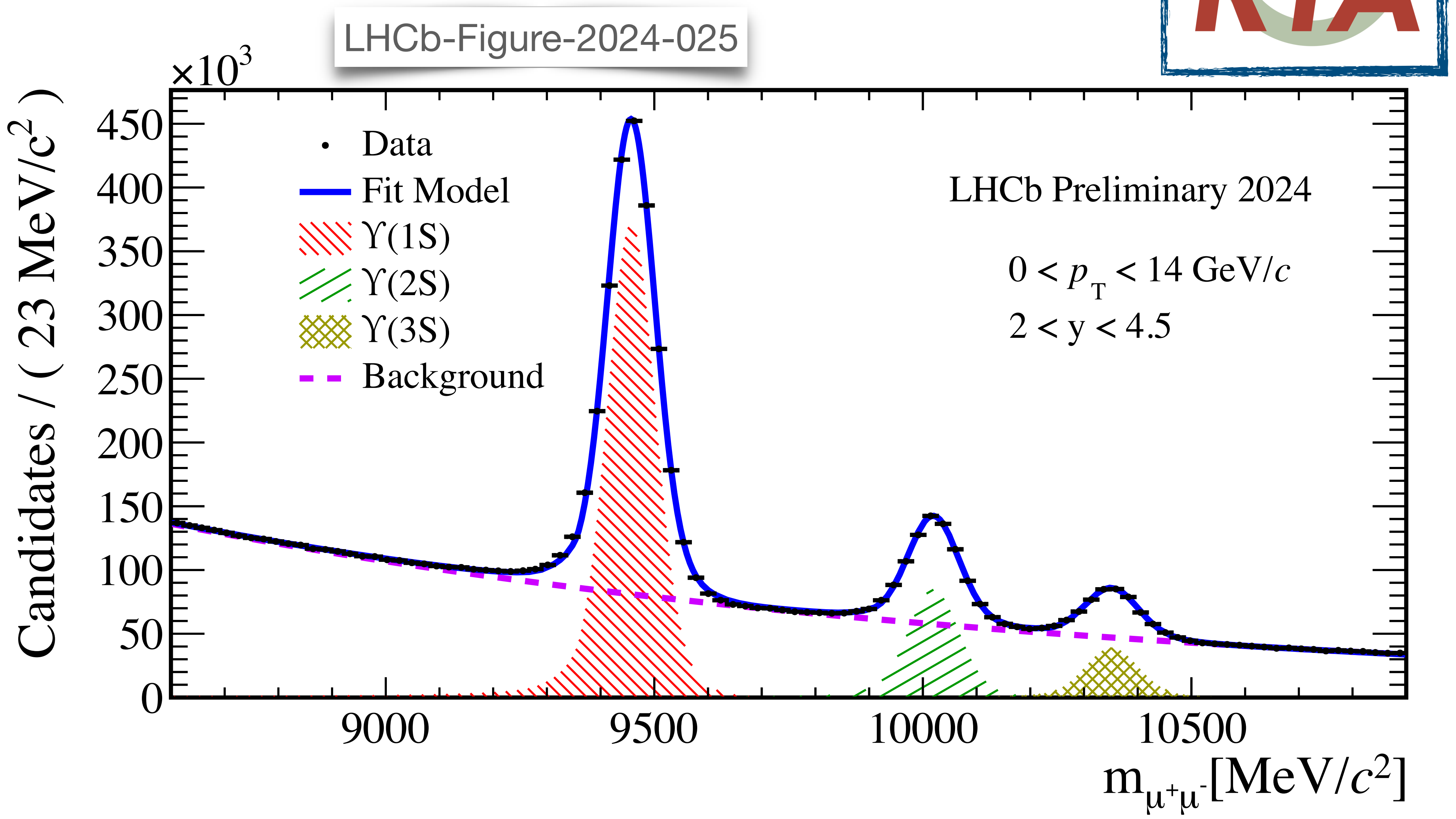
Installed additional 163 GPUs (now ~500 in total) to increase HLT1 compute power by 50%. Needed to run with high-performance at high luminosity.

Replaced old 4400 CPUs with newer versions. Increased total cores by >50%. Together with new servers, the HLT2 computing power has ~doubled.

Alignment and calibration

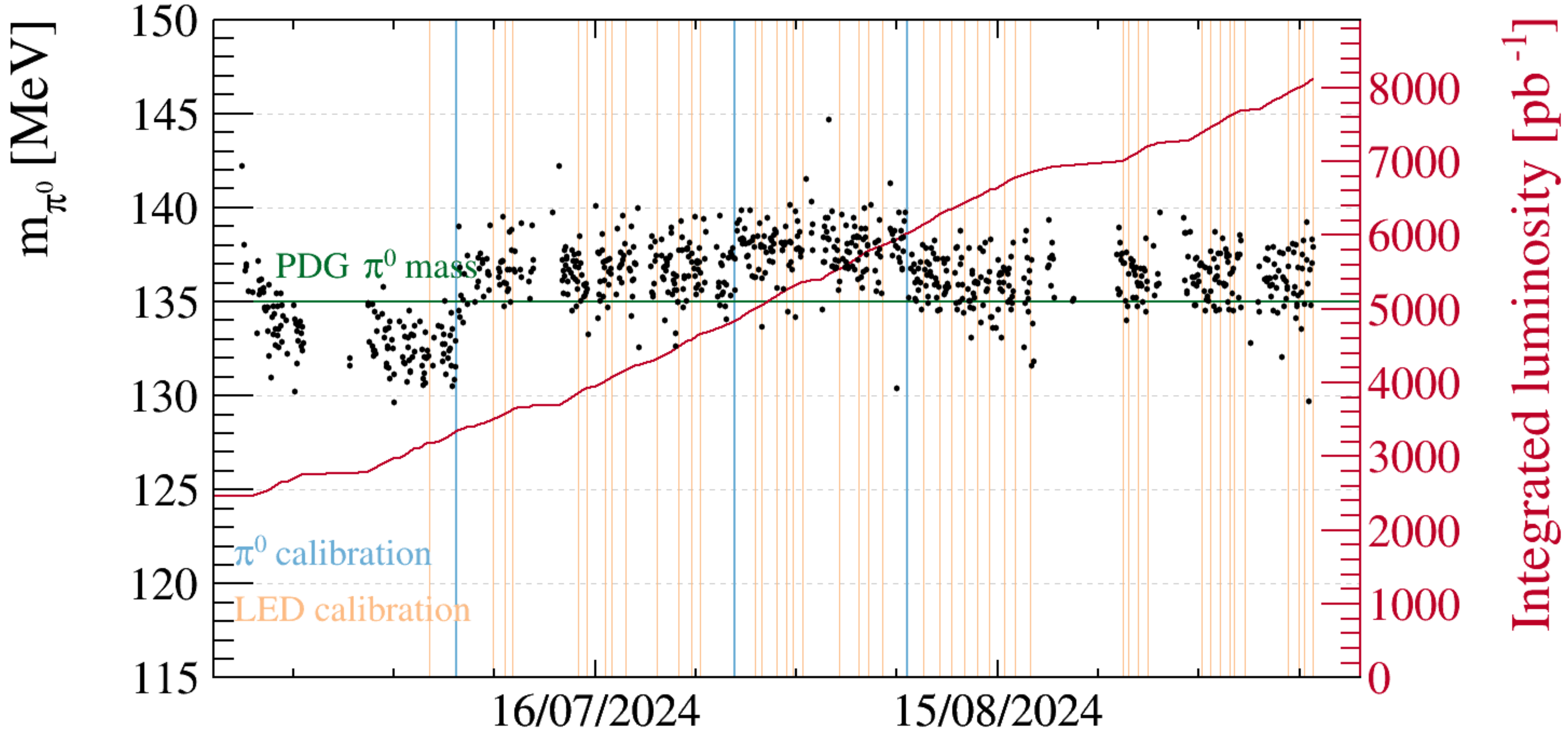
New alignment sequence:

- Improved resolutions.
- Close to Run 2 resolution.
- Using first magnet-off, then magnet-on data (sequently).
- Aligning all trackers (VELO, UT, SciFi) together (i.e. not individually in sequence)



ECAL calibration: both online systems working

- Absolute: using $\pi^0 \to \gamma\gamma$ events
- Relative: using the LED system ~fill
- Offline post calibration for higher *p* photons, ongoing.



Update of the magnetic field map:

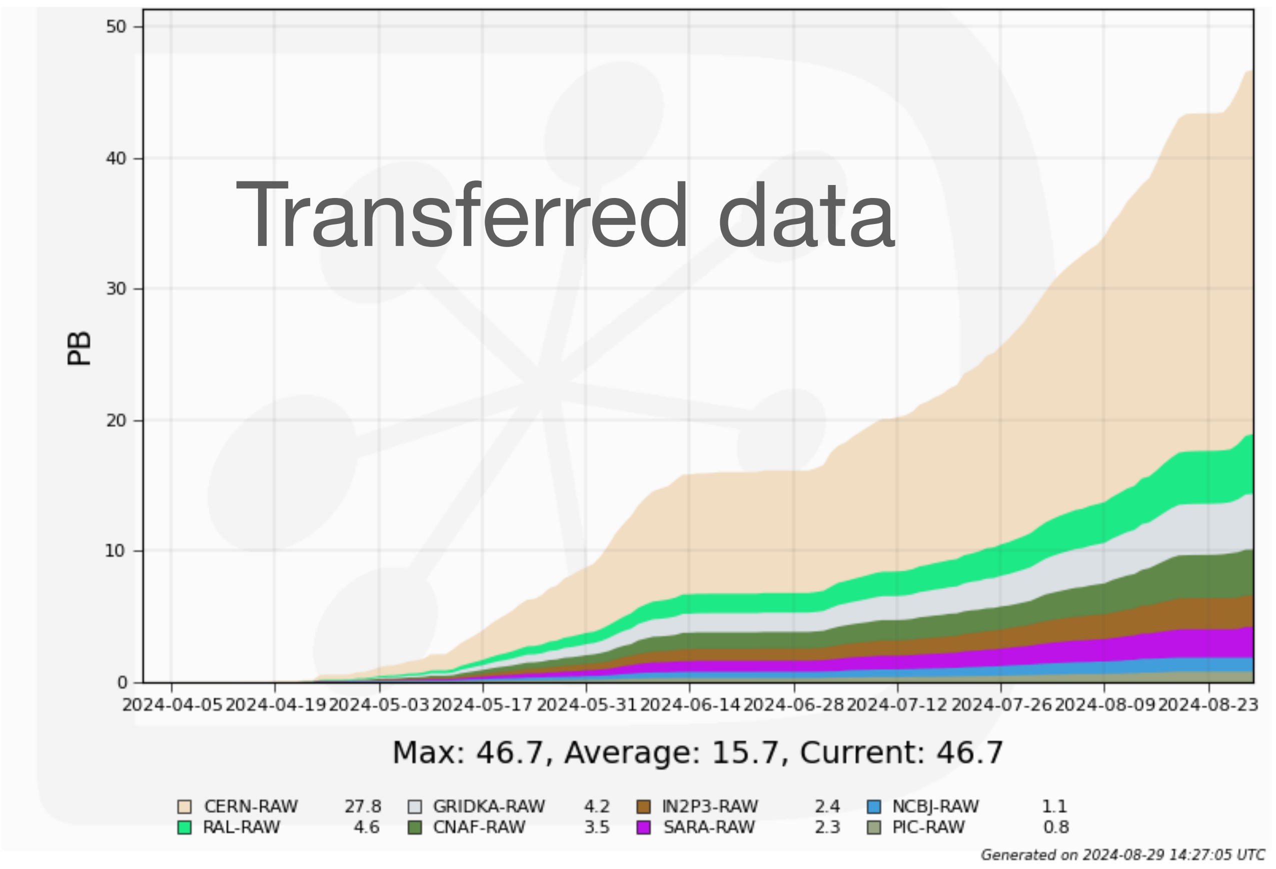
- Fitted to latest measurements
- Resulting on masses closer to their known values

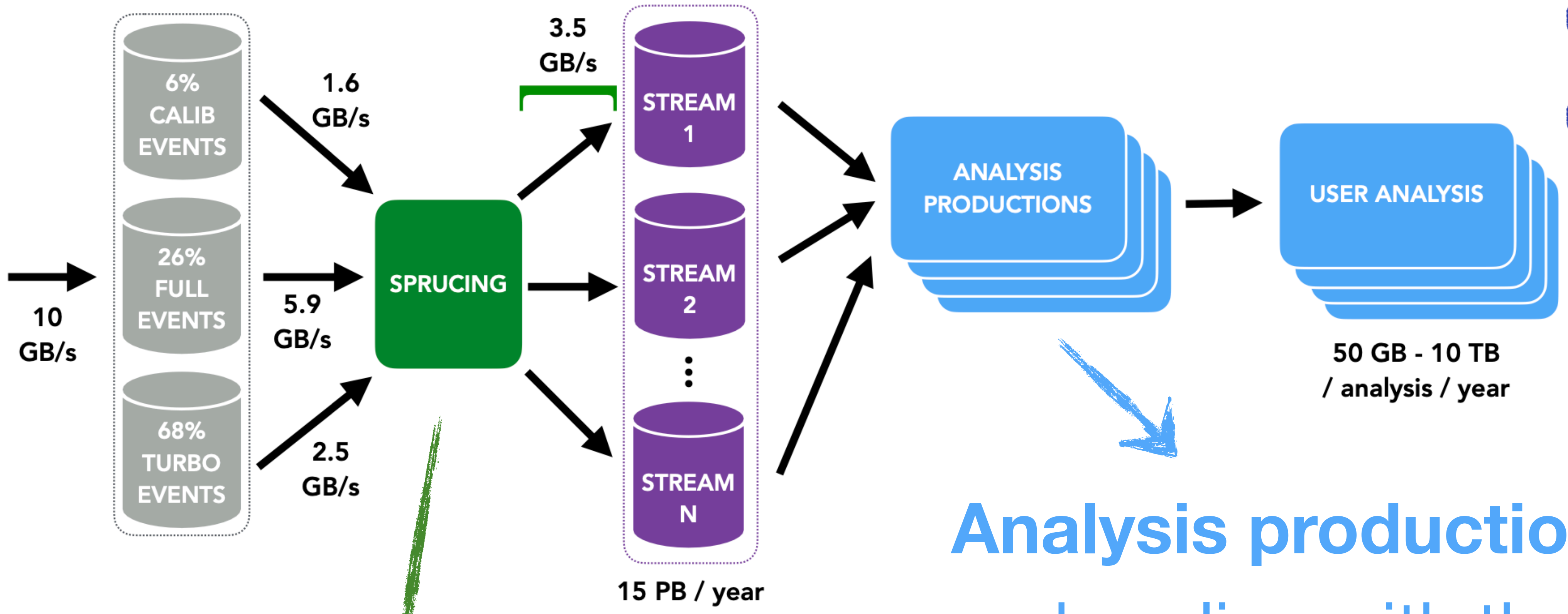
Offline data processing

Institute of High Energy Physics
Chinese Academy of Sciences

Exported more than 40 PB of RAW data from the detector in 2024

Processed more than 26 PB of data in 2024



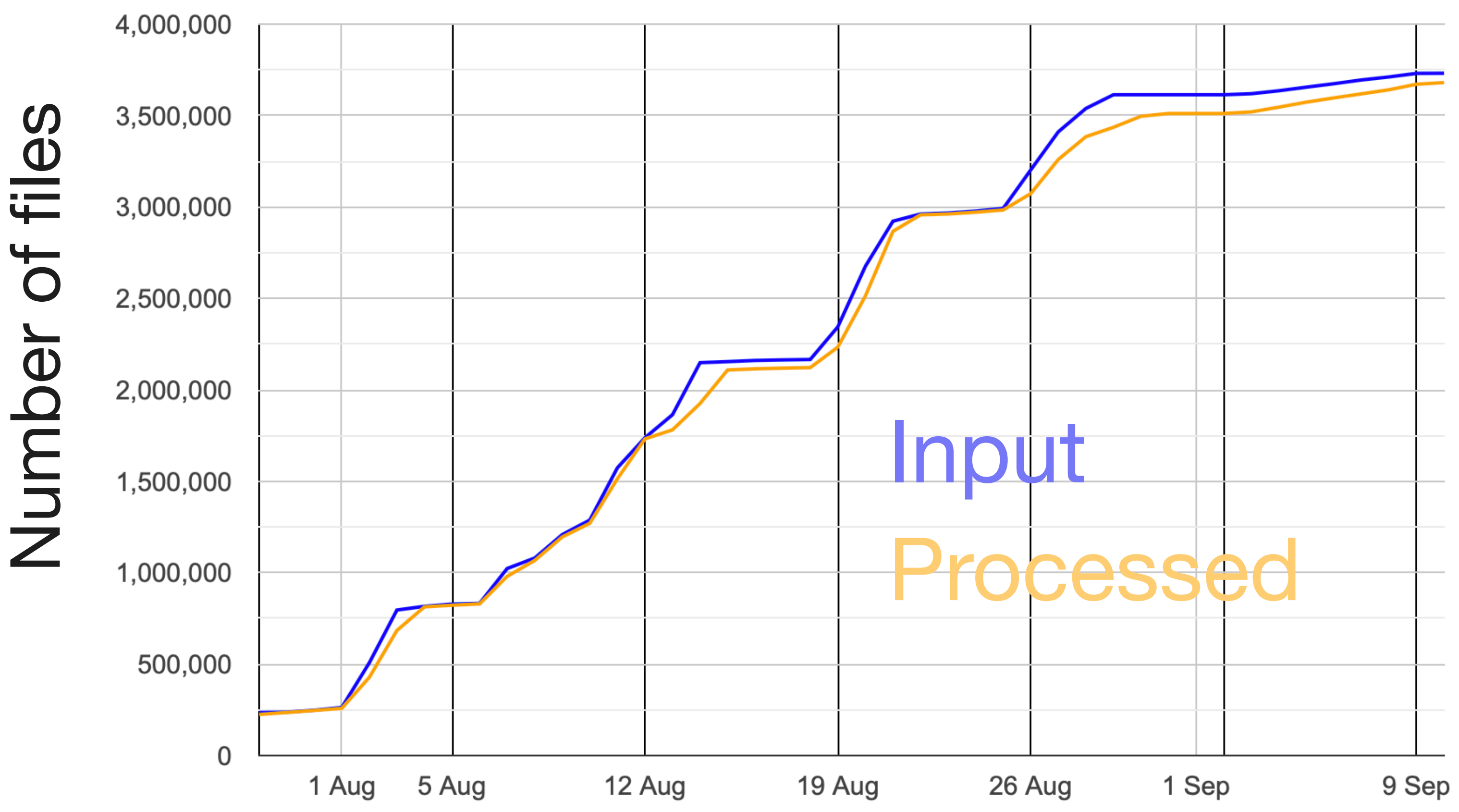


Welcome **new Tier-1**: IHEP (Beijing).

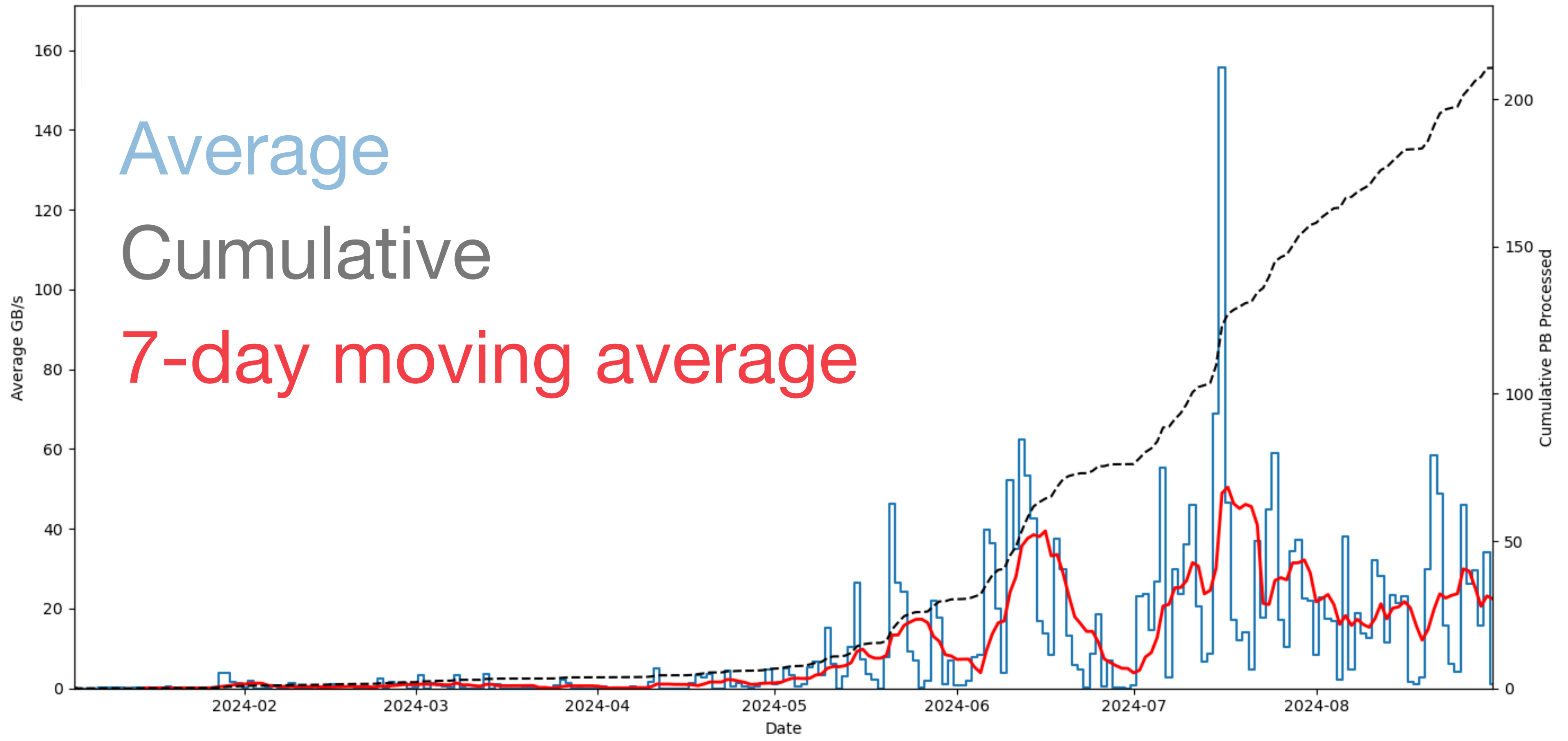
Data Challenge successfully completed:

- Transferred 190 TB in May/June
- Target rate of 1 GB/s exceeded

Analysis production framework fully operational and scaling with the increased load: >650 active AP

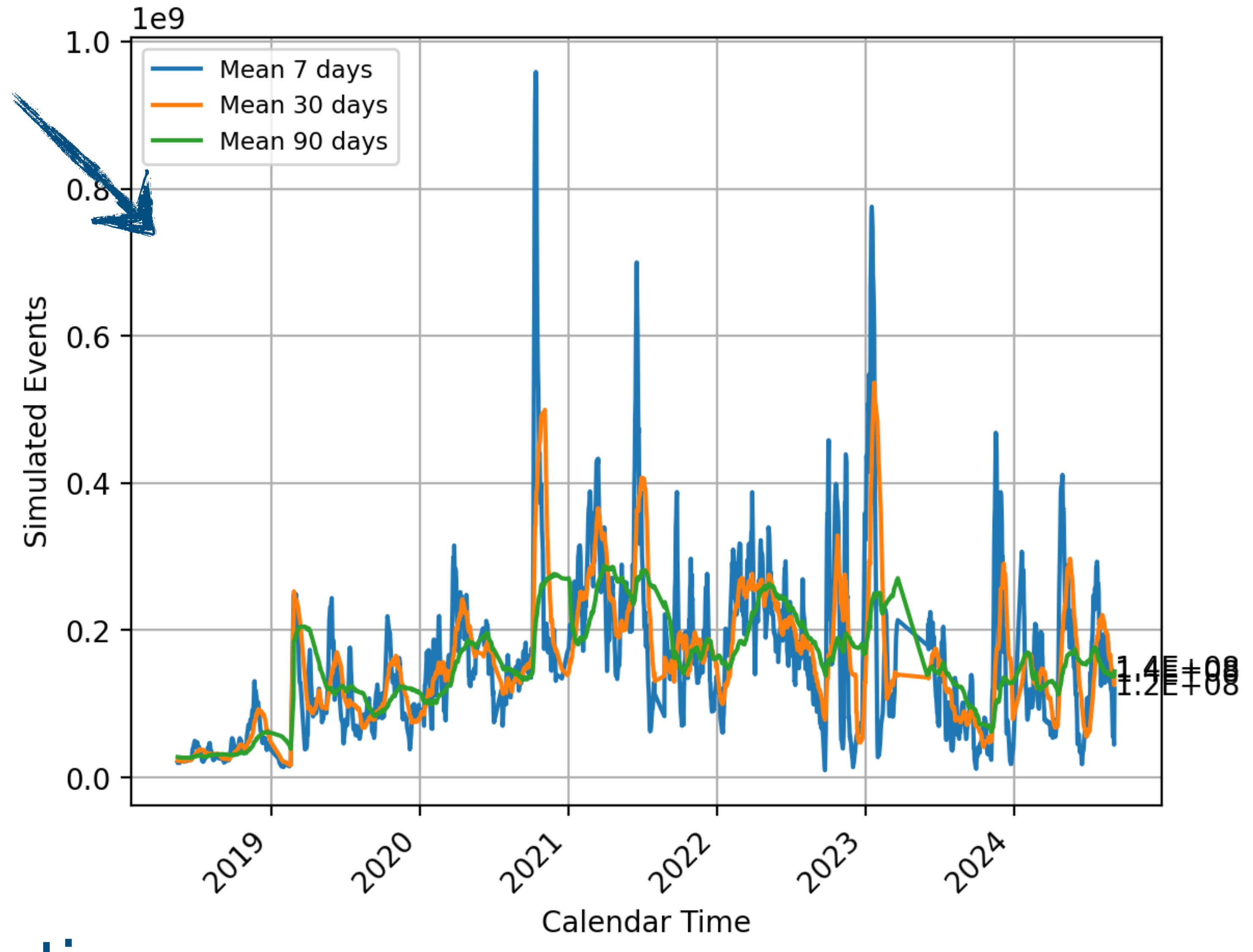


The offline chain has processed (spruce) the RAW data with very little delay



Simulation

Running production for Run1+2 and Run 3

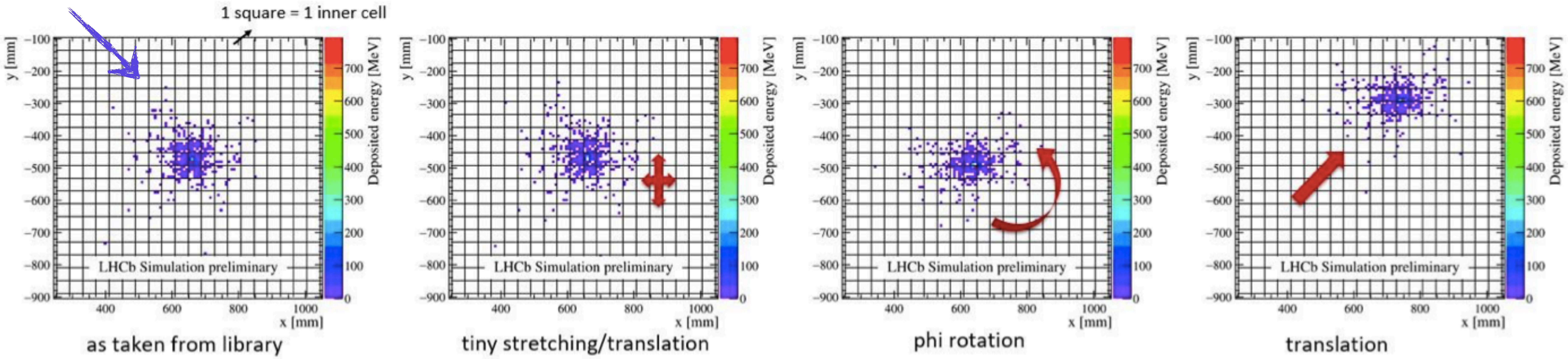


Large **collective effort** from
- simulation group
- subdetectors experts
- physics analysts

to make simulation more realistic w.r.t. detector geometry and conditions.

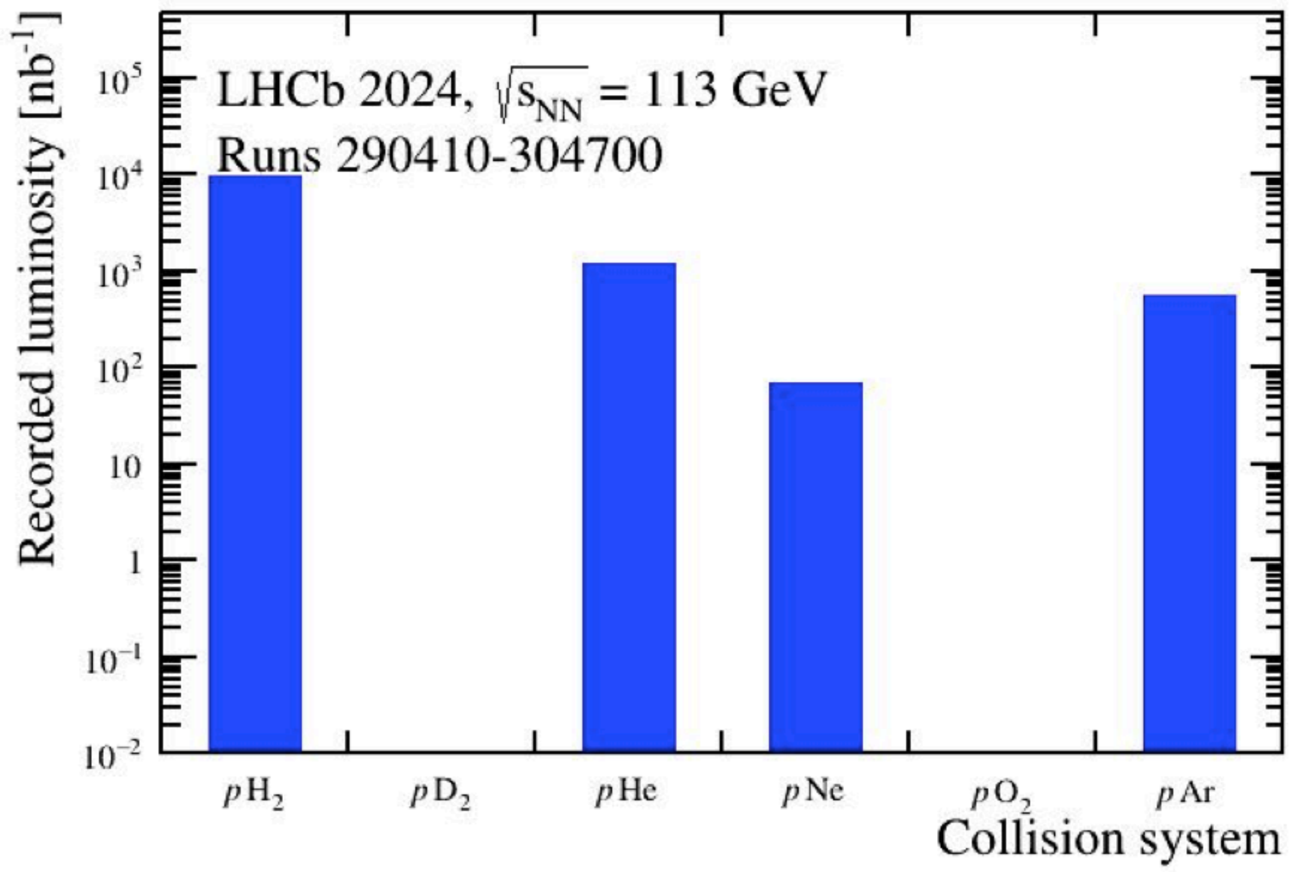
Recent and upcoming improvements:
- New magnetic field
- VELO hit efficiency ratio
- UT new frontend electronics design
- SciFi closer to data conditions
- RICH2 resolution closer to data
- CALO cluster corrections updated
- MUON low energy bkg. new parametrisation

Several **ongoing developments**. For example, calorimeter fast simulation based on point library and machine learning.



3. Plans for heavy ions run - 2024

Heavy Ions plans in 2024



- Unique full detector **rapidity coverage** w.r.t. other experiments → access larger kinematic regions.
- Hadron identification → open charm/beauty reconstruction and high eff. selection.
- Only experiment capable of **inject gases in the LHC** through SMOG and acquire proton-gas and lead-gas data → access intermediate energy range and high-*x*, less accessible by other experiments.

- Increase PbPb luminosity with magnet polarity inversion by 20%.
- Increase PbPb number of colliding bunches by 40%.

Thanks to ALICE, ATLAS, CMS and the LHC for their support!

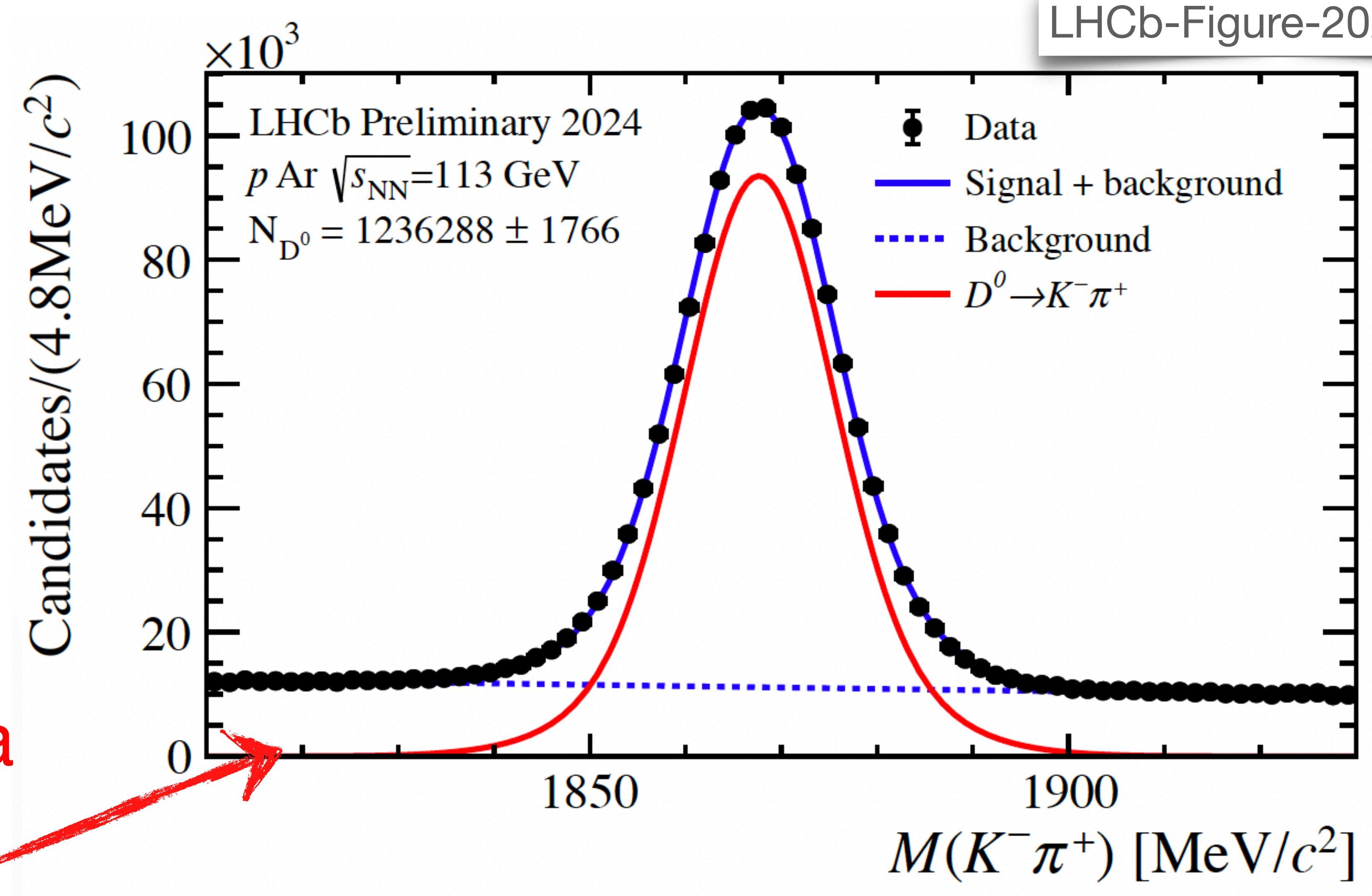
Already a big pAr SMOG data sample in 2024.
Now, eager to switch to PbAr.

LHCb-Figure-2024-023

The whole Heavy Ions physics programme will benefit:

- Ultraperipheral collisions
- Open charm/beauty
- Quarkonia
- Collective flow

88 hours injection
proton-Argon data
$D^0 \rightarrow K^-\pi^+$



4. Upgrade II

Upgrade II

Scoping Document ready to start LHCC review

Solid plan developed compatible with the LHC present schedule:

Run 3		LS3			Run 4				LS4		Run 5				LS5	Run 6	
2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041
TDR phase			Construction phase						Installation		Exploitation						

TDR phase within 2026, construction phase 6 years, to be fully ready at LS4.

Three detector scenarios are described in the scoping document:

Scenarios	Baseline	Middle	Low
L_{peak} (10^{34} $cm^{-2}s^{-1}$)	1.5	1.0	1.0

Different
- Physics potential
- Cost
- Complexity

Important experience gained from Upgrade I:

Start early, guarantee enough infrastructure/person-power support, and reduce complexity where possible.

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-LHCC-2024-010
LHCb-TDR-026
July 26, 2024

LHCb Upgrade II Scoping Document

LHCb collaboration

Abstract

A second major upgrade of the LHCb detector is necessary to allow full exploitation of the LHC for flavour physics. The new detector is proposed for installation during the long-shutdown 4 (LS4), and will operate at a maximum luminosity of $1.5 \times 10^{34}\,cm^{-2}\,s^{-1}$. By upgrading all subdetectors and adding new detection capability it will be possible to accumulate a sample of $300\,fb^{-1}$ of high energy pp collision data, giving unprecedented and unique discovery potential in heavy flavour physics and other areas. The baseline LHCb Upgrade II detector has been presented in a Framework Technical Design Report in 2022. Here, updated and additional scoping options with reduced detection capability and different choice of operational luminosity are presented. The costs and physics performance of each scenario are discussed, and an overview of the project management plans is presented.

Conclusions

- The LHCb collaboration continues to publish a wealth of results in flavour physics (and beyond).
- LHCb Upgrade I now running at full steam:
  - Integrated luminosity in 2024 already largely surpassed that of Run 2.
  - Running in nominal conditions: VELO closed and UT stable in global.
  - The alignment, calibration and particle reconstruction reached design performance.
  - The online and offline processing keeps pace with the challenging incoming data.
- Preparing for the heavy ions run.
- The Upgrade II scoping document has been submitted to the LHCC and is ready for review.

Thanks to the LHC for their support and excellent performance!

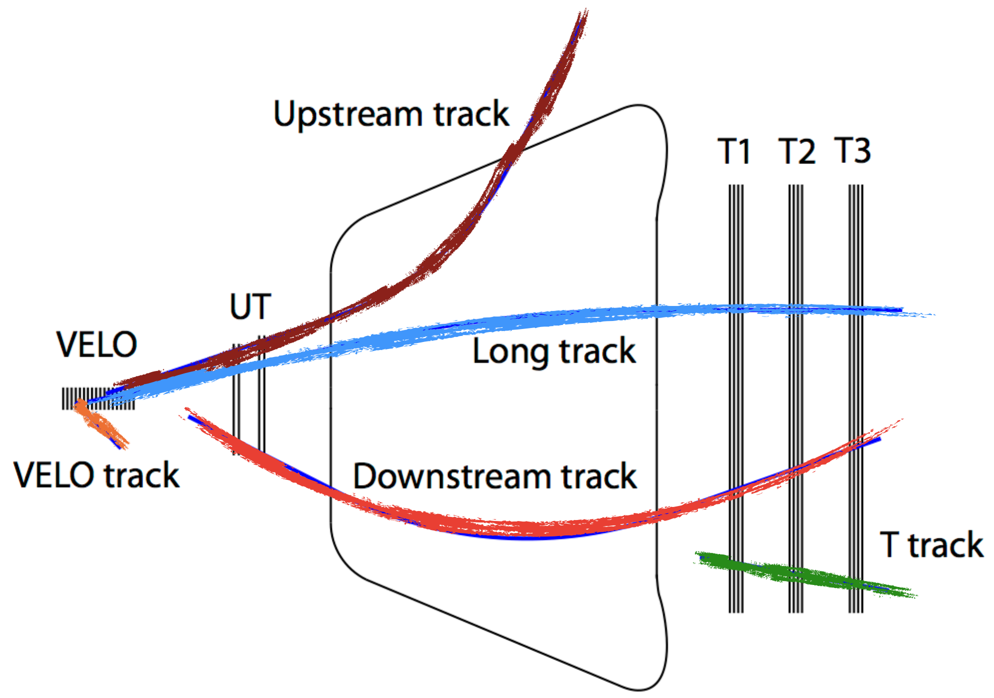
From the LHCb collaboration.

Backup

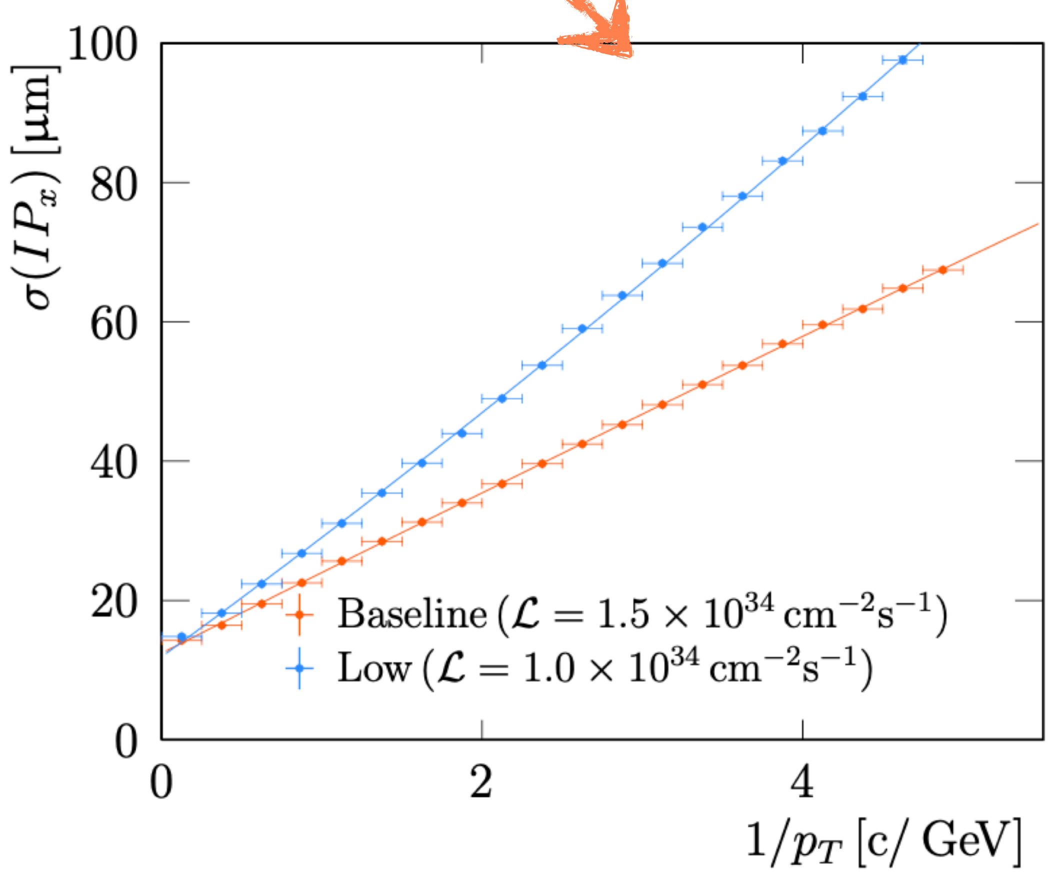
Scoping Document

Tracking performance:

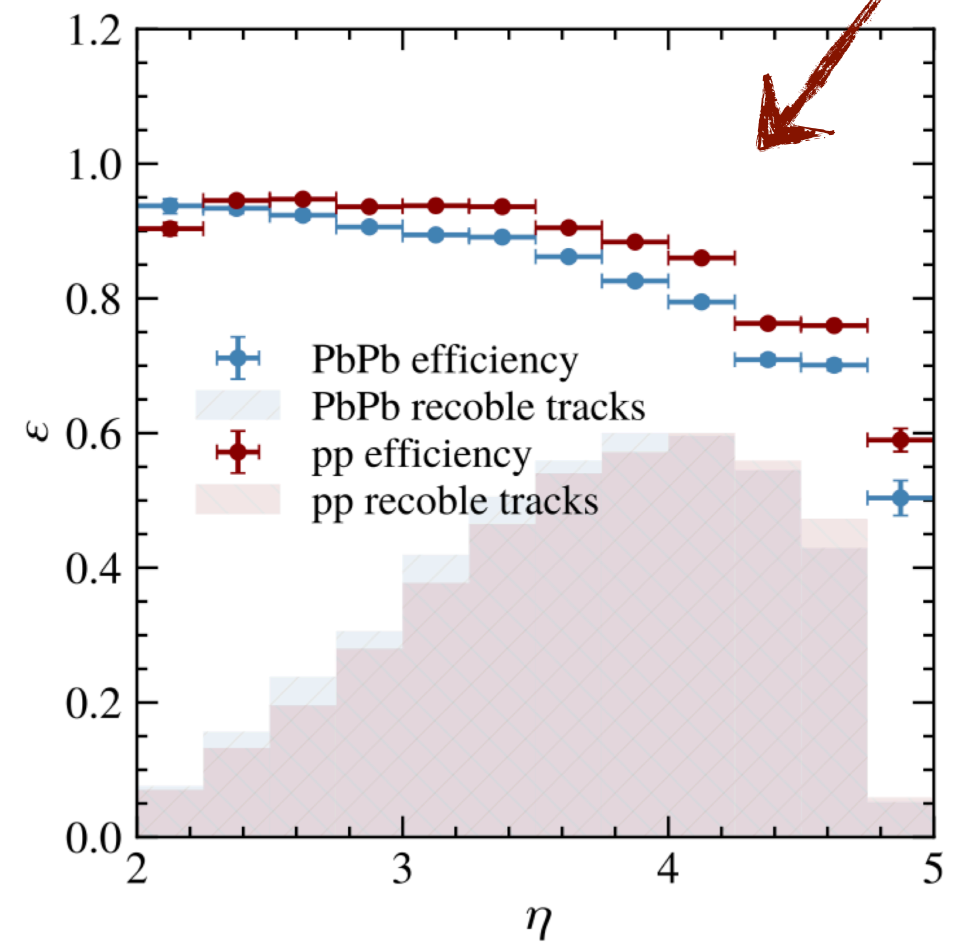
- Performance guaranteed > Run 3
- Tracking eff. similar to Run 3
- Acceptance loss in Low scenario
- Resolution momentum improvement
- High eff. on HI central events
- Timing crucial for downstream tracks



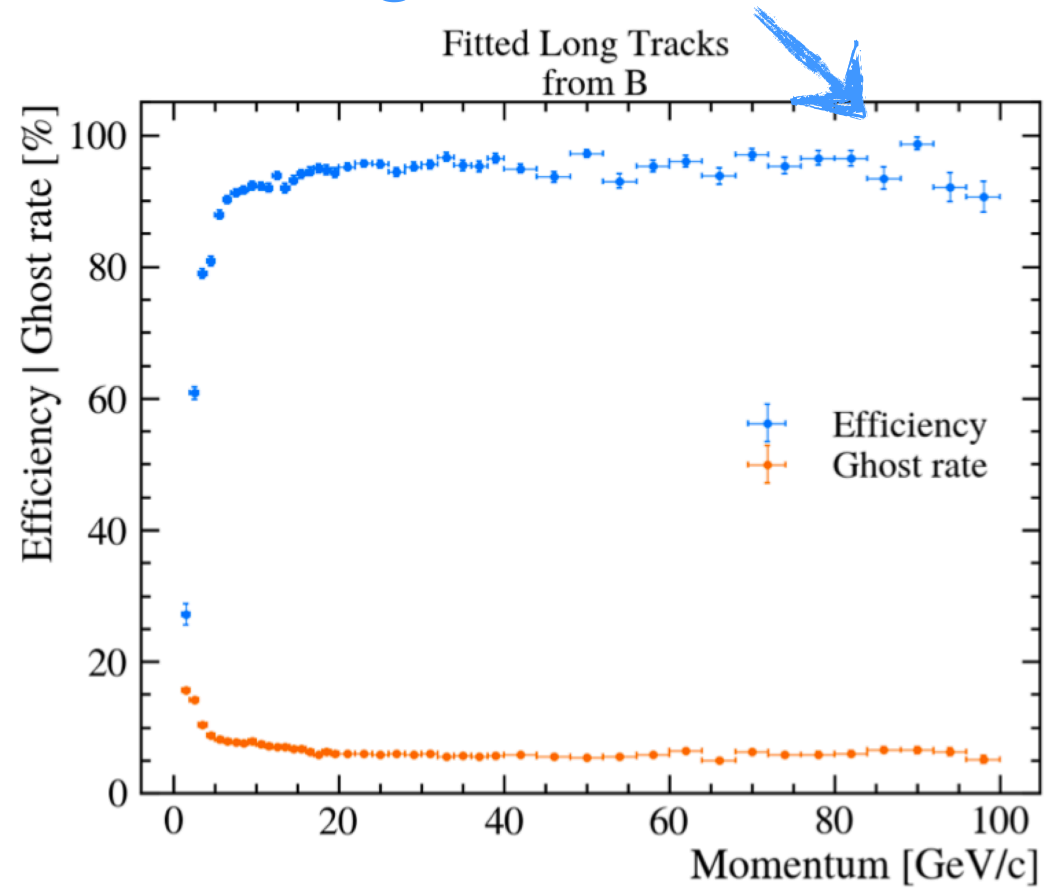
VELO IP resolution



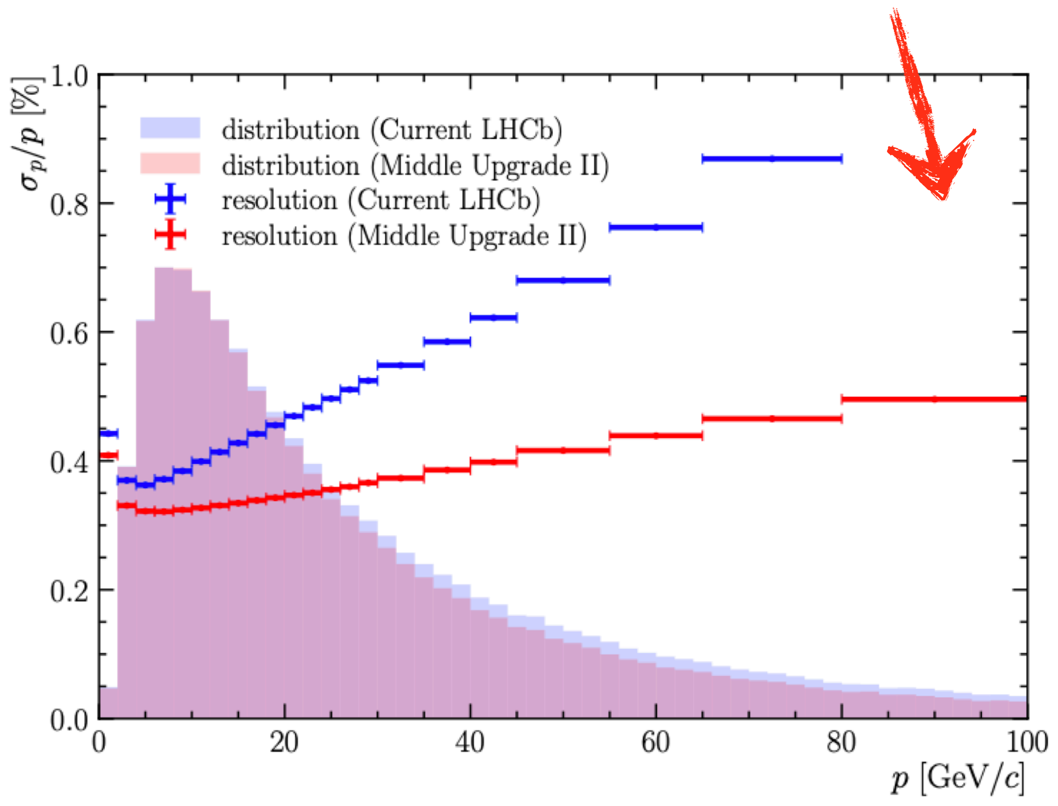
Upstream tracks eff.



Long tracks eff.



Downstream tracks resolution

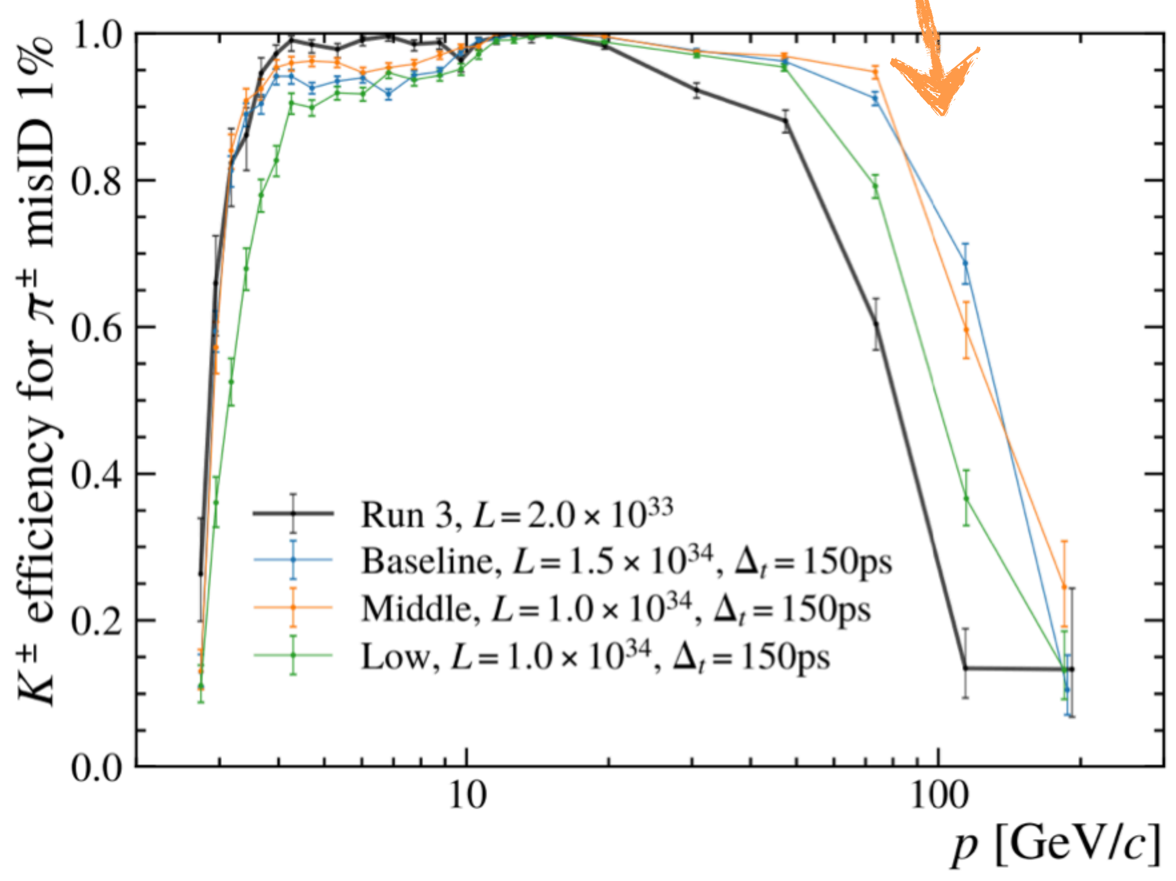


Scoping Document

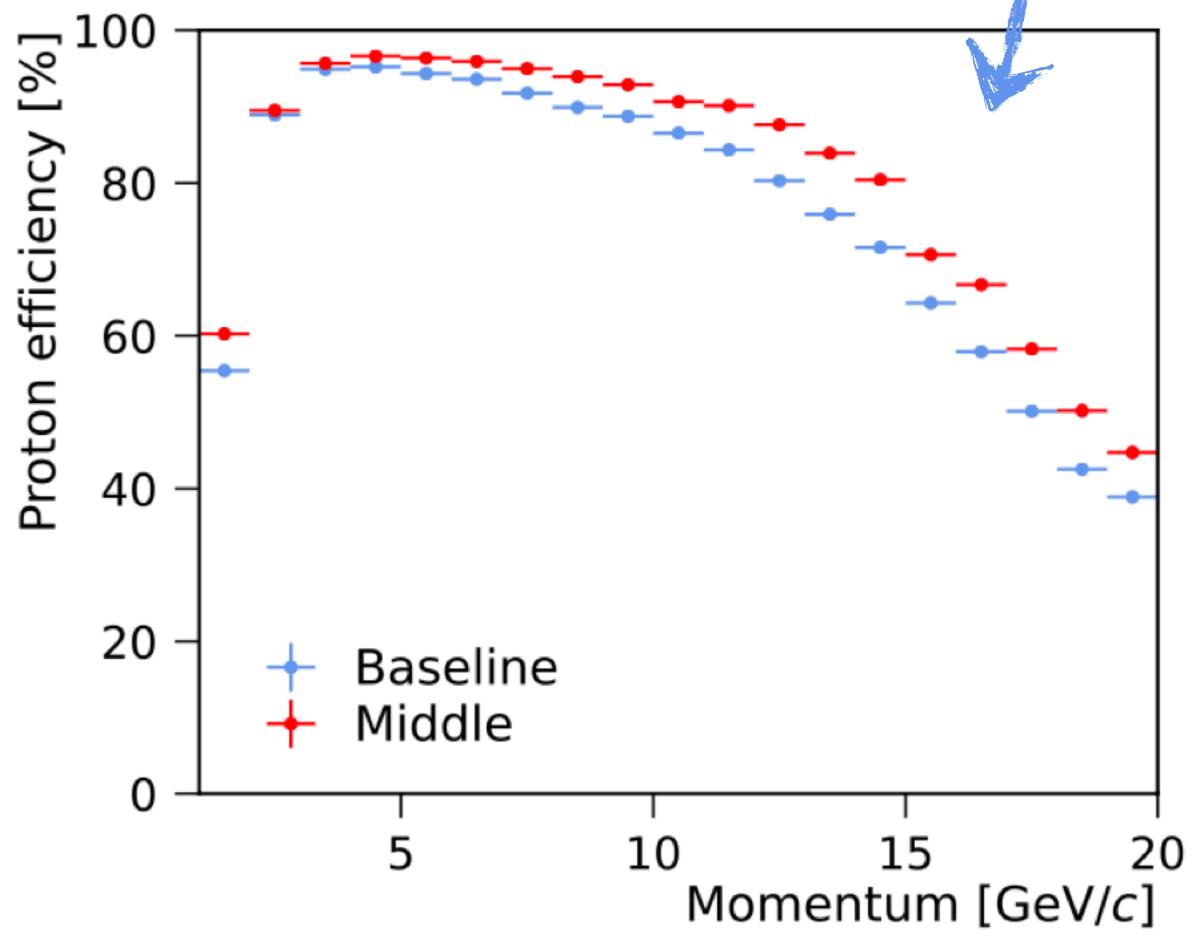
Particle identification performance:

- Good RICH performance, better actual time and Cherenkov angle resolution.
- TORCH complements RICH and improves the tagging power.
- PicoCal: Low scenario has strong impact on π^0 and electrons.
- Muon efficiency improved, more mitigations ongoing.

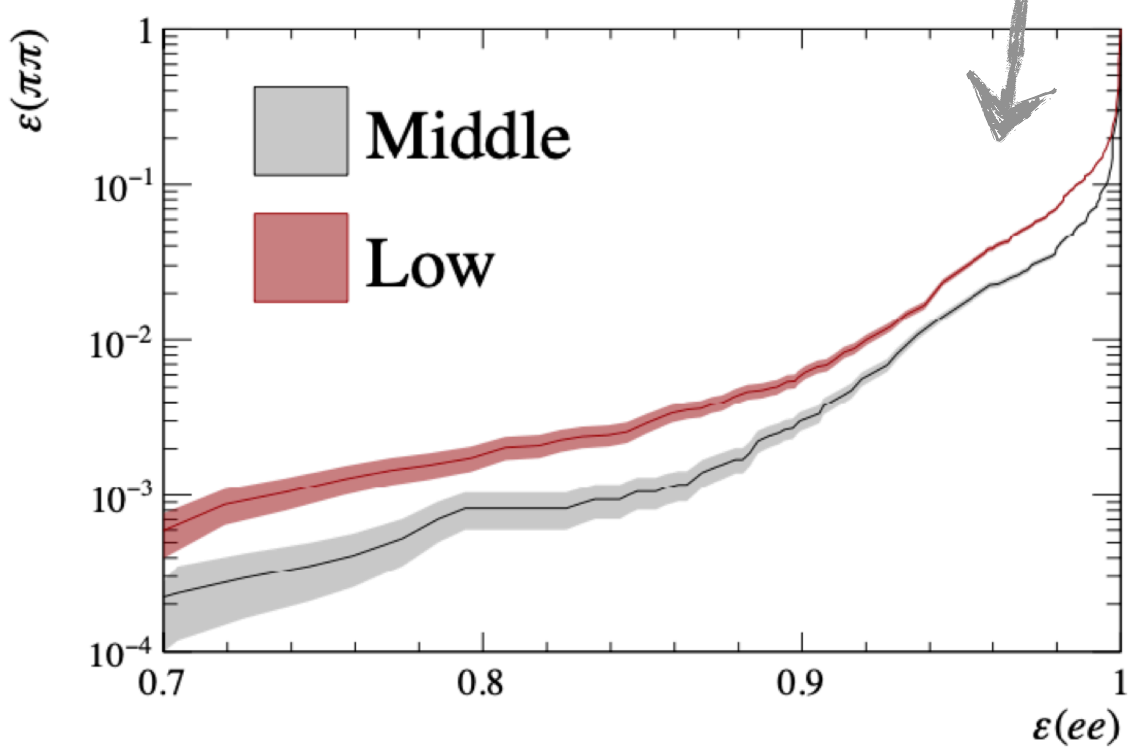
RICH kaon ID eff.



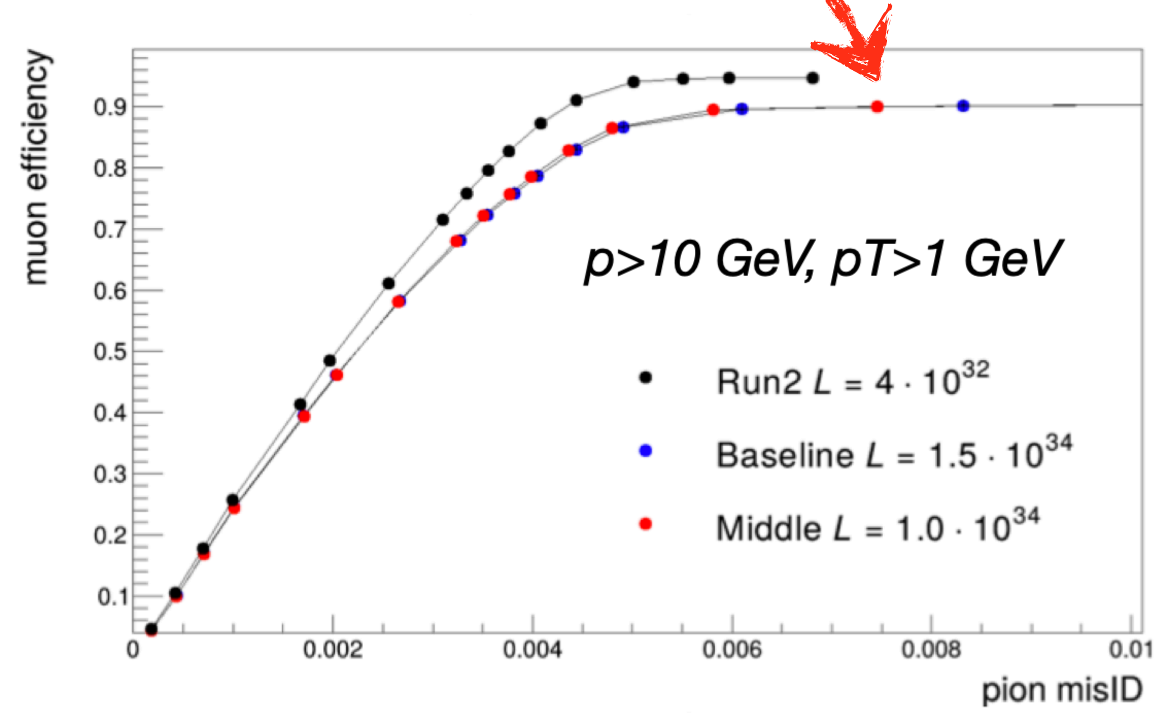
TORCH proton ID eff.



PicoCal electron ID eff.



Muon ID eff.



Scoping Document

Table 7: Summary of tracking detector scenarios.

Baseline $1.5 \times 10^{34}\,\mathrm{cm^{-2}\,s^{-1}}$	Middle $1.0 \times 10^{34}\,\mathrm{cm^{-2}\,s^{-1}}$	Low $1.0 \times 10^{34}\,\mathrm{cm^{-2}\,s^{-1}}$
	VELO	
32 stations, $\eta < 4.8$	32 stations, $\eta < 4.8$	28 stations, $\eta < 4.7$
module 0.8% X_0	module 0.8% X_0	module 1.6% X_0
RF foil 75 µm	RF foil 75 µm	RF foil 150 µm
	UP	
4 planes pixel $\times 1.7\,\mathrm{m}^2$	as baseline	remove corners
	Magnet Stations	
4 Sci panels $\times 3.5\,\mathrm{m}^2$	as baseline	remove
	Mighty-Pixel	
6 planes pixel $\times 2.1\,\mathrm{m}^2$	6 planes pixel $\times 1.3\,\mathrm{m}^2$	6 planes pixel $\times 1.3\,\mathrm{m}^2$
	Mighty-SciFi	
12 planes fibres	12 planes fibres	12 planes fibres
$25.9\,\mathrm{m}^2$/plane	shorter, $23.7\,\mathrm{m}^2$/plane	narrower, $18.9\,\mathrm{m}^2$/plane

Table 8: Summary of PID detector scenarios.

Baseline $1.5 \times 10^{34}\,\mathrm{cm^{-2}\,s^{-1}}$	Middle $1.0 \times 10^{34}\,\mathrm{cm^{-2}\,s^{-1}}$	Low $1.0 \times 10^{34}\,\mathrm{cm^{-2}\,s^{-1}}$
	RICH1/2	
inner:outer $\frac{1}{3}:\frac{2}{3}$	inner:outer $\frac{1}{4}:\frac{3}{4}$	inner:outer $\frac{1}{4}:\frac{3}{4}$
inner 1.4 mm SiPM	inner 2.0 mm SiPM	inner 2.0 mm SiPM
outer 2.8 mm SiPM	outer 2.8 mm SiPM	outer 2.8 mm MaPMT
new optics	new optics	new optics (RICH1 only)
750,000 channels	469,000 channels	445,000 channels
	TORCH	
18 quartz bars	12 quartz bars	removed
225,000 channels	158,000 channels	—
	PicoCal	
40 SpaCal-W	40 SpaCal-W	40 SpaCal-W
408 SpaCal-Pb	408 SpaCal-Pb	408 SpaCal-Pb
2864 Shashlik	2864 Shashlik	2864 Shashlik
double R/O	double R/O	single R/O except 176 inner
30,976 channels	30,976 channels	20,224 channels
	Muon	
µ-RWELL in R1/R2	µ-RWELL in R1/R2	µ-RWELL in R1/R2
96/192 new MWPC in R3	keep old MWPC in R3	keep old MWPC in R3
keep old MWPC in R4	keep old MWPC in R4	keep old MWPC in R4
additional shielding	keep HCAL	keep HCAL
718,848 channels	608,256 channels	608,256 channels