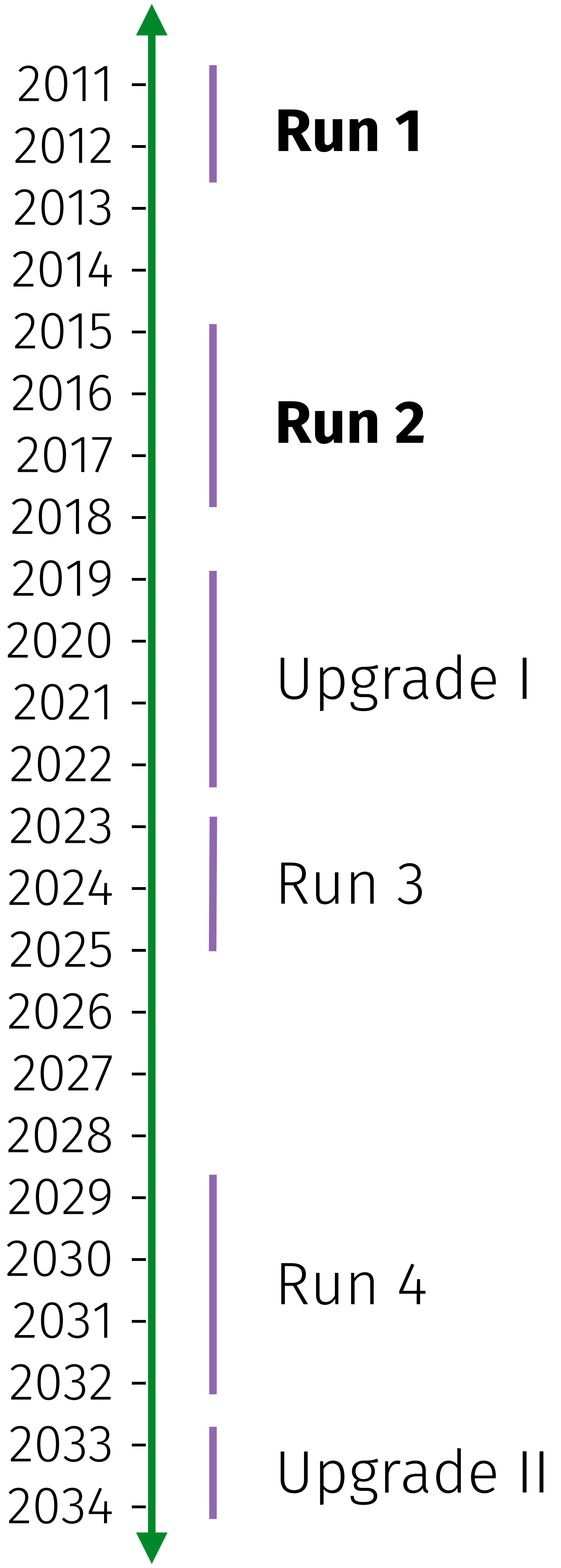
technische universität dortmund

FSP LHCb
Erforschung von Universum und Materie

LHCb performance and upgrades

Sophie Hollitt for LHC Days in Split, Croatia 3rd-8th October
On behalf of the LHCb Collaboration

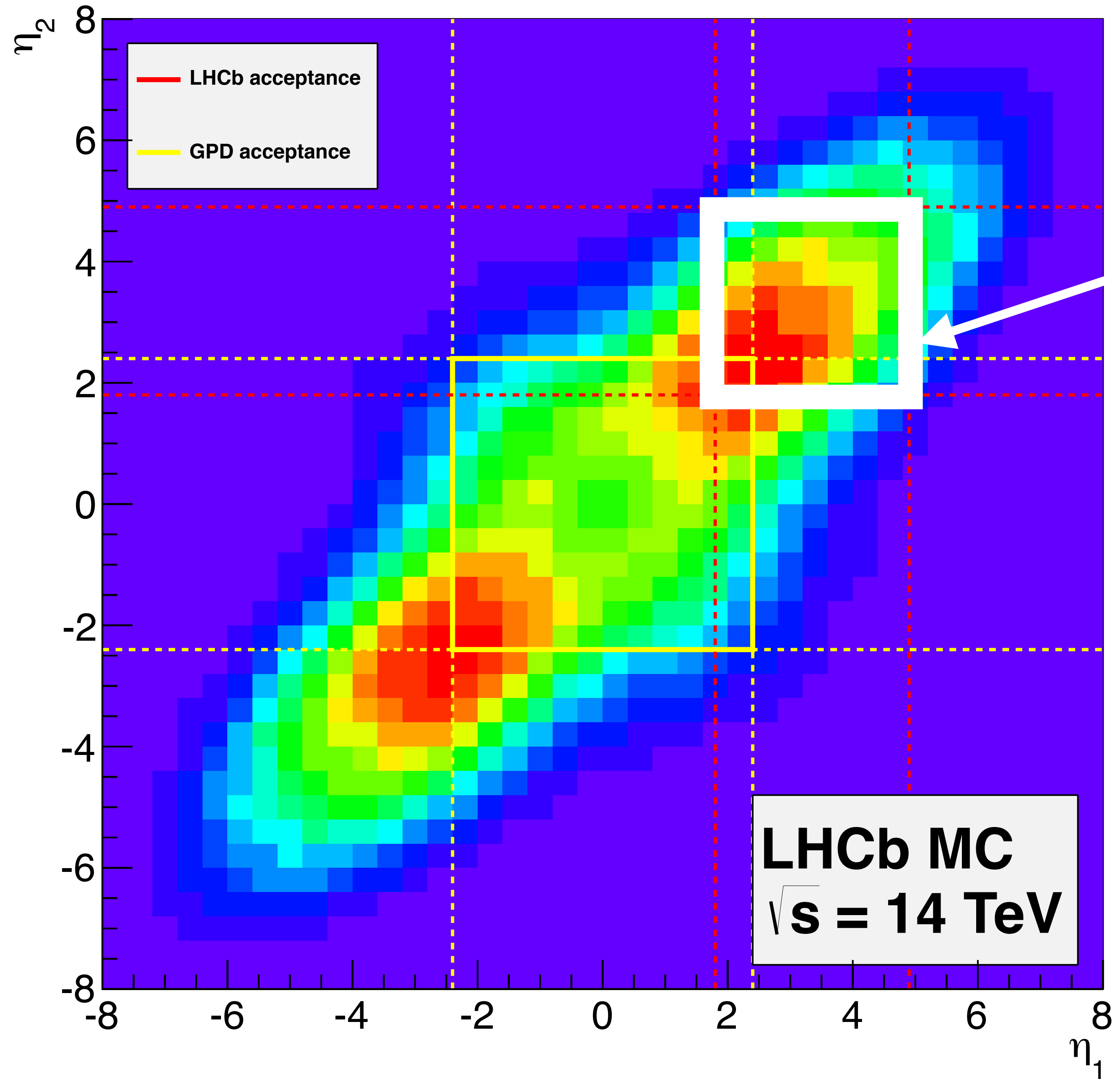
LHCb timeline



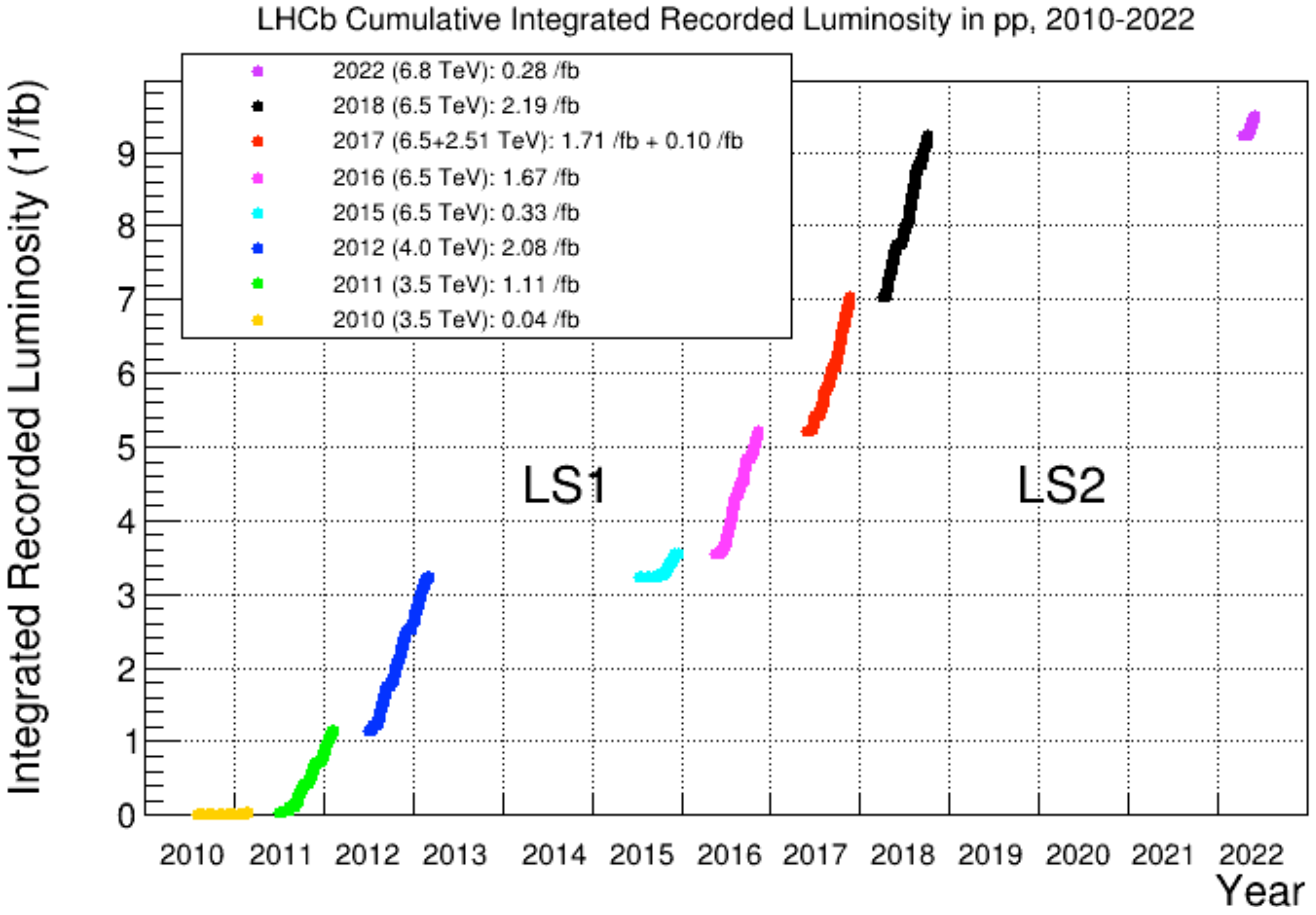
- Three main periods of LHCb to discuss:
  - Run 1+2 (existing data)
  - Run 3+4 (new detector in commissioning now)
  - Upgrade II/HL-LHC plans
- **First: Run 1+2 at LHCb**
  - **Overview of LHCb**
  - **Performance and trigger strategies**
  - Next talks: Overview of results
    - CPV, rare beauty and charm, EW precision, heavy ions, b and c spectroscopy…
- Next: performance predictions for upgrade LHCb detectors
  - Including status for Run 3

LHCb first principles

- The LHC has a huge cross section of b and c hadrons
  - $\sigma(b\bar{b})(7\ \text{TeV}) = 295\ \mu b$
    $\sigma(b\bar{b})(13\ \text{TeV}) = 590\ \mu b$
  - Factor of 20 larger for charm
  - ALL types of b and c hadrons produced
- LHCb designed as forward spectrometer to focus on $b\bar{b}$ production region
  - Detector acceptance $2 < \eta < 5$
- LHCb uses luminosity levelling
  - proton beams are displaced
  - keeps run conditions more stable during fills
  - reduces interactions per bunch crossing to 1-2

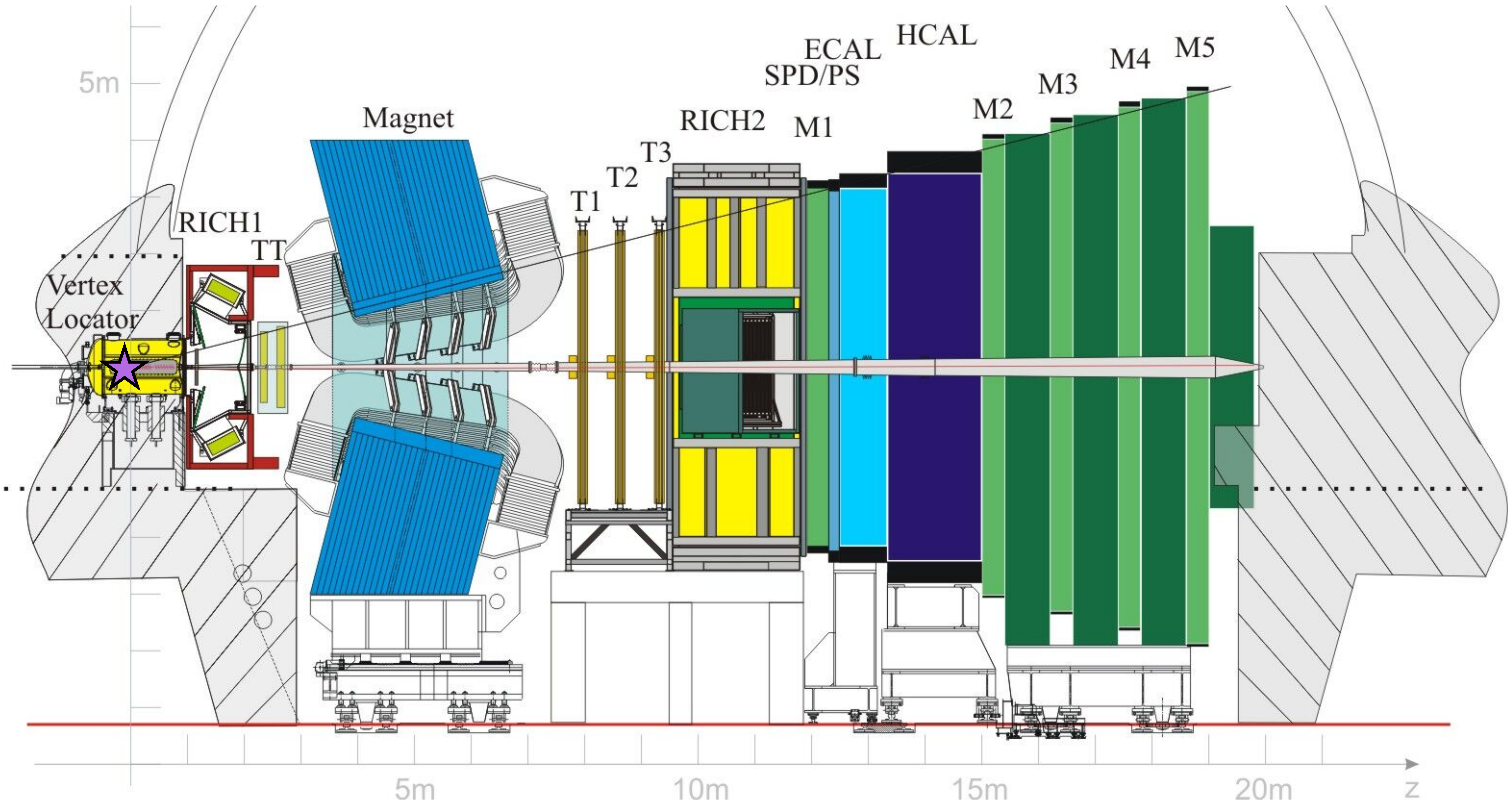


This region: 25% of $b\bar{b}$



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

The LHCb detector in Run 1+2

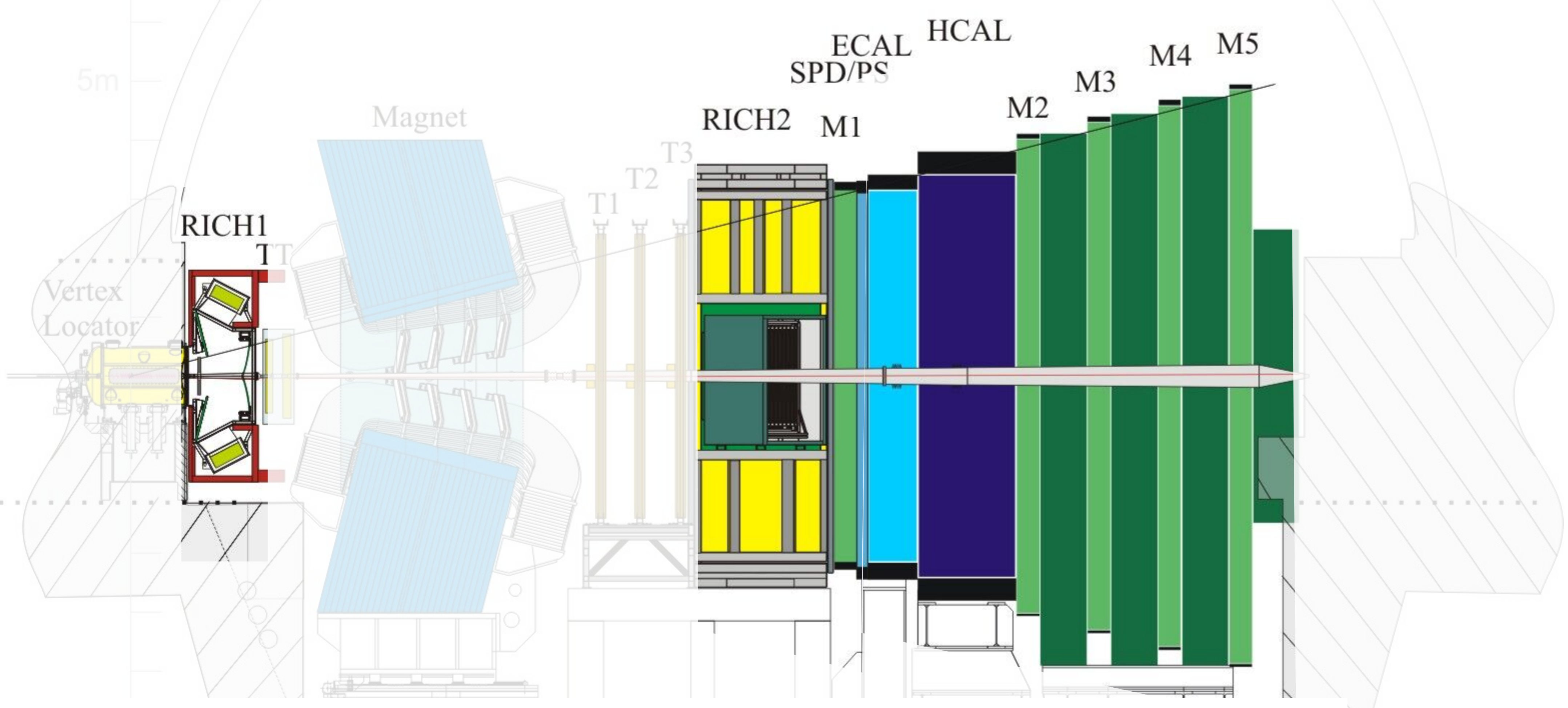


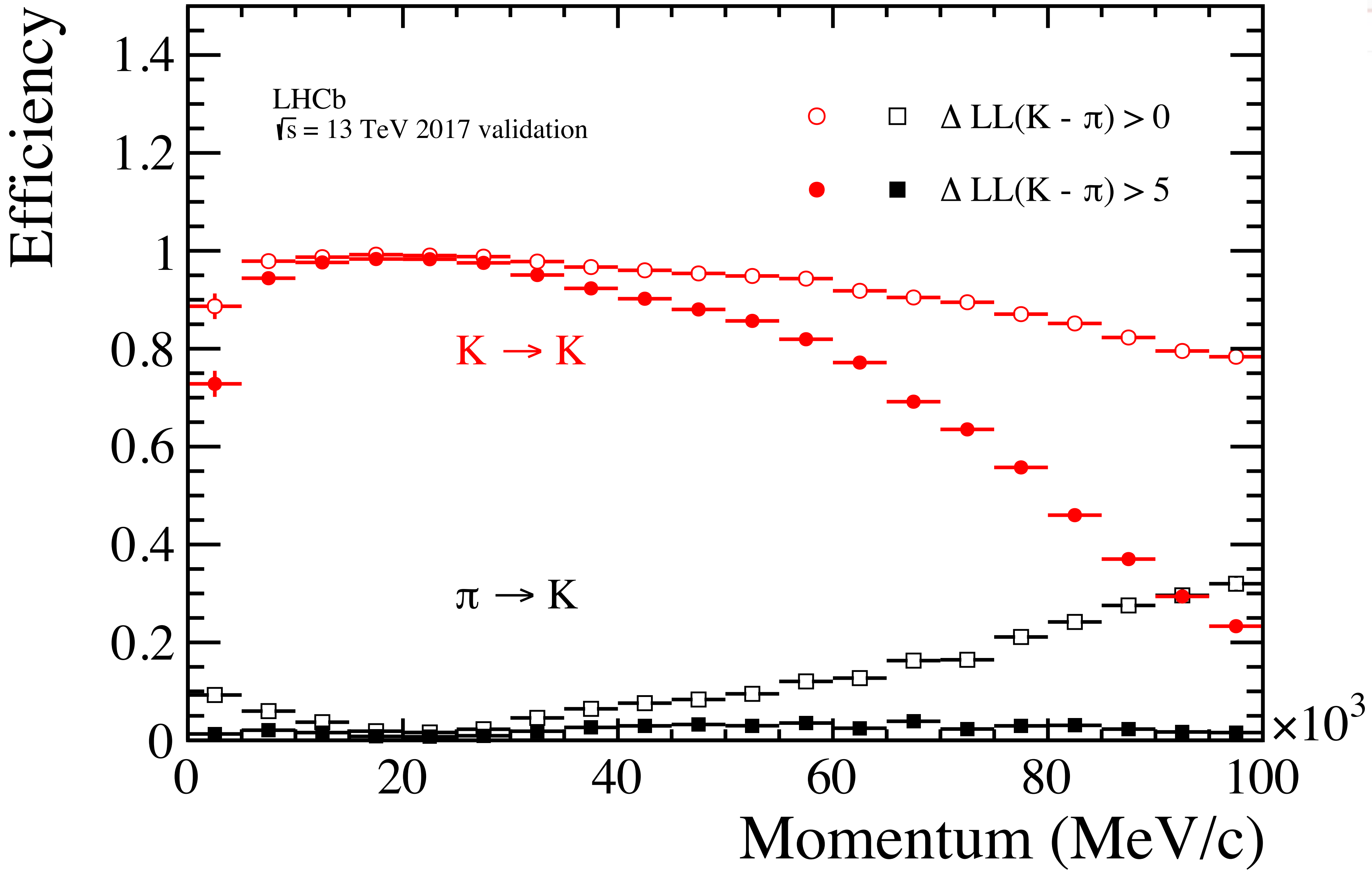
Working outward:

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

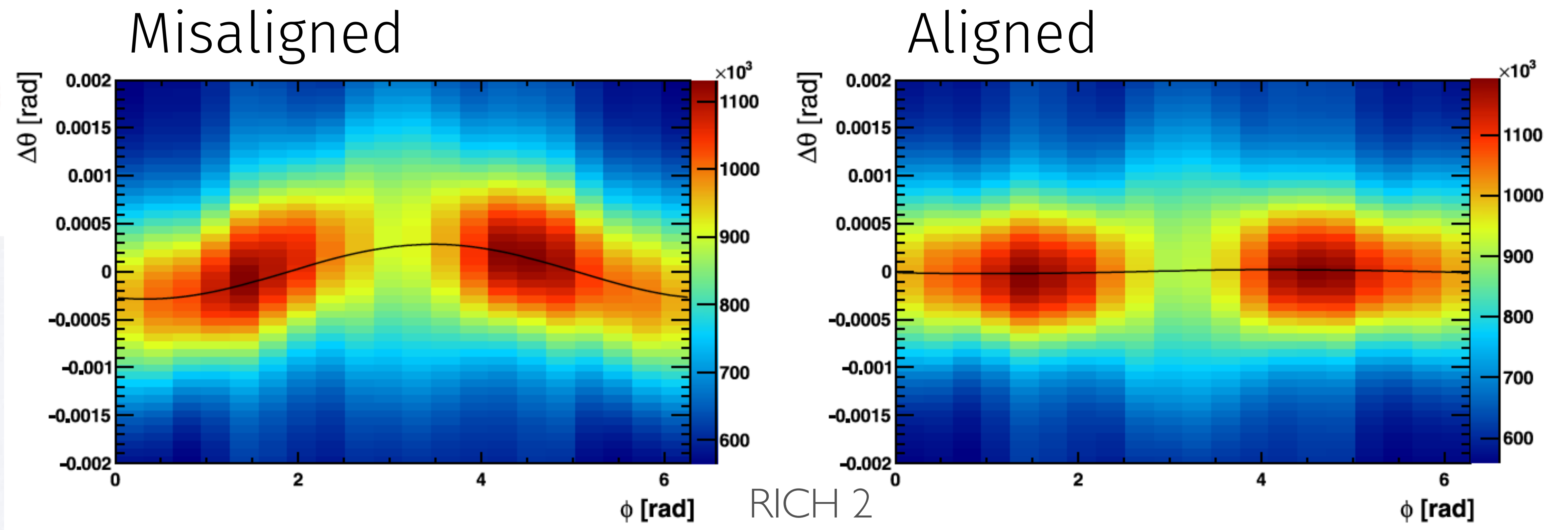
Tracking
Particle ID
Both

Particle identification and energy determination at LHCb

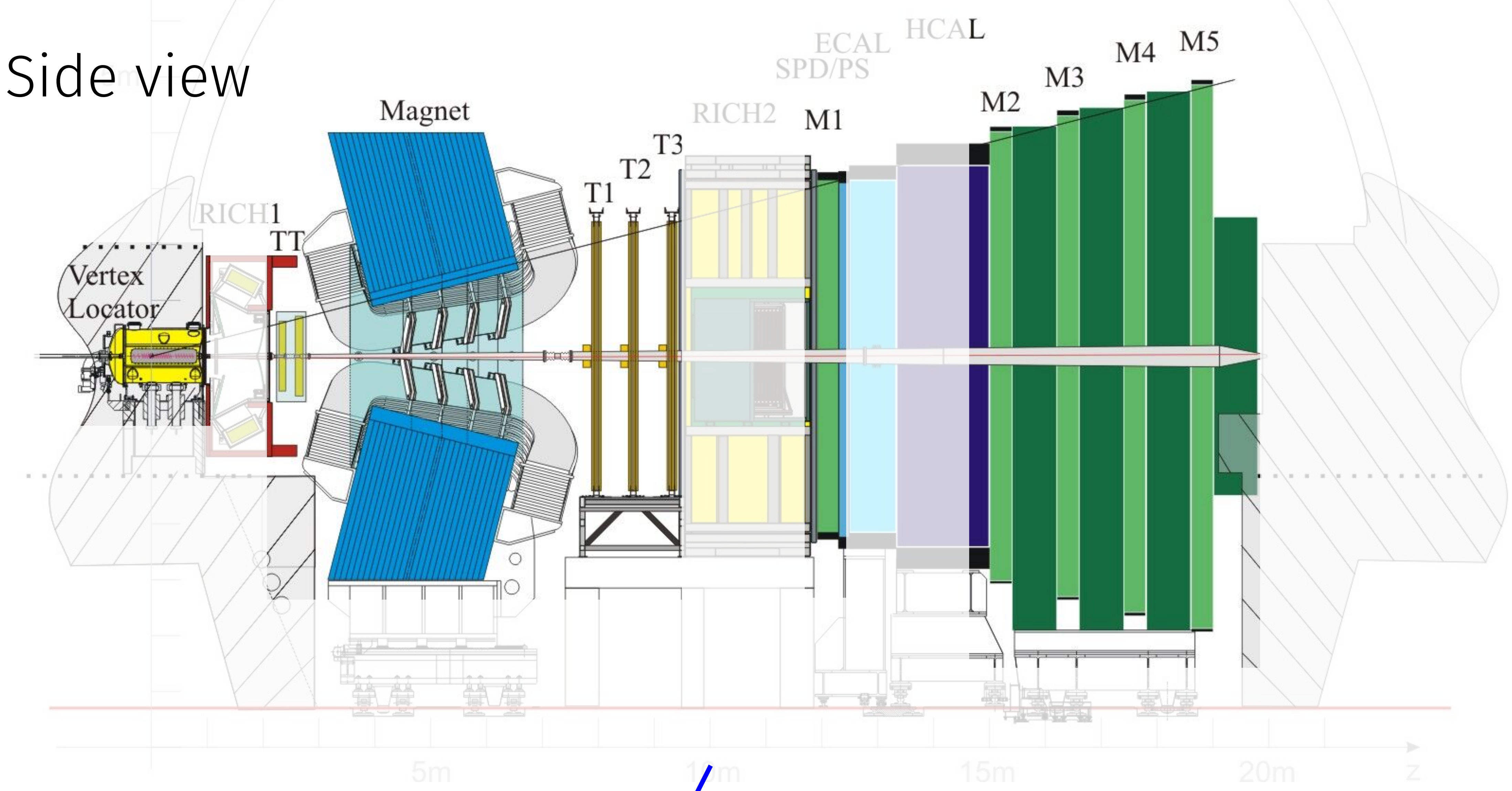


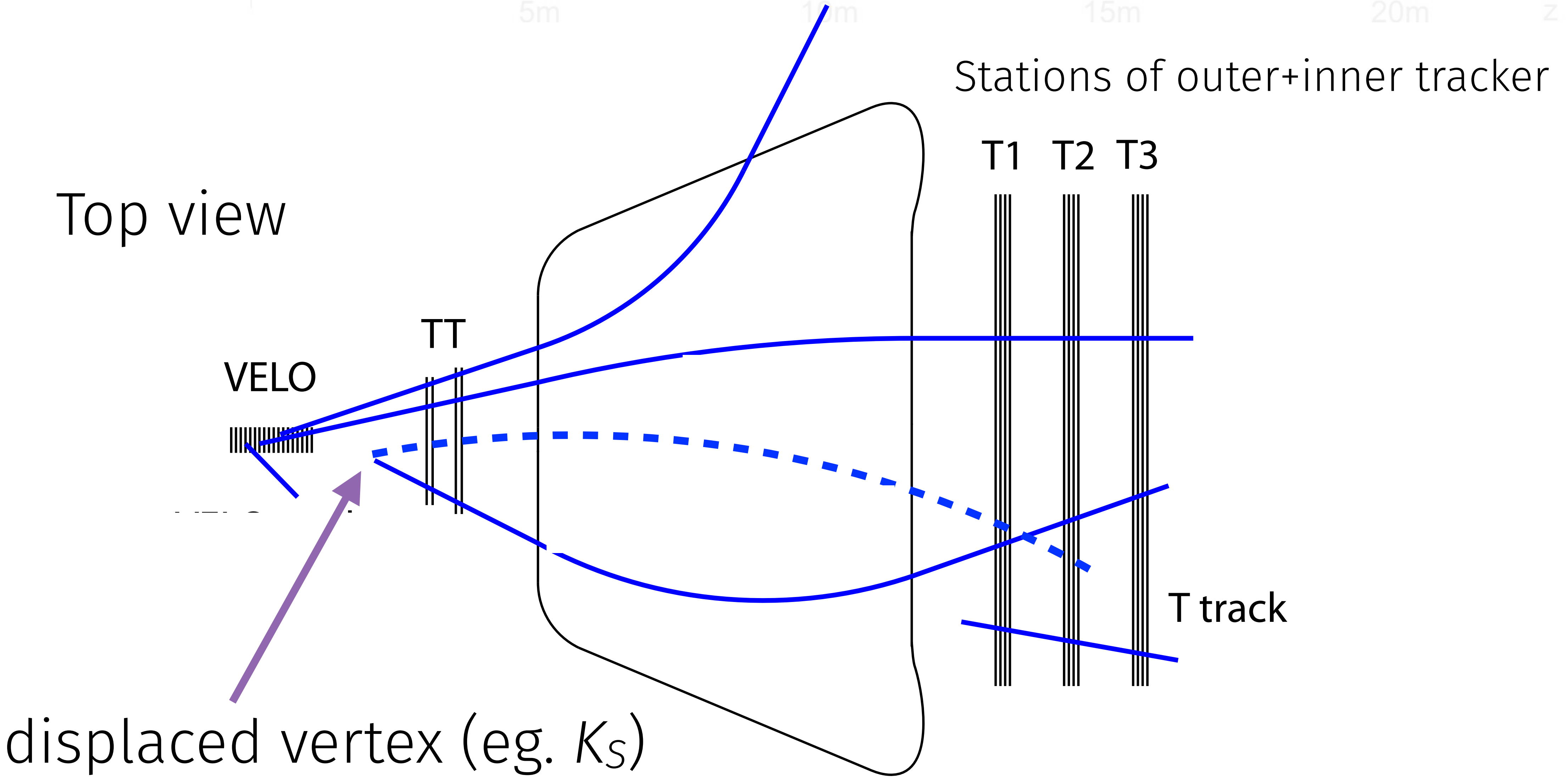


- ECAL resolution: 1 % + 10 %/ √(E[GeV])
- RICH detectors: Hadron ID at ~95% efficiency (misID $\pi \leftrightarrow K$ ~5%)
- Electron ID:
  - 97% electron ID efficiency
  - misID $e \leftrightarrow \pi$ ~5%
- Muon ID:
  - 97% muon ID efficiency
  - misID $e \leftrightarrow \pi$ ~1-3%

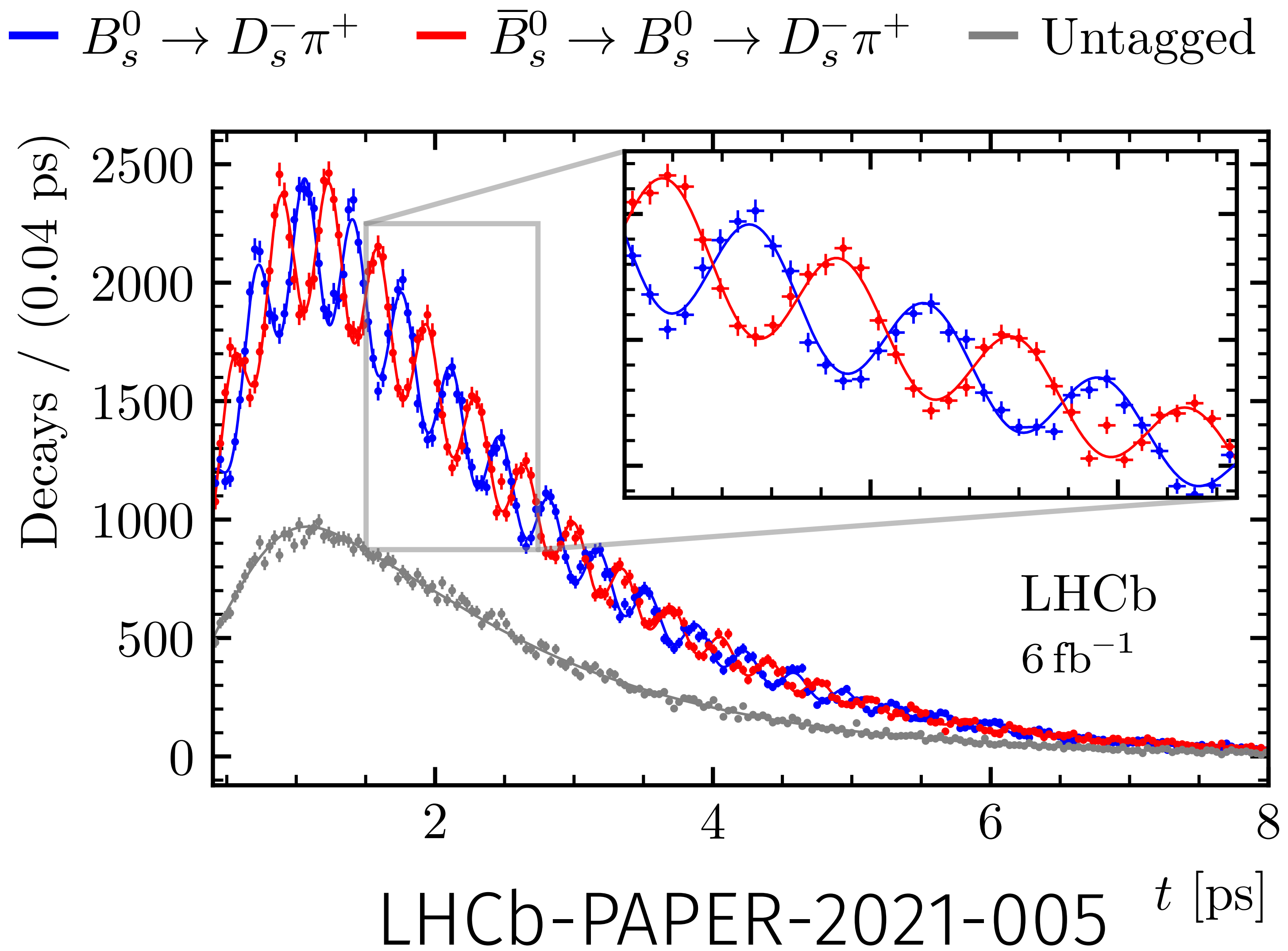


Tracking and vertexing at LHCb

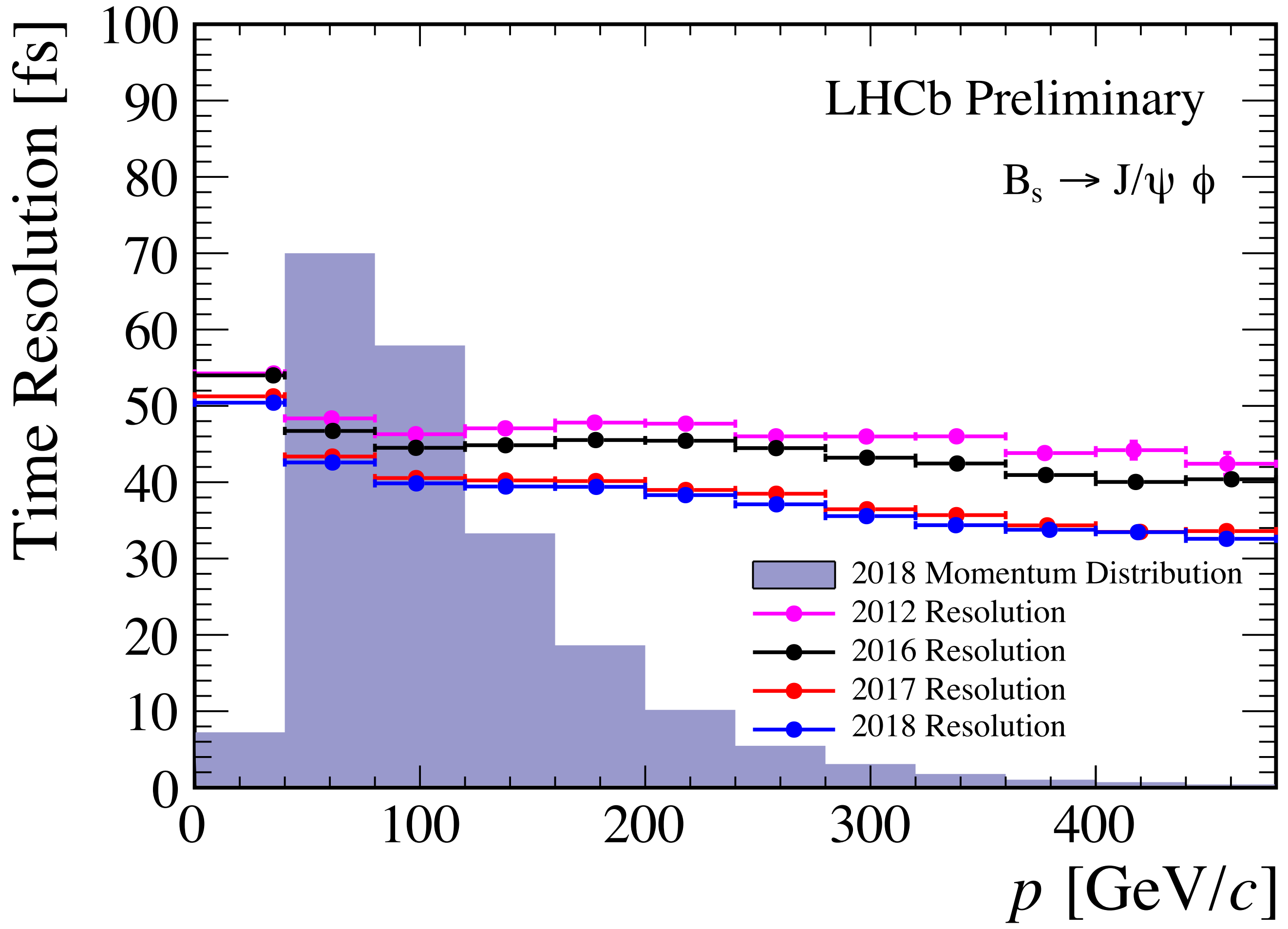




- Vertexing:
  - Best vertexing inside the VELO
    - But still reconstruct particles decaying downstream
  - (15 +29/p_T[GeV]) µm impact parameter resolution
  - 45 fs decay time resolution

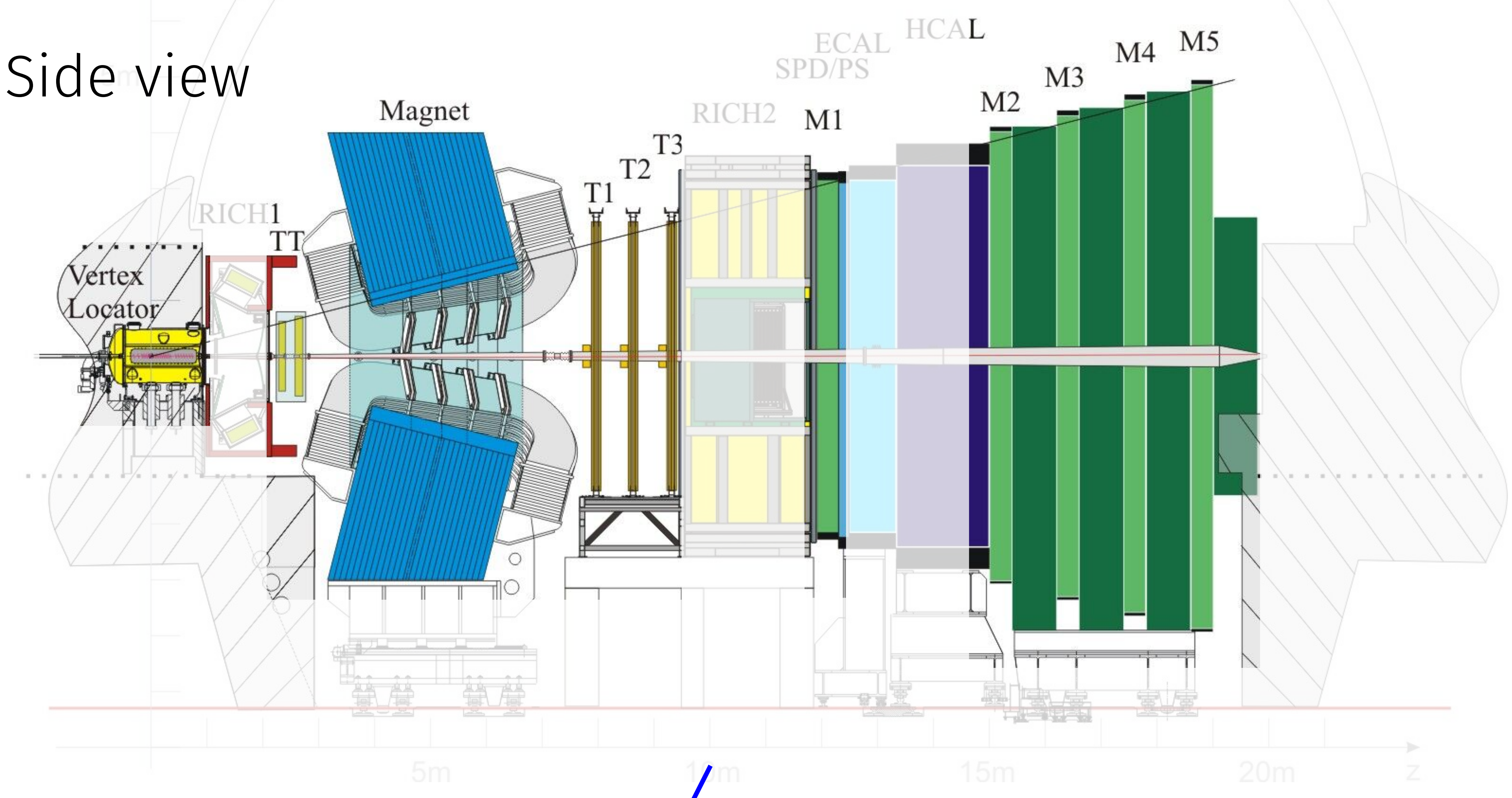


LHCb-PAPER-2021-005

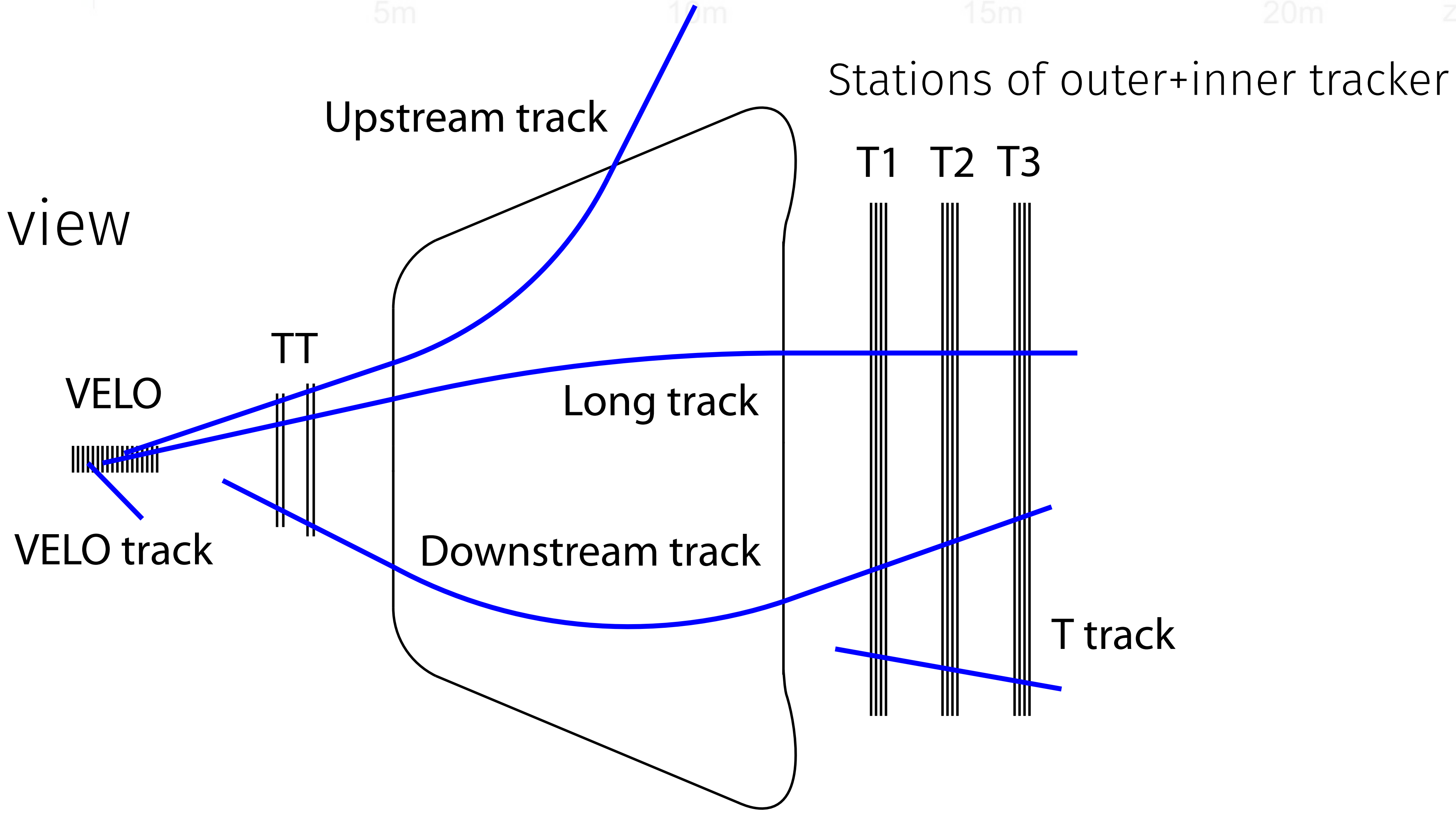


Tracking and vertexing at LHCb

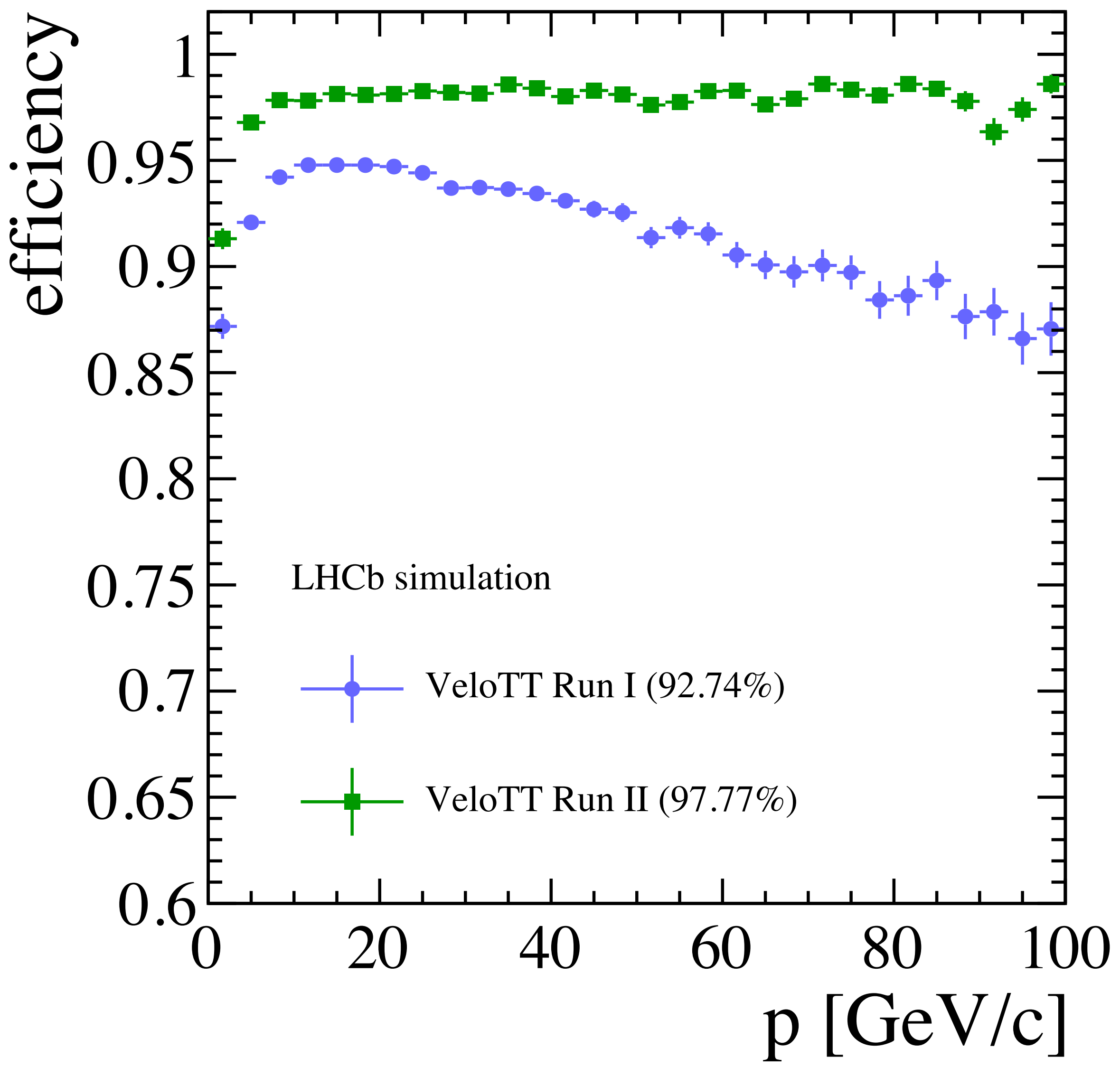
Side view



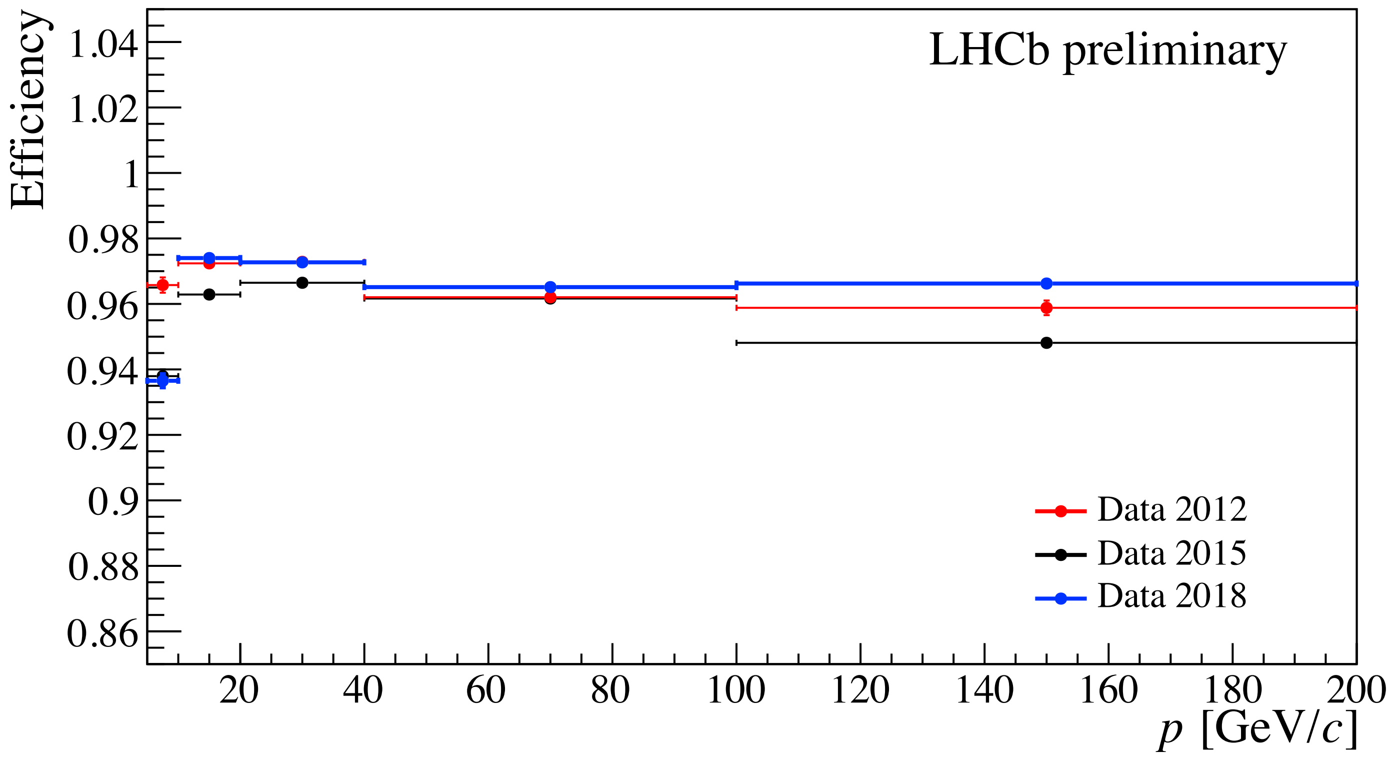
Top view



- Vertexing:
  - Best vertexing inside the VELO
    - But still reconstruct particles decaying downstream
  - $(15 + 29/p_T[\mathrm{GeV}])$ µm impact parameter resolution
  - 45 fs decay time resolution
- Tracking:
  - 96% track reconstruction efficiency
  - Momentum resolution:
    - $\Delta p/p = 0.4 - 0.6\,\%$ (5-100 GeV)
    - $\Delta p/p = 1\,\%$ (200 GeV)



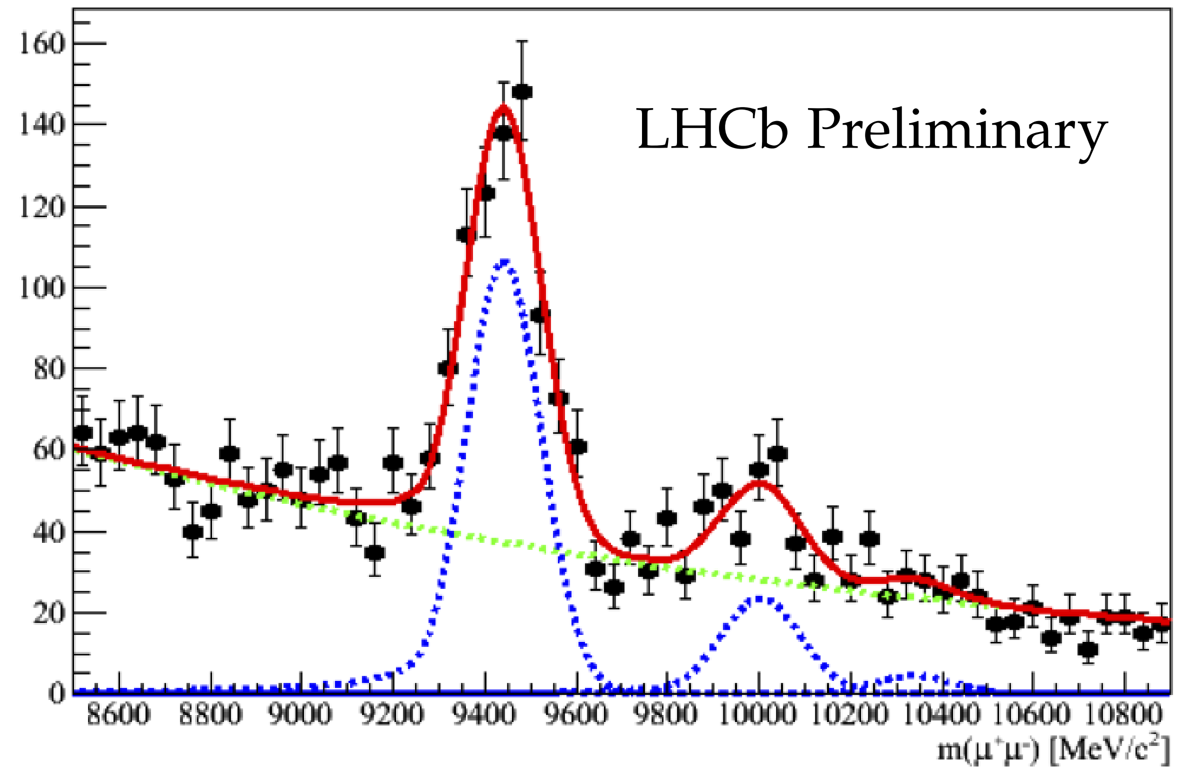
Muon tracking efficiency



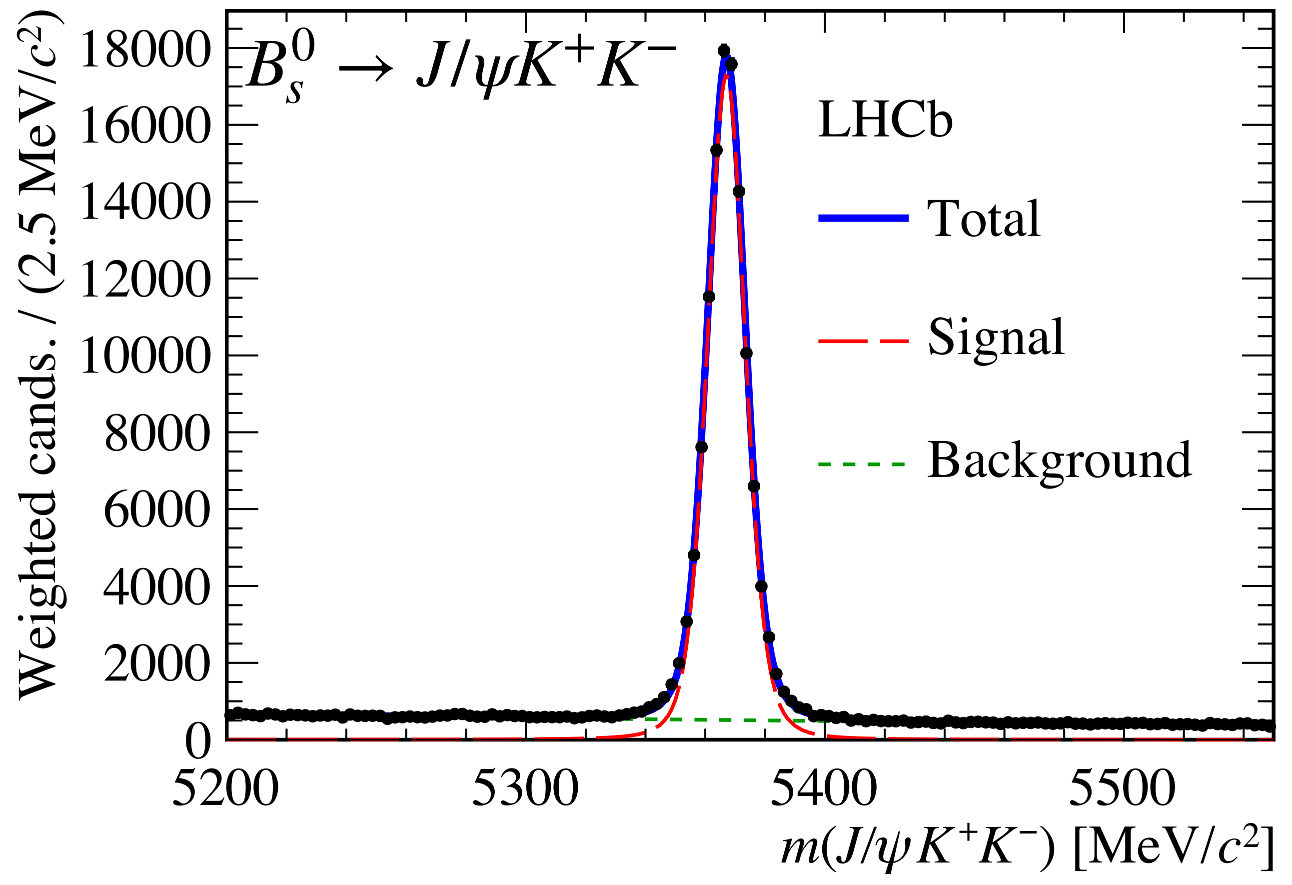
Mass resolution and trigger

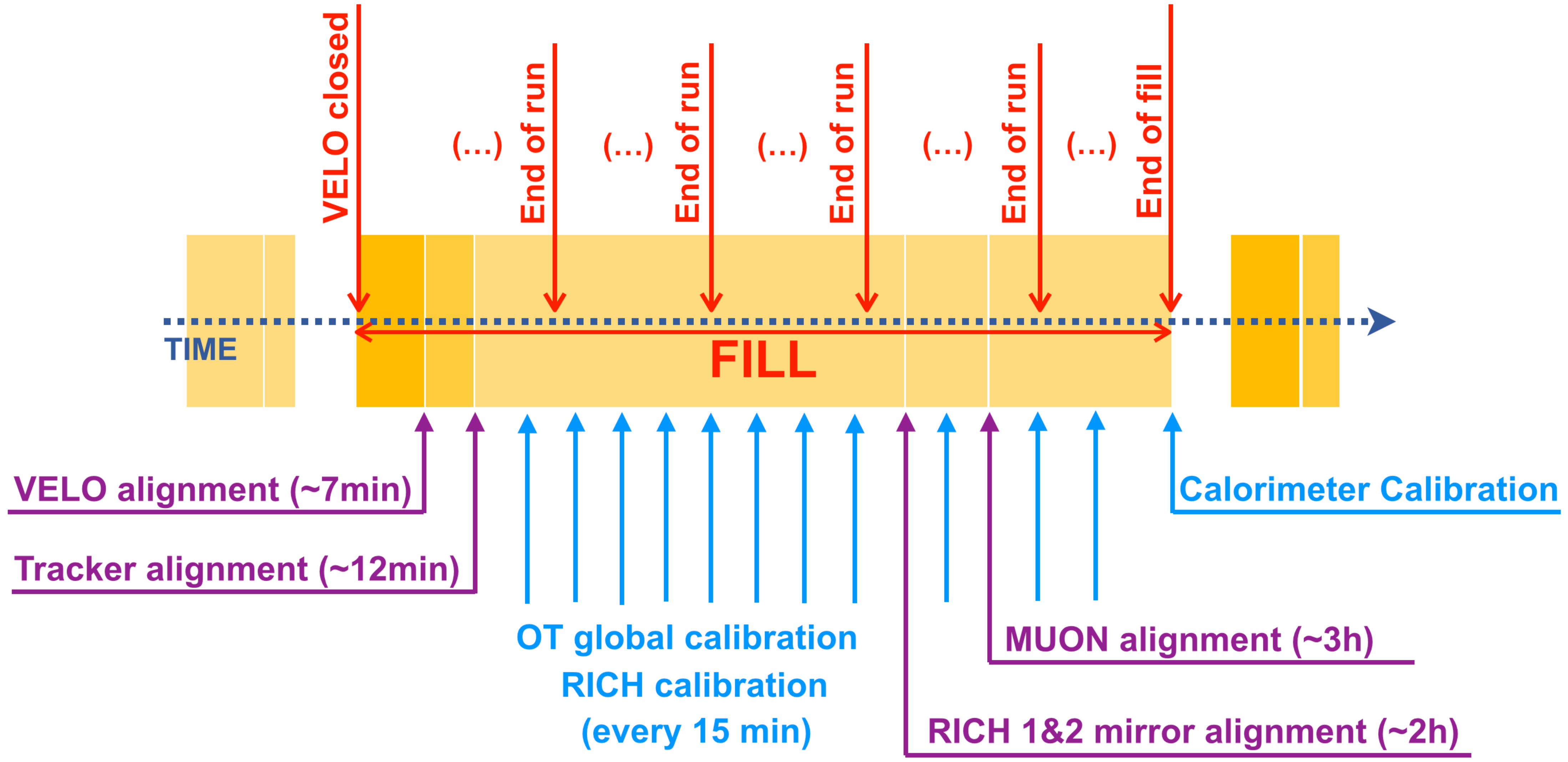
- Between Run 1 and Run 2, switched to buffer events before final reconstruction to allow real time alignment + calibration
- Mass resolution at LHCb:
  - ~8 MeV/c2 for B → J/ψ X decays with constraint on J/ψ mass
  - ~22 MeV/c2 for two-body B decays
  - ~100 MeV/c2 for Bs → φ γ, dominated by photon contribution

ϒ before alignment



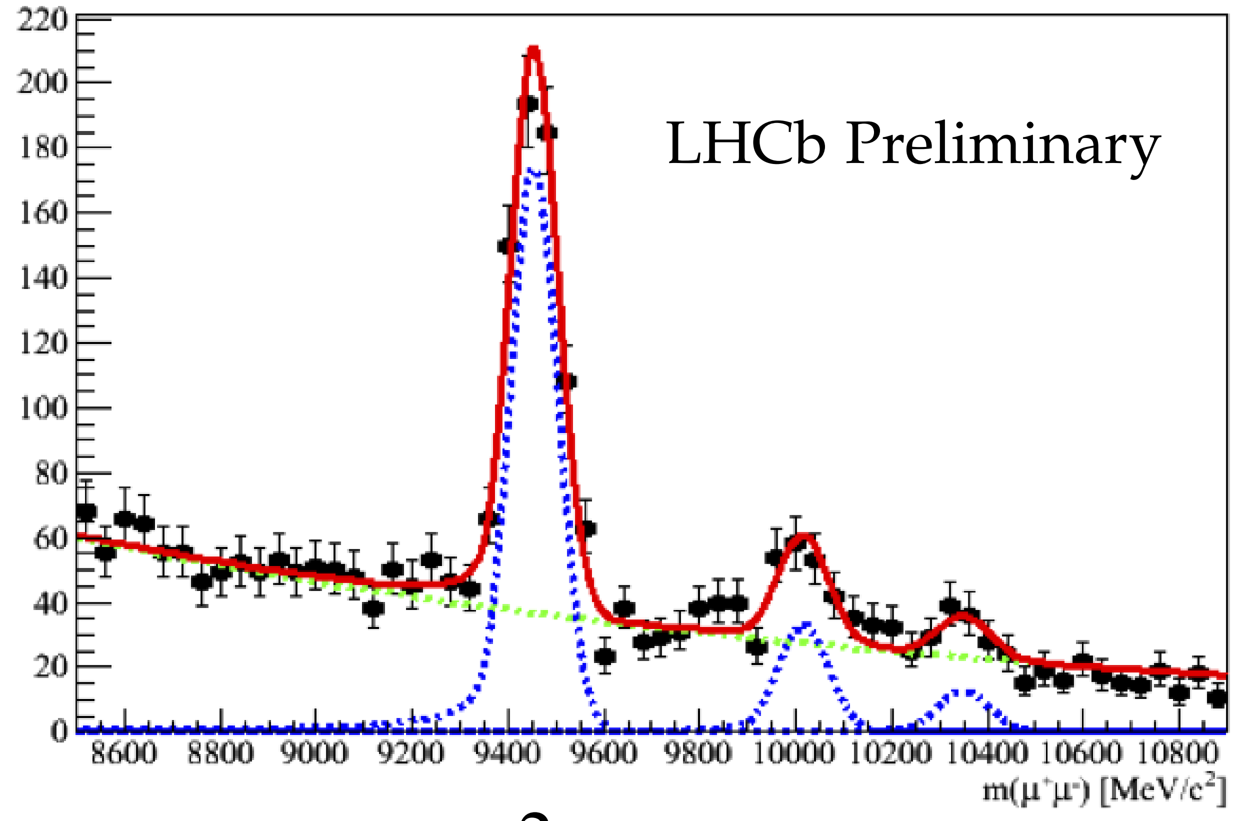
92 MeV/c^2 resolution





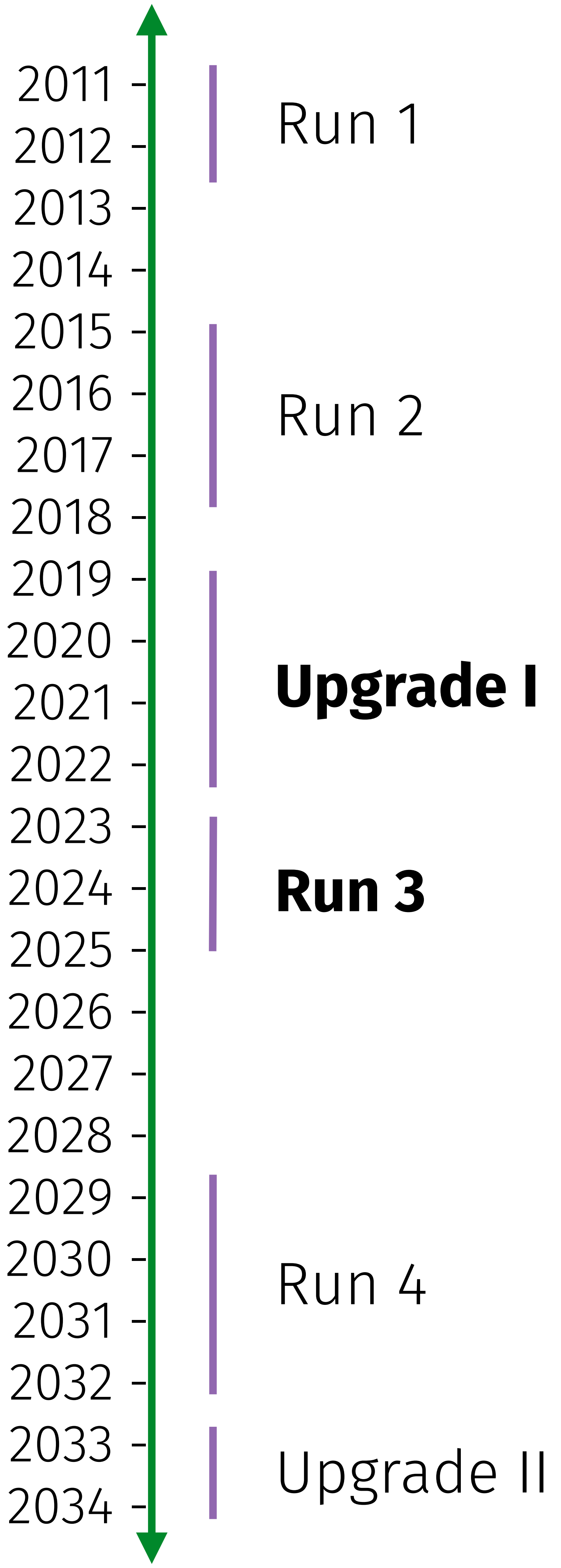
((~7min),(~12min),(~3h),(~2h)) - time needed for both data accumulation and running the task

ϒ after alignment

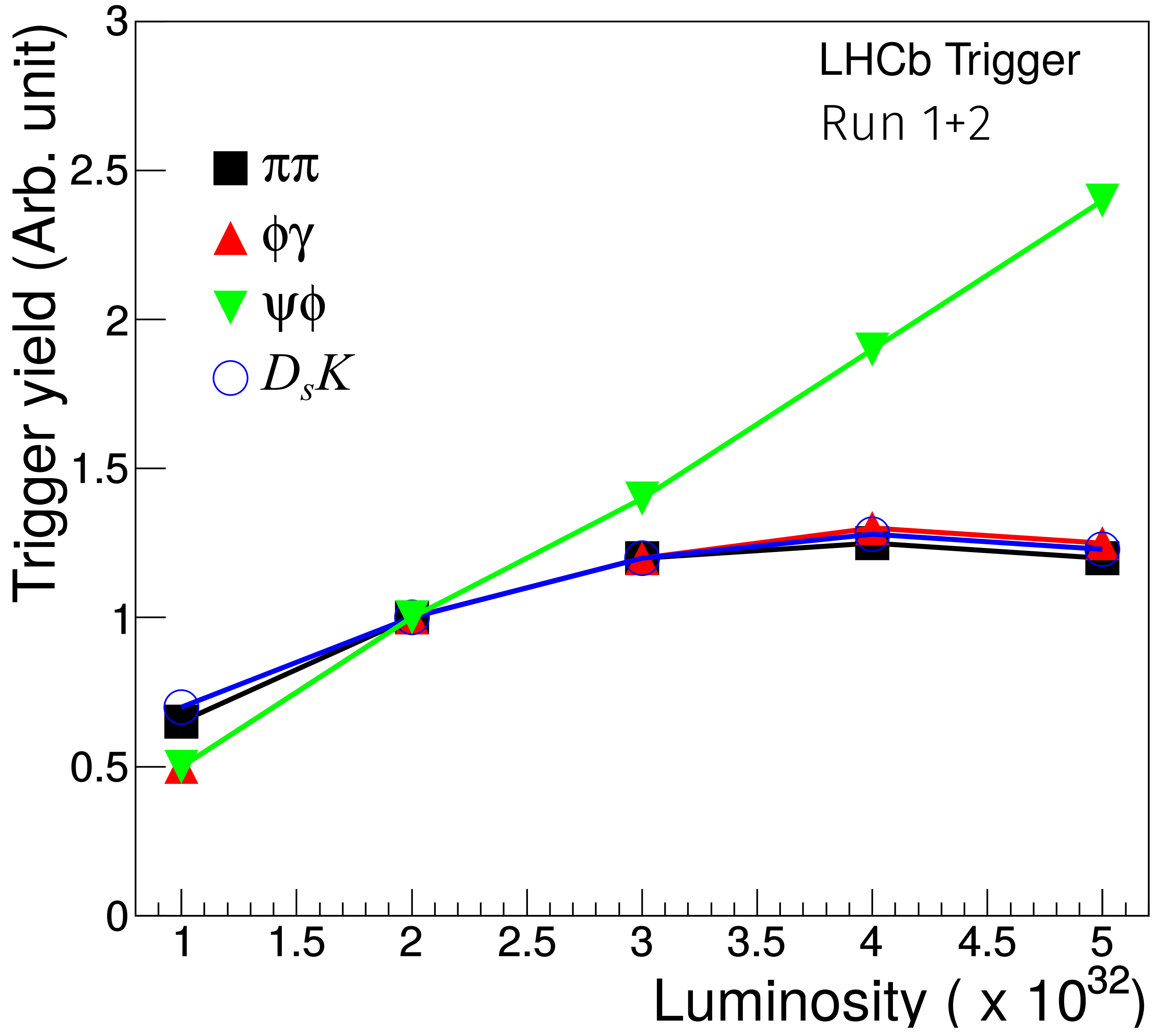


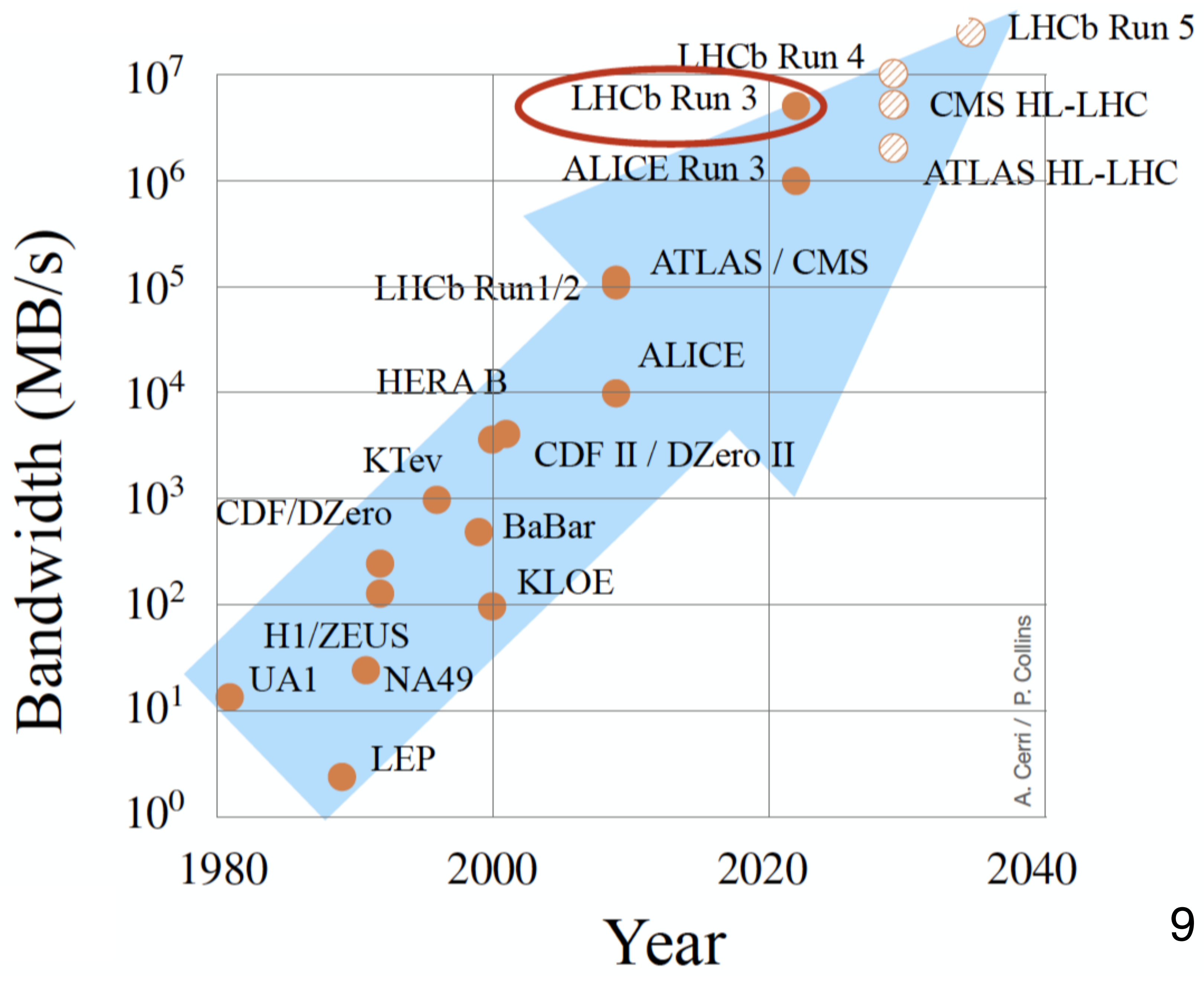
49 MeV/c^2 resolution

Run 3 and LHCb Upgrade I



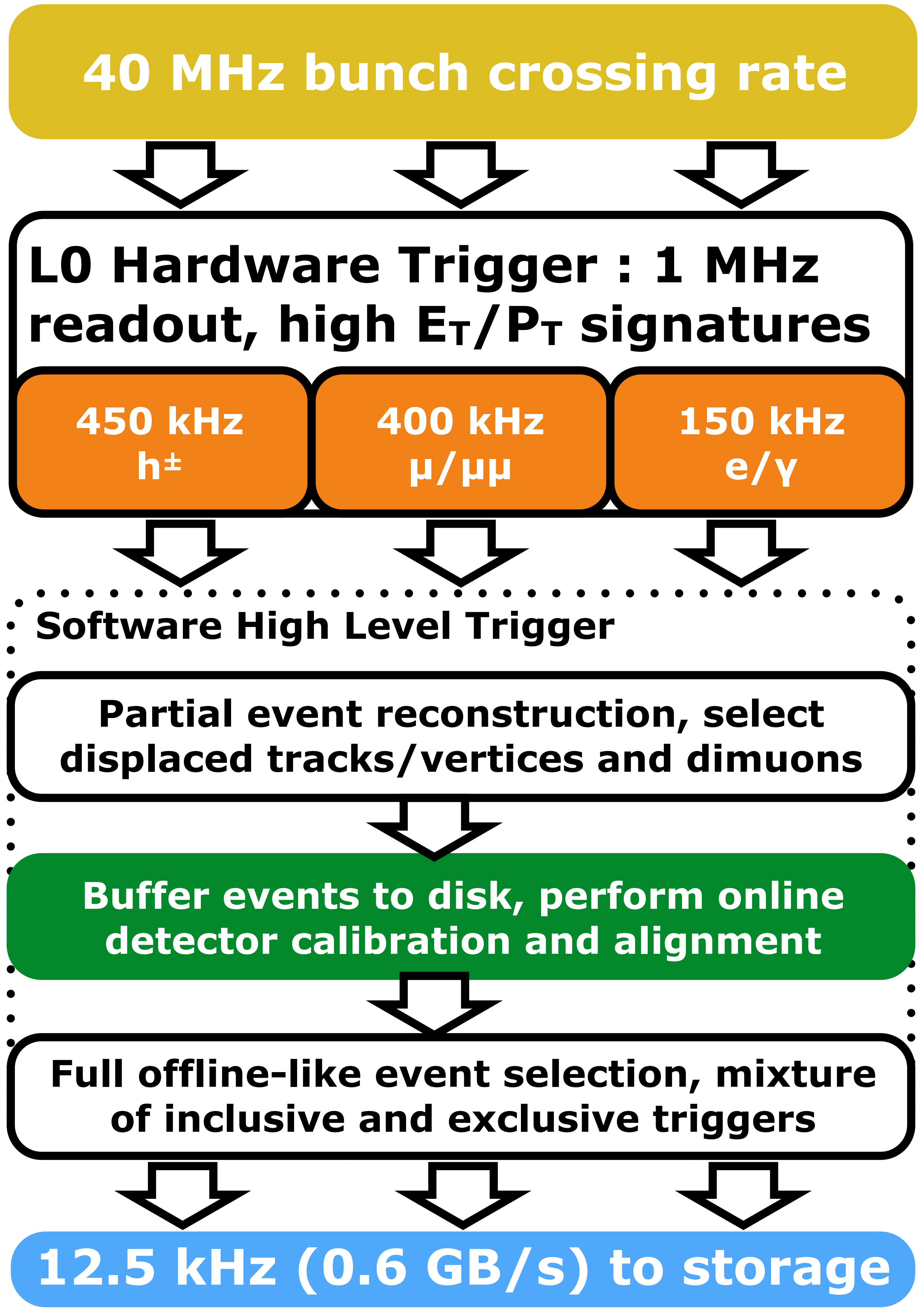
- Many current LHCb measurements are statistically limited
- Plan a new target luminosity for Run 3:
  - $L_{peak} = 20 \times 10^{32}\ \mathrm{cm}^{-2}\mathrm{s}^{-2}$
  - This is 5x larger than before
  - Expected pile-up: ~5
  - 50 fb^{-1} integrated luminosity Run 3+4
- We need a new trigger strategy to deal with this situation!
  - Run 1+2 hadronic trigger with hardware first stage is saturated
- We need new hardware and electronics too!



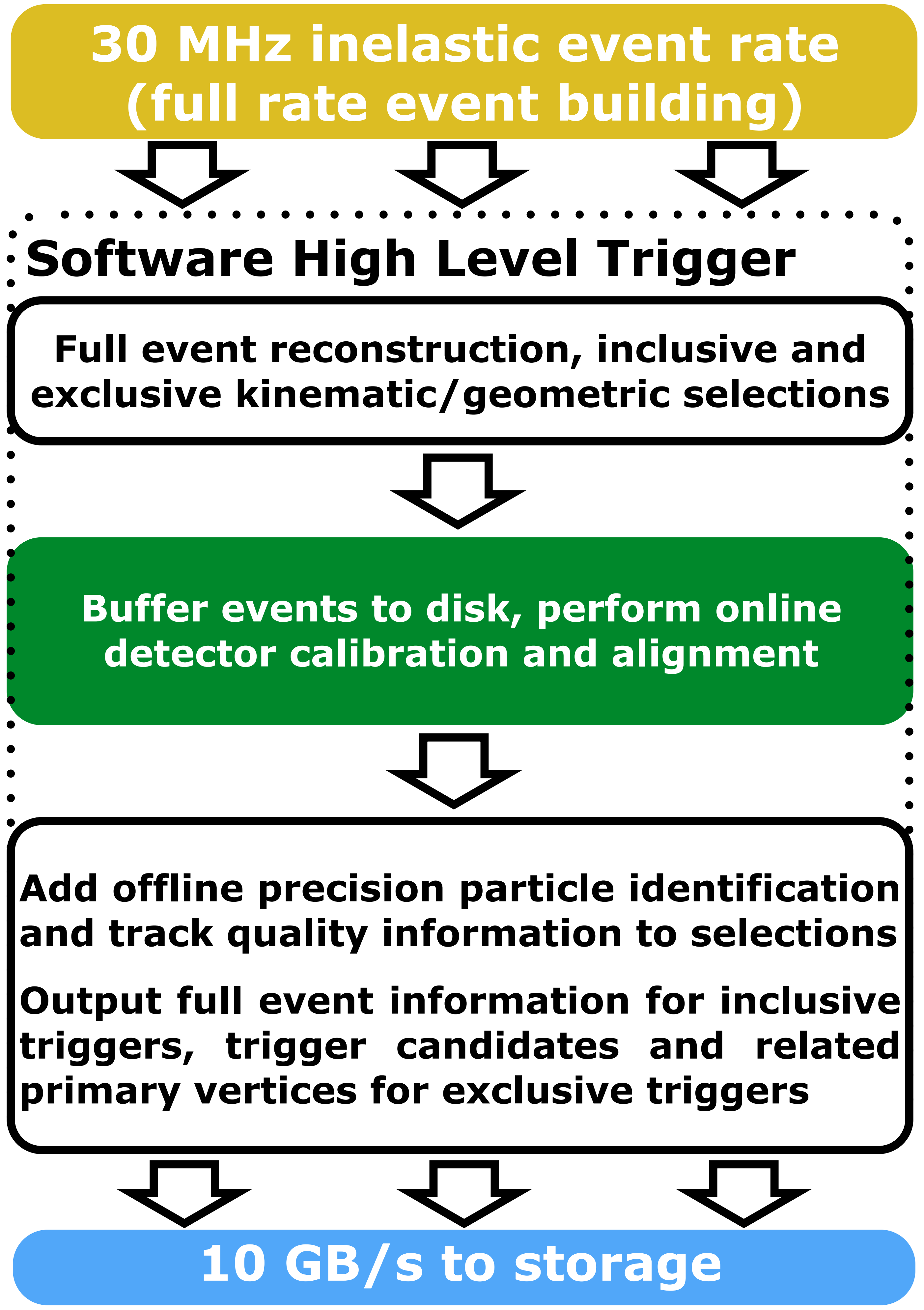


Upgrading the LHCb trigger and software

LHCb Run 2 Trigger Diagram

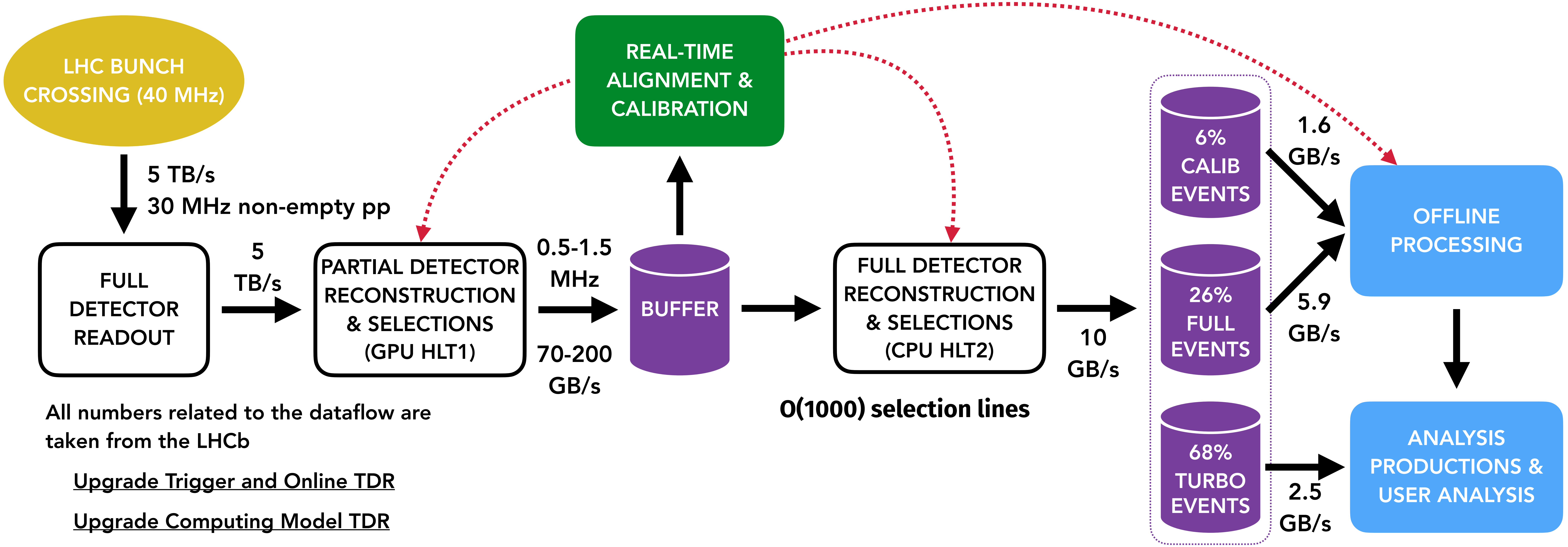


LHCb Upgrade Trigger Diagram



Upgrading the LHCb trigger and software

- First GPU trigger in a HEP experiment!

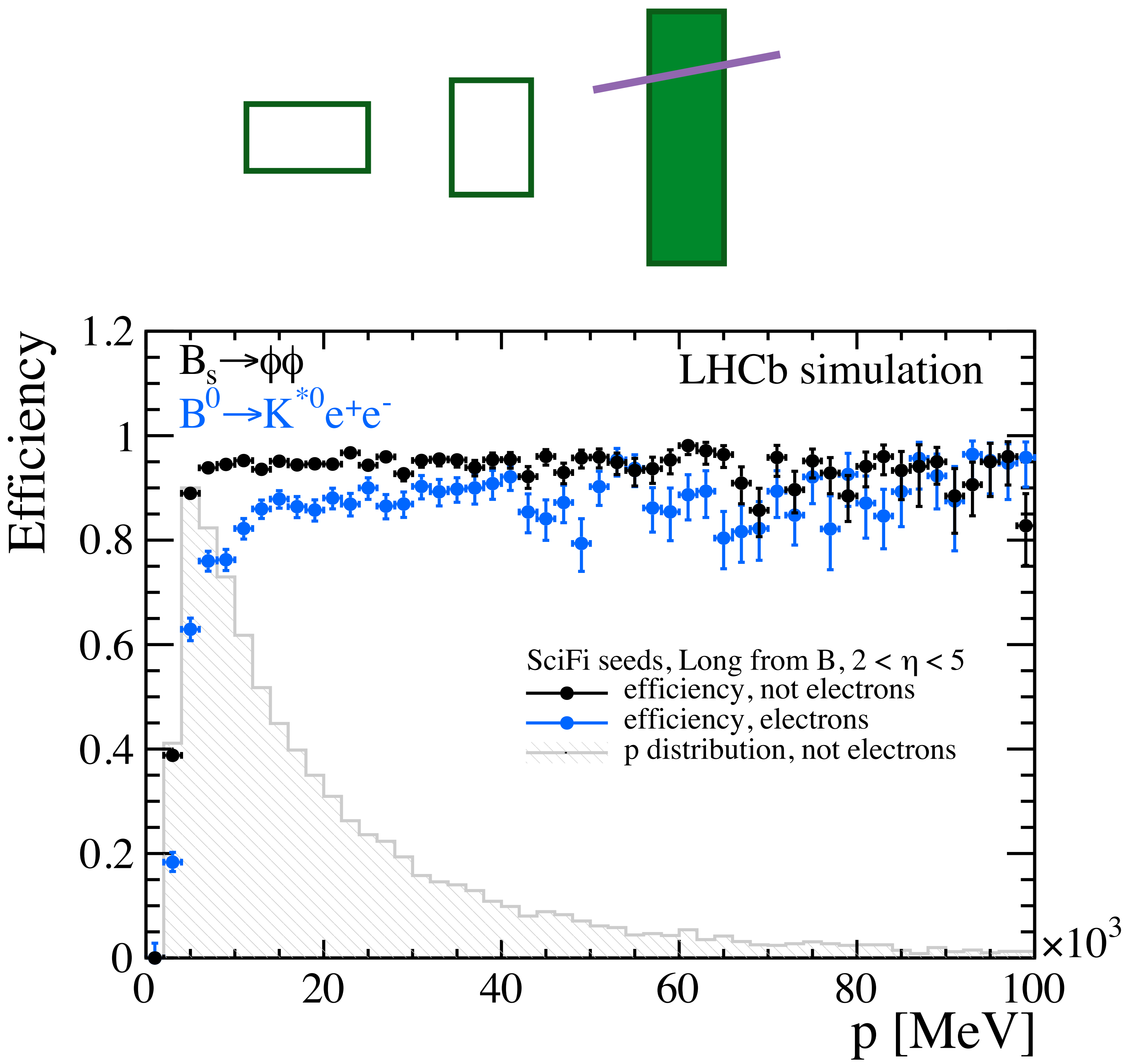


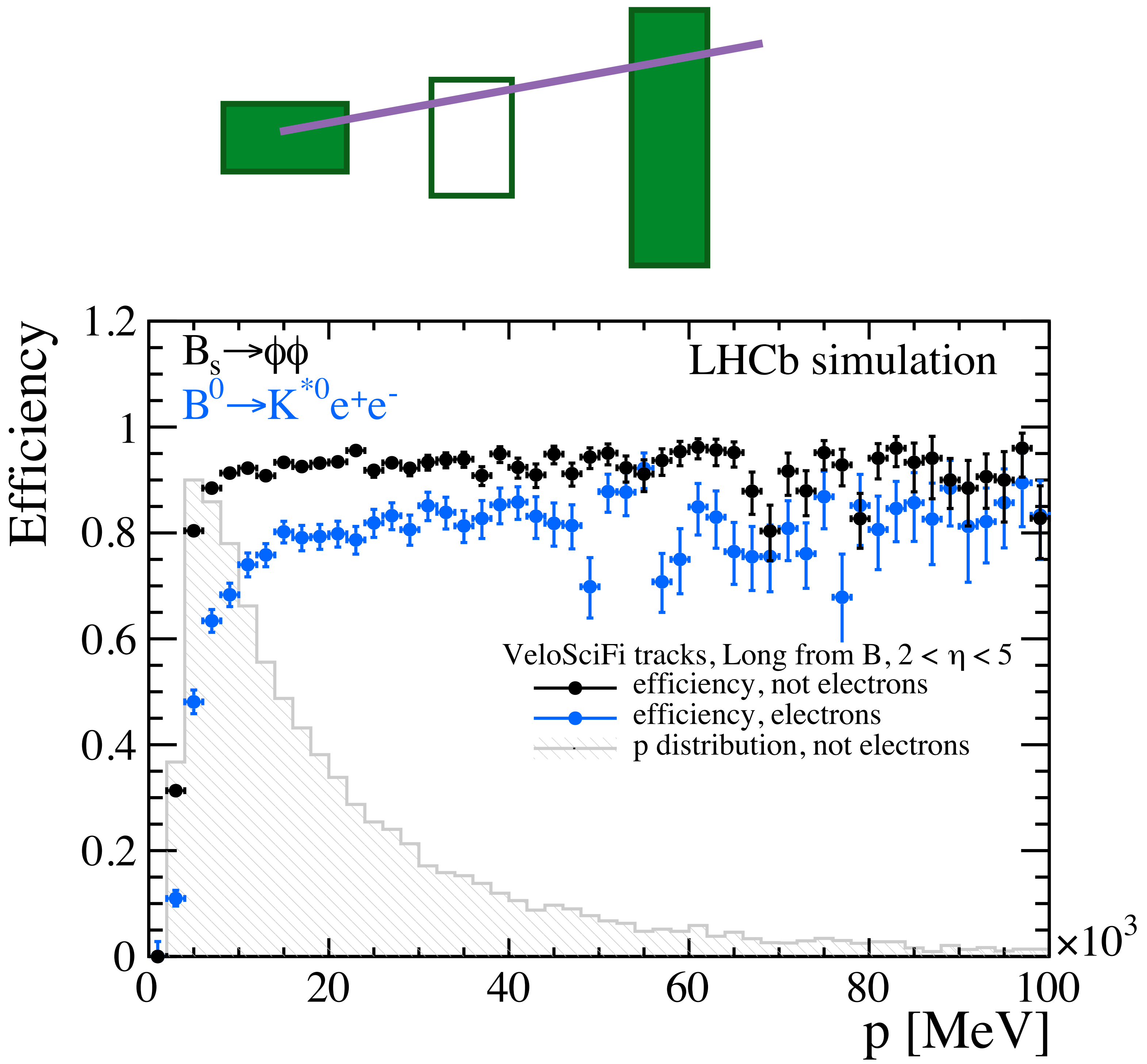
All numbers related to the dataflow are taken from the LHCb

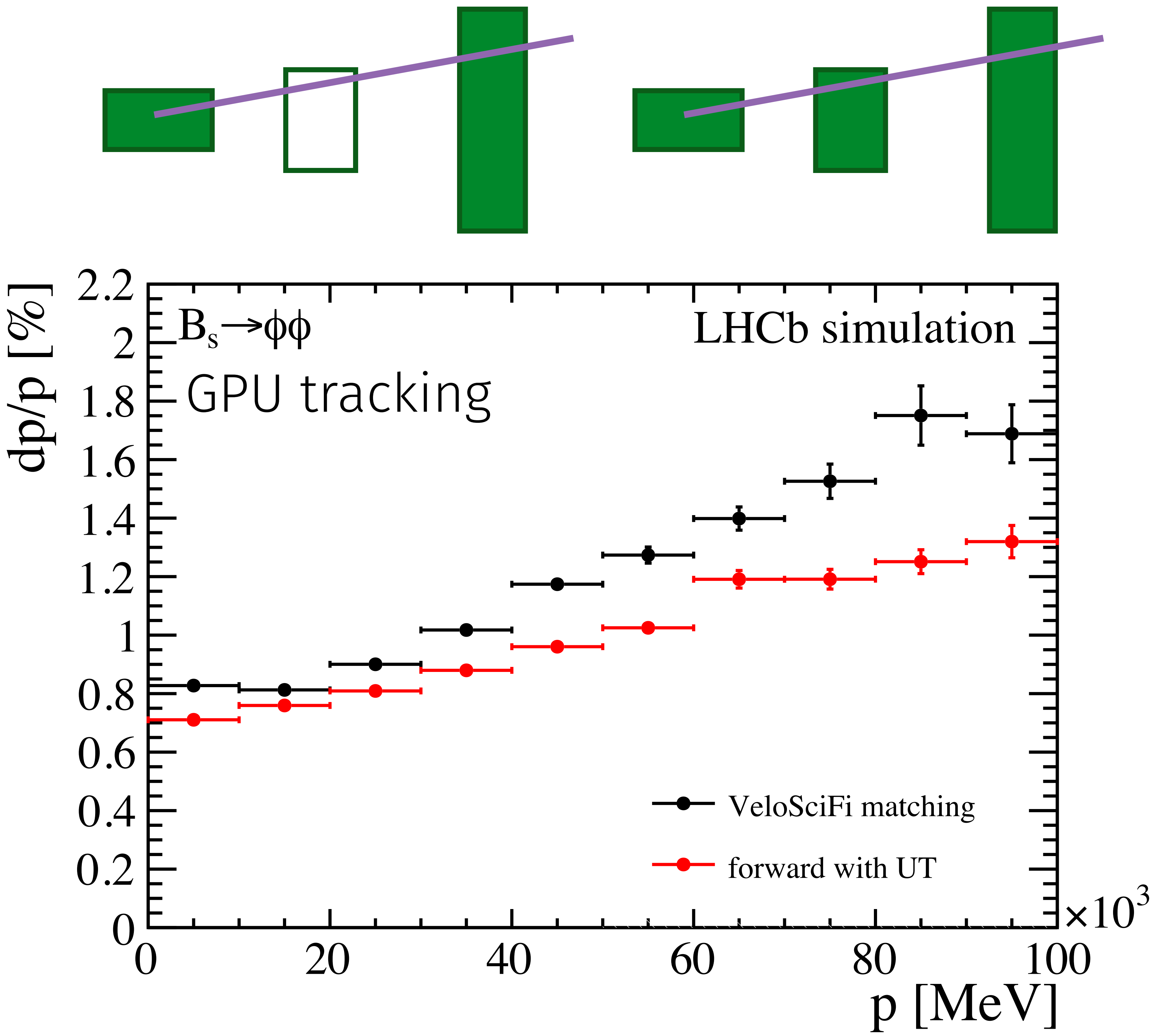
Upgrade Trigger and Online TDR

Upgrade Computing Model TDR

GPU tracking performance







- Tracking efficiency through different LHCb tracking stations
  - Excellent track reconstruction efficiency (> 99% for VELO, 95% for high-p forward tracks)
- At right: momentum resolution for pure GPU tracking

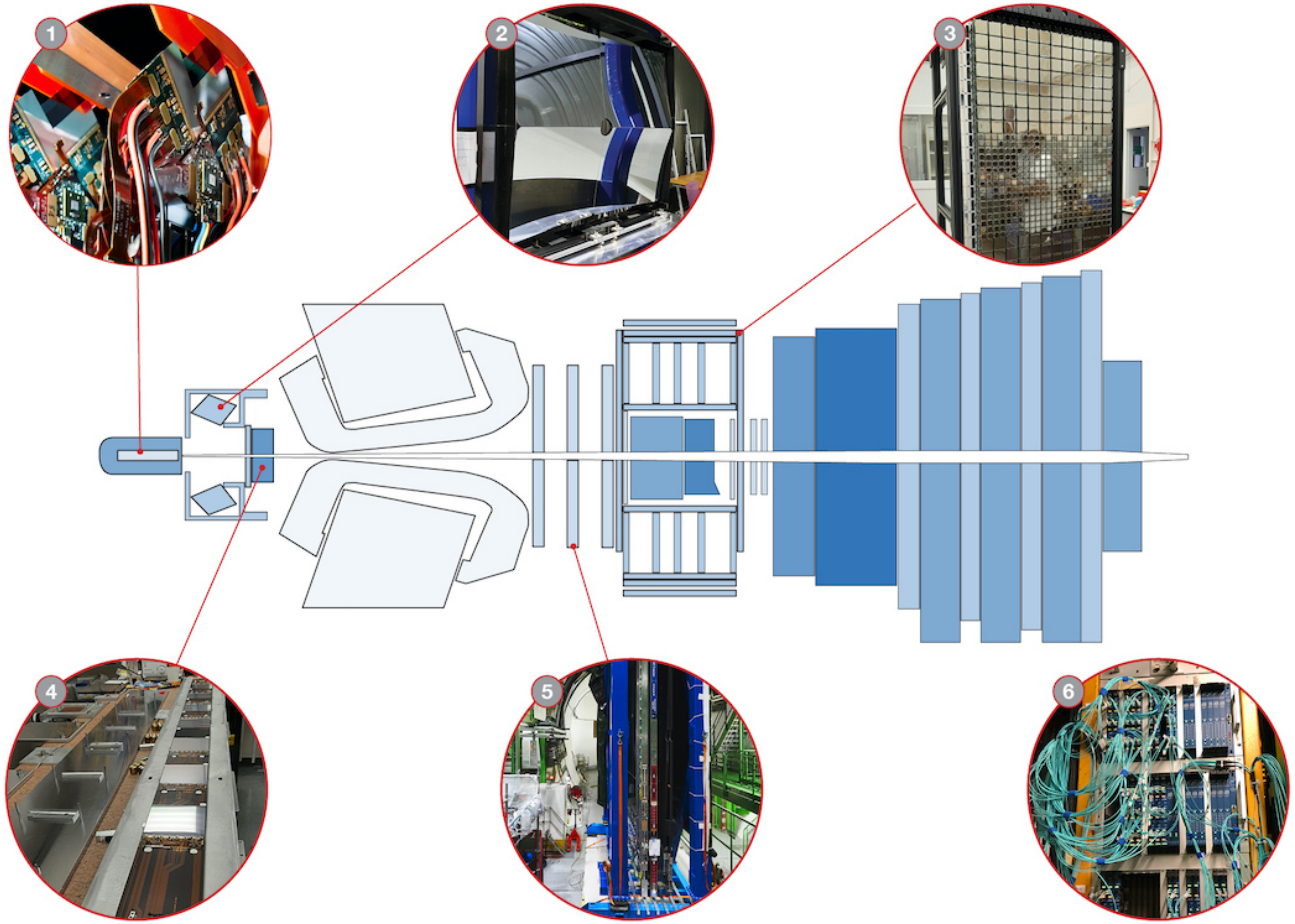
Upgrading the LHCb hardware

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.

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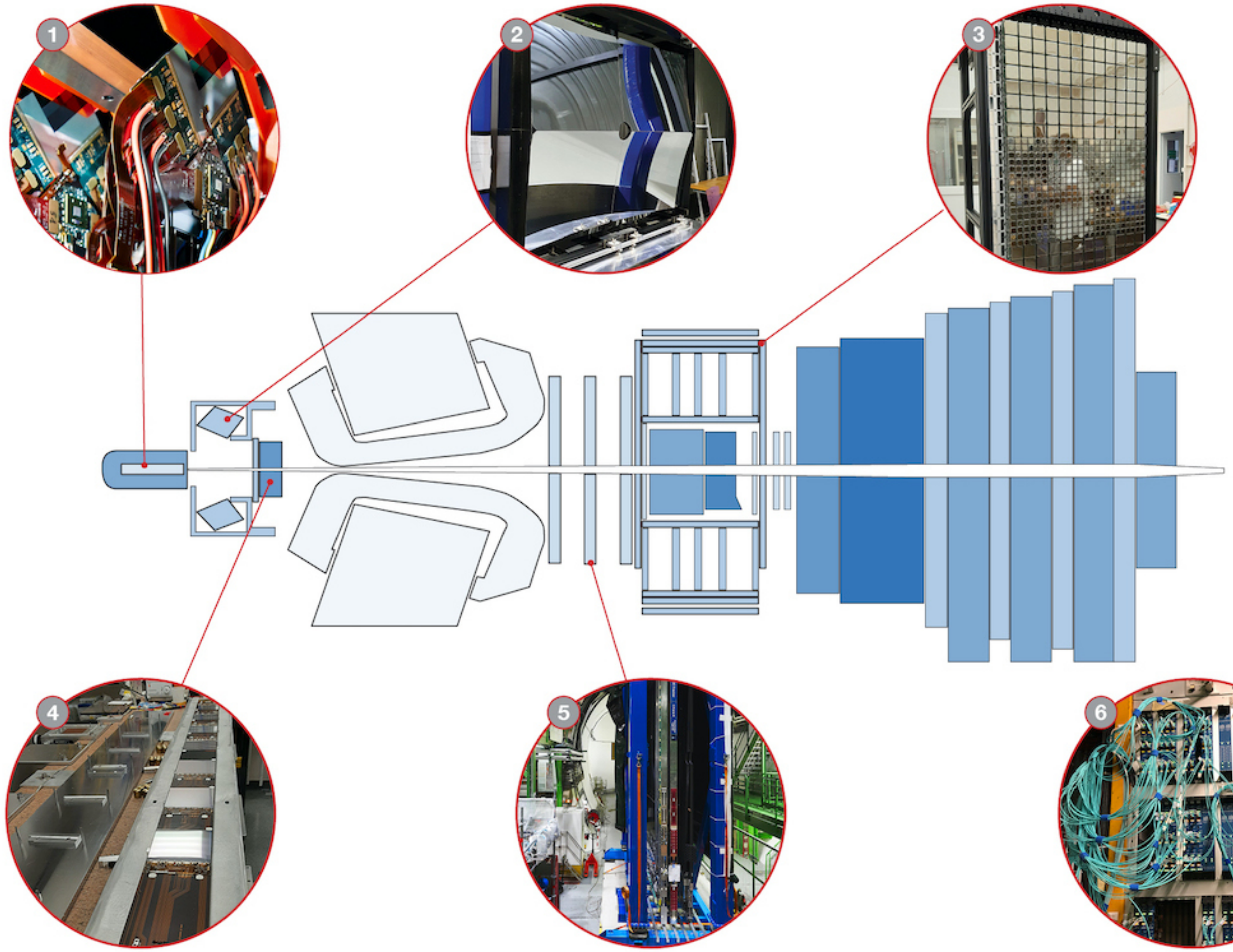

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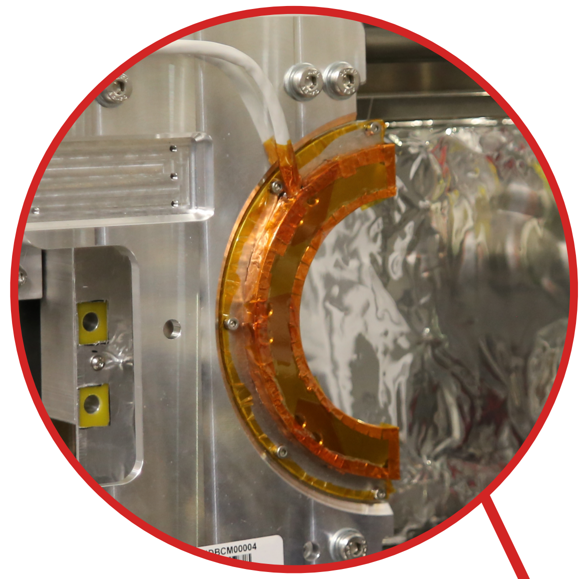
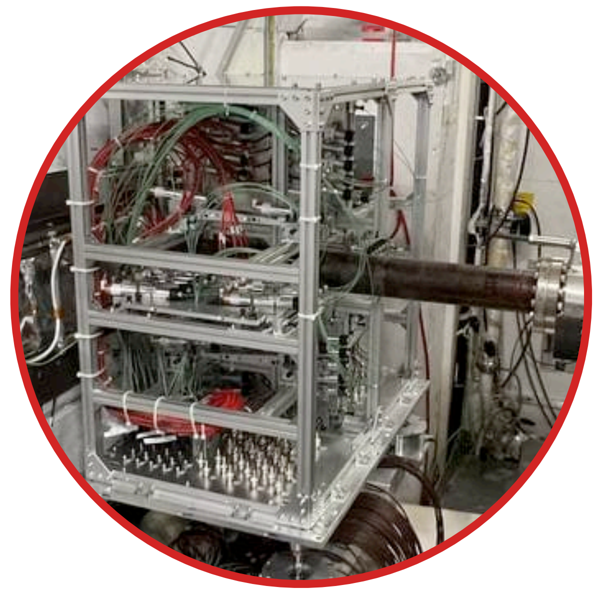
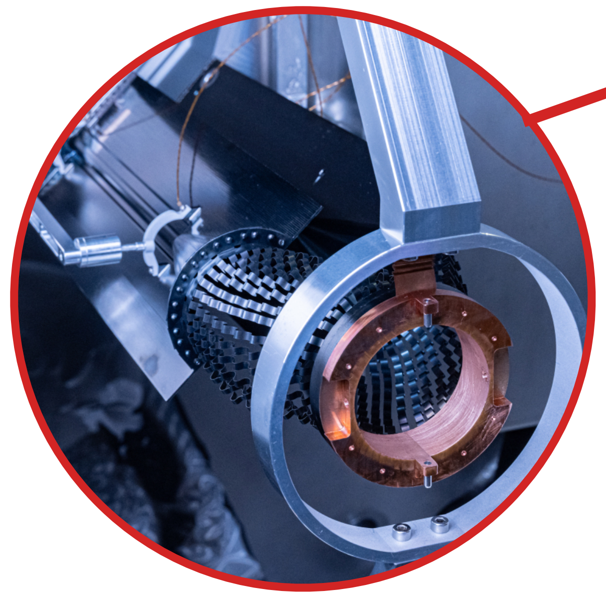
RADIATION SAFETY AT LHCb
Replaced Beam Conditions Monitors from Run1+2 and added new Radiation Monitoring System



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

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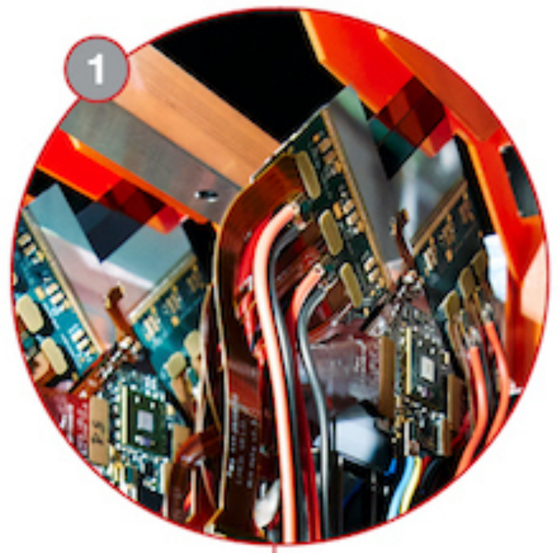

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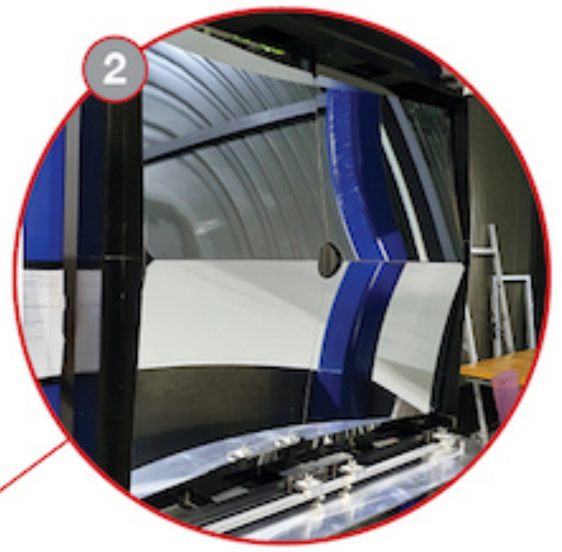

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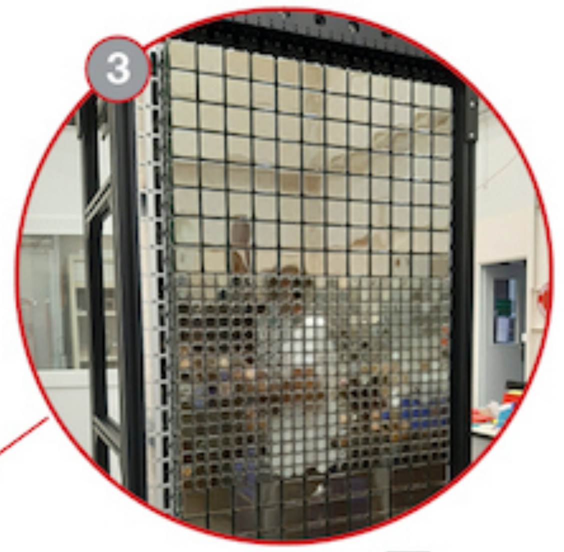

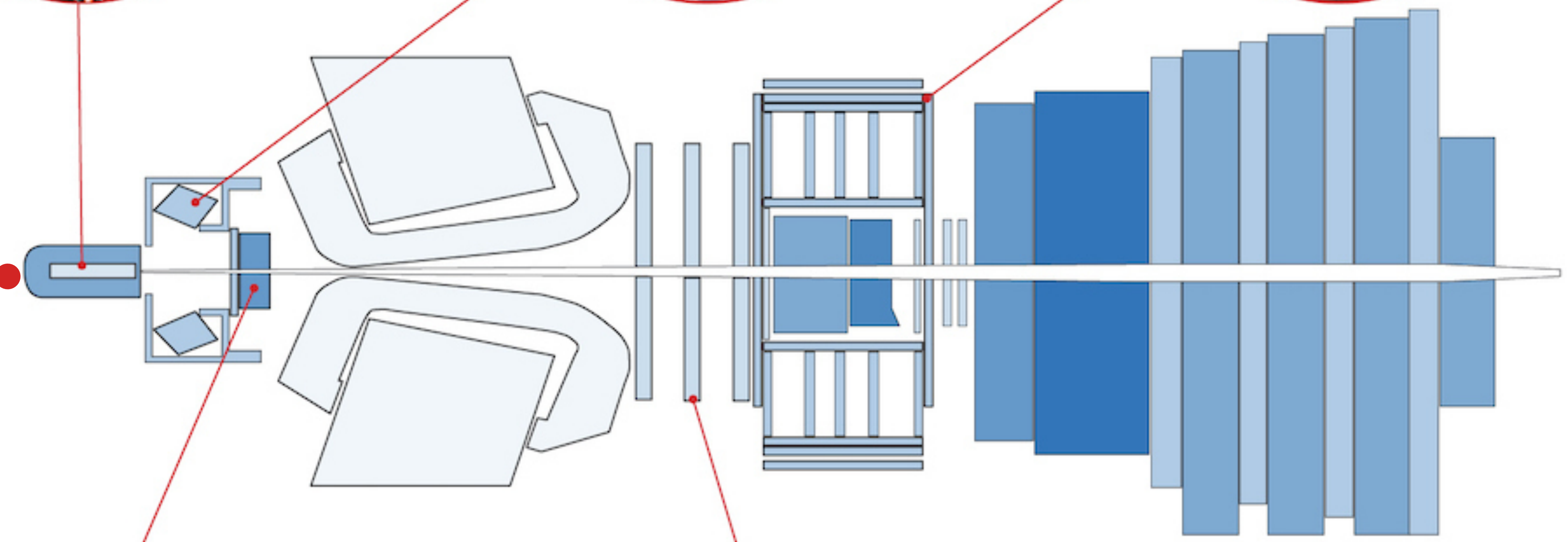

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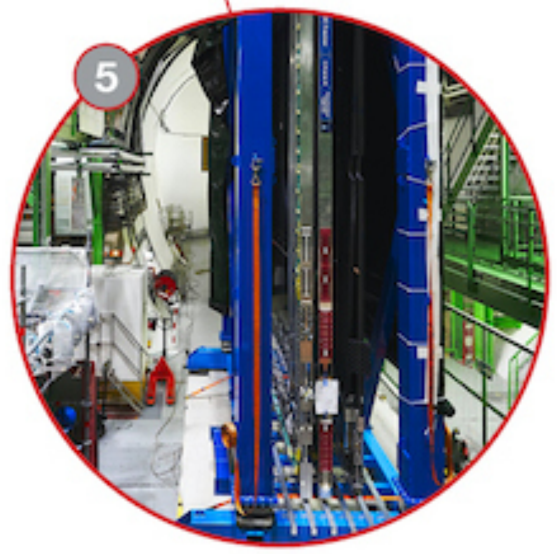

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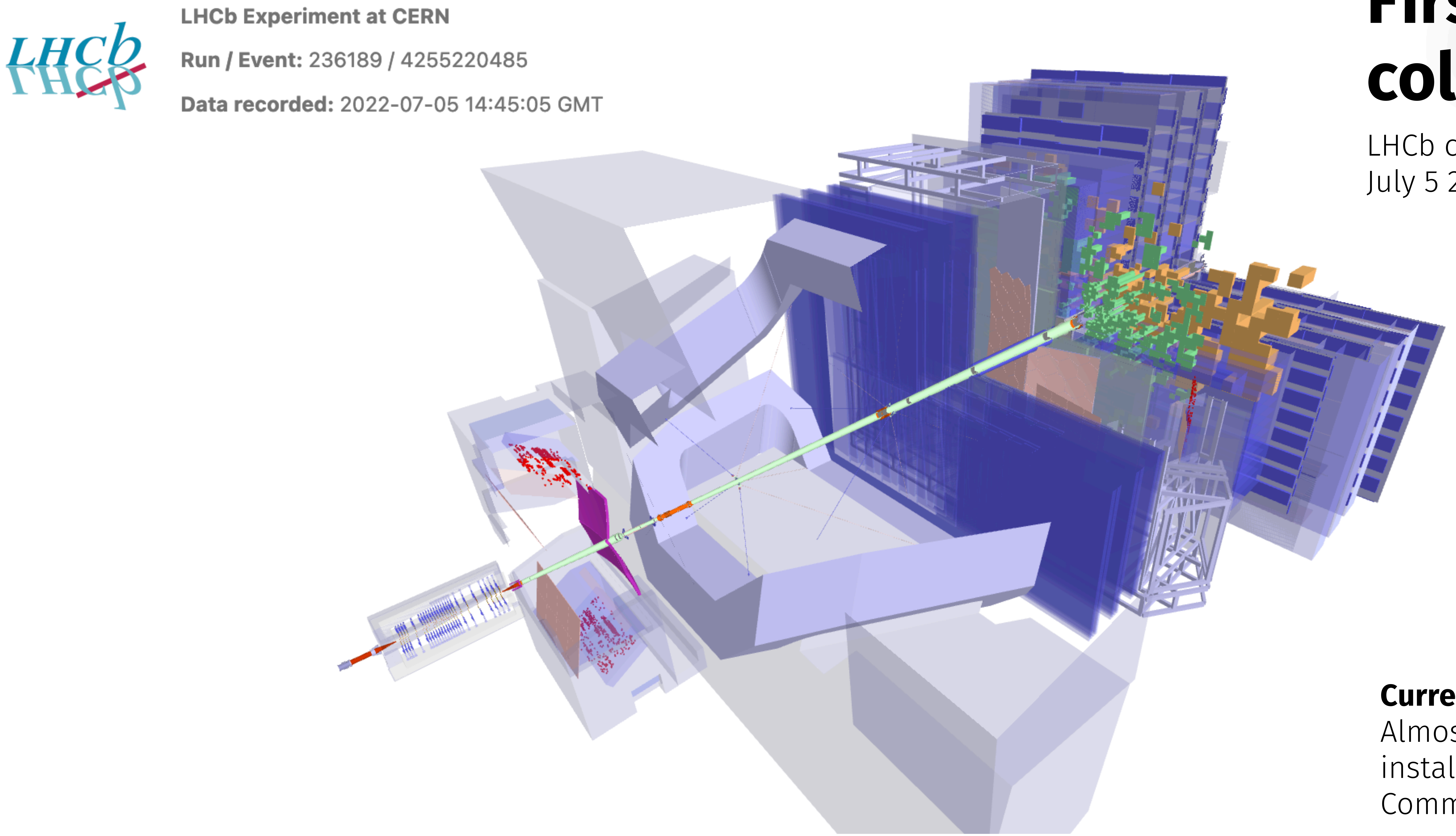
First collisions!

LHCb control room
July 5 2022

Current status:
Almost all of LHCb is installed!
Commissioning in progress



First collisions!

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July 5 2022

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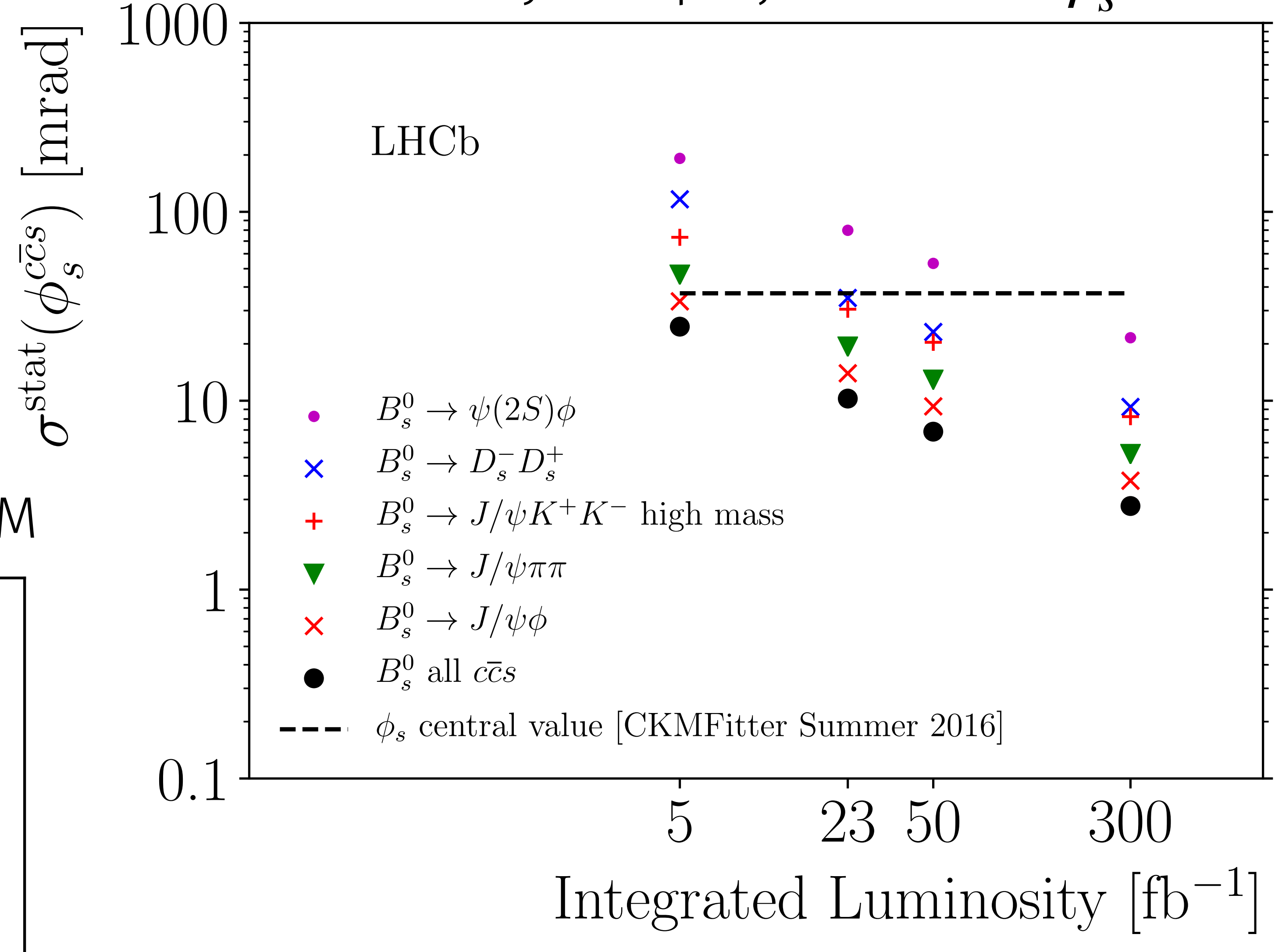
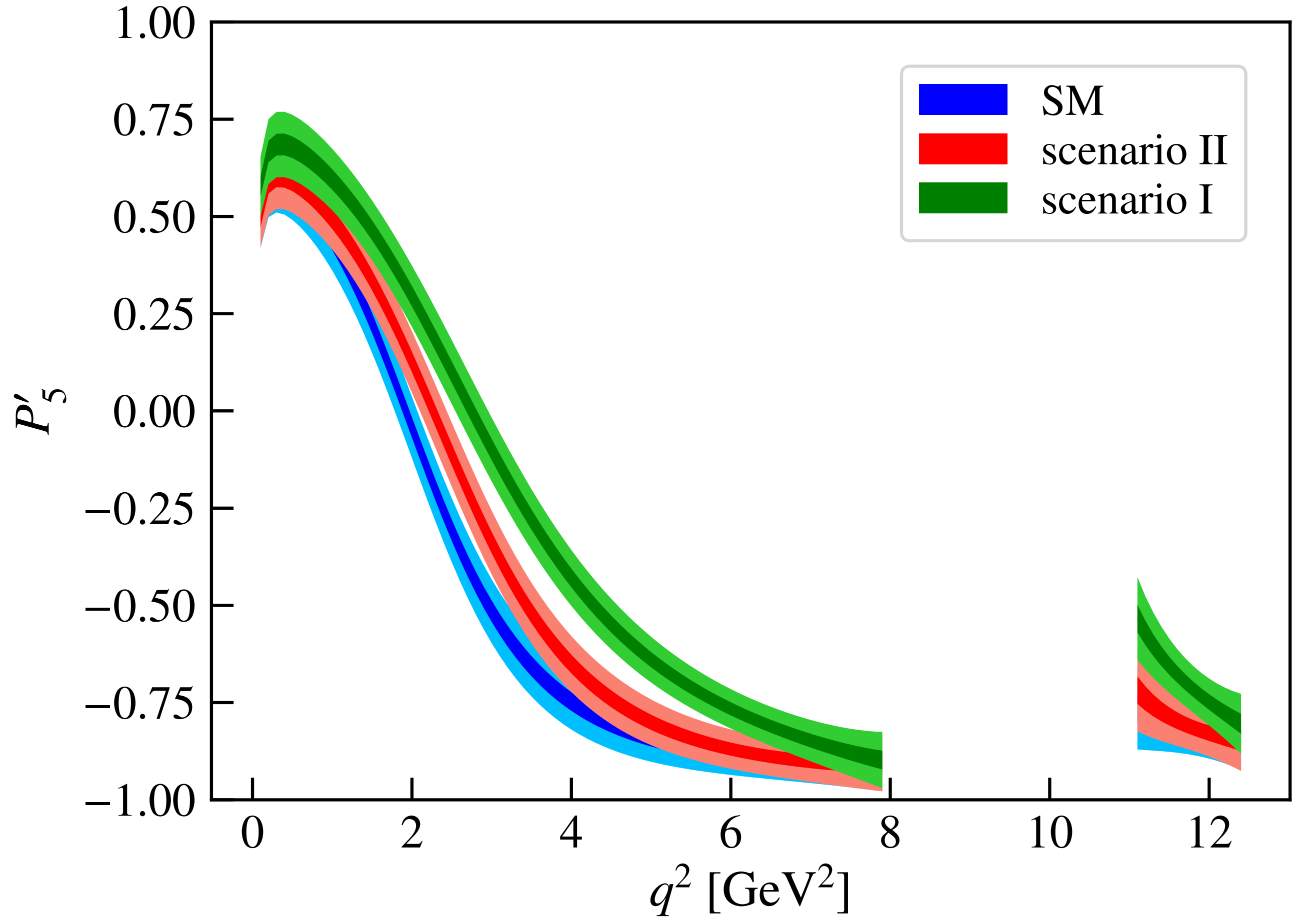
Run 3/4 performance projections

Observable	Current LHCb (up to 9 fb^{-1})		Upgrade I: After Run 3 (2025) (23 fb^{-1})	Upgrade I: After Run 4 (2032) (50 fb^{-1})
CKM tests				
γ ($B \to DK$, *etc.*)	$4°$	[9, 10]	$1.5°$	$1°$
ϕ_s ($B^0_s \to J/\psi\phi$)	32 mrad	[8]	14 mrad	10 mrad
$\lvert V_{ub}\rvert/\lvert V_{cb}\rvert$ ($\Lambda^0_b \to p\mu^-\overline{\nu}_\mu$, *etc.*)	6%	[29, 30]	3%	2%
$a^d_{\rm sl}$ ($B^0 \to D^-\mu^+\nu_\mu$)	36×10^{-4}	[34]	8×10^{-4}	5×10^{-4}
$a^s_{\rm sl}$ ($B^0_s \to D^-_s\mu^+\nu_\mu$)	33×10^{-4}	[35]	10×10^{-4}	7×10^{-4}
Charm				
ΔA_{CP} ($D^0 \to K^+K^-, \pi^+\pi^-$)	29×10^{-5}	[5]	13×10^{-5}	8×10^{-5}
A_Γ ($D^0 \to K^+K^-, \pi^+\pi^-$)	11×10^{-5}	[38]	5×10^{-5}	3.2×10^{-5}
Δx ($D^0 \to K^0_S\pi^+\pi^-$)	18×10^{-5}	[37]	6.3×10^{-5}	4.1×10^{-5}
Rare Decays				
$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B^0_s \to \mu^+\mu^-)$	69%	[40, 41]	41%	27%
$S_{\mu\mu}$ ($B^0_s \to \mu^+\mu^-$)	—		—	—
$A^{(2)}_{\rm T}$ ($B^0 \to K^{*0}e^+e^-$)	0.10	[52]	0.060	0.043
$A^{\rm Im}_{\rm T}$ ($B^0 \to K^{*0}e^+e^-$)	0.10	[52]	0.060	0.043
$\mathcal{A}^{\Delta\Gamma}_{\phi\gamma}(B^0_s \to \phi\gamma)$	$^{+0.41}_{-0.44}$	[51]	0.124	0.083
$S_{\phi\gamma}(B^0_s \to \phi\gamma)$	0.32	[51]	0.093	0.062
$\alpha_\gamma(\Lambda^0_b \to \Lambda\gamma)$	$^{+0.17}_{-0.29}$	[53]	0.148	0.097
Lepton Universality Tests				
R_K ($B^+ \to K^+\ell^+\ell^-$)	0.044	[12]	0.025	0.017
R_{K^*} ($B^0 \to K^{*0}\ell^+\ell^-$)	0.12	[61]	0.034	0.022
$R(D^*)$ ($B^0 \to D^{*-}\ell^+\nu_\ell$)	0.026	[62, 64]	0.007	0.005

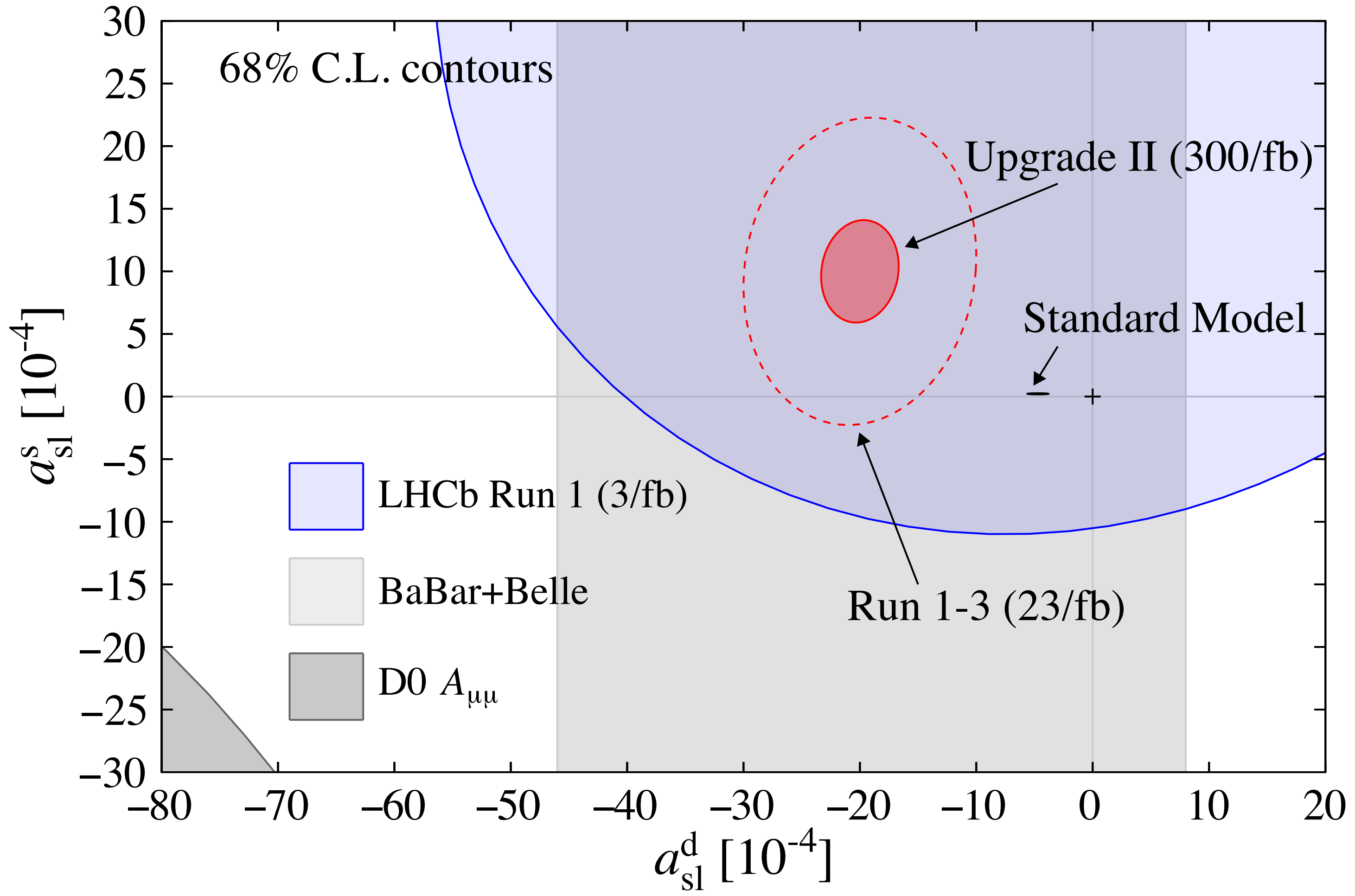
Uncertainty size projections for ϕ_s



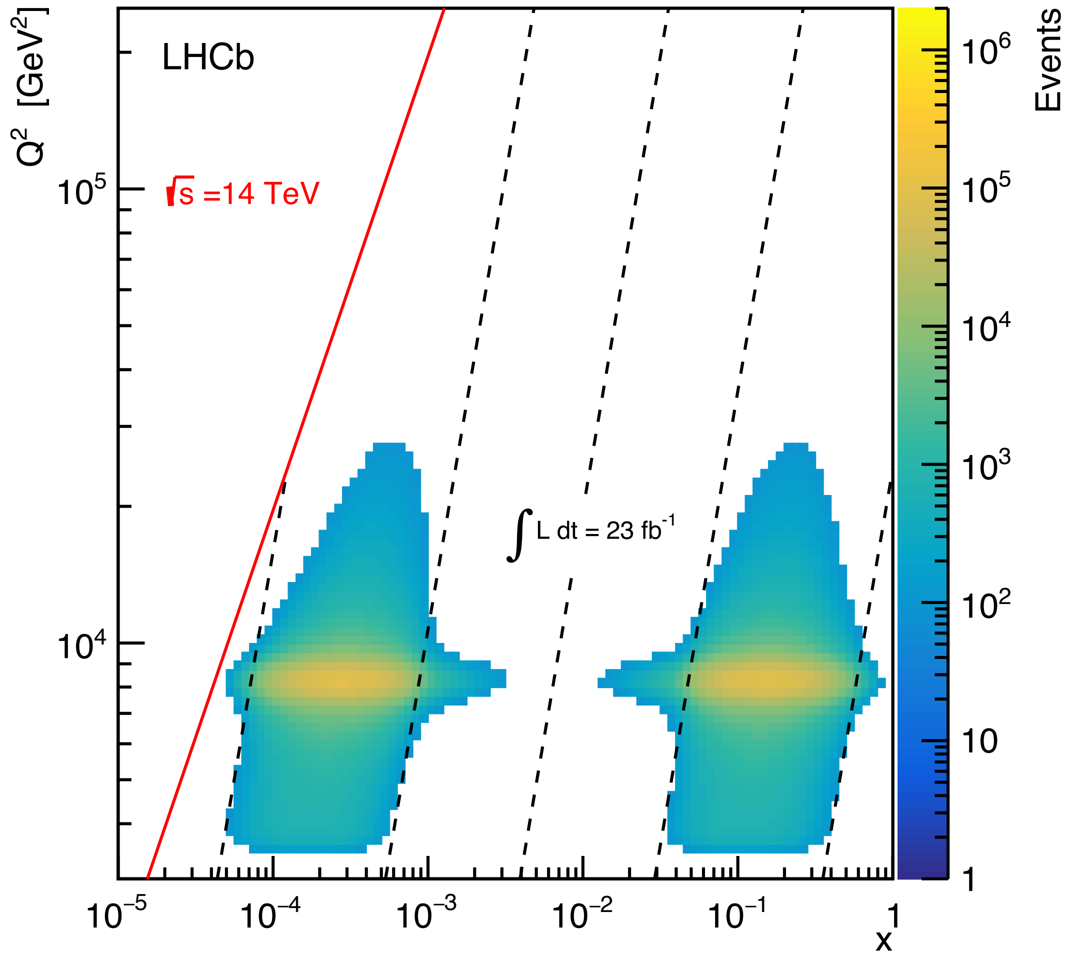
Uncertainty size projections for BSM



Uncertainty size projections for SL asymmetries



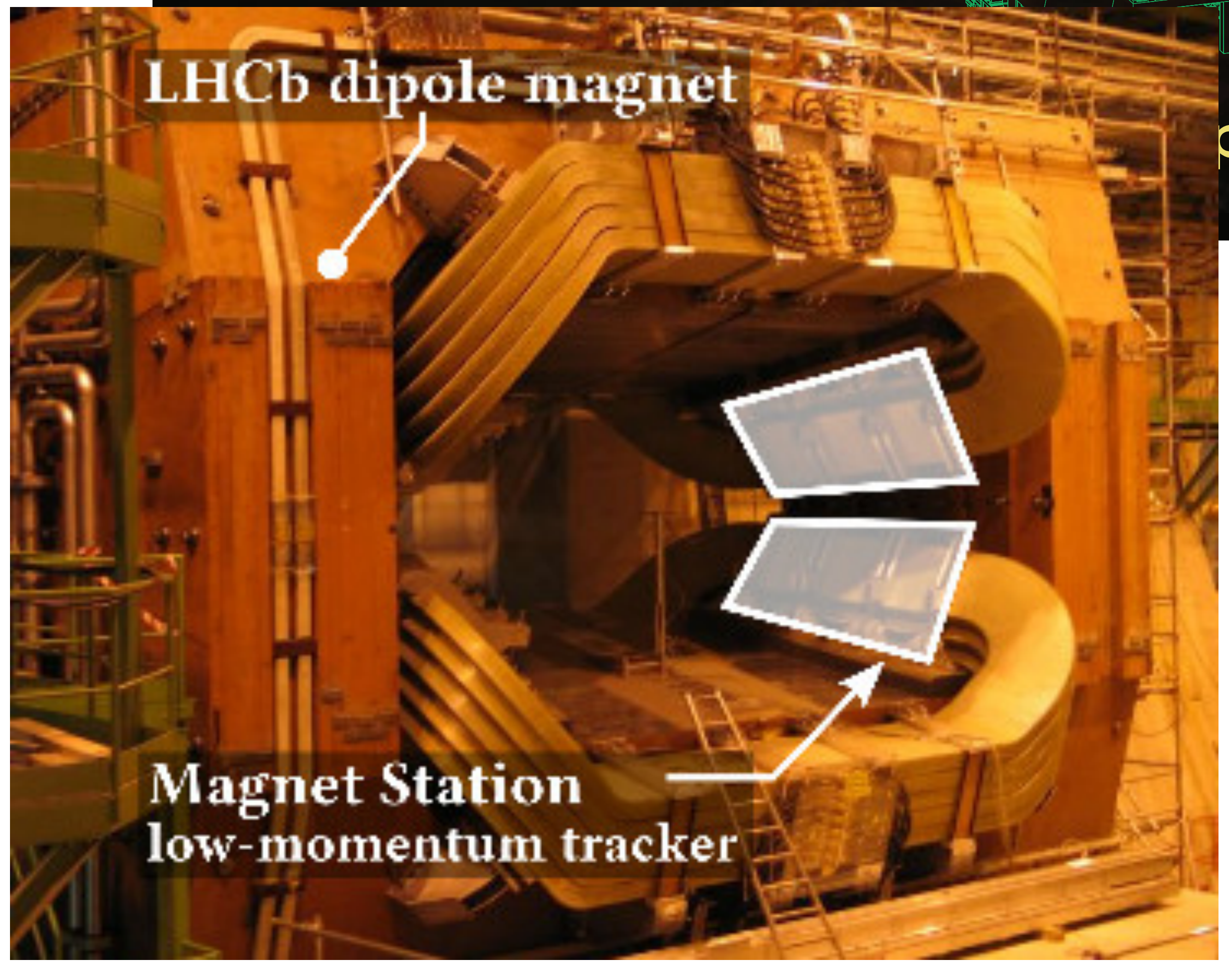
Z bosons in Run 3



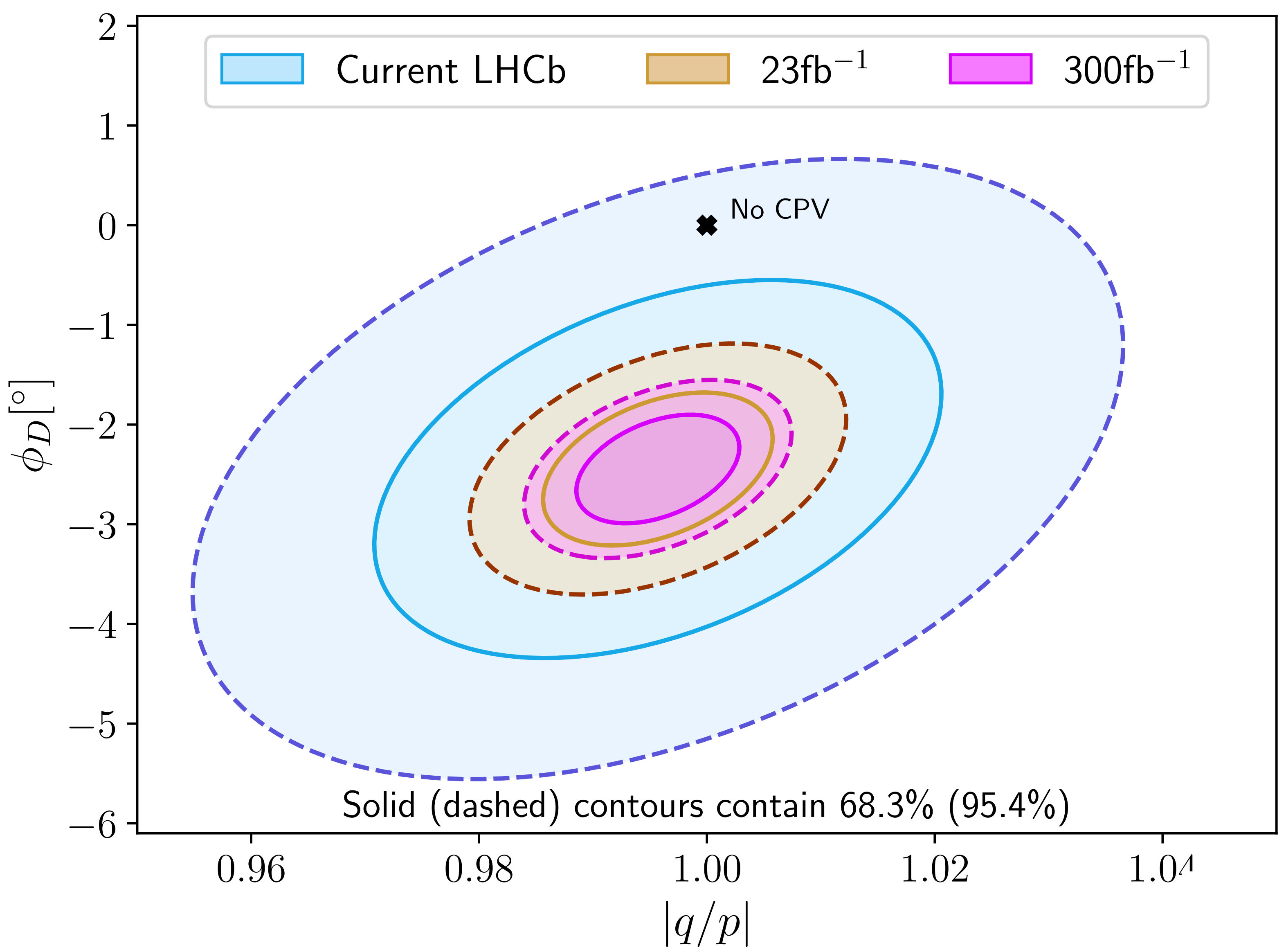
CERN-LHCC-2018-027

LHCb at the HL-LHC

- Target: 300 fb^{-1} in Run 5+6
  - Expected pile-up: 40
  - 200 Tb/second data produced
  - **GOAL: same LHCb physics performance in more difficult conditions**
- Separating events will require precision timing and new detectors
  - Aiming for a 4D VErtex LOcator
  - “5D” electron calorimeter
  - Timing improvements for all subdetectors
  - New tracking stations INSIDE magnet envelope (aim to have these in for Run 4)
- New technologies in R&D right now!
  - Subdetector technical reports expected after Run 3

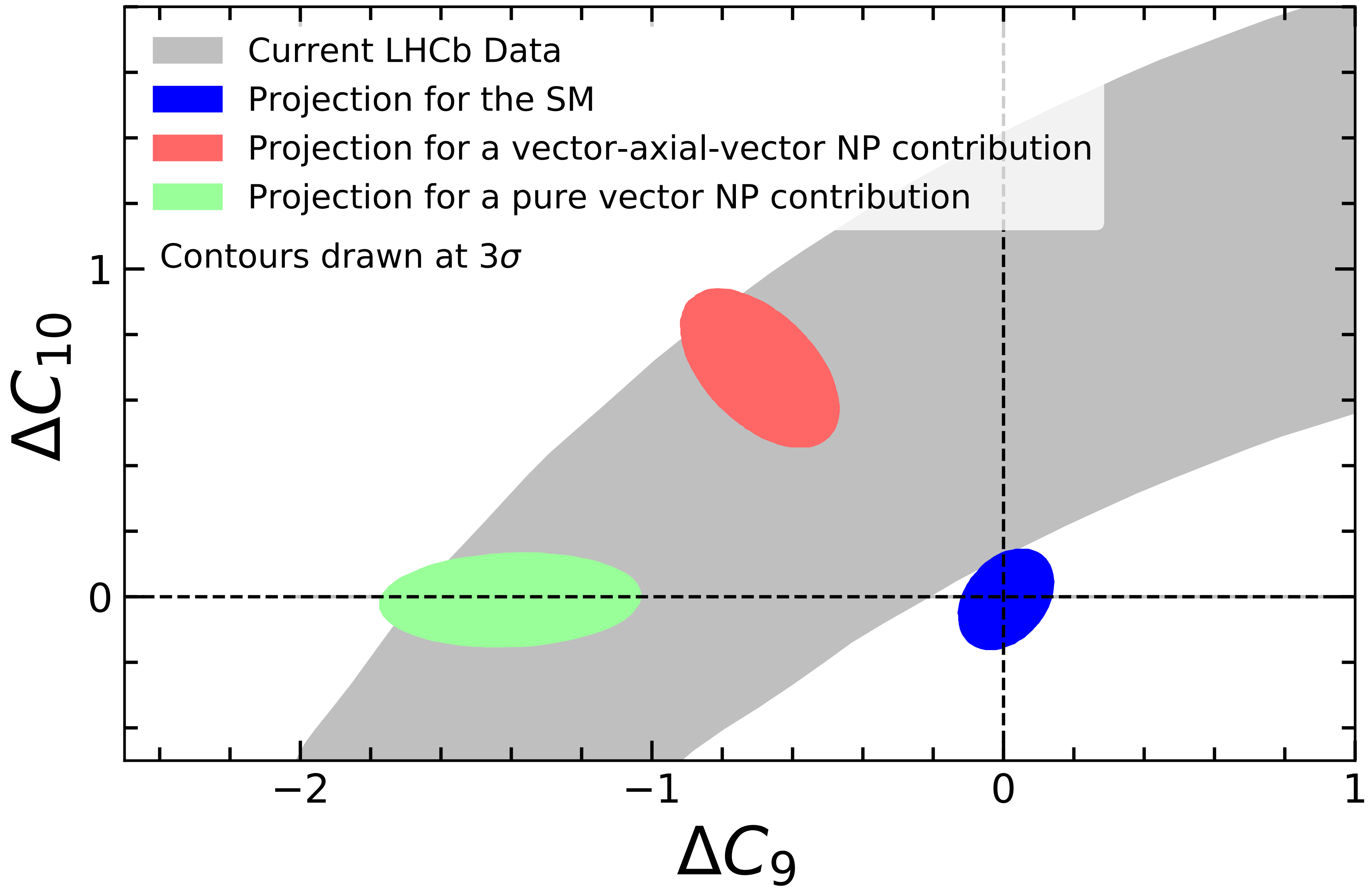


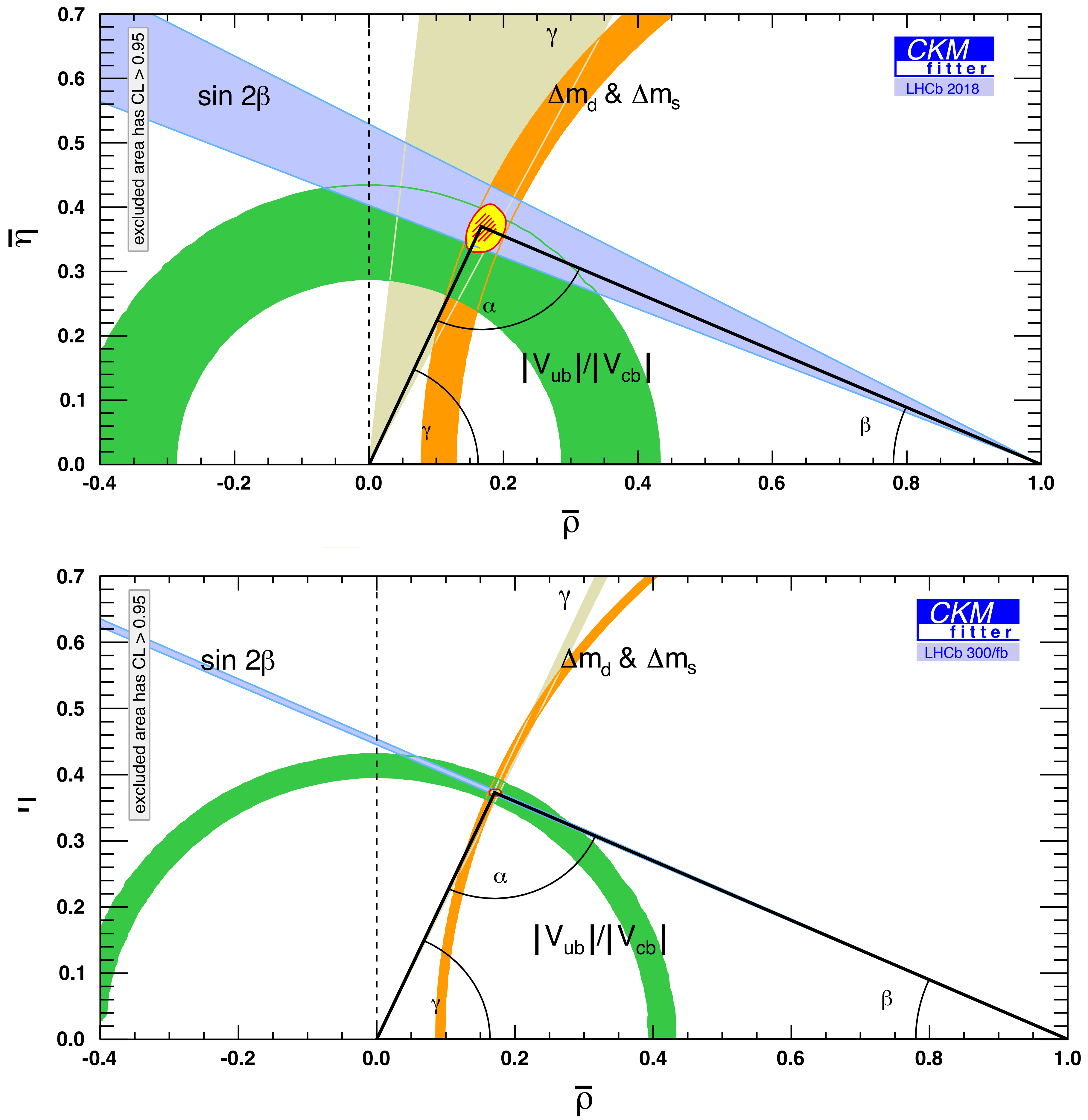
What could we achieve with HL-LHC?



Detailed studies of CPV and mixing in charm

Improved ability to classify possible NP from Rx anomalies





Vastly improved precision of CKM triangle Run 6

Please note: LHCb can't do it alone, these projections assume lots of hard work from LHC collider experts, some improvements from theory and updated measurements from other experiments!

Many more predictions:
CERN-LHCC-2021-012
LHCB-PUB-2018-009

Summary

- LHCb collected 9fb^{-1} of high quality data in 2011-2018
  - More about the physics we've achieved with this so far in the next few talks
  - Many analyses ongoing
- LHCb Upgrade I is in commissioning
  - Last subdetector installation scheduled for this Winter
  - Commissioning of hardware, software, online system progressing well
  - Expecting 10x more data (with 20x more hadronic events)
- Plans underway for LHCb Upgrade II
  - Expecting large pile up to reach 300 fb^{-1}
  - New technologies currently under investigation!

Backup slides

Run 3 Vertexing performance