Performance of the LHCb detector in the Run 2

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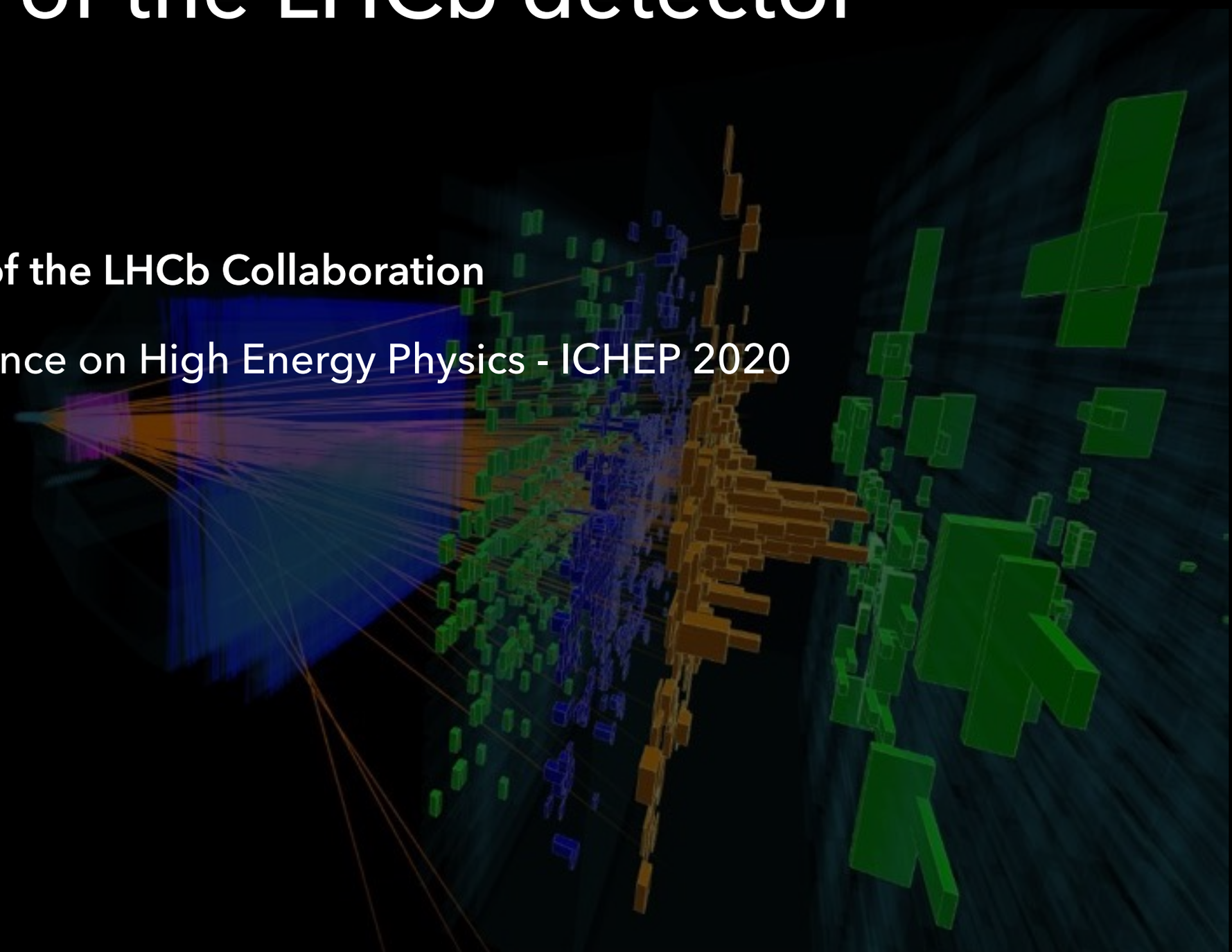
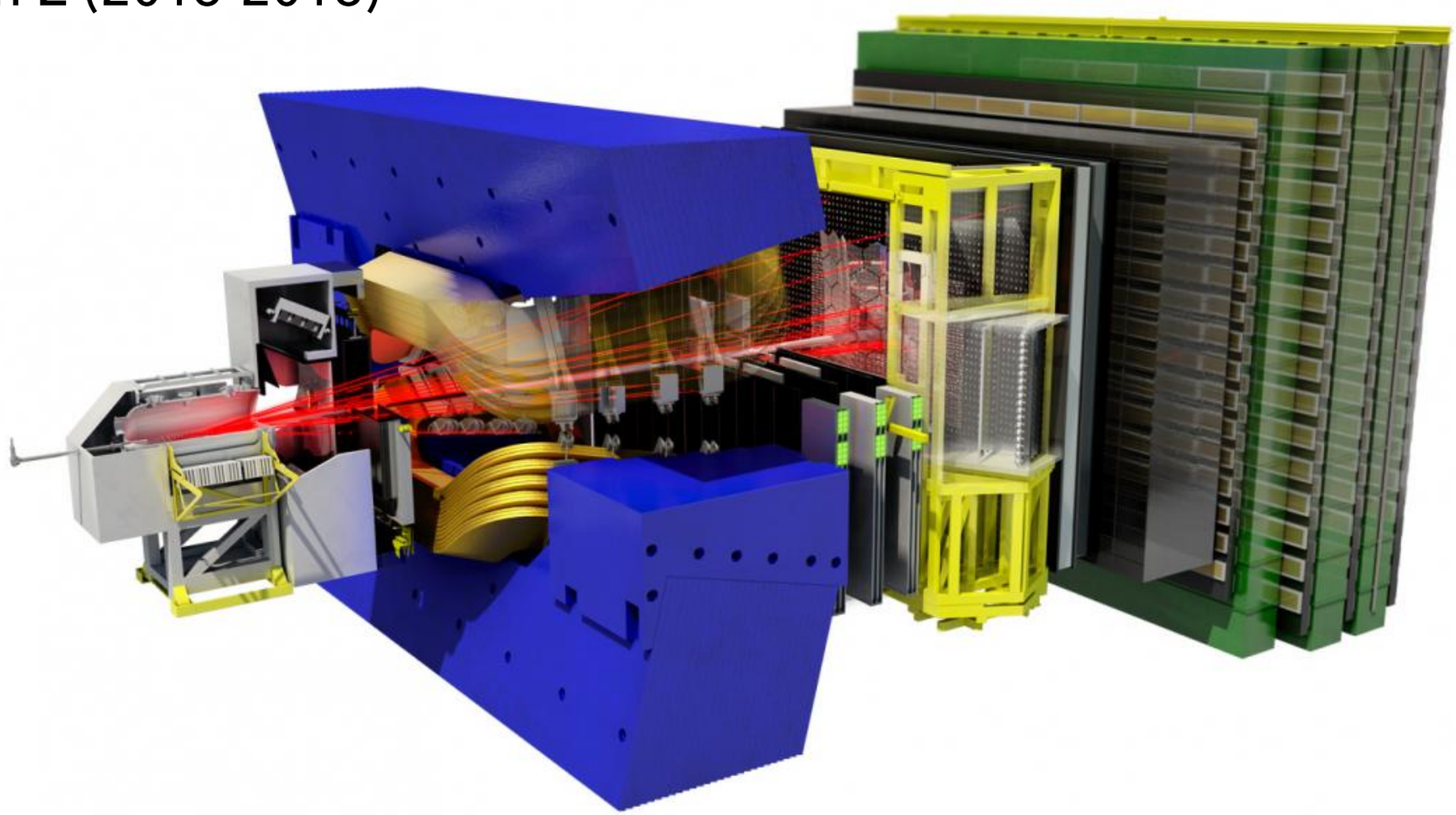
40*th* International Conference on High Energy Physics - ICHEP 2020

28*th* July 2020



The LHCb detector

- Single arm spectrometer in the forward region
- Main focus on CP violation and rare decays of beauty and charm hadrons
  - Wider physics programme (Electroweak, Exotica, Heavy Ions, …)
- Today's focus: recent progress on tracking and particle identification (PID) performance in Run 2 (2015-2018)



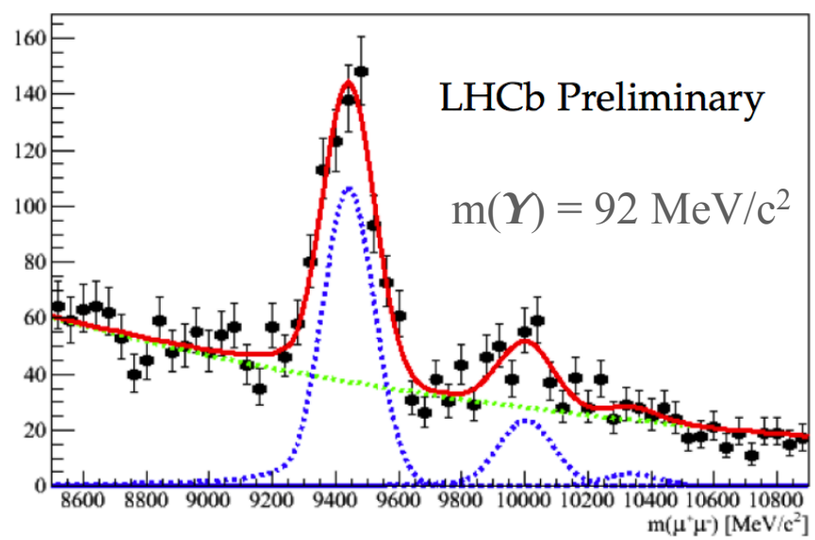
2008 *JINST* 3 S08005

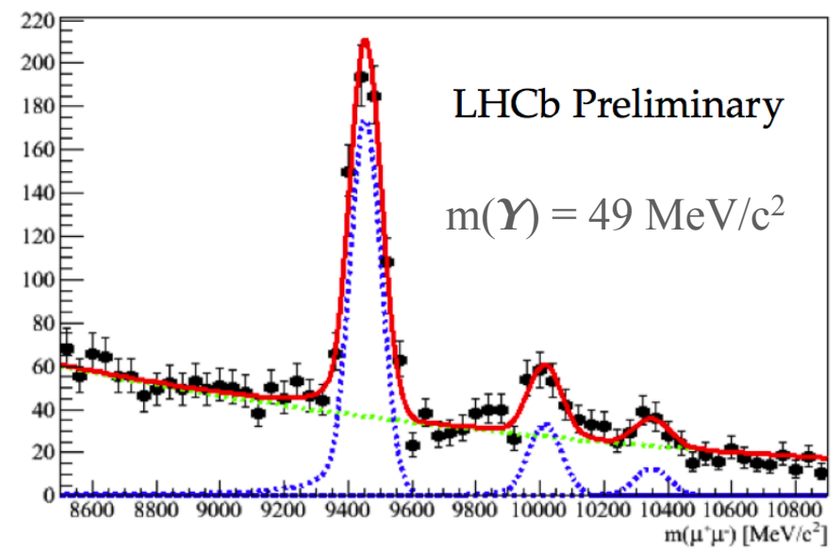
IJMPA 30 (2015) 1530022

Alignment and calibration at LHCb

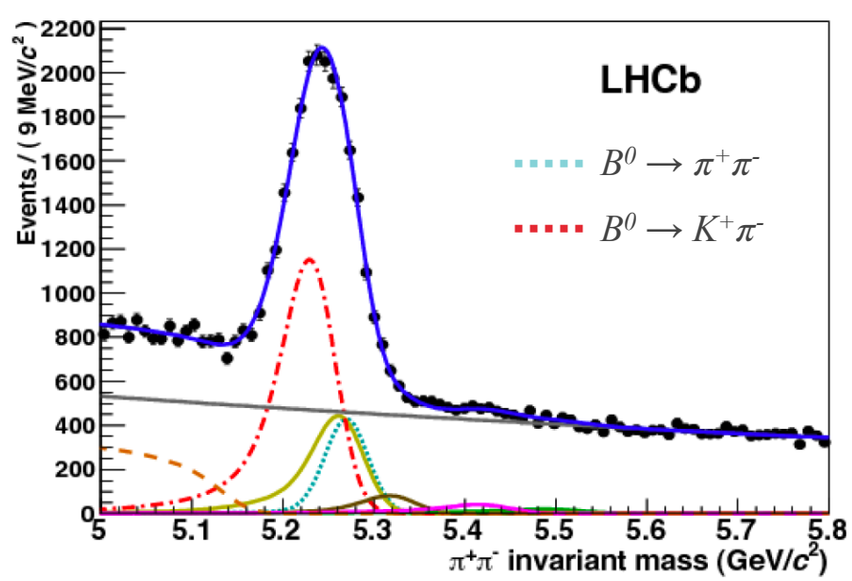
Better mass resolution and particle identification performances:

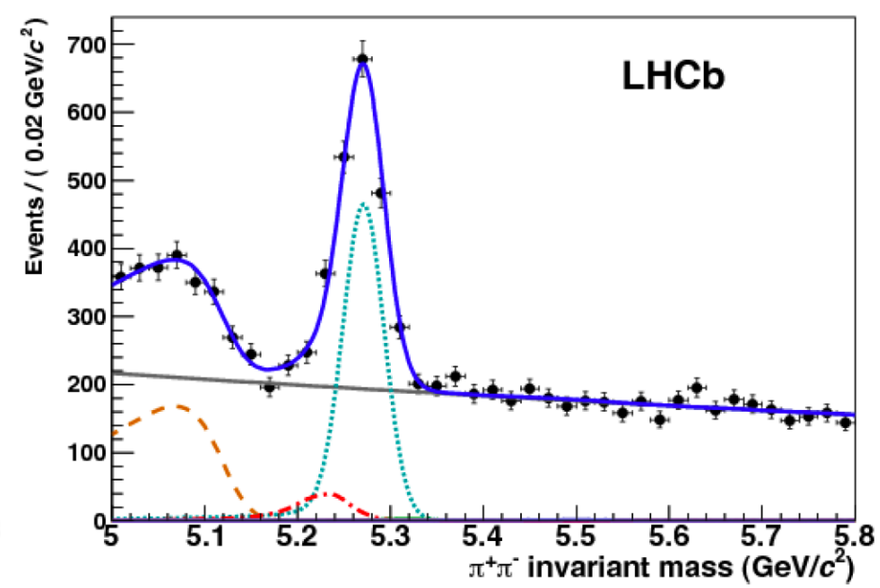
First vs Improved alignment in decays $\Upsilon(1S) \rightarrow \mu^+\mu^-$





$B^0 \rightarrow h^+h^-$ invariant mass with/without the PID information from RICH Cherenkov detectors

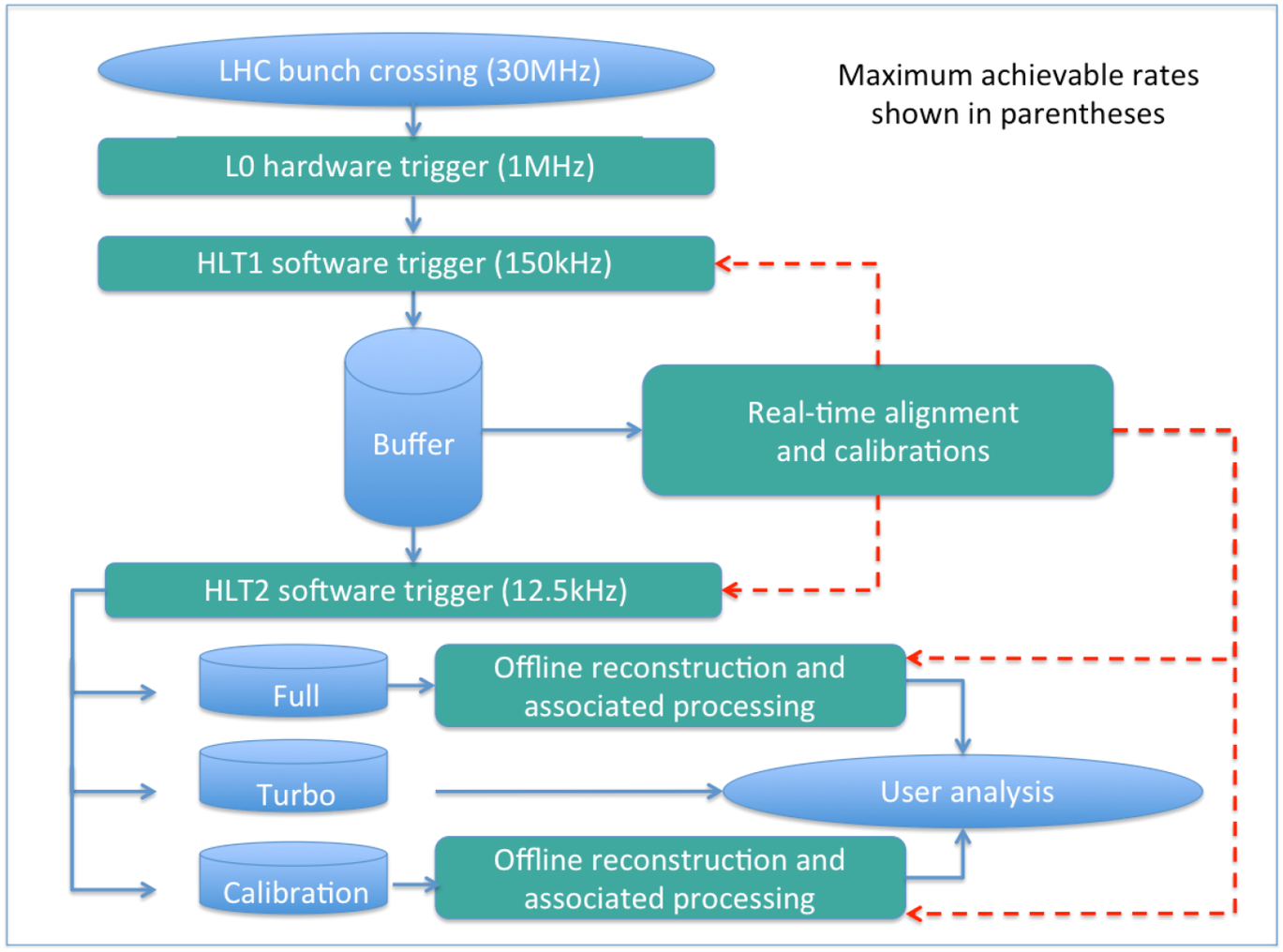




J.Phys. Conf. Ser. 664 (2015) 082010

The LHCb Trigger Scheme in Run 2

- From 2015 new real time analysis strategy
- Detector alignment and calibration performed in the trigger farm
- Same conditions online and offline ensured
  - Turbo stream: possible to run some analyses directly on the output of the trigger
- Selection of PID and tracking calibration samples at HLT2 level with dedicated calibration stream (**TurboCalib**)



2019 *JINST* 14 P04006

Comput.Phys.Commun. 208 (2016) 35-42

Tracking at LHCb

2008 *JINST* 3 S08005

IJMPA 30 (2015) 1530022

Vertex Locator

Retractable halves

8mm from beam in data taking

σ_{IP} = 20 μm for high p_T tracks

Dipole Magnet

4 Tm magnetic field

Polarity inverted every few weeks

T - Stations

Silicon microstrips/Straw tubes

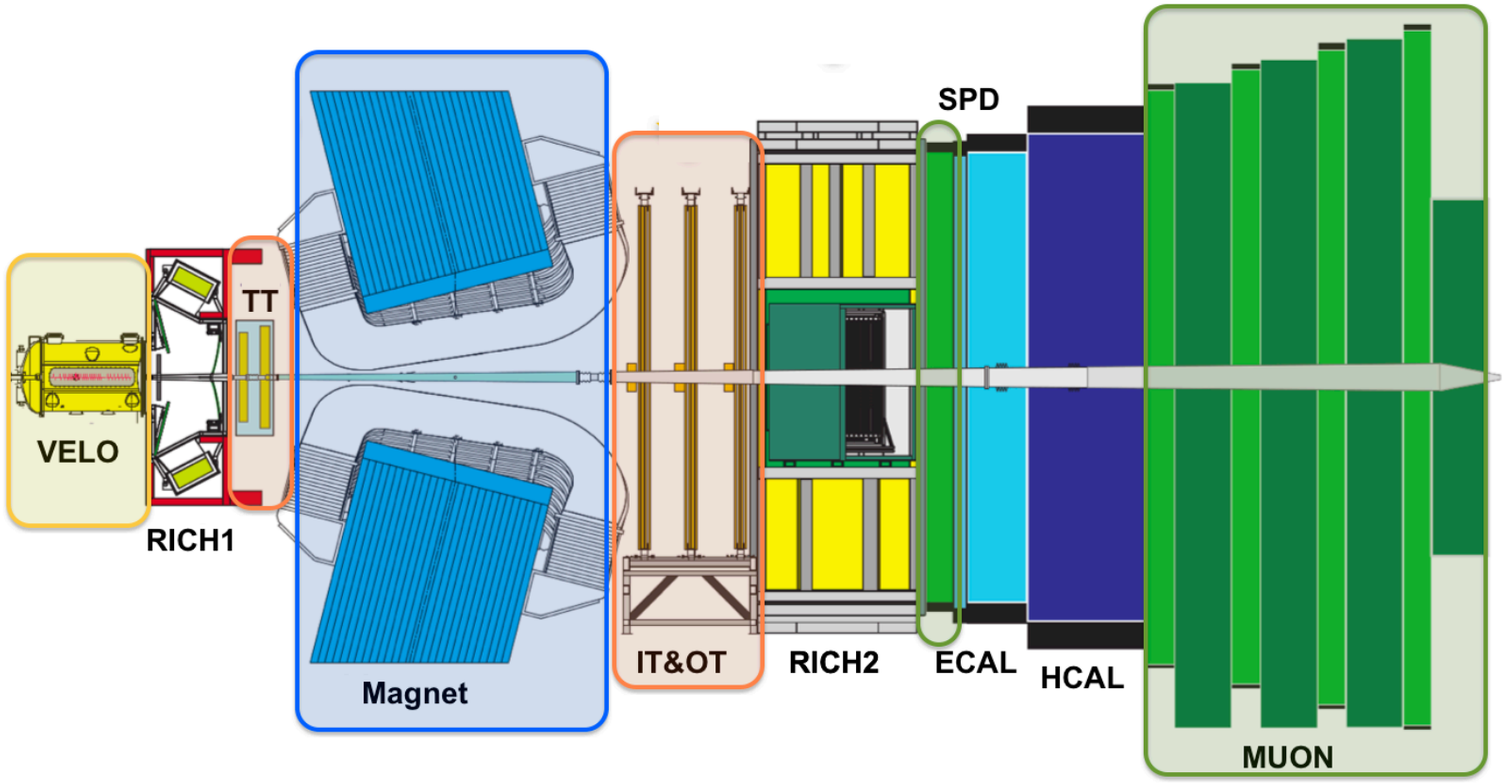
Δp/p ~ 0.4(0.6)% at 5(100)GeV

Muon Stations

Five stations (M1-M5)

MWPCs + triple GEM

ε(μ) ~ 97%



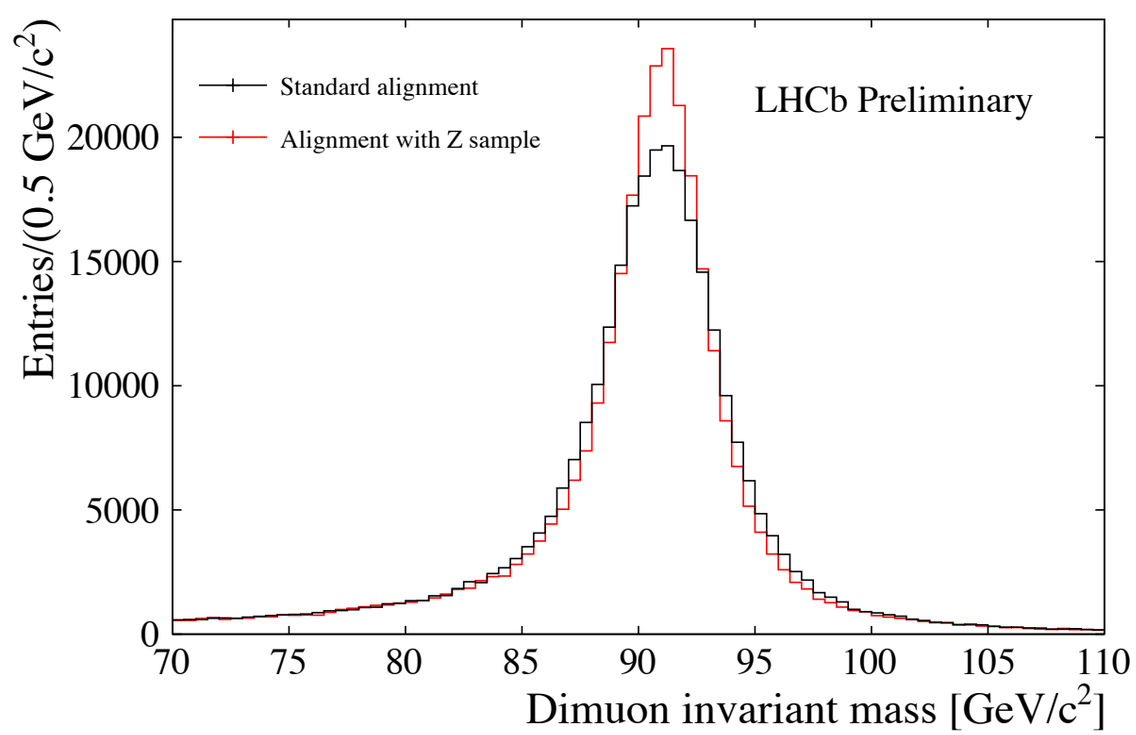
Alignment procedure

Nucl. Instrum. Meth. A845 (2017) 560

Nucl. Instrum. Meth. A600 (2009) 471

- Minimisation of the residuals of a Kalman filter fit
  - Multiple scattering and energy loss taken into account
  - Possible to apply mass and vertex constraints
- Sample used for alignment collected in a few minutes at the beginning of each fill
  - Minimum bias sample with vertex constraint for the VELO
  - D^0 two-body decay with mass constraint on D^0 candidates for tracker
- In 2017 additional alignment using 2016 $Z \to \mu^+\mu^-$ data
  - High p_T tracks are suitable for alignment
  - 35% improvement in Z mass resolution
  - Used in 2018 as starting point of the real time alignment
  - <u>No significant change on analyses using lower p_T tracks</u>

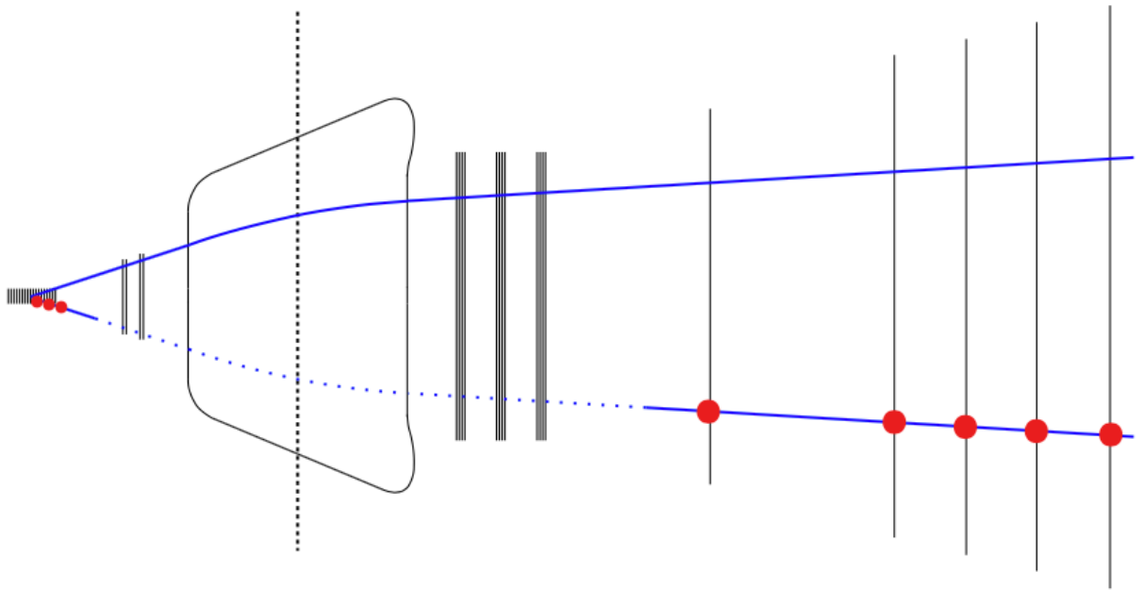
LHCb–FIGURE-2020-009



Tracking efficiencies

2015 *JINST* 10 P02007

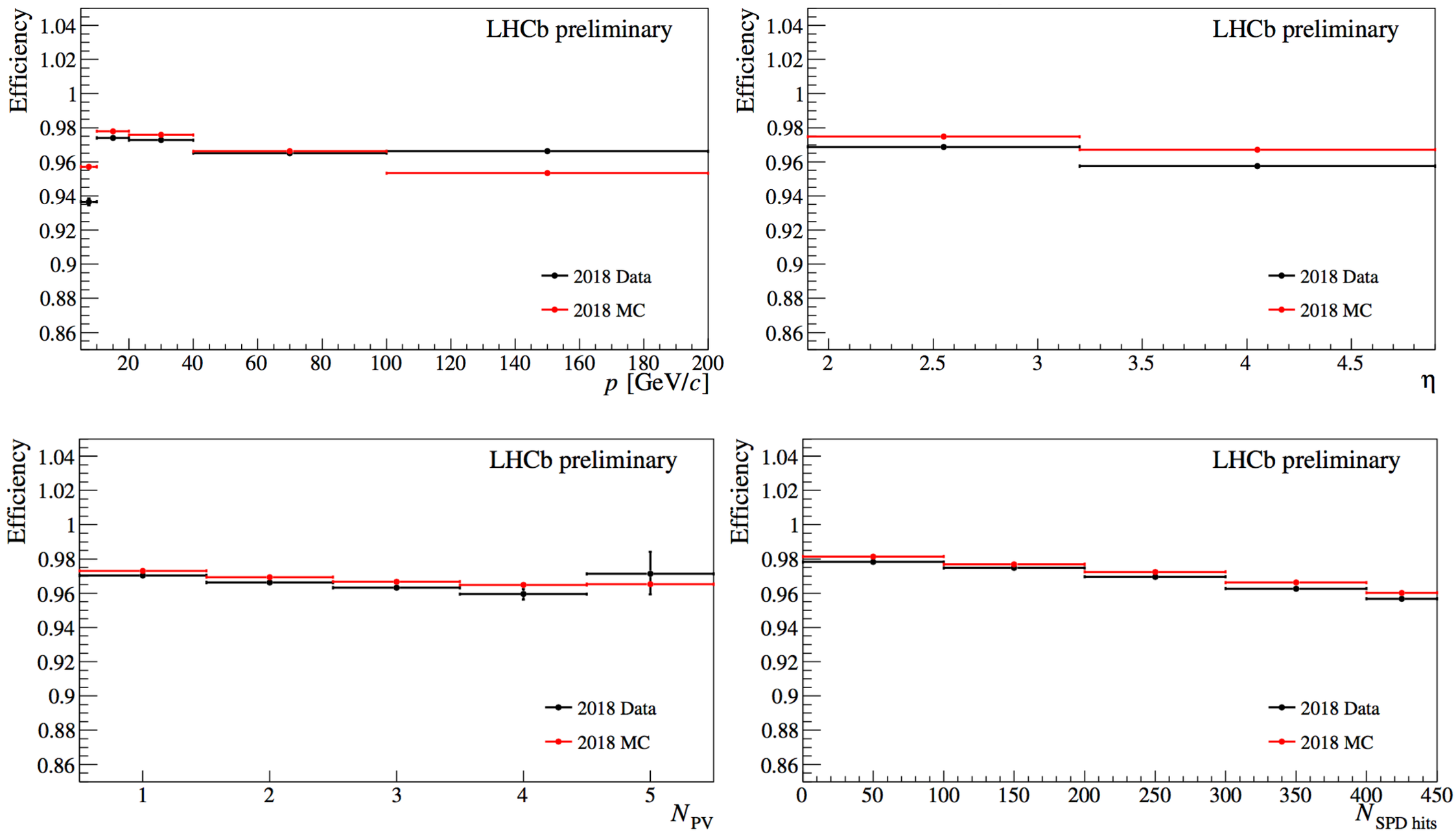
- Data driven efficiencies estimation using *tag and probe* method
  - Using $J/\psi \rightarrow \mu^+\mu^-$ because of clear signature left in the detector
  - Dedicated TurboCalib lines for calibration samples
- Calculate $\varepsilon^{DATA} / \varepsilon^{MC}$ to mitigate data/simulation discrepancies:
  - It cancels out first order systematic uncertainties



Tracking efficiencies

LHCb–FIGURE-2020-010

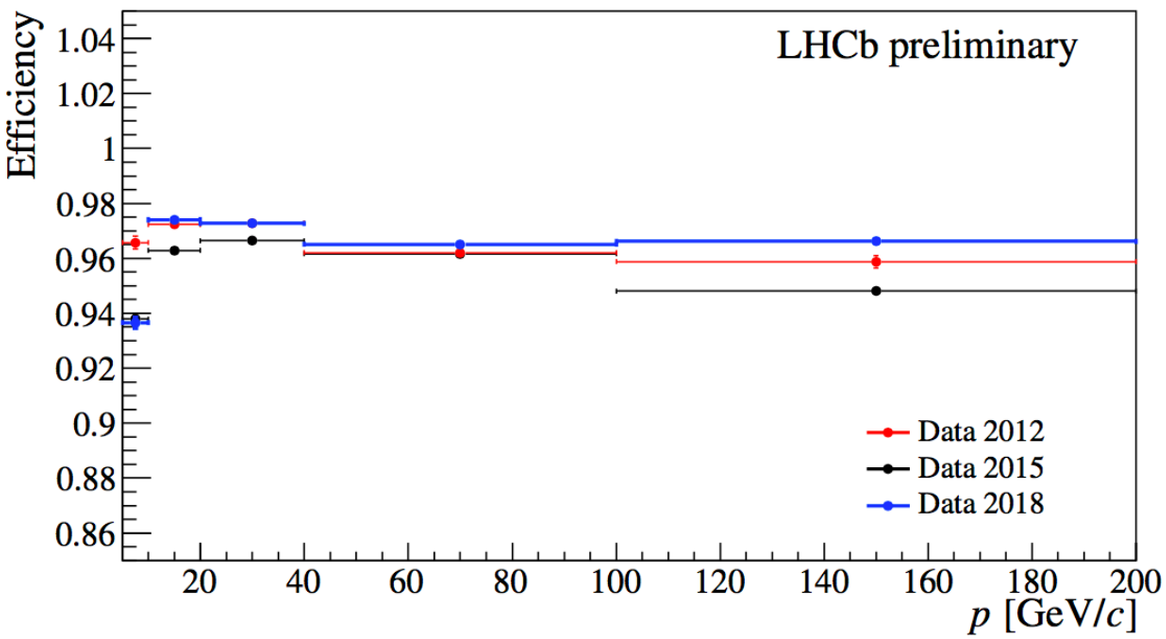
- Muonic efficiencies are above 95%
- ε^{DATA} / ε^{MC} agreement around 99%

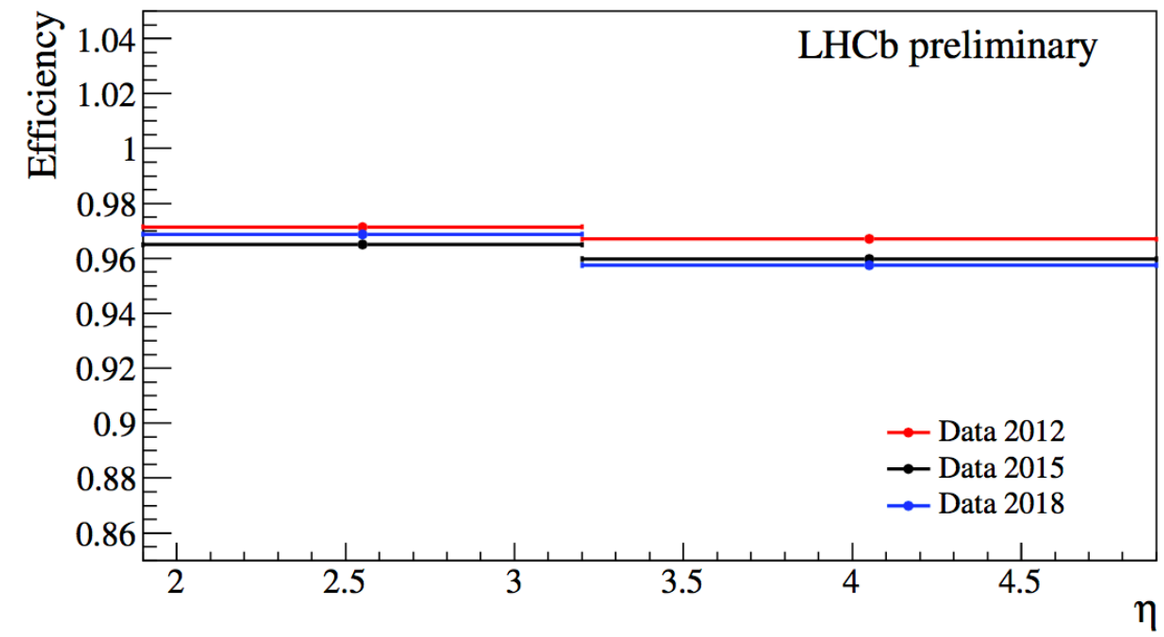


Tracking efficiencies

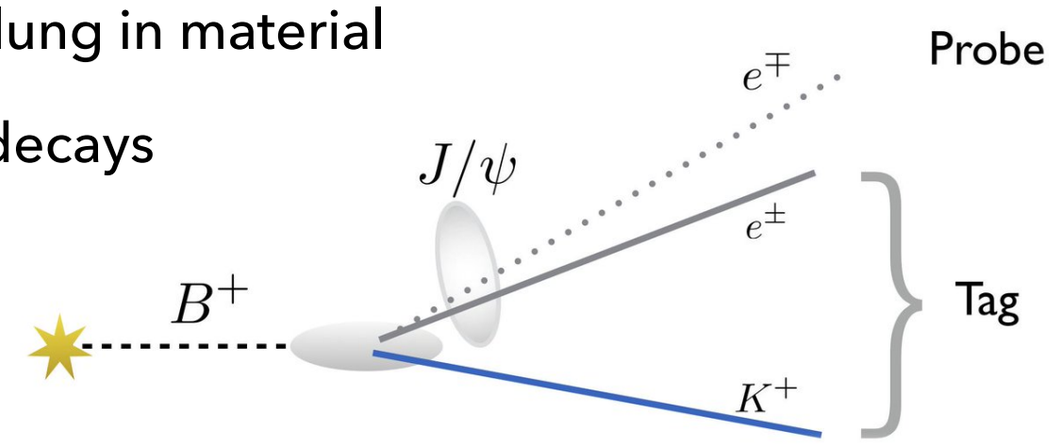
LHCb–FIGURE-2020-010

- Stability over the years:





- <u>Electron reconstruction efficiencies</u>: JINST 14 (2019) P11023
  - Energy loss along trajectory due to bremsstrahlung in material
  - Tag & Probe method using $B^+ \to J/\psi(e^+e^-)K^+$ decays
  - Tag is electron + kaon pair



PID at LHCb

2008 *JINST* 3 S08005

IJMPA 30 (2015) 1530022

Ring Imaging Cherenkov Detectors

PID for kaons, pions, protons

Wide momentum range coverage

$\varepsilon(\pi \rightarrow K)$ misID ~5%

Calorimeters

SPD, PS, ECAL, HCAL

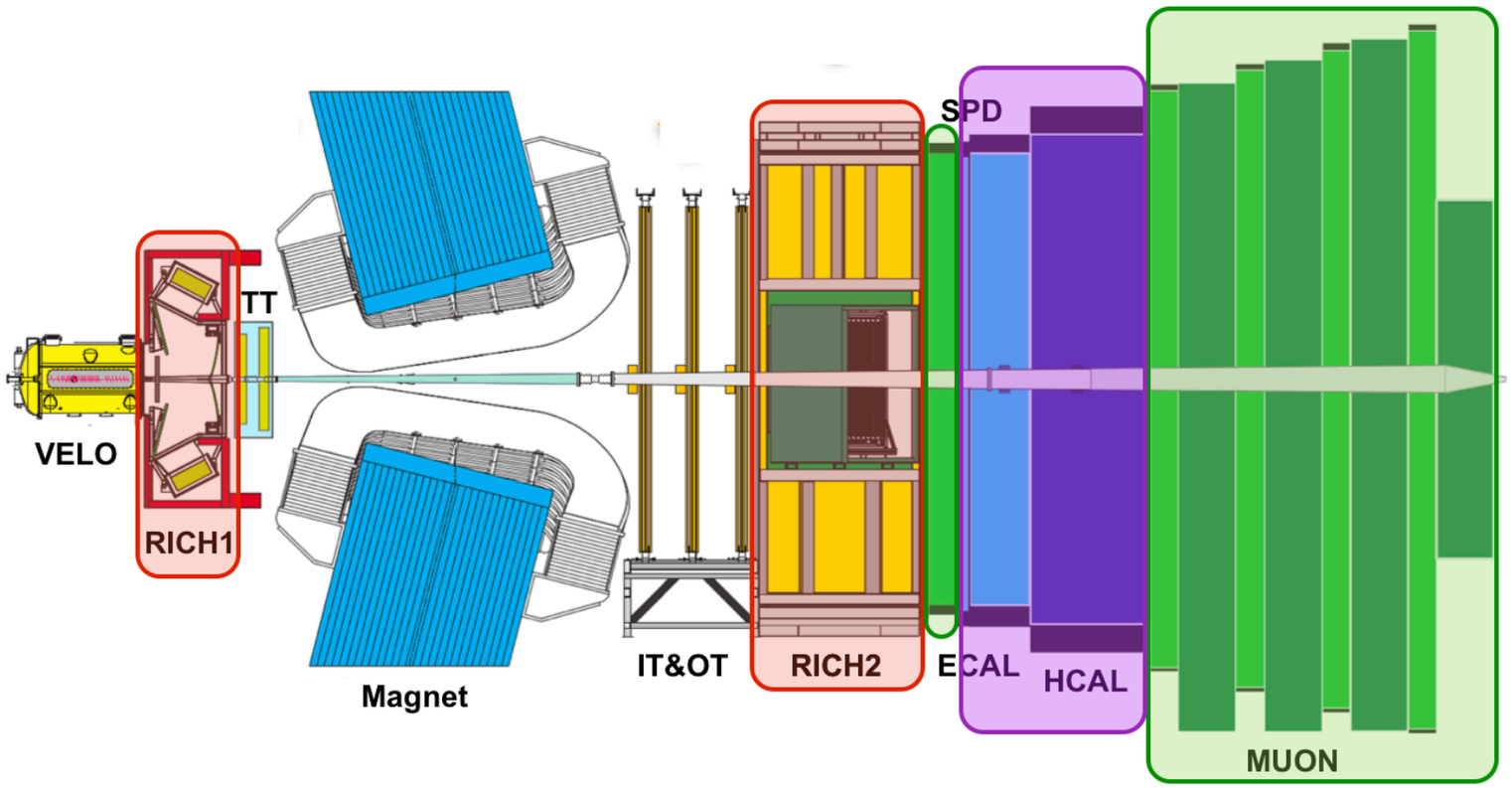
PID for e, γ, π^0

Energy and position for neutral objects and triggers for e, γ

Muon System

M1- M5, high purity PID for muons

$\varepsilon(\mu \rightarrow \pi)$ misID ~1-3%



PID strategy

CERN-LHCb–DP-2018-001

- **Charged PID**: combine PID info from RICH, CALO, MUON to single observables:
  - ΔLL(X - π): log likelihood difference between X and π hypothesis
  - `ProbNNX`: output of neural nets (NN) trained on simulation to identify X
- **Neutral PID**: dedicated NN - separate γ from other species (`IsNotE`,`IsNotH`)

Efficiencies calculated from data-driven techniques with calibration samples since PID response not perfectly described in simulation

Selection of PID calibration samples at HLT2 level with dedicated stream (**TurboCalib**)

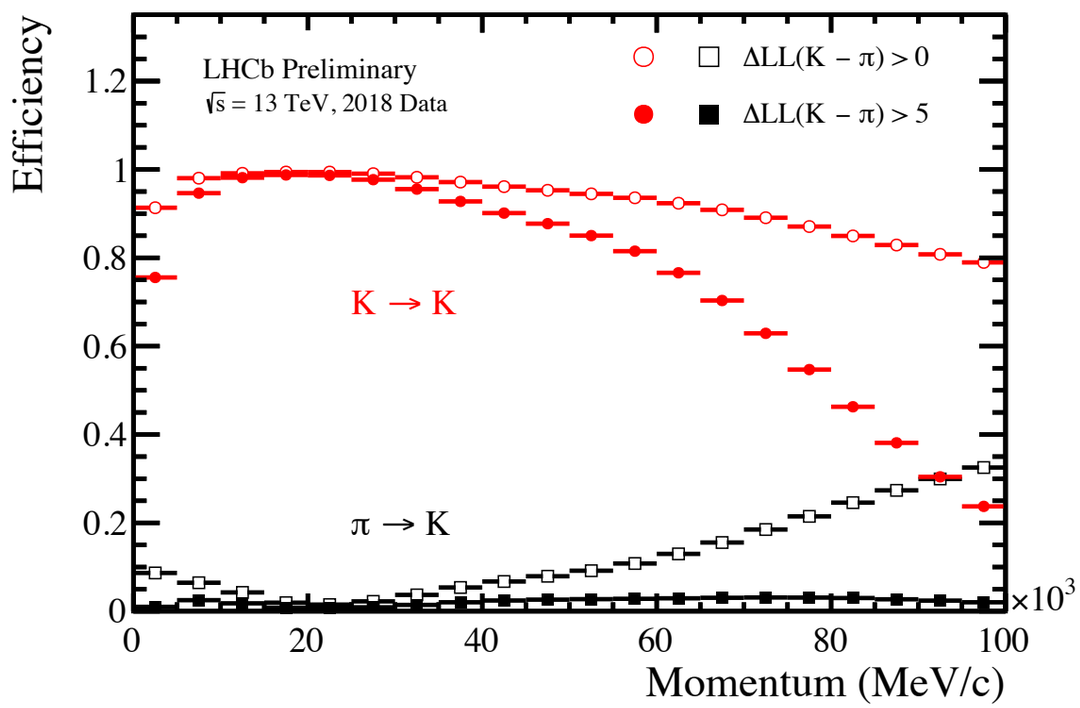
- High purity & High statistics
- Low multiplicity
- Large branching fractions

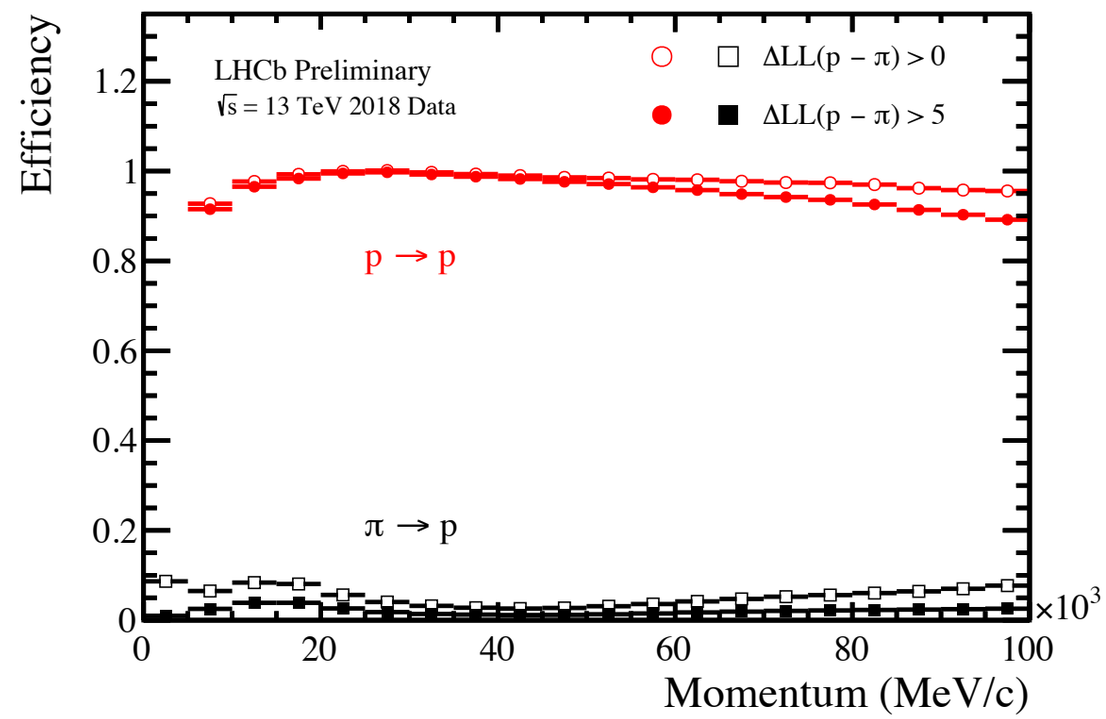
Species	Low momentum	High momentum
$e^{\pm}$	$B^+ \to J/\psi K^+$ with $J/\psi \to e^+e^-$	
$\mu^{\pm}$	$B^+ \to J/\psi K^+$ with $J/\psi \to \mu^+\mu^-$	$J/\psi \to \mu^+\mu^-$
$\pi^{\pm}$	$K^0_S \to \pi^+\pi^-$	$D^{*+} \to D^0\pi^+$ with $D^0 \to K^-\pi^+$
$K^{\pm}$	$D^+_s \to \phi\pi^+$ with $\phi \to K^+K^-$	$D^{*+} \to D^0\pi^+$ with $D^0 \to K^-\pi^+$
$p, \overline{p}$	$\Lambda^0 \to p\pi^-$	$\Lambda^0 \to p\pi^-$; $\Lambda^+_c \to pK^-\pi^+$

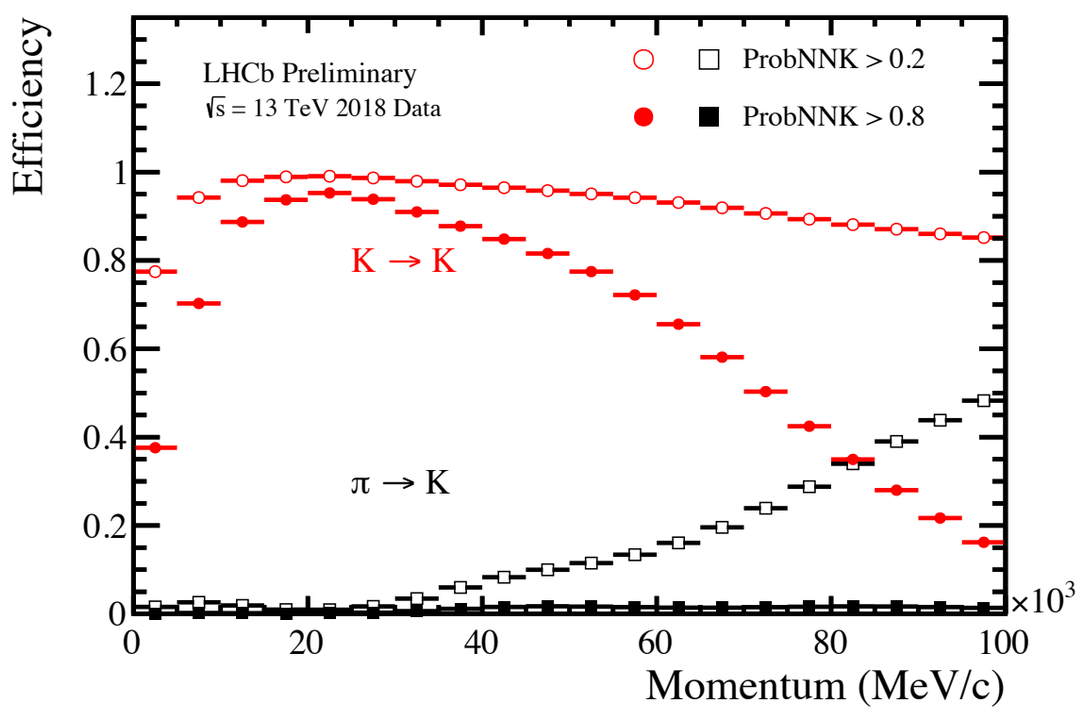
PID efficiencies - charged

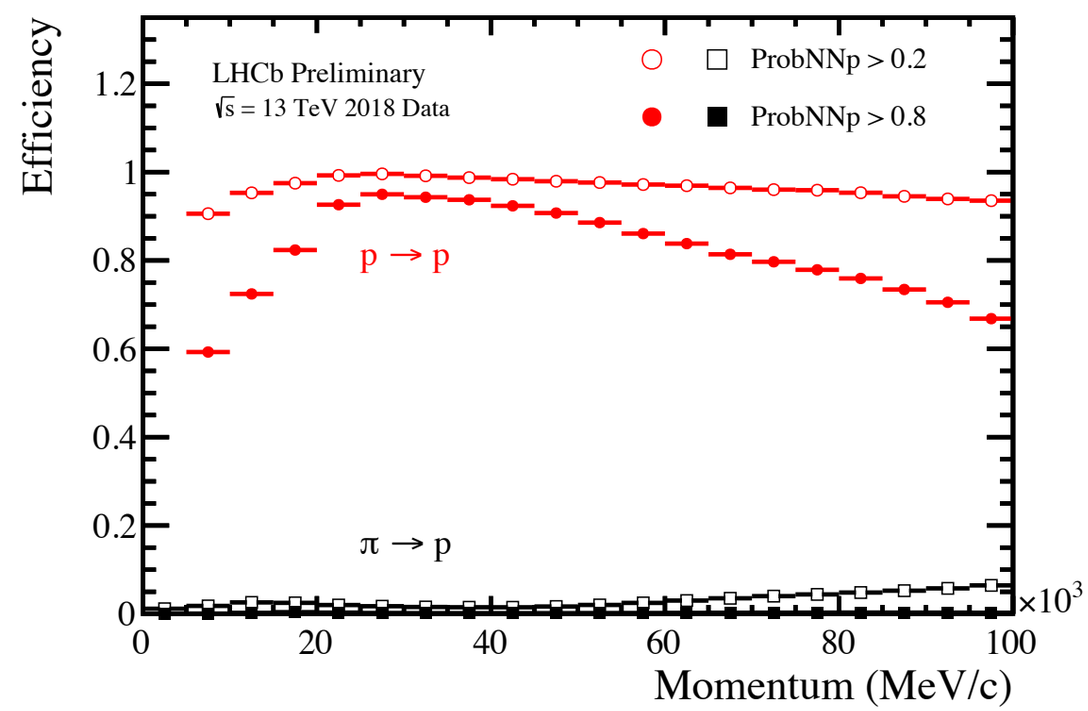
LHCb–FIGURE-2020-012

NEW!







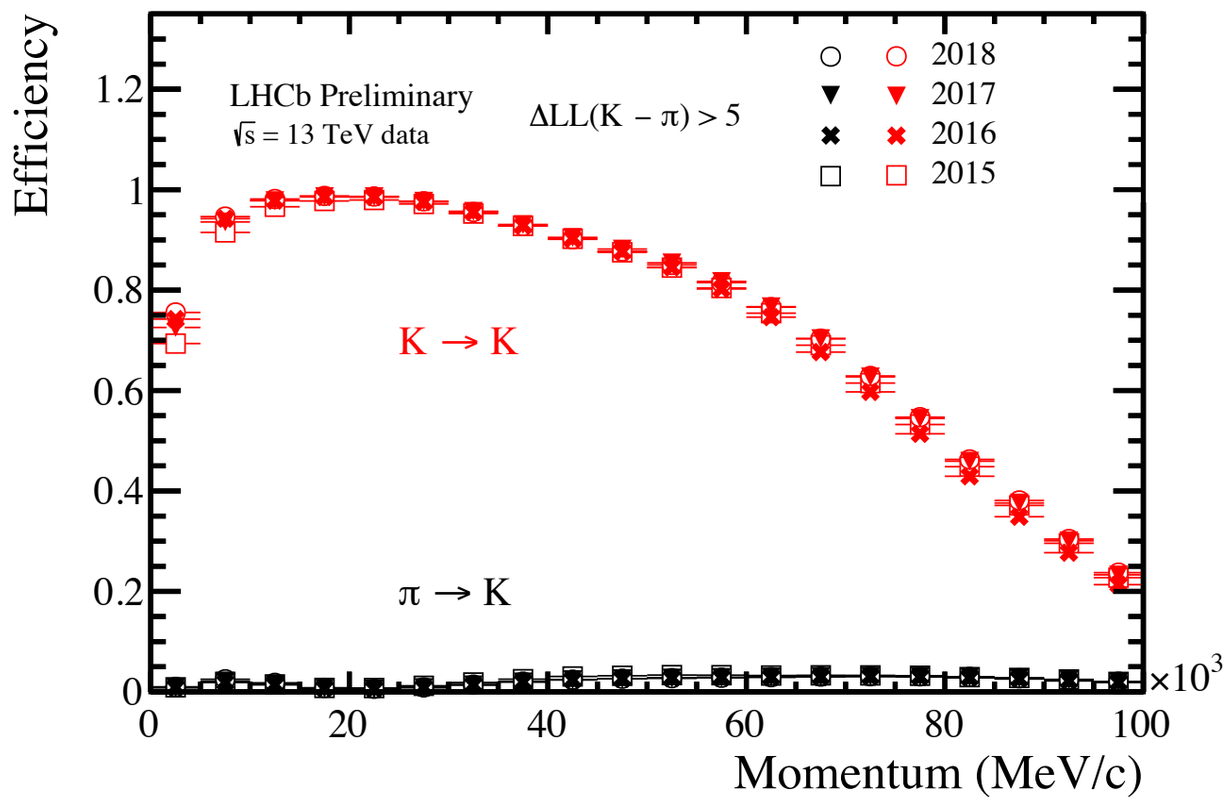


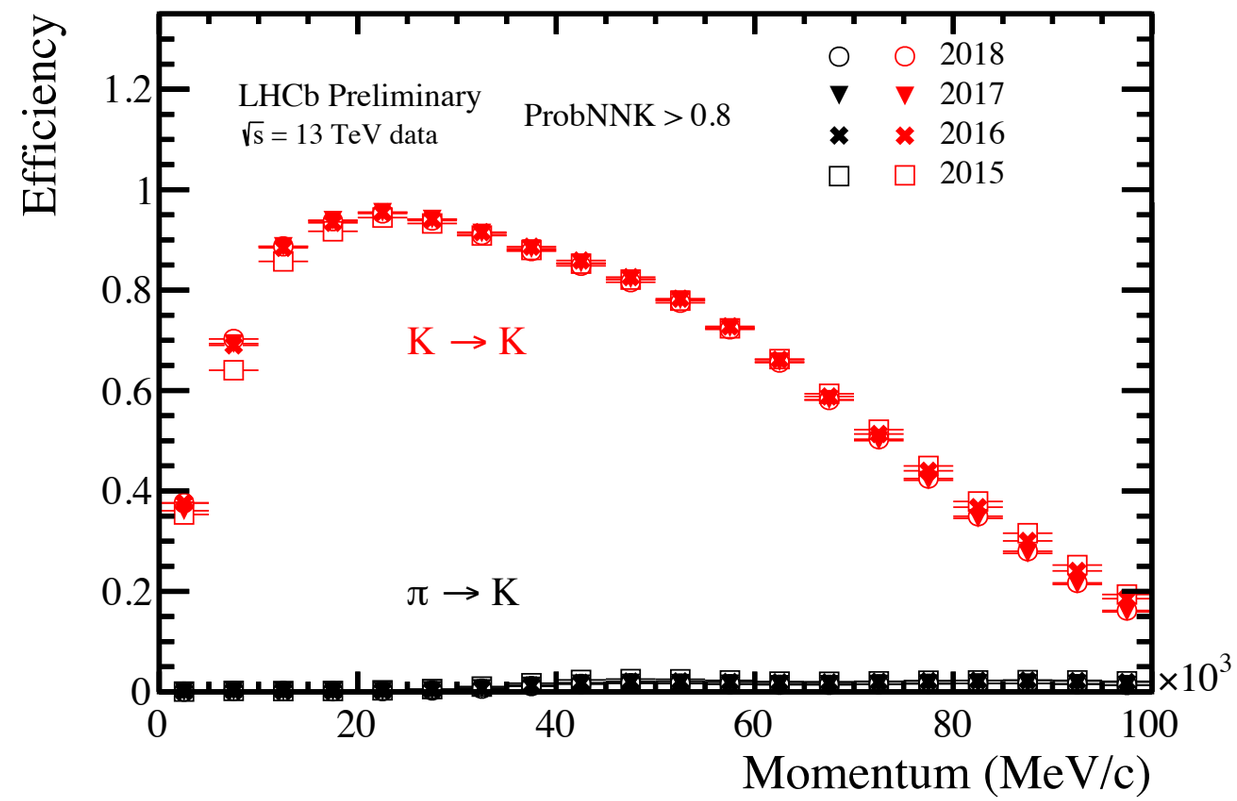
PID efficiencies - charged

LHCb–FIGURE-2020-012

NEW!

- Performance over the years:





Neutral PID performance

LHCb-PUB-2015-016-1

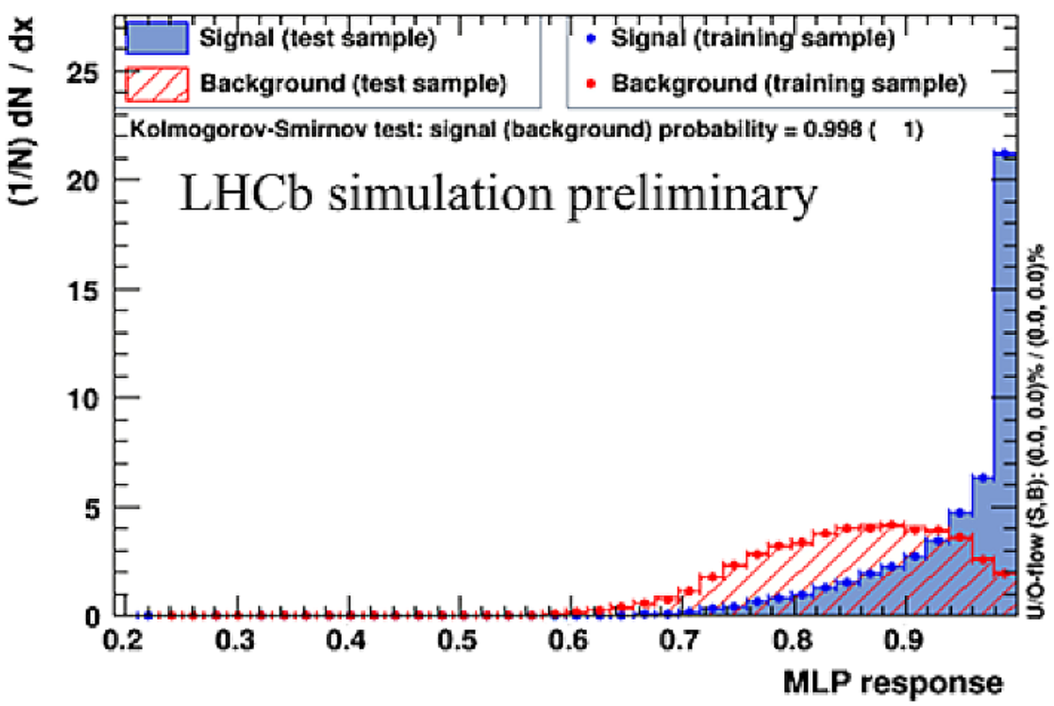
3 Neutral Networks trained on simulation to separate:

- γ from e^+, e^- $\longrightarrow$ `IsNotE`
- γ from hadrons $\longrightarrow$ `IsNotH`
- γ from π^0 $\longrightarrow$ `IsPhoton`

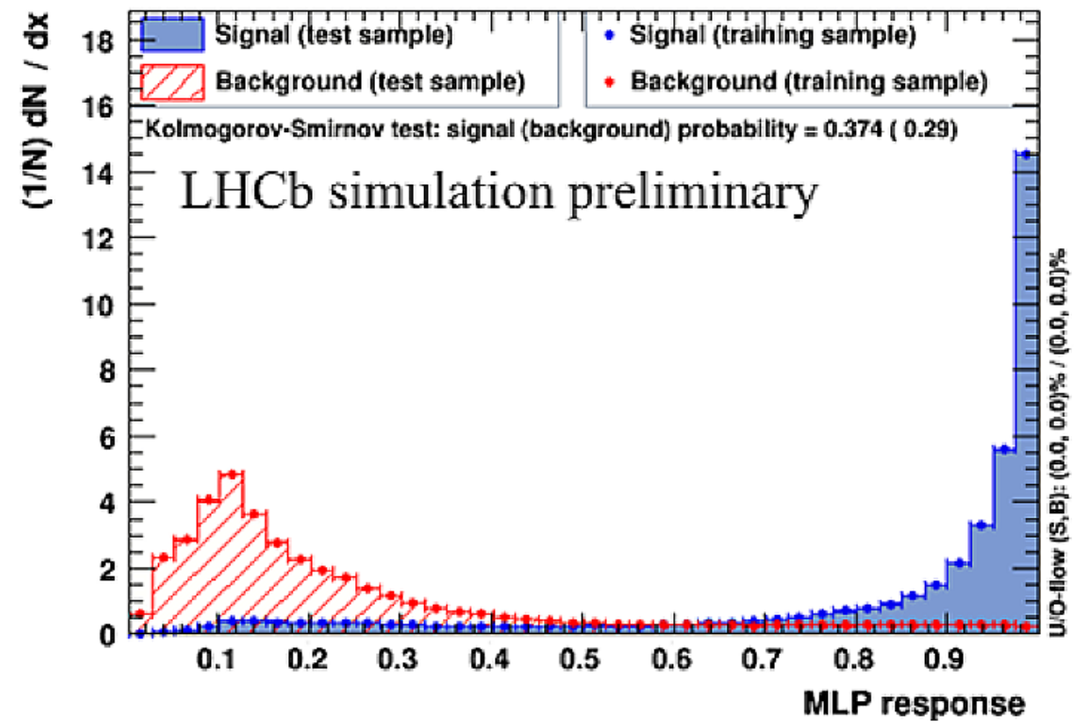
γ, π^0 calibration samples in Run 2

Species	Low momentum	High momentum
π^0		$D^{*+} \to D^0(\to K^-\pi^+\pi^0)\pi^+$
γ	$D_s^{*+} \to D_s^+\gamma$, $D_{(s)}^+ \to \eta'(\to \pi^+\pi^-\gamma)$	$B^0 \to K^*\gamma$, $B_s \to \phi\gamma$

`IsNotE` Signal: photons
Background: electrons



`IsNotH` Signal: photons
Background: non-em particles



LHCb–FIGURE-2020-011 - in preparation

Summary

- Precise alignment & calibration + particle identification is crucial at LHCb
- Novel computing strategy in Run 2 :
  - First experiment with a real-time calibration, alignment and reconstruction of the full detector
  - Offline data quality achieved online
  - Dedicated streams for selection of high statistics/purity calibration samples
- Muon tracking efficiencies well above 95%
- Dedicated strategy for electron reconstruction efficiencies
- Excellent PID performance during Run 2, providing the basis for Run 3

Summary

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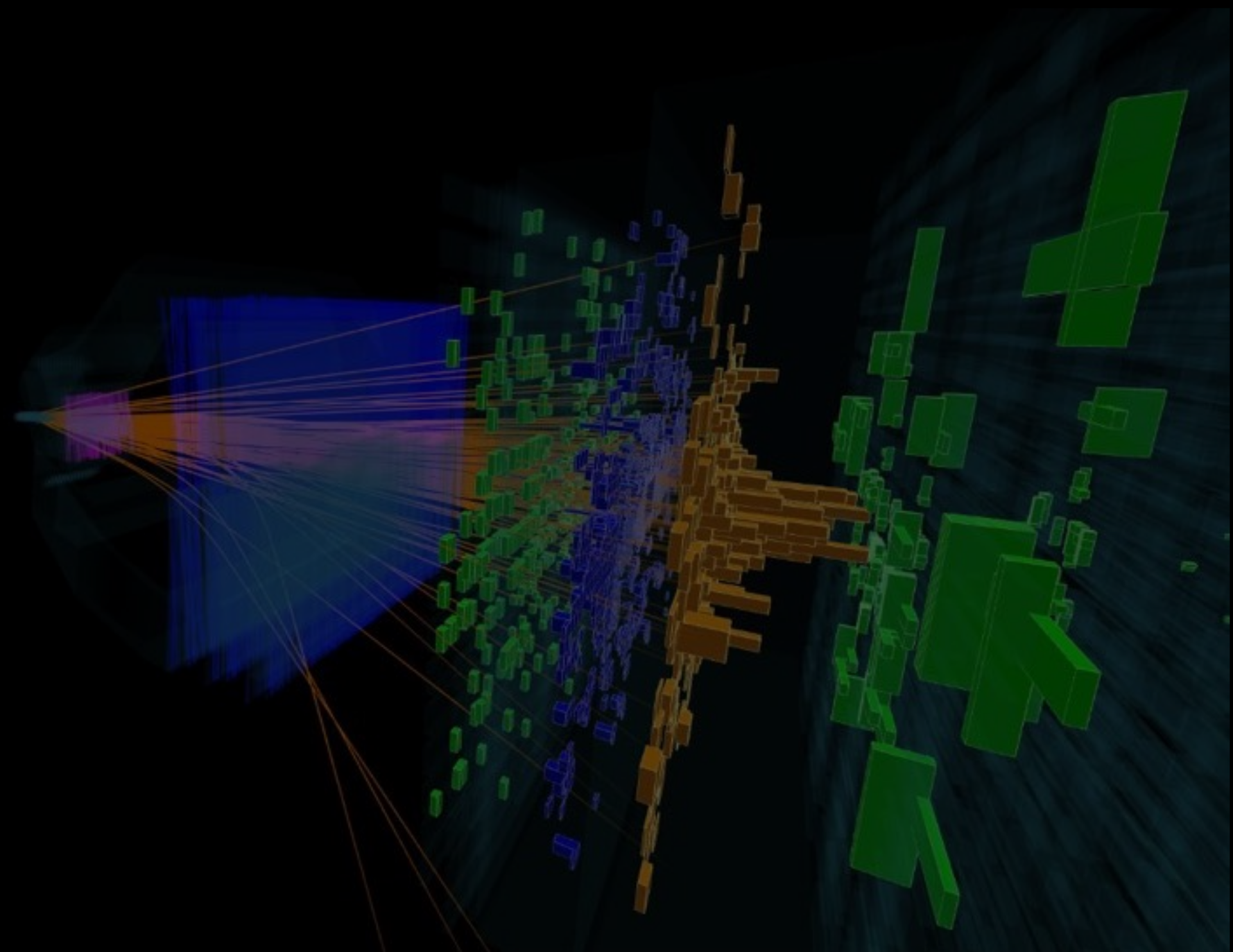
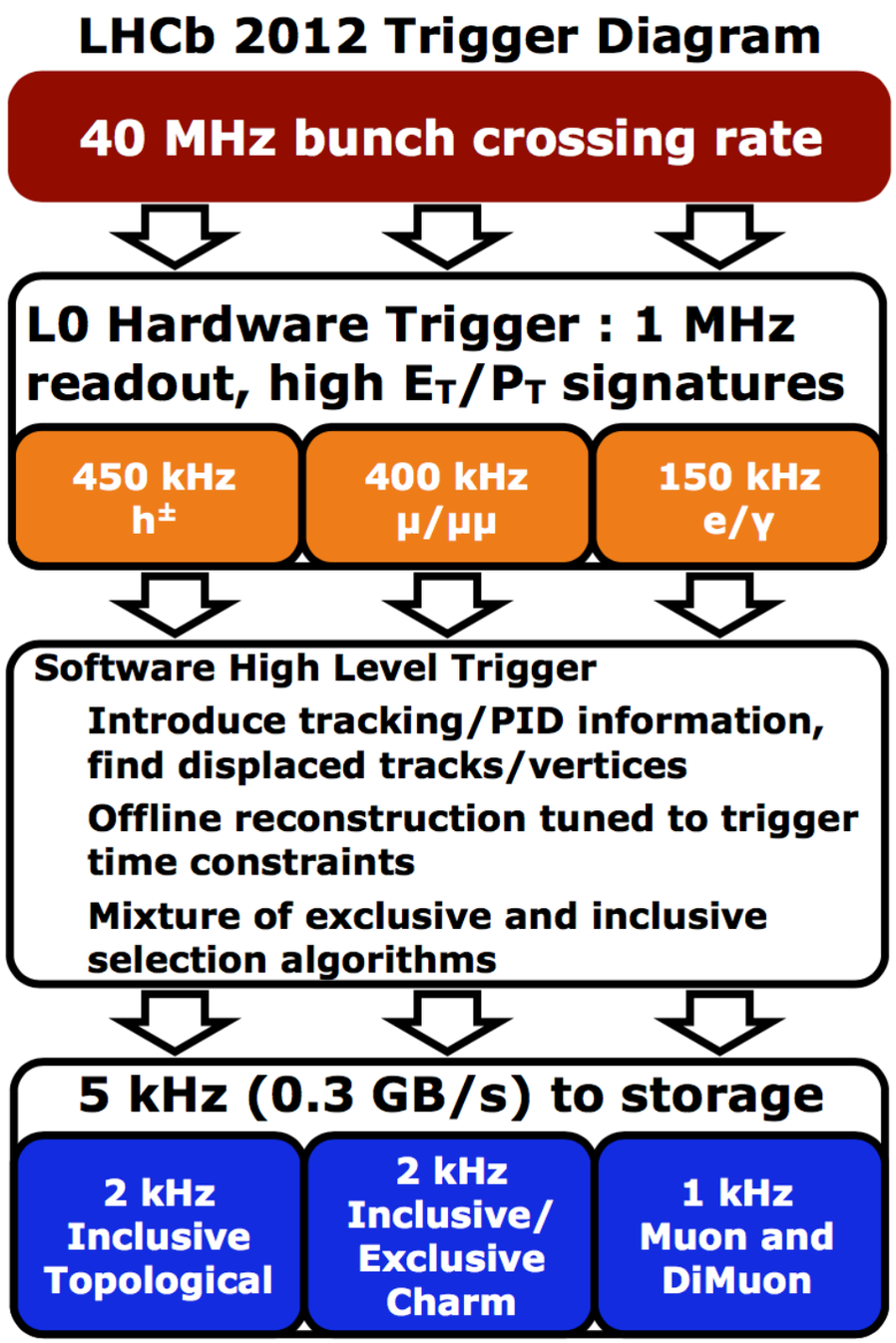
STAY TUNED FOR THE UPCOMING TALKS!

Backup



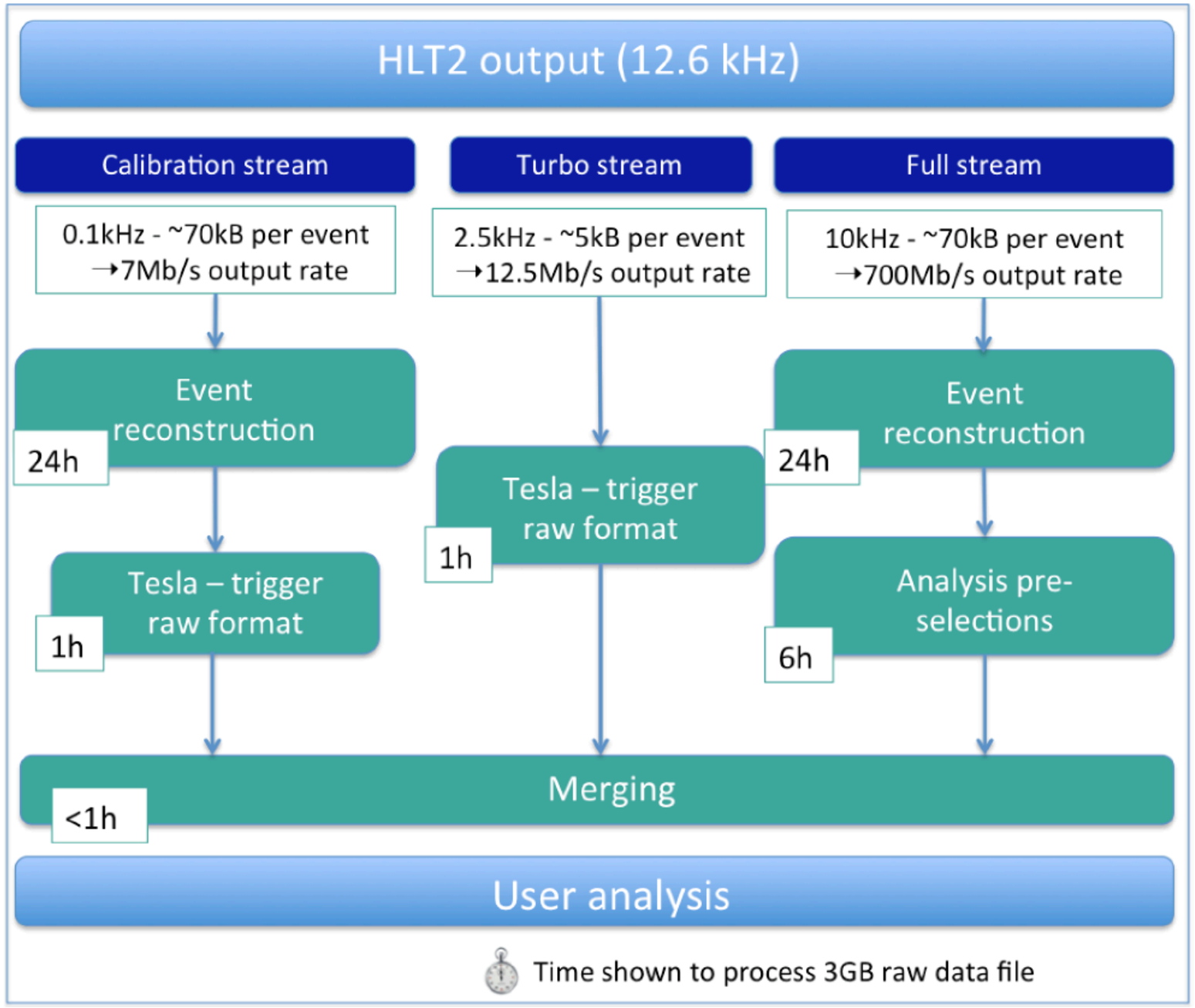
The LHCb Trigger in Run 1



Offline and online reconstruction do not match:

- At the trigger level only preliminary detector alignment and calibration, track reconstruction and PID
- Full alignment and calibration, tracking and PID information available only **offline**

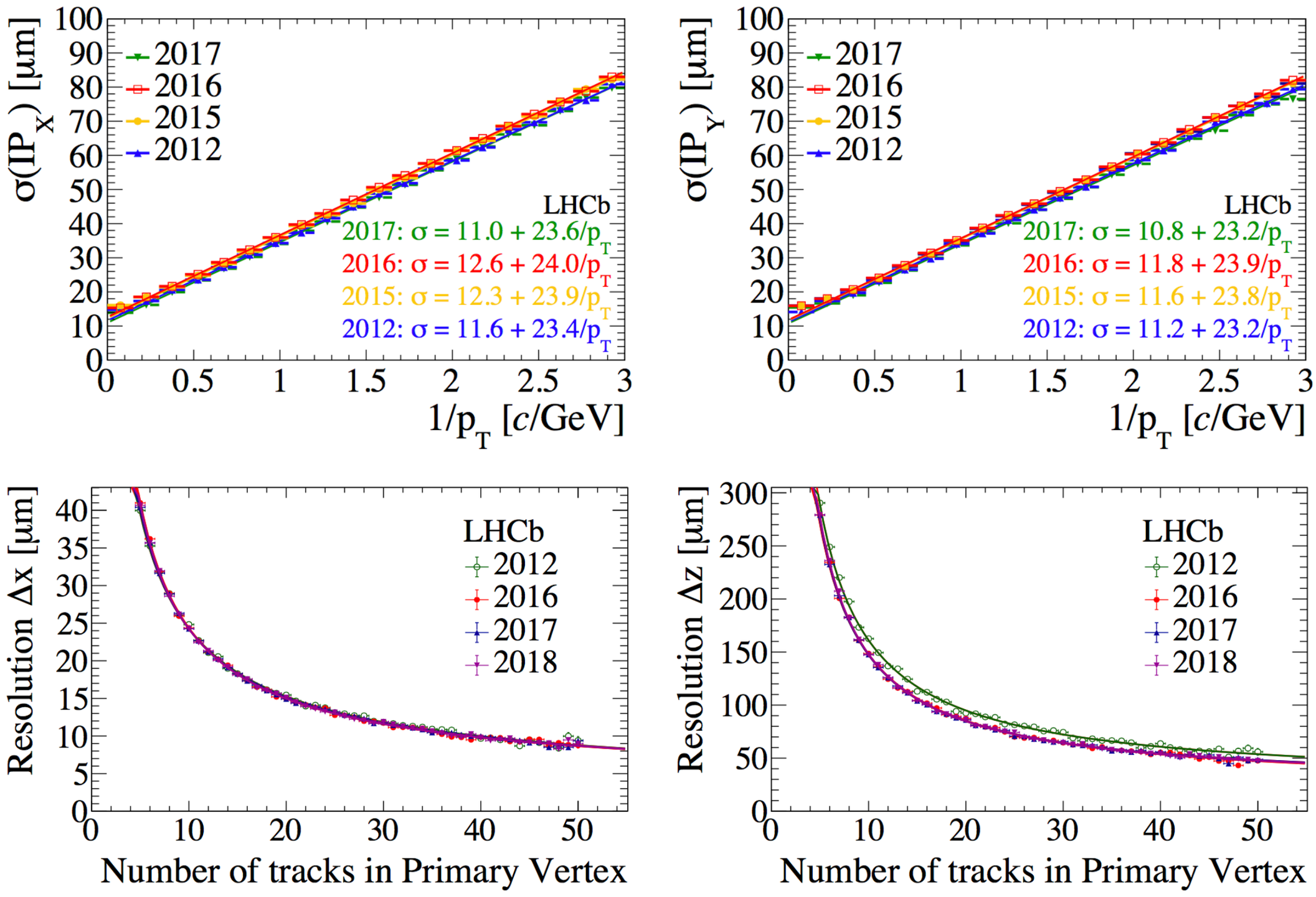
Run 2 trigger physics streams



Comput.Phys.Commun. 208 (2016) 35-42

VELO reconstruction

JINST 14 (2019) 04, P04013

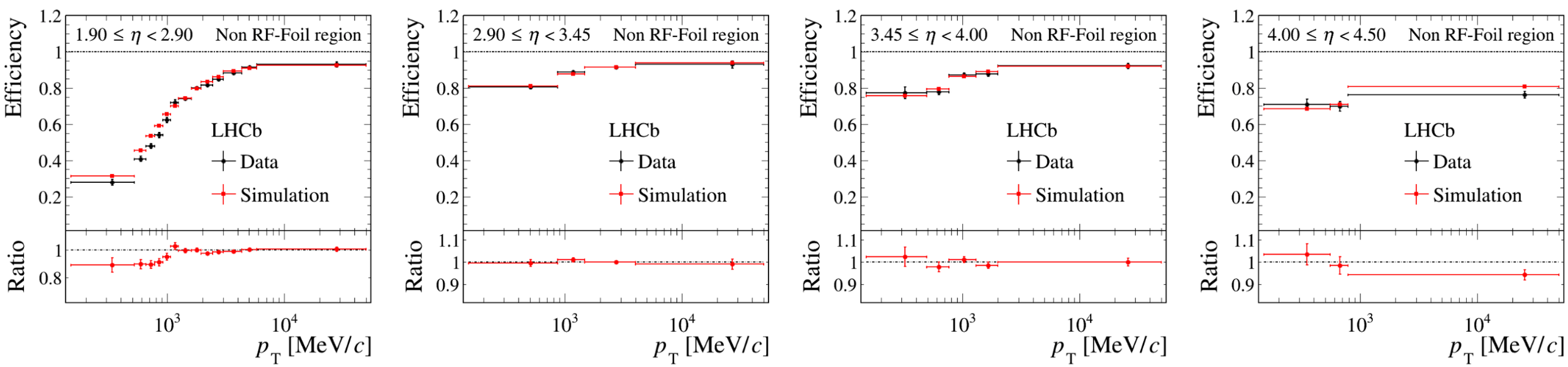


Electron reconstruction efficiencies

JINST 14 (2019) P11023

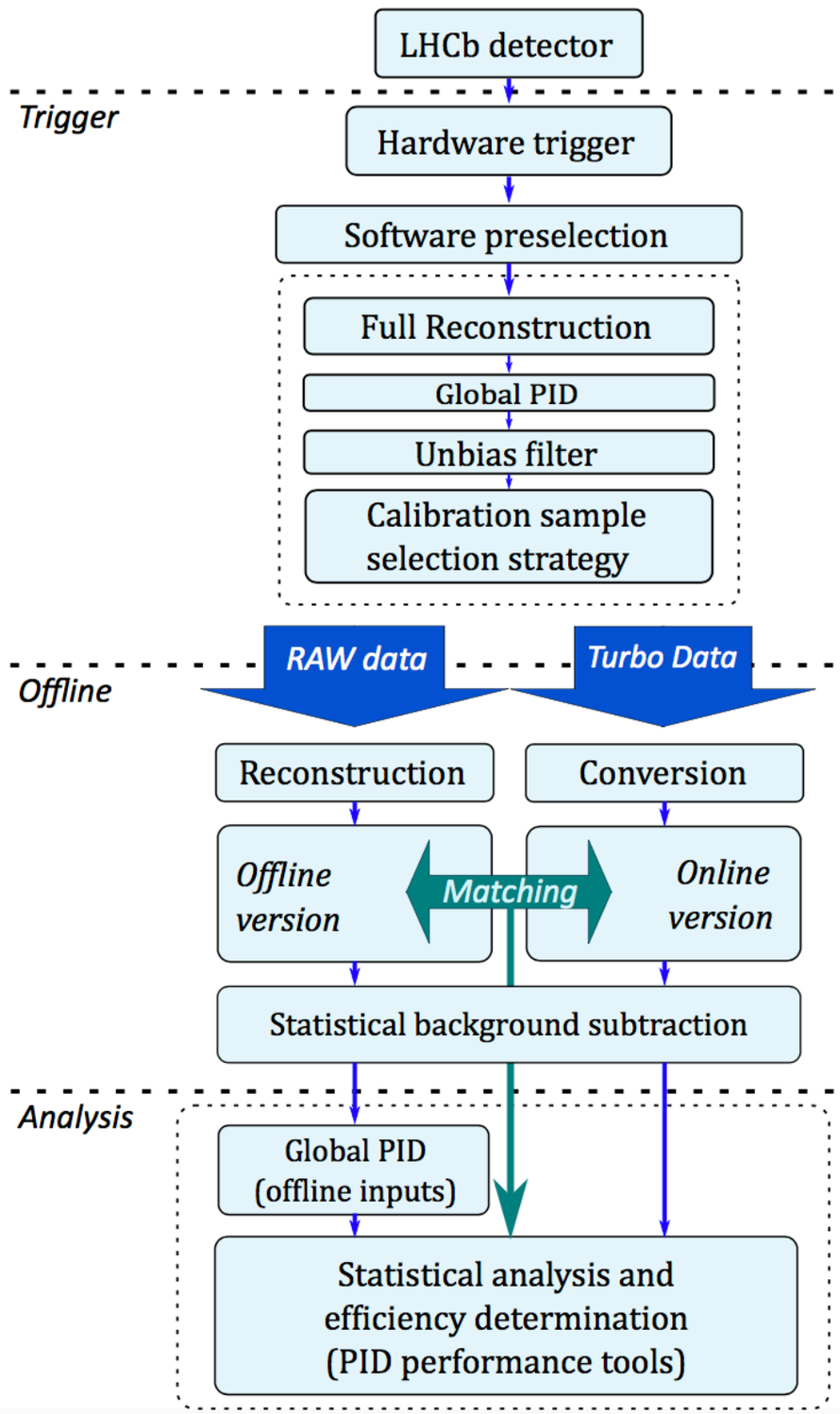
- Electron probe reconstructed using only VELO tracks
- Probe momentum inferred by kinematic and geometric constraints
- Fit to the $e^+e^- K^+$ invariant mass, with J/ψ mass constraint allows good signal/background separation

Split in **RF foil - non RF foil** region because of different amount of traversed material



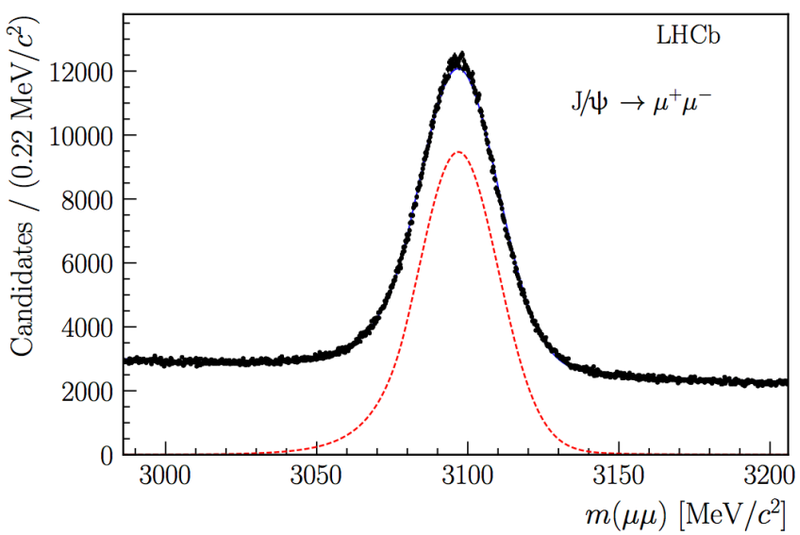
Computing model for PID calibration samples

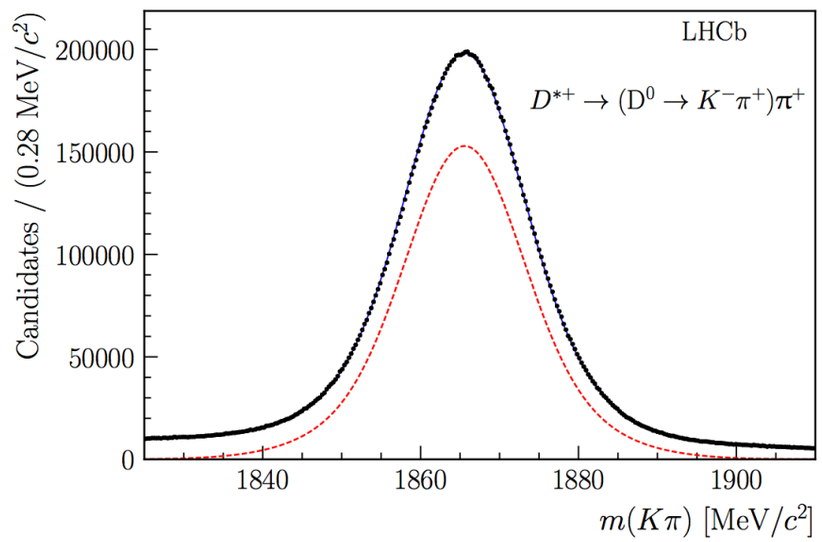
CERN-LHCb–DP-2018-001

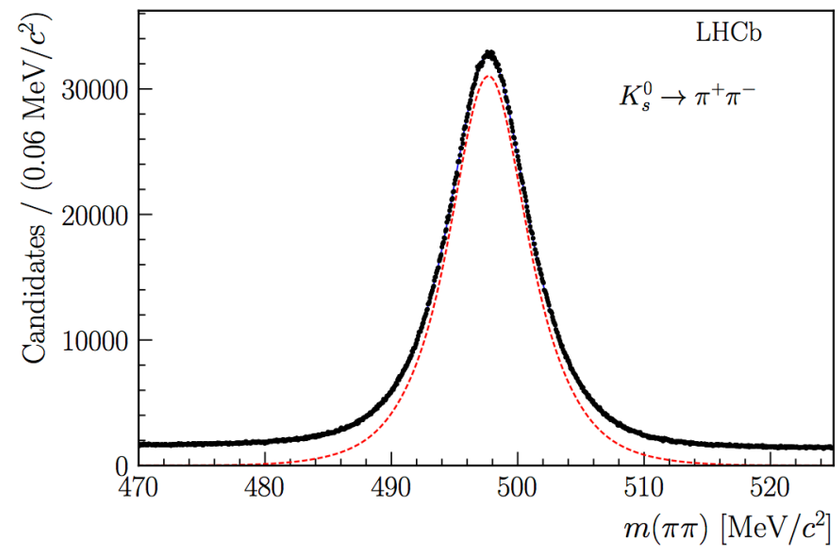


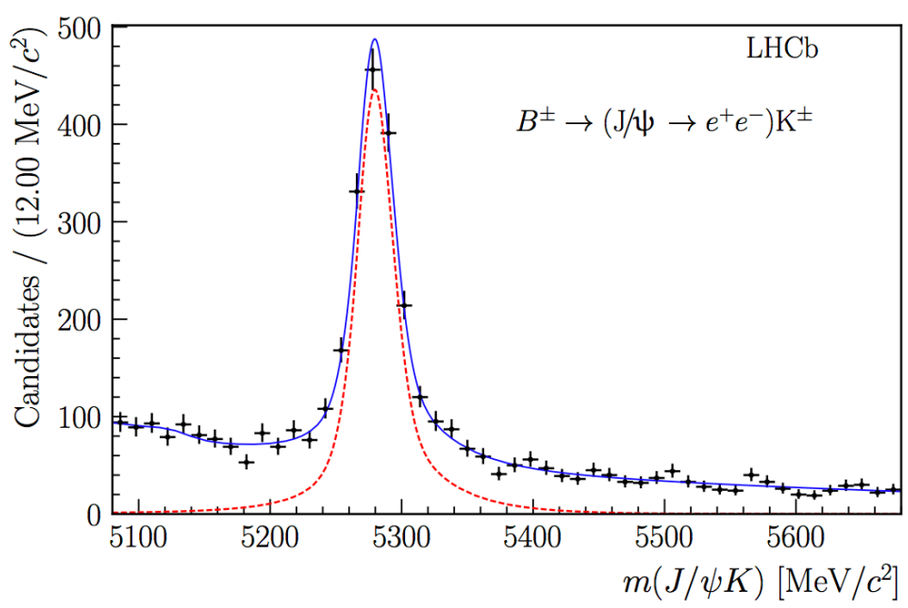
PID calibration samples

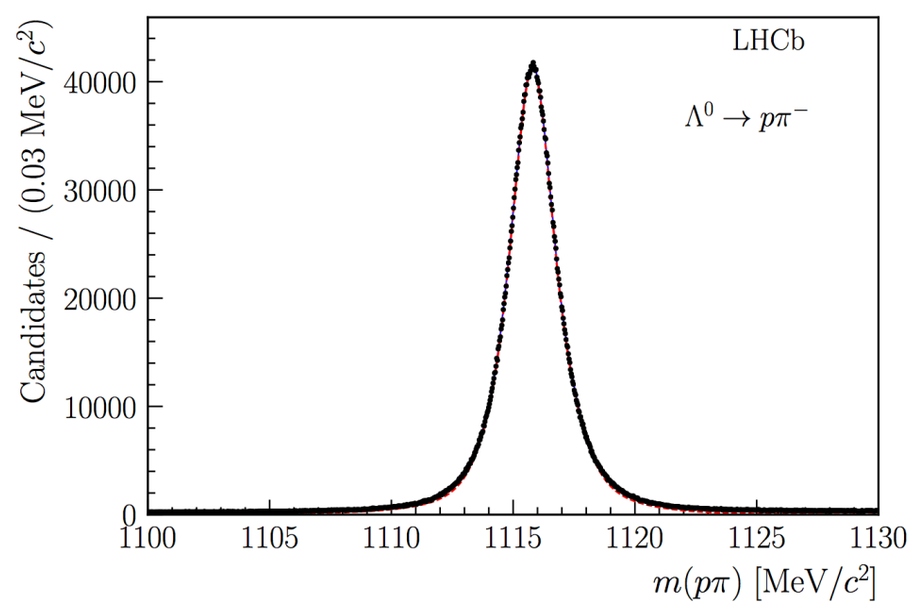
CERN-LHCb–DP-2018-001



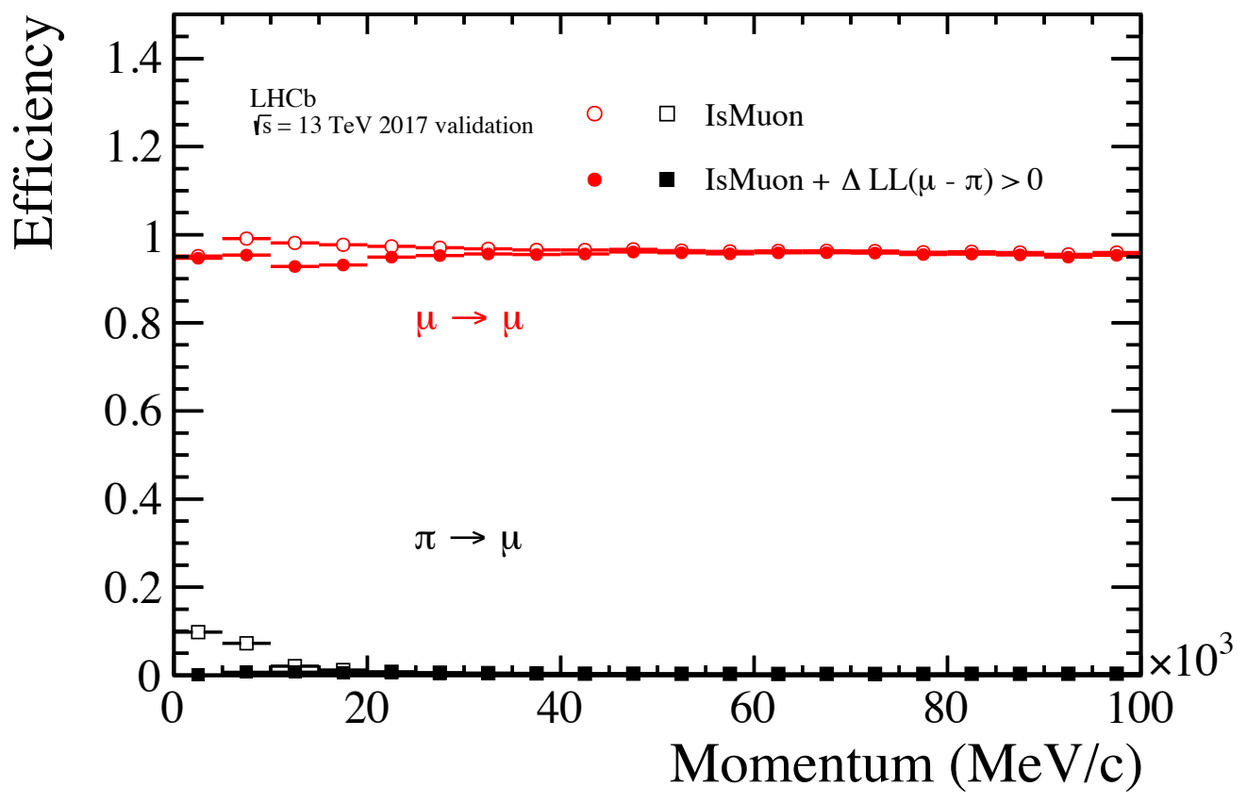


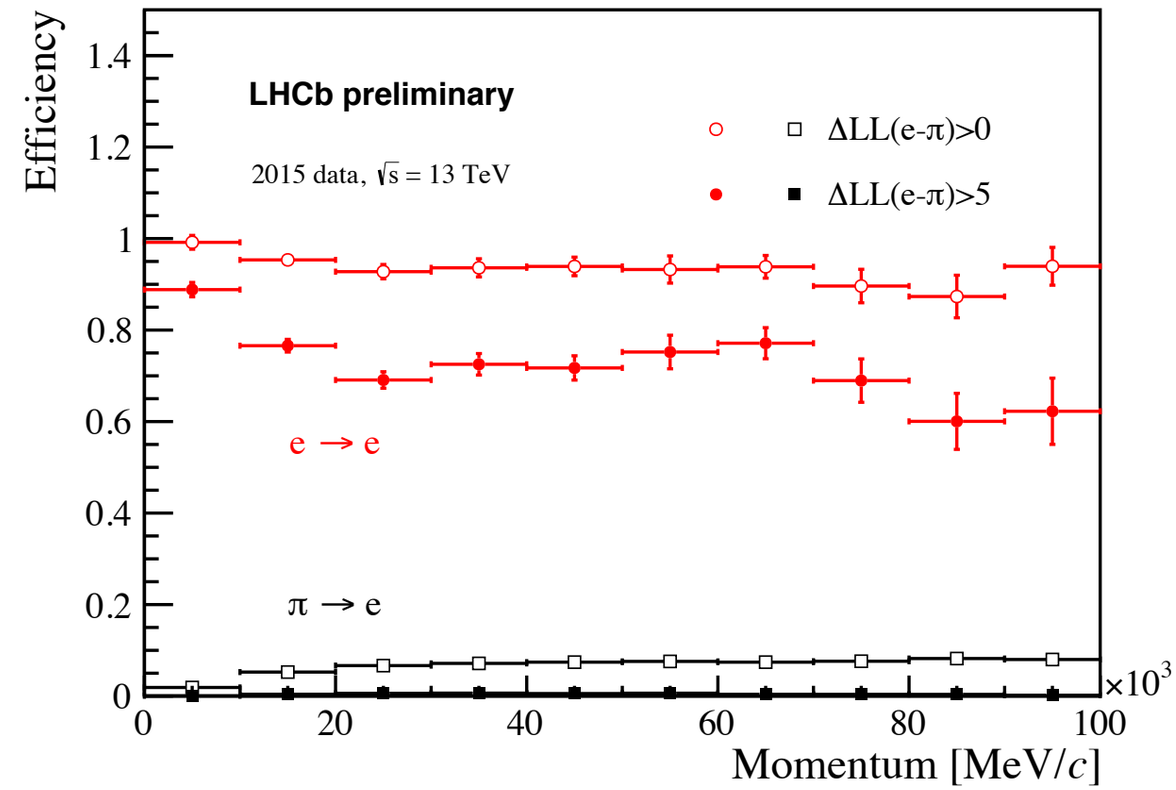






PID efficiencies - charged leptons





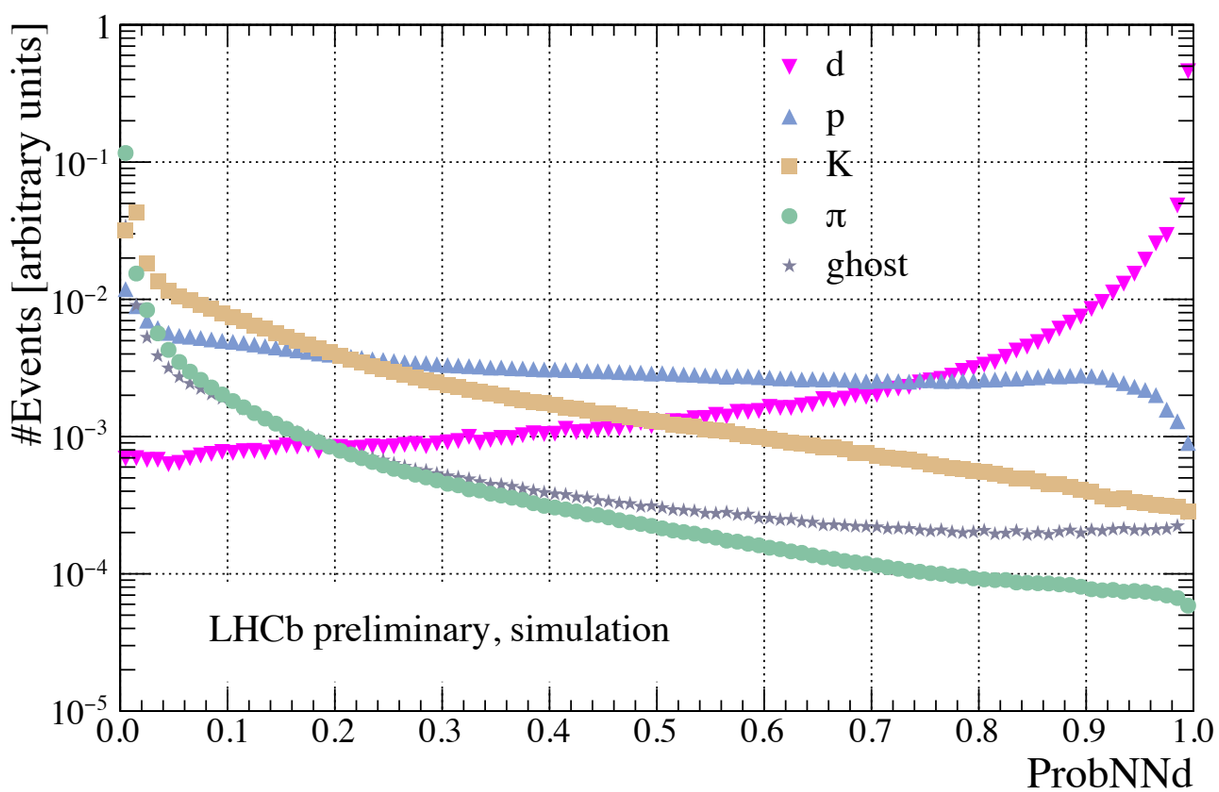
LHCb–FIGURE-2020-012 - in preparation

Deuteron PID performance

LHCb-FIGURE-2020-013

- Measurements of antideuteron production could help to improve the sensitivity of indirect Dark Matter searches
- Dedicated `ProbNN` and `DLL` classifiers recently developed

`ProbNNd` distributions from charged tracks from simulation



Deuterons from $\Lambda_b^0 \to d\overline{p}$

Other tracks from $\Lambda_c^+ \to pK^-\pi^+$