Novel Real-time Calibration and Alignment Procedure for LHCb Run II

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University of Bristol
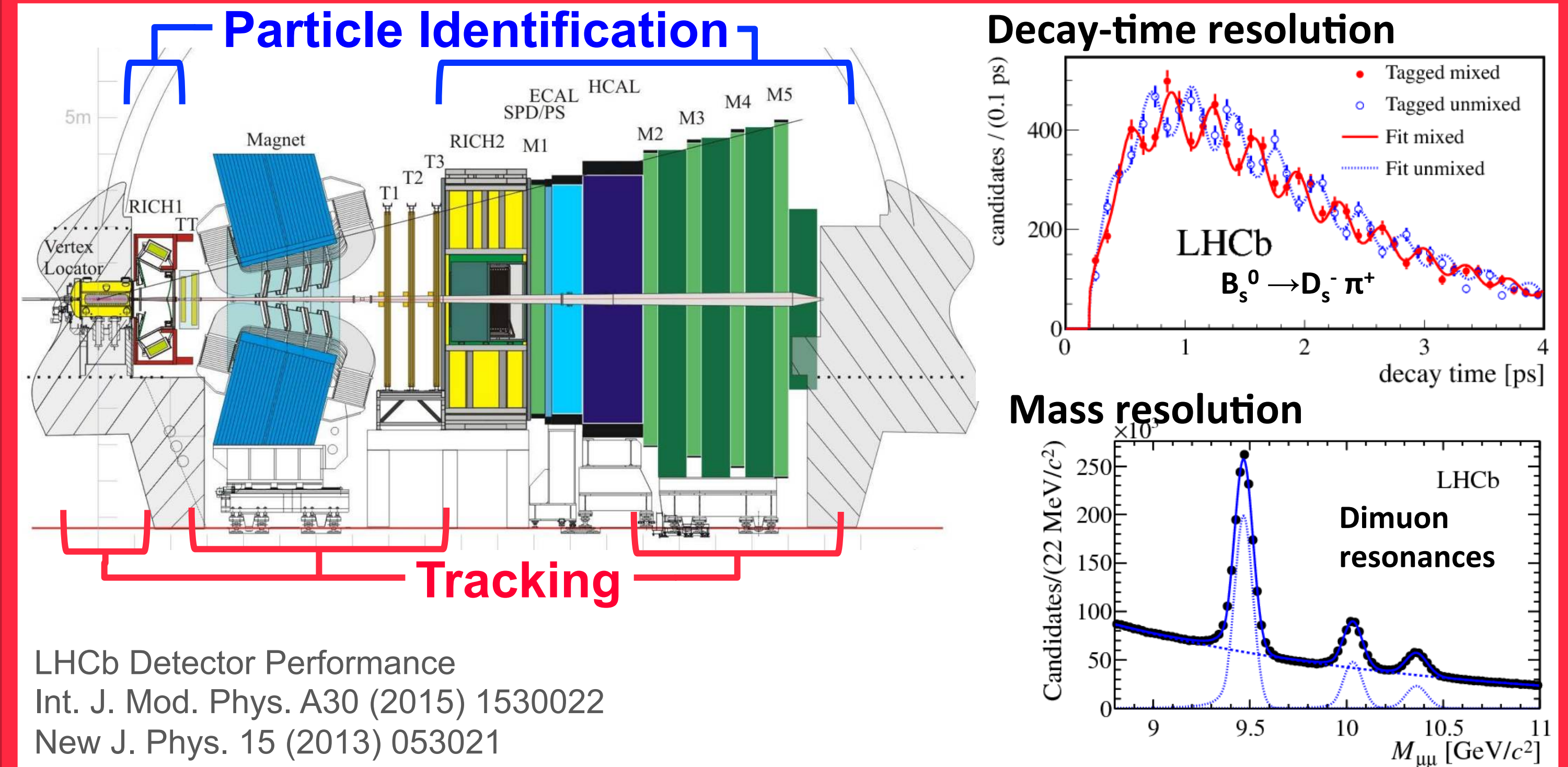
New challenges in Run II

- Increase in energy:
  $\sqrt{s}$ = 7(8) TeV $\Rightarrow$ 13 TeV
- 15% increase of inelastic collision rate
- 20% increase of multiplicity per collision
- 60% increase of $\sigma_{b\bar{b}}$ and $\sigma_{c\bar{c}}$
- Reduced bunch spacing:
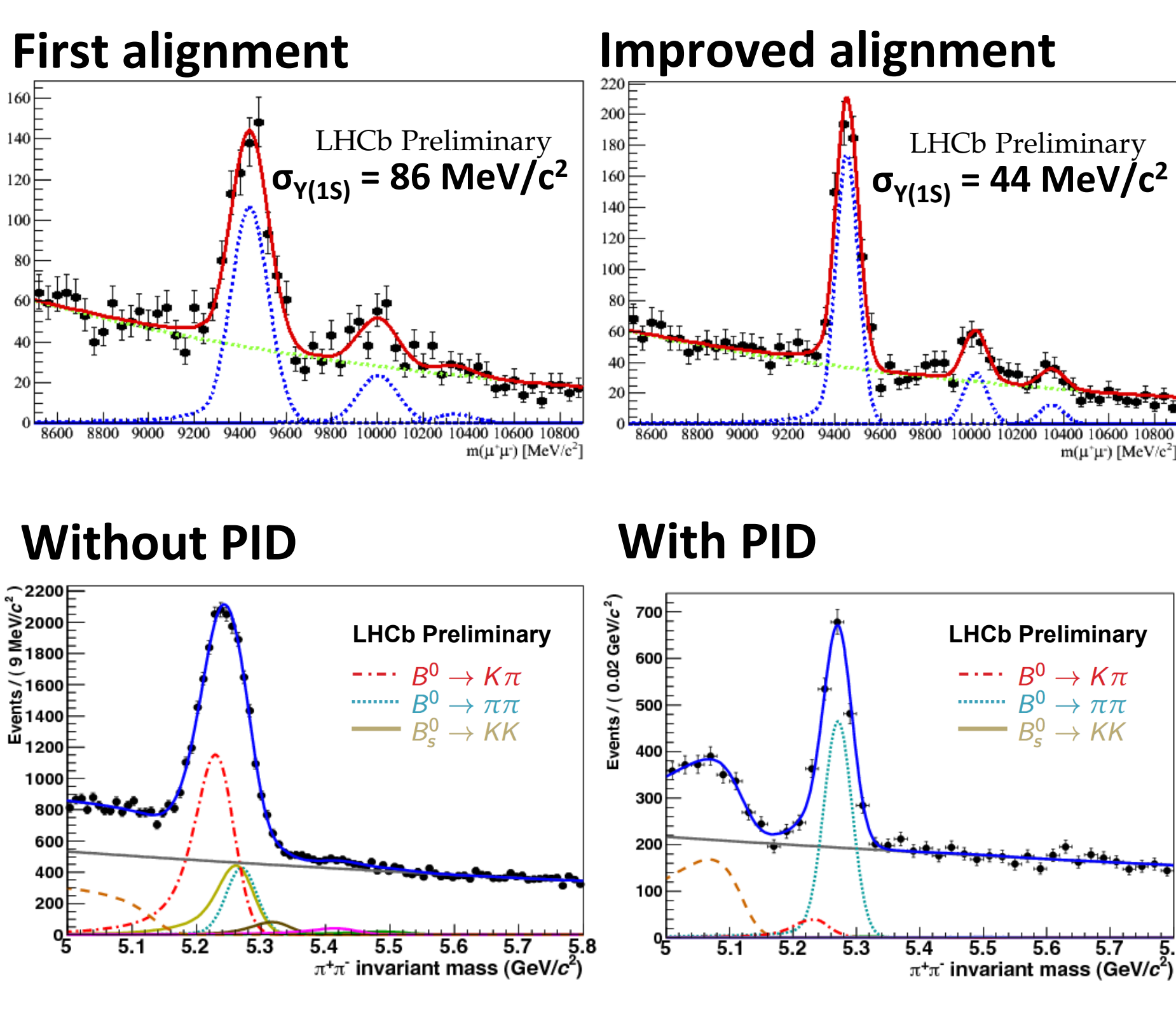 50 ns $\Rightarrow$ 25 ns

Real Time Alignment and Calibration

- Stable quality of alignment and calibration
- Particle identification useable in the high level trigger (HLT)
- Overall improved trigger efficiency
- No more differences between online and offline
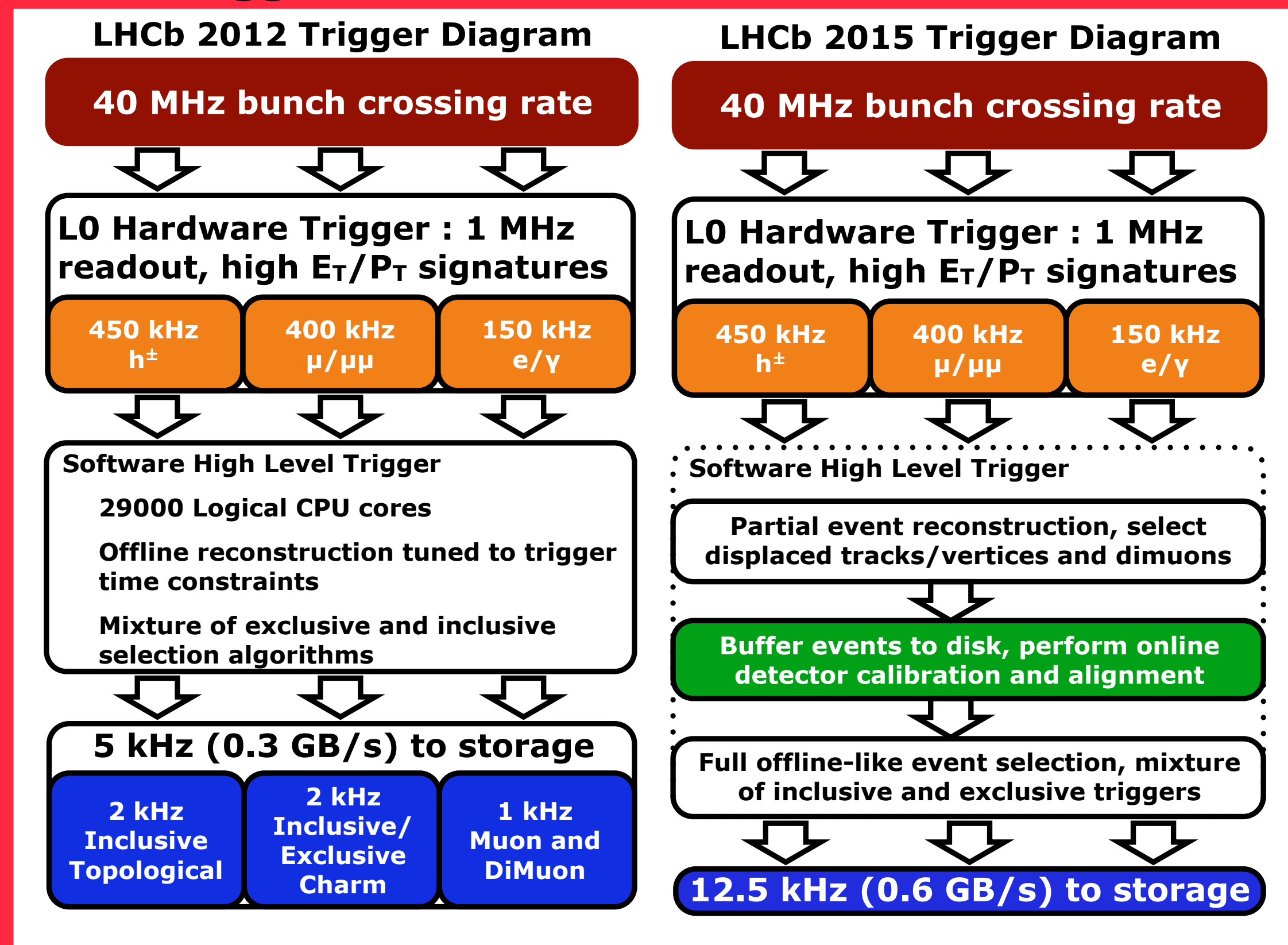- Physics analysis directly on trigger output (Turbo Stream)

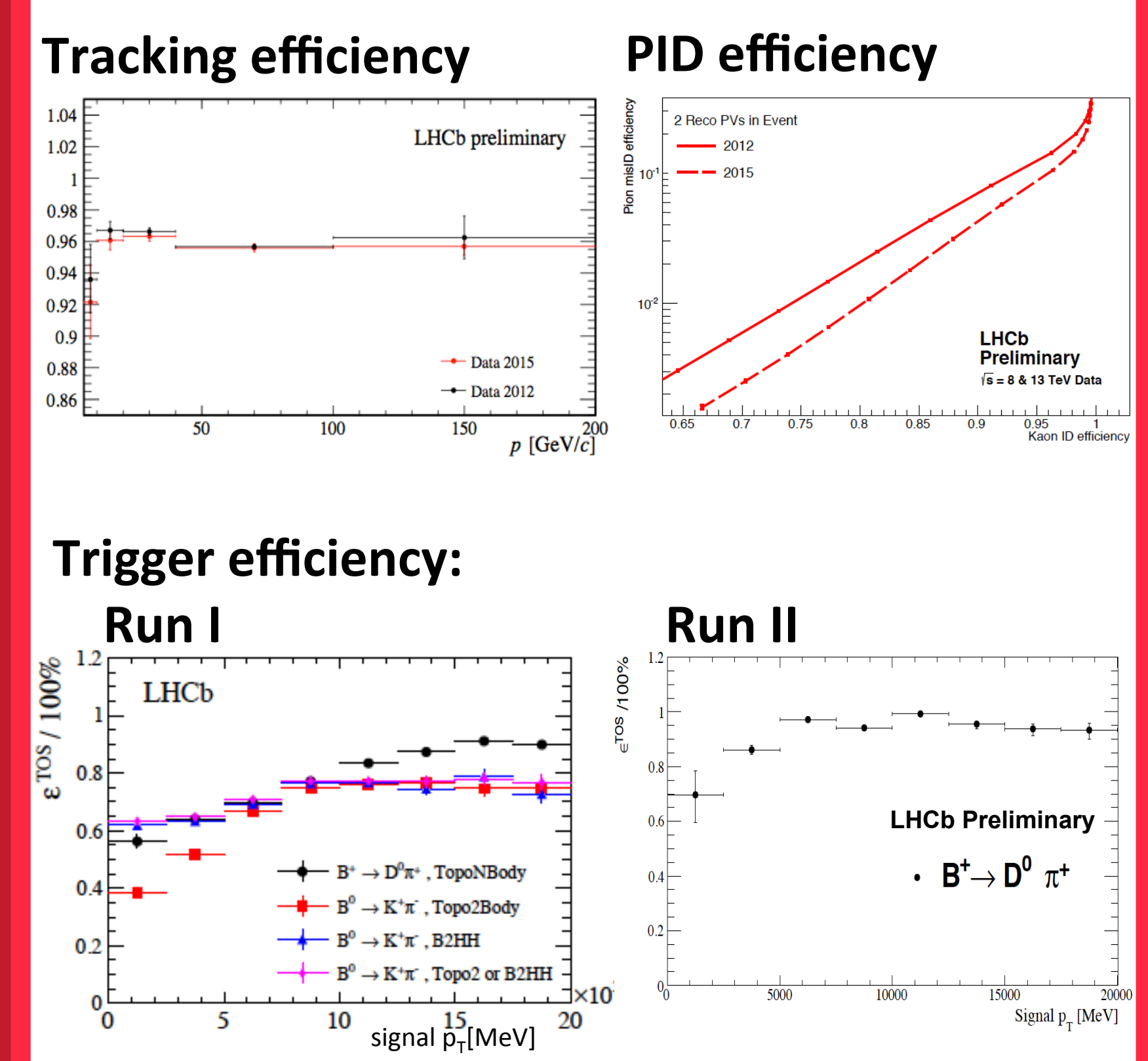## Performance of the LHCb Detector

LHCb Detector Performance
Int. J. Mod. Phys. A30 (2015) 1530022
New J. Phys. 15 (2013) 053021

Decay-time resolution

Mass resolution

Impact on Physics

First alignment

Improved alignment

Without PID

With PID

LHCb Trigger Schemes

LHCb 2012 Trigger Diagram

- **40 MHz bunch crossing rate**
- **L0 Hardware Trigger : 1 MHz readout, high E_T/P_T signatures**
  - 450 kHz $h^{\pm}$
  - 400 kHz $\mu/\mu\mu$
  - 150 kHz e/γ
- **Software High Level Trigger**
  - 29000 Logical CPU cores
  - Offline reconstruction tuned to trigger time constraints
  - Mixture of exclusive and inclusive selection algorithms
- **5 kHz (0.3 GB/s) to storage**
  - 2 kHz Inclusive Topological
  - 2 kHz Inclusive/ Exclusive Charm
  - 1 kHz Muon and DiMuon

LHCb 2015 Trigger Diagram

- **40 MHz bunch crossing rate**
- **L0 Hardware Trigger : 1 MHz readout, high E_T/P_T signatures**
  - 450 kHz $h^{\pm}$
  - 400 kHz $\mu/\mu\mu$
  - 150 kHz e/γ
- **Software High Level Trigger**
  - Partial event reconstruction, select displaced tracks/vertices and dimuons
  - Buffer events to disk, perform online detector calibration and alignment
  - Full offline-like event selection, mixture of inclusive and exclusive triggers
- **12.5 kHz (0.6 GB/s) to storage**

Performance in Run II

Tracking efficiency

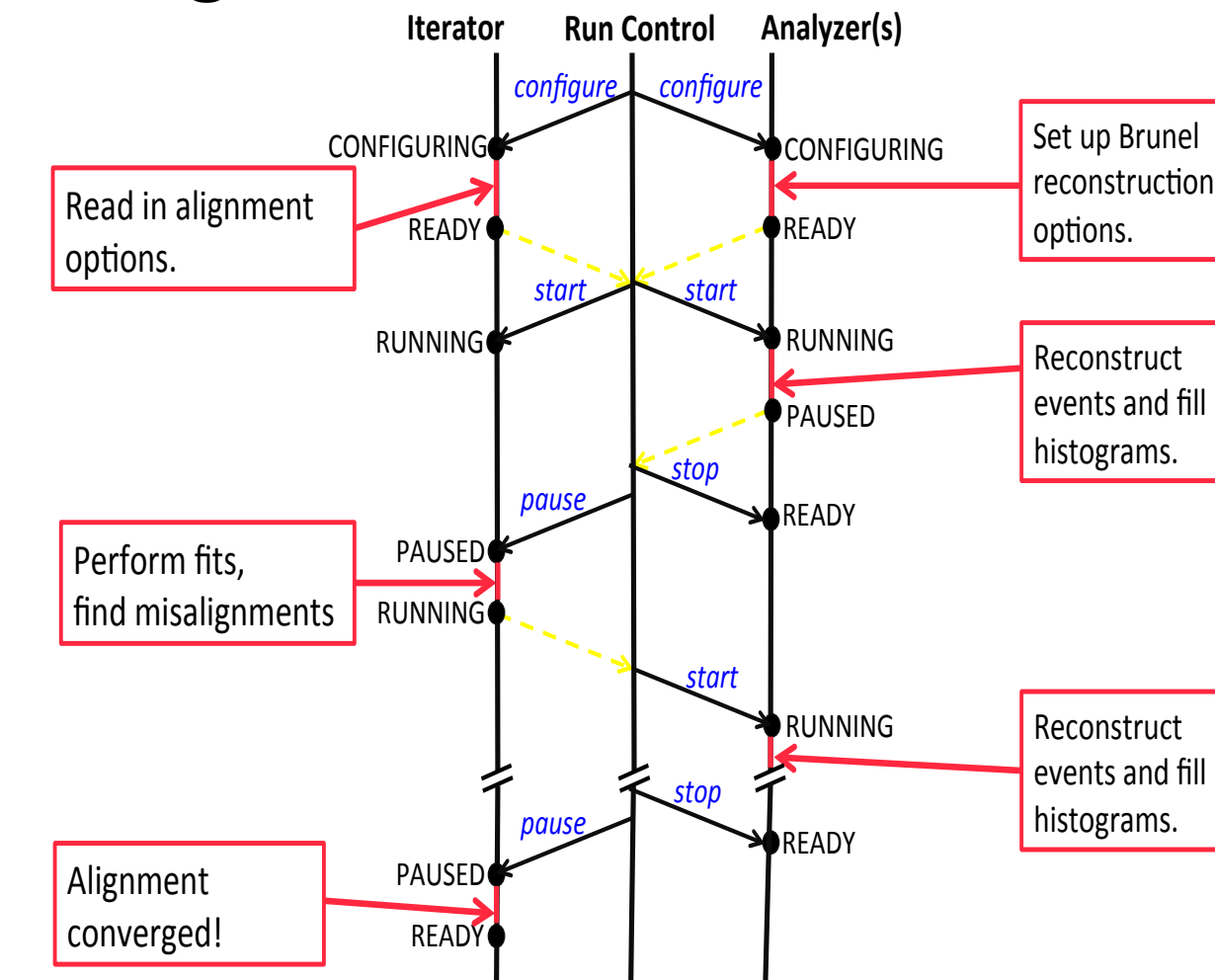
PID efficiency

Trigger efficiency:

Run I

Run II

Dedicated Framework and Procedure

- Alignments performed for each fill
- Dedicated trigger line for each task
- Event reconstruction parallelised on *analysers* (1700 nodes), computing of alignment constants by *iterator* (1 node)
- Calibrations on monitoring histograms
- VELO, Tracker & calibrations: automatic update of the constants if they differ by a given value
- RICH alignment & Muon alignment: monitoring mode

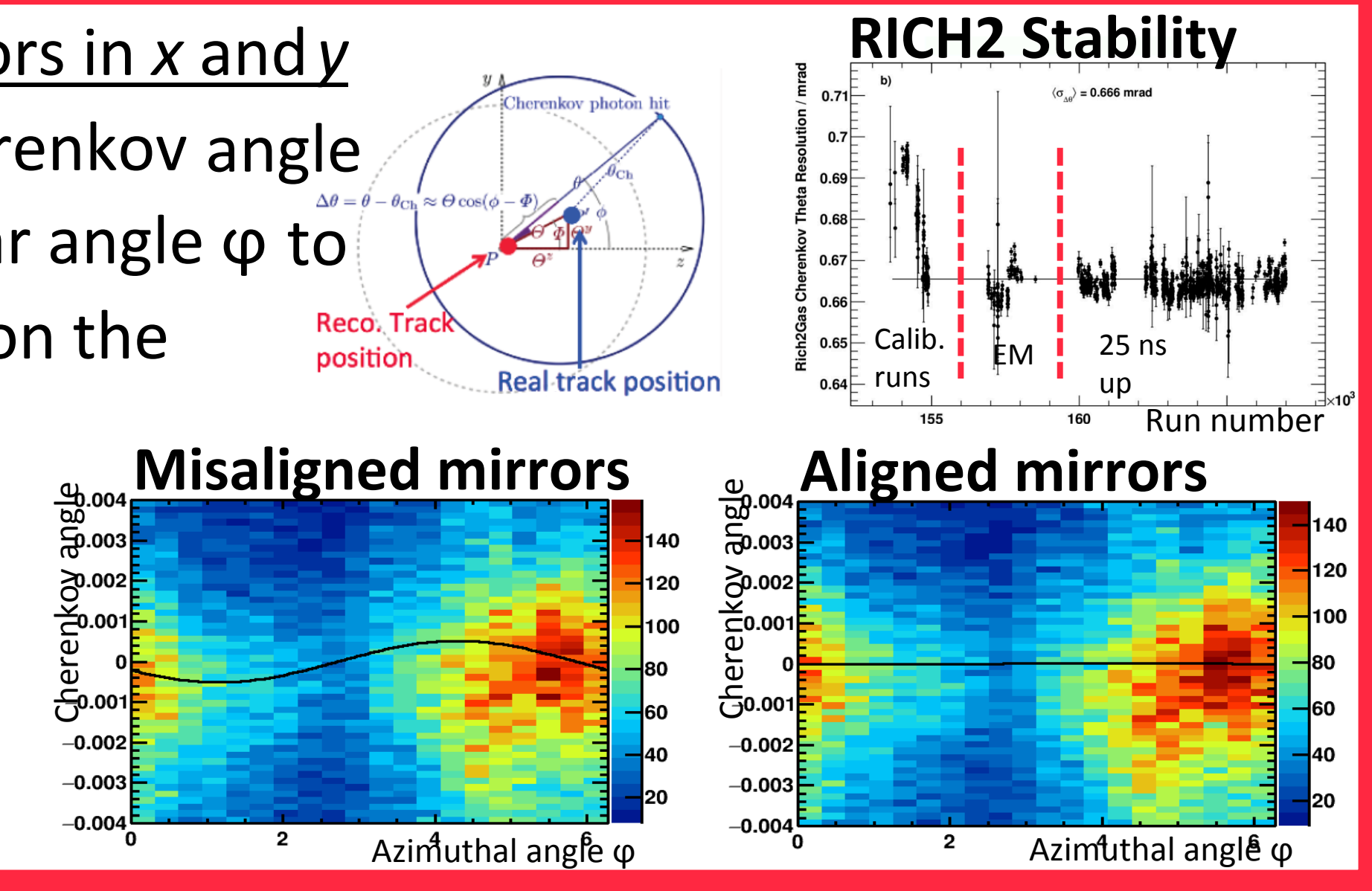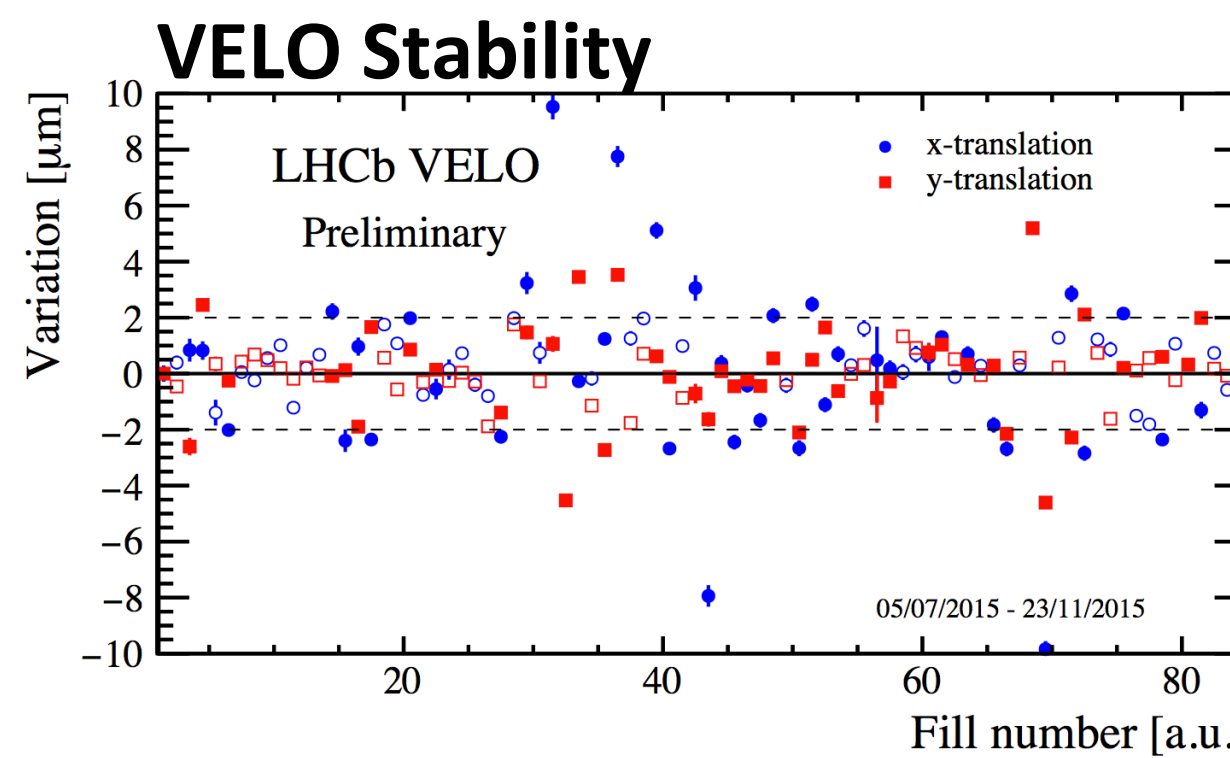### Example of alignment sequence using a Finite State Machine

Tracker Alignment: VELO, Tracker, Muon System

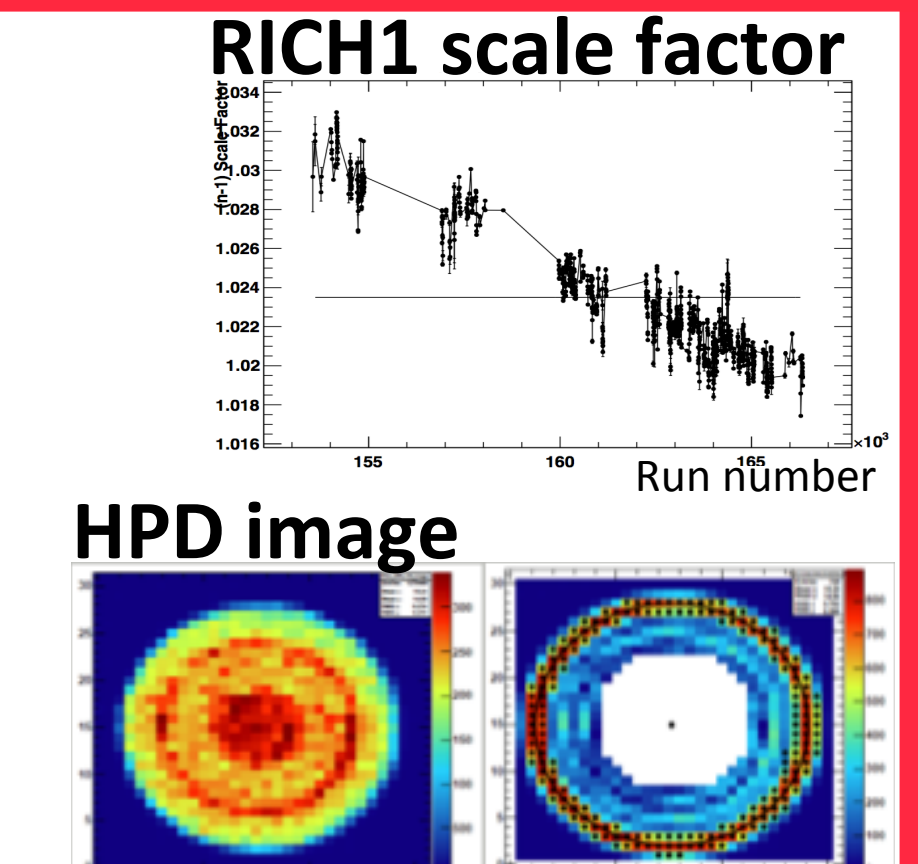Position and orientation of the full tracking system (700 elements)

Minimisation of residual of Kalman track fit using additional constraints

- Independent alignments:
- VELO: updated every $O(1)$ fills
- Tracker: updated every $O(1)$ weeks
- Muon: updated $O(1)$ per year
- ~7 minutes per task

VELO Stability

Outer Tracker Calibration

Global time alignment for all modules

- Fit the residual of the drift time to extract the global time delay t_0 caused by readout electronics $t_{meas} = t_0 + t_{flight} + t_{drift} + t_{prop}$
- Updated every $O(10)$ runs

OT Stability

RICH Mirror Alignment

Orientation of the RICH mirrors in x and y

- Fit the variation of the Cherenkov angle $\Delta\theta$ as a function of the polar angle φ to extract the misalignments on the detector plane (Θ_x, Θ_y)

  $$\Delta\theta = \Theta_x \sin\varphi + \Theta_y \cos\varphi$$

- Updated $O(10)$ per year
- ~30 minutes per task

RICH2 Stability

Misaligned mirrors
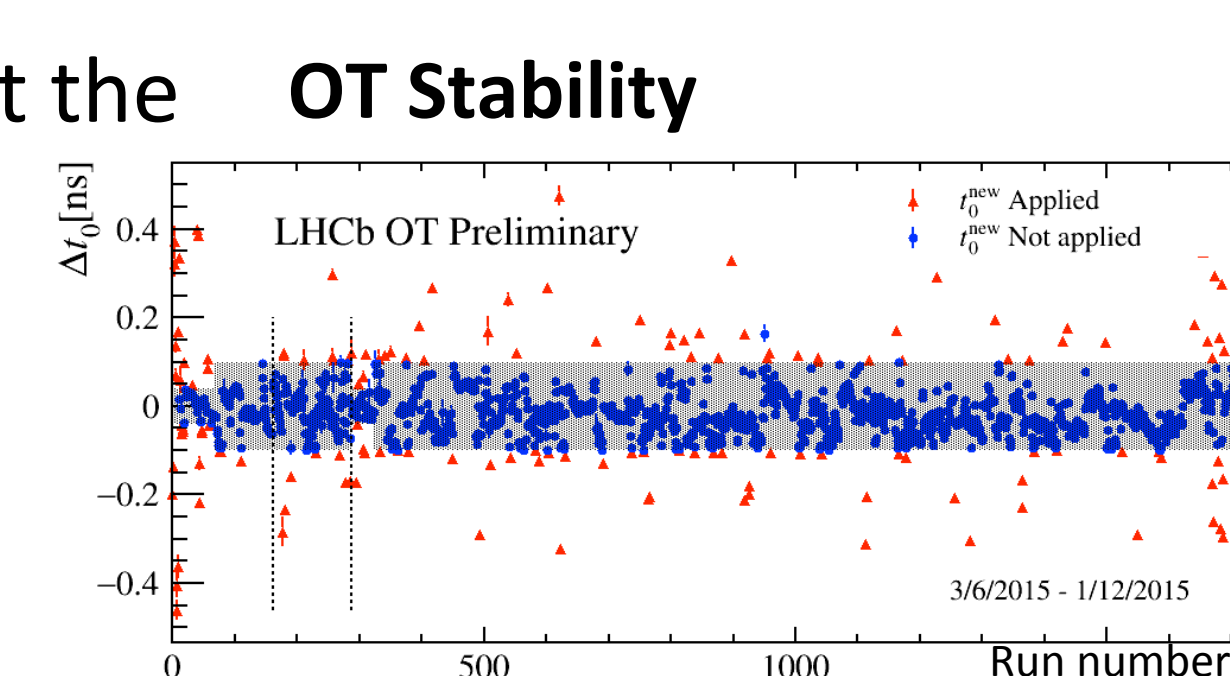

Aligned mirrors

RICH Calibration

- <u>Refractive index calibration:</u> Fit to the reconstructed-expected Cherenkov angle yields scale factor for the refractive index
- <u>HPD image calibration:</u> Sobel filter applied to each HPD and used to provide calibration
- Updated every run

RICH1 scale factor

HPD image

Calorimeter Calibration

<u>Relative calibration for each cell</u>

- Occupancy method and LED monitoring system: adjustment of high voltage settings to compensate for the aging of the detector
- Updated per fill
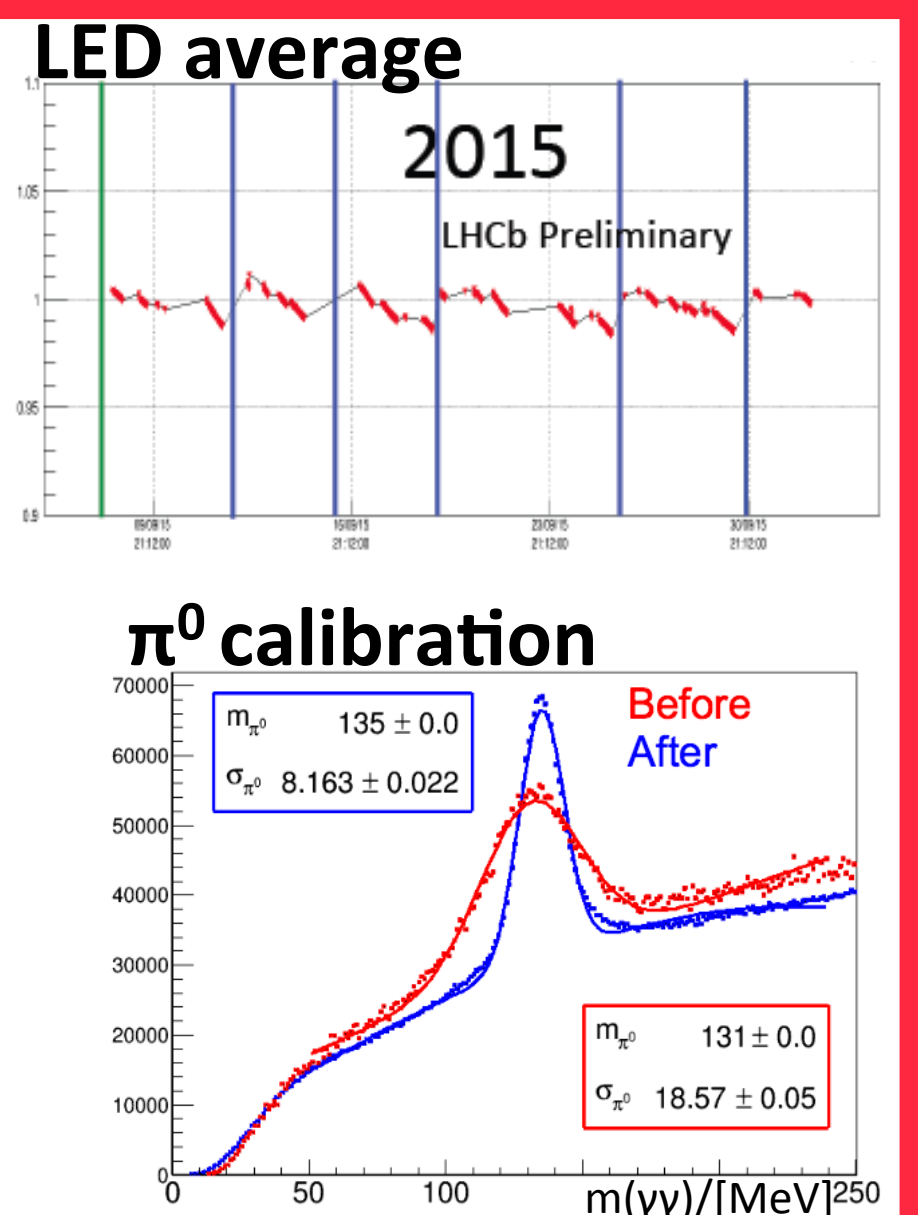
<u>Calibrate to the neutral π mass</u>

- Fit the π^0 mass distribution for each cell for $\pi^0 \rightarrow \gamma\gamma$
- Run on the HLT-farm during TS

LED average

π^0 calibration