LHCb's Real-Time Alignment in Run II

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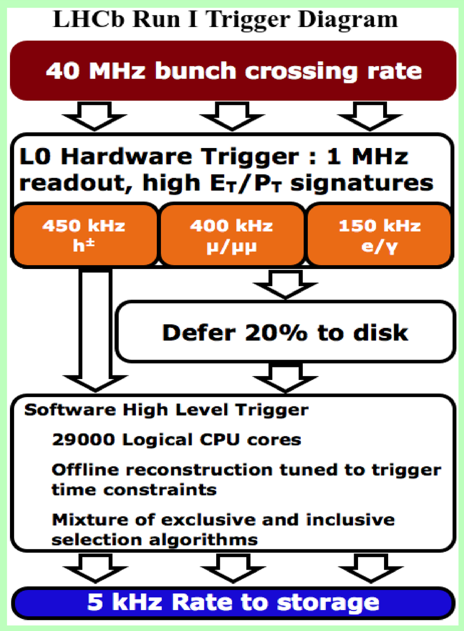
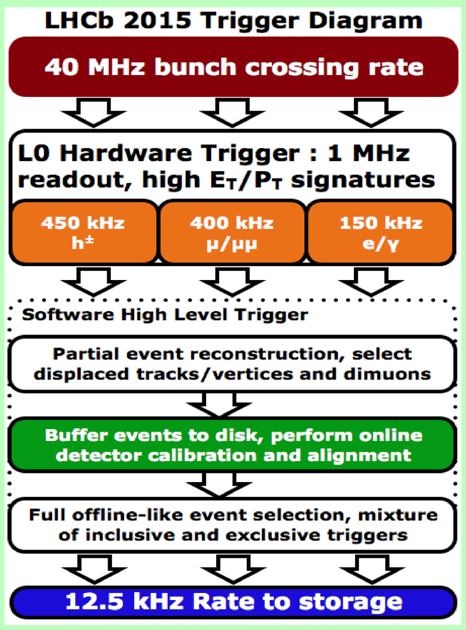
LHC Parameters from Run I to Run II*

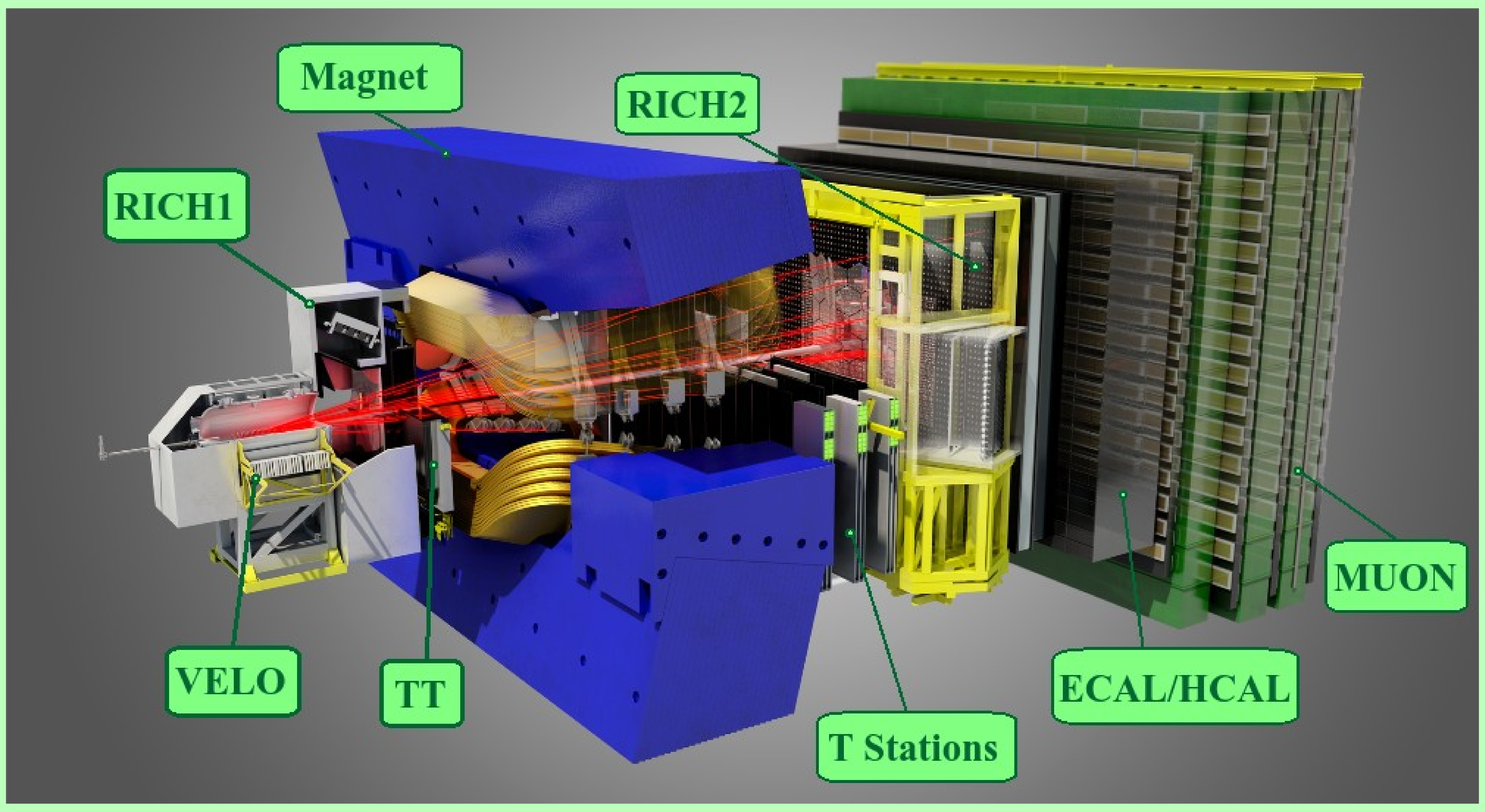
- Higher energy: $\sqrt{s}$ = 7/8 TeV → 13 TeV
  - 15% increase of inelastic collision rate
  - 20% increase of multiplicity per collision
  - 60% increase of $\sigma_{c\bar{c}}$ and $\sigma_{b\bar{b}}$
- More frequent collisions: Δt = 50 ns → 25ns
- Similar instantaneous $L = 4\cdot10^{32}$ cm^{-2} s^{-1}

Trigger Schemes





The LHCb Detector

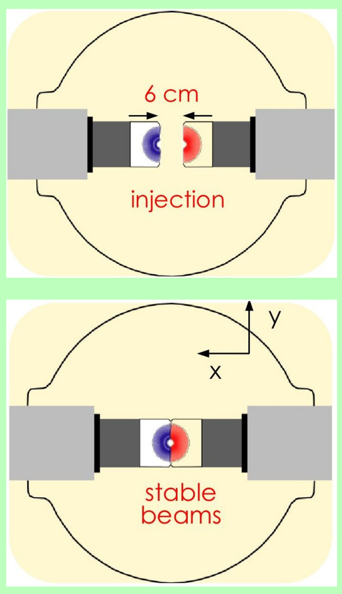


Alignment of Detector Elements

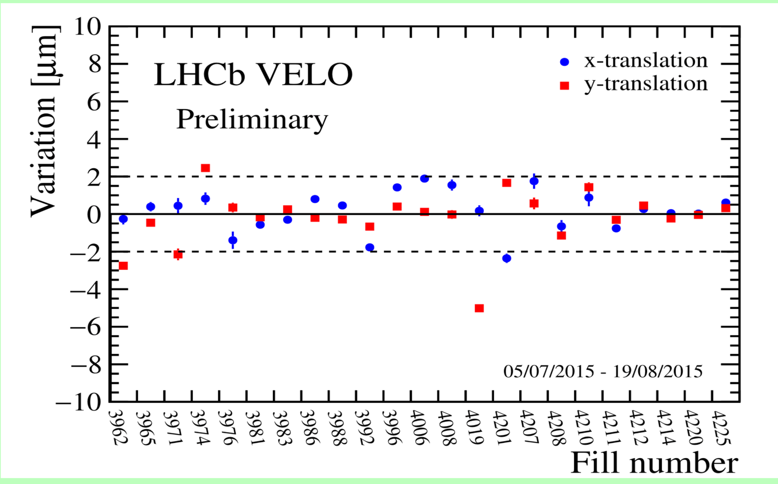
- Degrees of freedom: 3 translations and 3 rotations for each element
- Stations, layers and modules can be aligned independently
- Number of elements to be aligned:
  - VELO: 86
  - TT: 135
  - IT: 64
  - OT: 496
  - Muons: 10
- Constrained to nominal, survey and/or previously aligned position

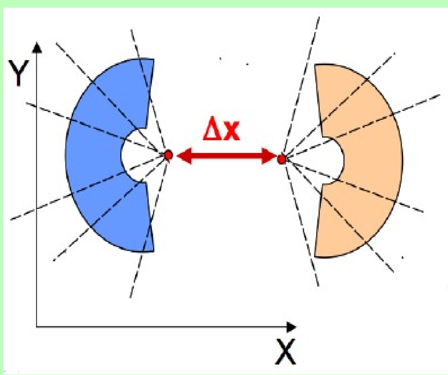
VELO Alignment

- VELO open during LHC filling and closed at the beginning of each fill when beam is declared stable
- Vertex constraint applied for the 2 half alignment
- Excellent IP (11.6 μm at high p_T) and PV resolution (13 μm for PV with 25 tracks)
- Variations observed between fills during the Run I:
  - x: RMS 3.7 μm; max var. ± 9 μm
  - y: RMS 2.5 μm; max var. ± 6 μm



VELO 2 half alignment stability in Run II

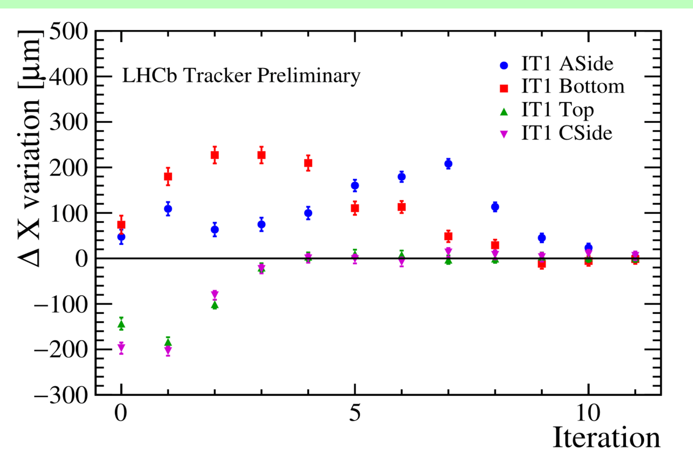




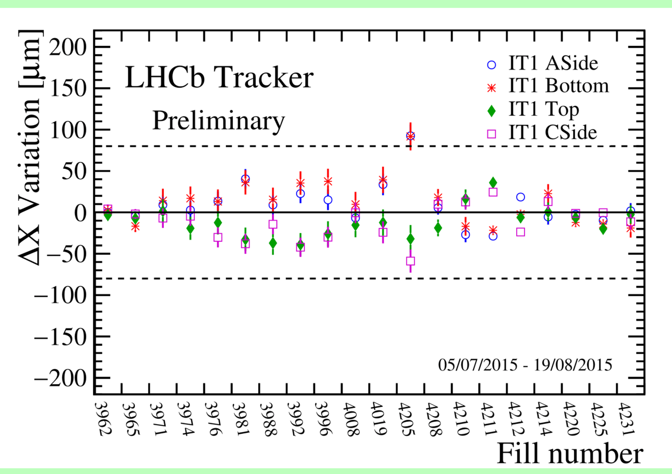
Tracker Alignment

- Variation due to magnet polarity change and some other additional small variation over time
  - Magnet polarity changed every few weeks
- Time variation of the alignment constants:
  - Translations within 100 μm
  - Rotations within 1 mrad
- A misalignment in the tracking system affects both the momentum scale and the momentum resolution

Tracker convergence for the first fill of Run II



Δx IT boxes stability in Run II



RICH Mirror Alignment

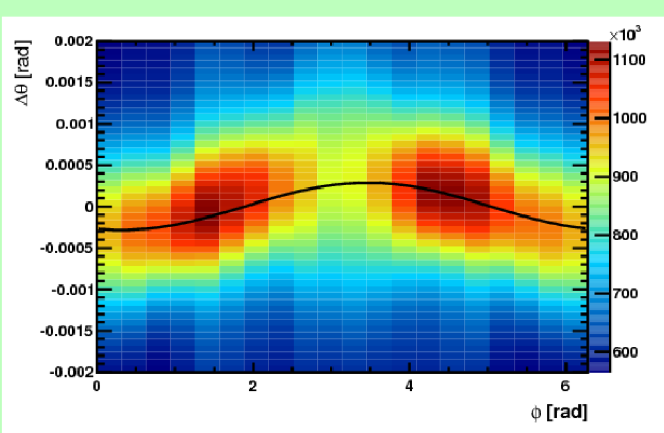
- The variation of the Cherenkov angle is fitted as function of the polar angle:

$$\Delta\theta = \theta_x \cos(\varphi) + \theta_y \sin(\varphi)$$

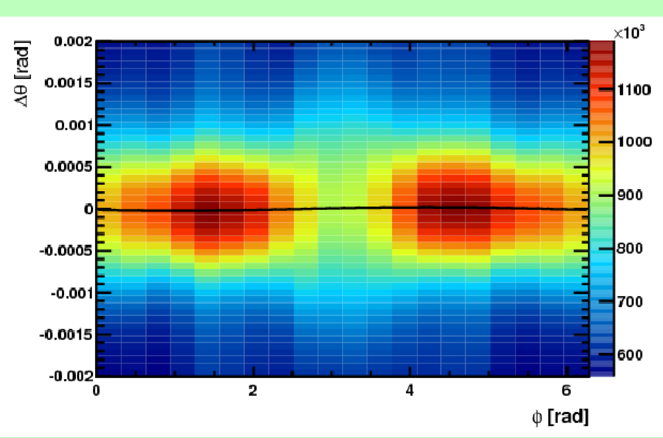
where the extracted θ_x and θ_y values correspond to a misalignment in the HPD detector plane

- Mirror pairs to align: 16 for RICH1 and 94 for RICH2
- The alignment constants (1090) are evaluated for each fill

Before mirror alignment



After mirror alignment



Advantages of Real-Time Alignment

- More effective trigger selection
- Minimizes the differences between online and offline performances
- Improves the stability of the alignment quality
- Early physics analysis performed directly on the trigger output

Real-Time Tracking Alignment

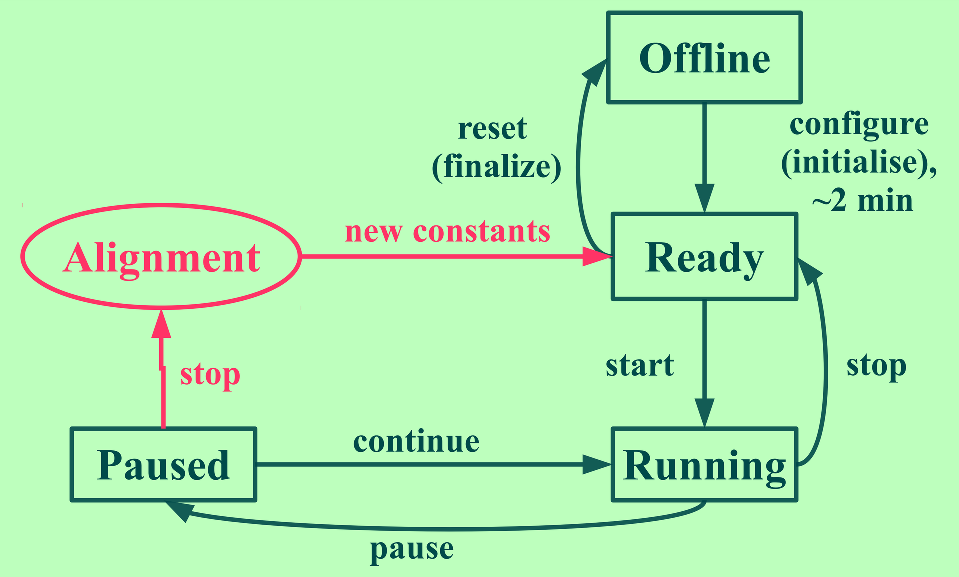
VELO: performed at the beginning of each fill, updated immediately if needed

Tracker system: run after the VELO for each fill and updated every few weeks

Muon stations: run after the tracker for each fill, variation not expected but run as monitoring

Real-Time Alignment

- Automatic evaluation at the beginning of each fill
- Track reconstruction parallelised on several nodes of the HLT farm
- χ2 minimization on one single node
- Compute the new alignment constants in a few minutes
- Special HLT1 selection line enriched with well known particle decays ($D^0 \to K\pi$, $J/\psi \to \mu\mu$, etc.)
- Two kind of alignment tasks (same state diagram):



Analyzer performs the track reconstruction based on the alignment constants computed by the iterator (~1700 nodes)

Iterator collects the output of the analysers and minimizes the χ2 computing the alignment constants for the next iteration (single node)

Tracking Alignment Method

$$\Delta\vec{a} = -\left[\Sigma_t \frac{\partial\vec{r}_t}{\partial\vec{a}}^T V^{-1} R V^{-1} \frac{\partial\vec{r}_t}{\partial\vec{a}}\right]^{-1} \left[\Sigma_t \frac{\partial\vec{r}_t}{\partial\vec{a}}^T V^{-1} \vec{r}_t\right]$$

$\vec{a}$ - alignment parameters; $\vec{r}_t$ - residual; V - covariance matrix of measurement coordinates;

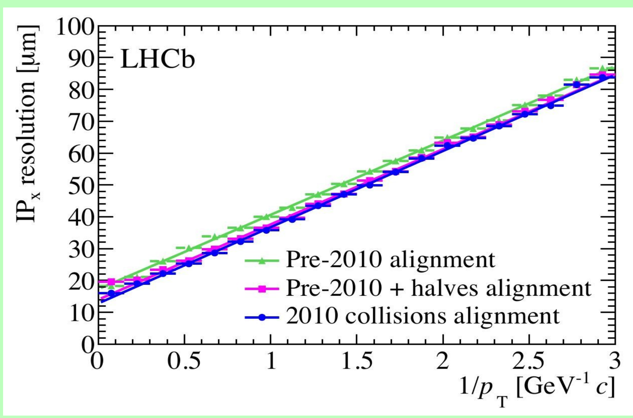
R - covariance matrix of residuals after track fit

The Kalman filter is used to minimise the χ^2 taking into account full track model
- Align multiple detectors at once
- Iterative procedure

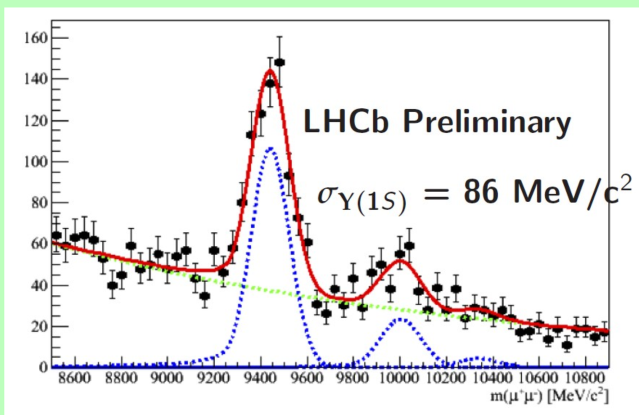
Advantages:
- Correctly take multiple scattering and energy loss into account
- Use magnetic field information
- Mass and vertex constraints can be applied, in addition to the canonical constraints

Alignment Impact on Physics Performance

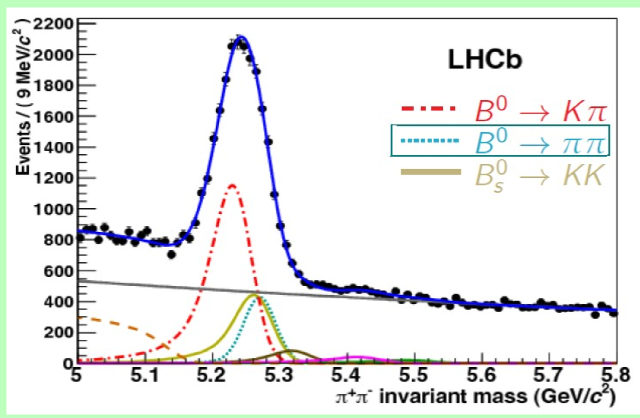
First alignment σ_{IP}(high p_T) = 14.0 μm



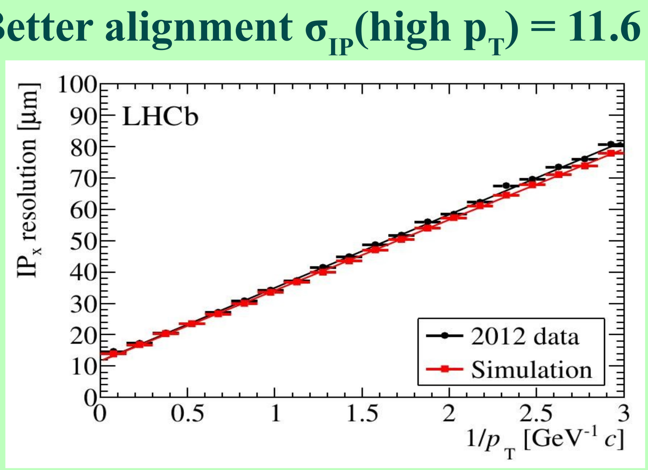
First alignment



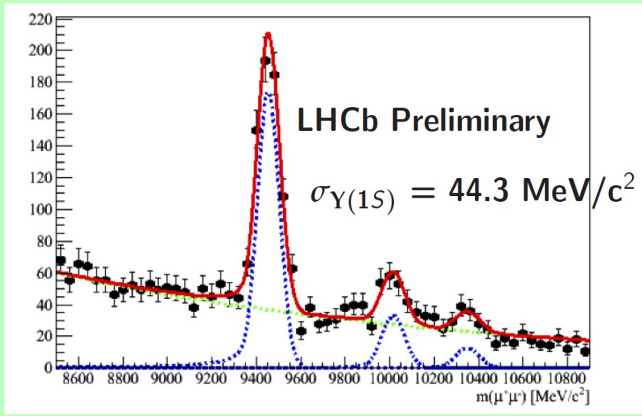
Without PID



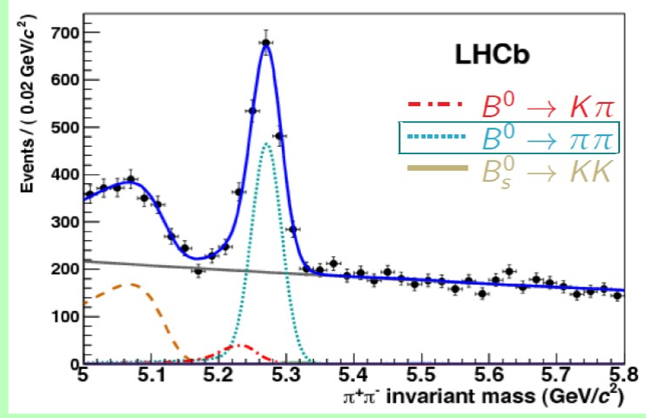
Better alignment σ_{IP}(high p_T) = 11.6 μm



Better alignment



With PID



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* Performance estimates based on expectations from simulations. The results obtained in the LHCb acceptance

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