Tracking and Alignment in LHCb

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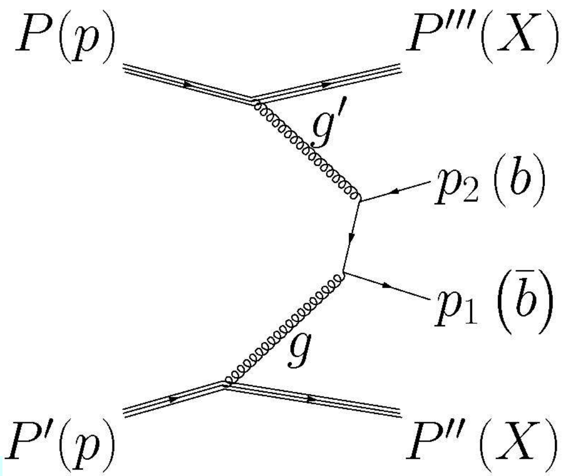
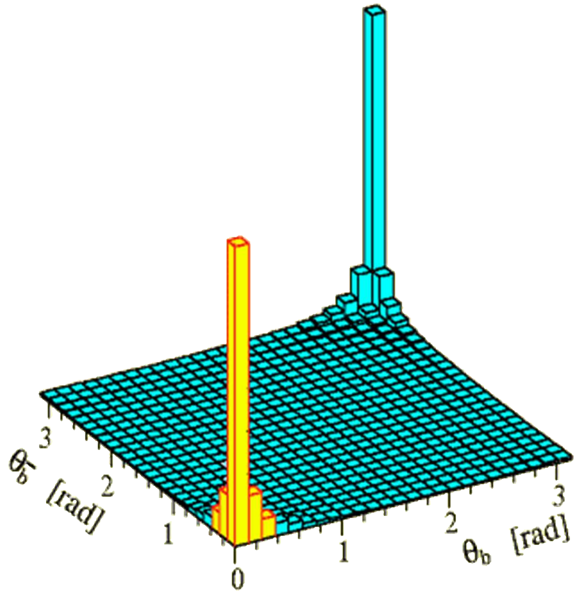
LHCb and B-physics

- LHCb - Large Hadron Collider beauty detector.
- LHCb aims lay primary in the B-physics sector.
- Nominal luminosity of about $2 \times 10^{32}\, cm^{-2} s^{-1} \Longrightarrow 10^{12}\, b\bar{b}$ per year.
- The dominant channel behavior explains the single-arm forward spectrometer geometry chosen for LHCb.

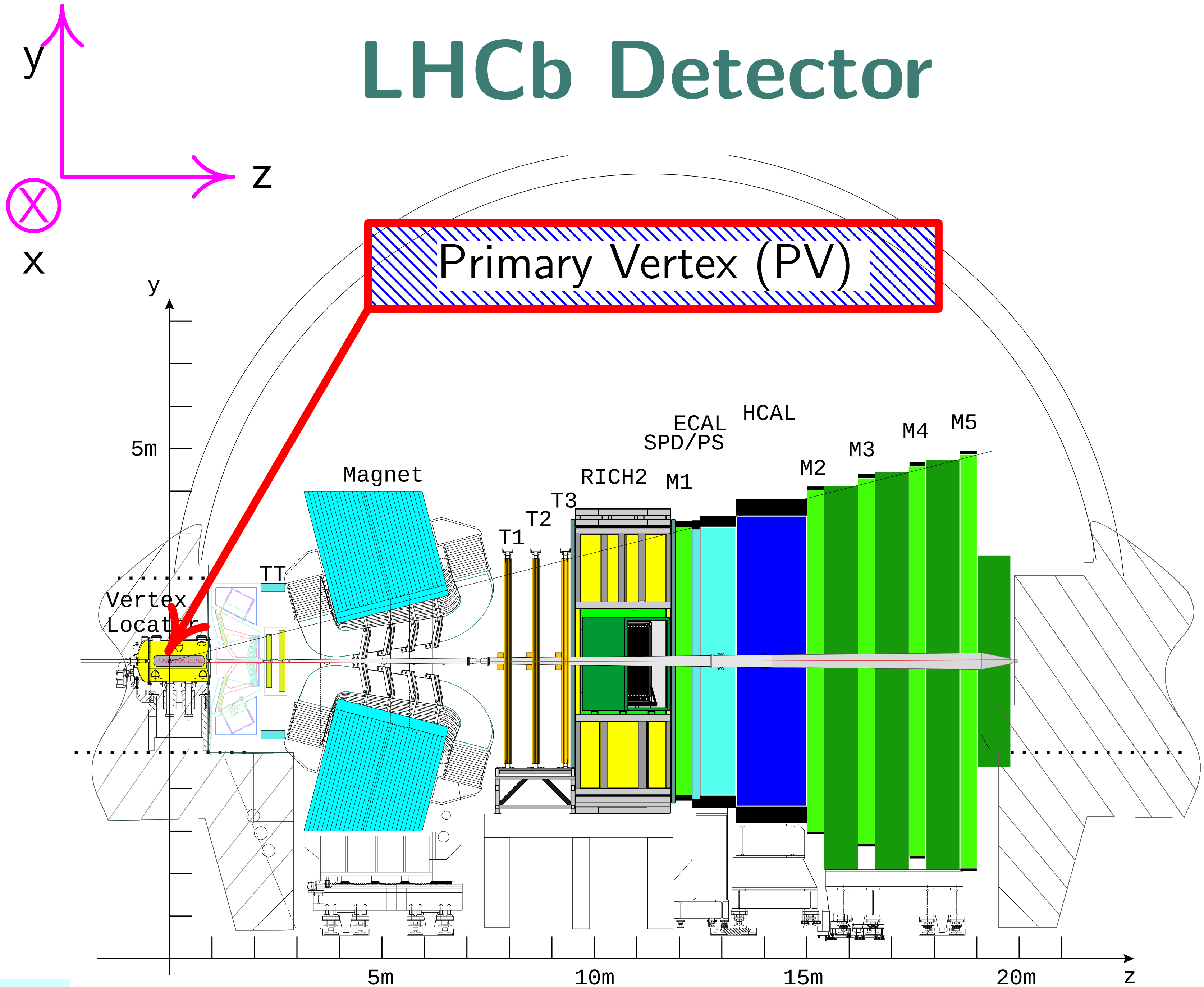
Gluon fusion before fragmentation



forward beaming of $b\bar{b}$ in the LHCb frame



LHCb Detector



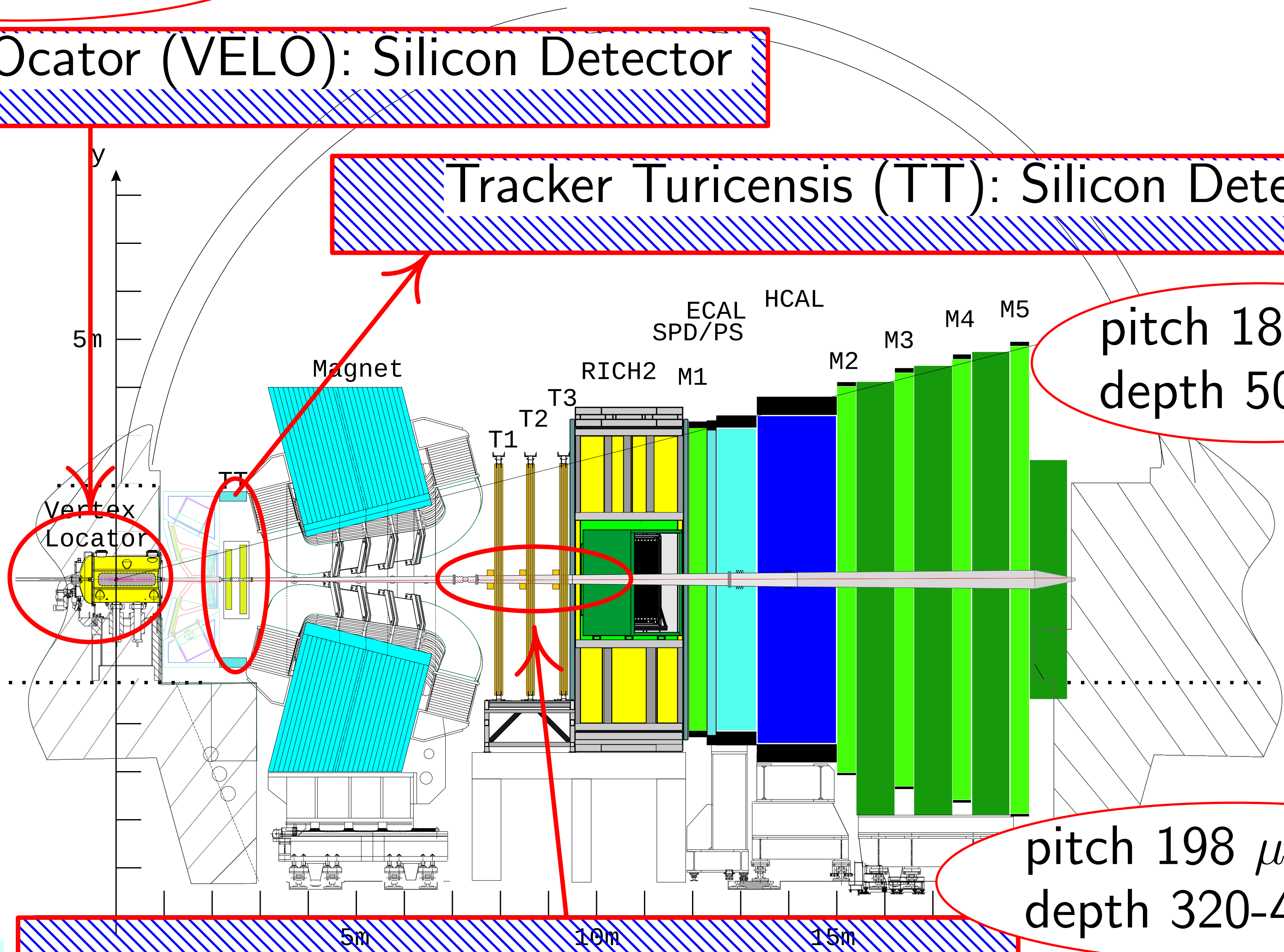
LHCb Detector

pitch 38-102 μm,
depth 300 μm

VErtex LOcator (VELO): Silicon Detector

Tracker Turicensis (TT): Silicon Detector

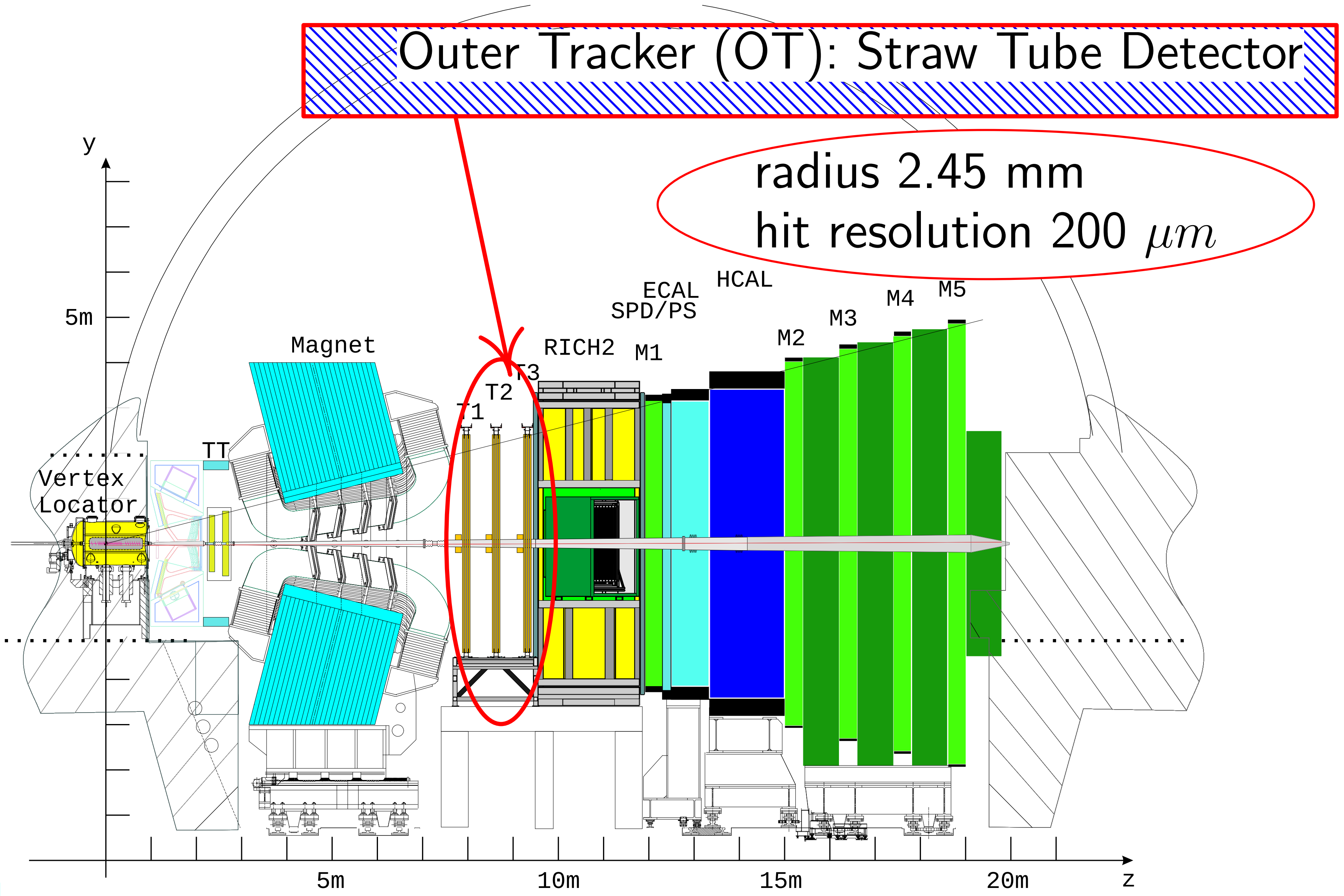
pitch 183 μm,
depth 500 μm



pitch 198 μm,
depth 320-410 μm

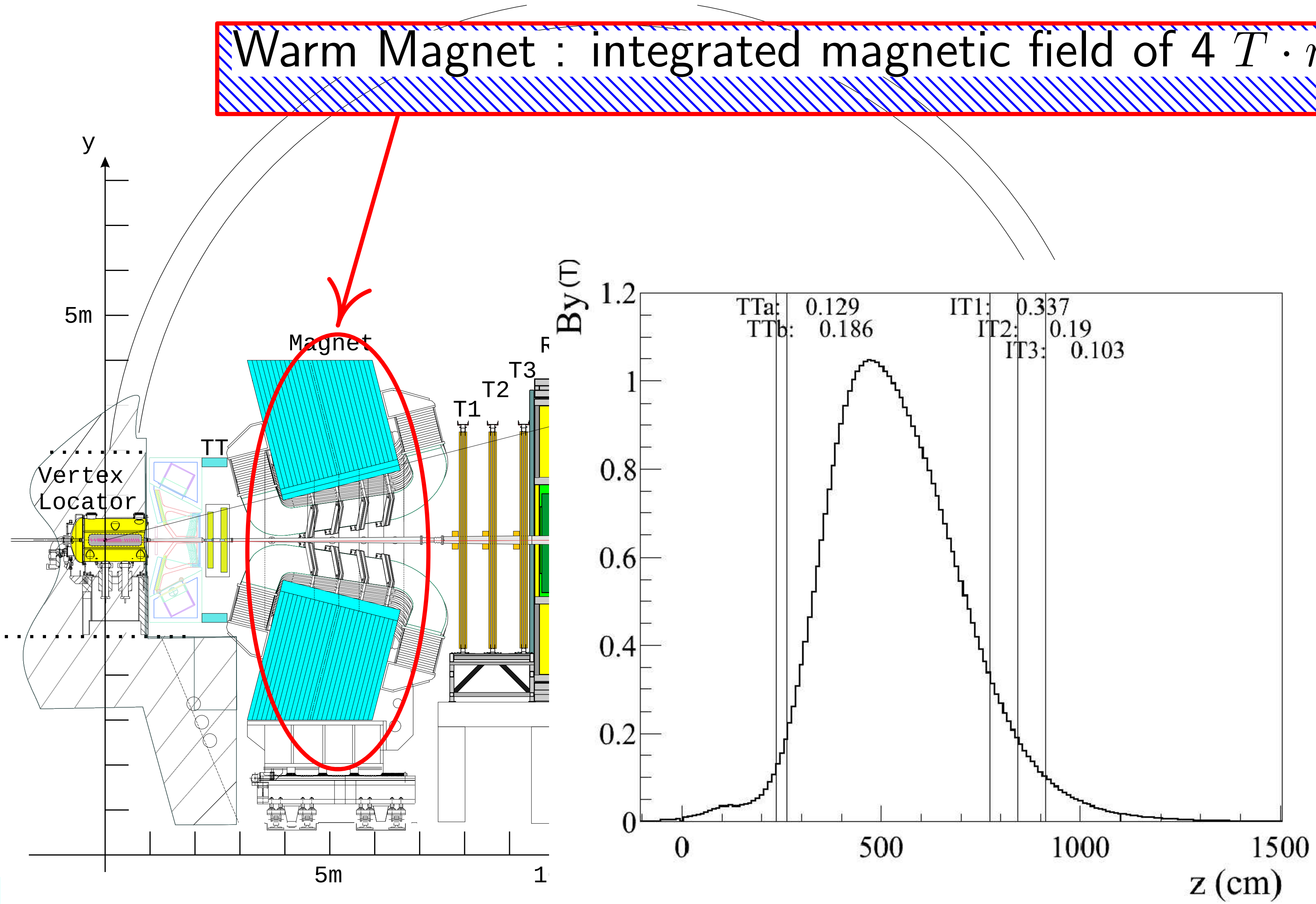
Inner Tracker (IT): Silicon Detector

LHCb Detector



LHCb Detector

Warm Magnet : integrated magnetic field of 4 $T \cdot m$

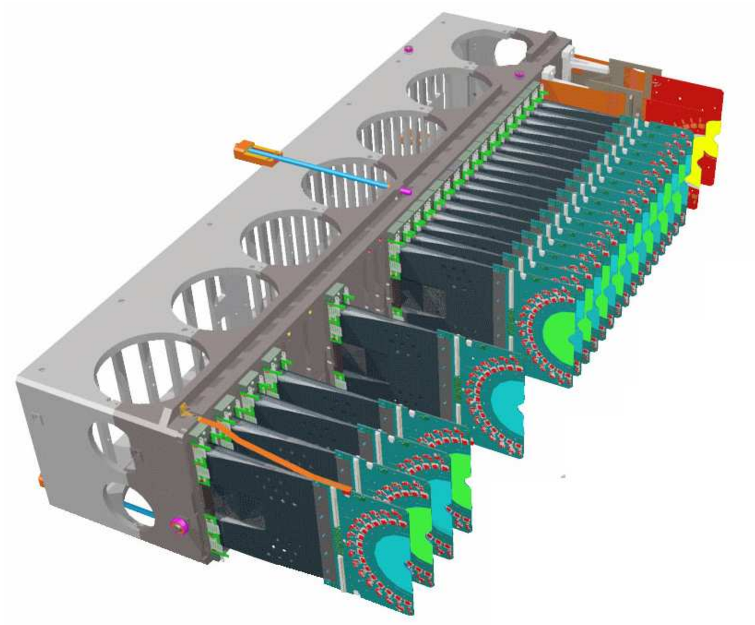


VErtex LOcator

- Primary Vertex (PV) is inside VELO, towards middle;
- VELO is a retractable detector, 2 VELO sides:
  ⋆ To protect from damage, VELO is in Open position before the beam is stable, and closed afterward.
  ⋆ Open VELO: sensors 30 mm further from the beam,
  ⋆ Closed VELO: sensors are about 8 mm from the beam line,

VELO double-sensor modules: R+ϕ

Schematic: one side of VELO



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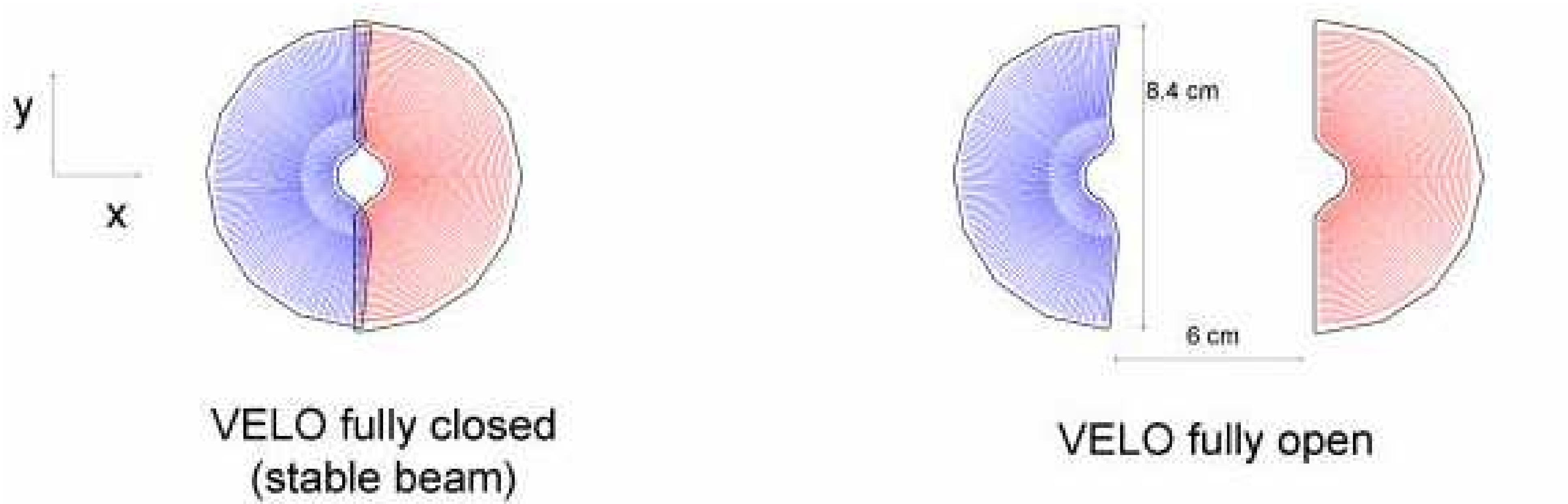
Schematic VELO sensors in Open and Closed positions

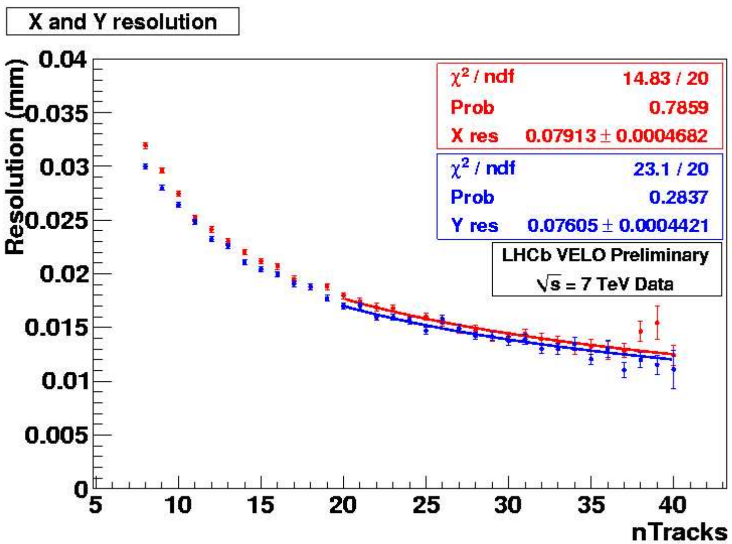


Primary Vertex Resolution

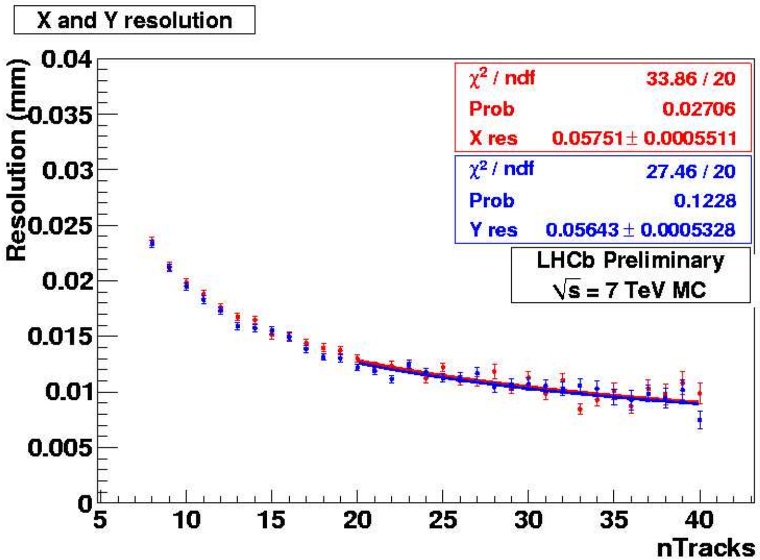
- Primary Vertex (PV) is determined with VELO tracks.
- Method: randomly split event track container in two, and reconstruct PV.
- Results close to expected,
  ⋆ A residual ≈ 40 % difference - e.g. when using 25 tracks.
  ⋆ Improving.

	MC	Data
$\Delta x (\mu m)$	11.5	15.8
$\Delta y (\mu m)$	11.3	15.2
$\Delta z (\mu m)$	57	91

PV resolution vs track used, real data



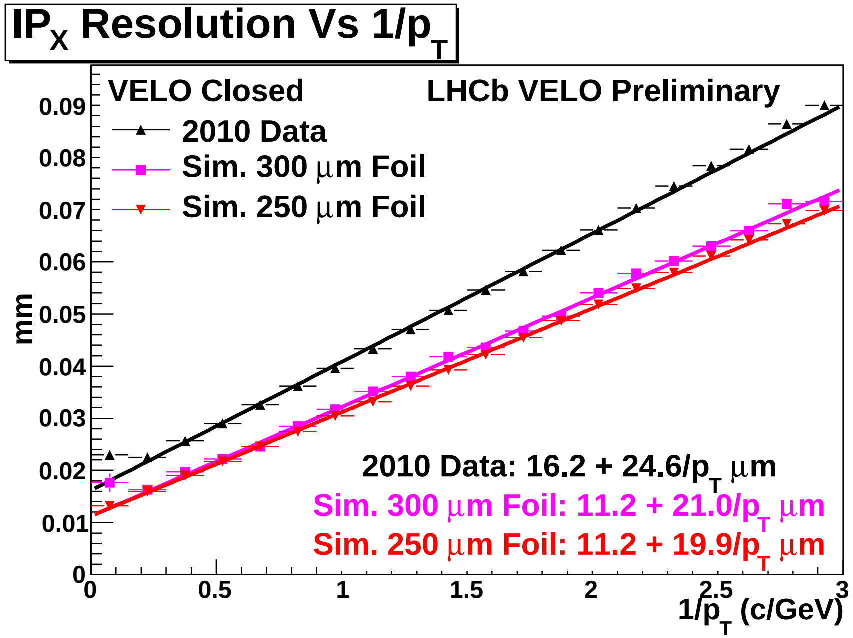
PV resolution vs track used, MC



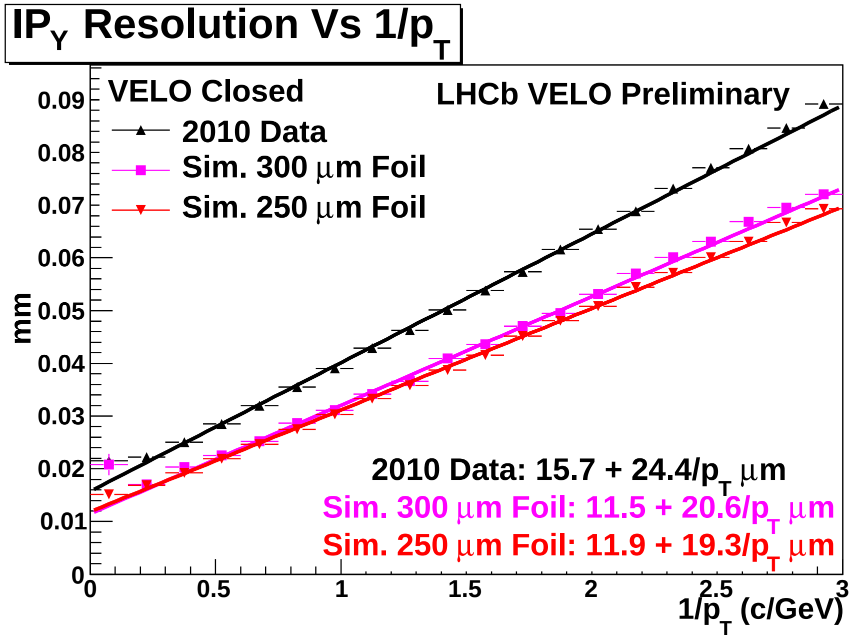
Impact Parameter Resolution

- Impact parameter (IP) - Closest approach to PV of a track.
- IP resolution is determined primarily by:
  ⋆ random scattering in VELO material, VELO misalignments and hit resolutions.
- IP resolution for MC and data given.

Impact Parameter resolution in X



Impact Parameter resolution in Y



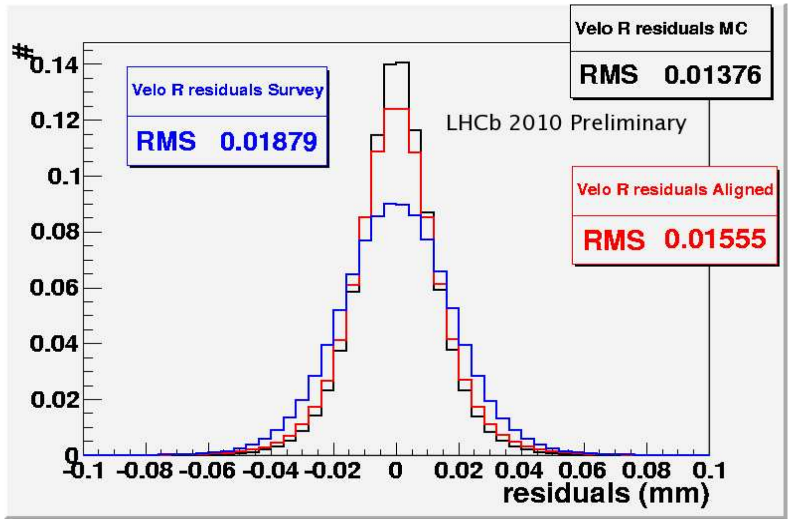
Impact Parameter Resolution

- Impact parameter (IP) - Closest approach to PV of a track.
- IP resolution is determined primarily by:
  $\star$ random scattering in VELO material, VELO misalignments and hit resolutions.
- IP resolution for MC and data given.
- 15-40 % difference between MC and data.
- Accounted for already.
  $\star$ Some disagreement in material description of MC.
  $\star$ Misalignment between VELO sides.
- Remaining:
  - residual misalignments of sensors, $\gtrsim 4.4\mu m$,
  - too optimistic hit resolution in MC,
  - charge sharing.

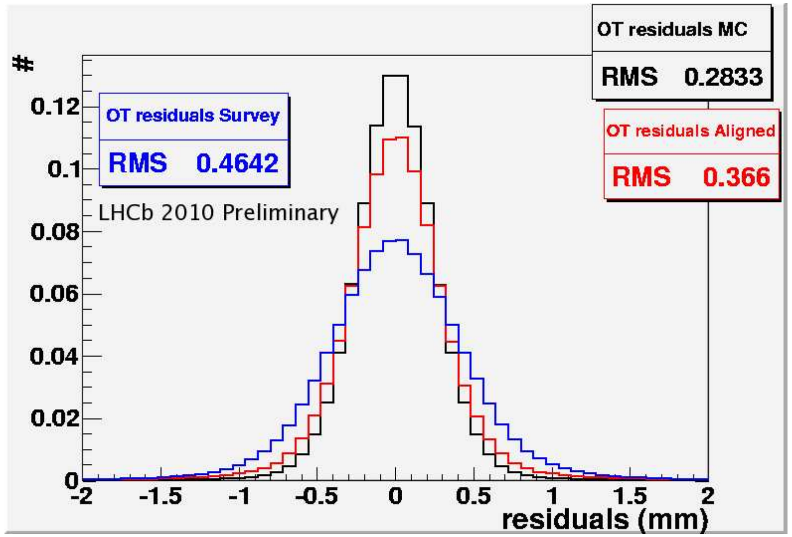
Alignment Status of Subdetectors

- Optical alignment of VELO, OT, IT, TT : Survey.
- Updated software alignment Aligned.
- Monte Carlo results: black histograms.
- $\mathbf{R}_{track} - \mathbf{R}_{hit}$, measurement residual distribution gauges the alignment quality.

VELO R-sensor residuals



OT residuals



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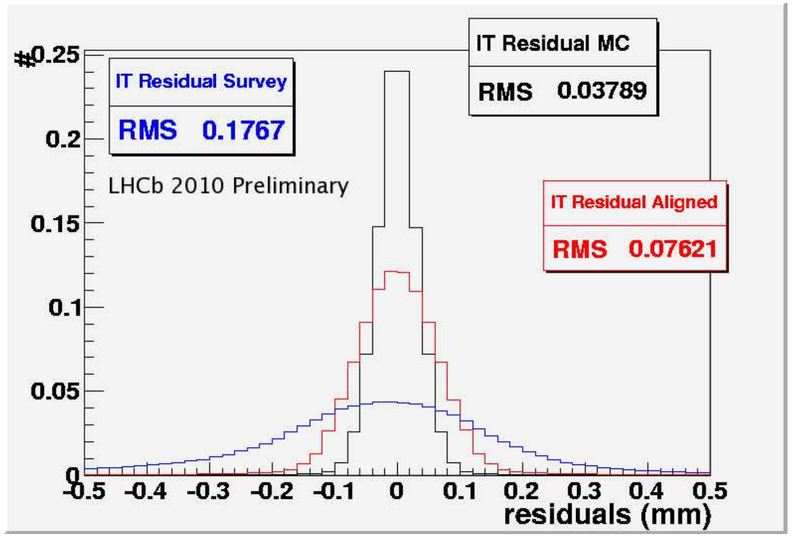
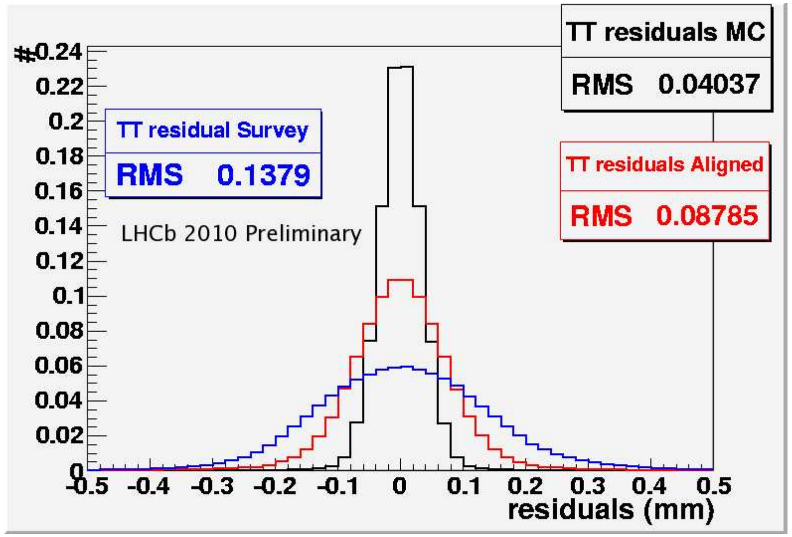
IT residuals



TT residuals

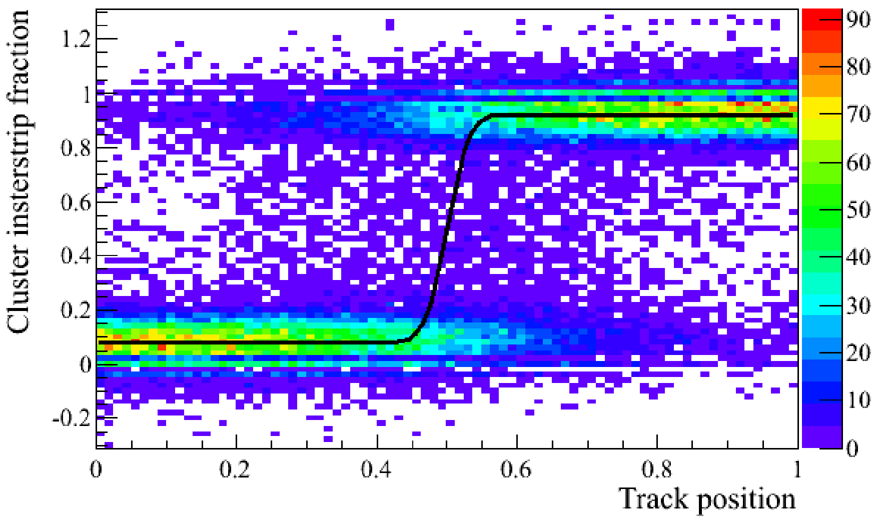


Silicon Trackers: Hit Resolution

- 40-50% difference between Monte Carlo and Data for IT and TT.
- IT and TT are single-sided silicon strip detectors.
- One source of disagreement was found in the charge sharing between neighboring strips.
  ⋆ This effect was overestimated in MC.
  ⋆ After correction: an increase from 40 μm to 50 μm for IT hit resolution.
- We expect residual misalignments to account for the rest.

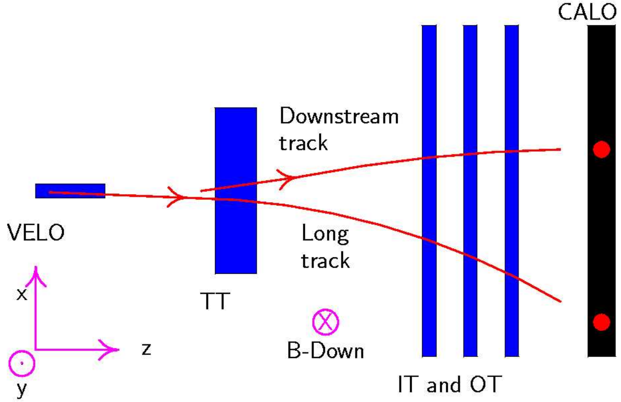
charge sharing between two strips

larger cluster of strips improve measurement resolution

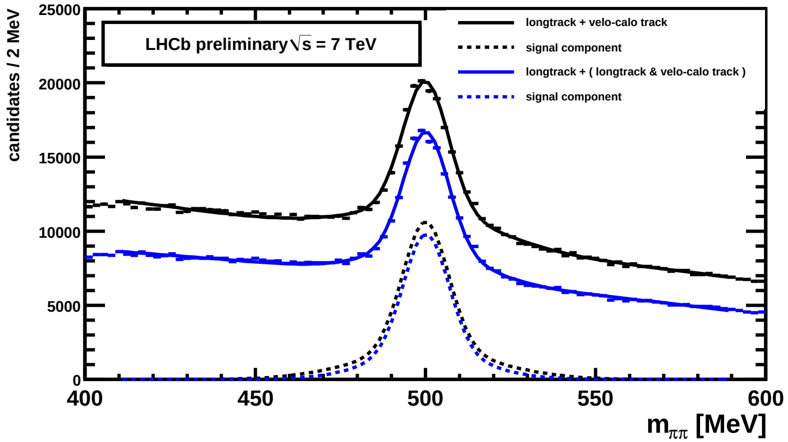


Long Track Efficiency

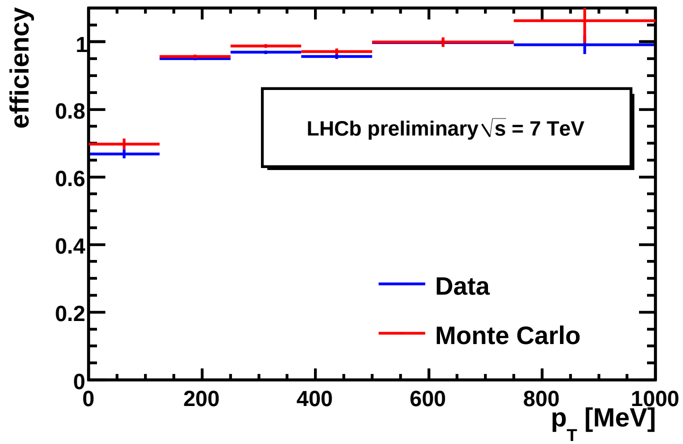
- Long track efficiency obtainable from K_S candidates.
- Method:
  - ⋆ Finds VELO segment and the associated CALO cluster,
  - ⋆ Gets Long tracks from reconstruction,
  - ⋆ K_S Candidates 1: VELO+CALO track and a Long track,
  - ⋆ K_S Candidates 2: 2 Long tracks.
- The method supplies IT/OT/TT efficiency in tracking.
- Results close to 100%, with MC and data agreement.



Long-Long K_S candidates, mass plot

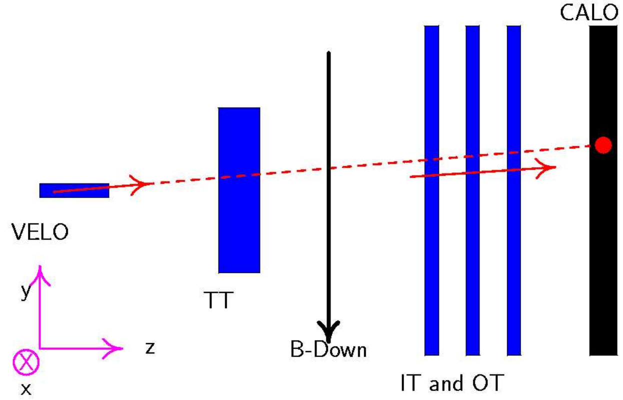


Efficiency as a function p_T



An Other Method for Track Efficiency

- Method, phase 1:
  ⋆ For all VELO segments, finds a corresponding CALO cluster in the bending plane (x,z)
  ⋆ Checks in the non-bending (z, y) plane,
  ⋆ Fits track VELO+CALO,



- Phase 2:
  ⋆ IT/OT/TT segments are matched to the found track.
  ⋆ the previous segments are provided by the various Pattern-Recognition algorithms.

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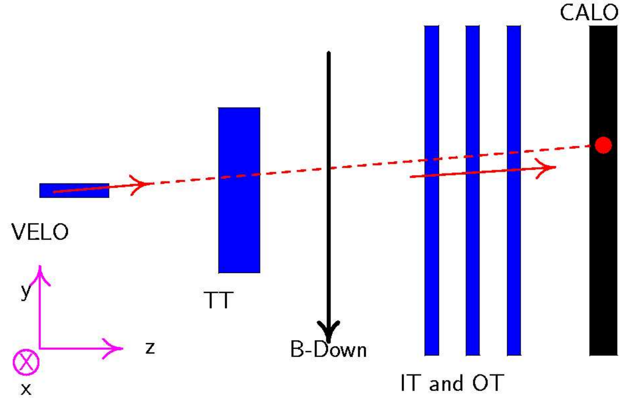

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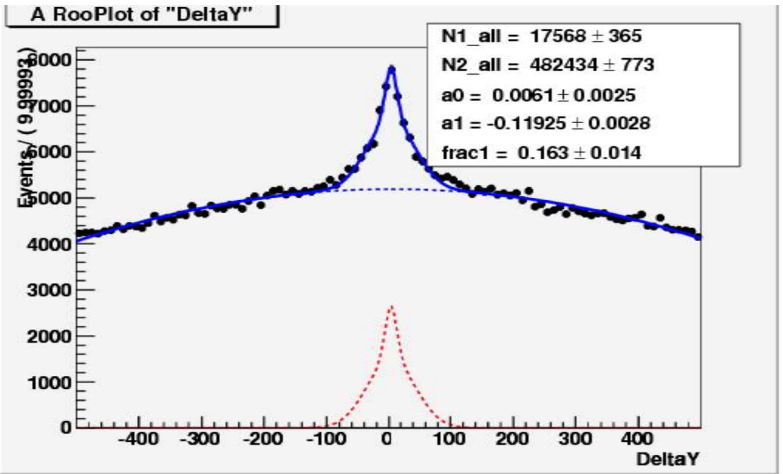
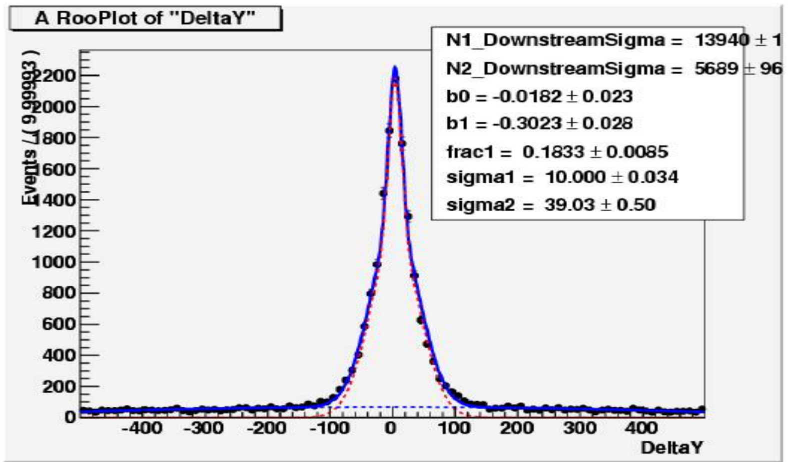
Difference in y for the track and CALO cluster position, includes all VELO+CALO tracks



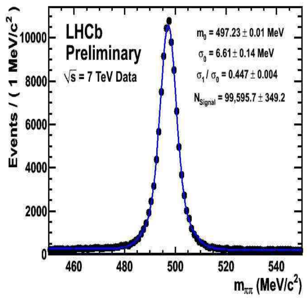
includes only VELO+CALO tracks, which have an associated Downstream segment



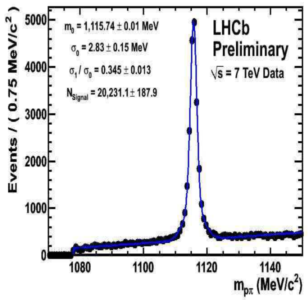
$$\epsilon_{eff} = \frac{n_2}{n_1}$$

Particle Zoo

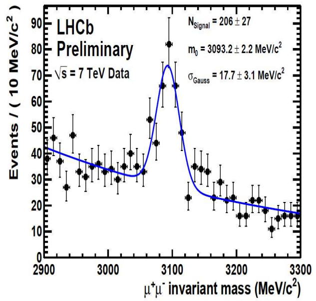
- Mass values of several detected particle agree with the PDG values to per mil level.
- Small signal widths , e.g. 2.8 MeV for Λ, 2.7 MeV Ξ^-, 8.5 MeV D^0, 2.5 MeV Ω, etc.



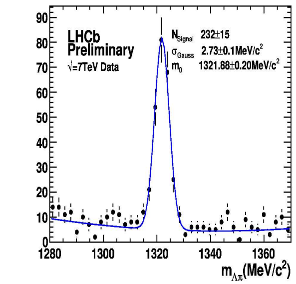
K_S



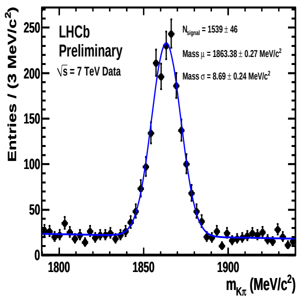
Λ



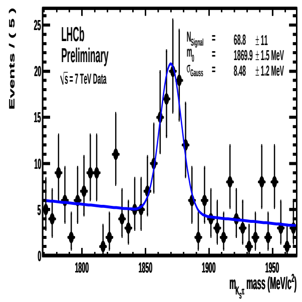
J/ψ



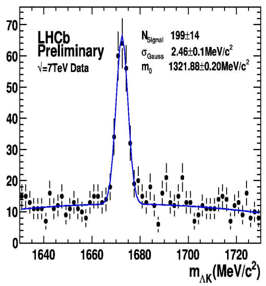
Ξ^-



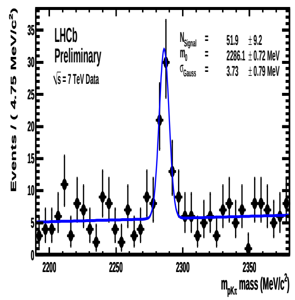
D^0



D^+



Ω



Λ_c Plus many more other ....

Summary and Conclusions

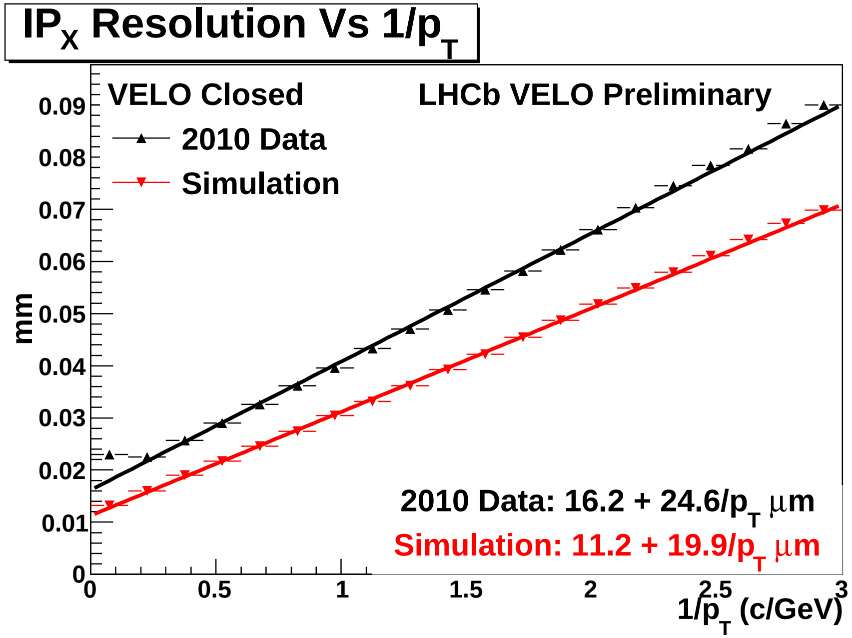
- Already more than 100 Million 7 TeV Collisions in the 2010 LHCb data.
- Main conclusion: Alignment and tracking are in good shape for physics analysis.
- Monitoring of alignment and tracking quality in progress.
- Already done gradual improvements in:
  - Detector description,
  - Tracking tools,
  - Alignment.
- As result, MC and data reconstruction give a better agreement.
- More to do ... but "Terra Nova" / "Terra Incognita" in sight, as we reconstruct particles from 7 TeV pp collisions with high precision.

Backup Slides

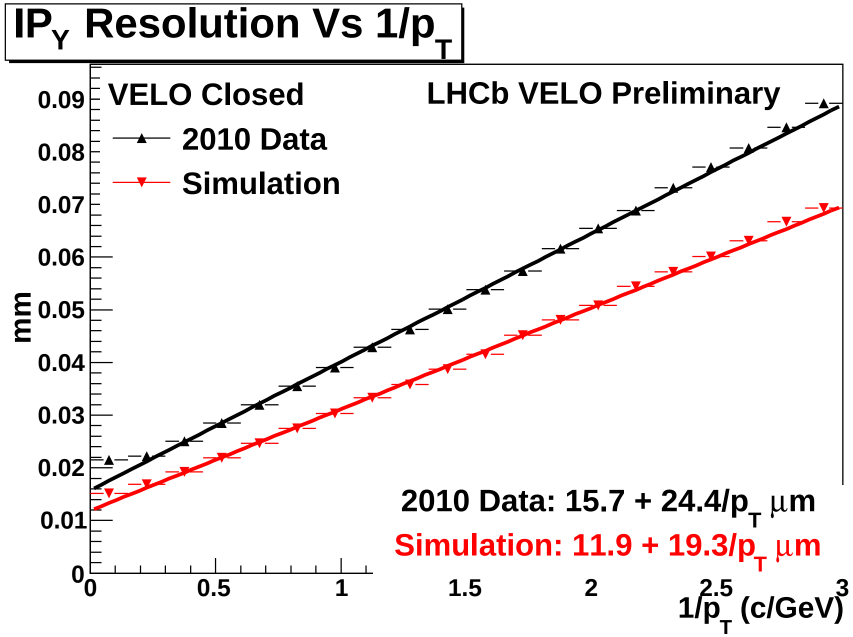
Impact Parameter (IP)

- 2010 data , VELO Closed

Impact Parameter resolution in X

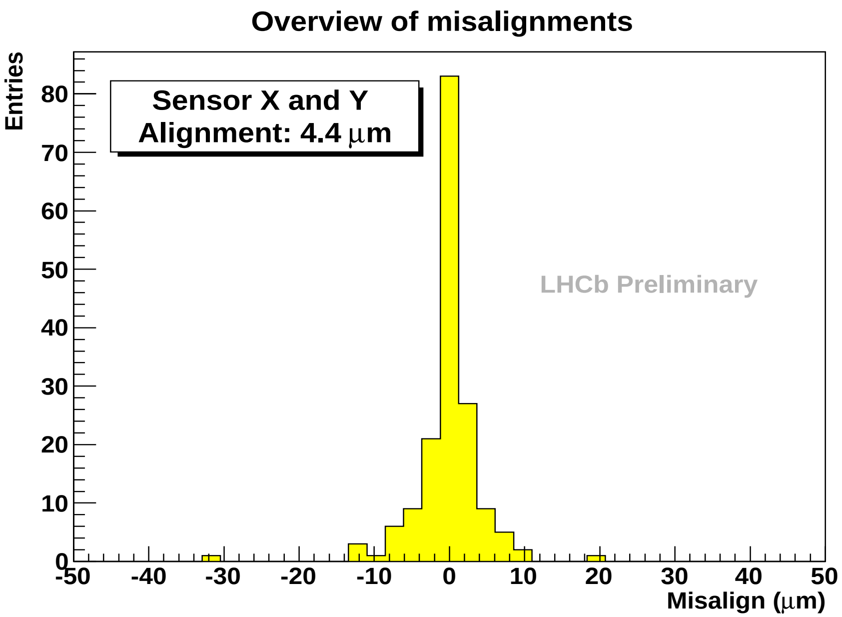


Impact Parameter resolution in Y



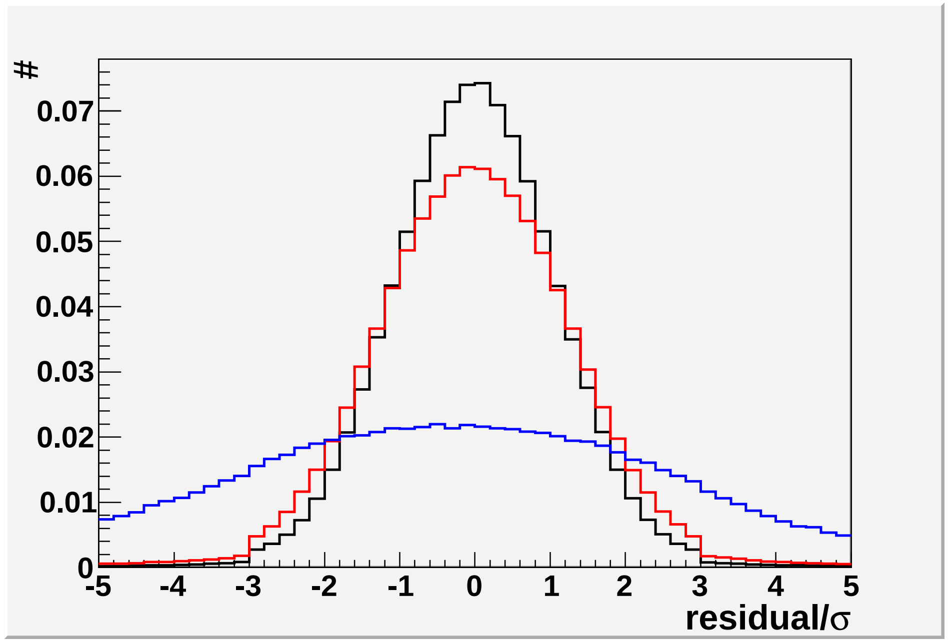
VELO Sensor Alignment

Sensor alignment correction for 88 sensors 168 DoF in X and Y

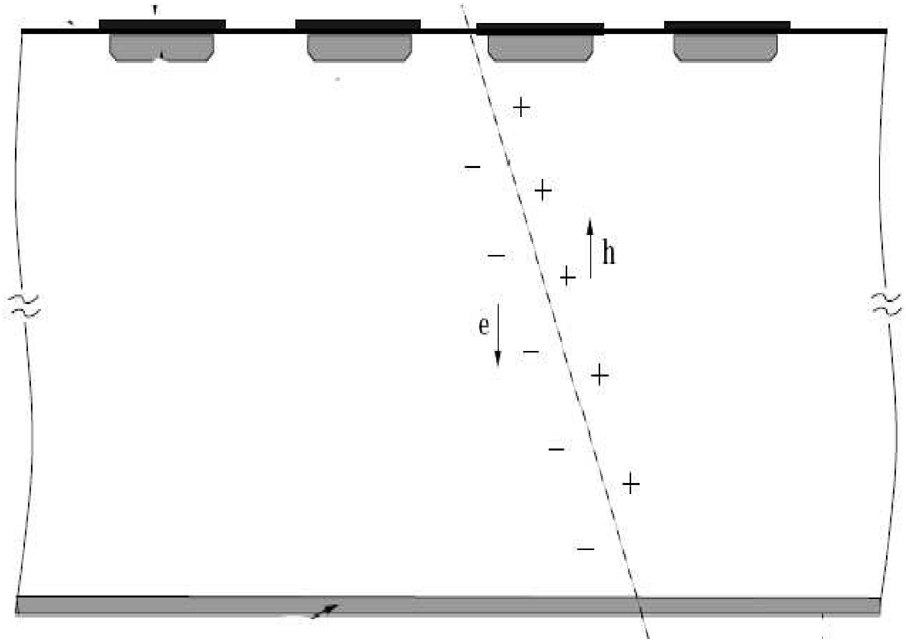


Residual Distributions for IT

IT pull plots



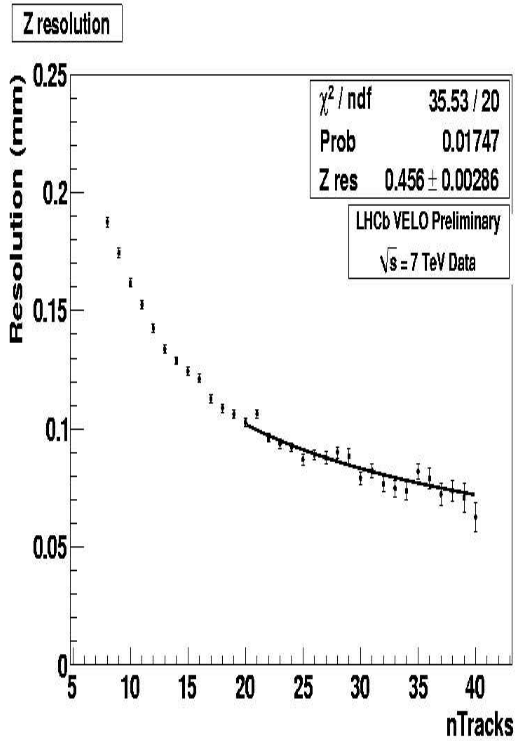
single-sided silicon strip sensor



Primary Vertex Z

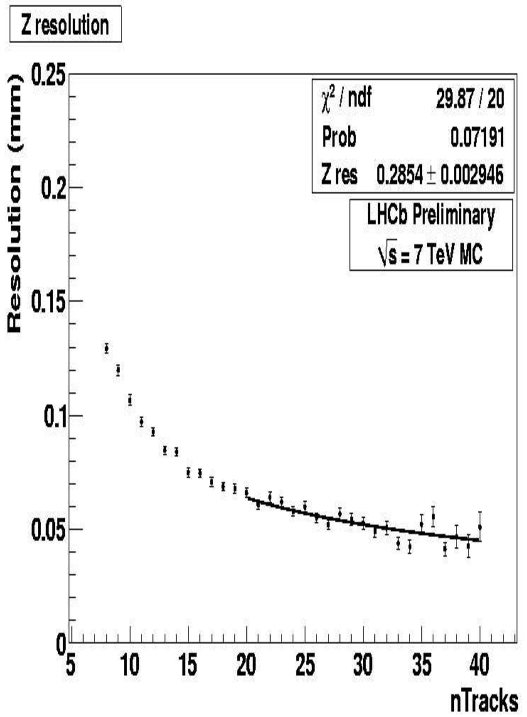
PV resolution vs track used

real data



PV resolution vs track used

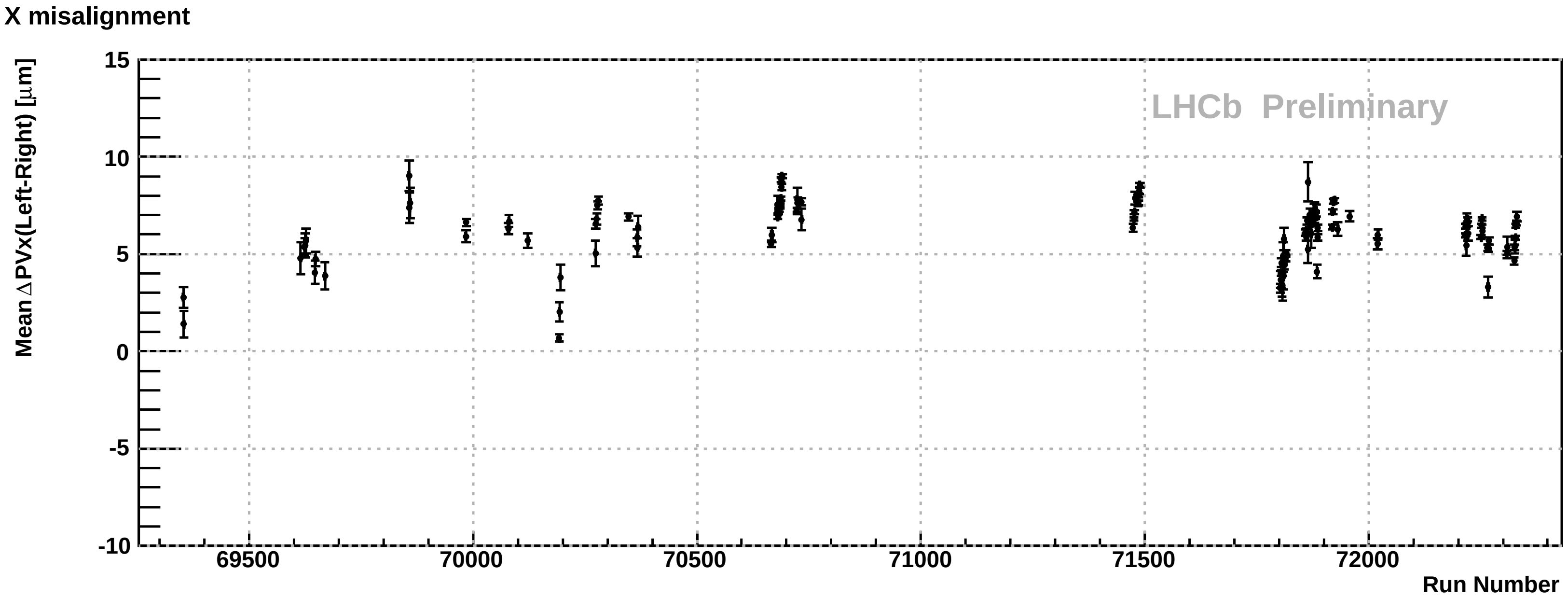
MC



VELO Stability, Sensor Alignment

- VELO retractable: Left/Right sides.
  ⋆ VELO is closed after stable beam conditions fulfilled.
- Primary Vertex reconstruction with tracks from separate sides.
  ⋆ Difference gives an estimate of misalignment between VELO sides.

ΔX difference of PV (μm)



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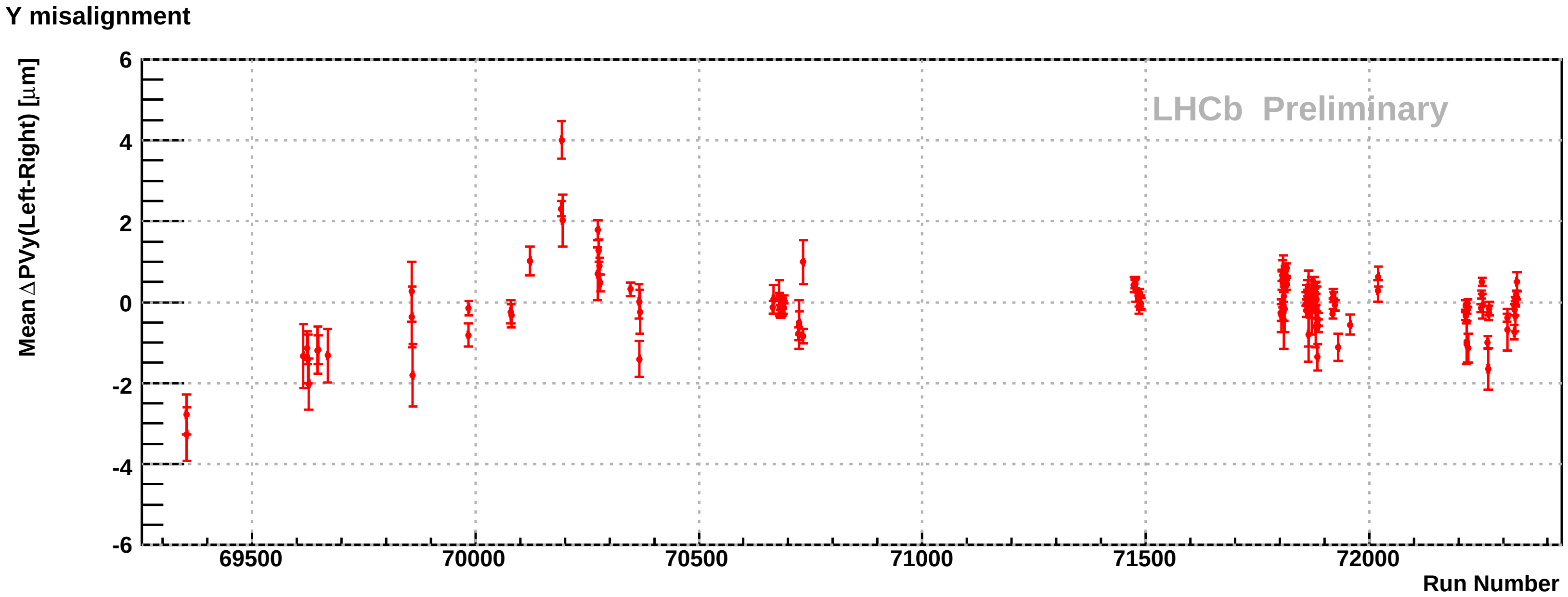

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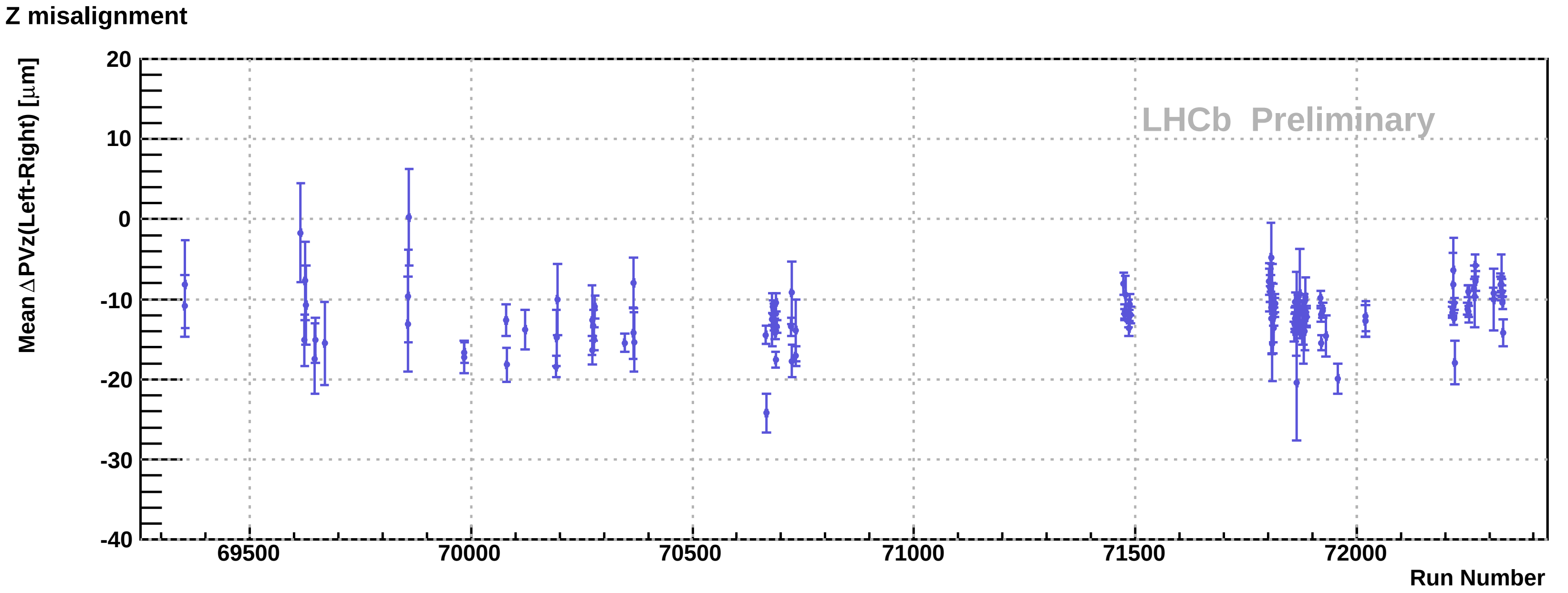
ΔZ difference of PV (μm)



Tracking Methods and Alignment

- Reconstruction phase:
  ⋆ various pattern recognition algorithm + Kalman-Filter tracking.
- Runge-Kutta extrapolator to deal with highly inhomogeneous field in the tracking stations.

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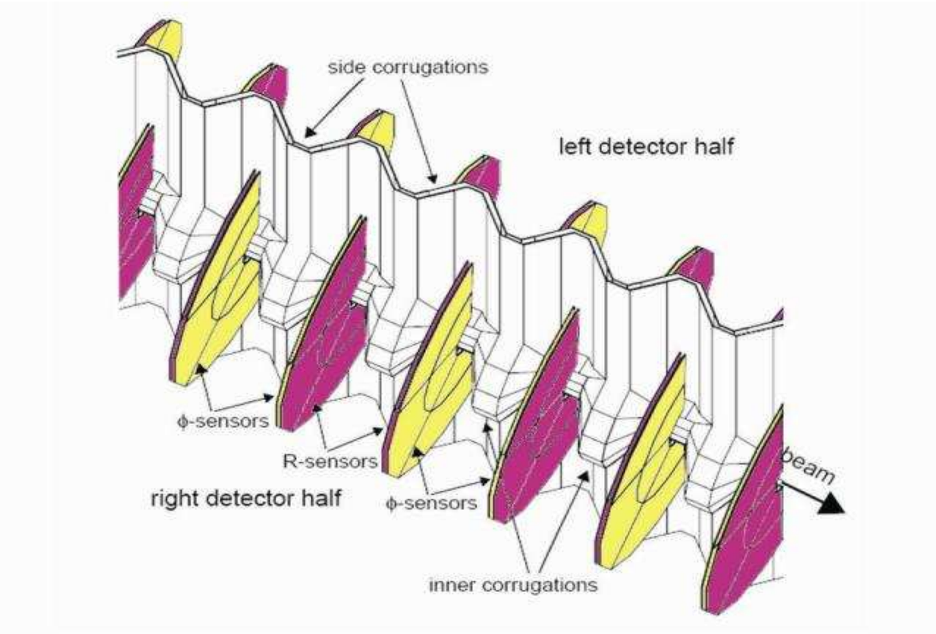
- Reconstruction phase:
  ⋆ various pattern recognition algorithm + Kalman-Filter tracking.
- Runge-Kutta extrapolator to deal with highly inhomogeneous field in the tracking stations.
- "Closed-form" alignment methods used:
  ⋆ Alignment with track model based on Kalman-Filter,
  ⋆ An alignment based on Millepede method, with parametrized trajectory - Volker Blobel,
- Equivalent methods, χ^2 minimization over alignment and track parameters simultaneously.

Impact Parameter and Material

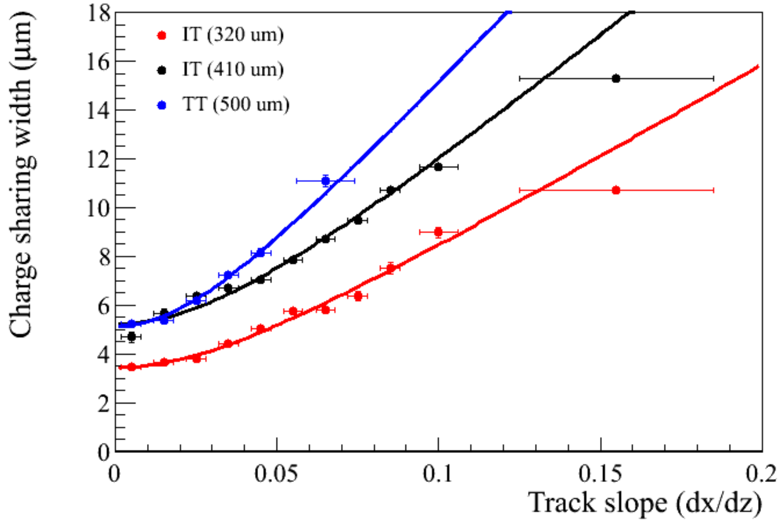
RF-foil divides Sides of VELO and prevents outgasing.



Silicon Trackers: Hit Resolution

- The charge sharing depends relatively strongly on the track slope.
- Note for the experts: previous fact is detrimental to some of the alignment parameters which couple strongly to the track slope.

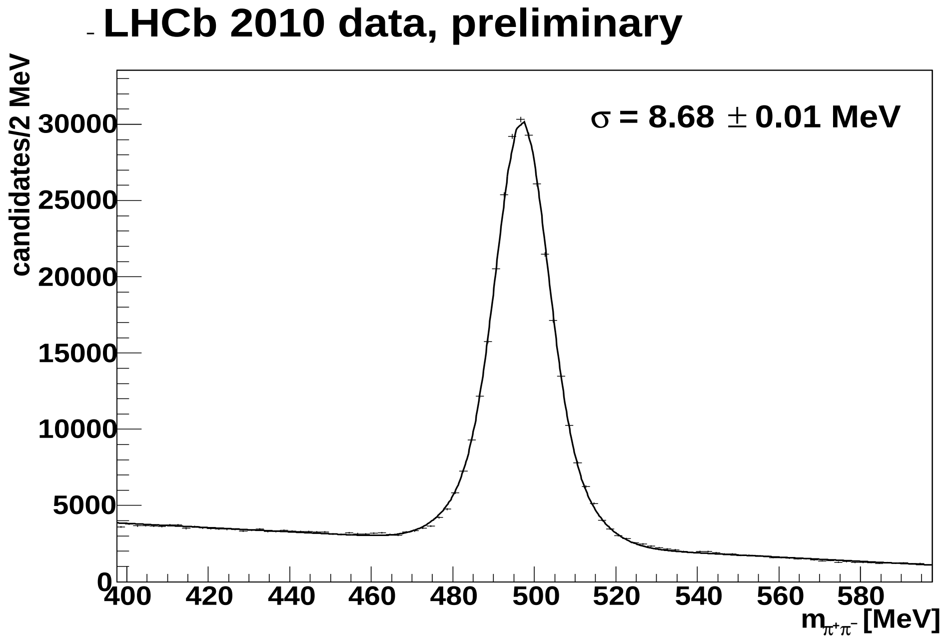
Charge sharing vs. on track slope



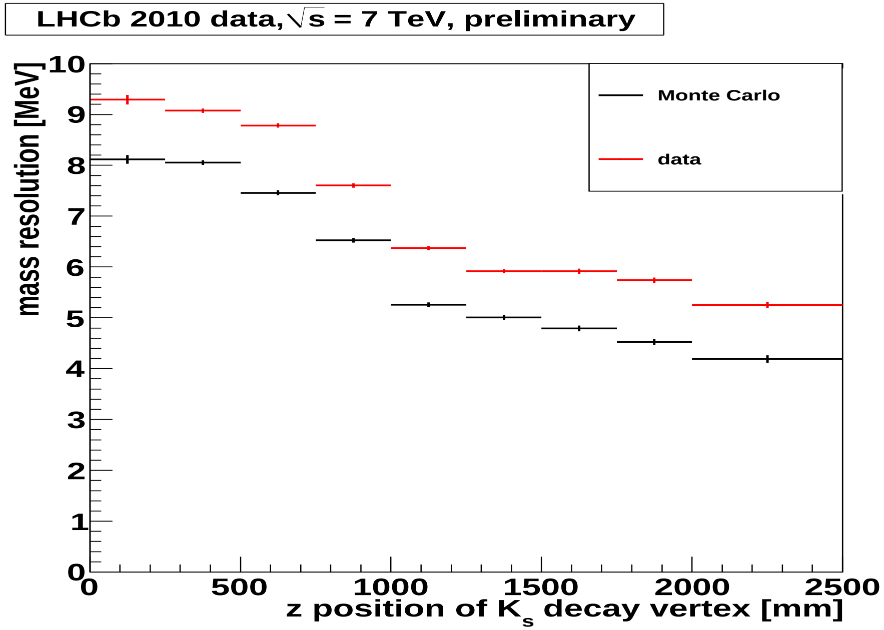
Downstream Tracks, Mass Resolutions

- The best physics candidates are made from Long tracks.
- Long lived particles: e.g., K_S and Λ may decay outside VELO.

Down-Downstream tracks for K_S



Mass resolution vs. z_{decay} for K_S



- Hence, some physics studies are possible even without VELO...