Tracking and Alignment in LHCb

Florin MACIUC on behalf of LHCb collaboration

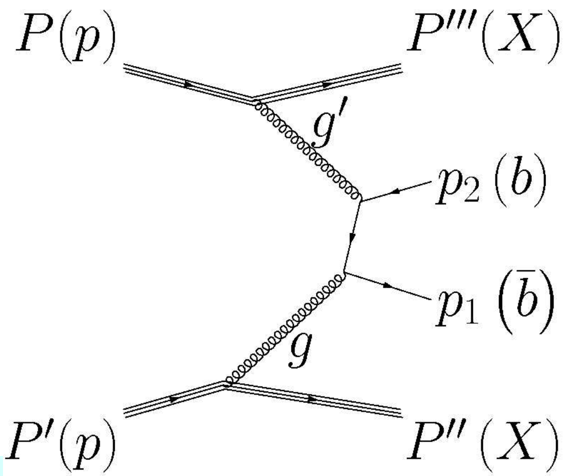
florin.maciuc@mpi-hd.mpg.de

Max-Planck Institute for Nuclear Physics Heidelberg

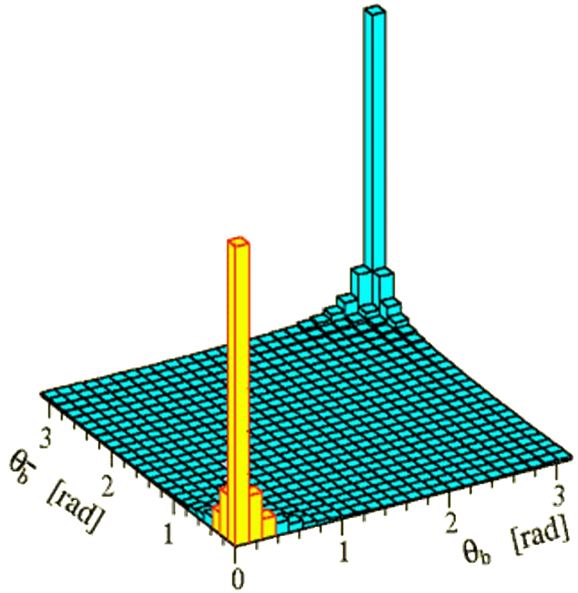
LHCb and B-physics

- 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.

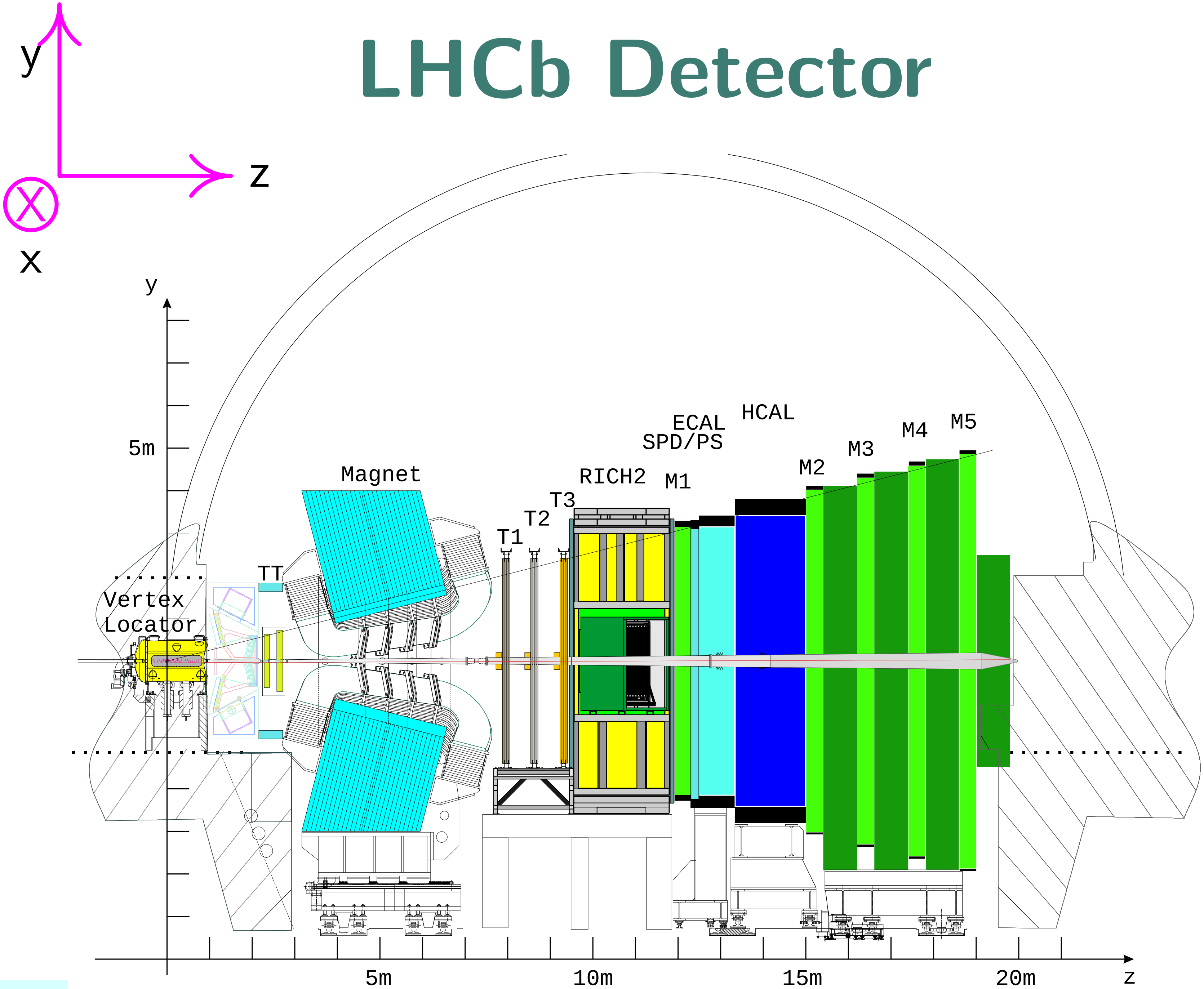
Gluon fusion before fragmentation



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



LHCb Detector



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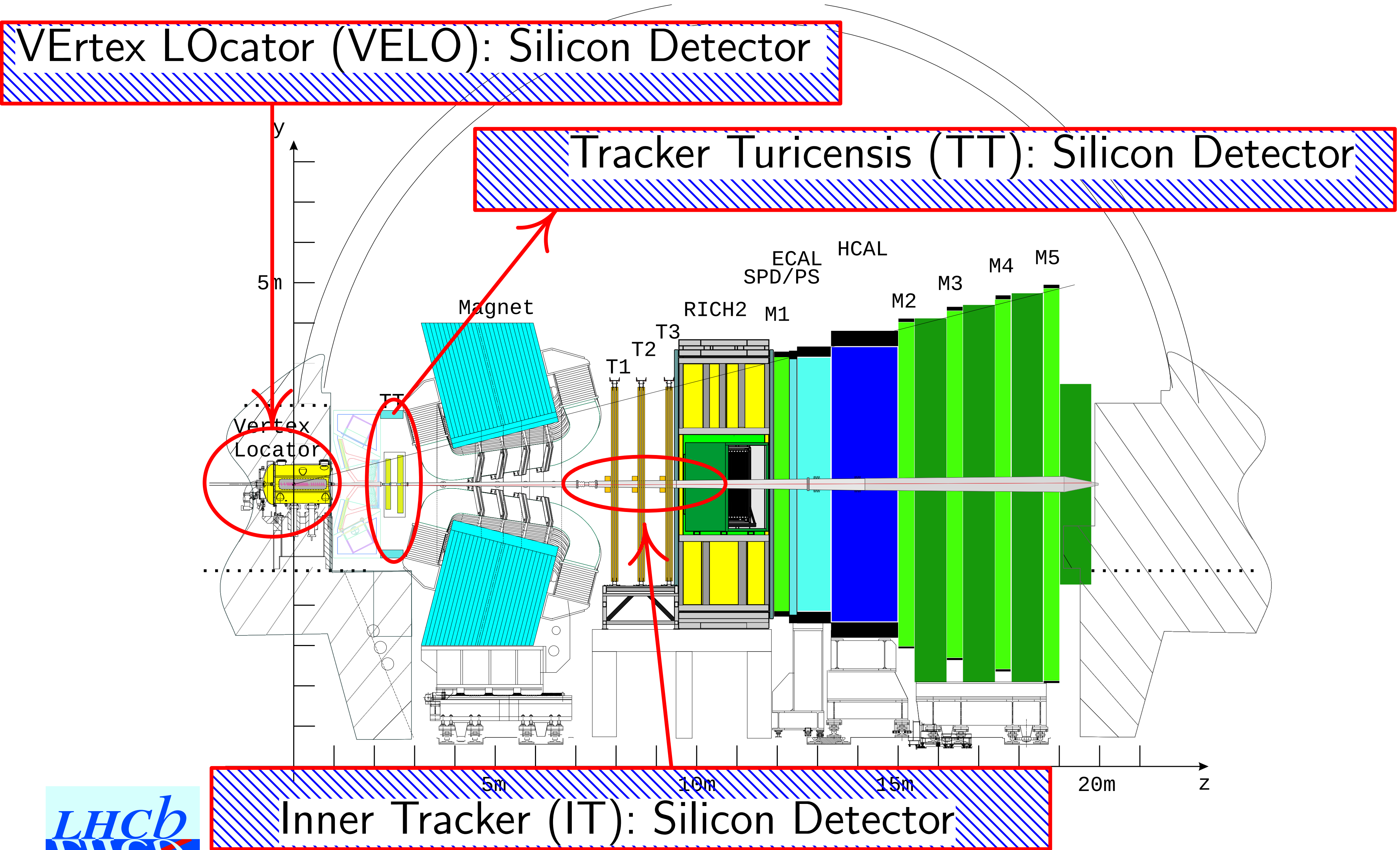

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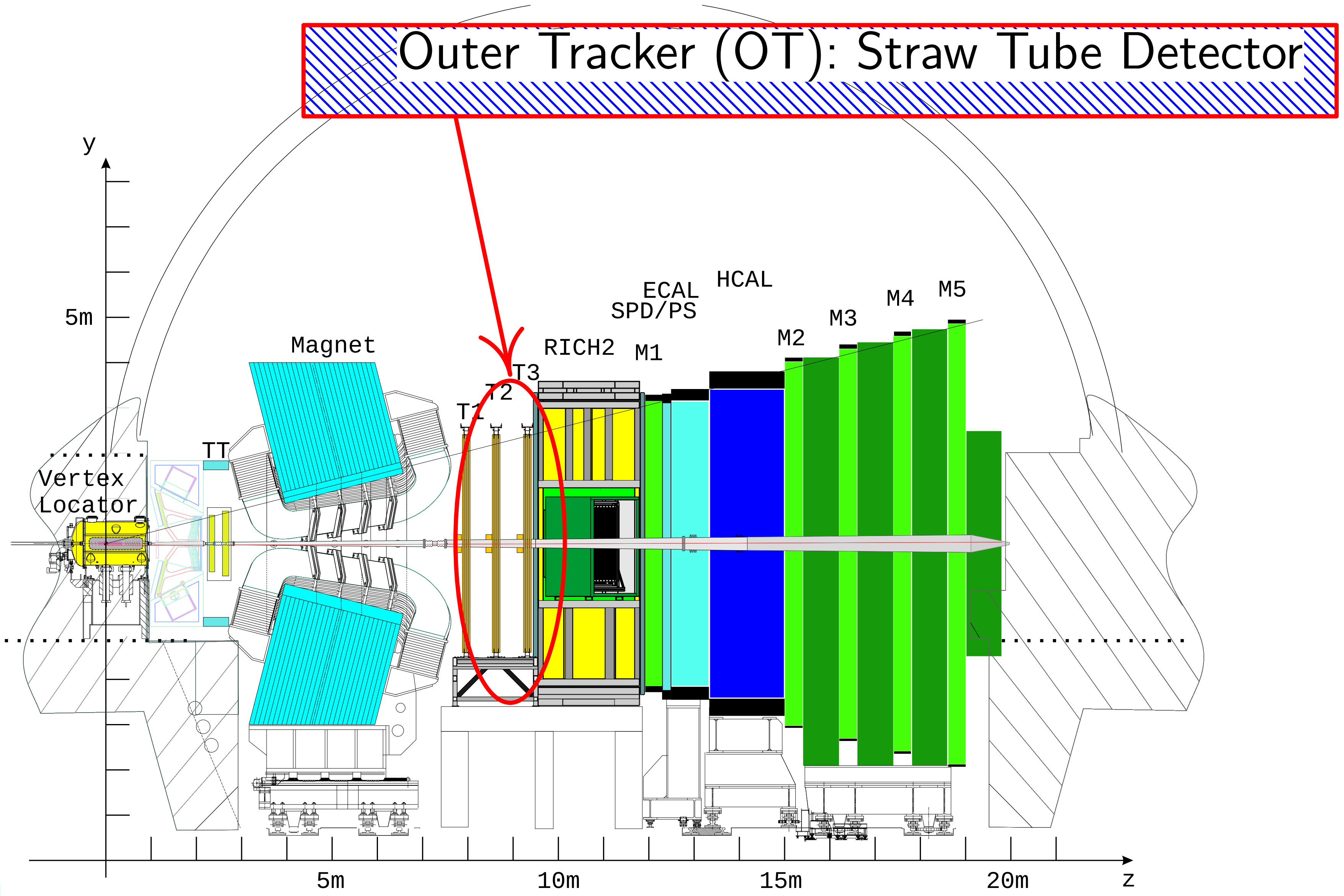
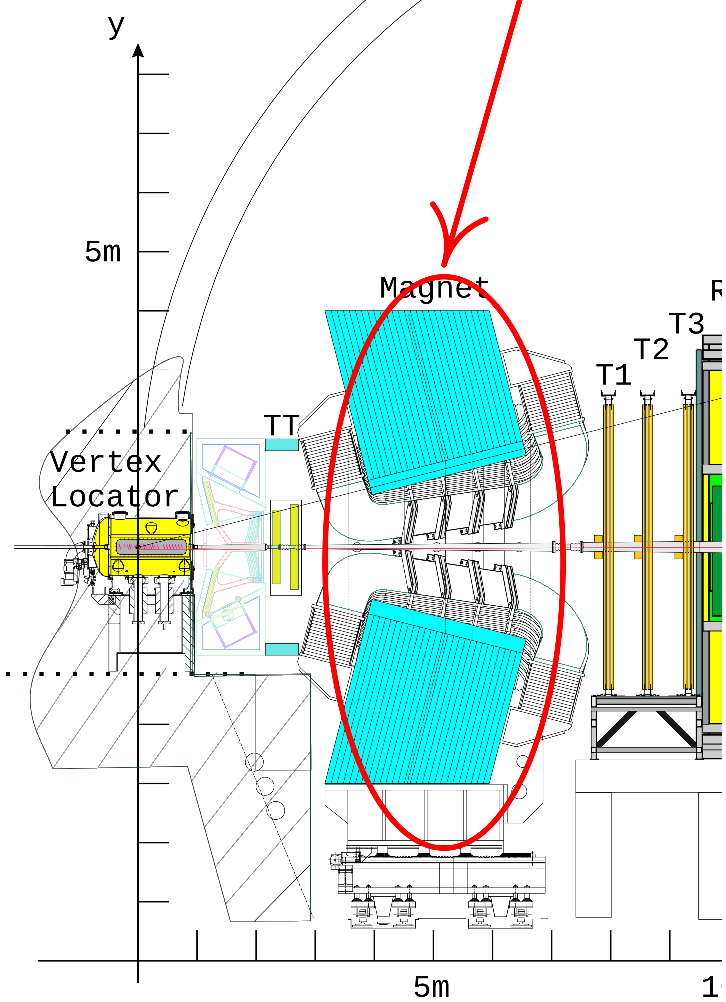
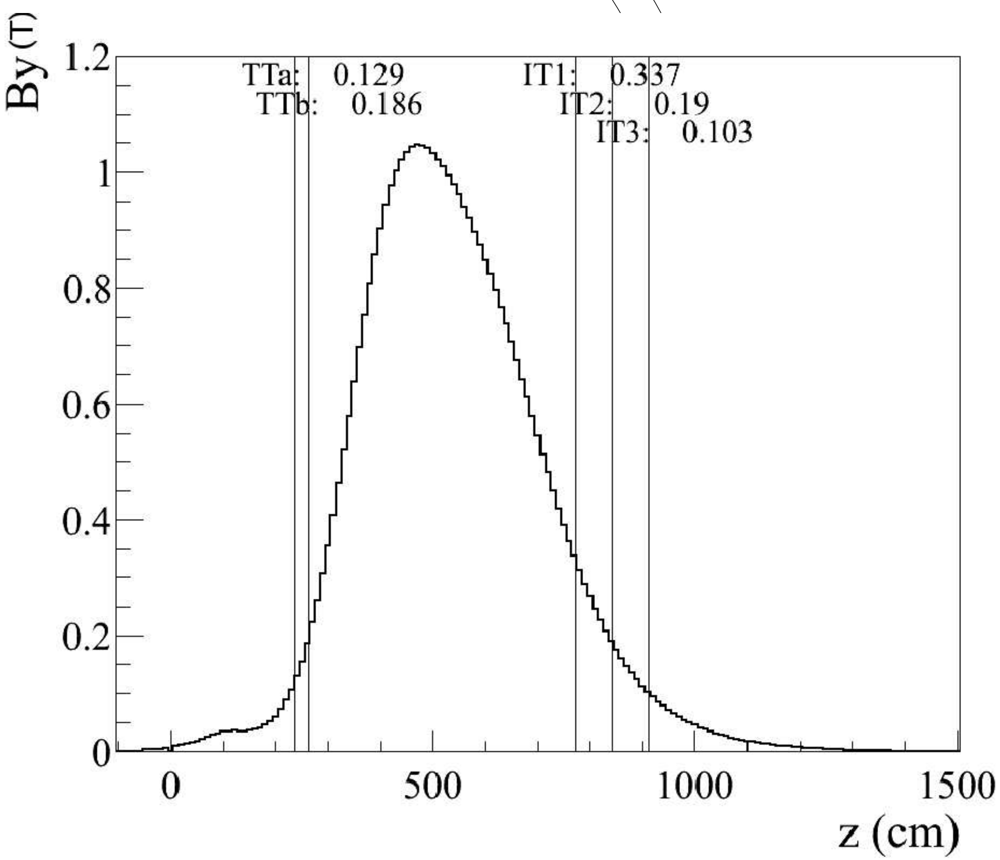


LHCb Detector

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



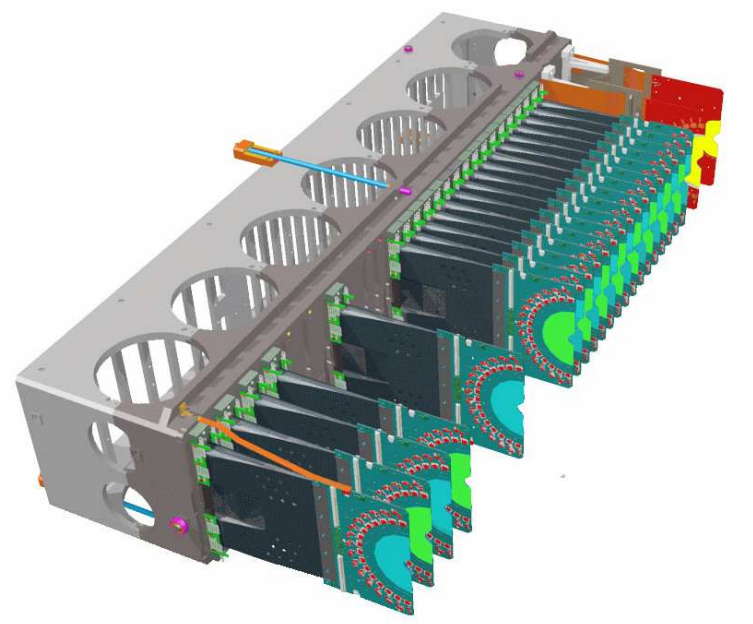


VErtex LOcator

- 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 sensor row on one side

Schematic: one side of VELO



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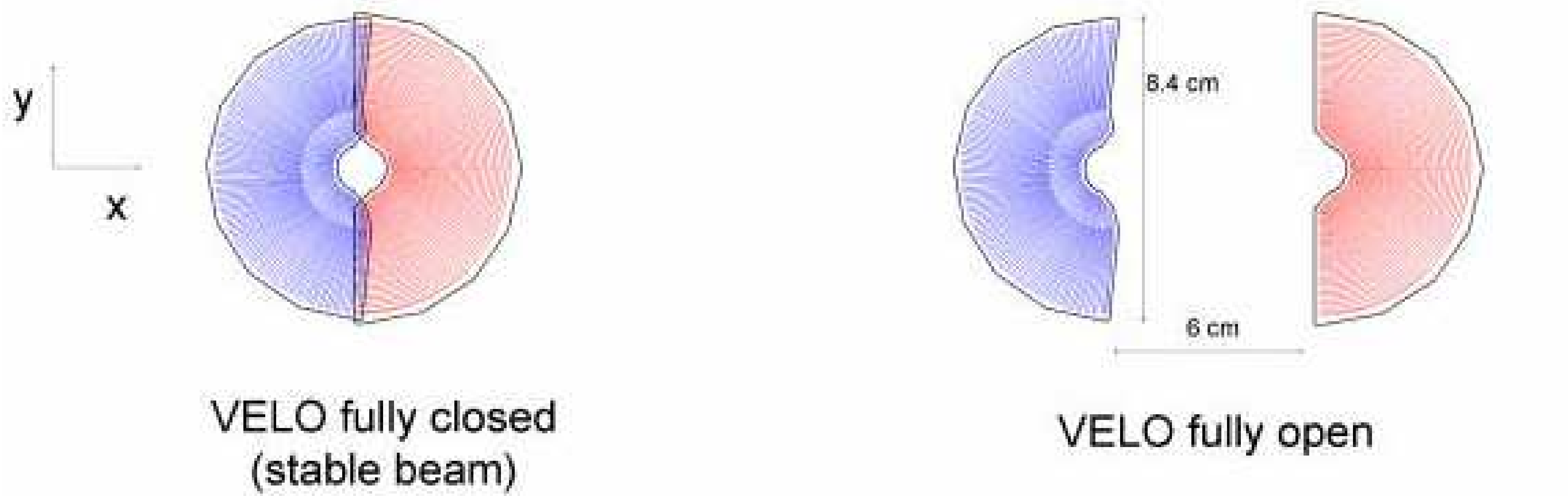
Schematic VELO sensors in Open and Closed positions



Tracking methods and alignment

- Reconstruction phase:
  $\star$ pattern recognition + Kalman-Filter tracking.
- Runge-Kutta extrapolator to deal with highly inhomogeneous field in the tracking stations.

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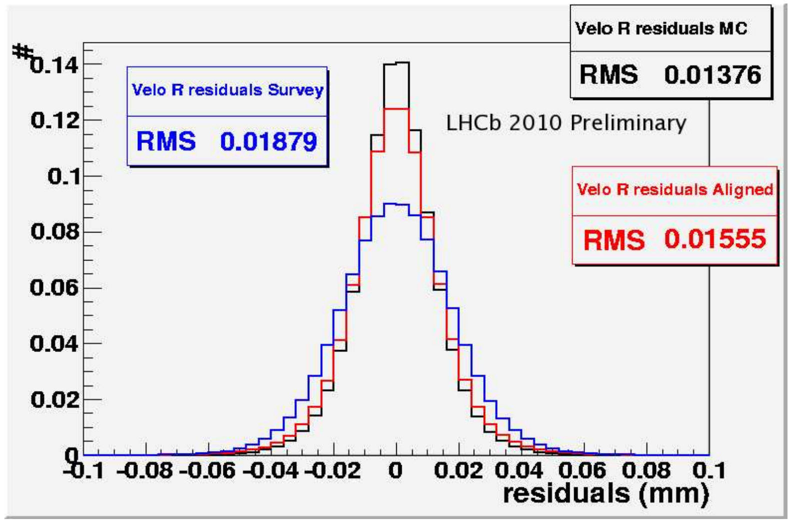
- Reconstruction phase:
  $\star$ pattern recognition + Kalman-Filter tracking.
- Runge-Kutta extrapolator to deal with highly inhomogeneous field in the tracking stations.
- "Closed-form" alignment methods used:
  $\star$ Alignment with track model based on Kalman-Filter,
  $\star$ An alignment based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

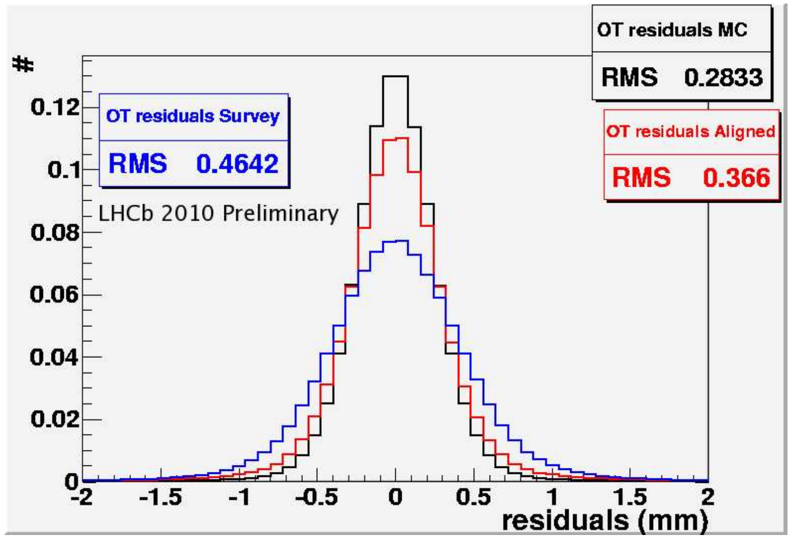
Alignment status of subdetectors

- 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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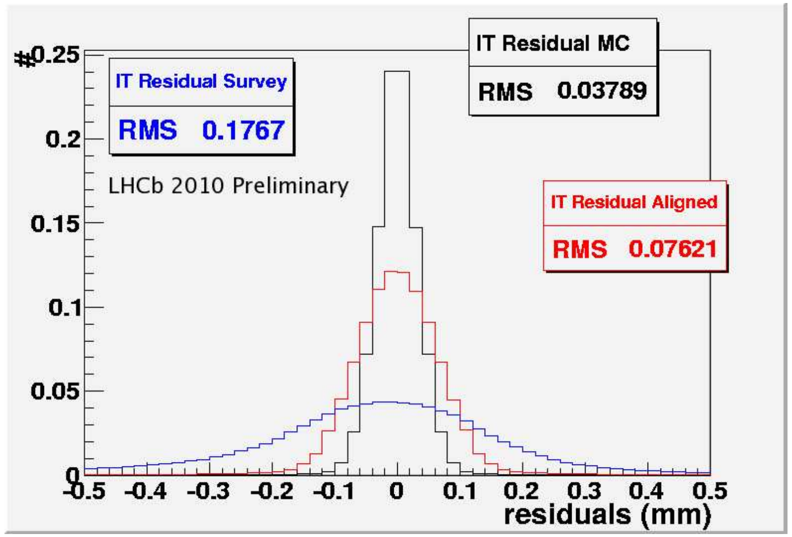
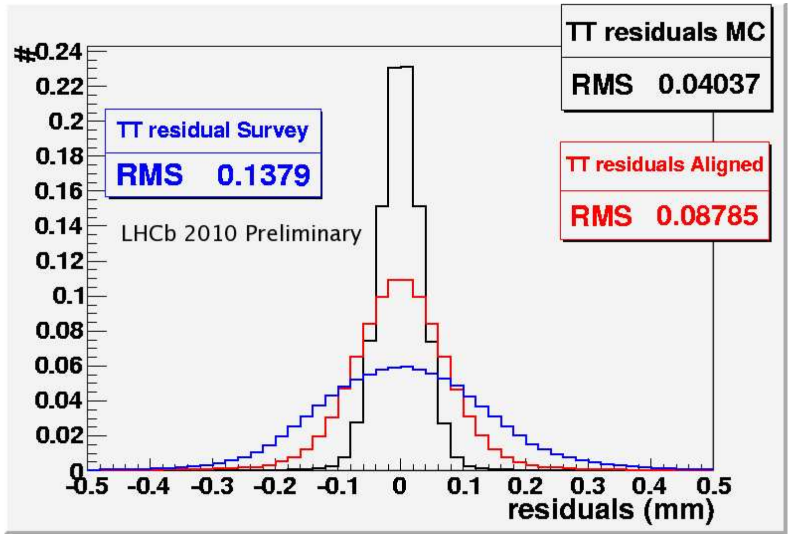
IT residuals



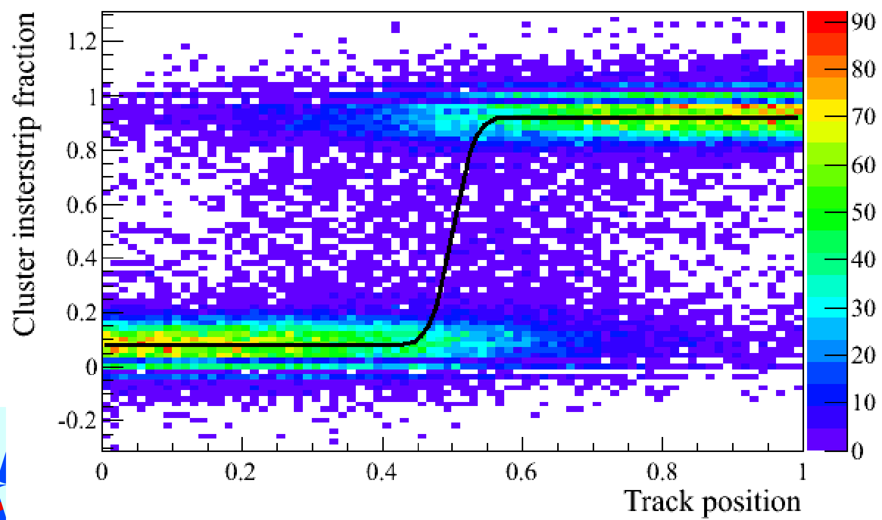
TT residuals



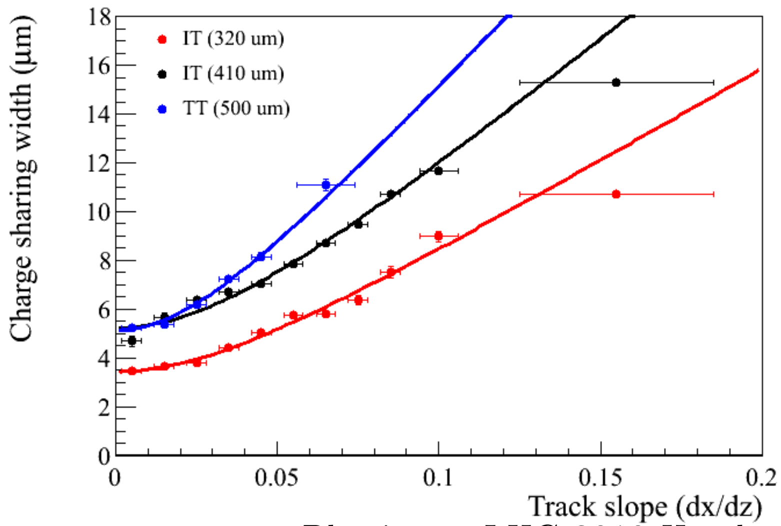
Alignment status

- 40-50% differece between Monte Carlo and Data for IT and TT.
- IT and TT are single-sided silicon strip detectors.
- One source of the disagreement was found in the charges sharing between neighboring strips - this effect was overestimated in MC.
  ⋆ It explains an increase from 40 μm to 50 μm in IT hit resolution.
  ⋆ Residual misalignments might account for the rest.
- 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 between two strips



Charge sharing vs. on track slope

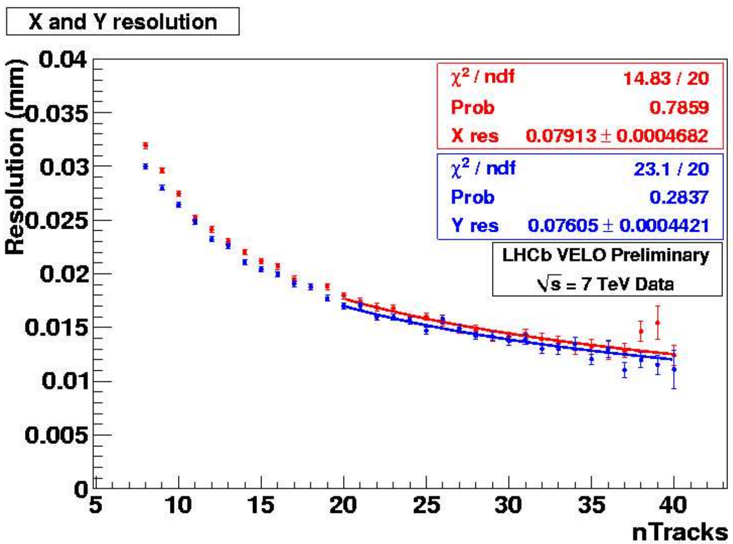


Primary Vertex Resolution

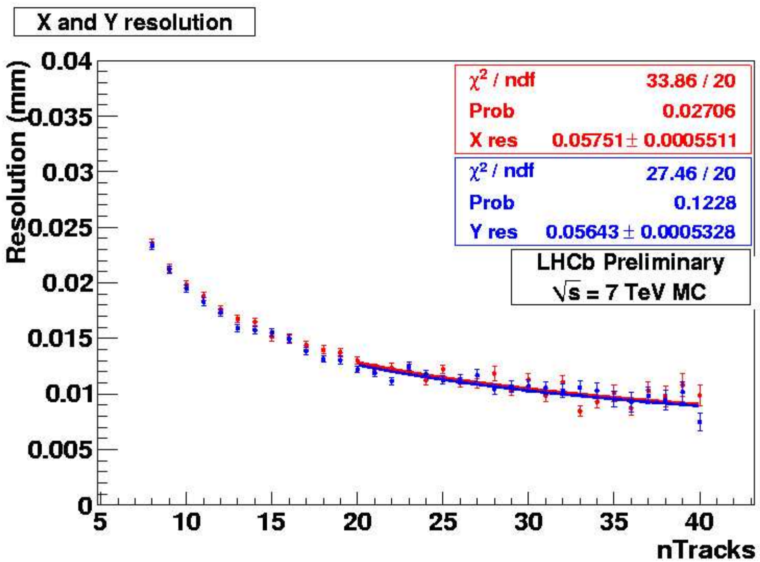
- Primary Vertex (PV) is determined with VELO tracks.
- Method: randomly split event track container in two, and reconstruct PV.
- Results close to expected,
  ⋆ A residual ≈ 40 % difference - e.g. when using 25 tracks.
  ⋆ Improving.

	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



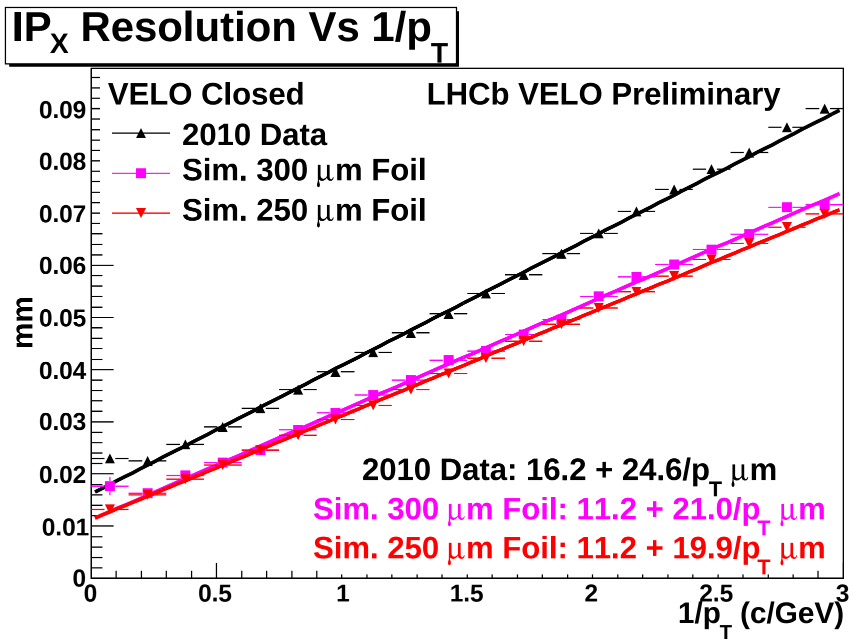
PV resolution vs track used, MC



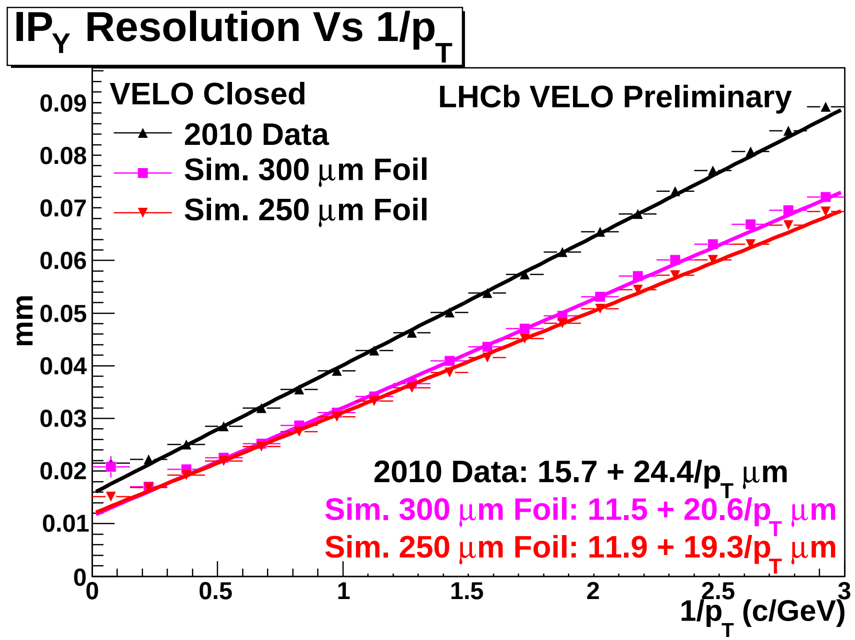
Impact Parameter Resolution

- 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

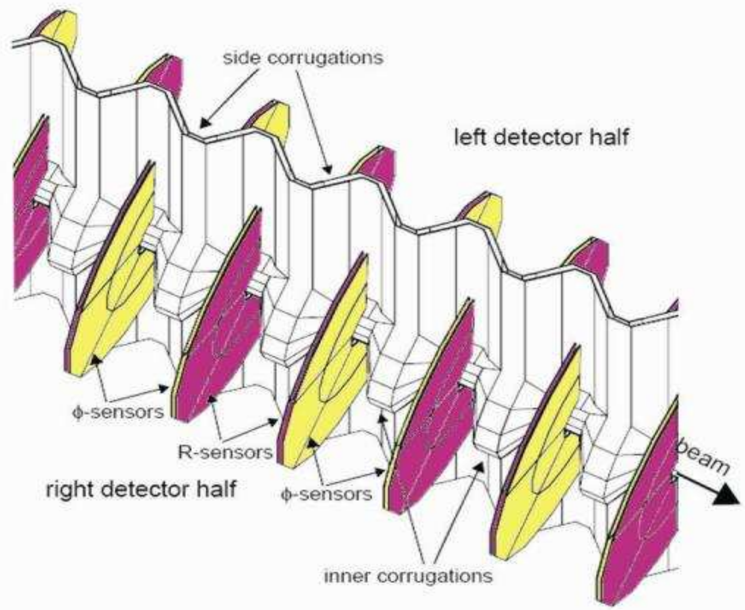


Impact Parameter resolution in Y



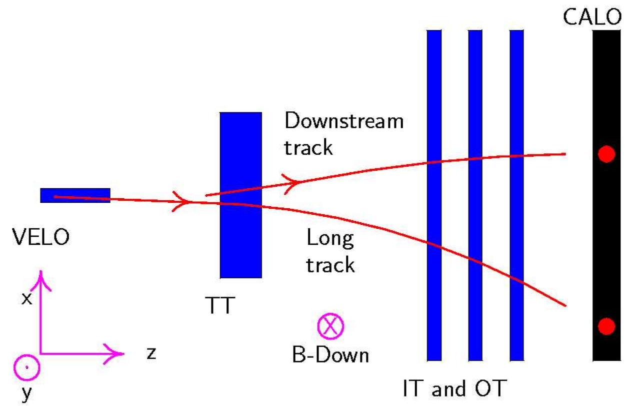
Impact Parameter Resolution

- Impact parameter (IP) - Closest approach to PV of a track.
- IP resolution is determined primarily by:
  ⋆ 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.
  ⋆ RF-foil in MC 250μm thick, 300μm real value.
  ⋆ Misalignment between VELO sides.
- Searching for other material or misalignments effects.



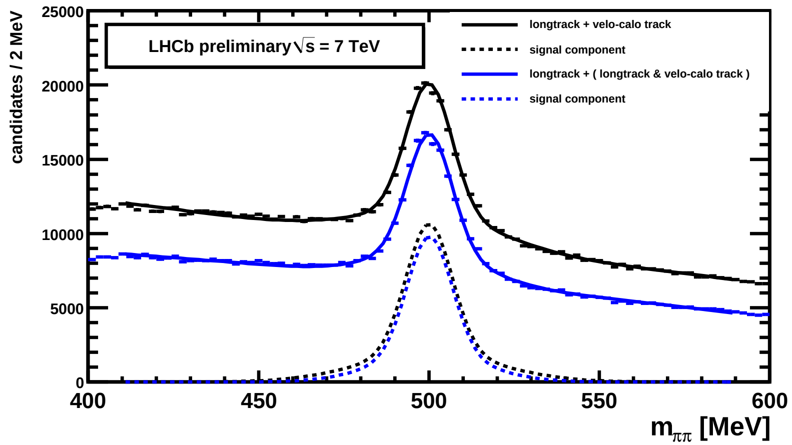
Long Track Efficiency

- Long track efficiency obtainable from K_S candidates.
- Method:
  ⋆ Find 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.

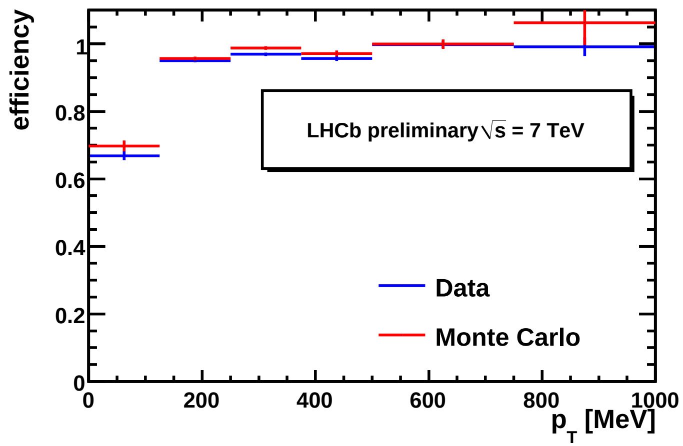


- The method supplies IT/OT/TT efficiency in tracking.
- Results close to 100%

Long-Long K_S candidates, mass plot

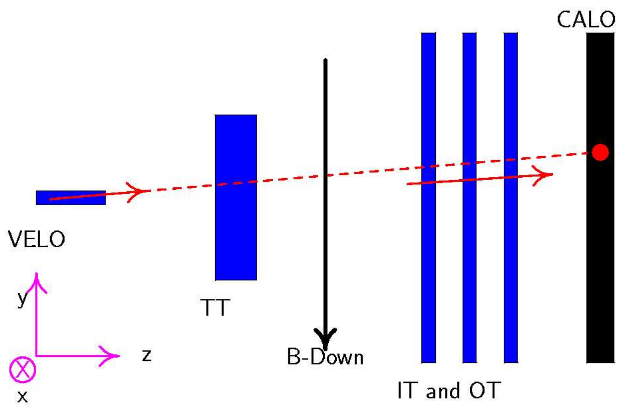


Efficiency as a function p_T

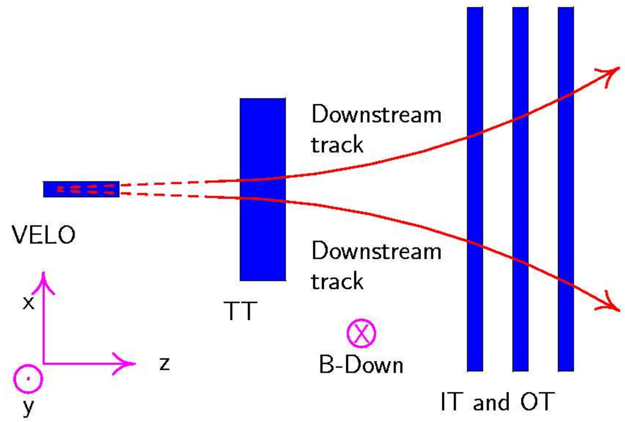


Other Methods for Track Efficiency

- Method 1:
  ⋆ Uses a VELO segment, finds CALO cluster in the non-bending (z, y) plane,
  ⋆ Fit track VELO+CALO,
  ⋆ IT/OT/TT segments are matched to the found track.
- Method 2:
  ⋆ Takes a K_S candidate with two Downstream tracks,
  ⋆ Compare number of candidates with one associated VELO segments, with those with 2 VELO segments.
- In place of K_S, J/psi could be used.



1st Method

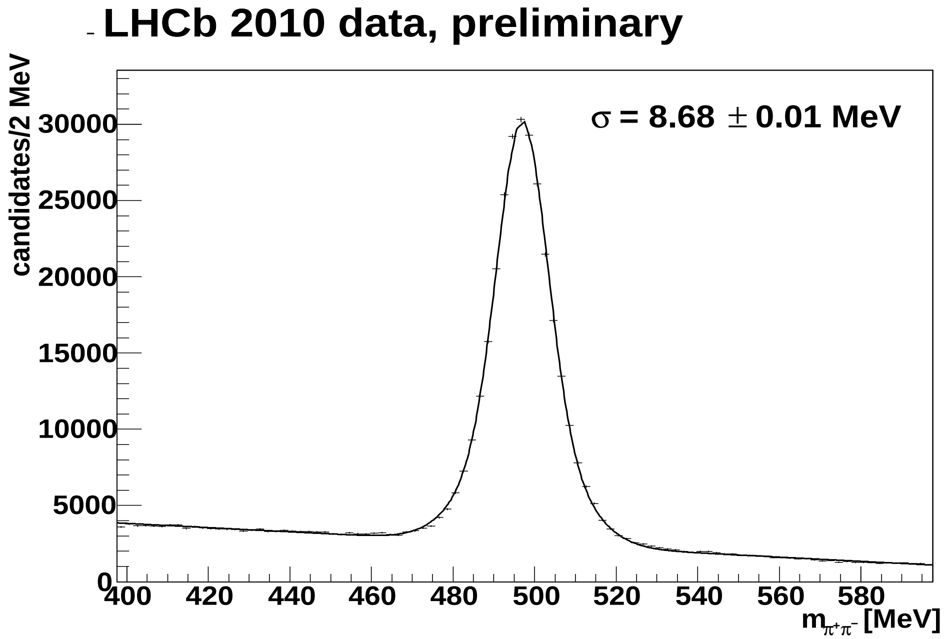


2nd Method

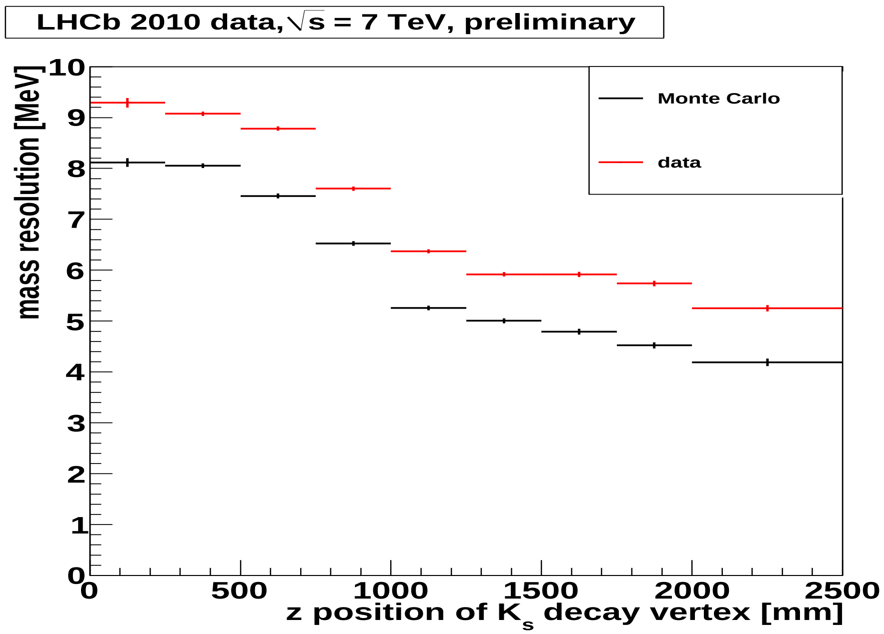
Downstream Tracks, Mass Resolutions

- 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



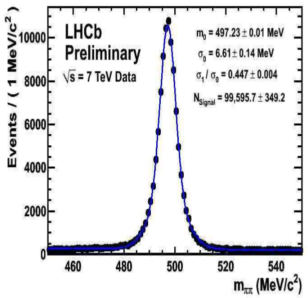
Mass resolution vs. z_{decay} for K_S



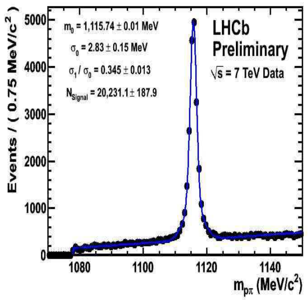
- Hence, some physics studies are possible even without VELO...

Particle Zoo

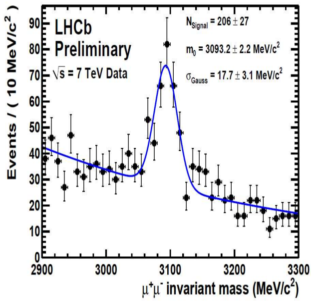
- Mass values of several detected particle agree with PDG values to per mil level.



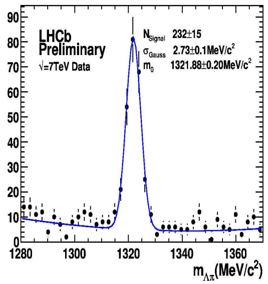
K_S



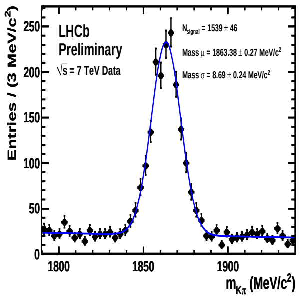
Λ



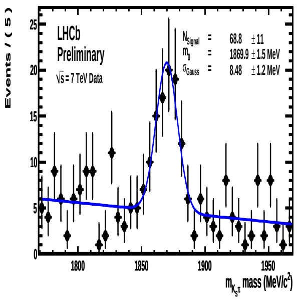
J/ψ



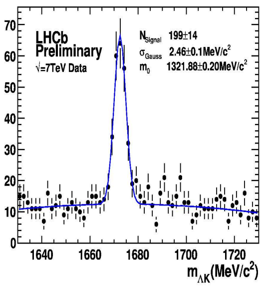
Ξ



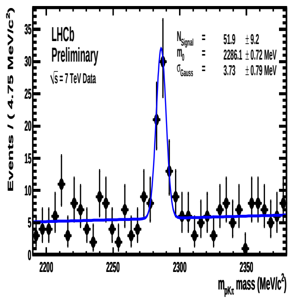
D^0



D^+



Ω



Λ_c

Plus many more other ....

Summary and Conclusions

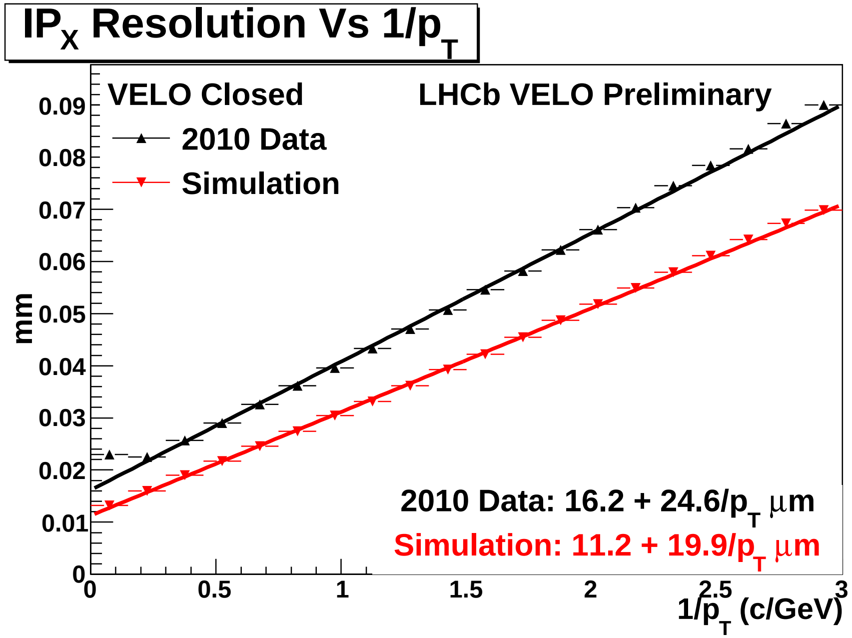
- Already more than 100 Million 7 TeV Collisions in the 2010 LHCb data.
- Main conclusion: Alignment and tracking are good shape for physics analysis.
- Monitoring of alignment and tracking quality in progress.
- Gradual improvements in:
  - Detector description,
  - Tracking tools,
  - Alignment.
- 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

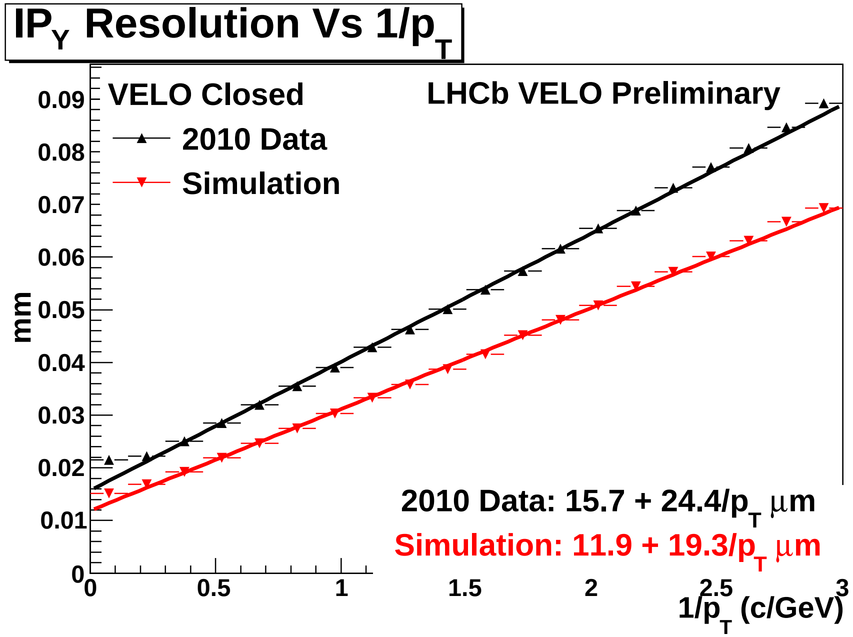
Impact Parameter (IP)

- 2010 data , VELO Closed

Impact Parameter resolution in X

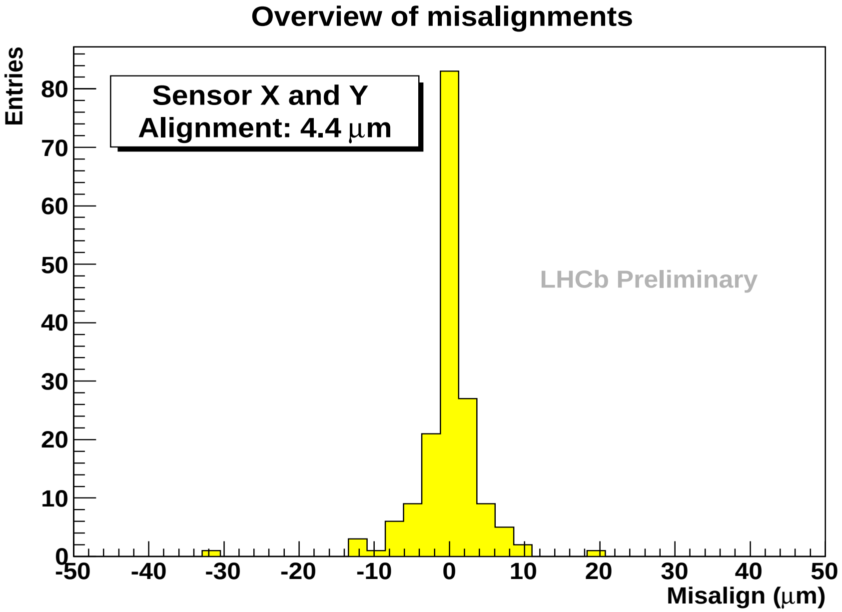


Impact Parameter resolution in Y



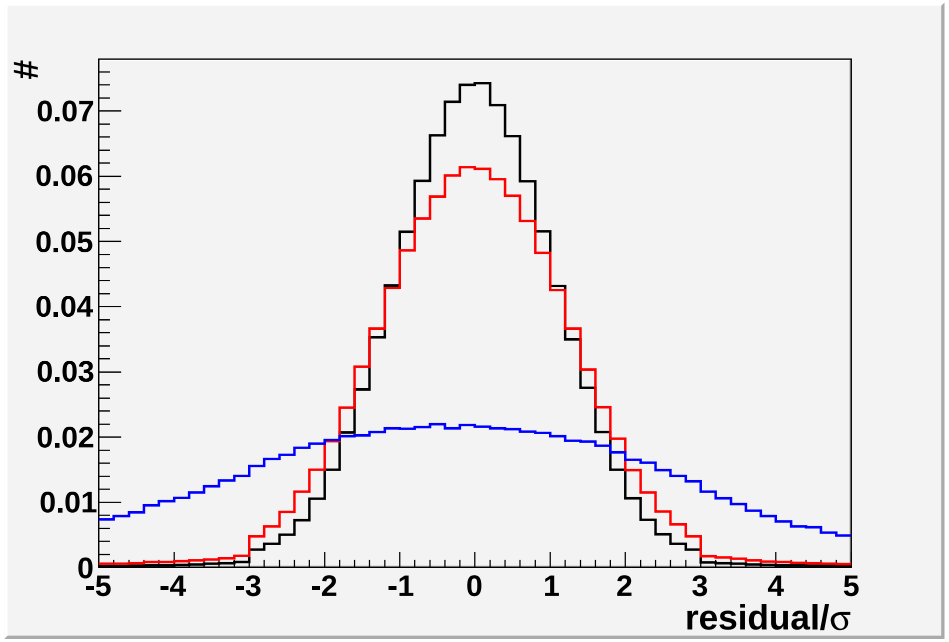
VELO Sensor alignment

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

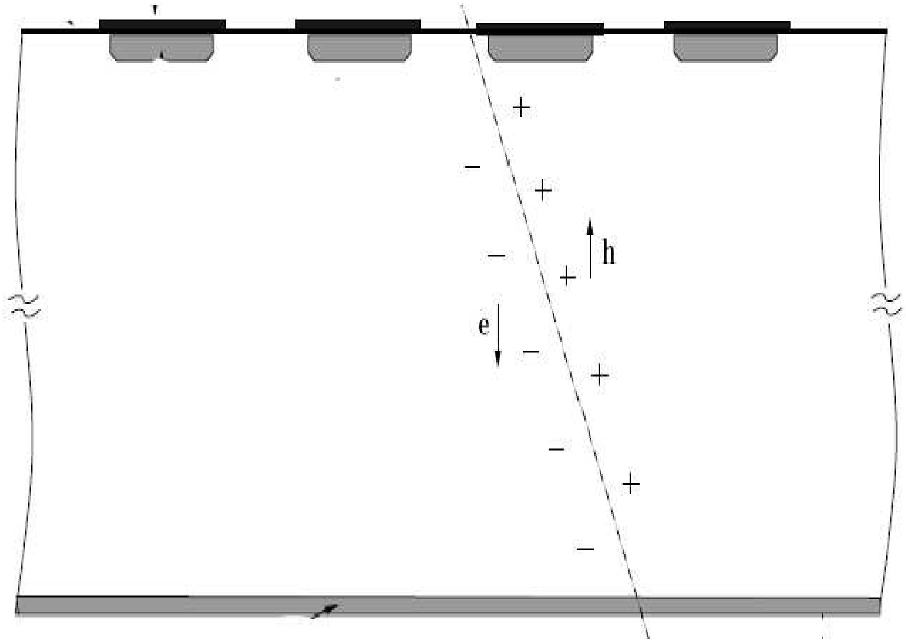


Residual distributions for IT

IT pull plots



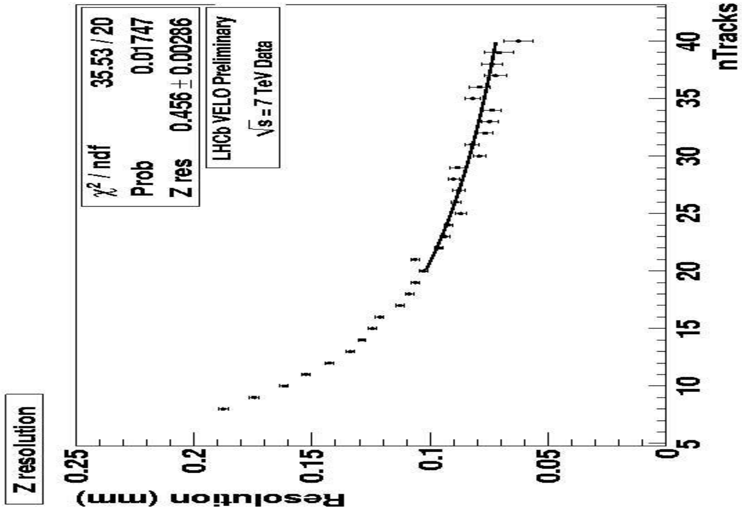
single-sided silicon strip sensor



Primary Vertex Z

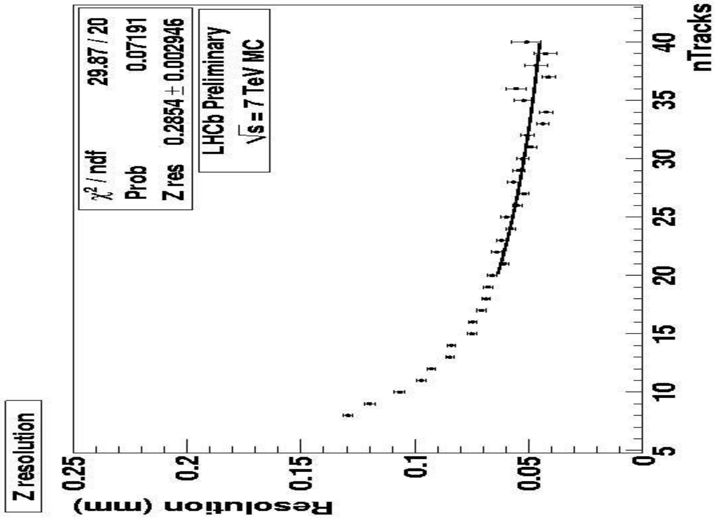
PV resolution vs track used

real data



PV resolution vs track used

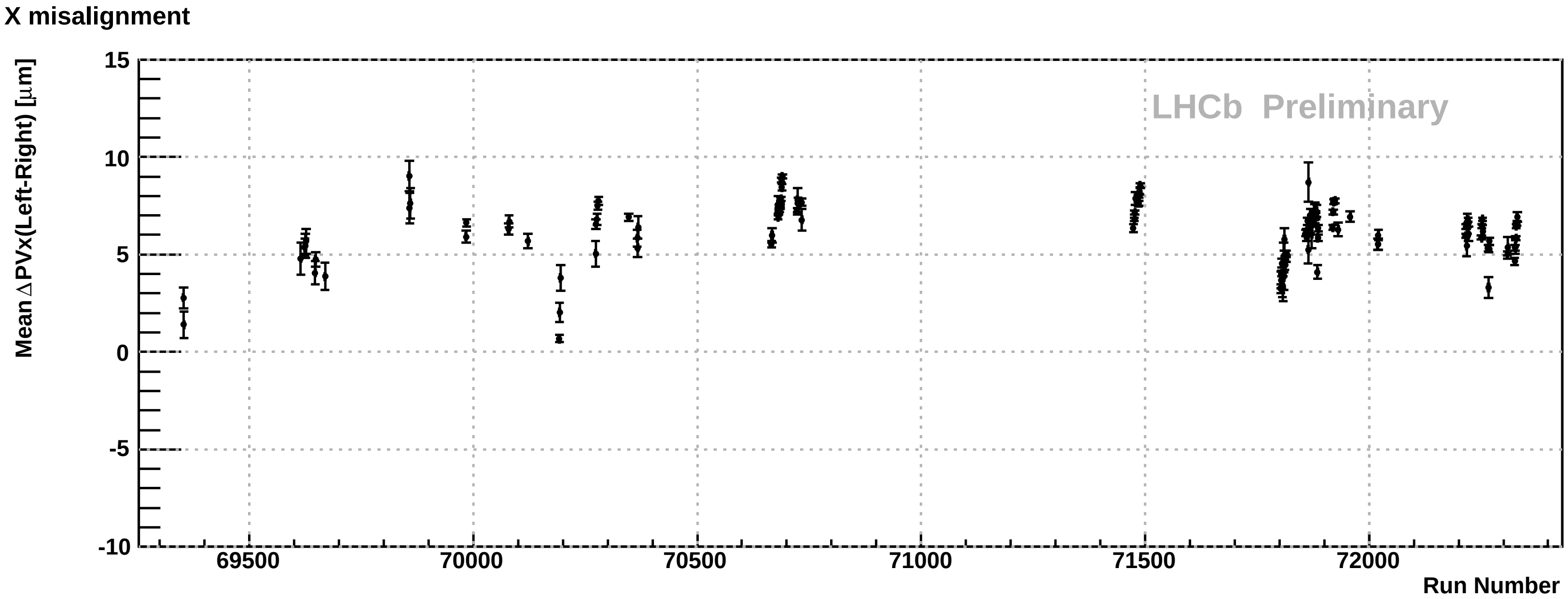
MC



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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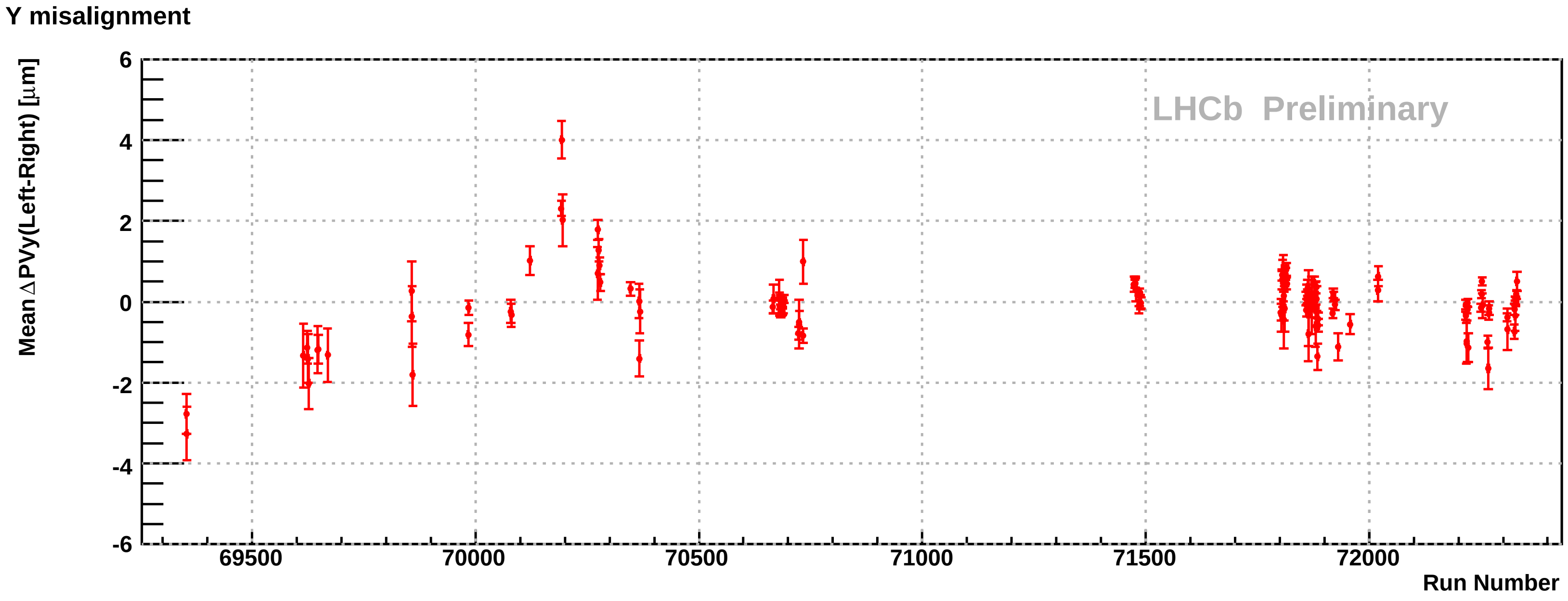

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ΔZ difference of PV (μm)