Alignment Challenge at LHCb

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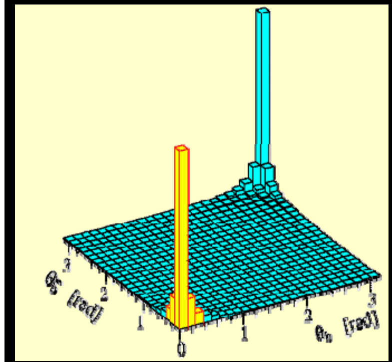
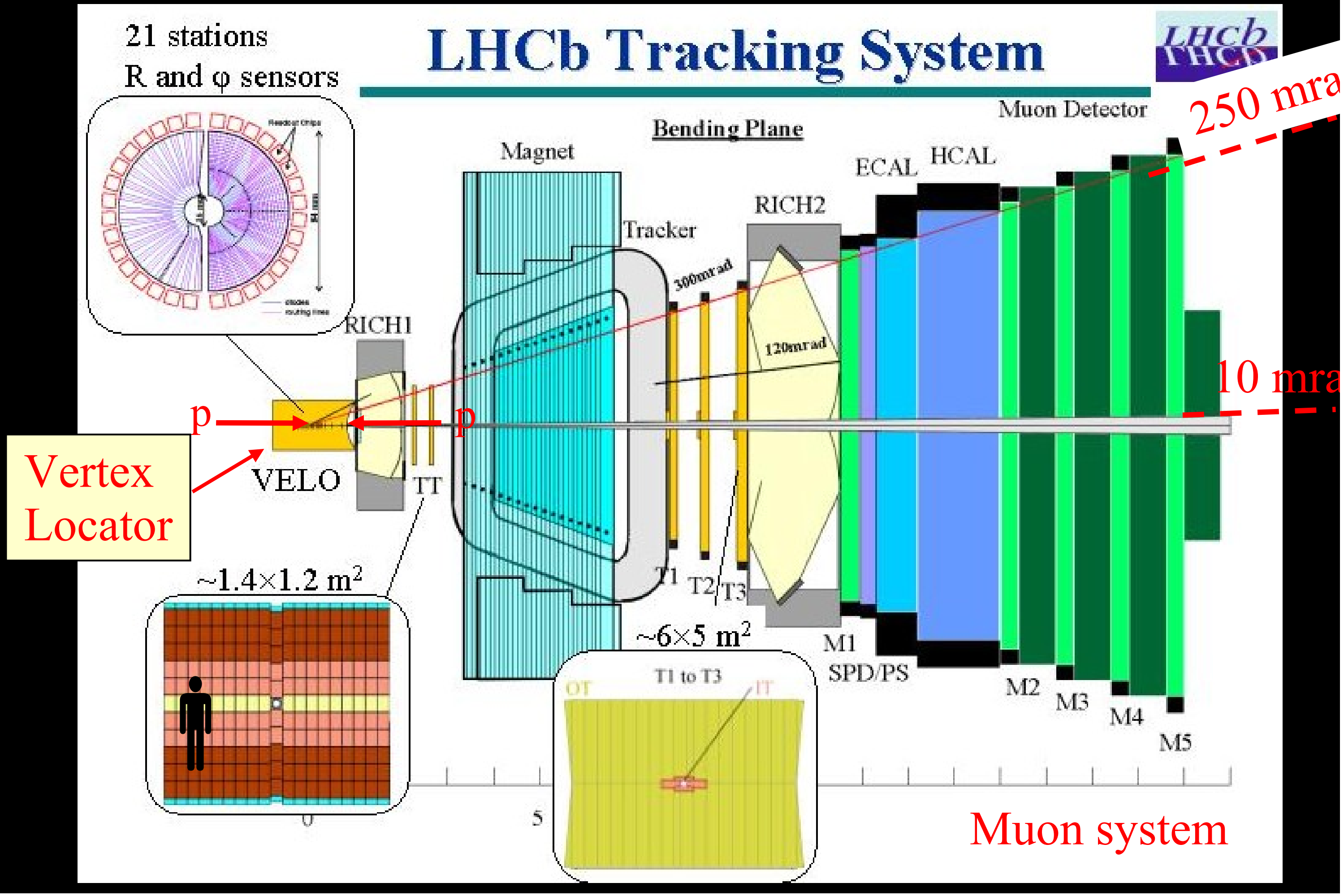
LHCb Experiment

- Large Samples of b decays for New Physics searches in CPV & rare B (&D) decays
  - B production predominately at small polar angles
  - LHCb optimized as single forward arm spectrometer





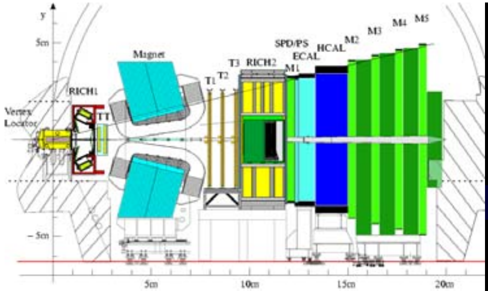
Tracking System Challenges

- Large track density

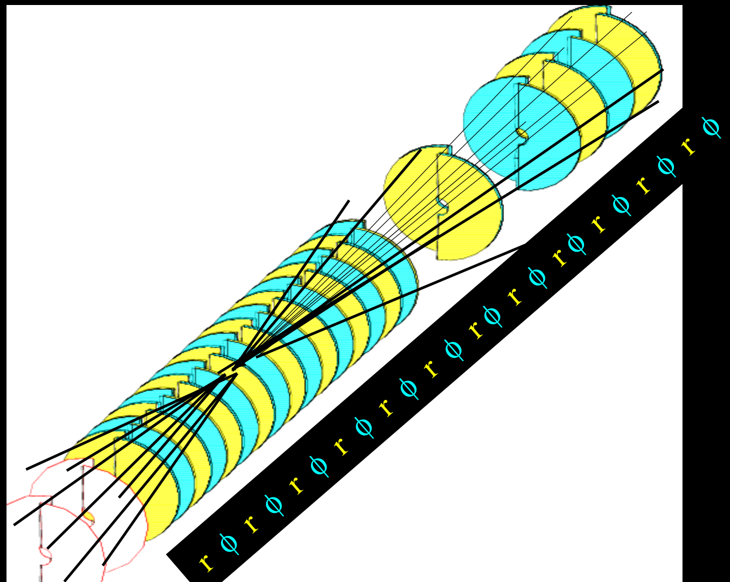
- Trigger uses tracking info
  - Requires good alignment
  - Online updating of constants if needed.

- Tracking algorithms need to be FAST, as they are executed online. Want offline pattern recognition very similar to online version, except for fine tuning of alignment & calibrations.

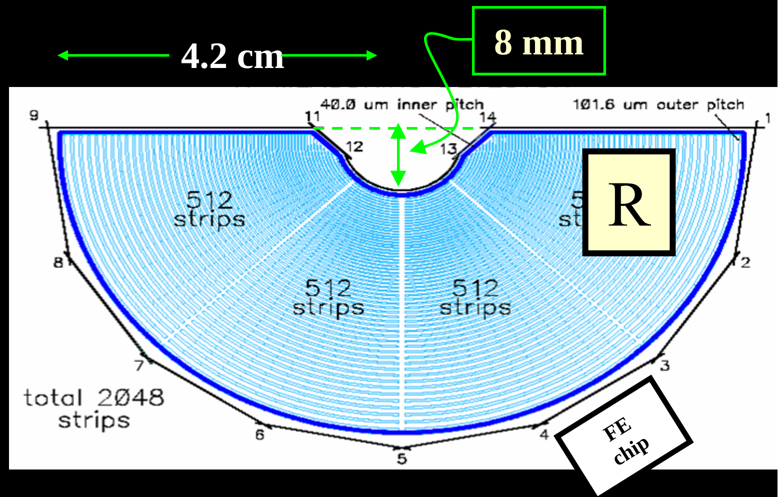
- Minimize material (no surprise here)



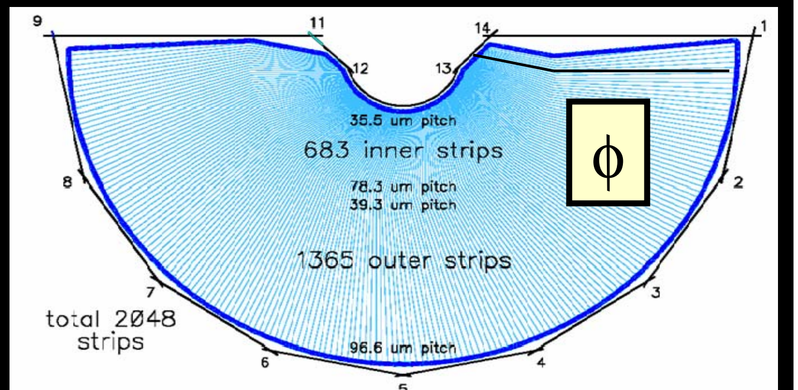
Vertex Locator



R-sensors
- ❑ 2048 strip in 45° sectors
- ❑ Strip pitch increase with R : 40µm→100µm

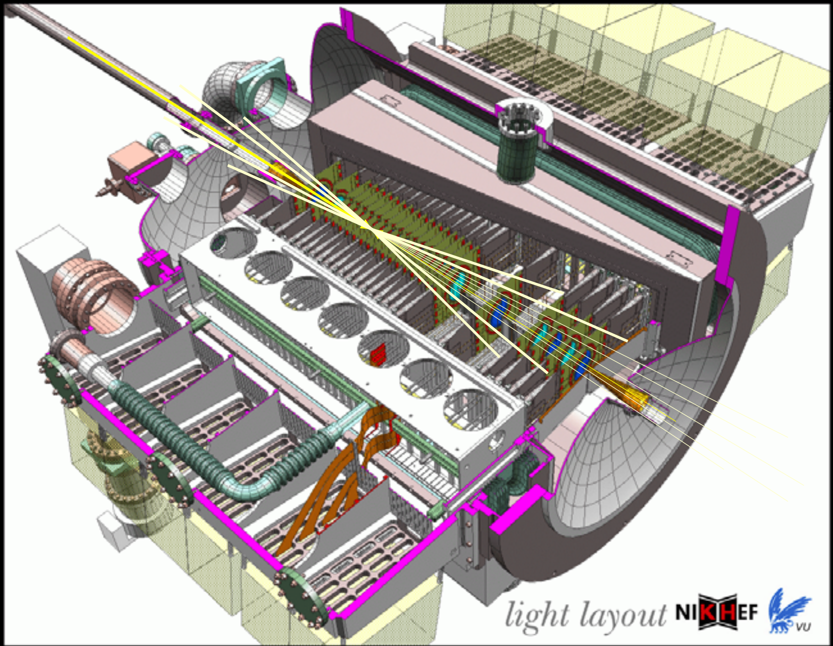


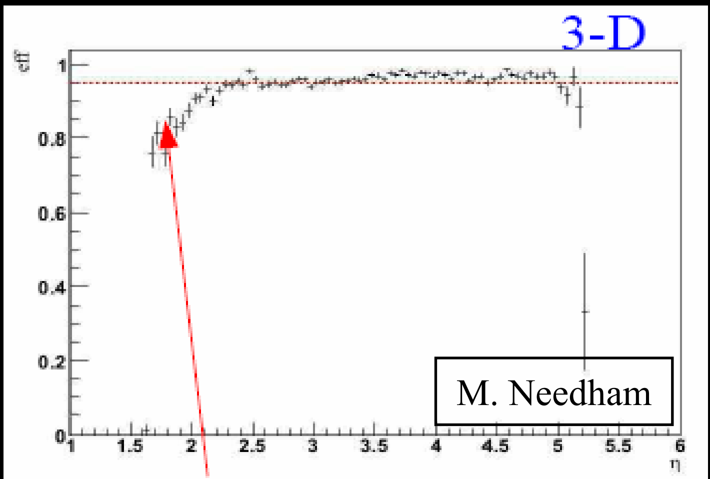
Φ-sensors
- ❑ 2048 strip in inner and outer regions
- ❑ Strip pitch increase with R : 36µm→97µm



- **21 tracking stations**
  - 4 sensors per station with r/ϕ geometry
  - Overlap regions for L/R alignment
  - Optimised for
    - Fast online 2D tracking
    - Vertex reconstruction
    - Offline track reconstruction

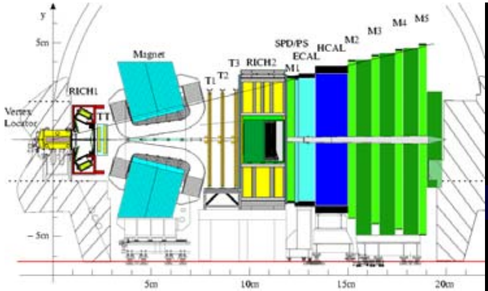
Vertex Detector Challenges





- Most precise device in LHCb <u>moves</u>
  - Retracted by ~ 3 cm in-between fills
  - Reinserted to ~ 8 mm after stable beams
- Integral part of the trigger
  - RZ (2D) tracking/trigger scheme requires transverse alignment between modules <20 μm.
  - Internal alignment monitoring/updating as necessary (online vs offline), 2D vs 3D
  - Rest of tracking system (online vs offline)
    - Momentum estimate using VELO-TT in HLT.
- Need for "same" tracking in HLT and offline:
  tradeoffs of speed/efficiency/ghost rate

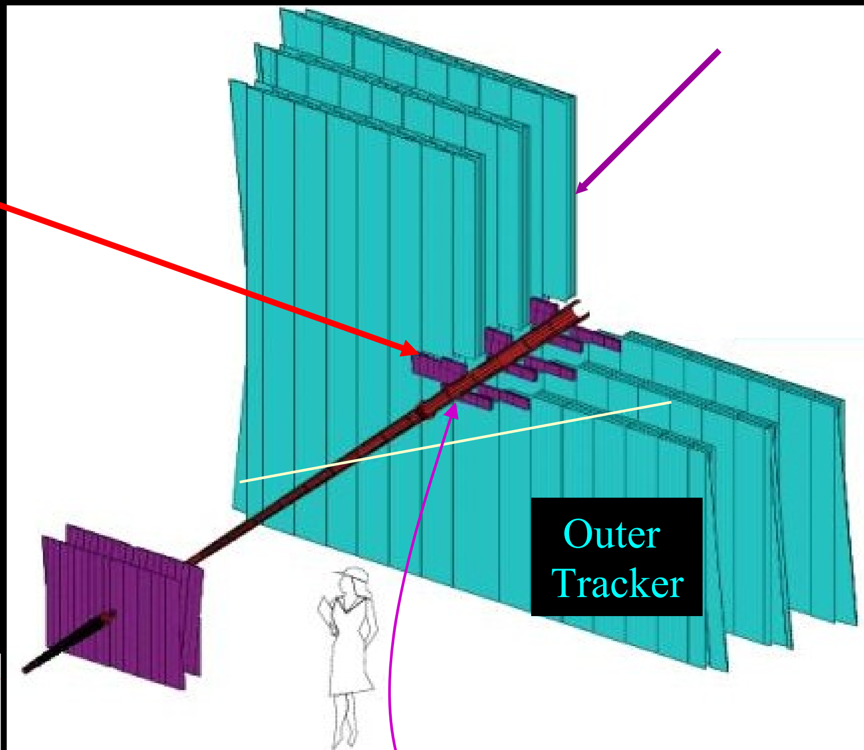
~4% ghost rate (3D)
~7% ghost rate (2D)



Tracking Stations

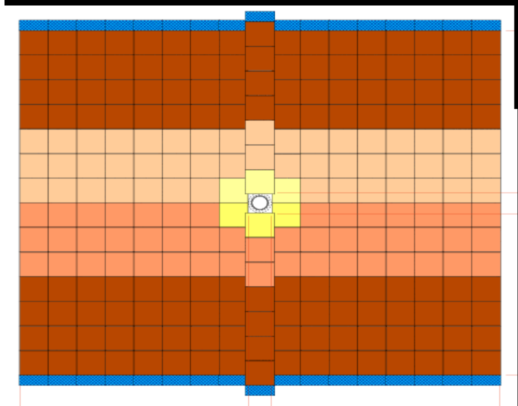
Outer Tracker
- 5.0 mm Straws
- Double-layer straws
- 4 layers: X:U(5°):V(-5°):X

Overlap regions between IT/OT to facilitate relative alignment



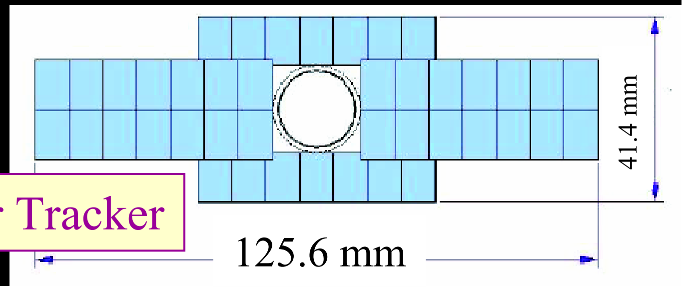
Trigger Tracker (TT)

Silicon Strips
- 198 μm pitch
- 1-2 sensor ladders
- 4 layers: XUVX
- 336 ladders to be aligned

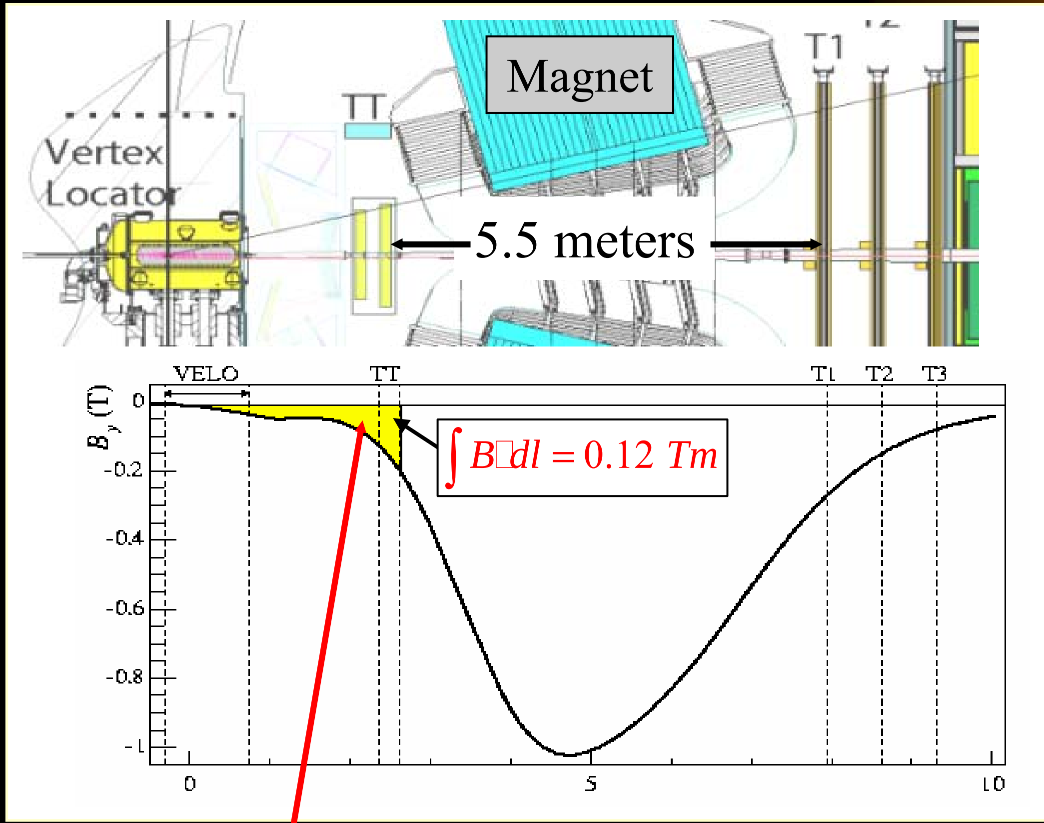


Silicon Strips
- 183 μm pitch
- 128 7-sensor ladders
- 4 layers: X:U(5°):V(-5°):X
- 128 ladders to be aligned

Inner Tracker



Magnetic Field

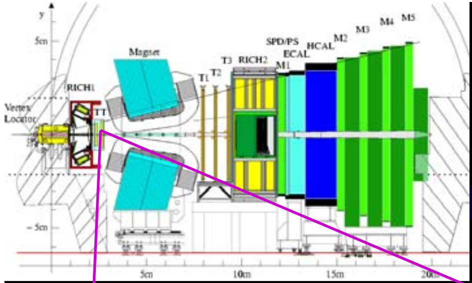


Very small field in VELO

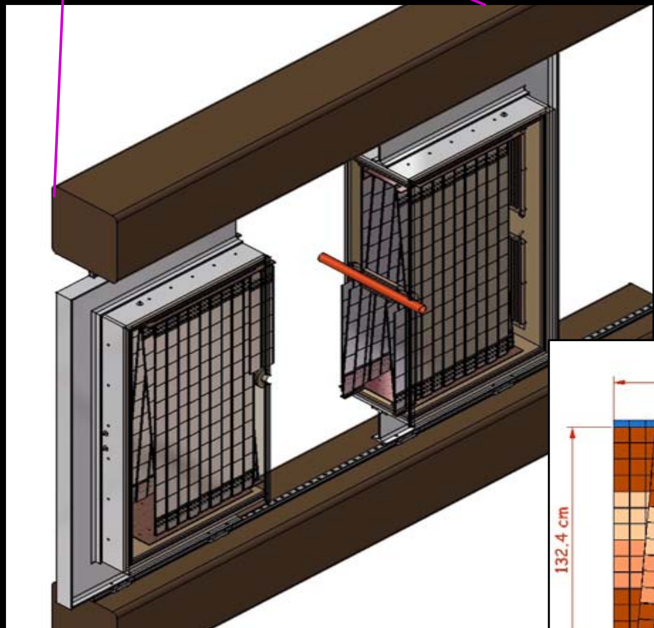
Non-uniform, non-negligible field in region of T Stations

$$\int B \cdot dl = 4\ Tm$$

Non-zero field in region of TT integral part of trigger: Δp/p ~30%



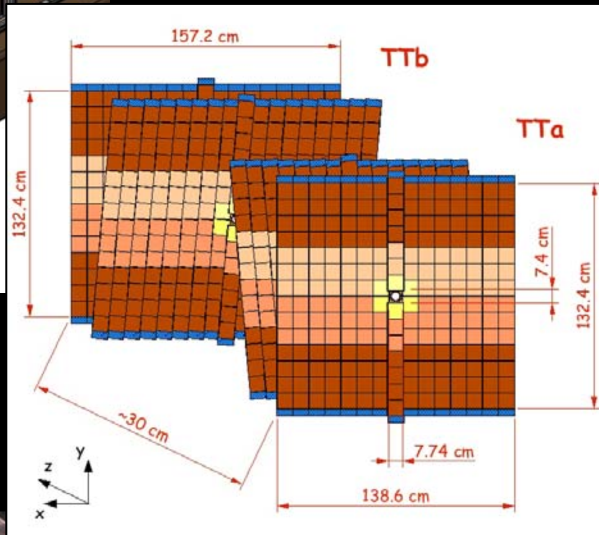
TT



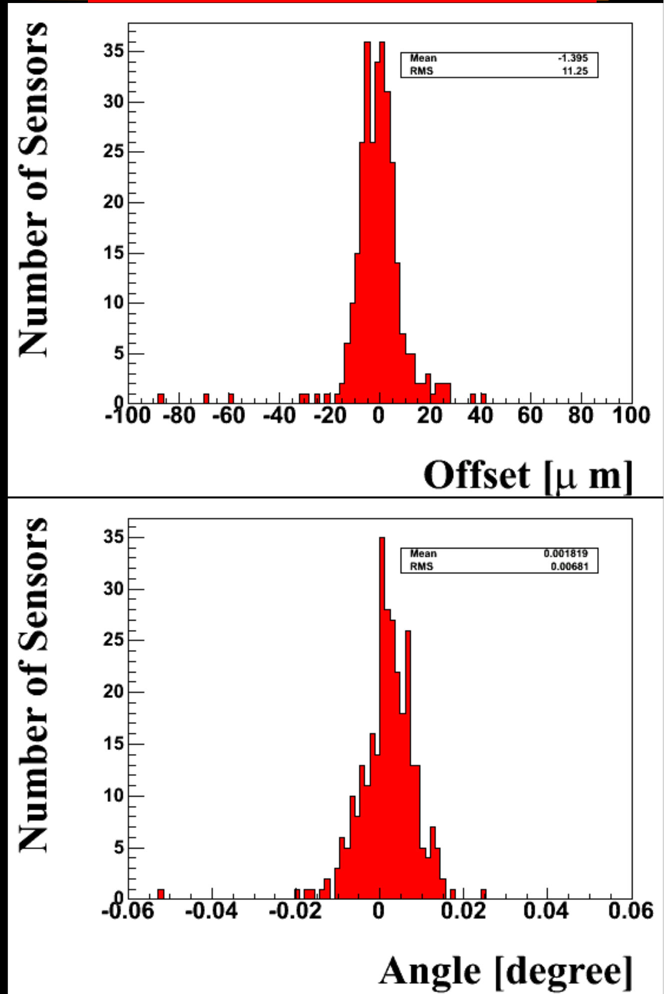
Silicon Strips

- 183 μm pitch
- 128 7-sensor ladders
- 4 layers: X,U(5°),V(-5°),X
- 128 ladders to be aligned

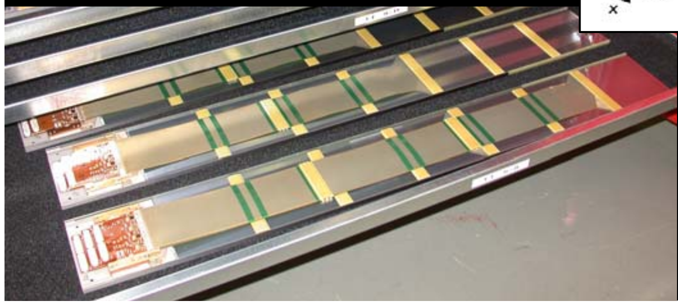
- 2% occupancy, max.

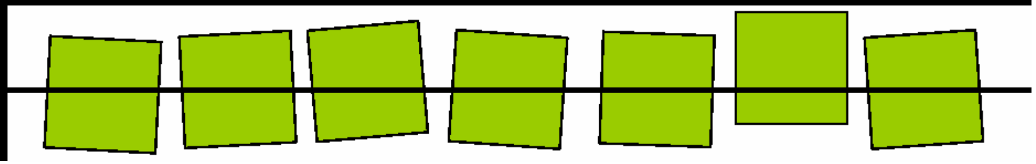


Ladder Alignment



Ladder Production



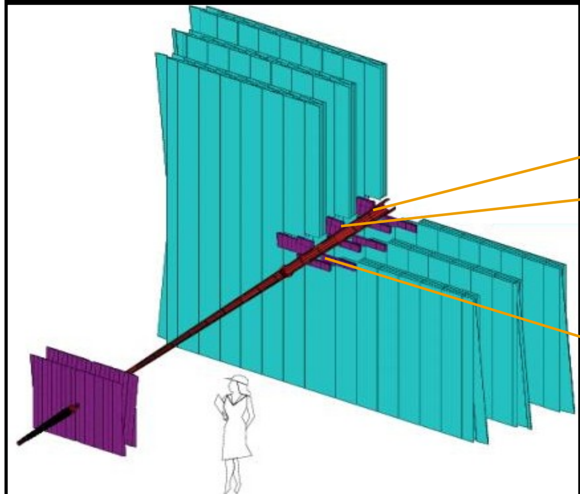


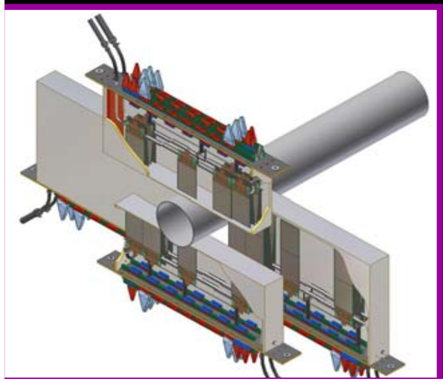
Inner Tracker

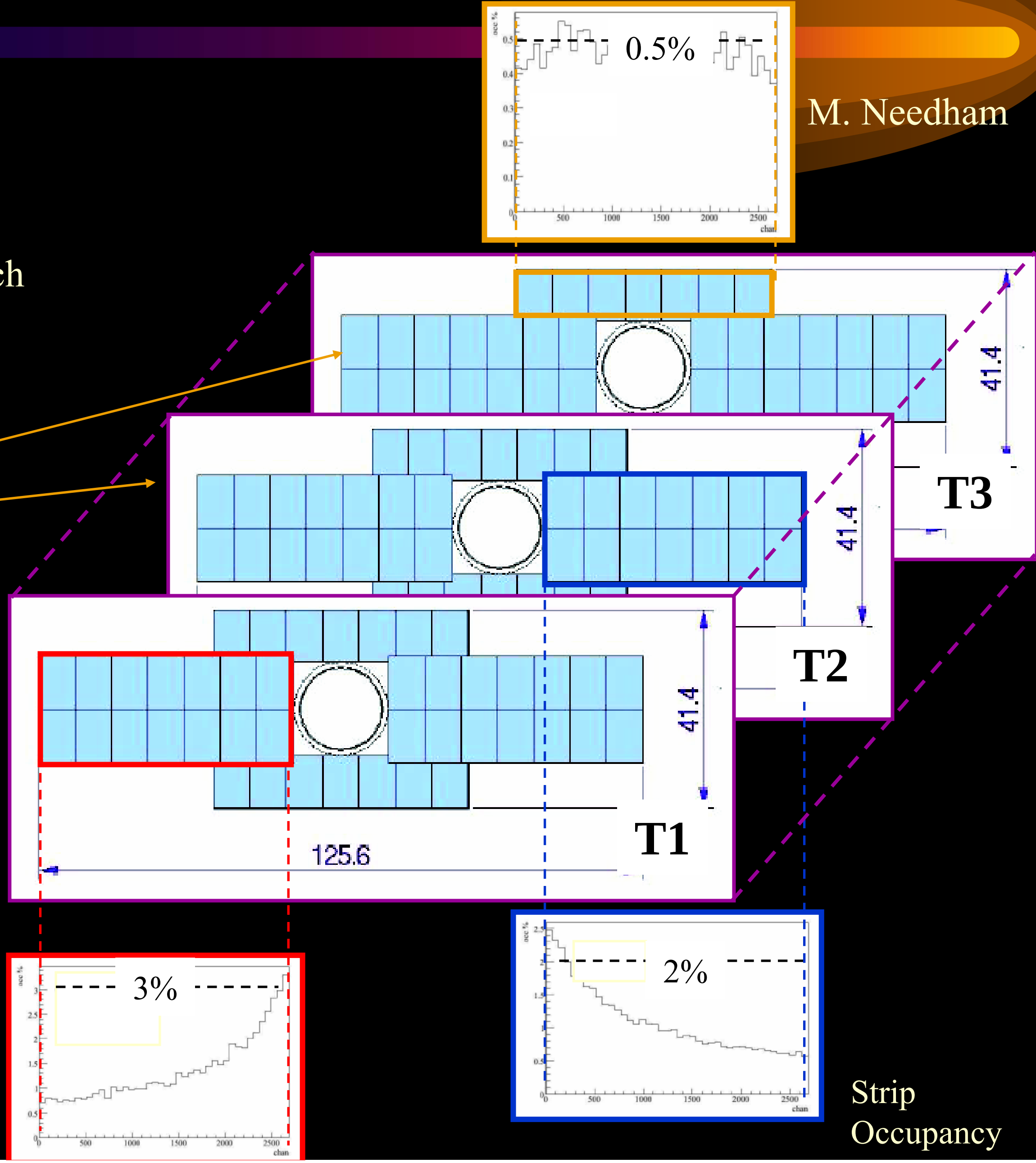
M. Needham

Silicon Strips

- 198 μm pitch
- 1-2 sensor ladders
- 4 layers: XUVX
- 336 ladders to be aligned, 6 pars each

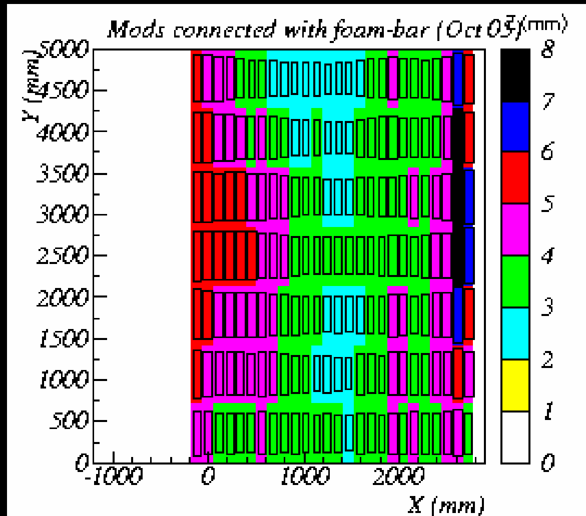


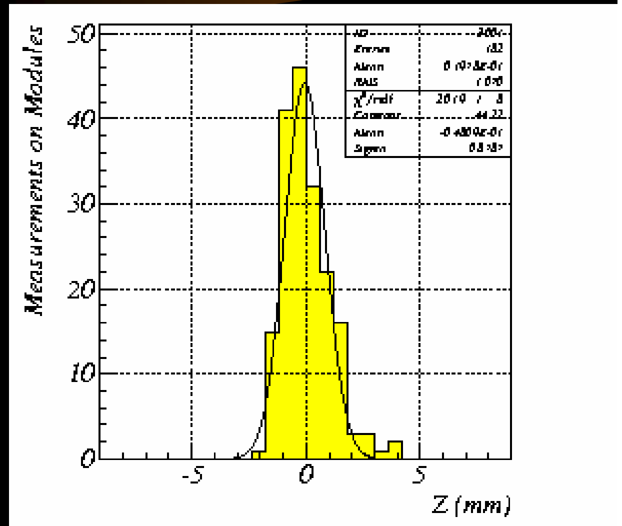




Outer Tracker

Detector is planar to within 0.9 mm

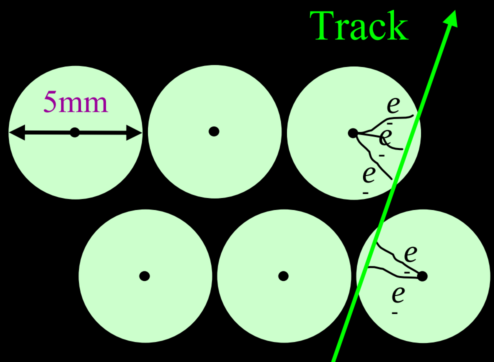


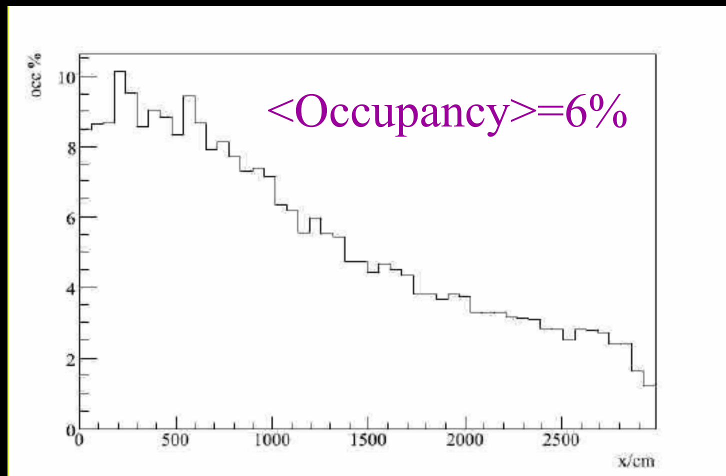


Outer Tracker

- ❑ Very large!
- ❑ 5.0 mm Straws
- ❑ Double-layer straws
- ❑ 4 layers: X:U(5°):V(-5°):X
- ❑ Single Hit Resolution ~ 200 µm.

- ❑ High occupancy



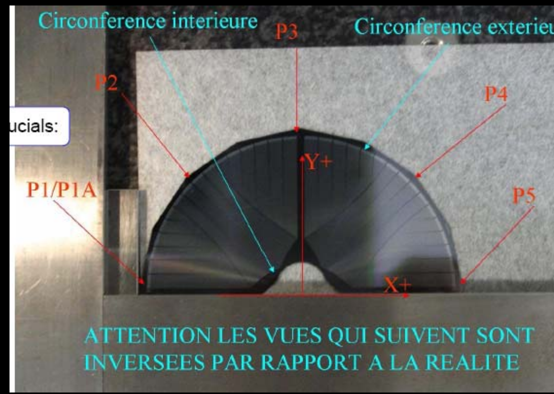


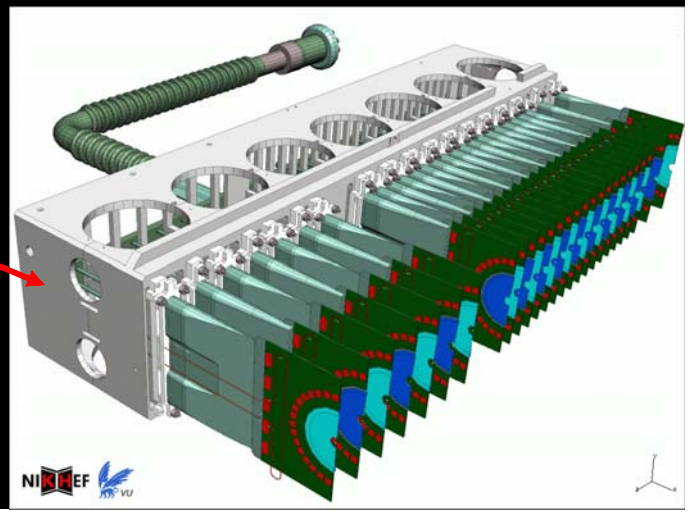
Hardware Alignment at LHCb

- Generally, the detector structures will be surveyed by the TS-SU group at CERN.
  - Precision is typically 0.3-0.5 mm (1σ) level in X, Y and Z, depending on the precision needed. VELO box surveyed to 0.3 mm.

- All points given with respect to the global LHCb frame nominal interaction point is (0,0,0).

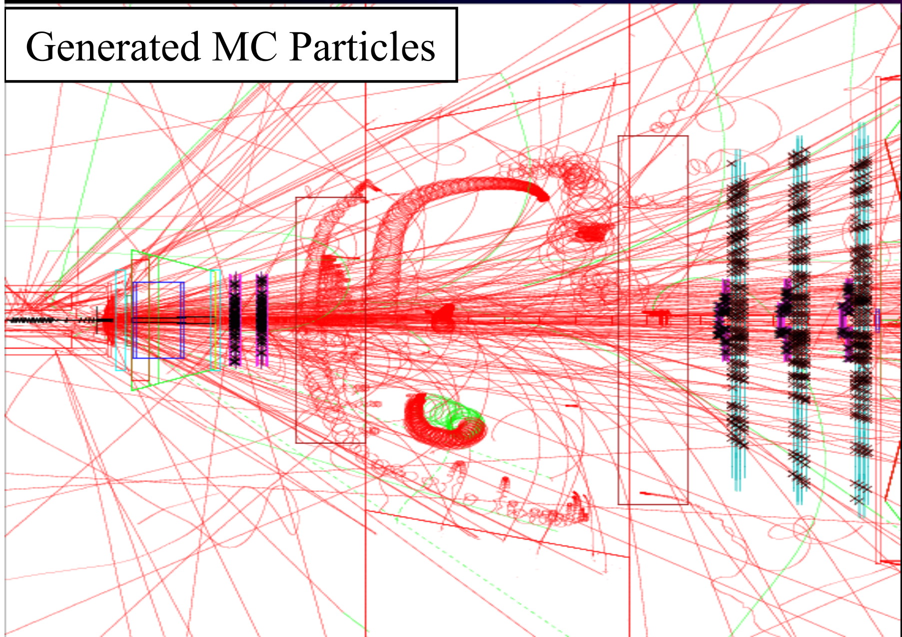
- VELO is most critical.
  - 5 fiducials on each sensor
  - Surveyed during module production
  - Will also be re-surveyed after installation in supporting base.

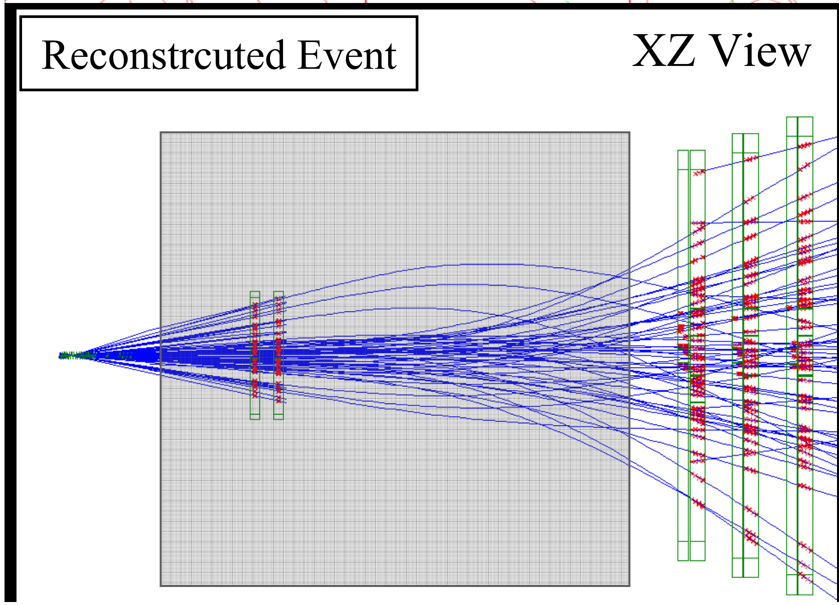




- Practice with test beam telescope.
  - Metrological measurements within a few microns of final tracking alignment.

Software Alignment at LHCb





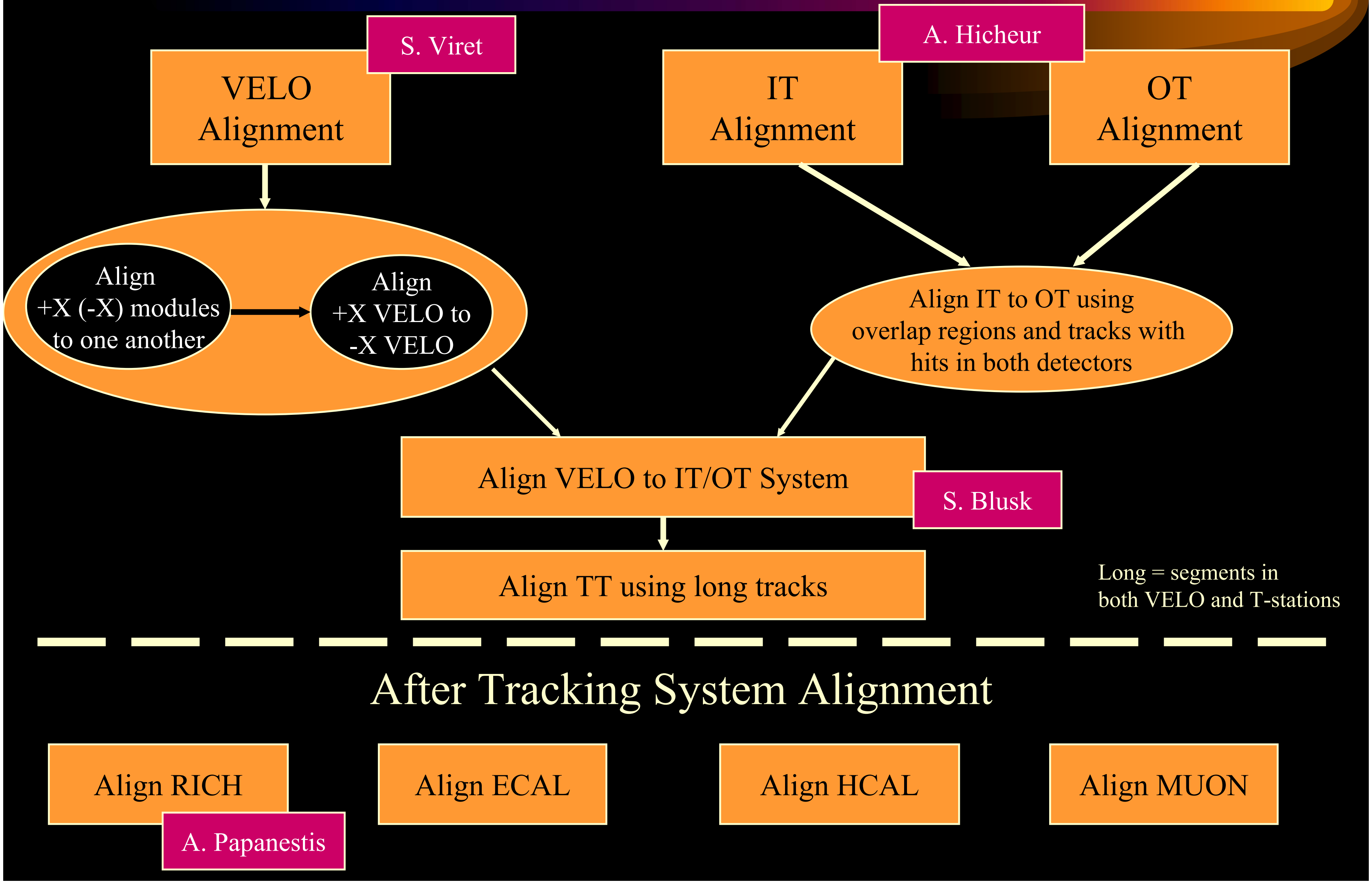
General Strategies

- **Magnet OFF data crucial**
  - Separate magnetic field effects from geometrical ones.
  - Commissioning
  - After access to service tracking system
  - Otherwise, periodically, based on unexplainable change in alignment

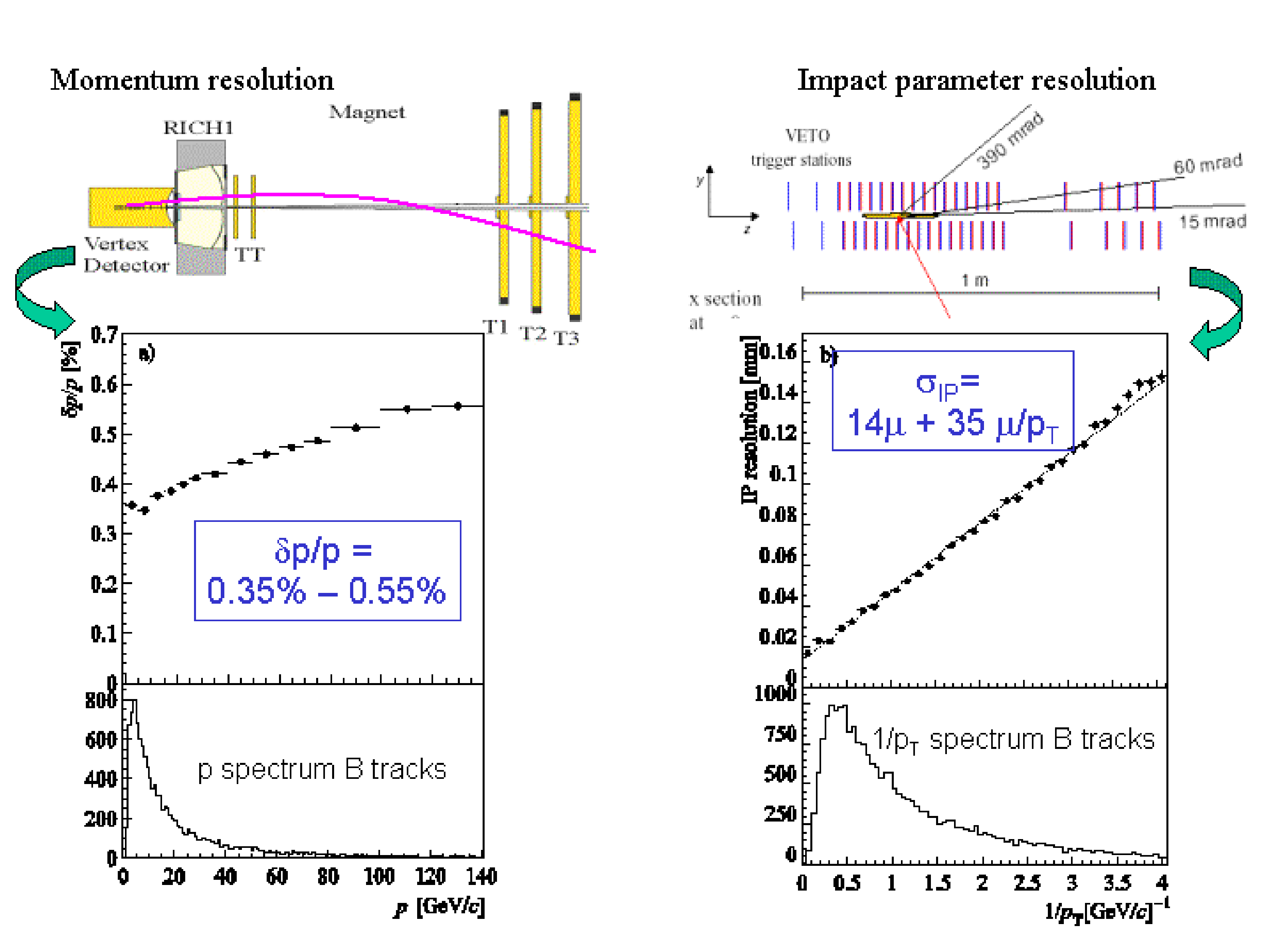
- Pre-selected track samples
  - Low multiplicity events
  - Isolation requirements around track (if necessary)
  - Magnet OFF: Use energy from calorimeter

- Magnet ON data
  - Tweak alignments from Magnet OFF
  - Cross-check with K_s, J/ψ, Y, D→Kπ, Z^0, *etc* (after *dE/dx* corrections and B field map validated)

General Flow of Alignment

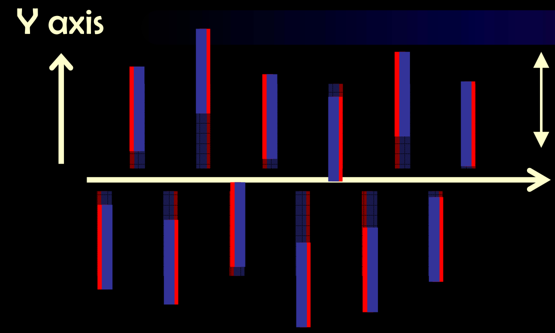


Tracking System, Expected Performance with Perfect Alignment

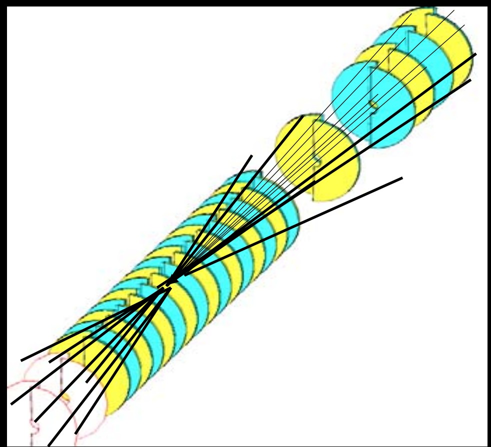


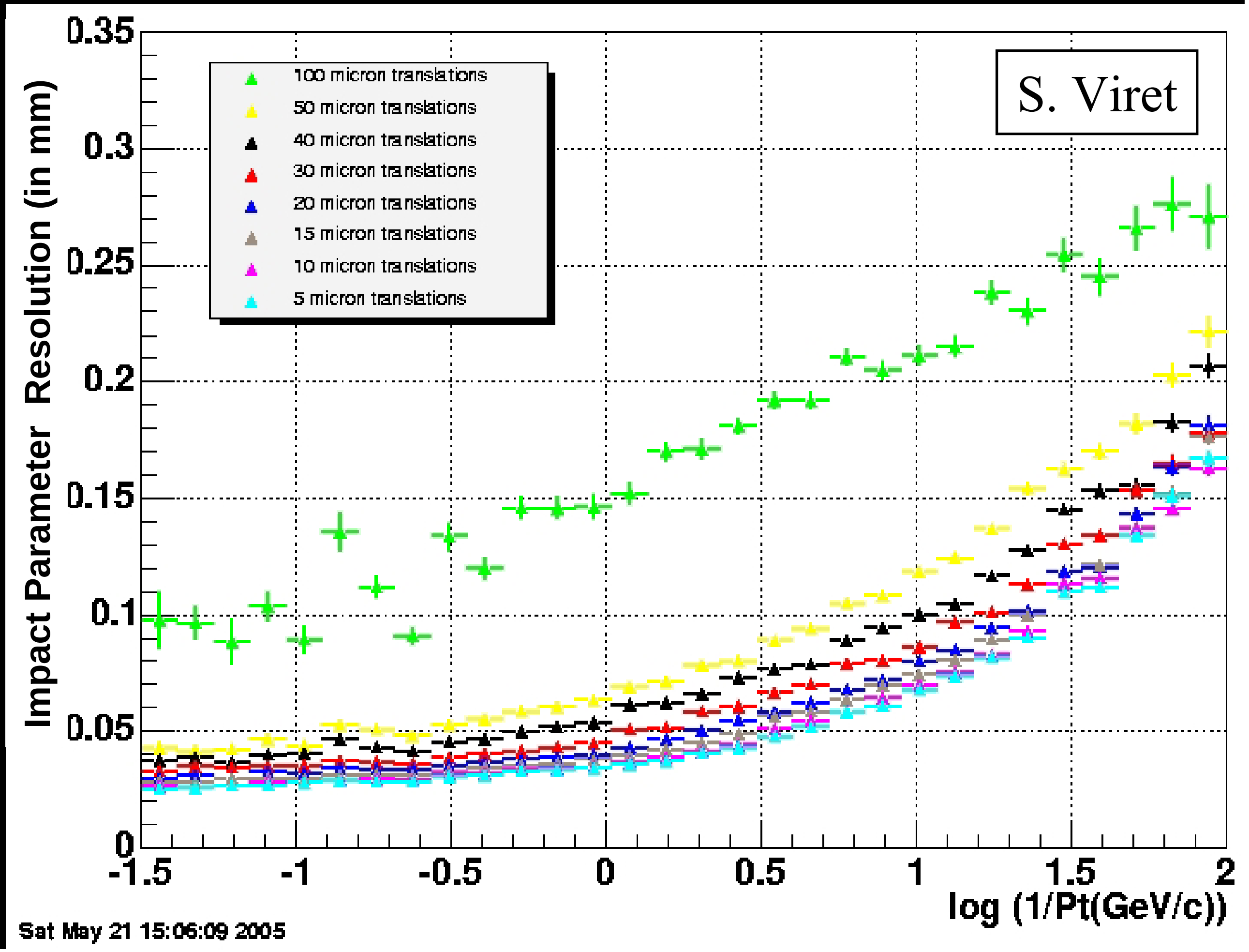
Some Impacts of Misalignment

Random Velo Misalignment



Mechanical placement, $\sigma < 20\ \mu m$,

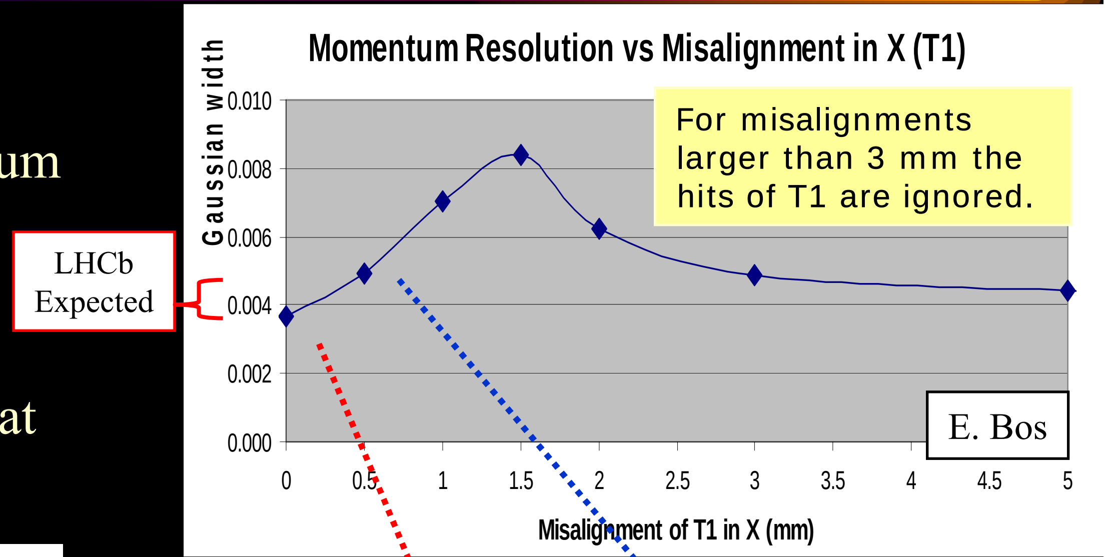


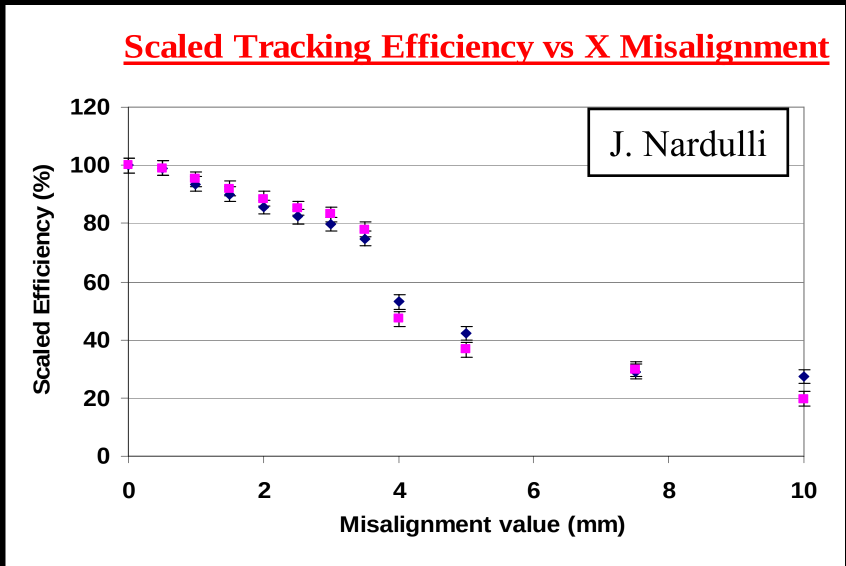


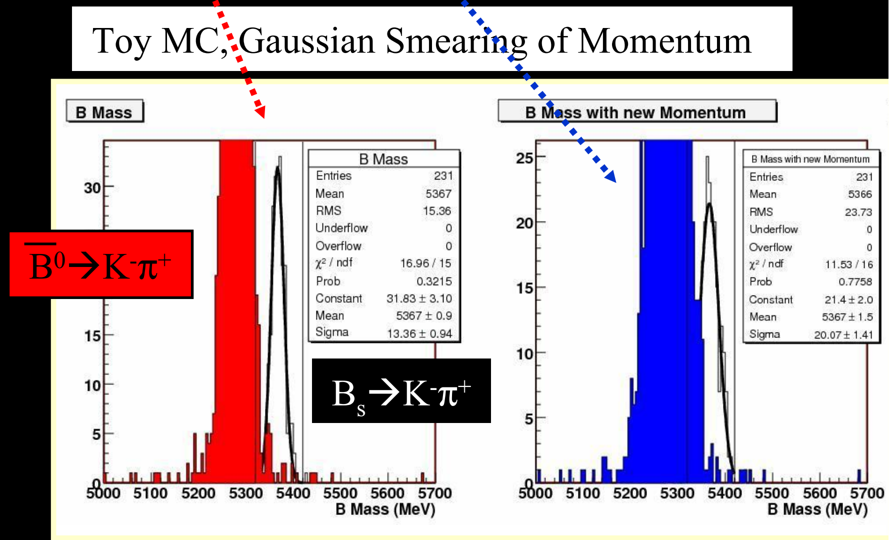
Misalignment of OT

- ❑ Tracking robust against misalignments up to ~500 μm, but:
  - ❑ ~20% degradation in momentum
    (not acceptable from physics view)
  - ❑ fewer hits per track

- ❑ Expect transverse alignment to be at the ~50 μm level, or better.



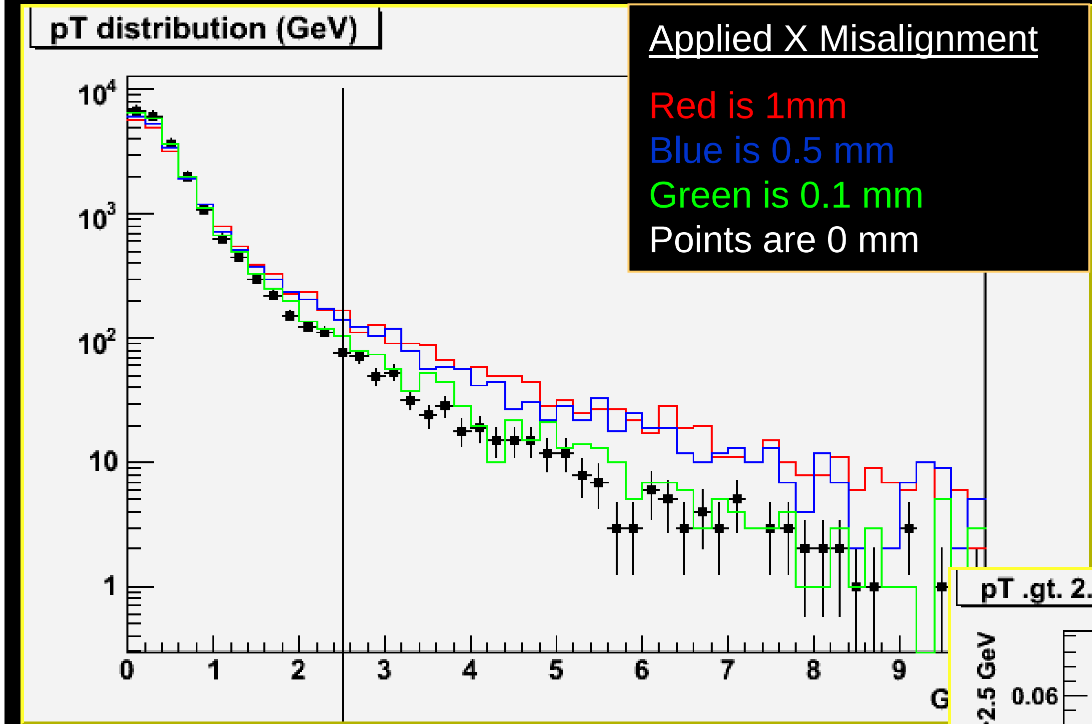


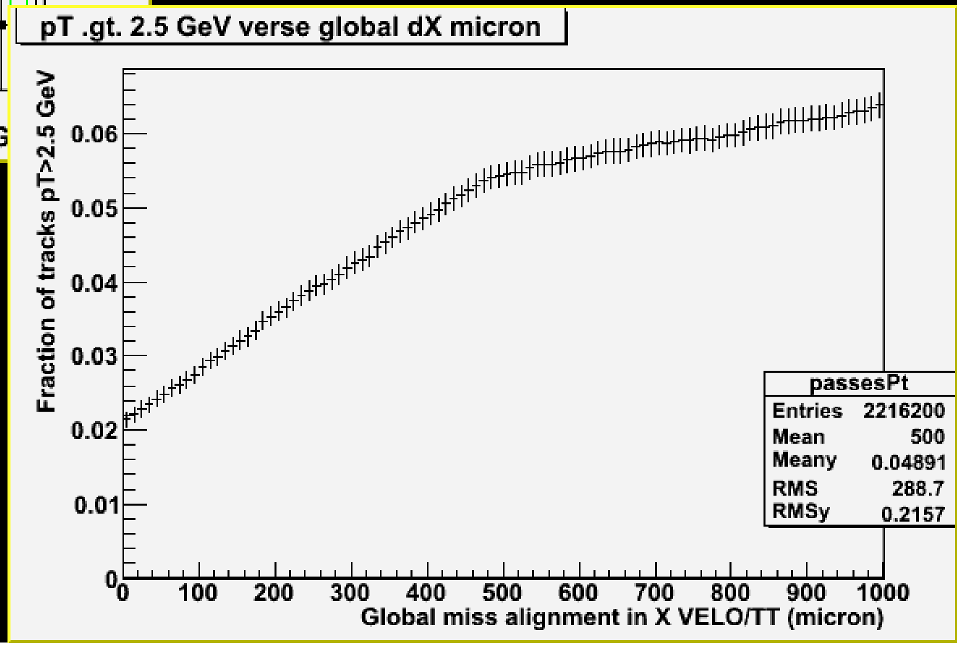


$\sigma_p/p = 0.004$ → $\sigma_p/p = 0.005$

VELO – TT Misalignment @ L1

D. Hutchcroft





- Fraction of tracks above 2.5 GeV p_T
- Double apparent rate at ~ 300 micron miss alignment
- Trigger requires X misalignment below ~100 micron

Summary

- LHCb Trigger requires "good" online alignment.

- Extraction/re-insertion of VELO every fill requires updating of some subset of alignment constants
  - Probably default alignment constants from previous run to start off (aside from an overall ΔX (ΔY) from VELO motion controller between fills)
  - Always update ? Or only when significant change?

- Large number of planes and overlap regions facilitate alignment between detectors

- Magnet OFF data critical to decoupling geometry from B field effects
  - More work needed on proving that dE/dx and B field mapping "issues" can be de-convoluted.

- Fine tuning of alignment for final offline analysis.

- Monitoring:
  - Low-level: #Hits/track, χ^2, IP, residuals, #tracks/event, etc
  - High level: Masses, mass resolutions, relative particle yields.