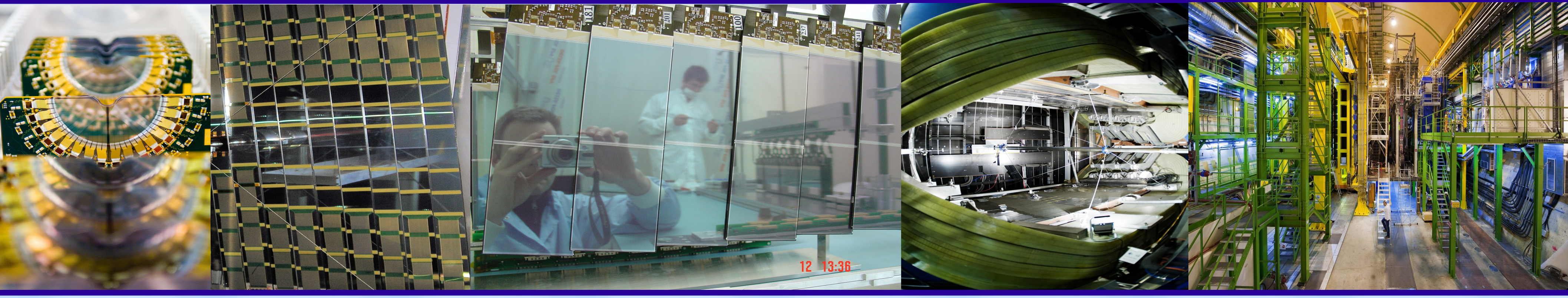


LHCb silicon detector alignment with first LHC beam induced tracks

Christophe Salzmann
on behalf of the LHCb collaboration

Special thanks to
Silvia Borghi, Marco Gersabeck, Chris Parkes
Jeroen van Tilburg, Louis Nicolas, Matt Needham
Adlene Hicheur, Vincent Fave, Florin Maciuc
Johan Blouw

Outline

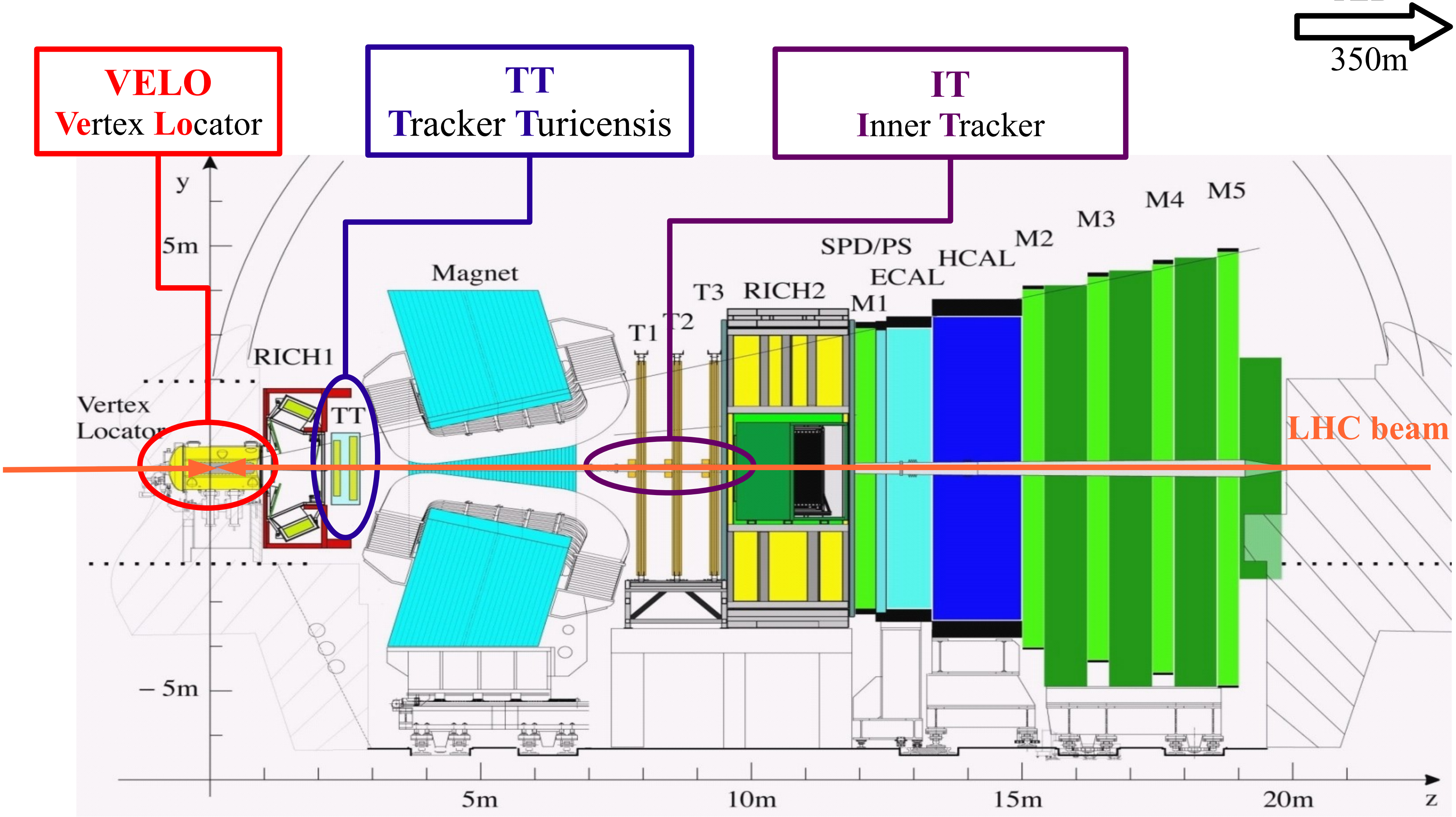
- Introduction
  - The LHCb detector
  - The beam dump called 'TED'
  - Alignment methods at LHCb
- Subdetector alignment
  - VELO (Vertex Locator)
  - TT (Tracker Turicensis)
  - IT (Inner Tracker)
- Results and summary

See also other LHCb talks

- *Marc Deissenroth:* OT alignment with cosmics
- *Silvia Pozzi:* Muon alignment with cosmics
- *Eduardo Rodrigues:* Misalignment effects on physics
- *Johan Blouw:* LHCb alignment and framework

LHCb

- The LHCb silicon tracking system consists of 3 subdetectors



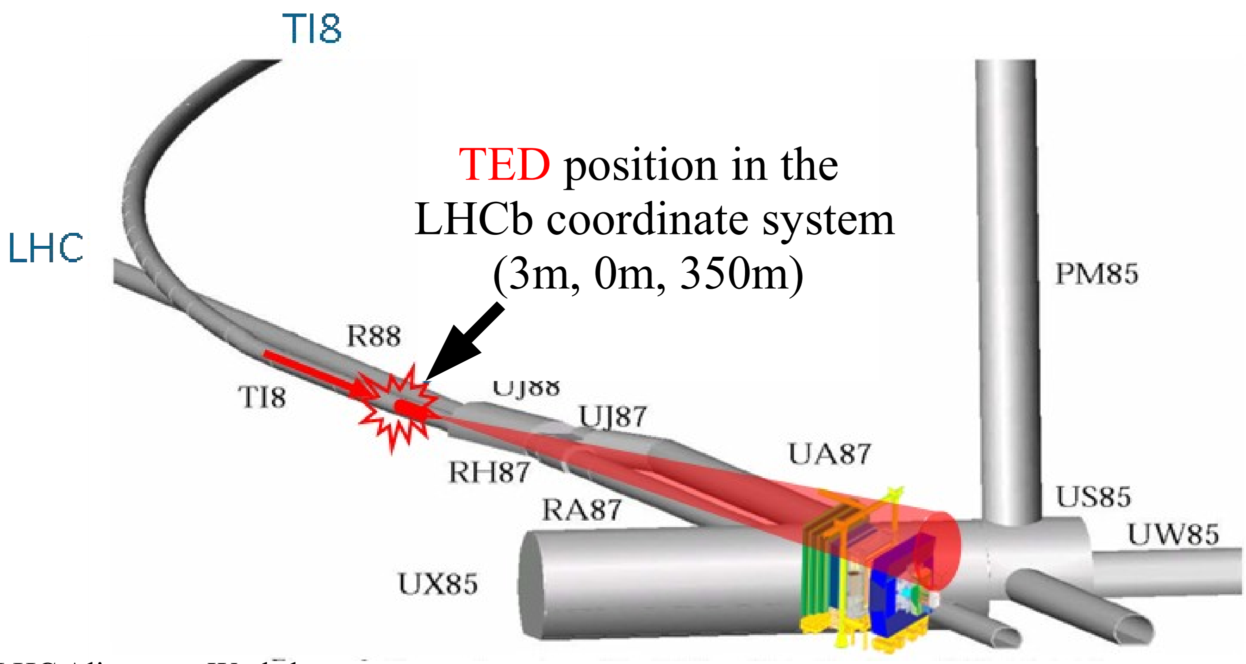
TED

LHCb silicon tracking system has **limited** cosmic data for alignment

Beam dump before the injection into LHC is called "**TED**"
SPS injection tests ("TED" runs)

- August 2008
- September 2008
- June 2009 (preliminary)

} This talk



TED runs:
Shots on the dump of
$\sim 5 \cdot 10^9$ protons every 48 seconds

VELO: low occupancy
< 0.2% (nominal: < 1%)
IT and **TT**: high occupancy
up to 6% (nominal: < 1%)
→ very challenging environment for track reconstruction

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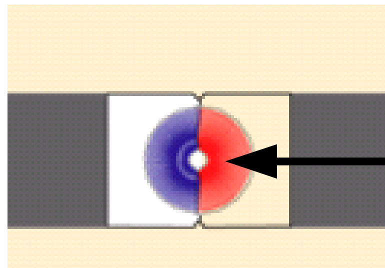
The two alignment methods

	Millepede method	K-track method
Procedure	χ^2 minimization with track correlation (closed form)	χ^2 minimization with track correlation (closed form)
Implemented Track Model	**Global** track model • No multiple scattering • Linear projection of measurements on track parameters (VELO implementation) • Global covariance matrix	**Local** track model • Kalman filter track model • Multiple scattering • Compute missing covariance matrix elements
Advantage	• Fast algorithm • Well-known method	• Uses LHCb's default track model • Possible to align full LHCb detector in one go
References	• NIM A566:5-13,2006 • Talk by V. Blobel	• NIM A600:471-477,2009 • Talk by W. Hulsbergen

VELO layout

2 retractable detector halves
21 modules per half (a module consists of R and Φ sensors, mounted back to back)

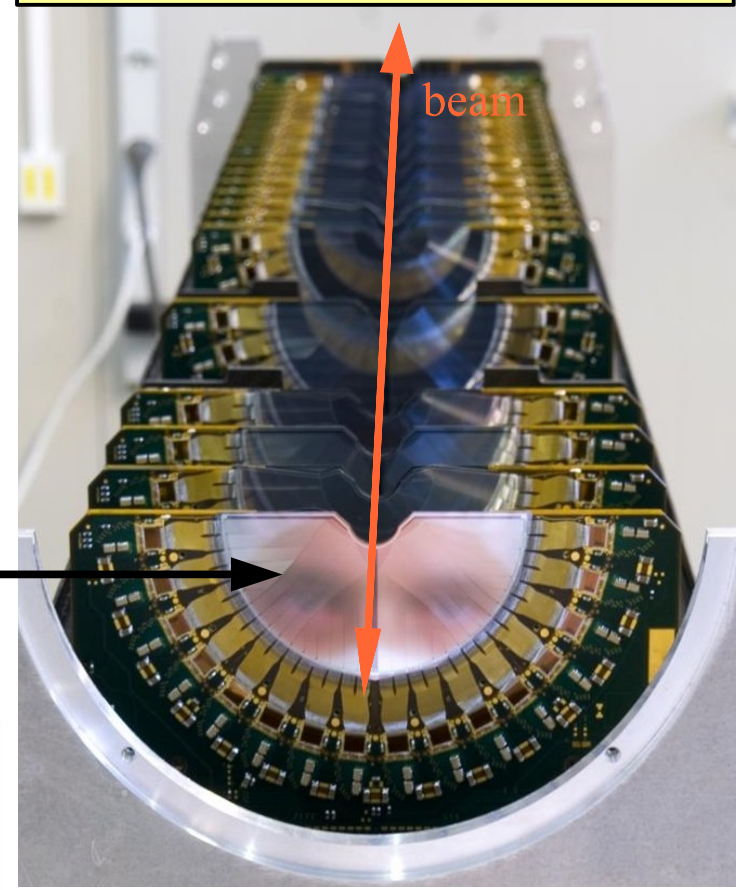
VELO open
30 mm from beam



VELO closed
8.2 mm from beam

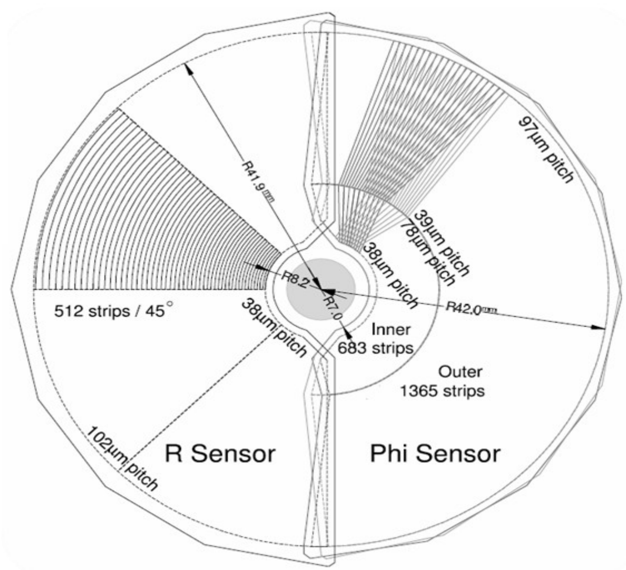
sensor

VELO detector half



Φ sensor:
- Measures **azimuthal angle**
- Strip pitch: 36 – 97 µm
- Stereo angles: -10° and 20°

R sensor:
- Measures **radial distance**
- Strip pitch: 40 – 102 µm



Module gives
R, Φ and z position
→ allows to convert to
space point (x, y, z)

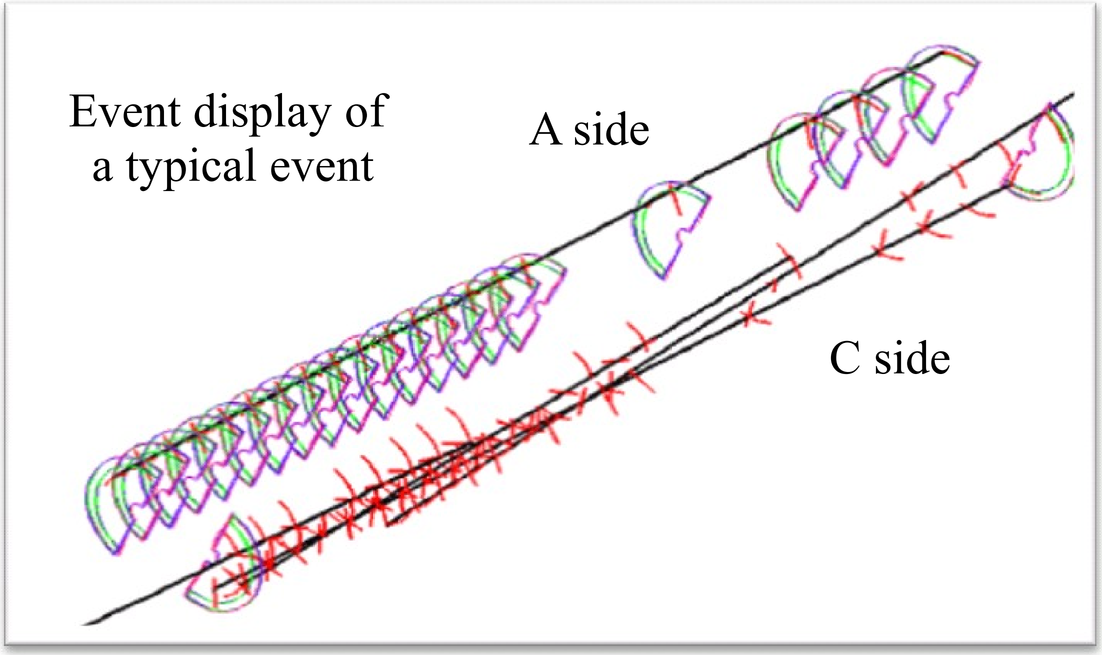
VELO track reconstruction

Tracks from the TED runs

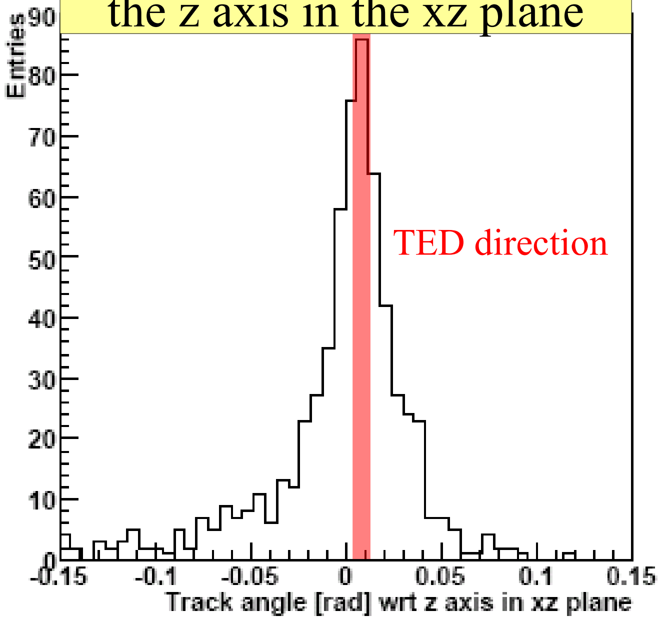
Standalone track reconstruction in VELO

~2000 tracks
Characteristics:
- **Tracks traverse full VELO**
- **Uniform distribution**

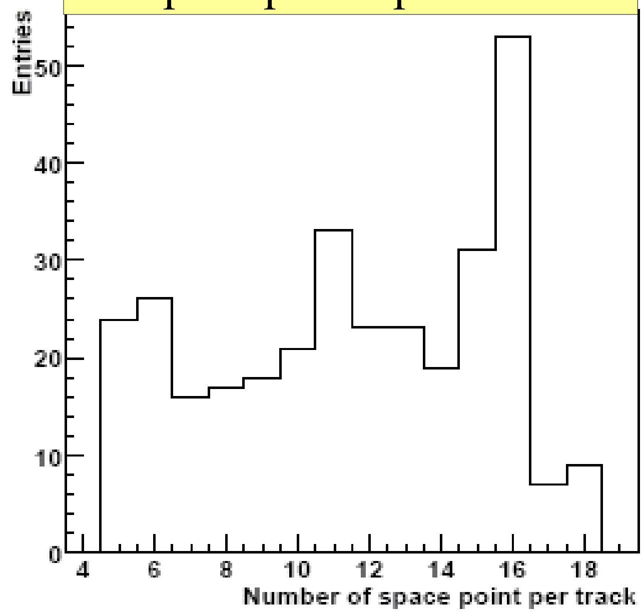
Event display of a typical event



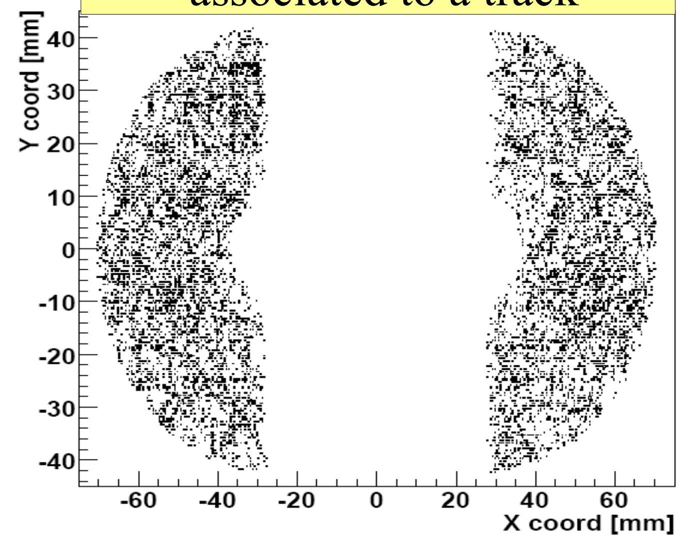
Track angle with respect to the z axis in the xz plane



Space points per track



Distribution of space points associated to a track



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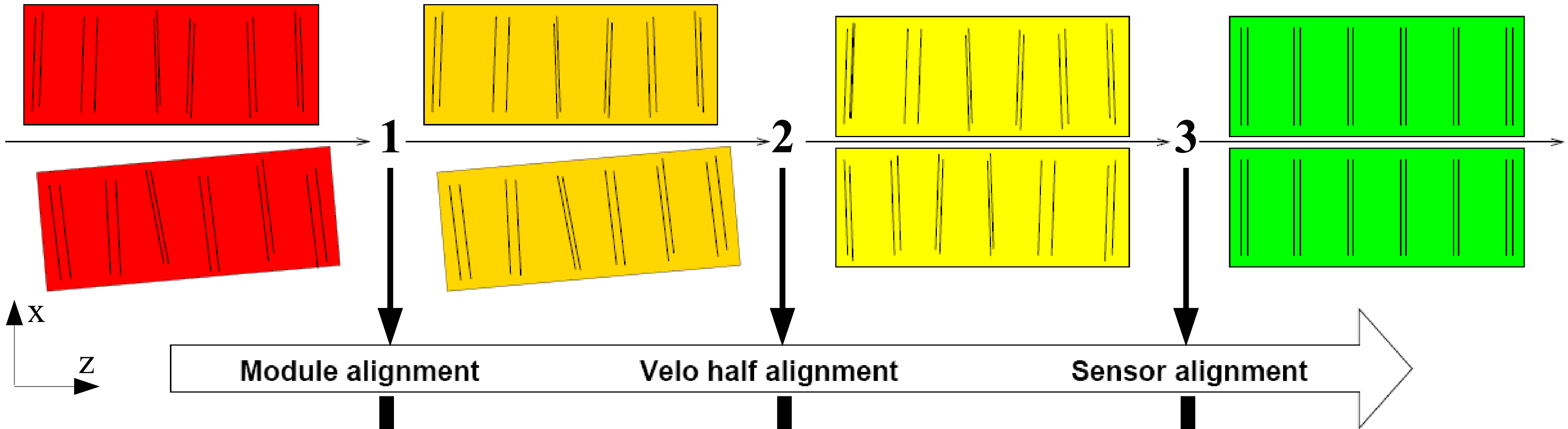
VELO alignment strategy



Align with 2008 TED data
(x and y translations and z rotation)

- **Millepede** method
- **K-track** method

Align with 2009 TED data
(requires closed VELO)

- **Millepede** method
- **K-track** method

Align with 2009 TED data
(requires high statistics)

- **Iterative histogram** method
- **K-track** method

Starting from optical survey of
- modules (precision: 10 µm)
- sensors (precision: 5µm)

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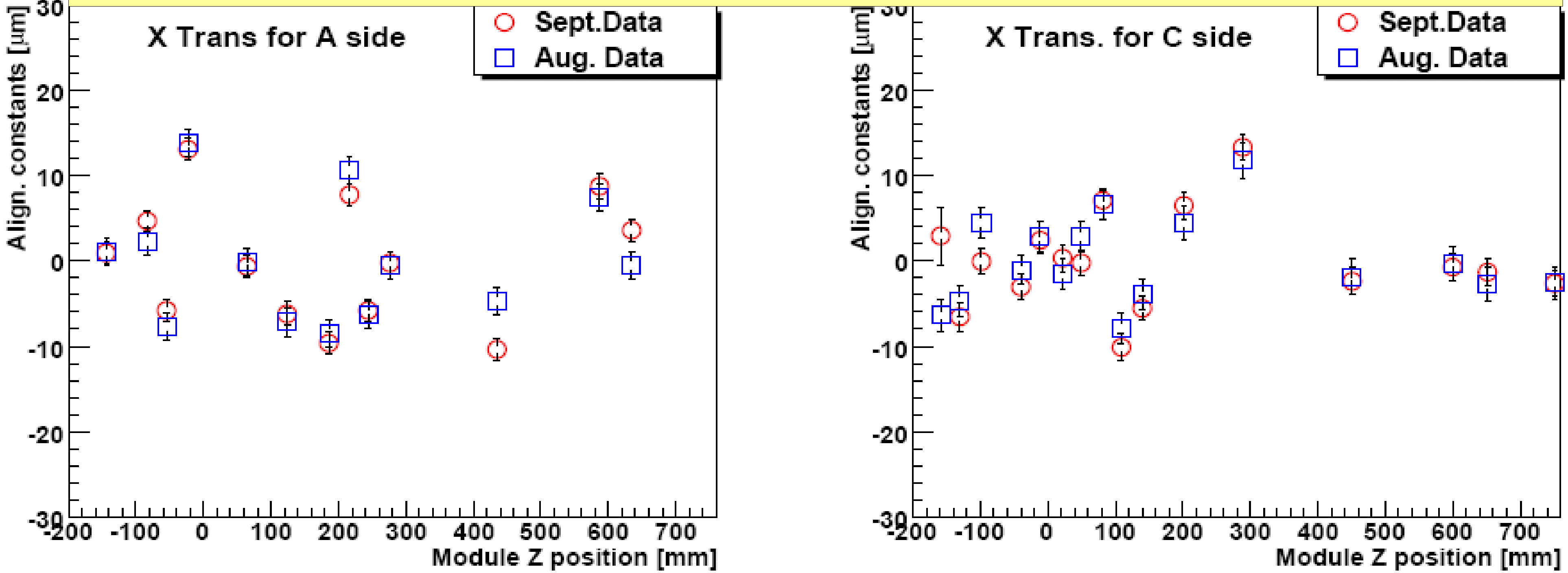
VELO survey validation

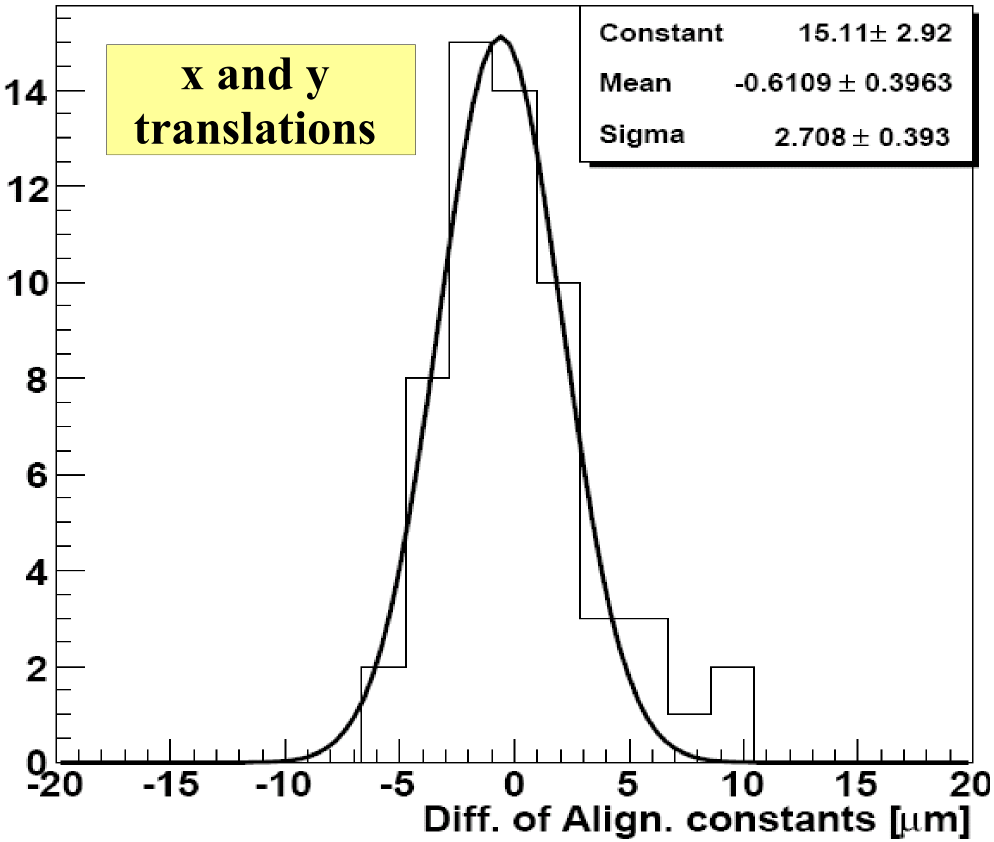
Difference between alignment constants and the survey positions

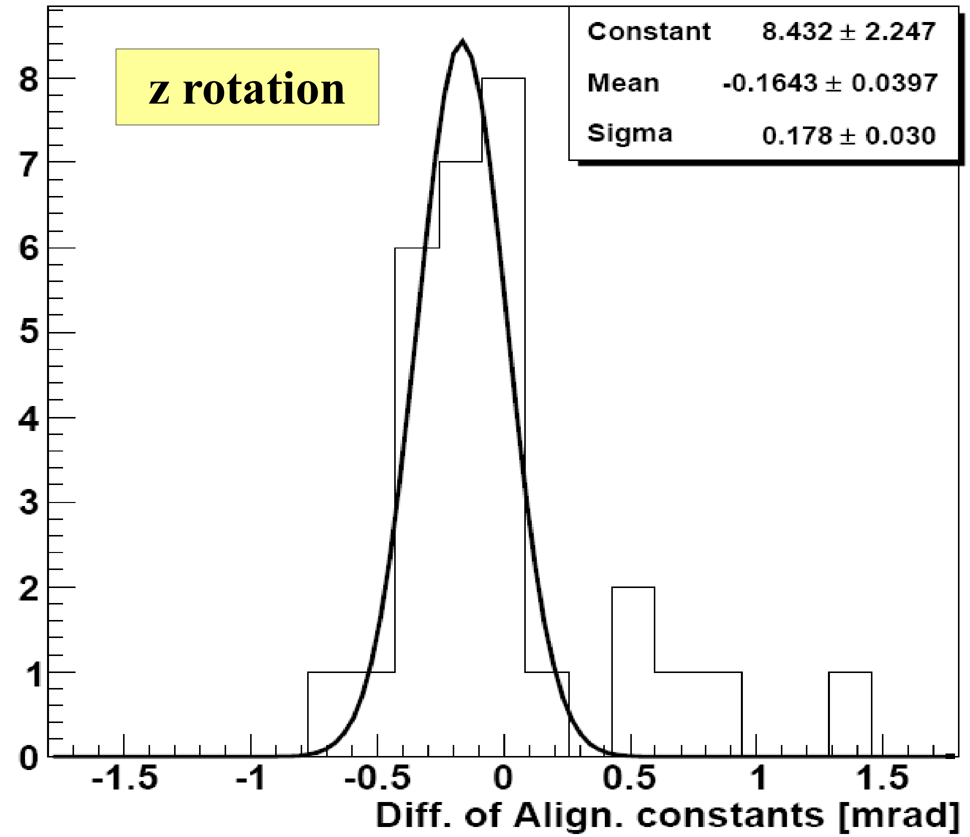


Displacement of modules from metrology is less than 10 µm

VELO alignment validation

Difference of alignment constants between **August and September data**





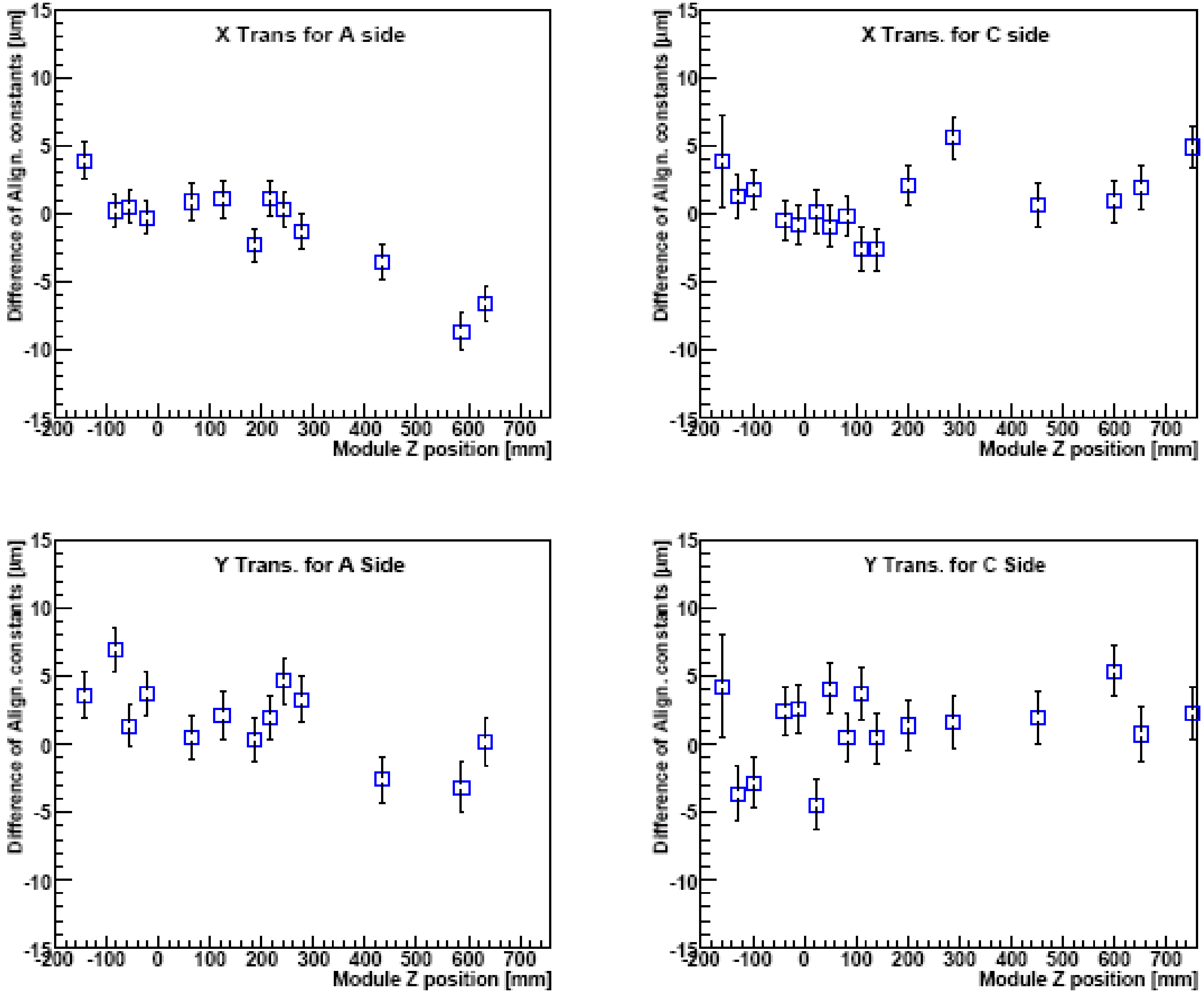
Estimate of alignment precision:

x and y translation: ~5 **μm**

z rotation: ~200 **μrad**

VELO alignment validation

Difference of the alignment constants between the two alignment methods **(Millepede and K-track)**



The two methods are in **good agreement** within alignment precision

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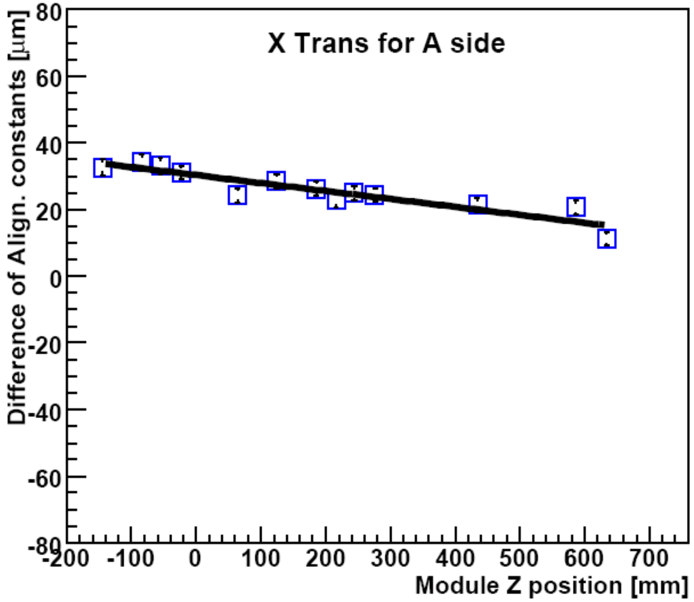
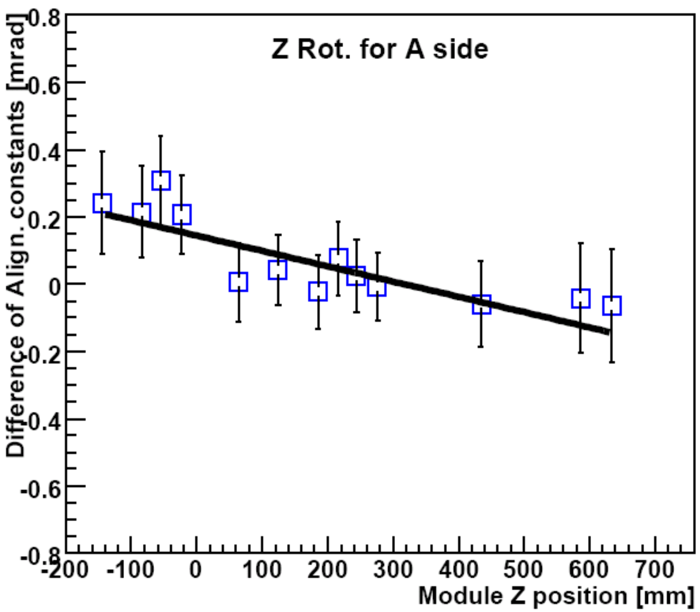
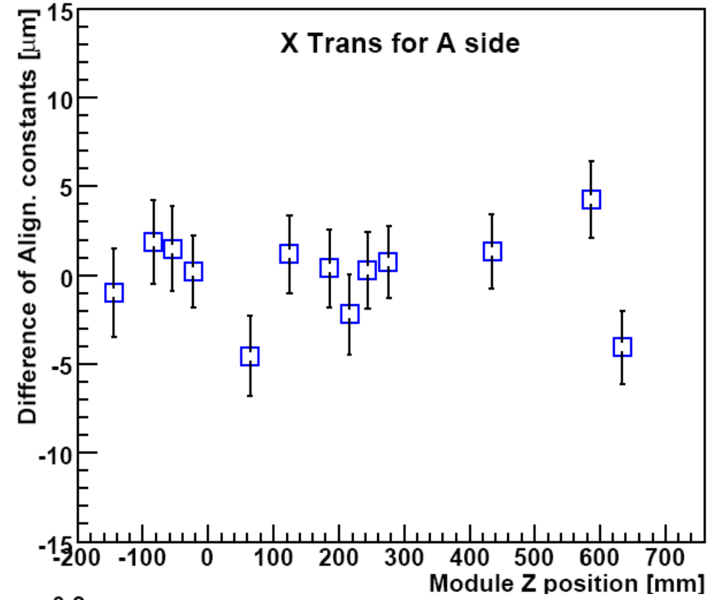
VELO alignment validation

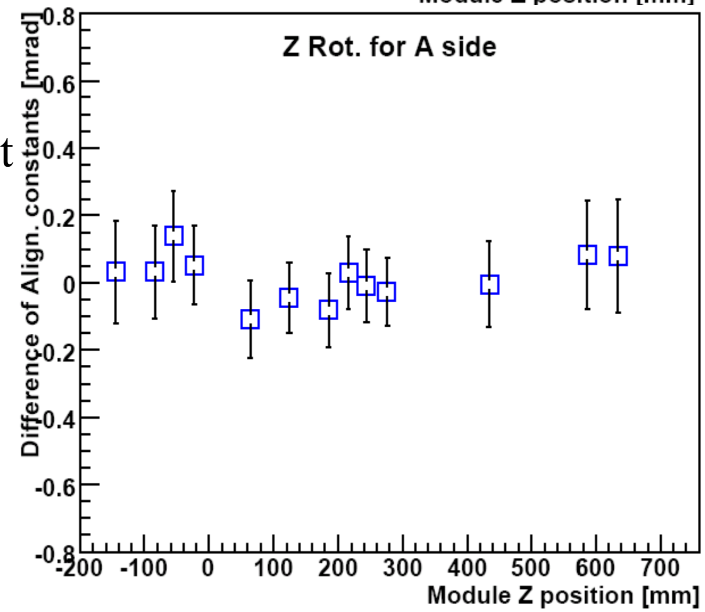
Difference of alignment constants between with and without survey





remove global mode



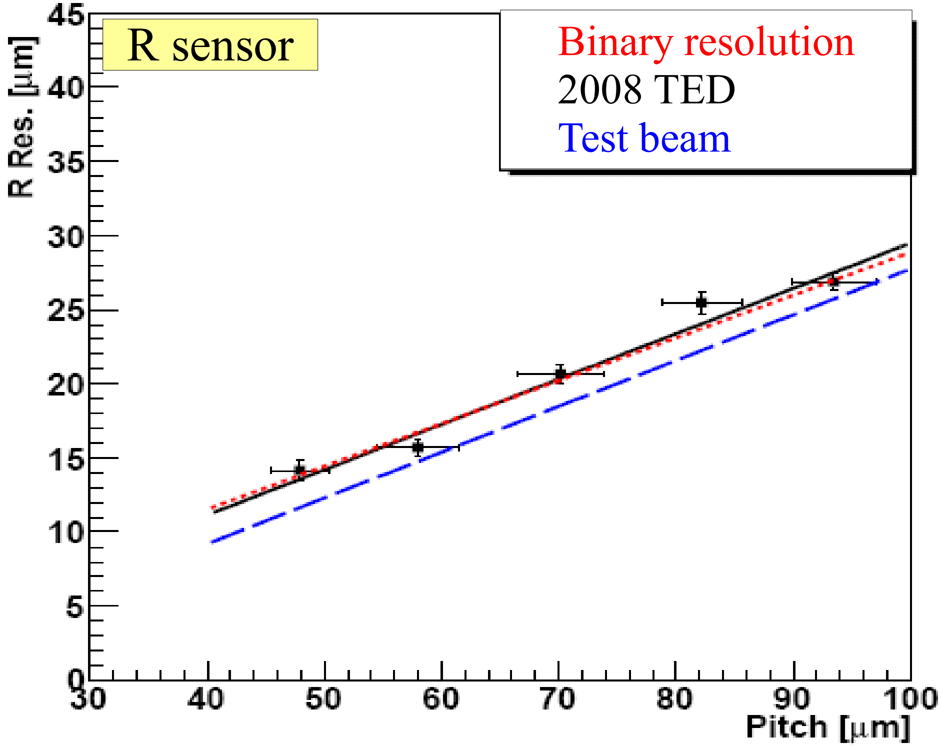


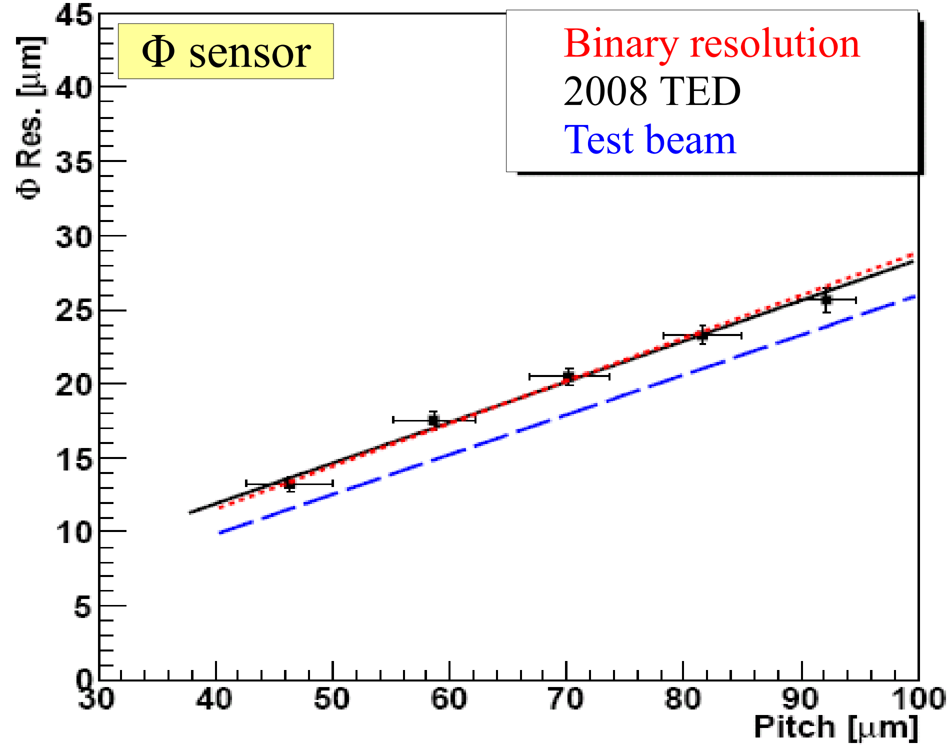
Module alignment is not sensitive to global displacement or shearing of the detector

Remember: internal VELO tracks used

VELO resolution

Dependence on the strip pitch



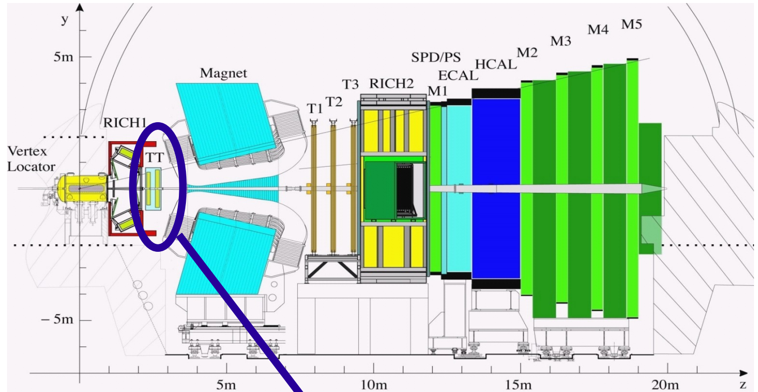


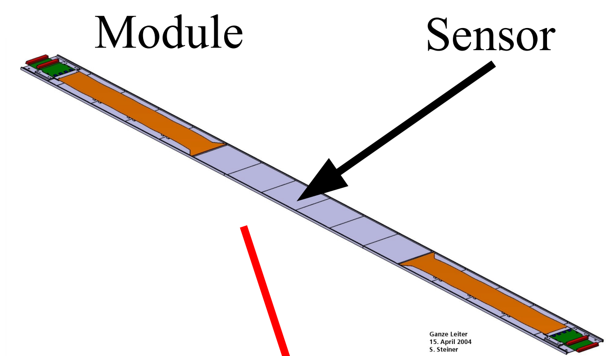
- 2008 TED data has large fraction of one-strip clusters (85% - 90%)
- Binary resolution: *pitch/√12*
- Test beam has more two-strip clusters

•→ 2008 TED resolution compatible with binary resolution

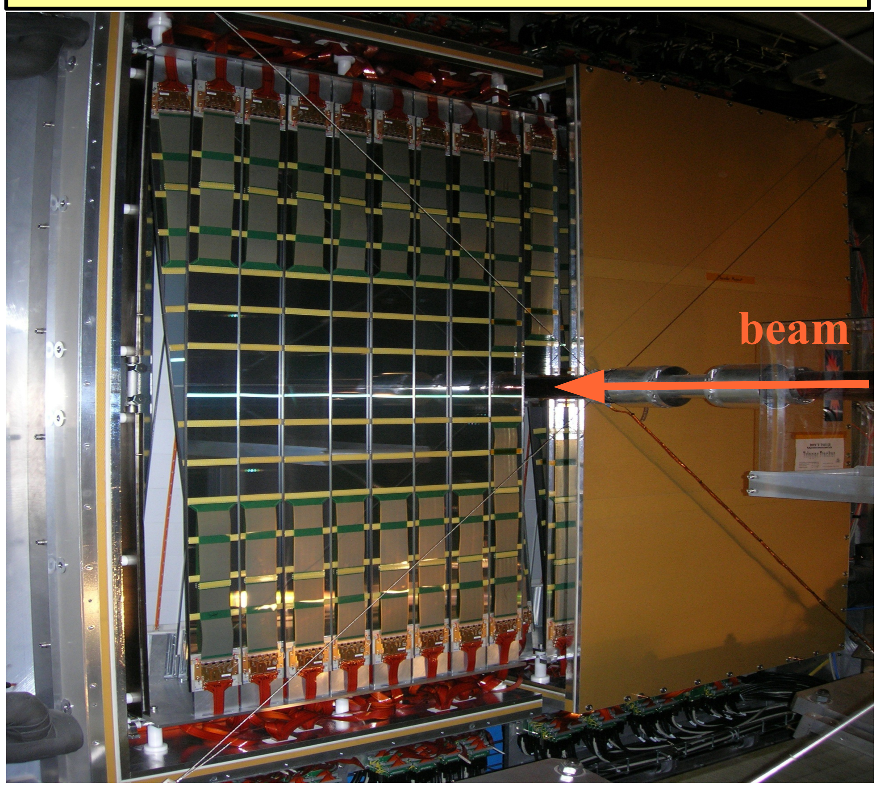
TT layout

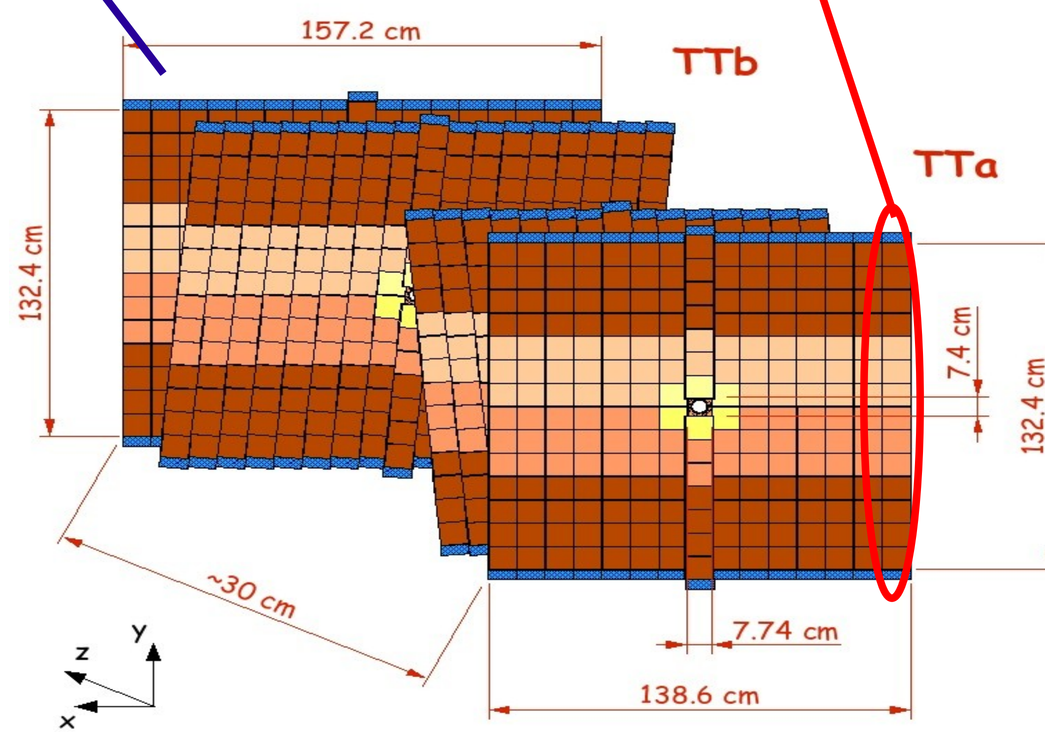
- **4** Layers (0°,+5°,-5°,0°)
- **64** Modules with **14** sensors
- Strip pitch: 183 μm
- Sensor size: 96.4 mm in x and 94.4 mm in y





TT station





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TT track reconstruction

Tracks from the TED runs

Only September data

No standalone TT track reconstruction (4 layers)

VELO track reconstruction

↓

VeloTT track reconstruction

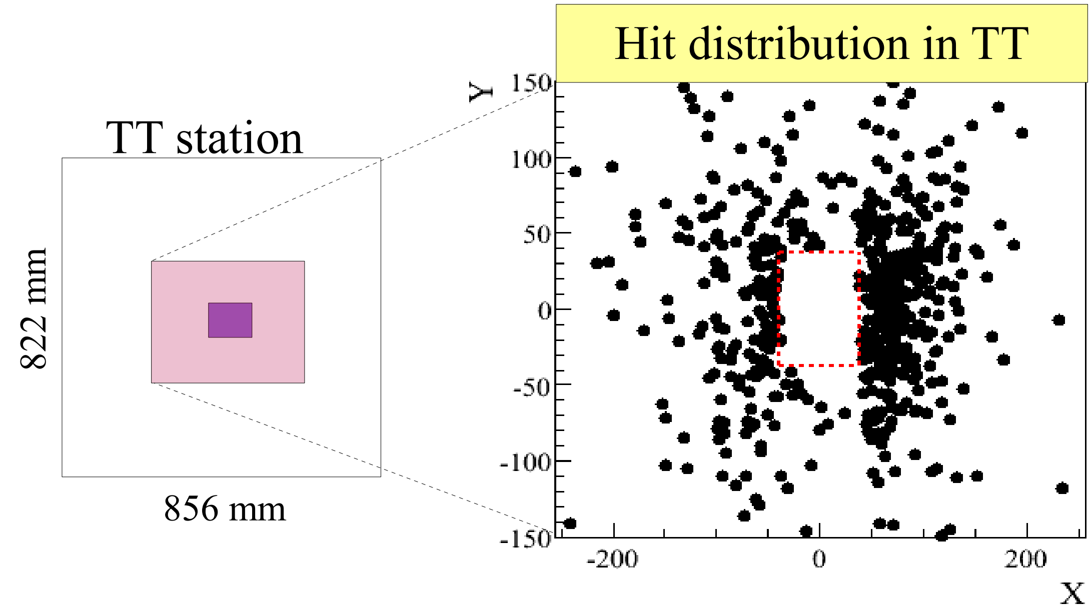
- VELO tracks as input
- Search hits in TT
- Require min. 3 TT hits (out of 4 layers)

↓

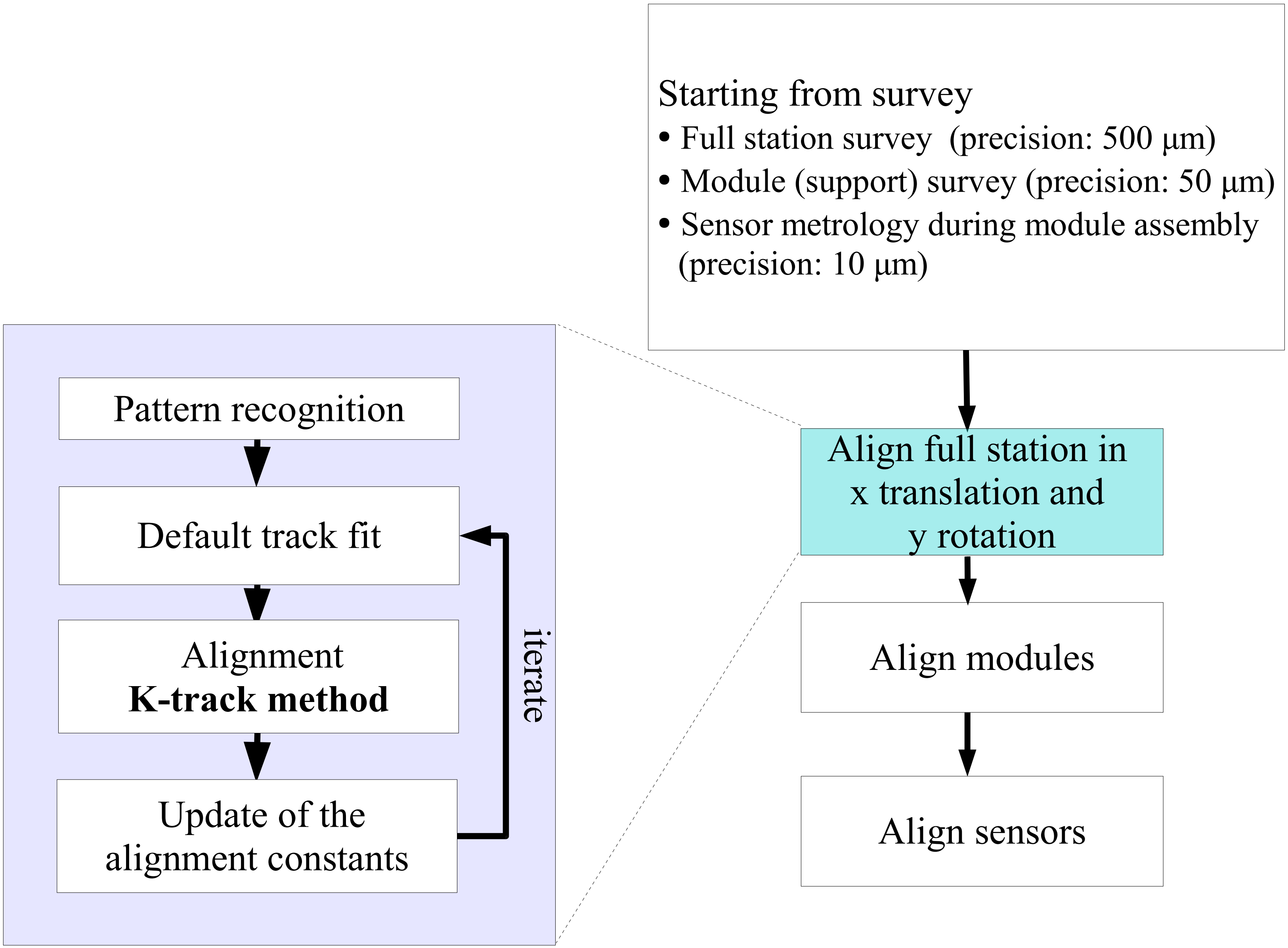
~ 550 VeloTT tracks

Characteristics:

- 54% of VELO tracks extended to TT
  → high occupancy in TT
- Tracks distributed around "beam pipe hole"



TT alignment strategy



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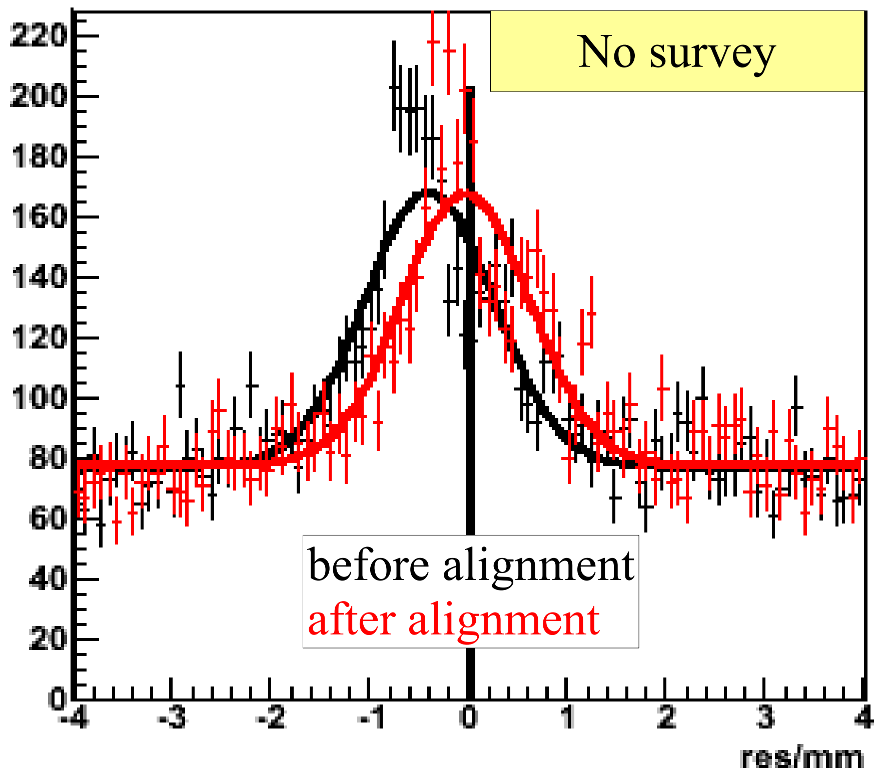
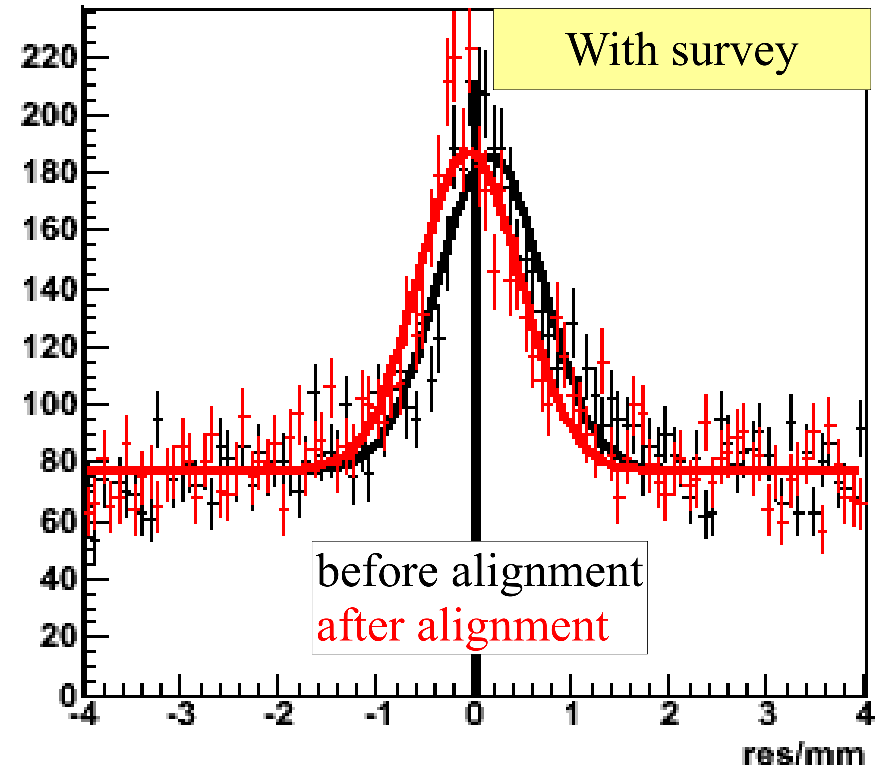
TT alignment validation

Residual of the TT hits to extrapolated VELO tracks



Alignment corrects offset

Mean:	-0.404 µm → -0.035 µm
Width:	0.655 µm → 0.646 µm



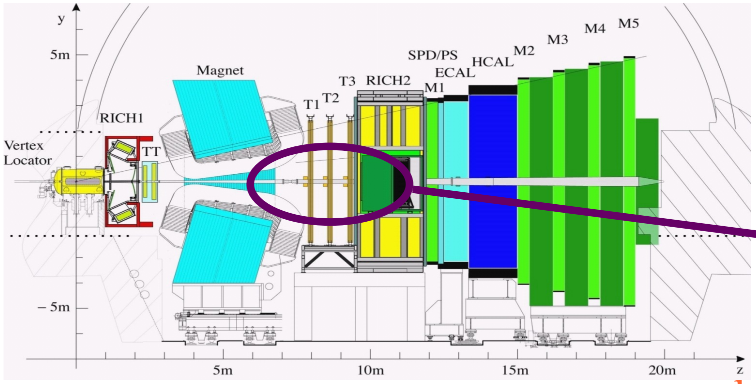
Survey improves residual

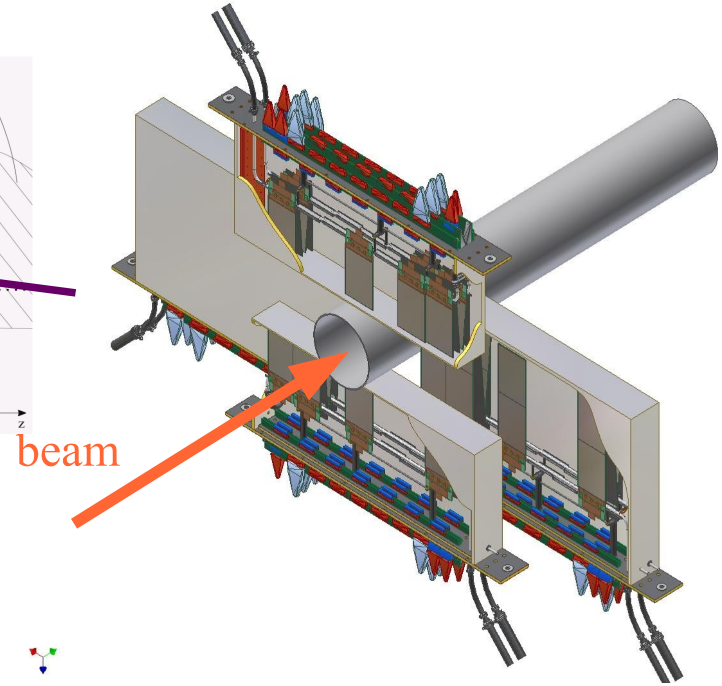
Mean:	0.162 µm → -0.053 µm
Width:	0.526 µm → 0.519 µm

Note: only alignment of full station

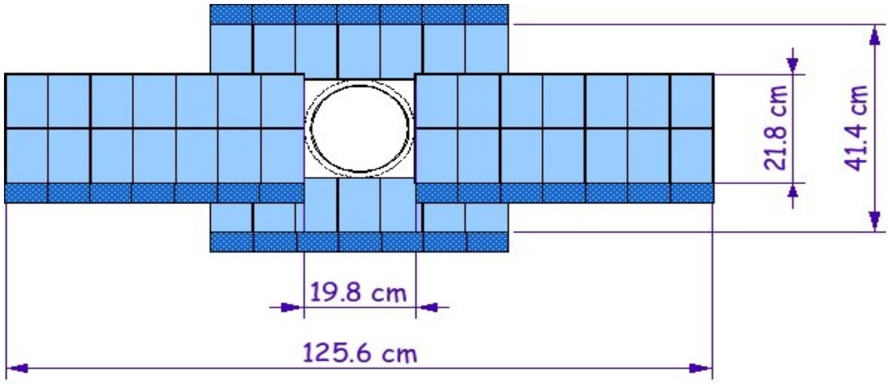
IT layout

- **3** stations with **4** boxes
  (top, bottom, A side, C side)
- Every box has **4** layers
  (0°,+5°,-5°,0°)
- Top/bottom boxes
  1 sensor ladders
- Side boxes
  2 sensor ladders
- Strip pitch: 198 μm
- Sensor size: 110 mm in x and 78 mm in y

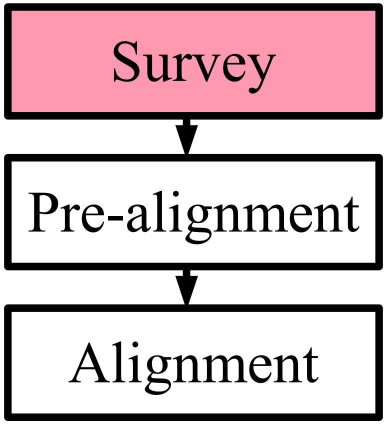




IT Box



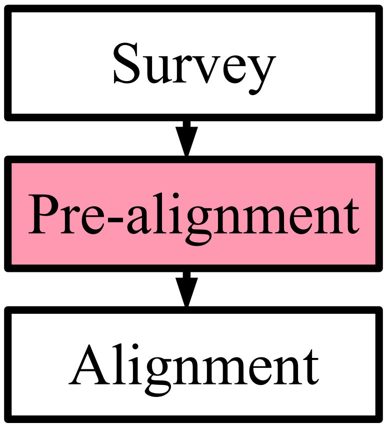
IT survey

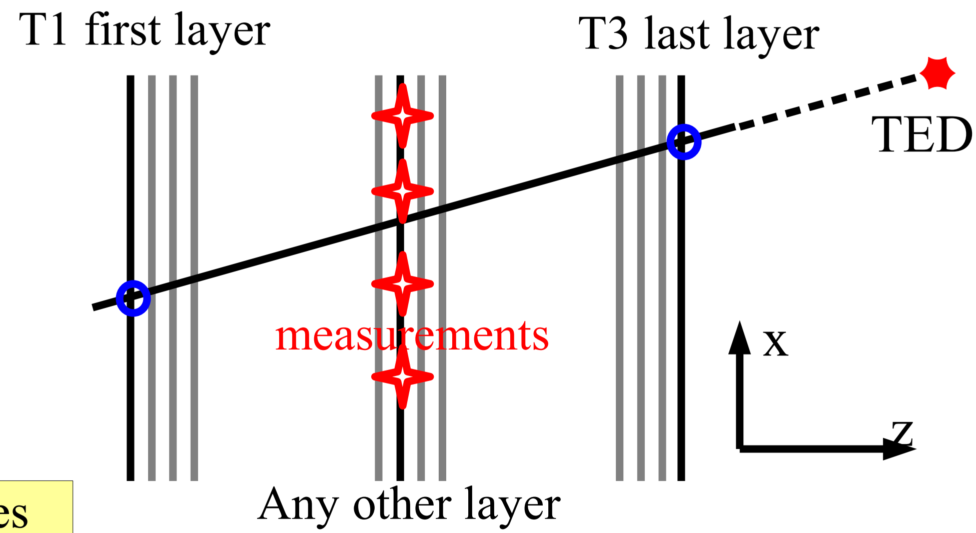


Survey

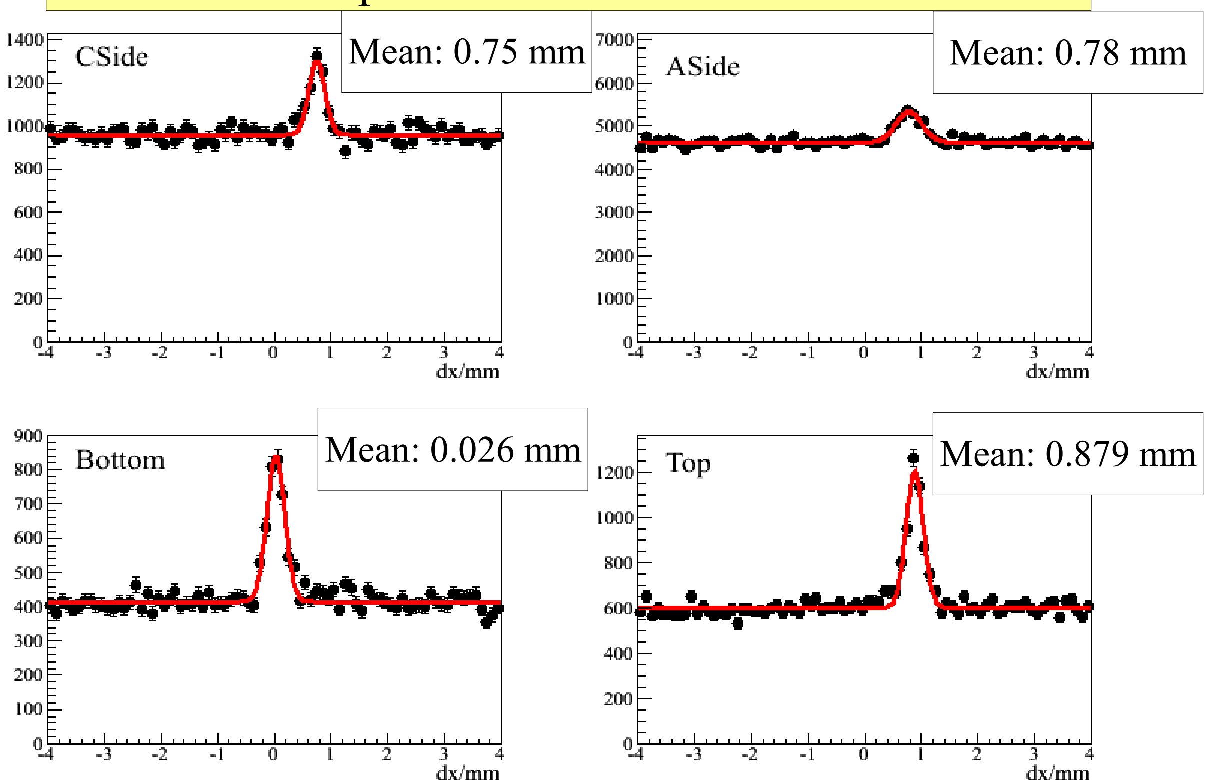
- Box photogrammetry (precision: ~ 1-2 mm)
- Layer survey (precision: ~ 50 µm)
  Only **x layer** surveyed
  Assume same correction for stereo layers
- Ladder survey (precision: ~ 50 µm)
  Only **x ladders** surveyed

IT pre-alignment





Estimate of x position of the middle station boxes



Simple pre-alignment tracking

- take hit in first layer of T1 and in last layer of T3 and draw line
- require to point towards TED
- confirm track with a hit in other layer of first or last station

Plot residual of the track to every hit:
→ mean gives estimate on box and layer x positions

IT track reconstruction

Tracks from TED runs

Use run with **lowest occupancy**

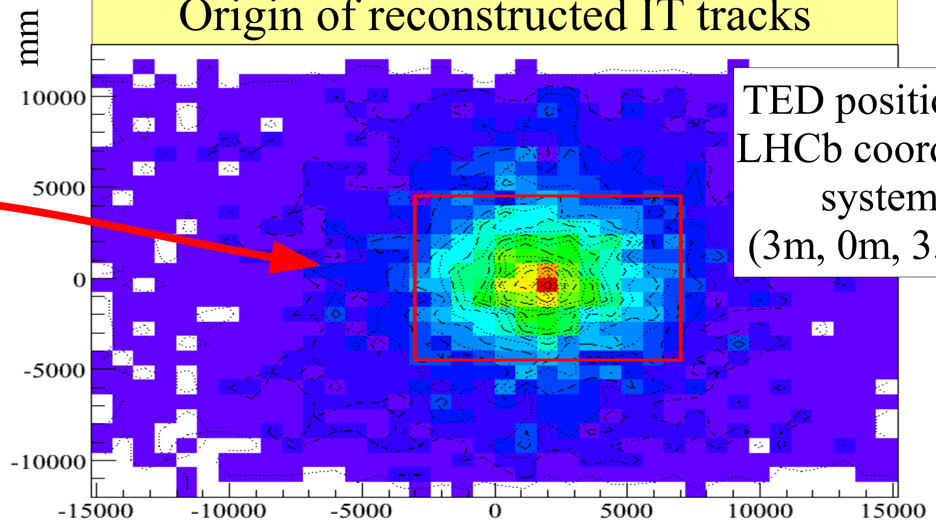
Standalone IT track reconstruction require track pointing toward TED

~ 4400 to 5000 reconstructed IT tracks

Characteristics:

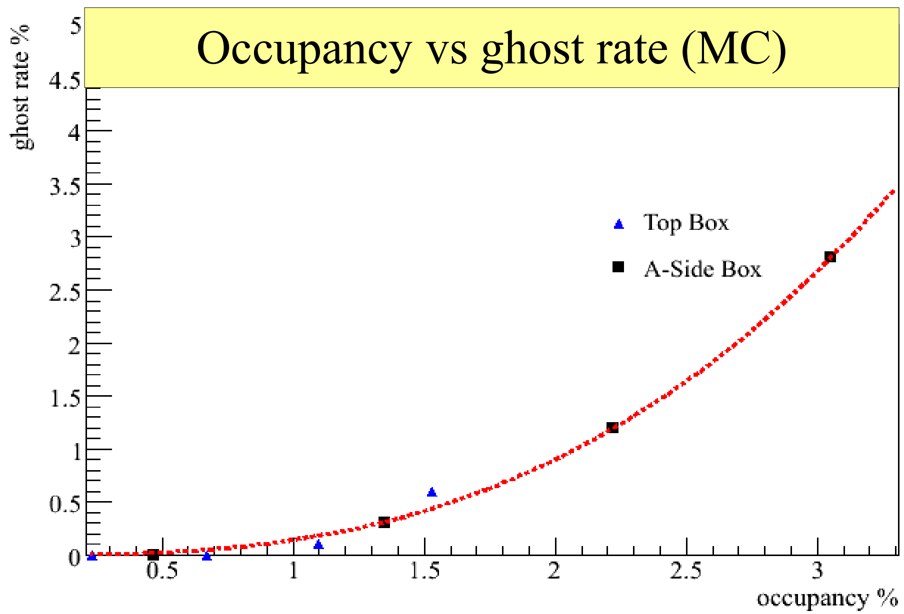
Huge combinatorial background

Origin of reconstructed IT tracks

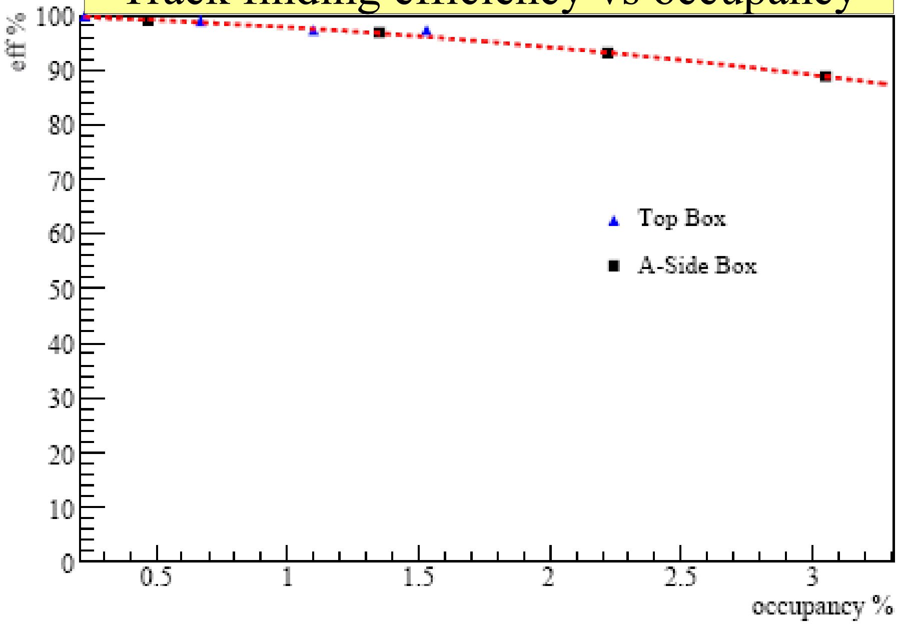


TED position in LHCb coordinate system: (3m, 0m, 350m)

Occupancy vs ghost rate (MC)



Track finding efficiency vs occupancy



IT alignment strategy

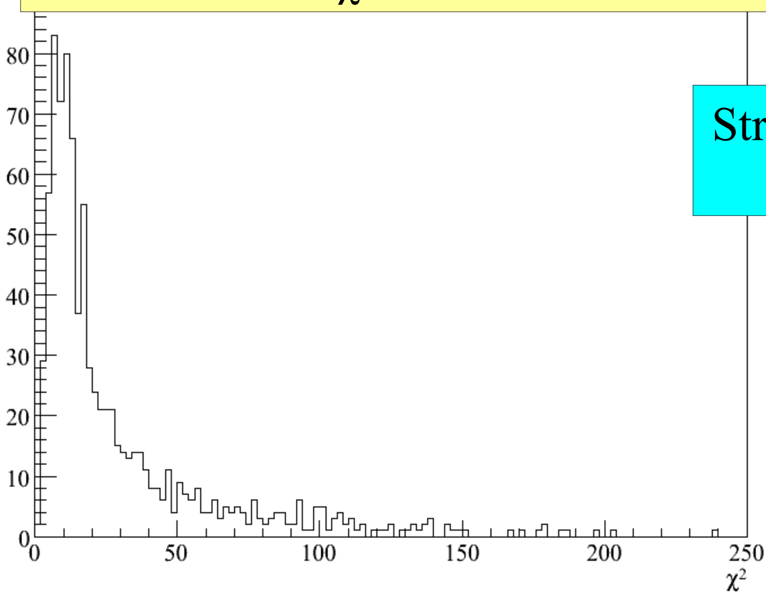
Survey
↓
Pre-alignment
↓
Alignment

iterate:

1. Pattern recognition
2. Default track fit
3. Track selection
4. Alignment **K-track** method
5. Update of the alignment constants

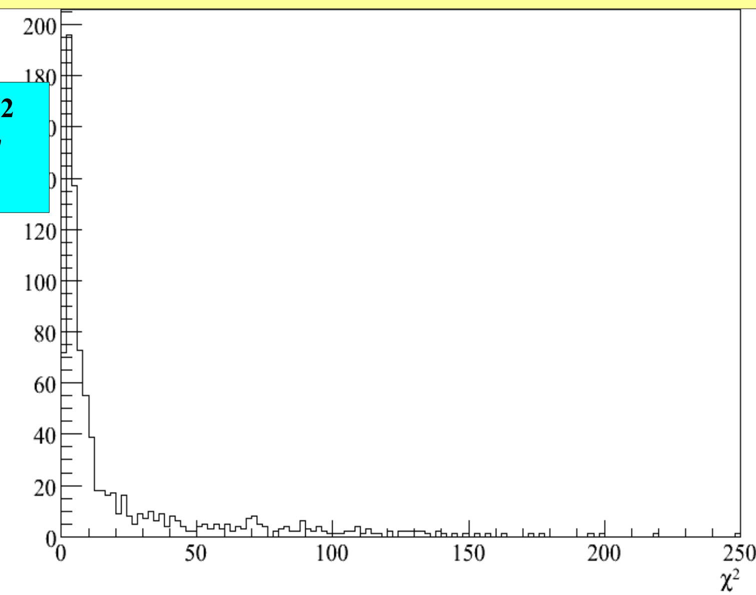
→ Align Boxes in x and y translation and z rotation
↓
→ Align Layers in x translation and z rotation
↓
→ Align Ladders in x translation

χ^2/dof distribution of reconstructed IT tracks after track selection



Strategy: **evolving χ^2** cut: 500 → 30

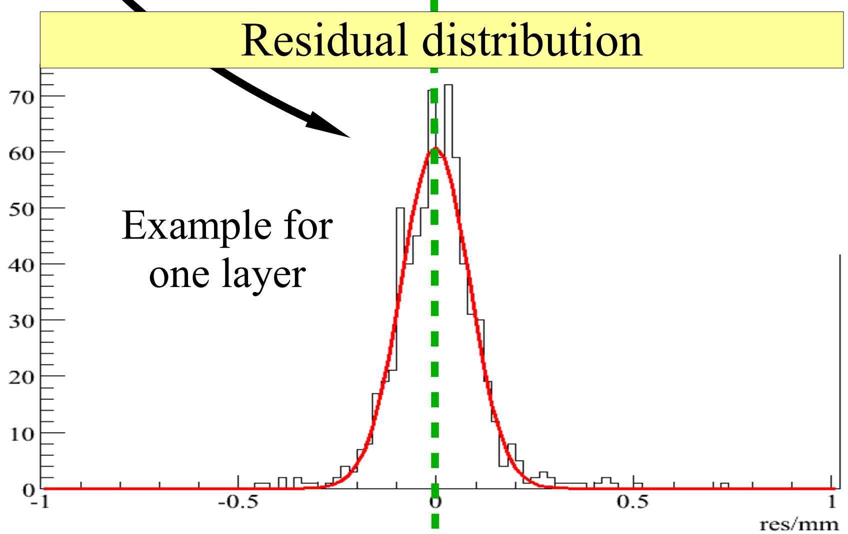
→ Align

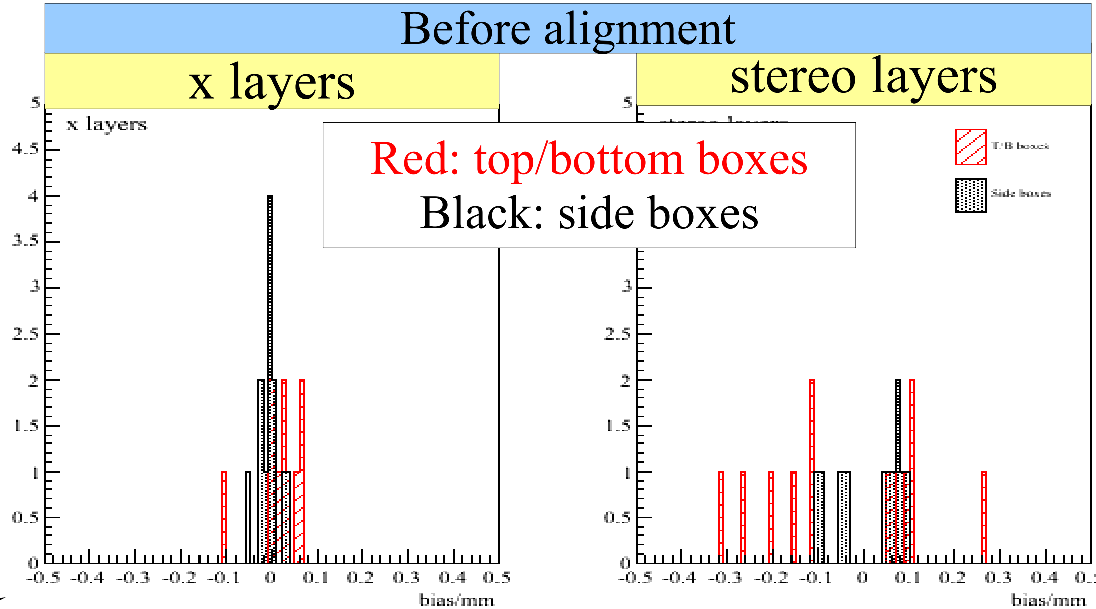


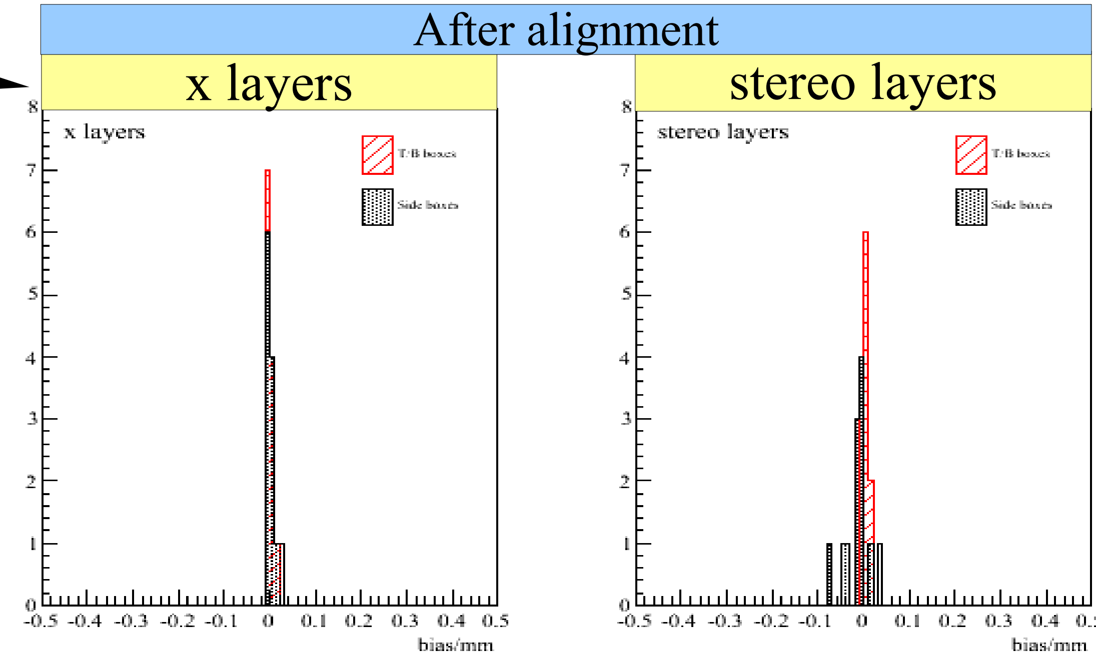
IT alignment validation

Procedure
- Alignment done using TED run with lowest occupancy
- Use other track samples to estimate layer bias

Fit gaussian to residual distributions of all 12 layers in every box and **plot the mean** (layer bias)

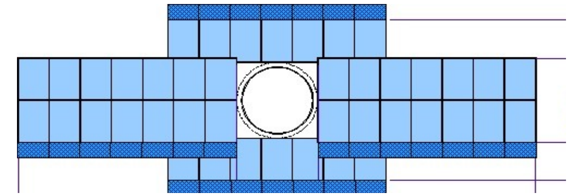




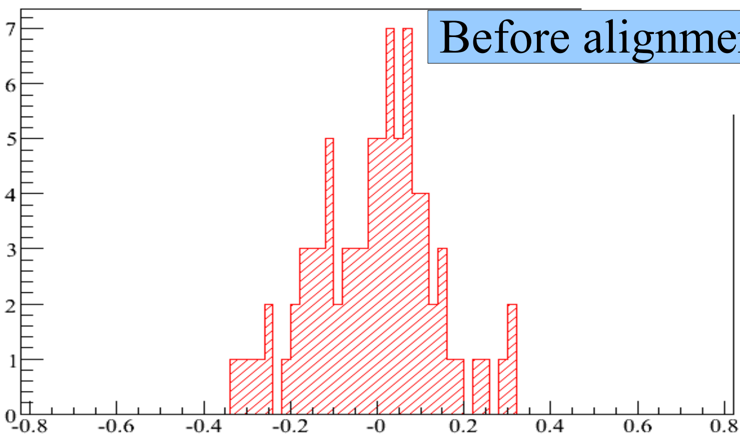


IT alignment validation

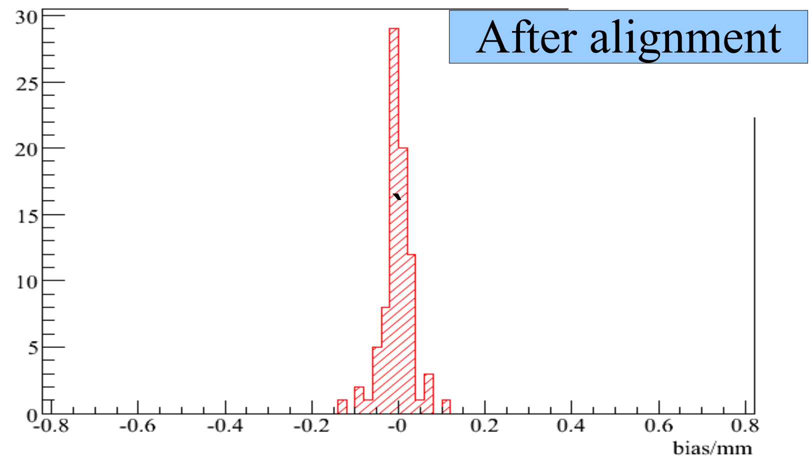
Repeat same procedure for ladders



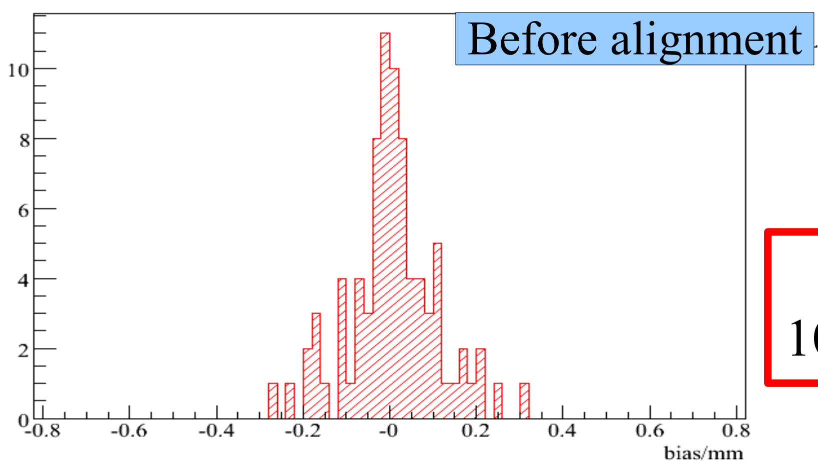
Ladder bias of the top boxes



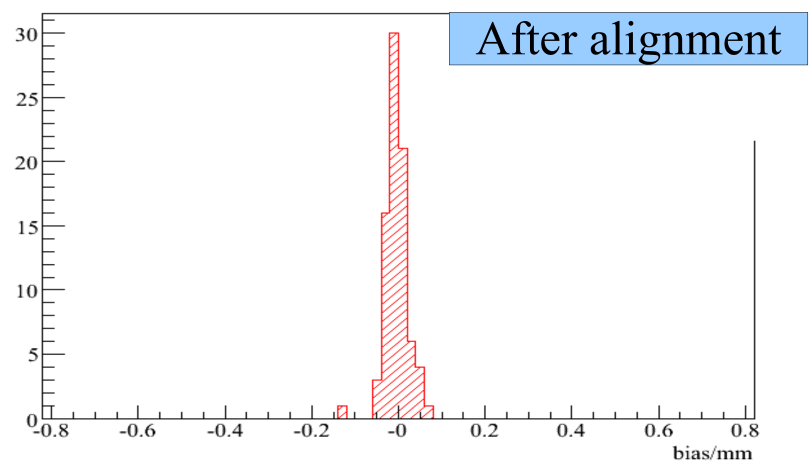
Sigma:
139 µm→ 35 µm



Ladder bias of the C side boxes



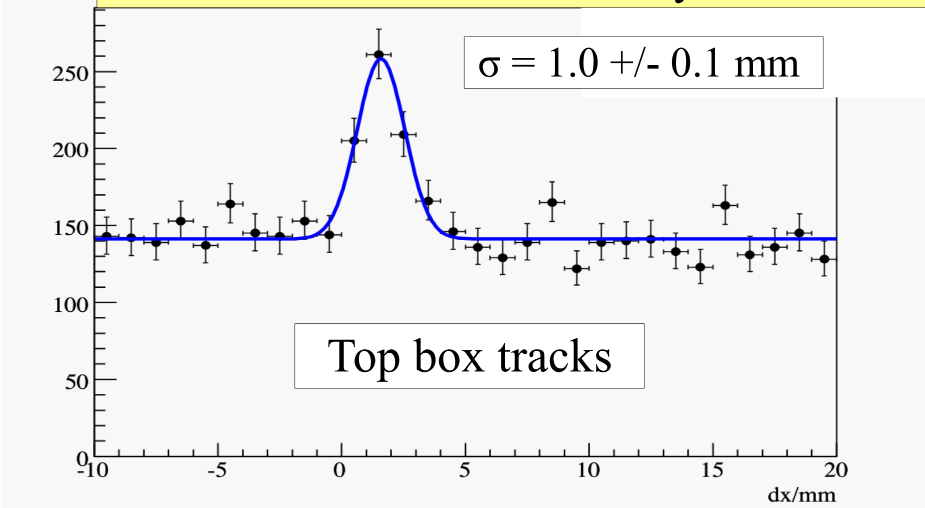
Sigma:
105µm → 28 µm

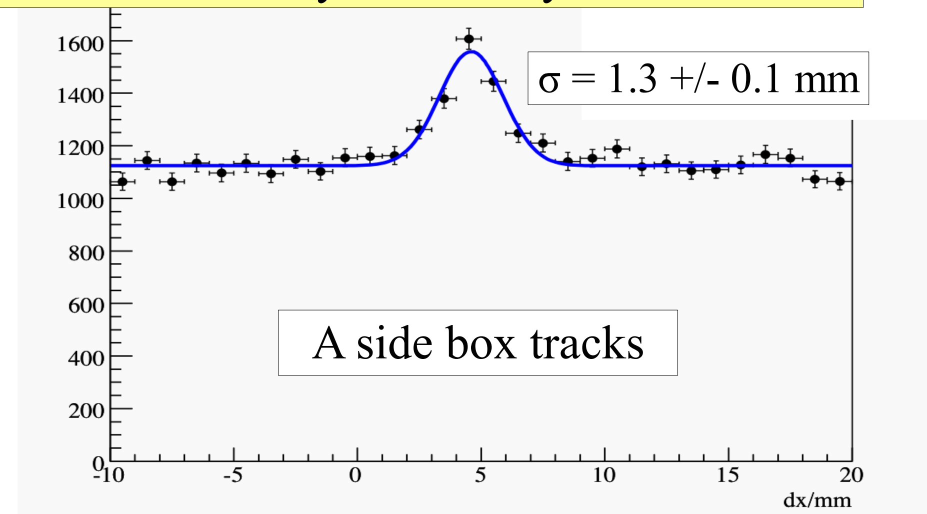


→ alignment accuracy is 30 µm

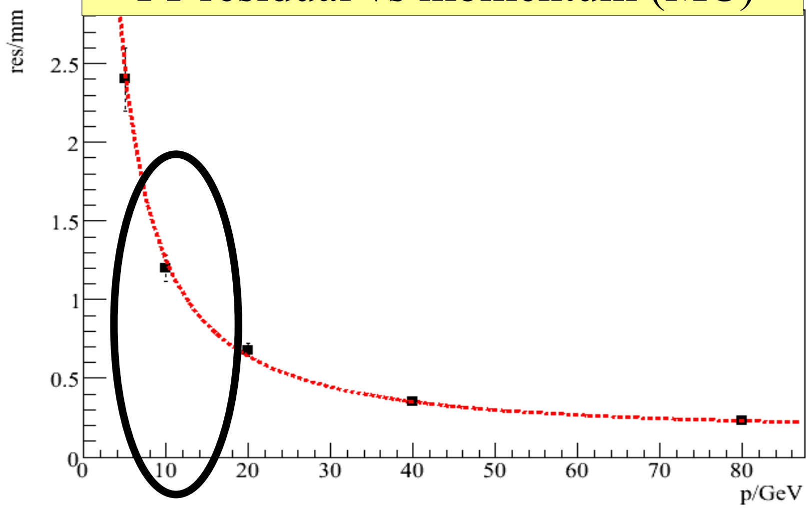
TT/IT alignment validation

Extrapolate IT tracks to last layer of TT station
Plot residual of every TT measurement in the last TT layer for every track





TT residual vs momentum (MC)

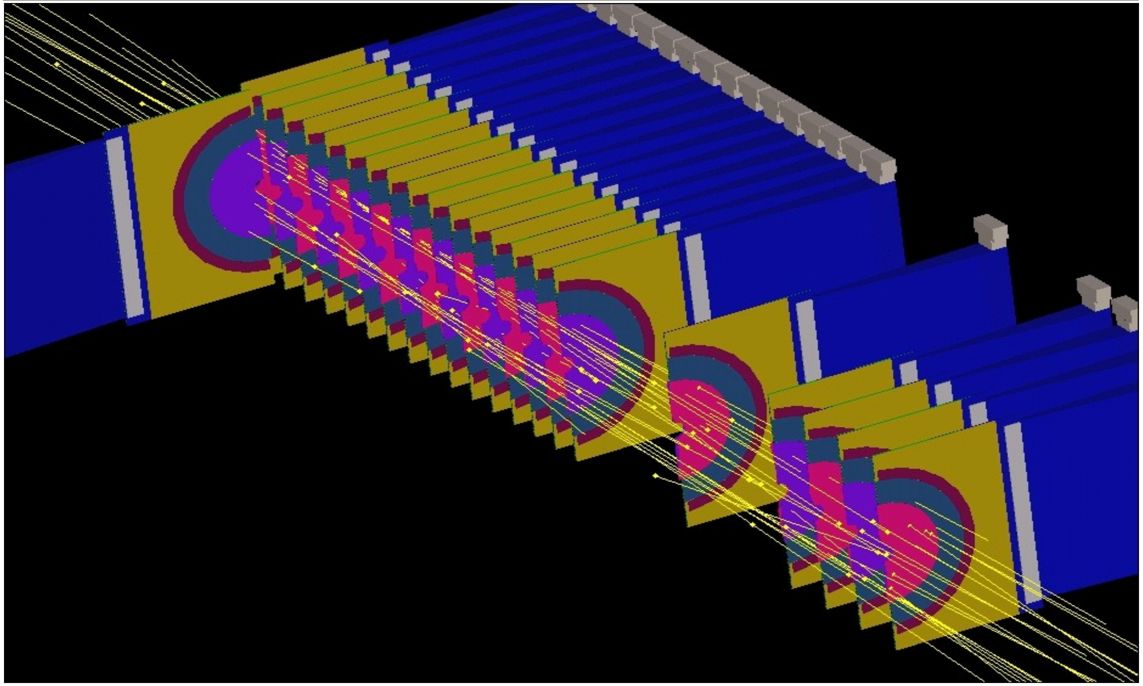


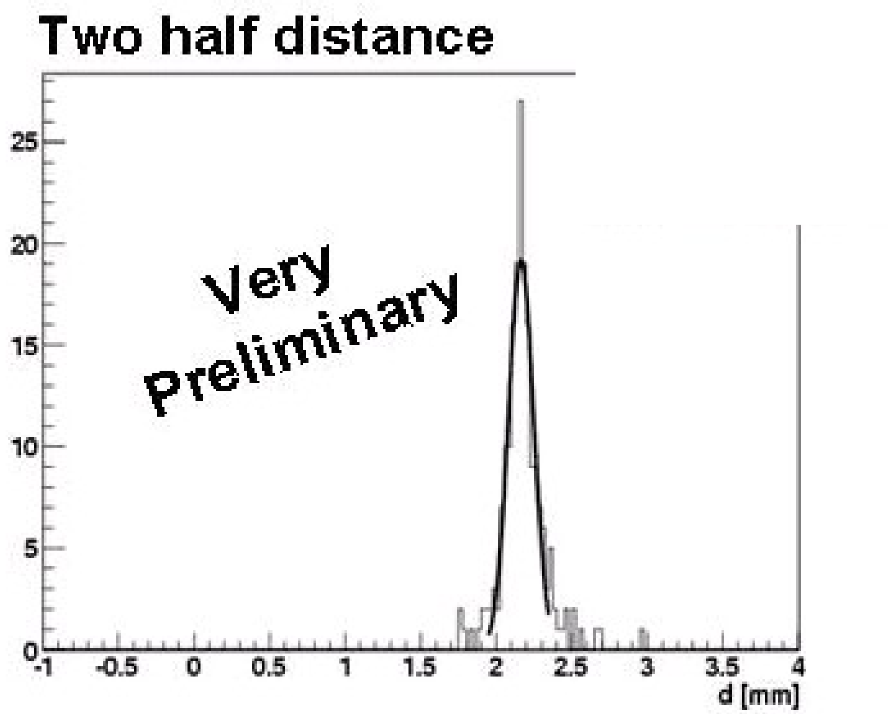
Validation shows good agreement with first MC sample:
- Track momentum: 10-15 GeV
- MC most muons with 10 GeV

VELO 2009 TED runs

- VELO almost in nominal close position
- 50k VELO tracks in 2009 data (2k tracks last year)

VELO tracks





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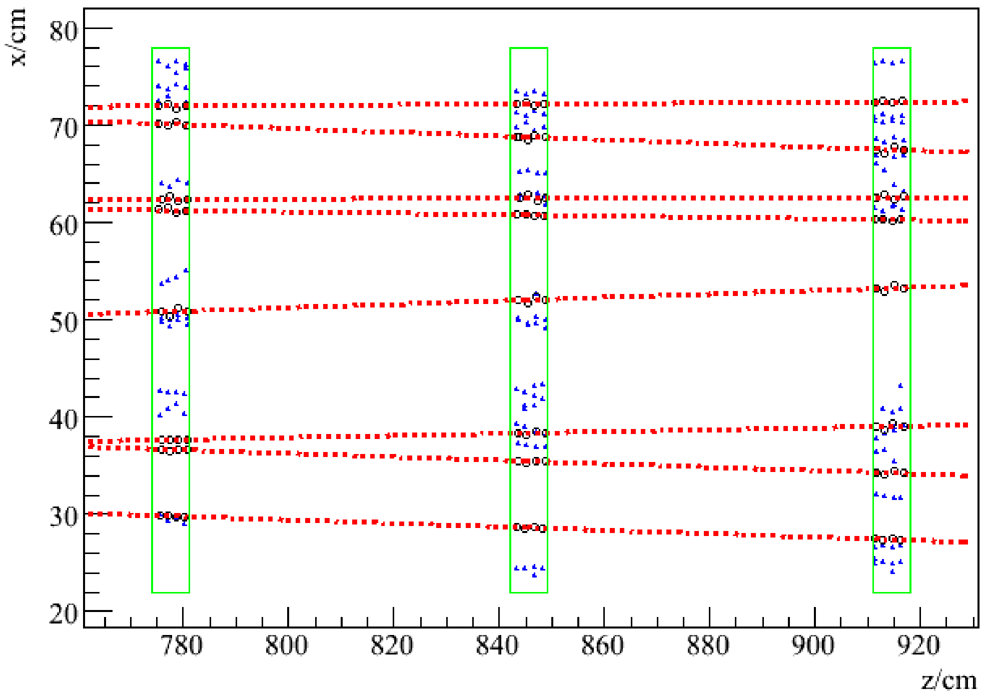
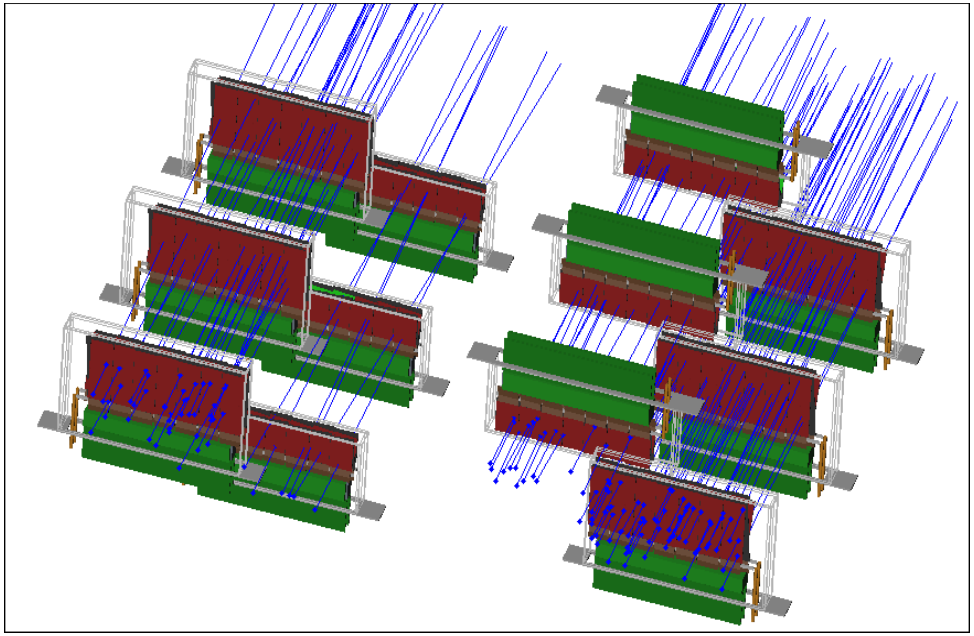
IT 2009 TED runs

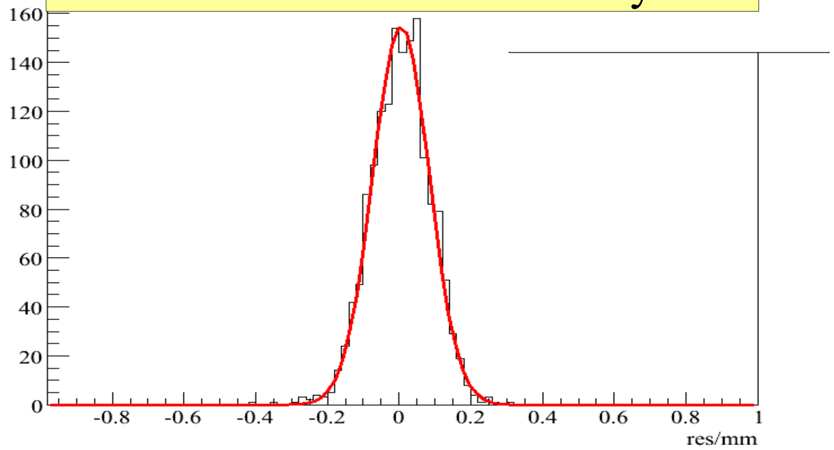
IT hits and tracks





- IT in **open** position
- Sample of ~ 12k IT tracks collected with low intensity (very useful for alignment)
- ~ 50k tracks in total
- Box and layer alignment performed
  - Alignment confirmed with a precision of 30 μm

Residual distribution of Layer



Conclusions and summary

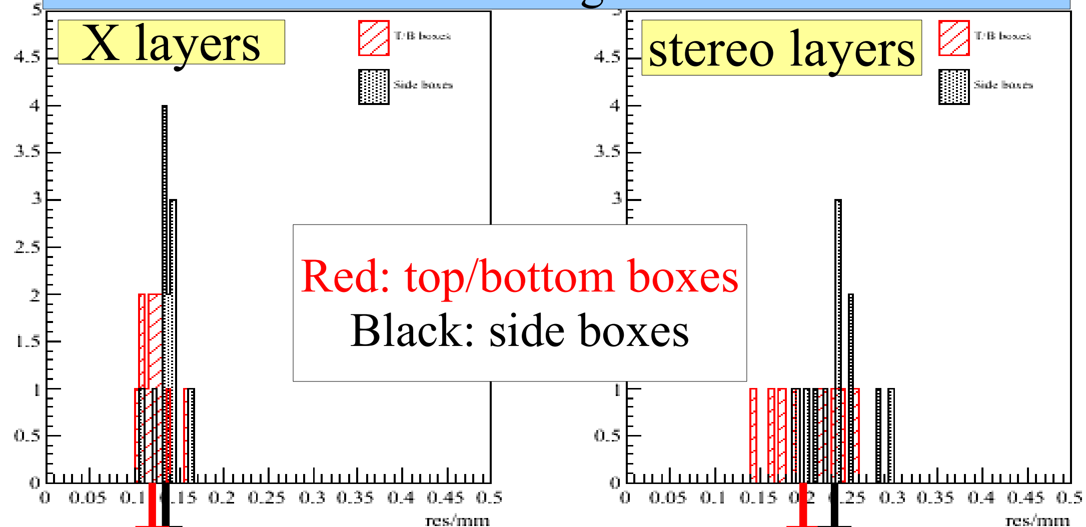
- **VELO**
  - Alignment of modules with precision of
    - x and y translation: 5 μm
    - z rotation: 200 μrad
  - Comparison of alignment methods show good agreement
- **TT**
  - Alignment of the full TT station
- **IT**
  - Alignment of boxes, layers
    and ladders with precision of
    - Ladder x translation: 30 μm
- **2008 TED data very useful**
  - First large sample of real tracks in silicon detectors
  - Successful initial alignment of silicon detectors
- **Outlook**
  - Further alignment with 2009 data

End

IT alignment validation

Instead of the mean plot the **width** of residual distribution

Before alignment

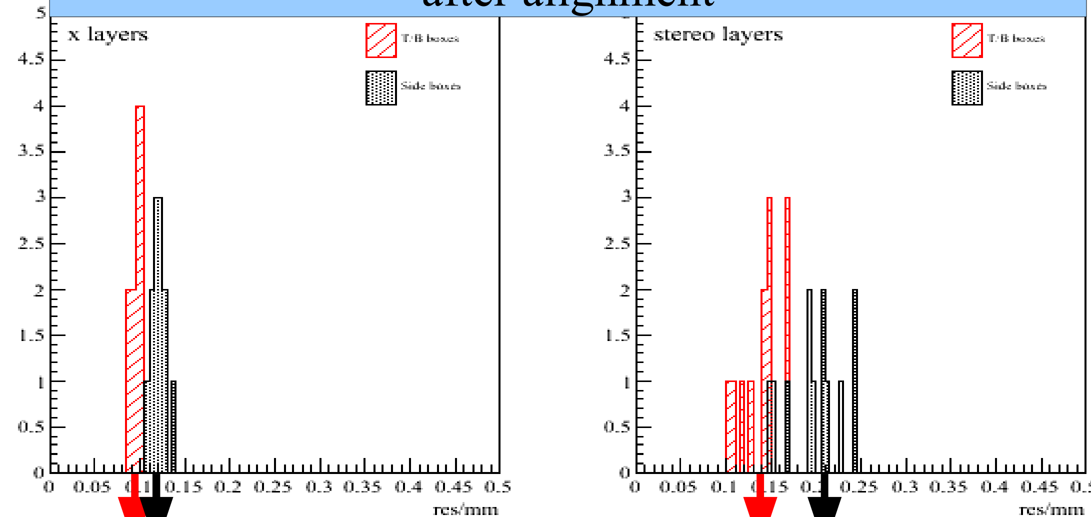


Red: top/bottom boxes
Black: side boxes

0.12 0.14

0.2 0.23

after alignment



0.09 0.11

0.14 0.21

IT residual width vs momentum