LHC*b* T-Station Alignment with Cosmics

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on behalf of the LHC*b* collaboration

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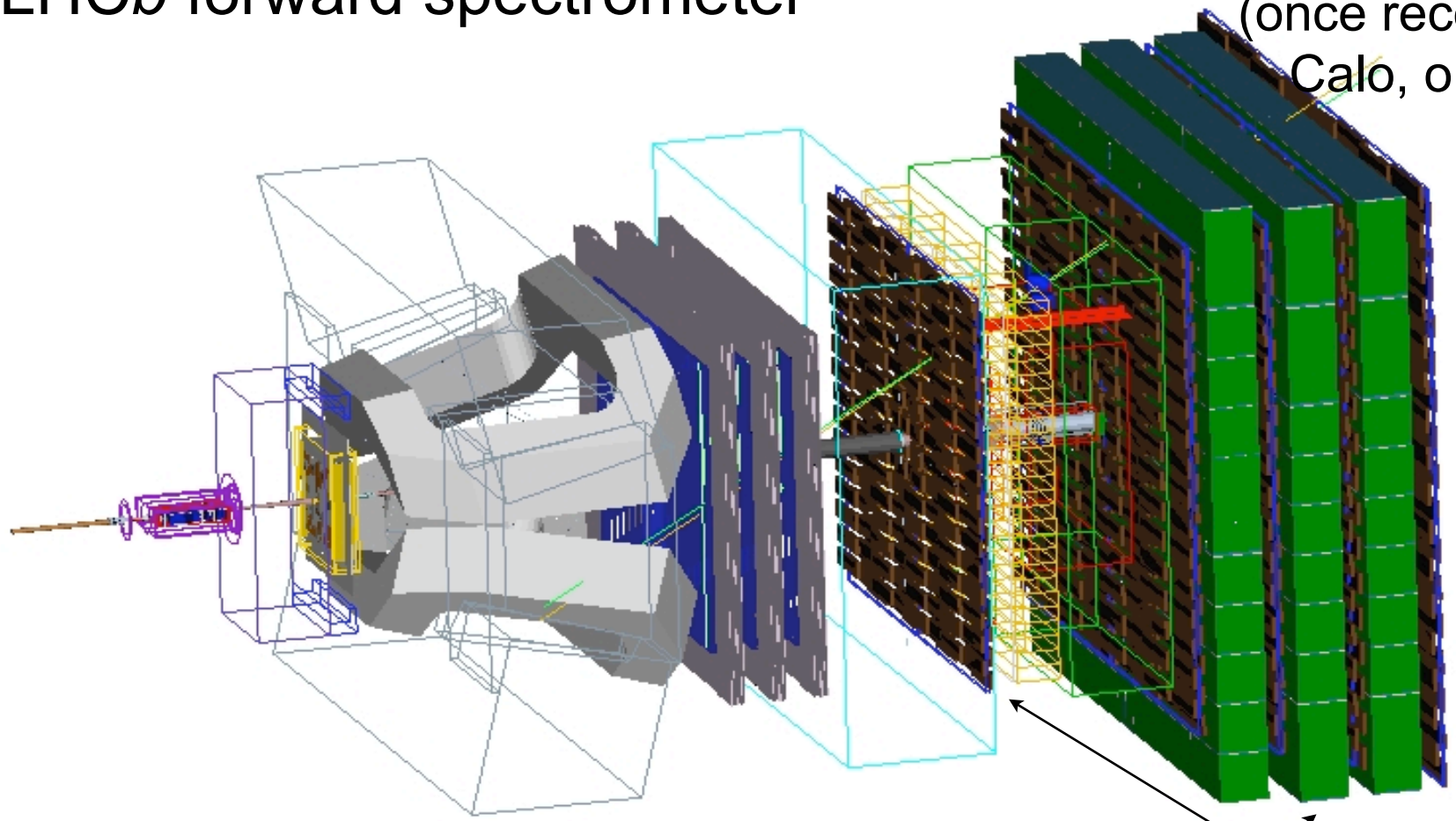
LHC*b* detector

LHC*b* forward spectrometer

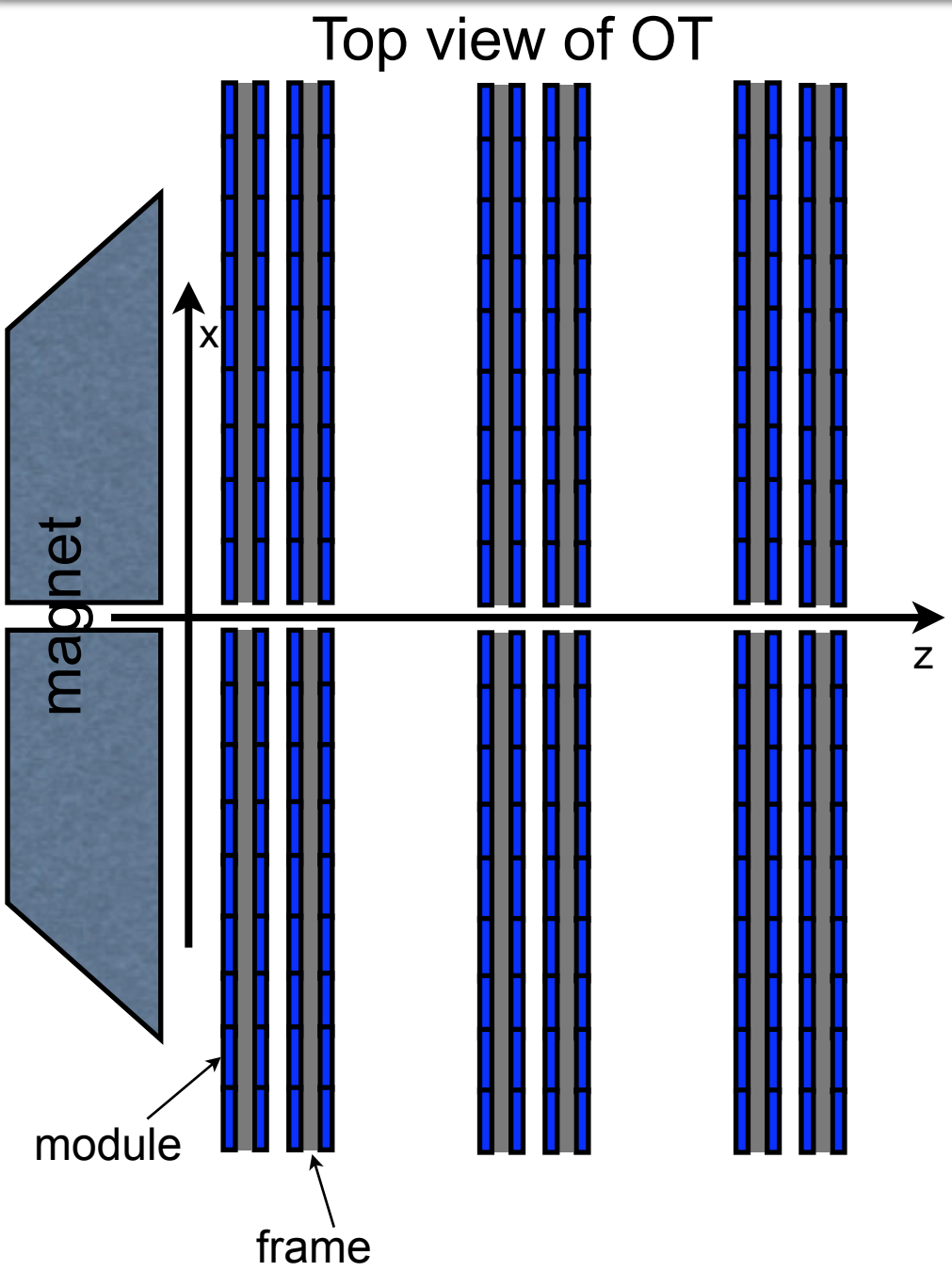
Cosmic particle track (once reconstructed in Calo, once in OT)



VeLo TT **Outer Tracker** ECal Muon Stations

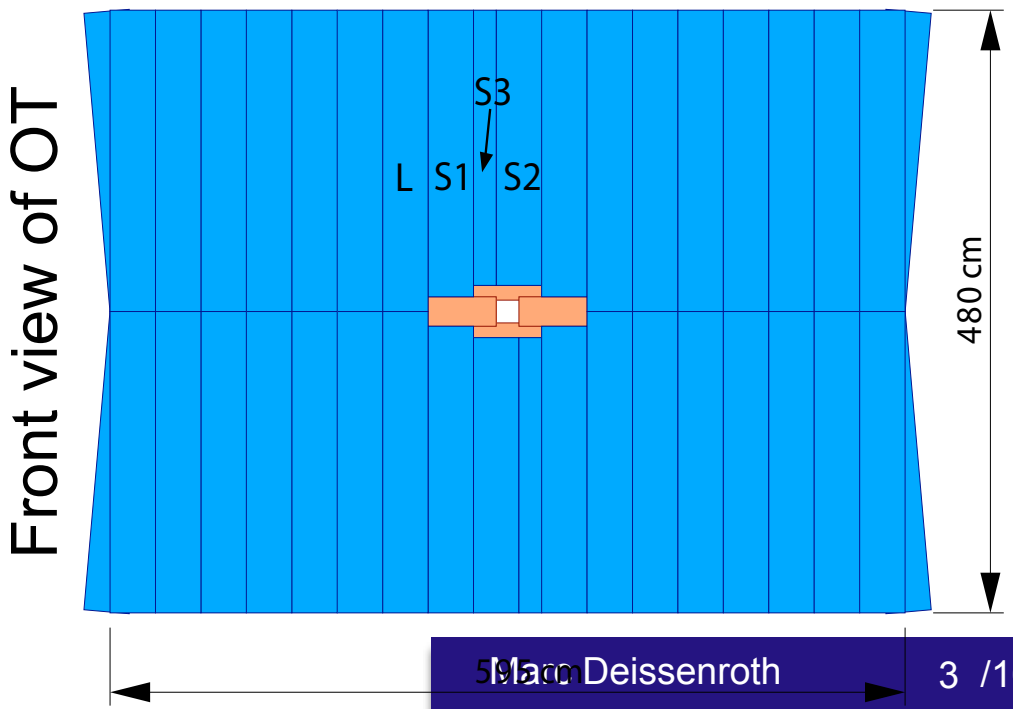
RICH1 Magnet IT RICH2 HCal

Outer Tracker



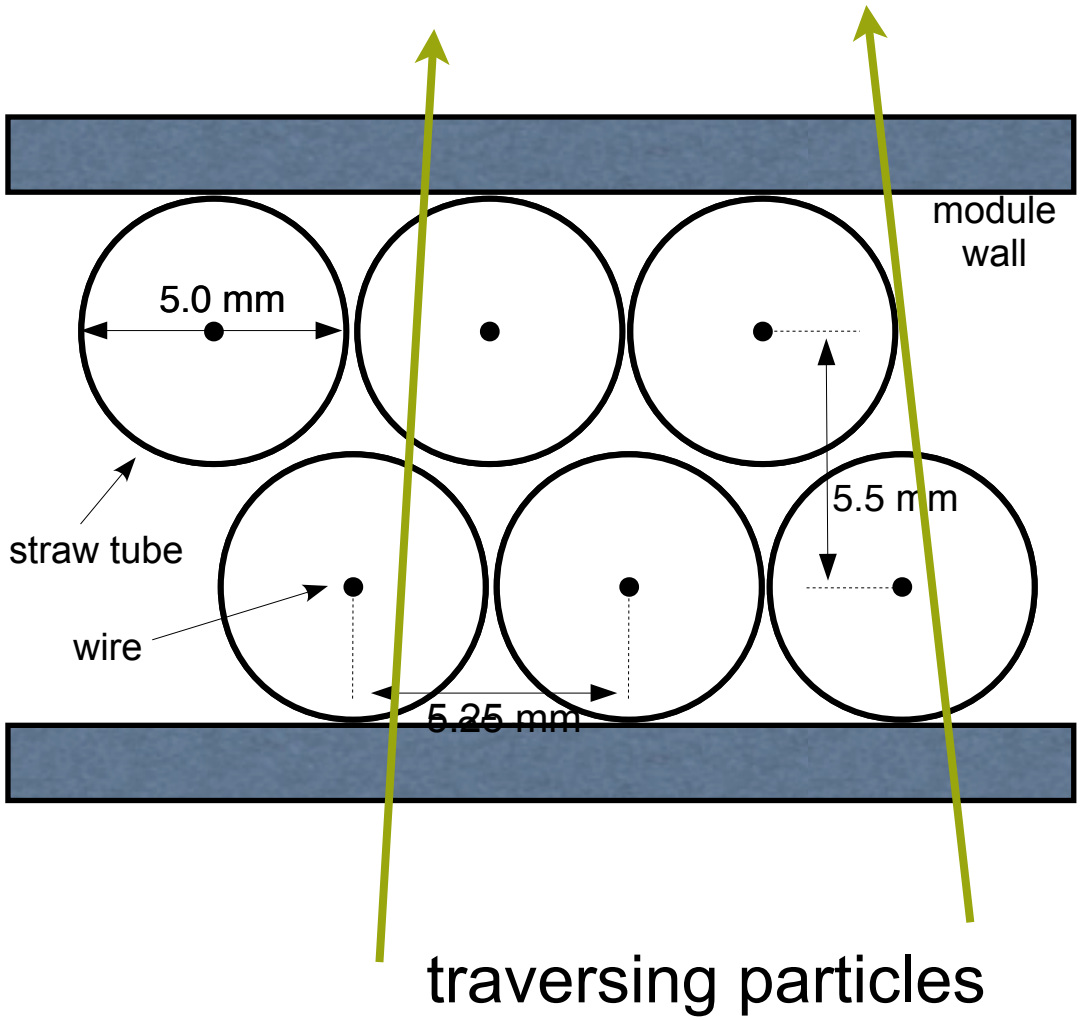
- 3 stations, 2 halves per station
- 2 support frames per half (movable)
- 9 modules per frame: half layer
- half layer angle w.r.t. y axis:

  $\mathbf{x}(0^\circ),\mathbf{u}(-5^\circ),\mathbf{v}(+5^\circ),\mathbf{x}(0^\circ)$
- main measurement direction: x
- y information via rotated half layers



Straw tubes

Profile of module with straw tubes



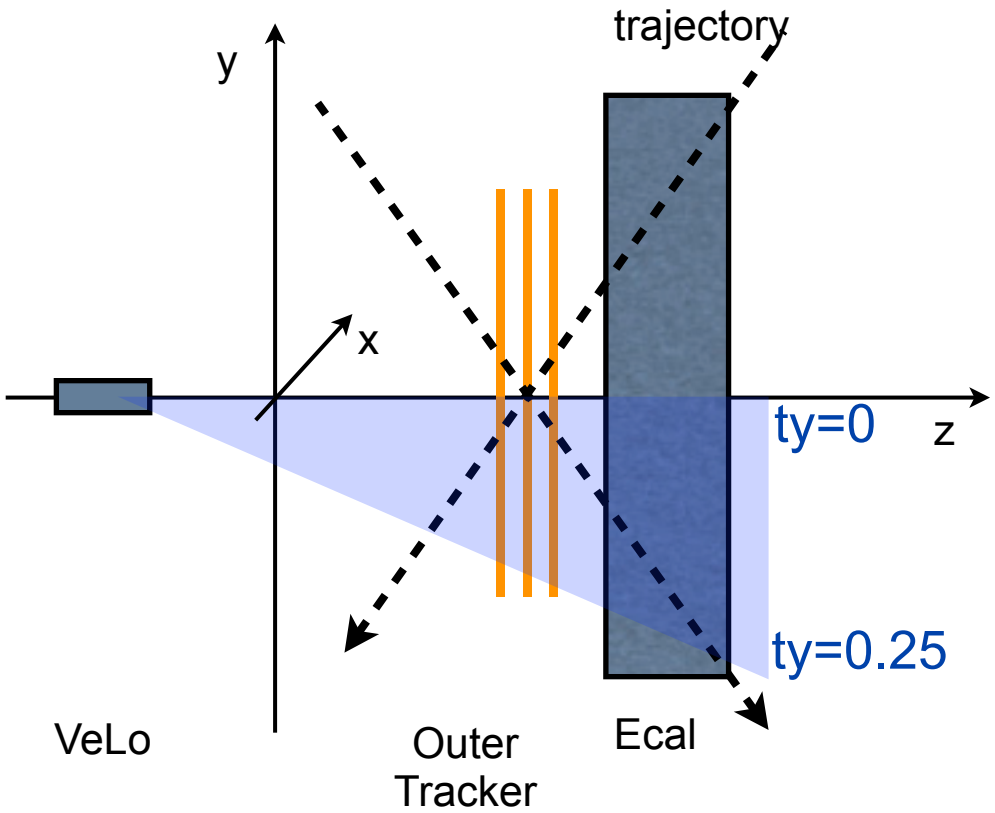
- straw tube = drift cell
- two monolayers per module:
  ≤ 2 hit per cluster
- resolution

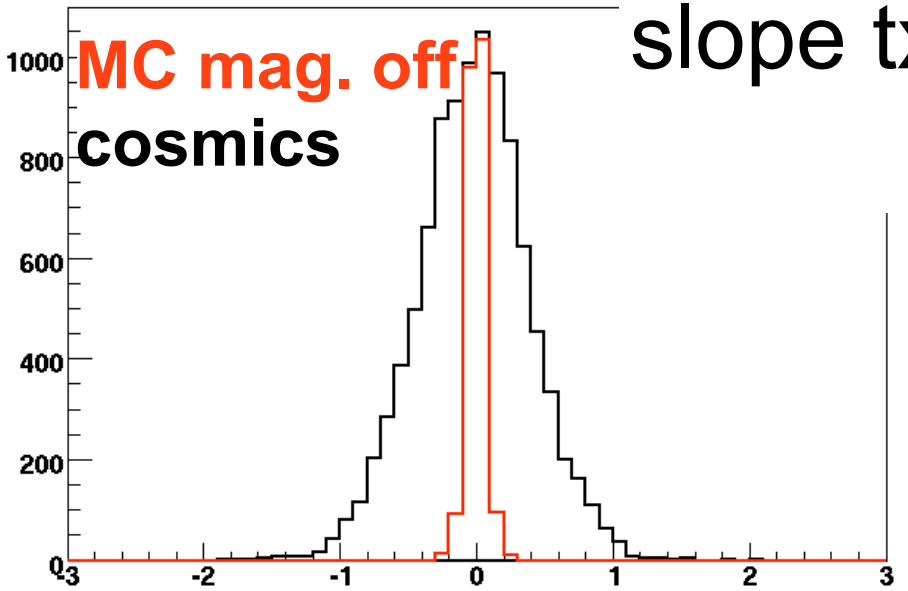
  with drift time : 200 μm

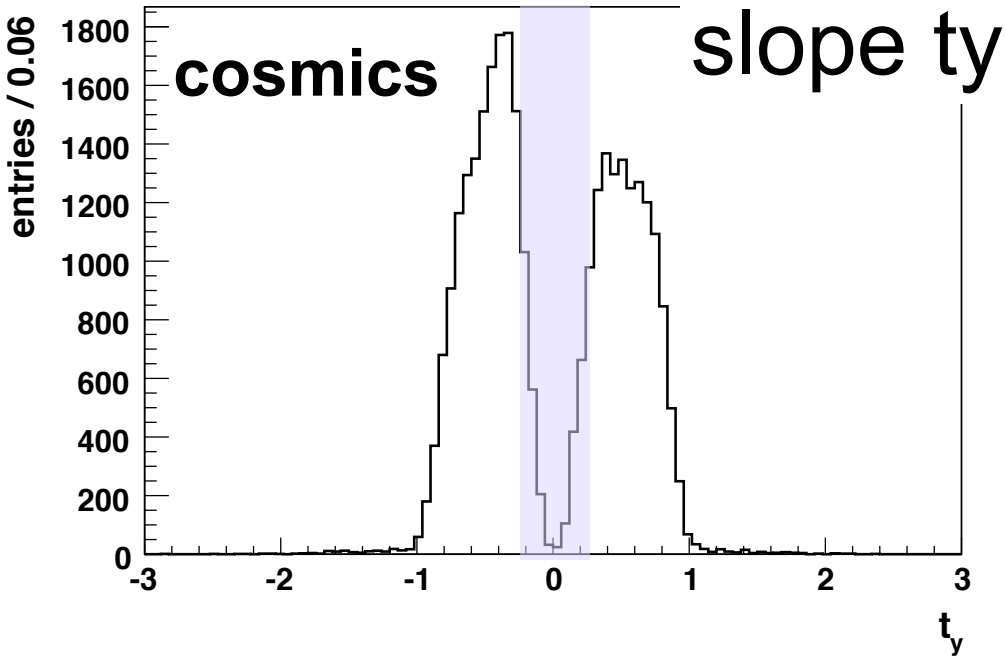
  without : $\frac{5\ \text{mm}}{\sqrt{12}} = 1.44\ \text{mm}$

Data & Tracks

- no magnetic field
- triggered with ECal + Muon St.
- 20000 tracks for alignment
- extreme slopes compared to pp collision data







OT Alignment

Two competitive alignment approaches:

- both minimize the χ^2 w.r.t. **local track and global alignment parameters simultaneously**

  1. standalone track fit; math based on Millepede algorithm

  2. standard LHCb Kalman filter track fit

- OT alignment with both algorithms:
  - results comparable
  - following results from approach 1
- alignment without using drift times:
  - track fit stable & no iterations needed (no hit ambiguity) & independent from calibration

  ➞ $\sigma_{meas}=1.44\text{mm}$

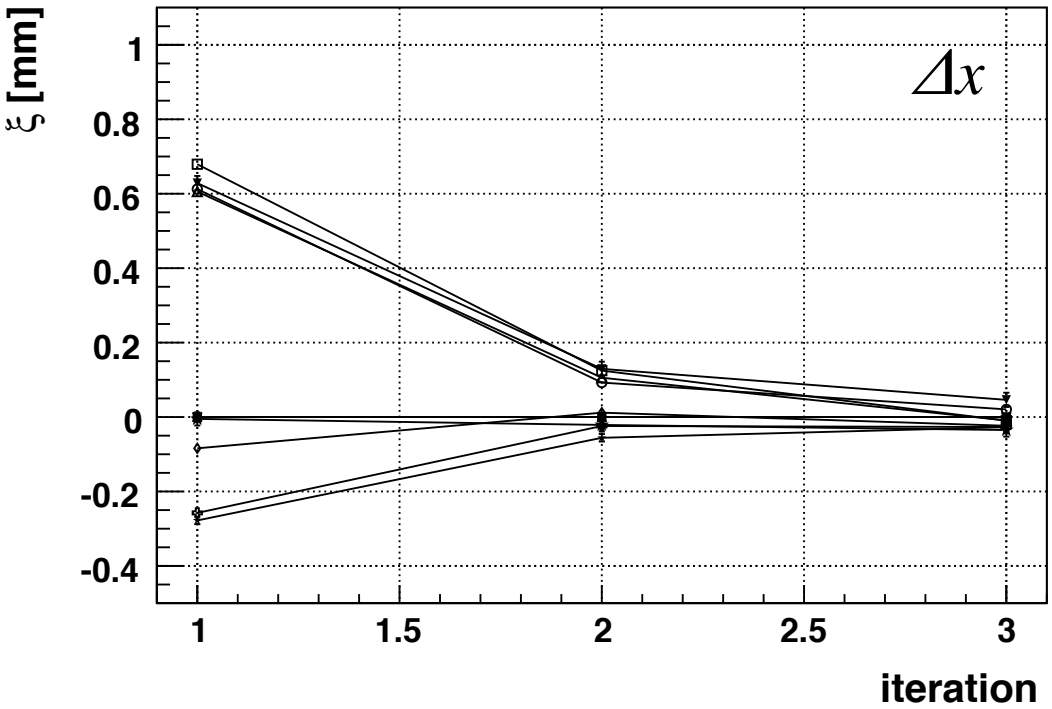
Alignment of OT I

Align for half layers

- Δx: main measurement direction,
  linear d.o.f. ➞ no alignment iterations required

Plot the ‘convergence‘ parameter

- $\xi = \Delta x_i - \Delta x_{i-1}$ $(i = iteration)$



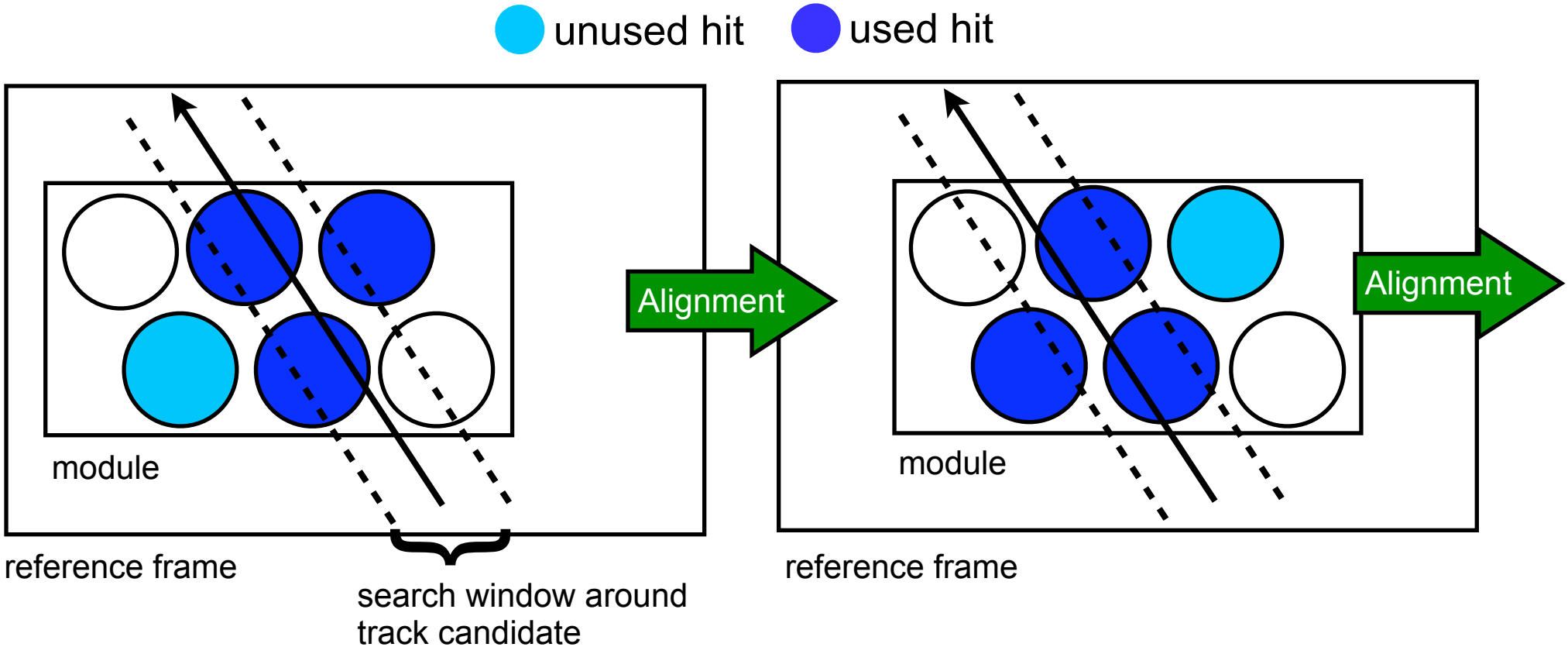
no convergence ($\xi=0$) after 1st iteration

↓

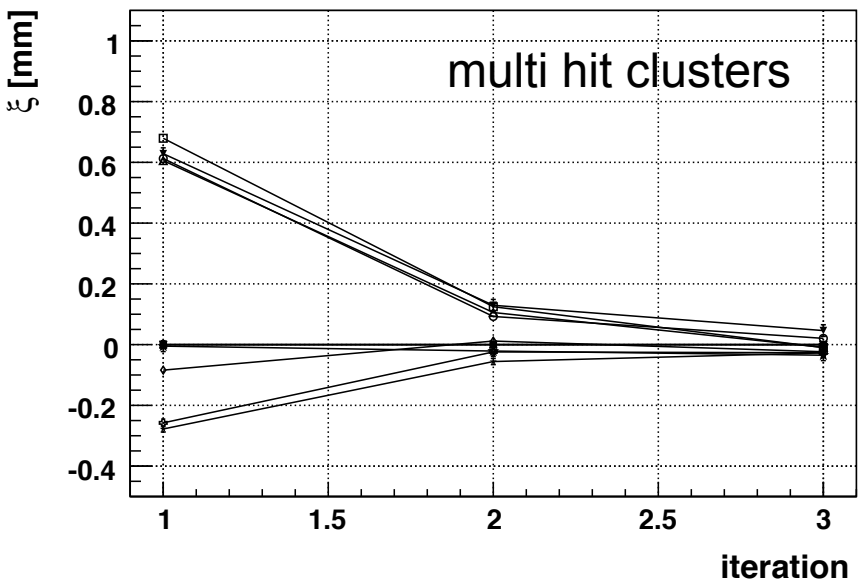
effect of the pattern recognition

Effect of pattern recognition

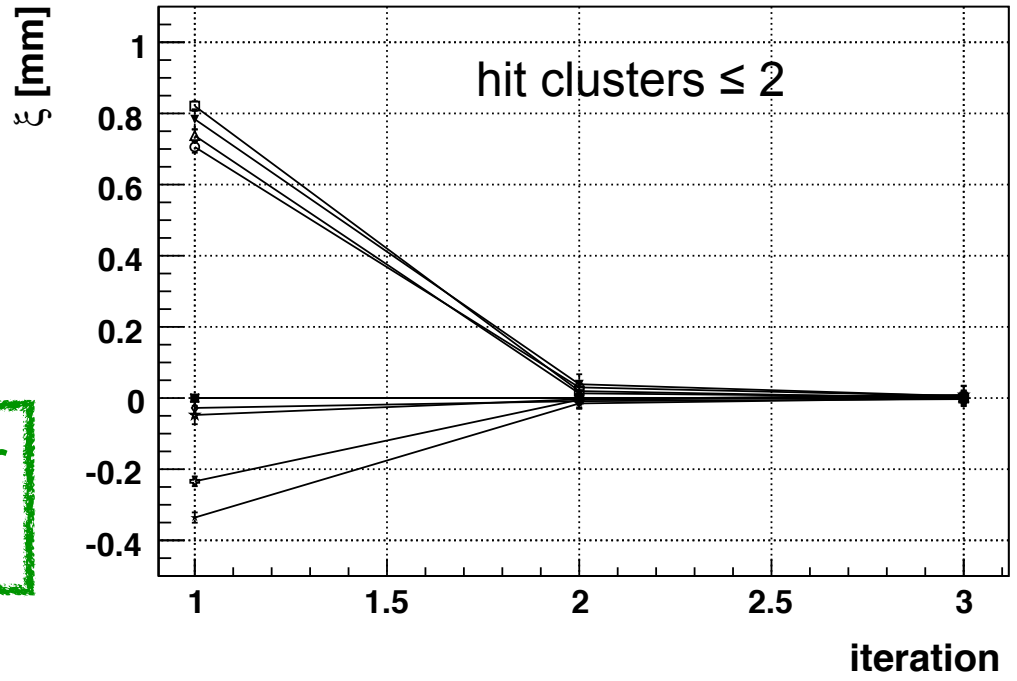
- tracks with multi hit clusters
- χ^2 minimization: alignment constants depend on track and its residual
- pattern recognition selects different hits in subsequent alignment iterations ➙ alignment constants change



Alignment of OT II



select tracks with
≤ 2 hit clusters



convergence after
one iteration

- following results with tracks comprising only ≤ 2 hit cluster

D.o.f. & Constraints

Align for

- Δx: main measurement direction
- Δz: z-scale important for correct momentum estimate
- $\Delta \gamma$: angle w.r.t. y axis

Constraints to avoid overall shift and rotations

- Δx: fix 1st and last parameter of x layers
  fix 1st and last parameter of *rotated* layers (constrain y direction)
- Δz: fix 2 parameters to set scale
- $\Delta \gamma$: same as for Δx

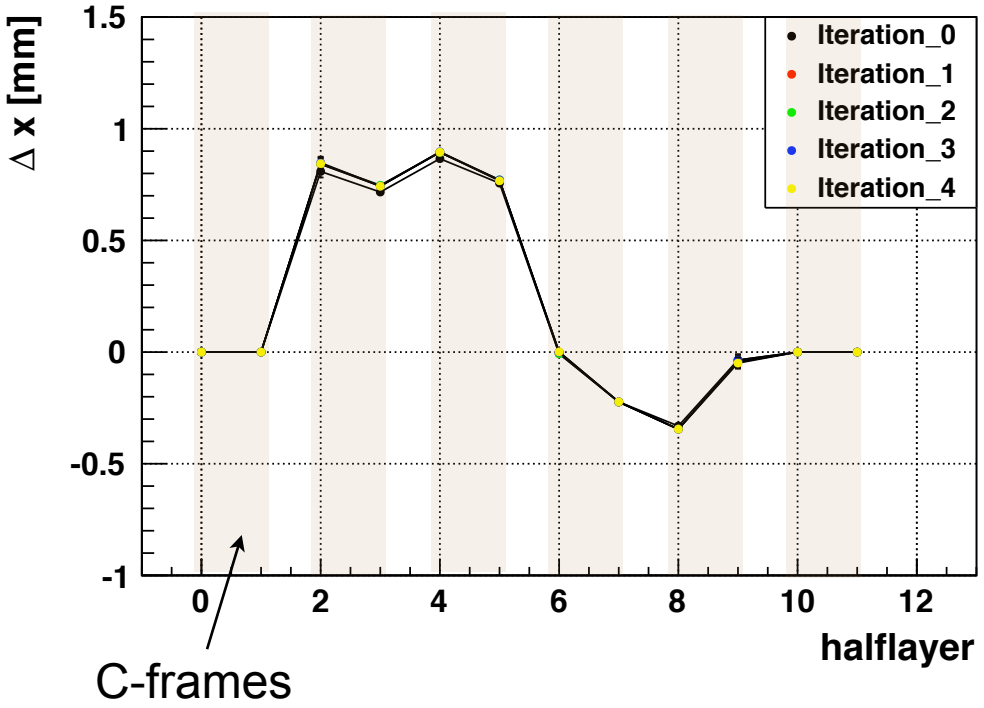
Results for alignment of half layers, then for modules

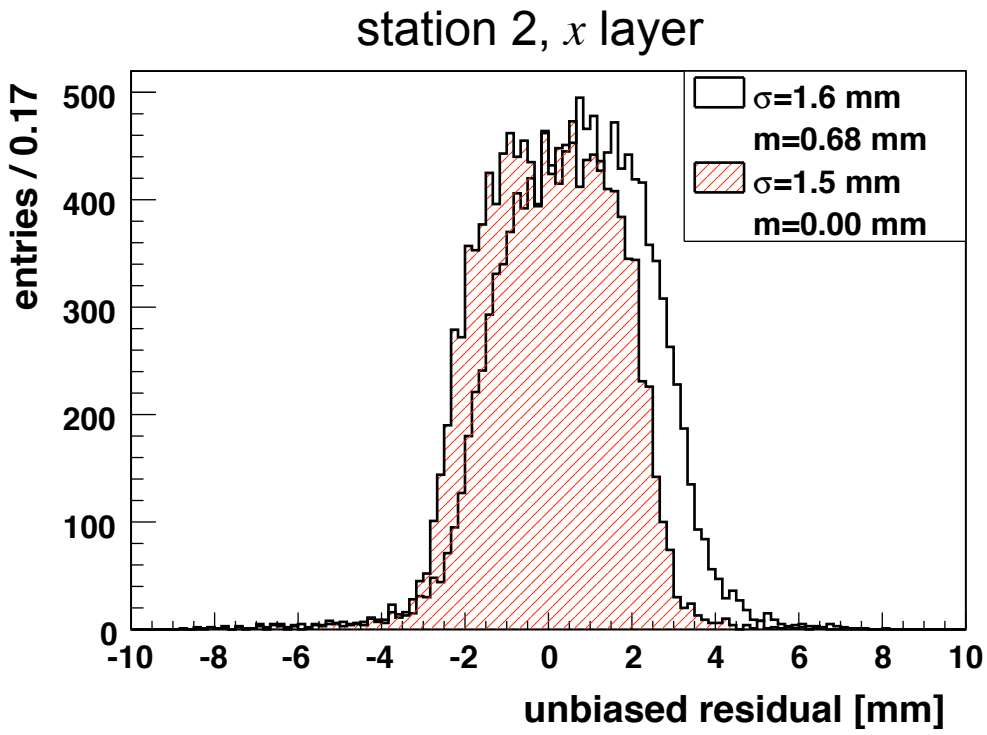
Half layer alignment Δx

- shifts of up to 1 mm (relative to the fixed layers)
- frame support of half layer evident
- clear improvement of unbiased track residual, e.g. for first x layer of station 2:

$m_{misalign} = 0.68$ mm → $m_{align} = 0.0$ mm

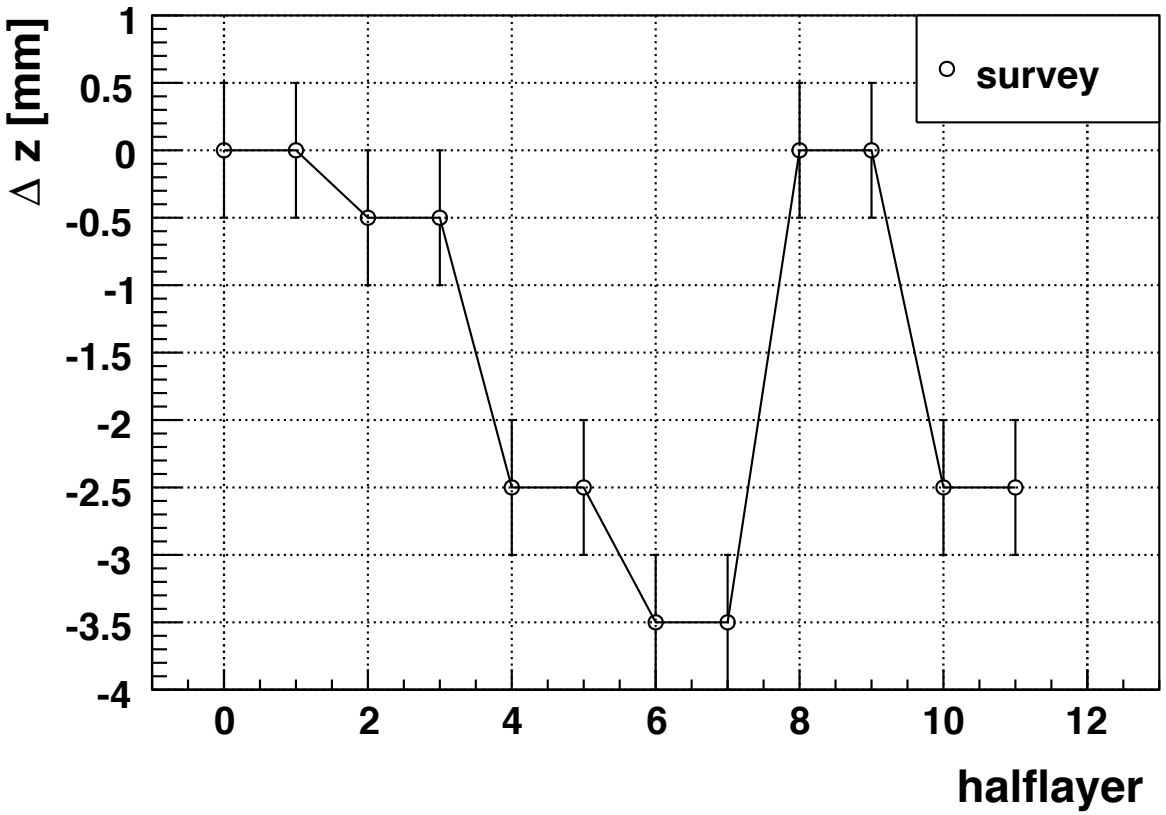
$\sigma_{misalign} = 1.60$ mm → $\sigma_{align} = 1.5$ mm





Half layer alignment Δz

- compare software alignment results with survey
- survey measures 1st and 5th C-frames,i.e. halflayer (0,1) and (8,9) to be at $\Delta z = (0 \pm 0.5)\ \mathrm{mm}$
- constrain halflayer 0 and 9 to surveyed position



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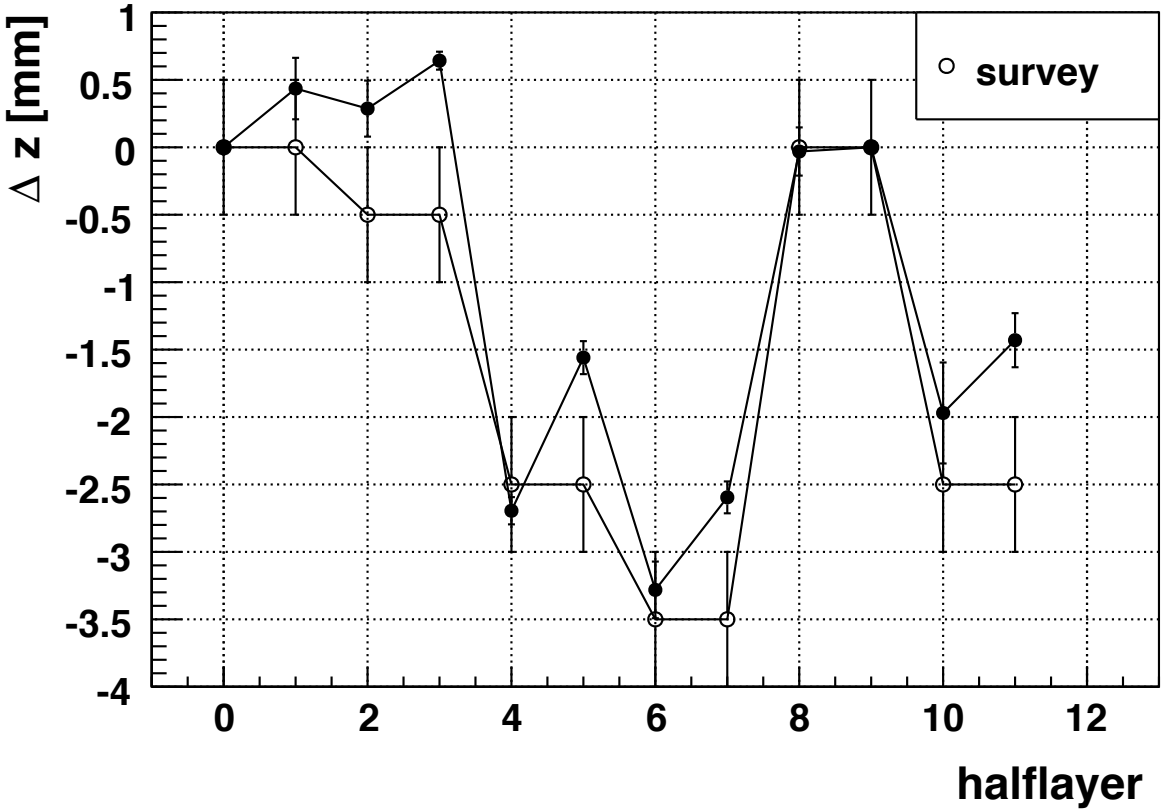
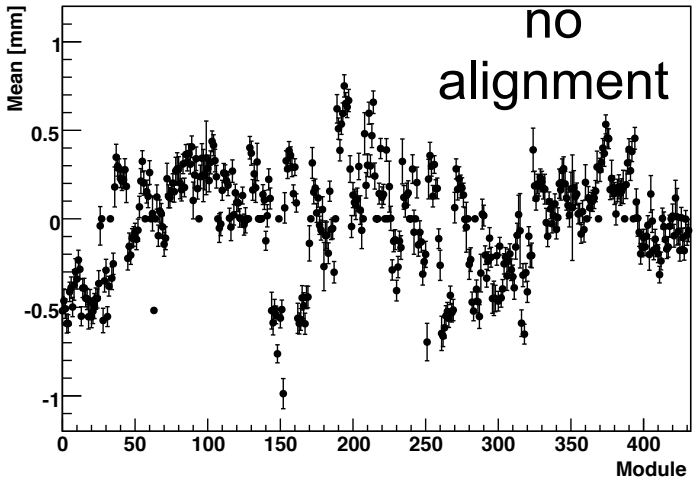


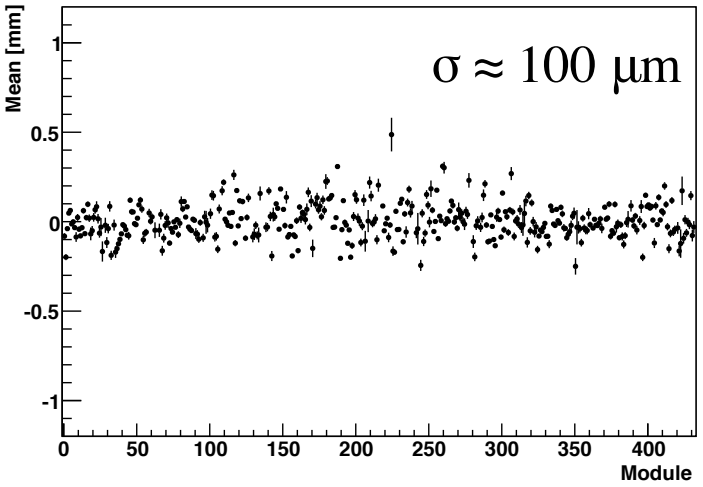
good agreement between survey and software results !

Module alignment

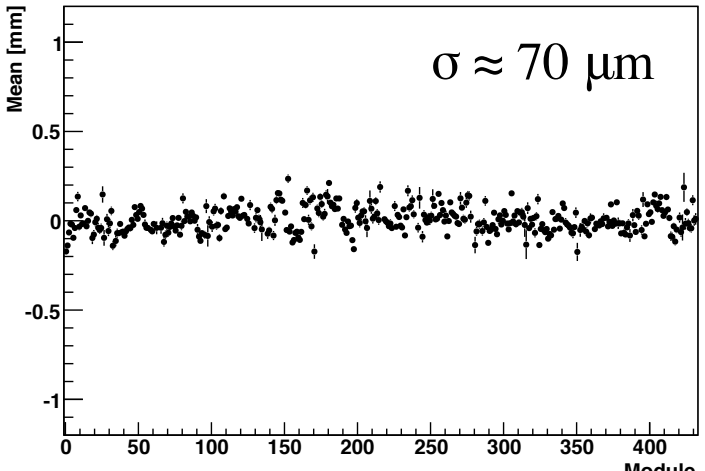
- using geometry obtained after half layer alignment
- align for Δx, Δz, $\Delta \gamma$ (γ rotation around z)
- mean of residuals improve significantly (subsample of alignment sample used for following plots) :



half layer alignment



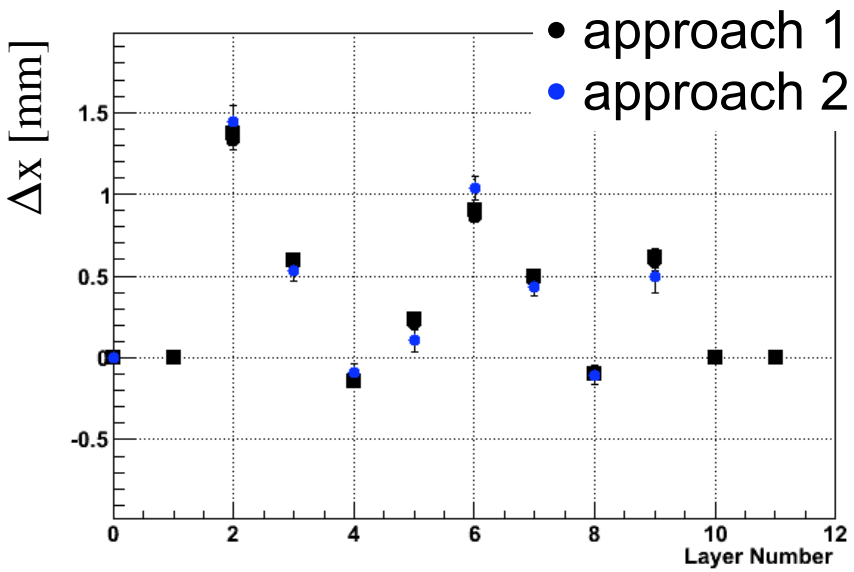
module alignment

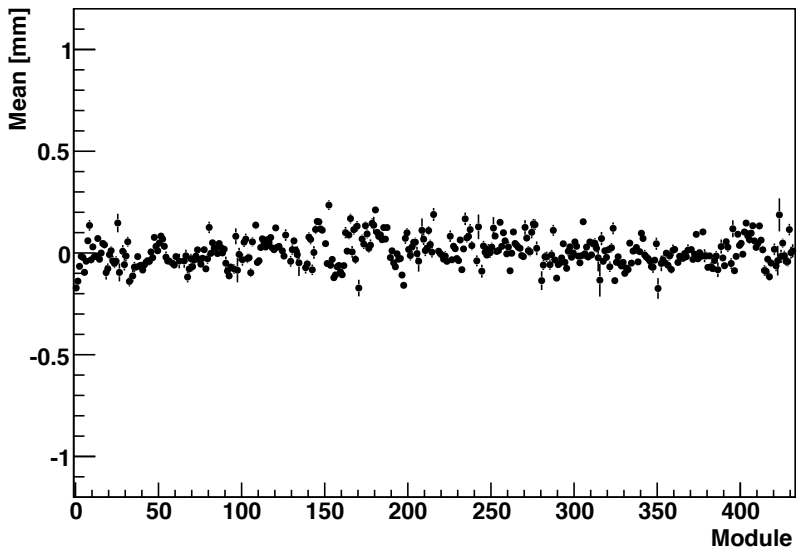


Alignment accuracy

Compare results of approaches

1. standalone track fit; math based on Millepede algorithm
2. standard LHCb Kalman filter track fit





difference of results < 100 µm

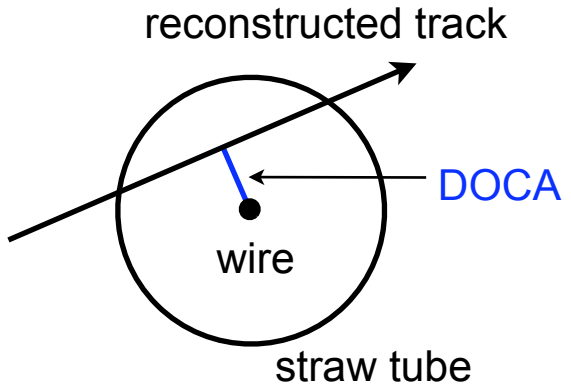
$\sigma_{mean} \approx 70$ µm

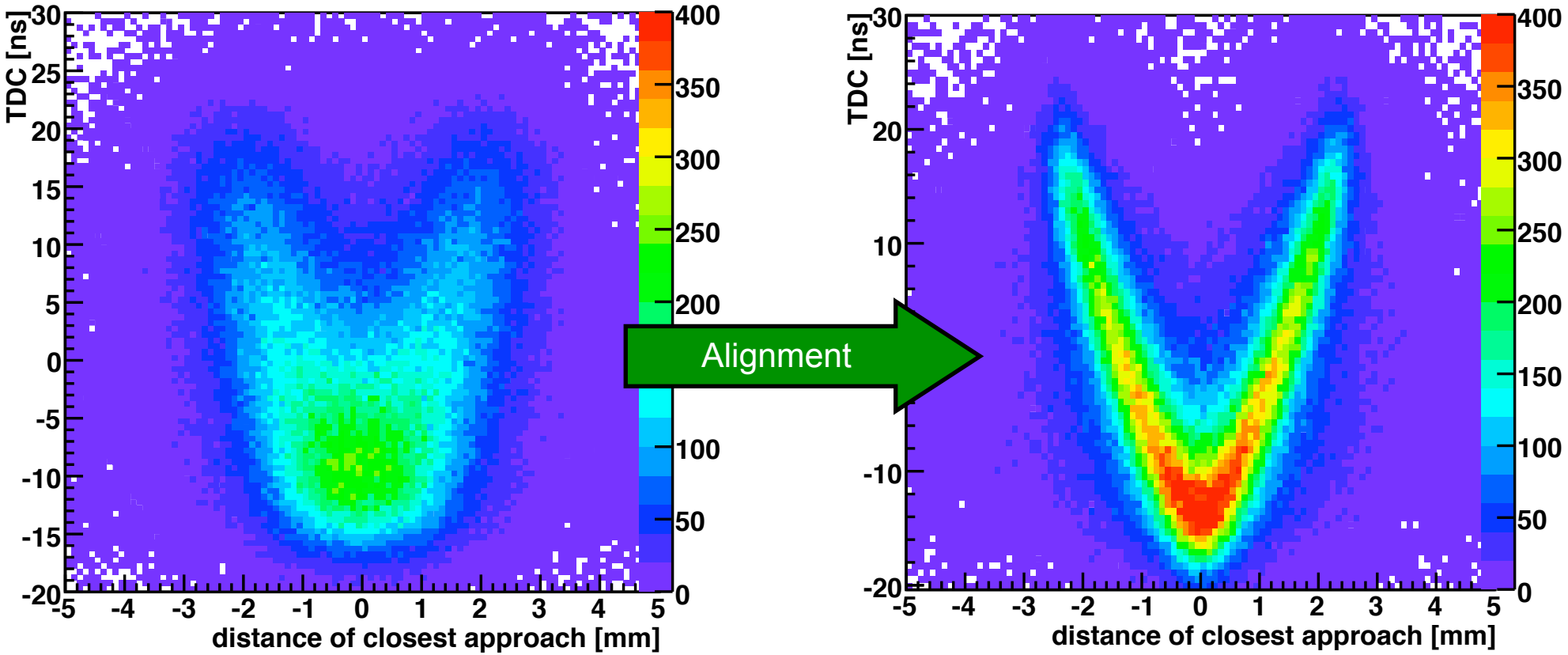
alignment accuracy $\sigma_{align} \approx 100$ µm

(including systematics and statistics)

Detector calibration

- validate alignment constants with calibration of space drift time relation (DOCA vs drift time)





Summary

- 2 implementations for the LHC*b* Outer Tracker alignment which give comparable results
- 20000 cosmics tracks for alignment
- hierarchic alignment for most sensitive d.o.f. Δx, Δz, $\Delta\gamma$
    - half layers
        - modules
- significant improvement of track residuals, alignment accuracy $\sigma_{\text{align}} \approx 100\ \mu\text{m}$
- survey measurements confirmed by software alignment
- validation of alignment constants by calibration of space drift time function

✓ Outer Tracker alignment software ready for data from first collisions