Alignment strategy for the ATLAS muon spectrometer

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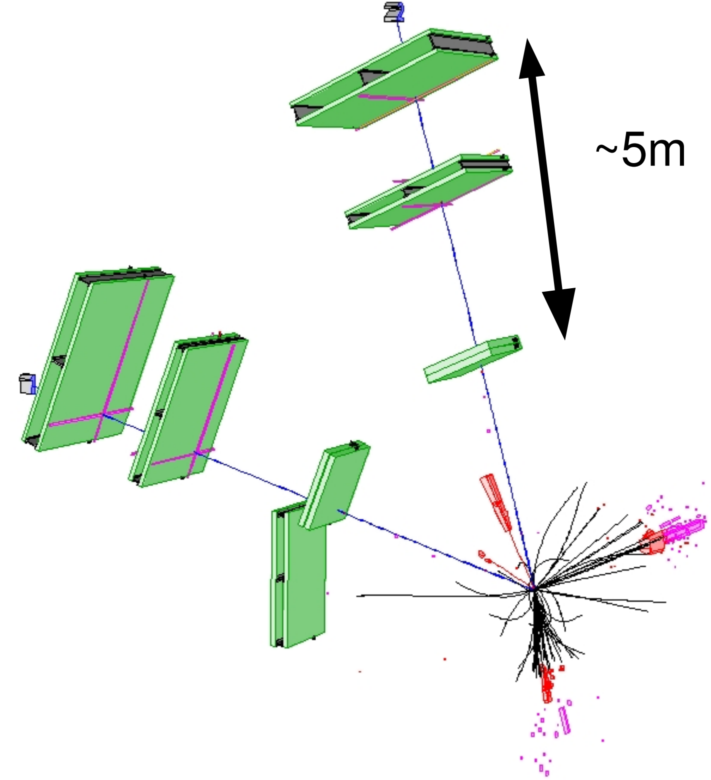
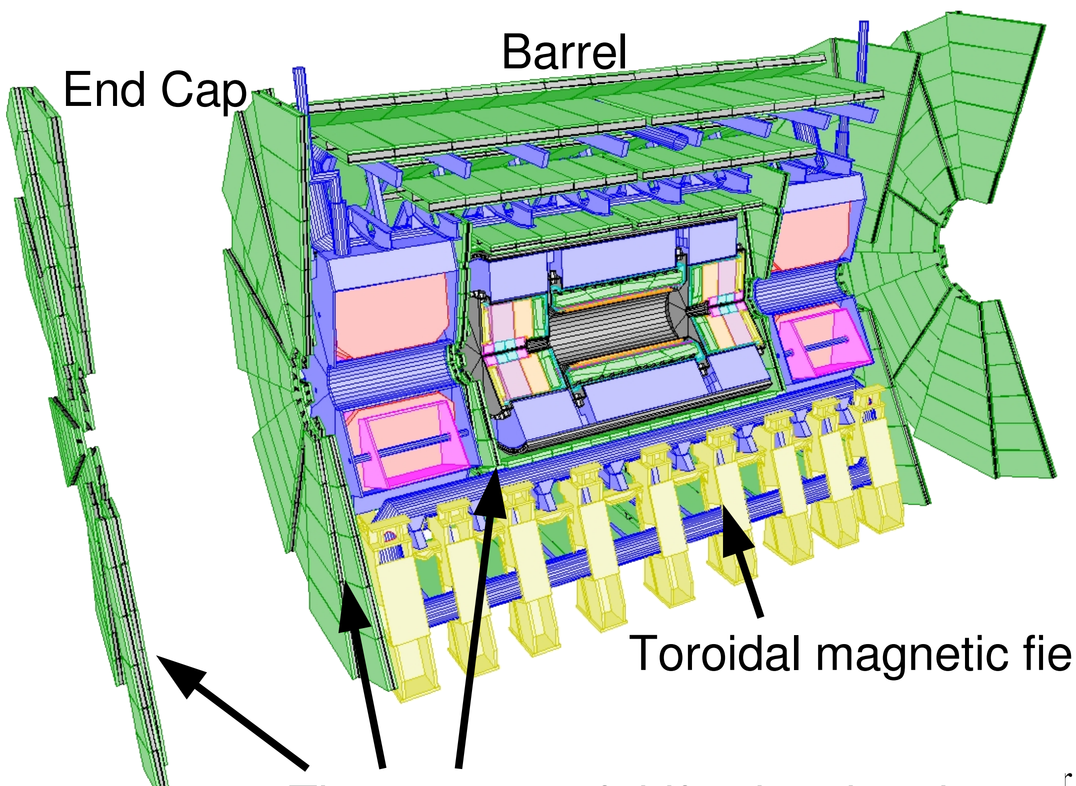
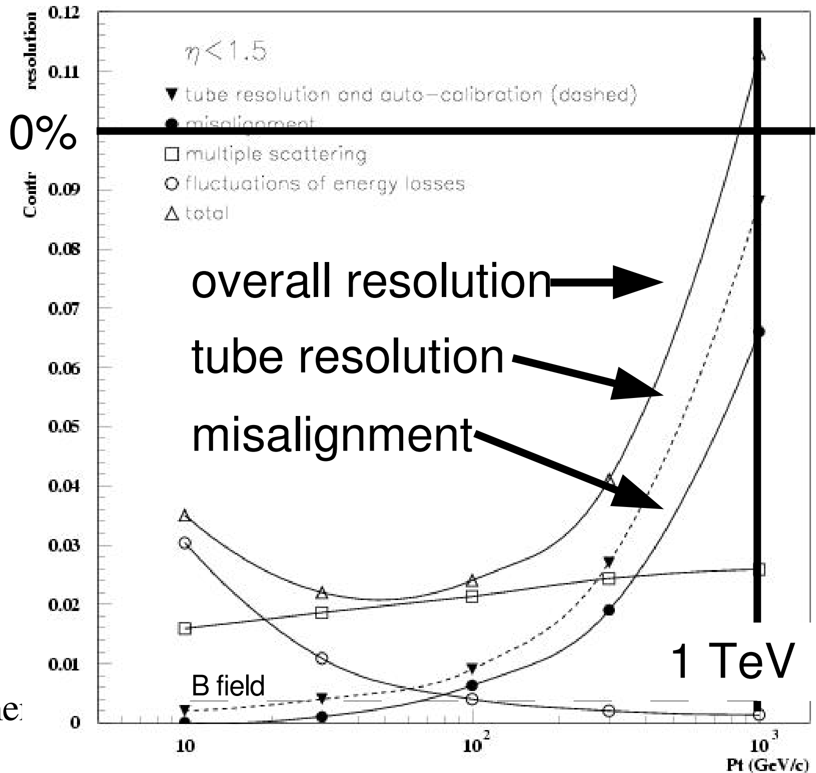
on behalf of the ATLAS muon alignment groups

The ATLAS muon spectrometer

- ⇨ Muon tracks measured in three points
- ⇨ Requirement: transverse momentum resolution of 10% at 1 TeV/c
  - ➡ Curvature: 400-700 μm
  - ➡ 10% resolution: 40 μm

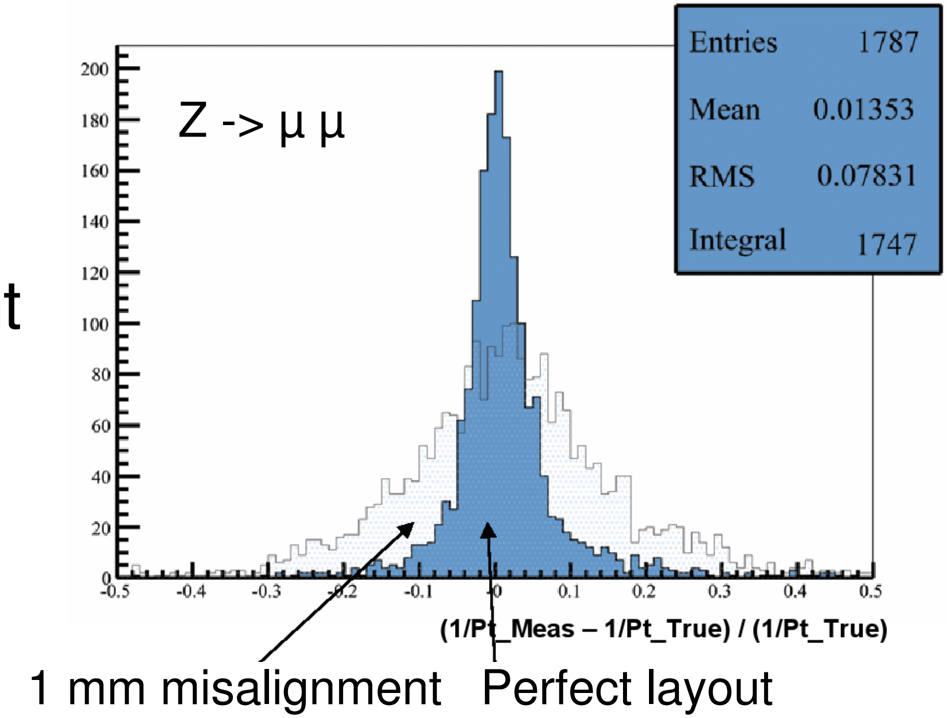


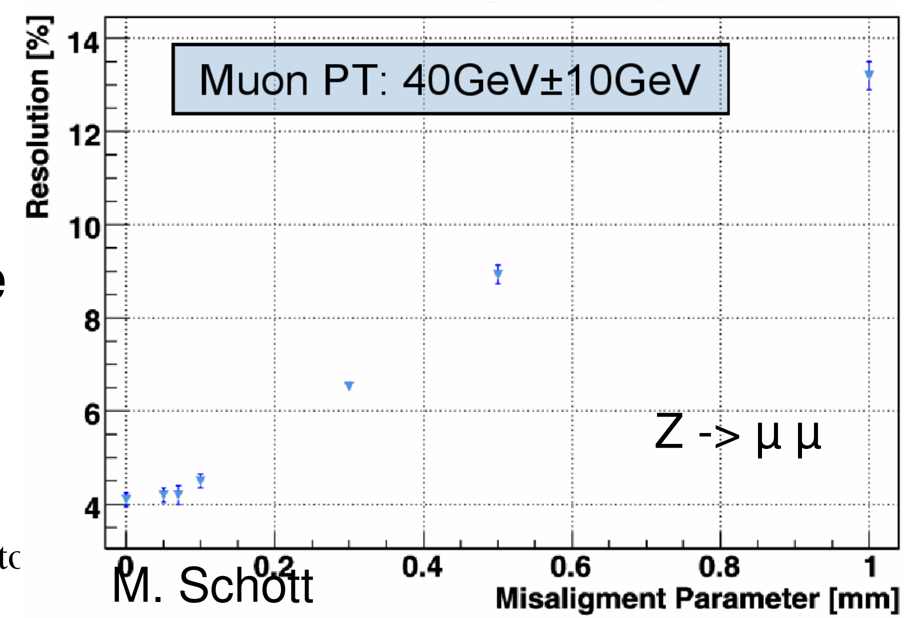




The misalignment

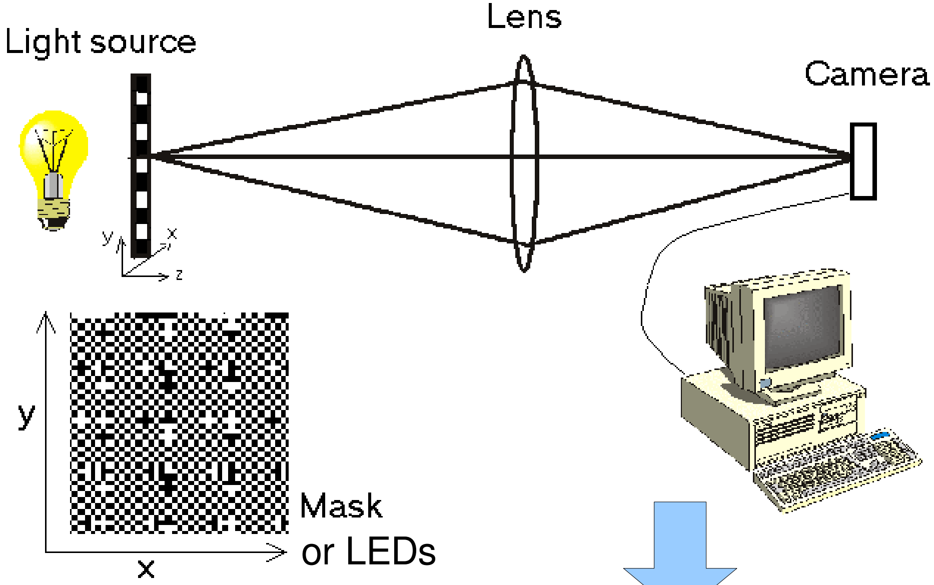
- Impact of misalignment:
  - huge loss on momentum resolution
  - foreseen with 1mm misalignment even for low momentum tracks
- Sources of misalignment:
  - Initial positionning of the chambers: 2 to 10 mm
  - Deformation of toroid due to weight (mm level)
  - Switch on B field (mm level)
  - Thermal expansion (< 1mm)
    - could evolve significantly in time
    - online monitoring is needed

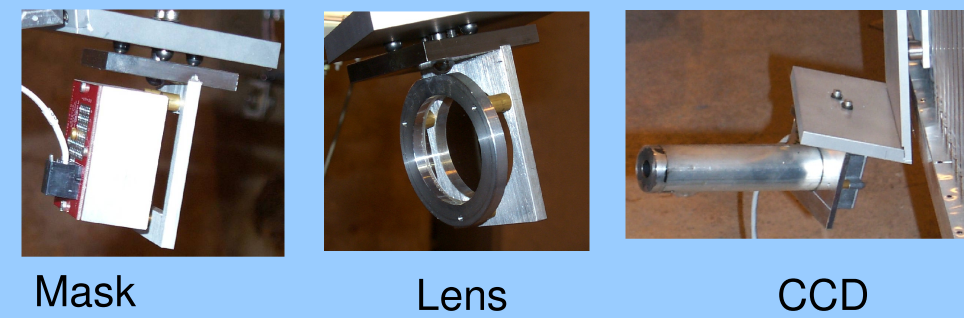


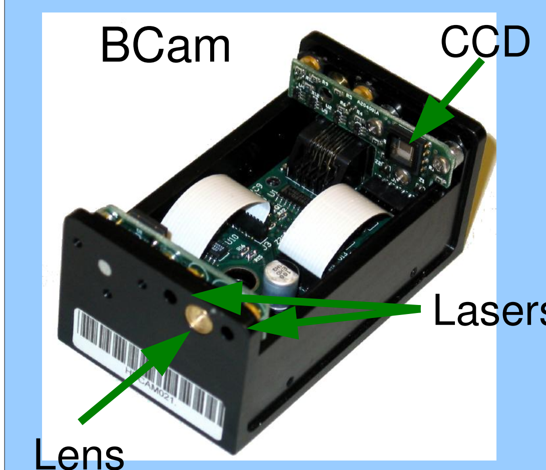


The optical alignment

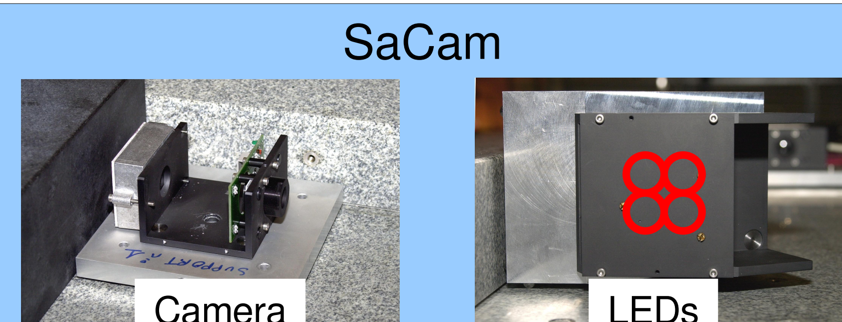
Optical elements attached to muon chambers





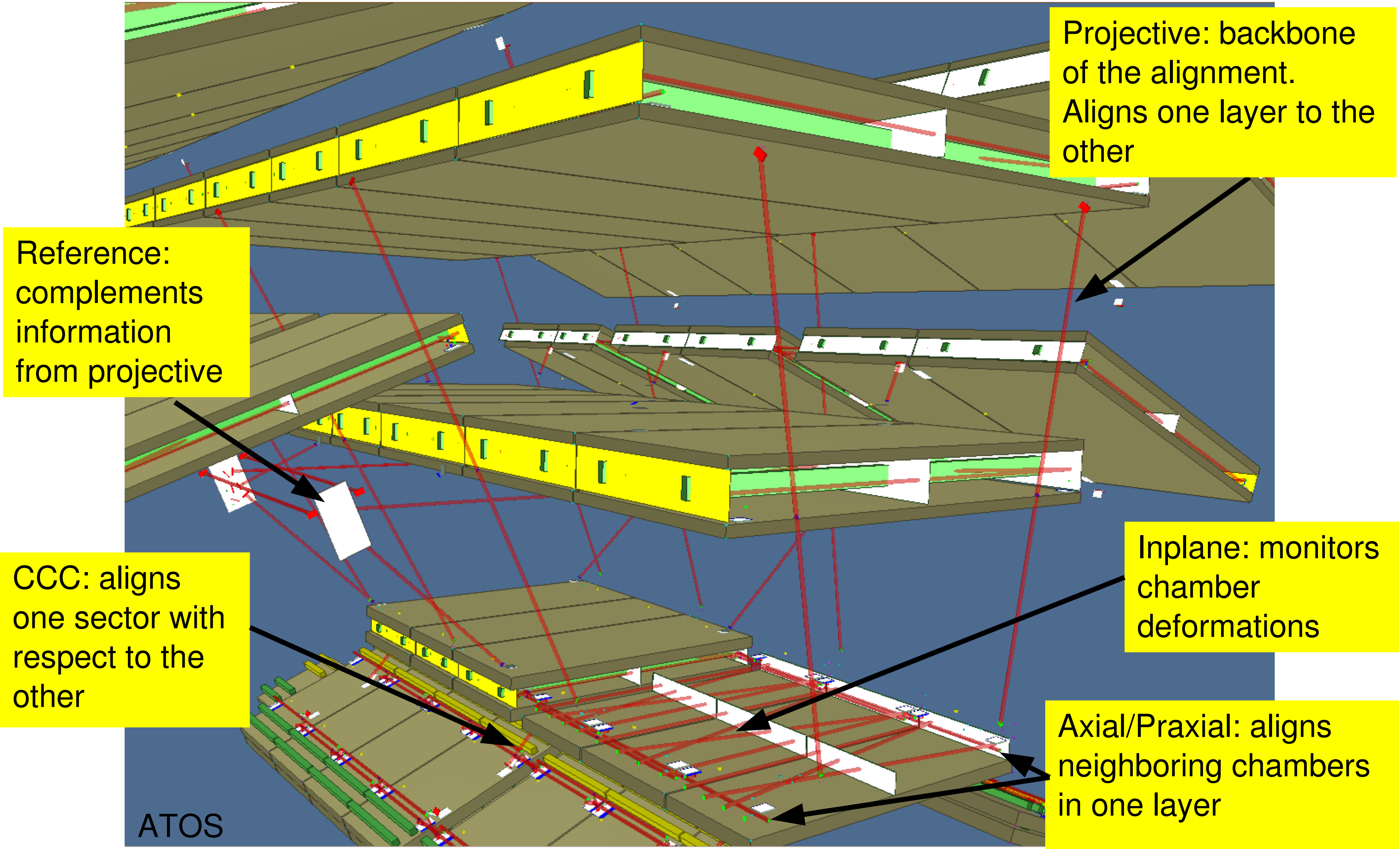


The main image parameters are:
- Translation in x
- Translation in y
- Rotation around optical axis
- Magnification

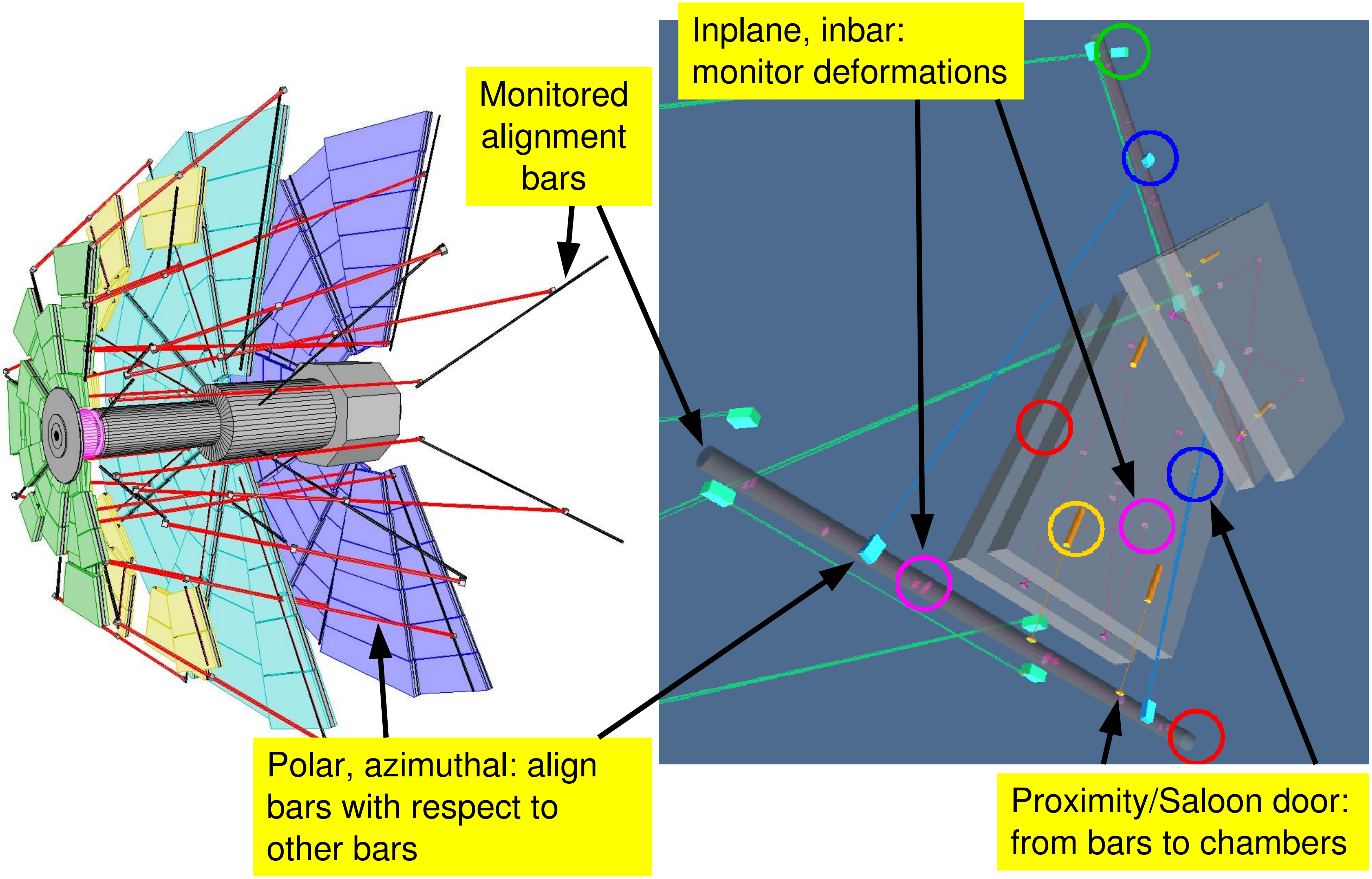


- Barrel: ~6000 optical lines
- End Cap: ~7000 optical lines
- Continuous readout (cycle=15 to 20 min)

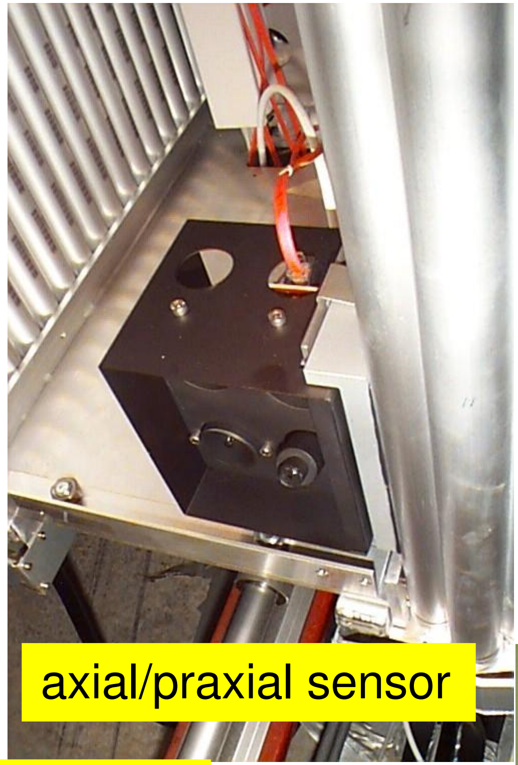
Layout of the optical sensors: barrel

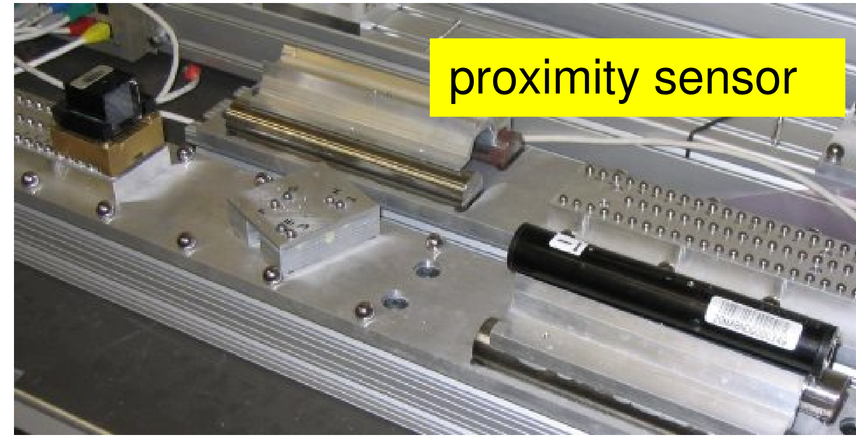


Layout of the optical sensors: end cap

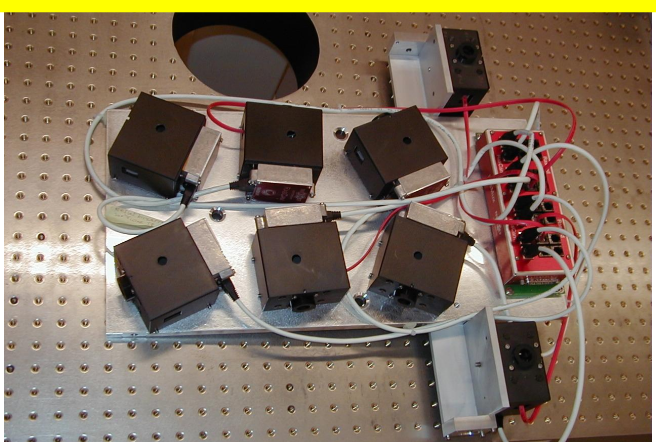


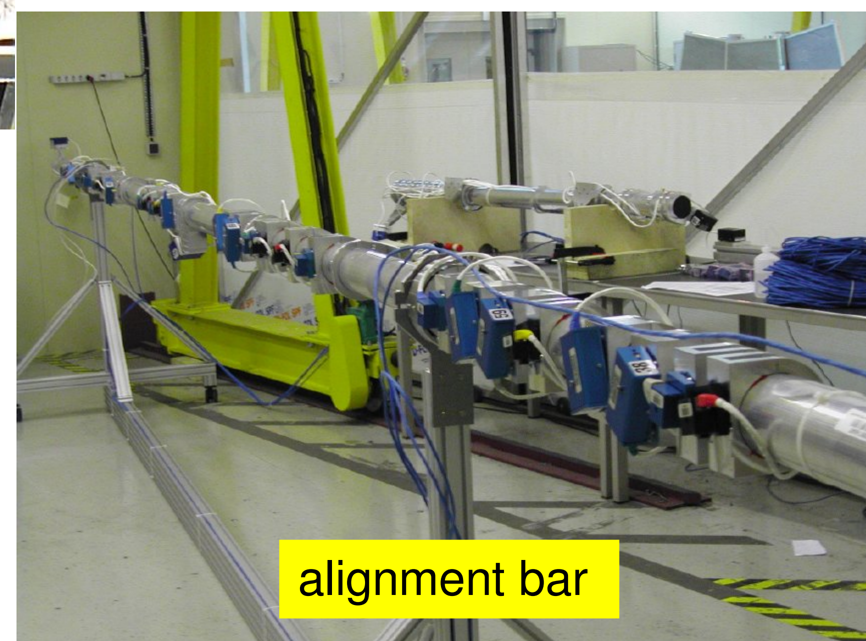
The optical sensors





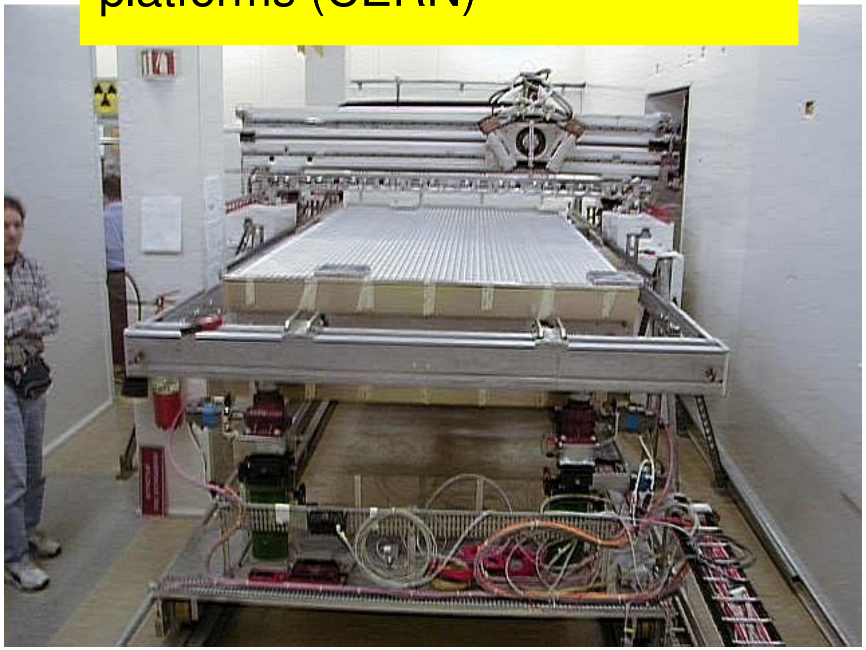
reference plate mounted on toroid

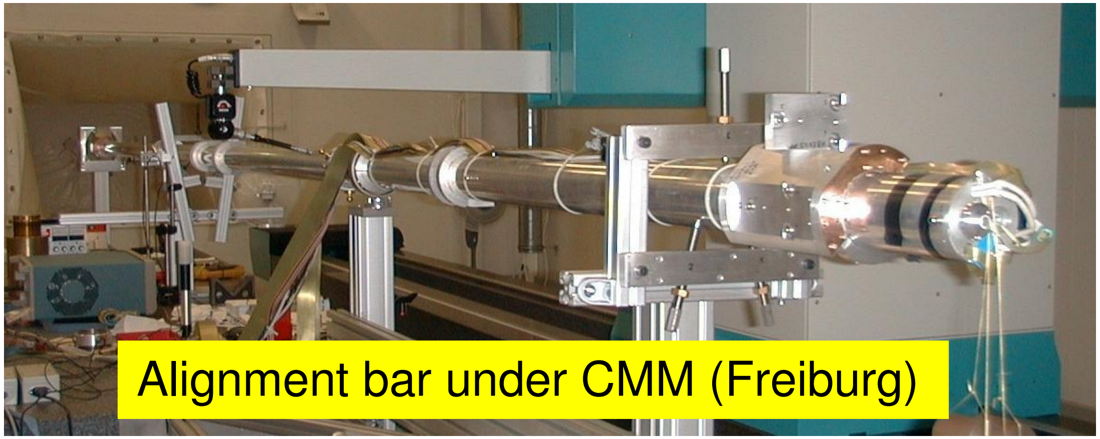


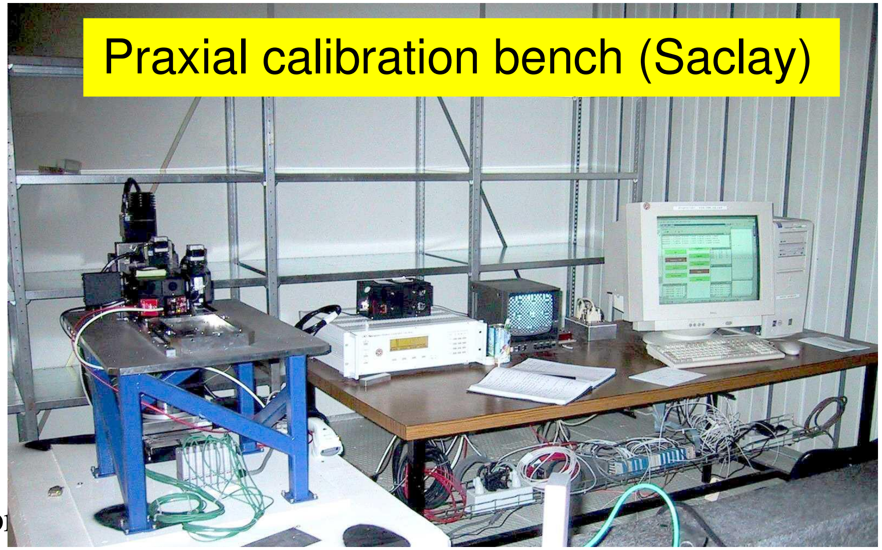


Calibrations

- Should know positions of optical elements w.r.t. chamber wires
- Measurements:
  - platform gluing on chambers
  - extension plates
  - alignment bars
  - optical sensors

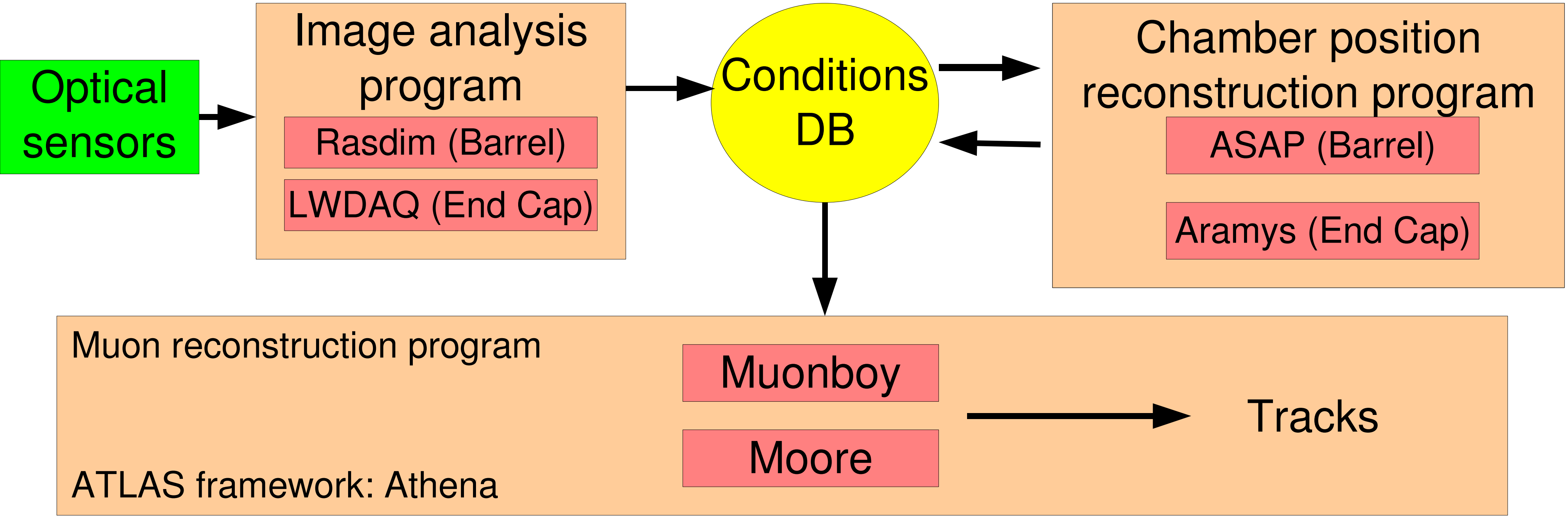

X-ray tomography: alignment platforms (CERN)


Alignment bar under CMM (Freiburg)


Praxial calibration bench (Saclay)


Projective calibration bench (Nikhef)

The alignment principle



- ⇨ 80% of ASAP and Aramys: detector description, calibrations
- ⇨ Parameters to determine:

	Position parameters	Deformation parameters	Number of elements	Number of parameters to determine
Barrel chamber	6	8	708	~10000
End cap chamber	6	9	544	~8200
End cap bar	6	9	96	~1400

Algorithm

Absolute alignment:

$$\chi^2 = \sum \frac{\left(x_{model} - x_{meas}\right)^2}{\sigma^2}$$

- compare measured sensor parameters with estimated ones
- x_{calc} is deduced from detector description and calibrations
- very sensitive to bad calibrations

Relative alignment:

$$\chi^2 = \sum \frac{\left(\left(x_{model} - x_{model}^{ref}\right) - \left(x_{meas} - x_{meas}^{ref}\right)\right)^2}{\sigma^2}$$

- assume a reference time is available where knowledge of the geometry is very accurate
- subtract the measured and estimated sensor parameters from this reference
- much less sensitive to bad calibrations

⇨ Relative alignment: extrapolate geometry w.r.t. a given time reference

⇨ Absolute alignment: does not need the time reference

⇨ Warning: both alignments are internal alignments

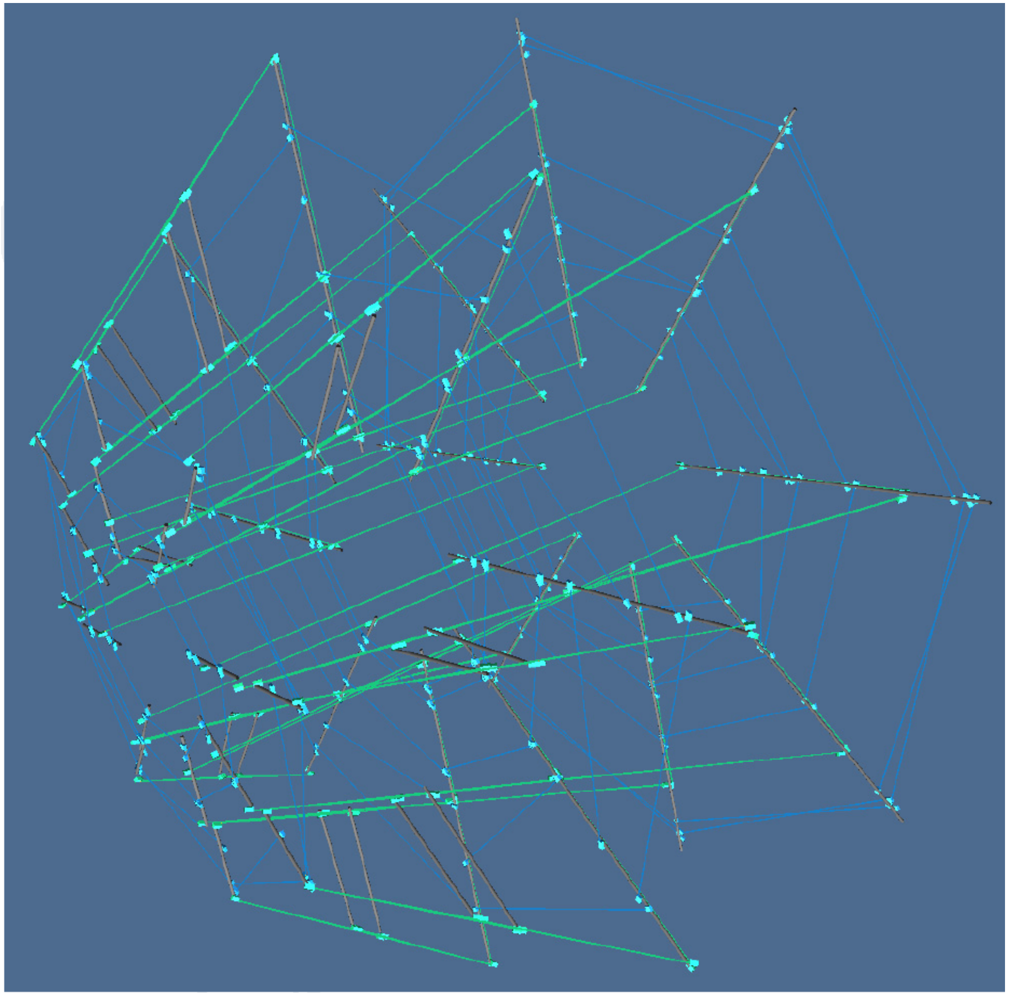
➡ no optical connection to inner tracker or beam pipe

⇨ ASAP and Aramys both implement absolute and relative modes

Note: track-based alignment is absolute alignment

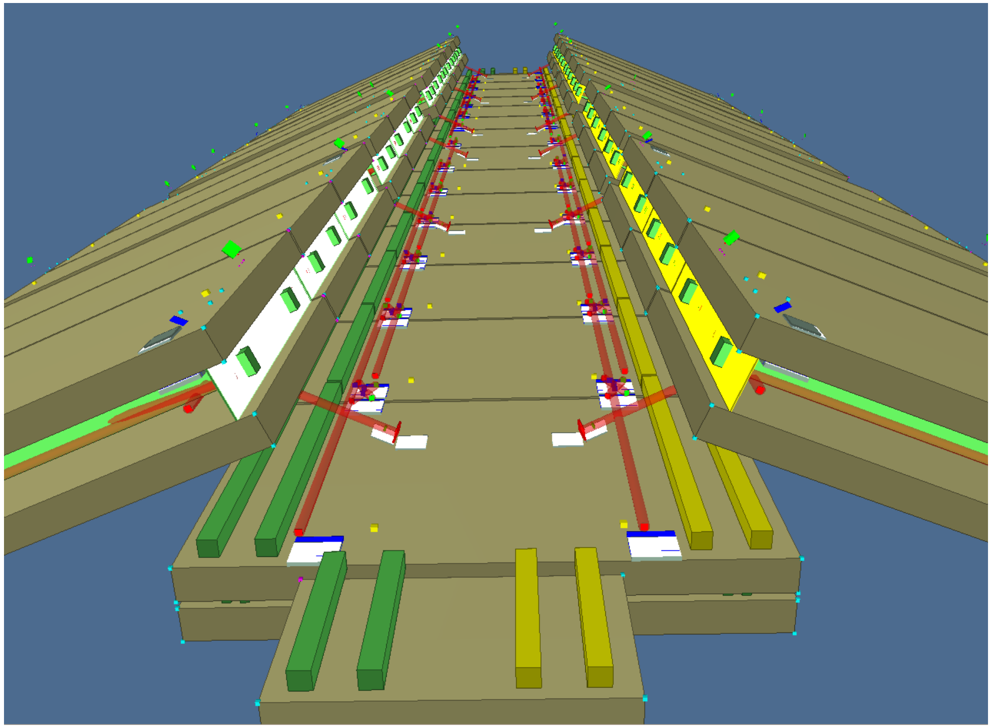
Algorithm

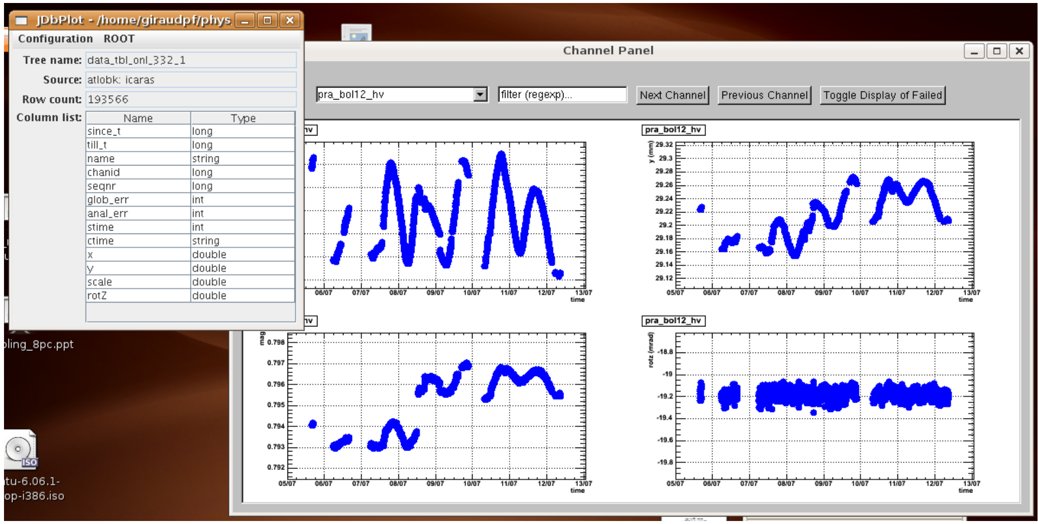
- ⇨ Aramys: end cap
  - ➡ minimization using Minuit.
  - ➡ implementation of factorization:
    - ☞ bar positions are fitted first
    - ☞ then chamber positions with respect to bars
    - ☞ takes advantage of the particular hardware
  - ➡ 4 minutes to fit the 2 end caps
- ⇨ ASAP: barrel
  - ➡ fast linear least square fitter
  - ➡ hardware does not allow factorization easily
  - ➡ problem to be investigated



Tools

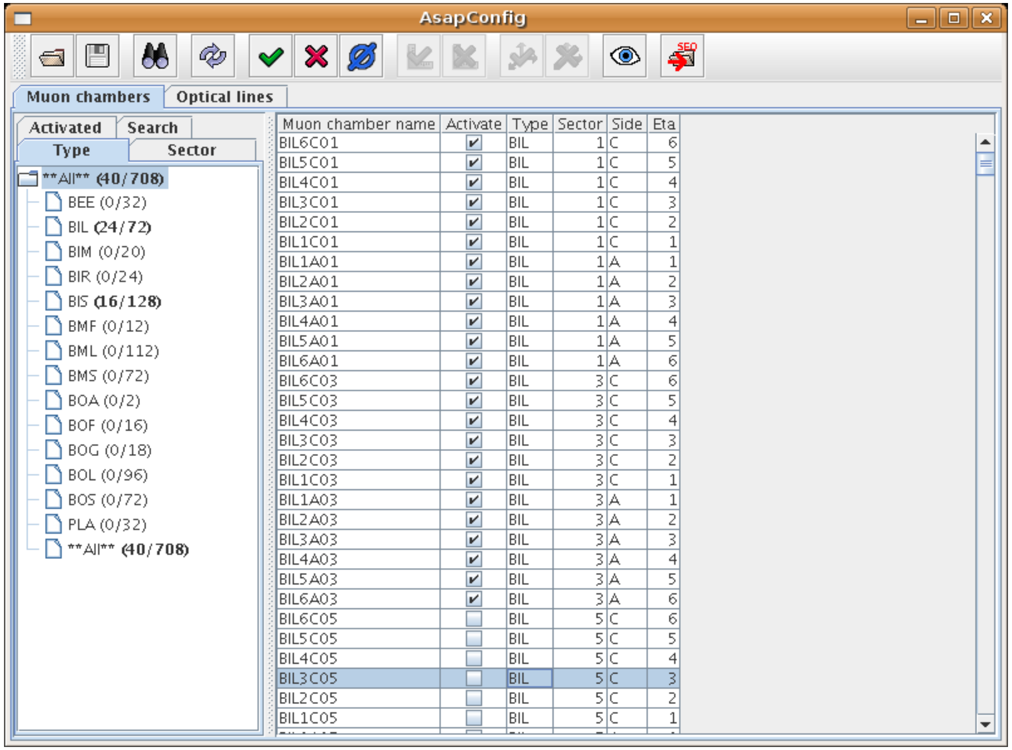
- ⇨ ATOS: 3D viewer
  - ➡ openGL
  - ➡ interactive navigation
  - ➡ informations/calculations about selected elements is displayed
  - ➡ debugging the detector description
- ⇨ JdbPlot: database browser
  - ➡ java
  - ➡ select database parameters
  - ➡ selection criteria (e.g. date)
  - ➡ gets ROOT tree, runs ROOT macro
  - ➡ monitoring





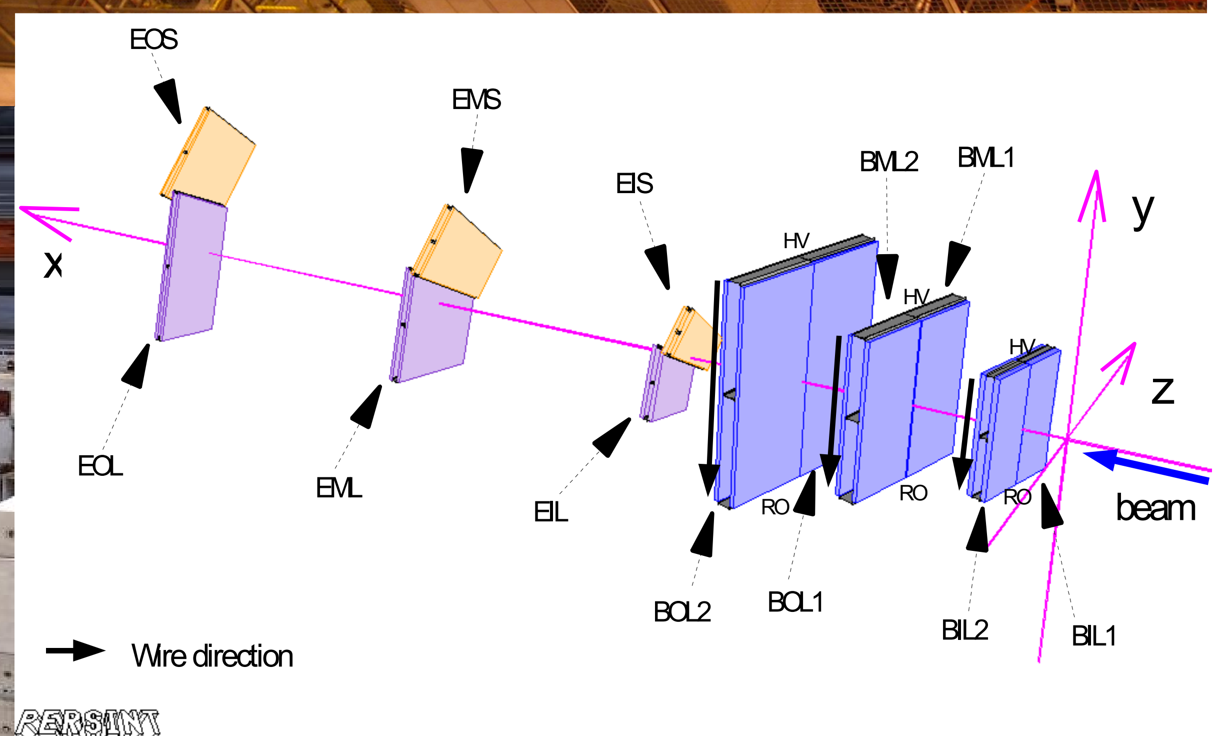
Tools

- ⇨ Ease the description of the alignment, in ROOT/C++:
  - ➡ Element class: handles trees of mechanical objects
  - ➡ XML format describing any Element trees
- ⇨ asapConfigGUI (java):
  - ➡ select subset of chambers and optical lines
  - ➡ save xml file used for 3D view or ASAP reconstruction
- ⇨ Alignment Application Server
  - ➡ check status, configure, run online alignment, via web
  - ➡ CORBA/java
  - ➡ prototype ready

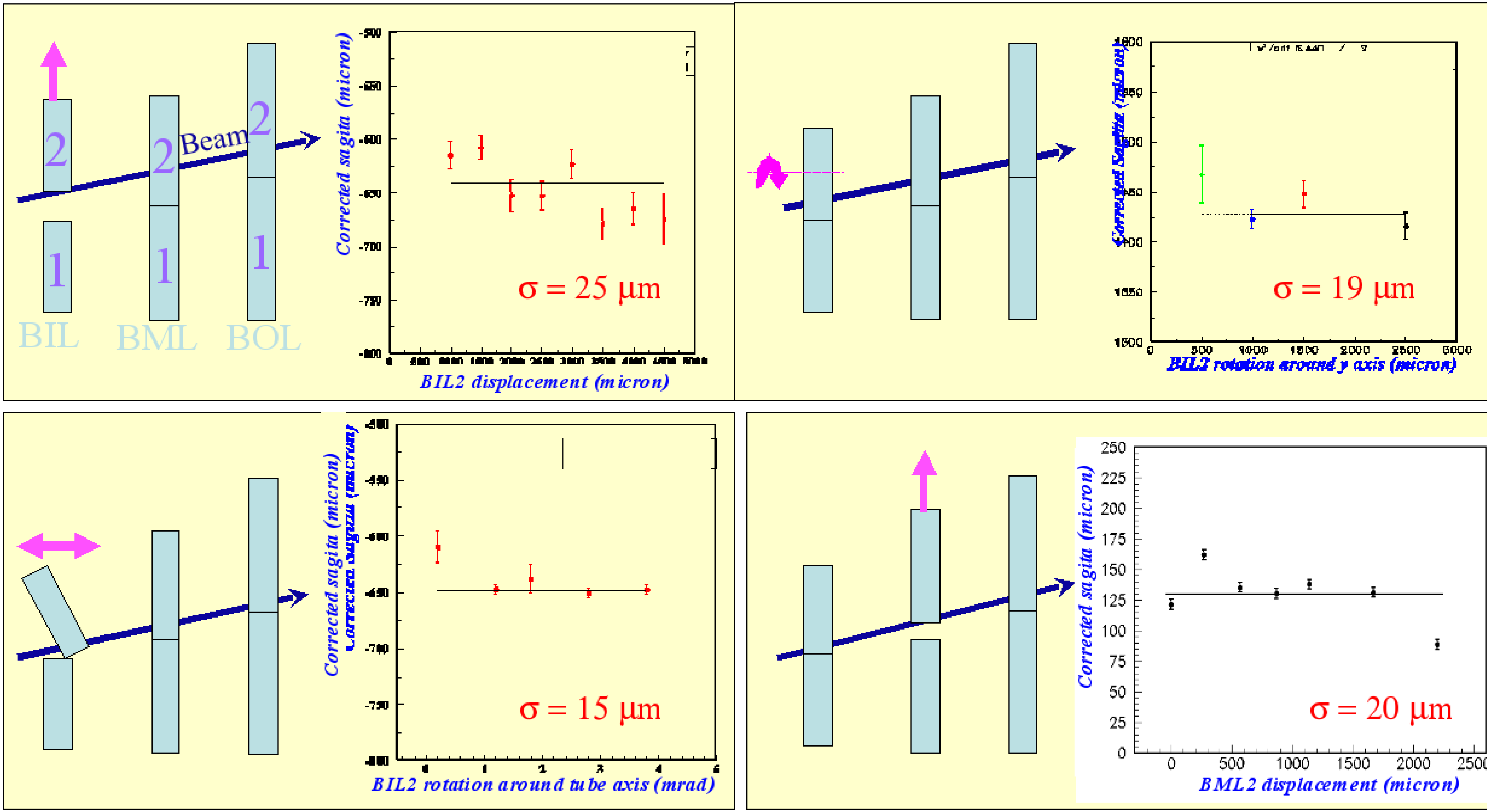


Validation: H8 test beam

- 6 barrel and 6 end-cap chambers were tested in beam (~1% of Atlas)
- 2002-2004
- Massive debugging of hardware and software



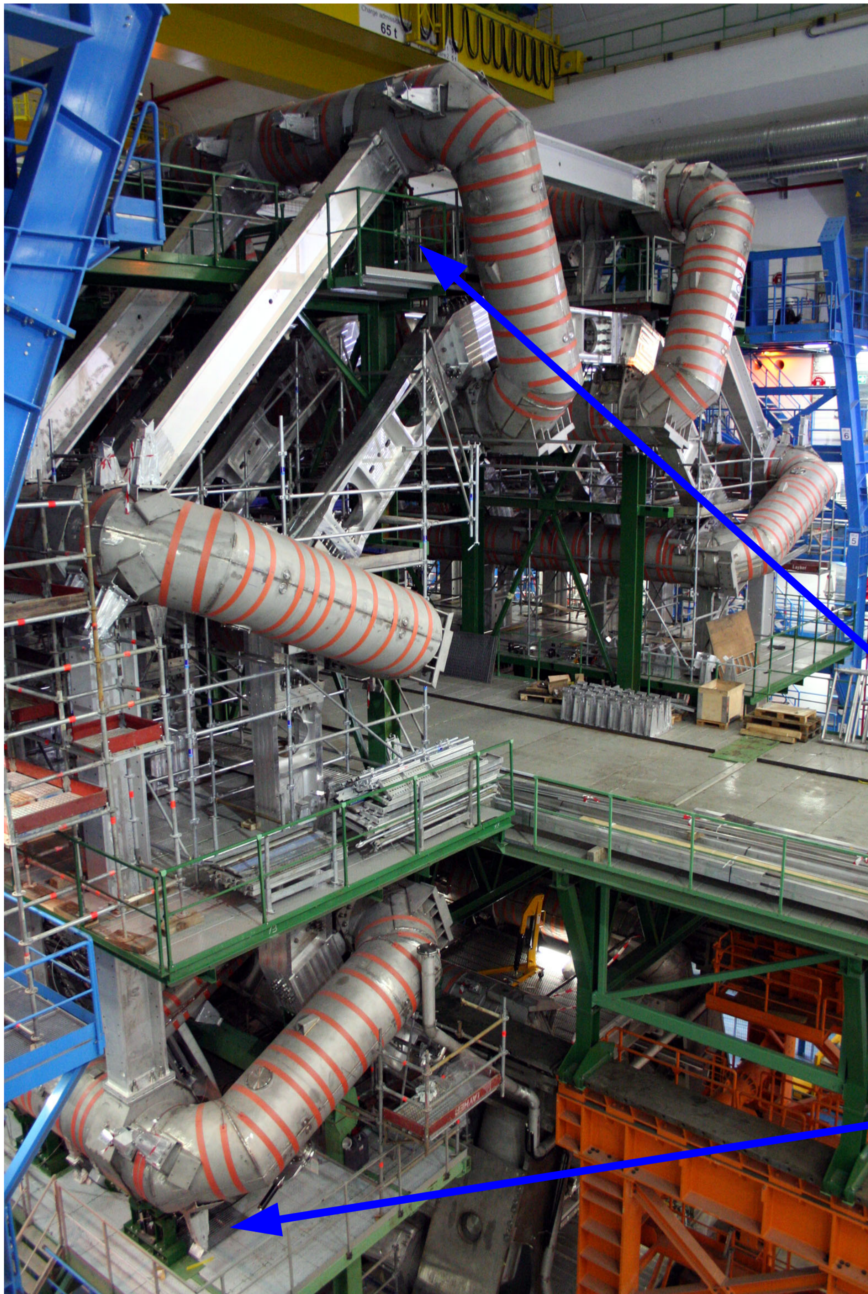
Test beam results



⇨ Alignment successful at 30μm (relative mode)

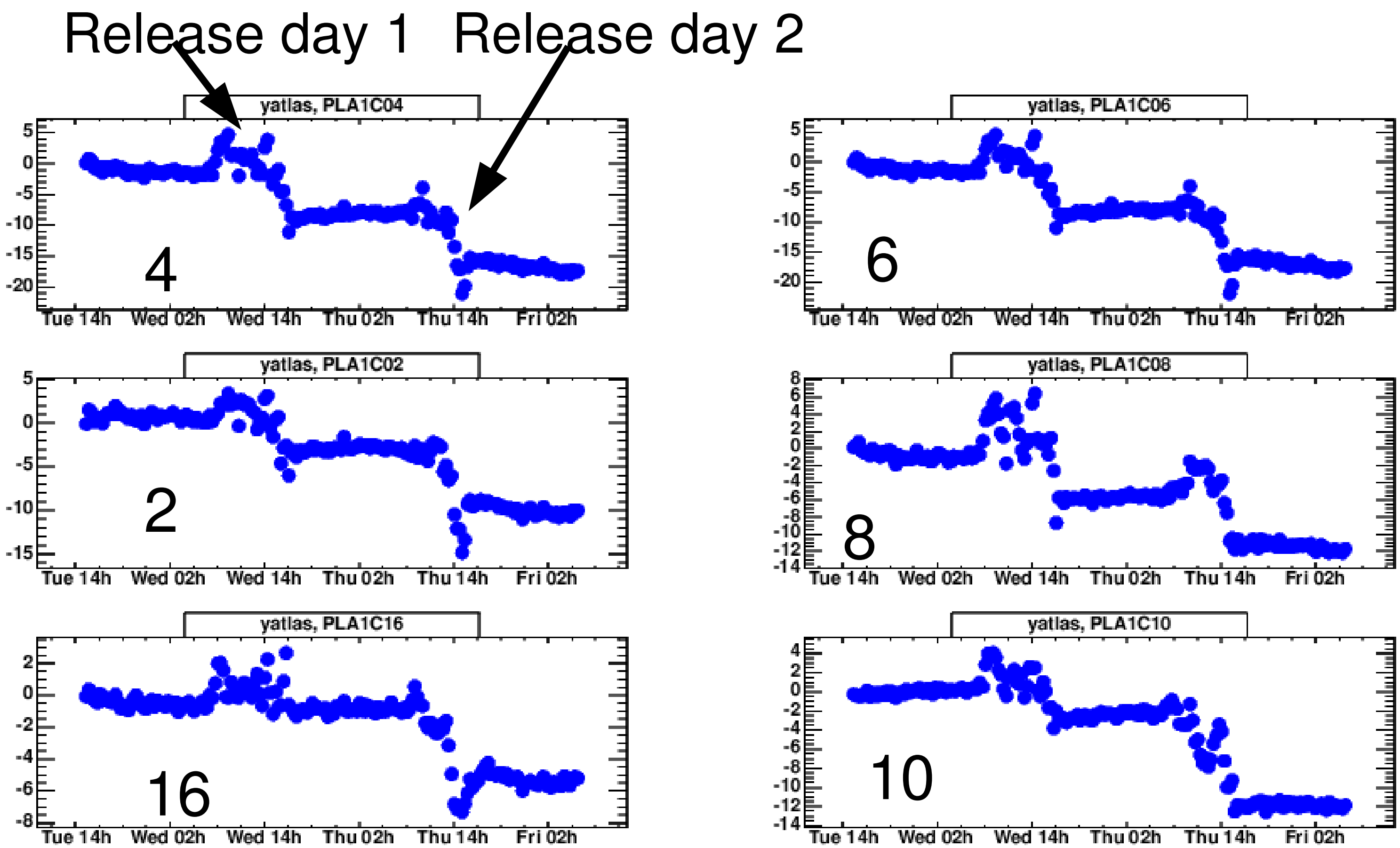
⇨ Absolute alignment successful at 120μm in end cap

Validation: toroid release



- ⇨ Toroid was supported by jacks during its assembly
- ⇨ Test for the alignment: monitor the toroid deformation during the release of the jacks

Toroid release results



⇨ Deformation found consistent with calculation and survey

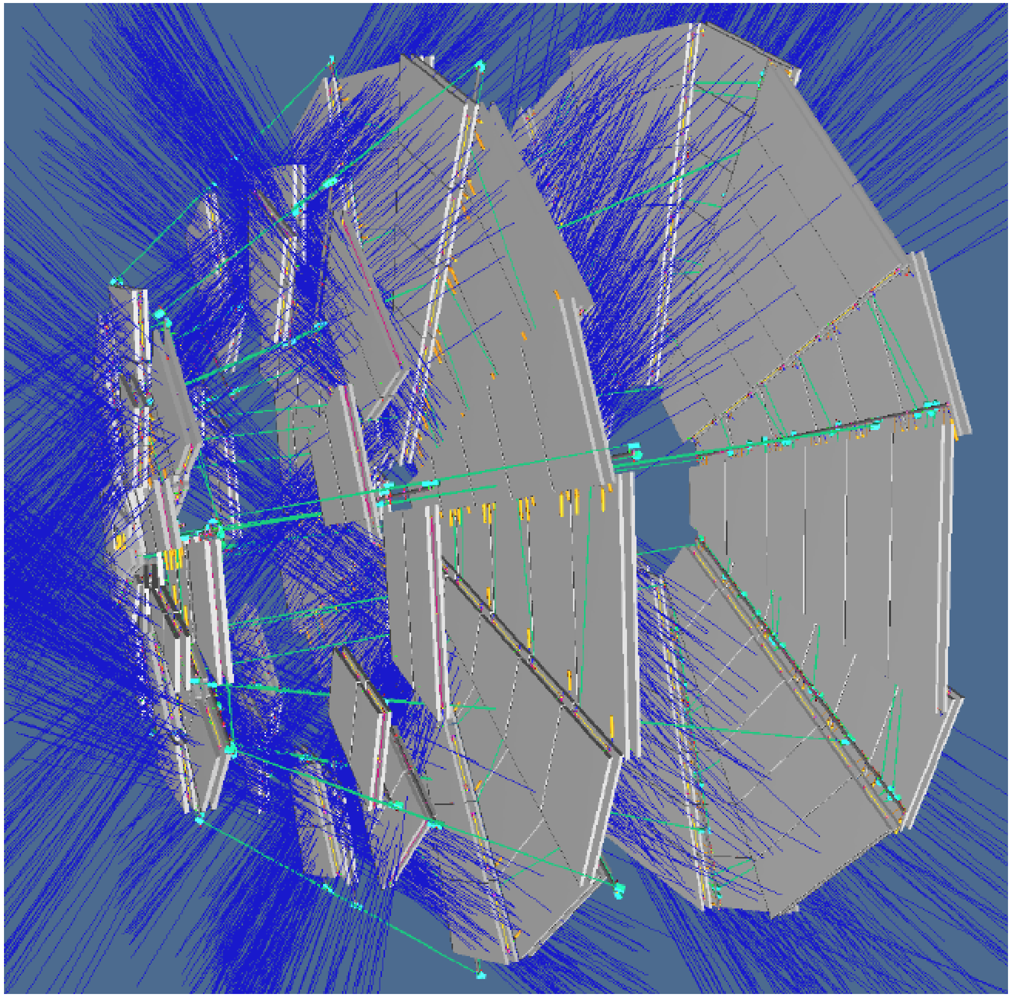
➡ ASAP: 17.6 mm

➡ geometers: 17 mm

➡ prediction (finite element): 18 mm

Alignment with straight tracks

- Several runs with straight tracks are foreseen:
  - cosmic ray runs: some chambers poorly illuminated
  - beam halo: end-cap mainly
  - run with:
    - toroid off
    - solenoid on
    - high momentum tracks selected using inner tracker
- Purpose:
  - debugging the optical alignment
  - reference geometry of the relative alignment

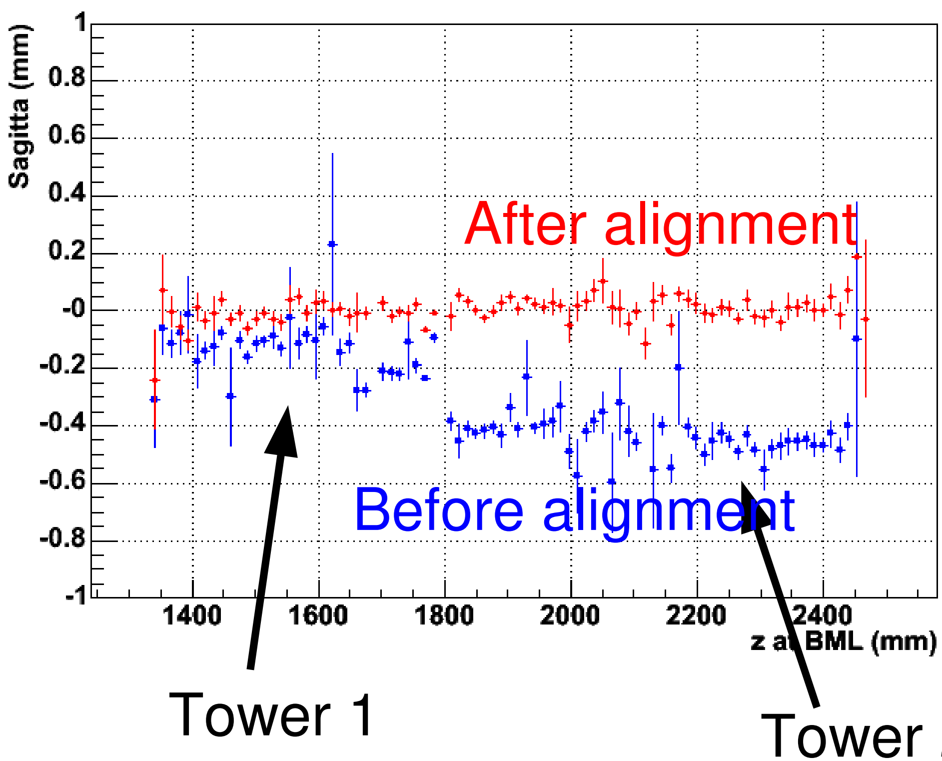


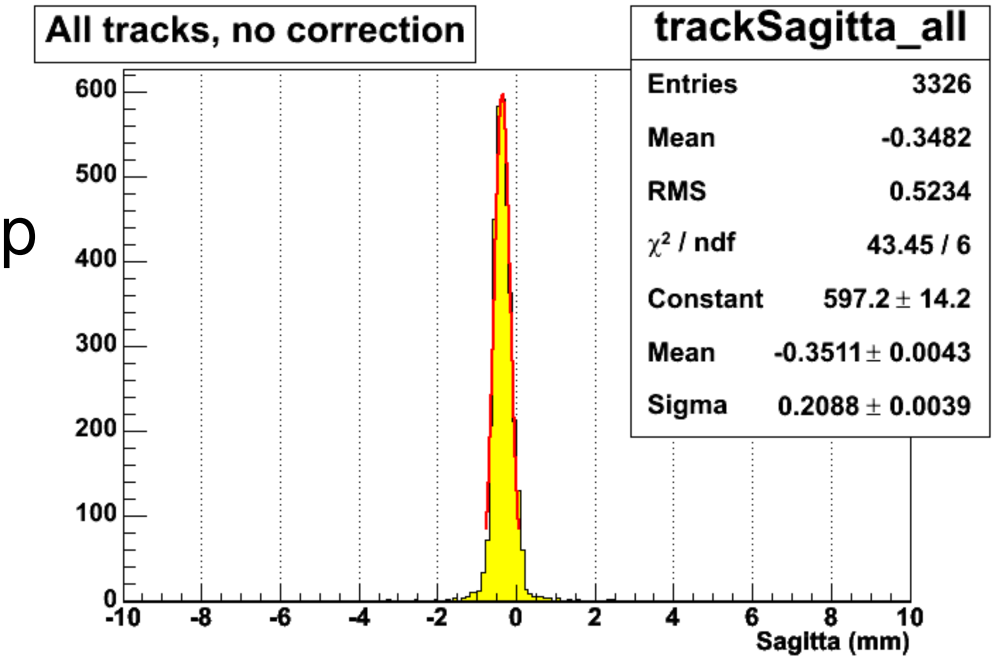
Endcap illuminated with cosmic rays

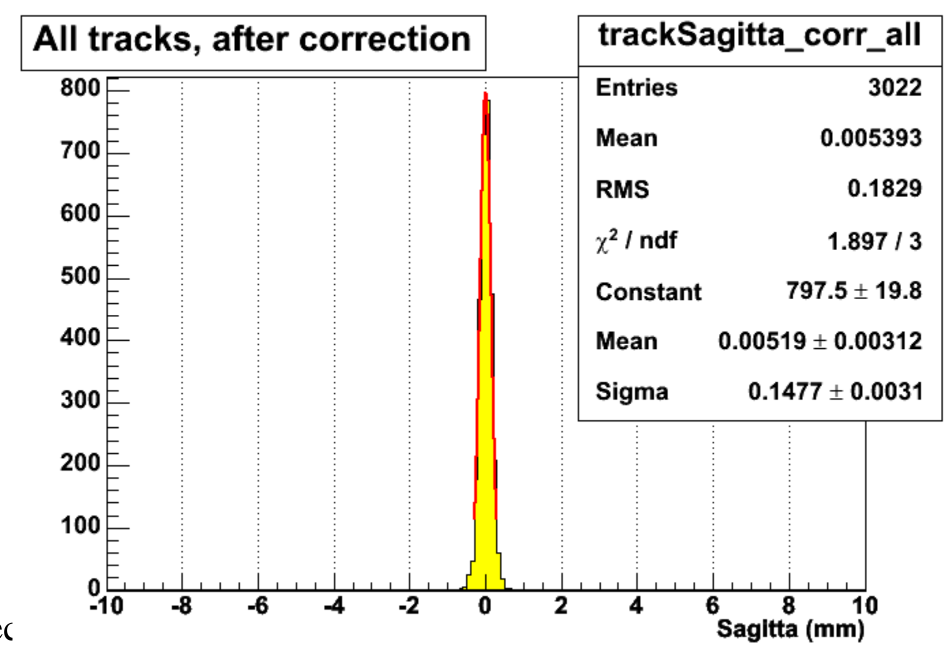
Alignment with straight tracks: test beam

- First trials at test beam
- Core: fast straight track fitter
  - track refit each minimization step
- Precision foreseen: < 20µm

$$\chi^2(chamber\ positions) = \sum_{tracks} \hat{\chi}^2_{track}$$

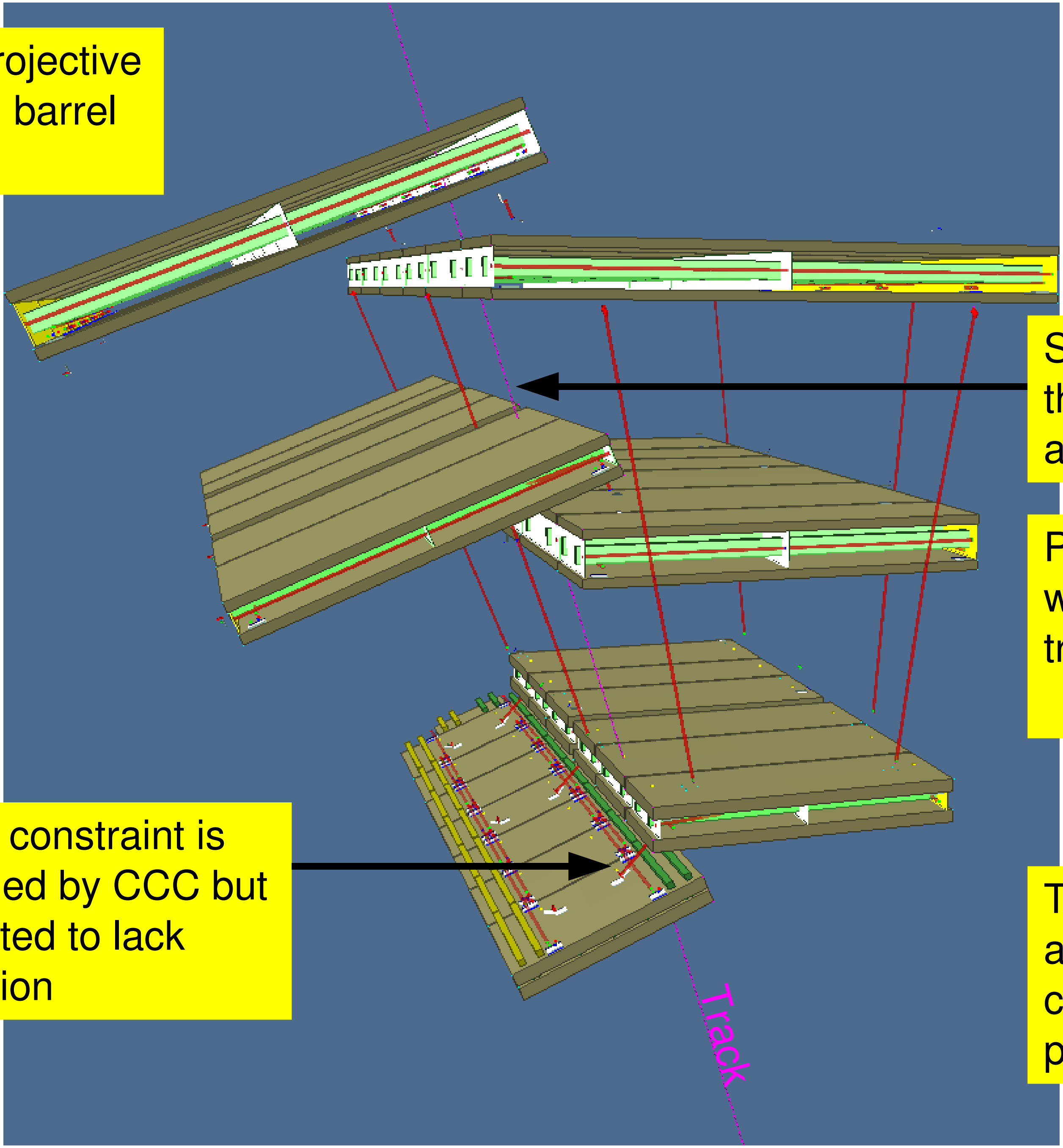






Some deficiencies of the optical alignment

Example: no projective sensor in small barrel sectors



Solution: use tracks in the overlap of small and large sectors

Perform a combined fit with optical and tracking information

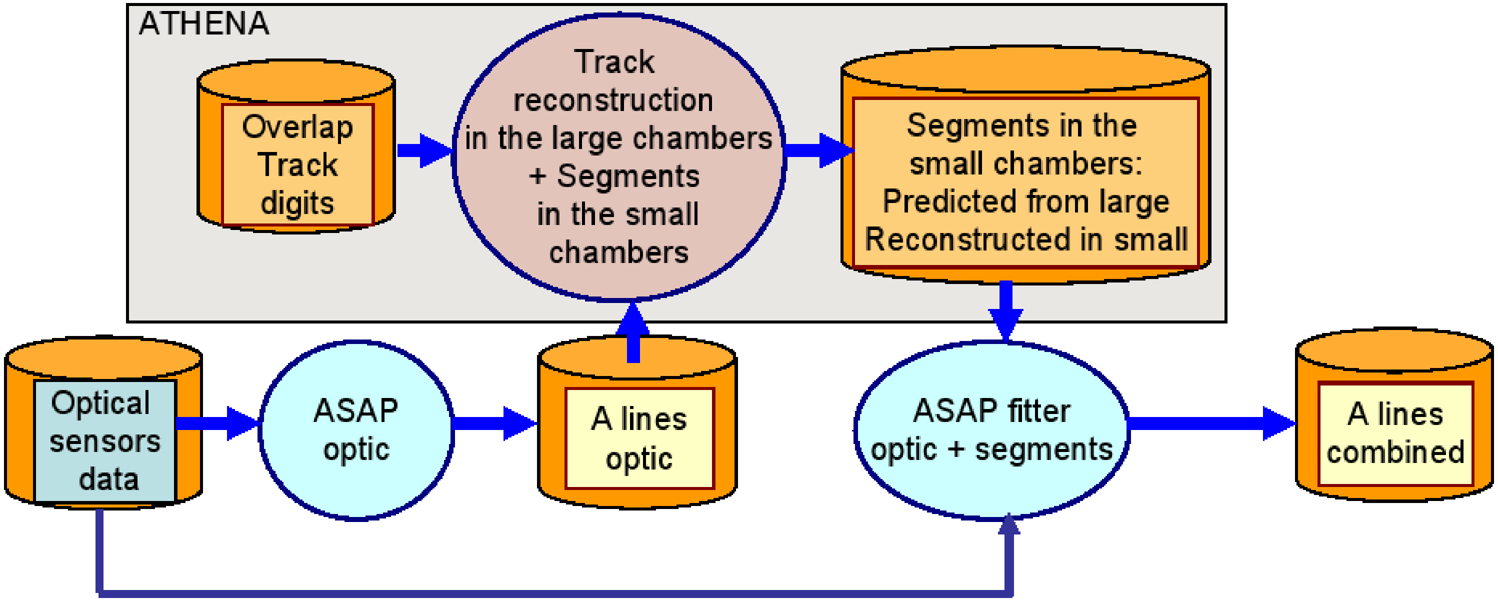
$$\chi^2 = \chi^2_{optical} + \chi^2_{tracks}$$

Some constraint is provided by CCC but expected to lack precision

This track-based alignment is performed continuously during physics runs

Track-based alignment in B-field

- TODO list:
  - flag interesting events in trigger
  - send events to a computing farm and dump information for the alignment
  - perform the optical+track combined fit
- Should perform this fit in several locations of the spectrometer (barrel and end-cap)
- Computing needs: ~50 PCs being set up in Munich Tier 2



Conclusion

- ⇨ The alignment of the Atlas muon spectrometer should be known at 30µm
- ⇨ Based mainly on optical sensors
  - ➡ Large hardware and software developments
    - ☞ many different types of systems
    - ☞ online operation
  - ➡ Succeeded validations
    - ☞ test beam
    - ☞ toroid release
- ⇨ Part of the alignment is based on tracks
  - ➡ Straight tracks for the commissioning
    - ☞ started to be understood at test beam
  - ➡ Tracks in B field during normal operation
    - ☞ complete problem to be investigated