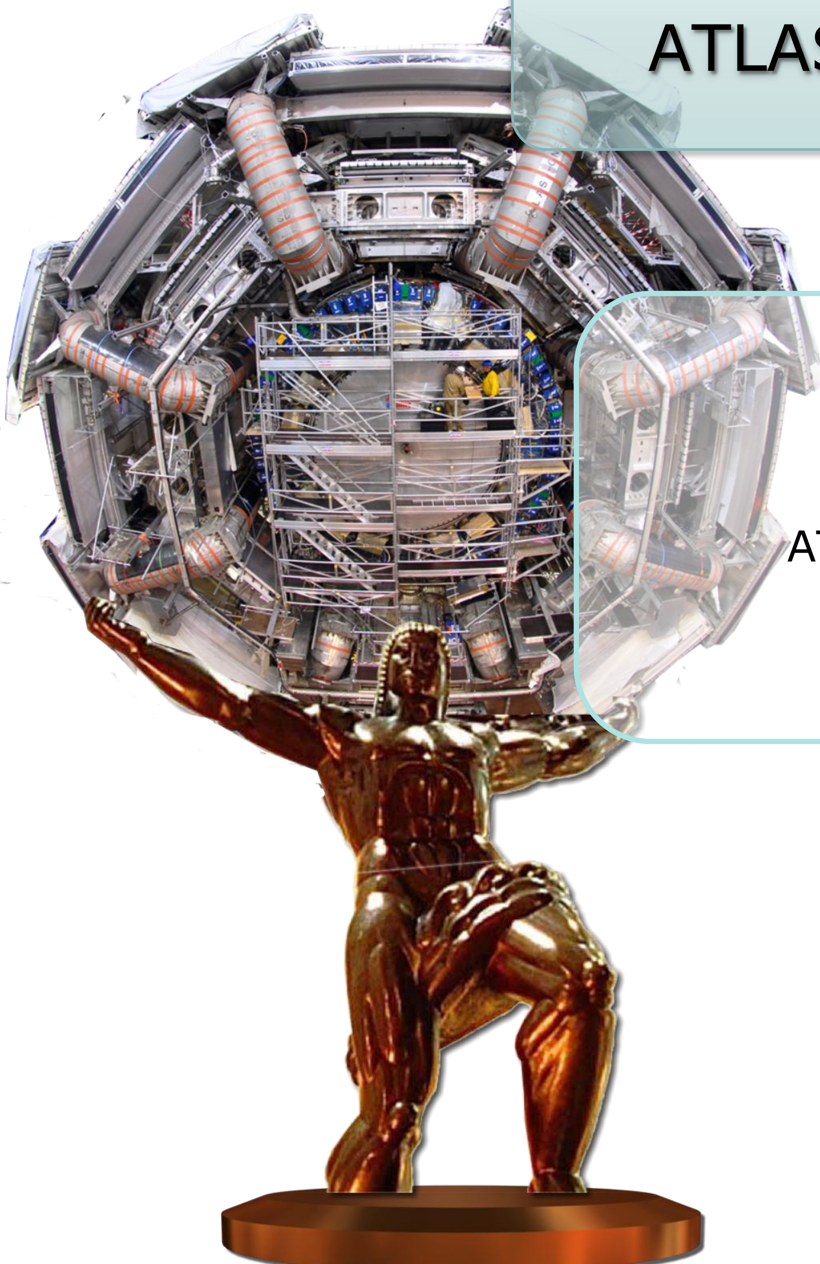
# ATLAS Inner Detector Alignment




Tobias Göttfert – MPI für Physik

on behalf of the
ATLAS Inner Detector alignment group

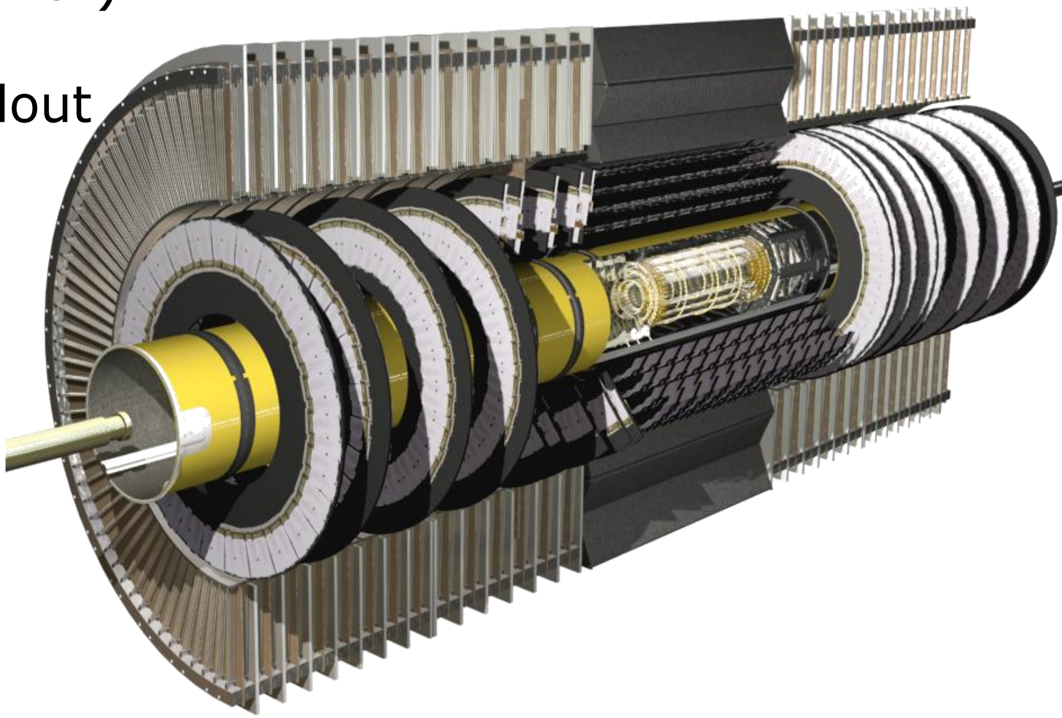

EPS HEP conference 2007
Manchester, 20.7.07


Max-Planck-Institut
für Physik
(Werner-Heisenberg-Institut)

# The ATLAS Inner Detector

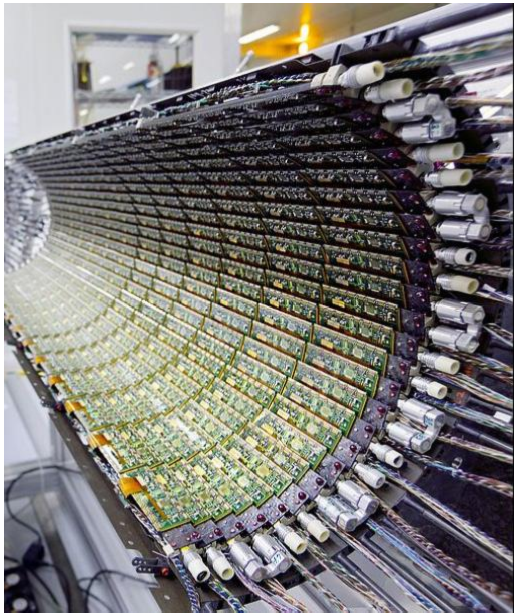
Three subdetectors in barrel and two endcaps:

- Pixel
  - silicon modules with time-over-threshold readout
  - pixel size 50 · 400 μm,
    resolution ~14 · ~115 μm
- SCT (SemiConductor Tracker)
  - double layer silicon strip modules with binary readout
  - pitch 80 μm,
    resolution ~23 μm
- TRT (Transition Radiation Tracker)
  - drift straw tubes with gold wire
  - 4 mm diameter,
    resolution ~170 μm

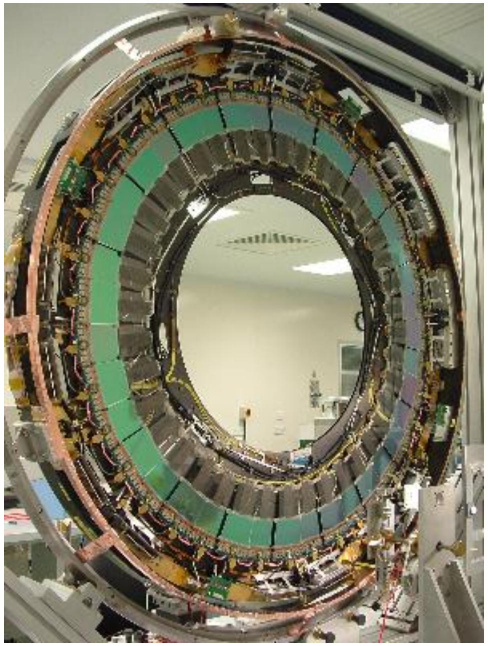


# The ATLAS Inner Detector

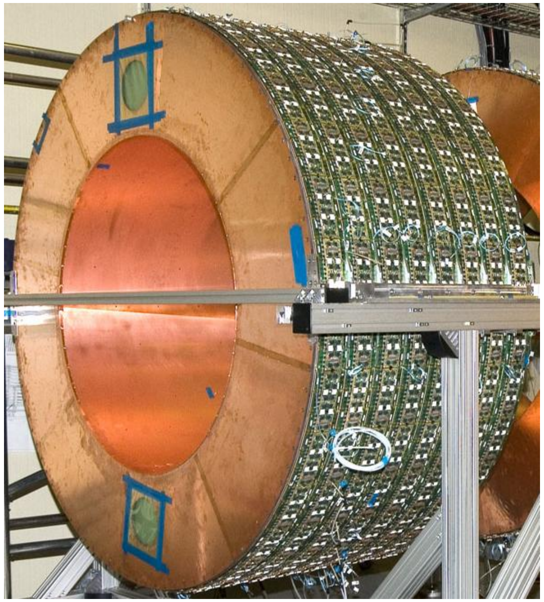
- Inner Detector has 1744 Pixel modules, 4088 SCT modules and 544 TRT modules (even more individual wafers and straw tubes)



Pixel barrel



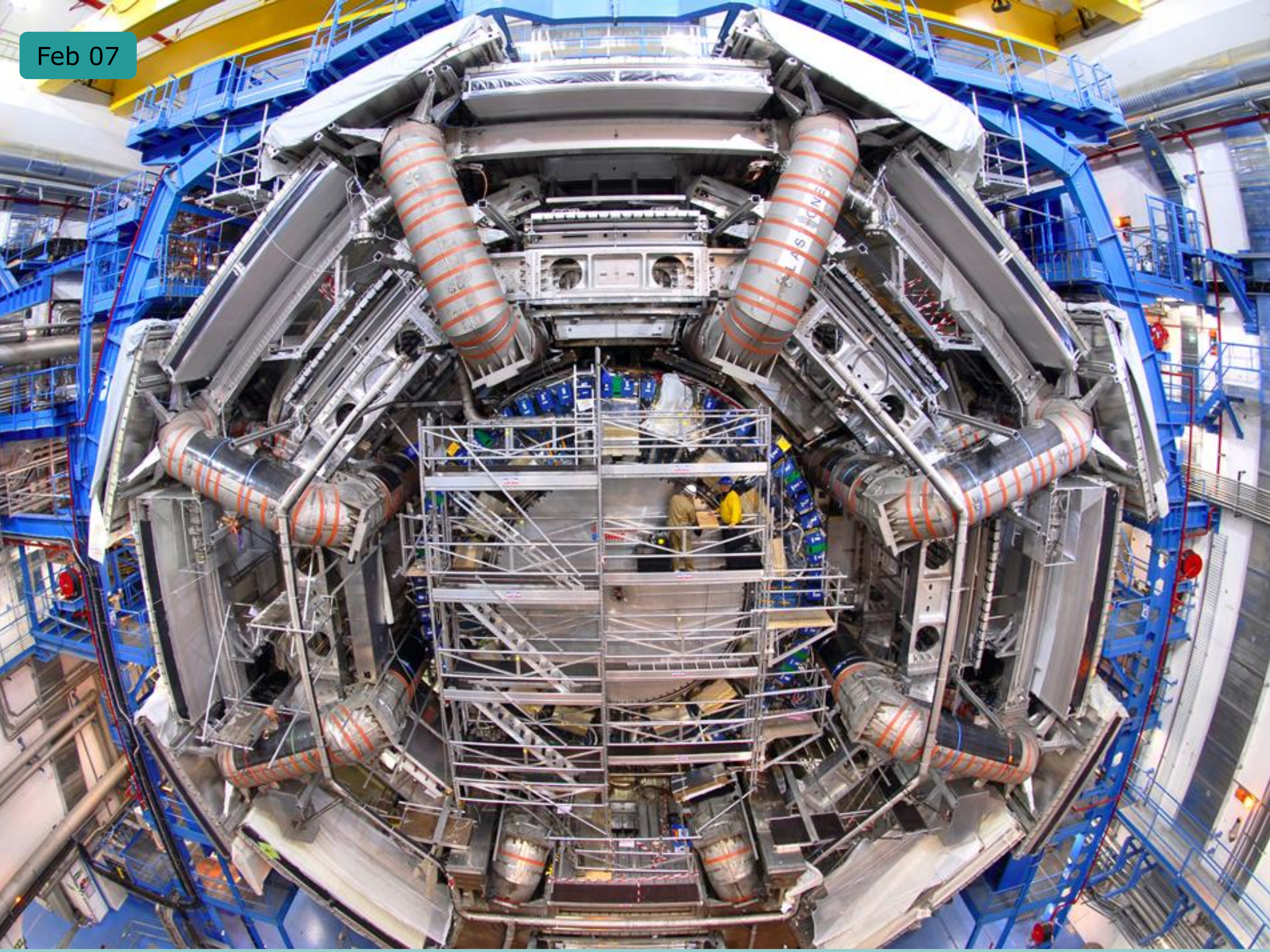
SCT endcap



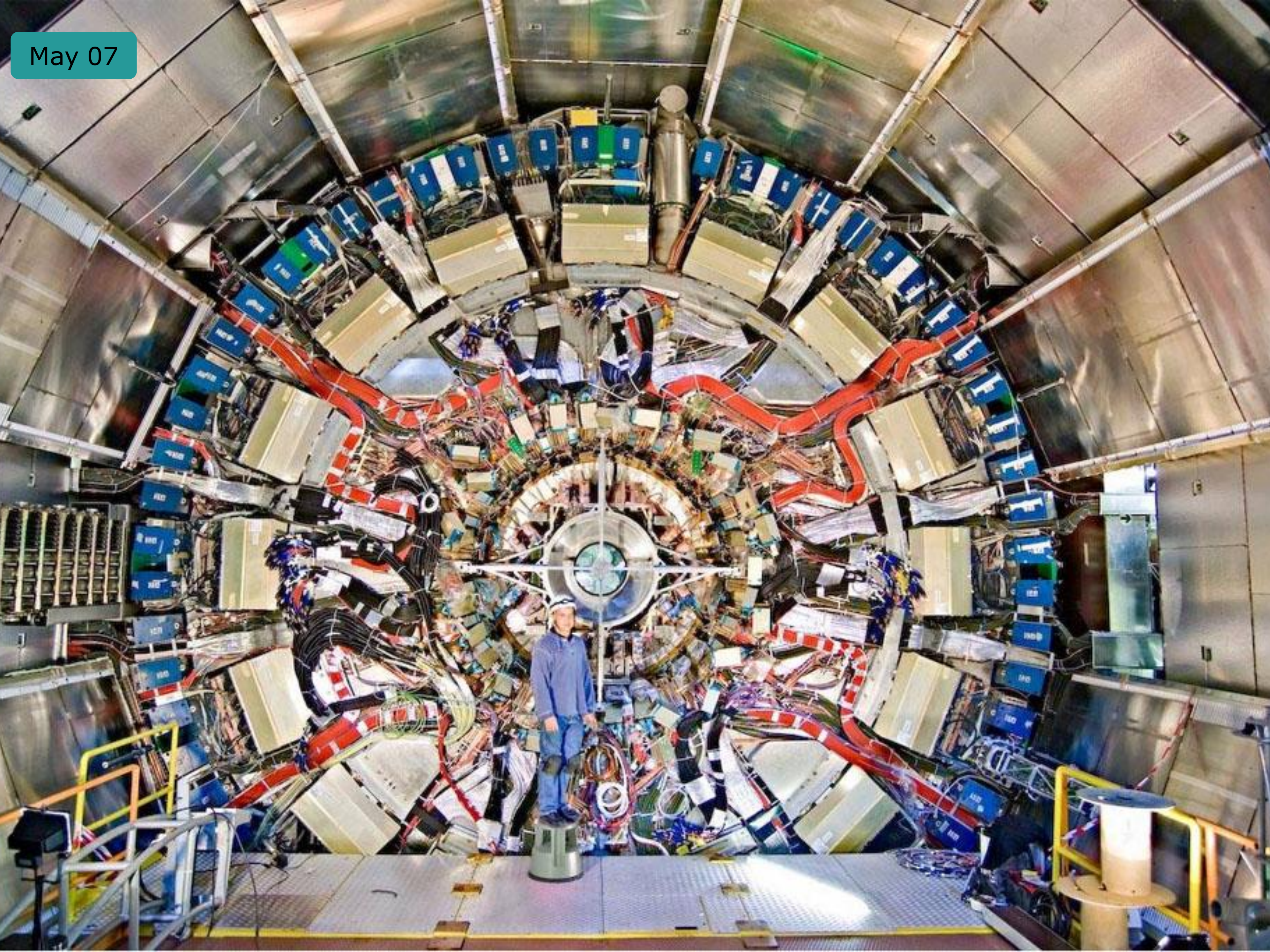
TRT endcap

- Modules are overlapping within a barrel layer / endcap disk
- SCT barrel has a hardware-based alignment system (FSI)

Feb 07



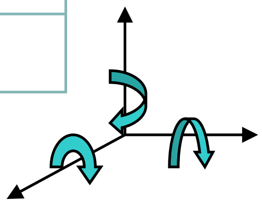
May 07



# The Alignment Challenge

- Parameters to determine:

| | Barrel | | | Endcap | | |
|---|---|---|---|---|---|---|
| | Pix | SCT | TRT | Pix | SCT | TRT |
| layers | 3 | 4 | 3 | 2 · 3 | 2 · 9 | 2 · 14 |
| modules | 1456 | 2112 | 96 | 2 · 144 | 2 · 988 | 2 · 14 |
| total | O(6k) · 6 DoF = O(36k) DoF | | | | | |



3 translations & 3 rotations per alignable structure

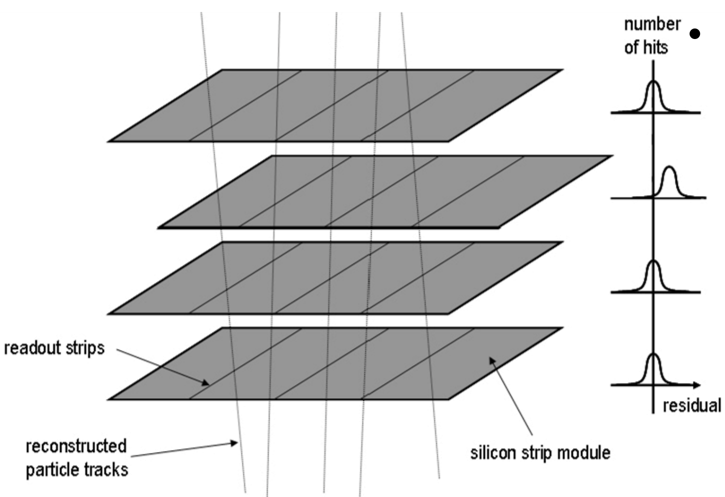
- Mounting and survey precision:
  O(100 μm), depending on subdetector
- Requirements:
  - track parameter resolution not to be worsened by more than 20%
  - b-tagging efficiency drops by 10% with a misalignment of O(10 μm)
- Required accuracy:
  O(10 μm) and less, depending on subdetector

# Alignment algorithms

- Track-based alignment algorithms were developed within the ATLAS software framework
- Track-based alignment works by minimizing residuals (distance between detector hitpoint and trackfit)

## Robust method

- centres residual and overlap-residual distributions
- aligns 2-3 degrees of freedom (DoF)
- iterative procedure




## $\chi^2$-based methods

$$\chi^2 = \sum_{tracks} r_i^T V^{-1} r_i$$

### Local$\chi^2$

- invert only 6x6 matrices per alignable structure
- iterate to get correlations back

### Global$\chi^2$

solve full linear system of equations with 36k parameters

## TRT Algorithm

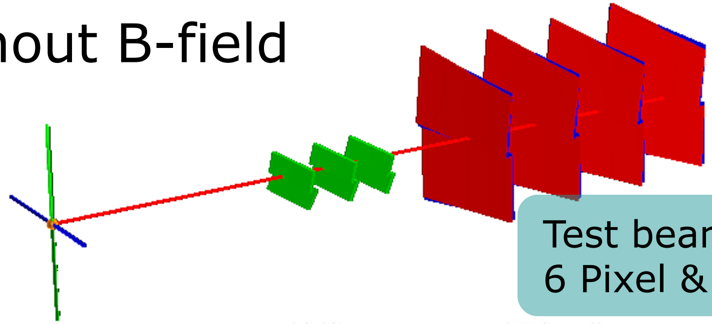
- global and local $\chi^2$ mode
- also has to calibrate R-t relation and $T_0$ of the tubes

Alignment algorithms were used for:

- Testbeam data
- Cosmics data
- Simulated data (CSC)

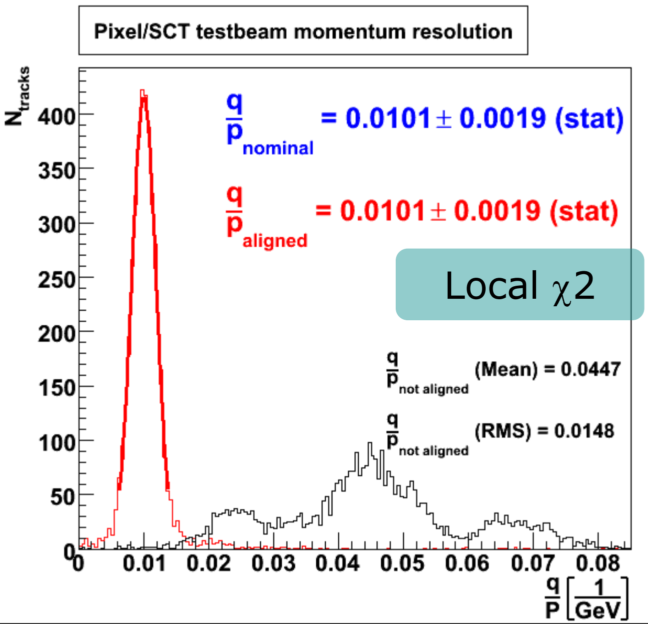
# CombinedTestBeam

- 2004 combined pion/electron run at the CERN SPS H8 beamline
- 2-180 GeV with and without B-field
- Recent results:



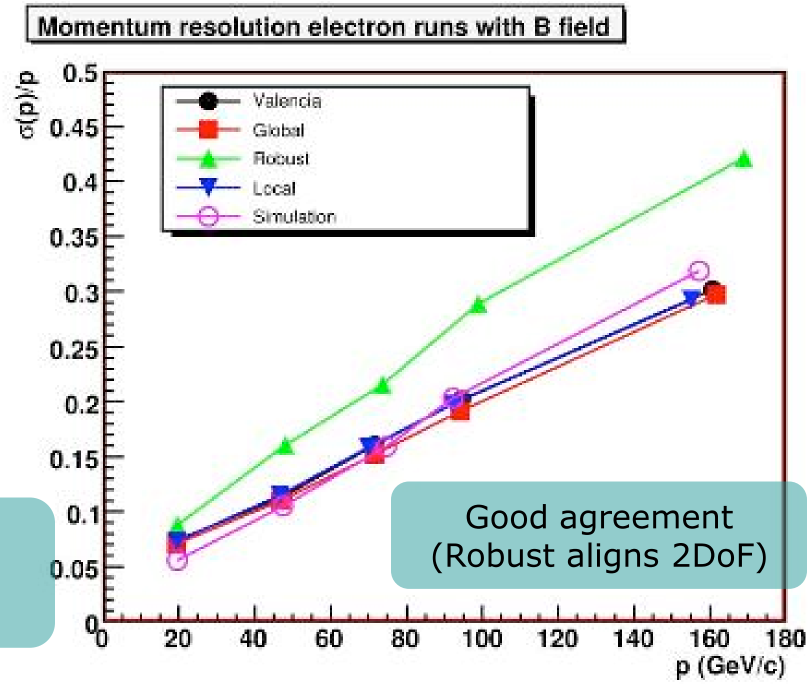
Test beam detector setup:
6 Pixel & 8 SCT modules

100 GeV pions momentum spectrum




Local $\chi 2$

Momentum resolutions after alignment

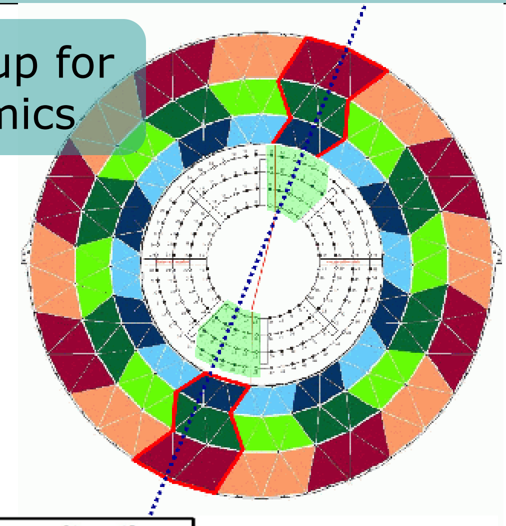


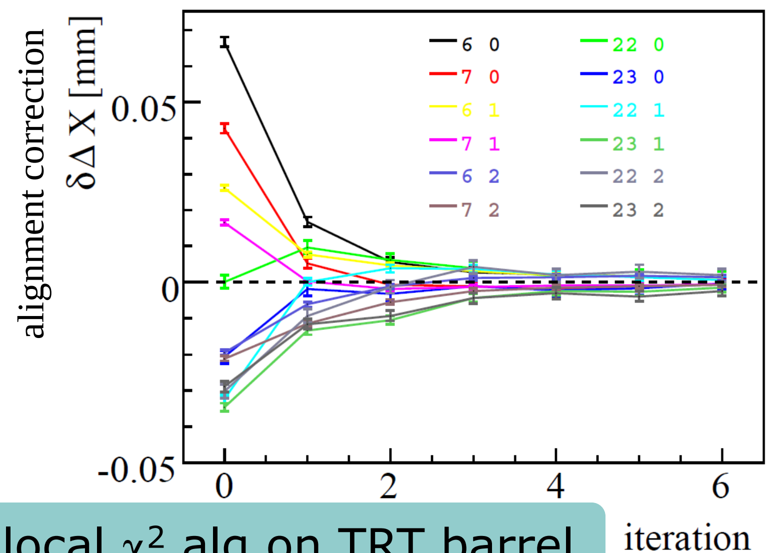

Good agreement (Robust aligns 2DoF)

# Cosmics alignment

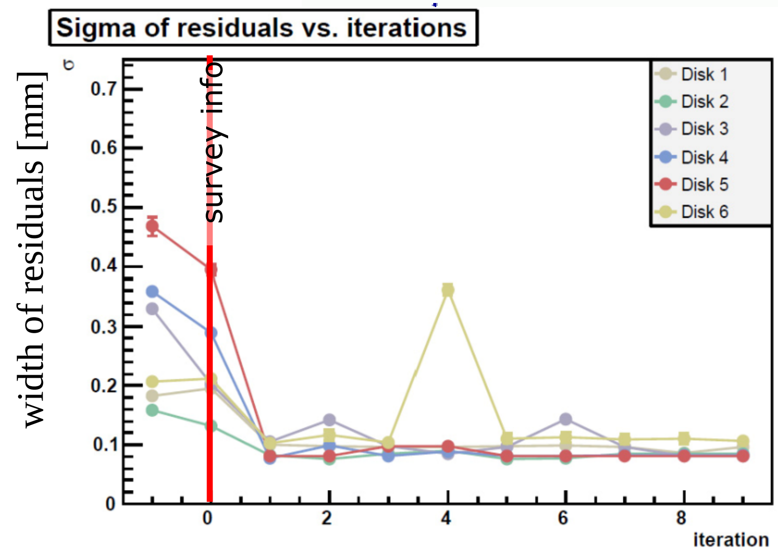
- TRT+SCT combined cosmic runs (2006)
  - ~500 SCT and 12 TRT modules (barrel), one endcap (endcap)
  - Only scintillator trigger added, no B-field, no momentum hardening
  - O(100k) tracks (barrel), O(10k) tracks (endcap)
  - In the endcap, only complete disks were aligned

detector setup for barrel cosmics






TRT local $\chi^2$ alg on TRT barrel




TRT Global $\chi^2$ on SCT endcap

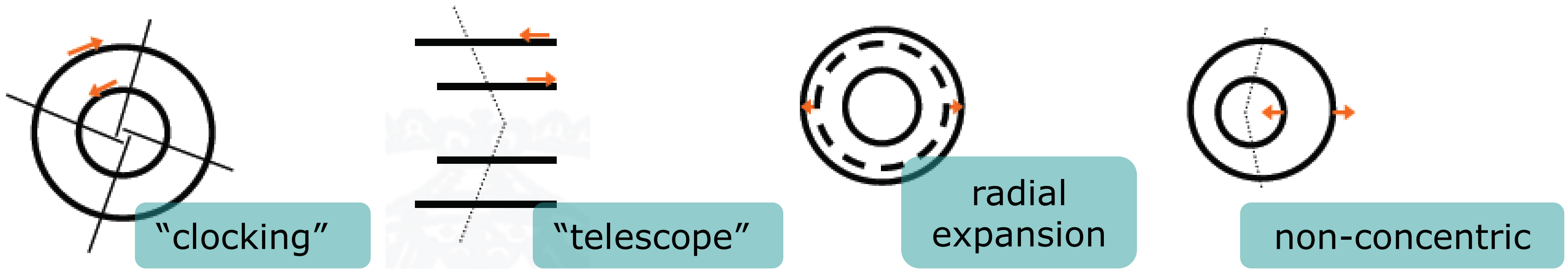
# Alignment of the CSC

CSC (Computing System Commissioning) Challenge:

- Alignment task is to align an educated guess of misaligned "as-built" detector geometry
- CSC misalignment scales:

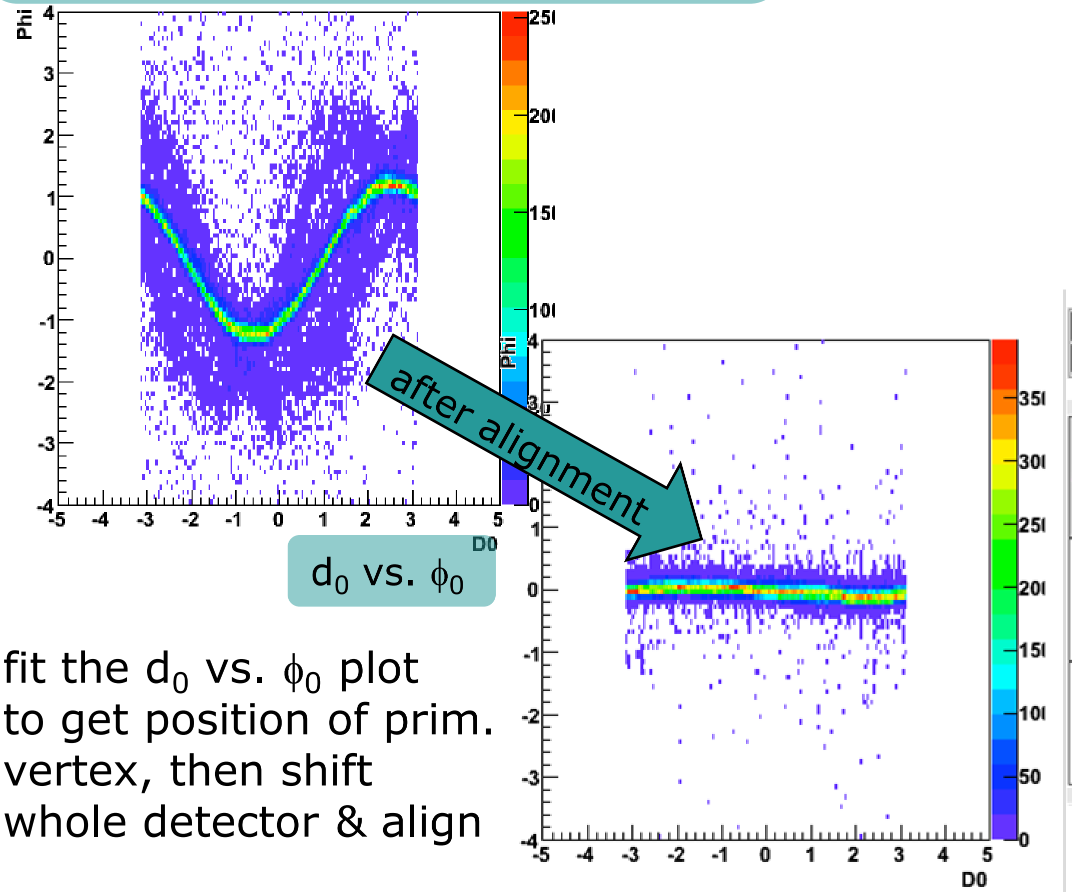
| | Level 1 (barrel, endcap) | Level 2 (layers, discs) | Level 3 (modules) |
|---|---|---|---|
| Misalignment | O(1 mm) | O(100 $\mu$m) | O(100 $\mu$m) |

- "Weak modes" leave $\chi^2$ for tracks from the interaction point unchanged; can be cured by
  - additional track samples (cosmics, beam halo…)
  - additional constraints (vertex, mass constraint…)



# CSC alignment – physics parameters

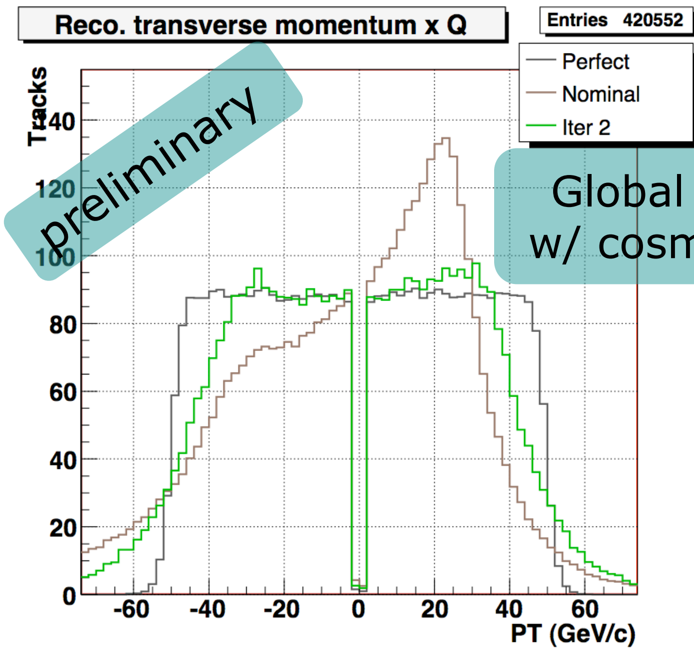
Correcting L1 resolves improper track impact parameter reconstruction:




$d_0$ vs. $\phi_0$

fit the $d_0$ vs. $\phi_0$ plot to get position of prim. vertex, then shift whole detector & align

Correcting L2 improves momentum scale:




Global $\chi^2$ w/ cosmics

L3 brings best resolution to physics quantities

# Calibration Stream

- ATLAS computing model requests that alignment constants are produced within 24h after data taking
- Select tracks from samples of different topology for
  - Alignment
  - TRT R-t calibration
- Estimation: about 1000 hits per alignable structure are needed to fulfill accuracy requirements
  - For Level1 and Level2, this is quick
  - Level3 is challenging
- Since largest time fraction is needed for reconstruction, select good alignment tracks in the EventFilter and put into dedicated CalibrationStream

# Conclusions

- Track-based alignment algorithms were developed within the ATLAS software framework
- They were successfully applied on
  - Testbeam data
  - Cosmics data
  - Simulated full ATLAS data (CSC)

  and will be applied on the data currently taken during pit commissioning
- Computing model requires that alignment constants are produced within 24 hours

Acknowledgments:

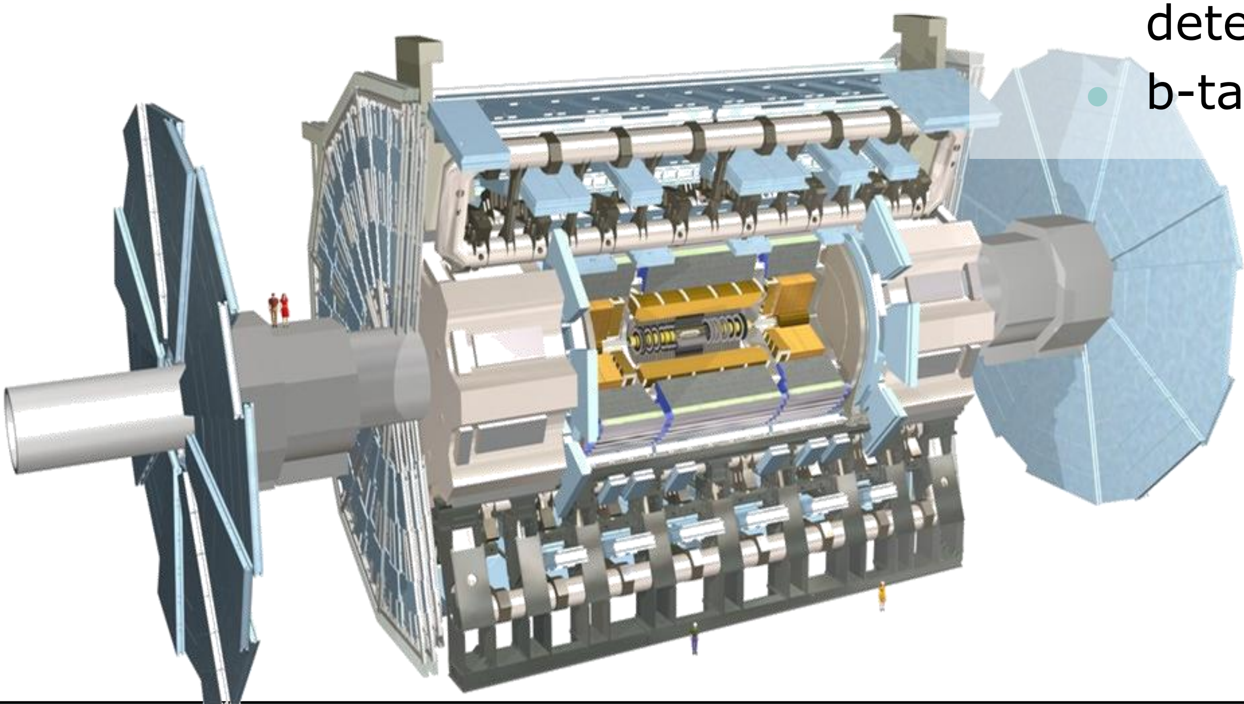
Many thanks to the whole ATLAS ID alignment group!

Many thanks to the whole ATLAS ID alignment group!

# Backup

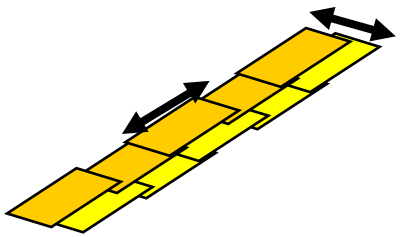
# ATLAS at the LHC

- General purpose experiment for the LHC
- Physics goals:
  - Search for the Higgs
  - Supersymmetry searches
  - Top quark measurements
- Tracking system (ID) in 2T magnetic field
  - efficient track reconstruction
  - precise momentum measurement
  - precise interaction point determination
  - b-tagging

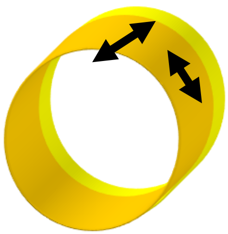


# Robust alignment

F. Heinemann



Sum over neighbours, take correlations into account

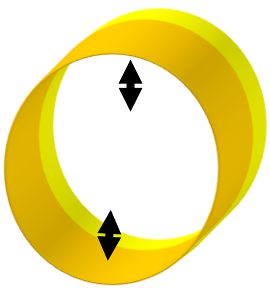


$$a = -\frac{\sum a_i / \sigma_i^2}{\sum 1/\sigma_i^2}, \quad \text{a} = \text{x, y; i} = \text{mean residual, mean Z overlap residual, mean R}\varphi \text{ overlap residual}$$

Sum over all modules in a ring

Correct for change in radius

$$z = -\frac{\sum \text{mean R}\varphi \text{ overlap residual}}{2\pi}$$



# The Global $\chi^2$ Approach

A. Morley

Method consists of minimizing a giant $\chi^2$ resulting from a simultaneous fit of all particle trajectories and alignment parameters:

$$\chi^2 = \sum_{tracks} r^T V^{-1} r$$

$$r(\pi, a, m)$$

- *r* = residuals
- *V* = covariance matrix
- π = track parameters
- *a* = alignment parameters
- *m* = measurement

Use the linear expansion (assume all second order derivatives negligible).

$$\frac{d\chi^2}{d\pi} = 0 \rightarrow \quad \pi = \pi_0 + \delta\pi = \pi_0 - \left(\frac{\partial e^T}{\partial \pi_0} V^{-1} \frac{\partial e}{\partial \pi_0}\right)^{-1} \frac{\partial e^T}{\partial \pi_0} V^{-1} r(\pi_0, a)$$

$$\frac{d\chi^2}{da} = 0 \rightarrow \quad \left(\sum_{tracks} \frac{dr^T}{da_0} V^{-1} \frac{dr}{da_0}\right) \delta a + \sum_{tracks} \frac{dr^T}{da_0} V^{-1} r(\pi_0, a_0) = 0$$

Key relation!

$$\frac{dr}{da} = \frac{\partial r}{\partial a} + \frac{\partial r}{\partial \pi}\frac{d\pi}{da}$$

Alignment Parameters are given by:

$$\delta a = -\underbrace{\left(\sum_{tracks} \frac{\partial r^T}{\partial a_0} W \frac{\partial r}{\partial a_0}\right)^{-1}}_{\mathcal{M}} \underbrace{\sum_{tracks} \frac{\partial r^T}{\partial a_0} W r(\pi_0, a_0)}_{\nu}$$

Where

$$W \equiv V^{-1}\hat{W} \equiv V^{-1} - V^{-1}E(E^T V^{-1} E)^{-1} E^T V^{-1}$$

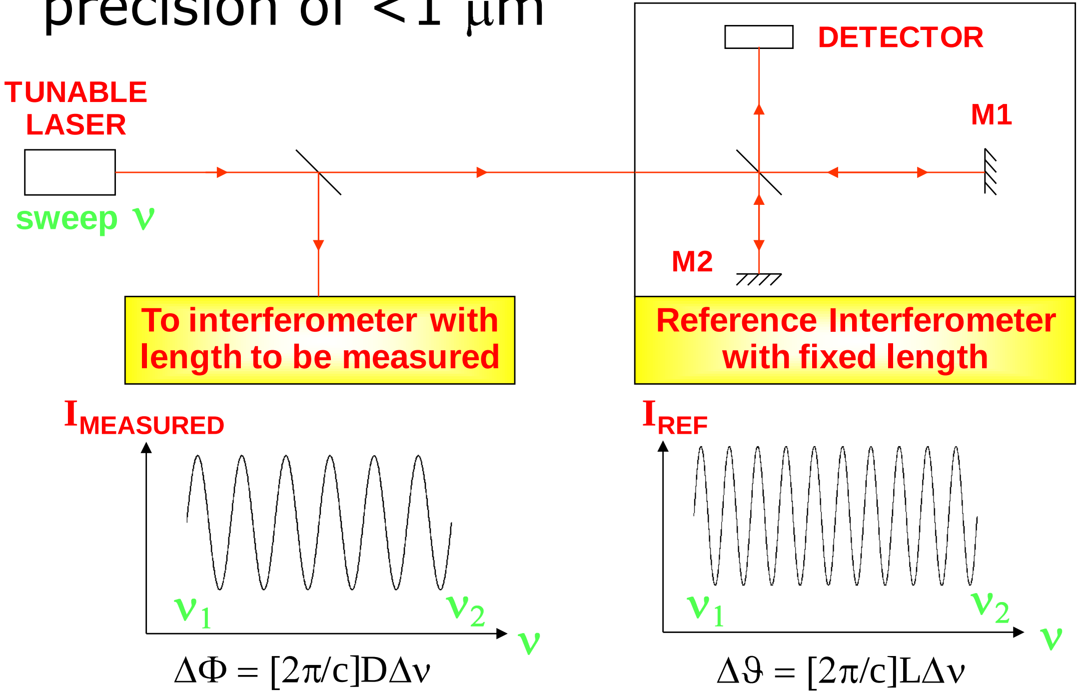
$$E = \frac{dr}{d\pi_0}$$

Similar approach to Millipede at CMS

# FSI

S. Gibson

- Frequency Scanning Interferometry for monitoring SCT detector distortions on short timescales
- Forms a geodetic grid in the SCT barrel
- 842 grid line length measurements simultaneously to a precision of <1 μm



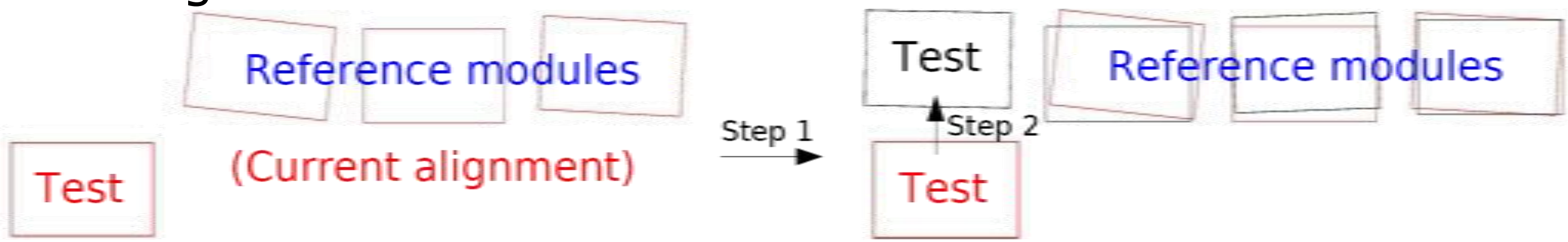

geodetic grid of SCT barrel

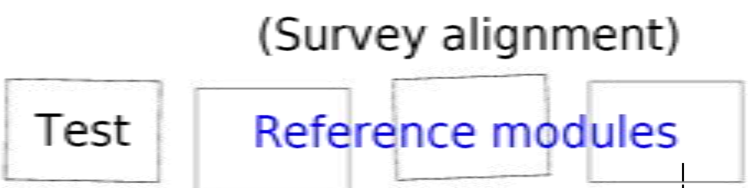
Ratio of phase change = Ratio of lengths

# Survey

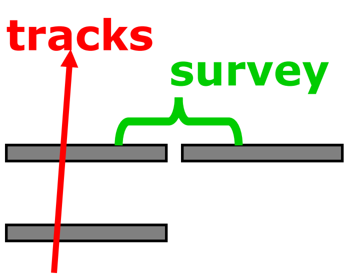
T. Golling

- additional $\chi^2$-term places constraints on module positions within a structure
- orthogonal to track information




module-to-module survey precision




| | Pixel sector | Pixel stave | SCT disk | SCT stave |
|---|---|---|---|---|
| $\delta x$ | 4.6 μ | 50 μ | 32 μ | 150 μ |
| $\delta y$ | 4.7 μ | 20 μ | 41 μ | 150 μ |
| $\delta z$ | 12.7 μ | 50 μ | 50 μ | 150 μ |
| $\delta\phi_x$ | 0.3 mrad | 1.7 mrad | 1.0 mrad | 2.5 mrad |
| $\delta\phi_y$ | 0.7 mrad | 5.0 mrad | 1.0 mrad | 5.0 mrad |
| $\delta\phi_z$ | 0.12 mrad | 1.7 mrad | 0.09 mrad | 2.5 mrad |