Forum on Tracking Detector Mechanics

04 July 2012

Survey and Large Scale Metrology of Tracking Detectors for LHC Experiments

From prototypes to final installations

Antje BEHRENS, Jean-Christophe GAYDE, Dirk MERGELKUHL

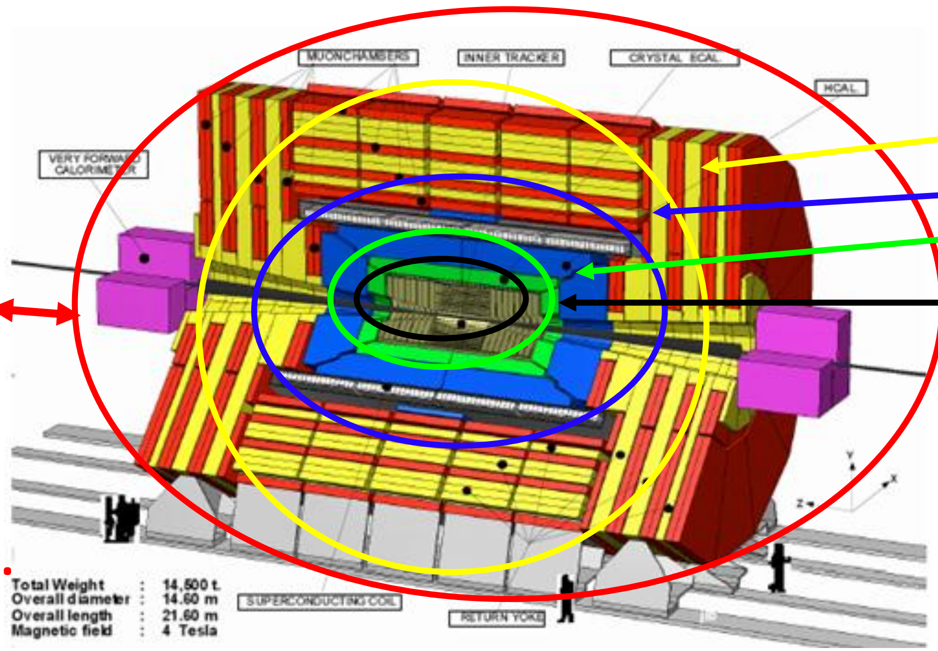
(CERN BE-ABP-SU-EM)

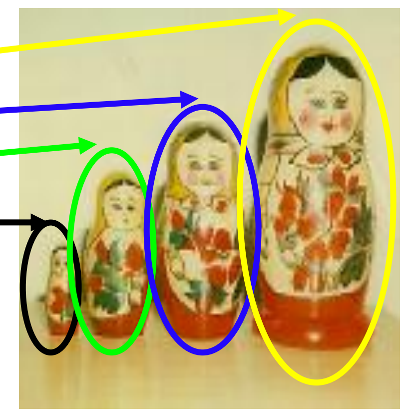
Large Scale Metrology Section

BE-ABP-SU Experiment metrology team

- Mandate:
  - Provide forms, dimensions and positions for all elements
  - Alignment of structures and detectors
  - During assembly and when all is closed
- This includes:
  - Prototypes, deformation tests, quality control, (pre-)assembly, alignment

What we see…





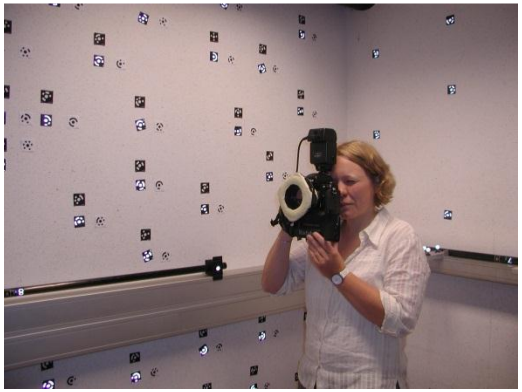
What we want to know…

Survey instrumentation

- Toolbox
  - Level
  - Theodolite
  - Photogrammetry
  - Special equipment

- A few times also
  - Laser Scanner
  - Laser Tracker

➔ Line of sight between instrument and object required!

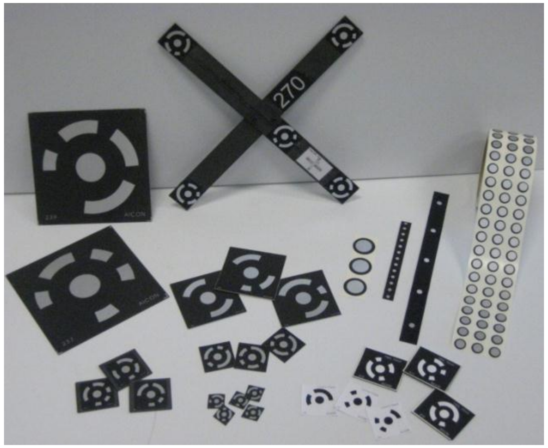


Photogrammetry

- Image acquisition needs no stable station
  - Photos taken on platform or scaffolding
  - Photos taken from cherry-picker during installation in cavern
- Mobile System with ‘high’ precision
  - Off-site interventions in factory (Pisa, Aachen…)
  - Clean rooms, assembly halls and experimental caverns
  - Inner detector components < 1m (1 sigma < 50 microns)
- Limited measurement time for large amount of points
  - Short interruption for installation, production process
- Camera system
  - PC (windows XP, W7)
  - Nikon D2X
  - Wireless module
  - Different lenses (17-24 mm)
  - Ring flash

Photogrammetry

- References
  - Carbon fibre scale bars (max. 1.5 m)
    - Calibration on CMM
  - Geodetic measurements
    - Total station
    - Laser tracker
- Software
  - AICON 3D Studio V. 10.0 – DPA PRO
- Targets
  - Coded / non-coded
  - Retroreflective / non-retroreflective
  - Button targets Hubbs / GMS / Aicon

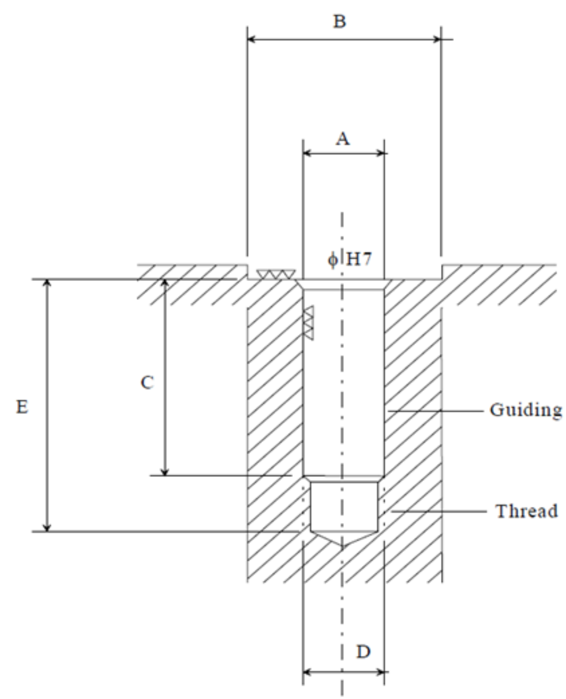


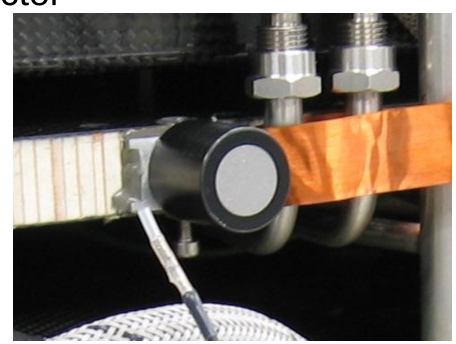
System optimized for measurement of signalized points only = highest precision
➔ We have to touch the detector

Pre-Discussion

- Survey reference point
  - 3D – survey reference hole for different survey targets
  - ➔ best solution, highest flexibility
- Define survey reference holes on detector
  - Already early in the design phase
  - Reference hole accessible and visible during all phases
  - Position on stable support
  - On individual detector elements as later on assembled groups
  - For theodolite and photogrammetry
  - Coordinates are given for centre of survey target
  - Sensitive elements are referred to reference holes by constructor

8H7 reference hole





Pre-Discussion

- Discussion with physicist/engineer/designer for each tasks
  - Define precisely the needs for geometrical control / alignment / survey
  - Define the stages when survey will be needed
  - Find reasonable solutions
  - Include alignment to the design
  - Define local coordinate system
  - We have to adapt to the experimental schedules

- Typically demanded precision
  - Detector control at manufacturing before assembly
    - 0.03-0.3 mm (max. 0.5 mm)
  - Relative position of detectors wrt other detectors
    - < 0.5 mm
  - Absolute position of detectors wrt accelerator geometry
    - < 1.0 mm
  - Deformation of detectors under special conditions
    - ~ 0.1 mm

Additional survey requirements

- Local network
  - Tripods bolted to the floor
  - Support points permanently fixed on walls / stable pillars
  - Temporary network points glued around detector
- Stable floor for theodolite measurements (concrete foundation)
- Access to detector for installation of survey target
- Line of sight between instrument station and points
- Constant temperature for significant results for dimension

Not so stable…

Some Examples

- Survey of prototypes
- Mockup tests
- Alignment of support structures
- Alignment for bonding tools

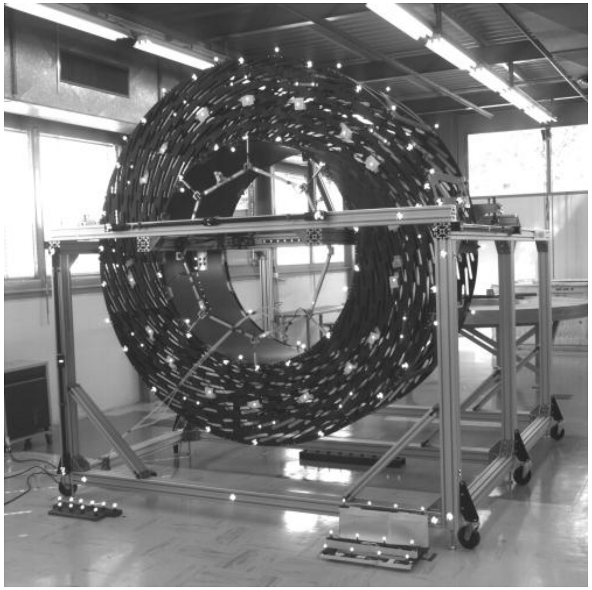
- Fiducialisation and geometrical control
- Fiducialisation sensitive detector elements
- Measurement at construction site
- Transfer to new references
- Integration of detectors on surface
- Deformation control
- Envelope measurements

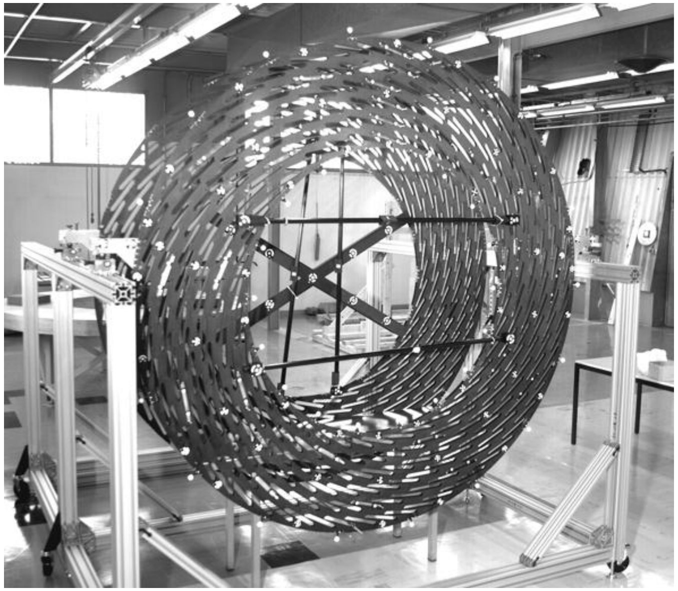
- Alignment in cavern

Survey of prototypes

CMS TOB (Tracker Outer Barrel) – Prototype support structure ‘big wheel’

- Photogrammetric measurements 1998 – 2000
- Reference holes on different layers
- Comparison to theoretical coordinates
- Circularity
- Comparison of two discs
- Alignment of two discs
- Deformation test

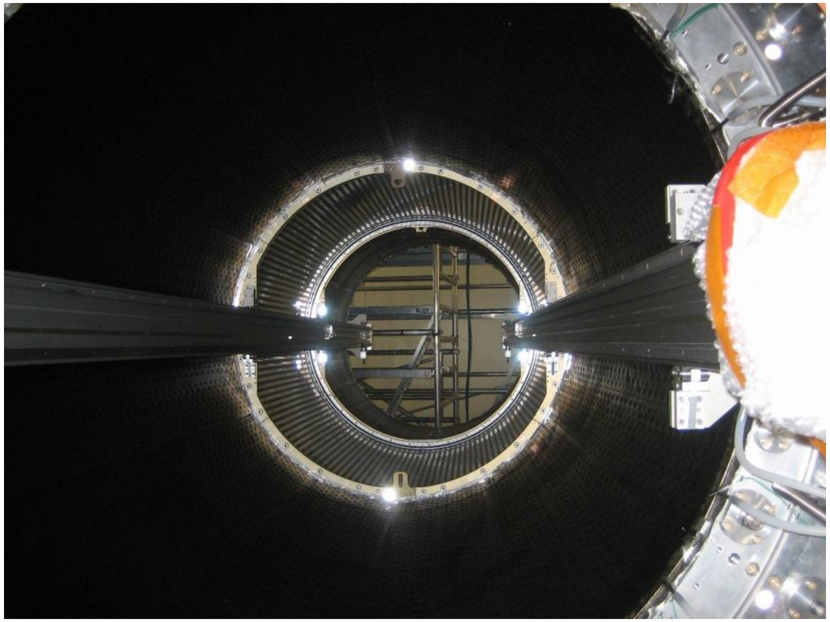


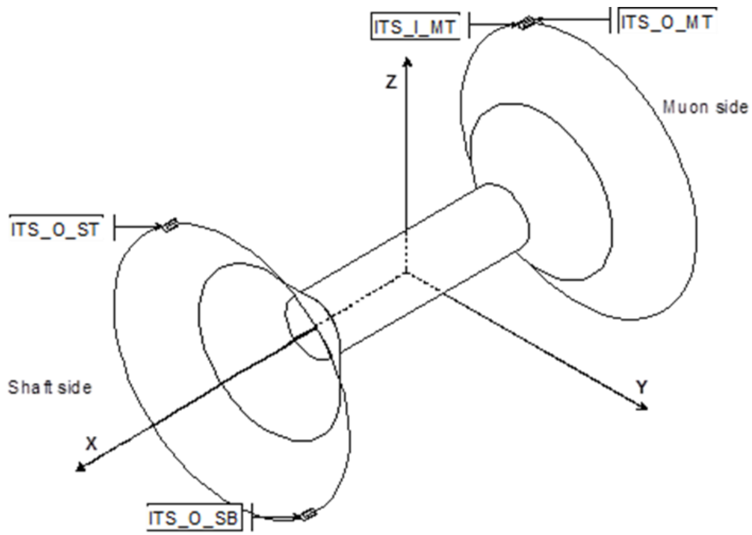


Mockup Tests

ALICE ITS dummy – insertion test in TPC

- Deformation measurement of ITS supports after charge with ITS dummy
- Repeatability of ITS dummy insertion
- ITS has been inserted 4 times, rails have been disconnected
- Relative precision 0.1mm in radial and vertical direction (1 sigma)





Alignment of support structures

ATLAS ID trolley, Floor rails and Cantilever for SCT insertion

- Level and theodolite measurements
- Alignment of ID trolley – frame and detector rails
- Alignment of ID trolley rails on floor
- Alignment of cantilever tool for SCT insertion

➔ to prepare for smooth insertion of SCT in TRT

Problem:

- False floor in SR1
- But theodolite requires a stable support
- Only few areas with concrete foundation
- Limited possibilities
- Reduced precision

Alignment for bonding tools

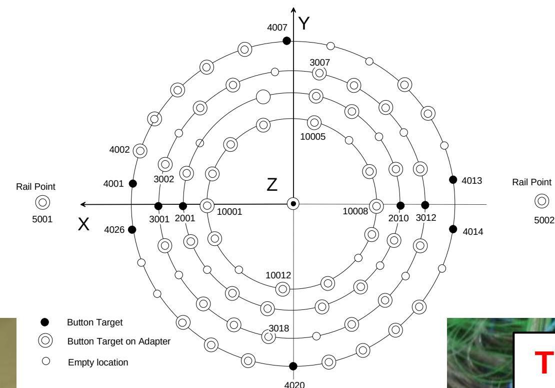
ATLAS – Alignment of Pixel jig in bonding tool

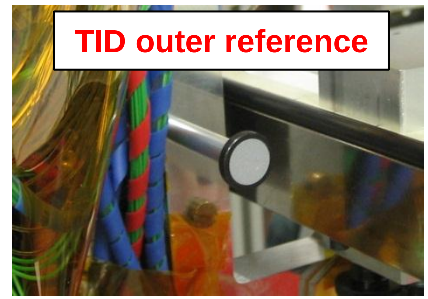
- Photogrammetric measurement of the bonding tool – inside and outside
- Circularity
- Afterwards alignment of the pixel jig to outside of bonding tool
- Precision 0.03mm in X-,Y- and Z-direction (1 sigma)

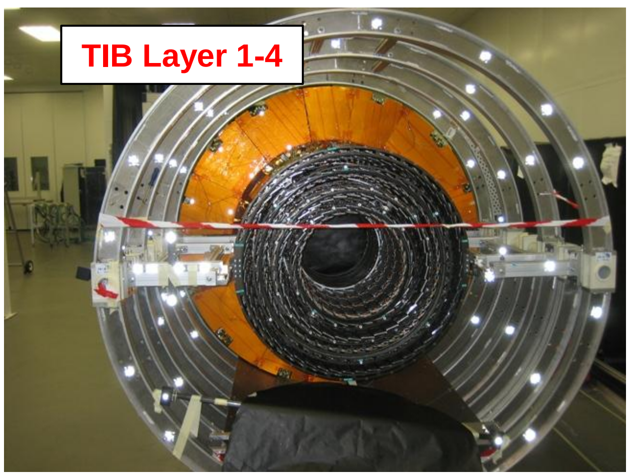
Fiducialisation and geometrical control

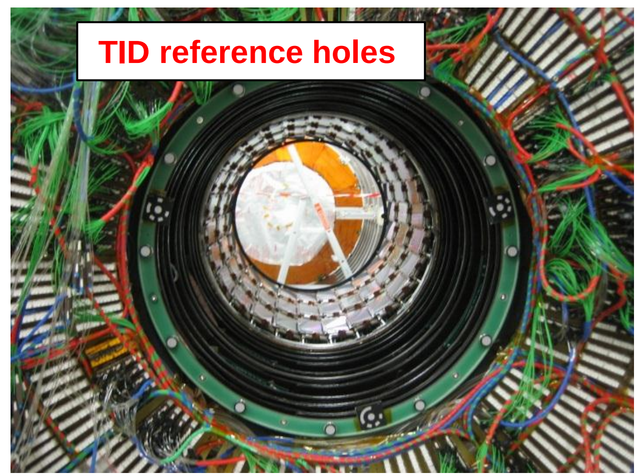
CMS TIB/TID – transfer from TIB Layer 1-4 to outer reference points

- Reference holes on TIB layer 1-4
- Referred to outer references on TID face (visible after insertion in TOB)
- Circularity and concentricity of Layer





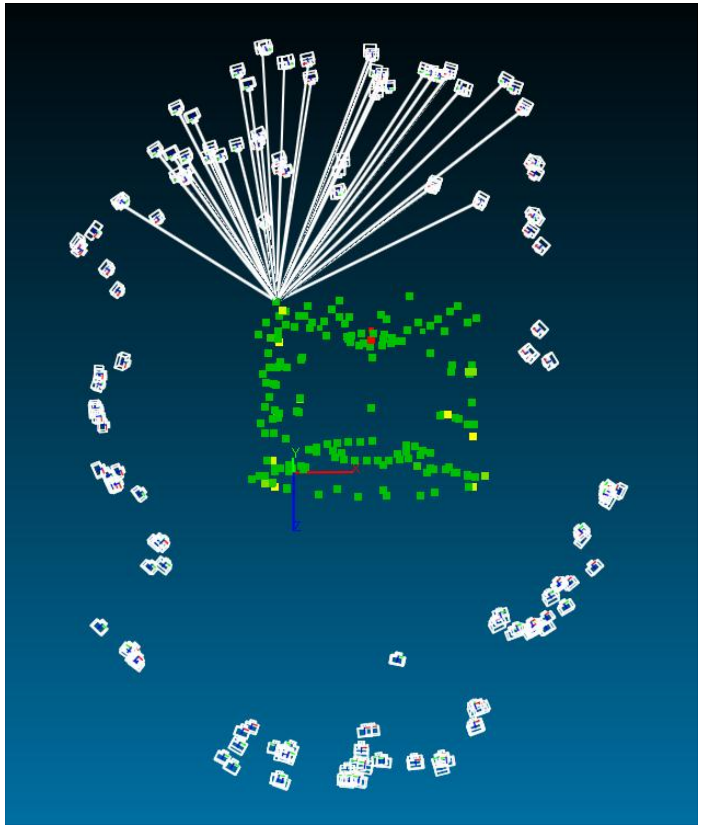




Fiducialisation and geometrical control

CMS TIB/TID – transfer from TIB Layer 1-4 to outer reference points

- 170 images
- 180 object points
- Precision in X-, Y- and Z-direction 0.05mm (1 sigma)
- 3D view of object points and images
- Geometry of intersection for each point
- ➔ precision
- Underexposed images
- ➔ robustness

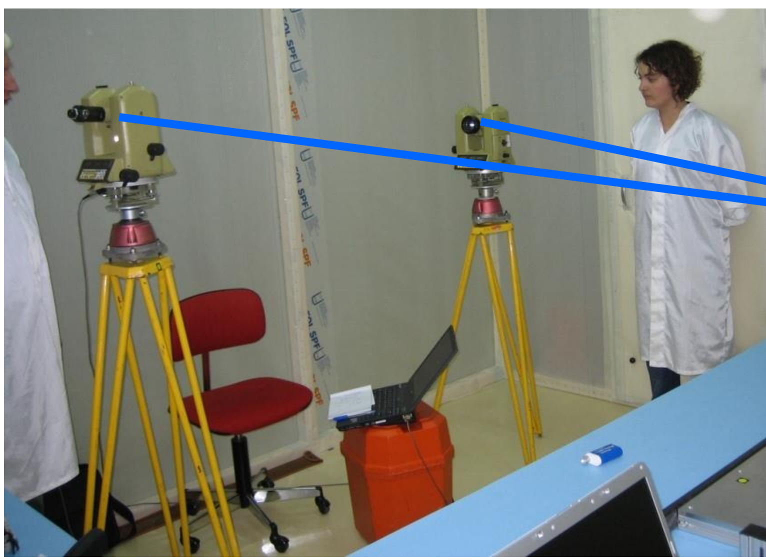


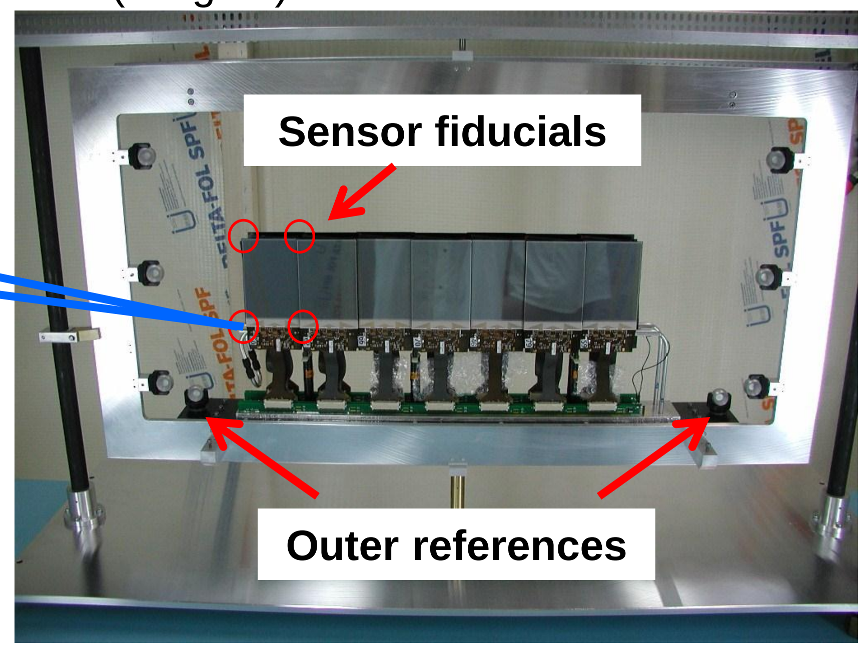
Fiducialisation sensitive detector elements

LHCb IT (Inner Tracker)

- Measurement in clean room by microtriangulation
- Angular observations of sensor fiducials
- White cross on black background of 0.3mm x 0.3mm
- Illumination by cold light, no optical disturbance
- Calibrated scale bars
- Transfer to outer references visible during insertion of all elements in IT box
- Precision in X-, Y- and Z-direction 0.05mm (1 sigma)

12 IT detectors

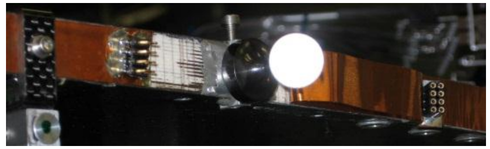


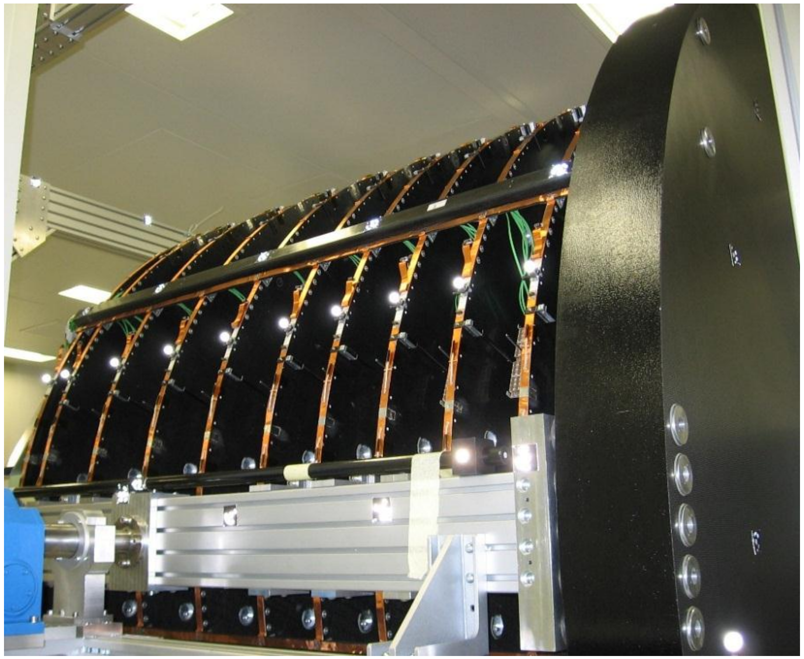


Measurement at construction site

CMS TEC +/- (Tracker End Caps)

- Several photogrammetric measurements at RWTH Aachen during construction phase
- TEC = 9 support disks for detector elements + 1 Back Disc
- Each with 4 reference points on circumference
- Assembly control in vertical position
- Deformation control in horizontal position

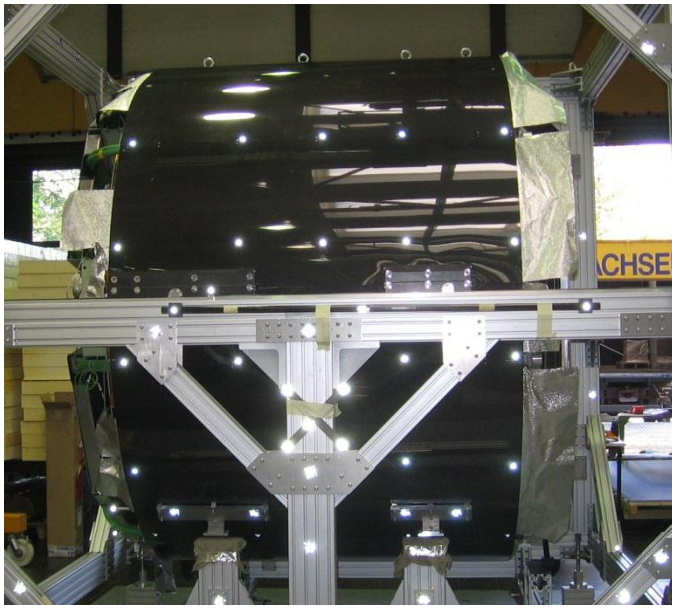


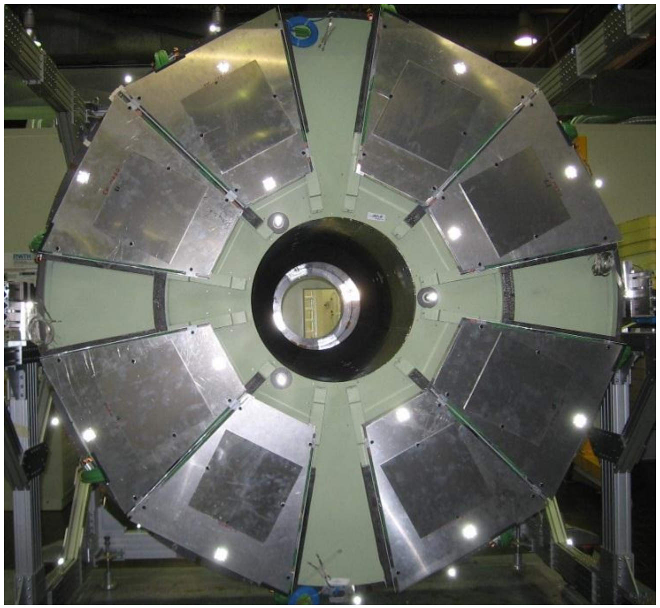


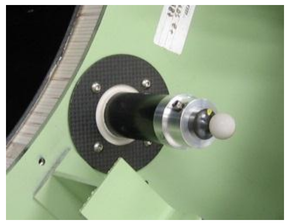
Measurement at construction site

CMS TEC (Tracker End Cap)

- Fiducialisation = transfer to outer references on Back Disc
  - 3 Support points for Alignment ring
  - 4 additional adapter on outer circumference
- Control with final supports
- Envelope measurement of protection skins



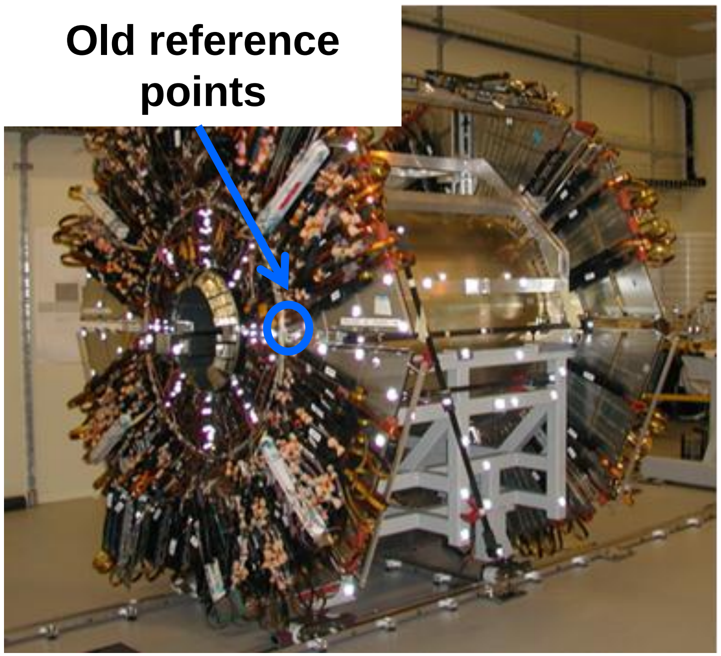


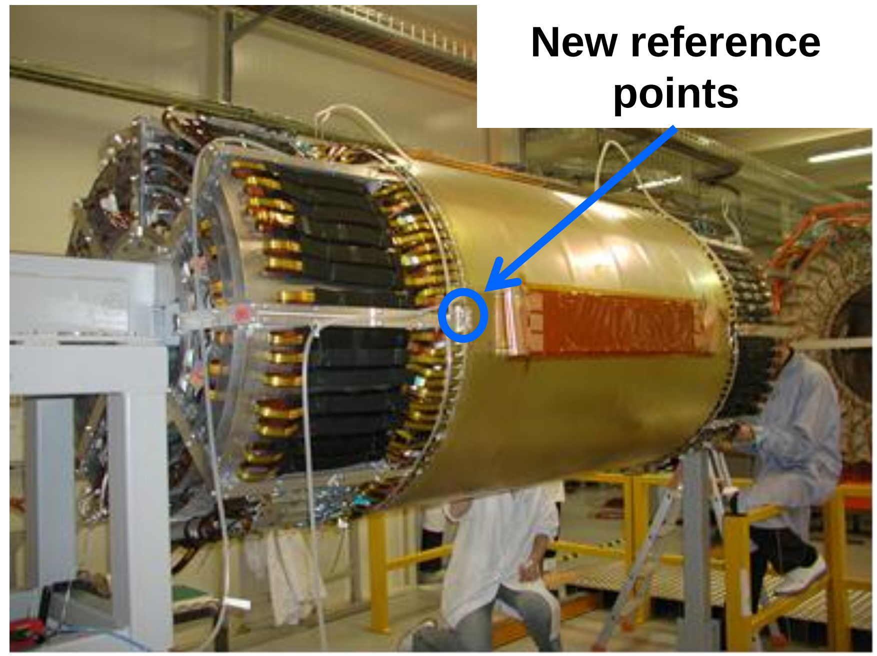


Transfer to new reference points

ATLAS SCT barrel – transfer to four new reference points

- Reference points not visible in future due to thermal enclosure
- Geometrical detector information transfered to new reference points



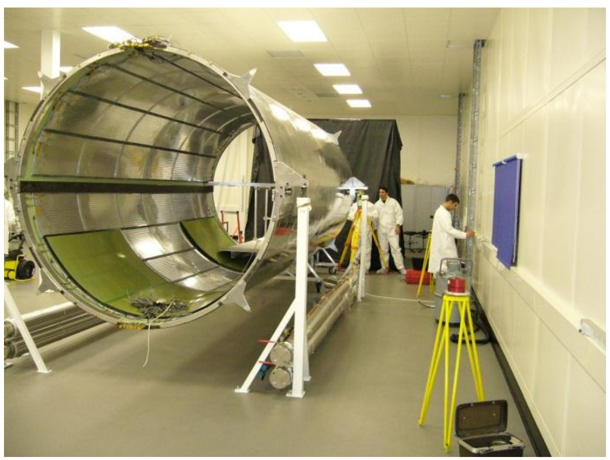


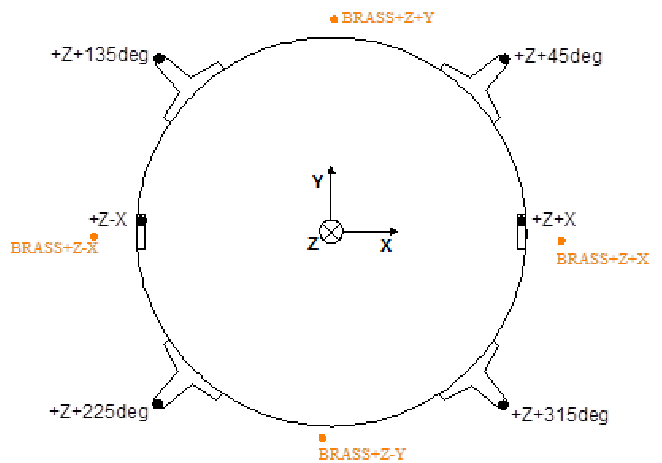
- Each transfer to new reference means loss of precision
- Number of transfers should be reduced to a minimum

Integration of detectors on surface

CMS Tracker integration in TST (Tracker Support Tube)

- Theodolite and photogrammetric measurements in clean room
- Network stations around TST = steel tripods fixed to floor
- Reference points TST:
    - Rail ends
    - Each face four ‘ears’
    - Each face four brass adapter
- Each detector measured wrt TST reference points
- BUT: Deformation of hidden central detectors due to advancing installation can not be detected by classical survey methods

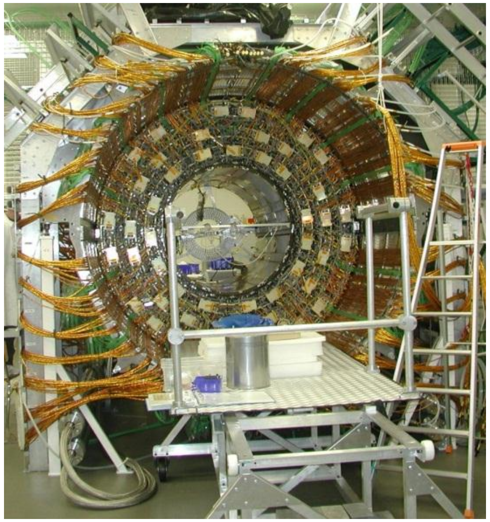


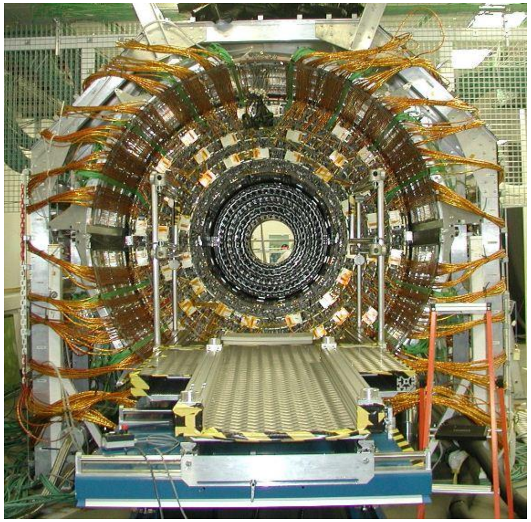


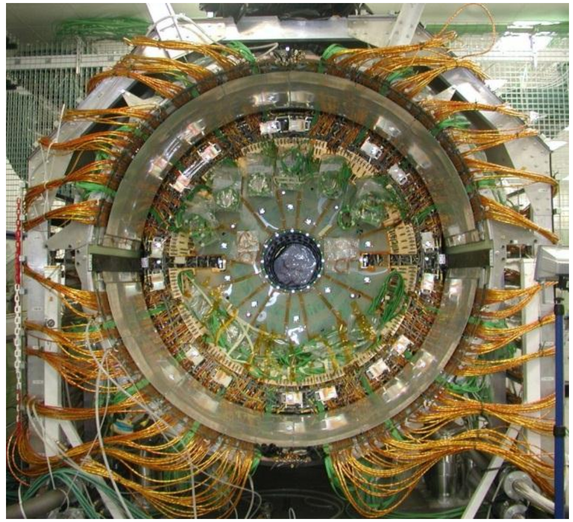
Integration of detectors on surface

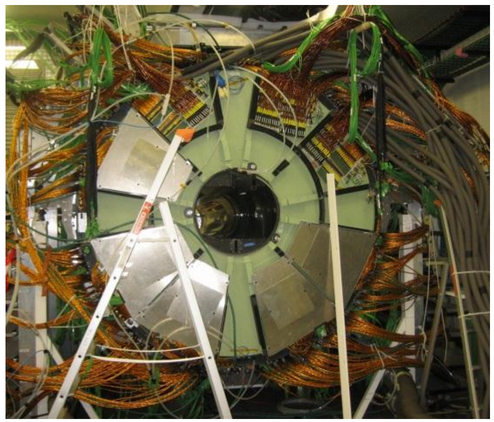
CMS Tracker integration in TST (Tracker Support Tube)

- TOB; TIB/TID+; TIB/TID-; central PST; TEC+; TEC-; forward PST









Deformation control

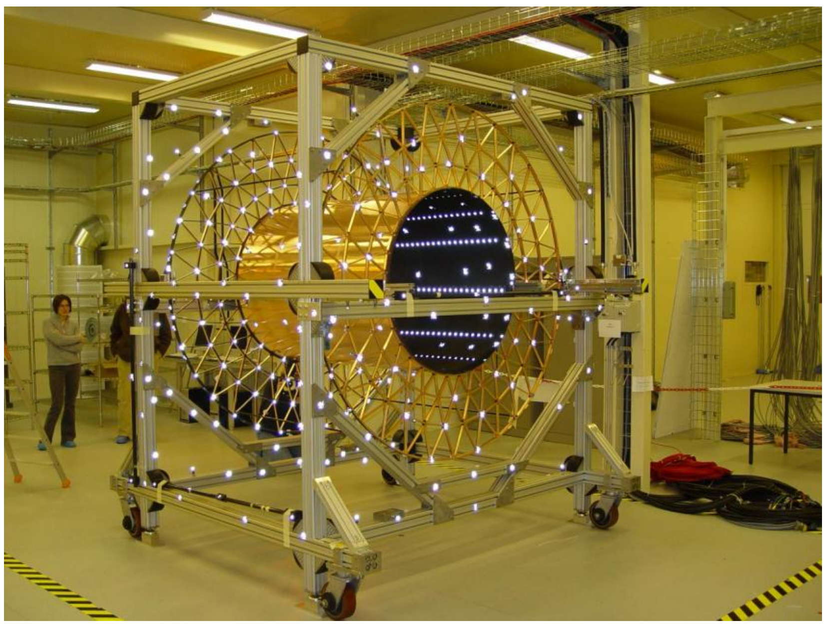
ATLAS pixel support tube – load test

- Leveling at 3 different load levels:
- Without charge, 2180g each end, 5080g A side and 5120g C side
- Measurement in 2 rotations of the pixel support tube
- Precision 0.05mm in vertical direction (1 sigma)

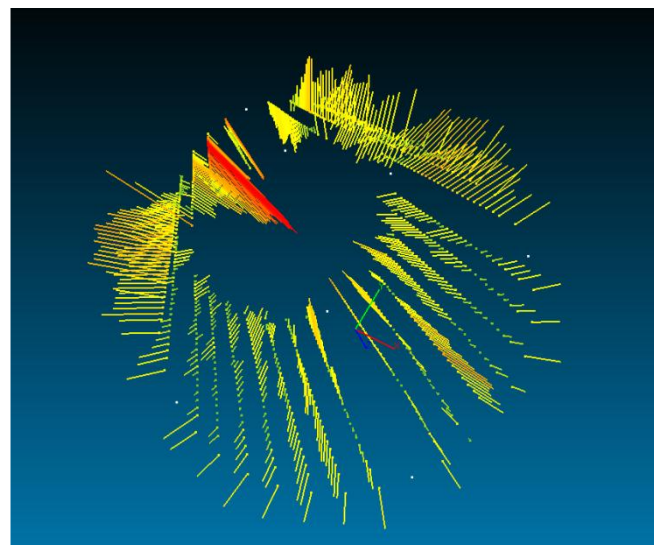
Envelope measurements

ATLAS TRT Barrel – photogrammetric measurement of inner cylinder

- 16 lines of target tape with 31 targets each
- Only signalized points
- 450 Images, 1700 object points, 124000 observations in bundle adjustment
- Precision 0.06mm in X-, Y- and Z-direction
- Cylindricity
- Comparison to measurement with Romer arm by PH/DT



Difference to best fit cylinder



Envelope measurements

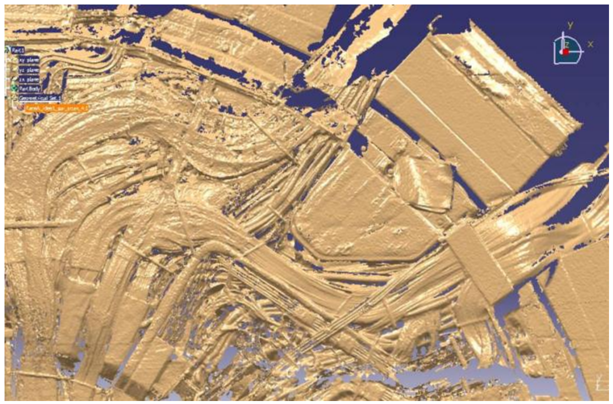
ATLAS ID services – Scanning of LAR Barrel face

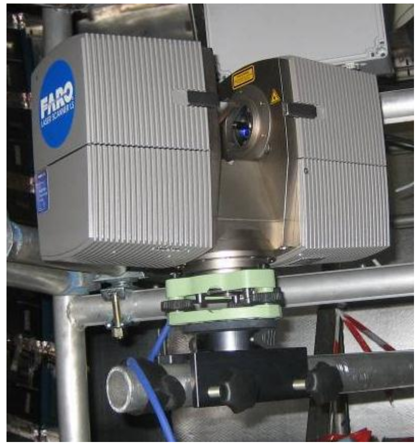
- Laser scanner Faro Photon 80 – contract work in 2009
- 16 and 12 Scanner stations on scaffolding each side
- Point distance between adjacent points 1mm to 3mm
- Precision in X-, Y- and Z- direction 3mm (1 sigma)
- Transformation in ATLAS coordinate system
- Point cloud has been reconstructed with Geomagic Studio
  - Automatically and manually filtered and cleaned ➔ very time consuming
  - Meshing has been performed (point cloud to triangular mesh)
  - Mesh has been cleaned, small holes filled up
  - Exported to Catia

Pre-processing from days to weeks depending on object complexity!

Missing elements In central part!

Outer part exported to Catia

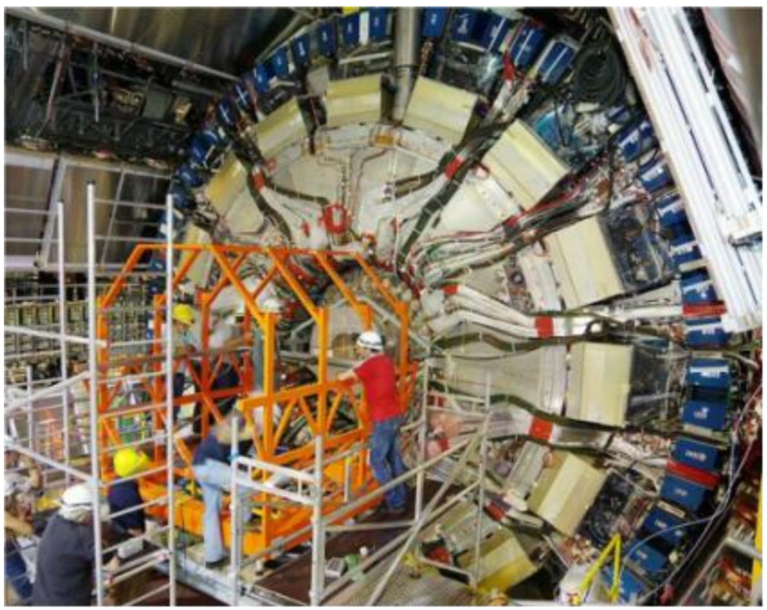


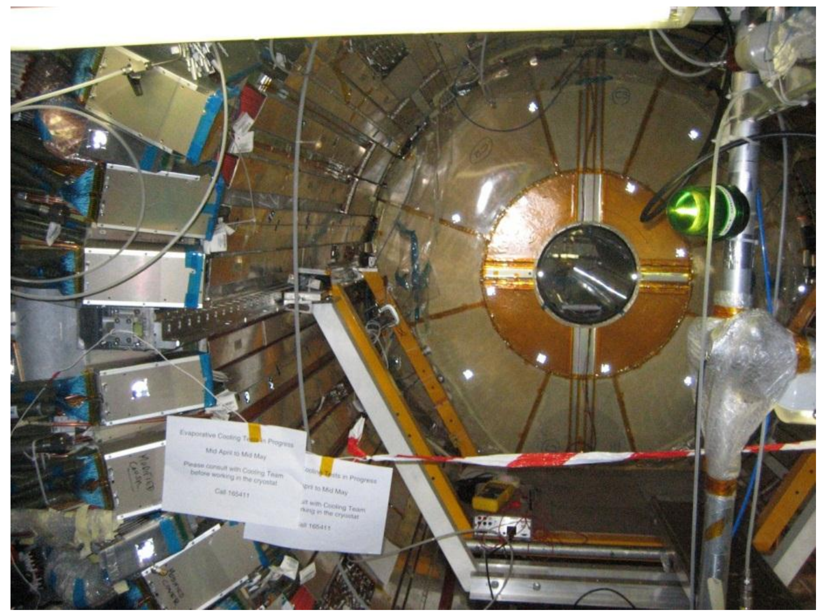


Alignment in cavern

ATLAS ID barrel - alignment in IWV

- Relative alignment of TRT/SCT to Inner Warm Vessel
- Precision 0.3mm in X-, Y- and Z-direction (1 sigma) in IWV coordinate system
- Precision 1.0mm in X-, Y- and Z-direction (1 sigma) in ATLAS coordinate system

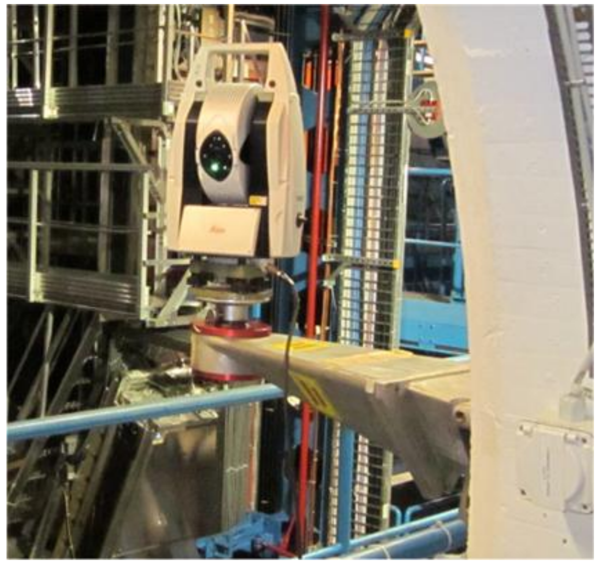




New survey instrumentation

- Leica HDS 6200
    - Up to 1 000 000 points per second
    - Point position accuracy at 5m = +-3mm

- Hexagon Metrology AT401 – Laser tracker in theodolite housing
    - As flexible and light as theodolite
    - Precision at 5m distance 0.03mm typical (1 sigma)
    - In addition mechanical precision for target and reference hole has to be included in the error budget



Conclusion

- All LHC experiments had survey requests for tracking detectors during
  - Construction
  - Validation / test phase
  - Installation
- Part of requests with highest precision demands
- Often fulfilled by photogrammetric measurements
- Some with special methods / equipment

➔ Adaptation to working condition

- Costs have been also shared by LHC experiments

- Permanent contact between SU and detector responsible

Lessons learned for the future

- Need to include the survey team very early in the project
- Define carefully the control and alignment needs
  - What has to be measured?
  - With respect to what?
  - At what stage?
  - Where?
  - What is the required precision / error budget?
- SU participation to design at early steps – integration of reference holes
- Definition of reference holes and special equipment (adapter…) needed by SU
- First fiducialisation of sensitive elements at construction site

➔ references carry the detector geometry information

If there are NO references there is a risk that NO precise survey can be performed!

- Future detectors will be become more complex – we have to adapt survey techniques and references

Thank you!