The ATLAS Detector Positioning System (ADEPO) to Control Moving Parts During ATLAS Closure

IWAA 2016 (03-07 Oct.) - Grenoble - France

J.-C. Gayde, D. Mergelkuhl, M. Raymond, CERN – Geneva – Switzerland
M. Daakir, IGN - Marne la Vallée - France
M. Dönszelmann, Radboud University, Nijmegen, The Netherlands
Vitali Batusov, JINR - Dubna - Russia

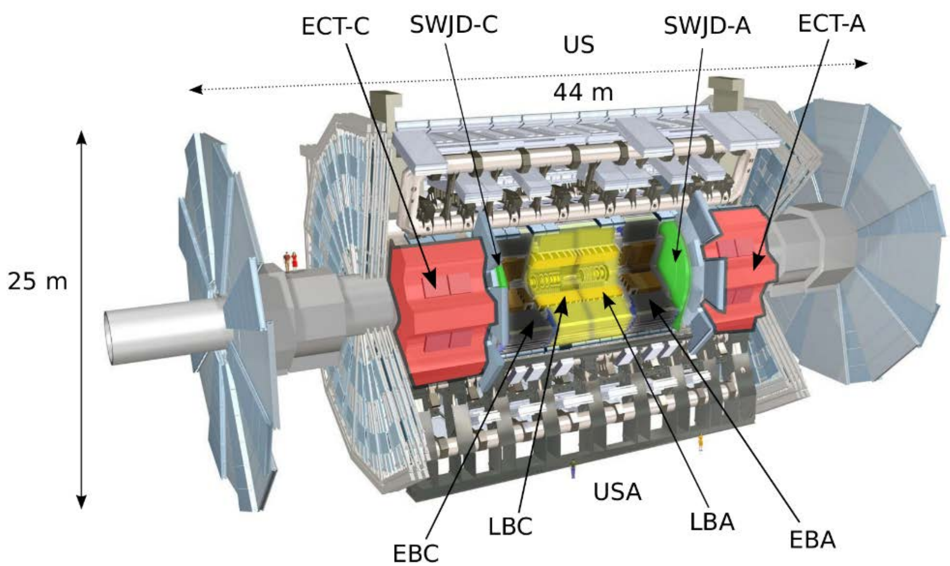
CERN | EN ENGINEERING DEPARTMENT

Table of contents

Introduction

ATLAS facts

- Length 44 m, diameter 25 m
- Weight: 7000 t
- Data: 3200 TB/year
- 3000 scientists from 38 countries



ATLAS requirements

- Regular maintenance and shut down periods
- Implies movement open/close of large sub-detectors of up to 900 t
- Manual adjustment and survey is iterative and time consuming

New ADEPO system should provide

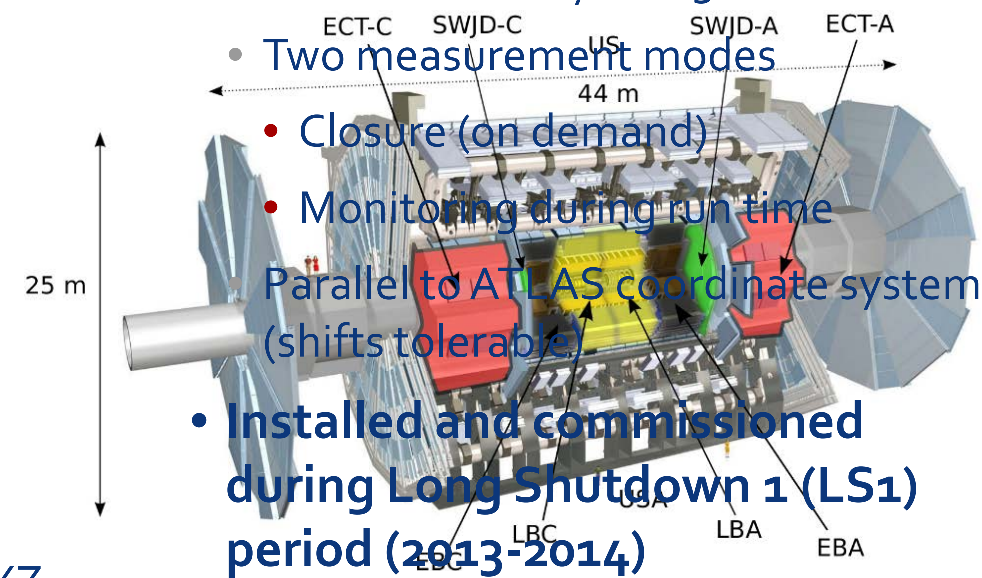
- Near real-time results
- Speed up closure
- Precise re-positioning
- Entirely managed by ATLAS Technical Coordination

ADEPO system specifications

- **6 detectors to be re-positioned**
  - 2x ECT – 240 t
  - 2x SW – 103 t
  - 2x EB – 900 t
  - *In total ~2500 t of detector are moved*
- **Measurement range**
  - Along X : +- 20 mm (radial)
  - Along Y: -10/+30 mm (vertical)
  - Along Z+ (side A): -10/+40 mm
  - Along Z- (side C): -40/+10 mm
- **Repositioning 0.3 mm**
- **Measurement precision**
  - 0.1 mm at 1 sigma level along XZ directions (radial and longitudinal)

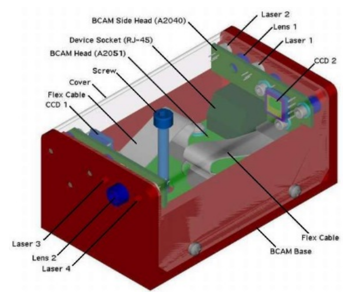
- **Environmental constraints**
  - Resist to 1 Tesla magnetic field
  - Radiation dose of 2Gy for lifetime
- **Measurement requirements**
  - Measurement cycle < 30 seconds
  - Two measurement modes
    - Closure (on demand)
    - Monitoring during run time
  - Parallel to ATLAS coordinate system (shifts tolerable)
- **Installed and commissioned during Long Shutdown 1 (LS1) period (2013-2014)**

  => project < 2 years

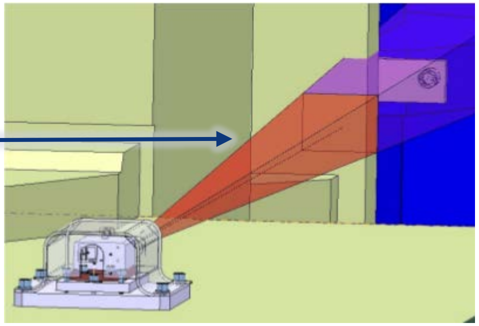


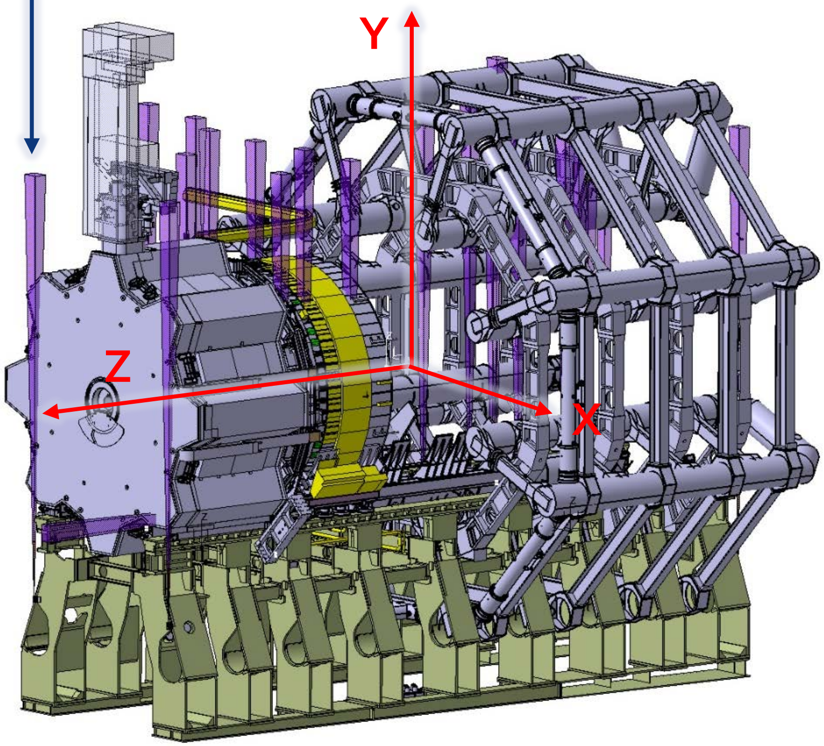
Choice of layout and sensors

Layout based on experience of previous alignment systems



BCAM's field of view



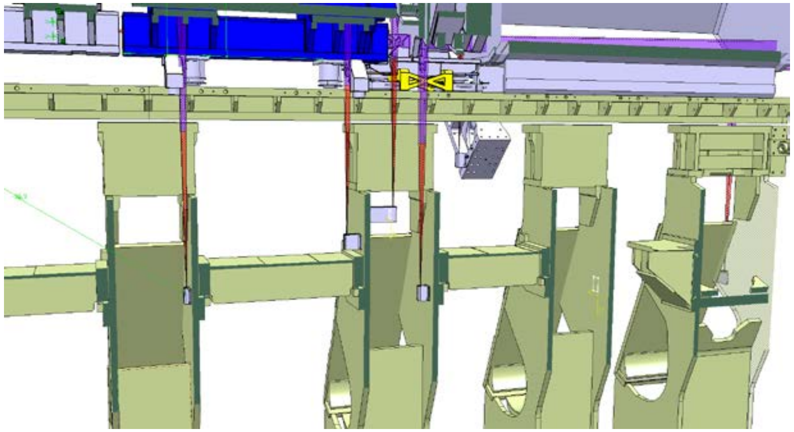


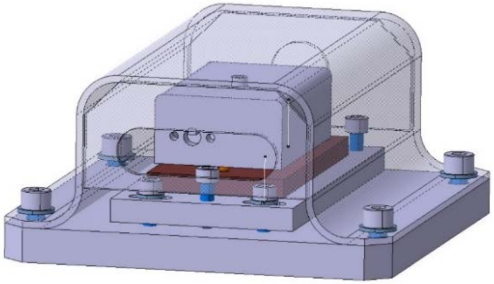
- BCAMs as proven camera sensors originally developed for ATLAS
- BCAMs attached to feet => max. stability
- Independency of each BCAM line
- Optical 2D measurement => less sensors
- Redundant system for error detection with 4 BCAMs and up to 8 prisms per detector
- BCAMs with protection to avoid damage
- Passive targets on mobile parts => no cabling

ADEPO System description

System is based on:

- 28 BCAMs on feet/rail system
- 44 passive targets (corner cubes)
- 1 driver and 4 multiplexers
- 24 protections
- Reference ATLAS feet/rail system
- LWDAQ for acquisition and measurement
- Movement/Positioning using push/pull system

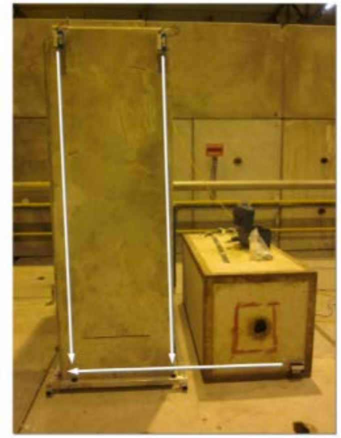


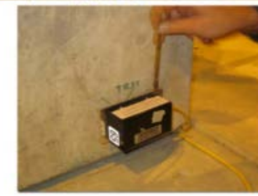


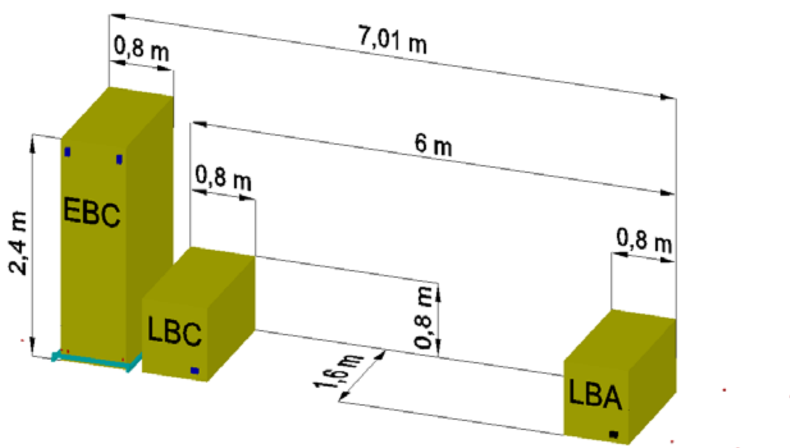
- **Adjustment concept:**
  - Adjustment using additional observations (detectors rigid body)
  - Blunder detection: Application of IRLS (Iteratively Reweighted Least Square)
    - K. Jacobsen, "Block Adjustment. Institute for Photogrammetry and Surveying Engineering", Univ. Hanover, 2002, Germany
    - Successfully tested in validation setup, still to be integrated in the present version of ADEPO
- **System is considered as additional system and traditional survey is maintained!**
- **New references after each closure!**

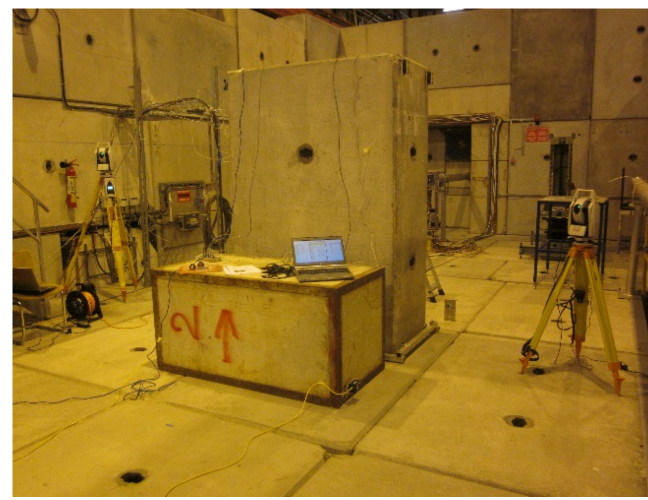
Validation setup and results

- Demand: 0.1 mm at 1 σ
- Repeatability: < 0.005 mm
- Displacement results: 0.04 +- 0.01 mm at 1 σ
- Verified by AT401 for detector EBA/EBC
- IRLS (Iteratively Reweighted Least Square) proved efficiency





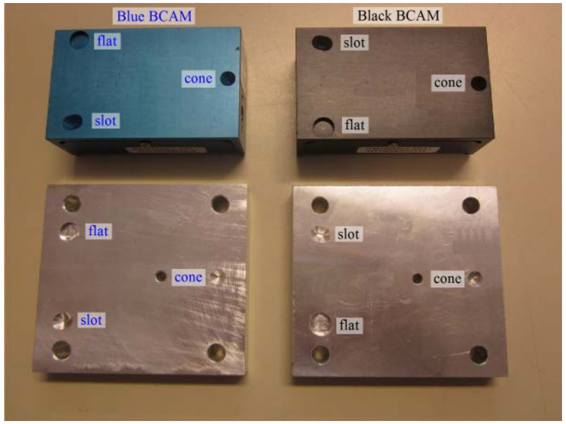


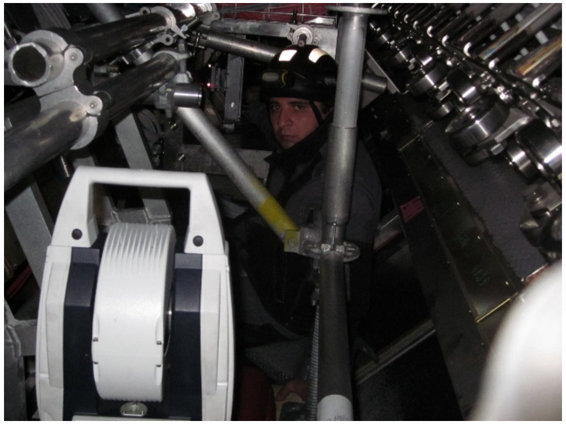


Result of displacement test at 2.1 m → mean offset = 35 µm+- 11 µm

Installation in ATLAS cavern

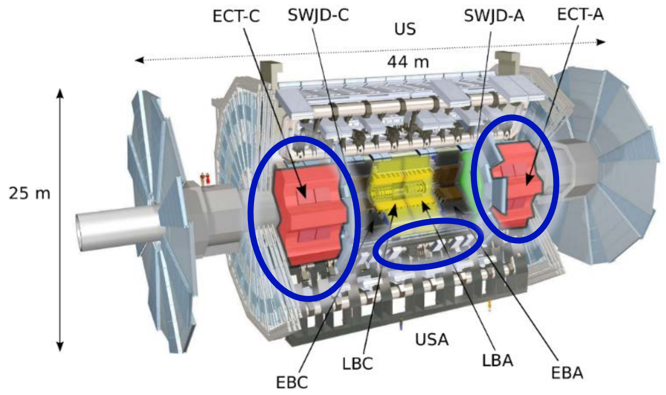
- Installation and adjustment in ATLAS open position => prisms invisible, first verification can only occur after closure
- Inside detector behind layers of muon chambers
- Integration in completed detector => limited lines of sight/space
- Adjustments by AT401 in absolute system mandatory using special adapter plate





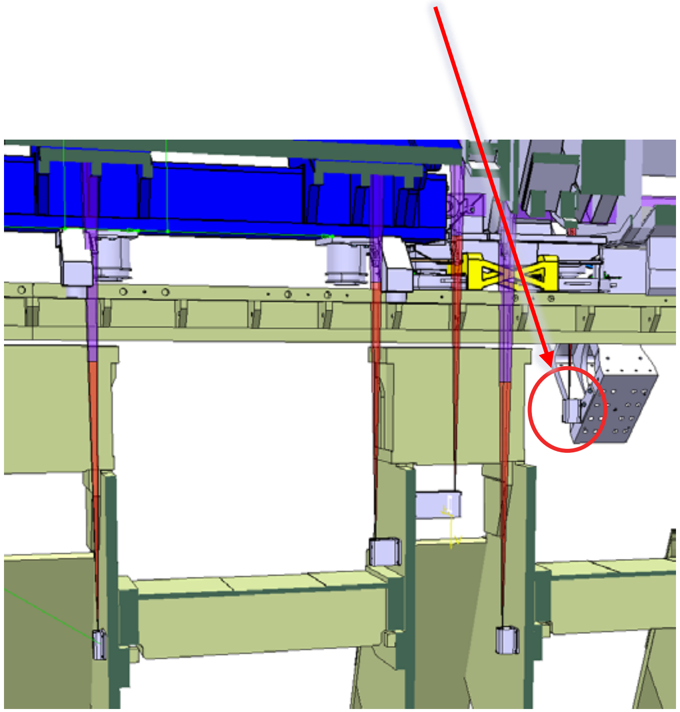
Commissioning

- Problem of hidden lines on ECT
- Hidden lines in saddle beams
  - Due to difference of as-built to 3D-model



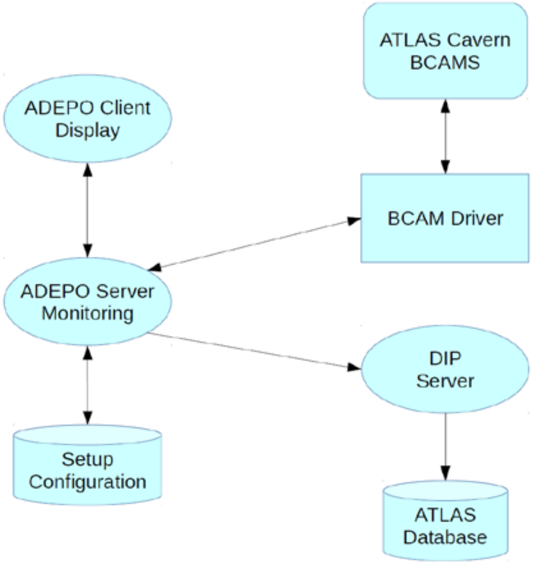
- Separation of flashes
- Change of flash times
- Definition of zones for BCAM measurements in case of 2 prisms
- Identified broken connector

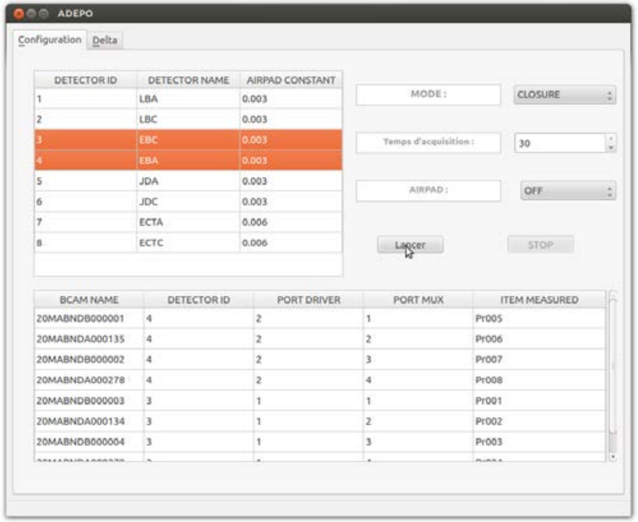
- Concession to integration constraints with 4 BCAMs on BT warm structure
  - Movement of BCAMs on BT structure due to deformation of support structure

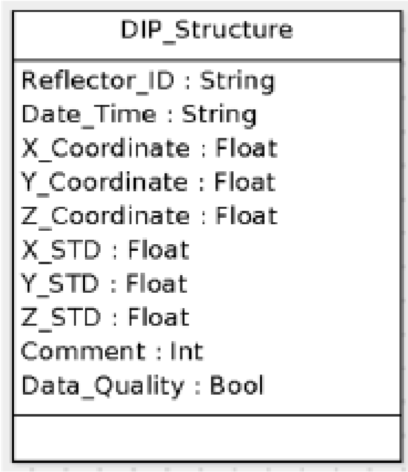


ADEPO user interface

- Interface and server structure integrated in technical infrastructure (ATLAS network)
- GUI with 2 modes for closure and monitoring
  - Closure measurement time defined in sec.
  - Monitoring default 10 loops
- Data storage via DIP (Data Interchange Protocol) in ATLAS database





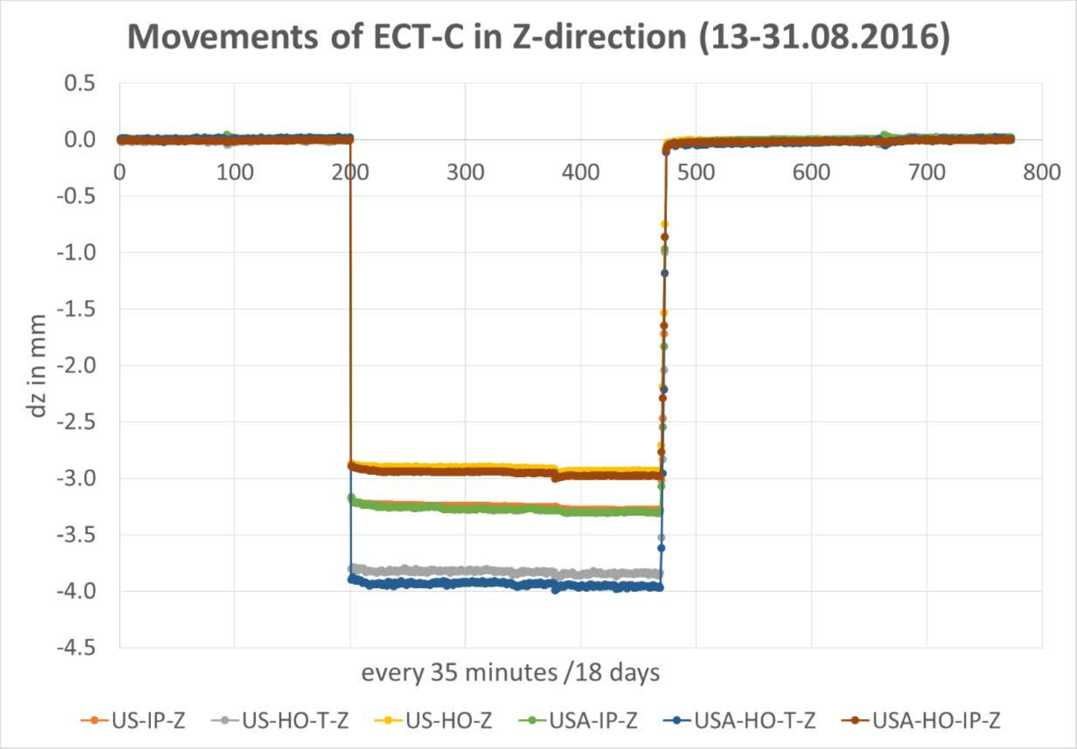


Results ATLAS closure

- Intensive use of ADEPO for closure of Technical Stop 2015/16
- Six detectors closed with in average 3 iterations of BCAM measurements
  - Maximum of 7 iterations
  - Average time for mechanical correction ~ 20 minutes
- Average difference of ADEPO results to reference position
  - 0.3 mm along monitored X, Z directions (or closer with respect to nominal values)
- Results for each detector confirmed by Laser Tracker measurements
  - Single iteration for survey

Short-term results for ECT – B-Fied on/off

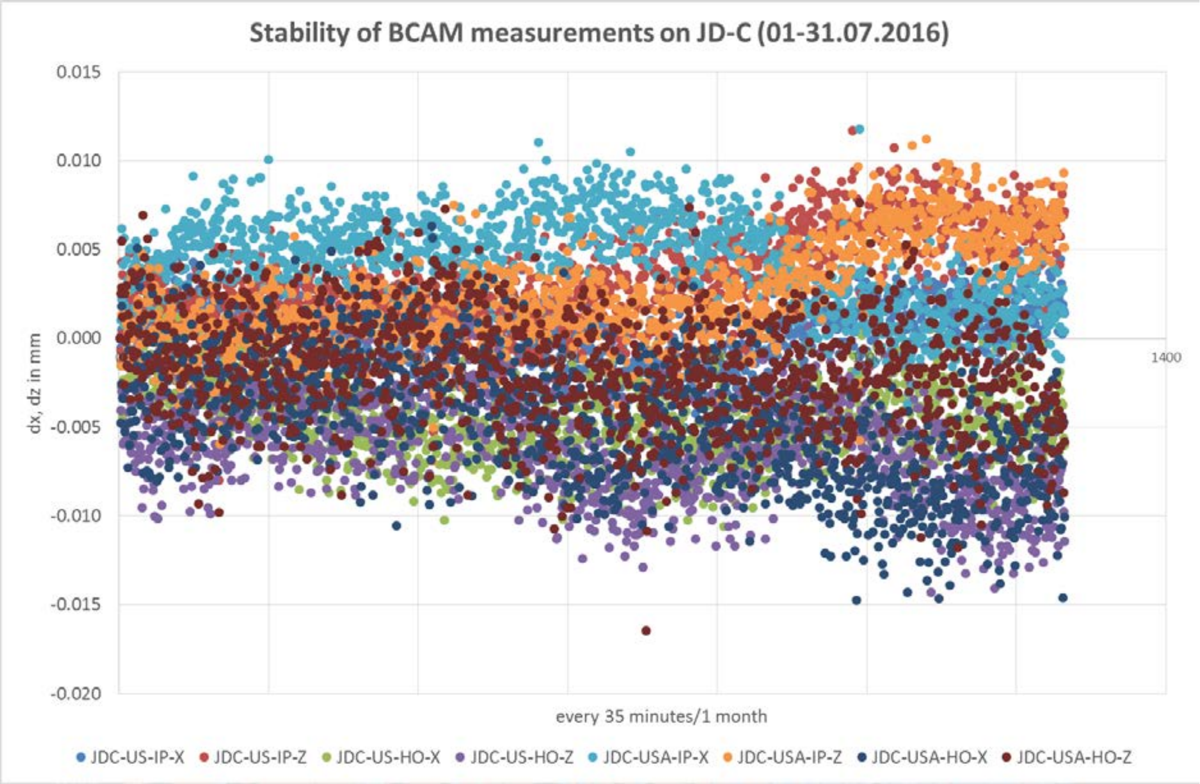
- Demand from physics side for movement of ECT under magnetic field for field map
- Due to strong magnetic field no survey measurements available previously (only Muon Barrel alignment system)



- Quench at measure 200
- Back to nominal after 1 week with magnet down
- Movement of 3-4 mm with b-field of BT and ECT
- Deformation of BCAM support due to B-field
  - US-IP-Z, USA-IP-Z

Medium term results (1 month)

- One month repeatability on individual BCAMs of Small Wheel and JD C-side
  - Average precision (repeatability 1 month): 2-3 µm
- BCAM lines of 1.5-3.0 m measure a detector stability within ± 0.015 mm



Conditions:
No change of magnetic field!

Conclusion

- System installed and commissioned during LS1 2013-2014
- ADEPO has two operating modes:
  - On-demand for closing operation
  - As monitoring system (magnetic field, long-term)
- First use for relative movements during closure of LS1
- Successful use in TS2015/16 with gain of 2-3 hours for each of the 6 moving detectors during closure operation
  - Average 3 iterations using ADEPO
- Geodetic survey of detectors maintained and justified by long-term movements at level of civil engineering

- **ADEPO generates substantial gain in time, precision (relative) and comfort for technical coordination and survey team !**

Outlook

- Consolidation of few BCAM lines due to differences in 3D model with respect to the as-built construction

- Complete implementation of:
  - proposed adjustment using additional observations
  - blunder detection to identify in-valid measurements

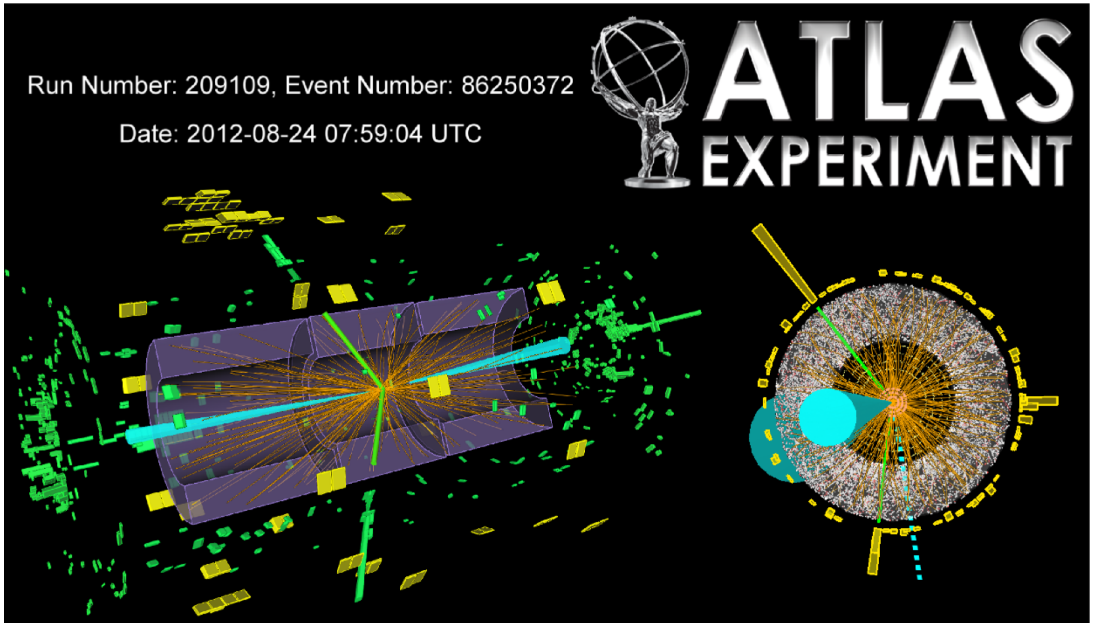
- Acquisition of reference data after each movement during detector opening to minimize influence of mechanical deformation
  - Weight of shifted detectors represents ~2500 tons

- **Possible increase of time savings at a level of ~4 hours for each single detector closure**

➔ Up to 20 % gain in ATLAS closure schedule for the technical coordination

Thanks for your attention!

Candidate Event Selected in Higgs Search Analyses



CERN

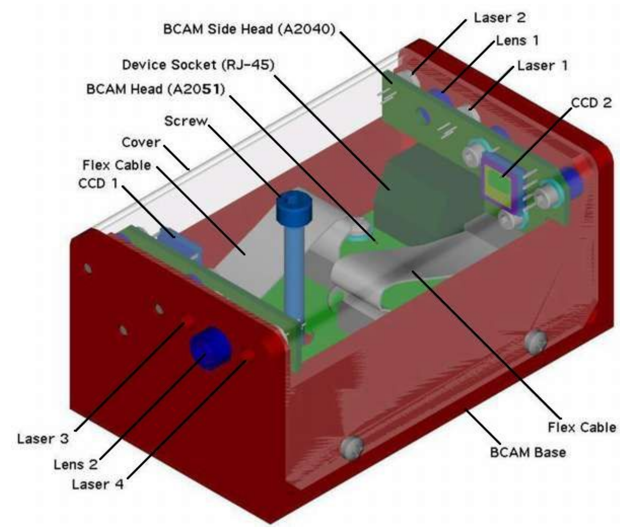
EN

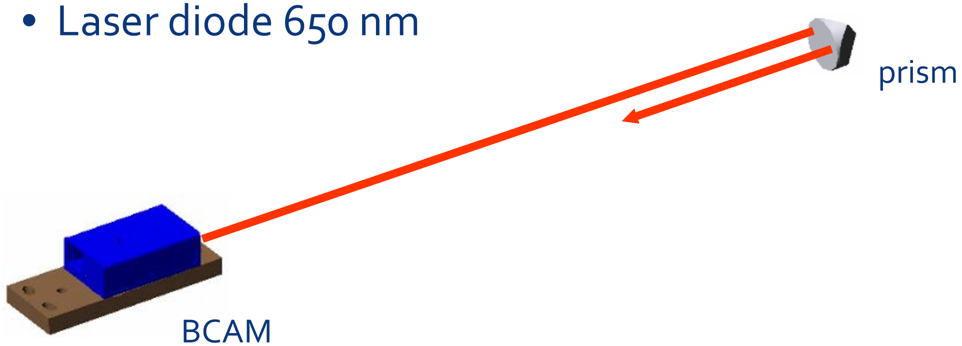
ENGINEERING
DEPARTMENT

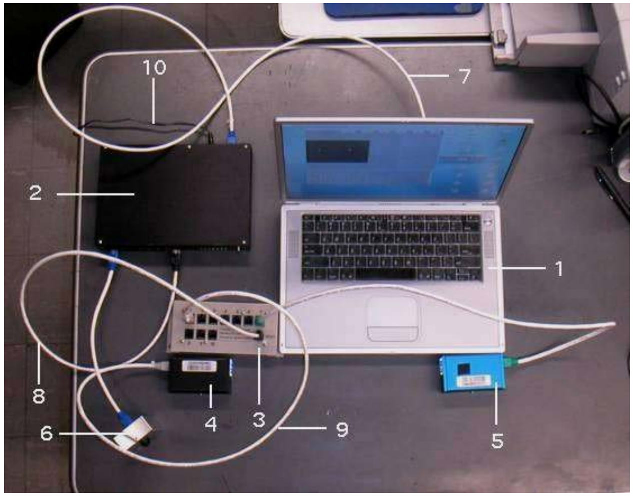
BCAM equipment

Brandeis CCD Angle Monitor – BCAM:

- BCAM resists magnetic field and radiation as developed for ATLAS Muon system
- Sensor size 344 x 244 pixel, 10 μm/pixel
- Field of view: 40 mrad x 30 mrad
- Camera focal length: 75 mm
- Minimal working distance 0.7 m
- Absolute precision 50 μrad (2D)
- Relative precision 5 μrad (2D)
- Isostatic mount system
- Delivered calibrated
- Laser diode 650 nm

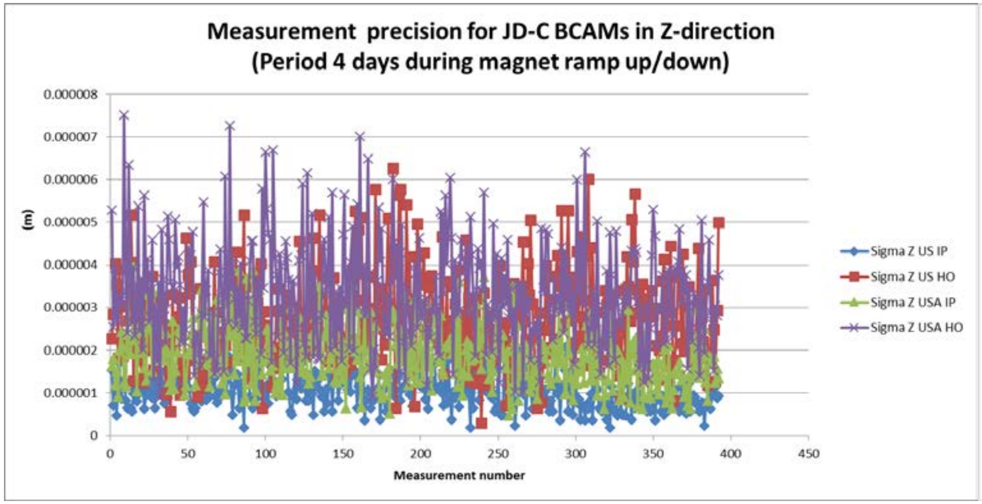


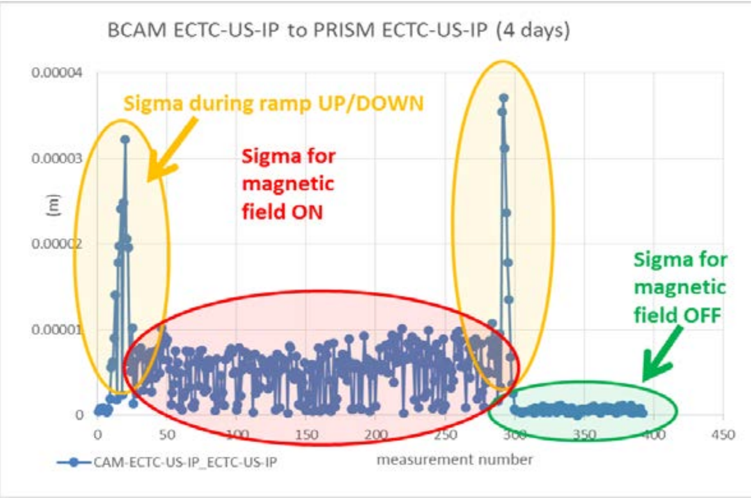




Results ECT ramp up/down (short-term)

- Due to high magnetic field no survey measurements available before (only Muon alignment system)
- Demand from physics side for movement of ECT under magentic field for magentic field map

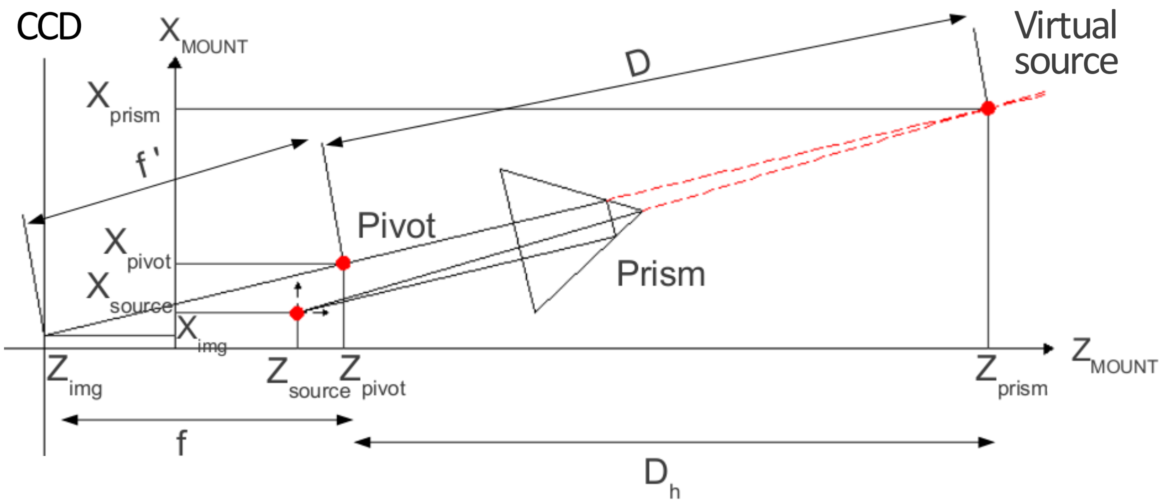




Formulas corner cubes

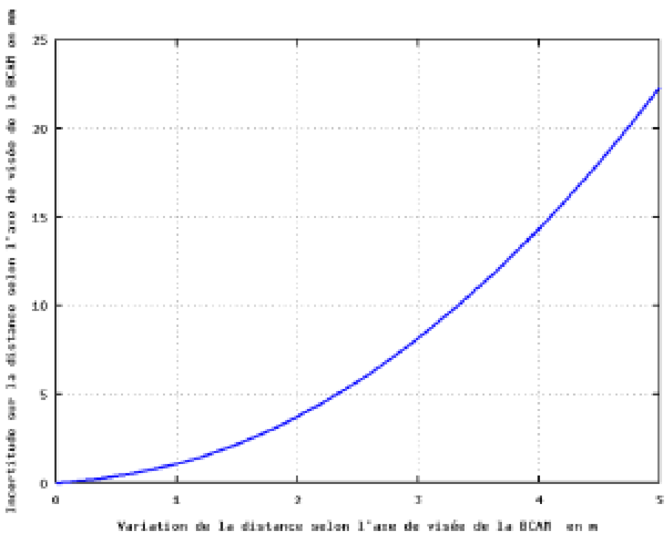
- BCAMs perpendicular to beam/prism (5° => error ~10 μm)
- In case of BCAM-Prism measurements the virtual source is measured at twice the distance of the real one
- Use of theoretical values for projection of D on Z axis
- In the BCAM mount system the following formula applies:

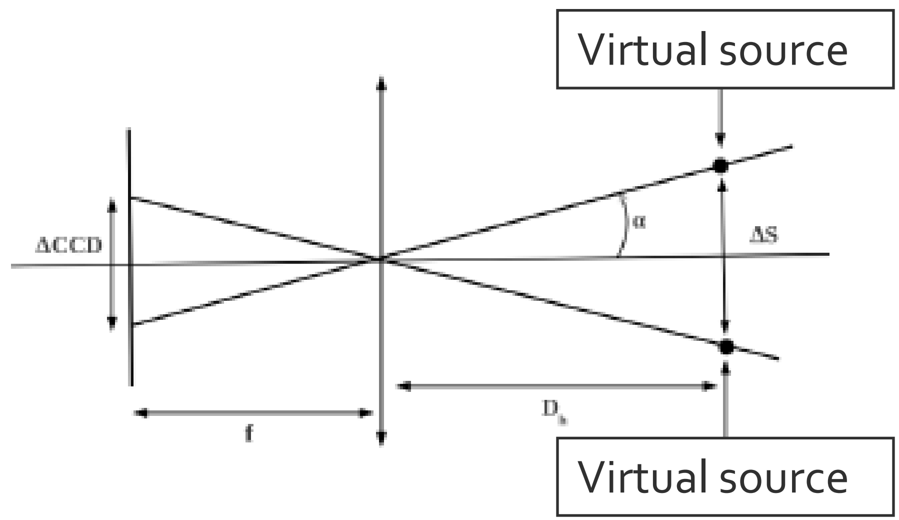
$$\vec{P}_{prisme} = \frac{1}{2} \cdot \sum_{i=1}^{2} (\vec{S}_{source_i} + \vec{P}_{pivot} - (\vec{P}_{img_i} - \vec{P}_{pivot}) \cdot \frac{D}{f'})$$



Formulas corner cubes

- Projection of D on Z-axis is: $D_h = \frac{\Delta S}{2 \tan \alpha}$
- Error propagation corresponds to: $\sigma_{D_h} = \frac{D_h}{\Delta S}\sqrt{\sigma^2_{\Delta S} + 8 D_h^2 \sigma_\alpha^2}$

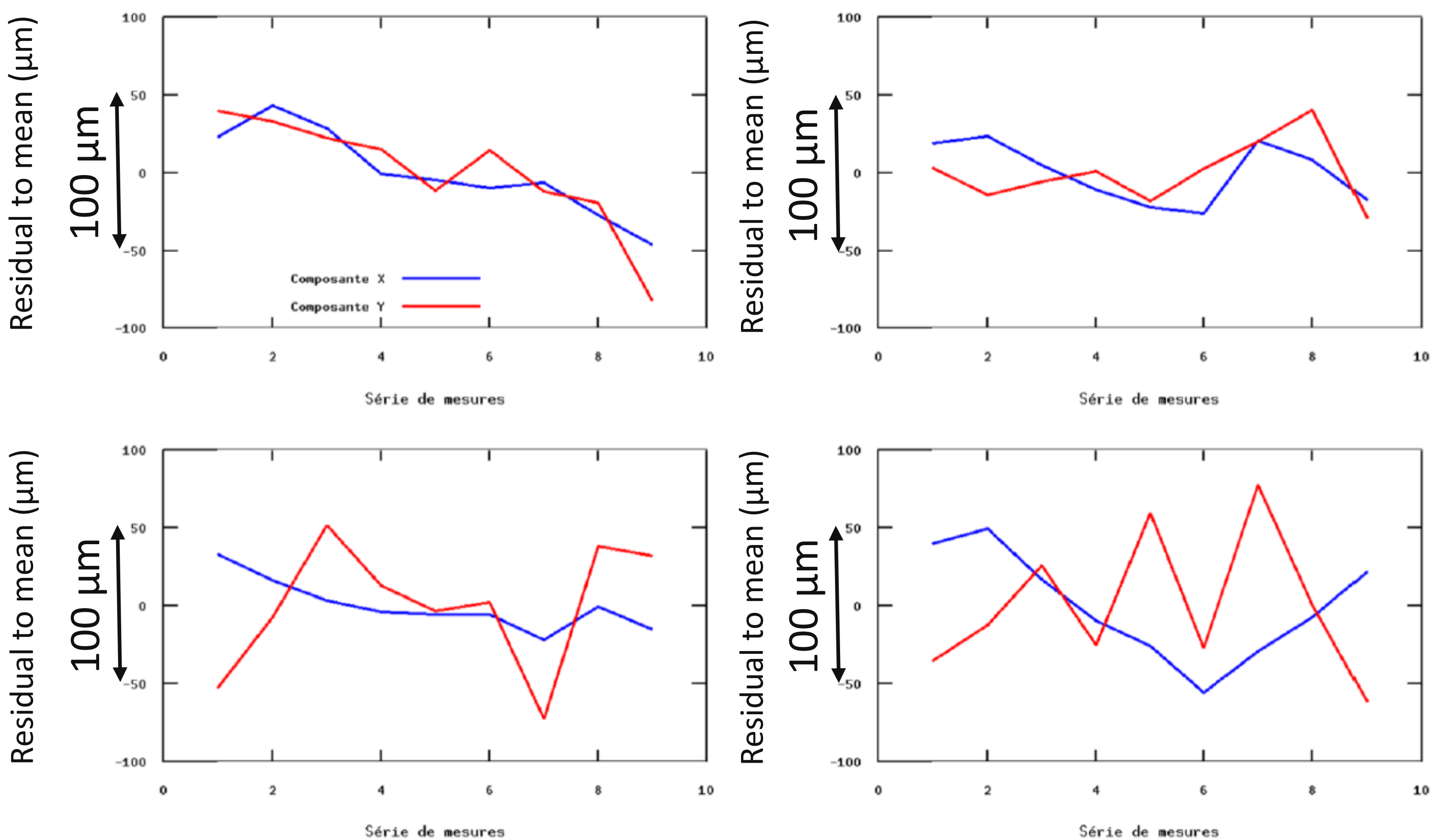




- **Precision of 4 mm at 2 m results in an error of 5 um for XY directions**

Validation results

Result of displacement test at 2.1 m: mean offset = 35 µm+- 11 µm



Adjustment concept

- Single detector is considered as rigid and non-deformable object
- As consequence
  - Observations are linked by constraints
  - Calculation of prism coordinates is linked by additional observations
- Equation systems for a single detector with 4 prisms:

$$
\begin{aligned}
f_1 &= \sqrt{(X_{p_1} - X_{p_2})^2 + (Y_{p_1} - Y_{p_2})^2 + (Z_{p_1} - Z_{p_2})^2} - D_{1-2} \\
f_2 &= \sqrt{(X_{p_1} - X_{p_3})^2 + (Y_{p_1} - Y_{p_3})^2 + (Z_{p_1} - Z_{p_3})^2} - D_{1-3} \\
f_3 &= \sqrt{(X_{p_1} - X_{p_4})^2 + (Y_{p_1} - Y_{p_4})^2 + (Z_{p_1} - Z_{p_4})^2} - D_{1-4} \\
f_4 &= \sqrt{(X_{p_2} - X_{p_3})^2 + (Y_{p_2} - Y_{p_3})^2 + (Z_{p_2} - Z_{p_3})^2} - D_{2-3} \\
f_5 &= \sqrt{(X_{p_2} - X_{p_4})^2 + (Y_{p_2} - Y_{p_4})^2 + (Z_{p_2} - Z_{p_4})^2} - D_{2-4} \\
f_6 &= \sqrt{(X_{p_3} - X_{p_4})^2 + (Y_{p_3} - Y_{p_4})^2 + (Z_{p_3} - Z_{p_4})^2} - D_{3-4}
\end{aligned}
$$

Blunder detection

Stability of sensors and targets is a main problem of alignment systems

- Redundant layout
  - Minimum of 8 observations for 3 unknowns
- Adjustment using additional observations (rigid detectors)
- Identification of invalid lines

The proposed mathematical approach has been successfully tested in validation setup!

- Application of IRLS (Iteratively Reweighted Least Square)
  - Based on L2–norm
  - K. Jacobsen, "Block Adjustment. Institute for Photogrammetry and Surveying Engineering", Univ. Hanover, 2002, Germany

$$\begin{cases} if\ \hat{v}_i < 2 \cdot \sigma_0\ then:\ P_i = 1 \\ else:\ P_i = k \cdot \dfrac{\sigma_0^2}{\hat{v}_i^2}\ with\ k \geq 1 \end{cases}$$

Blunder detection

Stability of sensors and targets is a main problem of alignment systems

- Redundant layout
- Adjustment using additional observations (rigid detectors)
- Application of IRLS (Iteratively Reweighted Least Square)
- Identification of invalid lines

$$\begin{cases} if\ \hat{v}_i < 2 \cdot \sigma_0\ then:\ P_i = 1 \\ else:\ P_i = k \cdot \dfrac{\sigma_0^2}{\hat{v}_i^2}\ with\ k \geq 1 \end{cases}$$