Integration, Installation, and Commissioning of Large Monitored Drift Tube Chambers of the ATLAS Barrel Muon Spectrometer

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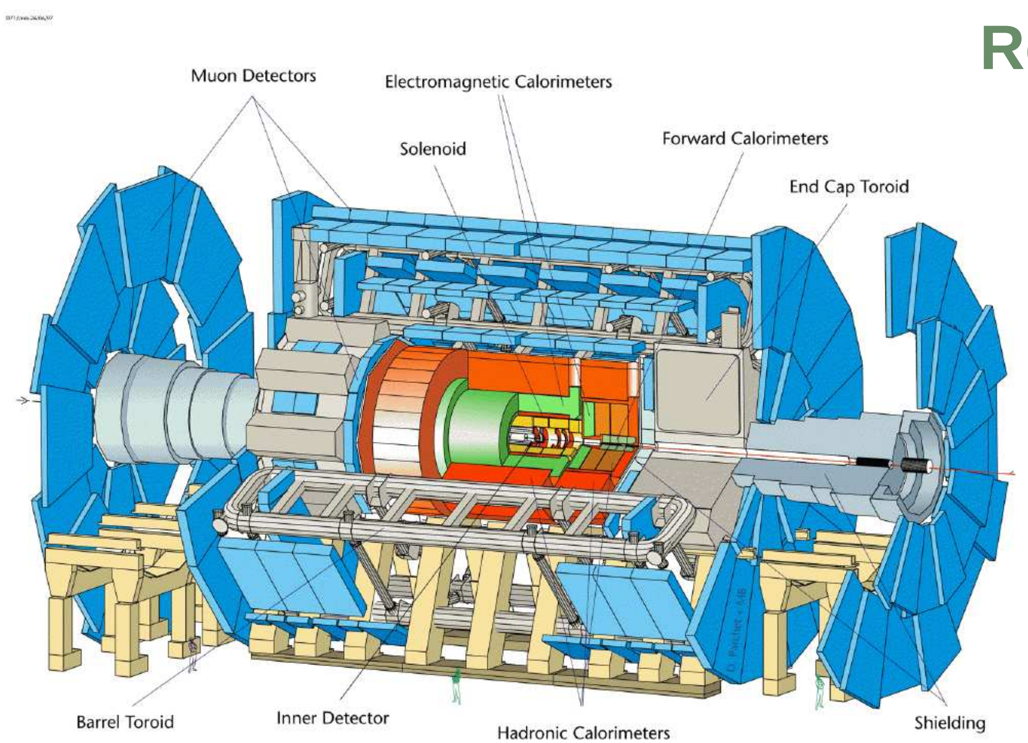
Overview

- Introduction
- Integration and Test of MDT Stations at CERN
- Installation in the ATLAS Detector
- Commissioning of the ATLAS Muon Spectrometer
- Calibration and Alignment of the ATLAS Muon Spectrometer
- Summary

Introduction

The ATLAS Muon Spectrometer

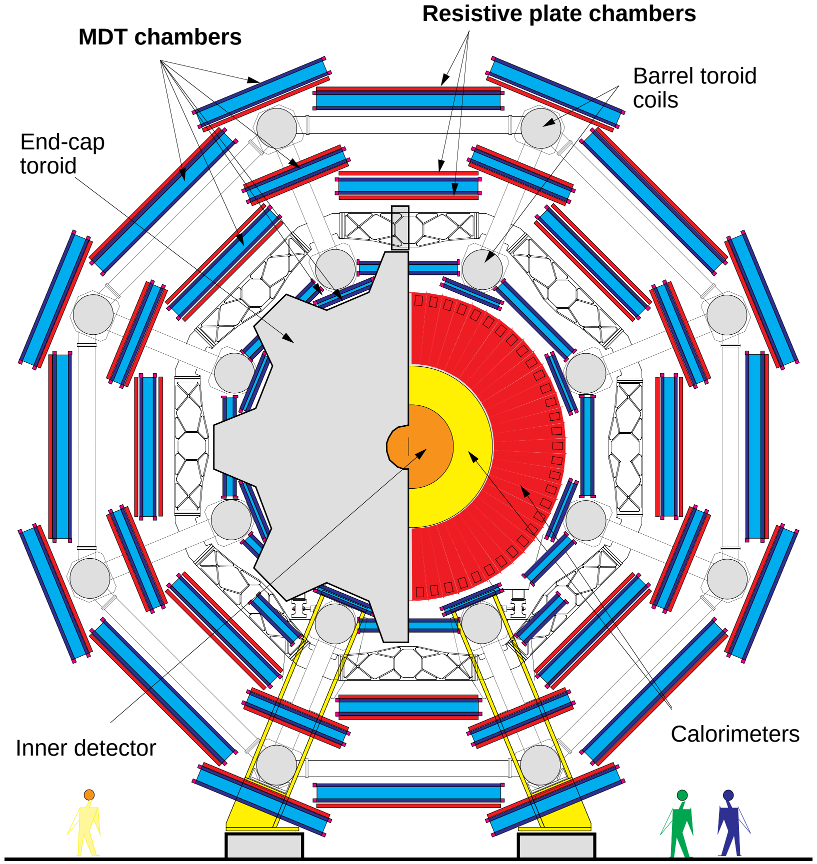
- Physics requirement: $\Delta p_T / p_T < 10\%$ up to 1 TeV
- Stand-alone operation



Realization

- Air core toroid magnet system
  - Dimensions: 45 m $\times$ 25 m
  - Active area: > 5500 m^2
  - 788 trigger chambers
- 1206 precision chambers

The ATLAS Barrel Muon Spectrometer



- **3 Point Sagitta Measurement**
  50 μm point resolution needed
  (including alignment across 5–10 m)

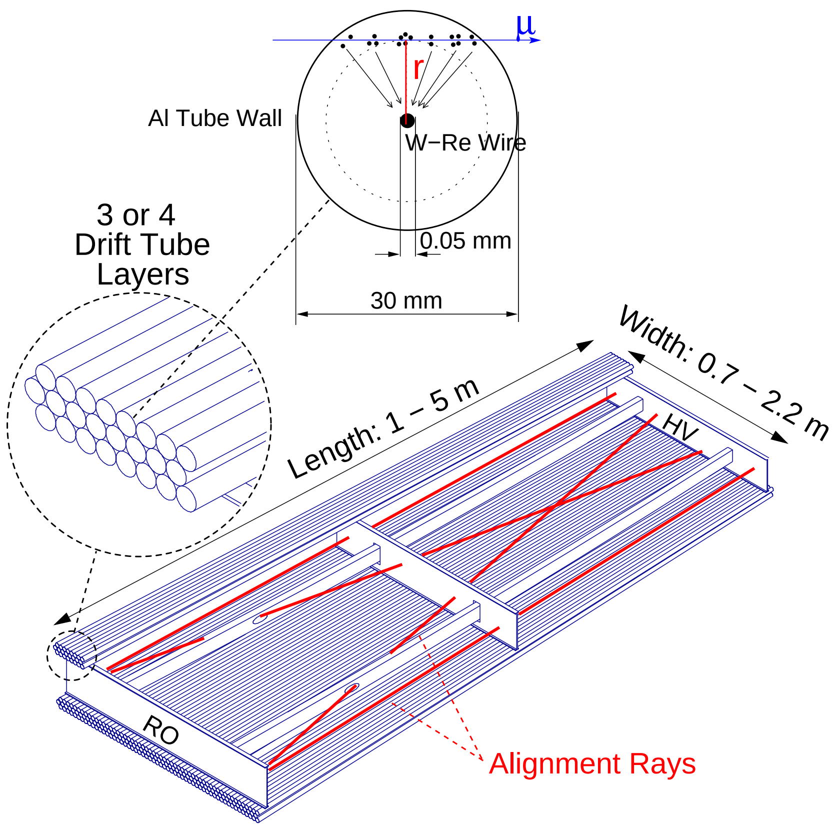
  - 656 Barrel muon stations
    (Status 29.10.06: 519 installed)
  - Outer and middle MDT layers equipped with RPC trigger chambers

88 MDT Chambers for outer-most (BOS) stations built at the Max-Planck-Institut für Physik (MPI) and Ludwig-Maximilians-University (LMU) Munich

Introduction (3)

Monitored Drift Tube Chambers

- Chamber size: 1-11 m^2
- Support frame of aluminum



BOS MDT Chamber size: 3.8 m $\times$ 2.2 m
2×3 layers, 72 tubes per layer

- Drift Tube Operating Parameters
  - Gas mixture: Ar/CO_2 = 93/7
  - Pressure: 3 bar
  - Gas gain: 2×10^4
  - Max. drift time: $\approx$ 700 ns
  - Resolution: $< 100\ \mu$m

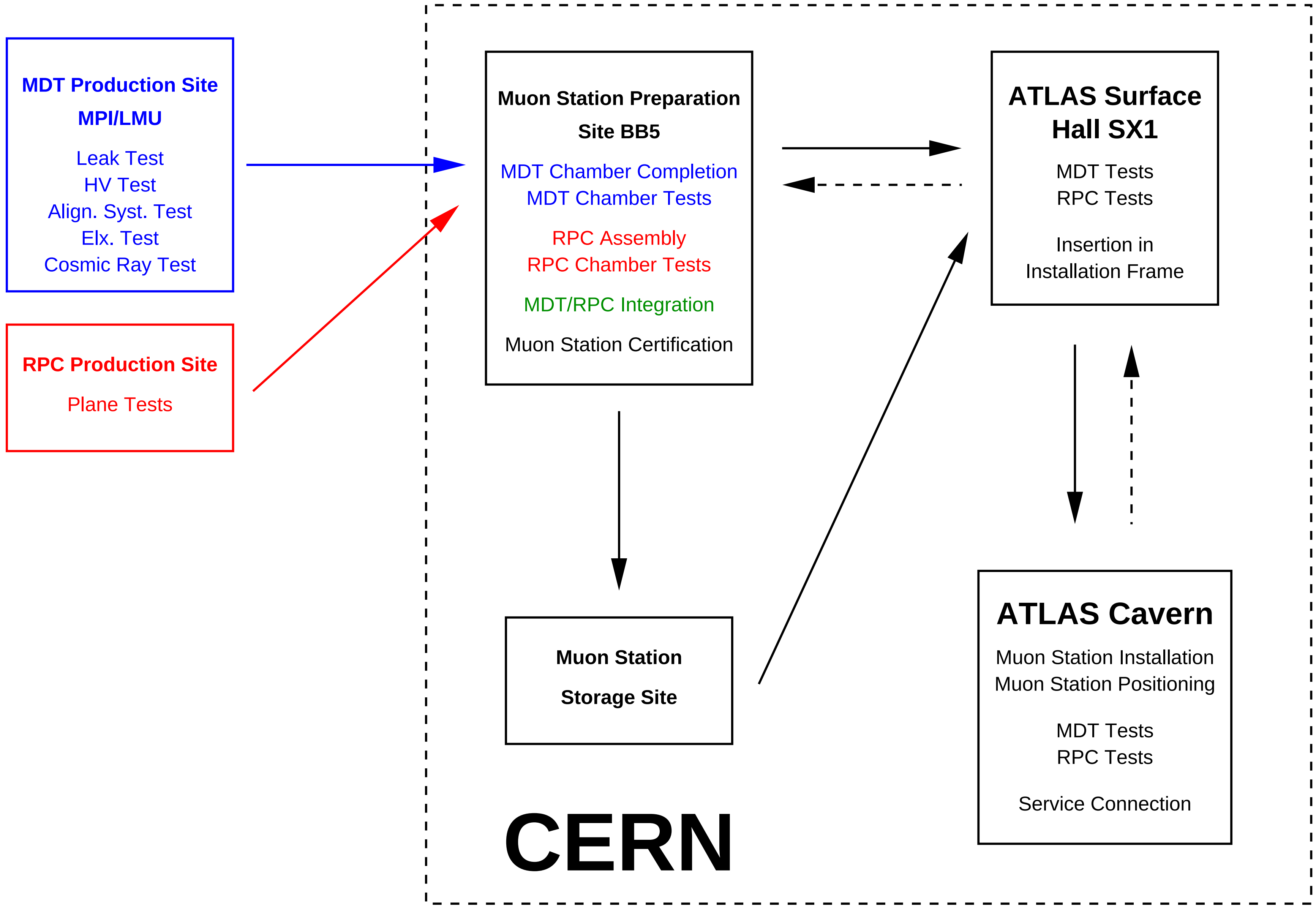
Monitored...

- Optical systems to monitor chamber deformations
- Optical chamber to chamber alignment

See also **N32-1** S. Horvat et al.: Final Evaluation of the Mechanical Precision of the ATLAS Muon Drift Tube Chambers

Introduction (4)

From Production to Installation. . .

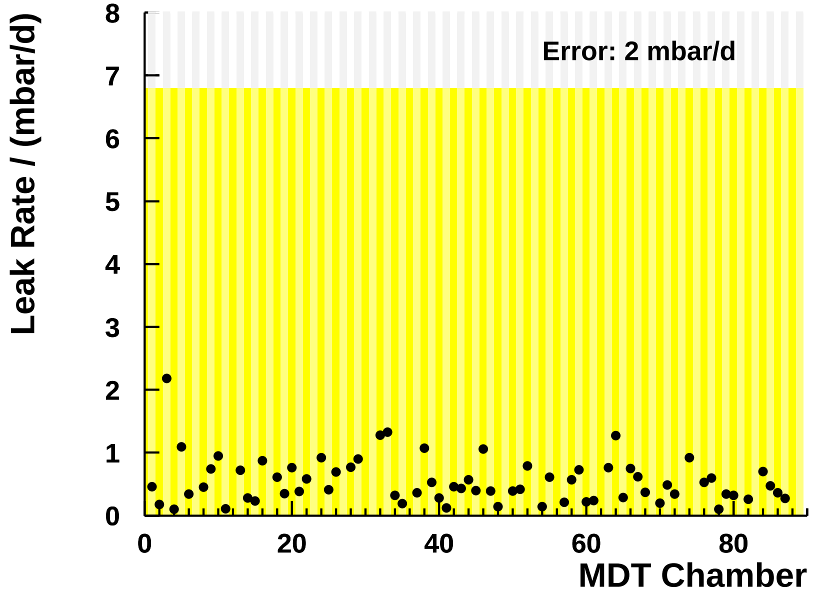


Integration and Test of MDT Stations at CERN

Integration & Tests (1)

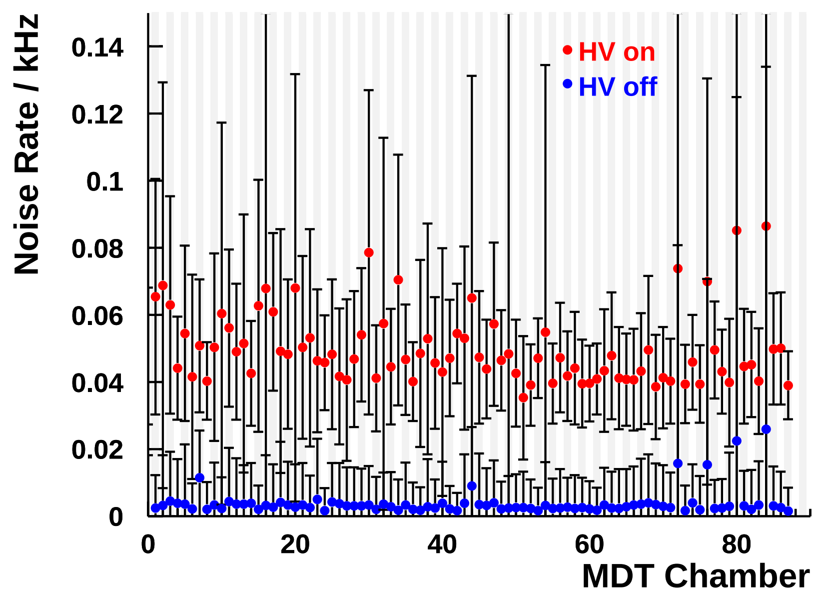
Tests of MDT Chambers after Shipment to CERN

Leak Test



Allowed leak rate: 7 mbar/day

Noise Test



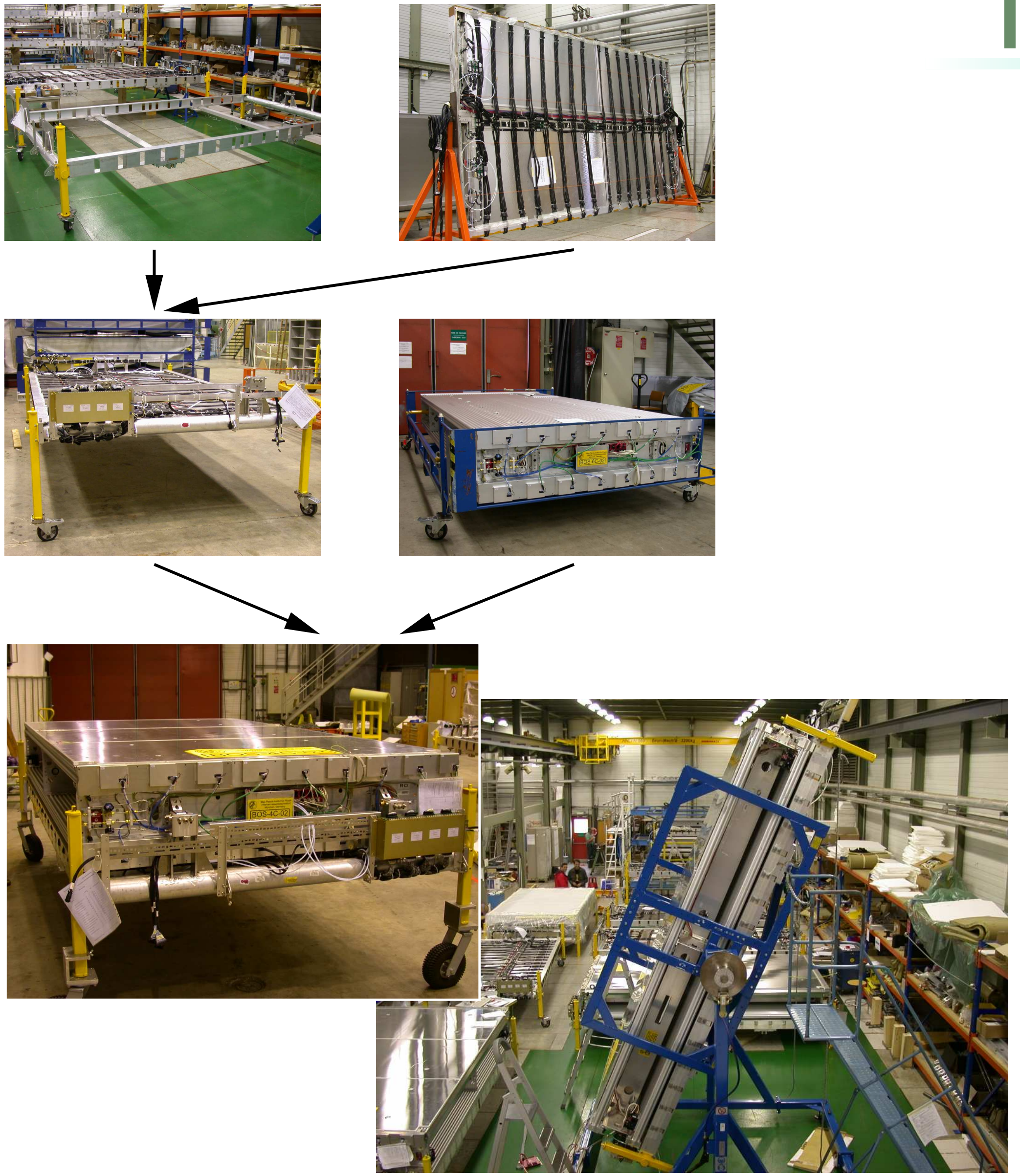
Allowed noise rate: 5KHz

All 88 MDT chambers successfully passed all tests

Very low failures rates for all components

(e.g. only 14 of 36192 tubes with broken wires)

Integration & Tests (2)



- MDT and RPC combined to muon station (weight: 1 t)
- Precise mechanical adjustment: 0.5 mm
- Additional sensors (B-field, chamber-to-chamber alignment)
- Sag compensation (chamber bent to follow wire sag)
- Cosmic Ray certification of completed station

See also **N24-4** A. Di Girolamo et al.: Cosmic Ray Certification of the ATLAS Muon Barrel Chambers

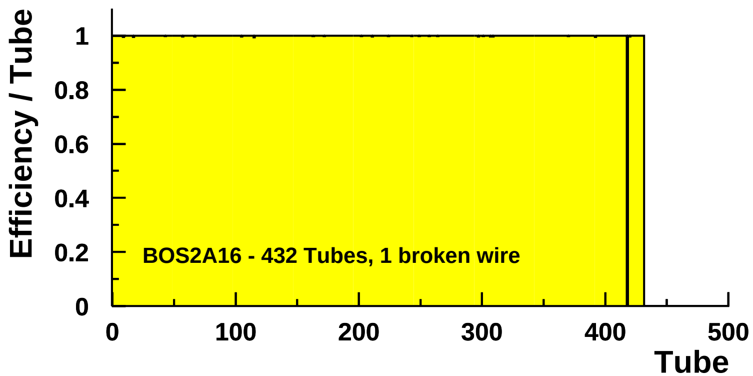
88 muon stations integrated and successfully certified (August 2005 to February 2006 — peak rate: 10 stations per week)

Installation in ATLAS

Installation (1)

MDT Tests at the surface

- Mechanical integrity and re-adjustment
- Pressure test
- Sensors (alignment, temp., B-Field)
- Noise test (w/o HV — bad contacts)
- Pulse test (continuity, broken wires)



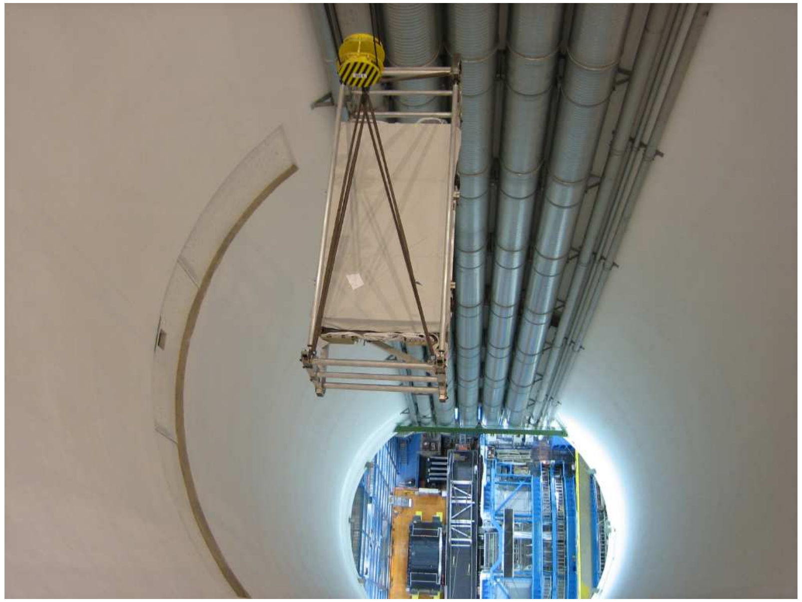
Installation Sequence

- Insertion into the installation frame
- Lowering into the cavern, change of cranes
- Docking of the installation frame to the ATLAS rail system
- Installation of the muon station with two winches
- Final positioning and fixation of support frame on rails

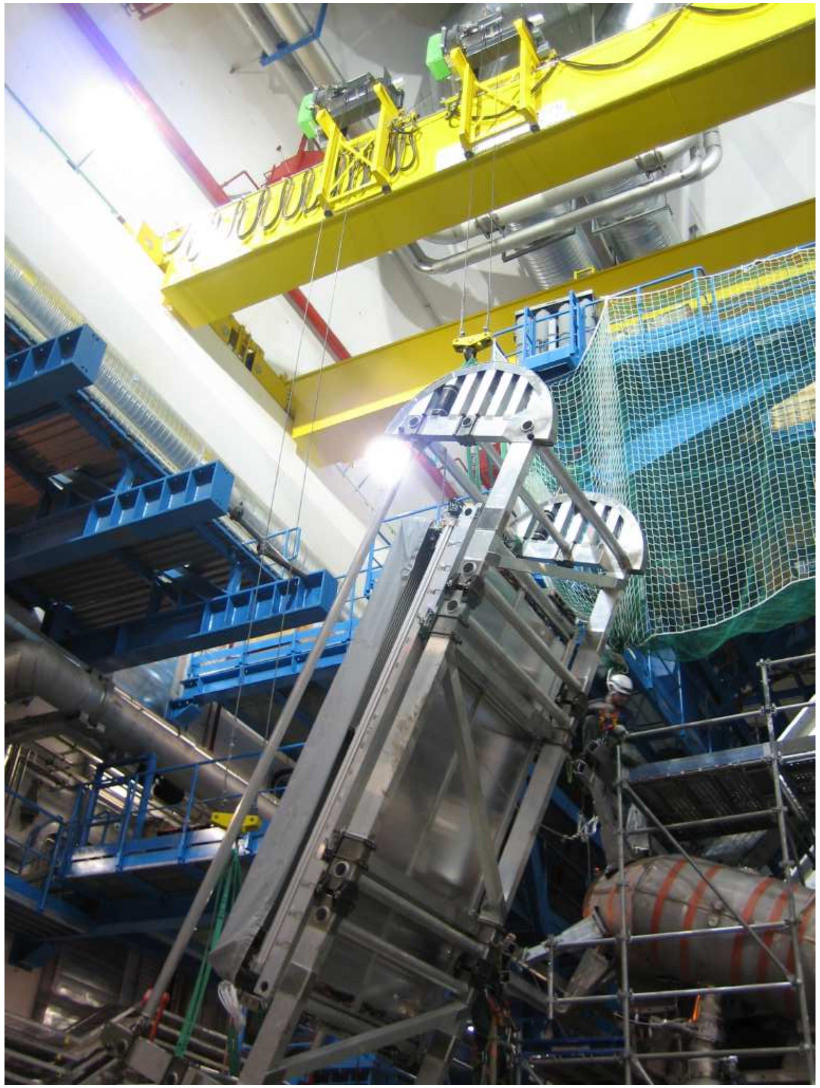
Installation (2)

At the surface

On the way down to UX15. . .



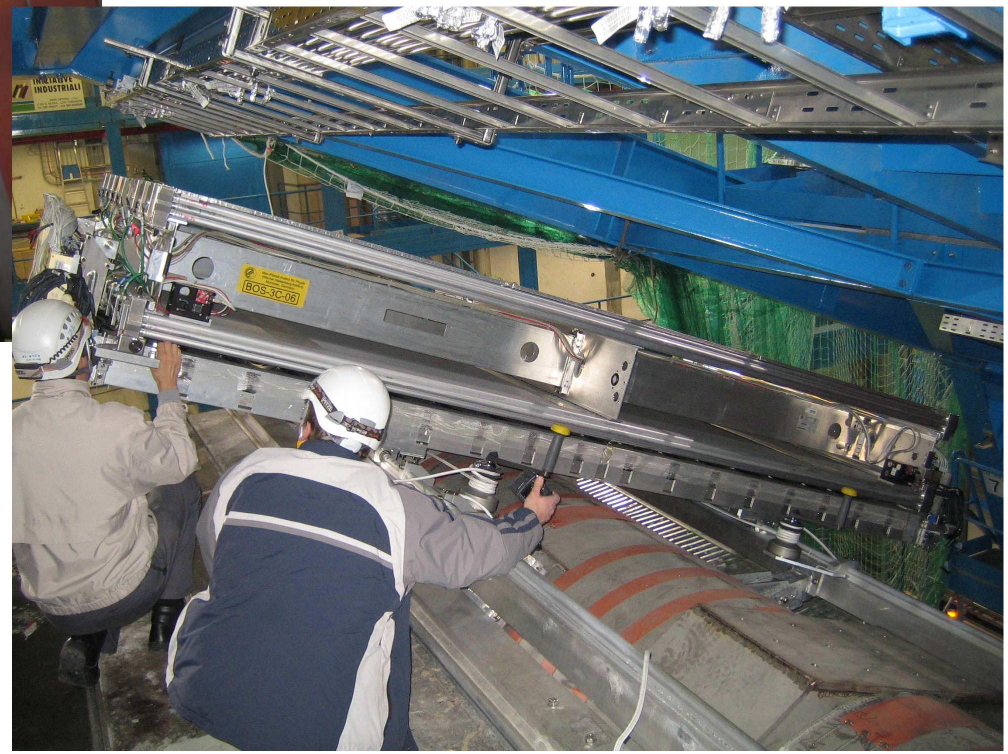
Installation in Sector 08



Installation (3)

Docking to ATLAS rail system. . .

Installed Muon Station



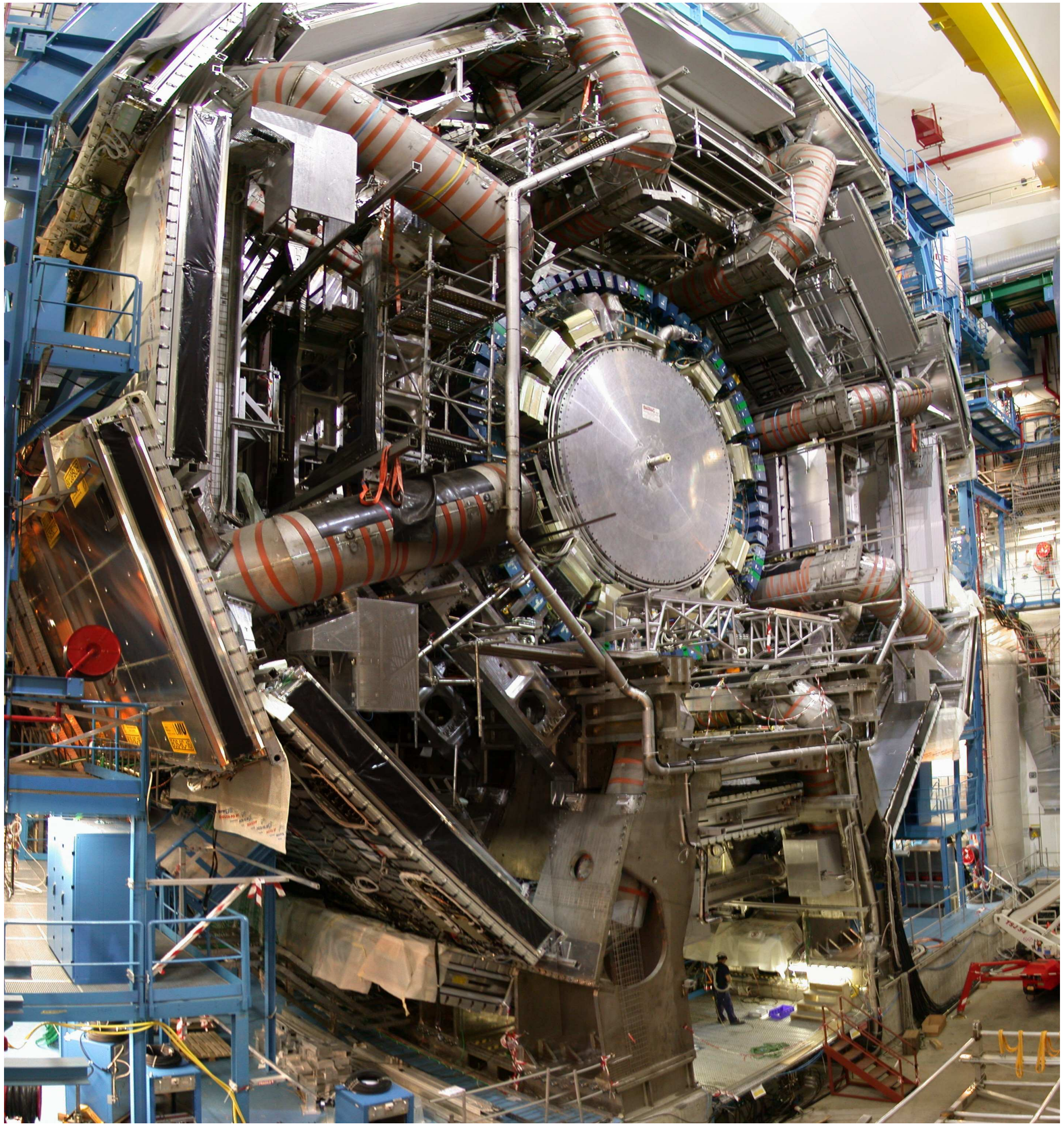
Installation rate: Up to 4 stations / day

Installation (4)

Final Positioning

View of Sector 06

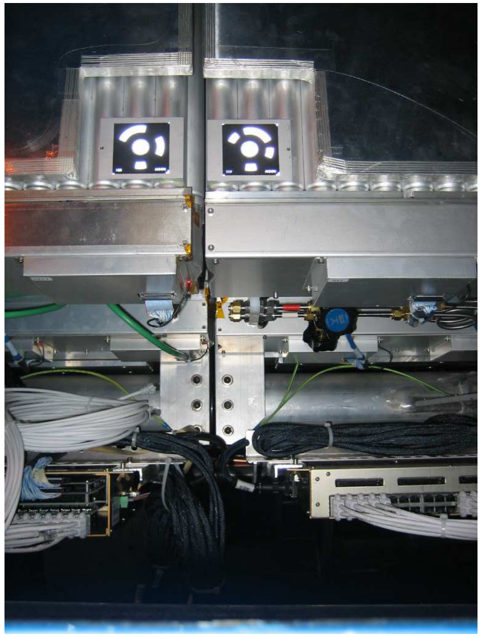
Installation (5)



Installation (6)

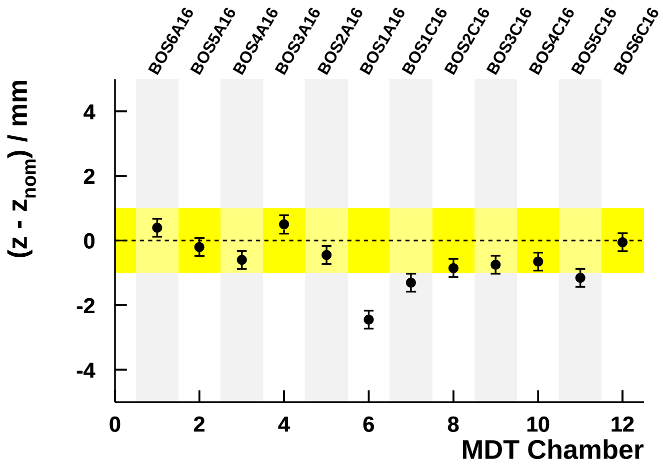
Station Positioning and Survey Results

- 2 of 4 bearings adjustable
- Final position fixed by 1 adjustable rail clamp
- Gap between stations: 8 mm

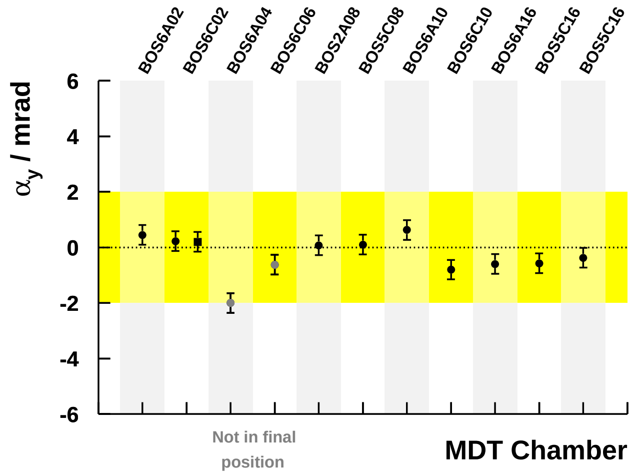


Positioning Rate:
Up to 4 stations / day

MDT Positions Sector 16



MDT Angle α_y



Commissioning of the ATLAS Barrel Muon Spectrometer

Commissioning (1)

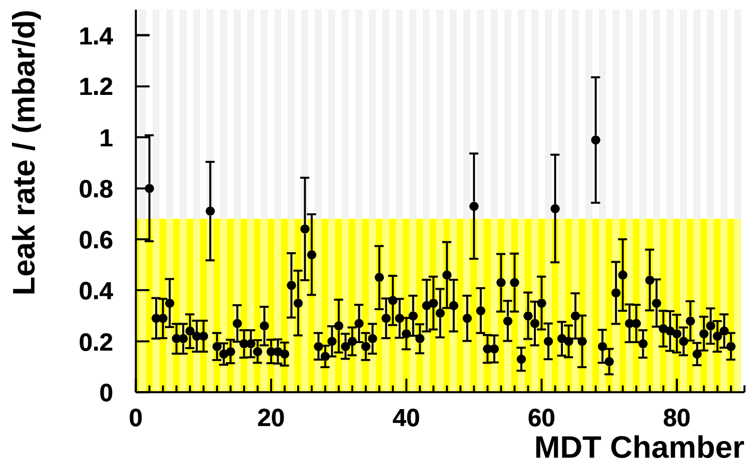
Tests after Installation in the ATLAS

Test	Total	Tested	Failed
Leak rate	88	85	0
HV Test	88	87	4
Sag Comp.	88	87	0
Inplane Align.	352	102	0
Ch.-Ch. Align.	528	130	25
DCS	88	36	0

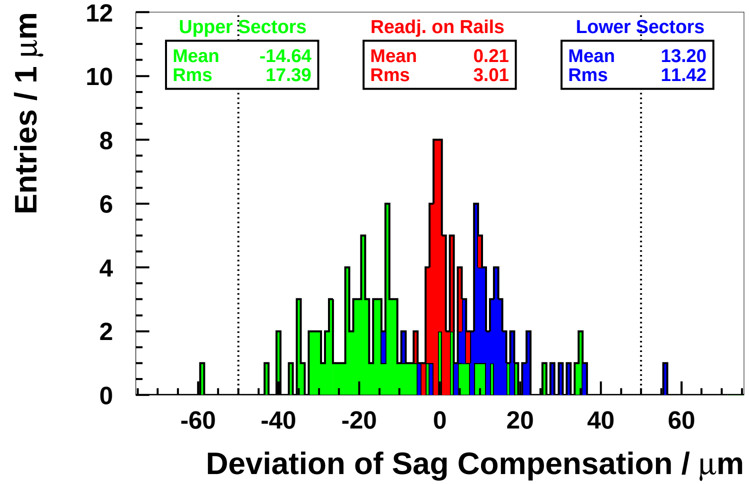
✔ **MDT Chambers OK**

✘ **Alignment sensors need to be checked**

Leak Rates



Sag Compensation



Commissioning (2)

Cosmic Ray Data Taking

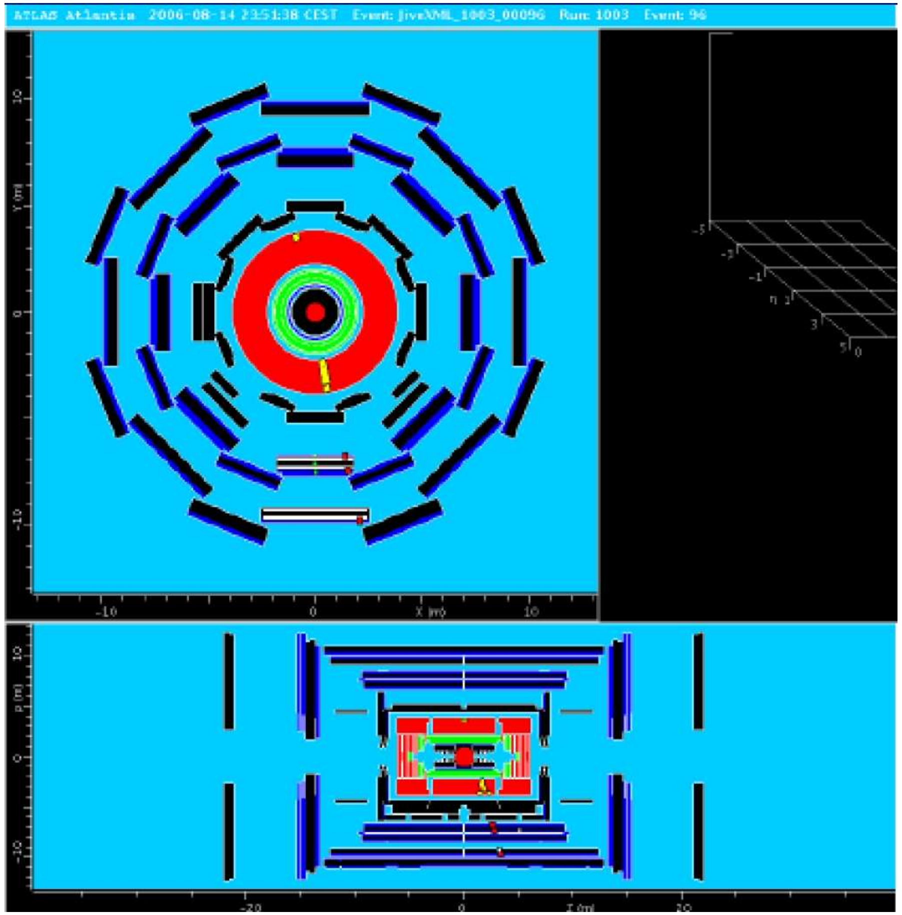
Old Setup

- Sector 13 middle and outer layer:
  2 $\times$ 3 muon stations
- Final DAQ
- Temporary power supplies and cabling
- Temporary gas system

New Setup

- Sector 13 inner, middle and outer layer:
  3 $\times$ 3 muon stations
  Sector 12 and 14 outer layer:
  1 + . . . muon stations each
- Final DAQ
- Final power supplies and cabling
- Temporary MDT gas system

Cosmic Ray Event



Getting ready for first run with barrel toroid magnet on

Calibration and Alignment of the ATLAS Muon Spectrometer

Calibration (1)

Uncertainty on space-drift time relation r(t) must be $< 20\mu$m to achieve required momentum resolution

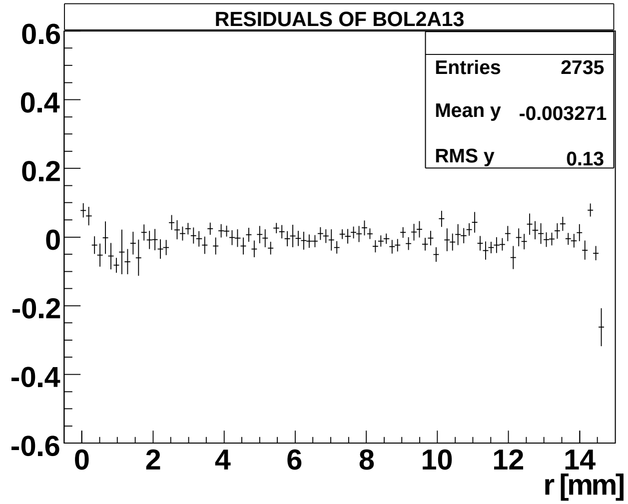
- r(t) depends on external parameters
  - Temperature
  - B-field
  - Gas mixture
  - Background
- Simulation only accurate to 100 μm
- No external reference $\Rightarrow$ Autocalibration
- Dedicated online calibration data stream (muons with $p_{\mu} > 6$ GeV/20 GeV)
- ATLAS calibration rate: once every 7 h (2 h if 5 $\times$ expected bgd)

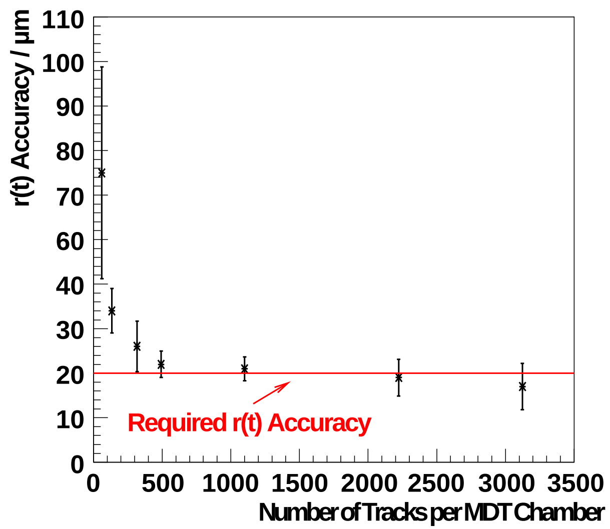
3 calibration centers: Munich — Rome — Michigan

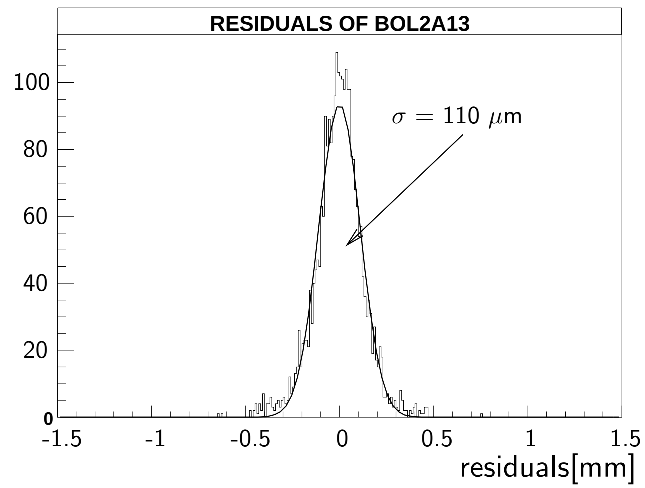
Calibration (2)

Results

- Semi-analytical Autocalibration algorithm[†]
  - Works for all Barrel and Endcap stations (MC studies, confirmed by first cosmic data)
  - Final r(t) independent of $r(t)_{init}$
  - Fulfills time requirements even at $5 \times$ background rate: Only 2000 tracks per station needed (30 min)





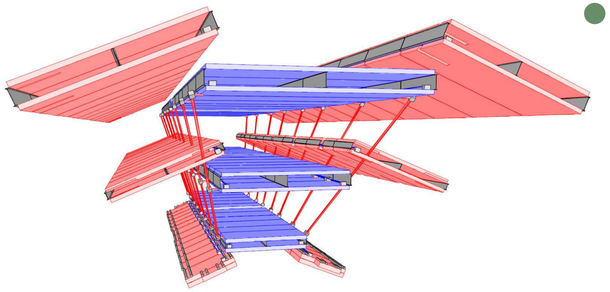


[†]Based on work by M. Deile (LMU, now at CERN)

Alignment (1)

Alignment Procedure in ATLAS

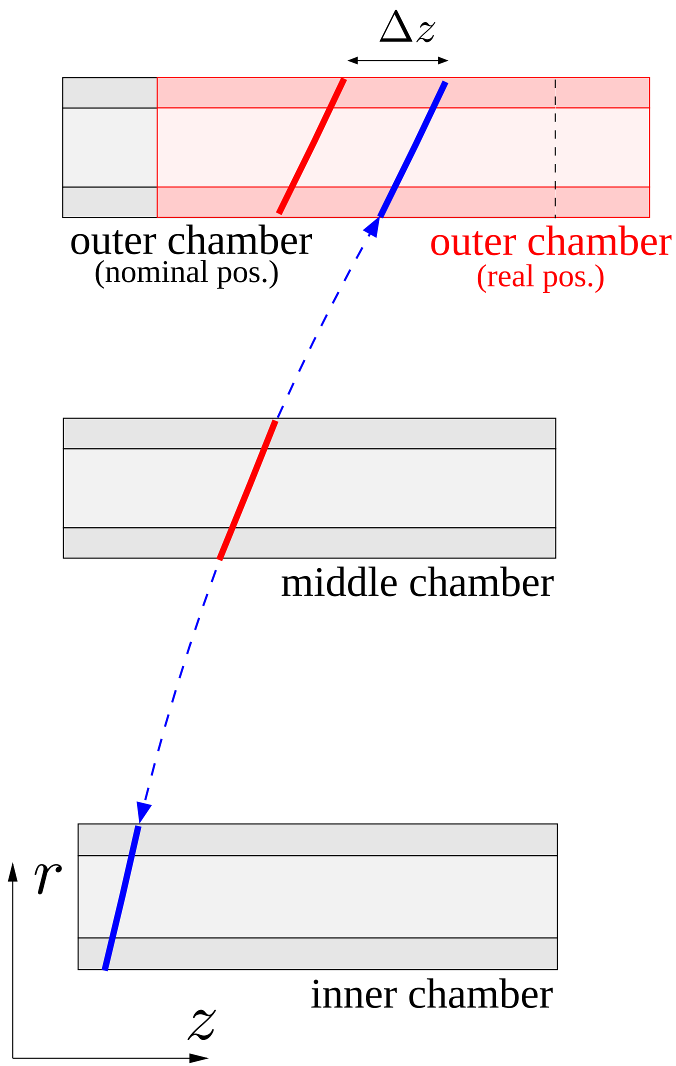
Two complementary approaches for the standard alignment procedure during ATLAS running:



- **Optical alignment**
  - System of LEDs, masks, lenses and CCDs to monitor positions/movements
  - Covers chamber deformations and movements
- **Alignment with tracks**
  - Curved tracks for regions where optical system does not cover all degrees of freedom
  - Cross check of optical measurements

Alignment (2)

Feasibility Study

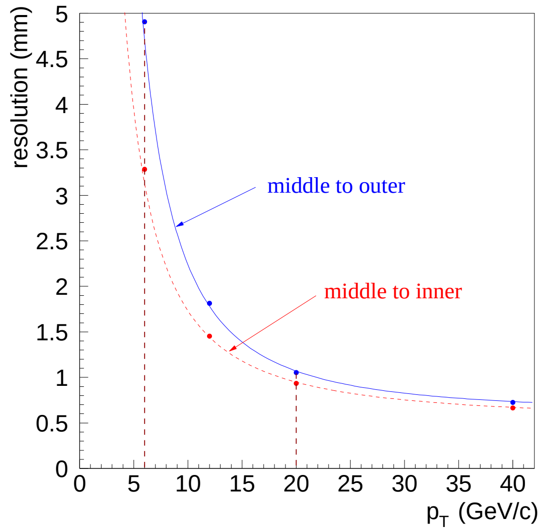


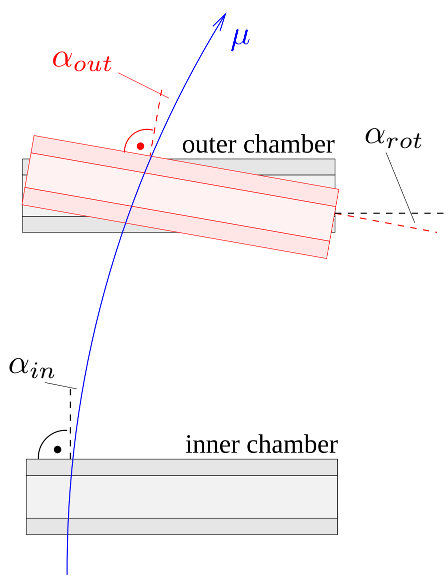
Method

- Determine track segments in all MDT chamber
- Muon momentum estimated from deflection angles in inner and outer MDT
  - Independent of chamber shifts
  - Chamber rotations introduce syst. error
- Extrapolate track segment from middle MDT through B-field to inner and outer MDT chambers

Alignment (3)

Single track extrapolation





Number of tracks for 30 μm precision:

- At 6 GeV: 25000
- At 20 GeV: 1000

Syst. error on momentum measurement:

- Needed for alignment with 30 μm precision: $\alpha_{\rm rot} < 0.05$ mrad
- As installed: $\alpha_{\rm rot} \lesssim 5$ mrad
- Determine $\alpha_{\rm rot}$: Compare slope of extrapolation to track segment
  Number of tracks:
  - At 6 GeV: 2000000
  - At 20 GeV: 80000

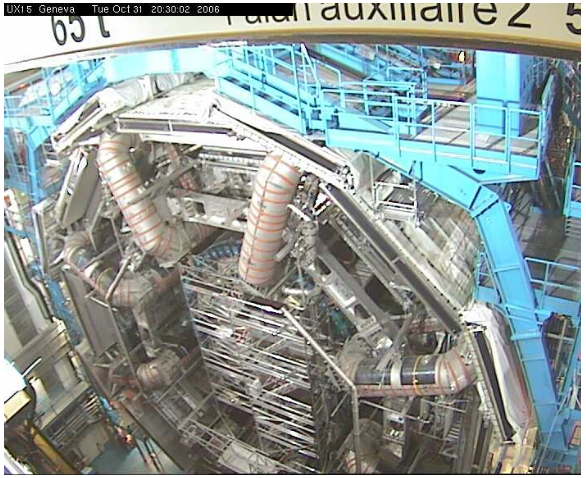
Method will be further studied with cosmic data during Toroid test

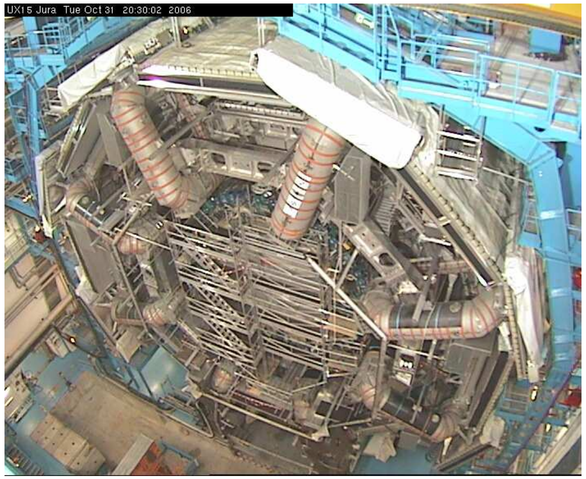
Summary (1)

- **All 88 BOS MDT chambers sucessfully integrated and commissioned** (August 2005 – February 2006)
  - No transport damage
  - No failures
  - Peak integration rate: 10 stations / week

- **All 88 BOS MDT stations sucessfully installed in ATLAS** (February 10th – June 29th)
  - Peak installation and positioning rate: 4 stations / day
  - All stations except 2 in final positions
  - All stations except 4 preliminary tested
    - No serious damage observed
  - Service connections under way
  - Commissioning in progress

Summary (2)





- **ATLAS muon cosmic ray test in progress**
  - 1/4 sector with final read-out
  - 2+ BOS MDT stations participating
  - First data with toroid magnet on expected soon
    - Calibration and alignment studies
- **80% of barrel muon stations installed**
- **First TGC big wheel finished**

ATLAS is getting ready for physics. . .

Thank you

Thank you to all who helped building, testing, integrating and installing the 88 MPI/LMU MDT stations:

AT CERN

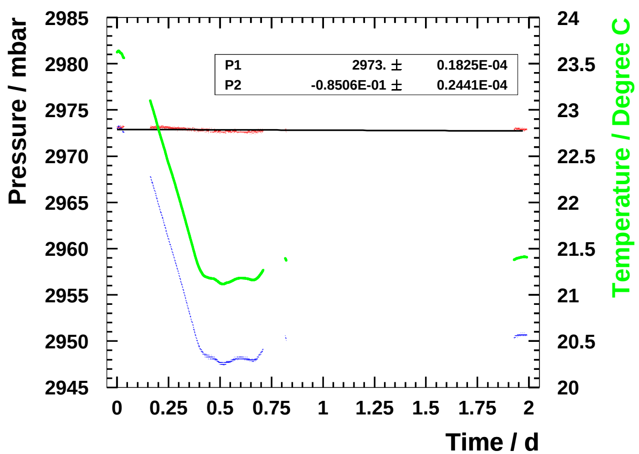
- ATLAS Technical coordination
- The installation teams
- The crane driver and transport people
- Stefanie Zimmermann (CERN) for coordinating the integration efforts
- Fabio Cerutti (INFN Frascati) and Ludovico Pontecorvo (INFN Rome 1) for coordinating the ATLAS surface tests
- The RPC community
- The Saclay alignment team

. . . and our own technicians and engineers, especially

- Sonja Leber
- Thomas Haubold
- Peter Klemm
- Markus Lippert
- Reinhard Sedlmeyer
- Attila Varga
- Holger Wetteskind
- Alexander Wimmer
- Jürgen Zimmer

Additional Slides

Leak Rate Measurement



Determination of leak rate for each Multilayer

- Allowed ATLAS leak rate: $2 \times N_{Tube} \times 10^{-8}$ bar · l/s
  - Checked at MPI/LMU
- Pressure measurement $p(t)$
- Temperature measurement $T(t)$ (18 on-chamber sensors)
- Temperature correction $p_{corr}(t) = p(t) - dT(t) \cdot p(0)/T(0)$
- Linear fit to pressure drop $p_{corr}(t)$
- Duration: 2–4 days (up to 6 MDT)
- Accuracy: 2 mbar/d

Maximum allowed leak rate: 10 × ATLAS leak rate

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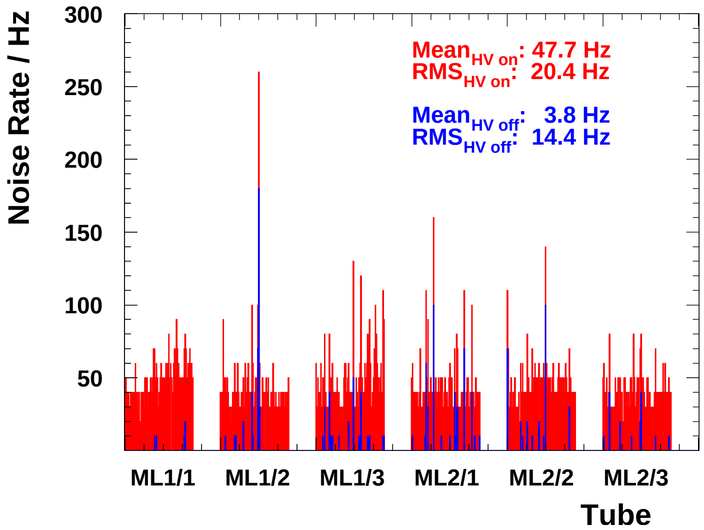
Noise Test



- Random trigger
- Measurement #Hits / Tube
- Convert to noise rate using active time window of read-out electronics (1 μs / Event)
- Eff. threshold: -50 mV
- Measurement with and without HV (3080 V)
  - Identification of dead channels
  - Differentiation electronic and discharge noise

Test of on-chamber electronics and MDT response

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Failure Rates

Component	Total Number	In Munich	At CERN	Percentage
Leaky O-Ring Seals	289712	0	0	0
Disconnected Tubes	36192	18	1	0.05
Broken Wires	36192	11	3	0.04
Frontend-Elx Cards	4876	50	40	1.85
HV Splitter Boxes	88	0	3	3.41
DCS Boxes	88	0	4	4.55
T-Sensors	1584	2	3	0.32
Alignment-Sensor comp.	1056	0	3	0.28
B-Field Sensors	176	—	3	1.70

Very low failures rates in all categories

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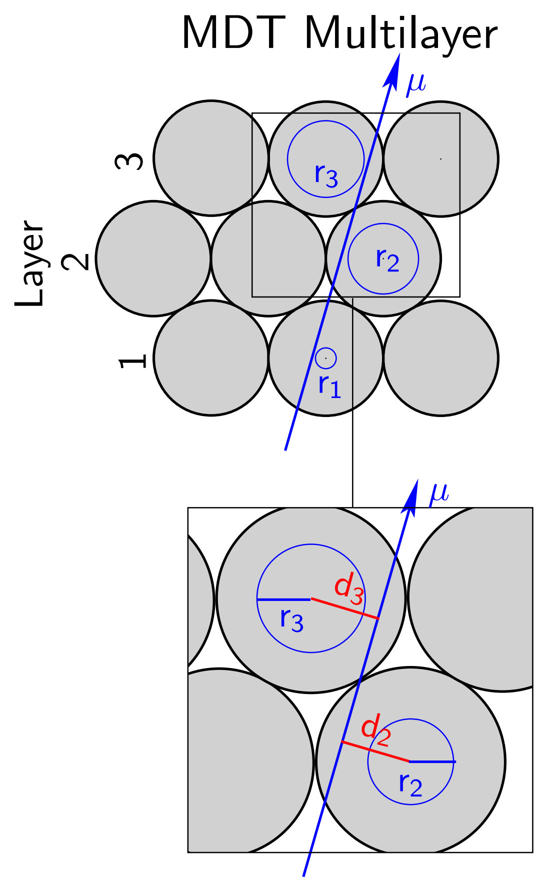
Autocalibration (1)

Autocalibration: Determination of the space-drift time relation r(t) without an external tracking reference

Needs: Initial space-drift time relation $r(t)_{init}$



Idea:

Use $r(t)_{init}$ to reconstruct straight segments in multilayers

Principle of the Autocalibration:

- $d_k :=$ distance k-th anode wire $\leftrightarrow$ track
- $r(t_k) :=$ drift radius of the the k-th hit
- Residual $\Delta(t_k) := r(t_k) - d_k$
- Use $\Delta(t)$ to improve $r(t)_{initial}$

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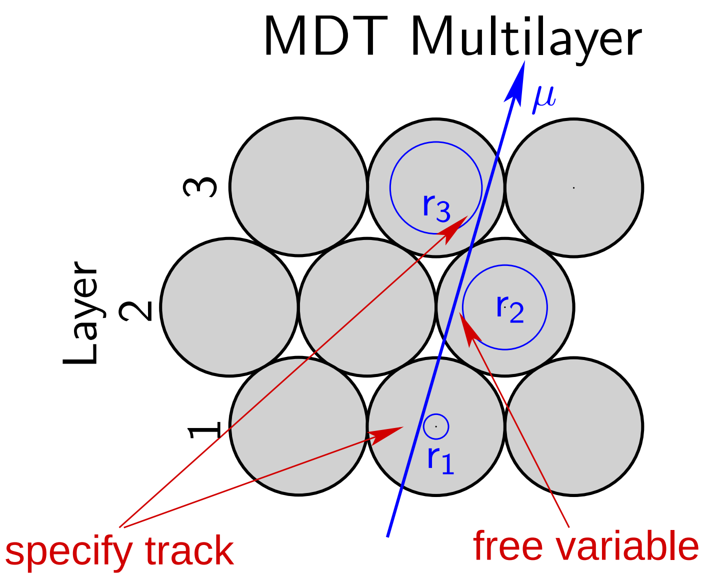
Autocalibration (2)

Semi-analytic Autocalibration

Residuals $\Delta(t)$ can be calculated analytically: $\Delta(\delta r(t_1), \delta r(t_2), \delta r(t_3))$

Problem:

For a chamber with three layers it is in general impossible to define all three variables $\delta r(t_k)$, for $k = 1..3$



Solution:

- Parametrize $r(t)$
- Take n tracks of different angles of incidence and obtain the parameters by minimizing:

$$\chi^2 = \sum_n \frac{[\Delta_{measured} - \Delta(\delta r(t_1), \delta r(t_2), \delta r(t_3))]^2}{\sigma^2}$$

- $r(t)_{new} = r(t)_{initial} - \delta r(t)$

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