



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

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MPI Munich



LMU Munich

- Introduction
- Tests and Commissioning at the Production Site
- Integration and Commissioning at CERN
- Installation in the ATLAS detector
- Summary and Outlook





# Introduction

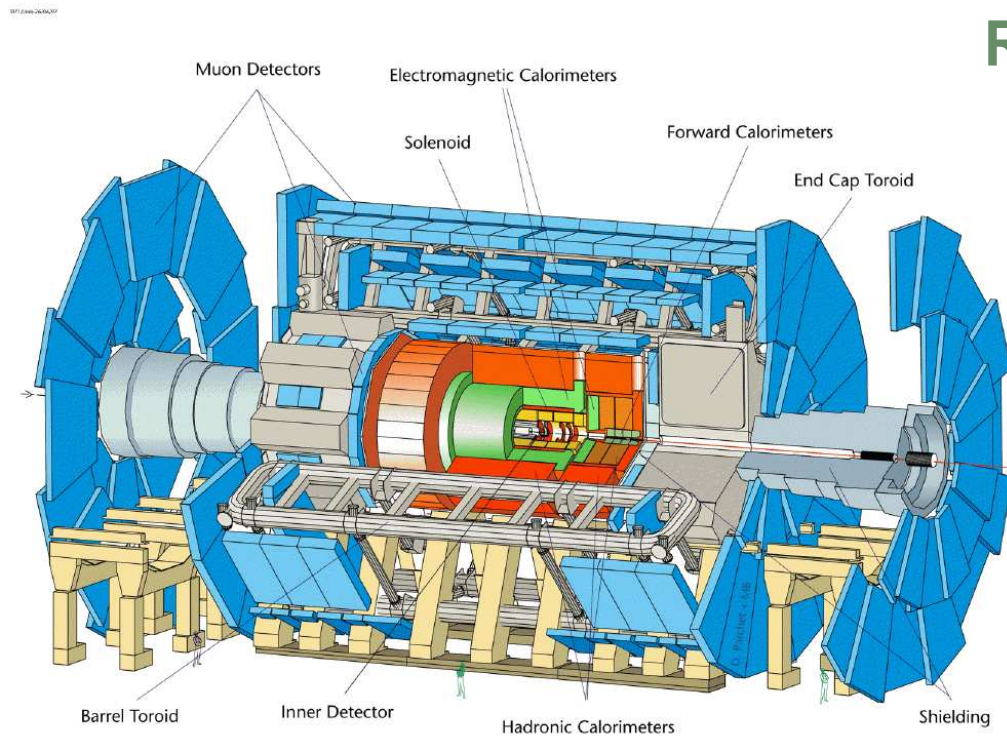
# Introduction (1)

## The ATLAS Muon Spectrometer

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

## Realization

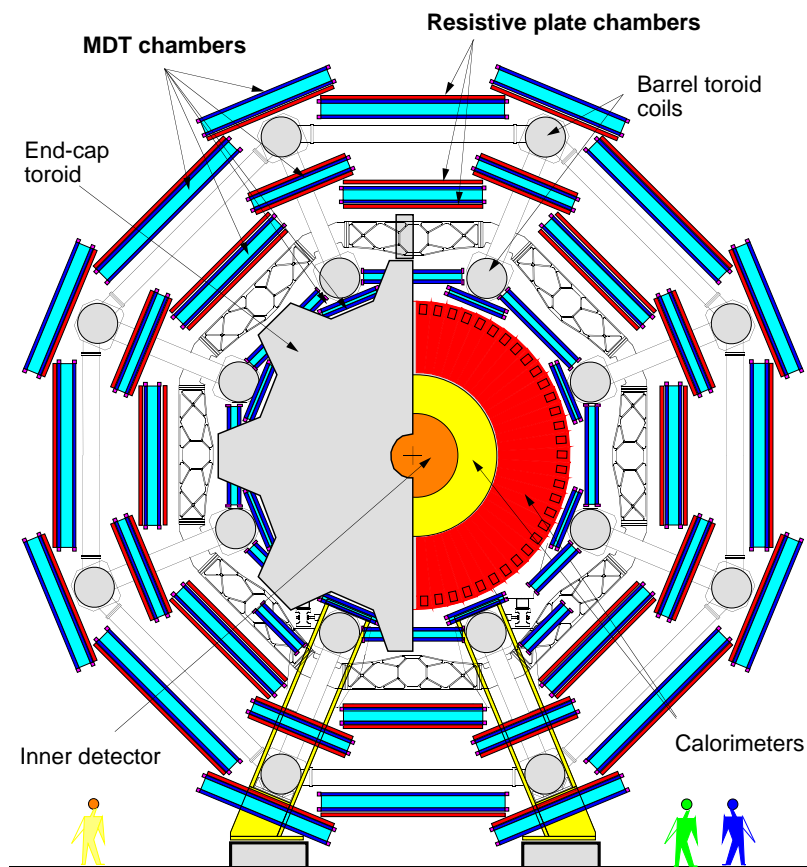
- Air Core Toroid Magnet System
- Dimensions: 45 m  $\times$  25 m
- Active Area:  $> 5500 \text{ m}^2$
- 788 Trigger Chambers
- 1206 Precision Chambers



# Introduction (2)

## The ATLAS Barrel Muon Spectrometer

- **3 Point Sagitta Measurement**  
50  $\mu\text{m}$  point resolution needed  
(including alignment across 5–10 m)

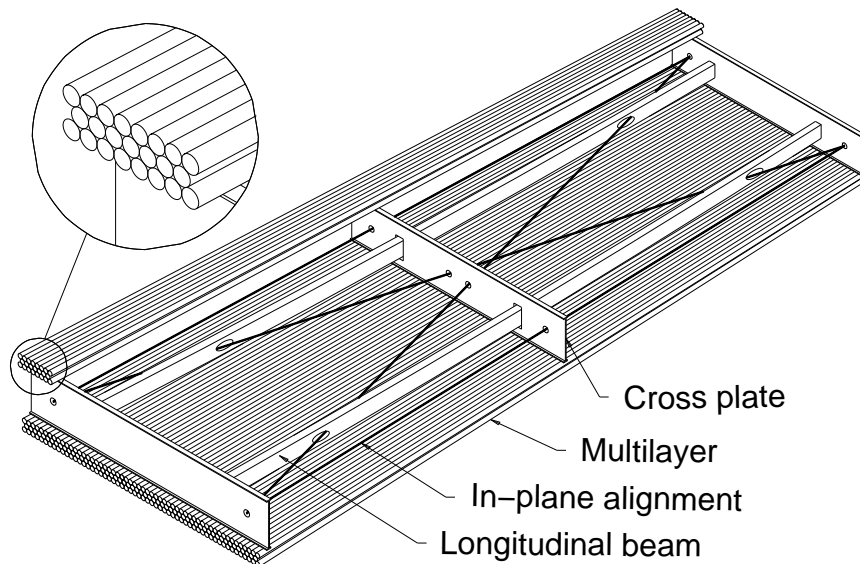


- **576 Trigger Chambers:**  
Resistive Plate Chambers (RPCs)
- **656 Precision Detectors:**  
Monitored Drift Tube (MDT) Chambers  
**88 MDT Chambers for outermost (BOS) stations built at the Max-Planck-Institut für Physik (MPI) and Ludwig-Maximilians-University (LMU) Munich**

# Introduction (3)

## Monitored Drift Tube Chambers

- 2 multilayer of 3 (or 4) drift tube layers
- Support frame of aluminum
- Chamber size: 1-11 m<sup>2</sup>
- Drift tubes
  - 3 cm diameter
  - Gas mixture: Ar/CO<sub>2</sub> = 93/7
  - Pressure: 3 bar
  - Gas gain:  $2 \times 10^4$
  - Max. drift time:  $\approx 700$  ns
  - Resolution:  $< 100 \mu\text{m}$



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

### Monitored...

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



# Test and Commissioning at the Production Site



# At the Production Site...

## At MPI

- Wire positions (during construction)
- Layer / multilayer parameters (during construction)
- Inplane alignment monitor calibration (during construction)
- Alignment platform positions
- Leak test
- Wire tension measurement
- Wire resistance measurement
- Chamber test (at storage hall)
- $t_0$  calibration (at storage hall)
- Longterm leak rate measurement (at storage hall)

**88 of 88 BOS MDT chambers built**

## At LMU

- Wire resistance measurement
- Leak rate measurement
- High voltage test
- Front-end electronics test / noise test
- Cosmic Ray Calibration
  - Chamber commissioning (complete functional test, tube response, homogeneity)
  - Chamber calibration (wire positions, geometry)
  - $t_0$  calibration

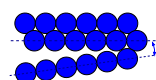
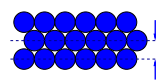
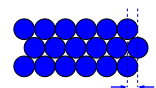
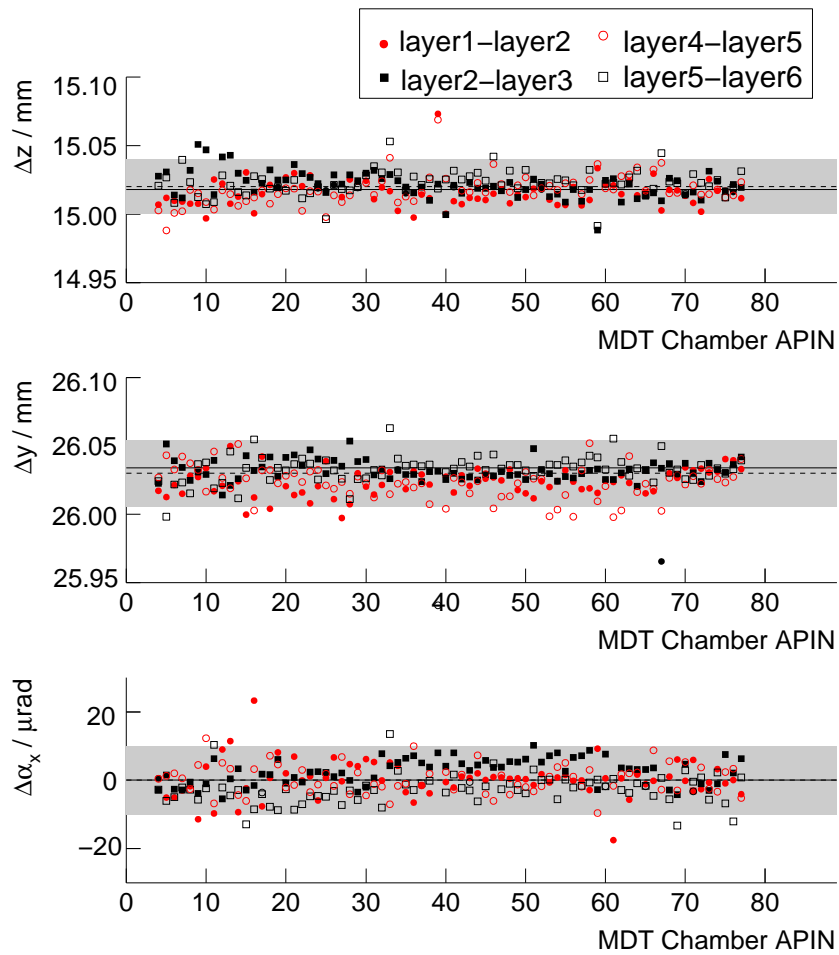
**82 BOS MDT chambers commissioned**



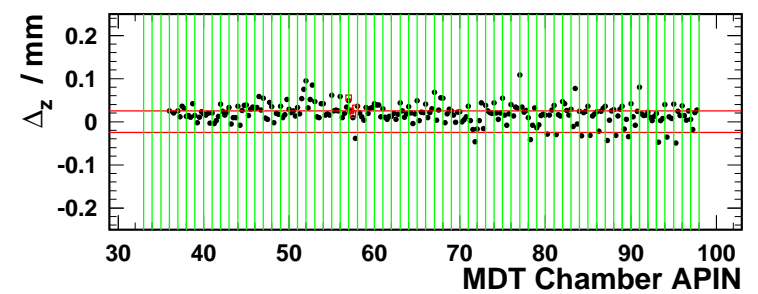
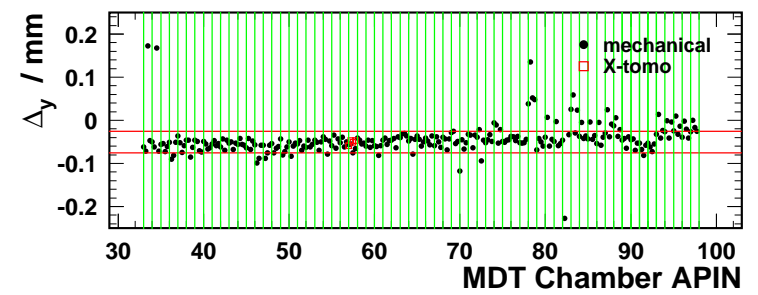
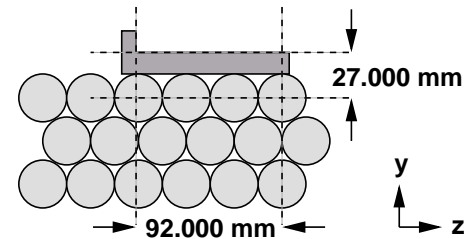


# Meas. during Construction

## Inter-Layer Parameters



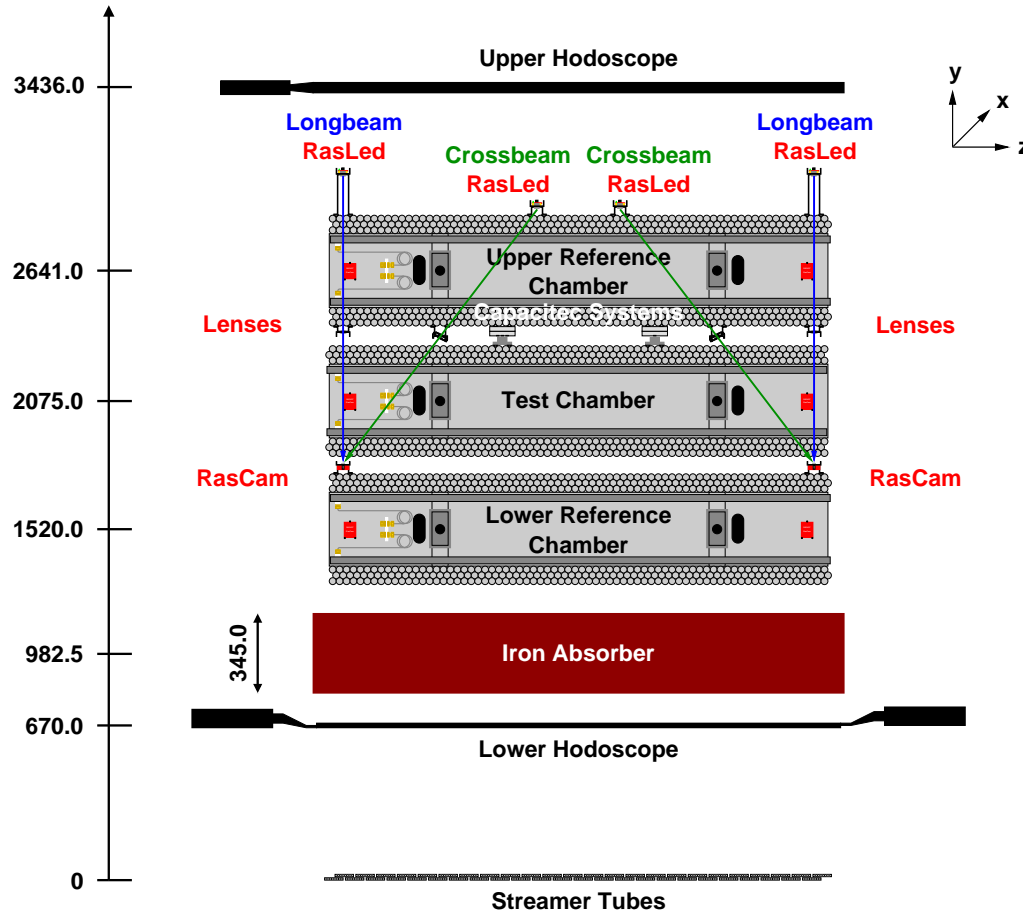
## Alignment Platform Positions





# The Cosmic Ray Facility

## Setup



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

- Cosmic Ray trigger with full chamber coverage (8.7 m<sup>2</sup>)
- Reference tracking with 2 MDT chambers
- Optical and capacitive monitoring of relative chamber positions (< 5 μm precision)

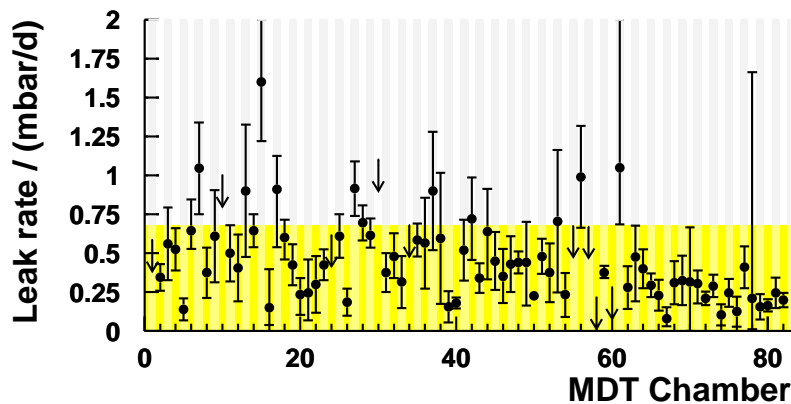
## Methods

- Chamber Response
  - Measure drift time spectra
  - Derive parameter set from fit to rising/trailing edge
- Wire position measurement
  - Compare measured drift radius with prediction from reference MDTs
  - Precision:  $\mathcal{O}(10\mu\text{m})$

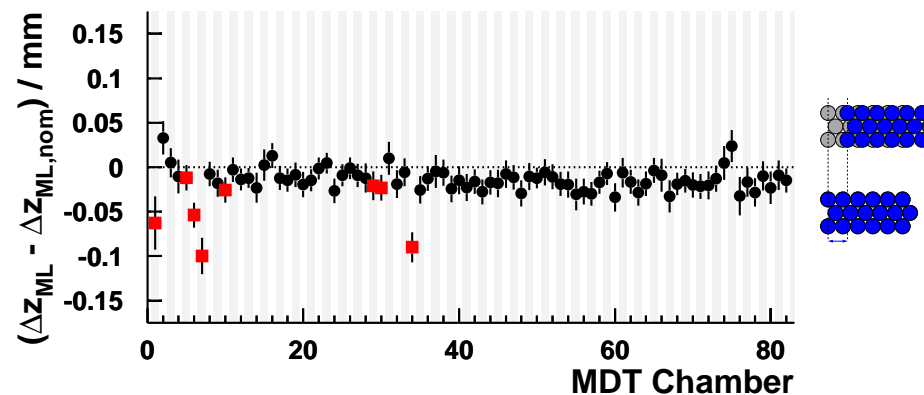


# Results from Chamber Calib.

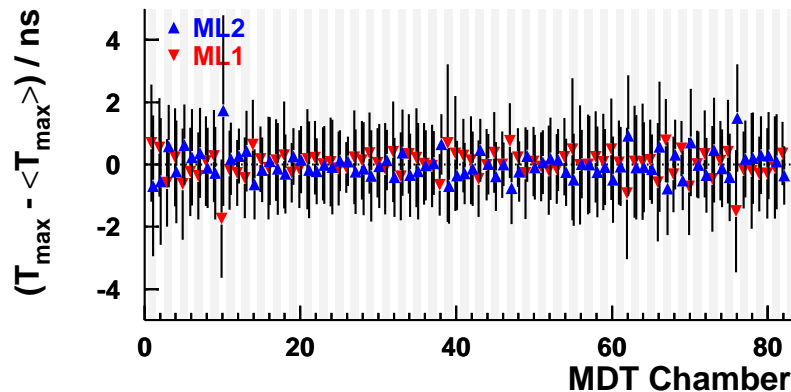
### Leak Rate



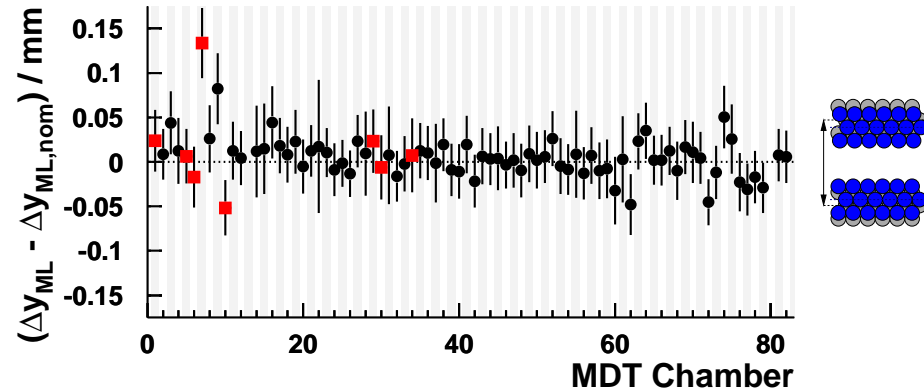
### Multilayer z-Shift (HV side)



### Drift Properties / Homogeneity



### Multilayer y-Distance (RO side)





# Integration and Commissioning of ATLAS Barrel Outer Small Muon Stations at CERN



## Commissioning

### Guarantee required performance of MDT chamber

- Leak test
- HV test
- Noise test
- Cosmic Ray test (after integration)

## Integration

### Completion of MDT chamber and mating with trigger chamber

- Install and test additional sensors
- Mount RPC trigger chamber in common support
- Mount MDT chamber on common support
- Adjustment of MDT chamber

## Installation schedule demands 8 BOS integrations / week

### RPC group

- 13 technicians
- 5 physicists

### Saclay alignment group

- 1 technician

### MPI/LMU MDT group

- 6 technicians
- 2 electricians
- 3 physicists

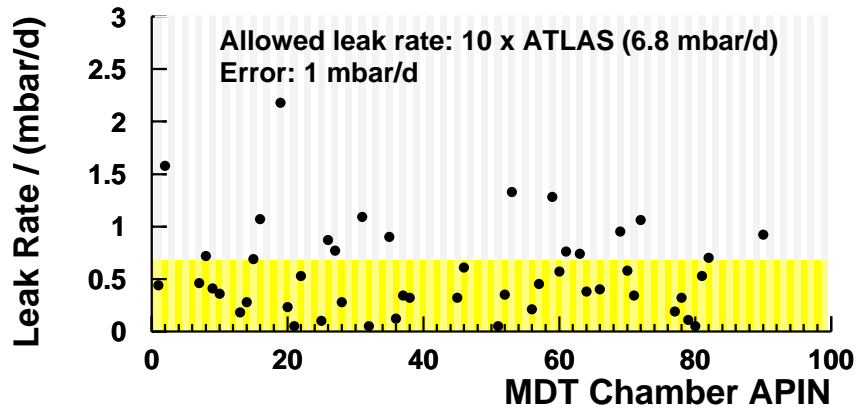
**Total manpower: 30 people**



# MDT Tests — Results

MDT Chambers have to be transported 600 km from Munich to CERN

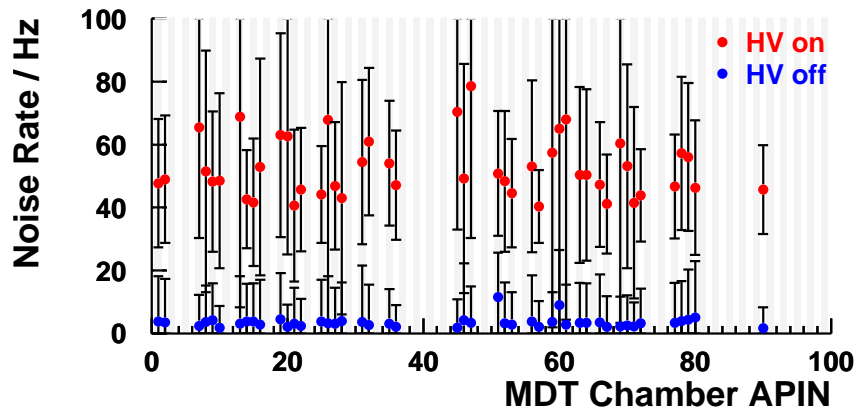
## Leak Test



## Statistics

- No gas leaks  
(approx. 170,000 O-ring seals)
- 1 broken wire (of 21216)
- 3 tubes with increased dark current—all fixed (of 21216)
- Minimal intervention on front-end electronics:
  - 7 cards exchanged (of 2652)
  - 2 HV splitter boxes exchanged (of 50)

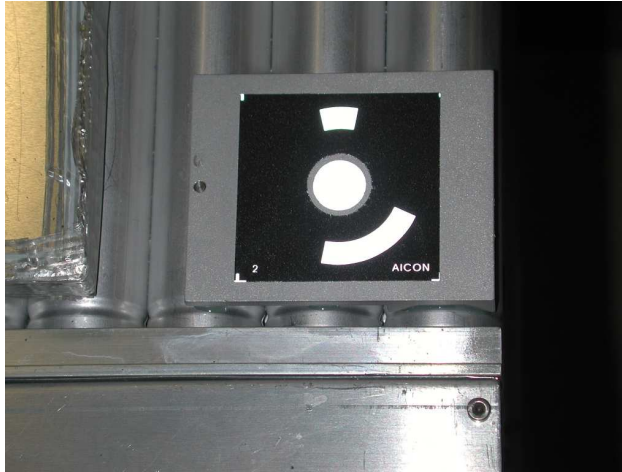
## Noise Test



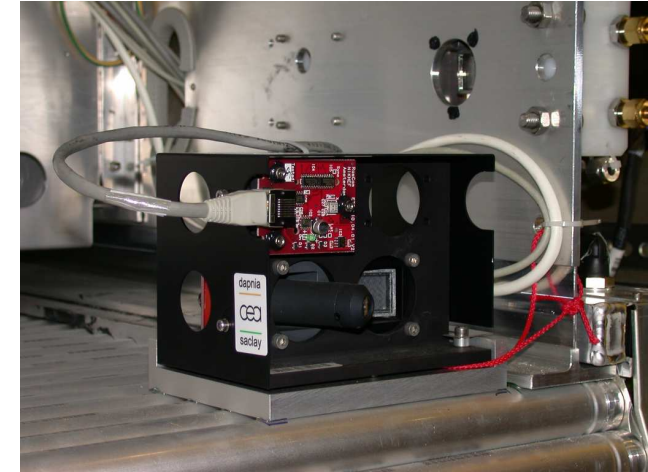
All 50 MDT chambers sent to CERN passed all tests

# Integration (1)

## Survey Targets



## Alignment Sensors



## B-Field Sensors



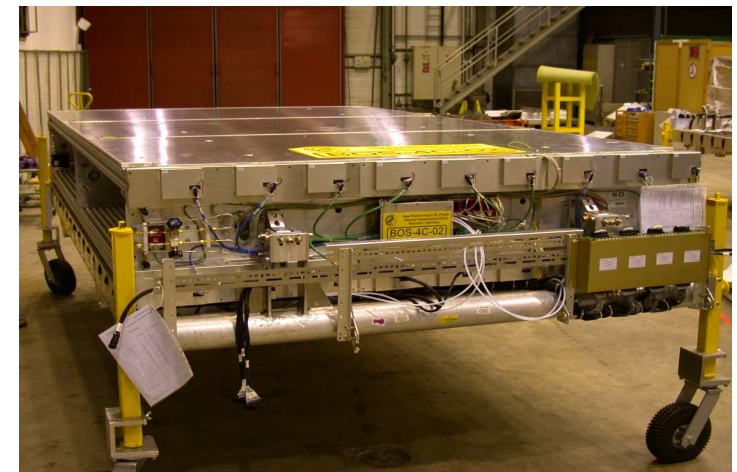


# Integration (2)

## Integration of the RPC Trigger Chamber and MDT Chamber

Most complicated muon stations to integrate due to common support frame (station position outside magnet coils)

Different than any other ATLAS MDT station



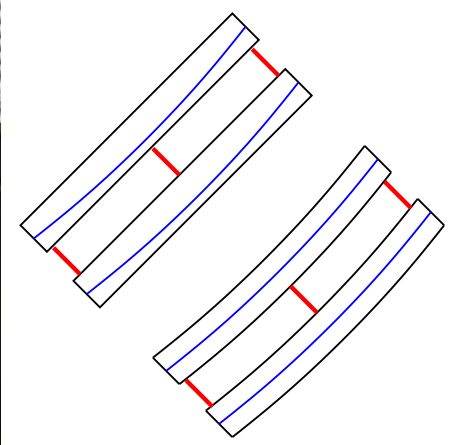
# Integration (3)



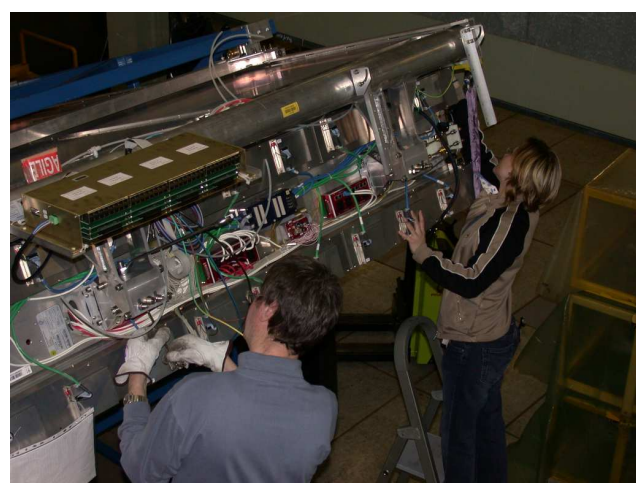
## Rotation of Muon Station



## Sag Compensation



## MDT Alignment



## Fully Integrated Muon Station

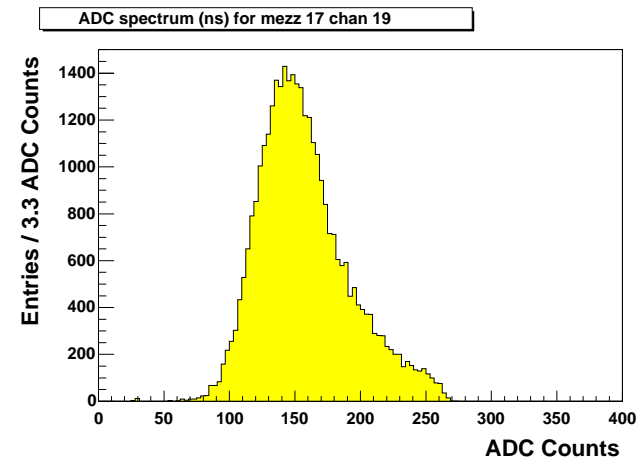


# Cosmic Ray Test — Results

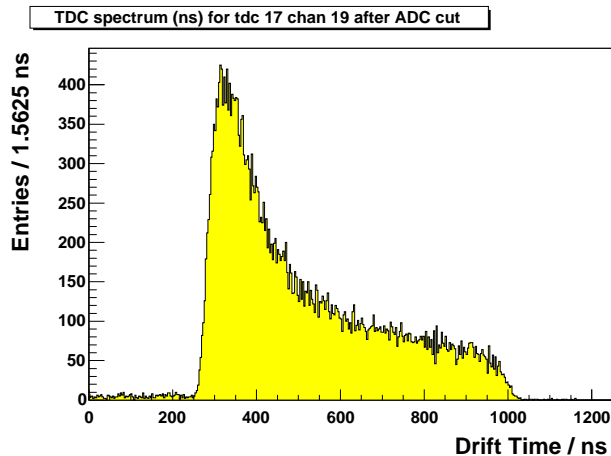
Test of complete ATLAS muon stations  
(MDT and RPC chamber + trigger elx)



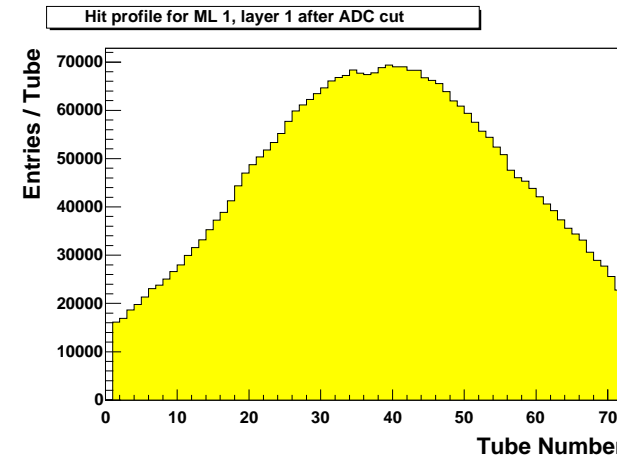
## ADC Spectrum



## Drift Time Spectrum



## Hit Map



**42 BOS MDT chambers already passed all tests without any failure**



# Installation in the ATLAS Detector

# Installation in ATLAS



Early installation of 10 BOS stations in February/March 2005

- MDTs tested at surface
- Successful installation
- MDTs tested after installation
  - No gas leaks
  - No broken wires
  - Alignment systems working





# Summary and Outlook



# Summary & Outlook (1)

## Stringent tests at production sites and at CERN ensure required performance of ATLAS MDT chambers

- 88 BOS MDT chambers built
- 82 MDT chambers commissioned and calibrated at Munich so far
  - Uniform response of all chambers
  - Consistent chamber geometry
- 50 MDT chambers successfully tested at CERN
- 42 BOS muon stations successfully integrated and commissioned at CERN
- 10 BOS muon stations successfully installed in ATLAS
- ...
- Integration of remaining 46 BOS muon stations until end of year
- Installation of next 48 stations starting mid November 2005

N.B. More on commissioning of ATLAS muon stations: Talk N37-2 by Stephanie Zimmermann

# Summary & Outlook (2)

## Part of the Munich MDT team at CERN



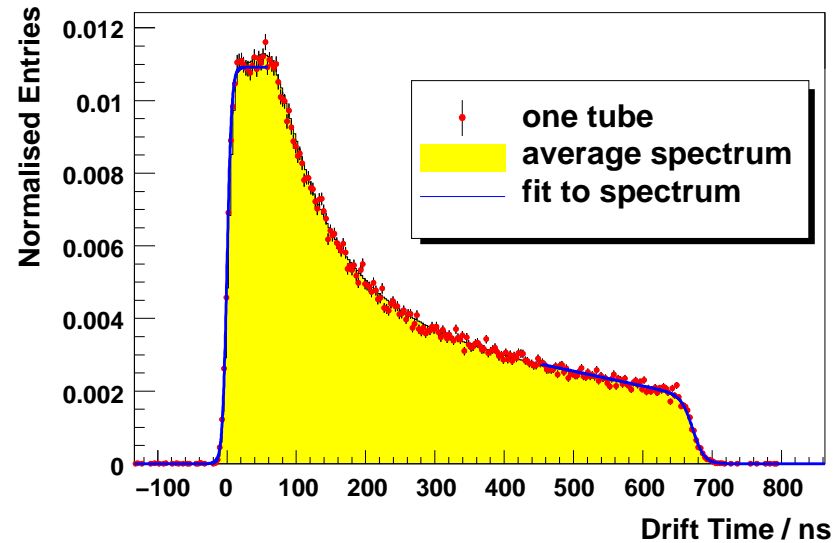
Thank you to all who helped building, testing, integrating and installing,  
 especially S. Leber, P. Bauer, B. Erdmann, P. Klemm, M. Lorch, D. Müldner,  
 U. Schorer, R. Sedlmeyer, I. Thiel, A. Varga, H. von der Schmitt, H. Wetteskind,  
 S. Witt, and J. Zimmer,  
 and our colleagues from the RPC community, Saclay, and from CERN





# Additional Slides

# Drift Time Spectra



Leading edge

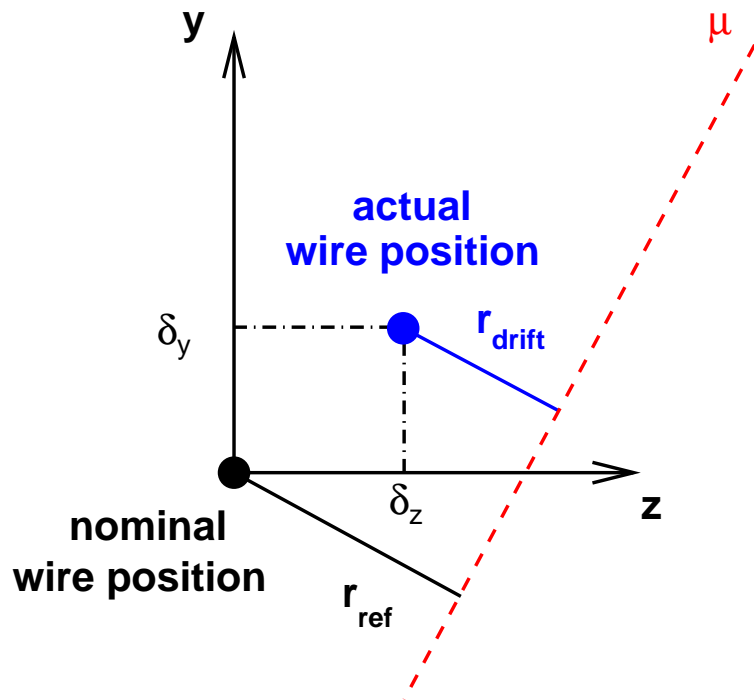
Trailing edge

$$F(t) = p_0 + \frac{A_0}{1 + \exp\left(\frac{t_0 - t}{T_0}\right)}$$

$$G(t) = p_m + \frac{\alpha_m \cdot t + A_m}{1 + \exp\left(\frac{t - t_m}{T_m}\right)}$$

Back

# Wire Position Meas.



$$y = y_0 + m^{-1} \cdot z$$

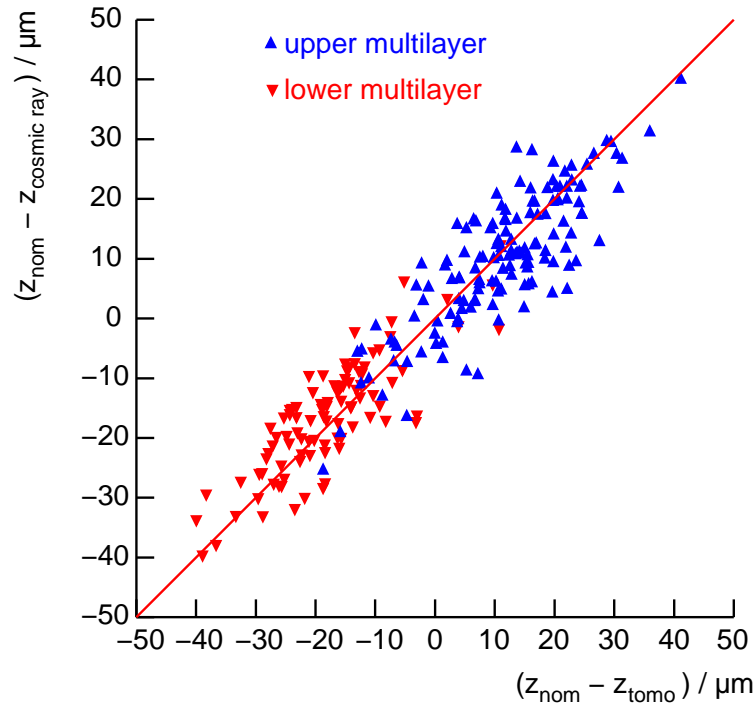
- Wire positions derived from comparison of predicted drift radius  $r_{\text{ref}}$  (weighted average reference tracks) and measured drift radius  $r_{\text{drift}}$  in the test chamber

$$\Delta r = r_{\text{drift}} - r_{\text{ref}} \approx \delta_z - m \cdot \delta_y$$

- $\delta_y$  from linear fit of  $\Delta r$  vs.  $m$
- $\delta_z$  from  $\langle \Delta r' \rangle = \delta_z - \langle m \rangle \cdot \delta_y' \approx \delta_z$  ( $\Delta r'$  with corrected  $y$  pos.)
- Grid scaling factor  $\gamma$ :  

$$z(n) = z_0 + \gamma \cdot g_{\text{nom}} \cdot n$$

Back



BOS5A08

(Exceptional chamber with known production error)

Comparison of measurements of Cosmic Ray Facility with X-Ray Tomograph gives accuracy

- Perpend. to chamber plane
  - $\delta_y$ :  $25 \mu\text{m}$
  - $\delta_{y, \text{Layer}}$ :  $4.5 \mu\text{m}$
  - $\alpha_{x, \text{Layer}}$ :  $17 \mu\text{rad}$
- In chamber plane
  - $\delta_z$ :  $8 \mu\text{m}$
  - $\delta_{z, \text{Layer}}$ :  $2 \mu\text{m}$
  - $g$ :  $0.15 \mu\text{m}$
- Agreement with Monte Carlo

Back