The LMU ATLAS
Cosmic Ray Facility

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- Introduction
- The Cosmic Ray Facility
- First Results
- Conclusions and Outlook
People

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Students

Computing Group

Mechanical Workshop

Elektronic Workshop
The Large Hadron Collider (LHC)

- pp collider
- 27 km circumference
- 14 TeV center-of-mass energy
- Luminosity: $1.034 \times 10^{34} \text{ (cm}^2 \text{s)}^{-1}$
- 25 ns bunch distance
- Startup: 2006
The ATLAS Detector

- Length: 44 m
- Diameter: 22 m
- Weight: 7000 t

It would swim!
The ATLAS Detector (2)
The ATLAS Muon System

- Bunch crossing identification
- Event topologies
- Trigger for single or multi-muon
- Track matching with Inner Detector
- Measurement of muon tracks
- Identification and momentum measurement

Purpose
Physics Performance

- Bunch crossing ID: \( \sigma > 4 \) ns
- High \( p_T \) Trigger: 20 GeV
- Low \( p_T \) Trigger: 6 GeV
- \( \Delta p_T/\Delta p_T: 2.5\% \) at 50 GeV
- \( \eta \geq 2.7 \)
- \( 11\% \) at 1000 GeV
- \( \text{Area} \approx 6650 \text{ m}^2 \)
- Readout channels: \( \approx 800000 \)
- Number of chambers: \( \approx 800 \)
- Trigger Chambers - RPC, TGC

The ATLAS Muon System (2)
Principle of Operation

- Ionization of gas by charged particle
- Avalanche multiplication in high electric field near wire
- Electrons drift to anode
- Field near wire
- Nail on anode wire
- Measurement of drift time w.r.t. external trigger signal

Drift Tubes (T)
Average resolution: 80 /µm
Pressure: 3 bar
Gas Chamber: 2 x 10⁻⁴
Gas mixture: Ar : CO₂ = 93 : 7
Anode wire diameter: 50 /µm (W-Re)
Wall thickness: 0.4 mm (Al)
Tube radius: 14.6 mm

ATLAS:
Impact radius

- Use r-t relation to convert drift time to

Principle of Operation (cont.)

Drit Tubes (2)
Quality Control of Drift Tubes

Up to now: almost 1700 tubes tested for MPI BOS chambers is tested.

Sample of about 15% of all drift tubes

- Gas Leak Rate
- Wire Tension
- Leakage Current
- Wire Position
Monitored Drift Tube (MDT) Chambers

All chamber positions are monitored by optical sensors or with muon tracks.

In ATLAS 3 precision chambers form a so-called tower in projective geometry.

Chambers monitored by optical sensors

- Position measurement with \( 40 \mu m \)
- 2 Multilayers of 3 (or 4) tube layers
- Projective alignment

Monitored Drift Tube (MDT) Chambers

- Axial alignment
- In-plane alignment
- Longitudinal beam
Assembly of MDT Chambers

- Dimensions:
  - 3.8 m × 2.2 m × 0.5 m
  - 432 tubes per chamber
  - 72 tubes per layer
  - 2 multilayer with 3 tube layers

MPIMunich builds 88 BOS Barrel Outer Small) MDT chambers
Final Production Step

- Gas tightness
  \(< 2 \cdot 10^{-8} \text{ bar l/s } \times \text{ number of tubes}\)  

- Electronic test
  - HV boards
  - Signal boards
  - Amplifier/TDC boards

- Performance test
  - HV stability / Leakage current
  - Noise level
  - Efficiency
  - Drift time spectra

- Chamber geometry / wire positions
Cosmic Ray Test

CERN

Chambers must be tested at

(Chambers)

Very small capacity (10% of all

but

Accuracy: $2.4\text{ mm}$

chamber geometry

Measurement of wire position

X-Ray Tomograph at CERN
Each BOS chamber has approximately 3500 O-ring seals.

Leak Chasing

Evacuate chamber with helium.

Connect to helium detector.

Apply helium from outside to each triplet of tubes.

Further improvement by overpressure method.

Very successful method!
The Cosmic Ray Facility

- Upper Hodoscope
- Upper Reference Chamber
- Test Chamber
- Lower Reference Chamber
- Iron Absorber
- Lower Hodoscope
- Iarocci Tubes
The Hodoscopes (1)

Upper Hodoscope

- 42 scintillators
- Dimensions: 2.3 m × 0.09 m × 0.04 m

Lower Hodoscope

- 2 × 38 scintillators
- Dimensions: 2.3 m × 0.1 m × 0.08 m
- Staggered by half of the width, readout at different sides
  → effective width of 0.05 m, mean time
- Hardware trigger logic requires a hit in overlapping counters
The Hodoscopes

Time: Time resolution > 800 ps

Lower Hodoscope defines trigger situation in x-direction

MDT wires (perpendicular to segmentation) allows track reconstruction through the chambers

Trigger for muon tracks through the hodoscopes
The Iarocci Detectors and the Iron Absorber

- Resolution: 0.3 cm
- Operating Voltage: 4300 V
- CO₂ : C₄H₁₀ : AR = 60 : 30 : 10
- Gas mixture: CO₂ : C₄H₁₀

Muon with energy ≥ 0.6 GeV suppressed

34 cm iron absorber

Iarocci detectors (24 x 8 channels) measure deviation arising from multiple scattering. Estimate of muon energy from multiple scattering.

- Gasmixture: CO₂, C₄H₁₀, Ar
- Operating Voltage: 4300 V
- Resolution: 0.3 cm
The MDT Reference chambers

- Known geometry and wire positions
- Both chambers were measured in the X-Ray Tomograph chamber
- Capacitive system monitors test chamber position w.r.t. upper reference chamber
- Optical alignment system monitors position of reference chambers w.r.t. each other
- Operating Voltage: 3160 V (gas gain: 4 × 10^4, 2 × nominal ATLAS gas gain)
- Gas mixture: AR : CO² = 93 : 7 at 3 bar absolute
- Allow reconstruction of muon tracks (6 points with 80 μm resolution each)
distance of chambers: 4 μm

Resolution in direction of light beam: 1–20 times worse
Resolution perpendicular to light beam: 2 μm

Principle of Operation

Coded mask illuminated by LED

CCD
Lens
Resolution: 2 μm

Horizontal distance sensor-step
• Capacitance depends on vertical and step (placed on test chamber) over metal reference chamber (mounted on up)
• Capacitance sensor (mounted on up)

Principle of Operation

Alignment Monitors (2) - Capacitive System
Aim: Measurement of the Wire Positions and Layer Distances in Test Chamber

20 h data taking, 1,000,000 recorded events (→ 5000 events / m tube)

- Measurement of the Layer Distances
- Wire Positions in the Test Chamber
- Alignment of the Chambers with Muon Tracks
- Determination of the r-t Relation
- Operating Parameters
- Setup
First Results (2) - Setup

Upper Hodoscope

Upper Reference Chamber

Test Chamber

Lower Reference Chamber

Iron Absorber

Lower Hodoscope

Iarocci Tubes
Gas mixture: Ar: CO₂ = 92.59 : 7.41

Gas Pressure: 3.000 ± 0.002 ± 0.005 bar

Operating Voltage: 3160 V (gas gain: 4 × 10⁴)

Temperature: 19.5 ± 0.5 °C

Maximum measured deviation in alignment systems: 5 μm

Chambers rigid bodies with fixed positions

First Results (3) - Operating Parameters
First Results (4) - Drift Time Spectra

Rate of background hits: typically $\gtrsim 0.25\%$ (2\% for all tubes)

RMS spread of maximum drift time

in one multilayer: $1.6$ ns

Mean Value: (757.9$\pm$0.1) ns

Standard dev.: (0.97$\pm$0.08) ns

Upper Triple Layer

Lower Triple Layer
First Results (5) - R-t Relation

Method

- Linear interpolation to get r(t) for ar
- Discrete set of value (r', t')
- All other wire distances known
- Use tracks through wires in upper
- Measurement of the Drift Time at fixed radii r1 and r2
Longer than in other layers, scaled to match (drift times 7 ns longer) lower reference chamber will be.

Drift times of upper multilayer in precision: 20–30 μm.

1 global R-t relation.
Results:

Reference chamber reference chamber (or test chamber) and lower reference chamber by comparison of track segments in upper alignment relative to the lower reference cham-

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Upper Reference Ch.</th>
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<tbody>
<tr>
<td>T</td>
<td>-8.06 ± 0.07</td>
</tr>
<tr>
<td>U</td>
<td>0.04</td>
</tr>
<tr>
<td>V</td>
<td>2.1 ± 0.4</td>
</tr>
<tr>
<td>U</td>
<td>0.4</td>
</tr>
<tr>
<td>W</td>
<td>6.23 ± 0.04</td>
</tr>
<tr>
<td>U</td>
<td>0.04</td>
</tr>
<tr>
<td>X</td>
<td>2.460 ± 0.004</td>
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<tr>
<td>U</td>
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<td>X</td>
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<td>U</td>
<td>0.03</td>
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<tr>
<td>y</td>
<td>0.097 ± 0.003</td>
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<tr>
<td>U</td>
<td>0.03</td>
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<tr>
<td>z</td>
<td>1.08 ± 0.04</td>
</tr>
<tr>
<td>U</td>
<td>10.4</td>
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<tr>
<td>δ</td>
<td>2.1 ± 0.4</td>
</tr>
<tr>
<td>U</td>
<td>10.4</td>
</tr>
<tr>
<td>α</td>
<td>-0.13 ± 0.07</td>
</tr>
<tr>
<td>U</td>
<td>10.4</td>
</tr>
</tbody>
</table>

First Results (7) - Chamber Alignment
Symmetry axis of track distribution (nominally wire position) and track from tube center (nominal wire position) reference chambers to calculate drift.

Use reconstructed track from reference drift time:

- Measure drift time

First Results (8) - Wire Positions in Test Chamber
First Results (9) - Wire Positions in Test Chamber (cont.)

Precision

Syst. error: 8 &m (r-t relation)
Stat. error: 3 &m (5000 tracks)

Estimated Energy < 2.5 GeV

\[ \text{Sigma} = 0.213 \text{ mm} \]

\[
\begin{array}{c c c c c c c c c}
0 & 100 & 200 & 300 & 400 & 500 & 600 & 700 & 800 \\
\end{array}
\]

\[
\begin{array}{c c c c c c c c c}
-30 & -20 & -10 & 0 & 10 & 20 & 30 \\
\end{array}
\]

\[
\begin{array}{c c c c c c c c c}
2 & 1 & 0 & -1 & -2 & -3 \end{array}
\]

\[
\begin{array}{c c c c c c c c c}
\Delta w, \text{ Cosmic Ray} & \Delta w, \text{ Tomograph} \\
\end{array}
\]

\[
\begin{array}{c c c c c c c c c}
\text{Std. dev.: (4.2)} \text{ &m} & \text{Mean: (4.0)} \text{ &m} \\
\end{array}
\]
Average over 8 tubes to increase precision:

\[ r_{\text{track}} - r_{\text{meas}} \approx \frac{1}{m} \cdot m^2 \cdot \delta_z \]

Vertical tube offset:
- Difference of track distance (from reference chambers) and measured distance.
- Difference of track distance (from reference chambers) and measured distance.

Method

**First Results (10) - Layer Distances**
Layer 1–2
Cosmic Ray
26.040 ± 0.010 mm
Tomogaph
26.046 ± 0.003 mm

Layer 2–3
Cosmic Ray
26.012 ± 0.010 mm
Tomogaph
26.018 ± 0.003 mm

Layer 1–2
Cosmic Ray
(4.7 ± 1) µm
Slope: (-18 ± 7) µm
Middle Layer

Layer 2–3
Cosmic Ray
(4.7 ± 1) µm
Slope: (-47 ± 7) µm
Lower Layer

Results (cont.)
Conclusions

• Successful and stable data taking with the LMU ATLAS Cosmic Ray Facility
  – 3 BOS MDT chambers working
  – Trigger working
  – (Prototype) Alignment monitors working
  – Stable environmental conditions

• Horizontal distances between MDT wires can be measured with 10 μm precision in 20 h

• Vertical distance between tube layers in a MDT multilayer can be determined with 10 μm precision in 20 h
• Divide **Hodoscope trigger** into 5 segments to select more tracks in a plane perpendicular to the MDT wires
  → increase rate of useful events by 50%

• Measure position of **Alignment Platforms** relative to wires with silicon strip detectors
  → achievable precision: 3 μm

• **Electronic tests**
  – Final front end electronics
  – Final readout modules
Outlook (2)

- Test BOS MDT with mounted RPC trigger chamber

- Test of MDTs in different orientations

- Gas studies

- Development of track reconstruction algorithms for the ATLAS Muon Spectrometer

- Development of fast and efficient in-situ calibration methods during LHC data taking