The LMU ATLAS

Cosmic Ray Facility

Jörg Dubbert

LS Schaile

MLL Seminar 07.02.02

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

People

Meta Binder, Johannes Elmsheuser, Frank Fiedler,
Ralf Hertenberger, Nigel Hessey, Oliver Kortner,
Alois Kraus, Felix Rauscher, Marc Rykaczewski,
Oliver Sahr, Dorothee Schaile, Arnold Staude,
Hartmut Steffens, Wolfram Stiller, Raimund Ströhmer,
Thomas Trefzger, Balazs Ujvari, Attila Varga,
Vadym Zhuravlov

Students

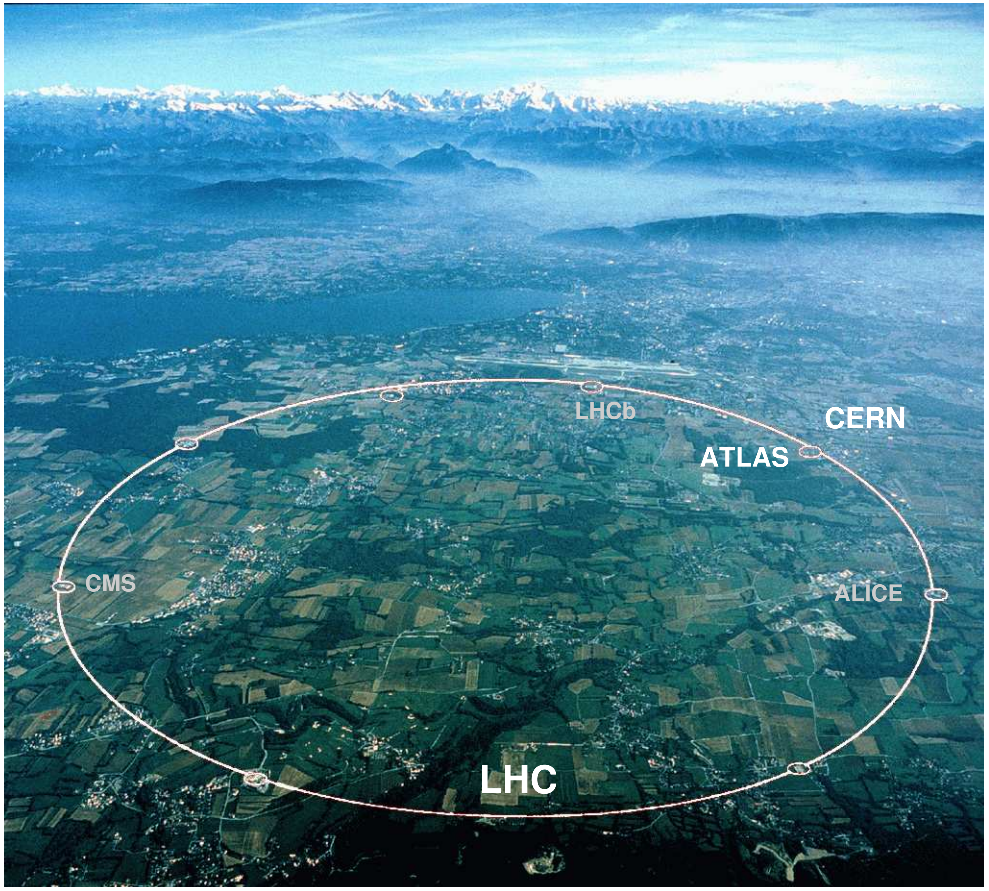
Computing Group

Mechanical Workshop

Elektronic Workshop

The Large Hadron Collider LHC

- pp collider
- 27 km circumference
- 14 TeV center-of-mass energy
- Luminosity: $10^{34}\left(\mathrm{cm}^2\ \mathrm{s}\right)^{-1}$
- 25 ns bunch distance
- Startup: 2006

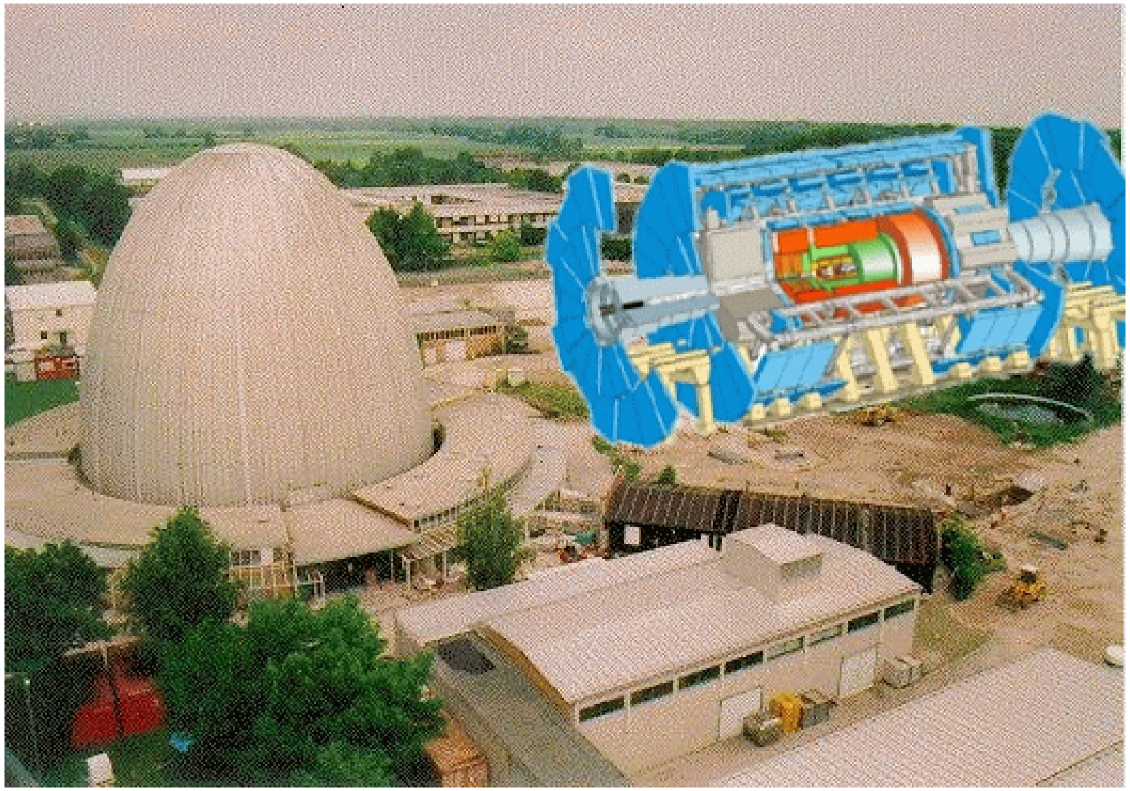


The ATLAS Detector (1)

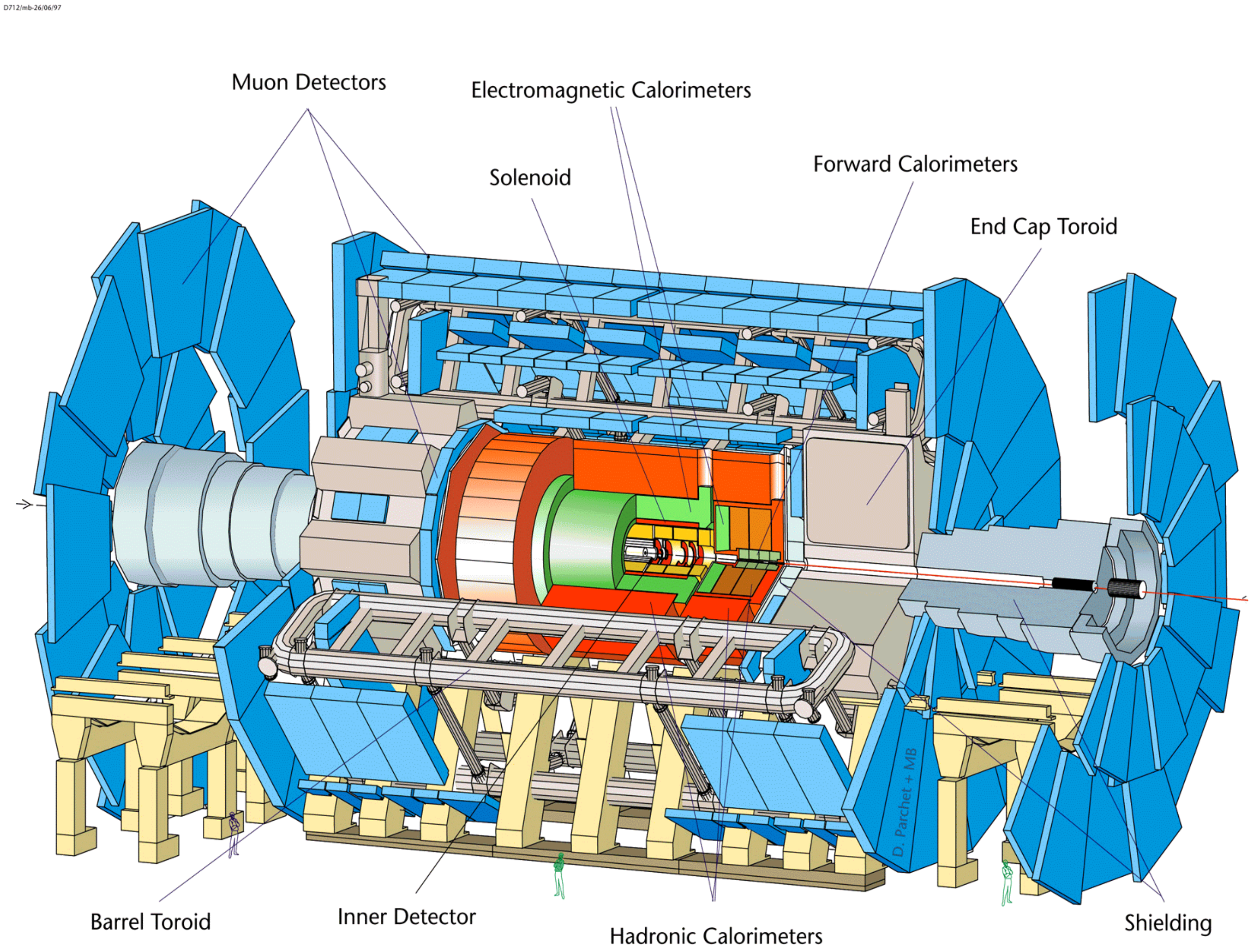
A Toroidal LHC ApparatuS

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

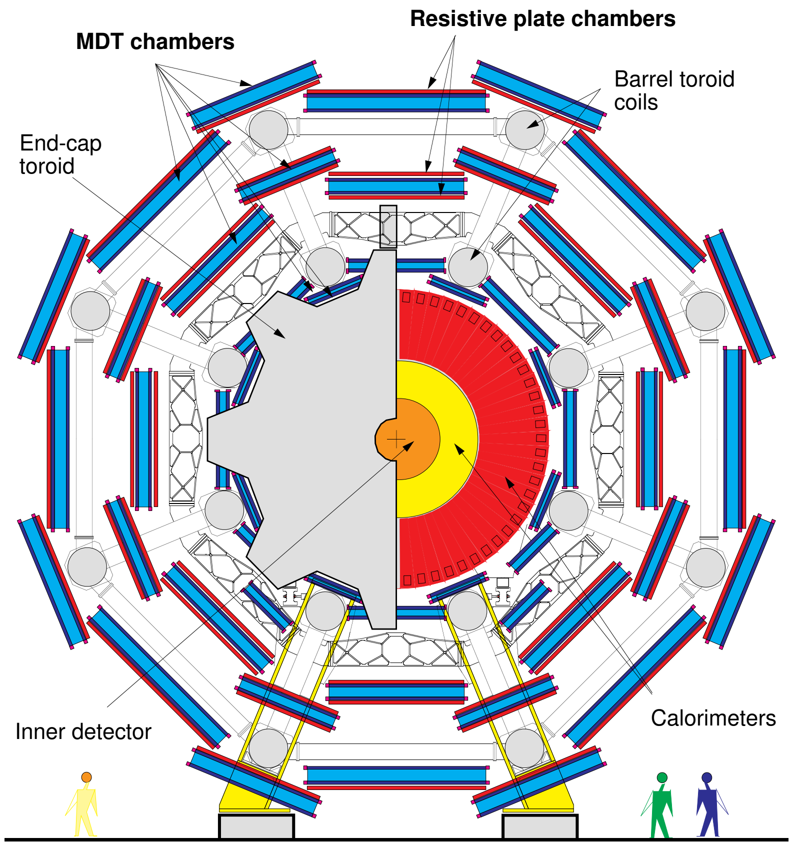
  It would swim!



The ATLAS Detector (2)



The ATLAS Muon System (1)



Purpose

- Identification and momentum measurement of muon tracks

  Track matching with Inner Detector

- Trigger for single or multi-muon event topologies

- Bunch crossing identification

The ATLAS Muon System (2)

Precision Chambers - MDT, CSC

- Number of chambers: $\approx$ 1200
- Readout channels: $\approx$ 450000
- Area: $\approx$ 5500 m^2

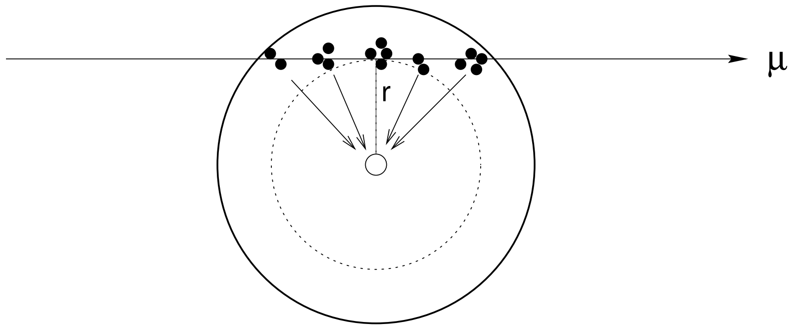
Trigger Chambers - RPC, TGC

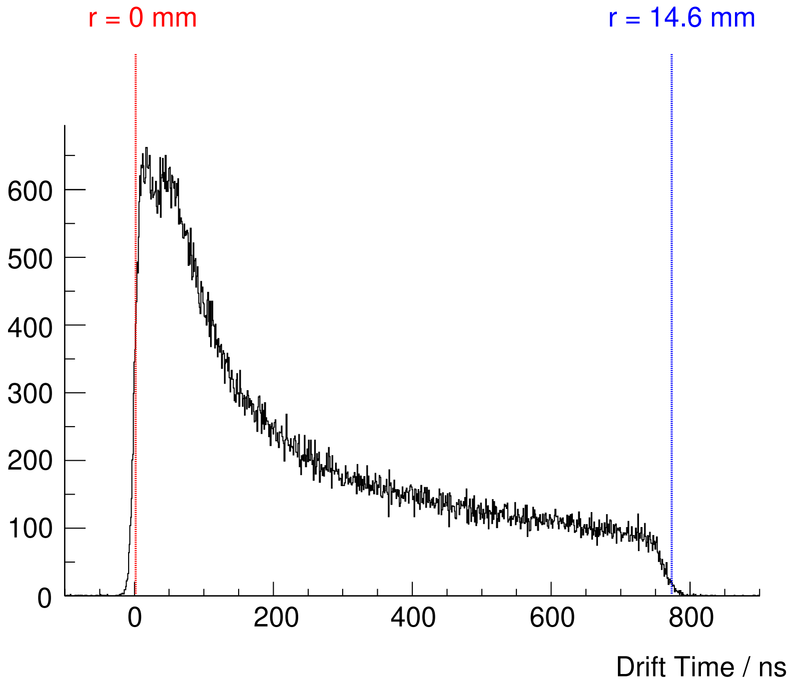
- Number of chambers: $\approx$ 800
- Readout channels: $\approx$ 800000
- Area: $\approx$ 6650 m^2

Physics Performance

- Pseudo-Rapidity coverage: $\eta \leq 2.7$
- $\Delta p_T / p_T$: 2.5% at 50 GeV, 11% at 1000 GeV
- Low p_T Trigger: 6 Gev
- High p_T Trigger: 20 GeV
- Bunch crossing ID: $\sigma \leq$ 4 ns

Drift Tubes (1)

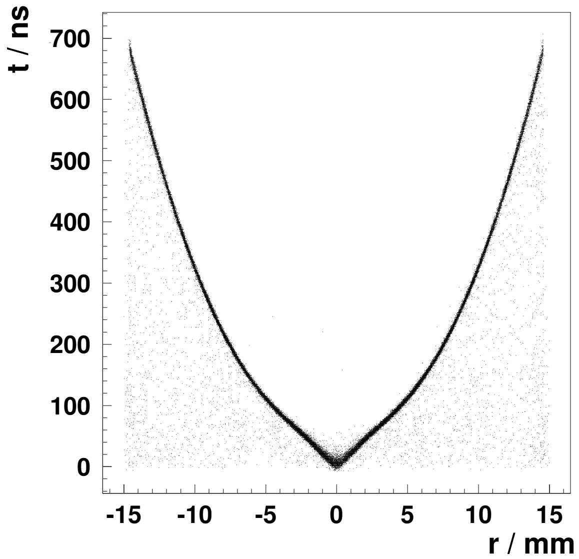


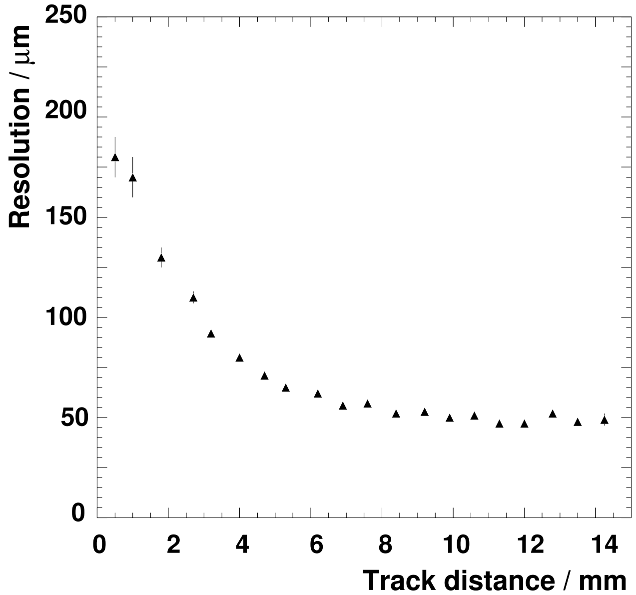


Principle of Operation

- Ionisation of gas by charged particles
- Electrons drift to anode
- Avalanche multiplication in high **E**-field near wire
- Ions drifting to cathode induce signal on anode wire
- Measurement of drift time w.r.t. external trigger signal

Drift Tubes (2)





Principle of Operation (cont.)

- Use r-t relation to convert drift time to impact radius

ATLAS:

Tube radius: 14.6 mm

Wall thickness: 0.4 mm (Al)

Anode wire diameter: 50 μm (W-Re)

Gas mixture: Ar : $CO_2 = 93 : 7$

Gas Gain: 2×10^4

Pressure: 3 bar

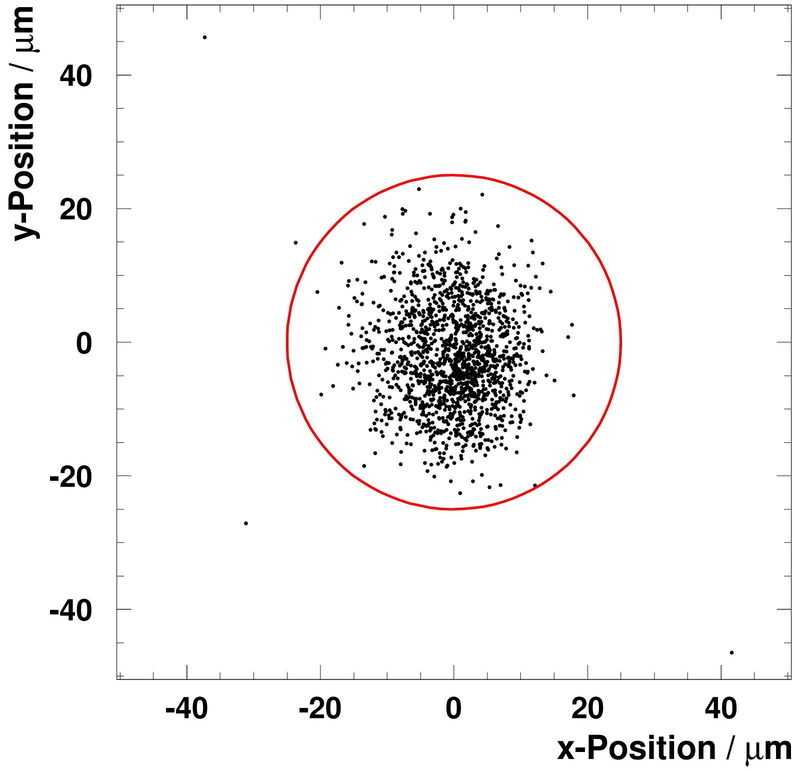
Average resolution: 80 μm

Quality Control of Drift Tubes

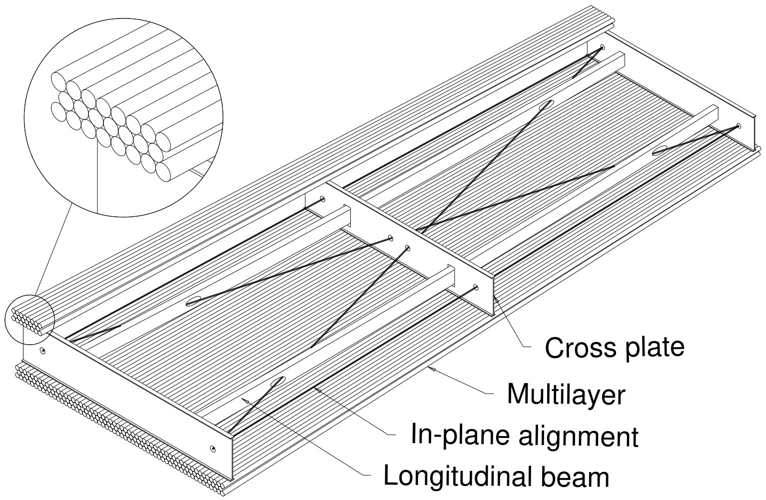
- Wire Position
- Leakage Current
- Wire Tension
- Gas Leak Rate

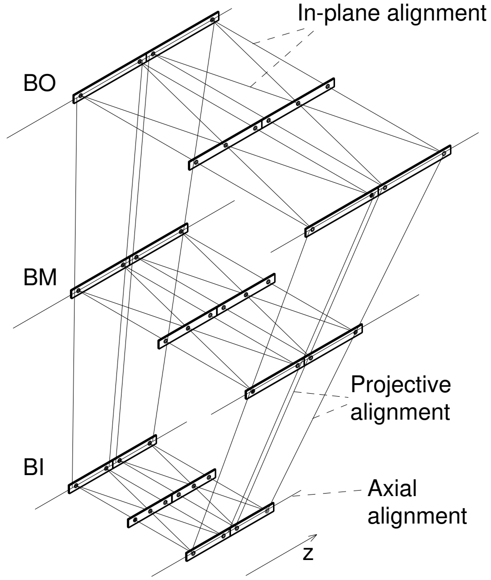
Sample of about 15% of all drift tubes for MPI BOS chambers is tested

Up to now: almost 1700 tubes tested



Monitored Drift Tube (MDT) Chambers





- 2 Multilayers of 3 (or 4) tube layers
- Position measurement with 40 μm resolution
- Chambers monitored by optical sensors

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

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

Assembly of MDT Chambers

MPI Munich builds 88 BOS

(Barrel Outer Small) MDT chambers

- 2 multilayer with 3 tube layers
- 72 tubes per layer

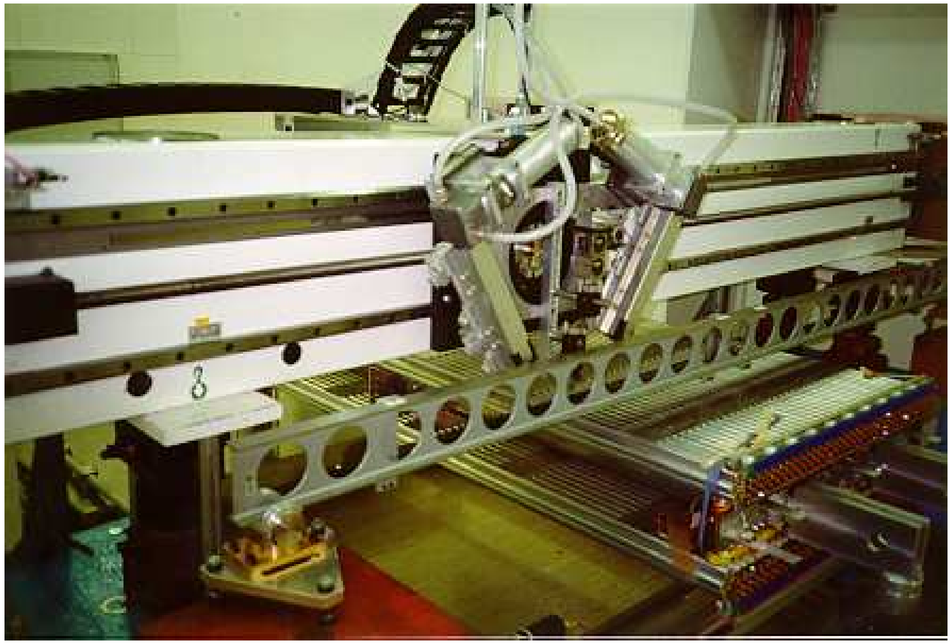
  $\rightarrow$ 432 tubes per chamber
- Dimensions:

  $3.8 \text{ m} \times 2.2 \text{ m} \times 0.5 \text{ m}$

Final Production Step

- **Gas tightness**
  ($< 2 \cdot 10^{-8}$ bar l /s $\times$ 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**

X-Ray Tomograph at CERN



- Measurement of wire position / chamber geometry
- Accuracy: 2 μm

but

- Very small capacity (10% of all chambers)
- Chambers must be tested at CERN

$\rightarrow$ **Cosmic Ray Test**

Leak Chasing

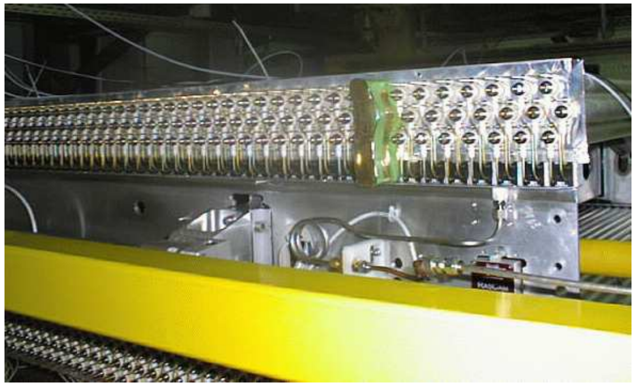
Each BOS chamber has approximately 3500 O-ring seals

Leak chasing with helium

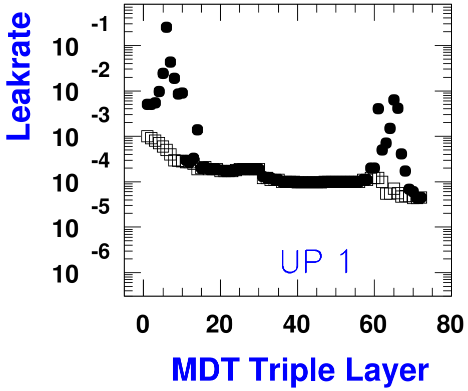
- Evacuate chamber
- Connect to helium detector
- Apply helium from outside to each triplet of tubes

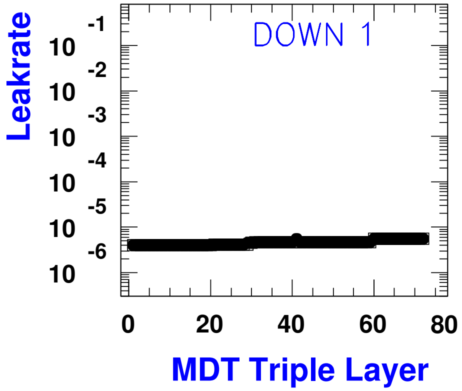
Very successful method!

Further improvement by *overpressure method*

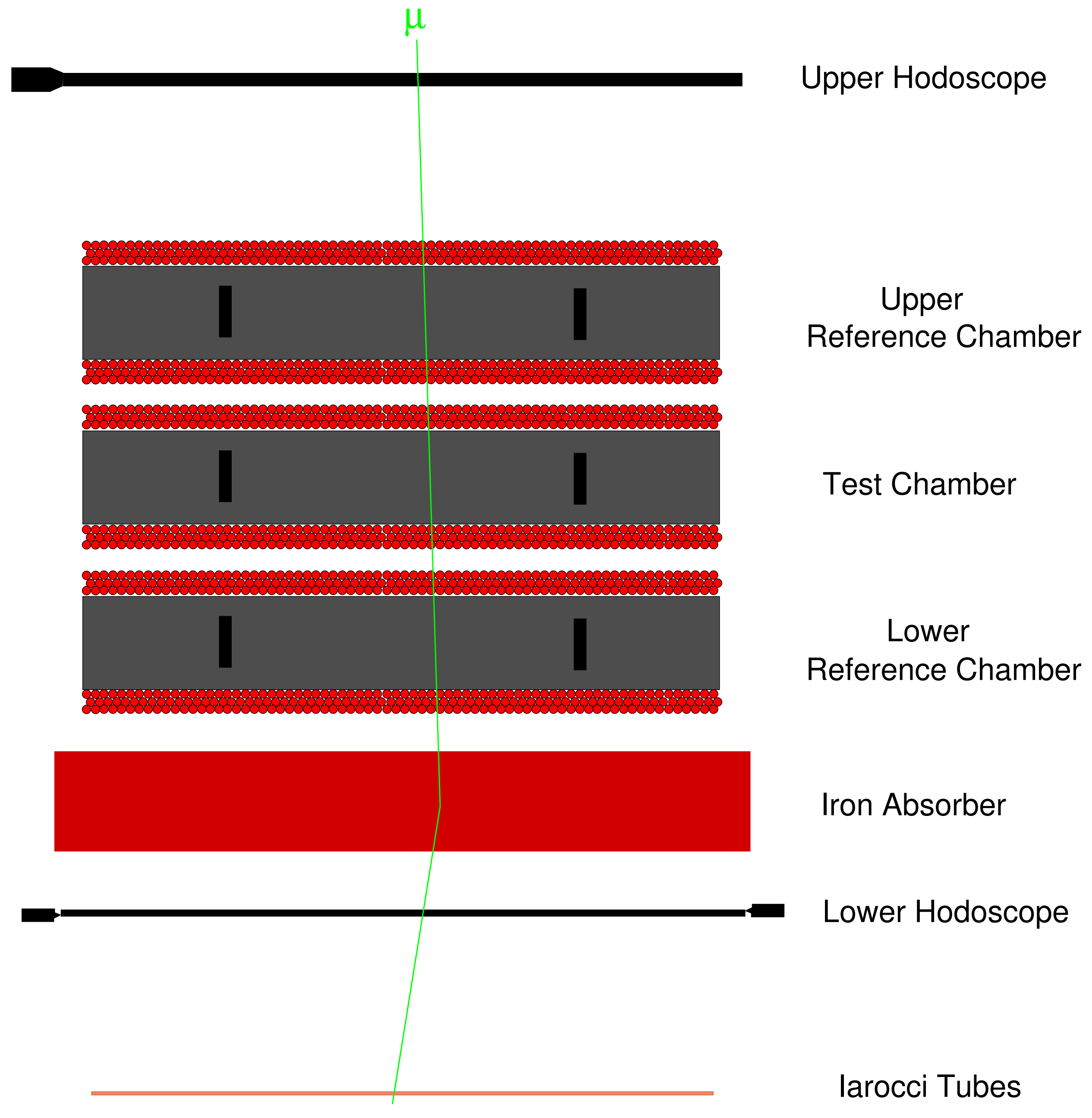


BOS 2C 08





The Cosmic Ray Facility



The Hodoscopes (1)

Upper Hodoscope

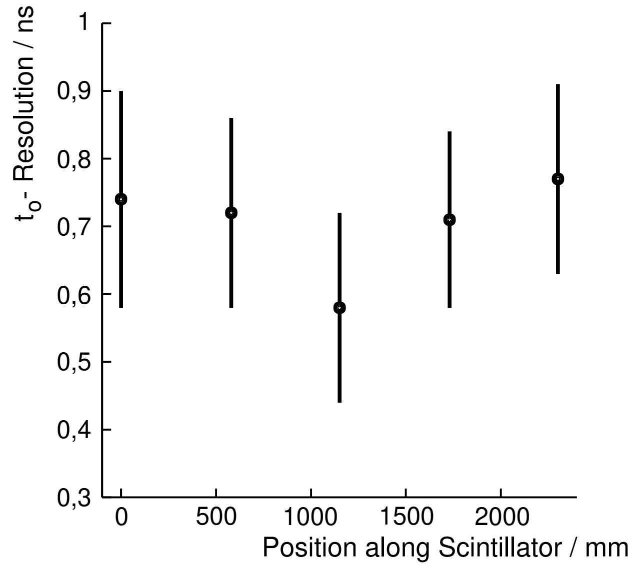
- 42 scintillators
- Dimensions: 2.3 m $\times$ 0.09 m $\times$ 0.04 m

Lower Hodoscope

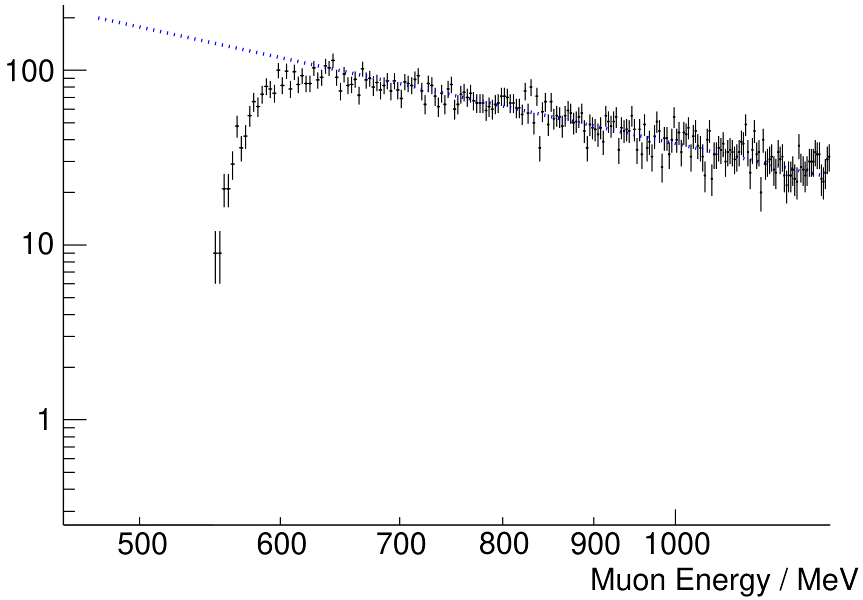
- 2 $\times$ 38 scintillators
- Dimensions: 2.3 m $\times$ 0.1 m $\times$ 0.08 m
- Staggered by half of the width, readout at different sides
  $\rightarrow$ effective width of 0.05 m, mean time
- Hardware trigger logic requires a hit in overlapping counters

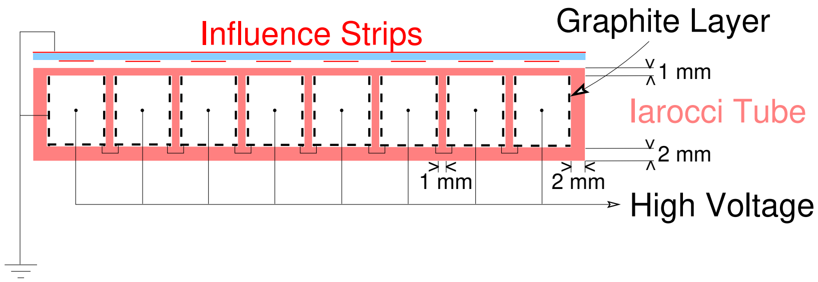
The Hodoscopes (2)

- Trigger for muon tracks through the chambers
- Segmentation (perpendicular to MDT wires) allows track reconstruction in x-direction
- Lower Hodoscope defines trigger time: **Time resolution $<$ 800 ps**



The Iarocci Detectors and the Iron Absorber





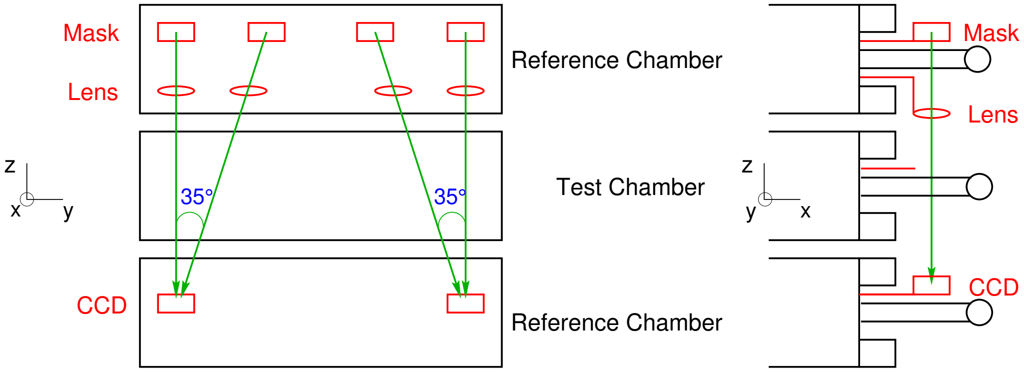
- Iarocci detectors (24×8 channels) measure deviation arising from multiple scattering
  $\rightarrow$ estimate of muon energy
- Gas mixture:
  $CO_2 : C_4H_{10} : Ar = 60 : 30 : 10$
- Operating Voltage: 4300 V
- Resolution: 0.3 cm

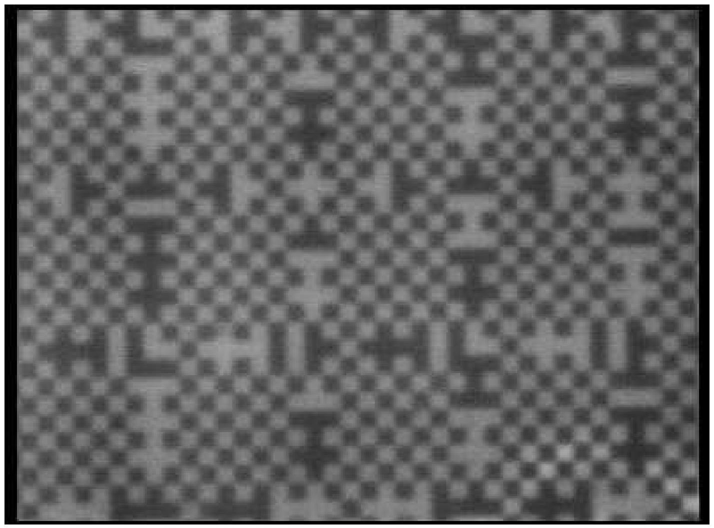
- 34 cm iron absorber
- Muons with energy $\leq$ 0.6 GeV supressed

The MDT Reference chambers

- Allow reconstruction of muon tracks (6 points with 80 μm resolution each)
- Gas mixture: $Ar : CO_2 = 93 : 7$ at 3 bar absolute
- Operating Voltage: 3160 V (gas gain: 4×10^4, $2 \times$ nominal ATLAS gas gain)
- Optical alignment system monitors position of reference chambers w.r.t each other
- Capacitive system monitors test chamber position w.r.t. upper reference chamber
- Both chambers were measured in the X-Ray Tomograph
  $\rightarrow$ known geometry and wire positions

Alignment Monitors (1) - RasNiK System



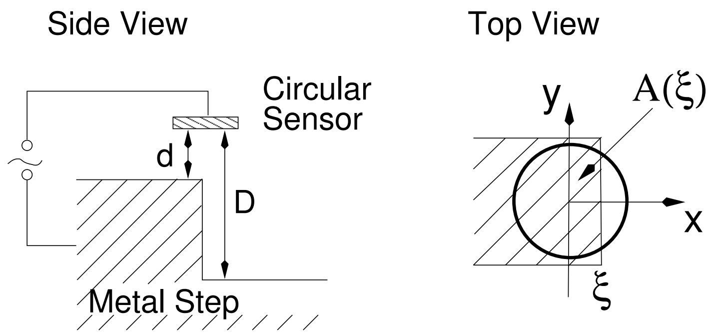


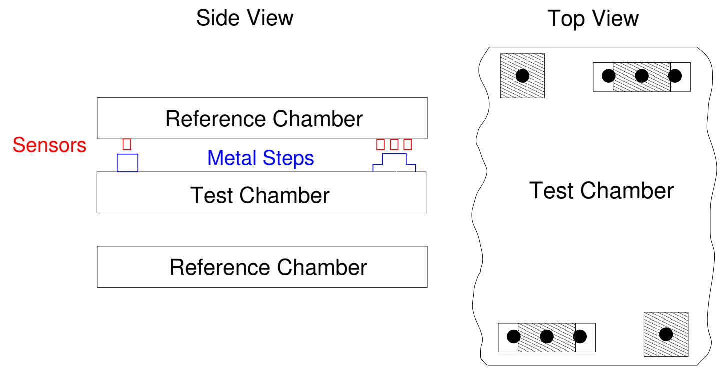
Principle of Operation

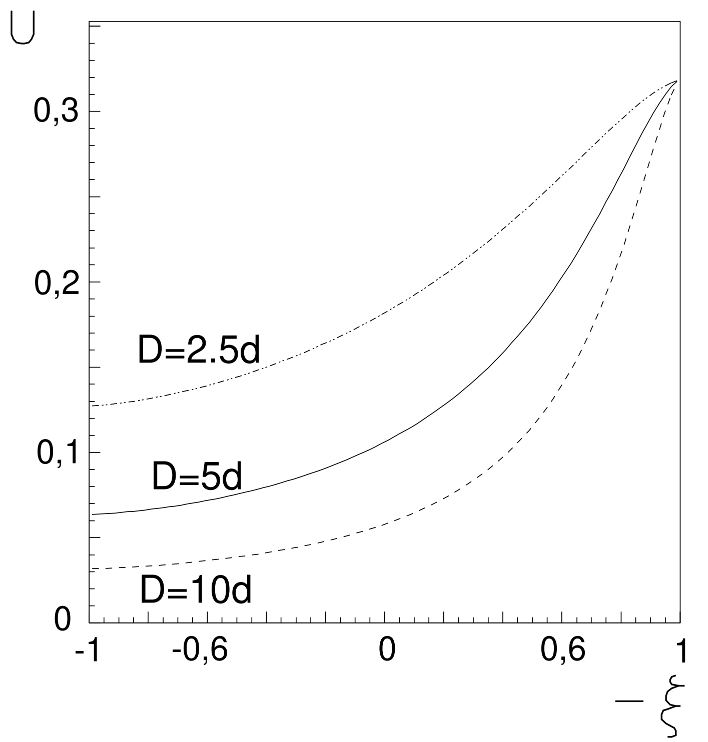
- Coded mask illuminated by LED
- Lens
- CCD

- Resolution perpendicular to light beam: 2 μm
- Resolution in direction of light beam: 10–20 times worse $\rightarrow$ use inclined beams to measure distance of chambers: 4 μm

Alignment Monitors (2) - Capacitive System







Principle of Operation

- Capacity sensor (mounted on upper reference chamber) over metal step (placed on test chamber)
- Capacity depends on vertical and horizontal distance sensor-step

Resolution: 2 μm

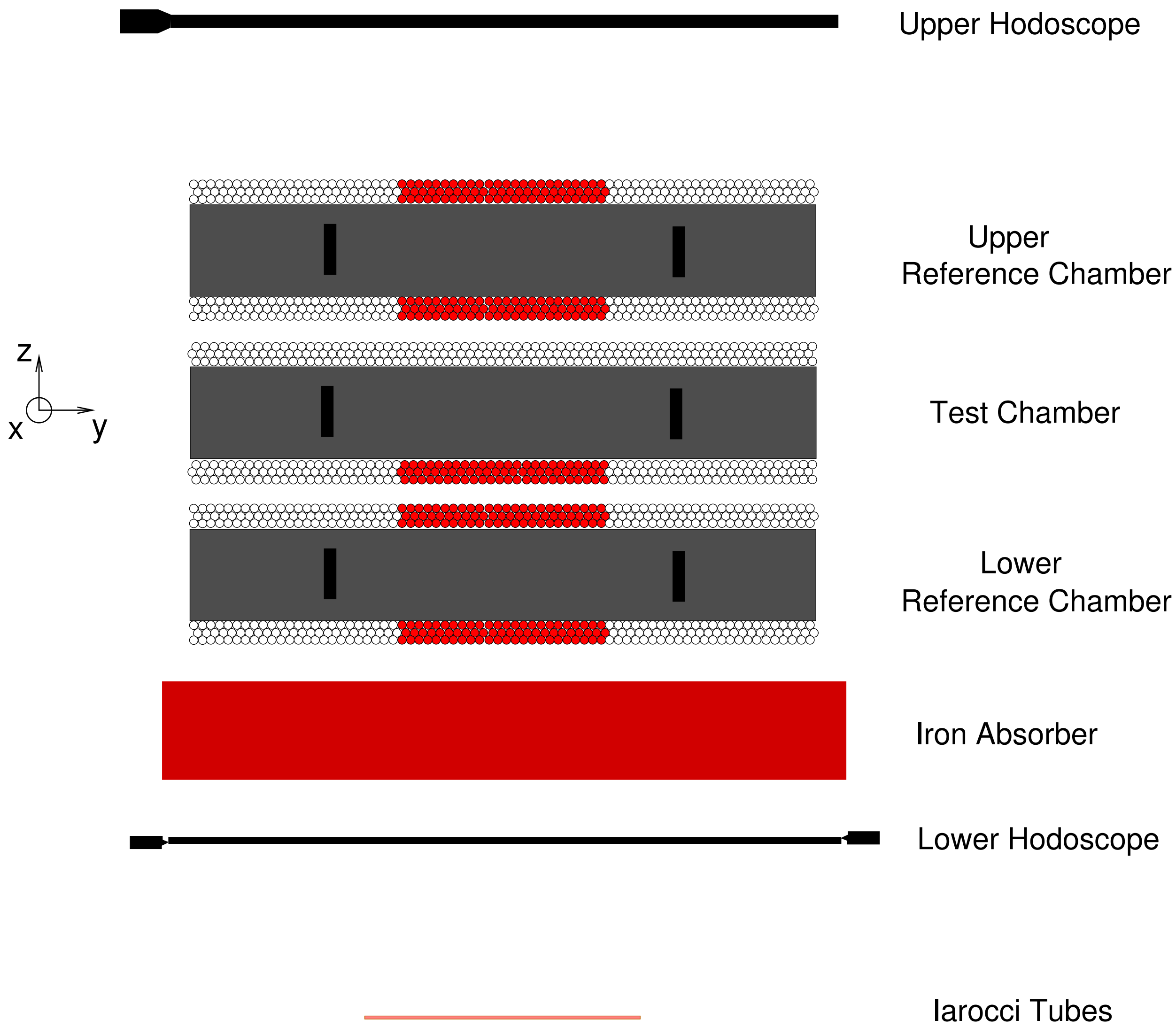
First Results (1) - Overview

Aim: Measurement of the Wire Positions and Layer Distances in Test Chamber

20 h data taking, 10000000 recorded events ($\longrightarrow$ 5000 events / m tube)

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

First Results (2) - Setup



First Results (3) - Operating Parameters

- Gas mixture:

  Ar : $CO_2 = 92.59 : 7.41$

- Gas Pressure:

  $3.000 \pm 0.002 \pm 0.005$ bar

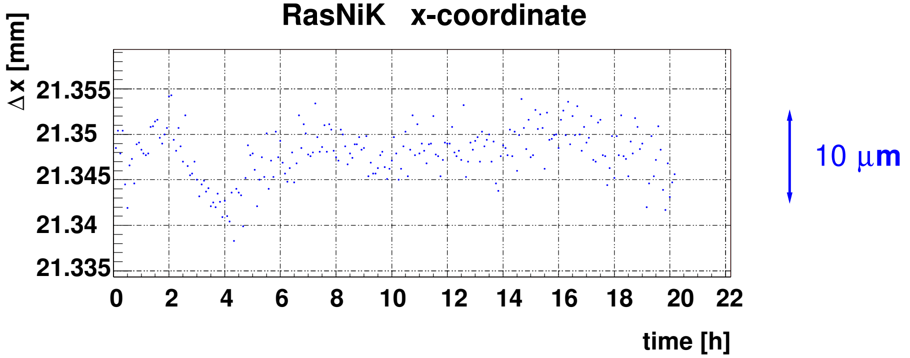
- Operating Voltage:

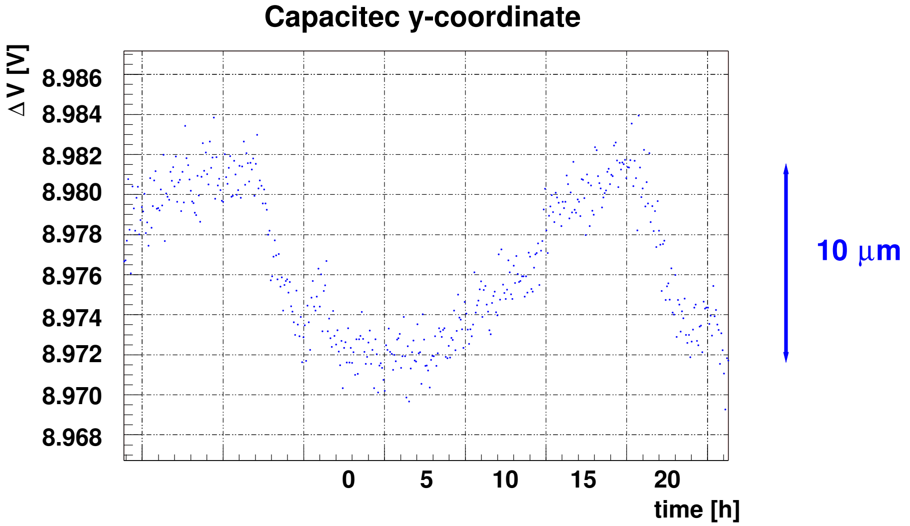
  3160 V (gas gain: 4×10^4)

- Temperature: 19.5 ± 0.5 °C

- Maximum measured deviation in alignment systems: 5 μm

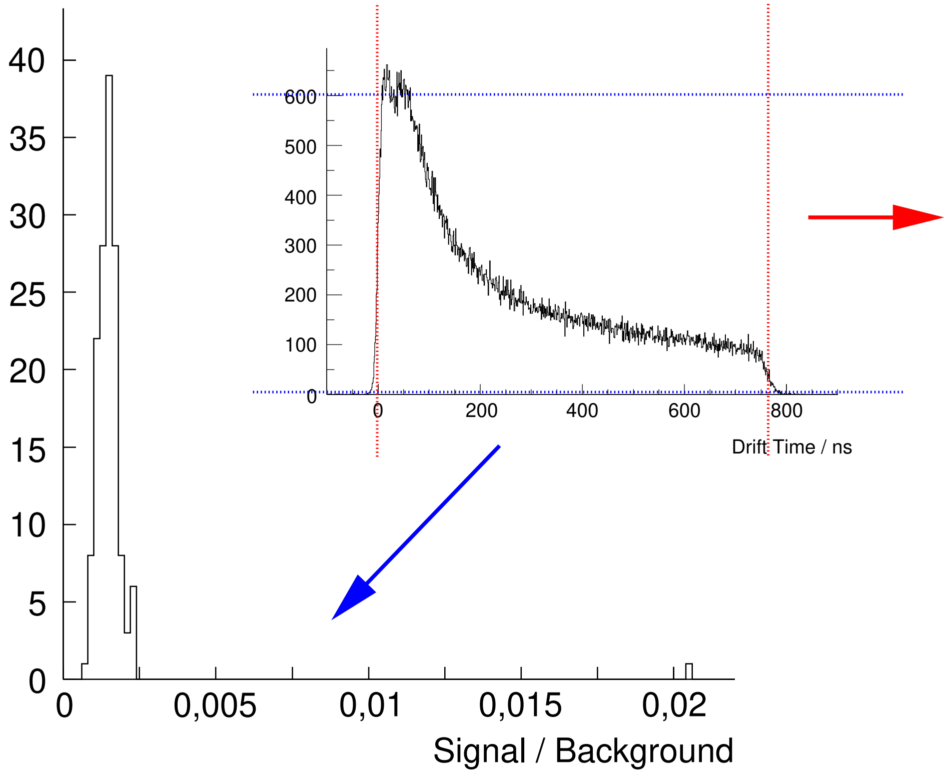
  $\rightarrow$ chambers rigid bodies with fixed positions



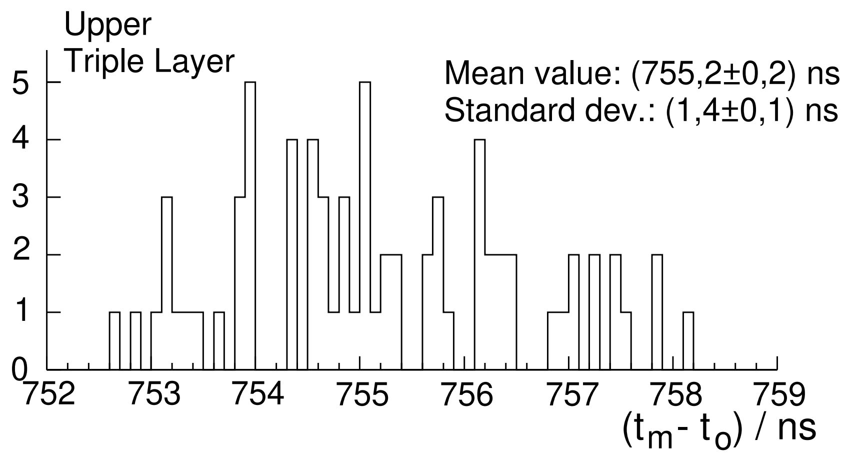


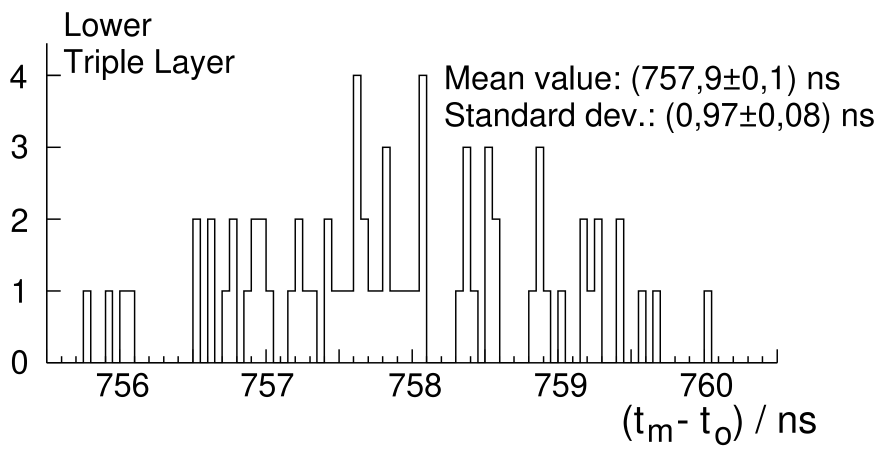
First Results (4) - Drift Time Spectra

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



- RMS spread of maximum drift time in one multilayer: $\lesssim 1.6$ ns

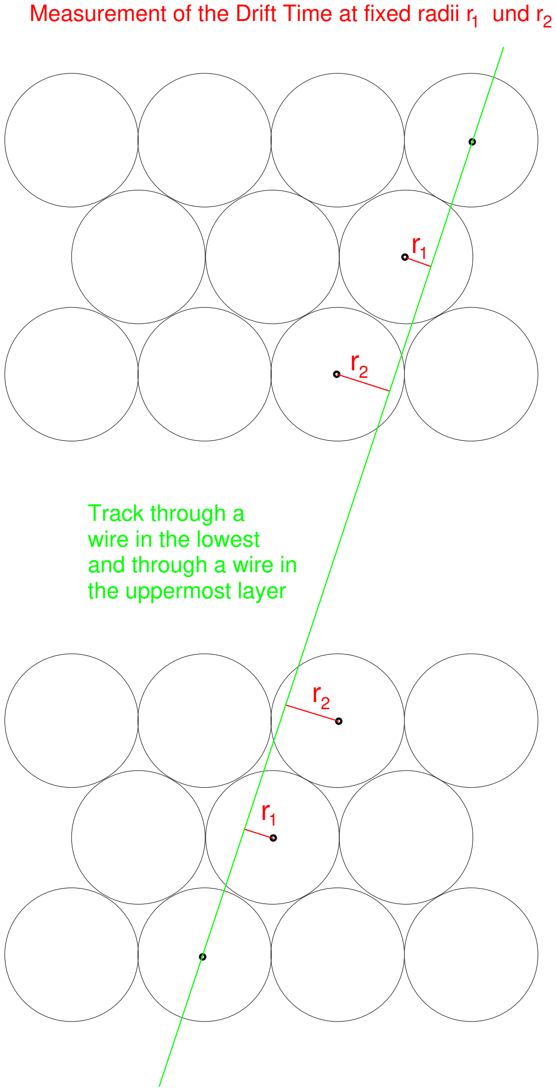




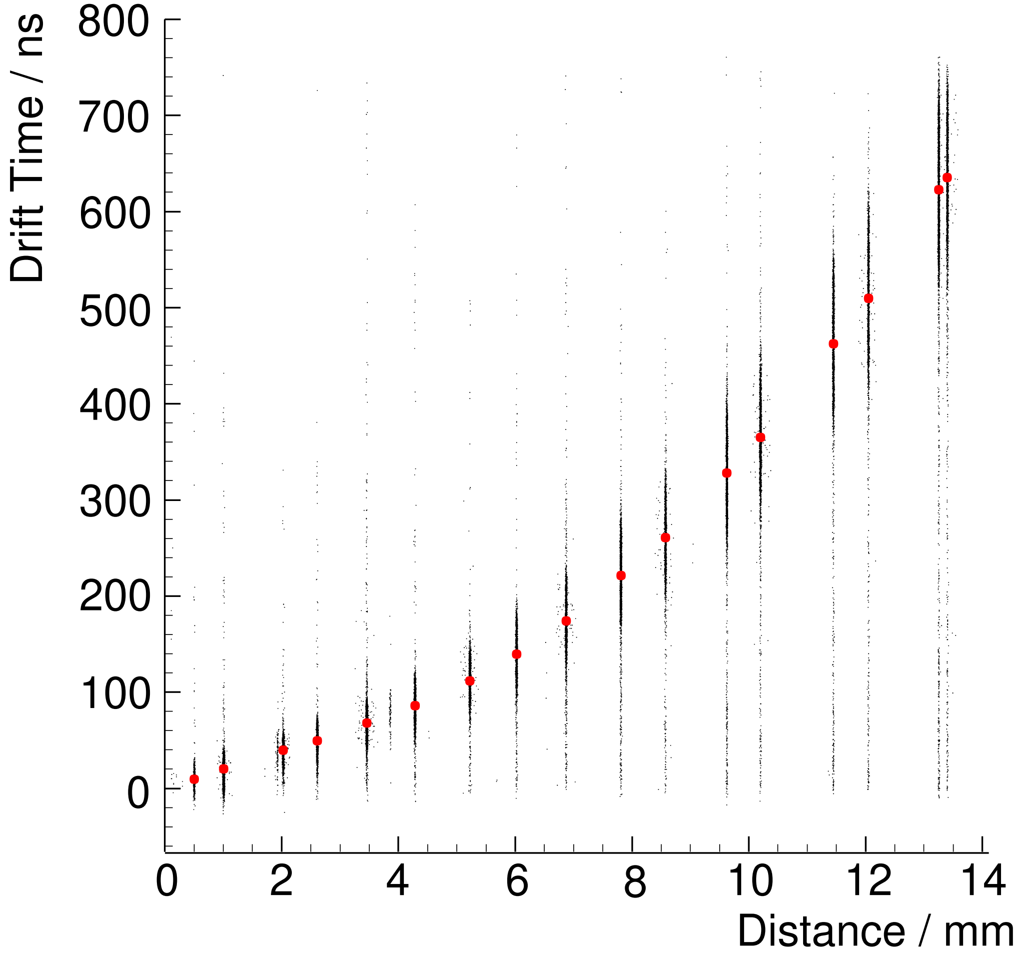
First Results (5) - R-t Relation

Method

- Use tracks through wires in uppermost and lowest layer of reference chamber
- All other wire distances known
- Discrete set of value (r,t)
- Linear interpolation to get r(t) for arbitrary t

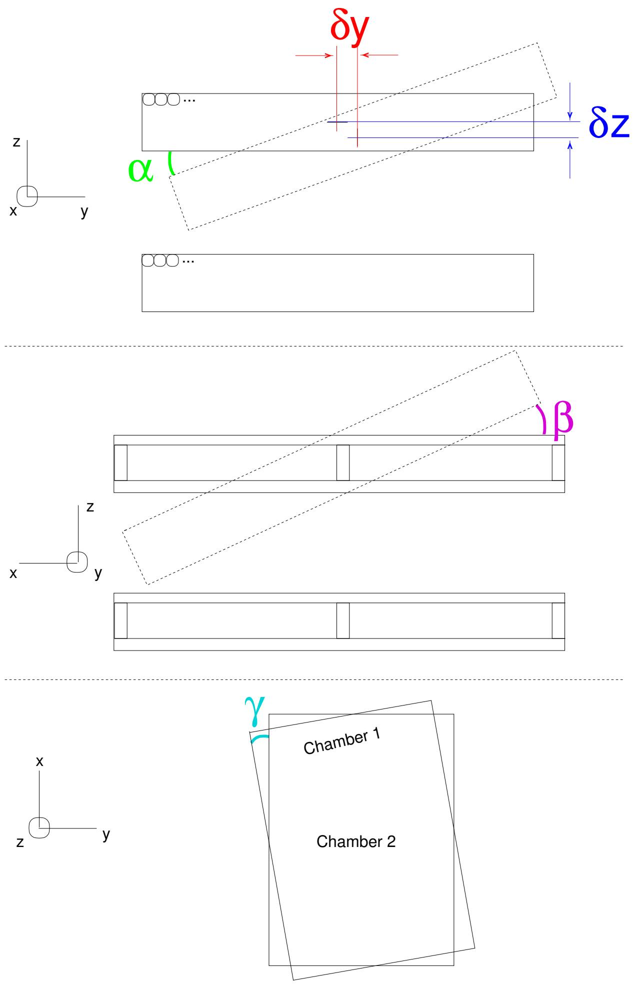


First Results (6) - R-t Relation (cont.)



- 1 global r-t relation
- Precision: 20–30 μm
- Drift times of upper multilayer in lower reference chamber will be scaled to match (drift times 7 ns longer than in other layers)

First Results (7) - Chamber Alignment



Aligment relative to the lower reference chamber by comparison of track segments in upper reference chamber (or test chamber) and lower reference chamber

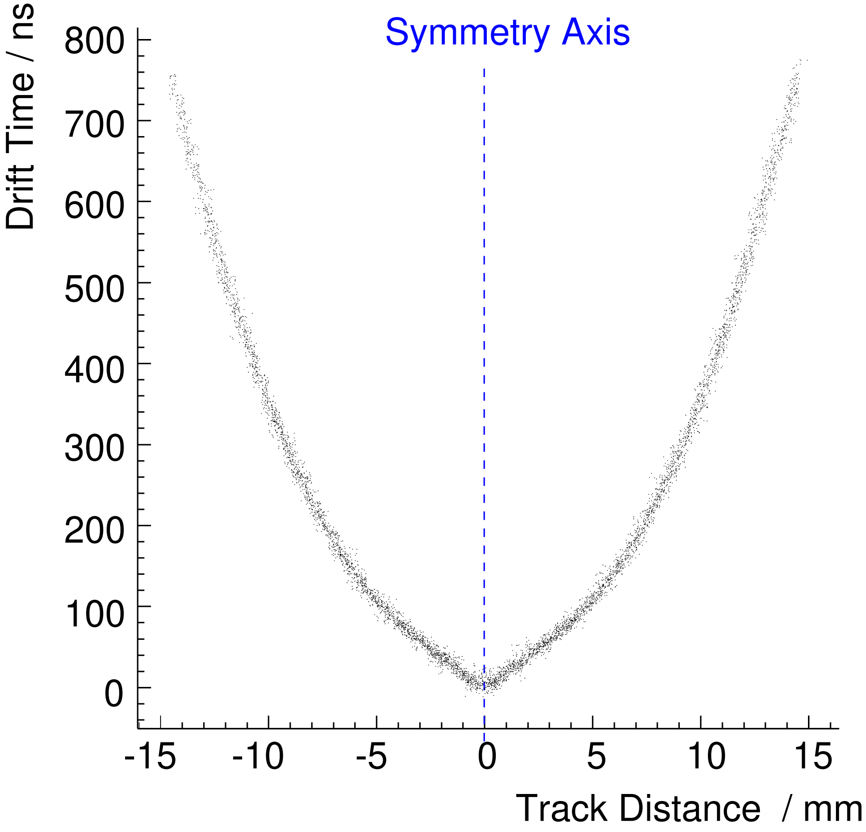
Results:

Parameter	Upper Reference Ch.	Test Ch.
α / 10^{-4}	-8.06 ± 0.07	-7.3 ± 0.1
β / 10^{-4}	2.1 ± 0.4	0.0 ± 0.4
γ / 10^{-4}	6.23 ± 0.04	-1.08 ± 0.04
δ_y / mm	2.460 ± 0.004	0.097 ± 0.003
δ_z / mm	-0.31 ± 0.03	1.42 ± 0.02

First Results (8) - Wire Positions in Test Chamber

Method

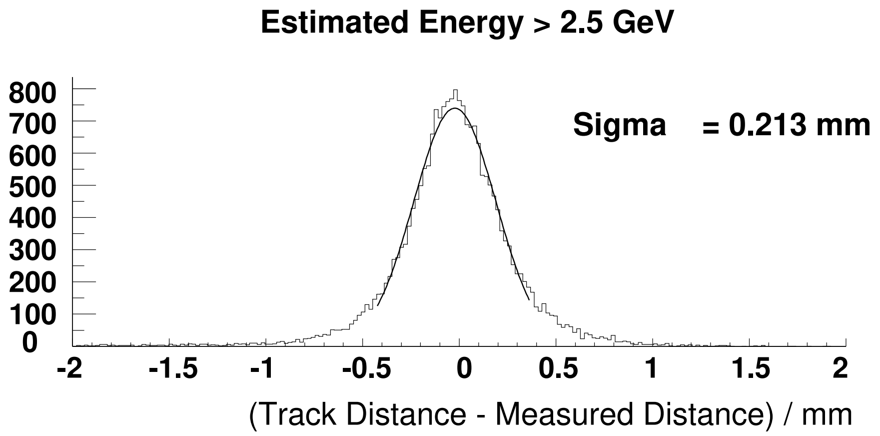
- Measure drift time t_{drift}
- Use reconstructed track from reference chambers to calculate distance r_{track} from tube center (nominal wire position)
- Symmetry axis of r_{track}-t_{drift} distribution gives horizontal wire position



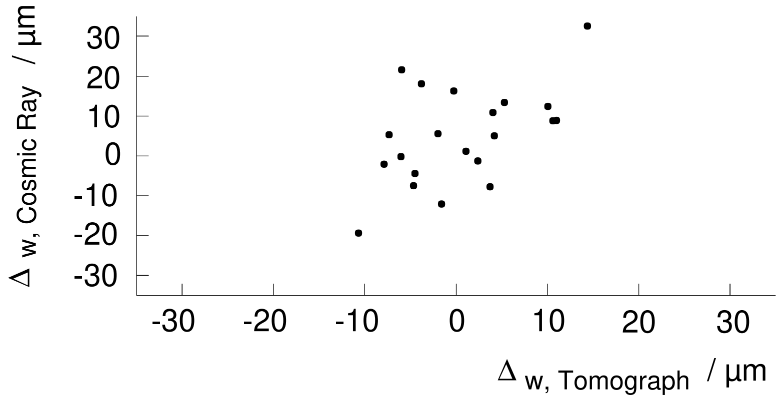
First Results (9) - Wire Positions in Test Chamber (cont.)

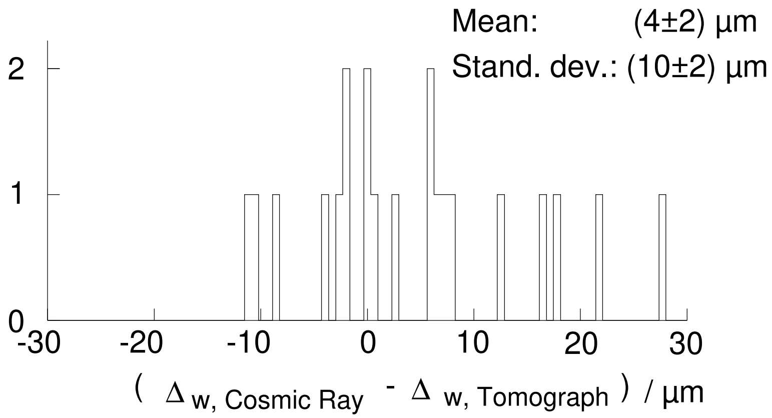
Precison

- Stat. error: 3 μm (5000 tracks)
- Syst. error: 8 μm (r-t relation)
- Total error: 9 μm

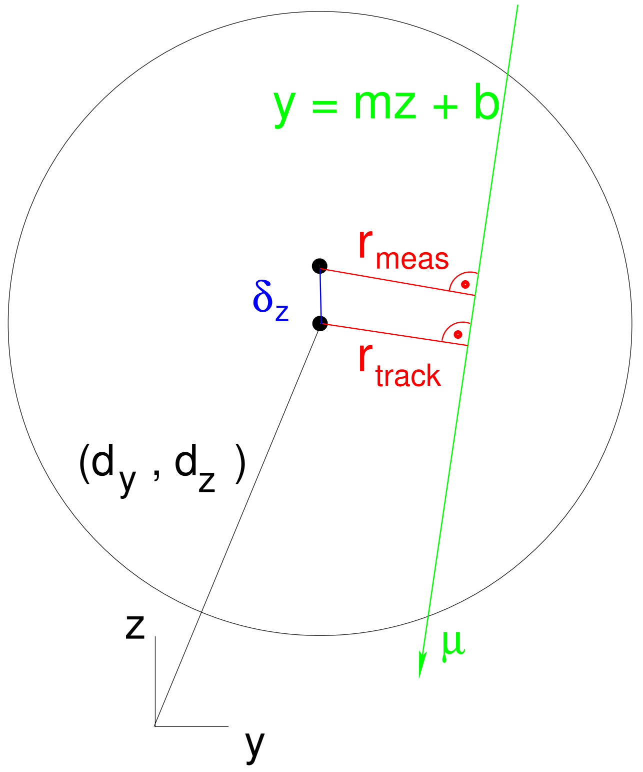


Results





First Results (10) - Layer Distances



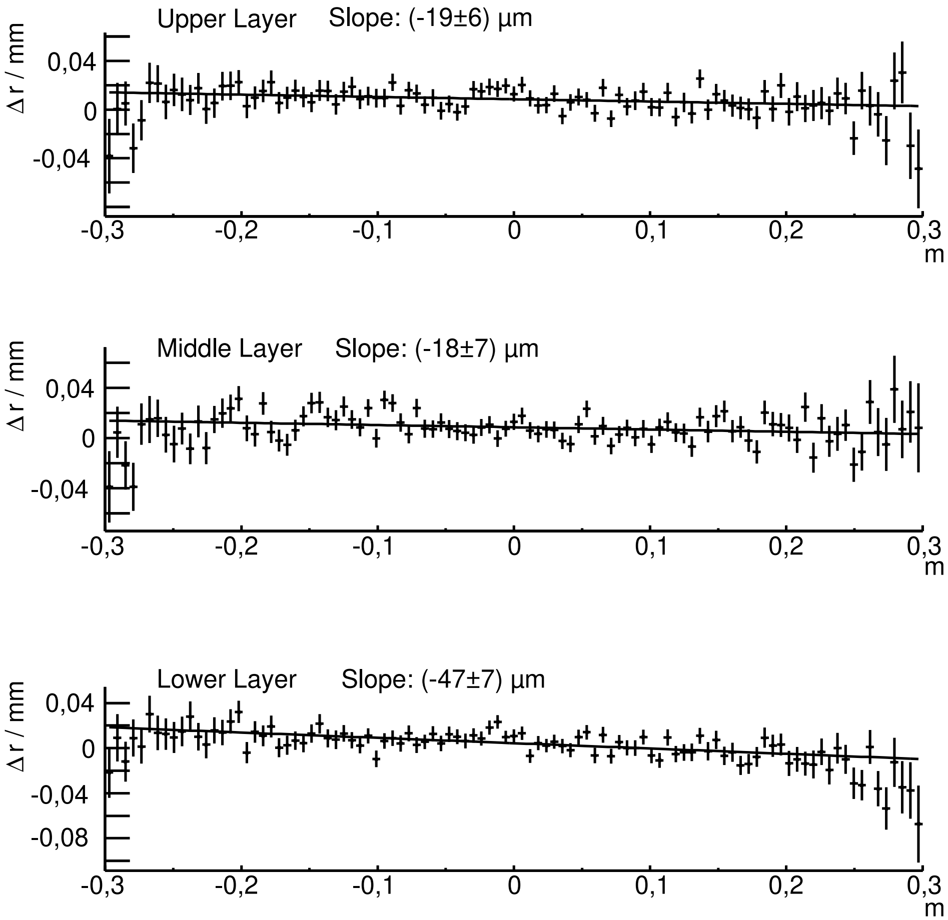
Method

Difference of track distance (from reference chambers) and measured distance (from r-t relation) depends on vertical tube offset:

$$r_{\mathrm{track}} - r_{\mathrm{meas}} = \pm\delta_z \cdot \frac{m}{\sqrt{1+m^2}} \approx \pm\delta_z \cdot m$$

Average over 8 tubes to increase precision

First Results (11) - Layer Distances (cont.)



Results

	Layer 1–2
Tomograph	26.018 ± 0.003 mm
Cosmic Ray	26.012 ± 0.010 mm

	Layer 2–3
Tomograph	26.046 ± 0.003 mm
Cosmic Ray	26.040 ± 0.010 mm

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

Outlook (1)

- Divide **Hodoscope trigger** into 5 segments to select more tracks in a plane perpendicular to the MDT wires
  $\rightarrow$ increase rate of useful events by 50%

- Measure position of **Alignment Platforms** relative to wires with silicon strip detectors
  $\rightarrow$ 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**