Construction and Test of a Full Prototype Drift-Tube Chamber for the Upgrade of the ATLAS Muon Spectrometer at High LHC Luminosities

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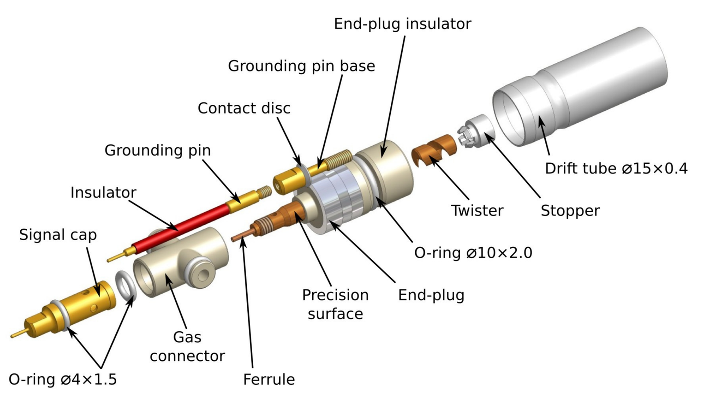
Abstract

For the planned high-luminosity upgrades of the Large Hadron Collider (LHC) background rates of neutrons and gamma rays of up to 14 kHz/cm^2 are expected which exceed the rate capability of the current ATLAS precision muon tracking detectors, the Monitored Drift Tube (MDT) chambers, with a drift tube diameter of 30 mm. So called sMDT chambers with a drift tube diameter of 15 mm have been developed for upgrades of the ATLAS muon spectrometer. A full sMDT prototype chamber has been constructed and tested in a muon beam at CERN and with cosmic muons at high gamma irradiation rates of up to 23 kHz/cm^2. The chamber design and construction procedures will be discussed. The test results demonstrate the required track reconstruction efficiency and spatial resolution of the sMDT chambers at background rates well beyond the maximum expected value. The sense wire locations in the prototype chamber have been measured with few µm precision with cosmic rays using precise reference chambers and confirm a wire positioning accuracy of better than the 20 µm required.

Drift Tube Design



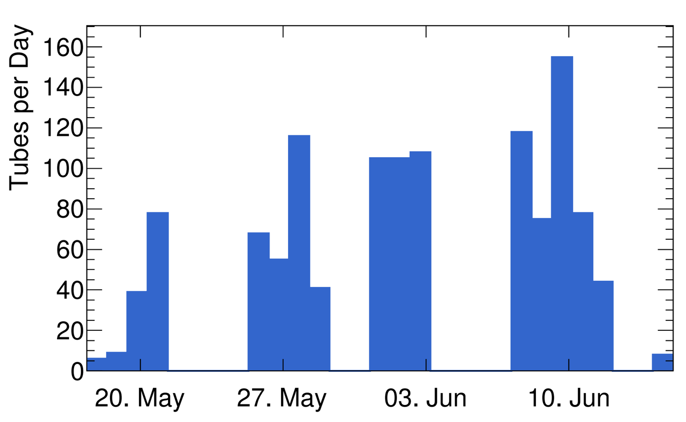
Outer tube diameter	15 mm ± 0.1 mm
Tube wall	0.4 mm Al
Anode wire	50 µm W-Re
Gas	Ar/CO_2 = 93/7
Pressure	3 bara
Operating voltage	2730 V
Gas gain	20000
Max. drift time	185 ns

Advantages of Smaller Drift Tubes

- 7.8× lower detector occupancy
  - Shorter max. drift time (700→185 ns)
  - Tube diameter (14.6→7.1 mm)
- Less space charge
  - $\sim R^3$ for γ's
  - $\sim R^4$ for charged hadrons
  - ⇒ Improvement by factor 8 and 16, resp.
- Twice the number of layers in the same volume
  - More robust pattern recognition
  - Better tracking efficiency
- Easy to integrate into the existing infrastructure

Drift Tube Production and Quality Assurance

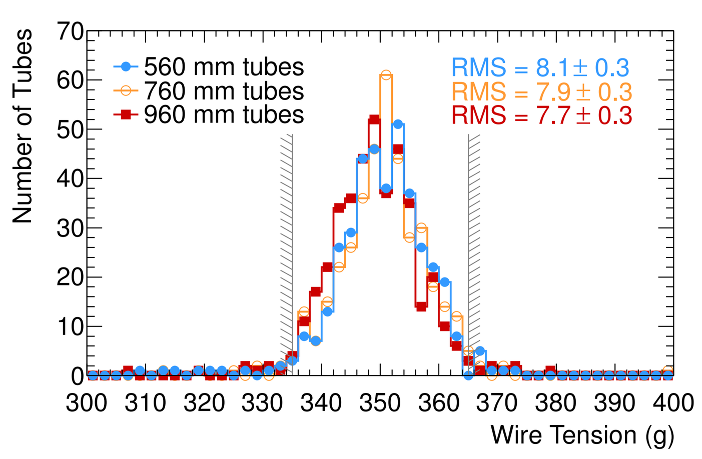
- 1204 tubes produced, 3 different lengths
- Entirely manual production, manpower 4 persons
- Production rate: up to 160 tubes / day



Daily tube production

Full quality assurance of all tubes

- Wire tension measurement, limit (350 ± 15) g
- Gas leak test, limit 1 × 10^{-5} mbar L/s
- HV dark current measurement at 3010 V, limit 5 nA

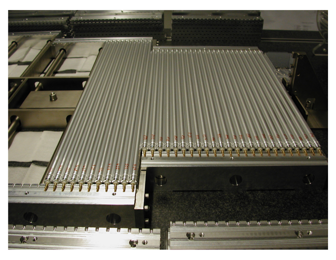


Measured wire tension

Test	Tested Tubes	Passed	Failure Rate (%)
Wire Tension	1204	1129	6.3[1]
Leak Test	1171	1164	0.6
HV	1164	1159	0.4
Total	**1204**	**1116**	**7.7**

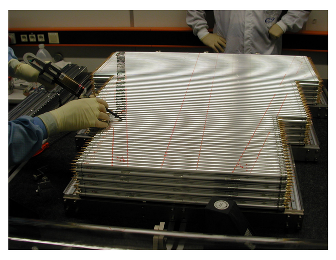
[1] High failure rate at beginning of prod. only, later <1%

Chamber Assembly Procedure

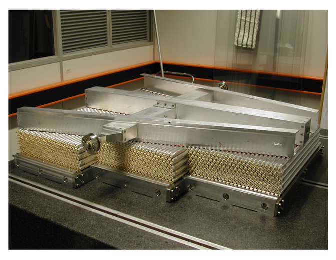


Inserting first tube layer into jigs.

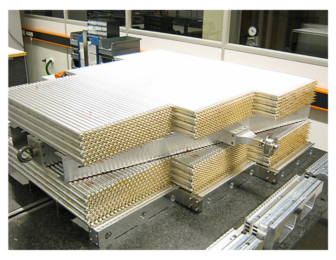
Gluing of second tube layer.



Applying glue for spacer frame.

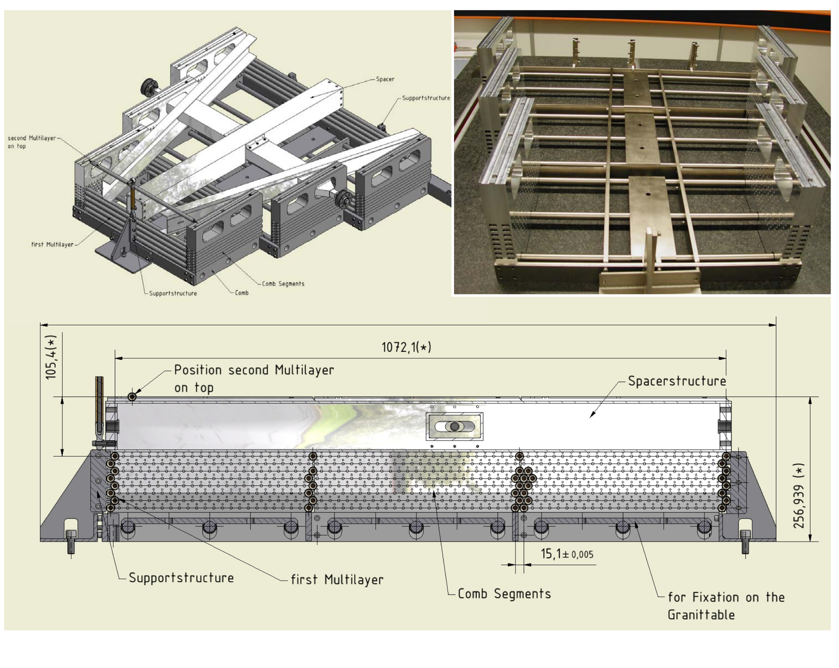


Spacer frame glued to first ML.



Finished chamber.

Precision Assembly Jiggs



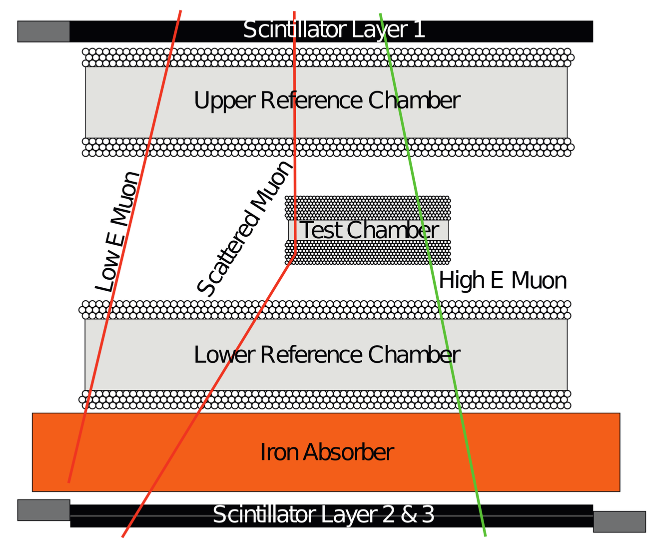
Finished Chamber

Front-End Electronics

- New passive front-end cards
  High connector density necessitates 3-dimensional design
- Compatible with ATLAS active front-end cards and readout scheme
- New Amplifier-Shaper-Discriminator chip under development

Wire Position Measurement

Cosmic ray test stand, LMU Munich
Used to test all ATLAS MDT chambers constructed in Munich (accuracy: 5 µm)

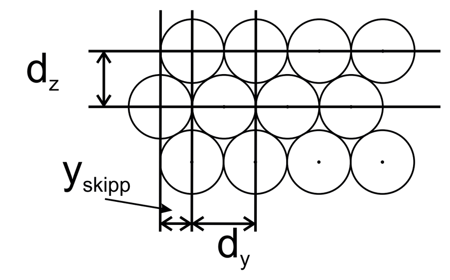


- reconstruction of muon tracks in the reference chambers
- extrapolation to the test chamber
- compare the reconstucted tracks with the hits in the test chamber

Results:

- Deviations of the wires from the (optimized) target positions are with 19 µm for δ_y and 16 µm for δ_z well within the requirements of 20 µm.
- Good agreement with the design values

Parameter	nominal	measured
d_y	15.100 mm	15.1018 ± 0.0003 mm
d_z	13.078 mm	13.091 ± 0.007 mm
y_{skip}	7.550 mm	7.550 ± 0.0005 mm
ML dist.	90.400 mm	90.382 ± 0.010 mm

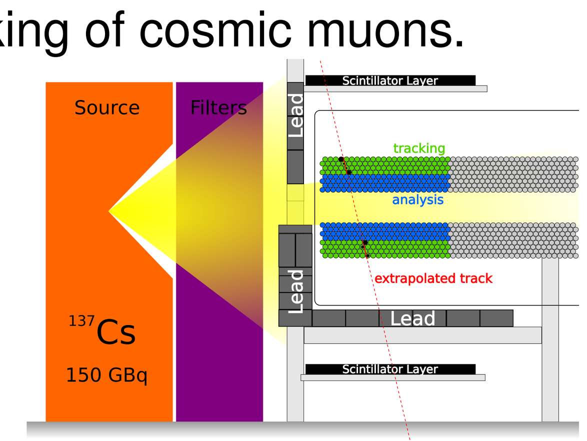


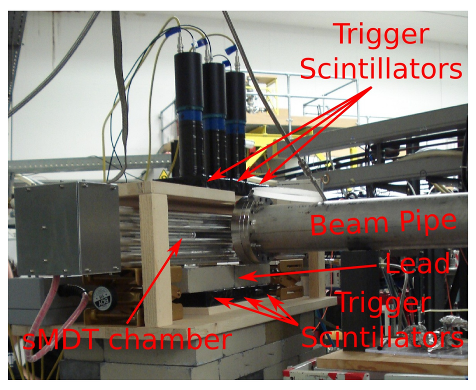
Measurements at High Background Rates

Measurement principle: Central tube layers of the chamber irradiated, outer (shielded) layers used for tracking of cosmic muons.

GIF 2011
- 150 GBq ^{137}Cs source
- flux up to 10 kHz/cm^2

Tandem accelerator 2011
- 20 MeV protons
- flux up to >100 kHz/cm^2

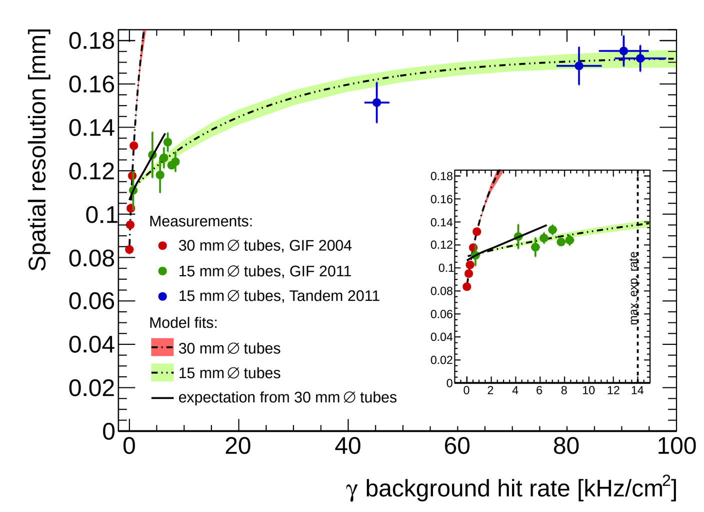


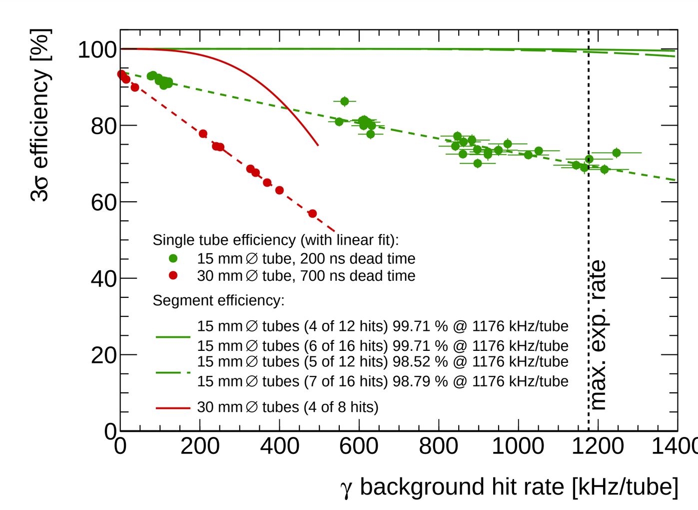


Analysis strategy:

1. Use track reconstructed in shielded part of the chamber to determine off-track residuals in irradiated tubes.
2. Correct for track uncertainty and multiple scattering due to low energy muons ⇒ resolution σ.
3. Determine 3σ efficiency.

Results



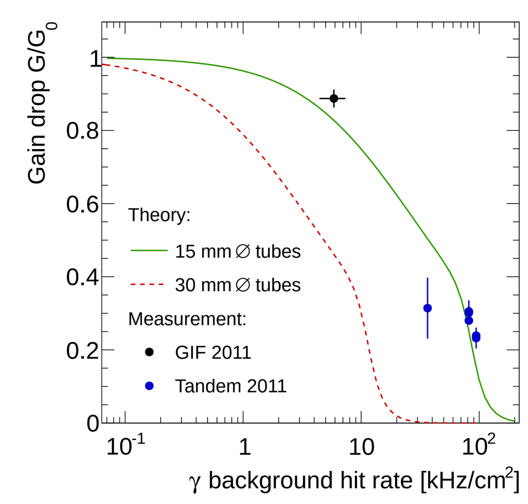


Iterative calculation of the gas gain with Diethorn's formula:

$$G = \left[\frac{E_{wire}}{3E_{min}}\right]^{\frac{r_{wire}E_{wire}\ln 2}{\Delta V}}$$

where E_{wire} is the electric field at the sense wire which depends on the space charge density and thus the background flux.

G_0 = nominal gain = 20 000.



Conclusions

- Successful construction of 1200 drift tubes with low failure rate.
- Chamber assembly procedures and time frame (1 chamber per week) validated.
- Wire positioning accuracy (20 µm) validated with cosmic muons.
- Measured up to the highest expected rates of 14 kHz/cm^2, 1175 kHz/tube:
  - Tracking efficiency >70% per tube and >99% with 8-layered chamber.
  - Spatial resolution <140 µm per tube and <50 µm with 8-layered chamber.

⇒ Fulfill all requirements for operation at High Luminosity-LHC.