Construction and Test of a Prototype Chamber for the Upgrade of the ATLAS Muon Spectrometer

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TIPP 2011, Monday 13 June 2011

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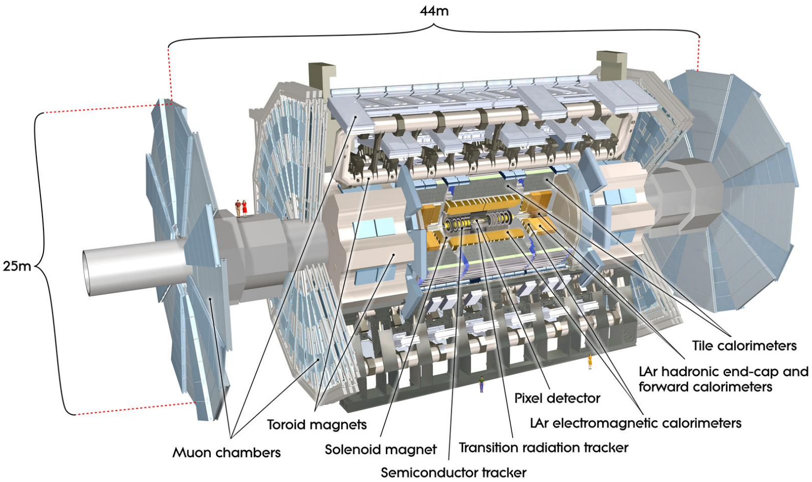
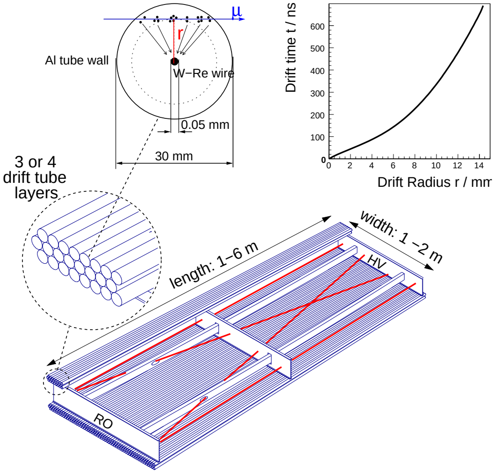
Outline

1. The ATLAS Muon Spectrometer
2. Challenges Arising with Increasing LHC Luminosity
3. Improvement of the Tracking Capability of the Muon Chambers
4. Design and Construction of a Full-Scale Prototype Chamber
5. Test of the Chamber Performance

The ATLAS Muon Spectrometer

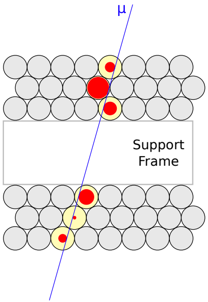


The ATLAS Monitored Drift Tube Chambers

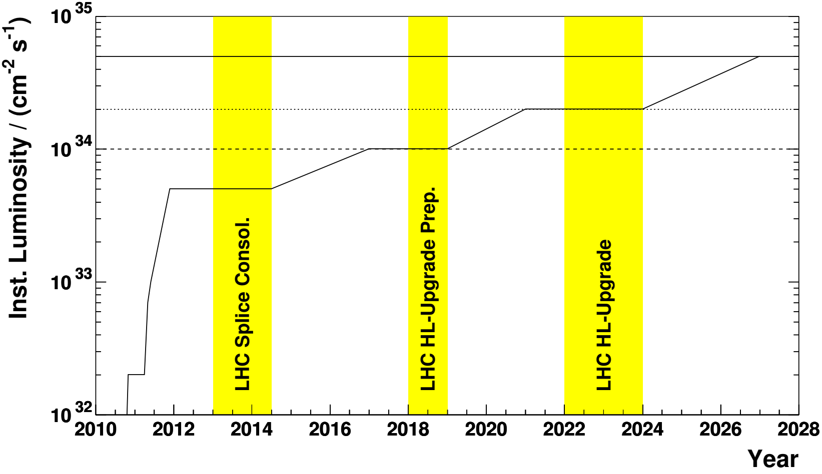


MDT chamber parameters:

- Gas Mixture: Ar/CO_2 (93/7)
- 3 bar absolute pressure
- Max. drift time: ≈ 700 ns
- Single-tube resolution: 80 μm
- Wire pos. accuracy: 20 μm
- Track rec. accuracy: 35 μm



LHC Luminosity Outlook

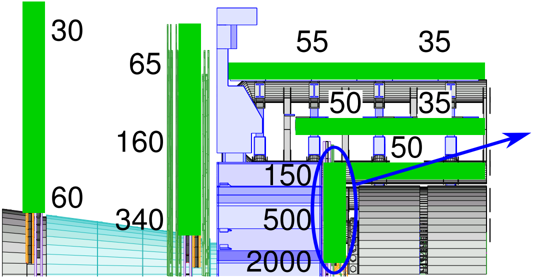


Cavern Background

- High background rate from n, γ from secondary reactions in detector components and shielding material
- Background rate expected to increase proportional to luminosity increase

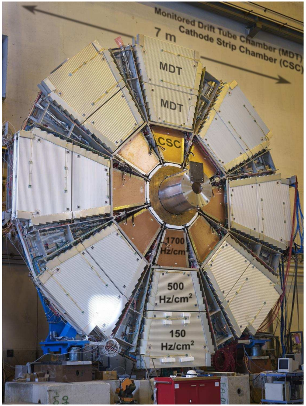
$\Rightarrow$ Background rate capability exceeded in the inner forward region (*Small Wheel*) of the muon spectrometer

Expected rate in Hz/cm^2 at nominal LHC luminosity:



safety factor 5 included

(Radiation Background Task Force, 2005)



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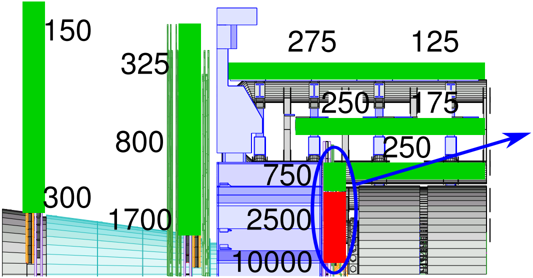
Expected rate in Hz / cm^2 at
5$\times$ nominal LHC luminosity:



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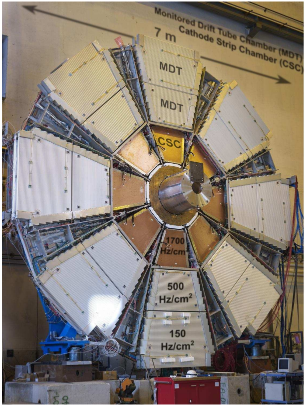
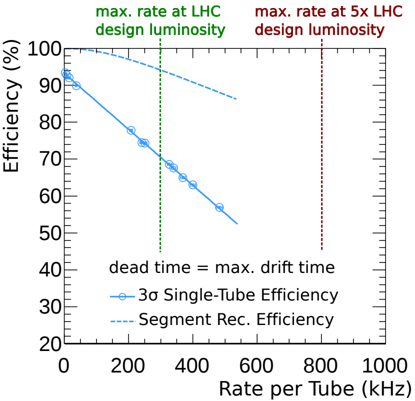
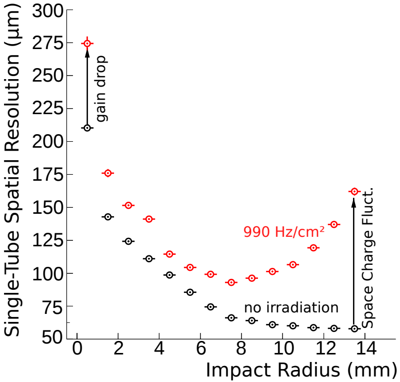
(Radiation Background Task Force, 2005)



Performance Loss of MDTs at High Rates

Background n and γ's cause drop of efficiency and spatial resolution.

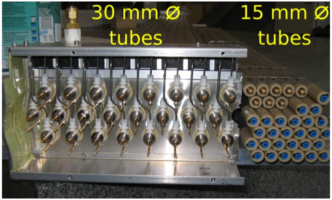


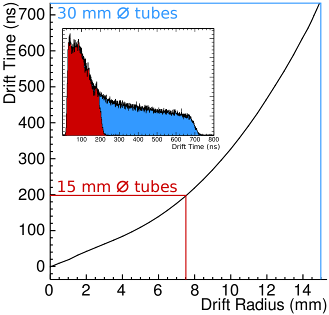


Luminosity ($cm^{-2}s^{-1}$)	Min. Occupancy outer SW	Max. Occupancy middle SW
1×10^{34}	8 %	13 %
2×10^{34}	16 %	25 %
5×10^{34}	40 %	65 %

including safety factor 5, Radiation Task Force

Smaller Drift Time Diameter



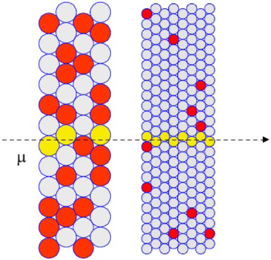


Drift gas: Ar/CO_2 (93:7), 3 bar

Reducing the tube diameter from 30 to 15 mm:

- $7\times$ lower occupancy due to
  - shorter maximum drift time (factor 3.5)
  - smaller tube diameter (factor 2)
- Space charge effects lower by factor 10 ($\#e_{\text{prim}} \propto r$, $t_{\text{ion drift}} \propto r^2 \ln(r)$)
- More tube layers in the same volume $\Rightarrow$ better tracking efficiency

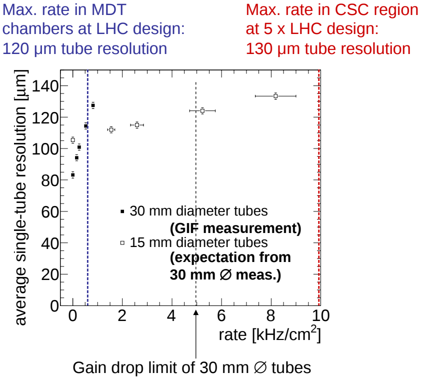
Rate: ~3 kHz / cm²
Occupancy: 42% 5%



Occupancies and Resolution

Comparison of 15 mm and 30 mm diameter tubes

- decline of the spatial resolution due to background rate much smaller (factor 10)
- 15 mm ⌀ tubes can be operated up to the highest expected rates
- safety factor 5 included (Radiation Task Force)

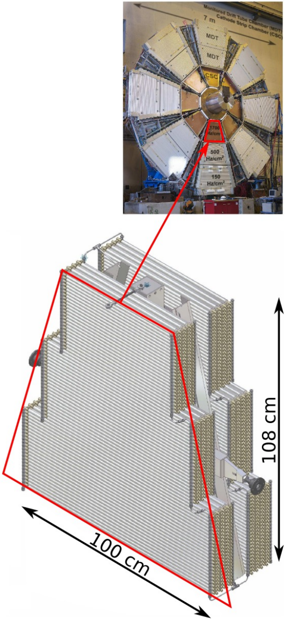


	15 mm ⌀ tubes		30 mm ⌀ tubes	
Luminosity $(\mathrm{cm}^{-2}\mathrm{s}^{-1})$	Min. Occupancy outer SW	Max. Occupancy inner SW	Min. Occupancy outer SW	Max. Occupancy middle SW
1×10^{34}	1 %	3.3 %	8 %	13 %
2×10^{34}	2 %	6.6 %	16 %	25 %
5×10^{34}	5 %	16.5 %	40 %	65 %

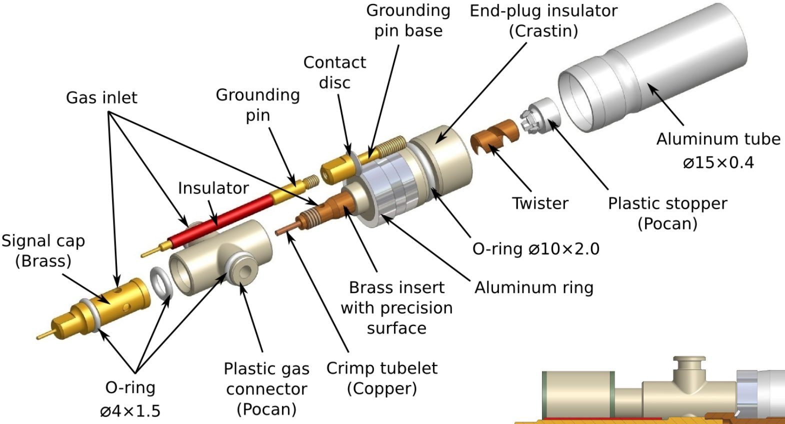
Design of a Small Drift Tube Prototype Chamber

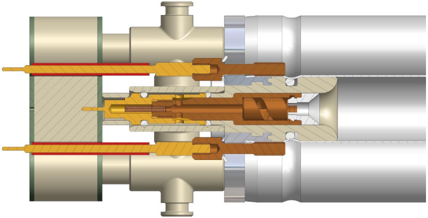
- Chamber size ≈1.1 m×1 m
- Trapezoidal shape to fit into a *Small Wheel*
- 3 tube lengths: 560, 760 and 960 mm
- 2×8 tube layers
- 1152 tubes in total
- New passive RO and HV front-end boards
- Active read-out boards (mezzanine boards, CSMs) from current ATLAS MDT chambers, new radiation hard electronics under development

Complete tube and chamber assembly in clean room.



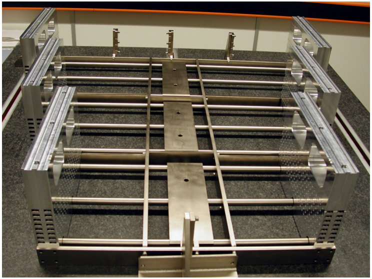
New Drift Tube Chamber Design



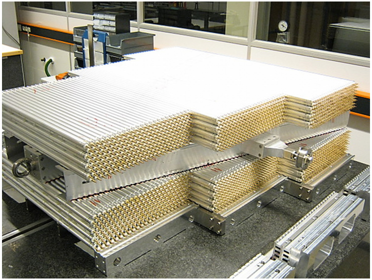


15 mm Diameter Drift Tube Prototype Chamber

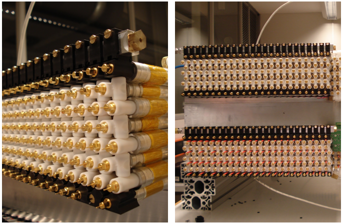
precision assembly jigs



glued multilayers



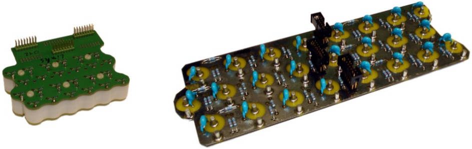
modular gas system



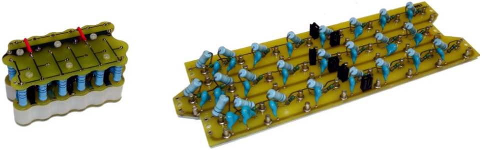
- Assembly of a whole multilayer in one day
- Wire pos. accuracy: 20 µm
- New modular gas system

New Front-End Electronics

New passive HV and read-out cards.
The 4$\times$ higher channel density requires 3-dimensional layout.

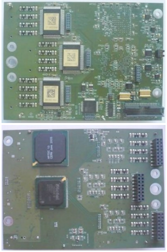


15 mm ⌀ tubes   30 mm ⌀ tubes

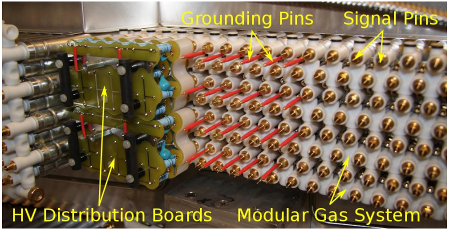


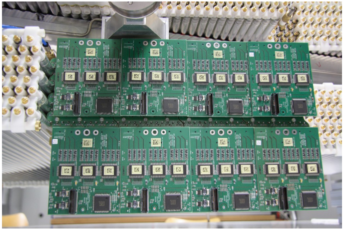
Prototype of new radiation hard active front-end cards

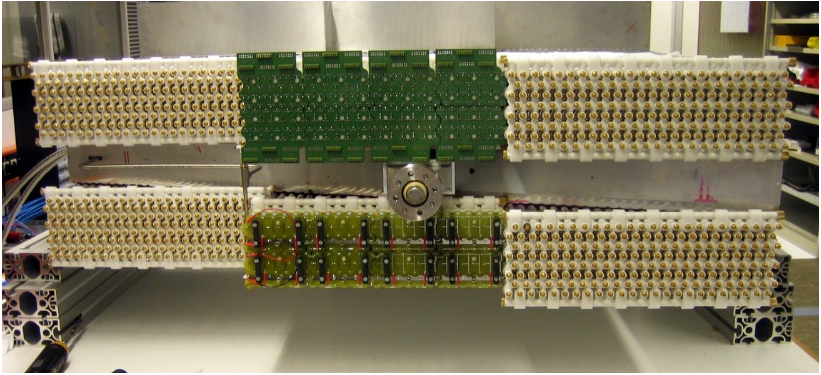
- ASD chip (Full analog and digital chip design submitted in May)
- TDC (CERN)
- FPGA for L1 trigger functionality



New Front-End Electronics





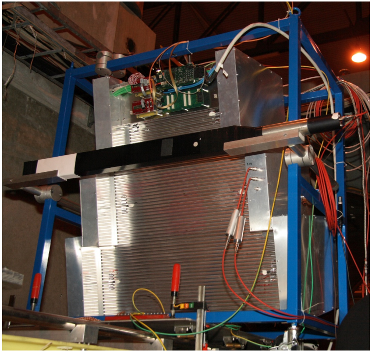


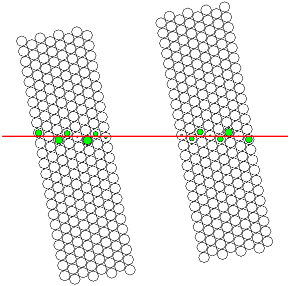
Test Beam Measurements

180 GeV muon beam at CERN (H8)

Goal:

Measurement of the spatial resolution and the efficiency without background radiation





Large number of layers allows measurements without an external reference system.

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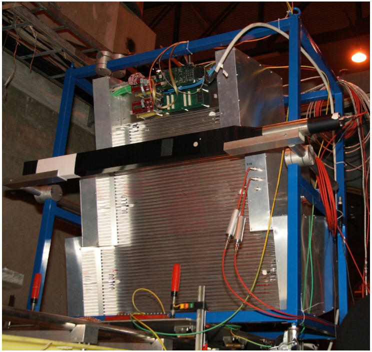

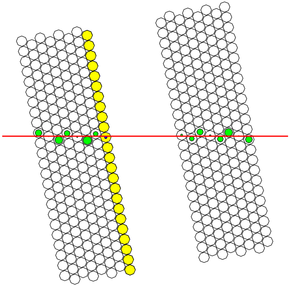

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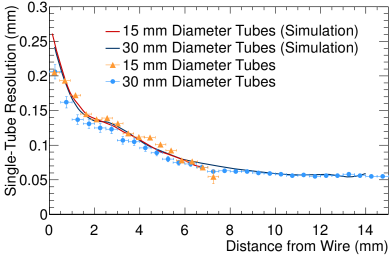
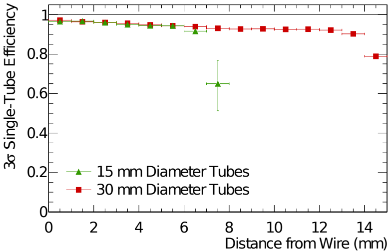
Test Beam Measurements

Stable operation of the prototype chamber in the test beam for one week.





- good agreement with 30 mm ⌀ tubes
- setup was not fully optimized (ASD calibration, gas flow)

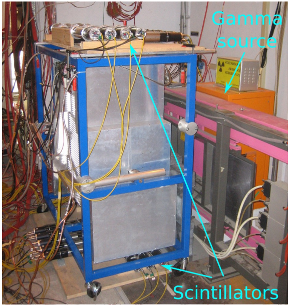
⇒ small improvements possible

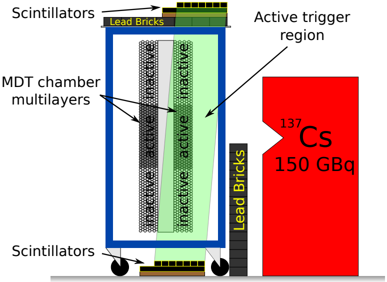
- perfect agreement with 30 mm ⌀ tubes
- drop at tube wall due to shorter ionization path

High-Rate Tests

CERN Gamma Irradiation Facility (GIF)

Goal: Measurement of spatial resolution and efficiency as a function of the background counting rate.



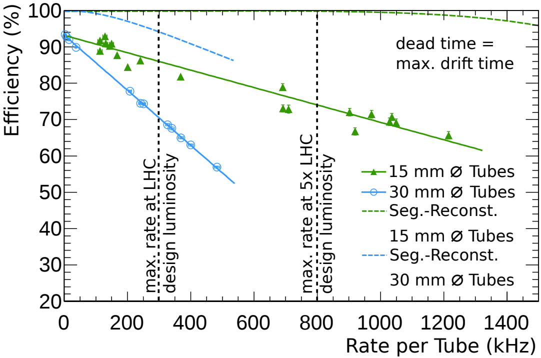


Challenges:

- No muon beam in the GIF → have to use cosmic muons
- Spatial resolution dominated by multiple scattering and track extrapolation uncertainties

High-Rate Tests

Results



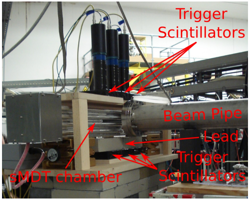
- Efficiency measurement shows good agreement with expectancy
- Resolution measurement not yet possible, need better trigger acceptance and better tracking

Summary

- The inner forward regions (Small Wheels) of the ATLAS muon spectrometer have to be replaced for high luminosity upgrades of the LHC.
- Monitored Drift Tubes are proven and well tested technology for high counting rates.
- Reducing the diameter of the drift tubes improves the rate capability further. This is fully sufficient for operation in new Small Wheels at the highest expected luminosities.
- Successful construction and operation of a full-scale prototype chamber with 15 mm diameter drift tubes.
- First application of two new small drift tube chambers in ATLAS after 2013 shutdown to fill acceptance holes.

Backup

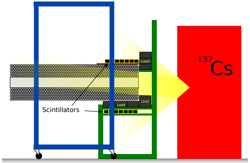
Further Tests



Irradiation with 20 MeV protons (May)

Goal: Study of the detector performance at high rates of highly ionizing particles

- Analysis ongoing



New setup for γ irradiation in the GIF (July)

Goal: Measurement of the spatial resolution at high background rates

- Wire position measurement with cosmic rays (June)
- H8 test beam with RPC and TGC trigger chamber groups for chamber integration studies (August)
- Long term ageing tests with n, γ irradiation (July)

Backup

Sector 13 Elevator Region