Development of Fast Muon Detectors for Upgrades of the ATLAS Muon Spectrometer

Philipp Schwegler

philipp.schwegler@cern.ch

Max-Planck-Institut für Physik, Munich

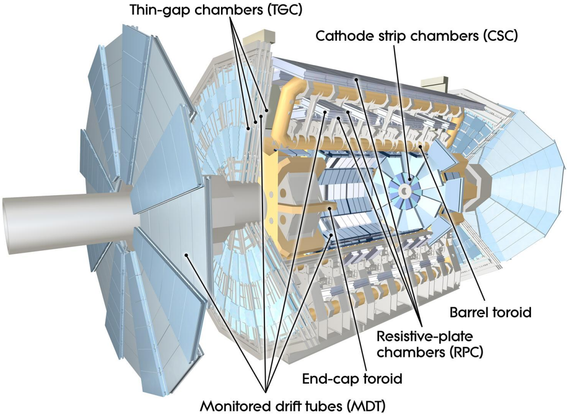
Particle Physics School Colloquium

March 16, 2012

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

MAX-PLANCK-GESELLSCHAFT

The ATLAS Muon Spectrometer



designed for LHC nominal luminosity:
$\mathcal{L} = 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$

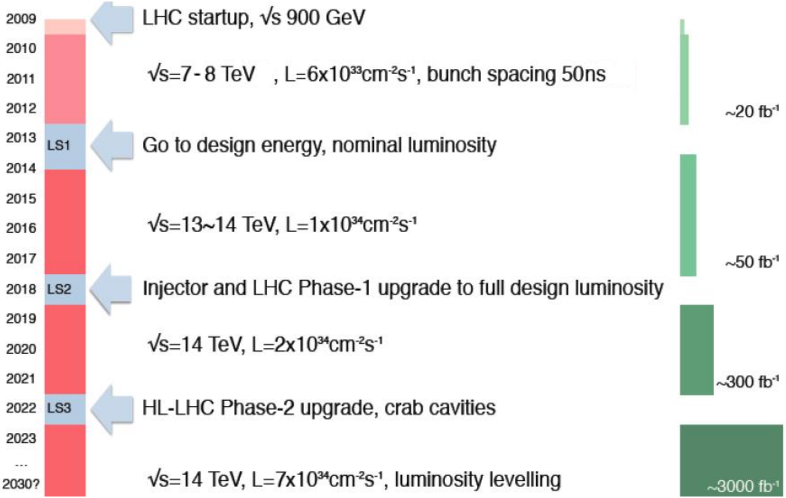
Precision tracking chambers

1150 Monitored Drift Tube Chambers (MDT)
32 Cathode Strip Chambers (CSC)

Trigger chambers

606 Resistive Plate Chambers (RPC)
3588 Thin Gap Chambers (TGC)

LHC Long Term Schedule

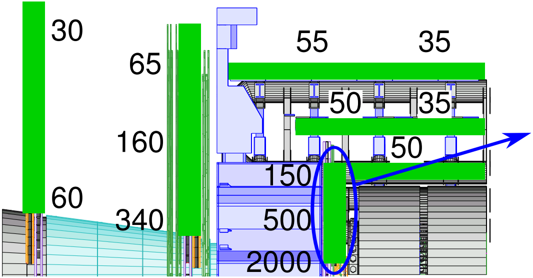


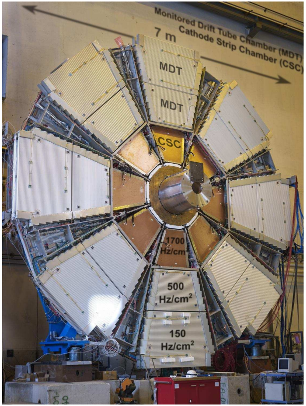
Rates in the ATLAS Muon Spectrometer

- Neutrons, γ's and charged hadrons from secondary reactions in detector components and shielding cause high background rates.
- Background rate increases proportional with the luminosity.

$\Rightarrow$ Rate capability in the *Small Wheels* (inner end cap layer) exceeded.

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



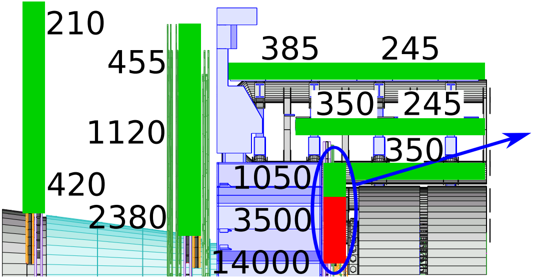


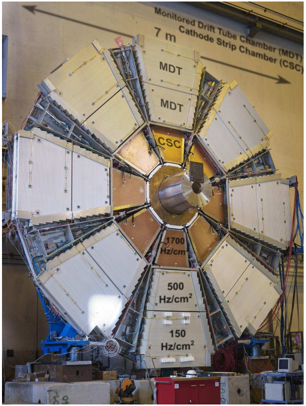
Rates in the ATLAS Muon Spectrometer

- Neutrons, γ's and charged hadrons from secondary reactions in detector components and shielding cause high background rates.
- Background rate increases proportional with the luminosity.

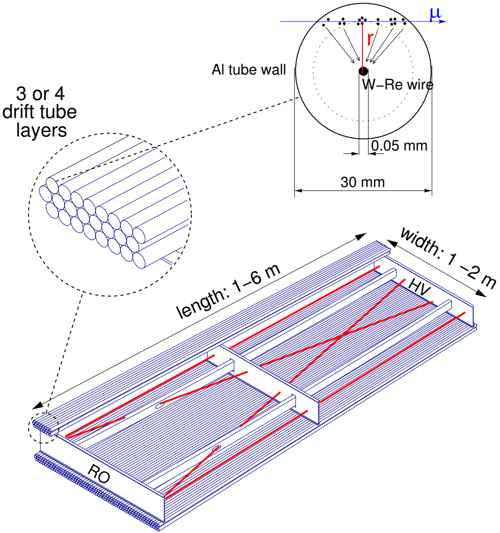
$\Rightarrow$ Rate capability in the *Small Wheels* (inner end cap layer) exceeded.

Expected rate in Hz / cm^2 at
7$\times$ LHC design luminosity:

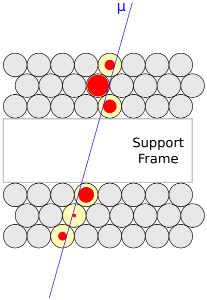




The (Current) ATLAS MDT Chambers

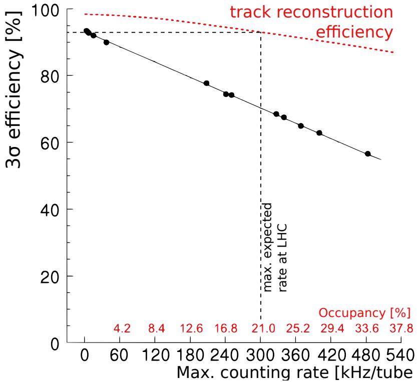


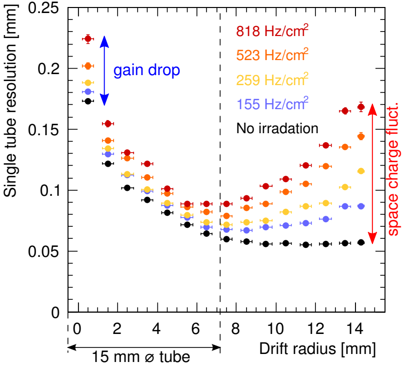
- gas mixture: Ar/CO_2 (93/7)
- at 3 bar absolute pressure
- max. drift time: ≈ 700 ns
- single tube resolution: 80 µm
- wire positioning accuracy: ≈ 20 µm
- chamber tracking resolution: ≈ 40 µm



Performance Loss at High Background Rates

Background hits cause drop of efficiency and resolution

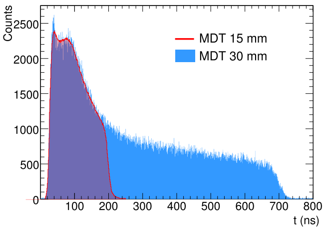


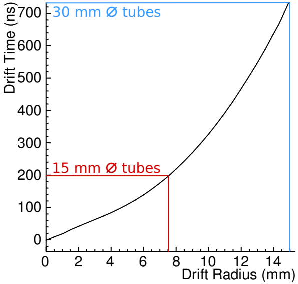


Background hits mask muon hits due to the electronics dead time.

Space charge created by background hits modifies the electric field.

sMDT's with Reduced Tube Diameter





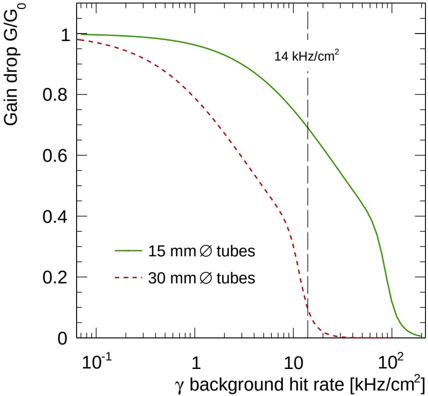
By reducing the outer tube diameter from 30 to 15 mm we gain:

- 7.8× lower detector occupancy
  - shorter max. drift time (700→185 ns)
  - inner tube diameter (14.6→7.1 mm)
- space charge reduced by factor ≥ 8 (see next slide)
- almost linear r(t) relationship
  - ⇒ less sensitive to space charge fluctuations
- more tube layers inside the same volume
  - ⇒ better tracking efficiency

Remaining parameters (gas mixture and pressure, gas gain, sense wire diameter, ...) kept for easy integration into existing infrastructure.

Space Charge

Reduction of the gas gain due to background hits:



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

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

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 = 20000

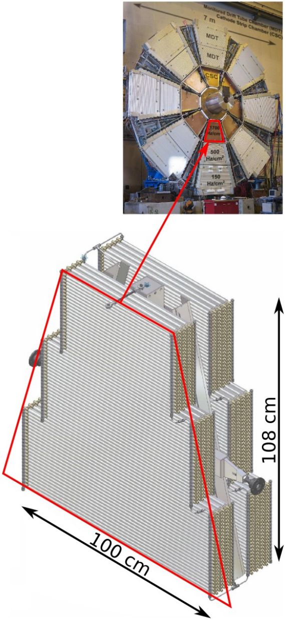
Space charge effects

- $\sim R^3$ for photons $\Rightarrow$ improvement by factor 8
- $\sim R^4$ for charged hadrons $\Rightarrow$ improvement by factor 16

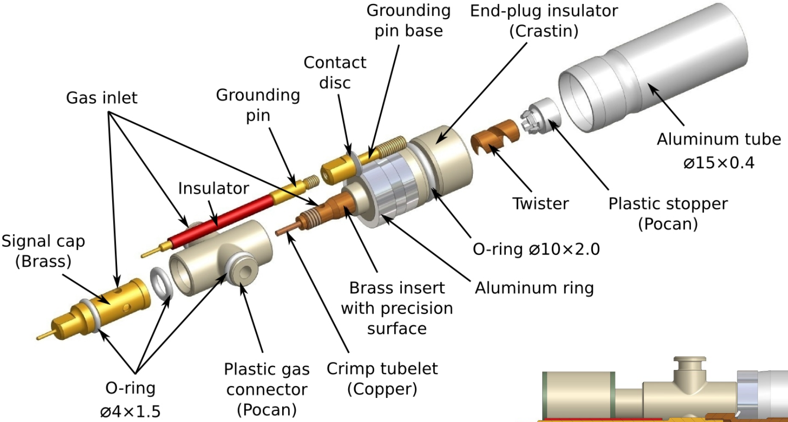
Design of a Small Drift Tube Prototype Chamber

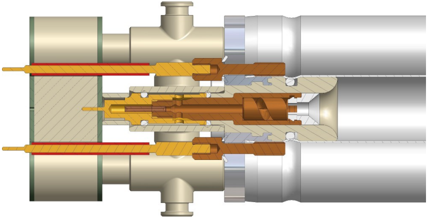
- Chamber size $\approx$1.1 m$\times$1 m
- Trapezoidal shape to fit into a *Small Wheel*
- 3 tube lengths: 560, 760 and 960 mm
- 2$\times$8 tube layers
- 1152 tubes in total
- New passive RO and HV front-end boards
- Active read-out boards (mezzanine boards, CSMs) from current ATLAS MDT chambers, new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

Complete tube and chamber assembly in clean room.



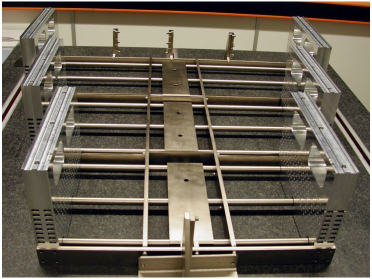
New Drift Tube Chamber Design



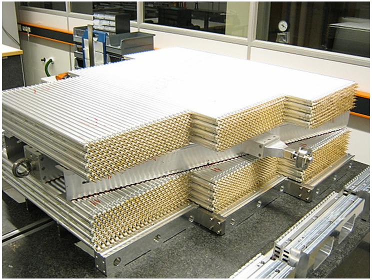


15 mm Diameter Drift Tube Prototype Chamber

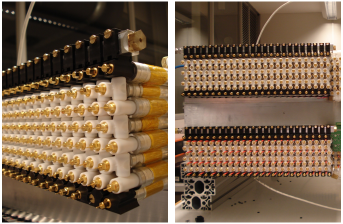
precision assembly jigs



glued multilayers



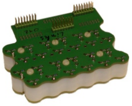
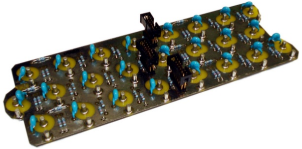
modular gas system



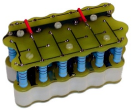
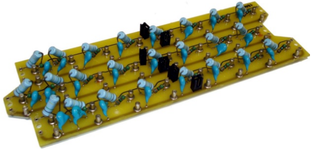
- Assembly of a whole multilayer in one day
- Wire pos. accuracy: 20 µm
- New modular gas system

New Front-End Electronics

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

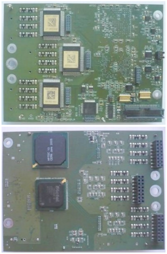



15 mm ⌀ tubes 30 mm ⌀ tubes

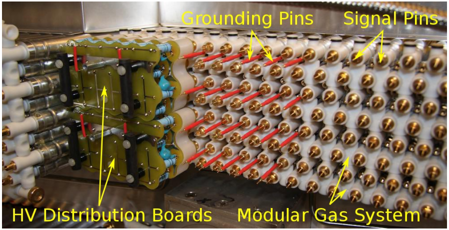



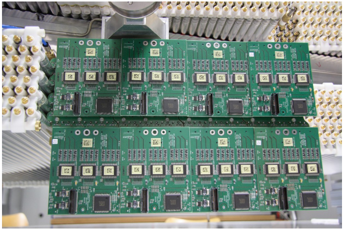
Prototype of new radiation hard active front-end cards

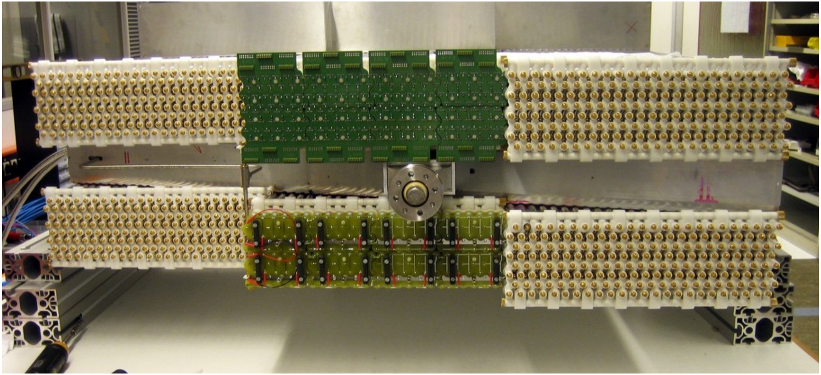
- ASD chip (Full analog and digital chip design submitted in May)
- TDC (CERN)
- FPGA for L1 trigger functionality



New Front-End Electronics



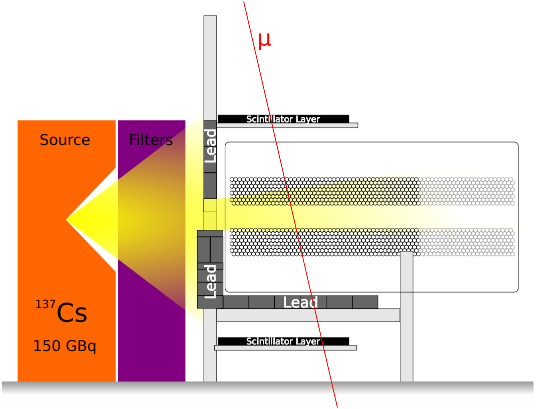




High Rate Tests

CERN Gamma Irradiation Facility (GIF)

Goal: Measurement of spatial resolution and efficiency of the sMDT's as a function of the background hit rate.

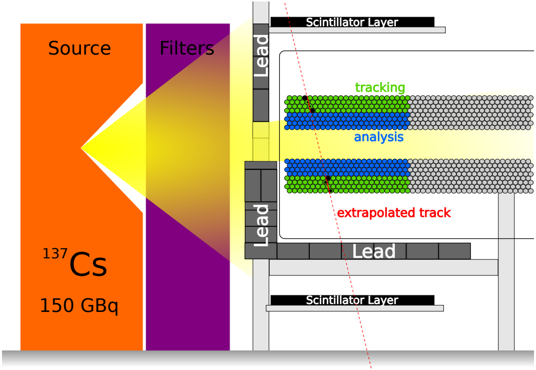


- No muon beam in the GIF → use (low energy) cosmic muons.

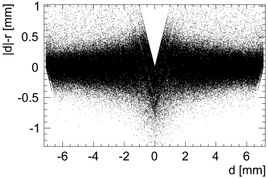
⇒ Corrections needed for implications of multiple scattering.

High Rate Tests

CERN Gamma Irradiation Facility (GIF)



- 16 tube layers in total
- 8 layers shielded for muon track reconstruction
- different rates in the central layers

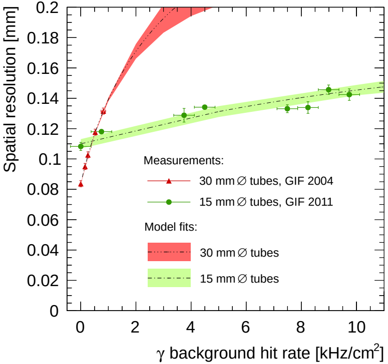


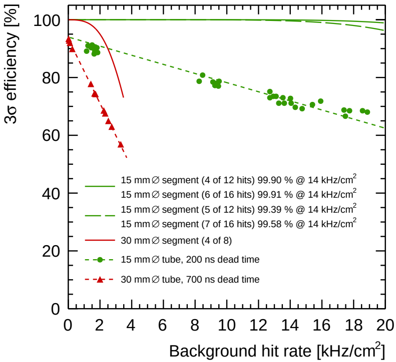
Determination of spatial resolution and efficiency

1. Distribution of residuals $|d| - r$ vs. $d \rightarrow$ fit in slices with Gaussian
2. Subtract contributions from track uncertainty and multiple scattering from Gaussian width $\Rightarrow$ spatial resolution σ as a function of d
3. Count fraction of hits with $|d| - r < 3\sigma \Rightarrow 3\sigma$ efficiency

High Rate Tests

Results



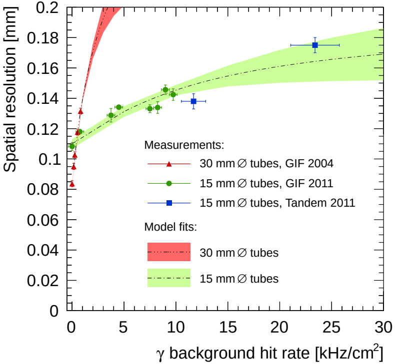


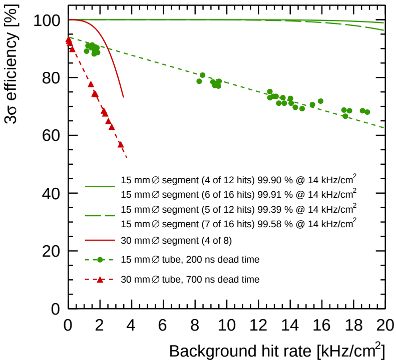
Measurements up to the highest expected rates:

- Single tube resolution 110–160 µm.
- 3σ single tube efficiency 95–70%.
- Track reconstruction efficiency >99%.

High Rate Tests

Results





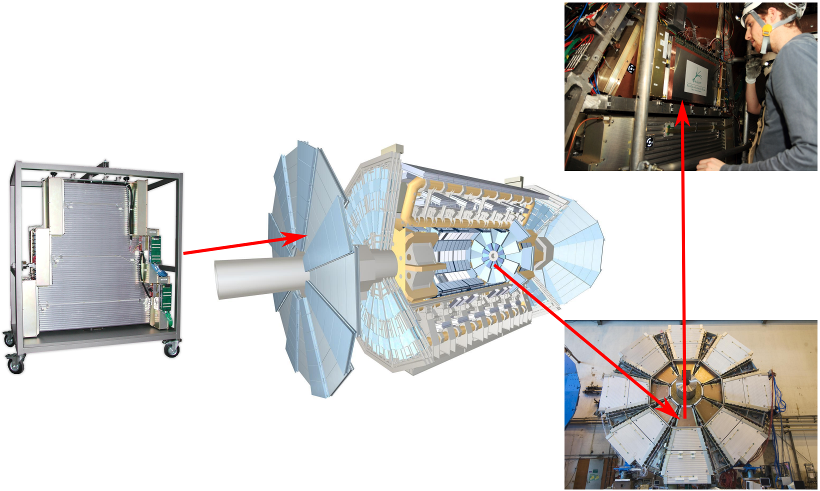
Measurements up to the highest expected rates:

- Single tube resolution 110–160 µm.
- 3σ single tube efficiency 95–70%.
- Track reconstruction efficiency >99%.

Outlook: Measurements in the real environment

Installation of sMDT chambers in the ATLAS cavern

During this year's winter shutdown two sMDT chambers were installed in the ATLAS cavern to measure the actual background hit rates and to study the performance in the real environment.



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. Measurements up to $14\,\mathrm{kHz}/\mathrm{cm}^2$ show:
    - Single tube resolution 110–160 µm.
    - 3σ efficiency 95–70%.

$\Rightarrow$ sMDT chambers fulfil the requirements for the planned upgrade of the Small Wheels.

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)