Performance of Fast High-Resolution Muon Drift Tube Chambers for LHC Upgrades

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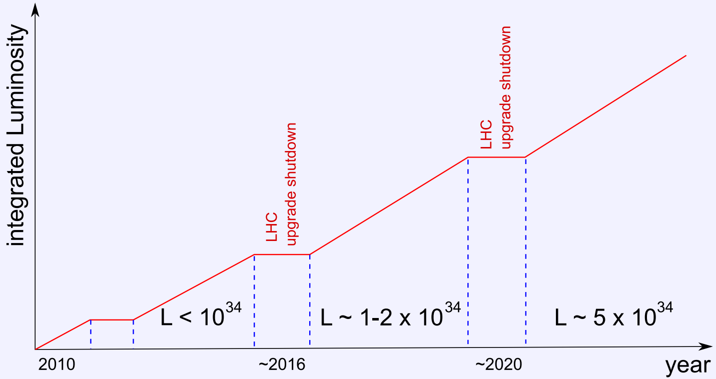
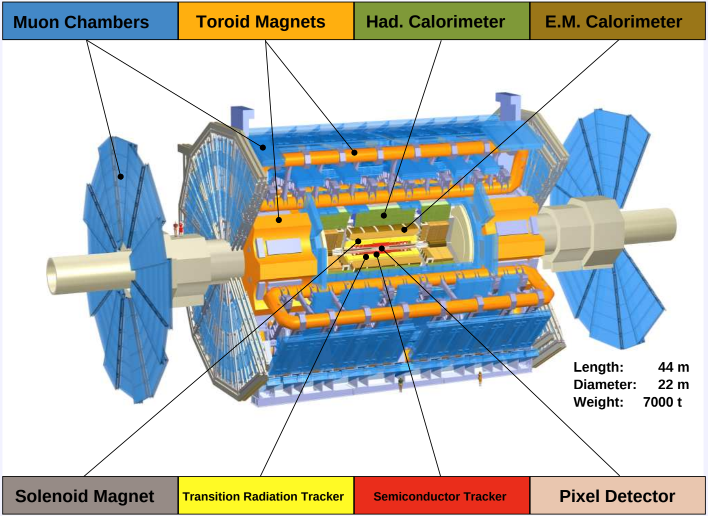
A Rough LHC Luminosity Upgrade Plan

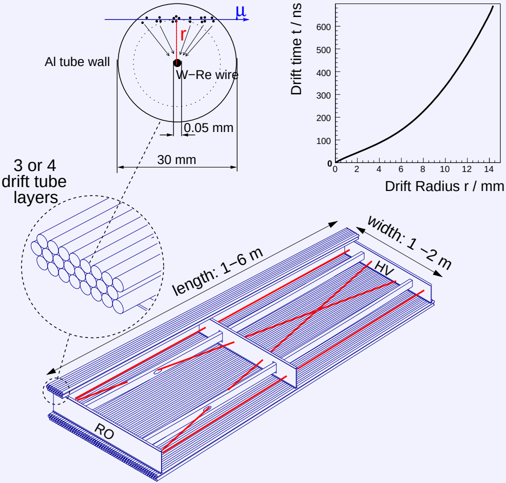


The ATLAS Detector at CERN



Current ATLAS Muon Precision Chambers

Monitored Drift Tube Chamber (MDT)



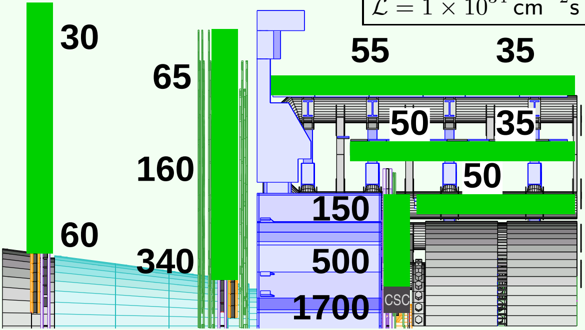
- Gas mixture: $Ar/CO_2 = 93/7$
- Gas gain: $2 \cdot 10^4$
- Max. drift time: $\approx$ 700 ns
- Single tube resolution: 80 μm
- Mechanical accuracy: 20 μm
- Track point reconstruction accuracy: 35 μm
- Optical alignment system

Background Rates in the Muon Spectrometer

Background irradiations are mainly γ's and neutrons ($\bar{E} \sim 1$ MeV) from secondary reactions in the calorimeters, shielding, beam-pipe and other detector components.

Expected Background Rates [Hz/cm^2] at LHC Luminosity

$\mathcal{L} = 1 \times 10^{34}\,\text{cm}^{-2}\text{s}^{-1}$



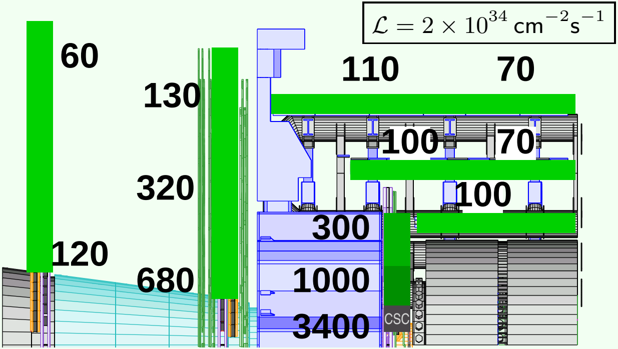
(including safety factor of 5)

- Track reconstruction efficiency $> 90\,\%$ for a tube occupancy up to 30 % (green)
- Max. occupancy in forward region: 14 %

Background Rates in the Muon Spectrometer

Background irradiations are mainly γ's and neutrons ($\bar{E} \sim 1\,\text{MeV}$) from secondary reactions in the calorimeters, shielding, beam-pipe and other detector components.

Expected Background Rates [Hz/cm^2] at $2\times$ LHC Luminosity



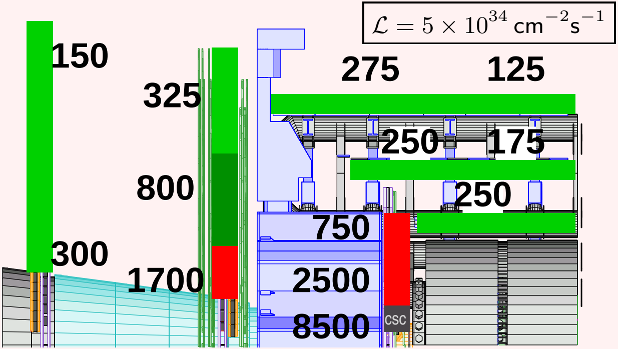
(including safety factor of 5)

- Track reconstruction efficiency $> 90\,\%$ for a tube occupancy up to 30 % (green)
- Max. occupancy in forward region: 28 % (dark green)

Background Rates in the Muon Spectrometer

Background irradiations are mainly γ's and neutrons ($\bar{E} \sim 1$ MeV) from secondary reactions in the calorimeters, shielding, beam-pipe and other detector components.

Expected Background Rates [Hz/cm^2] at $5\times$ LHC Luminosity



(including safety factor of 5)

- Track reconstruction efficiency $> 90\,\%$ for a tube occupancy up to 30 % (green)
- Max. occupancy in forward region: 70 %

Exchange of the Inner Muon Wheels

MDT chambers of inner forward region have to be replaced

To improve tracking:

- Faster detectors
- Smaller readout pitch to minimize occupancy
- More layers for better redundancy in pattern recognition

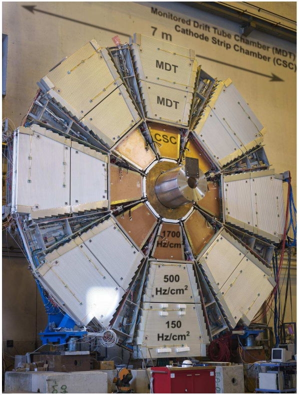
Constraints:

- Coverage of about $2 \times 40\,\mathrm{m}^2$.

$\rightarrow$ Reasonable cost-performance ratio

- Replacement maybe already 2016

$\rightarrow$ Established technology preferable



Currently: Cathode Strip Chambers (CSC) in region of highest irradiation.
$\Rightarrow$ Can we find a unique technology for the whole inner muon wheel ?

Smaller Tube Diameter at High Rates

Baseline

15 mm instead of 30 mm diameter tubes.
Same drift gas and gas gain as current MDT chambers.

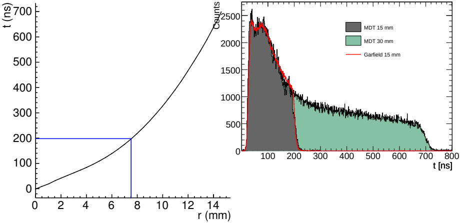
- Occupancy prop. to max. drift time: $\sim 3.5\times$ smaller
- Tube count rate prop. to r: $2\times$ smaller

$\Rightarrow$ **Occupancy per tube $7\times$ smaller**

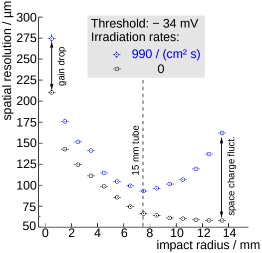
- Gain drop (space charge) prop. r^3: $\sim 8\times$ smaller

$\Rightarrow$ **Degradation of resolution by gain drop and space charge fluctuations greatly reduced**

Space-Drift-Time Relationship



Single Tube Resolution



15 mm Tubes at High Rates

Maximum hit rate and counting rate/tube in the CSC region

Luminosity $cm^{-2}s^{-1}$	Background hit rate (kHz cm^{-2})	Counting rate in 0.55 m tubes (kHz/tube)	Occupancy of 0.55 m tubes (%)
1×10^{34}	1.7	165	3.3
2×10^{34}	3.4	330	6.6
5×10^{34}	8.5	825	16.5

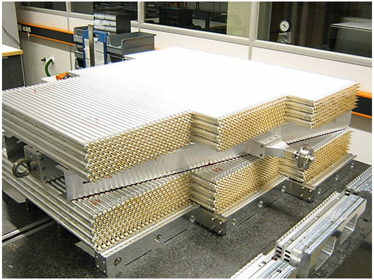
Including a safety factor of 5

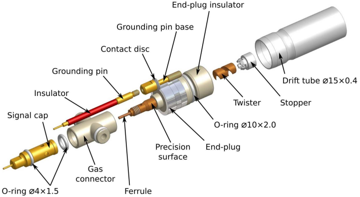
$\Rightarrow$ **Safe operation up to highest background even in worst-case scenario**

Prototype Chamber

- Chamber size: 1.1 m $\times$ 1.0 m
- Trapezoidal shape
  - Three different tube lengths of 560, 760, 960 mm
- Dimensions to fit in CSC-region
- 1152 tubes (3 times as many as largest muon chamber in ATLAS)
  - 2×8 tube layers
  - 72 tubes per layer
- Aimed wire position accuracy: 20 μm RMS

Aim: Prove assemble procedure and chamber precision, operate full size chamber in test-beams.



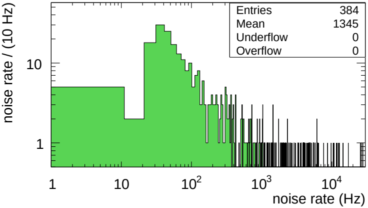


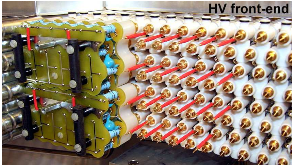
→ See poster `N48-222` for details on chamber construction.

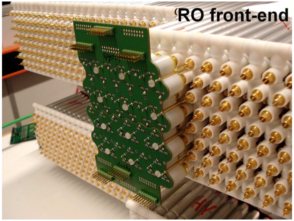
Prototype Chamber – Front-End

- New passive readout and high voltage boards
  - Low noise: Most channels below 100 Hz (32 mV)
  - No HV-trips observed
  - Low leakage currents: ~ 1.5 nA / tube
- Standard ATLAS active readout electronics for chamber testing

Noise Rate per Channel



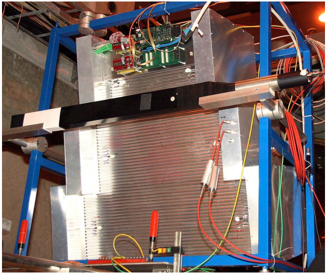


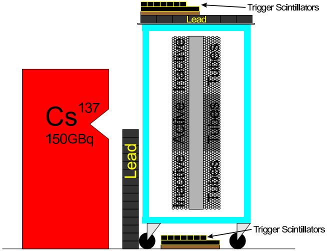


New radiation hard readout electronic under development:
- New preamplifier-shaper-discriminator chip → N47-113
- Use of Triple Modular Redundancy technology → N29-238

Test-Beam Efforts 2010

- 180 GeV muon beam at CERN
  - 27 M events collected
  - First and long-term operation of prototype chamber
  - Drift-tube resolution and efficiency measurement
- Gamma Irradiation Facility at CERN (^{137}Cs source)
  - Measuring cosmic muons.
  - High intensity γ-irradiation (~ 150 GBq)
  - Drift-tube resolution and efficiency measurement
- Proton Beam at Maier-Leibnitz-Laboratorium in Munich
  - Measuring cosmic muons
  - Irradiation with 20 MeV DC proton beam
  - Study response to strongly ionizing particles
  - Efficiency studies at highest background rates (up to 20 MHz/tube)

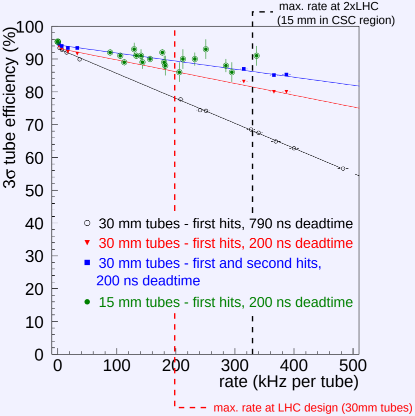




Tube Efficiency

Efficiency for hit on muon track within the drift-tube resolution

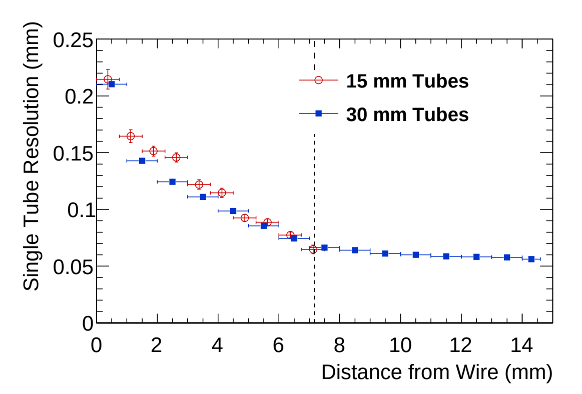
Tube Efficiency vs. Irradiation Rate



- Efficiency as expected
- No recovery of second hits necessary
- 3 sigma track eff. $> 97\,\%$ at $500\,$kHz/tube ($10\,\%$ occupancy)

Intrinsic Resolution

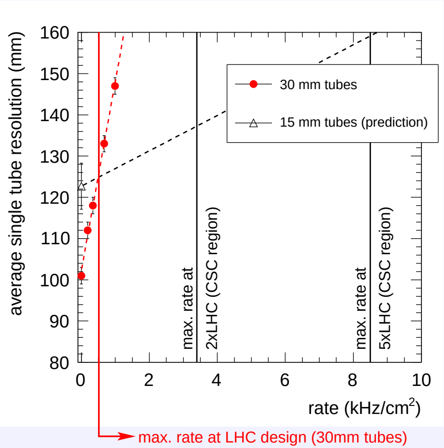
Single Tube Resolution



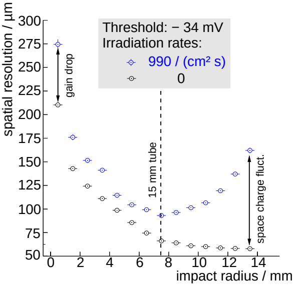
- Mean resolution of 15 mm tubes: $122.7 \pm 5.6\,\mu$m
- Good agreement with resolution of 30 mm tubes

Resolution

Single Tube Resolution vs. Rate



- Resolution of 15 mm better than 30 mm tubes at high background rates
- Degradation of resolution by gain drop and space charge fluctuations $\sim 8\times$ smaller.



Prediction to be confirmed – Data being analysed as we speak

Conclusions

Advantages of Thin Drift Tube Chambers

- Drift tubes are proven technology in ATLAS
- Assembly procedure and achievable precision well understood
- Can use existing services (gas and power system)

Conclusions

- Assembly and test of prototype chamber successful and working as expected
- Excellent performance even in region with highest expected irradiation (CSC region)
- Thin drift tube chambers good candidate for the replacement of precision chambers of the inner muon wheel (~ 2016)