Development of Precision Drift Tube Detectors for High Counting Rates at the Super-LHC

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Outline

- The **luminosity upgrade** of the LHC
  - the Super-LHC
- **Background rates** at the Super-LHC
  - motivation for smaller radius drift tubes for the ATLAS MDT chambers
- **Smaller radius drift tubes**:
  - Design issues
  - End plug design
  - First cosmic-ray tests and comparison with simulation
- **Conclusions and Outlook**

LHC upgrade: the Super LHC

LHC short term schedule:

- Beam commissioning at 7 TeV planned for May 2008
- Initial physics run in summer 2008
- Depending on how the machine goes, collect 10 fb^{-1}/exp at $2 \cdot 10^{33}$ $cm^{-2}s^{-1}$ luminosity by the end of 2009

LHC upgrade schedule:

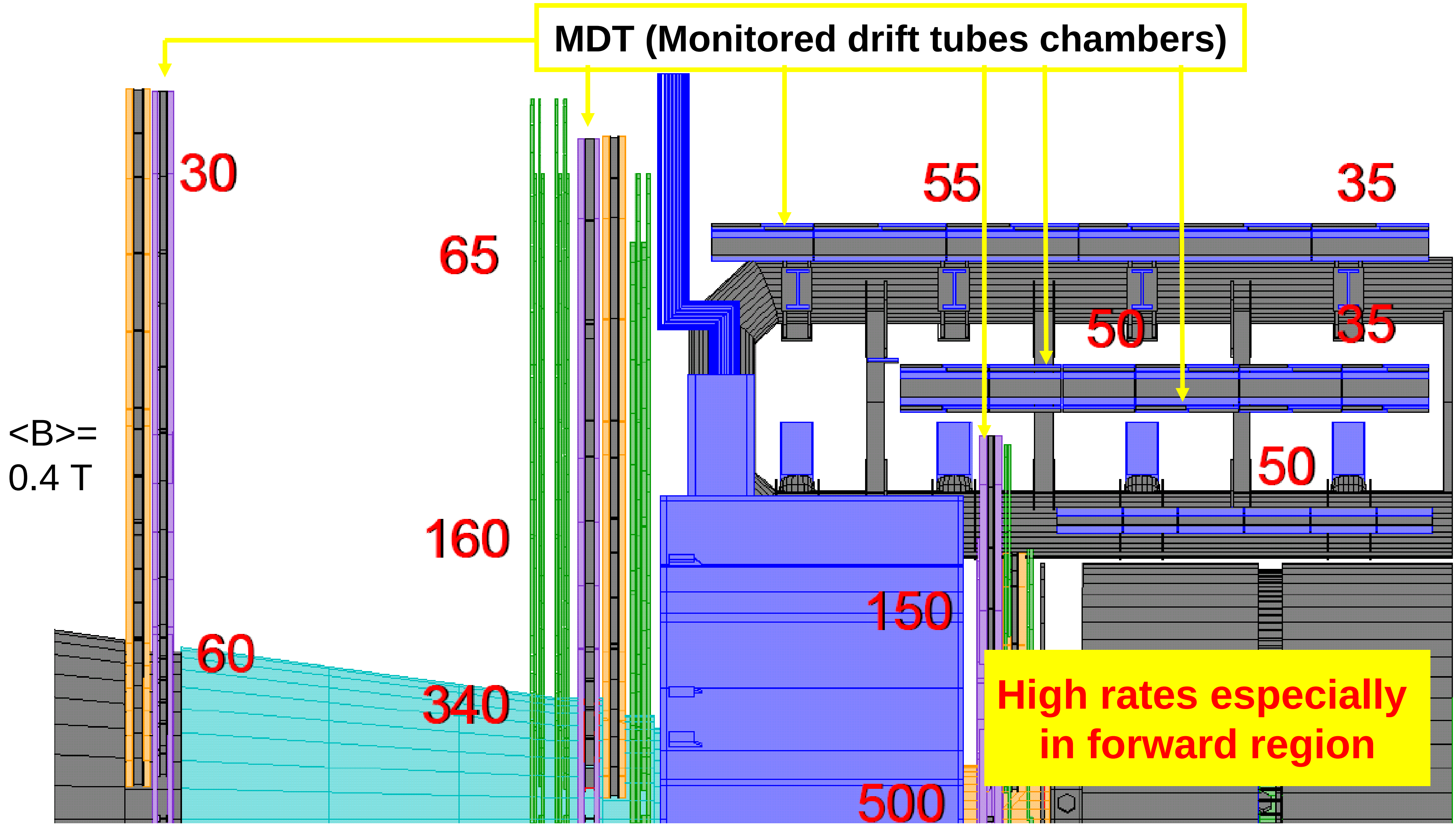
- **2009-2015:** a stretching of the machine parameters up to their limits will lead to a luminosity increase of about a factor 2.3
- **2015:** upgrade of the interaction regions, leading to stronger focussing (luminosity x2)
- **Later -** injector upgrade: increase in the bunch number, and finally increase of the center of mass energy by a factor of 2 (luminosity x10)

(assuming stable running conditions and nominal luminosity will be reached 2-3 years after LHC startup)

Up to 10x higher background rates at the S-LHC!

Radiation levels at the LHC

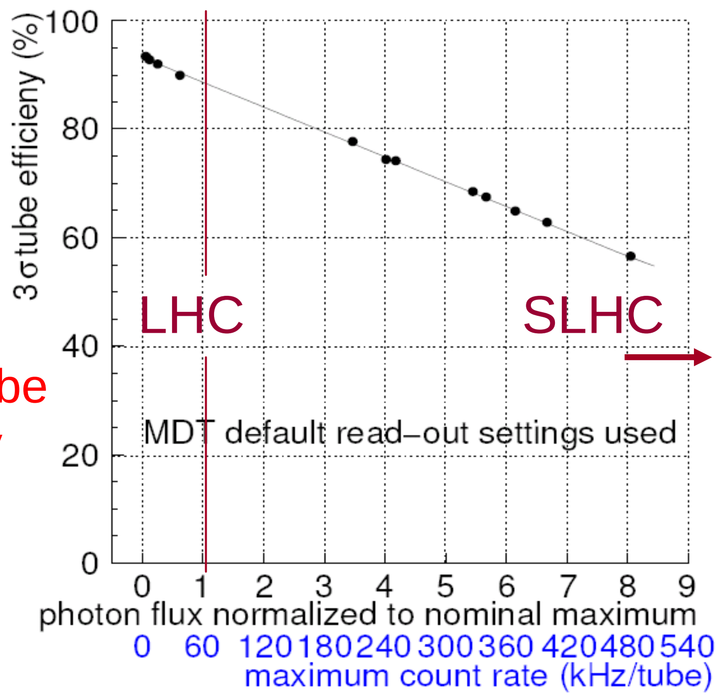
- Background rates **including a safety factor 5** [Hz/cm²] in the ATLAS Muon spectrometer for n-γ at $L = 10^{34}$ cm^{-2} s^{-1} (LHC nominal luminosity)

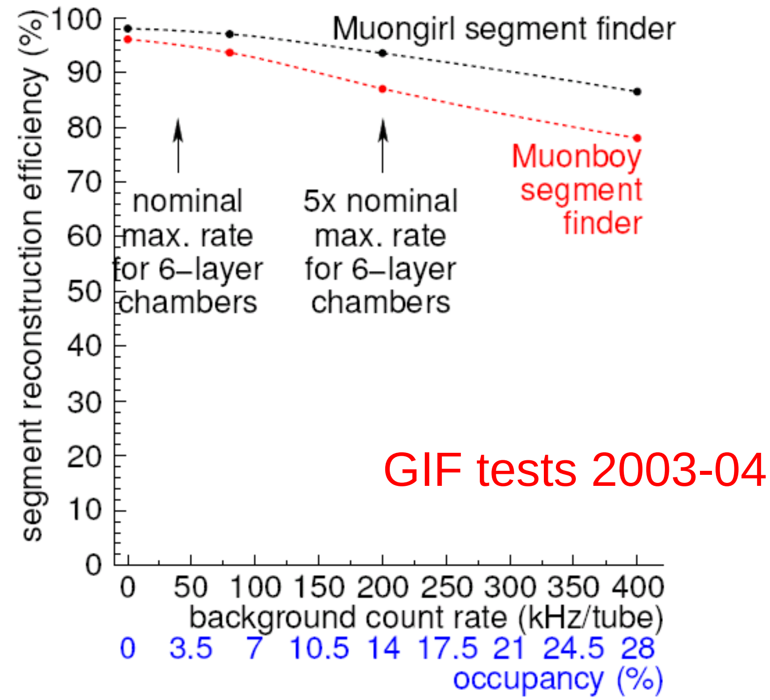


The ATLAS MDT Chambers at the S-LHC

- At high background rates:
  - Muon detection efficiency degradation because of high occupancy

Single tube
no safety
factor

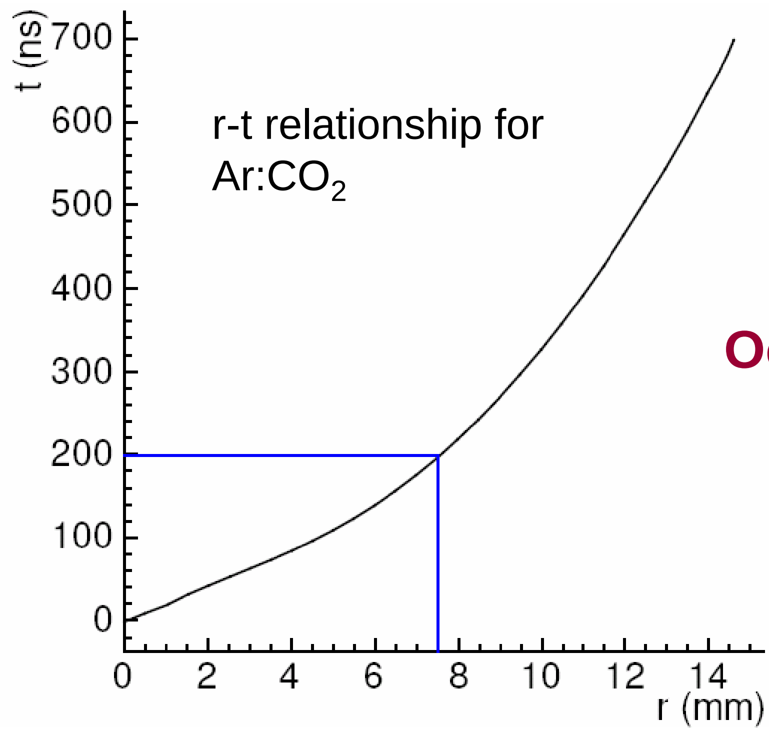




  - Degradation of the spatial resolution due to space charge fluctuations

Efficiency degradation at high rates

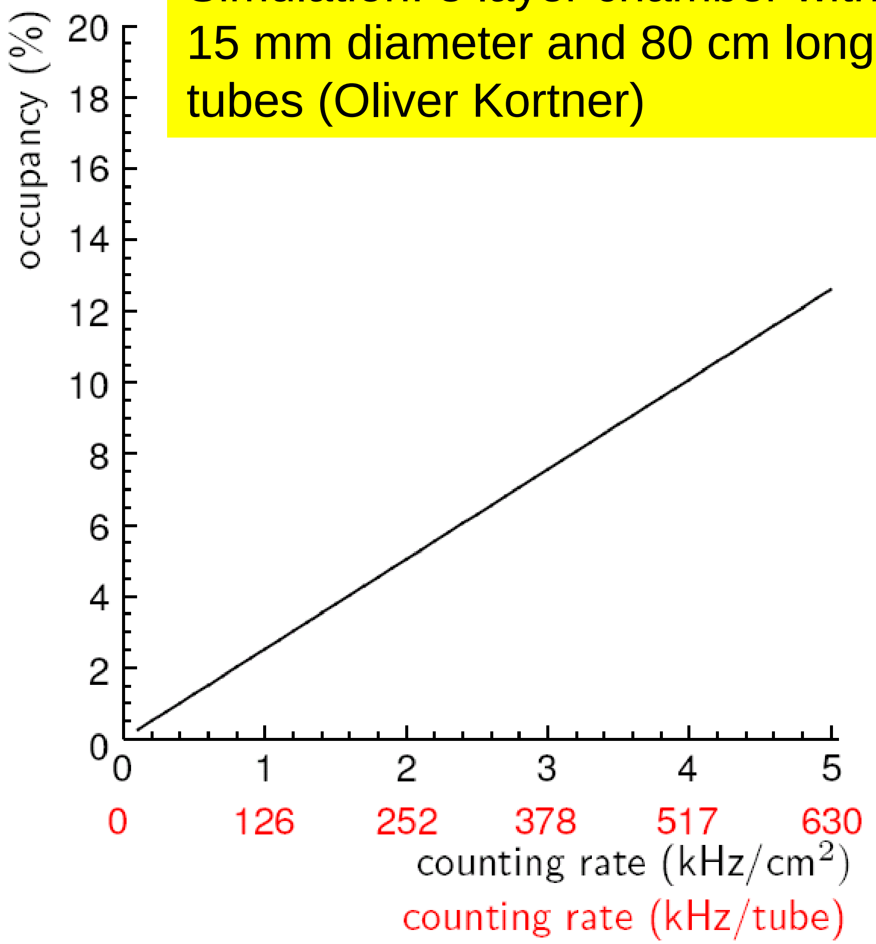
- **Efficiency** degradation critical at high rates because of high **occupancy**:
  - With 15 mm diameter tubes, the occupancy can be decreased by a factor 3.5
  - Occupancy per tube reduced by an additional factor 2 due to smaller wall surface
  - Occupancy of 30% up to 1500 kHz/tube!

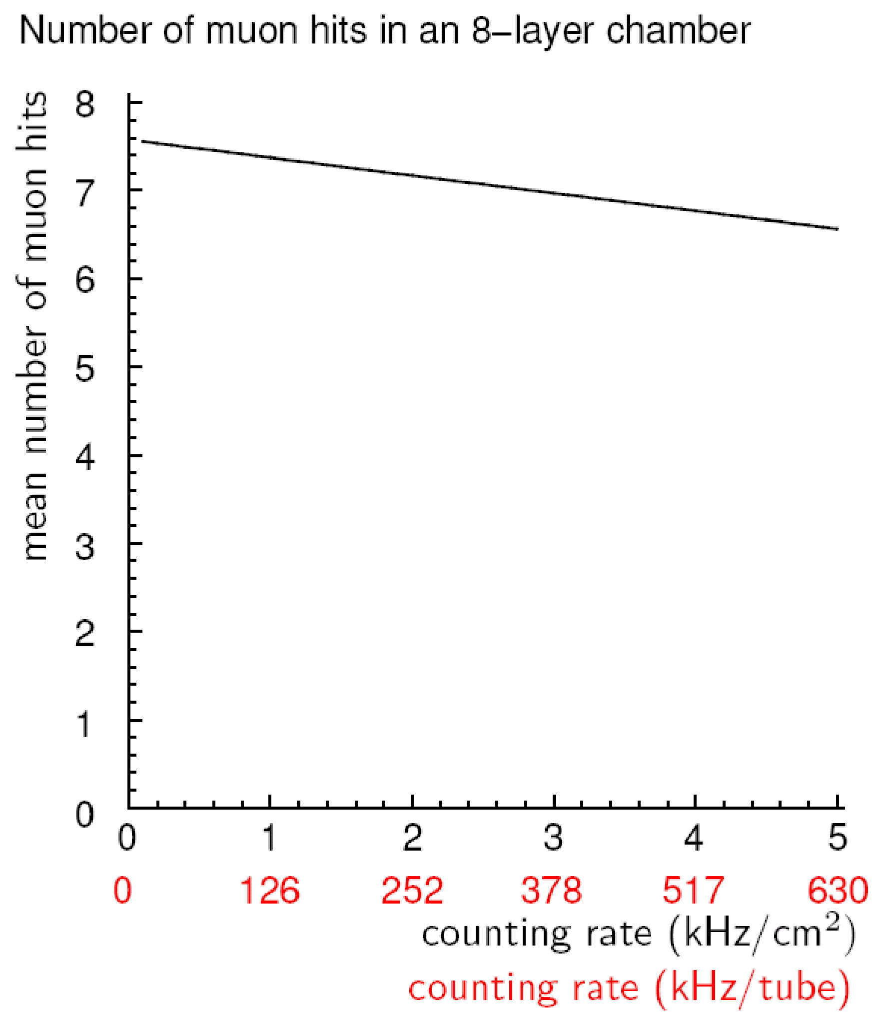


Occupancy = max drift time * count rate

Occupancies and number of muon hits

Simulation: 8 layer chamber with 15 mm diameter and 80 cm long tubes (Oliver Kortner)

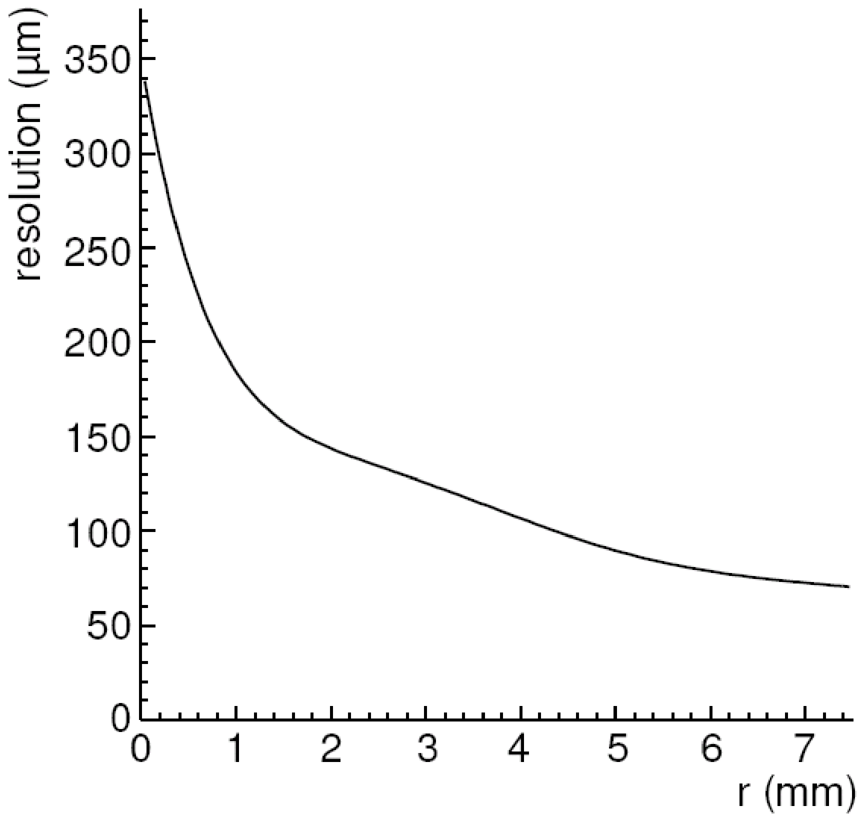




- Acceptable occupancies $\lesssim$10% up to the highest rates.
- Average number of muon hits in a chamber: $\geq$7.

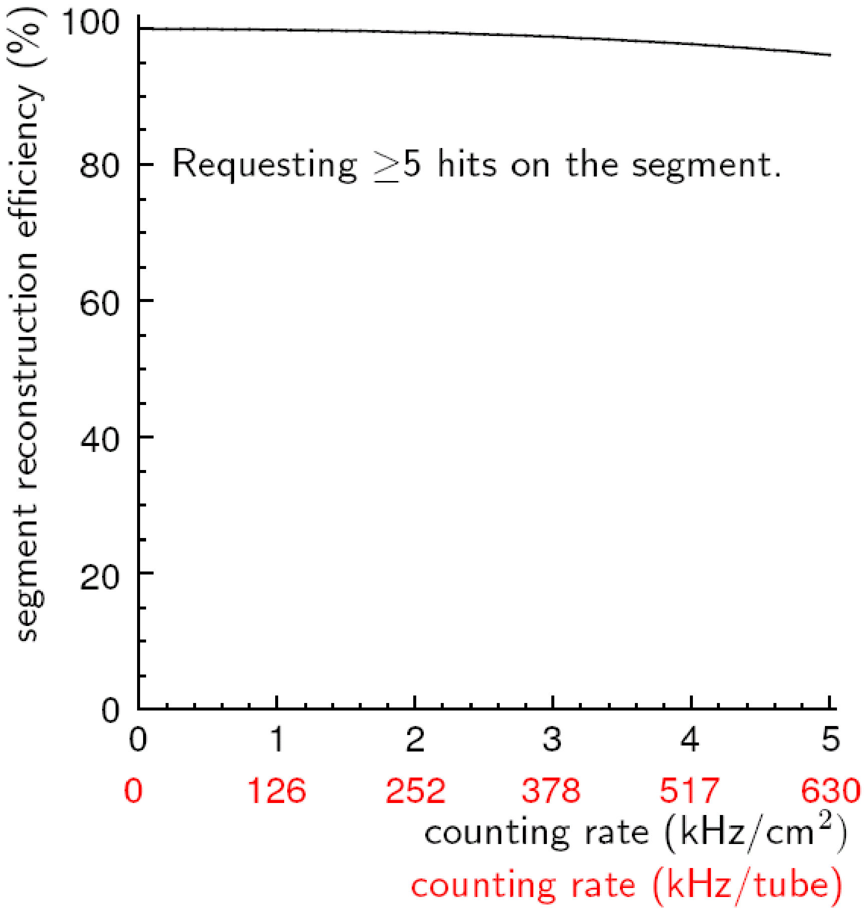
Reconstruction efficiency and resolution

Single-tube resolution



- Average single-tube resolution: $140\ \mu$m.

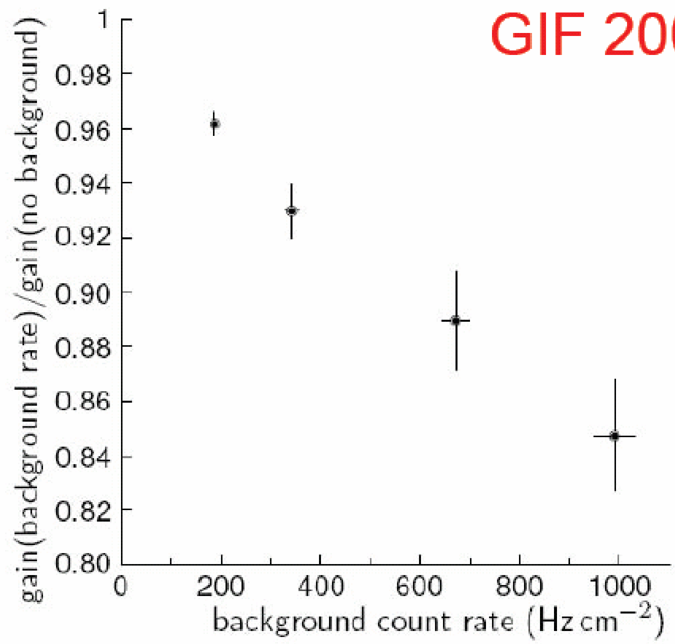
$\Rightarrow$ Superpoint resolution $140\ \mu\mathrm{m}/\sqrt{7}=53\ \mu$m.

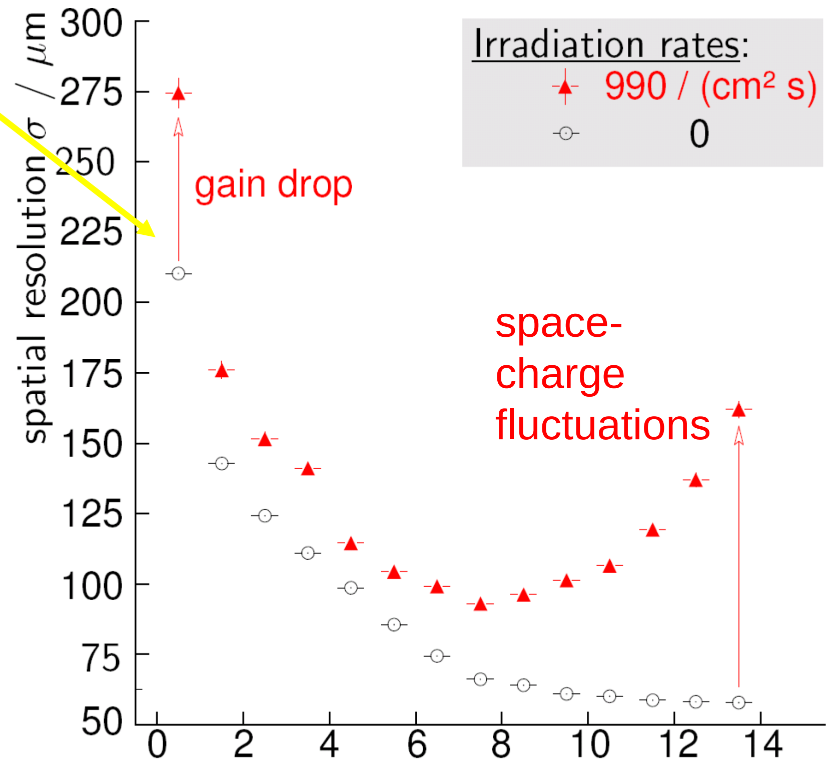


Simulation: 8 layer chamber with 15 mm diameter and 80 cm long tubes (Oliver Kortner)

Space charge considerations

- Degradation of the spatial resolution due to **space charge fluctuations**, not a critical issue: gas is linear





Drift radius [mm]

- Gas gain drop (at x10 LHC rates): 15%

- Change of operating voltage due to gain drop:
  - Proportional to **(drift radius)³** -> with 15 mm diameter tubes, operating limit is 40 kHz/cm²

Design of chambers with smaller tube diameter

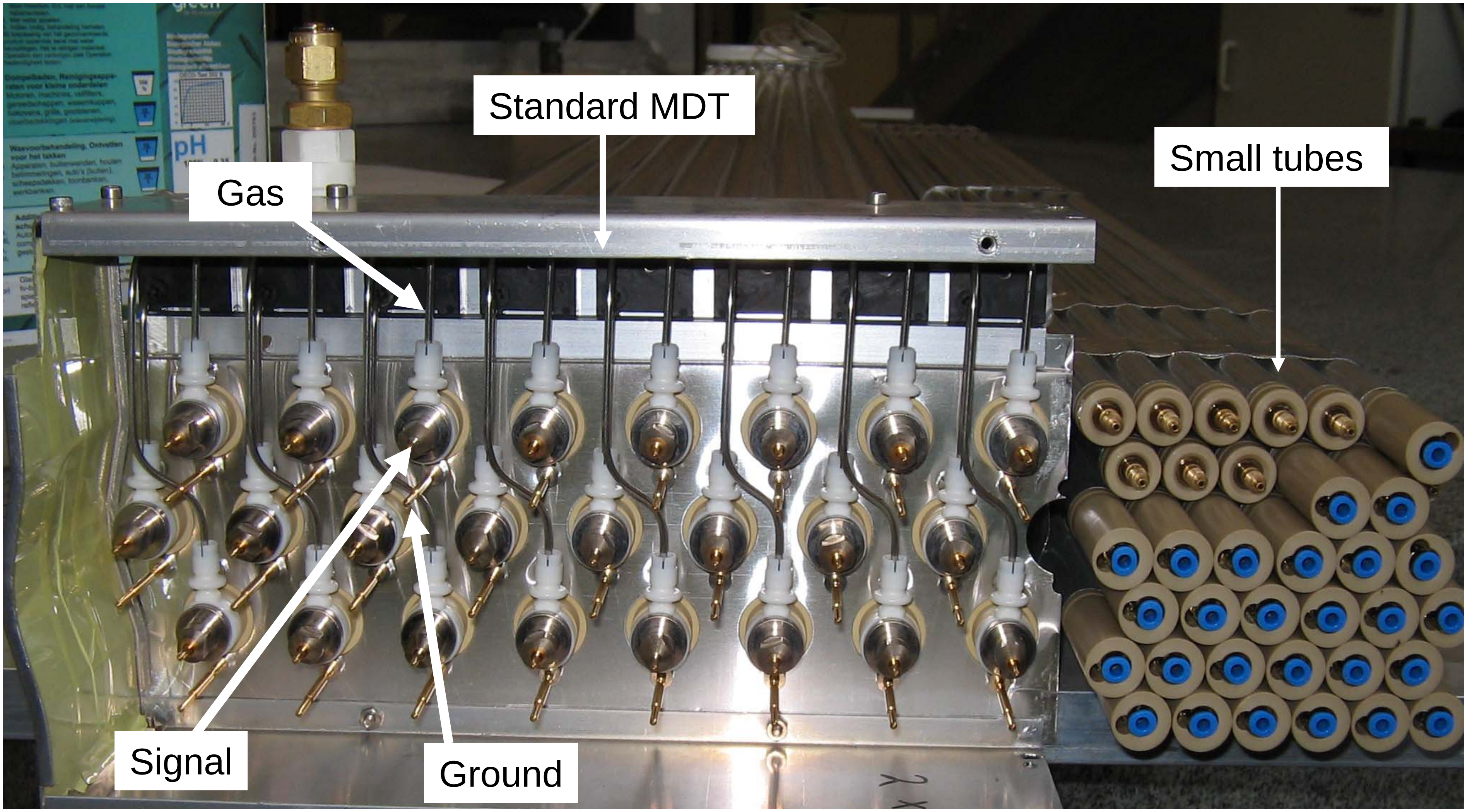
Baseline:

- Tubes with **15 mm** diameter
- Chambers with 2 x 8 layers
- Aluminium tube walls (0.4 mm thick)
- Tungsten-rhenium wire of 50 μm diameter
- Gas mixture: Ar:CO_2 (93:7) at 3 bars
- Gas gain: 20,000
- Same electric field as in the current tubes for r < 7.5 mm
  - Operating voltage: 2760 V

Diameter	**30 mm**	**15 mm**
gas	Ar:CO2 (93:7)	Ar:CO2 (93:7)
pressure	3 bar	3 bar
Wire	50 μm W-Re	50 μm W-Re
Tube wall	0.4 mm Al	0.4 mm Al
Operating voltage	**3080 V**	**2760 V**
Max drift time	**700 ns**	**200 ns**
Occ.@1500 kHz/tube	**100%**	**30%**
Operating limit due to space charge	**5 kHz/cm^2**	**40 kHz/cm^2**

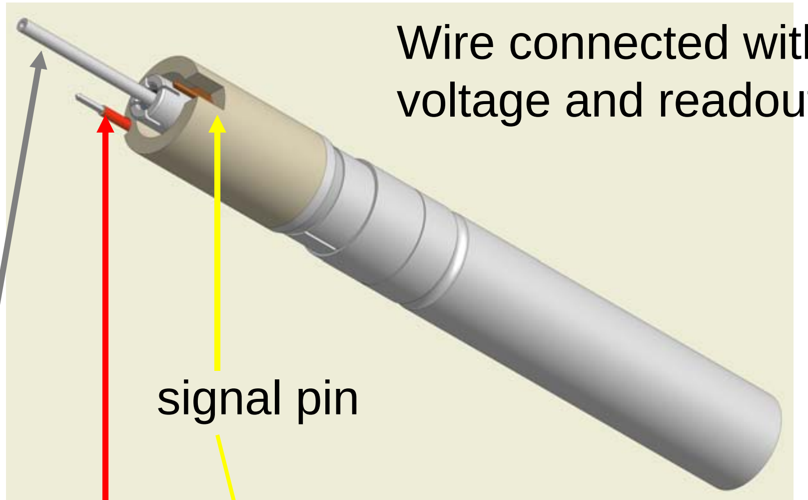
Design issues

4 times more tubes can be packed in the same space, **however** very limited space available for gas and electronics connection

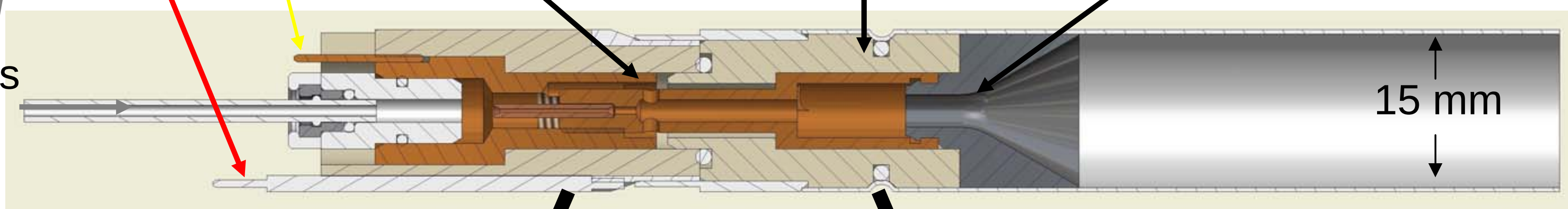


End-plug design

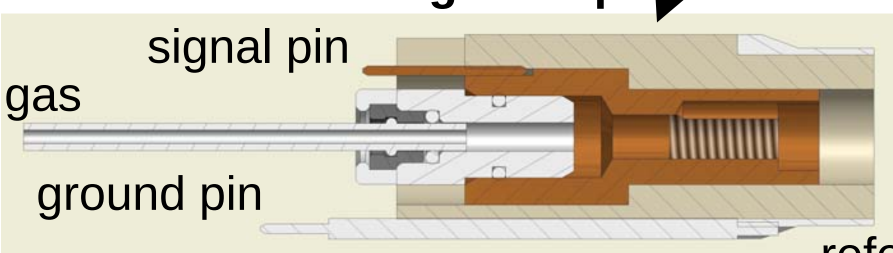
Wire connected with short shielded cables to high voltage and readout boards



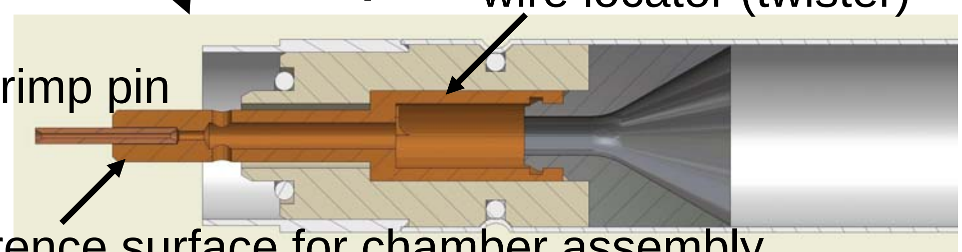
HV tests show no leakage current for operating voltages up to 3500 V



signal cap



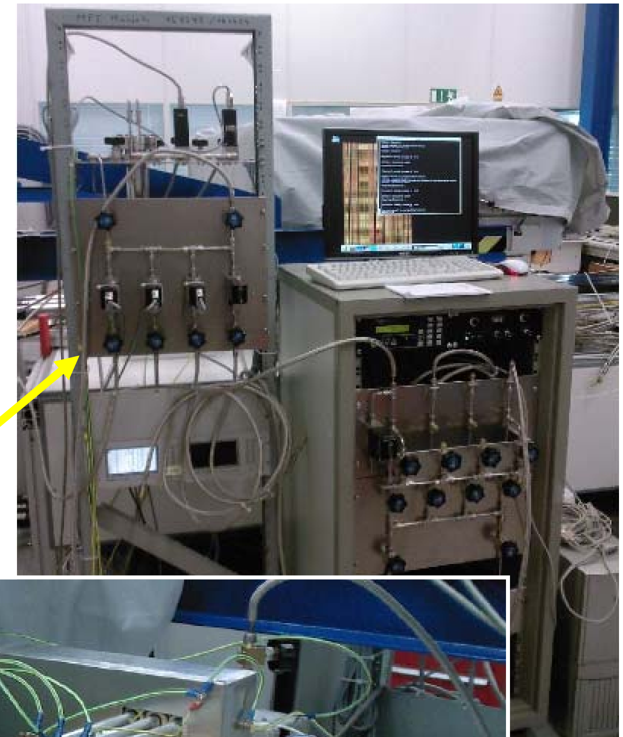
end cap

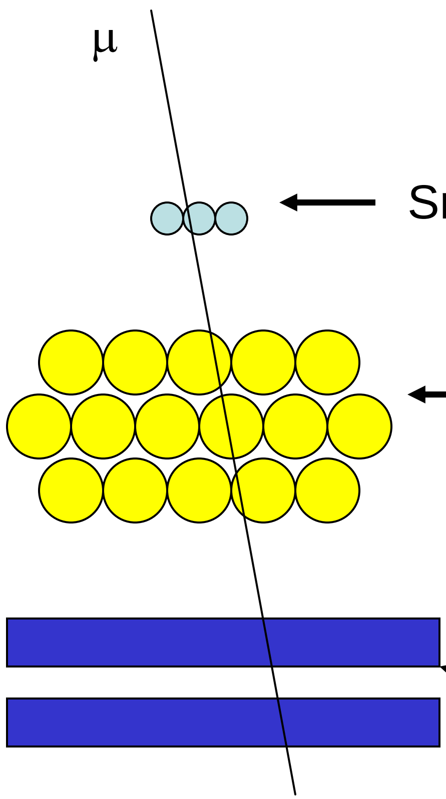


Cosmic-ray test setup

- 3 tubes with 15 mm diameter
- Operated at V = 2760 V
- Gas: Ar:CO_2 93:7 at 3 bars
- Standard MDT readout electronics

Gas mixing and control

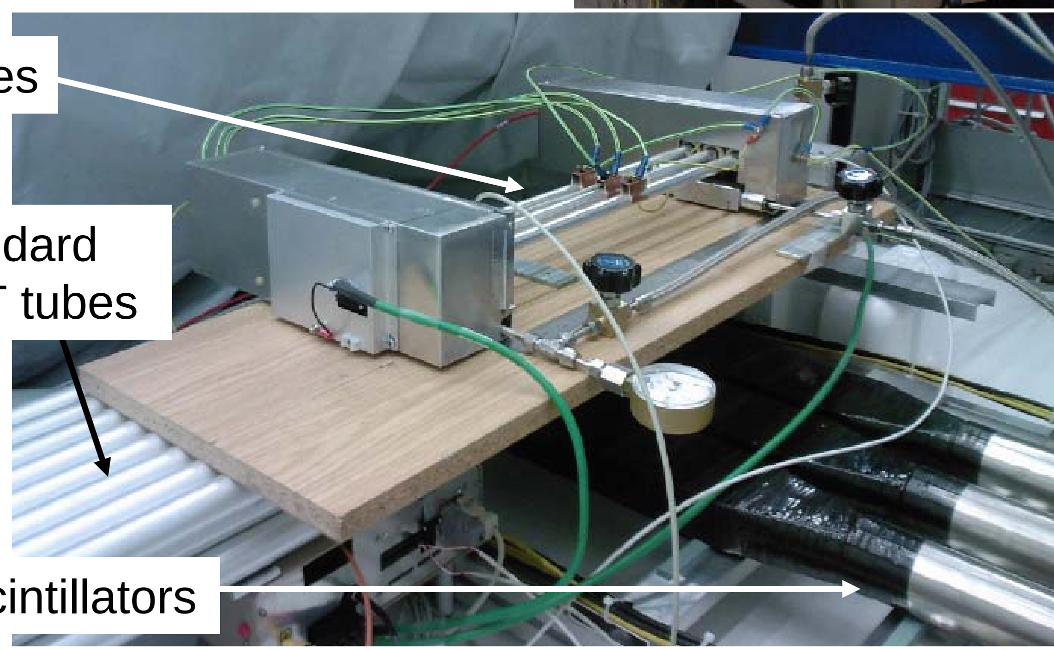




Small tubes

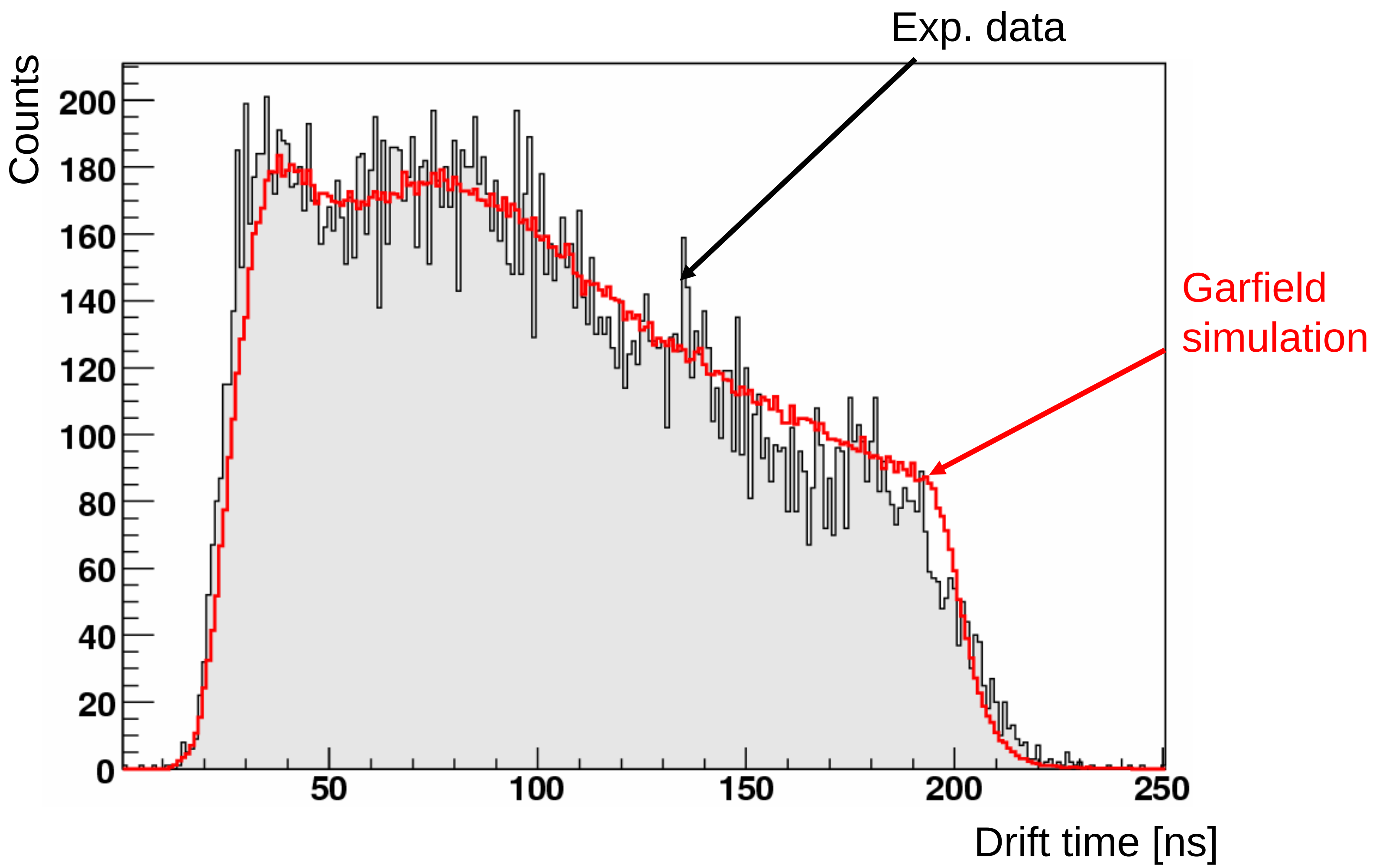
Standard MDT tubes

Scintillators



Cosmic-ray tests: drift time spectrum

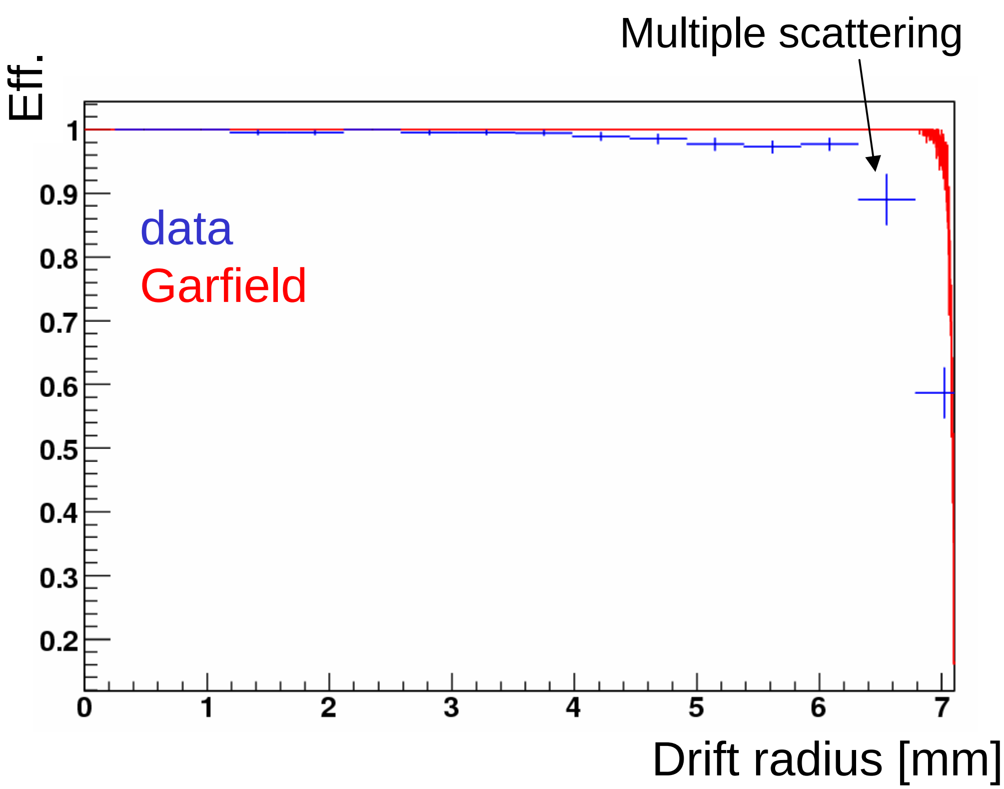
- Experimental max drift time: 180 ns
- Simulated max drift time: 177 ns

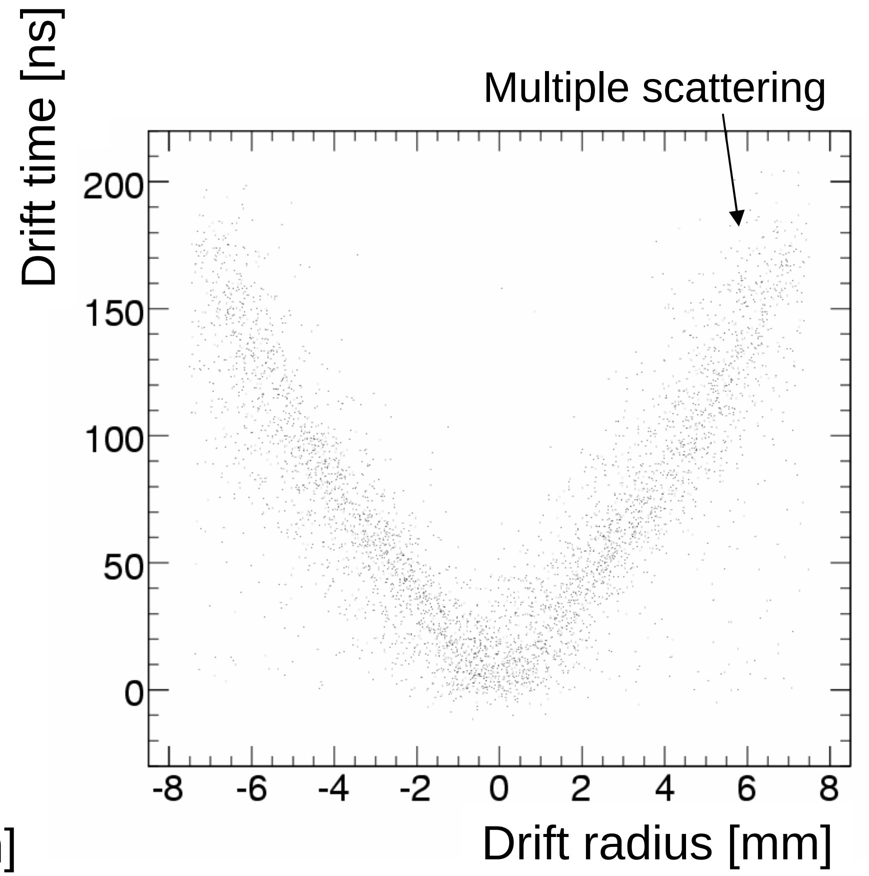


Cosmic-ray tests: results

- r-t relationship linear
- Very high single tube efficiency

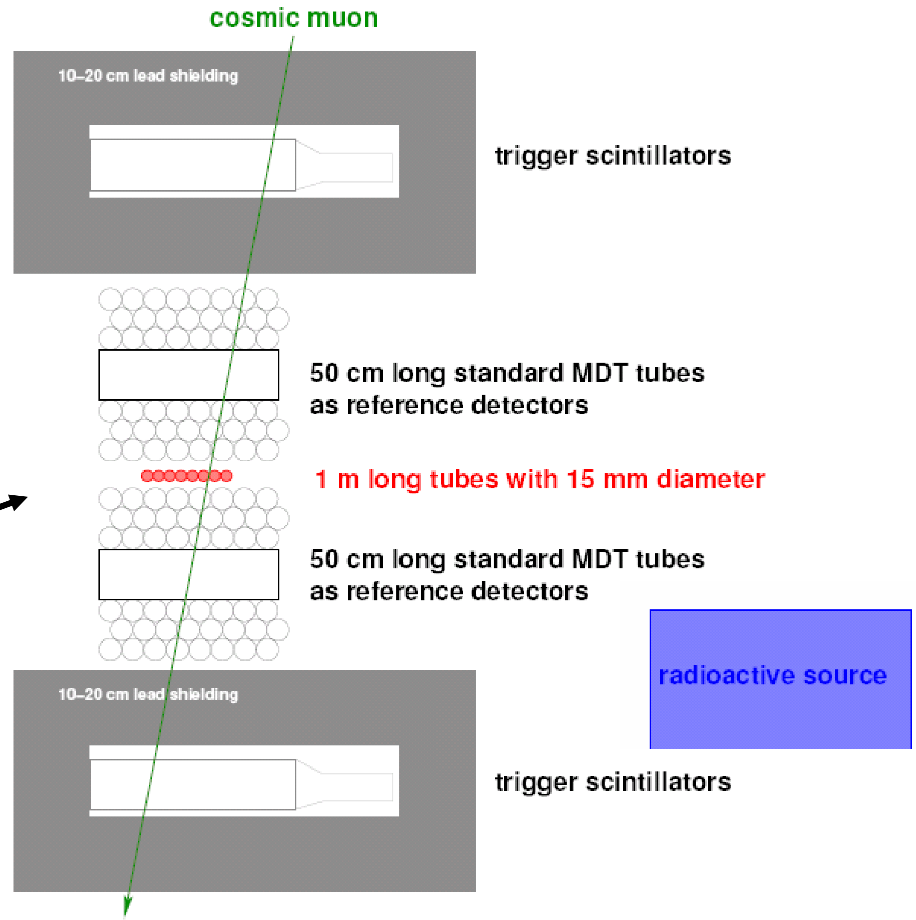
⇨ Good agreement with simulation



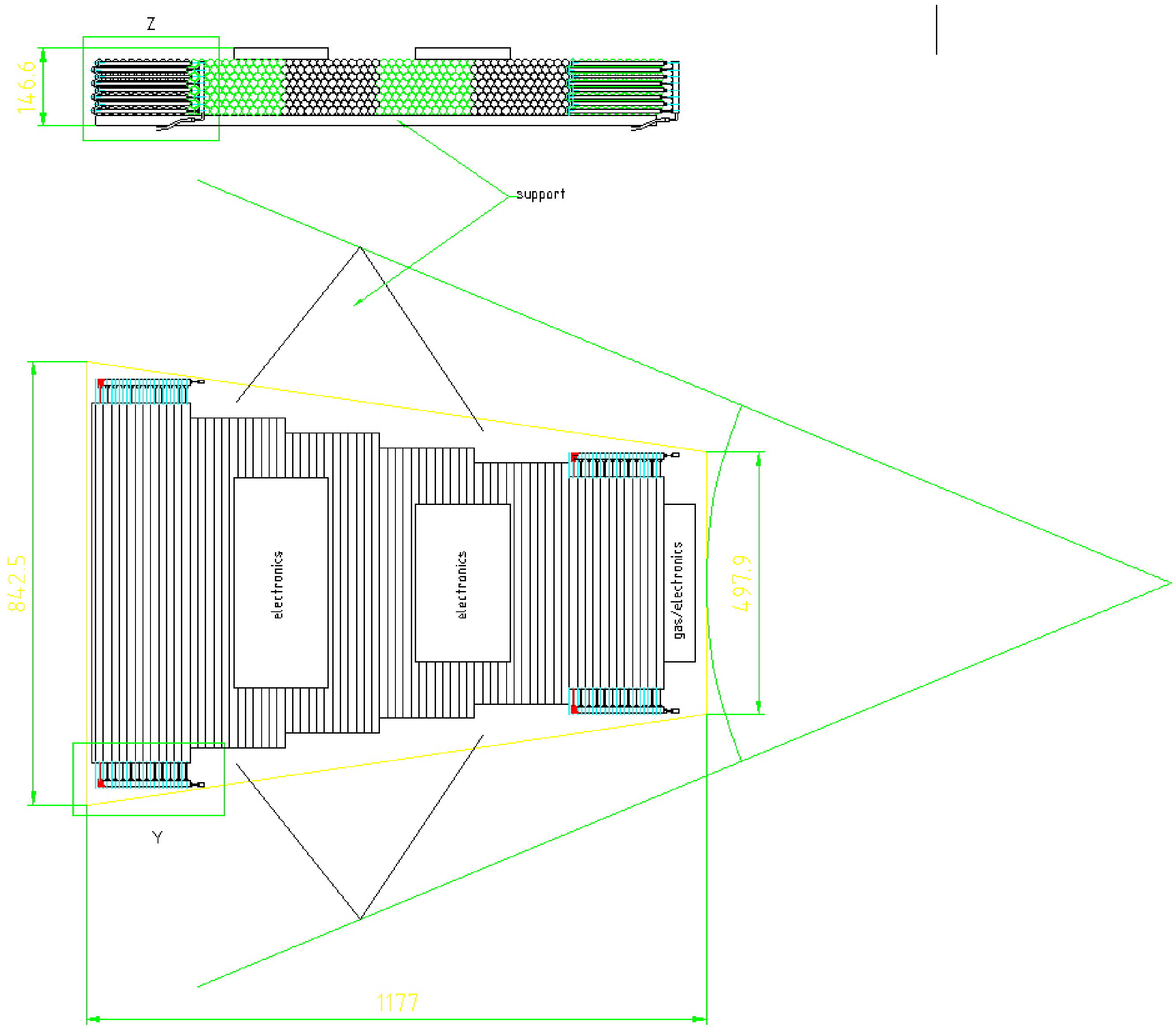


Outlook

- ATLAS MDT chambers will suffer from a huge radiation background at the Super-LHC (up to 5 kHz/cm^2)
- New chambers with 15 mm-diameter tubes will have ~**10x** higher operating limit
- First simulations and cosmic-ray tests show expected behaviour
- High rate tests in the Gamma Irradiation facility (GIF) at CERN are planned for **Jan-Feb 2008**
- Fully equipped prototype chamber planned for **2008**

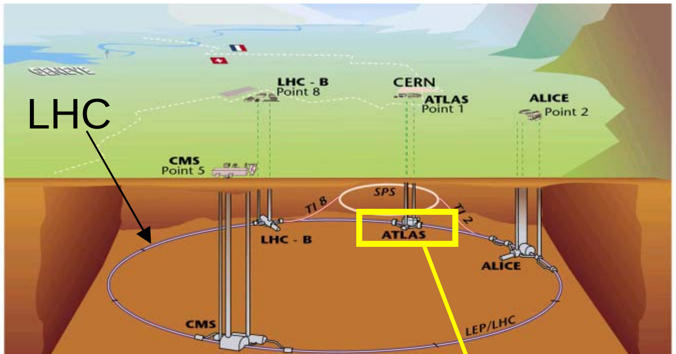


Chamber design



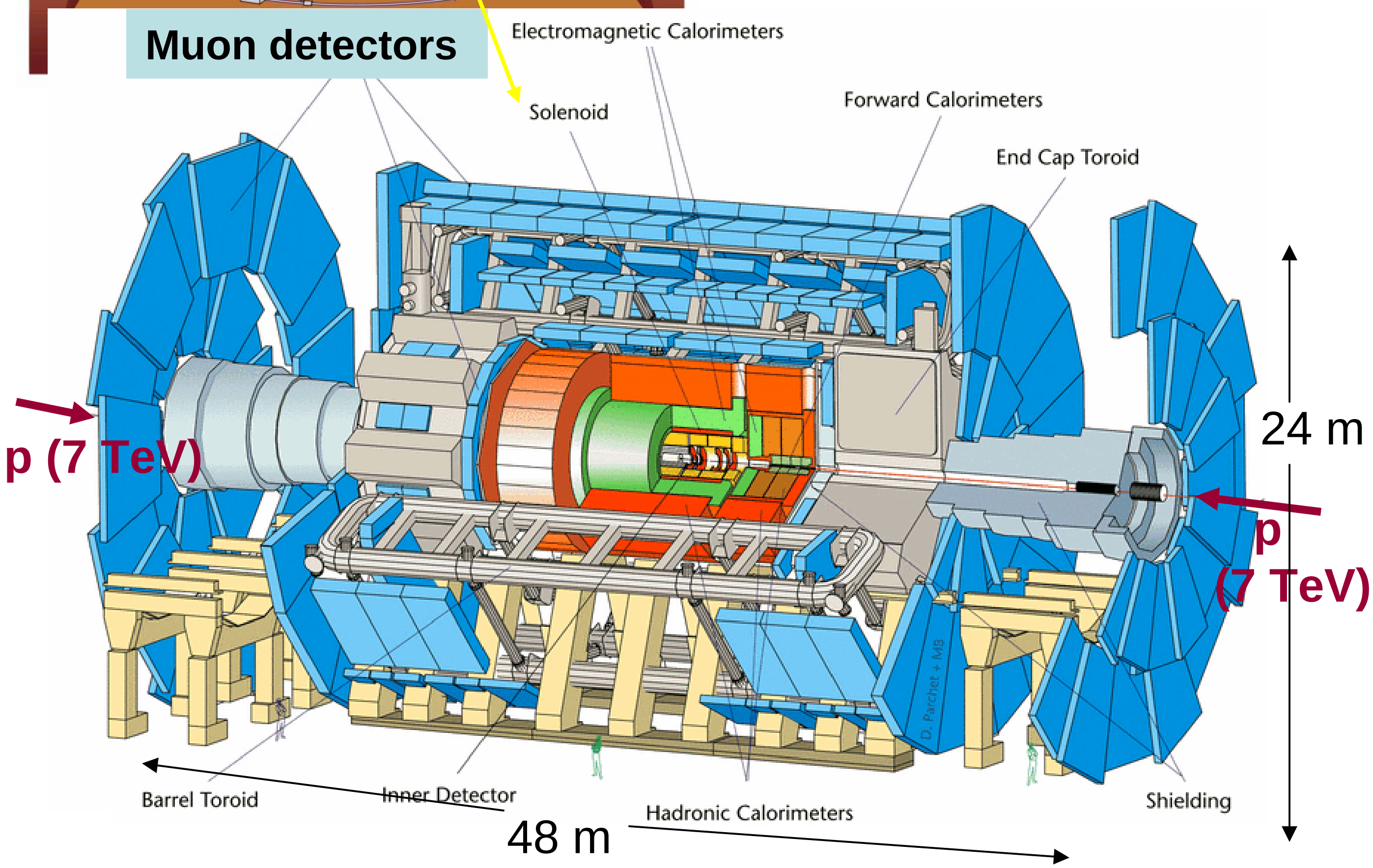
Spare slides

The ATLAS experiment at the LHC



The **Large Hadron Collider (LHC)** at CERN:

- pp collision (c.m. energy = 14 TeV)
- design luminosity: 10^{34} cm^{-2} s^{-1}



The ATLAS muon spectrometer:

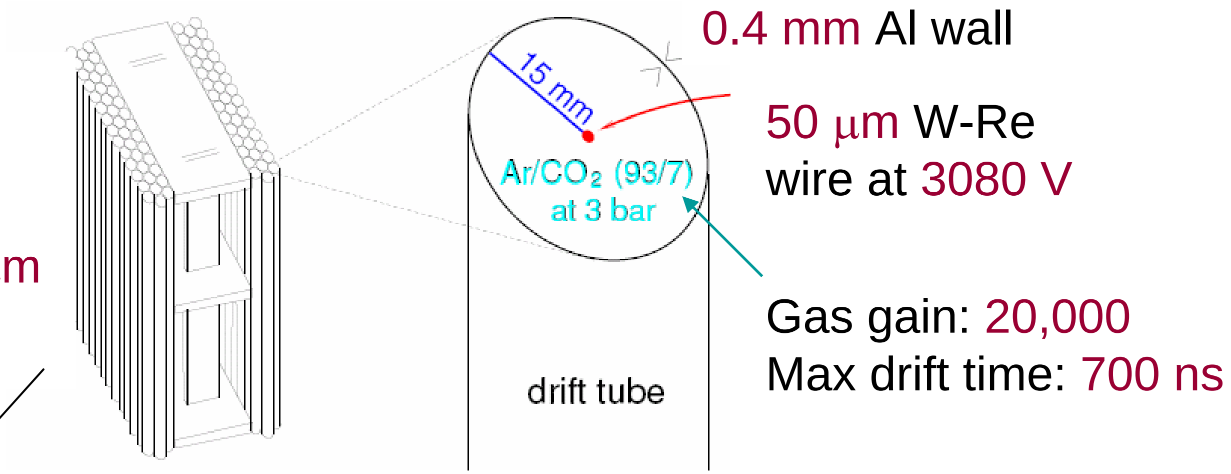
- Fast trigger chambers: RPC, TGC
- High resolution tracking detectors: **MDT**, CSC

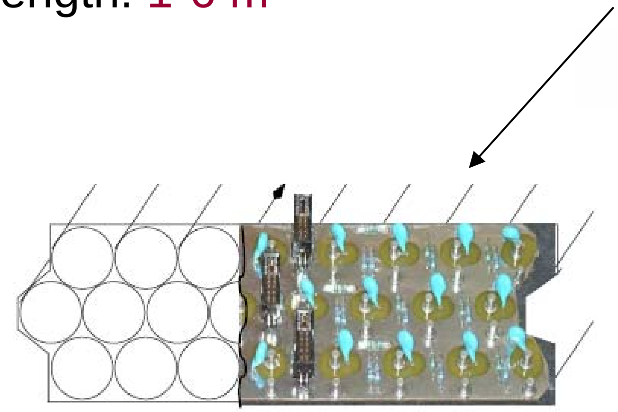
p(μ) reconstruction 3% accuracy

The ATLAS Monitored Drift-Tube chambers

Drift tube chambers:

- 2 x 4 layers
- Mechanical precision < 20 μm
- Length: 1-6 m





Chamber readout:

- 24 tubes connected to a shielded passive readout card
- Discriminator threshold set to 16^{th} p.e.
- Adjustable dead time: 790 ns, to avoid hits coming from multiple threshold crossings

Chamber performances:

- Resolution: ~80 μm
- Tracking efficiency: 90-95%

Chamber operating limits:

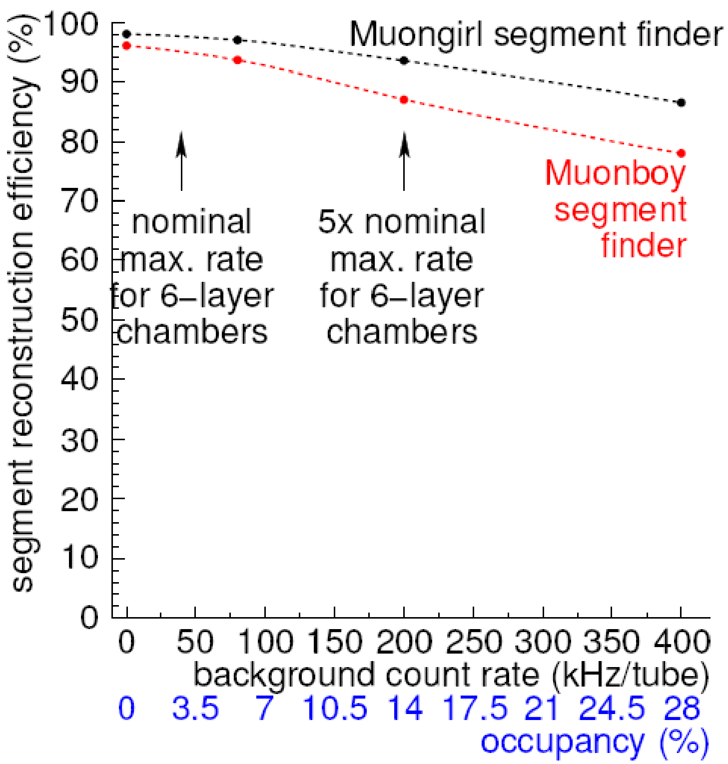
- gain drop: 5 kHz/cm^2
- high occupancy (> 50%): 700 kHz/tube

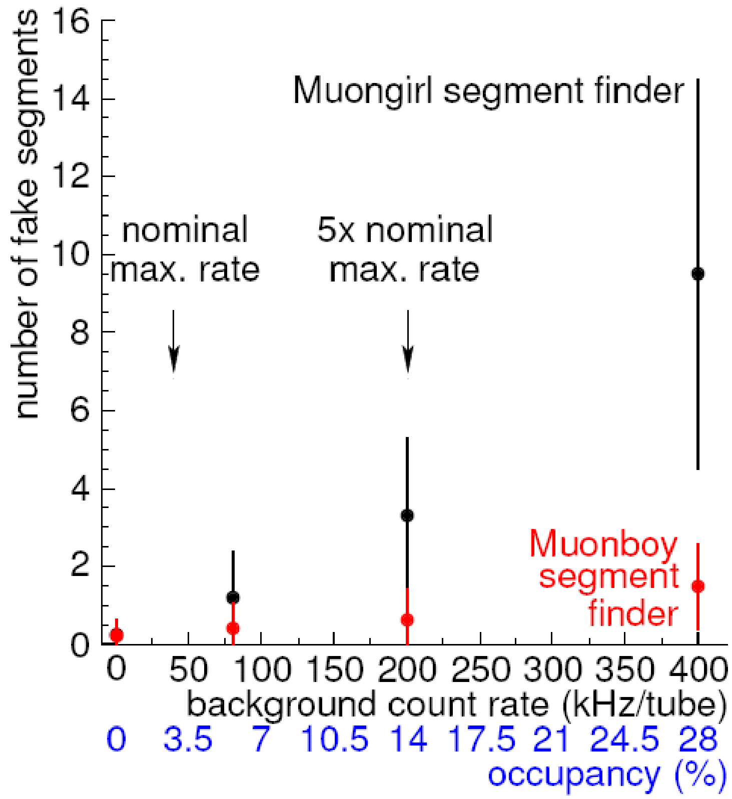
High Voltage tests

HVDC	endcap	+endplug	+tube
in Volt	in nA	in nA	in nA
100	0	0	0
500	0	0	0
1000	0	0	0
1500	0	0	0
2000	0	0	0
2500	0	0	2
3000	0	1	3
3500	0	1	2
4000	1	2	2
4500	1	3	2
5000	2	3	5
5500	2	11	23

Efficiency degradation at high rates

Results from test-beam measurements

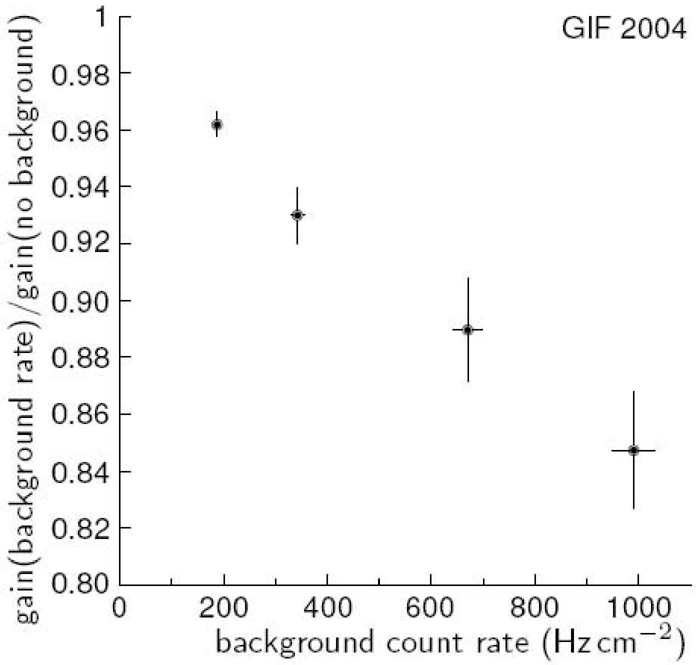




- Trade-off between efficiency and fake rate.
- Segment reconstruction efficiencies >90% are achievable for LHC background rates.

Drift-tube chambers well performant up to occupancies of 30%.

Space charge limitations



- Gas gain drop at 1 kHz/cm^2 ("10×ATLAS"): 15%, acceptable.
- Change of the operating voltage due space charge:

$$\Delta U = \frac{R^3 q \ln \frac{R}{R_a}}{4\pi\epsilon_0 \mu U_0} \times flux(\mathrm{cm}^{-2}\mathrm{s}^{-1})$$

R=15 mm, R_a=25 μm, μ=0.5 cm^2/(Vs),

$q = 20,000 \cdot 32$ keV/25 eV·e, U_0=3080 V.

⇒ ΔU=250 V at 5 kHz/cm^2 → no signal!

⇒ $R = 7.5$ mm: higher limit: 40 kHz/cm^2.

⇒ Occupancy, not space-charge defines operating limit!

- Other issues:
  - Larger readout bandwidth needed
  - Aging
  - Radiation damage to electronics and power supplies