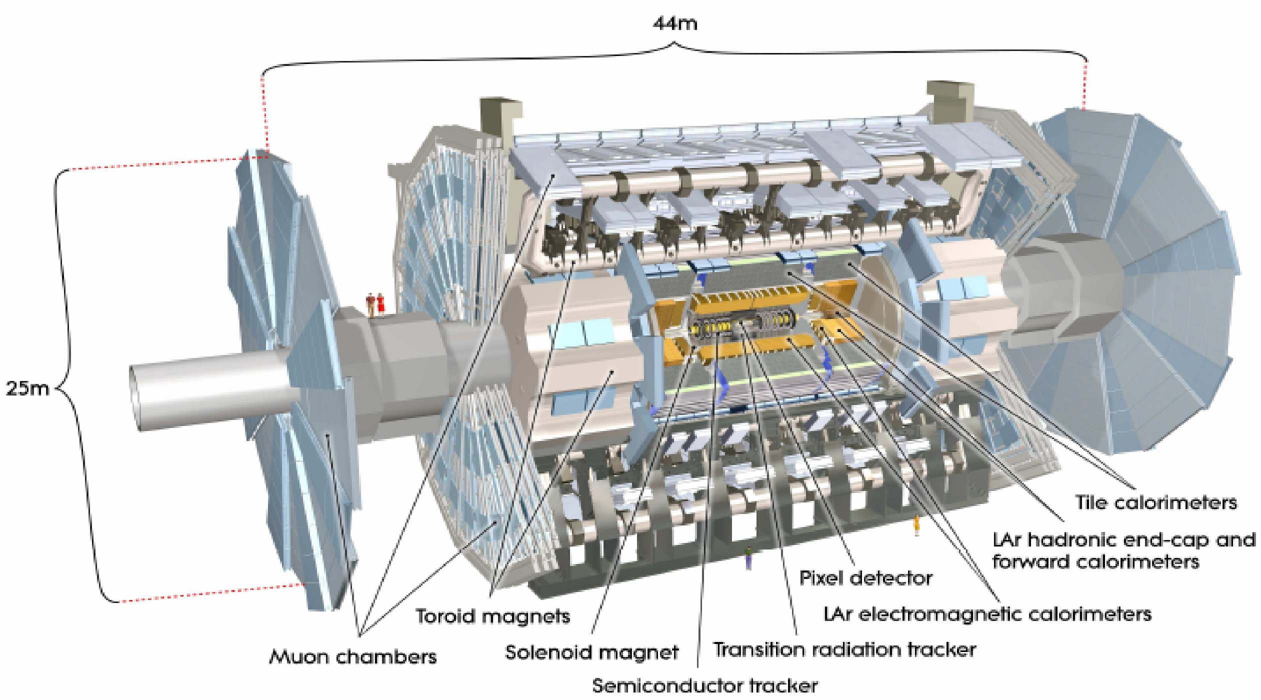
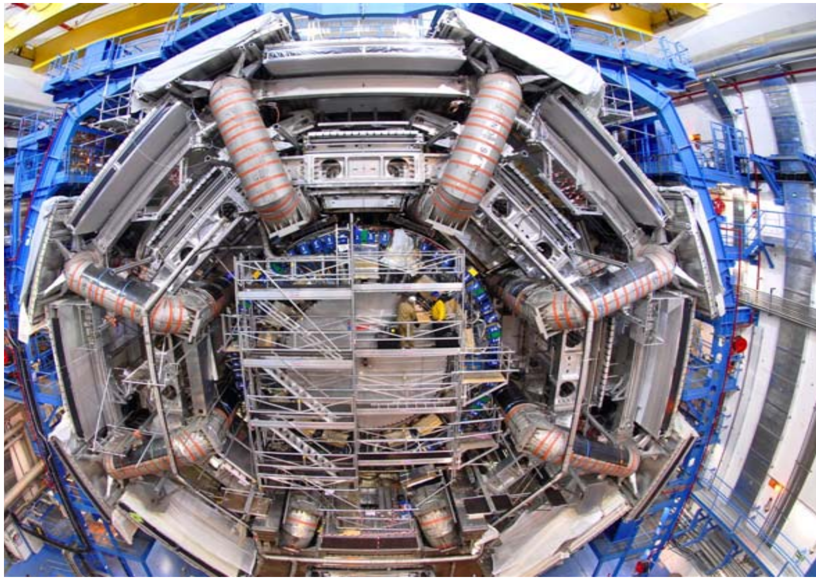
Precision Drift Tube Detectors for High Counting Rates

O. Kortner, H. Kroha, F. Legger, R. Richter
Max-Planck-Institut für Physik, Munich, Germany
A. Engl, R. Hertenberger, F. Rauscher
Ludwig-Maximilians University, Munich, Germany

ATLAS Muon Spectrometer

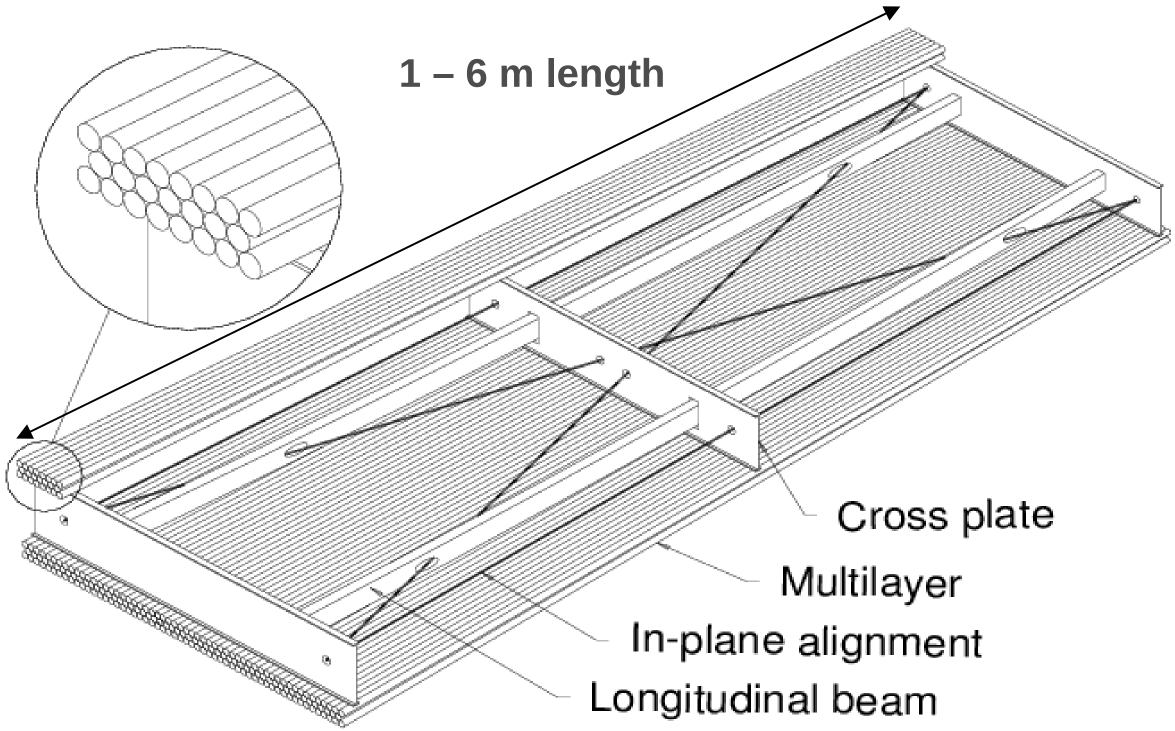
- Large area (5000 m^2) precision tracking (muon chambers with 35 μm position resolution).
- High muon detection efficiency at high background rates at LHC (air-core toroid magnet).





Monitored Drift Tube (MDT) Chambers

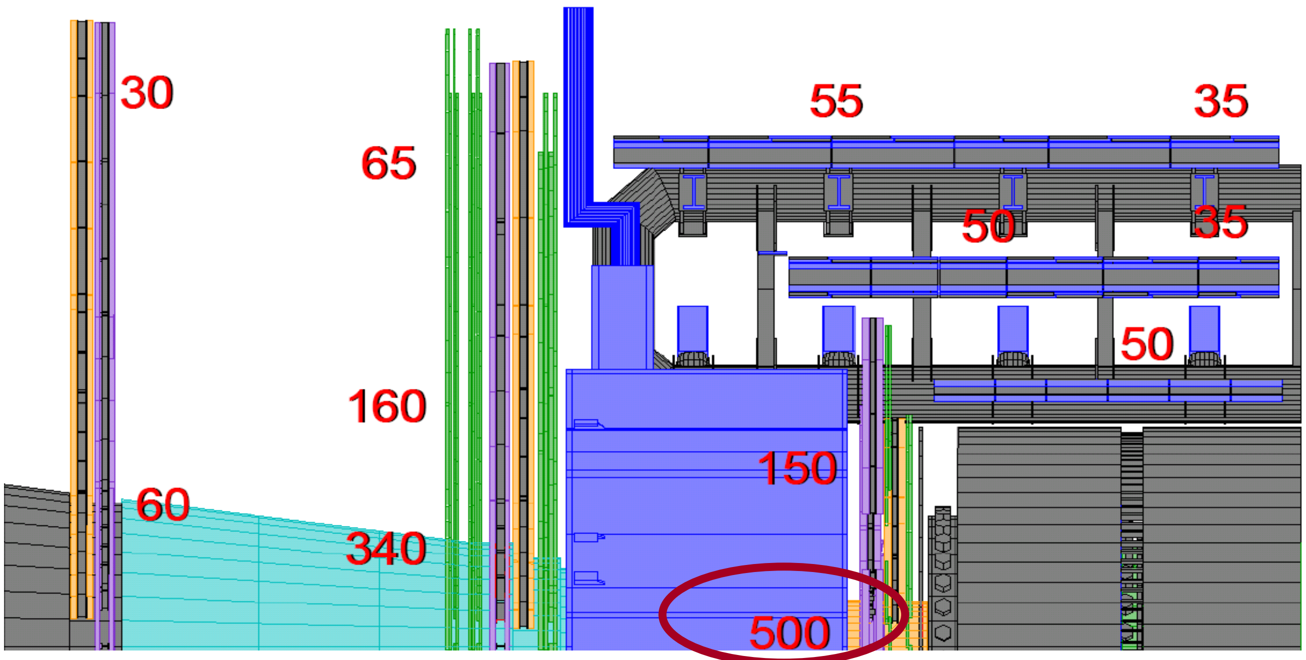
- 1150 chambers, 5000 m^2 area
- 350 k aluminum drift tubes, 30 mm diameter, 0.4 mm wall thickness
- Ar:CO_2 (93:7) gas at 3 bar
- 3080 V operating voltage (gas gain 20000)
- Max. drift time ~ 700 ns
- Wire pos. accuracy 20 µm
- Single-tube resolution 80 µm
- Chamber resolution 35 µm



Radiation levels at the LHC

- Background hit rates including safety factor 5 [Hz/cm^2] in the ATLAS muon spectrometer at LHC design luminosity 10^{34}/cm^{2}s. Low-energy neutrons from collision products and γ rays.

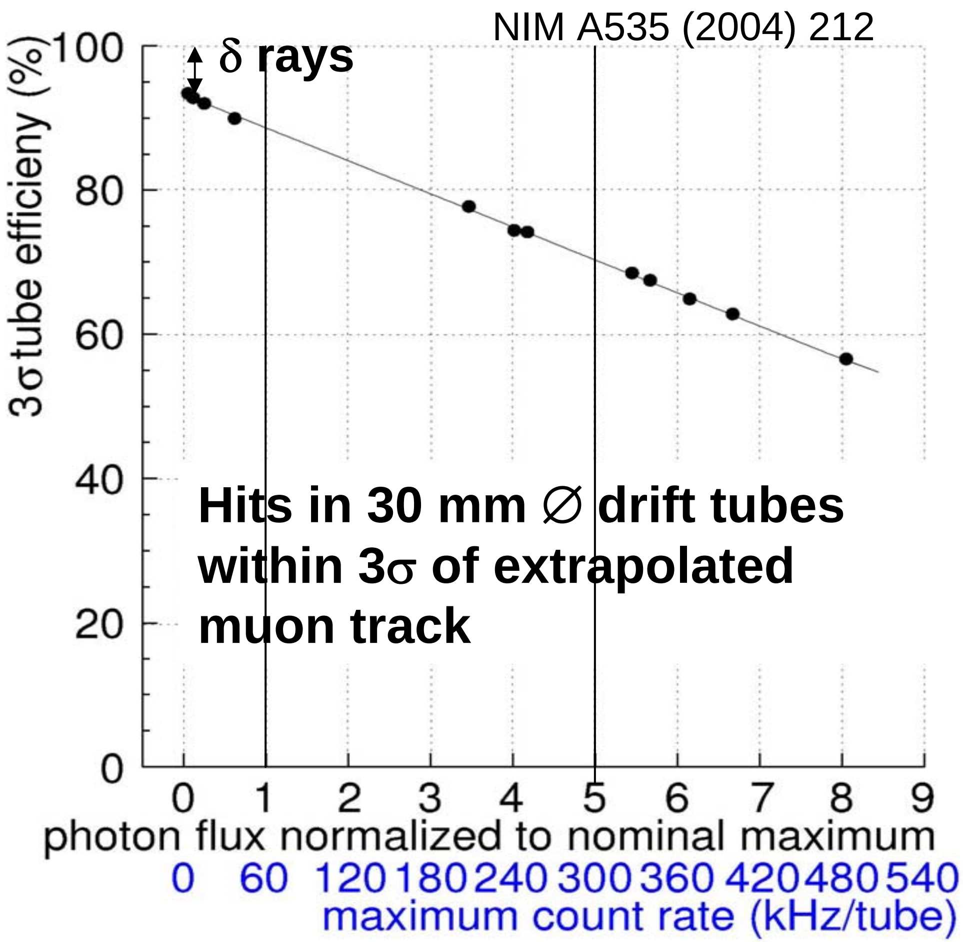
  Highest rate: 500 Hz/cm^2, 300 kHz/ tube (2 m long tubes and 2 x 4 layer chambers).
- Up to 10 x higher background rates to be expected at a high-luminosity upgrade of the LHC (S-LHC): maximum 5 kHz/cm^2, 3 MHz/ tube in very forward regions.

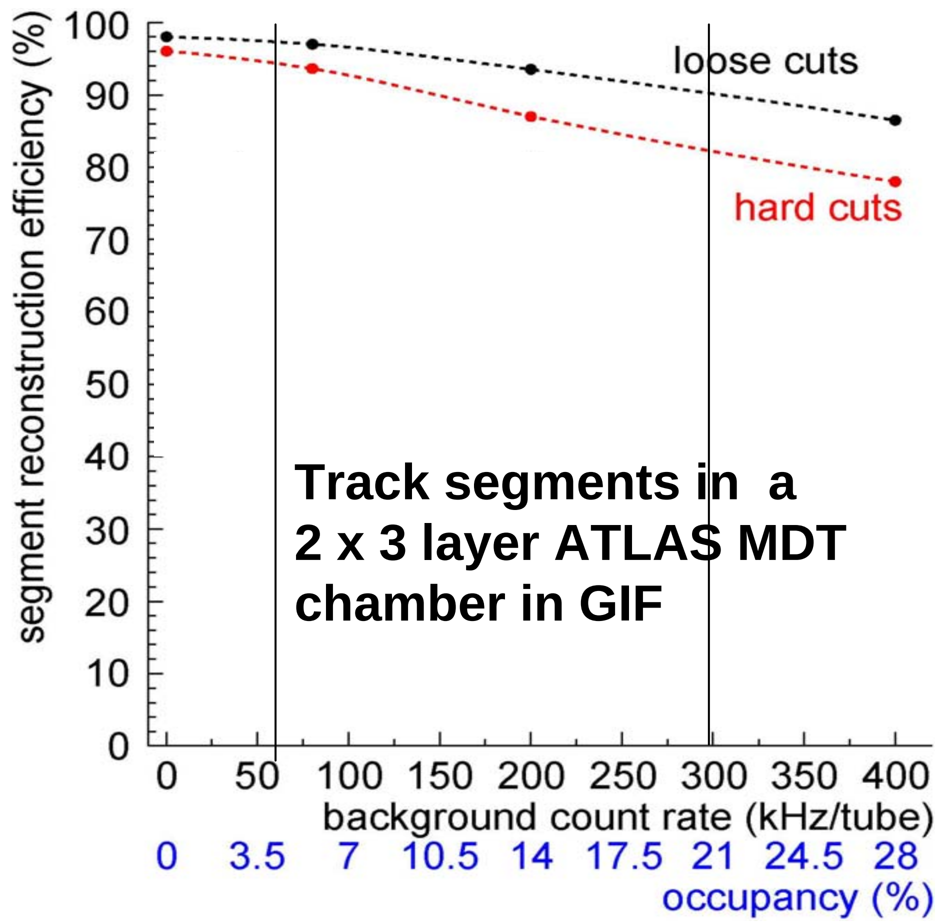


Quadrant of the ATLAS muon spectrometer with 3 layers of chambers in barrel and endcap regions

Rate capability of Drift Tube Chambers

Measurements at the CERN Gamma Irradiation Facility GIF 2003/04 with high-energy muon beam and beam telescope:



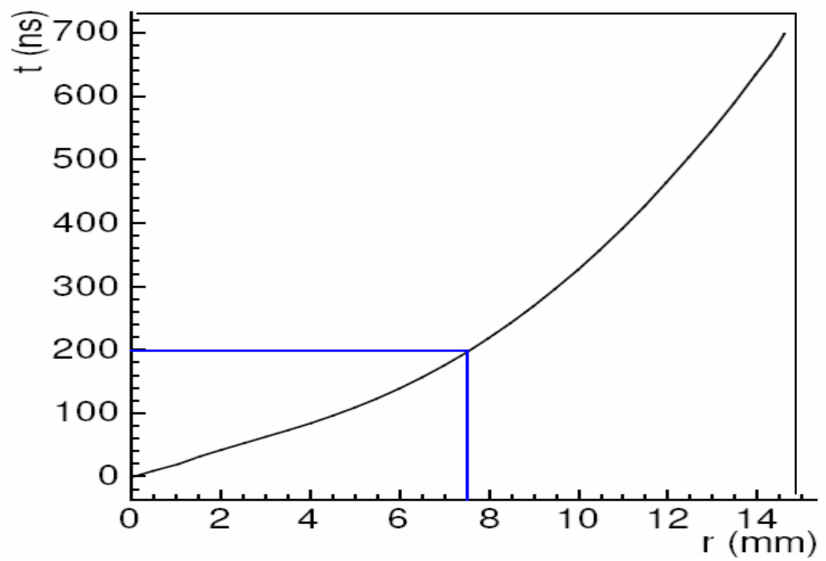


Efficient tracking up to ~30% drift tube occupancy.

Advantages of smaller drift tube diameter

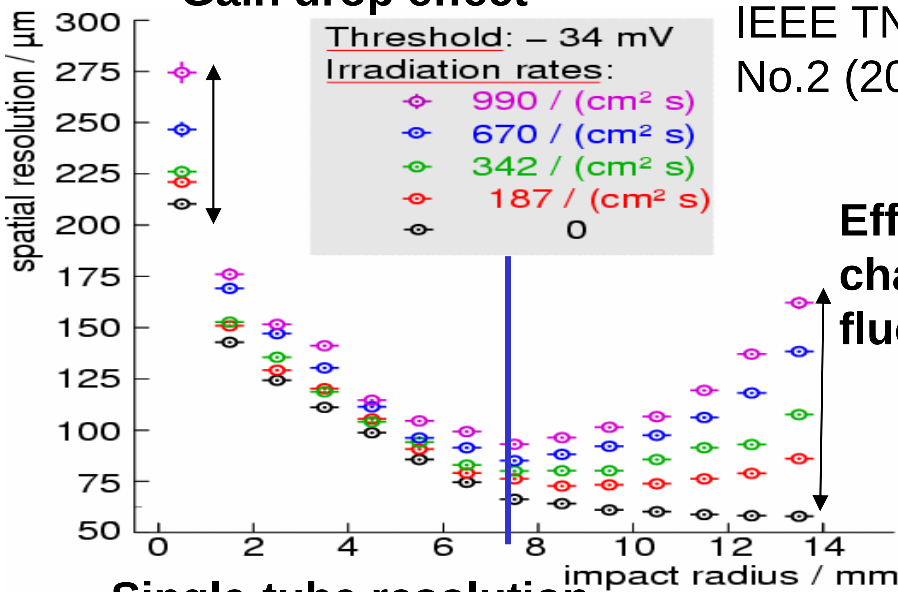
15 mm instead of 30 mm diameter tubes,
same drift gas and gas gain, same tube length:

- **Occupancy ~ max. drift time: 3.5 x smaller.**
- **Tube counting rate ~ tube circumference: 2 x smaller.**
- **Gain drop (due to space charge) ~ tube radius r^3: 8 x smaller.**
- **Degradation of spatial resolution due to radiation induced space charge fluctuations and gain drop strongly reduced.**



Space-drift time relationship

Gain drop effect



Single-tube resolution

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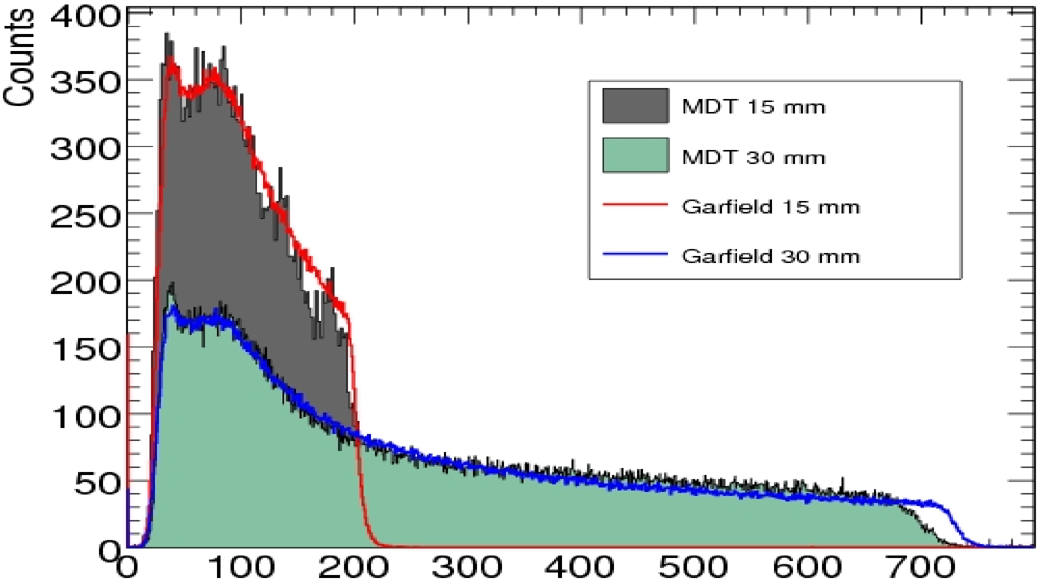
Effect of space charge fluctuations

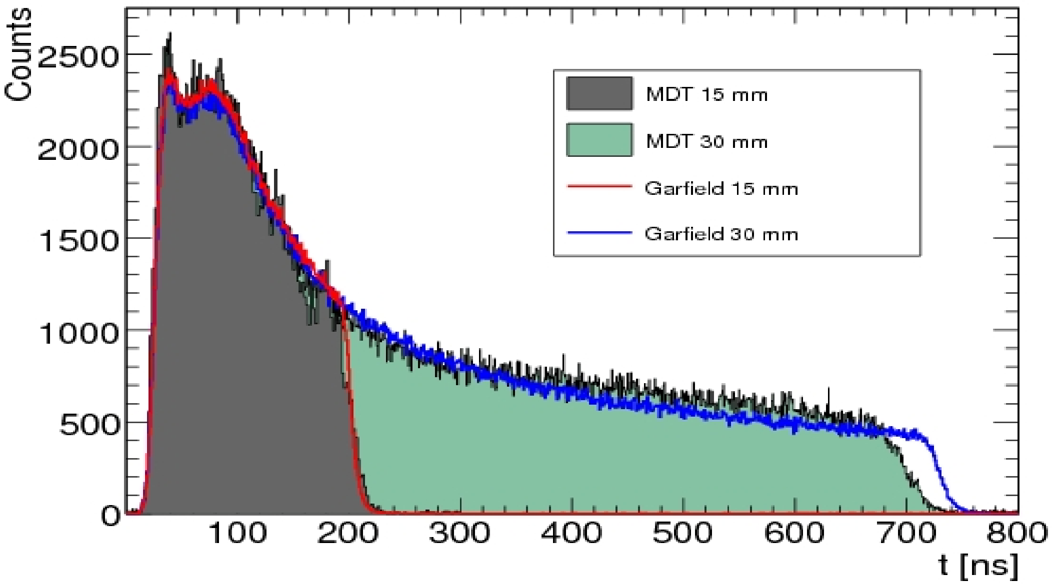
Advantages of smaller drift tube diameter

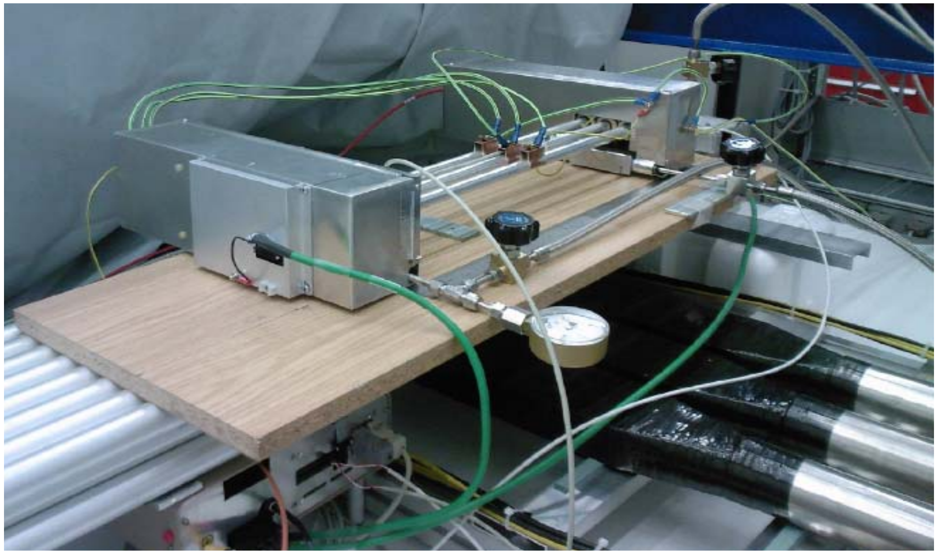
Maximum rate in 15 mm ∅ tubes at S-LHC

Diameter	Maximum drift time	Gain drop op. limit	Occupancy@ 700 kHz/ tube	Occupancy@ 1500 kHz /tube
30 mm	**700 ns**	**5 kHz/cm^2**	**50%**	**100%**
15 mm	**200 ns**	**40 kHz/cm^2**	**15%**	**30%**

Drift time spectra

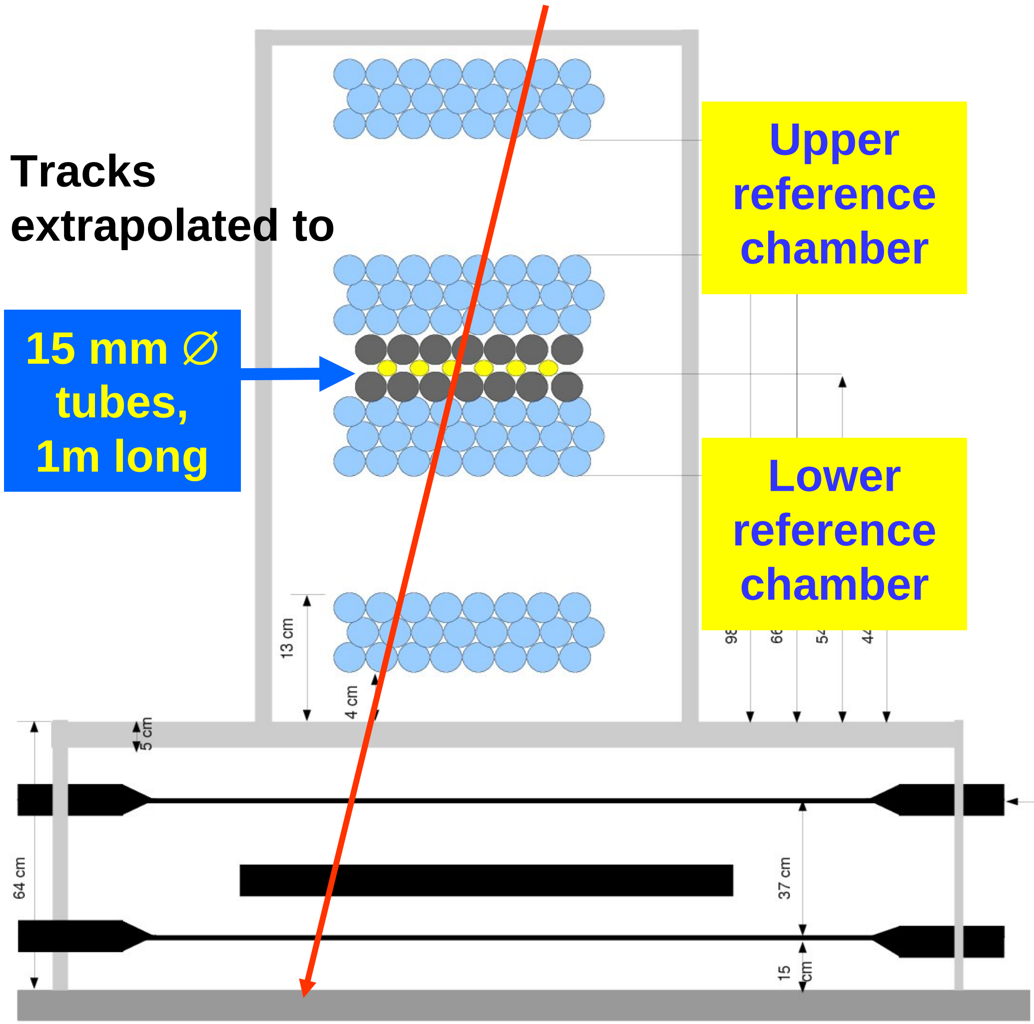


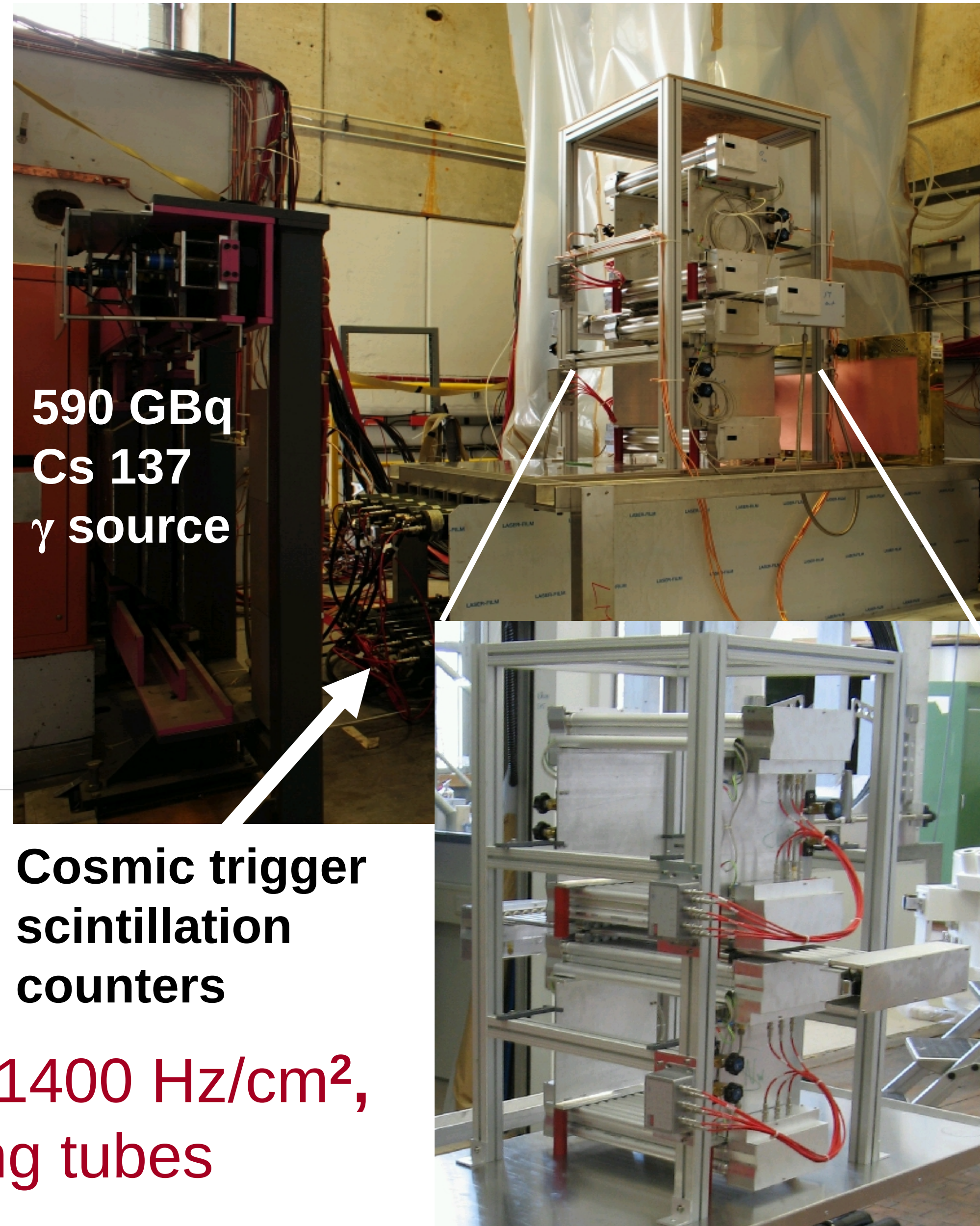




Cosmic ray
lab test setup

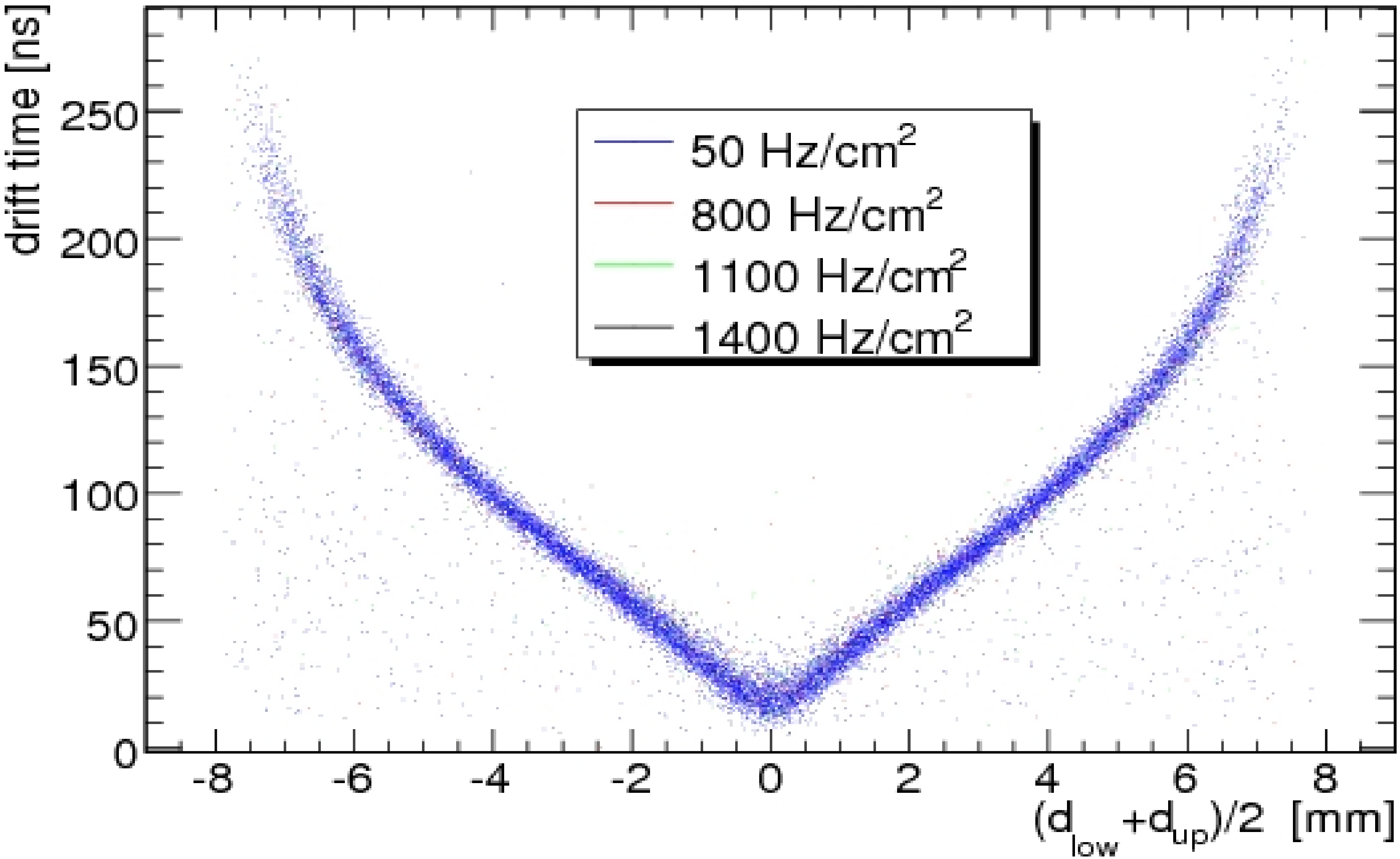
High rate tests at CERN GIF 2008





Adjustable background rates up to 1400 Hz/cm², only about 300 kHz/ tube in 1 m long tubes

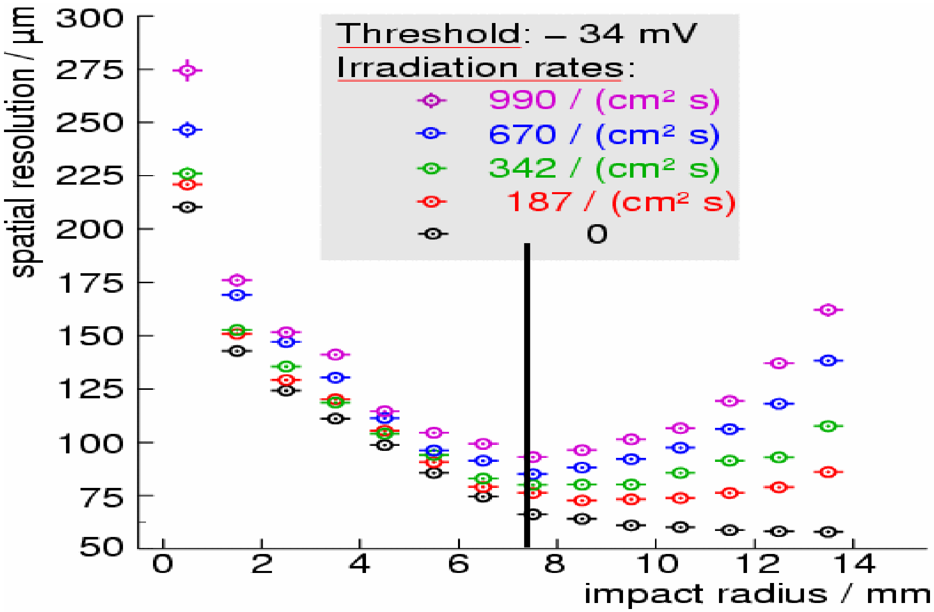
Space-drift time relationship

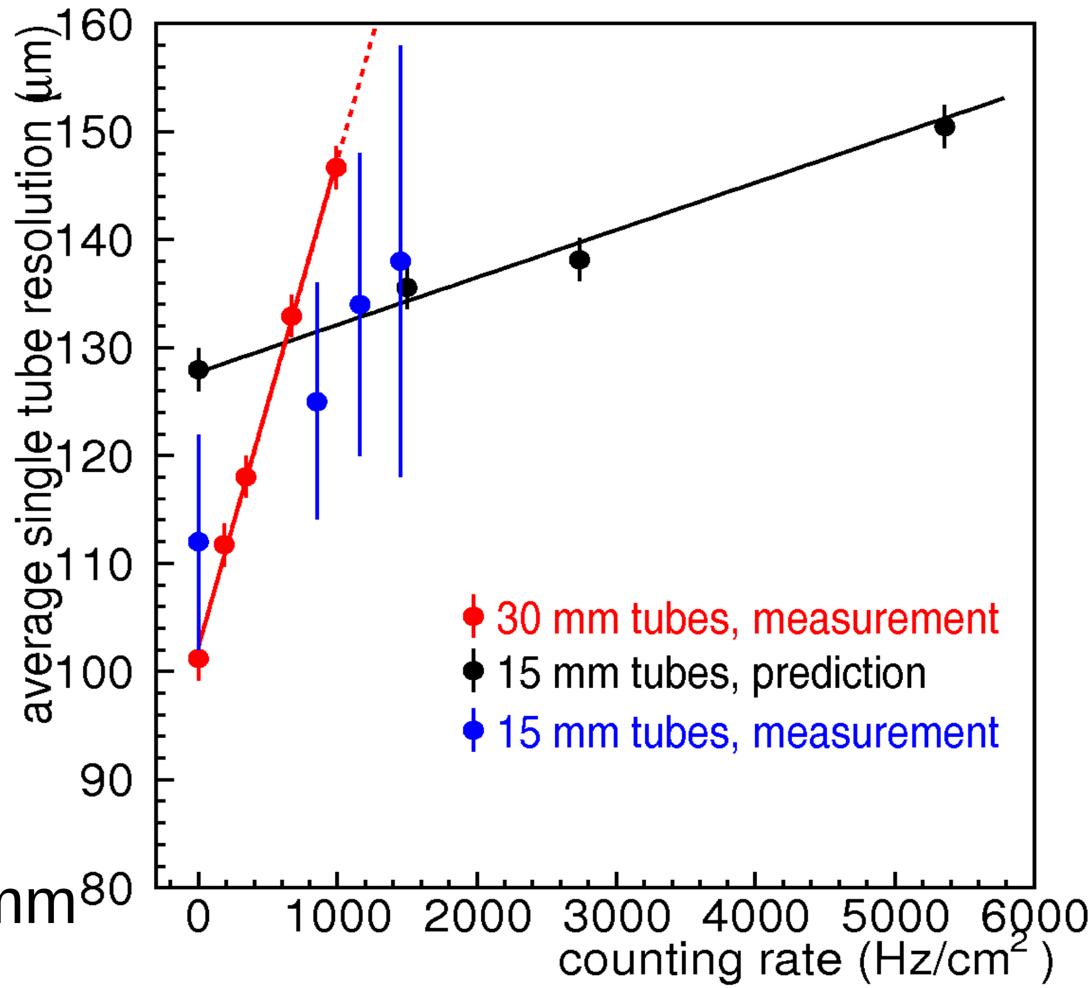


Expected drift distance, average of extrapolation from lower and upper reference chamber

Drift tube resolution

Earlier measurement for
30 mm ∅ tubes:



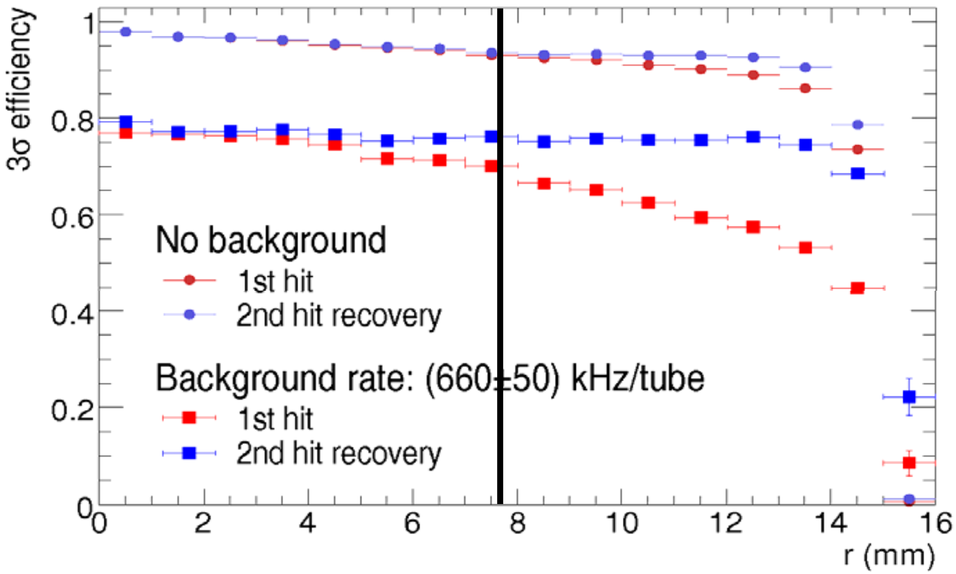


⇒ Prediction for 15 mm tubes:
average resolution for r < 7.5 mm
with space charge fluctuation
effect almost eliminated
gain drop 8 x smaller.

New measurement at GIF
for 15 mm ∅ tubes.

Drift tube efficiency

From 30 mm ∅ tube test

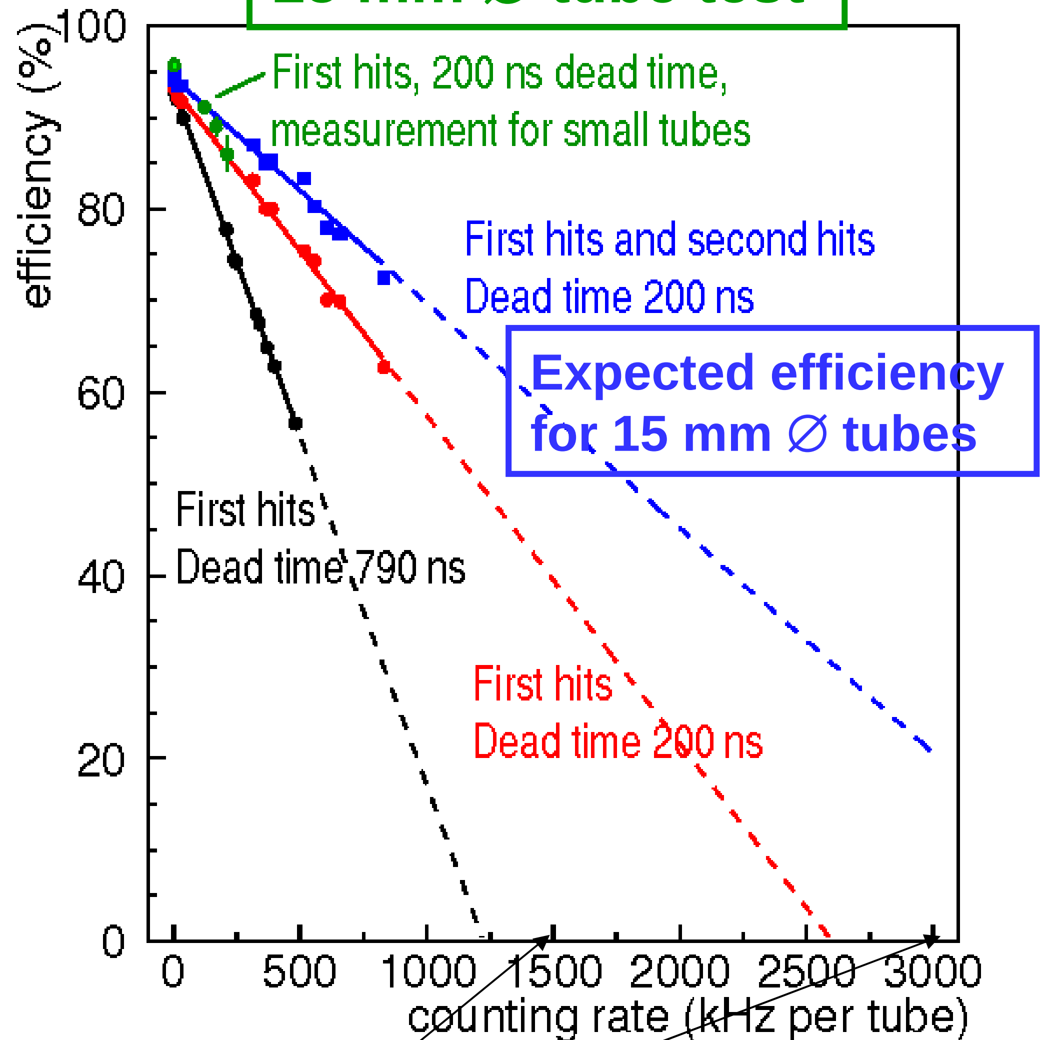


Standard dead time setting of readout electronics = 790 ns.

Minimum adjustable dead time of electronics = 200 ns, resulting in higher data rate.

Offline recovery of second hits masked by background hits.

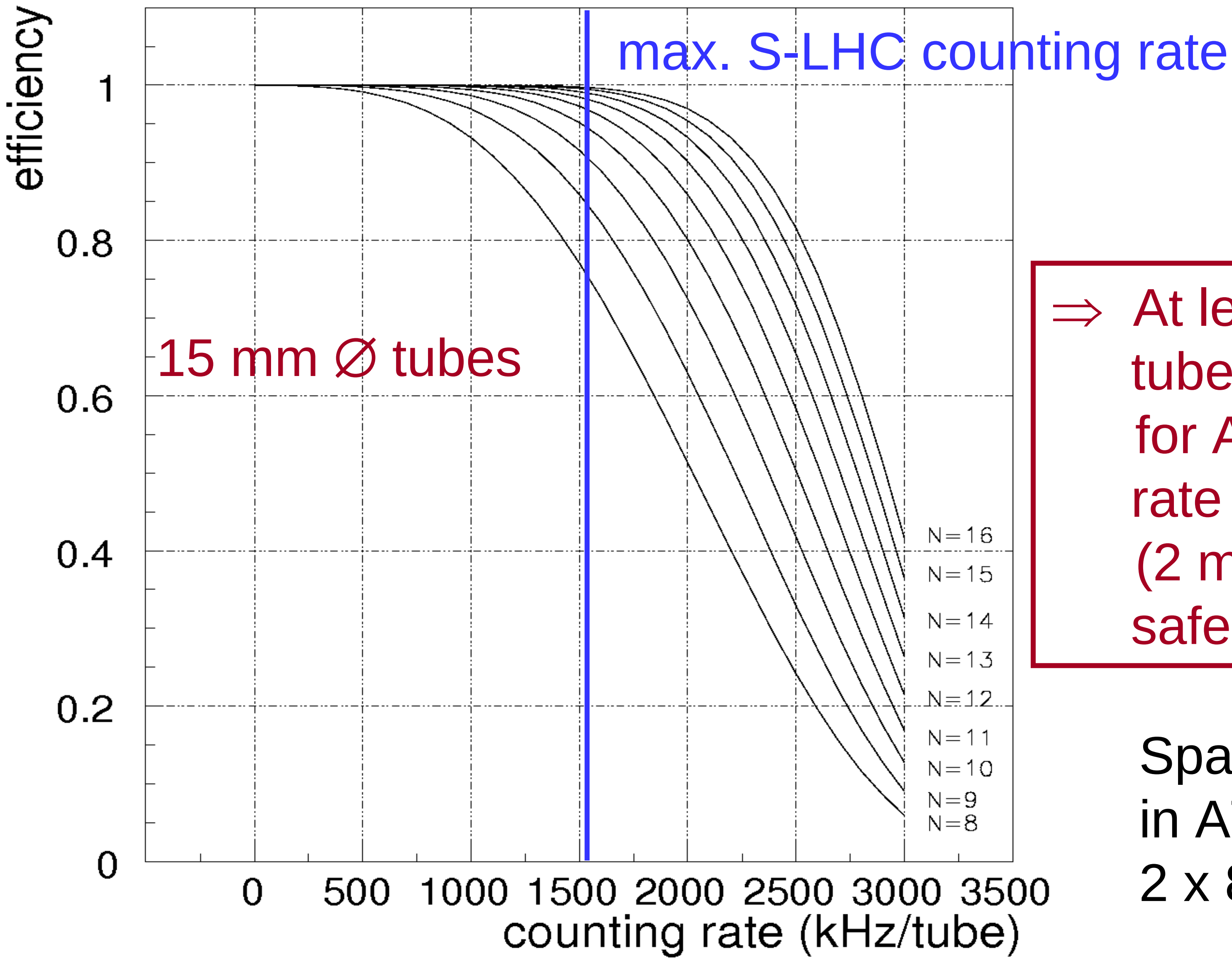
15 mm ∅ tube test



for 15 mm / 30 mm tubes: max. S-LHC counting rate

Chamber tracking efficiency

Segment reconstruction efficiency requiring at least 4 out of N hits



⇒ At least 2 x 7 drift tube layers needed for ATLAS highest rate regions (2 m long tubes, safety factor of 5)

Space available in ATLAS for 2 x 8 layers

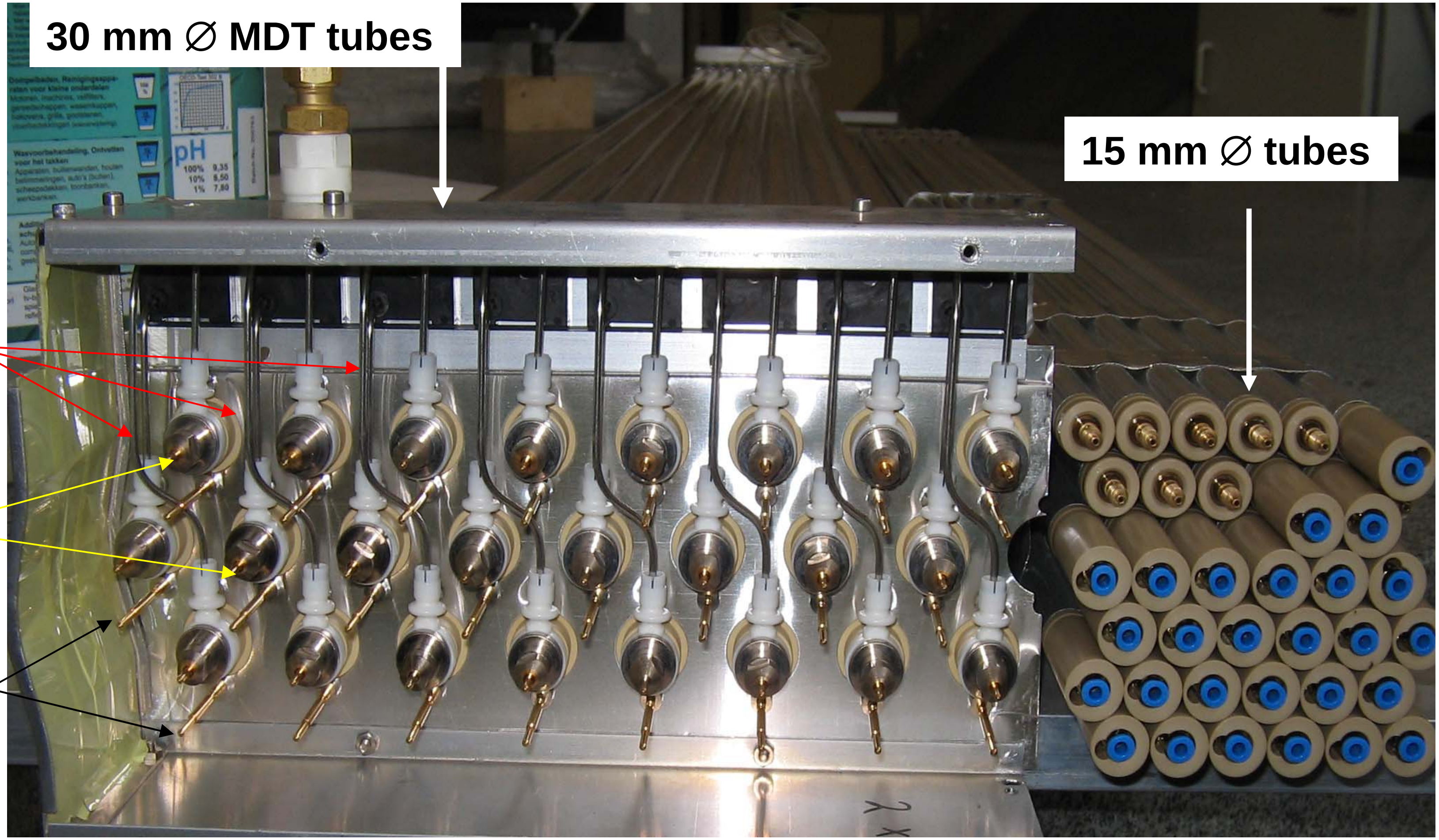
Chamber design

Builds on experience with the design of the existing MDT chambers

Gas connections

Signal pins

Ground pins



4 x denser tube packages:
challange for design of services connections

Chamber design

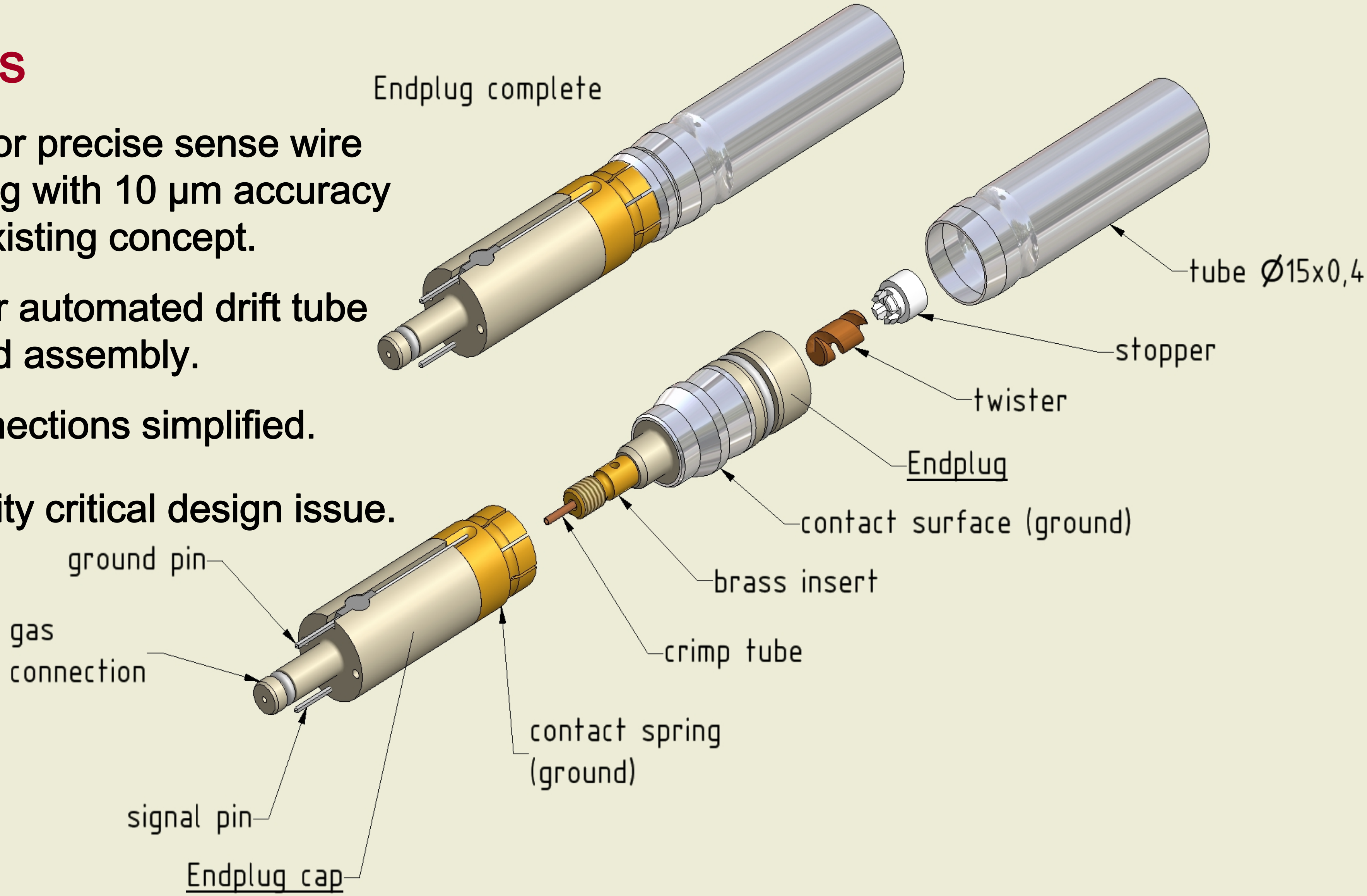
Endplugs

- Method for precise sense wire positioning with 10 µm accuracy follows existing concept.

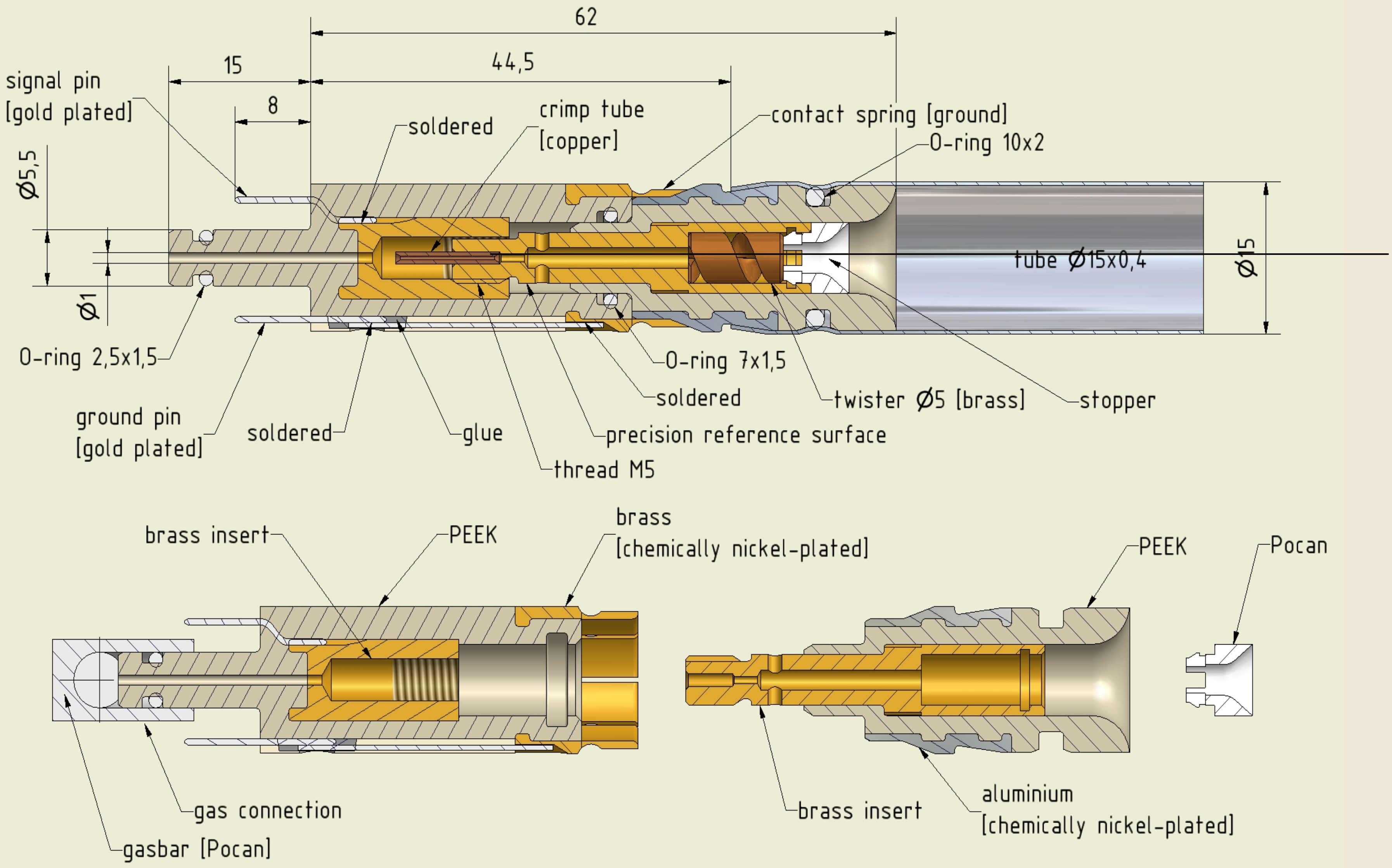
  Allows for automated drift tube wiring and assembly.

- Gas connections simplified.

- HV stability critical design issue.

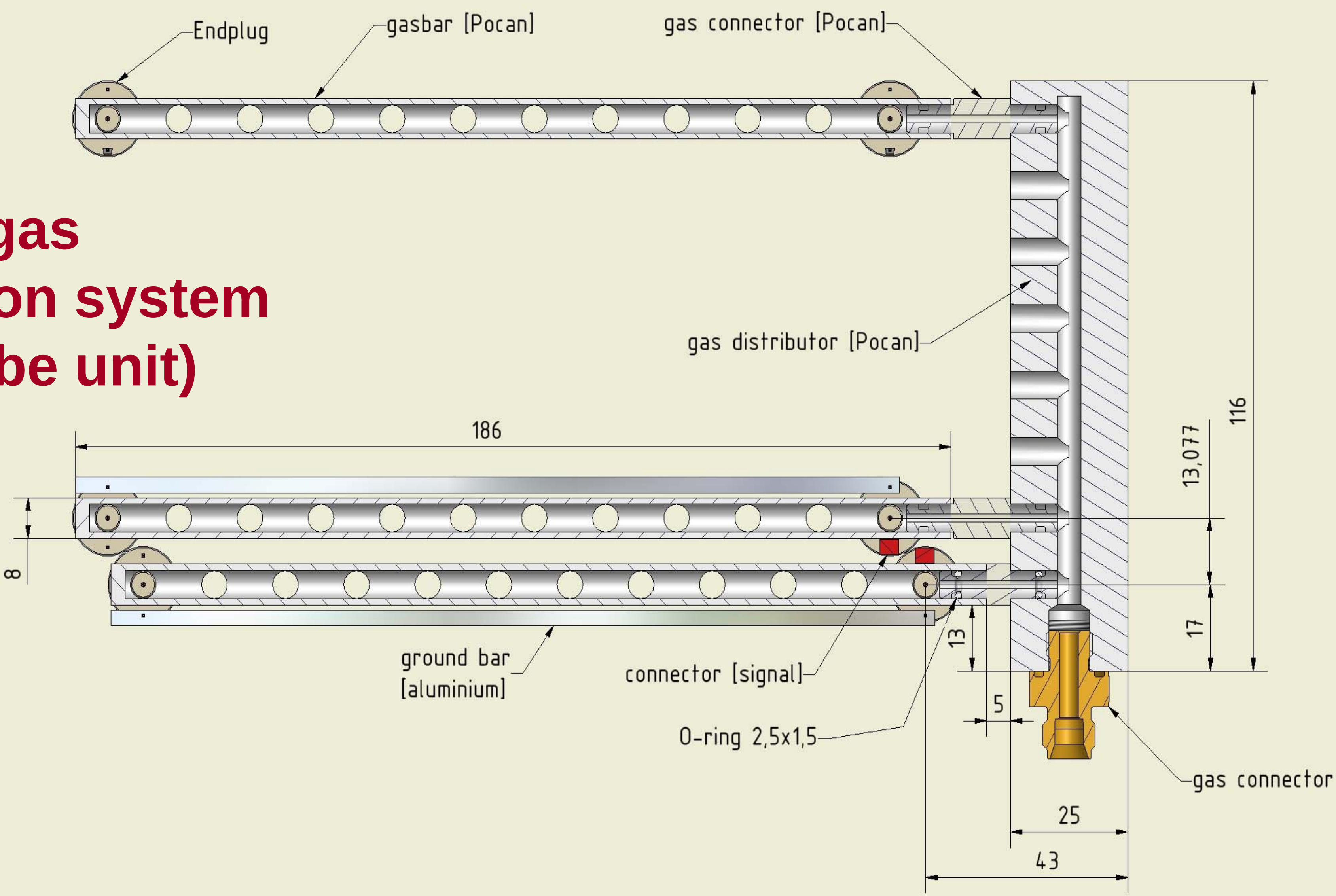


Chamber design



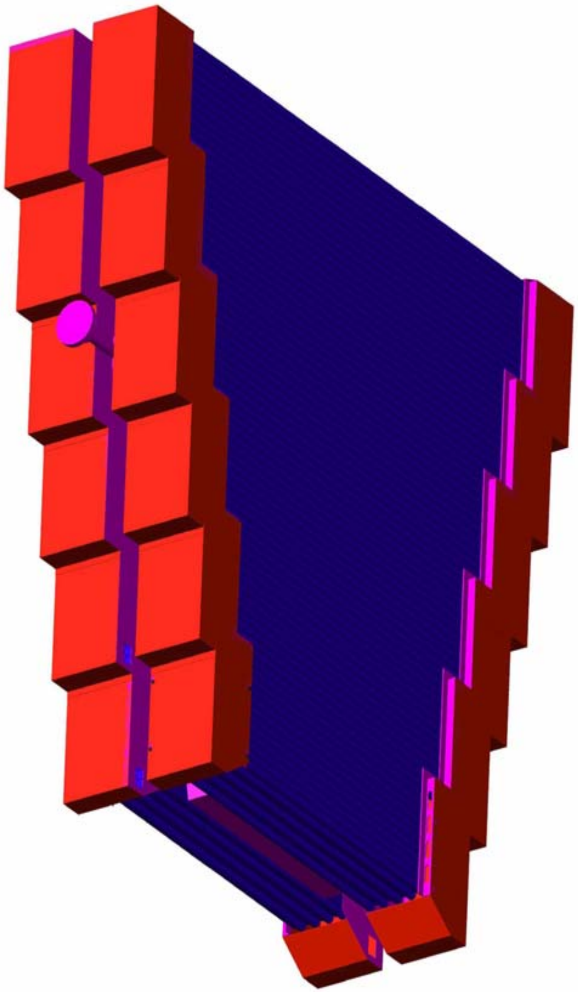
Chamber design

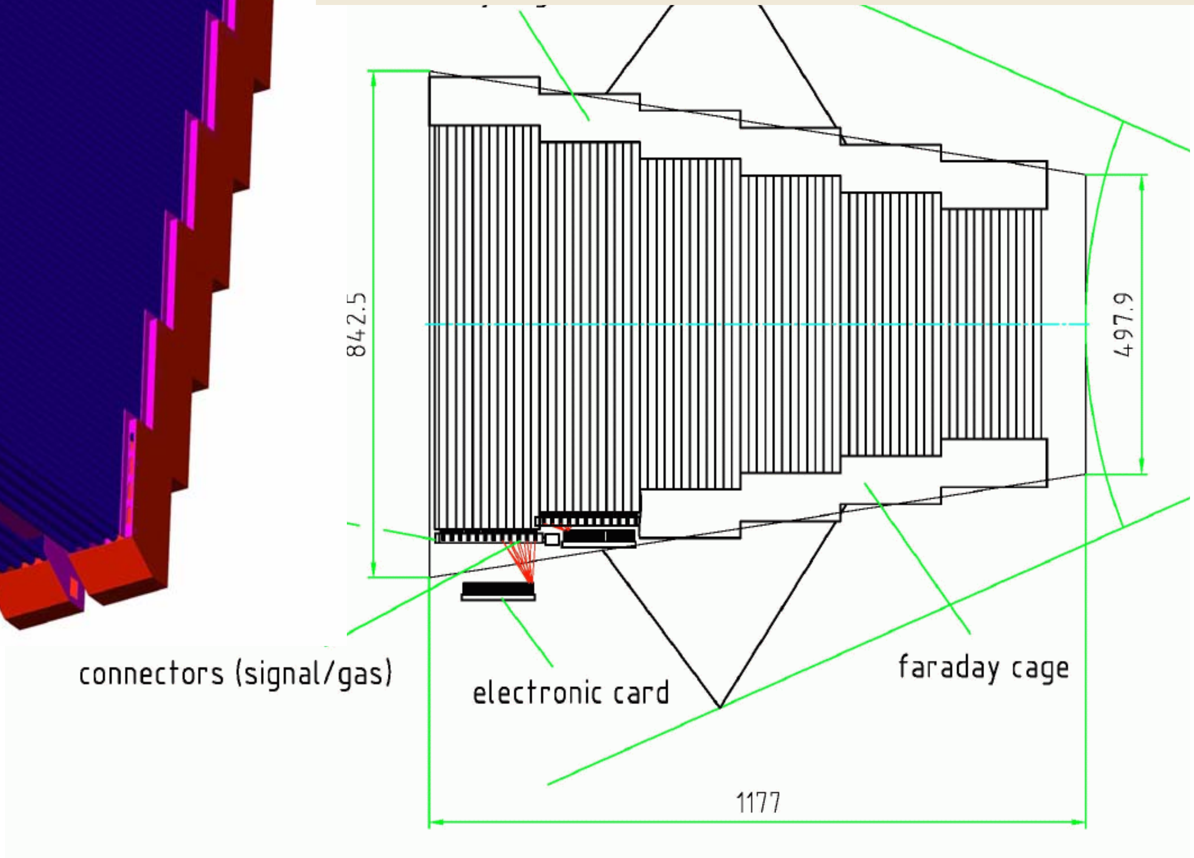
Modular gas distribution system (8 x 12 tube unit)

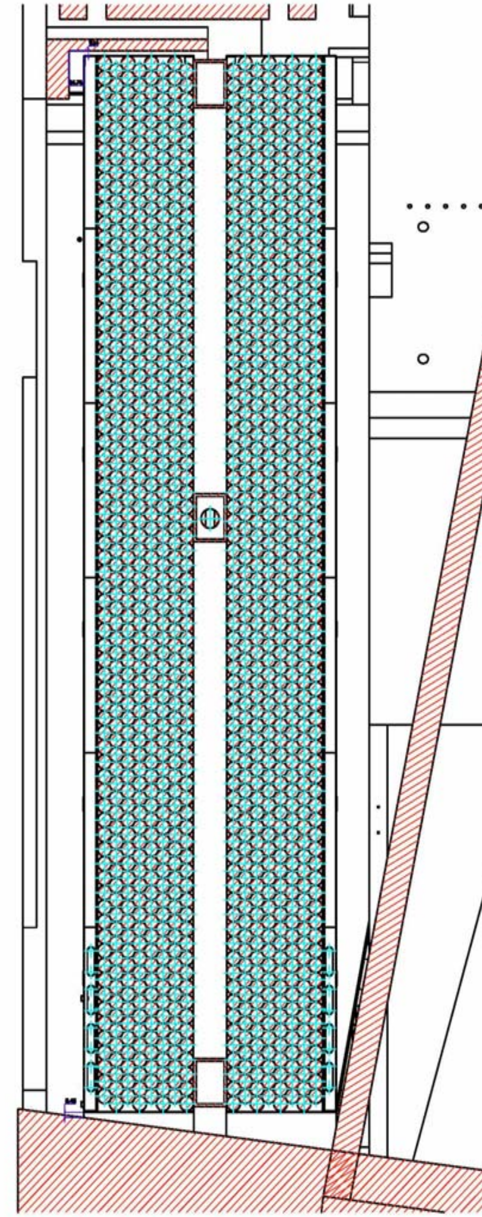


Chamber design

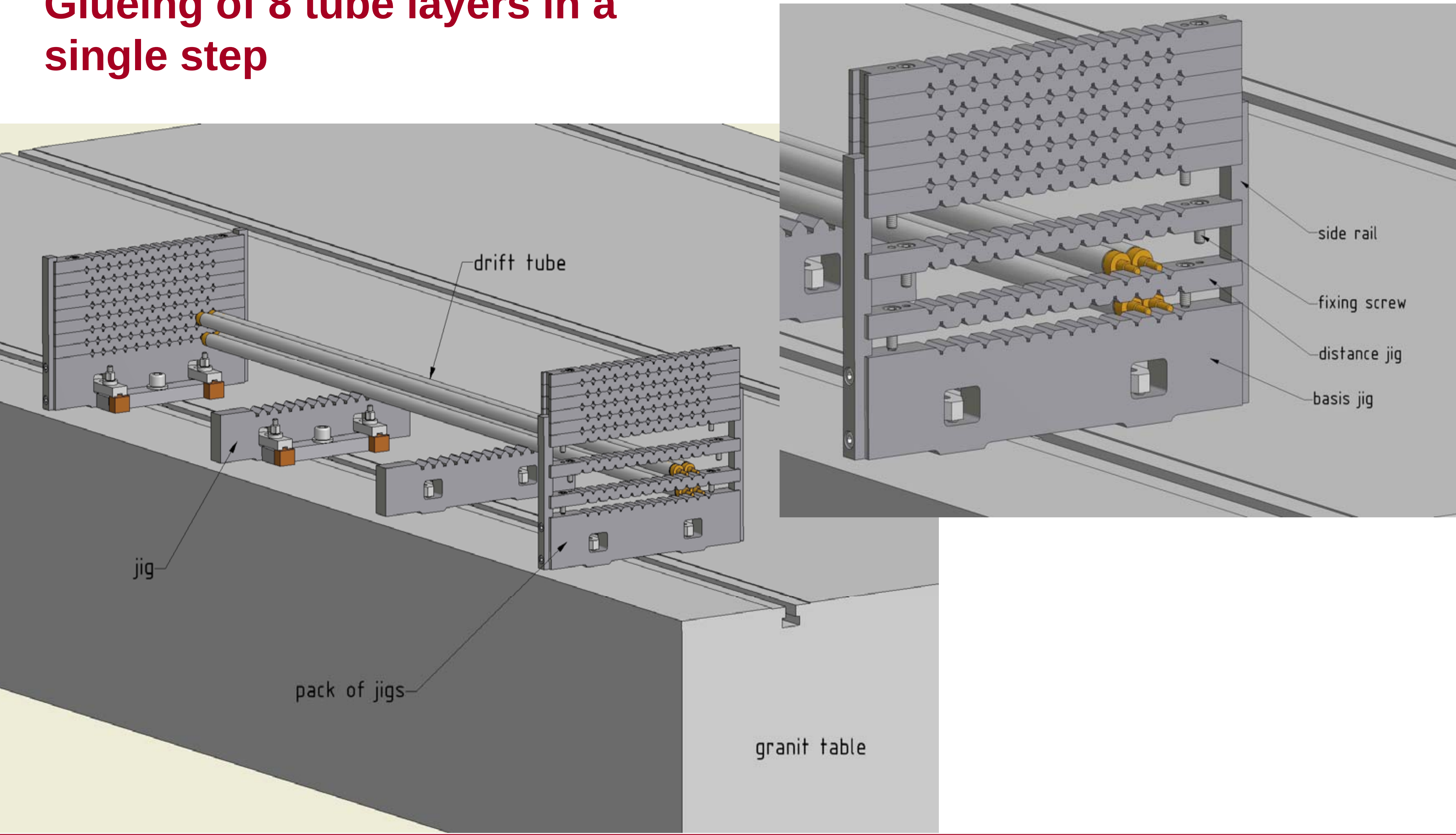
2 x 8 tube layers consisting of 8 x 12 tube units with gas distribution system, electronics card, Faraday cage







Glueing of 8 tube layers in a single step

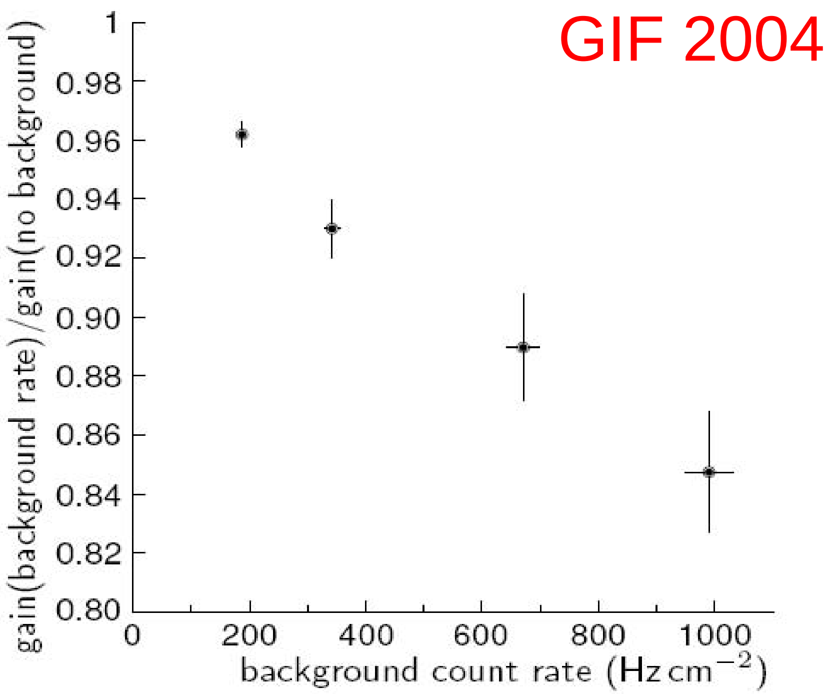


Conclusions

- Cylindrical drift tube detectors provide high-efficiency precision tracking at high background rates.
- Mechanically robust detector design for large detector areas.
- Option for muon detector upgrades for high-luminosity phase of the LHC: smaller tube diameters (50%) in high-background regions sufficient.
- Plan for complete prototype chamber next year.
- Performance extrapolation from high-rate tests of present ATLAS muon drift tube (MDT) chambers straight forward.
- For complete test at S-LHC background rates a new Gamma Radiation Facility at CERN with higher-intensity source and a muon beam is necessary.

Backup slides

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.

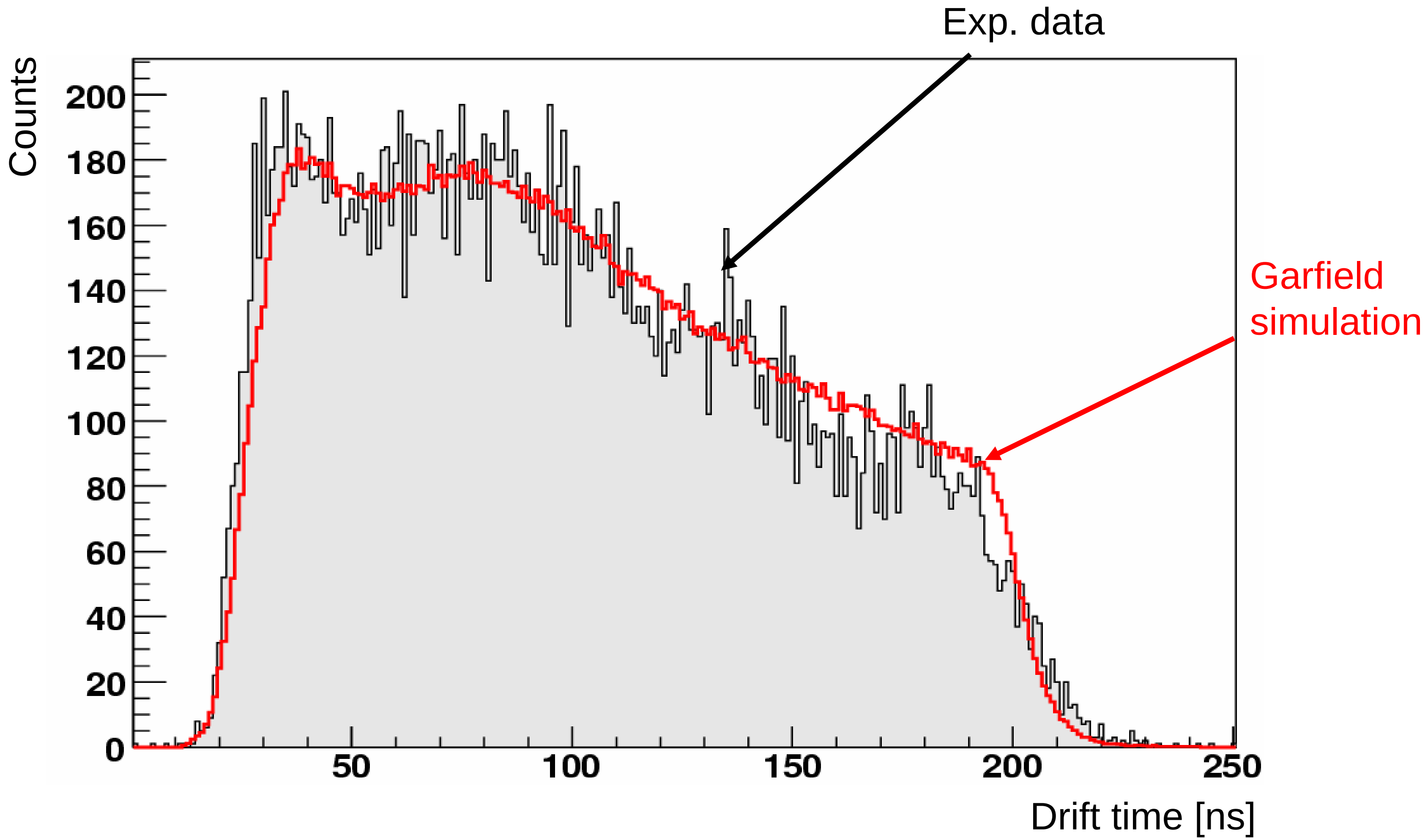
⇒ ΔU=250 V at 5 kHz/cm^2 → no signal!

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

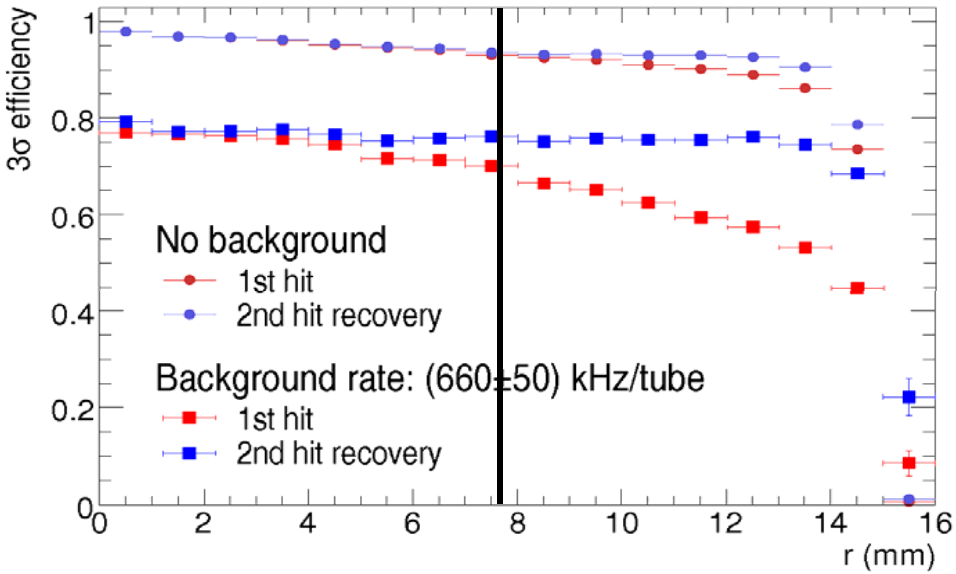
⇒ Occupancy, not space-charge defines operating limit!

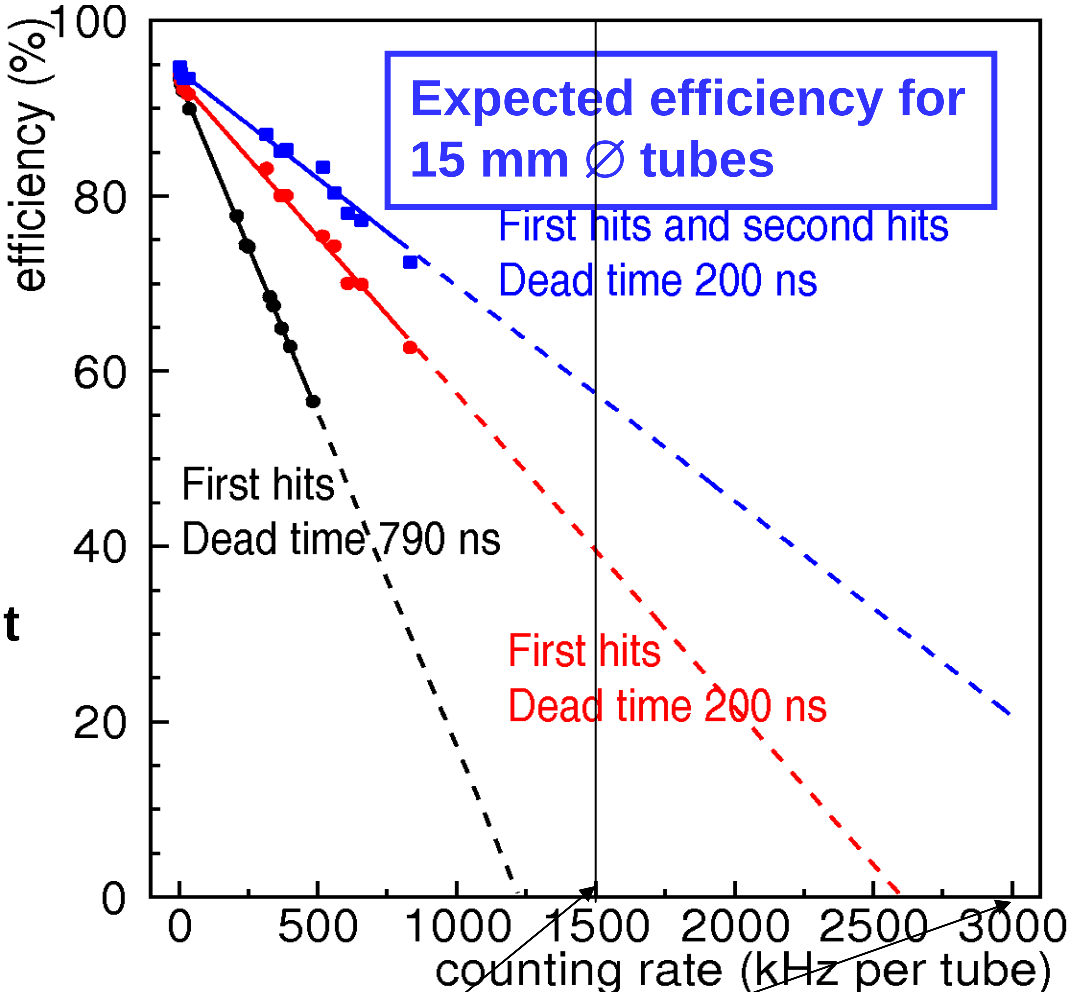
Cosmic-ray tests: drift time spectrum

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



For 30 mm ∅ tube test with muon beam telescope:





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