Development of Muon Drift Tube Detectors for High-Luminosity Upgrades of the LHC

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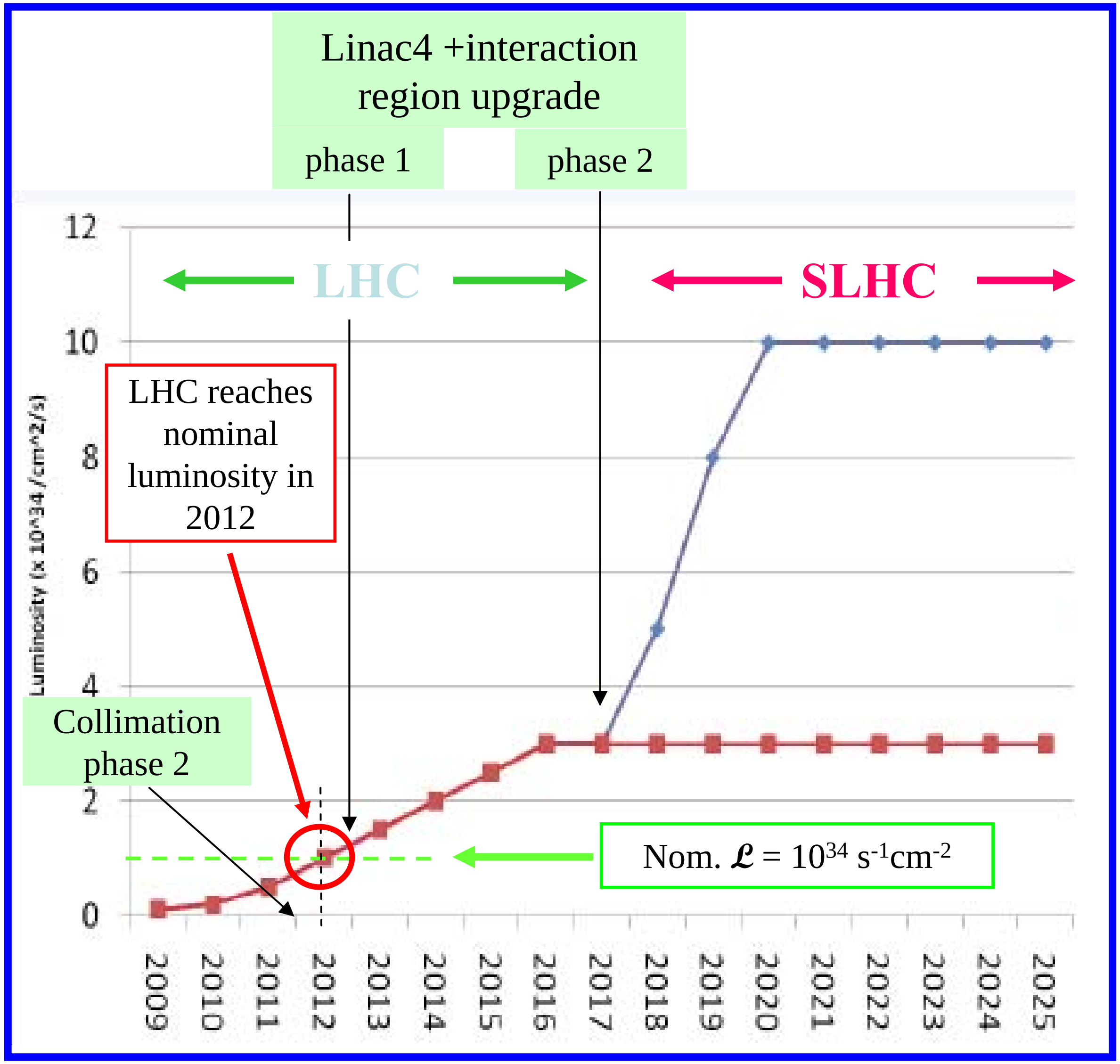
LHC Luminosity Upgrade Program



Phase 1 upgrade:

3 x design luminosity

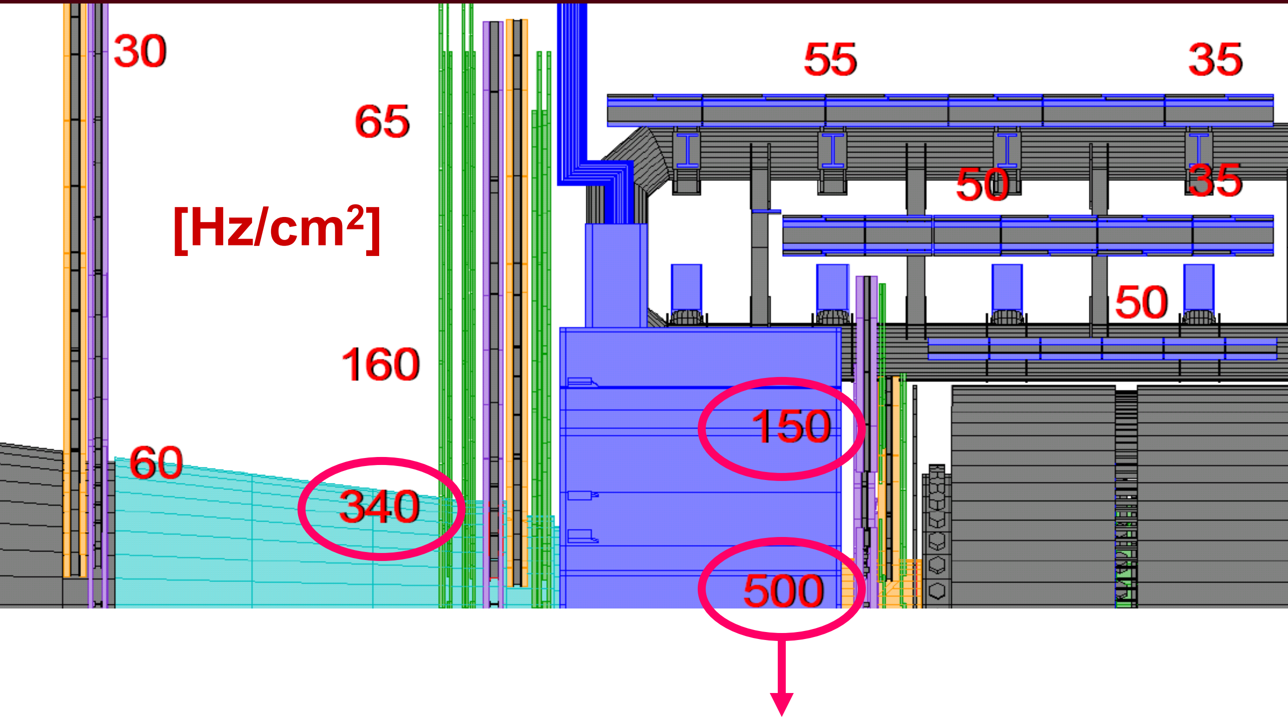
Phase 2 upgrade (S-LHC):

up to 10 x design luminosity

Increase of radiation background.

Consequences for pixel and tracking detectors, electronics, trigger and even muon detectors.

Radiation Levels at the LHC



Background counting rates **including** safety factor 5 in the ATLAS muon spectrometer at LHC design luminosity $10^{34}/cm^2s$.

Due to low-energy neutrons from pp collisions and sec. interactions in the detector and γ rays.

In ATLAS Muon Drift-Tube (MDT) chambers with 30 mm diameter drift tubes.

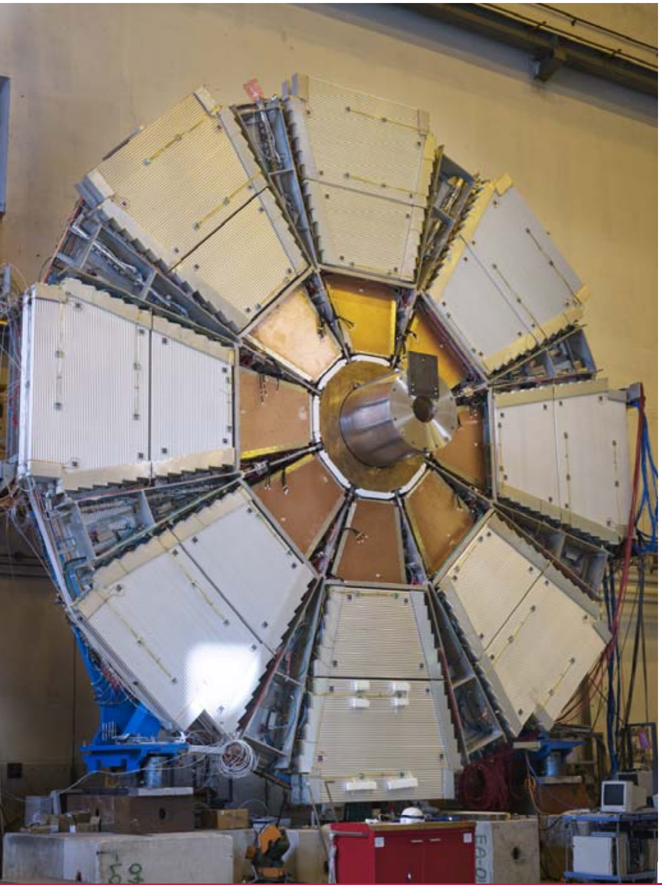
Highest rates in ATLAS MDT chambers (2m long tubes) for

LHC design lumi:	500 Hz/cm²,	300 kHz/ tube
Phase 1 upgrade:	1500 Hz/cm²,	900 kHz/ tube
S-LHC upgrade:	5000 Hz/cm²,	3000 kHz/ tube

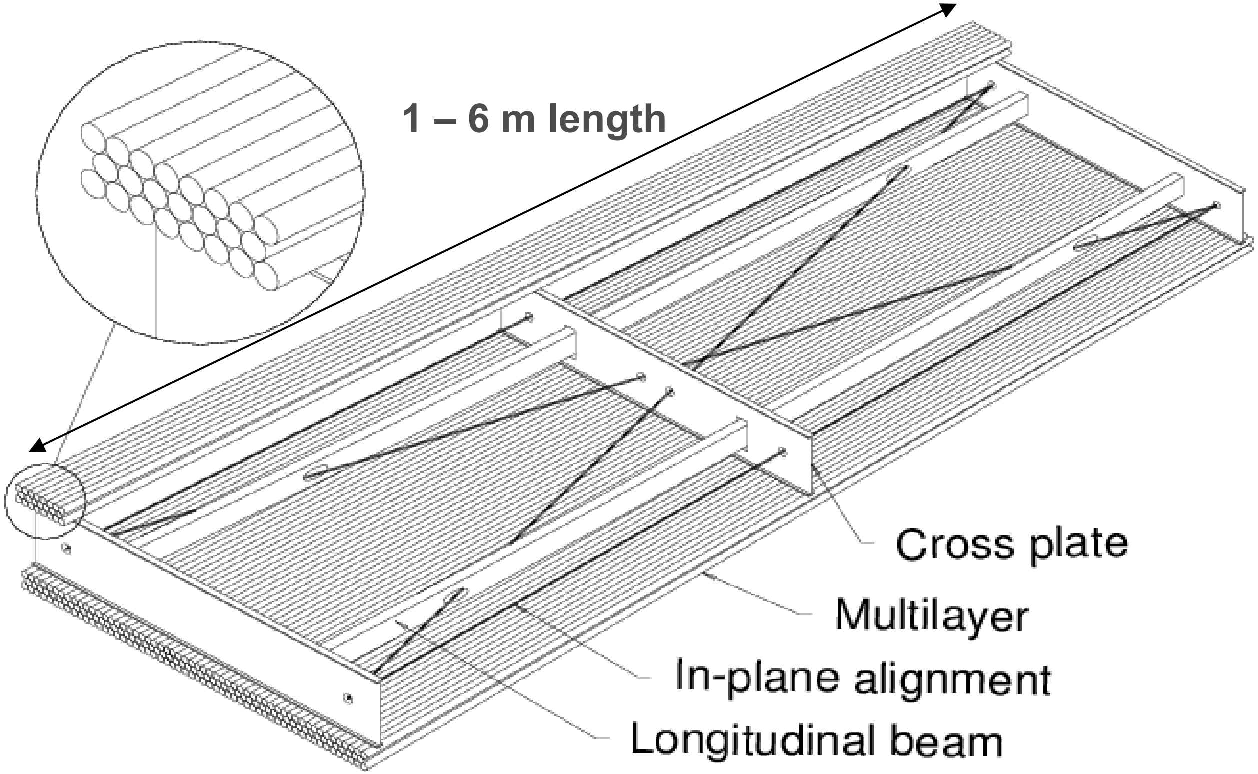
Assume background rates to increase roughly proportional to the luminosity.

Monitored Drift Tube (MDT) Chambers

- 1150 chambers, 5000 m² area
- 350000 aluminum drift tubes,
  30 mm diameter,
  0.4 mm wall thickness
- Ar:CO_2 (93:7) gas at 3 bar

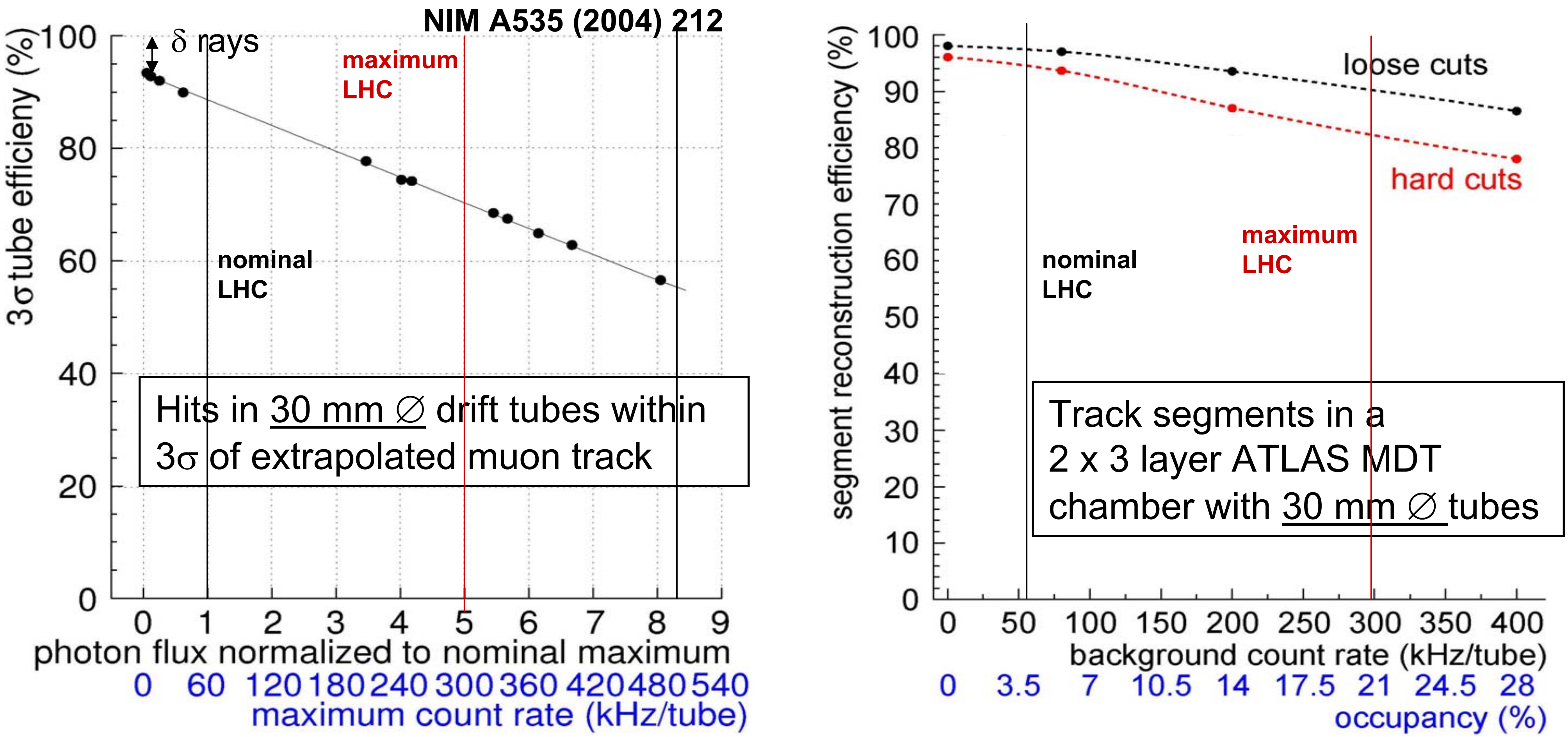


- 3080 V operating voltage (gas gain 20000)
- Max. drift time ~ 700 ns
- Wire pos. accuracy 20 μm
- Single-tube resolution 80 μm
- Chamber resolution 35 μm



Rate capability of Drift-Tube Chambers

Measurements at the CERN Gamma Irradiation Facility GIF in 2004
with high-energy muon beam and a silicon strip-detector beam telescope:



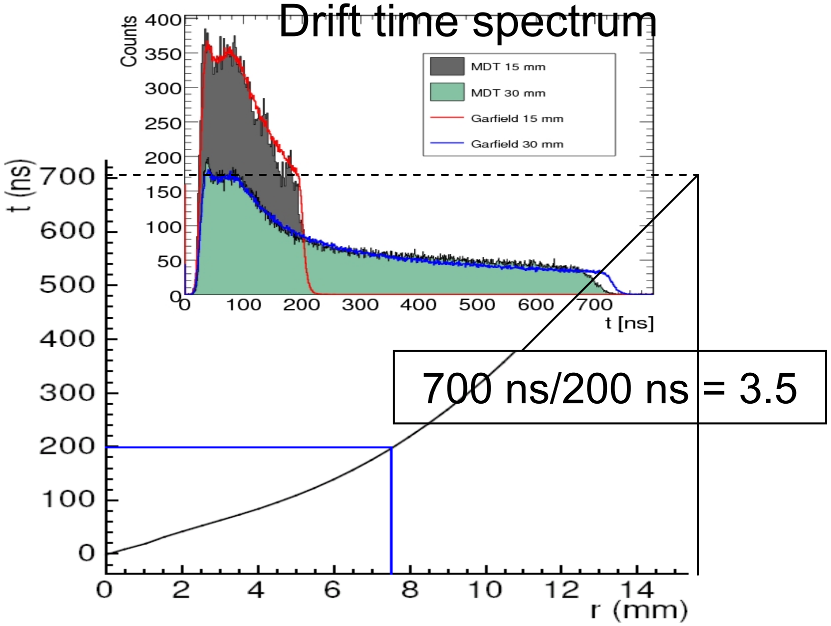
Efficient tracking up to ~30% drift-tube occupancy.

Smaller Drift-Tube Diameter for Highest Rates

Baseline: 15 mm instead of 30 mm ∅ tubes, with tube length, drift gas and gas gain unchanged (i.e. 2730 V op. voltage):

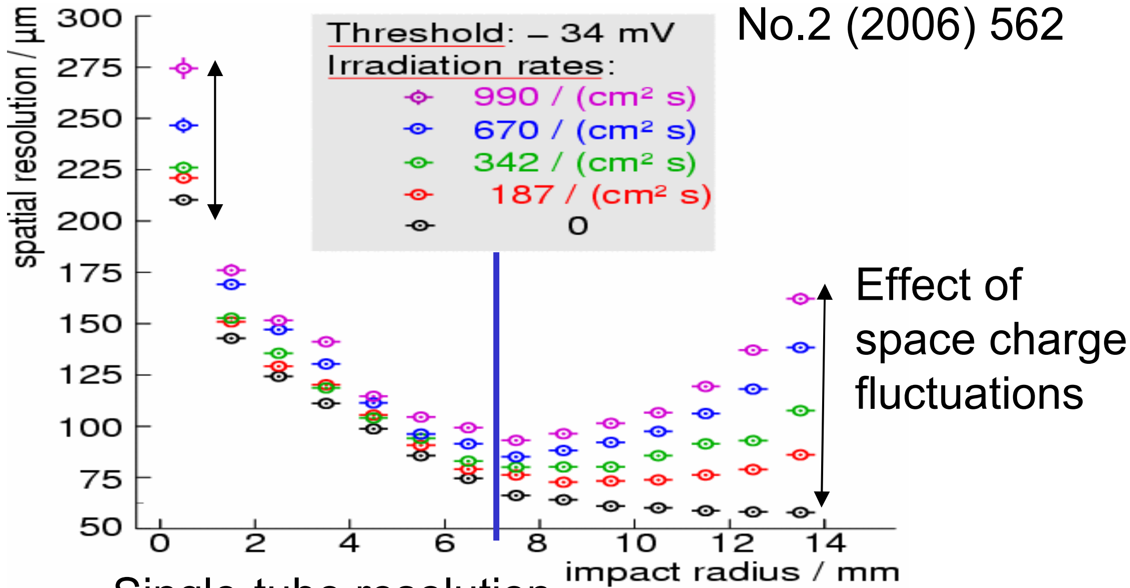
- ❑ Occupancy proportional to max. drift time: 3.5 x smaller.
- ❑ Tube counting rate ~ tube circumference: 2.0 x smaller.

  Occupancy 7 x smaller in total!
- ❑ Gain drop (due to space charge) ~ tube radius $R^3 \ln(R/R_{wire})$: 10 x less.
- ❑ Degradation of spatial resolution due to radiation induced space charge fluctuations (non-linear r-t-relationship) and gain drop strongly reduced.



Space-drift time relationship

Gain drop effect



Single-tube resolution

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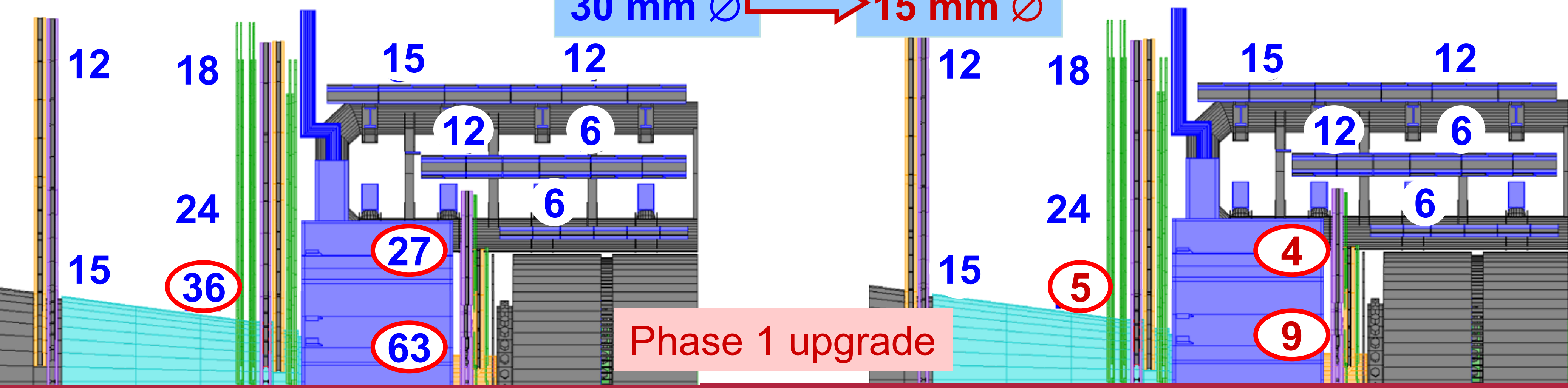
Drift Tube Occupancies at High Rates

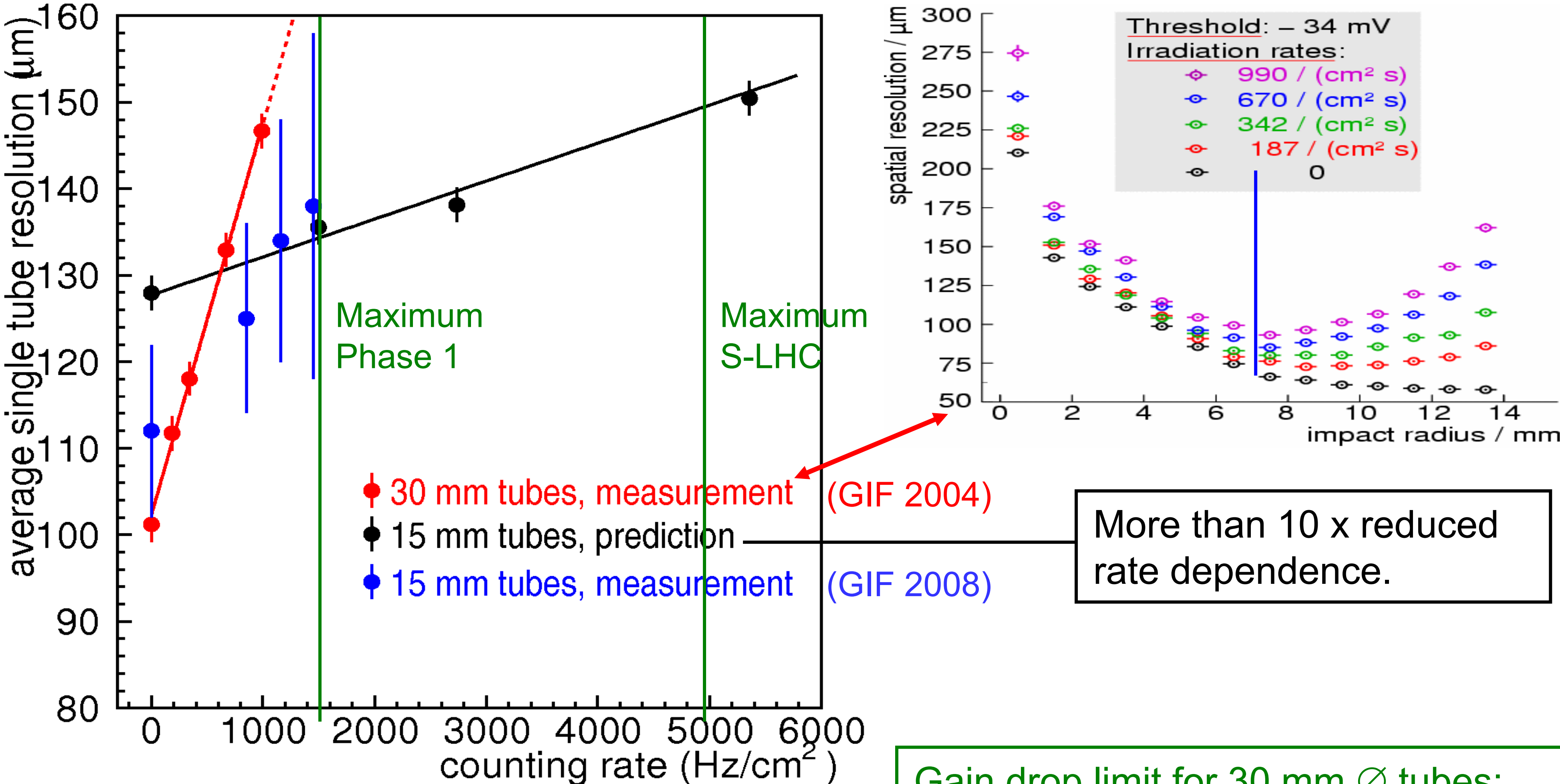
LHC luminosity upgrades: maximum rates incl. safety factor 5:

Luminosity (cm^{-2} s^{-1})	Background hit rate (kHz/cm^2)	Counting rate (kHz/tube)	Occupancy (%)	Occupancy (%)	
Tube ∅	15 mm/30 mm	15 mm	15 mm	30 mm	
1 x 10^{34}	0.5	150	3%	21%	LHC design
2 x 10^{34}	1.0	300	6%	42%	Phase 1 upgrade
3 x 10^{34}	1.5	450	9%	63%	
10 x 10^{34}	5.0	1500	30%	100%	S-LHC

30 mm ∅ ⇒ 15 mm ∅



Drift-Tube Spatial Resolution at High Rates

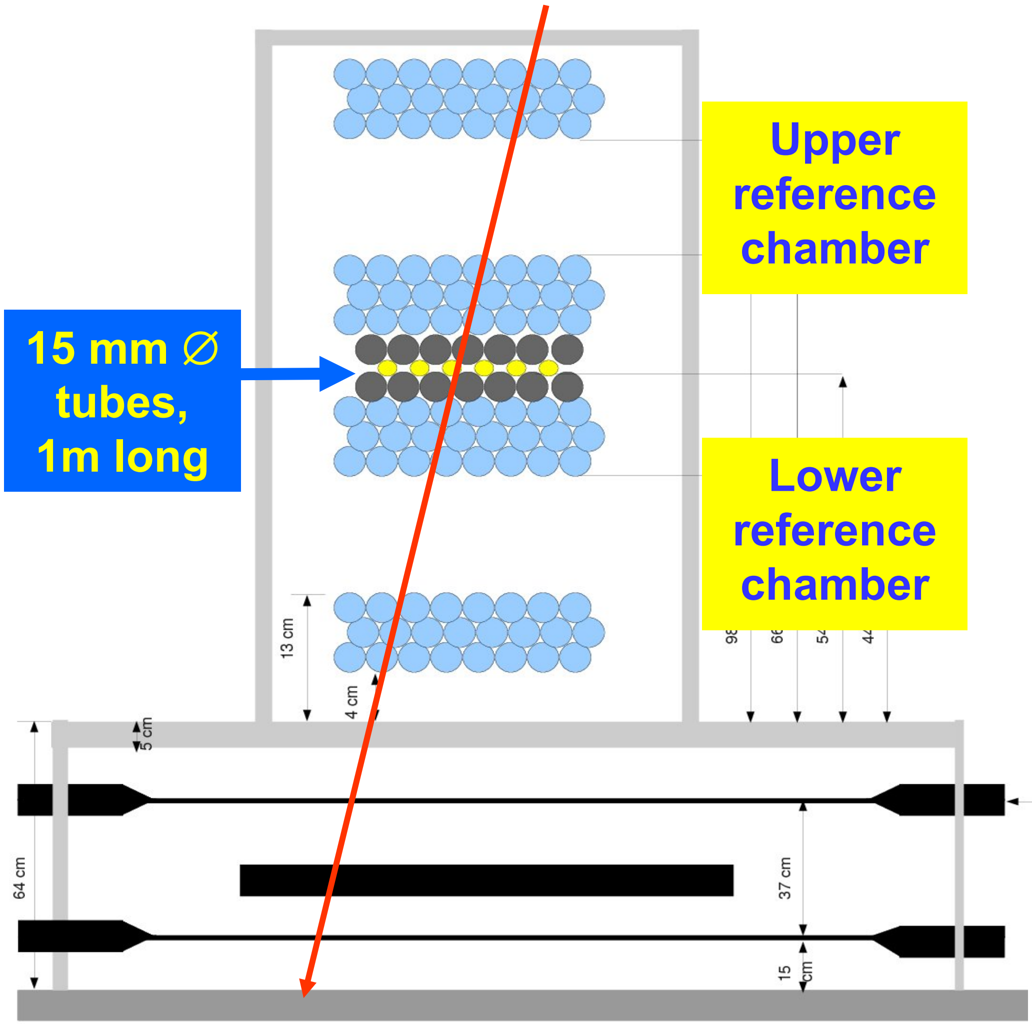


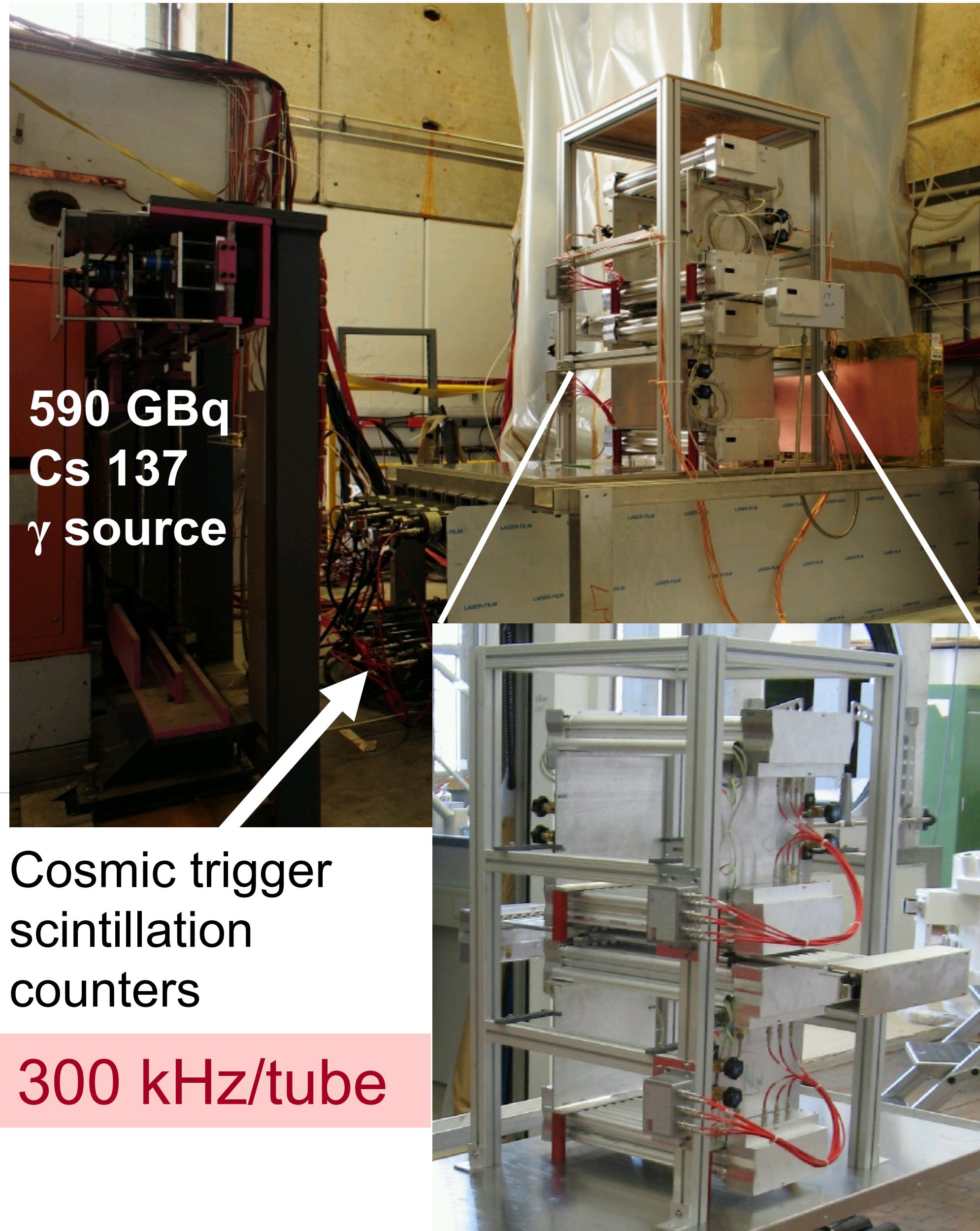
More than 10 x reduced rate dependence.

Gain drop limit for 30 mm ∅ tubes: increased to 50 kHz/cm² for 15 mm ∅ tubes.

The resolution can be improved by 20 μm by applying time slewing corrections using pulse height measurement.

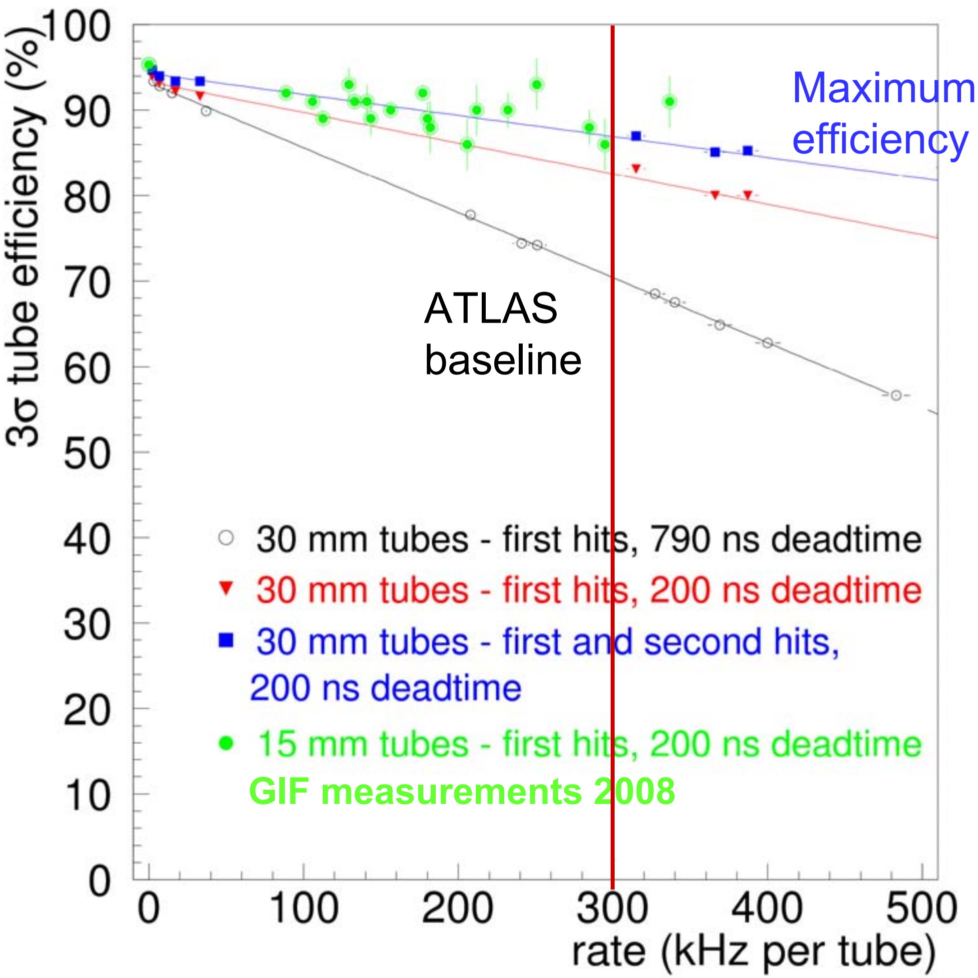
High-Rate Test at GIF 2008

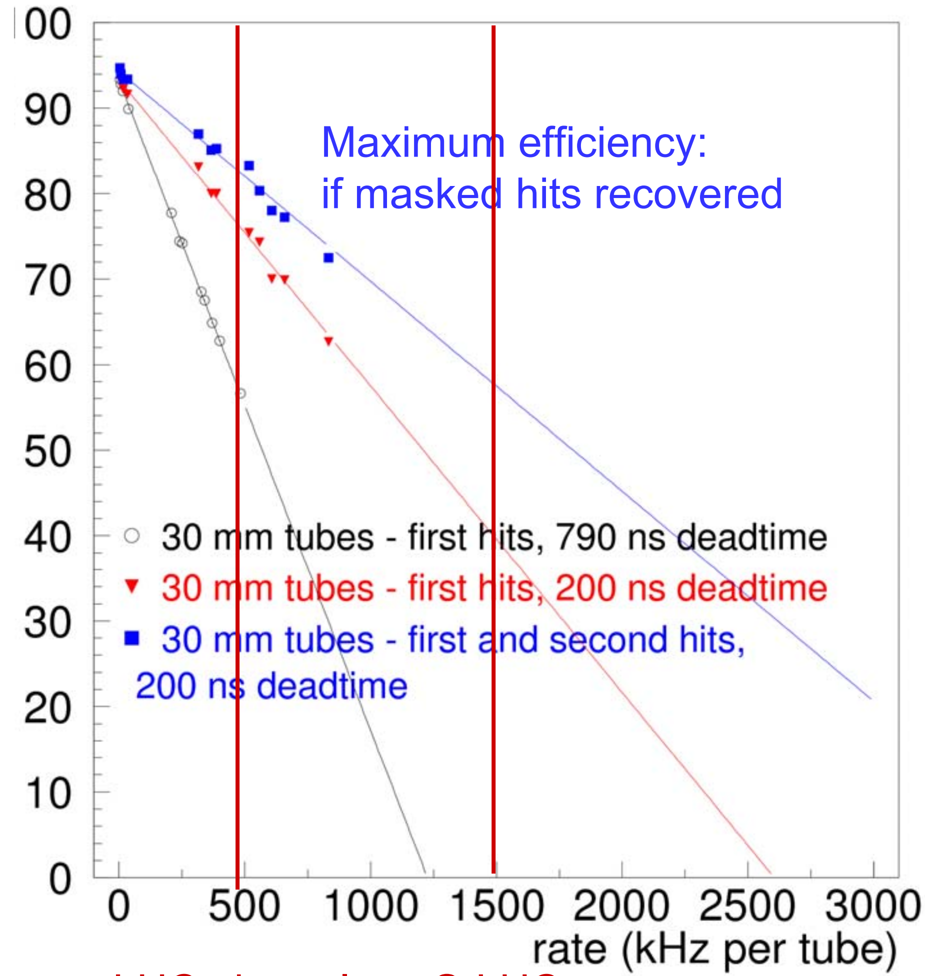




Background rates up to 1400 Hz/cm^2, 300 kHz/tube

Drift Tube Efficiency

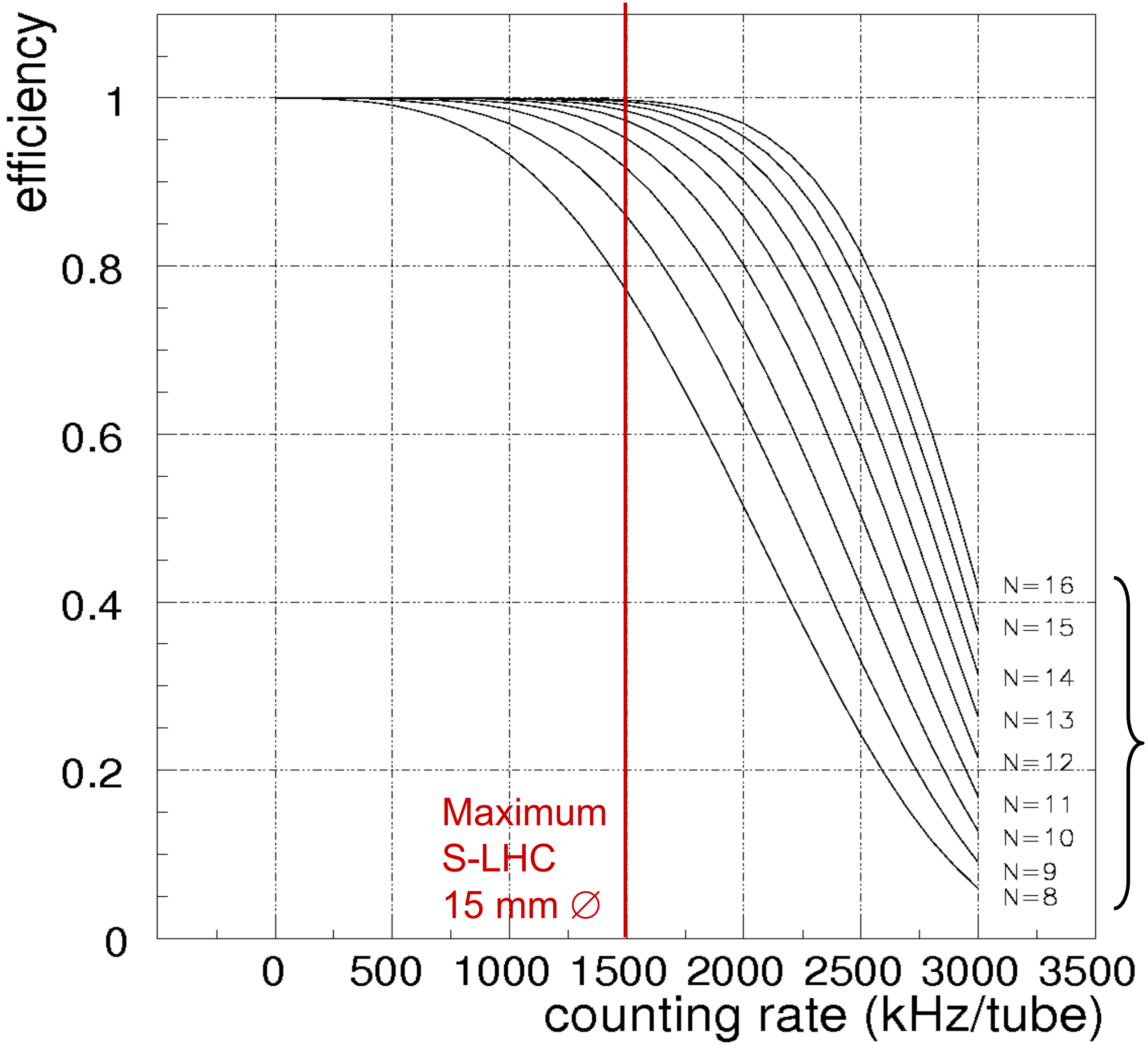




Maximum rates: LHC nominal, 30 mm ∅ | LHC phase I 15 mm ∅ | S-LHC 15 mm ∅

Chamber Efficiency

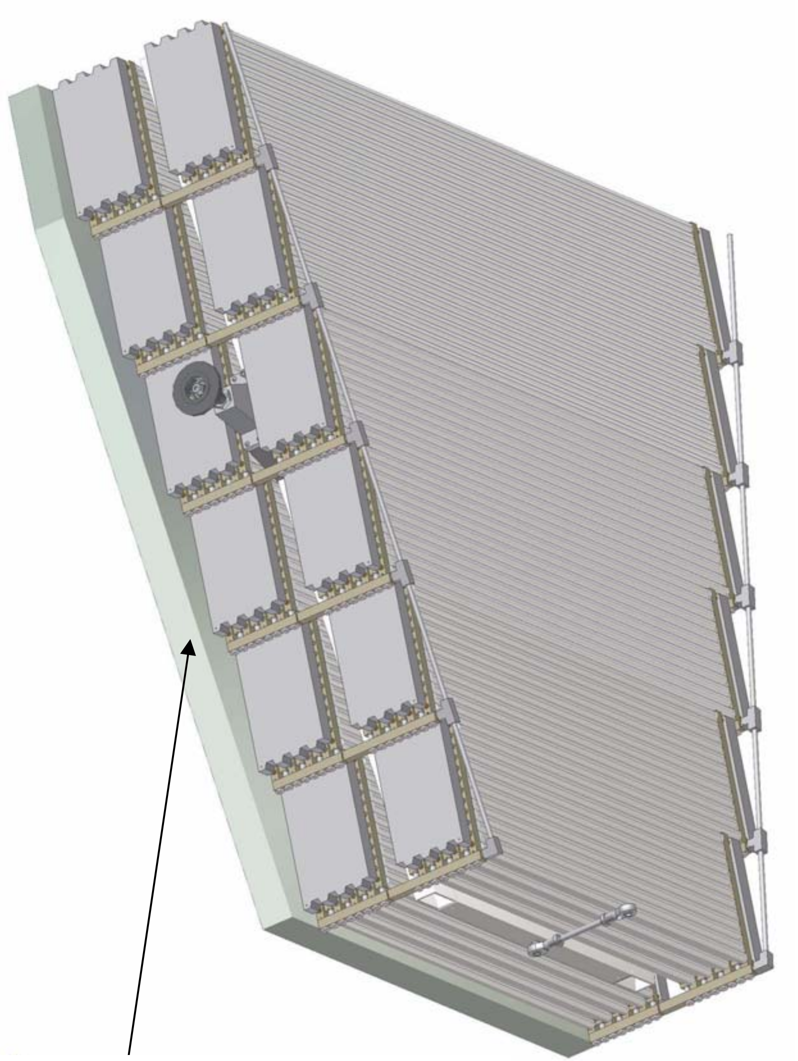
Segment reconstruction efficiency requiring at least 4 out of N hits



Statistical prediction from single-tube efficiency.

Number of tube layers

Chamber Design



Second coordinate
and trigger chamber

2 x 8 layers of drift tubes with 15 mm ∅ fit into the same volume as the present 2 x 4 layers of 30 mm ∅ tubes.

Efficient operation up to highest background rates (50 x nominal at S-LHC).

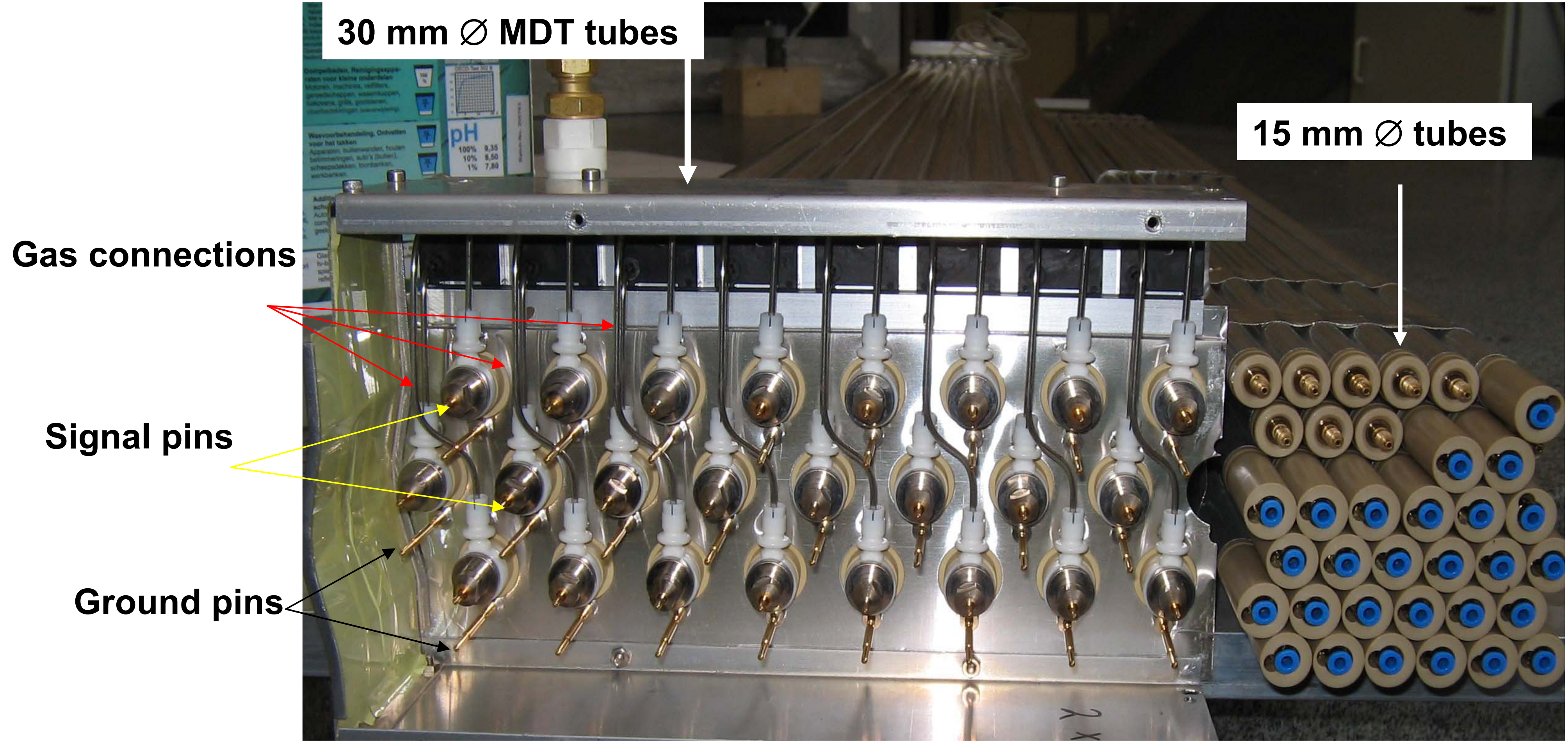
≤ **40 μm spatial resolution** up to 5 kHz/cm^2 counting rate (same as present MDT chambers at low background rate)
with **50 μm rms wire positioning accuracy.**

Consequences:

4 x denser tube package of gas and HV supplies, readout electronics.
More tube layers to be assembled.

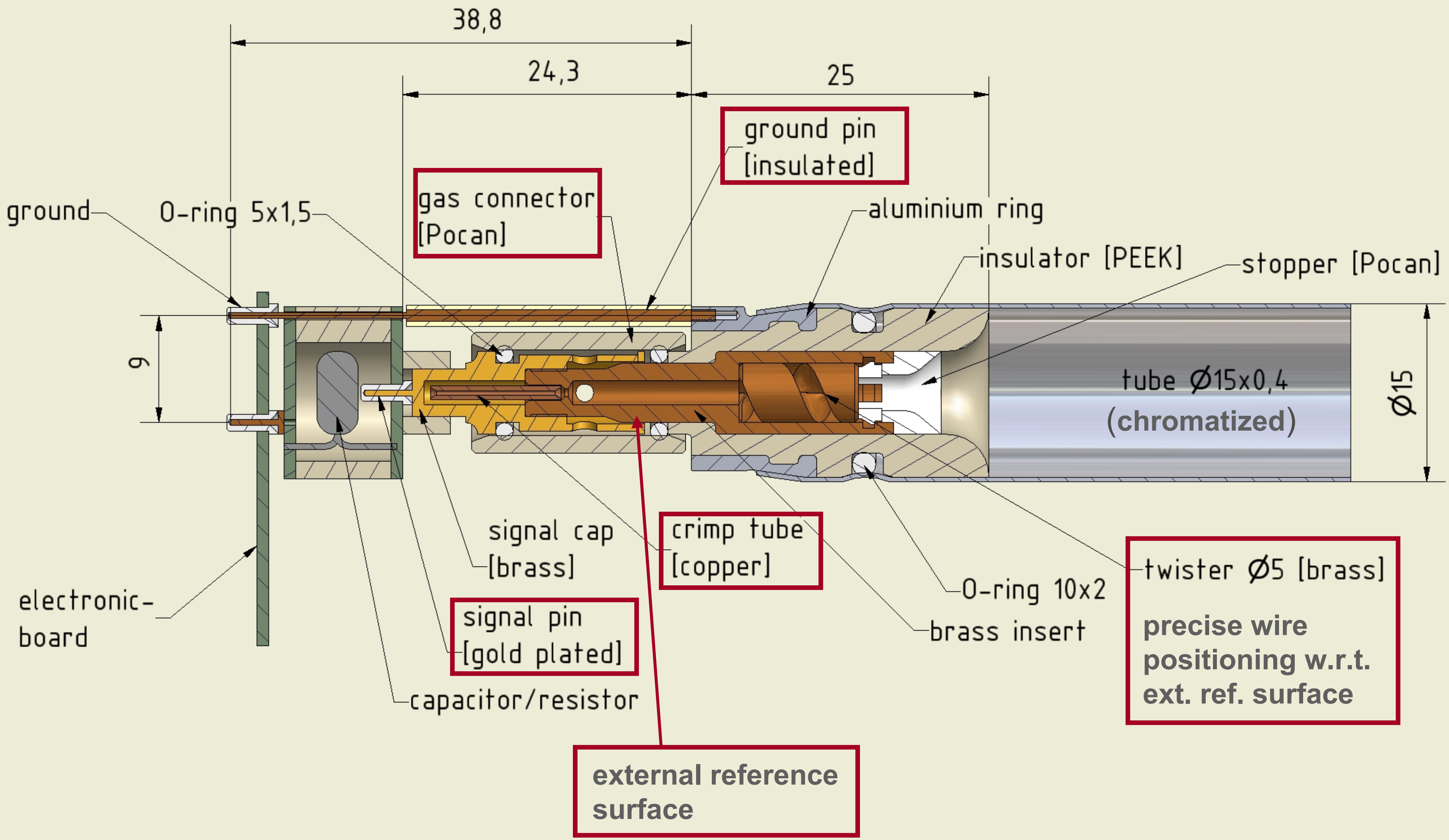
Chamber design

Builds on experience with the design of the existing MDT chambers

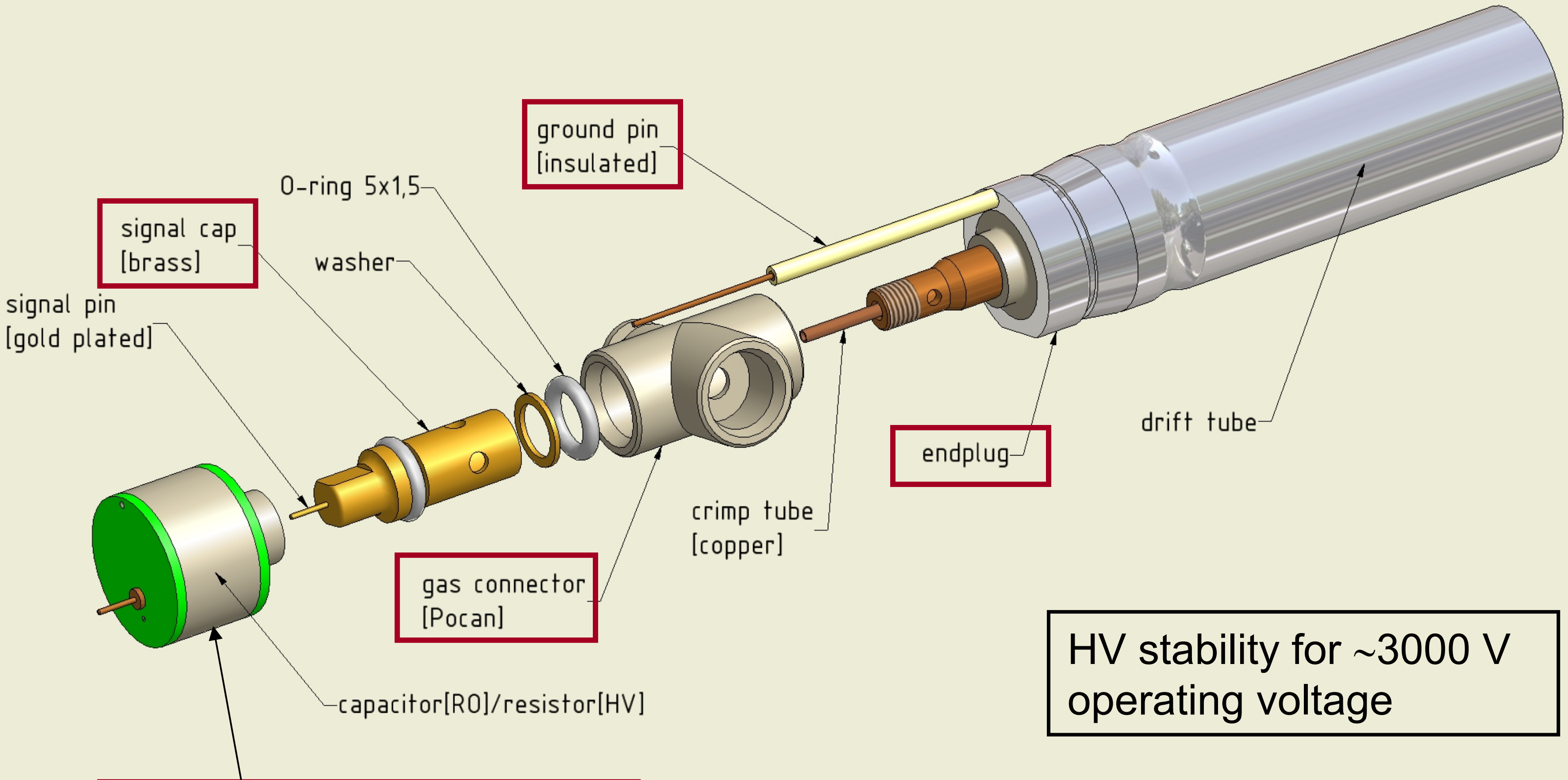


4 x denser tube packages:
challange for design of service connections

Drift Tube Design



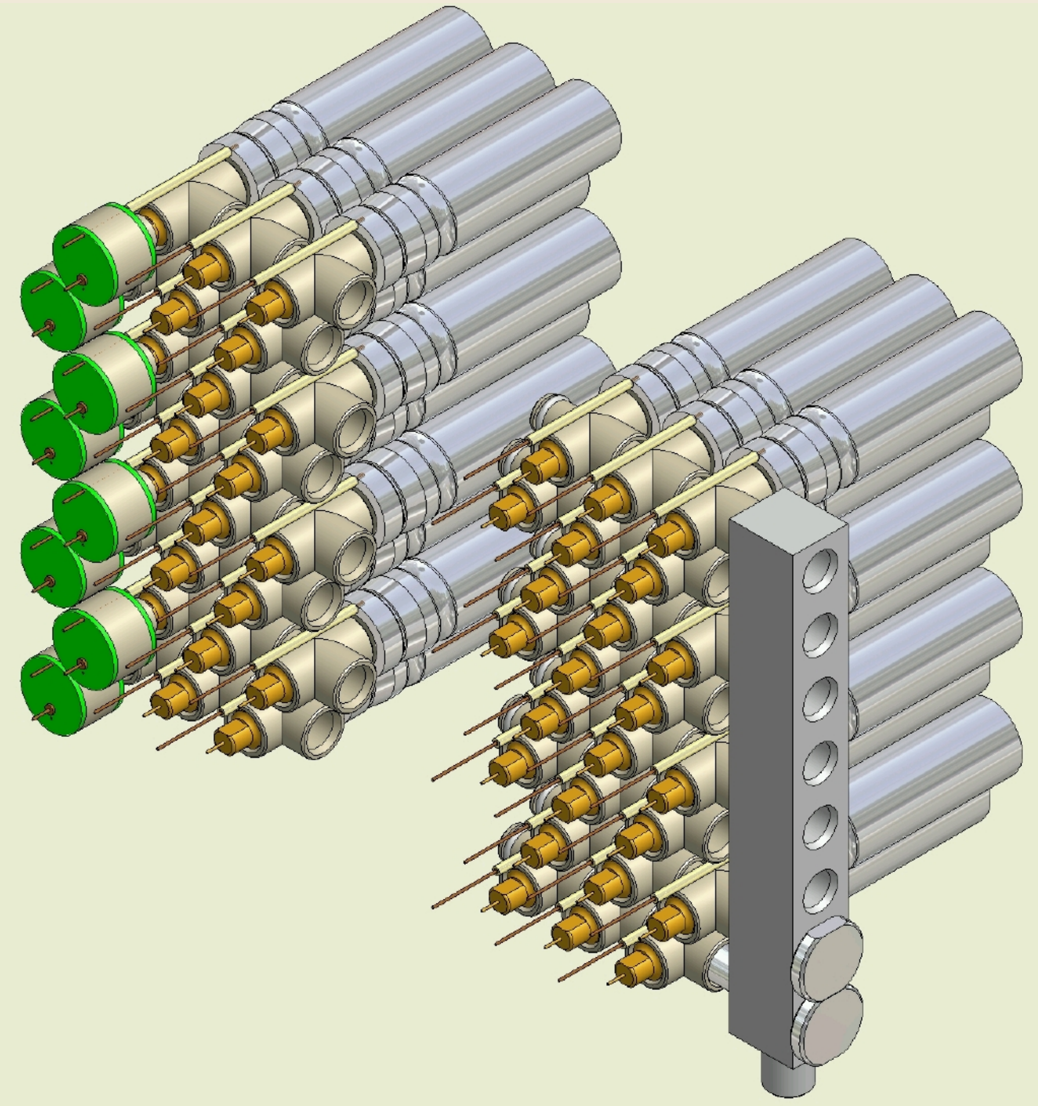
Electrical and Gas Connections

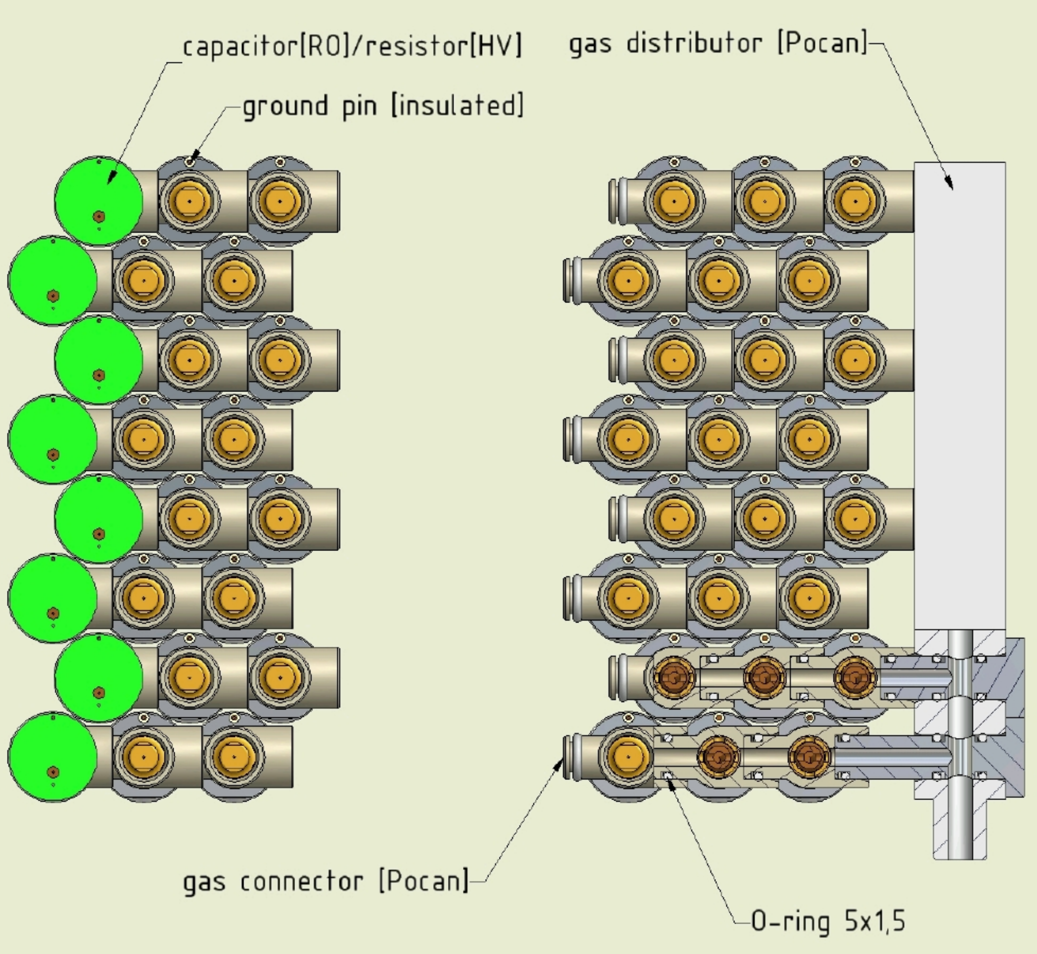


HV stability for ~3000 V operating voltage

Interface to readout electronics and HV distribution boards

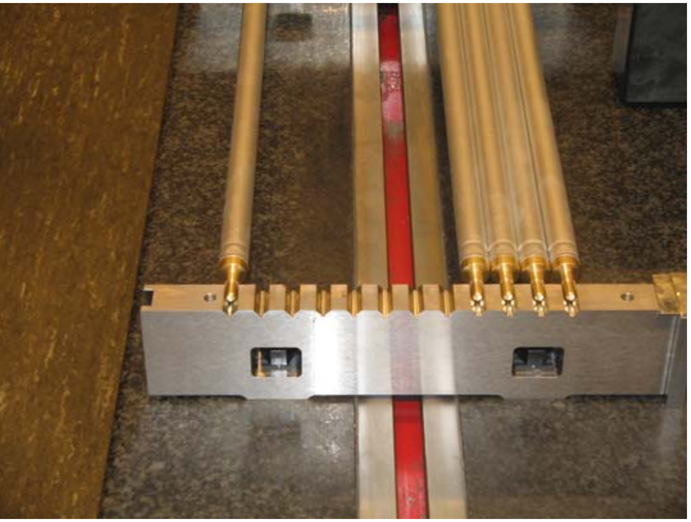
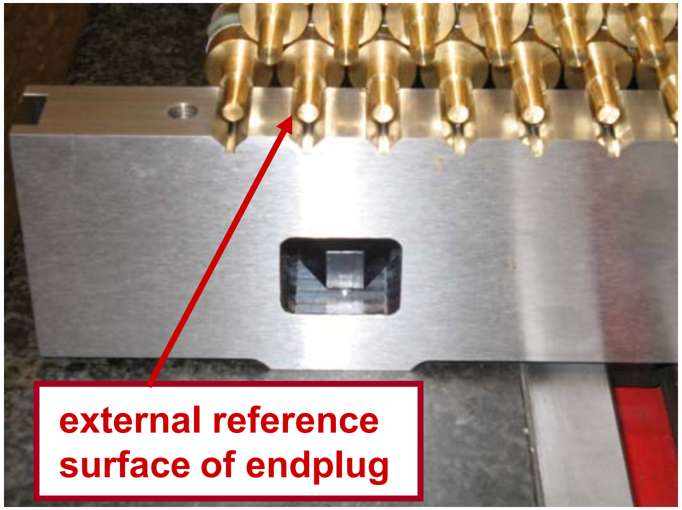
Gas Distribution System

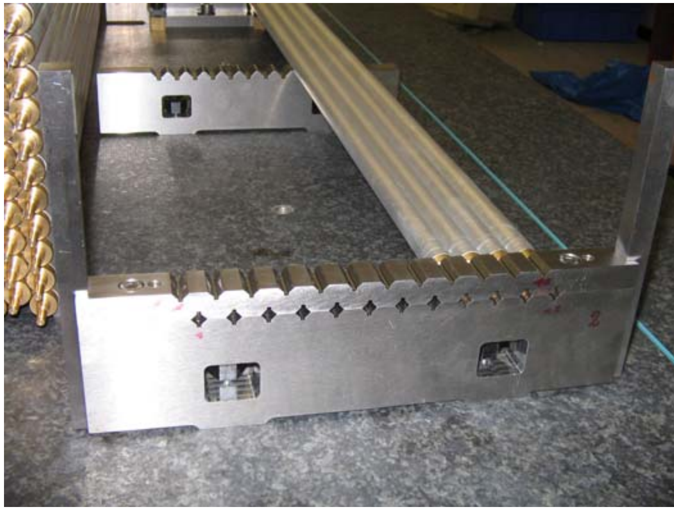
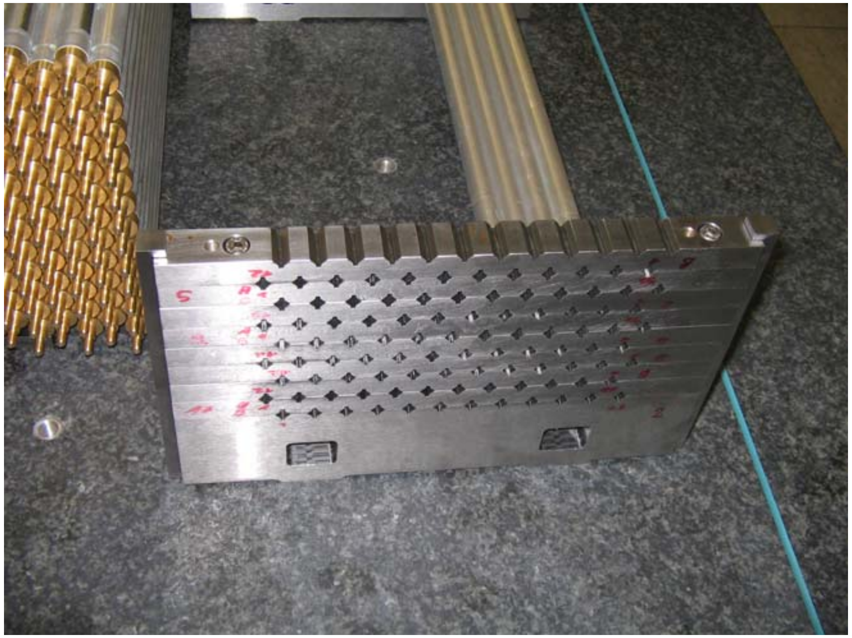
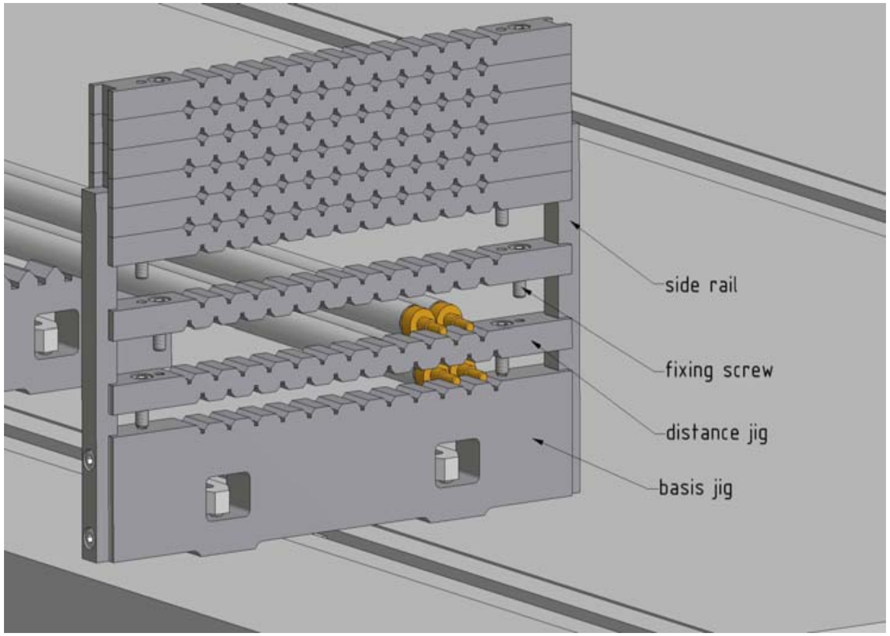




Chamber Assembly

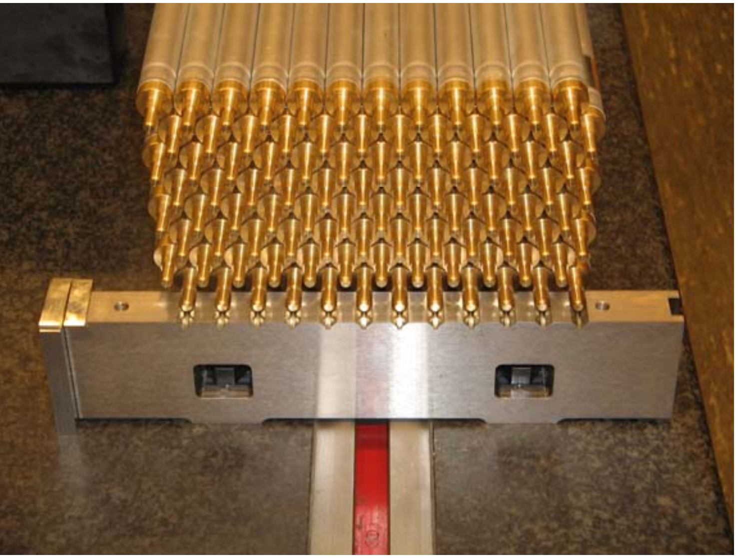
Assembly of 8 tube layers (one multilayer) per day in a single step

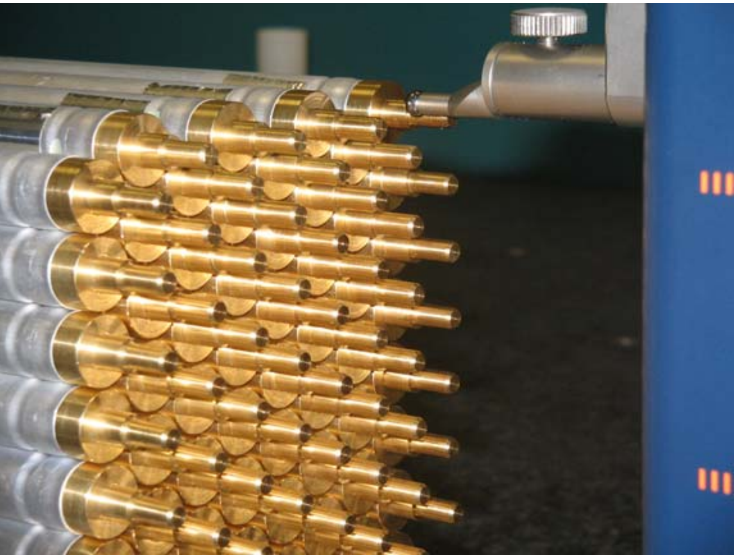



Chamber Assembly

Assembly of a 12 x 8 tube unit





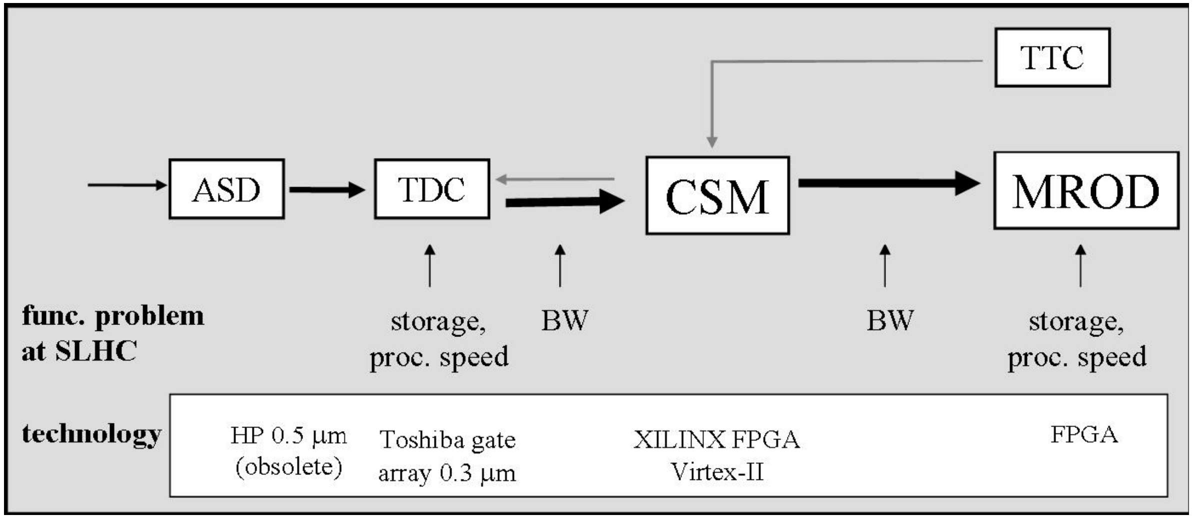
Standard aluminum tubes with 0.4 mm wall thickness and ±0.1 mm tolerance on diameter, concentricity and roundness, ±0.5 mm straightness work fine.

~ 50 μm rms tube positioning accuracy achieved as required.

Readout Electronics Upgrade

- New radiation hard front-end electronics (ASD and TDC chips) needed for new and part of remaining muon tracking chambers for Phase 1 and S-LHC luminosity upgrades.
  → Implementation of circuits in modern CMOS technology.

- New radiation hard chamber readout modules (CSM) with increased bandwidth for S-LHC.
  → Implementation using next generation FPGAs.



Conclusions

- Cylindrical drift tube detectors provide robust, high-efficiency precision tracking up to very high background rates.
- 15mm drift tube diameter suitable for highest rate regions at S-LHC background rates.
- Construction of a complete prototype chamber in progress.