Precision Muon Tracking Detectors and Read-out Electronics for Operation at Very High Background Rates at Future Colliders

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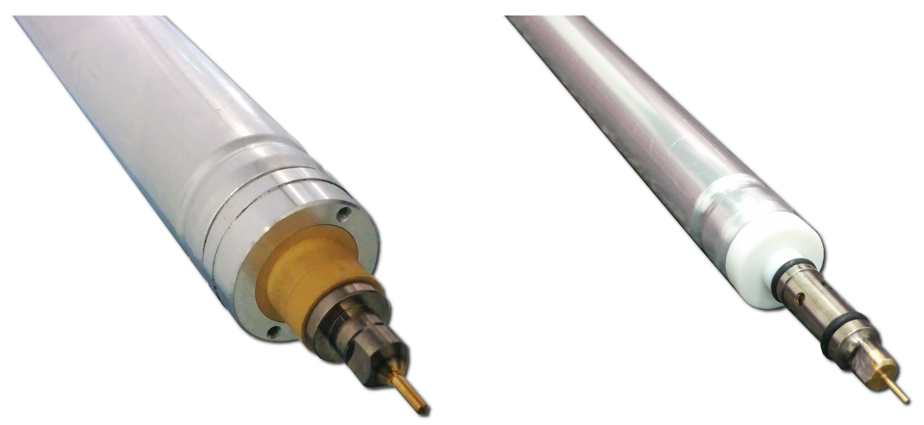
Motivation

- The muon spectrometers of experiments at HL-LHC at a Future Circular Hadron Collider (FCC-hh) require efficient muon tracking with very high spatial resolution (30-40 μm) at high background rates.
- ATLAS Monitored Drift Tube (MDT) chambers have proven high reliability and high-precision tracking up to neutron and γ fluxes of 500 $\frac{Hz}{cm^2}$.
- Background rates at HL-LHC are x 10 and at FCC x 40 than at LHC
- sMDT chambers are very well suited large area muon tracking at FCC experiments.
- Like the ATLAS MDT chambers for HL-LHC, sMDT chambers can also be used for high selective Level-1 muon triggers at FCC.

sMDT chambers

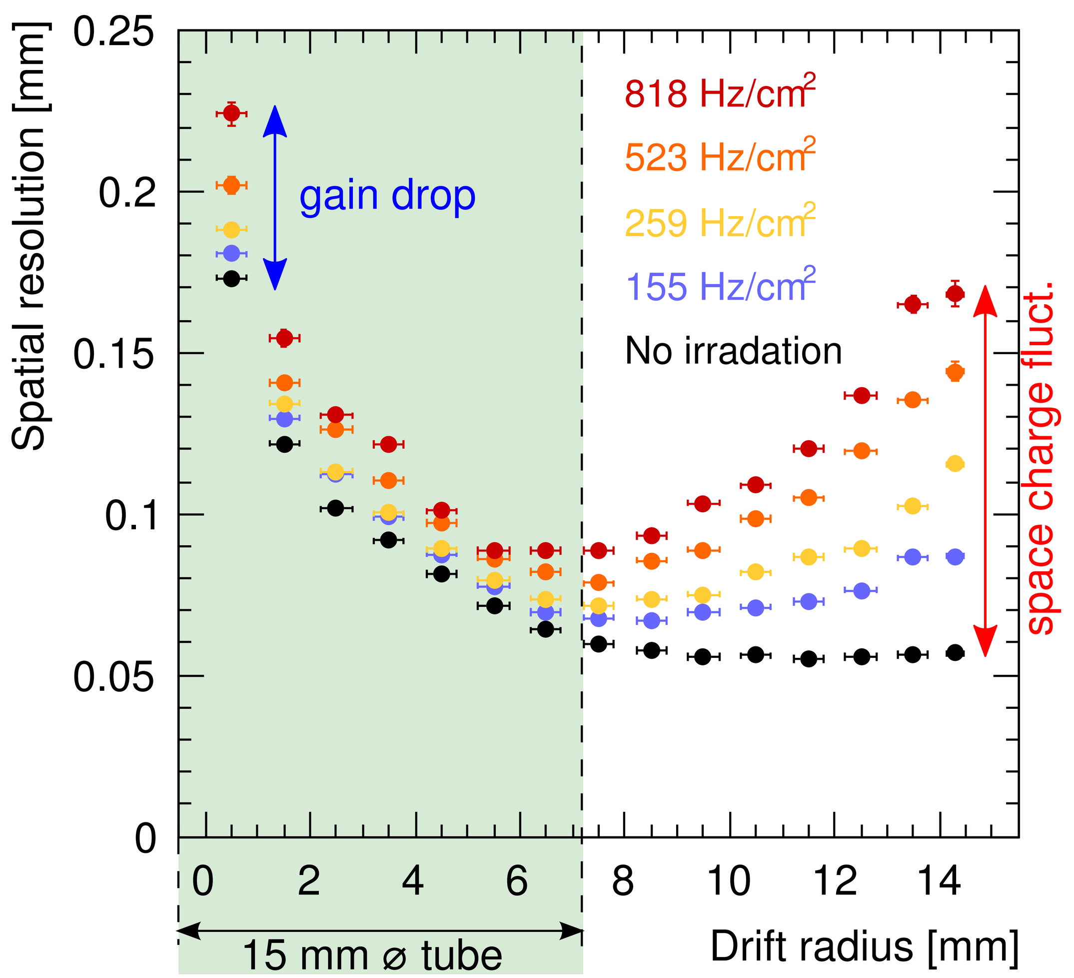


⌀30 mm MDT ⌀15 mm sMDT

MDT chambers:
Drift tube detectors with 30 mm tube diameter for precision tracking in the ATLAS Muon Spectrometer

sMDT chambers:
New drift tube detectors with 15 mm tube diameter

sMDT tube properties:



- ⇒ Operated with $Ar:CO_2$ (93:7) at a gas gain of 20000
- ⇒ 185 ns maximum drift time
- ⇒ 8 times lower occupancy compared to MDT chambers
- ⇒ Space charge effects strongly suppressed, gain loss $\sim R^3$
- ⇒ **An order of magnitude higher rate capability than MDT chambers** with existing MDT read-out electronics

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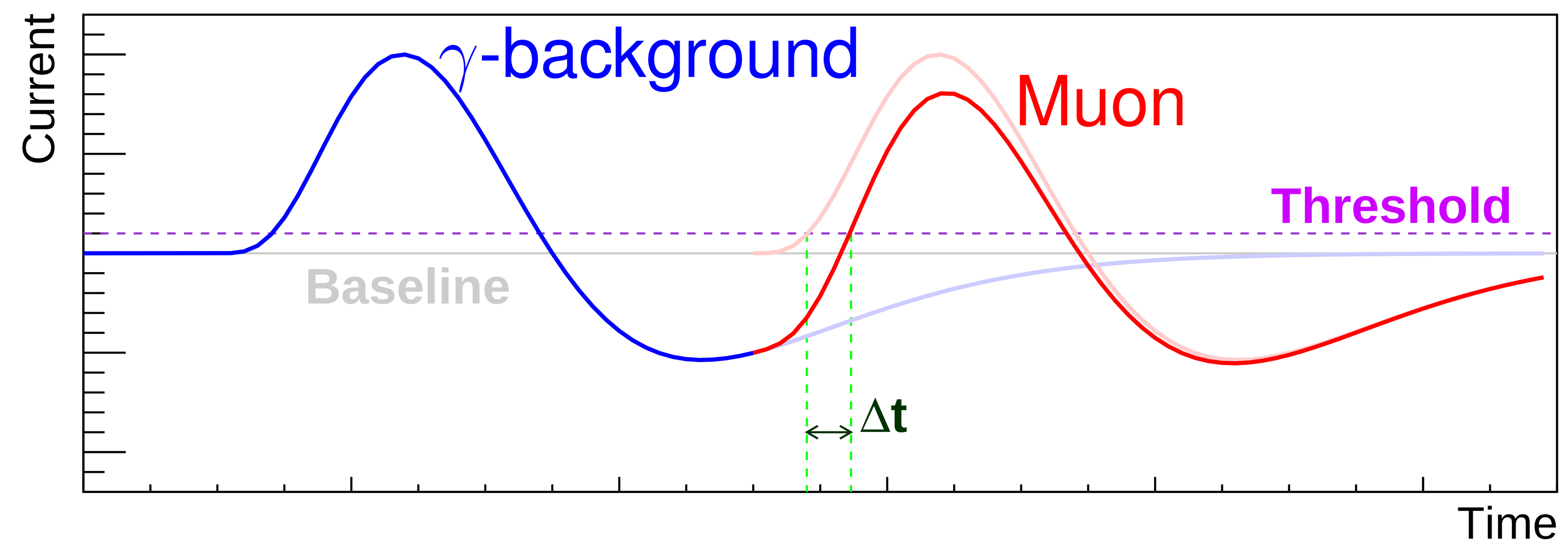
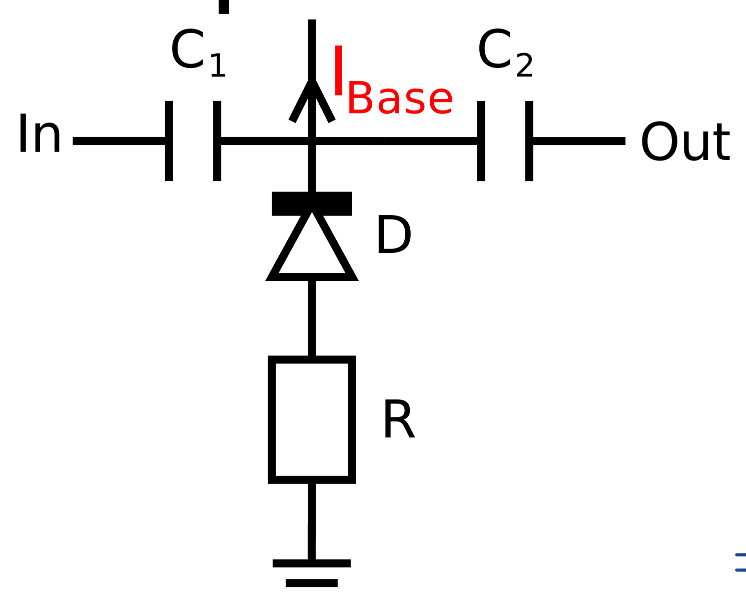
Limitation of sMDT performance due to signal pile-up with bipolar shaping of the read-out electronics

- Bipolar shaping used to guarantee baseline stability at high rates
- Disadvantage: overlap of signals with the bipolar undershoot of preceding background pulses lead to deterioration of the efficiency and spatial resolution of muon pulses



Improvement: Bipolar shaping with baseline restoration

Principle of baseline restorer (working point I_{Base})



- Diode is non-conducting for positive signal polarity ⇒ signal stays unchanged
- Diode is conducting for negative polarity (undershoot) ⇒ input current drained to ground

⇒ **Undershoot eliminated**

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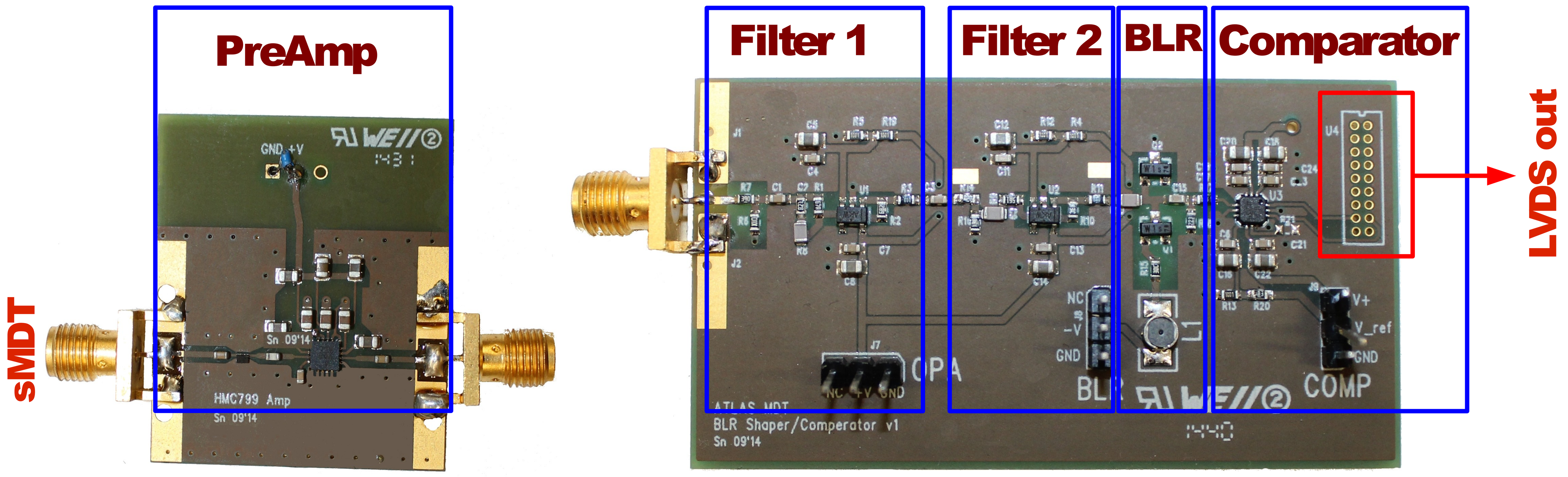
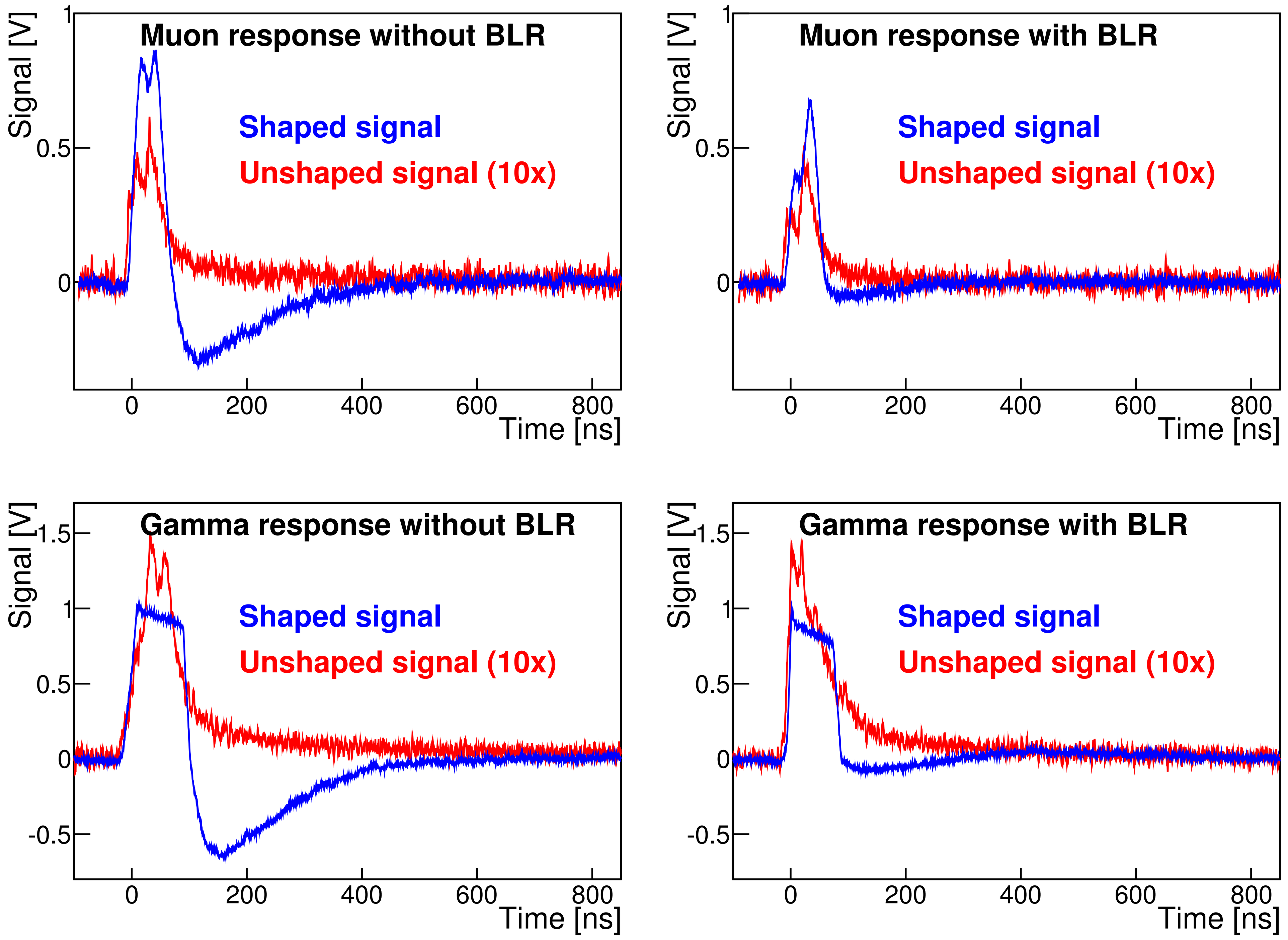
Bipolar shaping circuit with baseline restoration



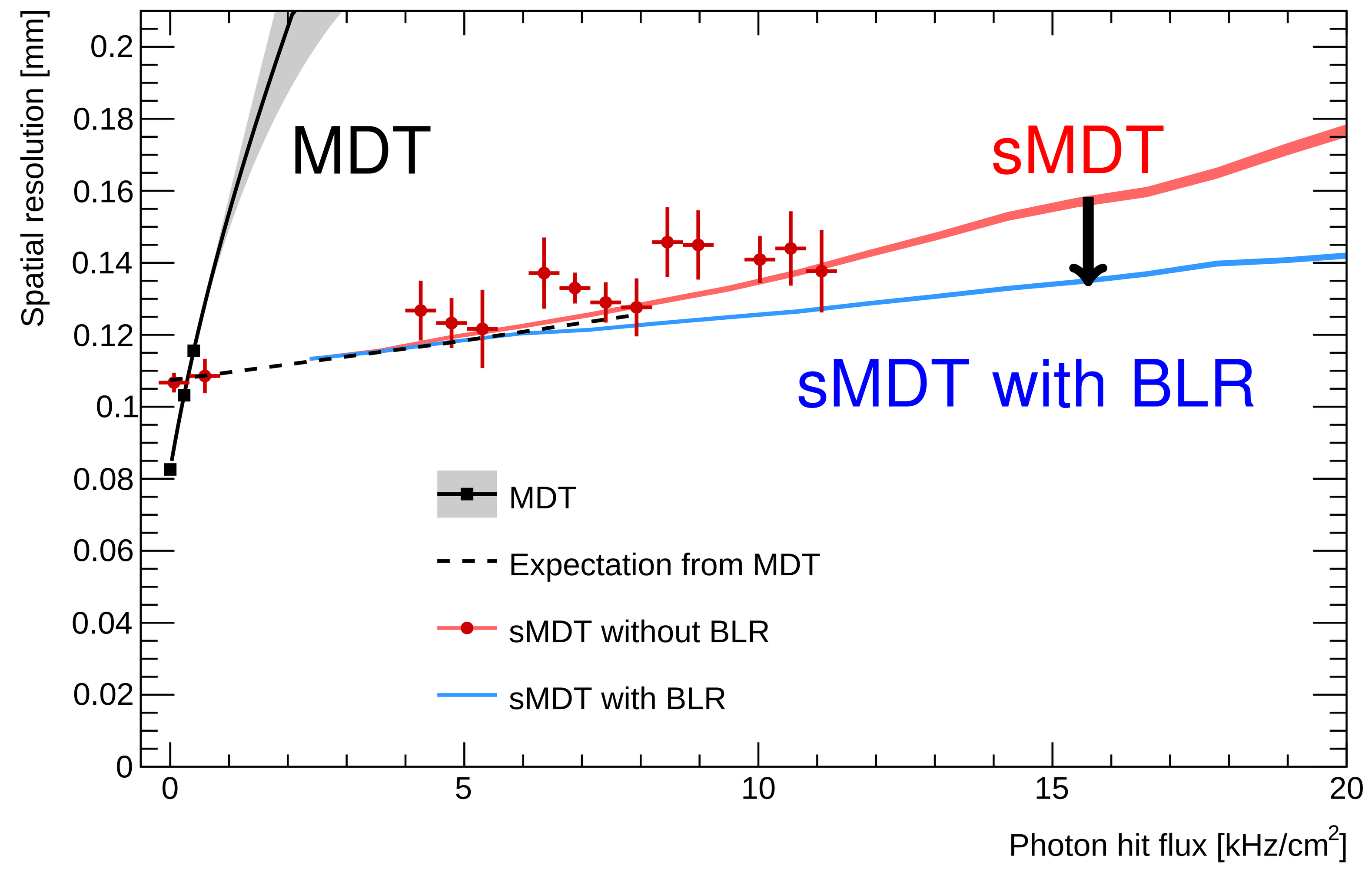
- High bandwidth (700 MHz) transimpedance amplifier (PreAmp)
- Bipolar shaping circuit (2 filter stages) with baseline restoration and comparator with LVDS output to TDC (as MDT read-out chip)

Bipolar shaped pulses with baseline restoration



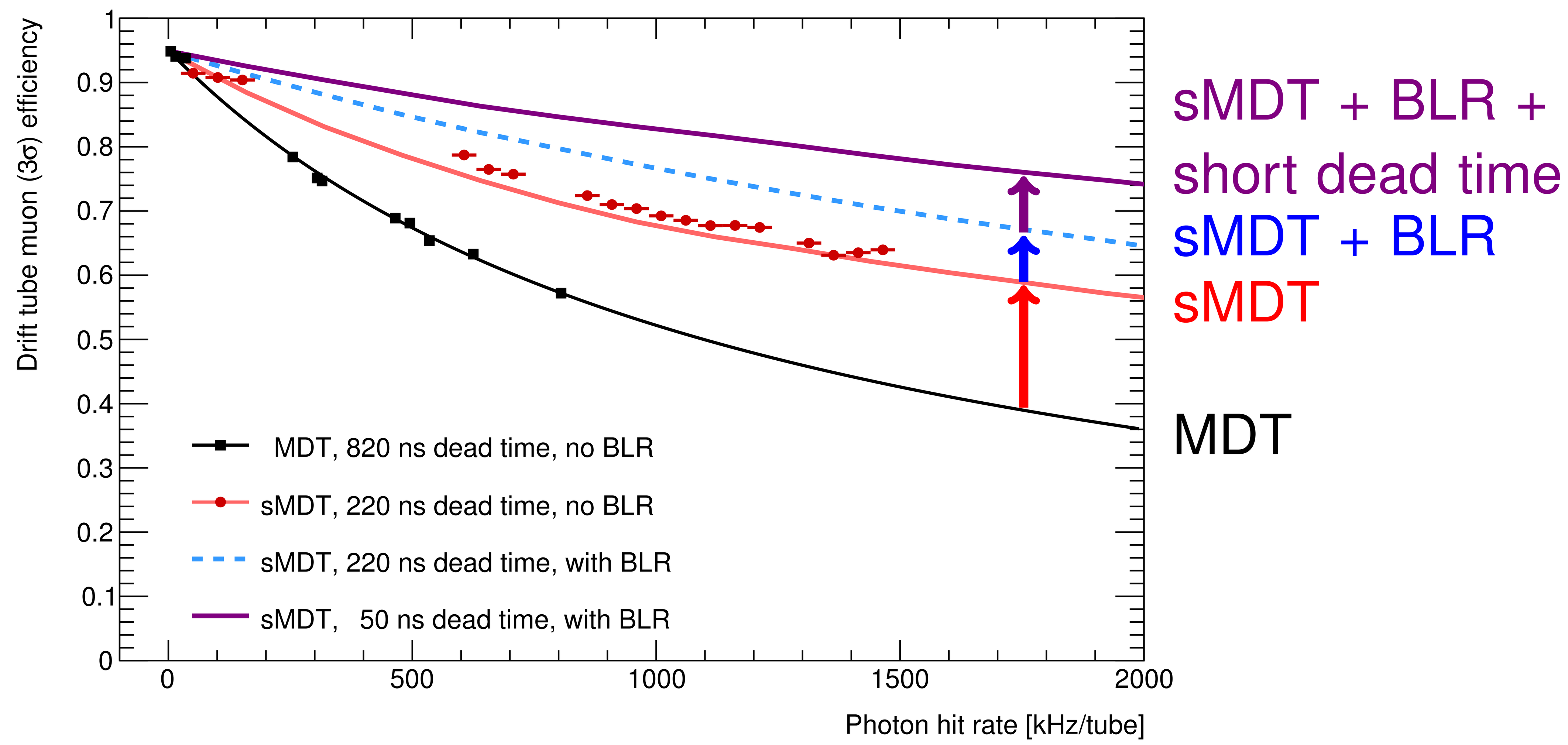
- γ-pulses push shaper in saturation (larger signals with longer undershoot compared to muon pulses)
- Clear undershoot suppression with baseline restoration

sMDT single-tube resolution under γ irradiation (GIF/CERN)



- sMDT resolution limited at high counting rates by signal pile-up effects of the electronics, in contrast to MDTs where space charge effects dominate
- Suppression of signal pile-up effects with baseline restoration

sMDT single-tube muon efficiency



- At high counting rates limited by read-out electronics
- Use of minimum electronics dead time possible for sMDTs
- Suppression of signal pile-up effects at short dead times with baseline restoration

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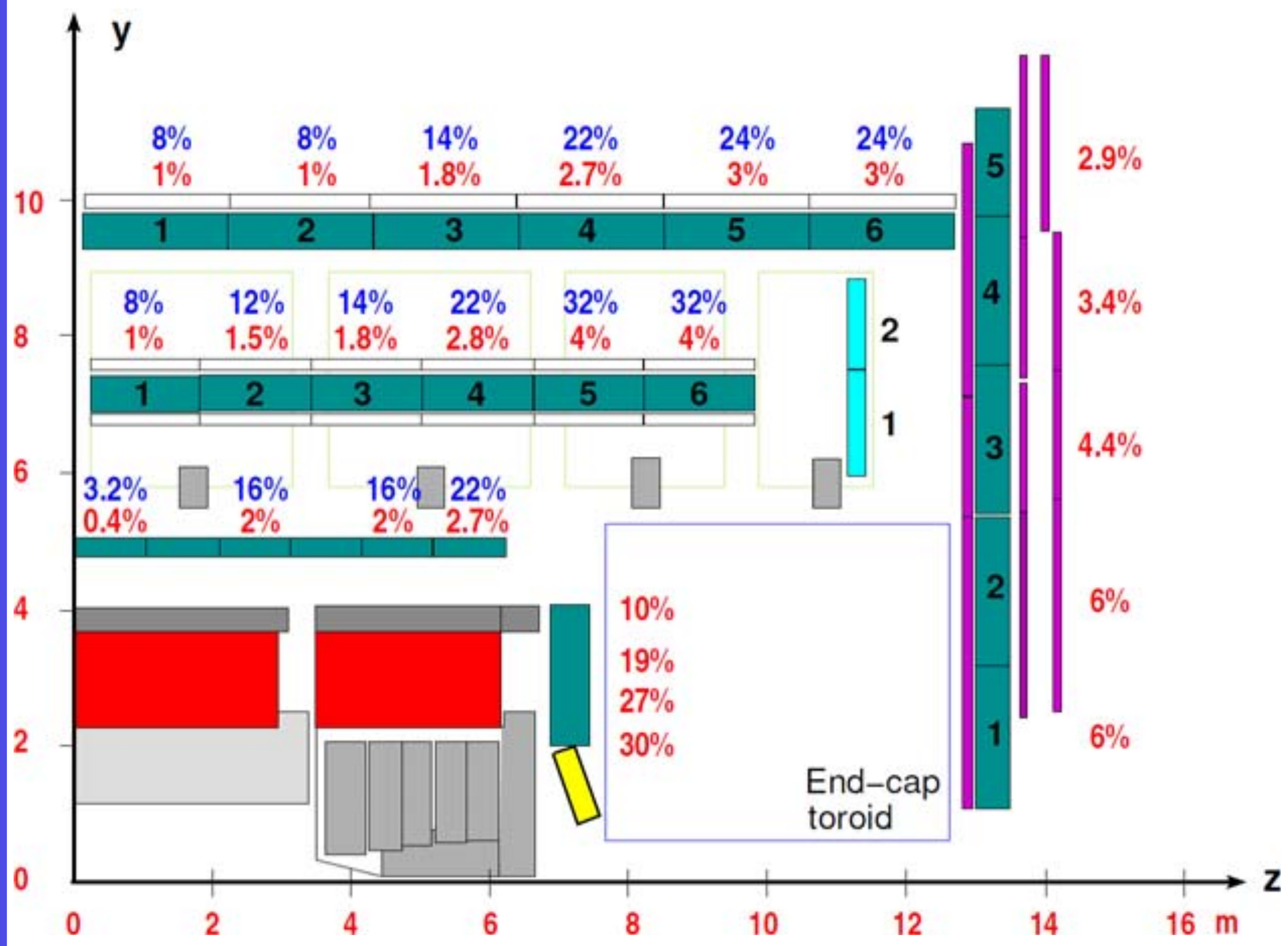
MDT and sMDT occupancies at HL-LHC and maximum FCC-hh luminosity

Occupancies of MDT and sMDT tubes at maximum FCC luminosity in the ATLAS geometry (ATLAS operating parameters and tube lengths)



Background rates in muon system

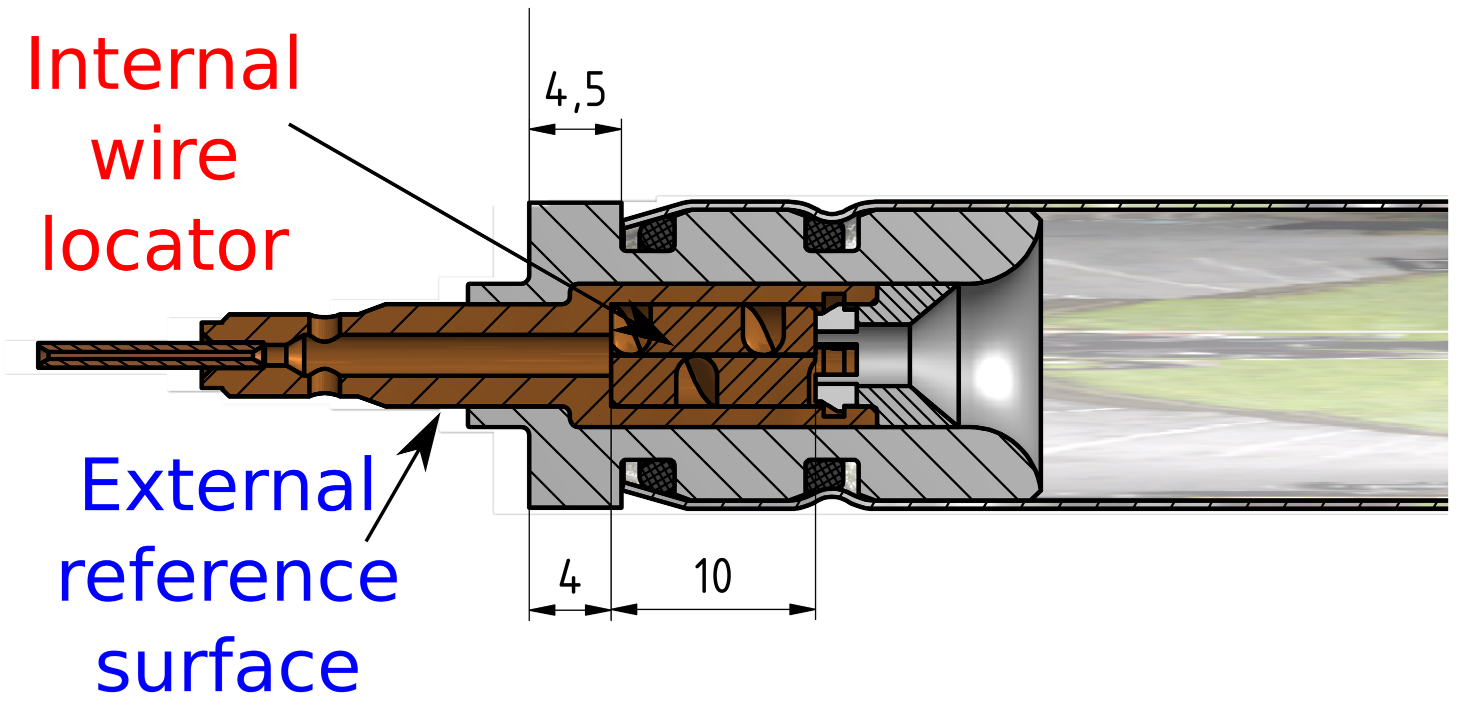
ATLAS at LHC design luminosity $\rightarrow$ x 10 at HL-LHC $\rightarrow$ x 4 at FCC-hh (MDT: max. 500 $\frac{Hz}{cm^2}$, max. 30% occupancy)

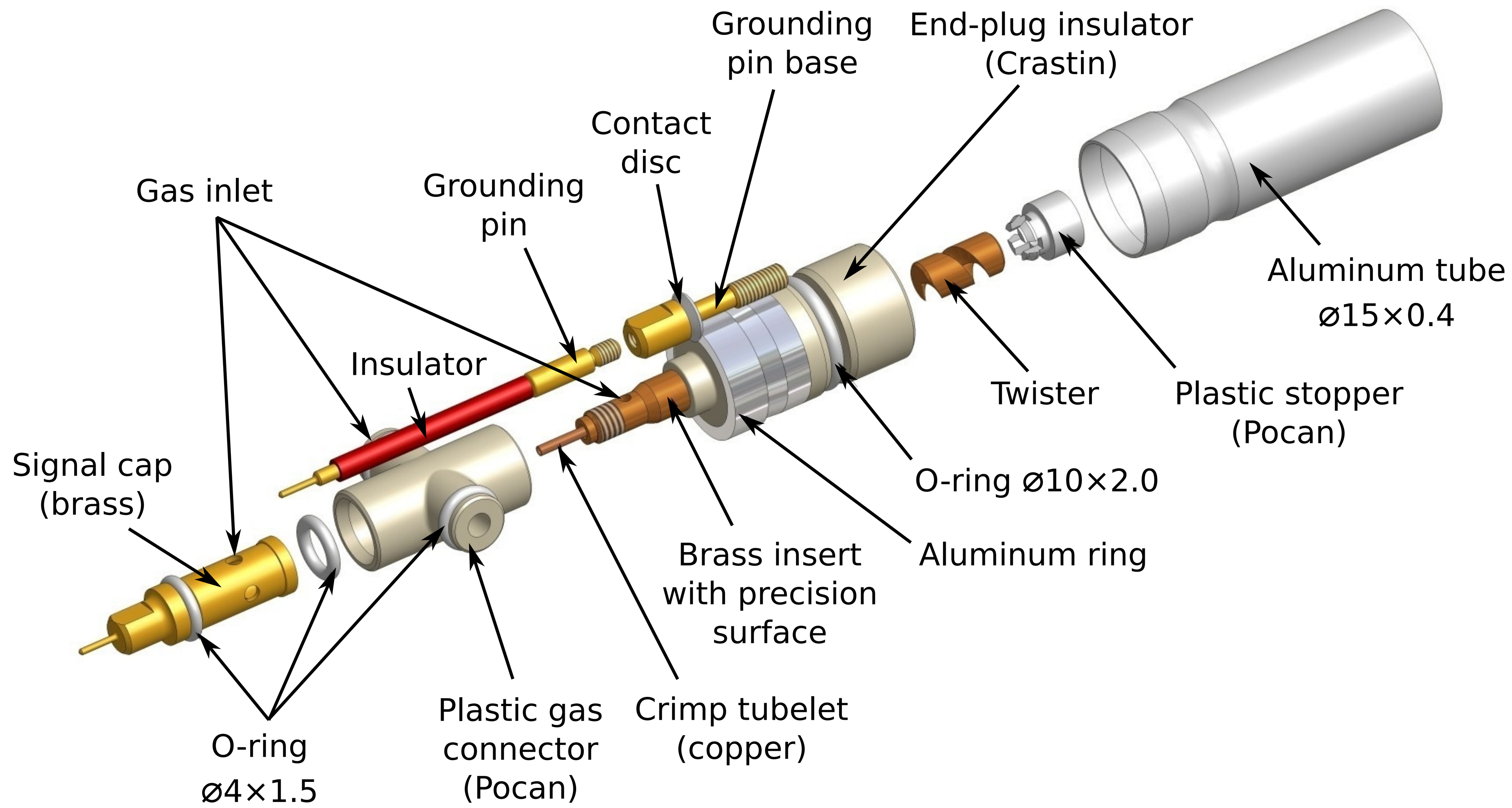
- Maximum sMDT occupancy at FCC is half of the MDT occupancy at HL-LHC
- FCC detectors not limited to ATLAS operating parameters and geometry

$\Rightarrow$ Further optimisation of tube parameters and read-out electronics

sMDT design and construction

- sMDT chamber design and assembly procedures optimized for mass production
- Simple and cheap drift tube design with high reliability
- Special plastic materials selected to prevent outgassing and cracking
- Industrial standard Al tubes
- Wire positioning accuracy better than 10 μm
- No wire aging observed up to 9 $\frac{C}{cm}$ charge on wire (15 x ATLAS requirement)





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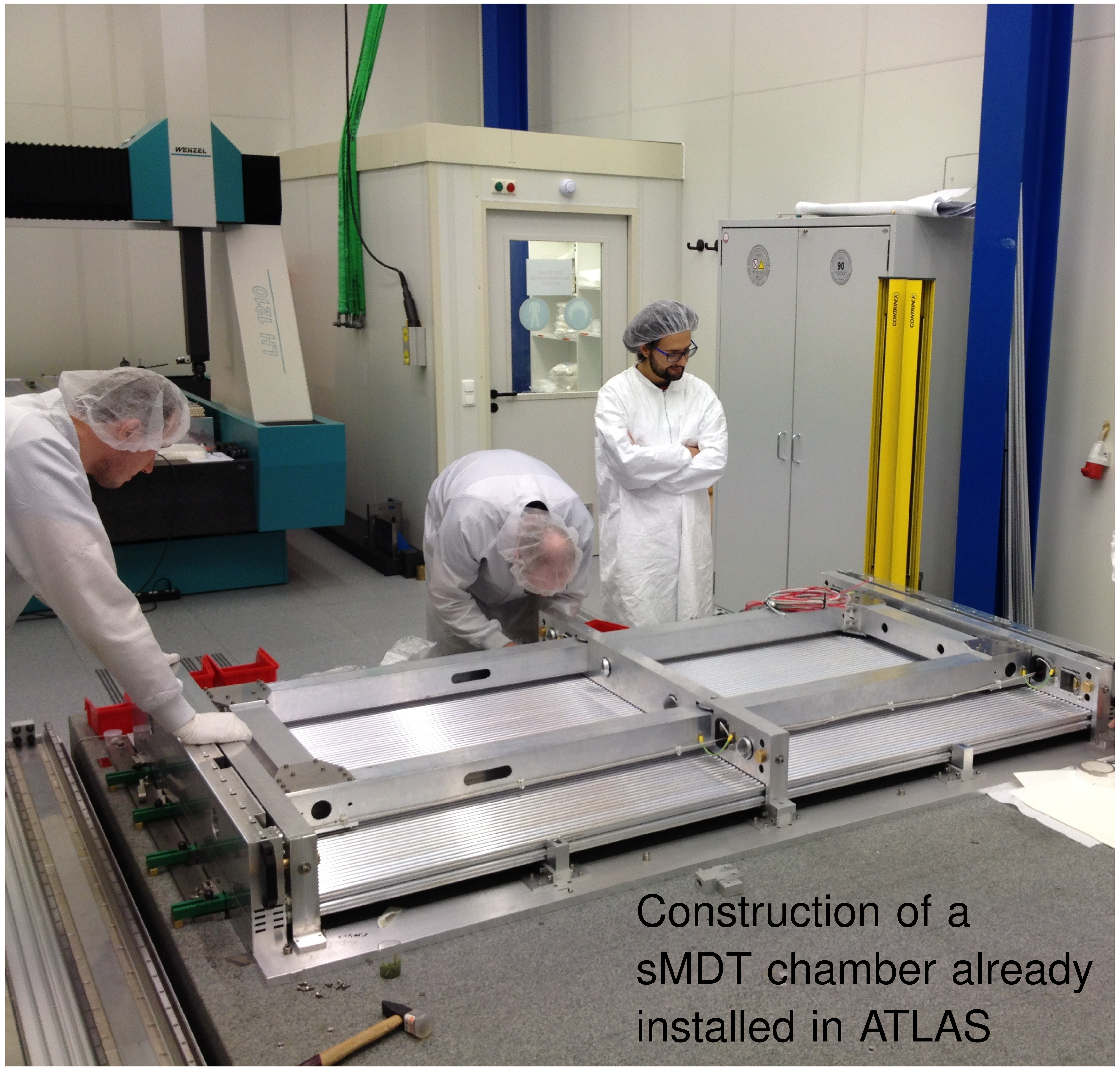
sMDT Chamber Construction

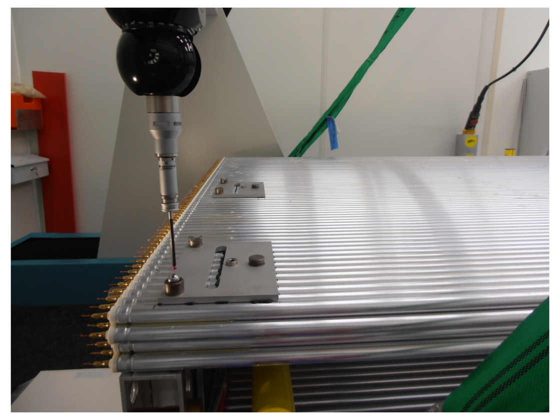


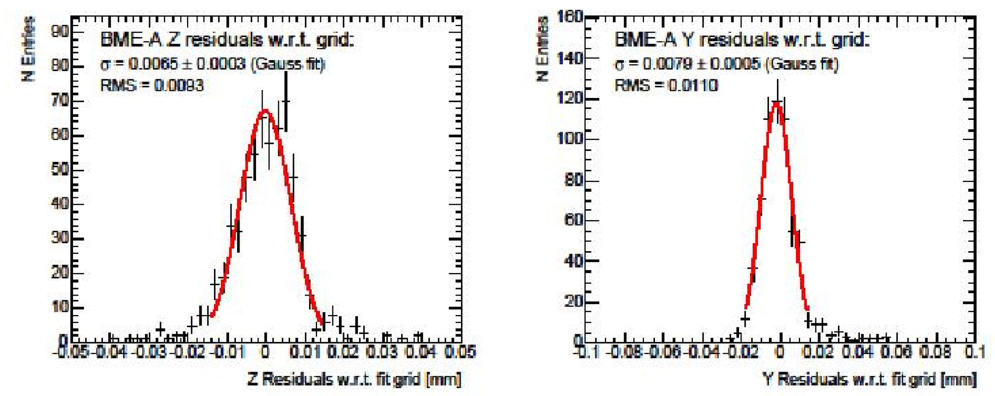
Construction of a sMDT chamber already installed in ATLAS

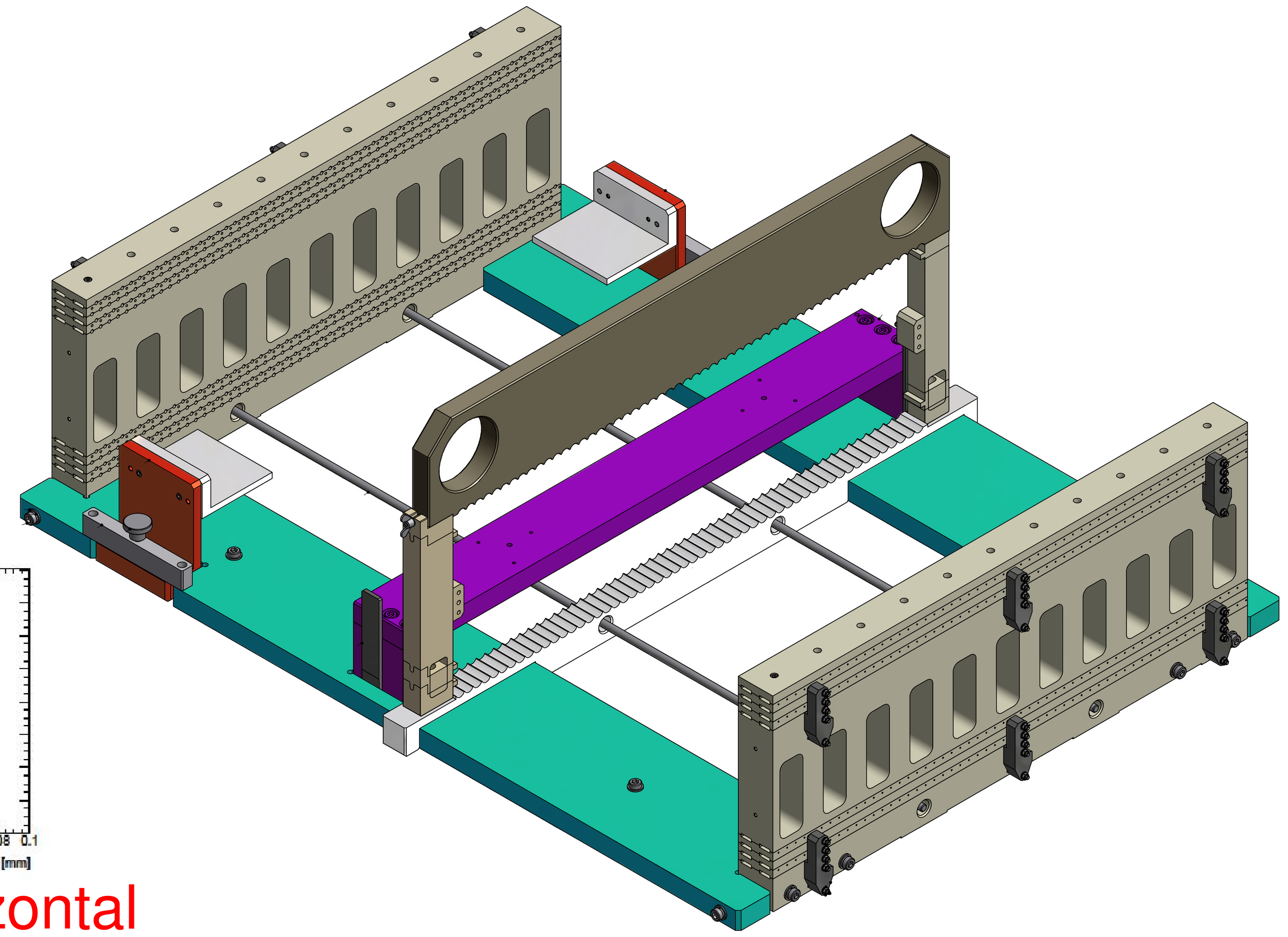
- Semi-automated drift-tube production and chamber assembly take place in a air-conditioned clean room
- Automated testing of tube leakage rate, leakage current and wire tension
- 2 sMDT chambers already installed in the ATLAS detector
- Additional 12 (16) sMDT chambers under construction until 2016 (2018)

Tube positioning using precisely machined jigs

3D coordinate measurement







Residual distribution of horizontal and vertical coordinates $(\sigma < 10\mu m)$

- Wire positioning accuracy is reached due to tube external reference surface and high precisely machined jigs.
- Wire positioning accuracy better than 10 μm (most precise chambers so far)
- Chamber assembly is conducted within one working day

Summary

- sMDT chambers are a well suited for high-accuracy large area muon tracking at high background levels as required for max. luminosity at the FCC.
- The high reliability of the MDT and sMDT chambers has been proven in ATLAS.
- An order of magnitude smaller occupancies of sMDT compared to MDT chambers.
- Space charge effects are strongly suppressed for sMDT tubes.
- Performance of sMDT tubes can be further increased by optimised read-out electronics.