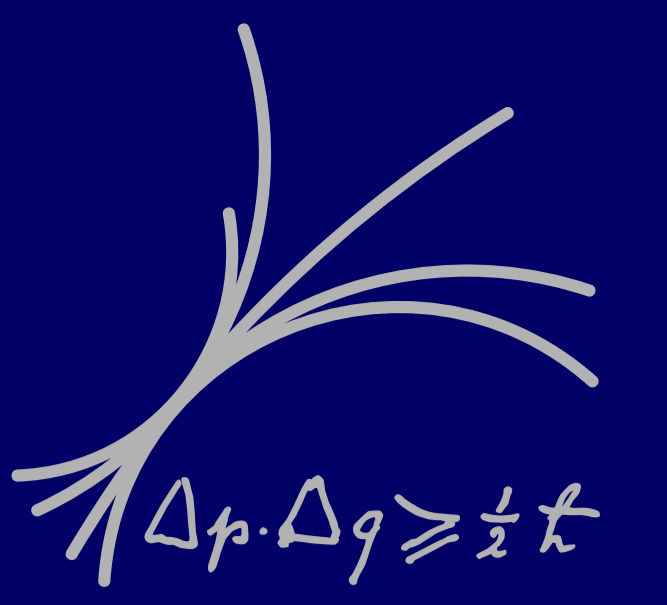




# Precision Muon Tracking Detectors and Read-out Electronics for Operation at Very High Background Rates at Future Colliders

S. Nowak O. Kortner H. Kroha R. Richter K. Schmidt-Sommerfeld Ph. Schwegler

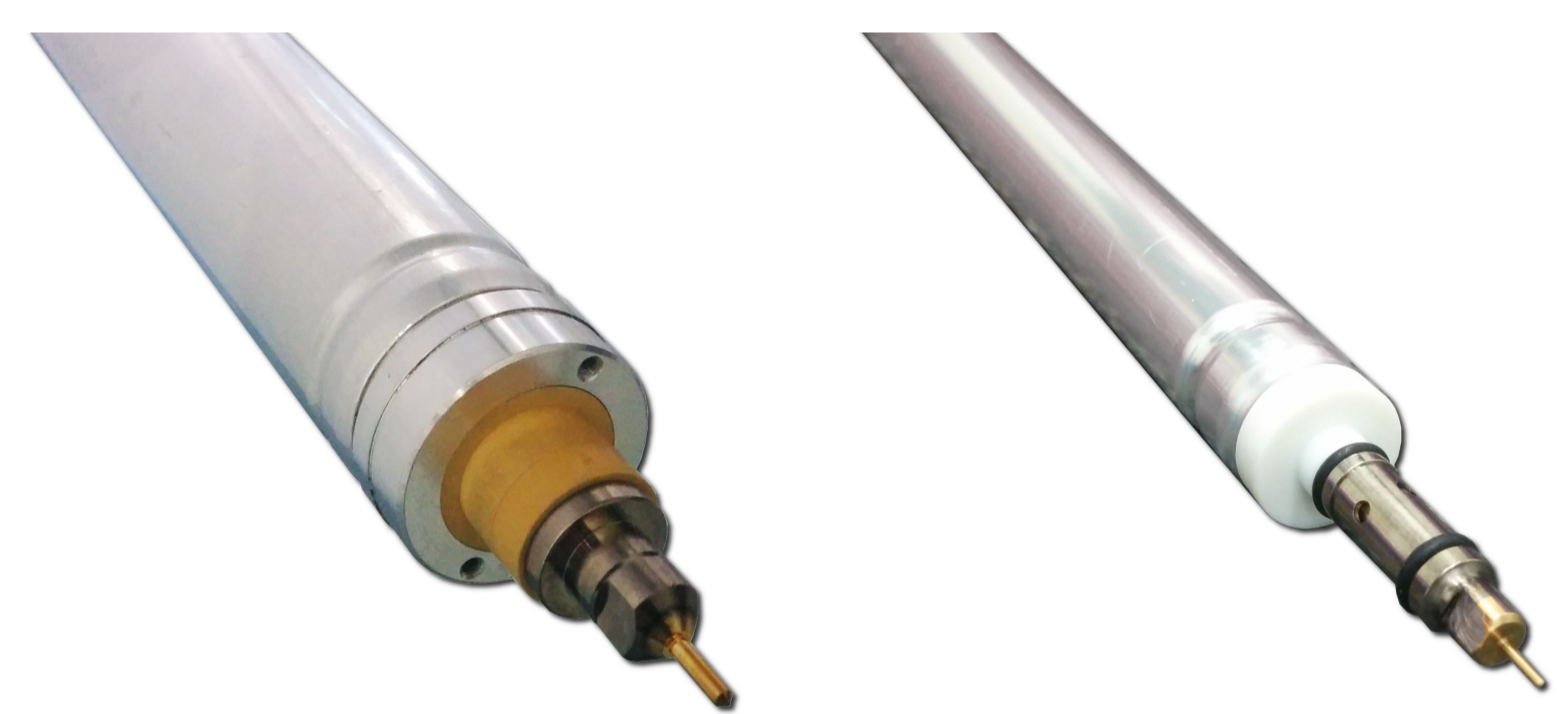
Max-Planck-Institut für Physik, Munich



## 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  $\mu\text{m}$ ) at high background rates.
- ATLAS Monitored Drift Tube (MDT) chambers have proven high reliability and high-precision tracking up to neutron and  $\gamma$  fluxes of  $500 \frac{\text{Hz}}{\text{cm}^2}$ .
- 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

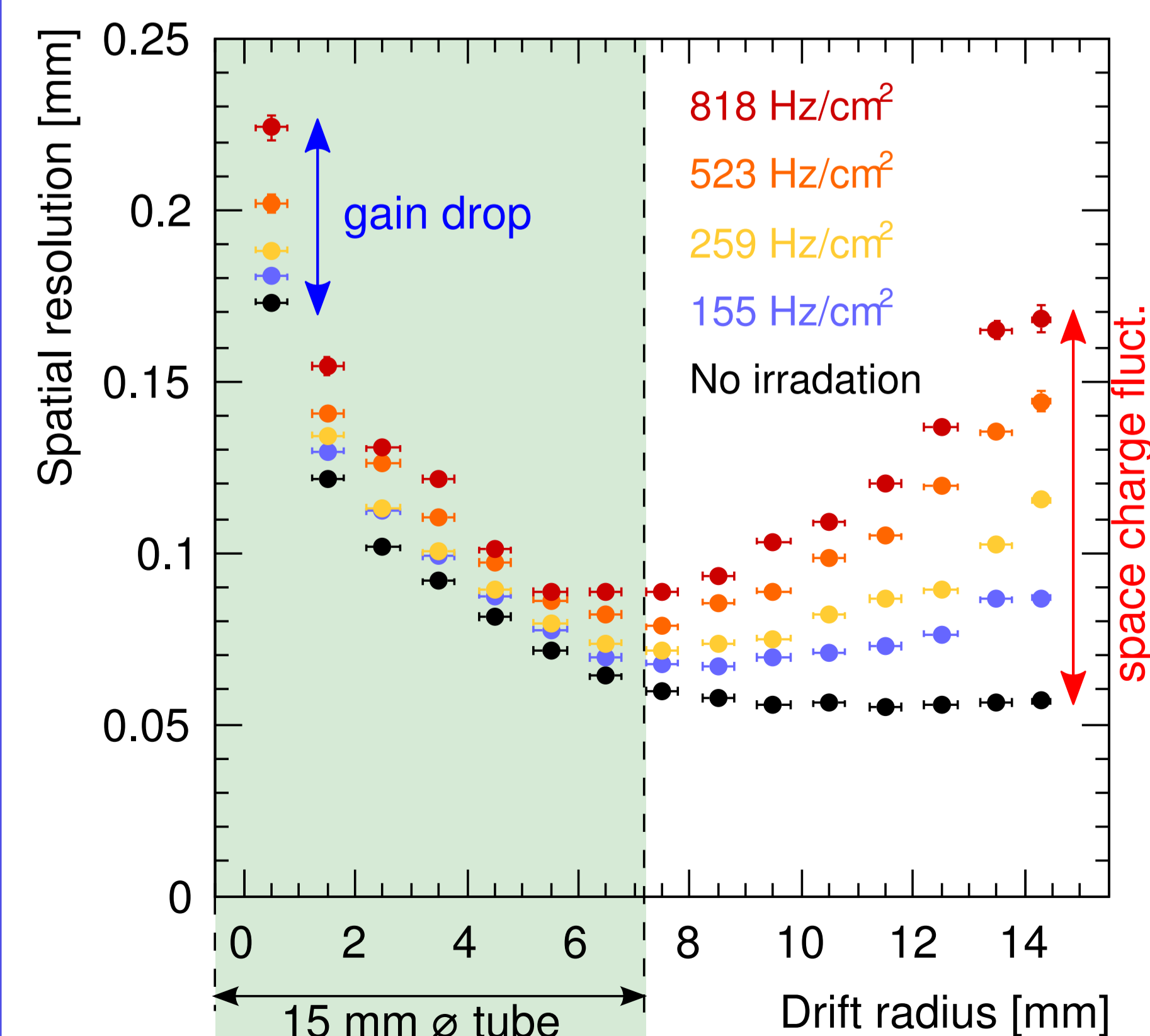
### MDT chambers:

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<sub>2</sub> (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

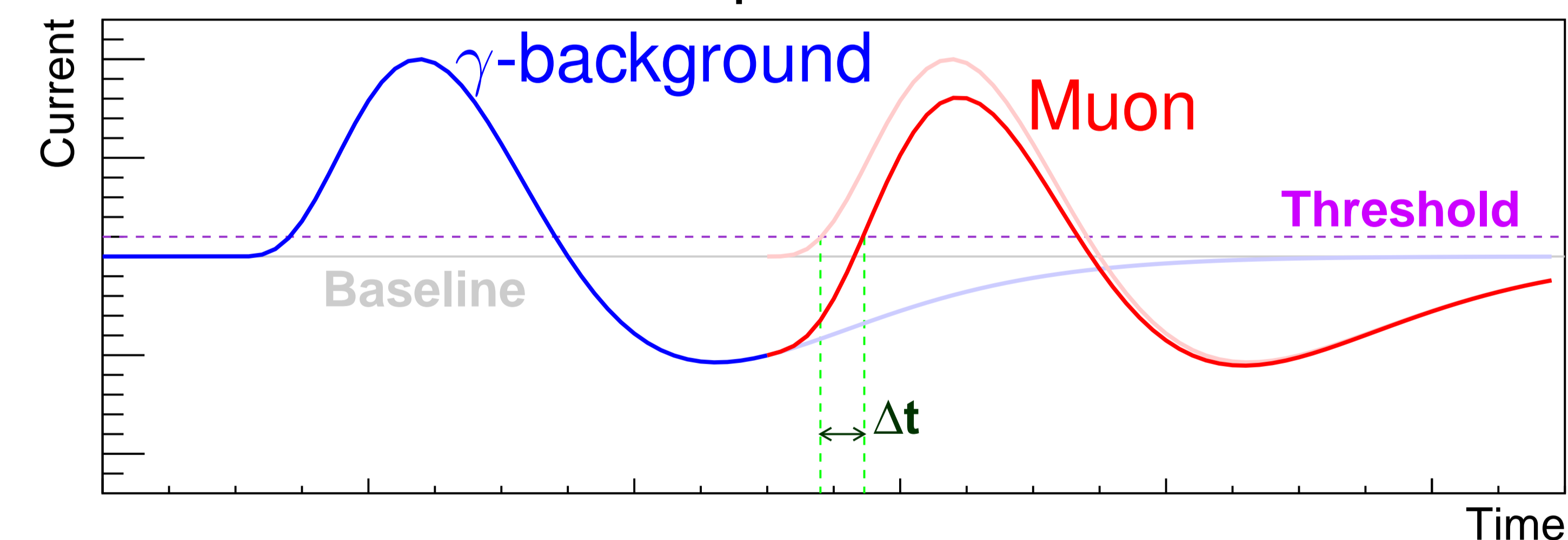
## Dr. Hubert Kroha



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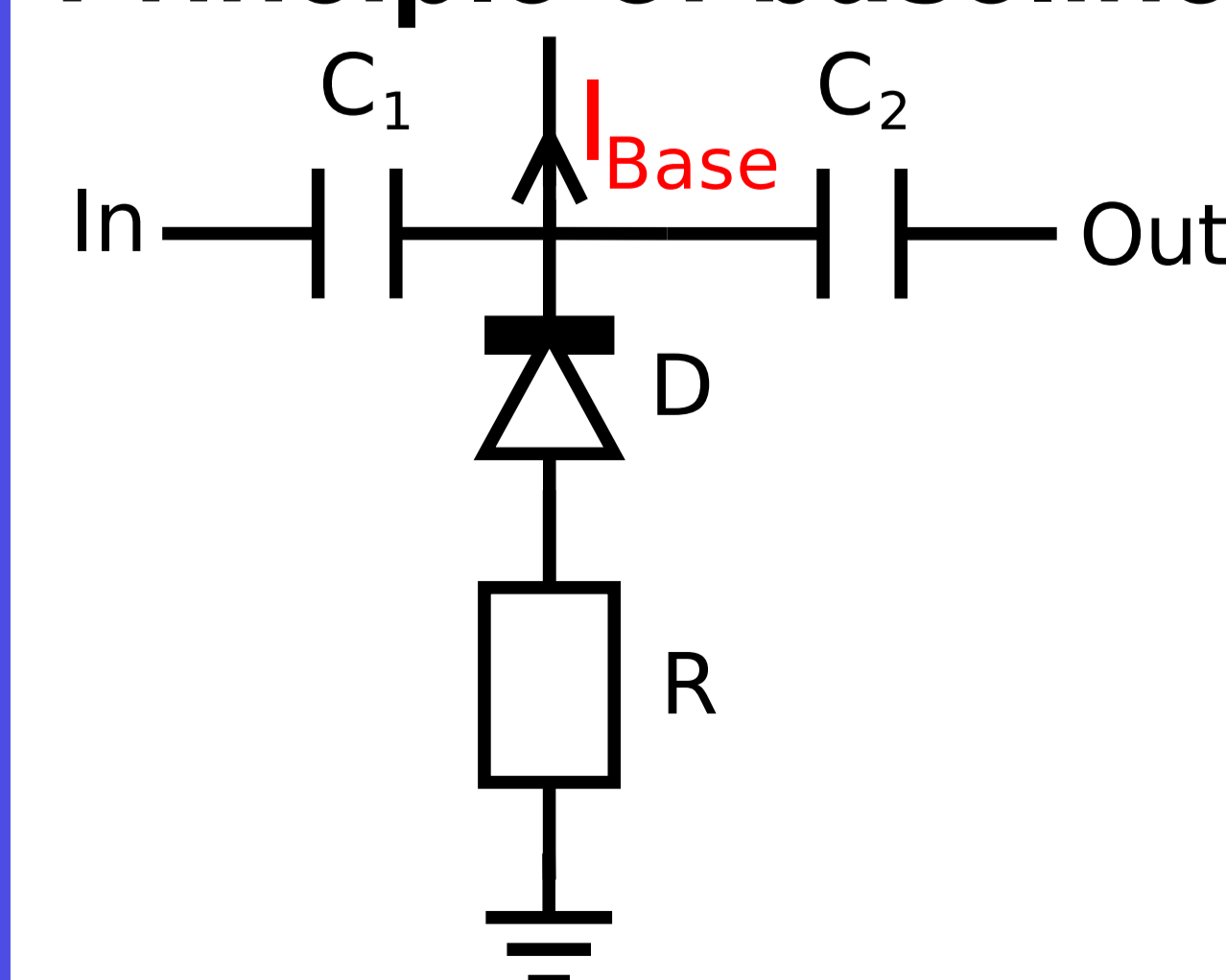
## Limitation of sMDT performance due to signal pile-up with bipolar shaping of the read-out electronics

- 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 $I_{Base}$ )



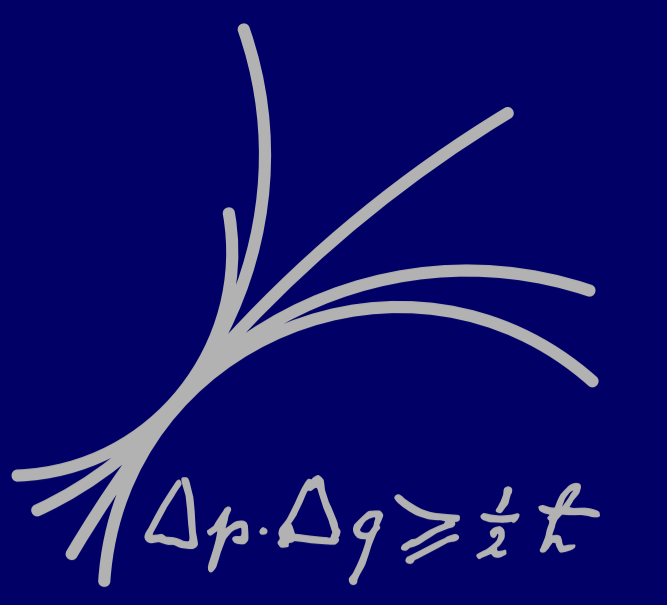
- Diode is non-conducting for positive signal polarity ⇒ signal stays unchanged
- Diode is conducting for negative polarity (undershoot) ⇒ input current drained to ground
- ⇒ **Undershoot eliminated**



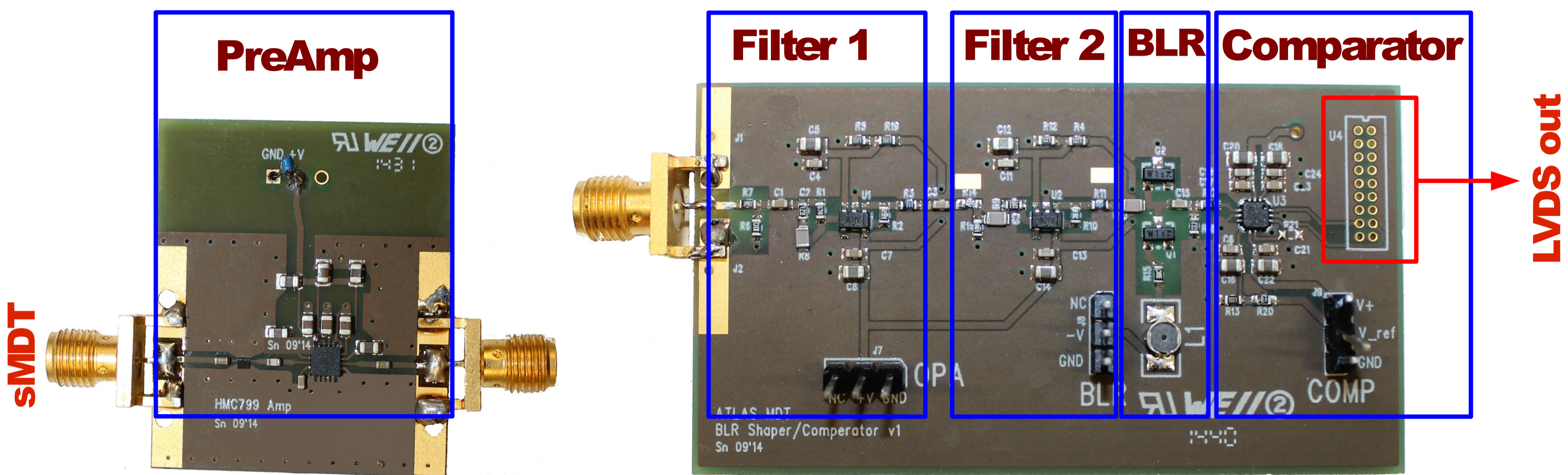
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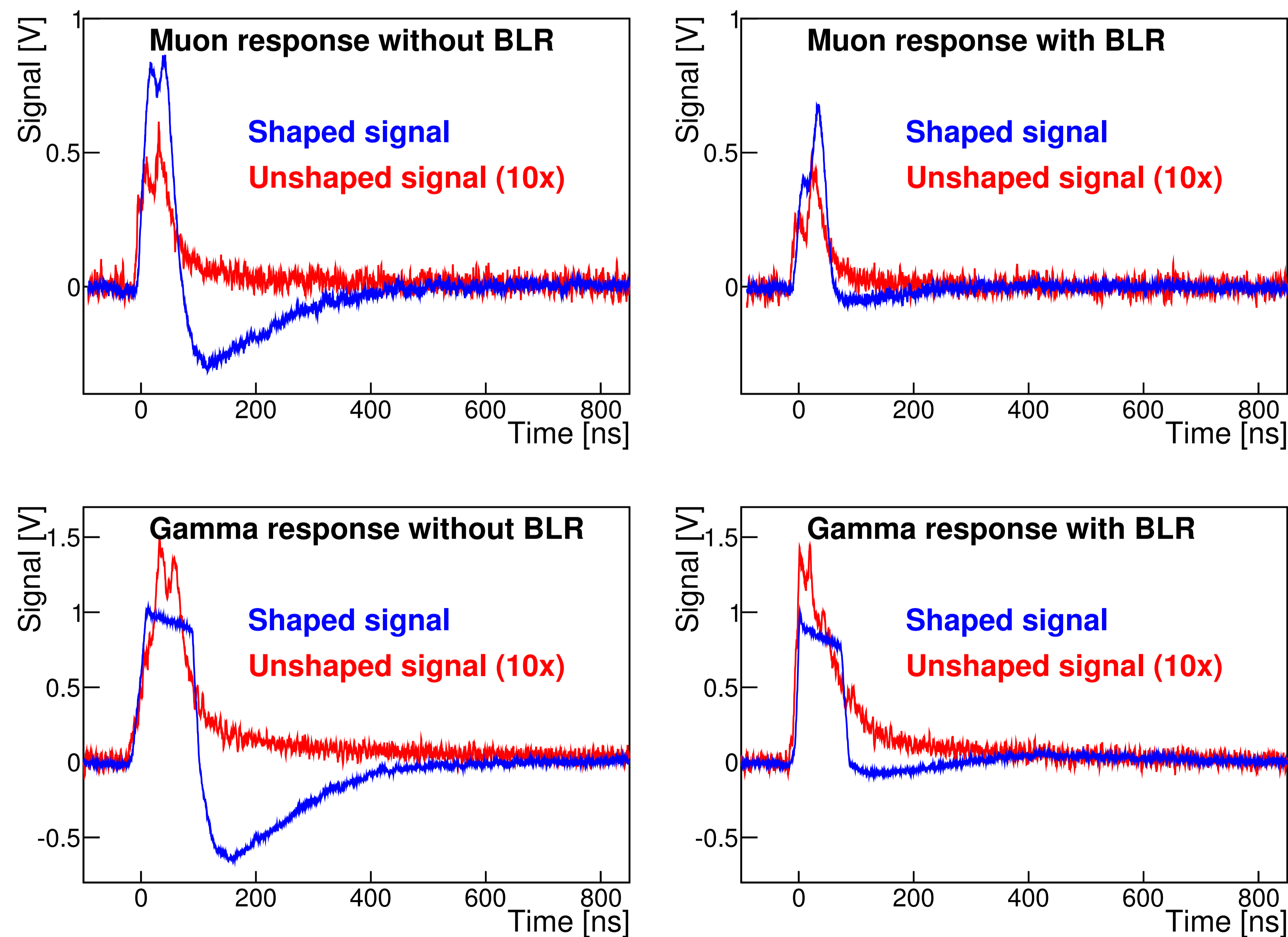


## Bipolar shaping circuit with baseline restoration



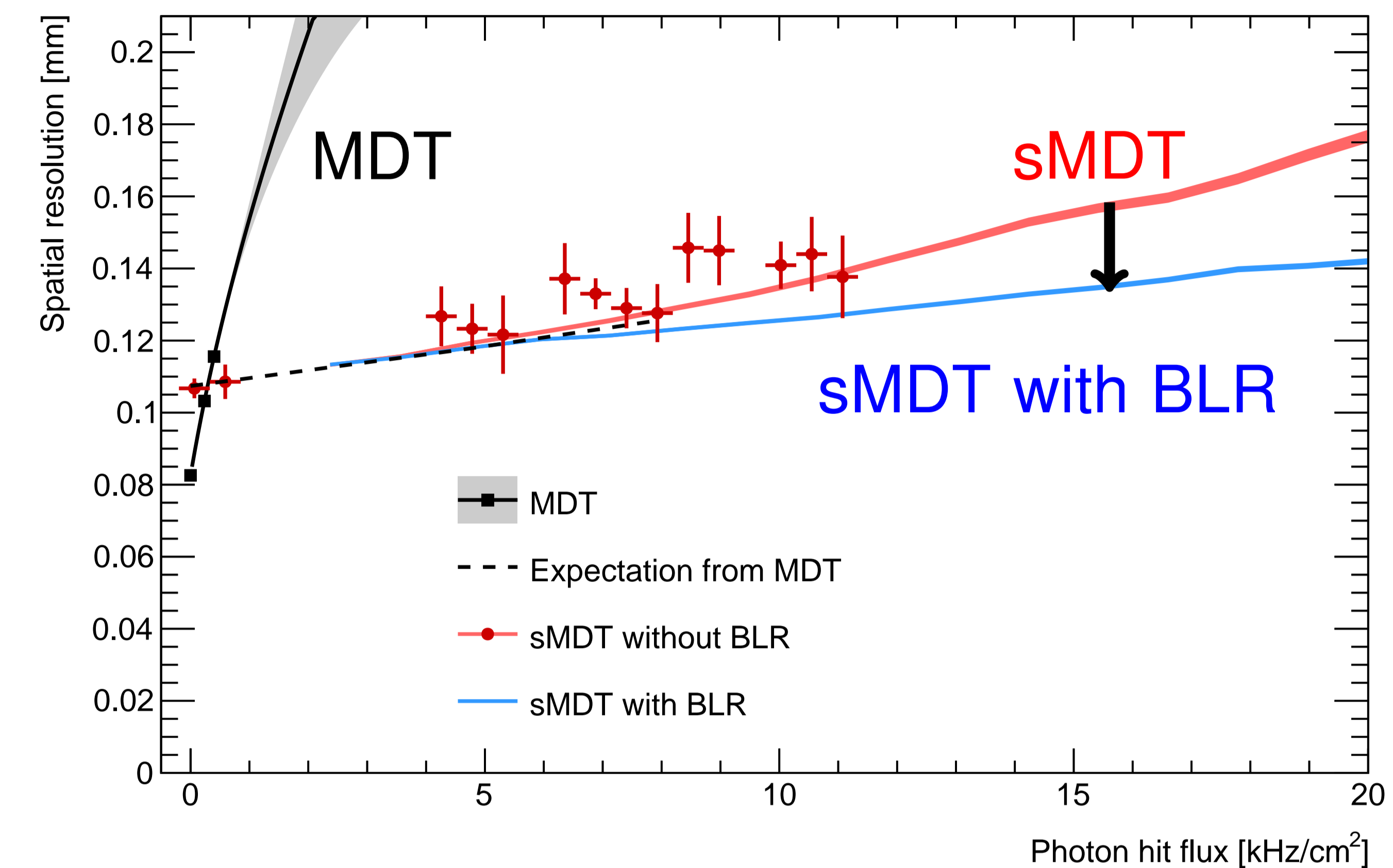
- High bandwidth (700 MHz) transimpedance amplifier (PreAmp)
- Bipolar shaping circuit (2 filter stages) with baseline restoration and comparator with LVDS output to TDC (as MDT read-out chip)

## Bipolar shaped pulses with baseline restoration



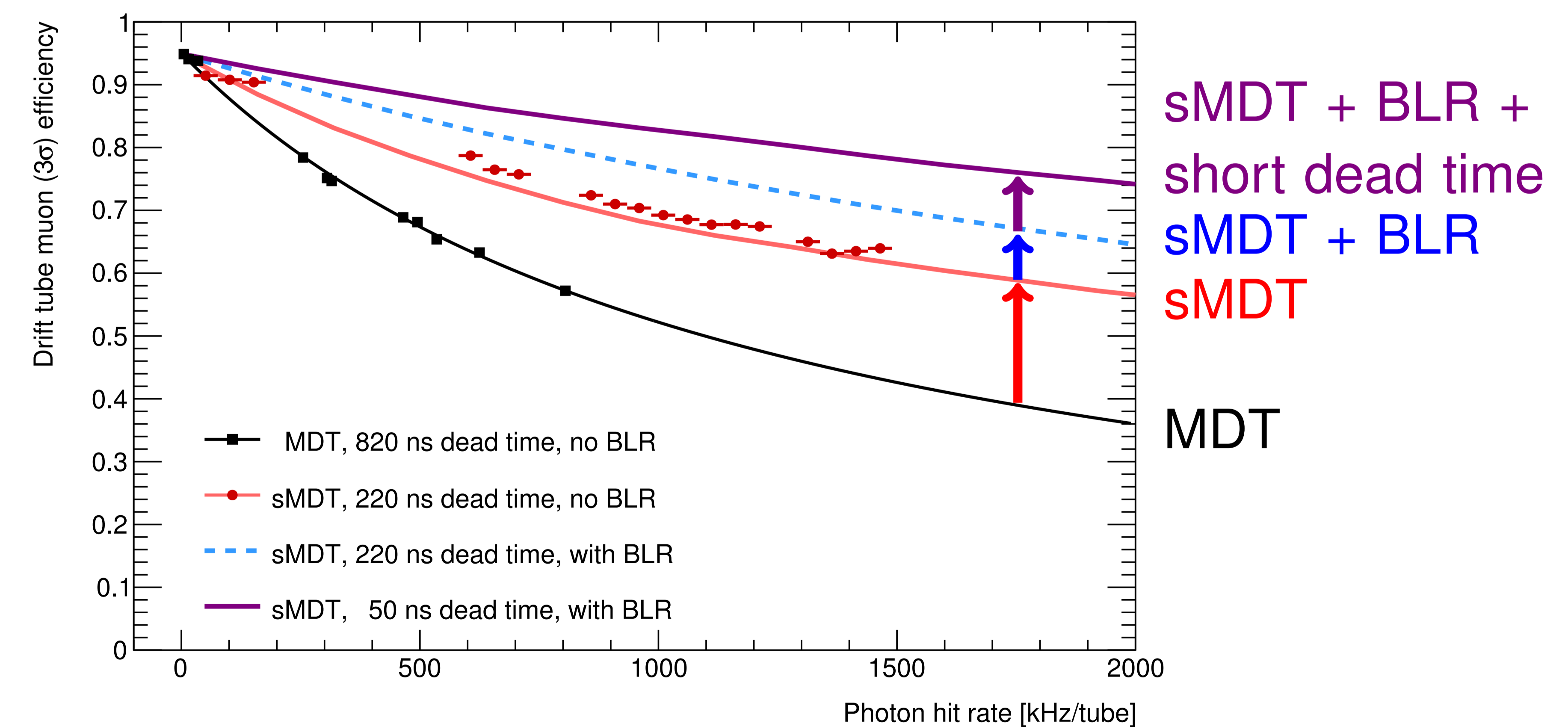
- $\gamma$ -pulses push shaper in saturation (larger signals with longer undershoot compared to muon pulses)
- Clear undershoot suppression with baseline restoration

## sMDT single-tube resolution under $\gamma$ 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



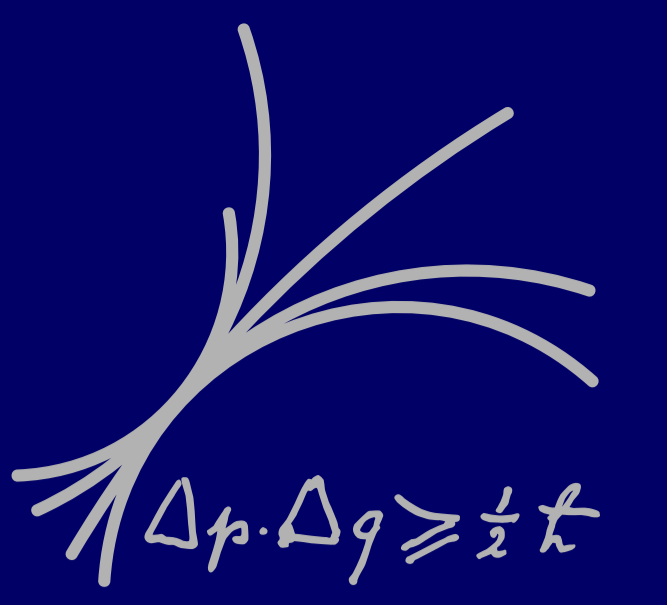
- At high counting rates limited by read-out electronics
- Use of minimum electronics dead time possible for sMDTs
- Suppression of signal pile-up effects at short dead times with baseline restoration



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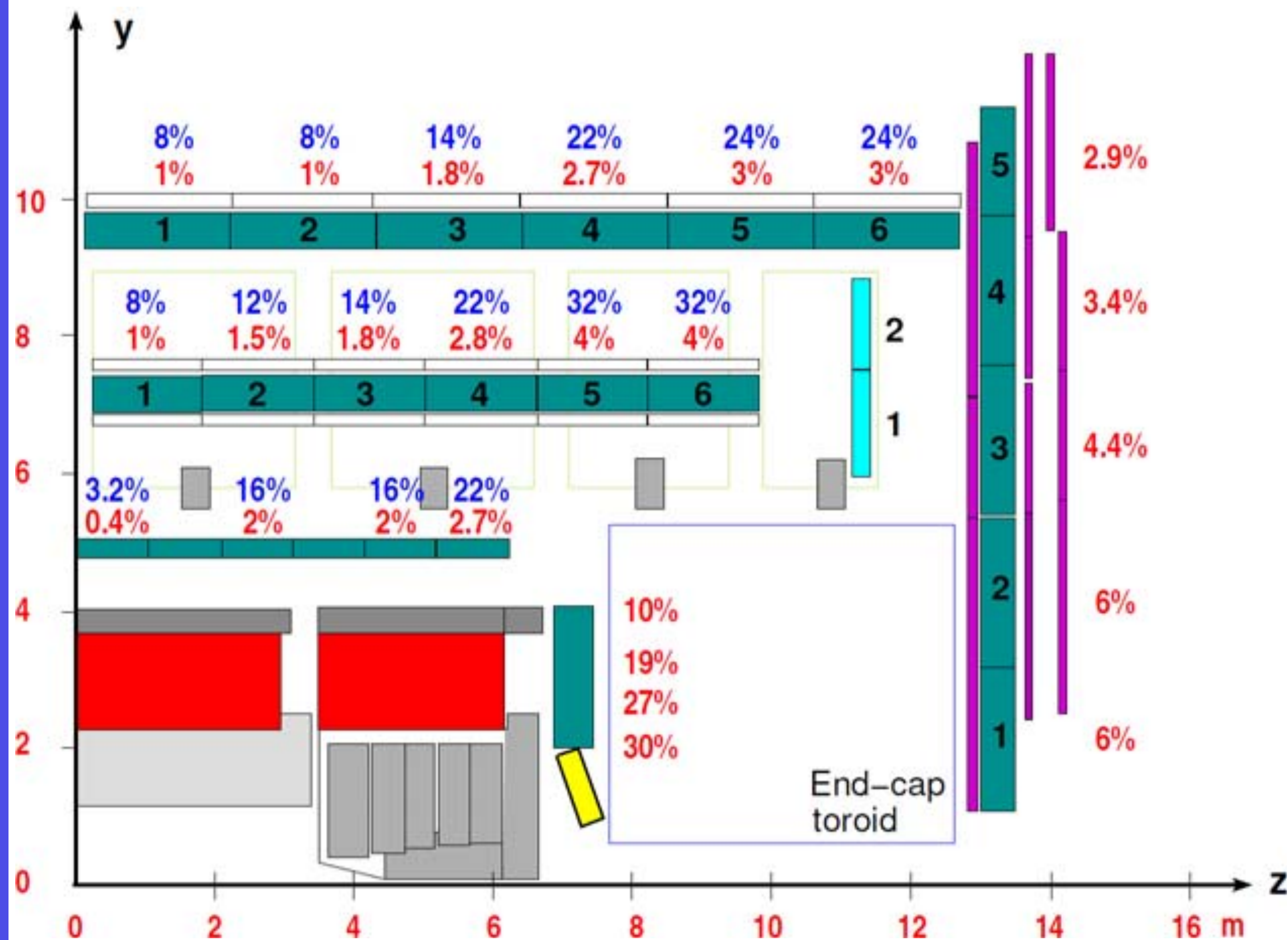
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## MDT and sMDT occupancies at HL-LHC and maximum FCC-hh luminosity

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



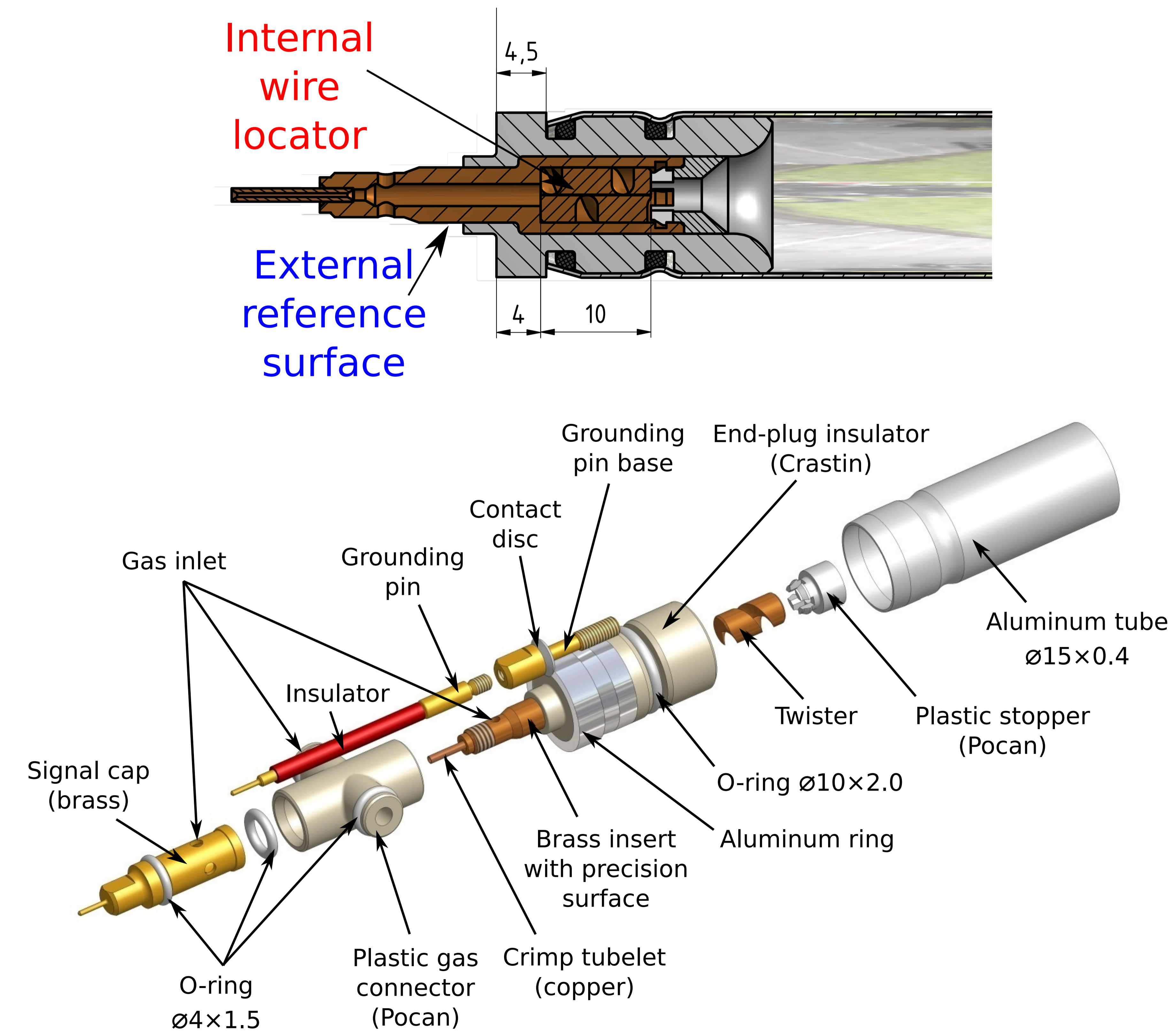
### Background rates in muon system

ATLAS at LHC design luminosity → x 10 at HL-LHC → 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
- ⇒ 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  $10 \mu m$
- No wire aging observed up to  $9 \frac{C}{cm}$  charge on wire (15 x ATLAS requirement)

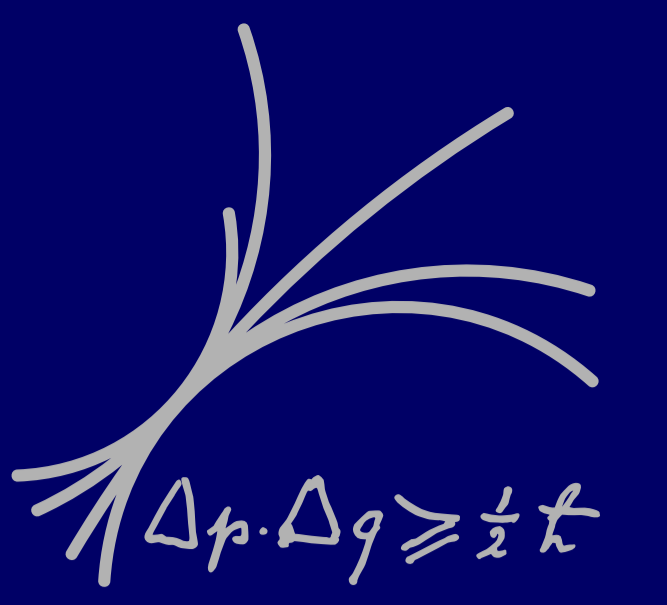




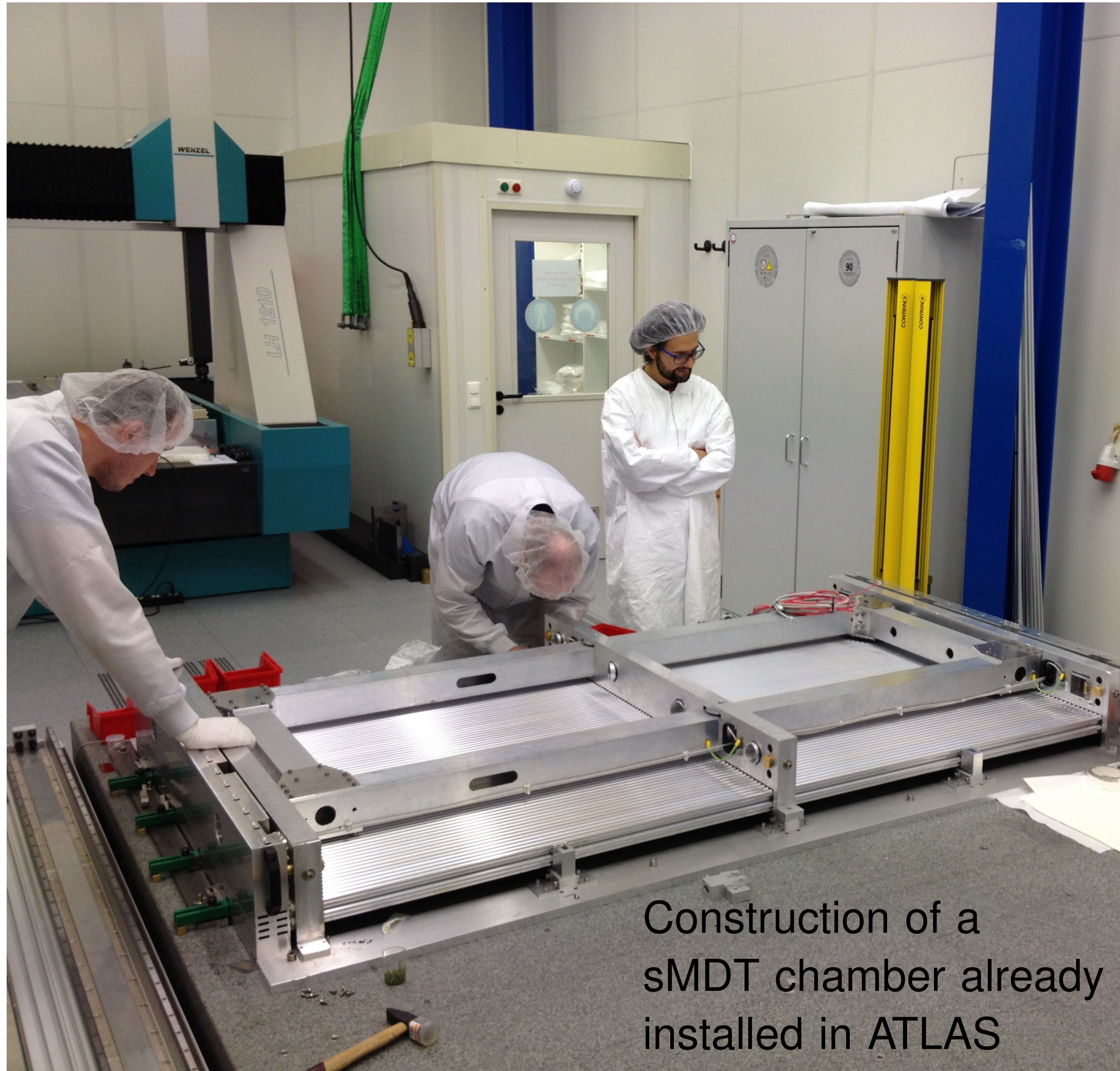
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## sMDT Chamber Construction

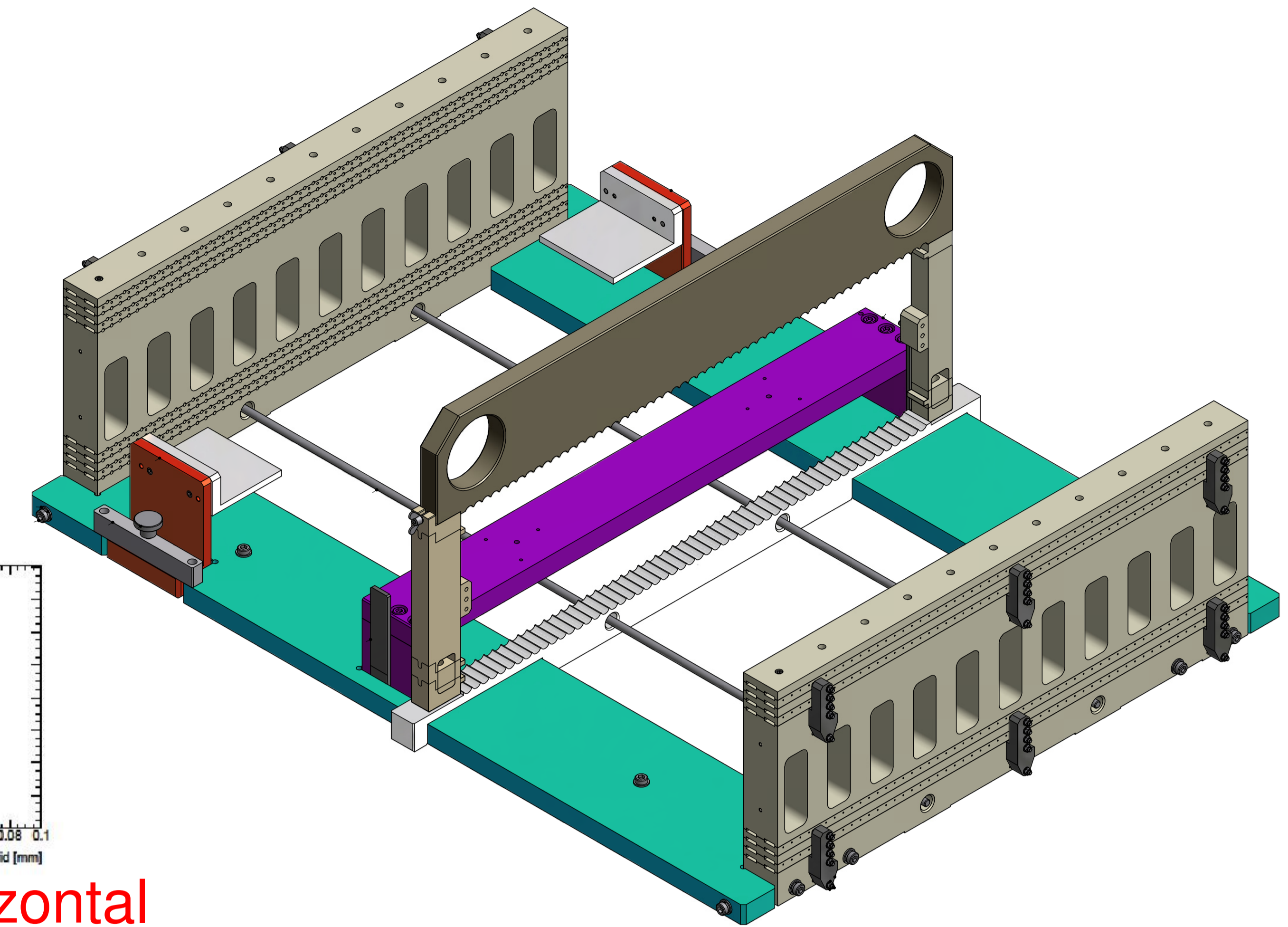
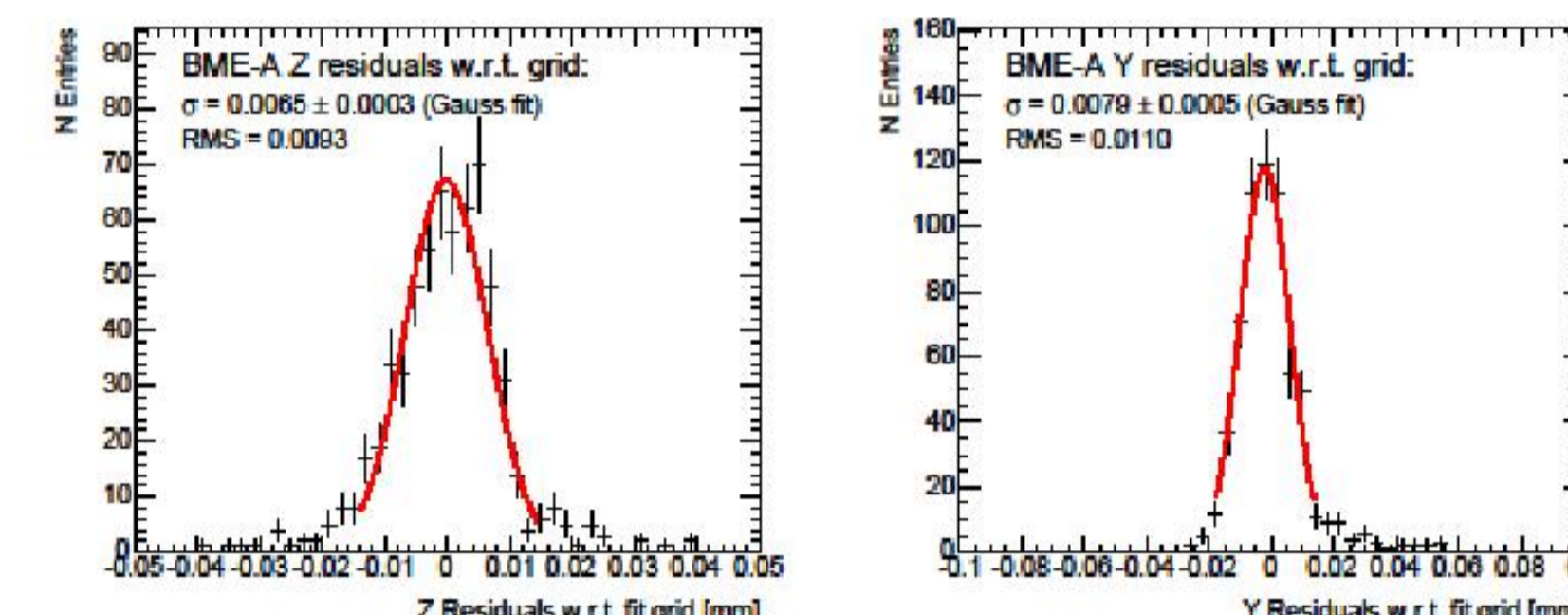
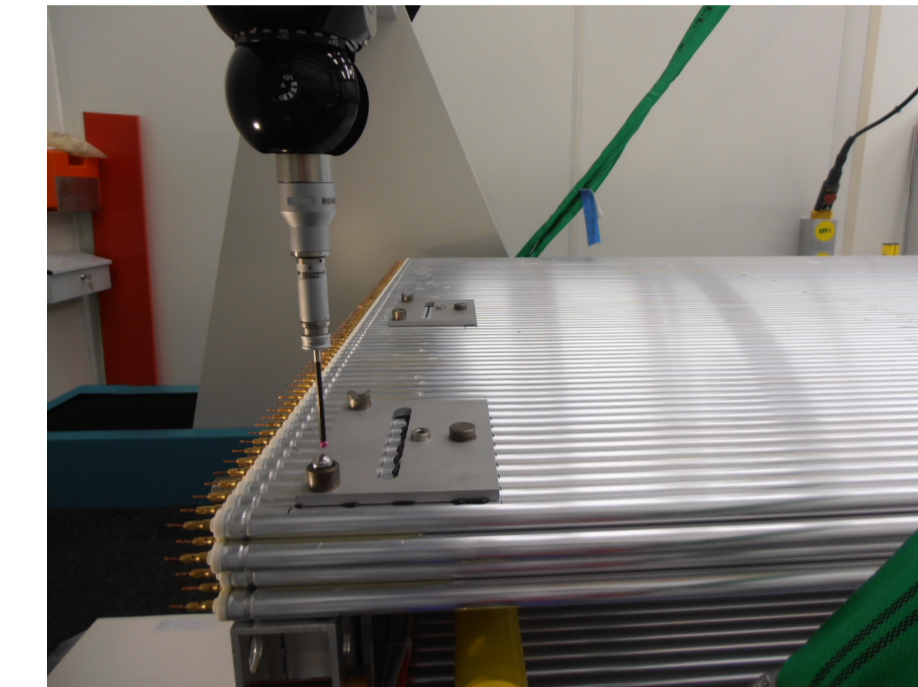


Construction of a sMDT chamber already installed in ATLAS

- 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 ( $\sigma < 10\mu\text{m}$ )

- Wire positioning accuracy is reached due to tube external reference surface and high precisely machined jigs.
- Wire positioning accuracy better than  $10\mu\text{m}$  (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.