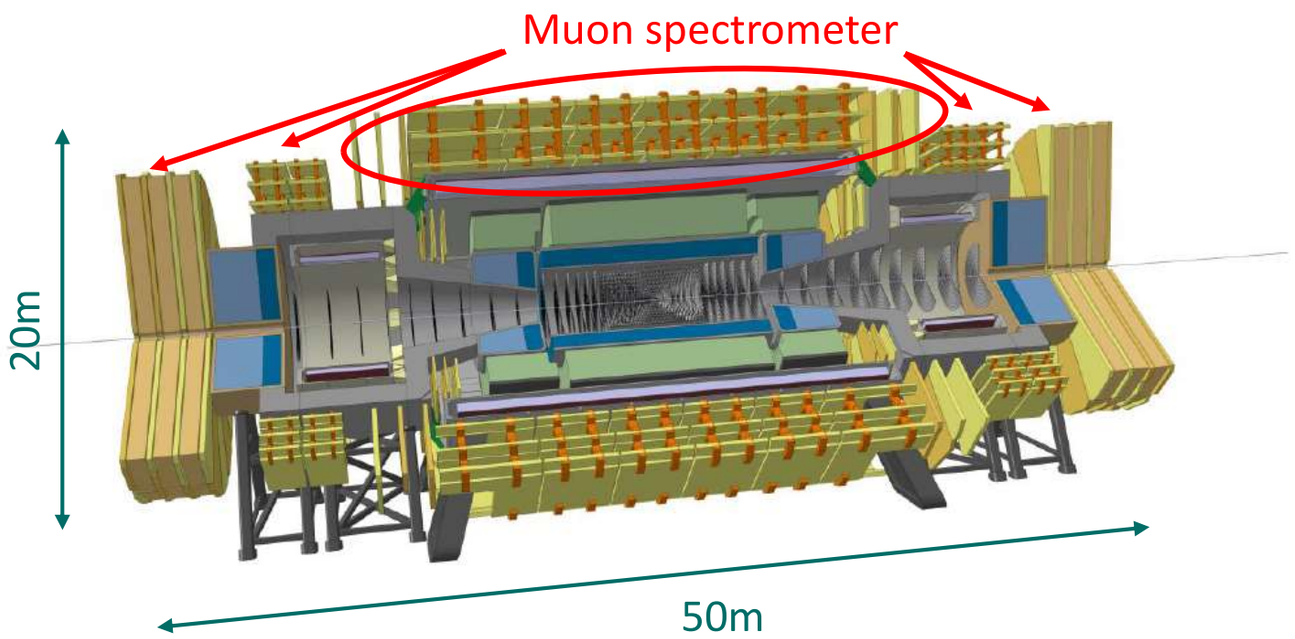
Performance of Muon Drift Tube Detectors and Fast Readout Electronics at Very High Counting Rates

Gregor Eberwein, Hubert Kroha, Oliver Kortner, Elena Voevodina

18.03.2021

MAX-PLANCK-INSTITUT FÜR PHYSIK

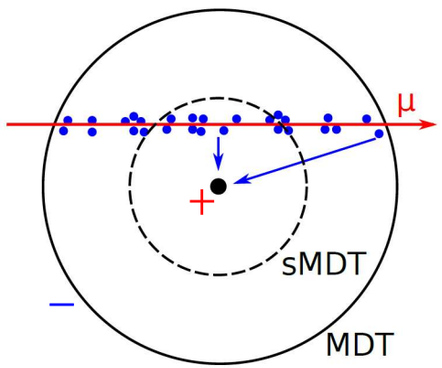
Muon detectors at future hadron colliders

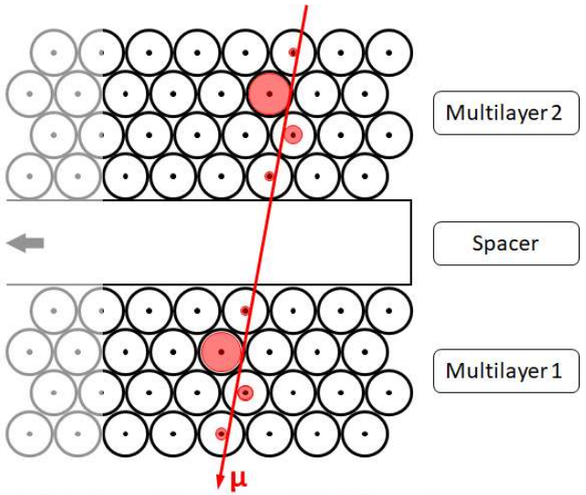


- Probing of Higgs-Boson properties, searches for physics beyond the Standard Model.
- HL-LHC: up to 10x LHC luminosity
- FCC-hh: up to 30x LHC luminosity (E_{cm}=100 TeV)
- Majority of hits in muon drift tubes stem from cavern background, rate scales with instantaneous luminosity.
- sMDT muon detector technology developed for such environments.

- Goal: Further improve sMDT detector performance at high background rates.

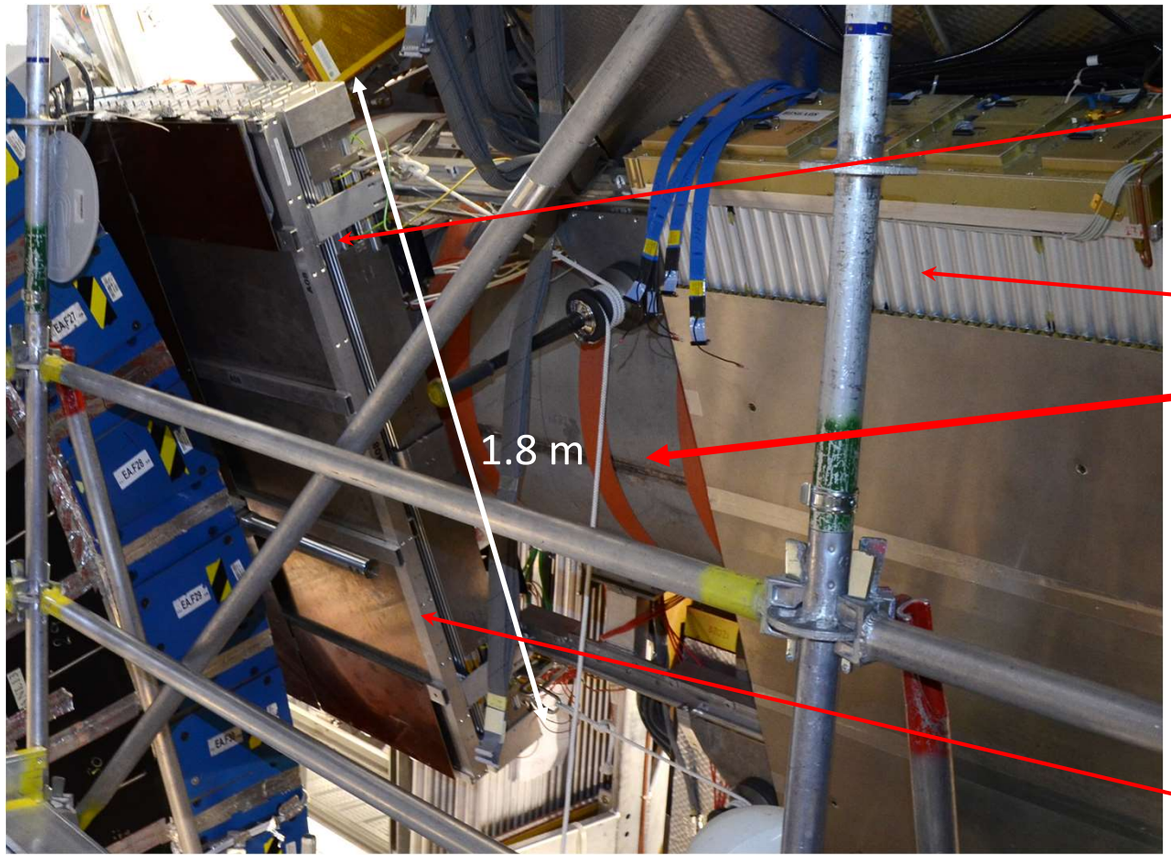
Small diameter Monitored Drift Tube (sMDT) detectors





- 15 mm tube diameter
- $ArCO_2$ (93:7) fill gas, 3bar abs.
- 2730 V between anode wire and tube wall, corresponds to nominal gas amplification near wire of 2 x 10^4
- Measured hit time converted to drift radius.
- Muon tracks reconstructed from hits in 8 layers of drift tubes.
- Spatial resolution of 30 µm with sense wire positioning accuracy <20 µm.

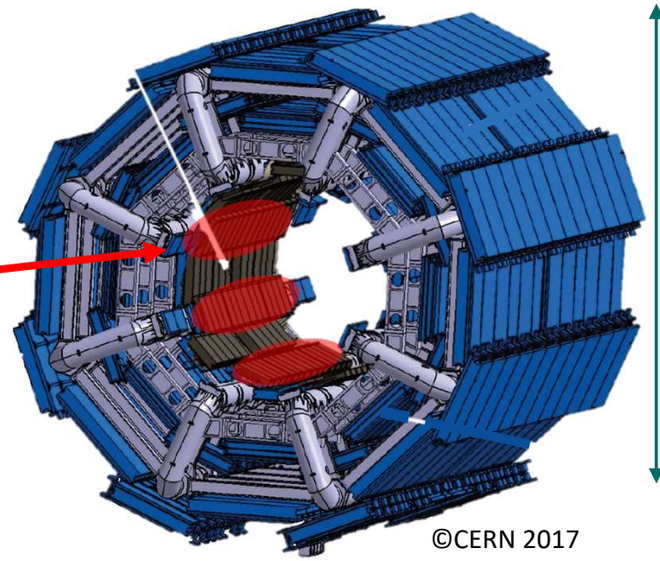
Installation of a sMDT muon chamber for the HL-LHC ATLAS upgrade



New sMDT chamber

Existing MDT chamber

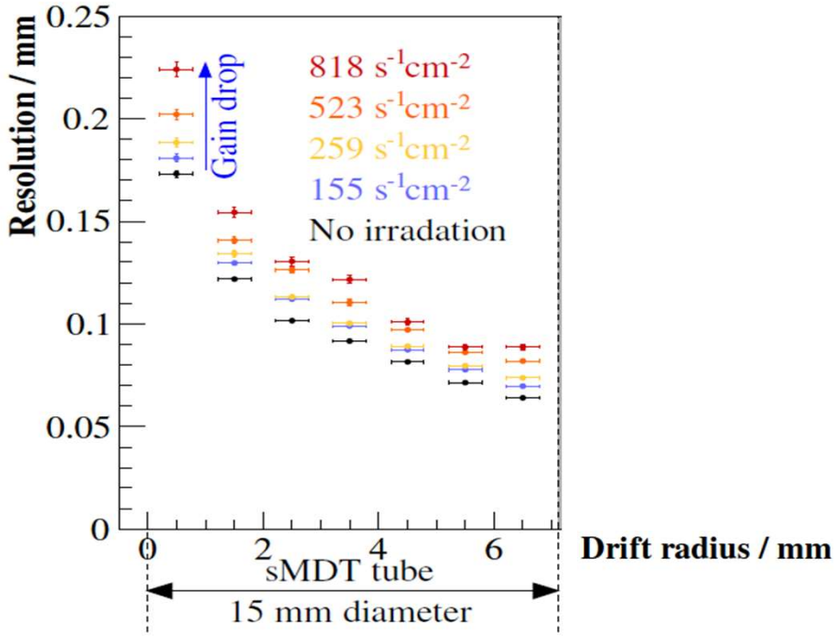
RPC - Trigger detector

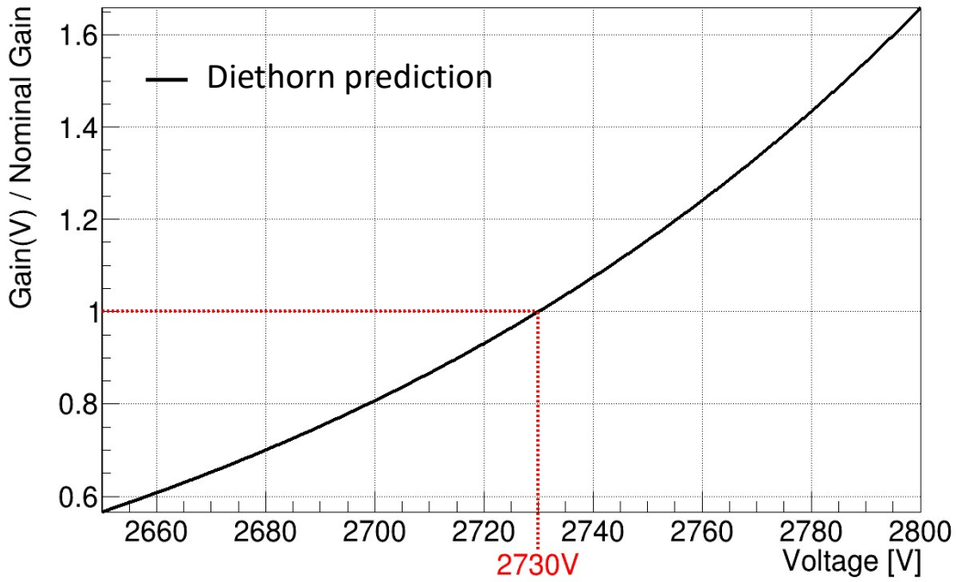


Existing MDT chambers

New sMDT chambers (112 in total)

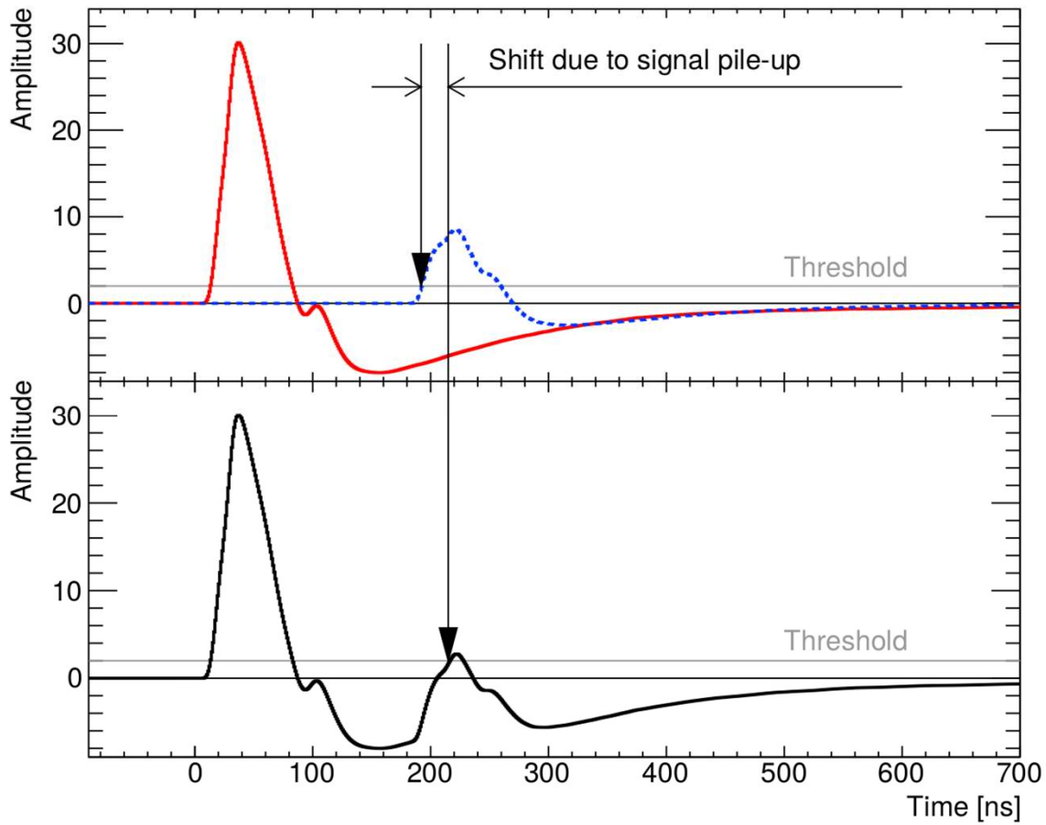
Gas gain loss in drift tubes due to space charge





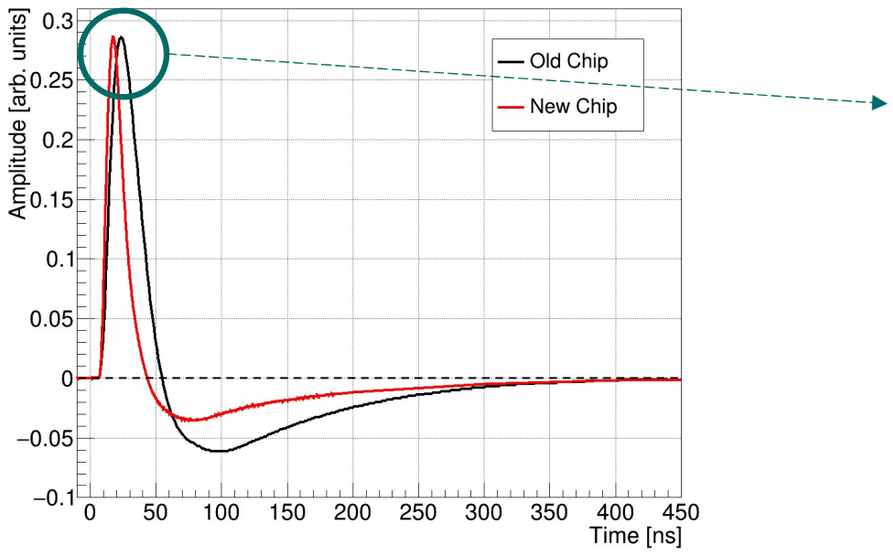
- Background radiation induces space charge in the tubes.
- Gain drop due to shielding of wire potential deteriorates spatial resolution.
- Adjust operating voltage to compensate for gain drop. Standard Diethorn formula used to predict the necessary adjustment.

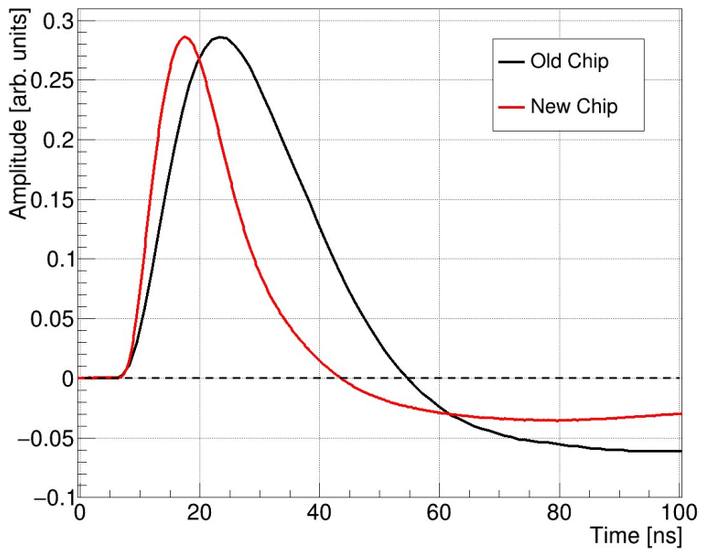
Readout electronics signal pile-up at high counting rates

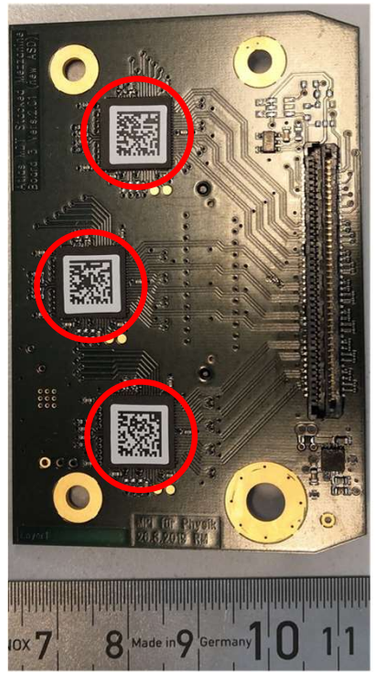


- Bipolar shaping of the readout chip causes an undershoot in the signal.
- Jitter in threshold crossing time of muon signal superimposed on preceeding background signal causes degradation of spatial resolution.

Improved pulse response of new readout chip

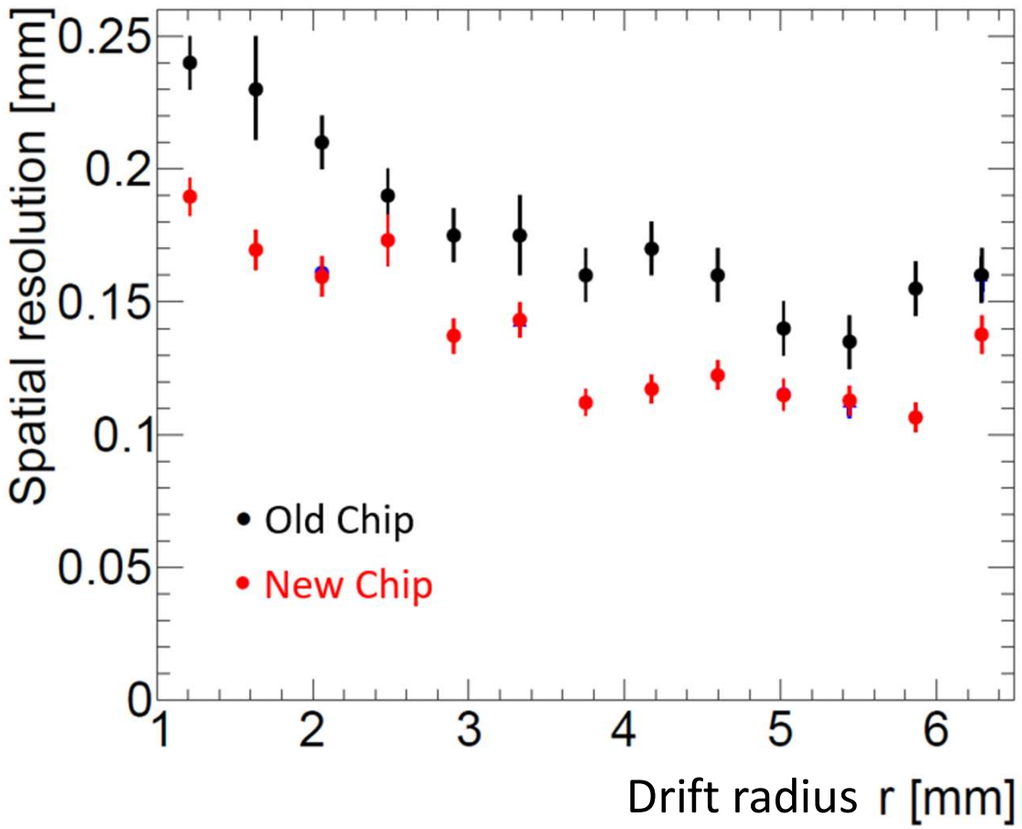






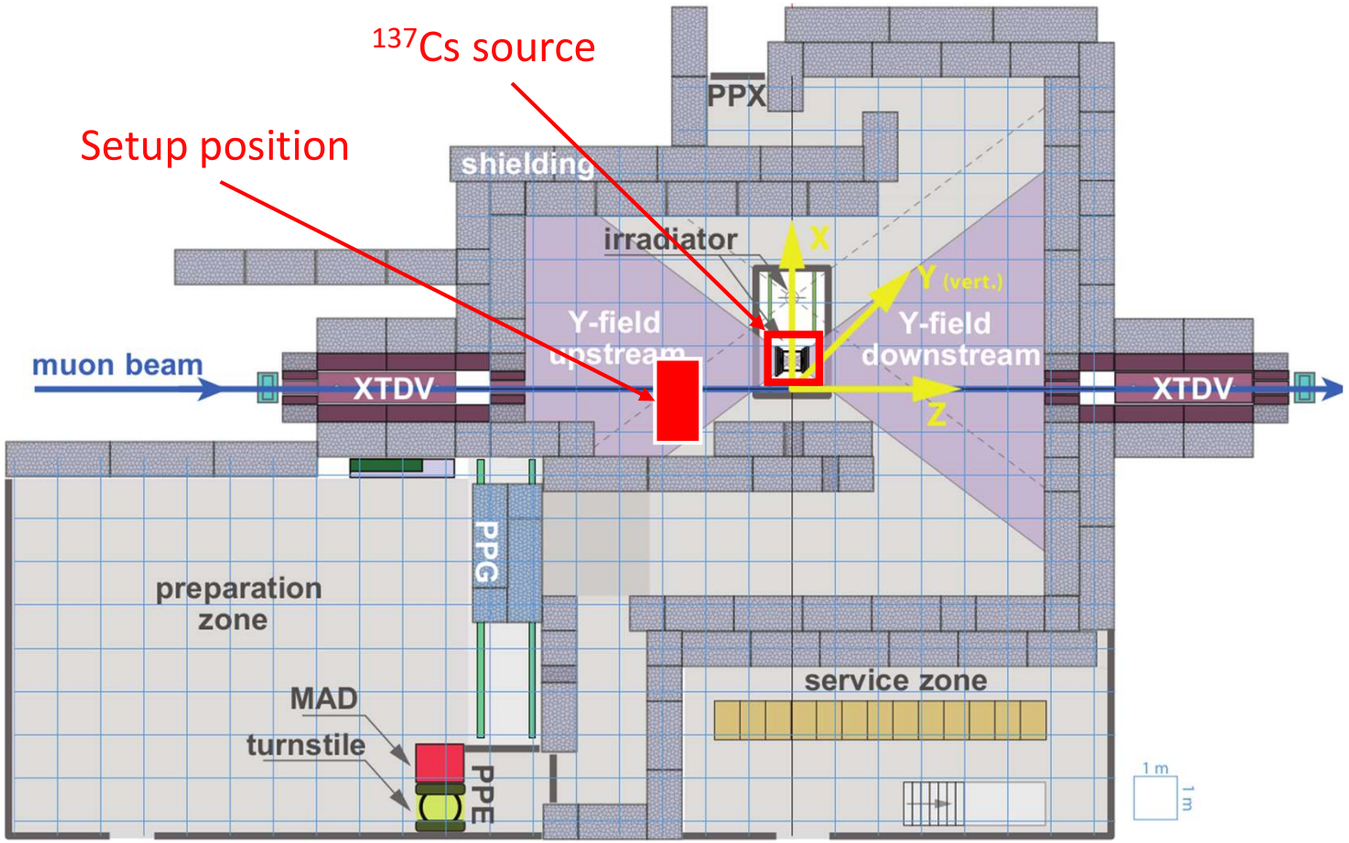
- New readout chip with reduced peaking time developed for ATLAS HL-LHC, with faster signal rise time to shorten the undershoot.
- Less threshold crossing time jitter, while adjusting the working point for defined noise rate.
- For even higher counting rates: Active baseline restoration circuits to suppress bipolar undershoot.

Drift tube spatial resolution with the new readout chip



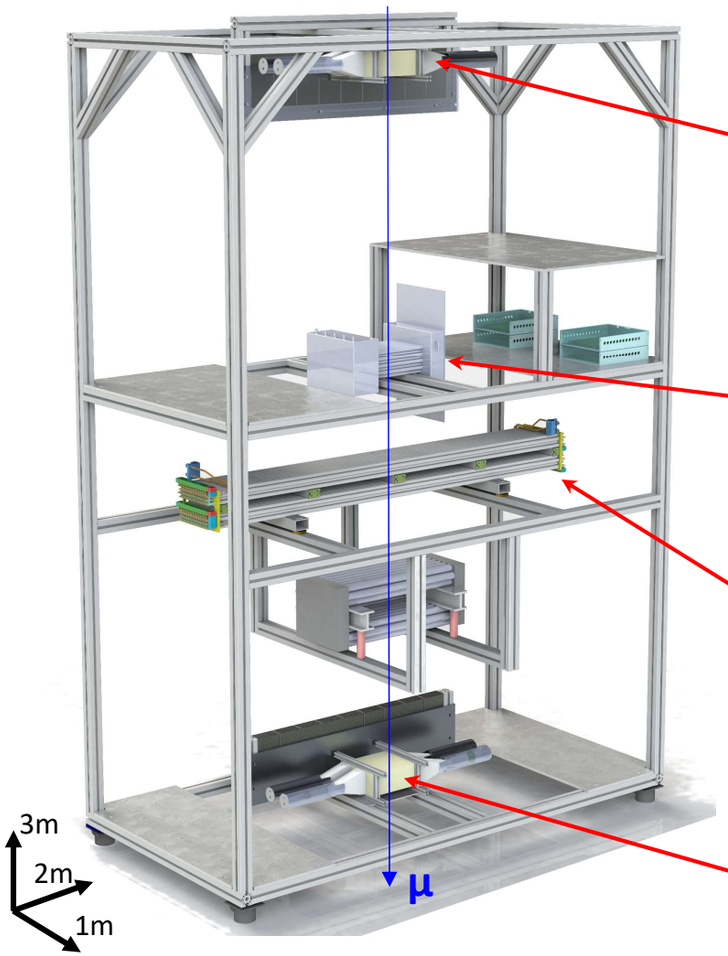
- Measurement on full-sized ATLAS sMDT chamber without background and signal pile-up
- Significantly better spatial resolution with new chip due to faster shaping

Measurement of resolution at high counting rates: Gamma Irradiation Facility at CERN (GIF++)



- Intense ^{137}Cs γ-source (13 TBq activity) to simulate cavern background
- Photon-spectrum with peak at 662keV
- Attenuation filters to adjust photon flux
- Muon beam available when accelerators (SPS) are running

Experimental setup at GIF++

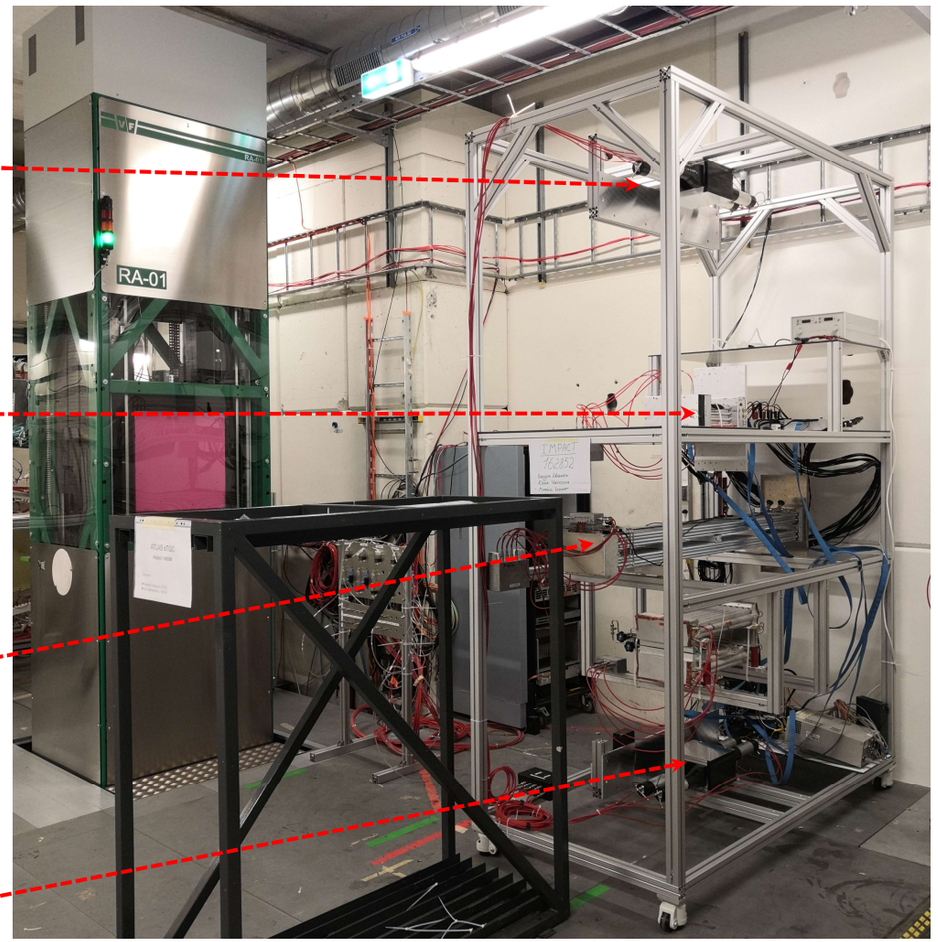


Top trigger hodoscope (shielded)

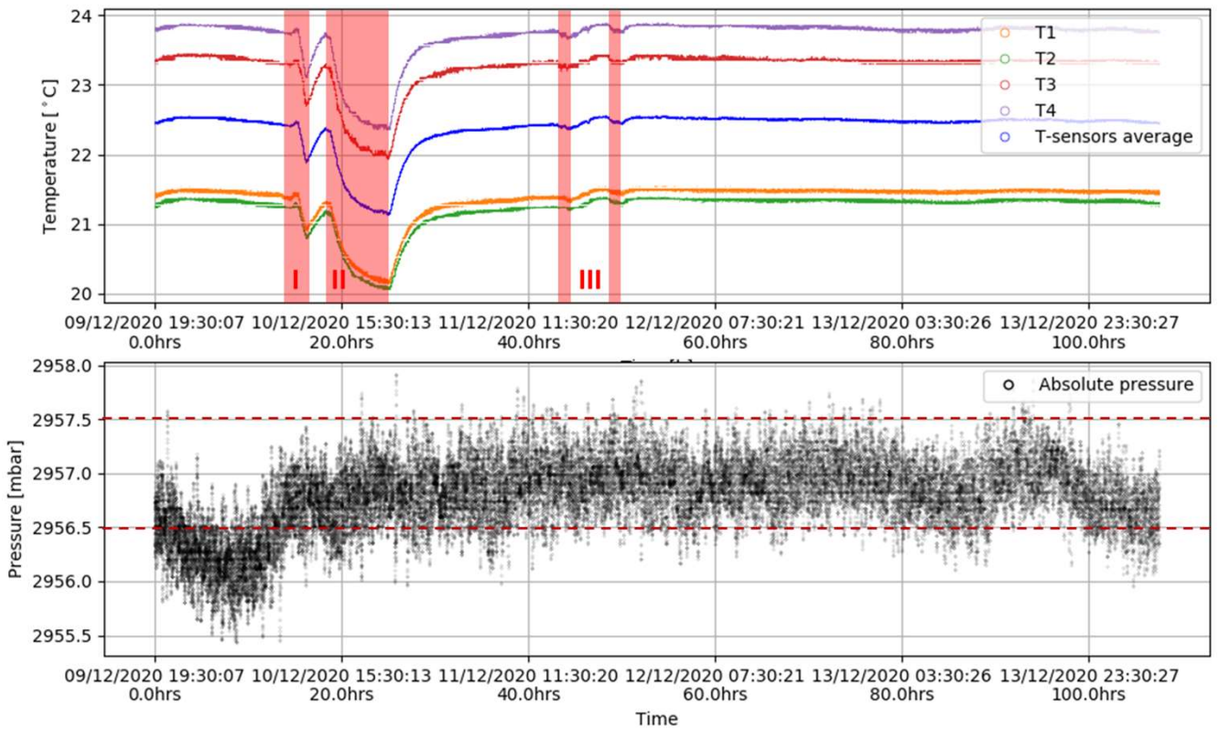
sMDT – 0.23 m tube length, old chip

sMDT – 1.6 m tube length, new chip

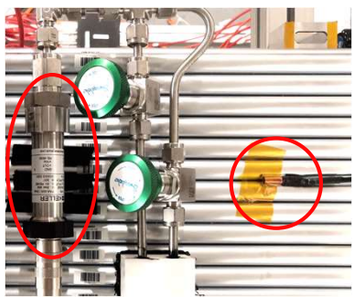
Bottom trigger hodoscope (shielded)



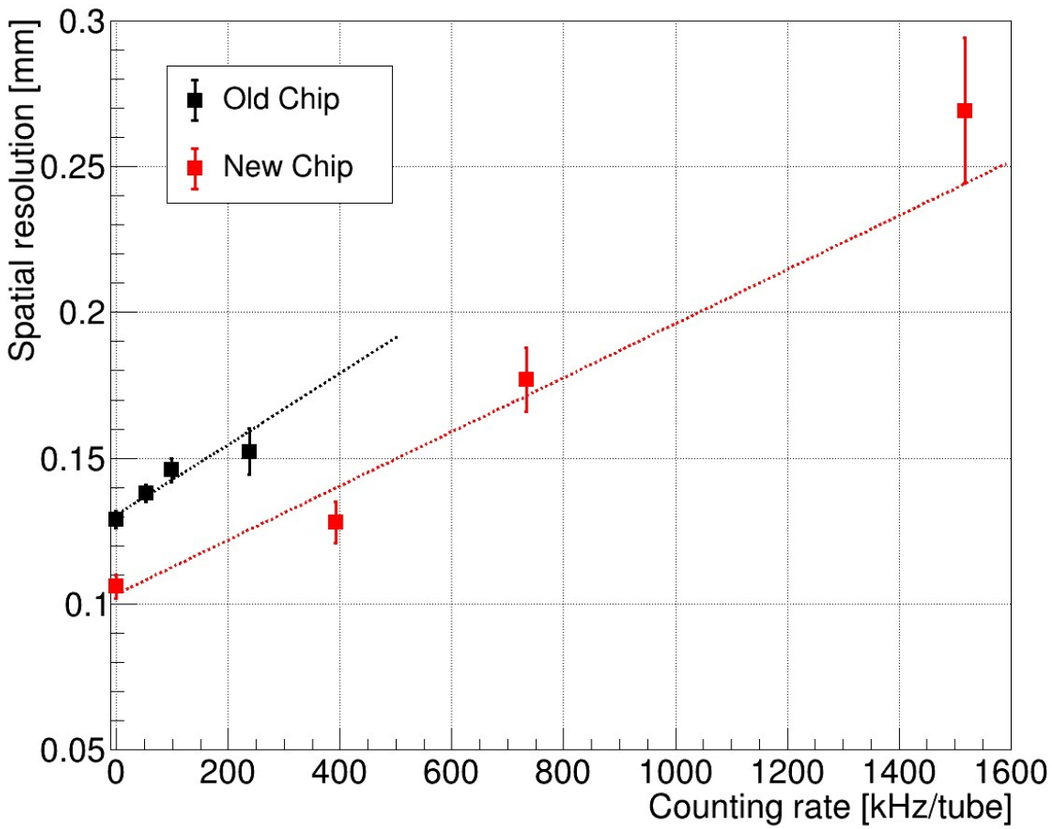
Temperature and pressure monitoring system



- Monitoring of gas temperature and pressure needed for precise measurement of spatial resolution
- Identification of time intervals to neglect in analysis (e.g.: I & II door open, III source off)

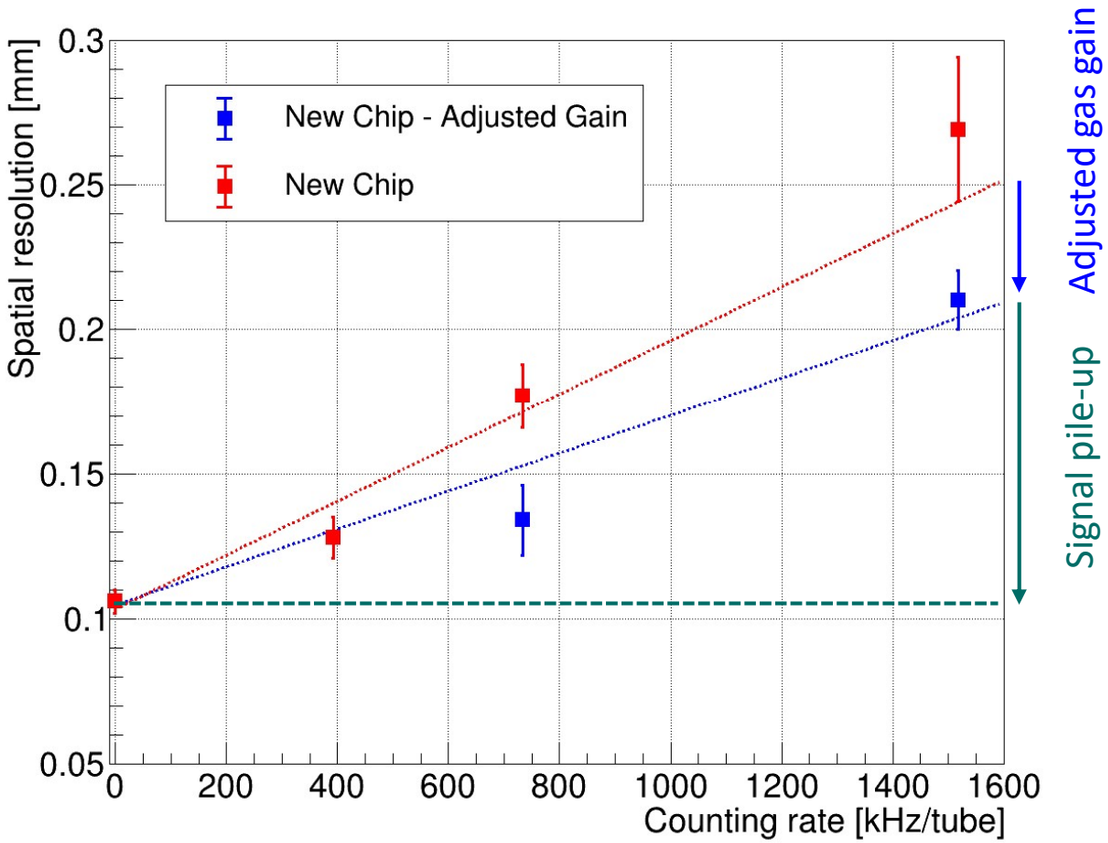


sMDT drift tube spatial resolution depending on the background counting rate



- Improvement of spatial resolution with new chip by 20-30%, increasing with higher counting rate: First indication of reduction of signal pile-up effect
- Operation up to 2.0 MHz counting rate/tube (expected for FCC-hh) feasible

Further improvements of spatial resolution



- Adjustment of operating voltage and gas gain at highest rate indicates significant improvement of spatial resolution
- Measurements at intermediate rates ongoing for confirmation

- Goal to eliminate remaining signal pile-up by implementing active baseline restoration in future readout chip
- Discrete BLR circuits tested at GIF++, data to be analyzed

Conclusions

- Confirmed that faster signal shaping (as in new readout chip) improves the spatial resolution of sMDT drift tubes with and without background radiation.
- Adjustment of the operating voltage to compensate for gas gain loss at high rates due to space charge improves the spatial resolution.
- sMDT precision muon tracking detectors with new readout electronics are well suited for operation at the HL-LHC and future hadron colliders.
- Next step of rate capability improvement: Development of readout electronics with active baseline restoration.