Test of high-resolution muon drift tube chambers for the upgrade of the ATLAS experiment

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PhD Recruiting Workshop - 3rd December 2019

ATLAS EXPERIMENT

Max-Planck-Institut für Physik
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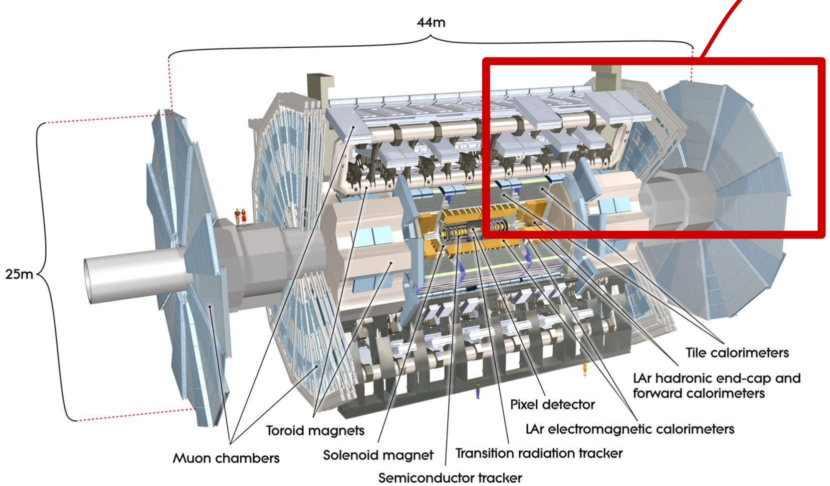
Technische Universität München

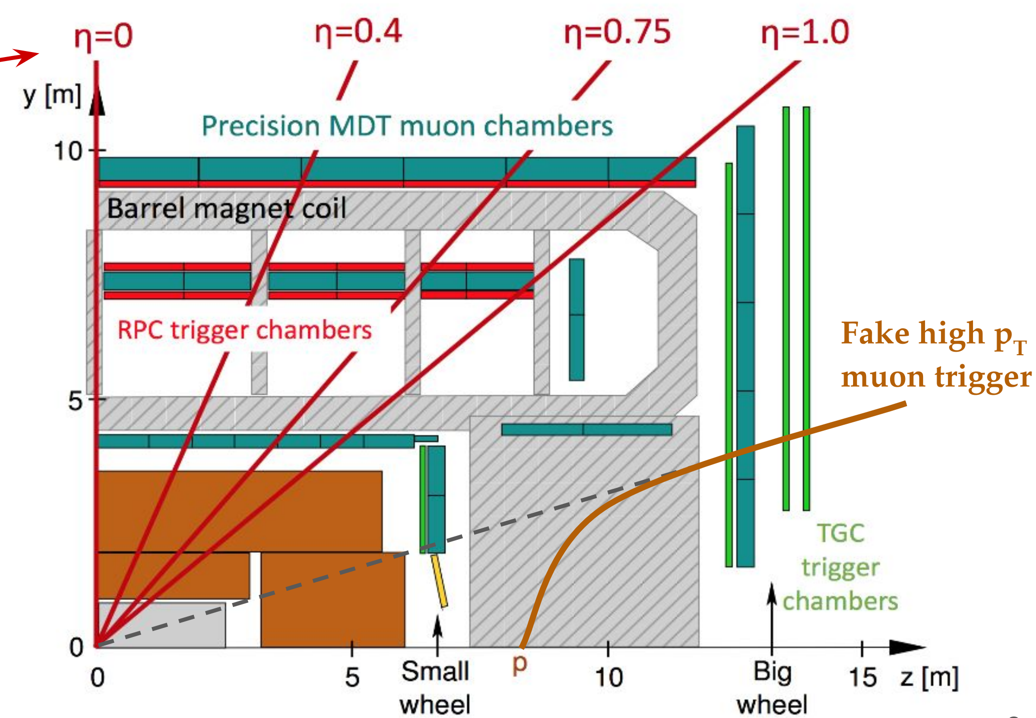
ATLAS Muon Spectrometer Upgrade

Muon spectrometer upgrade motivated by the upgrade of the high p_T muon trigger system.

Current high p_T muon trigger system based on a coincidence of three layers of:

- Resistive Plate Chambers (RPC) in the barrel region
- Thin Gap Chambers (TGC) for the endcaps





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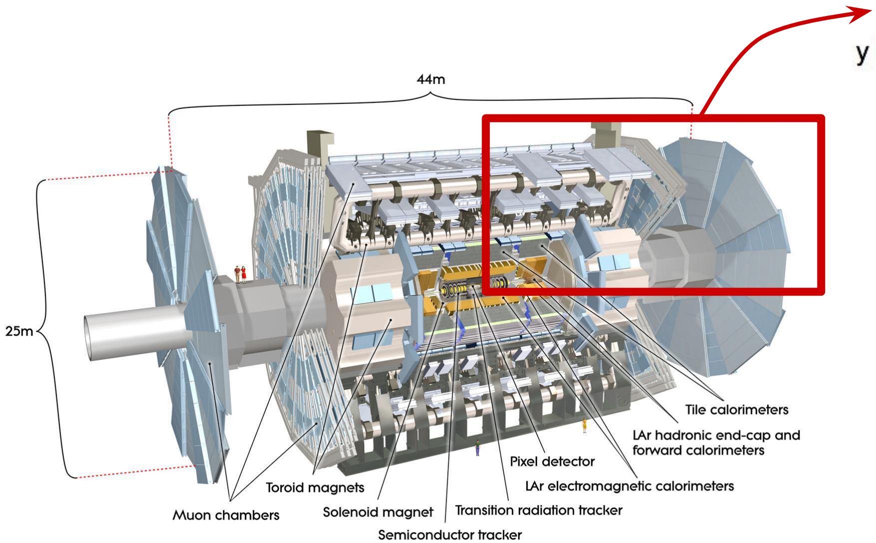
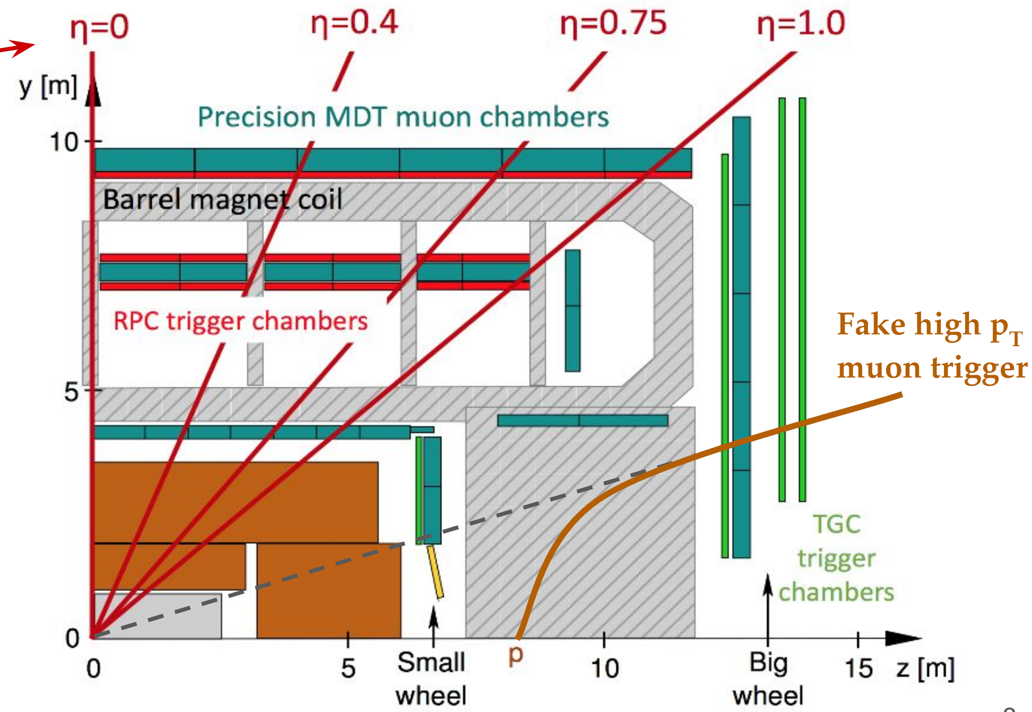
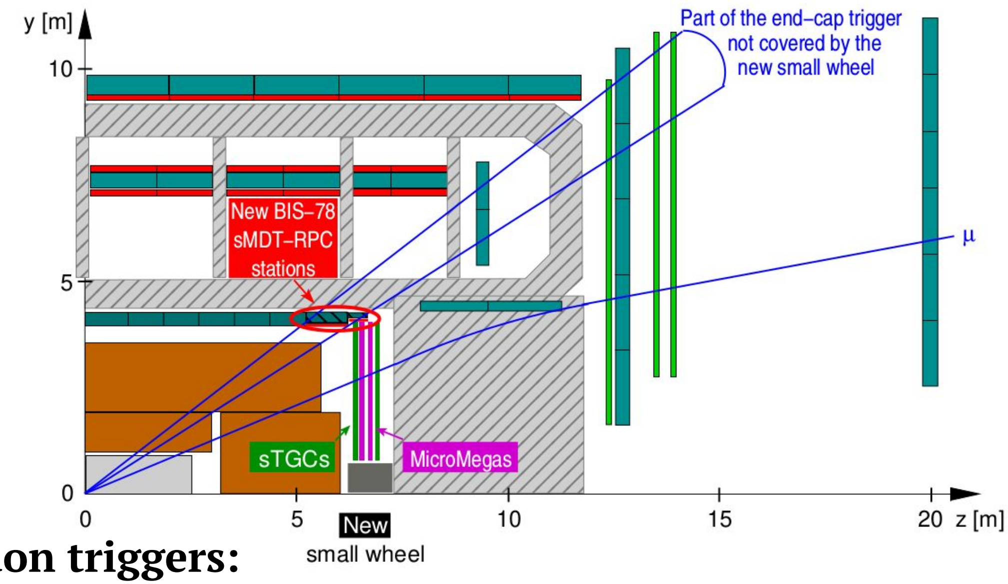
Fake high p_T muon triggers observed





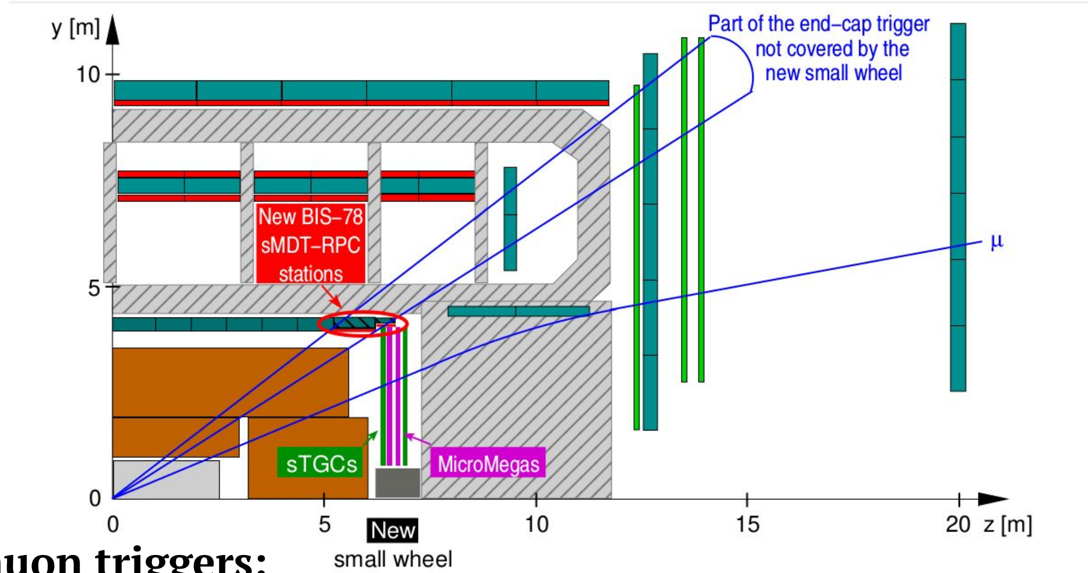
ATLAS Muon Spectrometer Upgrade



To suppress fake muon triggers:

- New small wheel with high-resolution trigger chambers;
- New thin-gap RPCs trigger chambers;
- Replace current MDTs in this region with new sMDT chambers due to spatial constraints.

ATLAS Muon Spectrometer Upgrade



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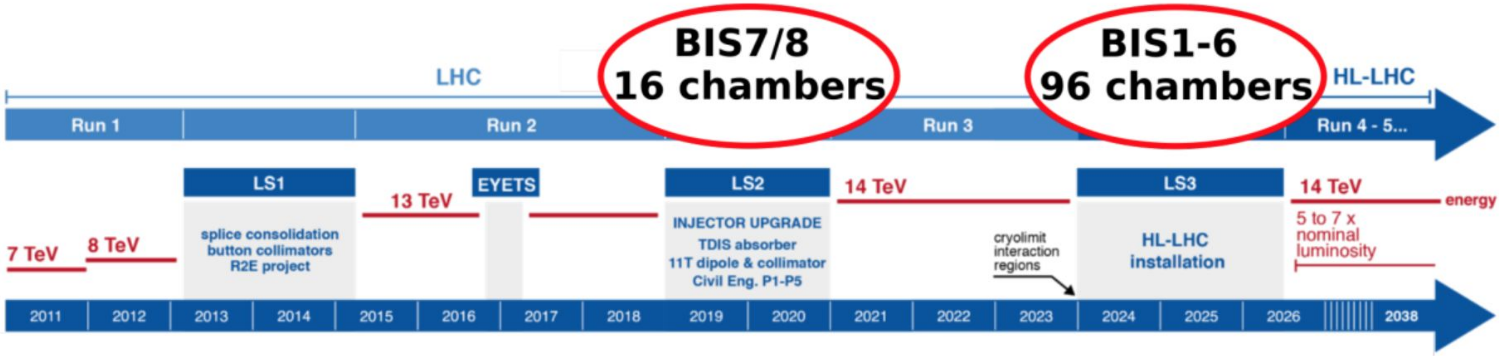
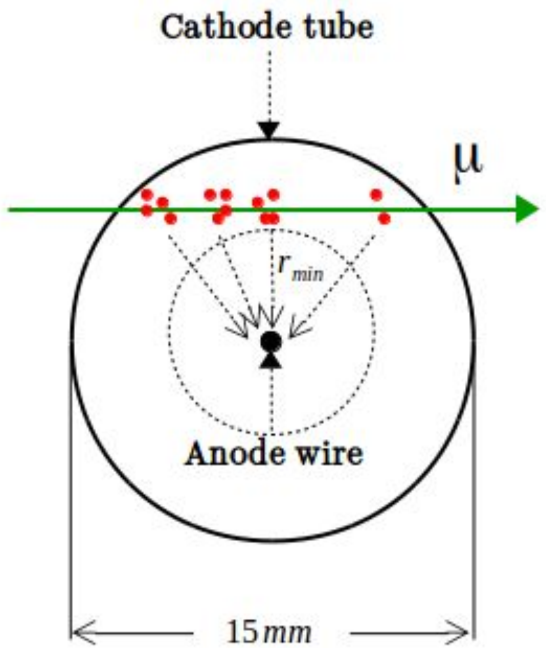


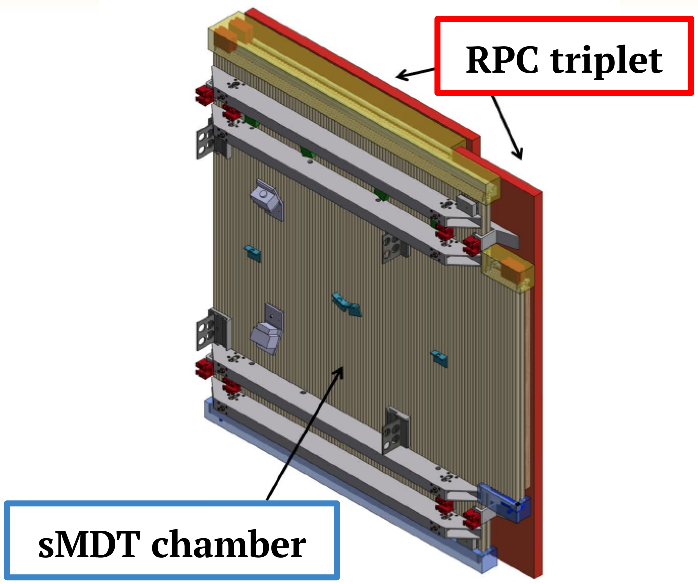
Working principle



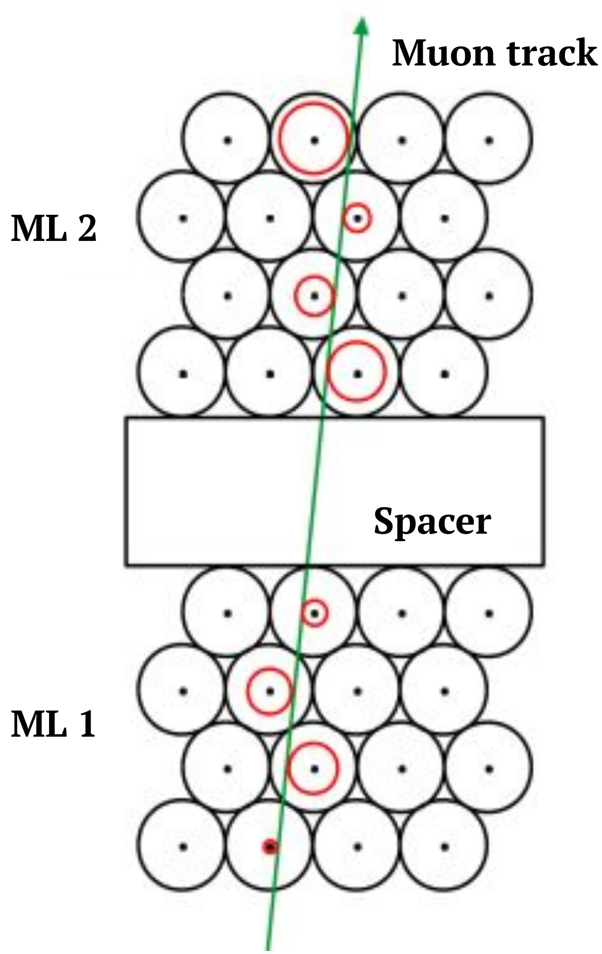
- Muon ionises the atoms of the gas
- Drift of the electrons to the anode wire
- Creation of the avalanche close to the wire
  - Electric field ~ 1/r

sMDT Operational Parameters

Parameter	sMDT
Gas mixture	Ar:CO_2 (93:7)
Gas pressure	3 bar (abs)
Gas gain	20 000
Wire potential	2730 V
Wire diameter	50 μm
Single tube resolution	~ 100 μm



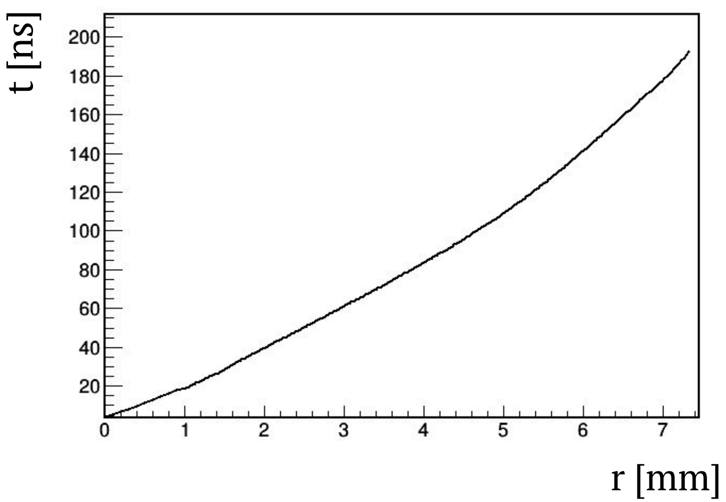
BIS78 sMDT chambers: Working principle



sMDT (**small Muon Drift Tubes**) chambers are used as precision tracking detectors

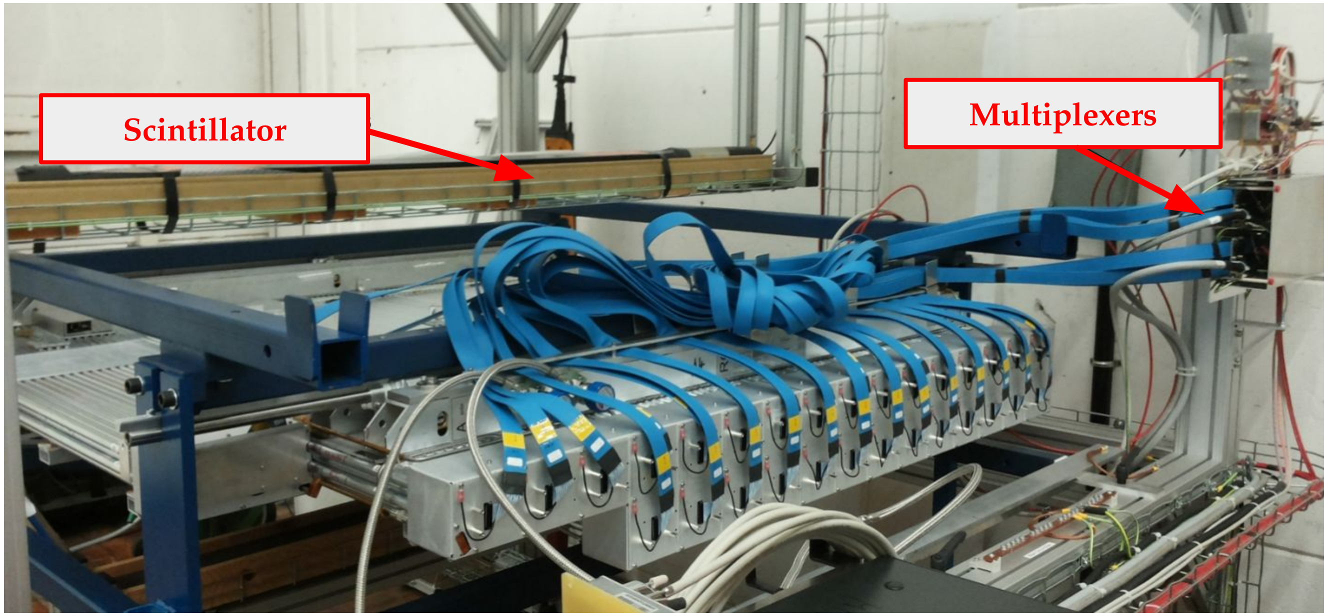
8 layers of tubes organised in 2 multilayers
Measurement of the electron drift time
Conversion of the drift time to the drift radius

Space to drift time relationship



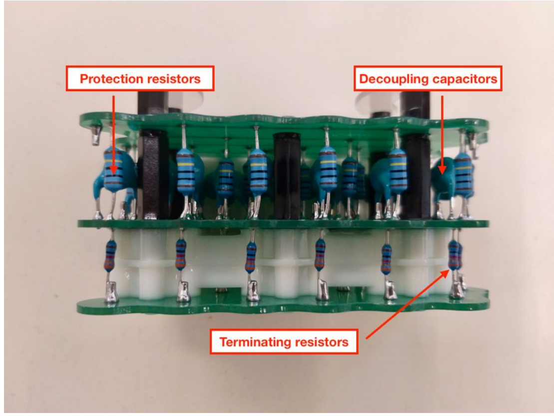
- Reconstruction of the muon trajectory

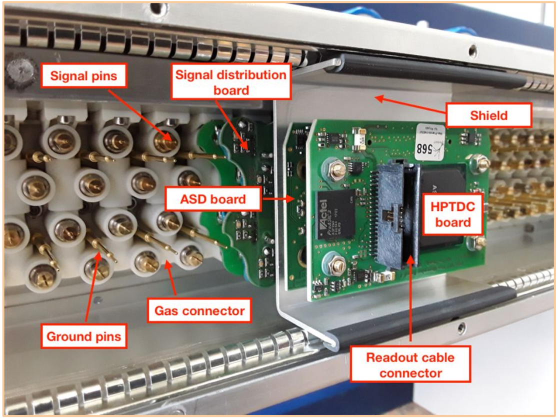
Cosmic ray - test stand



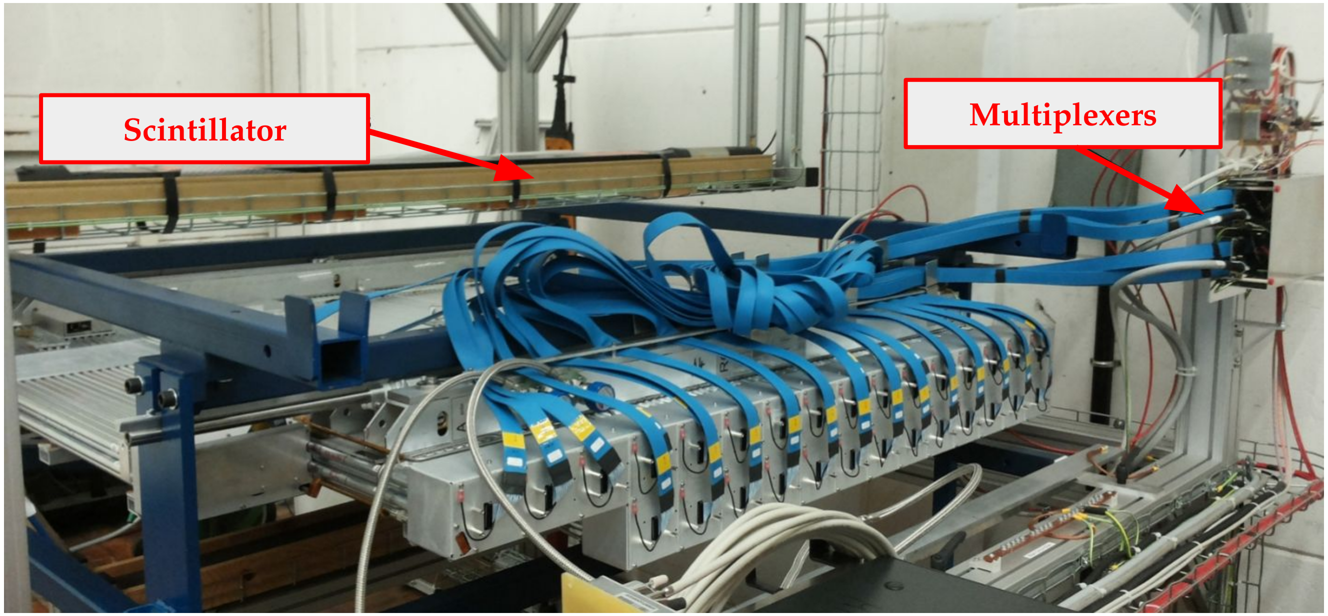
HV side

RO side





Cosmic ray - test stand



Measured quantities:

- Noise level
- Spatial resolution
- Muon detection efficiency

Noise level measurement

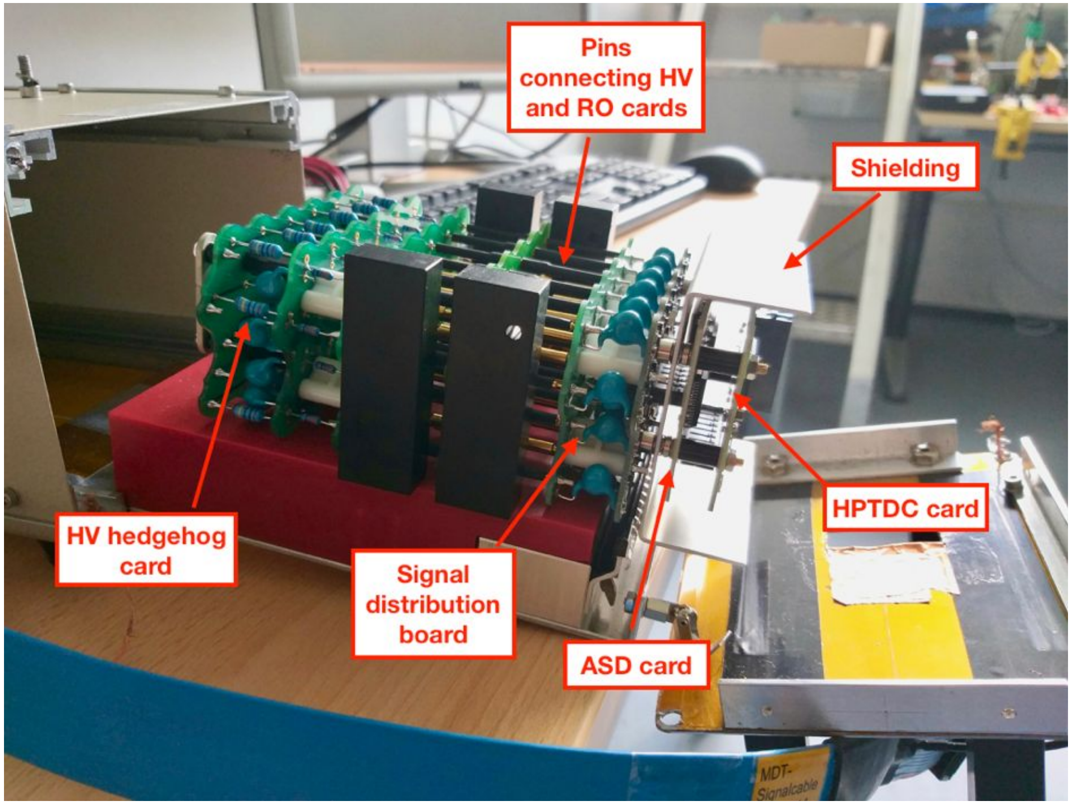
Noise levels are determined as a function of different discriminator threshold.

Off - chamber measurement

- Each mezzanine card is tested in a Faraday cage

On - chamber measurement

- On - chamber noise levels of each card compared with the results from the off - chamber measurement

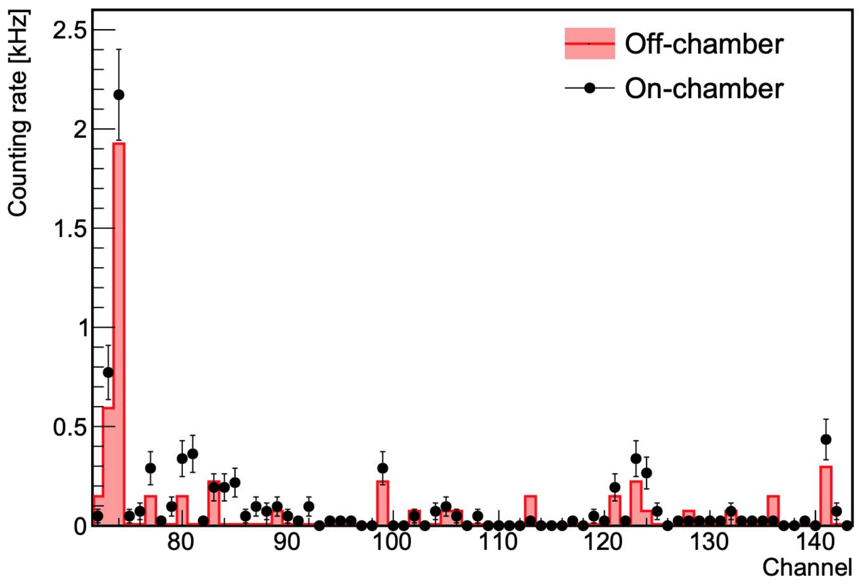


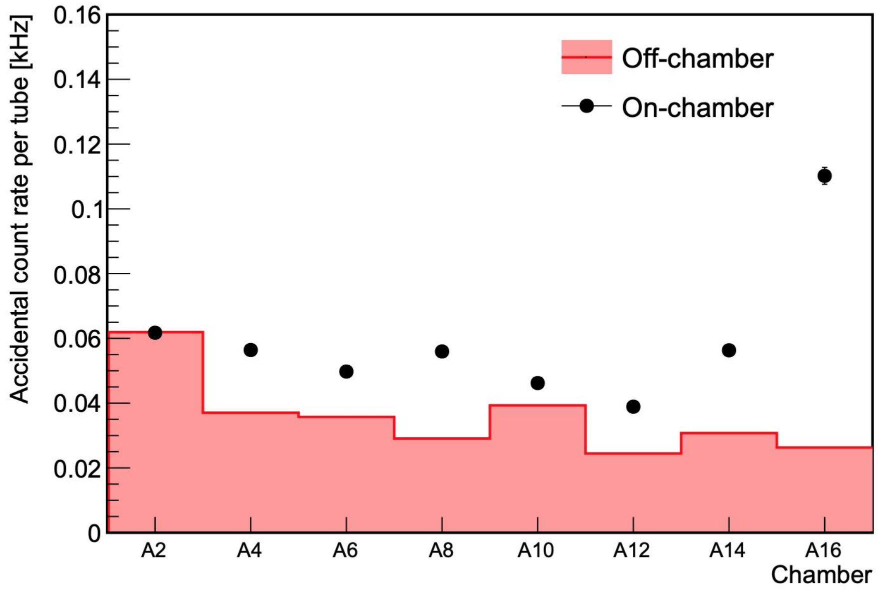
Noise level measurement

BIS78 - A2

All chambers

Segment of 3 mezzanine cards

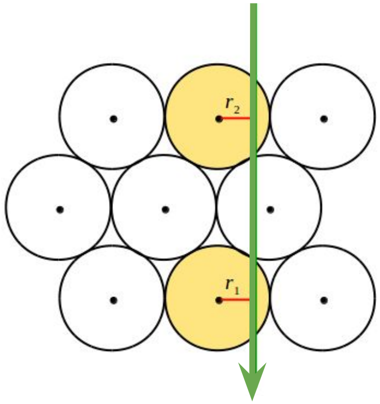




- On - chamber noise rates follow the shape of the off chamber expectation.
- Noise rates are low and do not exceed off - chamber expectation for more than a factor of 2.

Spatial resolution determination

- Low energy cosmic muons are prone to multiple scattering;
- Method that minimizes multiple scattering contribution needed;



For the track passing vertically

$$\sigma(r_{1/2}) = \sigma\left(\frac{r_2 - r_1}{\sqrt{2}}\right)$$

For tracks with inclination (|m<0.01|)

$$\sigma(r_{1/2}) = \sigma\left(\frac{r_2 - r_1}{\sqrt{2}} \mp \frac{m \cdot (z_2 - z_1)}{\sqrt{2 \cdot (1 + m^2)}}\right)$$

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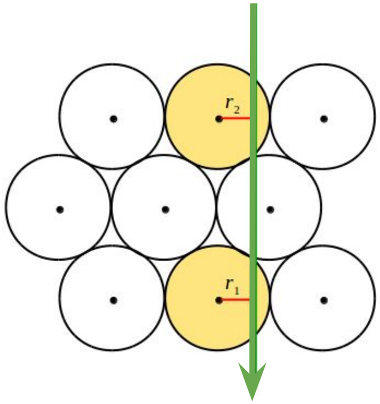

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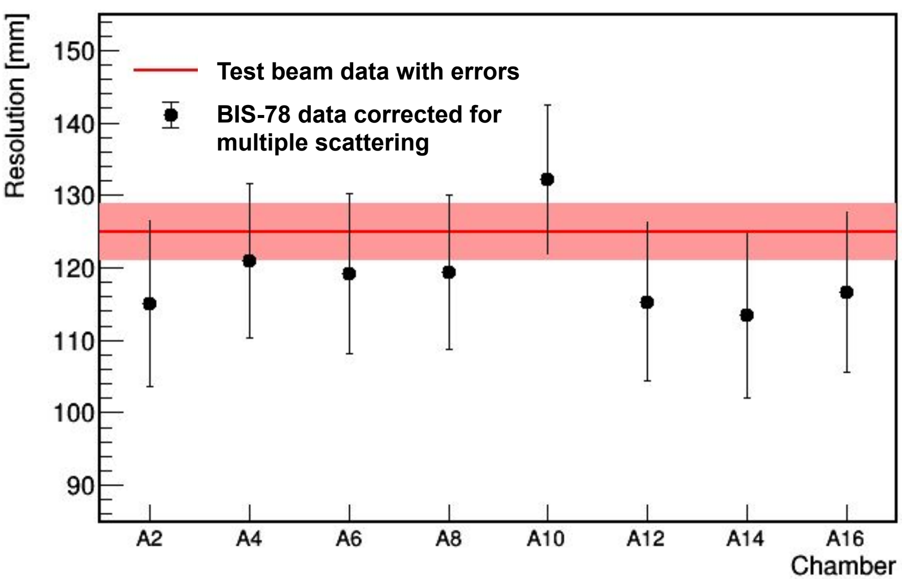
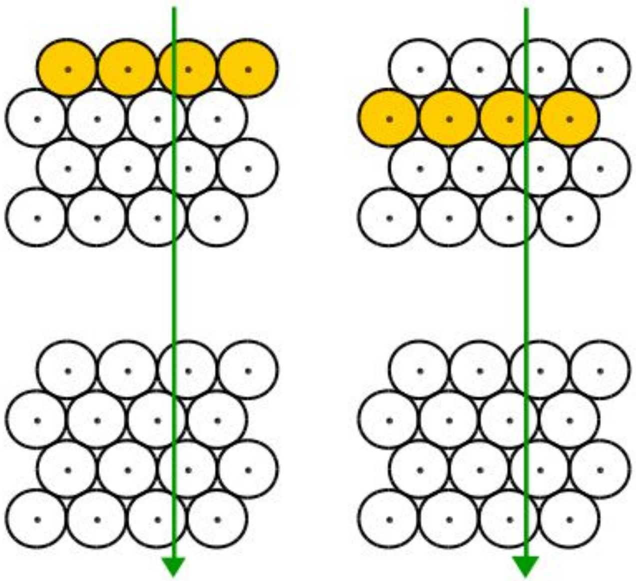


- All tested chambers have same spatial resolution within measurement uncertainties.
- Agreement with expectation from the test beam measurement with high energy muons.

Muon detection efficiency determination

The muon detection efficiency can be determined for every tube in a chamber.



- Muon track is reconstructed by excluding one layers of tubes.
- Check if the tube crossed by reconstructed track in excluded layer has a hit.
- Repeat process for each tube in a layer
- Repeat process for each layer in a chamber

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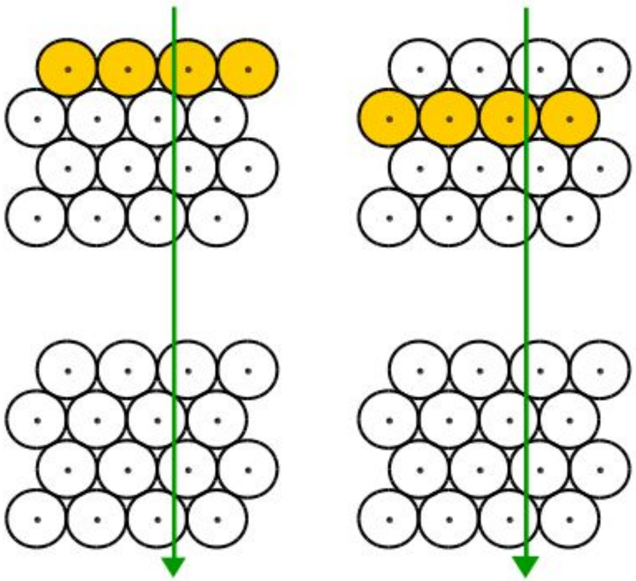

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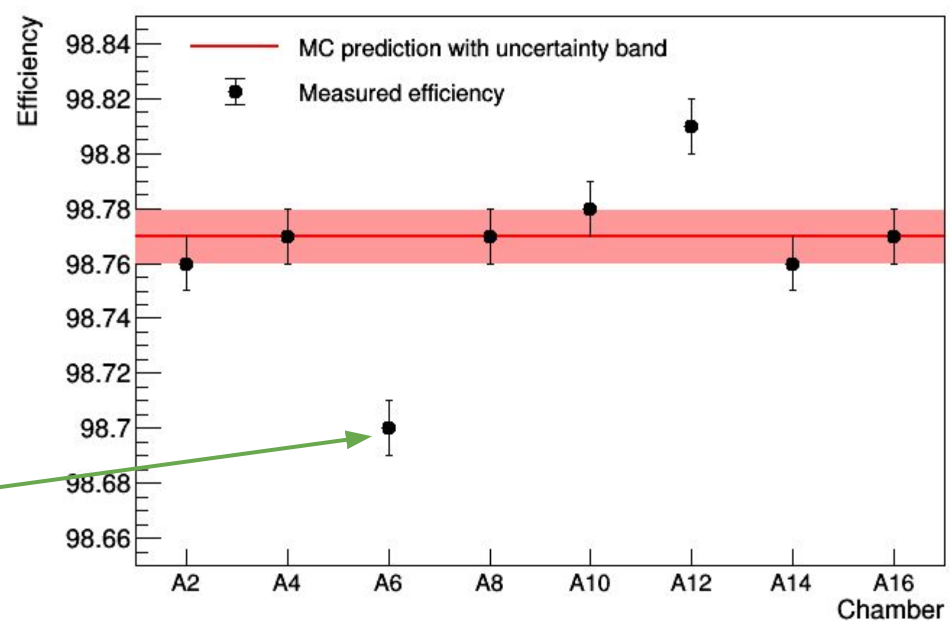
- Repeat process for each layer in a chamber

All chambers



- Measured efficiency in agreement with expected value

Due to the removed broken wire

Operational point of the new ASD chip

- For the HL-LHC a new first-level muon trigger is planned with increased maximum trigger rate to 1 MHz instead of 100 kHz;
- Beyond capability of the TDC chips on current front - end electronics;
  - Front-end boards will be replaced in the 2024/2026 of the LHC;
  - Development of the new ASD chip.

Parameter	Units	Specs	Legacy ASD	New ASD
Signal peeking time	ns	15	14.2	12
Amplification	mV/fC	8.9	10	21
Noise r.m.s	mV	8.5	8	4
Threshold spread	mV		12-16	4
Power consumption	mW		300	360

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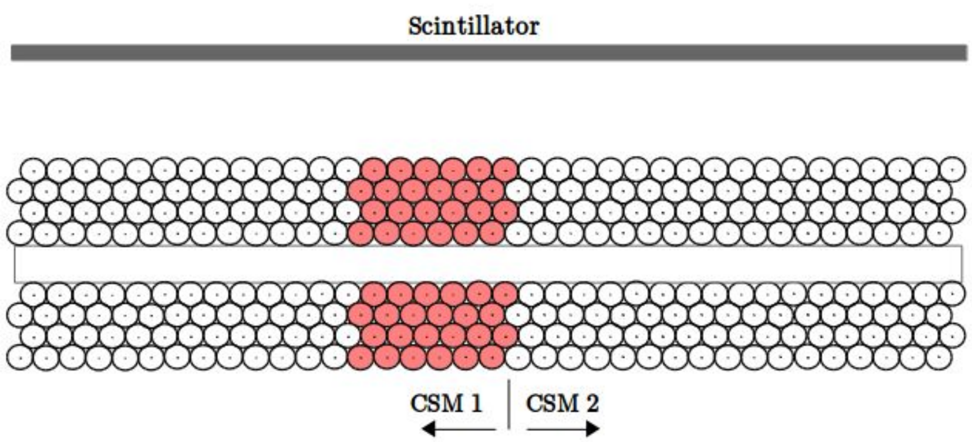

Measured quantities:

- Noise level measurement
- Spatial resolution
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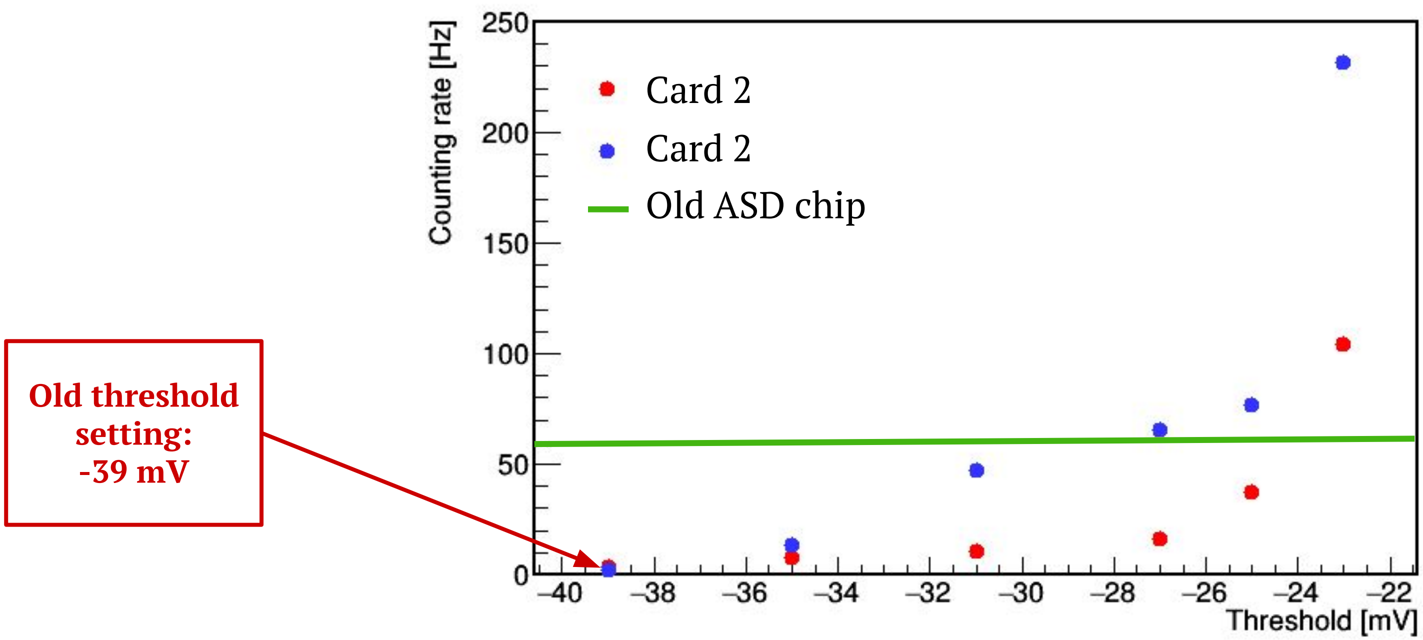
Noise level measurement

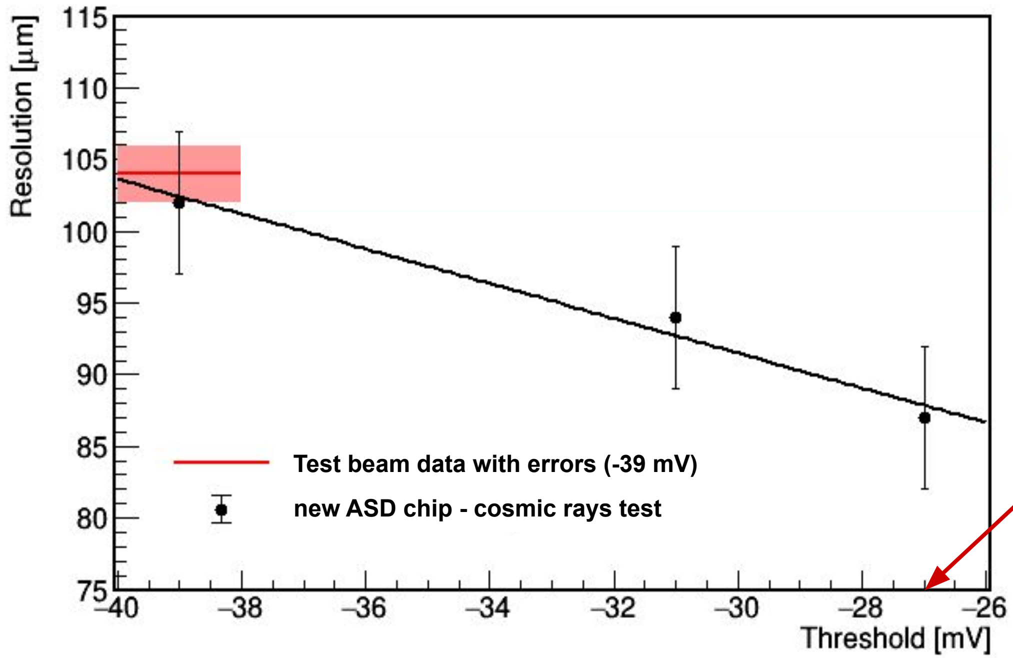
Noise rates determined as a function of the discriminator threshold.



- Lower noise rates compared to the old ASD chips
- Same note rates measured with new as with old chips for 12 mV lower threshold

Spatial resolution

Spatial resolution determined for thresholds: -39 mV, -31 mV and -27mV.

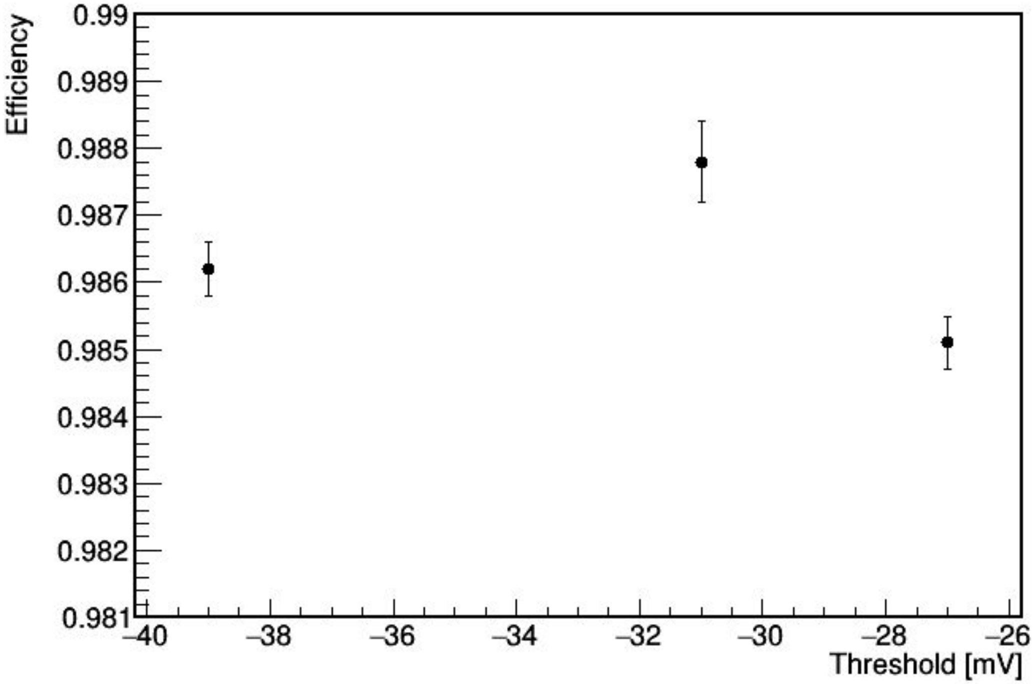


New recommended threshold: -27 mV

- An improvement of the spatial resolution at -39 mV.
- Spatial resolution of ~ 87 µm for 12 mV lower threshold.

Muon detection efficiency

Efficiency determined for thresholds: -39 mV, -31 mV and -27mV.



- Full efficiency at lower thresholds

Summary

BIS-78 sMDT chamber commissioning

- Noise rates in agreement with the intrinsic noise levels of the ASD chip
    - Average noise rate per tube ~ 60 Hz;
- All chambers have expected spatial resolution of ~ 125 µm;
- All tubes of the chambers are fully efficient with the average efficiency of ~ 98.76 % (in agreement with MC prediction).

New ASD chip operational point determination

Lower noise rates measured with new compared to old ASD chip.

Proposed new operational point is -27 mV:

- Noise rates comparable to values measured with old ASD chip;
- An improvement of the spatial resolution to ~87 µm;
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Thank you!

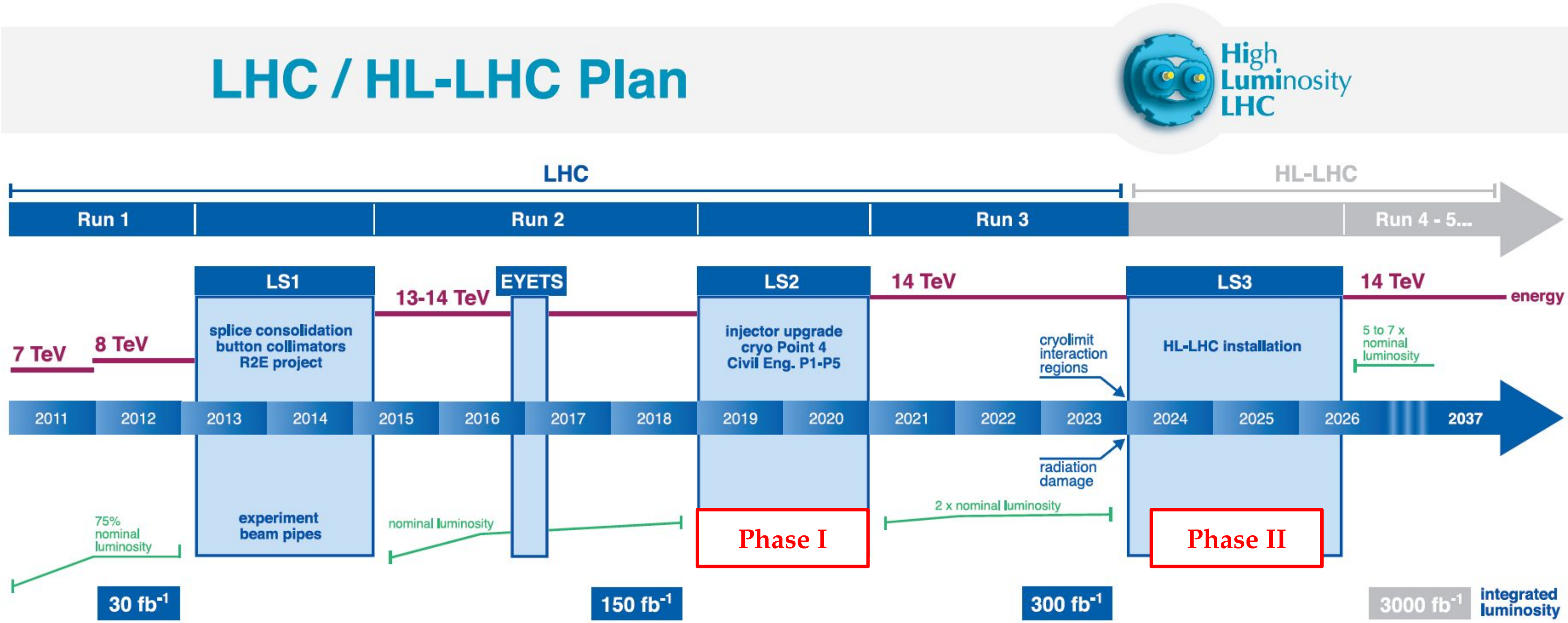
Backup

Towards High Luminosity LHC (HL - LHC)

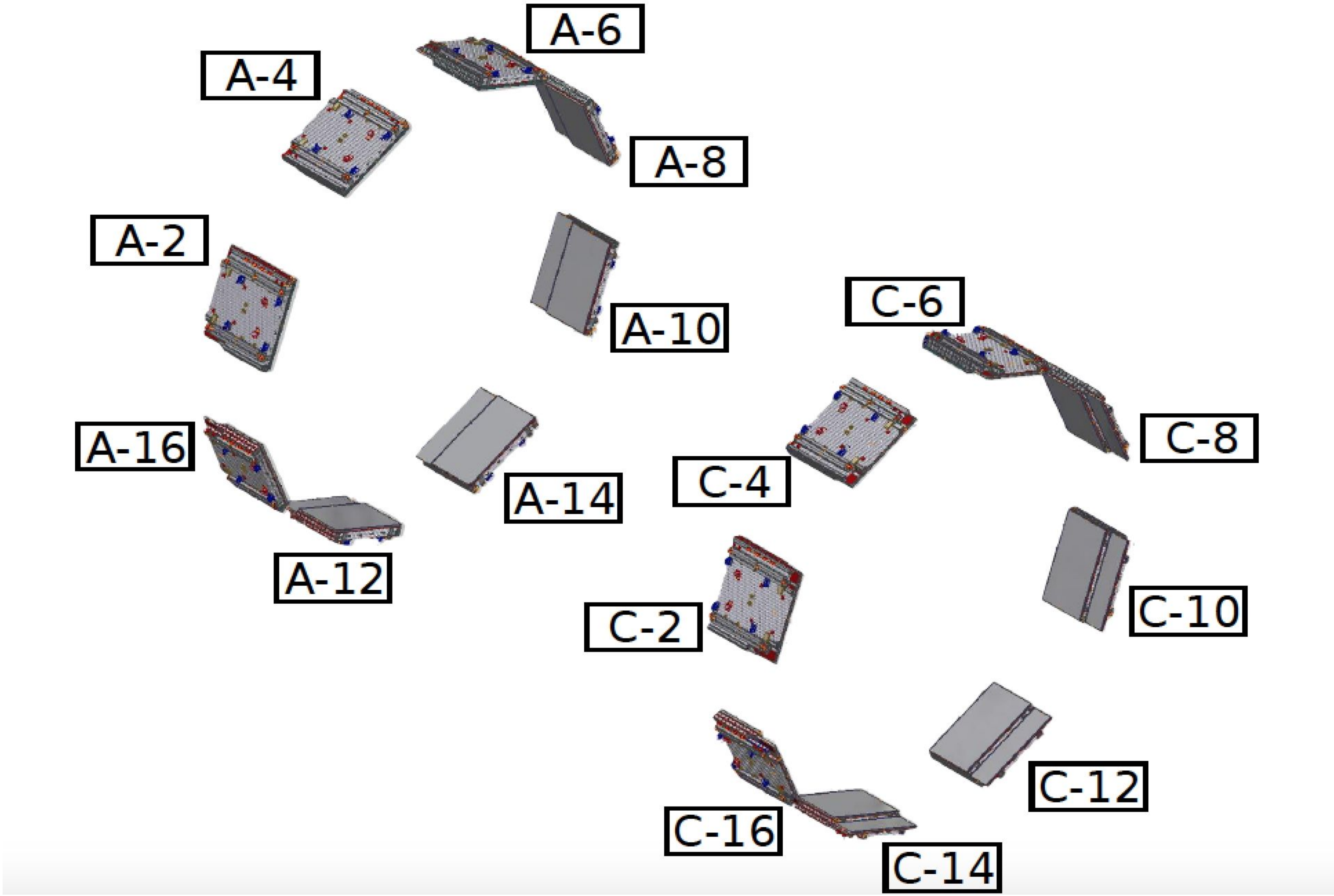
HL - LHC - major upgrade of the LHC to increase its discovery potential after 2025:

- Installation of the new accelerator components

Upgrade of the LHC experiments to withstand new conditions

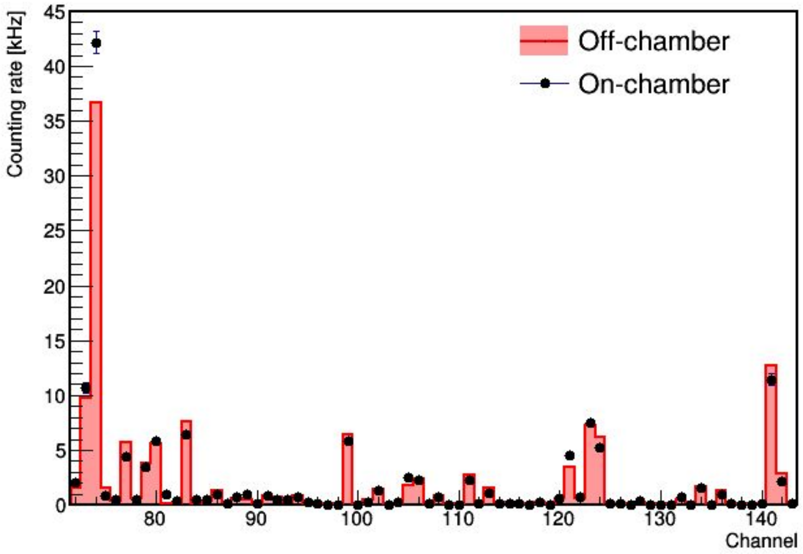


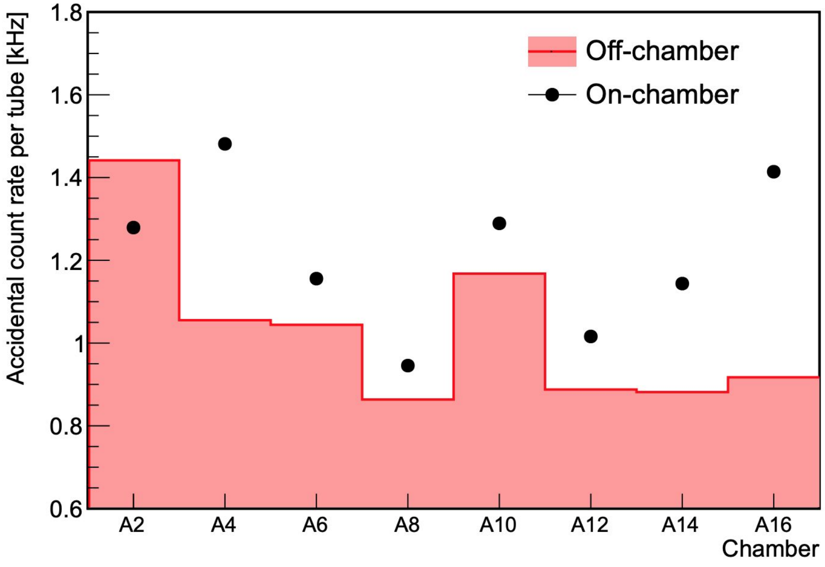
BIS-78 sMDT chambers



Noise measurement - hysteresis 2

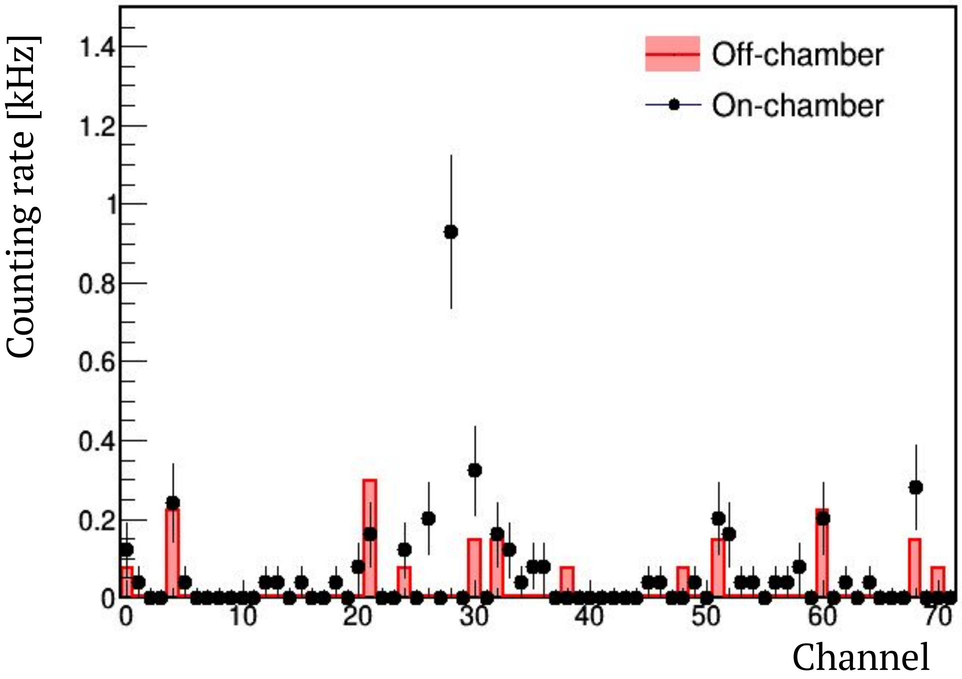
All chambers



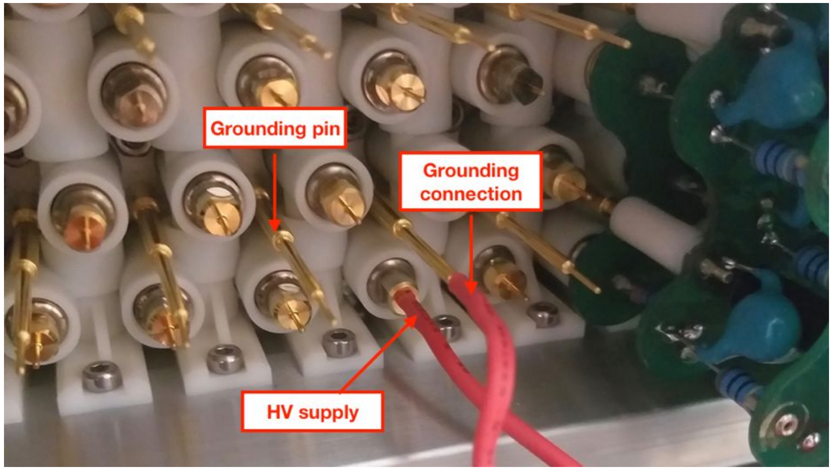


Noise measurement - hysteresis 2

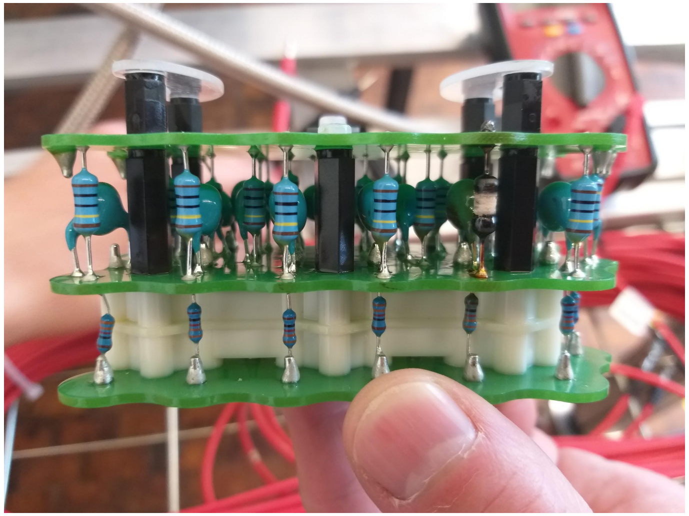
BIS78 - A16



Noise level measurement

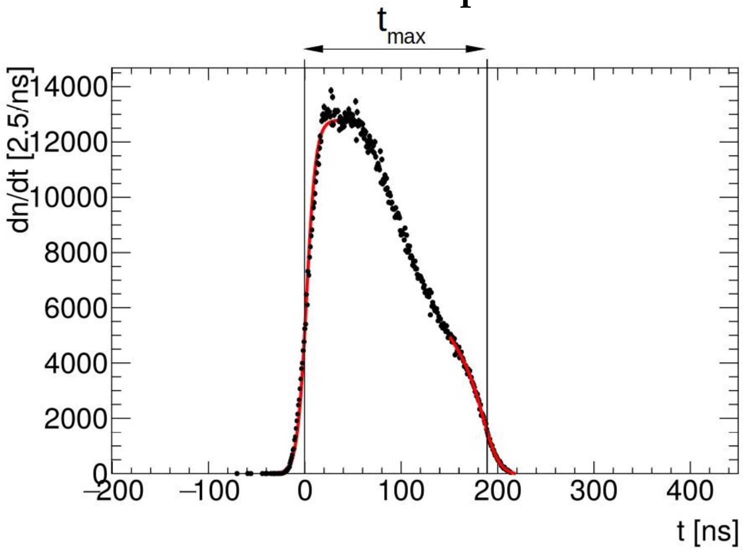


BIS78 - A6



Maximum drift time

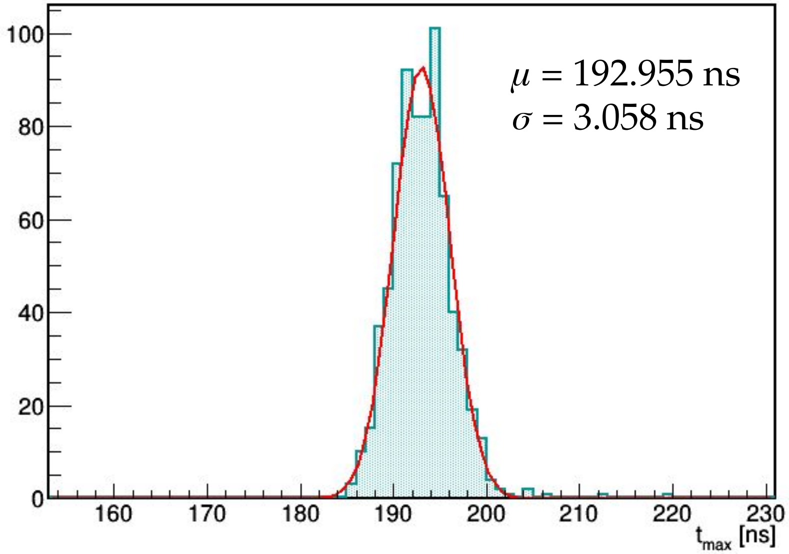
Drift time spectrum



Maximum drift time:

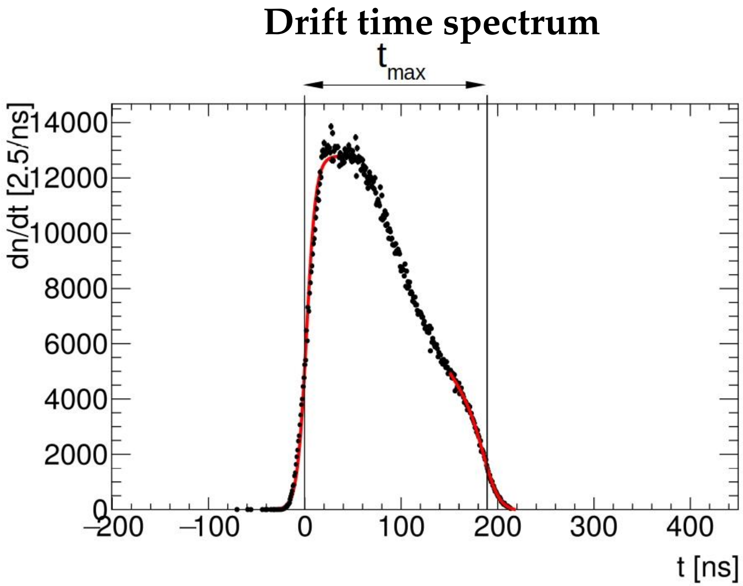
$$t_{max} = t_m - t_0$$

BIS78 - A4



- Standard deviation of the t_{max} distribution equal to the statistical accuracy of the t_{max} measurement.

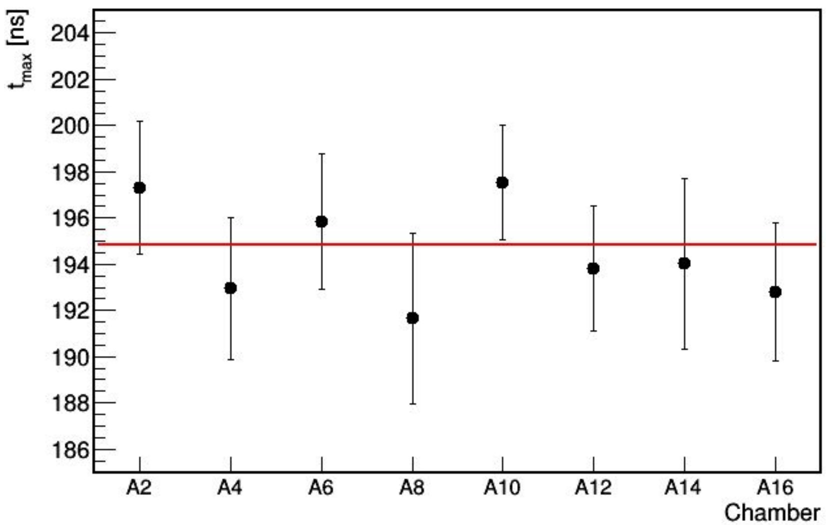
Maximum drift time



Maximum drift time:

$$t_{max} = t_m - t_0$$

All chambers



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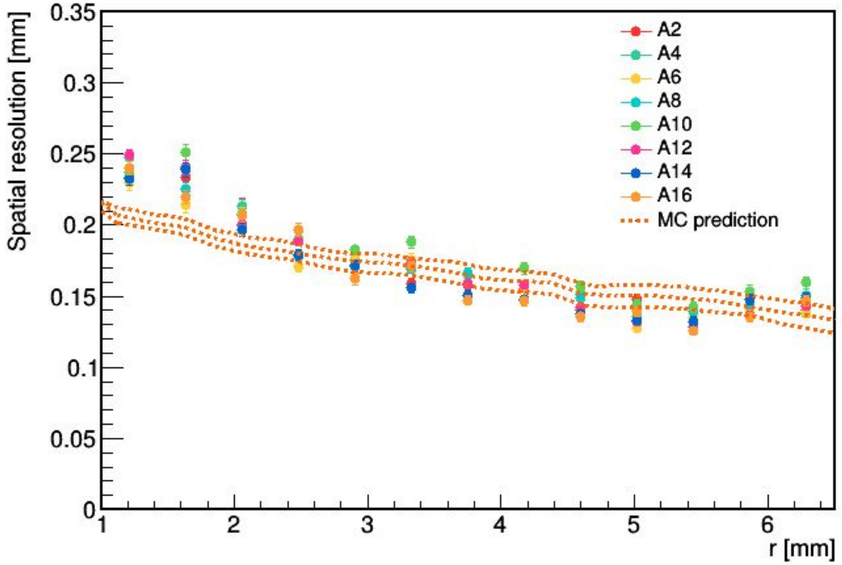
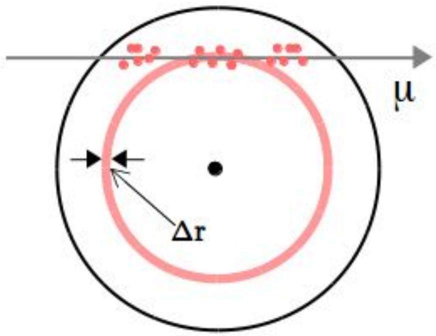
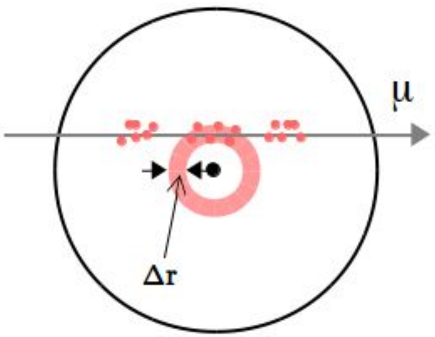
Spatial resolution

Spatial resolution vs drift radius

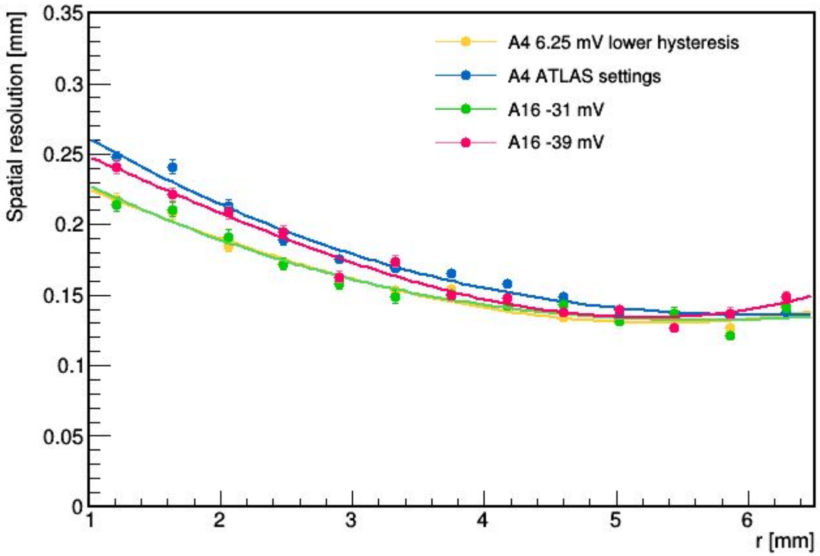


- All tested chambers have same spatial resolution.
- Determined resolution in agreement with MC prediction.





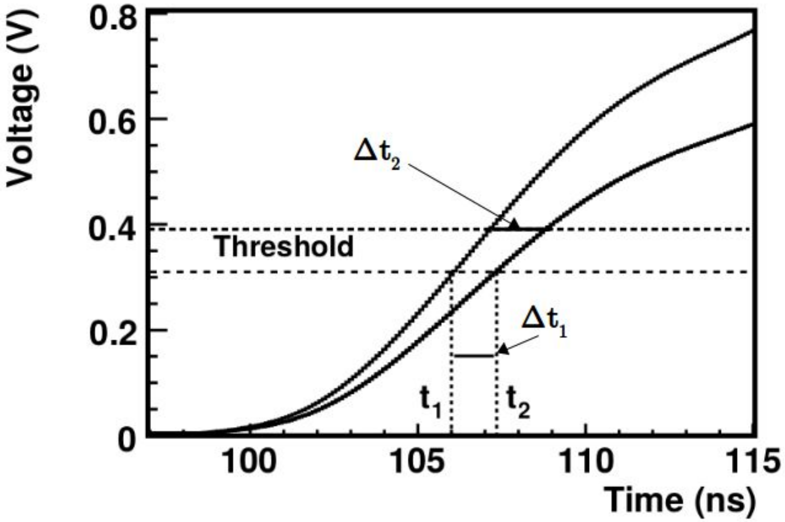
Spatial resolution



Spatial resolution determined for:

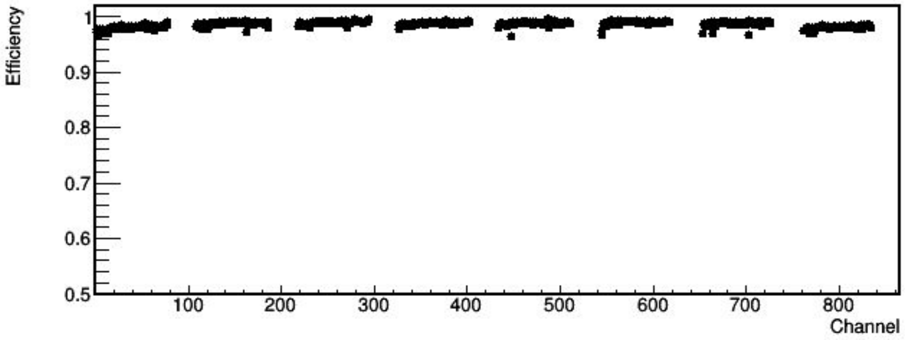
- 6.25 mV lower hysteresis;
- 8 mV lower threshold.

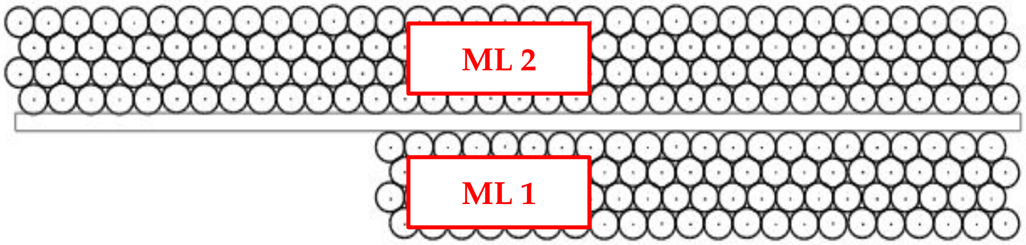
- Slightly better spatial resolution due to the lower effective threshold



Muon detection efficiency

BIS78 - A4





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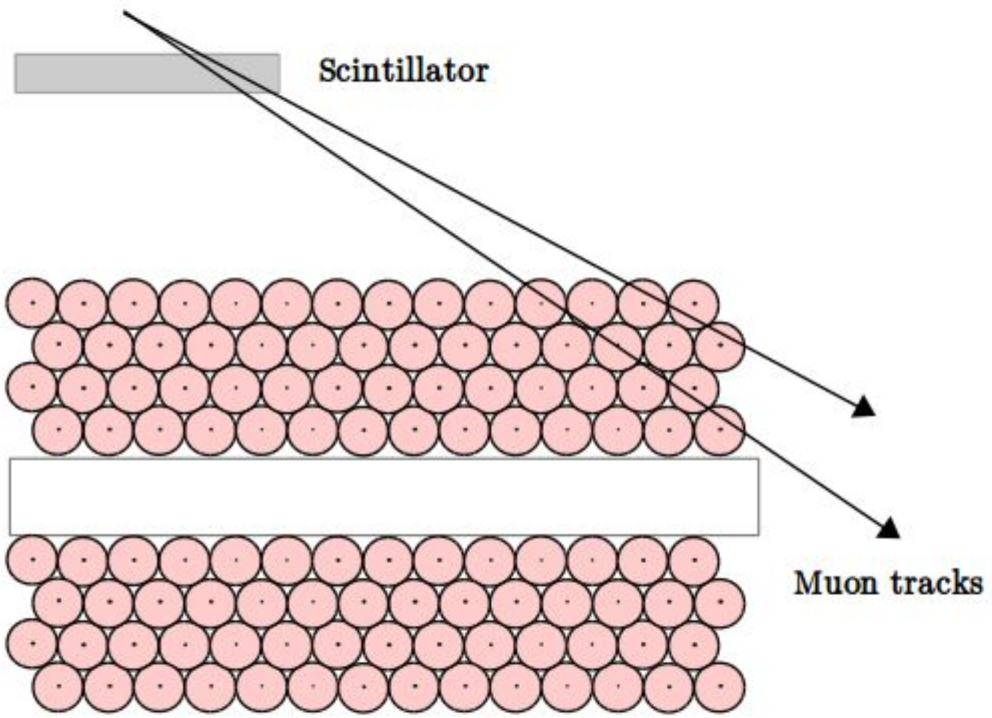

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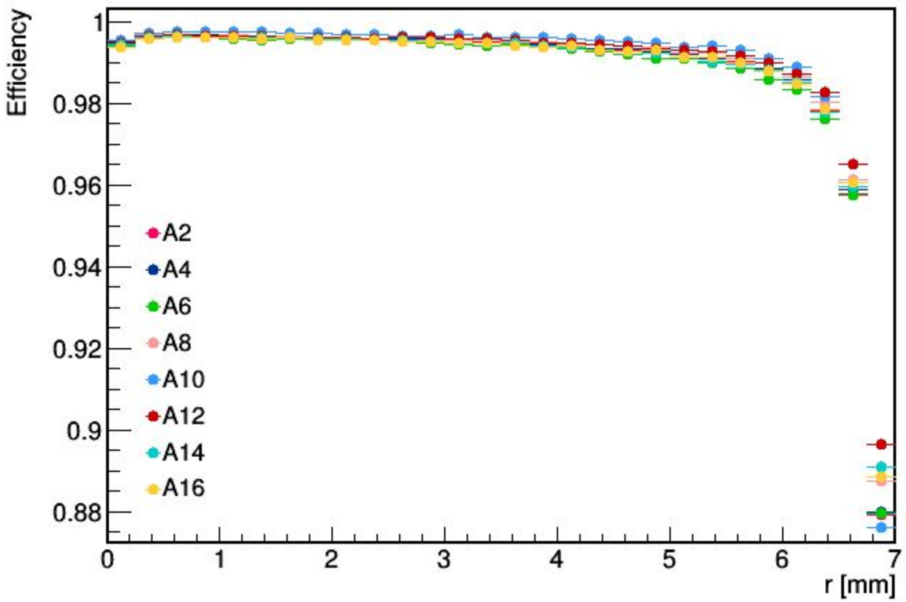
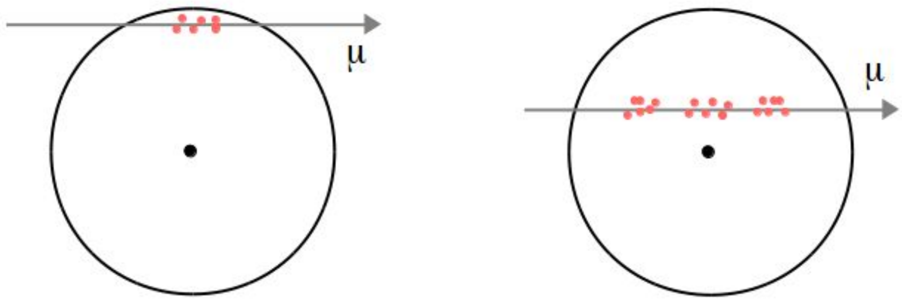


Near the tube wall:
Not enough primary ionisations electrons to cross threshold



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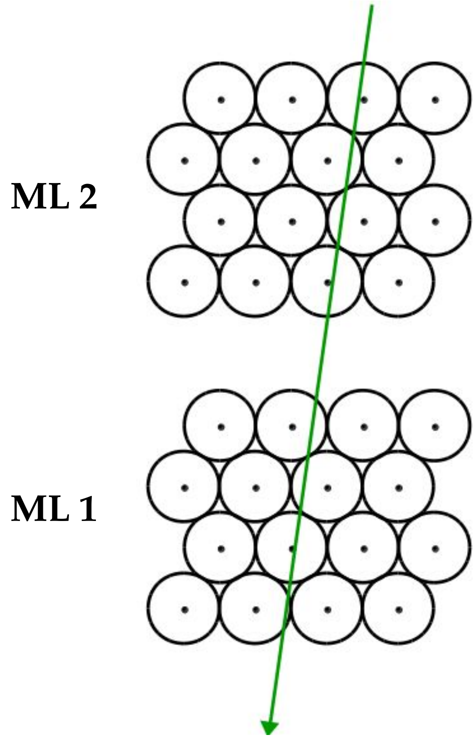
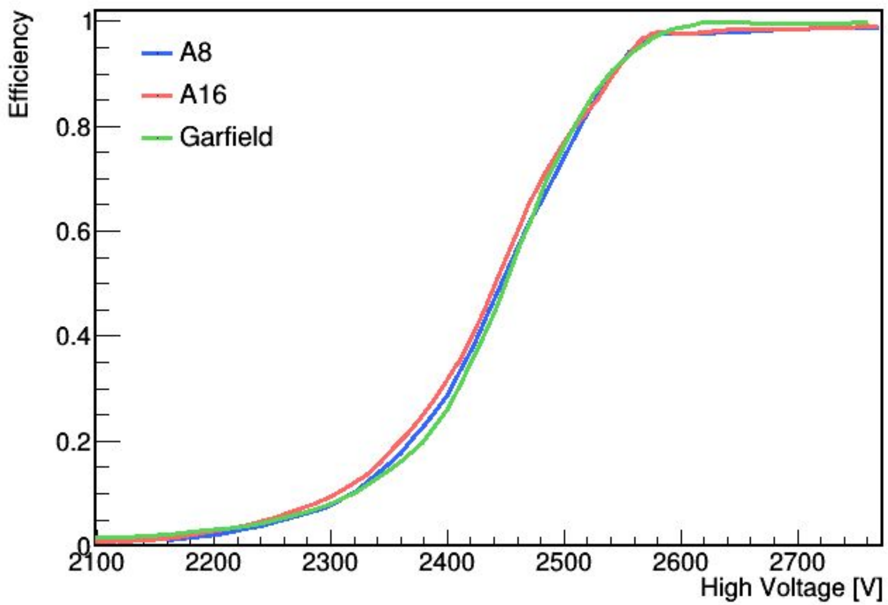


- Dependency of the muon detection efficiency on the applied high voltage was tested

- Multilayer 1: + 2730 V (Operational voltage)
- Multilayer 2: Applying voltages from + 2000 V to + 2770 V
- For each voltage cosmic ray data were taken



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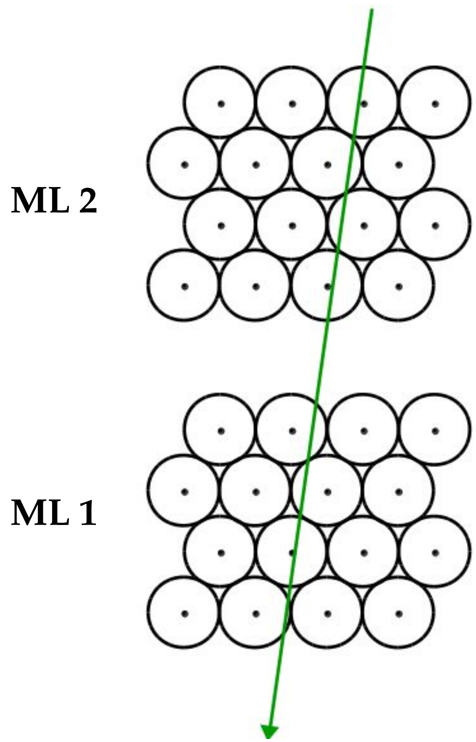

- Dependency of the muon detection efficiency on the applied high voltage was tested

BIS78 - A16