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

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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
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

Fake high $p_T$ muon triggers observed
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.
To suppress fake muon triggers:

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

Working principle

sMDT Operational Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>sMDT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas mixture</td>
<td>Ar:CO$_2$ (93:7)</td>
</tr>
<tr>
<td>Gas pressure</td>
<td>3 bar (abs)</td>
</tr>
<tr>
<td>Gas gain</td>
<td>20 000</td>
</tr>
<tr>
<td>Wire potential</td>
<td>2730 V</td>
</tr>
<tr>
<td>Wire diameter</td>
<td>50 µm</td>
</tr>
<tr>
<td>Single tube resolution</td>
<td>~ 100 µm</td>
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</table>
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

Scintillator

Multiplexers

Protection resistors
Decoupling capacitors
Terminating resistors

Signal pins
Signal distribution board
ASD board
Gas connector
Ground pins
Readout cable connector

Shield
Cosmic ray - test stand

Measured quantities:

- Noise level
- Spatial resolution
- Muon detection efficiency
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

- 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 ($|m|<0.01$)

$$\sigma(r_{1/2}) = \sigma\left(\frac{r_2 - r_1}{\sqrt{2}} + \frac{m \cdot (z_2 - z_1)}{\sqrt{2} \cdot (1 + m^2)}\right)$$
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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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- Repeat process for each layer in a chamber

- Measured efficiency in agreement with expected value

Due to the removed broken wire

All chambers

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.

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<th>New ASD</th>
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<td>Signal peeking time</td>
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<td>14.2</td>
<td>12</td>
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<td>Amplification</td>
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Measured quantities:
- Noise level measurement
- Spatial resolution
- Muon detection efficiency
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 -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 -27 mV.

- 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;
- Full efficiency.
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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

LHC / HL-LHC Plan

- 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

Counting rate [kHz]

Off-chamber
On-chamber
Noise level measurement

BIS78 - A6
Maximum drift time

Drift time spectrum

Maximum drift time:

\[ t_{\text{max}} = t_m - t_0 \]

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

\[ \mu = 192.955 \text{ ns} \]
\[ \sigma = 3.058 \text{ ns} \]
Maximum drift time

Drift time spectrum

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

Maximum drift time:

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

All chambers
Spatial resolution vs drift radius

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

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

- 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
Muon detection efficiency

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

BIS78 - A16