Precision Tracking at High Background Rates with the ATLAS Muon Spectrometer

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Rediscovery of the Standard Model

design: $\Delta p/p = 10\%$ @ 1 TeV

the ATLAS muon spectrometer works according to specs

ATLAS preliminary

Data 2010, $\sqrt{s} = 7$ TeV

Design: $\Delta p/p = 10\%$ @ 1 TeV $\mu \rightarrow \Delta x < 100 \mu m$
Cylindrical Drift-Tube Detector: principle

charged particle

Ar:CO\textsubscript{2} 93:7%
3 bar
3080 V
\(\phi = 3\) cm
gain=20000
\(\Delta r = 80\) \(\mu m\)

\(t_{\text{drift}}\):
measurement

\(r'_{\text{drift}}\):
\(f (t_{\text{drift}}, E\text{-field}, \text{hit rate}, \ldots)\)

autocalibration

\[ \begin{array}{c}
\text{Ar:CO}_2 \\
\text{linear}
\end{array} \]
Space Charge Fluctuations:

- positive ions \(\Rightarrow\) space charge 4 ms
- \(E\)-field \(<\) near anode
- \(E\)-field \(>\) near tube wall

Reduced gas-amplification, fluctuating max. drift-time
\(\Rightarrow\) reduced efficiency
\(\Rightarrow\) reduced spatial resolution
\(\Rightarrow\) rate limited

\[t_{\text{max}} = 4 \text{ ms}\]
Expected Background at HL-LHC: \( L = 5 \times 10^{34} / \text{cm}^2 \text{ s} \)

max. background hit rates:

10 kHz / cm\(^2\) \( @ \ L = 5 \times 10^{34} / \text{cm}^2 \text{ s} \)

high-rate capable detectors necessary

no ageing!

replacement: 2018
LMU Detector-Development Studies for different regions of the $\mu$-spectrometer

option for region of moderate background at HL-LHC:
linear and fast drift-gas (using unmodified 3cm drift-tubes)
gas with electron drift independent on electric field
reduced space charge fluctuations
less occupancy

regions of highest background for LHC and HL-LHC:
sMDT: drift-tubes with reduced radius (15mm) (H. Kroha 12:30)
reduced occupancy (factor 7)
linear region of rt-relation => small space charge fluctuations
high rate capability

micromegas (micromesh gaseous detector)
planar structure with geometrically optimized ion path length
direct position measurement
multi-track resolution
Linear, Fast Drift Gas  \( \text{Ar:CO}_2:\text{N}_2 \)  
option for 3cm drift-tubes at HL-LHC 

Garfield / Magboltz simulation 

less \( \text{CO}_2 \) => faster gas 
\( \text{N}_2 \): modifies only the region \( r < 0.4 \text{ cm} \) => more linear 

\[ \Rightarrow \text{Ar:CO}_2:\text{N}_2 \ 96:3:1 \ % \text{ Vol.} \]
Reduced Background Sensitivity Ar:CO$_2$:N$_2$

3 cm drift-tubes

gamma irradiation facility CERN

Ar:CO$_2$: $t_{\text{max}} = 680$ ns
Ar:CO$_2$:N$_2$: $t_{\text{max}} = 440$ ns

1900 Hz/cm$^2$:
Ar:CO$_2$: $\Delta r = 234$ $\mu$m
Ar:CO$_2$:N$_2$: $\Delta r = 129$ $\mu$m
Ageing Study of Ar:CO₂ 93:7 and Ar:CO₂:N₂ 96:3:1 for 3 cm drift-tubes

No ageing observed! 1 lifetime ATLAS in 6h

105 nA p 20 MeV
irradiated spot: 7 cm * 1 cm

=> 7 As / 7 cm = 1 * lifetime ATLAS
Option for 3cm Drift-Tubes @HL-LHC
Ar:CO$_2$:N$_2$  96:3:1 % Vol.

linear drift gas, strongly reduced space charge fluctuations

$t_{\text{max}} : 440 \text{ ns} \quad \longleftrightarrow \quad 680 \text{ ns}$
factor 1.5 less occupancy

no ageing

very small amount of afterpulses,
$t_{\text{max}}(\text{Ar:CO}_2:\text{N}_2)$ never longer than $t_{\text{max}}(\text{Ar:CO}_2)$

no streamer observed  @  gas gain 20000
Regions of Highest Background @ LHC and HL-LHC

Micromegas Detectors

features:

excellent position resolution
trigger capability
high rate capability
multiple track resolution

$X_{\text{strip}}, t_{\text{strip}} \Rightarrow$ position and angle of $\mu$-track
MicroMeGaS Detector 9x10 cm²

-930 V
Ar:CO₂ 93:7%
1 bar
-530 V
anode strips
pitch: 250 µm

-530 V
cathode
-900 V

5 mm
0.8 kV/cm
128 µm
40 kV/cm

amplifying mesh including pillar
Determination of Spatial Resolution with 160 GeV $\pi$ @H6 / CERN using tracking telescope

\[ \sigma_{sr} = \sqrt{\sigma_{ex}^2 - \sigma_{track}^2} \]

\(\sigma_{ex} = 55 \mu m\)

one detector excluded from fit

data: H6 / CERN July 2011

\[ \text{residual} \]

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<td>Mean</td>
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<tr>
<td>Sigma</td>
<td>$0.05456 \pm 0.00034$</td>
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</table>
4 standard micromegas: copper strips, 250 μm pitch
9 x 10 cm² Gassiplex readout

spatial resolution

E_{amp}=42.2 kV/cm
E_{amp}=39.1 kV/cm

data: H6 / CERN July 2011

hit efficiency

E_{amp}=42.2 kV/cm
E_{amp}=39.1 kV/cm

data: H6 / CERN July 2011

spatial resolution 35 μm @ 160 GeV π, orthogonal beam
tracking resolution < 20 μm to test large structures w. 4 micr.
efficiency > 99 % @ Ar:CO₂ 85:15 1 bar
Two Approaches to Reduce Sensitivity to Discharges

resistive strip technology

floating strip technology

idea:
discharge loads upper strip
discharge stops as potential on strip rises
fast recovery process, ageing?

5.8 MeV $\alpha$ induce discharges @ $3 \times 10^8$ e$^-$/mm$^2$

Data LMU July 2012
Resistive Strip MM in 11 MeV Neutron Beam @ LMU

Resistive strip MM

HV_mesh

stable running

I_mesh

$10^7 \text{ n/cm}^2 \text{s}$  30x30cm$^2$

MBT0 ATLAS

minimum bias trigger region

very high background rates

detector current scales similar to luminosity

stable running, ageing-test

CERN ATLAS MBT0
Summary: High Precision $\mu$ Tracking at HL-LHC

$\text{Ar:CO}_2:\text{N}_2$ 96:3:1 option for regions of medium hit-rates @ HL-LHC

fast linear drift-gas using 3cm MDT hardware, e.g. Big-Wheel

**micromegas:**
- excellent position resolution $\Delta r = 34 \, \mu\text{m}$
- 4 – 8 MM-detectors: track-res $< 20 \, \mu\text{m} \Rightarrow$ test of large structures
- efficiency $> 99 \%$ @ 1 bar Ar:CO$_2$
- resistive strip technology reduces deadtime due to discharges
- ageing test in MBT region ongoing

**future projects:**
- new Small-Wheel: MICROMEGAS as tracking chambers + TGC (thin gap chamber) as trigger chambers
- 2m * 0.6 m large MM structures currently under investigation
- construction of 2*4 layer module ongoing
Backup
Determination of Spatial Resolution – 3 Layer Method

- Interpolate track prediction by two detectors into 3rd and compare with measured hit in that detector.
- \[ \delta = r_3 - r_2 \frac{d_{13}}{d_{12}} - r_1 \left(1 - \frac{d_{13}}{d_{12}}\right) \]
  \[ (\Delta \delta)^2 = (\Delta r_3)^2 + \left(\frac{d_{13}}{d_{12}} \Delta r_2\right)^2 + \left[(1 - \frac{d_{13}}{d_{12}}) \Delta r_1\right]^2 \]
- 4 different triplett-equations & 4 \[ \Delta r_i \rightarrow \text{solvable system} \]
Investigation: End of Analog Signal

Ar:CO\(_2\):N\(_2\) 93:6:1 % Vol
very small amount of afterpulses,
\(t_{max}\) never longer than at Ar:CO\(_2\)
Analog Signal: Ar:CO2 93:7 %