The **Muon ATLAS MicroMegas Activity** (Micromegas R&D for ATLAS/sLHC)

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NTU Athens

On behalf of the **Muon ATLAS MicroMegas Activity** (MAMMA R&D)

See also poster #1024

EPS – HEP 2011
Outline

• Micromegas as an R&D project for ATLAS for sLHC

• Structure of Micromegas chamber with resistive strips

• Laboratory tests:
  o $^{55}$Fe source
  o X-ray gun

• Neutron beam tests at “Demokritos” lab in Athens:
  o V-I characteristics under neutron beam
  o Spark probability

• Beam tests at H6-SPS/CERN:
  o V-I characteristics
  o Spark probability
  o Tests in ATLAS cavern

• Future Plans
ATLAS upgrade for the s-LHC

LHC upgrade to happen in two phases

\[ L_{\text{Phase 1}} \approx 3 \, L_{\text{LHC}} \ (\sim 2014) \]

\[ L_{\text{Phase 2}} \approx 10 \, L_{\text{LHC}} \ (\text{s-LHC} > 2017) \]

Bunch Crossing = 25 ns / possibly 50 ns (Phase 2)

Muon Spectrometer affected regions:

- End-Cap Inner (CSC, MDT, TGC)
- End-Cap Middle \(|\eta| > 2\) (MDT, TGC)

Total area \(\sim 400 \text{ m}^2\)

Replace the Cathode Strip Chambers (CSC)
The expected neutron fluence (kHz/cm²) in the ATLAS Hall (ATLAS muon TDR, 1997)

The energy spectrum of the expected neutron background radiation in the Atlas Hall (ATLAS muon TDR, 1997)

MDT Backgrounds using hit rate
ATLAS Muon upgrade Imposed Specs

• Combine triggering and tracking functions
• Matches required performances:
  – Spatial resolution <80 μm (θ_{track}< 45°)
  – Good double track resolution
  – Time resolution ~ 5 ns
  – Efficiency > 99%
  – Rate capability > 5 kHz/cm²
  – 200 Hz/cm² due to neutrons with E>100 keV
  – Stability over about 5 years at phase-1 luminosity (≅1000 fb⁻¹)

• Cover large areas ~1m x 2m with industrial process
  – Cost effective & Robustness
Micromegas (I. Giomataris et al., NIM A 376 (1996) 29) are parallel-plate chambers where the amplification takes place in a thin gap, separated from the conversion region by a fine metallic mesh.

- The thin amplification gap (short drift times and fast absorption of the positive ions) makes it particularly suited for high-rate applications.
2008-2009: Demonstrated Performance

![Graph showing position resolution vs. strip width with data points and a trendline indicating Eff = 99.4%]

- Safe operating point with excellent efficiency (gas gain: $3-5 \times 10^3$).
- Superb spatial resolution has been demonstrated in beam test.
- Timing performance sufficient for triggering.
- Potential to deliver track vector in a single plane for track reconstruction and LV1 trigger.

Pillars contribute to the geometrical inefficiency of the chamber at the ~1% level.

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Sparks/Discharges

- Sparks are a major concern: they can create dead time and/or damage in the detector
- Sparks develop when local electron charge concentrations exceed a few $10^7$ e\(^-\) (Raether limit, $M<10^8$)
  
  For a gas gain of $10^4$ any ionization process creating $\geq 10^3$ electrons in a small volume risks the development of a spark, e.g. heavily ionizing particles induced by neutrons
- Two ways to approach the problem
  1. Avoid high concentrations of charge, e.g. by spreading the charge (multi-stage GEMs or Micromegas)
  2. Live with it and make the detector insensitive to sparks
- We opted for the latter and evaluated different resistive coating options ...

and it seems we found one doing the job
Induced charge

$C_A$  

Amp

Copper strip 0.15 mm x 10 cm

Resistive strip

C1  

C3  

C2  

C4  

R1

-HV

Mesh

C1 – capacitance Mesh to ground  
C2 – capacitance R-strip to ground  
C3 – capacitance R-strip to readout strip  
C4 – capacitance readout strip to ground  
$C_A$ – input capacitance of preamplifier
Eight resistive strip detectors tested

- Small 9 x 8 cm² chambers with 250 μm r/o strip pitch

<table>
<thead>
<tr>
<th>Chamber</th>
<th>$R_{GND}$ (MΩ)</th>
<th>$R_{strip}$ (MΩ/cm)</th>
<th>$N_R$:$N_{ro}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>R11</td>
<td>15</td>
<td>2</td>
<td>1:1</td>
</tr>
<tr>
<td>R12</td>
<td>45</td>
<td>5</td>
<td>1:1</td>
</tr>
<tr>
<td>R13</td>
<td>20</td>
<td>0.5</td>
<td>1:1</td>
</tr>
<tr>
<td>R14</td>
<td>100</td>
<td>10</td>
<td>1:1,2,3,4,72</td>
</tr>
<tr>
<td>R15</td>
<td>250</td>
<td>50</td>
<td>1:1,2,3,4,72</td>
</tr>
<tr>
<td>R16</td>
<td>55</td>
<td>35</td>
<td>x-y readout</td>
</tr>
<tr>
<td>R17</td>
<td>100</td>
<td>45</td>
<td>x-y readout</td>
</tr>
<tr>
<td>R18</td>
<td>200</td>
<td>100</td>
<td>x-y readout</td>
</tr>
<tr>
<td>R19</td>
<td>50</td>
<td>50</td>
<td>xuv readout</td>
</tr>
</tbody>
</table>

- Variety of resistance values
- Different configurations
- Gas gains
  - $2–3 \times 10^4$
  - $10^4$ for stable operation
Laboratory Tests

R12, R13 Gain for 93:7 and 85:15 Ar:CO₂

(⁵⁵Fe source, E_{drift} constant)

<table>
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<tr>
<th>Chamber</th>
<th>R_{GND} (MΩ)</th>
<th>R_{strip} (MΩ/cm)</th>
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<tr>
<td>R12</td>
<td>45</td>
<td>5</td>
</tr>
<tr>
<td>R13</td>
<td>20</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Ar:CO₂ 93:7

Ar:CO₂ 85:15

Mesh Voltage

Gain
R11, R12, and R13 are working fine with the $^{55}$Fe source and with X-ray gun.

Very good homogeneity along the strips

Clean signals up to $>1$ MHz/cm$^2$, but some loss of gain

Gain $\approx 5000$
Neutron Beam Test at Demokritos

- Exposed R11, R12, R13, R16 and a standard MM in a neutron beam at Demokritos NRC (Athens); serves as a Micromegas beam test lab
- Neutrons of 5.5 MeV with fluxes up to $1.5 \times 10^6$ n/cm$^2$ s
- Gas mixtures tested: Ar:CO$_2$ (80:20; 85:15, 93:7)

<table>
<thead>
<tr>
<th>Nuclear Reaction</th>
<th>Proton/Deuteron Energy Range (MeV)</th>
<th>Neutron Energy Range (MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^7\text{Li}(p,n)^7\text{Be}$</td>
<td>1.9 to 8.4</td>
<td>0.1 to 6.7*</td>
</tr>
<tr>
<td>$^2\text{H}(d,n)^3\text{He}$</td>
<td>0.8 to 8.4</td>
<td>3.9 to 11.5**</td>
</tr>
<tr>
<td>$^3\text{H}(d,n)^4\text{He}$</td>
<td>0.8 to 8.4</td>
<td>16.4 to 25.7***</td>
</tr>
</tbody>
</table>

Neutron fluences can reach $\sim 5 \times 10^6$ neutrons/cm$^2$ s but for $d$-$^3\text{H}$ is lower an order of magnitude compared to the $d$-$^2\text{H}$ reaction due to cross section energy dependence.
Neutron Test Beam

MM mesh currents in neutron beam

Gas: Ar:CO₂ (85:15)  Neutron flux: ≈ 1.5x10⁶ n/cm² s

**Standard MM:**
- Large currents
- Large HV drops, recovery time O(1s)
- Chamber could not be operated stably

**R11:**
- Low currents
- Despite discharges, but no HV drop
- Chamber operated stably up to max HV
Test Beam with 5.5 MeV Neutrons

Neutron flux $1.5 \times 10^6$ n/(cm$^2$ s)

- Typically a few sparks/s for gain $10^4$
- About 4x more sparks with 80:20 than with 93:7 Ar:CO$_2$ mixture

- Neutron interaction rate independent of gas
- Spark rate/n is a few $10^{-8}$ for gain $10^4$
Conclusions from neutron test

- R11, R12, R13, R16 worked fine in a neutron flux of up to $1.5 \times 10^6$ n/cm$^2$ s.
- Despite sparks, no HV breakdown, no dead time.
- Measured three Ar:CO$_2$ gas mixtures, 93:7 looks very interesting, with a spark rate almost a factor $\sim 4$ lower than for 80:20.
Beam test in SPS/H6

- R11, R12, R13, and P3 chambers were tested in +120 GeV pion beam (intensities 40 kHz & 5 kHz) for two Ar:CO$_2$ mixtures, 85:15 and 93:7

- Main goals:
  - Study HV and current behavior of resistive and non-resistive chambers in a hadron beam
  - Measure performance (spatial resolution and efficiency) of resistive chambers
  - Study performance of long strips (0.4 m & 1m, non-resistive)
  - A few million of events are being analyzed
Beam test in H6

Ar:CO$_2$ – 85:15
+120 GeV pions

Slow Control Monitor for P3

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Beam test in H6

R12 (Ar:CO$_2$ 85:15) 120 GeV pion beam

Ar:CO$_2$ – 85:15
Number of Clusters – Ar:CO2-85:15

Number of Clusters

Cluster Size

Number of Clusters – Ar:CO2-93:7

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Inclined tracks (40°) – µTPC

Run: 6248, Event: 11

R11

R12

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... and a two-track event
Assembly of large resistive MM
1.2 x 0.6 m²
MM test in ATLAS cavern

- During February the infrastructure was installed in the ATLAS cavern
  - Location on HO (side A) 6th floor, R=6 m
  - HV and ethernet cables to USA15; HV mainframe and DAQ PC in USA15
  - Gas pipe from GSX1 to location close to rack
  - Small rack connected to safety system
- End of March installation of MMs & DAQ
  - 2 MMs for triggering only (standalone)
  - 2 MMs (R16 with xy readout and R13)
  - DAQ using the SRS system and DCS
MM test in ATLAS cavern

Events as function of time taken 13.04.2011
Rate at $L \approx 2 \times 10^{32}$ cm$^{-2}$ s$^{-1}$ is about 1/minute

ATLAS Online Luminosity

<table>
<thead>
<tr>
<th>Luminosity (10$^{30}$ cm$^{-2}$ s$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
</tr>
<tr>
<td>250</td>
</tr>
<tr>
<td>200</td>
</tr>
<tr>
<td>150</td>
</tr>
<tr>
<td>100</td>
</tr>
<tr>
<td>50</td>
</tr>
<tr>
<td>0</td>
</tr>
</tbody>
</table>

CEST Time

time_s

Entries 191
Mean 1.303e+09
RMS 9141
Summary & Outlook

- Micromegas fulfills all the ATLAS imposed requirements; it seems to be a good candidate for the sLHC upgrade of the ATLAS small wheel.

- More work underway: four small resistive-strip MM chambers were installed in the ATLAS cavern and are read out through the SRS; recorded the first clean LHC collision tracks.

- More neutron studies on the large scale Micromegas will be conducted in the near future.

- A lot of work ahead of us for a complete Micromegas+Electronics system!
BACKUP SLIDES
Activation of the Micromegas Material

\[ E_n = 5.5 \text{MeV} \]

\[ ^{27}\text{Al(n,}\gamma)^{28}\text{Al} \quad \tau_{1/2} = 2.24\text{m}, \quad E_\gamma=1.8\text{MeV (100%)}, \quad E_e = 2.9\text{MeV (99%)} \]

\[ ^{27}\text{Al(n,p)^{27}\text{Mg}} \quad \tau_{1/2} = 9.46\text{m}, \quad E_\gamma=0.8\text{MeV (72%)}, \quad E_e = 1.6\text{MeV (29%)} \]

\[ E_\gamma=1.1\text{MeV (28%)}, \quad E_e = 1.8\text{MeV (71%)} \]

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Sparks R16/Charge vs E

Both gases (same gains physical corrected) - Vdrift scan - 04 & 07/02/2011

E (V/cm)

- R16 04.02.2011 (93/7)
- R16 07.02.11 (80/20)
2D readout: $R_{16xy}$ ($R_{19xuv}$)

- **x strips:** 250/150 µm r/o and resistive strips
- **y strips:** 250/80 µm only r/o strips
- **Resistive strips**
- **PCB**
- **Mesh**
- **Resistivity values**
  - $R_G \approx 55 \, \text{M}\Omega$
  - $R_{strip} \approx 35 \, \text{M}\Omega/\text{cm}$
R16 x-y event display ($^{55}$Fe $\gamma$)

Run: 6382, Event: 8

Default Map.

R16 x

R16 y