New generation of RPC detector for the ATLAS Muon detector upgrade

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Summary

- The ATLAS Muon Spectrometer Upgrade
- The new generation of RPC detectors
- BIS78 RPCs performances
- Conclusion
The challenge of Atlas Muon Spectrometer is to preserve its present muon identification and tracking performance, and its standalone and combined (with inner tracker detector) momentum resolution in much harsher conditions in terms of:

- particle rates
- integrated radiation
- pile-up

One of the upgrade scheduled for the HL-LHC, in order to improve the ATLAS muon spectrometer is the Resistive Plate Chamber (RPC) BI project.
• Present RPCs are certified for $100 \frac{Hz}{cm^2}$ for 10 Years equivalent to 5 HL-LHC years → insufficient reliability

• Rate capability: insufficient for the expected rate in HL-LHC and keeping the same level of trigger efficiency for the following years

• The present geometrical acceptance of the trigger in the barrel is only approximately 80%, primarily due to the toroid coils, support structure and services

• The present trigger and read out electronics are not compatible with the rate and the latency requirements of Atlas Phase II trigger and data acquisition scheme
The ATLAS Muon Spectrometer upgrade - BI Project

The BI project will consist in the coverage of the inner barrel of the ATLAS experiment with 272 triplets made of the new generation of RPC detectors

- More Redundancy (6->9 layers)
- Longer lever arm (2.3 m->4.5 m)
- More acceptance (80%->96%)
- Enhancement of selected critical chambers in more exposed region (need efficiency > 80%)
- New readout electronics better exploit the RPC performance
- Full trigger performance at 96% coverage any HL-LHC luminosity, with present gap efficiency at 70%-80%
- Better trigger selectivity
- Better tracking
The transition region $1<|\eta|<1.3$ of the muon system will suffer of 2 severe problems with increasing luminosity, concentrated in the far edges of small (even) sectors:

1) High LVL1 fake rate expected and no trigger chambers present between the IP and the Big Wheel

2) High photon induced counting rate, making in particular the BIS7 MDT performance insufficient for Phase II.

Two upgrades scheduled for the ATLAS spectrometer in Phase 1

1) Tracking and trigger upgrade in the $\eta > 1.3$ region with the New Small Wheel (NSW)

2) Upgrade of the ATLAS muon trigger in the barrel-endcap transition region with RPC
The ATLAS Muon spectrometer upgrade – BIS78 Project

Replace the BIS MDT 7 and 8 chambers with an integrated new generation RPC + sMDT chamber in the same envelope

BIS RPC layout
Main advantages for the BIS 7-8 location:

- This area is upstream of the cryostats where most of the fake muons are generated
- Solve the MDT rate problem
- Perfectly projective with the holes
- Robust against pileup
- Provides momentum selectivity
The new generation of RPC detectors

<table>
<thead>
<tr>
<th></th>
<th>Atlas Standard RPC</th>
<th>BIS78 RPC</th>
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</thead>
<tbody>
<tr>
<td>Detector</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas Gap width</td>
<td>2 mm</td>
<td>1 mm</td>
</tr>
<tr>
<td>Electrode Thickness</td>
<td>1.8 mm</td>
<td>1.2 mm</td>
</tr>
<tr>
<td>Gas Mixture</td>
<td>95% TFE, 4.7% i-C4H10, 0.3% SF6</td>
<td>95% TFE, 4.7% i-C4H10, 0.3% SF6</td>
</tr>
<tr>
<td>Time Resolution</td>
<td>1 ns</td>
<td>~0.4 ns</td>
</tr>
<tr>
<td>Space Resolution</td>
<td>6 mm</td>
<td>1 mm</td>
</tr>
<tr>
<td>Gaps per chamber</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Readout electronics</td>
<td>2D orthogonal</td>
<td>2D orthogonal</td>
</tr>
</tbody>
</table>
The new generation of RPC detectors

Amplifier parameters
- Silicon standard components
- Gain: 0.2-0.4 mV/fC
- Power consumption: 3-5 V 1–2 mA
- Band-width: 100 MHz

Discriminator parameters
- SiGe full custom
- Power consumption: 2-3 V 4-5 mA
- Threshold: 0.5 mV
- Band-width: 100 MHz

1. Minimum Threshold of 0.3 mV
2. Detectable signal of 1-2 fC
3. Time-over-threshold measurement achievable directly within the Front-End

Reduction of a factor 10 in the charge produced inside the gas gap
Rate capability up to 10 kHz/cm^2
**BIS78 RPCs construction**

- BIS7S 288 FE channels
- BIS7L 312 FE channels
- BIS8L 264 FE channels
- BIS8S 240 FE channels

**BIS7 Modules assembled:**
- 2 BIS7L
- 2 BIS7S

**BIS8 in construction**

Gas gap

X,Y ReadOut Strips
The BIS7s Module 1 middle singlet performance are reported. The parameters averaged all over the surface are taken at the knee point of the plateau (5.6 kV).
**BIS78 RPCs performance – Efficiency curves**

Efficiency curve averaged all over the singlet surface

- Between 92%-93% of efficiency at 5.6kV for each singlet and 95% at 5.7kV
- The Front-End electronics threshold is set to the middle of its dynamic range for both readout layers

Efficiency curve shows the expected behaviour with the desired efficiency level
**BIS78 RPCs performance – Modules homogeneity**

<table>
<thead>
<tr>
<th>Position</th>
<th>Efficiency</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>92%</td>
</tr>
<tr>
<td>2</td>
<td>92.2%</td>
</tr>
<tr>
<td>3</td>
<td>91.8%</td>
</tr>
<tr>
<td>4</td>
<td>92.5%</td>
</tr>
<tr>
<td>5</td>
<td>92.1%</td>
</tr>
<tr>
<td>6</td>
<td>91.5%</td>
</tr>
<tr>
<td>7</td>
<td>91.8%</td>
</tr>
<tr>
<td>8</td>
<td>92%</td>
</tr>
</tbody>
</table>

Efficiency at 5.6 kV
For each position tested

The efficiency shows an homogeneous behaviour all over the singlet surface within the statistical fluctuation.
**BIS78 RPCs performance – Cluster size**

Cluster Size of ETA layer Averaged all over the surface

Average cluster size $\eta = 1.3 - 1.5$

Cluster Size of PHI layer Averaged all over the surface

Average cluster size $\phi = 1.4 - 1.8$
**BIS78 RPCs performance – Output signal width distribution**

ETA Output Signal Width distribution

Distribution of Width of the output signals of the ETA layer

Obtained by taking the width of the first signal of each cluster

- Time over Threshold measurement
- Time walk correction for the time resolution
Distribution of Width of the output signals of the PHI layer

Obtained by taking the width of the first signal of each cluster

- Time over Threshold measurement
- Time walk correction for the time resolution
**BIS78 RPCs performance – Noise rate map**

The map of the noise rate for each channel of the readout layer

Average channel noise of 0.2-0.3 Hz/cm^2

The noise rate shows the expected behaviour, since it is lower than 1-2 Hz/cm^2 which is the requirement
**BIS78 RPCs performance – Noise rate map**

The noise rate map of the PHI side shows the expected behaviour, since it is lower than 1-2 Hz/cm^2 which is the requirement.

Average channel noise of 0.4-0.6 Hz/cm^2

The map of the noise rate for each channel of the readout layer.
**BIS78 RPCs performance – Time resolution**

Time of Flight method for Time resolution calculation

![Diagram](image)

Time resolution calculated as the sigma of the gaussian fit over the distribution of the difference between the arrival time of the signals of the 2 singlets (\(\Delta T\))

Time walk effect can be corrected by using the function \(F(\text{Amplitude})\), which correlate the time when the signal passes the threshold and its amplitude
**BIS78 RPCs performance – Time resolution**

Time resolution without correction

\[
\sigma_{\sqrt{2}} = 0,4 \text{ ns}
\]

Time resolution with time walk correction

\[
\sigma_{\sqrt{2}} = 0,35 \text{ ns}
\]
The BIS78 project is under construction and its installation is scheduled for March 2020.

The performance obtained by this new generation of RPCs is the one expected and perfectly suitable for ATLAS Phase-1 and Phase-2.

The BIS78 modules tested up to now showed a consistent behaviour between each other and the following performance:

- Between 92%-93% of efficiency at 5,6kV and 95% at 5,7kV for each singlet.
- Cluster size of 1.3-1.5 for Eta layer and 1.5-1.8 for Phi layer.
- Channel noise of 0.4 Hz/cm^2 for eta layer and 0.6 Hz/cm^2 for phi layer.
- Time resolution of 400 ps raw and 350 ps with time walk correction.
Conclusion

Thank you!
Subsections of the Muon System:

- **Thin Gap Chambers**
  - For triggering and 2nd coordinate measurement (non-bending direction) at ends of detector.

- **Resistive Plate Chambers**
  - For triggering and 2nd coordinate measurement in central region.

- **Monitored Drift Tubes**
  - Measure curves of tracks with a resolution of 80 μm

- **Cathode Strip Chambers**
  - Measure precision coordinates at ends of detector with a resolution of 60 μm
The ATLAS Muon Upgrade

- Present RPCs are certified for \(100 \text{ Hz cm}^2\) for 10 Years equivalent to 5 HL-LHC years \(\rightarrow\) insufficient reliability

- Rate capability: insufficient for the expected rate in HL-LHC and keeping the same level of trigger efficiency for the following years

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