Bringing the ATLAS Muon Spectrometer to Life with Cosmic Rays

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On behalf of the ATLAS Muon Collaboration

Cosmic ray event in ATLAS

The ATLAS Muon Spectrometer

Monitored drift tubes - Coverage - Number of chambers - Number of channels - Function	MDT $ \eta < 2.7$ (innermost layer: $ \eta < 2.0$) 1088 339 000 Precision tracking
Cathode strip chambers - Coverage - Number of chambers - Number of channels - Function	CSC $2.0 < \eta < 2.7$ 32 31 000 Precision tracking
Resistive plate chambers - Coverage - Number of chambers - Number of channels - Function	RPC $ \eta < 1.05$ 544 359 000 Triggering, second coordinate
Thin gap chambers - Coverage - Number of chambers - Number of channels - Function	TGC $1.05 < \eta < 2.7$ (2.4 for triggering) 3588 318 000 Triggering, second coordinate

A complex system:

- 4 different technologies (MDT,CSC,RPC,TGC)
- Large area (10,000 m²)
- Many channels (1M)
- Many degrees of freedom (5300 chambers)

The ATLAS Muon Spectrometer

In a difficult environment:

large magnetic field variations and temperature gradients

Measurements from MDT temperature sensors

The ATLAS Muon Spectrometer

Built to:

- Provide an efficient muon trigger and Bunch Crossing (BC) identification
- Achieve high precision momentum measurement

Type	Function	Chamber resolution (RMS) in			Measurements/track		Number of	
		z/R	ϕ	time	barrel	end-cap	chambers	channels
MDT	tracking	35 μm (z)	—	—	20	20	1088 (1150)	339k (354k)
CSC	tracking	40 μm (R)	5 mm	7 ns	—	4	32	30.7k
RPC	trigger	10 mm (z)	10 mm	1.5 ns	6	—	544 (606)	359k (373k)
TGC	trigger	2–6 mm (R)	3–7 mm	4 ns	—	9	3588	318k

Momentum measurement & MDT resolution

- the MDT single tube resolution is a function of the drift path;
- $\langle \Delta r \rangle_{\text{single}} = 80 \div 90 \mu\text{m}$, dependent on background, electronics and reconstruction algorithm;
- 3 [4] tubes $\rightarrow \Delta r_{\text{multilayer}} \approx 50 \mu\text{m}$;
- needed for high p_T muons ;
- systematics must NOT spoil the overall accuracy;
- calibrations and alignment better than $30 \mu\text{m}$

Alignment system: 12232 optical sensors
Autocalibration with dedicated data stream

Reconstruction

The Muon Spectrometer
standalone reconstruction is
complemented by the Inner
Detector tracking

Muon Spectrometer: main source of cosmic triggers

- High statistics collected in autumn 2008 (full ATLAS)
- Few high statistics runs studied in great detail
- Subdetectors runs in 2009: RPC runs in January
- “muon slice” runs at the end of April

Cosmic triggers

- Sources of level 1 muon trigger:
 - RPCs in the barrel,
 - TGCs in the endcap
- Coarse time alignment
- In the barrel trigger based only on ϕ view, triggers from top sectors artificially delayed by 5BC
- In the endcap both η (bending) and ϕ (non-bending) view

RPC system performance

Dead strips < 2%
Noisy channels < 1%

In 2008 problems with

- Synchronzation
- Gas
- Temperature (reduced HV in top sectors)

Affected the overall efficiency
(70% of trigger coverage)

Most of the problems were fixed
during the winter shutdown,
current trigger coverage is 95.5%

RPC trigger coverage

Low-pt trigger coverage

- Commissioning ongoing
- Trigger coverage increased from 70% in 2008 to current 95.5%
- Full detector for 2009 run.

High-pt trigger coverage

RPC trigger timing

RPC performance

Random Trigger

Noise = $N \text{ hits} / (N_{\text{trigger}} \times \text{RO-Window}) / \text{strip Surf}$
HV = 9600 V, Vth = 1000 mV (Working Point)

Distribution of RPC hits per event with RPC cosmic trigger (not filled area) and with random trigger (black filled area).

HV = 9600 V, Vth = 1000 mV (Working Point)

RPC performance

Efficiency vs HV

Cluster size vs HV

TGC system performance

- 99.8% of chambers operational
- Single dead channels < 0.01%
- Clustered dead channels < 0.1%
- Noisy channels (>2.5% occupancy) < 0.04%

XY_View_C

Run 91060, 1/physics_TGCwBeam
/MuonDetectors/TGC/XY_View_C

XY_View_A

Run 91060, 1/physics_TGCwBeam
/MuonDetectors/TGC/XY_View_A

- Full trigger coverage
- All sectors read-out, bottom 1/3 used for triggering

TGC performance

TGC detector
efficiency

TGC trigger
synchronization

MDT system performance

Statistics/chamber in one long 2008 run

Out of 1100 chambers:

- 2 chambers not yet installed
- 3 chambers not readout (gas system problems)
- 2 chambers with HV off
- 32 chambers with HV off for 1 of the 2 multilayers

No data available
 O(1M)

O(100k)
 O(10M)

MDT efficiency

HitsPerTubeAdcCut BML2A07

BML2A07 Tube #

EfficiencyPerTube BML2A07

BML2A07 Tube #

MDT BI Segment efficiency

MDT BM Segment efficiency

MDT BO Segment efficiency

Tube & segment efficiencies in cosmic ray events

- 0.1% single dead channels
- 1% clustered dead channels (being fixed)
- Noisy channels (> 5% occupancy) < 0.2%

Alignment

In autumn 2008 :

- the **barrel optical system** was fully installed
- 99.7% of the sensors were functioning correctly

Type	Total	Working	Broken
Projective	117	117	0
Axial	1036	1031	5
Praxial	2010	2008	2
Reference	256	253	3
CCC	260	260	0
BIR-BIM	32	32	0
Inplane	2110	2101	9
Total	5817	5798	19
%		99.7	0.3

- 99% of all relevant alignment **sensors in the endcaps** were functioning
- only very few failed during the several months of data-taking in 2008.
- The effect of the missing sensors on the final alignment quality was negligible.

Alignment system performance

BARREL

- Barrel Optical Alignment: at 200 μm level for large sectors (0.5-1mm for small ones)
- Track based alignment : improvement to <50 μm level

ENDCAP

Endcap Optical Alignment:

sagitta residuals within the
design specification

MDT calibration

- MDT tubes are calibrated using the muon tracks through the iterative auto-calibration procedure
- A large number of tracks is needed and a dedicated high rate stream extracted from Level 2 trigger has been foreseen for this purpose for p-p collisions
- The stream has been regularly extracted and distributed to the 3 Calibration Centers (Ann Arbor, Munich, Rome) during the cosmic data taking to test the full calibration chain
- But calibrations for cosmic runs were produced from the complete ATLAS events to benefit from the larger statistics of non pointing tracks
- The space-time relation in the chambers with too low statistics has been obtained from a dedicated chamber located at the surface and connected to the same gas distribution (“gas monitoring chamber”)

MDT t0

- The arrival time of the cosmons is asynchronous with respect to the 40MHz clock of the experiment which gives the time reference for the time digitization
- The t0 for the MDT should therefore be computed on an event by event basis
 - Either from the time measured by the triggering detector
 - Or extracting it from a fit to the drift times of the hits on a segment
- The second approach was adopted in the cosmic analysis to recover also the effect of the not yet optimal time alignment of the trigger detectors
- To help the fit preliminary rough t0 values were obtained for each chamber from the drift time spectra

CSC system performance

- 98.5% of chambers operational
- Dead channels $< 0.1\%$
- Calibration data collected
- ROD firmware problem prohibited full integration in ATLAS DAQ during 2008
- Fix on the way for 2009 run

Muon Spectrometer performance

Correlation between MDT hits and
RPC eta strips

Reconstructed TGC tracks
interpolated to MDT middle layer
vs MDT hit

Tracking

Momentum comparison between
“pointing” standalone tracks
reconstructed in the top “hemisphere”
and in the bottom one ($P_{\text{top}} < 25 \text{ GeV}$)

6 GeV/c, as expected for tracks
crossing twice the calorimeters,
and in agreement with 3 GeV/c
between Muon standalone and
Inner Detector momenta

A “Tag&Probe” method to measure efficiencies
in one hemisphere when a good track
(eventually combined to the Inner Detector one)
is present in the opposite one is currently under
development.

MUON – Inner Detector Comparison

NB : very
preliminary
alignment and no
relative MUON-
Inner Detector
alignment yet!

Conclusion

- The cosmic events collected in 2008, mostly with muon triggers, are used for detailed studies of the Muon Spectrometer detector and standalone reconstruction.
- Most of the problems observed in the 2008 cosmic runs have been understood and fixed.
- Cosmic data to be collected next summer, with a full trigger coverage and an improved time alignment, will be used for detailed studies of combined reconstruction performance, dead material, alignment with respect to the Inner Detector.
- The ATLAS Muon Spectrometer is alive and ready for beam!