Operational Experience of the Triple-GEM Detectors of the LHCb Muon System: Summary of 2 years of data taking

Alessandro Cardini / INFN Cagliari, Italy
Giovanni Bencivenni / LNF INFN, Italy
Patrizia de Simone / LNF INFN, Italy

Outline

- The LHCb Experiment
- Designing Triple-GEM detectors for LHCb
- The Operational Experience
 - High Voltage optimization
 - Gas monitoring
 - Some other points
- Conclusions

The LHCb Experiment

The LHCb Muon System

- It provides:
 - hardware muon trigger (L0 muon)
 - muon(s) p_T estimate(s)
 - muon identification at the High Level software Trigger (HLT) and for offline event reconstruction
- 5 stations separated by Fe walls, projective geometry
- Mainly made of multi-wire proportional chambers
- First muon station (M1) located in front of the calorimeter
- M1 improves the p_T estimate at L0 trigger level
- In M1 central region (up to) 500 kHz/cm² → triple GEM detectors
- M1R1: 0.6 m² → 12 chambers of 20x24 cm² active area

LHCb Triple-GEM Detectors

Requirements: digital pad readout, up to 500 kHz/cm², 96% efficiency in 20ns time window, low cluster size (<1.2), no aging

Non-standard gaps: 3mm (ioniz.) / 1mm / 2mm / 1mm (induct.)

2 detectors in logical-OR pad-by-pad to improve performances & reliability

Innovative gas mixture: Ar/CO₂/CF₄ at 45/15/40

Wide working plateau: 70V

No aging effects seen up to 2.2 C/cm² during R&D

Muon Station M1

Calorimeters (C-side)

M1R1

LHC Beam pipe

Muon Station

Calorimeters (A-side)

Zooming on
M1R1...

Operations in LHCb

HV-related issues:

Tuning the detector working point

GEM Powering Circuit

- Custom-made multichannel HV power supply, electrically equivalent to an active resistive divider
- Detector current measured only on last GEM foil – all data logged by ECS
- Protection resistors on HV filters on detector + 1 M Ω in series on sectors for each GEM foil

HVGEM System Current Monitor

Sparks and Shorts

- Nowadays, LHCb Triple-GEM detectors are probably the ones running in the most severe conditions → operating point is very critical
- Sparking events are detected by current monitor (not detecting which GEM foil is sparking)
- (Continuous) sparking could eventually result in a GEM foil short → we need to minimize discharge probability in normal operations
- In these years of data taking we had some GEM in short, 1/2/1 respectively in 2010/2011/2012
- All these shorts occurred on first GEM (G1), the first amplification stage... Why?

Detector A15A1L current vs. time → Sparking recovered by itself in this particular case

Tuning the HV Working Point

- Initial working point defined during R&D:
 - $G_{\min} \sim 4000$ (min. required efficiency)
 - $G_{\max} \sim 17000$ (PSI discharge probability measurements)
- “Traditional” considerations on Raether limit and laboratory measurements with alphas suggested GEM gains decreasing from GEM1 to GEM3
- April 2010: $G \sim 6000$ (435V/425V/415V)
- Readjusted to lower gain values during 2010 and 2011
- May 2012: go symmetric! → 3x415V, safer for GEM1, $G \sim 4300$

Detector performances in 2012

Offline muon efficiency monitor

3 x 415V working point

within the
rectangle
there are the
chambers on
the sides of
the beam pipe

μ Chambers efficiency M1R1

μ Chambers efficiency M1R1

chamber num code

1	A18A2
2	A18A1
3	C18A1
4	C18A2
5	A17A2
6	C17A2
7	A16A2
8	C16A2
9	A15A2
10	A15A1
11	C15A1
12	C15A2

1/2 triple-
GEM not
working

What we learned on HV

- Gain fine tuning needed because we observed
 - Sparking
 - Detector current instabilities
- It seems that in LHCb
 - Sparking rate is higher than expected: neutrons background
 - Low Z material of the detector: neutron converter → HIP → discharges
 - GEM1: Usually at a higher voltage → more sensitive to discharges
- Solutions
 - 1. Reduce the gain - done
 - 2. Put all 3 GEMs at the same voltage – done
 - 3. Reduce the total voltage on GEMs and keep same gain by slightly changing the gas mixture (reducing CF_4 and/or adding isobutane) – proposed, under evaluation

Operations in LHCb

Gas-related issues:

Monitoring the Gas Mixture

The LHCb GEM Gas System

- Made by CERN Gas Group - Open-loop system
- Ar/CO₂/CF₄ in percentages 45/15/40
- Flows: ~80 cc/min per detector – monitored by ECS
- Fresh mix analysis permanent tools:
 - Gas Chromatographer (GC)
 - H₂O + O₂ measurement
- Possibility of sampling return gas with portable GC

2012 GEM Current Jumps

- Observed some “jumps” in ALL triple-GEM detector luminosity-normalized currents all along this year
- True Gain variations! → detector signals move correspondently in time

Investigations performed

Possible causes of a gain change:

- Gas
 - GC-analysis show correct gas mixture within O(1%)
 - Small gas fraction changes (1%) create too-small gain changes (~5%)
- HV
 - 24 independent HV modules
- Temperature & Pressure
 - No temperature variations seen
 - Pressure variations not correlated

➔ *Origin of this problem*

Premixed Gas Test

- Inject gas from pre-mixed bottle **only on half of the detectors**

- Should be the same gas... but 20% current increase observed!

➔ It's definitely something related to gas...

At last...

- Some correlations were found by Gas Group (R. Guida, B. Mandelli et al., see poster N14-132)
- It appears that some of the gain jumps are in coincidence with the change over of the CF_4 bottles
- Looking carefully at GC analysis some variations of O_2/N_2 seen... is this correlated?
- Situation not yet clear – will carefully monitor future CF_4 bottle changes

What we learned? What to improve?

- Gas mixture is a very critical point
- Gas monitoring units (GC, ...) are excellent devices, but sometimes you do not know what to look for
- Imperative to implement redundant gas checking tools
 1. Automatic current/luminosity checks - done
 2. Independent gain monitoring tool with a small source-irradiated triple-GEM detector – in progress

GEM Gas Monitoring Tool

Operations in LHCb

Other issues:

“Classical” aging

Integrated charges in 2012

A18A2L: 18 mC/cm ²	A18A1L: 34 mC/cm ²	C18A1L: 31 mC/cm ²	C18A2L: 13 mC/cm ²
A18A2R: 12 mC/cm ²	A18A1R: 23 mC/cm ²	C18A1R: 17 mC/cm ²	C18A2R: 21 mC/cm ²
A17A2L: 50 mC/cm ²			C17A2L: 42 mC/cm ²
A17A2R: 59 mC/cm ²			C17A2R: 60 mC/cm ²
A16A2L: 35 mC/cm ²			C16A2L: n/a
A16A2R: 35 mC/cm ²			C16A2R: 35 mC/cm ²
A15A2L: 30 mC/cm ²	A15A1L: 33 mC/cm ²	C15A1L: 33 mC/cm ²	C15A2L: 34 mC/cm ²
A15A2R: 29 mC/cm ²	A15A1R: 36 mC/cm ²	C15A1R: 41 mC/cm ²	C15A2R: 18 mC/cm ²

- E 2012
- No indications of classical aging
- We expected twice this value → Operating detector on the safe side!

Conclusions

Triple-GEM Efficiencies in 2012

Average Luminosity $\sim 4 \times 10^{32} / \text{cm}^2/\text{s}^{-1}$

μ Chambers efficiency M1R1

	fill	run
4/5	2587	114436
11/5	2609	115063
3/6	2692	117276
8/6	2712	117776
10/6	2718	118240
16/6	2734	118730
4/7	2806	120195
16/7	2843	121798
30/7	2892	124224
2/8	2902	124494
16/8	2976	125788
28/8	3011	126677
4/9	3025	127070
16/9	3067	128426
30/9	3113	129596

Excellent Performance Overall

- The LHCb GEM detectors are operating in very hard conditions (high irradiation, long runs)
- A few shorts on G1 occurred during these years of data taking → tune working point → situation improved
- Effect of heavy ionizing particle has to be taken seriously into account in a hadron collider environment
- Monitoring and debugging tools are never enough

Backup slides

Why Triple-GEM were chosen

- The requirements for detectors for the inner region (R1) of the first muon station (M1) ($\sim 0.6\text{m}^2$ but $\sim 25\%$ of the muon acceptance) are:
 - Rate Capability up to 0.5 MHz/cm^2
 - Station Efficiency 96% in a 20 ns time window (*)
 - Cluster Size 1.2 for a $10\times 25\text{ mm}^2$ pad size
 - Radiation Hardness 1.6 C/cm^2 in 10 years (**)
 - Detectors active area $20\times 24\text{ cm}^2$
- (*) A station is made of two detectors “in OR”. This improves time resolution and provides some redundancy
- (**) Estimated with $50\text{ e}^-/\text{particle}$ at 184 kHz/cm^2 with a gain of ~ 6000
- With a long R&D work (2000-2003) we demonstrated that Triple-GEM detectors are an adequate solution for the M1R1 region

Triple-GEM Design and Optimization

- Triple-GEM detector with anode pad readout - preamplifier and discriminator (CARIOCAGEM)
- Non-standard gaps
 - T1 is 1 mm to decrease the probability that a ionization in T1 could trigger the discriminator → hits in advance → worsening of time resolution
 - Induction gas is 1 mm to have fast signals
- Standard CERN GEMs, 200x240 mm² active area, 6 sectors
- Full chamber is made by two detectors in OR pad-by-pad, via the front-end electronic board → more redundant detector

Gas Choice

- Fast and non-flammable gas
- CF_4 represent 40% of the mixture
- Requires a slightly higher voltage on GEM foils than a more classical Ar/CO_2 70/30 mixture

Triple-GEM Detector Time Response

Gas Gain

Full Chamber Performance

- Excellent time resolution with 2 detectors in OR
- Wide HV operating plateau

Ageing Tests during R&D

- Many aging tests performed, exceeding expected LHCb integrated charge
 - Local: 6 keV X-Rays, $\sim 1 \text{ cm}^2$
 - Large Area: PSI π M1 hadron beam, $\sim 15 \text{ cm}^2$
 - Full detector: Enea-Casaccia 25 kCi ^{60}Co source, $0.5 \div 16 \text{ Gray/h}$
- For all tests except high-rate Casaccia, no ageing was observed
- High-rate Casaccia tests showed a gain reduction effects, found to depend on a low gas flow to irradiation ratio
- All ageing effect, if present, can be compensated by readjusting the detector HV

Tuning the HV Working Point

- Working point defined during R&D work
- “Traditional” considerations on Raether limit suggested a gain decreasing from G1 to G3
- April 2010: 435V/425V/415V, G~6000
- October 2010: Some instabilities observed → Tested some reduced configurations: 430V/420V/410V and 425V/415V/405V
- May 2011: Switched to more conservative 420V/415V/410V
- June 2011: Some instabilities on a few detectors → 415V/415V/410V on these
- May 2012: go symmetric! → 3x415V, more safe for G1, G~4300

High Luminosity and HV filters

- LHCb designed to run at average luminosity of $2 \times 10^{32} / \text{cm}^2 / \text{s}^{-1}$
- HV filter and protection resistors calculated to have a low (but unavoidable) voltage drop on GEM foils
- Now running routinely $4 \times 10^{32} / \text{cm}^2 / \text{s}^{-1}$
→ gain depends on instantaneous luminosity
- Planning to redesign these HV filters, to be replaced during LS1

Detector Gain Monitoring

- 10x10 cm² triple-GEM detector
- ⁹⁰Sr source → monitor detector current
- Possibility of using fresh or return gas, or gas from premixed bottle (reference)
- Working but not in normal operation
- Will be completed and integrated in LHCb ECS during LS1