**1.0 INTRODUCTION: THE UPGRADE OF THE CMS MUON SYSTEM WITH TRIPLE-GEM DETECTORS**

The LHC will be upgraded in several phases that will allow to significantly expand its physics program. After the long shutdown in 2019 (LS2) the accelerator luminosity will be increased to \(2 - 3 \times 10^{34} \text{cm}^{-2} \text{s}^{-1}\) and later up to \(5 \times 10^{34} \text{cm}^{-2} \text{s}^{-1}\) in 2024-26. To cope with the corresponding increase in background rates and to keep the trigger rate at an acceptable level while not compromising the physics potential, the forward muon system of the CMS experiment will be upgraded with Gas Electron Multiplier (GEM) detectors. During LS2, 144 triple-GEM detectors will be installed in the first station of the muon detector (GE1/1 station) \([1]\). The GE1/1 DAQ system will be based on the VFAT3 fronted chip, which has been derived from VFAT2 \([2]\) and optimized for the GEM signal charge characteristics and CMS requirements.

**1.1 GE1/1 V3 ELECTRONICS**

![Diagram of GE1/1 V3 Electronics]

**1.2 “SLICE TEST” READOUT ELECTRONICS AND CHANNEL LOSS ISSUE**

Ten Triple-GEM detectors were installed in the CMS endcap at the beginning of 2017 as a “Slice Test”, with the aim of acquiring installation and commissioning expertise and demonstrating the integration into the CMS online system. The ten chambers were coupled in five detectors called “GEMINI”, instrumented with VFAT2 ASICs \([2]\). The GEMINI in slot 2 has been later instrumented with a test version of the v3 electronics.

During Run II of the LHC, CMS has observed irreversible channel loss in the VFAT chips. Such channel loss has been detected during the daily “s-curve” measurement using the VFAT calibration module. Being the width of the s-curve the channel ENC, disconnected channels show a low value consistent with zero added capacitance.

In order to understand the origin of such channel loss, a measurement campaign has been launched in June 2018.

![S-curve measurement. Sweeping the input signal amplitude (Vcal) on a given channel and counting hits for a constant threshold.](image)

**2.1 INVESTIGATION ON CHANNEL LOSS MECHANISM**

Different hypotheses have been considered as origin of the channel loss

- **0. “Normal” Operation**
  - 1. High charge event in the gas volume:
    - 1.1 Large energy loss from MIP in the Landau tail
    - 1.2 High primary ionization from background particles
  - 1.3 Propagating discharge
  - 2. Low voltage operation
  - 3. Hybrid disconnecting from the readout board

**Experimental setup to reproduce scenarios 0, 1.1 and 2:**

- GE1/1 detector operated at gain 1E4 in Ar/CO2 70/30
- VFATs split in different groups:
  - 1.1 VFATs continuously irradiated with Cd119 x-ray source
  - 2. Low Voltage is off while High Voltage is on

**Procedure:**

- Monitoring of HV stability (mainframe and DCS)
- Daily Scurve on all the VFATs -> Comparison of scurves sigma values (ENC) between different scans

Definition of “dead” VFAT channel = the ENC’s compatible to the hypothesis that the channel is no more connected to the strip (= 0 pF input capacitance -> ENC < 0.5 Fc), or the channel is no longer responding (empty Scurve).

**2.2 RESULTS**

- No channel losses in normal operation (even in VFAT6 and 7, continuously irradiated with two Cd109 x-ray sources)
- We found dead channels only after 3 different high current events recorded by the HV DCS -> Hypothesis 0, 1.1 and 2 ruled out

**The top plots show a 2-D view of the scurves measured using the VFAT3 calibration module. The red points show the mean value from the error function fit, their error bars show the ENC the s-curve response per channel.**

**Top right scurve taken after high current event. Bottom left: current drawn by the GEM electrodes as recorded by the DCS.**

**3.1 CORRELATION BETWEEN DISCHARGES AND CHANNEL LOSS**

**Experimental setup to reproduce scenarios 1.2 and 1.3:**

- GE1/1 detector operated at high gain in Ar/CO2 70/30 with drifted drift plane -> alpha particles can enter the gas volume
- Am241 alpha source
- Antenna coupled with GEM3 Bottom HV wire
- G3B decoupled signal -> Preamplifier

**Procedure:**

- Set HV working point
- Scope triggered on antenna signal
- G3B signal discriminated to count the alphas
- S-curve taken after every discharge

**Discharge at G = :5E5 -> some channels lost & pulse of type b**

**3.2 RESULTS**

We collected a high number of events monitoring the HV stability and the VFAT health (taking s-curves) at different gain values. The signal picked from the GEM3 bottom electrode showed two different behaviours:

- **a)** Single pulse on antenna + high current drawn by only one electrode: called PRIMARY DISCHARGE
- **b)** Multiple afterpulses + almost all electrodes show high current: called SECONDARY DISCHARGE

\[ \begin{align*}
\text{Collected 6M events at G = 1E4} \\
\text{Collected 3M events at G = 2.5E4} \\
\text{Collected 3M events at G = 6E4}
\end{align*} \]

\[ \Rightarrow \text{No channel loss in the frontend} \]

\[ \text{Pulses from G3B always of type a) \]}

**During successive tests, the correlation between secondary discharges has been confirmed, and the hypothesis 1.2 has been ruled out. The behaviour of the GEM3 bottom electrode indicates that the discharge propagates to the anode plane, causing the energy of the discharge to be released to the input channels of the ASIC.**

The addition of external components in front of the ASIC inputs can mitigate the damage. Other mitigation strategies to be implemented on the detector side are under investigation.

**4. DISCHARGE RESISTANT HYBRID DESIGN**

![External input protections added on the VFAT hybrid, between the ASIC input and the detector strip, in order to mitigate the effect of secondary discharges propagating to the anode plane.](image)

**Design under investigation**

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**CMS GEM FRONT-END ELECTRONICS OPERATIONAL EXPERIENCE**

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