# CMS GEM FRONT-END ELECTRONICS OPERATIONAL EXPERIENCE


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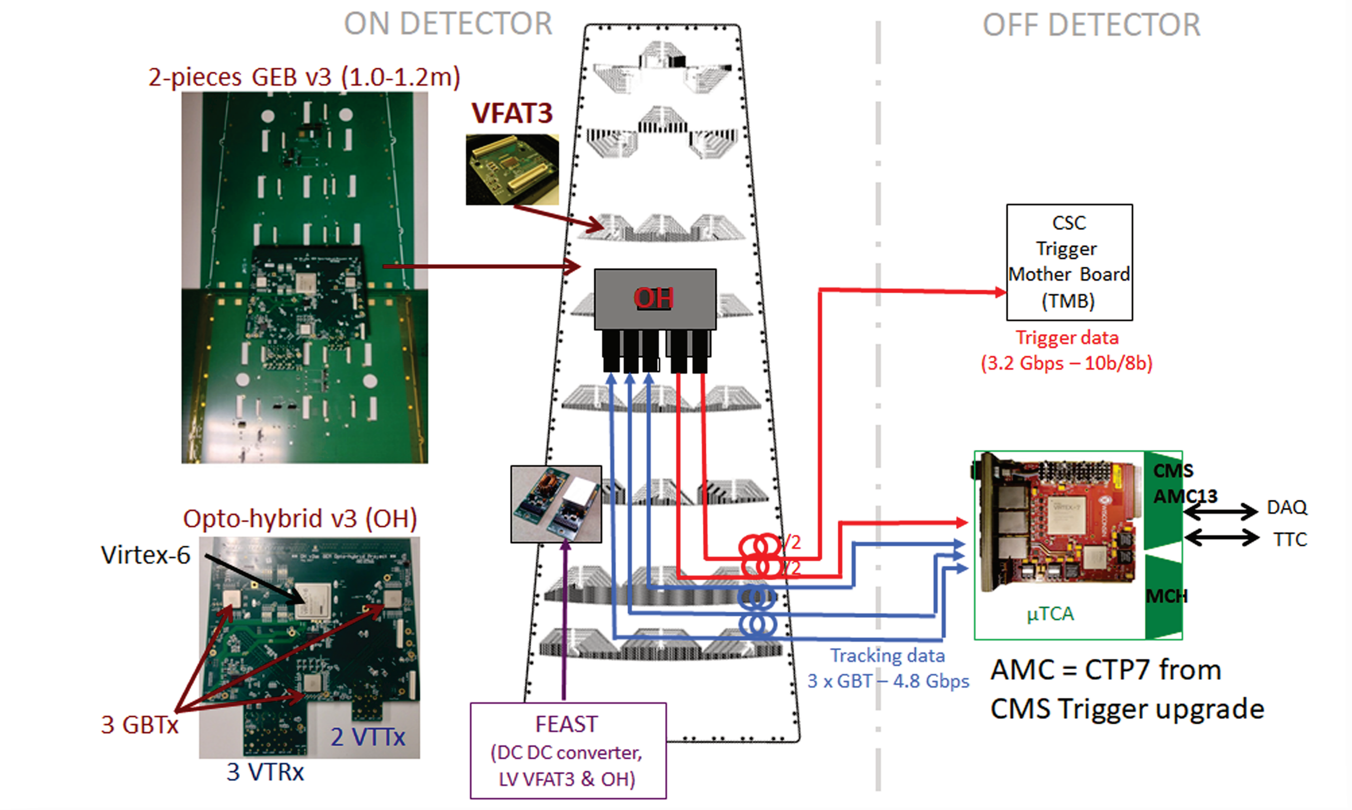
## 1.0 INTRODUCTION: THE UPGRADE OF THE CMS MUON SYSTEM WITH TRIPLE-GEM DETECTORS

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 x $10^{34}$ $cm^{-2}$ $s^{-1}$ and later up to 5 x $10^{34}$ $cm^{-2}$ $s^{-1}$ 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 wil 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



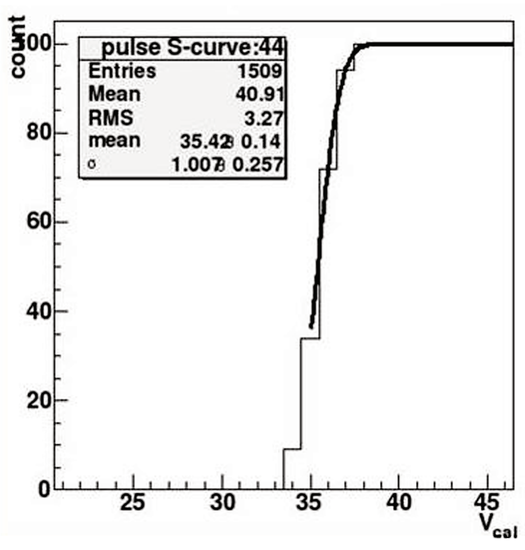

## 1.2 "SLICE TEST" READOUT ELECTRONICS AND CHANNEL LOSS ISSUE

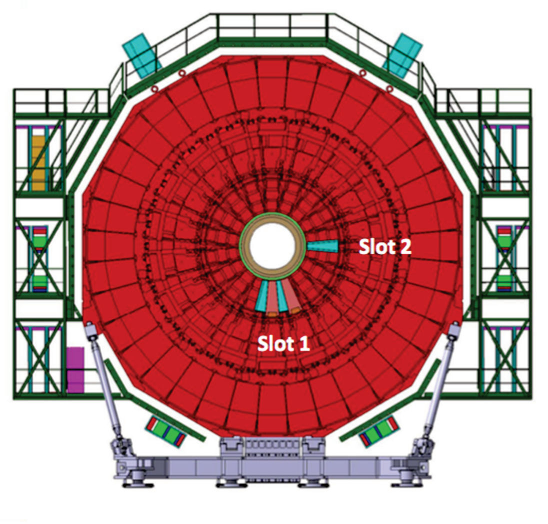
Ten Triple-GEM detectors were installed in the CMS endcap at the beginning of 2017 as a "Slice Test", with the aim of acquiring installation and commissioning expertise, and demonstrating the integration into the CMS online system. The ten chambers were coupled in five detectors called "GEMINI", instrumented 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



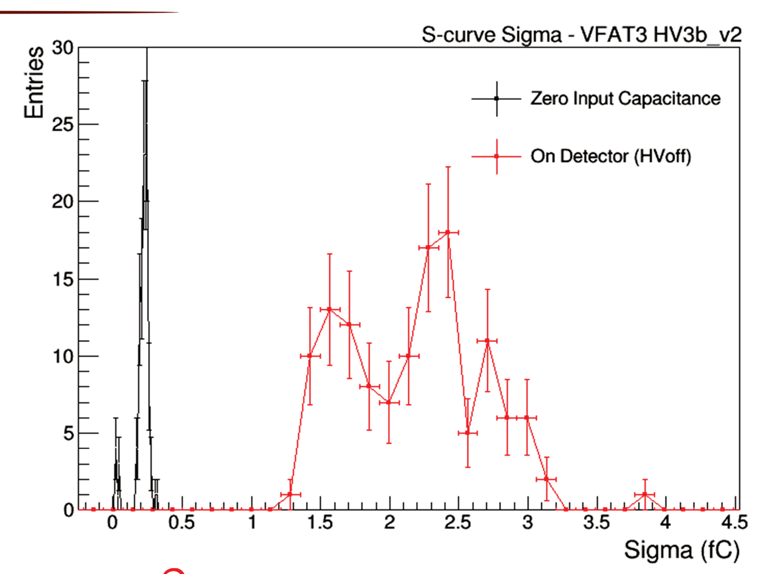




Left: S-curve measurement. Sweeping the input signal amplitude (VCal) on a given channel and counting hits for a constant threshold. [2]

## 2.1 INVESTIGATION ON CHANNEL LOSS MECHANISM

**Different hypotesis** 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. Improper LV operation
3. Hybrid disconnecting from the readout board



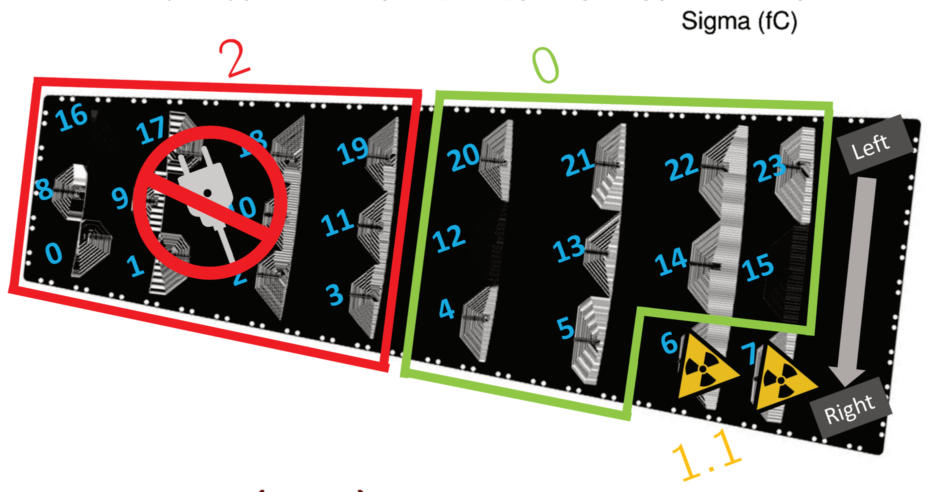

**Experimental setup to reproduce scenarios 0, 1.1 and 2:**

GE1/1 detector operated at gain 1E4 in Ar/CO2 70/30

VFATs splitted in different groups:

1.1 VFATs continously irradiated with Cd109 x-ray source

2. Low Voltage is off while High Voltage is on




**Procedure:**

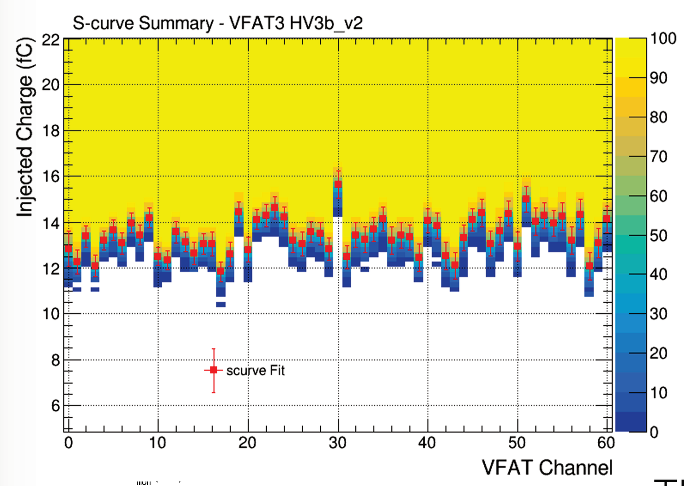
- Monitoring of HV stability (mainframe and DCS)
- Daily Scurve on all the VFATs -> Comparison of scurves sigma values (ENC) between different scans

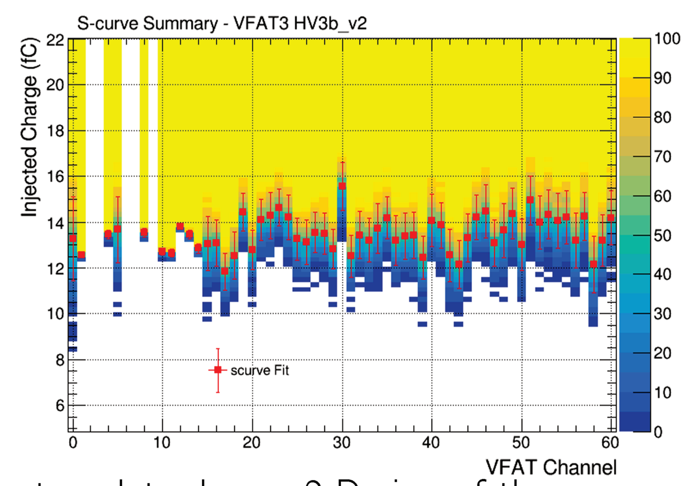
Definition of "dead" VFAT channel = the ENC is compatible to the hypothesis that the channel is no more connected to the strip (≈ 0 pF input capacitance -> ENC ≤ 0.5 fC), or the channel is no longer responding (empty Scurve).

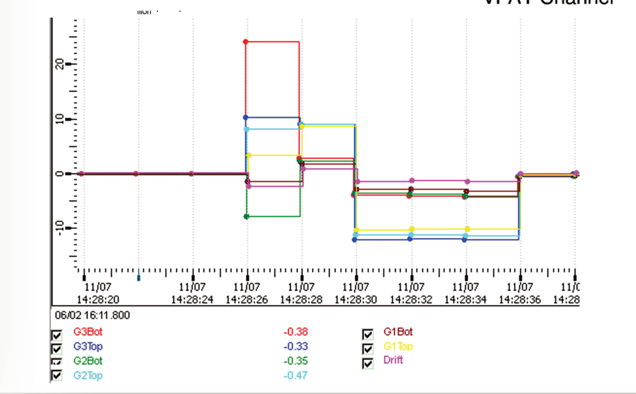
## 2.2 RESULTS

**After 3 months (2018.07.09 - 2018.10.01) of monitoring:**

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



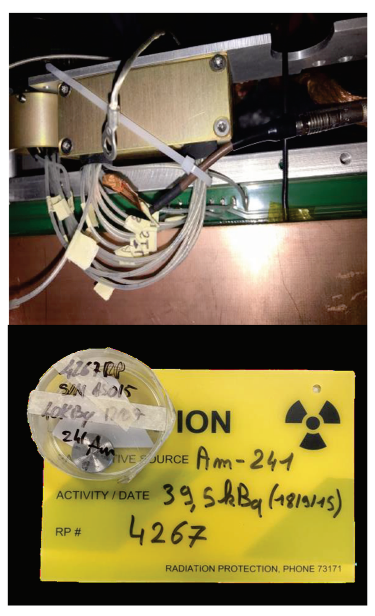
The top plots show a 2-D view of the scurves measured using the VFAT3 calibration module. The red points show the mean value from the error function fit, their error bars show the ENC the s-curve response per channel.

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 drilled drift plane -> alpha particles can enter the gas volume
- Am241 alpha source
- Antenna coupled with GEM3 Bottom HV wire
- G3B decoupled signal -> Preamp



**Procedure:**

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

## 3.2 RESULTS

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

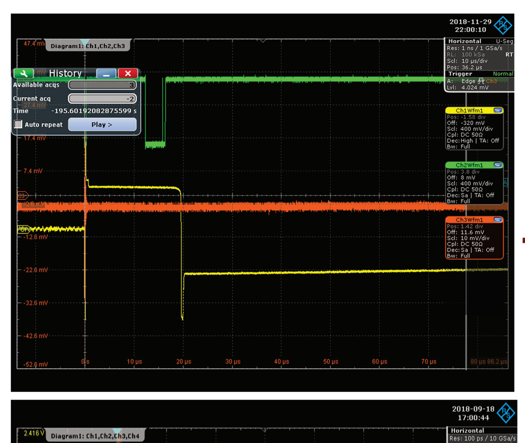
**a)** Single pulse on antenna + high current drawn by only one electrode: called PRIMARY DISCHARGE

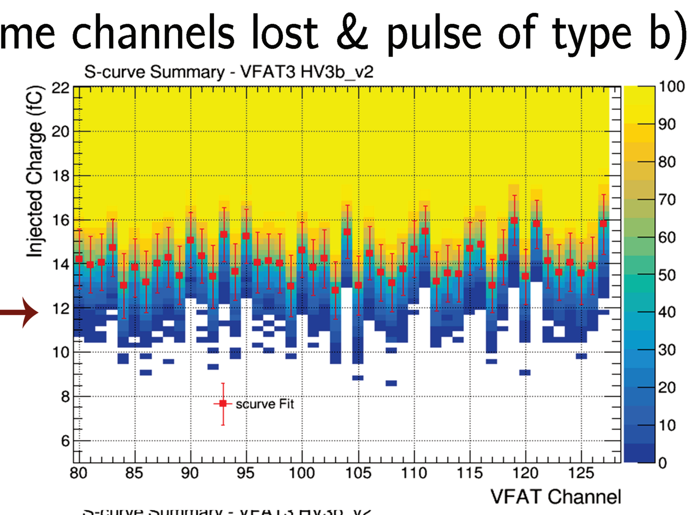
**b)** Multiple afterpulses + almost all electrodes show high current: called SECONDARY DISCHARGE

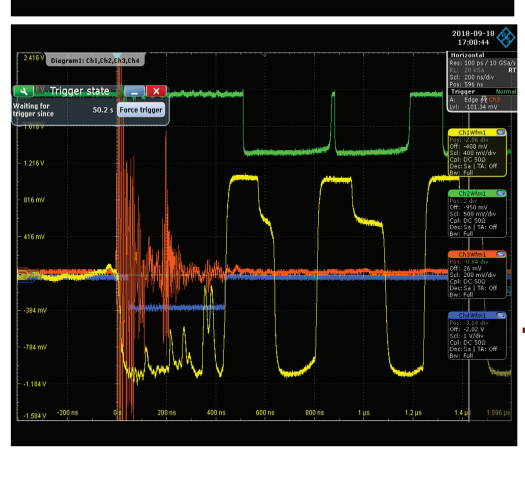
- Collected 6M events at G = 1E4
- Collected 3M events at G = 2.5E4
- Collected 3M events at G = 6E4

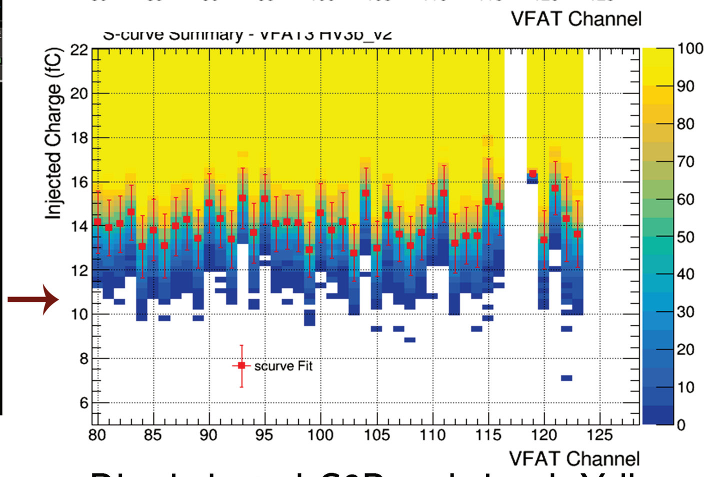
} → No channel loss in the frontend. Pulses from G3B always of type a)

Discharge at G = 1E5 -> some channels lost & pulse of type b)








Left: Oscilloscope screenshot. Green: Discriminated G3B pad signal. Yellow: G3B pad signal. Orange: antenna signal. Blue: Discriminated antenna signal

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.

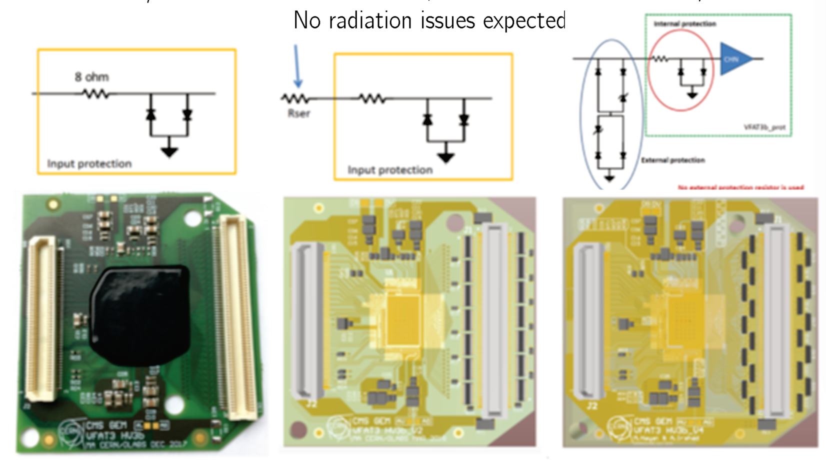
The addition of external components in front of the ASIC inputs can mitigate the damage. Other mitigation strategies to be implemented on the detector side are under investigation.

## 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.

(Design under investigation)

| HV3b_V2 | HV3b_V3 | HV3b_V4 |
|---|---|---|
| Initial baseline: Internal input protection only<br>Channels burnt with E>28uJ/disc | Ext. input protection (R=330 Ω)<br>OK after 500 ESD 470uJ/disc<br>X-talk +15%; Noise +20%<br>No radiation issues expected | Ext. input protection (diodes)<br>OK after 500 ESD 470uJ/disc |




[1] A. Colaleo et al. (2015) CMS Technical Design Report for the Muon Endcap GEM Upgrade. CERN-LHCC-2015-012, CMS-TDR-013.

[2] P. Aspell et al. (2008) https://cds.cern.ch/record/1069906/