03/10/19

-24th GEM Workshop-

GEM Spark Protection Studies

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Slides content courtesy of J.Merlin & F.Licciulli

Outline

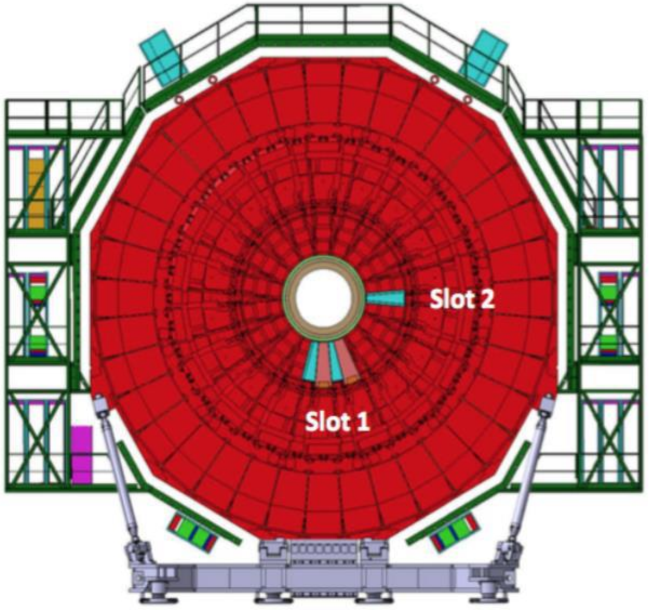
1. Slice Test issues & Discharge mechanism
2. Propagation probability studies on full size GE1/1 and 10x10 prototype
3. Mitigation strategies implemented in GE1/1 design & in GE2/1 design
4. Future of mitigation strategies on VFATs

Slice Test issues & Discharge mechanism

Slice Test Observations

Slice Test experience:

- 5 Super-Chambers in the negative end-cap
- Continuons operation within the CMS framework
- First experience with services: DCS, DSS, DAQ, DQM and analysis



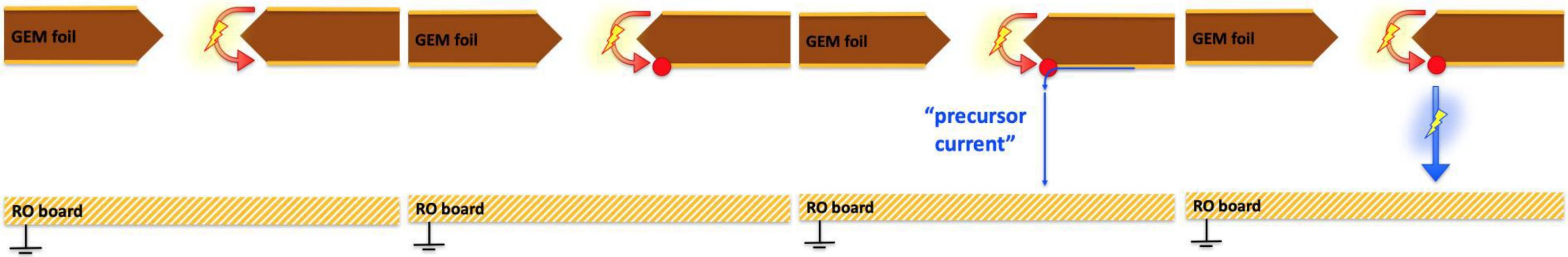
First opportunity to observe real-life discharges

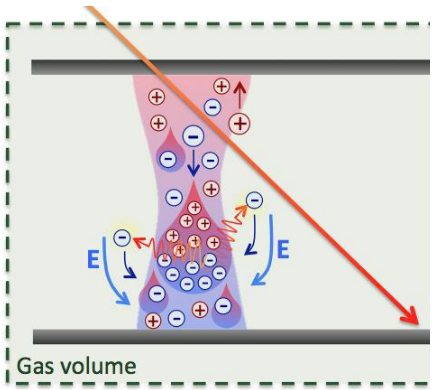
Observation of gradual channel loss caused by discharges propagating to the R/O plane

New R&D campaingn to undestand the discharge propagation and develop mitigation techniques

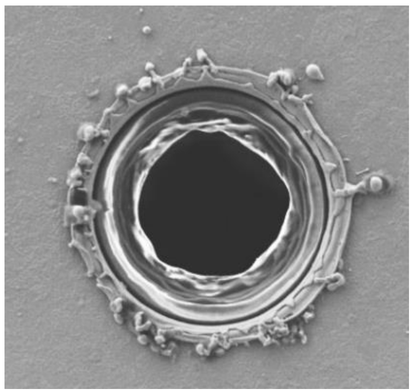
With the help of new tools and techinques to study discharges developed by RD51, ALICE GEM and CMS GEM groups

Discharge Propagation principle



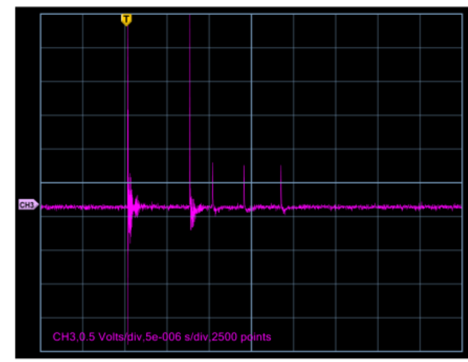


Typical developement of avalanche into a streamer



SEM picture of a GEM hole (bottom) after a 2mJ discharge

A. Utrobičić et al. (University of Zagreb), MPGD Stability Workshop, June 2018



Typical EM interferences caused by propagating discharges in GEM detectors

Step 1:

Primary discharge casued by the high charge density within the avalanche

Step 2:

Creation of hot spot on the copper near the hole rim (> $2500\,^{\circ}C$)

Step 3:

Thermoionic emission of electrons in the gas enanched by the local electric field (Schotty effect)

Step 4:

Developement of the precoursor current into a streamer causing a second discharge

Propagation probability studies on full size GE1/1 and 10x10 prototype

Available Options

Channel loss rate = BKG rate * discharge prob. * propagation prob. * damage prob.

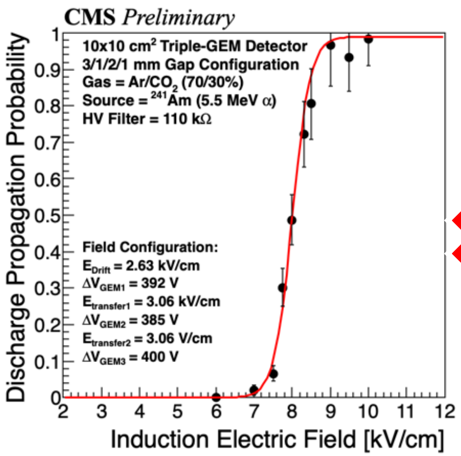
Discharge Probability → Propagation Probability → Damage Probability

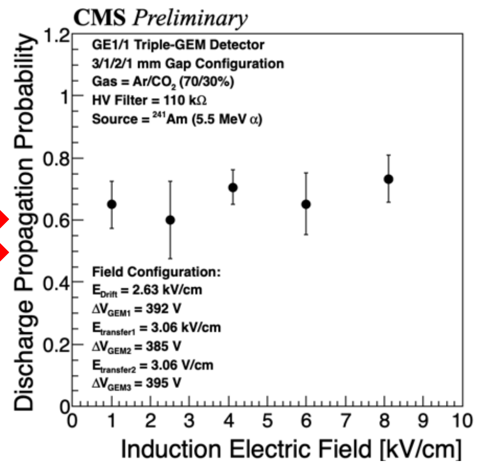
- Intrinsic to all gaseous detectors.
- Low probability with GEM ($\sim 10^{-9} \div 10^{-10}$)
- «No pain No Gain» parameter

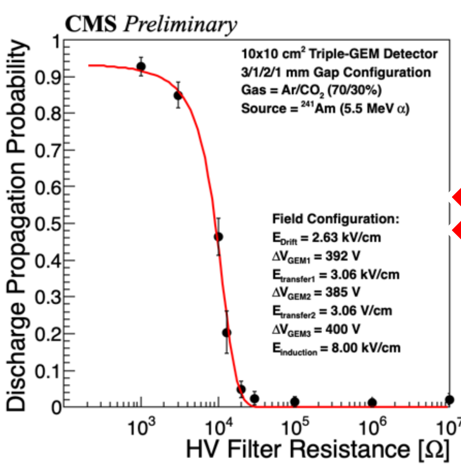
- Complex Process depending on:
  - Gap thickness
  - Gap Capacitances
  - Electric Fields
  - ...

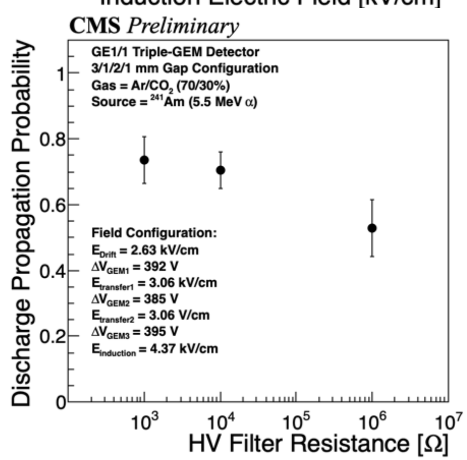
Discharge Propagation Probability

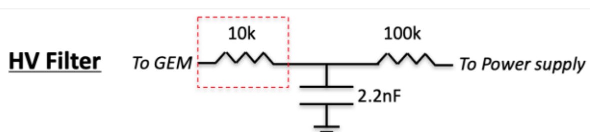
$10 \times 10\ cm^2$ detector — **'Large' GE1/1 detector**











Test on 'small' $10\times10\ cm^2$:

- **Influence of the induction field and filter resistor (left plots)**

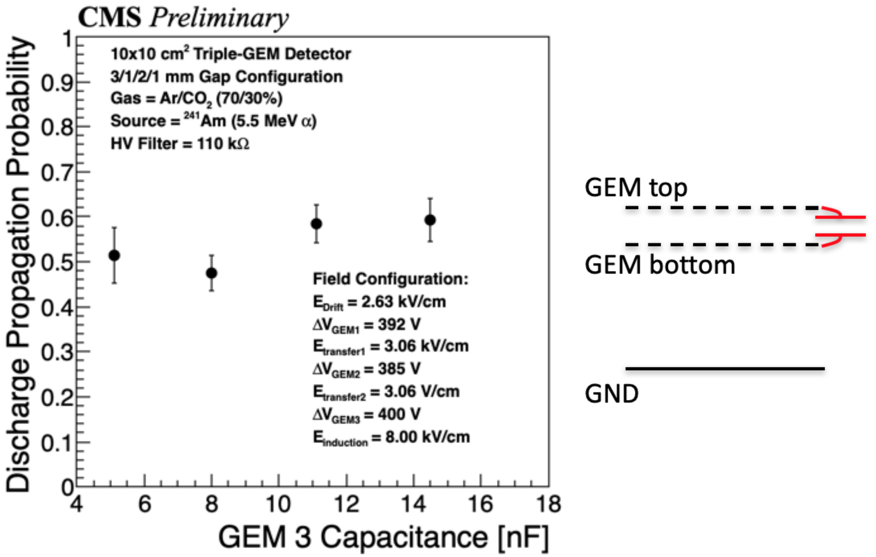
Test on 'large' GE1/1 :

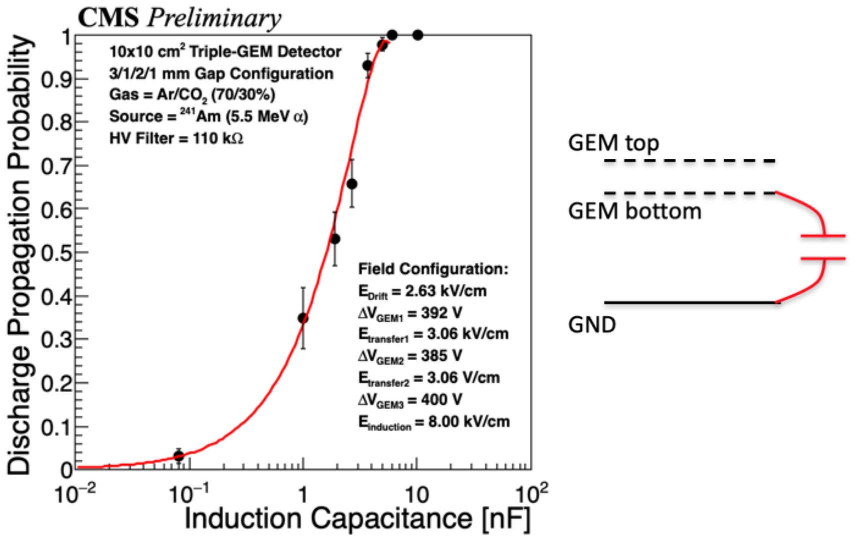
- **No dependency on the induction field**
- **No effect from the filter resistor**
- **Clear inconsistency between 'small' and 'large' detectors**
- **Clear increase of the propagation probability with the induction capacitance → i.e. Sufficient ammount of energy on the foil to feed the precursor current and trigger discharge propagation**
- **All measurements indicate that the discharge propagation is more likely to happen in large foils due to the availability of energy directly stored on the foils**

Discharge Propagation Probability

Further Studies to understand differences between small and large chambers:

- **No dependency on the GEM foil capacitance → no influence on the primary discharge energy**
- **Clear increase of the propagation probability with the induction capacitance → i.e. Sufficient ammount of energy on the foil to feed the precursor current and trigger discharge propagation**
- **All measurements indicate that the discharge propagation is more likely to happen in large foils due to the availability of energy directly stored on the foils**

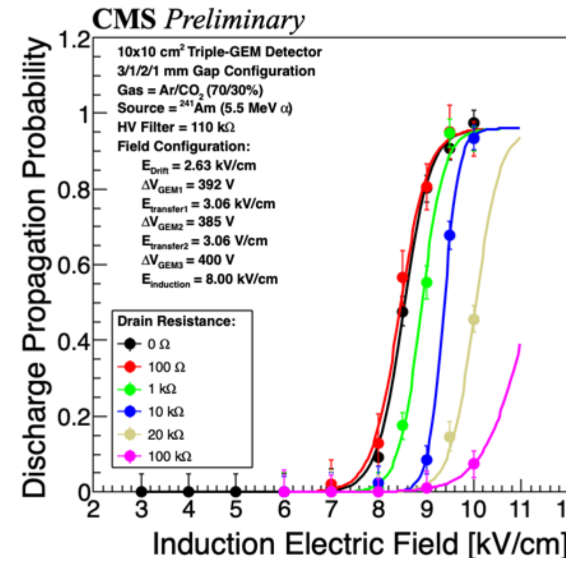


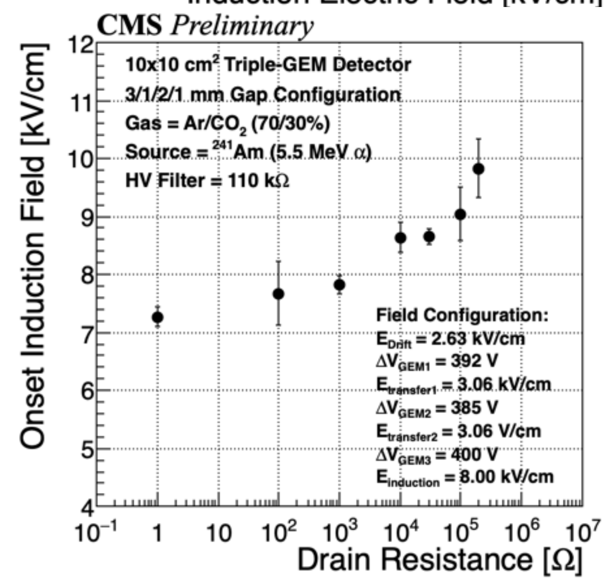


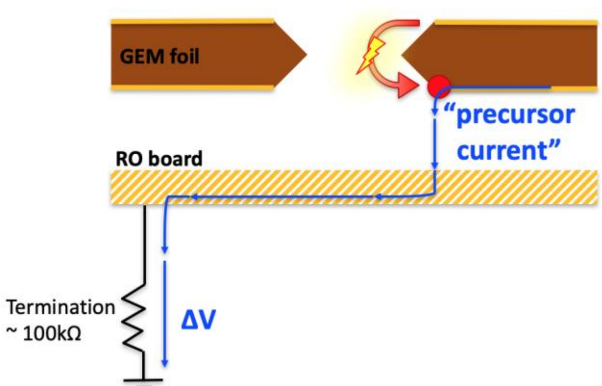
Propagation Mitigation

Self-quenching of the precursor current:

- **Drain resistor between readout strips and ground causes temporary reduction od the induction field after the primary discharge**
- **The precursor current cannot grow and develop into a streamer regardless the energy avaiable on the GEM foil**
- **Efficient way to stop propagation before it happens**
- **Specific de-coupling circuit can be implemented between readout board and electronics**







Available Options

Channel loss rate = BKG rate * discharge prob. * propagation prob. * damage prob.

Discharge Probability	Propagation Probability	Damage Probability

Discharge Probability

- Intrinsic to all gaseous detectors.
- Low probability with GEM ($\sim 10^{-9} \div 10^{-10}$)
- «No pain No Gain» parameter

Propagation Probability

Understood the process of propagation in large detectors
→Mainly driven by large induction capacitance

Found 3 ways to mitigate discharge propagation:

- Reduce foils capacitance
- Increase filter resistance
- Use drain resistor

Damage Probability

Depends mainly on:

- Energy of the propagationg discharges
- Electronics input protection

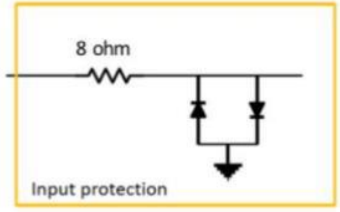
New VFAT Hybrid Design

HV3b_V2

Initial baseline

Internal input protection only (diode)

Channels burnt with E>28uJ/disc



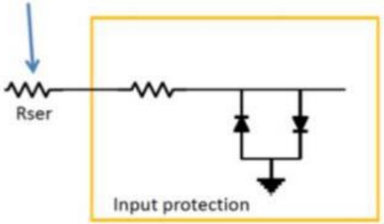
HV3b_V3

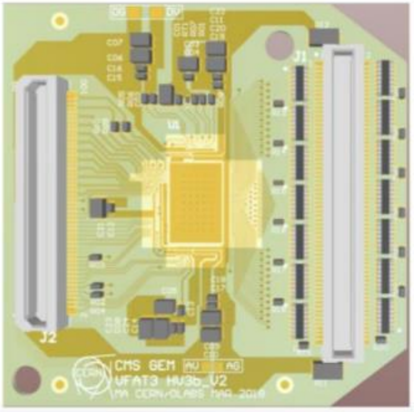
Ext. input protection (R=330 Ω)

OK after 500 ESD 470uJ/disc

X-talk +15%; Noise +20%

No radiation issues expected





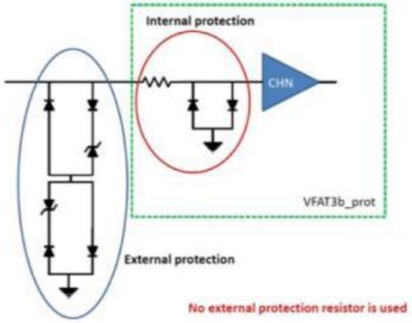
HV3b_V4

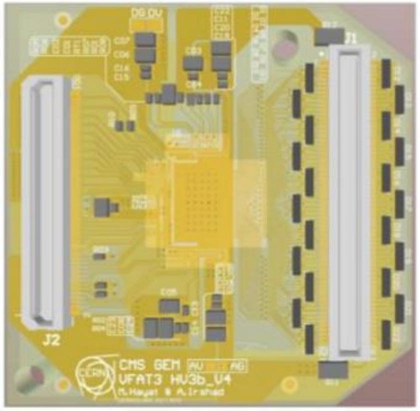
Ext. input protection (diodes)

OK after 540 ESD 470uJ/disc

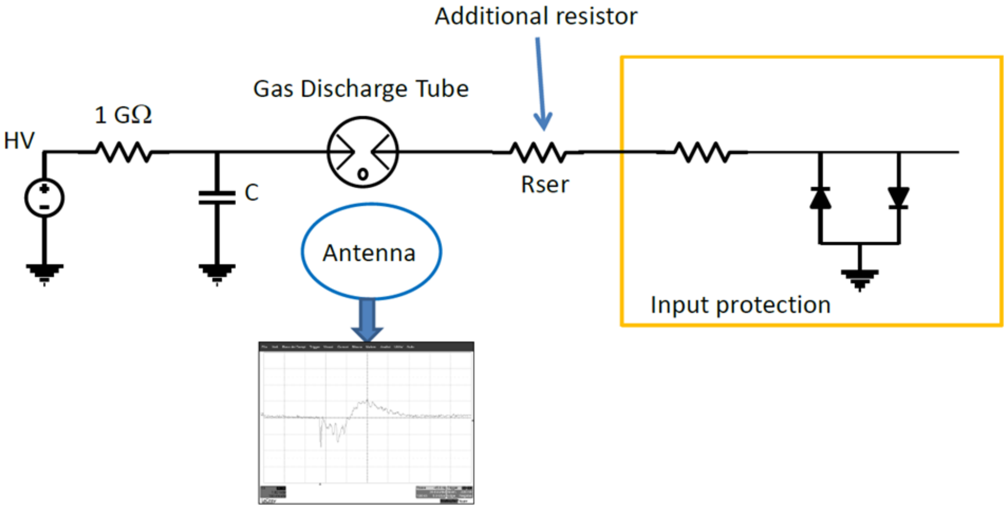
No increase of noise observed

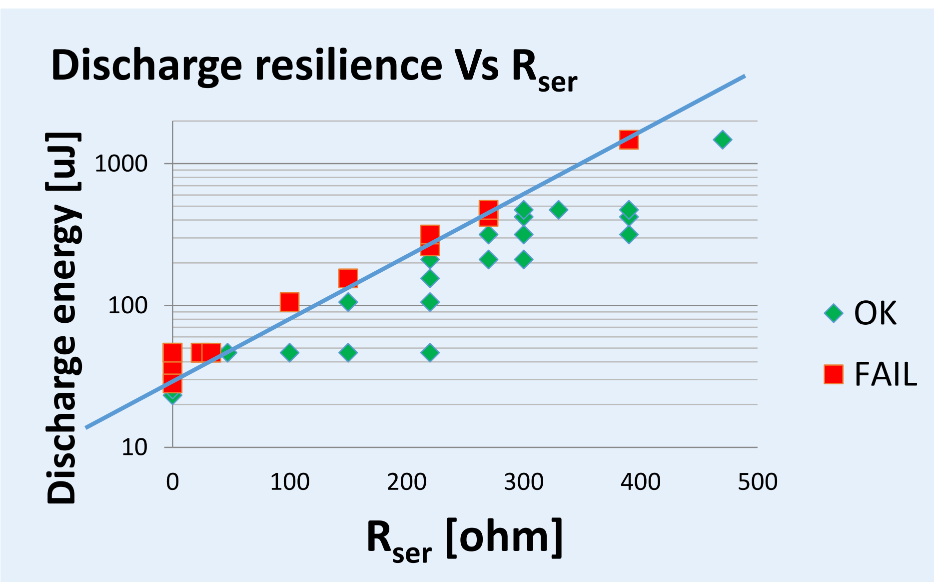
Rad Hard studies OK (10Mrad)





Test on HV3b_V3





The series resistor:

- **Dissipates part of the discharge energy**
- **Adds noise and increases cross talk**

Value of 470Ω is fine for discharges energies up to 1.5mJ

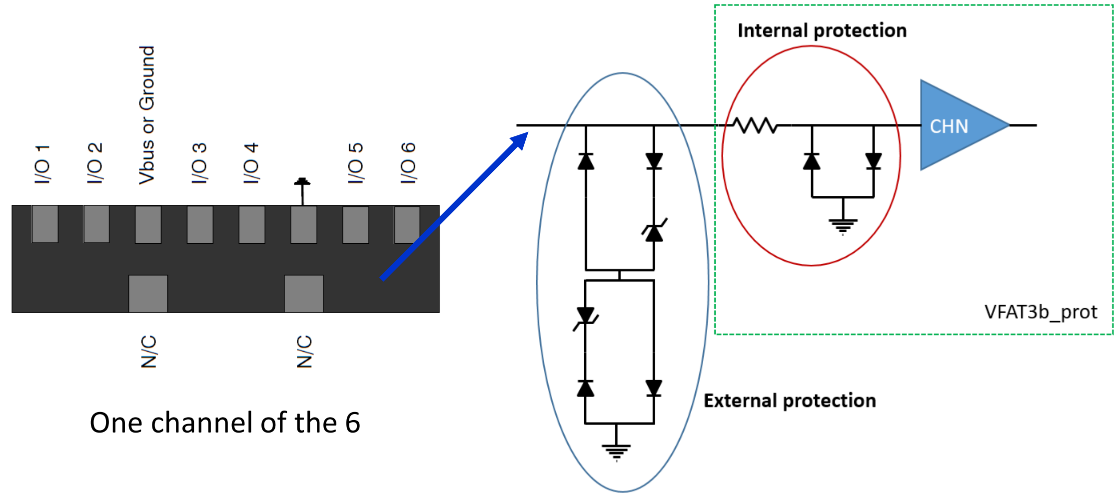
Many resistor models of the same value was tested to find the most resilient one

Chosen Resistor Array:

Panasonic	EXB2HV471JV

Test on HV3b_V4

Component: On Semiconductor ESD7016
Features:
- high energy ESD capability
- ultra-low capacitance 0.15pF typical, I/O to GND
- small dimensions: 3.3 mm x 1 mm



In lab with the injection circuit:

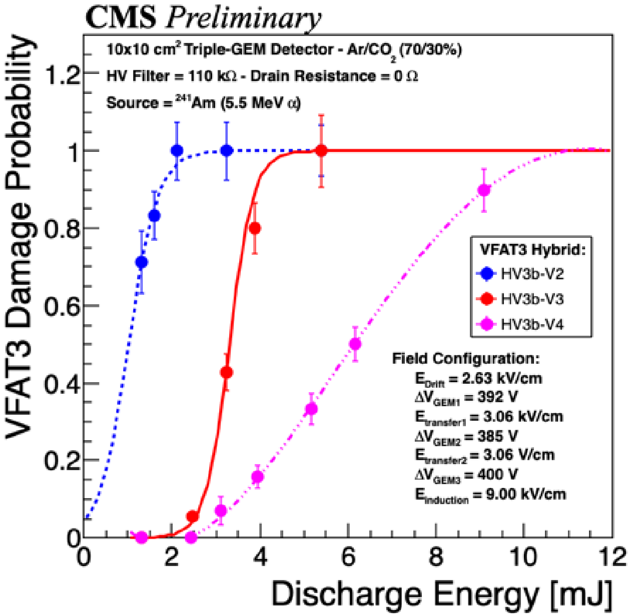
- Channel perfectly working after 540 ESD discharges (about 470 μJ/dis.)
- Noise before/after discharges about 800 e-
- No measurable noise contribution of the external protection

In 904 HV4 mounted on the chamber: one discharge → all analogue channels broken.

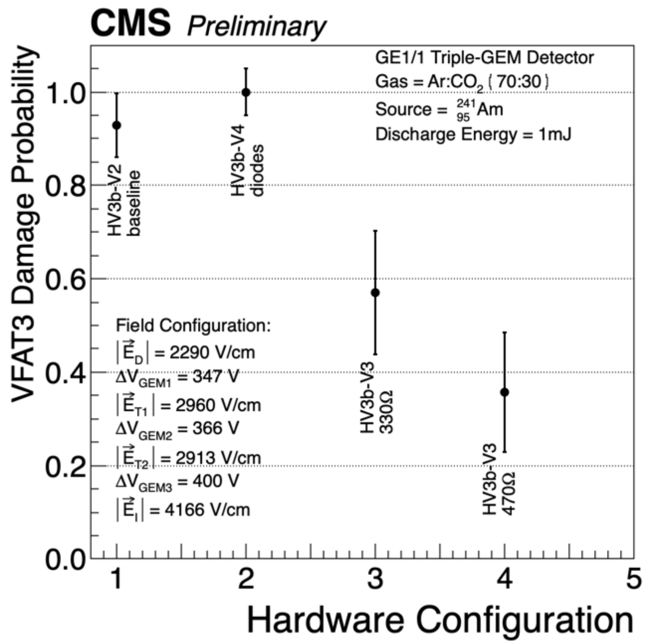
Solution rejected!

Damage Probability

'Small' detector



'Large' detector



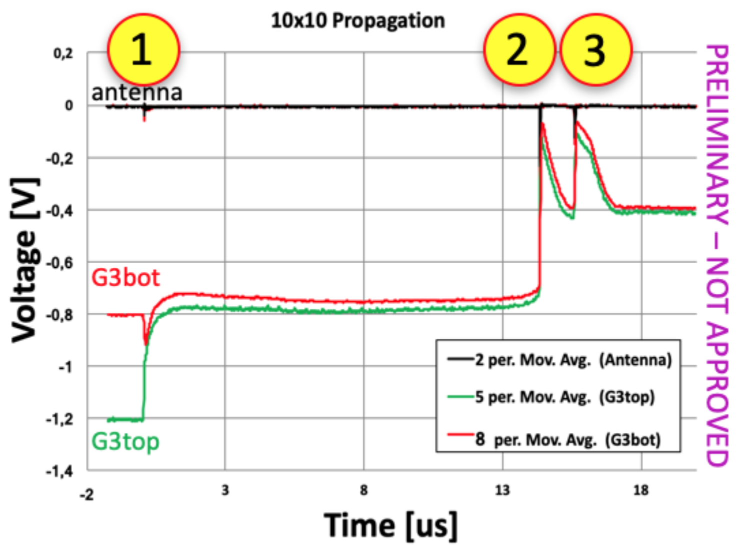
First validation on small 10x10 detectors:

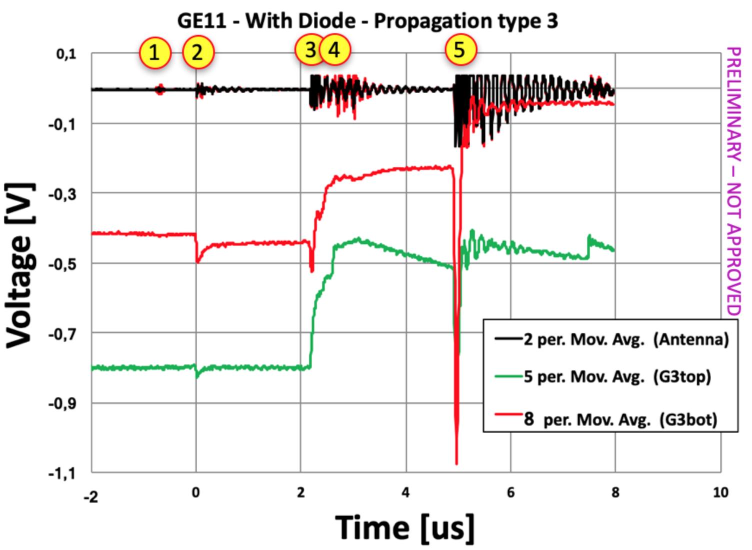
- Observation meet expectations
- Energy required to cause VFAT damage is higher in Hydrid V3 & V4
- Input protection circuits are efficient at norminal operating voltage and above

Comparison with large detectors:

- Damage probability of all hybrids is higher than expected to be → beacuse discharges accumulate more energy during the propagation
- Hybrid V3 with 470Ω gives the lowest damage probability, so far...

Structure of the Propagation





Small Detector:

1. Primary discharge in GEM3
2. Propagation from GEM3 to Readout
3. Re-ignition of the propagation

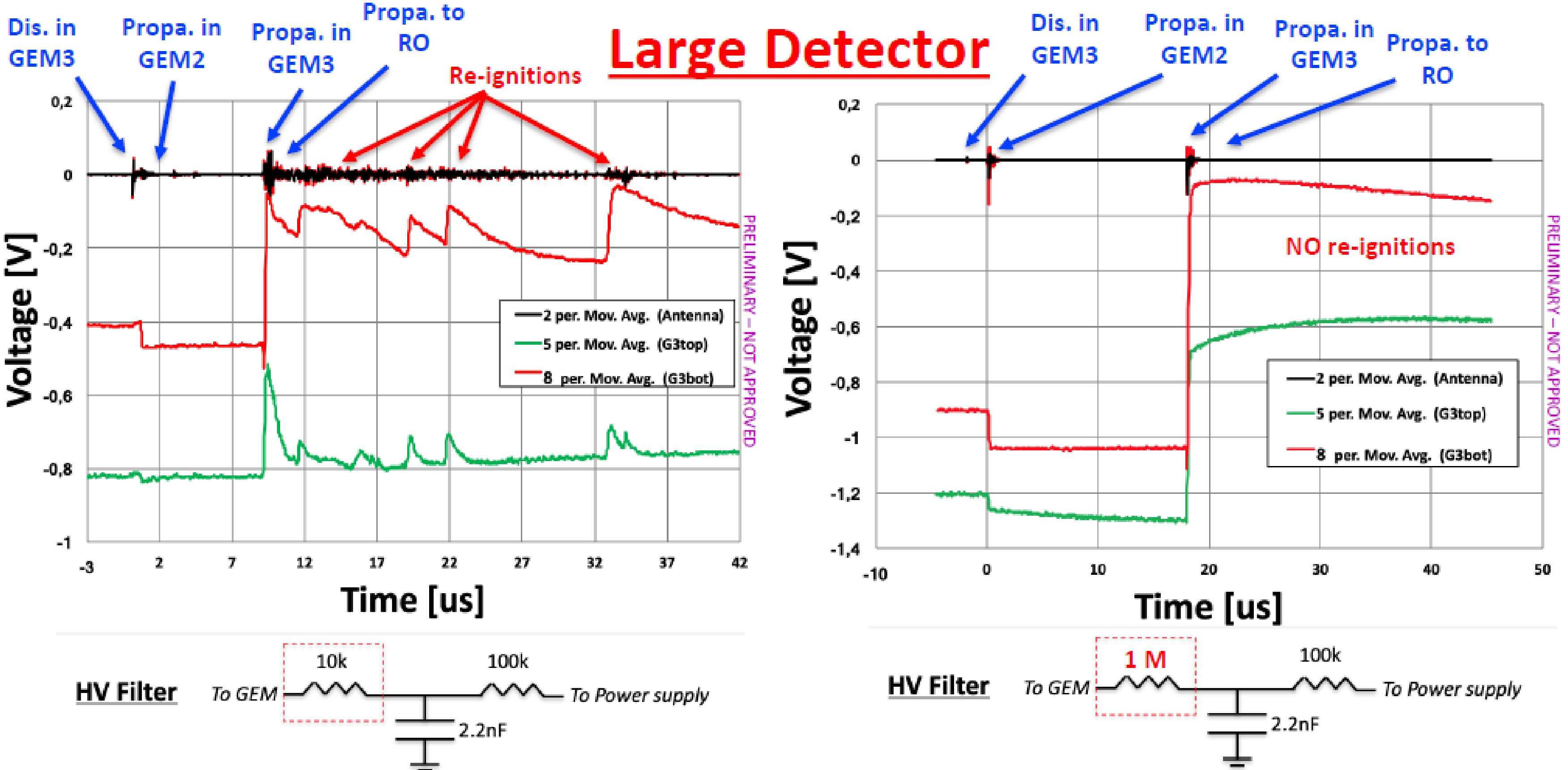
Propagation process in small detectors is simple and localized

Large Detector:

1. Primary discharge in GEM3
2. Propagation backwards in GEM2
3. Propagation forward in GEM3
4. Propagation from GEM3 to Readout
5. Re-ignition of the propagation

Propagation process in large detectors is more complex (discharges ''travel'' backward and forward, accumulating more energy)

Discharge Propagation Re-ignition



In-depth investigations with large detectors:

- **Further studies indicates that the damage probability in large detectors is mainly due to propagations re-ignitions**
- **Re-ignitions are fed by the energy stored in the filter → can be mitigated tuning the filter capacitance**

Available Options

Channel loss rate = BKG rate * discharge prob. * propagation prob. * damage prob.

Discharge Probability → **Propagation Probability** → **Damage Probability**

Discharge Probability

- Intrinsic to all gaseous detectors.
- Low probability with GEM ($\sim 10^{-9} \div 10^{-10}$)
- «No pain No Gain» parameter

Propagation Probability

Understood the process of propagation in large detectors
→Mainly driven by large induction capacitance

Found 3 ways to mitigate discharge propagation:

- Reduce foils capacitance
- Increase filter resistance
- Use drain resistor

Damage Probability

Understood the process of damage in large detectors
→mainly due to propagation re-ignition

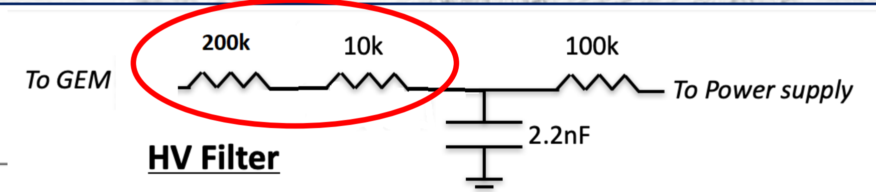
Found 2 ways to mitigate VFAT damage:

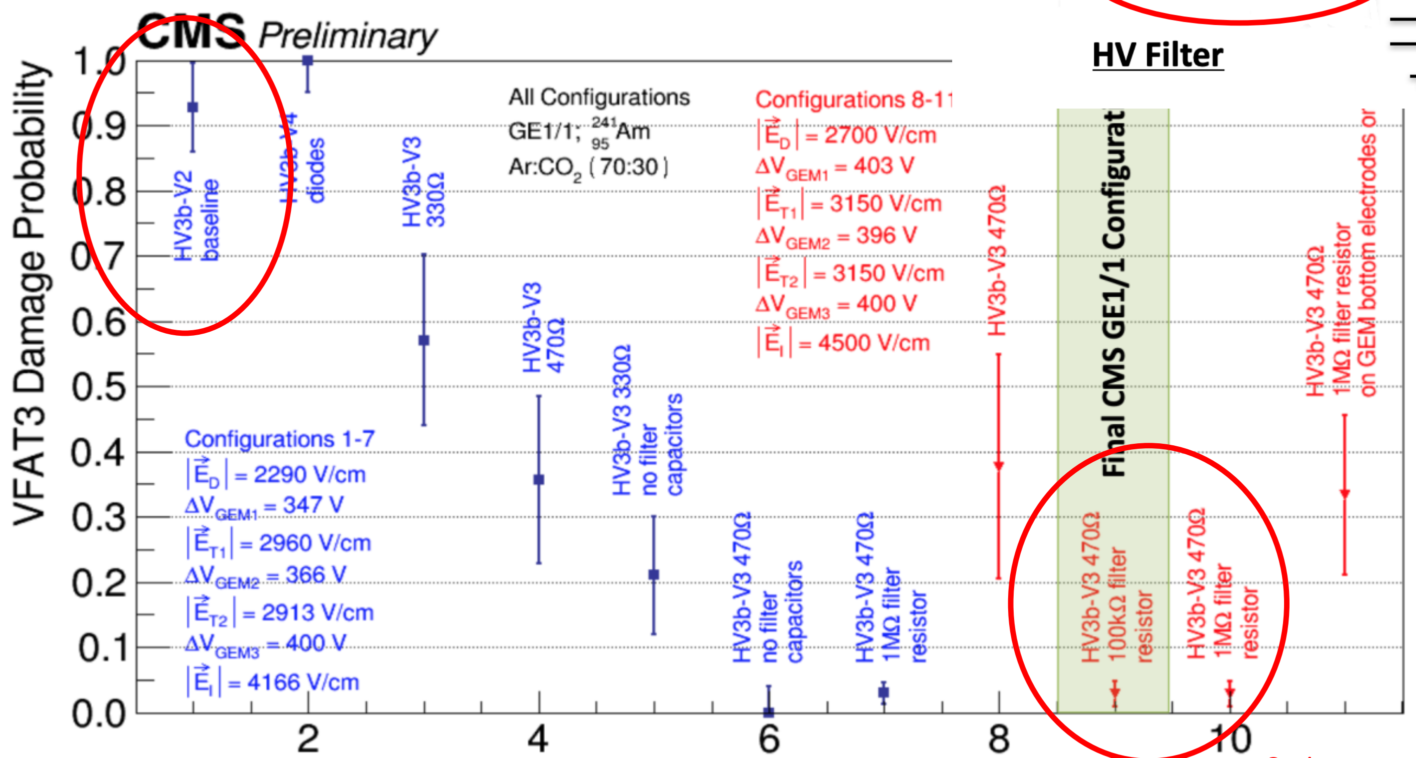
- Improve electronic input protection
- Increase the de-coupling with the filter capacitance

Mitigation strategies in GE1/1 & GE2/1 design

Mitigation for GE1/1

Baseline configuration used during slice test
~95 ÷ 100% damage probability





Final chose for the HV filter → 210kΩ

HV3b_V3 with 470Ω protector resistor chosen

Optimum configuration to reduce damage probaility

Optimum configuration for GE1/1

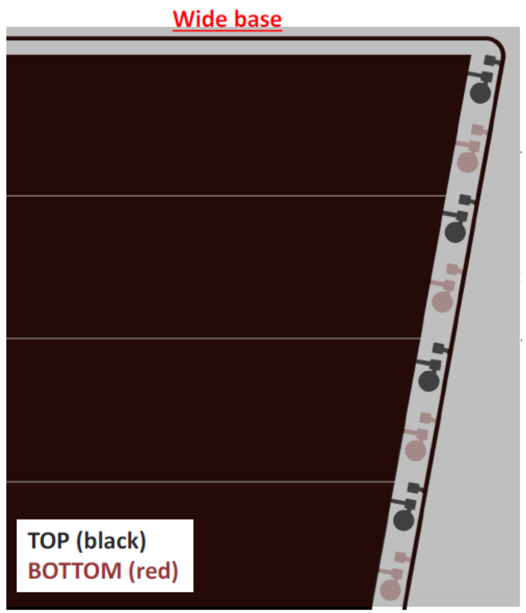
- **Optimum configuration allows the reduction of the damage proability by almost 2 order of magnitude**
- **No side effect on detector performance (No impact on rate capability in GE1/1 and GE2/1 project)**

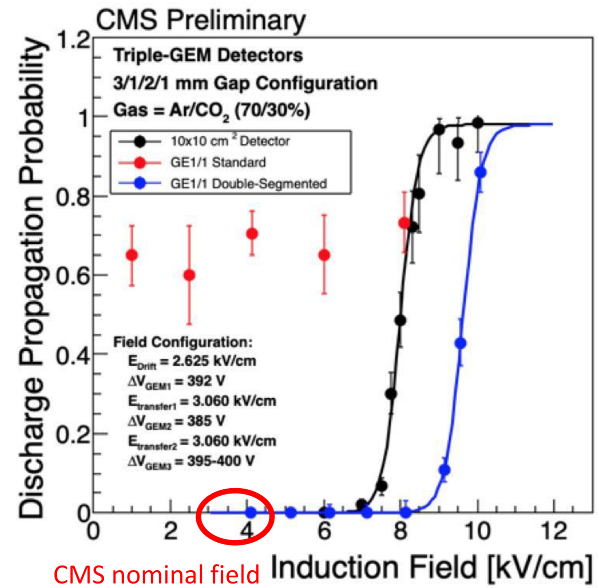
Mitigation for GE2/1

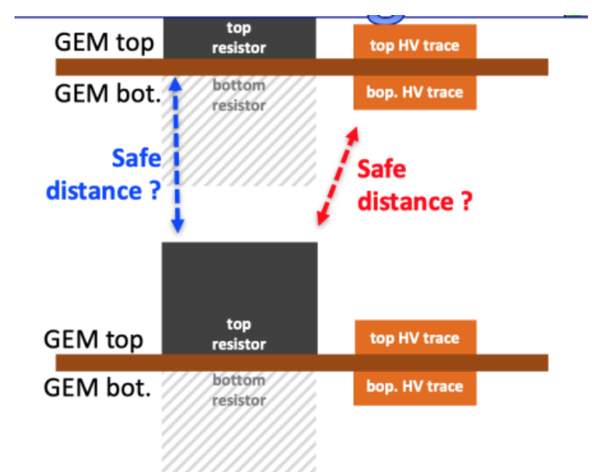
Double Segmented foils:

First prototype produced and assembled:

- Reduce capacitance, improve foil protection and HV sector de-coupling
- First measurements are very promising (no propagation so far)





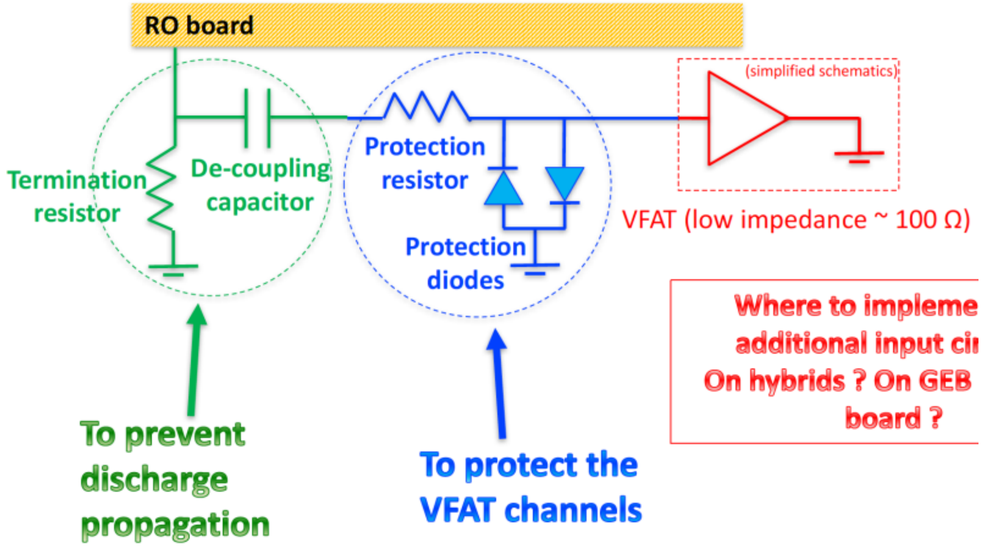


Future of mitigation strategies on VFATs

Mitigation for VFATs

Sandwich boards

Prototype boards designed and producec



- De-coupling circuit and better VFAT protection
- Test is on-going on large detector
- Integration to final chambers is under investigation

Foreseen studies on VFAT protection

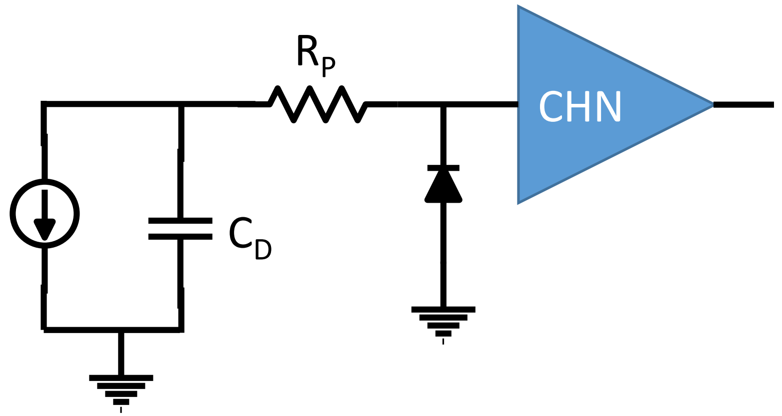
Study on new components

Components used in the protection circuits have to sustain voltages up to 400 V during a discharge → **New study to assure the resiliance of the components**

Study on new protecting circuits

Circuit never tested due to the double component which would have involved a larger hybrid

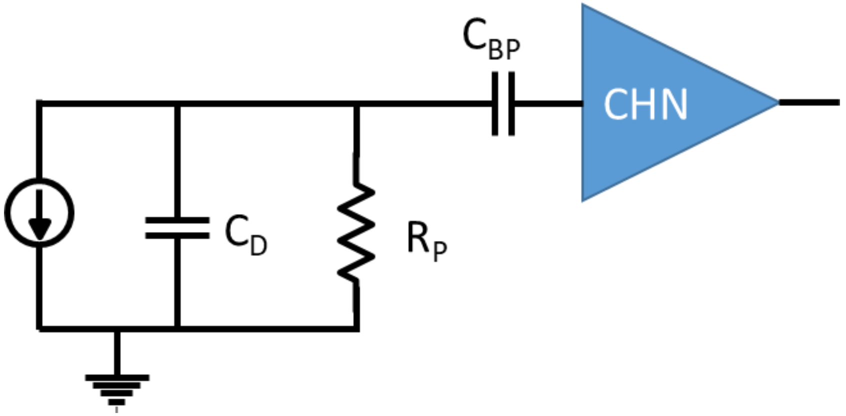
To be tested using Sandwich board



Foreseen studies on VFAT protection

Study on new protecting circuits

Simulations results are promising



Values of:

$$C_{BD} \approx 10nF$$
$$R_P = 100k\Omega \div 1M\Omega$$

The circuit maintans the nominal gain of the chip

Probabily better use higher values of R_P for reduce the ENC

Conclusion

- **GEM discharge mitigation study is completed for GE1/1**
- **Extensive R&D campaign was conducted in 2018/2019:**
  - **Understanding of the propagation process and structure of the discharges**
  - **Understanding of the electronics damage process in large detectors**
  - **Mitigation techniques were determined and implemented for GE1/1, production schedule was updated accordingly with no impact on**
  - **Mitigations techniques at the design level are under investigations for GE2/1 and ME0 (first results are very encouraging)**
- **R&D campaign on the VFAT protection circuit is scheduled to start in November:**
  - **Evaluating the noise and the influence on the gain associated with the different circuit solutions, in order to find the best compromise.**

Bibliography

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BACKUP

Rate Capability