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Impact of Single-Mask Hole Asymmetry on the properties of GEM Detectors

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On behalf of the CMS-Muon Group

Abstract

A single-mask Gas Electron Multiplier (GEM) technique overcomes the cumbersome practice of alignment of two masks and allows the production of foils with very large area as needed for the CMS muon forward upgrade. However, the holes obtained with refinements in the single-mask technique are conical in shape and hence asymmetric compared to the symmetric holes of double-mask Technology where the holes are bi-conical. The hole geometry and their uniformity define the performance of the detectors which are constructed with such GEM foils. To evaluate the effect of this asymmetry on triple-GEM detectors, such foils have been characterized experimentally. A series of tests have been conducted on a special prototype with three single-mask GEM foils, studying effective gain and its uniformity, rate capability, charging-up behaviour, energy resolution and their variations with time when continuously irradiated with a particle source. The results have also been compared for two different hole orientations.

Motivation and GEM Upgrade

- The CMS muon system [1, 2] is designed to provide robust, redundant and fast identification of the muons traversing the system, in addition to trigger capabilties and momentum measurement.
- The high |η| region of the total CMS Muon acceptance is only equipped with CSC chambers and presents an opportunity for instrumentaion with a detector technology that could sustain high radiation environment for long-term. Therefore, CMS-Muon Colloboration has proposed to install two layers of triple-GEM chambers known as GE1/1 and GE2/1 in the endcap
- Experiments to face high rate at LHC
- RPC rate capability limited by space charge and problem of Aging
- Muon detector requirements
  - Detector should be able to cope up with high rate
  - Good position and temporal resolution
  - Should be radiation resistant
- Suitable option
  - Micropattern gas detectors such as GEM's

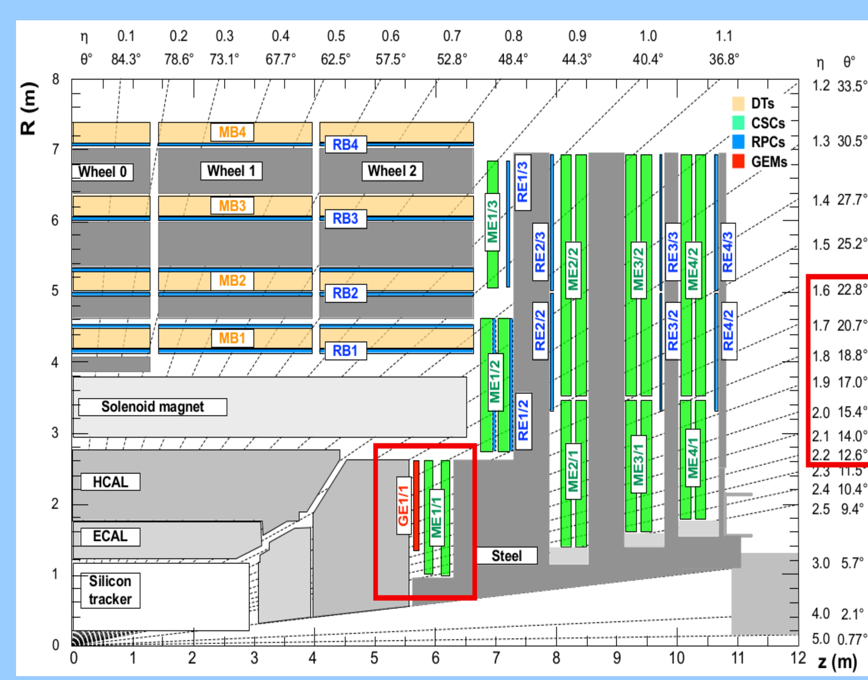

Fig. 1: A quadrant of the R-z cross-section of the CMS detector, highlighting (in red) the location of the GE1/1 station in the pseudo-rapidity region 1.6 < |η| < 2.4 [2]

Prelude

GEM

- Thin double-sided metal-coated polymer foil chemically pierced by a high by a high desity of holes [3]
- Typical parameters:
  - Kapton metal coated ~50µm
  - Pitch ~140µm
  - Cu thickness ~5µm
  - Hole density ~50µm to 100mm^{-2}

Performance

- Rate Capability ~10^5 Hz/cm^2
- Spatial Resolution ~100µm
- Temporal Resolution ~5ns
- Detection Efficiency ~98%

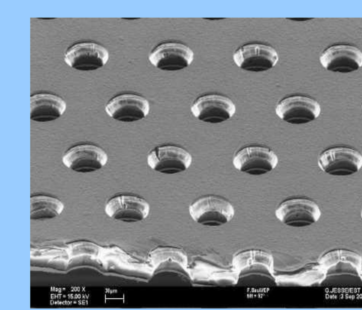

Fig. 2: GEM Hole distribution

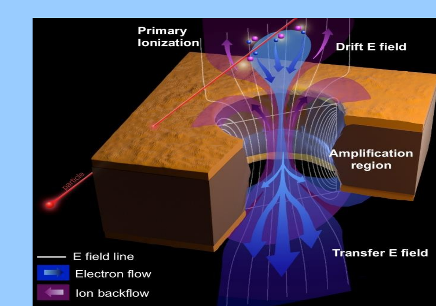

Fig. 3: Amplification Process in a Single Hole

Fig. 4: Double-mask

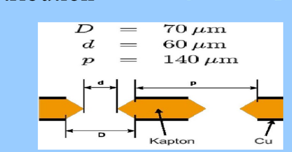

Fig 5: Sketch showing Pitch and hole distribution

Fig. 6: Single-mask

CMS Muon Requirements

GE1/1

- Pseudo-rapidity region 1.5 < |η| < 2.2
- 36 super-chambers per endcap, each spans 10^0
- To be installed during LS2 (2019-20120)

GE2/1

- Pseudo-rapidity region 1.6 < |η| < 2.4
- Tripple-GEM chambers arranged in two layers per endcap and spaning 20^0 [4]
- 18 chambers per layer, 36 chambers per endcap

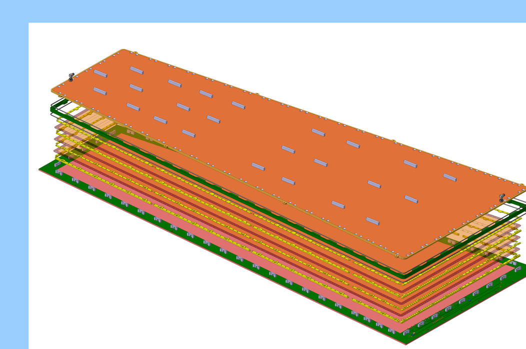

Fig 7: Tripezodal shaped GE1/1 detector to be used in CMS and the kind of large area GEM foils used in it

Formulation of the Problem?

- CMS upgrade requires large area GEM foils
- Foils produced due to Doule-mask technique are limited to only 40 cm x 40 cm
- Single-mask technique [5] is used to produce large area GEM foils
- Single-mask technique gives rise foils with asymmetric Holes as shown in Fig. 6 and Fig. 8.
- These holes can be irraidaited with two different ways named as "**Orientation A**" and "**orientation B**" as shown in Fig. 8.

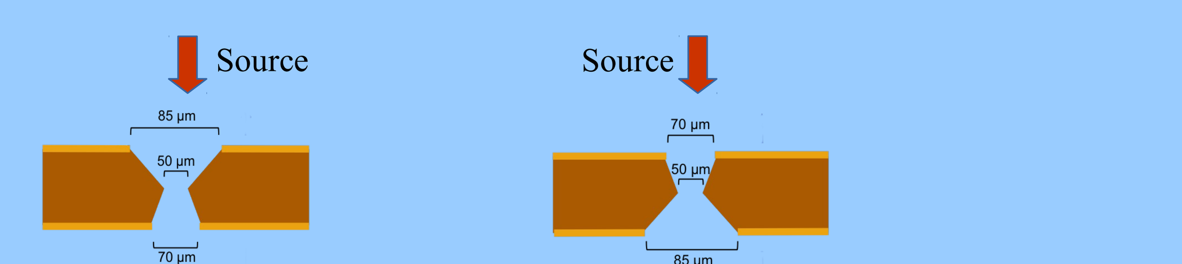

Fig 8: Single-mask Single Asymmetric Holes: "**Orientation A**" (left) and "**Orientation B**" (right) facing the incident radiation.

Question: Is there any effect on the properties of the detector due to this hole Asymmetry?

To Answer: Test Detector

- Constructed a detector with a symmetric gap confugration (2/2/2/2) mm
- Two active windows (top and bottom), each with active area 10 cm X 10 cm
- Can be irradiated on both the sides
- Minimise human error etc.

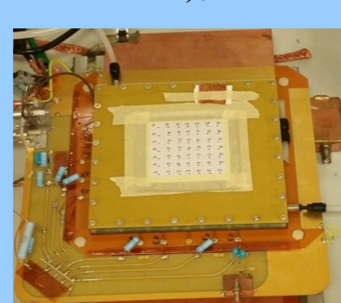

Fig. 9: Tripple GEM Detector

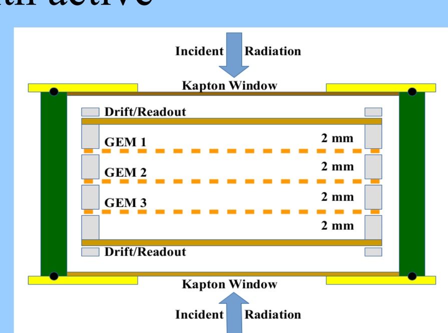

Fig. 10: (2/2/2/2) Symmetric Gap Sketch

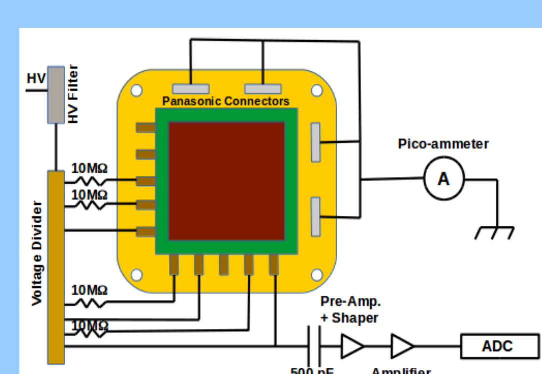

Fig. 11: Detector with applied potential and setup

Results

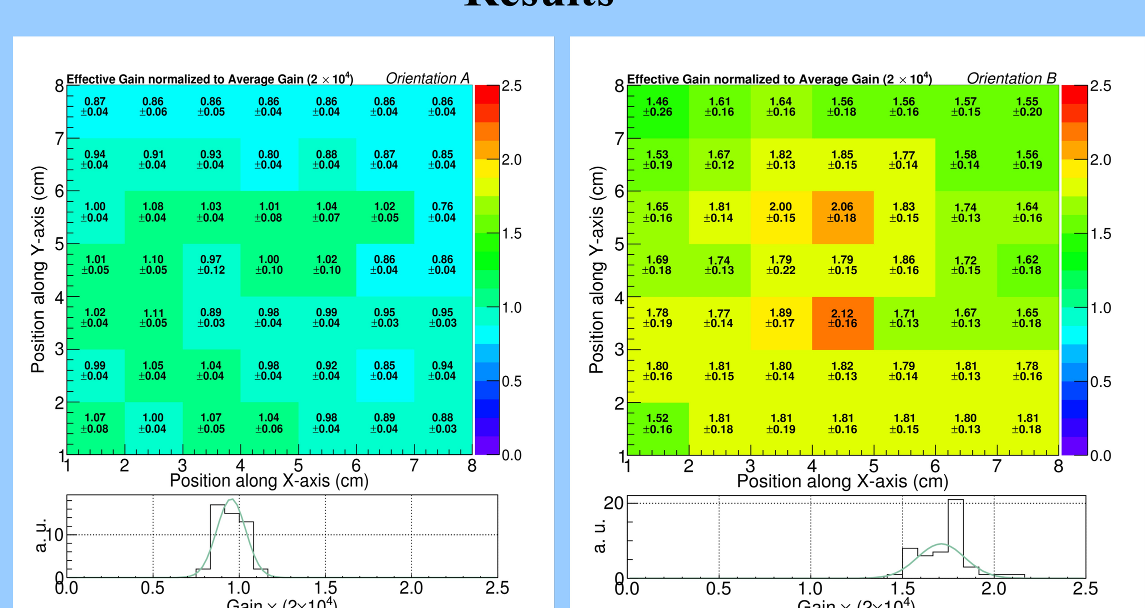

Fig 13: The active window's (10 cm X 10 cm) were divided into 7 X 7 = 49 sectors of each almost 1 cm x 1 cm. Each sector was radiated with Fe-55 source and gain was measured when "Orientation A" and "Orientation B" of the foils were facing the incident source. The gain at equal electrical field of each sector has been Normalized to an avergae gain of 2 x 10^4. Gain is observed to be almost 1.8 times higher in "Orientation B" compared to "Orientation A" .

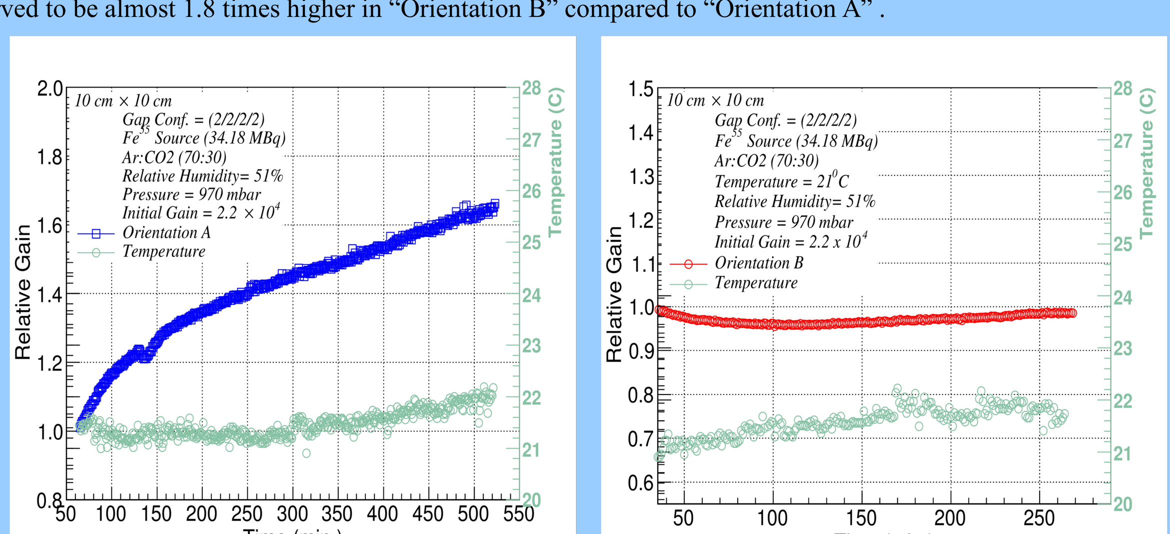

Fig 15: Normalized gain as a function of time when the detector was contineosly irradiated with source Fe-55. Gain increases in "Orientation A" upto 1.6 times the initial gain after the duration of around 8 hours while in "Orientation B" gain is almost flat. While, humidity, pressure and temperature were constant during the measurement but temperature has been added in the plot to demonstrate its stability.

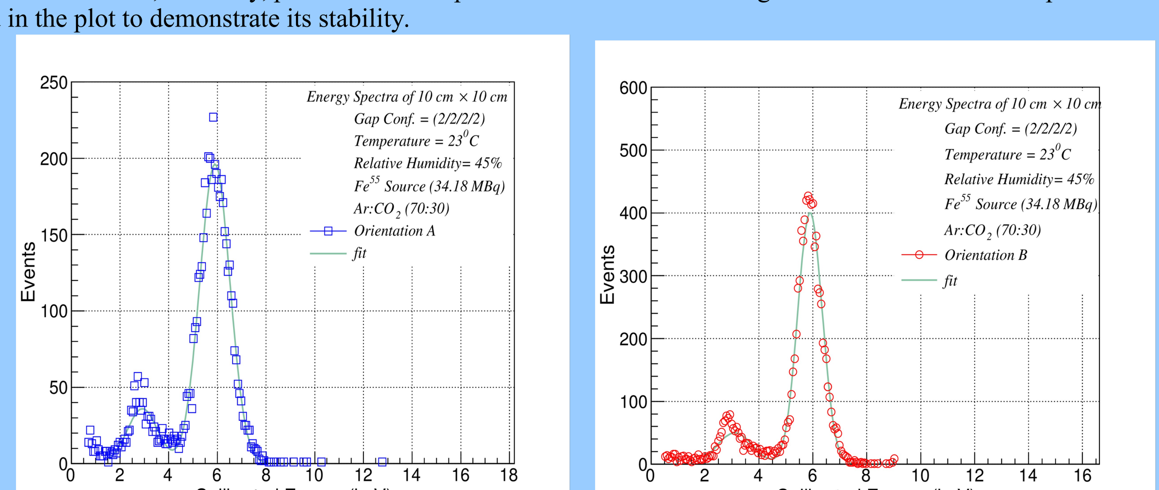

Fig 16: The best values of the energy resolution ~23.71%±0.02 and ~18.06%±0.01 measured in "Orientation A" and in "Orientation B" with Fe-55 source. The resolution has been measured at a gain of 2.2 x10^4.

Results

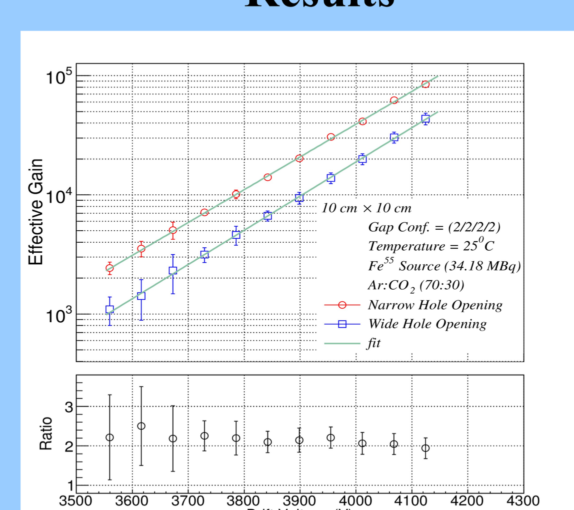

Fig 12: Gain measured in a triple GEM 10 cm x 10 cm detector when all the three foils either with "Orientation A" or with "Orientation B" were facing the Incident source (Fe-55). The ratio plot in the bottom shows that the gain almost 2 times higher in "Orientation B" compared to "Orientation A". Similar result has been presented at MPGD-2017 by CMS Muon Group and here we confirm the results once again.

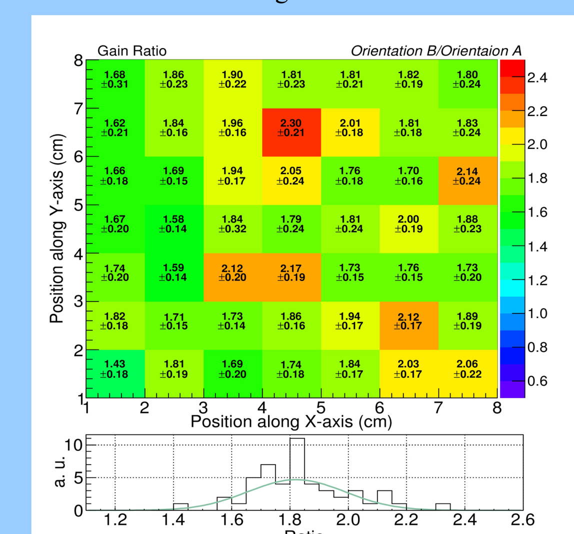

Fig 14: Ratio of gains between "Orientaion B" and "Orientaion A" in each sector. The bottom histogram gives the mean value of the ratio of gains and is nearly equal to 1.8. The result demonstrates that the gain is 1.8 times higher in "Orientation B" compared to "Orientation A".

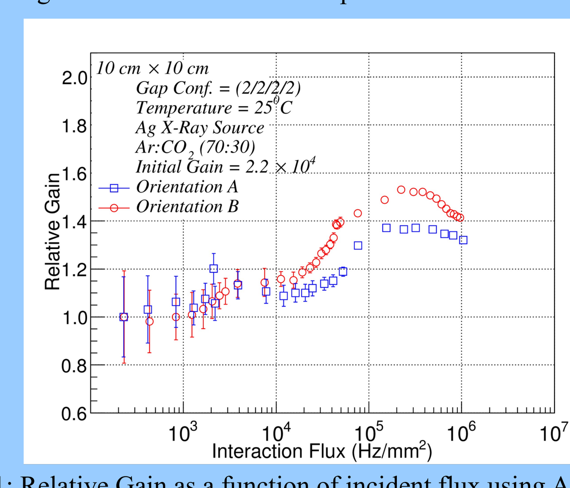

Fig 21: Relative Gain as a function of incident flux using Ag target X-ray Source. The Incident flux was varied from 10^2 to 10^6 using copper attenuators of 1mm thick, transparency increases till 5 x 10^4 and after that a typical "bump" is observed (CMS region of interest < 10^4). Similar result was reported to MPGD-2017 by CMS Muon Group and we confirm the result once again.

Results

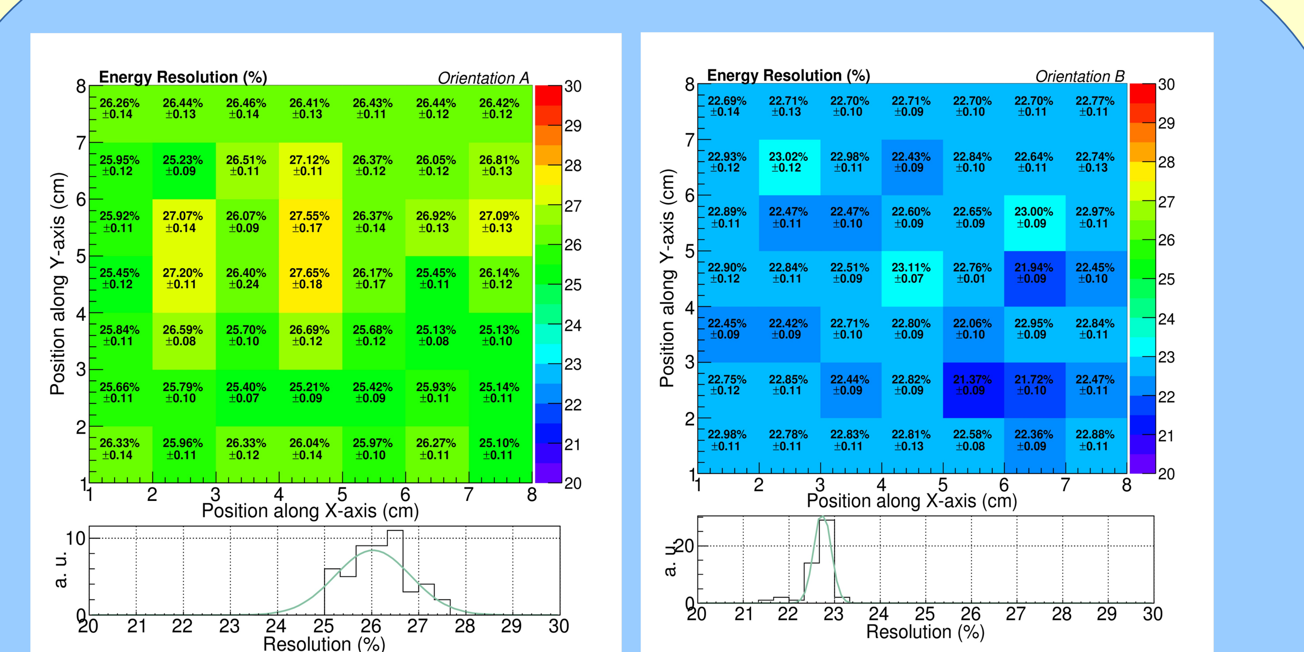

Fig 17: The active window's (10 cm x 10 cm) were divided into 7 x 7 = 49 sectors of each almost 1 cm x 1 cm. Each sector was radiated with Fe-55 source and resolution's were measured when "Orientation A" and "Orientation B" of the foils were facing the incident source. The resolutions were measured at equal electrical fields. Further the plots at bottom show the mean of the resoultions which is ~26% in case of "Orientation A" and ~22.8% in case of "Orientatiation B" respectivelly.

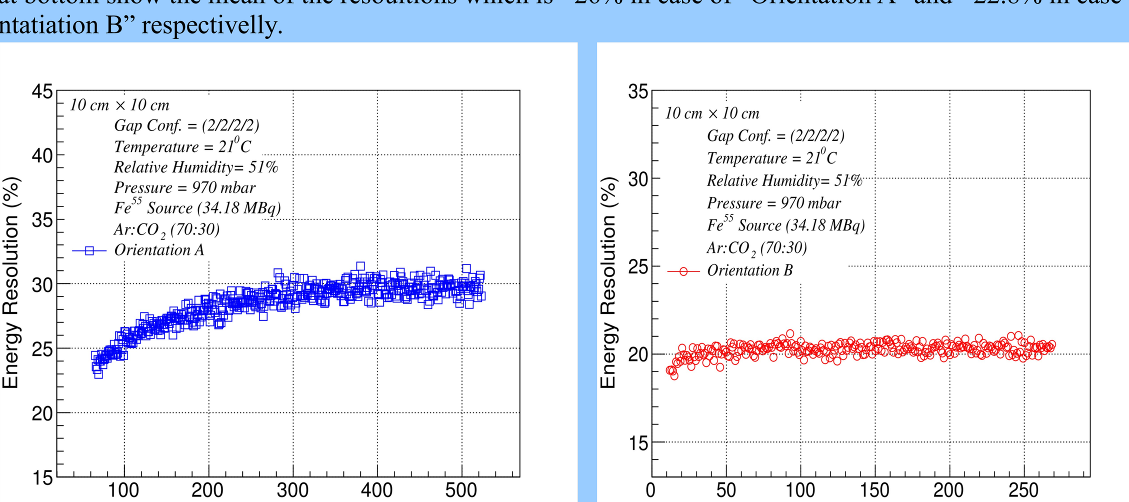

Fig 18: Enery resolution measured as a function of time with the initial gain of 2.2 x 10^4 when detector was contineously Fe-55 source. Resolution in "Orientation A" varies from ~24% to ~30%. The variation may be attributed to the change in gain as also shown in Fig. 20. On the other hand resolution in "Orientation B" is observed to show to less fluctuations and is almost flat at ~20%..

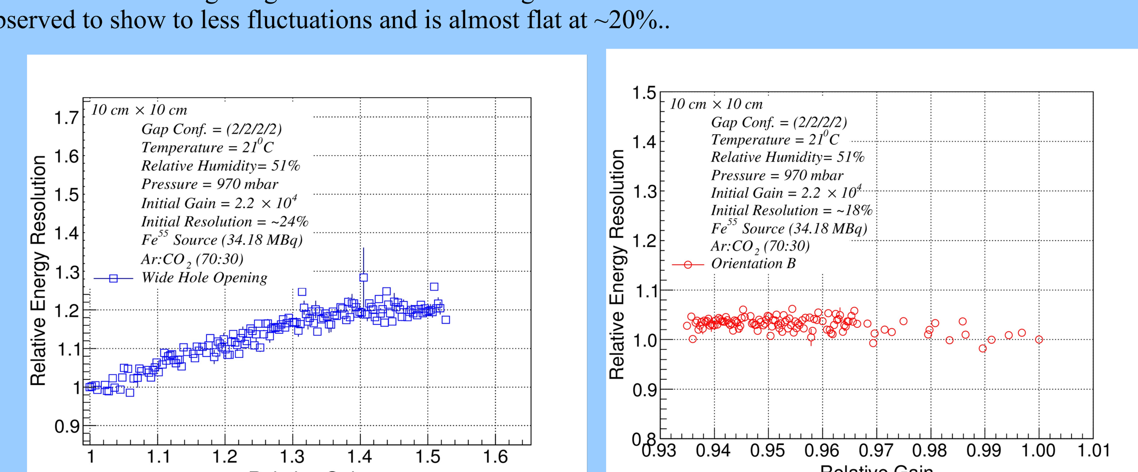

Fig 19: The relative resolution measured as a function of relative gain when detector was contineously irradiated with Fe-55 source. The effect on energy resolution is clearly seen due to change in gain in "Orientation A" while as "Orientation B" doesn't appear to be much affected due to more stable gain.

Summary

- Single-mask foils with asymmtric holes were tested for gain, resolution, charging up, rate capability etc.
- We observed that the hole asymmetry strongly affects the properties of the detector
- While some of the similar reslults measured in some different test compaign were reported by CMS Muon group in MPGD-2017 and here we confirm those results once again.
- Our results show that "Orientation B" facing the incident radiation performs better compared to the "Orientation A"

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