Test results of a real-size RPC for 3rd and 4th stations of Muon Chamber of the Compressed Baryonic Matter Experiment at FAIR, Germany.

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Overview

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3. Test set-up at GIF++
4. Test results
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   - Efficiency
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Motivation - CBM experiment

- The Compressed Baryonic Matter (CBM) is an upcoming (under construction) experiment in the Facility for Anti-proton and Ion Research (FAIR) in Darmstadt, Germany.

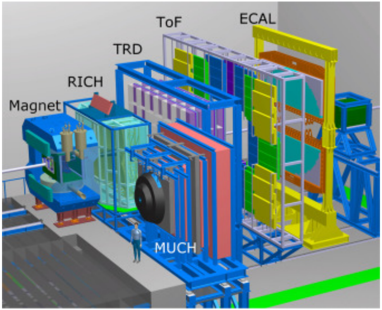


Figure 1: *Schematic layout of the CBM experiment.*

- Various detector systems:
  - Micro-Vertex Detector (MVD).
  - Silicon Tracking System (STS).
  - Ring Imaging Cherenkov detector (RICH).
  - Muon Chambers (MuCh).
  - Transition Radiation Detector (TRD).
  - Time-of-Flight Detector (ToF).

- MuCh will be the muon detection system of the CBM experiment.

Motivation - Muon Chamber (MuCh)

- The total absorber of MuCh will be sliced with muon-detectors placed in between them.
- It will facilitate momentum dependent track identification, improving the efficiency of detection of low momentum muons.

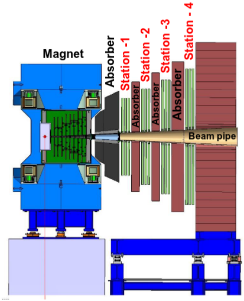


Figure 2: *Schematic layout of the CBM-MuCh.*

- MuCh will have 4 different stations to house detectors for muon detection.
- Each station will house 3 detector layers.
- Station-1 and Station-2 ⟶ Gas Electron Multipliers (GEMs).
- Station-3 and Station-4 ⟶ Resistive Plate Chambers (RPCs).

Motivation - The Problem

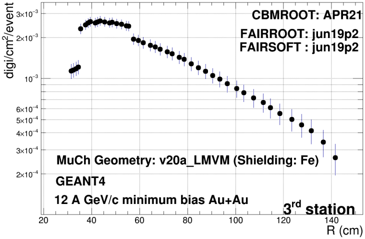


Figure 3: *Digi density for 3rd station of CBM-MuCh.*

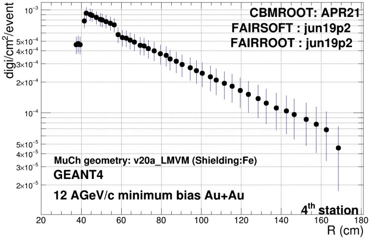


Figure 4: *Digi density for 4th station of CBM-MuCh.*

- The numbers on the Y-axis when multiplied with the interaction rate (∼10 MHz) gives the expected particle rate on the detectors.
  - 3^{rd} station ⟶ ∼30 kHz/cm^2.
  - 4^{th} station ⟶ ∼10 kHz/cm^2.
- **Aim** ⟶ To test a real size RPC for it's various properties including muon detection efficiency in presence of very intense γ source as a background.

Detector

One real size detector was developed, clubbed with specially designed PCB, integrated with MuCh-XYTER, tested rigorously in local laboratory with cosmic rays and then tested at GIF++, Cern, Switzerland.

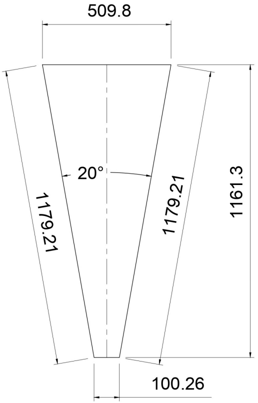


Figure 5: *Detector dimensions (mm).*

- Shape: Trapezoidal.
- Segmentation: 20°.
- Each electrode thickness: 1.2 mm.
- Bulk resistivity of electrodes: $\sim(3\times10^{9}$ - $1\times10^{10})$ Ωcm.
- Gas gap thickness: 2 mm.

The real sized PCB

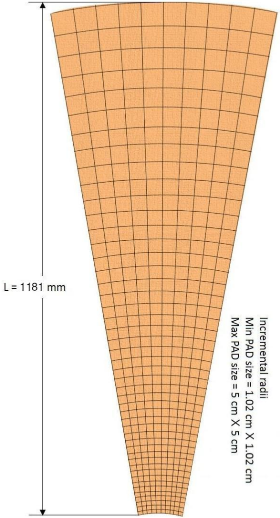


Figure 6: *Schematic design of readout PCB.*

- The PCB is of 1181 mm in length, and 2.4 mm thick.
- The trapezoidal shaped signal pickup PCB contains trapezoidal pads of progressive dimensions.
- There are 46 rows and 10 columns of pads $\Longrightarrow$ 460 pads in total.
- Each column segmentation $\longrightarrow 2^\circ$.
- The size of the smallest trapezoidal pad is $\sim$(1.01 cm $\times$ 1.01 cm).
- The size of the largest trapezoidal pad is $\sim$(5.0 cm $\times$ 5.0 cm).
- The dimensions of all the pads in each row are exactly the same.

The real sized PCB (contd.)

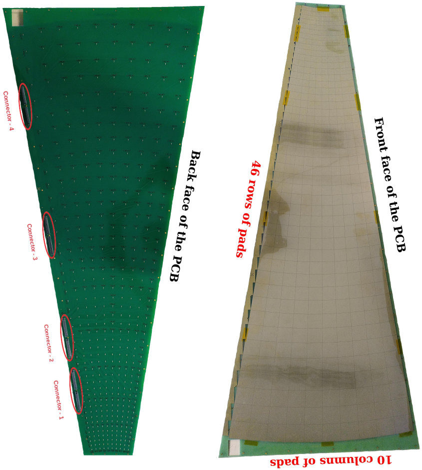


Figure 7: *Actual image of the read-out PCB.*

- In the back side of the PCB there are total 04 numbers of connectors with 1.27 mm pitch have been placed for insertion of FEE boards.
- Each pad is connected via a 10 nF capacitor to the respective channel of the FEE connector.
- The PCB has been outlined with the through holes for screwing at the board edge in order to attach it to the detector firmly for efficient charge collection.
- **Electronics and DAQ chain:** $\longrightarrow$ **MuCh-XYTER based**.
- Self-triggered electronics.

Experimental set-up at GIF++

- GIF++ is located on the H4 beamline which provides high-energy muon beam ($\leq$ 150 GeV/c) in EHN1 North Area of CERN.
- It houses Cs-137 gamma source.
- Our RPC detector was tested in GIF++ during November-2021 beamtime.
- The RPC was positoned at ∼84 cm away from the Cs-137 source house in the upstream region.

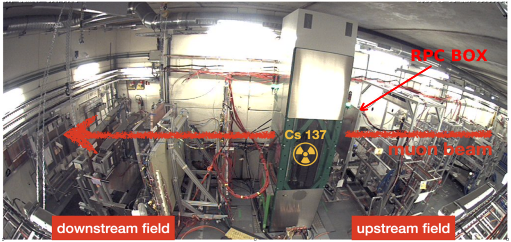


Figure 8: *Experimental facility site at GIF++[1].*

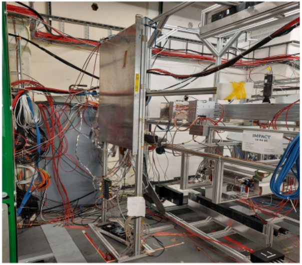


Figure 9: *The RPC box in the upstream region.*

Photon flux

- Strength of the Cs-137 source $\longrightarrow$ $\sim$14 TBq (as of 2014).
- There are different attenuation filters to vary the photon flux.
- The incident photon flux at our detector at it's psition with different attenuation factors has been tabulated in Table 1.

Attenuation factor	Photon flux (MHz/cm^2)
22	2.72
46	1.36
100	0.69

Table 1: Photon flux incident on RPC at different attenuation factor.

- The values were calculated by *Lagrangian extrapolation* of the simulated photon current values mentioned in the reference[2].

Trigger schematics

- Coincidence signals from three different scintillators were used:
  - Paddle scintillator -1 and 2 (At the begining and end of the hall).
  - CBM scintillator $\longrightarrow$ $\sim$(45 mm $\times$ 50 mm) positioned behind the second paddle scintillator.

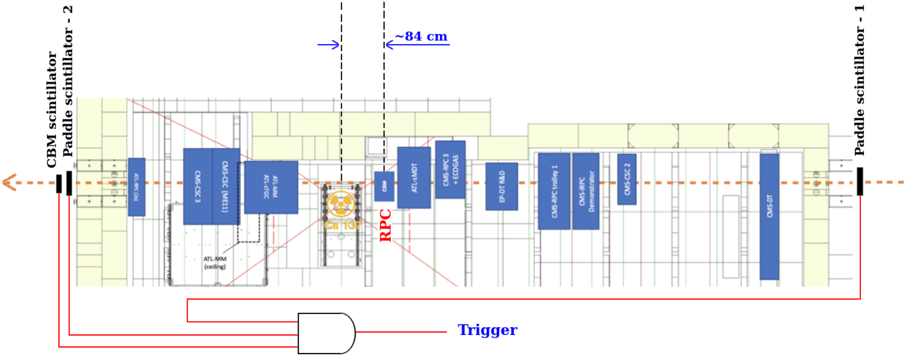


Figure 10: *A schematic representation of the experimental site along with the generated trigger scheme [1]. The figure is not to scale.*

Test parameters

Data recording conditions

- Different photon rates incident on the detector.
- Different applied high voltage to the detector.
- Different signal threshold (will discuss only at one threshold here).
- Different position of the beam hitting the detector (will discuss only at one such position here).

Gas

- Mixture components & ratio:

$$R134a : i - Butane : SF_6 :: 95.2\% : 4.5\% : 0.3\% \quad (by \quad volume)$$

- Humidity in gas: $\longrightarrow$ 40%.
- Flow rate: $\longrightarrow$ 5 ℓ/hr.

Electronics

- Signal threshold: $\longrightarrow$ $\sim$15 fC.
- MuCh-XYTER based electronics and DAQ chain **(Self-triggered).**

Test results

A quick I-V

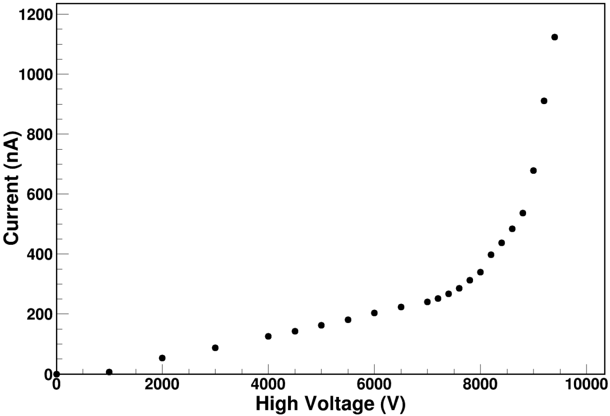


Figure 11: *A quick I-V characteristics of the detector.*

- The breakdown voltage is just above 8000 V.

Current

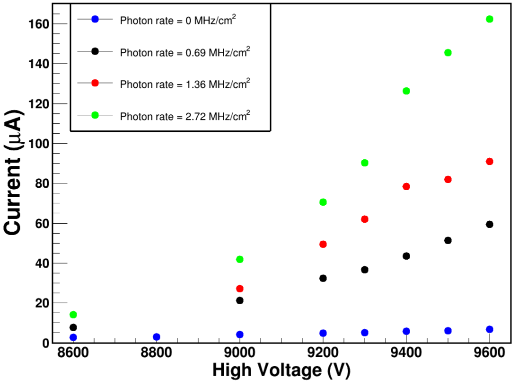


Figure 12: *Current variation as a function of high voltage at different γ-intensities.*

- γ-intensities $\longrightarrow$ 0 MHz/cm^2, 0.69 MHz/cm^2, 1.36 MHz/cm^2, and 2.72 MHz/cm^2.
- The current increased with an increase in the photon rate falling on the detector.

Beam spot @ 9600 V (Beam - ON and Source - OFF)

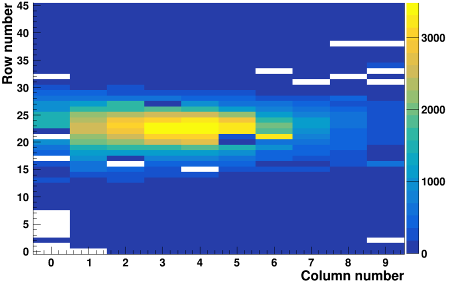


Figure 13: *Hit distribution of the pads throughout the whole detector.*

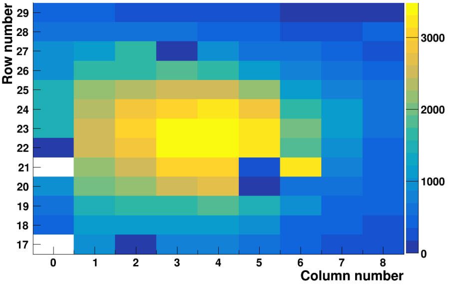


Figure 14: *Hit distribution of the pads in and around the beam spot region.*

- The detector has been positioned in such a way the beam hit around the middle region.
- The approximate pad dimension $\longrightarrow$ 23 mm $\times$ 23 mm.
- The most intense region of the muon beam has an area of $\sim$ (92.6 mm $\times$ 92.6 mm)

Time correlation studies

- The timing information of the hits have been measured w.r.t to the trigger time.

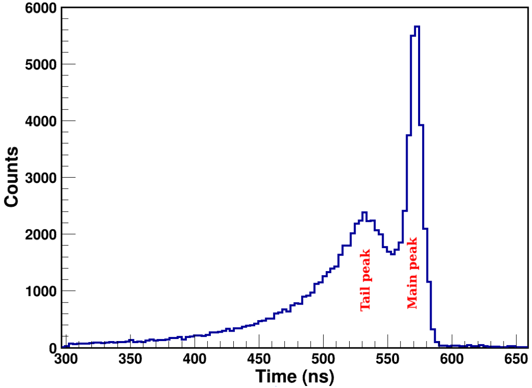


Figure 15: *Time correlation spectra at 9200 V in absence of photon flux.*

- The single channel resolution of MuCh-XYTER is ∼3.125 ns.
- Observation: Two peaks in the time correlation spectra v.i.z "Main peak" and "Tail peak".

Time correlation studies - Comparison at different voltages

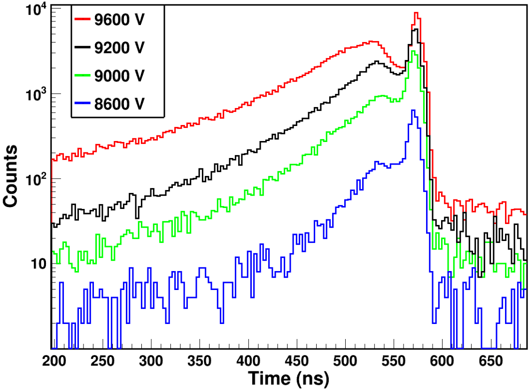


Figure 16: *Time correlation spectra at different applied voltages in absence of photon flux.*

- Things to keep in mind: Self-triggered electronics and low threshold enviornment.
- Observation: As the high voltage is increased from 8600 V to 9600 V, the tail peak becomes more and more dominant.

Time correlation studies - Comparison at different γ-rates

- Applied voltage to the RPC $\longrightarrow$ 9600 V.

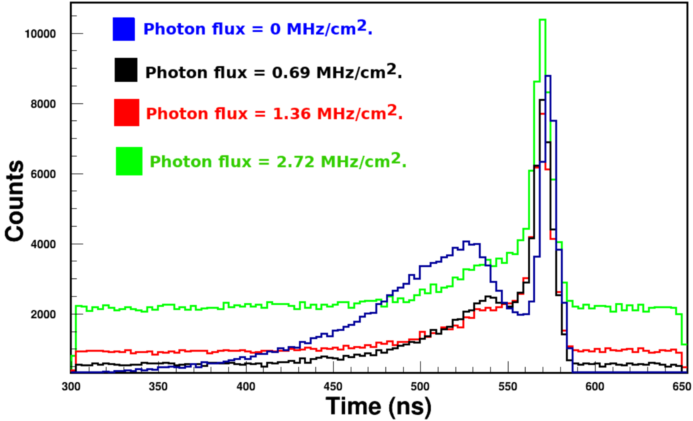


Figure 17: *Time correlation spectra at different photon flux.*

- Observation: As the photon rate falling on the detector is increased the grass-level of the time correlation spectra also increases.

Efficiency studies

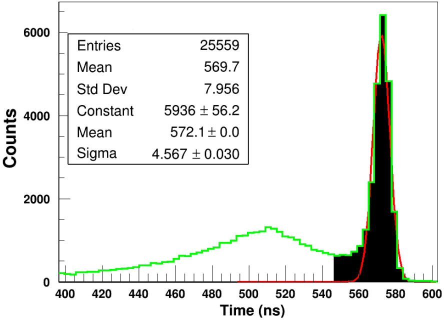


Figure 18: *A typical measured time corelation spectra at 9300 V in absence of photons.*

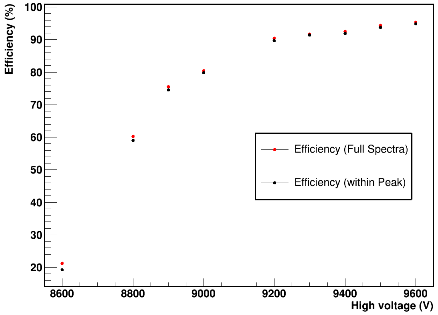


Figure 19: *Comparison of efficiency calculations for different regions of the spectra.*

- Observation: No significant change in the efficiency values.
- For further efficiency calculations, the hit(s) lying within the "Main peak" have been considered.

Efficiency studies- Comparison at different voltages

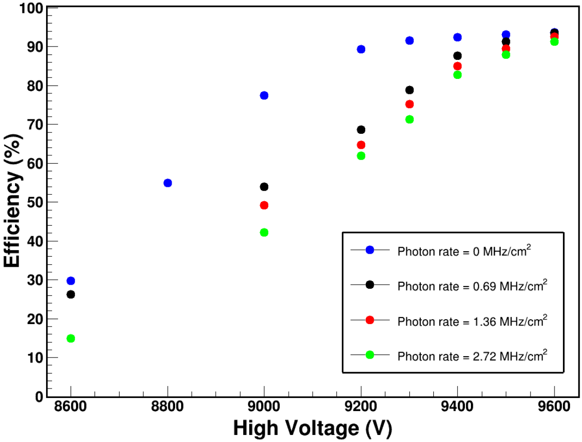


Figure 20: *Efficiency variation as a function of voltage at different photon flux.*

Observations:

- In absence of background photons, muon detection efficiency increased with increase in the high voltage.
- A similar trend was observed at different other photon rates.
- A plateau ∼95% efficiency was obtained in absence of the photon flux from 9400 V.

Efficiency studies- Comparison at different γ-rates

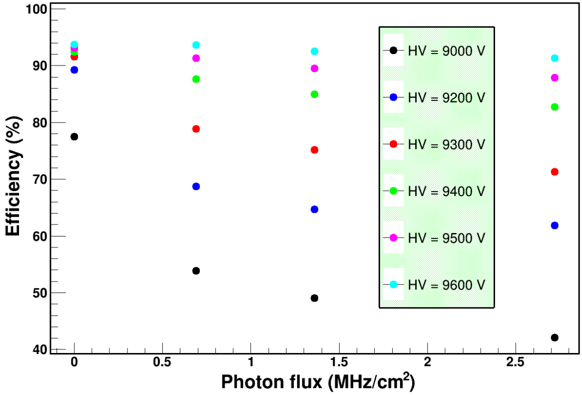


Figure 21: *Efficiency variation as a function of incident photon flux.*

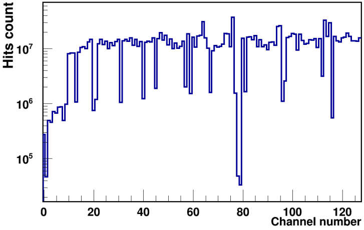
Observations:

- The muon detection efficiency of the detector at any particular voltage, reduced in presence of photon background.
- The RPC has shown muon detection efficiency of $> 90\%$ at applied voltage of 9600 V in presence of $\sim 2.72 MHz/cm^2$ photon flux.

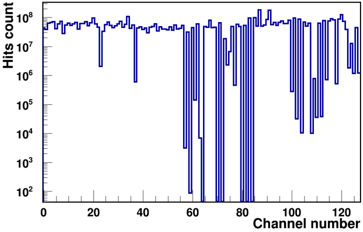
Hits per unit area per unit time studies - Digi rate studies

- There were 4 numbers of Front-end Electronics Boards (FEBs) connected with the PCB to read each and every pads.
- Each FEB has 128 channels connected to 128 pads individually via a 10 nF capacitor.
- Being self triggered electronics, the FEB-channels of MuCh-XYTER records all signals (data) which crosses the set threshold value.
- We coin a term called **"digi"** which is essentially signal recorded by the electronics and DAQ chain.
- Each digi refers to one corresponding signal crossing the implemented threshold level and are being recorded afterwards.
- The hit distribution pattern in all the 128 channels in each of the 4 FEBs at a operational voltage of 9600 V when photons were falling on the RPC at a rate of 2.72 MHz/cm^2 have been shown in the next slide.

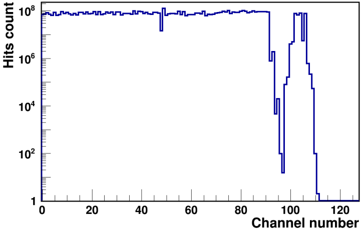
FEB channels hits @ 9600 V with 2.72 MHz/cm^2 γ-rate



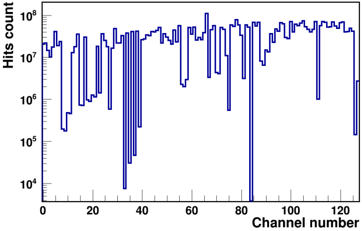
(a) *Hit counts in FEB-0.*



(b) *Hit counts in FEB-1.*



(c) *Hit counts FEB-2.*



(d) *Hit counts in FEB-3.*

Digi rate studies - Area calculation

- To calculate the digi rate, an area consisting of 16 pads lying well within the centre of the beamspot has been considered.
- The effective area is $\longrightarrow$ $\sim$84.64 cm^2.

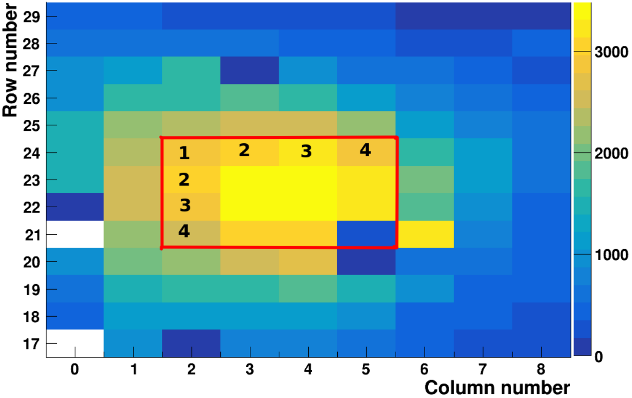


Figure 23: *Selected area or pads for digi rate calculation.*

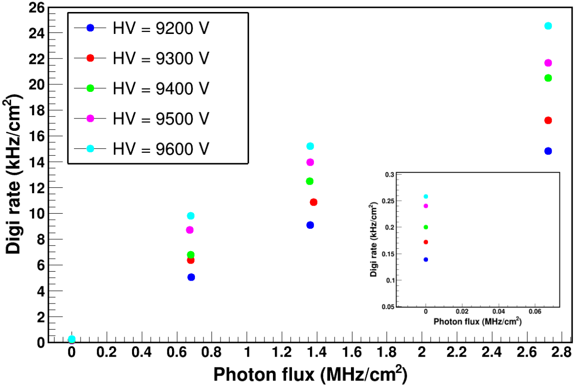


Figure 24: *Variation of digi rate as a function of incident photon flux at different applied high voltages. The photo in the inset shows the variation during source OFF condition.*

Observations:

- At any particular voltage the digi rate increases as the number of incident photon increases.
- At any particular photon flux the digi rate increases as the applied voltage increases.
- Maximum digi rate of $\sim 24.56 kHz/cm^2$, @ 9600 V with γ-flux of $\sim 2.72 MHz/cm^2$.

Digi rate studies - Efficiency variation with γ-flux

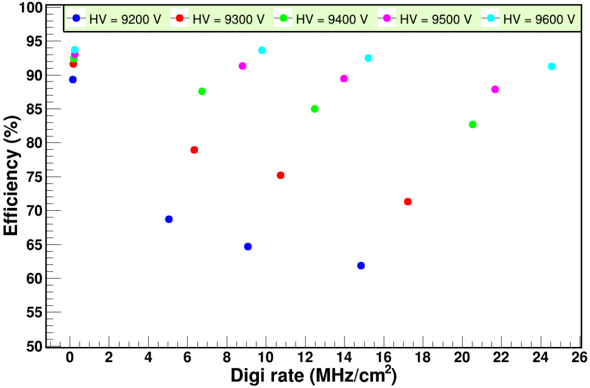


Figure 25: *Variation of muon detection efficiency of RPC as a function of digi rate.*

Observations:

- At any particular voltage, the efficiency dropped as the digi-rate increases.
- The drop in the efficiency is very significant in lower voltage values.
- At 9600 V the detector has retained an efficiency >90% at a digi-rate of $\sim 24.56 kHz/cm^2$.

Summary

- A real-size single gas RPC along with paded structure read-out PCB (different from standard stip read-out technique) and dedicated self triggered electronics chain has been developed for its application in 3^{rd} and 4^{th} stations of MuCh detector set-up of the CBM experiment.
- The detector has been successfully tested for its muon detection efficiency in absence and presence of intense photon flux at GIF++ facility in CERN, Switzerland with an idea to study its performance and determine the optimum operating voltage at a high photon environment.
- The detector has shown muon detection efficiency of $> 95\%$ in absence of photon flux and $> 90\%$ in presence of $\sim 2.72 MHz/cm^2$ photon flux as background at an operating voltage of 9600 V with a threshold of $\sim$15 fC.
- One can effectively infer that the developed real-size RPC can work successfully with a charged particle detection efficiency of >90% even at harsh photon environment.

Outlook and Acknowledgement

Outlook

- It has to be tested for high particle rate handling capability as well as its long term performance.
- The detector is currently installed at mCBM experiment at GSI, Germany.

Acknowledgement

- We sincerely acknowledge M. Jaekel, G. Pezzullo, A. Dubey, C. Ghosh, J. Kumar (VECC) and other colleagues of GIF++ for their constant support and help throughout the testing period.
- RG acknowledges Dr. D. S. Kothari Fellowship scheme (award letter number F.4-2/2006 (BSR)/PH/18-19/0113 dated 16/10/2019) by University Grants Commission, New Delhi, India.
- RG would like to thank Prof. Amlan Chakraborty for his constant support during the CERN visit.

References

https://ep-news.web.cern.ch/content/gamma-irradiation-facility-gif-during-and-beyond-run-3

D. Pfeiffer et., al, The radiation field in the Gamma Irradiation Facility GIF++ at CERN, **Nuclear Inst. and Methods in Physics Research, A 866 (2017) 91-103**.

THANK YOU

Back up slides

ADC vs Time

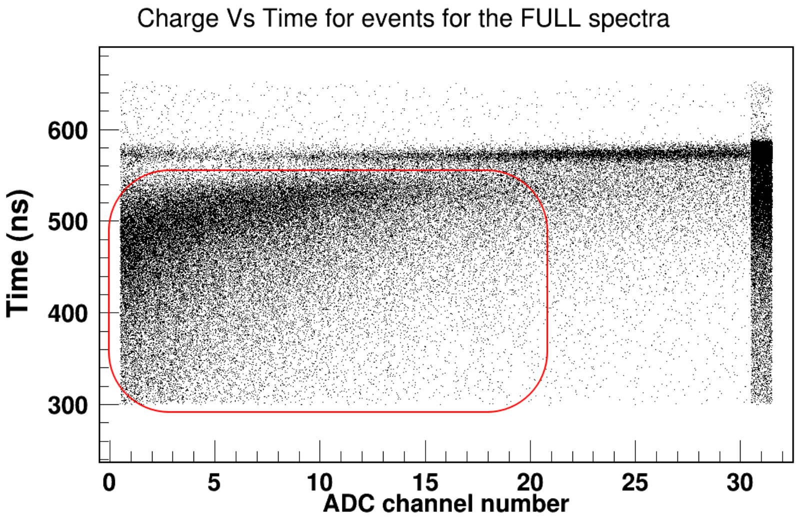


Figure 26:

Spill structure - Beam ON, source OFF

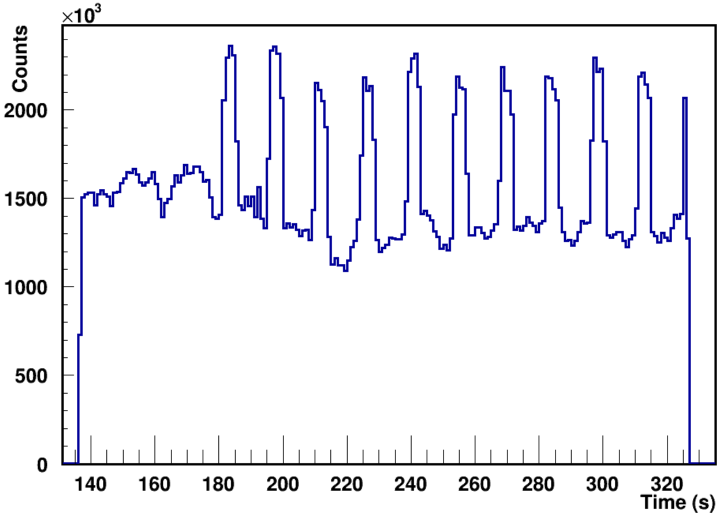


Figure 27:

FEB mapping on PCB

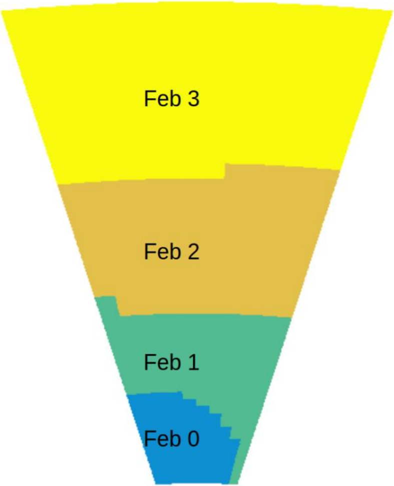
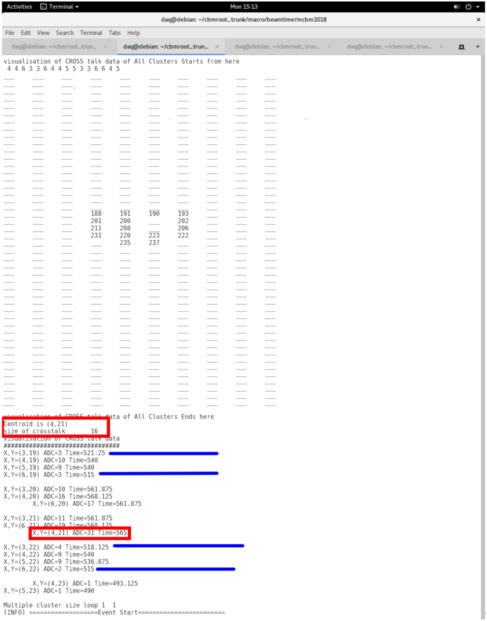


Figure 28:

Example of an event



First hit with maximum ADC in an event