MUCH RPC related activities in CBM Experiment

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Outline

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2. Detector details
3. Test set-up at GIF++
4. Test results
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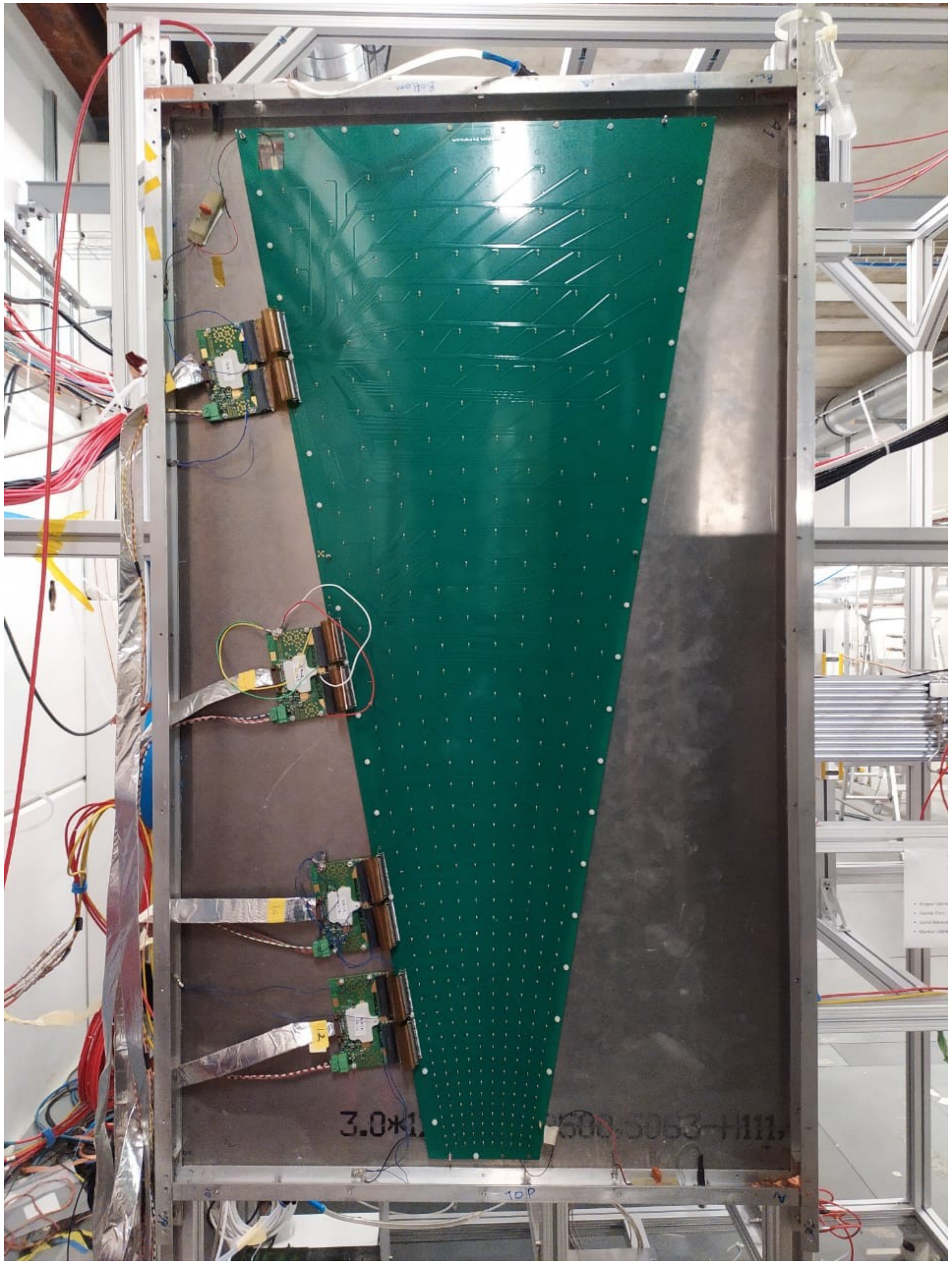
   - Efficiency
   - Digi rate
5. Summary
6. Outlook



Introduction

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

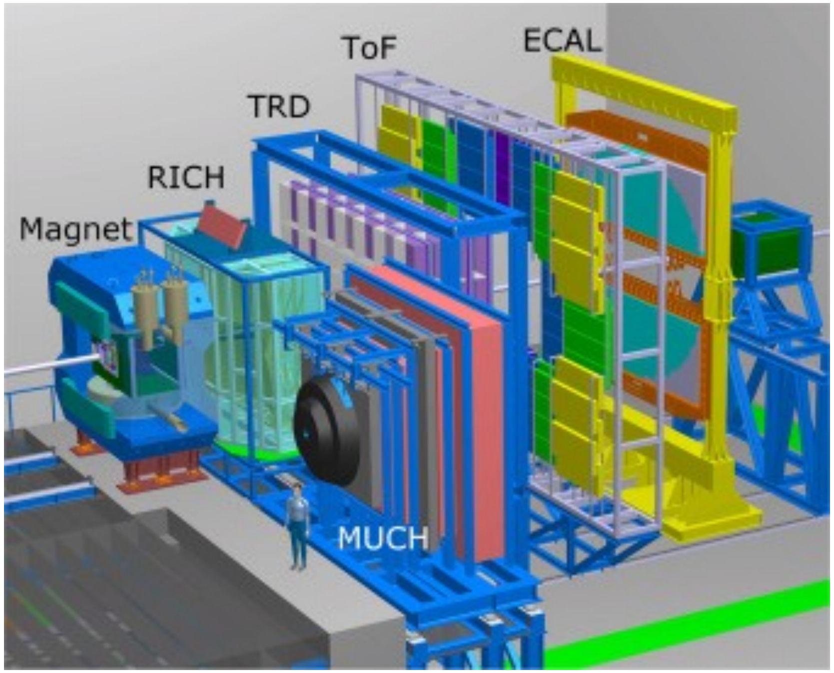


Figure 1: *Schematic layout of the CBM experiment.*

- 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.

Introduction

- 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.

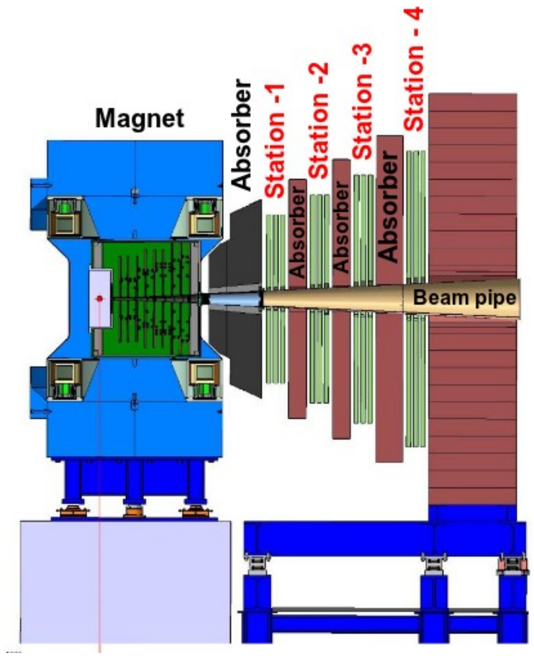
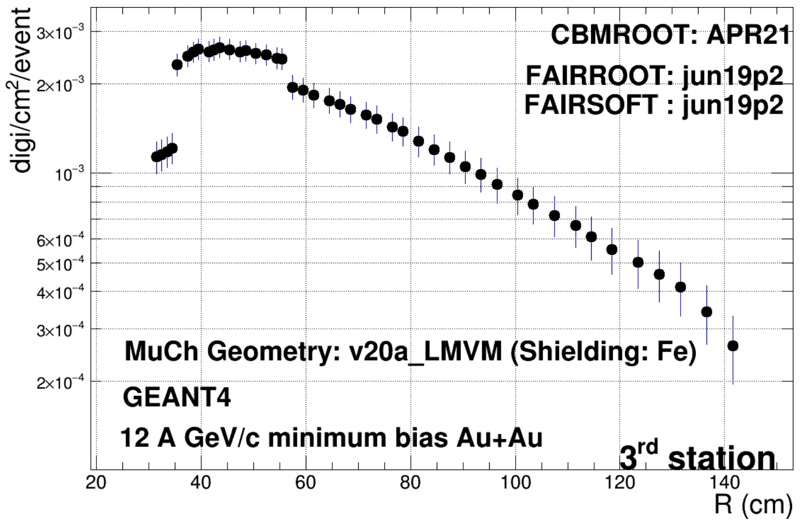


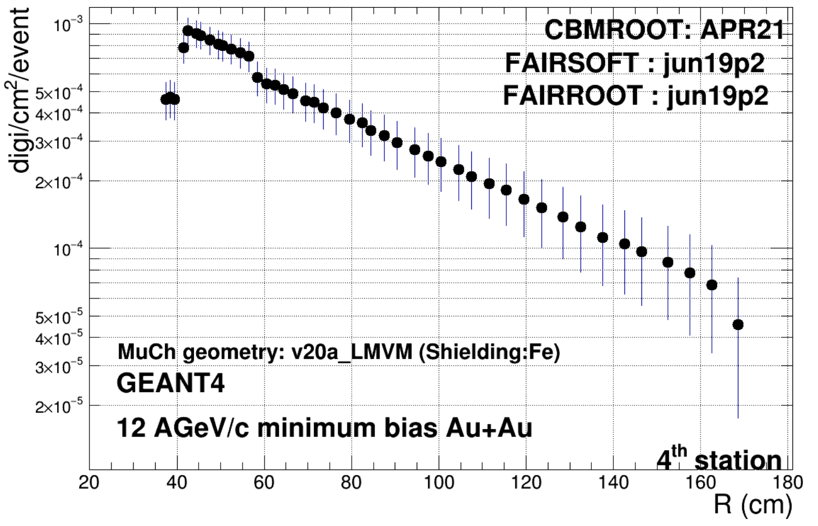
Figure 2: *Schematic layout of the CBM-MuCh.*

- 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).

Expected rate



Digi density for 3rd station



Digi density for 4th station

The numbers on the Y-axis when multiplied with the interaction rate (~10 MHz) gives the expected particle rate on the detectors.

- 3rd station ––→ ~30 kHz/cm^2
- 4th station ––→ ~10 kHz/cm^2

Motivation to install Resistive Plate Chamber (RPC) for the 3rd and 4th stations of MuCh

Challenges for muon detection:

- ✓ high rate capability
- ✓ Good position resolution
- ✓ Should be radiation resistant
- ✓ Large area detector – modular
- ✓ Data to be readout in a self triggered mode

Advantages of RPC:

- ✓ Robust, low cost, easy to fabricate
- ✓ Good position resolution (~ cm)
- ✓ Bakelite is radiation resistant
- ✓ Large area detector is easy to make
- ✓ Good time resolution (~ 1 ns)

Challeges in developing RPC for CBM Experiment:

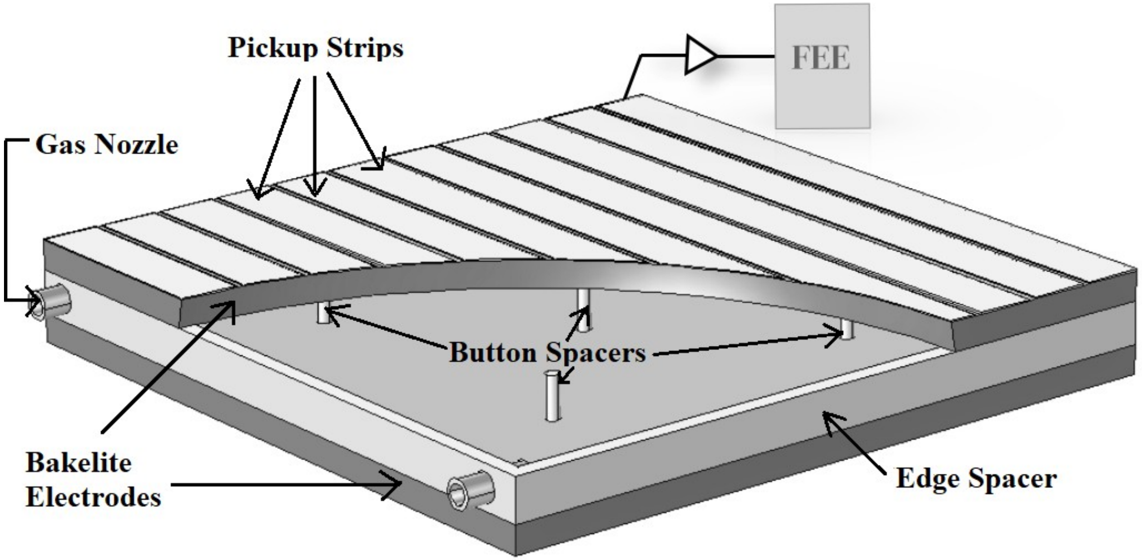
$$Rate\ Capability = \frac{1}{\rho\, t < Q >}$$

"ρ" is the bulk resistivity of the electrode plates.
"t" is the total thickness of the electrode plates.
"Q" is the average charge per RPC signal.

By optimising these three parameters,
RPC can achieve the required rate capability

RPC detector

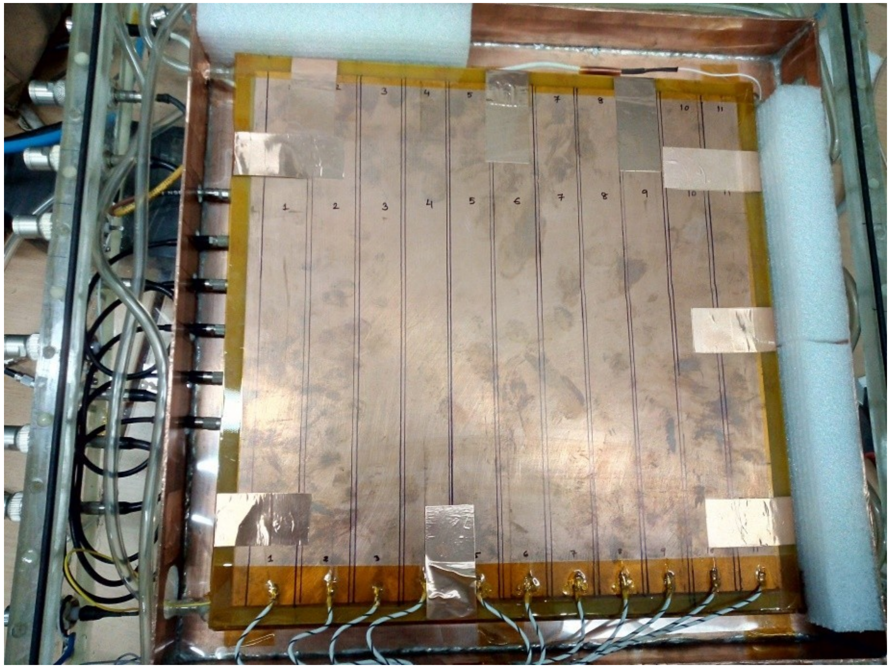
- First introduced by R. Santanico and R. Cardarelli in **1981**
- **Gaseous** parallel plate detector
- Working principle : **Ionization** of gas and **electron multiplication**, **avalanche** of charge carriers due to high electric filed applied between the electrode plates
- Electrode plates , bakelite or glass – volume resistivity **$\rho = 10^{7} - 10^{12}$ Ω-cm**
- **Induced signal** on copper pick-up strips
- High volume resistivity prevents the avalnche charge to spread throughout the electrode surface → **small dead area**
- Gas composition decides the mode of operation in RPC, **avalanche mode** and streamer mode



Block Diagram of a RPC

Testing of the prototype RPC at GIF++, CERN

- ❑ E = 0.66 MeV; max. dose-rate ~0.5 Gy/h @ 1m from source (±37° angle) and 2.5 Gy/h @ glass contact
- ❑ Several attenuation factors available (up to ~ 50,000)
- ❑ μ-beam from T2 on H4 beam-line (100 GeV; **~10^5 /spill**.



- The RPC prototype, Strip dimension~ 27.7 cm x 2.3 cm. Total Strips – 11
- 2 mm gap between two strips.
- Gas: humidified CMS RPC mixture

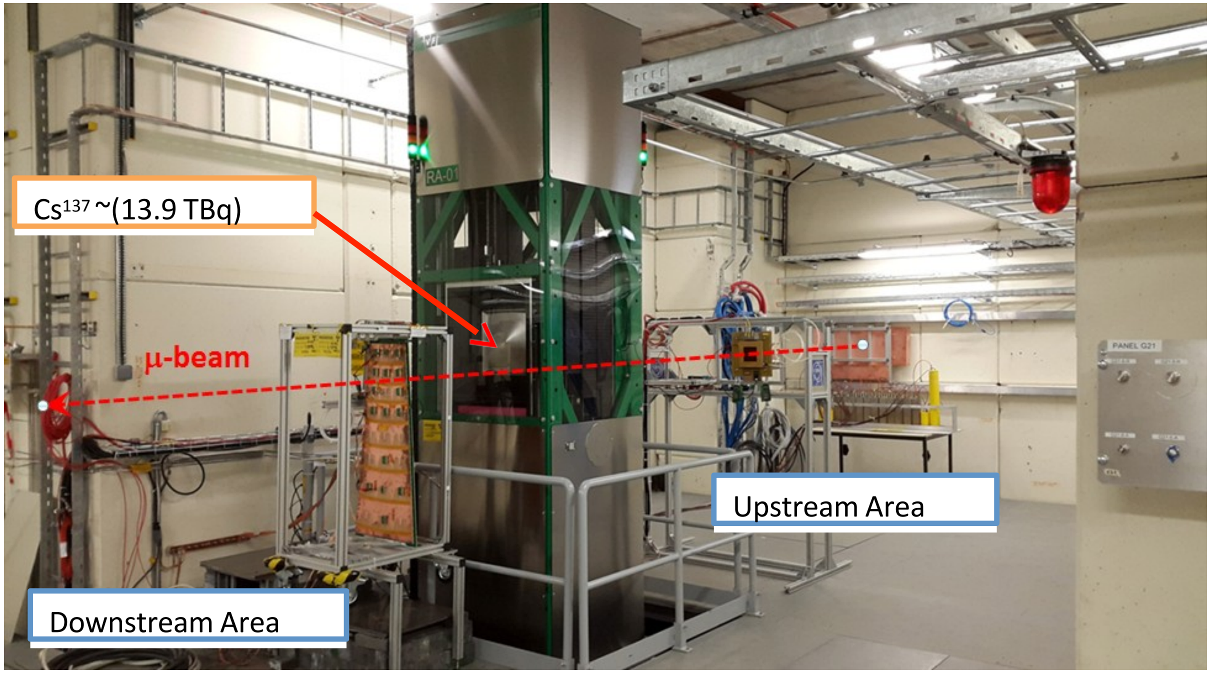
95.2 % R134a + 4.5 % iC_4H_{10} + 0.3 % SF6 (humidity 60%)

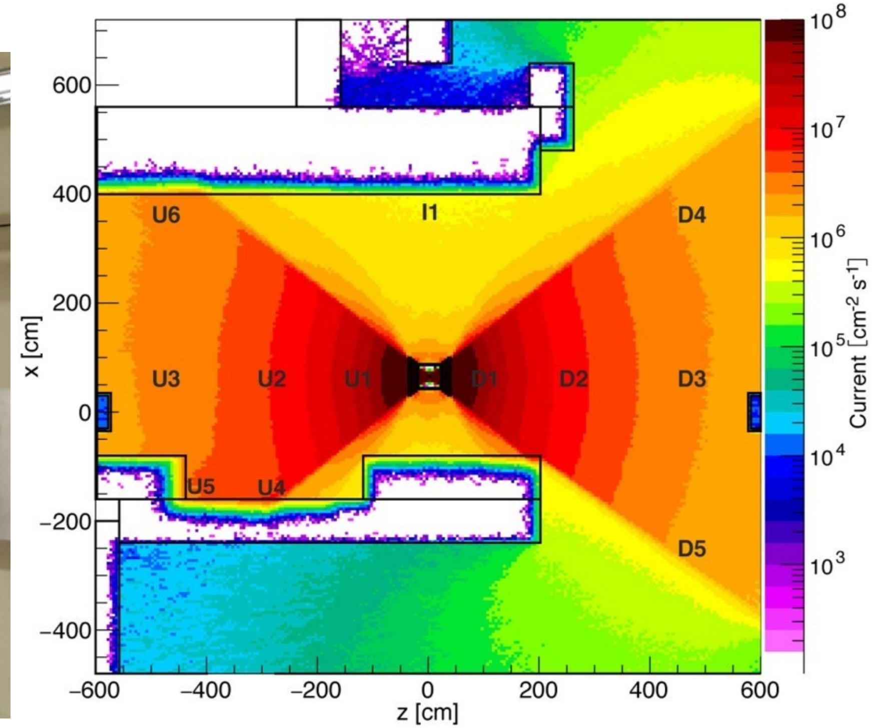
Aim being :

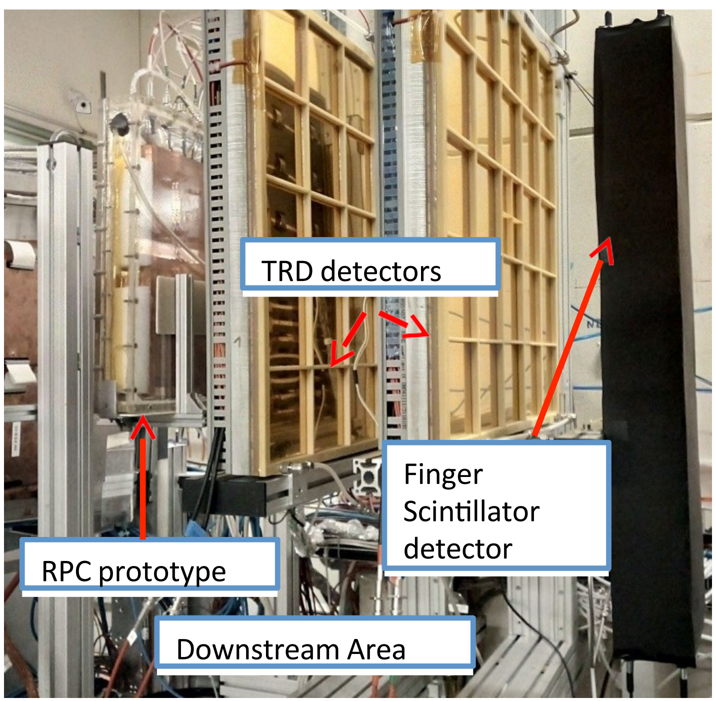
-- to test the response of the detector to charged particles in presence of high gamma irradiation.

-- testing with actual electronics for CBM : MuCh- XYTER

Testing of the prototype RPC at GIF++, CERN







- The RPC detector under test was placed at ~ 167 c from the source point (1 position)
- The detector is directly in front of the irradiator and is operating under a particle flux ~ 4 x 10^7 /2
- 11 RPC strips connected to 11 channels of MuCh Xyter
- One muon trigger Channel consisting of three fold of finger scintillator (3 cm x 12 cm) located in front of TRD detectors and two big paddle scintillators placed outside GIF++ bunker.

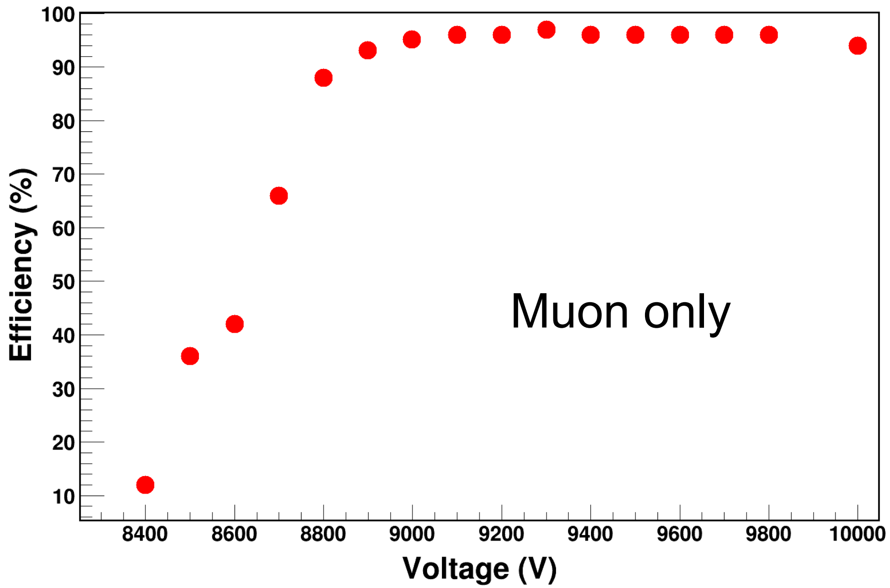
Test results at GIF++ (2018)

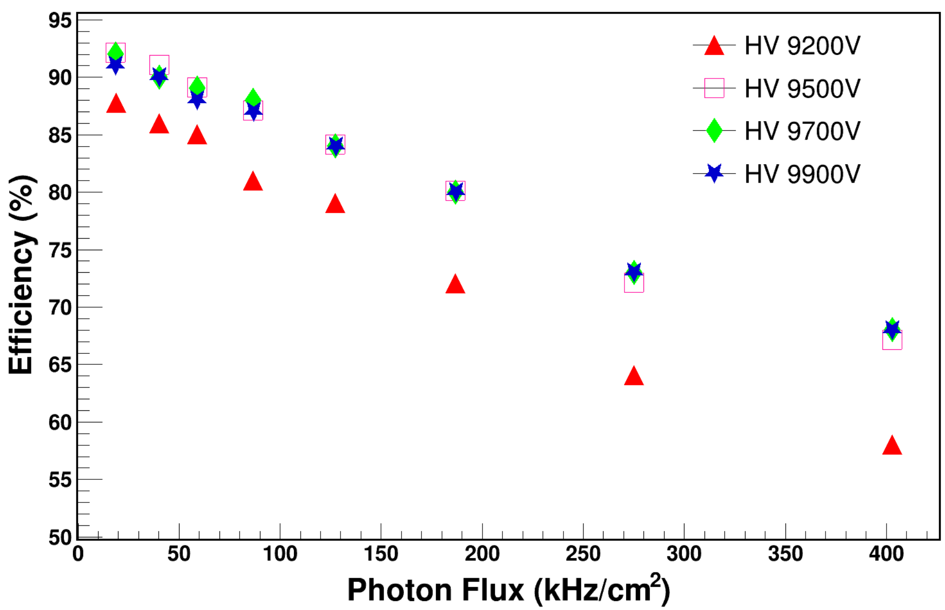
M. Mondal, J. Saini, Z. Ahammed

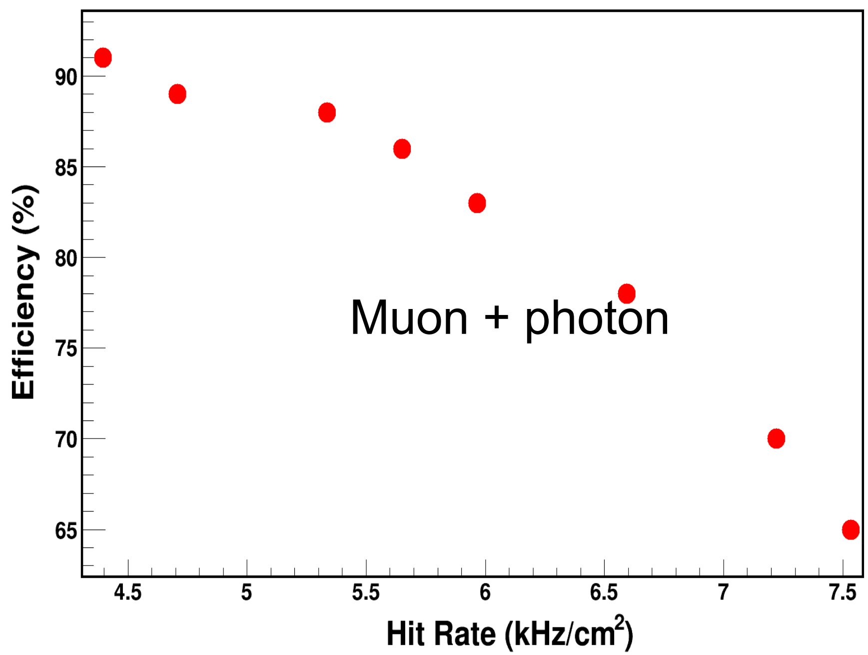
- RPC dimension:- 30 cm x 30 cm x 0.2 cm.
- Electrode :- 0.2 cm thick bakelite plates.
- Resistivity :- ~ 3 x 10^{10} Ωcm.

- Pick-up strips:- 2.3 cm x 30 cm.
- Much XYTER :- 2.0.
- Threshold :- ~ 50 fC.

Gas : R134a : Iso-butane : SF6 :: 95.2 : 4.5 : 0.3

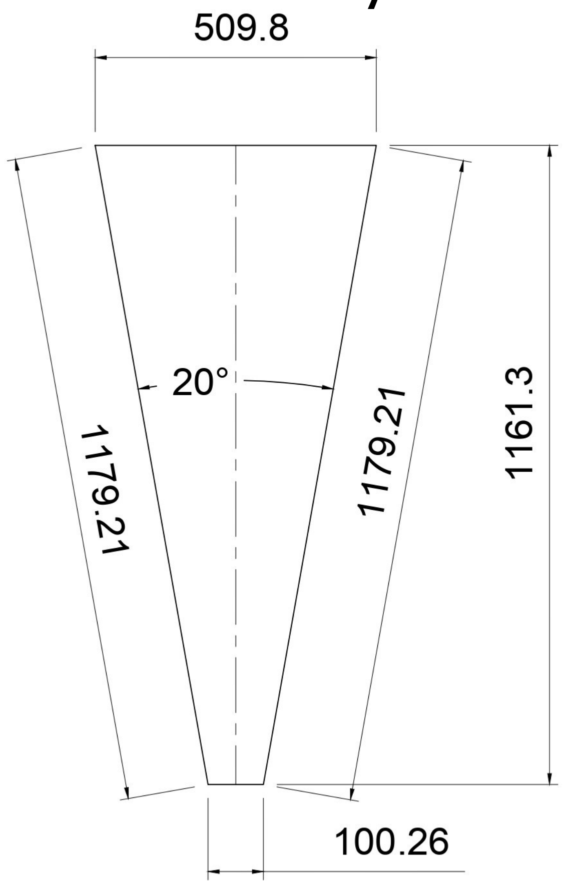






Chamber Design Parameters

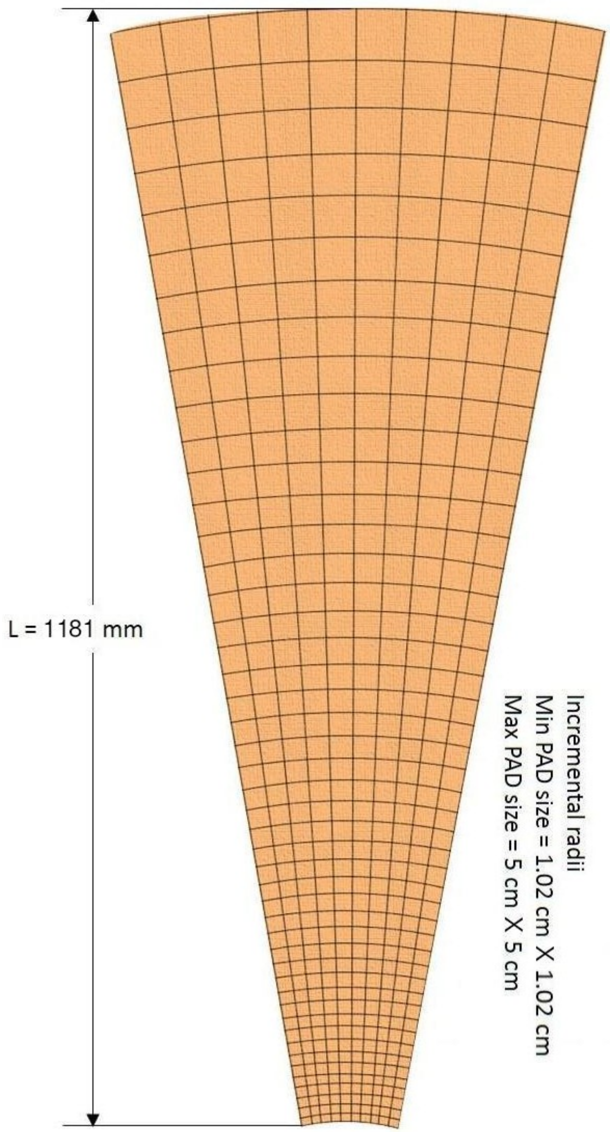
One real size detector(**Bakelite RPC**) was developed, clubbed with specially designed PCB, integrated with MuCh-XYTER, tested rigorously in local laboratory with cosmic rays and then tested at GIF++, CERN, Switzerland in the year 2021.



Detector dimensions for 3rd stattion (mm).

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

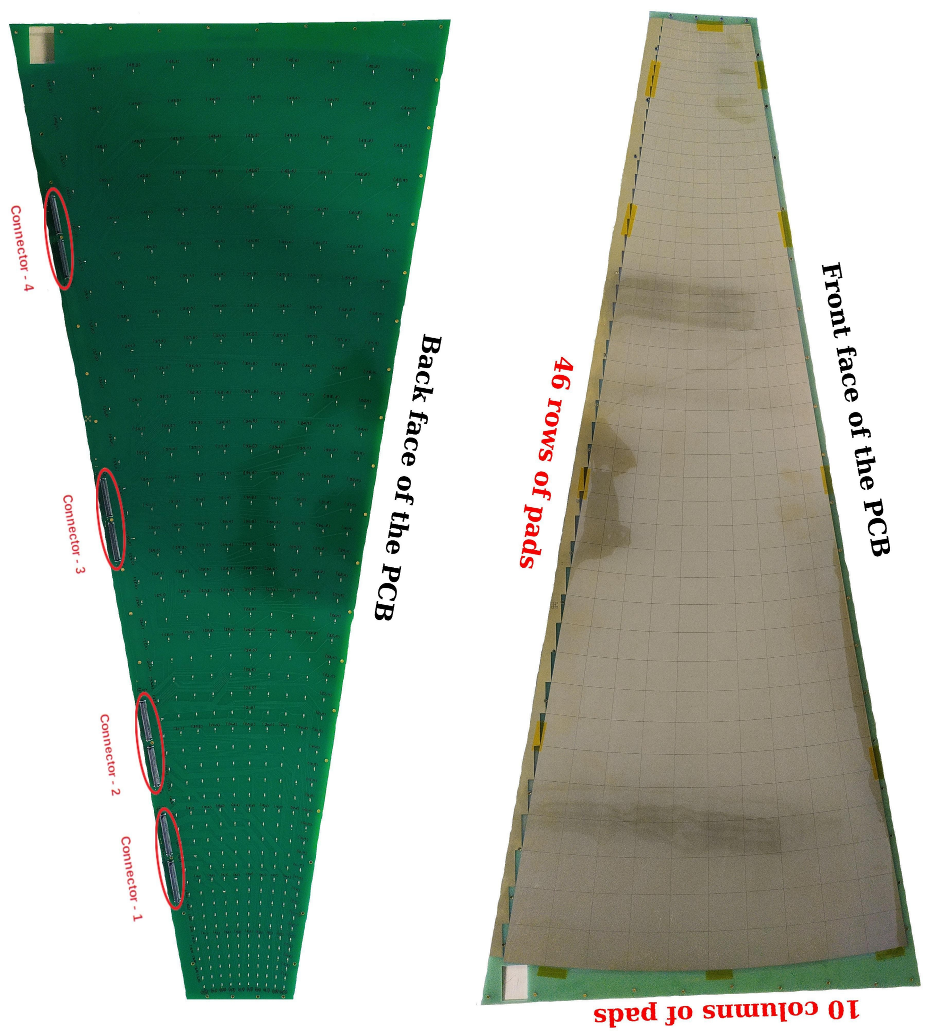
Readout PCB



Schematic design of readout PCB for 3rd Station

- 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°.
- 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.

Readout PCB Design



Actual image of the readout PCB.

- In the back side of the PCB there are total 04 numbers of connectors with 1.27 mm pitch 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.

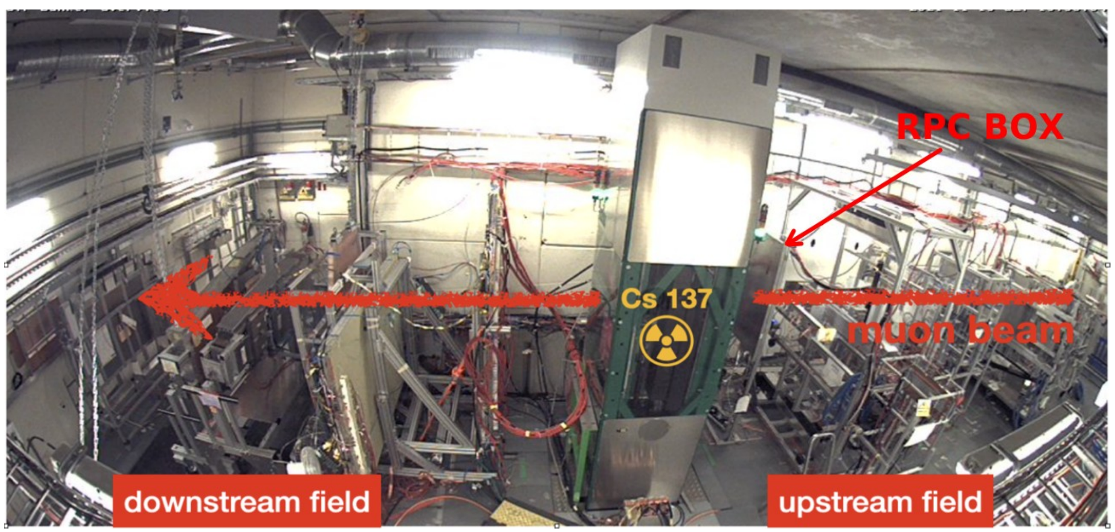
Electronics and DAQ chain:

- −→ **MuCh-XYTER based**.

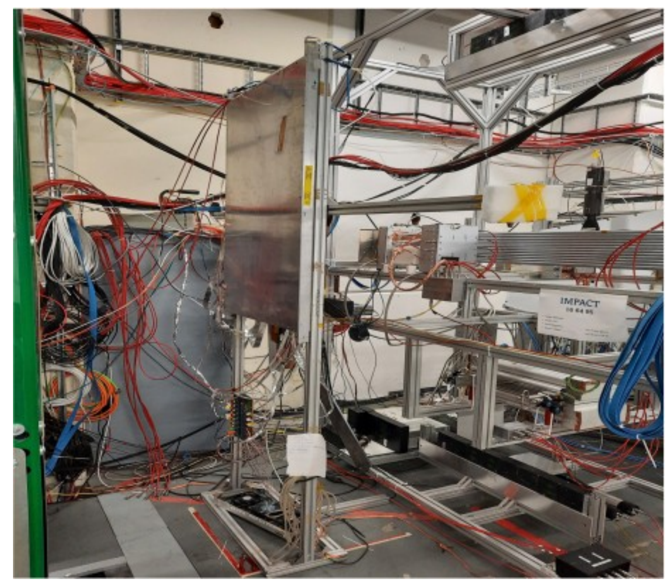
Self-triggered electronics.

GIF++ Setup(2021)

- 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 in the upstream region.



Experimental facility site atGIF++.



The RPC box in the upstream region.

Photon Flux

- Strength of the Cs-137 source $--\rightarrow \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 mentioned in NIMA 866(2017)91-103

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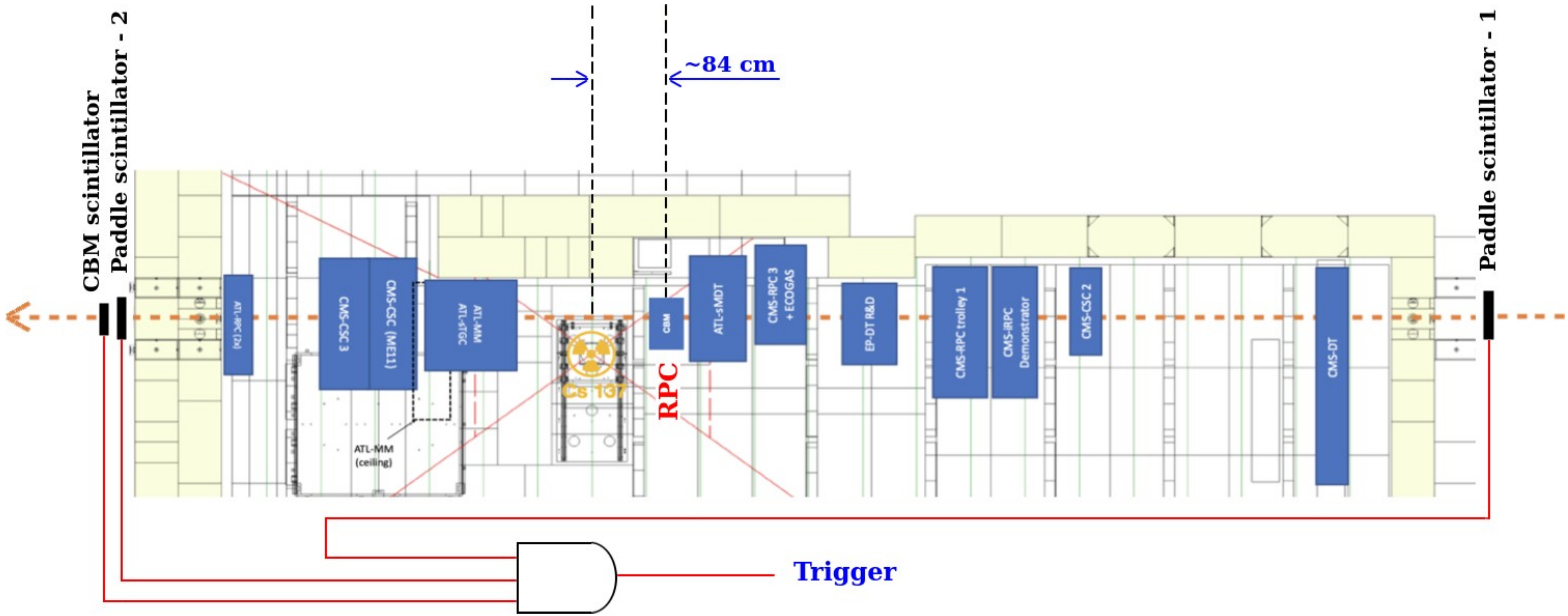
Trigger Scheme

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



A schematic representation of the experimental site along with the generated trigger scheme. The figure is not to scale.

Operation of the Detector

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

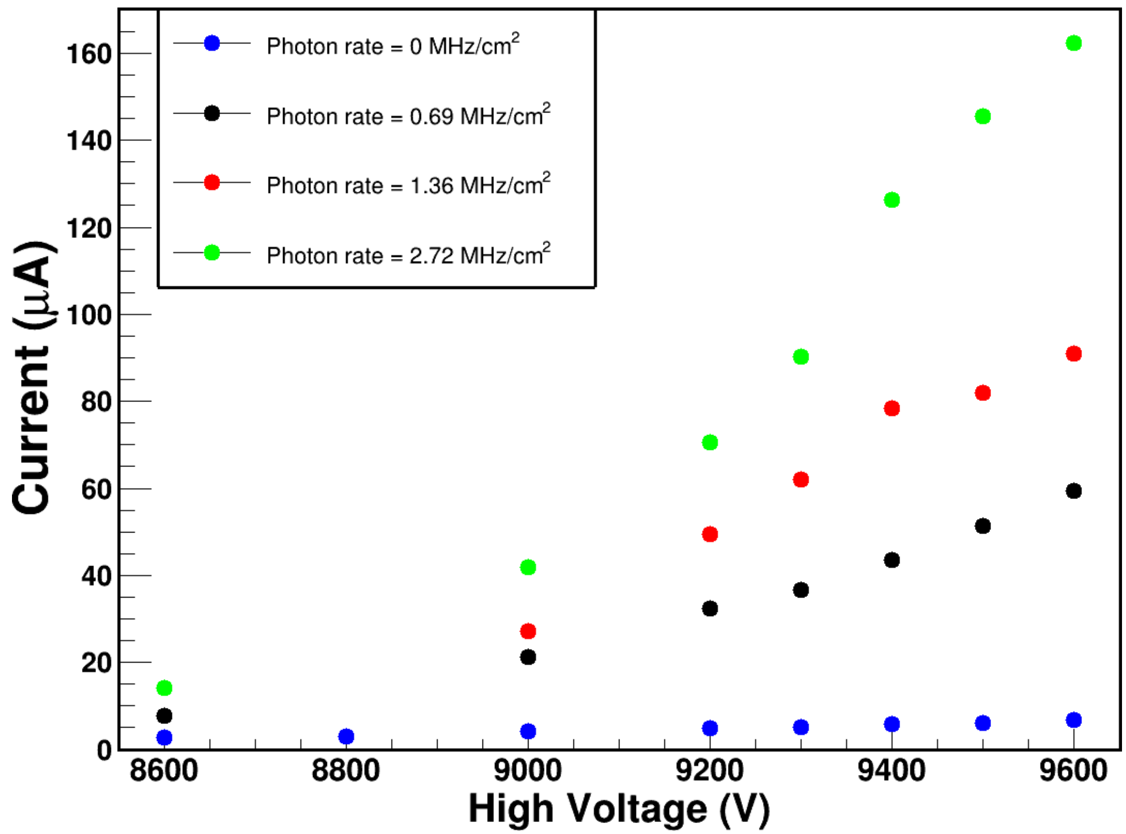
Mixture components & ratio:

- $R134a : i - Butane : SF_6 :: 95.2\% : 4.5\% : 0.3\%$ (*by volume*)
  - Similar to MuCH RPC gas ratio
- Humidity in gas: $--\rightarrow$ 40%.
- Flow rate: $--\rightarrow$ 5 l/hr.

Electronics

- Signal threshold: $--\rightarrow$ $\sim$15 fC.
- MuCh-XYTER based electronics and DAQ chain

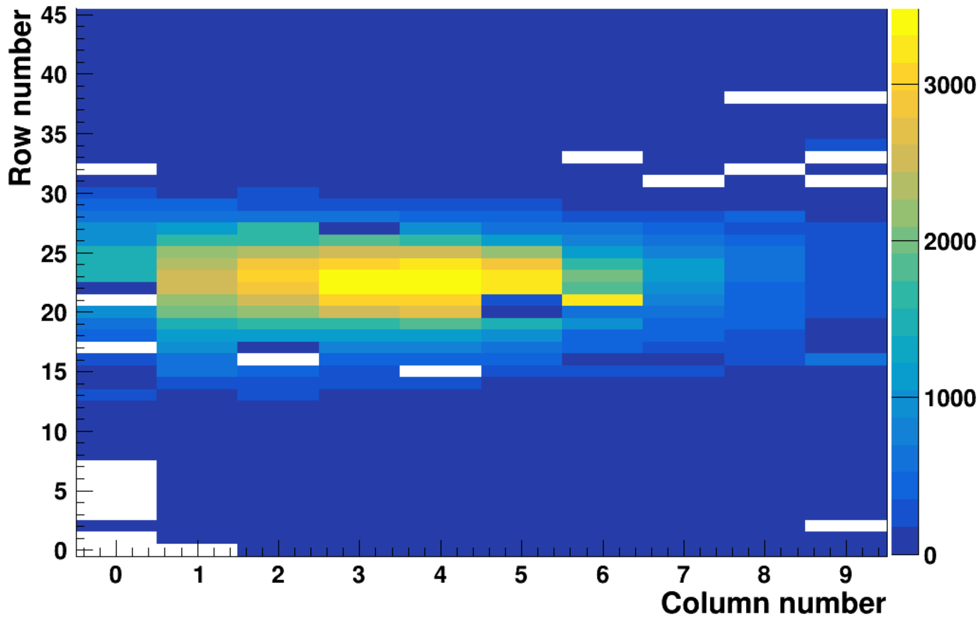
Current vs. photon flux



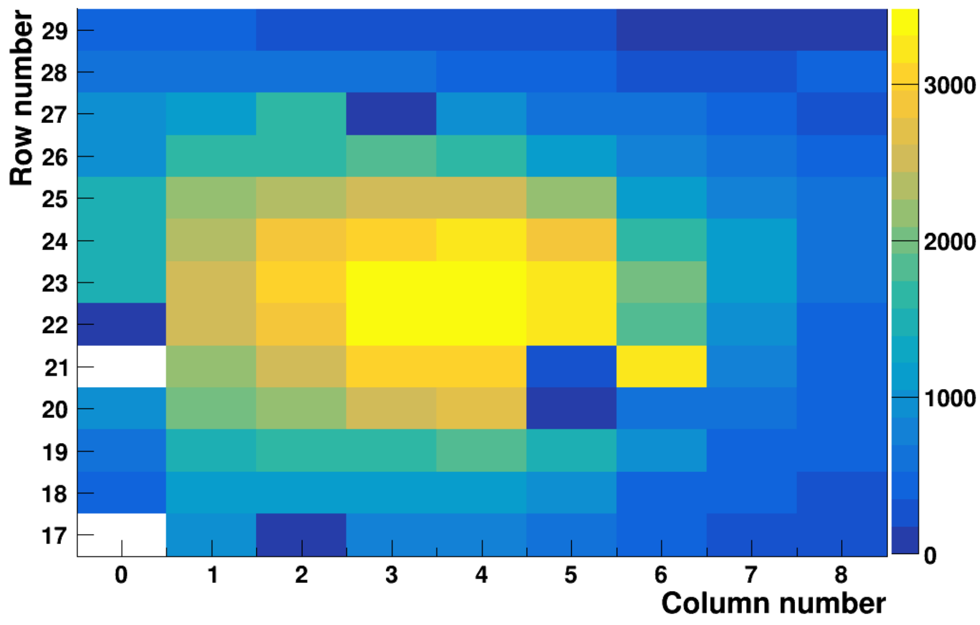
Current variation as a function of high voltage at different γ-intensities.

- γ-intensities —→ 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.

Hit distribution



Hit distribution of the pads throughout the whole detector.

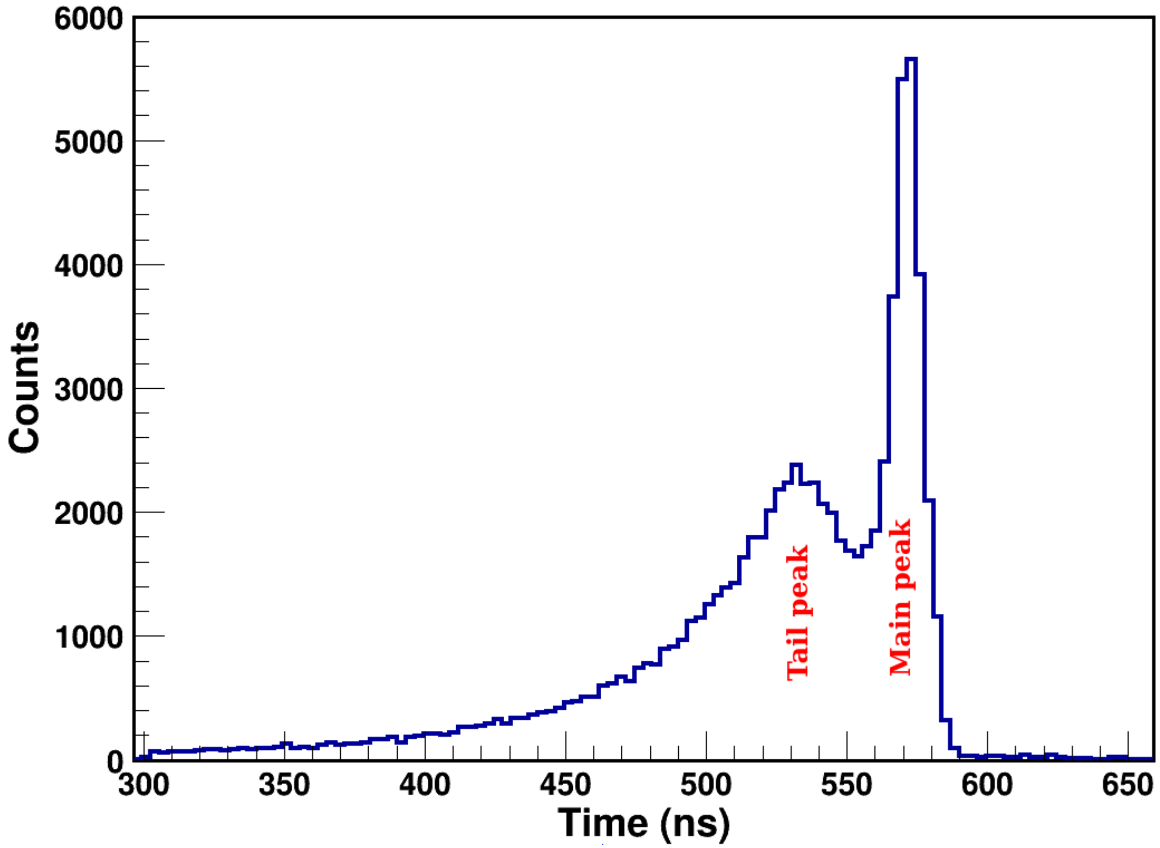


Hit distribution of the pads in and around the beam spot region.

- The detector has been positioned in such a way the beam hit around the middle region.
- The approximate pad dimension−→ 23 mm × 23 mm.
- The most intense region of the muon beam has an area of ∼ (92.6 mm × 92.6 mm)

Timing Spectra

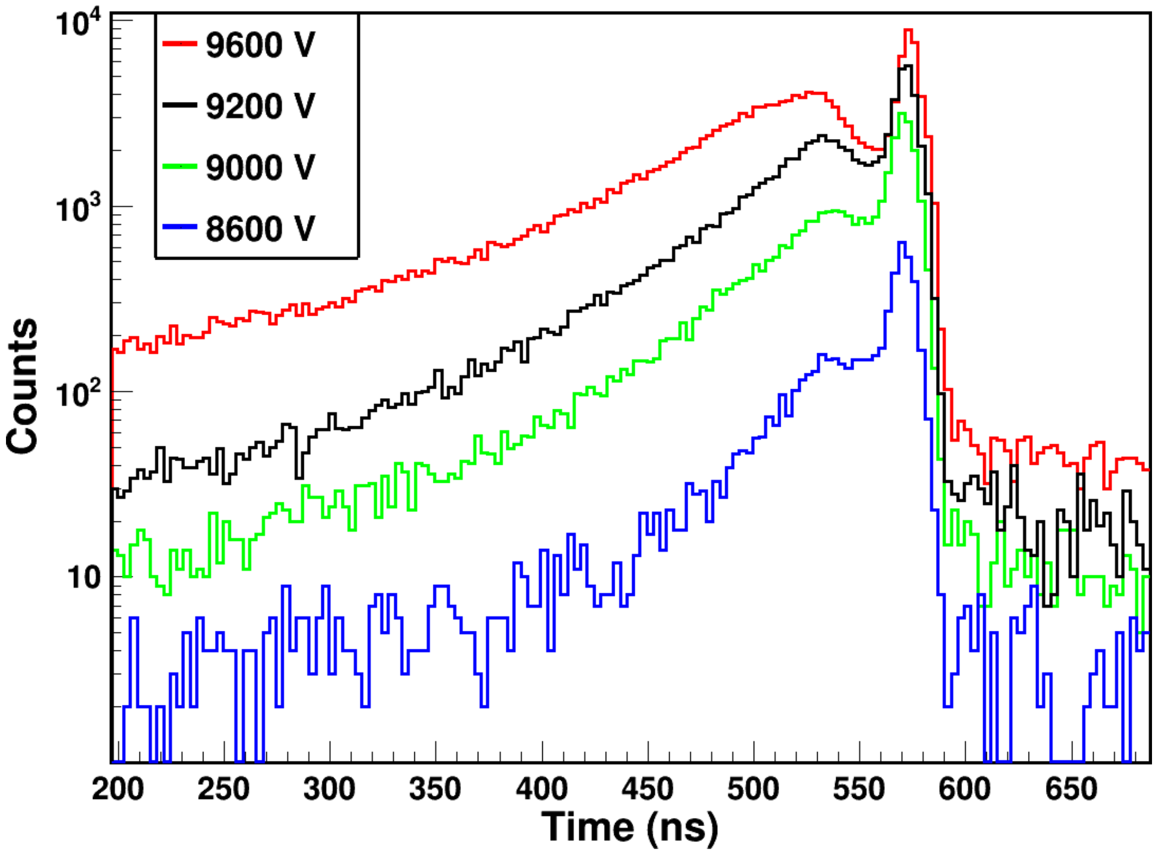
- The timing information of the hits have been measured w.r.t to the trigger time.



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".

Timing Spectra

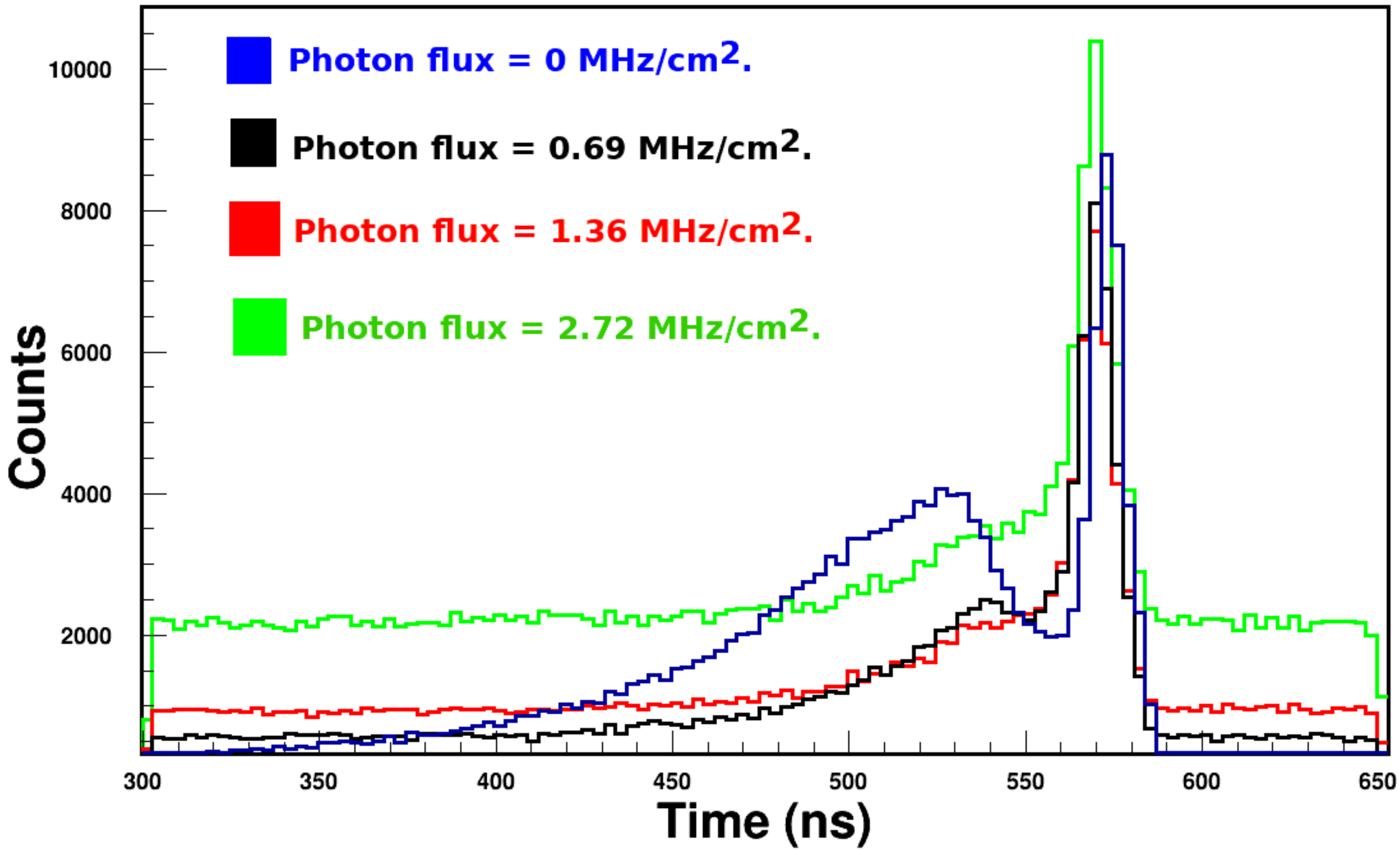


Time correlation spectra at different applied voltages in absence of photon flux.

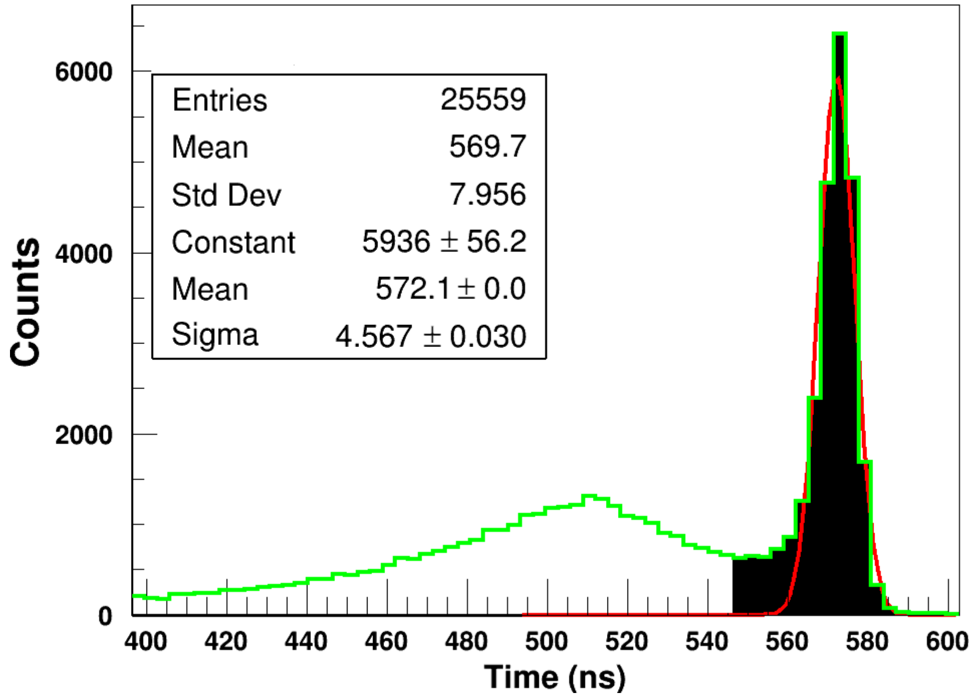
- Things to keep in mind: Self-triggered electronics and low threshold enviornment.
- Observation: As the high voltage is increased from 8600 V to 9600 V, the tail peak becomes more and more dominant.

Timing Spectra

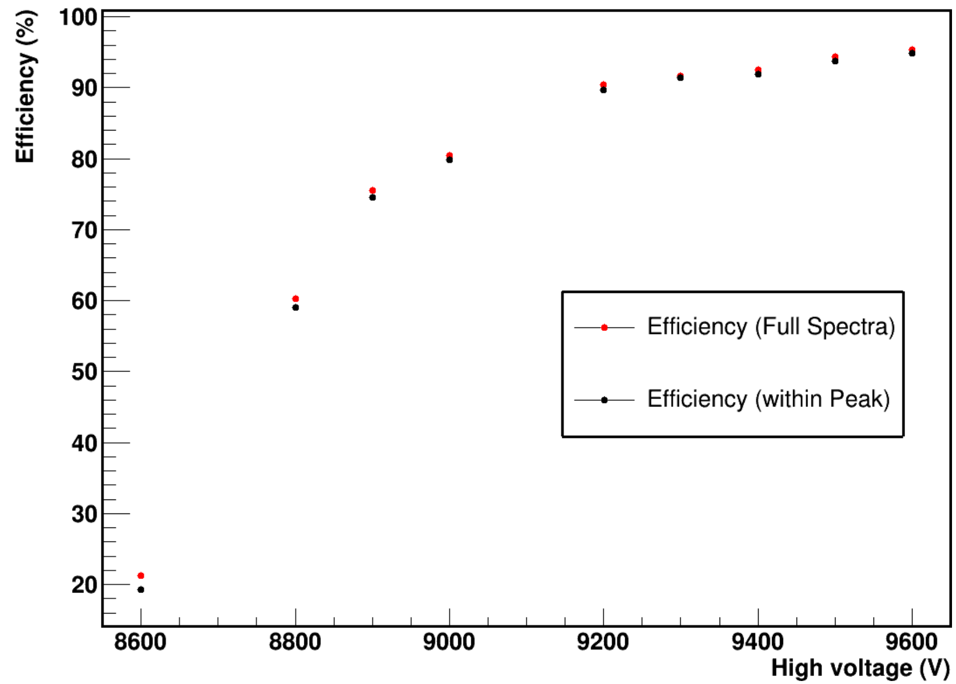
- Applied voltage to the RPC ⟶ 9600 V.



Timing Spectra and efficiency



A typical measured time spectra at 9300 V



Comparison of efficiency corelation for different regions of the photon 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 vs. Voltage

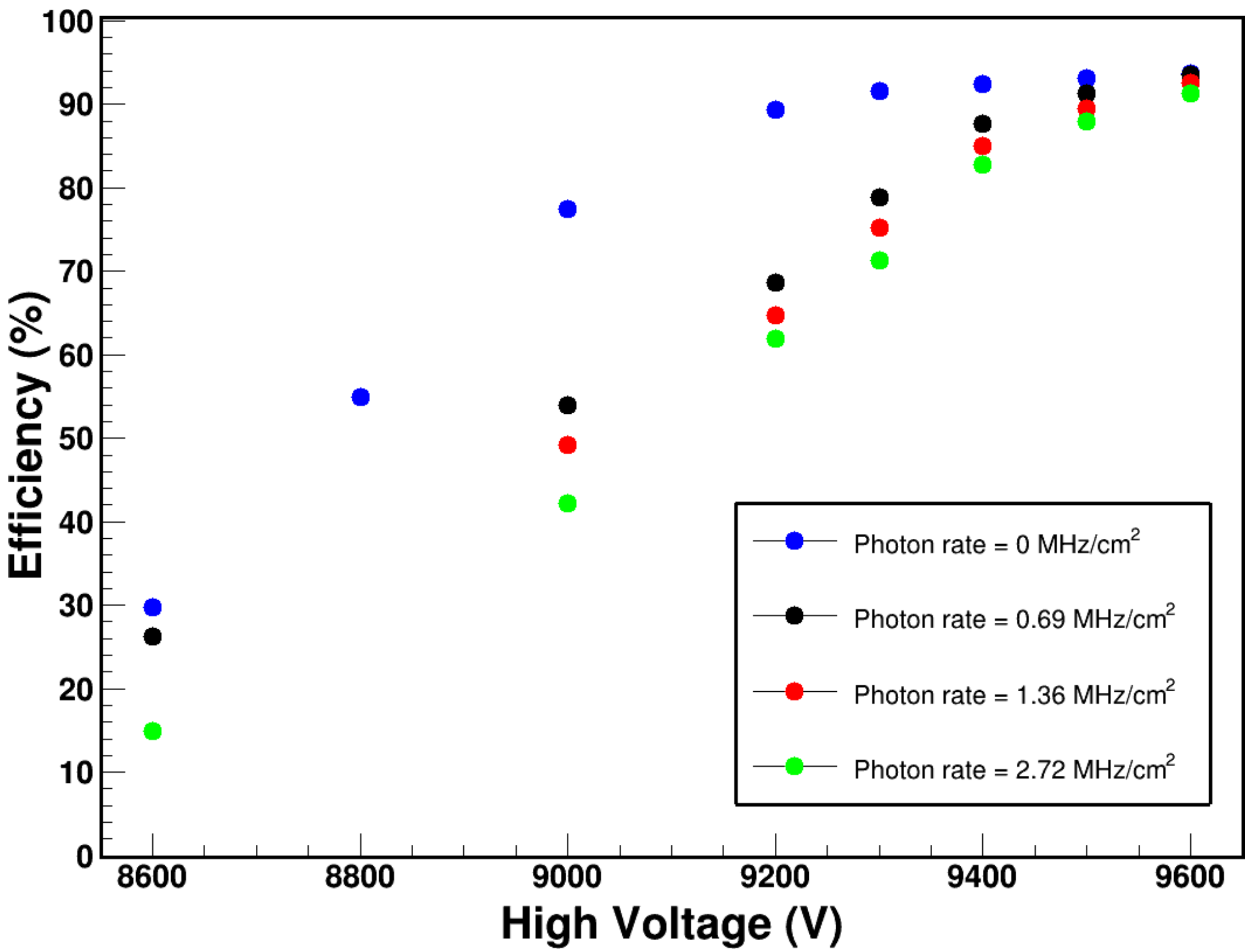
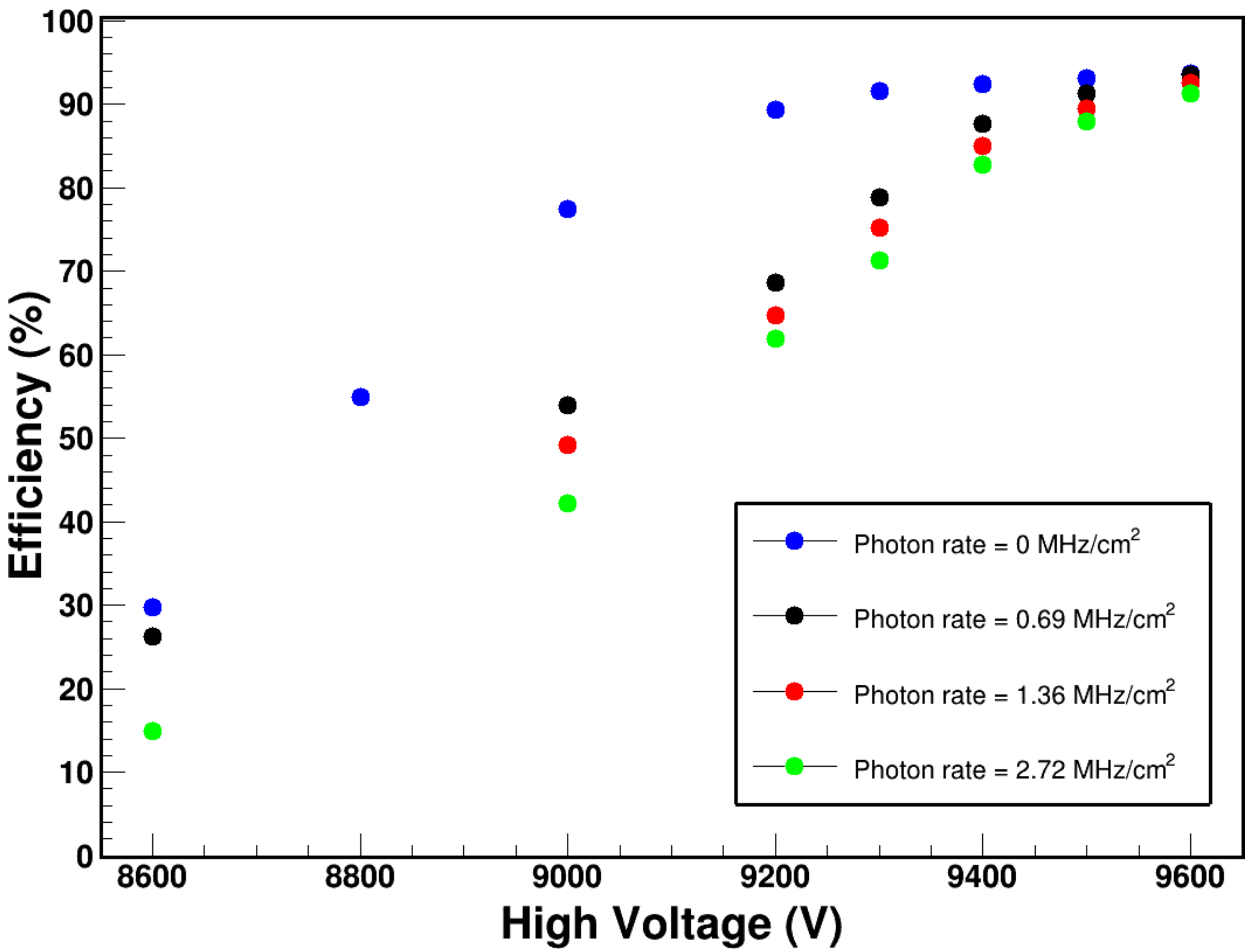


Figure 20: *Efficiency variation as a function of voltage at different photon flux.*

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 vs Photon Flux



Efficiency variation as a function of voltage at different photon flux.

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Efficiency vs Photon Flux

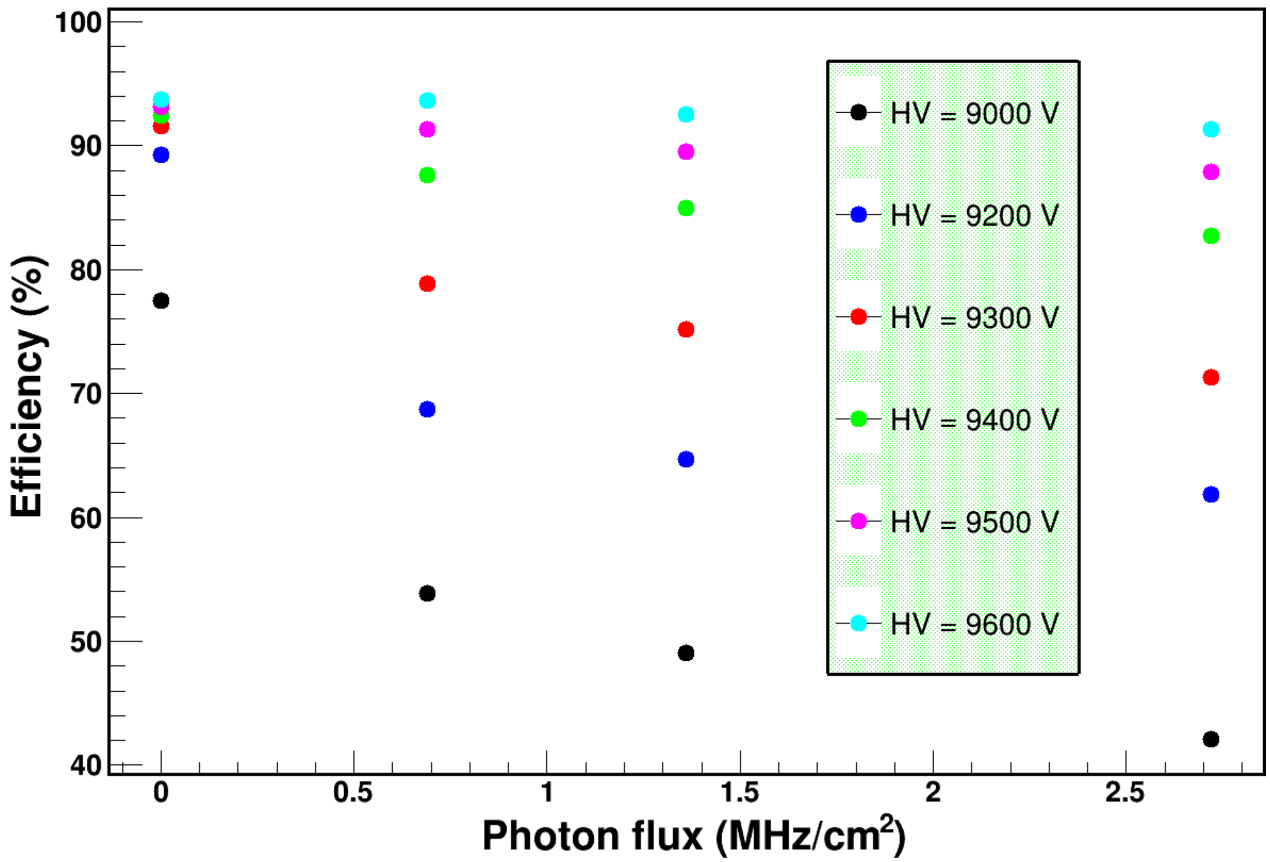
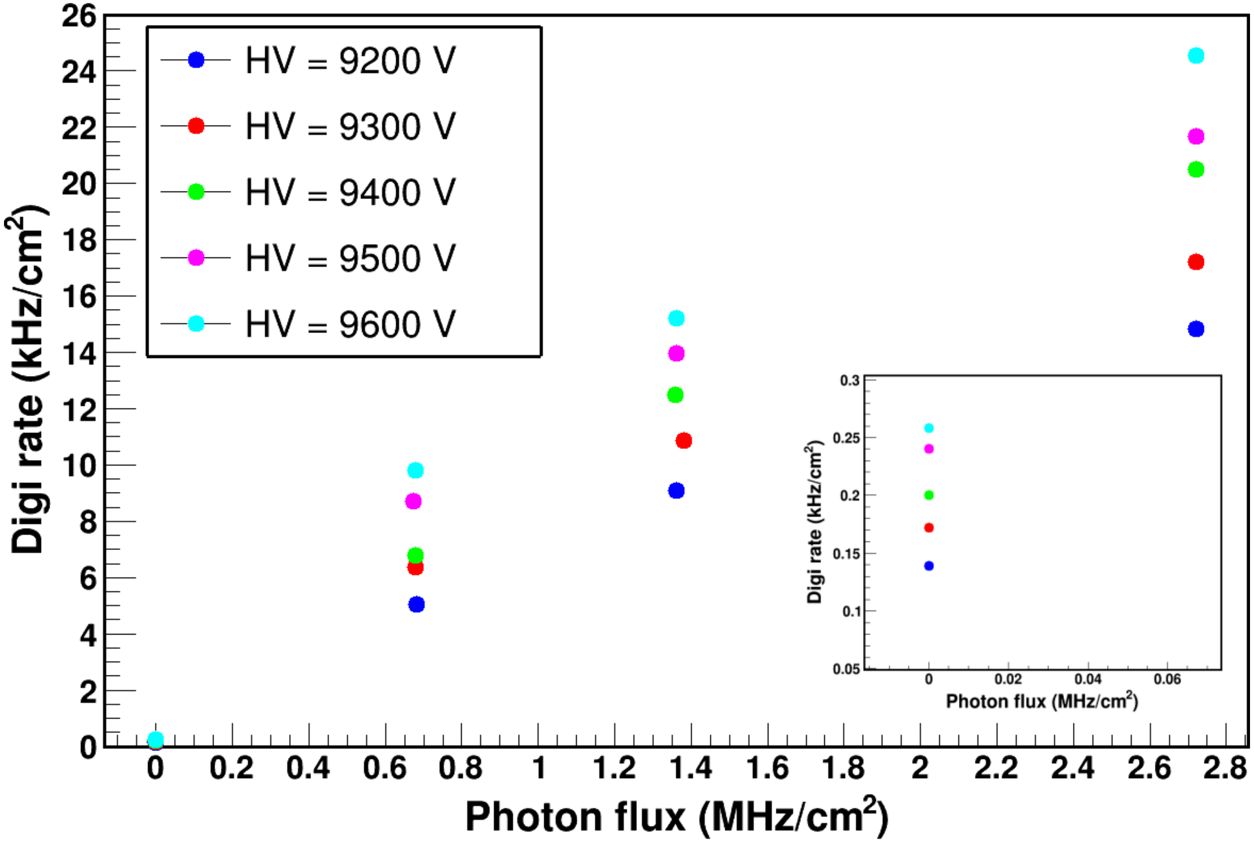


Figure 21: *Efficiency variation as a function of incident photon flux.*

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.

Measured Digi Rate

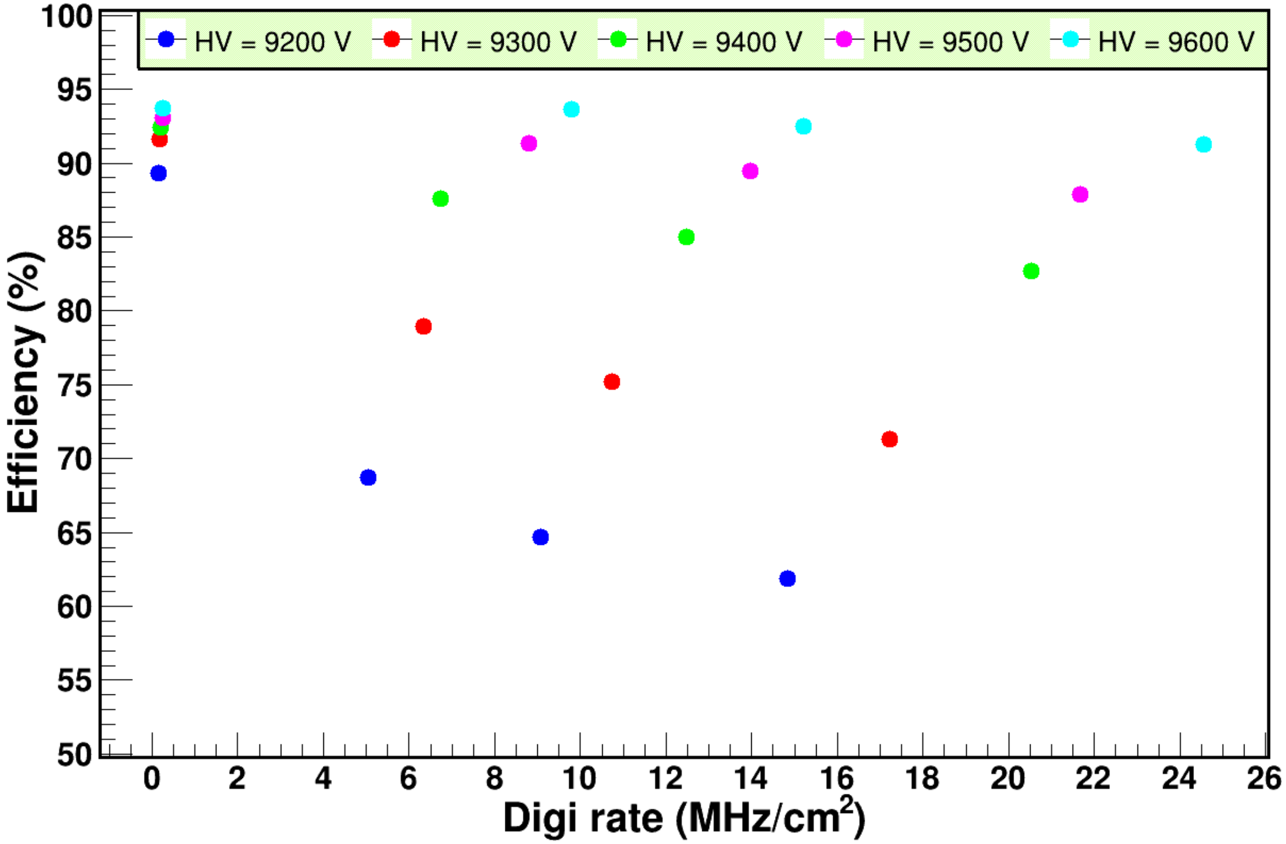


Variation of digi rate as a function of incident photon flux at different applied high voltages. The photo in the inset shows the variation during source OFF condition.

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 $\sim 2.72 MHz/cm^2$.

Efficiency vs. Digi rate

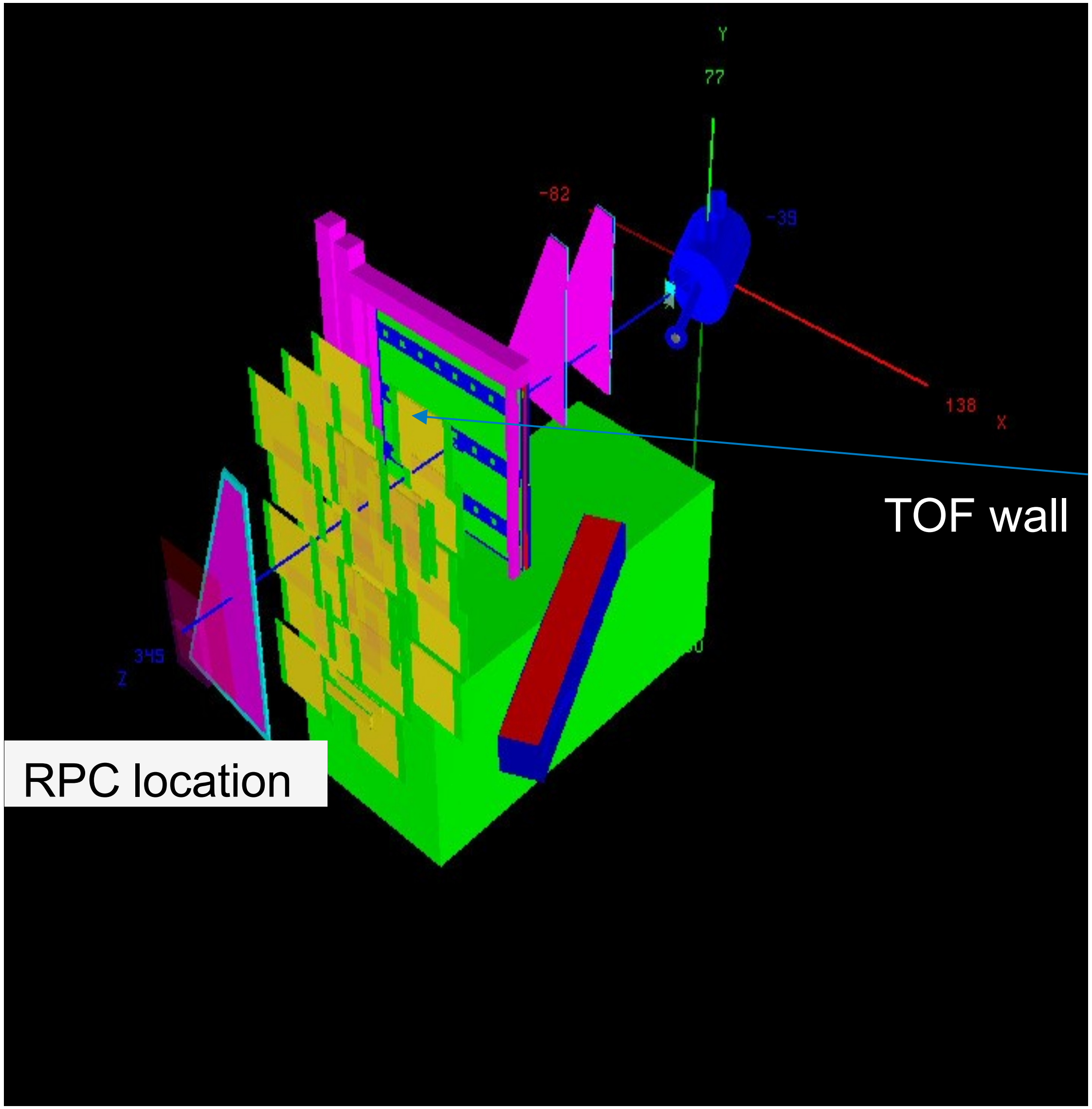


Variation of muon detection efficiency of RPC as a function of digi rate.

Observations:

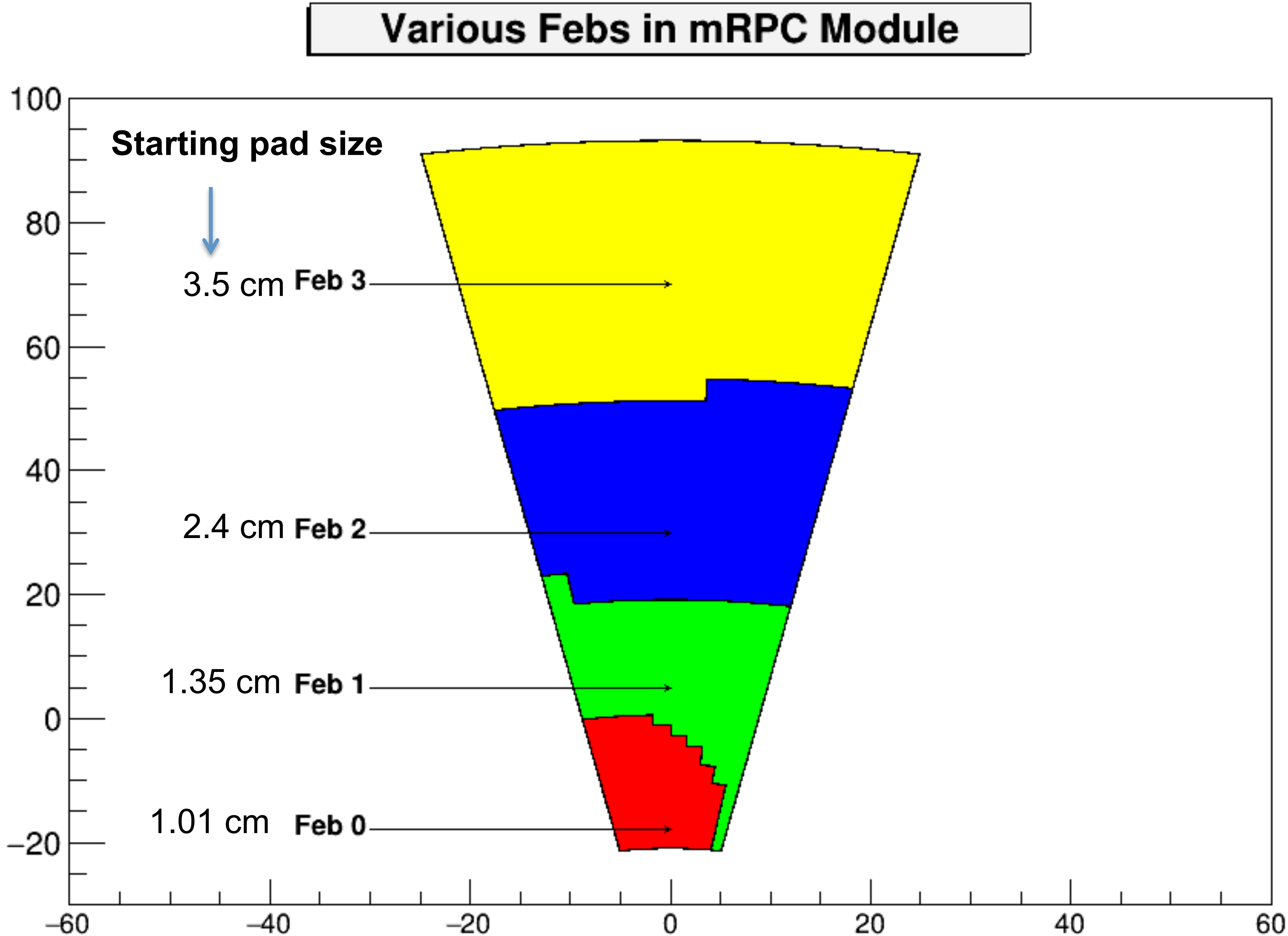
- At any particular voltage, the efficiency dropped as the digi-rate increases.
- The drop in the efficiency is very significant in lower voltage values.
- At 9600 V the detector has retained an efficiency >90% at a digi-rate of $\sim 24.56 kHz/cm^2$.

Tests@mCBM

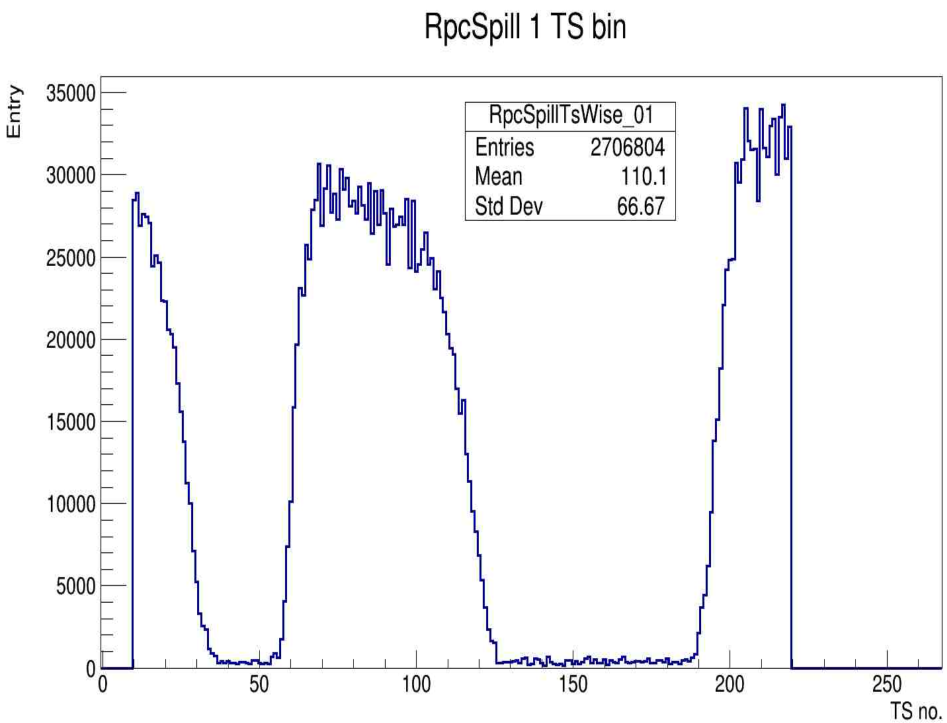


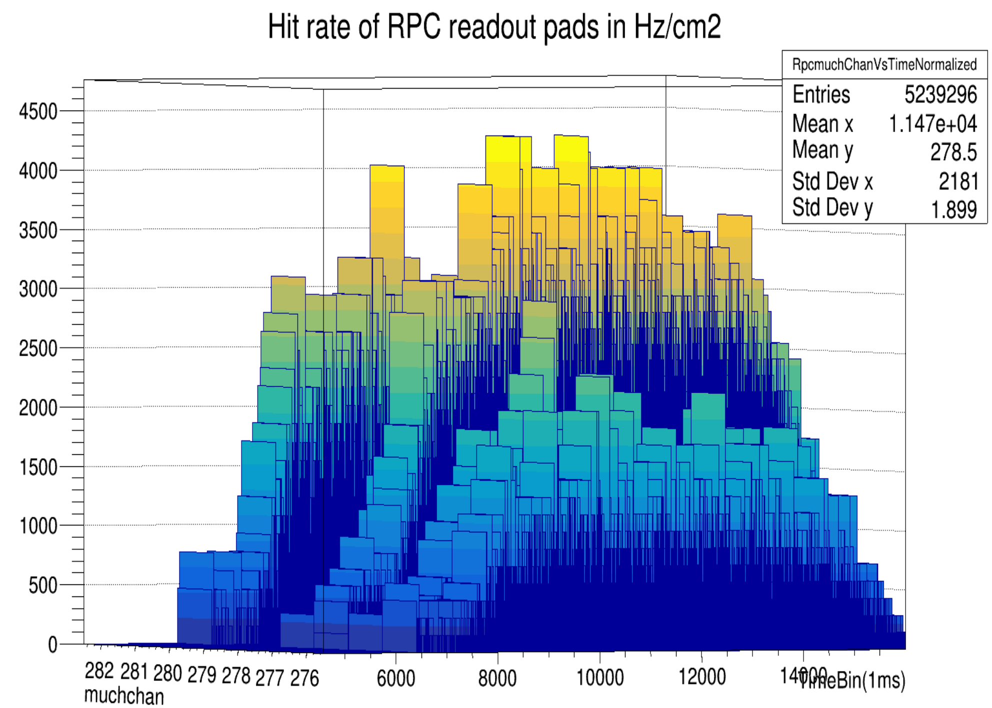
MuCH RPC

mCBM gas : R134a:SF6:: 97.5 : 2.5


Various Febs in mRPC Module
Starting pad size
3.5 cm Feb 3
2.4 cm Feb 2
1.35 cm Feb 1
1.01 cm Feb 0
100
80
60
40
20
0
−20
−60
−40
−20
0
20
40
60

Low Intensity Run

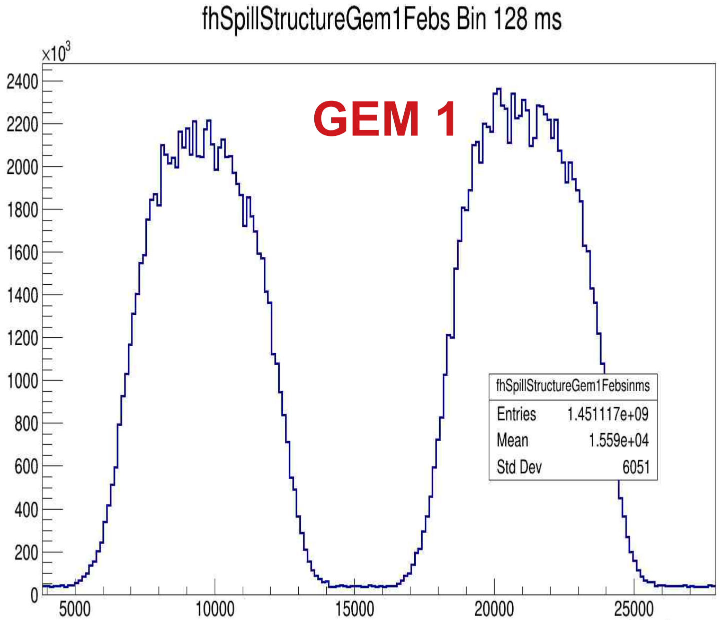


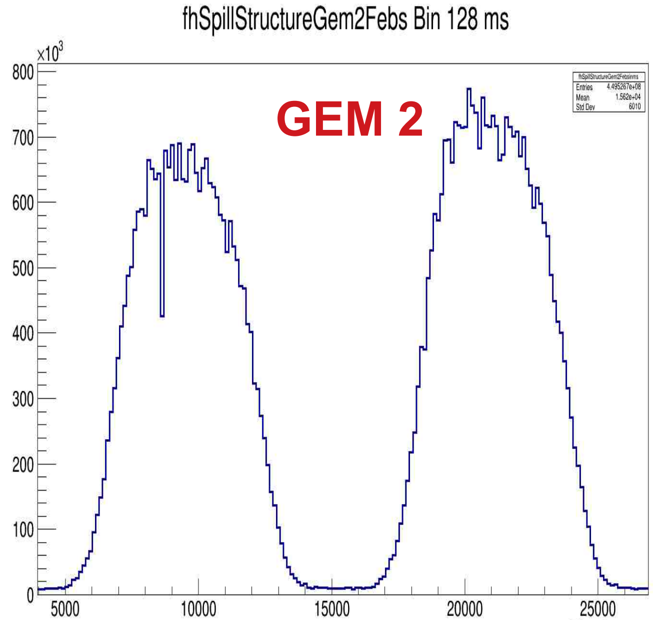


Run No. 2516
RPC HV 5525 Volts

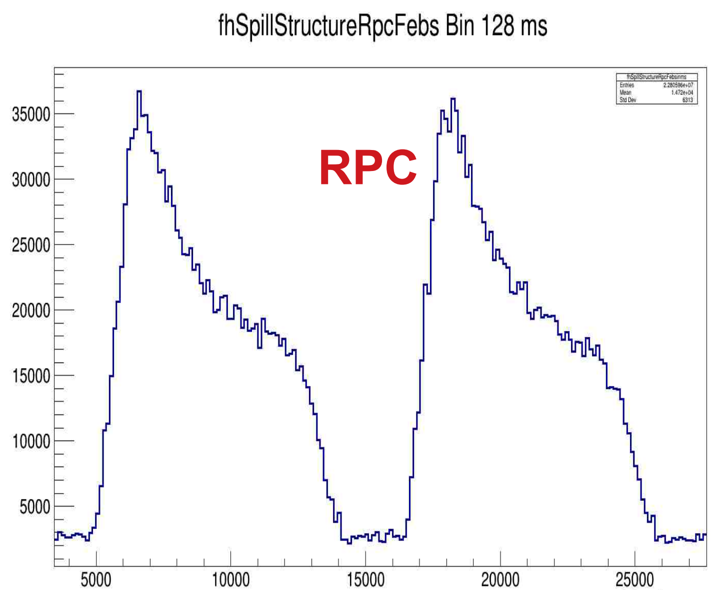
Beam Intensity~ 10^7

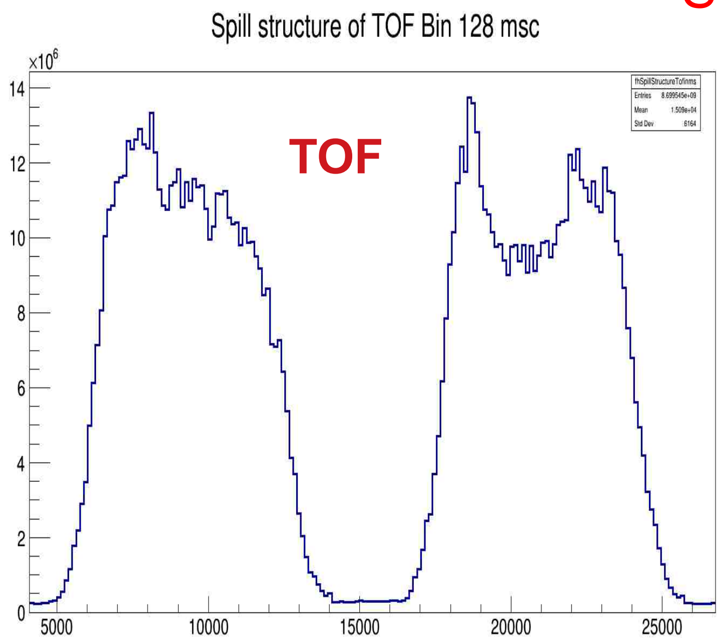
Spill Structure (high Intensity)



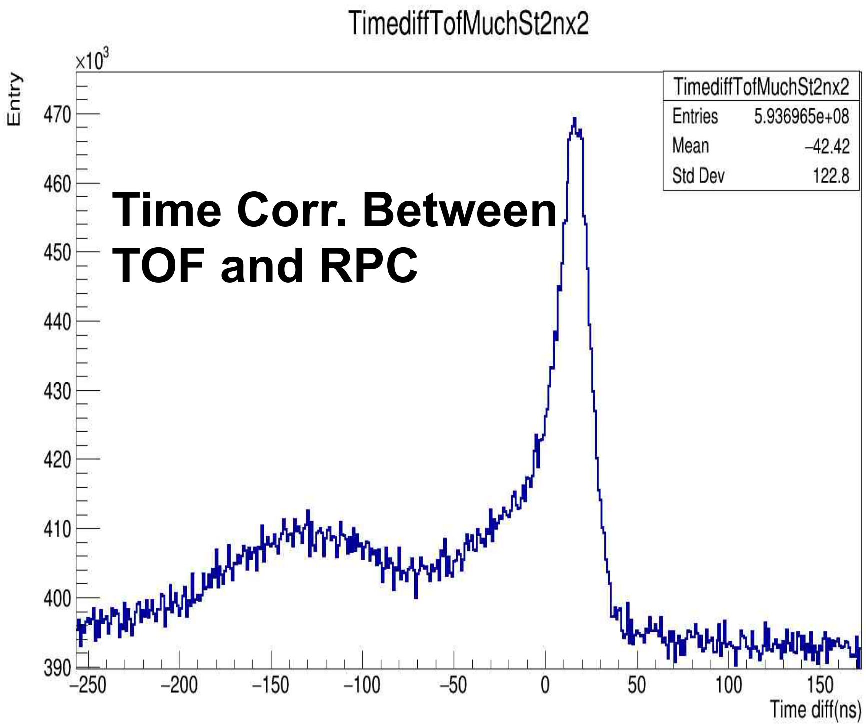


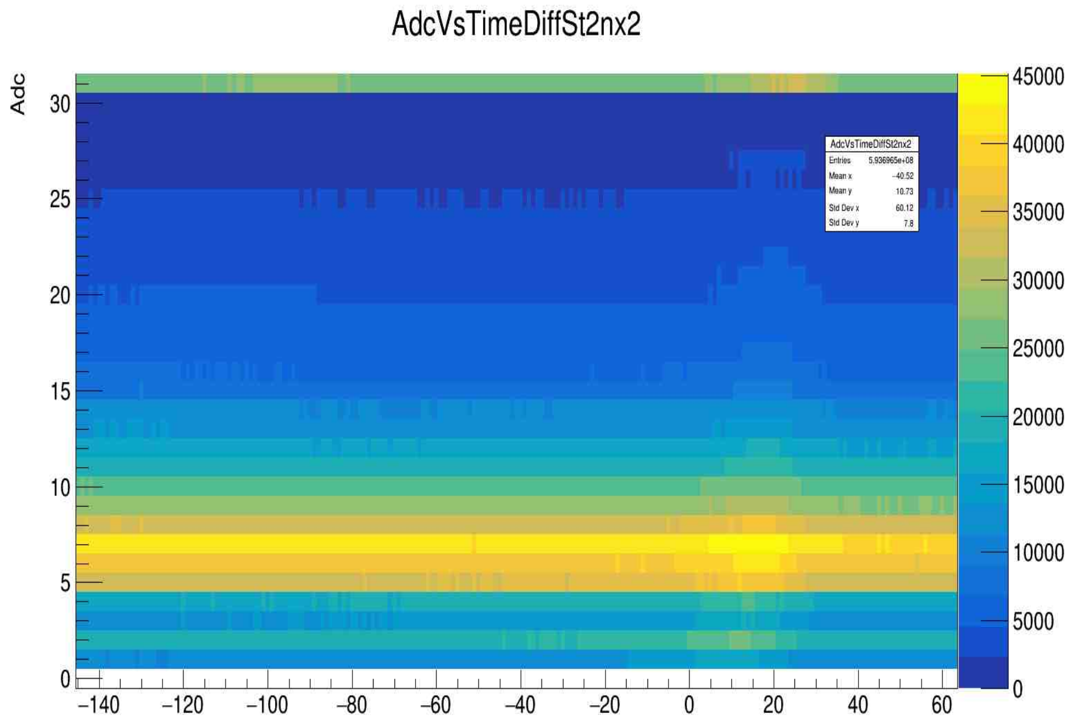
Run: 2570
RPC HV=
Au+ Nickel (4mm)
Beam Intensity= 2.5x10^8/ Spill

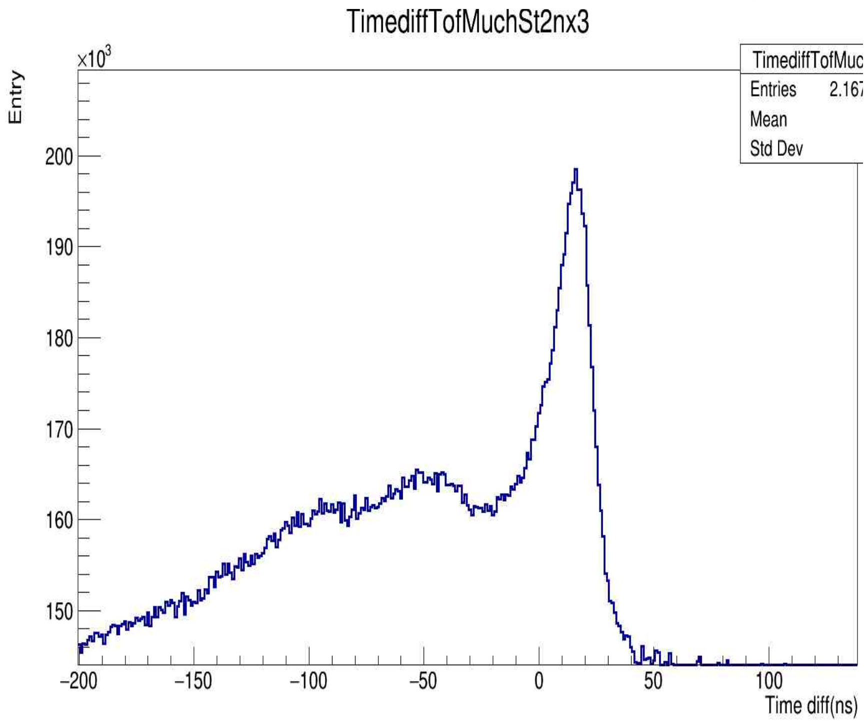


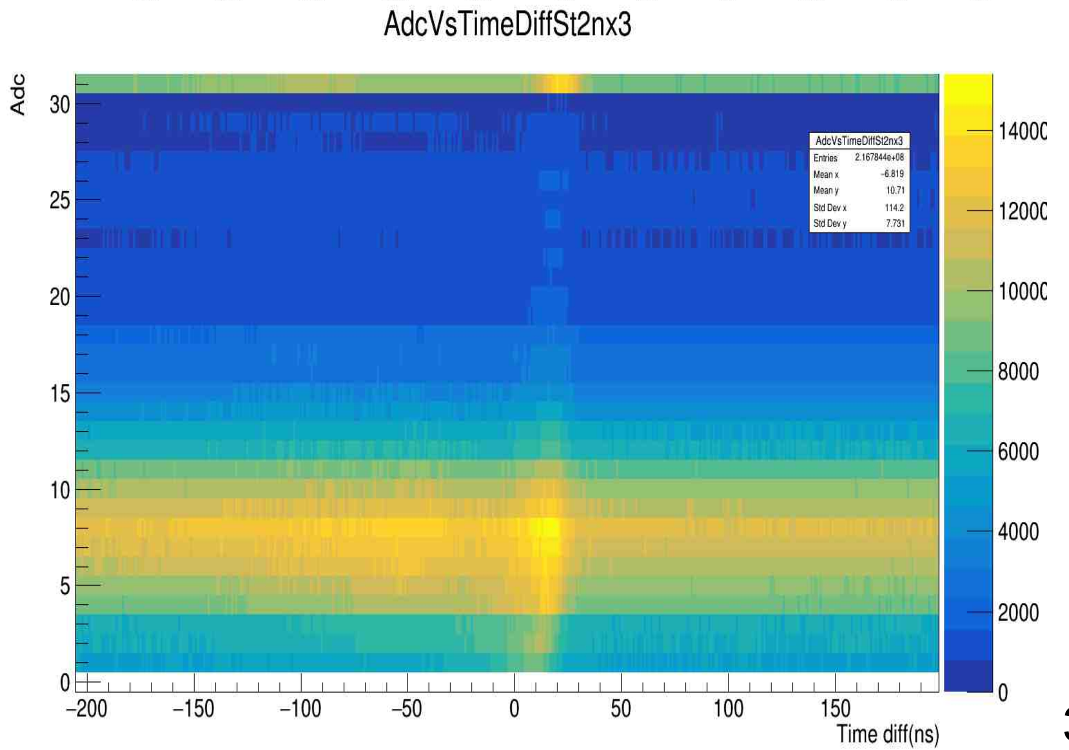


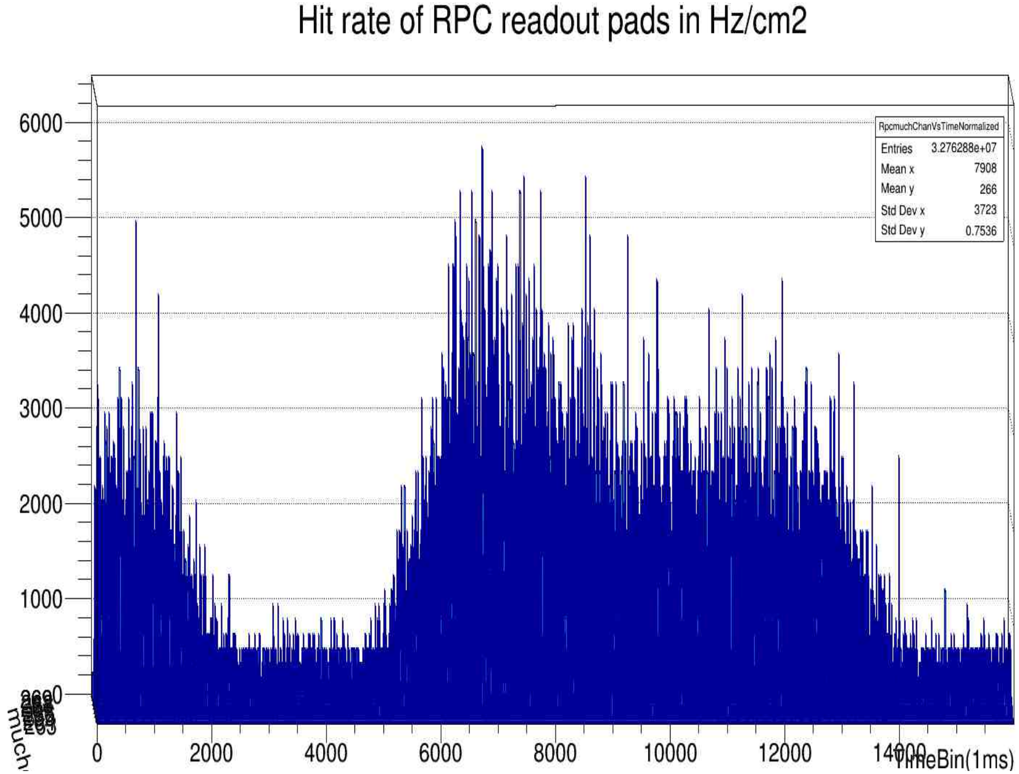
Much RPC Time diff with TOF sm0

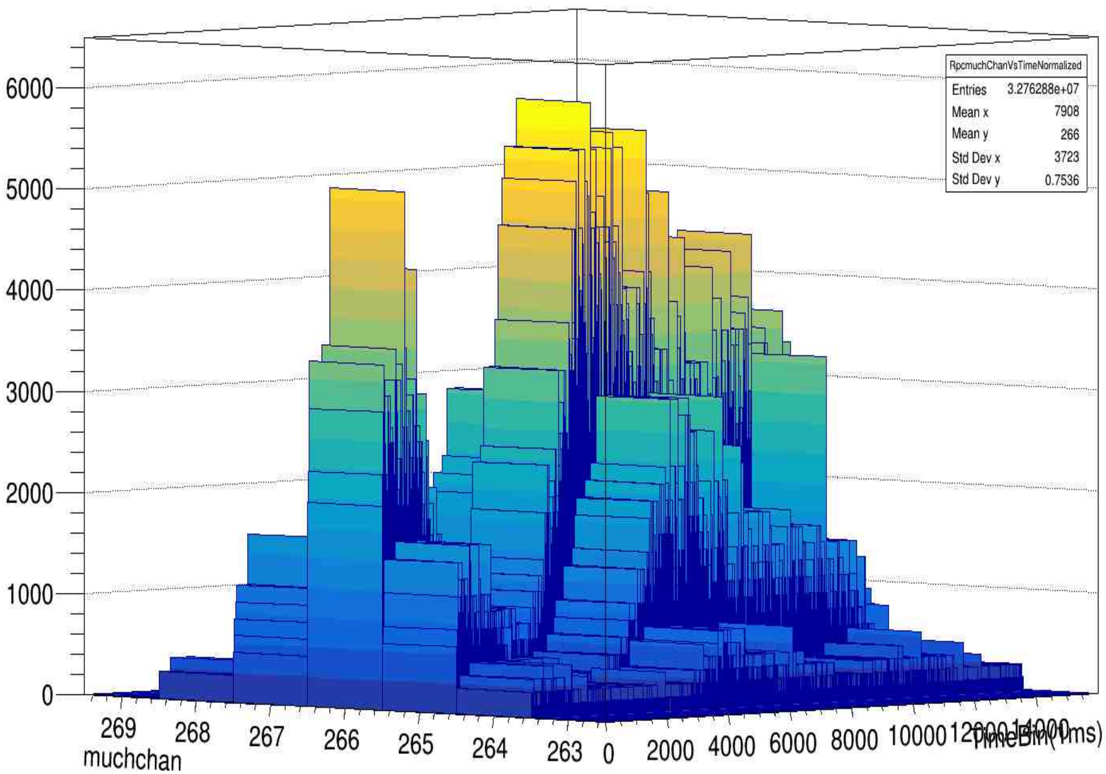












RPC rate: calculated with 1 ms time bin

This goes upto 5.5 KHz/cm^2

Further data analysis ongoing
Plan to have further tests for optimization of various parameters

Summary and Plan for 2023-25

RPC results so far:

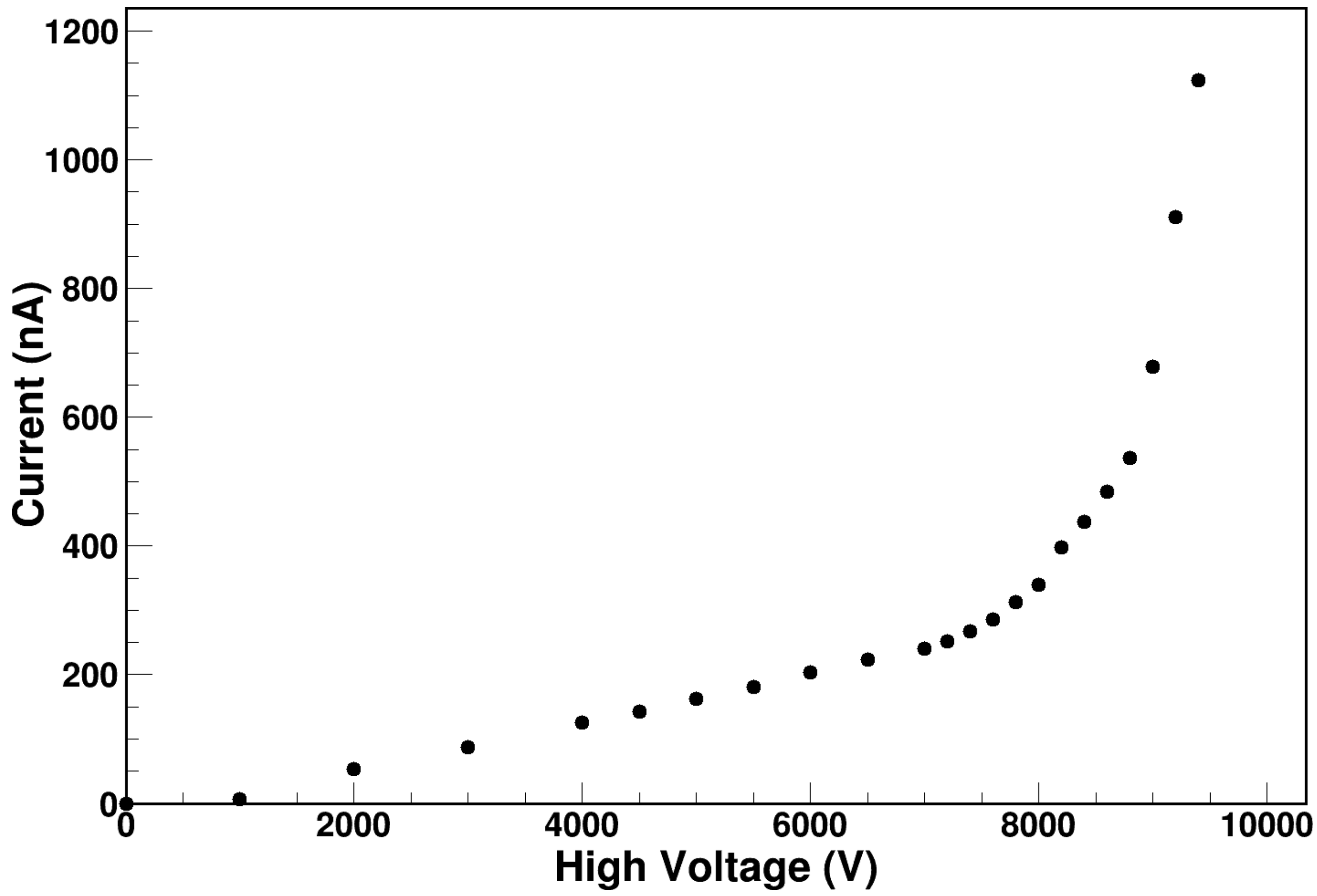
- GIF++ test shows >90% muon efficiency in presence of upto 25 kHz/cm^2 Digi rate on detector
- mCBM shows non-linear response of the chamber at much lower Digi rate(5.5 kHHz/cm^2)
- *Differences: DAQs were different, Different Gas mixtures*
  (mCBM gas : R134a:SF6:: 97.5 : 2.5)
  (GIF++ gas: R134a : iso-Butane : SF_6 :: 95.2% : 4.5% : 0.3%)
- Cross-talk looks to be an issue

Request for testing with RPC:

1. High rate test with CBM gas mixture (not the ones used in the last mCBM runs)
2. New chambers will be tested
3. Different orientations to expose different pad sizes
4. Tests at SPS GIF++ and with pion beam .

Thank you

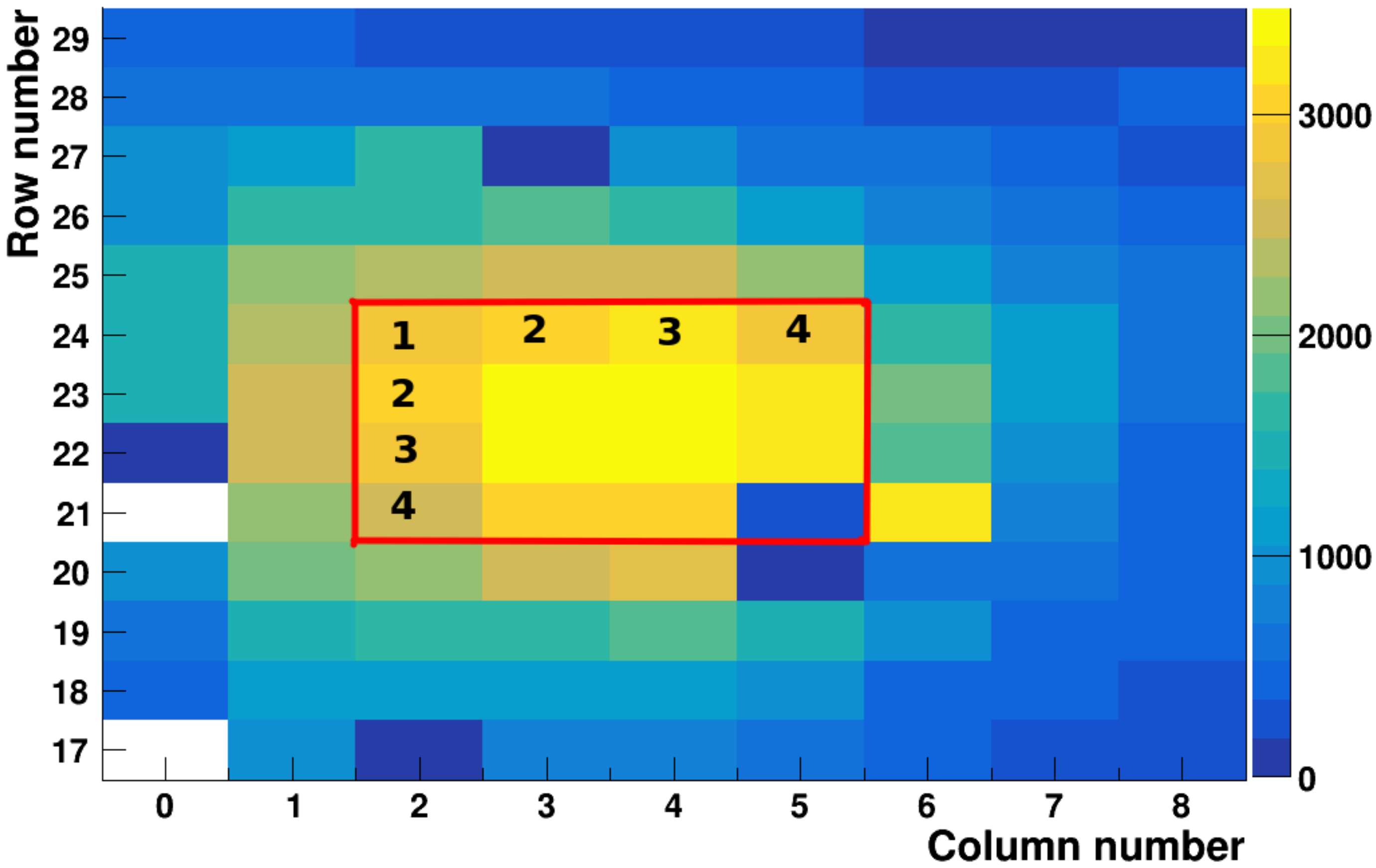
BACKUP Slides



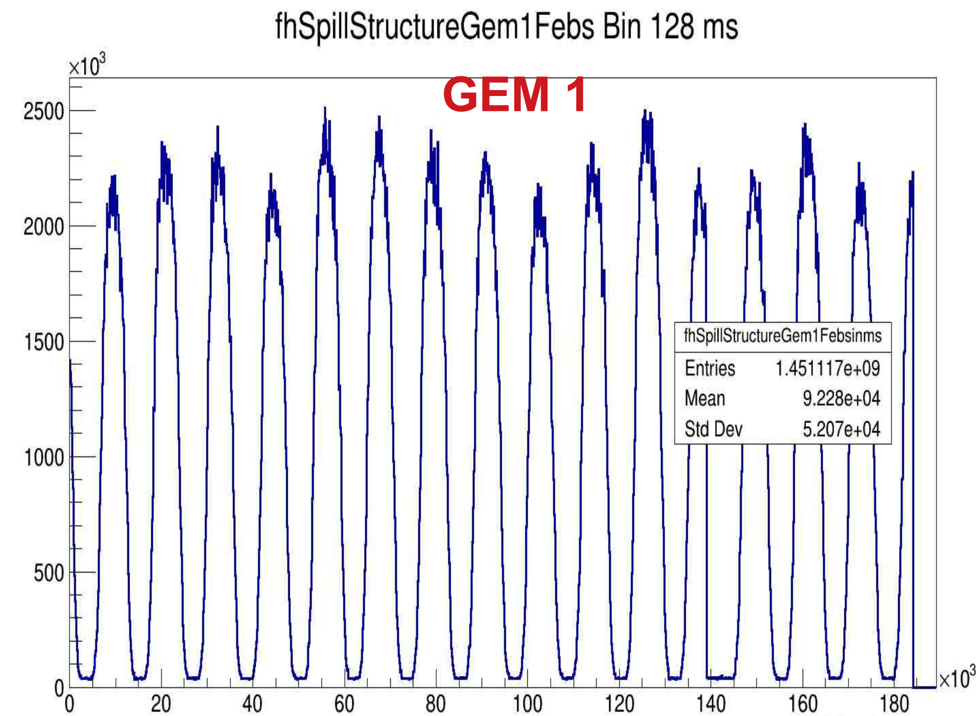
A quick I-V characteristics of the detector

The breakdown voltage is just above 8000 Volts

- 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.



Selected area or pads for digi rate calculation.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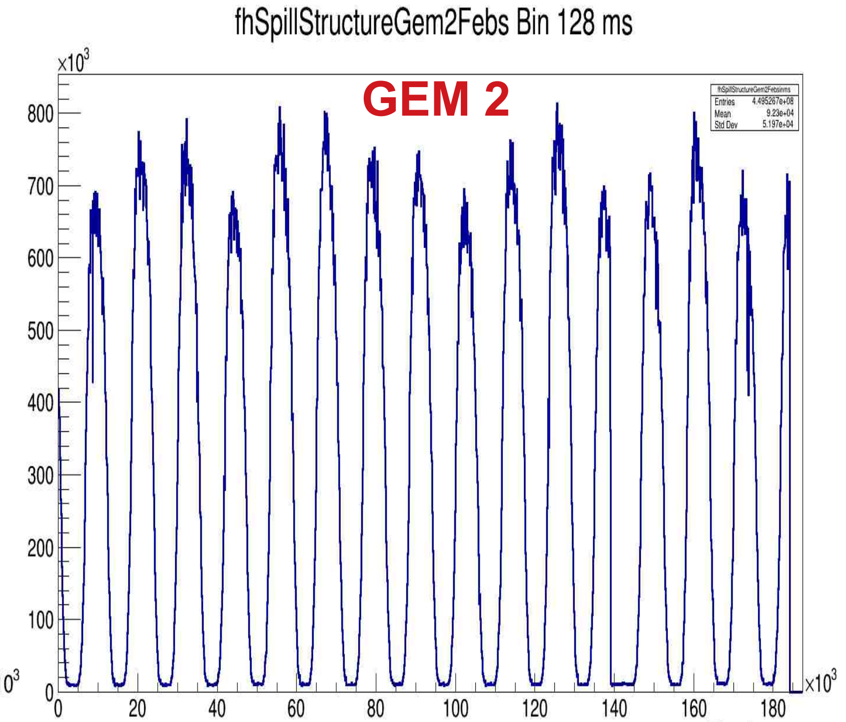
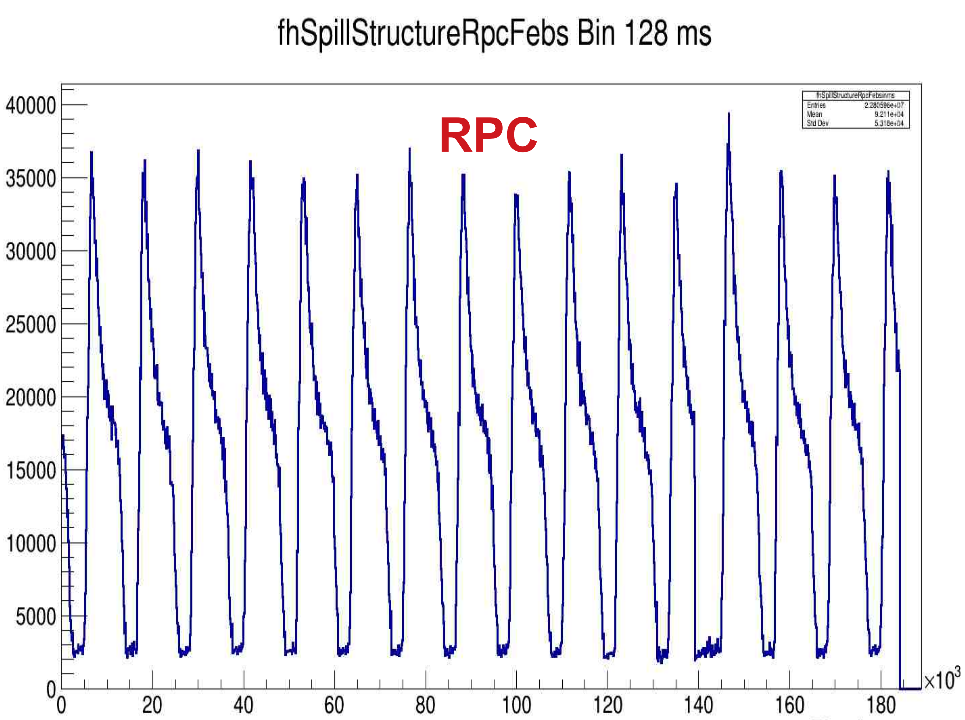
GEM 1
fhSpillStructureGem1Febsinms
Entries 1.451117e+09
Mean 9.228e+04
Std Dev 5.207e+04


fhSpillStructureGem2Febs Bin 128 ms
GEM 2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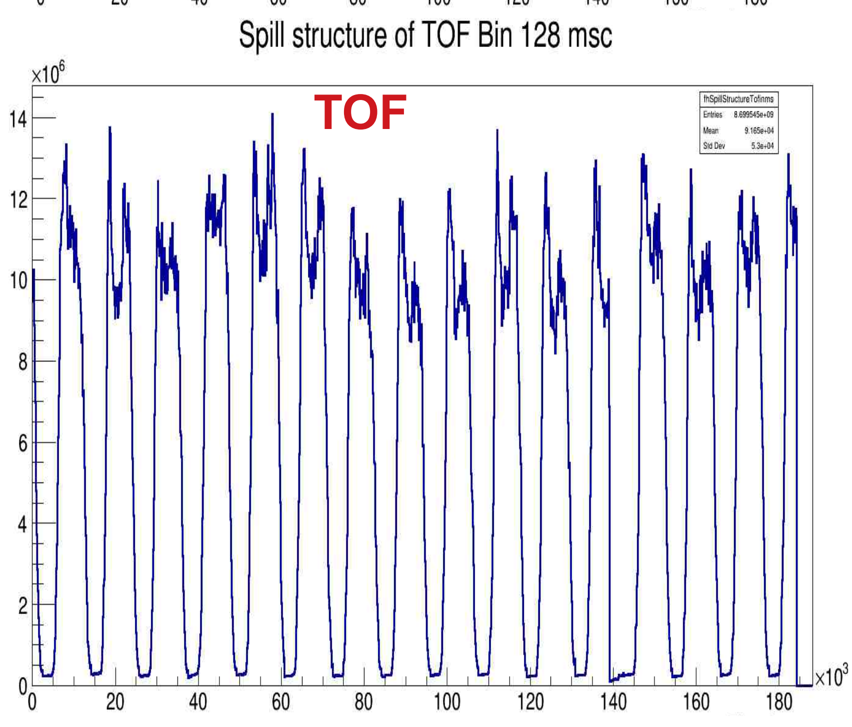
RPC


Spill structure of TOF Bin 128 msc
TOF