Developments of Gas Electron Multipliers at HU

Anusha Liyanage

Hampton University Nuclear Physics Group
29th September, 2015

What is GEM

- A gas electron multiplier (GEM) is a type of gaseous ionization detector used in nuclear and particle physics and radiation detection.
- GEMs are one of the class of micropattern gas detectors; this class includes micromegas and other technologies.
- GEM is a charge amplification device.
- GEMs were invented in 1997 in the Gas Detector Development Group at CERN by physicist Fabio Sauli.

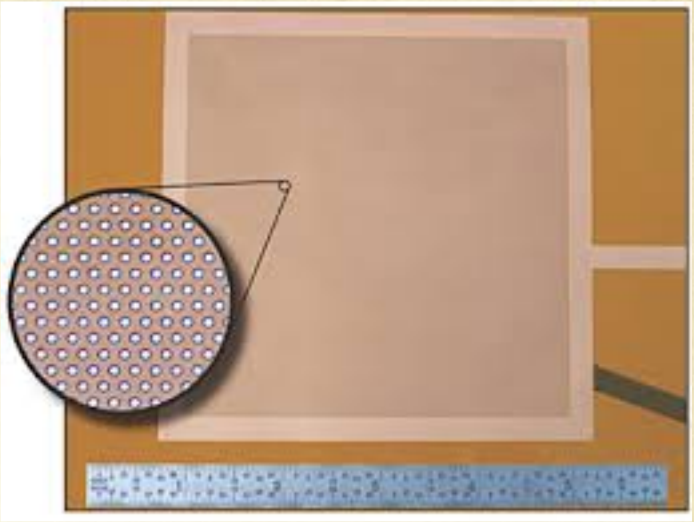
Motivation :
The number of electrons created by ionization is relatively small, around 100. Since the background noise count can be as many as 1,000, it's very difficult to identify signals from the background. Therefore, the amplification of the signal electrons needed. Making avalanche of electron, a single electron is amplified to 10,000 electrons which finally hit the sensor.

Why GEMs

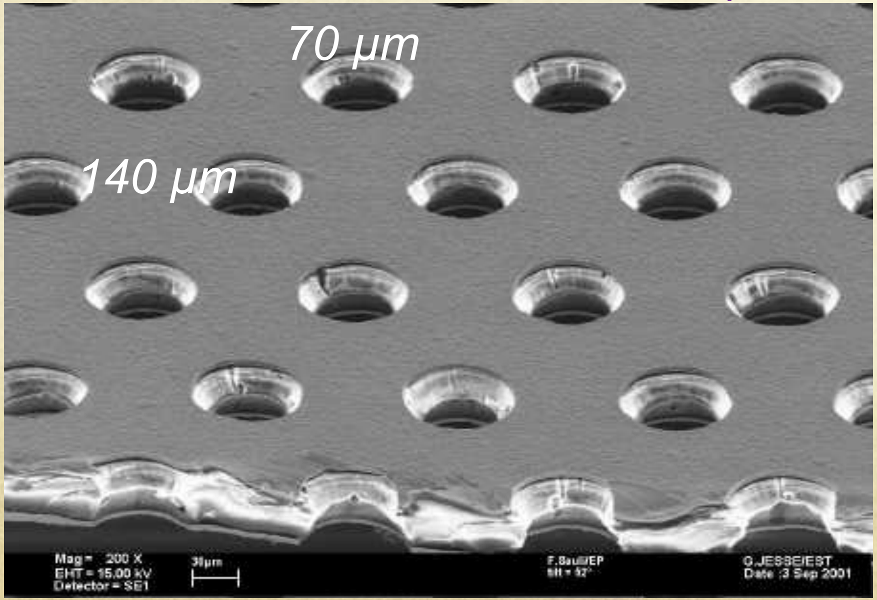
- Compact design, versatile, ease of manufacturing.
- Flexible detector shape and readout patterns.
- Safe non-explosive gas mixtures.
- High time and position resolutions.
- High achievable gains ($\sim 10^5$) in a multiple pre-amplification structure.
- Very high radiation rate capability.
- High sturdiness and reliability.
- Works in harsh radiation environment.
- High performance at relatively low cost.

GEM Foils

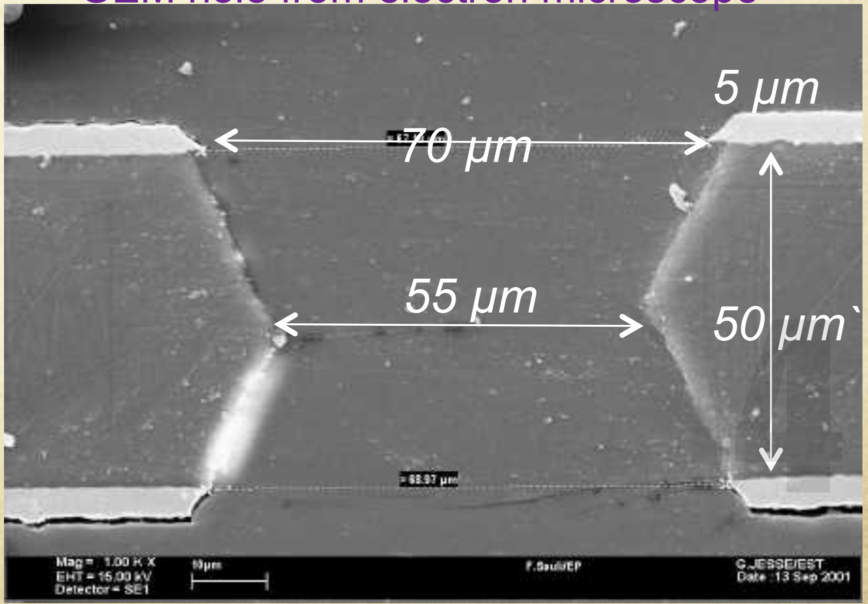
- GEM foils are made of a thin Kapton covered on both sides by Copper.
- High density of tiny, a photolithography and acid itched holes (~100/mm^2)
- Holes pitch: 140 μ m.
- Holes diameter in copper: 70 μ m +/-5 μ m.
- Holes diameter in Kapton: 50 μ m +/-5 μ m.
- Foils are stretched, framed and glued.



GEM foil from electron microscope



GEM hole from electron microscope



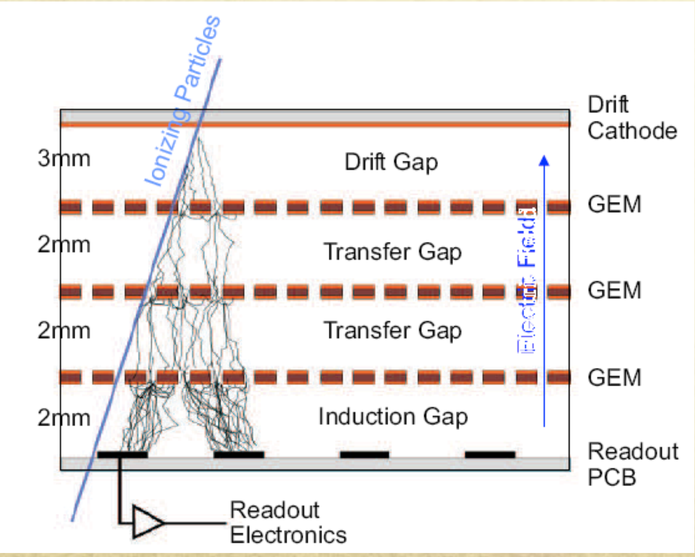
GEM Needs

- Careful optimization of the etching and cleaning procedures.
- A good and regular insulation between the grid electrodes, with no sharp edges, metallic fragments or conducting deposits in the channel.
- Sealed and maintain under Ar/CO_2 70:30 gas mixture.
- Several independent voltage settings:
  - A drift voltage to guide electrons from the ionization point to the GEM,
  - An amplification voltage, and
  - An extraction/transfer voltage to guide electrons from the GEM exit to the readout plane.
- Applied voltage on the foils to creates a uniform electric fields between foils.
- A voltage of 150–400 V is placed across the two copper layers, making large electric fields in the holes.

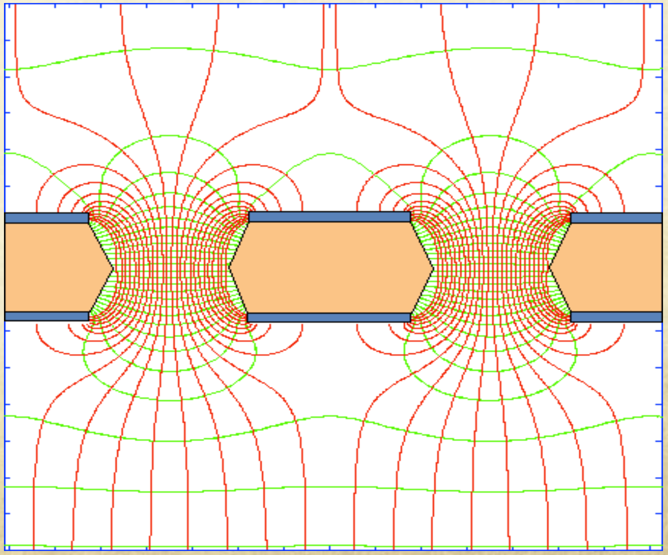
How GEM Works

- Coulomb interaction of the fast charge particles with the electron in the atomic shells of the detector medium (Ar:CO_2 gas) creates an electron-iron pair.
- Created electrons drift toward the GEM plane through the applied external electric field (Drift field) and pass through the holes.
- Excited and ionized atoms are produced by the avalanche multiplication in the hole region due to the strong electric field.
- Since the electrons exit the back of the GEM, a second GEM placed after the first one will provide an additional stage of amplification.
- The electron cloud drifts toward the readout plane (Induction gap).

Schematics of triple-GEM detector



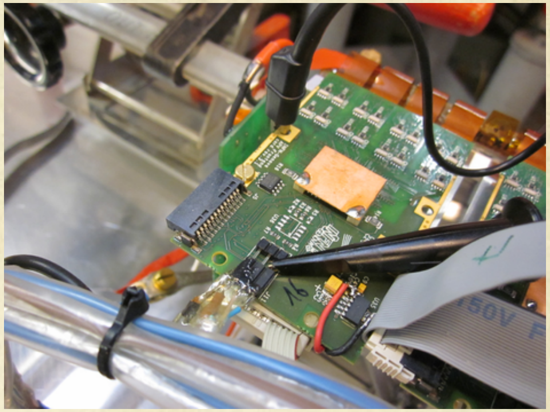
Electric field lines in a GEM hole.



GEM Data Acquisition System

- Use APV25 to read analogue signals coming from the GEM strips.
- The chip contains 128 channels of preamplifier and shaper driving a 192 column analogue memory into which samples are written at the 40MHz frequency.
- The latancy selects the sample to read out and the requested samples from the memory can then be processed with a filter, shaper and through an analogue multiplexer.

APV25 front-end card



MPD Rev. 3.0

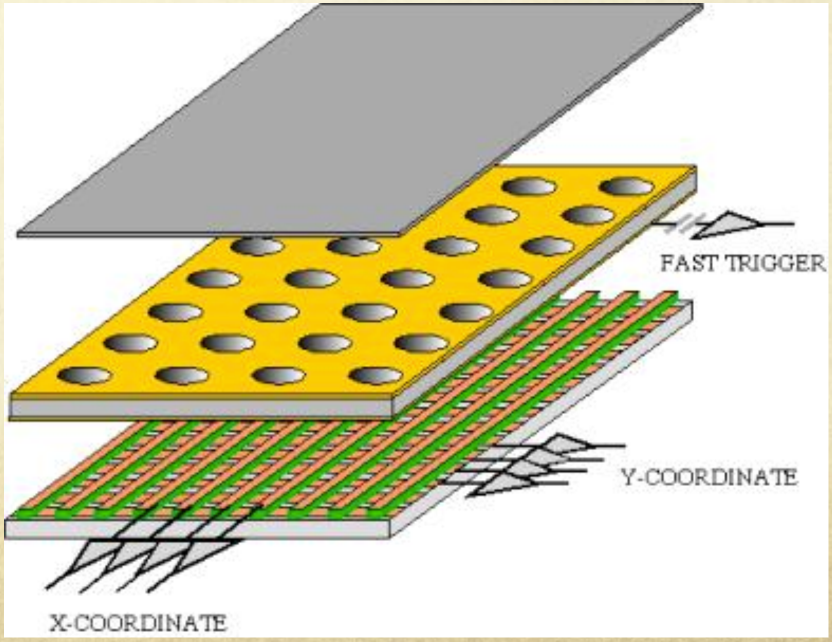
- The MPD (Multi Purpose Digitizer) Board has been designed to readout 16 APV25 front-end cards, reading out the analog data streams. And transmitting both the control and configuration signals.
- The FPGA mounted on it handle the VME interface, APV25 triggering, APV25 configuration etc…
- Use V7768 VME controller with universe II tundra chip on it (From INFN, Rome).

What actually ADC records....?

- The charge is collected on a 2D readout plane, consisting of a copper strips at pitch of 400 μm.
- ADC actually records the integration of the analog pulse over time for the total charge registered by a strip and digitizes it.
- Timing (or latency) relative to the external trigger needs to be configured in order to

"catch" the pulse for integration.

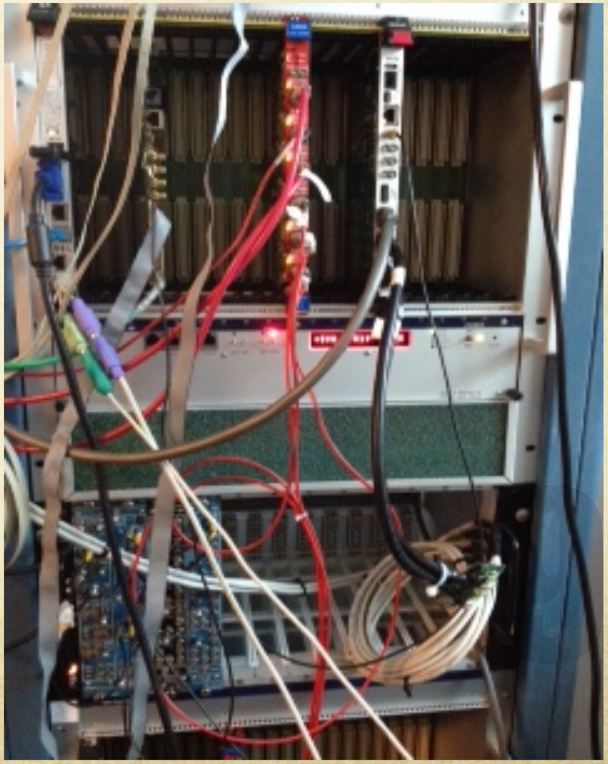
GEM detector : Read out plane



Our setup at HU

- GEM DAQ: NIM modules, HV modules, MPD
- Ar/CO_2 70:30 gas flow
- 10 cm x 10 cm single GEM and 3-GEM telescope.
- Trigger scintillators.

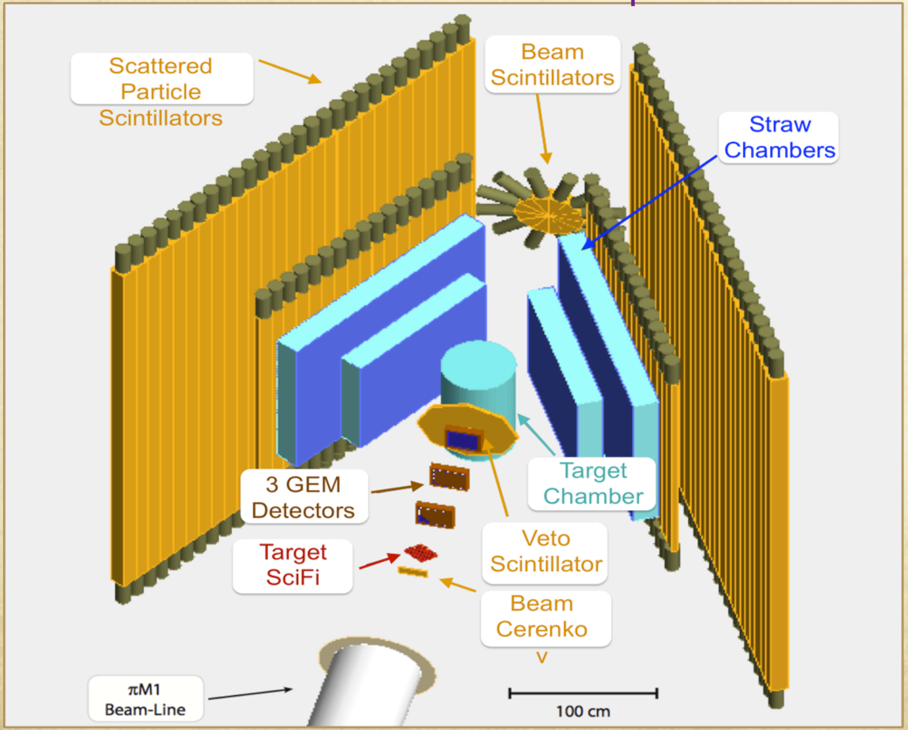




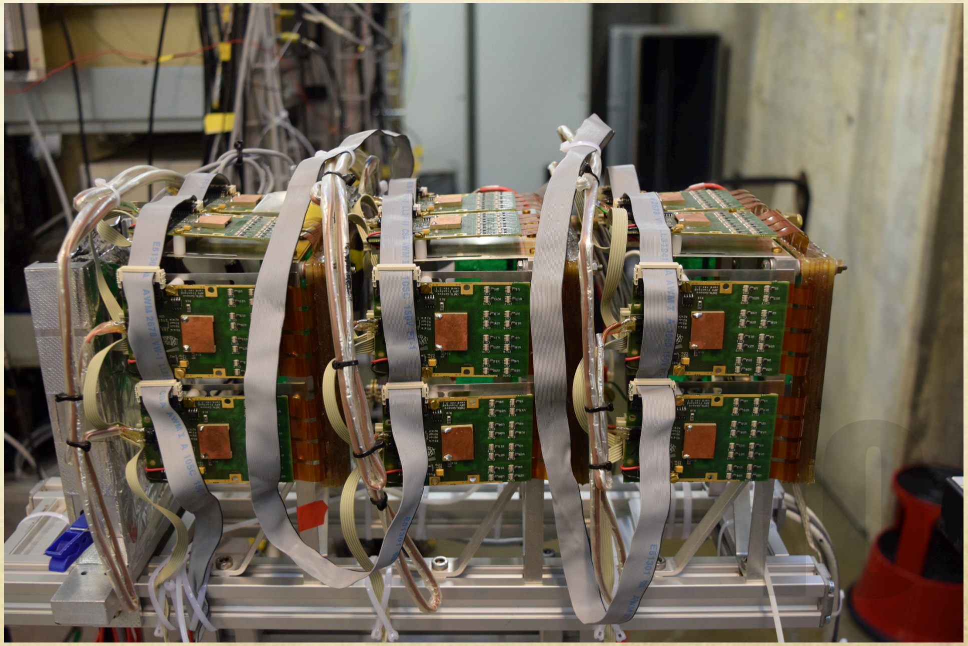
GEMs at PSI

- PSI πM1 beam line provides a beam with ~2 cm radius at the scattering target.
- Use GEM detectors to determine the precise particle scattering angles.
- 3 GEMs (10 x 10 cm^2 each) along the beam line.
- Use SiPM (73 V ± 10 mV) for trigger.
- Expect ~100 µm spatial resolution.
- Existing from OLYMPUS.

MUSE Detector Setup



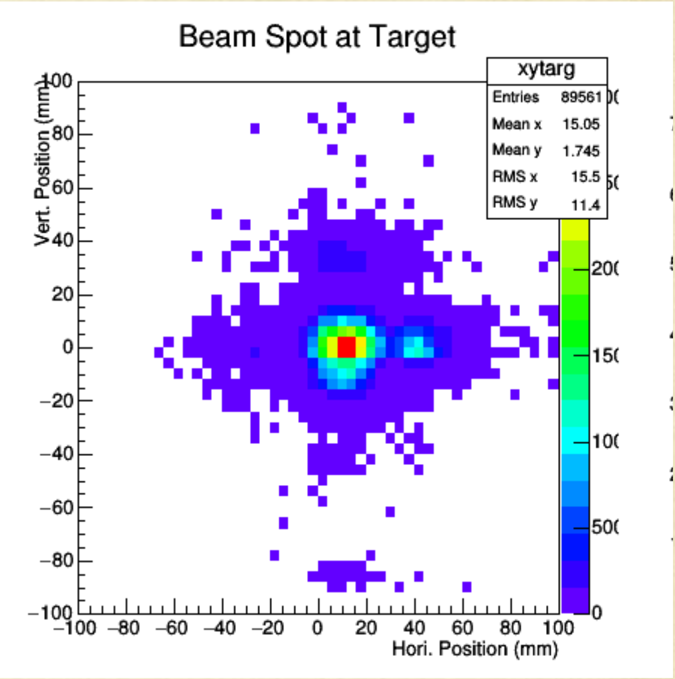
GEM telescope at PSI



MUSE GEM data analysis

Motivation

- The noise present in the raw ADC affect how precise the original signal is.



- This includes random disturbances or variations which even change the original signal.
- As the signal transmitted over a long distances, these random variations become more significant.
- The raw ADC generated by the noise can be misidentified as those generated by the true cluster charges on GEMs which can produce ghost tracks.

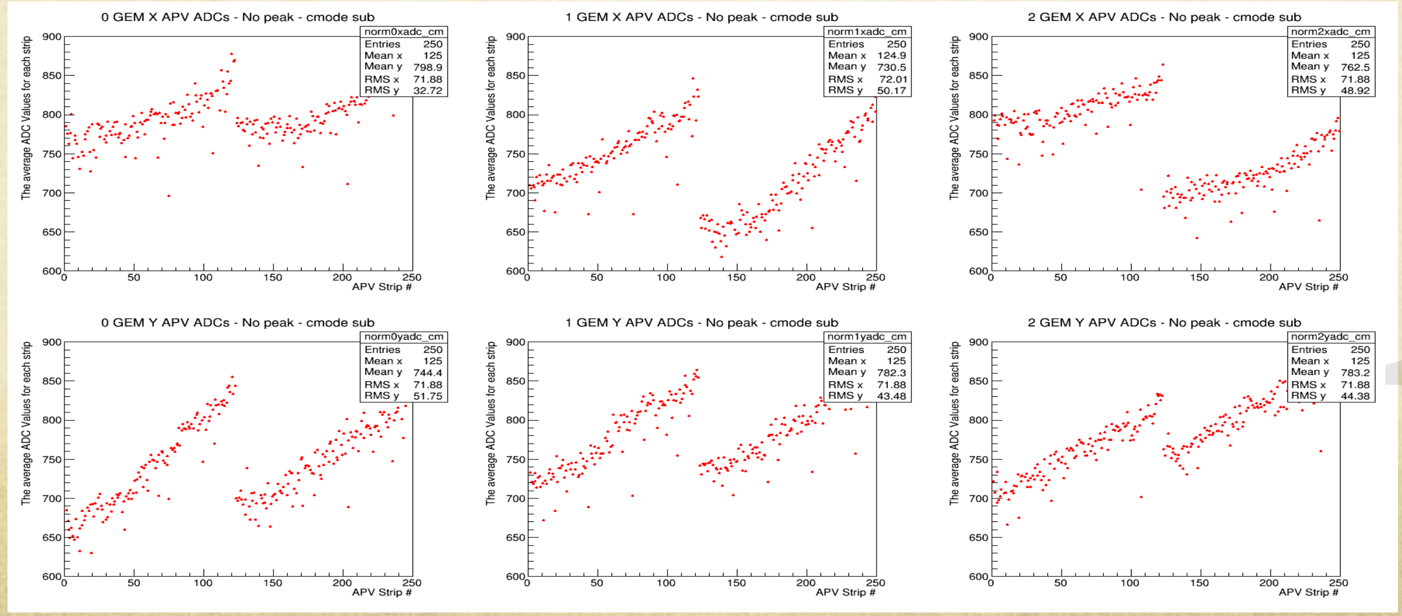
(1) Common-mode noise subtraction.

The various noise types, the so-called common-mode noise can be determined per event, a correlated up and down per event for all channels together.

(2) Bin-to-bin pedestal subtraction.

The raw ADC has a pedestal and is prone to noise. The individual pedestal can be determined by averaging each channel over many events.

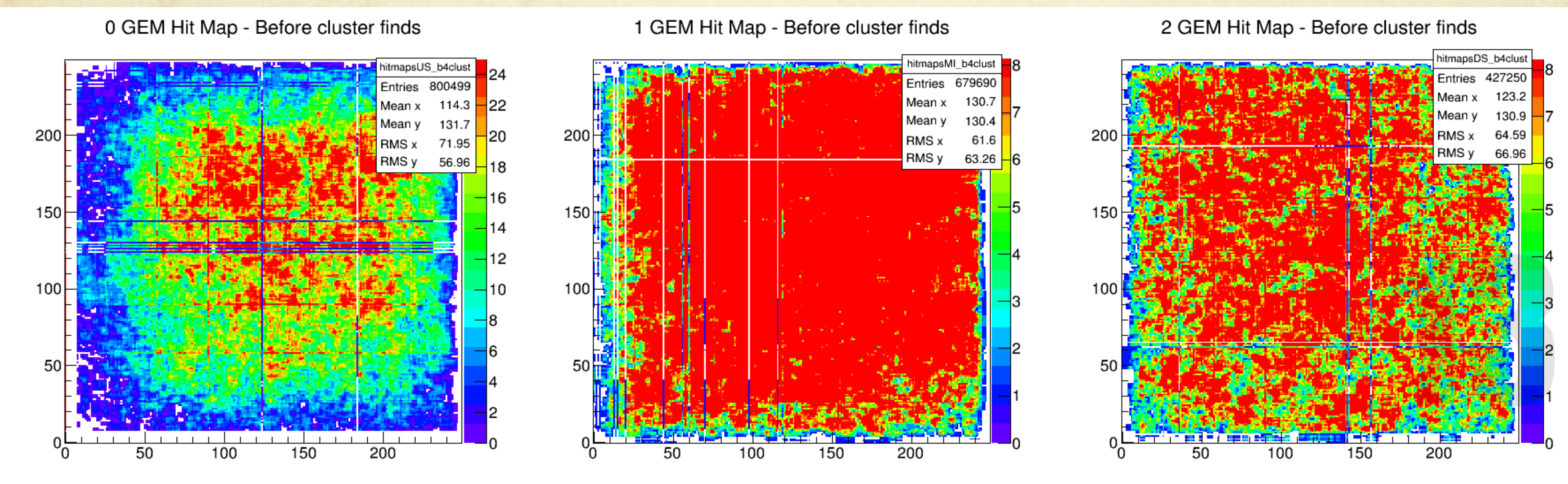
The average ADC histogrammed for all channels (After common mode subtraction).



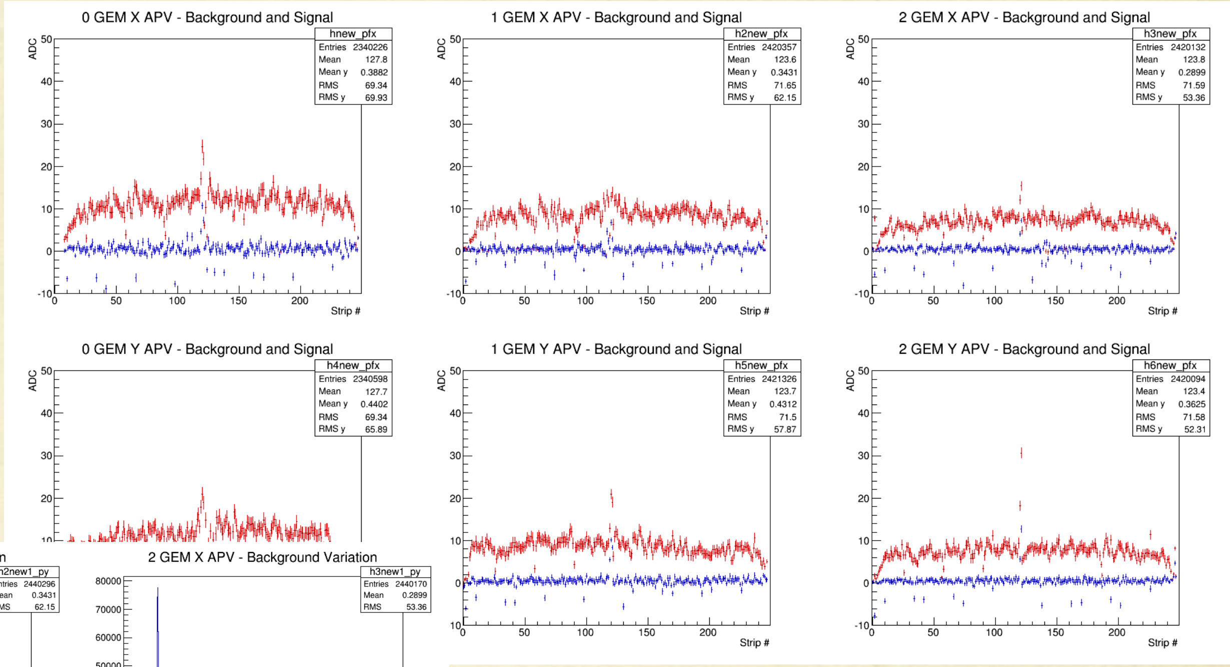
(3) Dead channel masking.

- Observed there are many strips, particularly on 0 GEM, have no hits and seem dead.
- Same time, we can see few strips, always get fired, called “hot channels” and they also considered as dead.
- Cluster position is determined by the mean value of the Gaussian fit on the ADCs.
- The purpose of masking the dead channels is to neglect the dead channels and involve only channels which have ADCs greater than the threshold for the Gaussian fit. This effects mostly if several dead channels are close by (ex: 1 GEM).

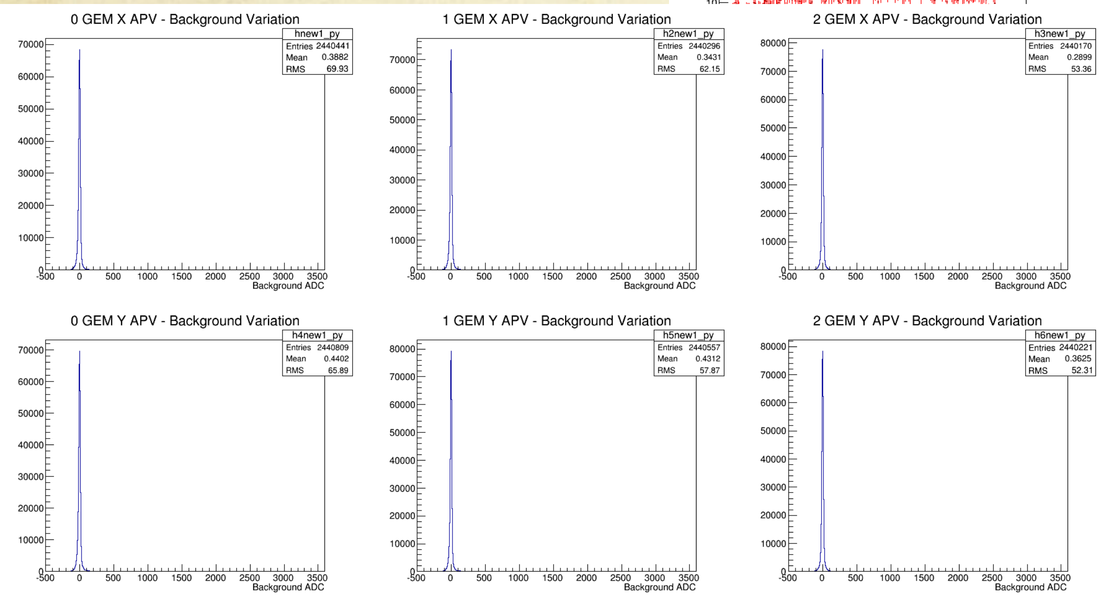
2D Hit distribution on GEMs



The signal (red) and the background (blue) on each strip after using the dead channel masking, common-mode noise and bin-2-bin pedestals subtractions.



The RMS of noise



GEM Efficiency Analysis

- The GEM detector has moved to far back to fully eliminate the 10 x 10 cm^2 GEMs.

- SiPM is a 4 mm thick 12x12 cm^2 scintillator array with two Si PMTs at the top and bottom ends.
- It is attached to the third GEM and the trigger is produced if both Si PMTs get fired.

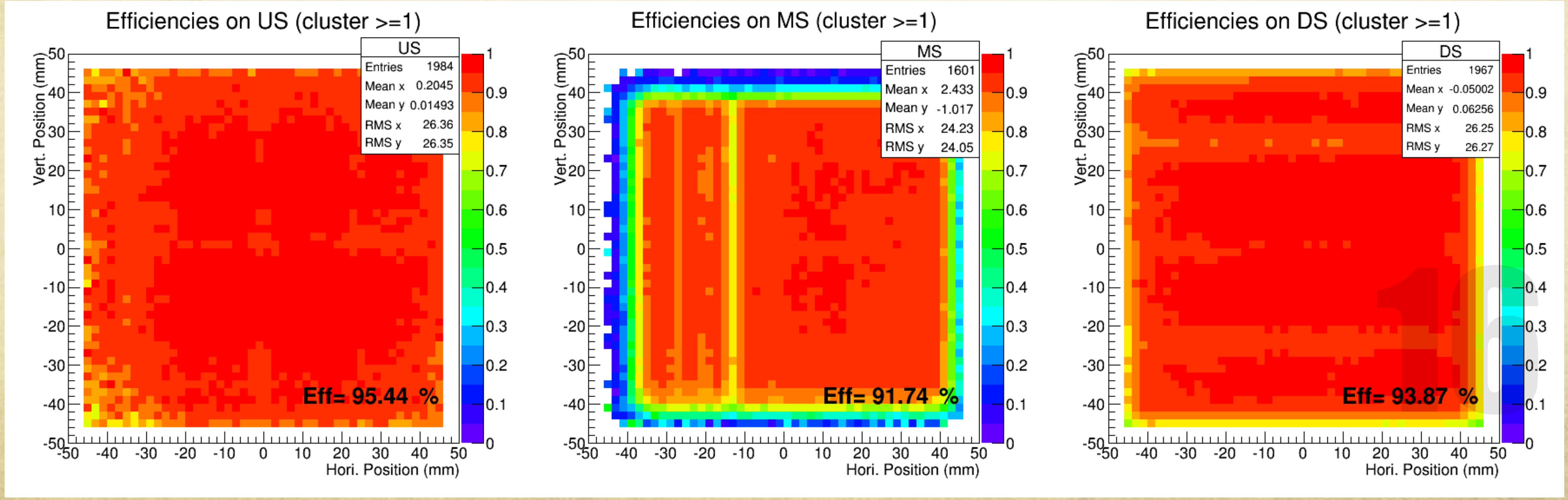
GEM Efficiency Analysis

The maximum charge cluster is selected on the first two GEMs and make the track from that two clusters and project to the third GEM.

$\text{Efficiency}_{(\text{max chg cluster, cuts})}$ =(Projected track positions on the third GEM only if the third GEM has at least one cluster in it's vicinity) / (Projected track positions on the third GEM, No condition on the third GEM)

Vicinity cut = ±1 cm

December, 2014 test run: Run = 2549-2595
p = +160 MeV/c, Trigger= SiPM 1 + 2x2 sc, Trigger rate ~20 kHz, DAQ rate ~1 kHz, 10 x10 collimator.



In progress ......

- Gain matching : Calibrate channel-2-channel gain variations to obtain uniform ADC on each channel.
- Optimize the cluster findings.
- Improve the GEM data read out speed using the new controller, XVR15 and JVME drive.

Conclusion

- GEMs are a very promising technique for the gas amplification and many of their advantages already have been proven in various applications.
- Efficiency expect to be around 98-99 % after improving the cluster findings and the channel-2-channel gain calibrations.

Thank You

Detector Gas

- Avalanche multiplication is possible in any gas or gas mixture.
- however preferred by specific requirements such as a low operating voltage, high stability, and high gain.
- In noble gases, gas multiplication occurs at lower fields than in gases composed of complex molecules, making noble gases the main component of most detector gas fillings.
- The # of e-p pairs increase with the atomic number of the gas atoms, and since xenon and krypton are expensive the natural choice is argon.
- The energy is absorbed by ionizing or excitation. The excited noble gas atoms can only return to their ground state through the emission of photon. These photons can release electrons that cause new avalanches. The same effect can be caused by ionized argon atoms being neutralized on the cathode, radiating the energy balance as a photon.
- Quench gas is needed to absorb these extra photons which make up the smaller part of a detector gas mixture.
- A simple non–flammable quencher gas which shows no aging effects is CO_2
- Limit the oxygen contamination in a detector in order not to lose charge due to attachment.
- Therefore, Ar/CO_2 mixture with 70/30 is normally used.