Update on CMS GEM test beam analysis and simulations

13th RD51 Collaboration Meeting

Friday, 7 February 2014

Sinem Salva Diblen
Ghent University

on behalf of
CMS GEM collaboration

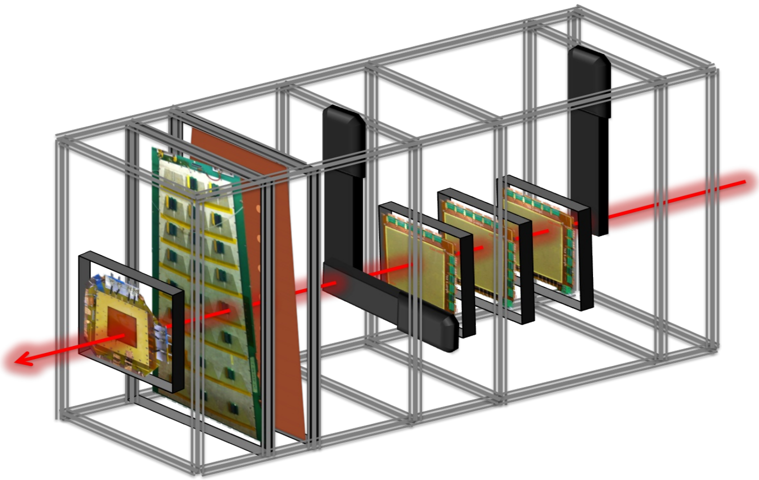
Outline

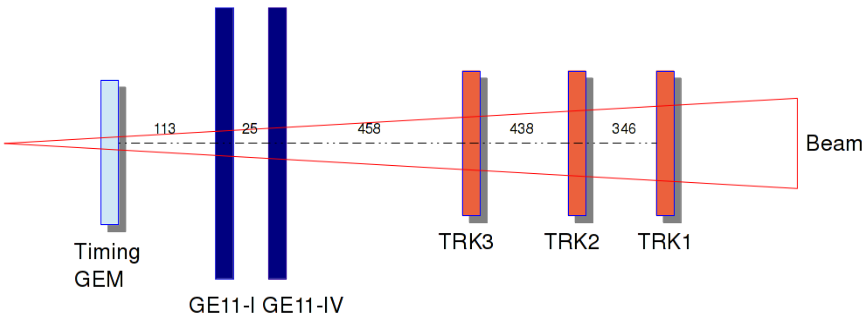
- Test beam setup and analysis of CMS GEMs
  - CERN (November, 2012)
  - FNAL (October, 2013)

- Standalone GEM simulation
  - FastSim for digitization
  - Garfield simulation

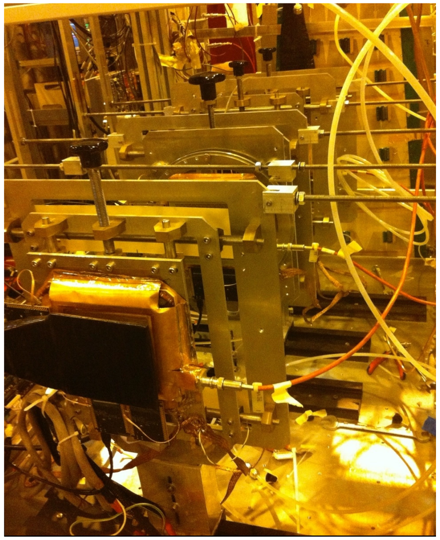
- Conclusion and future plans

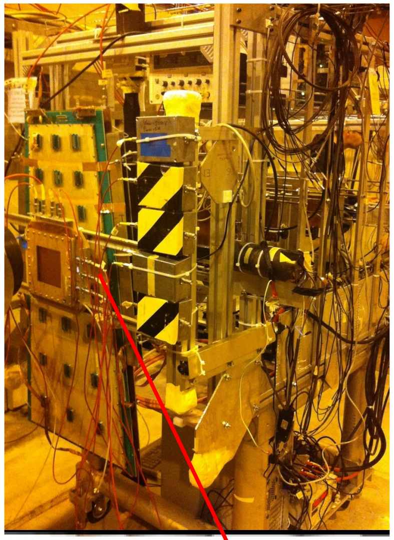
Test Beam Setup at CERN



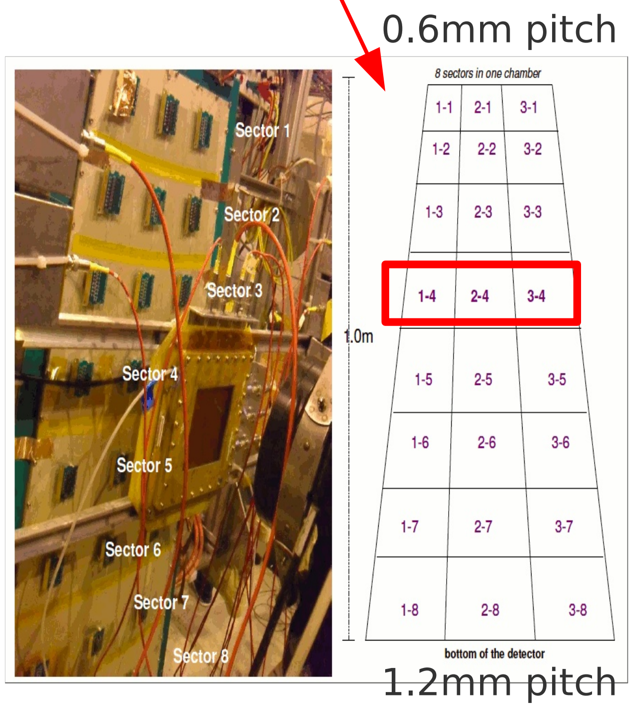


- **3 Trackers (10x10 triple GEMs) with 0.4 mm pitch**
- **1 Timing GEM**
- **GE11-I**
- **GE11-IV**
- **3 Scintillators for Trigger**

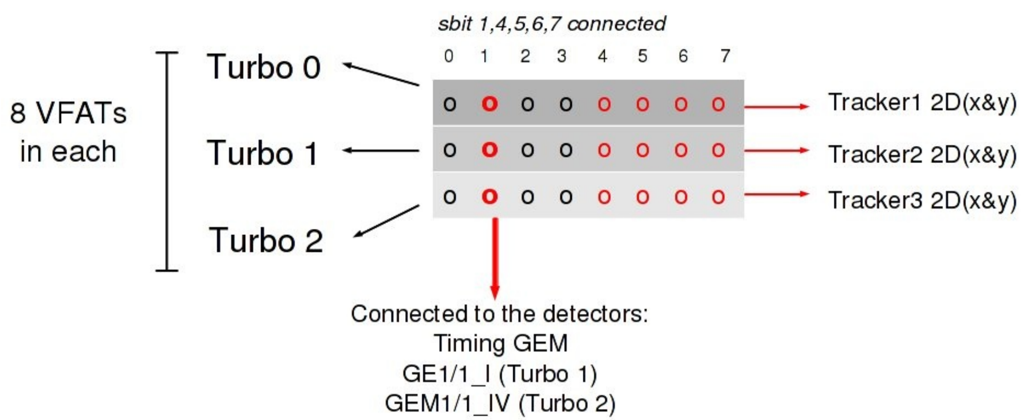




- 2 GE1/1 size (990 x 220 x 445 mm³)
- Gap configuration: 3-1-2-1 mm
- 2 different sectors tested
- Data taken with VFAT and SRS system
- Runs with both pions and muons at 150GeV

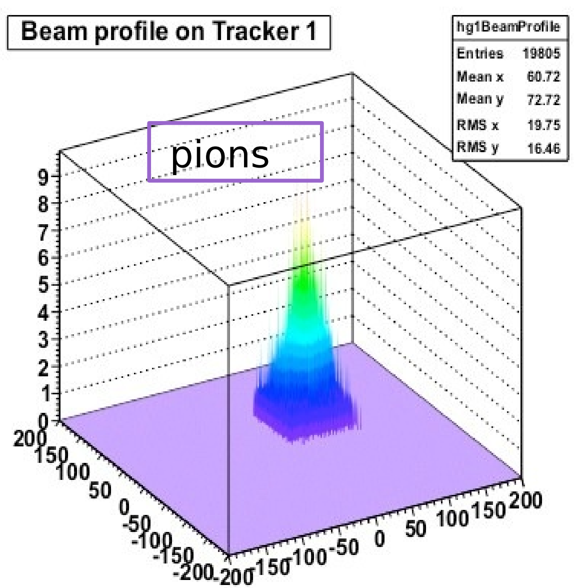


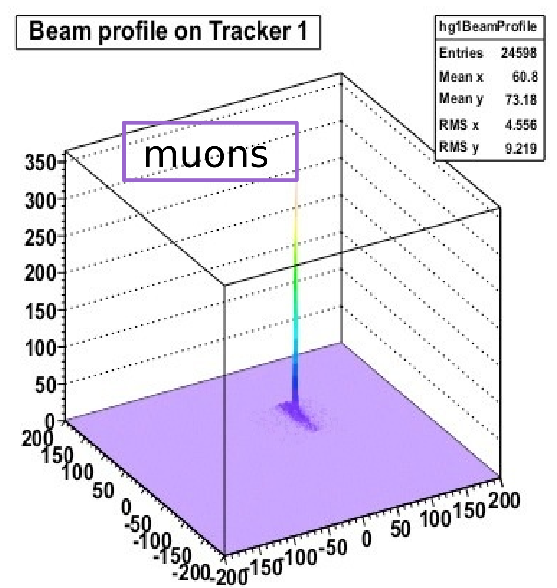
Analysis with VFAT Electronics



- Collected data from the VFAT2 chips with TURBO front-end electronics

Beam Profiles



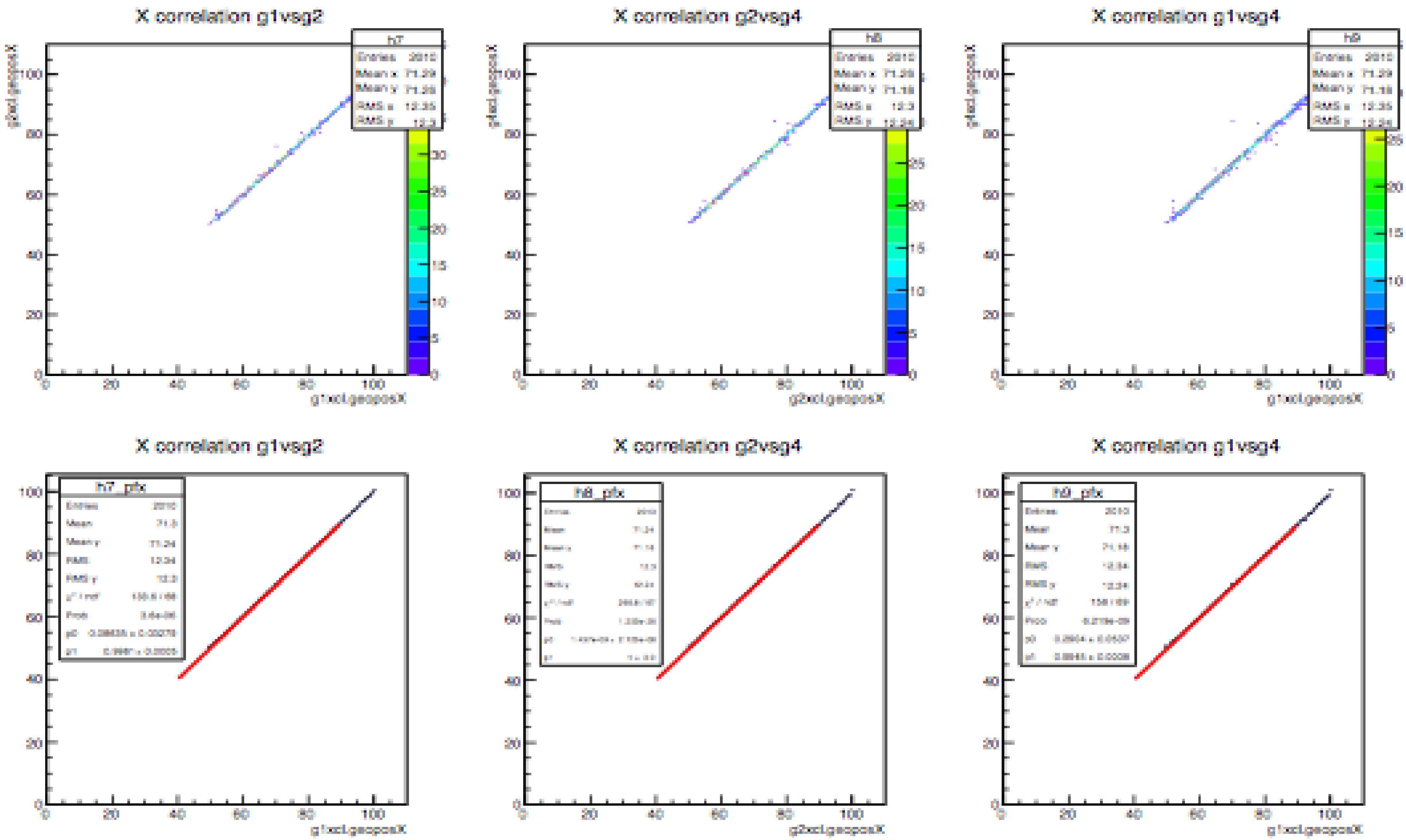


- Voltage varied from 3850 to 4250
- Gas: $Ar/CO_2/CF_4$ (45/15/40)

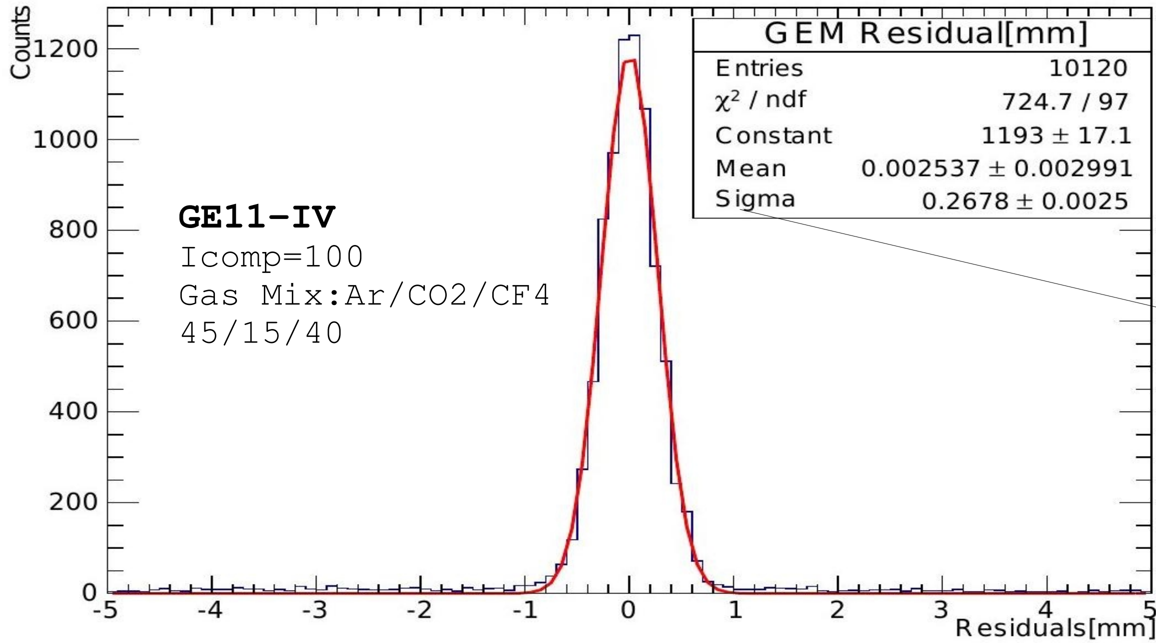
Analysis results

- Spatial resolution
- Cluster size
- Cluster size distribution
- Efficiency

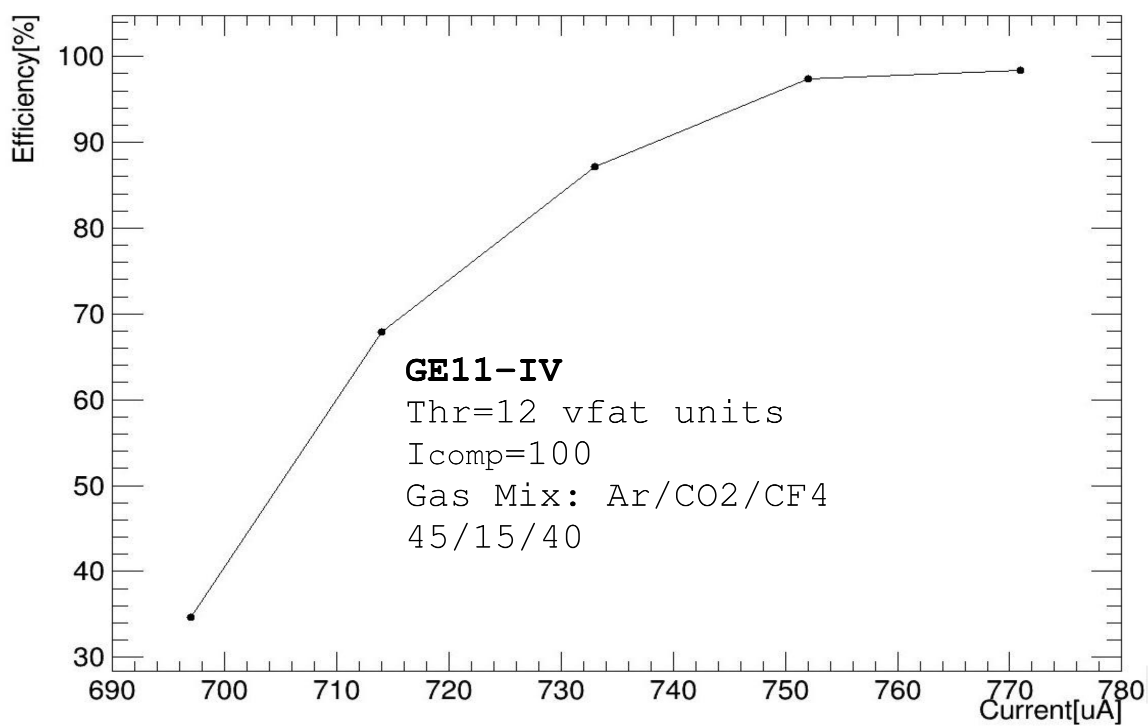
Correlation Plots



Residuals and efficiency

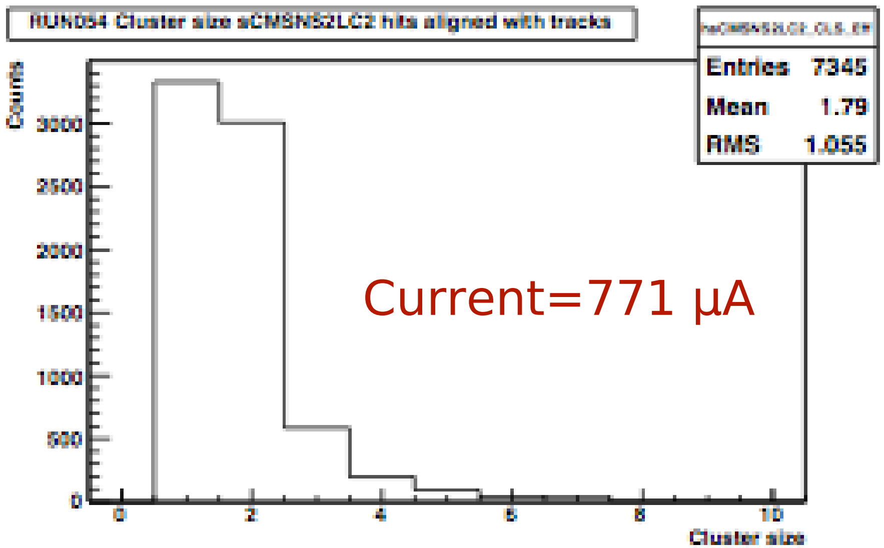


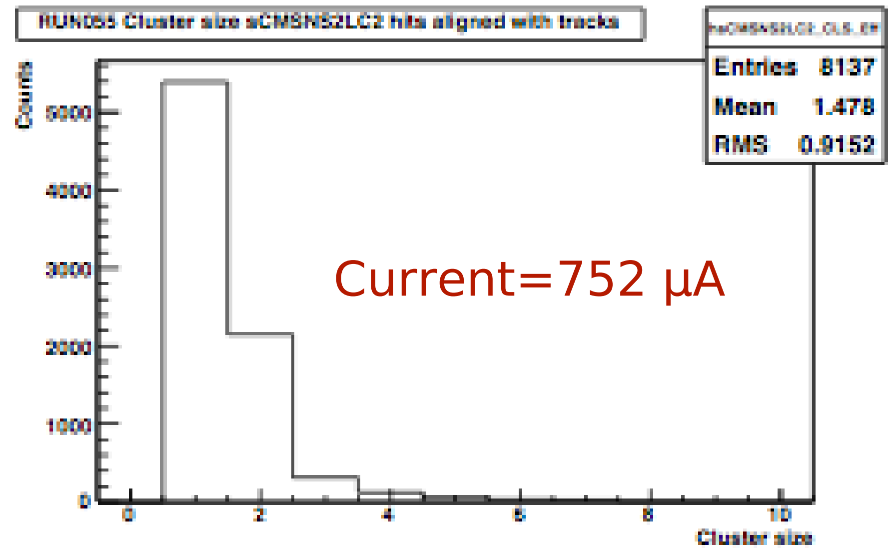
σ=267 μm
~ (pitch/√12)

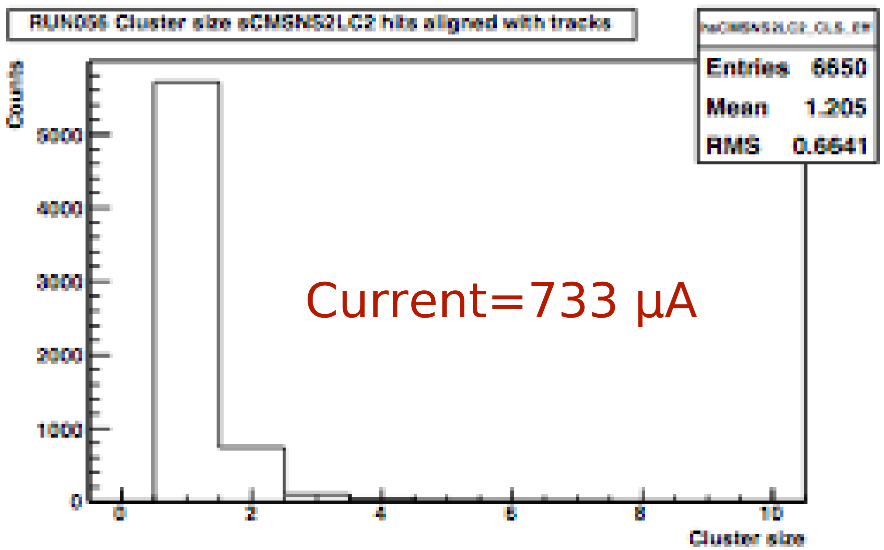


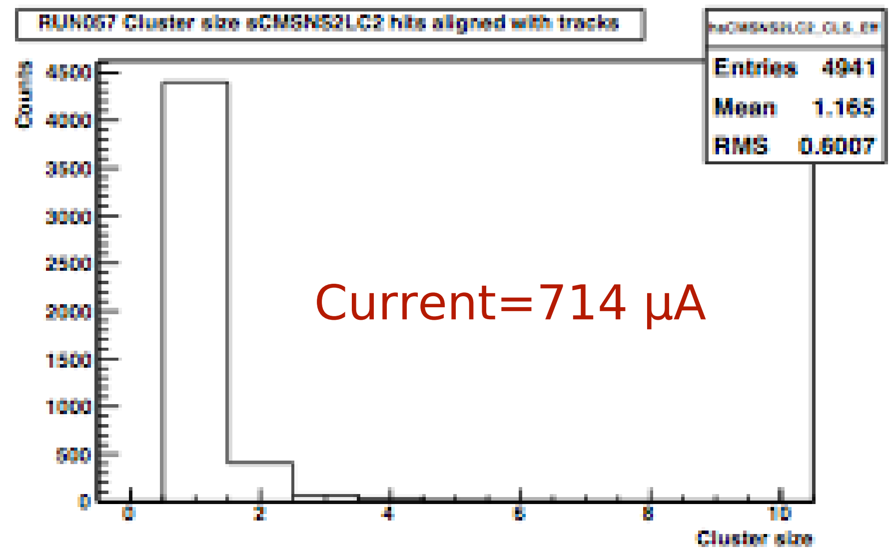
HV from 3850
to 4250

Cluster size distribution

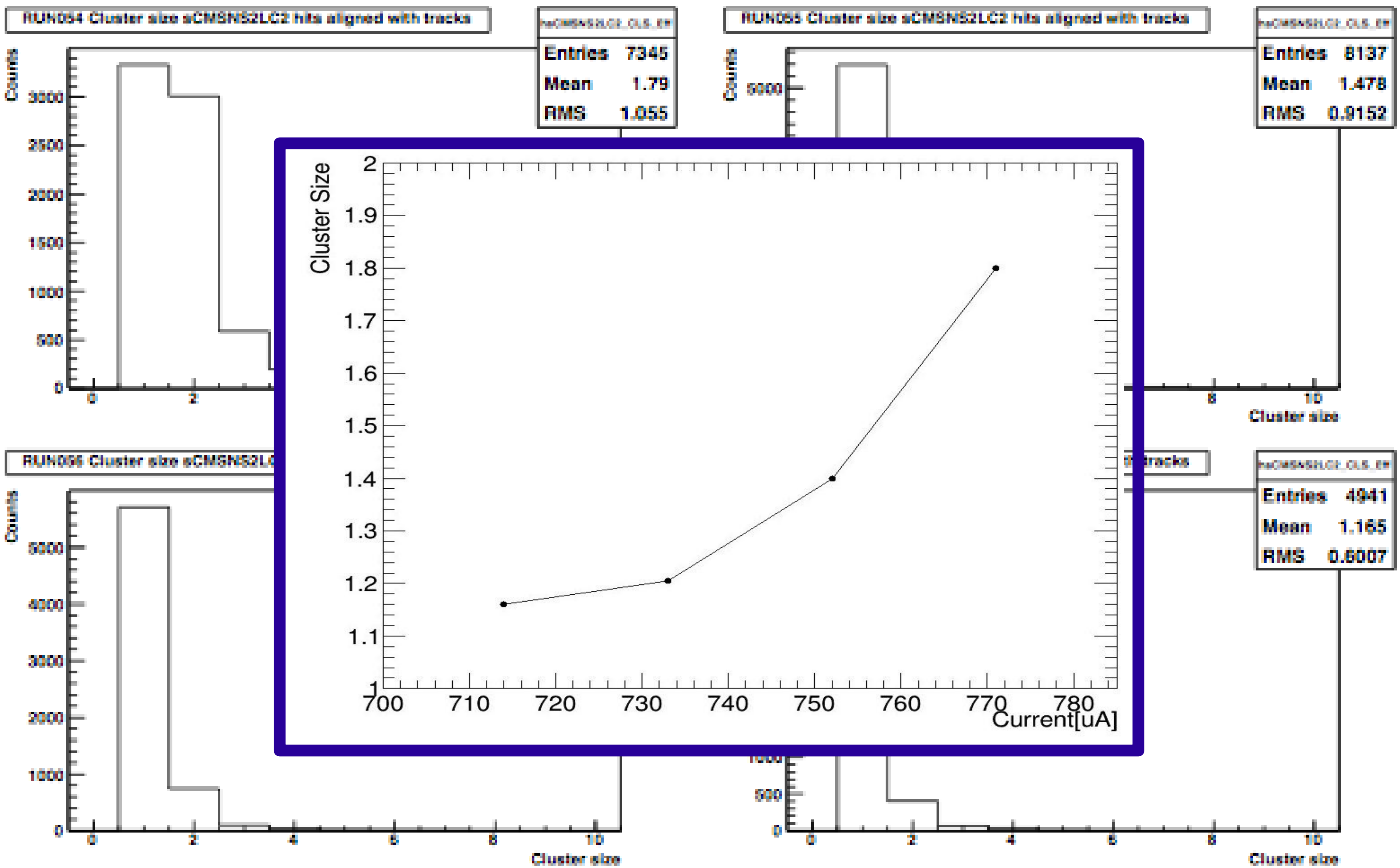








Cluster size distribution



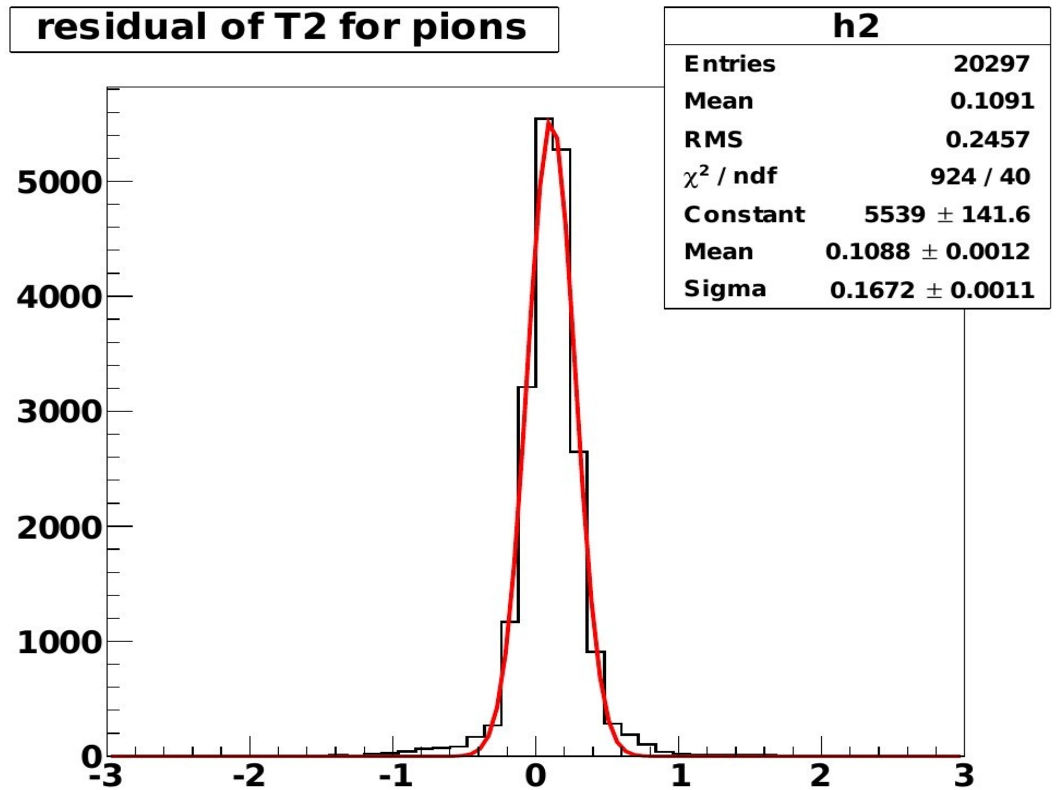
Track reconstruction and residual of tracker 2

Reconstruction of the track by using the hit positions in trackers 1 and 4

$$X = \alpha Z + \beta$$
$$slope = \alpha = \frac{X_1 - X_4}{Z_1 - Z_4}$$
$$intercept = \beta = X - \alpha Z$$

Residual of tracker 2 represents the difference between the coordinates of the points extrapolated from trackers 1 and 4 and the one measured in tracker 2:

$$R(T_2) = X_{2m} - X_{2p} = X_{2m} - \frac{X_1 - X_4}{Z_1 - Z_4} Z_2 - X_1 + \frac{X_1 - X_4}{Z_1 - Z_4} Z_1$$



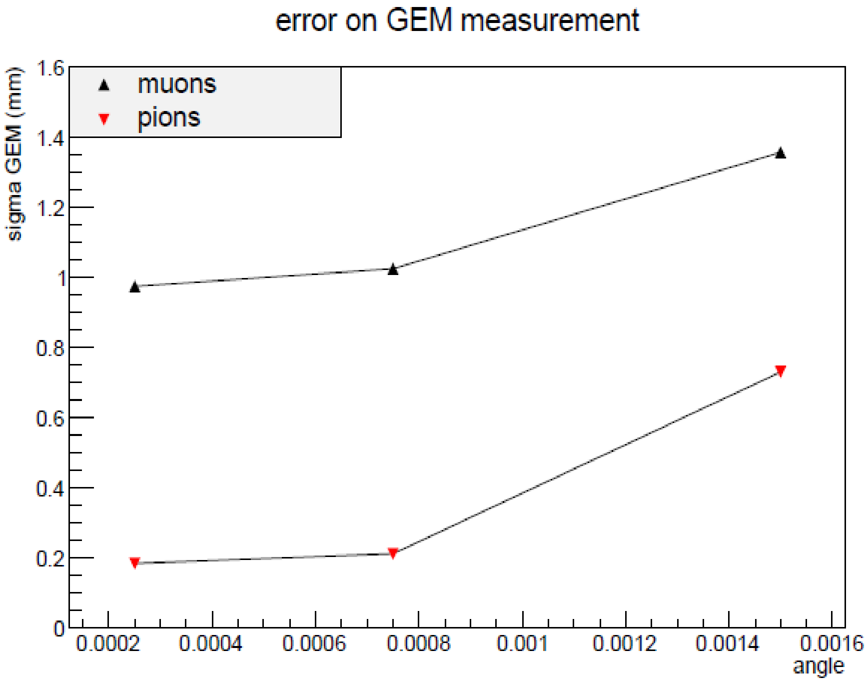
$$\sigma = \frac{\sigma_R}{\sqrt{1.507}}$$

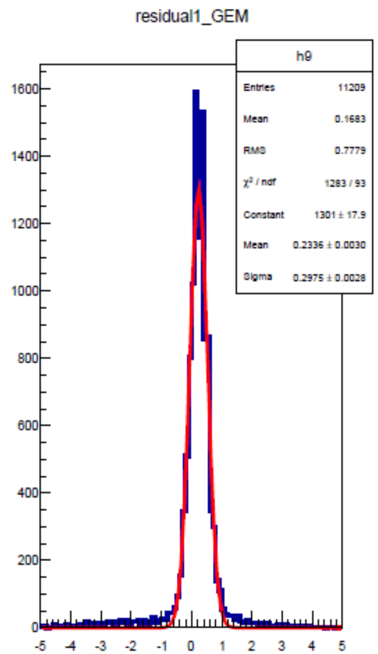
$$\sigma_{theoretical} = \frac{pitch\ size}{\sqrt{12}} = \frac{0.4mm}{\sqrt{12}}$$

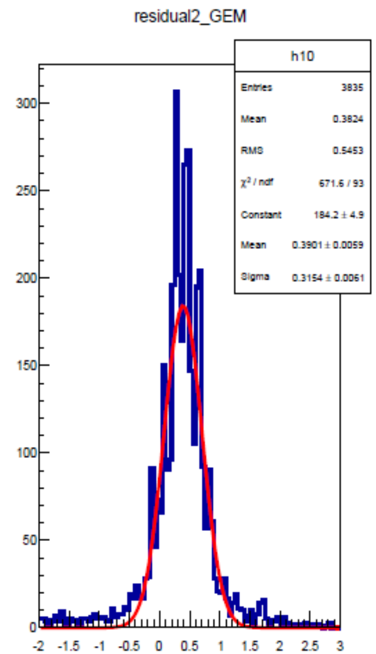
For pions: $\sigma_R = 0.1672mm$ which gives $\sigma = 0.136mm$

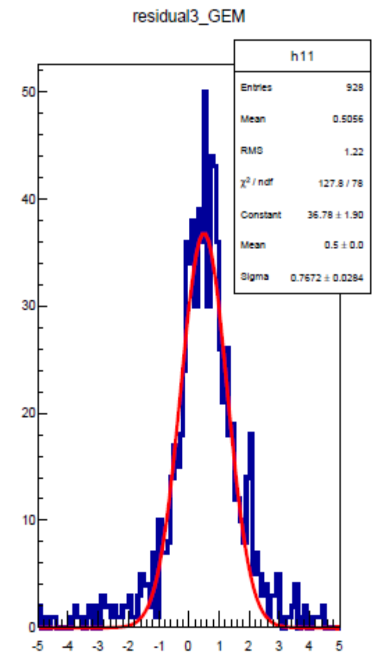
M. Abi Akl
Texas A & M University

Spatial resolution of the GEM as a function of angle for pions and muons





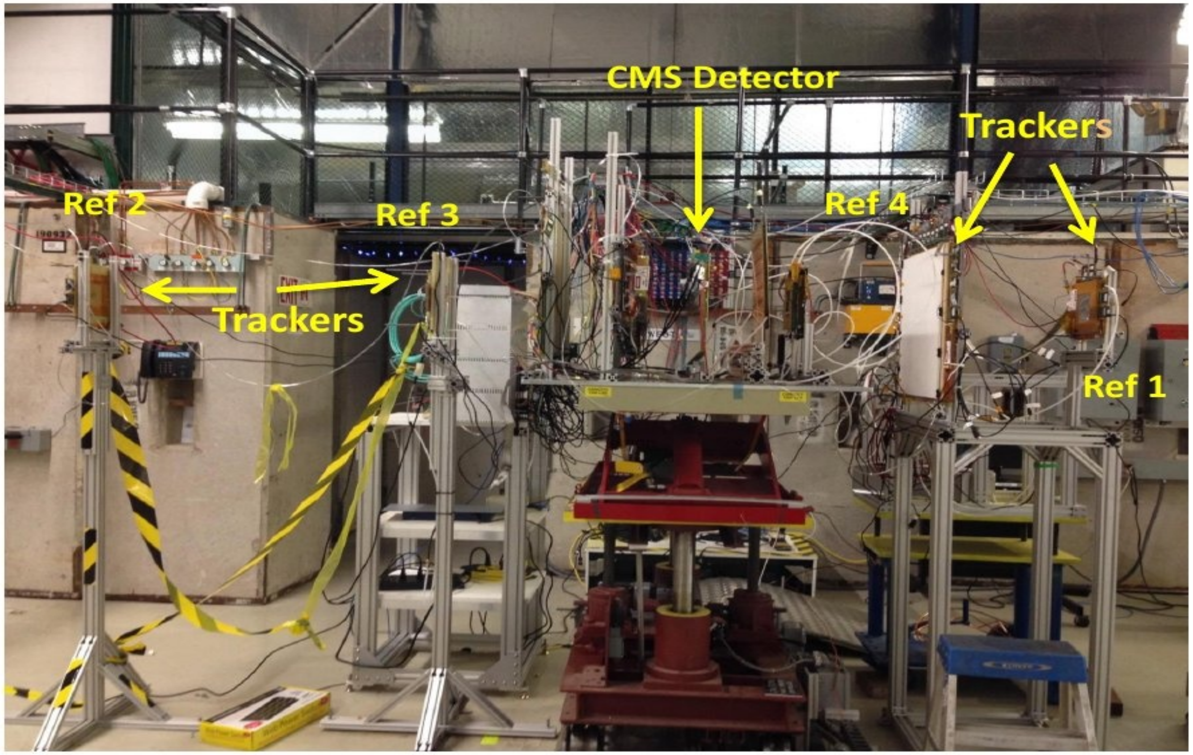


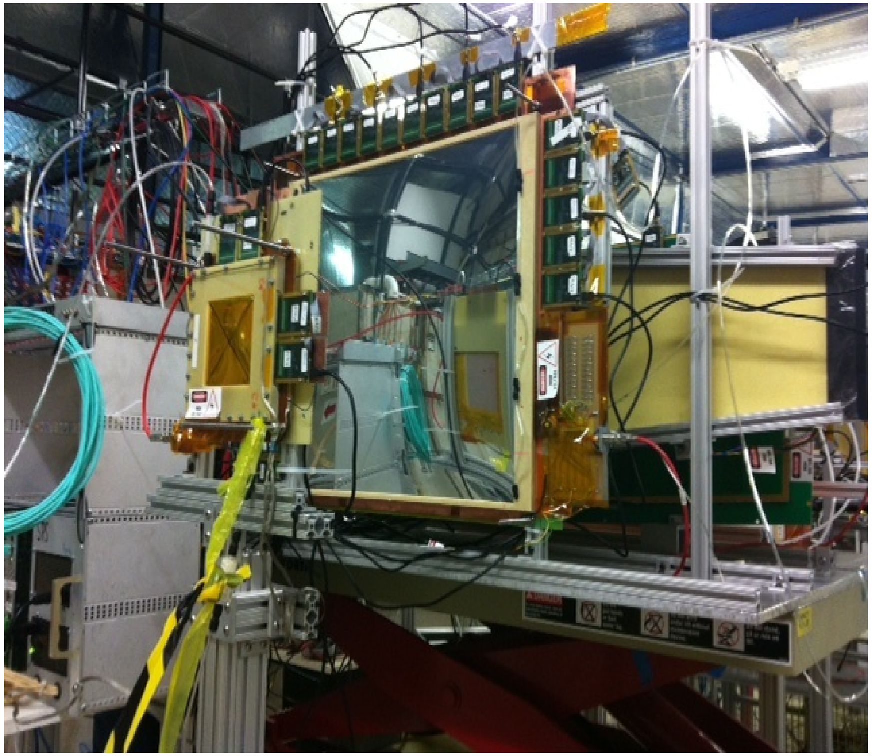


The spatial resolution of GEM for muons is higher than that for pions. In an attempt to explain this difference, it's checked if the Multiple Scattering could be a reason for bad resolution for muons ► MCS could not explain this difference.

The problem could be the data or taking measurements with the muon beam, it's being investigated.

Test Beam Setup at FNAL

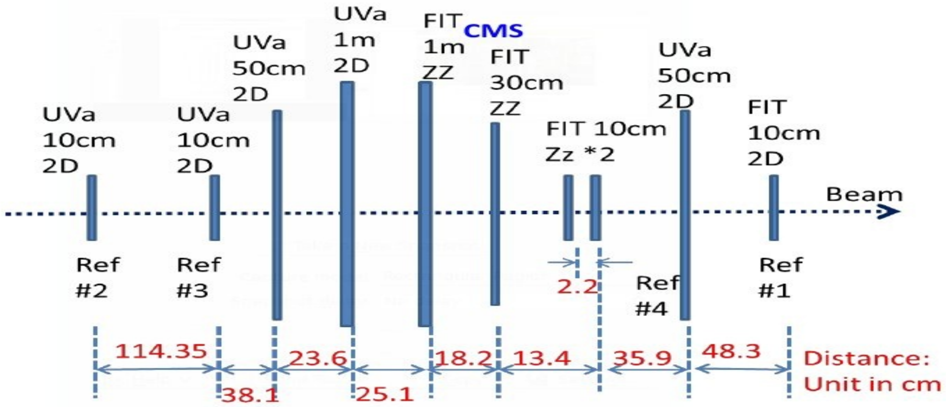




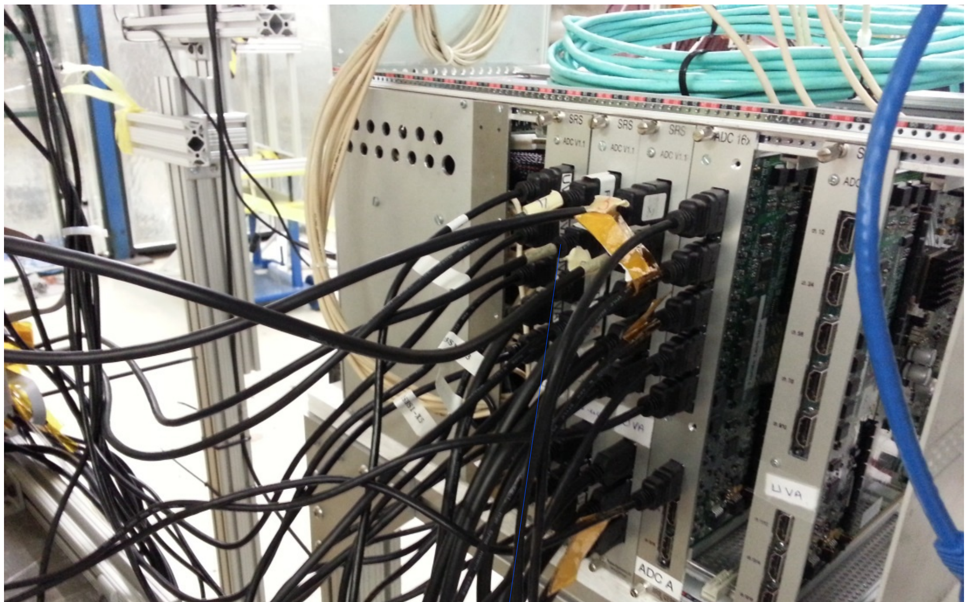
- 10 Triple GEM detectors → 4 fixed tracking detectors and 6 test detectors on the movable table (all detectors aligned with laser)

- Gas: Ar/CO2 (70/30) and 2 trackers with Ar/CO2 (80/20)

Detector configuration

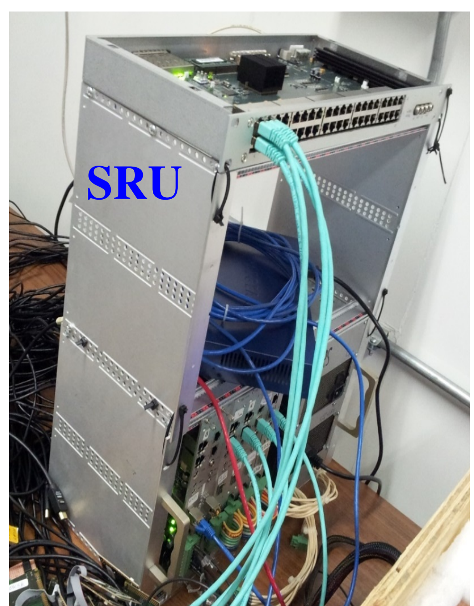


SRS Electronics at FNAL



ADCs

FECs

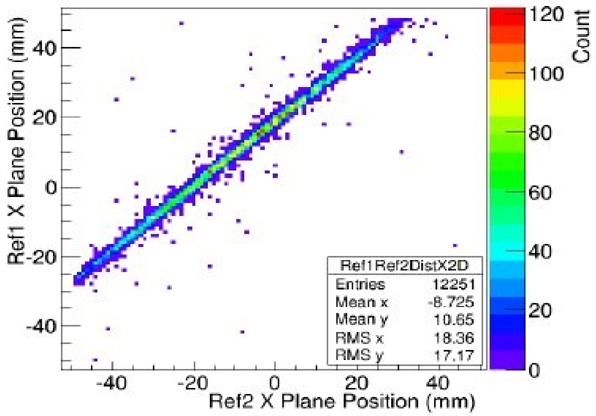


- APV25 Hybrids for the GEMs
- SRS readout with DATE
- APVs with SRS, SRU, FEC and ADC

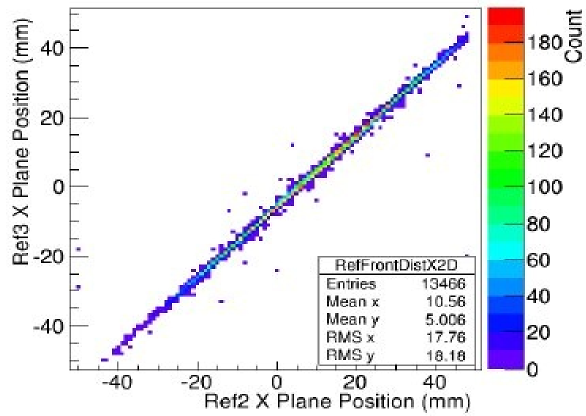
K. Gnanvo
(FloridaTech Team)

Correlation Plots for Reference Detectors

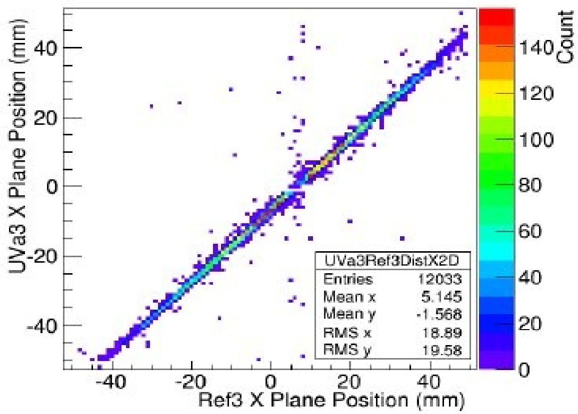
Ref1 vs. Ref2 X plane



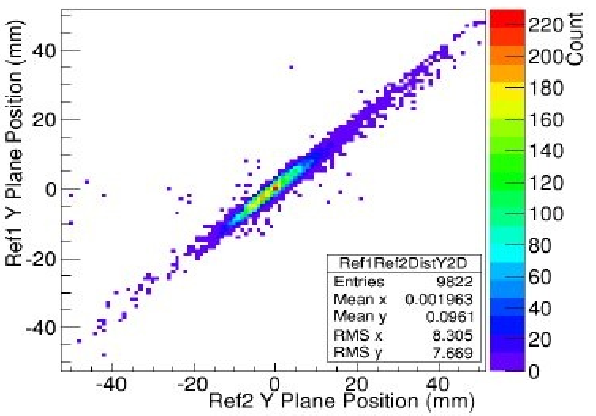
Ref3 vs. Ref2 X plane



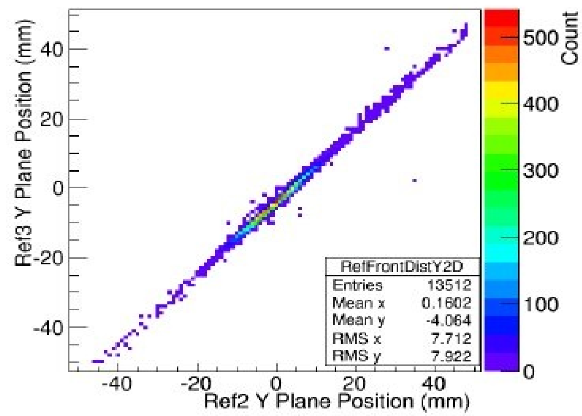
Ref4 vs. Ref3 X plane



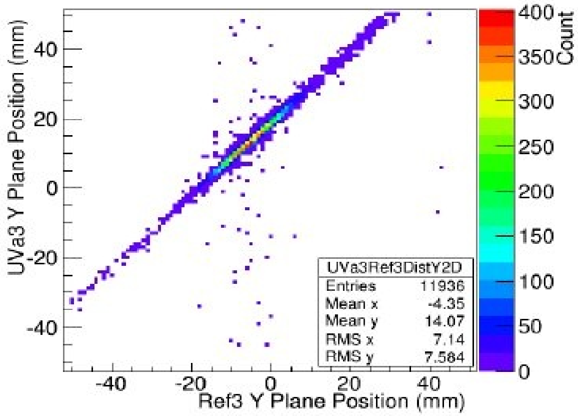
Ref1 vs. Ref2 Y plane



Ref3 vs. Ref2 Y plane



Ref4 vs. Ref3 Y plane

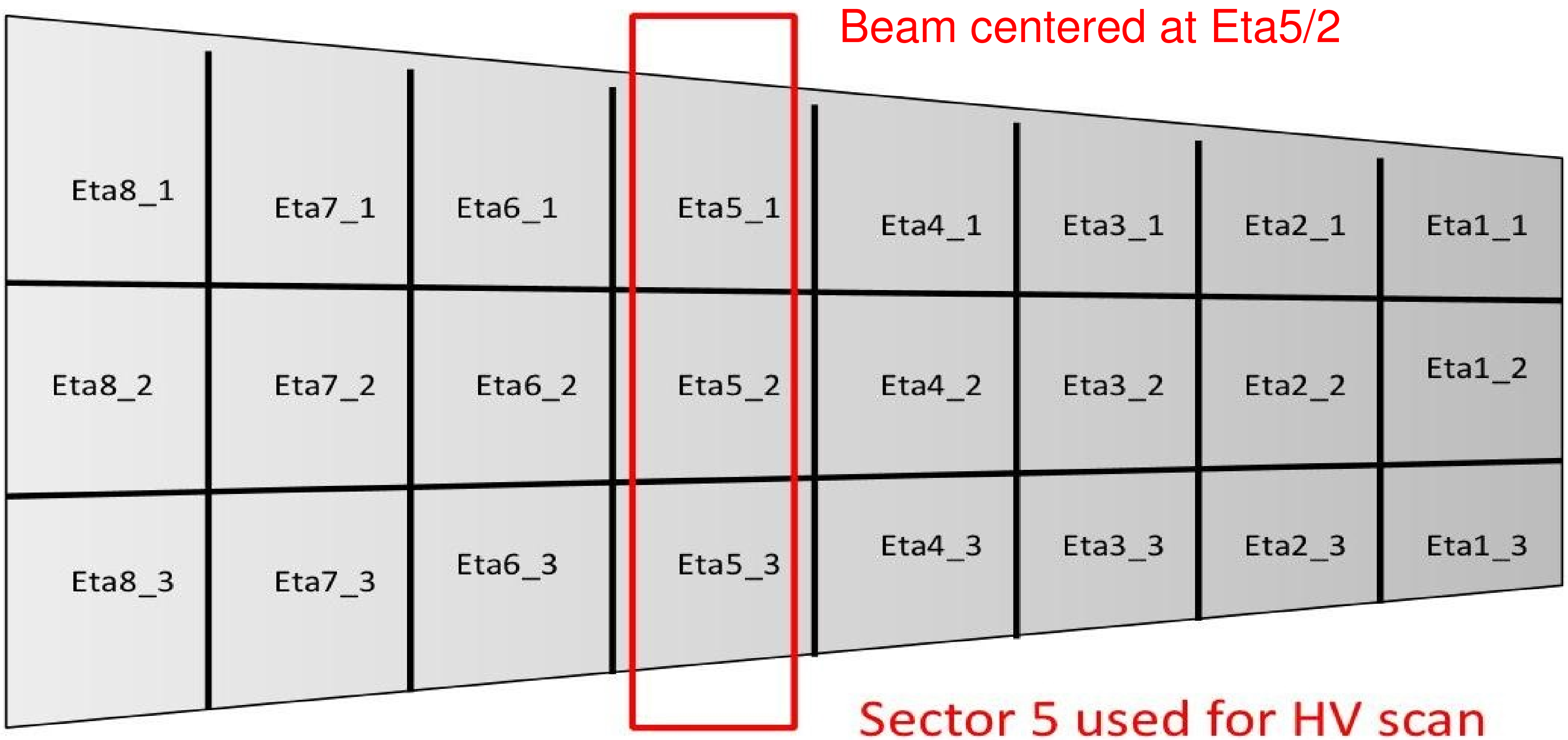


- Correlation plots are not aligned, so not centered at zero

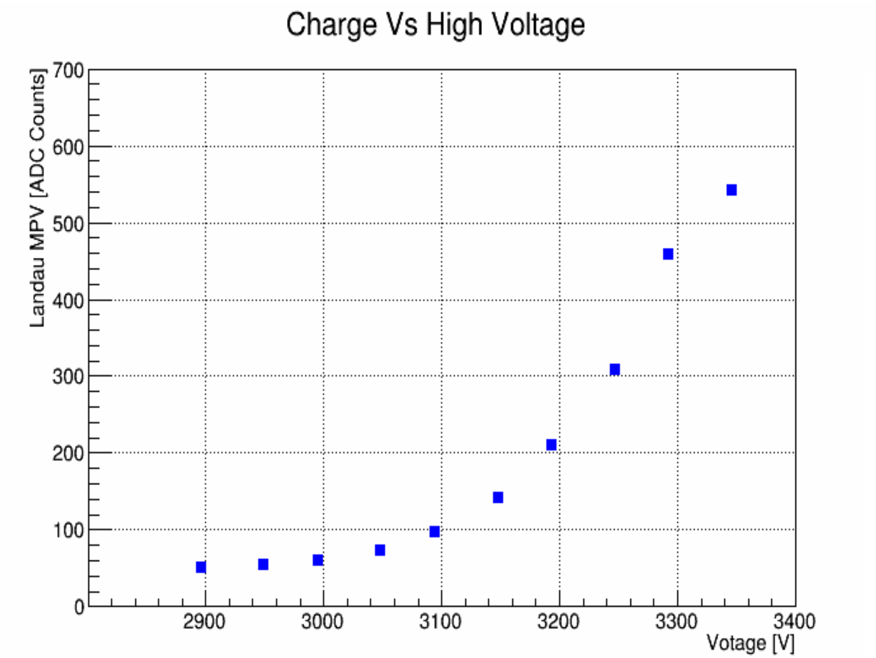
High Voltage Scan Results

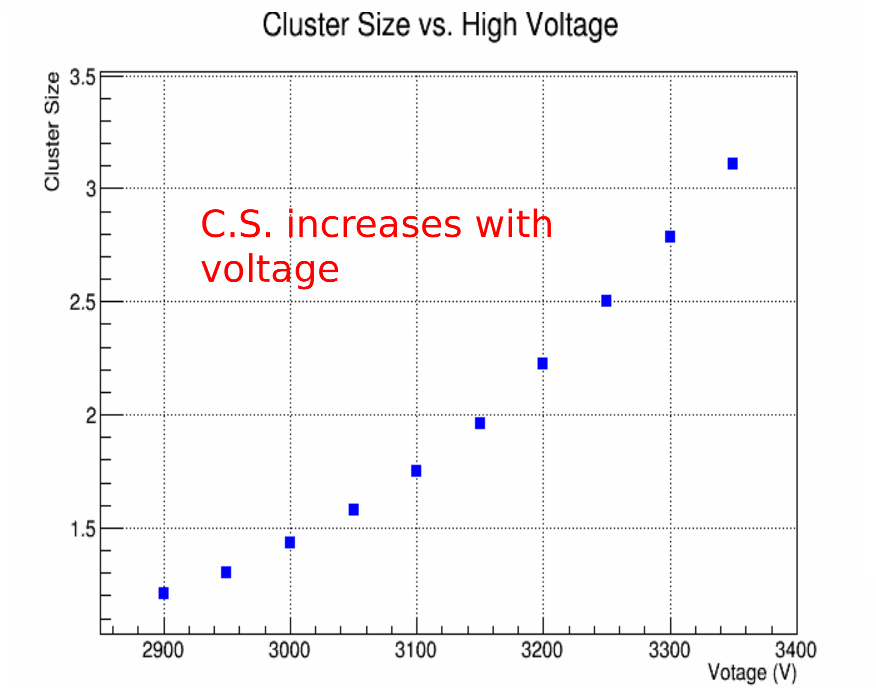
- Voltage varied from 2900V to 3350V
- Beam Energy : 32GeV
- Beam focus on sector 5, inclination 0 deg
- 15K events taken at each voltage value
- Gas mixture: Ar/CO_2 70:30

M. Hohlmann
V. Bhopatkar
A. Zhang
(FloridaTech Team)

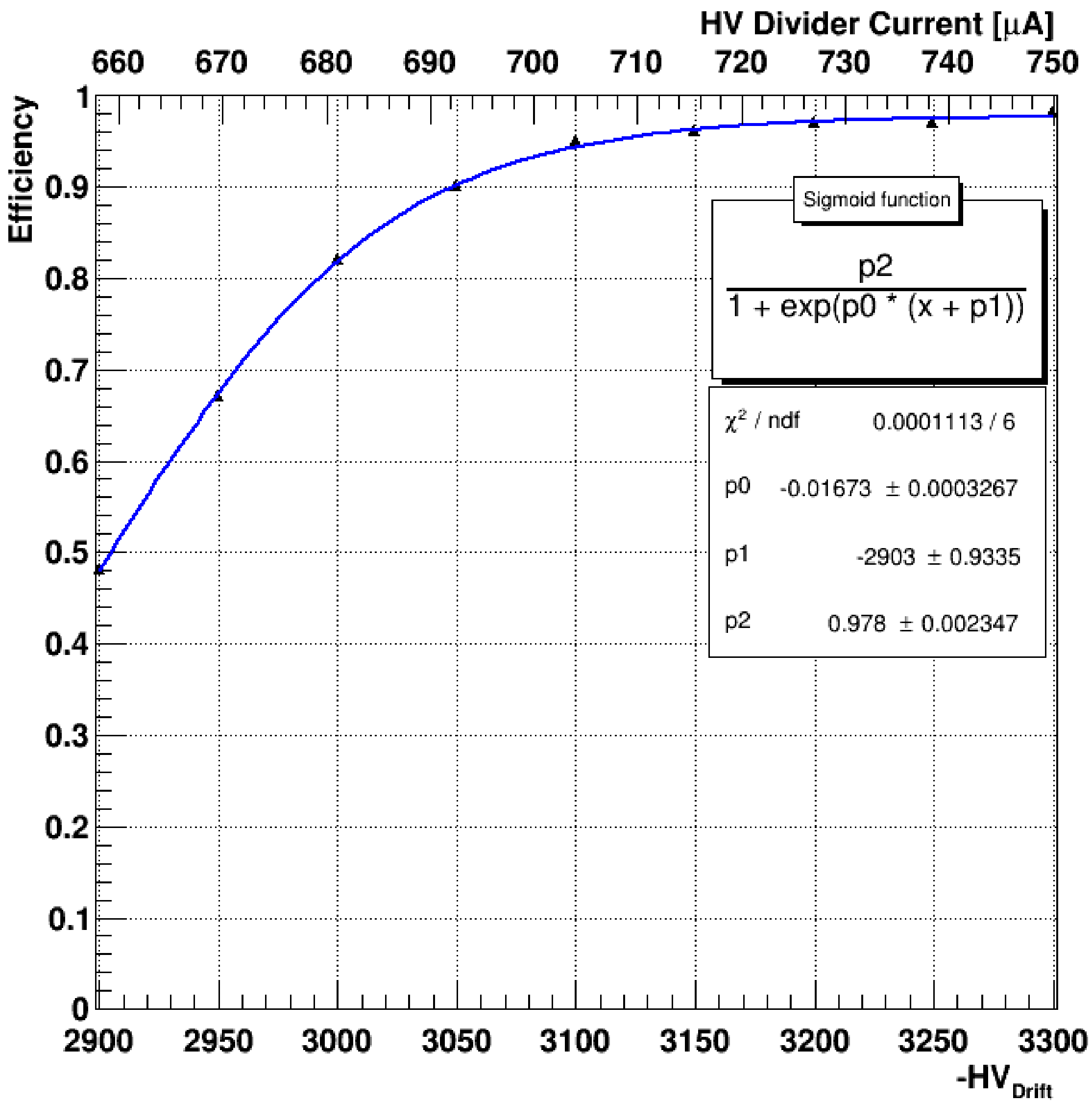


High Voltage Scan



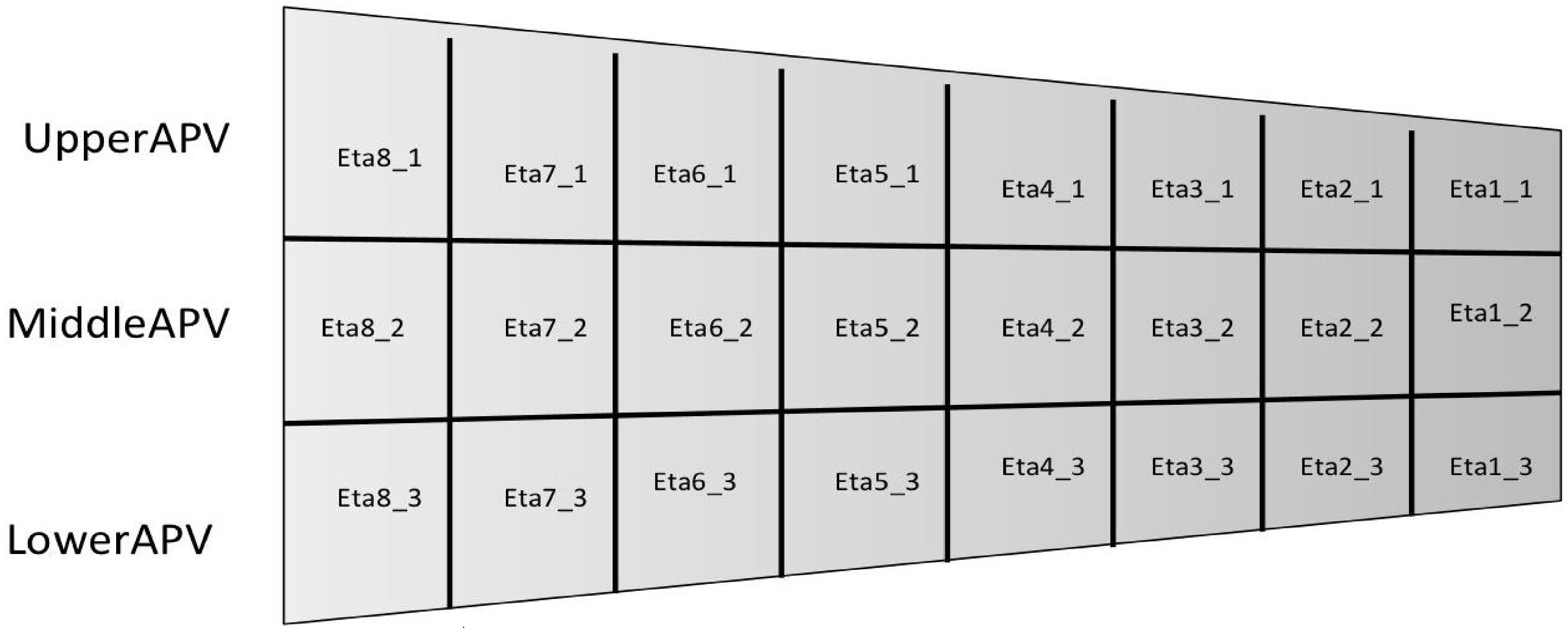


Efficiency curve



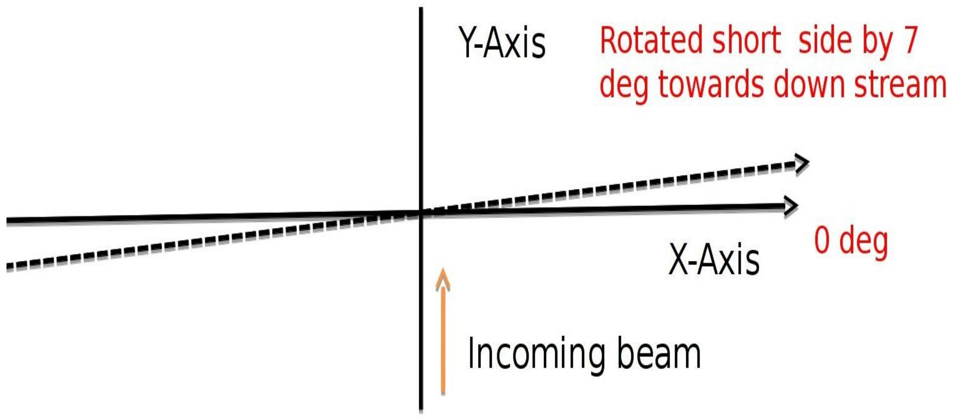
Error is less than 1 %
Error bars are smaller than marker size

Schematic diagram of detector for position scanning



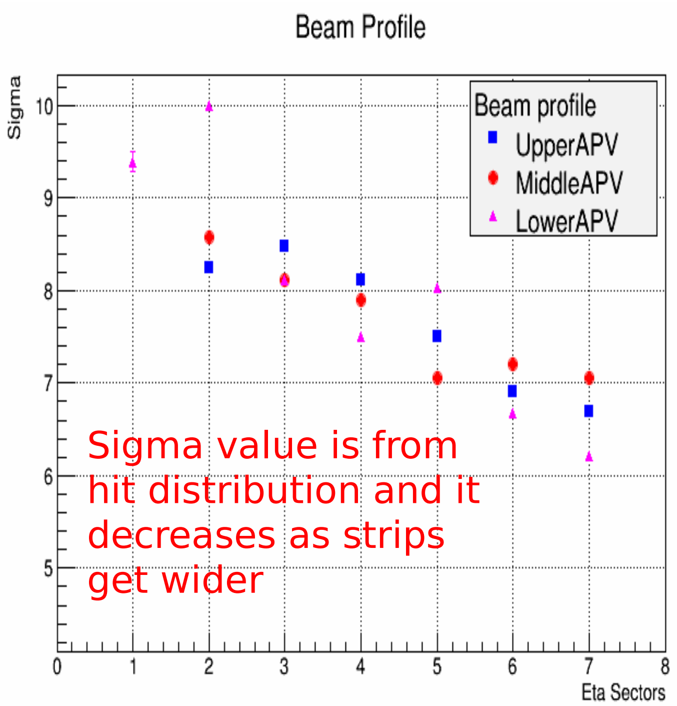
<u>Data taking conditions:</u>

- Collected data with respect to 3 APV positions: Upper, Middle and Lower
- Beam Energy : 32GeV
- Voltage = 3300V
- Inclination: 0 deg for Upper and Lower positions
  7 deg for Middle position
- 15K events taken at each sector
- Gas mixture: Ar/CO2 (70/30)

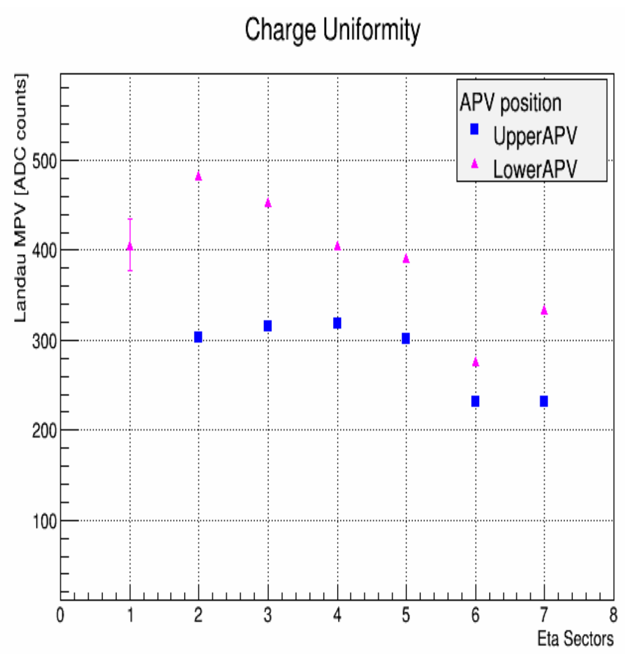


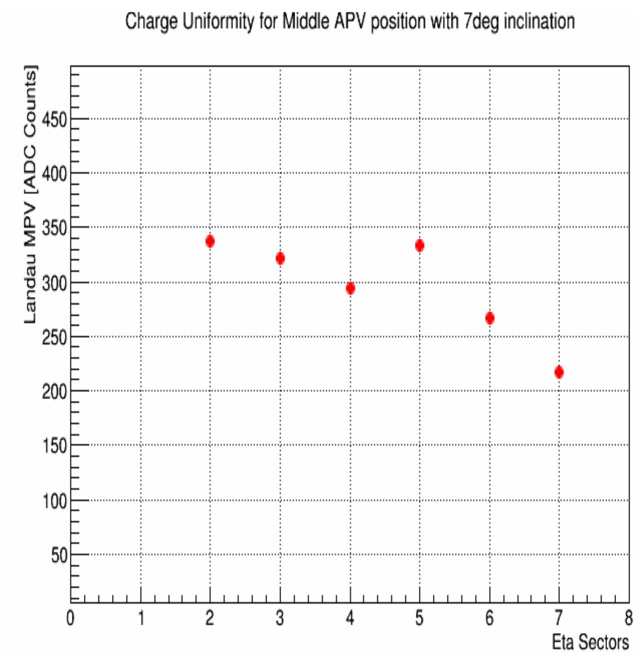
UNIVERSITEIT GENT

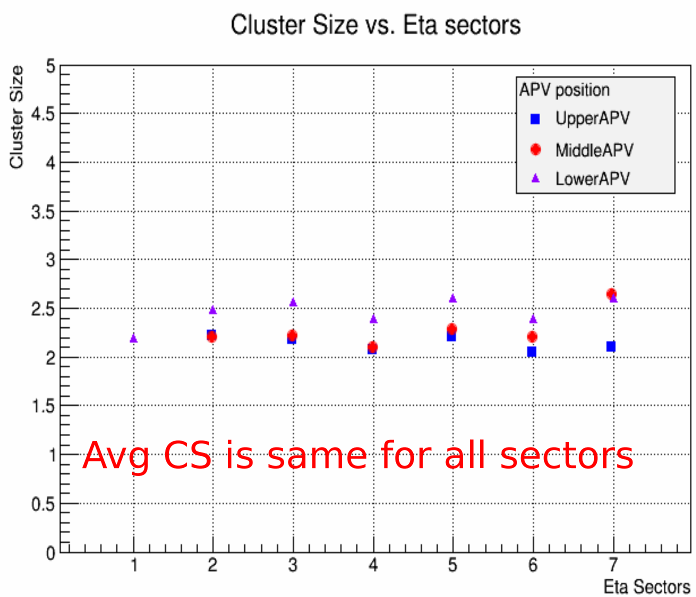
Position Scan Results



Sigma value is from hit distribution and it decreases as strips get wider

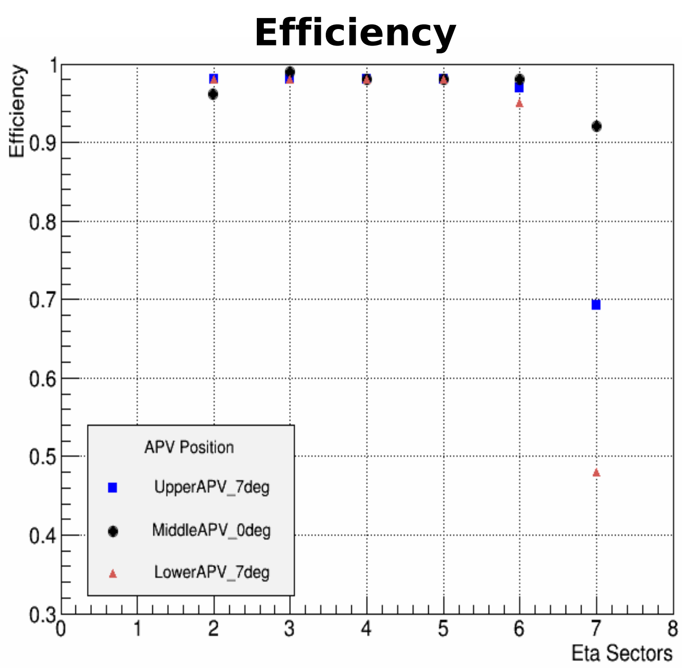






Avg CS is same for all sectors

Error is less than 1 %
Error bars are smaller than marker size

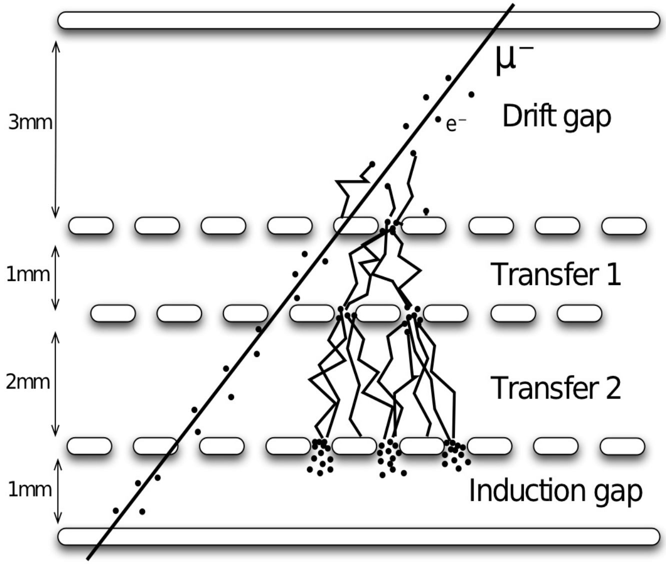


M. Hohlmann
V. Bhopatkar
A. Zhang
(FloridaTech Team)

Clusterizer results from FastSim

FastSim :

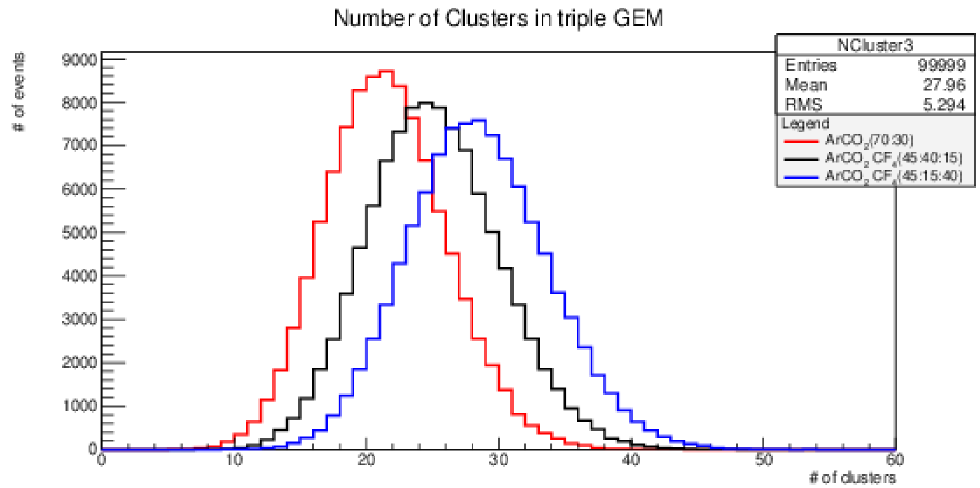
- Creation of a muon track (ionisation, cluster size distribution)
- Diffusion (longit. and transv. for different fields in the different gaps)
- Gain for the GEM foil (and fluctuation with an exponential)
- Transparency
- Induction of the signal on several strips
- Convolution with the VFAT3 transfer function
- Electronics threshold
- Computation of the cluster size, spatial resolution and efficiency(function of current)

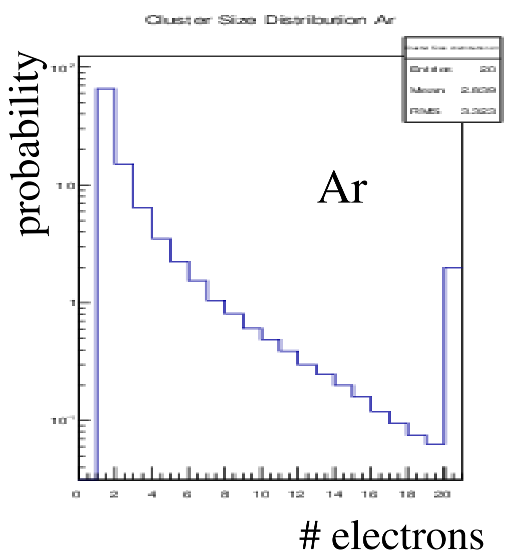


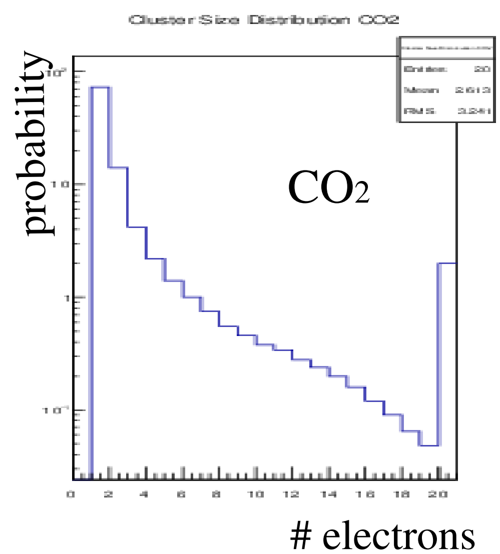
T. Maerschalk
Universite Libre de Bruxelles

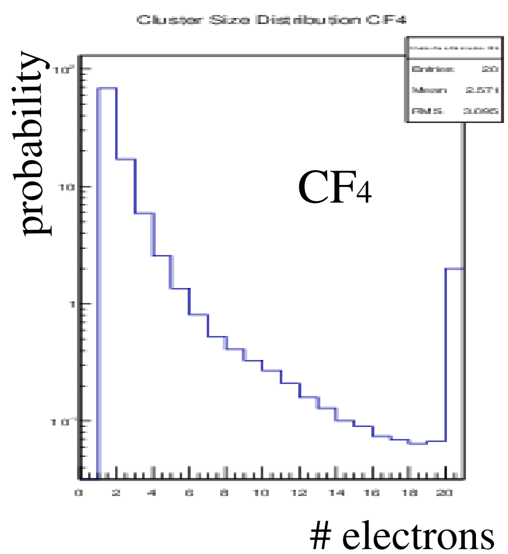
Muon Track

- We take a random number of clusters
- For each cluster we take a random number on a uniform distribution between 0 and 7 mm (gives the position of the cluster)
- Then we take a random number in the ionization cluster size distribution (probability to have n electrons in one cluster)

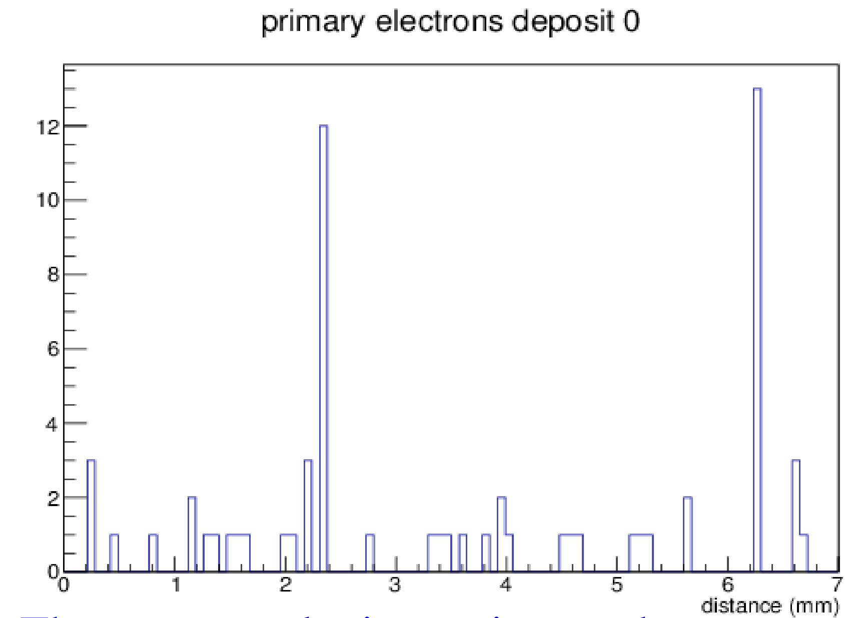






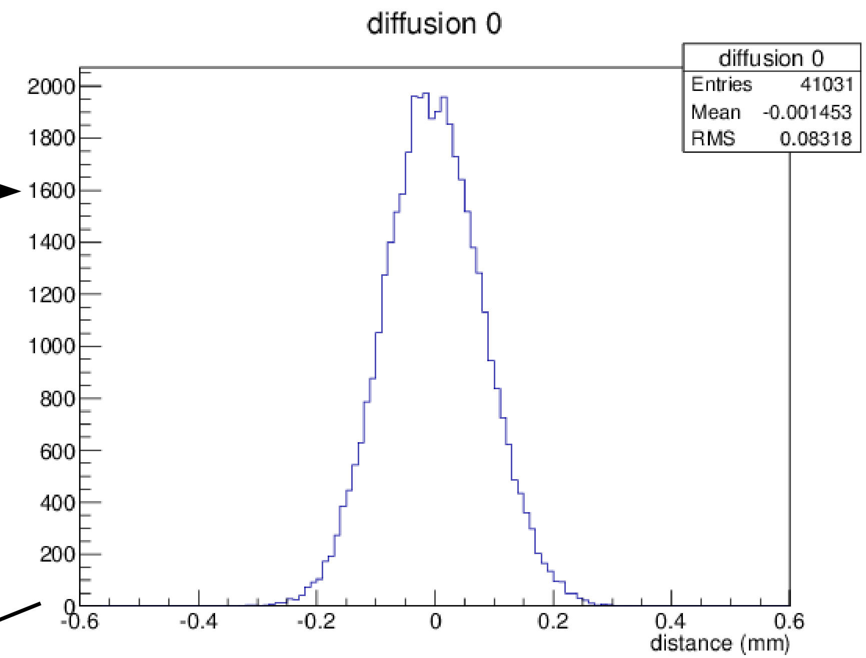


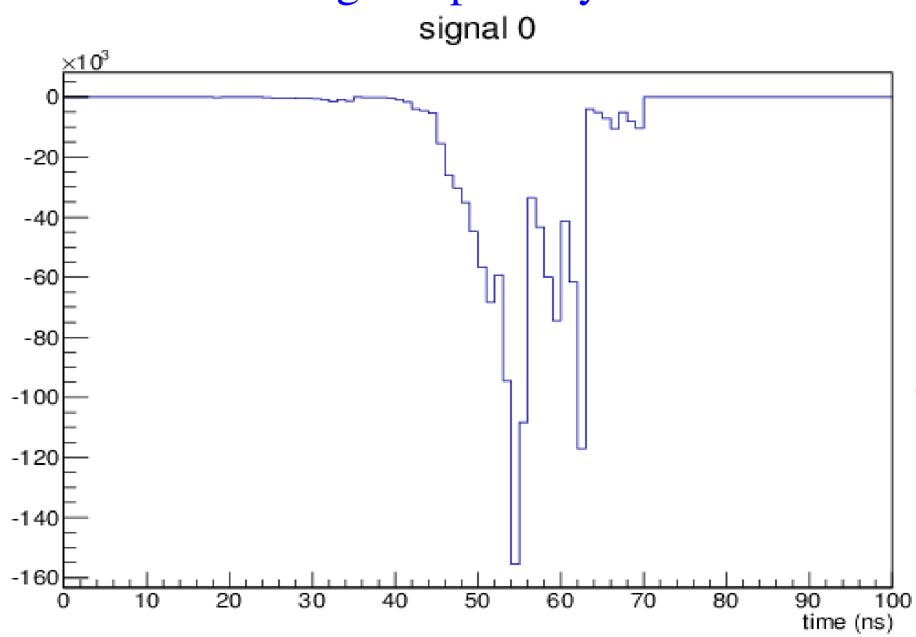
Signals from the FastSim



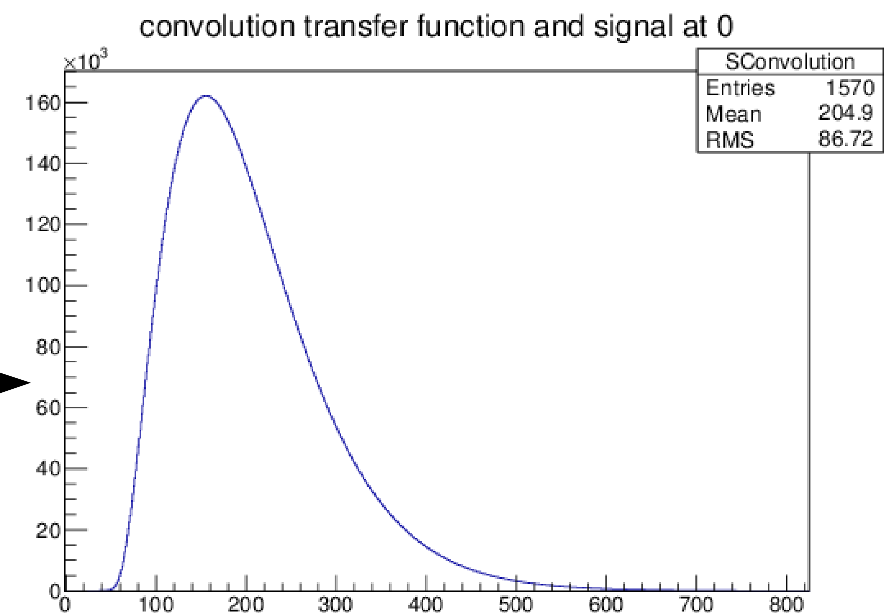
The muon track gives primary electrons

These electrons diffuse





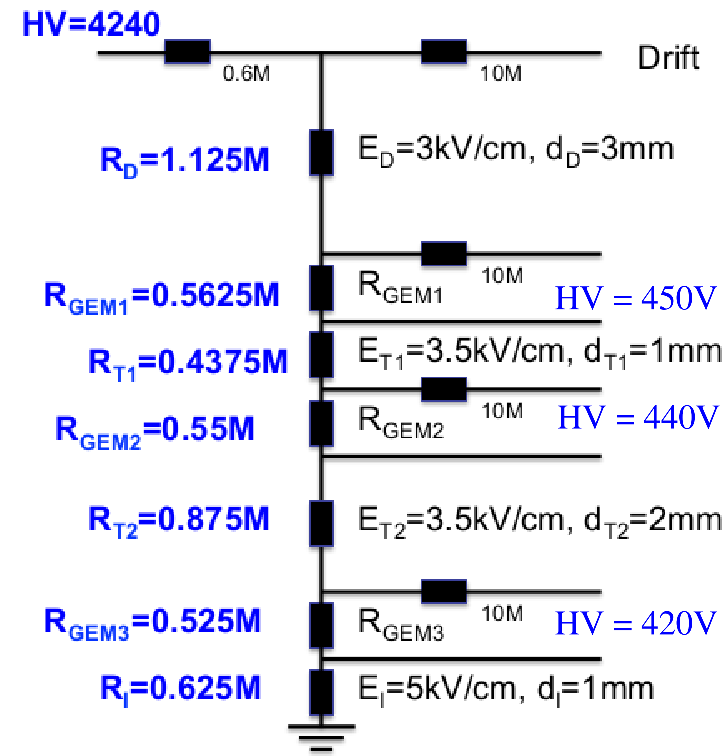
They induce a signal

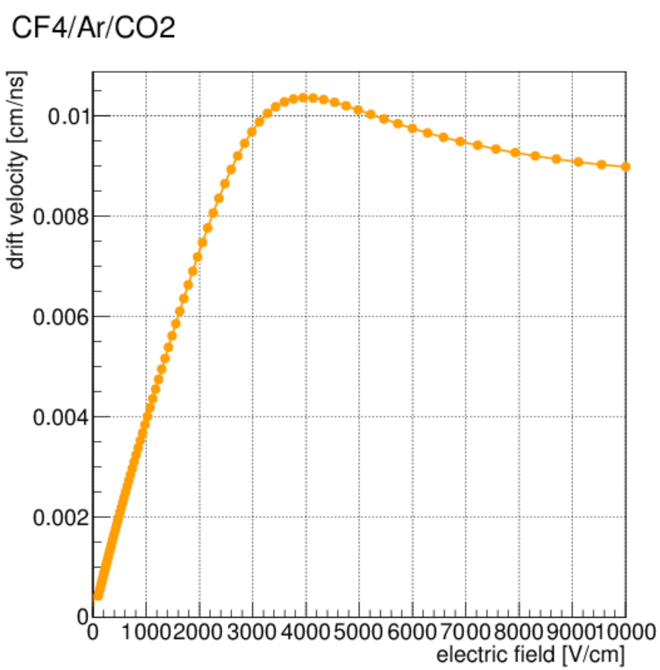


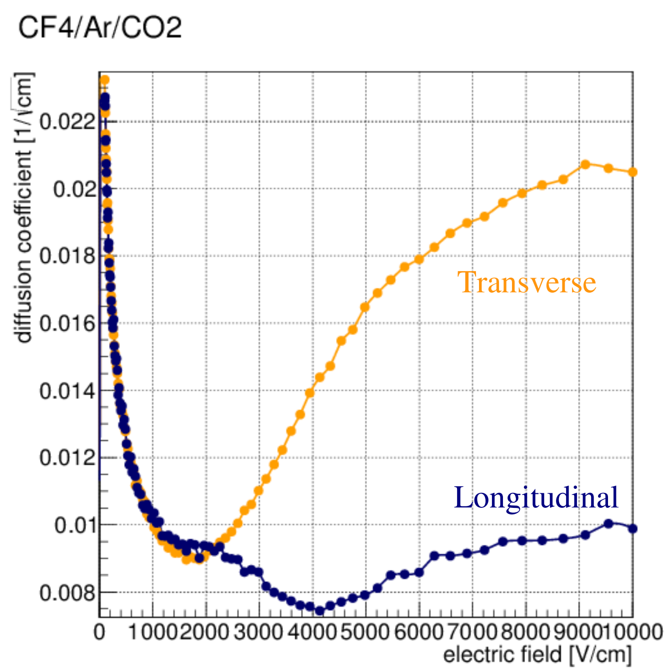
The signal is convoluted

- The electric field in my simulation changes 3 parameters (the drift velocity, and the 2 diffusion coefficients)

- This field is calculated with the current by: $E = U/d = I.R/d$

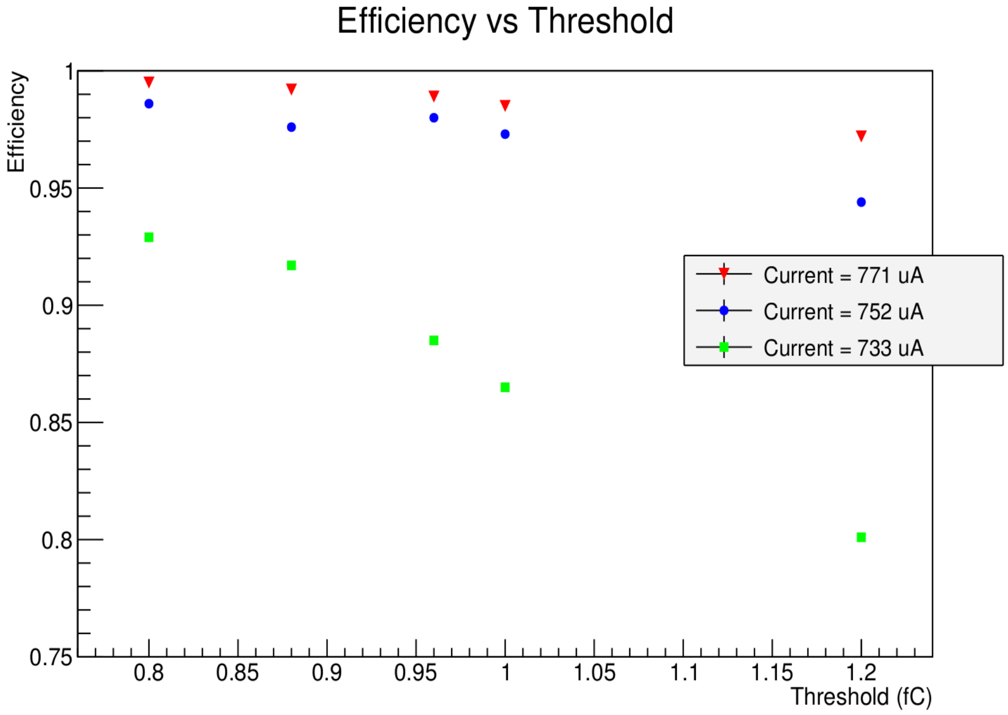




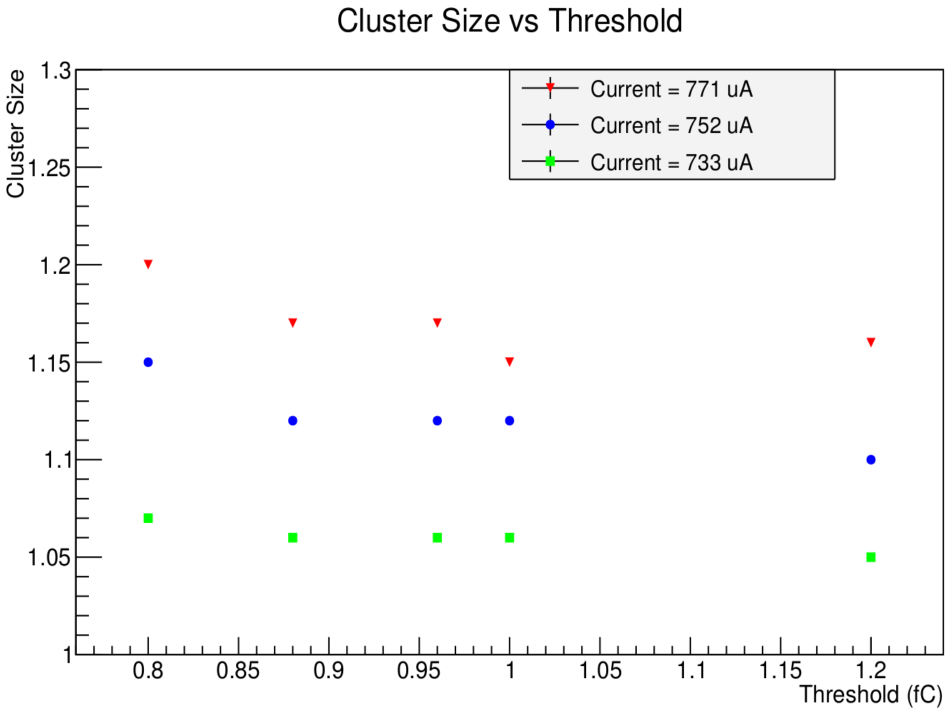


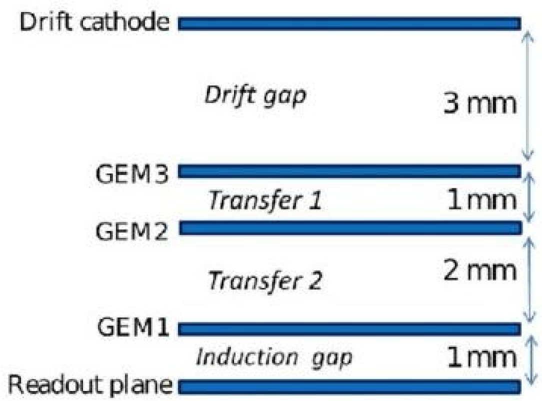
The study of these properties has been done with Garfield

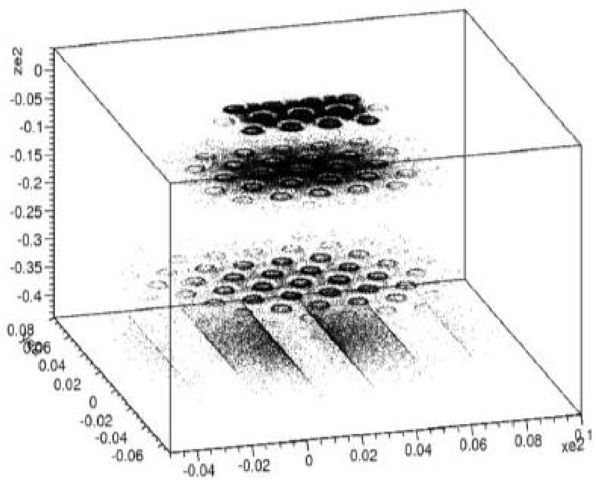
Results for clusterizer



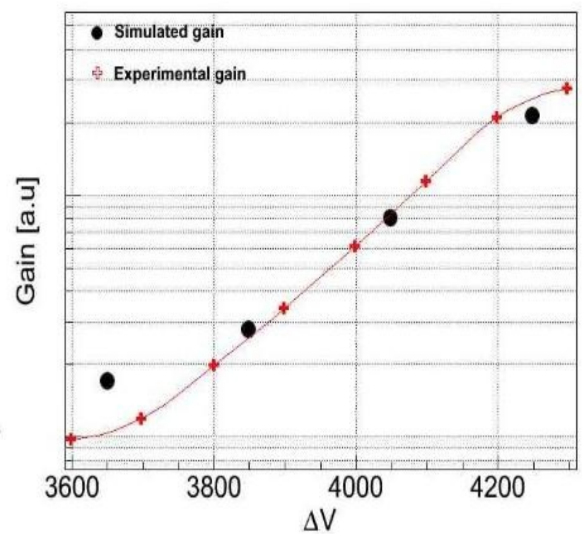
Pitch = 880 um
Ar/CO2/CF4 (45/15/40)



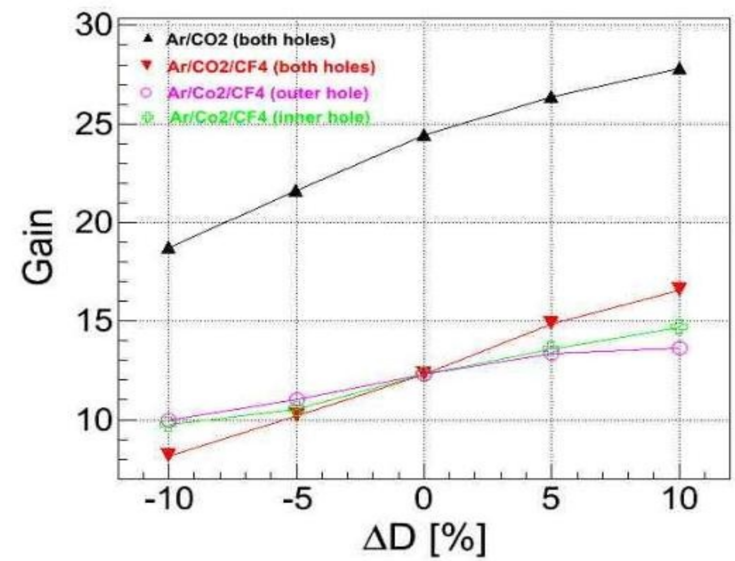




Electrons endpoints (garfield ntuple)



Simulated gain compared to exp.



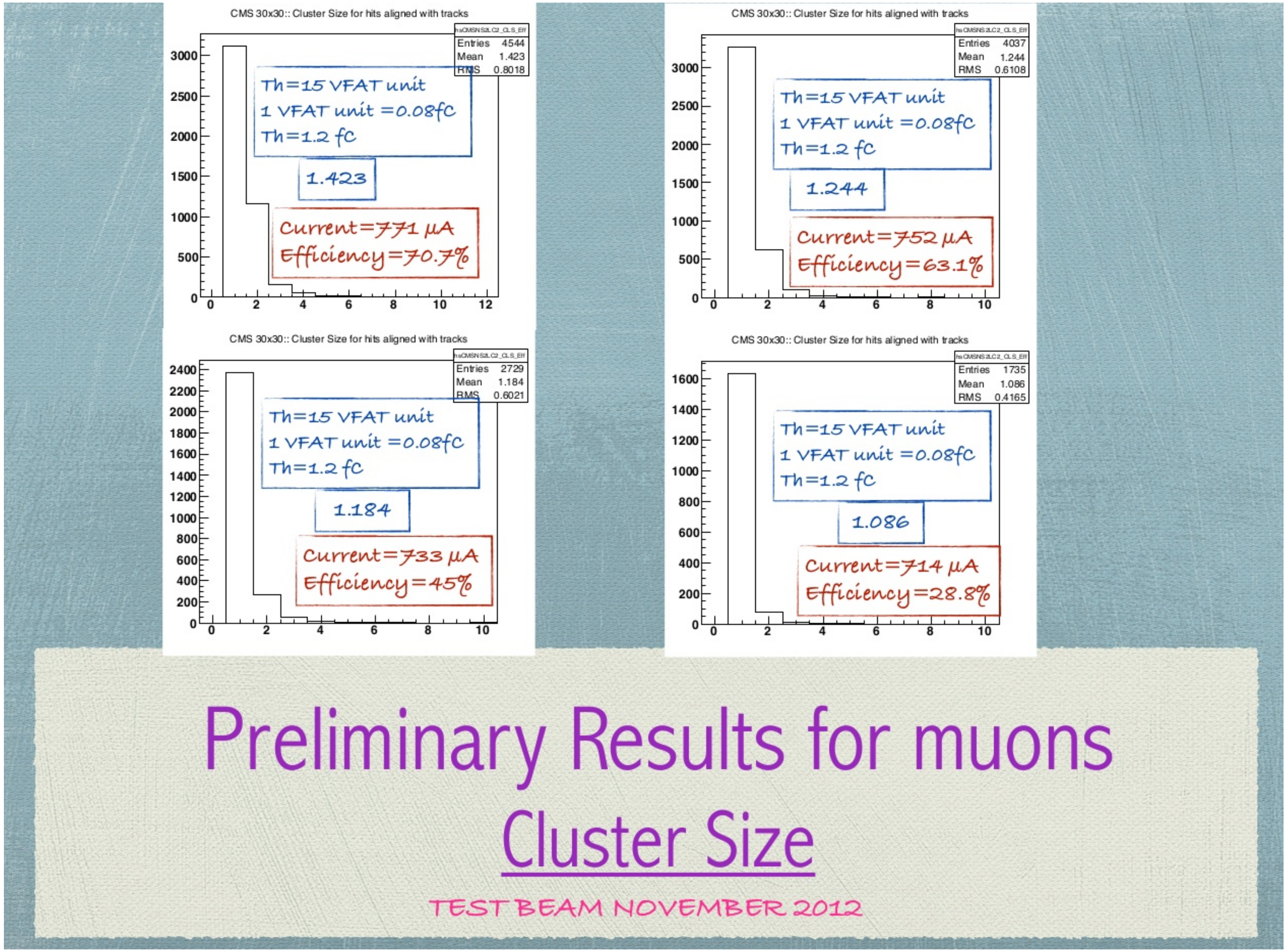
Total Gain in single GEM as a function of variation of hole size

- Electric field solution in ANSYS
- Field map used by Garfield++ for electron avalanche calculation

Y. Maghrbi
Texas A & M University

Conclusion and Future Work

- VFAT test beam analysis results and FastSim are compatible with eachother
- The plateau is about 98% for the CMS GEMs efficiency
- Initial ideas for the future Test Beam
  - December 2014 in H4 with small 1m magnet (RD51 Test Beam)
  - Tests of final GE1/1 and super chamber (to be used for the slice test later on)
  - Performance tests of irradiated chambers at GIF
  - 2 Front-end electronics: CMS VFAT2 hybrid and APV SRS



Sector 4 → pitch = 880 um

Track reconstruction and residual of tracker 2

Reconstruction of the track by using the hit positions in trackers 1 and 4

$$X = \alpha Z + \beta$$
$$slope = \alpha = \frac{X_1 - X_4}{Z_1 - Z_4}$$
$$intercept = \beta = X - \alpha Z$$

Residual of tracker 2 represents the difference between the coordinates of the points extrapolated from trackers 1 and 4 and the one measured in tracker 2:

$$R(T_2) = X_{2m} - X_{2p} = X_{2m} - \frac{X_1 - X_4}{Z_1 - Z_4} Z_2 - X_1 + \frac{X_1 - X_4}{Z_1 - Z_4} Z_1$$

Residual of tracker 2 represents the difference between the coordinates of the points extrapolated from trackers 1 and 4 and the one measured in tracker 2

UNIVERSITEIT GENT

Track reconstruction by minimizing chi-squared

- The track of the particle is reconstructed by using the hit positions of the particle in all three trackers for each event.

- The hit coordinates (Z_1, X_1), (Z_2, X_2) and (Z_4, X_4) for each event that can be extracted from the ntuple, are used to find the track of the particle represented by a straight line of the form $X = aZ + b$.

- The fitting procedure aims at determining the parameters *a* corresponding to the slope and *b* corresponding to the intercept along with their errors σ_a and σ_b by minimizing the quantity called chi-squared

$$\chi^2(a,b) = \sum_{i=1}^{N} \frac{(X_i - aZ_i - b)^2}{\sigma_i^2}$$

where σ_i is the error on the i^{th} measurement, which in our case is the error of the tracker found in the calculation of tracker resolution (for pions 0.136mm).

The minimization of the quantity consists of solving the equations:

$\frac{\partial \chi^2}{\partial a} = 0$ and $\frac{\partial \chi^2}{\partial b} = 0$ in order to find the parameters a and b.

Since the measurement error in the data will introduce some uncertainty in the determination of *a* and *b*, we must estimate the error on these two parameters σ_a and σ_b respectively.

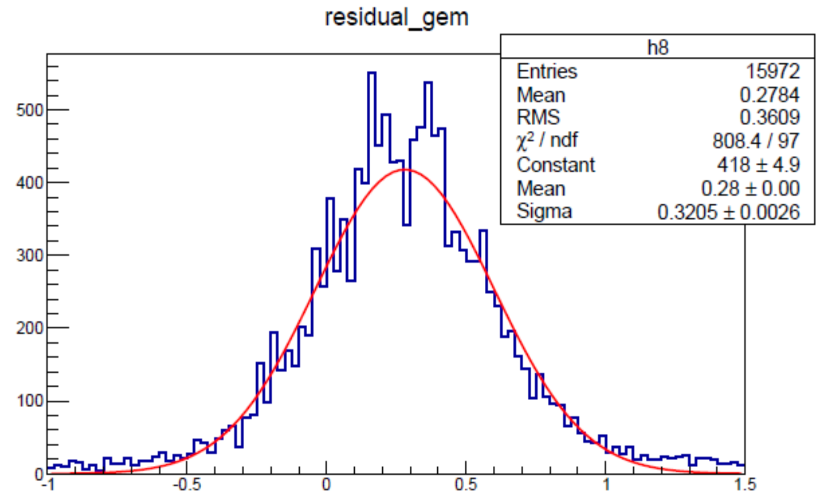
Again by using propagation of error we find the variance σ_a^2 and σ_b^2 as well as the covariance of a and b.

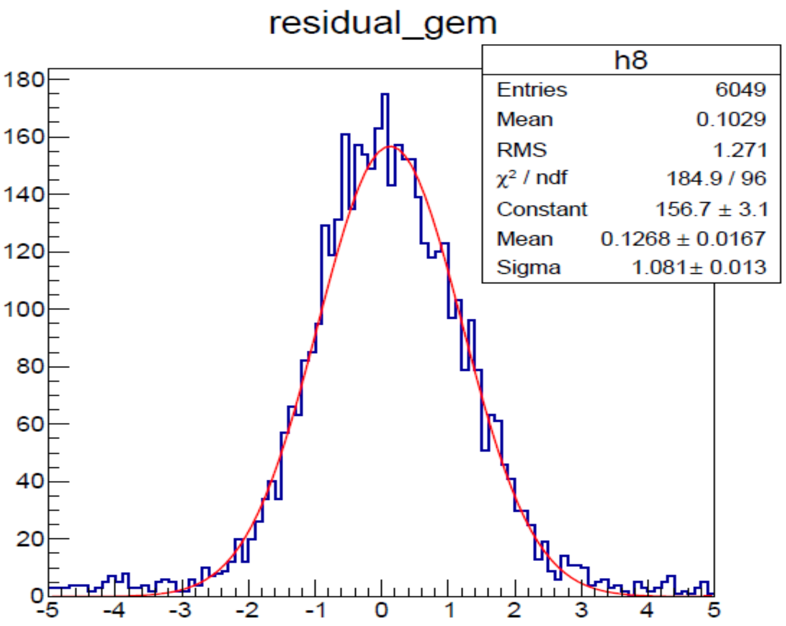
The slope *a*, the intercept *b* and the errors σ_a, σ_b, and *Cov(a,b)* were calculated for each event, and by looping over all the events, we obtained a distribution of each.

two conditions were applied;

- selecting only one track
- $\chi^2 < 1.5$. This condition gave a good spatial resolution without losing so many events.

Plots of the residual of GEM for pions (left) and muons (right)





The residual of the GEM represents the difference between the coordinate of the points extrapolated from trackers 1, 2 and 4 (by minimizing $\chi^2(a,b)$ to find *a* and *b*) and the one measured in the GEM:

$$R(GEM) = X_m - X_p = X_m - aZ_{GEM} - b$$

By using propagation of error and assuming that *a* and *b* are correlated variables, we can write the equation as follows:

$$\sigma_R^2 = \left(\frac{\partial R}{\partial X_m}\right)^2 \sigma_{GEM}^2 + \left(\frac{\partial R}{\partial a}\right)^2 \sigma_a^2 + \left(\frac{\partial R}{\partial b}\right)^2 \sigma_b^2 + 2\frac{\partial R}{\partial a}\frac{\partial R}{\partial b} Cov(a,b)$$

$$\sigma_R^2 = \sigma_{GEM}^2 + Z_{GEM}^2 \sigma_a^2 + \sigma_b^2 + 2Z_{GEM} Cov(a,b)$$

σ_R is the standard deviation of the fit of the GEM residual

σ_{GEM} is the error on the GEM position measurement which is what we aim at finding in this work.

σ_a, σ_b, and *Cov(a,b)* are taken from the mean of their distributions.

From the Gaussian fits:

For pions: σ_R*=0.3205*. By using the equation derived above $\boldsymbol{\sigma_{GEM} = 0.2205mm}$

The pitch of the irradiated sectors (1/4 and 3/4) of the GEM corresponds to 0.88 mm.
$\boldsymbol{\sigma_{GEM\ theo} = \frac{0.88}{\sqrt{12}} = 0.254mm}$.

This value is very close to the experimental value for pions that we just found.

For muons: σ_R*=1.081* as seen in the figure below so $\boldsymbol{\sigma_{GEM} = 1.056mm}$.

In the calculation $\boldsymbol{\sigma = 0.136mm}$ (which is found with pion run) was used.

Again the spatial resolution of the GEM is worst for muons than for pions and it doesn't match with the predicted theoretical value.