Alignment of a Muon Tomography Station with GEM Detectors

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Committee Members :

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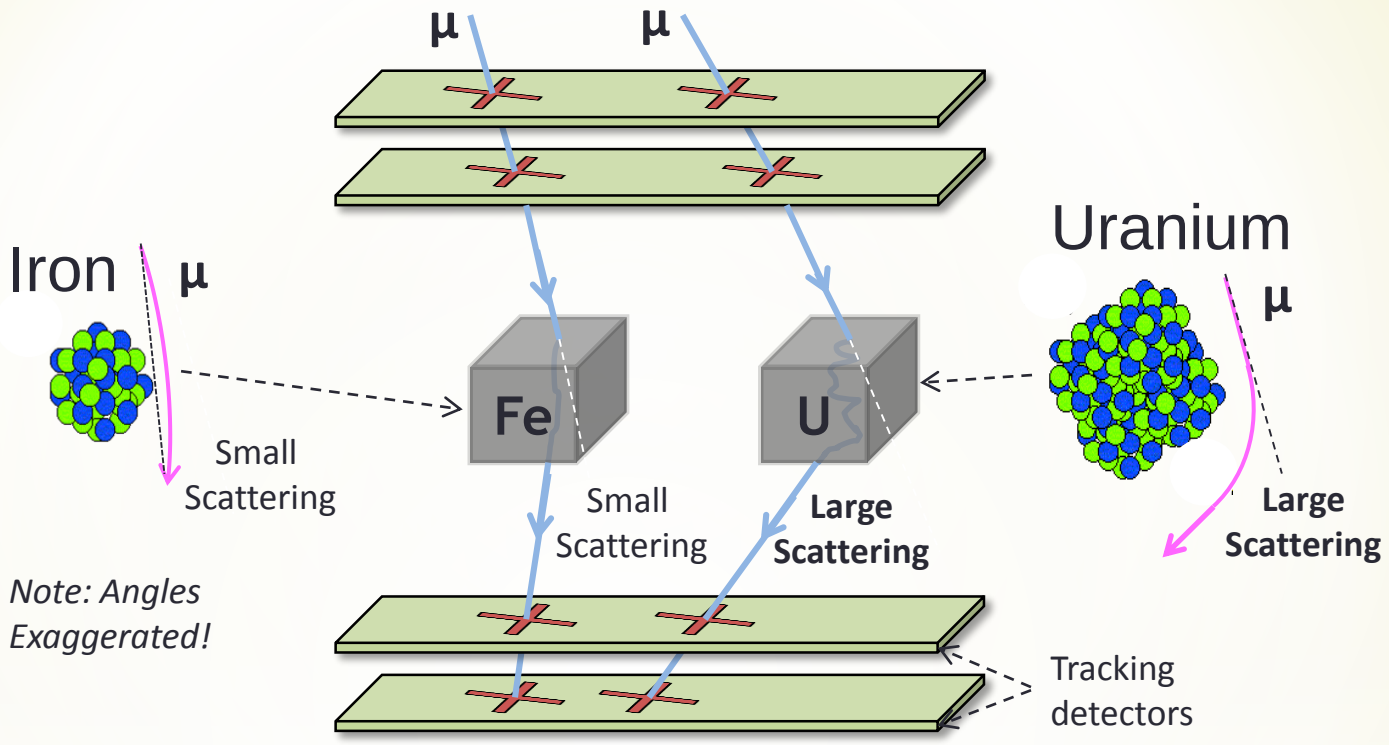
Outline

- What is Muon tomography?
- The Gas Electron Multiplier
- Scalable Readout System(SRS)
- Alignment of GEM Detectors Using Tracks
- Conclusion
- Future Work

Muon Tomography Concept

Incoming muons (from natural cosmic rays)



Multiple Coulomb scattering to 1st order produces Gaussian distribution of scattering angles θ with width $\sigma = \Theta_0$:

$$\Theta_0 = \frac{13.6\,\mathrm{MeV}}{\beta c p}\sqrt{\frac{x}{X_0}}[1+0.038\ln(x/X_0)]$$

$Z \rightarrow$ Charge Number

$\beta c \rightarrow$ Velocity

$p \rightarrow$ Momentum

$X_0 \rightarrow$ Radiation Length

$x \rightarrow$ Width of Medium

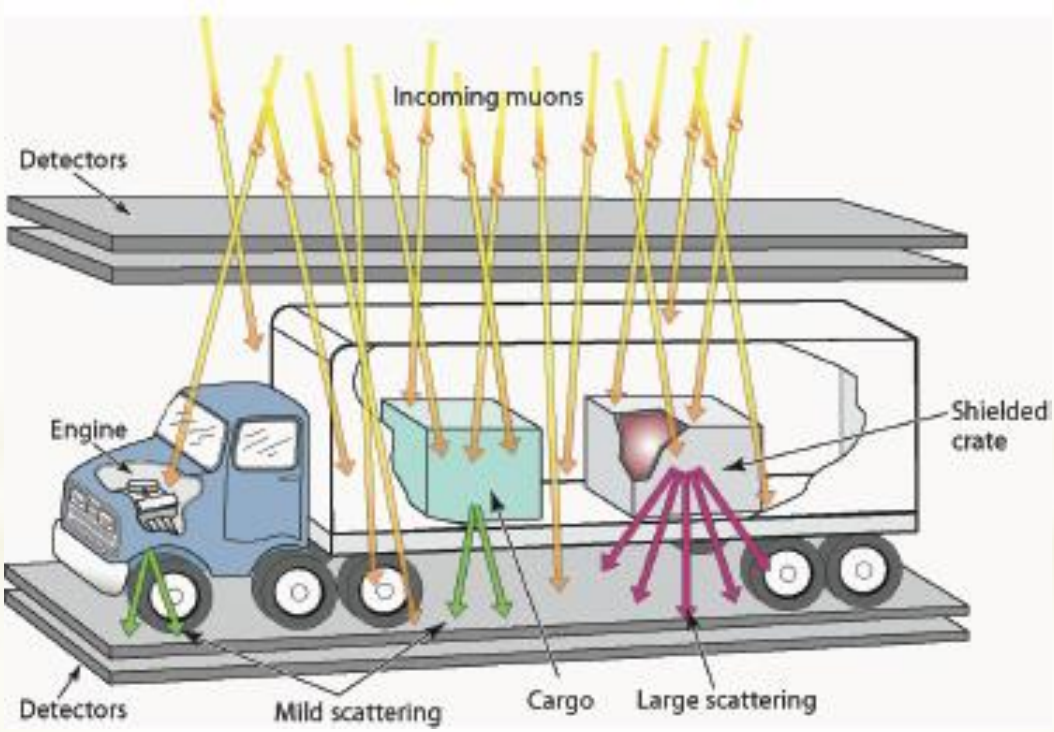
Where X_0 may be approximated by

$$X_0 = \frac{716.4 g cm^{-2} A}{Z(Z+1)\ln(287/\sqrt{Z})}$$

Source; M.Staib,defense presentation

Muon Tomography

- Over 120 million vehicles enter the United States each year and they can transport hidden nuclear weapons or nuclear material.
- Muon Tomography can be used to detect shielded materials.

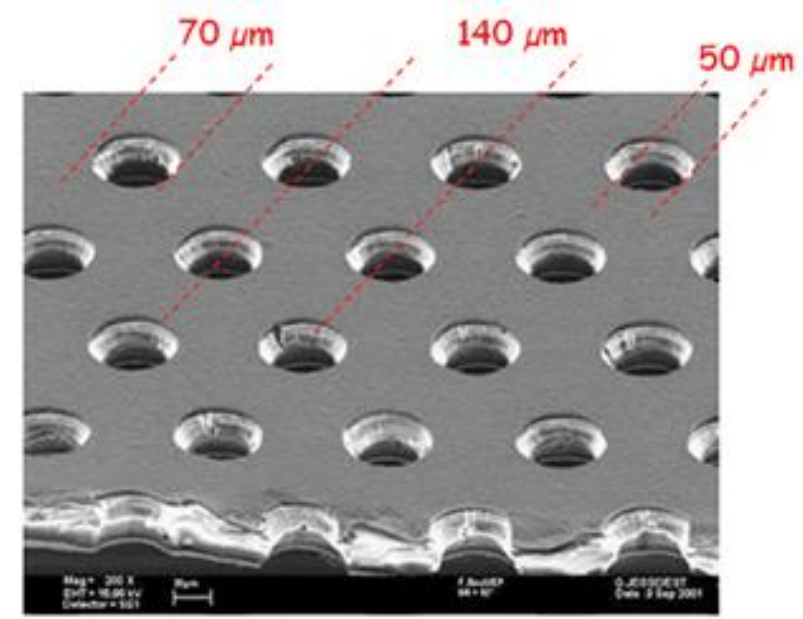


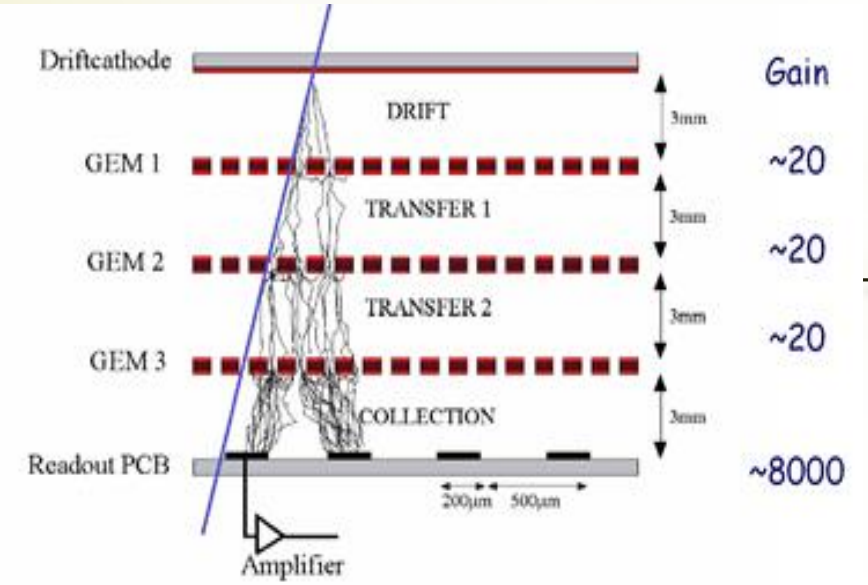
Source of picture:Muon Tomography(google)

The Gas Electron Multiplier

- Using an electric field to accelerate electrons to produce ionization
- 30 cm ⩤ 30 cm GEM foils with

  12 parallel sectors
- Mixture of Ar and CO_2 with the ratio 70/30



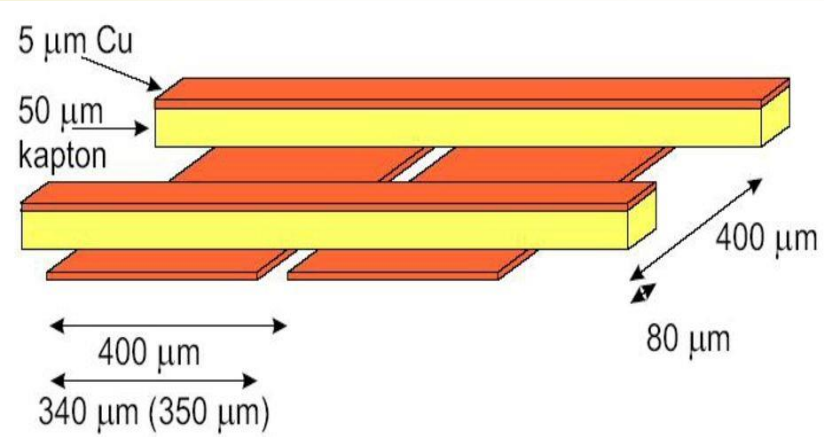


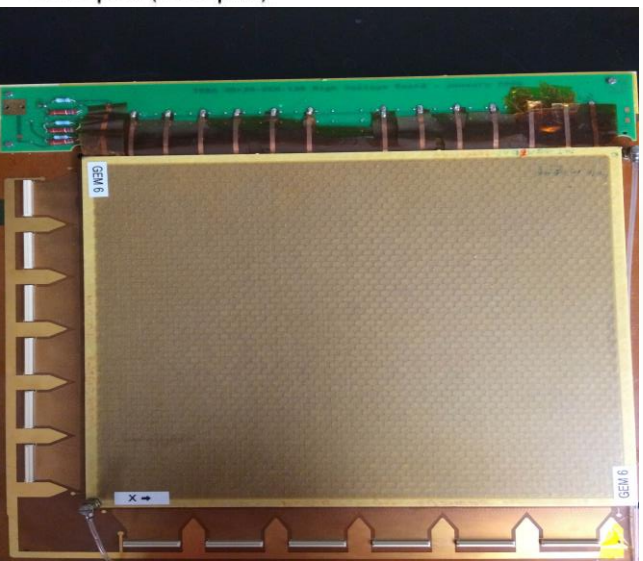
→ The triple GEM detector

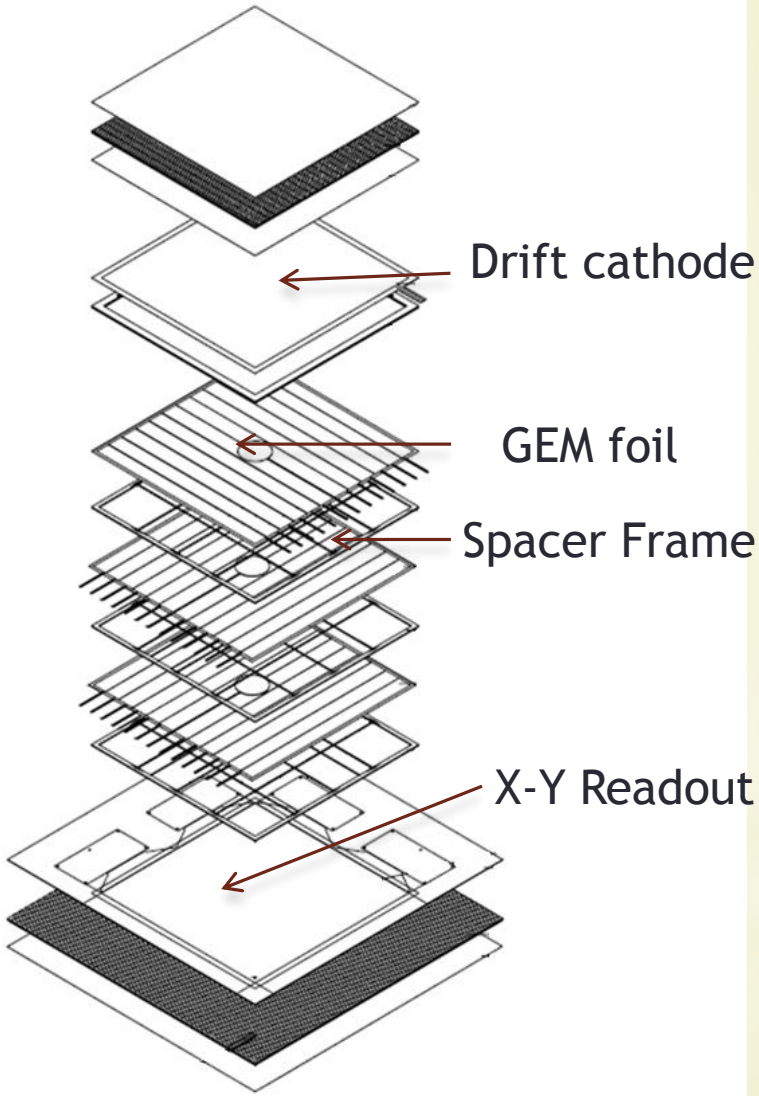
Soource of pictures: Gas Electron Multiplier(google)

The Gas Electron Multiplier

- Two-dimensional readout
- 3 mm drift gap between GEM layers







Soource of pictures: Gas Electron Multiplier(google)

Data Acquisition

- Detector Data is sent to DAQ for event by event.
- DATE(Data Acquisition and Test Environment) is used for collecting raw data from all FECs.
- AMORE(Automatic MOnitoRing Environment) is used for offline and online analysis.
- Common and publisher folders are created for AMORE version using for MTS .

Data AcQuisition-Electronics

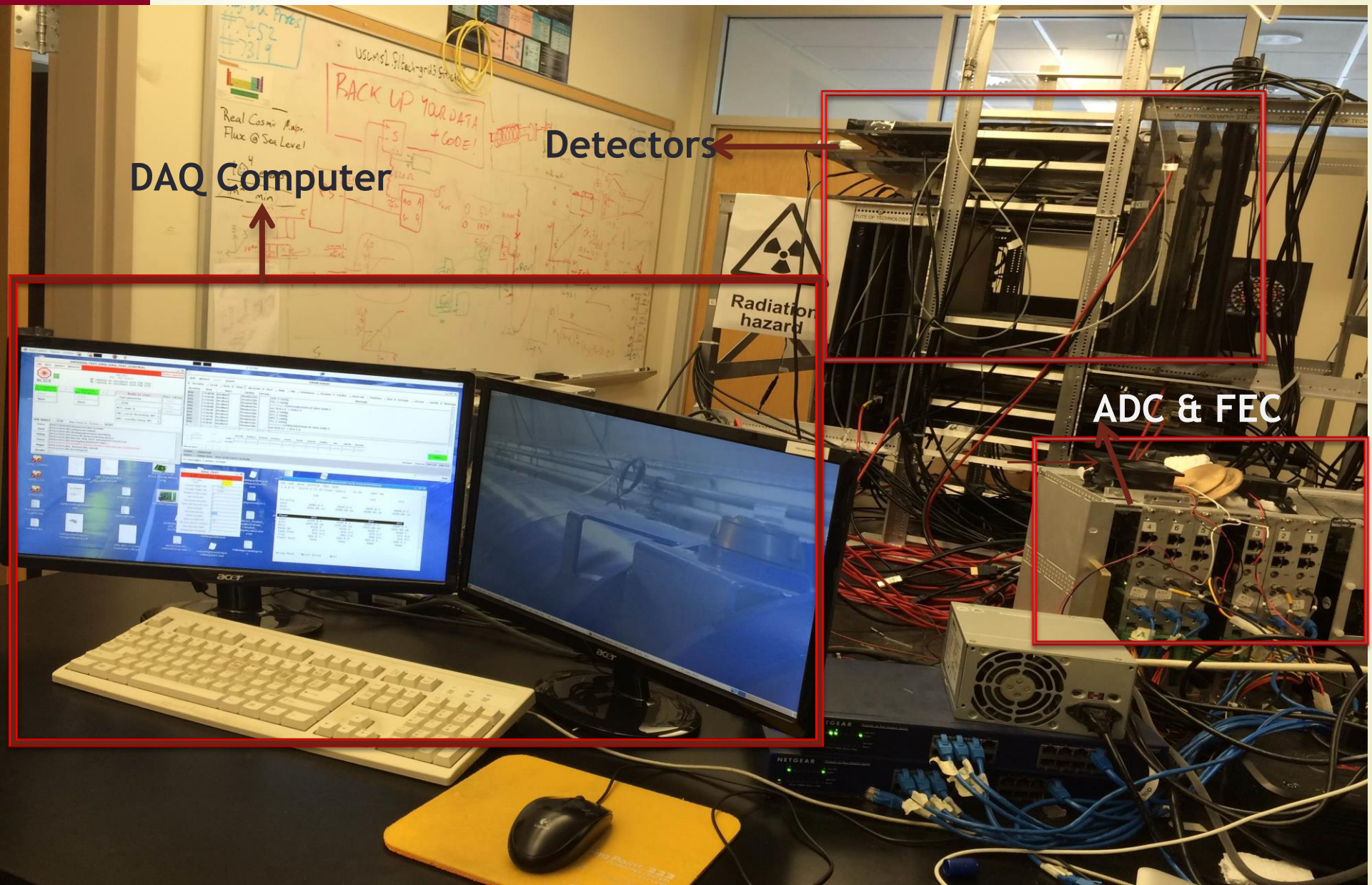
APV25
-128 readout channels
-Each channel consists of Pipeline with 192 memory elements

ADC
-Digitalizing the data That APV sends out

FEC
-I/O for trigger and clocks

Soource of pictures: Scalable Readout System(google)

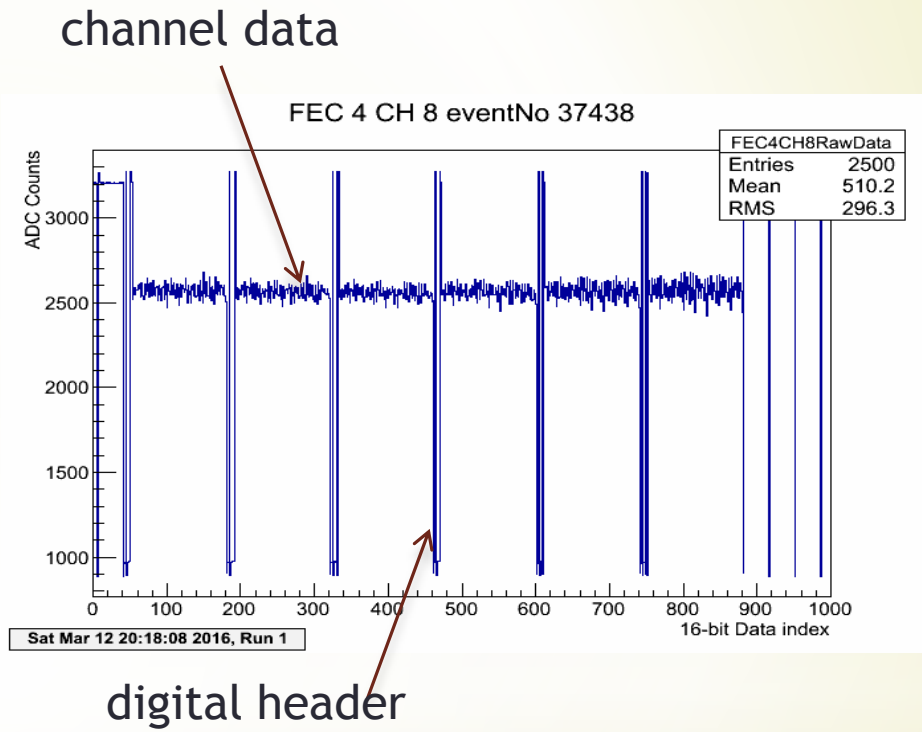
Scalable Readout System (Data Collection)



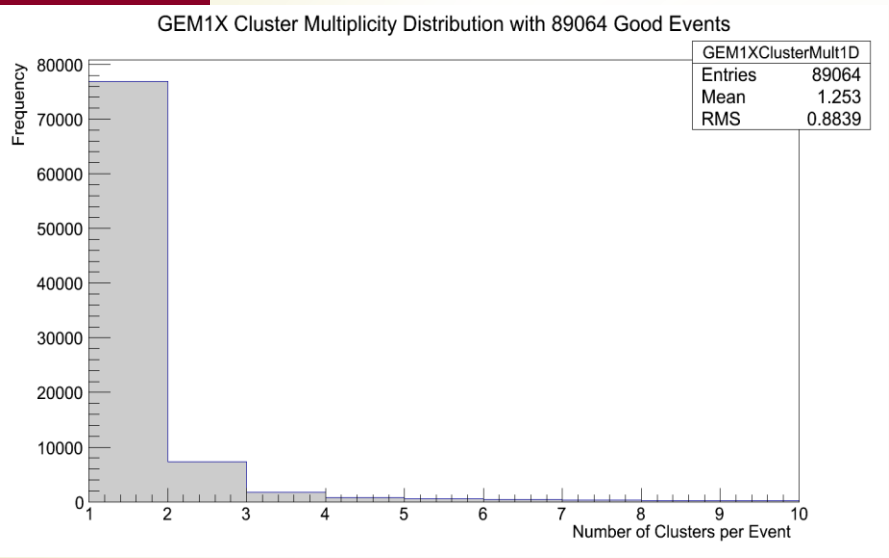
Data Collection

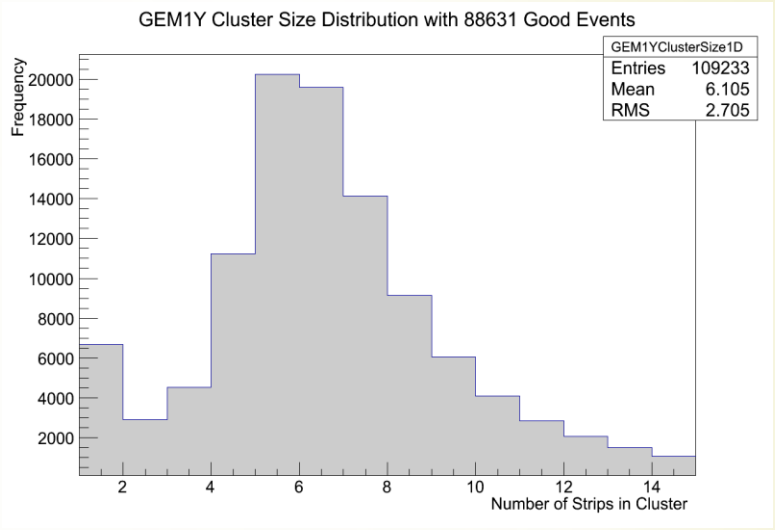
Pedestal

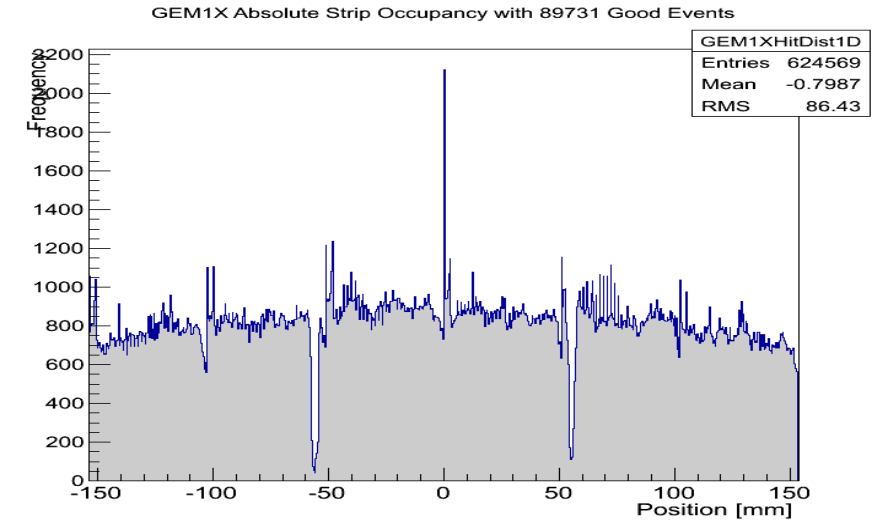
- The baseline values of channels have to be subtracted from the APV output
- Pedestal run type should be selected
- The bias voltage is set to 2000 V
- There is no gas gain in the detector

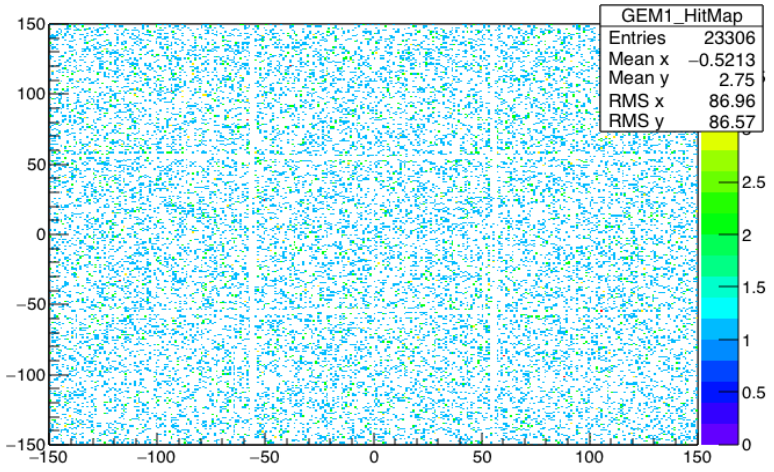


Online Monitoring Plots



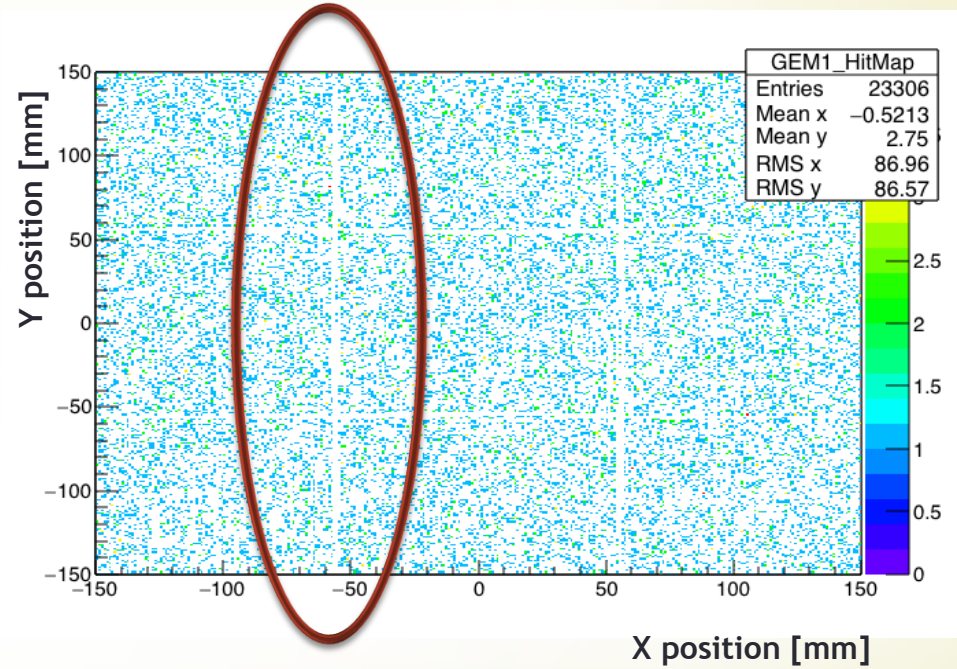






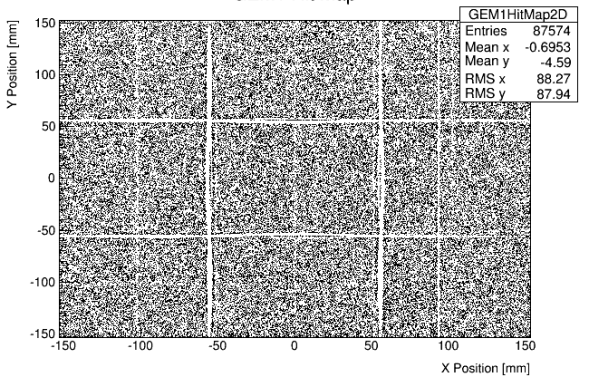
Hit Map

- 2D Hit map shows the hits in x strip vs y strip
- There is no track selection

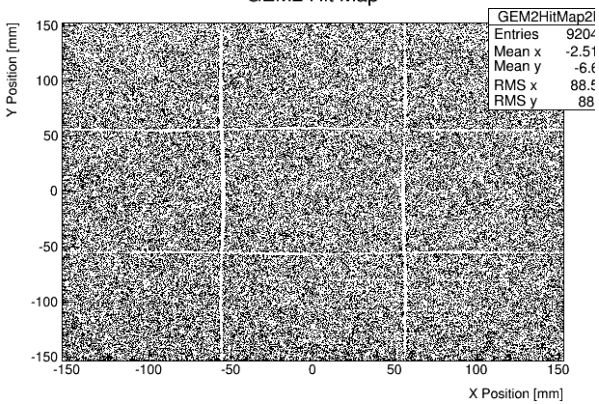


2D Hit Map

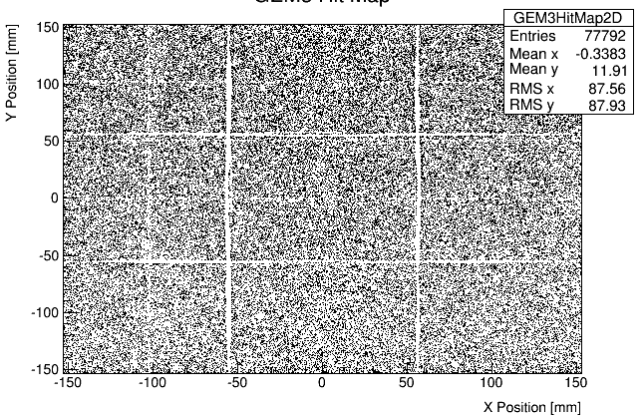
GEM1 Hit Map



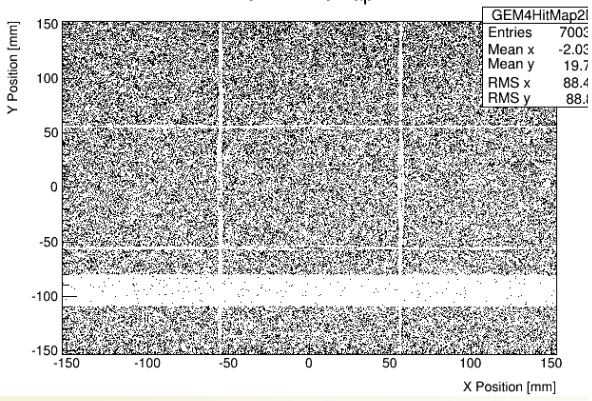
GEM2 Hit Map



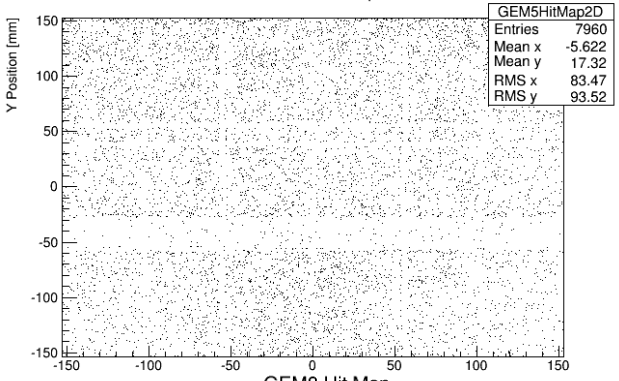
GEM3 Hit Map



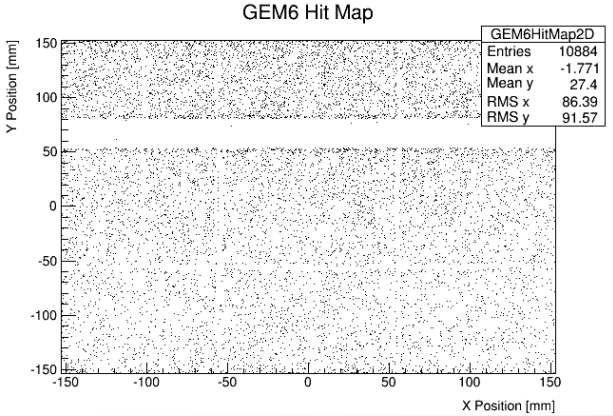
GEM4 Hit Map



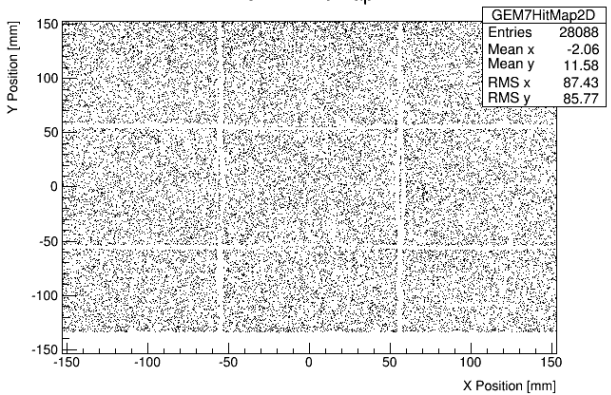
GEM5 Hit Map



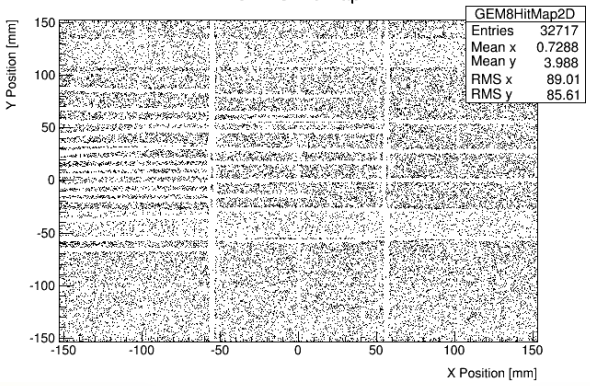
GEM6 Hit Map



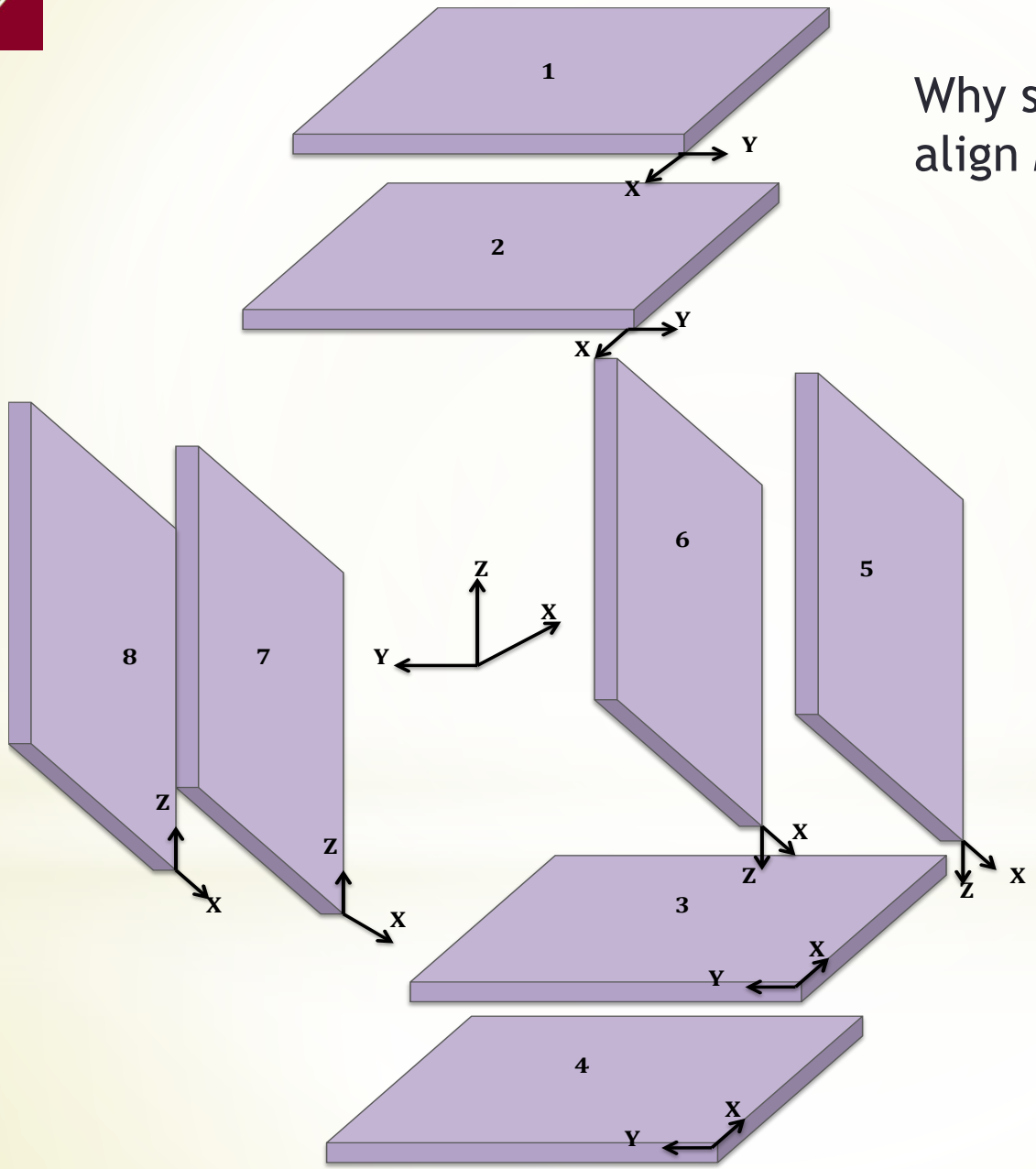
GEM7 Hit Map



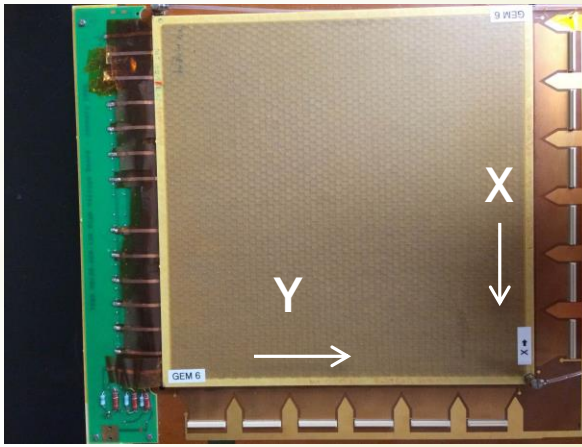
GEM8 Hit Map



Global and Local Coordinate systems



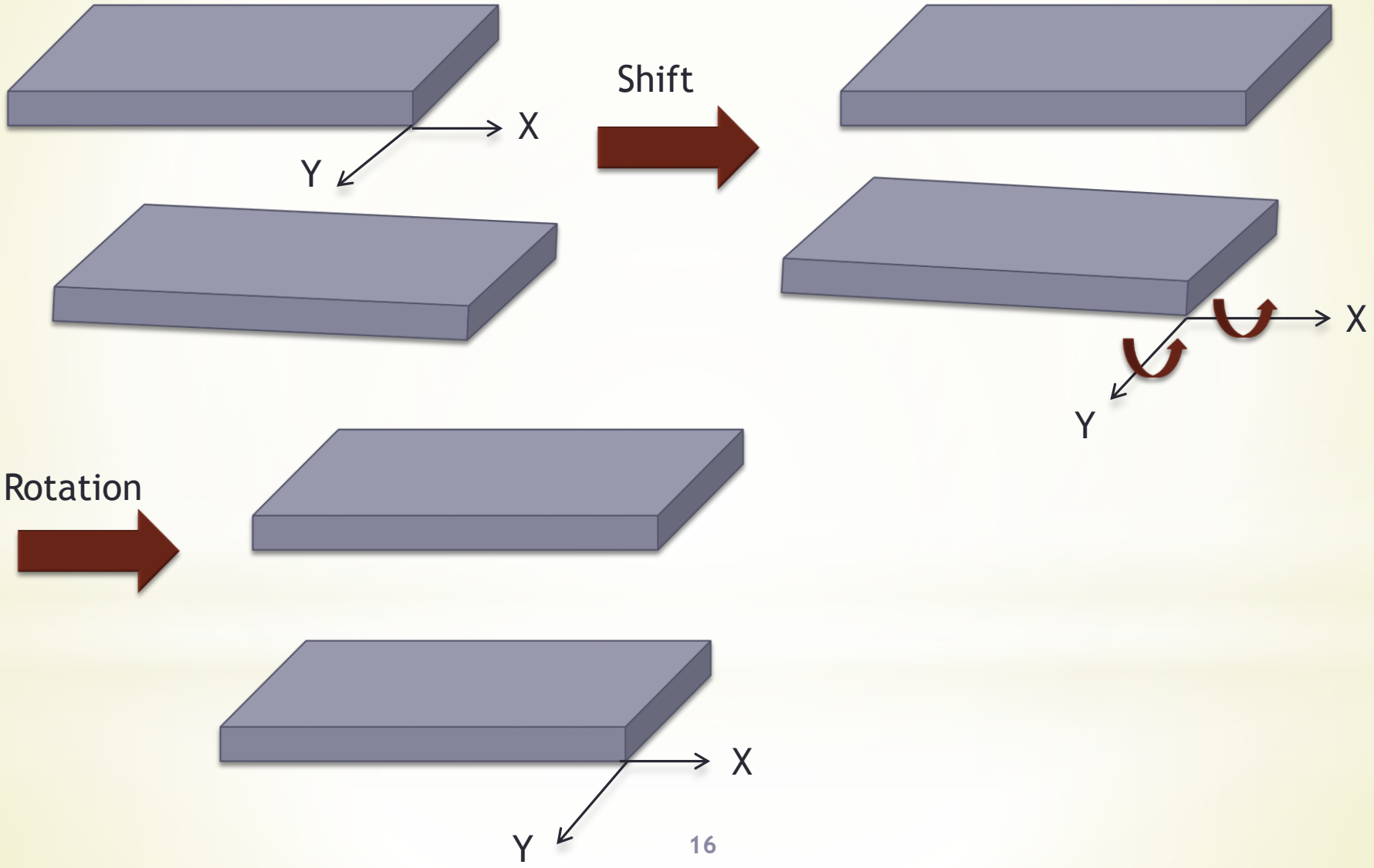
Why should we align MTS?



What are the Alignment Steps for Top and Bottom Detectors?

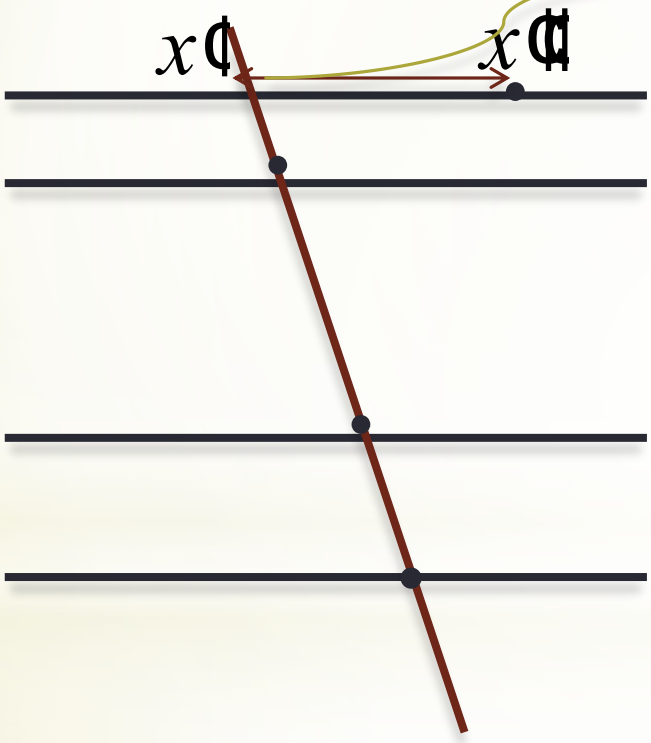
1- Defining GEM 1 as a reference.
2- Finding the initial shift parameters by calculating the Chi Square of fitted tracks.
3- Shifting each detector iteratively in X-Y plane.
4- fitting straight lines to the hits in X and Y in each iteration.
5- Taking 20% of the residual mean value as the shift parameter in the next iteration.
6- Rotating detectors in X-Y plane with respect to GEM 1.
7- Optimizing the rotation angles

Shifting and Rotating



Finding Residual Distance

- Finding the residual distance between the hit positions and the points of fitted track
- Minimizing the residual distance



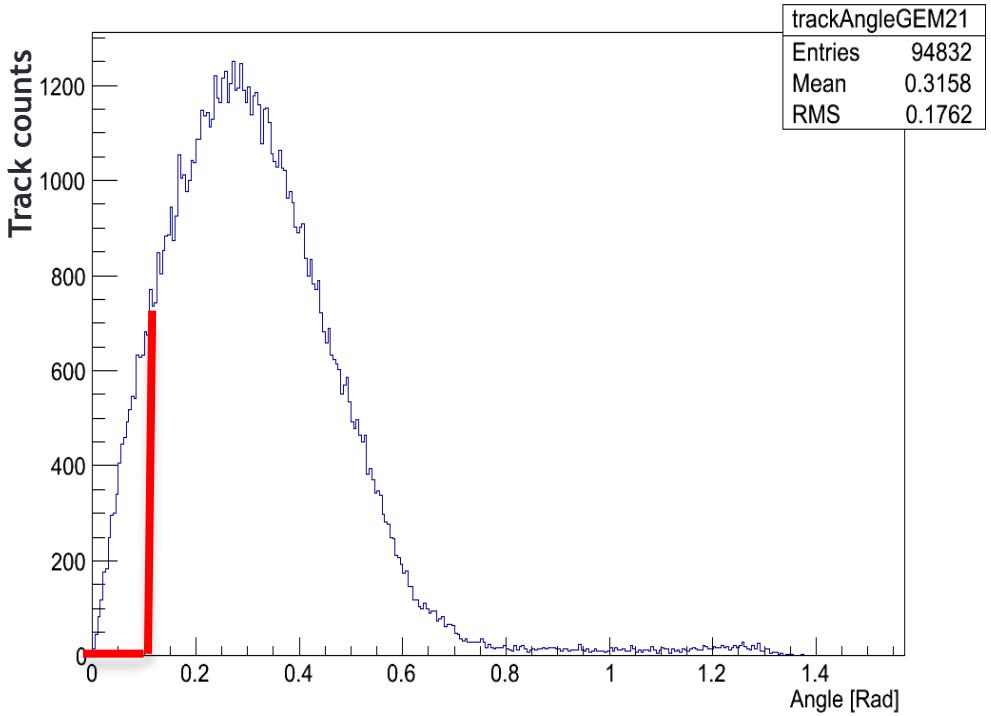
Residual Distance

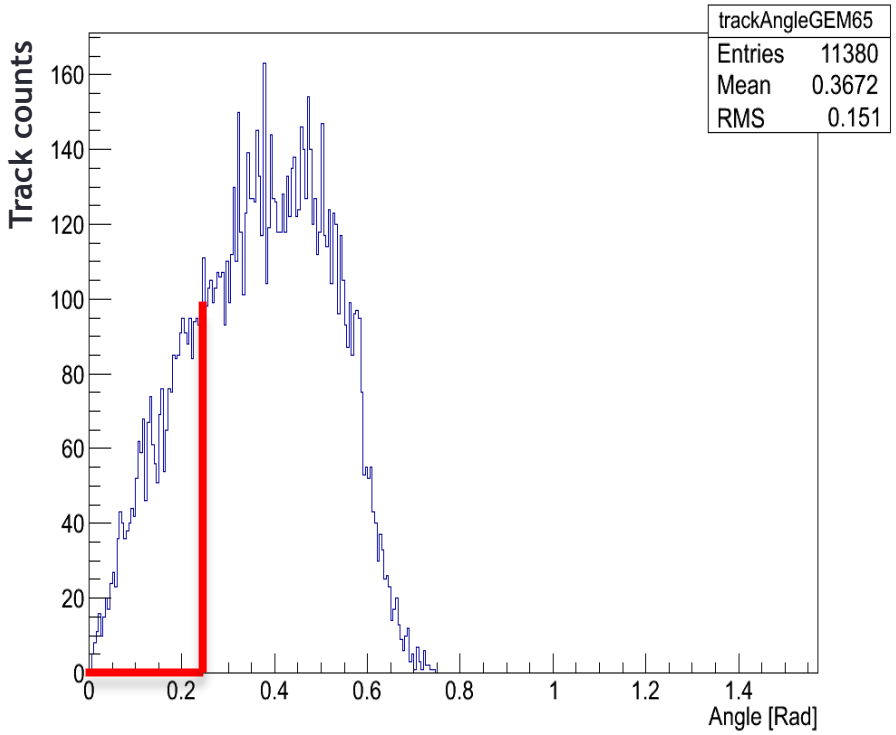
$$\Delta x = x' - x''$$

q_{avg}

$$x = az + b$$

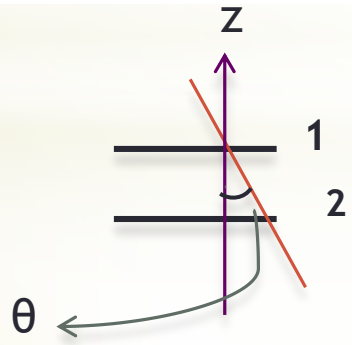
Track Selection





Angle range:

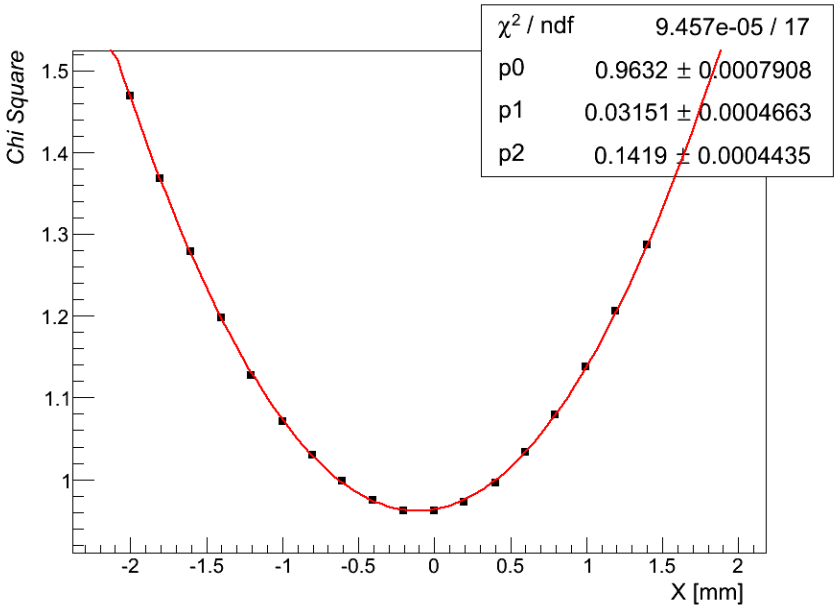
$0 \leq \theta \leq 0.08$

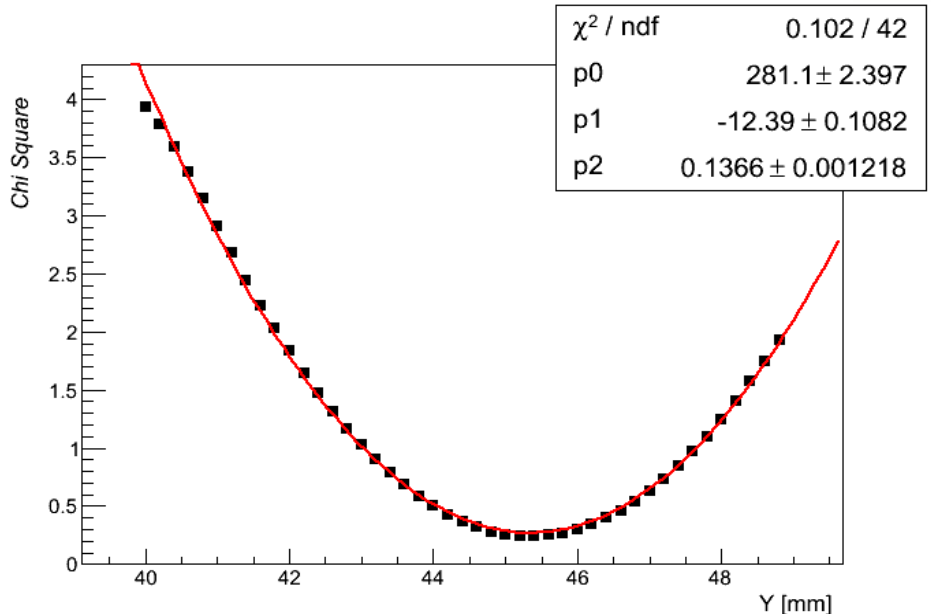


Angle range:

$0 \leq \theta \leq 0.25$

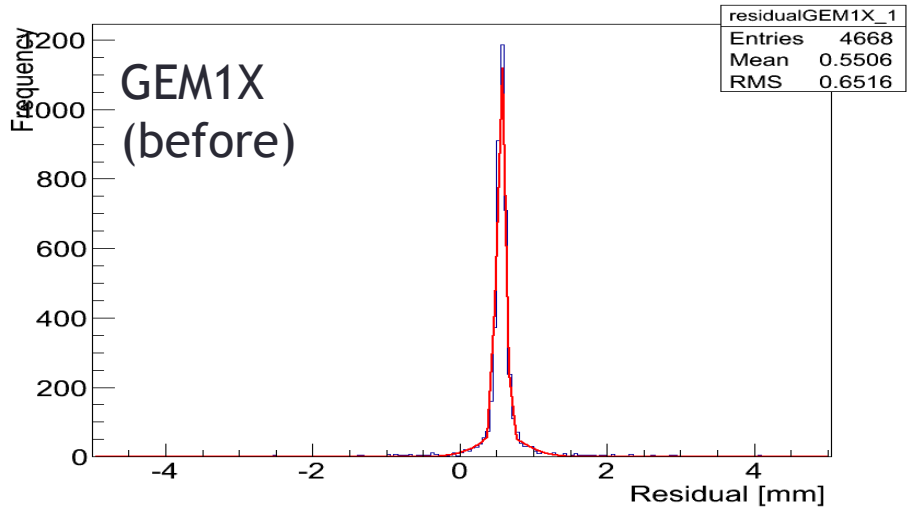
Chi Square For X and Y for GEM 1

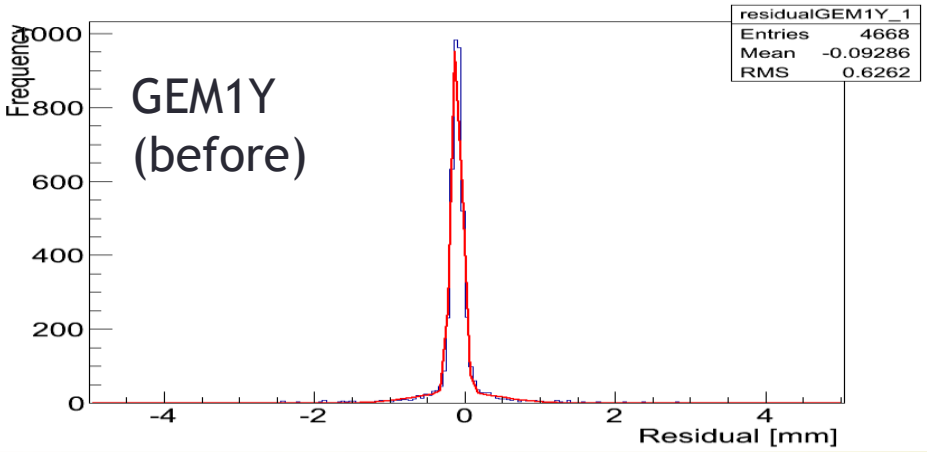


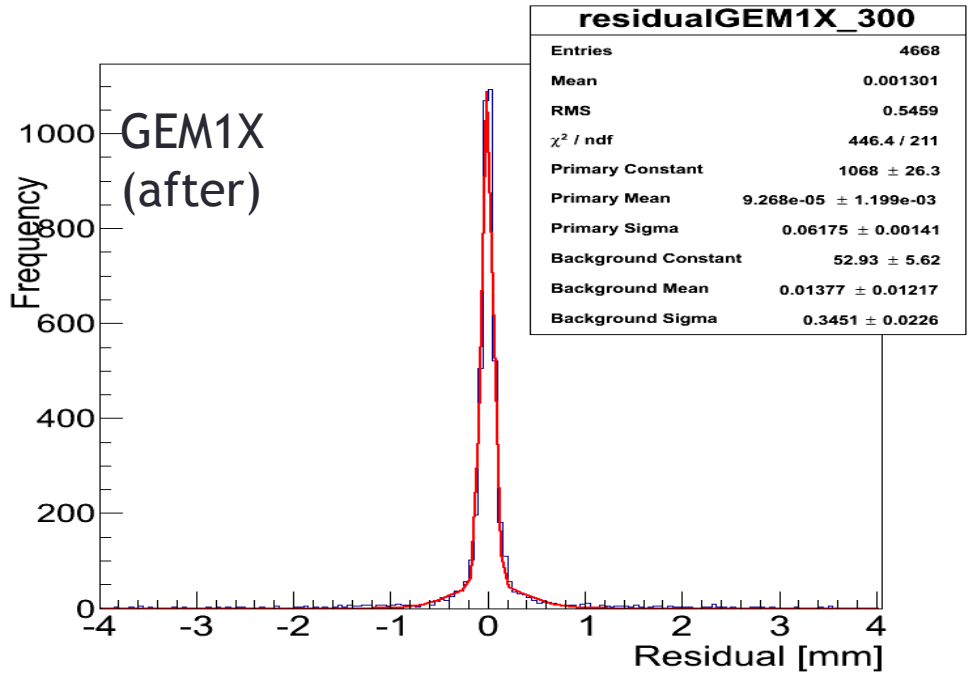


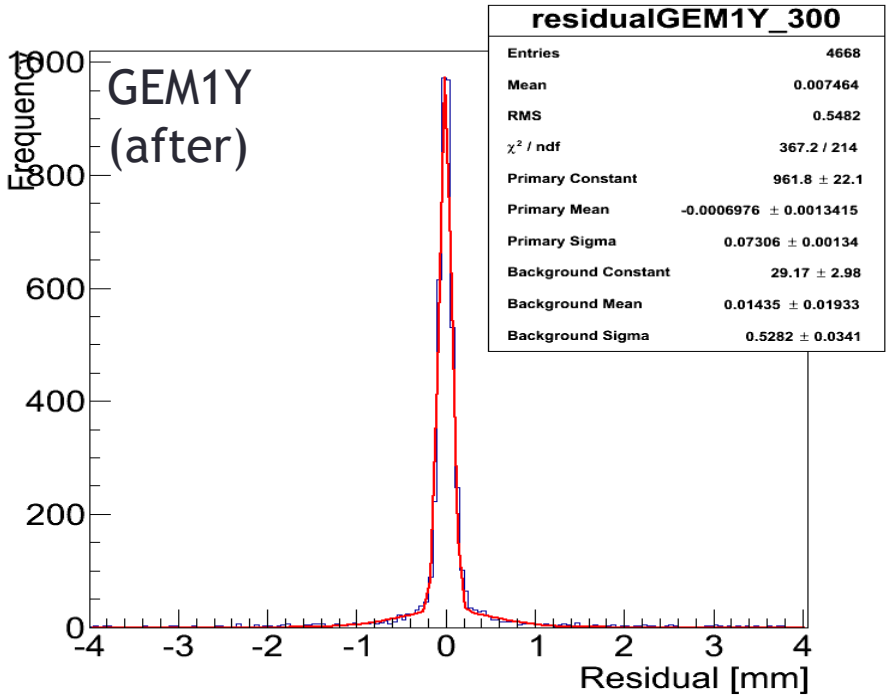
For finding the initial values of GEM1X and GEM1Y,X and Y are changed in a specific range with a 0.2 mm step. The same calculation is done for other GEMs.

Residual Distributions for GEM1 before and after iterative alignment

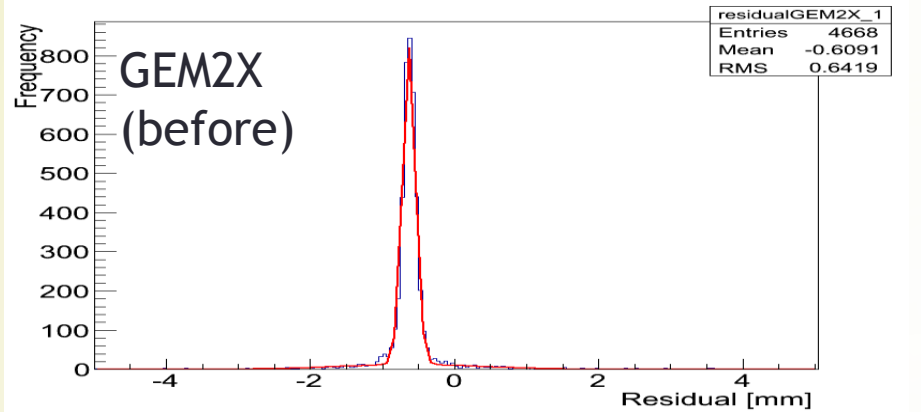


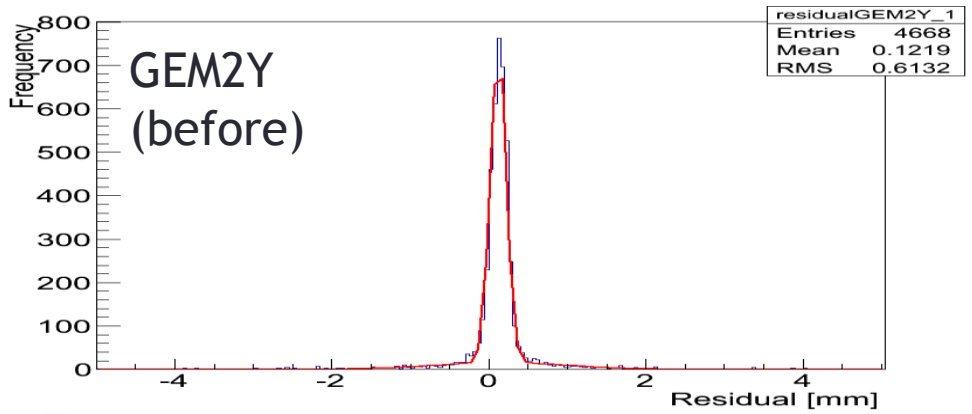


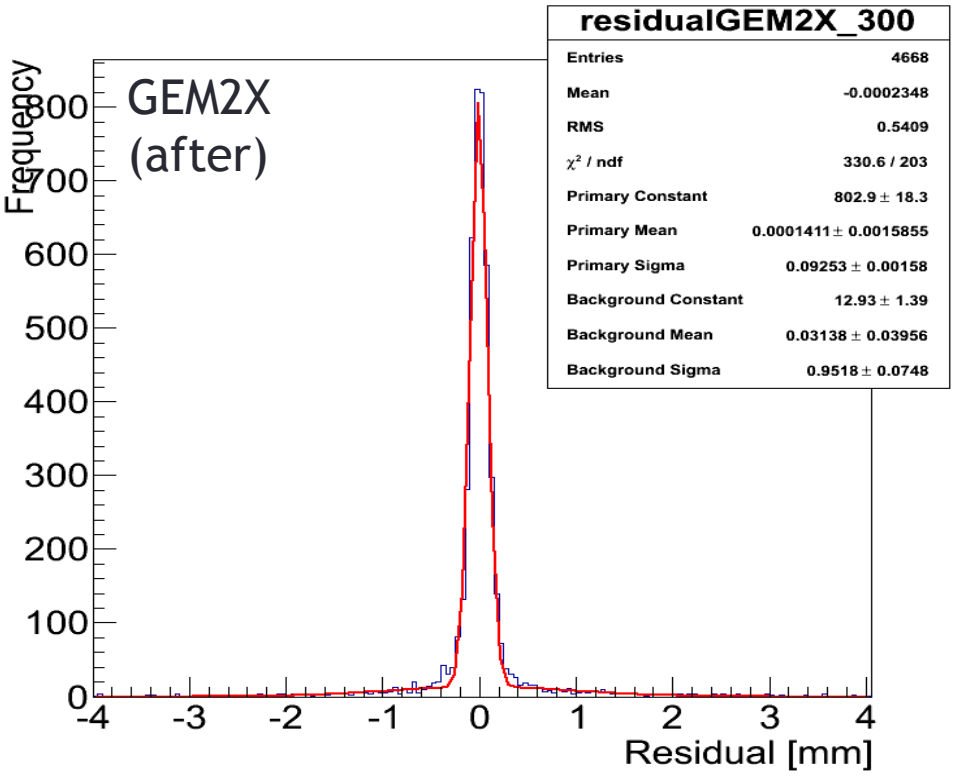


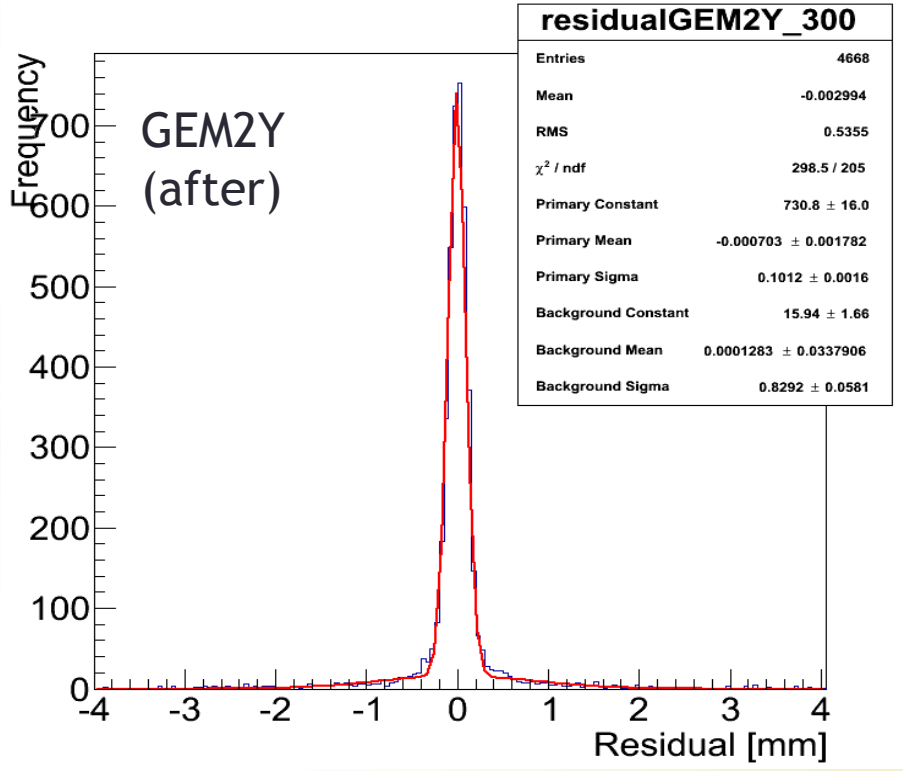


Residual Distributions for GEM2 before and after iterative alignment

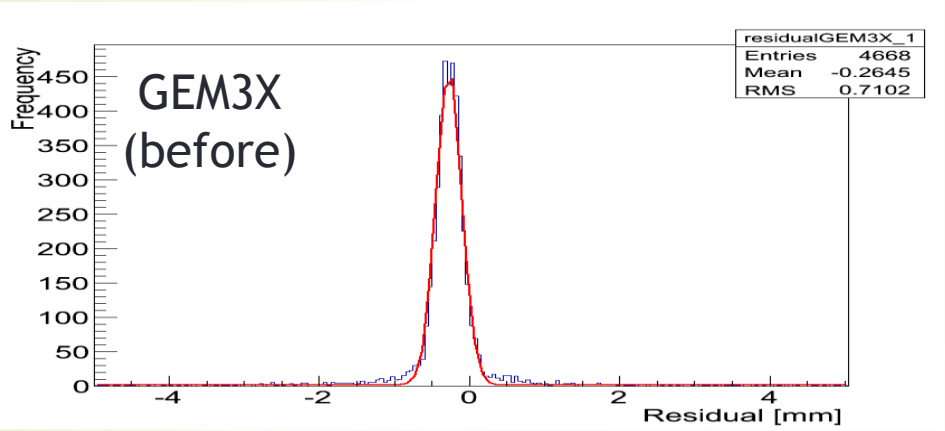


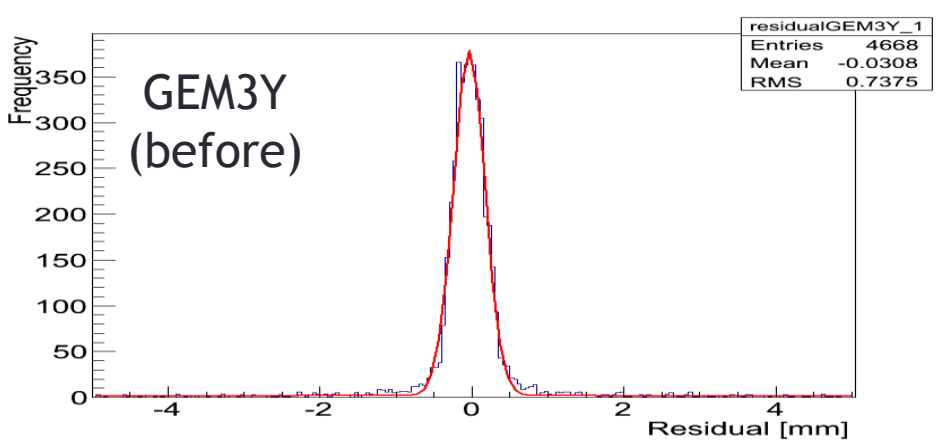


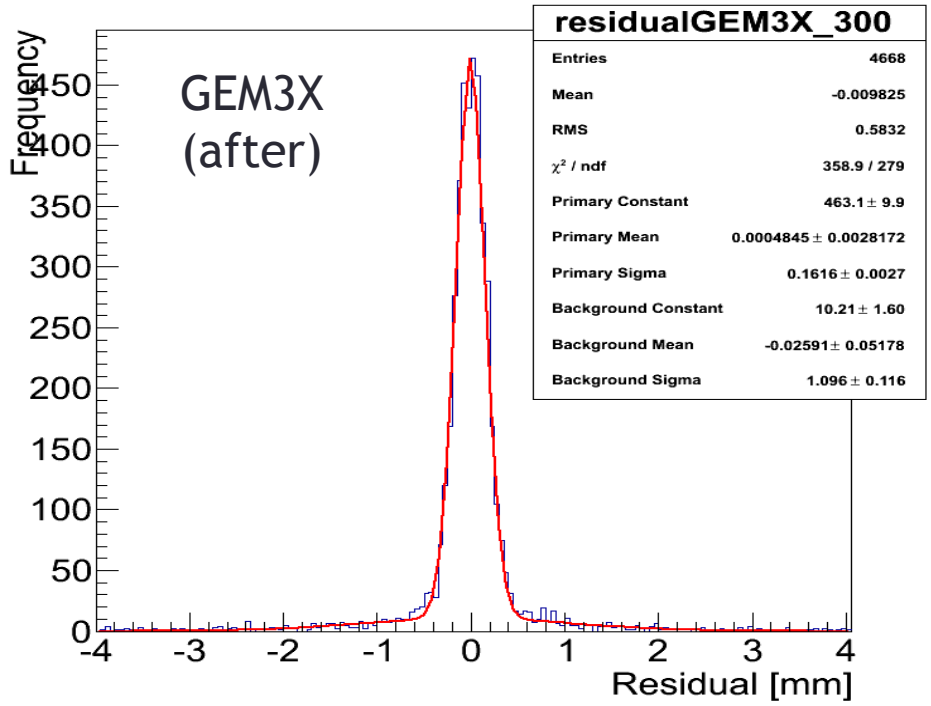


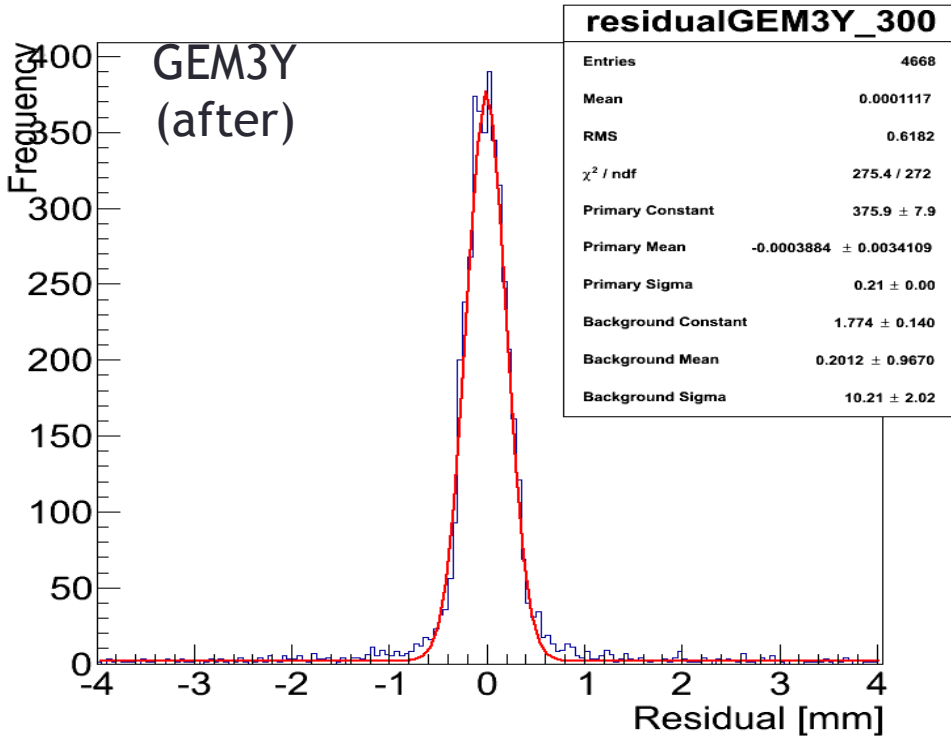


Residual Distributions for GEM3 before and after iterative alignment

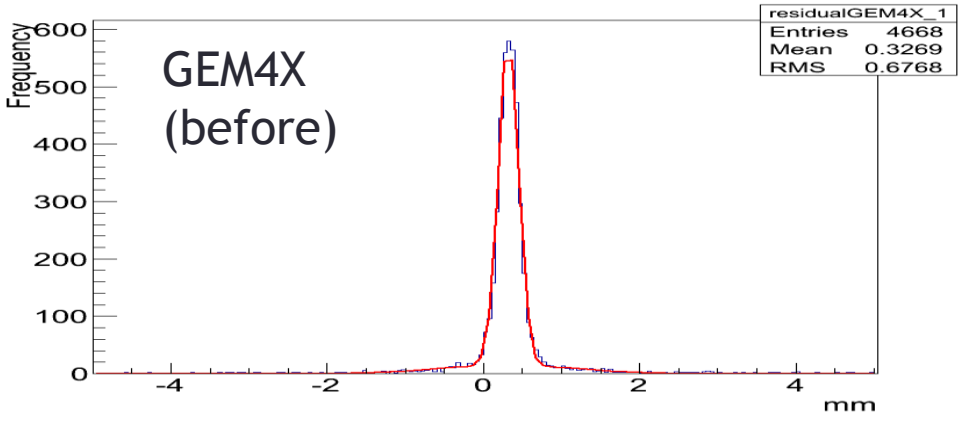


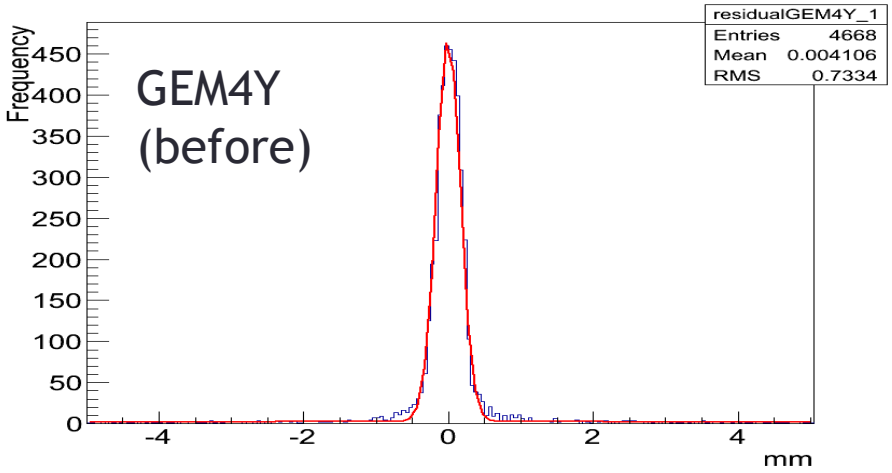


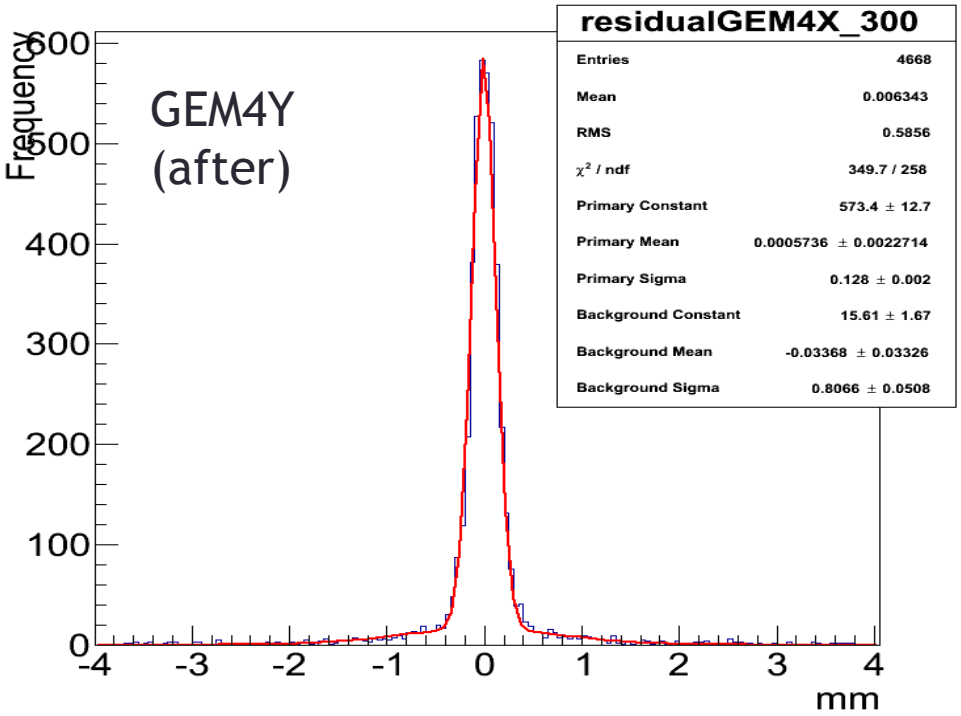


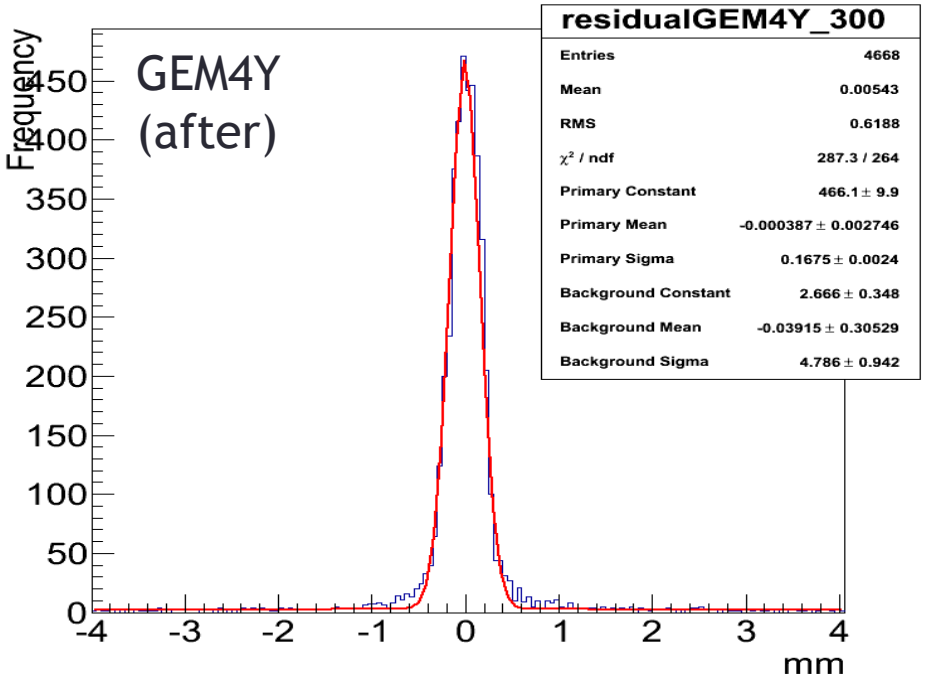


Residual Distributions for GEM4 before and after iterative alignment

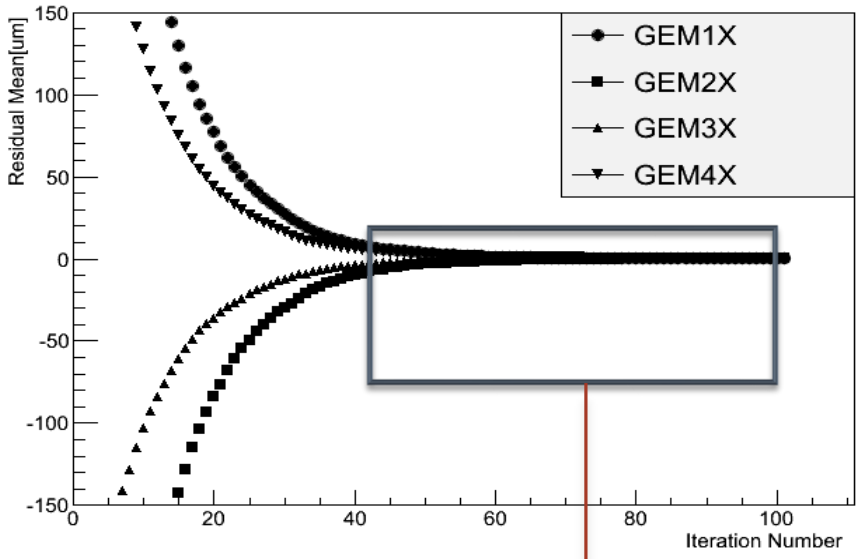


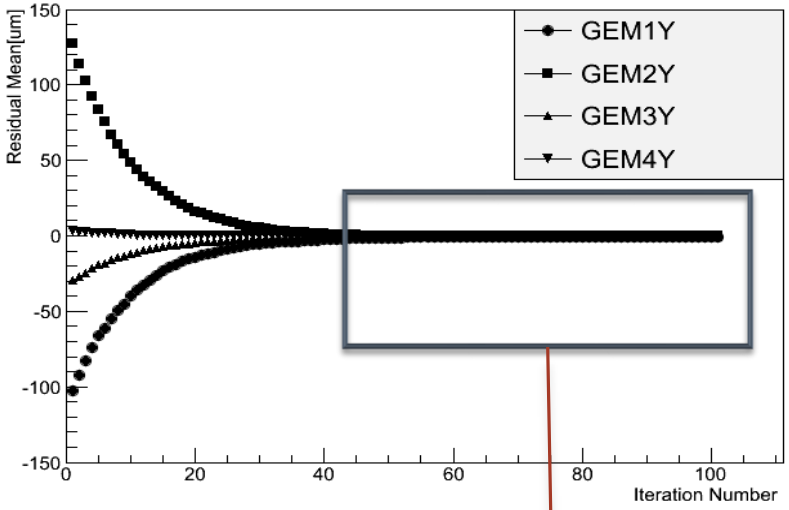


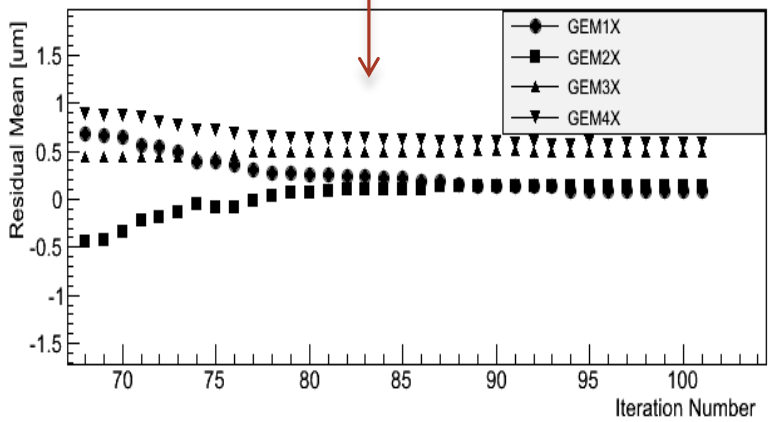


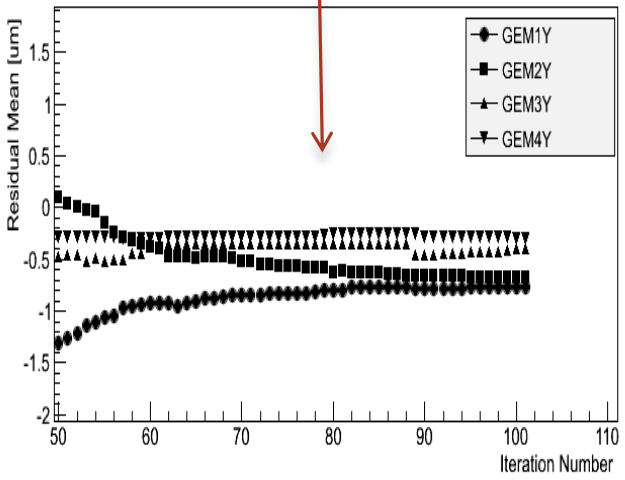


Residual Mean for every detector versus iteration number(TB)

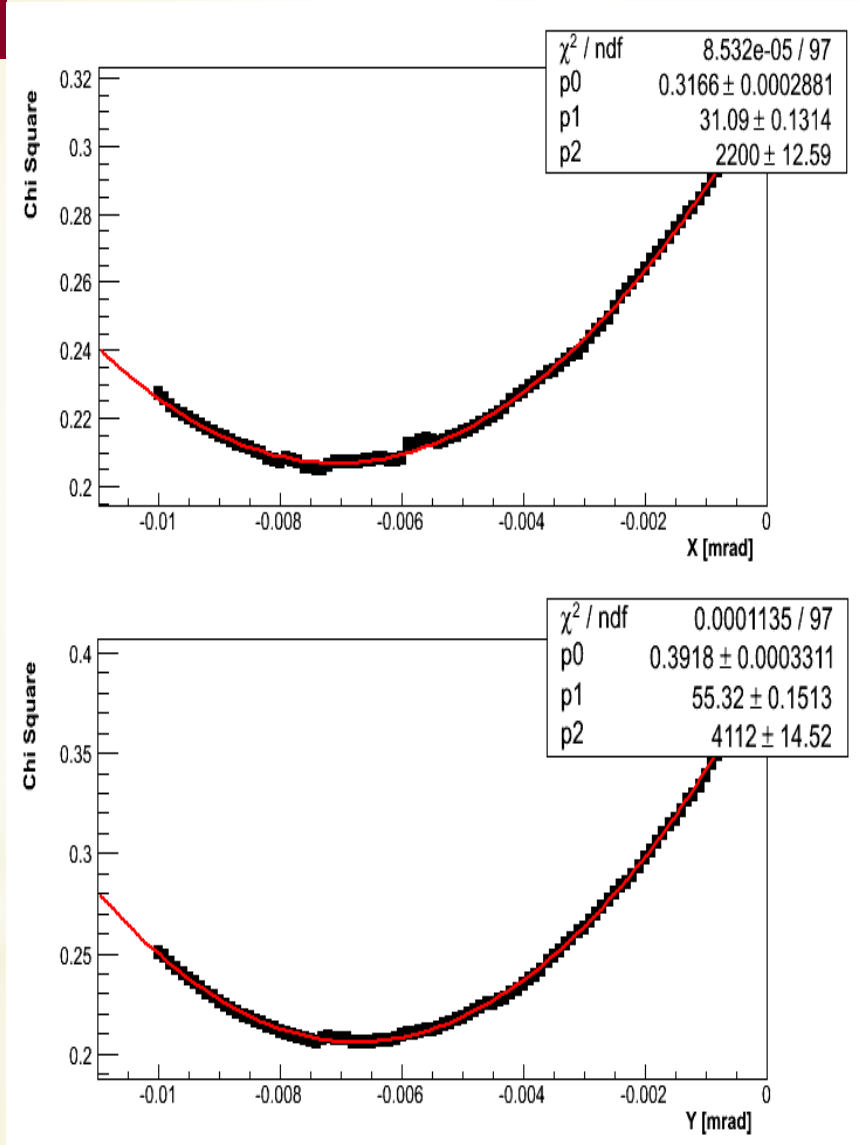






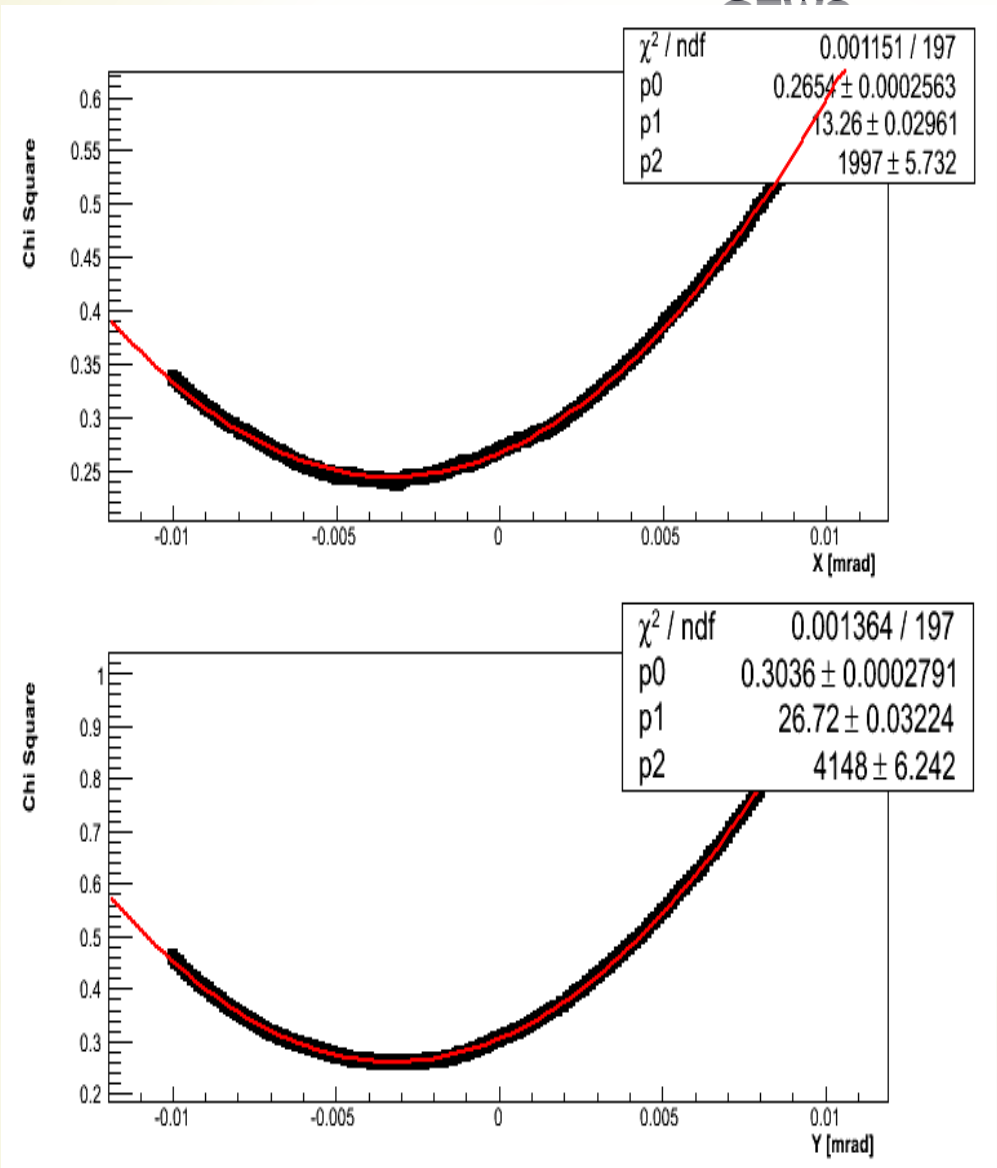


Chi Square For Θx (top) and Θy (bottom) GEM2



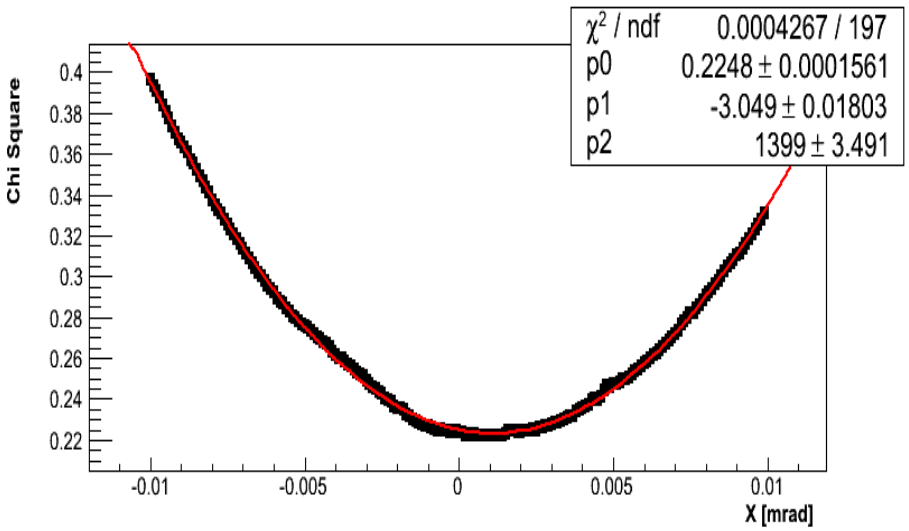
For optimizing rotation angle the shift parameters and GEM 3 & GEM 4 rotation angles are kept fixed and GEM 2 rotation angle is changed in a small range with 1 mrad step.

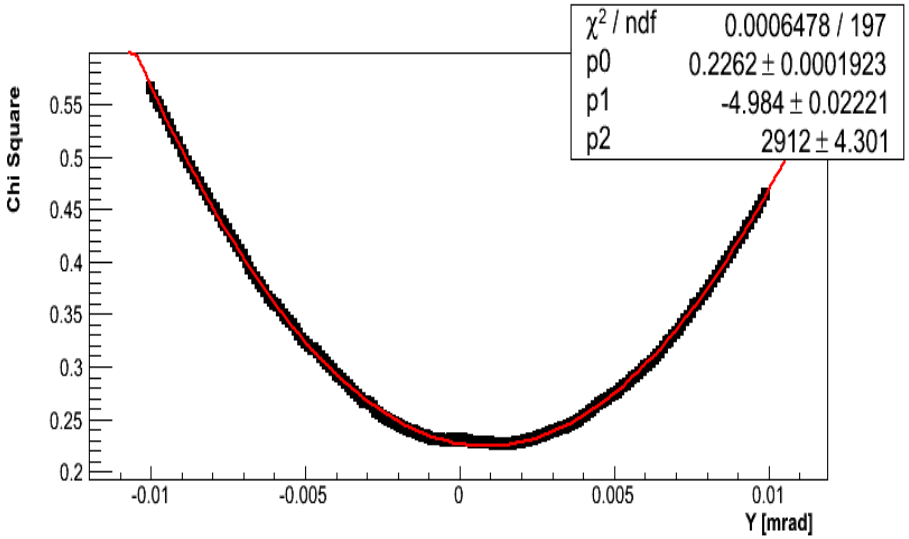
Chi Square For Θx (top) and Θy (bottom) GEM3



GEM 2 & GEM 4 rotation angles are fixed.
GEM 3 rotation angle is changing in a small range with 1 mrad step.

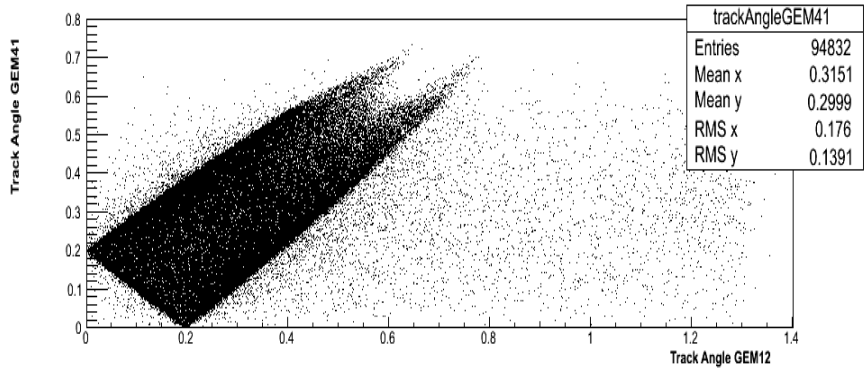
Chi Square For Θx (top) and Θy (bottom) GEM4

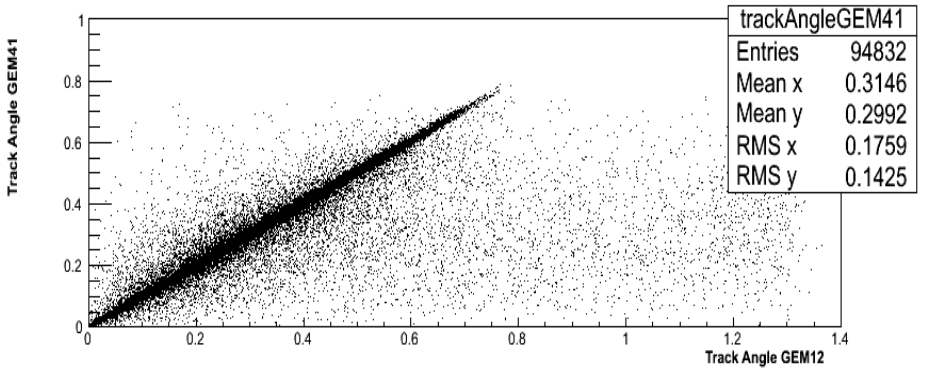


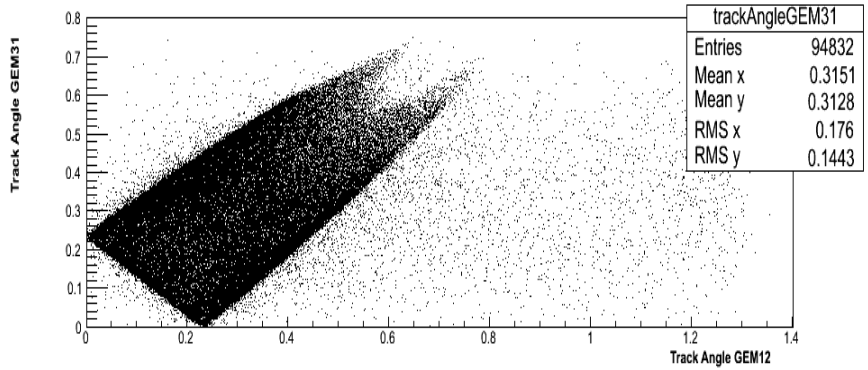


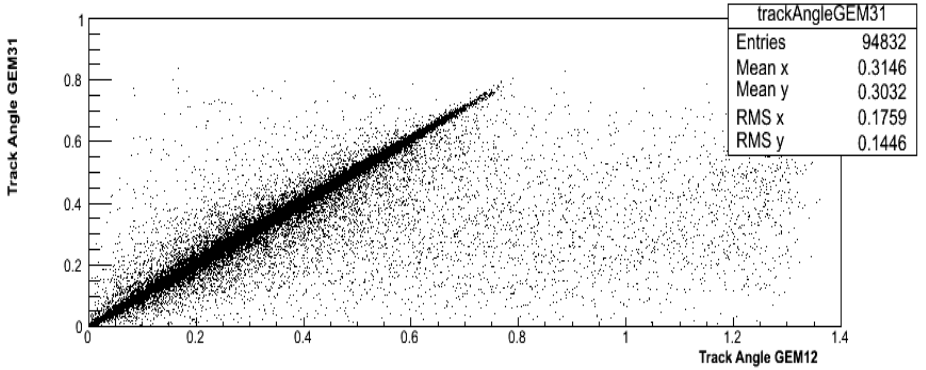
GEM 2 & GEM 3 rotation angles are fixed.
GEM 4 rotation angle is changing in a small range with 1 mrad step.

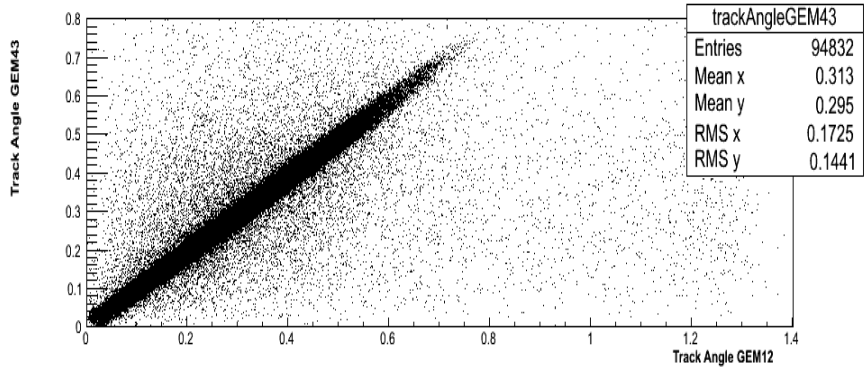
Track Angles Between GEMs Before and After Alignment(TB)

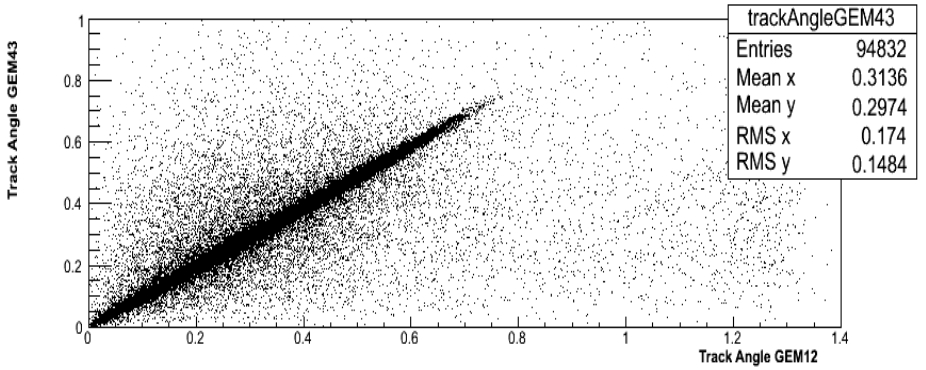












Final Shift parameters[mm] and Rotation Angles[rad] for Top and Bottom GEMs

GEM1X	GEM1Y	GEM2X	GEM2Y	GEM3X	GEM3Y	GEM4X	GEM4Y
-0.3355	-45.296	0.5460	-45.392	0.3383	45.3045	-0.5632	45.4053

q	GEM2	GEM3	GEM4
q_X	0.00256	0.0031	0.001089
q_Y	0.00172	0.00322	0.000562
q_{avg}	0.00214	0.00316	0.0008255

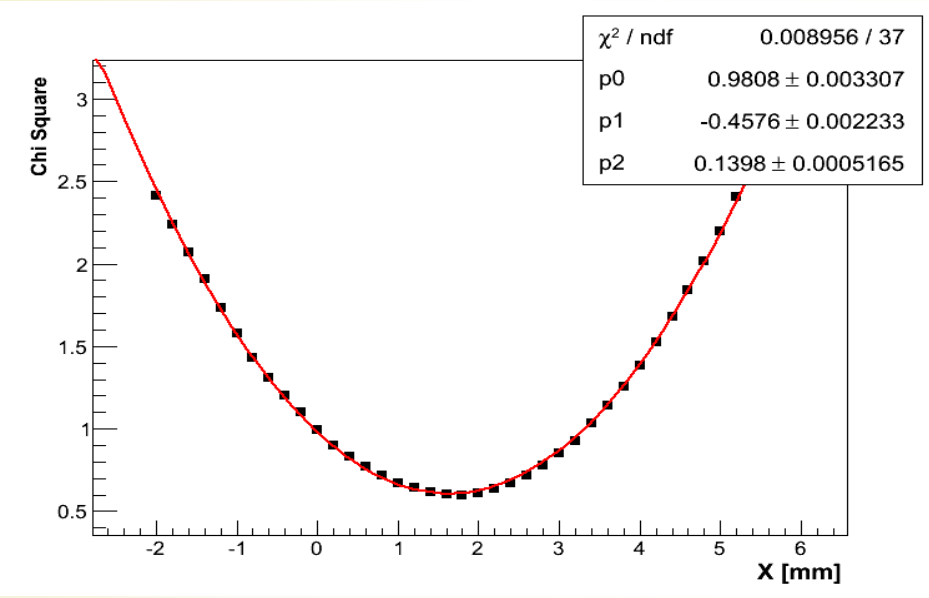
σ and residual mean before and after alignment

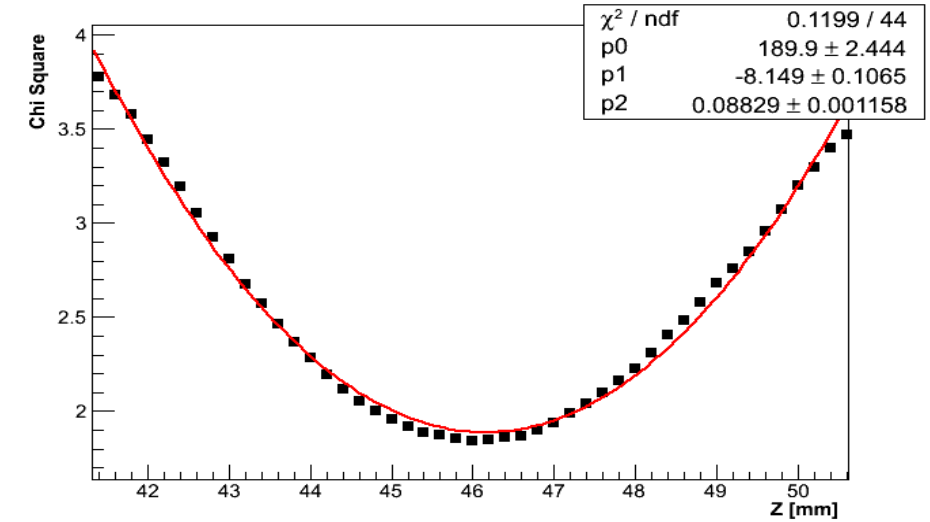
	σ (before)	σ (after)	Mean (before)	Mean (after)
GEM1X	0.06023	0.06175	0.5506	0.001301
GEM1Y	0.07238	0.07306	-0.09286	0.007464
GEM2X	0.09244	0.09253	-0.6091	-0.0002348
GEM2Y	0.1011	0.1012	0.1219	-0.002994
GEM3X	0.171	0.1616	-0.2645	-0.009825
GEM3Y	0.2087	0.210	-0.0308	0.0001117
GEM4X	0.1289	0.1280	0.3269	0.006343
GEM4Y	0.1672	0.1675	0.004106	0.00543

What are the Alignment Steps for Left and Right Detectors?

1- Defining GEM 5 as a reference.
2- Finding the initial shift parameters by calculating the chi square of fitted tracks.
3- Shifting each detector iteratively in X-Z plane.
4- fitting straight lines to the hits in X and Z in each iteration.
5- Taking 20% of the residual mean value as the shift parameter in the next iteration.
6- Rotating detectors in X-Z plane with respect to GEM 5.
7- Optimizing the rotation angles

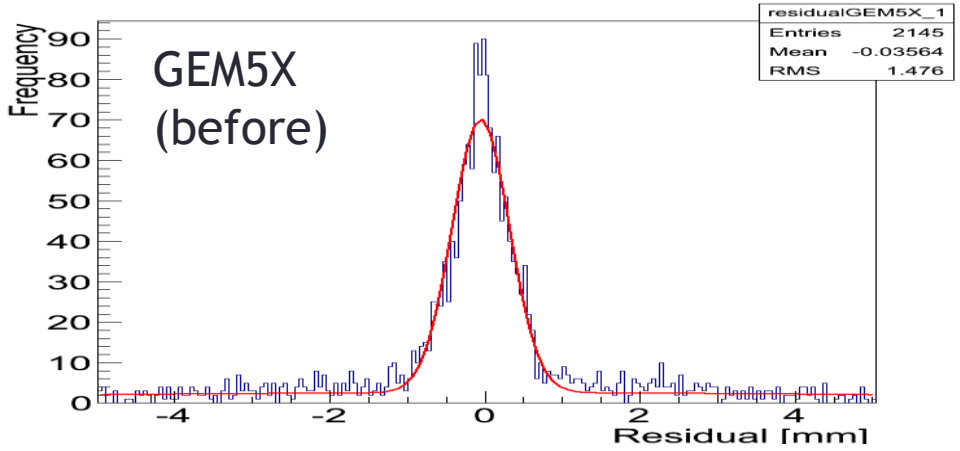
Chi Square For X and Z for GEM5

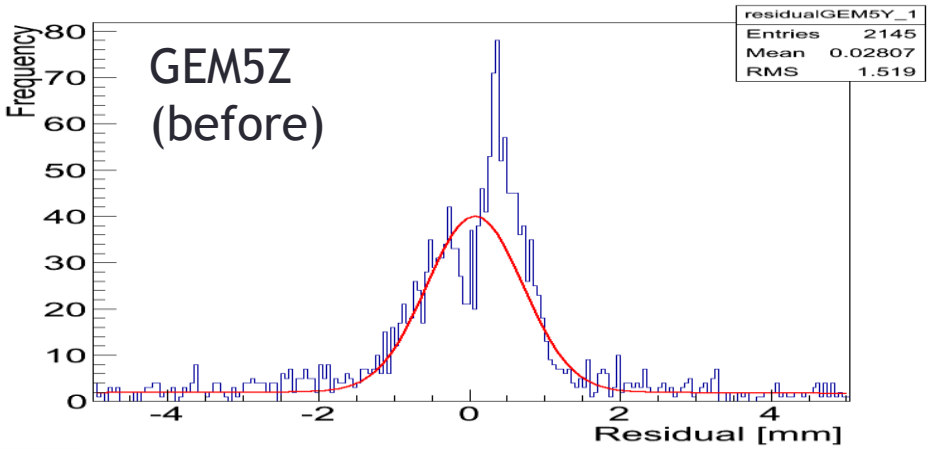


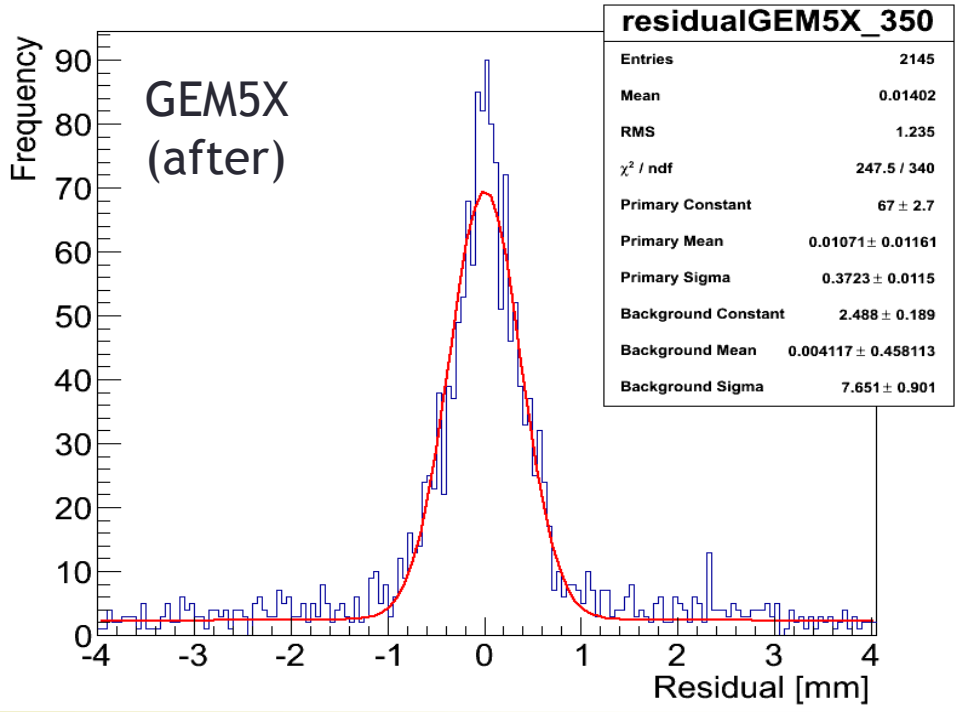


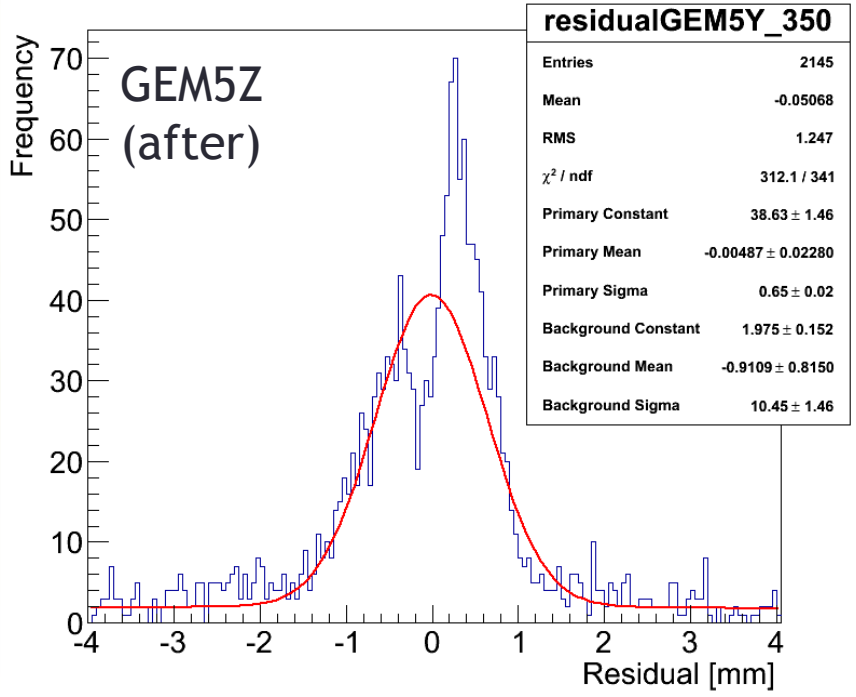
For finding the initial values of GEM5X and GEM5Z,X and Z are changed in a specific range with a 0.2 mm step.
The same calculation is done for other GEMs.

Residual Distributions for GEM5 before and after iterative alignment

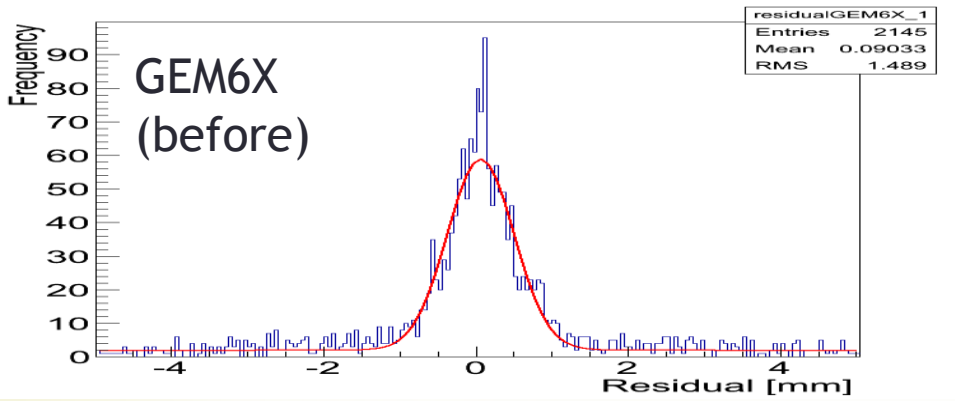


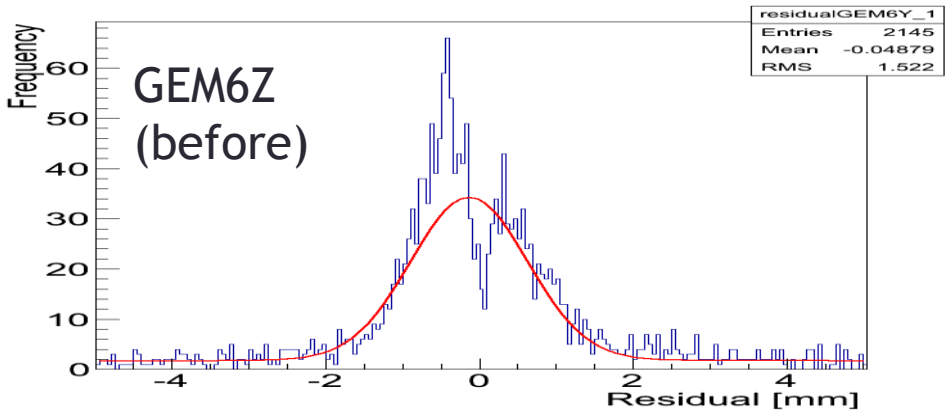


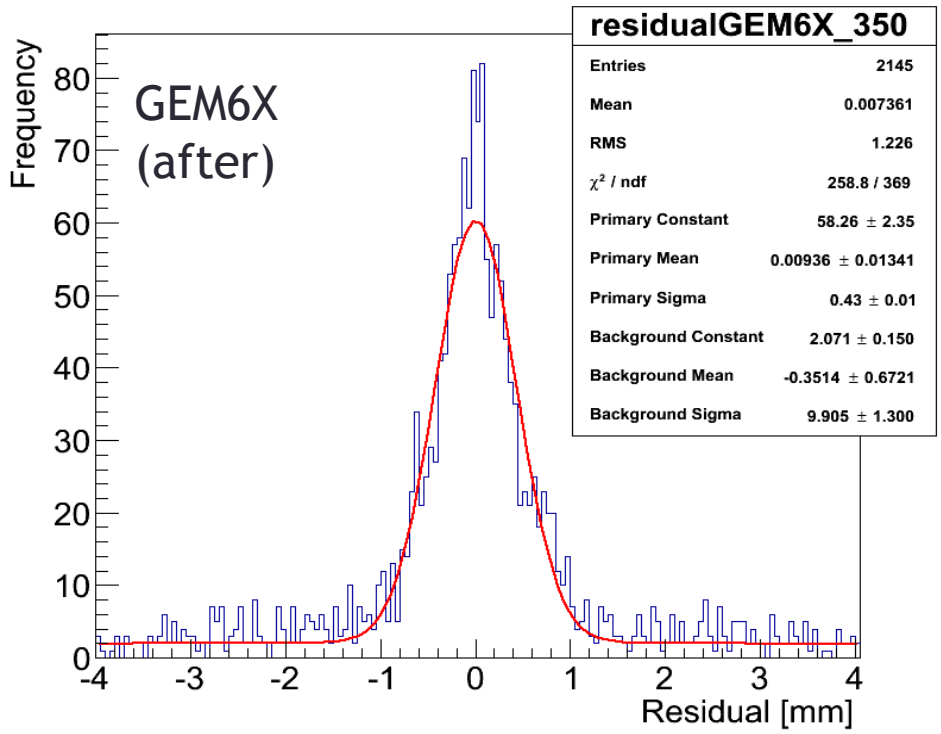


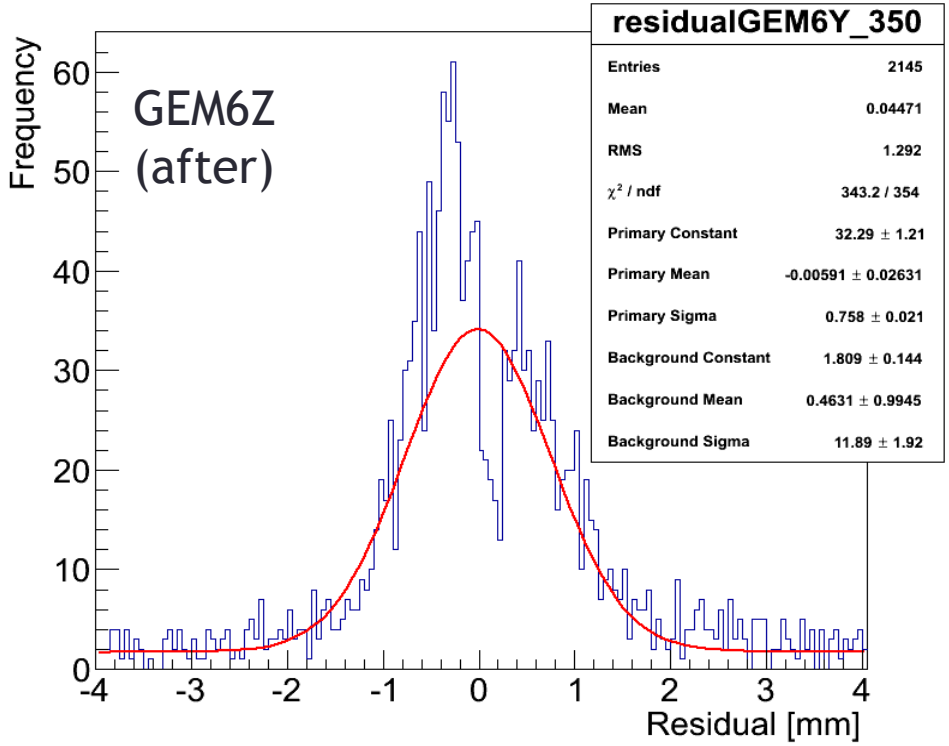


Residual Distributions for GEM6 before and after iterative alignment

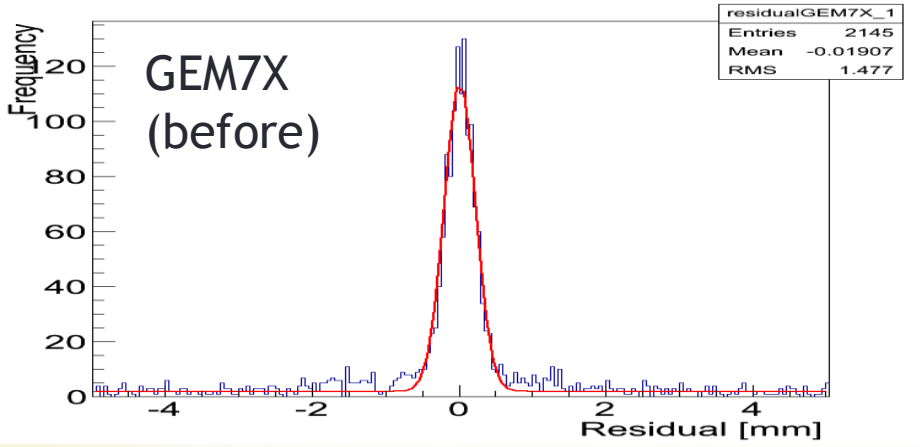


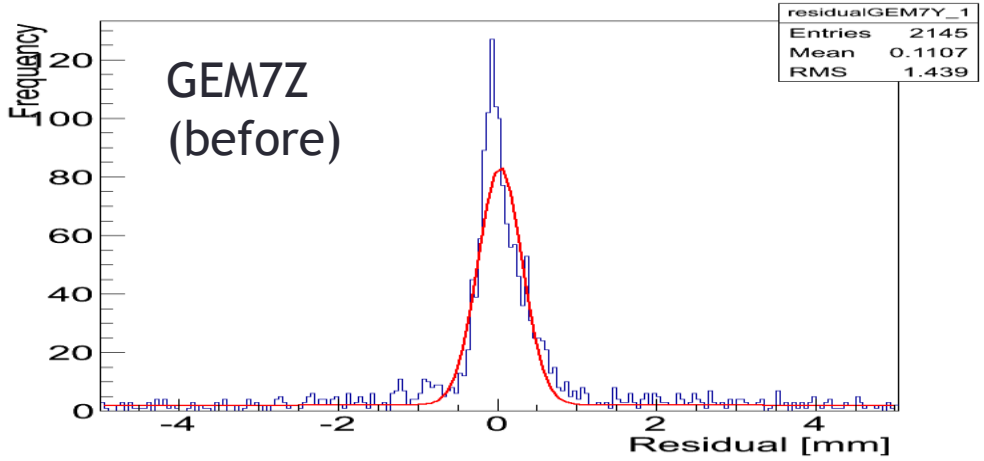


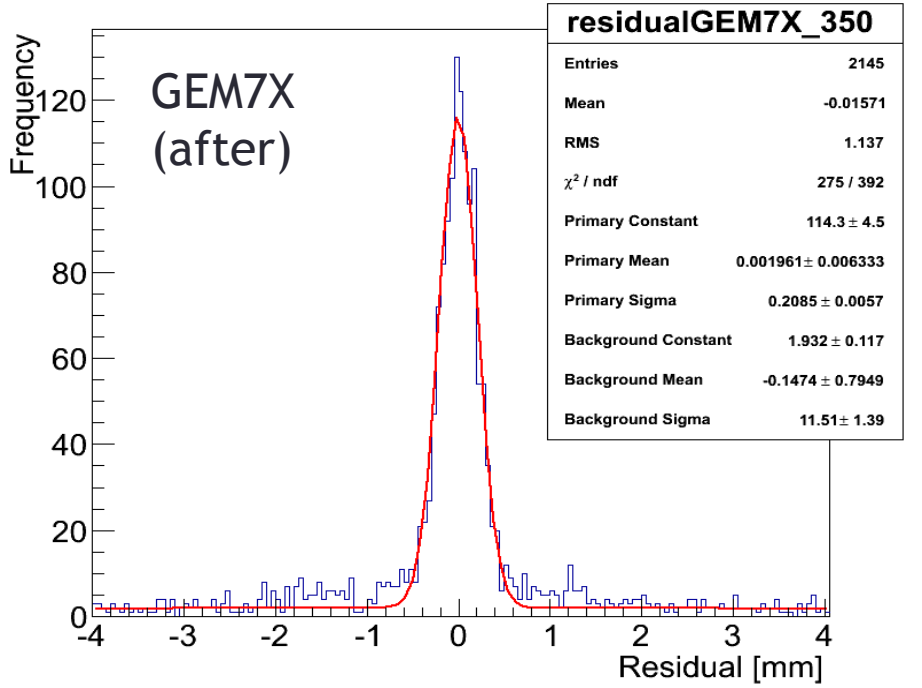


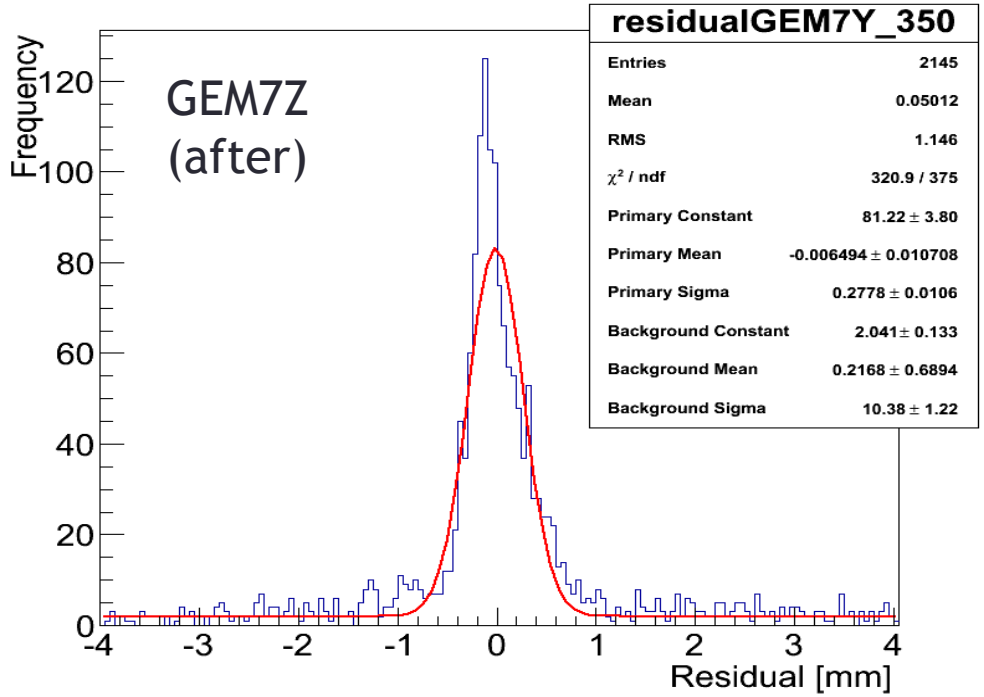


residual distributions for GEM7 before and after iterative alignment

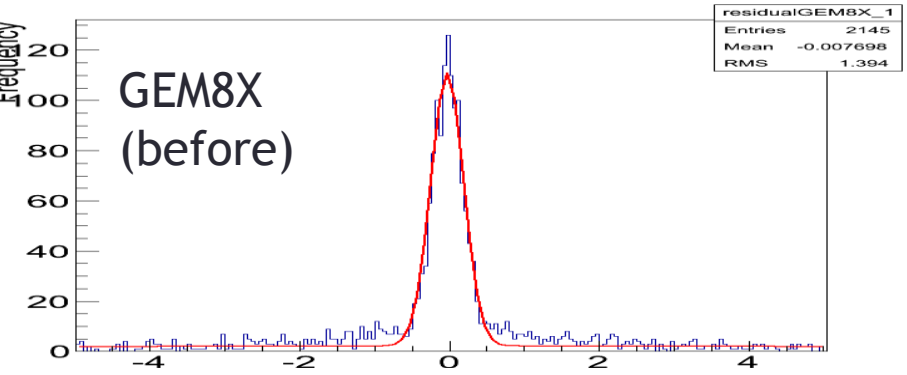


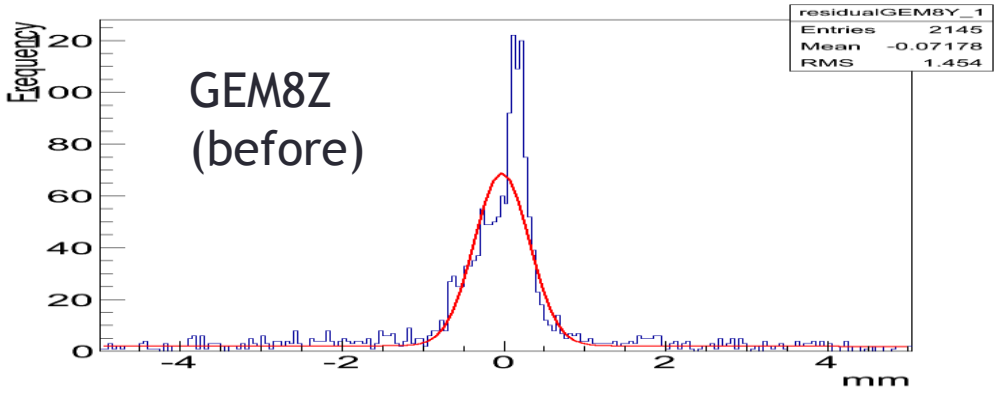


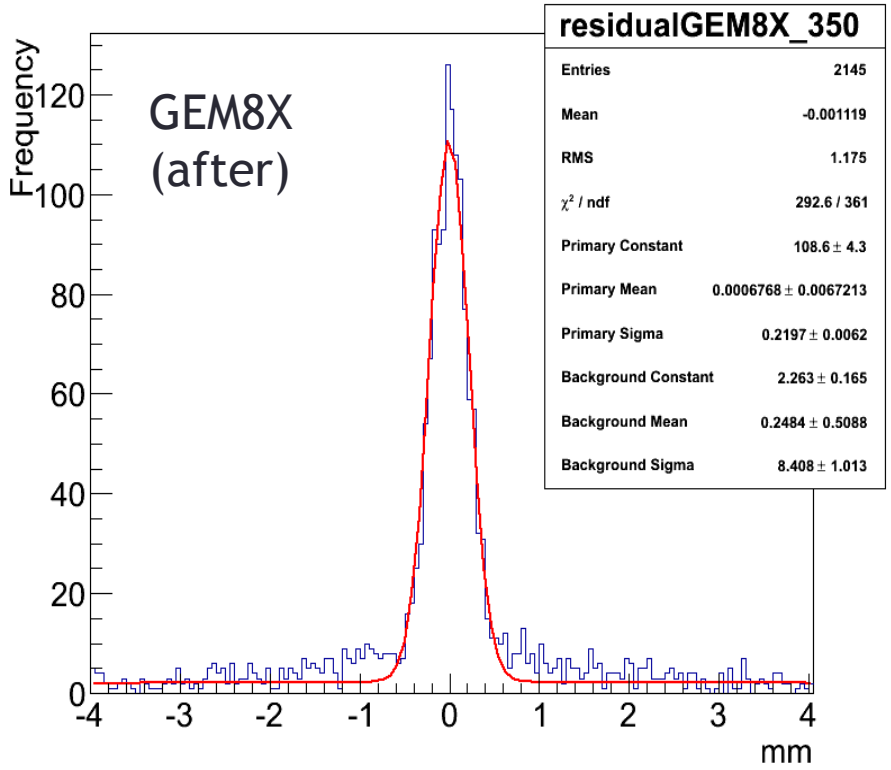


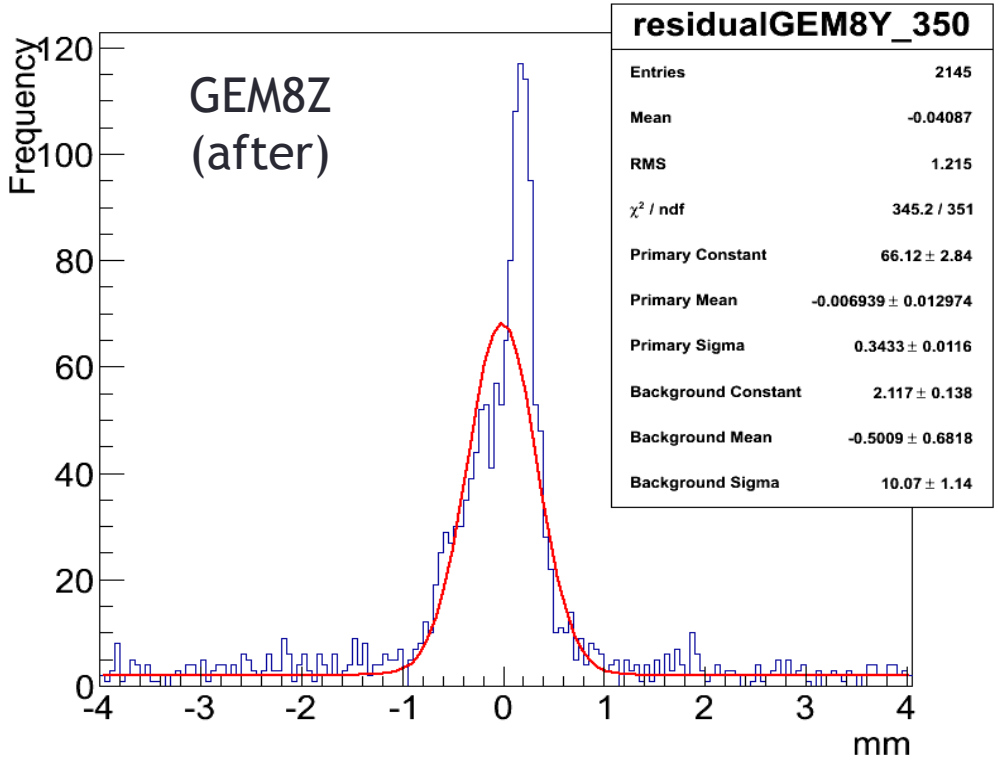


residual distributions for GEM8 before and after iterative alignment

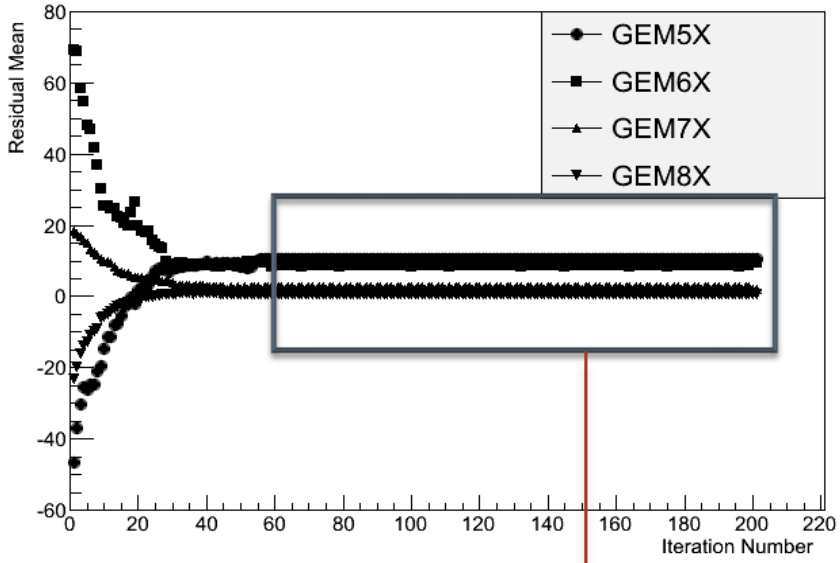


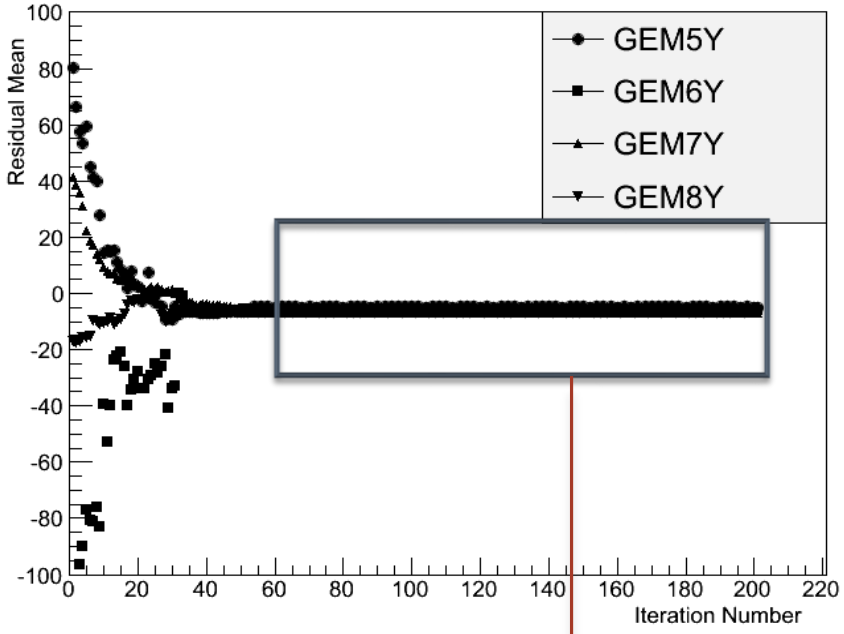


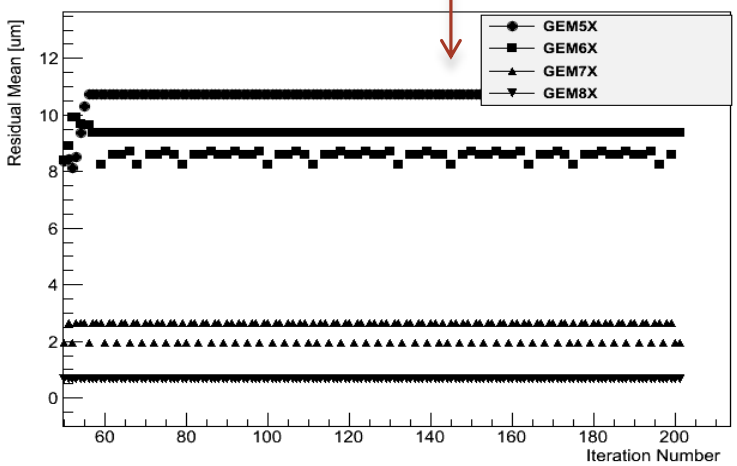


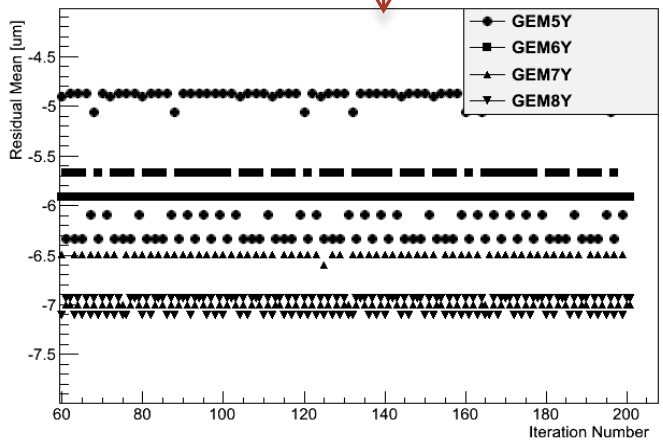


Residual Mean for every detector versus iteration number(LR)

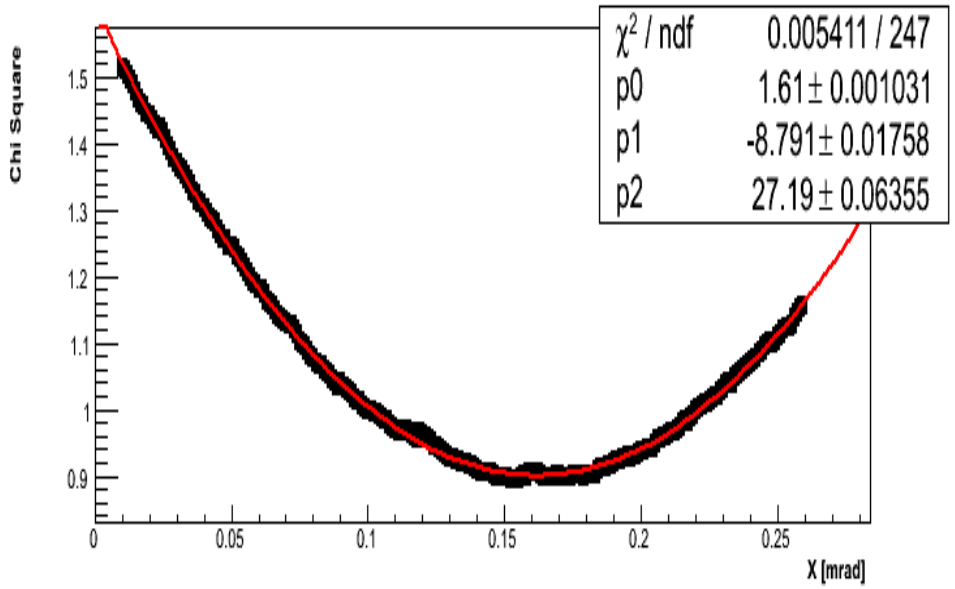


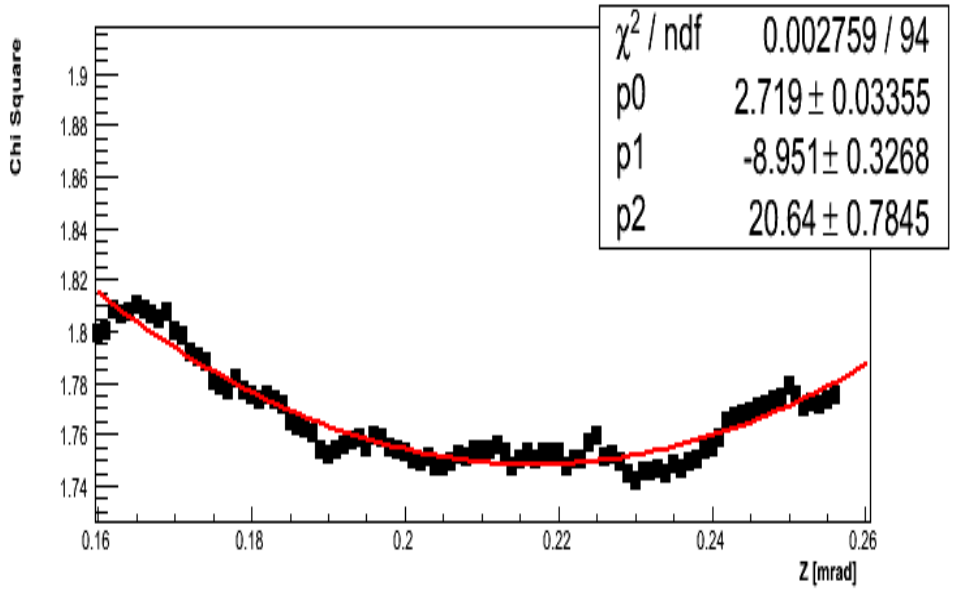






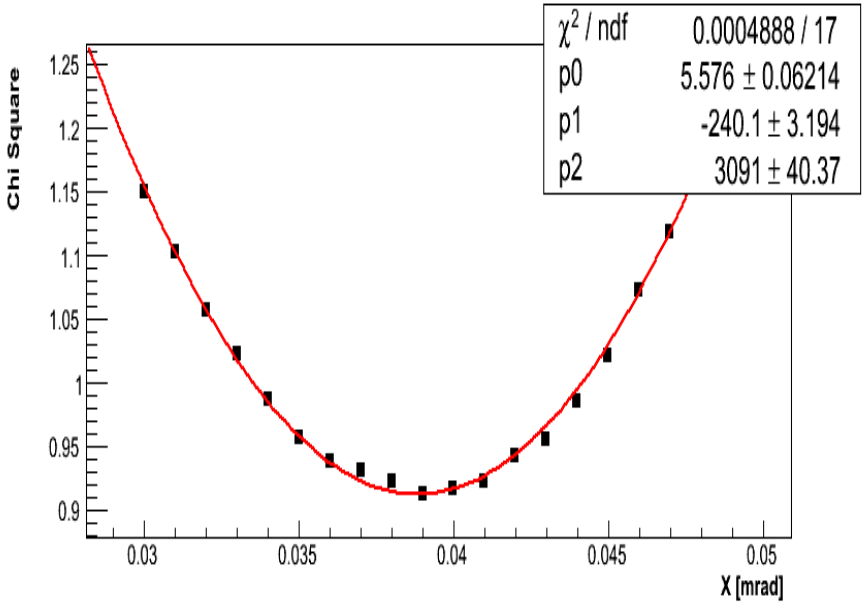
Chi Square For Θx and Θz GEM6

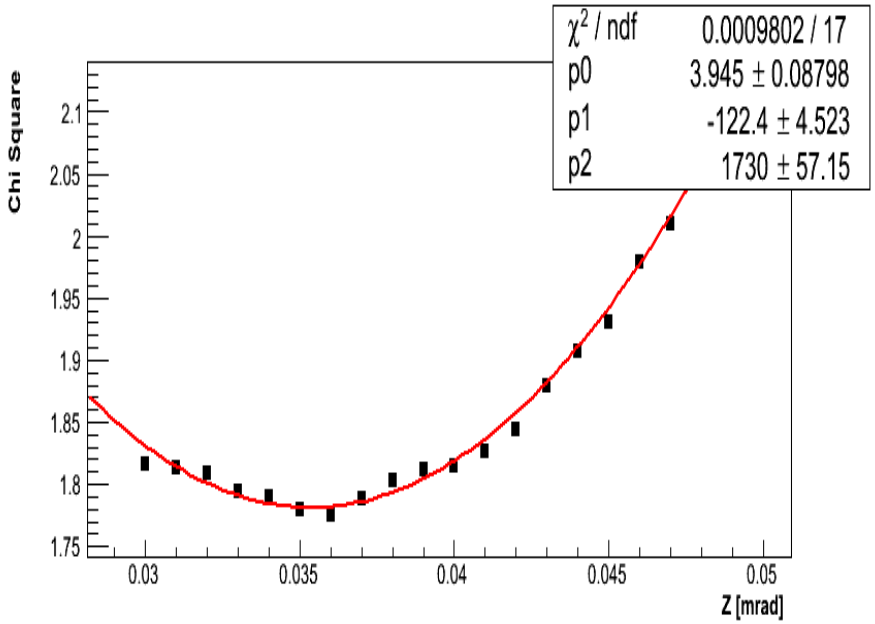




For optimizing rotation angle the shift parameters and GEM 7 & GEM 8 rotation angles are kept fixed and GEM 6 rotation angle is changed in a small range with 1 mrad step.

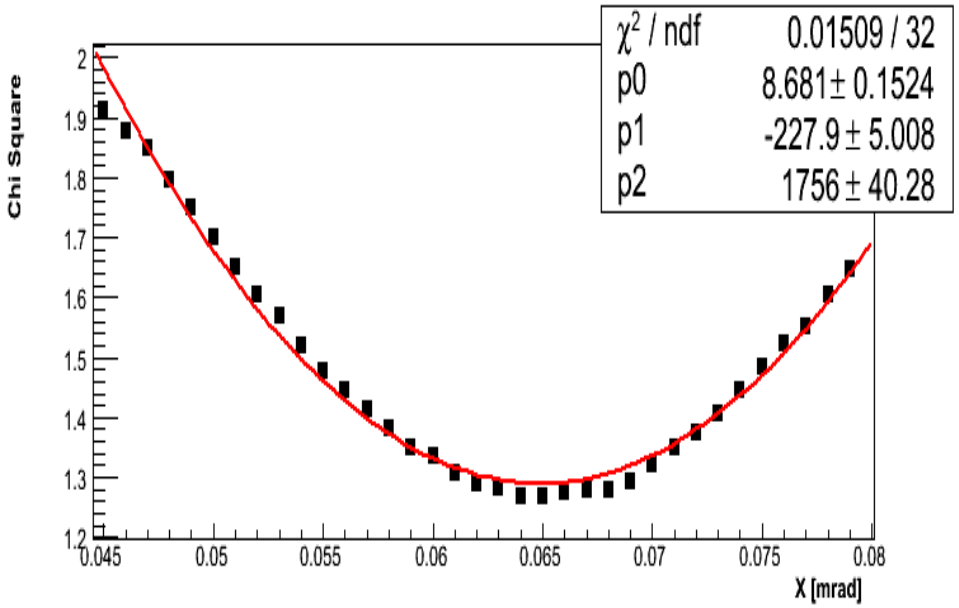
Chi Square For Θx (top) and Θz (bottom) GEM7

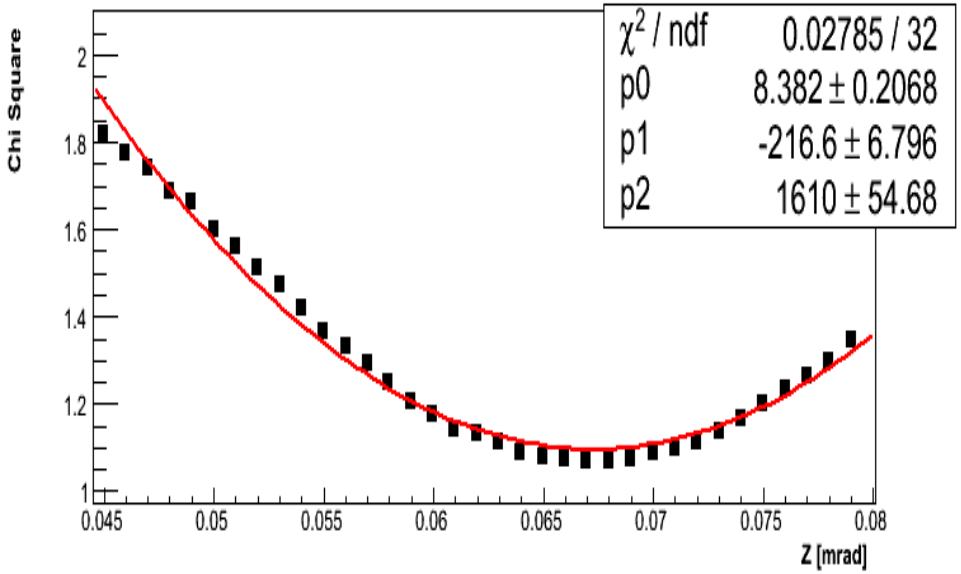




GEM 6 & GEM 8 rotation angles are fixed.
GEM 7 rotation angle is changing in a small range with 1 mrad step.

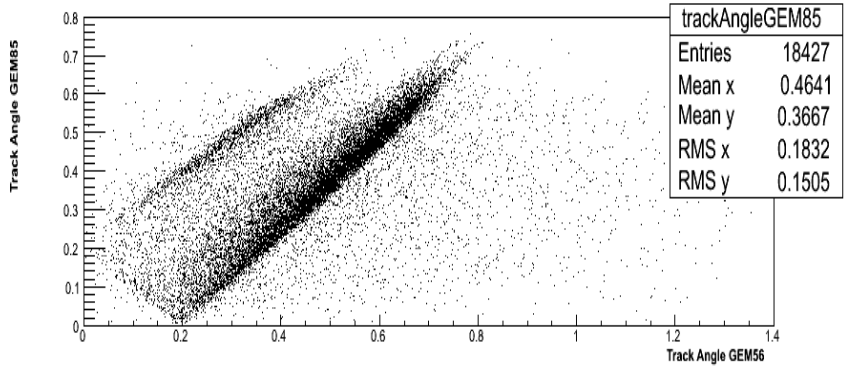
Chi Square For Θx (top) and Θz (bottom) GEM8

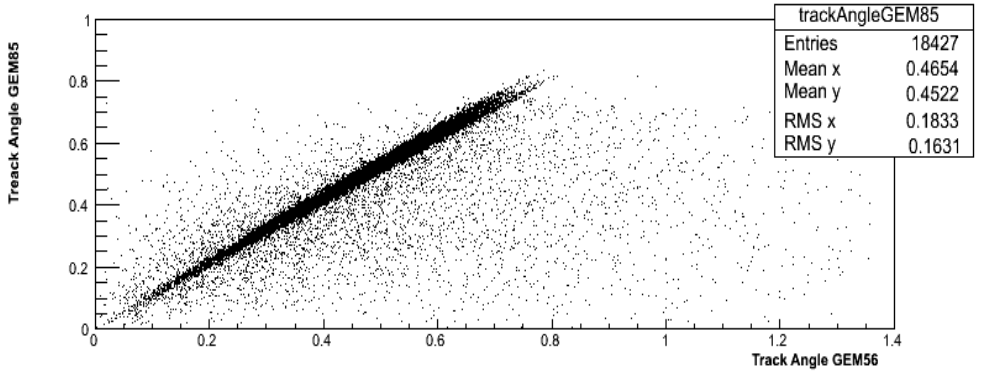


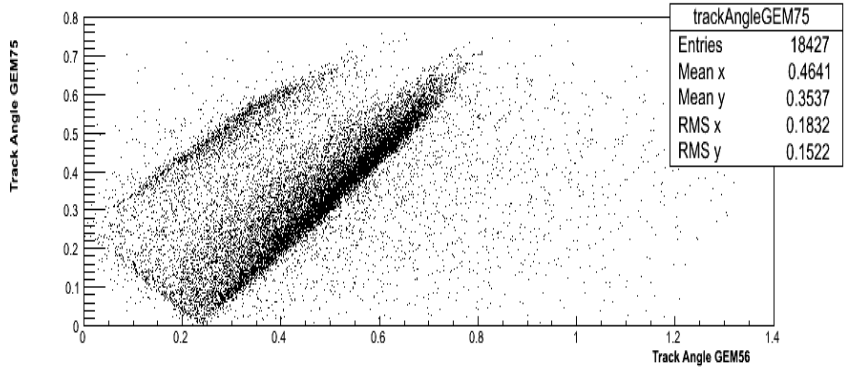


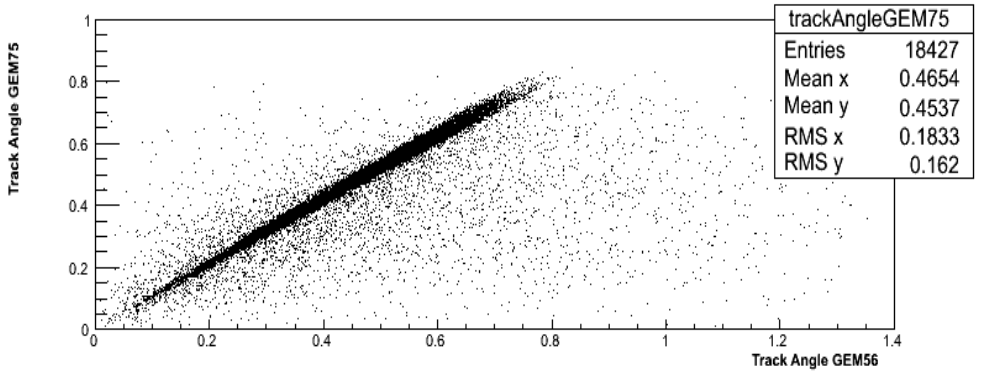
GEM 6 & GEM 7 rotation angles are fixed.
GEM 8 rotation angle is changing in a small range with 1 mrad step.

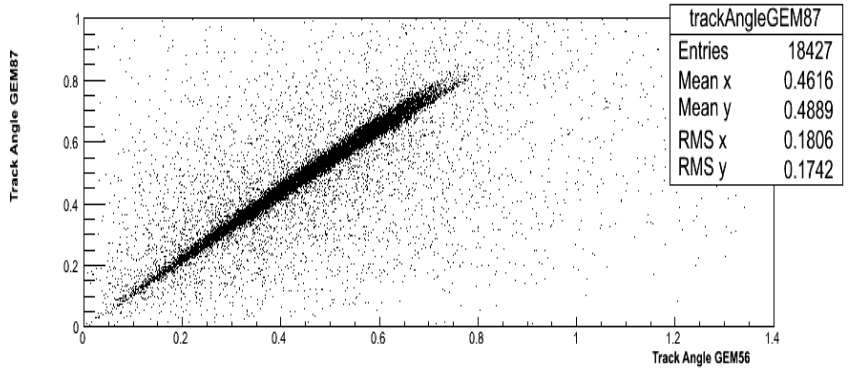
Track Angles Between GEMs Before and After Alignment(Left and Right Detectors)

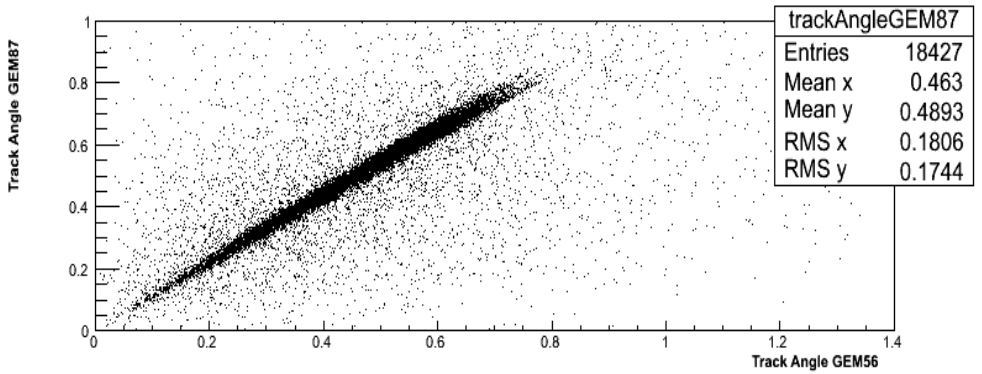












Final Shift parameters[mm] and Rotation Angles[rad] for Left and Right GEMs

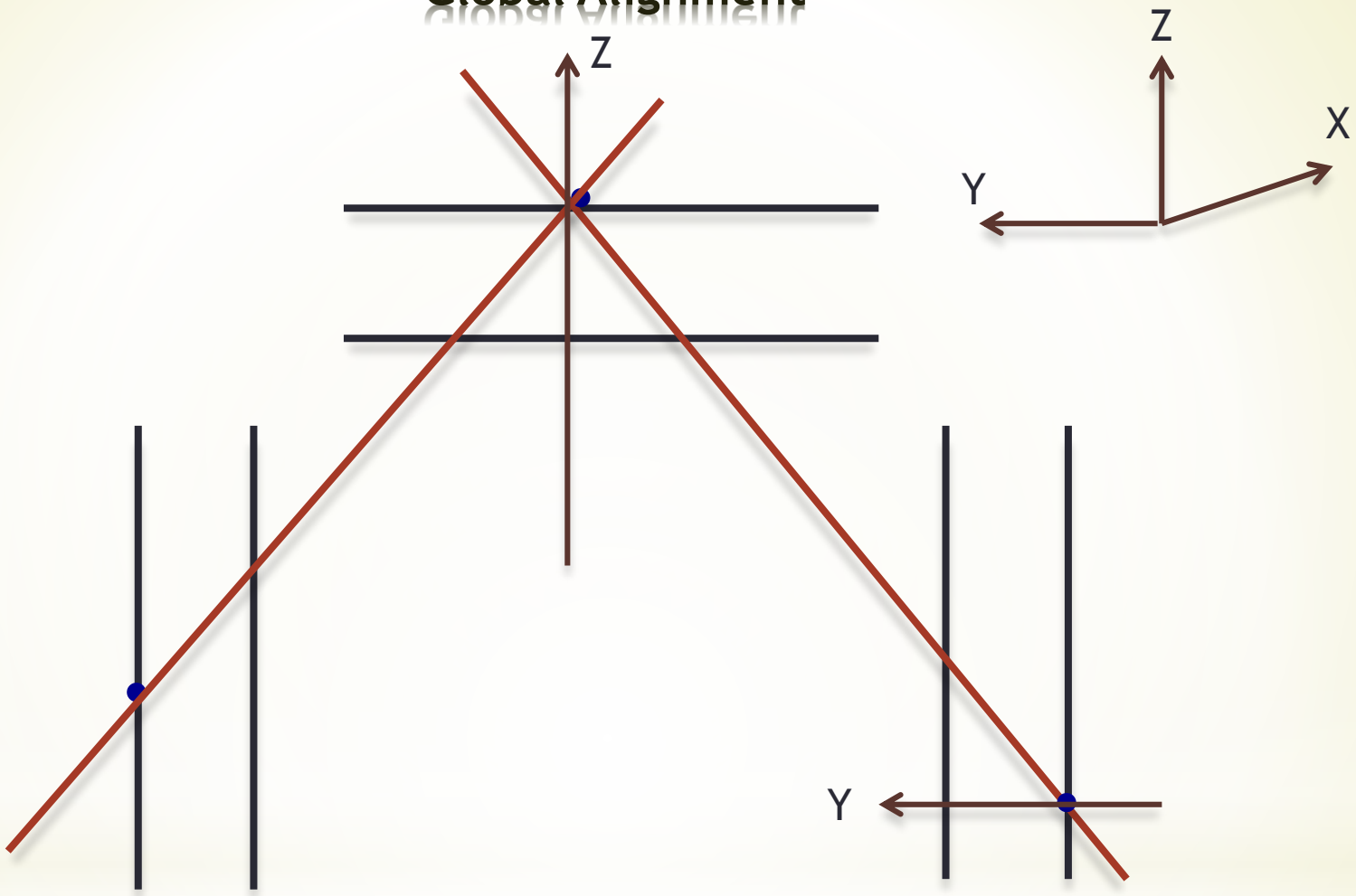
GEM5X	GEM5Y	GEM6X	GEM6Y	GEM7X	GEM7Y	GEM8X	GEM8Y
-1.6851	-45.4046	-1.7710	-45.1968	1.4670	45.5243	1.5378	45.5904

q	GEM6	GEM7	GEM8
q_X	0.005167	0.0388	0.0434
q_Y	0.0109	0.0354	0.04939
q_{avg}	0.00803	0.0371	0.04639

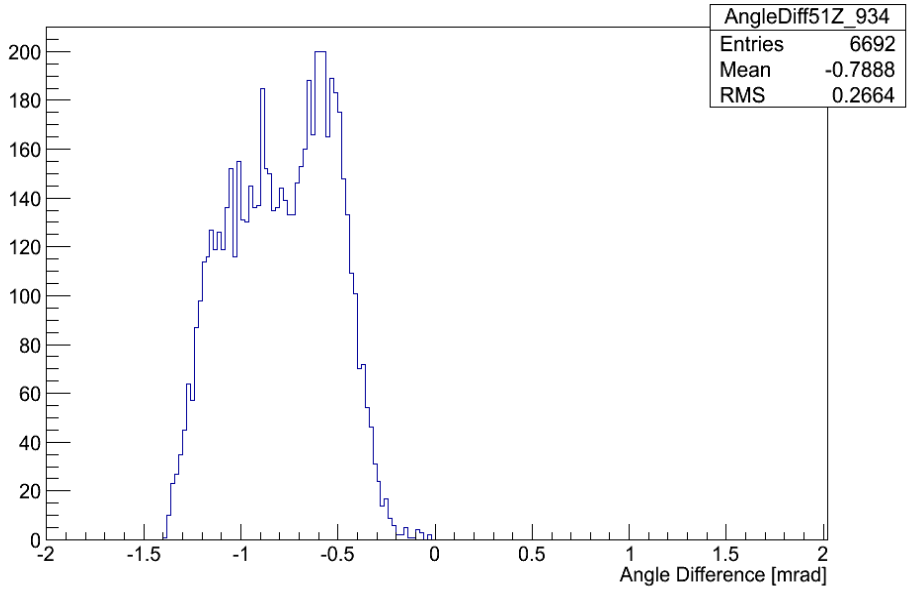
σ and residual mean before and after alignment

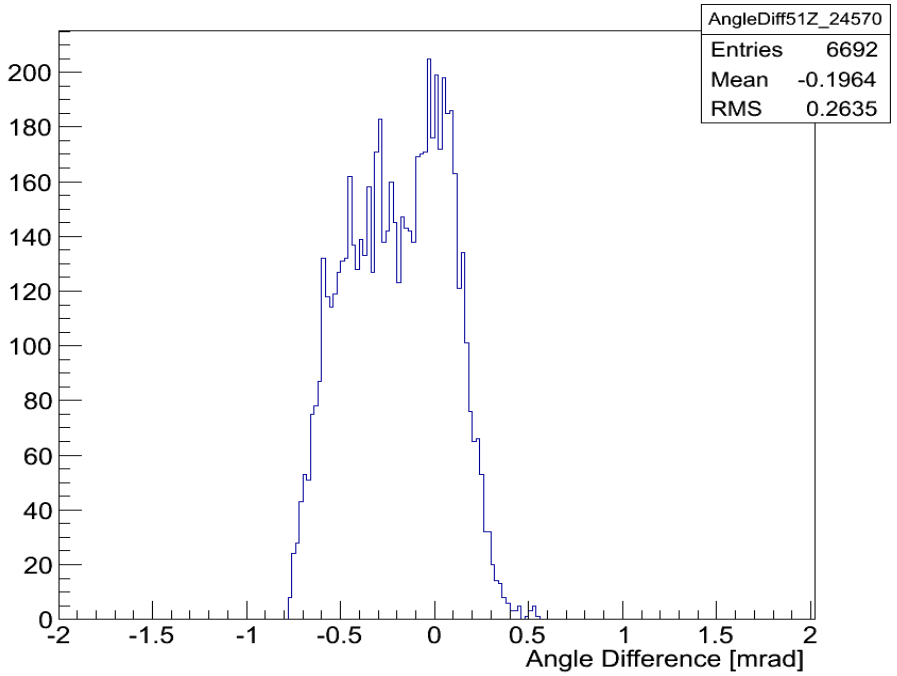
	σ (before)	σ (after)	Mean (before)	Mean (after)
GEM5X	0.3697	0.3723	-0.03564	0.01402
GEM5Y	0.639	0.65	0.02807	-0.05068
GEM6X	0.4395	0.430	0.09033	0.007361
GEM6Y	0.7626	0.758	-0.04879	0.04471
GEM7X	0.2122	0.2085	-0.01907	-0.01571
GEM7Y	0.2763	0.2778	0.1107	0.05012
GEM8X	0.2197	0.2197	-0.007696	-0.001119
GEM8Y	0.3394	0.3433	-0.07178	-0.04087

Global Alignment



Angle Difference for Global Alignment





Final Shift Parameters [mm] for the Global Alignment

X	Y	Z	Mean Angle Difference (before)	Mean Angle Difference (after)
5.8	-1.8	6.6	-0.7888	-0.1964

Conclusions

- The alignment is done precisely because:
  1) The residual mean values are almost 0 after alignment.
  2)The Chi Square tests show a parabolic trend.
  3)The track angles are diagonal after alignment.

- The best final shift parameters and rotation angles is calculated from the track candidates.

Future Work

- Using more detectors in order to get better statistics for doing alignment.
- Using 3D fit for doing Global Alignment
- Redesigning the Printed Circuit Board(PCB) of detectors
- Placing GEM 5 and GEM 6 completely vertical in the frame
- Using web base software Slow Control Run Initialization Byte-wise Environment(SCRIBE)
- Using cluster to process data

Thanks!
Questions?