Calibration of HyCal and GEM Z position

- Solving the following system of equations, for each double arm Moller, we have an analytic solution for Z:
  - $E_{beam} + m = E_1 + E_2$, where m is electron mass, E1, E2 are energy of scattered electrons
  - $P_1 \sin(\theta_1) = P_2 \sin(\theta_2)$ where P_1 and P_2 are scattered electron momenta, and theta are their polar angle in lab
  - $P_1 \cos(\theta_2) + P_2 \cos(\theta_2) = P_{beam}$
  - $\sin(\theta_1) = \frac{R_1}{\sqrt{R_1^2 + z^2}}$ and $\cos(\theta_1) = \frac{z}{\sqrt{R_1^2 + z^2}}$

  - It can be solved without neglecting electron mass:

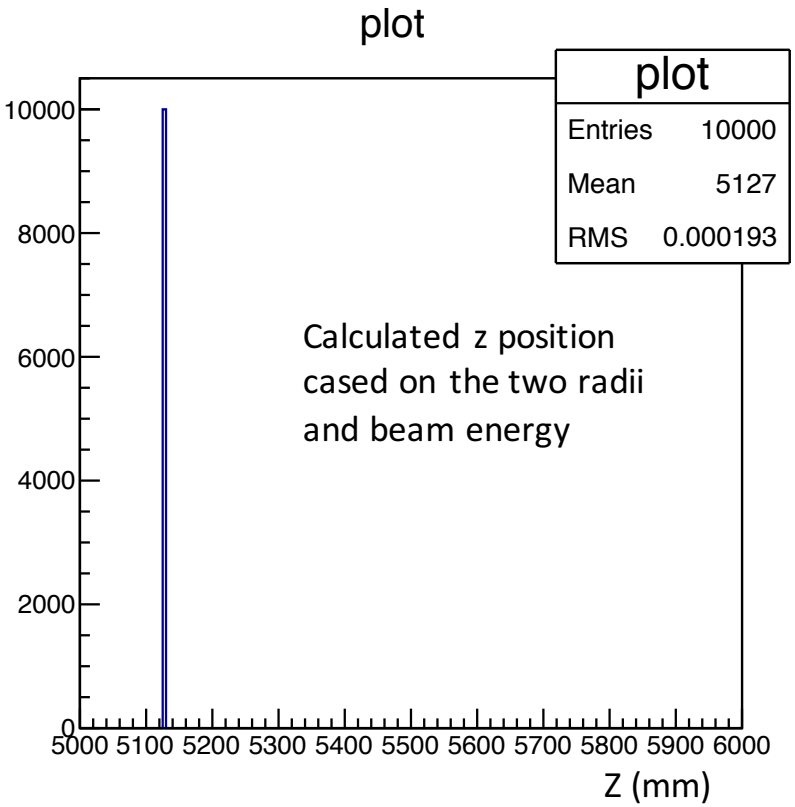
$$z = \sqrt{(m + E_{beam}) R_1 R_2 / (2m)}$$

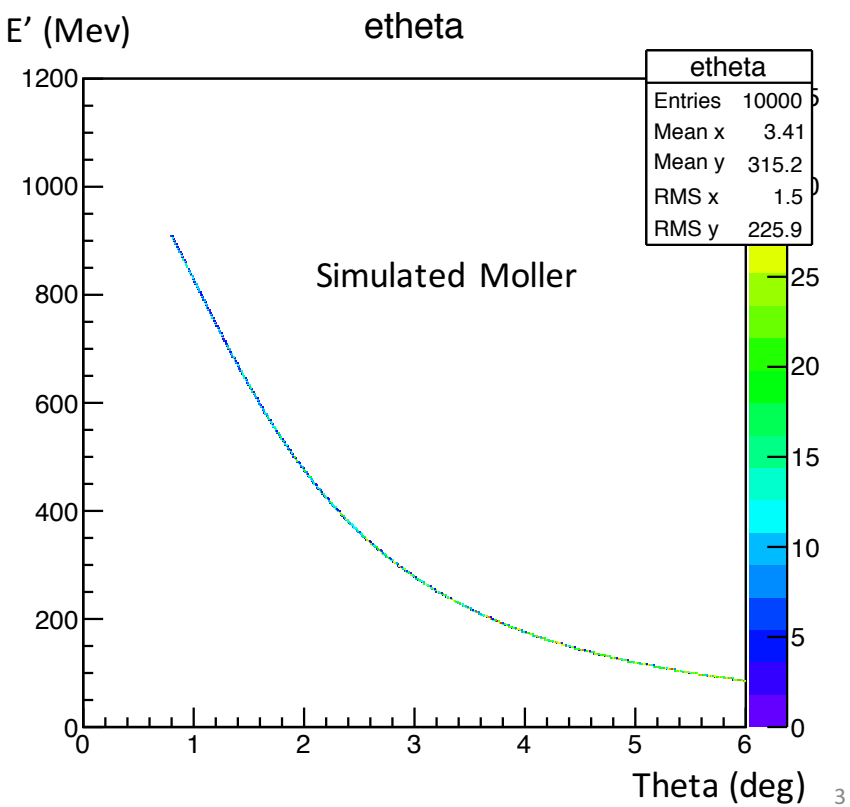
Testing the Formula

- Simple MC to generate double arm Mollers based on kinematics (only need the scattering angle of one of the scattered electron)
- Energy of the scattered Moller electron, without neglecting electron mass:
  - $E' = \frac{m\times(E_{beam}+cos^2(\theta)E_{beam}+m\left(1-cos^2(\theta)\right))}{E_{beam}-cos^2(\theta)E_{beam}+m(1+cos^2(\theta))}$
  - Using conservation to get the angle and energy of the other electron
  - Given a predefined z position of a detector, calculate the radii of the two electrons
  - Plug back to the expression of z in the previous page to check consistency

Testing the Formula

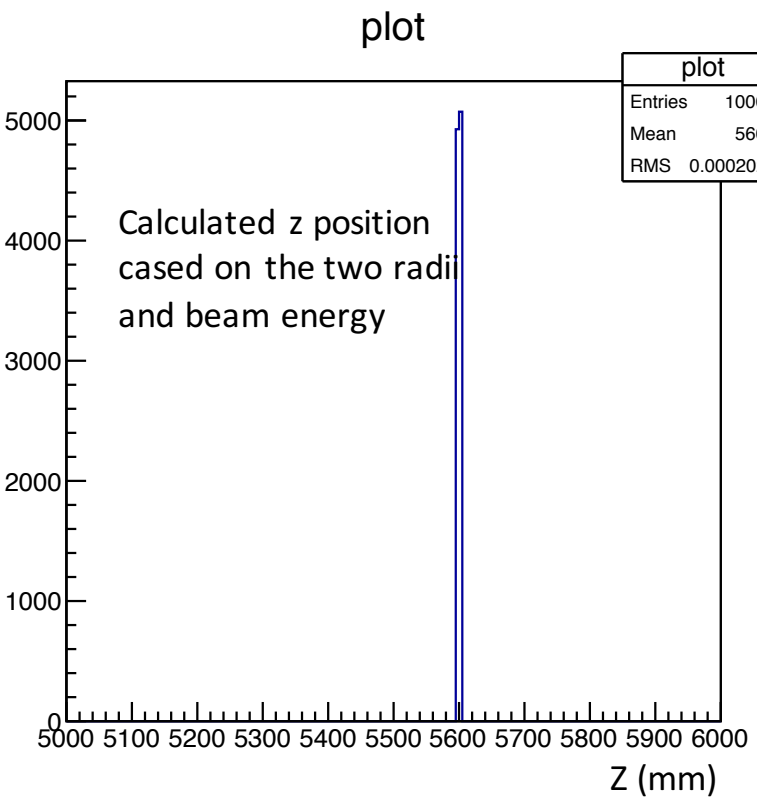
Setting z = 5127 in the simulation

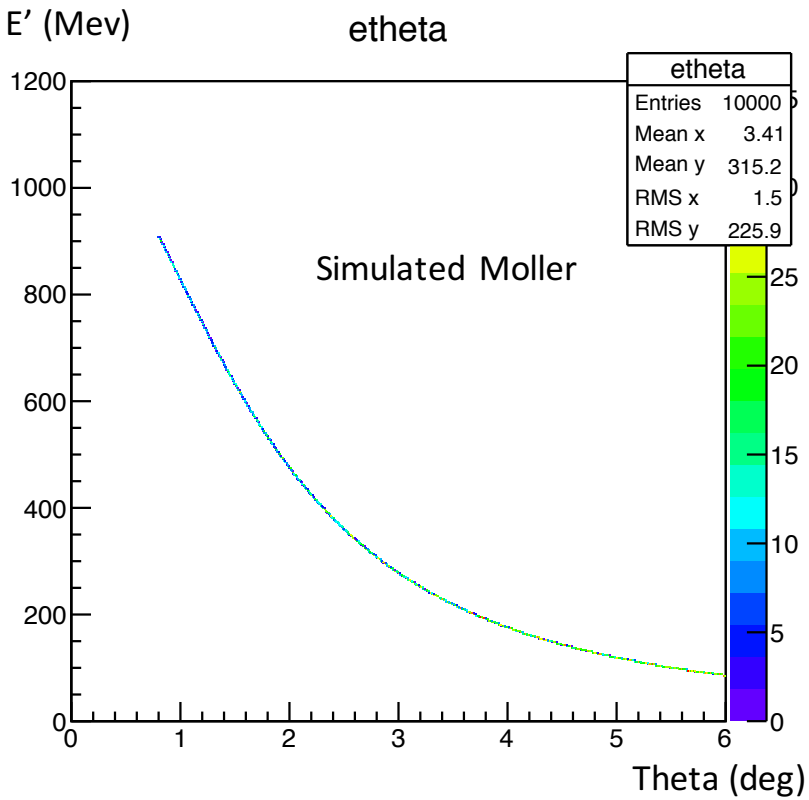




Testing the Formula

Setting z = 5600 in the simulation

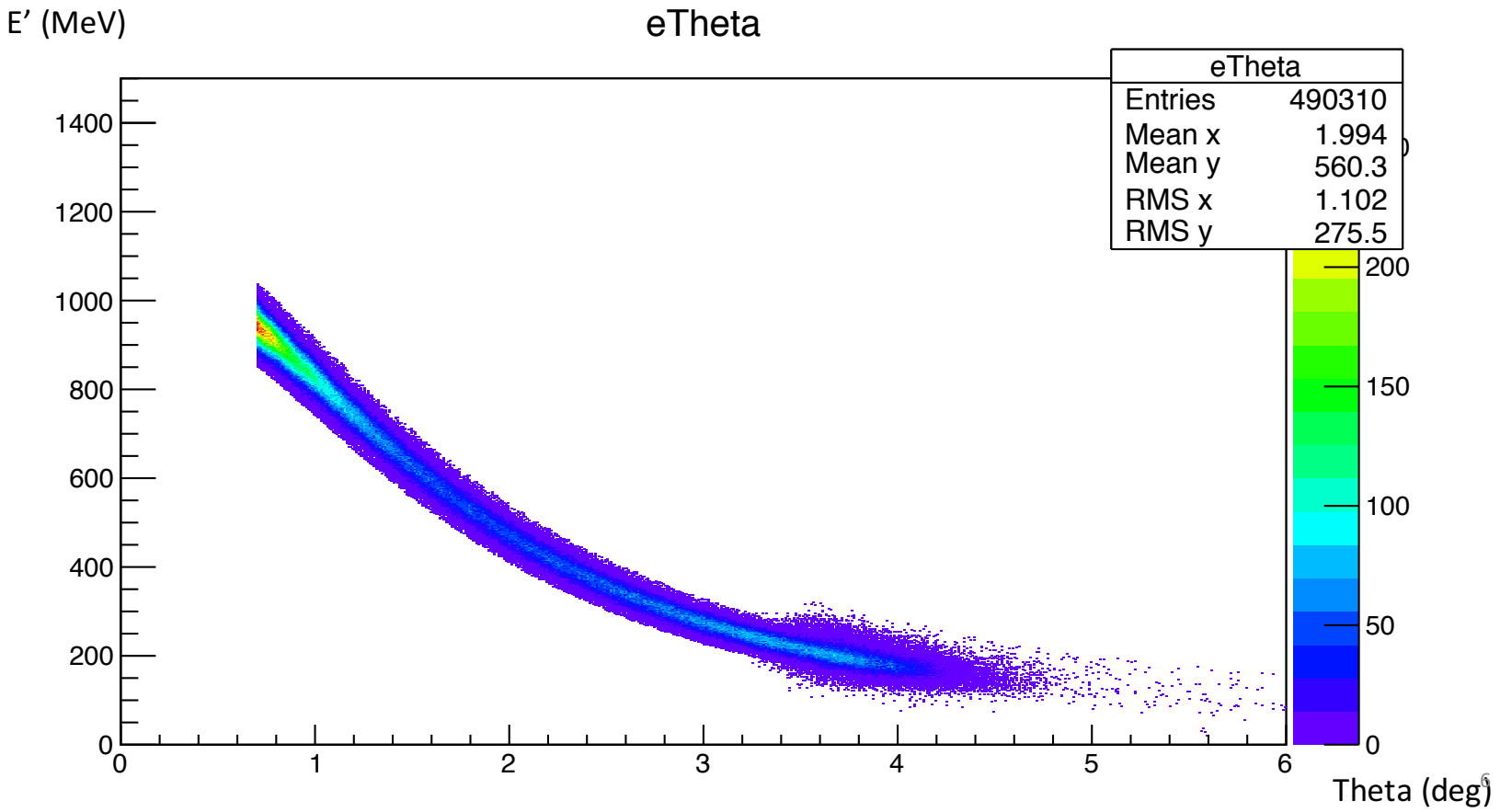




Analysis Procedure

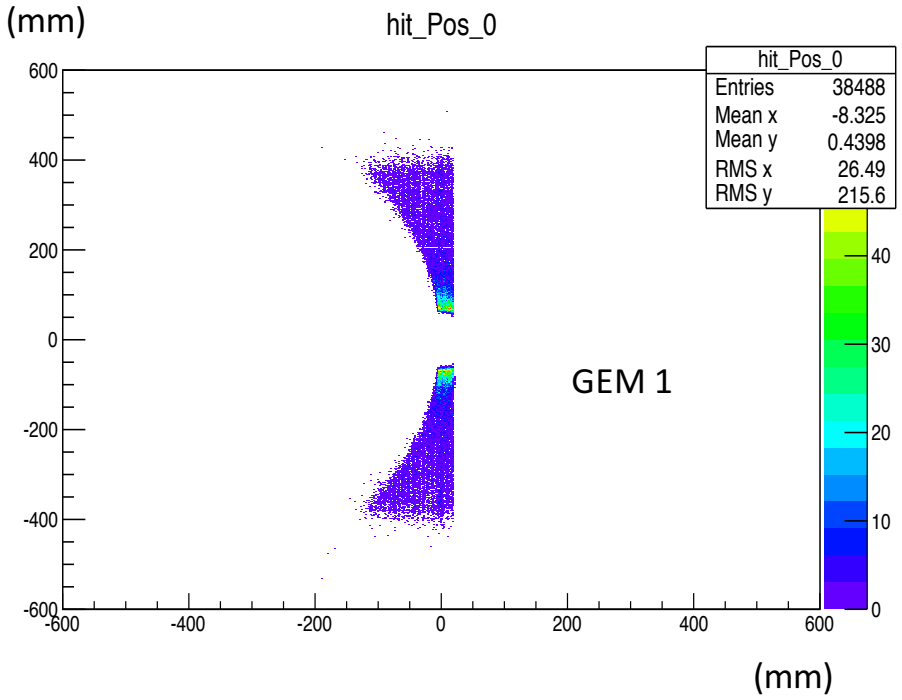
- Using C_{12} run 1345
- Assuming GEM1, GEM2 and HyCal position are at {5304, 5264, 5815} mm
- Make sure the offset is included for both GEMs and HyCal
- First selecting double arm Moller based on HyCal alone:
  - $|E_1 - E_{expect}| / E_{expect}$ and $|E_1 - E_{expect}| / E_{expect}$ both less than $4 \times 0.026/\mathrm{sqrt}(E_{expect})$
  - $|E_1 + E_2 - E_{beam}| / E_{beam} < 4 \times 0.026/\mathrm{sqrt}(E_{beam})$
  - $\Delta\boldsymbol{\varphi} < 20$ deg
  - Scattering angles > 0.7 deg
  - Two clusters events
- Project GEM hits to HyCal surface and do a match with radius {20, 30, 40} mm for {PWO, transition, LG}
- Each GEM has its own double arm Moller acceptance, use those to calculate z independently (must without any projection when calculating z)
  - Reduce $\Delta\boldsymbol{\varphi}$ cut to 5 deg when using GEM coordinates, due to better resolution

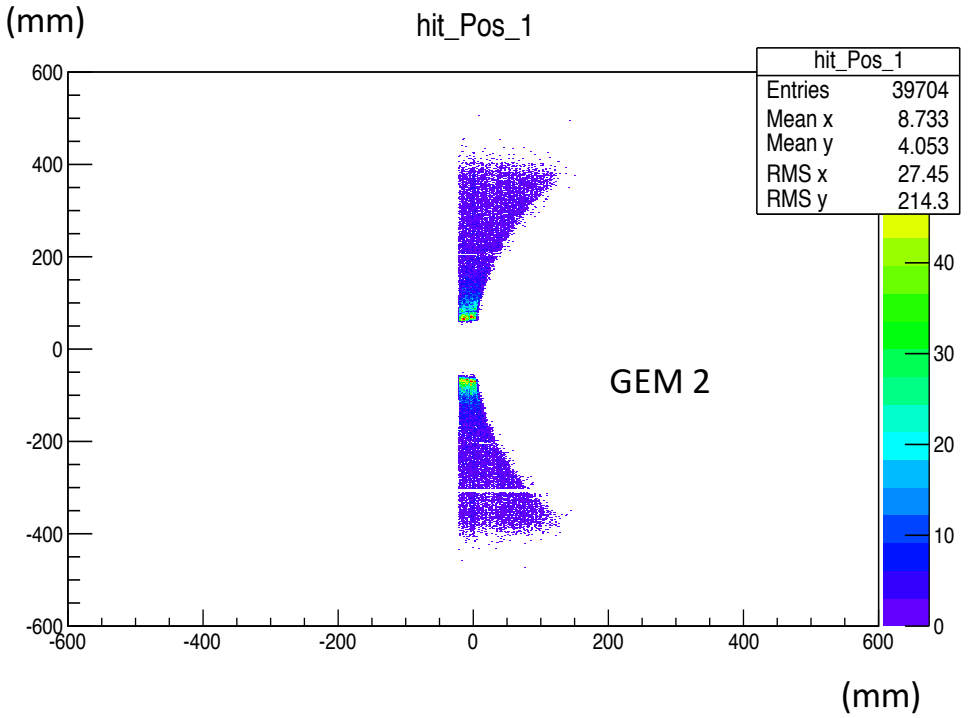
Selecting Moller Events Candidates Using Only HyCal



Double Arm Mollers on Each GEM

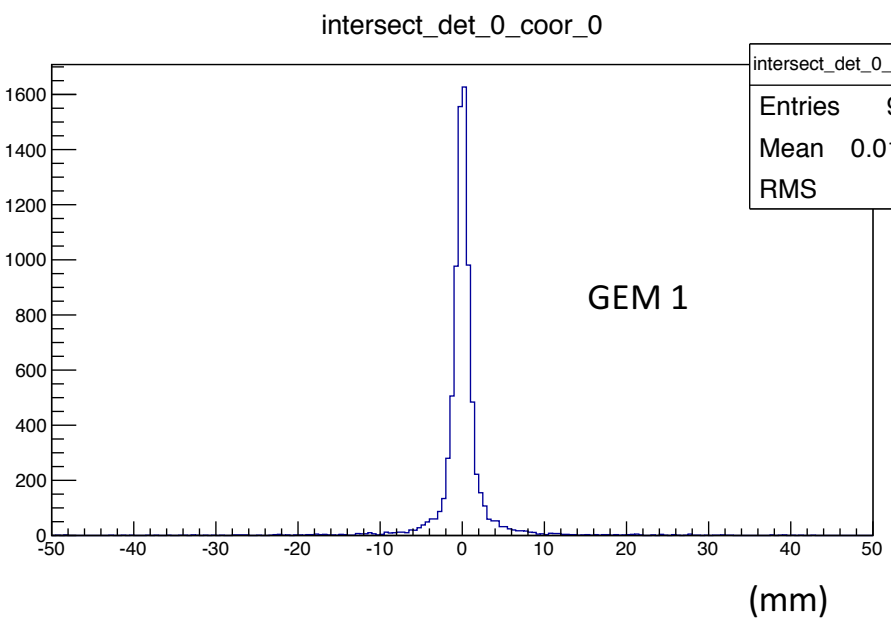
After requiring $\Delta\varphi < 5$ deg

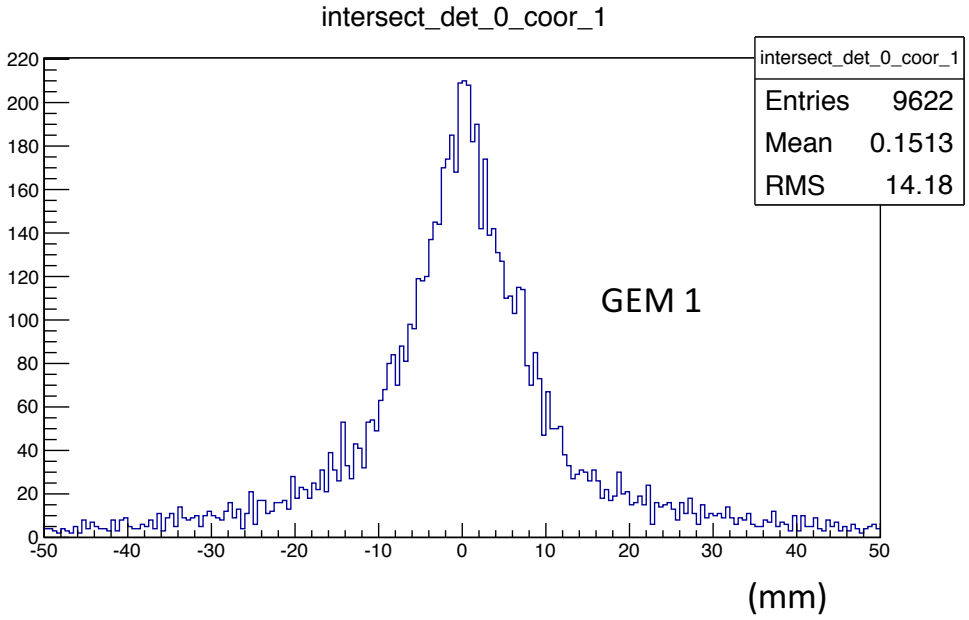




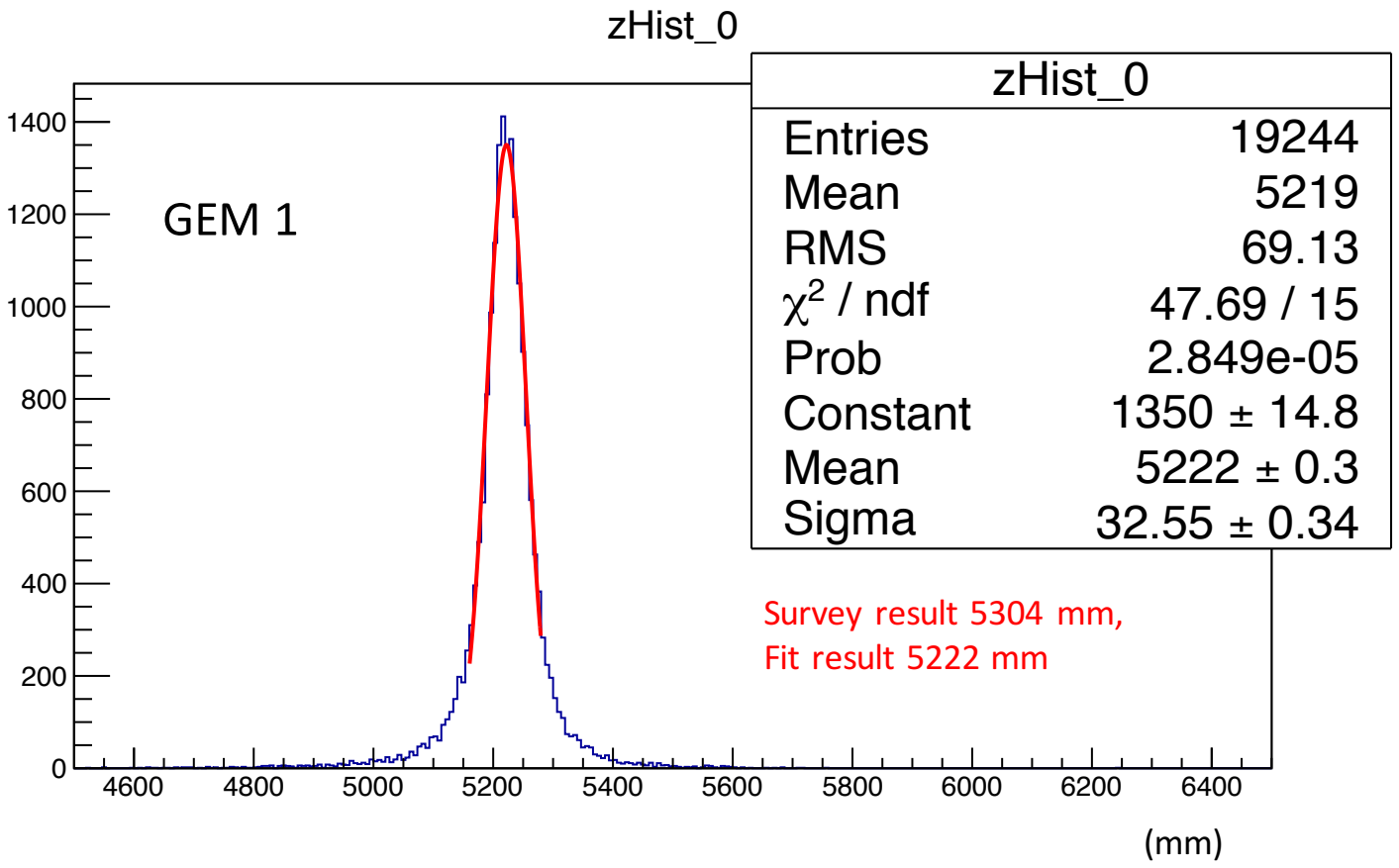
Double Check the Offsets

Using two straight lines determined by four Moller scattering electrons to determine the beam spot position, using data set in the previous page

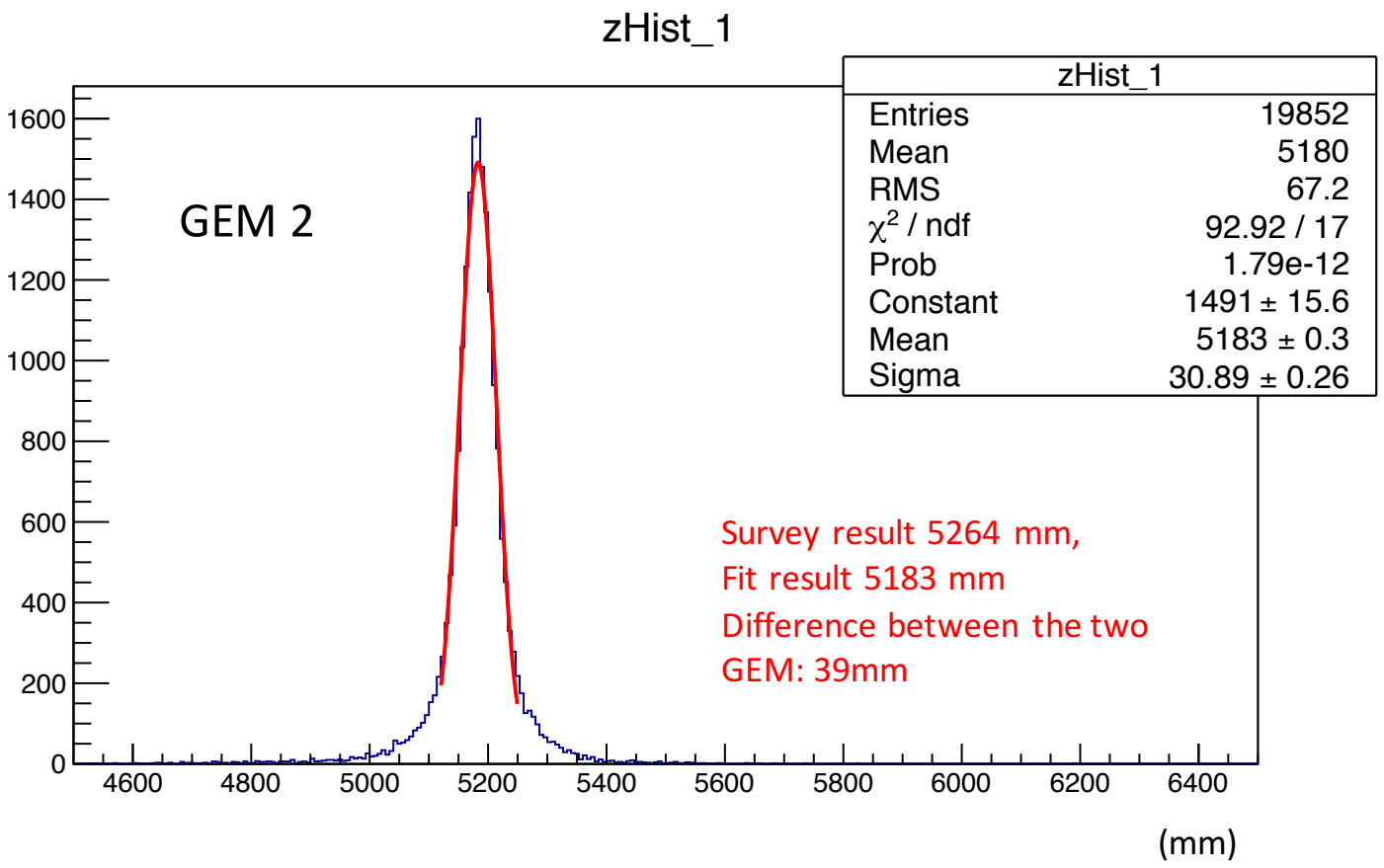




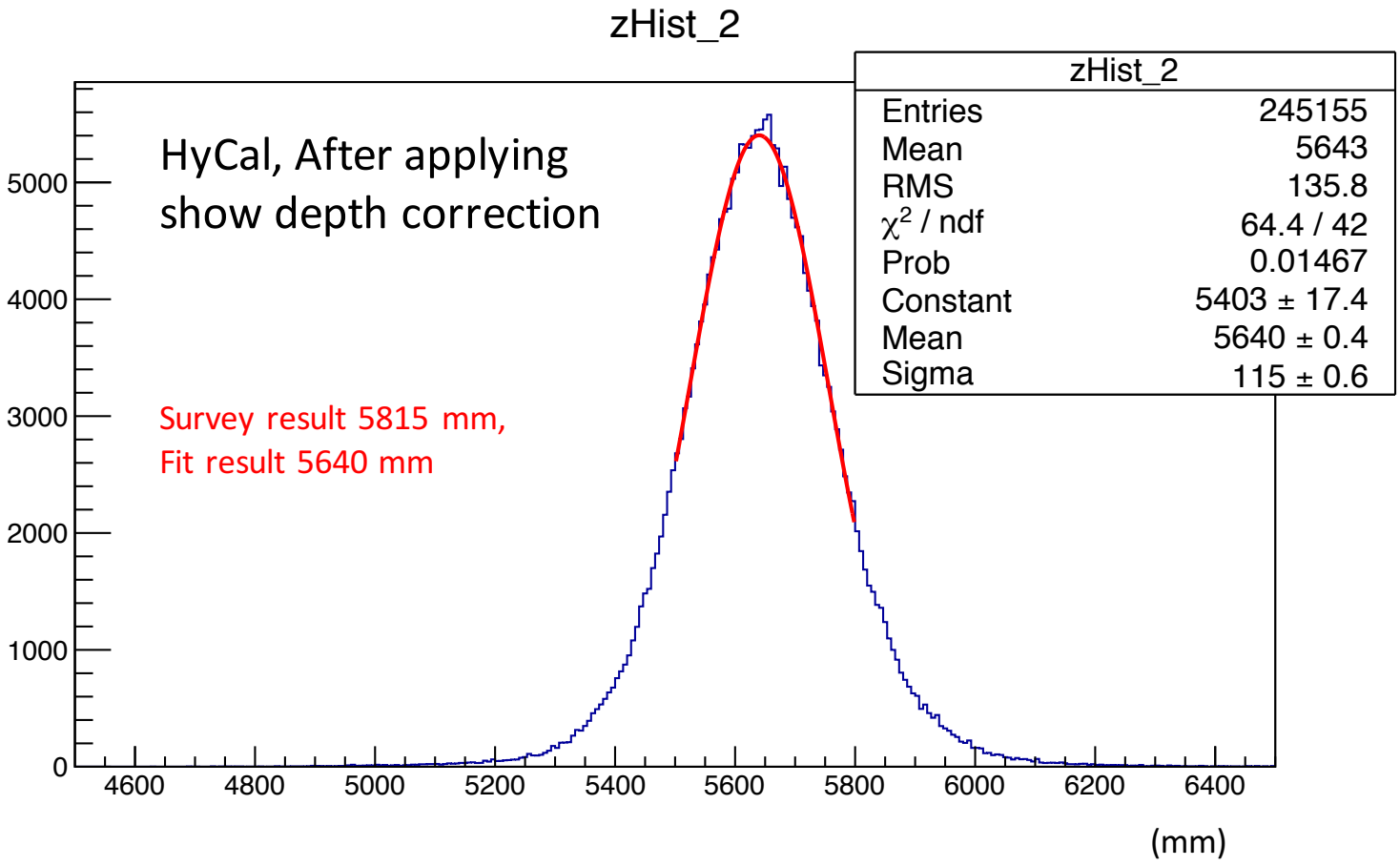
Determine the Z position



Determine the Z position



Determine the Z position

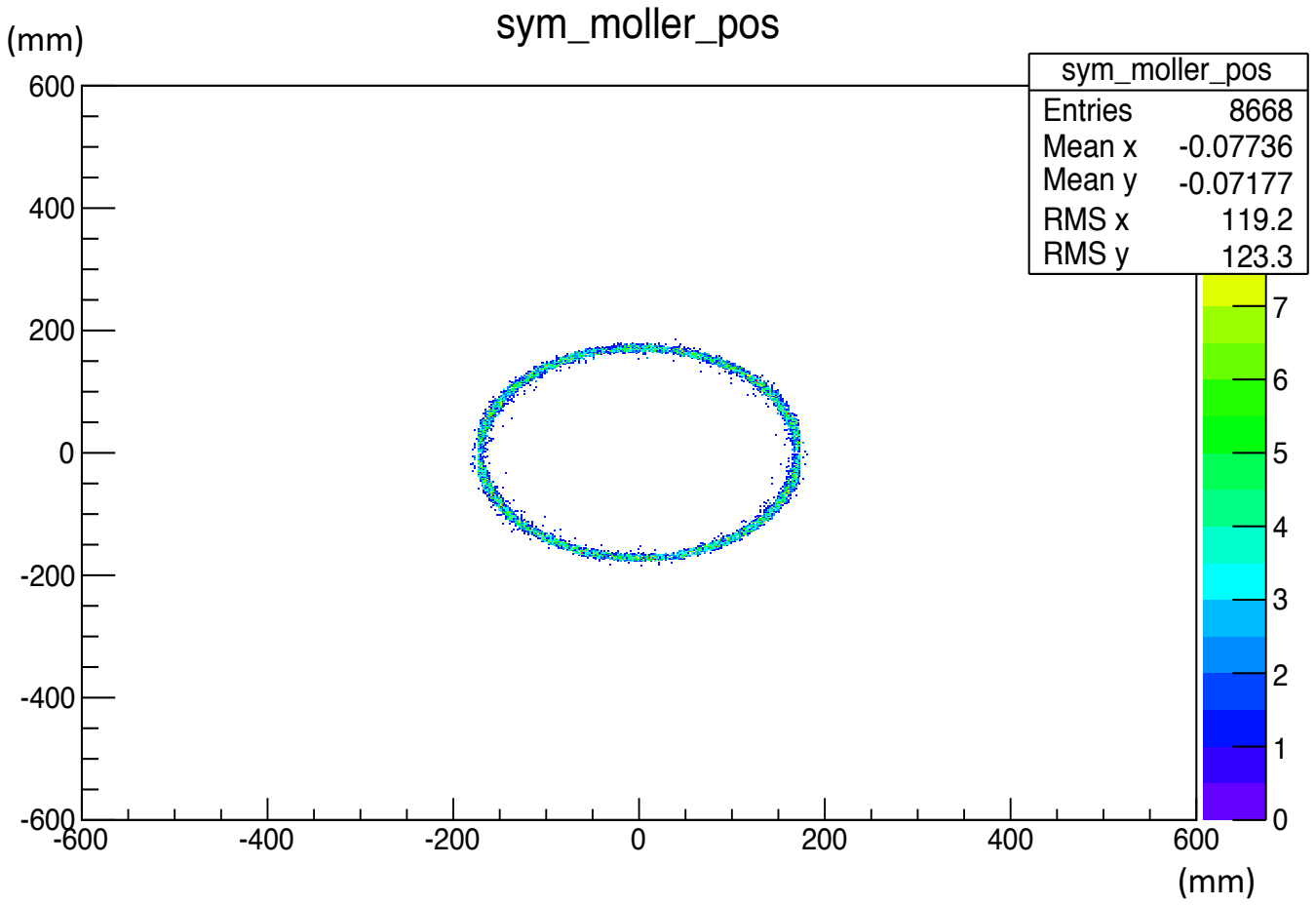


Checking the Result

- Moller scattering has a minimum opening angle in lab frame, which correspond to scattering angle = 90 deg in center of mass frame
  - $tan^2(\theta_{lab}) = \frac{2m}{E_{beam}+m}$
  - At 1.1 GeV, the minimum opening angle is 3.491 deg
- In order word, we are looking for symmetric Mollers in the lab frame
- Using $|R_1 - R_2| < 10$ mm to select symmetric Mollers for both HyCal and GEM
- Due to statistics, need to use entire GEM, so project GEM to the same plane at z = 5815mm

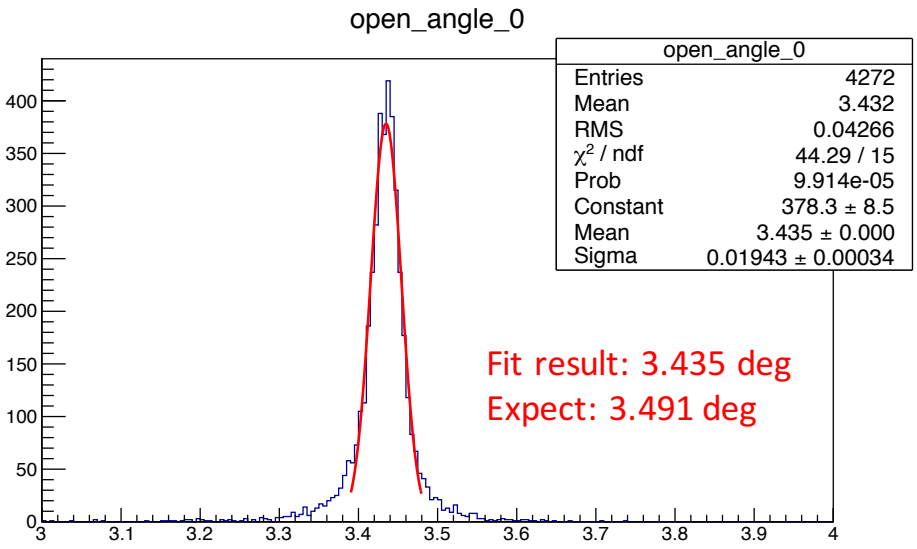
- We can again check the ΔR vs R distribution to see if every thing matches

Symmetric Moller Distribution

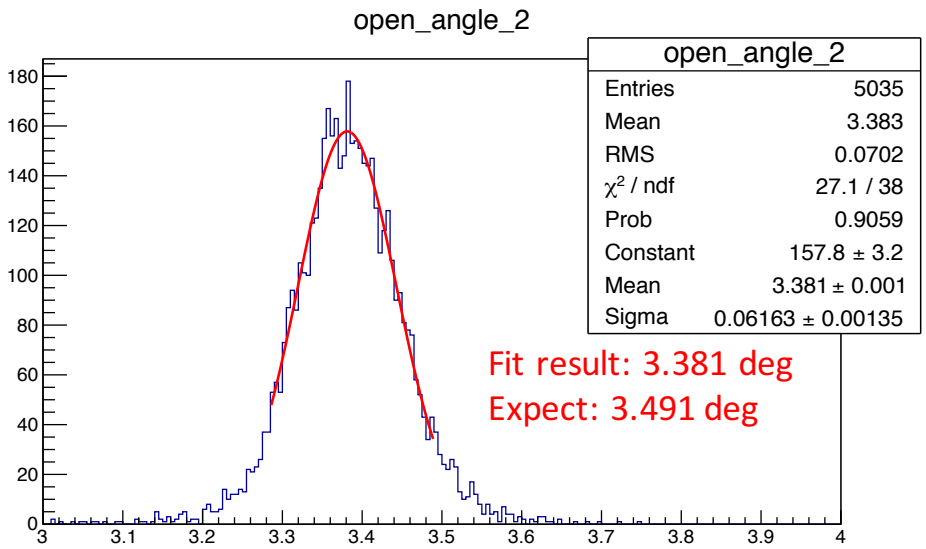


Minimum Opening Angle

From GEM

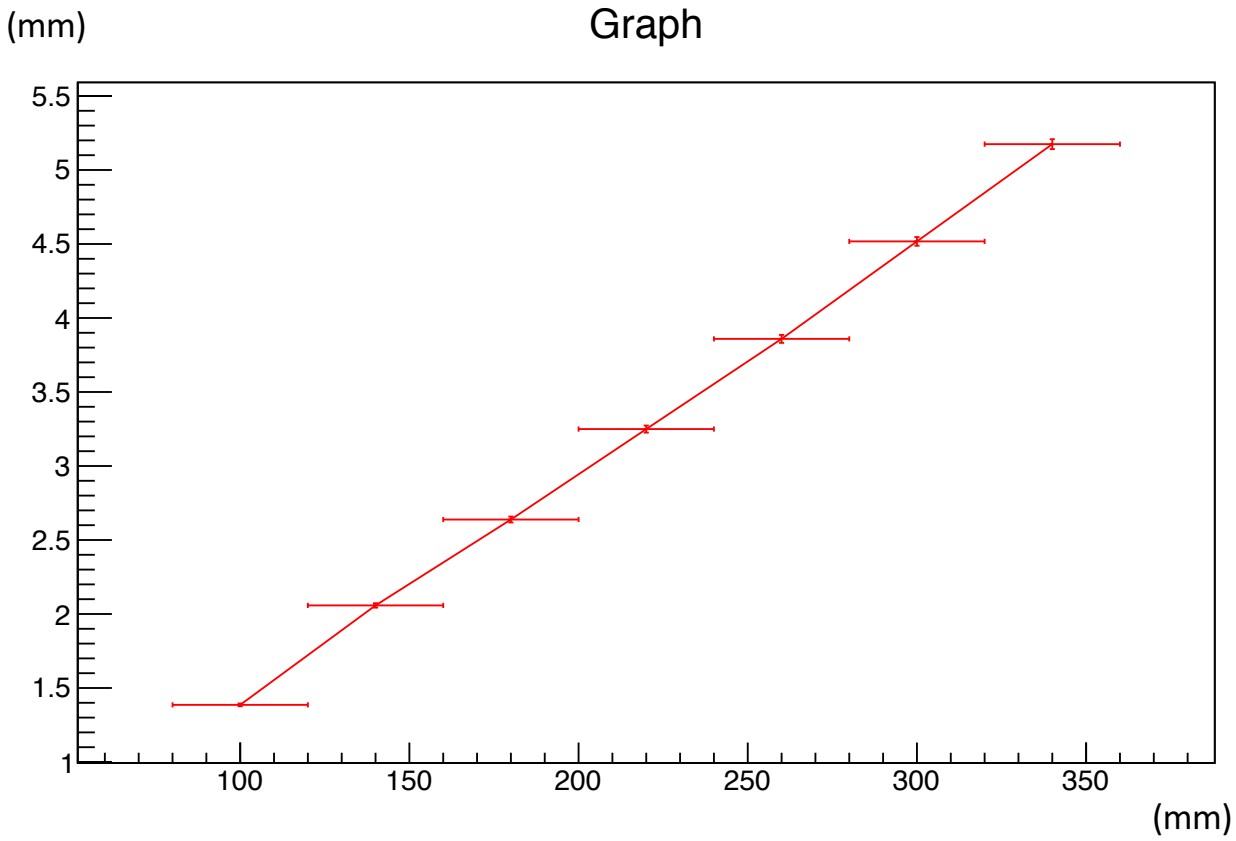


From HyCal



With the Survey setting

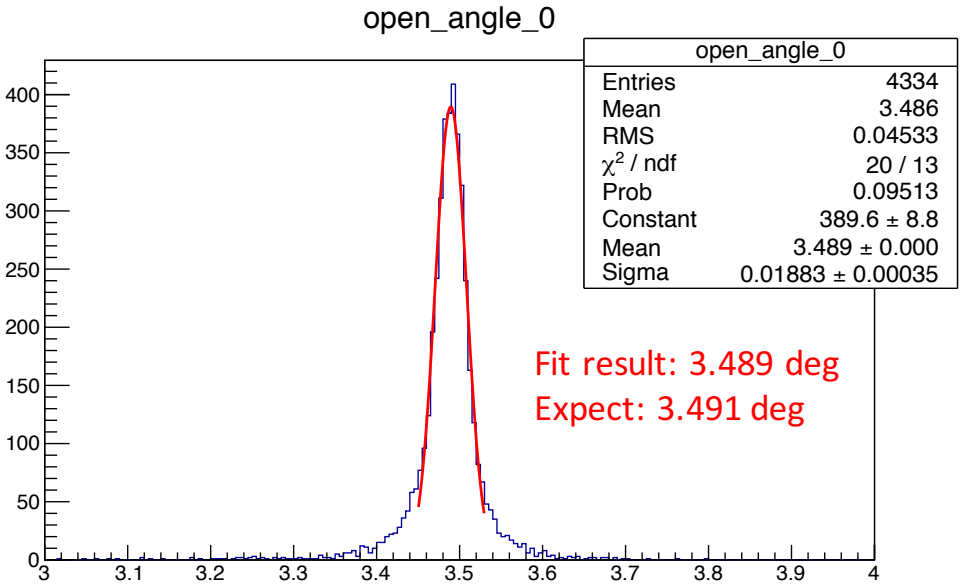
$R_{GEM} - R_{HyCal}$ vs R_{GEM}



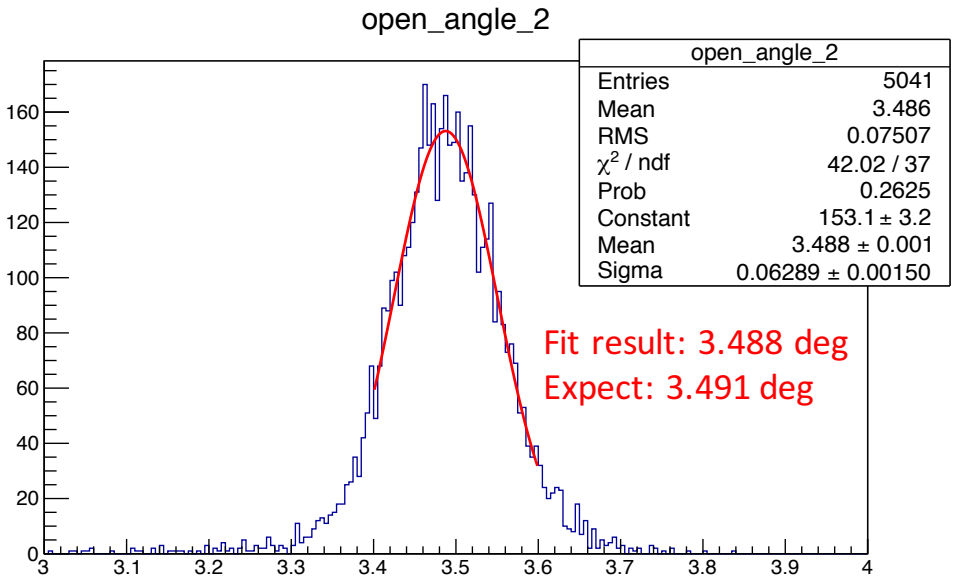
With the Survey setting

Minimum Opening Angle

From GEM

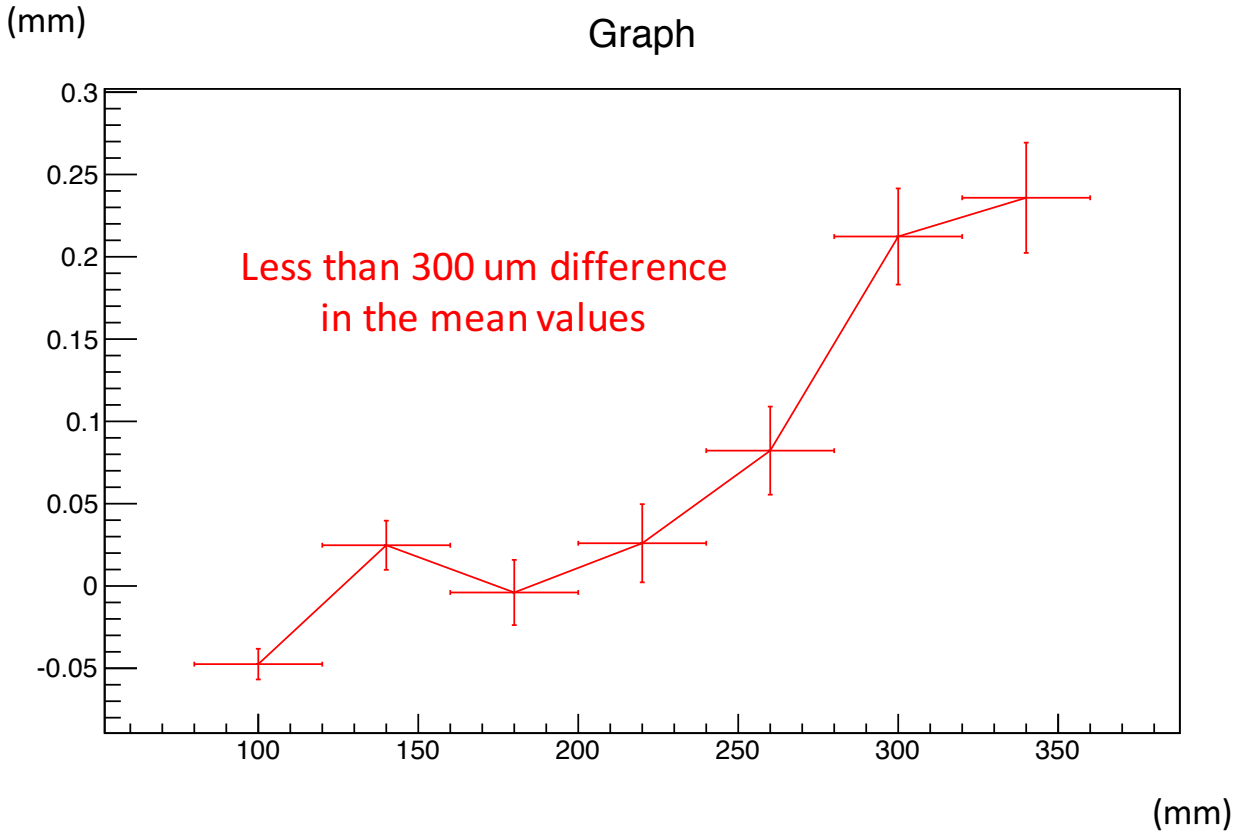


From HyCal

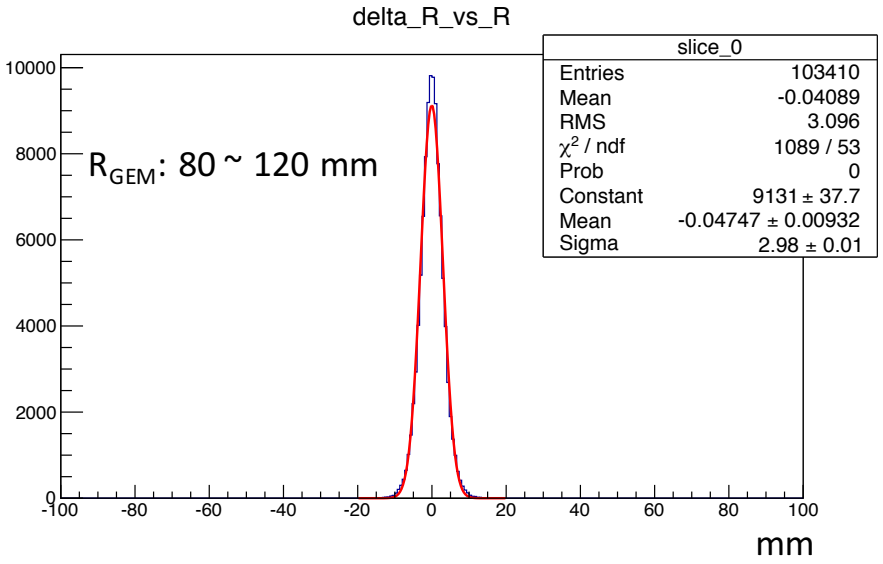


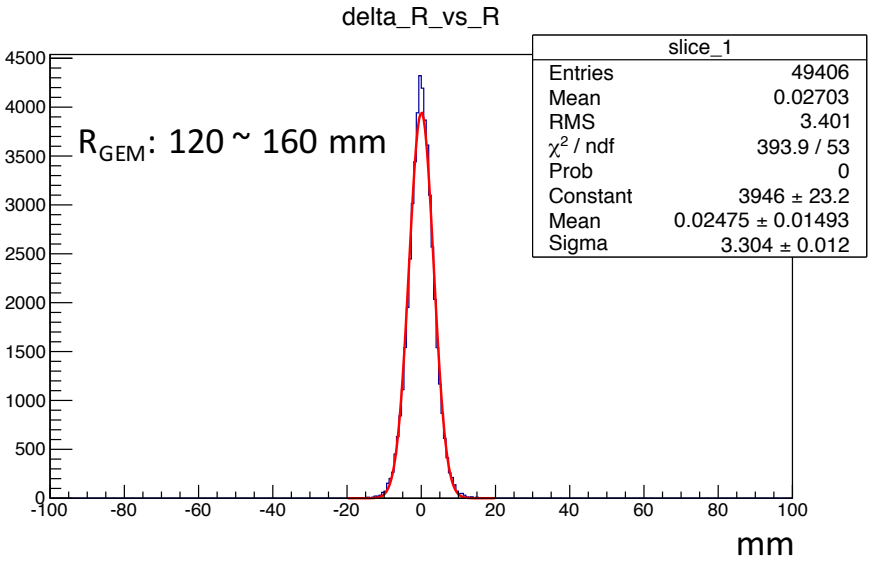
With the New setting

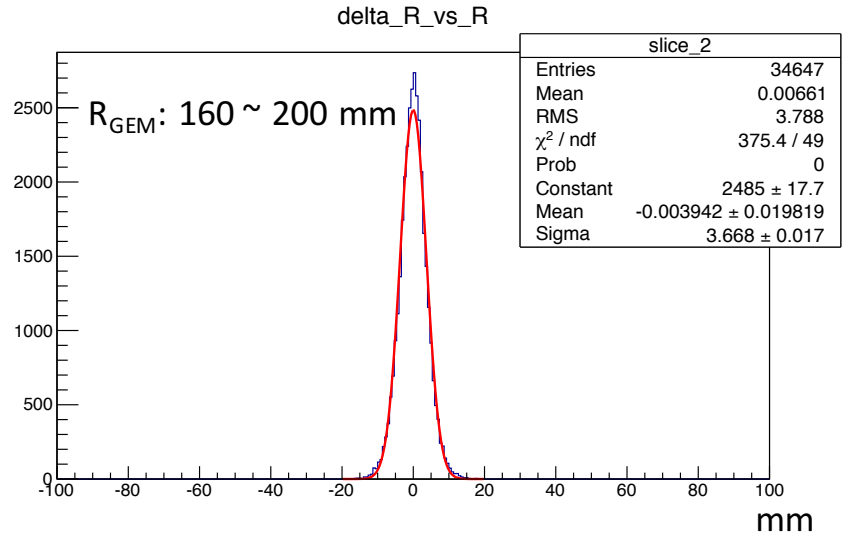
$R_{GEM} - R_{HyCal}$ vs R_{GEM}

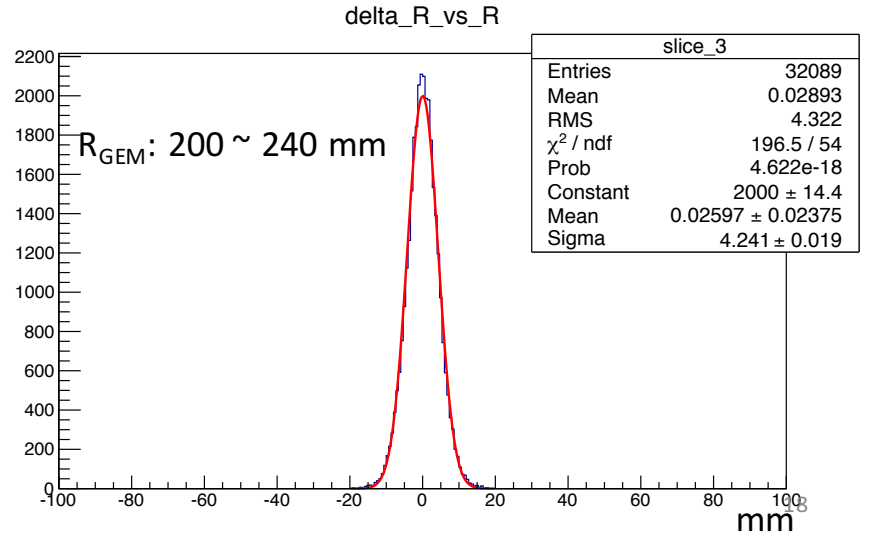


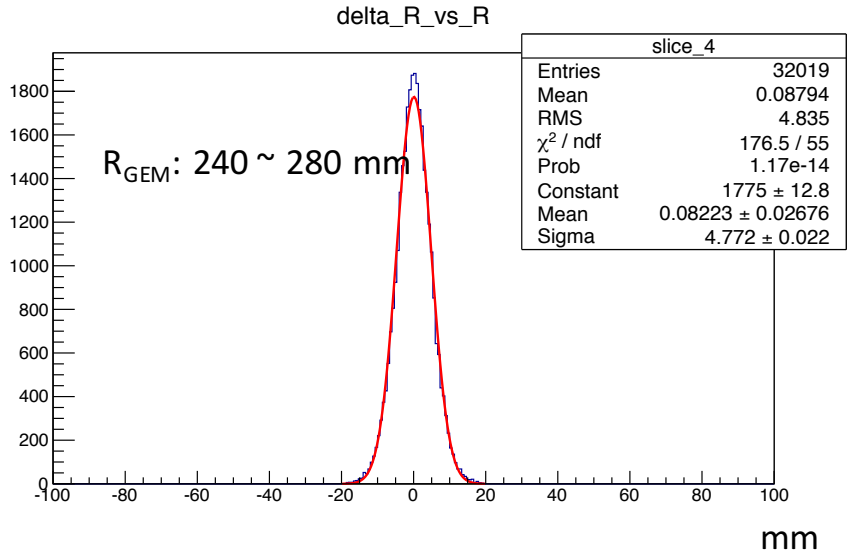
With the New setting

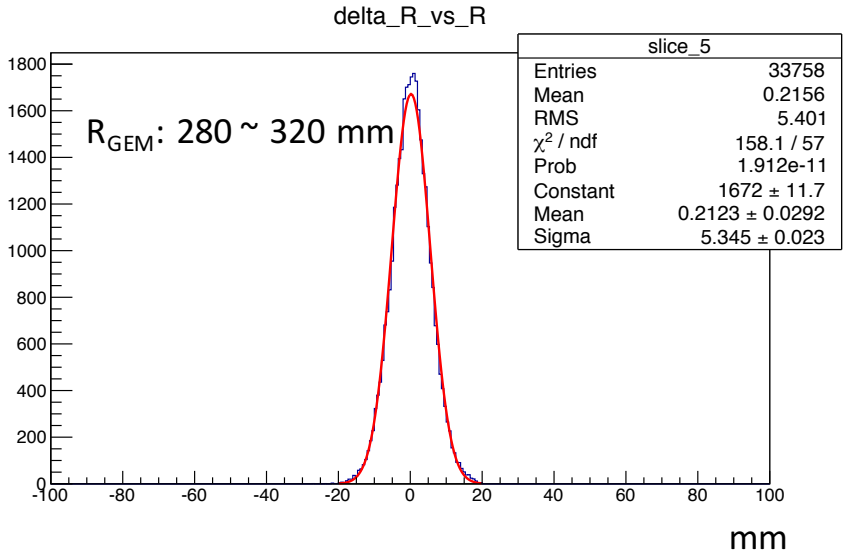

delta_R_vs_R
slice_0
Entries 103410
Mean -0.04089
RMS 3.096
χ² / ndf 1089 / 53
Prob 0
Constant 9131 ± 37.7
Mean -0.04747 ± 0.00932
Sigma 2.98 ± 0.01
R_GEM: 80 ~ 120 mm
mm

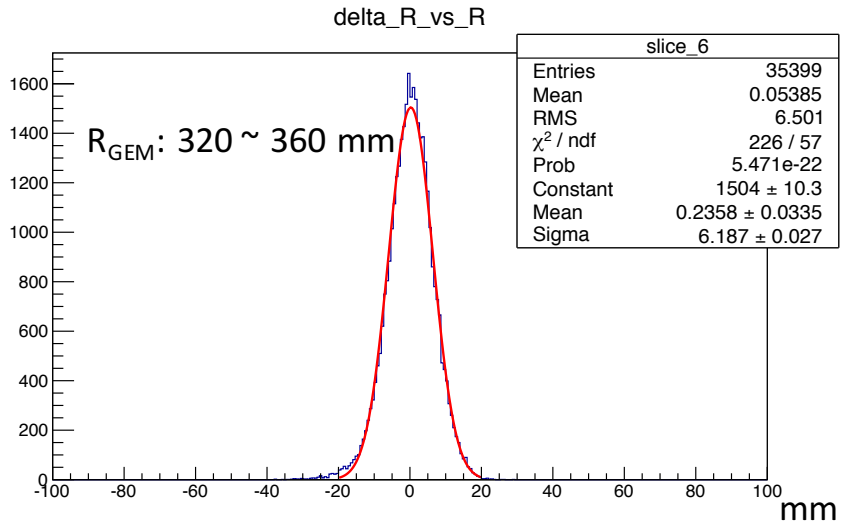

delta_R_vs_R
slice_1
Entries 49406
Mean 0.02703
RMS 3.401
χ² / ndf 393.9 / 53
Prob 0
Constant 3946 ± 23.2
Mean 0.02475 ± 0.01493
Sigma 3.304 ± 0.012
R_GEM: 120 ~ 160 mm
mm


delta_R_vs_R
slice_2
Entries 34647
Mean 0.00661
RMS 3.788
χ² / ndf 375.4 / 49
Prob 0
Constant 2485 ± 17.7
Mean -0.003942 ± 0.019819
Sigma 3.668 ± 0.017
R_GEM: 160 ~ 200 mm
mm


delta_R_vs_R
slice_3
Entries 32089
Mean 0.02893
RMS 4.322
χ² / ndf 196.5 / 54
Prob 4.622e-18
Constant 2000 ± 14.4
Mean 0.02597 ± 0.02375
Sigma 4.241 ± 0.019
R_GEM: 200 ~ 240 mm
mm


delta_R_vs_R
slice_4
Entries 32019
Mean 0.08794
RMS 4.835
χ² / ndf 176.5 / 55
Prob 1.17e-14
Constant 1775 ± 12.8
Mean 0.08223 ± 0.02676
Sigma 4.772 ± 0.022
R_GEM: 240 ~ 280 mm
mm


delta_R_vs_R
slice_5
Entries 33758
Mean 0.2156
RMS 5.401
χ² / ndf 158.1 / 57
Prob 1.912e-11
Constant 1672 ± 11.7
Mean 0.2123 ± 0.0292
Sigma 5.345 ± 0.023
R_GEM: 280 ~ 320 mm
mm


delta_R_vs_R
slice_6
Entries 35399
Mean 0.05385
RMS 6.501
χ² / ndf 226 / 57
Prob 5.471e-22
Constant 1504 ± 10.3
Mean 0.2358 ± 0.0335
Sigma 6.187 ± 0.027
R_GEM: 320 ~ 360 mm
mm