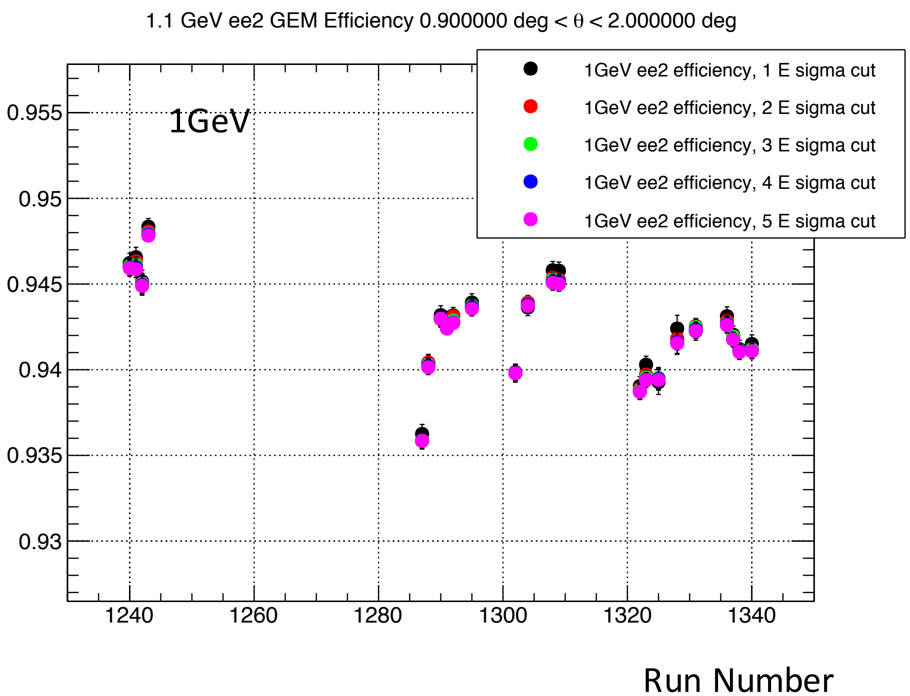
Progress Update

- GEM efficiency position dependency and energy dependency
- GEM efficiency stability

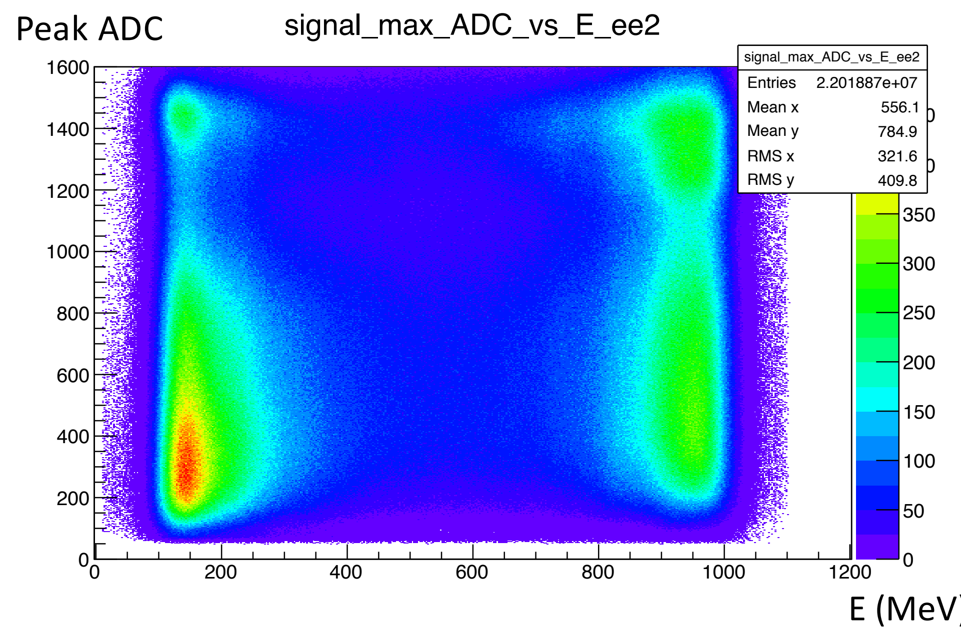
- Extracting the ep/ee ratio from 2.2 GeV calibrated runs
  - Selection cuts
  - Extracted ratio using 4 different methods
  - Stability of the extracted yields

A few problems mentioned last week

Time dependency of the GEM efficiency



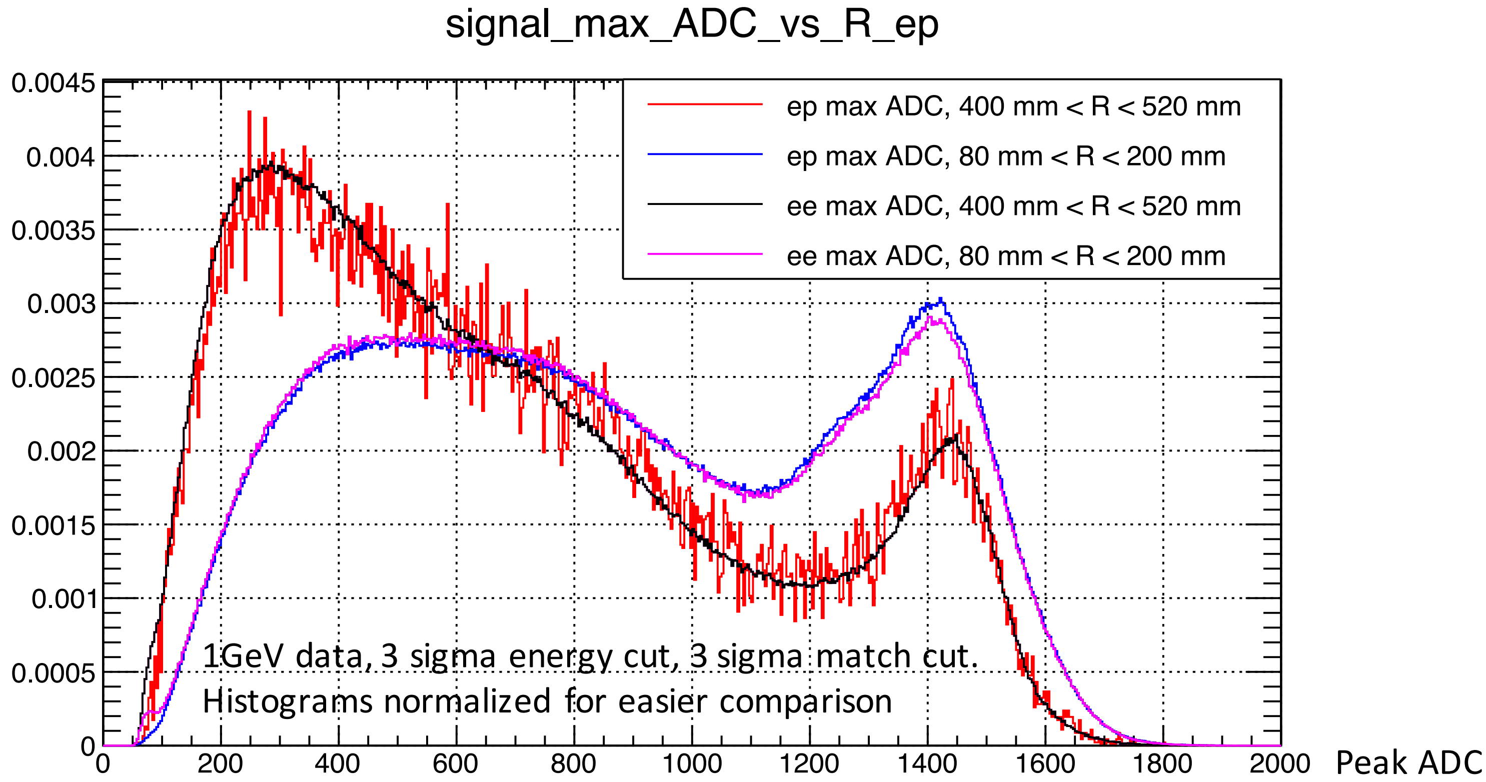
Peak ADC (maximum of the 3 time samples) vs. Moller cluster energy (1GeV data)



Smaller peak ADC values for the lower energy Moller electron, not certain it is R or E dependent. But smaller peak value will lead to lower efficiency

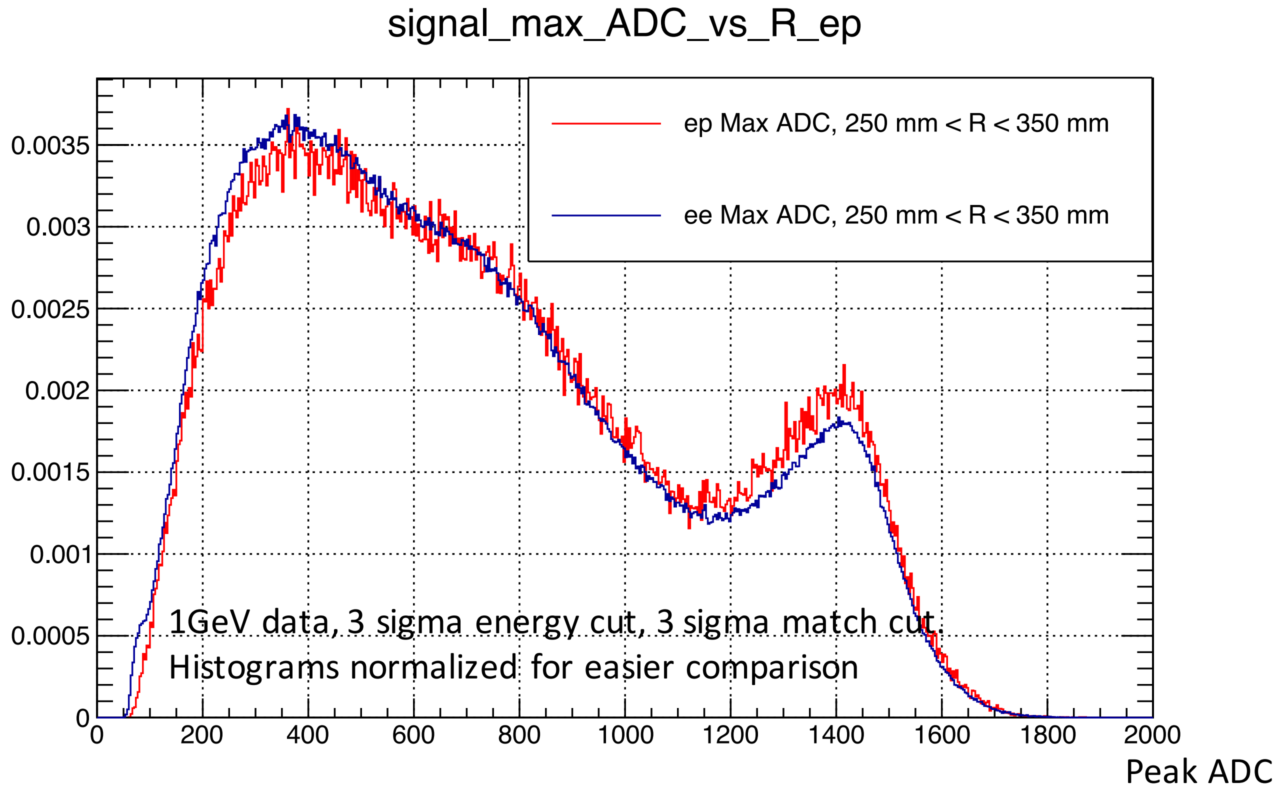
R and E dependence of the GEM Efficiency

- If it is R dependent, we should see similar shift for ep at larger R
- Look at the peak ADC spectrum for ep and ee at the same R bins



R and E dependence of the GEM Efficiency

- There is “probably” a very small energy dependency, after all, ionization energy loss increase logarithmically with E (but ep tend to be more concentrated at smaller R in the same bin)



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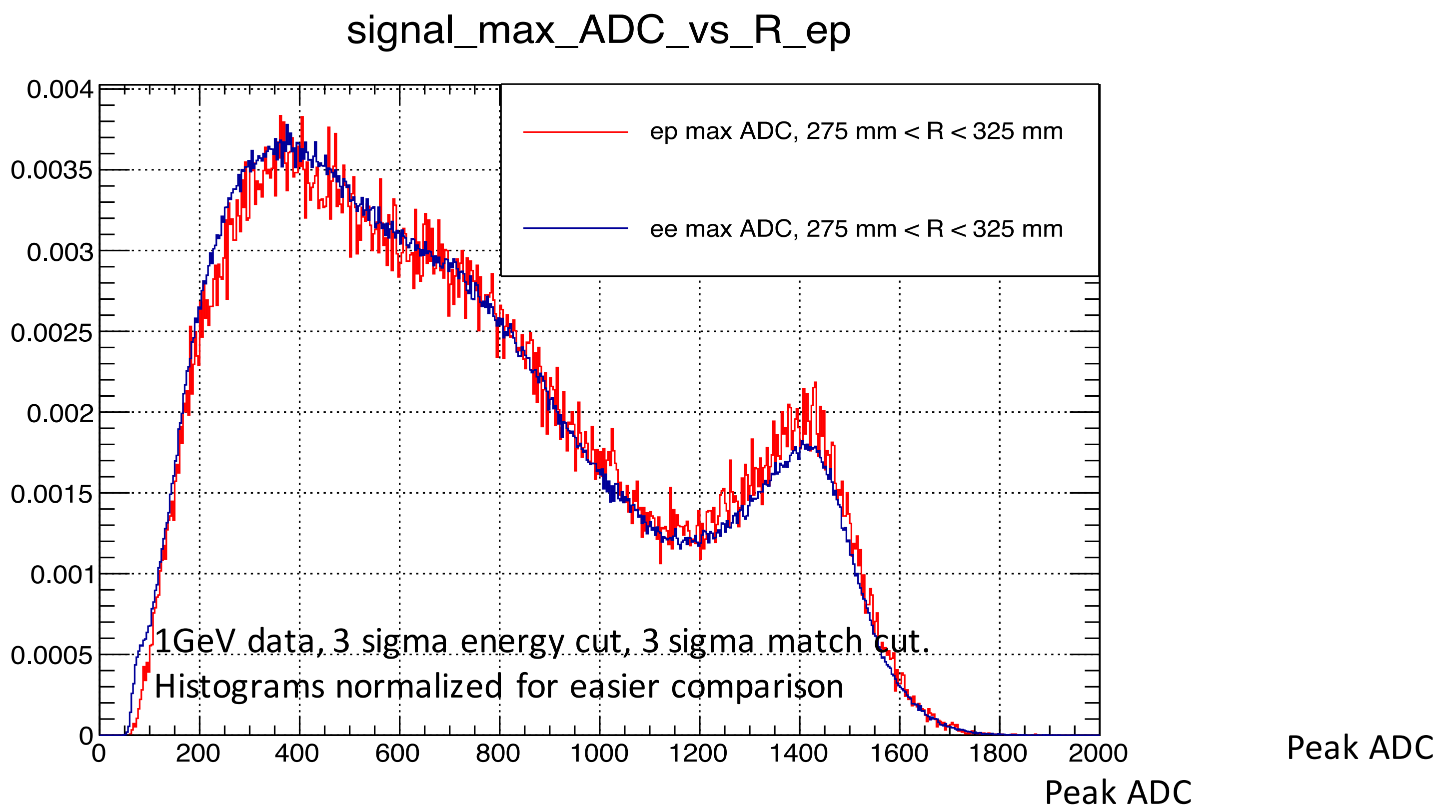
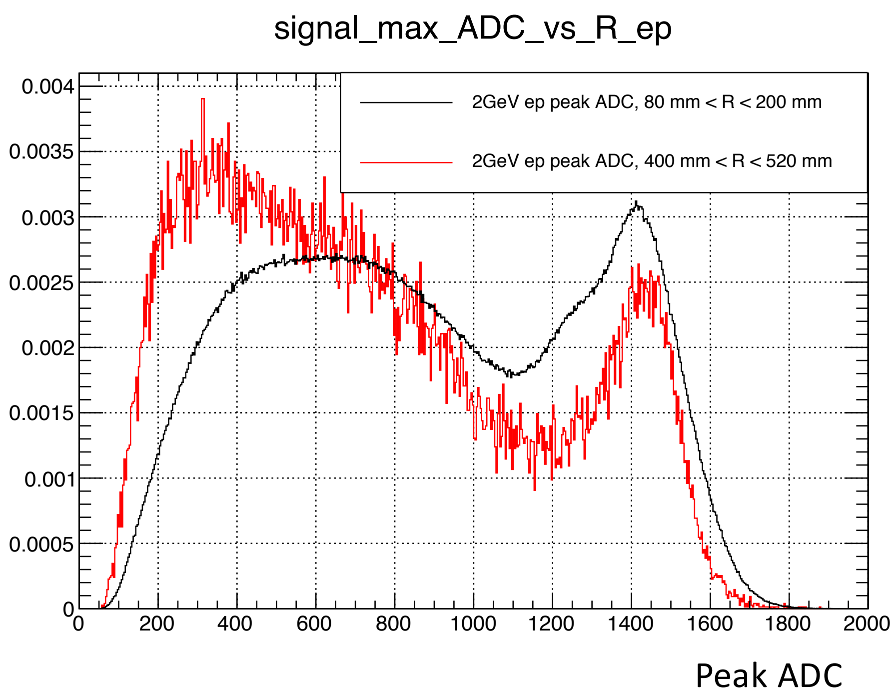
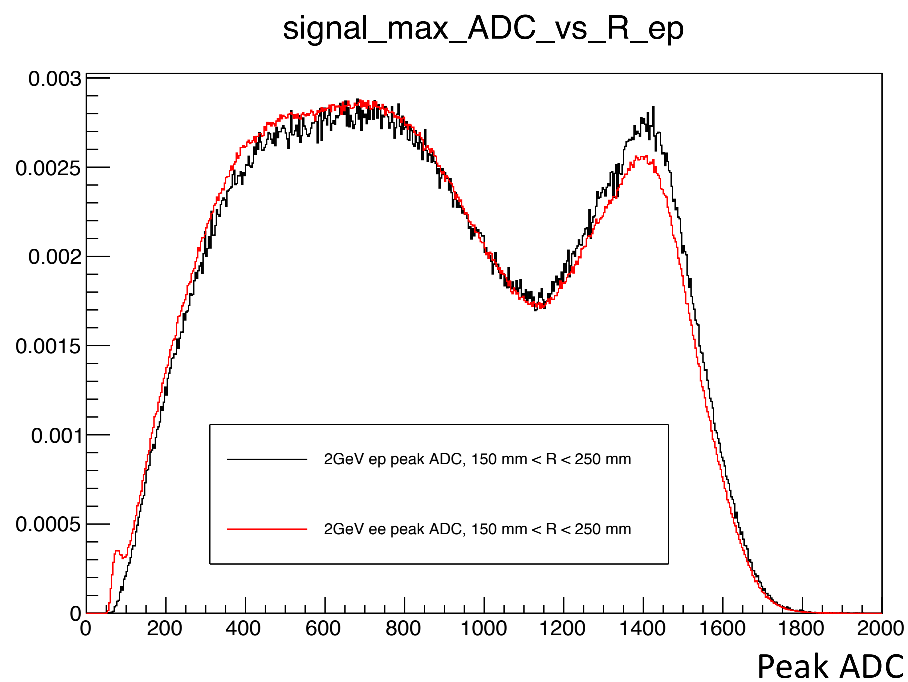


R and E dependence of the GEM Efficiency

- Similar tendency on the R and E dependency of the GEM efficiency observed for 2.2 GeV data

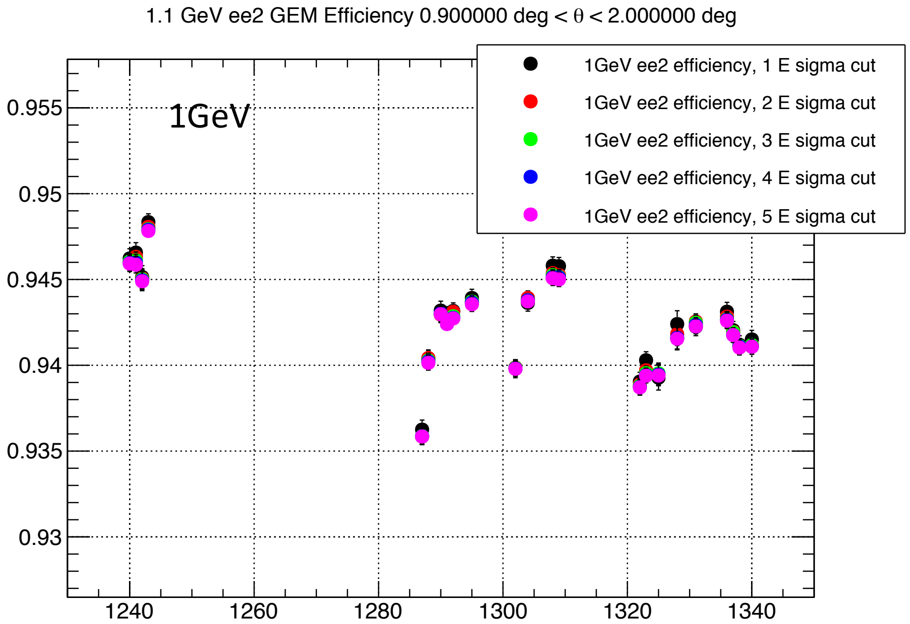




2GeV data, 3 sigma energy cut, 3 sigma match cut. Histograms normalized for easier comparison

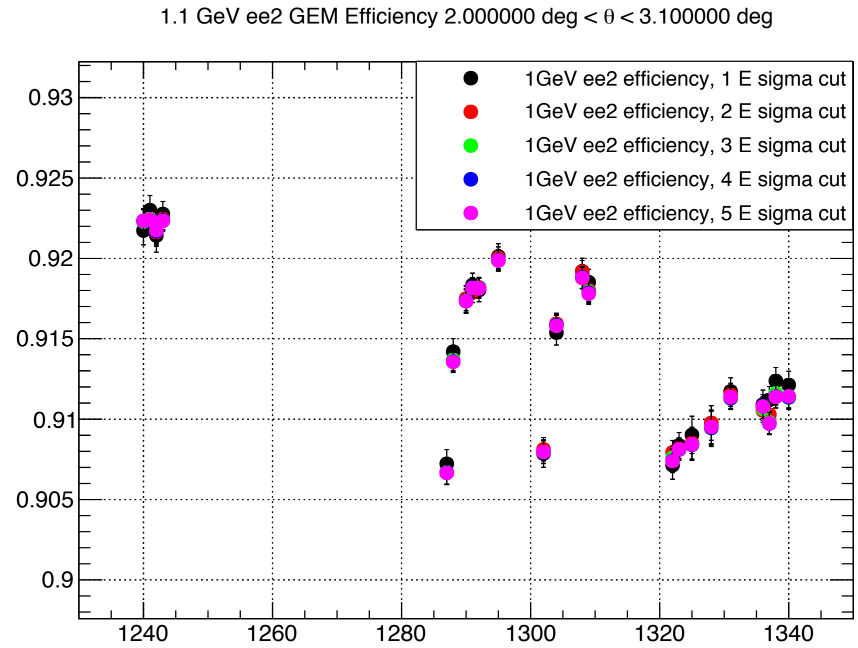
Time Dependency of the Efficiency

0.9 deg < Theta < 2 deg



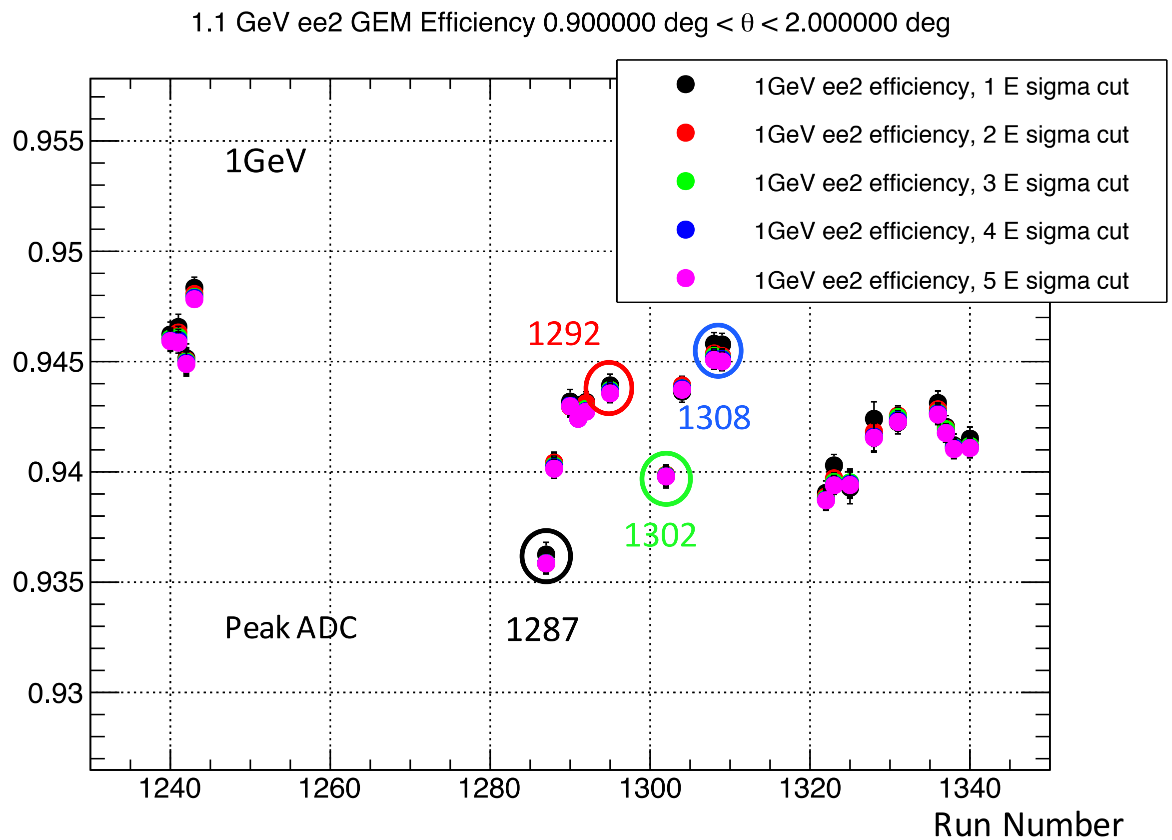
Run Number

2 deg < Theta < 3.1 deg



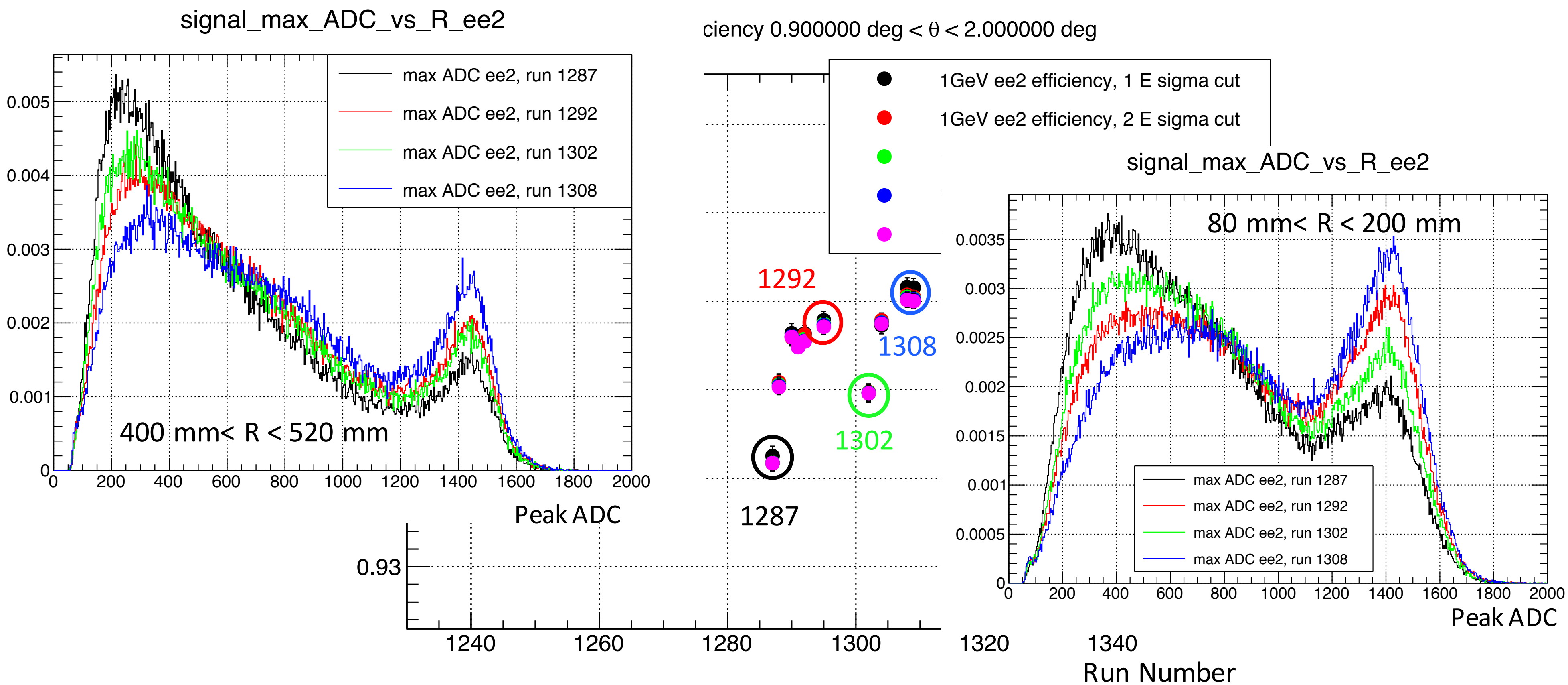
Run Number

Time Dependency of the Efficiency



Following the same logic, let's pick four runs and look at their peak ADC spectrum

Time Dependency of the Efficiency



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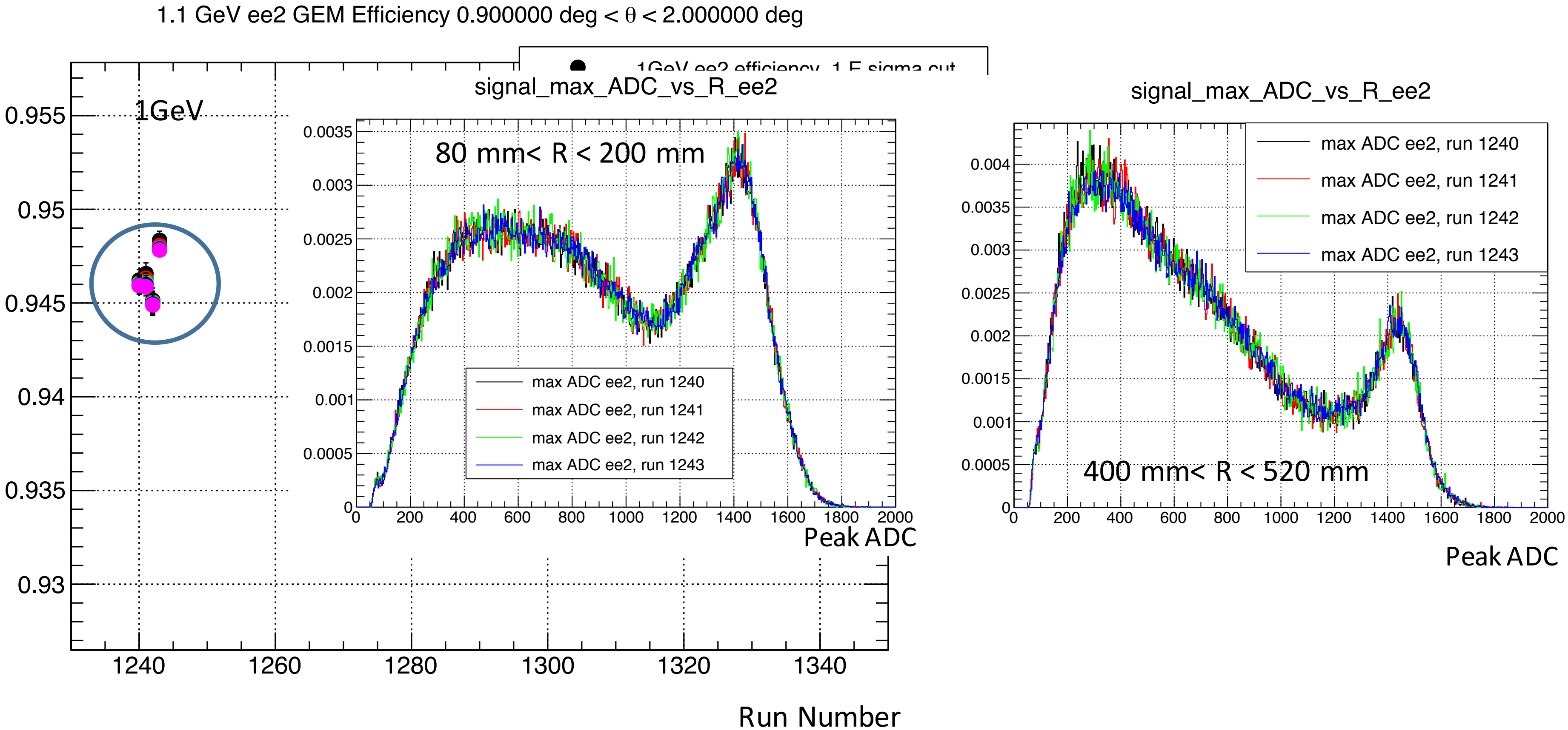

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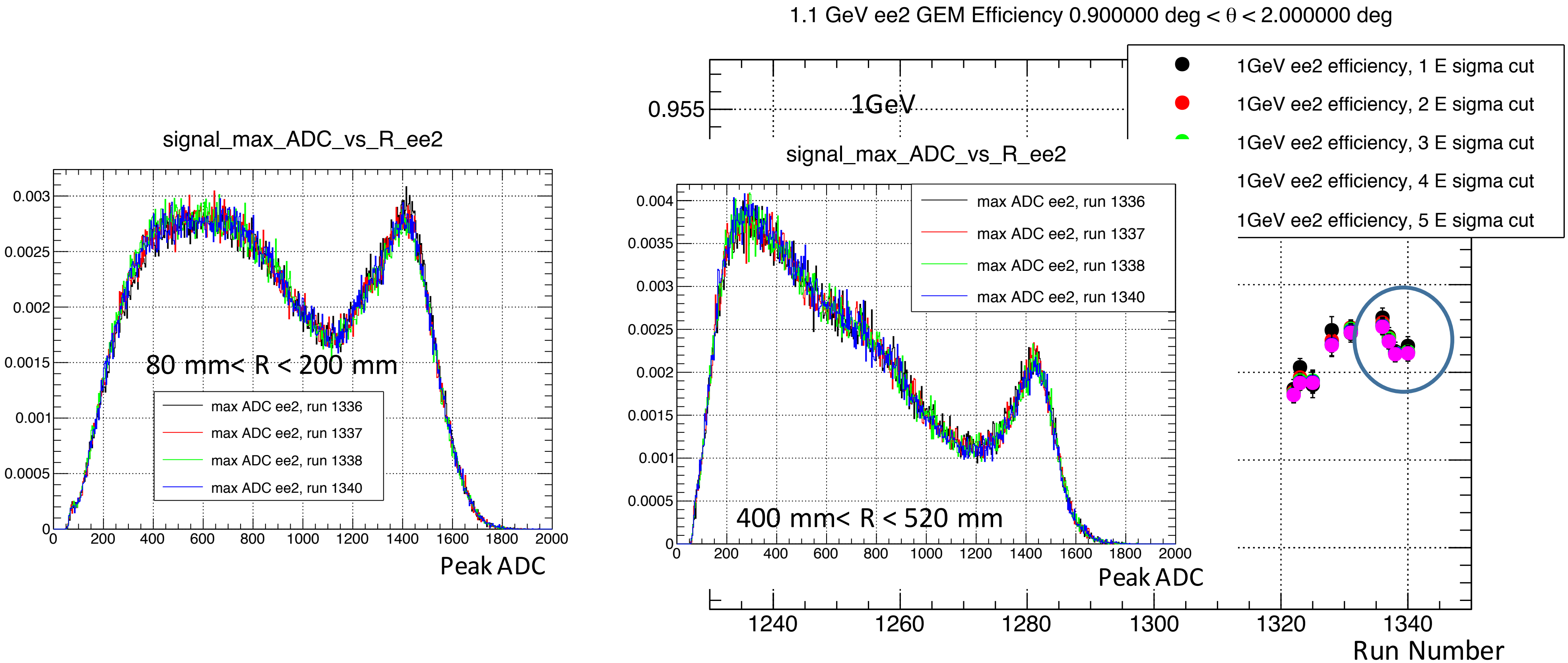

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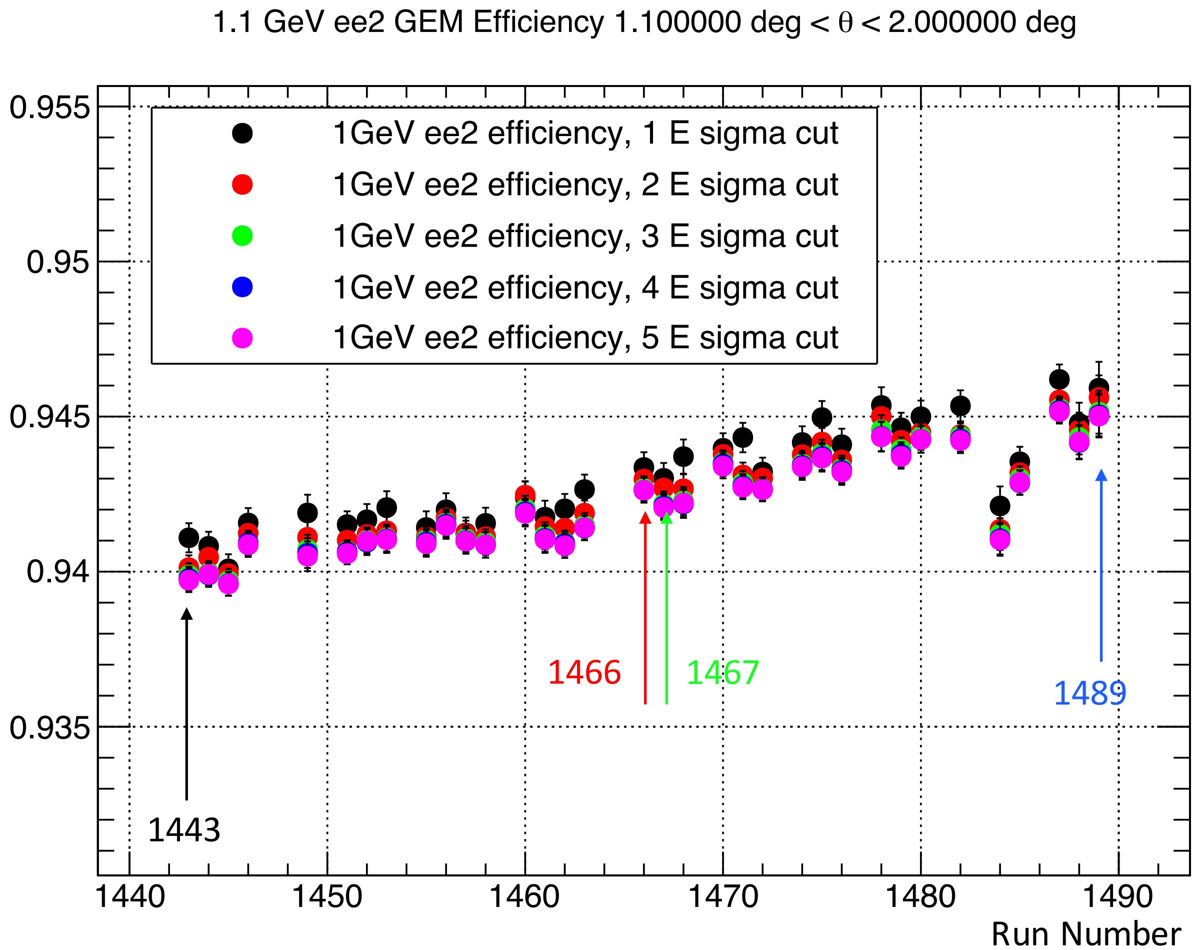
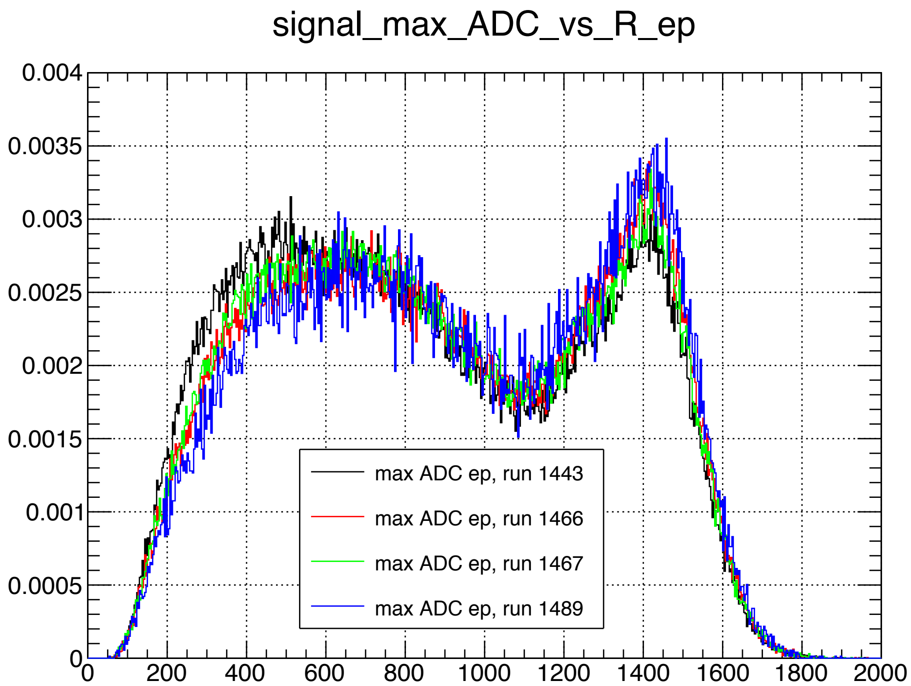


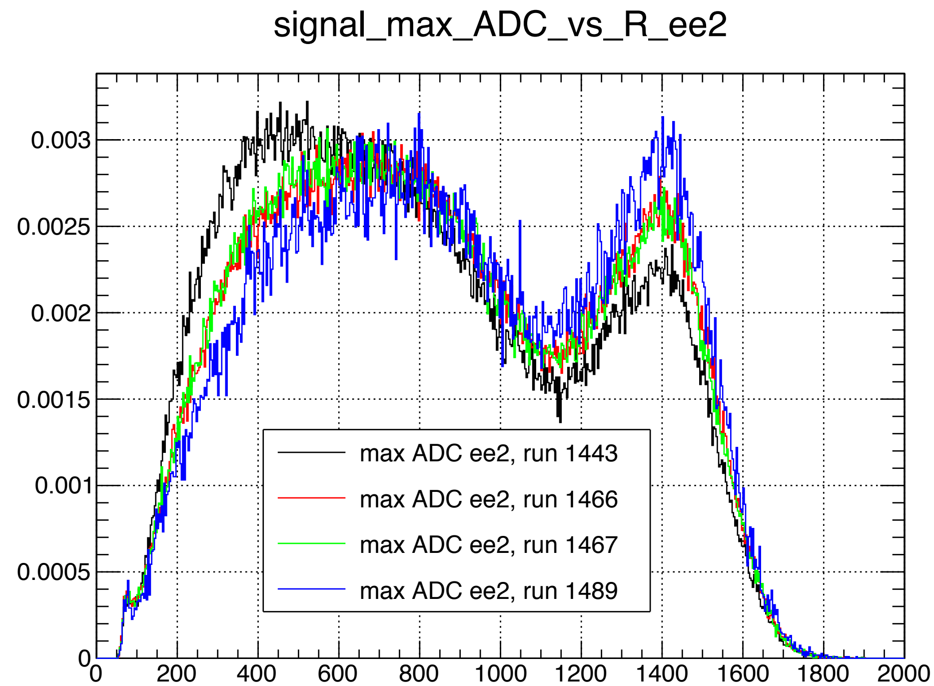
Time Dependency of the Efficiency

80 mm< R < 200 mm, 2GeV ep



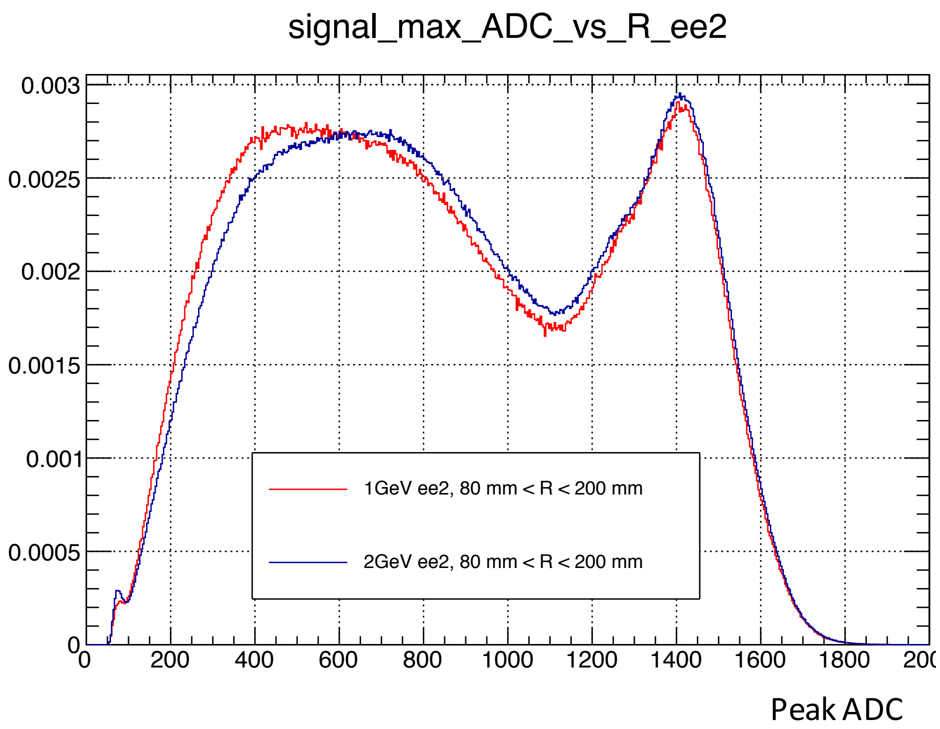
Peak ADC

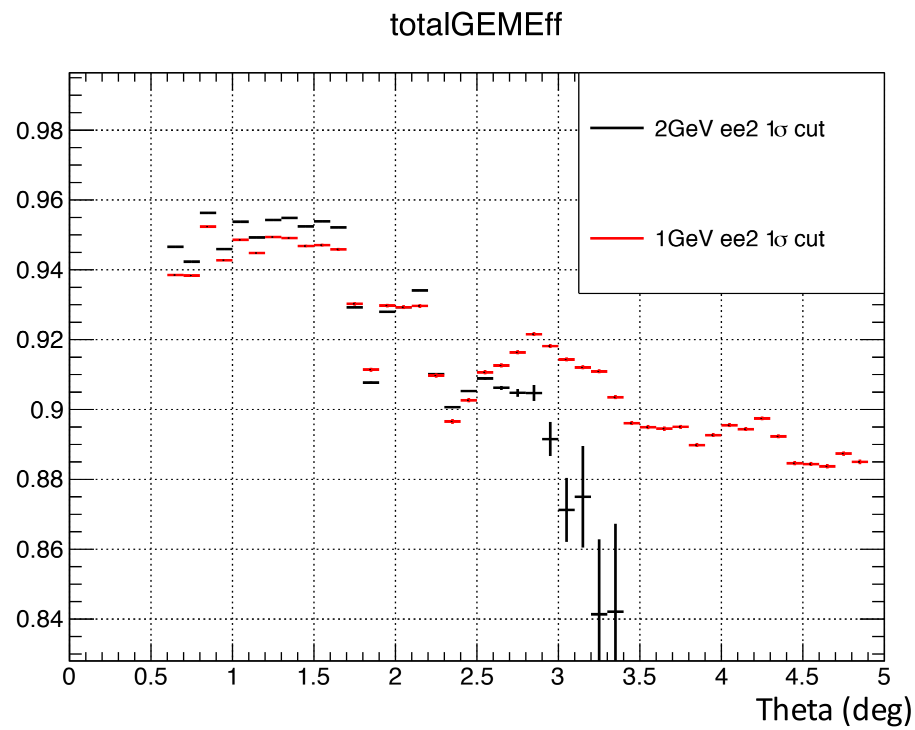
150 mm< R < 250 mm, 2GeV ee



Peak ADC

Time Dependency of the Efficiency





Summary for the GEM Efficiency

- GEM efficiency has a strong dependency on R, a very small dependency on E
  - The energy dependent part is likely to be at the 0.1% level (rough estimation), more precise estimation may need to rely on precise GEM digitization

- Time variable of the GEM efficiency
  - Strong correlation observed between the efficiency of the chamber and the shift of the peak ADC value
  - Exact reason not certain, maybe due to gas flow, pressure, temperature, HV shift…

- If using single arm Moller technique, energy independent part of the GEM efficiency and acceptance will be canceled, which includes the R dependency and the time dependency

Recommended runs for 2.2 GeV

- 1443, 1444, 1445, 1446 (1431, 1448)
- 1449, 1451, 1452, 1453 (1448, 1454)
- 1455, 1456, 1457, 1458 (1454, 1459)
- 1460, 1461, 1462, 1463 (1459, 1465)
- 1466, 1467, 1468 (1465, 1469)
- 1470, 1471 (1469, 1473)
- 1474, 1475, 1476 (1473, 1477)
- 1478, 1479, 1480 (1477, 1481)
- 1482, 1484, 1485 (1481, 1486)
- 1487, 1488, 1489 (1486, 1490)

- Black numbers are production runs and blue numbers are empty target runs to be used to subtract background for the corresponding production runs
- The background rate for 2.2 GeV is low, so using the closest single empty target run to do the subtraction should give very close result
- Subtracted yields are obtained in each sub-period, and then being summed up to get the total subtracted yield
- Extra care needed when empty target runs are reused

Statistical Error Propagation

- Assume I have a run format: n_1, N_1, n_2, N_2, n_3..., where n_i are yields from empty target runs, and N_i are yields from production runs

If no re-usage of empty target run

- Obtaining subtracted yields for each sub-period as:
  - $S_1 = N_1 - c_1 \times n_1$ with $\delta S_1 = \mathrm{sqrt}(N_1 + c_1^2\, n_2)$
  - $S_2 = N_2 - c_2 \times n_2$ with $\delta S_2 = \mathrm{sqrt}(N_2 + c_2^2\, n_2)$
  - ...
  - Where c_i is the live charge ratio between the corrsponding production run and empty target run

- And the total subtracted yield is:
  - $S_t = S_1 + S_2 + \ldots = (N_1 + N_2 + \ldots) - (c_1 n_1 + c_2 n_2 + \ldots)$
  - $\delta S_t = \mathrm{sqrt}(\delta S_1^2 + \delta S_2^2 + \ldots)$

If reuse empty target run

- Obtaining subtracted yields for each sub-period as:
  - $S_1 = N_1 - c_1(n_1+n_2)$ with $\delta S_1 = \mathrm{sqrt}(N_1 + c_1^2\,(n_1+n_2))$
  - $S_2 = N_2 - c_2(n_2+n_3)$ with $\delta S_2 = \mathrm{sqrt}(N_2 + c_2^2\,(n_2+n_3))$
  - ...
  - Where c_i is the live charge ratio between the corrsponding production run and empty target run

- And the total subtracted yield is:
  - $S_t = S_1 + S_2 + \ldots = (N_1 + N_2 + \ldots) - (c_1 n_1 + (c_1 + c_2)n2 + \ldots)$
  - δS_t does not equal to $\mathrm{sqrt}(\delta S_1^2 + \delta S_2^2 + \ldots)$
  - $\delta S_t = \mathrm{sqrt}(\,(N_1 + N_2 + \ldots) + c_1^2\, n_1 + (c_1 + c_2)^2\, n_2 + \ldots\,)$

- So when reuse empty target runs, there are $c_i c_{i+1}$ terms appear in the error propagation

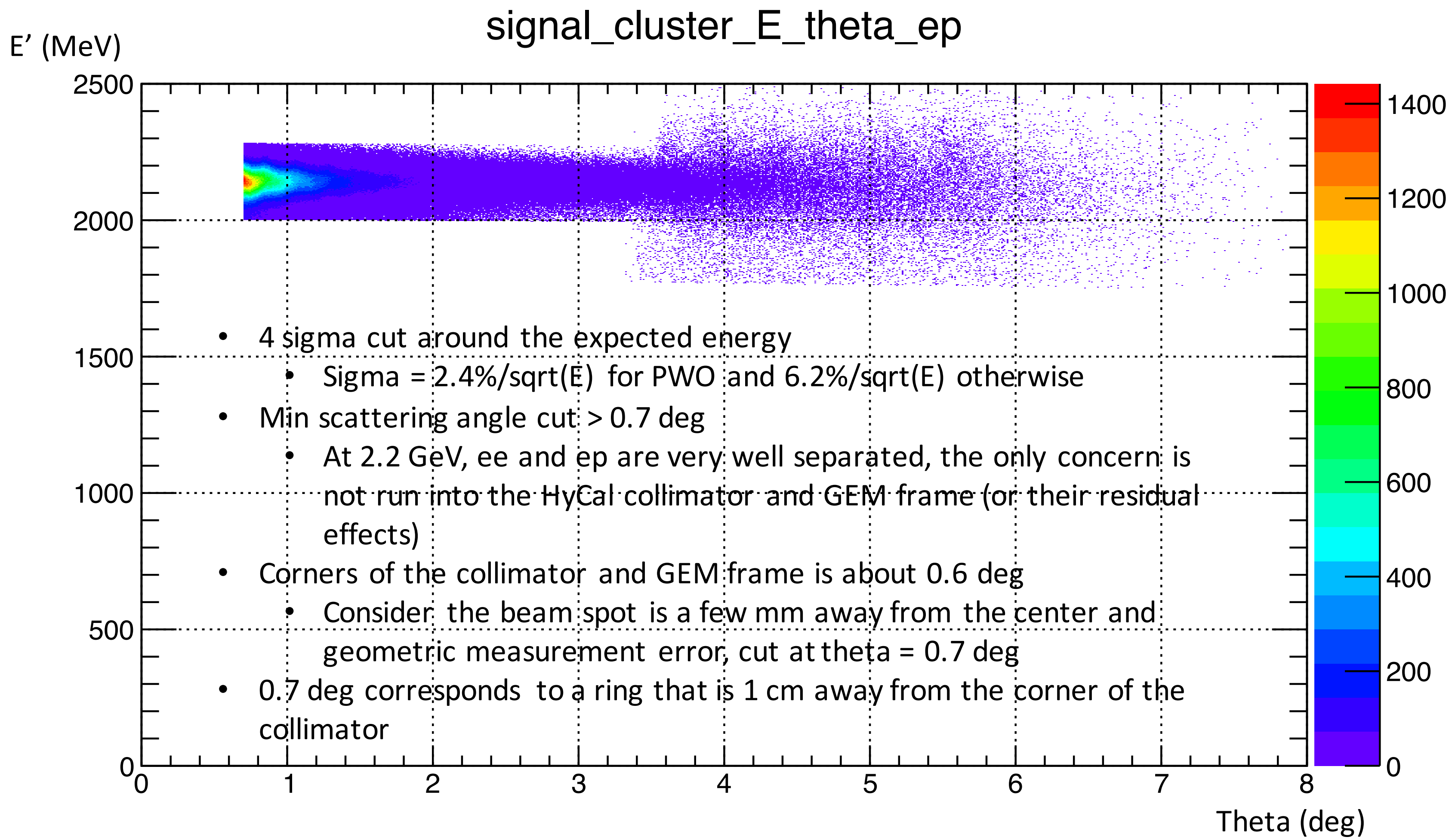
Extracting the ep / ee ratio

- General Event selection:
  - For ep:
    - simple energy cut around the expected E' with cut size depend on the local detector resolution
    - Cluster size cut: module > 2 to further reduce possible accidental match between GEM and discharge channels
  - For ee:
    - Single arm Moller: simple energy cut around the expected E' with cut size depend on the local detector resolution
    - Double arm Moller:
      - Elasticity: $|E_1 + E_2 - E_{beam}| < n \times \text{sqrt}(\delta E_1^2 + \delta E_2^2)$, where δE are the expected energy resolution for each cluster
      - energy cut around the expected E' with cut size depend on the local detector resolution
      - Coplanarity: azimuthal angles of the two electrons differ by around 180 deg
      - Vertex z: using kinematics to determine the interaction vertex by using the two R coordinates of the two electrons

Extracting the ep / ee ratio

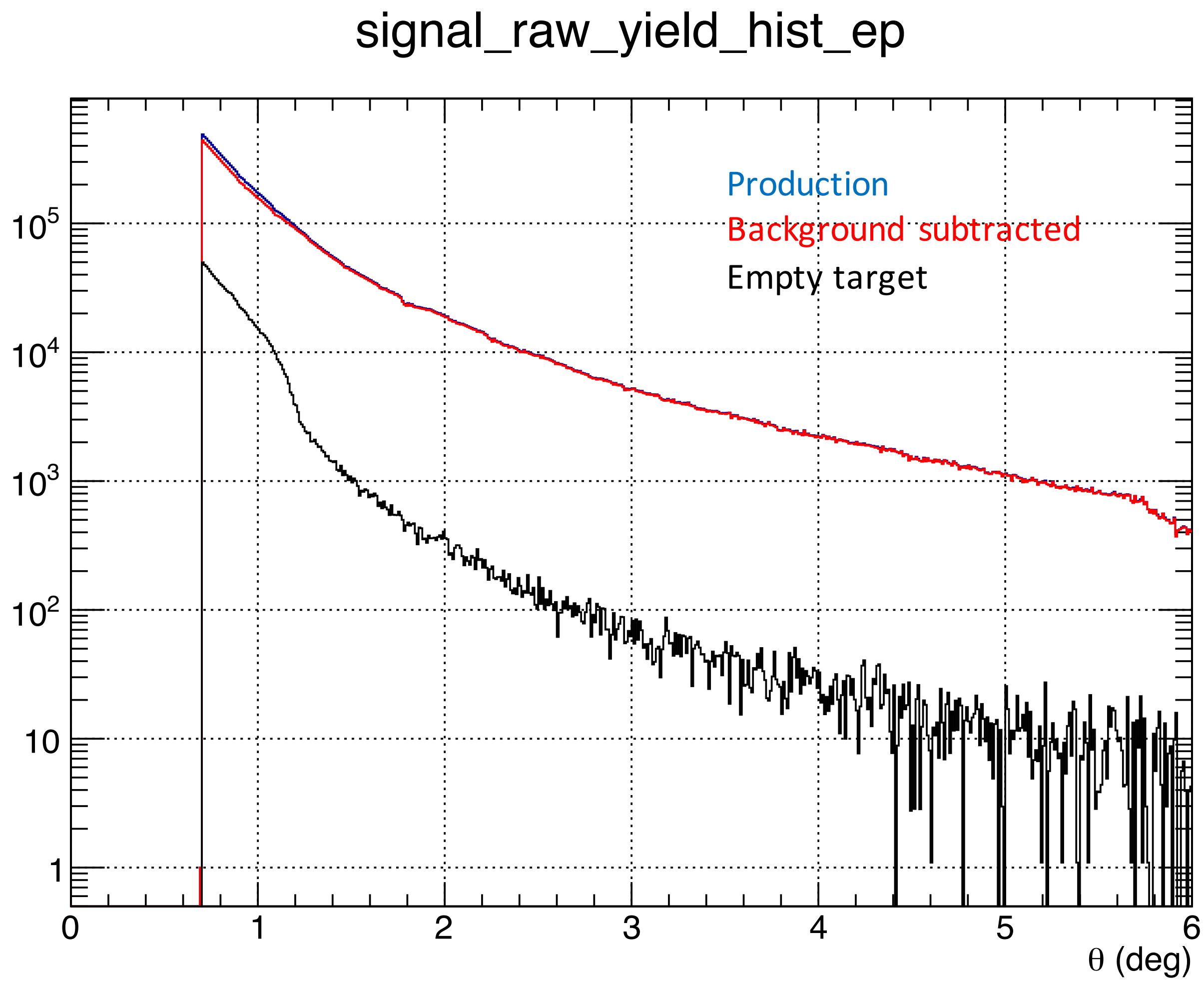
- At least four different ways to form the ratio, luminosity is always canceled by the ratio:
  - ep / single arm Moller (ee1): for ep in each theta (Q^2) bin, normalize it to the Moller yield selected using single arm Moller technique
    - Best at cancellation of energy independent detector acceptance and efficiency
    - Worst in ee signal to background ratio
  - ep / double arm Moller (ee2): for ep in each theta (Q^2)bin, normalize it to the Moller yield selected using double arm Moller technique
    - Partial cancellation for energy independent detector acceptance and efficiency
    - Best at ee signal to background ratio
  - ep / integrated double arm Moller (inte Moller)
    - No cancellation for energy independent detector acceptance and efficiency
    - The only way to include ep bins in region that is not "effectively" covered by Moller
- GEM detectors are always required for the above three types of ratio
  - ep / (HyCal double arm + GEM single arm Moller) (s_ee1): using HyCal to select double arm events first. When using GEM, apply the ep / single arm Moller method
    - Excellent ee signal to background ratio
    - Complete cancellation for the energy independent acceptance and efficiency from GEM

ep selection



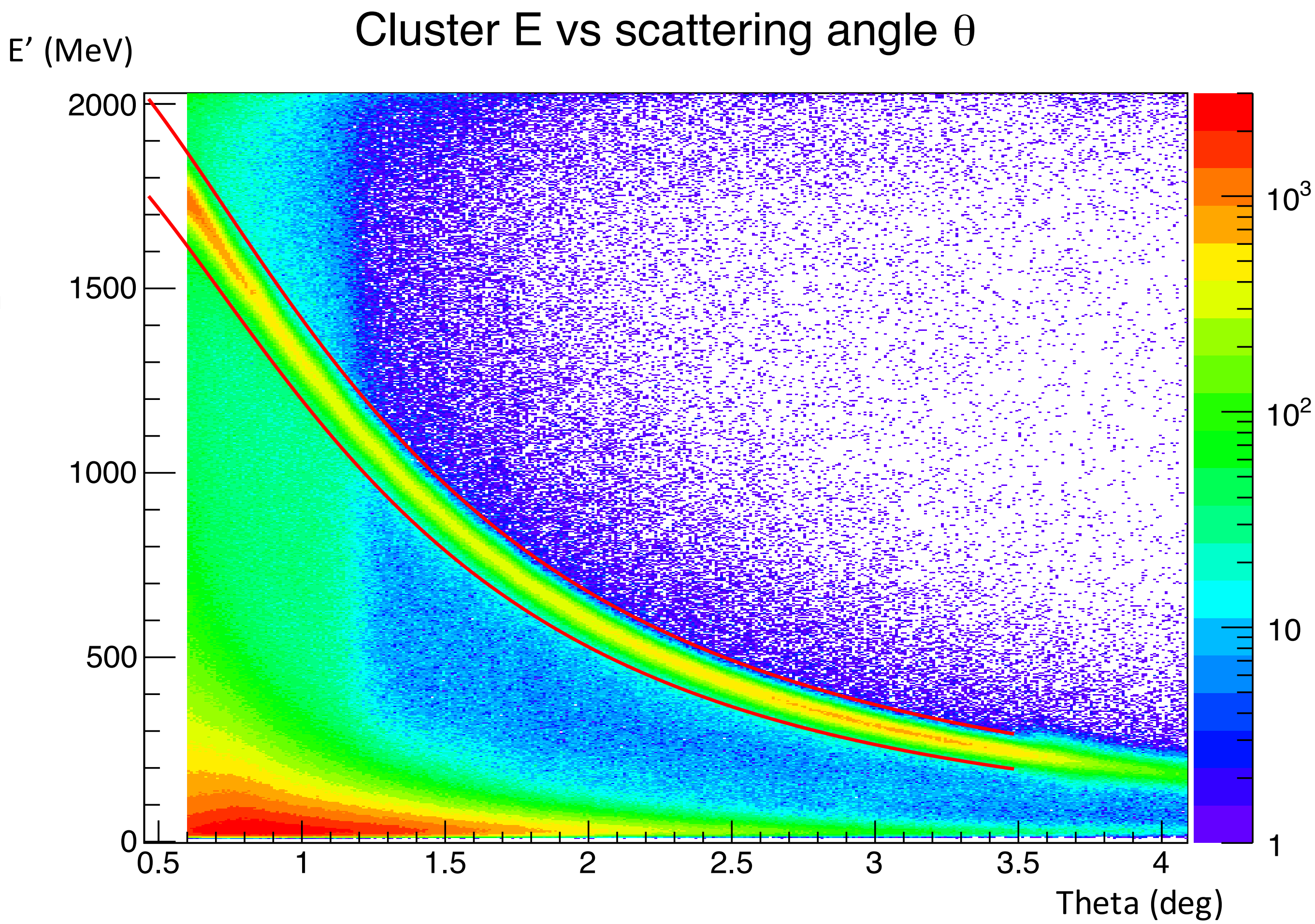
- 4 sigma cut around the expected energy
  - Sigma = 2.4%/sqrt(E) for PWO and 6.2%/sqrt(E) otherwise
- Min scattering angle cut > 0.7 deg
  - At 2.2 GeV, ee and ep are very well separated, the only concern is not run into the HyCal collimator and GEM frame (or their residual effects)
- Corners of the collimator and GEM frame is about 0.6 deg
  - Consider the beam spot is a few mm away from the center and geometric measurement error, cut at theta = 0.7 deg
- 0.7 deg corresponds to a ring that is 1 cm away from the corner of the collimator

ep signal to background ratio



Double Arm Moller Selection – Expected E Cut

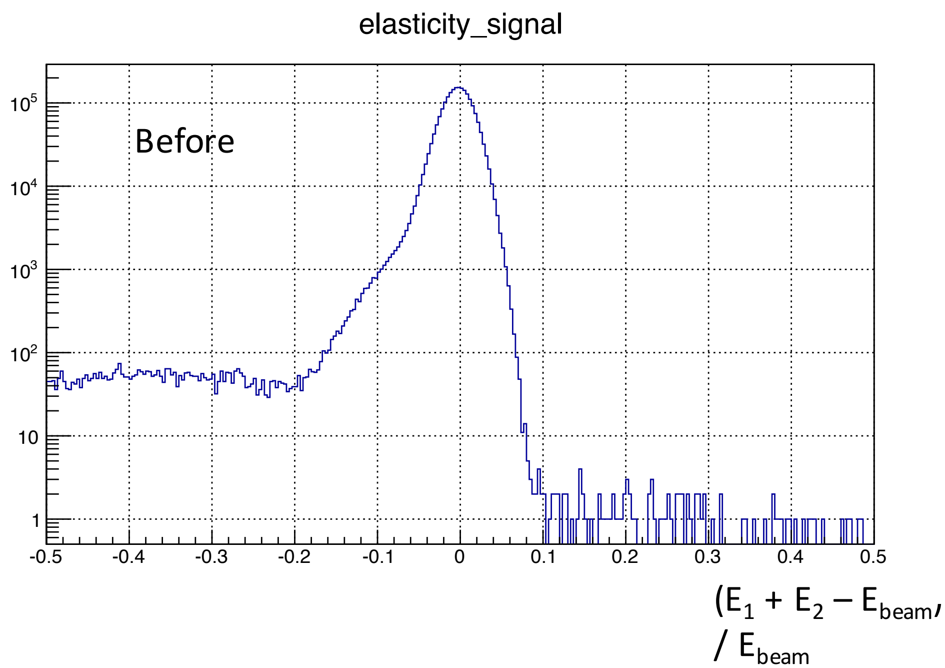
- Selecting events within 4 sigma of the expected energy (sigma 0.024/sqrt(E)), marked by the red lines
- Basically the only cut if doing single arm Moller

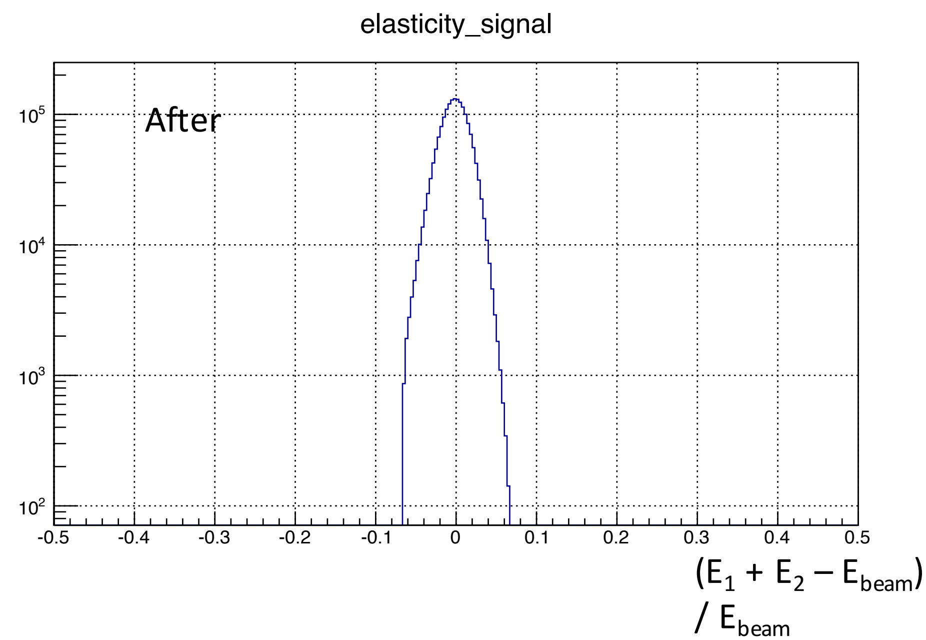


Double Arm Moller Selection -- Elasticity

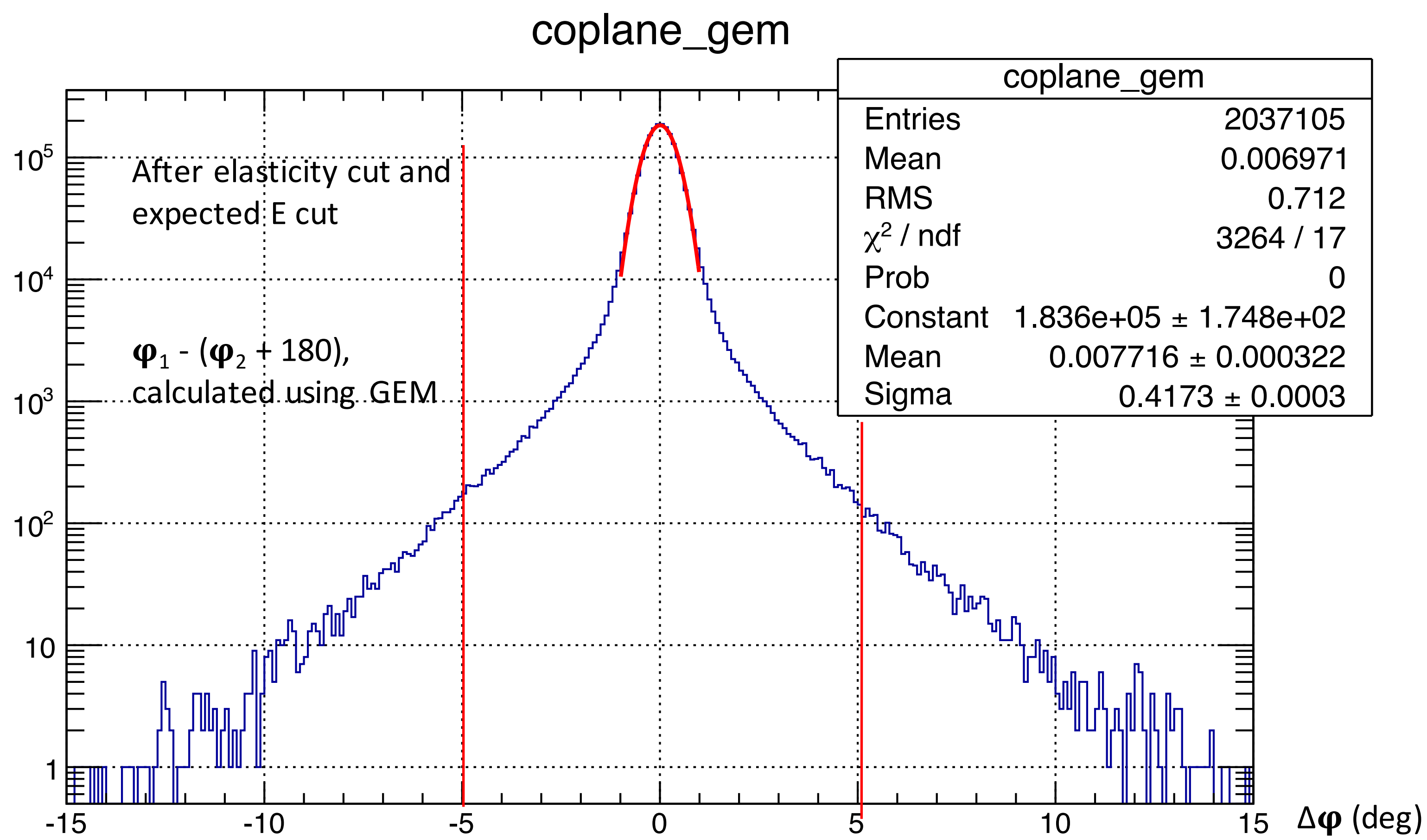
$|E_1 + E_2 - E_{beam}| < 4. \times \mathrm{sqrt}(\delta E_1{}^2 + \delta E_2{}^2)$

if multiple pairs satisfies the cut, pick the pair that has smallest $|E_1 + E_2 - E_{beam}|/\mathrm{sqrt}(\delta E_1{}^2 + \delta E_2{}^2)$



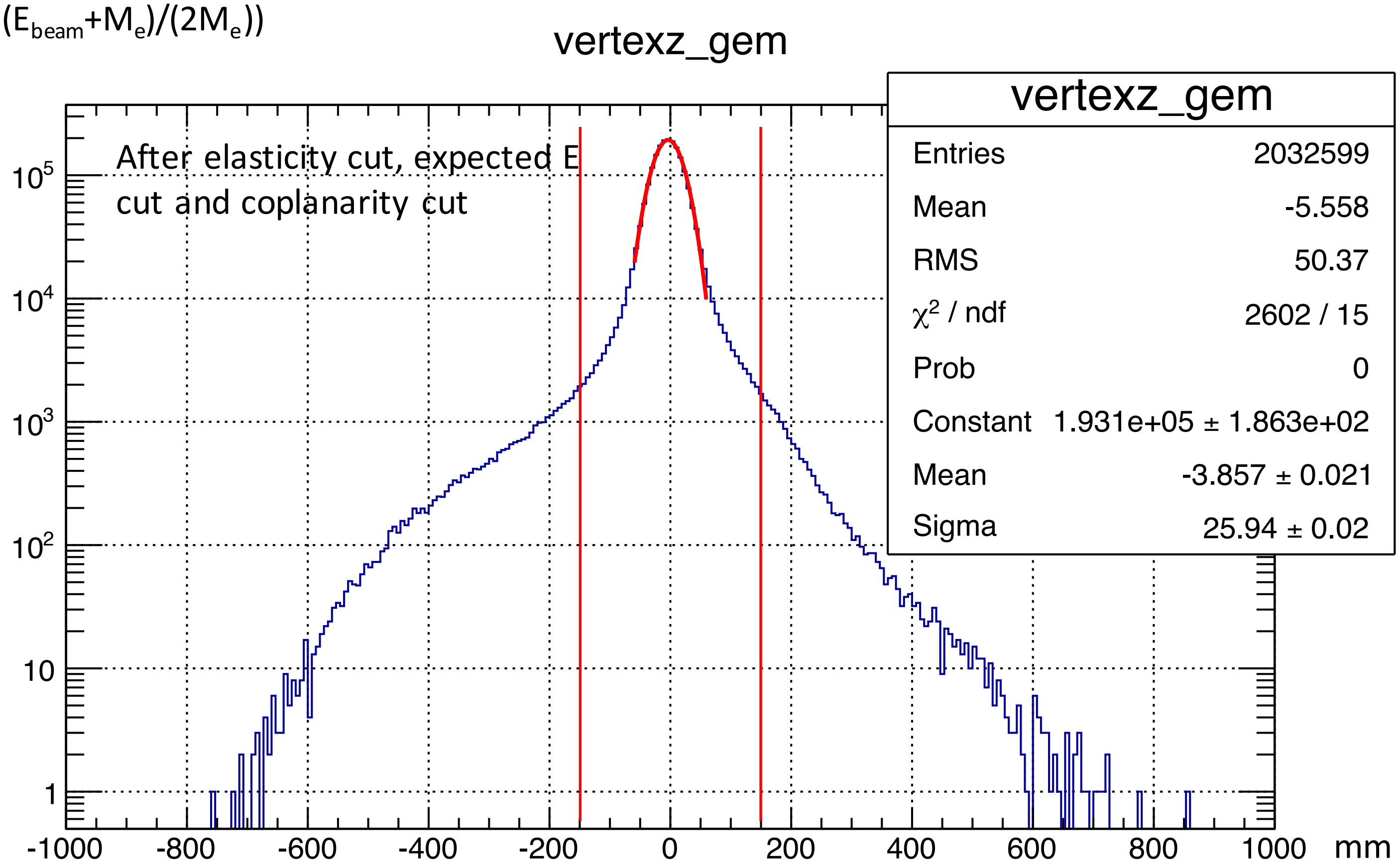


Double Arm Moller Selection -- Coplanarity

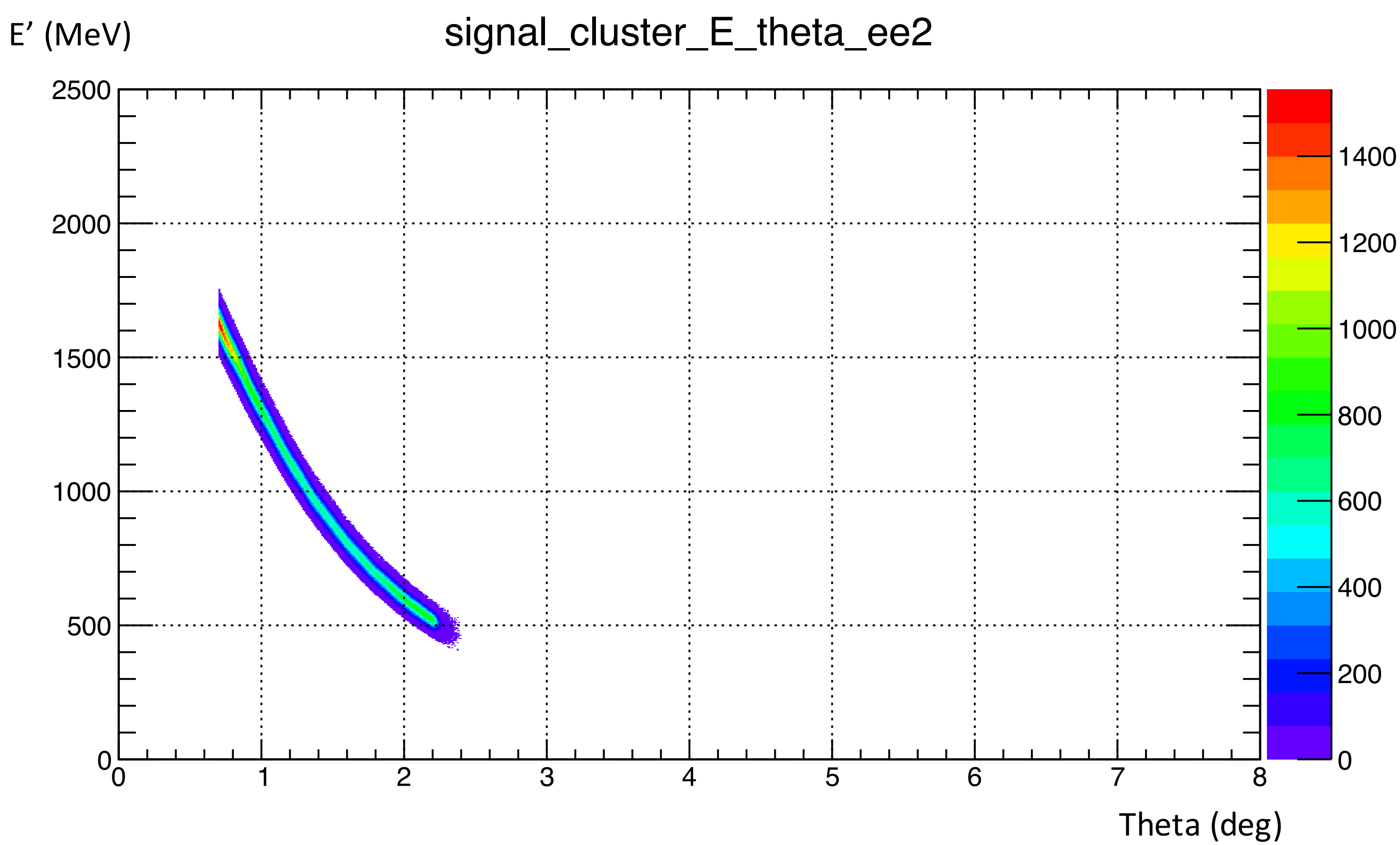


Double Arm Moller Selection – vertex z

$Vz = Sqrt(R_1R_2 \times (E_{beam}+M_e)/(2M_e))$

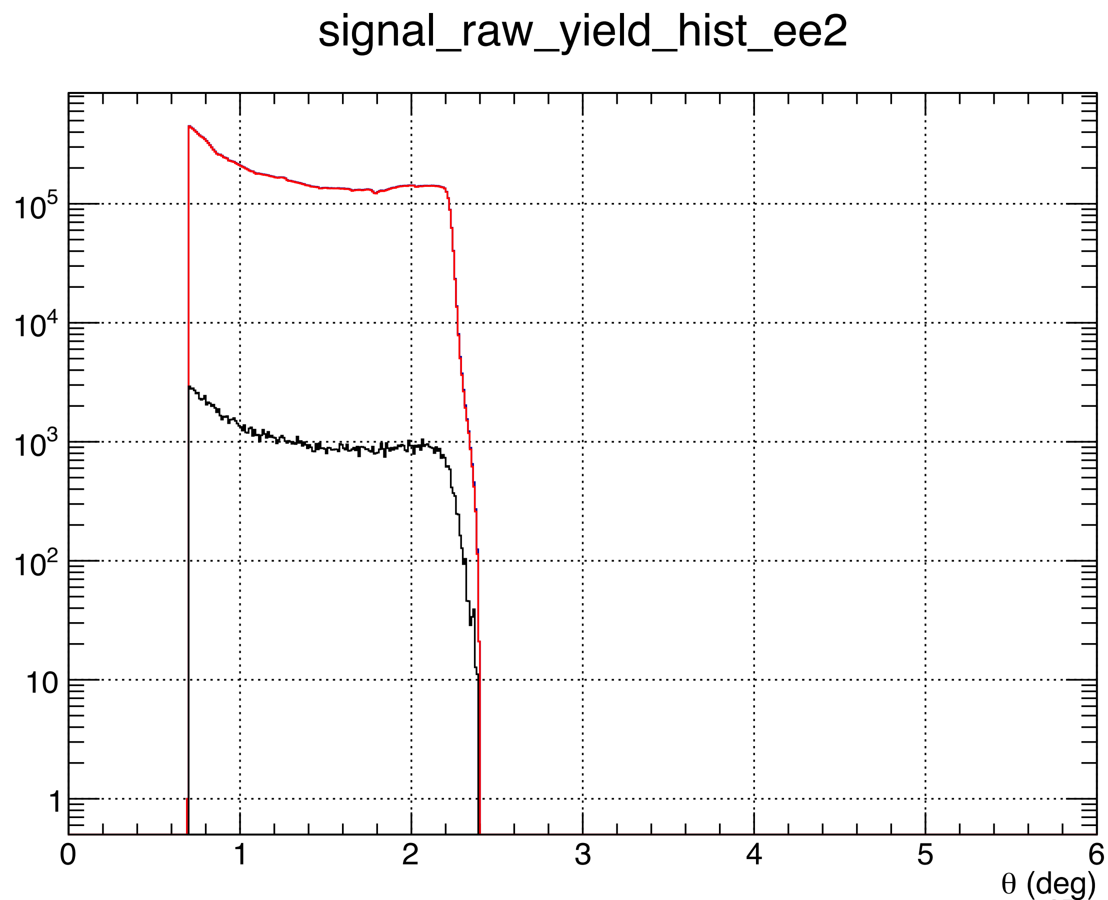


Double Arm Moller Cluster E vs theta after all cuts



ee2 signal to background ratio

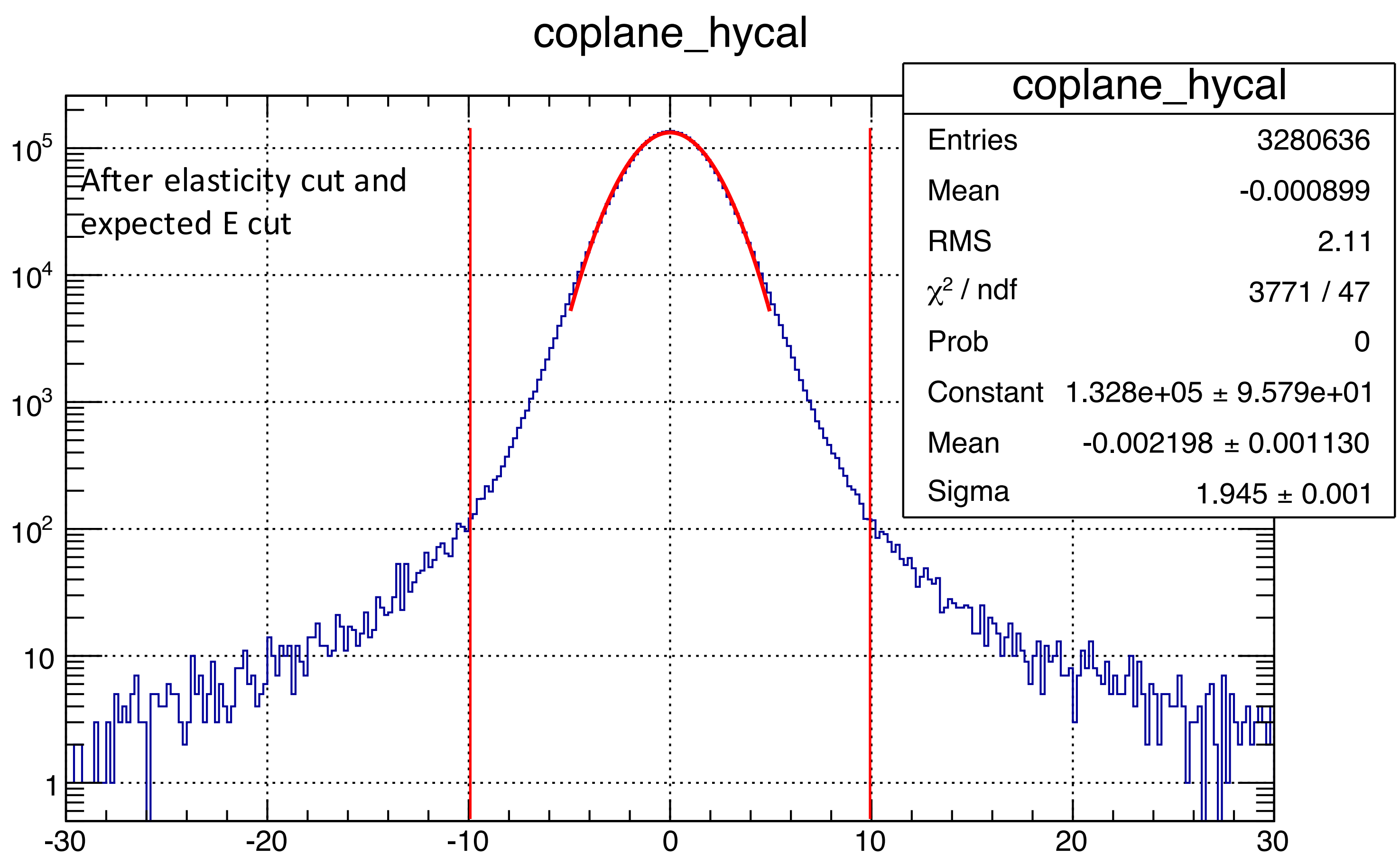
- ee2 is very clean, typically a sub-percentage background
- If cutting the min theta angle at 0.7 deg, the expected drop of the ee2 yield should be at 2.35 deg
- Due to finite detector resolution (including multiple scattering), the yield drops earlier than that
- Selecting events from 0.7 to 2 deg to avoid this effect



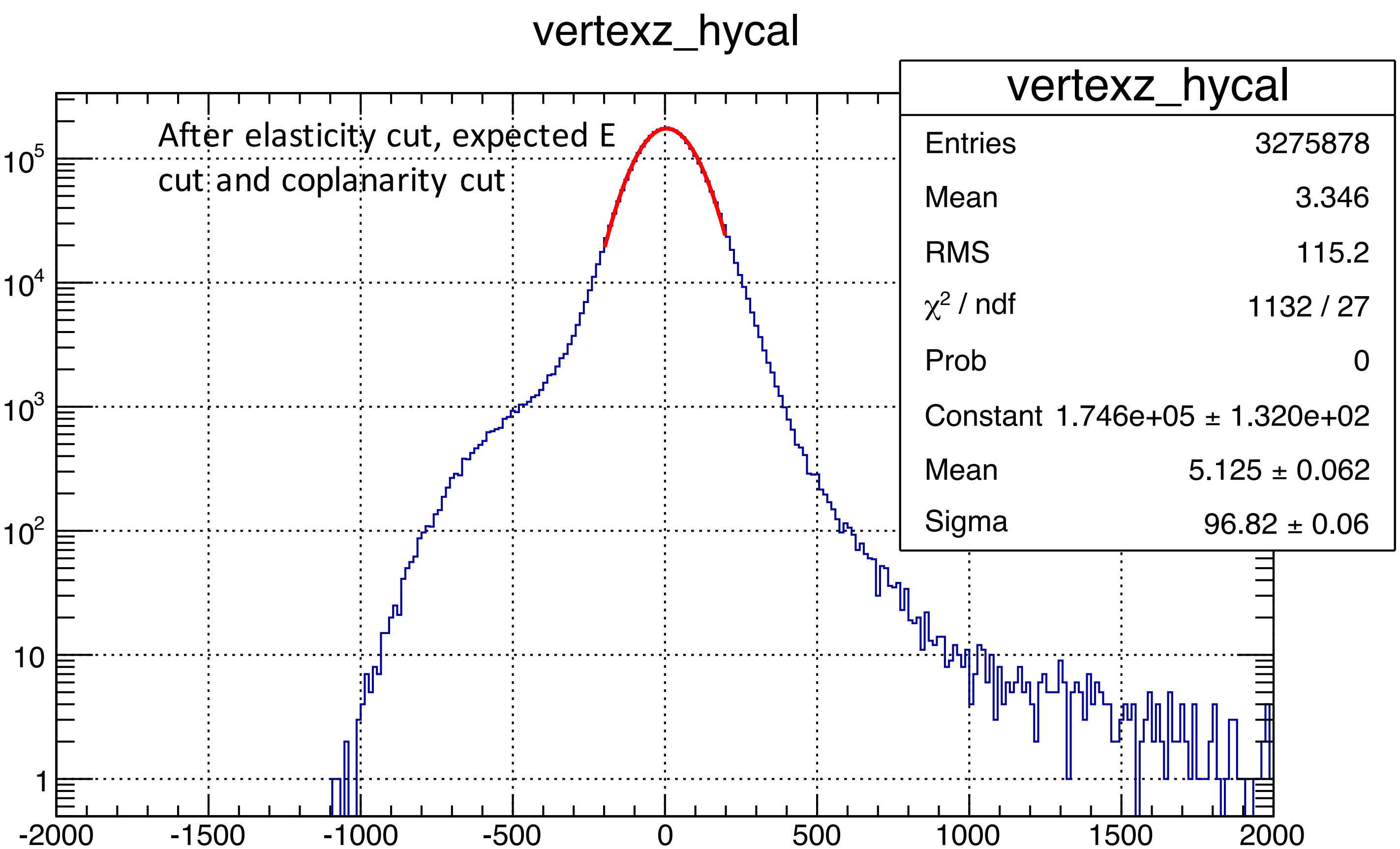
Double arm selection with HyCal

- The previous double arm selection require GEM matched hits from the start
  - GEM detector acceptance and efficiency also got convoluted from the start
- We can select double arm Moller first with HyCal along, and then Apply GEM
  - When selecting events with HyCal, all position related cut should be enlarged, these includes:
    - Min theta angle cut (0.6 deg instead of 0.7 deg)
    - Expected energy cut (6 sigma instead of 4 sigma with GEM)
    - Coplanarity (10 deg cut instead of 5 deg)
    - Vertex z (500 mm insdead of 150 mm)
- After selecting ee2 with HyCal, use only hits that have matched hits found on GEM and apply single arm Moller technique
- Cuts related to single arm Moller technique can now be tighten, which includes min theta cut and expected energy cut

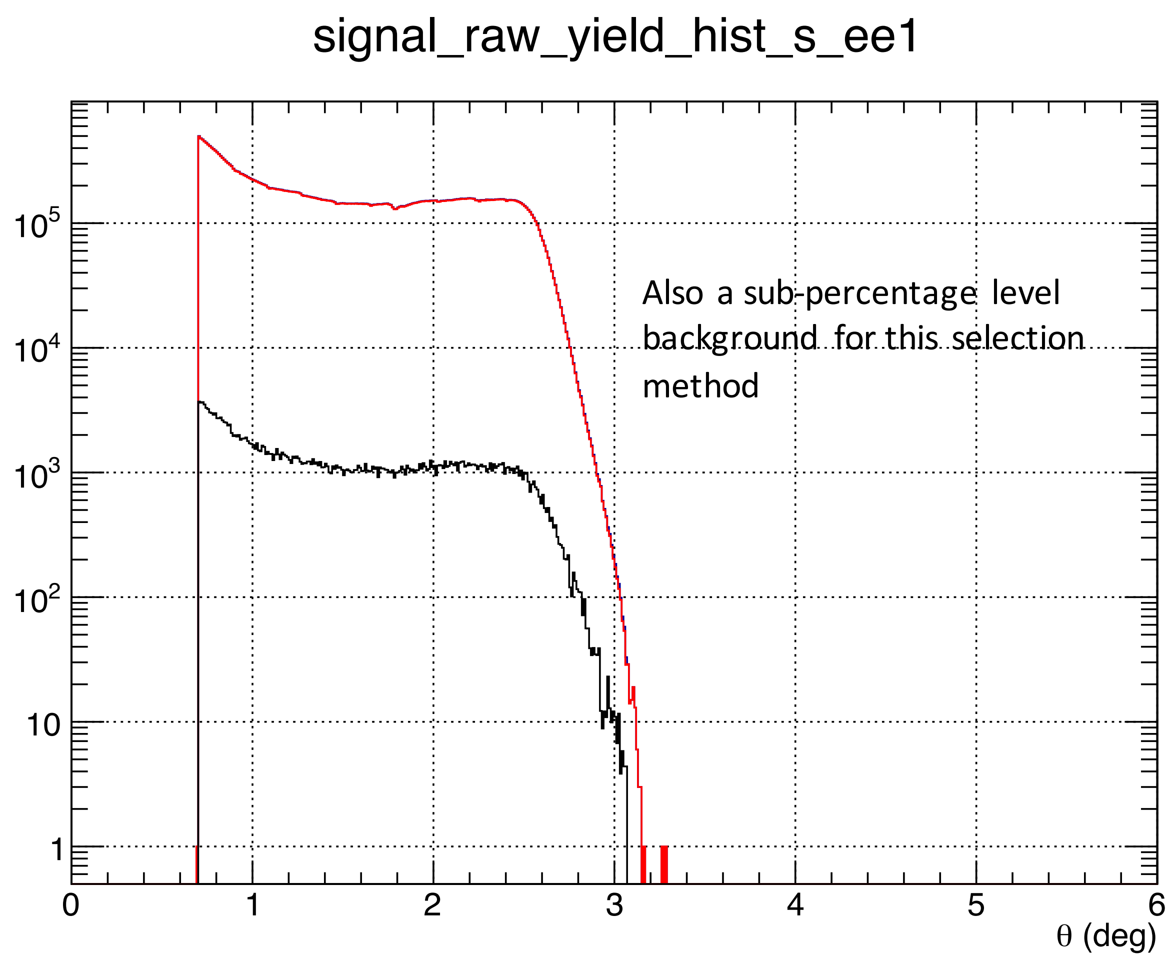
Double arm selection with HyCal -- coplanarity



Double arm selection with HyCal – vertex z

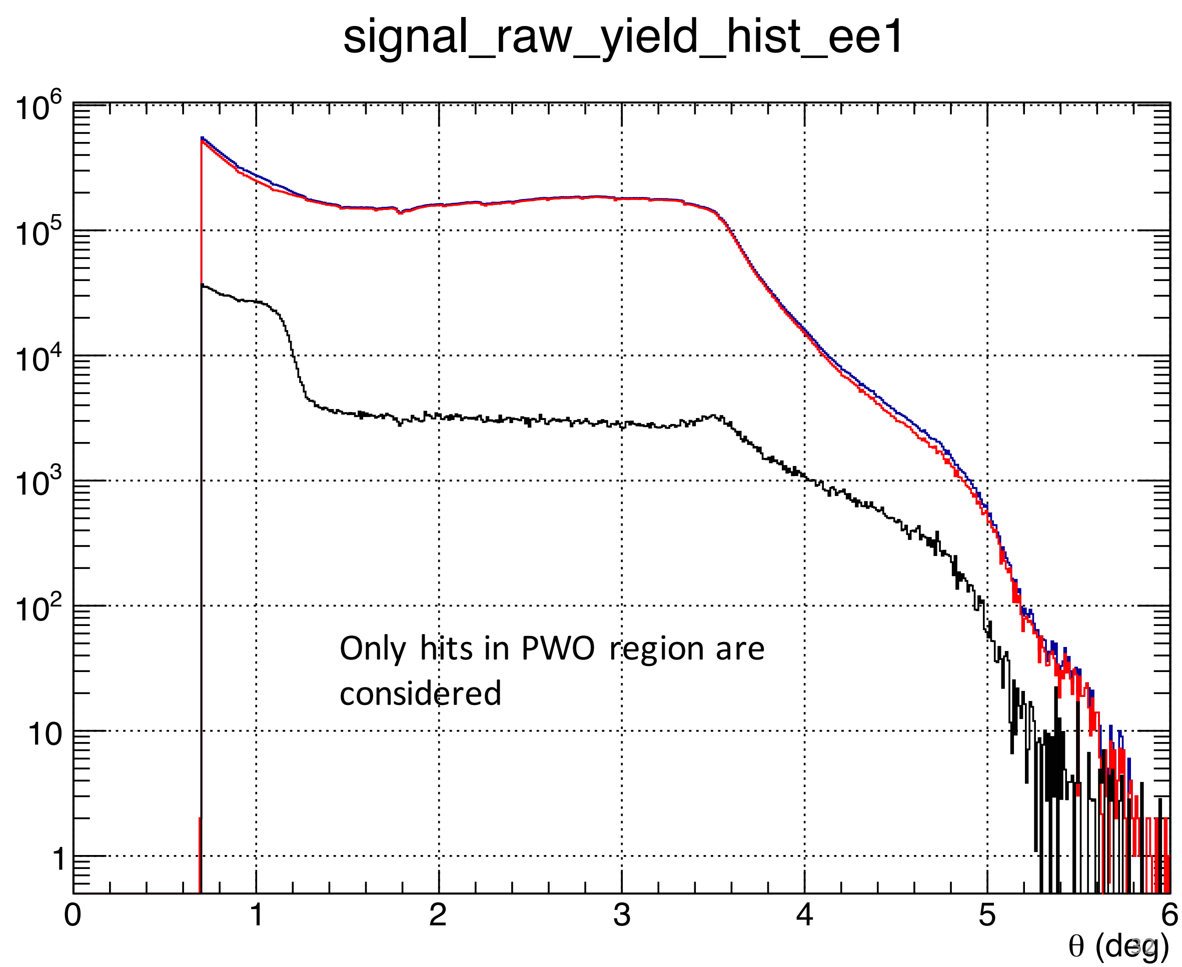


ee2 (select with HyCal) signal to background ratio



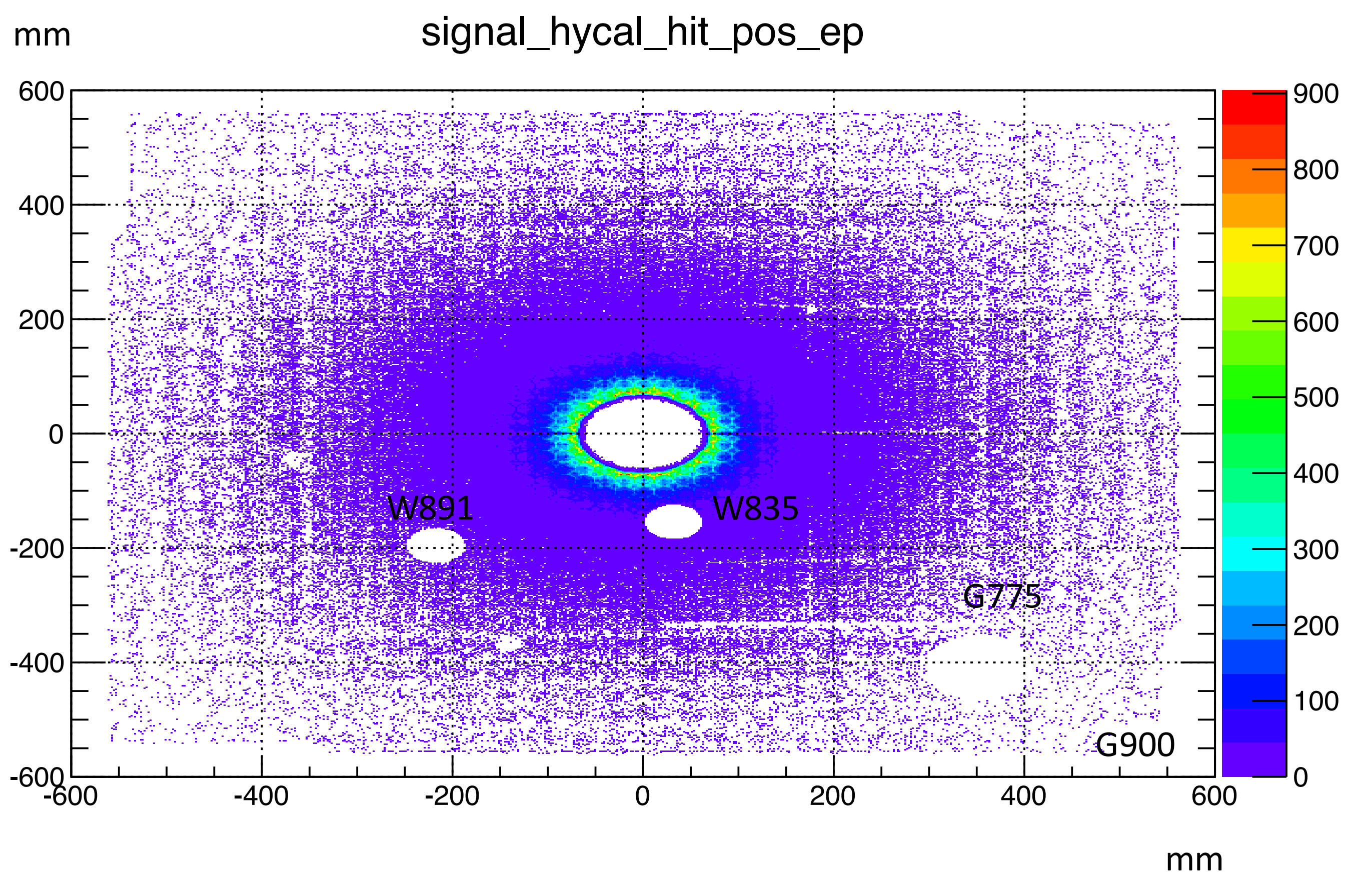
ee1 signal to background ratio

- Selecting single arm Moller
  - Min theta > 0.7
  - Expected E cut at 4 sigma
- ~10% background at theta < 1.2 deg
- A few percent background at theta > 1.2 deg

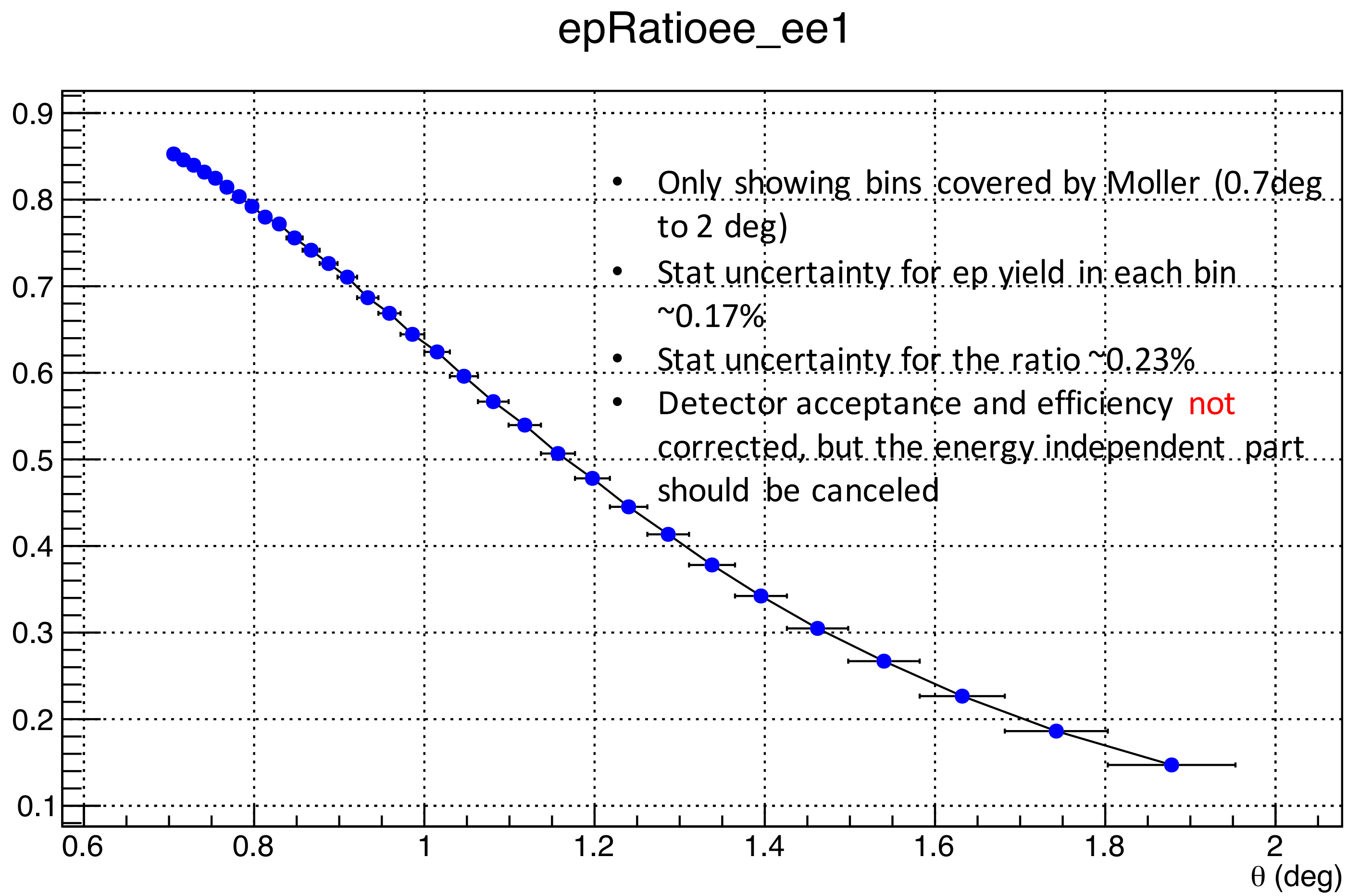


Dead Modules on HyCal

- Dead Modules: W835, W891, G775, G900
- A few modules also have relative low trigger efficiency
- For this plot, cutting hits appear within 1.5 times of modules size, measured from the dead module center
- Using HyCal hit position to make this cut, maybe using GEM? Or Both?



ep to single arm Moller ratio



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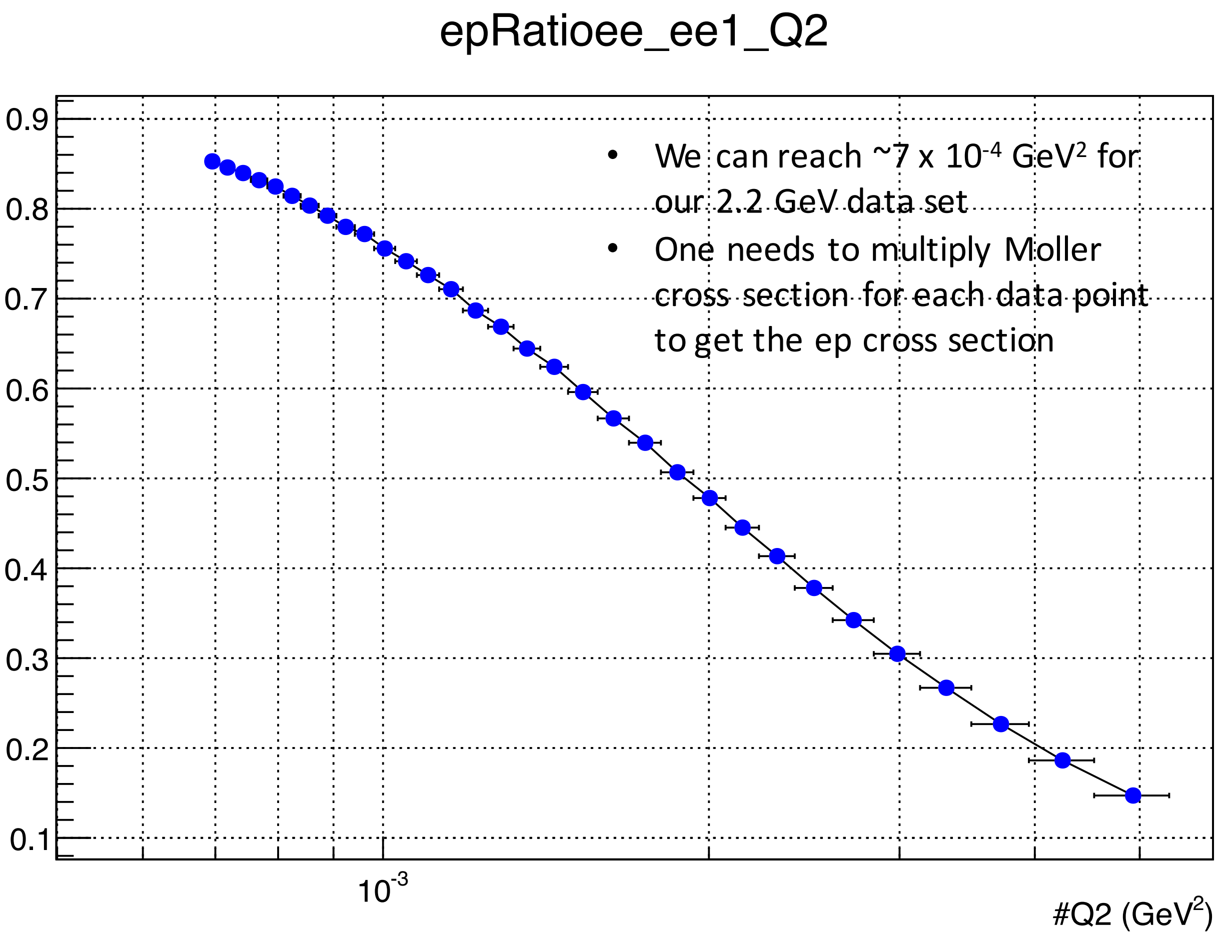
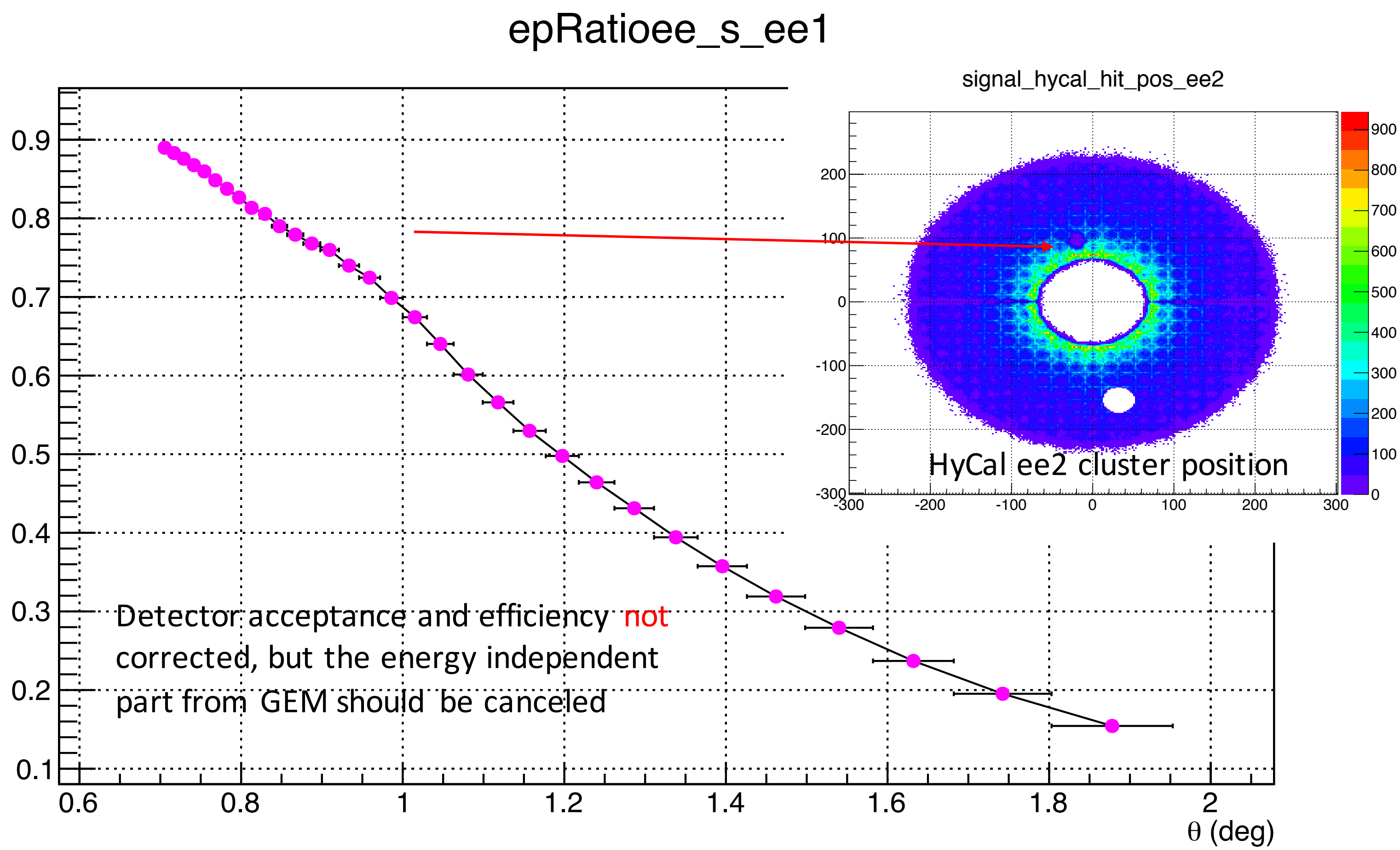


- We can reach ~7 x 10^{-4} GeV^2 for our 2.2 GeV data set
- One needs to multiply Moller cross section for each data point to get the ep cross section

ep ratio to ee2 (HyCal selected)



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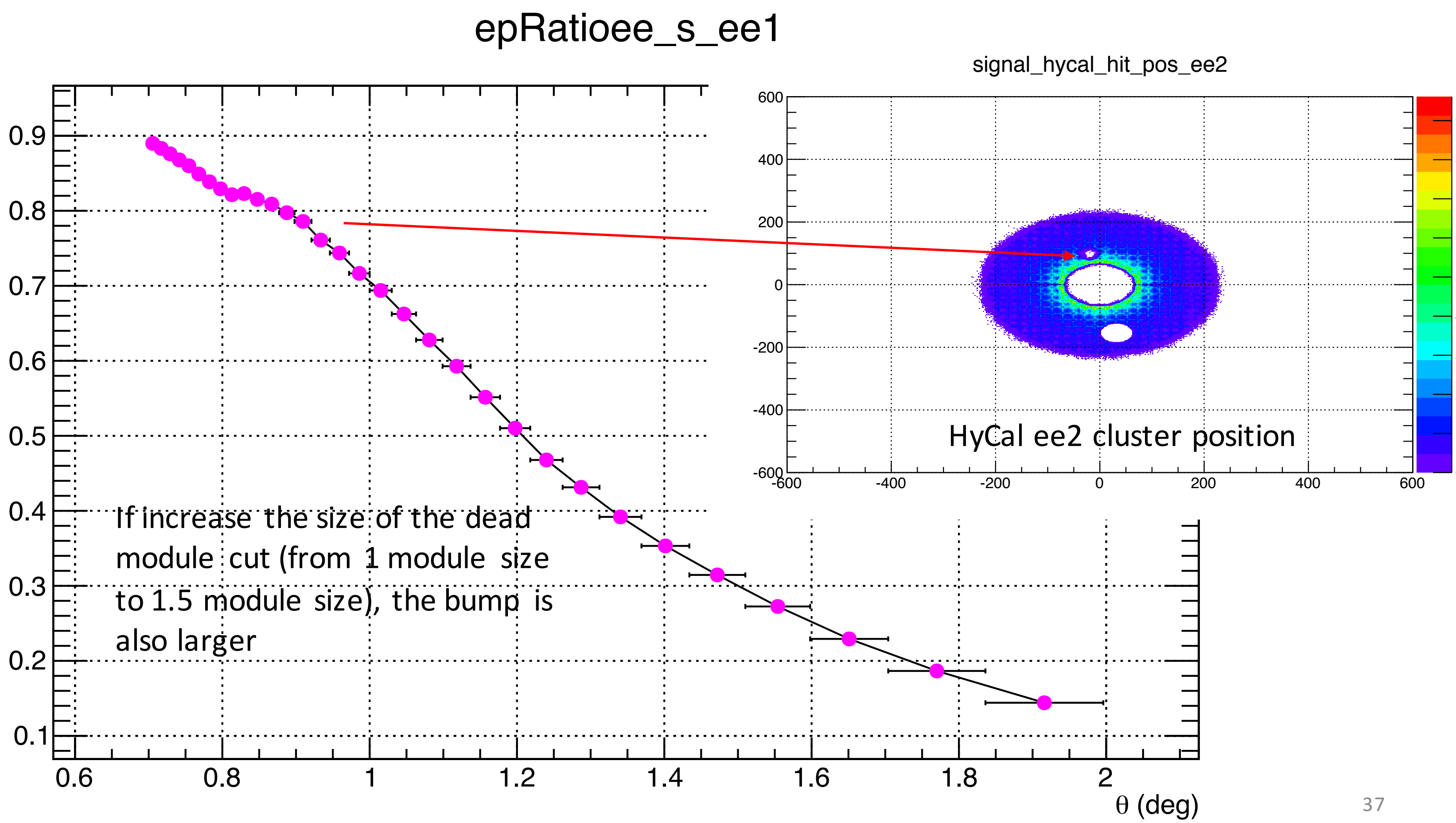
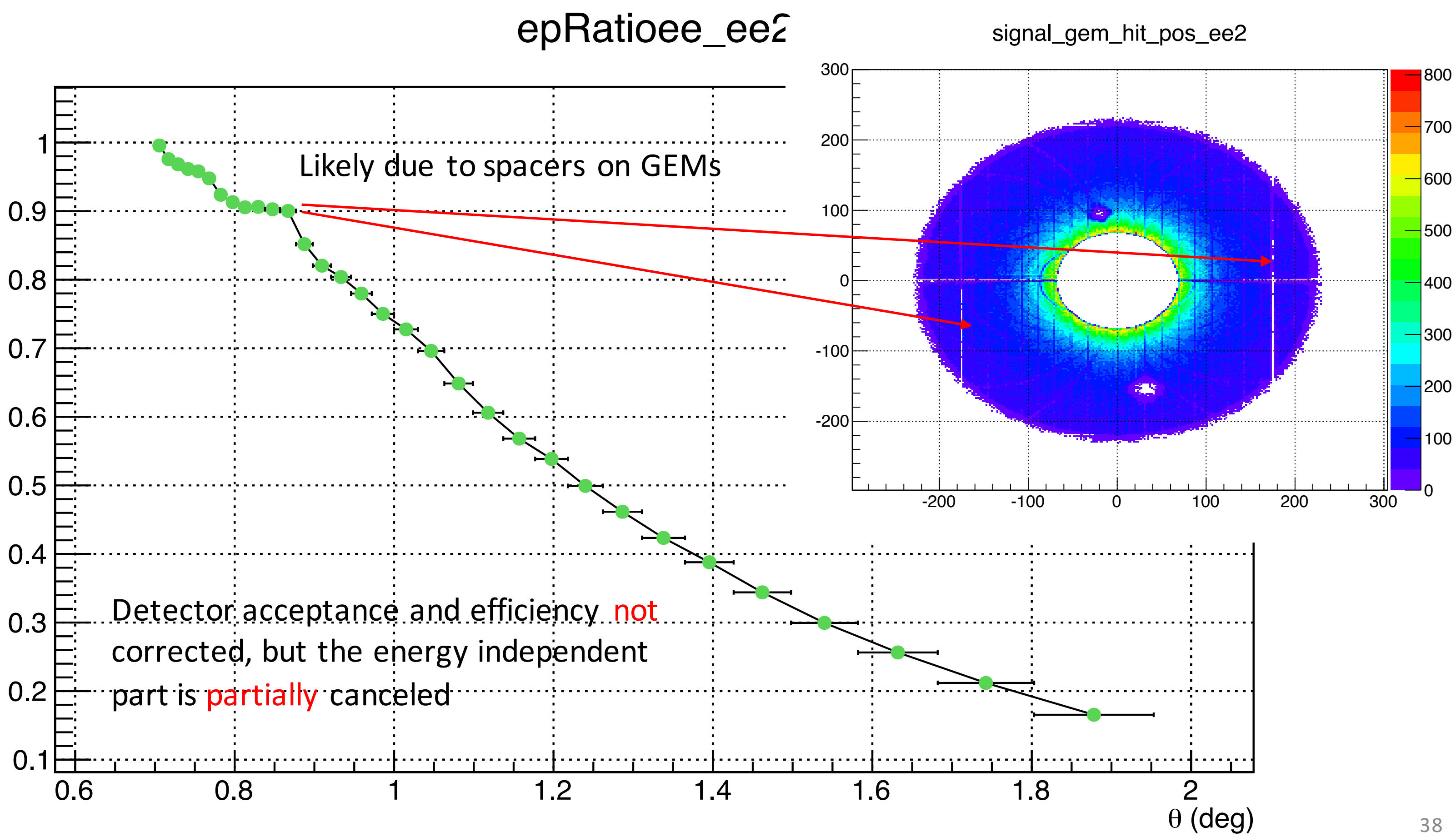
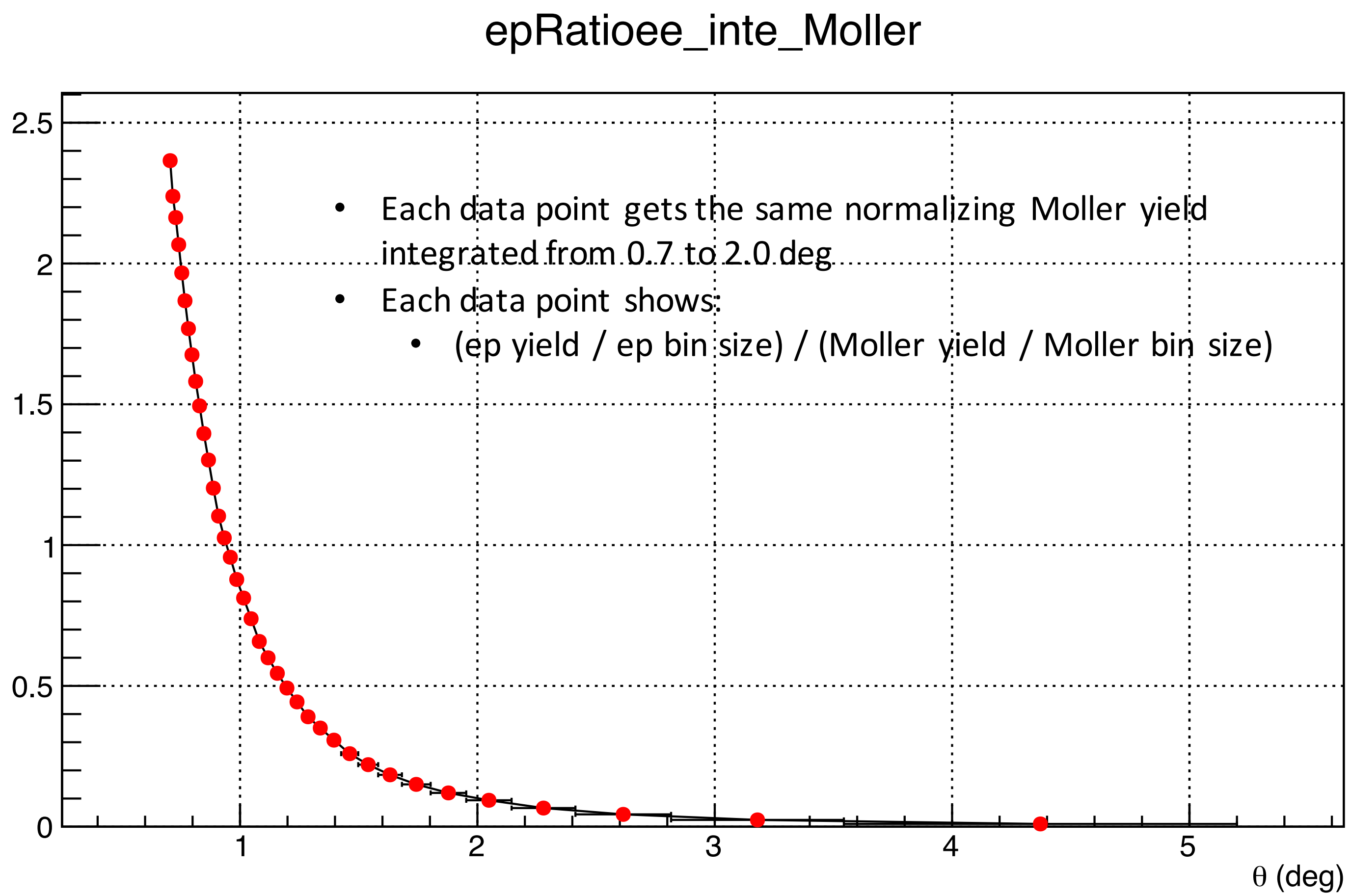


If increase the size of the dead module cut (from 1 module size to 1.5 module size), the bump is also larger

ep ratio to ee2 (Require GEM from start)



ep ratio to integrated ee2 (Require GEM from start)



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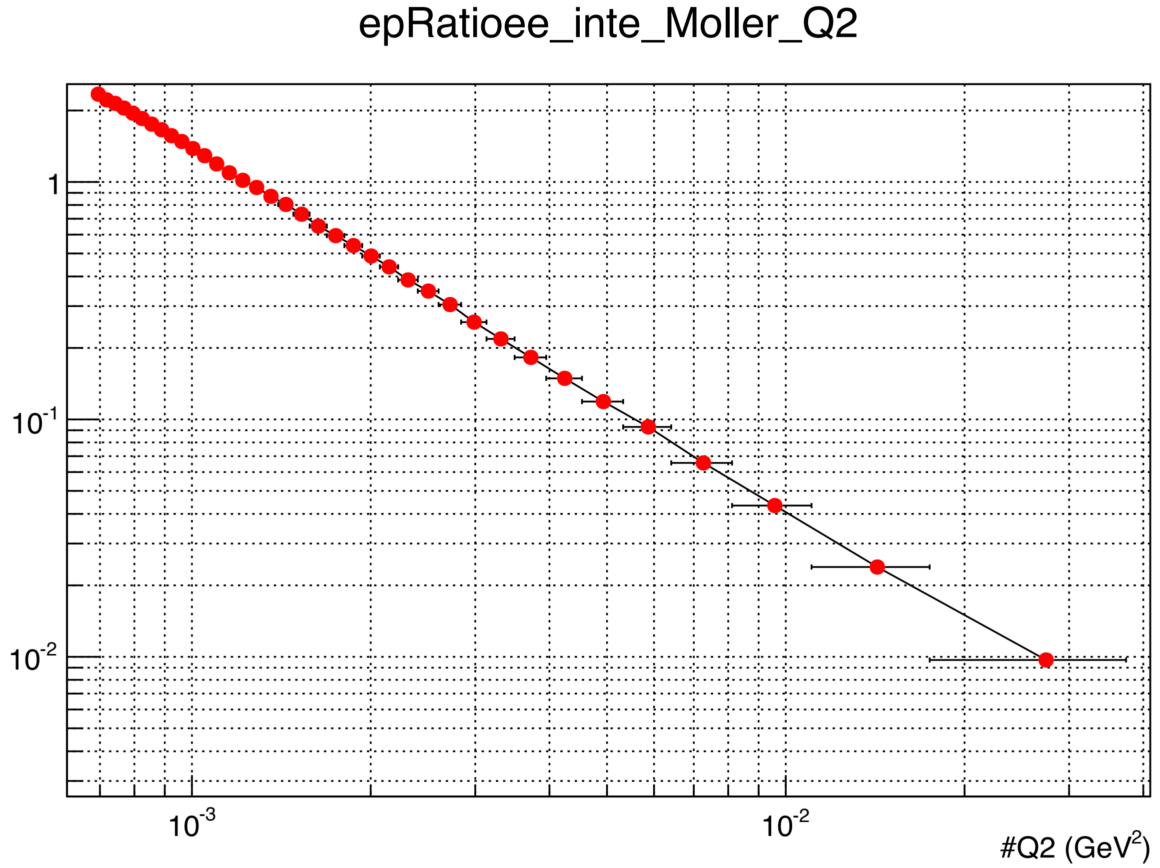
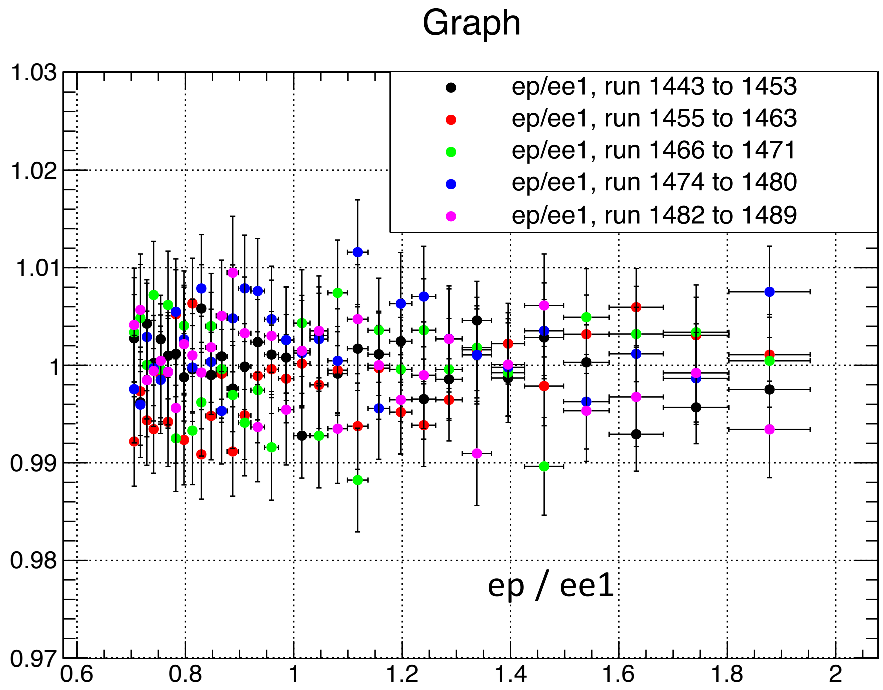
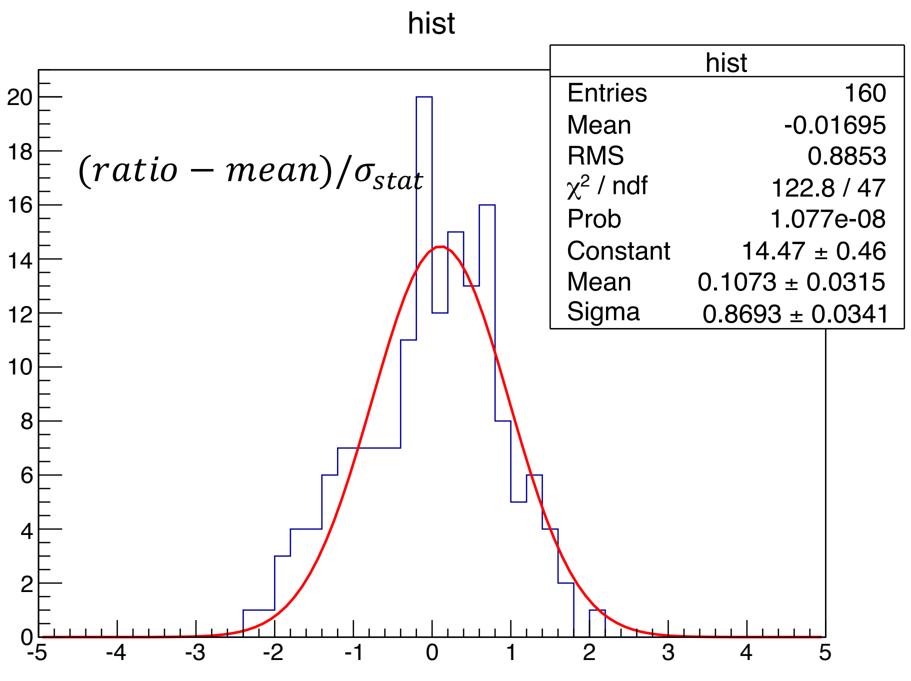


Time Variation of the ep/ee ratio

- Separate the 2.2 GeV recommended runs into 5 sub-periods, and look at the stability of the ep/ee ratio in different angle bins extracted using the 4 different methods
  - Statistical uncertainty of each angle bin is about ~0.5%





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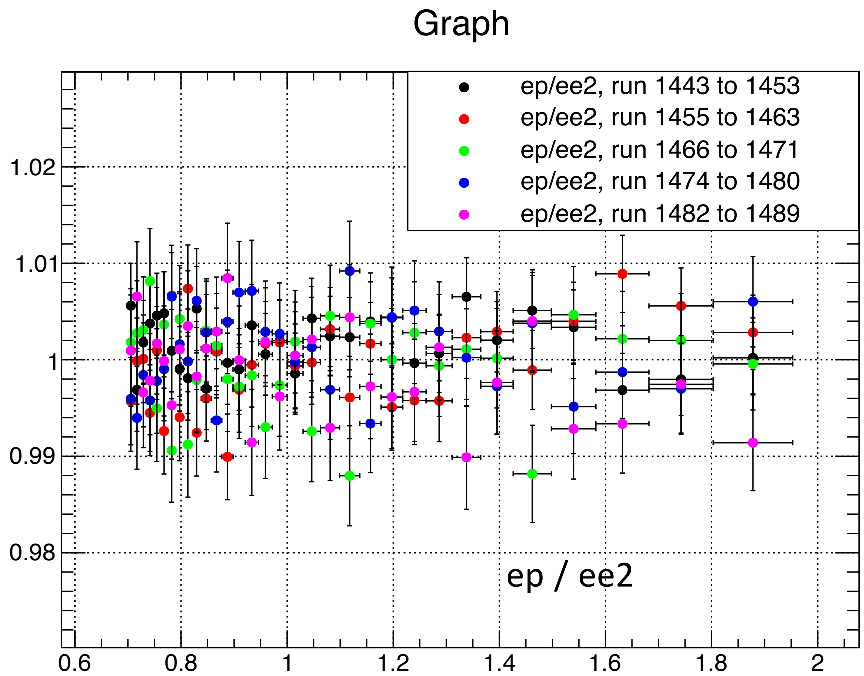

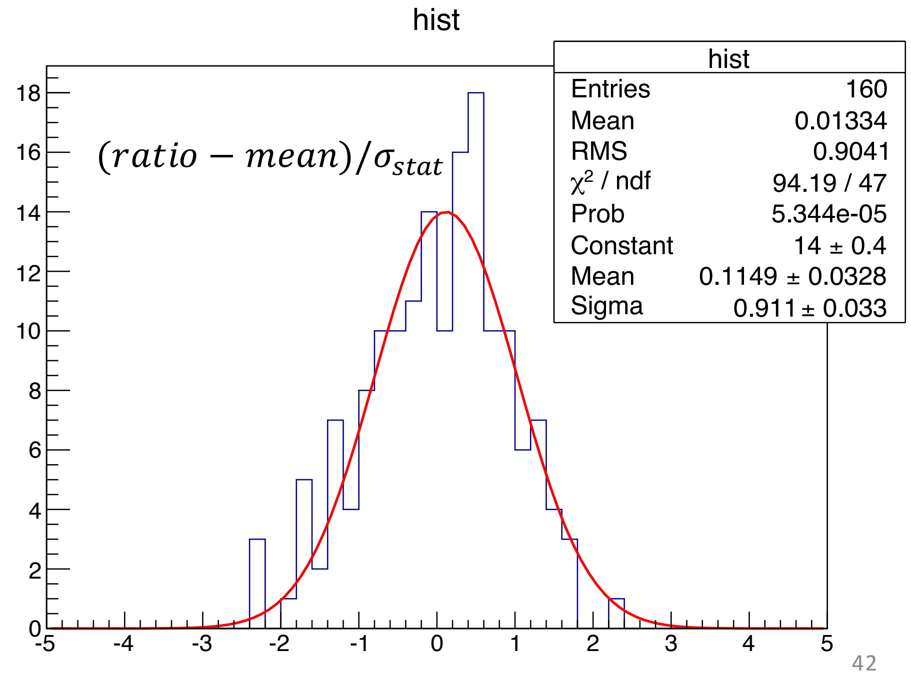

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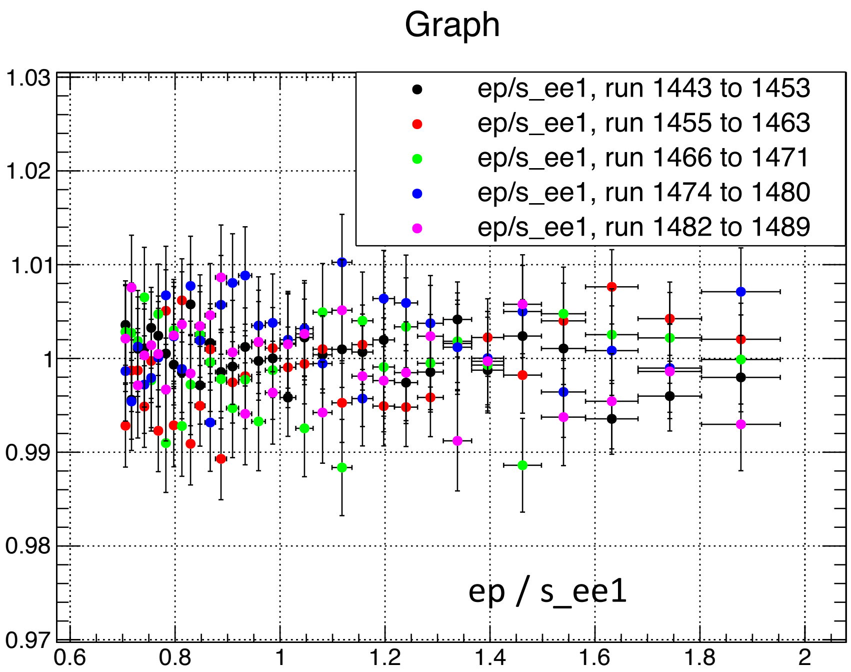

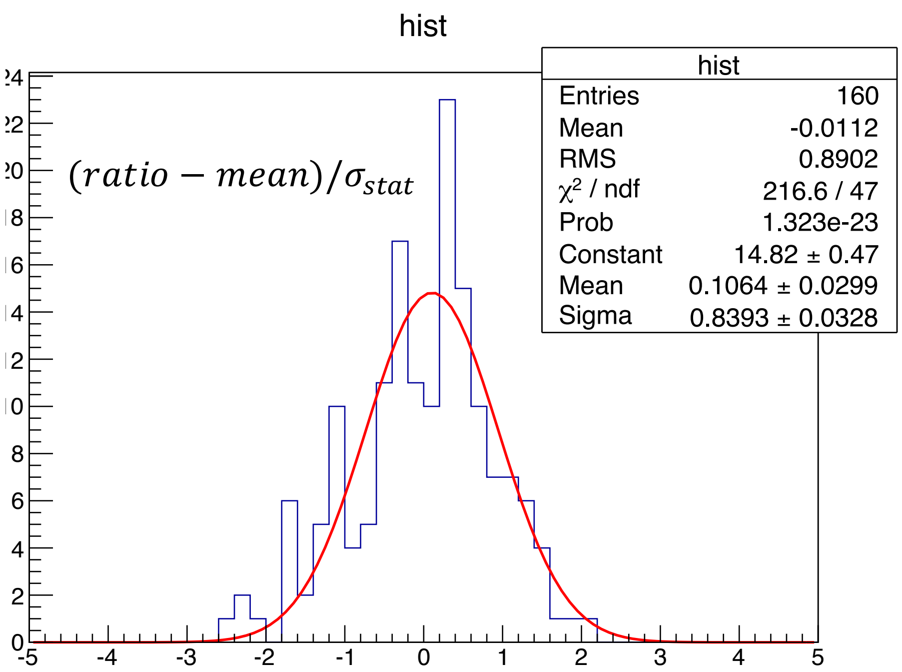

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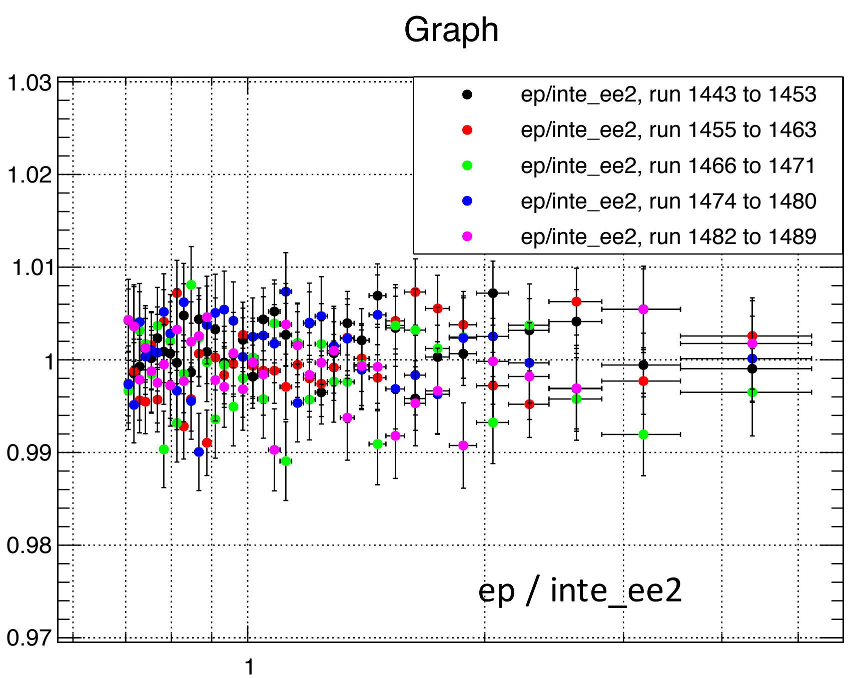
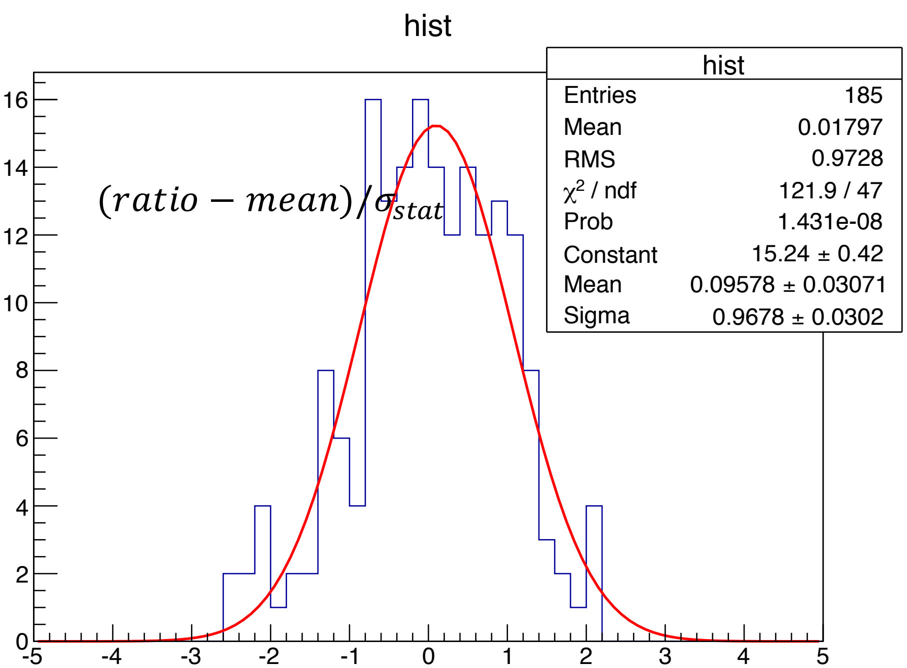
- Separate the 2.2 GeV recommended runs into 5 sub-periods, and look at the stability of the ep/ee ratio in different angle bins extracted using the 4 different methods
  - Statistical uncertainty of each angle bin is about ~0.5%





Summary

- The two single arm Moller methods seems to be the most promising approach at the moment
  - At least they are able to cancel most of the GEM efficiency and acceptance
  - Background for ee1 is very low at 2GeV, if not, the special single arm Moller method is going to ensure that
- Integrated double arm Moller method is still necessary, so GEM efficiency still needs to be precisely determined (and corrected)
  - Maybe we should focus on single arm Moller for theta < 2 deg first, after that this part of the data can be used as consistency check
- To do:
  - Get the simulation running and do acceptance and radiative correction using the two single arm Moller methods