Elastic and Inclusive Scattering for CLAS12

UCONN-MIT CLAS12 Analysis Workshop 2019

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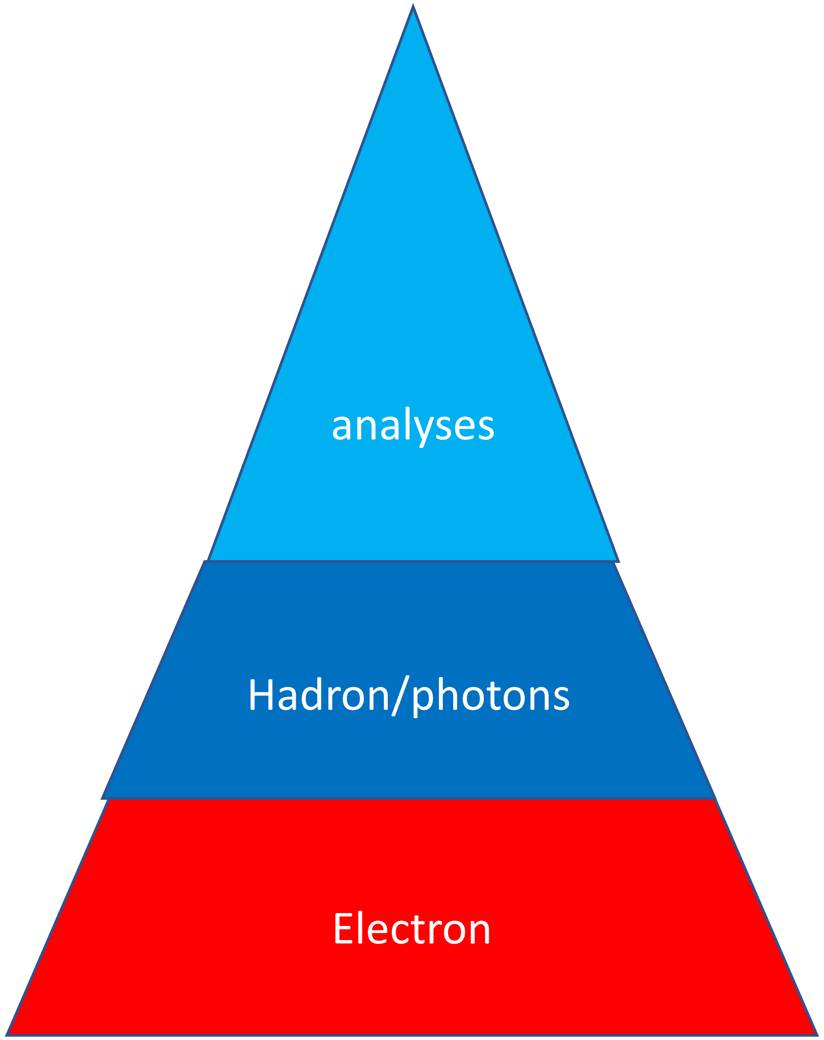
09/03/2019

What are we going over today?

- Purpose
- Overview of CLAS12
- Data Analysis
- Conclusion

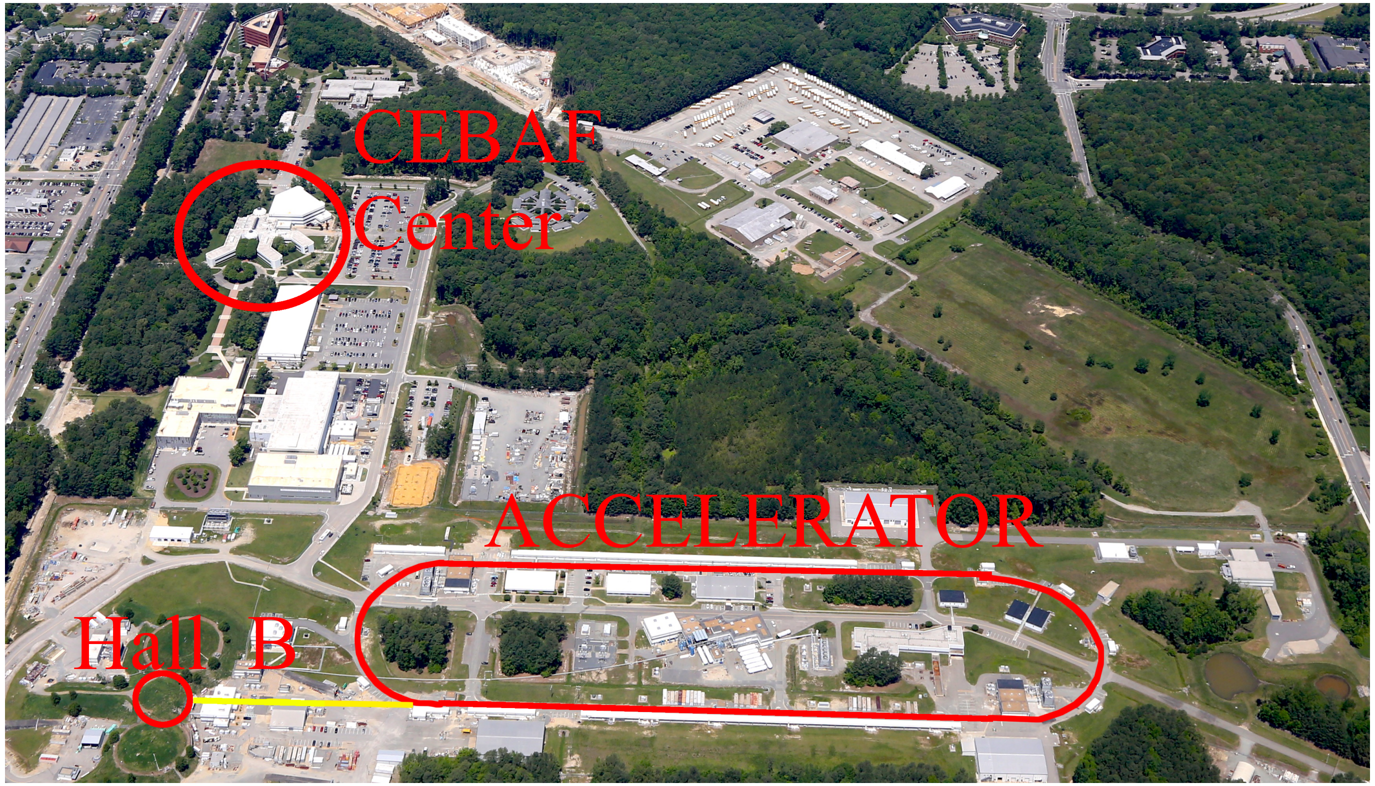
The elastic scattering is to CLAS12 what the standard candle is to astronomers.

- The elastic cross section is a good metric to aid in
  - Optimizing electron particle ID
    - Provide information on detector efficiency
  - Gauge overall electron ID performance
  - Validate the accumulated charge, or effectively the integrated luminosity, which is instrumental in calculating cross section measurements of other channels
  - Provide a sandbox for developing and testing new analysis techniques to be used in other analyses.
- Provide a solid foundation for analysis of more complex experiments

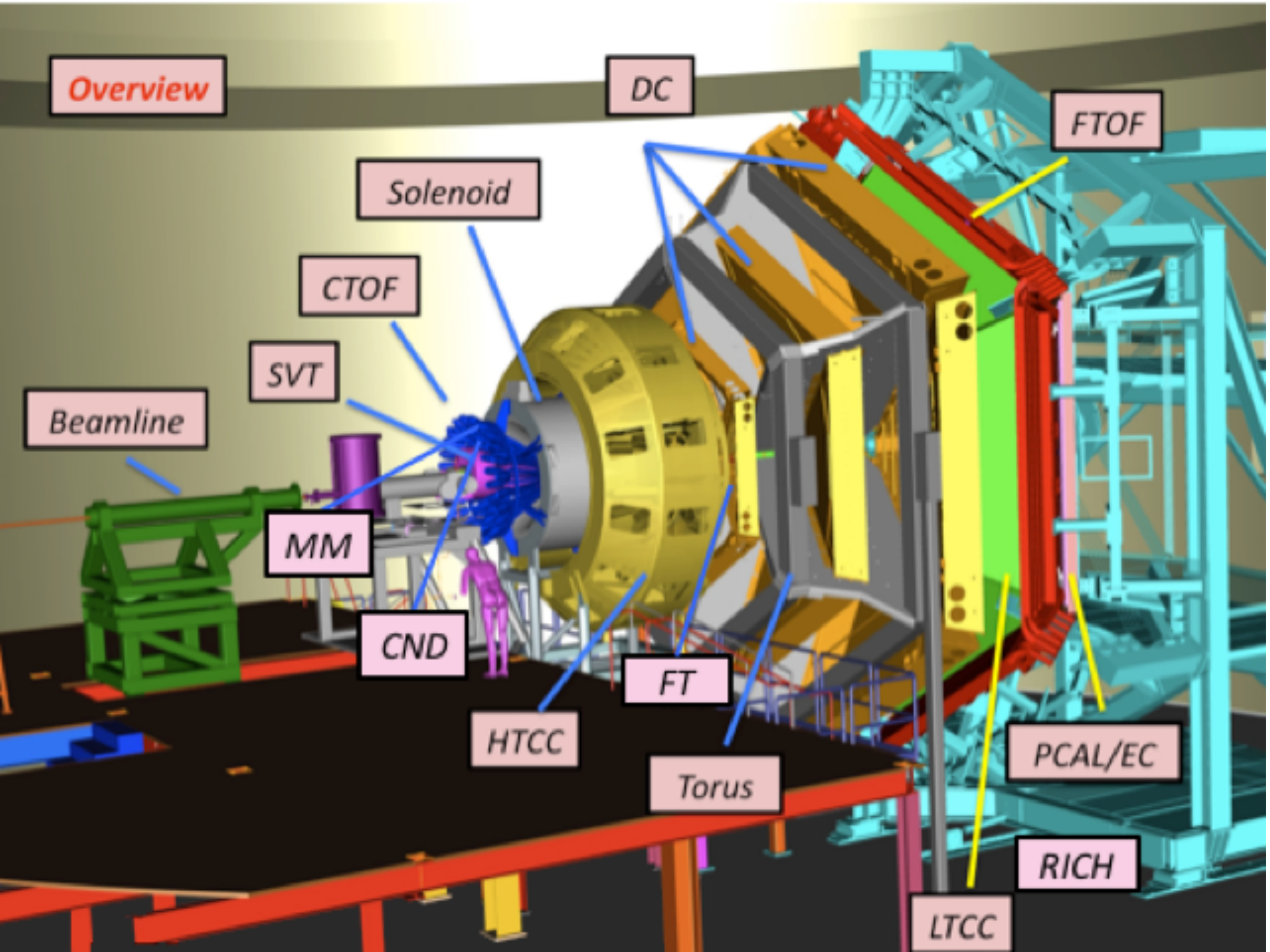


JLAB is the home of CLAS12.

- Thomas Jefferson National Accelerator Facility in Newport New, Virginia
- 4 experimental Halls (A, B, C, and D)
- Data was taken with the Continuous Electron Beam Accelerator Facility Large Acceptance Spectrometer (CLAS12) in Hall B



CLAS12 is uniquely designed to provide coverage over a wide kinematic range for charged and neutral particles.



Charged Particle ID Design Specs:

- Momentum information from drift chambers: ${}^{dp}/_{p} < 1\%$
- Timing information from time-of-flight: $\approx 60 \; - 160 \; ps$

CLAS12 has an abundance of data, but we will focus on 7 GeV to illustrate the analysis framework that is in place.

- Data used in this analysis from run 5700
  - RG-K Run period (Fall 2018)
  - Skim 4
    - ➢ Select events with identified electron in forward detector with any other particles present.

Data Property	
Cook Version	v13
Software version	6.3.1
Beam Energy	7.546 GeV
Beam Polarization	86%
Current	30 nA
Target	Unpolarized LH2
Field Settings (t/s)	outbending (1/-1)
Run	5700
File Range	Entire Run(not all files cooked)
Number of Negative Tracks	~30M
Accumulated UNGATED charge	14800.72308 nC

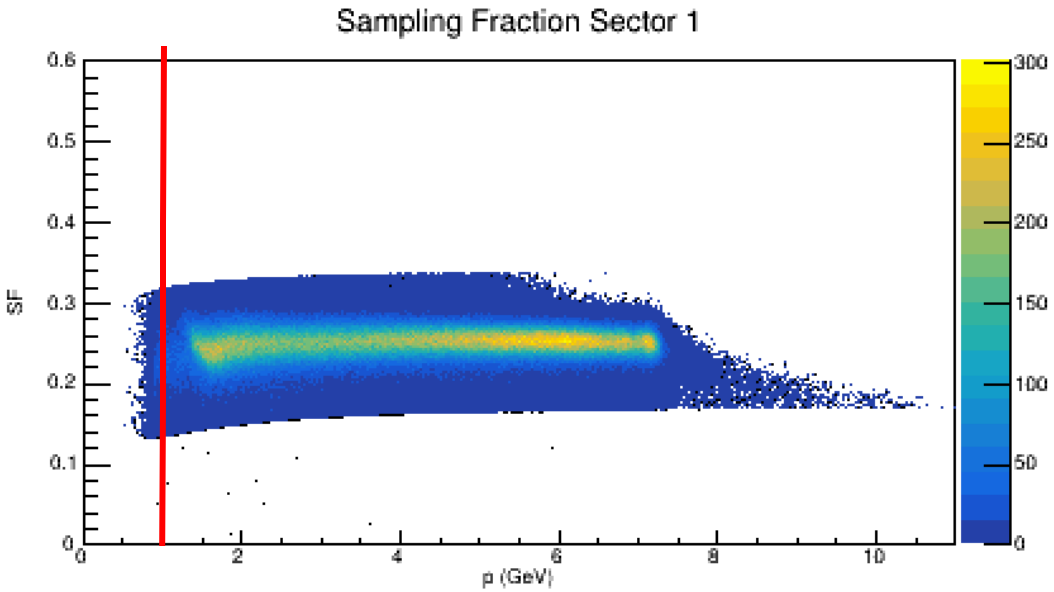
Table 2 : Run Properties (calibrated as of July)

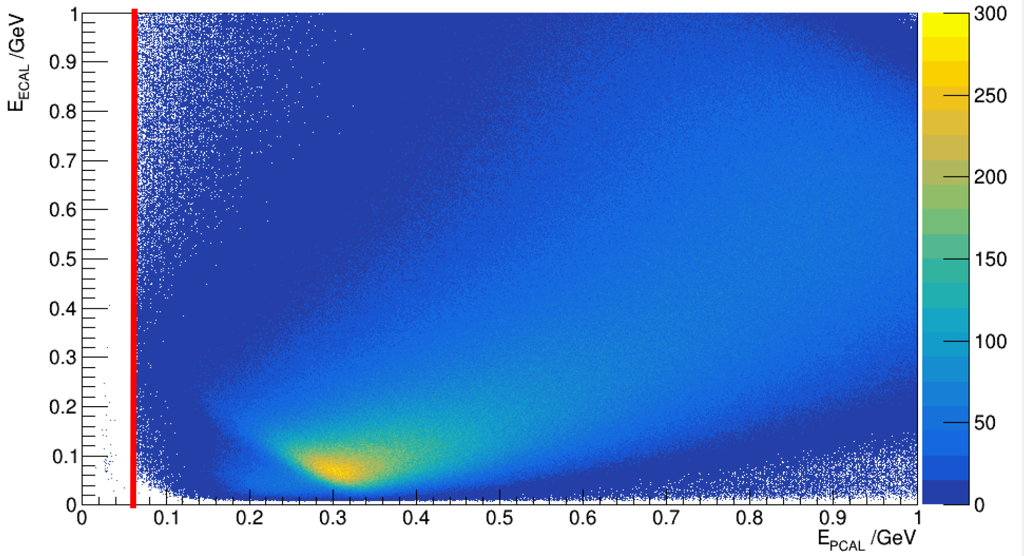
Selecting the electron allows us to explore the elastic and inclusive events – and compare the data with simulation.

- Electron Particle ID
- Event Selection
  - Elastic: $ep \rightarrow eX(p)$
  - Inclusive: $ep \rightarrow eX$
- Kinematic Distributions between Data and Simulation

Electron ID requires multiple cuts to select a clean sample.

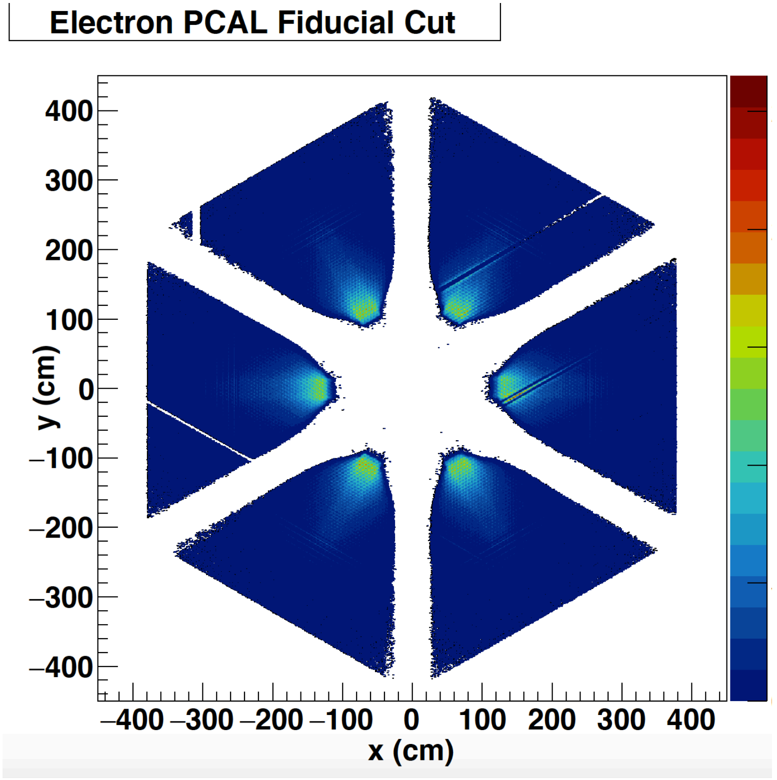
- Cuts include:
  - Sampling fraction
  - Minimum energy deposited in calorimeter
  - Minimum momentum
  - Number of photoelectrons in Cherenkov counters
  - Pre-shower calorimeter fiducial cut
  - Drift chamber fiducial cut
  - Vertex position

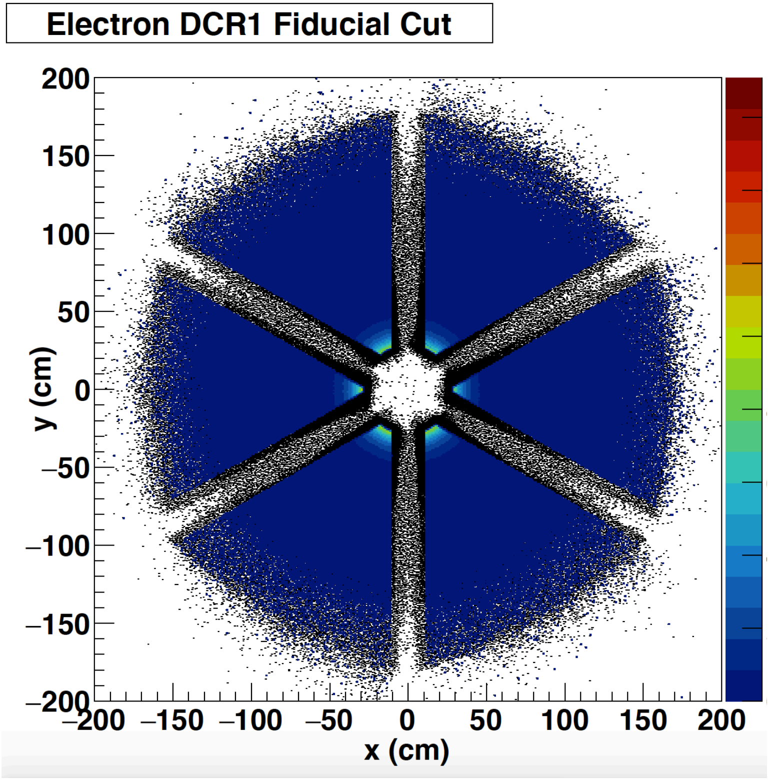


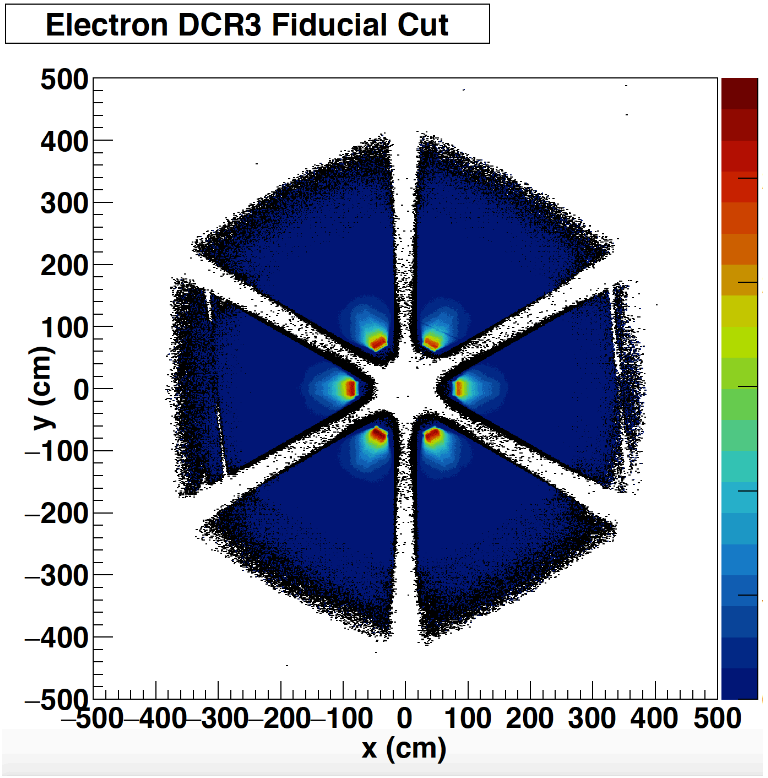


Geometrical cuts on the detector volume remove inefficient detection regions.

Fiducial volume cuts on PCAL, and drift chamber region 1 and 2



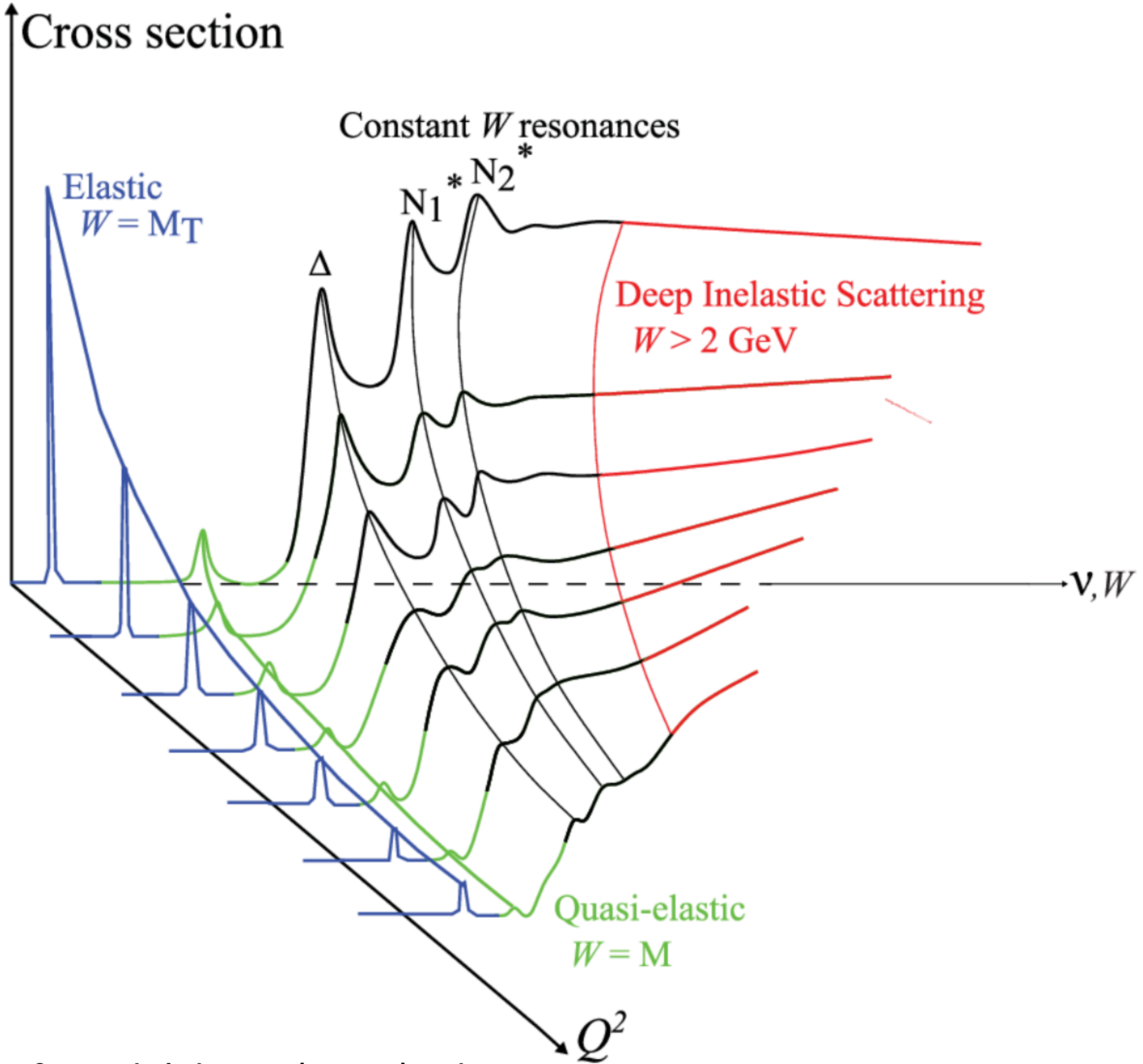




Now that the electron is detected there are two channels we can look into.

- Two Channels
  1. **Elastic**
     - Select events about proton mass using fits to data
     - Remove background
  2. Inclusive
     - $W > 1.0\ GeV^2$
     - $Q^2 > 1.0\ GeV^2$ (pQCD applicable)
     - $y < 0.8$ (reduce elastic radiative background to better match the model)

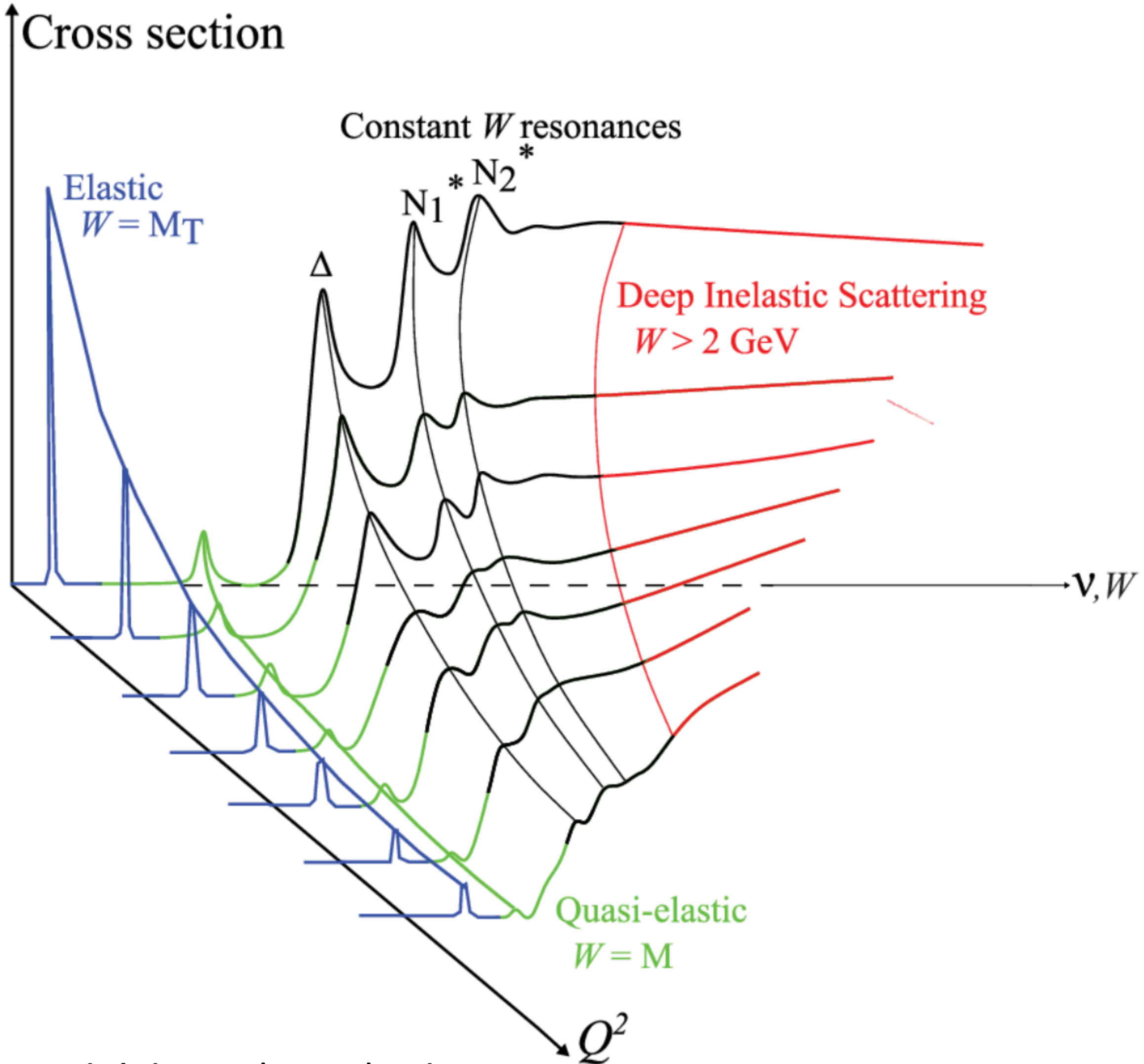
$$Q^2 = (e - e')$$
$$y = E_e - E_{e'}$$
$$W^2 = m_p^2 - Q^2 + 2m_p\nu$$



Ref - Zieliński, R. (2017). The g2p Experiment: A Measurement of the Proton's Spin Structure Functions.

Each analysis shares a set of requirements – most of the emphasis will be on applying these to the elastic channel.

- Both analyses require:
  - Going over generator details
  - Compare data to simulation
  - Acceptance Corrections
  - Radiative Corrections
  - Integrated luminosity



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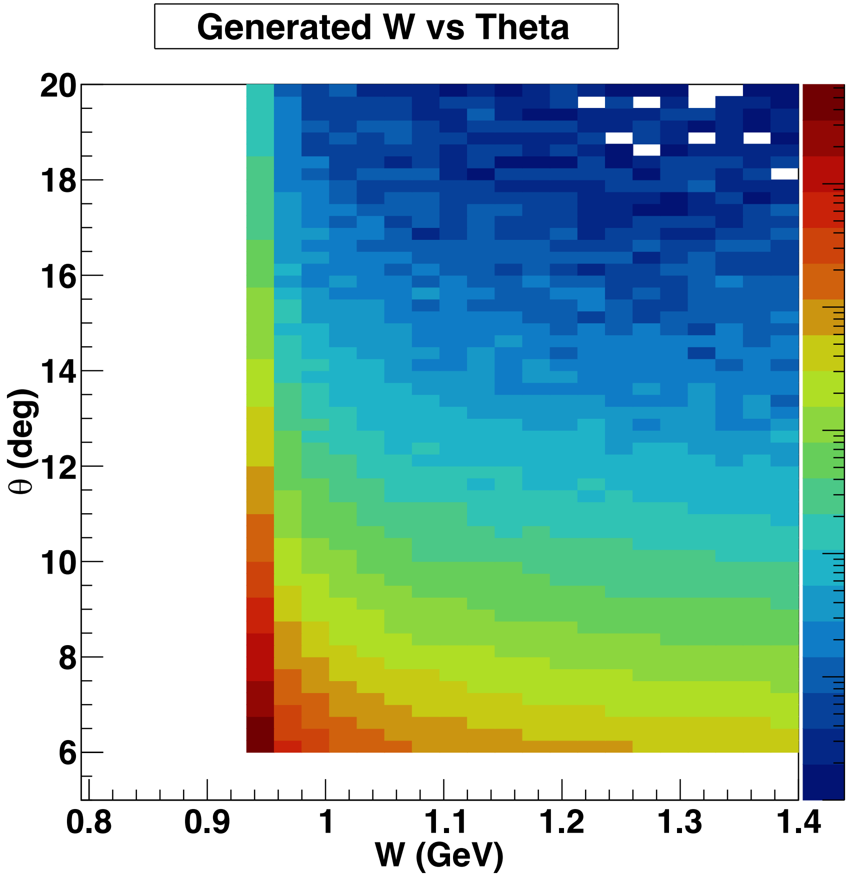
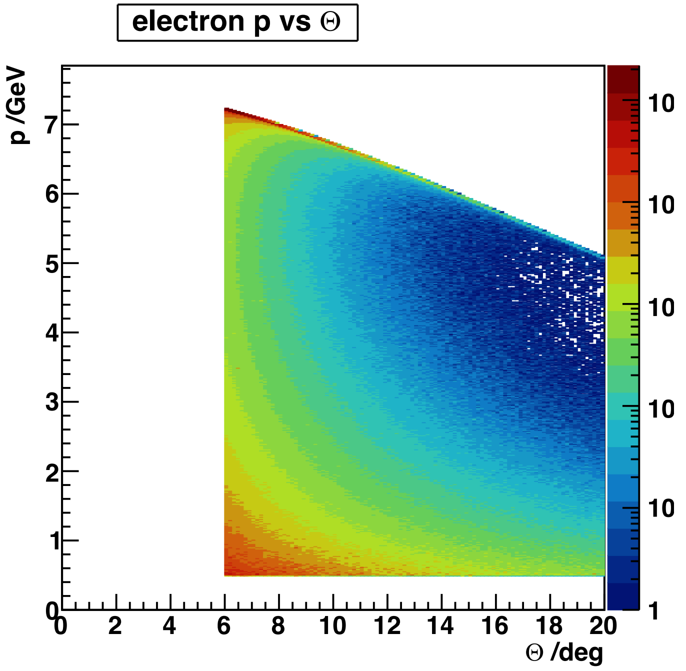
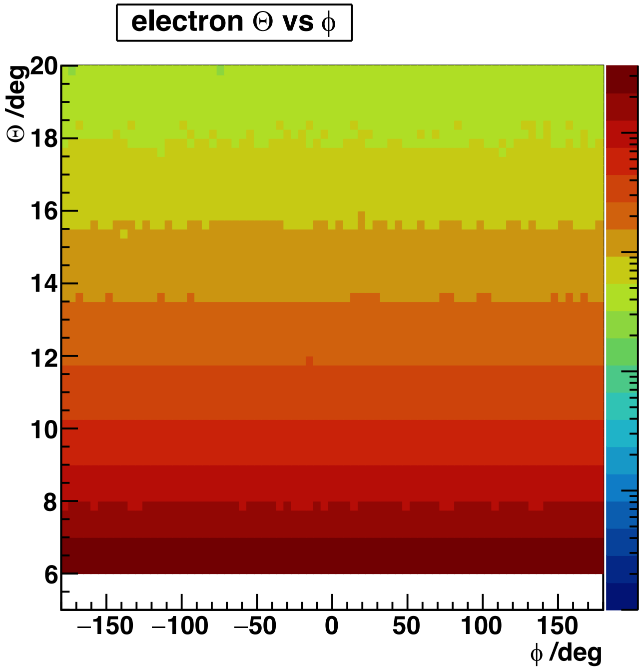
Compare the agreement of data to simulation by first generating elastic events.

- Peter Bosted Elastic Generator
  - Generate events with radiative effects
  - Beam energy: 7.546 GeV
  - Angular coverage: 6-60 deg

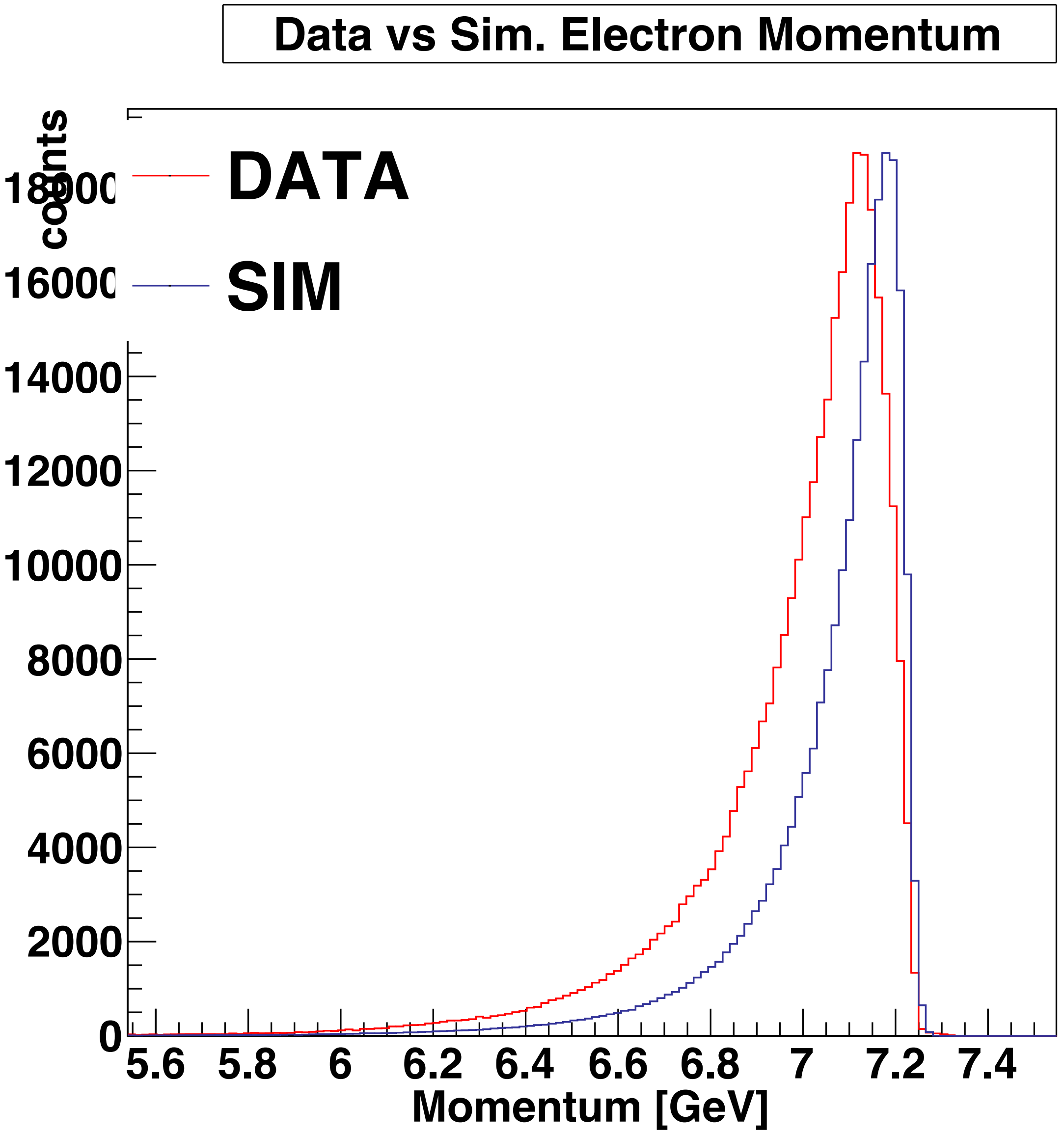






After selecting the final state electrons in data and simulation compare the kin. variables.

- Does the model match the data – check:
  - **Momentum**
  - Theta
  - Phi
  - W



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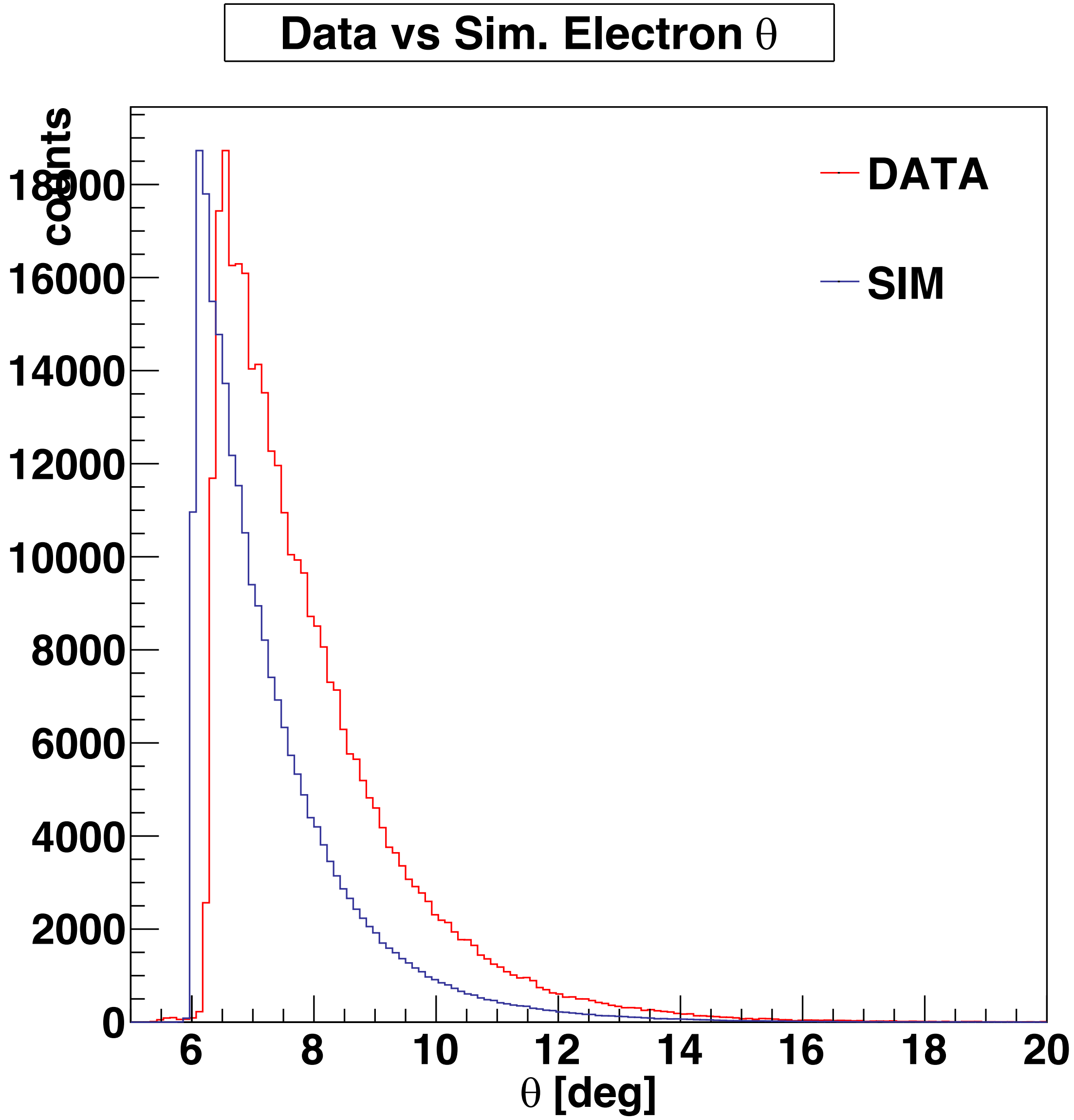

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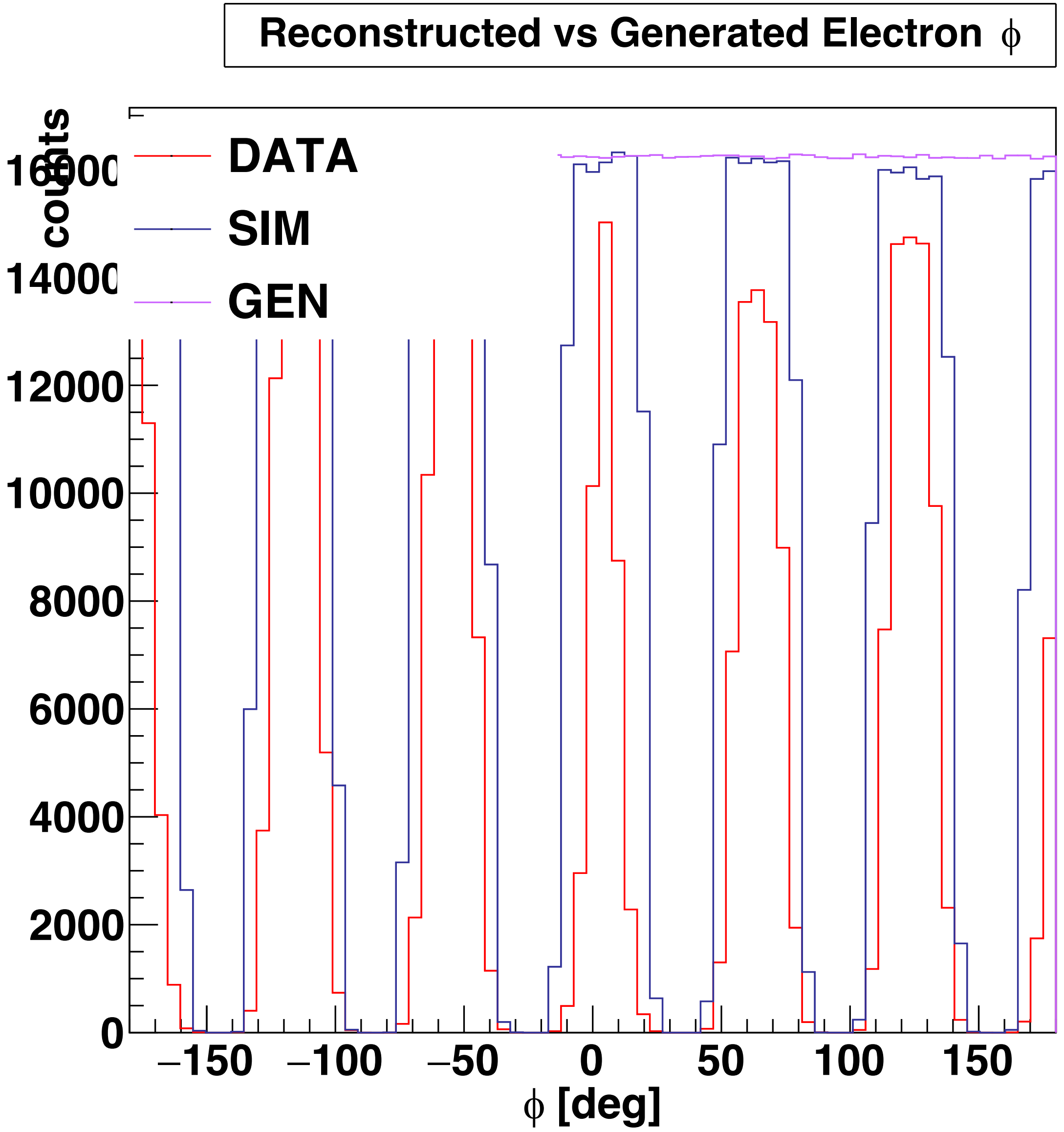
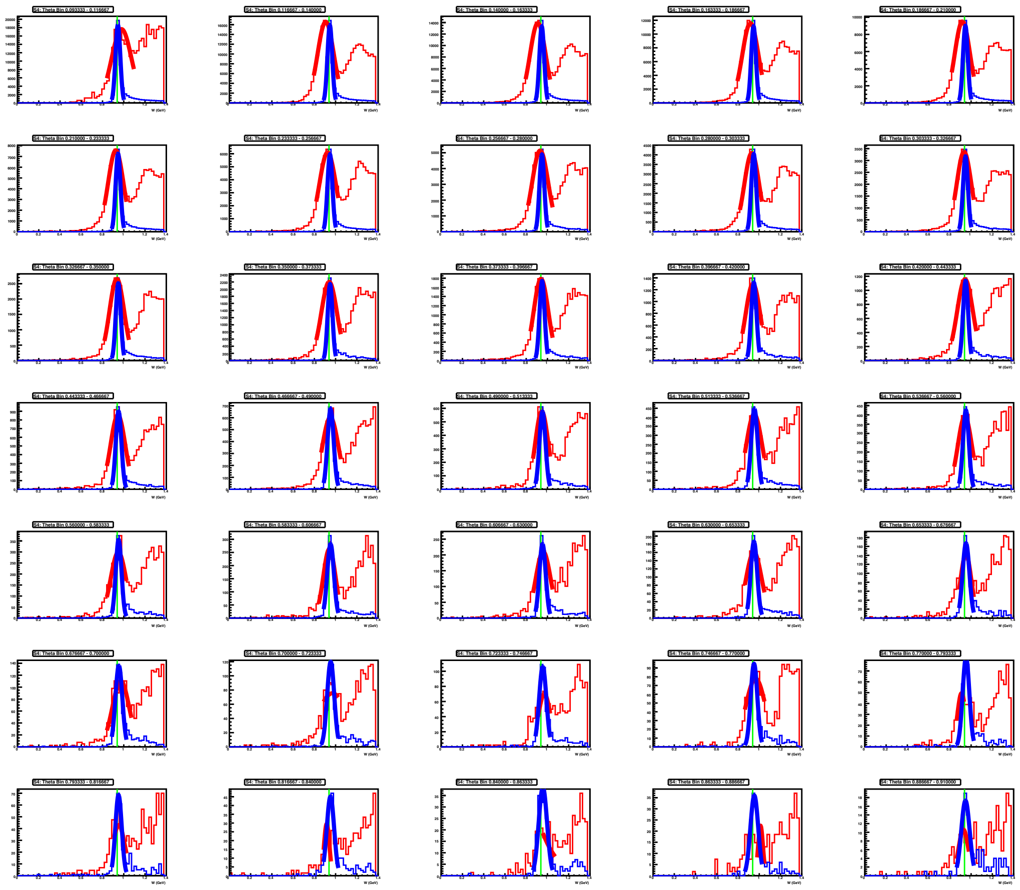
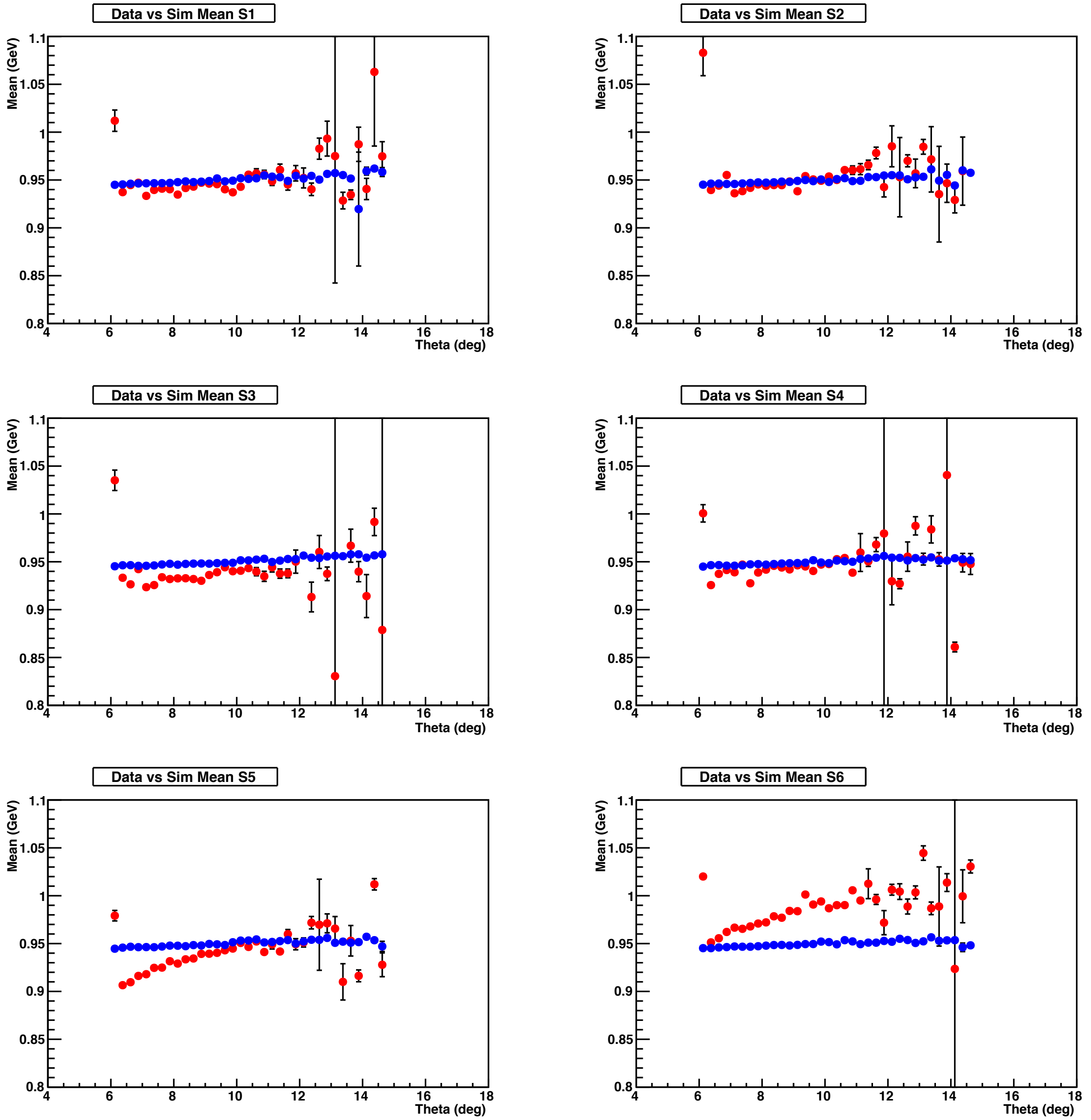


How does the elastic peak mean position compare between data and sim?

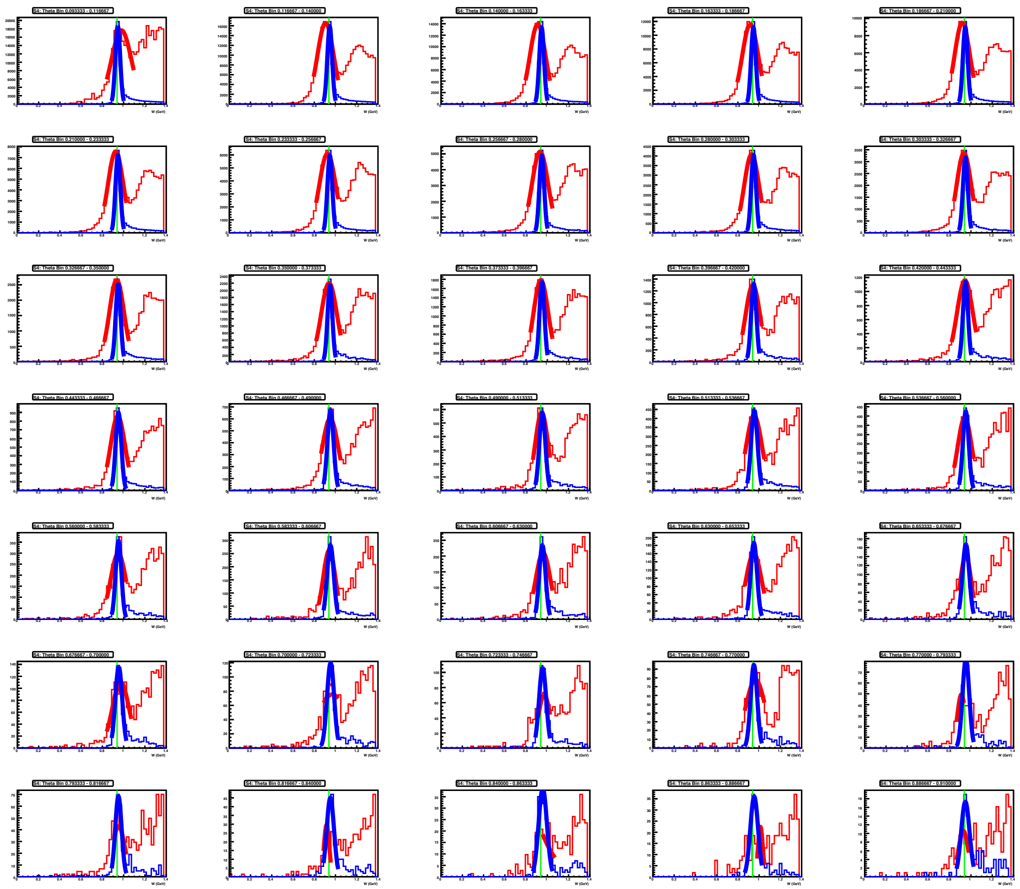
MEAN PEAK POS FROM GAUS FIT

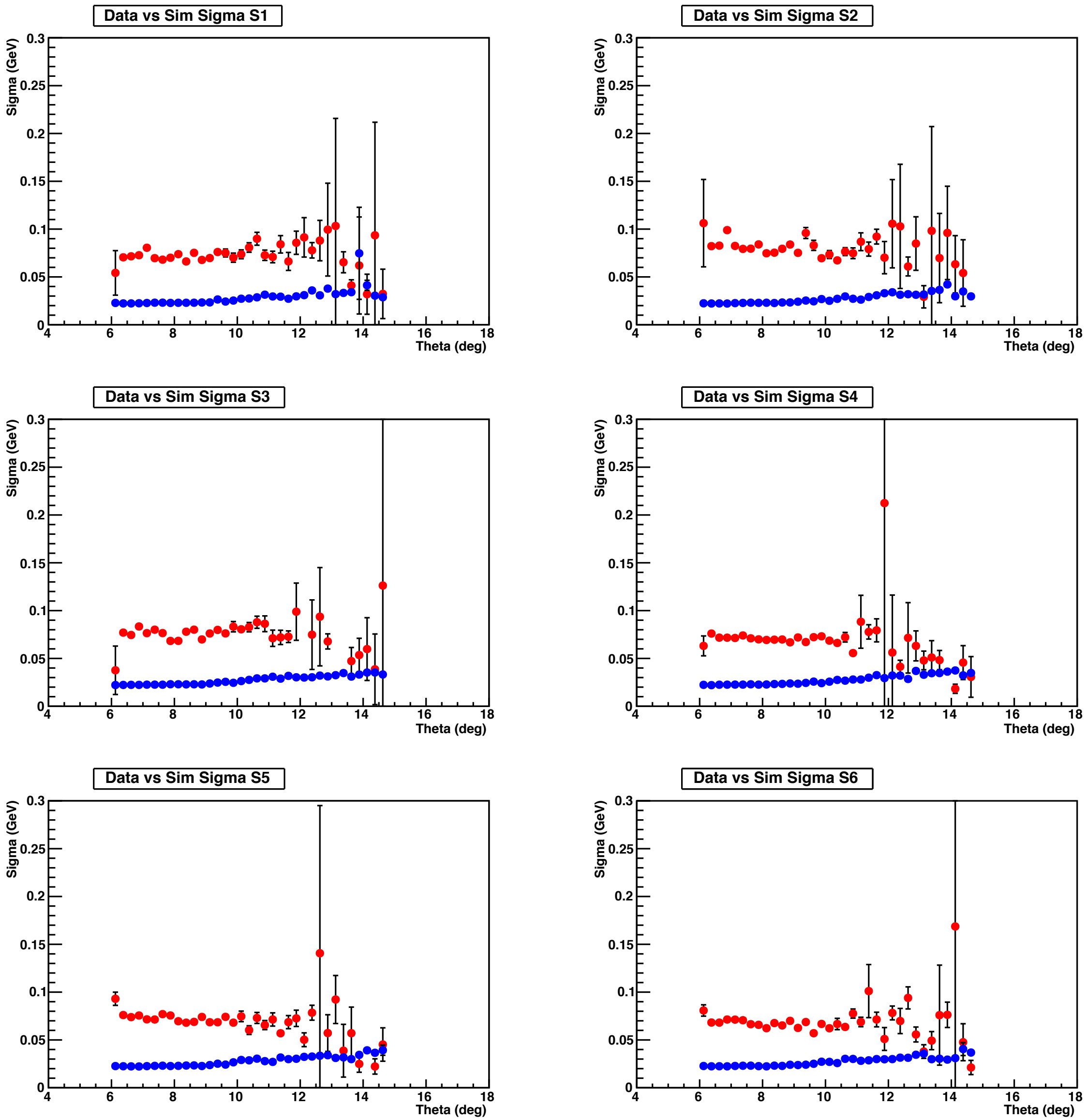




How does the elastic peak σ compare between data and sim?

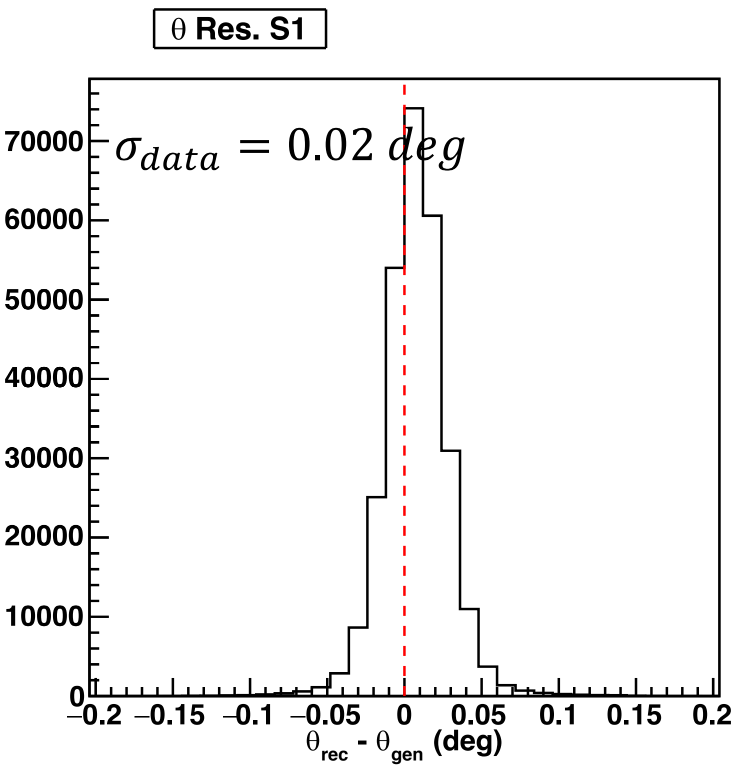
SIGMA FROM GAUS FIT



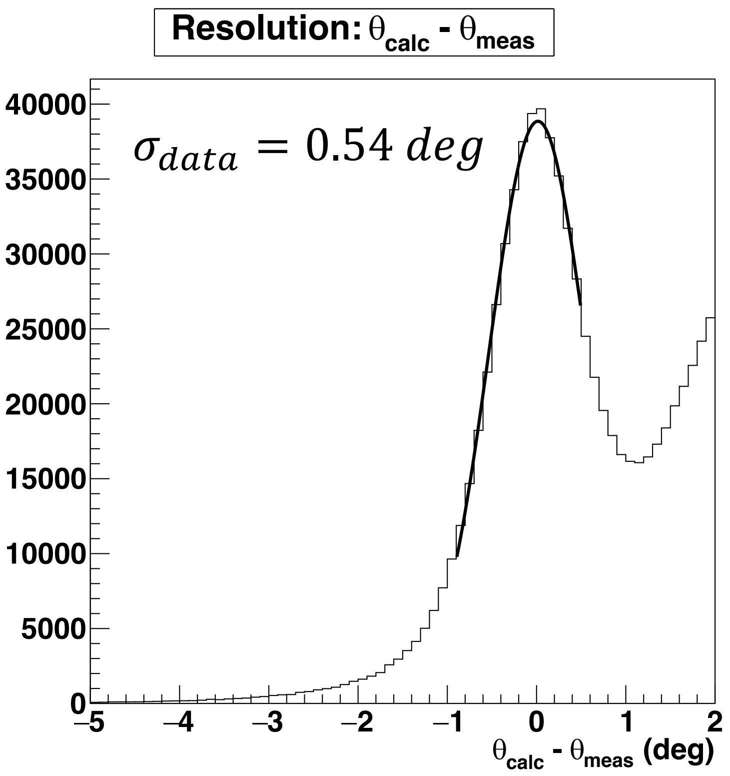


How does the resolution between data and simulation compare?

- Resolution is defined here by taking the difference between the reconstructed value and generated value.
- When looking at 'resolution' in data – look at difference in calculated theta (using momentum) and measured theta.
  - Downside is that the momentum resolution is also tangled into this calculation.

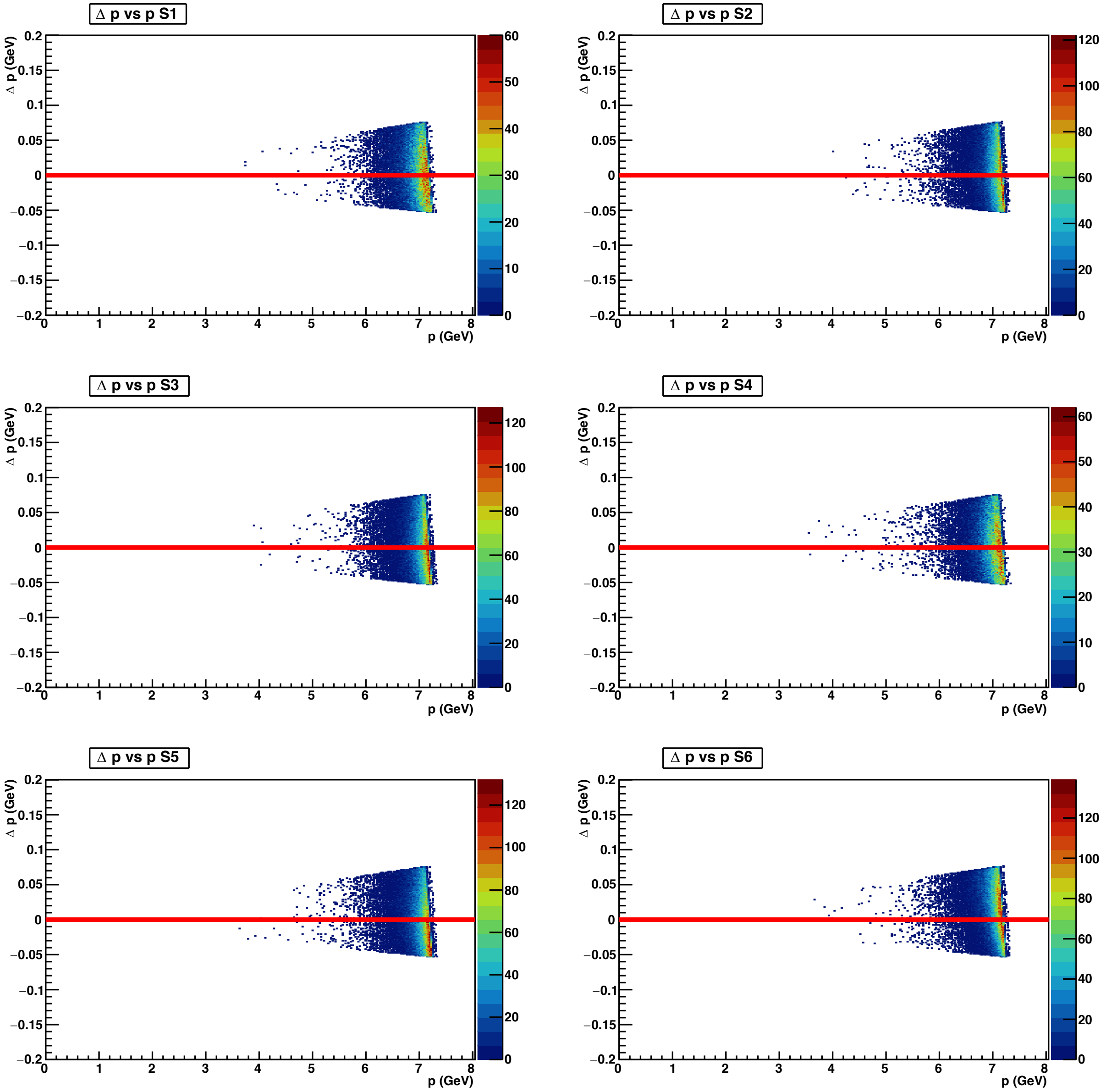


GEMC Theta Resolution



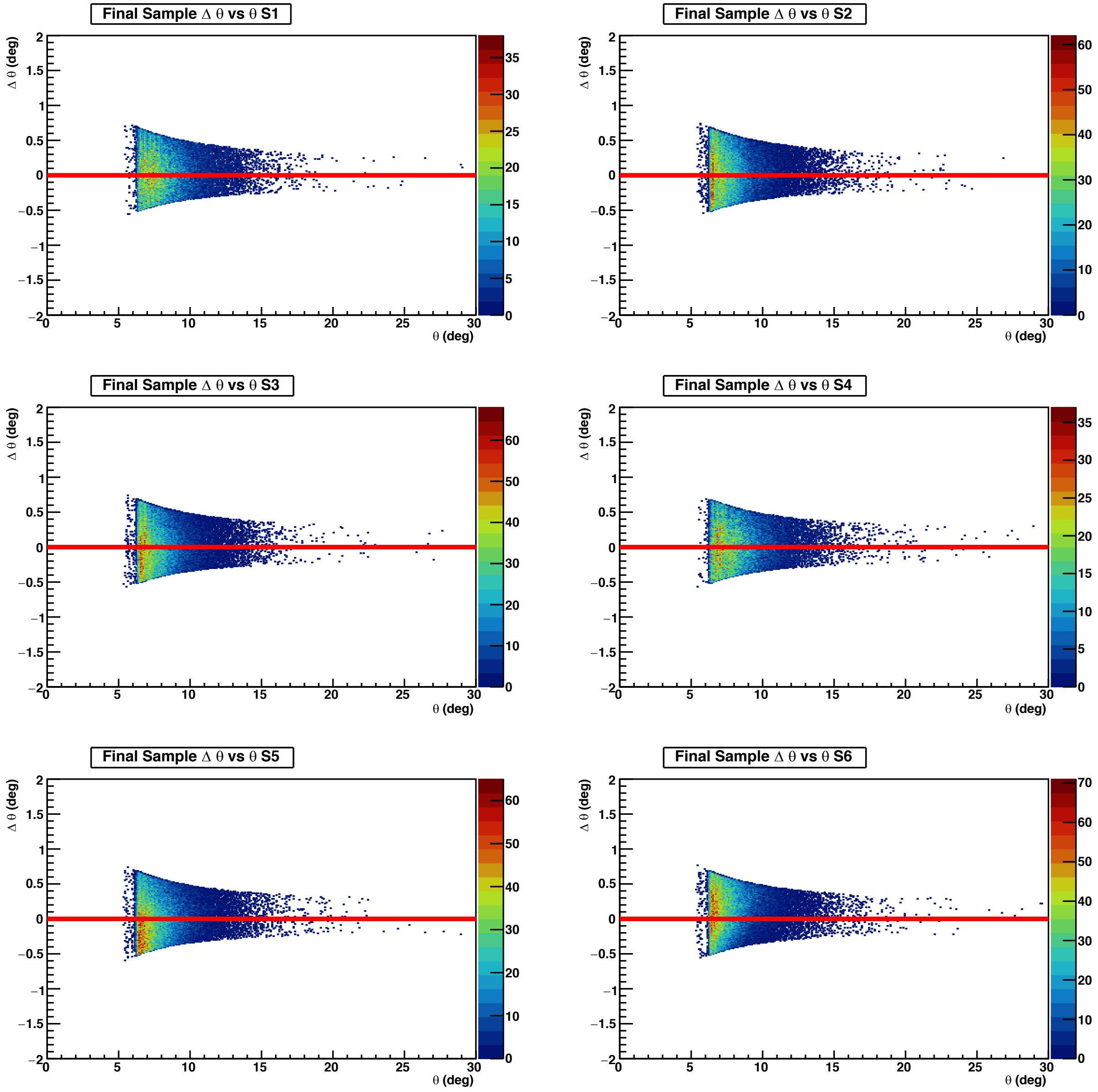
Data Theta Resolution

Resolution of momentum and theta from data is extracted after W cuts.



$$\Delta p \ vs \ p$$

Resolution of momentum and theta from data is extracted after W cuts.

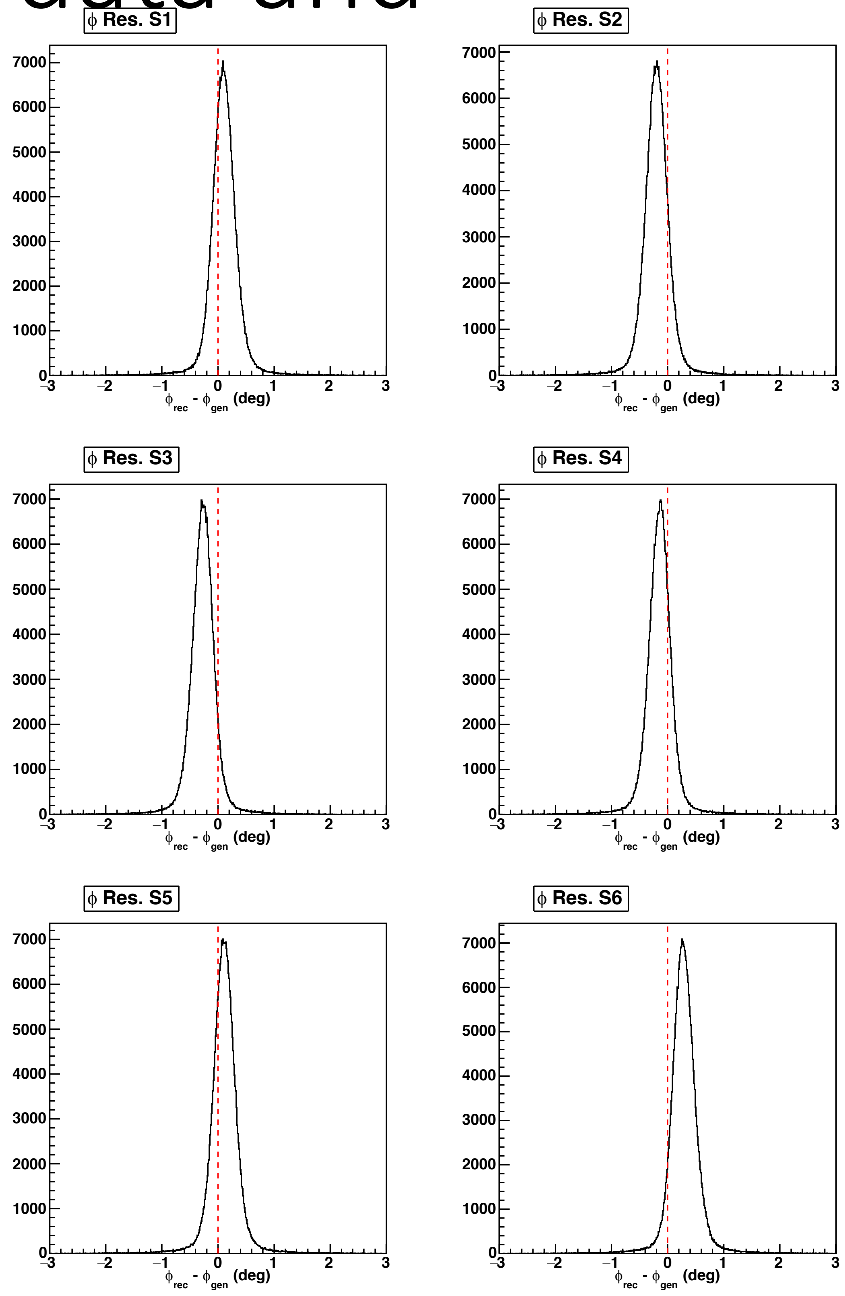


$\Delta\theta \ vs \ \theta$

How does the resolution between data and simulation compare?

- Resolution is defined here by taking the difference between the reconstructed value and generated value.
- In its current form, simulation has better resolution than that in seen in data.

GEMC Phi Resolution



The elastic signal sits atop of background, which to first order we can remove.

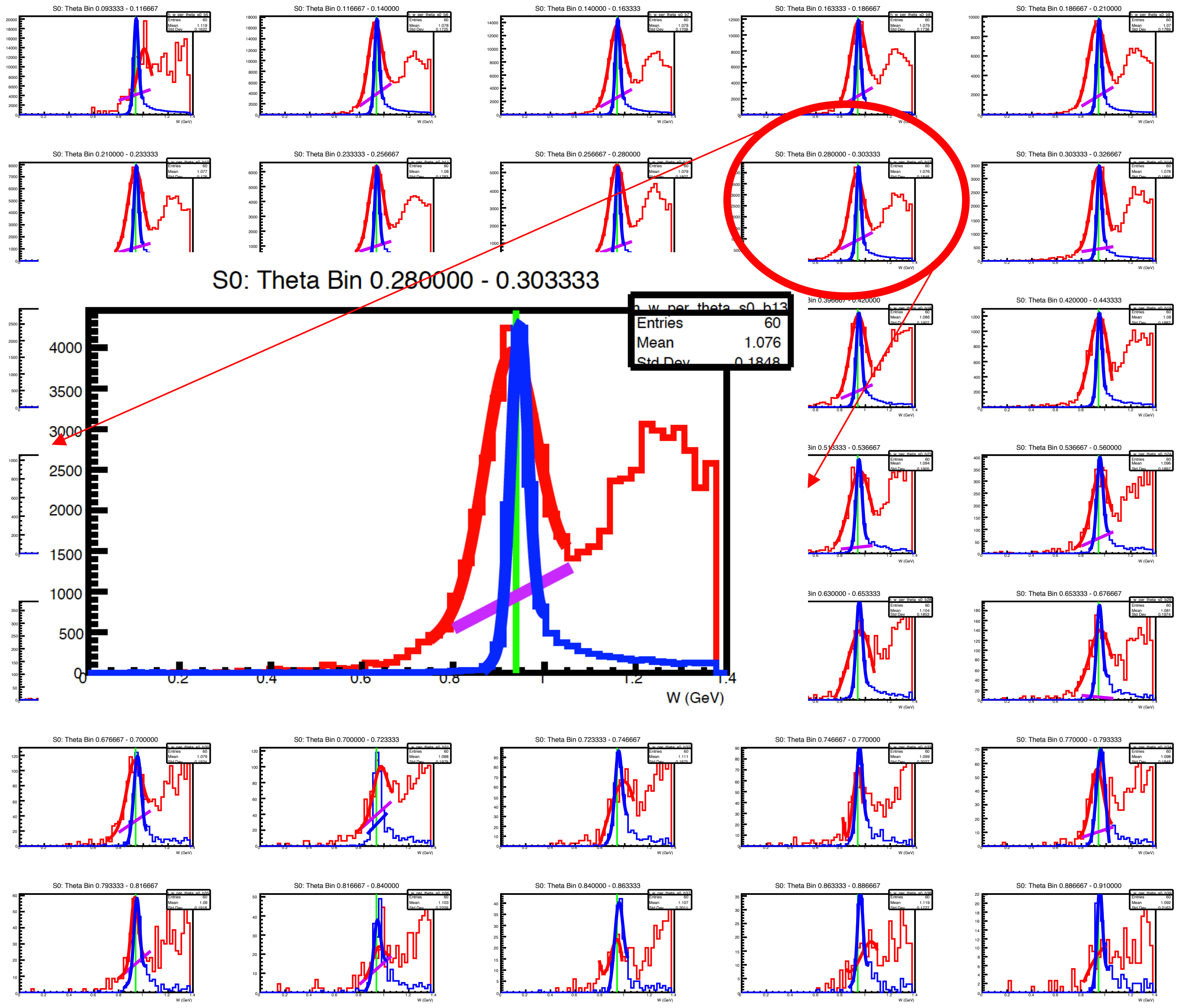
But remember the elastic peak sits on top of background!

Recall we want to determine:

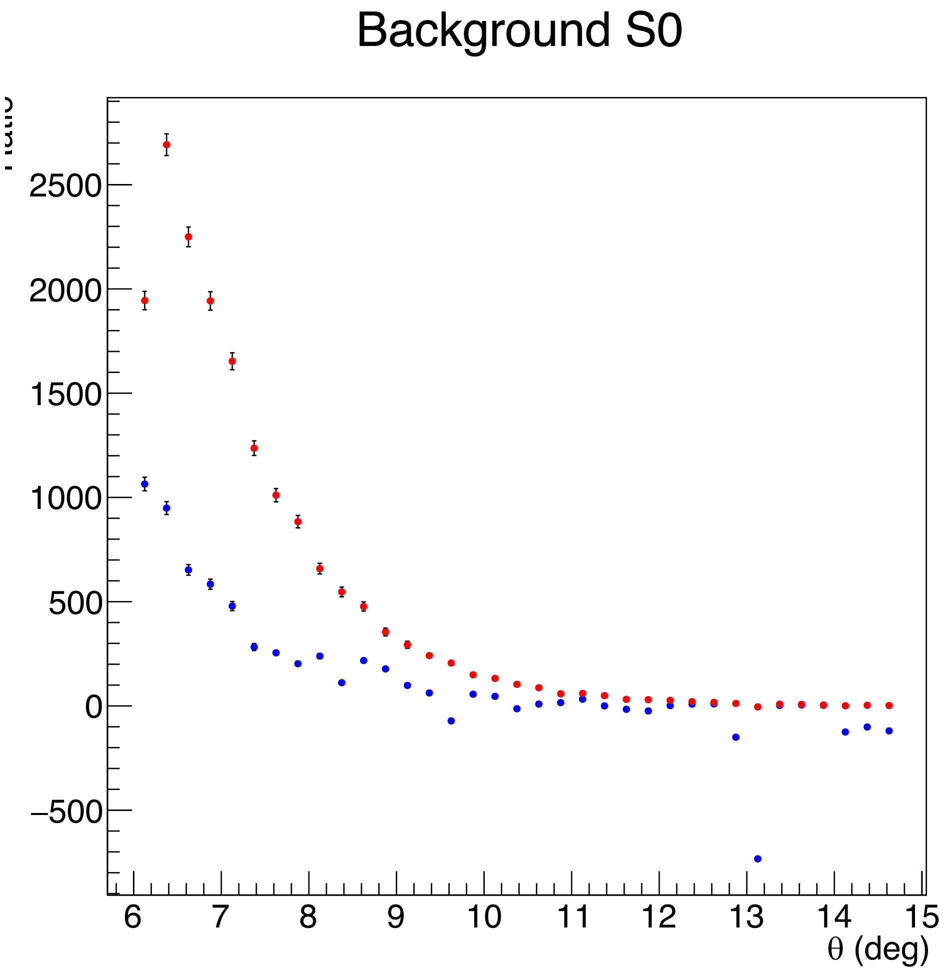
$$\left(N_{tot} - N_{bkg}\right)_{bin}$$

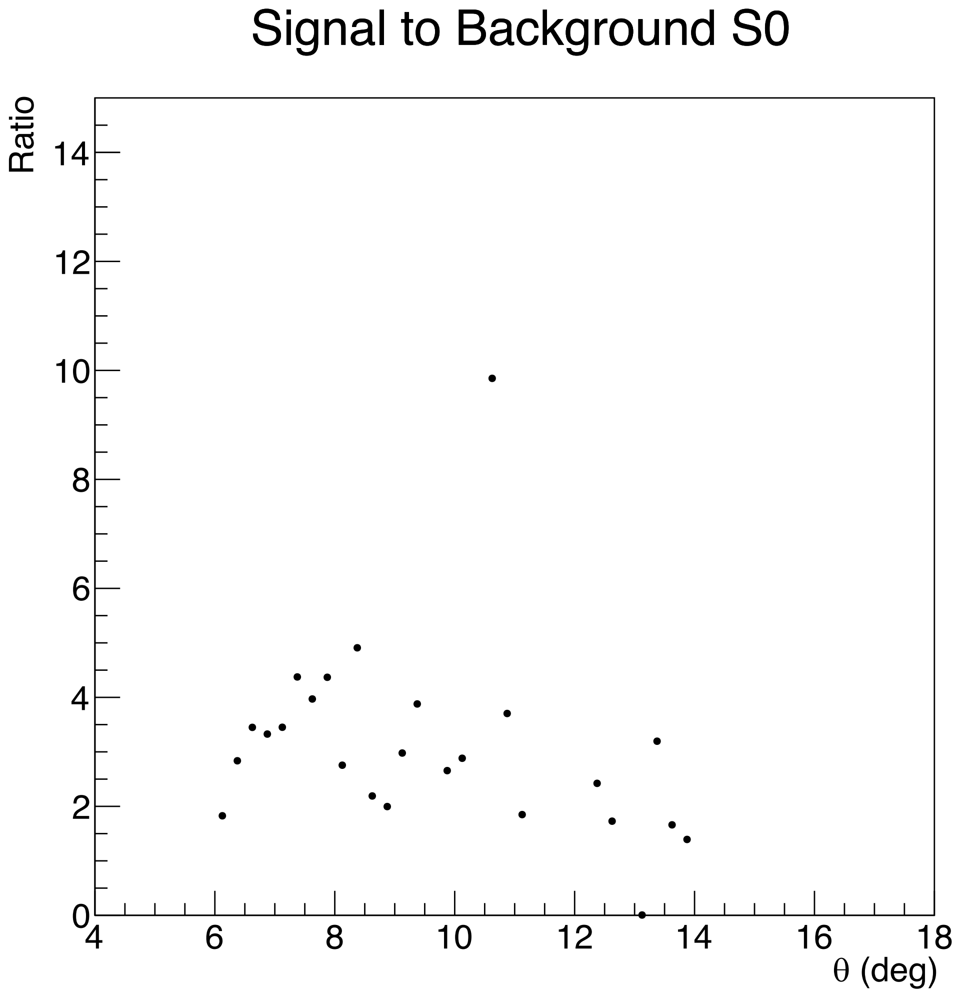
Determine number of total events with area under

$N_{tot} \sim$ gaus + 1st order polynomial
$N_{bkg} \sim$ 1st order polynomial



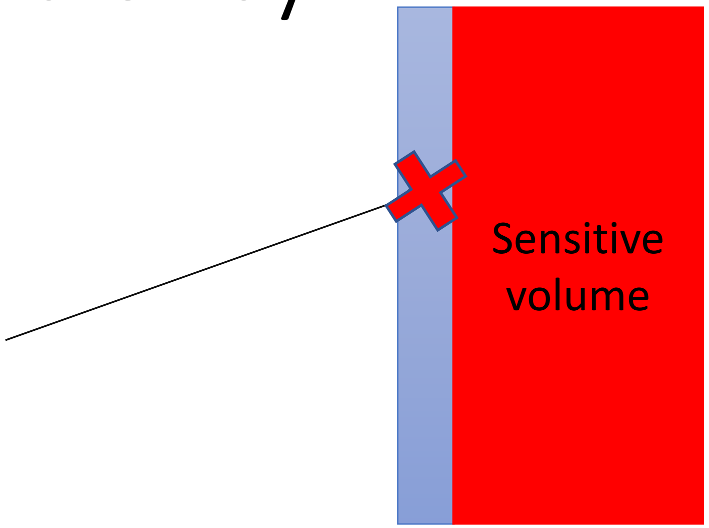
Elastic Scattering – Check the signal to background rates and ratio from the fits to the W spectrum.

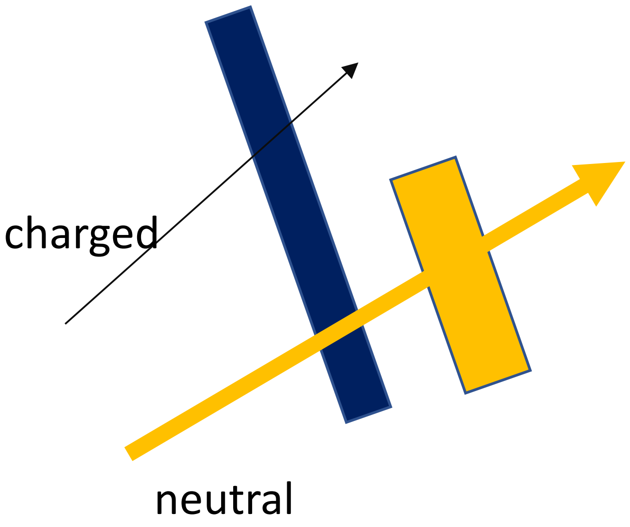




Acceptance corrections are important to account for the geometry and detector efficiency.

- Why?
  - To account for effects created by limited geometrical coverage and efficiency of the detector.
  - Total acceptance ≈ detector efficiency × geometrical acceptance
  - Hard to separate combined effects so account for this with one number.
  - Insight into binning scheme
- How is it represented?
  - $\mathcal{A} = \frac{N_{rec}}{N_{gen}}$
- Depends on
  - Polar and azimuthal angle of particle
  - Momentum of particle (i.e. low energy particles not registered due to energy loss before making it to the sensitive detector region)
  - Particle species (i.e. difference detector coverage for charged vs neutral particles)
  - Model dependent behavior





Acceptance Corrections

- Definitions:
  - Total Acceptance for bin b: $\mathcal{A}_{total} = \frac{N_{rec}}{N_{gen}} = \frac{N_{rec}^{gen}+N_{rec}^{mig}}{N_{gen}} = \mathcal{A}_t + \mathcal{A}_m$
  - True Acceptance for bin b: $\mathcal{A}_t = \frac{N_{rec}^{gen}}{N_{gen}}$
  - Migration Acceptance for bin b: $\mathcal{A}_m = \frac{N_{rec}^{mig}}{N_{gen}}$
  - Bin Purity for bin b: $\mathcal{P} = \frac{N_{rec}^{gen}}{N_{rec}} = \frac{N_{rec}^{gen}}{N_{rec}^{gen}+N_{rec}^{mig}}$

General form for the acceptance correction can be represented by a matrix.

- In general we want to find a matrix that gives us the estimated true number of events, t_{b}, for bin b given the observed number of events n_b.

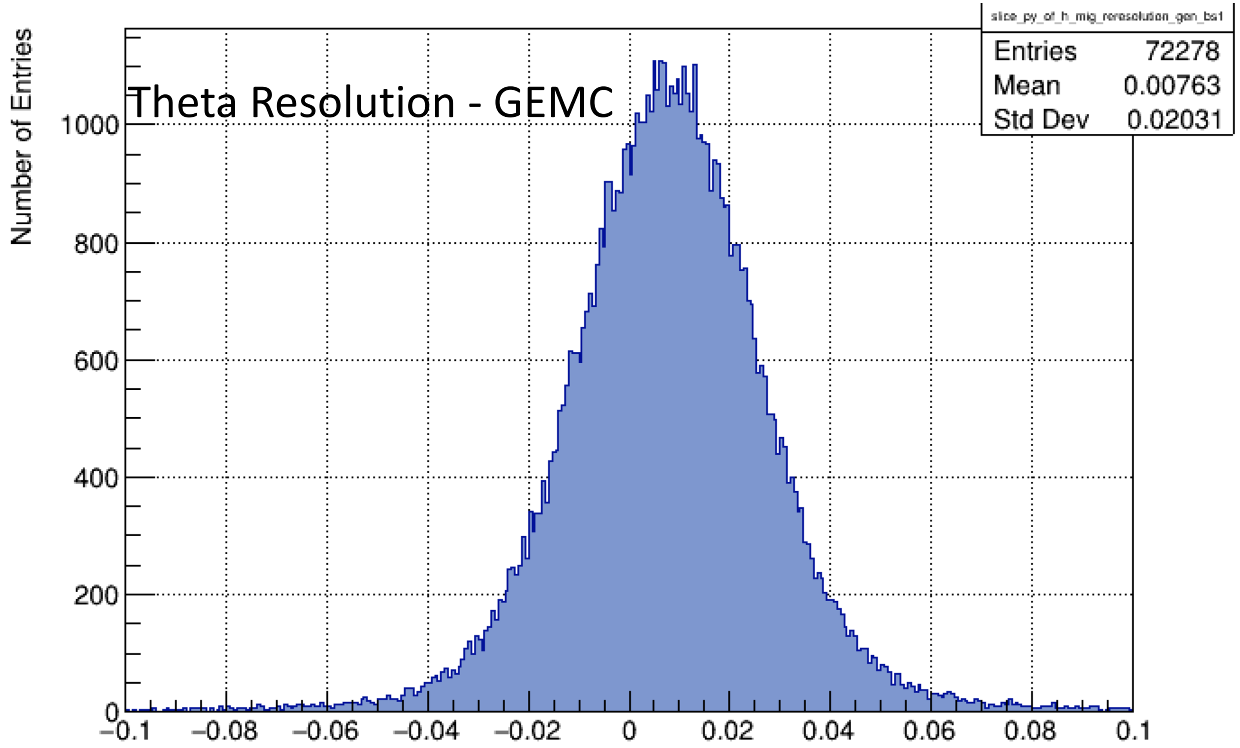
$$\begin{pmatrix} t_1 \\ t_2 \end{pmatrix} = \begin{pmatrix} a_{00} & a_{01} \\ a_{10} & a_{11} \end{pmatrix} \begin{pmatrix} n_1 \\ n_2 \end{pmatrix}_{meas}$$

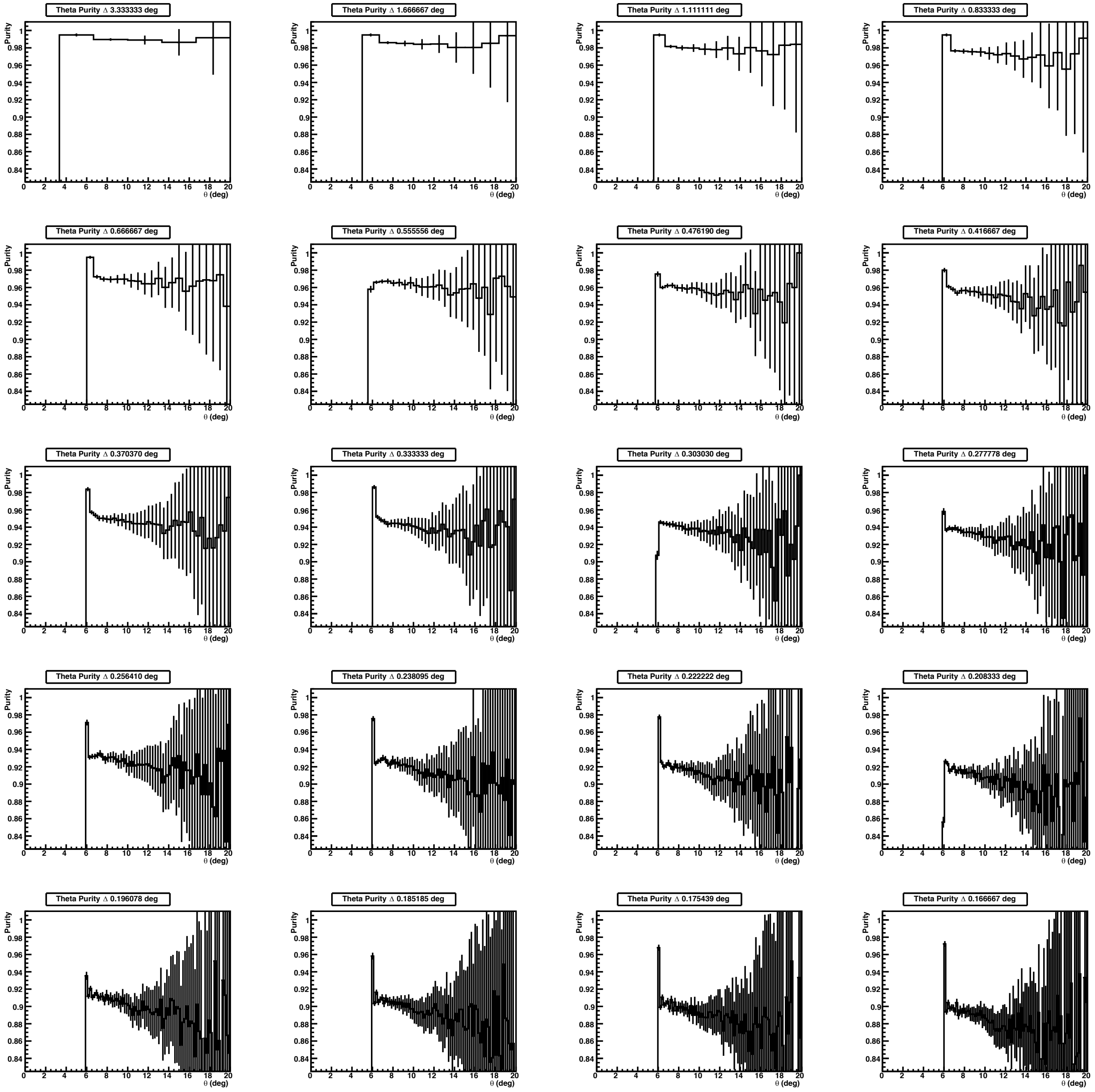
- Bin-by-Bin Acceptance Method:
  - Assume that all of diagonal matrix elements are 0 -> lose information

- Unfolding Method
  - Use the full acceptance matrix with matrix inversion techniques
  - Retains full information

Acceptance Corrections – Elastic

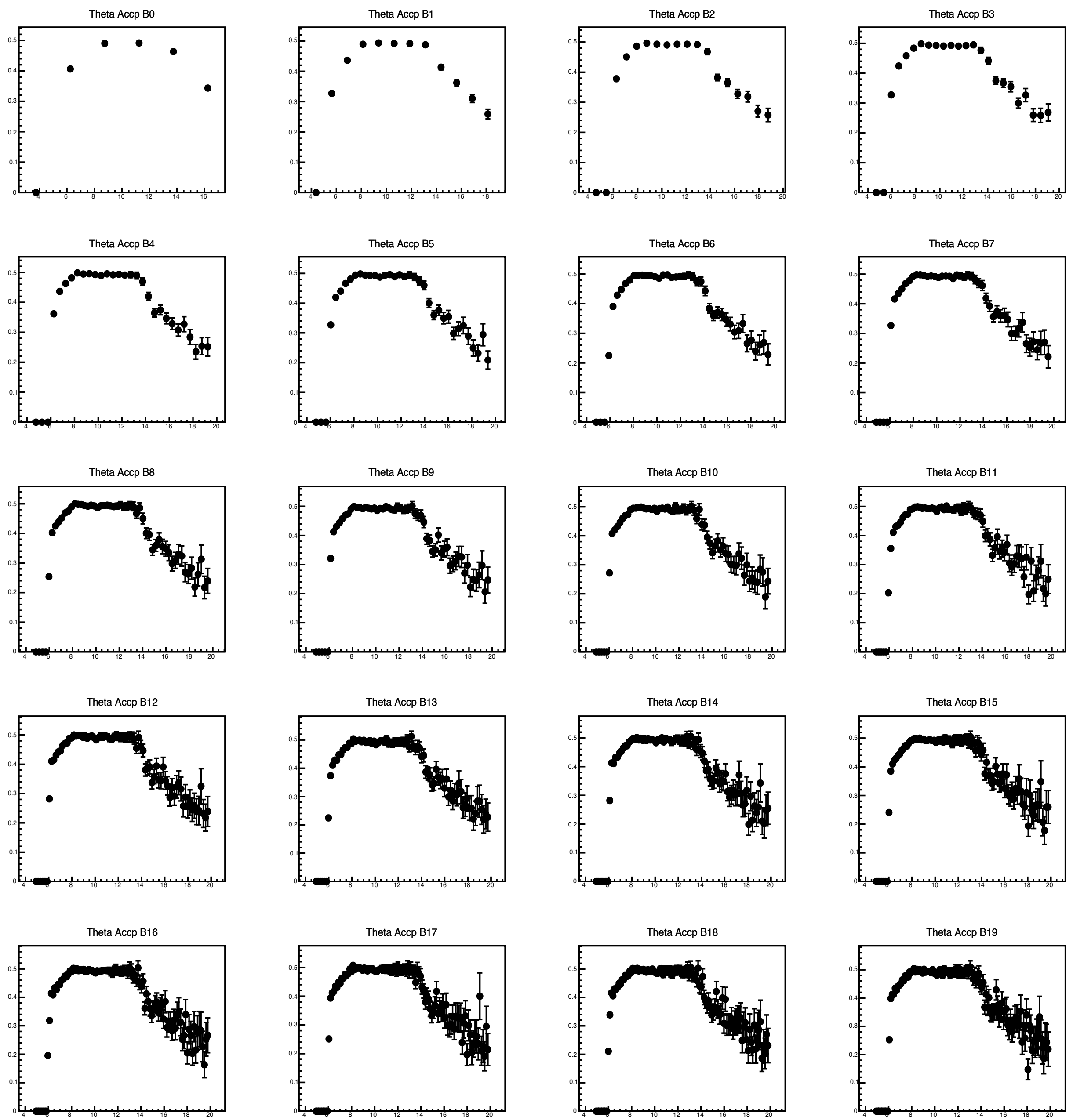
- Choosing bin size based on purity and resolution
- θ resolution $\sim 0.02\ deg$





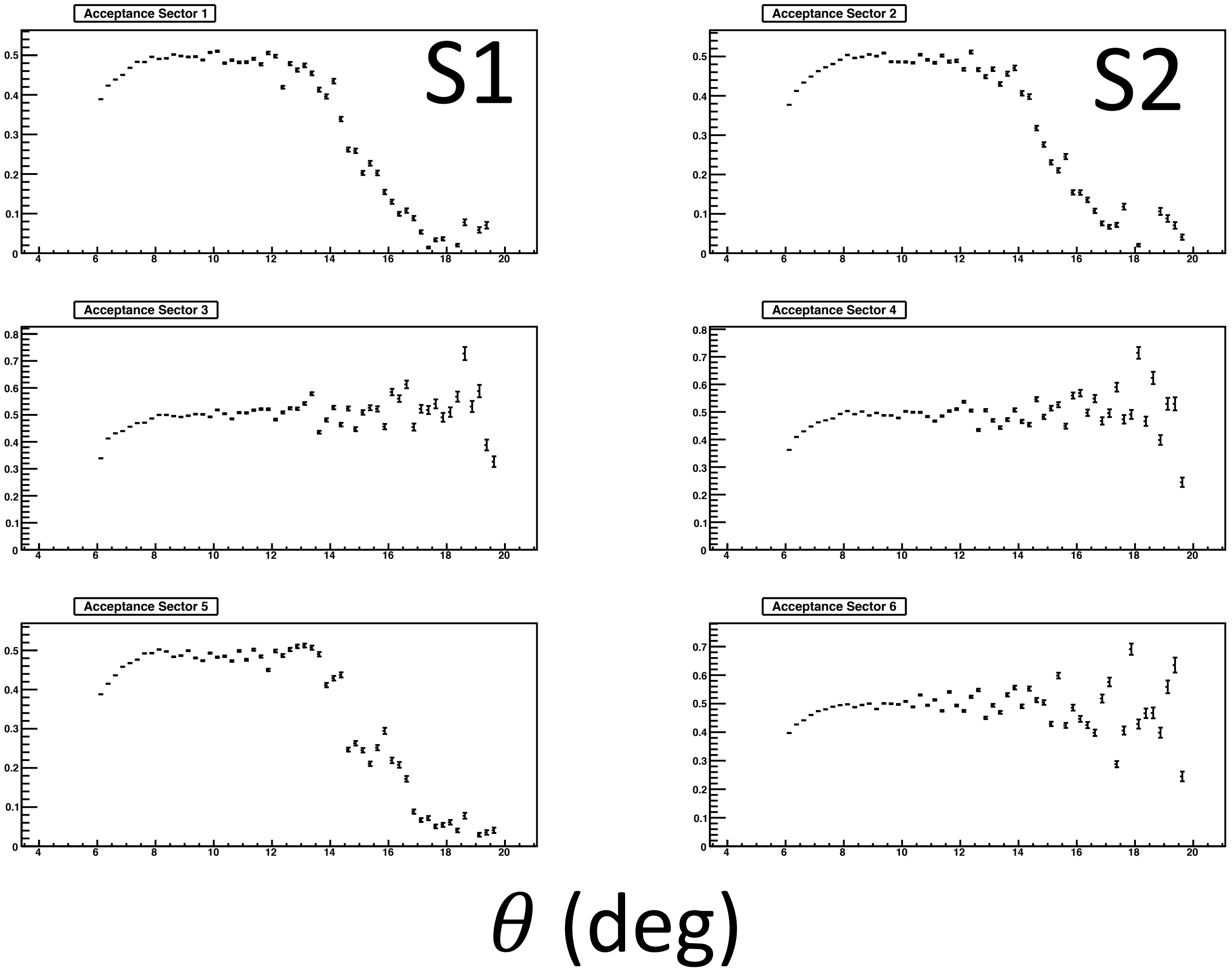
Acceptance Corrections – Elastic

- Acceptance Correction along θ: $\mathrm{N_{bins}}$ over $(5.0°, 20.0°)$ integrated over all sectors



Acceptance Corrections – Elastic

- Acceptance corrections for θ per sector.

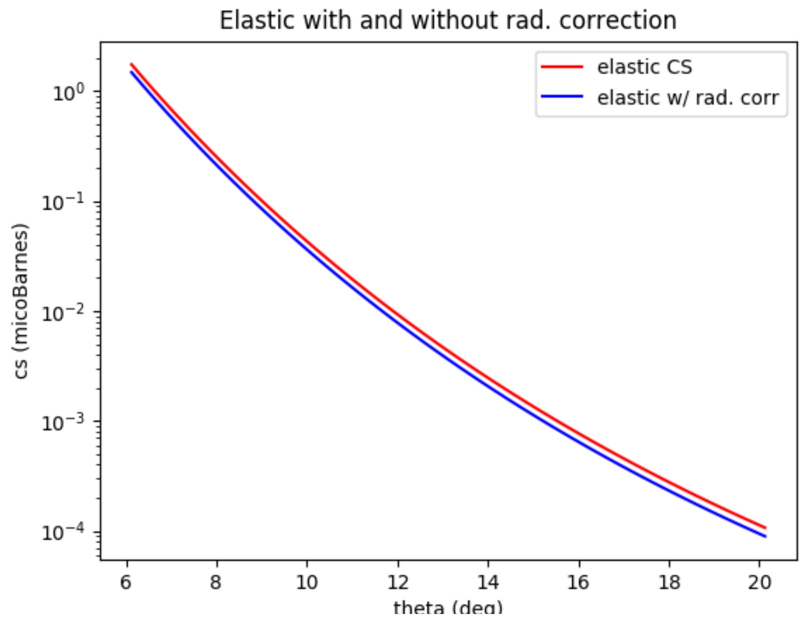


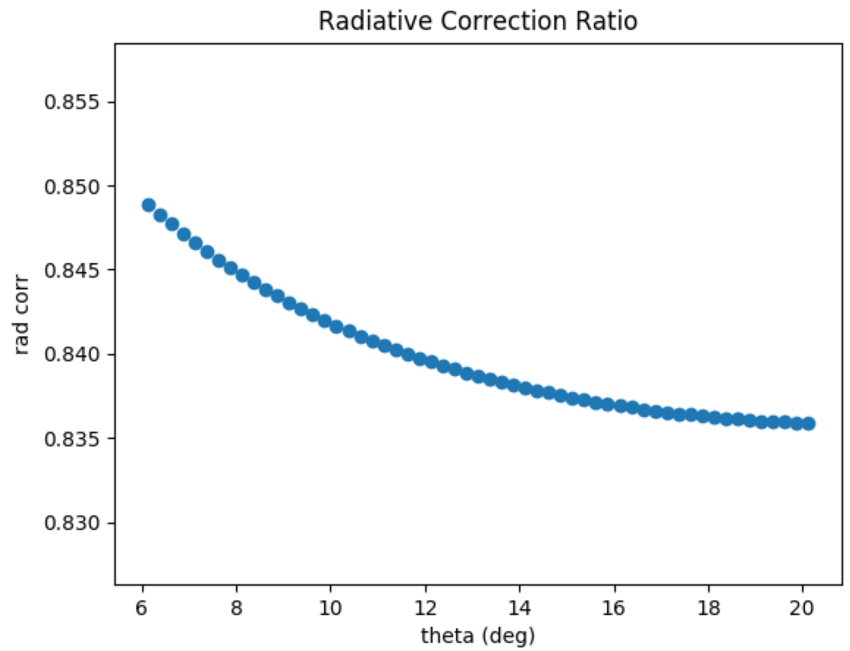
Radiative Correction - Elastic

- To get the radiative correction
  - Calculate the ratio of cross sections with and without radiative corrections for each theta bin.
  - RC > 1 $\rightarrow$ remove events radiated into bin
  - RC < 1 $\rightarrow$ add events radiated out of bin

$$\sigma_{measured} \cong contributions\ from\ radiative\ CS$$

$$\sigma_{Born} \cong (\sigma_{measured}) \frac{\sigma_{Born}}{\sigma_{rad}}$$





Rad. correction determined by ratio of elastic w/ and w/o rad. Corr.

The road to extract elastic cross section requires measuring the number of events for a channel.

- Recall, in general a differential cross section is

$$\frac{\Delta\sigma_{bin}}{\Delta X} = \frac{N_{bin}}{\mathcal{A}_{bin}\,\mathcal{L}_{int}\Delta X}$$

- In the limit of $\Delta X \to 0$ then

$$\lim_{\Delta X \to 0} \frac{\Delta\sigma_{bin}}{\Delta X} = \frac{d\sigma}{dX}$$

It also requires determining the acceptance, luminosity, and other factors.

- Recall, in general a differential cross section is

$$\frac{\Delta\sigma_{bin}}{\Delta X} = \frac{\left(N - N_{bkg}\right)_{bin}}{\mathcal{A}_{bin}\mathcal{L}_{int}\Delta X}$$

Binned variables

Integrated Luminosity

Acceptance

- In the limit of $\Delta X \rightarrow 0$ then

$$\lim_{\Delta X \to 0} \frac{\Delta\sigma_{bin}}{\Delta X} = \frac{d\sigma}{dX}$$

Taken together the measured elastic cross section for bin b is given here.

- Specifically for elastic scattering the cross section is:

$$\sigma_b = \frac{N_b}{\mathcal{A}_{bin}\,\mathcal{L}_{int}\,C_b R_b\,\Delta\theta\,\Delta\phi\,\sin(\theta_b)}$$

- $\mathcal{A}_{bin}$ = acceptance
- $\mathcal{L}_{int}$ = integrated luminosity
- C_b = bin centering correction
- R_b = radiative correction
- $\Delta\theta$ = theta bin size
- $\Delta\phi$ = phi bin size
- θ_b = theta bin center

Next step will look into the inclusive e- channel.

- Two Channels
  1. Elastic
     - Select events about proton mass using fits to data
     - Remove background
  2. **Inclusive**
     - p(e,e')X
     - $W > 1.0\ GeV^2$
     - $Q^2 > 1.0\ GeV^2$ (pQCD applicable)
     - $y < 0.8$ (reduce elastic radiative background to better match the model)

$$Q^2 = (e - e')$$
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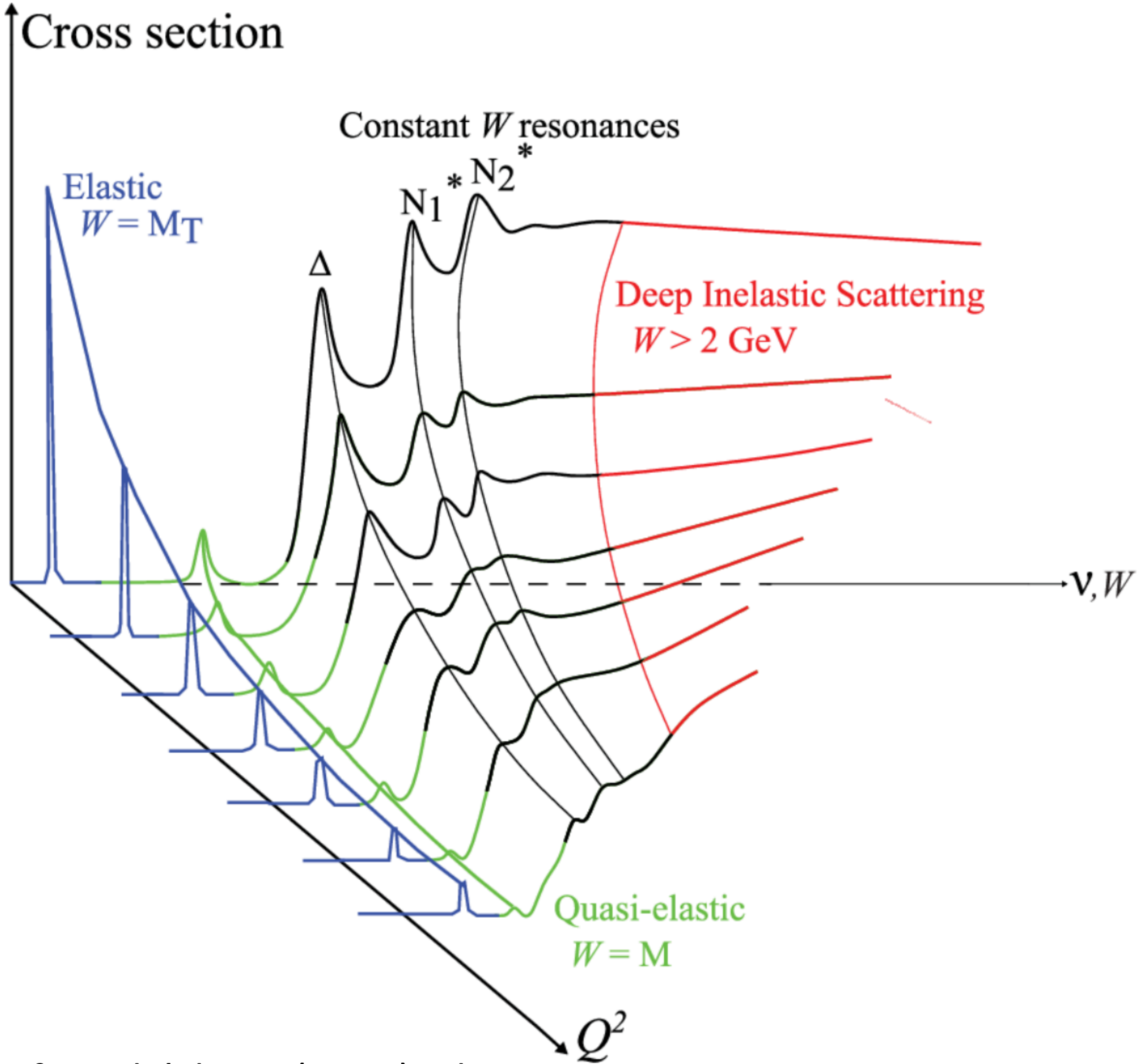
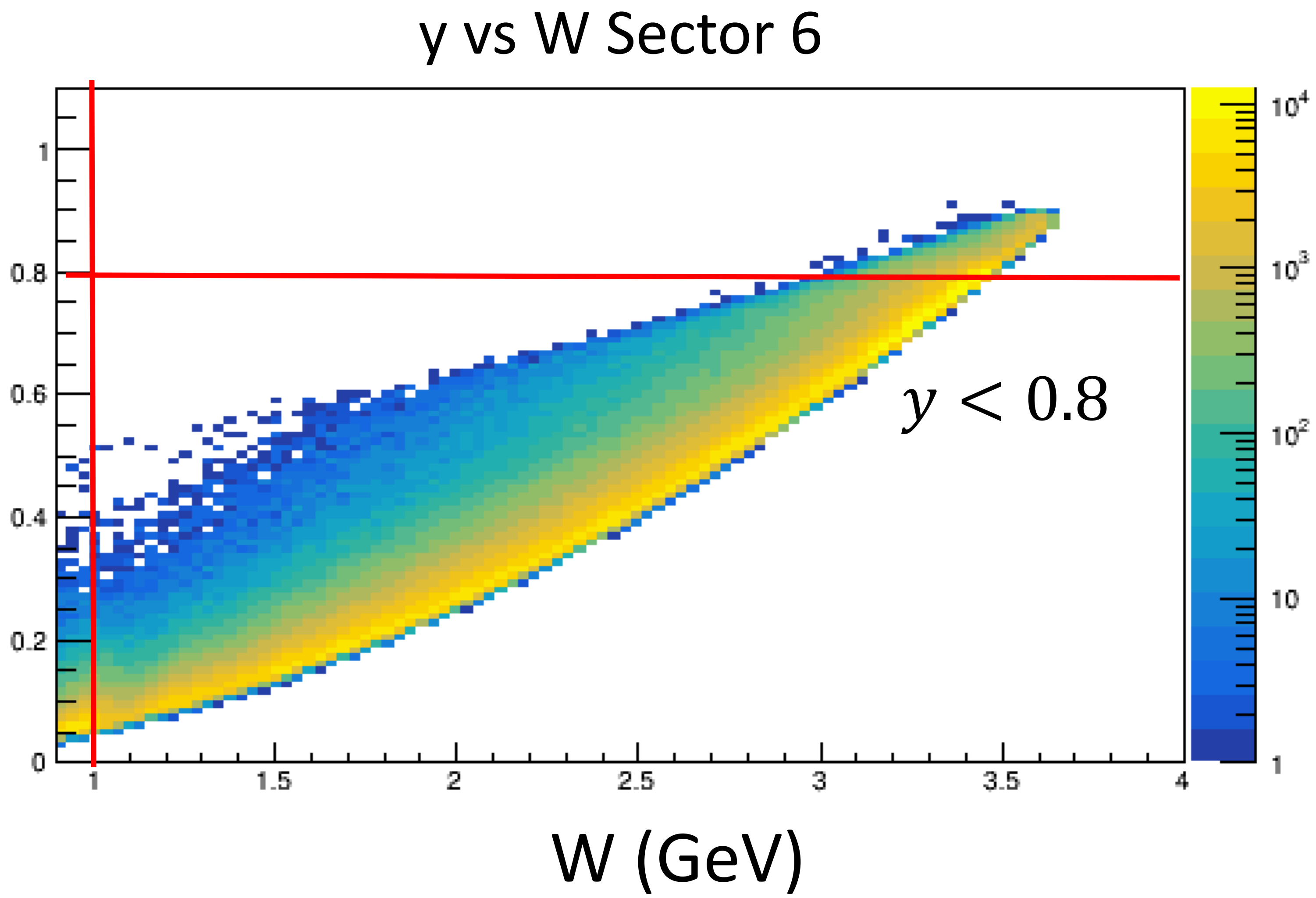
$$W^2 = m_p^2 - Q^2 + 2m_p\nu$$



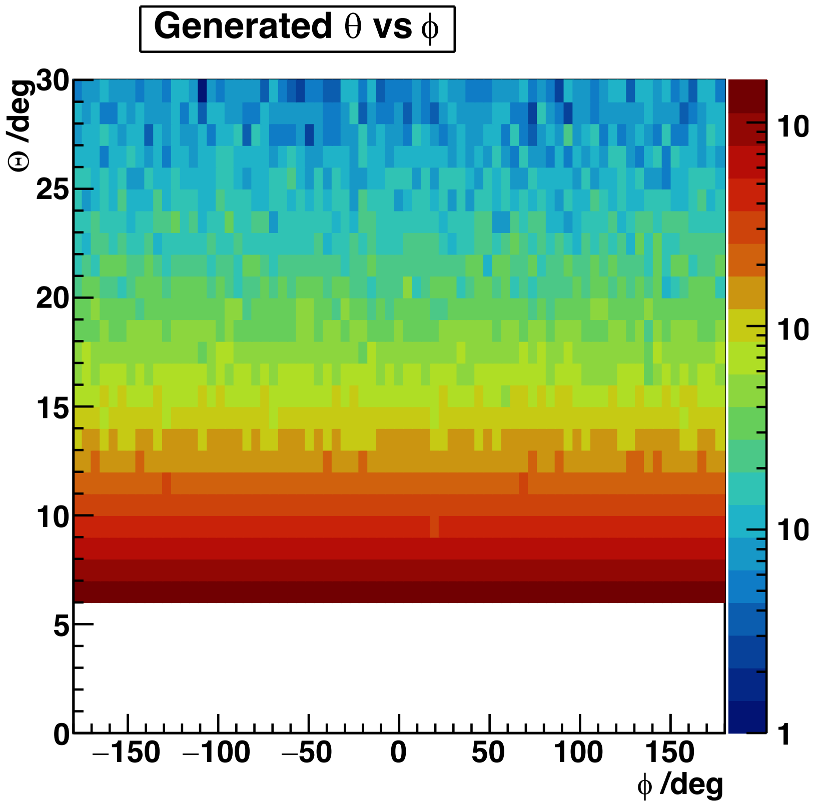
Ref - Zieliński, R. (2017). The g2p Experiment: A Measurement of the Proton's Spin Structure Functions.

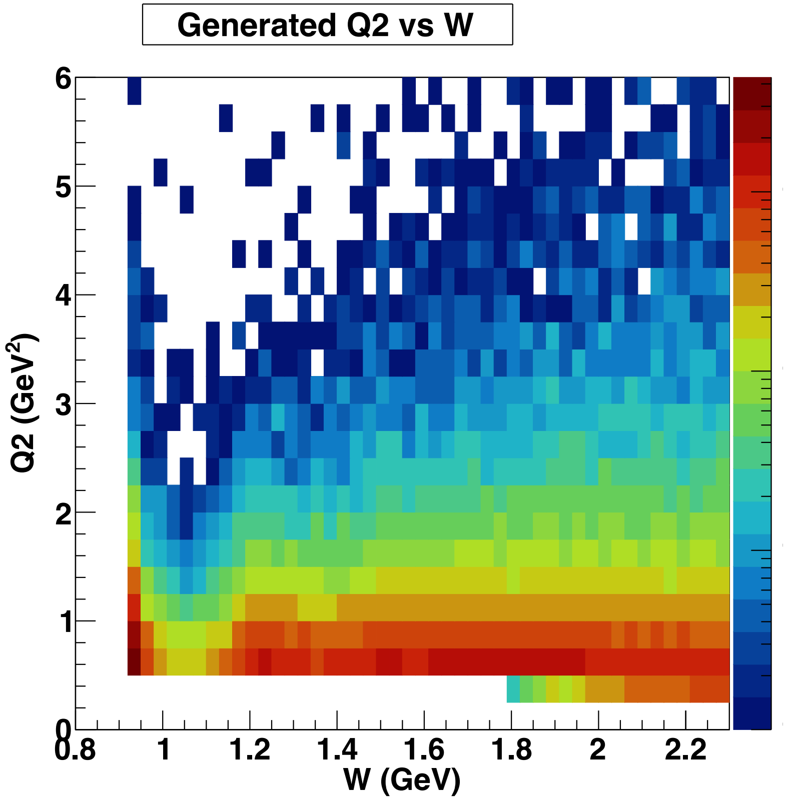
Now we start looking into the inclusive channel - p(e,e')X



Electron PID remains similar as before so we jump to looking at the generator for inclusive p(e,e')X.

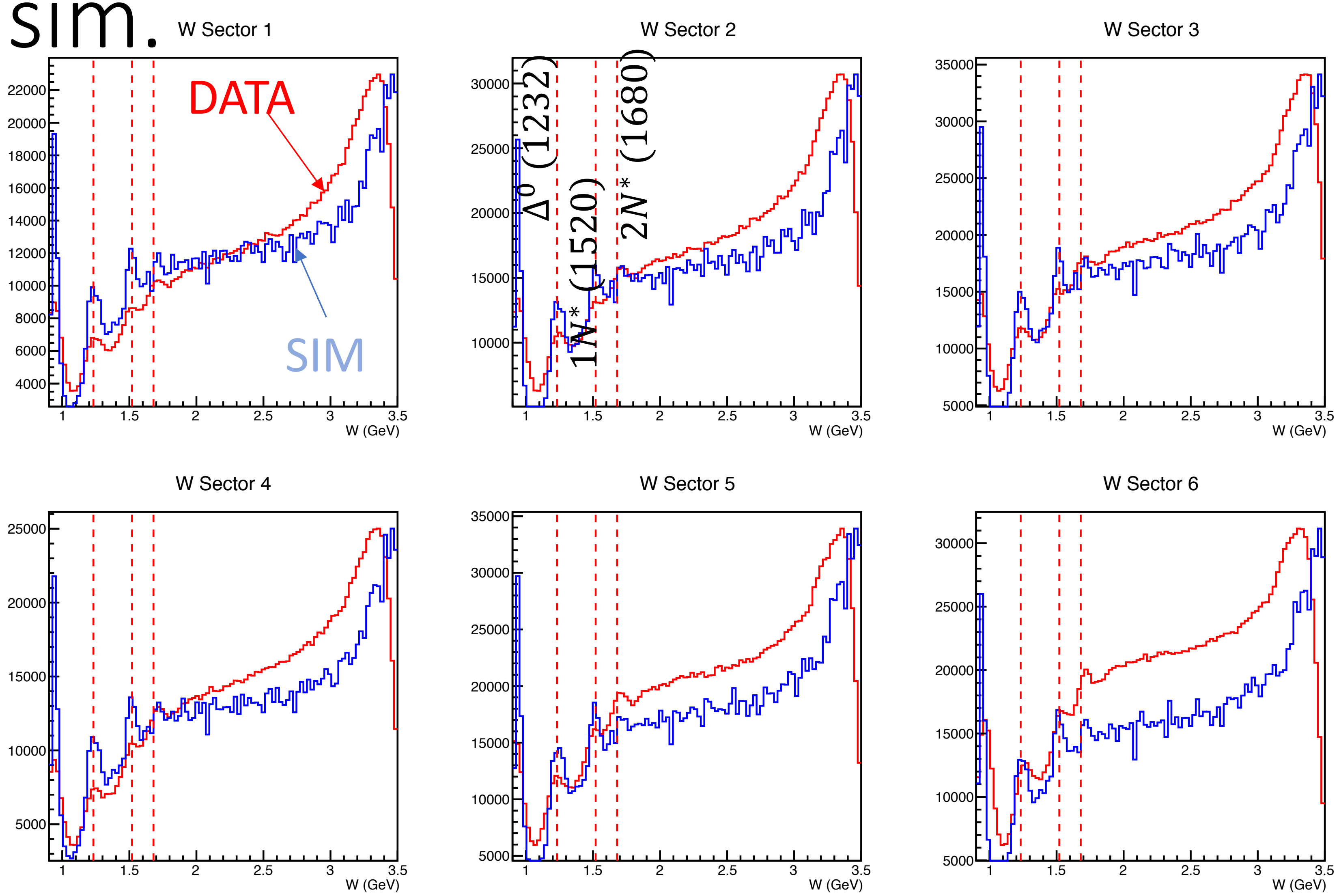
- Misak generator with Bosted parameterization of structure functions (with Radiative effects)
- Beam Energy: 7.546 GeV





Inclusive p(e,e')X– Compare the W spectrum between data to sim.

- Similarly – does the simulation match the data?



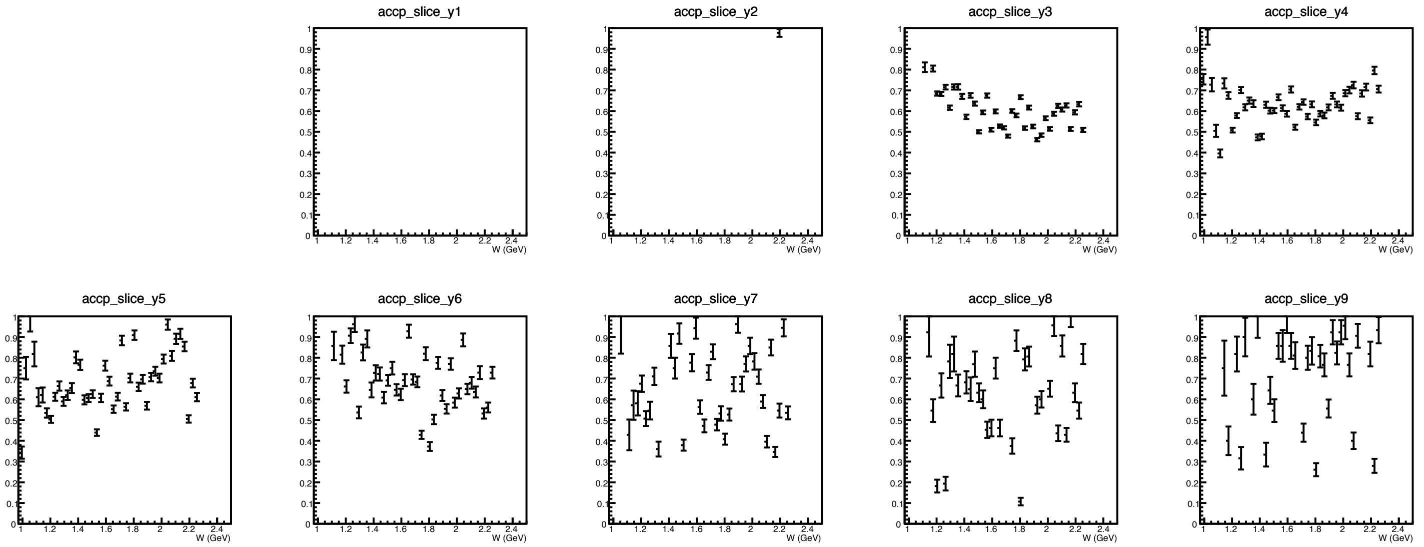
W integrated over Q2 for each sector for the final inclusive sample. Simulation (blue) is scaled to maximum height of the data.

Since the inclusive p(e,e’)X channel is a 2D problem the acceptance is now binned over Q2 and W.

- 2-Dimensional Problem
  - Cross section is binned in terms of Q^2 and W
  - Events can migrate up-down and left-right across 2-D space

Grid Properties	Q2 Bins	W Bins
min	1.0	0.9
max	6.0	2.1
Bin size	0.25 GeV^2	0.03 GeV
Number of bins	20	40

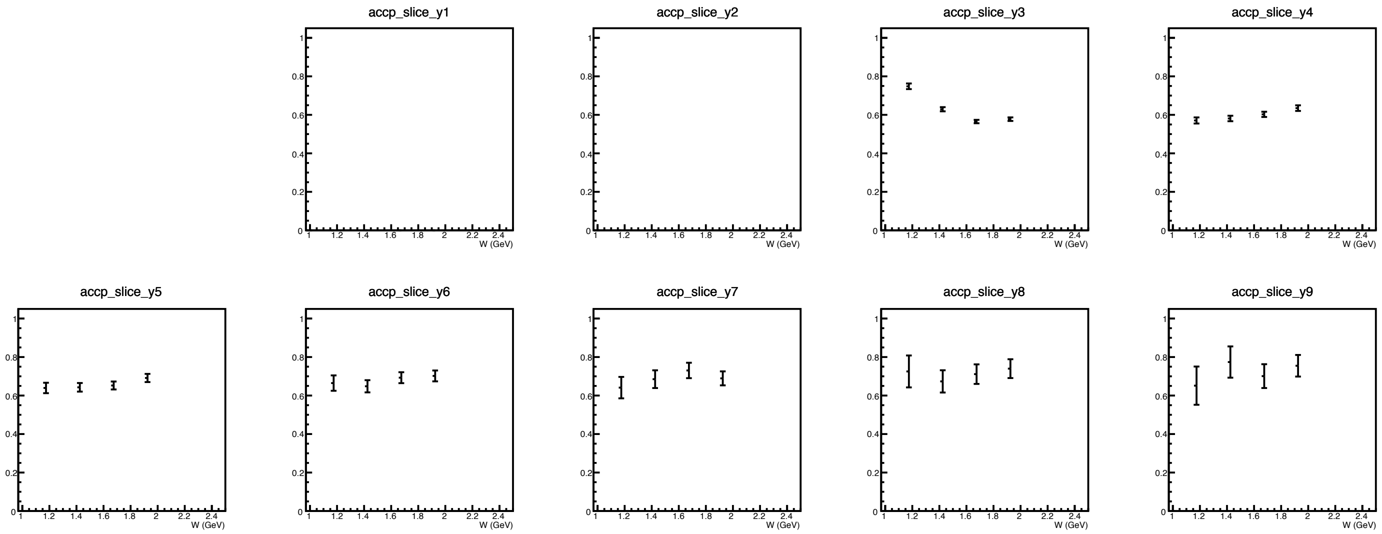
Nominal binning choice for inclusive studies.



Acceptance over W for each Q^2 bin.

Since the inclusive p(e,e’)X channel is a 2D problem the acceptance is now binned over Q2 and W.

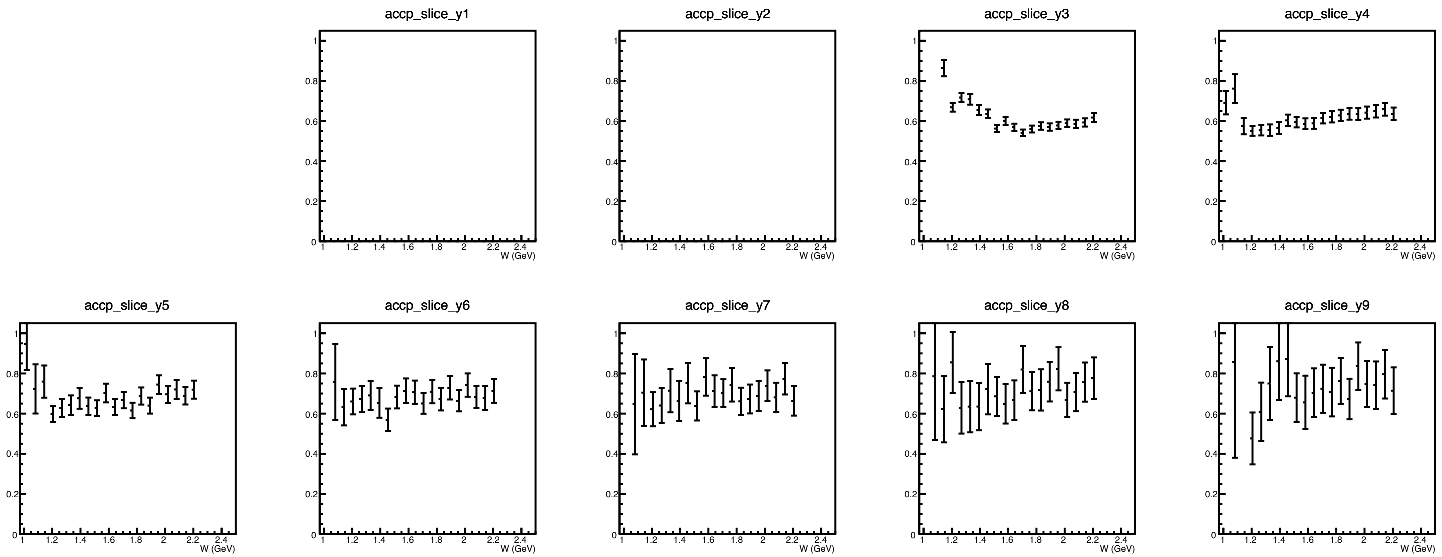
- Change W bin size, keeping Q^2 bin sizes fixed



Acceptance over W for each Q^2 bin. 4 W bins.

Since the inclusive p(e,e')X channel is a 2D problem the acceptance is now binned over Q2 and W.

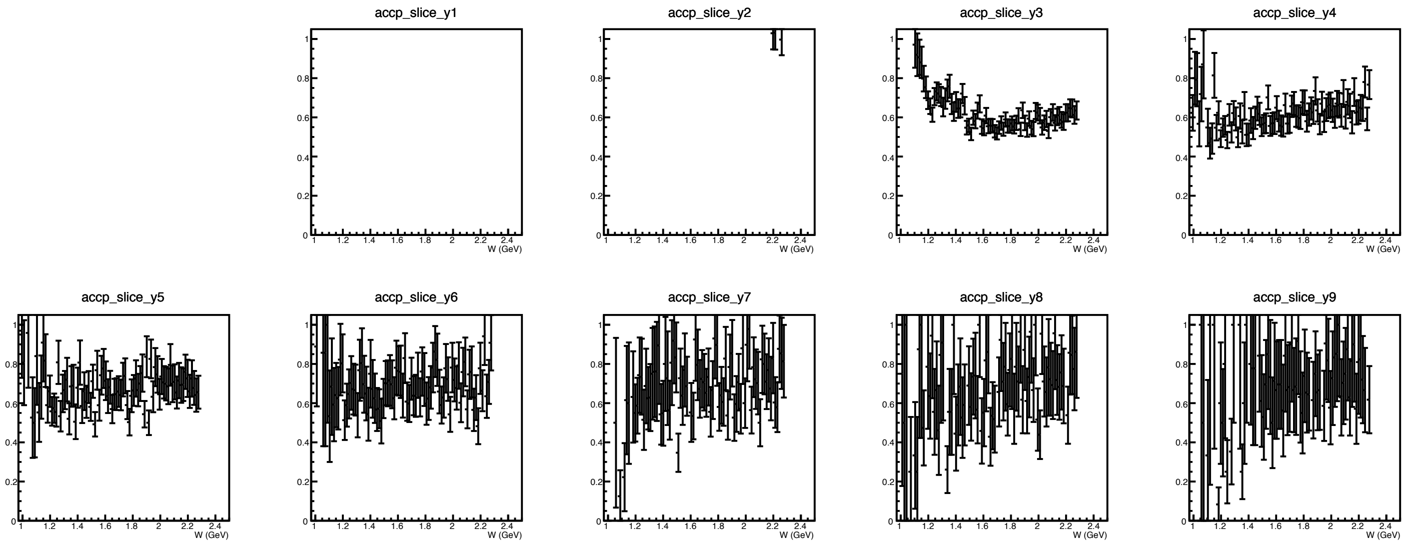
- Change W bin size, keeping Q^2 bin sizes fixed



Acceptance over W for each Q^2 bin. 19 W bins.

Since the inclusive p(e,e')X channel is a 2D problem the acceptance is now binned over Q2 and W.

- Change W bin size, keeping Q^2 bin sizes fixed



Acceptance over W for each Q^2 bin. 90 W bins.

Final Remarks

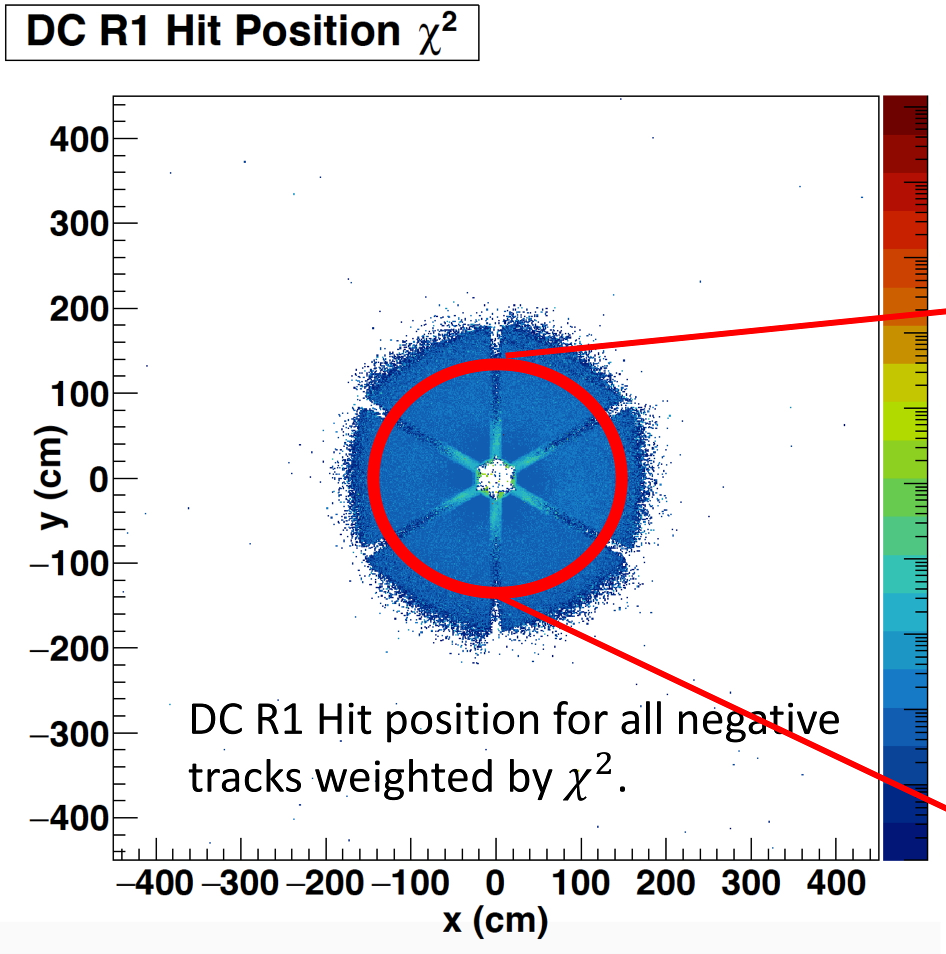
- The elastic cross section is to CLAS12 what the standard candle is to astronomers – we can use the elastic cross section to gauge not only electron PID, but also the status of CLAS12.
  - Use this to validate CLAS12 integrated luminosity - important for other exp.

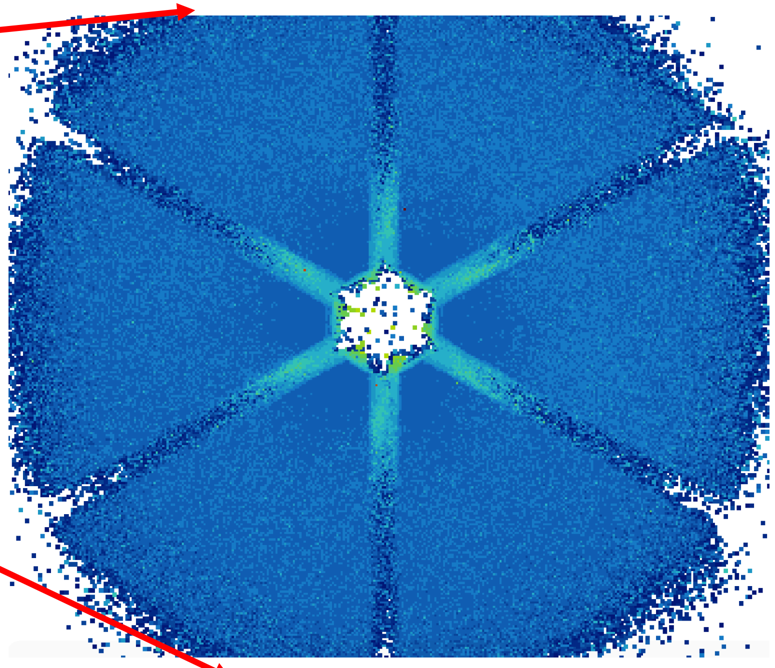
- Extend the analysis to data taken at 10 GeV!

Backups

Electron PID:

- Plot REC::Traj χ^2 over the surface of DC R1
  - Large χ^2 for a track → bad fit (light blue/ green regions)





Event Builder Cut Name	Cut Info
Nphe	Nphe > 2
SF Cut	+- 5σ SF cut
PCAL Energy Dep.	> 0.06 GeV

Additional Cuts
DCR1 Fiducal
DCR3 Fiducial
PCAL Fiducial

Table2 : Event Builder Cuts

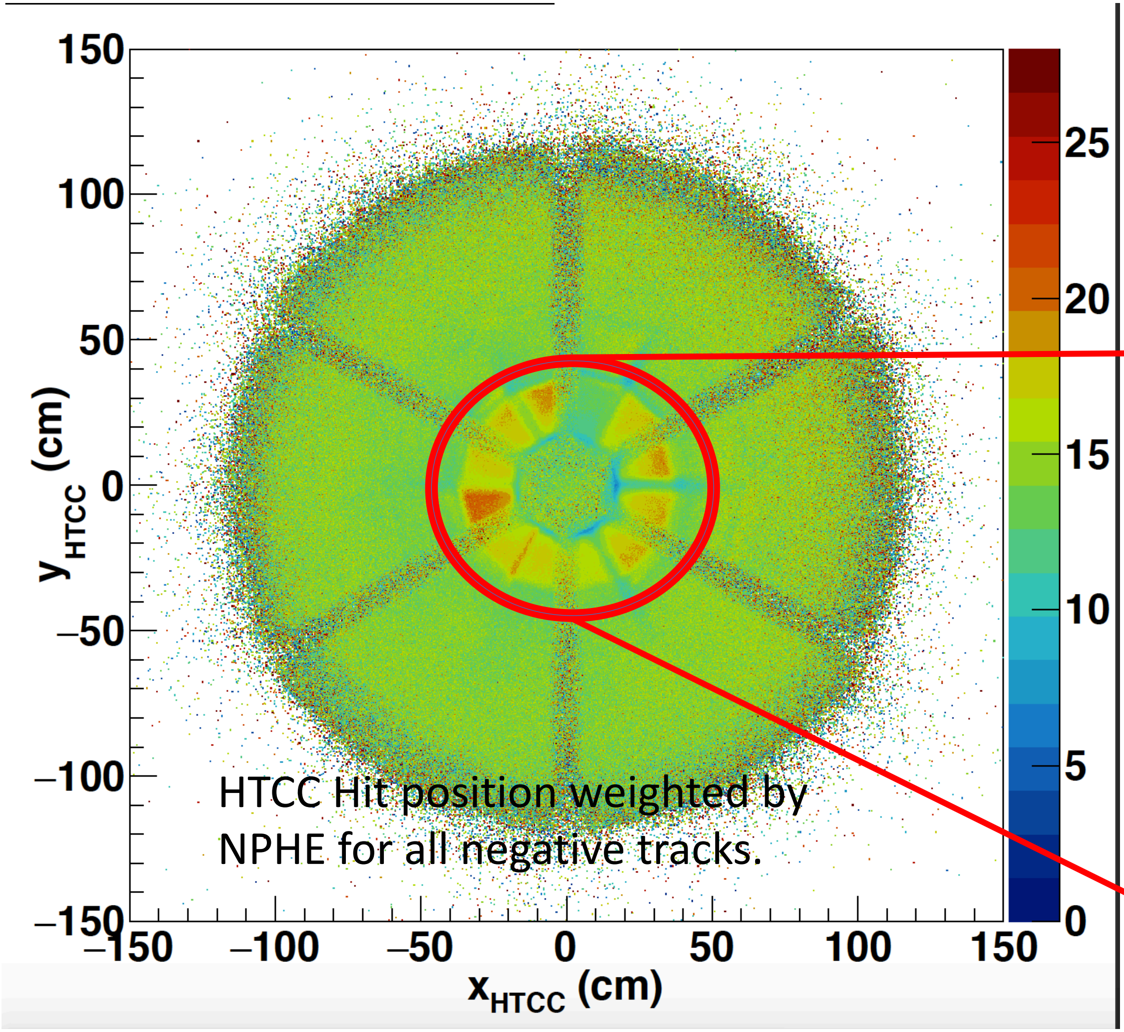
Electron PID:

- Plot REC::Traj Hit Position and NPHE over the surface of HTCC

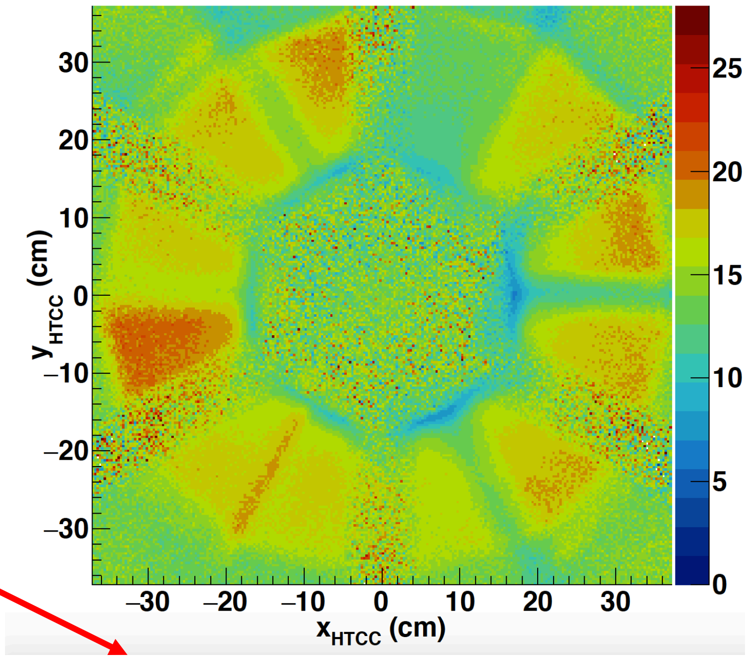
Event Builder Cut Name	Cut Info
Nphe	Nphe > 2
SF Cut	+- 5σ SF cut
PCAL Energy Dep.	> 0.06 GeV

Additional Cuts
DCR1 Fiducal
DCR3 Fiducial
PCAL Fiducial

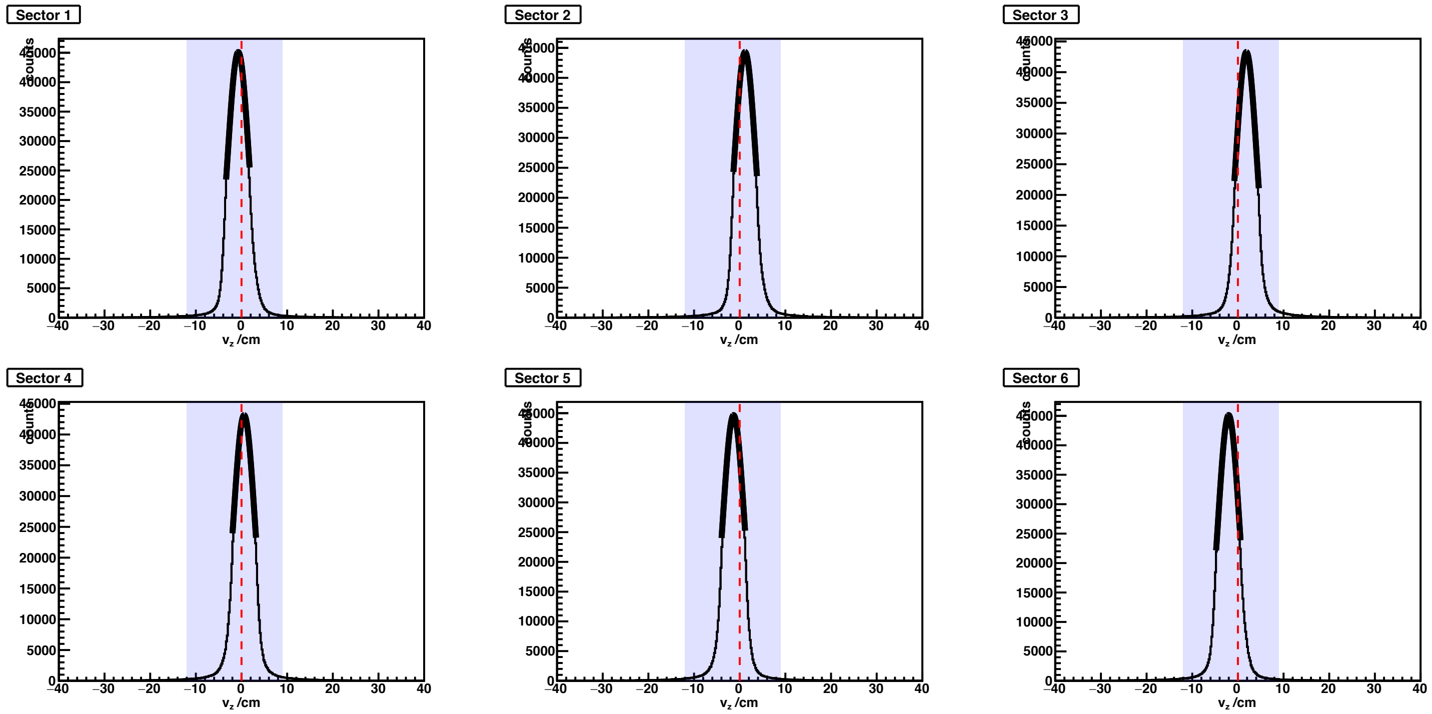
Table2 : Event Builder Cuts

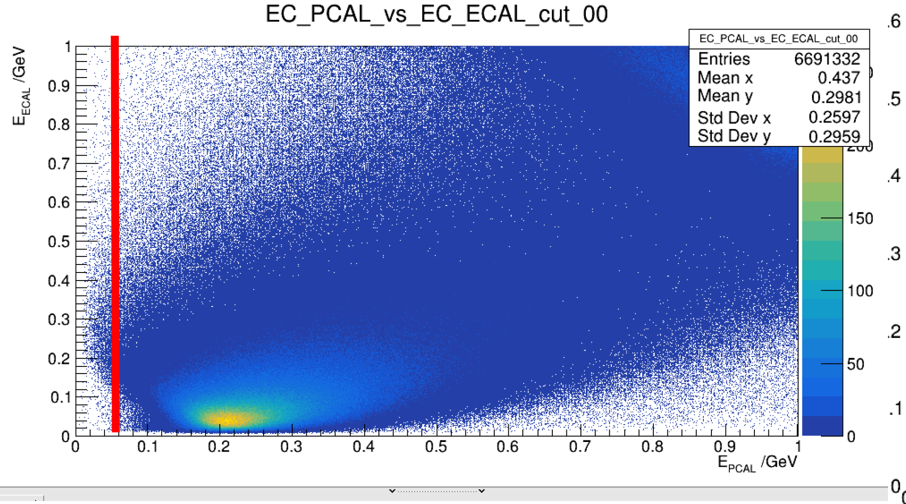


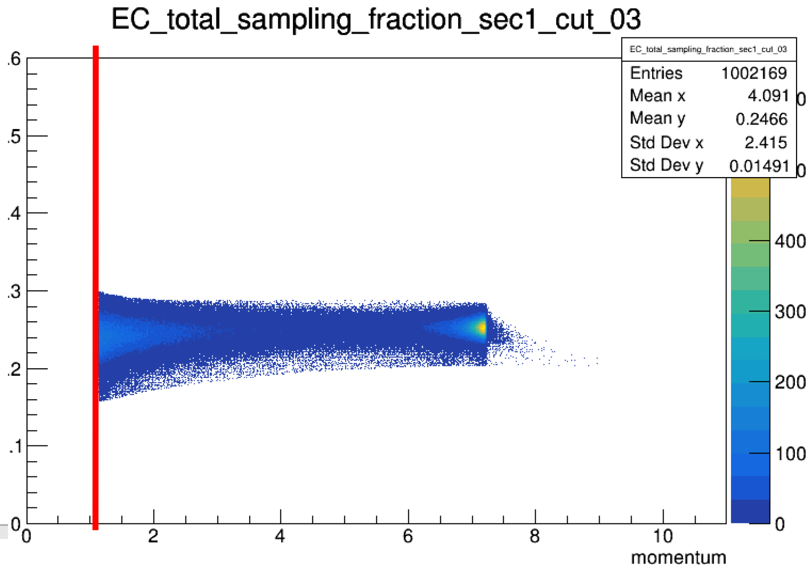
HTCC Hit position weighted by NPHE for all negative tracks.

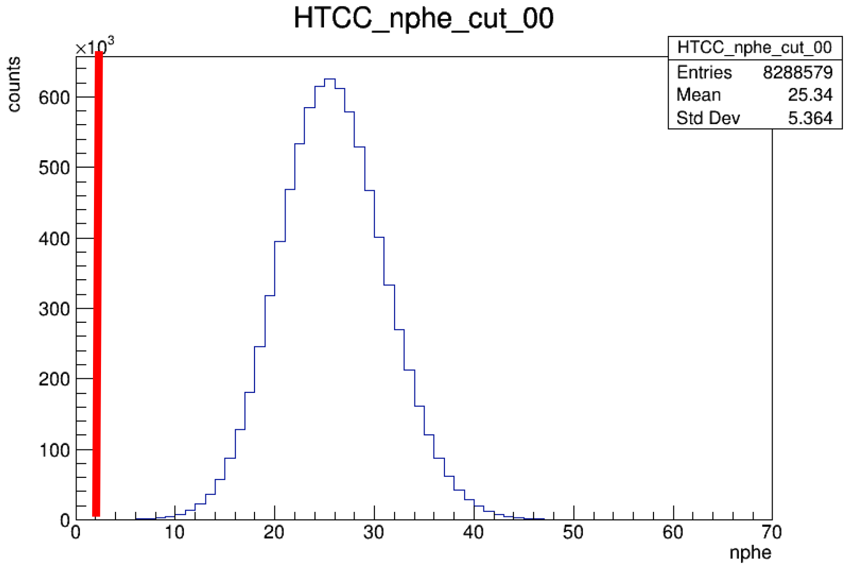


Simulation PID

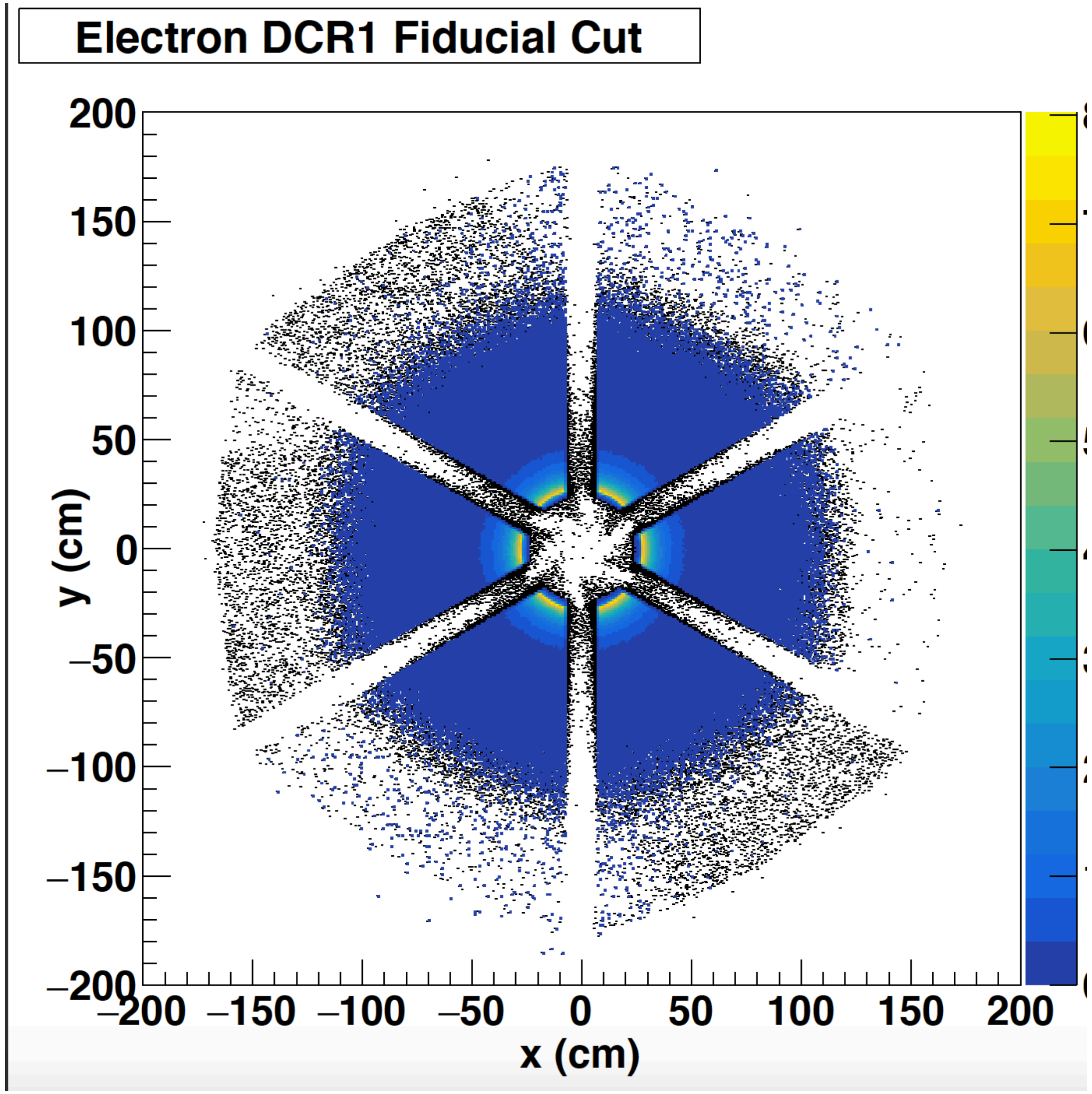








Simulation Electron PID



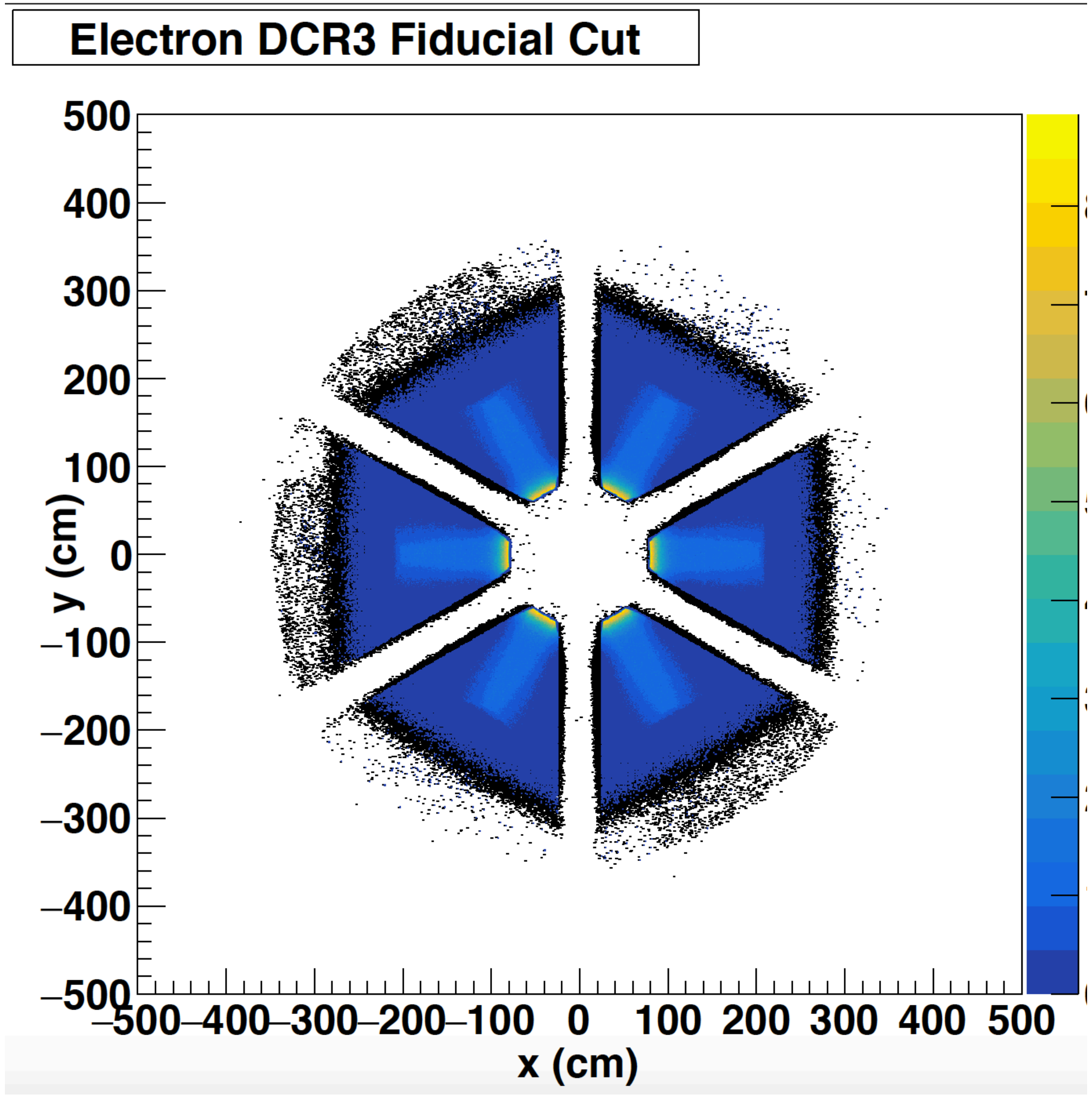
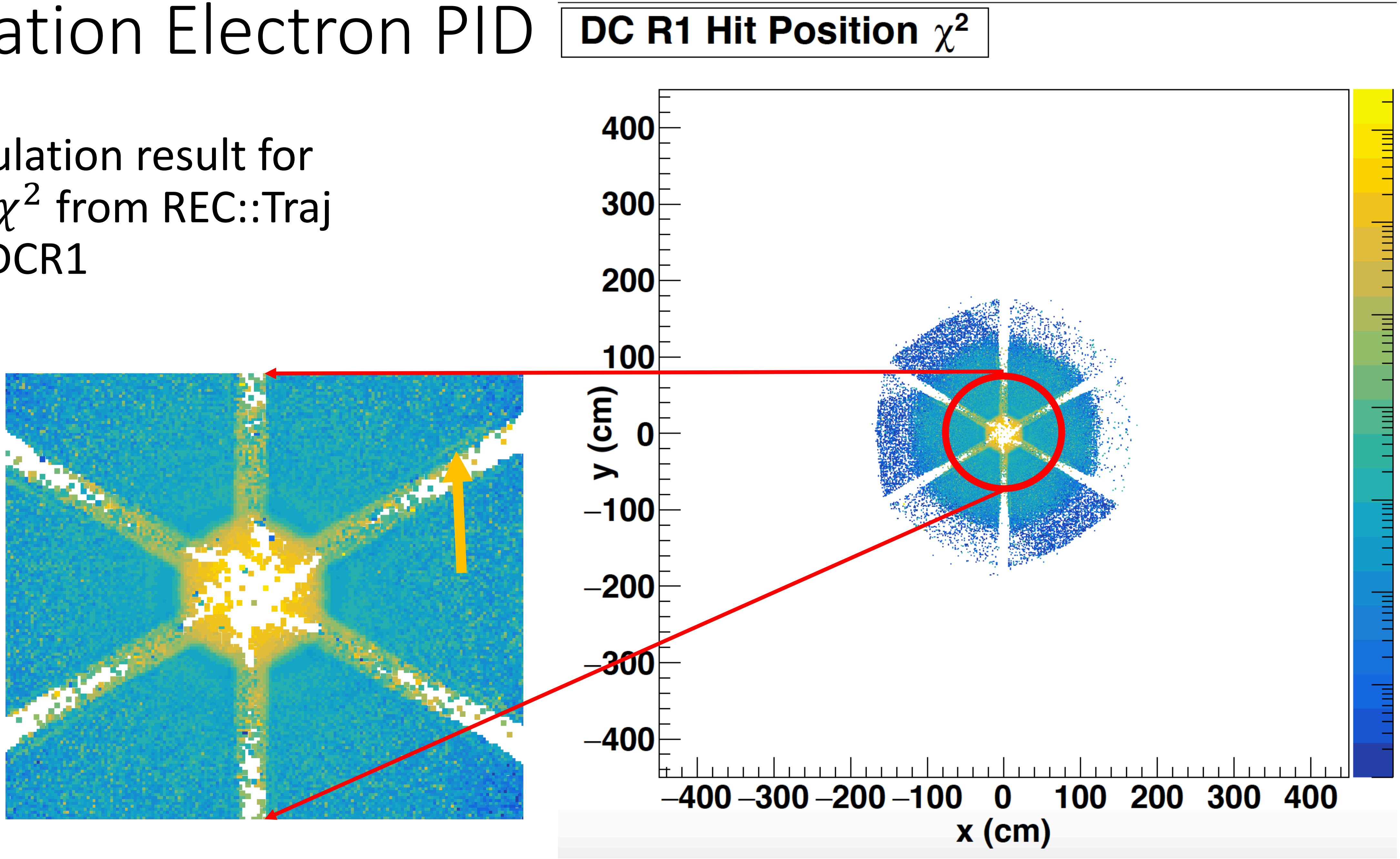


Figure 2: Fiducial cuts on the region 1 and 3 drift chambers as well as the PCAL.
Negative tracks (black) and the selected electron candidates using EB PID (blue).

Simulation Electron PID

- Simulation result for the χ^2 from REC::Traj for DCR1



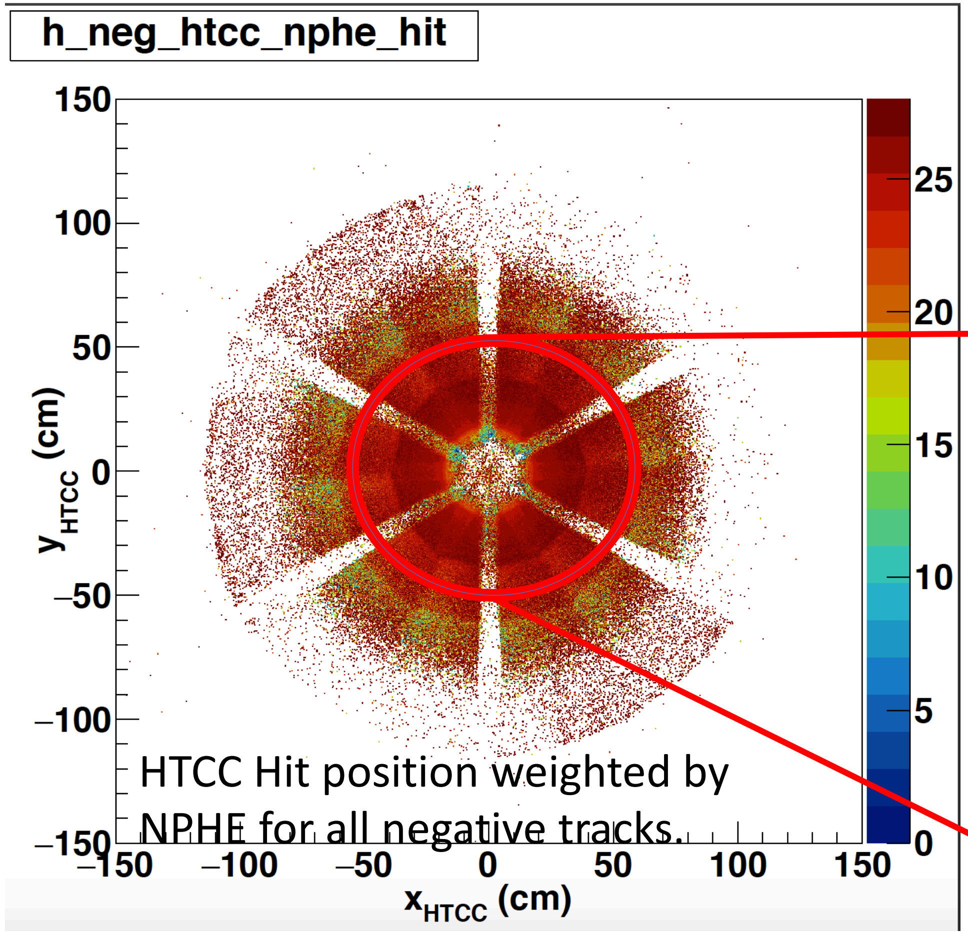
Electron PID:

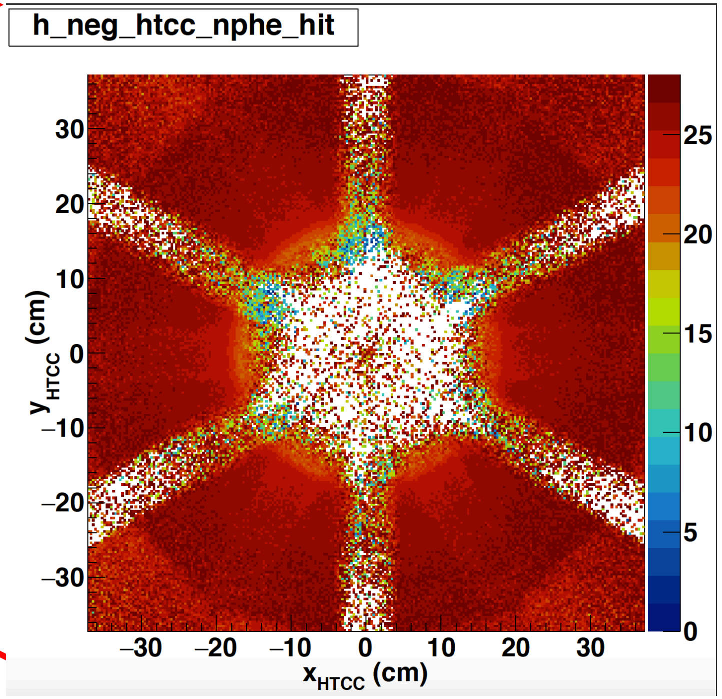
- Plot REC::Traj Hit Position and NPHE over the surface of HTCC

Event Builder Cut Name	Cut Info
Nphe	Nphe > 2
SF Cut	+- 5σ SF cut
PCAL Energy Dep.	> 0.06 GeV

Additional Cuts
DCR1 Fiducal
DCR3 Fiducial
PCAL Fiducial

Table2 : Event Builder Cuts





Radiative Corrections

Placing tighter w cut, removes more elastic events at larger Angles. This is why we see a downward trending RC value at larger angles.