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An Update on the "Tagged" EMC Effect Analysis

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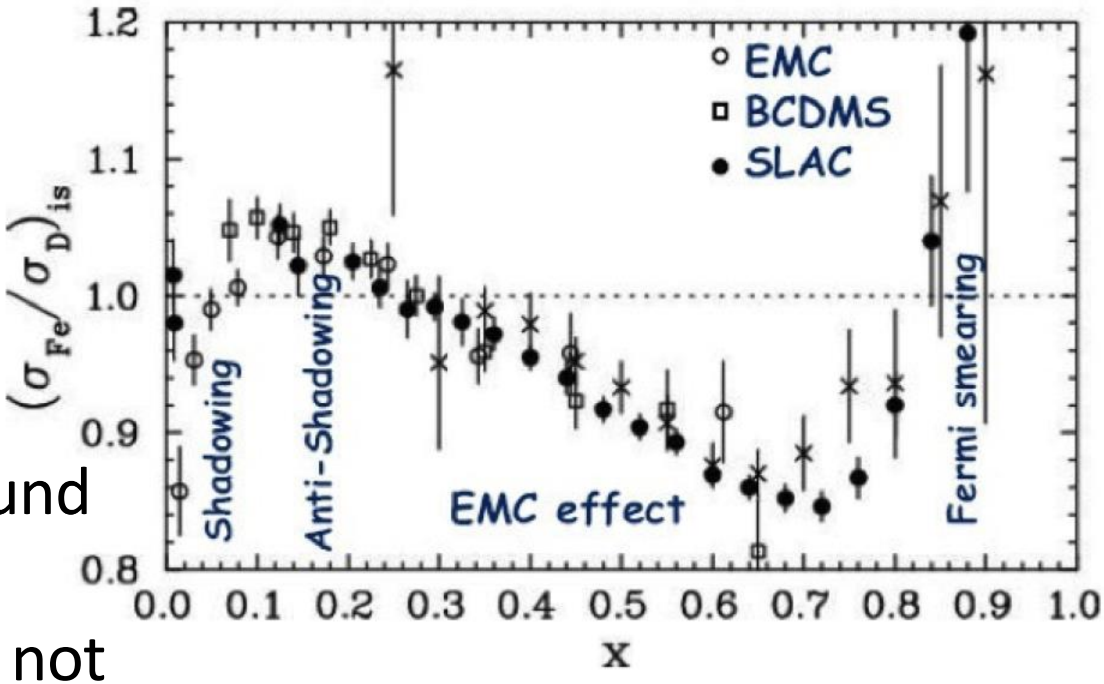
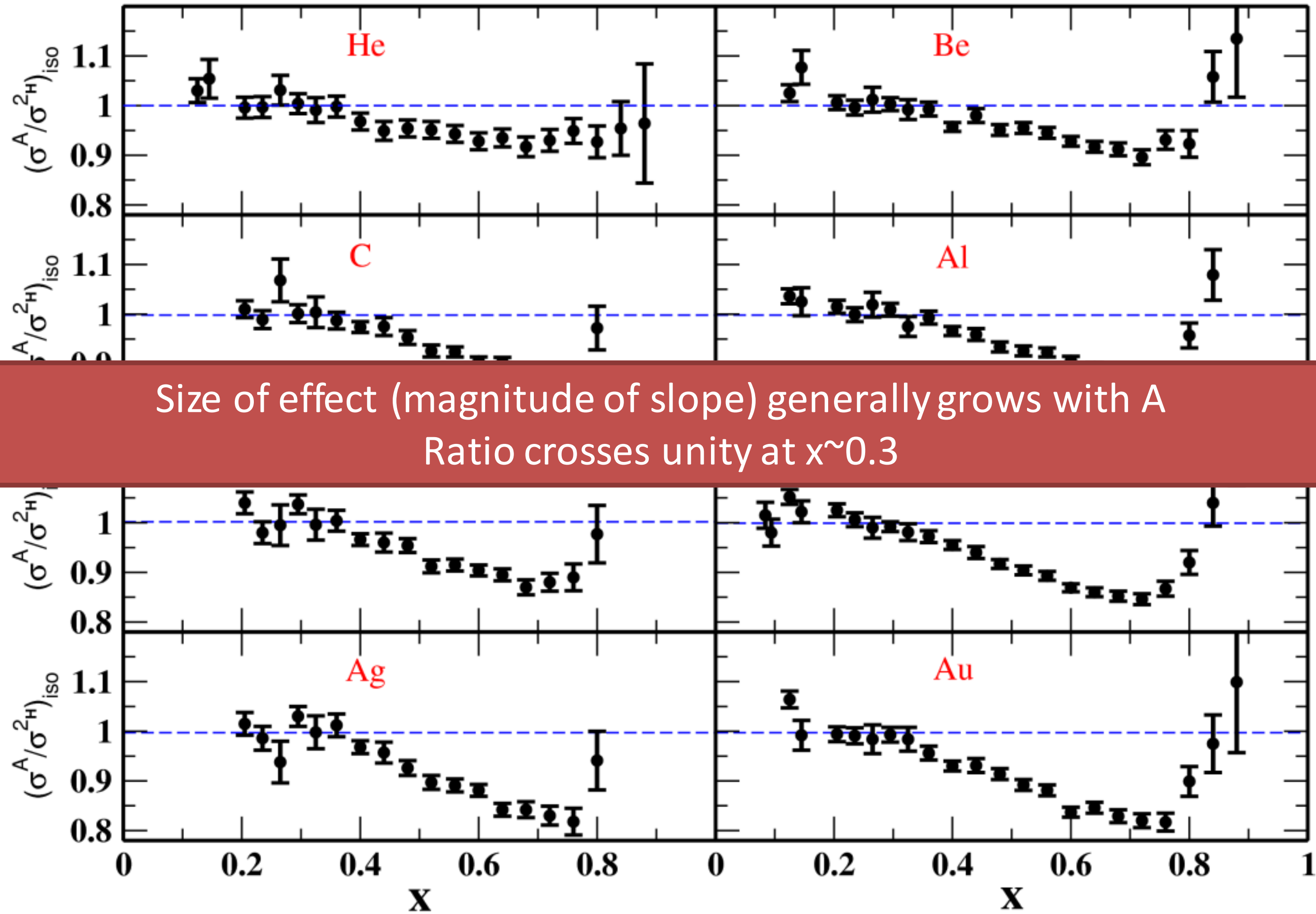
DIS and the EMC Effect

- Scale of DIS is several GeV, while nuclear binding energy scale is several MeV
- Expect DIS off bound nucleon ≈ DIS off free nucleon
- EMC Effect: DIS off bound N ≠ DIS off free N
- Origin of EMC Effect is not well understood



Universality of the EMC Effect

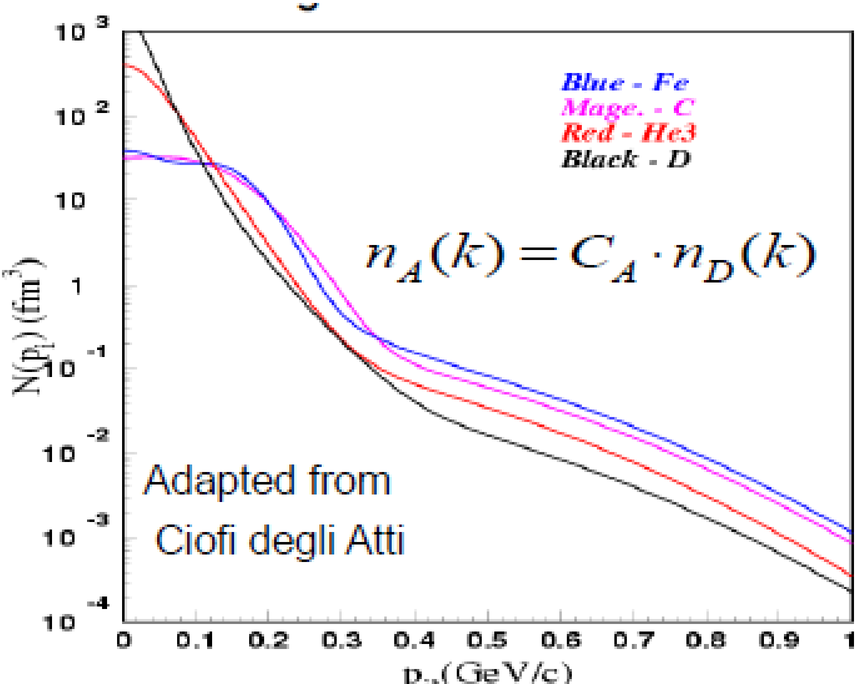
Data from CERN, SLAC, JLAB



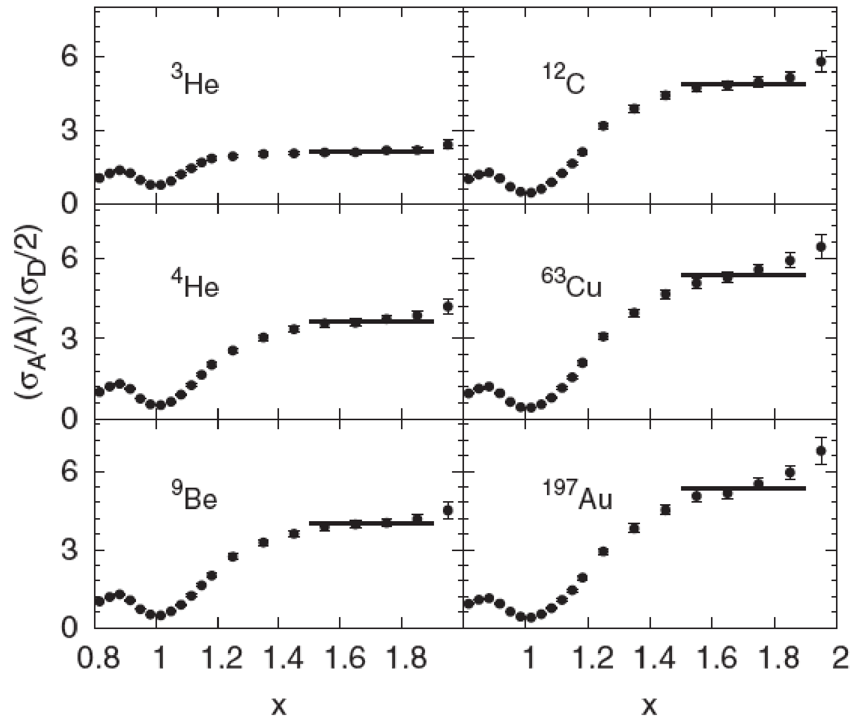
Size of effect (magnitude of slope) generally grows with A
Ratio crosses unity at x~0.3

Universality of SRC (Scaling)

- A Short Range Correlation (SRC) pair is a pair of nucleons with large relative momenta ($p_{rel} > p_F$) and small CM momenta ($p_{CM} < p_F$)!
- Scale is a few tens of MeV
- At high nucleon momenta, strength is different but shapes of distributions are similar



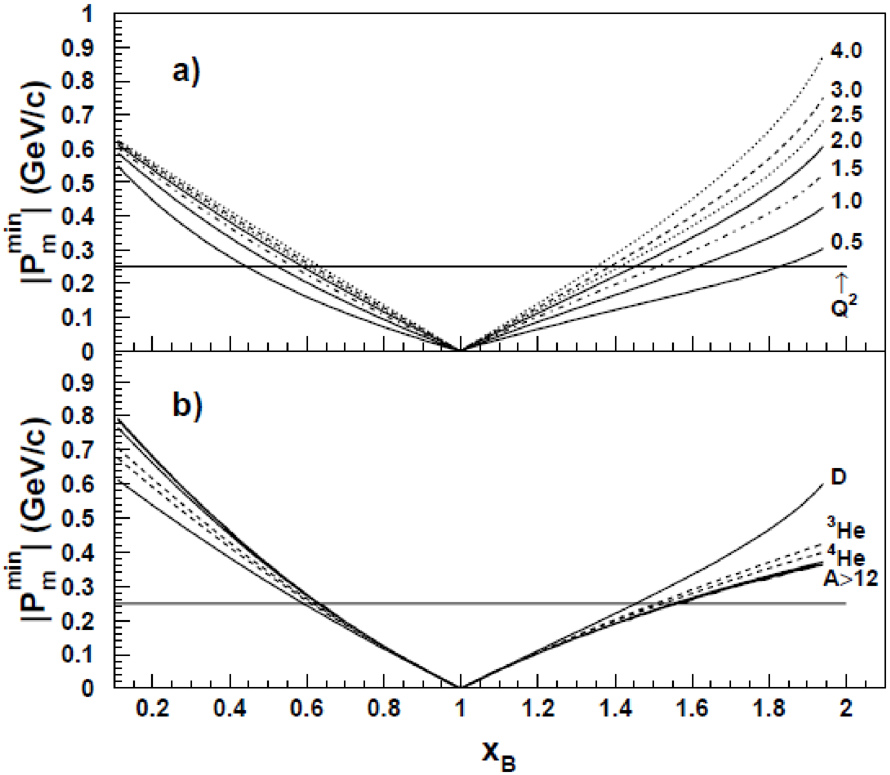
A(e,e')



N. Fomin et al., Phys. Rev. Lett. **108** (2012) 092502

$$a_2(A/d) = \frac{\sigma\,(A)\;/\;A}{\sigma\,(d)\;/\;2}$$

Selecting High-Momentum Nucleons in SRC

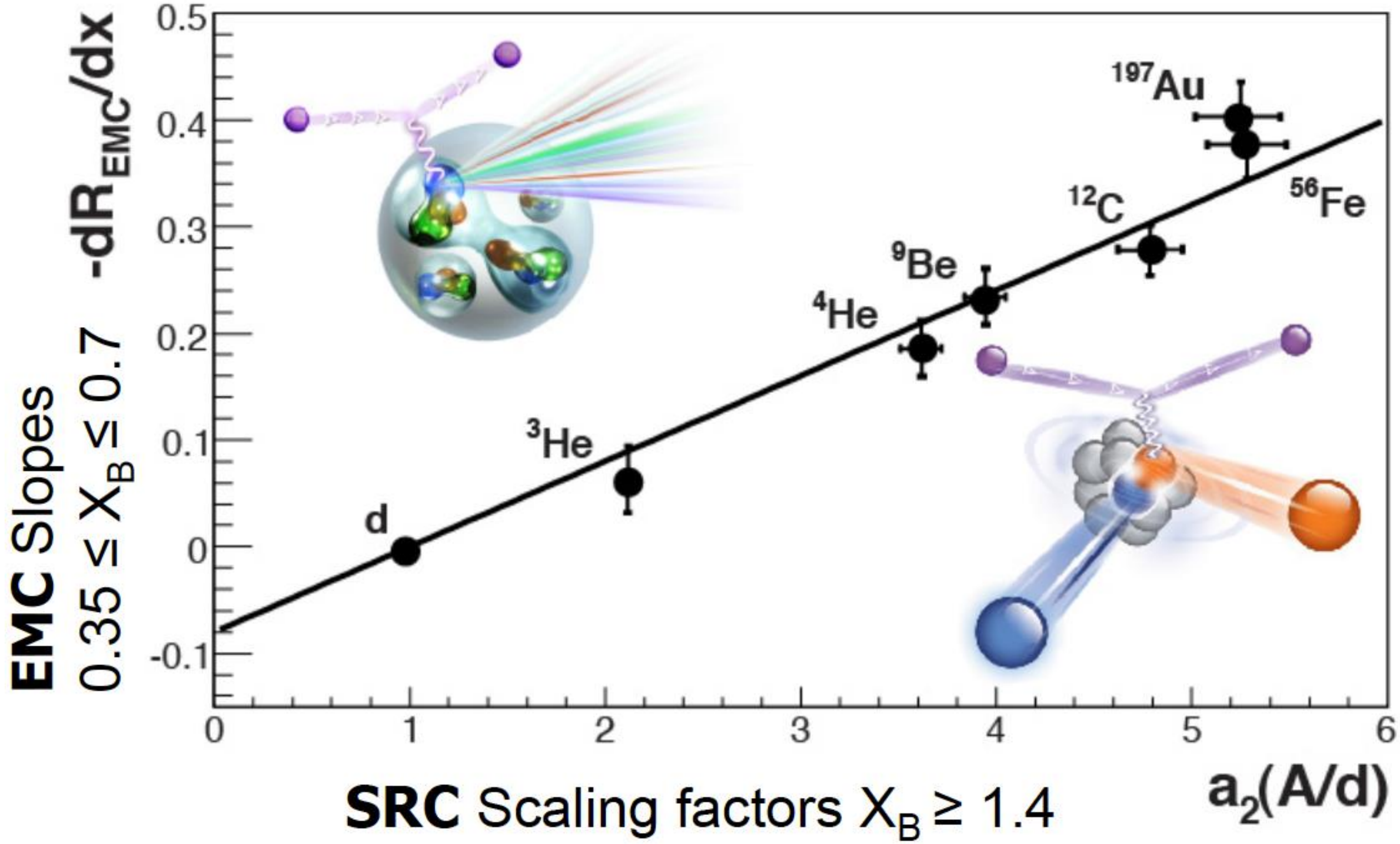


In inclusive scattering, x_B determines the minimum momentum of the nucleon in the nucleus and enables selection of interactions with nucleons having $p > p_F$

- Almost all these nucleons are members of a SRC pair!
- Knocking out one member results in the recoil ejection of the other member in the opposite direction.
- Approximately 90% of SRC pairs are proton-neutron pairs, 5% are p-p, and 5% are n-n pairs, but this has some momentum dependence.

- Korover et al., PRL **113** 022501 (2014)
- R. Subedi et al., Science **320** (5882), 1476 (2008)
- Tang et al. **PRL** 042301 (2003)

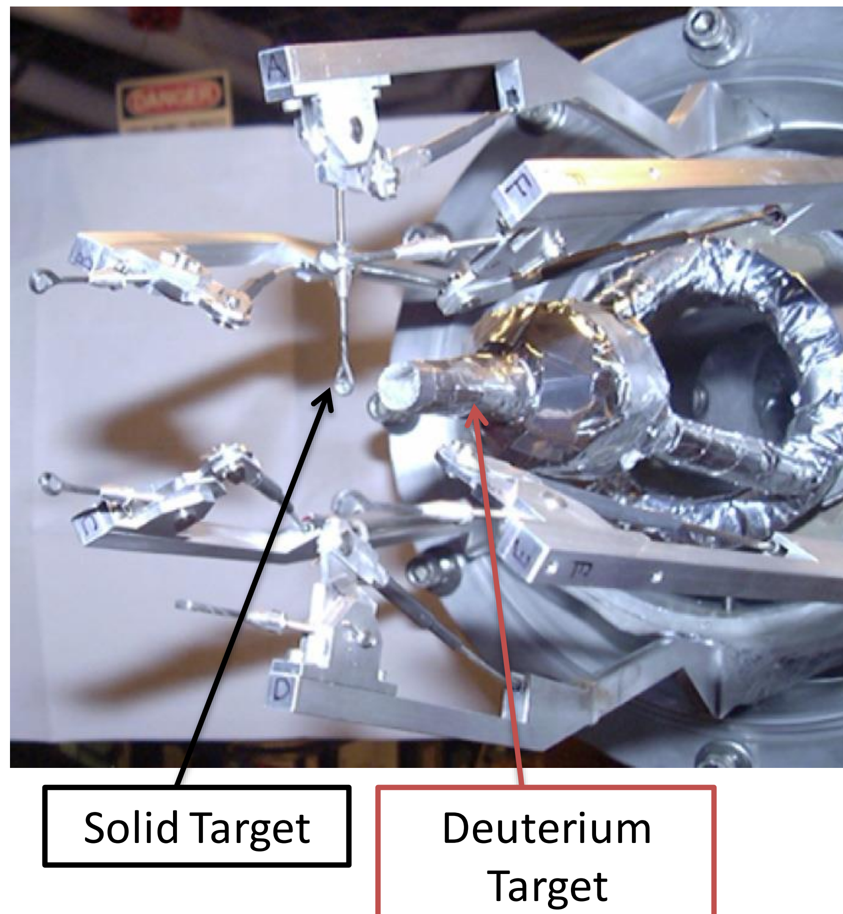
These Two Phenomena are Clearly Correlated



L. Weinstein et al, PRL **106**, 052301 (2011); O. Hen et al, PRC **85**, 047301 (2012)

Study EMC-SRC Correlation with "Tagged" EMC

- Analyze CLAS data from the Eg2c run period
- Choose events with EMC Kinematics
- Study EMC events with backwards-recoiling (with respect to the momentum transfer) proton with $k>k_F$
- Naïve Expectation if EMC effect arises from SRC pairs: Flat $[\sigma(A)/A]/[\sigma(d)/2] \approx a2(A/d)$!

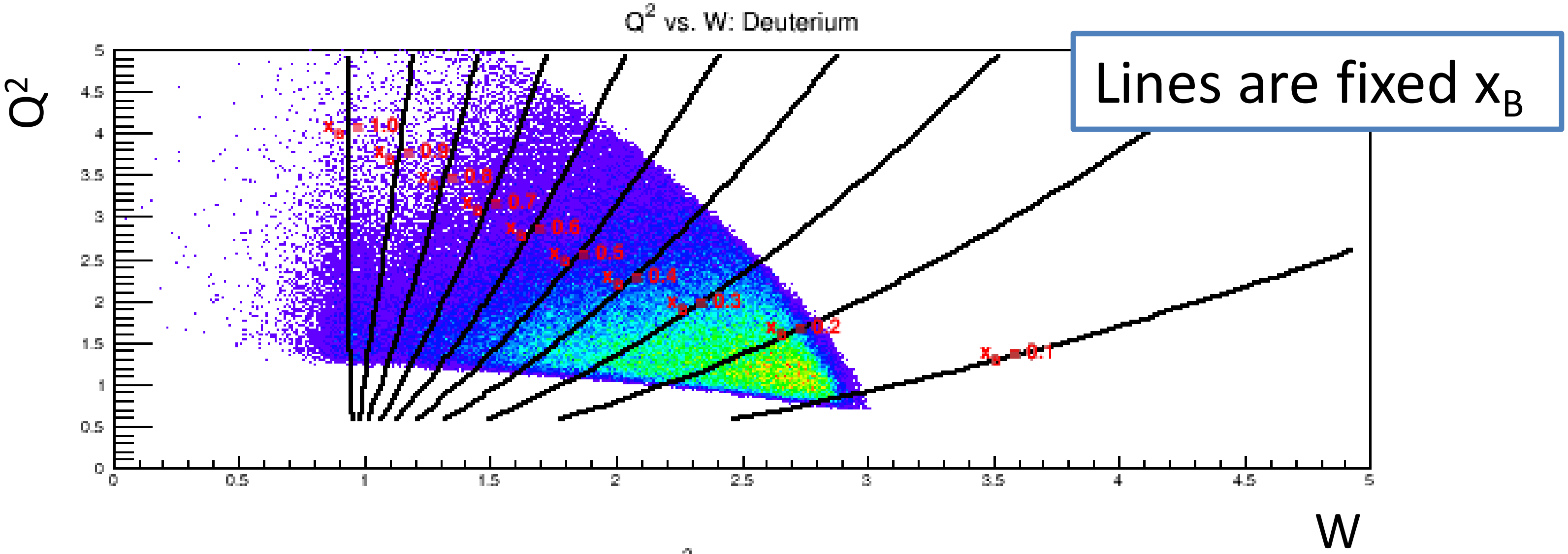


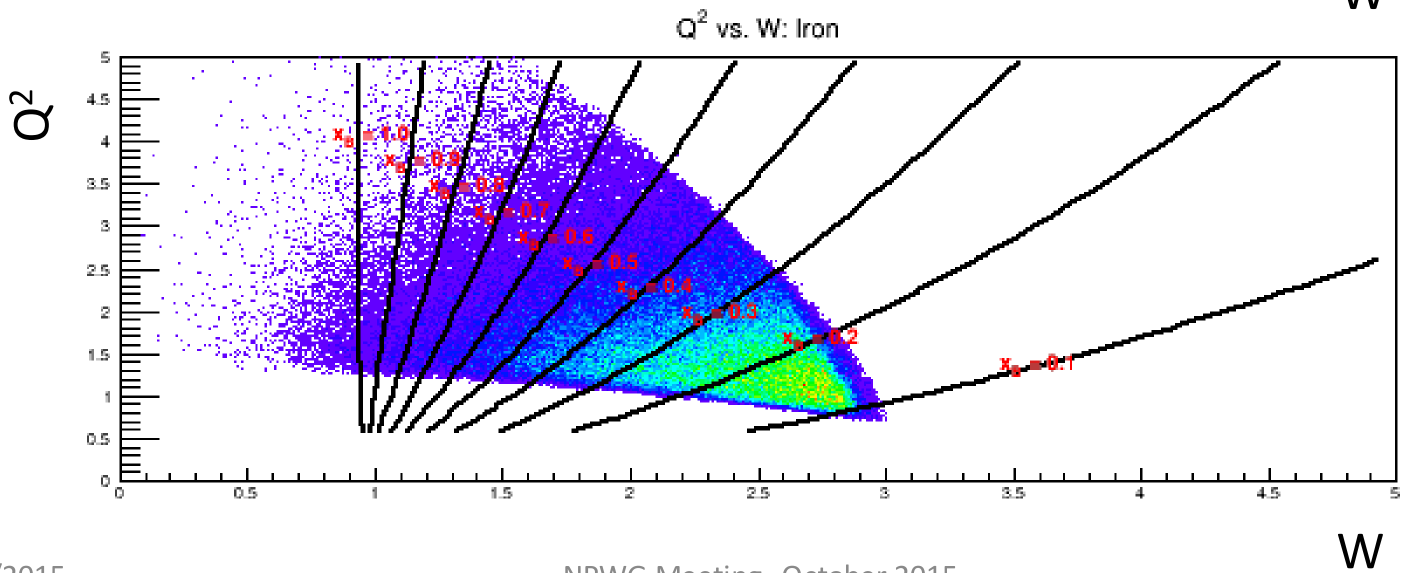
Particle ID/Fiducial Cuts/Vertex Corrections

- Electron PID and fiducial cuts are taken from the CT analysis
- Proton PID is similar to the one used by Or Hen for his SRC analysis
- No fiducial cuts been applied for protons (only considering large theta angles)
- Empirical (theta-dependent) vertex corrections have been applied for both the electrons and protons

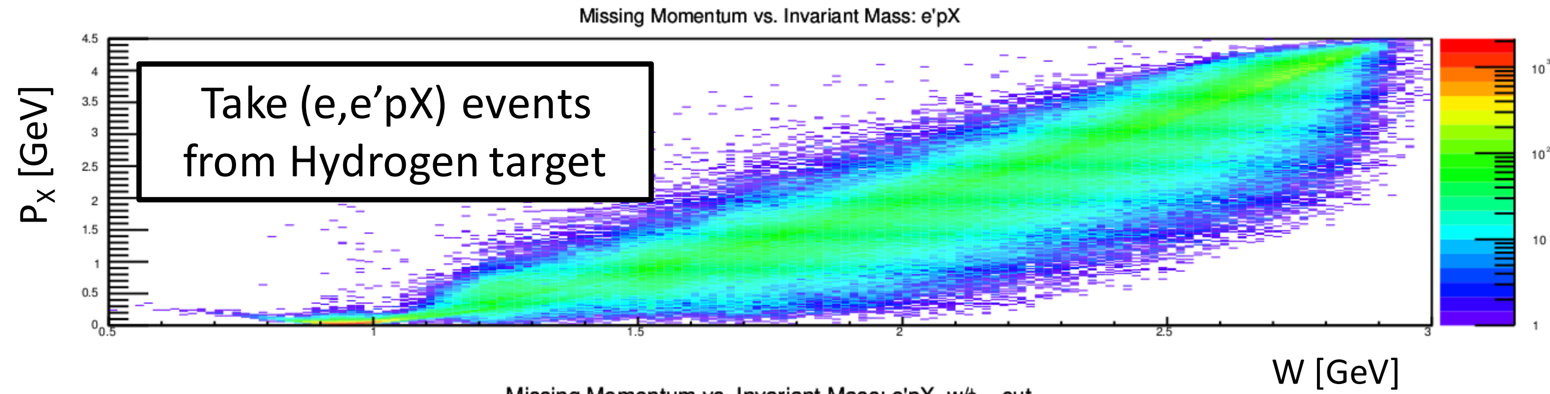
*Specifics can be found in slides at the end of this presentation

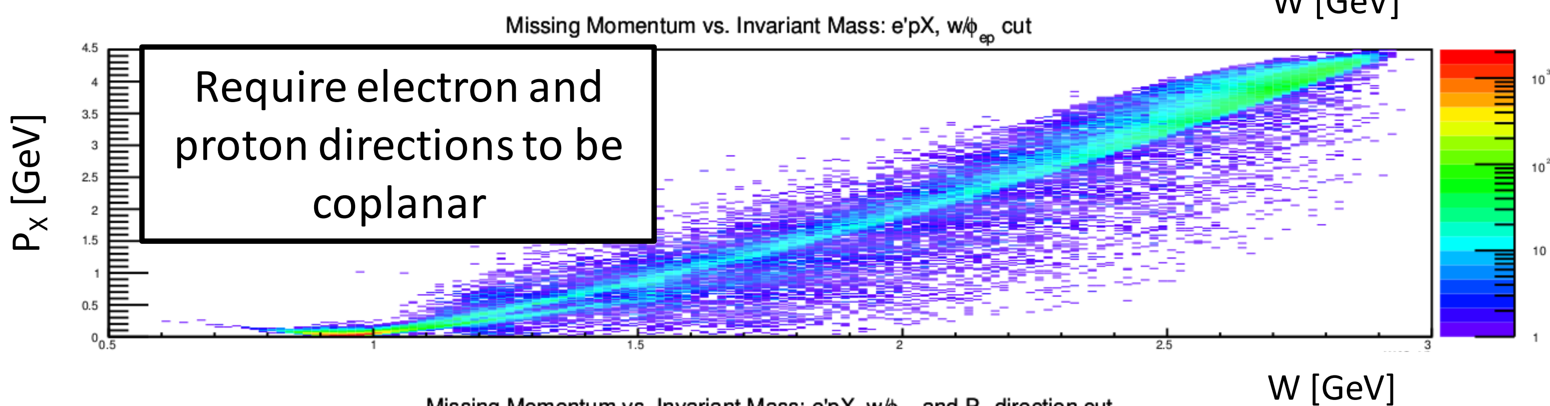
Kinematics: All Good Electron Events

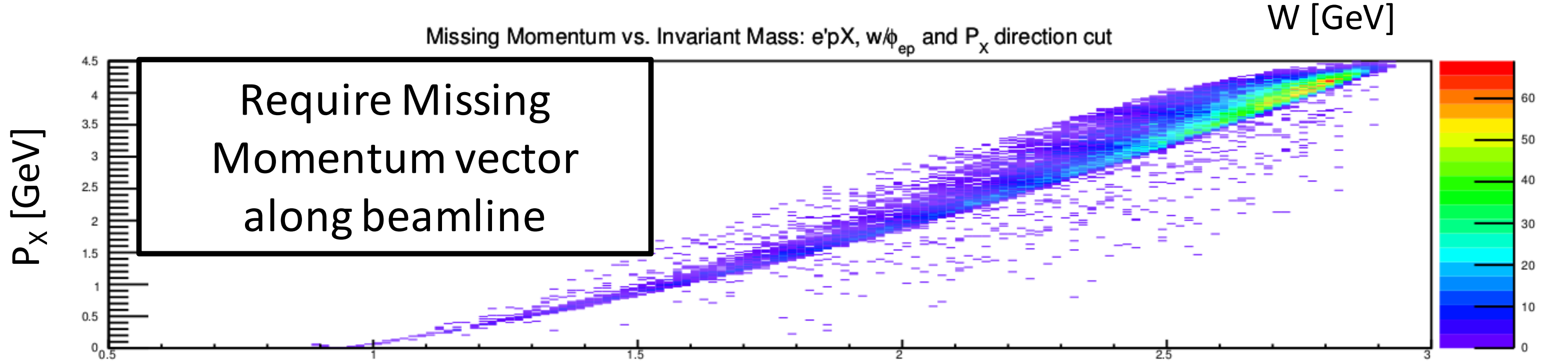




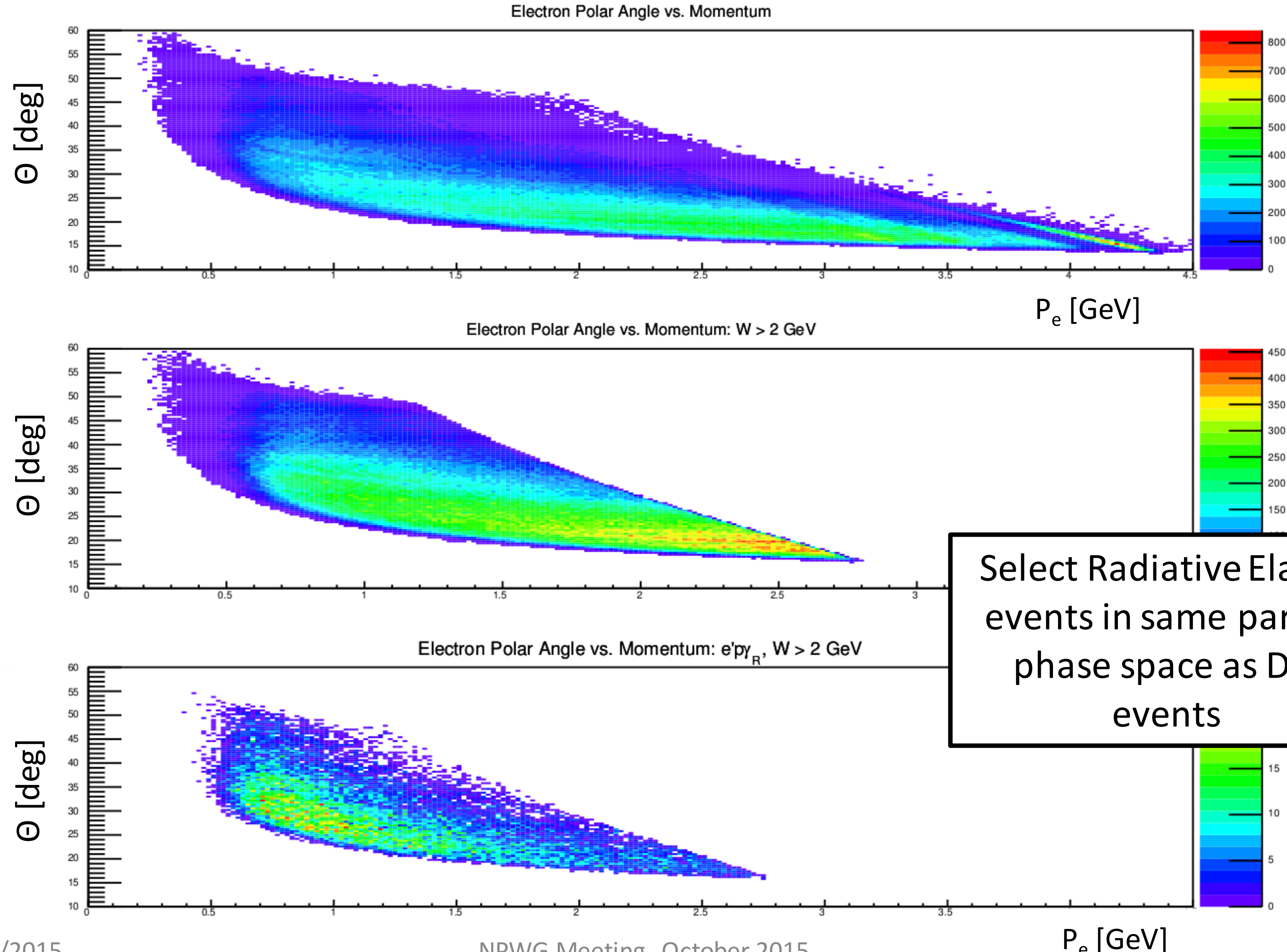
Electron Momentum Corrections





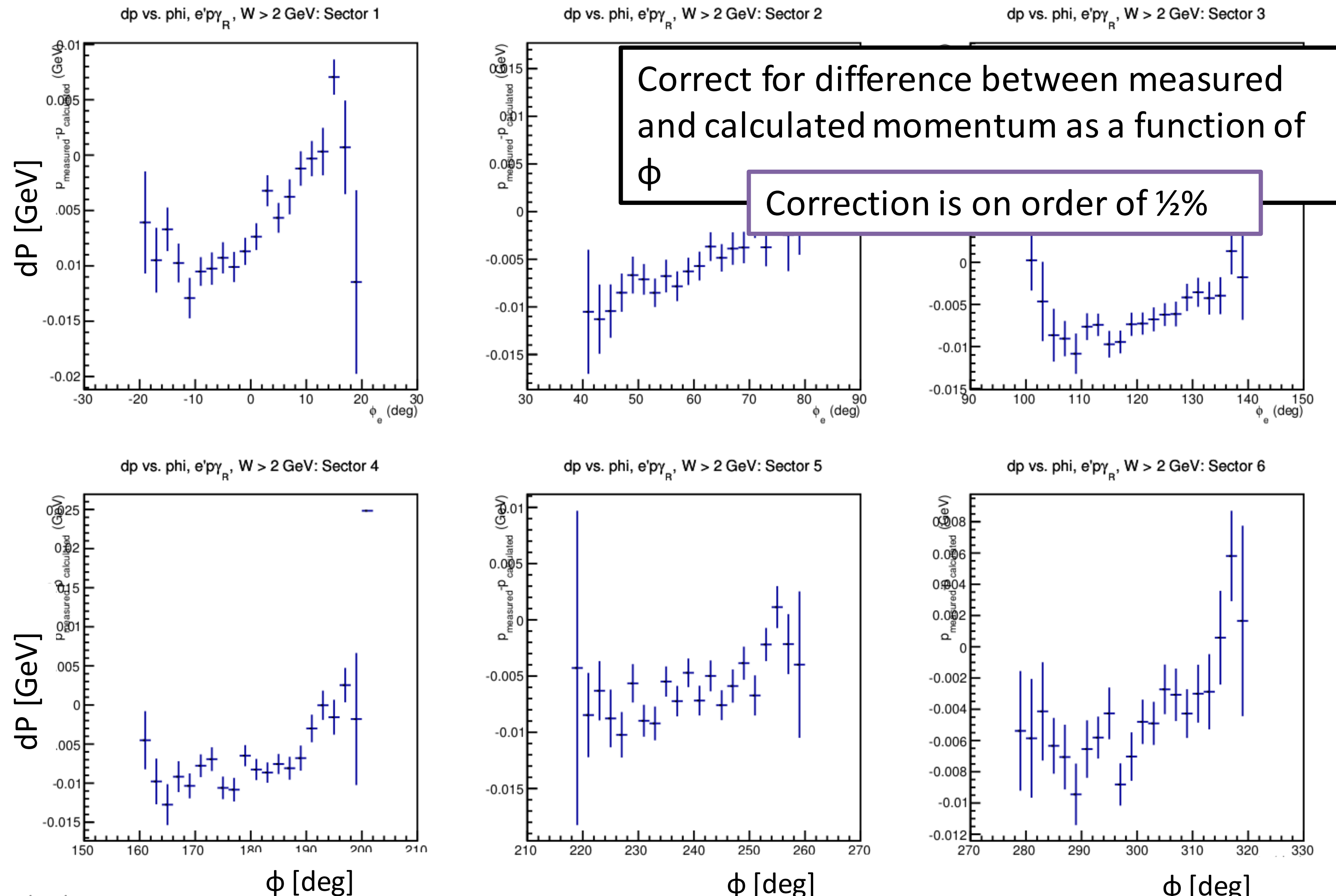


Electron Momentum Corrections



Select Radiative Elastic events in same part of phase space as DIS events

Electron Momentum Corrections

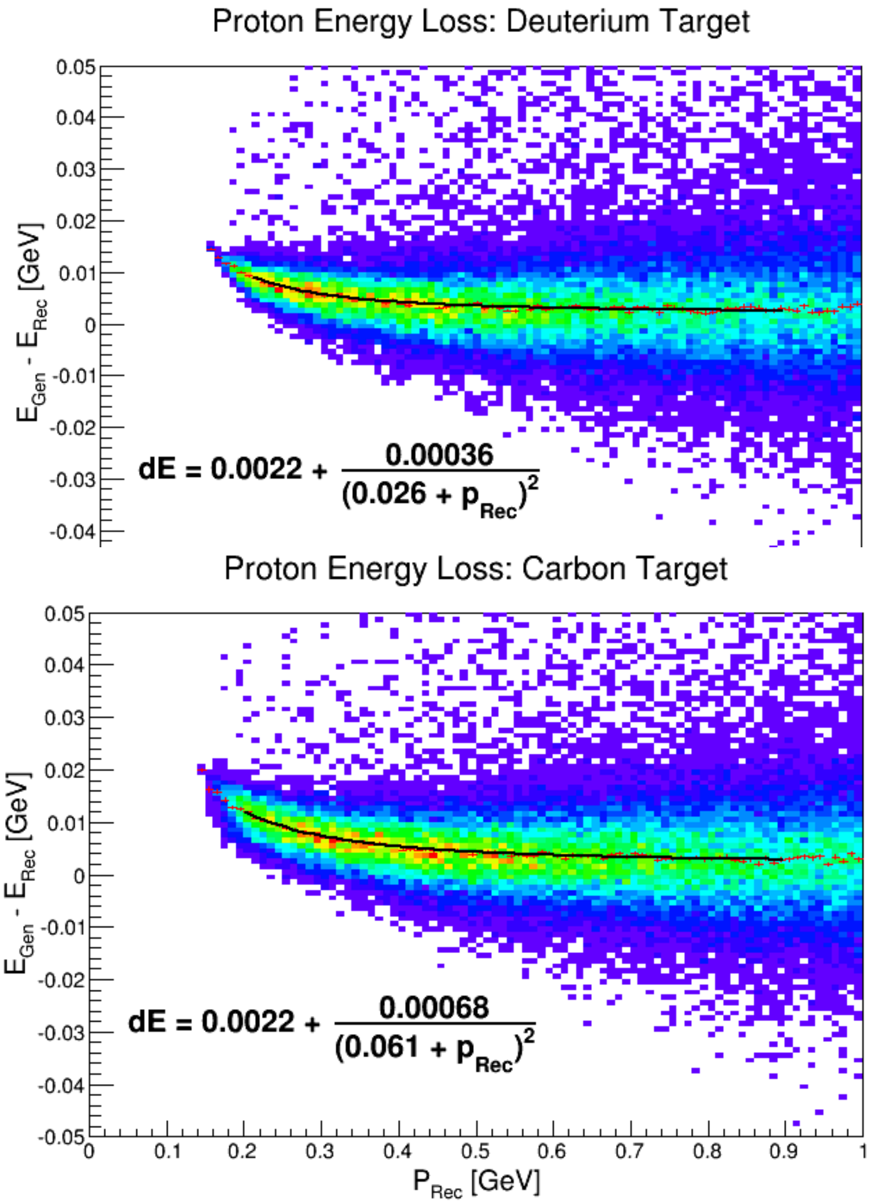


Correct for difference between measured and calculated momentum as a function of φ

Correction is on order of ½%

Proton Momentum Corrections

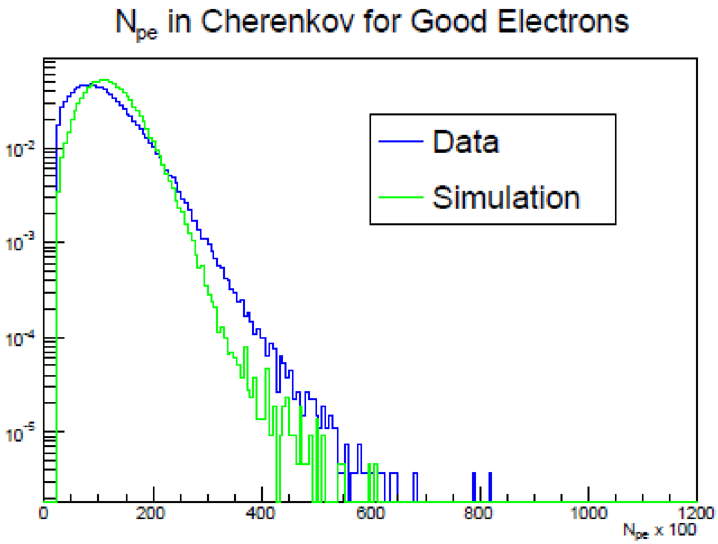
- A correction for the proton energy loss is made using the CLAS Geant3 simulation
- For low energy protons (< 250 MeV/c), there is a large momentum correction; as well as a large uncertainty in the CLAS detection efficiency.

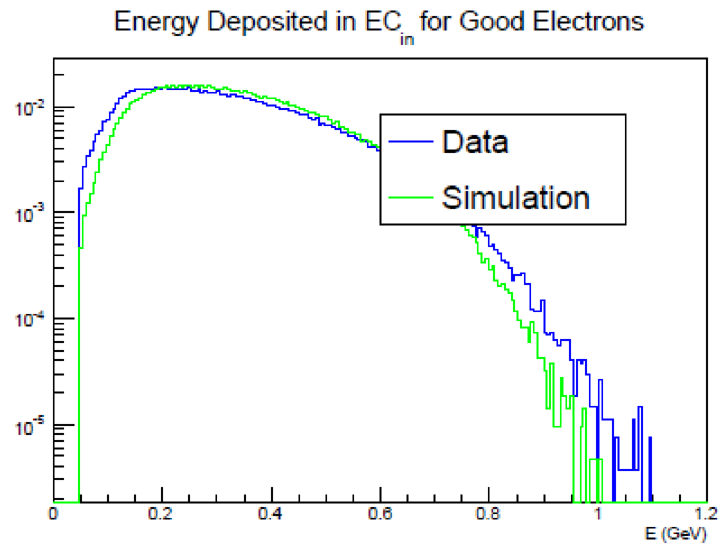


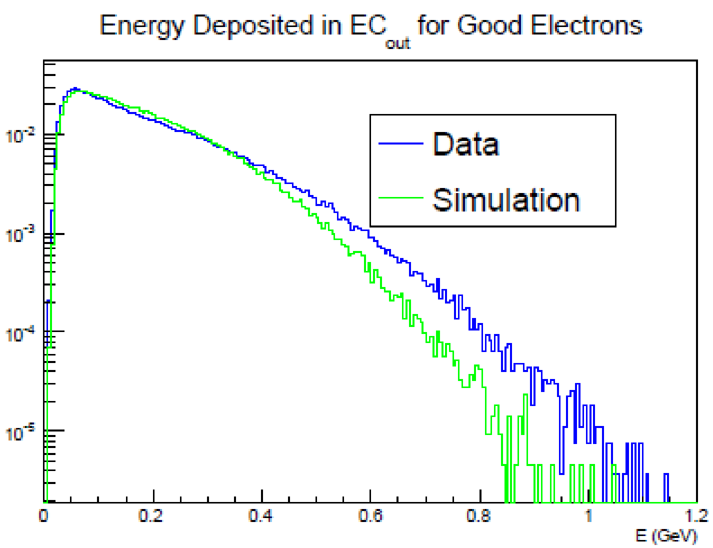
Simulation Studies

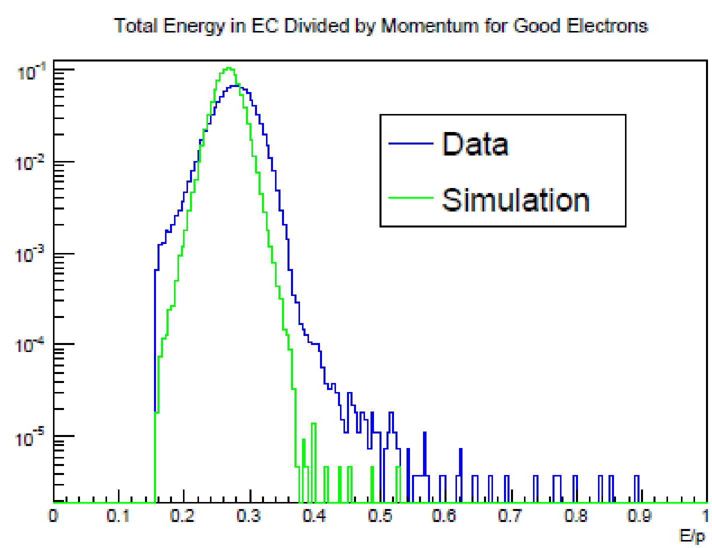
- Acceptance corrections are needed because of the different locations of the solid and liquid targets with respect to CLAS.
- The first step was to compare the detector responses for the simulation and data. We used real data as an input to the simulation to do this
- The next step was to develop acceptance corrections using a DIS event generator (*Lepto*)

Checking the Simulation: Detector Response

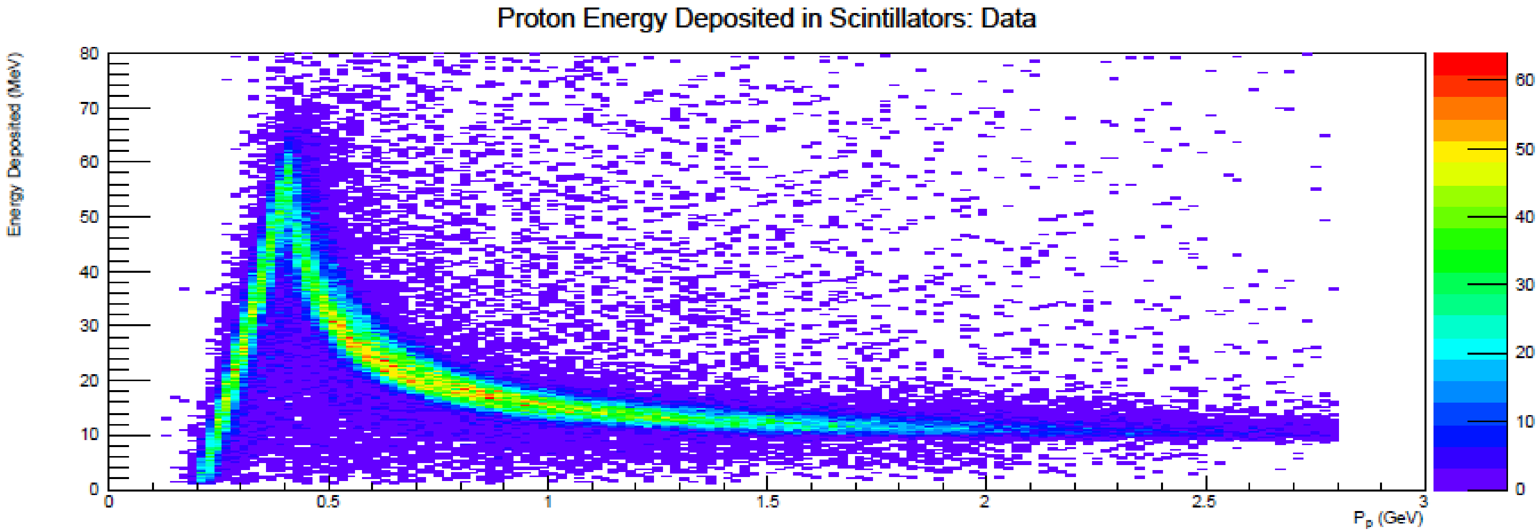


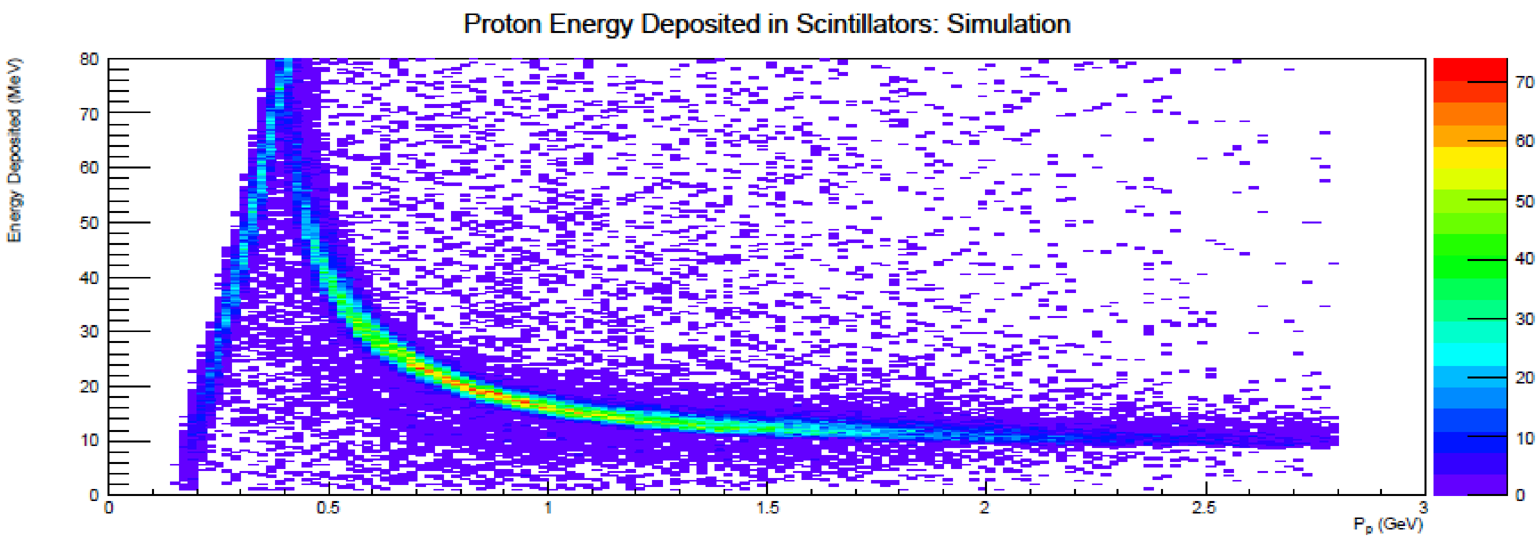




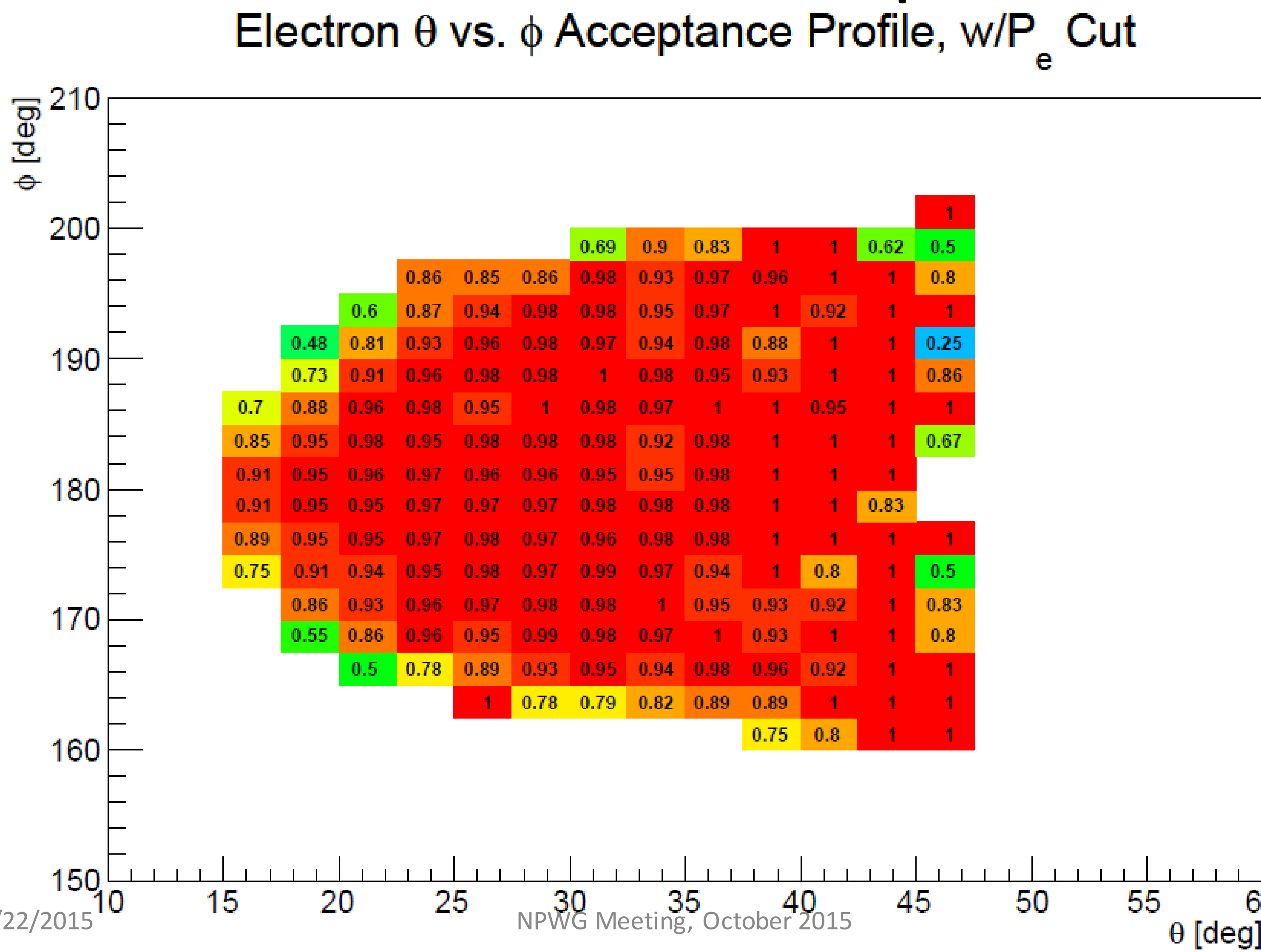


Checking the Simulation: Detector Response





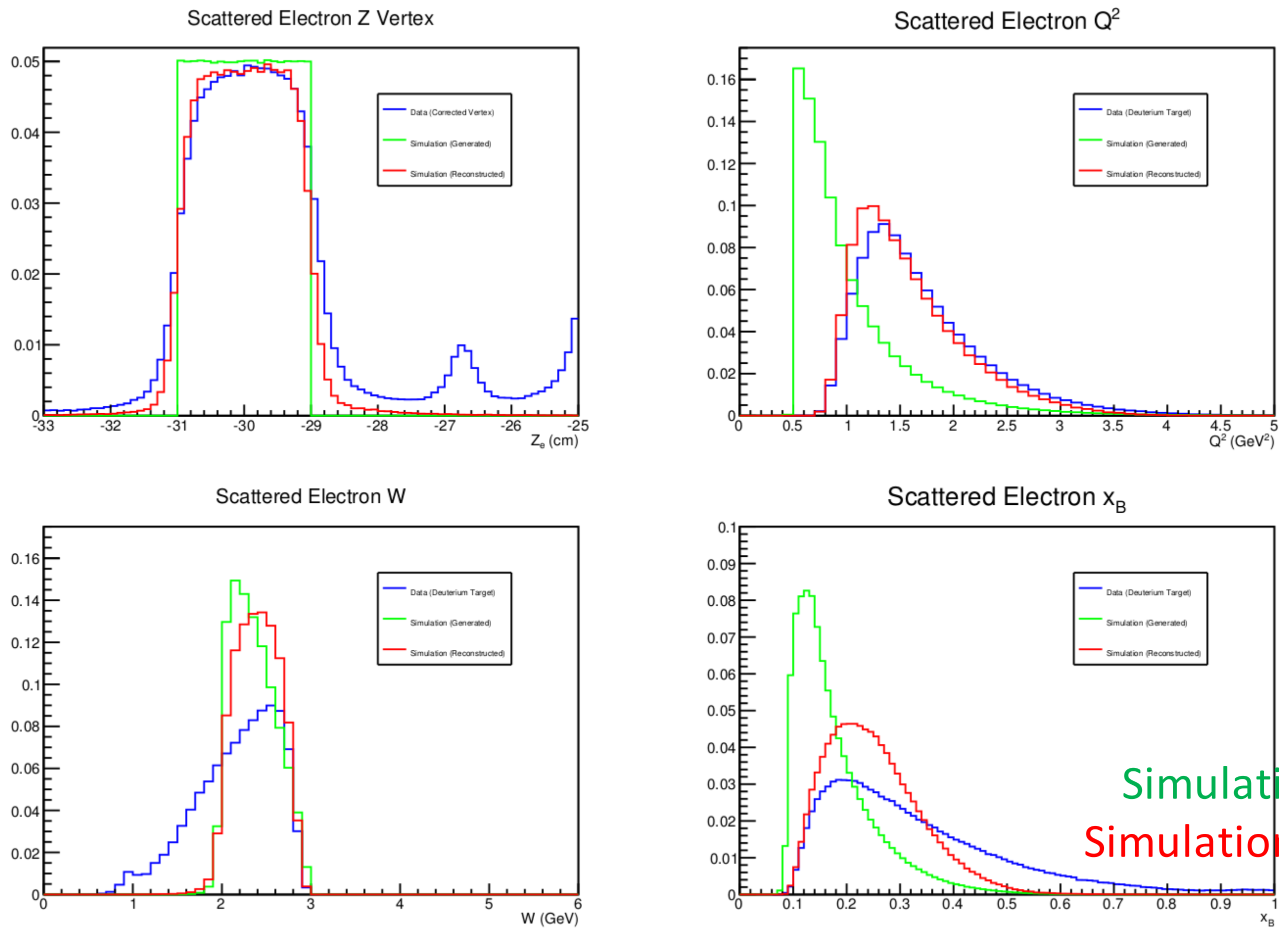
Checking the Simulation: Acceptance with Data as Input



Lepto Event Generator

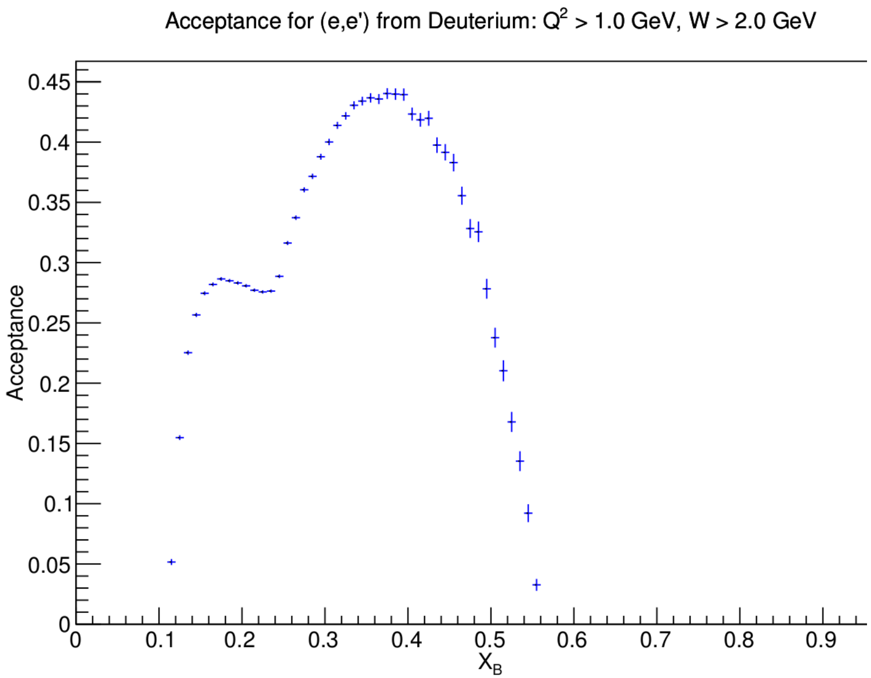
- The *Lepto* event generator is used to simulate complete deep inelastic electron-nucleon scattering events
- The hard interaction is based on standard model electroweak cross-sections
- Parton Showers can be implemented in several ways; hadronization is implemented via *Pythia/Jetset*
- Time was spent to tune parameters to match experimental distributions
- We modified *Lepto* to include a model for the nucleon momentum distribution and the generation of the pair's spectator nucleon

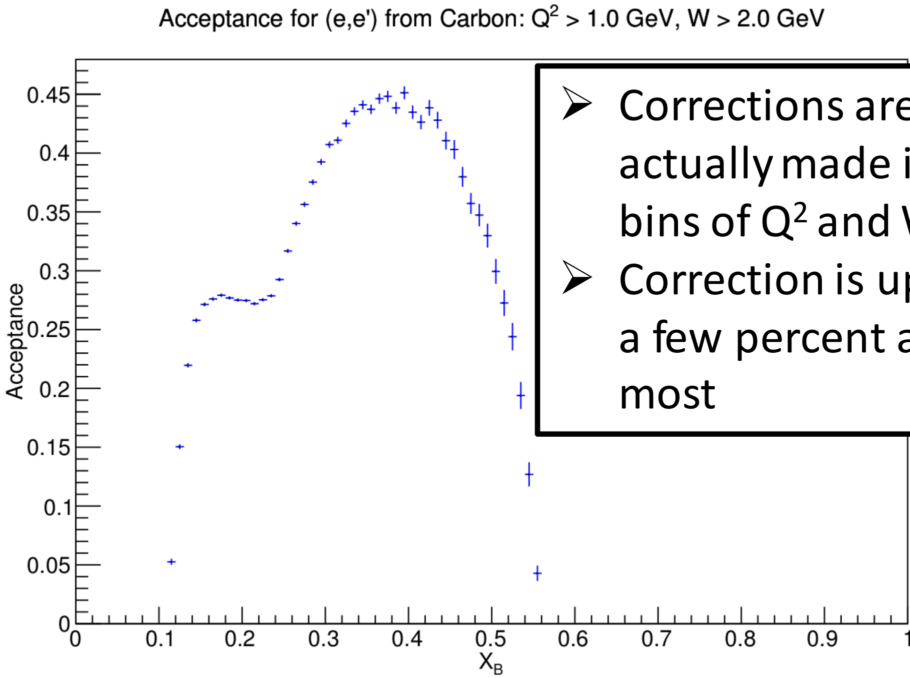
Data/*Lepto* Comparison: Kinematic Distributions



Data
Simulation: Generated
Simulation: Reconstructed

Inclusive Acceptance Corrections





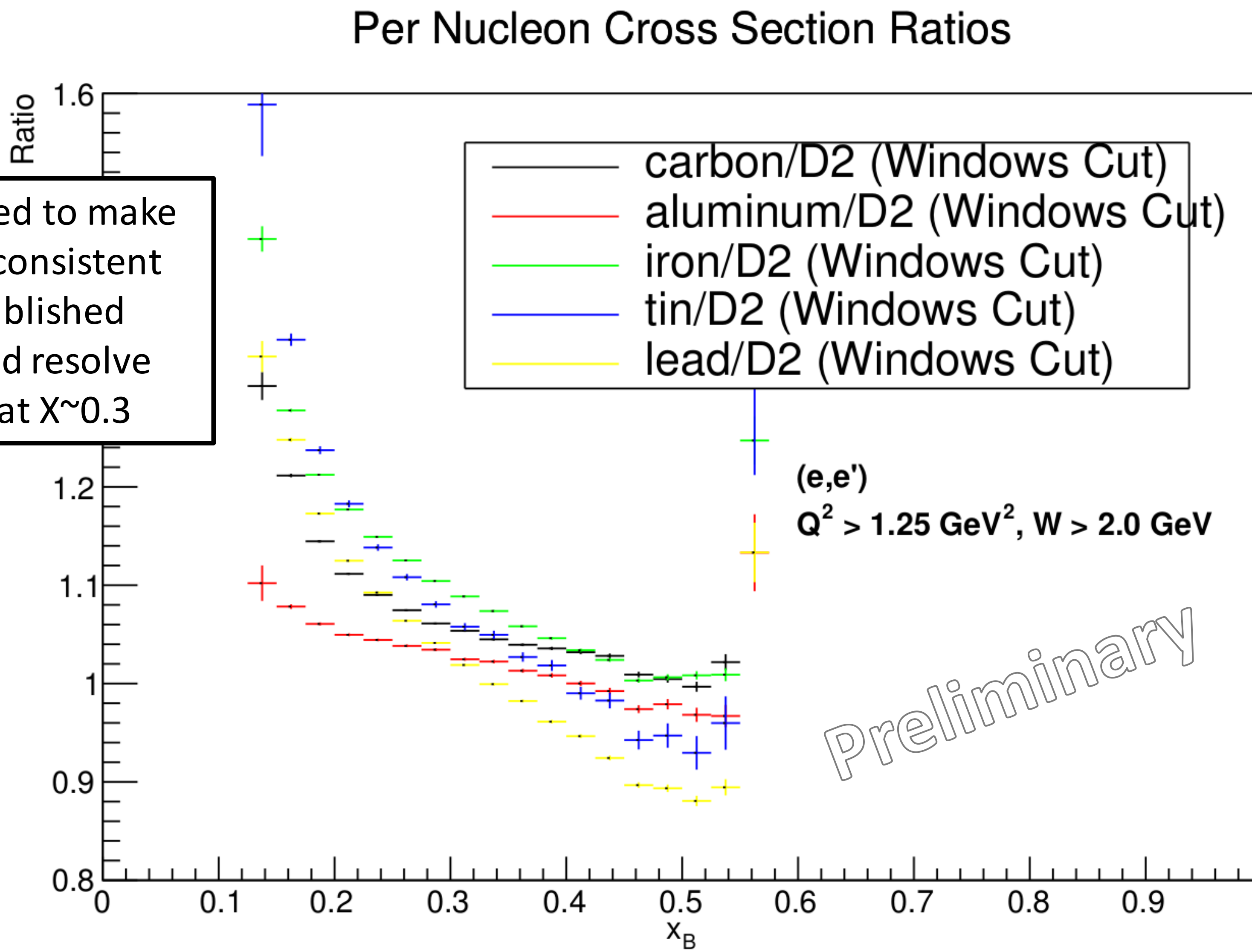
- Corrections are actually made in bins of Q^2 and W
- Correction is up to a few percent at most

Semi-Inclusive corrections are forthcoming…

Inclusive (Traditional) EMC

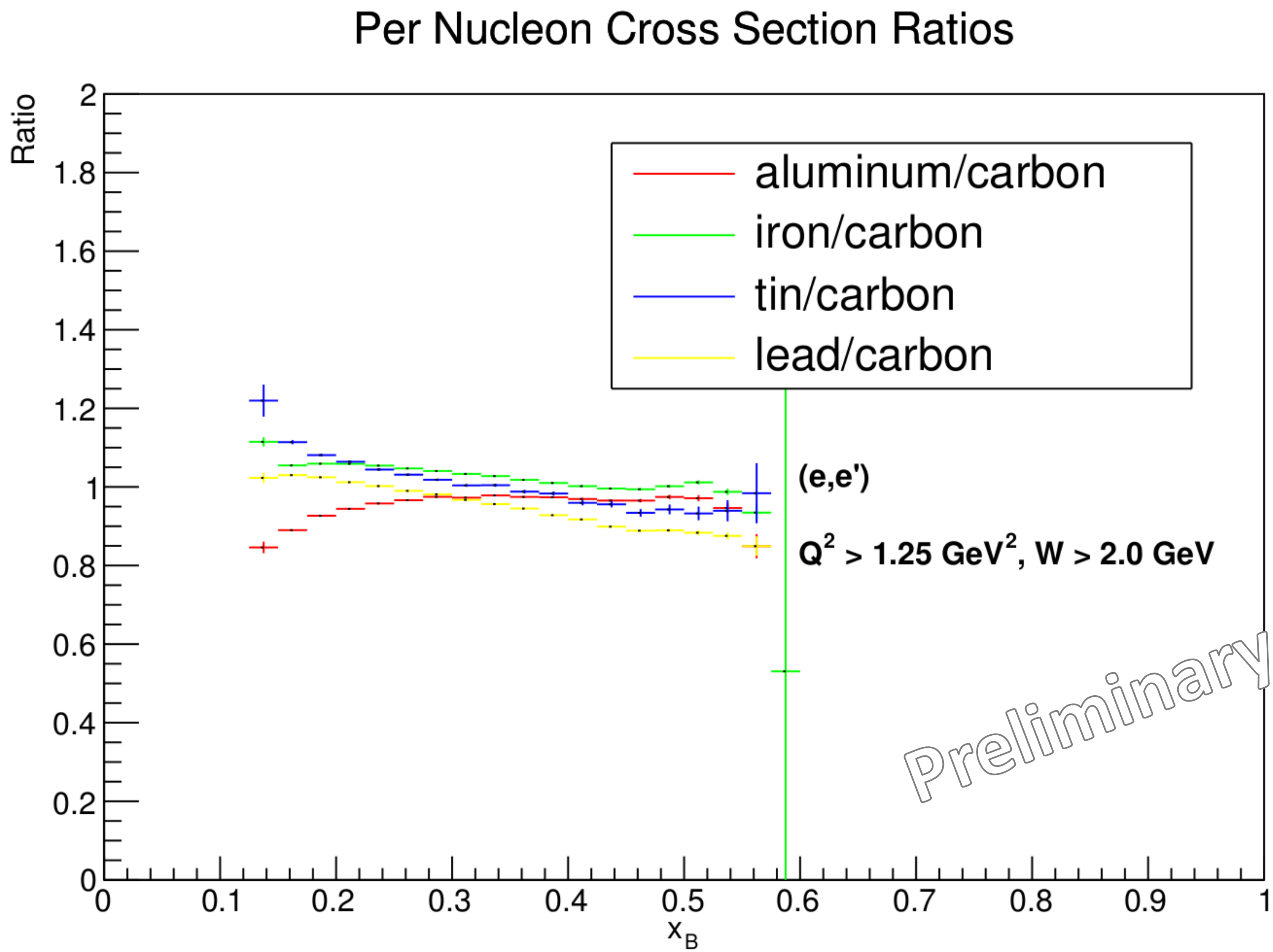
- Data analyzed for ^{12}C, ^{56}Fe, ^{208}Pb, ^{27}Al and ^{119}Sn – and compared to Deuterium.
- Corrections Applied:
  - Cryo-target window removal
  - Electron momentum corrections
  - Acceptance corrections
- Corrections Completed (but not applied):
  - Coulomb Corrections- Using EMA formalism
  - Isoscaler corrections – 1% for Fe, 7.5% for Pb
- Need to Complete:
  - Radiative Corrections
  - Systematic studies

Inclusive (e,e'): Solid to Deuterium Ratios



Will need to make slopes consistent with published data and resolve offsets at X~0.3

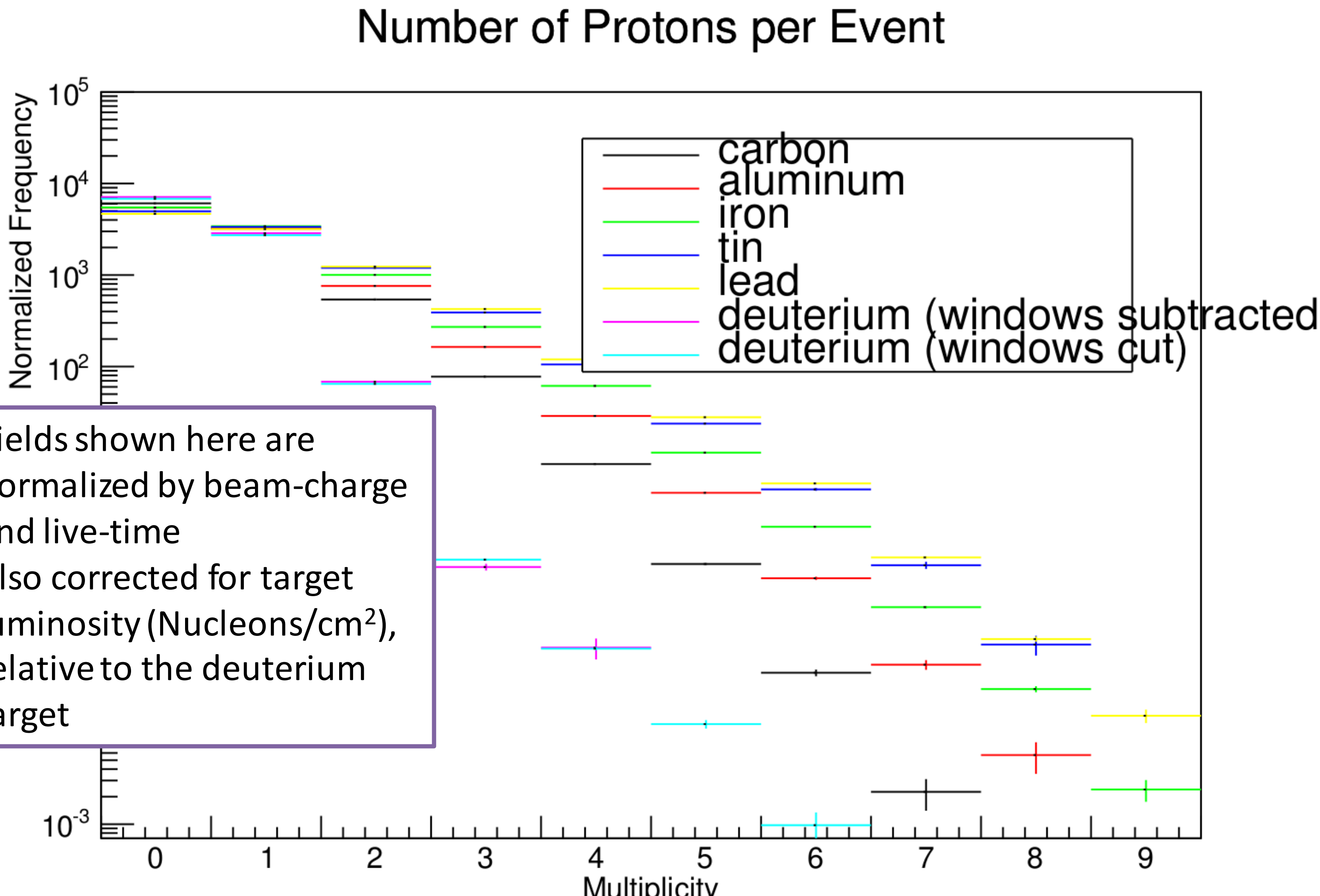
Inclusive (e,e'): Solid to Solid (^{12}C) Ratios



EMC “Tagged” by Backward-Recoiling Protons

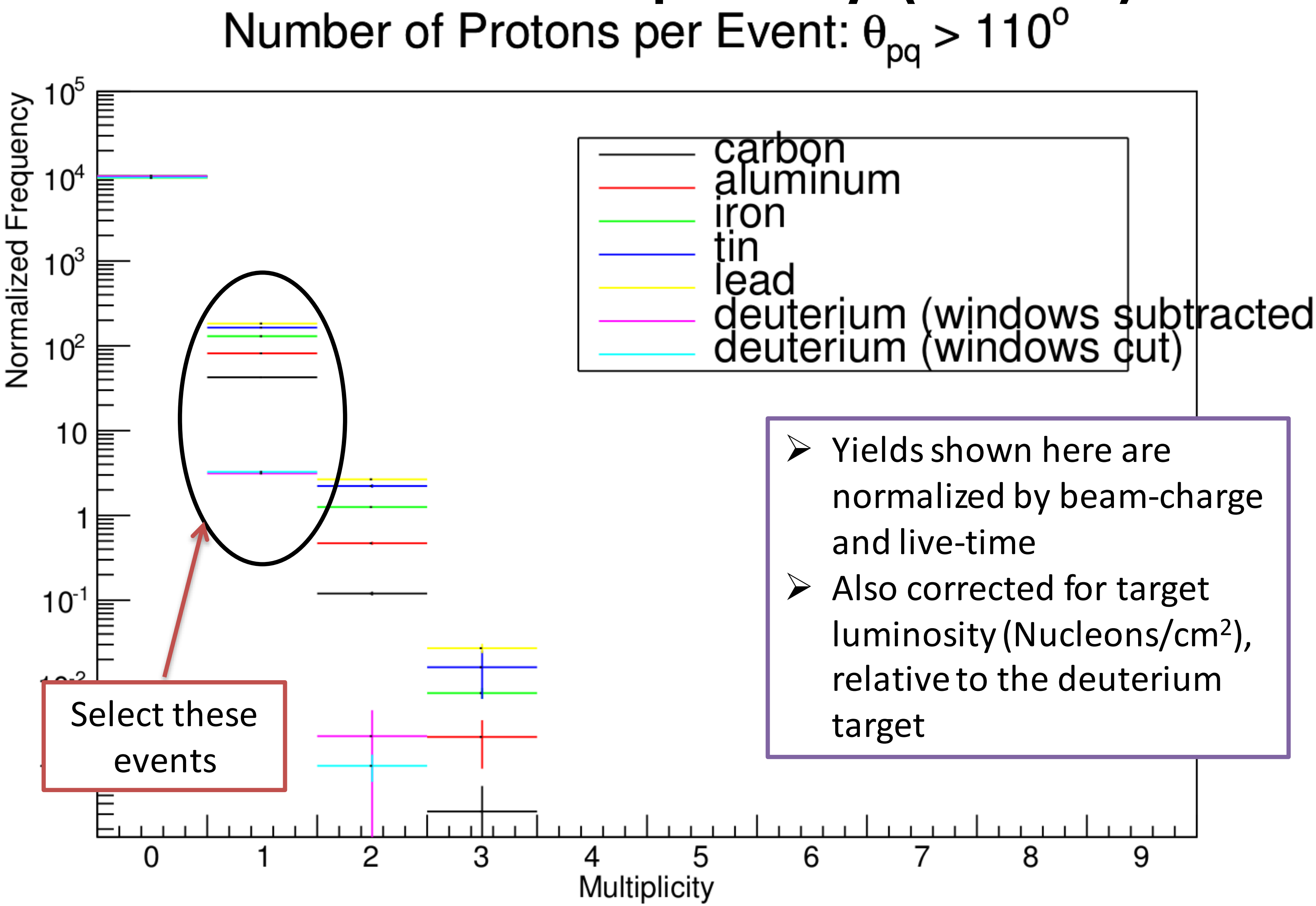
- Corrections Applied:
  - Cryo-target window removal
  - Proton Energy loss correction (small effect above 300 MeV/c)
- Corrections Completed (but not applied):
  - Coulomb Corrections
  - Effect of pp pairs - ~20%, momentum dependent?
- Need to Complete:
  - Acceptance Corrections
  - Radiative Corrections
  - Isoscaler corrections for “tagged”
  - Nuclear transparency
  - Systematic uncertainties

Proton Multiplicity



- Yields shown here are normalized by beam-charge and live-time
- Also corrected for target luminosity (Nucleons/cm^2), relative to the deuterium target

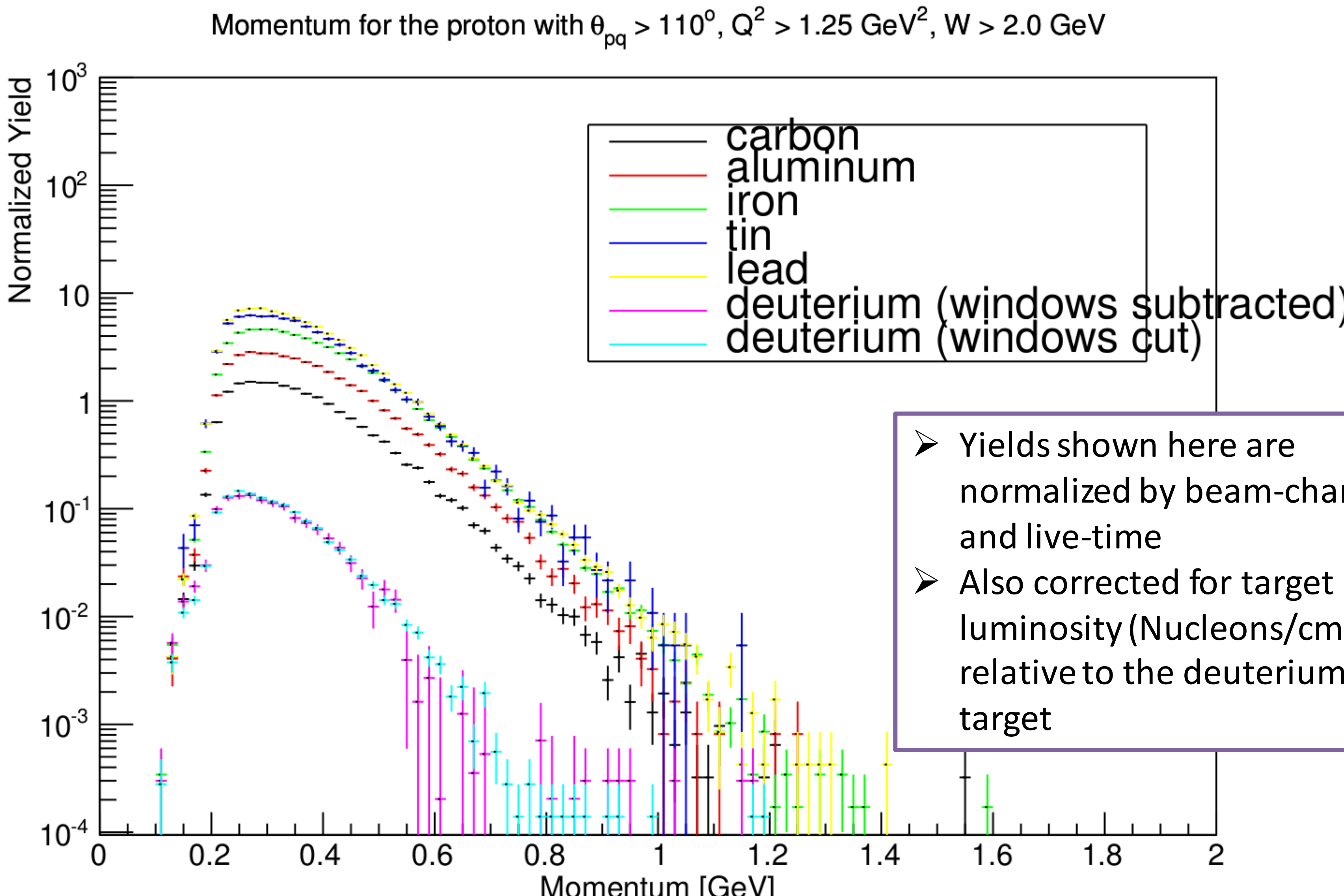
Proton Multiplicity (cont.)



Select these events

- Yields shown here are normalized by beam-charge and live-time
- Also corrected for target luminosity (Nucleons/cm^2), relative to the deuterium target

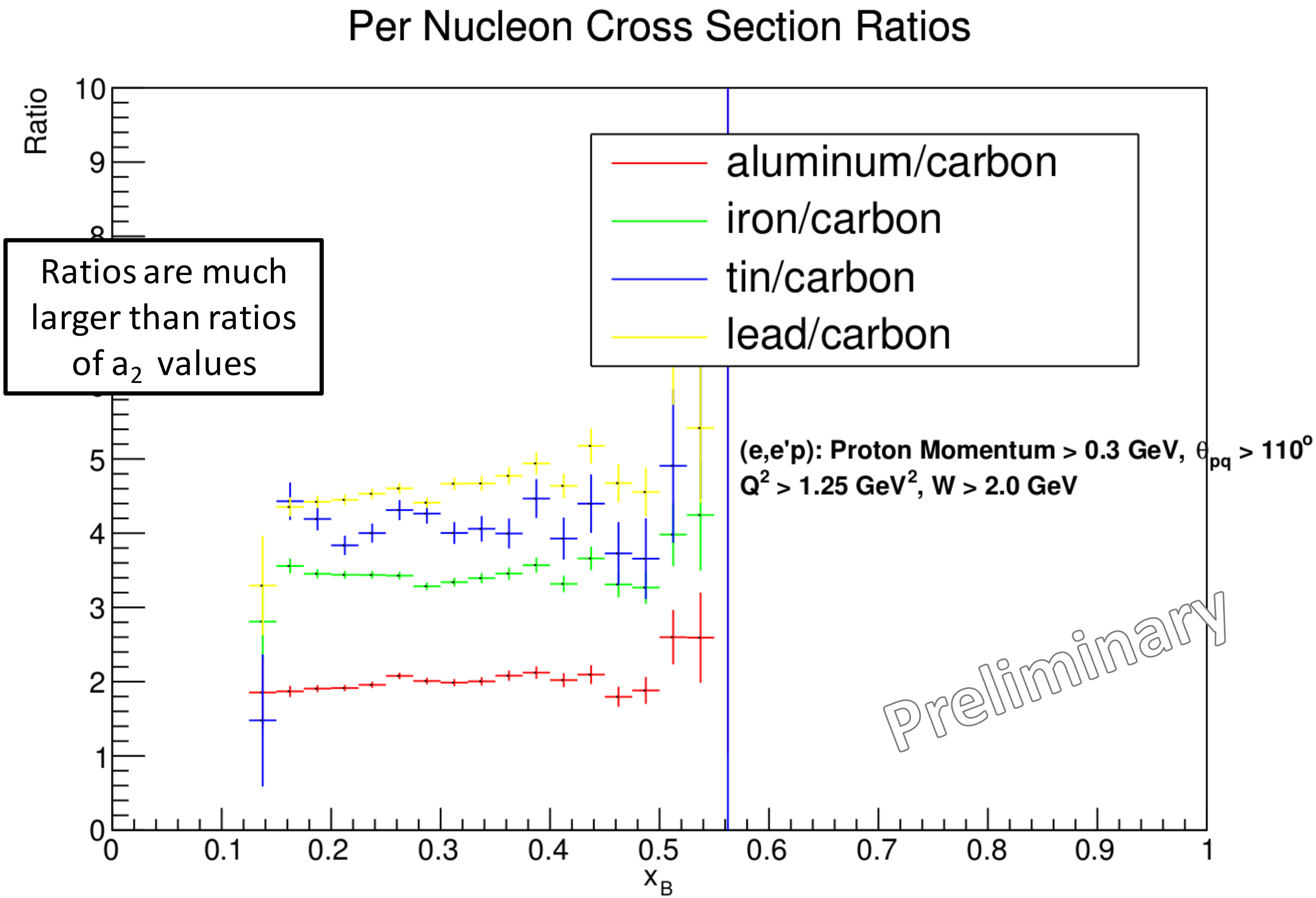
Proton Momentum Distributions



- Yields shown here are normalized by beam-charge and live-time
- Also corrected for target luminosity (Nucleons/cm^2), relative to the deuterium target

Semi-Inclusive (e,e'p): Solid to Solid (^{12}C) Ratios

Ratios are much larger than ratios of a_2 values

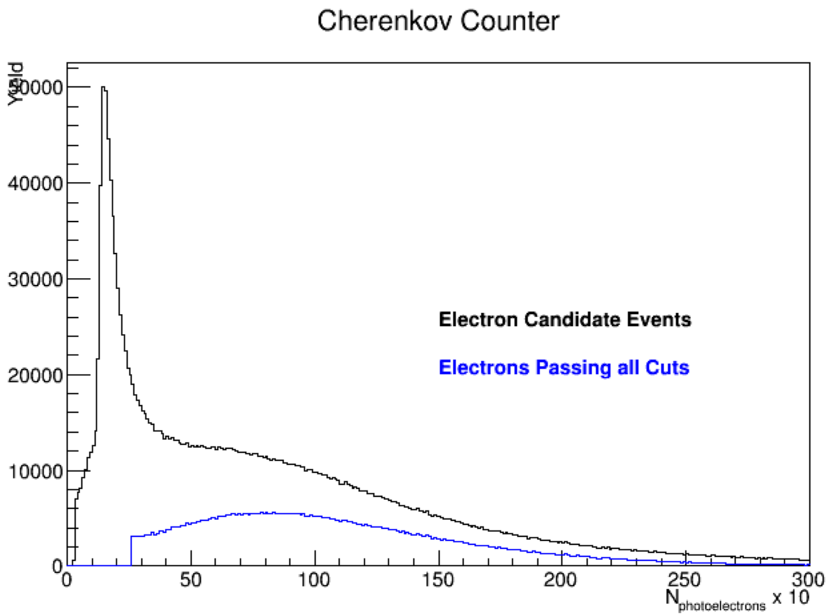


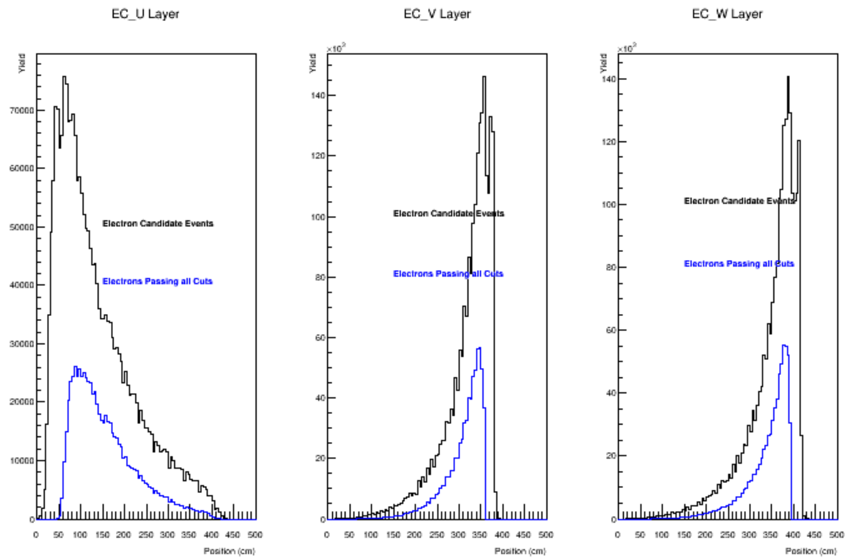
Conclusions

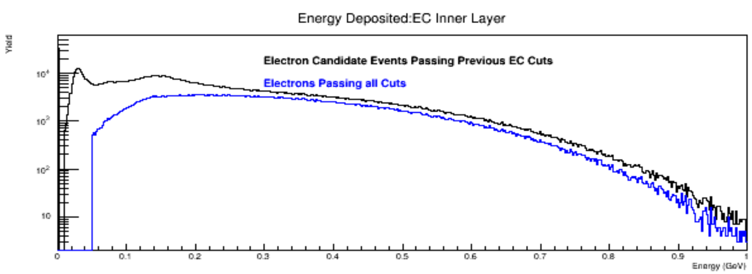
- Inclusive results are close to completion. Ratios are consistent with unity and display EMC behavior. But some work is still needed to match published data.
- Semi-Inclusive (“Tagged”) results are quite surprising.
  - Not corrected for acceptance (early studies suggest it might be large >35%), but this won’t effect solid-to-solid ratios
  - Are there potential background effects not being taken into account?

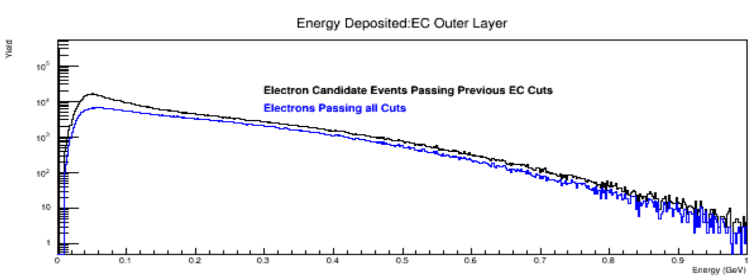
Additional Slides

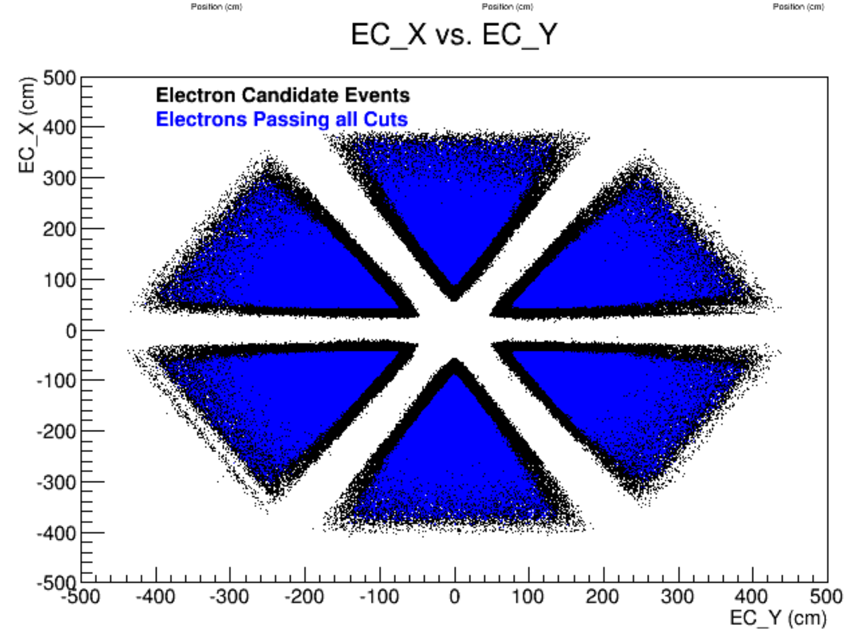
Electron Particle ID





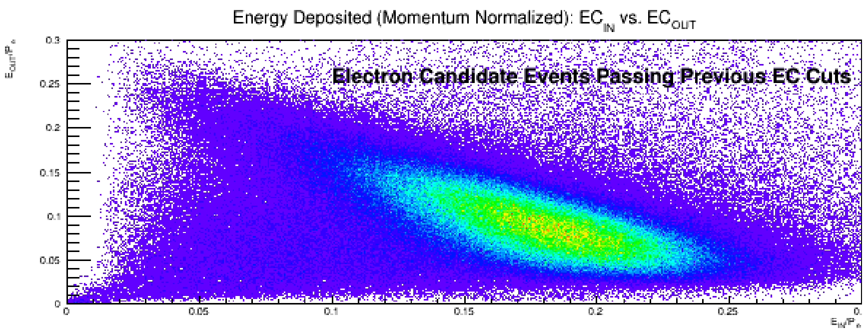


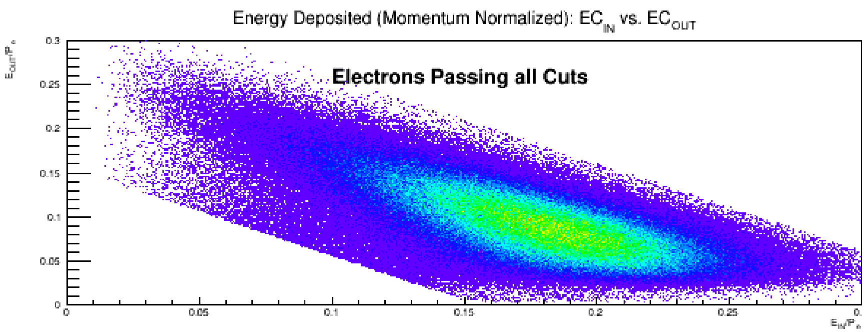


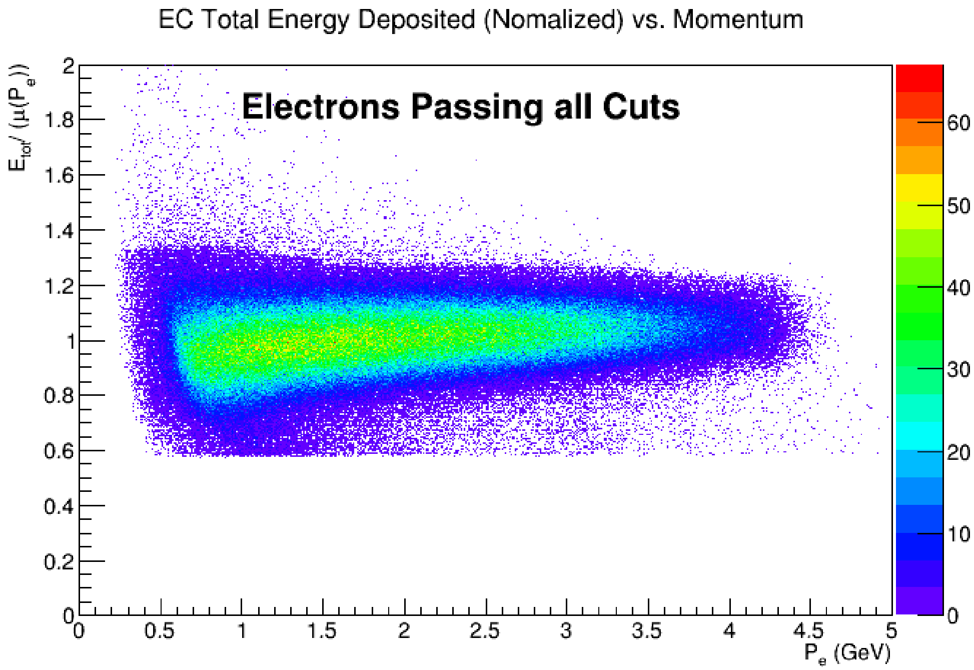


in

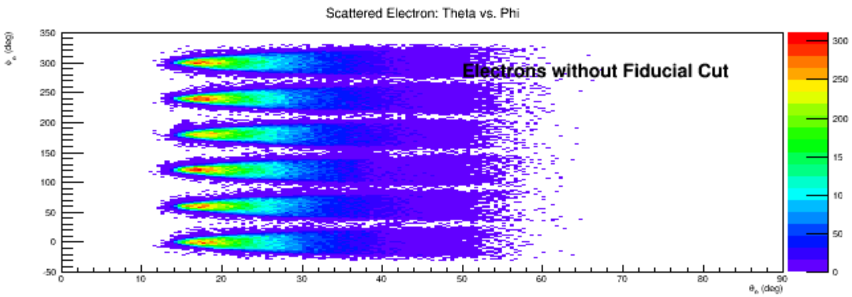
Electron Particle ID (cont.)

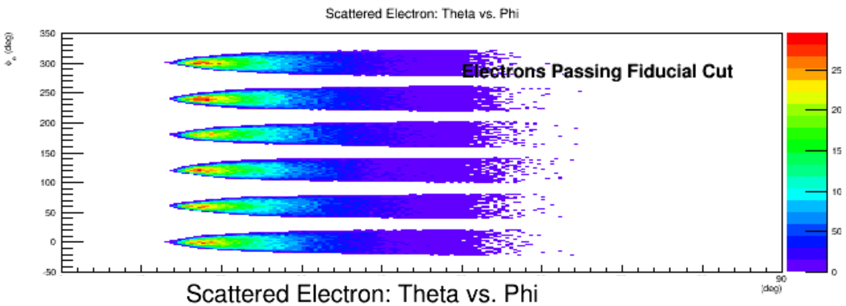


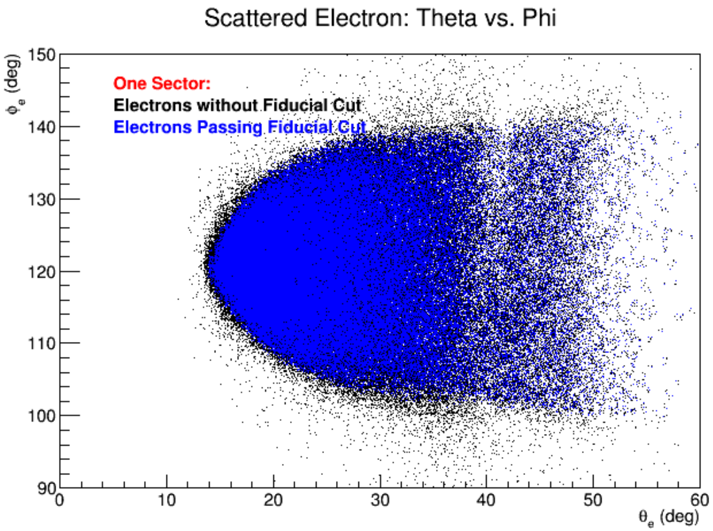


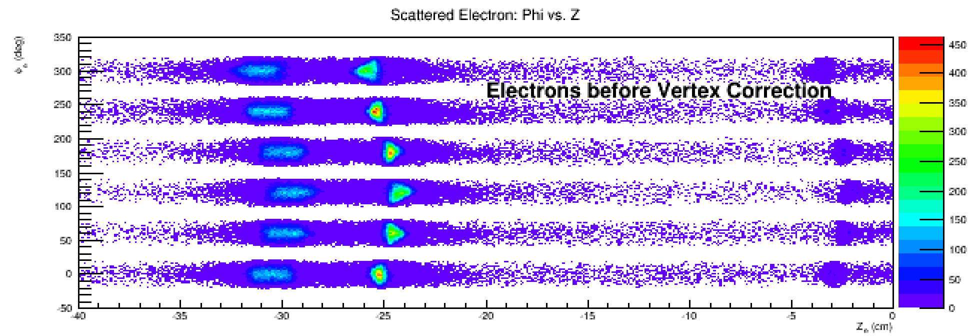


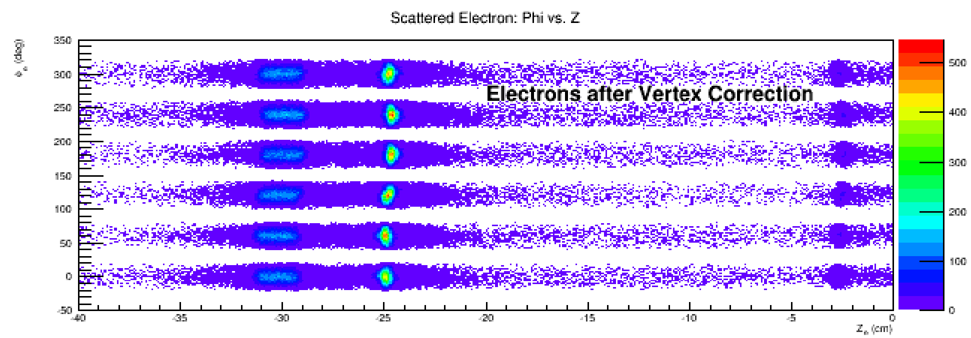
Electron Fiducial Cuts/ Vertex Corrections



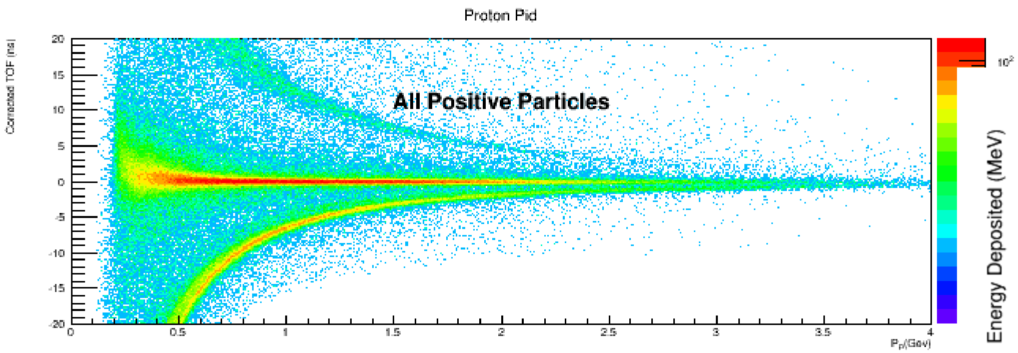


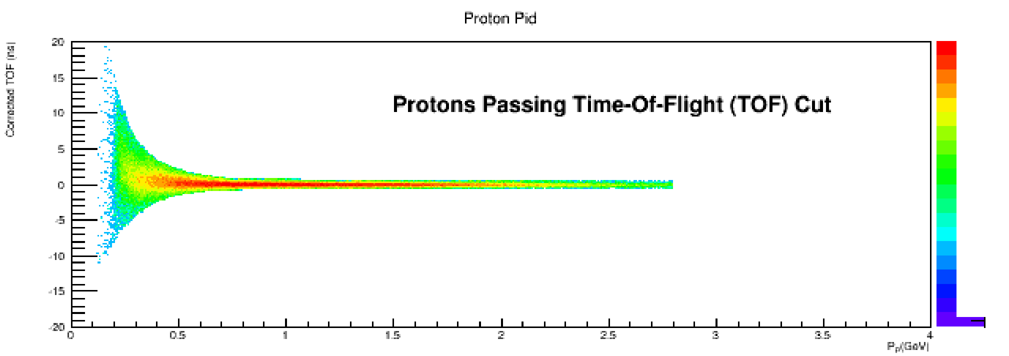


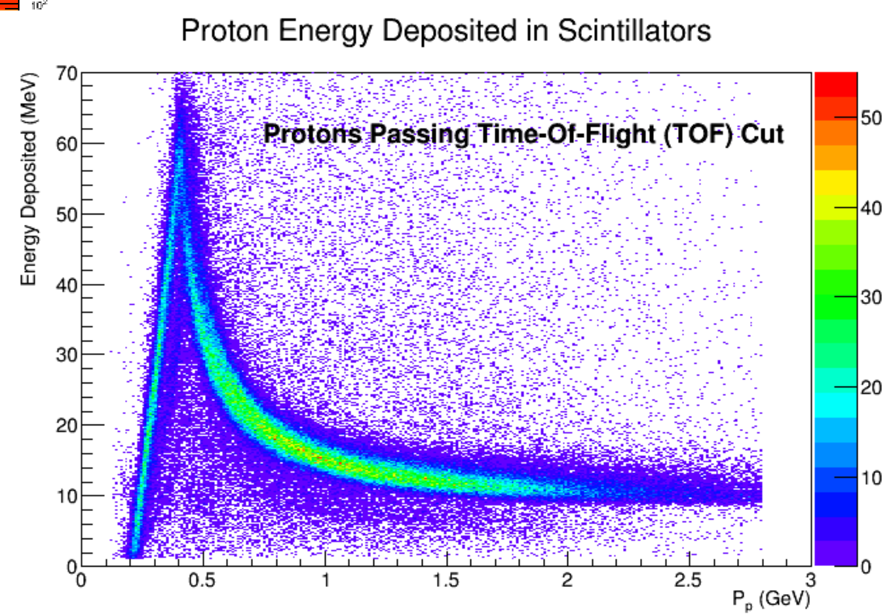




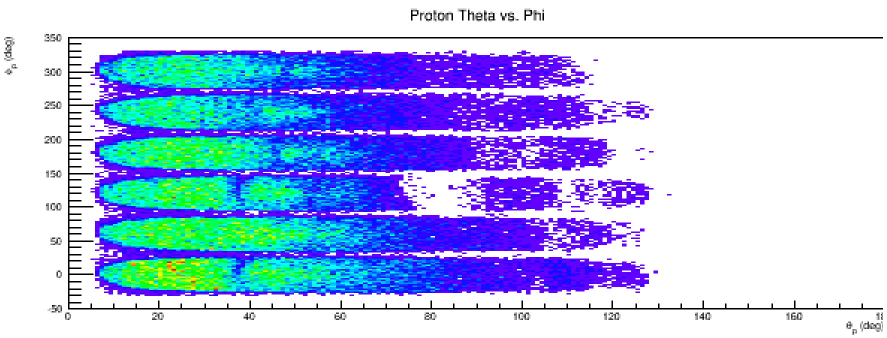
Proton Particle ID

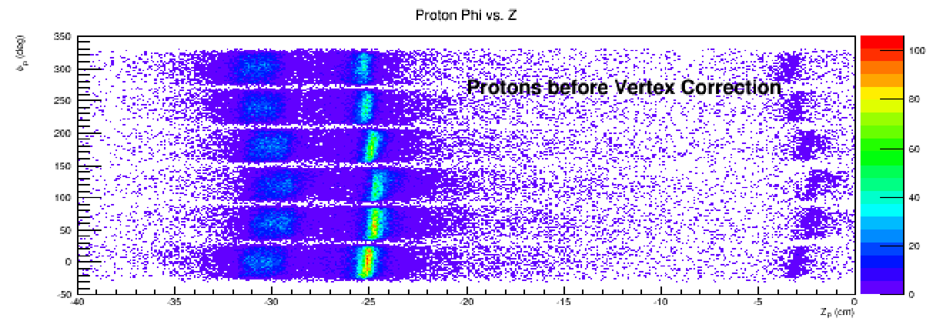


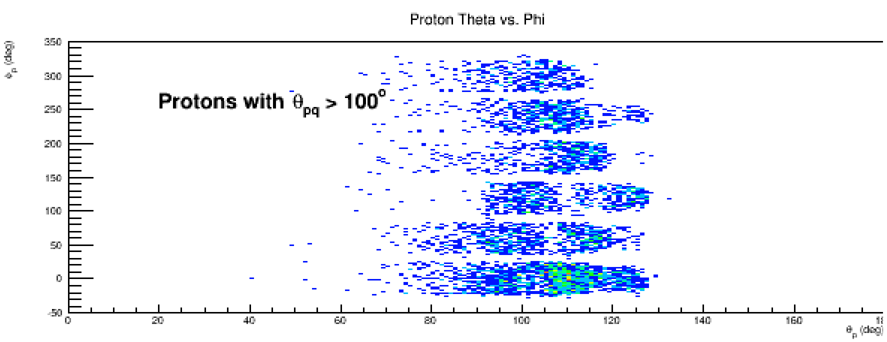


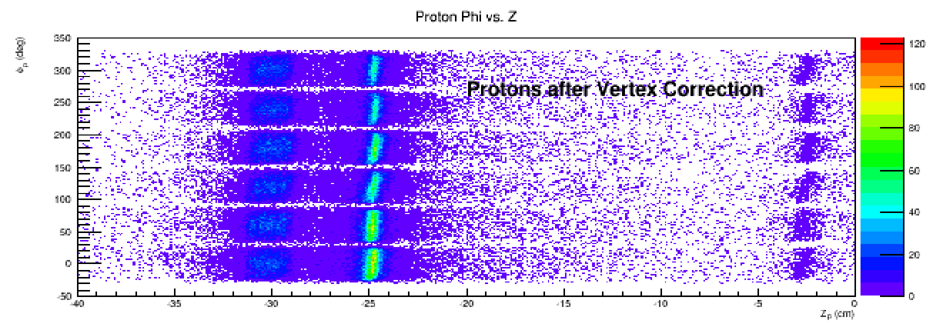


Proton Fiducial Cuts/ Vertex Corrections

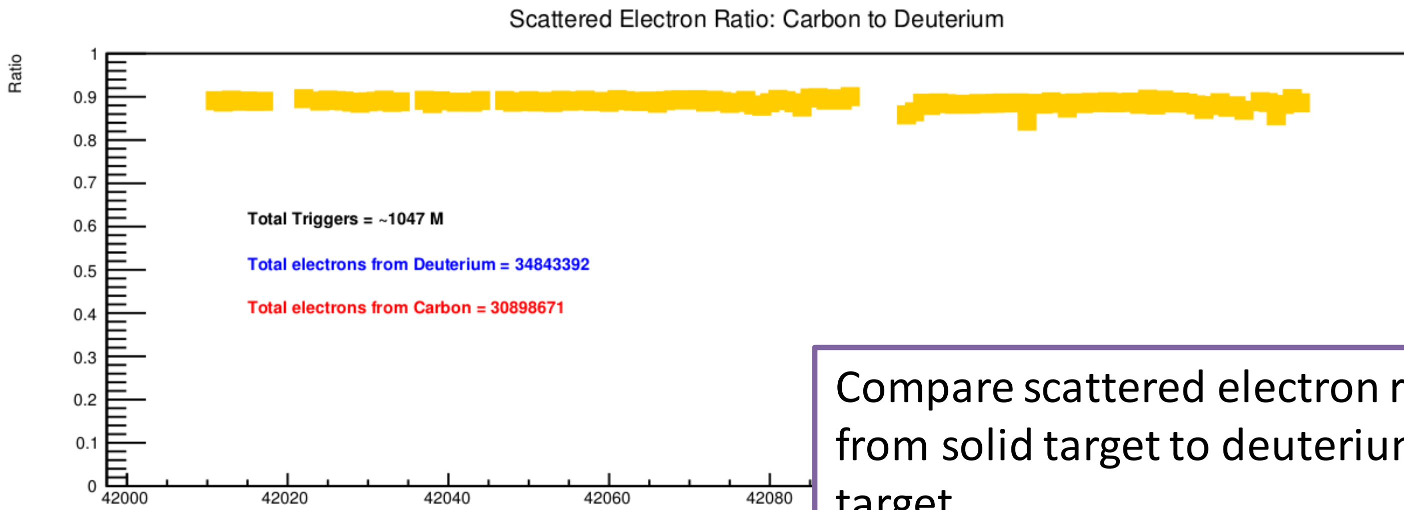




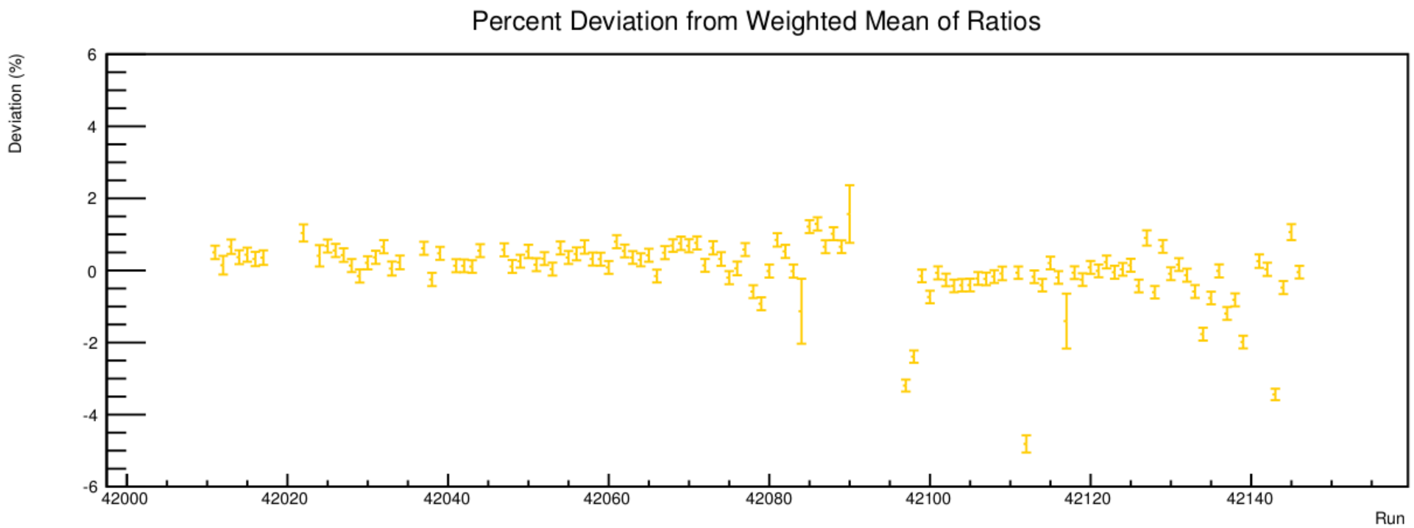




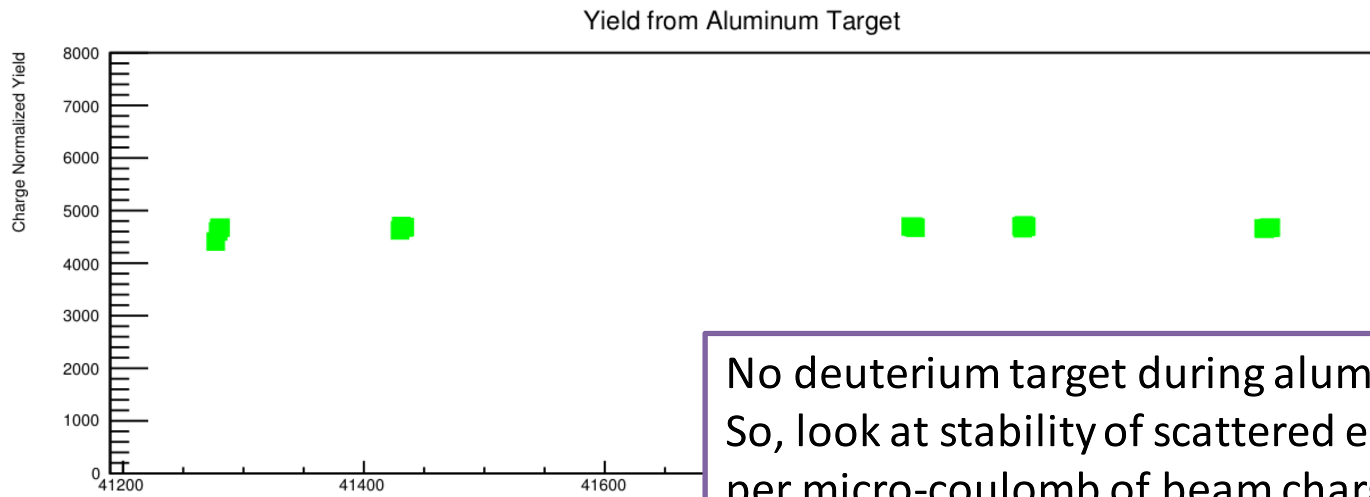
Data Quality Checks: C, Fe, Sn, Pb



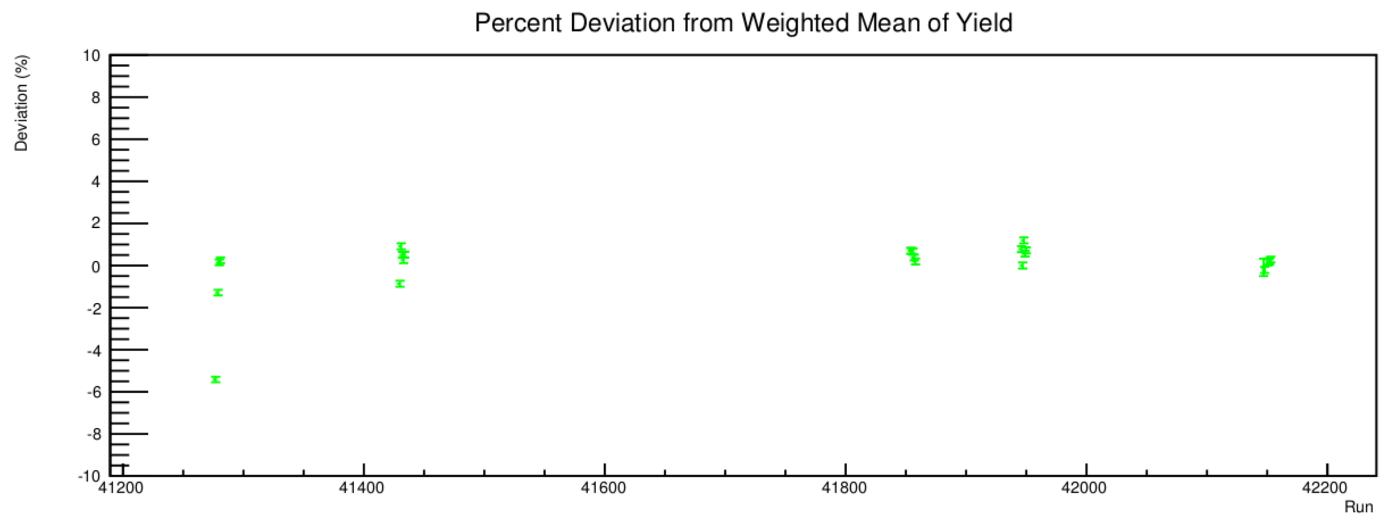
Compare scattered electron ratio from solid target to deuterium target



Data Quality Checks: Aluminum



No deuterium target during aluminum runs…
So, look at stability of scattered electron yield per micro-coulomb of beam charge



Simulation: Nucleon Momentum Distributions

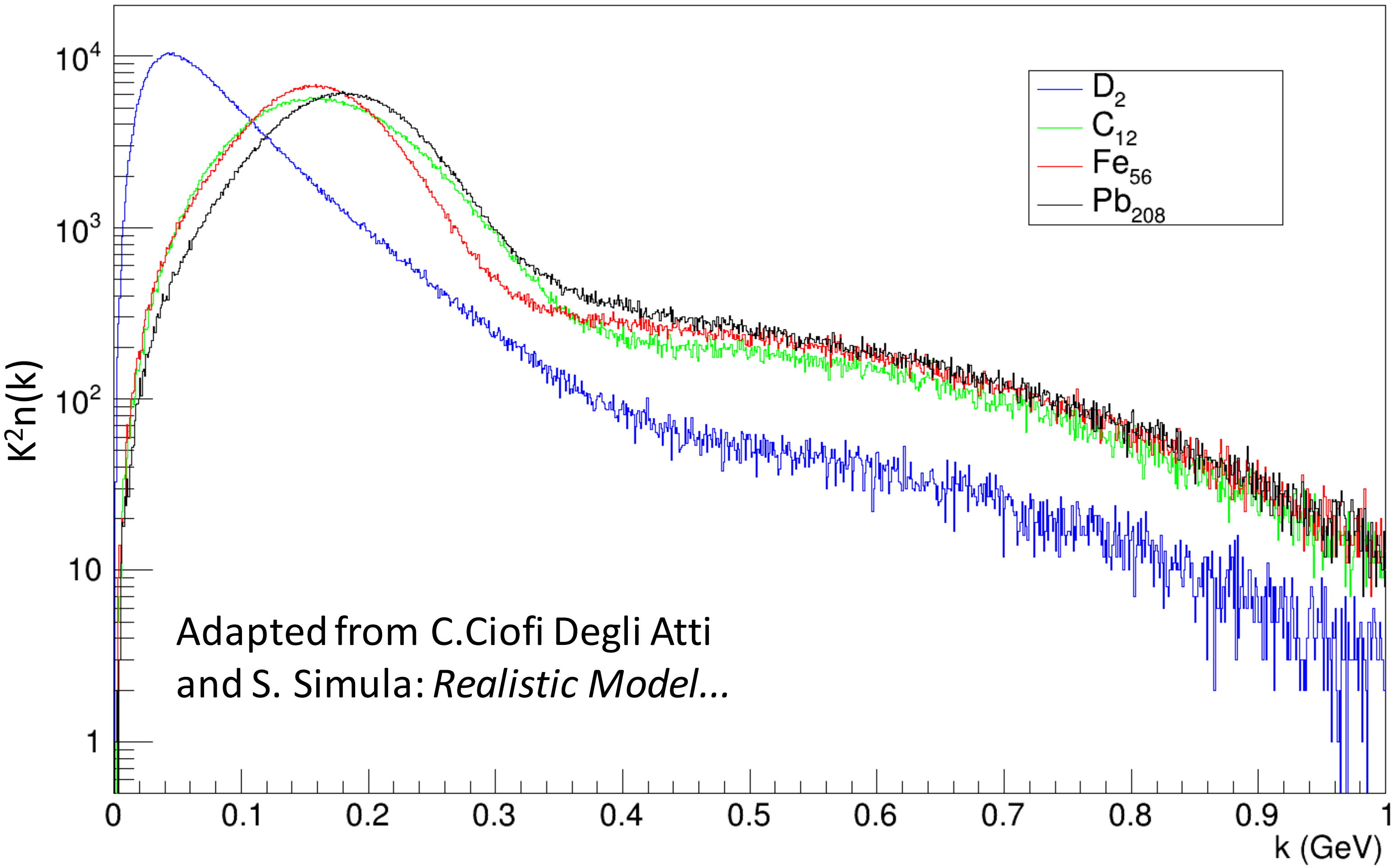
- Nucleon momentum distribution:

$$n(k)=n_0(k)+n_1(k)$$

- n_0 takes into account the mean-field picture and n_1 is included if NN correlations are considered
- Calculation for various nuclei has been performed.
- The distribution is normalized to

$$\int_0^{\infty} dk\, k^2 n(k) = 1$$

Nucleon Momentum Distributions



Simulation: Generating the Spectator Nucleon

- Event Generator was modified to place nucleons in SRC pairs above the Fermi Momentum
- A spectator nucleon is generated when the struck nucleon has sufficient initial momentum
- The spectator nucleon has momentum opposite the struck nucleon in the pair's center of mass frame
- For the solid targets, n-p pairs are generated 95% of the time. The pair center of mass momentum components are sampled from Gaussian distributions with σ = 110MeV/c.

Simulation: Inclusive Acceptance Corrections