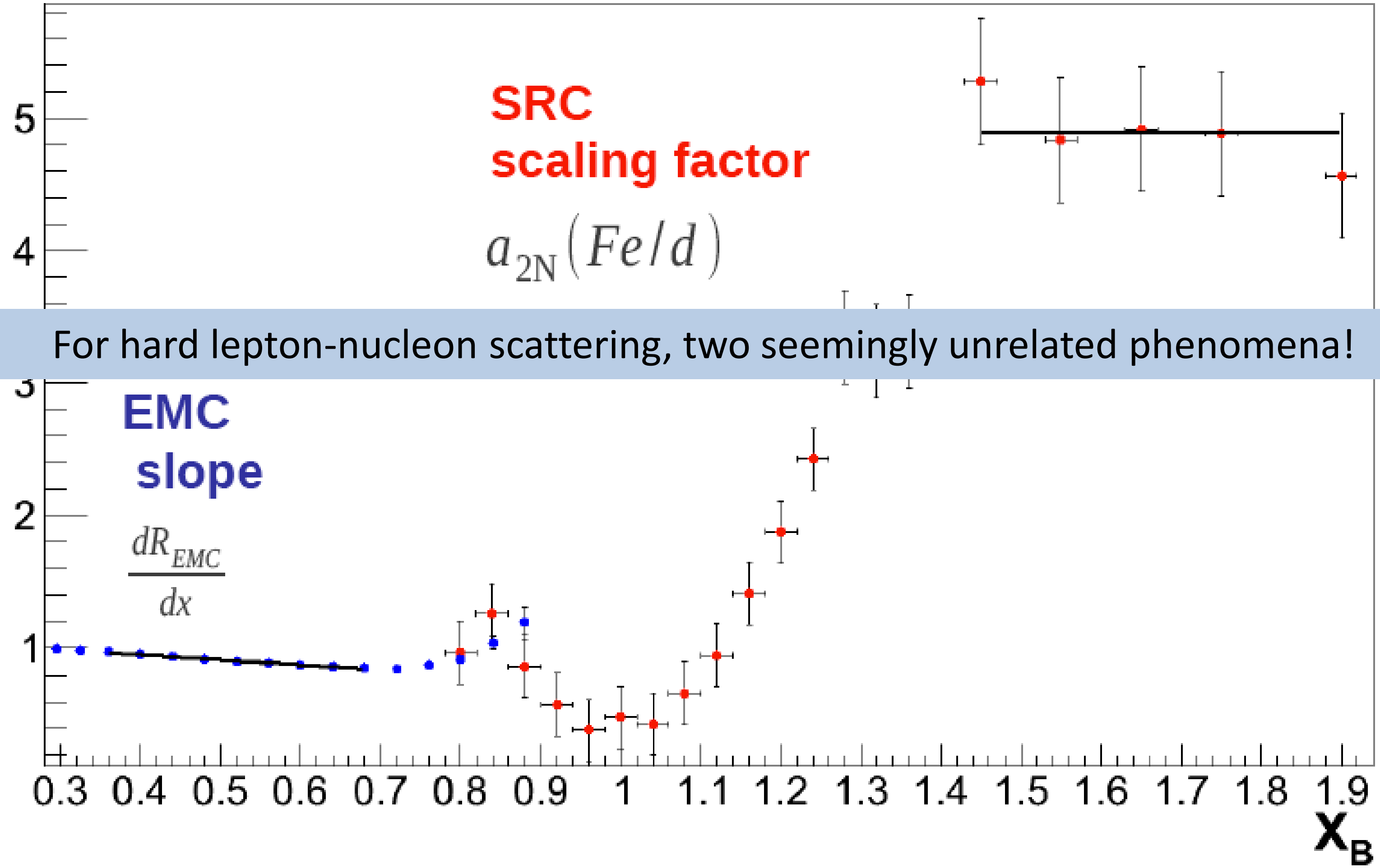
The "Tagged" EMC Effect

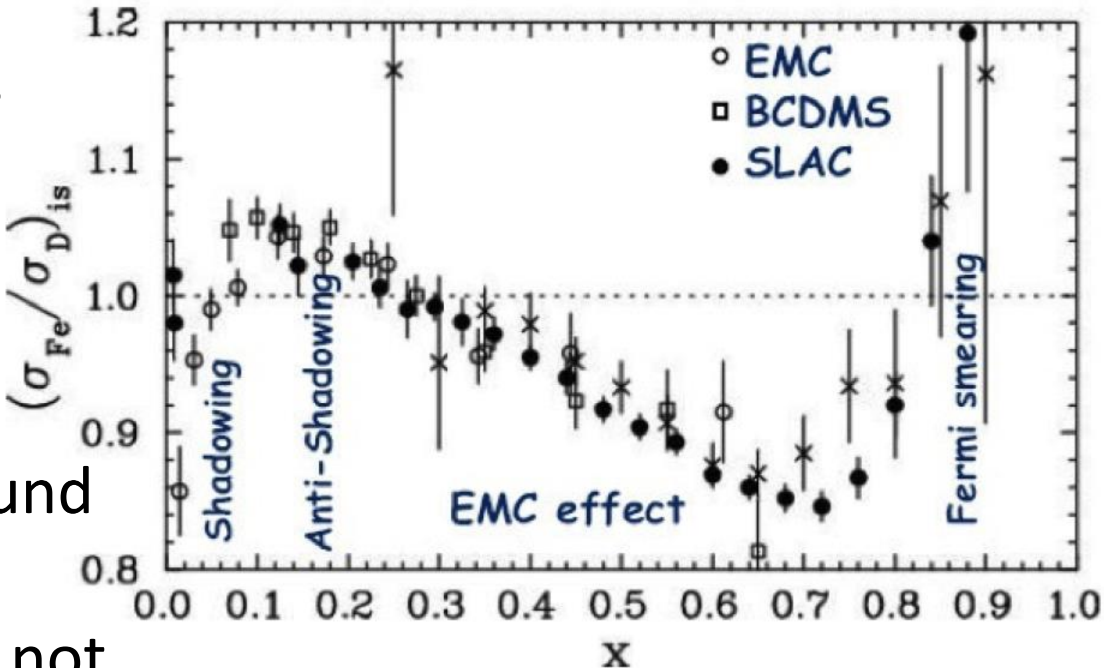
Barak Schmookler & Shalev Gilad, MIT



For hard lepton-nucleon scattering, two seemingly unrelated phenomena!

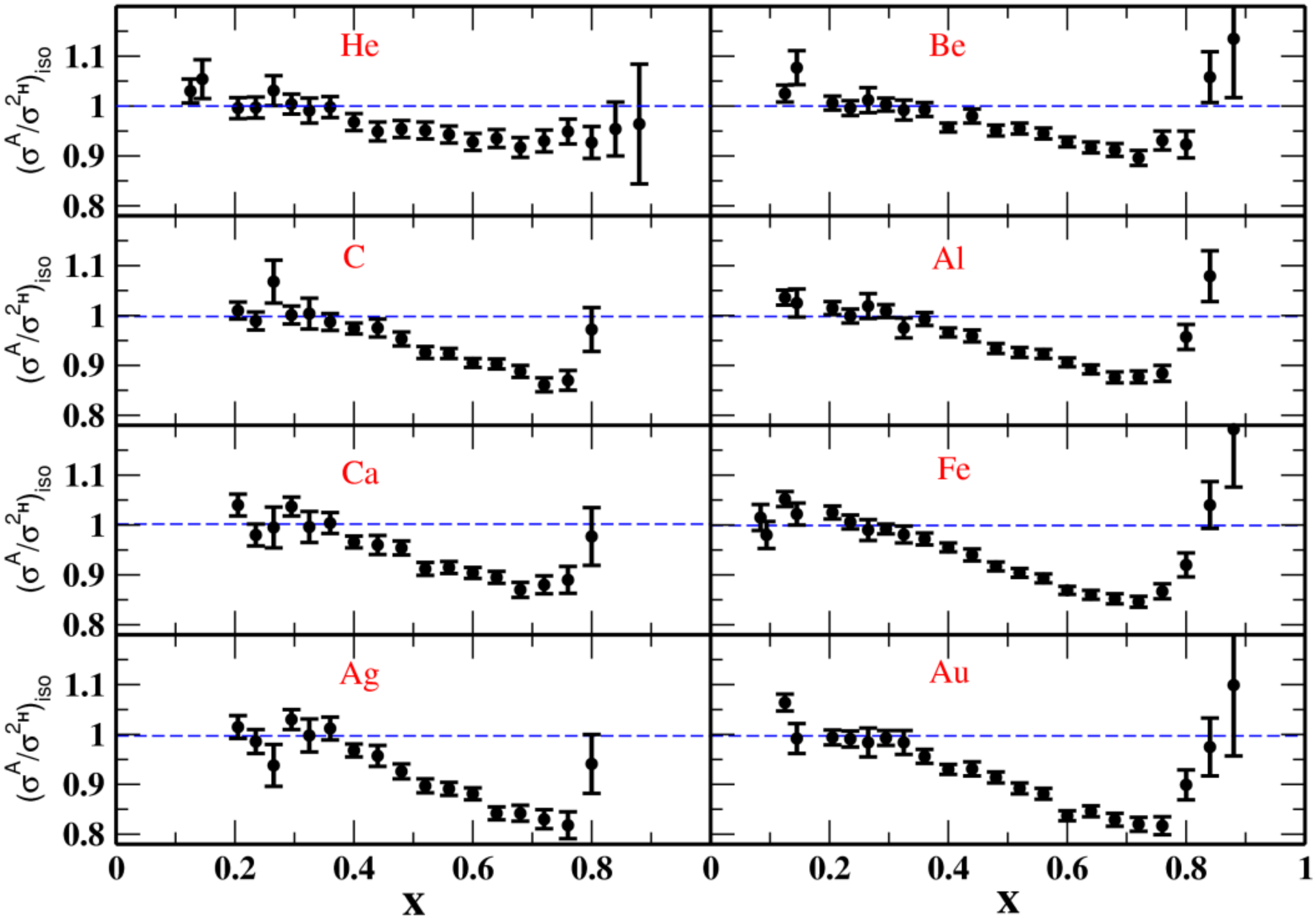
DIS and the EMC Effect

- 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



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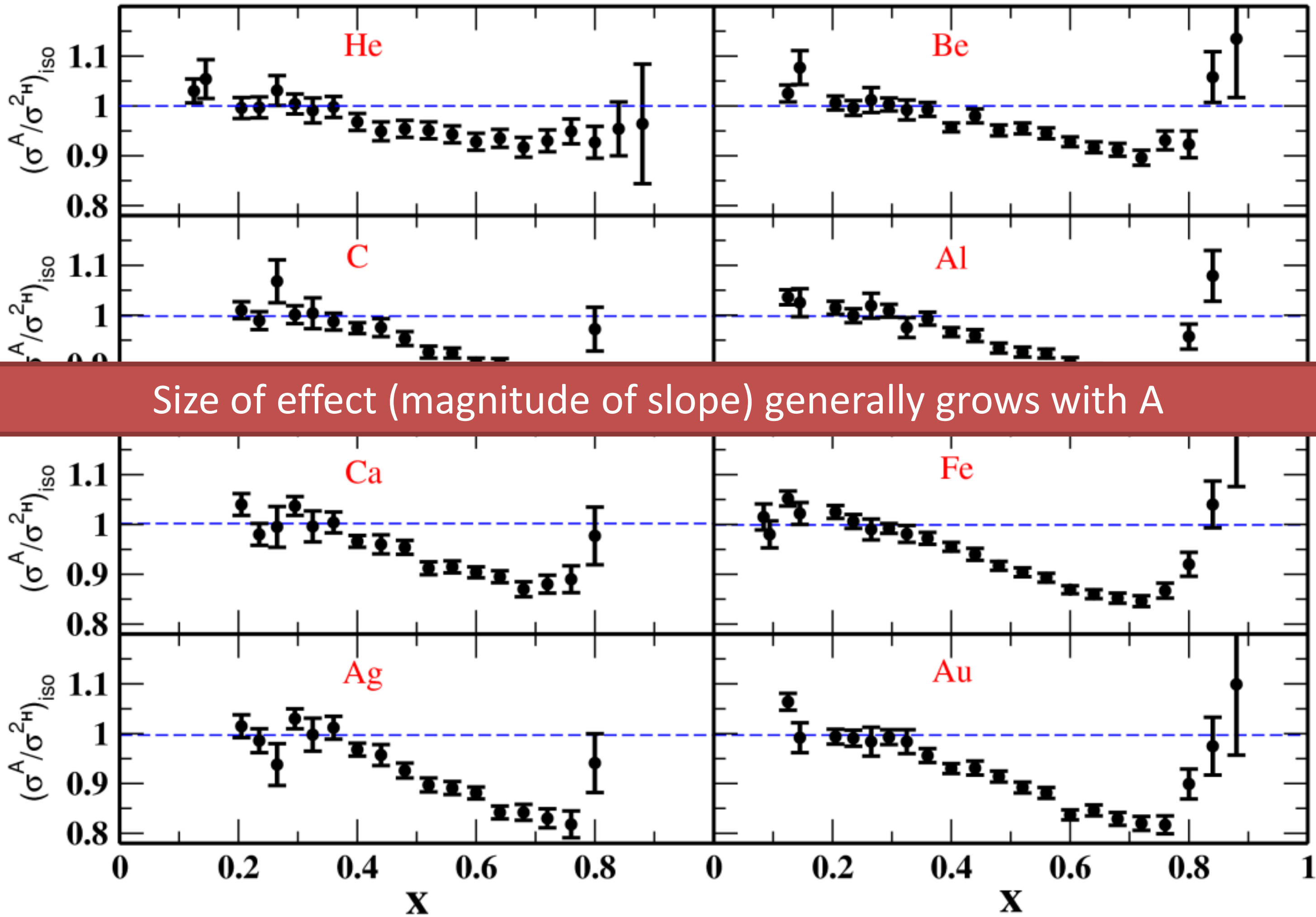
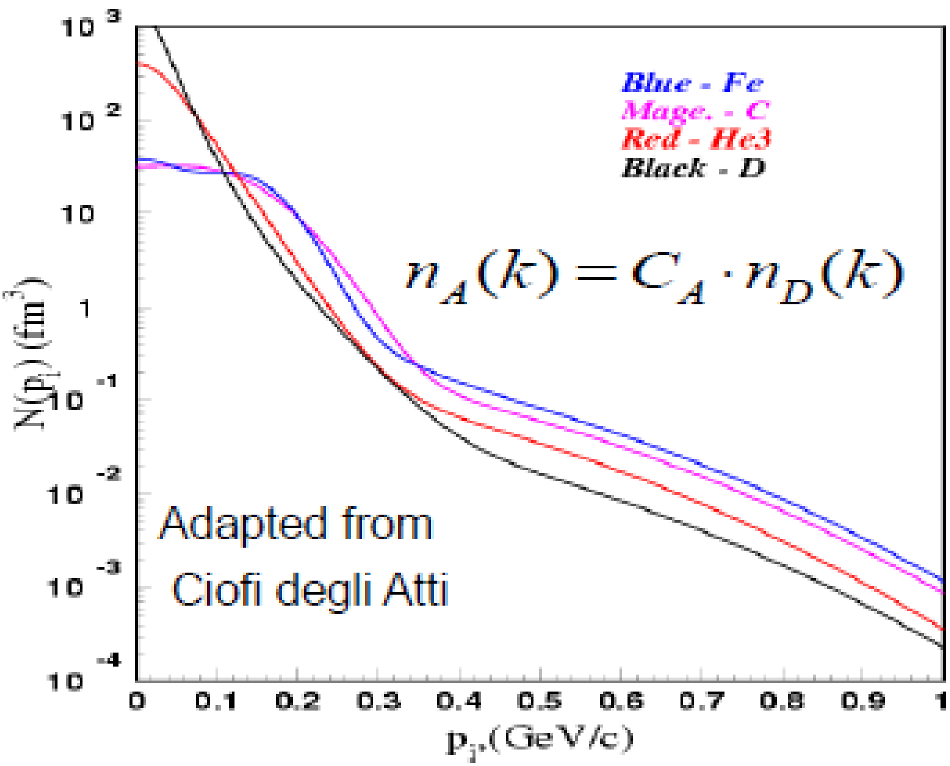


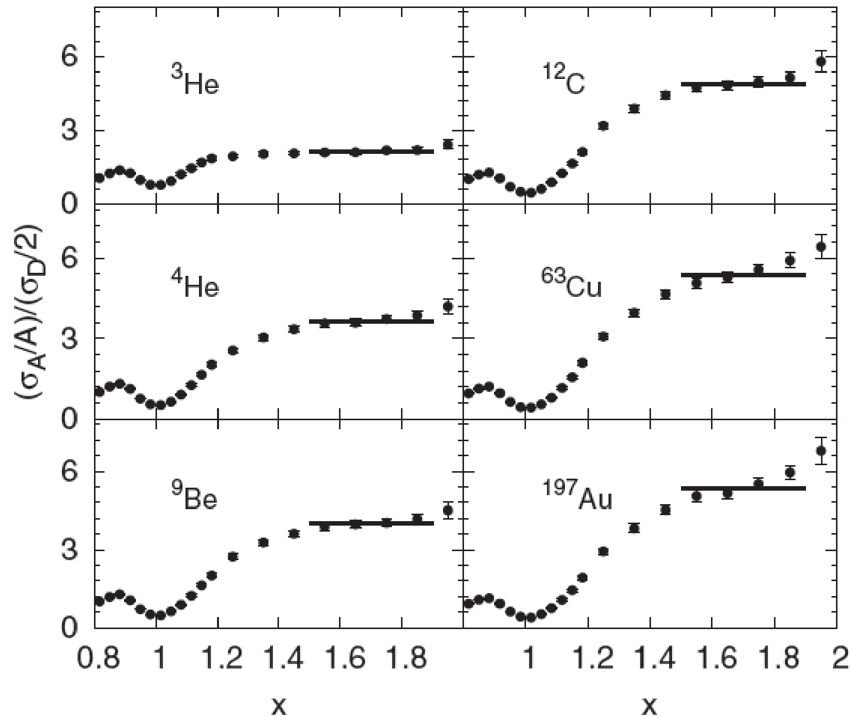
Size of effect (magnitude of slope) generally grows with A

Universality of SRC (Scaling)

- Scale is a few tens of MeV
- At high nucleon momenta, strength is different but shapes of distributions are similar



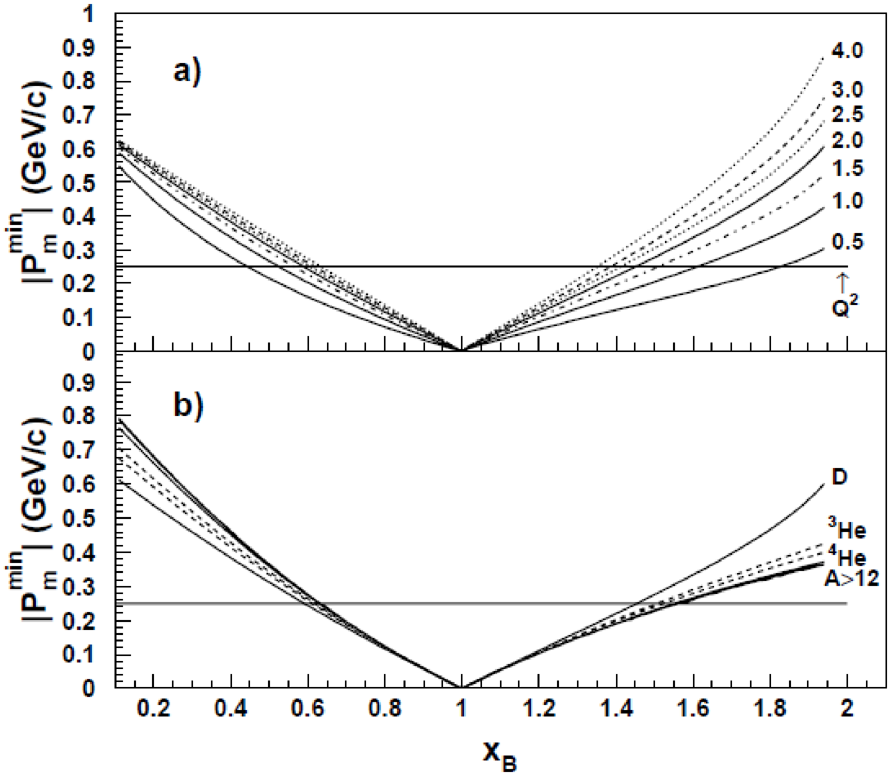
A(e,e')



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

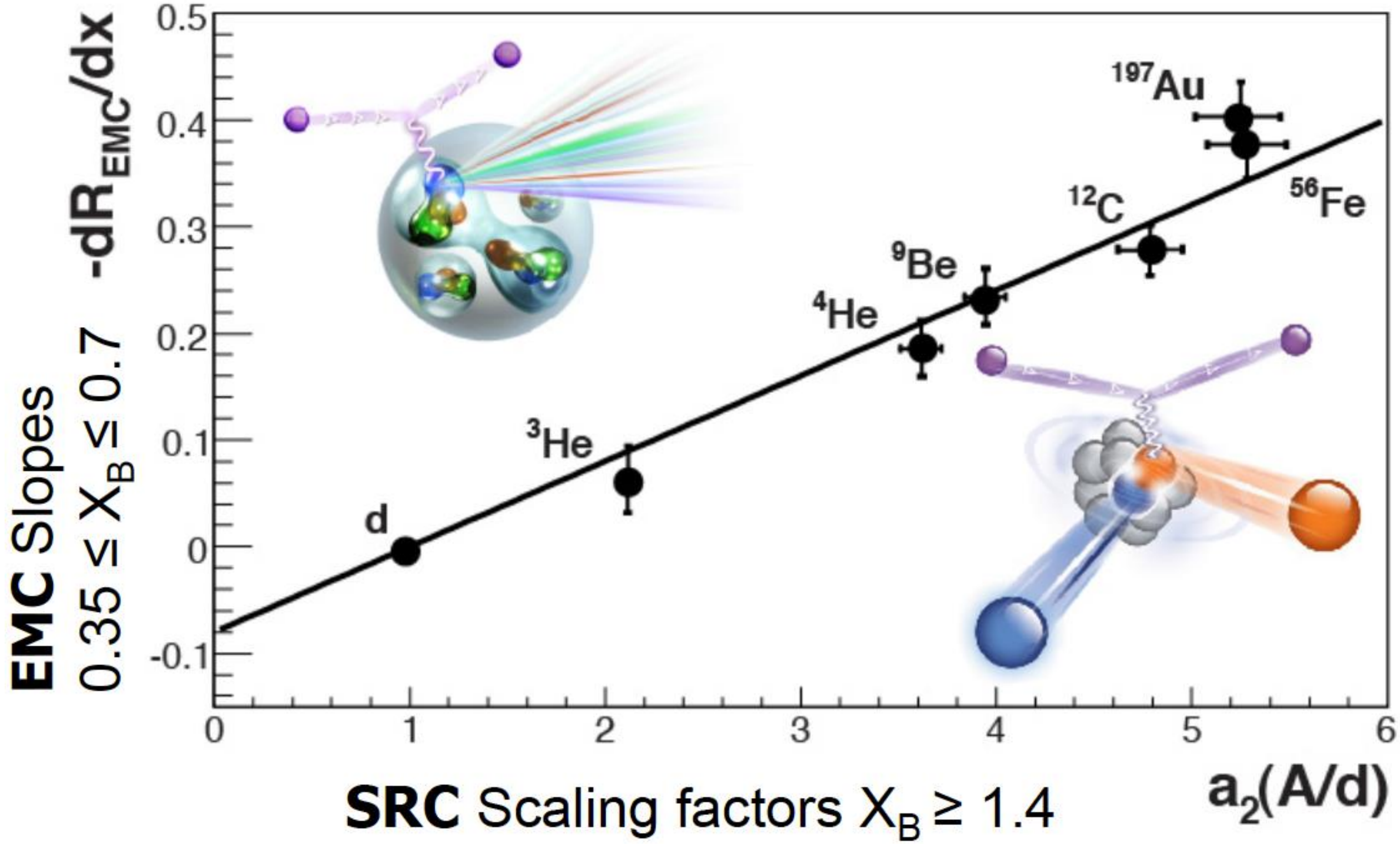


- Almost all these nucleons are members of a SRC pair: a pair of nucleons with large relative momenta ($p_{rel} > p_F$) and small CM momenta ($p_{CM} < p_F$)!
- Knocking out one member results in the recoil ejection of the other member in the opposite direction!
- Approximately 90% of SRC pairs are proton-neutron pairs, 5% are p-p, and 5% are n-n pairs.!

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

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

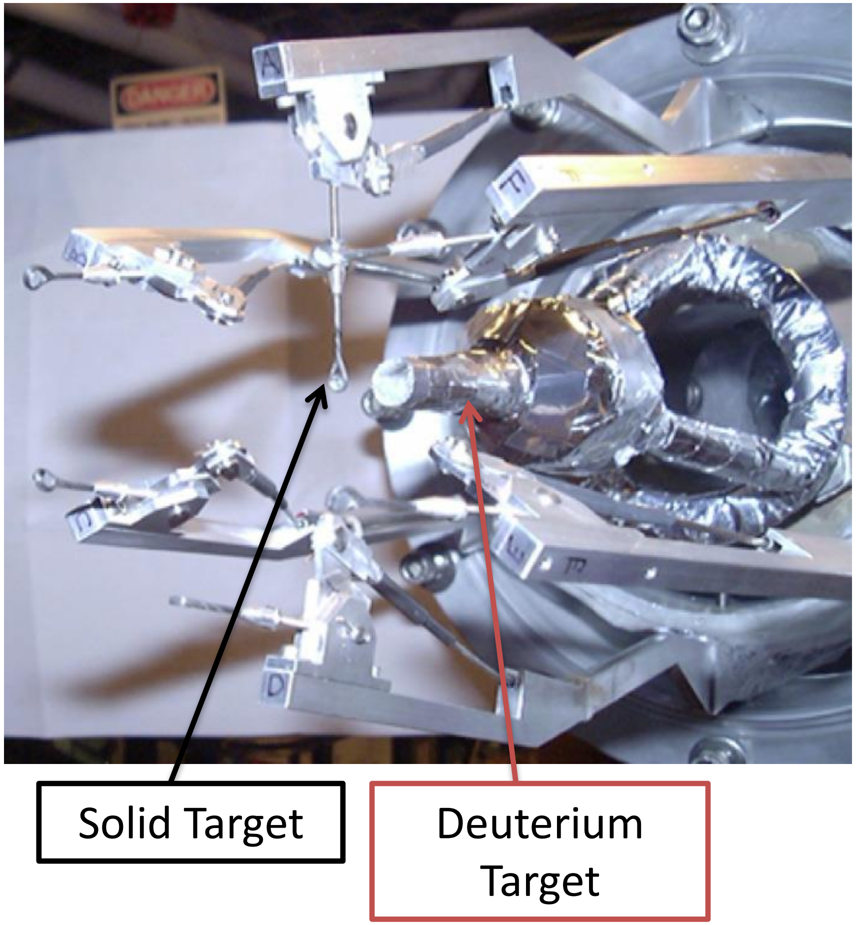
These Two Phenomena are Clearly Correlated



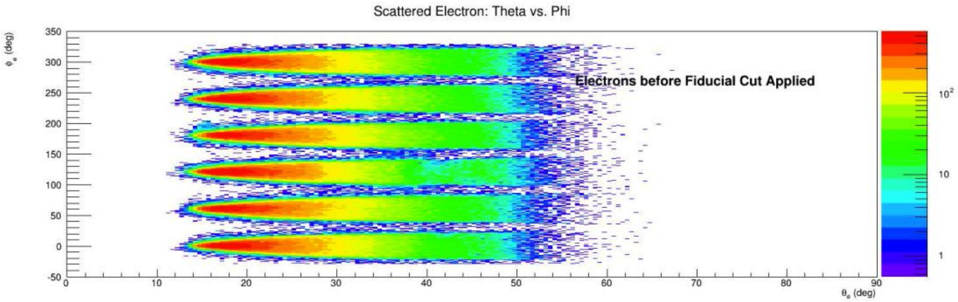
L. Weinstein et al, PRL **106**, 052301 (2011); O. Hen et al, PRC **85**, 047301 (2012)

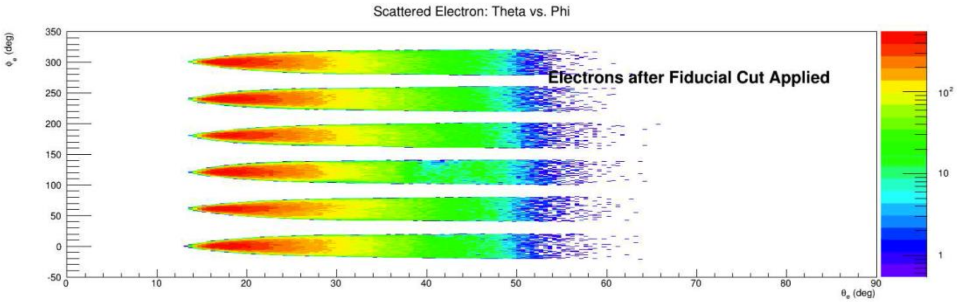
Study EMC-SRC Correlation with "Tagged" EMC

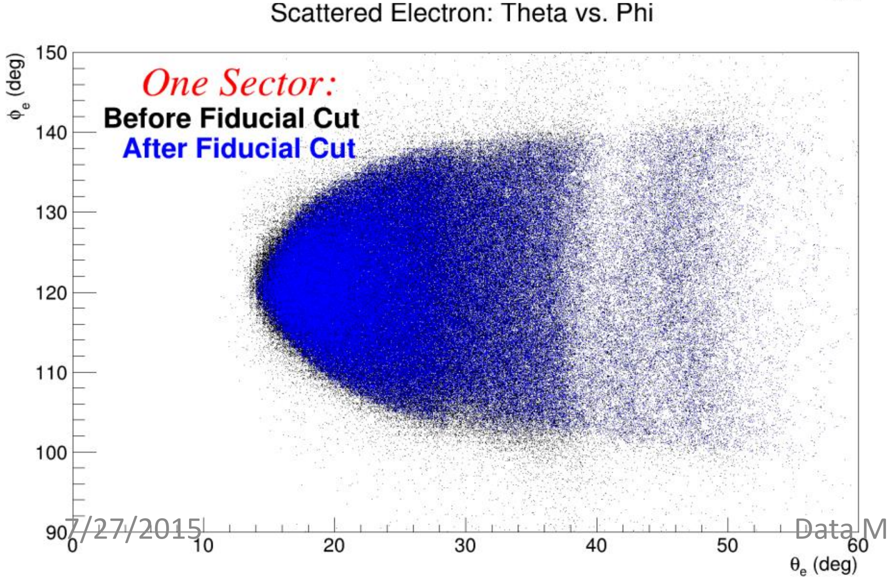
- Analyze CLAS data from the Eg2c run period
- Events with EMC Kinematics
- Study EMC events with backwards-recoiling proton with $k>k_F$
- Expectation: Flat $[\sigma(A)/A]/[\sigma(d)/2] \approx a2(A/d)$!

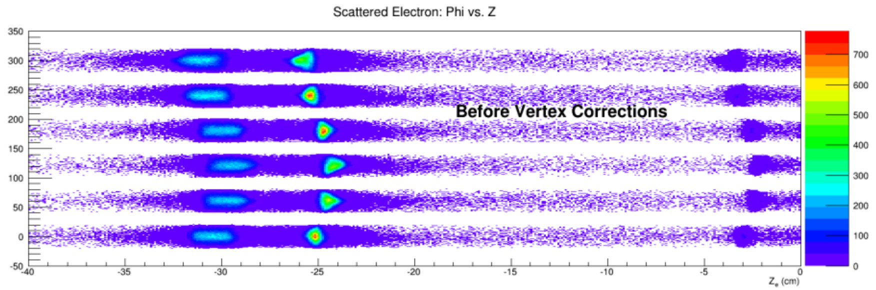


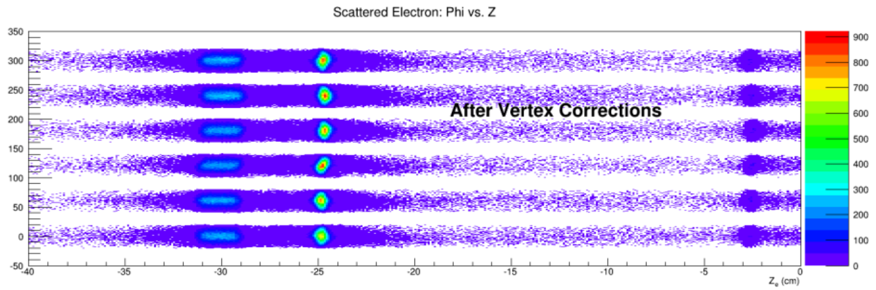
Electron Fiducial Cuts / Vertex Corrections



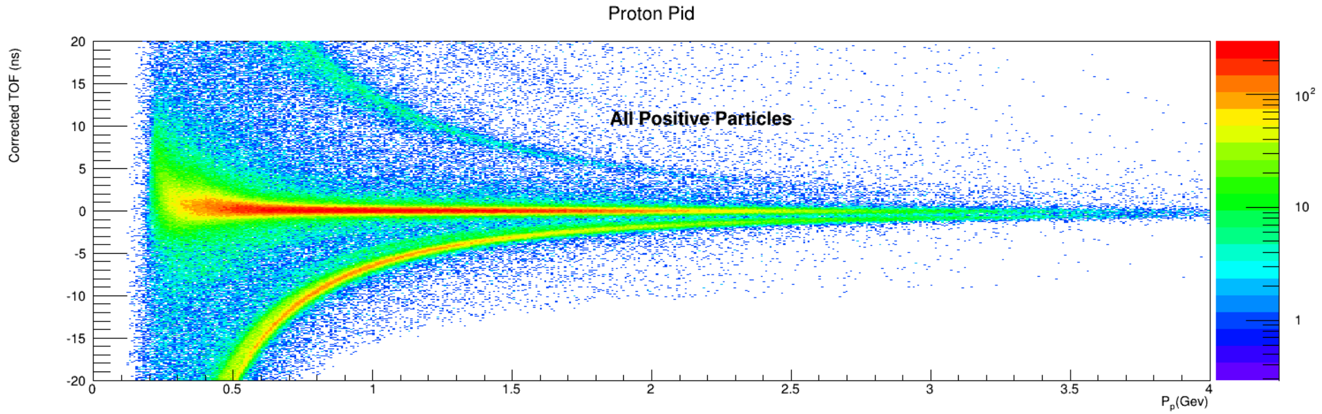


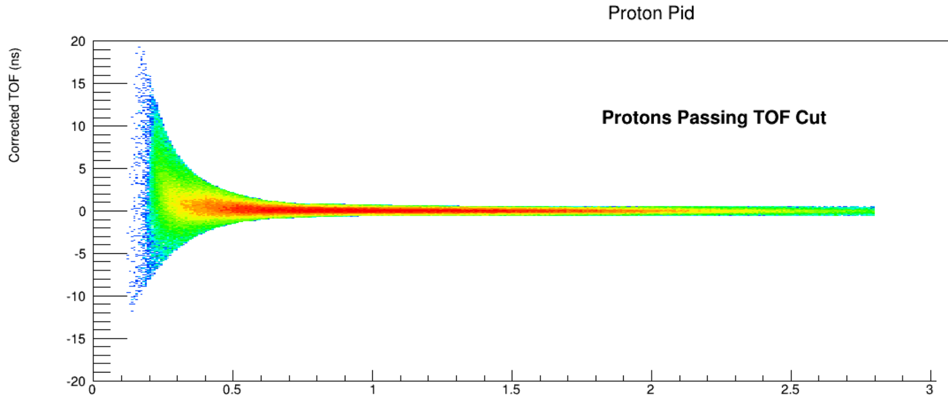


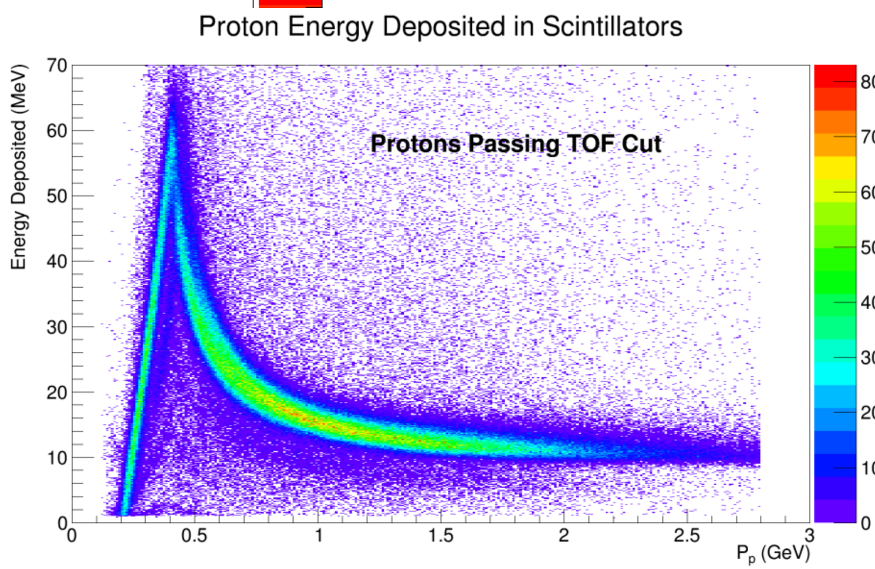




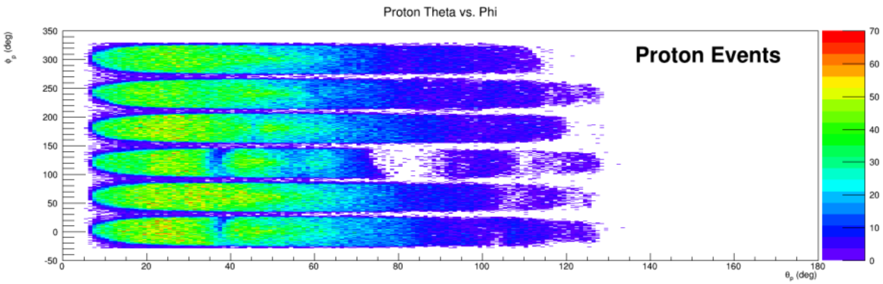
Proton Particle ID

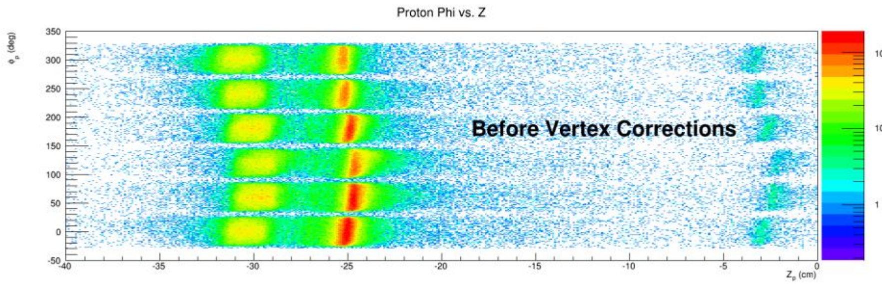


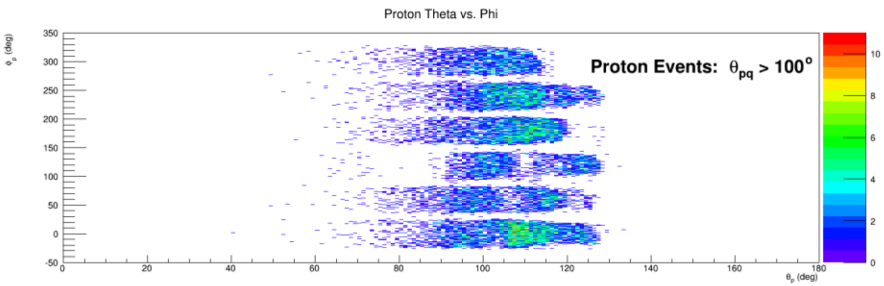


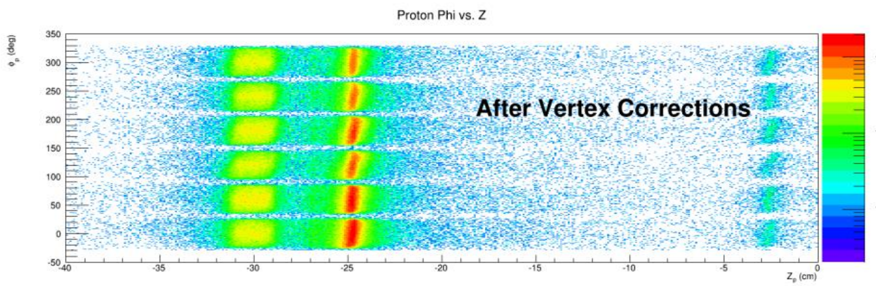


Proton Fiducial Cuts/ Vertex Corrections



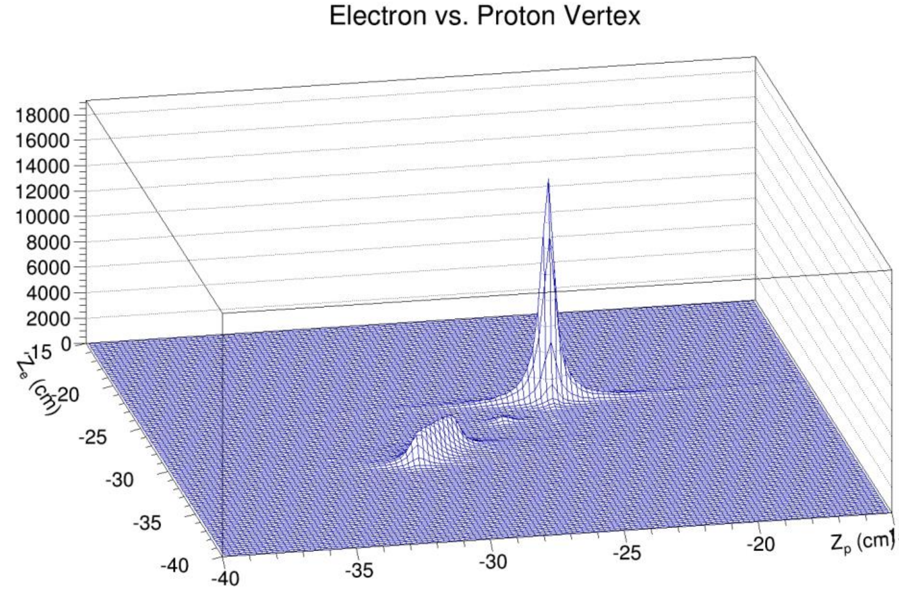




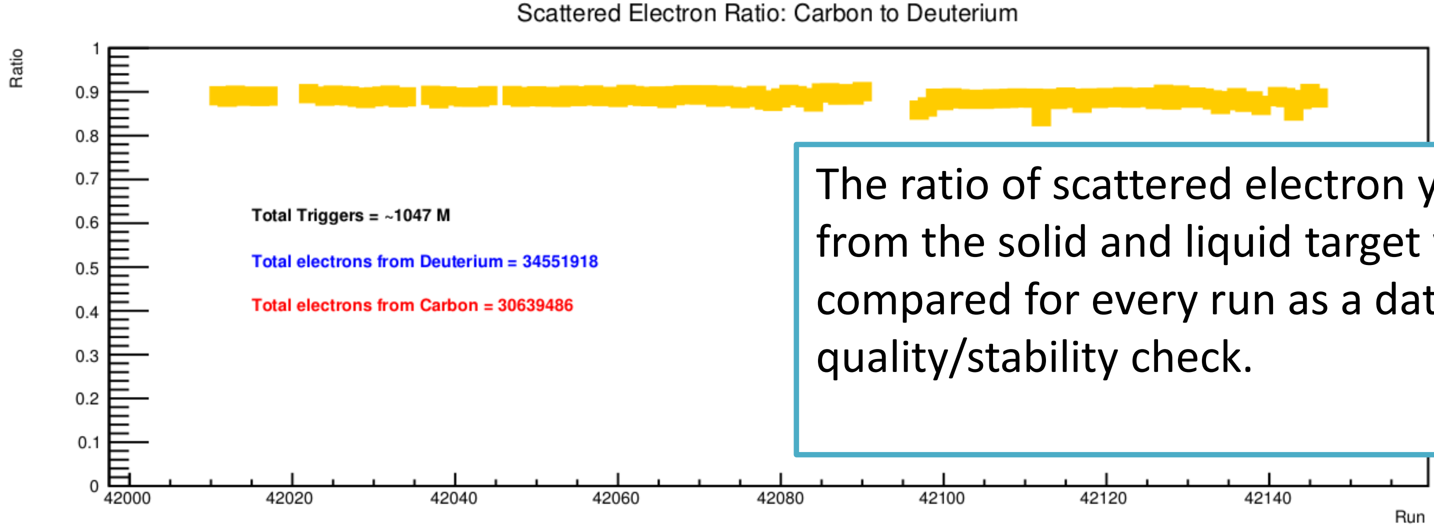


Vertex Selection (cont.)

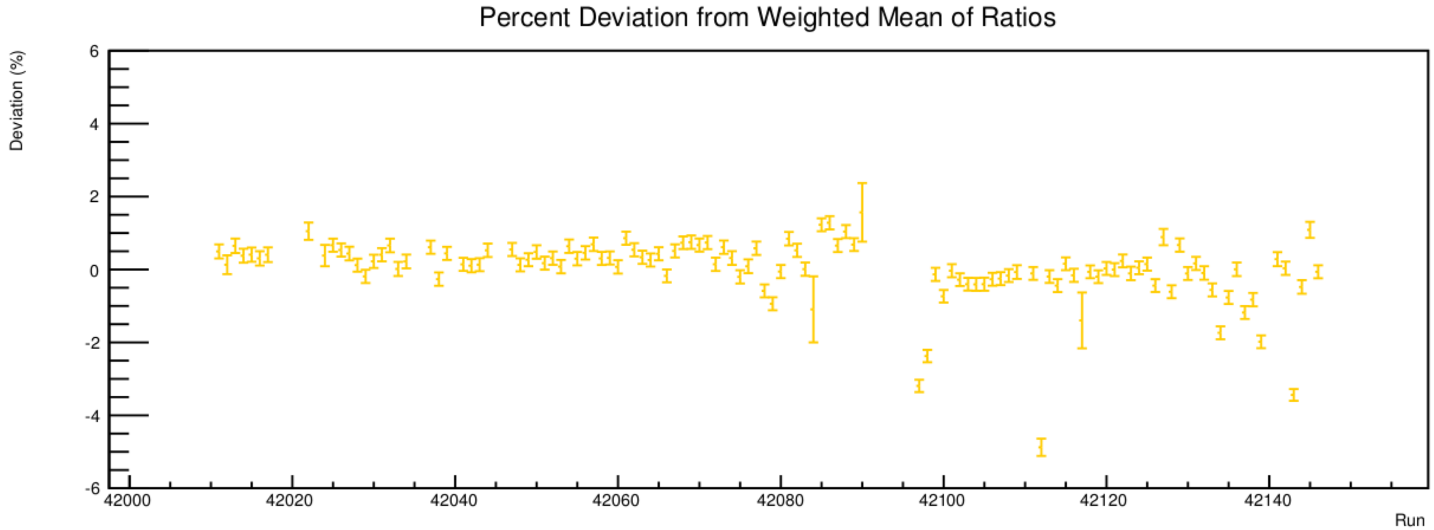
- Targets are well separated, with few accidentals
- The solid target electron vertex has an rms of 2.5mm; proton vertex rms is 5mm.
- A vertex difference may eventually be applied



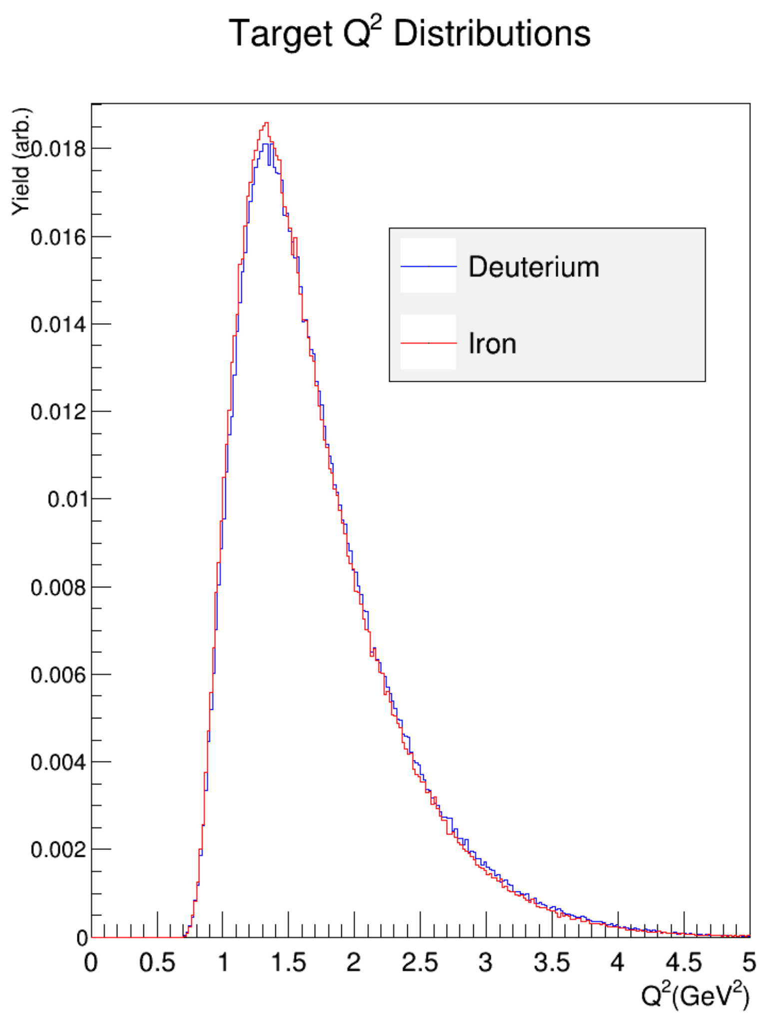
Data Ensemble/Data Quality Checks

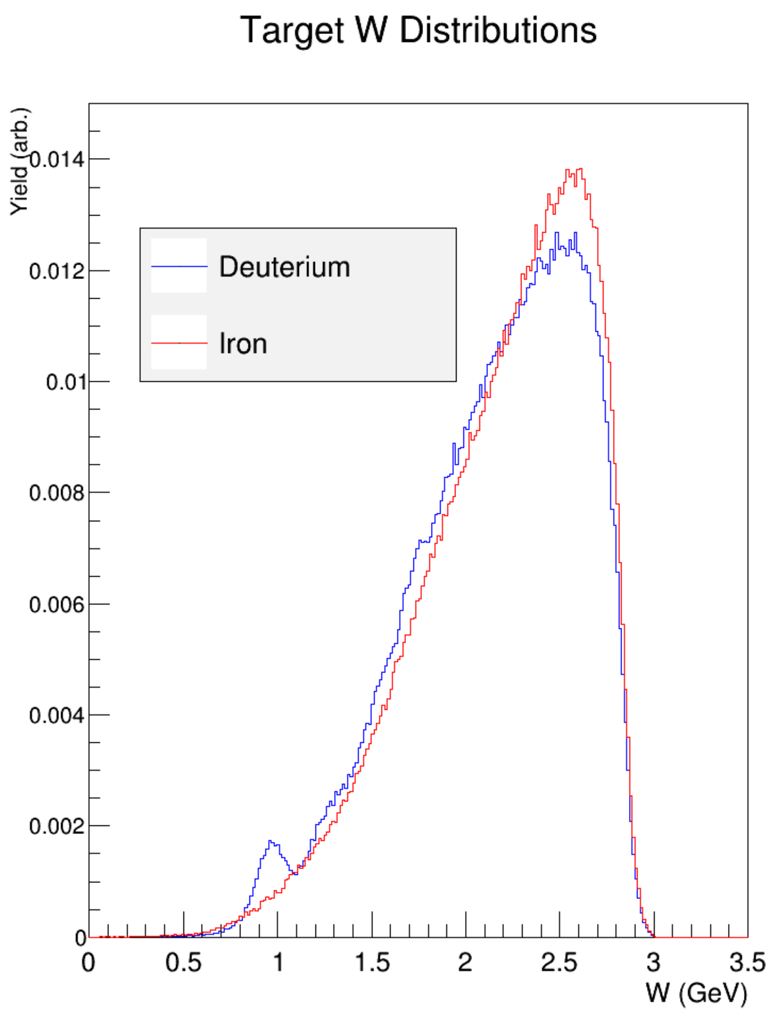


The ratio of scattered electron yield from the solid and liquid target was compared for every run as a data quality/stability check.



Target Kinematic Distributions





Monte Carlo Simulations

- Results need to be corrected to account for different positions of solid and liquid targets.
- Acceptance corrections are on the order of 2-4% for inclusive DIS (e,e'); and 15-20% for the semi-inclusive DIS (e,e'p) with the proton backwards to the momentum transfer.
- Inclusive Scattering:

$$Acc_{x,inc} = \frac{N_{e^-,rec}}{N_{e^-,gen}}$$

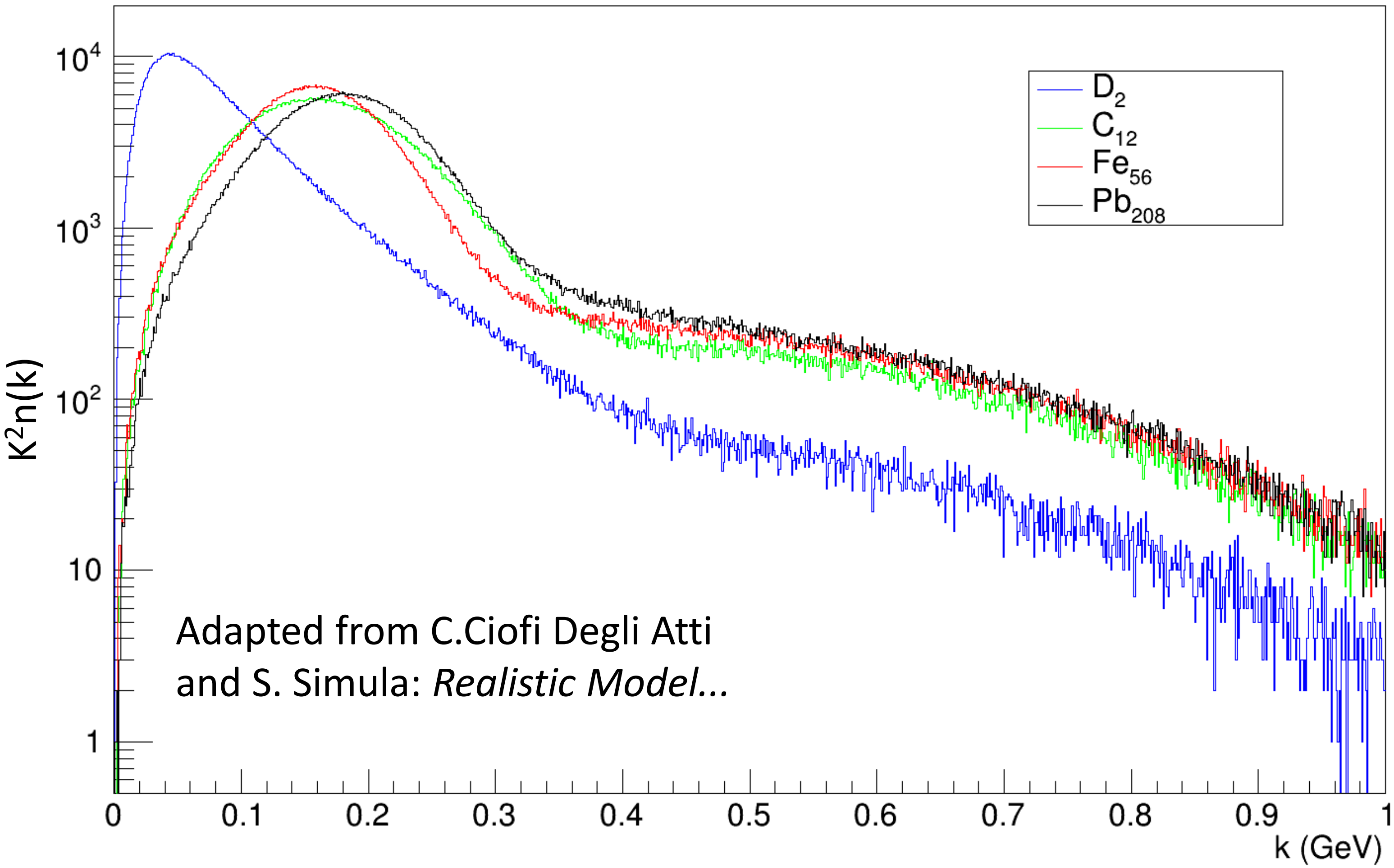
- Semi-Inclusive Scattering:

$$Acc_{x,SI} = Acc_{x,inc} \times Acc_{x,recoil}$$

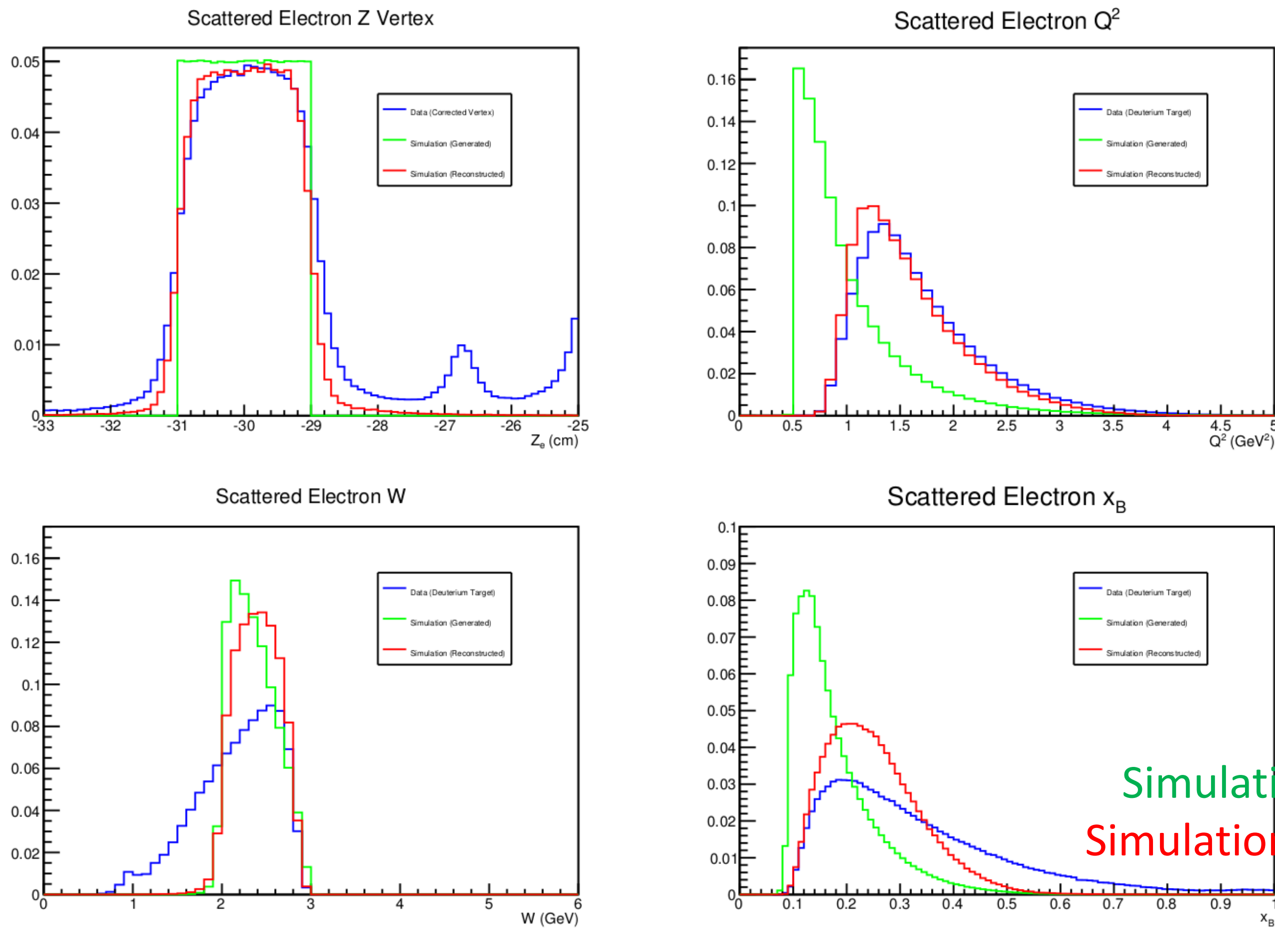
Lepto Event Generator

- 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

Nucleon Momentum Distributions

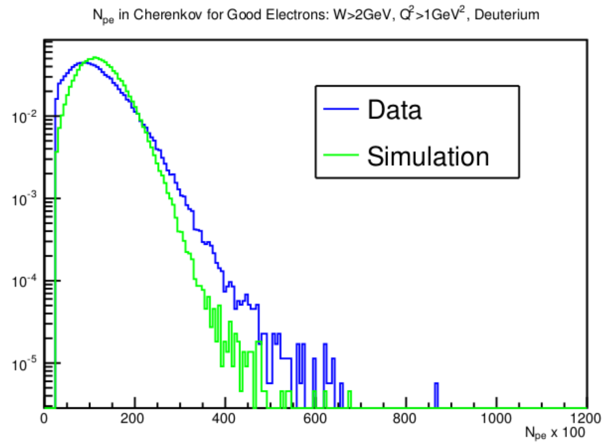


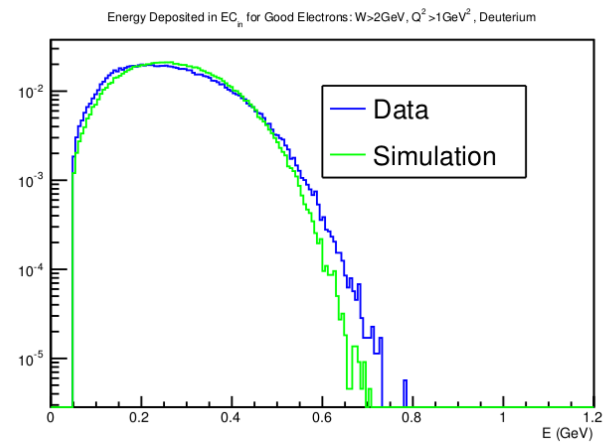
Data/Simulation Comparison: Kinematic Distributions

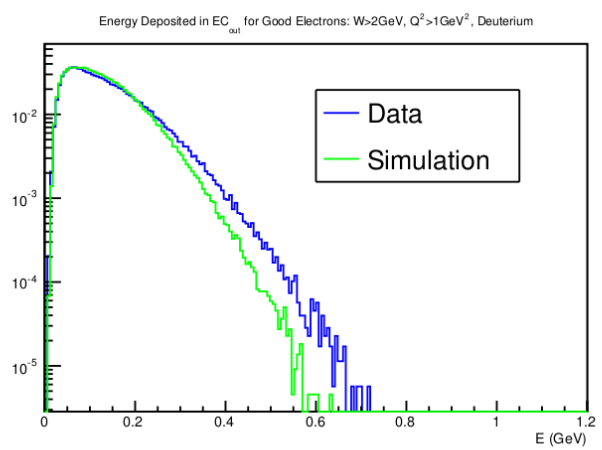


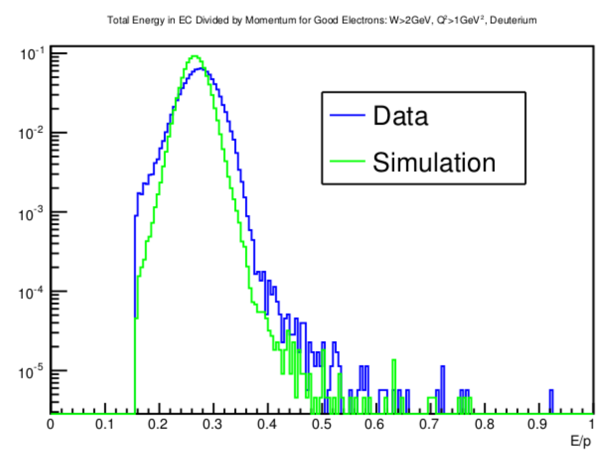
Data
Simulation: Generated
Simulation: Reconstructed

Data/Simulation Comparison: Detector Response





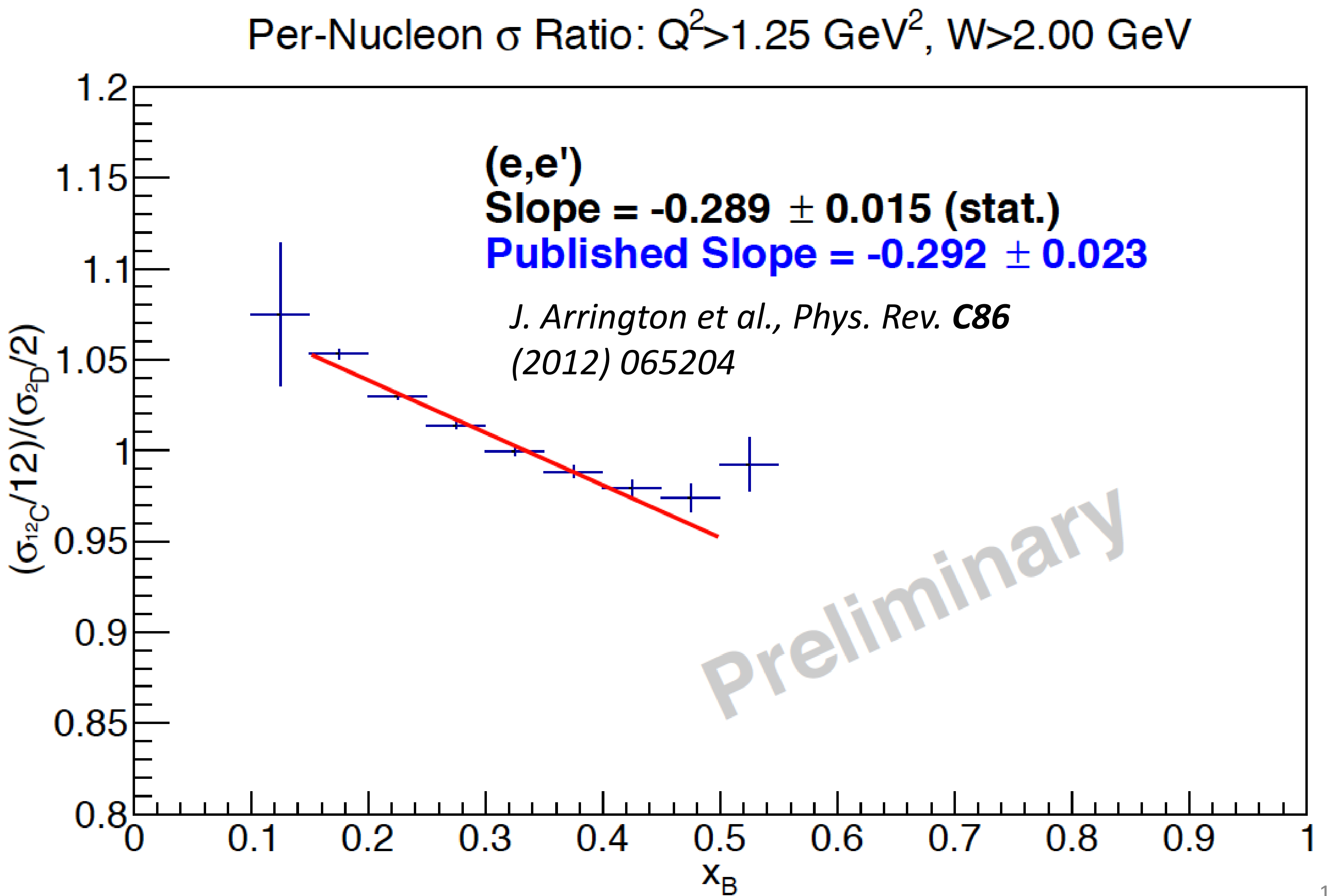




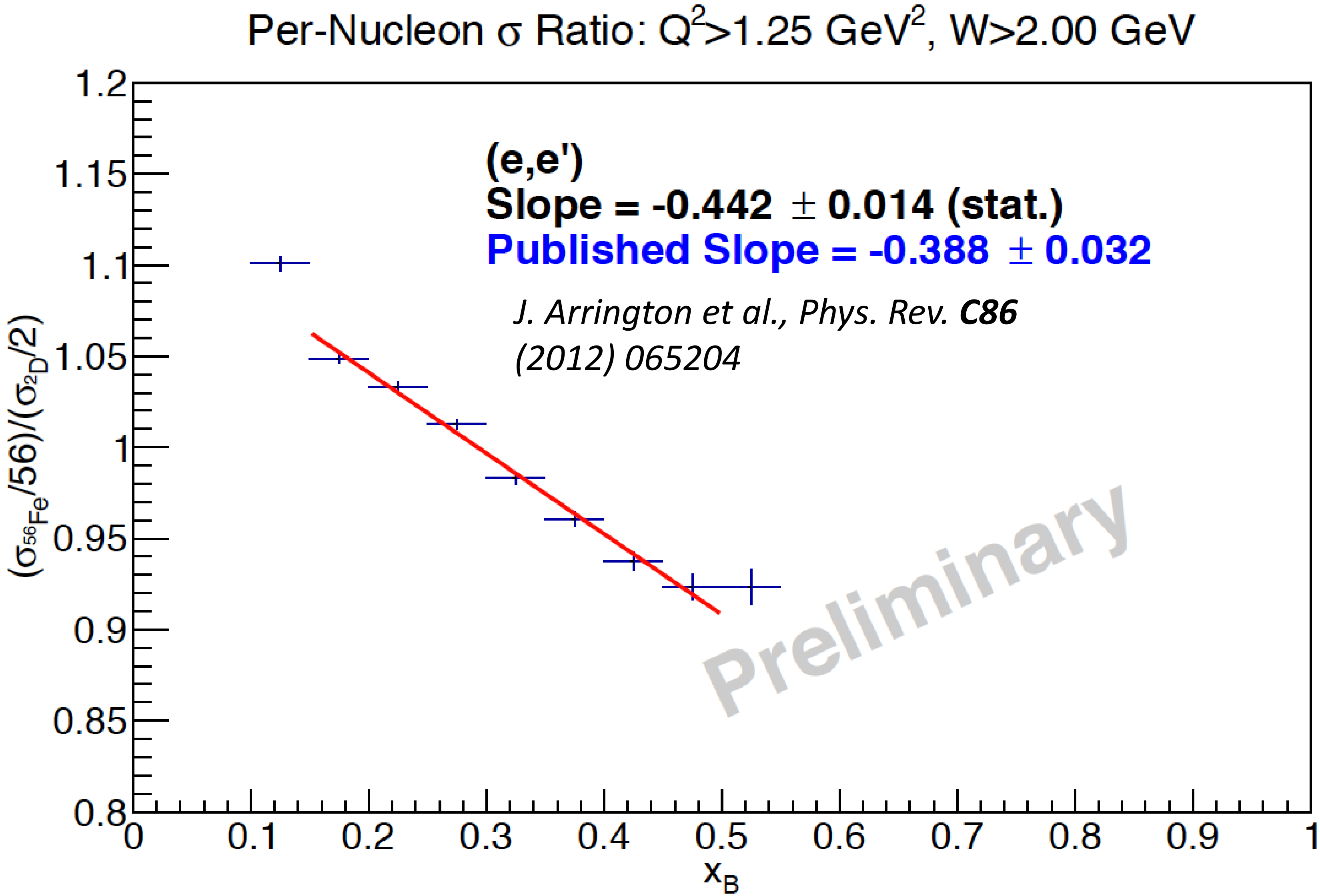
Inclusive (Traditional) EMC

- Data analyzed for ^{12}C, ^{56}Fe, ^{208}Pb (will be analyzed for ^{27}Al and ^{119}Sn)
- Slope uncertainties are determined by statistical uncertainties only on data points
- Corrections Applied:
  - Cryo-target window subtraction (not done as function of x) – 2.5%
  - Acceptance corrections (preliminary) <3%
  - Radiative correction factor (taken from other eg2 analysis)
  - Isoscaler corrections – 1% for Fe, 7.5% for Pb
- Need to Apply:
  - Coulomb corrections
  - Systematic errors

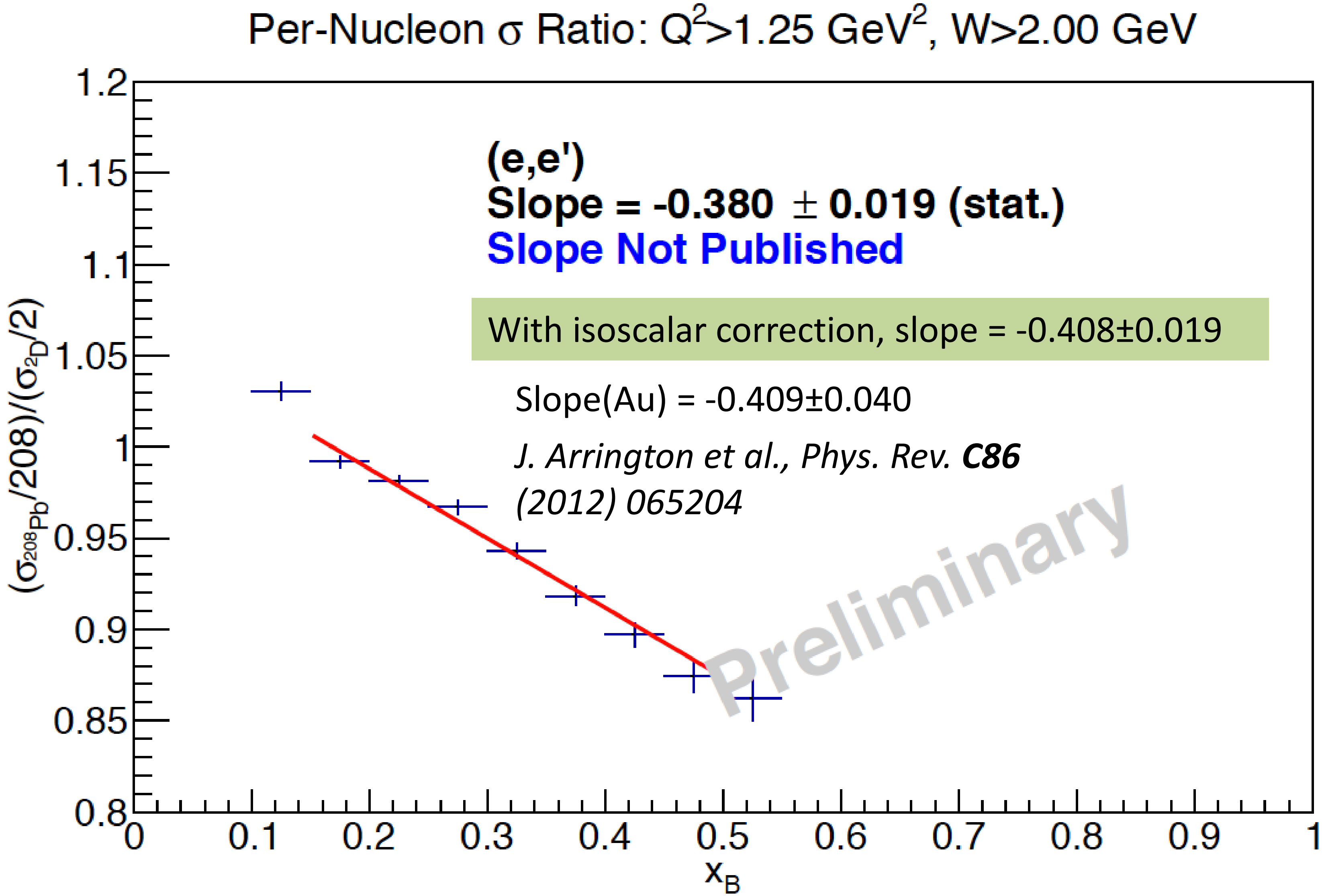
Inclusive EMC: $^{12}C/d$



Inclusive EMC: ^{56}Fe/d



Inclusive EMC: ^{208}Pb/d

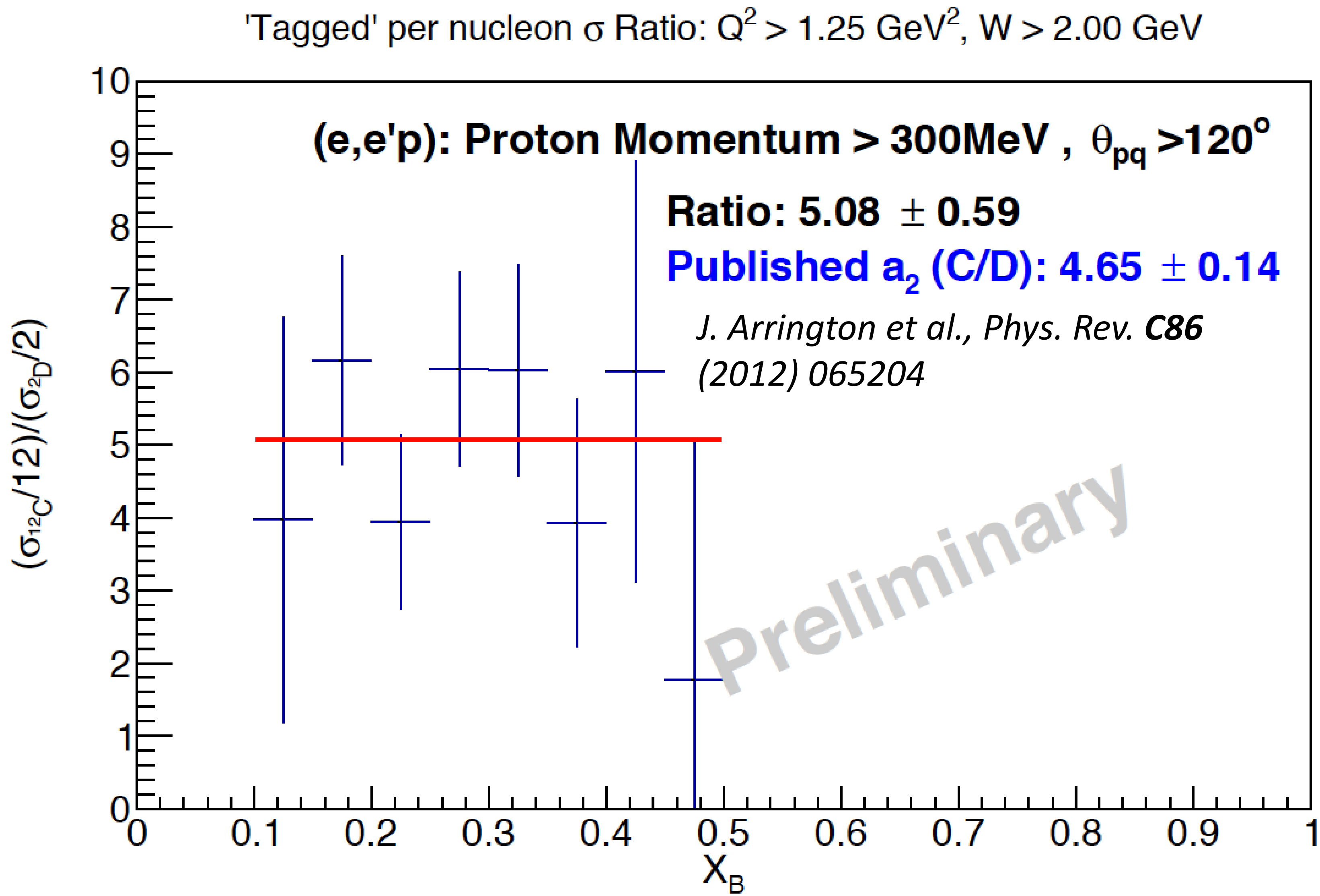


EMC “Tagged” by Backward-Recoiling Protons

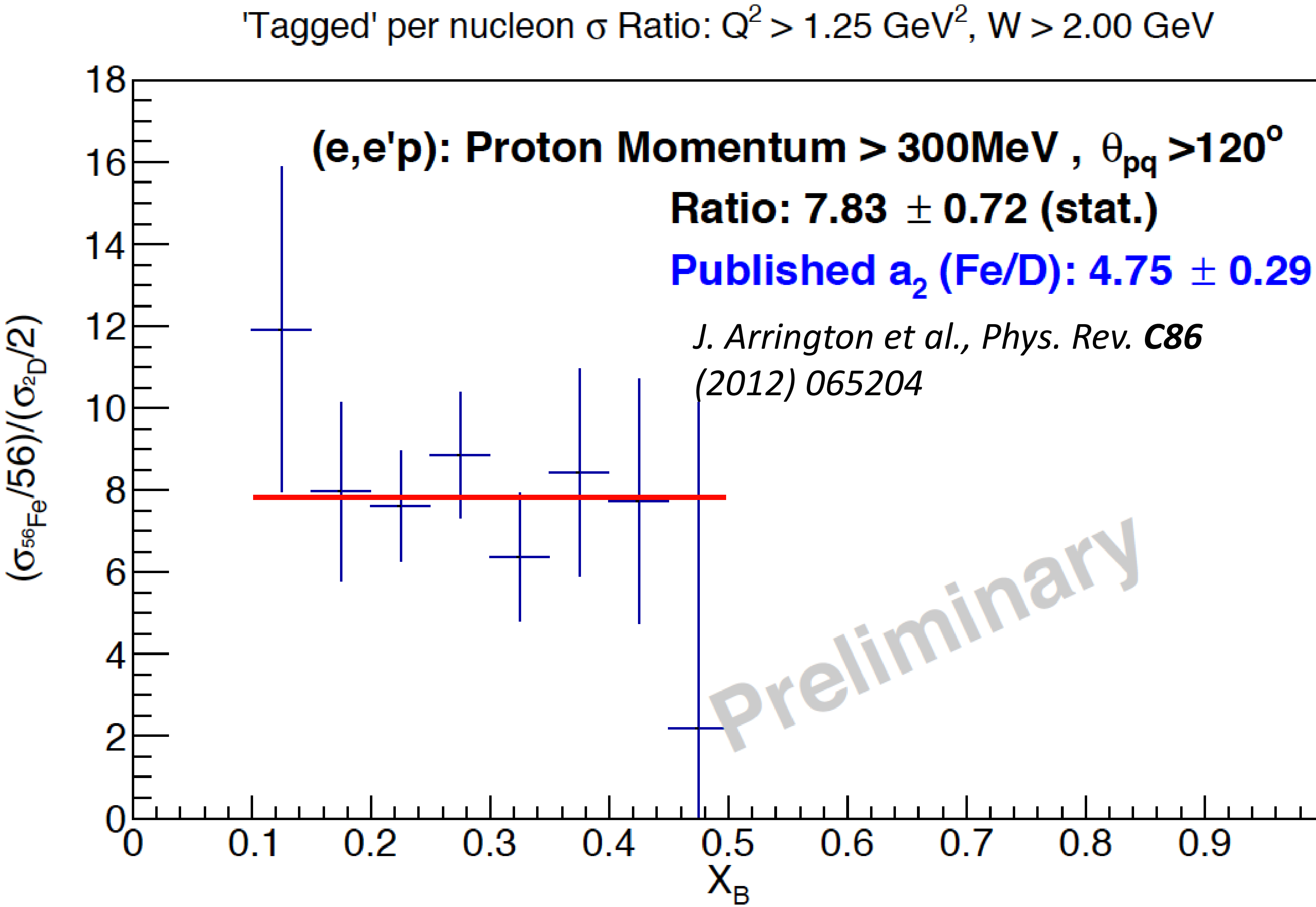
- Corrections Applied:
  - Acceptance Correction (~15-20% effect)
  - Proton Energy loss correction (small effect above 300 MeV/c)
  - Radiative Correction factors (same applied as inclusive case)

- Corrections to be performed:
  - Cryo-Target Window Subtraction – 2.5%?
  - Taking into account contributions by ~5% pp pairs - ~20%?
  - Coulomb corrections
  - Isoscaler corrections for “tagged”
  - Protons transparency
  - Systematic uncertainties

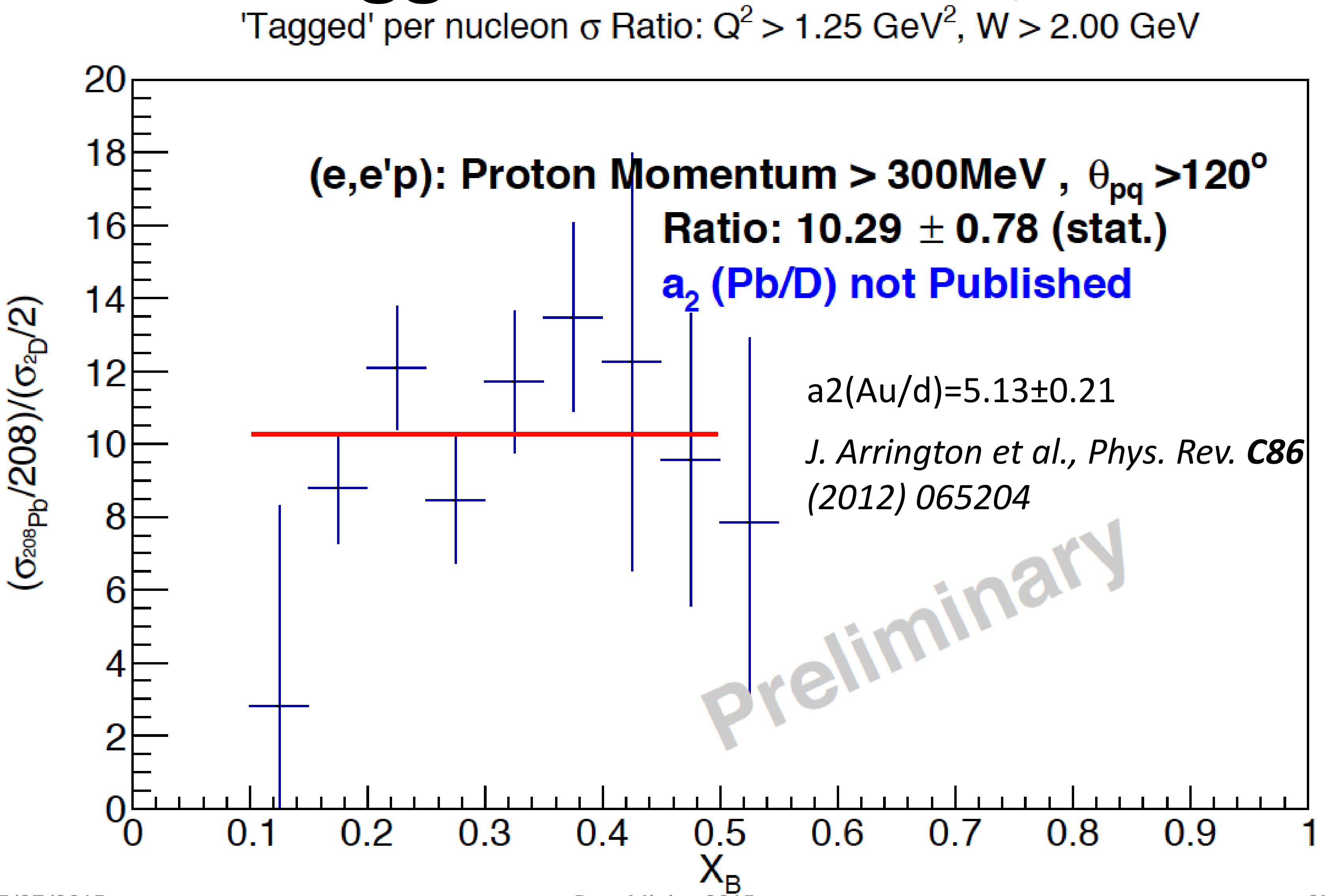
“Tagged” EMC: $^{12}C/d$



“Tagged” EMC: ^{56}Fe/d



"Tagged" EMC: ^{208}Pb/d



Summary of (Preliminary) Results

Nucleus (A)	Published EMC Slope (A/d)	Measured EMC Slope (A/d)*	"Tagged" EMC Ratio (A/d)*	a_2(A/d)
^{12}C	-0.292±0.023	-0.289±0.015	5.08±0.59	4.65±0.14
^{56}Fe	-0.388±0.032	-0.442±0.014	7.83±0.72	4.75±0.29
^{207}Pb (^{197}Au)	(-0.409±0.040)	-0.380±0.019 **-0.408±0.019**	10.29±0.78	(5.13±0.21) will extract

* Uncertainties are fits uncertainties from statistical uncertainties only of data points

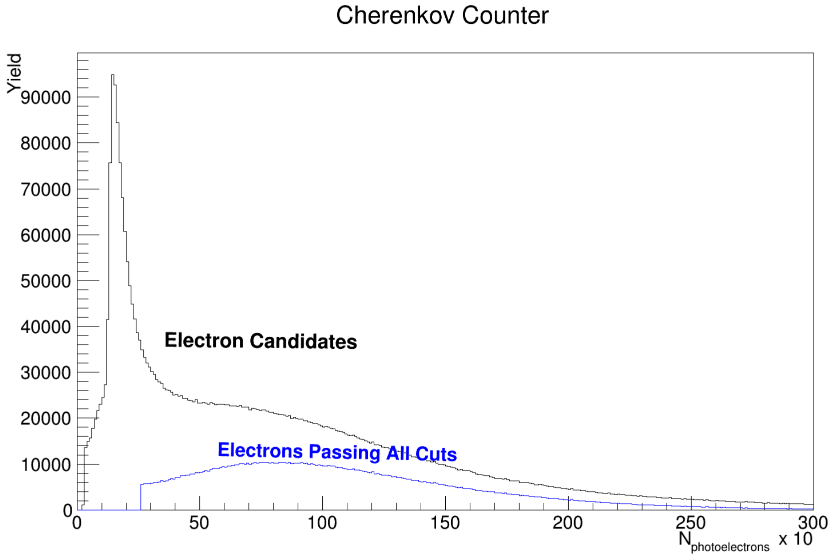
- "Tagged" EMC ratios seem to be flat
- Value of "tagged" ^{12}C/d EMC ratio is consistent with a2(^{12}C/d)
- Ratios of "tagged" ^{56}Fe/d and ^{208}Pb/d are much larger than a_2(^{56}Fe/d) and a_2(^{197}Au/d)
- Ratios of "tagged" (^{56}Fe/d)/(^{12}C/d) and (^{208}Pb/d)/(^{12}C/d) behave roughly like the ratios of the corresponding EMC slopes?
- Relative strength of the EMC effect is kept in the EMC effect "tagged" by backwards-going protons?

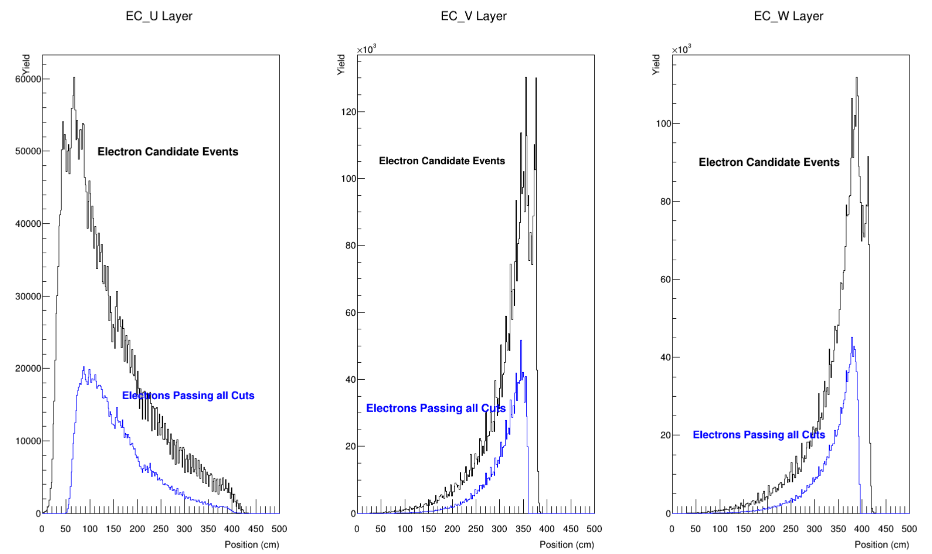
Next Steps

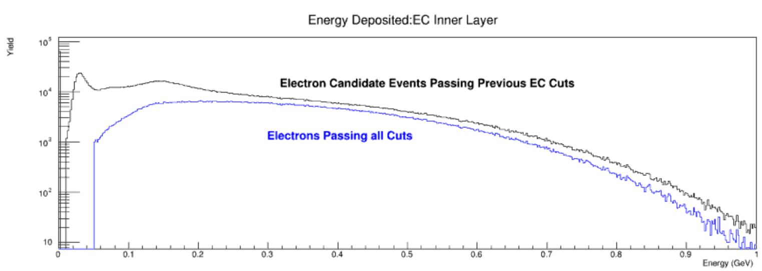
- Finish necessary corrections, systematic studies
- Try to reproduce *Deeps* results on deuterium
- Continue work on electron momentum/angle corrections using hydrogen data (with Stepan)
- Try to better understand “tagged” results:
  - Look for pions backwards to the momentum transfer for the various targets
  - Look at charge distribution of forward-going hadron jet. Is this doable?

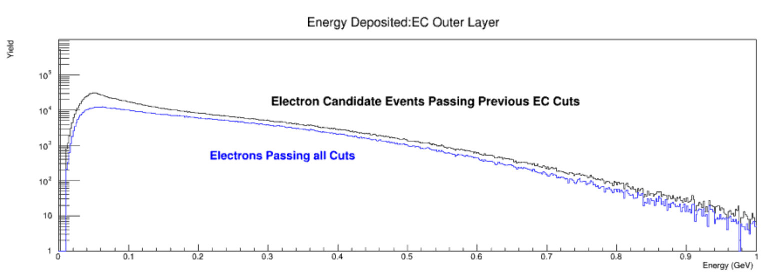
Additional Slides

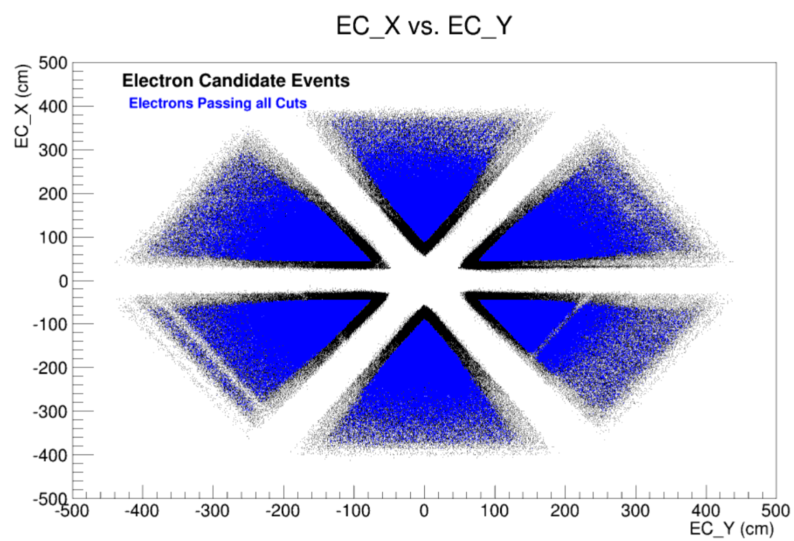
Electron Particle ID



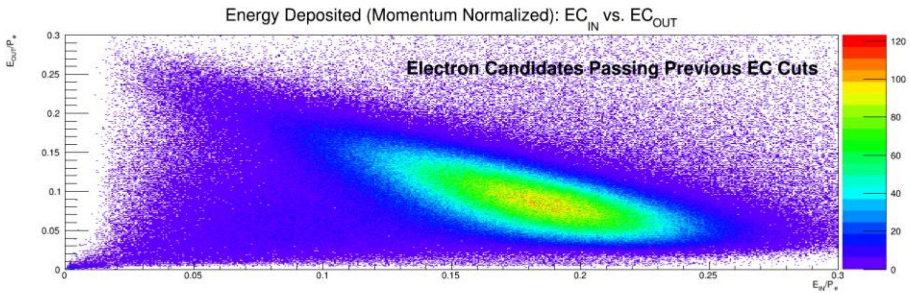


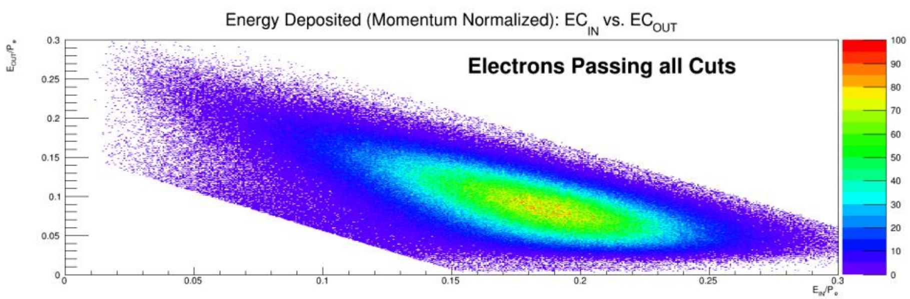


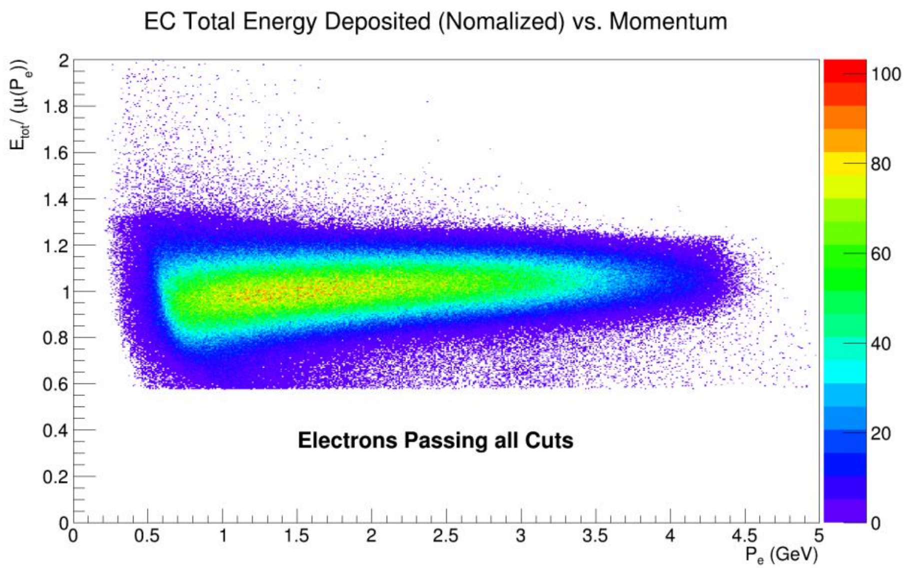




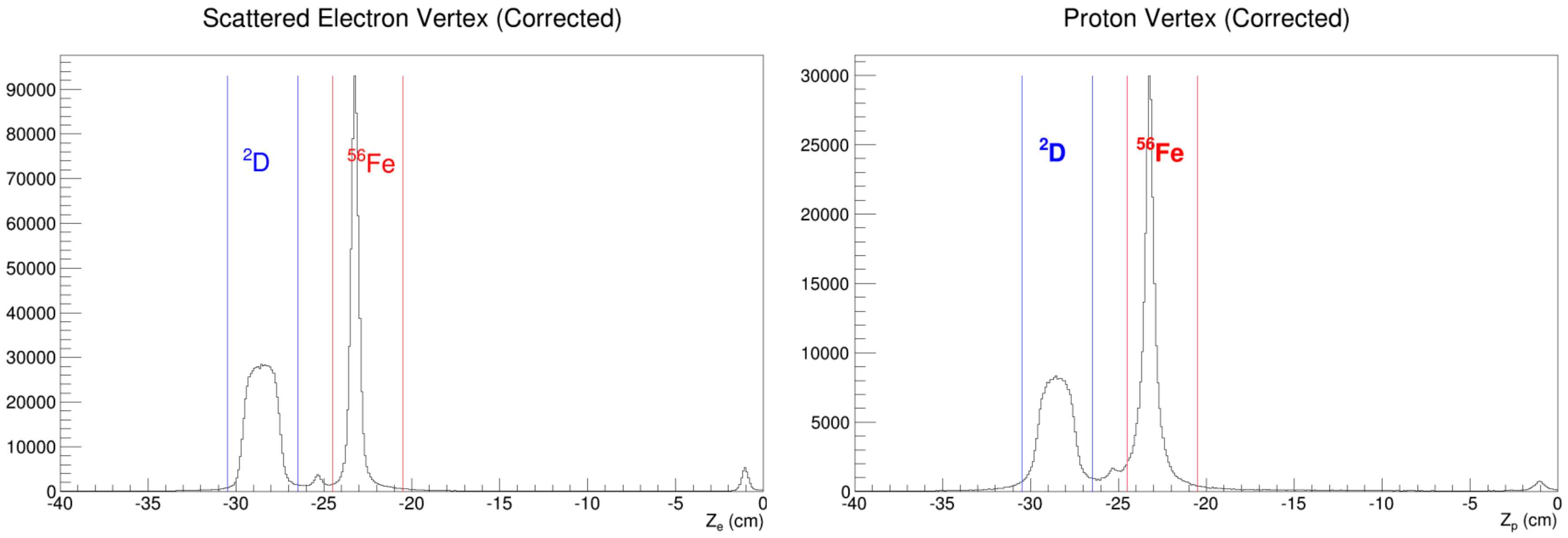
Electron Particle ID (cont.)



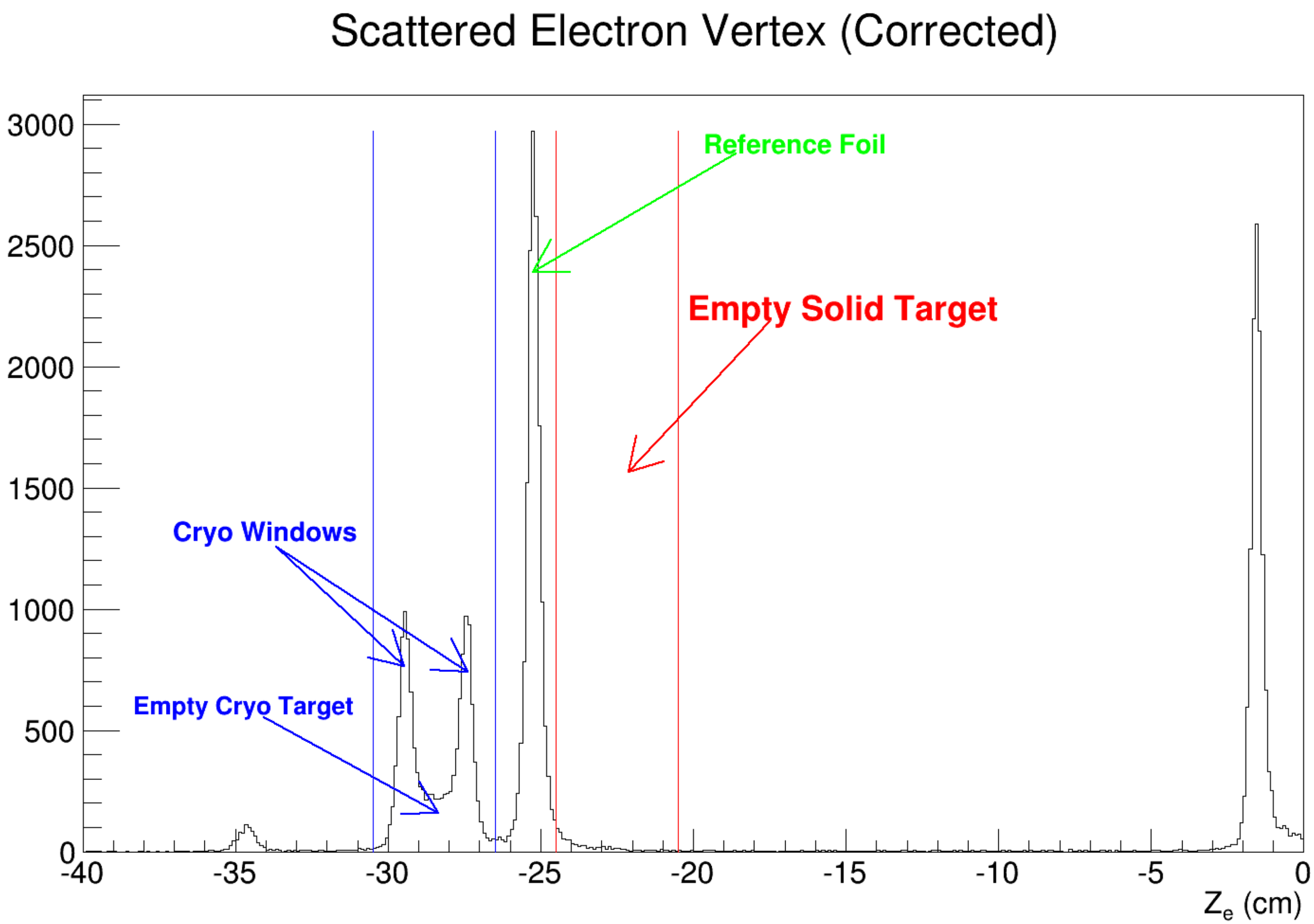




Vertex Selection



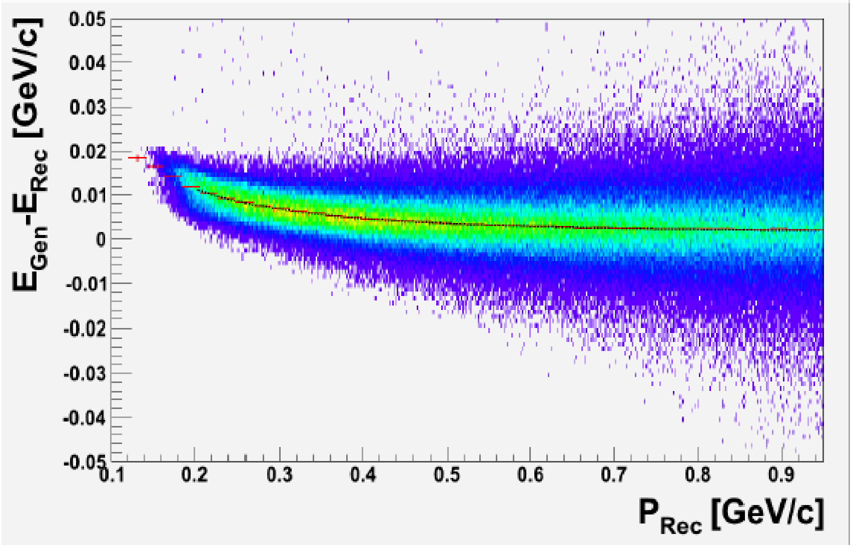
Cryo Target Windows

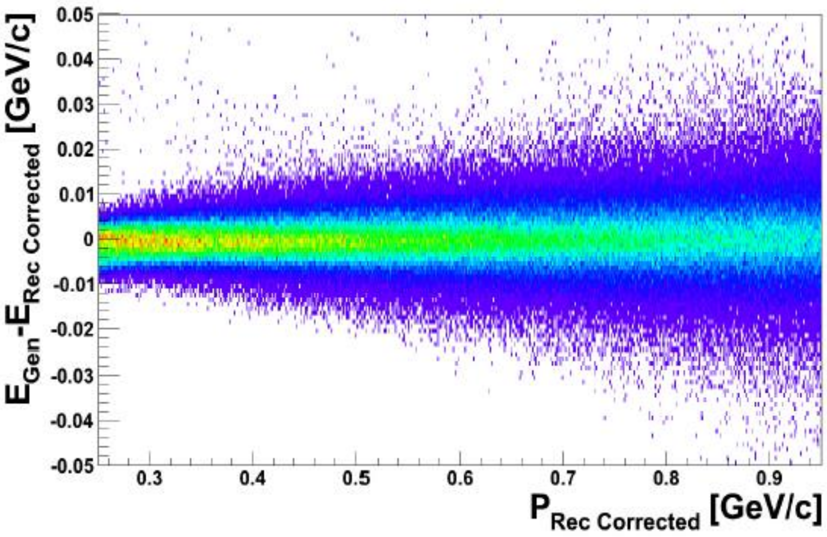


Proton Energy Loss Correction

- A correction for the proton energy loss is made using the CLAS Geant3 simulation
- $dE = 0.0013 + \frac{0.00084}{(0.074+|P_{Rec}|)^2}$
- For low energy protons, there is a large momentum correction; as well as a large uncertainty in the CLAS detection efficiency.
- So we select:

  $P_{rec,Cor} > 300$ MeV/c





Simulation: Nucleon Momentum Distributions

- Nucleon momentum distribution:

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

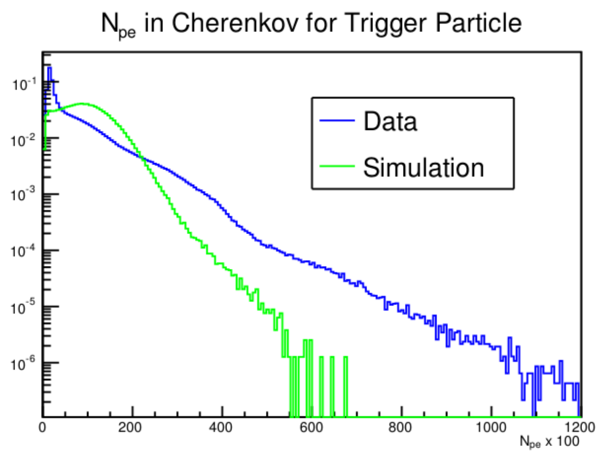
- n_0 takes into account the mean-field picture and n_1 is included if NN correlations are considered
- Calculation for various nuclei has been performed.
- The distribution is normalized to

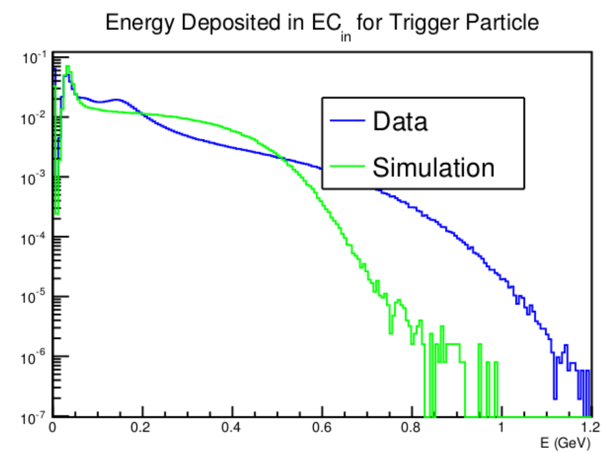
$$\int_0^\infty dk\, k^2 n(k) = 1$$

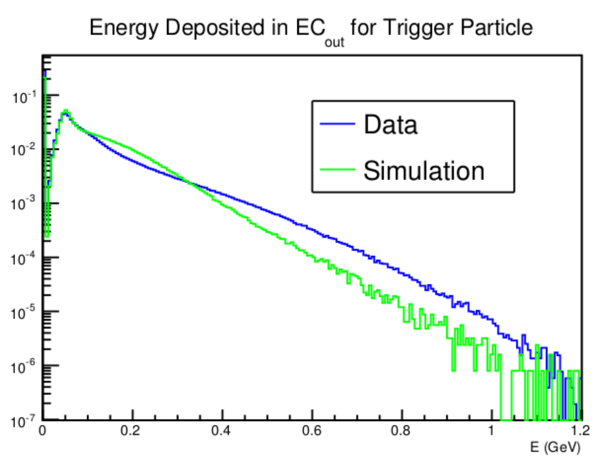
Simulation: Generating the Spectator Nucleon

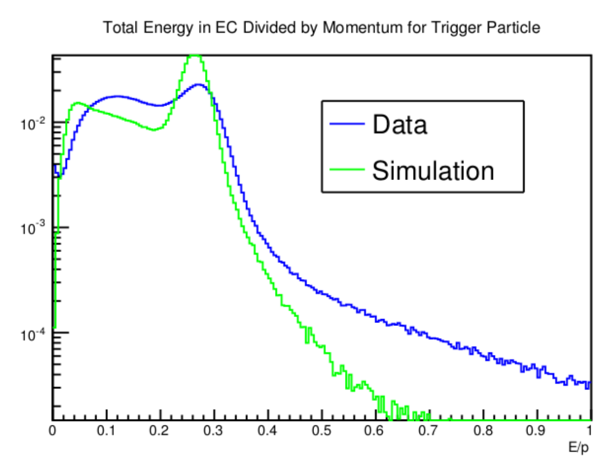
- Event Generator was modified to place nucleons in SRC pairs above the Fermi Momentum
- A spectator nucleon is generated when the struck nucleon has sufficient initial momentum
- The spectator nucleon has momentum opposite the struck nucleon in the pair's center of mass frame
- For the solid targets, 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.

Data/Simulation Comparison: Detector Response









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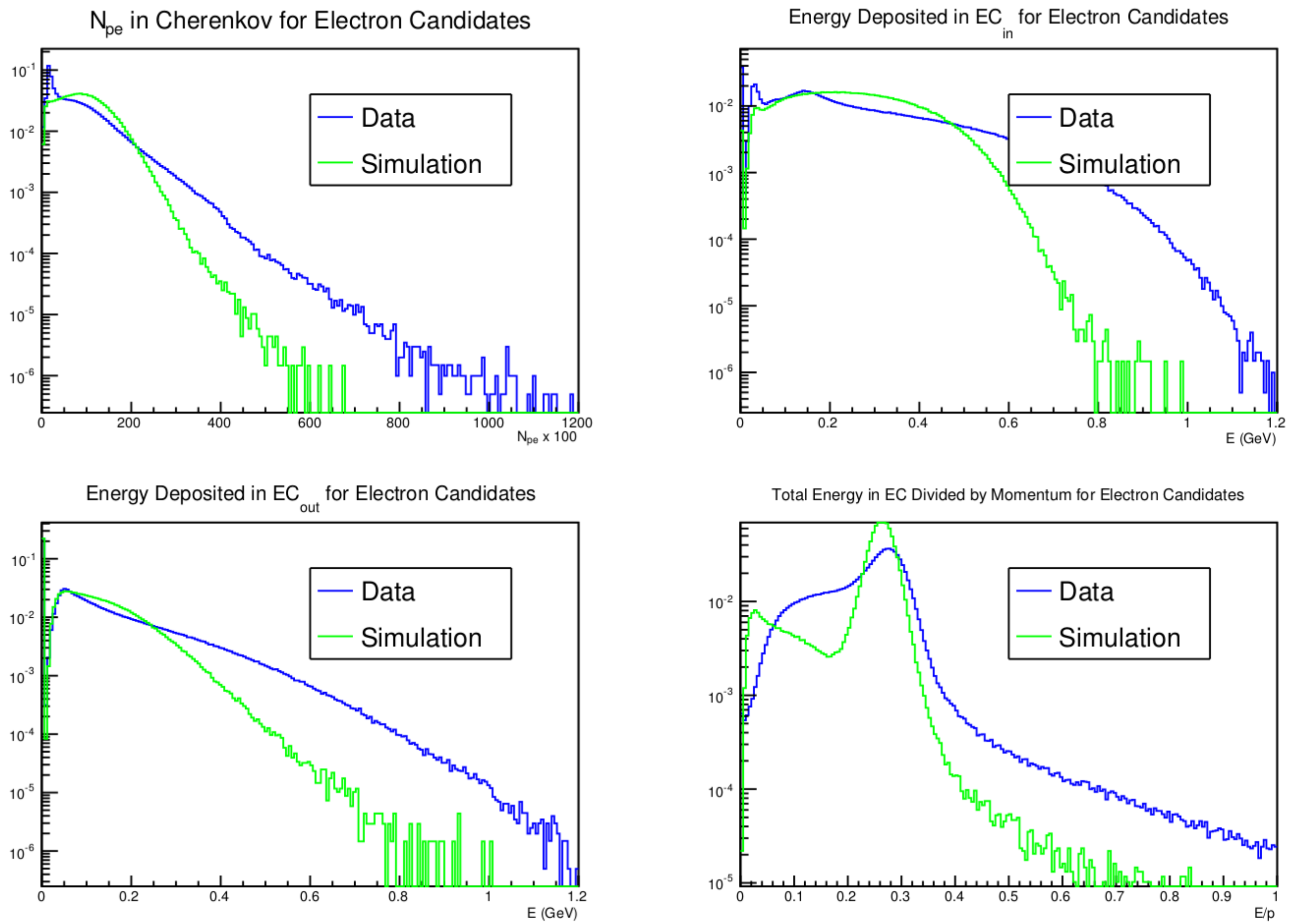

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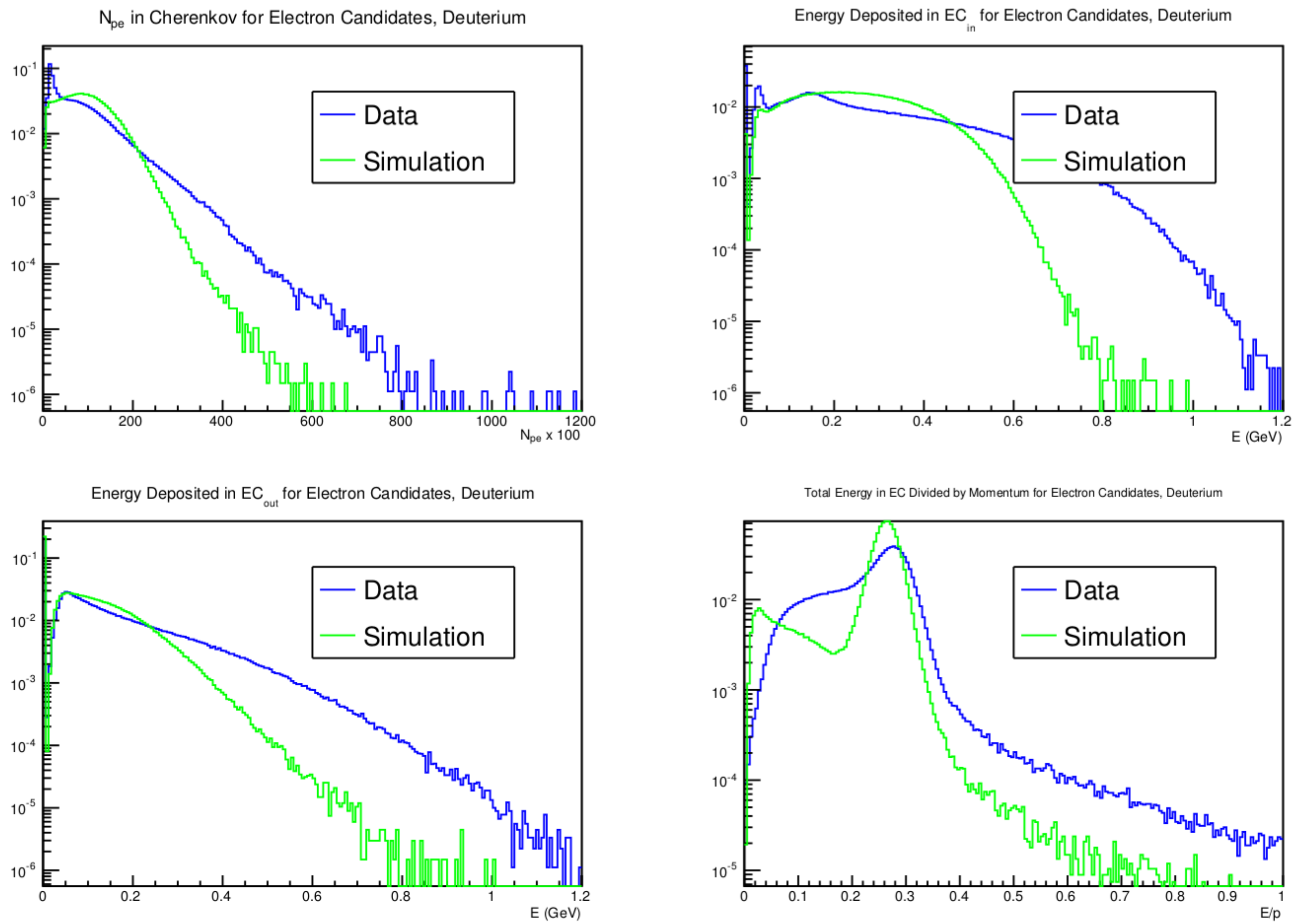
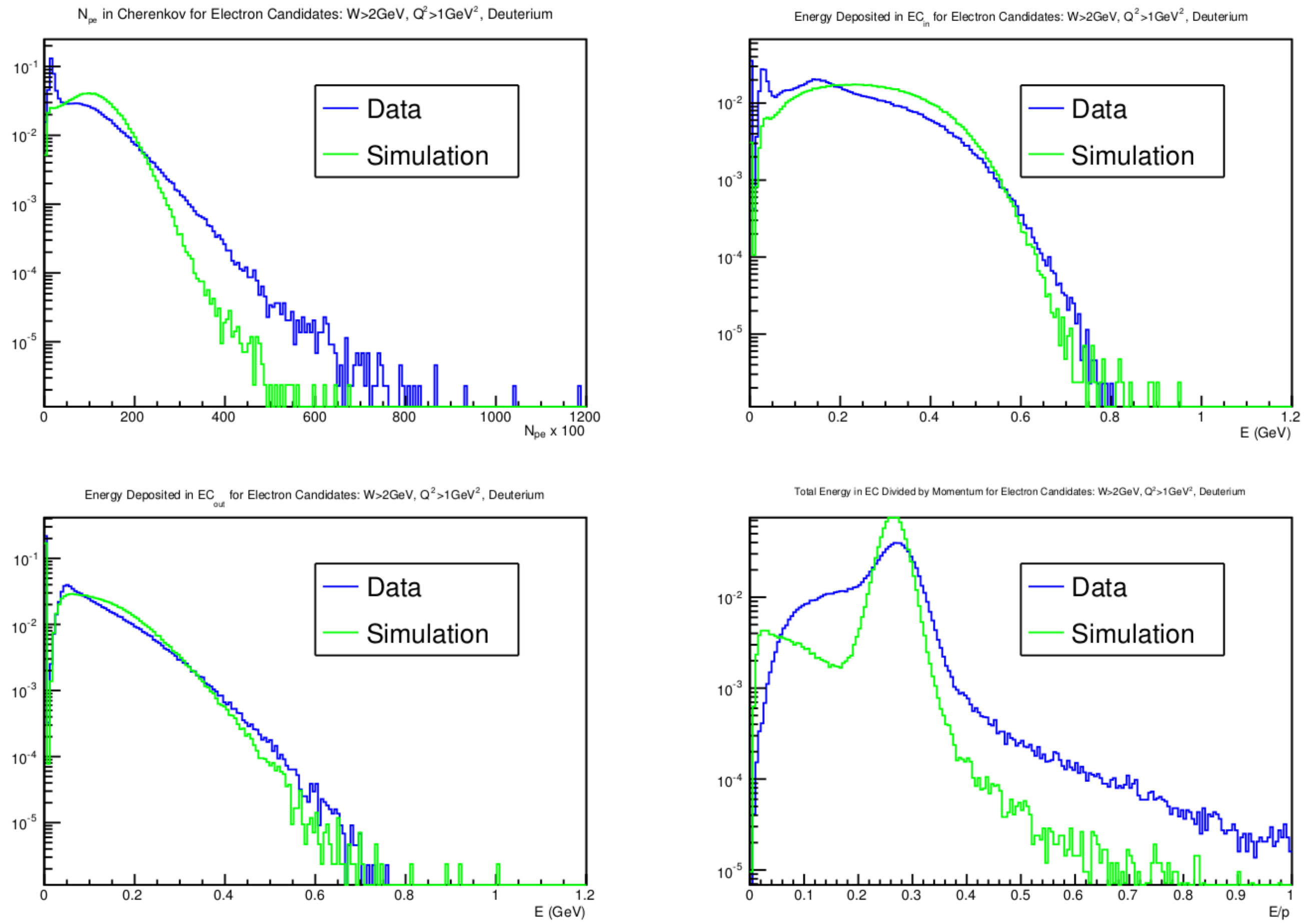


Data/Simulation Comparison: Detector Response



Neutrons and Protons F_2