BONuS12 Analysis Status Report

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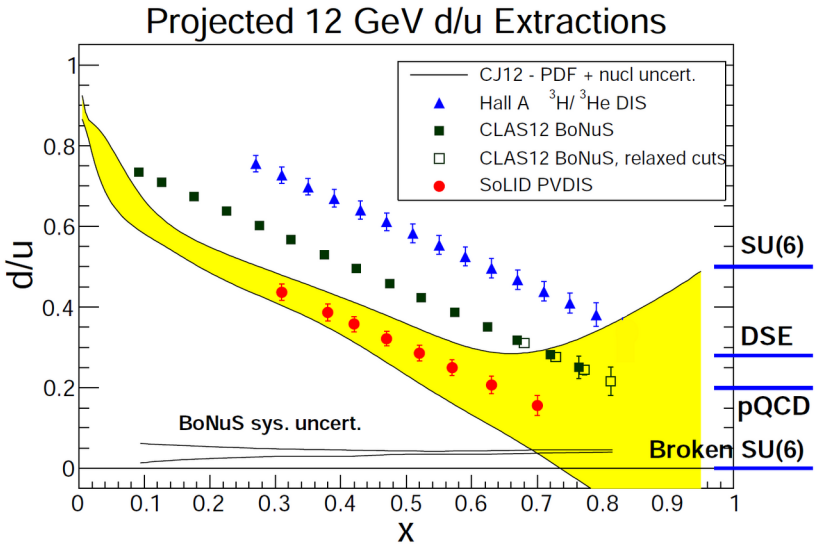
(On behalf of the CLAS Collaboration)

- **Physics Motivations.**
- **Experimental Setup.**
- **Status of Data Analysis.**
- **Conclusions.**

BONuS12: Spectator Tagging of Barely Off-Shell Neutrons in D(e, e`p_s)X

- DIS experiments have provided precise measurements on F_2^p, F_2^d up to fairly large x, but less precision on F_2^n specially at large x, where the theoretical modules have different predictions.

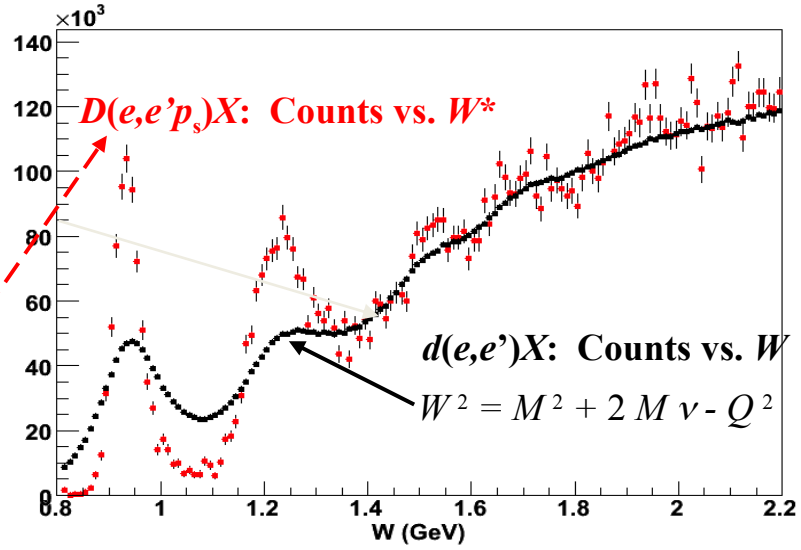


- F_2^n is obtained from measurements on bound neutrons, but F_2^n extraction at large *x* introduces theoretical model dependence on nuclear corrections (Fermi motion, nucleon off-shell corrections, FSI, .

- **BONuS12** constrains the nuclear uncertainties by using the **Spectator Tagging** technique, where correcting the neutron's kinematics implemented by measuring the spectator-proton results in improved resolution and constrains the kinematics of the knocked initial neutron to the phase-space where the nuclear uncertainties are minimized.

$$W^{*2} \approx M^{*2} - Q^2 + 2M\nu\,(2 - \alpha_s)$$

$$M^{*2} = (M_d - E_s)^2 - \vec{p}_s^{\,2} \qquad \alpha_s = \frac{E_s - p_{s_{||}}}{M_s}$$



BONuS12 Nuclear Uncertainties

Final State Interactions:

- Struck neutron interacts with the spectator p.
- Proton momentum is enhanced.
- FSIs are small at low p_s and large θ_{pq}.

Target Fragmentation:

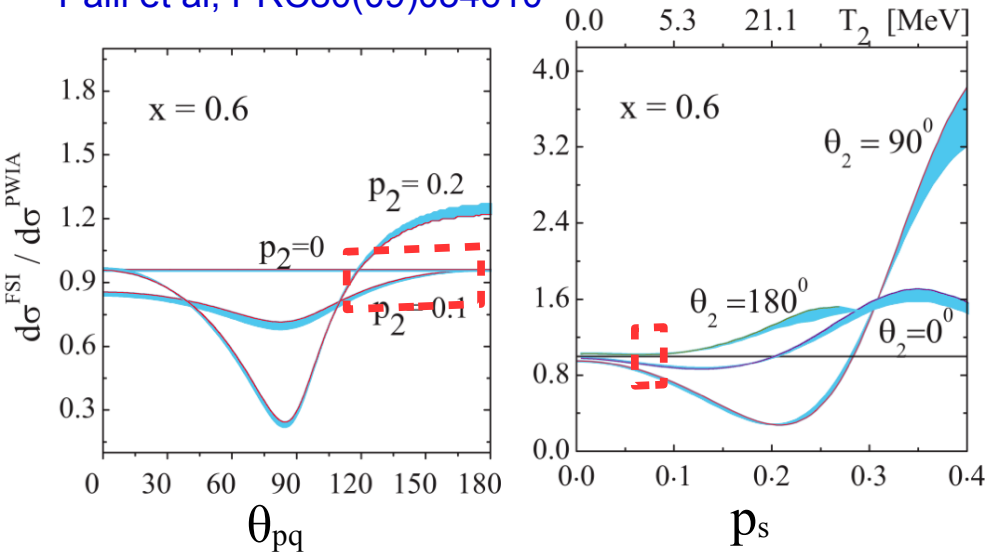
- e n → e p X (where n → π^- p) and
  e p → e p X (where p → π^0 p).
- TF enhances the proton yield only at forward angles ($\cos\theta_{pq}$ >0.6).

Off-Shell Corrections:

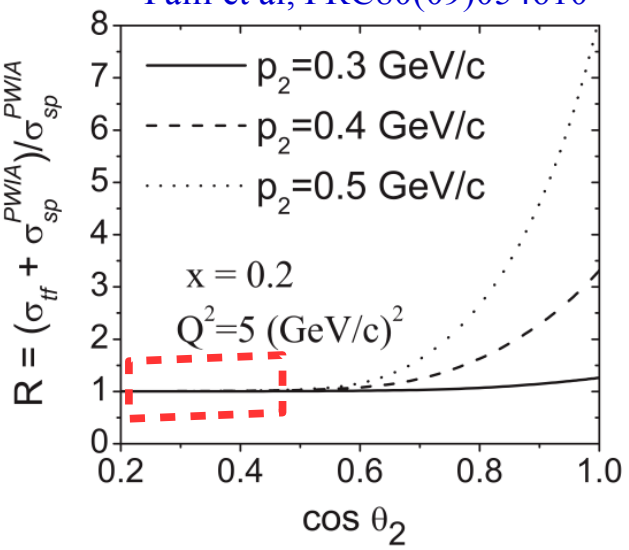
- Less than 2% in our region.

Overall systematic uncertainties will be less than 6%

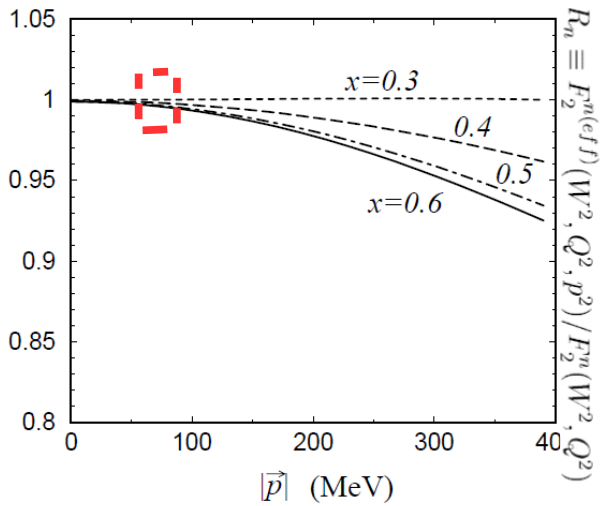
Palli et al, PRC80(09)054610



Palli et al, PRC80(09)054610



Melnitchoul et al, PRL B335,11(1994)



F_2^n/F_2^p Extraction Method

$\underline{D(e,e')X}$

$$R_{\text{inc}}(x,Q^2) = \frac{Y_{\text{inc}}^{\text{Data}}}{Y_{\text{inc}}^{\text{MC}}} \propto \frac{F_{2d}^{\text{true}}(x,Q^2)}{F_{2d}^{\text{Gen}}(x,Q^2)}$$

$$Y_{\text{inc}}^{\text{Data}}(x,Q^2) \sim \mathcal{L}\cdot \text{A}(x,Q^2)\cdot \eta(x,Q^2)\cdot \Delta\sigma_{\text{inc}}(x,Q^2),$$

$$Y_{\text{inc}}^{\text{MC}}(x,Q^2) \sim \mathcal{L}_{\text{LUND}}\cdot \text{A}(x,Q^2)\cdot \eta(x,Q^2)\cdot \Delta\sigma_{\text{inc}}^{\text{Sim}}(x,Q^2),$$

With the assumption that $\Delta\sigma \propto F_{2d}$

$\underline{D(e,e'p_s)X}$

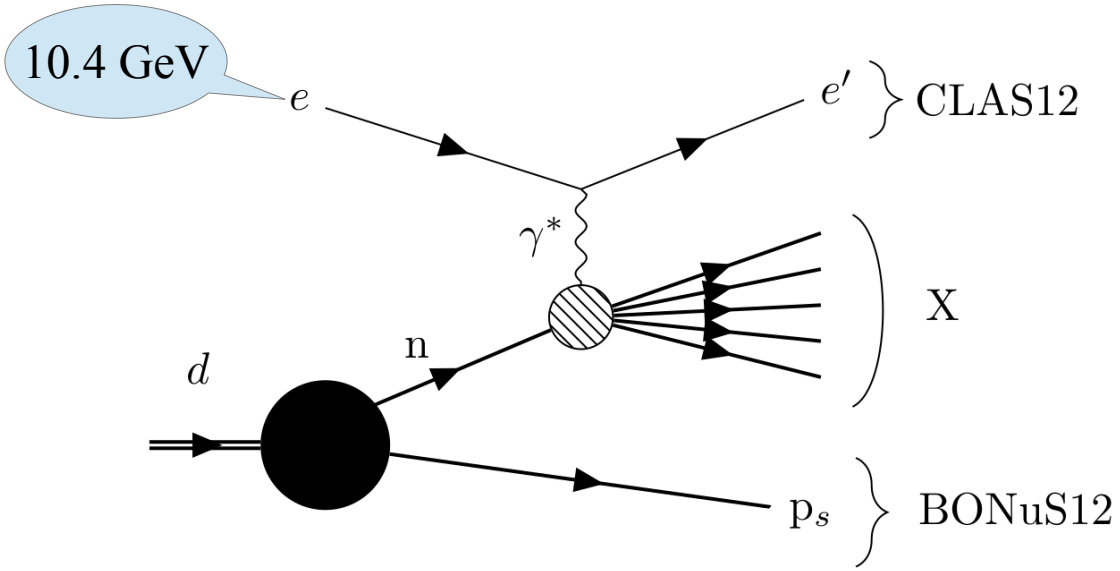
$$R_{\text{tag}}(x',Q^2) = \frac{Y_{\text{tag}}^{\text{Data}}}{Y_{\text{tag}}^{\text{MC}}} \propto \frac{F_{2n}^{\text{true}}(x',Q^2)}{F_{2n}^{\text{Gen}}(x',Q^2)}$$

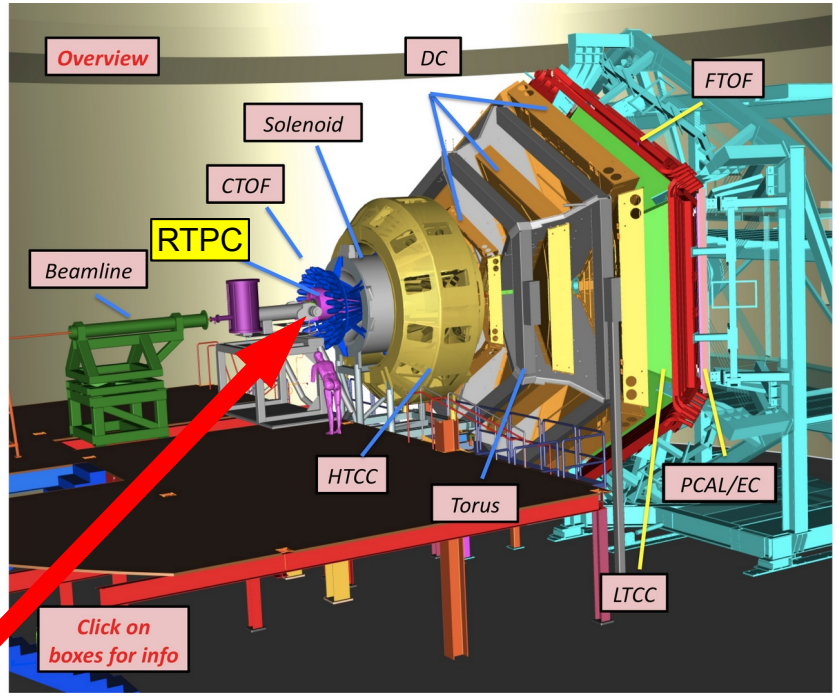
$$SR = \frac{R_{\text{tag}}(x',Q^2)}{R_{\text{inc}}(x,Q^2)} = \frac{\left(Y_{\text{tag}}^{\text{Data}}/Y_{\text{tag}}^{\text{MC}}\right)}{\left(Y_{\text{inc}}^{\text{Data}}/Y_{\text{inc}}^{\text{MC}}\right)} = \frac{\left(Y_{\text{tag}}^{\text{Data}}/Y_{\text{inc}}^{\text{Data}}\right)}{\left(Y_{\text{tag}}^{\text{MC}}/Y_{\text{inc}}^{\text{MC}}\right)} = \text{Constant}\cdot \frac{\left(\frac{F_{2n}}{F_{2d}}\right)^{\text{true}}}{\left(\frac{F_{2n}}{F_{2d}}\right)^{\text{Gen}}}$$

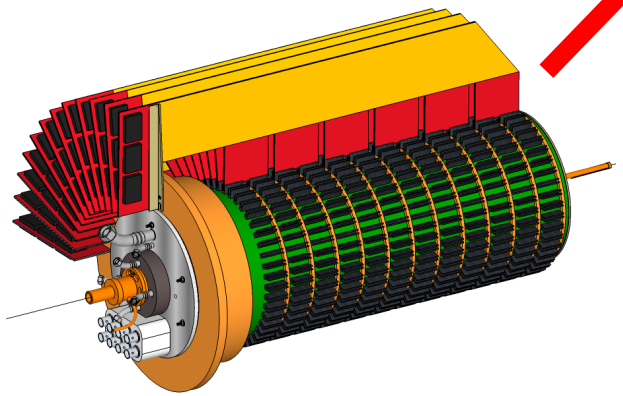
$$\left(\frac{F_{2n}}{F_{2d}}\right)^{\text{true}} = \text{Constant}\cdot \left(\frac{F_{2n}}{F_{2d}}\right)^{\text{Gen}} * \frac{\left(Y_{\text{tag}}^{\text{Data}}/Y_{\text{inc}}^{\text{Data}}\right)}{\left(Y_{\text{tag}}^{\text{MC}}/Y_{\text{inc}}^{\text{MC}}\right)}$$

$$\left(\frac{F_2^n}{F_2^p}\right)^{\text{true}} = \left(\frac{F_{2n}}{F_{2d}}\right)^{\text{true}} * \left(\frac{F_{2d}}{F_{2p}}\right)^{\text{fit}} \quad \& \quad \frac{d}{u} \approx \frac{4F_{2n}/F_{2p} - 1}{4 - F_{2n}/F_{2p}}$$

BONuS12 Experimental Setup





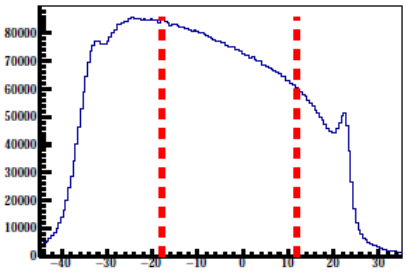


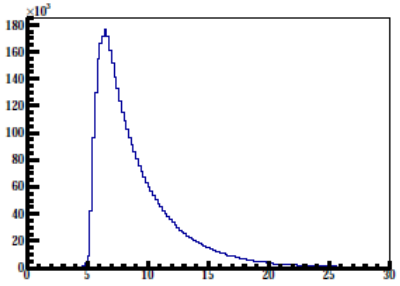
Beam Energy	Target	Spring 2020	Summer 2020
1 Pass Data	H2	81M	185M
	D2	37M	45M
	4He	19M	44M
	Empty	1M	22M
	Total	138M	296M
5 Pass Data	H2	151M	266M
	D2	2275M	2355M
	4He	77M	51M
	Empty	21M	45M
	Total	2524M	2717M

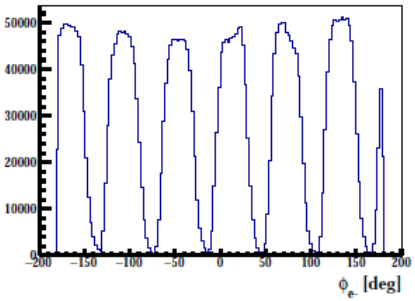
February – March 2020 | MEDCON6 | August-September 2020

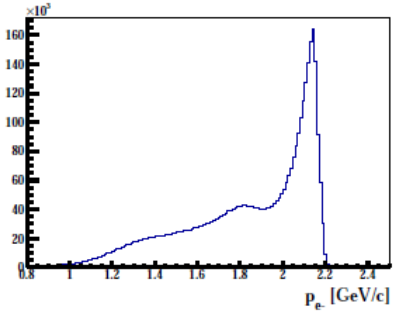
2.1 GeV Calibration Data

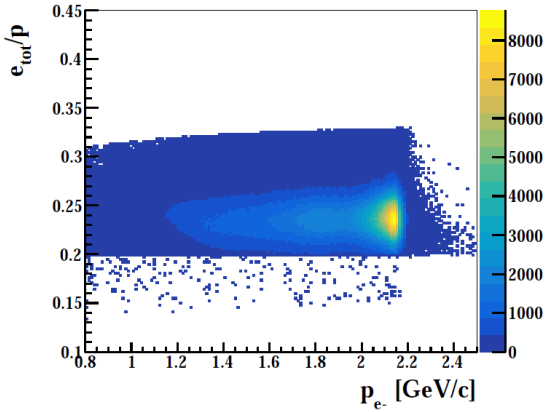
Electron Selection : 2.14 GeV on H_2 target



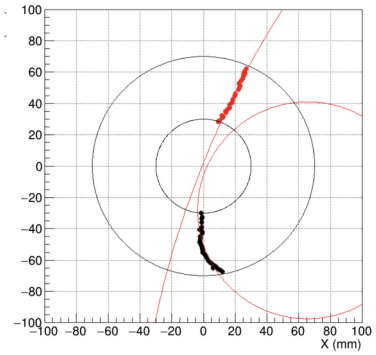


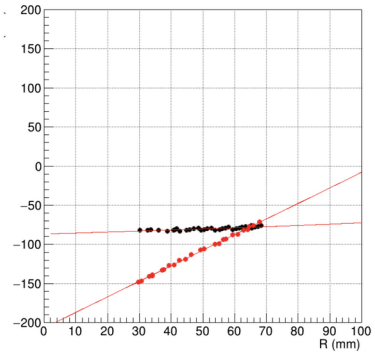


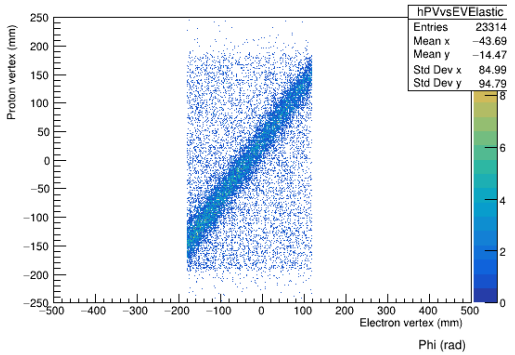


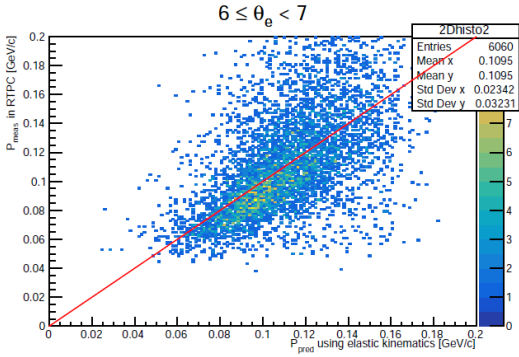


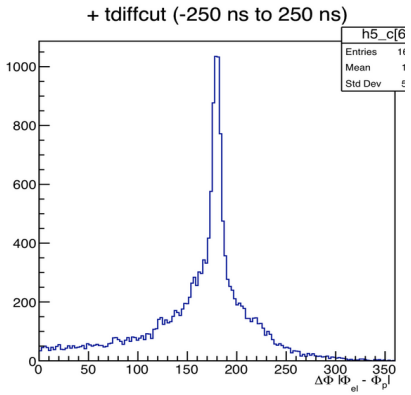
Radiative elastic e- in coincidence with good p tracks:

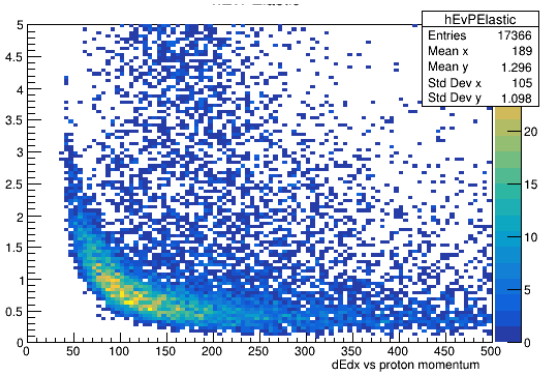










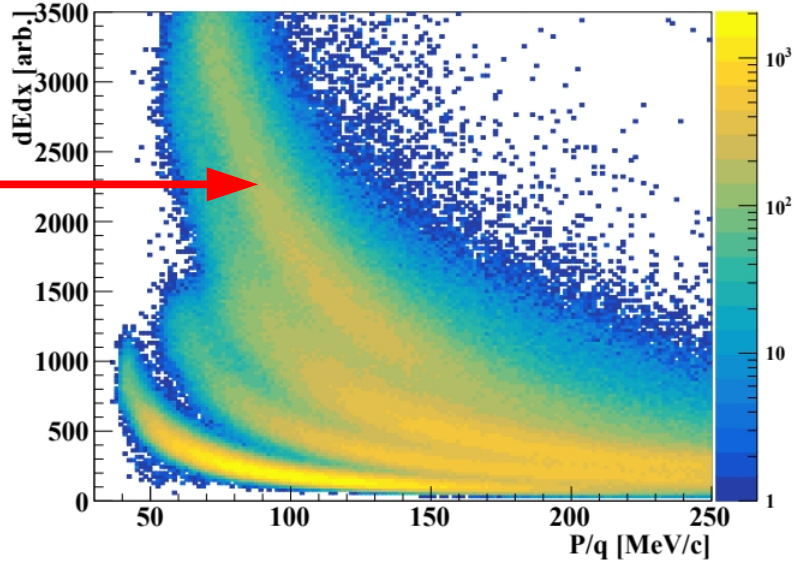


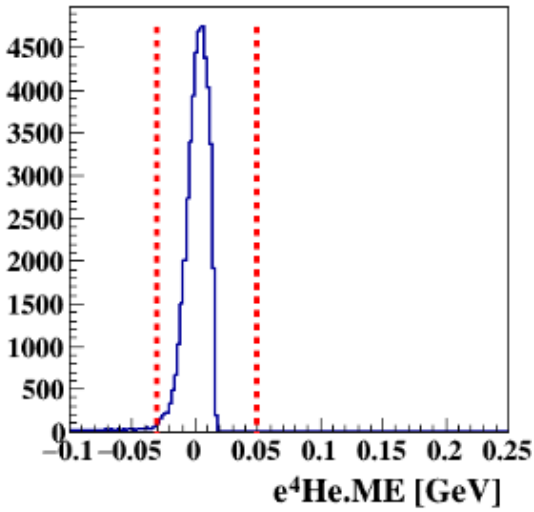
BONuS12 RTPC Resolutions

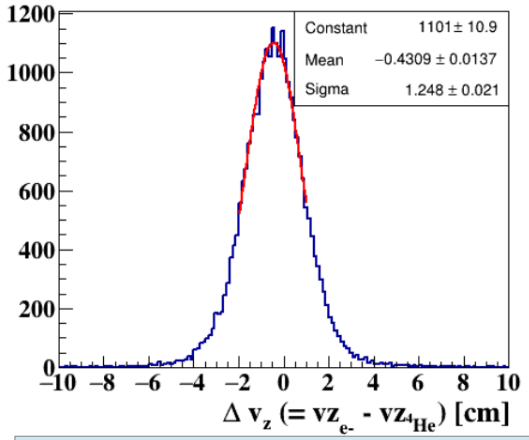
2.14 GeV e- beam on ^{4}He target

Elastic Events on ^{4}He:

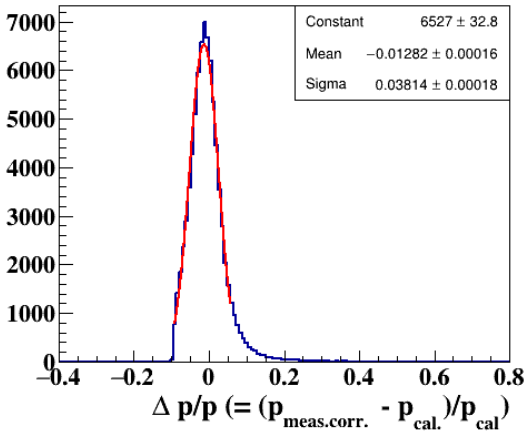
$$e^4He \rightarrow e^4He$$



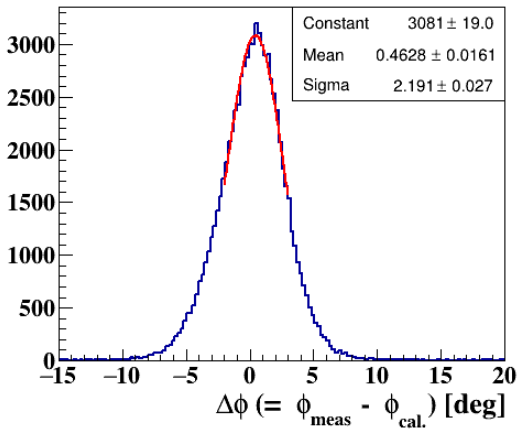




1.2 cm combined CLAS12-RTPC vertex resolution



4% momentum resolution



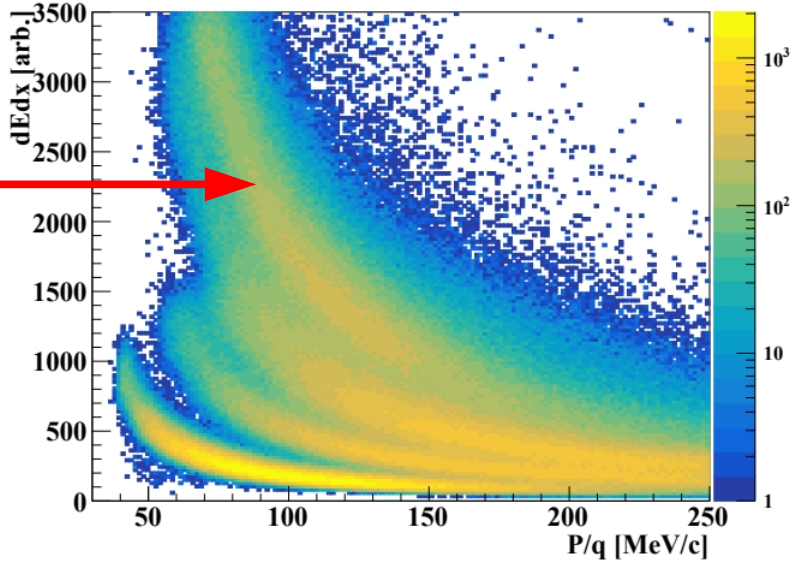
2° azimuthal angle resolution

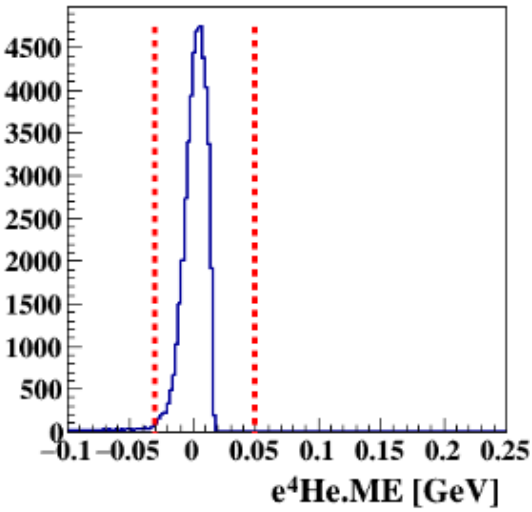
BONuS12 RTPC Detection Efficiency

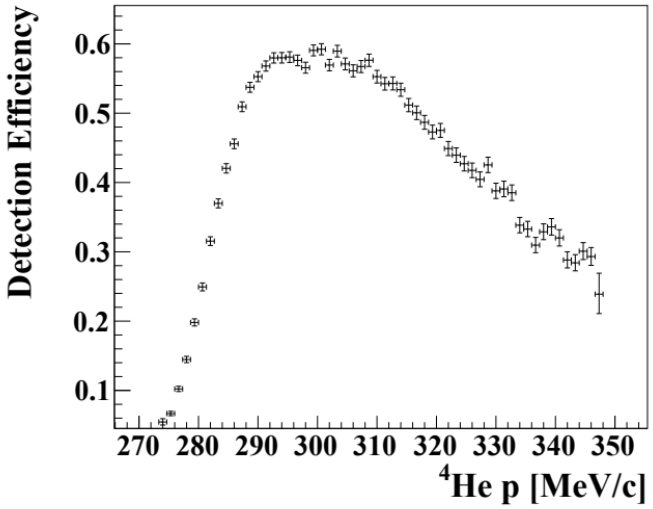
2.14 GeV e- beam on ^{4}He target

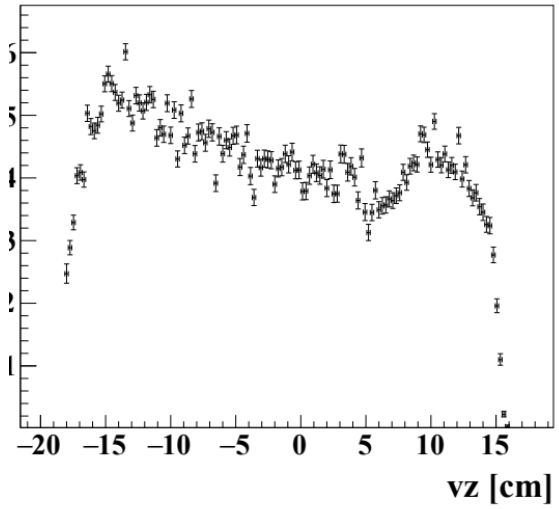
Elastic Events on ^{4}He:

$$e^4He \rightarrow e^4He$$









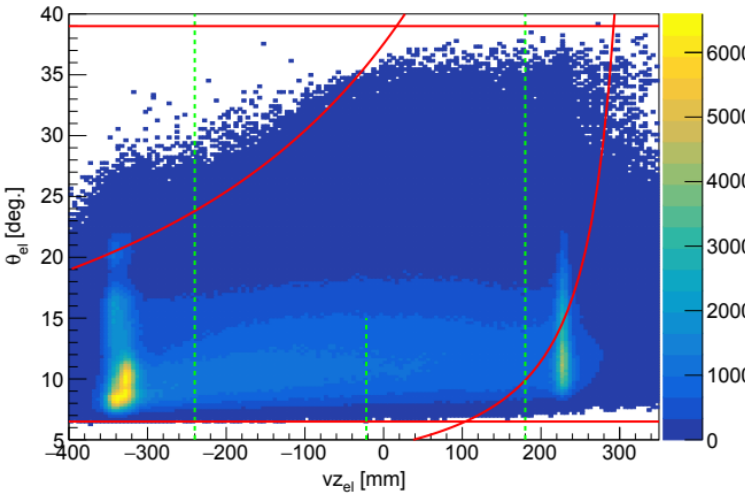
Nuclear Instruments and Methods in Physics Research A 1062 (2024) 169190

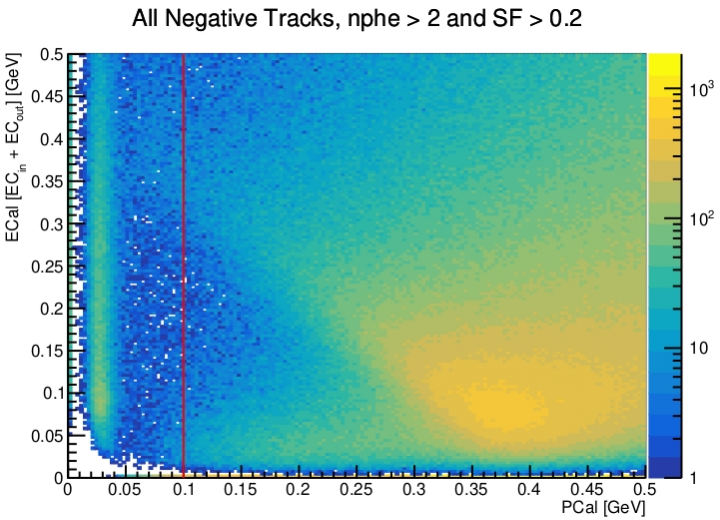
nDIS Events Selection @10.4 GeV

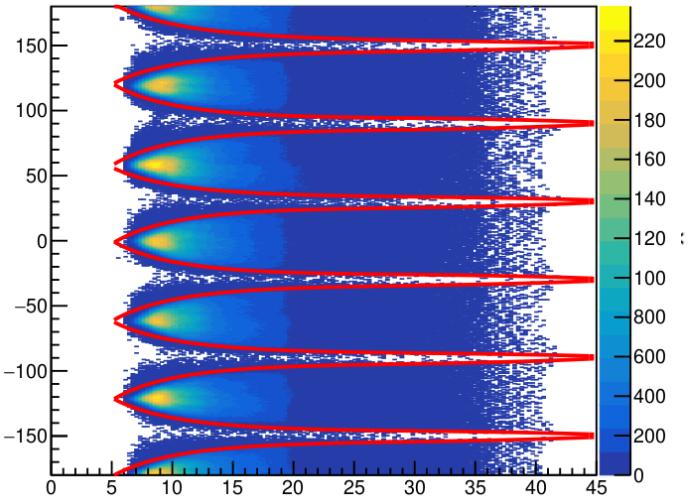
e- @10.4 GeV beam on D_2 target

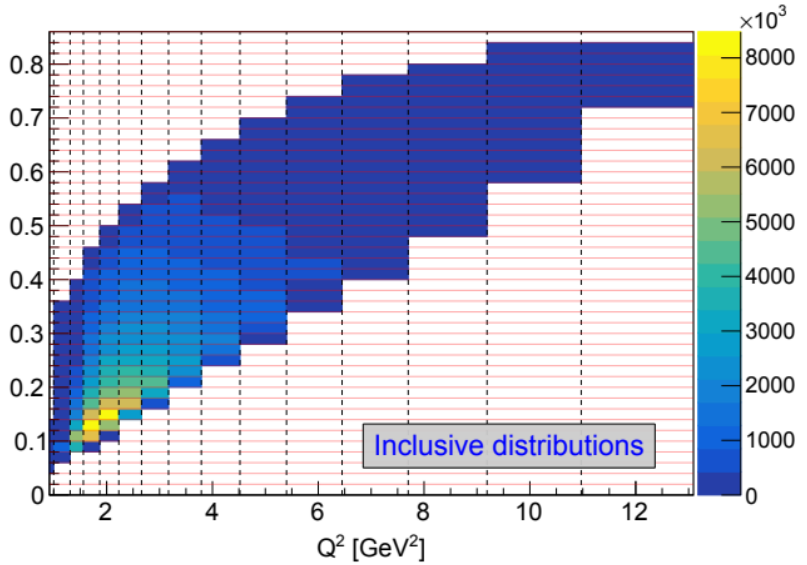
Electron selection cuts
- PID = 11
- nphe > 2
- $E_{tot}/p > 0.2$
- $EC_{in} > 10$ MeV
- $E_{PCal} > 100$ MeV
- DC fiducial cuts
- E' > 2 GeV

Additional DIS cuts
- W > 1.8 GeV
- $Q^2 > 1.0$ GeV^2









nDIS Events Selection @10.4 GeV

Proton Selection on D_2 target

RTPC track quality cuts:

- The radius of curvature of tracks (< 0)
- Cut on χ^2 of helix fitter (< 5)
- Number of hits in a track (> 10)
- Cut on the maximum radius (67-72) mm
- Fiducial cut (vz: (-210, 180)mm)

Coincidence cuts

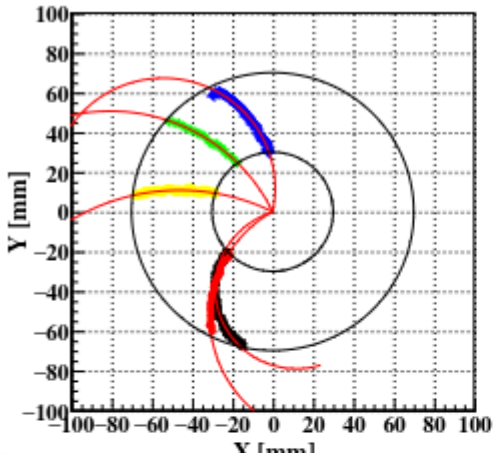
- Vertex coincidence cuts
- Timing coincidence

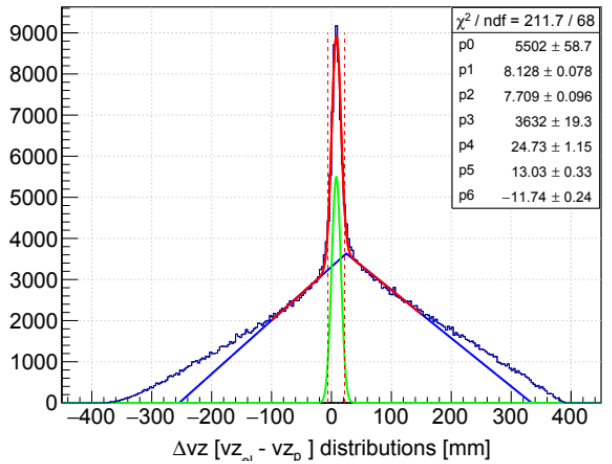
PID Cuts:

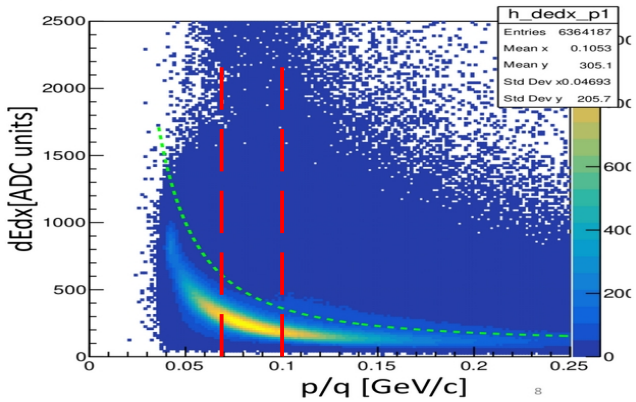
- Cuts on dEdx vs. p/q band for proton selection

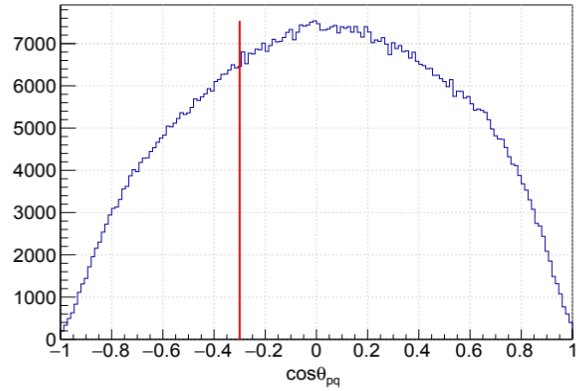
DIS & VIP cuts

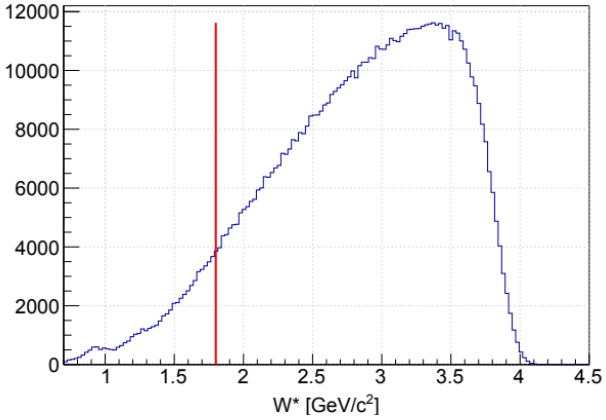
- W* > 1.8 GeV
- 0.07 < p < 0.1 GeV/c
- $\cos(\theta_{pq}) < -0.3$

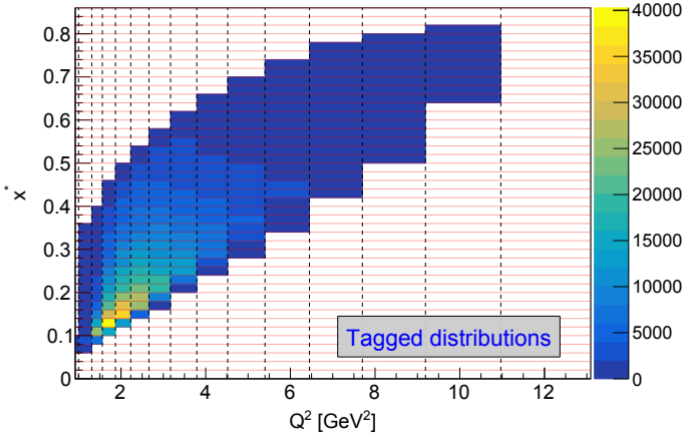






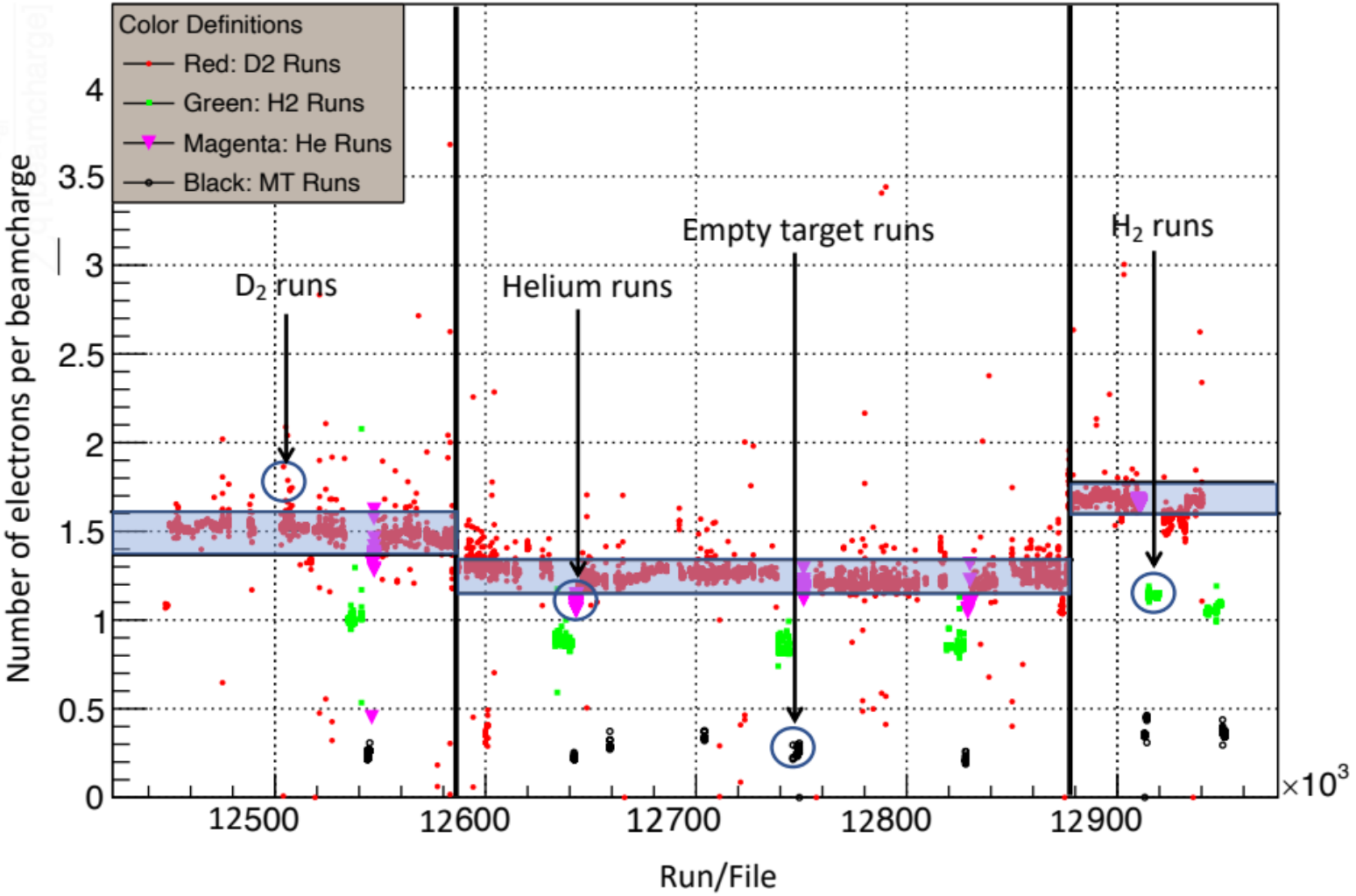






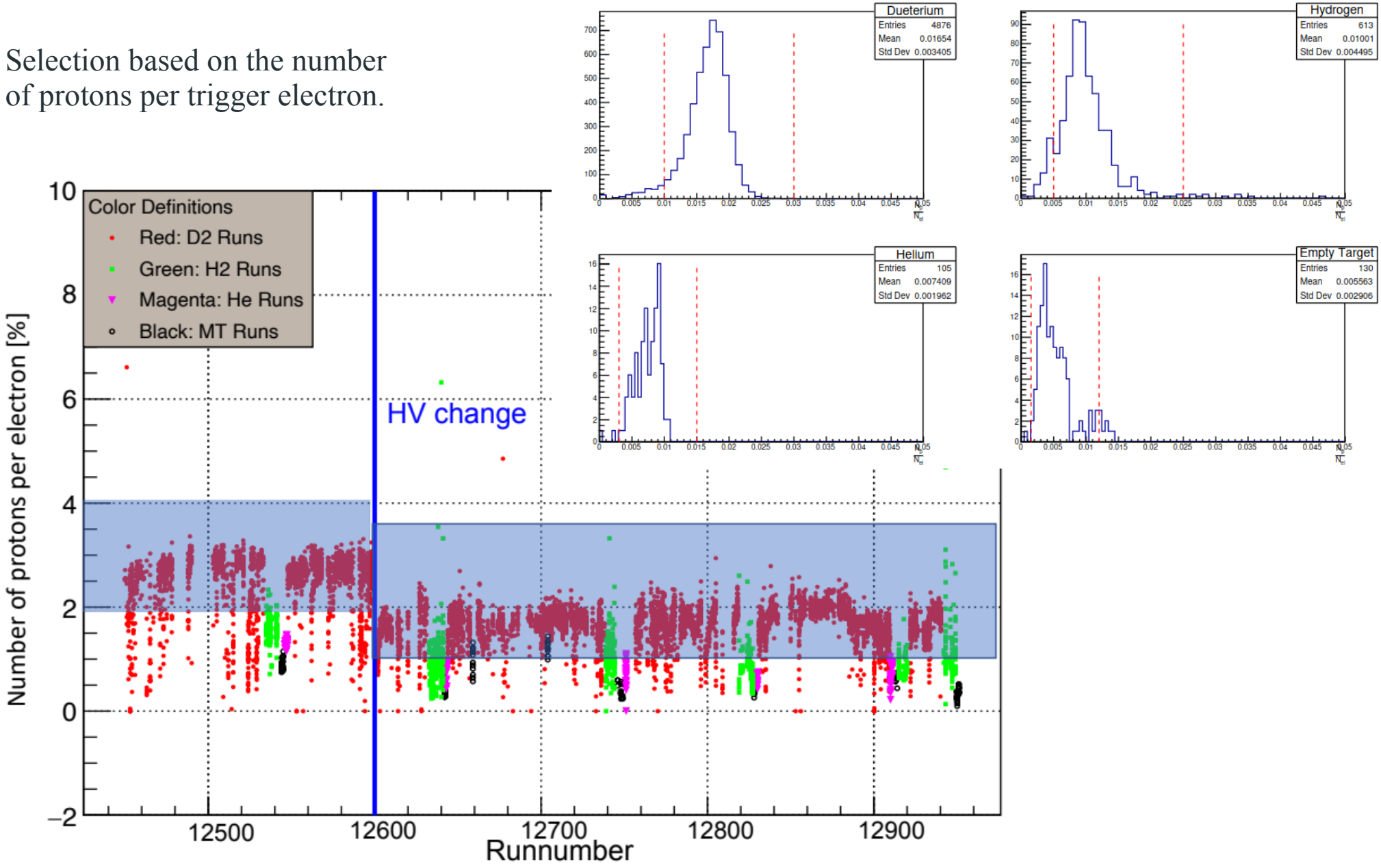
Run/File Data Evaluation & Selection (1/2)

- Selected based on the normalized electron yield per beam-charge, which is expected to be stable for same the same run conditions.



Run/File Data Evaluation & Selection (2/2)

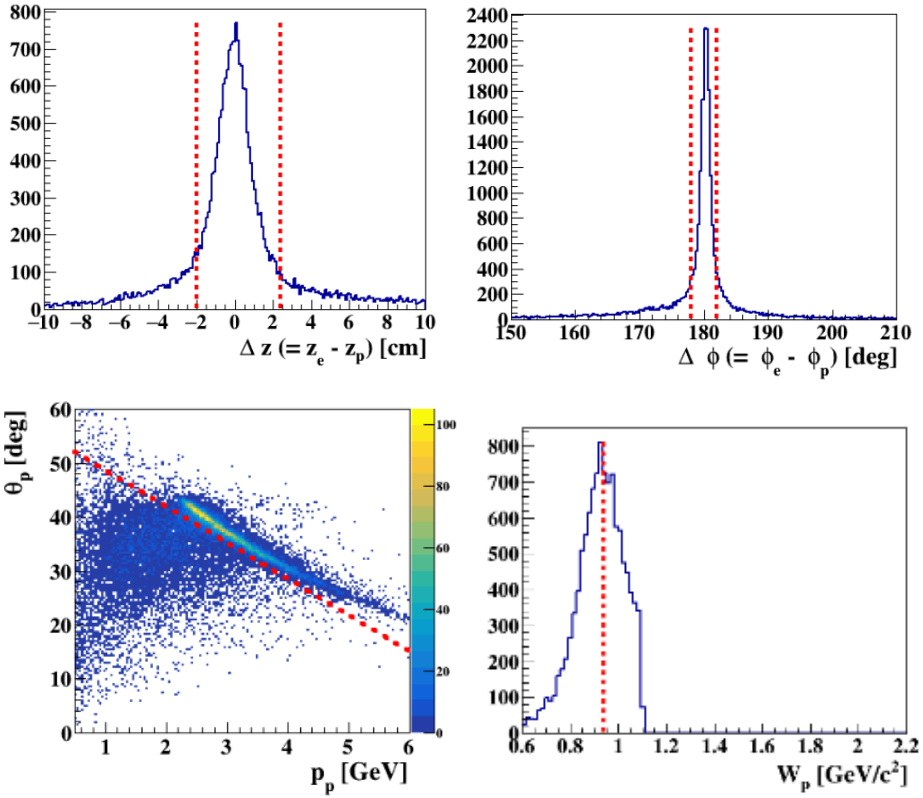
- Selection based on the number of protons per trigger electron.

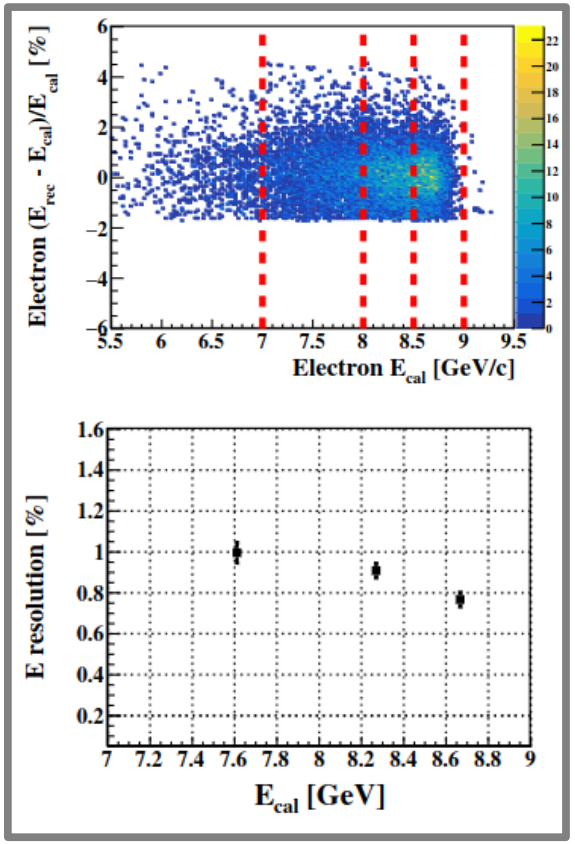


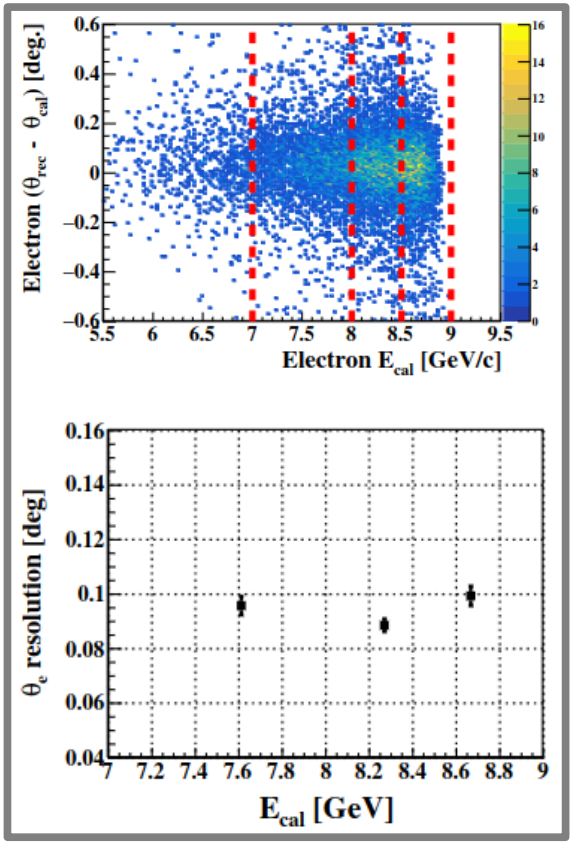
Data/MC Electron's Resolutions (1\2)

- Observed electron's E and θ resolutions from **Real Data** using the ep elastic events

ep→ep at 10GeV

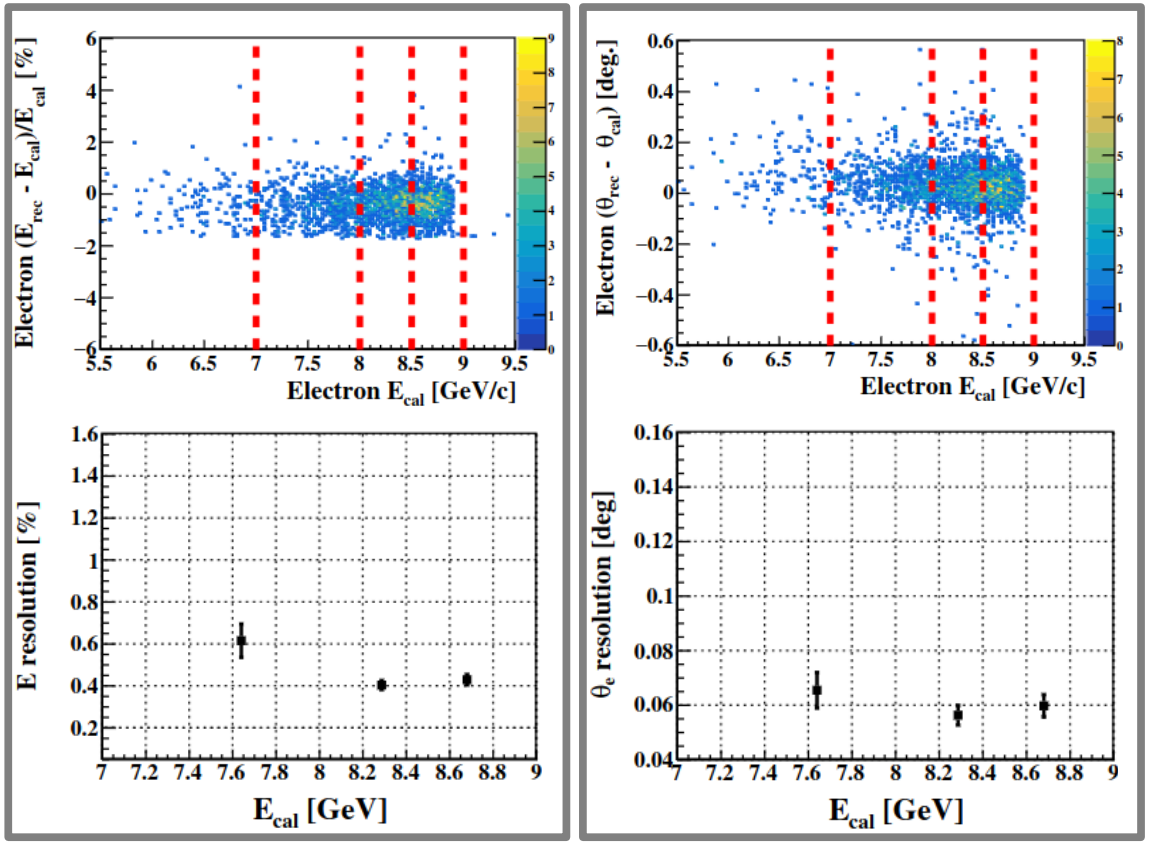




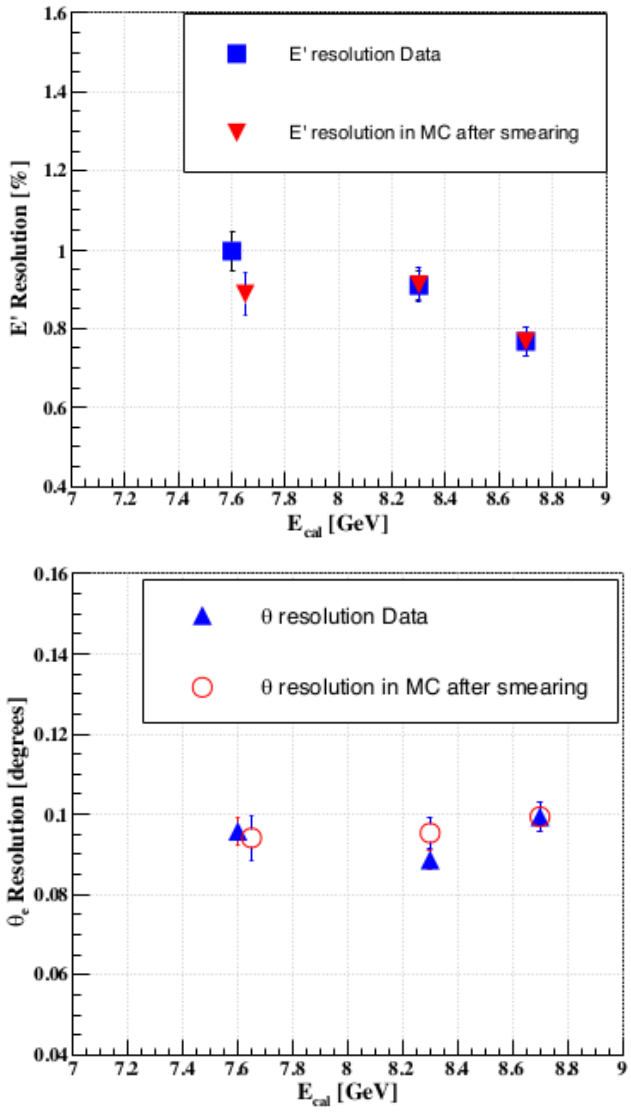


Data/MC Electron's Resolutions (2\2)

- Observed electron's E and θ resolutions from **GEMC** using the MC ep elastic events @ 10 GeV



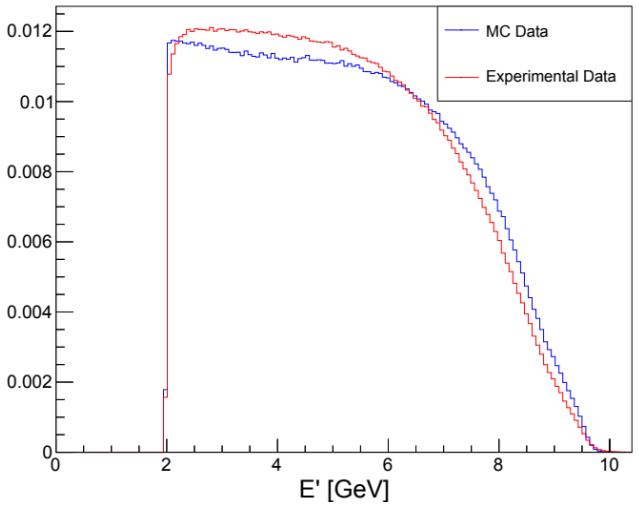
- MC resolutions after applying an ad-hoc smearing to the electron's E & θ:

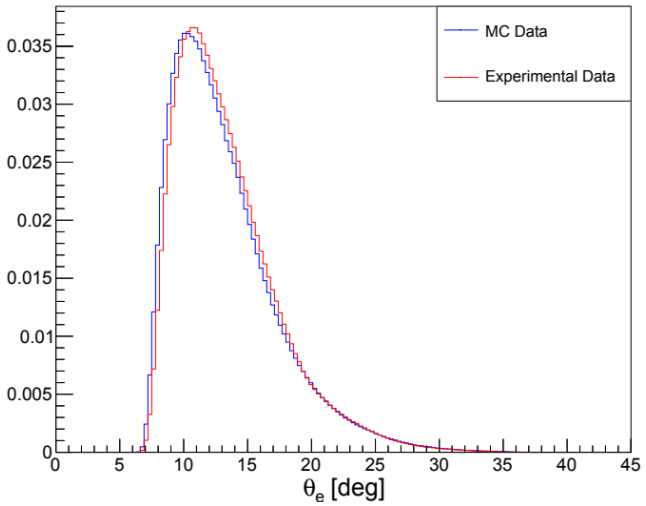


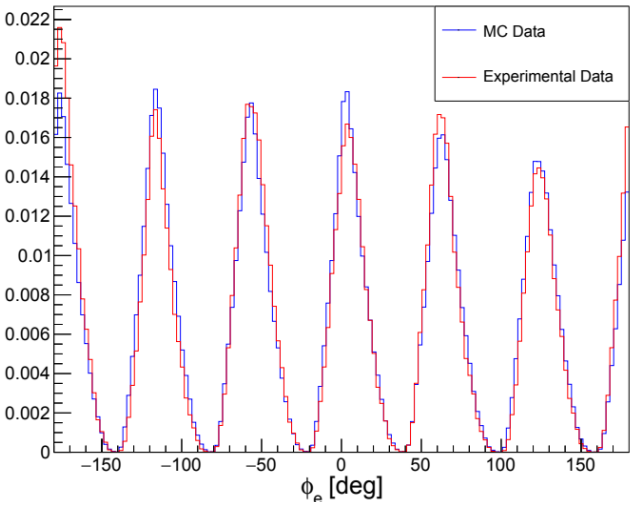
Data/MC Comparison: D(e,e')X

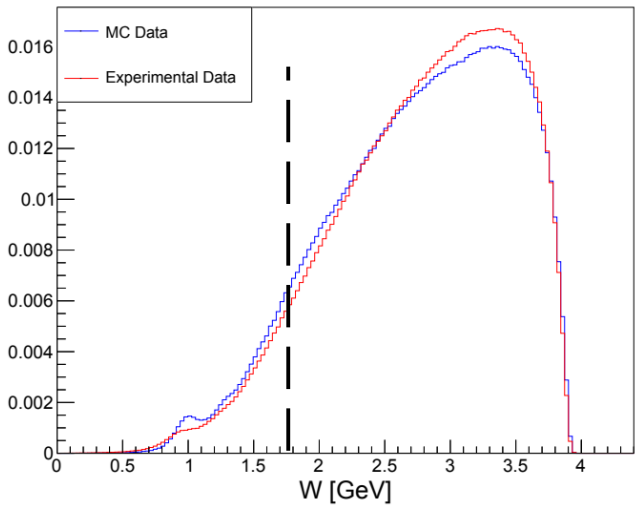
- Improved RTPC in GEMC for RG-F.
- **Generator**: An extension version from previous Bonus experiment that accommodates the higher beam energy.

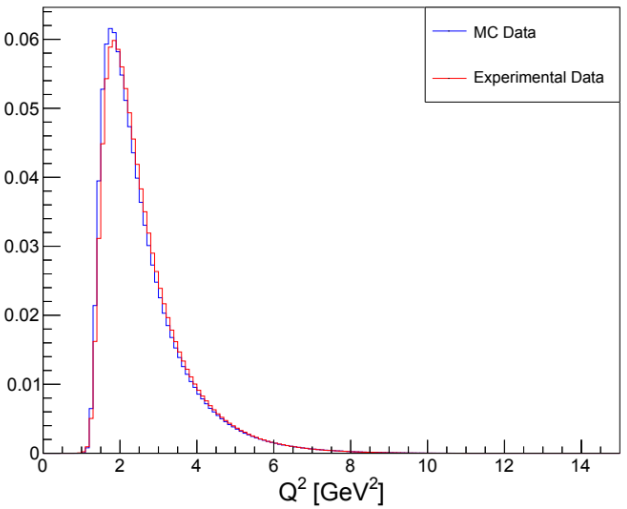
Inclusive e^- kinematics

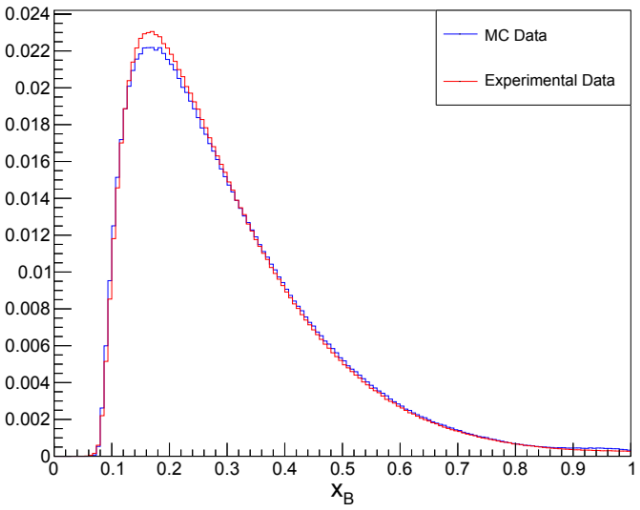






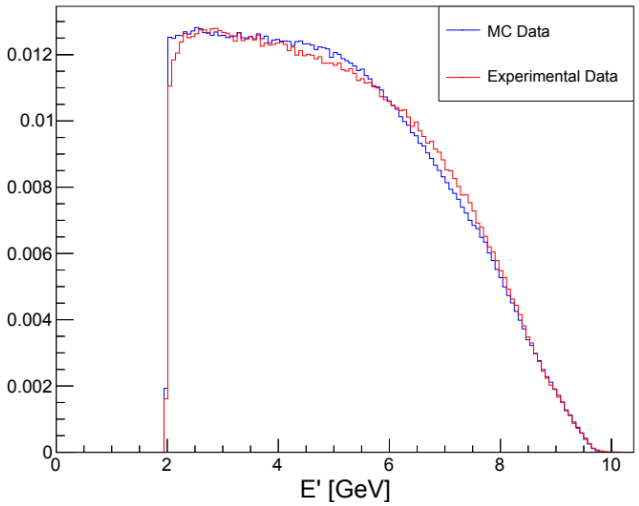


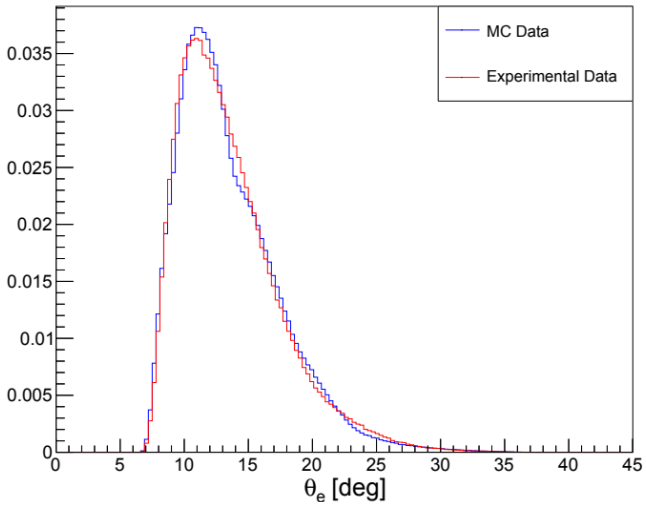


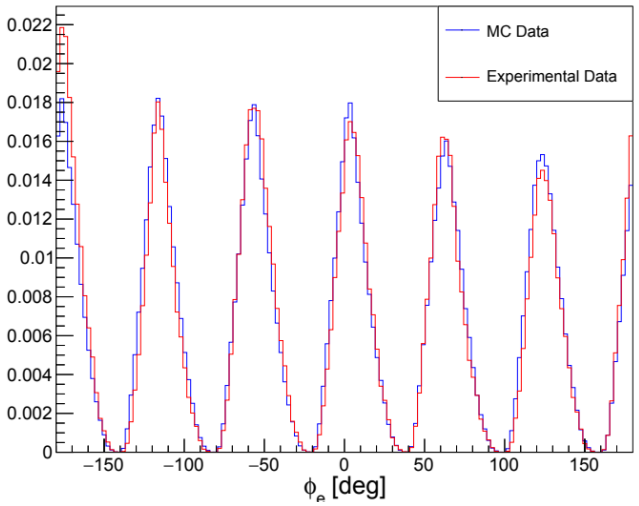


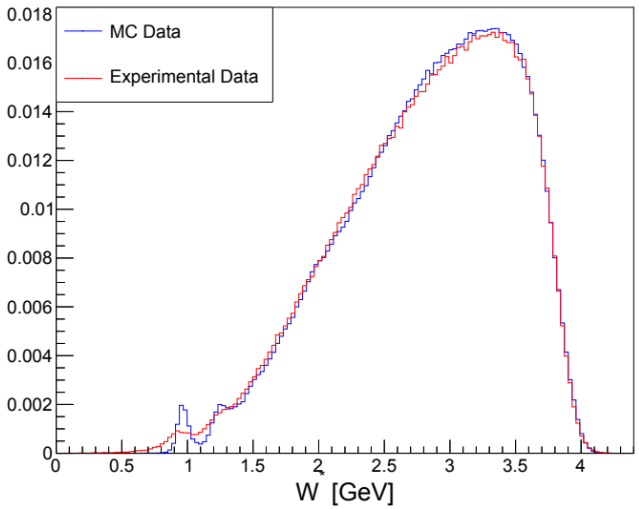
Data/MC Comparison: D(e,e'p_s)X

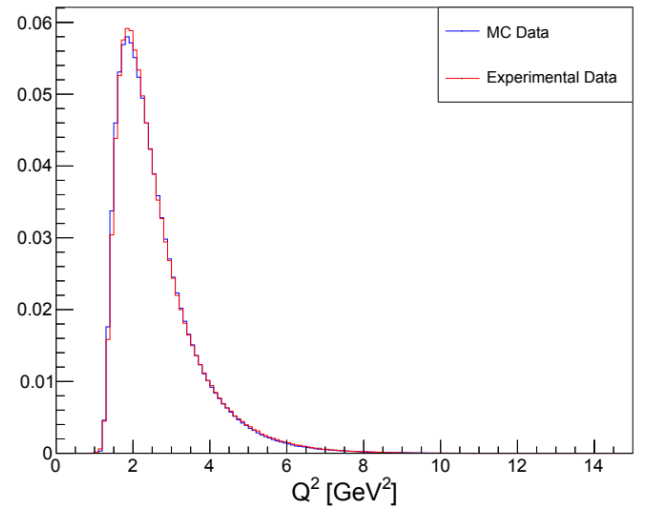
Tagged nDIS e^- kinematics

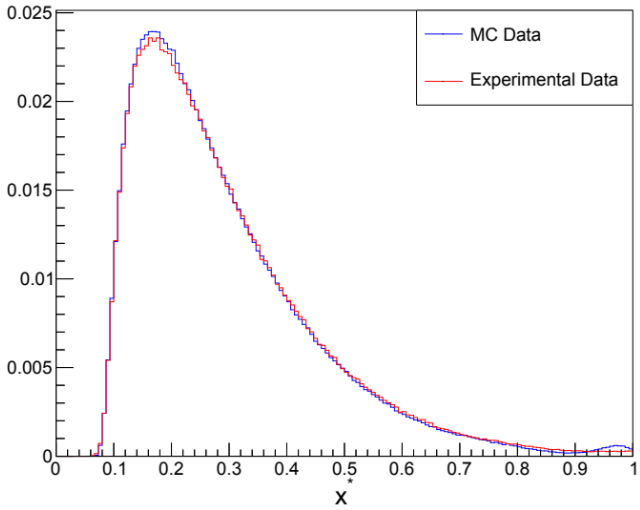






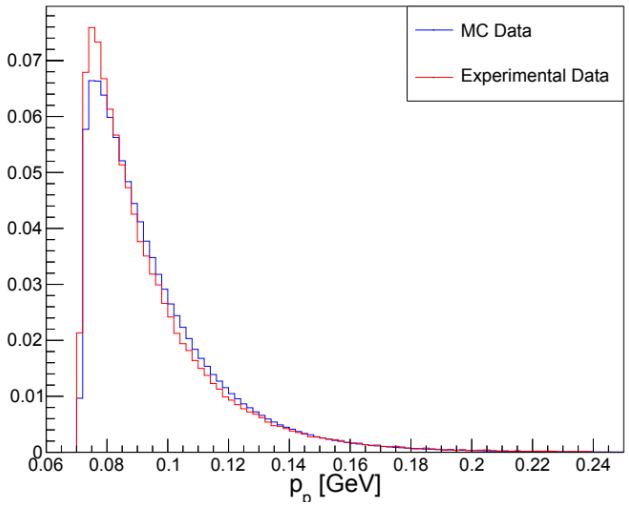


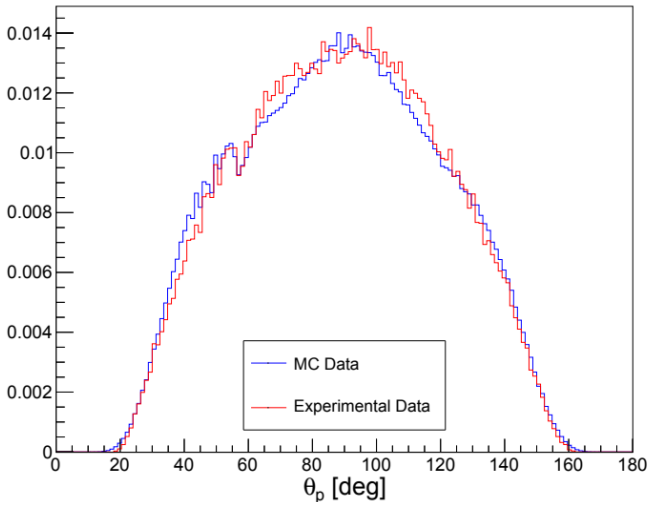


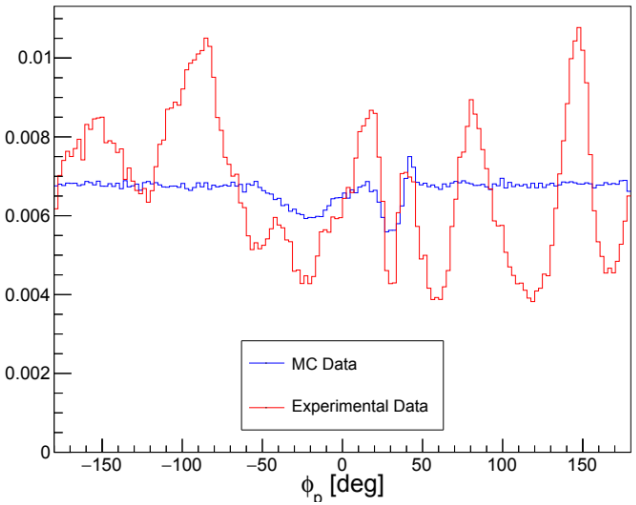


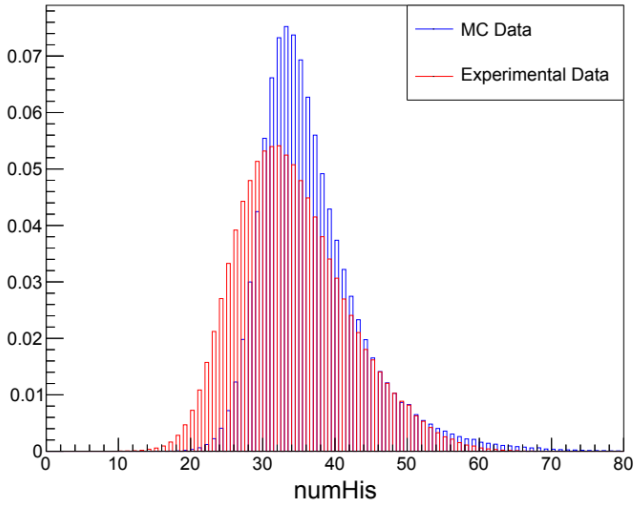
Data/MC Comparison: D(e,e'p_s)X

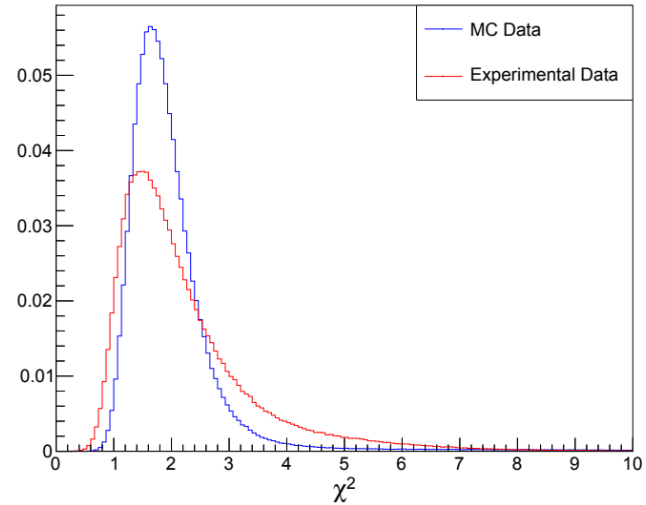
p_s kinematics

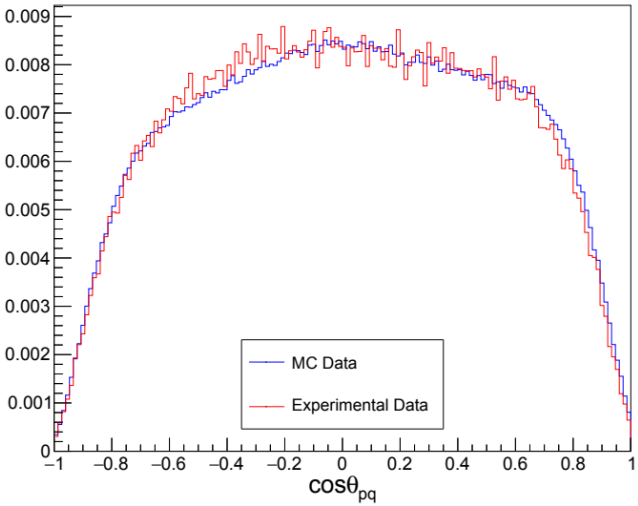








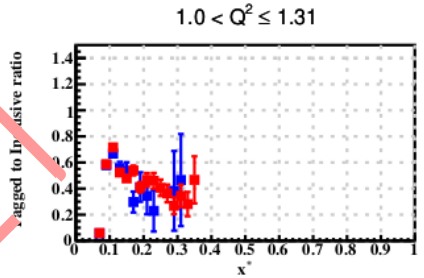


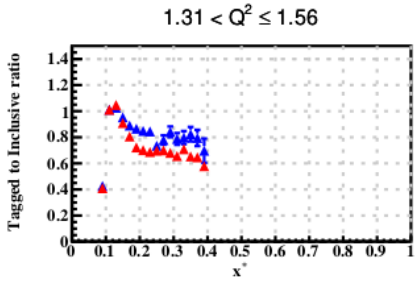


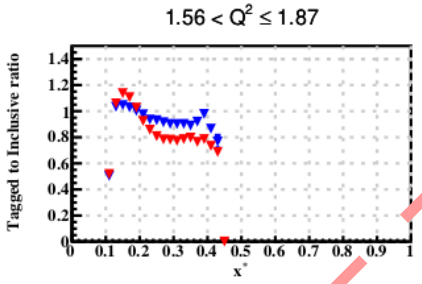
Data/MC Yield Ratios

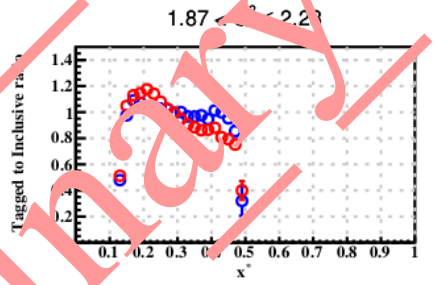
$$\left(\frac{F_{2n}}{F_{2d}}\right)^{\text{true}} = \text{Constant} \cdot \left(\frac{F_{2n}}{F_{2d}}\right)^{\text{Gen}} * \frac{\left(\Upsilon_{\text{tag}}^{\text{Data}} / \Upsilon_{\text{inc}}^{\text{Data}}\right)}{\left(\Upsilon_{\text{tag}}^{\text{MC}} / \Upsilon_{\text{inc}}^{\text{MC}}\right)}$$

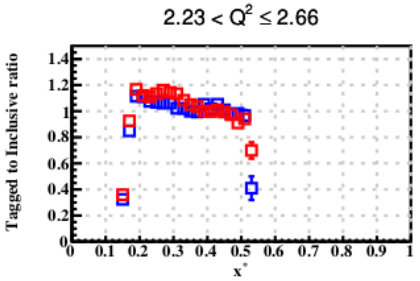
Blue: Data
Red: MC

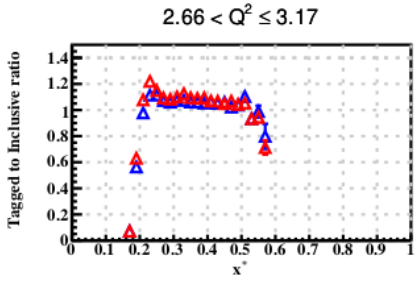


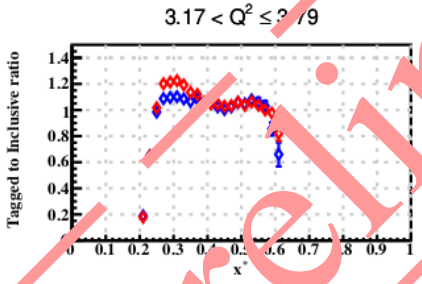


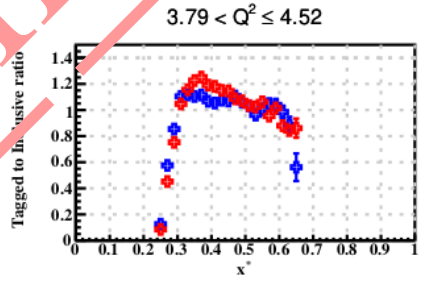


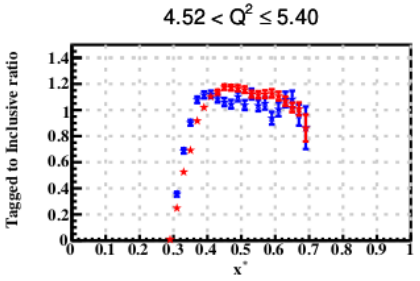


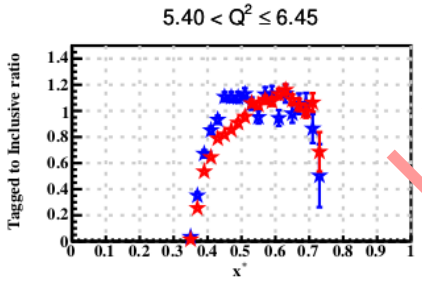


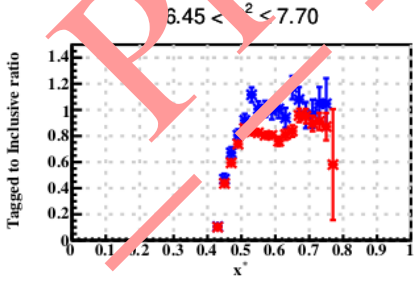


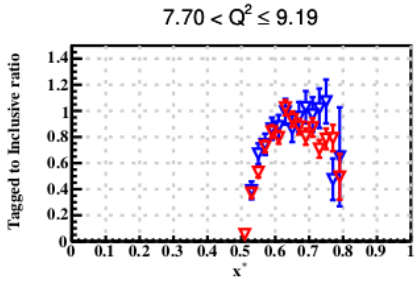


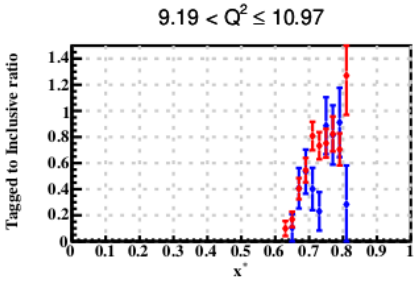






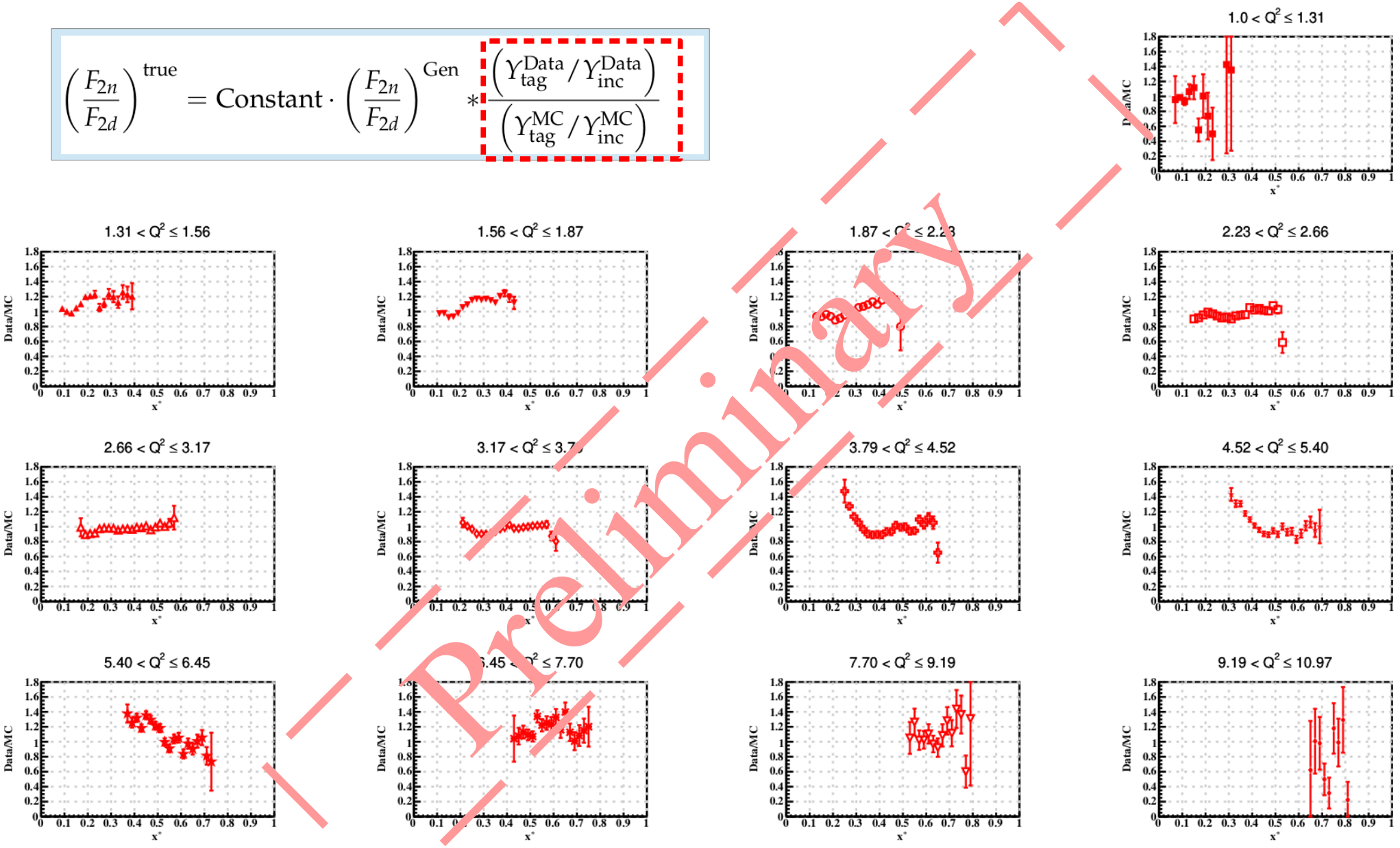






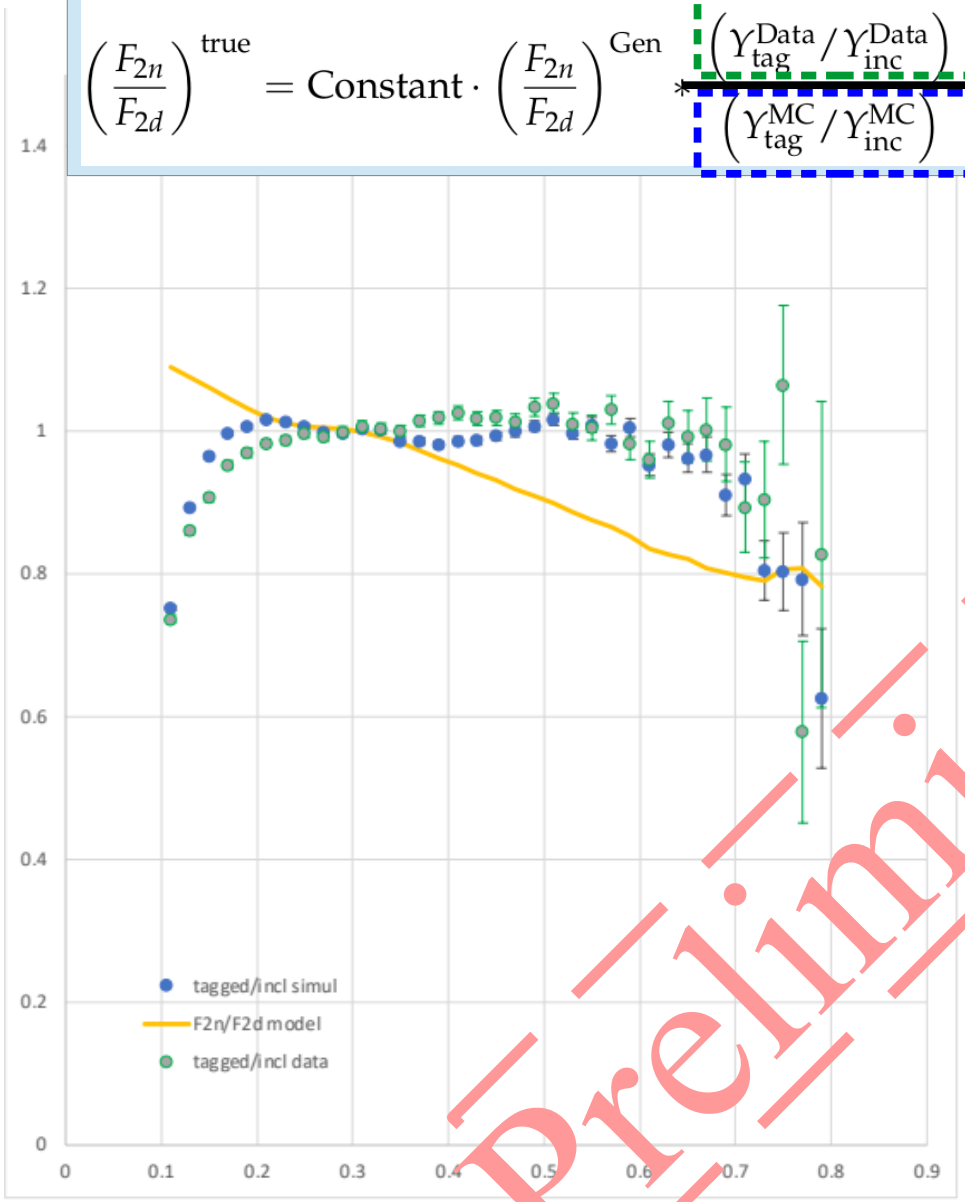
Super Ratios

$$\left(\frac{F_{2n}}{F_{2d}}\right)^{\text{true}} = \text{Constant} \cdot \left(\frac{F_{2n}}{F_{2d}}\right)^{\text{Gen}} * \frac{\left(\Upsilon_{\text{tag}}^{\text{Data}} / \Upsilon_{\text{inc}}^{\text{Data}}\right)}{\left(\Upsilon_{\text{tag}}^{\text{MC}} / \Upsilon_{\text{inc}}^{\text{MC}}\right)}$$

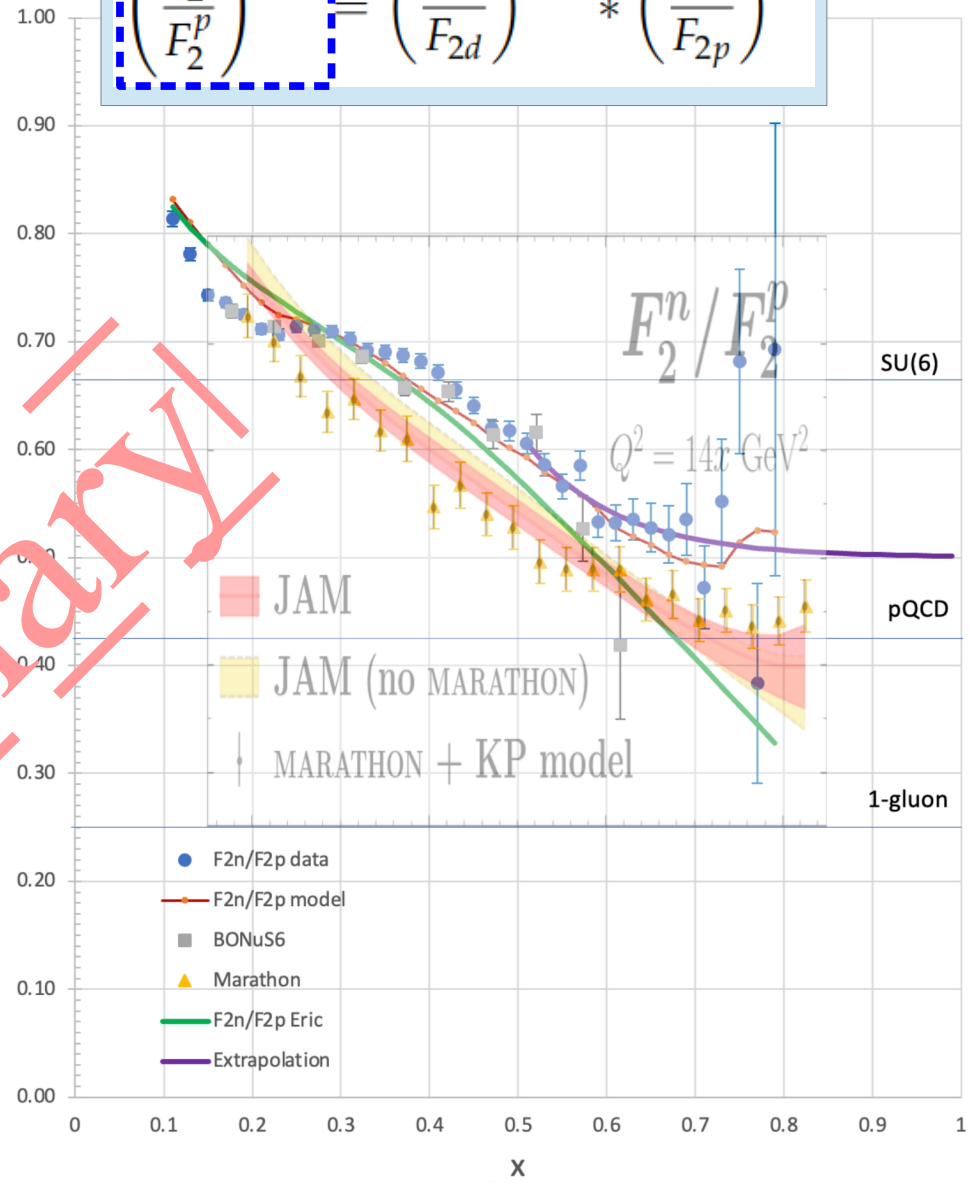


Q²-Integrated Results

$$\left(\frac{F_{2n}}{F_{2d}}\right)^{\text{true}} = \text{Constant} \cdot \left(\frac{F_{2n}}{F_{2d}}\right)^{\text{Gen}} * \frac{\left(\Upsilon_{\text{tag}}^{\text{Data}} / \Upsilon_{\text{inc}}^{\text{Data}}\right)}{\left(\Upsilon_{\text{tag}}^{\text{MC}} / \Upsilon_{\text{inc}}^{\text{MC}}\right)}$$



$$\left(\frac{F_2^n}{F_2^p}\right)^{\text{true}} = \left(\frac{F_{2n}}{F_{2d}}\right)^{\text{true}} * \left(\frac{F_{2d}}{F_{2p}}\right)^{\text{fit}}$$

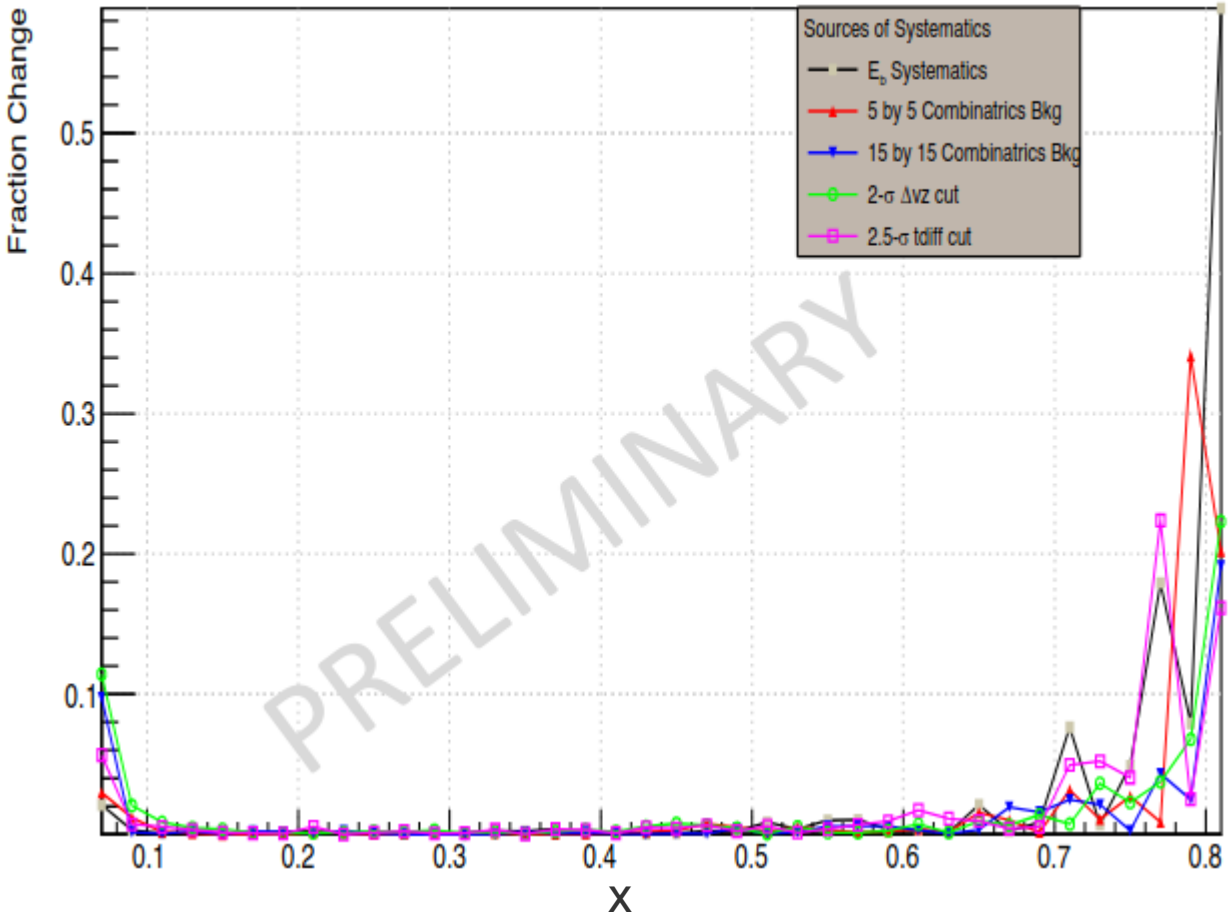


Preliminary!

Ongoing Systematic Uncertainties

Systematics studies are done by varying the different cuts and calculate the super-ratio fraction change bin-by-bin:

- Beam Energy.
- Pair-Symmetric background correction.
- RTPC accidental background.
- RTPC fiducial cut.
- Electron-proton vertex correspondence.
- Electron-proton timing cut.
- Helium Conatmination correction.



Other Physics Topics Accessible with BONuS12

In addition to measuring F_2^n, the **BONuS12 dataset** is a golden dataset to study:

- Exclusive nDVCS $e^- D \rightarrow e^- n \gamma p$
- Tagged-p nDVCS $e^- D \rightarrow e^- p \gamma (n)$
- Neutron Elastic Scattering
- Coherent DVCS off D
- Coherent DVMP off D
- Semi-inclusive reaction p(e,e`p)X
- D(e, e`pp$_s$)X
- EMC effect in D
- SIDIS on the neutron
- Diffractive scattering off D

- More Physics:
  - DVCS off bound nucleons.
  - DVMP off bound nucleons.
  - The role of the final state interaction in hadronization and medium modified fragmentation functions.
  - The medium modification of the transverse momentum dependent parton distributions.
  - ... and more

Conclusions

◊ **BONuS12** extends the measurement of the **spectator-tagged neutron structure functions** over a **larger kinematic range**, with much improved statistics. Many additional physics topics can be explored.

◊ Particles identification has been carried out and tuned over the **Summer2020** dataset.

◊ **Golden Runs/Files** have been identified.

◊ **Event generator / simulation** have been tuned and reproducing the measured phase-space.

◊ **First results** have been extracted and will be submitted in days to the DPWG for an analysis review.