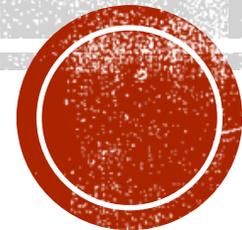


Exclusive Meeting — Deuteron Tagging

Jan Vanek

University of New Hampshire

03/09/2026



OVERVIEW

- MC sample luminosity
- QA of reconstructed information from ZDC for tagged neutrons
- Updated efficiency correction and systematic uncertainty calculation



MC SAMPLE LUMINOSITY

NEW SIMULATION PRODUCTION

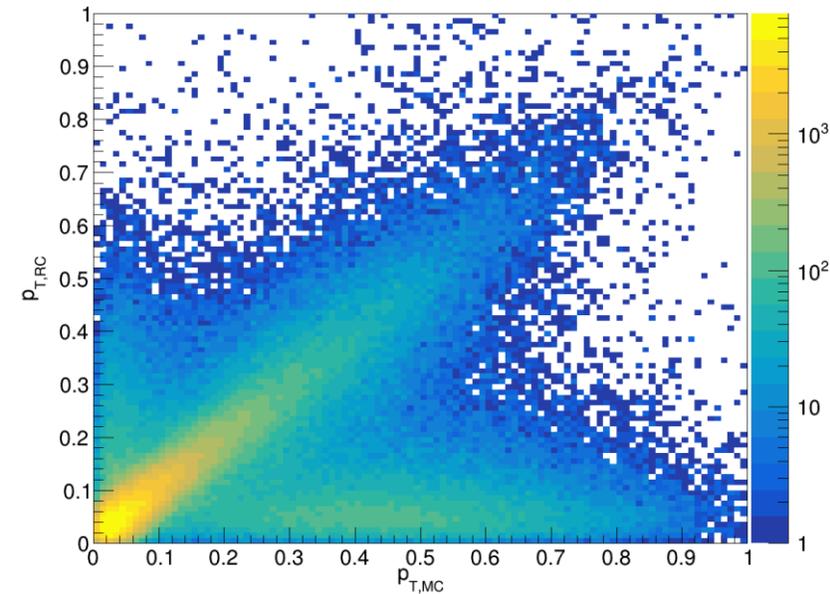
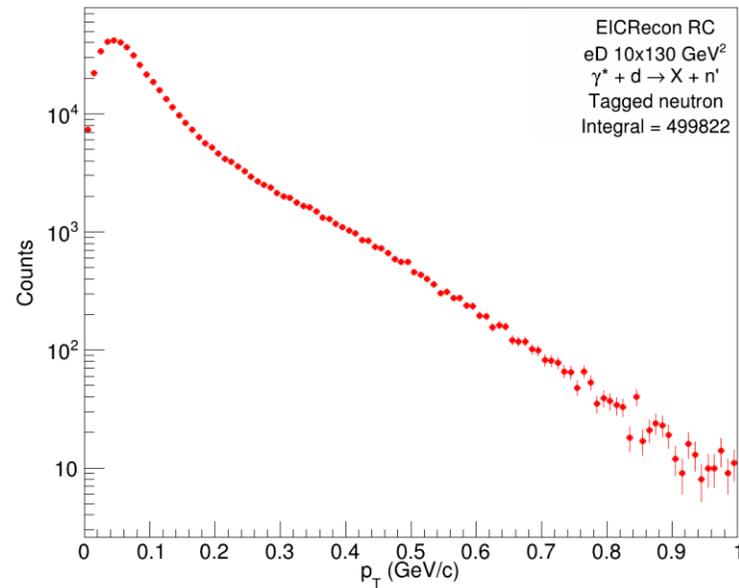
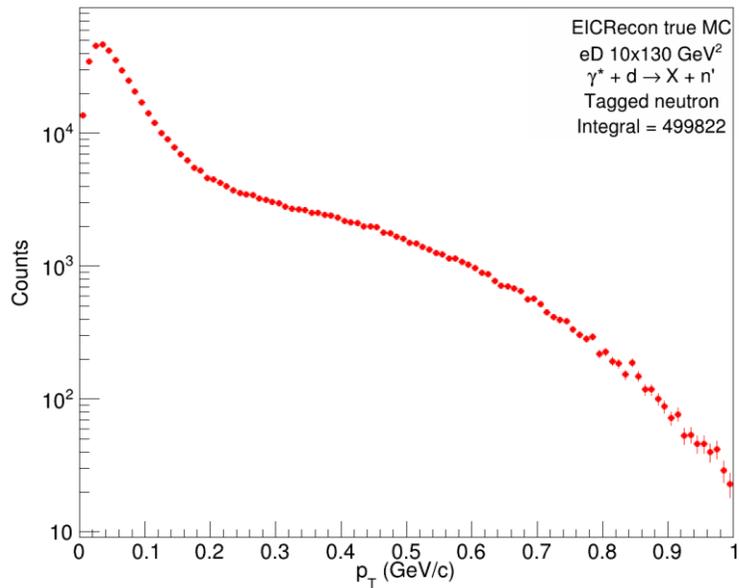
- Generated in BeAGLE
- First pass of main simulation production:
 - 40M events of eD $10 \times 130 \text{ GeV}^2$
 - 20M of en and 20M of ep
 - 20M total (10M+10M) submitted for official simulation campaign
- Luminosity and cross section:
 - en : $\sigma_{tot} = 3.538 \cdot 10^{-4} \text{ mb}$, $L_{int} = N_{evt}/\sigma_{tot} = 20\text{M}/(3.538 \cdot 10^{-4} \text{ mb}) = 20\text{M}/(3.538 \cdot 10^8 \text{ fb}) = 0.056 \text{ fb}^{-1}$
 - ep : $\sigma_{tot} = 3.707 \cdot 10^{-4} \text{ mb}$, $L_{int} = 0.056 \text{ fb}^{-1}$ (same as en after rounding)
 - Total integrated luminosity (true MC only): $L_{int} = 0.112 \text{ fb}^{-1}$
 - Total integrated luminosity (EICRecon): $L_{int} = 0.056 \text{ fb}^{-1}$
 - Samples not available yet in production
 - Expected luminosity for year 2: $L_{int} = 11.4 \text{ fb}^{-1}$
- Produced additional 40M BeAGLE for true MC studies
- RC samples used so far have only 500k events per spectator (1M total)



ZDC QA

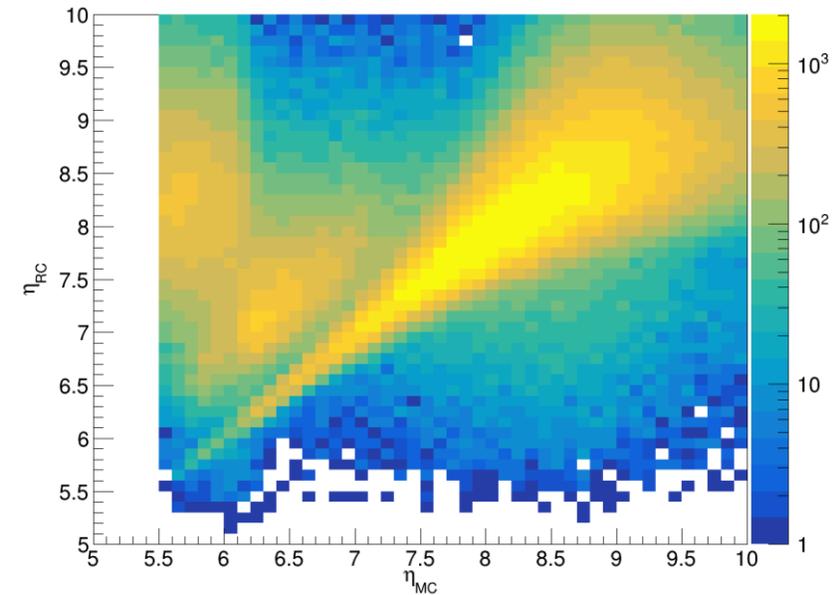
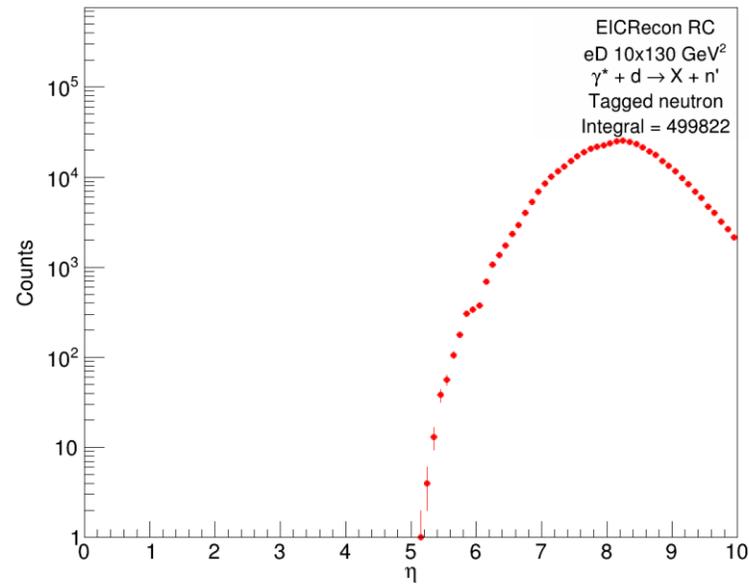
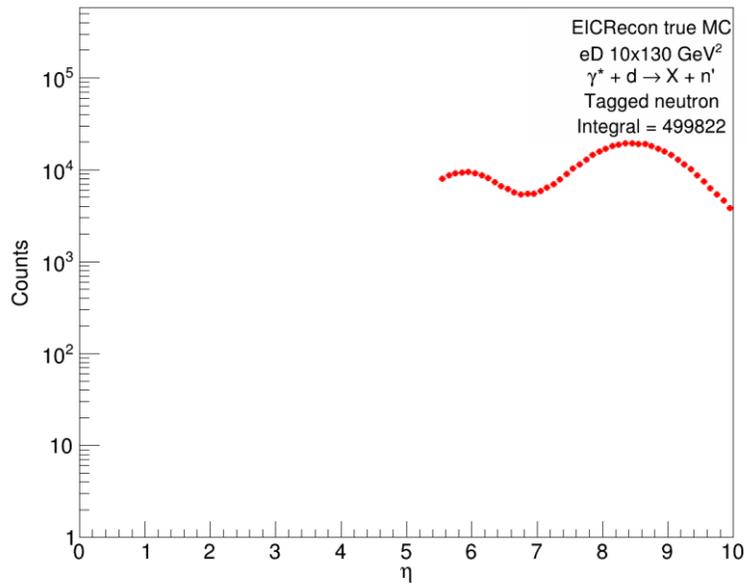
TAGGED NEUTRON p_T

- (left) True MC spectator neutron p_T
- (middle) RC spectator neutron p_T
- (bottom) True MC p_T Vs. RC p_T



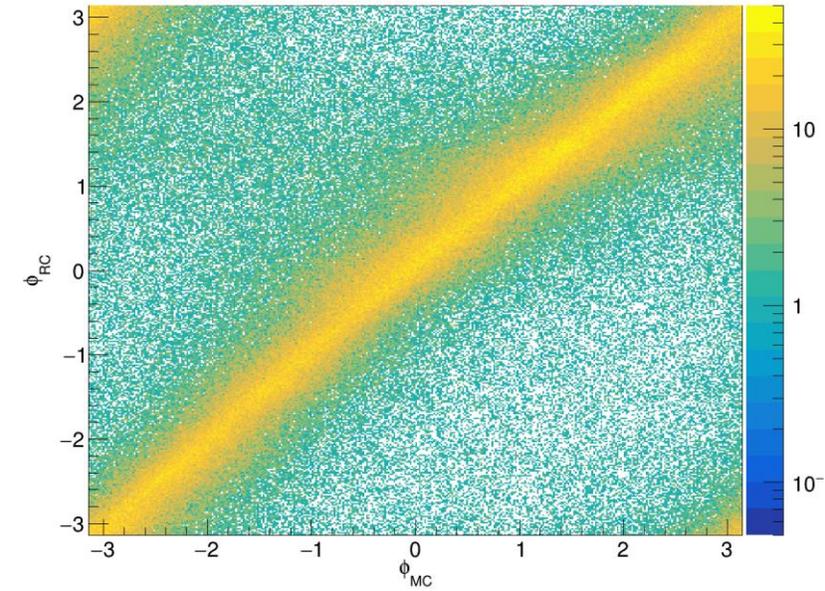
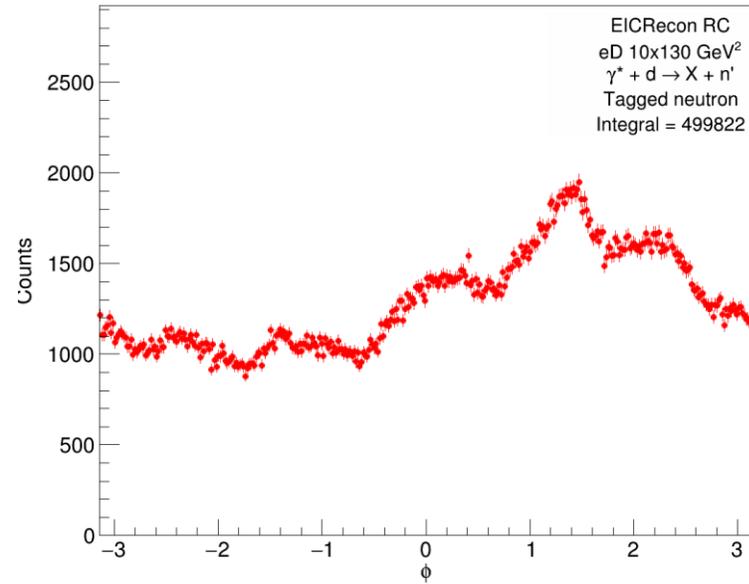
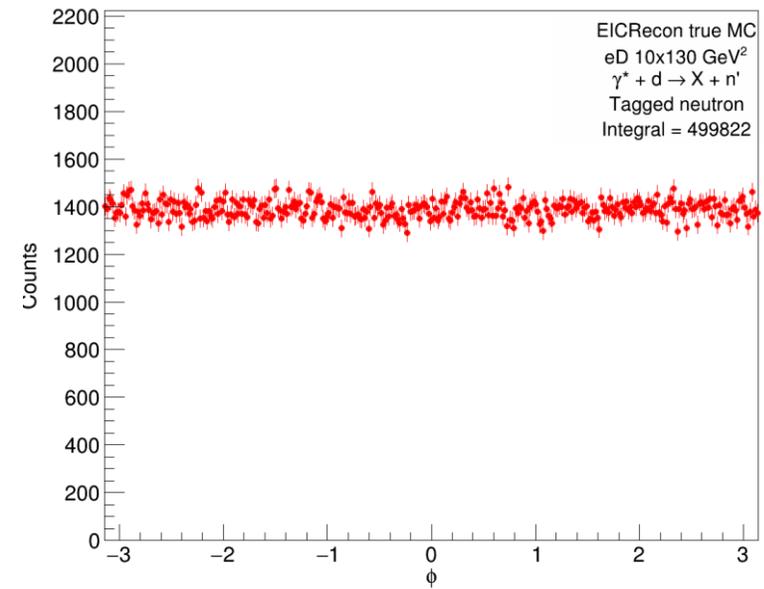
TAGGED NEUTRON η

- (left) True MC spectator neutron η
 - What is the second peak at about $\eta = 6$?
- (middle) RC spectator neutron η
- (bottom) True MC η Vs. RC η



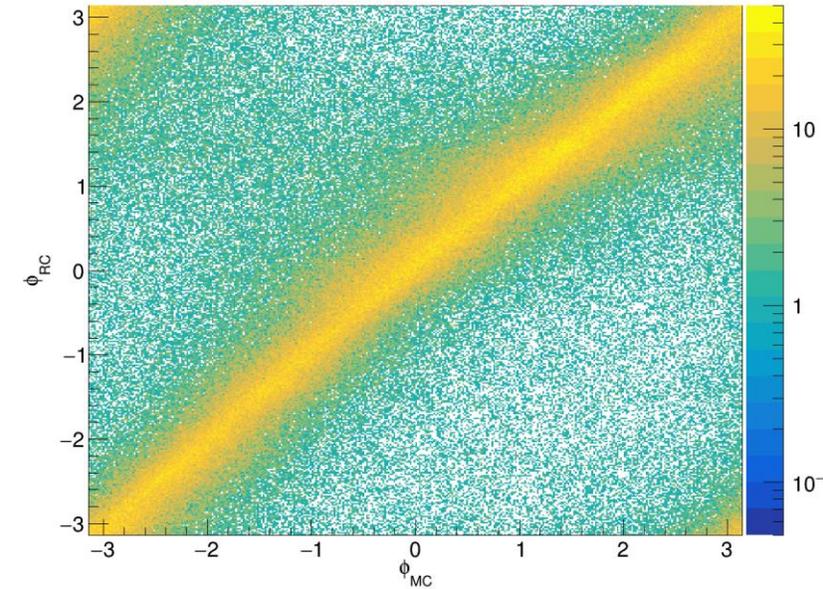
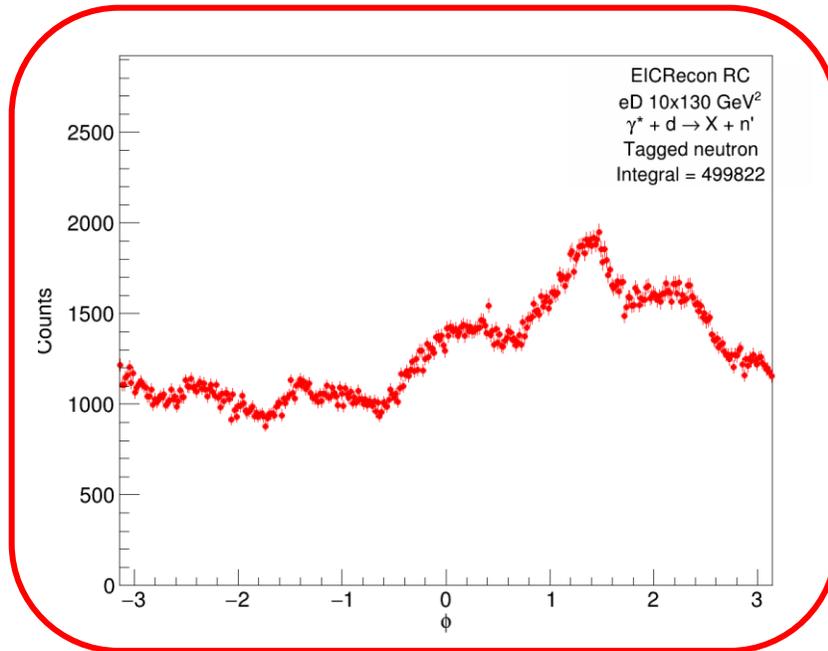
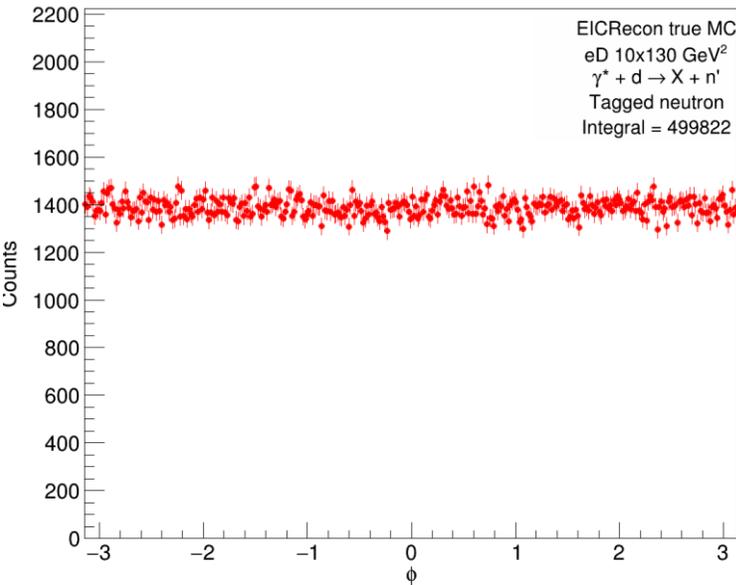
TAGGED NEUTRON ϕ

- (left) True MC spectator neutron ϕ
- (middle) RC spectator neutron ϕ
 - RC ϕ has odd modulation
- (right) True MC ϕ Vs. RC ϕ



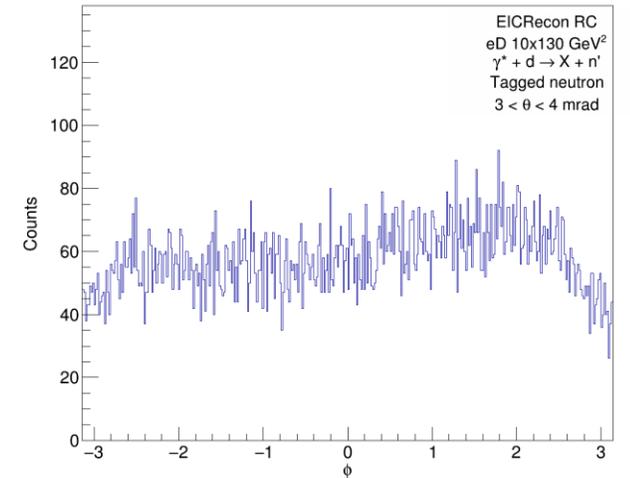
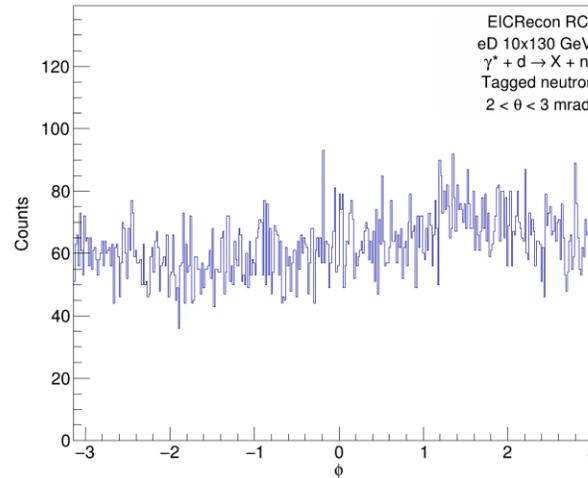
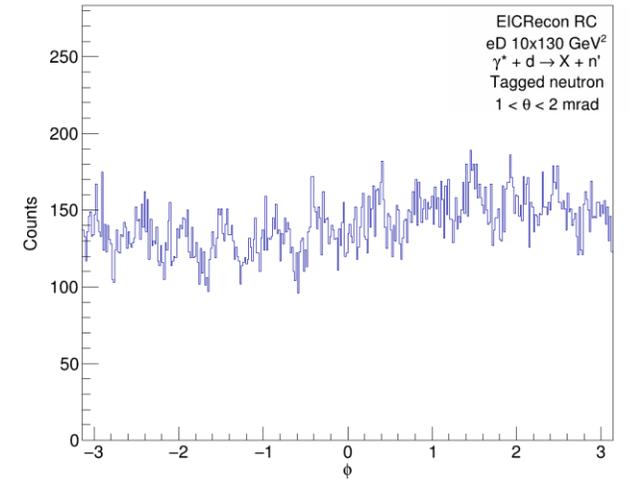
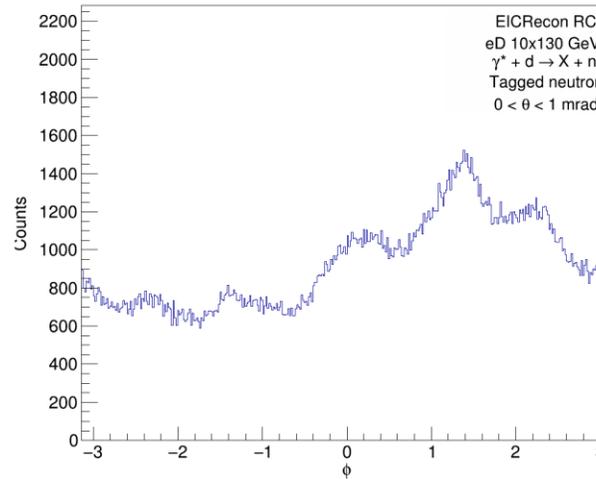
TAGGED NEUTRON ϕ

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- (middle) RC spectator neutron ϕ
 - RC ϕ has odd modulation
- (right) True MC ϕ Vs. RC ϕ



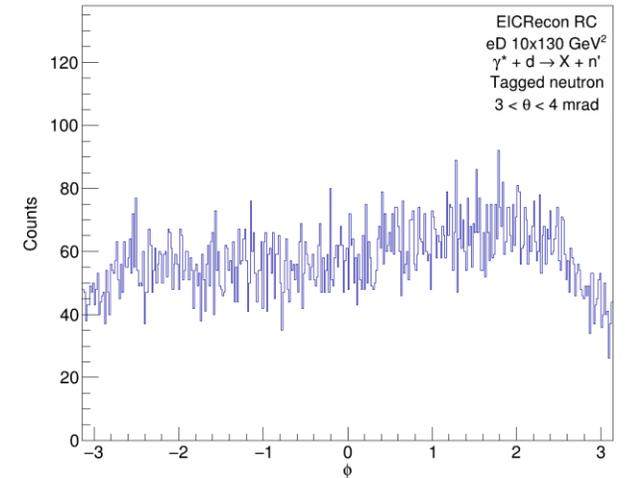
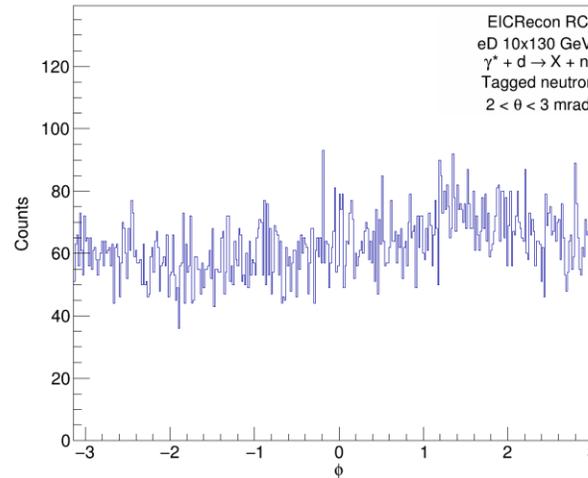
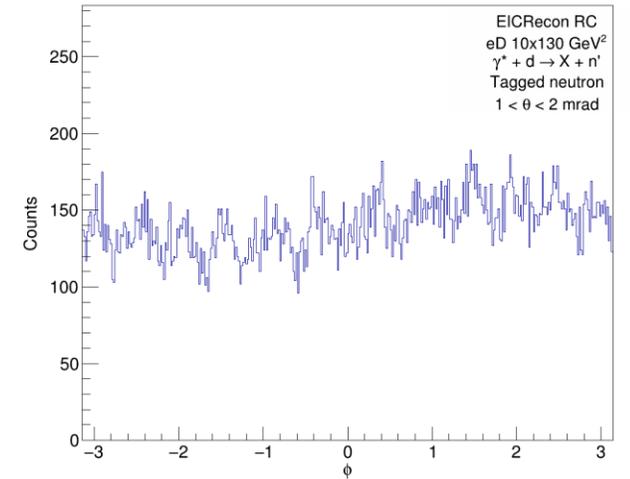
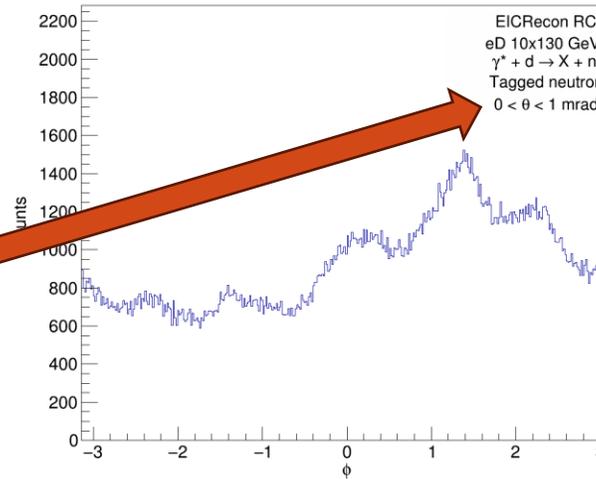
TAGGED NEUTRON ϕ FOR DIFFERENT θ

- RC spectator neutron ϕ for different polar angle θ values
- Large modulation of RC ϕ is present mainly for small polar angles



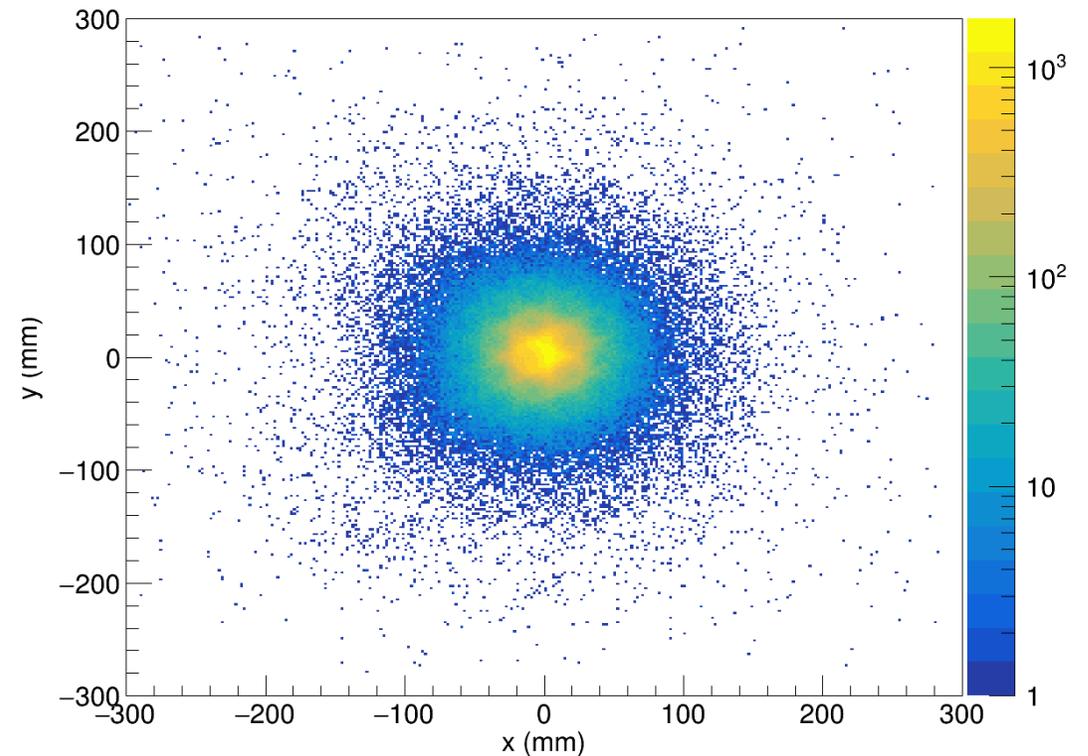
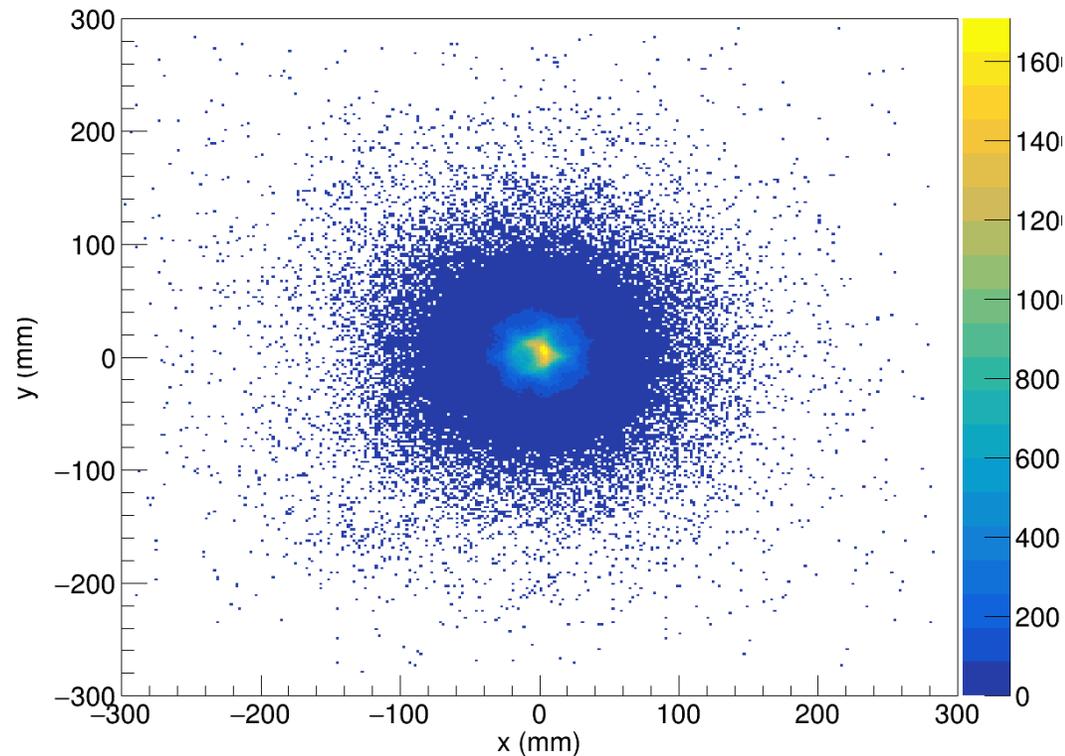
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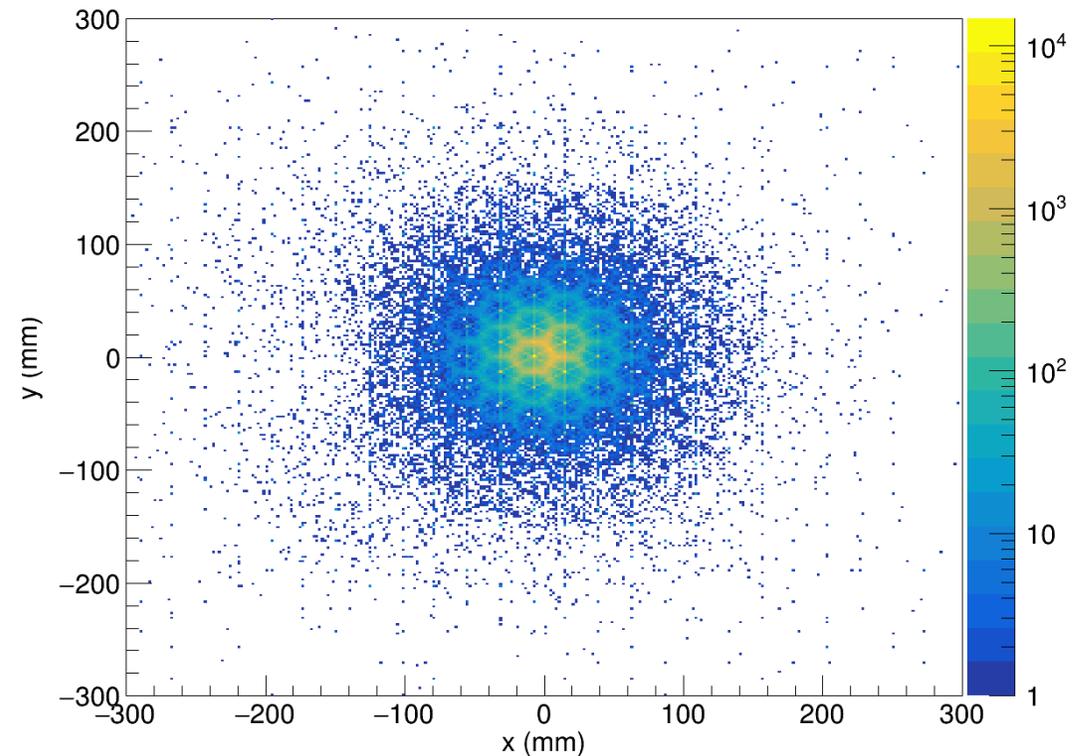
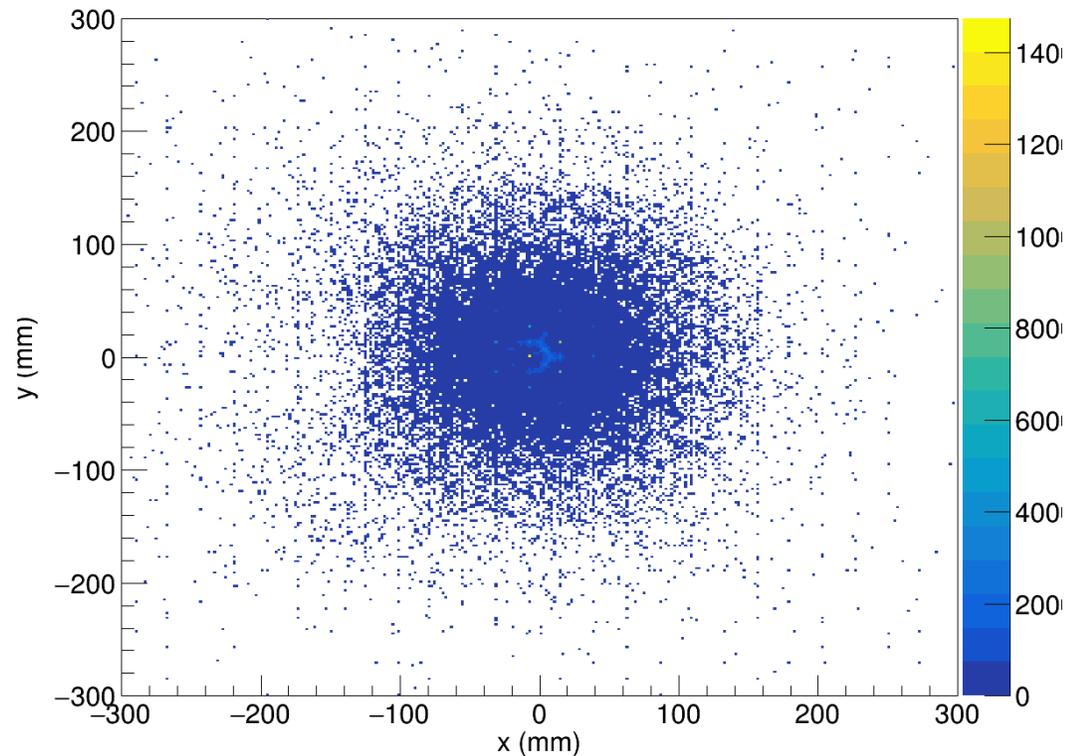
ZDC (x, y) HIT MAP – RC CLUSTERS

- Position of leading (max. energy) ZDC RC clusters in (x, y) plane
 - (left) Linear scale
 - (right) Log scale



ZDC (x, y) HIT MAP – TRUTH CLUSTERS

- Position of leading (max. energy) ZDC truth clusters in (x, y) plane
 - (left) Linear scale
 - (right) Log scale
- Truth clusters reveal significant acceptance pattern in ZDC that affects TDIS measurement

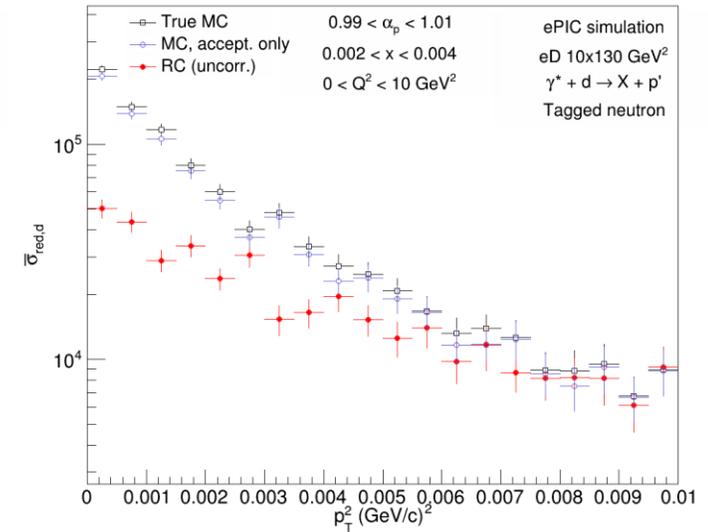
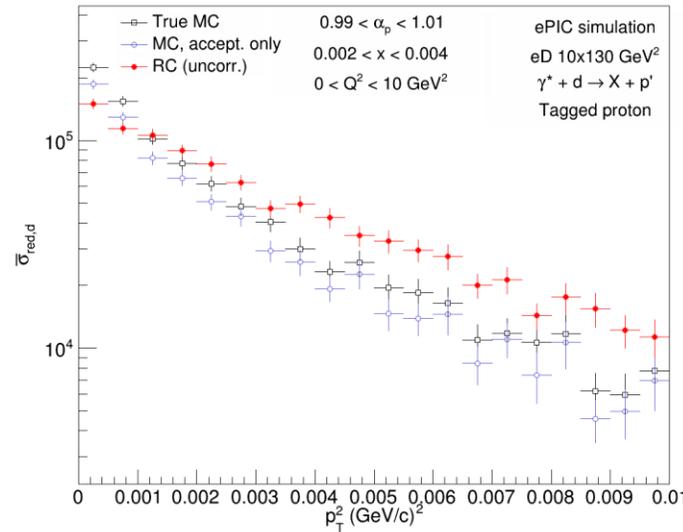




UPDATED EFFICIENCY

DEUTERON REDUCED CROSS SECTION

- (left) Deuteron reduced cross section in EICRecon calculated using **tagged protons**
- (left) Deuteron reduced cross section in EICRecon calculated using **tagged neutrons**
- Example plots for one α_p , x_{bj} , and Q^2
- Original simulation sample
 - 500k events
 - Waiting for new production



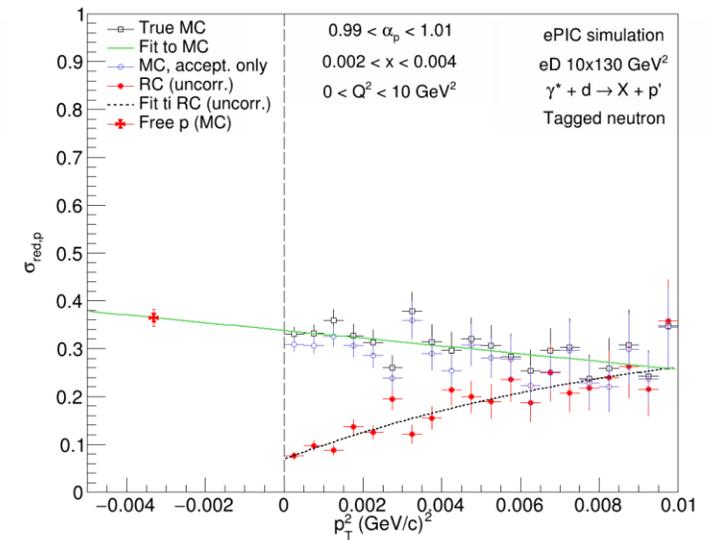
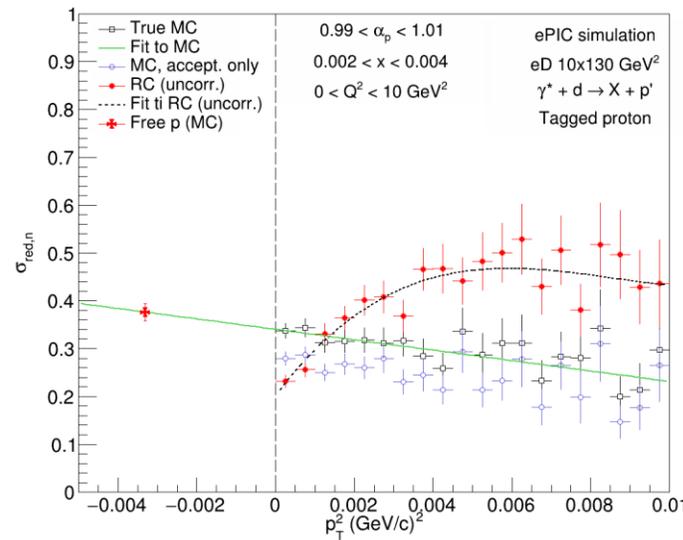
NUCLEON REDUCED CROSS SECTION – UNCORRECTED

- (left) **Neutron** reduced cross section in EICRecon
- (left) **Proton** reduced cross section in EICRecon

- Example plots for one: α_p , x_{bj} , and Q^2

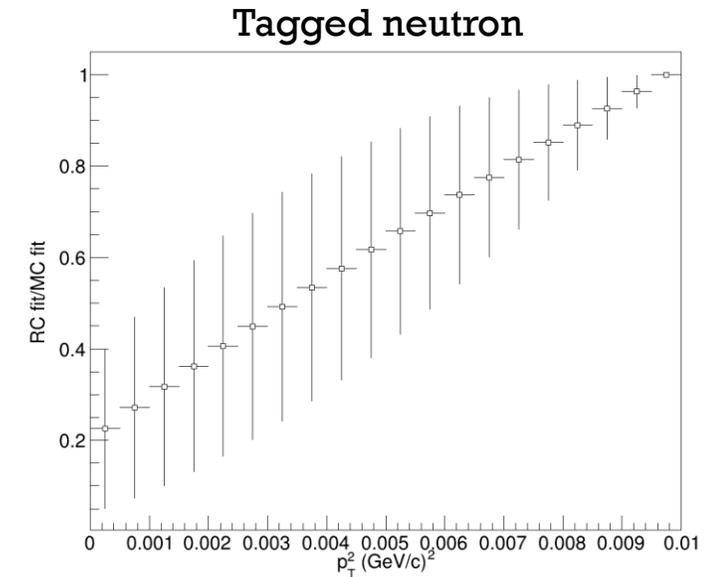
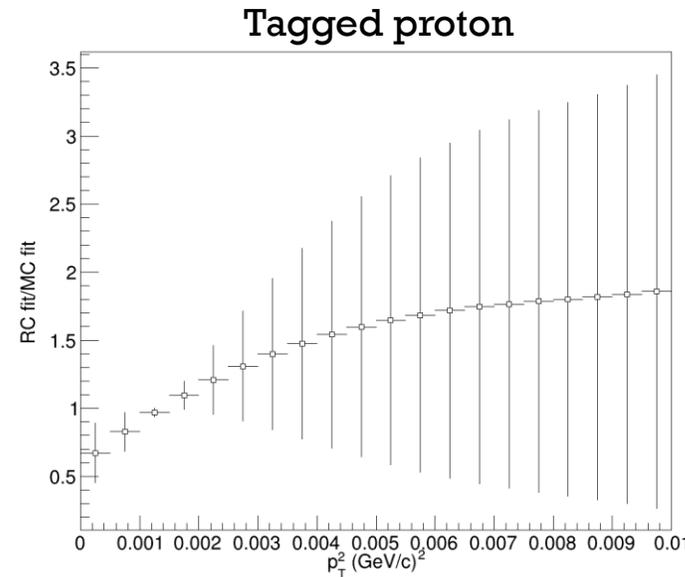
- **Update:**

- RC fitted with 3rd order polynomial



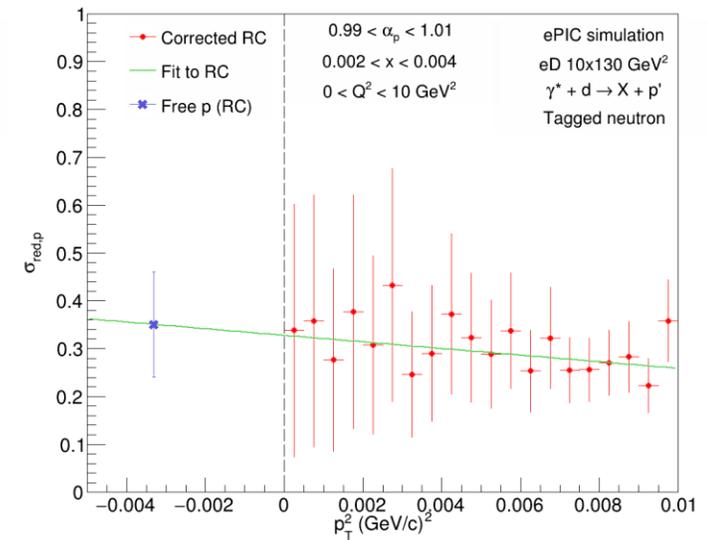
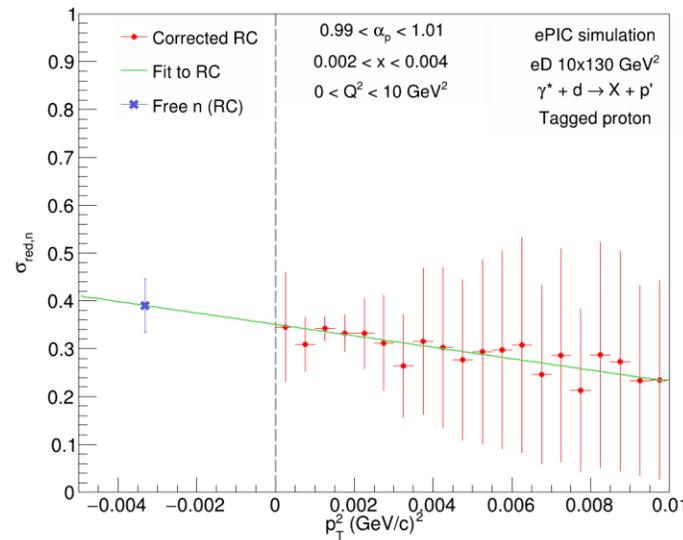
EFFICIENCY AND ACCEPTANCE

- Simple efficiency correction using ratio of MC and RC **fit functions** to nucleon reduced cross section
 - RC/MC
 - Functions evaluated at histogram bin centers
- Associated relative systematic uncertainty:
 - $|RC - MC|/MC$
 - Added in quadrature to statistical uncertainty for final results (shown later)
- Example plots for one: α_p , x_{bj} , and Q^2



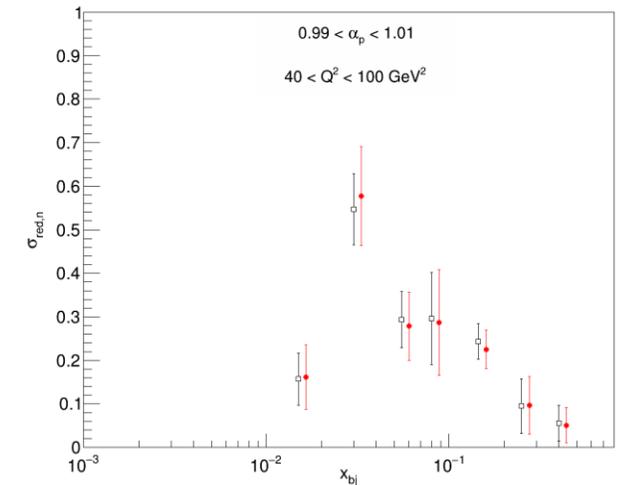
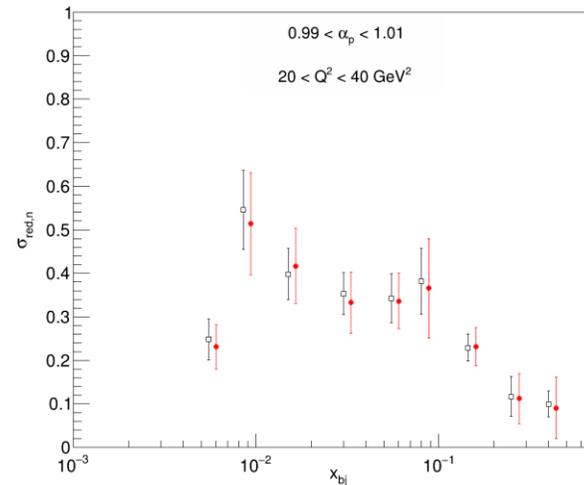
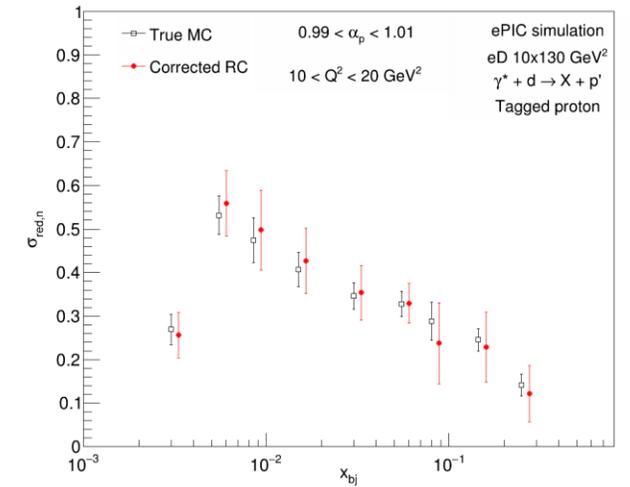
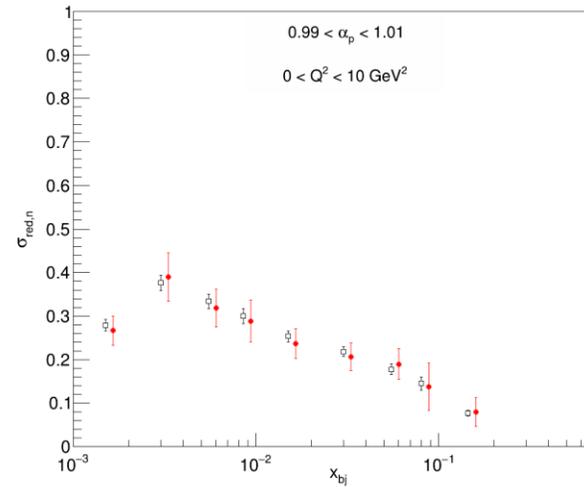
NUCLEON REDUCED CROSS SECTION — CORRECTED

- (left) **Neutron** reduced cross section in EICRecon
 - Corrected
- (left) **Proton** reduced cross section in EICRecon
 - Corrected
- Example plots for one: α_p , x_{bj} , and Q^2
- New corrected cross sections using updated efficiency



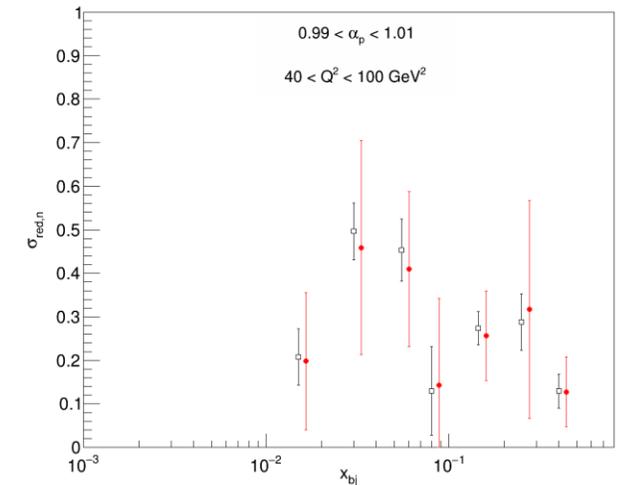
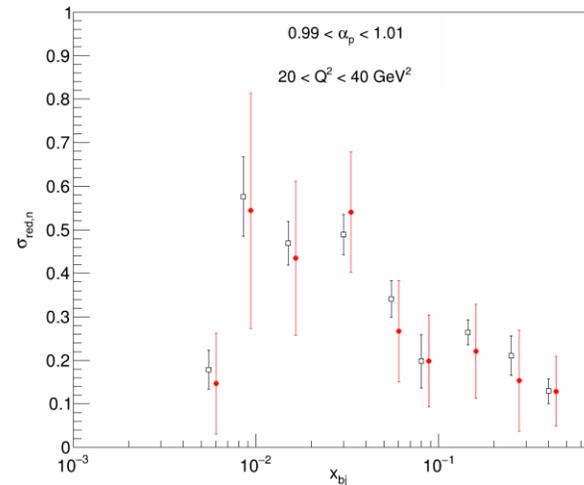
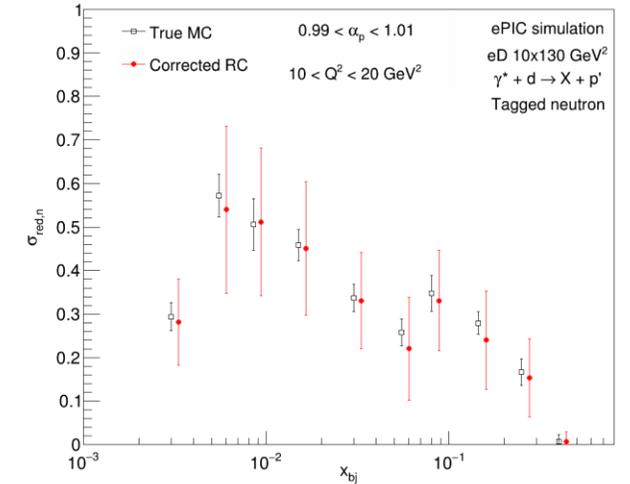
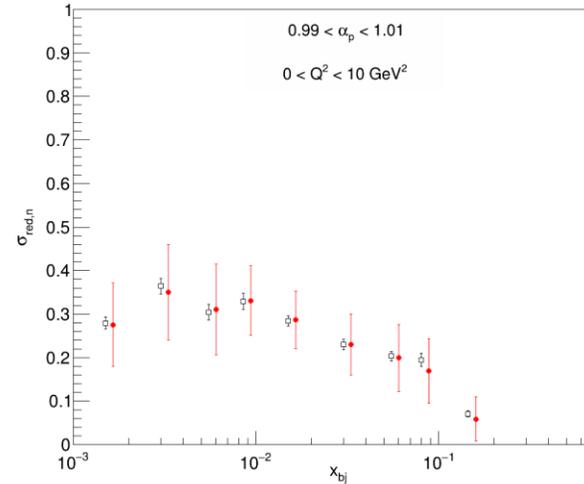
REDUCED CROSS SECTION VS. x_{bj} (eN)

- Comparison of the MC and RC **neutron** reduced cross sections
- Reasonably consistent result
- Uncertainties dominated by systematics



REDUCED CROSS SECTION VS. x_{bj} (eP)

- Comparison of the MC and RC **proton** reduced cross sections
- Tagged neutron analysis requires more attention
 - Much worse performance of RC
 - Large difference between MC and RC at low p_T^2
 - Different behavior than in original paper
 - Under investigation
- Uncertainties dominated by systematics



SUMMARY AND OUTLOOK

- Observe significant acceptance pattern in ePIC ZDC in current geometry implementation in EICRecon
 - Has negative impact on small p_T^2 resolution, causing issues for TDIS measurement
- Updated efficiency calculation and corresponding systematic uncertainty
 - MC nucleon reduced cross section fitted with linear function
 - RC nucleon reduced cross section fitted with 3rd order polynomial
 - Efficiency and systematic uncertainty calculated from ratio of (difference between) fit functions
- Outlook:
 - Writing analysis note



THANK YOU FOR ATTENTION



BACKUP

NEW SIMULATION PRODUCTION

- Generated in BeAGLE
- Standard post-processing for simulation campaign
 - BrEGLE to HepMC conversion
 - Afterburner
 - Generate HepMC trees
- Main simulation production:
 - 20M events of eD 10x130 GeV²
 - 10M of en and 10M of ep
 - 10M total (5M+5M) submitted for official simulation campaign
- Test production for framework validation:
 - 2M events of eD 18x110 GeV²
 - Same energy as in original paper A. Jentsch, Z. Tu, C. Weiss: [Phys. Rev. C 104, 065205.](#)

VARIABLES

- Scattered electron

- $Q^2 = -q^2 = -(p_{e,beam} - p_{e,scat})^2$

- $x = \frac{Q^2}{P \cdot q}$

- $x_{nucleon} = \frac{Q^2}{2P_{nucl} \cdot q} = \frac{x}{2 - \alpha_p}$

- Kinematic variables

- $y = \frac{p_d \cdot q}{p_d \cdot p_{e,beam}}$

- $1 - \epsilon = \frac{y^2}{1 + (1 - y)^2}$

- Light-cone momentum fraction:

- $\alpha_p \equiv \frac{2p_p^+}{p_d^+} = \frac{2(E_p + p_{z,p})}{E_d + p_{z,d}}$

- Proton transfer momentum

- $p_{T,p} = \sqrt{p_{x,p}^2 + p_{y,p}^2}$

- Fine structure constant

- $\alpha_{em} = \frac{1}{137}$

- Luminosity and cross section

- $L_{int} = \frac{N_{events}}{\sigma_{tot}}$

- $mb = 2.568 \text{ GeV}^{-2}$

- Results from paper: A. Jentsch, Z. Tu, C. Weiss: [Phys. Rev. C 104, 065205](#).

- $\sigma_{tot} = 4.5 \cdot 10^{-5} \text{ mb}$

- For new simulation production (10x130 GeV²):

- $\sigma_{tot} = 3.538 \cdot 10^{-4} \text{ mb (en)}$

- $\sigma_{tot} = 3.707 \cdot 10^{-4} \text{ mb (ep)}$

- Test sample (18x110 GeV²):

- $\sigma_{tot} = 3.869 \cdot 10^{-4} \text{ mb (en)}$

DEUTERON REDUCED CROSS SECTION

- Differential cross section on d can be written in terms of deuteron reduced cross ($\sigma_{red,d}$) section and photon flux:

$$\bullet d\sigma_d = Flux(x, Q^2) \times \sigma_{red,d} \times dx dQ^2 \frac{d\phi_{e'}}{2\pi} [2(2\pi)^3]^{-1} \frac{d\alpha_p}{\alpha_p} \frac{dp_{T,p}^2}{2} d\phi_p$$

- Photon flux:

$$\bullet Flux(x, Q^2) = \frac{2\pi\alpha_{em}^2 y^2}{Q^4(1-\epsilon)x} = \frac{2\pi\alpha_{em}^2 [1+(1-y)^2]}{Q^4 x}$$

- Deuteron reduced cross section

$$\bullet \sigma_{red,d} = \frac{1}{Flux} \frac{d\sigma_d}{dx dQ^2 (d\phi_{e'}/2\pi) d\Gamma_p}, \text{ where } d\Gamma_p = [2(2\pi)^3]^{-1} \frac{d\alpha_p}{\alpha_p} \frac{dp_{T,p}^2}{2} d\phi_p$$

- Measured reduced cross section (integrated over $d\phi_p$)

$$\bullet \bar{\sigma}_{red,d} = \left(\frac{2.568}{L_{int}} \right) \frac{Q^4 x}{2\pi\alpha_{em}^2 [1+(1-y)^2]} \frac{[4(2\pi)^3] \alpha_p}{\Delta\alpha_p} \frac{dN}{\Delta x \Delta Q^2 \Delta p_{T,p}^2 2\pi}$$

- $\Delta x, \Delta Q^2, \Delta p_{T,p}^2, \Delta\alpha_p$ are bin widths

- Scattered electron
- Spectator proton + struck deuteron
- Photon flux

A. Jentsch, Z. Tu, C. Weiss: [Phys. Rev. C 104, 065205](#).
M. Strikman and C. Weiss: [Phys. Rev. C 97, 035209](#).
C. Weiss and W. Cosyn: [Phys. Rev. C 102, 065204](#).

- Full azimuthal coverage for electron
 - $(\Delta\phi_{e'}/2\pi) = 2\pi/2\pi = 1$
- Full azimuthal coverage for spectator
 - $\Delta\phi_p = 2\pi$

POLE EXTRAPOLATION METHOD

- $\sigma_{red,n} = \frac{\bar{\sigma}_{red,d}(x,Q^2)}{[2(2\pi)^3]S_d(p_{pT},\alpha_p)[pole]}$
- $\bar{\sigma}_{red,n}$ at the pole corresponds to a free n
 - $p_{pT}^2 \rightarrow -a_T^2$ which means negative (unphysical) p_{pT}^2
- Solution is to experimentally measure $\sigma_{red,n}$ as a function of p_{pT}^2 for small positive values and extrapolate to the pole
 - We are using DIS on bound n to extract F_2 of free n
- Same measurement can be done for p
 - Cross check with proton F_2 extracted with traditional method
 - Can be used to select optimal deuteron spectral function
- Deuteron spectral function
 - $S_d(p_{pT}, \alpha_p)[pole] = \frac{R}{(p_{pT}^2 + a_T^2)^2}$
 - Position of pole
 - $a_T^2 = m_N^2 - \alpha_p(2 - \alpha_p)\frac{M_d^2}{4}$
 - Extrapolation done for $\alpha_p = 1$
 - Residue of spectral function
 - $R = \alpha_p^2 m_N \Gamma^2 (2 - \alpha_p)$
 - $\Gamma^2 = 0.007885 \text{ GeV}$