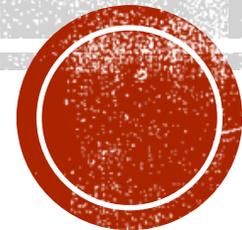


# Exclusive Meeting — Deuteron Tagging

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02/09/2026



# OVERVIEW

- New simulation production of  $eD$  collisions
  - Updated cross section from corresponding simulation
- Updated TDIS in  $eD$  framework
  - Fixed reduced cross section calculation and pole removal with help from Alex

# 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 GeV<sup>2</sup>
    - 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 GeV<sup>2</sup>
  - 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](#).

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

- For new simulation production (10x130 GeV<sup>2</sup>):

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

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

- Test sample (18x110 GeV<sup>2</sup>):

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

# 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
    - $R = \alpha_p^2 m_N \Gamma^2 (2 - \alpha_p)$
    - $\Gamma^2 = 0.007885 \text{ GeV}$

# TAGGED PROTON – BeAGLE

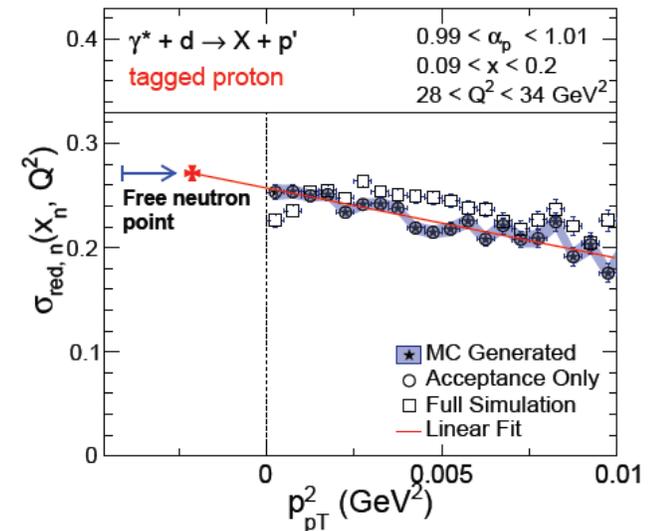
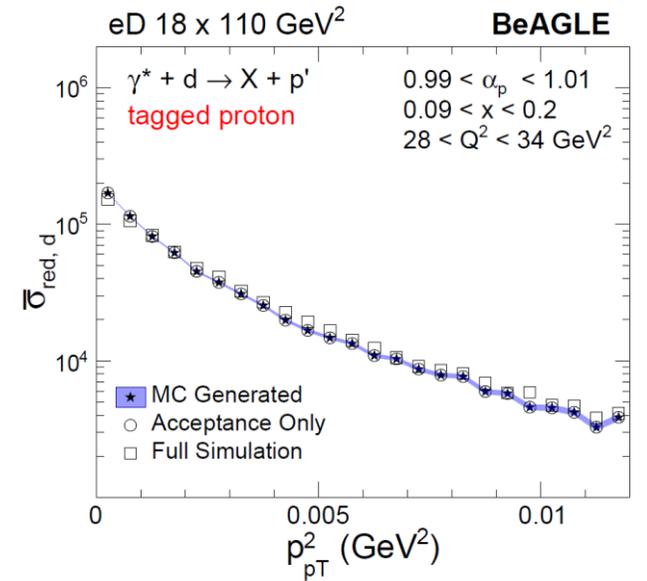
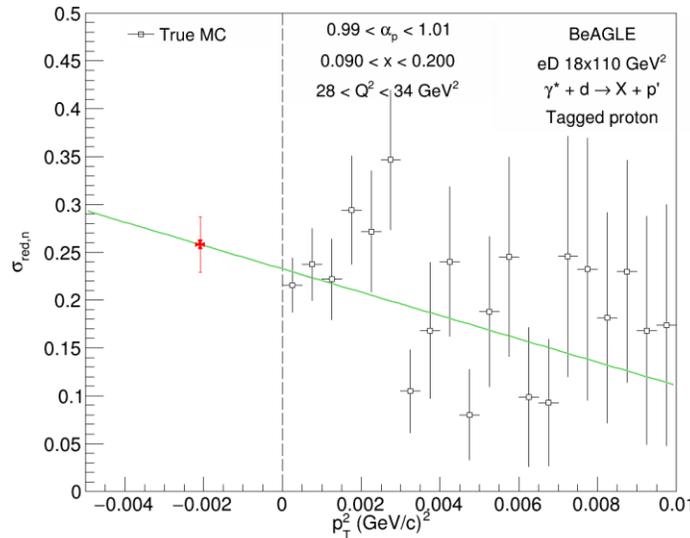
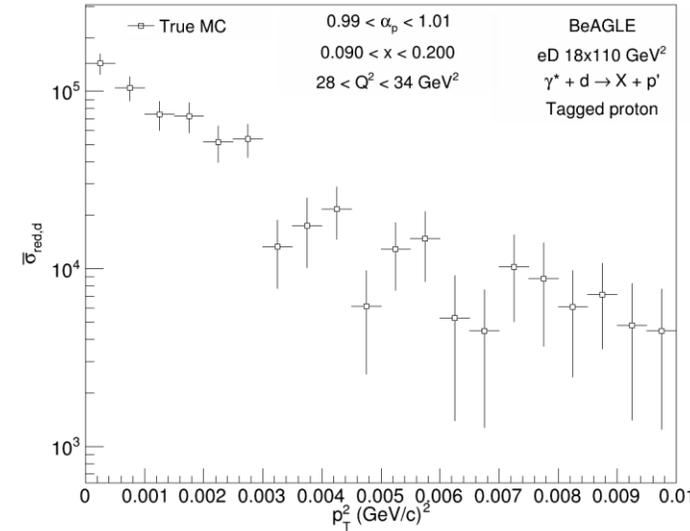
- Deuteron reduced cross section in BeAGLE calculated using tagged protons

- (left) My, (right) From paper

- Neutron reduced cross section in BeAGLE calculated using tagged protons

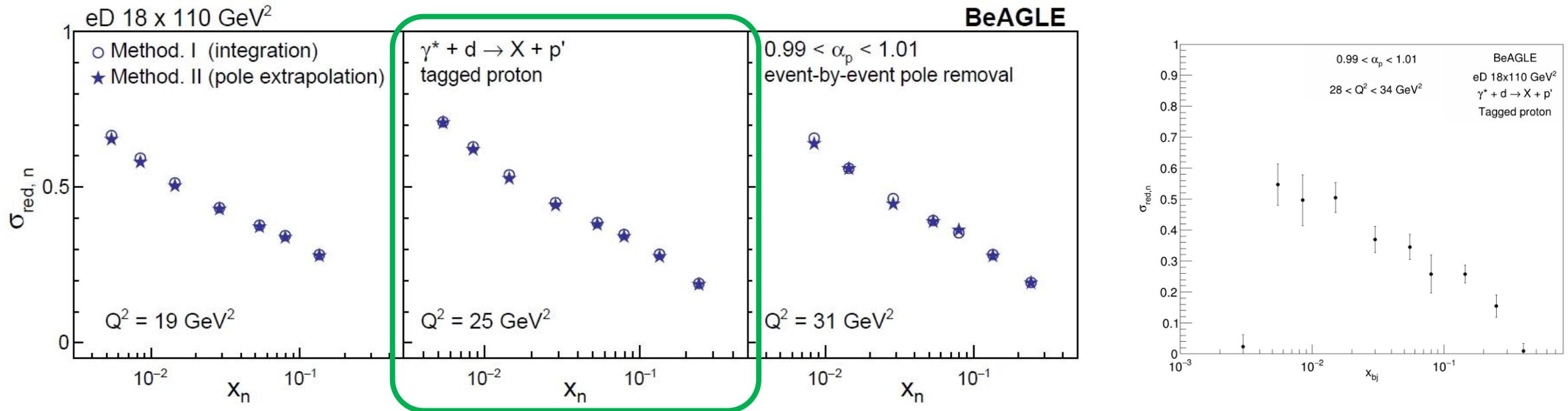
- (left) My, (right) From paper
- Red point is extrapolated to pole

- Same kinematic bin
- Same collision energy
  - 18x110 GeV<sup>2</sup>
- 2M events
- Results appear consistent**



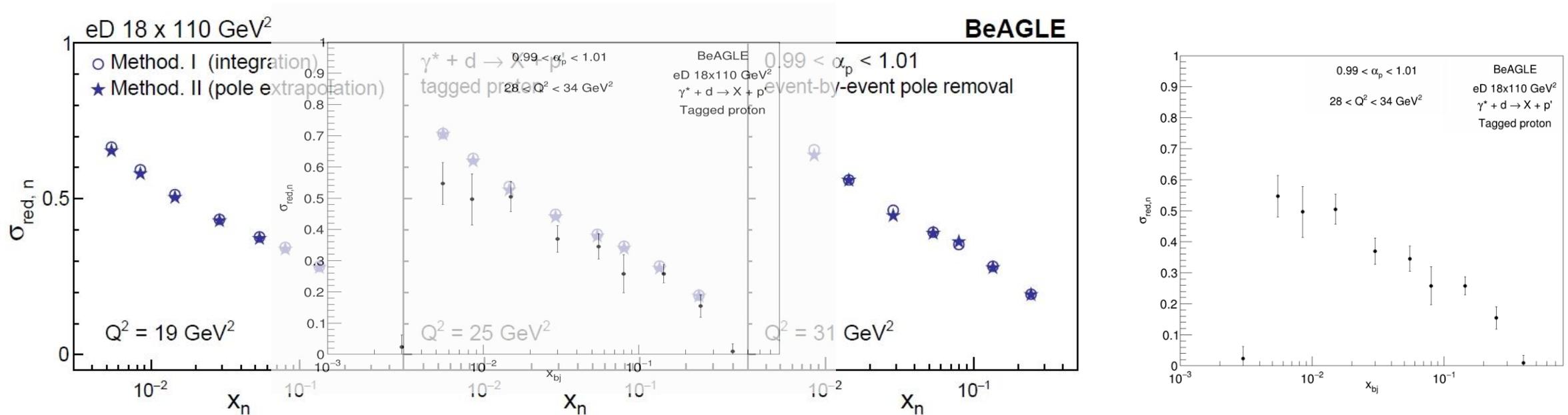
# REDUCED CROSS SECTION VS. $x_{bj}$

- Comparison of the neutron reduced cross section from paper and for my framework
  - Collision energy:  $18 \times 110 \text{ GeV}^2$
  - Results seem to be reasonably consistent with available statistics in the new simulation
- New:** Multiple bins in  $x_{bj}$ 
  - Same binning as original paper



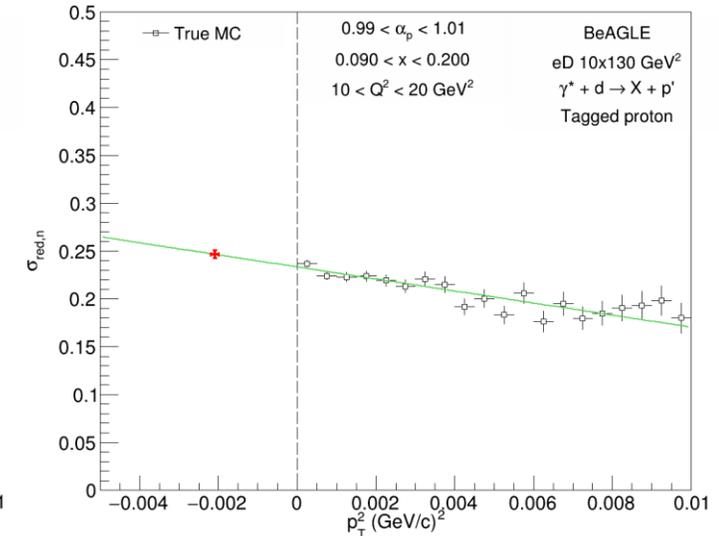
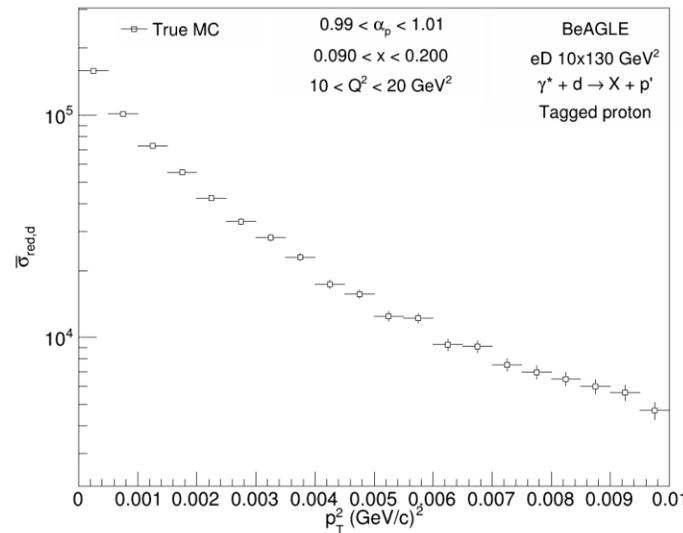
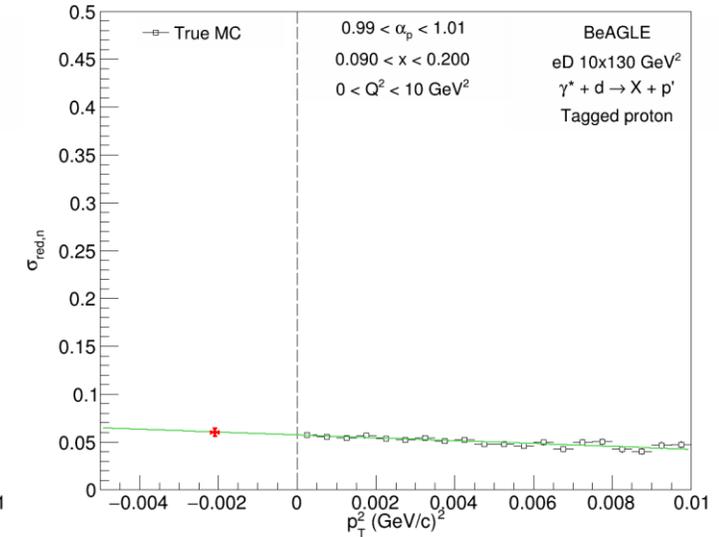
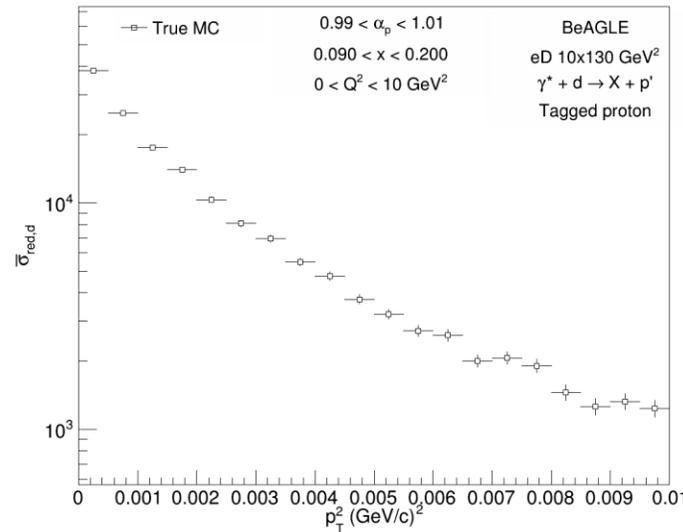
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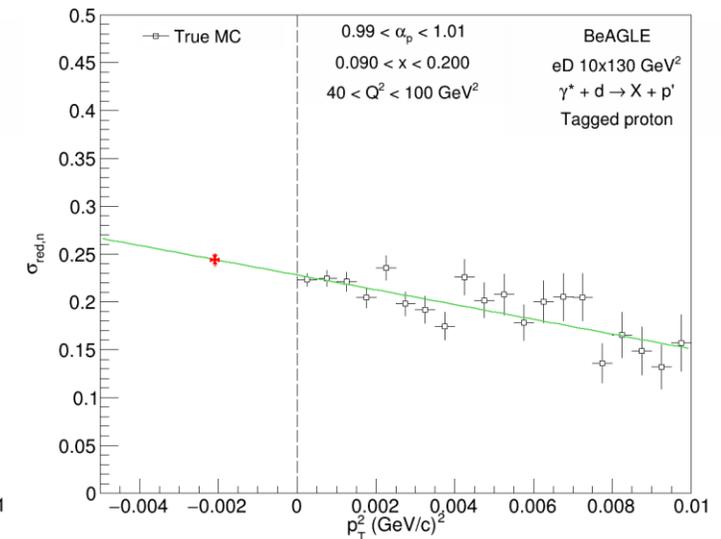
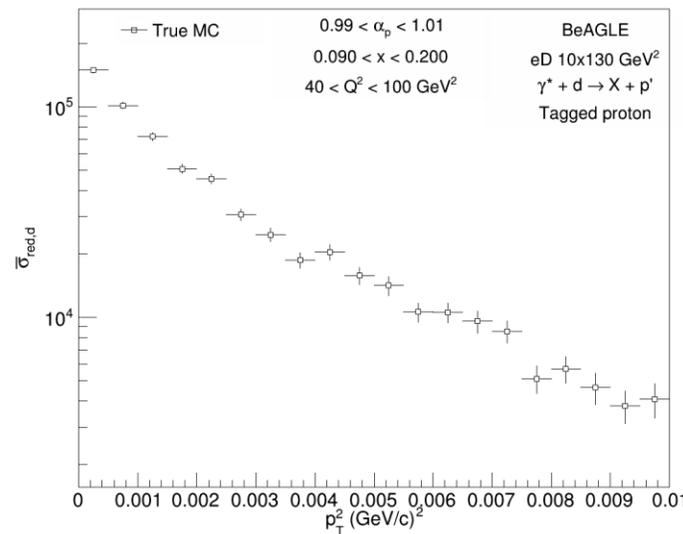
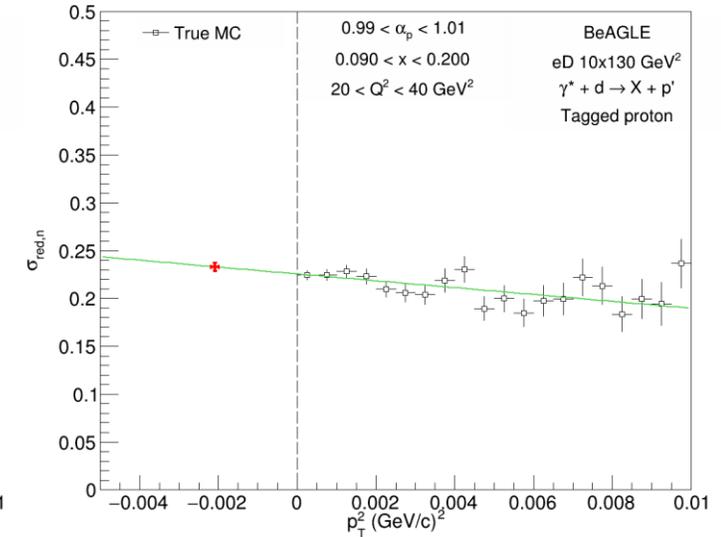
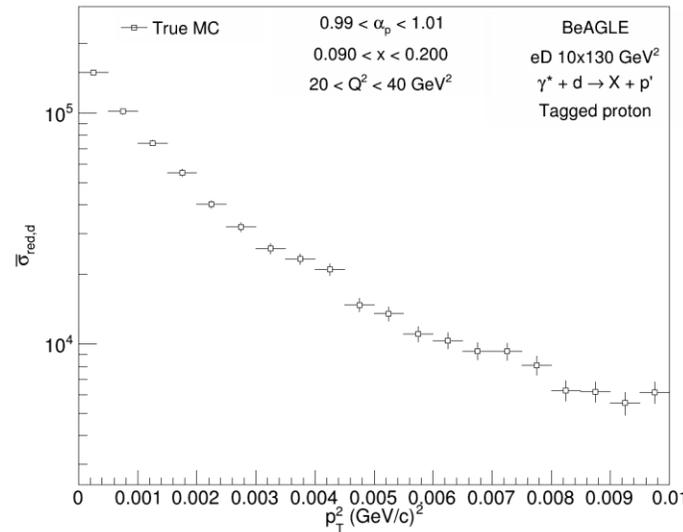
# TAGGED PROTON — BeAGLE (NEW RESULTS)

- (left) Deuteron reduced cross section in BeAGLE calculated using tagged protons
- (right) Neutron reduced cross section in BeAGLE calculated using tagged protons
- Showing plots for:
  - Fixed  $\alpha_p$  and  $x_{bj}$
  - Different  $Q^2$  bins in  $0 < Q^2 < 100 \text{ GeV}^2$
- New simulation sample
  - 20M events



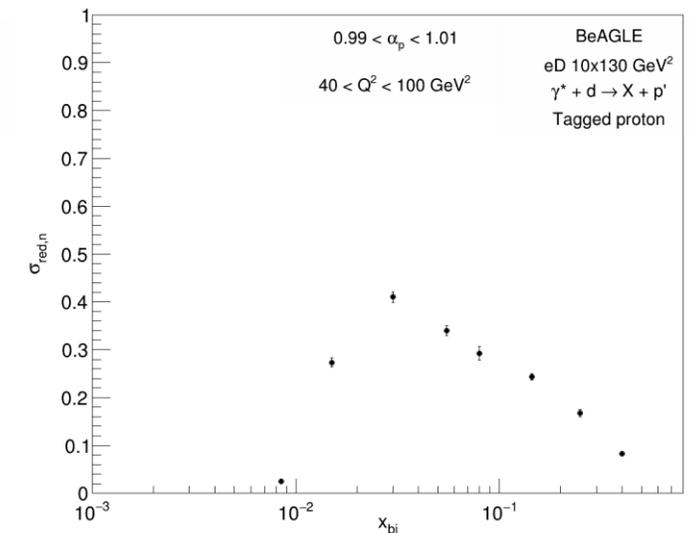
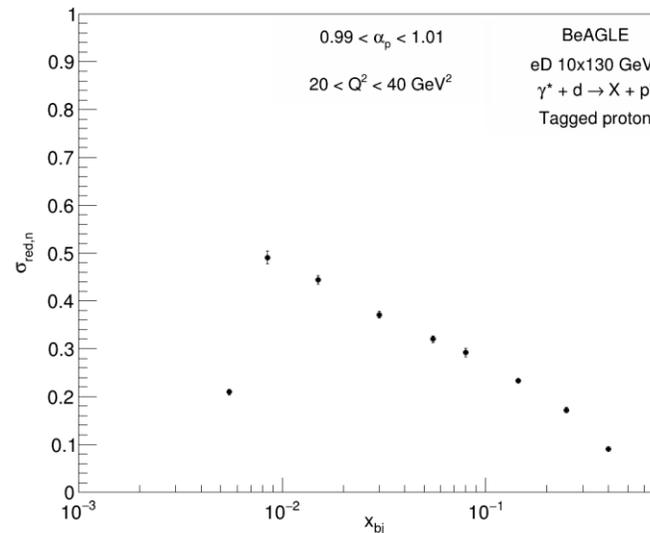
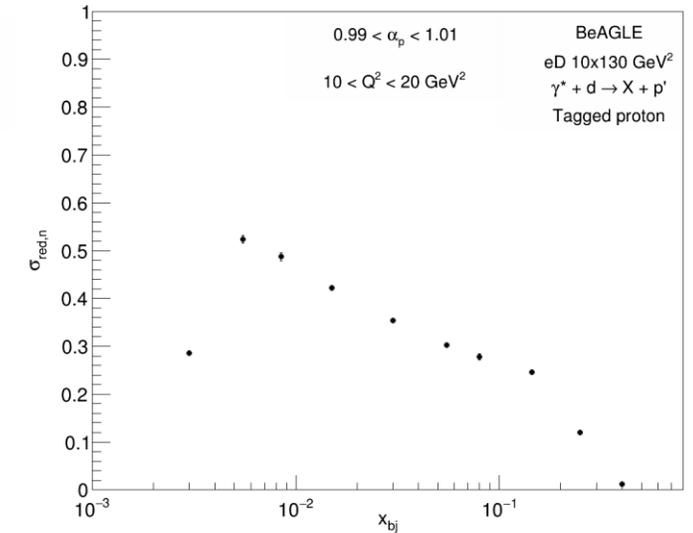
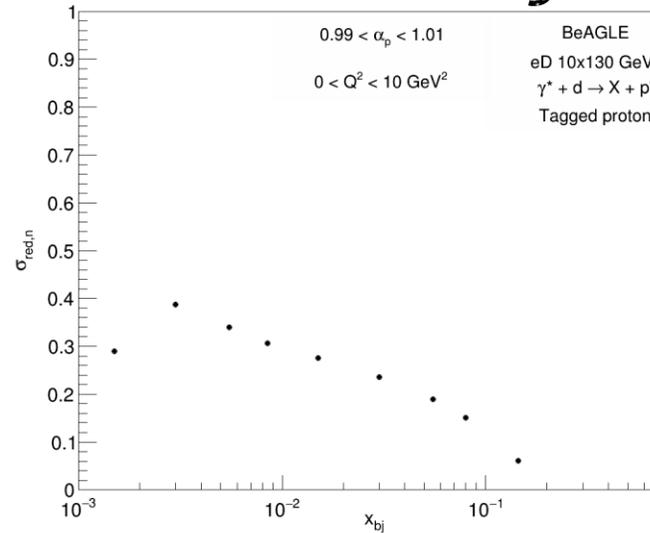
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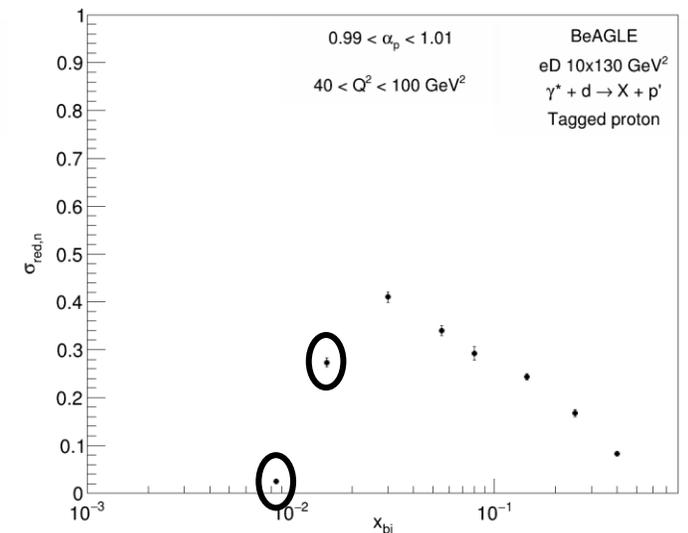
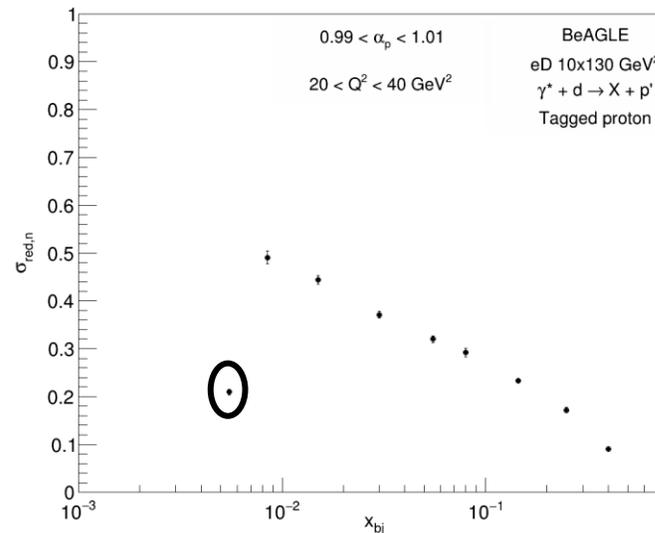
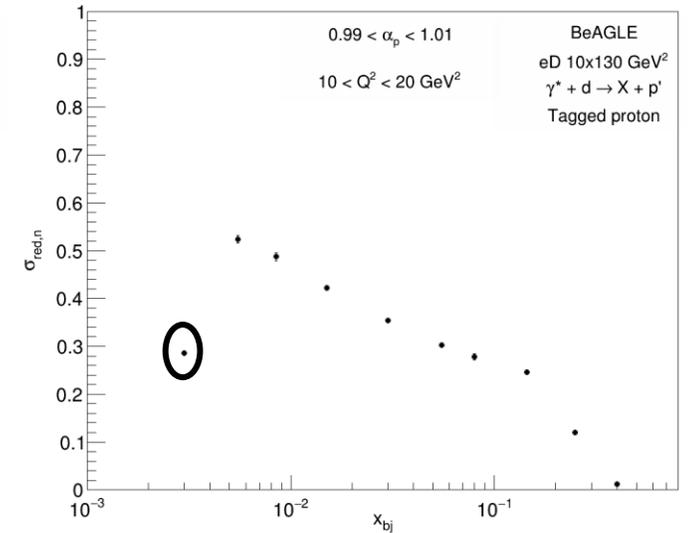
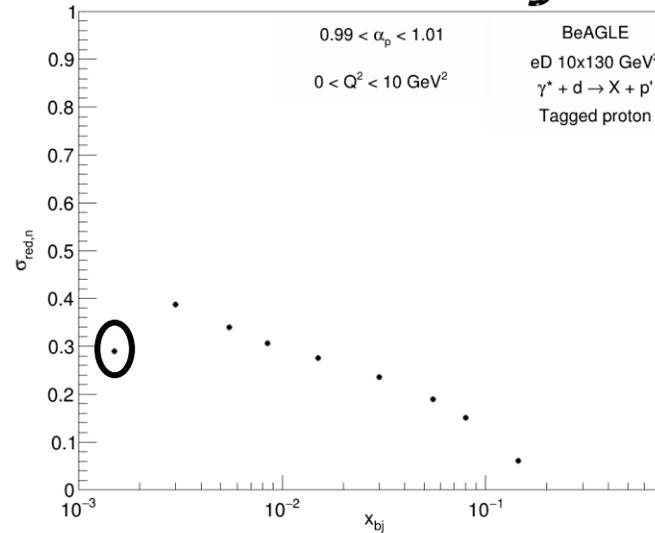
# REDUCED CROSS SECTION VS. $x_{bj}$ (NEW RESULTS)

- Comparison of the neutron reduced cross section from paper and for my framework
  - Collision energy: 10x310 GeV<sup>2</sup>
- **New:** Multiple bins in  $x_{bj}$ 
  - Same binning as original paper
- Individual panels:
  - Different  $Q^2$  bins in  $0 < Q^2 < 100$  GeV<sup>2</sup>
  - Fixed  $\alpha_p$  bin
- Overall  $x_{bj}$  looks reasonable



# REDUCED CROSS SECTION VS. $x_{bj}$ (NEW RESULTS)

- Comparison of the neutron reduced cross section from paper and for my framework
  - Collision energy:  $10 \times 310 \text{ GeV}^2$
- **New:** Multiple bins in  $x_{bj}$ 
  - Same binning as original paper
- Individual panels:
  - Different  $Q^2$  bins in  $0 < Q^2 < 100 \text{ GeV}^2$
  - Fixed  $\alpha_p$  bin
- Overall  $x_{bj}$  looks reasonable
  - Open question are only low  $x_{bj}$  points in each  $Q^2$  bin



# SUMMARY AND OUTLOOK

- TDIS framework in  $eD$  now verified using true MC simulation in BeAGLE
  - Tagged proton only for now
- Updated cross section values corresponding to different simulations
- Added  $x_{bj}$  binning to framework
  
- Outlook:
  - Update true MC tagged neutron framework
  - Update RC framework
  - Ongoing – production of new large simulation sample in official ePIC campaign