Exclusive Meeting – Deuteron Tagging

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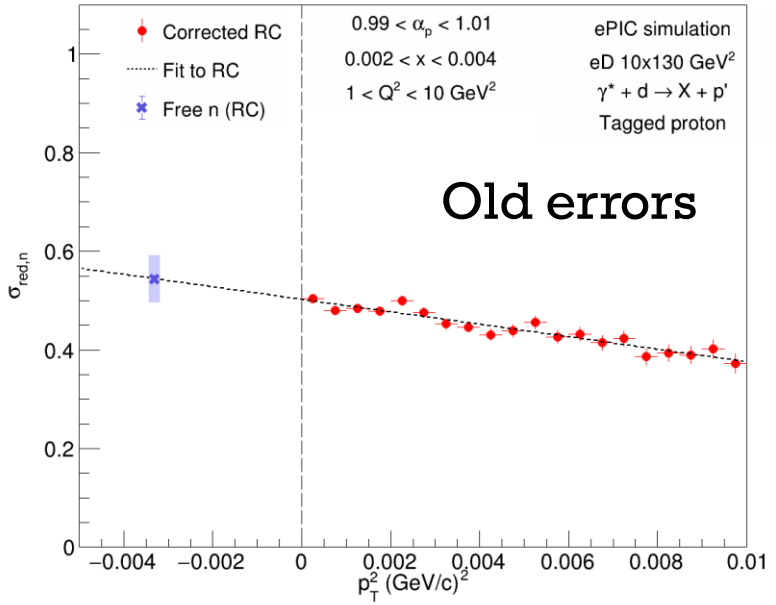
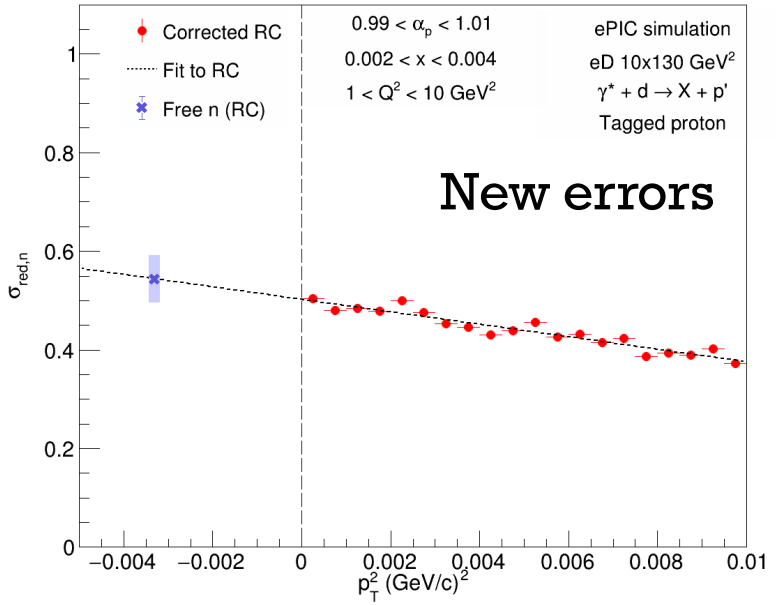
OVERVIEW

- Updated statistical uncertainties
  - Projection to expected luminosity
- Systematic uncertainties
  - Comparison of two approaches
    - All uncertainties correlated in p_T
    - Uncertainty of spectator reconstruction uncorrelated in p_T
- Results for theory colleagues for ESR
  - Integrated (p_T) deuteron reduced cross section

STATISTICAL UNCERTAINTIES

- Calculated from statistics in each p_T^2 bin and ratio of expected (L_{ex}) and expected generated (L_{gen}) luminosities
  - Statistics gain: $G = \frac{L_{ex}}{L_{gen}}$
    - $L_{gen} = 0.056\ \text{fb}^{-1}, L_{gen} = 1.5\ \text{fb}^{-1}$
  - Old relative stat. err.: $\sigma_{old} = \frac{1}{\sqrt{N(p_T^2)}}$
  - New relative stat. err.: $\sigma_{new} = \frac{1}{\sqrt{G \cdot N(p_T^2)}}$
  - Scale for stat. err.: $S = \frac{\sigma_{new}}{\sigma_{old}}$
- Re-scale all statistical errors using scale S in corresponding bin

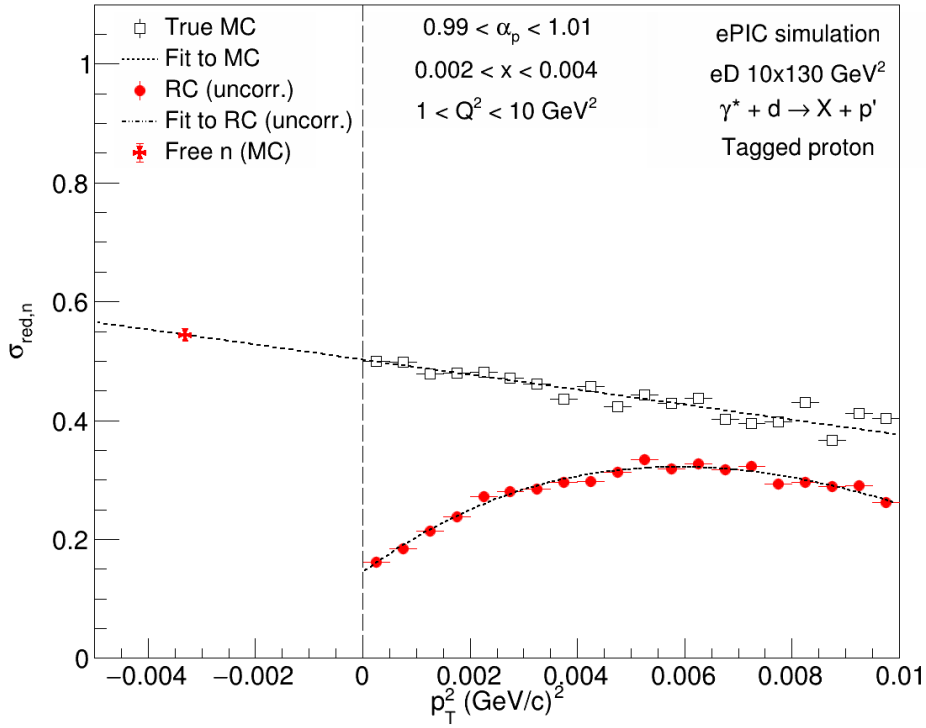




SYSTEMATIC UNCERTAINTIES

- Sources of systematic uncertainties:
  - Luminosity: $\sigma_{lumi} = 1\ \%$
  - Theory/extrapolation: $\sigma_{th} = 2\ \%$
  - Proton reconstruction: $\sigma_{p} = 10\ \%$
  - Neutron reconstruction: $\sigma_{n} = 20\ \%$
- **Method 1:**
  - Spectator reconstruction uncorrelated in p_T
  - Move central value each point of MC reference according to Gaussian distribution:
    - Mean in original central value
    - Width based on spectator reconstruction sys. uncert.
  - Generate 10 different smeared distributions and correct RC
    - Fit the smeared distributions and extract 10 new extrapolated nucleon reducer cross sections ($\sigma_{red,n/p,i}$)
  - Estimate systematic uncertainty of spectator reco. as standard deviation from nominal value ($\sigma_{red,n/p}$): $\sigma^2_{n/p,reco} = \frac{\sum_{i=1}^{N}\left(\sigma_{red,n/p} - \sigma_{red,n/p,i}\right)^2}{N}$
  - Total systematic uncertainty: $\sigma_{sys} = \sqrt{\sigma^2_{lumi} + \sigma^2_{th} + \sigma^2_{n/p,reco}}$

Uncorrected



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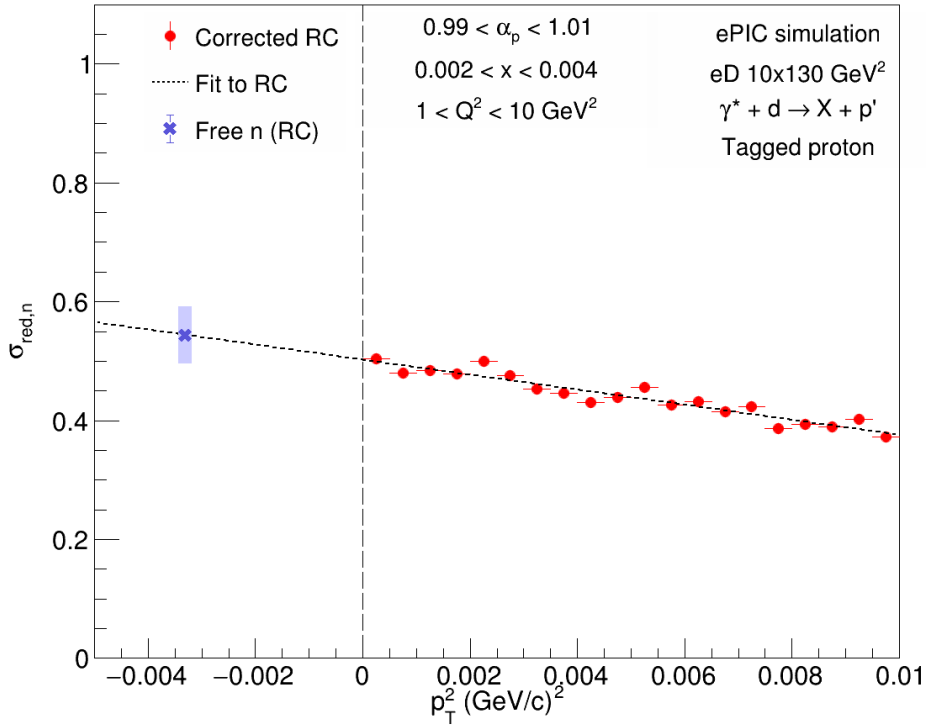

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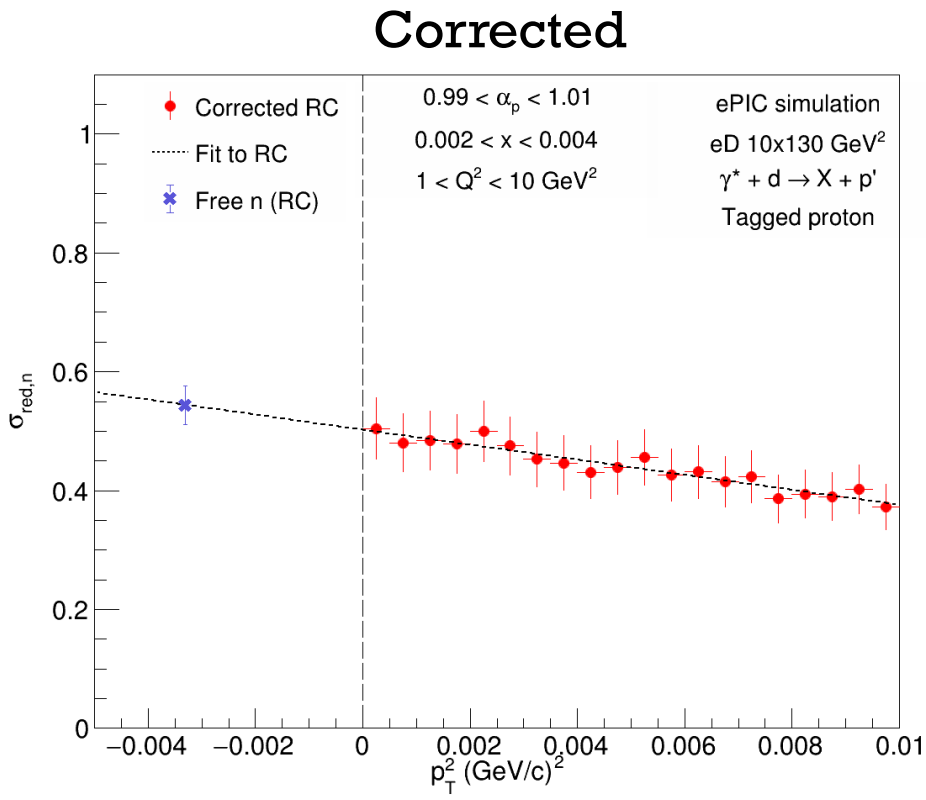
- **Method 2:**
  - Spectator reconstruction correlated in p_T
  - First, get the corrected nucleon cross section
  - Add statistical and systematic uncertainty in quadrature for each point
    - Systematic uncertainty on each point given directly by:

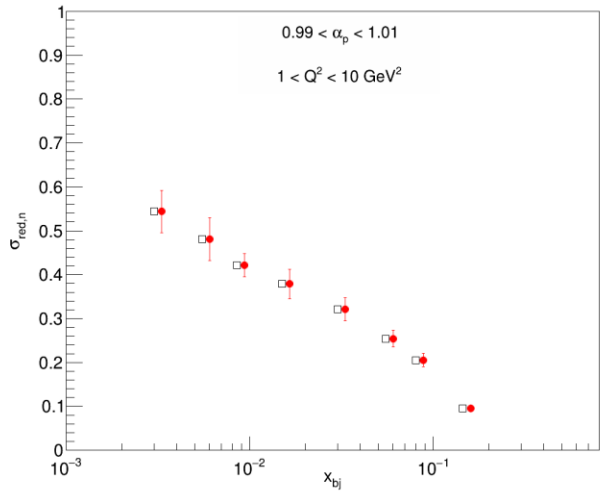
$$\sigma_{sys} = \sqrt{\sigma_{lumi}^2 + \sigma_{th}^2 + \sigma_{n/p}^2}$$

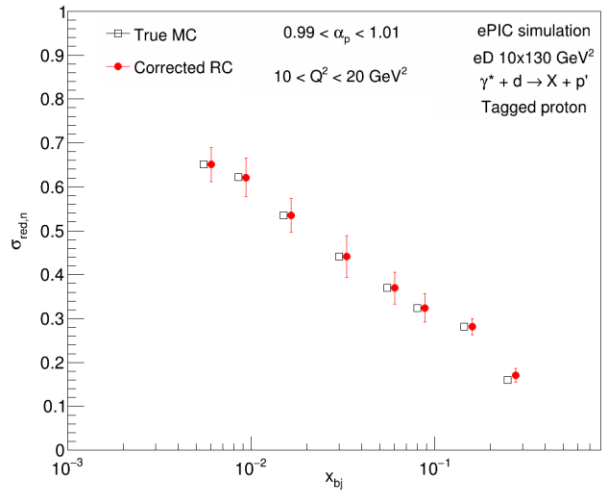
  - Perform extrapolation using corrected RC distribution with combined uncertainties
  - Extract total uncertainty on extrapolated point from the fit

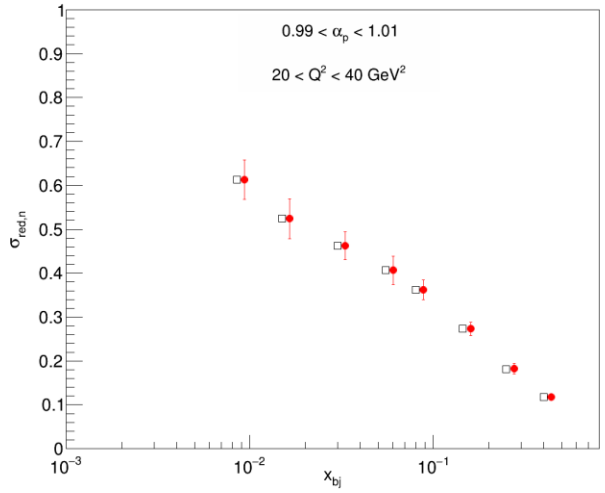


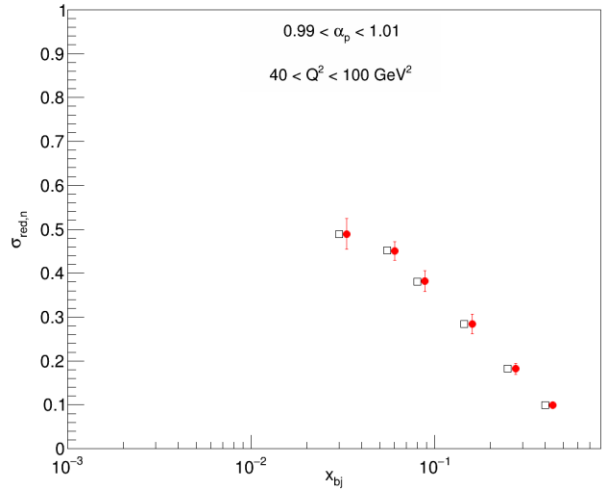
RESULTS (eN) – METHOD 1 (UNCORRELATED)

- Comparison of the MC and RC **neutron** reduced cross sections
- **Method 1** systematic uncertainty
  - Spectator reconstruction uncorrelated in p_T
- Uncertainties dominated by systematics



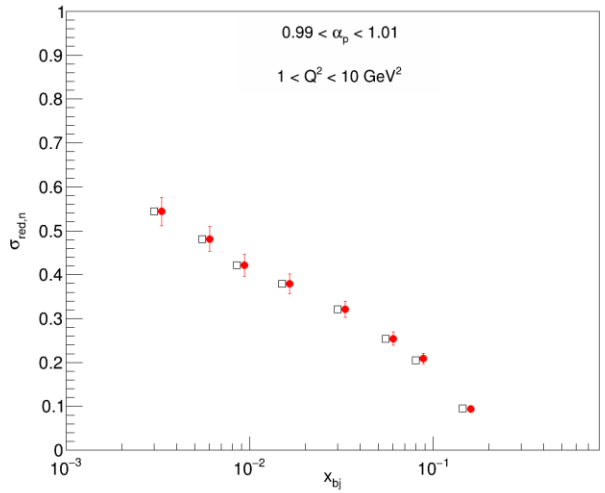


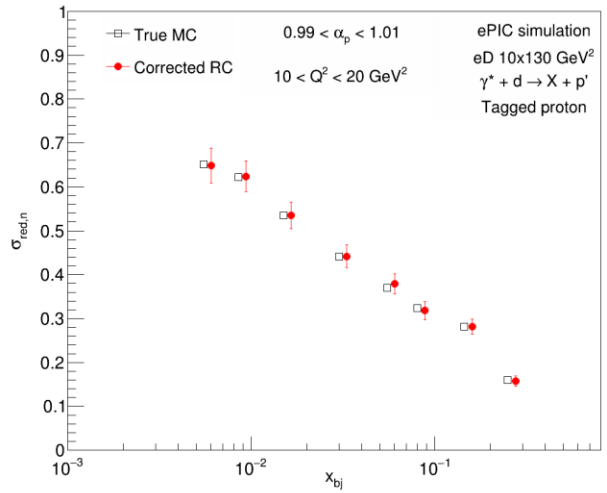


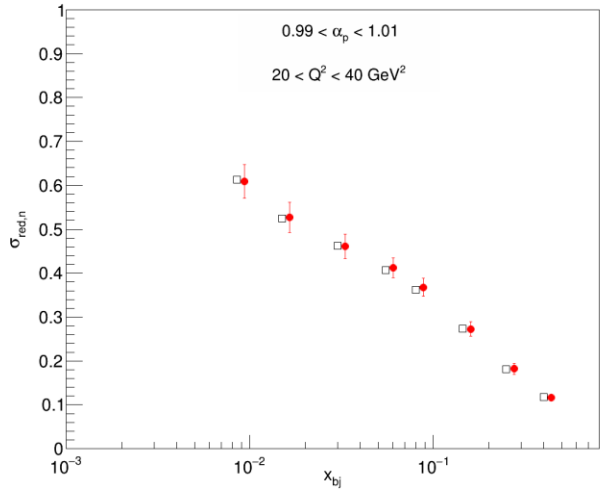


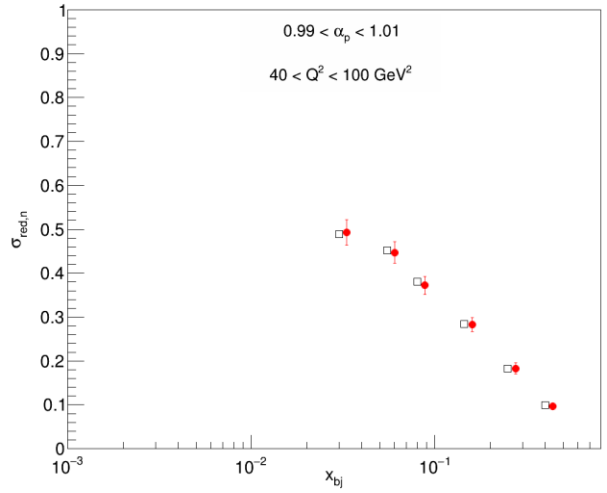
RESULTS (eN) – METHOD 2 (CORRELATED)

- Comparison of the MC and RC **neutron** reduced cross sections
- **Method 2** systematic uncertainty
  - Spectator reconstruction correlated in p_T
- Uncertainties dominated by systematics









RESULTS (eP) – METHOD 1 (UNCORRELATED)

- Comparison of the MC and RC **proton** reduced cross sections
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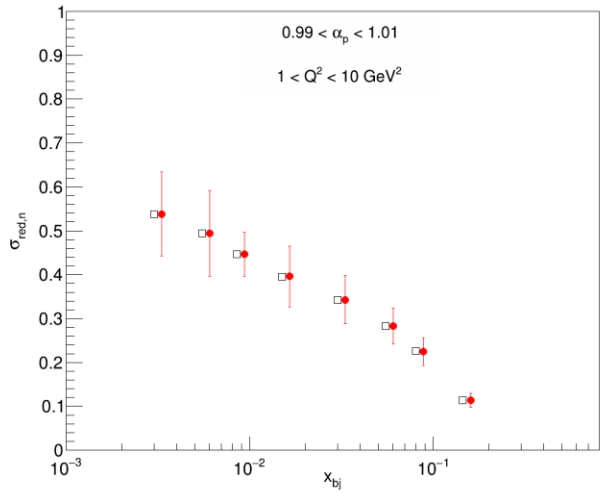
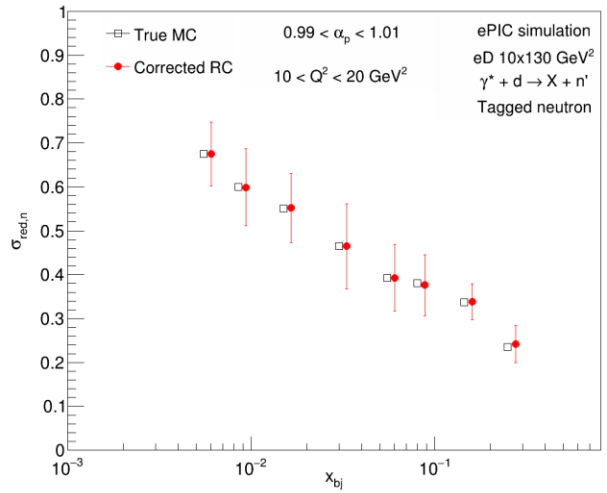
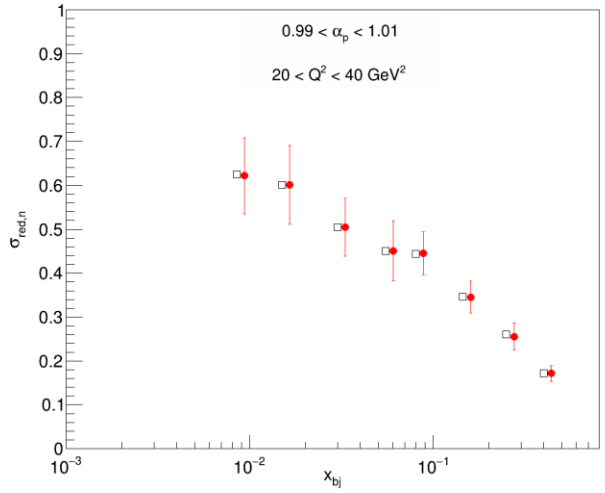
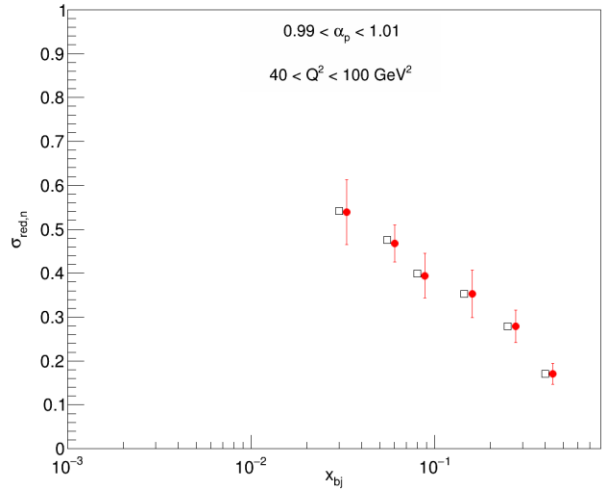
- Uncertainties dominated by systematics









RESULTS (eP) – METHOD 2 (CORRELATED)

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- **Method 2** systematic uncertainty
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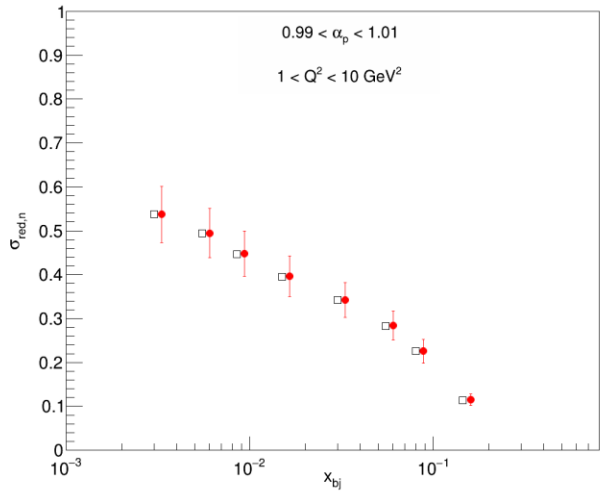
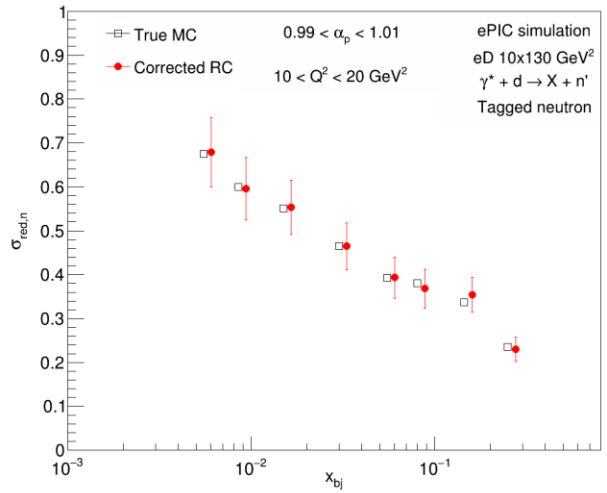
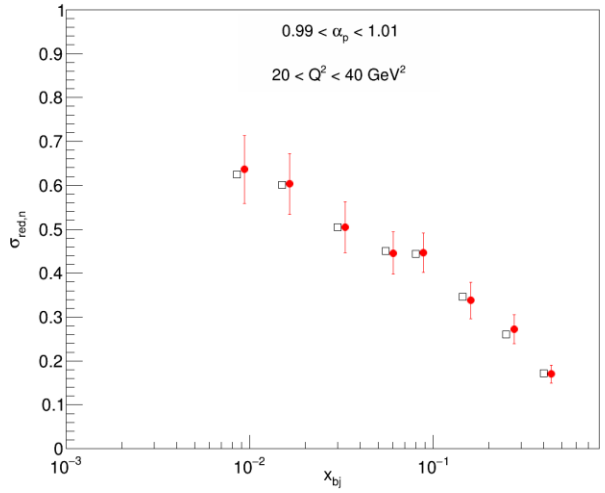
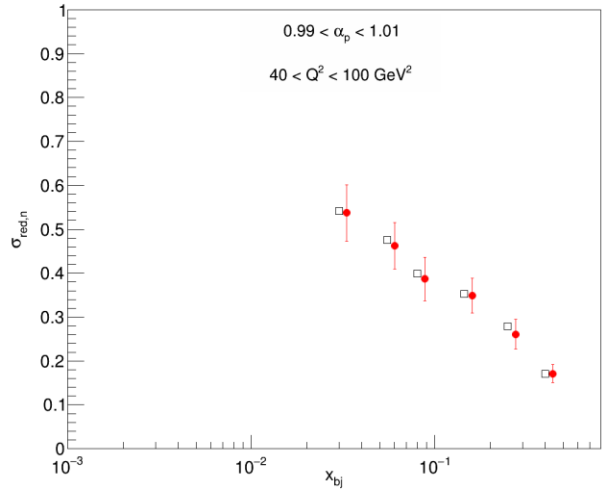




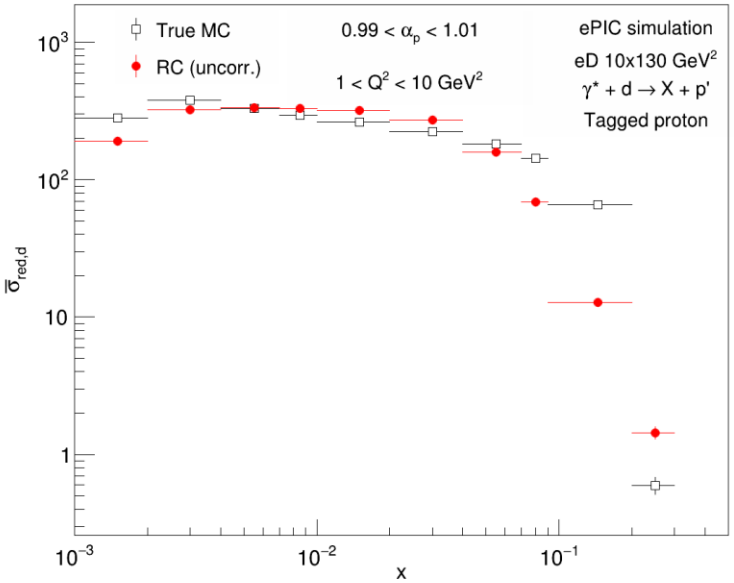


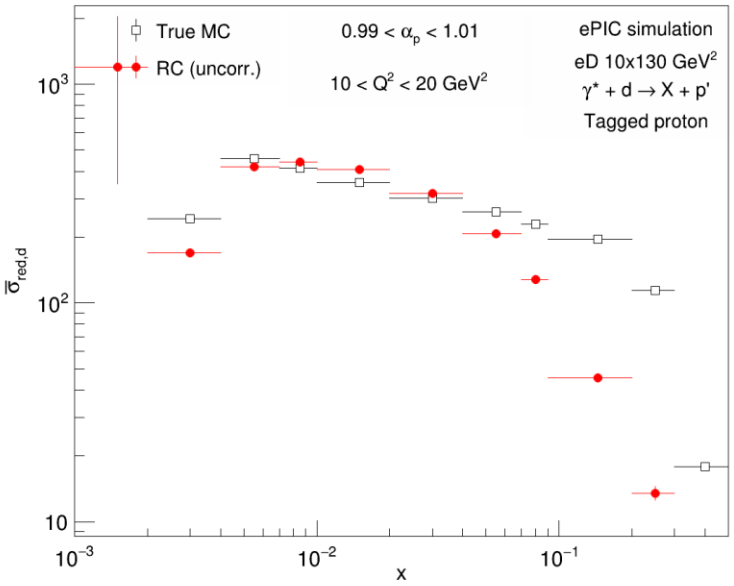


IMPACT STUDY FOR ESR

- New plots/data points for theory colleagues
  - Deuteron reduced cross section in (x, Q^2) bins
    - Integrated over p_T

- Deuteron reduced cross section (original):
  - $\mathrm{d}\sigma_d = Flux(x, Q^2) \times \sigma_{red,d} \times \mathrm{d}x\mathrm{d}Q^2 \frac{\mathrm{d}\phi_{e'}}{2\pi} [2(2\pi)^3]^{-1} \frac{\mathrm{d}\alpha_p}{\alpha_p} \frac{\mathrm{d}p_{T,p}^2}{2} \mathrm{d}\phi_p$





IMPACT STUDY FOR ESR

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- Deuteron reduced cross section (new):
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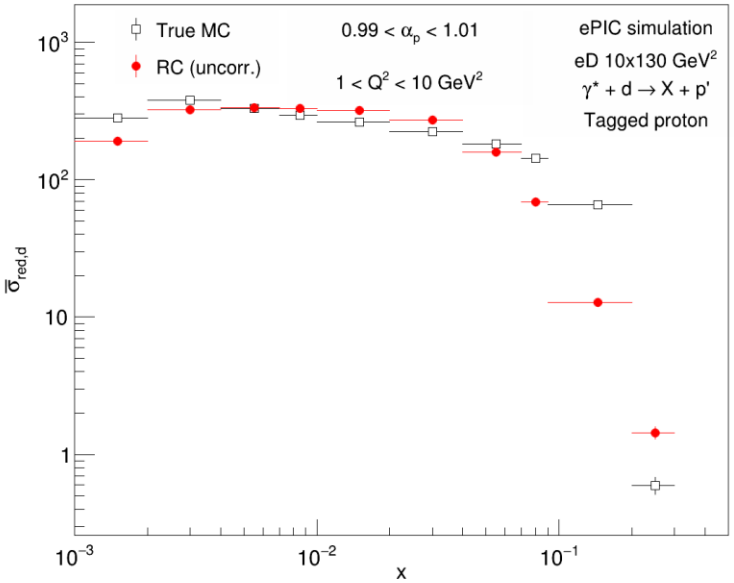
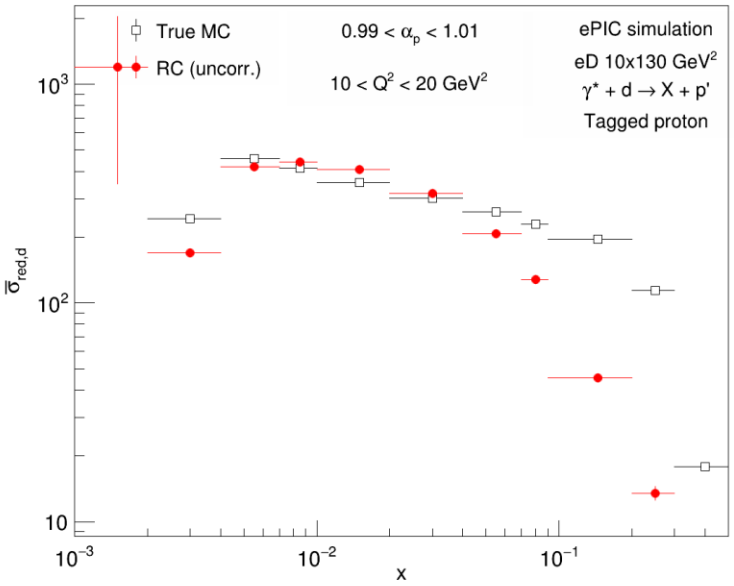
  - Is this correct?

- **Result with α_p cut**
  - Effectively introduces p_T cut?

- Need to cross check that values make sense
  - Currently no reference





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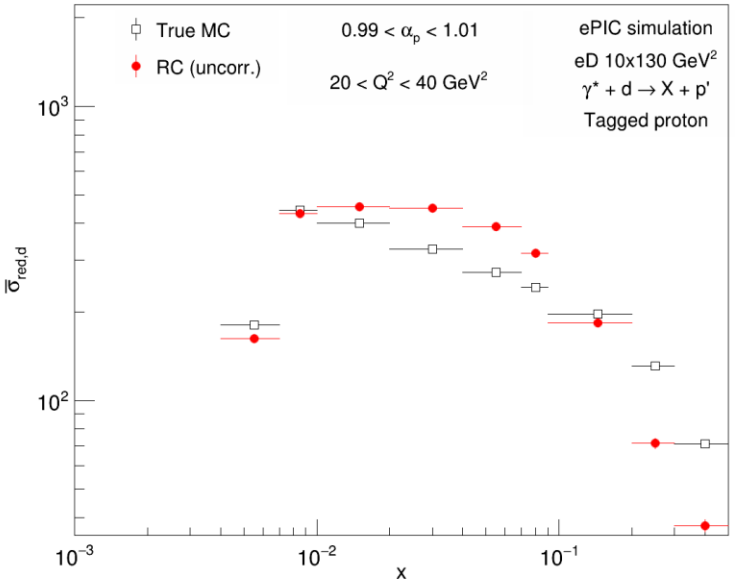

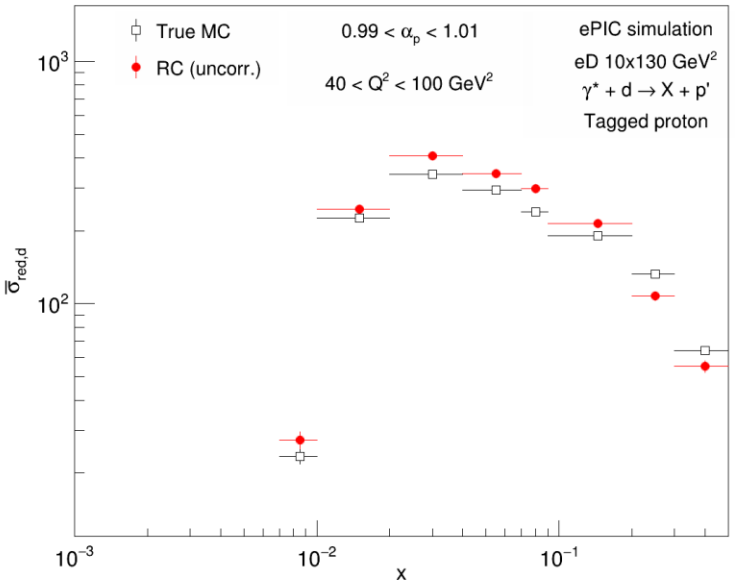

SUMMARY AND OUTLOOK

- Updated statistical uncertainties to match projected luminosity
- Updated systematic uncertainties
  - Two methods to evaluate spectator reconstruction uncertainty
- Prepared results for our theory colleagues for impact study in the ESR paper
- Outlook:
  - Analysis note approval
  - Update AN and paper, once we agree on the systematics
  - Scheduling of Physics Forum for results approval

THANK YOU FOR ATTENTION

BACKUP

NEW SIMULATION PRODUCTION

- Generated in BeAGLE
- First pass of main simulation production:
  - 40M events of eD 10x130 GeV^2
    - 20M of en and 20M of ep
  - 20M total (10M+10M) submitted for official simulation campaign
- Luminosity and cross section:
  - en: $\sigma_{tot} = 3.538 \cdot 10^{-4}\mathrm{mb}$, $L_{int} = N_{evt}/\sigma_{tot} = 20\mathrm{M}/(3.538 \cdot 10^{-4}\mathrm{mb}) = 20\mathrm{M}/(3.538 \cdot 10^{8}\mathrm{fb}) = 0.056\ \mathrm{fb}^{-1}$
  - ep: $\sigma_{tot} = 3.707 \cdot 10^{-4}\mathrm{mb}$, $L_{int} = 0.056\ \mathrm{fb}^{-1}$ (same as en after rounding)
  - Total integrated luminosity (true MC only): $L_{int} = 0.112\ \mathrm{fb}^{-1}$
  - Total integrated luminosity (EICRecon): $L_{int} = 0.056\ \mathrm{fb}^{-1}$
  - Expected luminosity for year 2: $L_{int} = 11.4\ \mathrm{fb}^{-1}$
- Produced additional 40M BeAGLE for true MC studies

VARIABLES

- Scattered electron
  - $Q^2 = -q^2 = -\left(p_{e,beam} - p_{e,scat}\right)^2$
  - $x = \frac{Q^2}{P \cdot q}$
  - $x_{nucleon} = \frac{Q^2}{2P_{nucl} \cdot q} = \frac{x}{2-\alpha_p}$
- 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:
  - $\alpha_p \equiv \frac{2p_p^+}{p_d^+} = \frac{2\left(E_p + p_{z,p}\right)}{E_d + p_{z,d}}$
- 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
  - $L_{int} = \frac{N_{events}}{\sigma_{tot}}$
    - $\text{mb} = 2.568\ \text{GeV}^{-2}$
    - 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 ($10\text{x}130\ \text{GeV}^2$):
      - $\sigma_{tot} = 3.538 \cdot 10^{-4}\text{mb}\ (en)$
      - $\sigma_{tot} = 3.707 \cdot 10^{-4}\text{mb}\ (ep)$
    - Test sample ($18\text{x}110\ \text{GeV}^2$):
      - $\sigma_{tot} = 3.869 \cdot 10^{-4}\text{mb}\ (en)$

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:
  - $\mathrm{d}\sigma_d = Flux(x,Q^2) \times \sigma_{red,d} \times \mathrm{d}x\mathrm{d}Q^2 \frac{\mathrm{d}\phi_{e'}}{2\pi} [2(2\pi)^3]^{-1} \frac{\mathrm{d}\alpha_p}{\alpha_p} \frac{\mathrm{d}p_{T,p}^2}{2} \mathrm{d}\phi_p$
- Photon flux:
  - $Flux(x,Q^2) = \frac{2\pi\alpha_{em}^2 y^2}{Q^4(1-\epsilon)x} = \frac{2\pi\alpha_{em}^2[1+(1-y)^2]}{Q^4 x}$
- Deuteron reduced cross section
  - $\sigma_{red,d} = \frac{1}{Flux} \frac{\mathrm{d}\sigma_d}{\mathrm{d}x\mathrm{d}Q^2(d\phi_{e'}/2\pi)\mathrm{d}\Gamma_p}$, where $\mathrm{d}\Gamma_p = [2(2\pi)^3]^{-1} \frac{\mathrm{d}\alpha_p}{\alpha_p} \frac{\mathrm{d}p_{T,p}^2}{2} \mathrm{d}\phi_p$
- Measured reduced cross section (integrated over $\mathrm{d}\phi_p$)
  - $\bar{\sigma}_{red,d} = \left(\frac{2.568}{L_{int}}\right) \frac{Q^4 x}{2\pi\alpha_{em}^2[1+(1-y)^2]} \frac{[4(2\pi)^3]\alpha_p}{\Delta\alpha_p} \frac{\mathrm{d}N}{\Delta x \Delta Q^2 \Delta p_{T,p}^2 2\pi}$
    - $\Delta x,\ \Delta Q^2,\ \Delta p_{T,p}^2, \Delta\alpha_p$ 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
  - $p_{pT}^2 \to -a_T^2$ 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
  - $S_d(p_{pT},\alpha_p)[pole] = \frac{R}{\left(p_{pT}^2+a_T^2\right)^2}$
  - 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
    - $R = \alpha_p^2 m_N \Gamma^2(2-\alpha_p)$
    - $\Gamma^2 = 0.007885\ \mathrm{GeV}$

A. Jentsch, Z. Tu, C. Weiss: Phys. Rev. C **104**, 065205.
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