Exclusive Meeting – Deuteron Tagging

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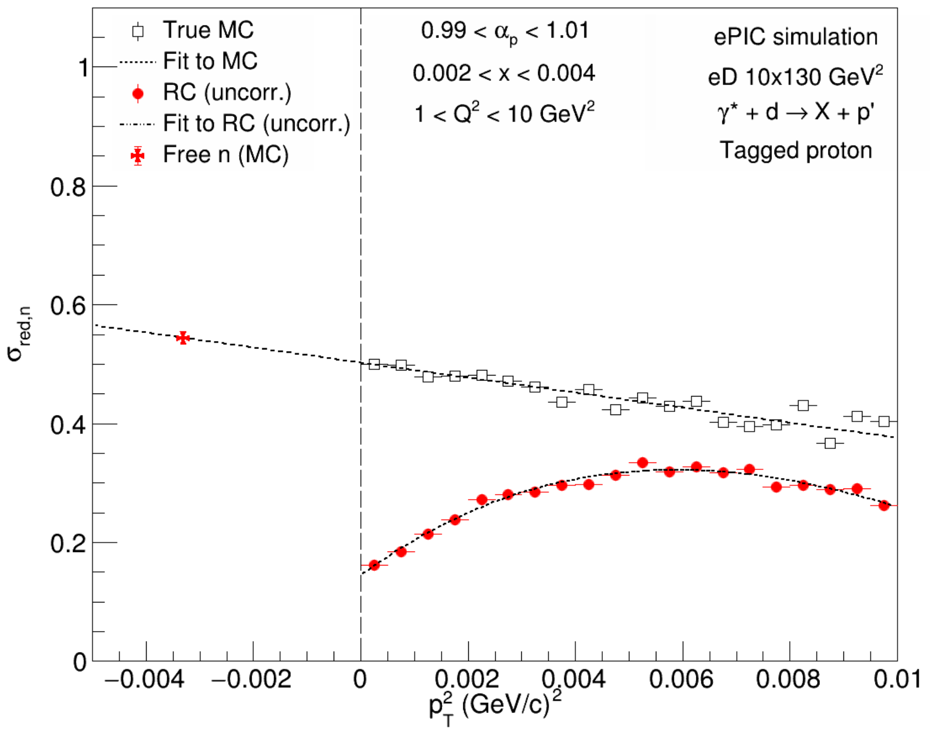
OVERVIEW

- New systematic uncertainties

SYSTEMATIC UNCERTAINTIES

- Sources of systematic uncertainties:
  - **Luminosity:** $\sigma_{lumi} = 1.5\ \%$
    - From YR and current discussions
  - **Theory/extrapolation:** $\sigma_{th} = 2\ \%$
    - From original paper
      - A. Jentsch, Z. Tu, C. Weiss: Phys. Rev. C **104**, 065205.
  - **Beam effects:** $\sigma_{beam} = 1.5\ \%$
    - Crossing angle, angular divergence, beam momentum spread
    - Based on values cited by ATLAS or HERA
      - ATLAS Collaboration, The European Physical Journal C 83 (2023).
      - HERA Collaboration, Nuclear Physics B 816, 1–61 (2009).
  - **Proton reconstruction:** $\sigma_p = 2\ \%$
    - Uncertainty of the transport matrix
    - Based on values cited by ATLAS
      - ATLAS Collaboration, The European Physical Journal C 83 (2023).
  - **Neutron reconstruction:** $\sigma_n = 1\ \%$
    - Uncertainty of the primary vertex resolution
    - Based on values cited by HERA and ePIC Roman Pot studies
      - HERA Collaboration, Nuclear Physics B 816, 1–61 (2009).

Uncorrected

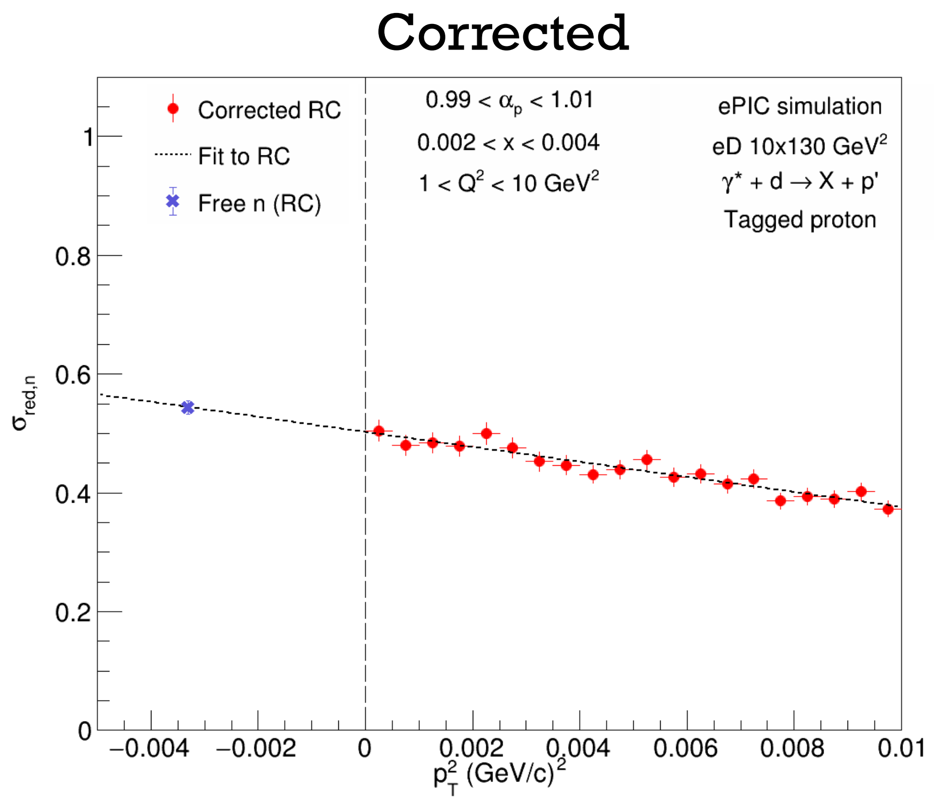


SYSTEMATIC UNCERTAINTIES

- Total systematic uncertainty:
  - $\sigma_{sys} = \sqrt{\sigma_{lumi}^2 + \sigma_{th}^2 + \sigma_{beam}^2 + \sigma_{n/p}^2}$
  - Added in quadrature to statistical uncertainty point-by-point

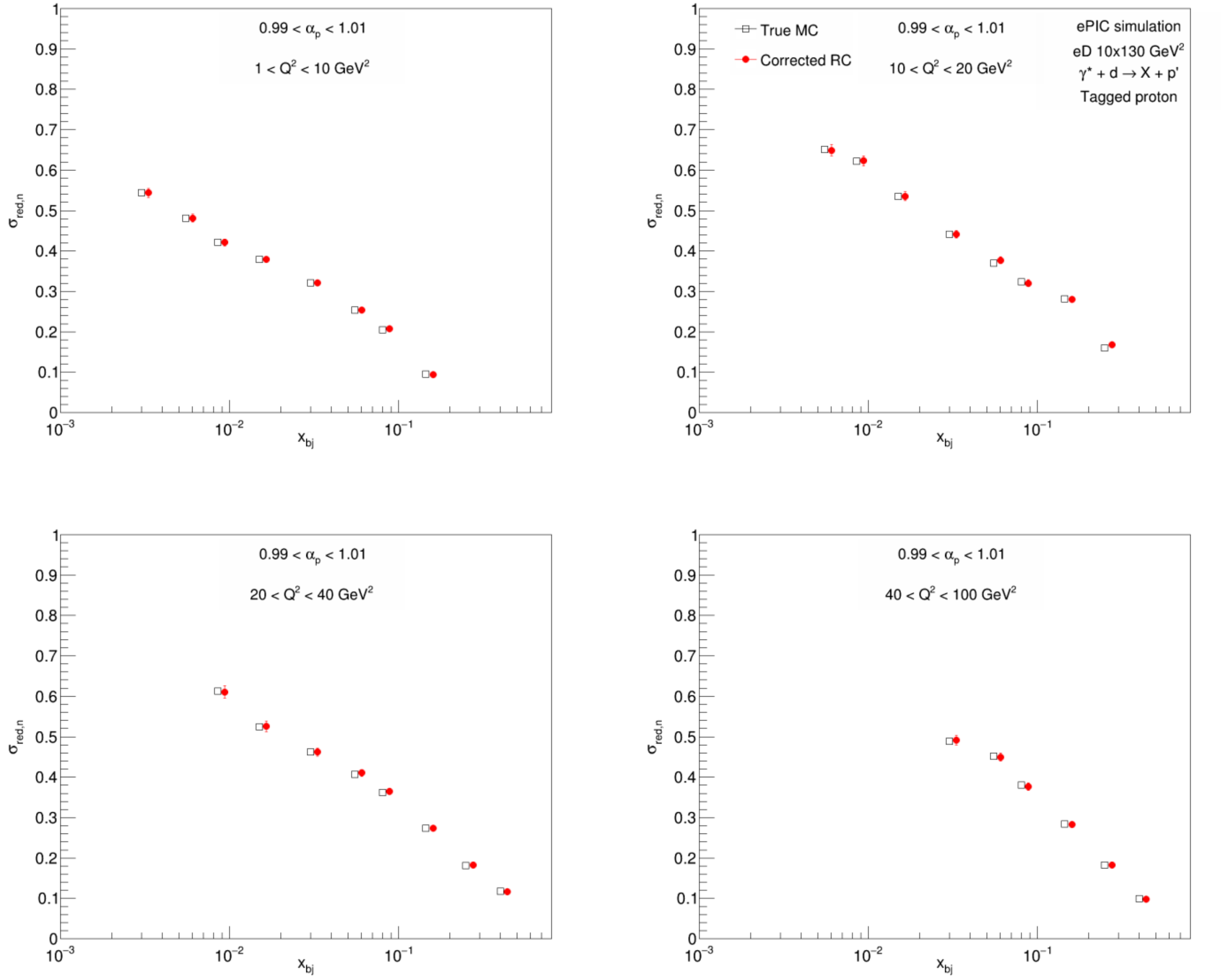
- Linear fit performed to distribution with combined uncertainties

- Extrapolated total uncertainty based on 1σ confidence interval of the fit function



RESULTS (eN)

- Comparison of the MC and RC **neutron** reduced cross sections



RESULTS (eP)

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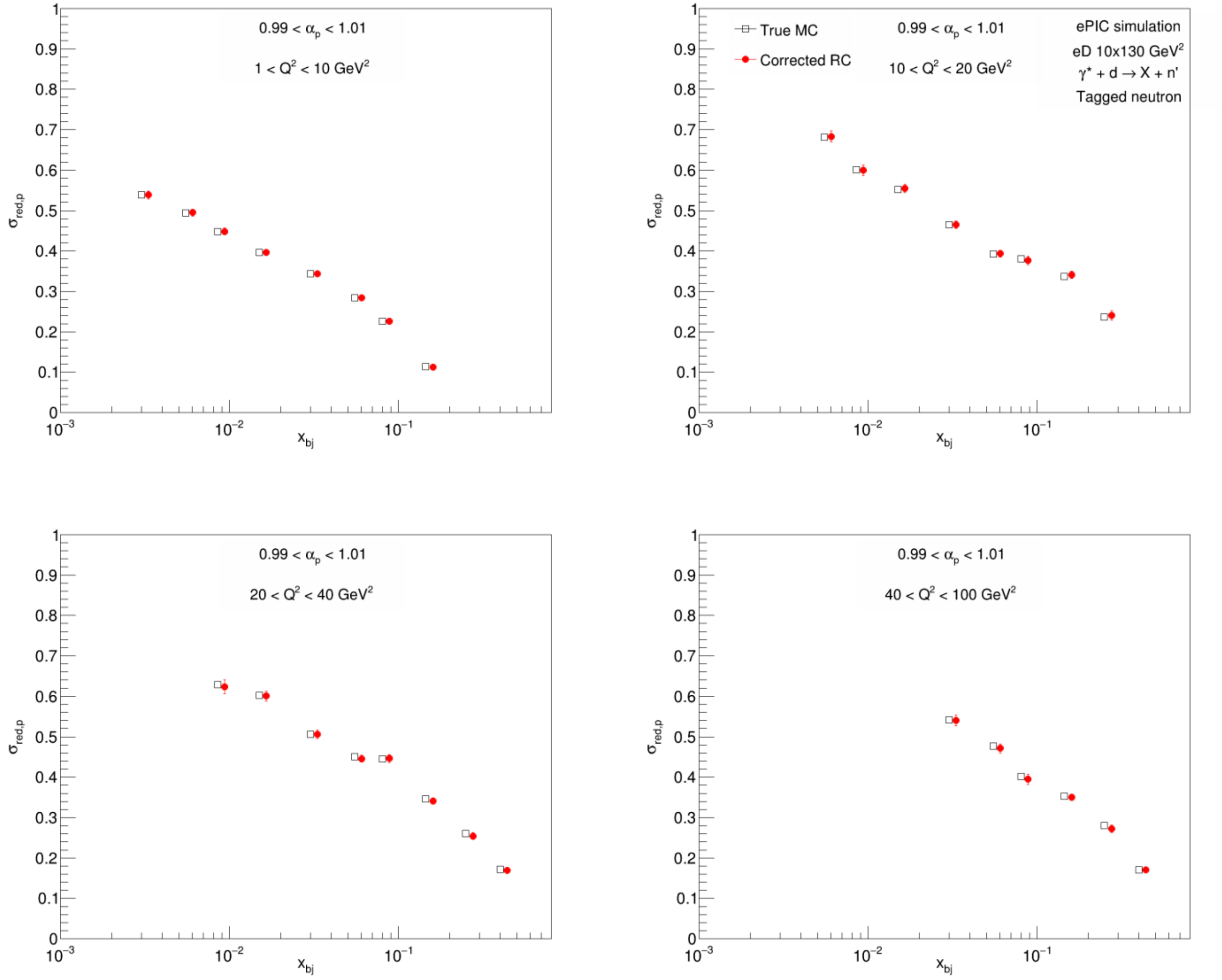

SUMMARY AND OUTLOOK

- Updated systematic uncertainties
  - Based on previous and current experiments which use similar experimental techniques

- Outlook:
  - Analysis note approval
  - Update AN and paper, once we agree on the systematics
  - Physics Forum on July 7 for results approval

THANK YOU FOR ATTENTION

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BACKUP

NEW SIMULATION PRODUCTION

- Generated in BeAGLE
- First pass of main simulation production:
  - 40M events of eD $10\text{x}130\ \text{GeV}^2$
    - 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): $L_{int} = 0.056\ \text{fb}^{-1}$
  - Expected luminosity for year 2: $L_{int} = 11.4\ \text{fb}^{-1}$
- Produced additional 40M BeAGLE for true MC studies

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
  - $L_{int} = \frac{N_{events}}{\sigma_{tot}}$
    - $\text{mb} = 2.568\ \text{GeV}^{-2}$
    - 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 (10x130 GeV^2):
      - $\sigma_{tot} = 3.538 \cdot 10^{-4}\text{mb}\ (en)$
      - $\sigma_{tot} = 3.707 \cdot 10^{-4}\text{mb}\ (ep)$
    - Test sample (18x110 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
    - $R = \alpha_p^2 m_N \Gamma^2(2-\alpha_p)$
    - $\Gamma^2 = 0.007885$ GeV

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