Exclusive Meeting – Deuteron Tagging

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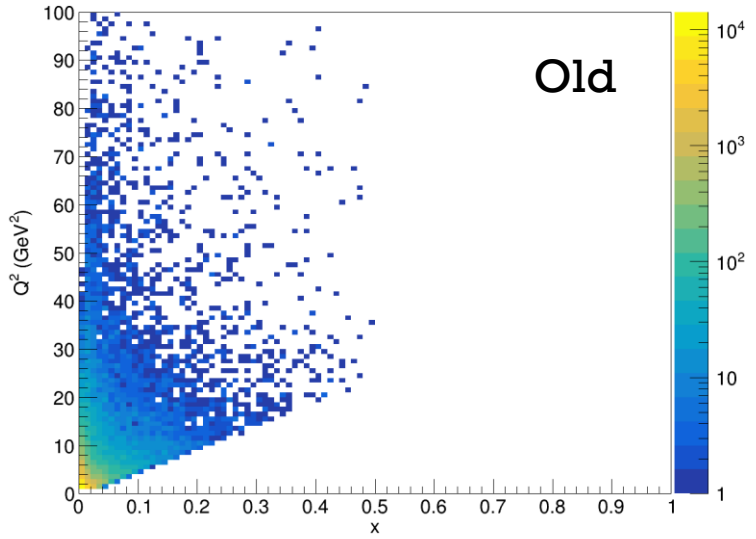
05/04/2026

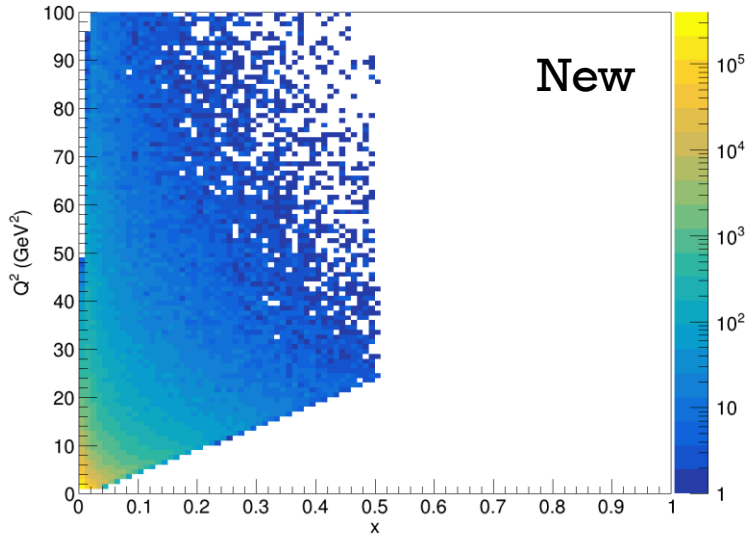
OVERVIEW

- Updated scattered electron finding
  - Both True MC and RC
- Updated spectator finding
  - Both True MC and RC
- Updated systematic uncertainty calculation
- New results
  - Full statistics of official simulation production

SCATTERED ELECTRON FINDING – MC

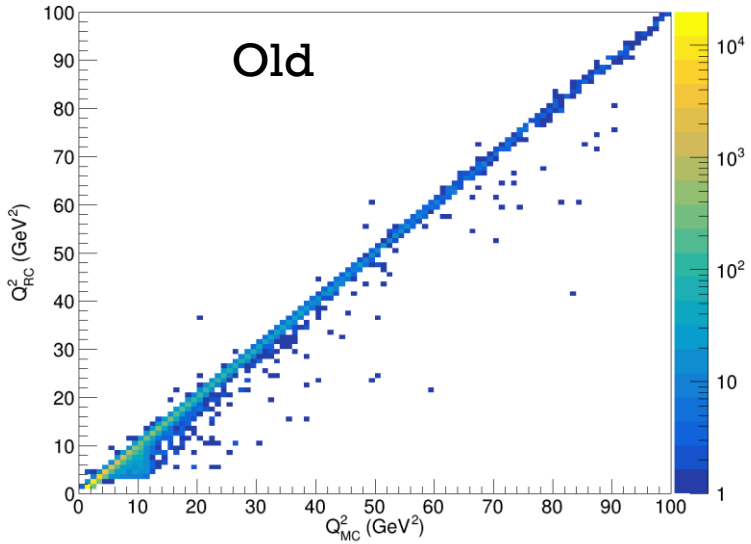
- Old:
  - Find electron with highest momentum in the event
- New:
  - Find electron which has the beam electron as a parent
- Not a major change, but ensures that we are really selecting True MC scattered electrons
  - Old version worked well, but new method is better
- Note: New has higher statistics
  - Old: 500k events
  - New: 10M events

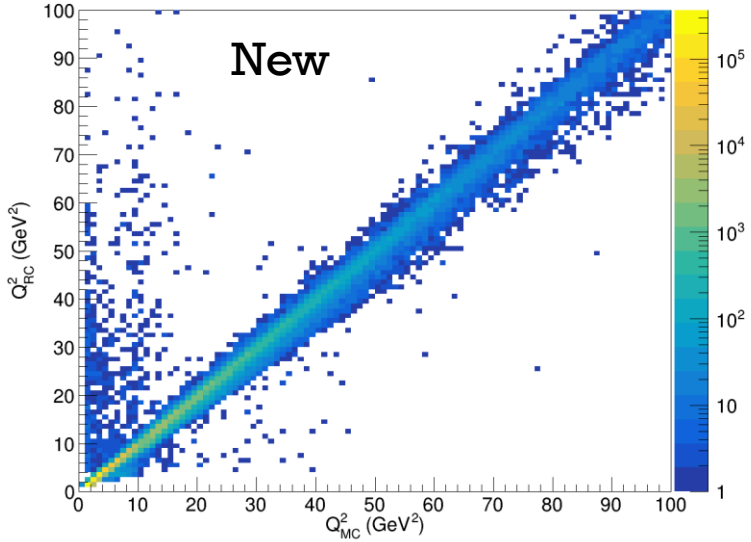




SCATTERED ELECTRON FINDING – RC

- Old:
  - Direct RC to True MC matching
- New:
  - Find negative charged track with well matched nECAL or bECAL cluster with $0.8 < E/p < 1.2$
  - If more such cluster-track pairs are found, select the one with the highest momentum
  - Correct momentum magnitude using energy deposition in ECAL
    - Verified that this method provides better (x, Q^2) distribution and MC vs. RC for scattered electron kinematics
  - Main source of efficiency drop in final cross sections
  - Worse performance, but that is expected

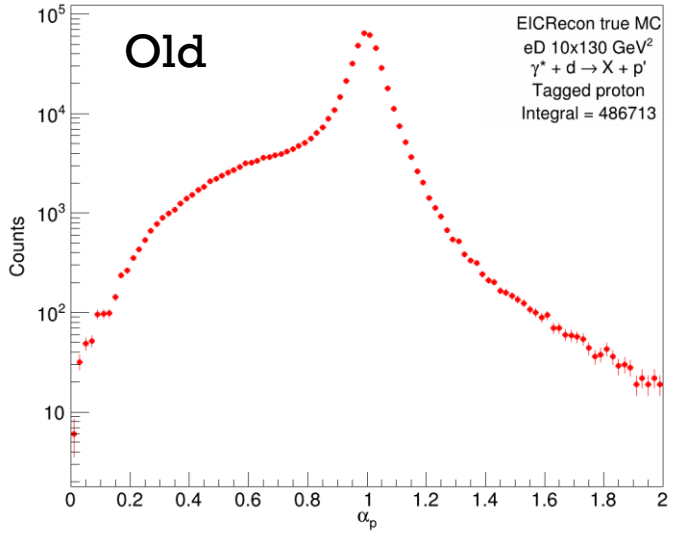




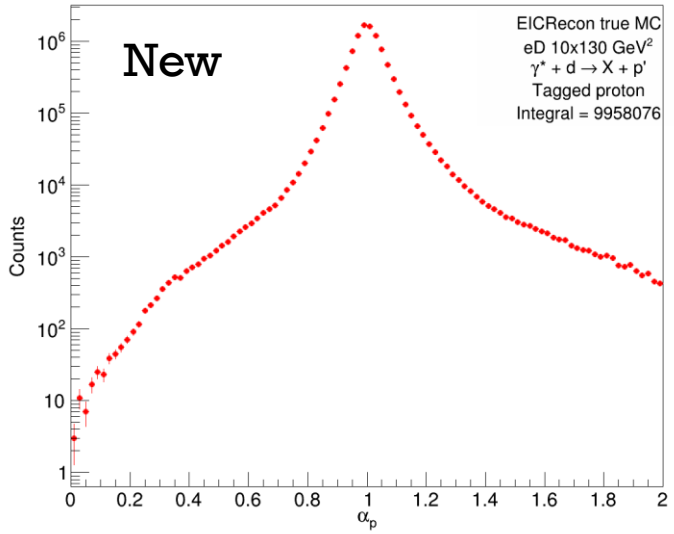
SPECTATOR SELECTION – MC

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

- Old:
  - Find True MC proton/neutron with $\eta > 5.5$
  - Issue: Some events have 2 such protons/neutrons
    - One is the spectator
    - Second one is from DIS process – don't want this one
  - Was accepting wrong spectator causing contamination of MC
    - Shoulder at low α_p



- New:
  - If 2 MC spectator candidates are in one event, take the one with larger η as spectator
    - Based on MC and MC vs. RC η distributions (see next slide)



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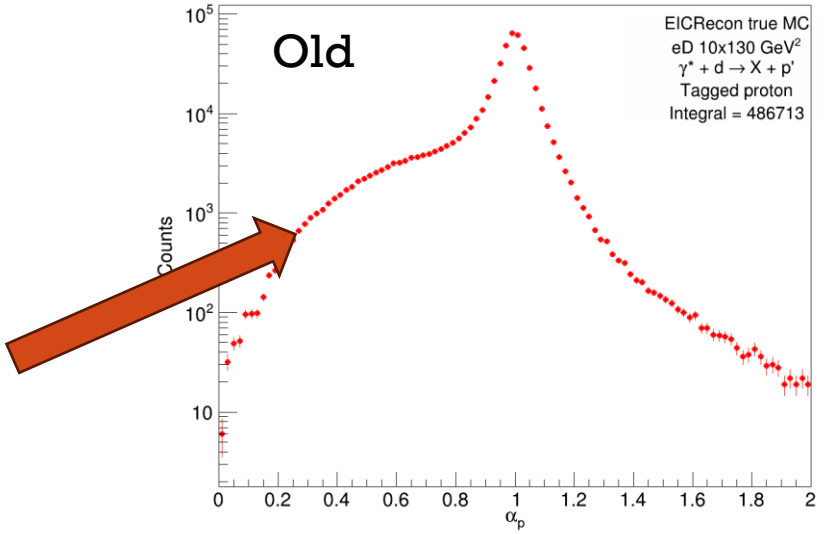
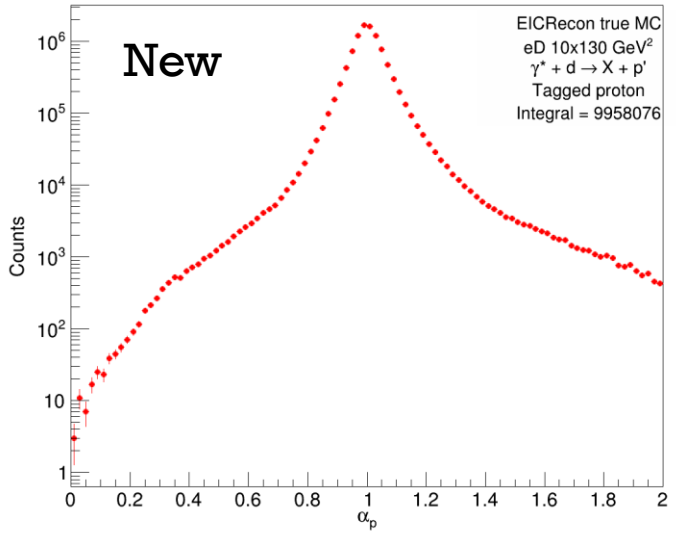


- New:
  - If 2 MC spectator candidates are in one event, take the one with larger η as spectator
    - Based on MC and MC vs. RC η distributions (see next slide)
  - Shoulder gone

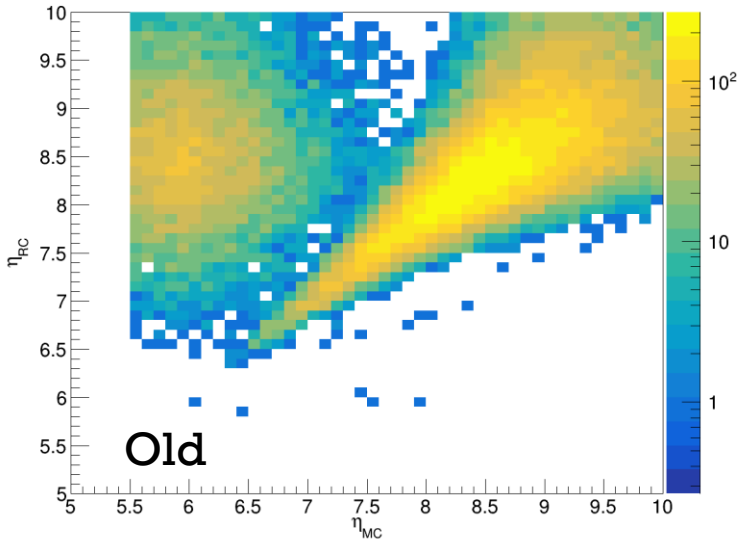


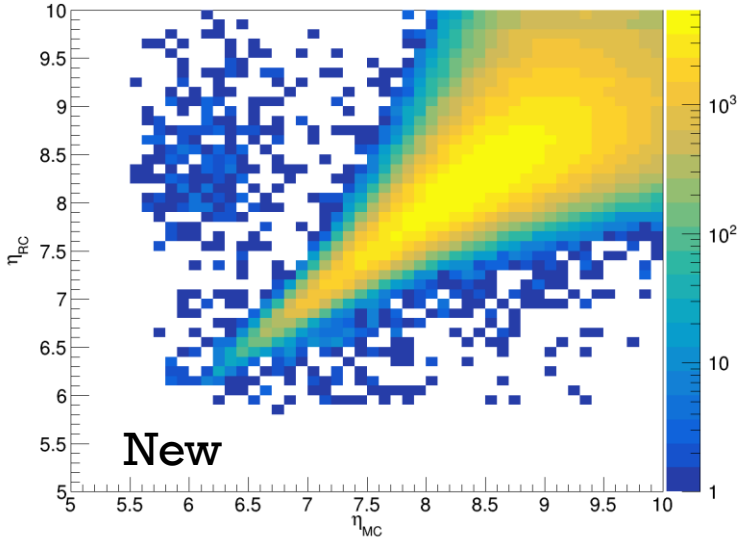
SPECTATOR SELECTION – RC

- Old:
  - Accept only events with strictly one RC spectator candidate in OMD or ZDC
  - Region at $\eta_{MC} \approx 6$ and $\eta_{RC} \approx 8.5$ caused mainly by bad MC selection (see previous slide)

- New:
  - If 2 candidates are found (rare), use the one with larger η as spectator
  - Region at $\eta_{MC} \approx 6$ and $\eta_{RC} \approx 8.5$ still has some events, here more likely contamination when the "wrong" DIS proton is the only particle reconstructed by the OMD or ZDC

Tagged proton



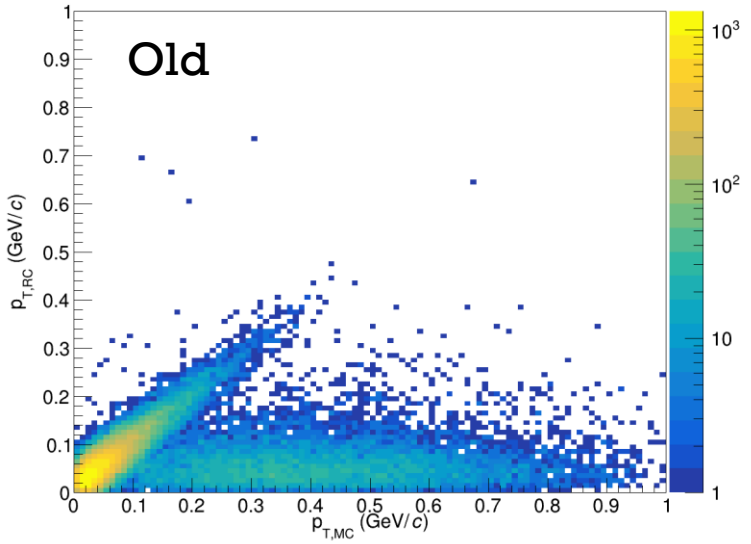


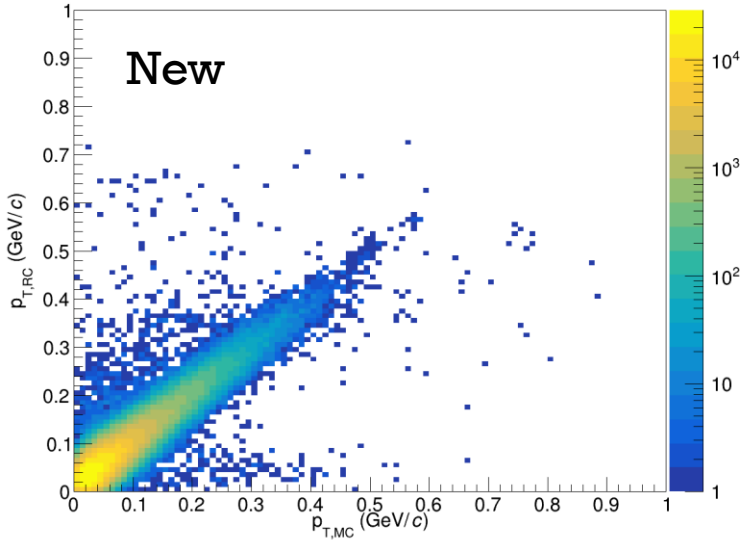
SPECTATOR SELECTION – RC

- Old:
  - Accept only events with strictly one RC spectator candidate in OMD or ZDC
  - Shoulder at low $p_{\mathrm{T,RC}}$ caused mainly by bad MC selection (see slides 5 and 6)

- New:
  - If 2 candidates are found (rare), use the one with larger η as spectator
  - Shoulder eliminated
    - Contamination in η comes from DIS protons which have very low p_{T} and are thus harder to differentiate from real spectators

Tagged proton





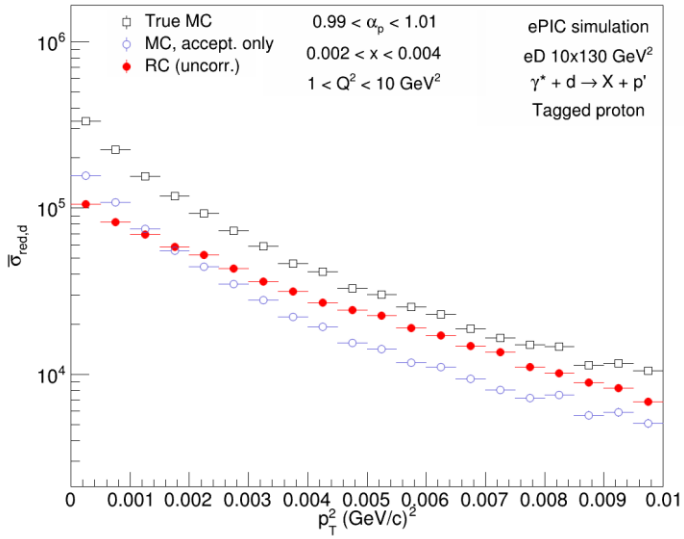
DEUTERON REDUCED CROSS SECTION

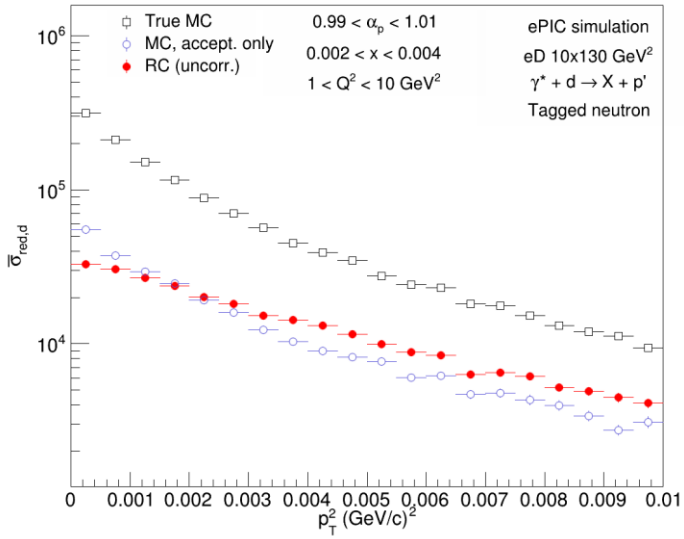
- (top) Deuteron reduced cross section in EICRecon calculated using **tagged protons**
- (bottom) Deuteron reduced cross section in EICRecon calculated using **tagged neutrons**

- Comparison of True MC (black), acceptance only MC (blue), and RC (red)
  - Acceptance only = MC distribution for accepter RC events
    - Reflects only efficiency loss, but not bin migration that changes p_T^2
    - Acc. Only/True MC largely p_T^2 independent, within statistical precision

- More substantial overall efficiency loss dominated by new electron finding algorithm

- Full simulation statistics

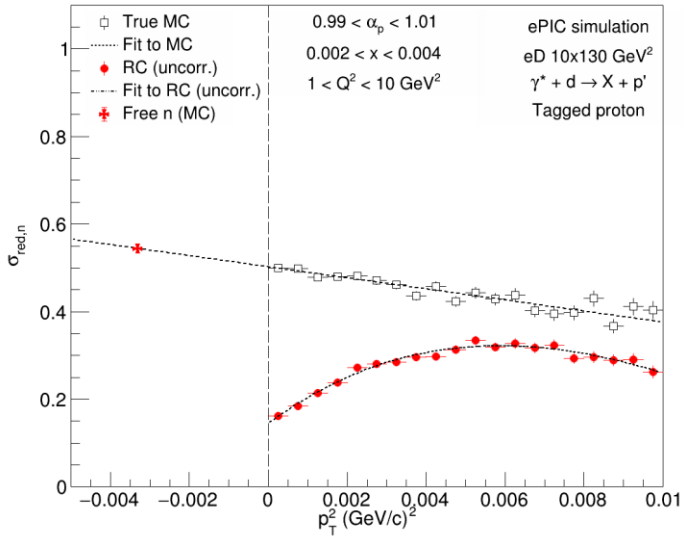


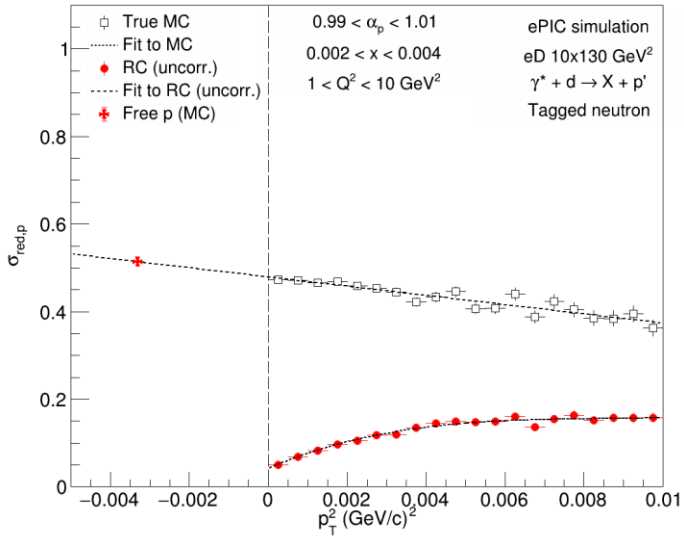


NUCLEON REDUCED CROSS SECTION – UNCORRECTED

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

- Not showing acceptance only
  - Pole removal for acceptance only is difficult for matched MC events, as matching $\alpha_{p,MC}$ is not constrained due to contamination





NUCLEON REDUCED CROSS SECTION – UNCORRECTED

- (top) **Neutron** reduced cross section in EICRecon
- (bottom) **Proton** reduced cross section in EICRecon

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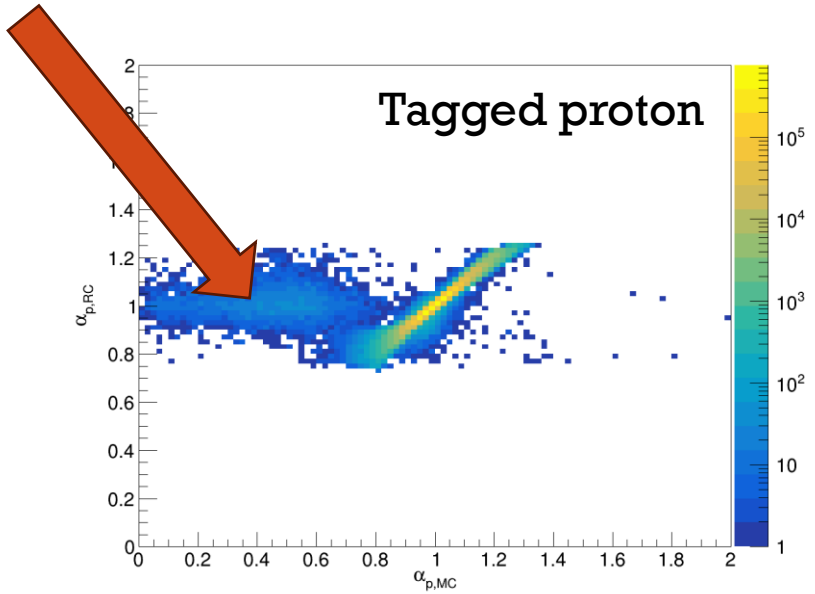
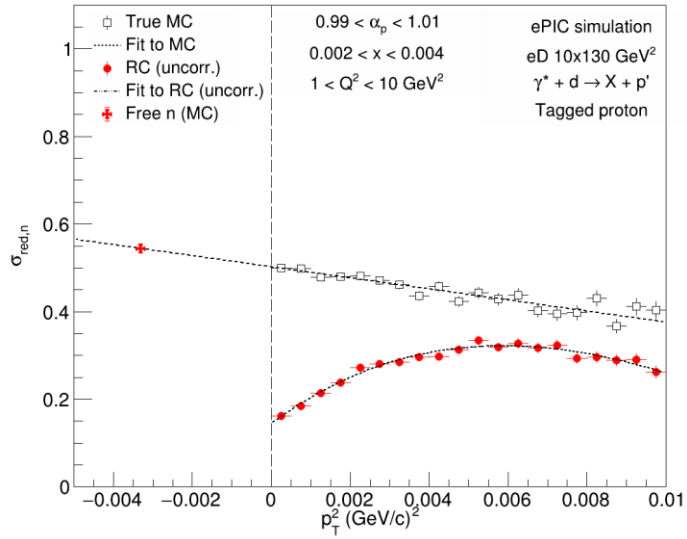
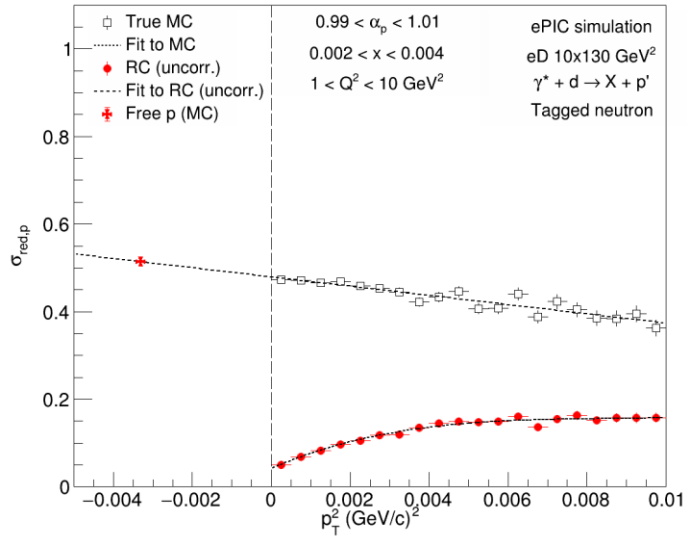
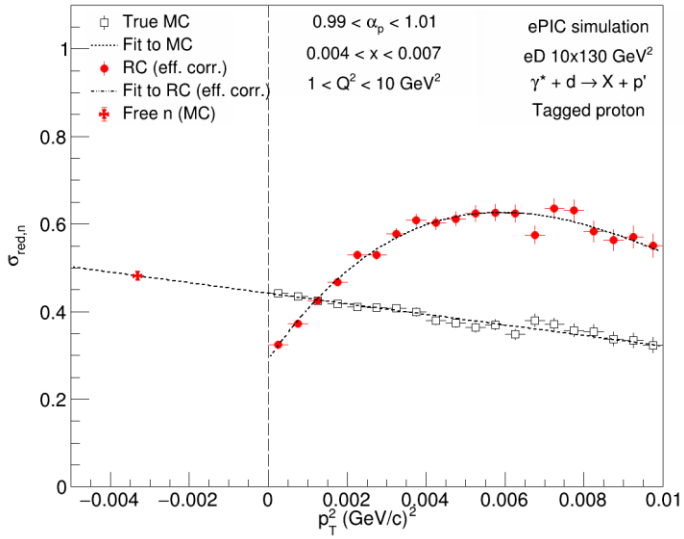


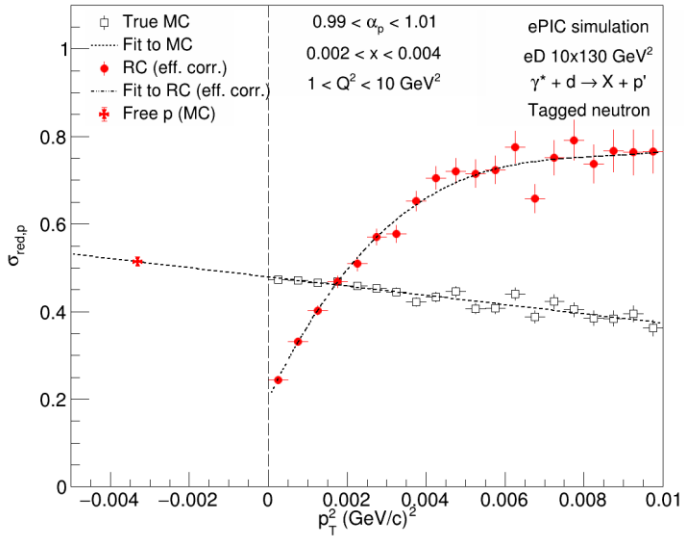




NUCLEON REDUCED CROSS SECTION – CORRECTED

- (top) Efficiency corrected **neutron** reduced cross section in EICRecon
- (left) Efficiency corrected **proton** reduced cross section in EICRecon





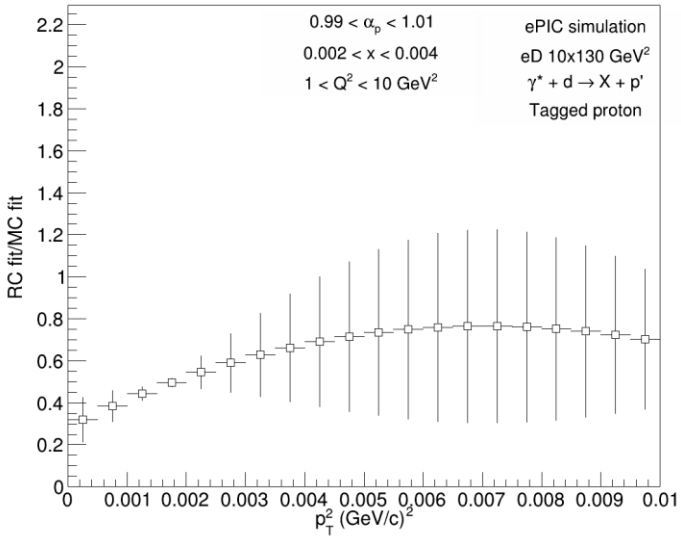
- Efficiency correction only, no bin migration correction
  - Efficiency calculated from integrals of deuteron deduced cross sections (Slide 9) for Acceptance only and True MC
  - $Eff. = \frac{I_{\text{acc.only}}}{I_{\text{True}_{\text{MC}}}}$

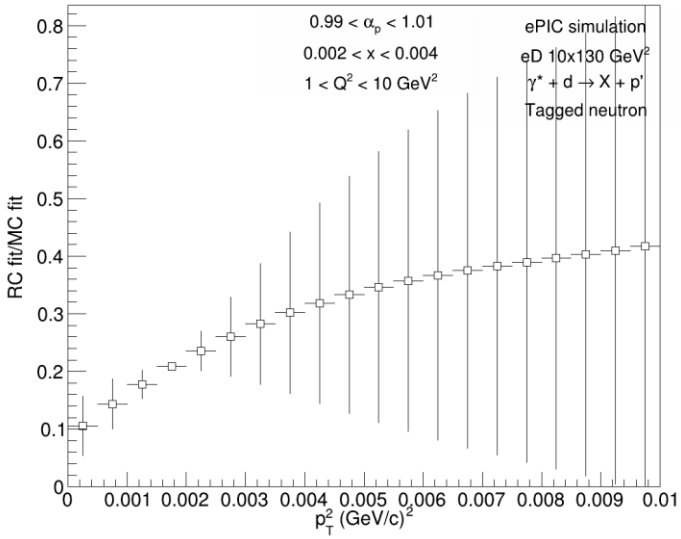
- The systematic uncertainty is now calculated using the relative shift of the eff. corrected RC to True MC
  - Using difference between the fit functions
  - The systematic uncertainty only accounts for the bin migration and not for the overall efficiency loss

EFFICIENCY AND ACCEPTANCE

- Efficiency and bin migration correction using ratio of MC and RC **fit functions** to nucleon reduced cross section
  - RC/MC
  - Functions evaluated at histogram bin centers

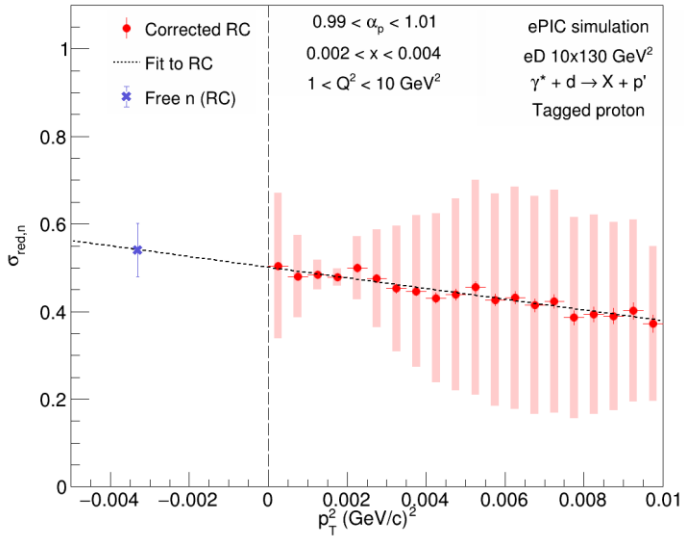
- New associated relative systematic uncertainty:
  - $|\boldsymbol{Acc.Only - MC}|/\boldsymbol{MC}$
  - Added in quadrature to statistical uncertainty for final results (shown later)



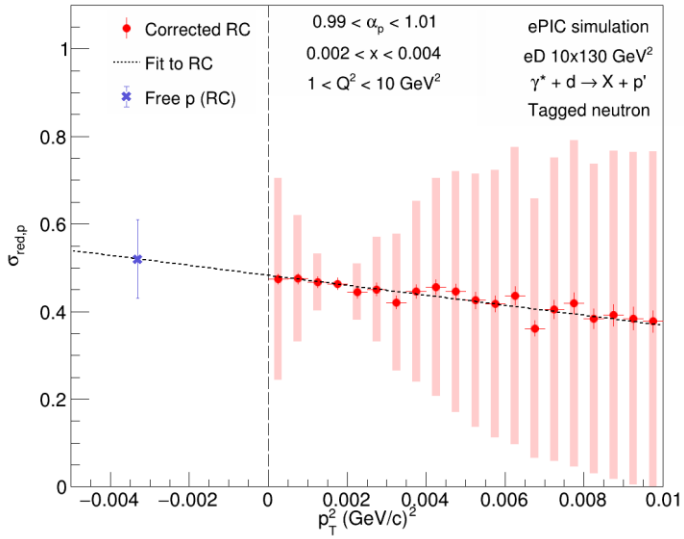


NUCLEON REDUCED CROSS SECTION – CORRECTED

- (top) **Neutron** reduced cross section in EICRecon
  - Corrected
- (bottom) **Proton** reduced cross section in EICRecon
  - Corrected



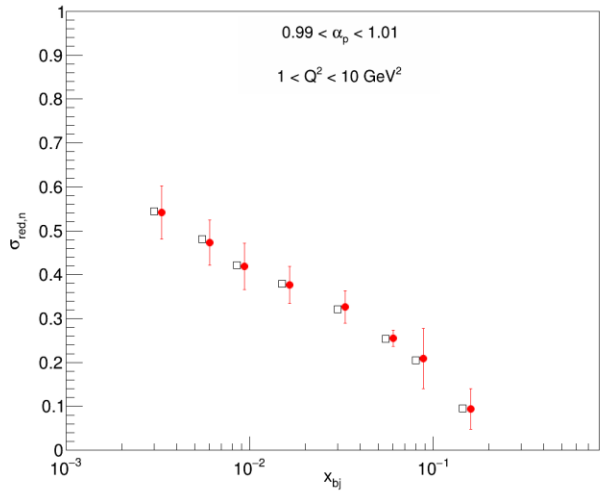
- New corrected cross sections using updated efficiency
- Now plotting statistical and systematic uncertainties separately
  - Stat. – error bars
  - Sys. – shaded bands

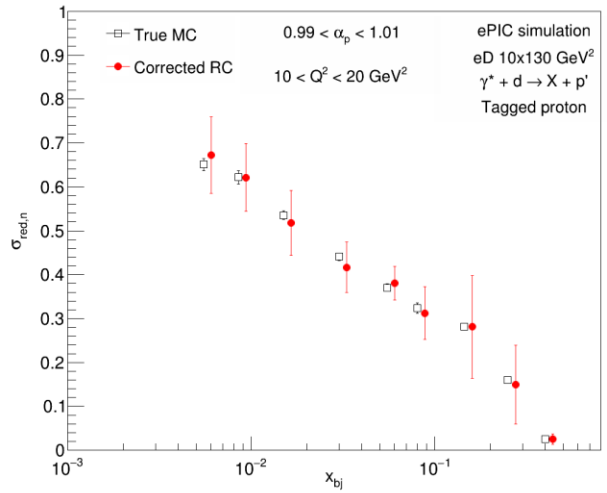


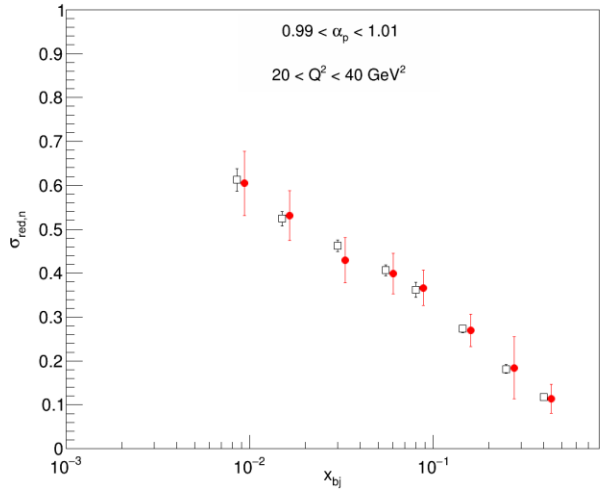
- Linear fit done to distribution with total uncertainties

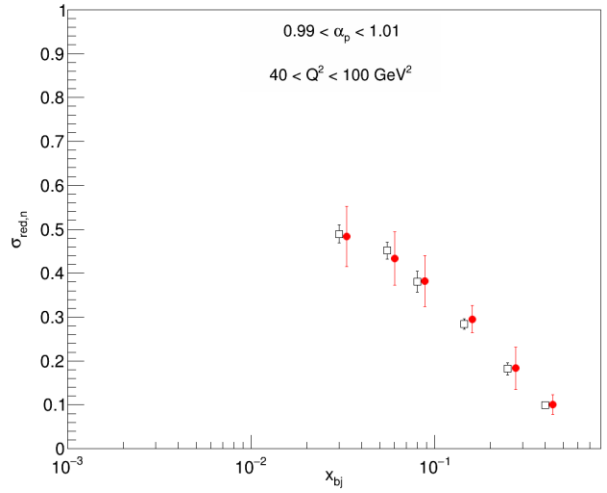
REDUCED CROSS SECTION VS. x_{bj} (eN)

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



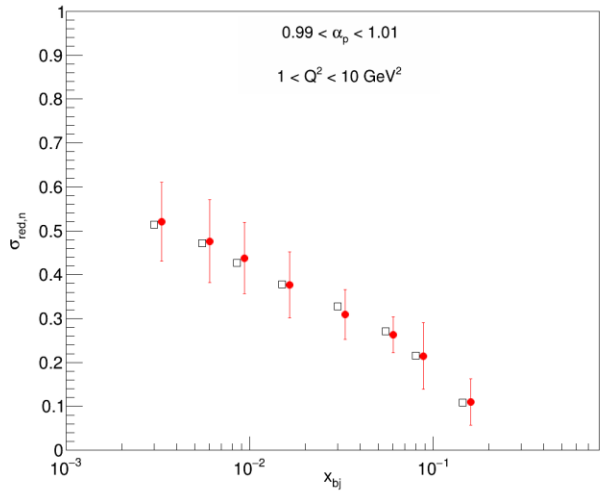


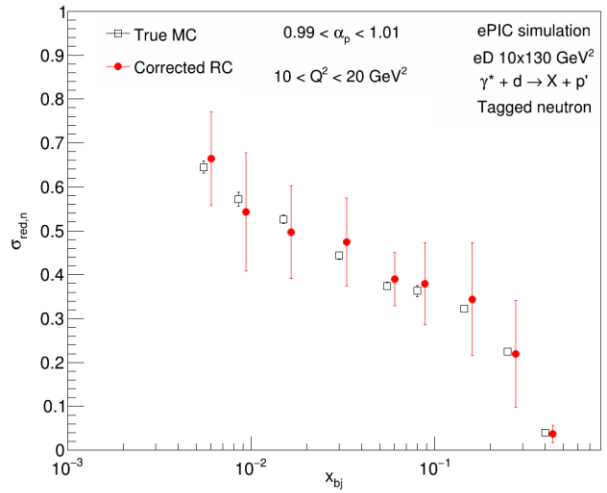


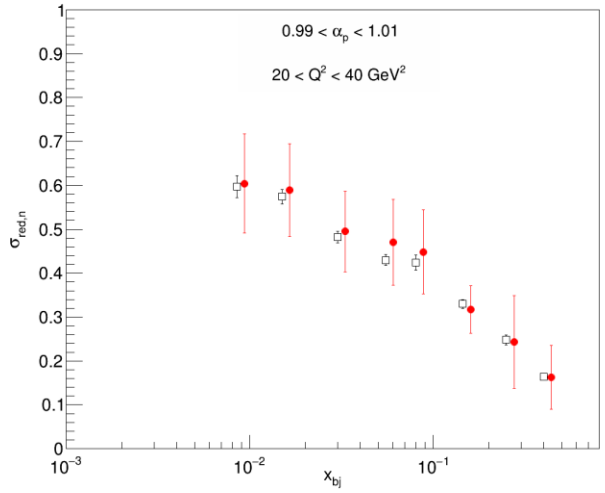


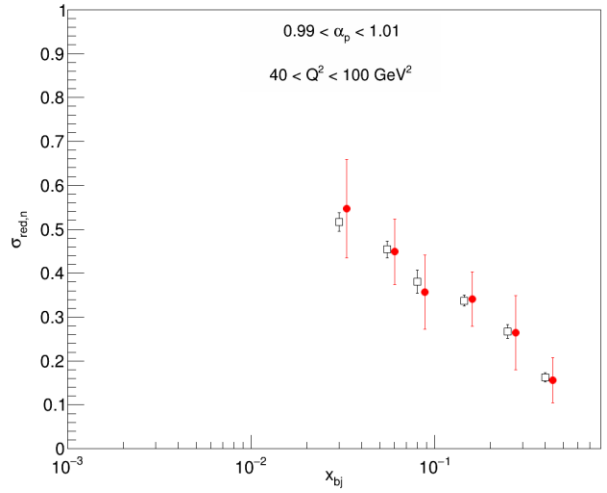
REDUCED CROSS SECTION VS. x_{bj} (eP)

- Comparison of the MC and RC **proton** reduced cross sections
- Somewhat worse performance than for neutron deduced cross section
  - Caused likely by worse ZDC resolution compared to OMD in current implementation of EICRecon
- Uncertainties dominated by systematics



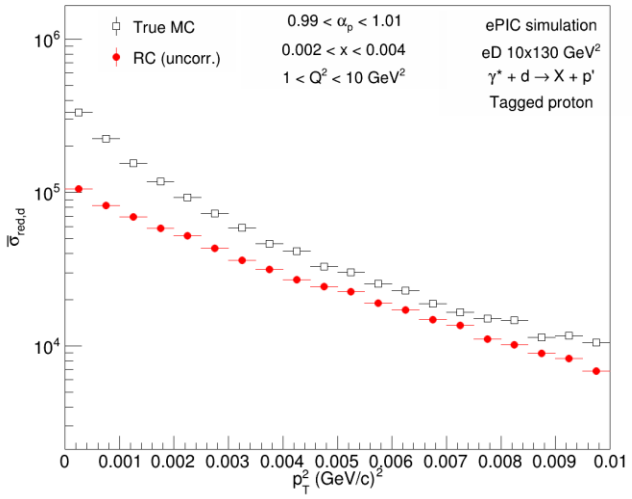


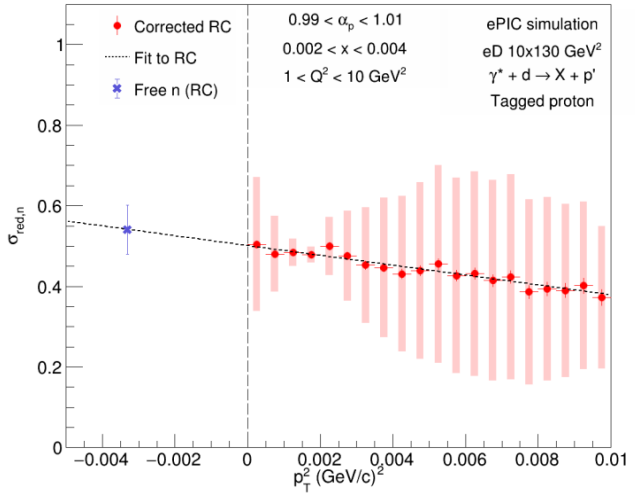


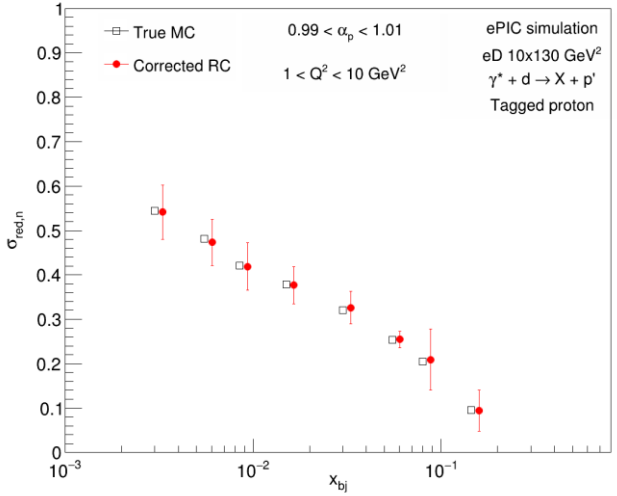


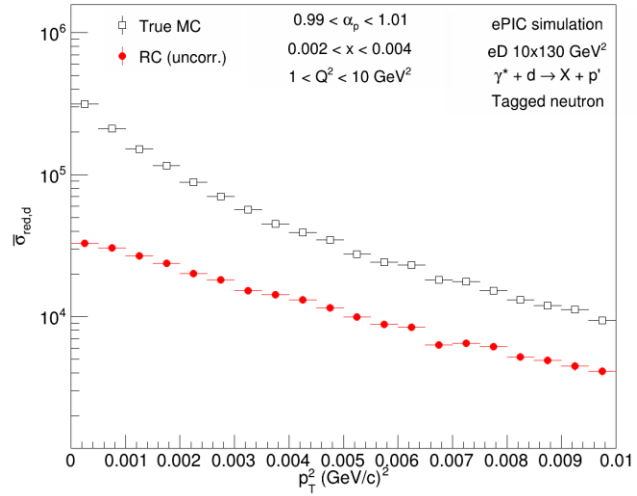
UPDATED PAPER FIGURES

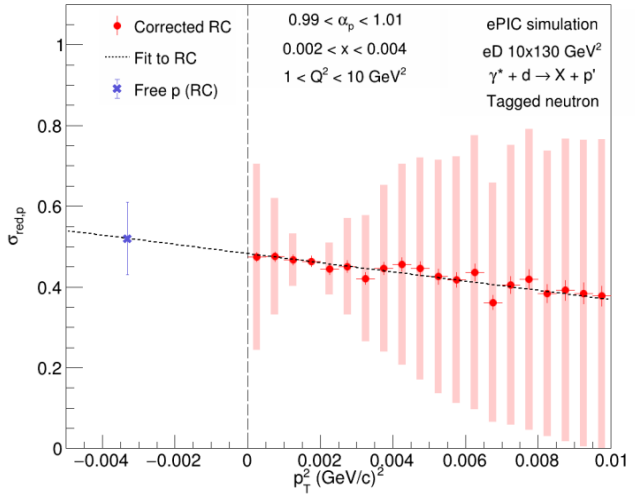
- To demonstrate the procedure, we will focus only on the first Q^2 bin

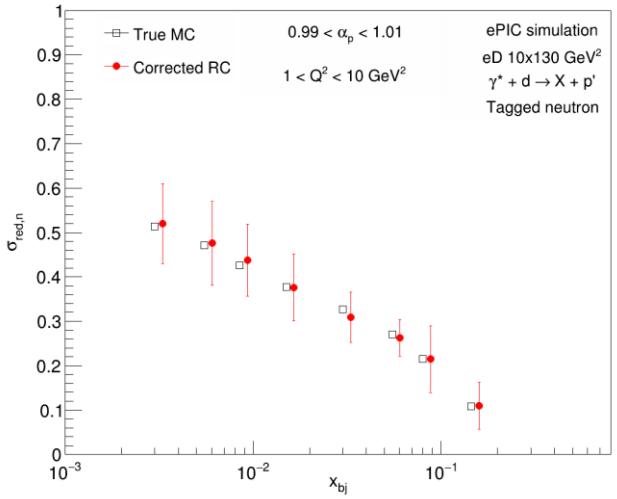












SUMMARY AND OUTLOOK

- All technical details of analysis should now be resolved
- Implemented all comments from Stephen to analysis itself and the analysis note
- Results and note should be ready for approval by WG and later by the Collaboration
- Outlook:
  - Analysis note approval
    - New version will be sent later today after updating all figures
  - Update figures and address comments to my section of early science paper
    - Later this week
  - 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

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

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