Exclusive Meeting – Deuteron Tagging

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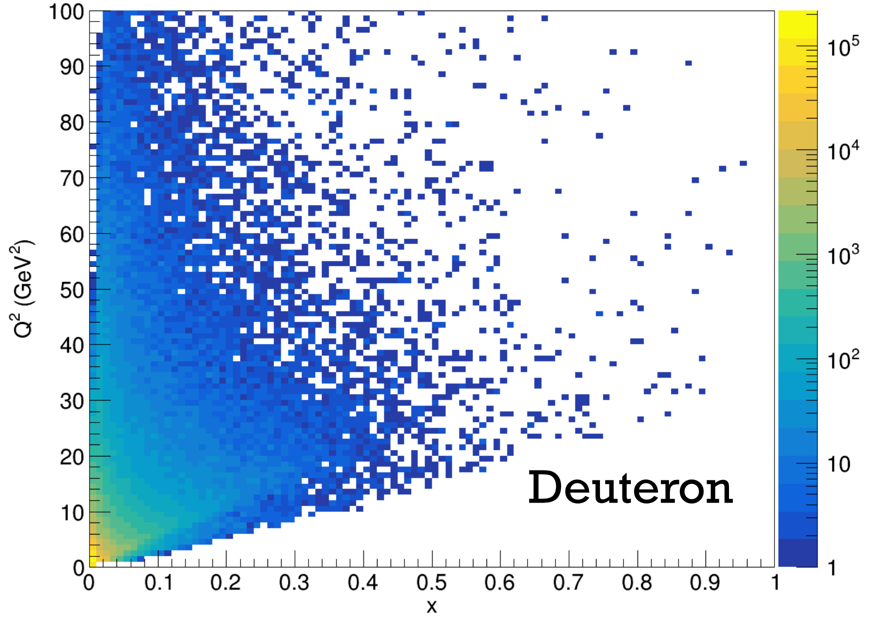
OVERVIEW

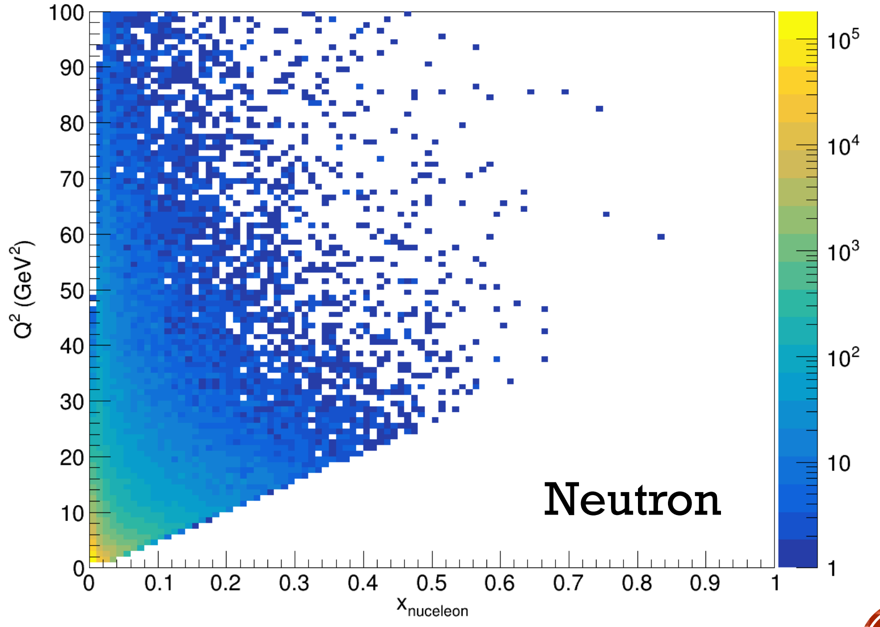
- Extraction of deuteron and neutron reduced cross section from HepMC **and EICRecon** simulation output
  - True MC information, without any beam or detector effects
  - Simulation setup:
    - eD DIS events at 10x130 GeV^2 (simulation by Alex)
    - Scattering on neutron, tagging of protons
  - Goal:
    - Reproduction of deuteron reduced cross section from A. Jentsch, Z. Tu, C. Weiss: Phys. Rev. C **104**, 065205

- Today:
  - Fixed x calculation
    - Fixed more minor bugs in x calculation
  - New kinematic binning
    - Optimization for the new simulation
  - Added framework that uses MC information from EICRecon

x CALCULATION

- Scattered electron kinematic distribution
- $Q^2 = -q^2 = -\left(p_{e,beam} - p_{e,scat}\right)^2$
  - p_e - electron 4-momenta before and after scattering
- $x = \frac{Q^2}{P \cdot q}$
  - P – 4-momentum of **deuteron**
- $x_{nucleon} = \frac{Q^2}{2P_{nucl} \cdot q} = \frac{x}{2-\alpha_p}$
  - P_{nucl} – 4-momentum of **nucleon**
  - α_p – light cone momentum fraction (see backup)
- (top) x from deuteron 4-momentum
- (bottom) x from neutron 4-momentum

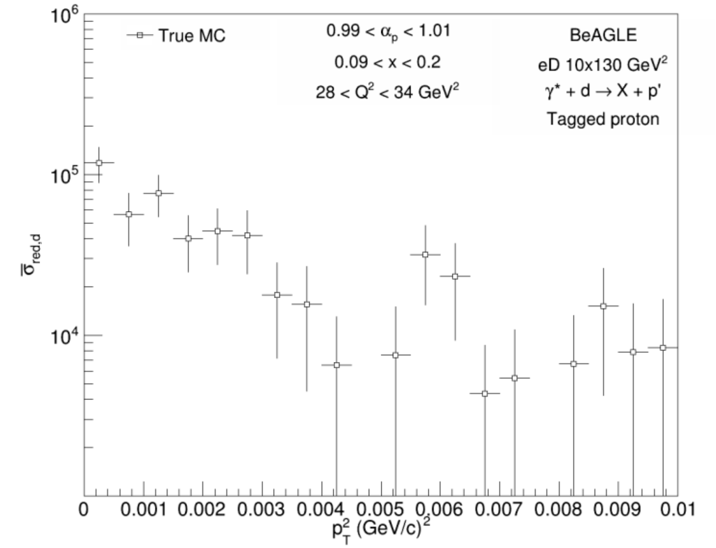


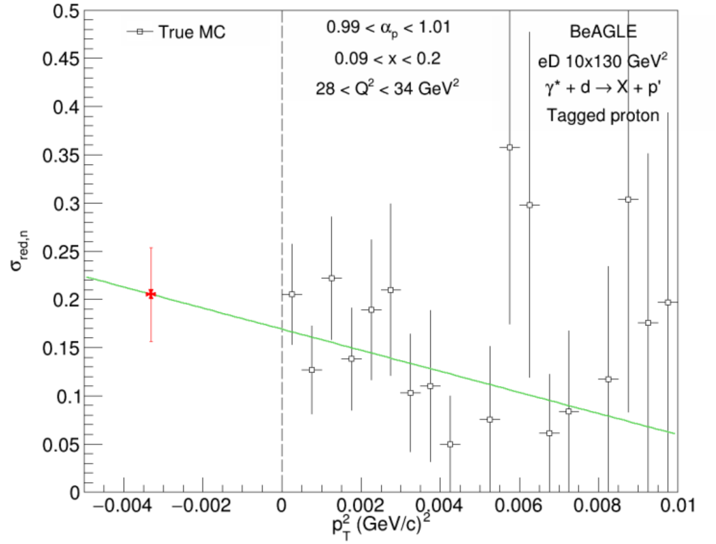


ORIGINAL VERSION WITH NUCLEON x

- (top) Deuteron reduced cross section using tagged protons
- (bottom) Neutron reduced cross section using tagged protons

- Original version, with typo in the code
  - Using nucleon $x_{nucleon}$
  - Calculated directly from MC information
    - HepMC files contain information about beam neutrons





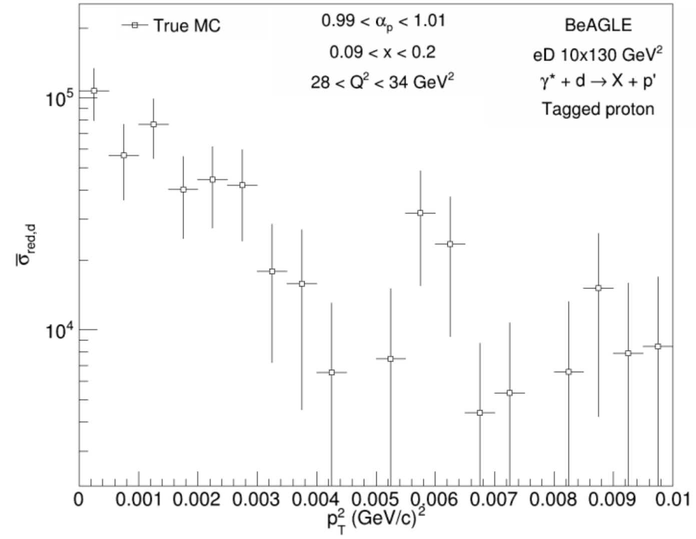
A. Jentsch, Z. Tu, C. Weiss: Phys. Rev. C **104**, 065205.

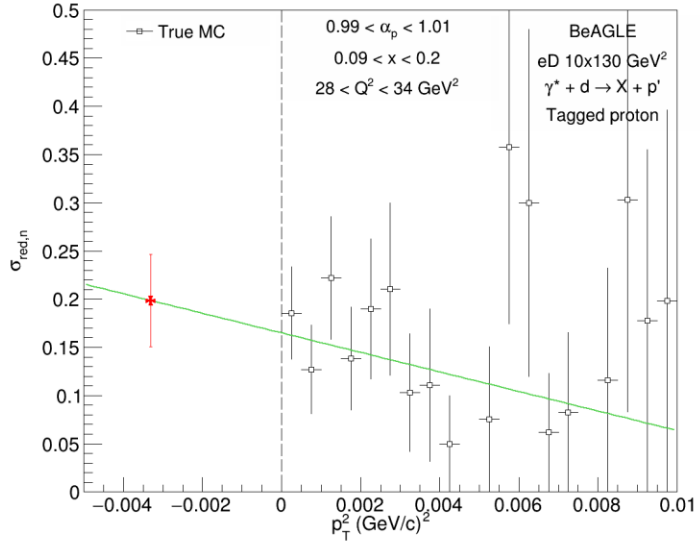
NEW VERSION WITH DEUTERON x

- (top) Deuteron reduced cross section using tagged protons
- (bottom) Neutron reduced cross section using tagged protons

- New version, with fixed typo
  - Using deuteron x
  - Calculated using $x_{nucleon} = \frac{x}{2-\alpha_p}$

- Framework still appears to work
  - Within errors with the limited statistics





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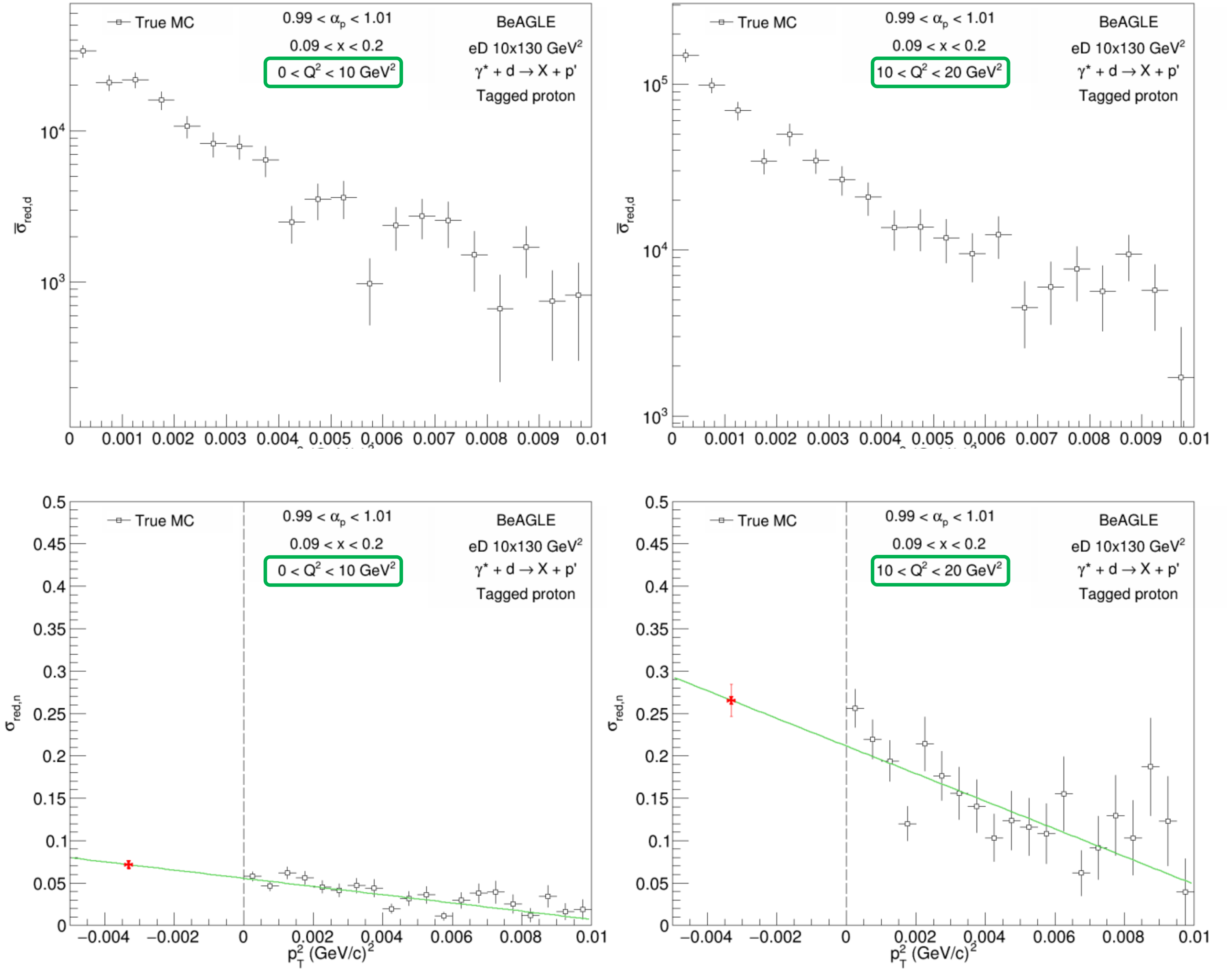
NEW BINNING

- New binning in Q^2 optimized for the new simulation
  - True MC from HepMC output



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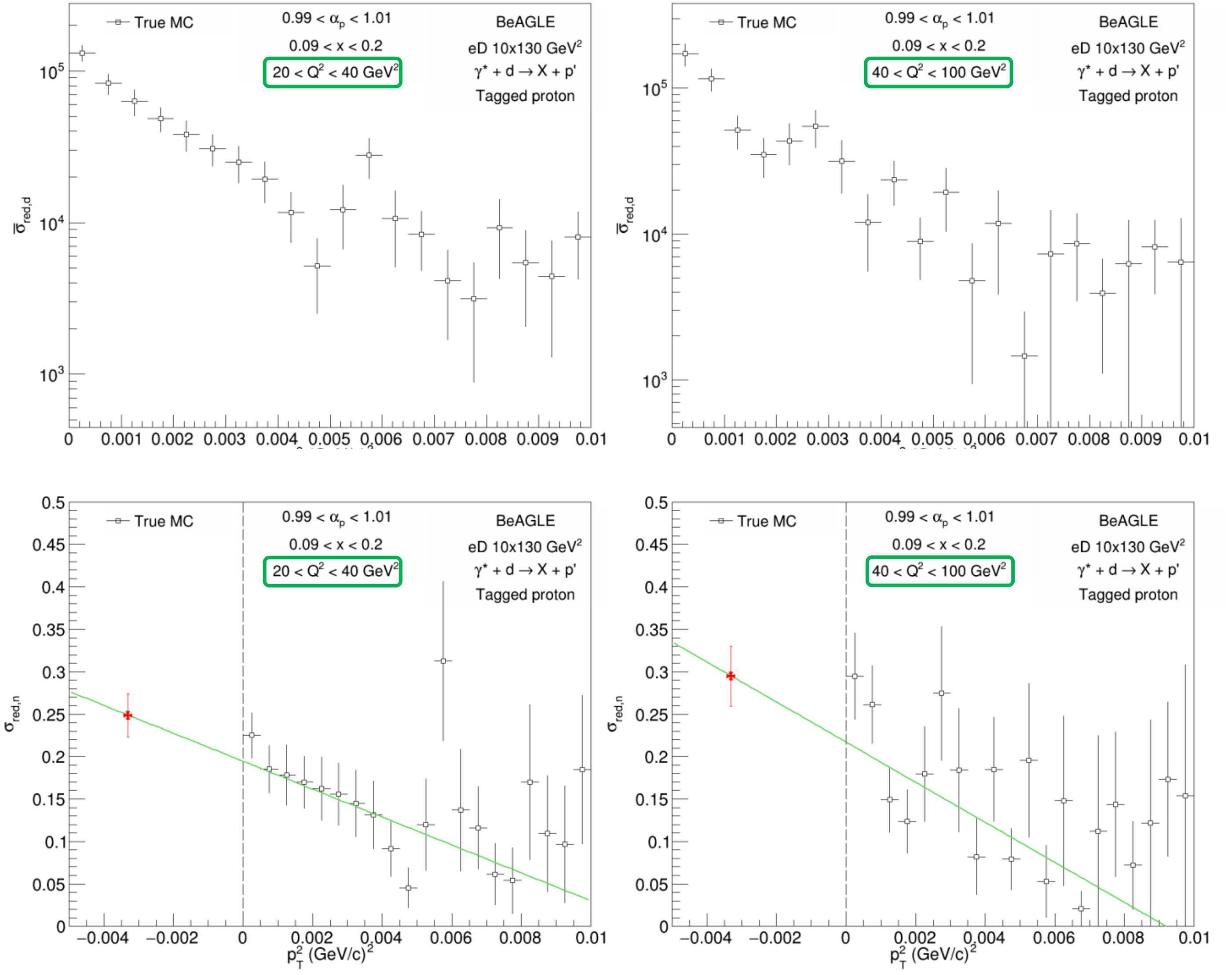
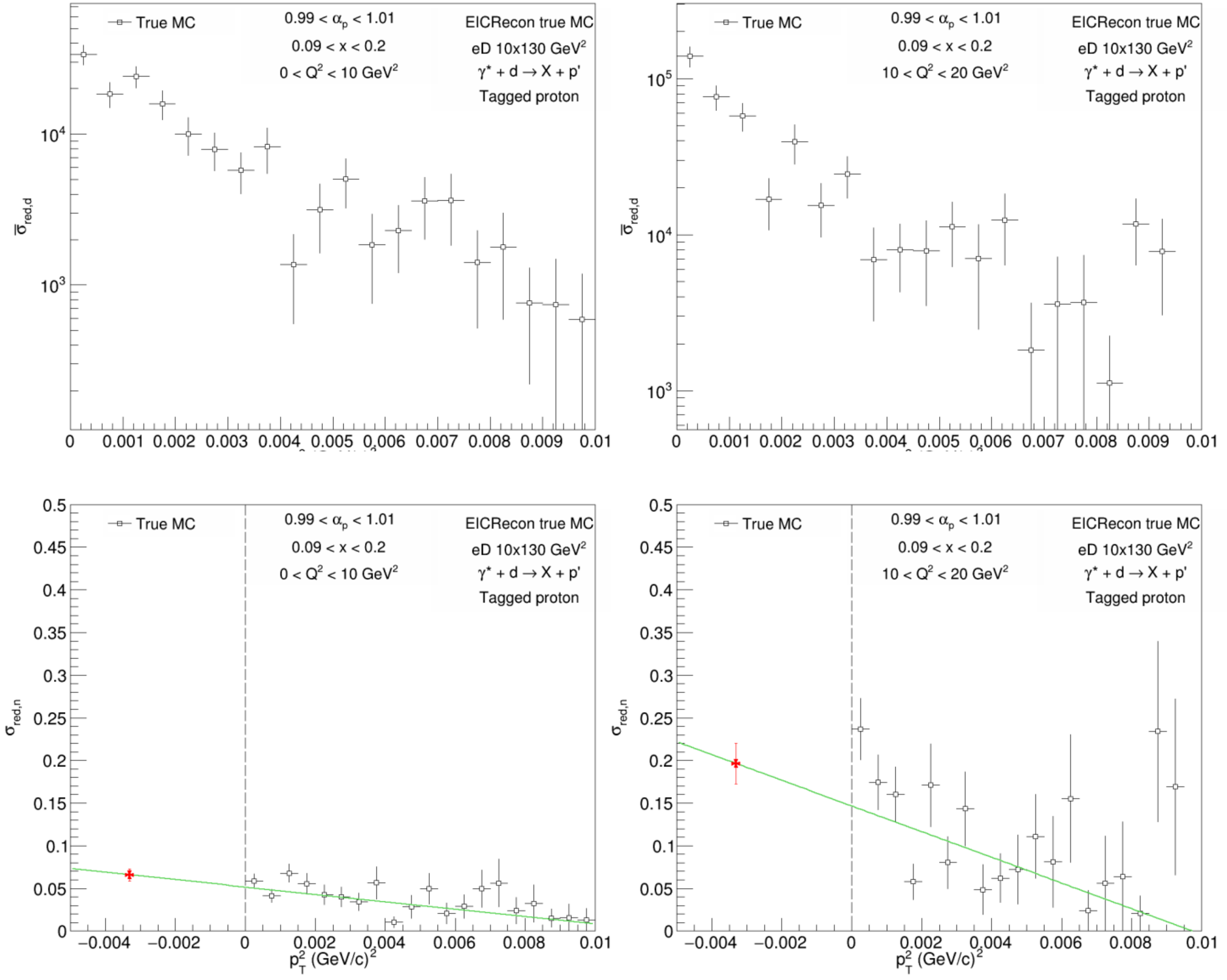


A. Jentsch, Z. Tu, C. Weiss: Phys. Rev. C **104**, 065205.

MC IN EICrecon

- MC information from EICRecon for the same underlying HepMC simulation
  - True MC information, without and beam effects and crossing angle
  - MCParticlesHeadOnFrameNoBeamFX
- Framework in EICRecon seems to be working
- See difference compared to HepMC output
  - Lower number of accepted events with EICRecon
  - Origin of difference currently being investigated
- New binning in Q^2 optimized for the new simulation
  - True MC from HepMC output



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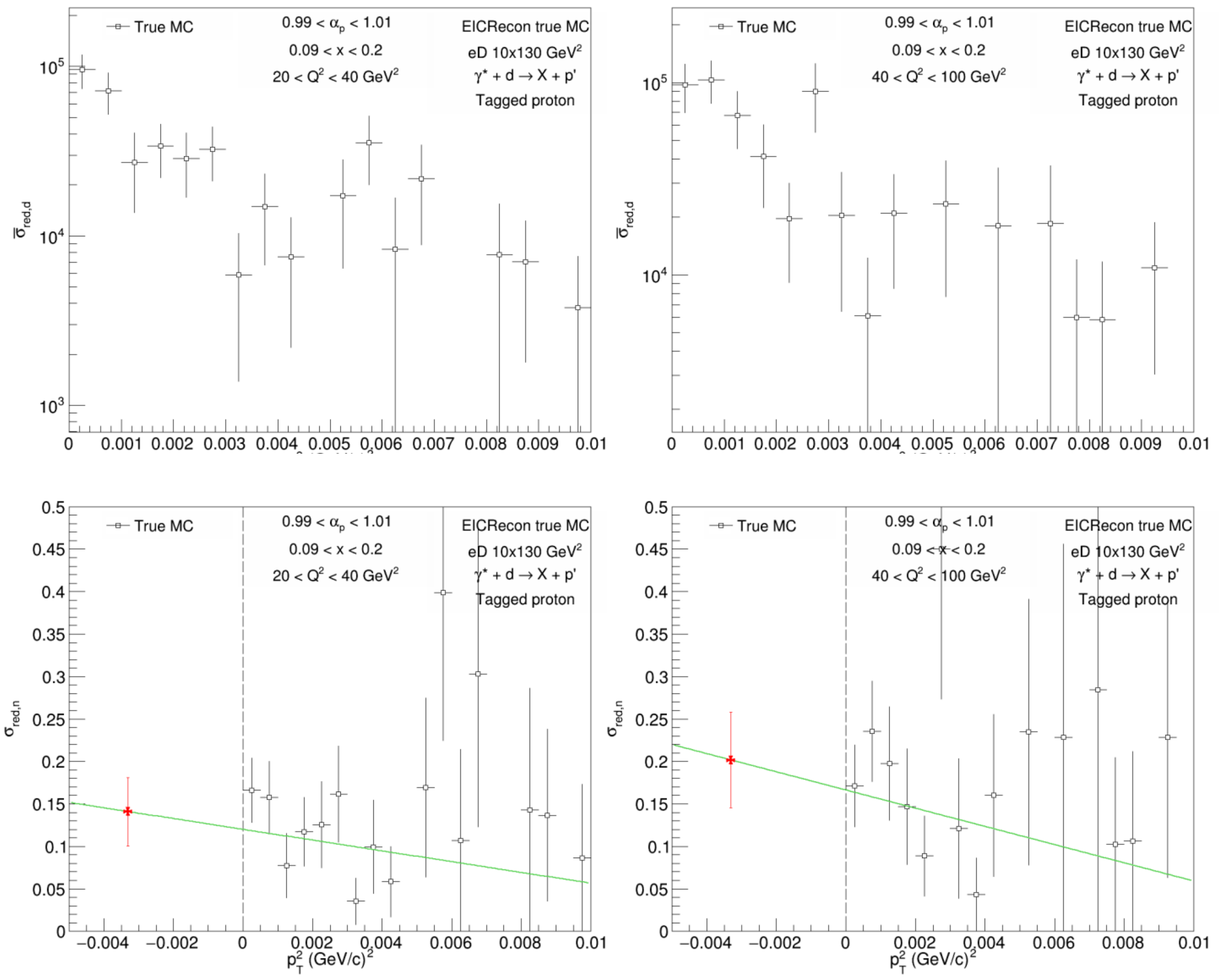

A. Jentsch, Z. Tu, C. Weiss: Phys. Rev. C **104**, 065205.

SUMMARY AND OUTLOOK

- Fixed x calculation
- New binning in Q^2 optimized for the new simulation
- Implemented full framework for output from EICRecon
  - True MC only for now
- Result appears consistent with previously published result
  - Published result from A. Jentsch, Z. Tu, C. Weiss: Phys. Rev. C **104**, 065205.
  - Notes:
    - This study and published results at different energy
    - Statistics of current MC is low

- To-do/outlook:
  - Cross-checks of framework with EICRecon output
    - Understanding of difference between reading HepMC directly and accessing MC information from EICRecon
  - Adding RC level information
    - Later, as it likely requires full efficiency and acceptance correction

11

BACKUP

VARIABLES

- Scattered electron
  - $Q^2 = -q^2 = -\left(p_{e,beam} - p_{e,scat}\right)^2$
  - $x = \frac{Q^2}{2\ P \cdot q}$
  - $x_{nucleon} = \frac{Q^2}{2P_{nucl} \cdot q} = \frac{x}{2-\alpha_p}$
- 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
  - $L_{int} = \frac{N_{events}}{\sigma_{tot}} = \frac{N_{events}}{4.5 \cdot 10^{-5}\mathrm{mb}}$
    - $\mathrm{mb} = 2.568\ \mathrm{GeV}^{-2}$

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:
  - $\mathrm{d}\sigma_d = Flux(x,Q^2) \times \sigma_{red,d} \times \frac{\mathrm{d}x}{2}\mathrm{d}Q^2 \frac{\mathrm{d}\phi_{e'}}{2\pi}[2(2\pi)^3]^{-1}\frac{\mathrm{d}\alpha_p}{\alpha_p}\frac{\mathrm{d}p_{T,p}^2}{2}\mathrm{d}\phi_p$
- 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 $\mathrm{d}\phi_p$)
  - $\bar{\sigma}_{red,d} = \left(\frac{2.568}{L_{int}}\right)\frac{Q^4 x}{2\pi\alpha_{em}^2[1+(1-y)^2]}\frac{[4(2\pi)^3]\alpha_p}{\Delta\alpha_p}\frac{\mathrm{d}N}{\Delta x \Delta Q^2 \Delta p_{T,p}^2}$
    - $\Delta x,\ \Delta Q^2,\ \Delta p_{T,p}^2, \Delta\alpha_p$ 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
  - $\Delta\phi_p = 2\pi$
  - We are also integrating over full 2π

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

- We can measure/calculate this
- External input from model/experiment

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

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