Exclusive Meeting – Deuteron Tagging

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OVERVIEW

- Extraction of deuteron and neutron reduced cross section from HepMC 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:
  - Deuteron reduced cross section
    - Overview of online only report from last week
    - Important for context of updates for today
  - Neutron reduced cross section and its extrapolation
    - New for today

VARIABLES

- Scattered electron
  - $Q^2 = -q^2 = -\left(p_{e,beam} - p_{e,scat}\right)^2$
  - $x = \frac{Q^2}{2\,P \cdot q}$
- 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
  - $\sigma_{red,d,meas} = \left(\frac{2.568}{L_{int}}\right)\frac{Q^4 x}{2\pi\alpha_{em}^2[1+(1-y)^2]}\frac{[4(2\pi)^3]\alpha_p}{\Delta\alpha_p}\frac{\mathrm{d}N}{\Delta x\Delta Q^2\Delta p_{T,p}^2\Delta\phi_p}$

- Scattered electron
- Spectator proton + struck deuteron
- Photon flux

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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
  - $\Delta\phi_p = 2\pi$

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- Measured reduced cross section (integrated over $d\phi_p$)
  - $\bar{\sigma}_{red,d} = \left(\frac{2.568}{L_{int}}\right) \frac{Q^4 x}{2\pi\alpha_{em}^2[1+(1-y)^2]} \frac{[4(2\pi)^3]\alpha_p}{\Delta\alpha_p} \frac{dN}{\Delta x \Delta Q^2 \Delta p_{T,p}^2 \bcancel{\Delta\phi_p}}$

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    - $\Delta x,\ \Delta Q^2,\ \Delta p_{T,p}^2, \Delta\alpha_p$ are bin widths

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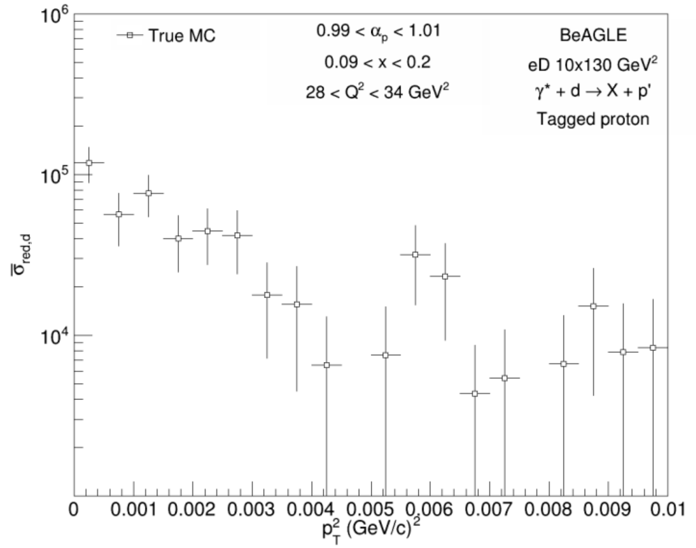
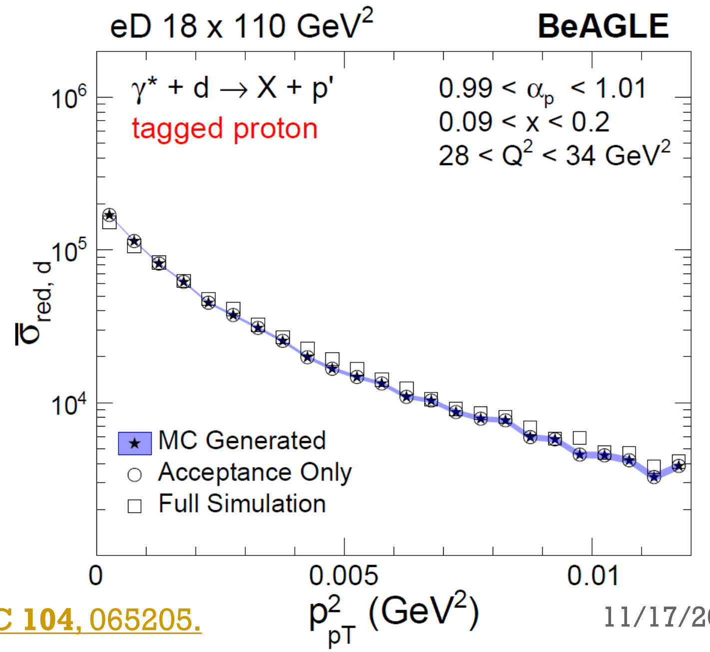
TRUE MC DEUTERON REDUCED CROSS SECTION

- Extracted deuteron reduced cross section using tagged protons
  - (top) This study
  - (bottom) Published
  - Both in the same kinematic bin for comparison
- Simulation in this study has much lower statistics (ca. 500k events), so not many events fit in the same kinematic bin (ca. 90 evens pass)
- Results seem to be reasonably consistent
- Published results and this study are at a different energy
  - Comparison needs to be done with some caution





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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
  - $S_d(p_{pT},\alpha_p)[pole] = \frac{R}{(p_{pT}^2+a_T^2)^2}$
  - 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
    - $R = 2\alpha_p^2 m_N \Gamma^2 (2-\alpha_p)$
    - $\Gamma^2 = 0.007885$ GeV

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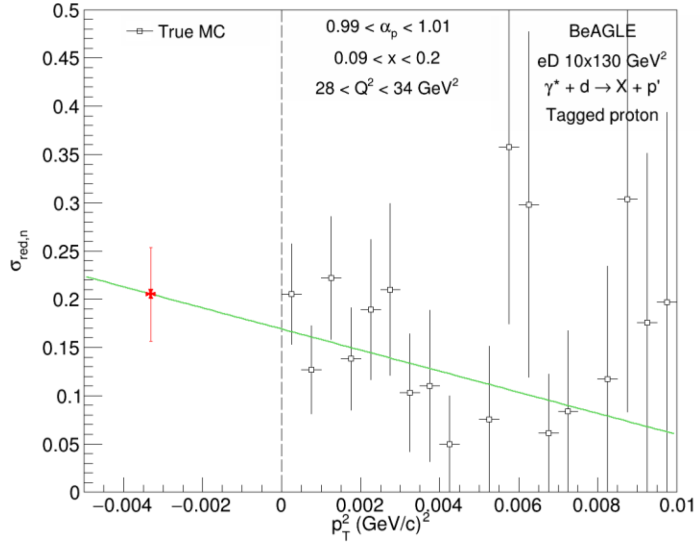
TRUE MC NEUTRON REDUCED CROSS SECTION

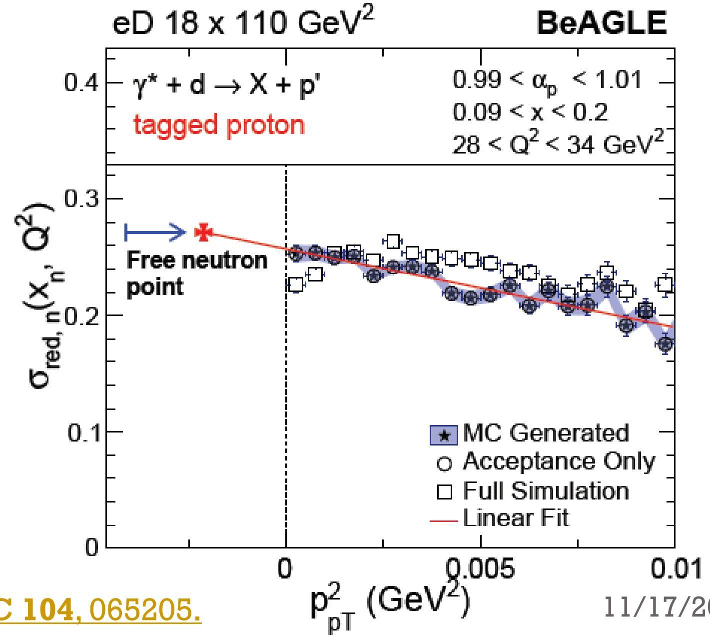
- Extracted **neutron** reduced cross section using tagged protons
  - (top) This study
  - (bottom) Published
  - Both in the same kinematic bin for comparison

- Linear fit to data to extrapolate to $p_T^2 = -\alpha_p^2$

- Results seem to be reasonably consistent

- Published results and this study are at a different energy
  - Comparison needs to be done with some caution





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SUMMARY AND OUTLOOK

- Implemented first version of framework for extraction of deuteron **and neutron** reduced cross section from HepMC simulation output
- Implemented extrapolation method to evaluate free neutron cross section

- 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:
  - Start implementing the same framework on EICRecon output
    - First just for MC, using MCParticles
    - RC level information
      - Later, as it likely requires full efficiency and acceptance correction