Deuteron (spectator) tagging at the EIC

Kong Tu

BNL

10.21.2021

Collaborators: A.Jentsch and C.Weiss. Recent preprint: *arXiv:2108.08314*

Why deuteron?

- Big questions in nuclear physics – deuteron might provide a clue if not the answer!
  - EMC effect, and its interplay with SRC (large x or EMC region)
  - Neutron structure, 3D parton distributions, etc.
  - Gluon modification (~gluon “EMC”), shadowing effect, etc.

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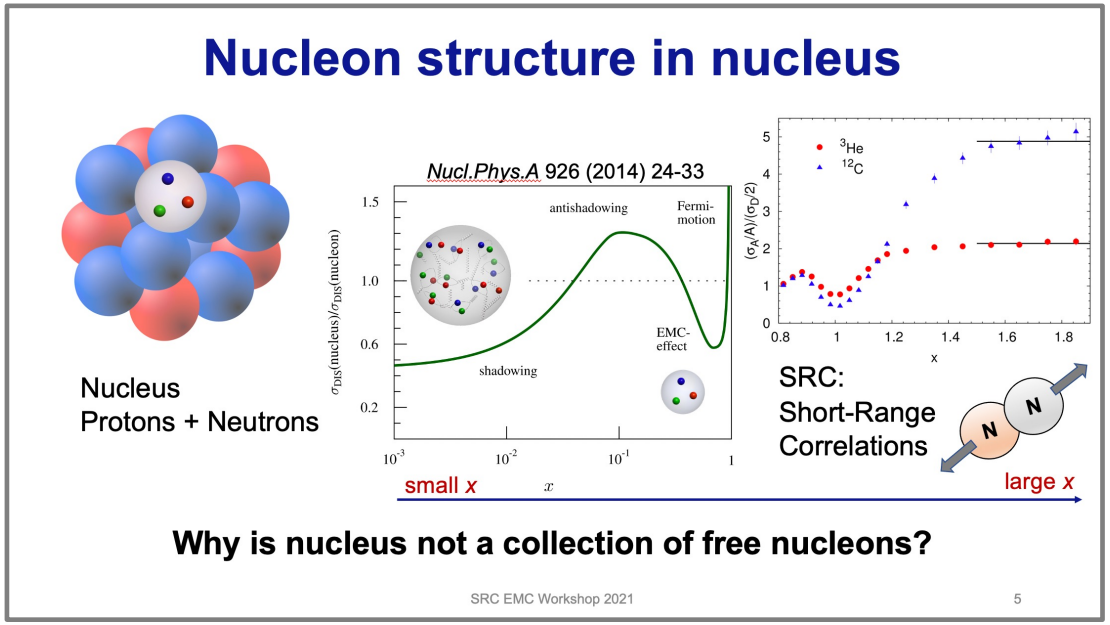
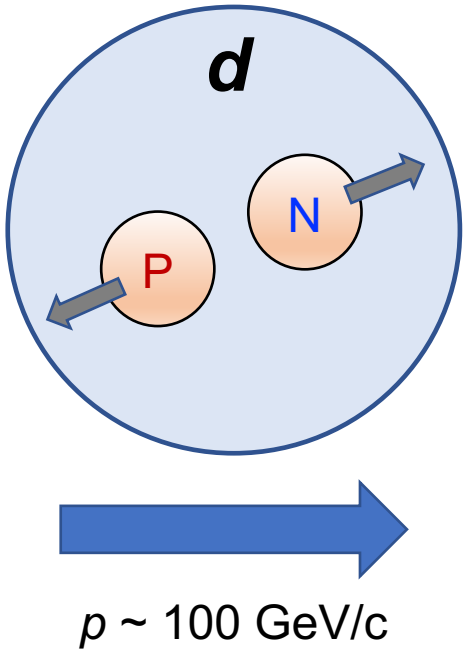
Our (favorite) approach is to study light nuclei, e.g., deuteron associated with breakups

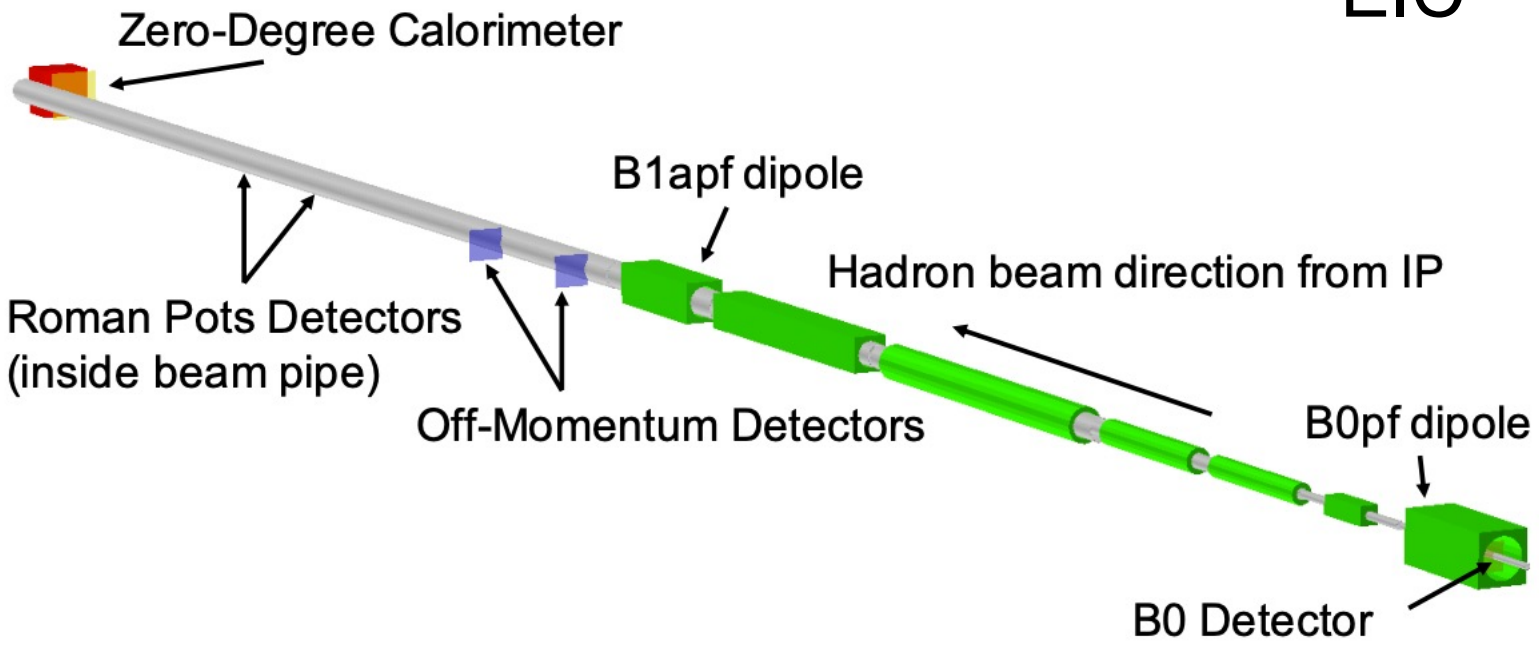


EMC-SRC workshop Mar 26, 2021

Deuteron at a collider!



EIC



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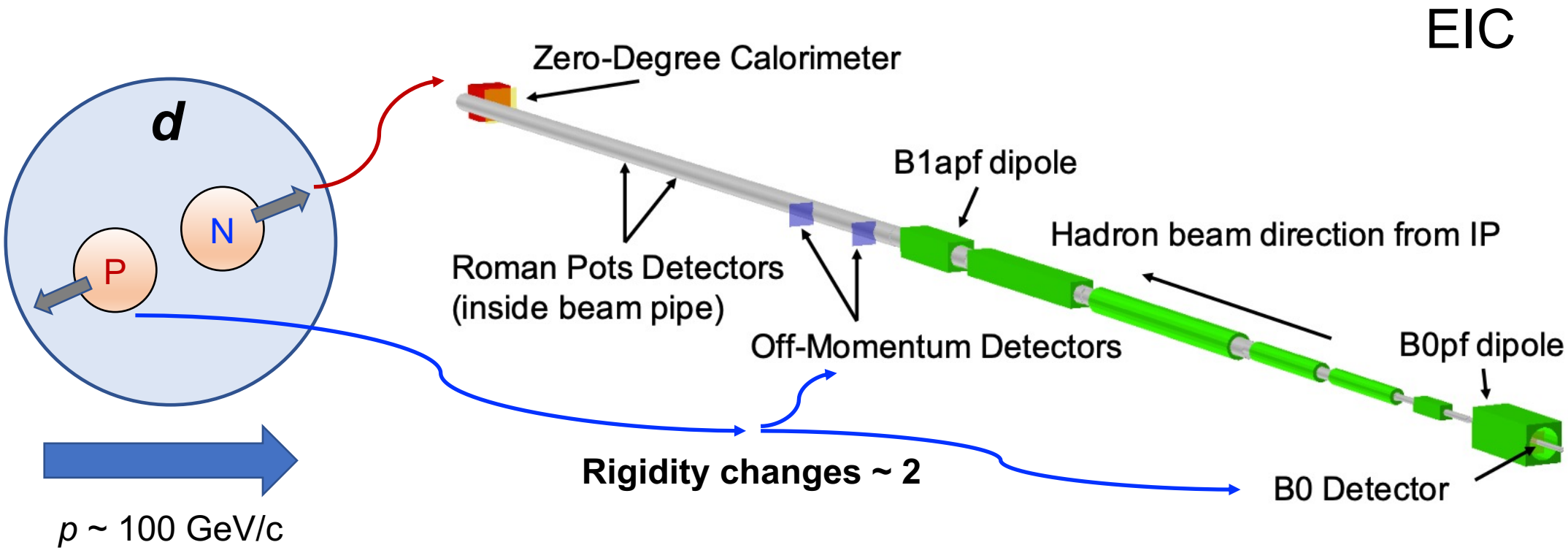
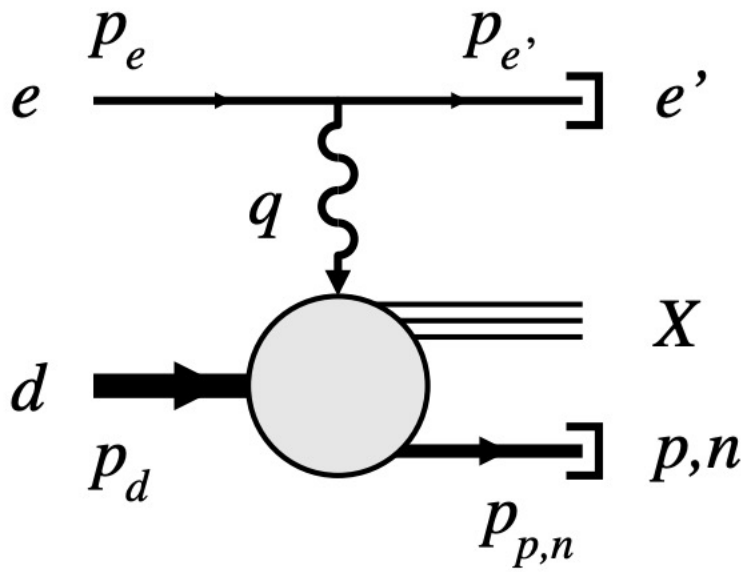


Easy access:
~0 GeV/c fermi momentum ~ 100 GeV/c in the lab

Free neutron structure

(A.Jentsch, ZT, C.Weiss (2021), arXiv:2108.08314)



Tagged DIS + on-shell extrapolation
(see Cosyn, Weiss 2020)

Idea of this measurement:

- Standard DIS measurement (e.g., only scattered electron);
- Tag a spectator, full kinematic reconstruction (p_T, alpha)

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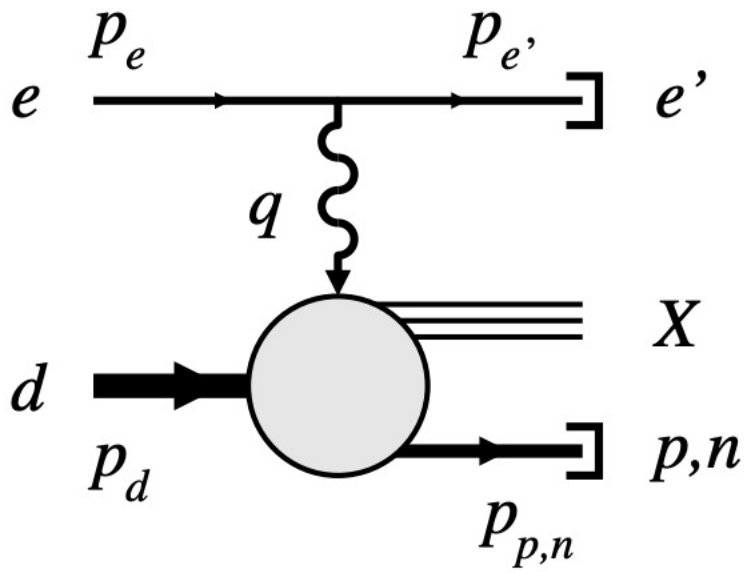

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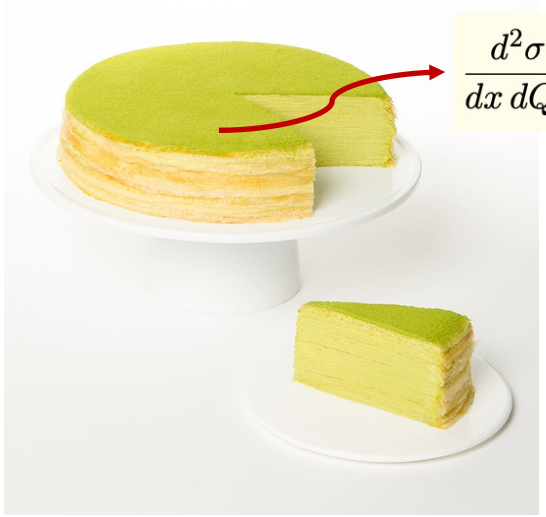

$$\frac{d^2\sigma}{dx\,dQ^2} = \frac{4\pi\alpha^2}{xQ^4}\left[\left(1-y+\frac{y^2}{2}\right)F_2(x,Q^2) - \frac{y^2}{2}F_L(x,Q^2)\right].$$

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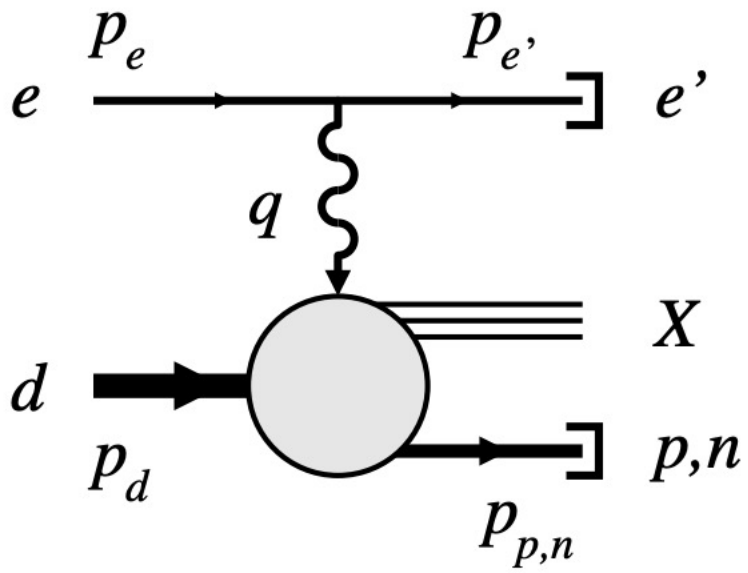

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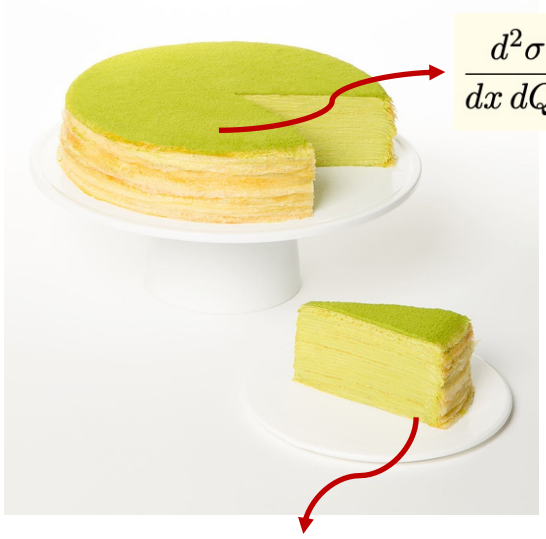

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(further) Differential in spectator kinematic variable: p_T, alpha, phi…

Tagged DIS

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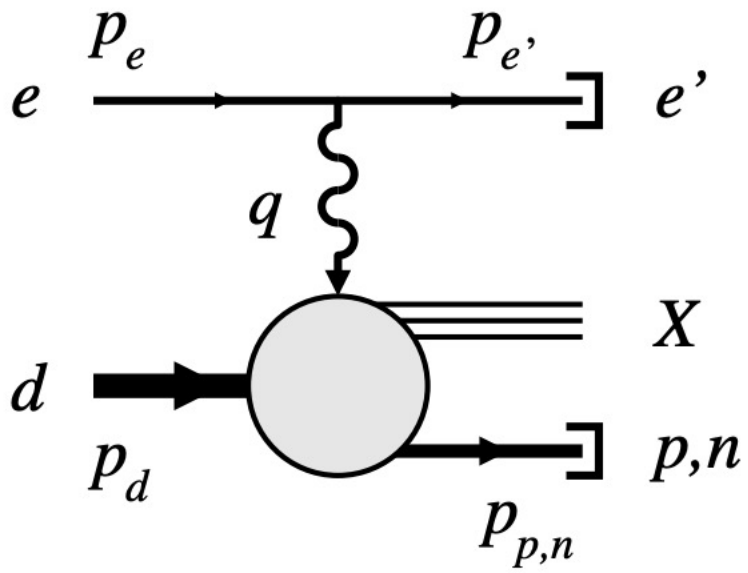

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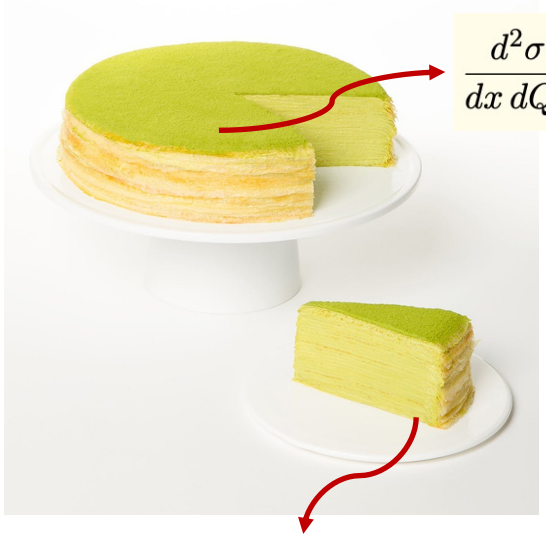

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Big advantage - p_T, alpha behavior (dependence) which points us to where the free neutron is…

Method 1. vs 2

- Method 1.
  - Integral of all spectator kinematics; (full cake)
  - Only “know” DIS is on the neutron (proton tagged)
- Advancement:

  Better than inclusive eD DIS.
- Difficulty:

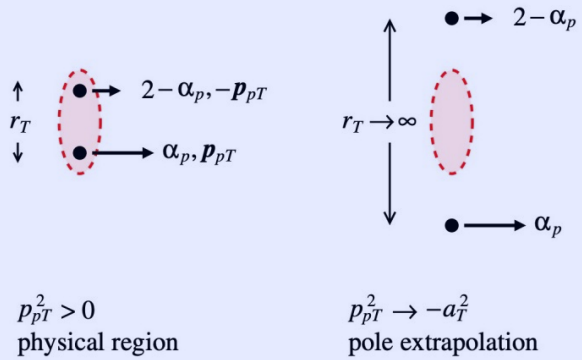
  FSI, nuclear binding, etc.

- Method 2.
  - Differential in spectator kinematics; (a slice of cake)
  - Extrapolate to free nucleon
- Advancement:

  ✕ No FIS, nuclear binding, etc.
- Difficulty:

  Experimental capability of high-precision meas. on spectator

Method. 2



- The resulting distribution is F_2 as a function of $p_{T,spect}^2$.

$$F_{2,n}(x,Q^2) = \frac{F_{2,d}}{[2(2\pi)^3]S_d(p_{T,spect},\alpha_{spect})}$$

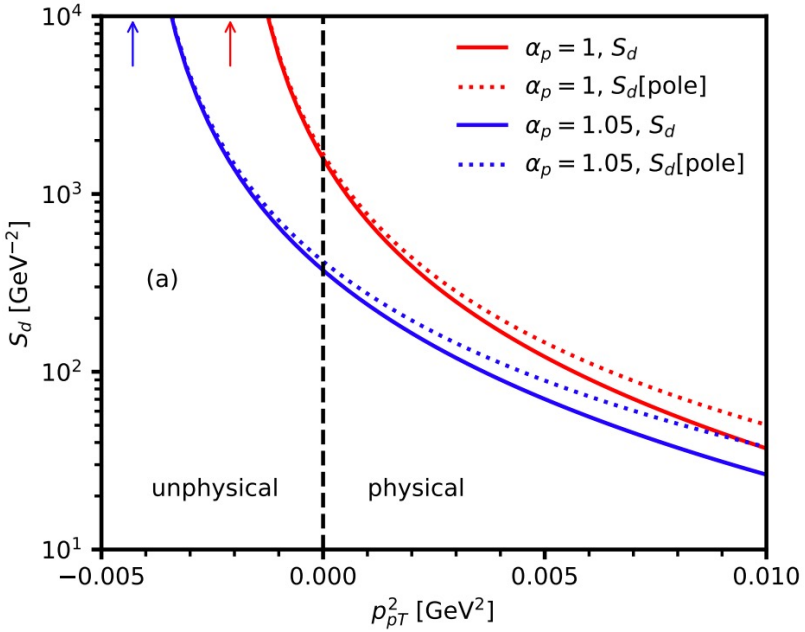
- Extrapolate to $p_{T,spect}^2 \to -a_T^2$ to extract F_2 to extract free nucleon F_2.
  - Method eliminates nuclear binding effects.

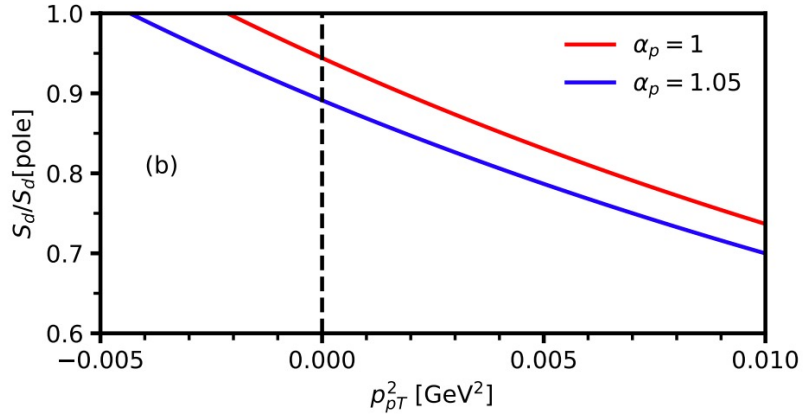
A. Jentsch. DIS 2021
& arxiv:2006.03033

- Deuteron (well known!) pole function can be used
- Short-distance extrapolation to $-a_T^2 \sim -0.005$ GeV^2

(Model independent, except for < 1% uncertainty on details of parametrizations of the pole based on the D wfs.)

arXiv:2108.08314





Spectator p_T^2

BeAGLE + detector simulations

- BeAGLE, general-purposed eA MC generator, see M.Baker's talk, or https://wiki.bnl.gov/eic/index.php/BeAGLE.
- Deuteron treatment is special in BeAGLE, we use the "C. Ciofi degli Atti and S. Simula" parametrizations of the D w.f., Phys.Rev.C53:1689,1996
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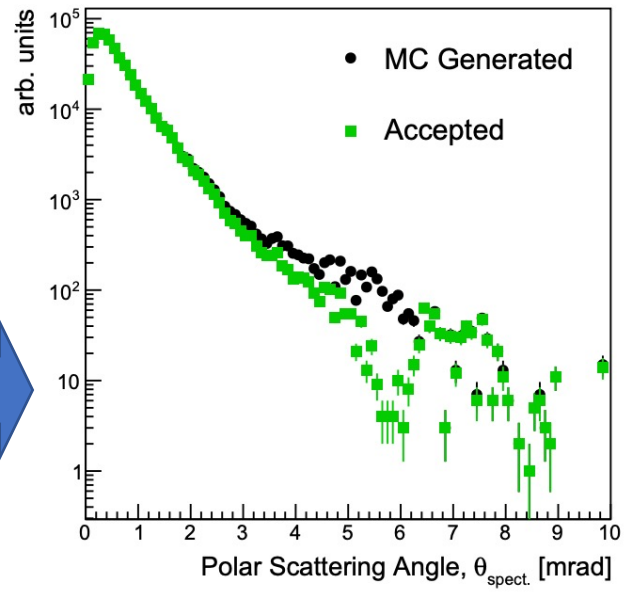
See A.Jentsch's talk

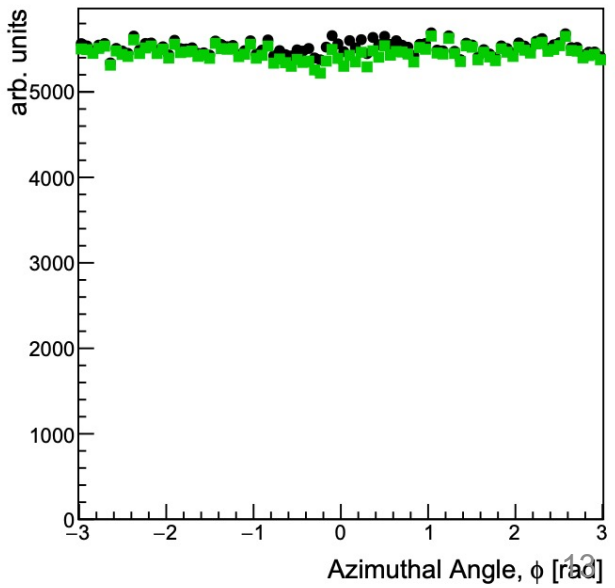
- FF simulations –

~ IP6 configuration

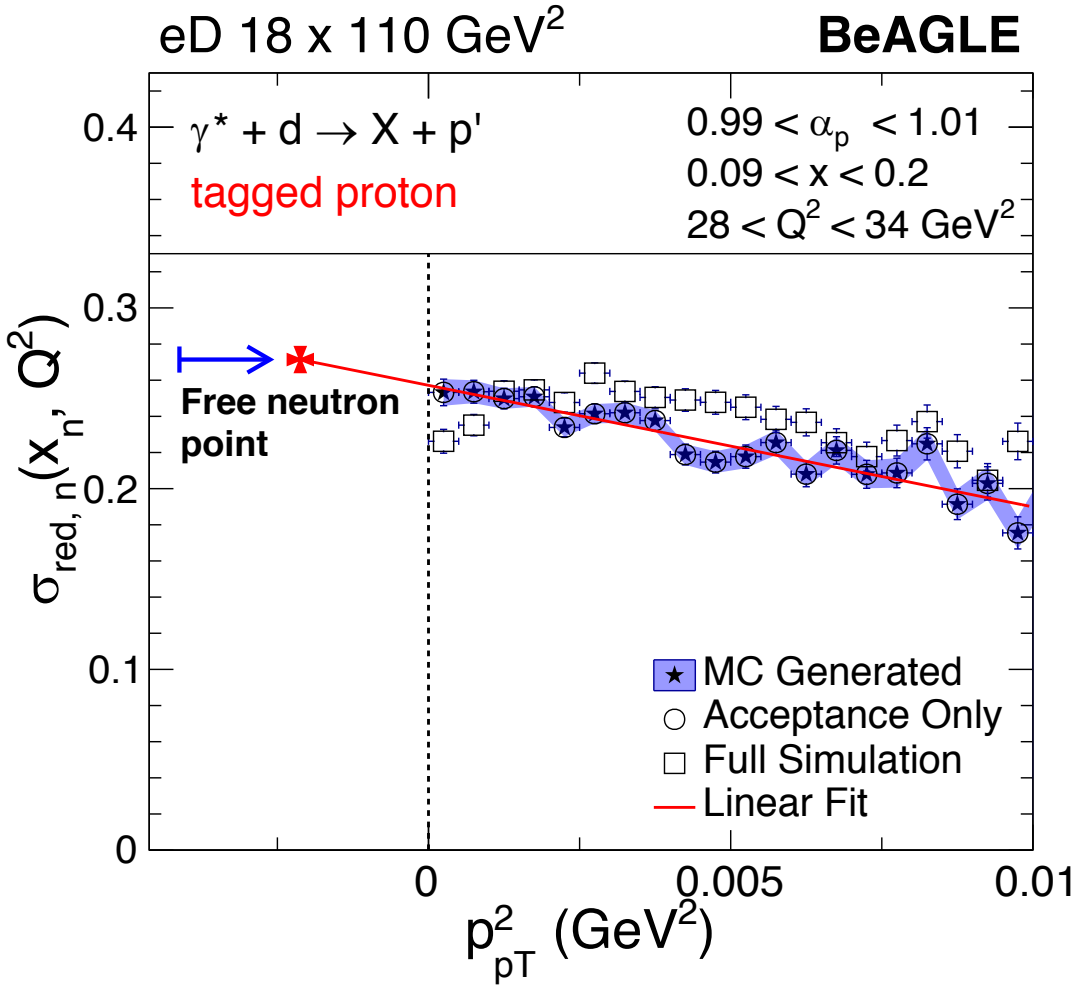
Example of proton spectator acceptance in polar angle and azimuthal angle

Great acceptance!





Results - 1



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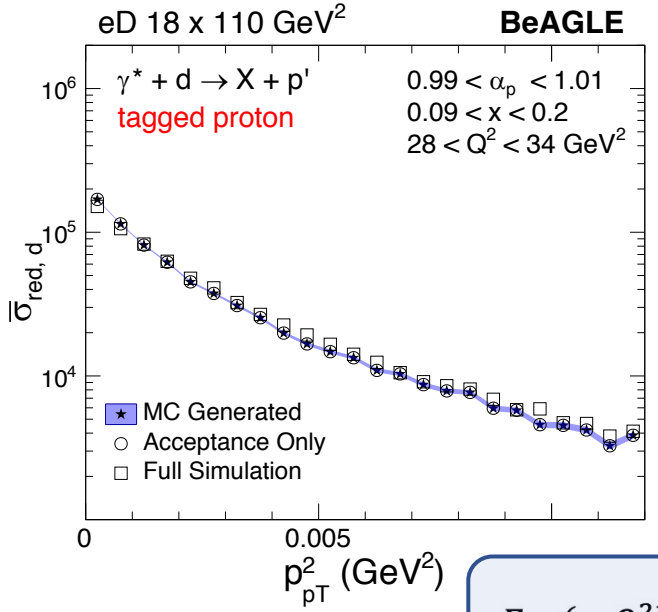
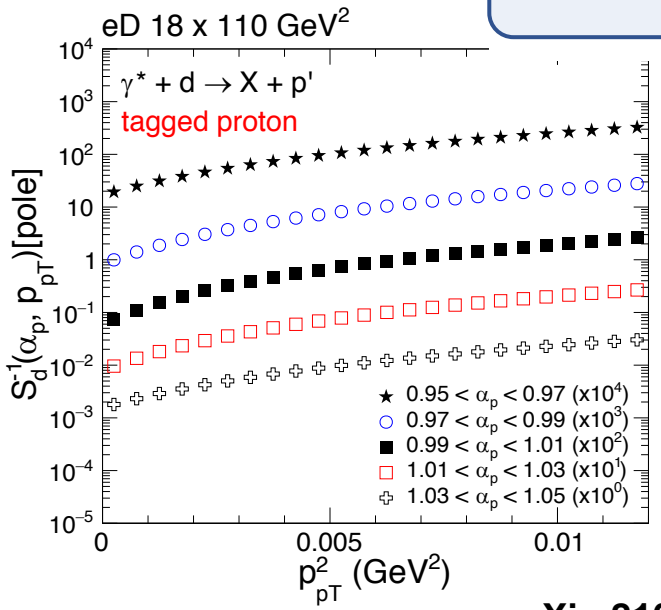


Reduced cross section on deuteron w. tagging

$$F_{2,n}(x, Q^2) = \frac{F_{2,d}}{[2(2\pi)^3] S_d(p_{T,spect}, \alpha_{spect})}$$



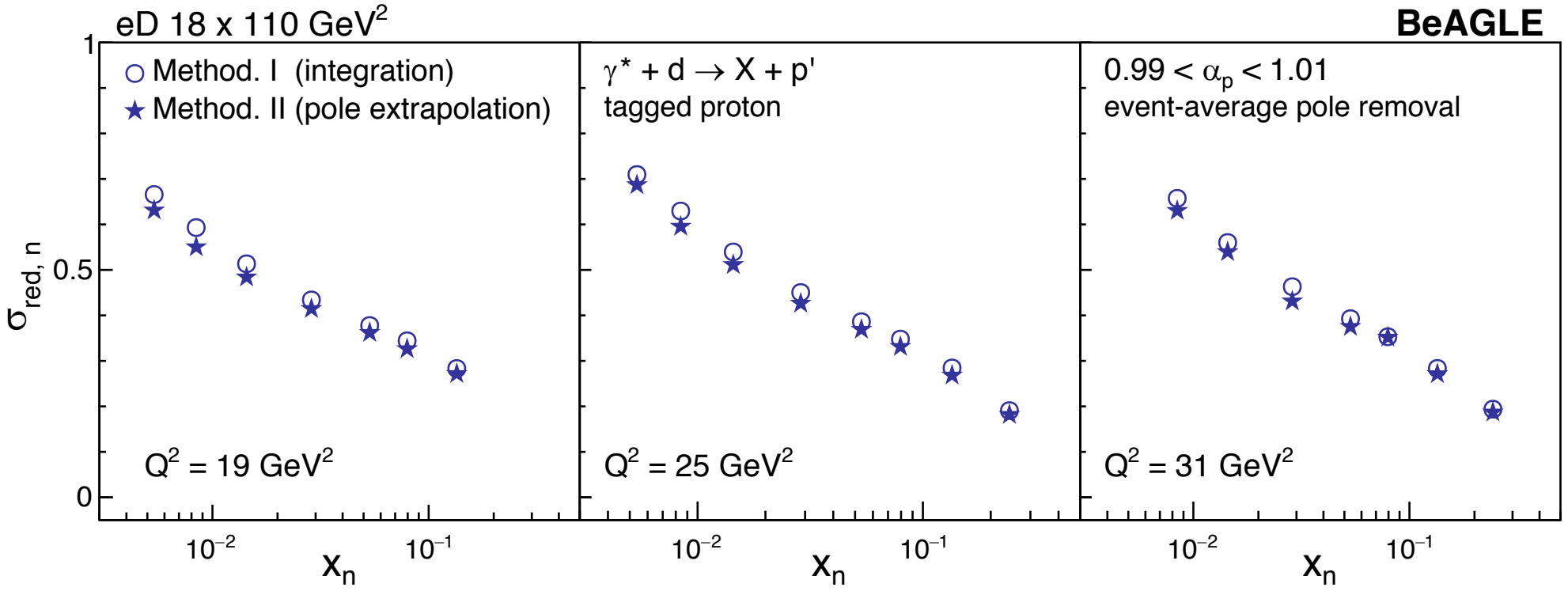
Event-averaged pole factors

Systematics not shown, but ~ a few %

arXiv:2108.08314

Results - 2

$x_n = x_{bj} / (2 - \alpha)$



- In BeAGLE we expect: Method. 1 = Method. 2
- Difference observed is due to the systematic effect of using “event-averaged” pole factor.
- However, event-by-event pole will be largely smeared by detector effects!

arXiv:2108.08314

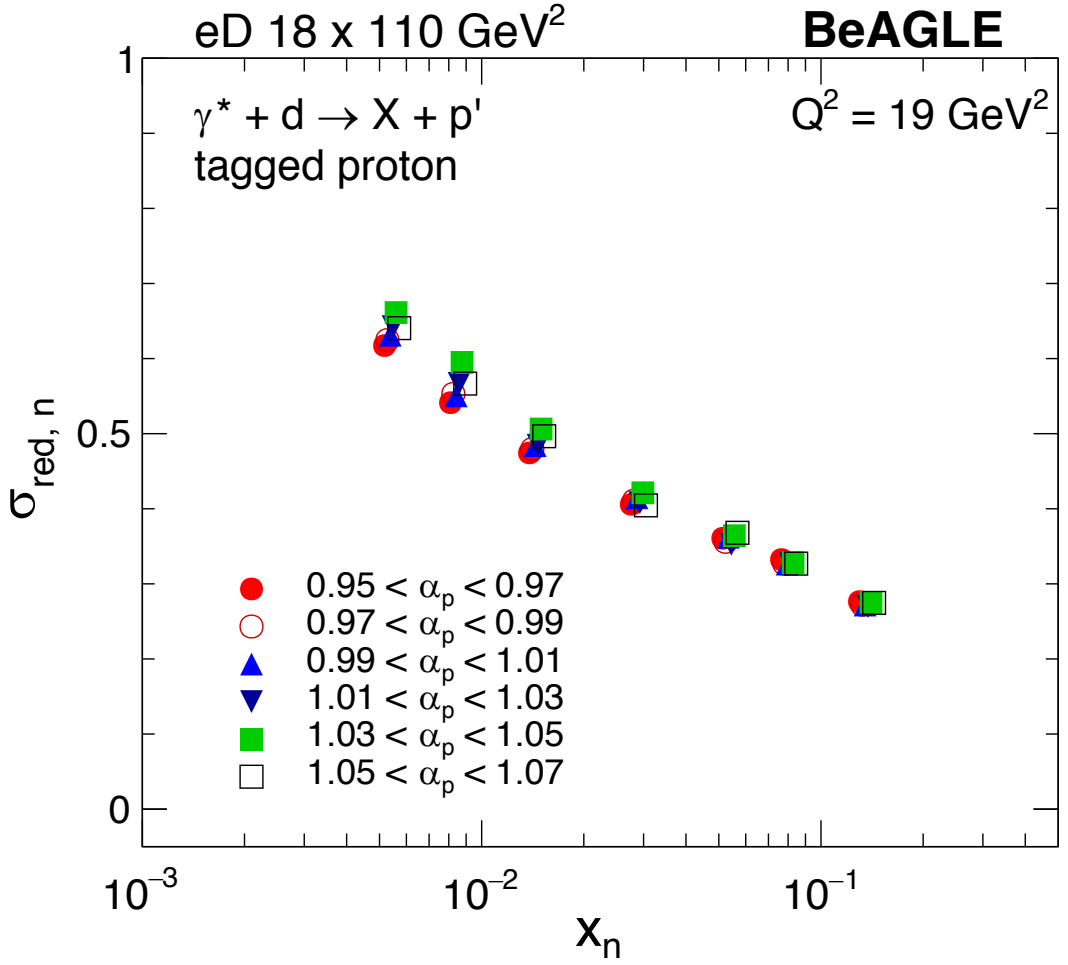
Result - 3

- Extrapolation can be performed in different alpha bins;

- Robust results

(small difference at low x also comes from event-averaged pole factors)

- EIC shows promising capability of making these measurements



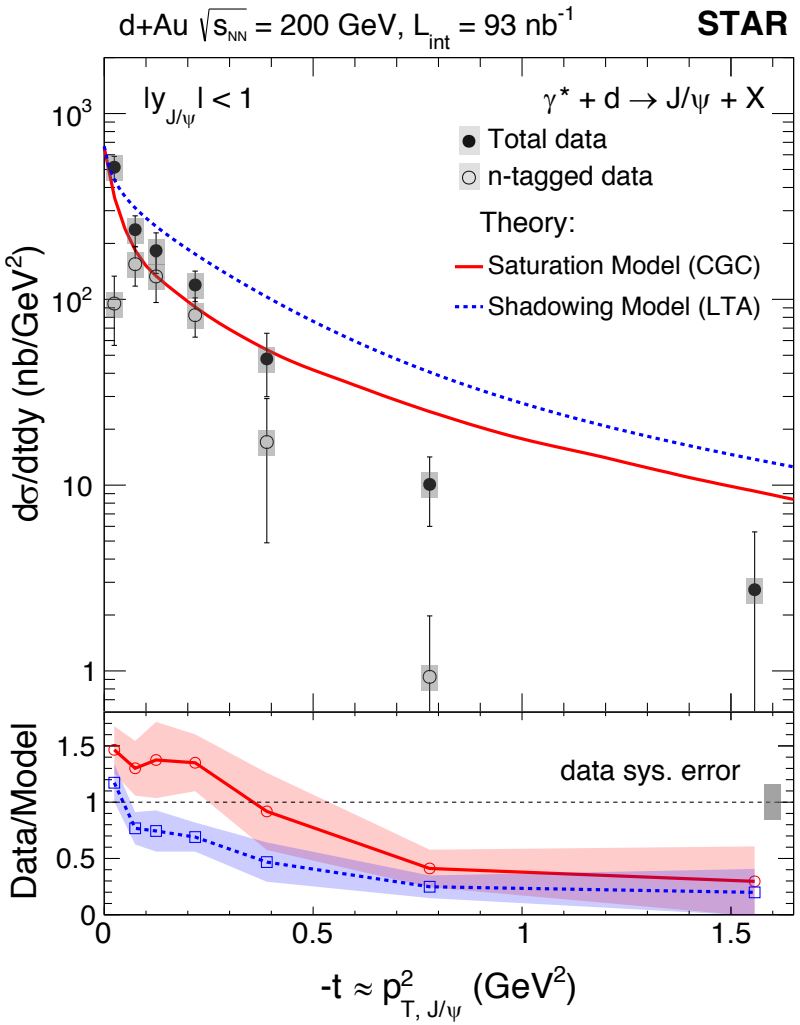
arXiv:2108.08314

Other possibilities

- Tagged DIS process with different (high) momentum region – EMC effect and SRC.
- Tagged DIS process with azimuthal dependence (e.g., to probe FSI).
- Meas. w. Deuteron polarization (see W. Cosyn's talk)
- Other processes, diffractive VM (*Phys.Lett.B* 811 (2020) 135877), incoherent DVCS with spectator tagging, etc.

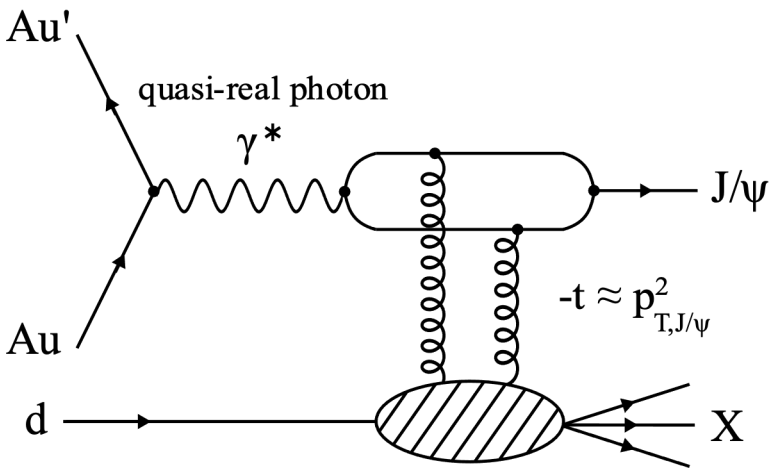
Collaborative efforts between experimentalists and theorists are greatly needed towards the EIC.

Data with spectator tagging at Collider

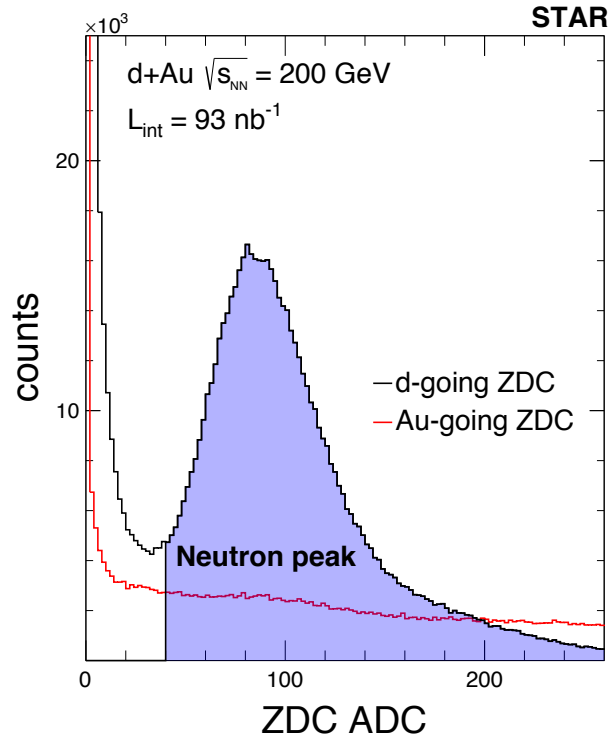


arXiv:2109.07625

Ultra-Peripheral Collisions of Deuteron-Gold (dAu)



Tagging a neutron in ZDC at STAR!

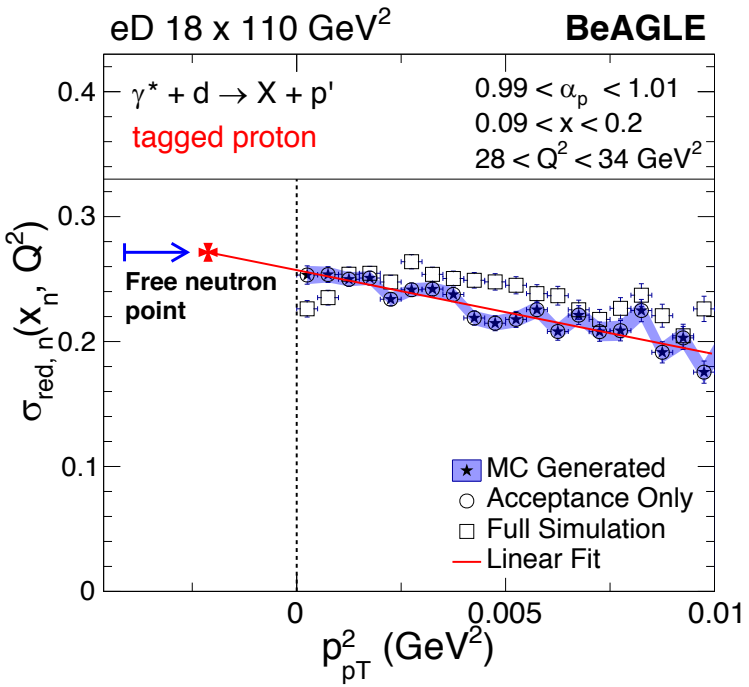


EIC will be able to tag neutrons, protons, photons with large acceptances

Summary

- Free neutron structure can be measured with high precision at the EIC – feasible from simulation studies based on BeAGLE and FF detectors.
- Next step (A.Jentsch, M.Strikman, ZT, C.Weiss)
  - EMC-SRC in deuteron, high-momentum spectator tagging.
  - Pushing the limits of FF detectors at the EIC.
- Deuteron with tagging at the EIC – many great and unique opportunities.

[Similar for He3 with double tagging, see Dien's talk.]



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