Brookhaven National Laboratory

Photoproduction of J/ψ off the deuteron at RHIC

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Accepted in PRL (*arXiv:2109.07625)*

Motivation

➢ What is the *simplest* nuclear target fragmentation?

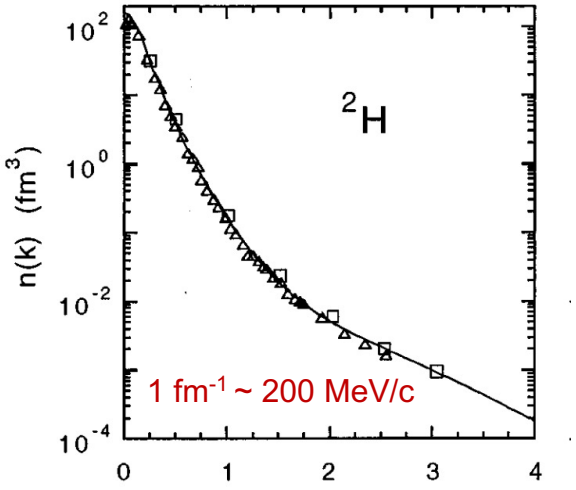
Deuteron system – *pn* config. with only one spectator.

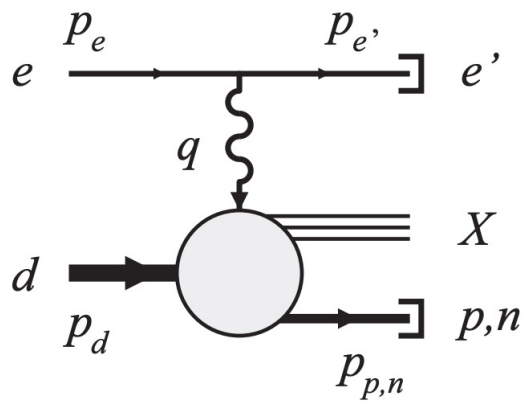
✓ Theoretically well understood, e.g., deuteron wavefunctions, binding, deuteron pole, etc.

✓ Experimentally (relatively) easy to measure in terms of the final-states. *Forward detectors* are especially useful.

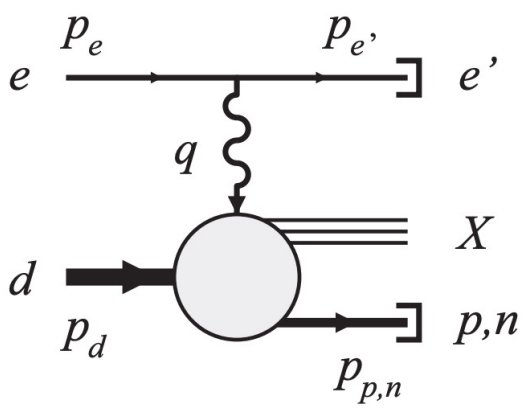
✓ Monte Carlo model – available and easy to use, e.g., **BeAGLE** event generator.

PhysRevC.53.1689





What can deuteron tell us?



Phys. Rev. C 104, 065205

By looking at the *target fragmentation (spectator)*

Tagged DIS measurements:

High internal nucleon momentum

- EMC effect and its interplay with Short-Range Correlations (SRC)

Low internal nucleon momentum

- Free nucleon structure.

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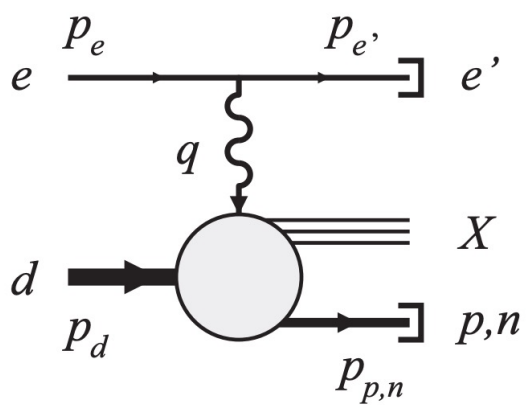

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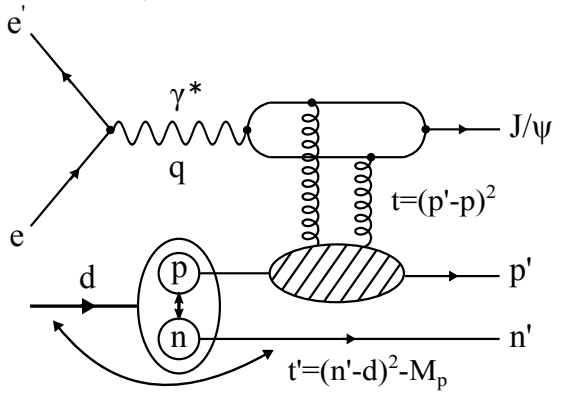

Phys. Lett. B 811 (2020) 135877

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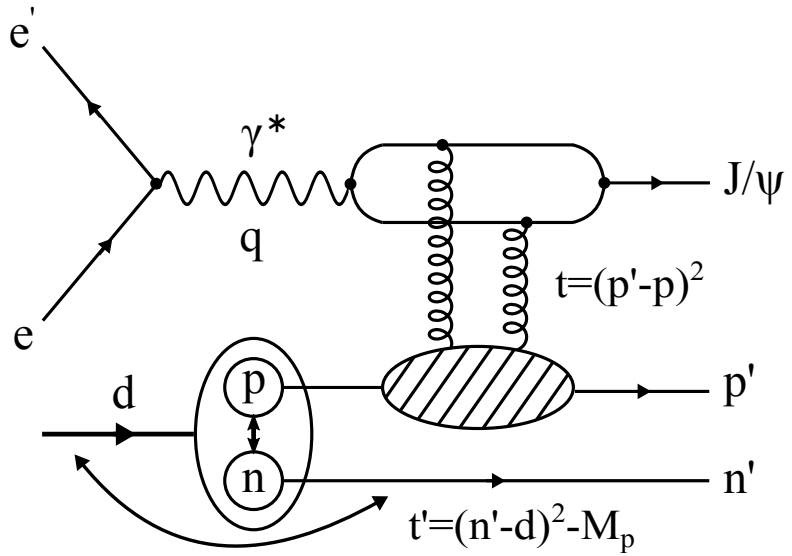
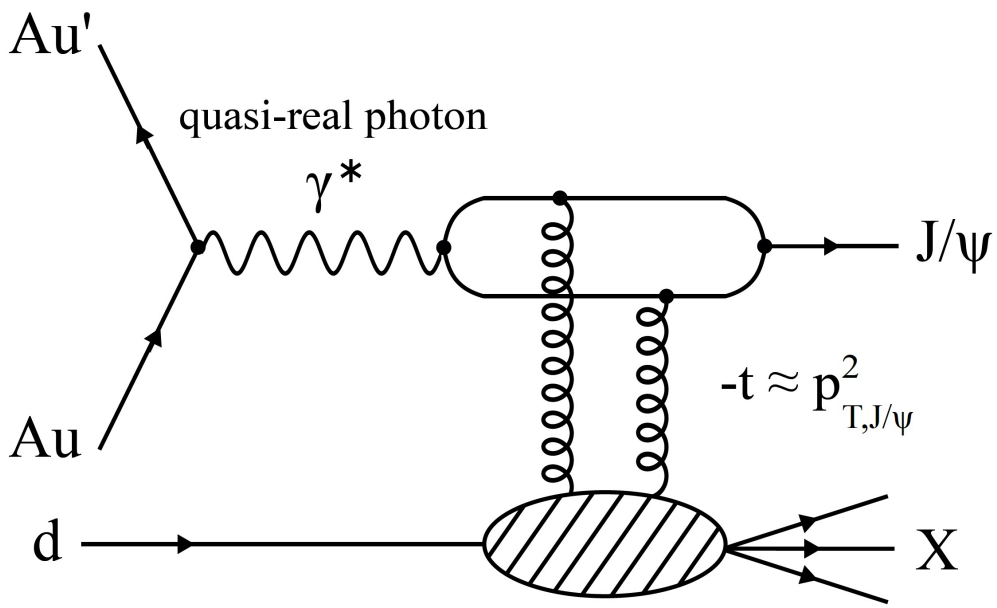
Going more exclusive

Exclusive VM production, e.g., **J/ψ**

- What role does nucleon d.o.f plays in gluon density? e.g., SRC
- By changing **the configurations, energies**, etc, sensitive to different physics phenomena.

What data do we have?





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(*arXiv:2109.07625*)

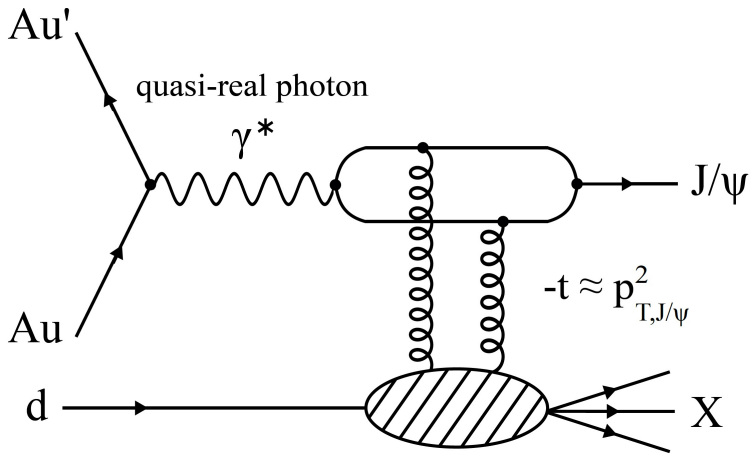
STAR UPC d+Au events are unique, never measured before:

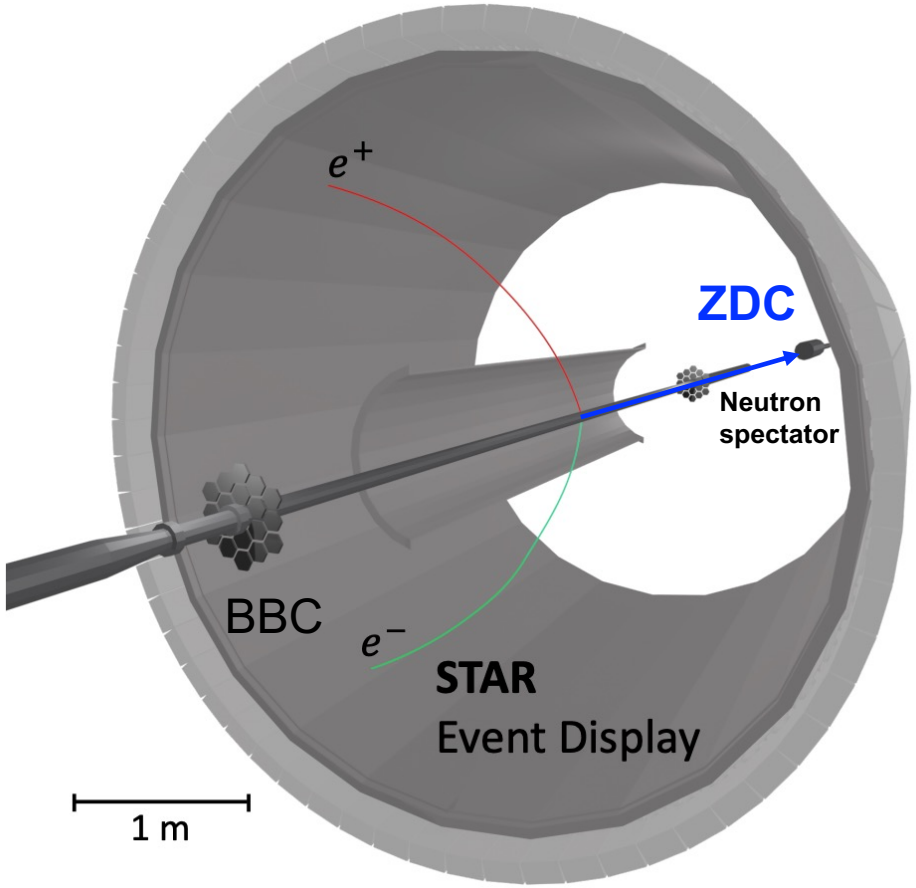
- W ~ 25 GeV, x ~ 10^{-2}, Q^2 ~ 0
- ZDC can be used for forward tagging – incoherent breakup.
- Unique kinematic range not for saturation or shadowing but a good baseline

UPC on *deuteron*

$$d + Au \rightarrow J/\psi(e^+e^-) + n + X$$

An incoherent J/ψ production event!





Trigger:

1. No ZDC requirement, this is important. (See S.Klein's talk)
1. Back-to-back calorimeter tower trigger (BEMC).
2. Low event activity (multiplicities, BBC, etc..)

Using ZDC to detect nuclear breakup – tagging forward nucleon in exclusive events.

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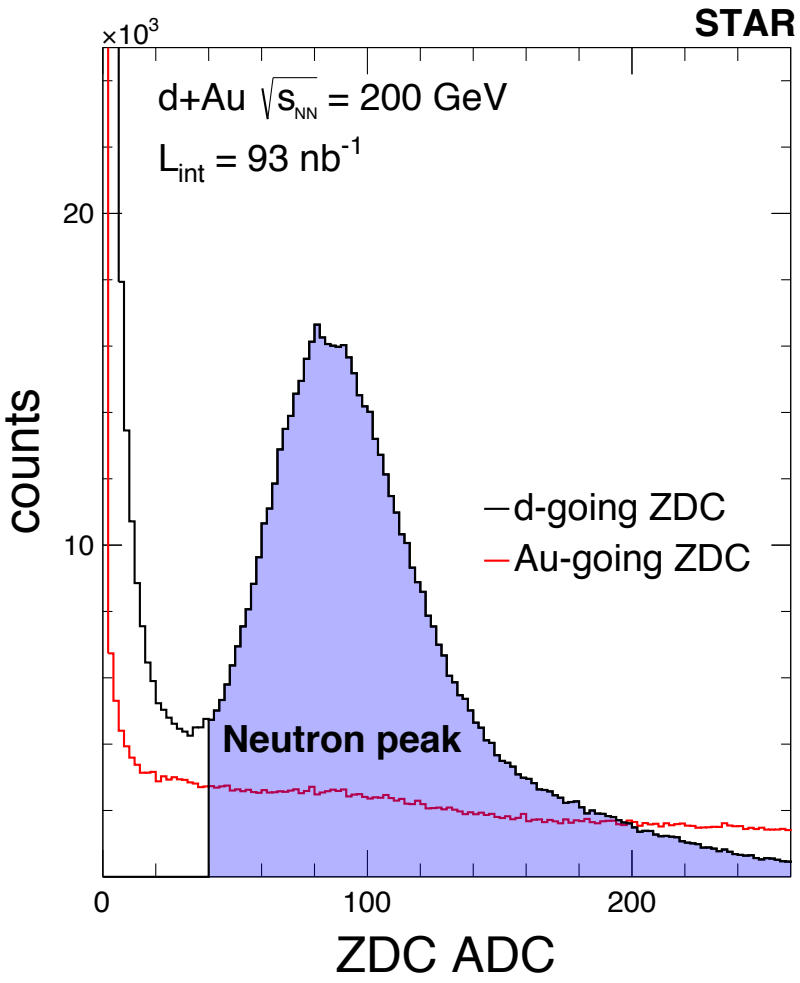
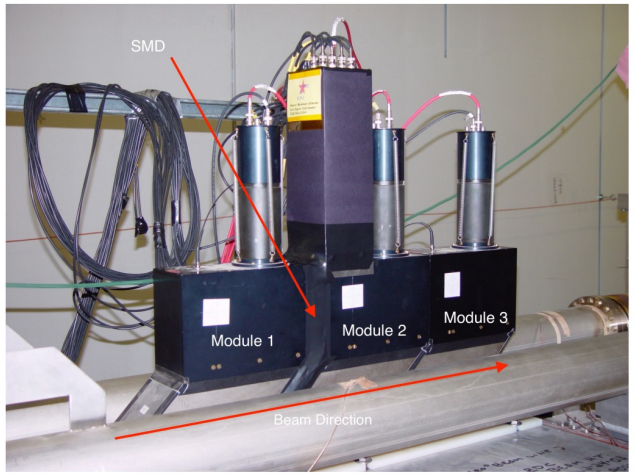
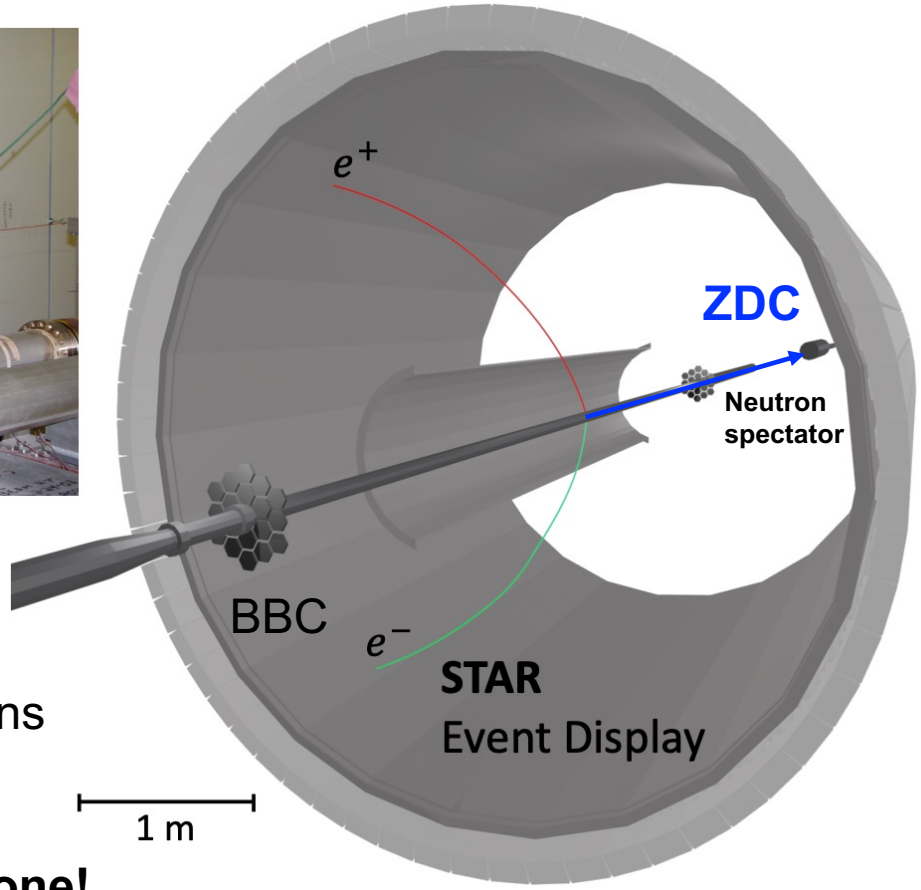






ZDC resolution can only separate up to 3-4 neutrons with large uncertainty.

Deuteron, there is only one!

No neutron from gold
→ photon-gold collisions very rare!

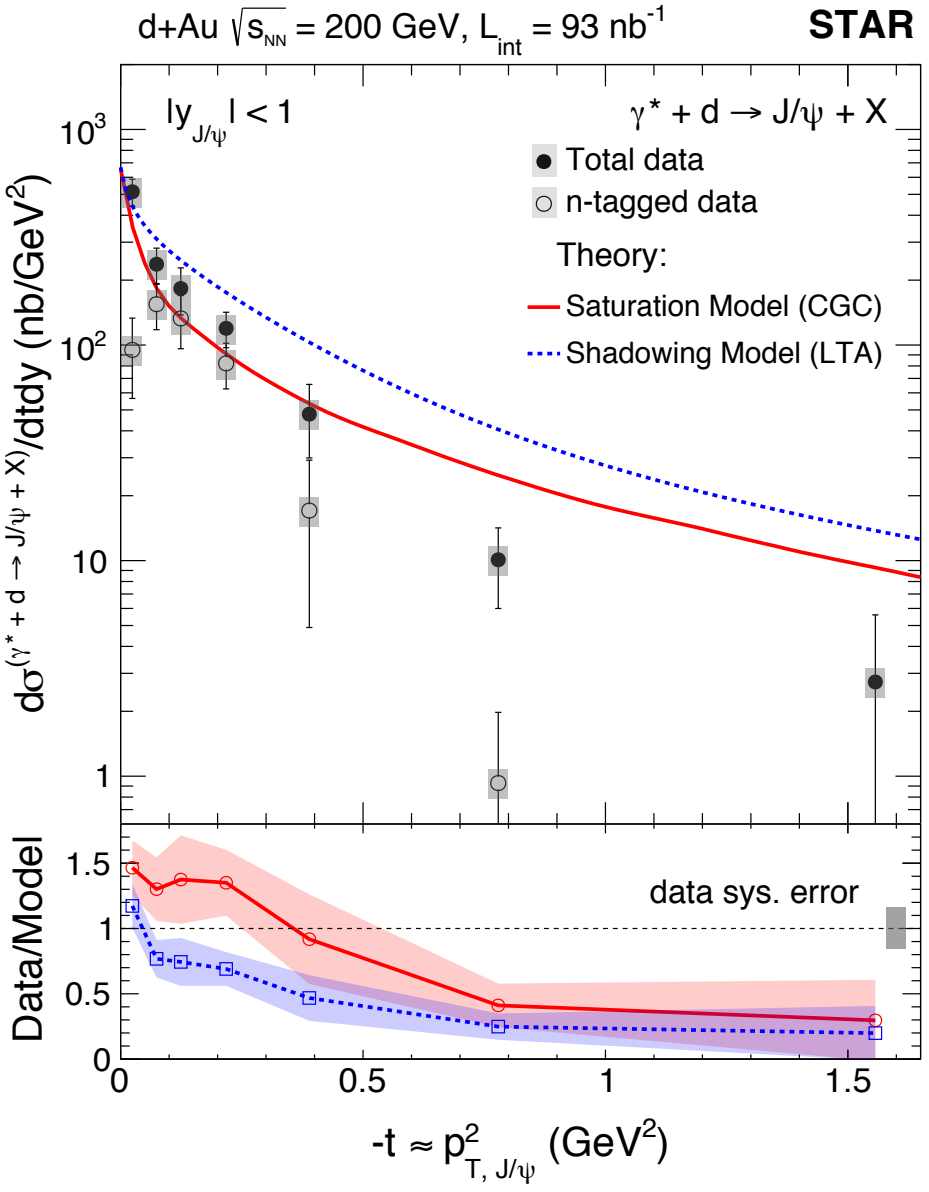
Using ZDC to detect nuclear breakup – tagging forward nucleon in exclusive events.

Results

- ✓ Correcting the photon flux from gold nucleus, reporting γd cross section.
- ✓ **Neutron-tagged data at low *-t*, expectation of incoherent deuteron breakup.**
- ✓ High *-t* is limited by ZDC acceptance. This shows the importance of the ZDC acceptance.

Model data comparison

- ✓ A good baseline system to test the CGC and LTA shadowing model.
- ✓ Saturation model describes the data better Favors nucleon fluctuations in the CGC (see B. Schenke's talk)



Models

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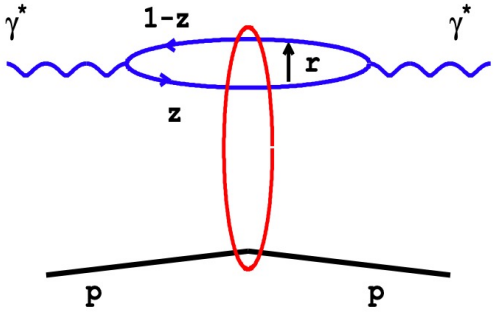
Model A

Saturation model

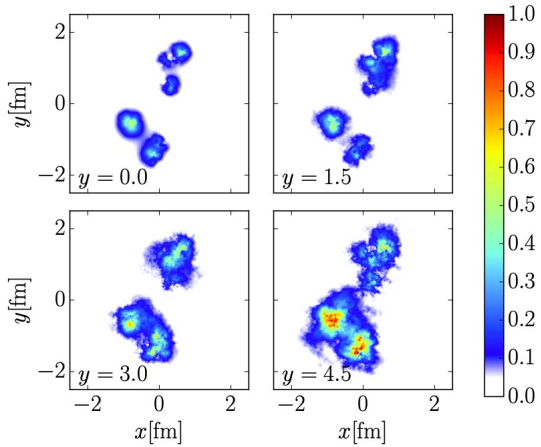
- **Color Glass Condensate** (CGC)

- Dipole-target scattering with small-x evolution equation + saturation scale Q_s

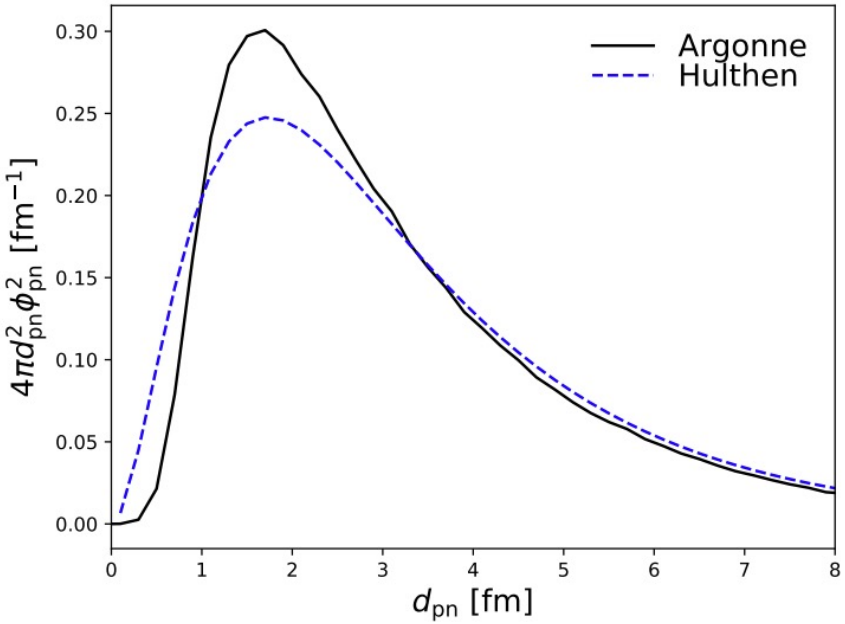
✓ Deuteron wavefunction and nucleon shape fluctuations.



[Mantysaari, Schenke, 2019]



Deuteron density & fluctuations



Wavefunction

Phys. Rev. C 101, 015203 (2020)

Models

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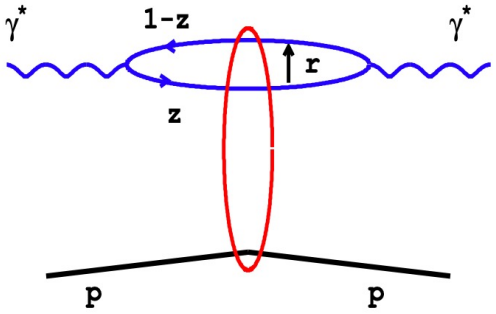

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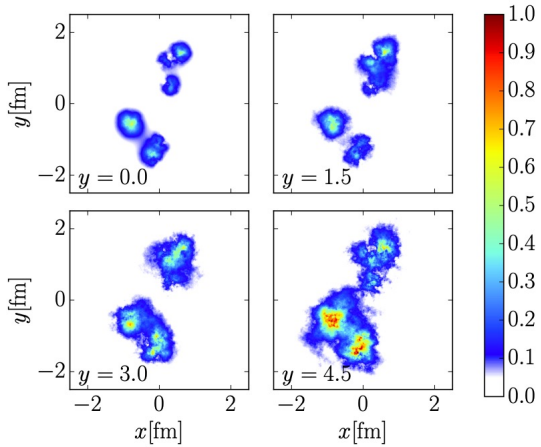


Deuteron density & fluctuations

Phys. Rev. C 101, 015203 (2020)

(from B. Schenke's talk)

Incoherent diffraction:

Initial state: $|i\rangle$; Final state: $|f\rangle$; Amplitude for diffractive scattering: $\mathscr{A}$

Squared transition amplitude, which enters in the cross section:

H. I. Miettinen and J. Pumplin, Phys. Rev. D18 (1978) 1696

$$\sum_{f\neq i} |\langle f|\mathscr{A}|i\rangle|^2 = \sum_f \langle i|\mathscr{A}^*|f\rangle\langle f|\mathscr{A}|i\rangle - \langle i|\mathscr{A}|i\rangle\langle i|\mathscr{A}^*|i\rangle$$
$$= \langle i|\mathscr{A}^*\mathscr{A}|i\rangle - |\langle i|\mathscr{A}|i\rangle|^2$$

Sum over final states includes all possible states for the final state target

Average over all possible initial states → cross section

$$\frac{d\sigma^{\gamma^*A\to VA}}{dt} = \frac{1}{16\pi}\left(\left\langle\left|\mathscr{A}^{\gamma^*A\to VA}\right|^2\right\rangle - \left|\left\langle\mathscr{A}^{\gamma^*A\to VA}\right\rangle\right|^2\right)$$

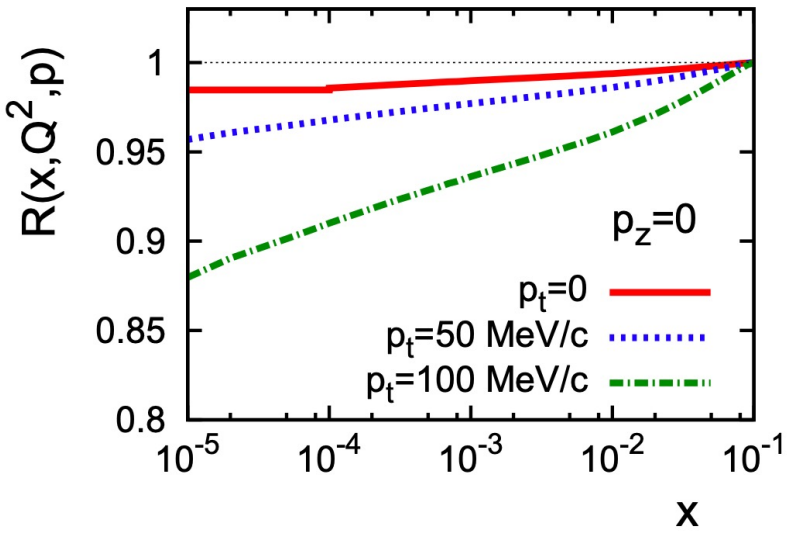
4 Björn Schenke, BNL

CGC or IP-Sat:
The framework has been constrained by HERA data;

Interesting to go to the simplest nuclear breakup and see if this works for incoherent diffraction.

Models

Prediction on $F_{2,D}/F_{2,p}$



Only a few % shadowing effect, but it is important to understand the nuclear breakup, e.g., incoherent production off deuteron.

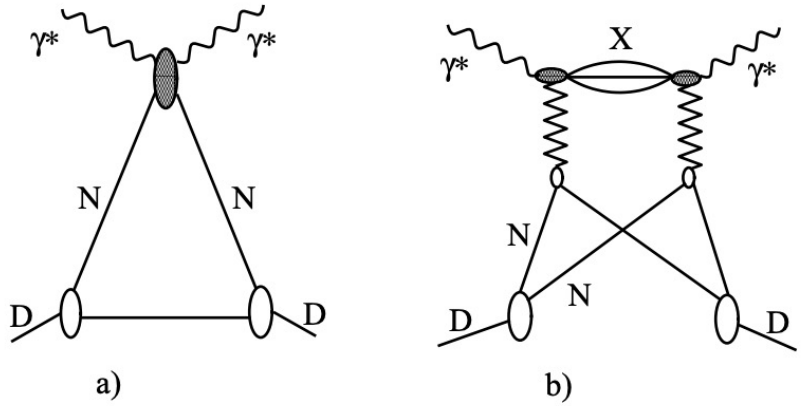
Model B

Shadowing model

- **Leading Twist Approximation**

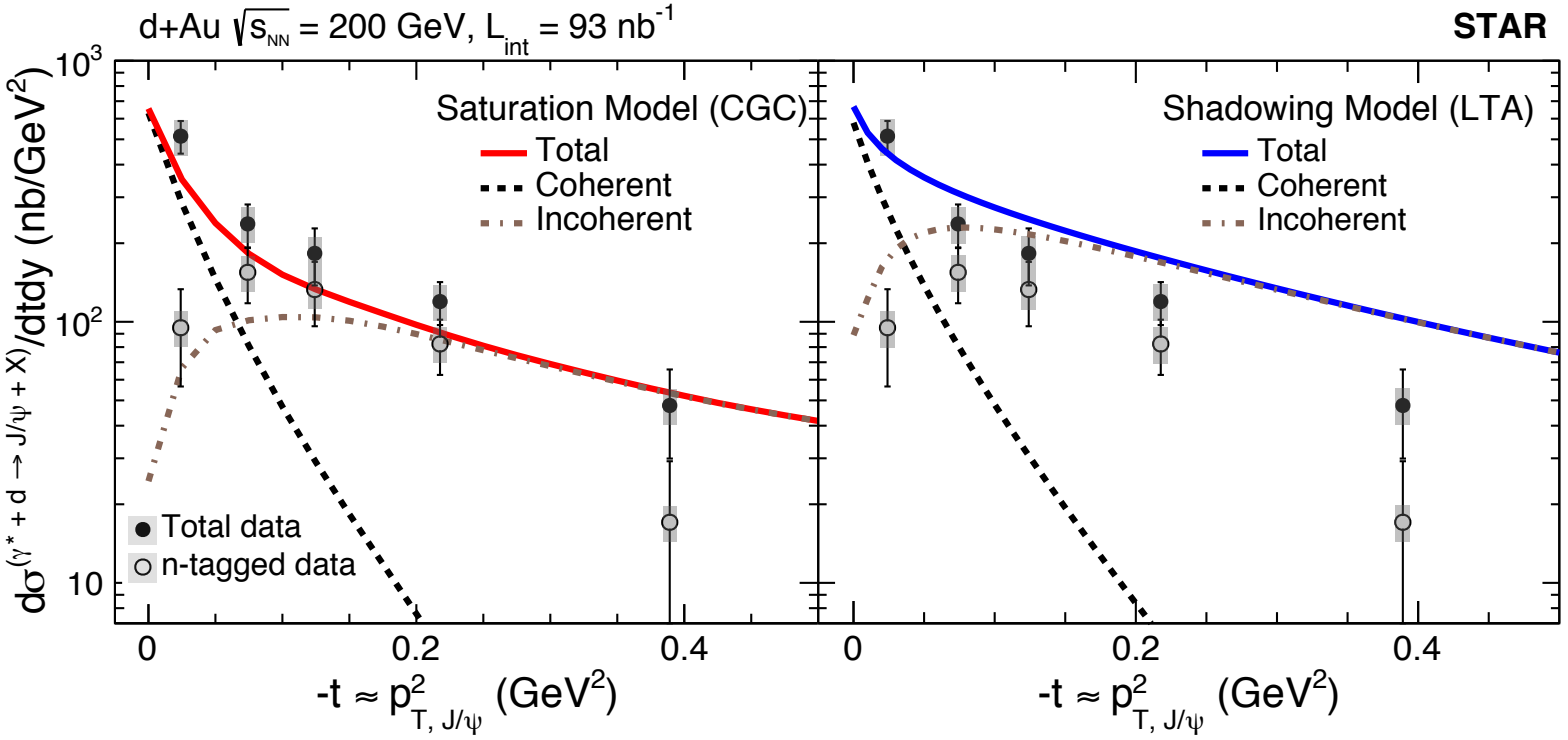
- Combination of Gribov-Glauber theory, QCD factorization, and HERA diffractive data

✓ Deuteron wavefunction and nucleon shape fluctuations.



L. Frankfrut,, V. Guzey, M. Strikman (Physics Reports 512 (2012) 255-393)

Deuteron breakup



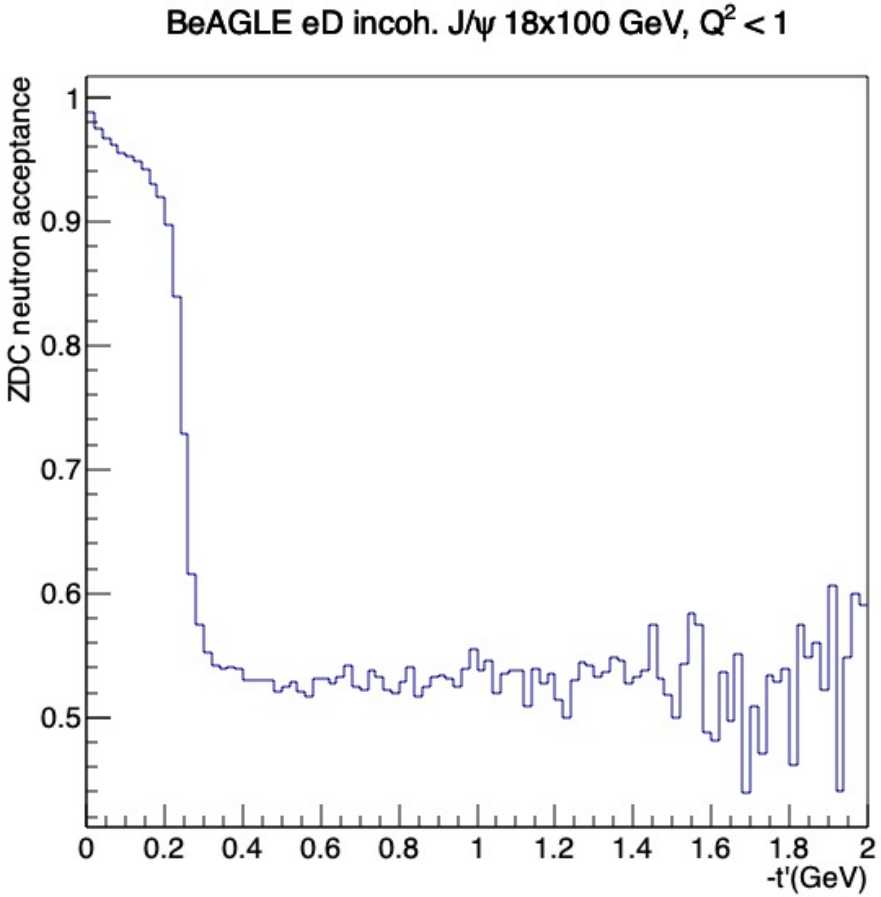
A breakdown view

- CGC and LTA uses the same ***d*** wavefunction – AV18, with nucleon/cross section fluctuations.

✓ **CGC has a smaller χ^2/dof**

Deuteron breakup

BeAGLE incoherent
(elastic nucleon and dissociation)



BeAGLE simulation:

ZDC acceptance of forward neutron from incoherent production of eD 18x110 (same deuteron energy)

based on ~ STAR ZDC acceptance

Detector simulation is only at the Toy level

Deuteron breakup

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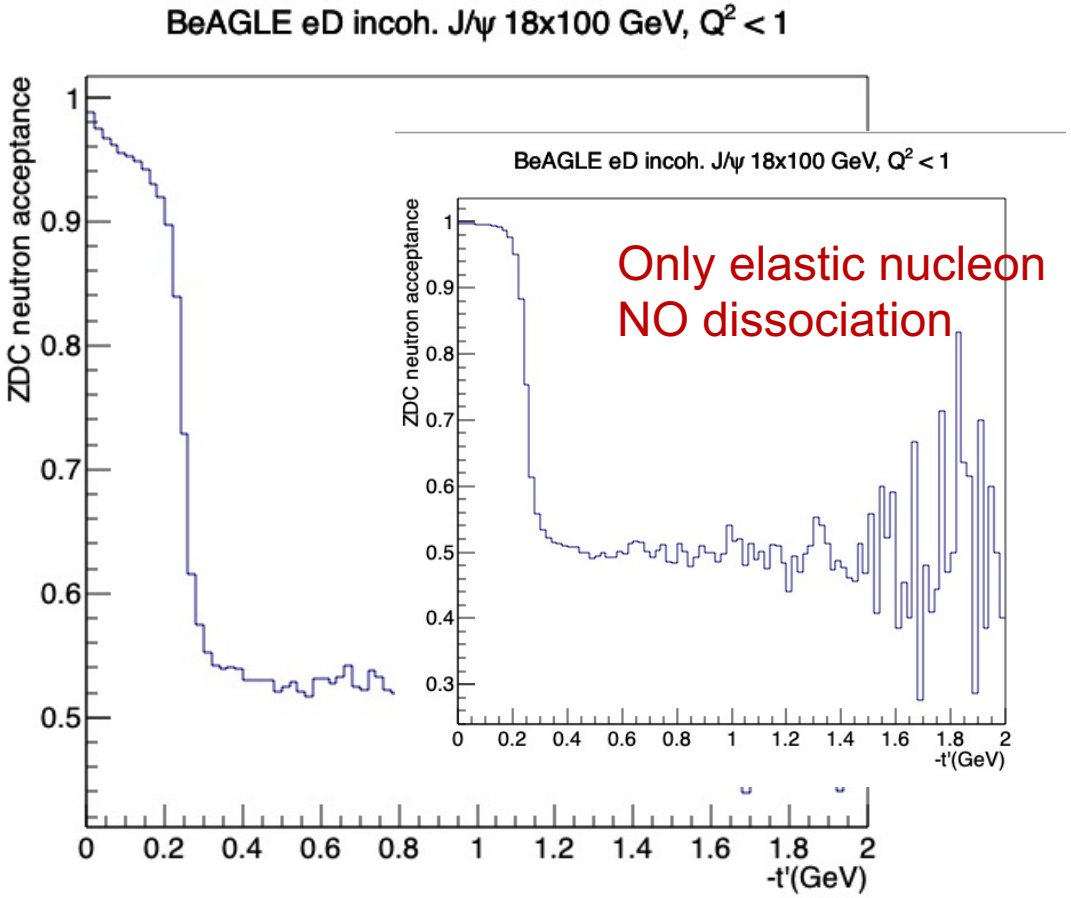

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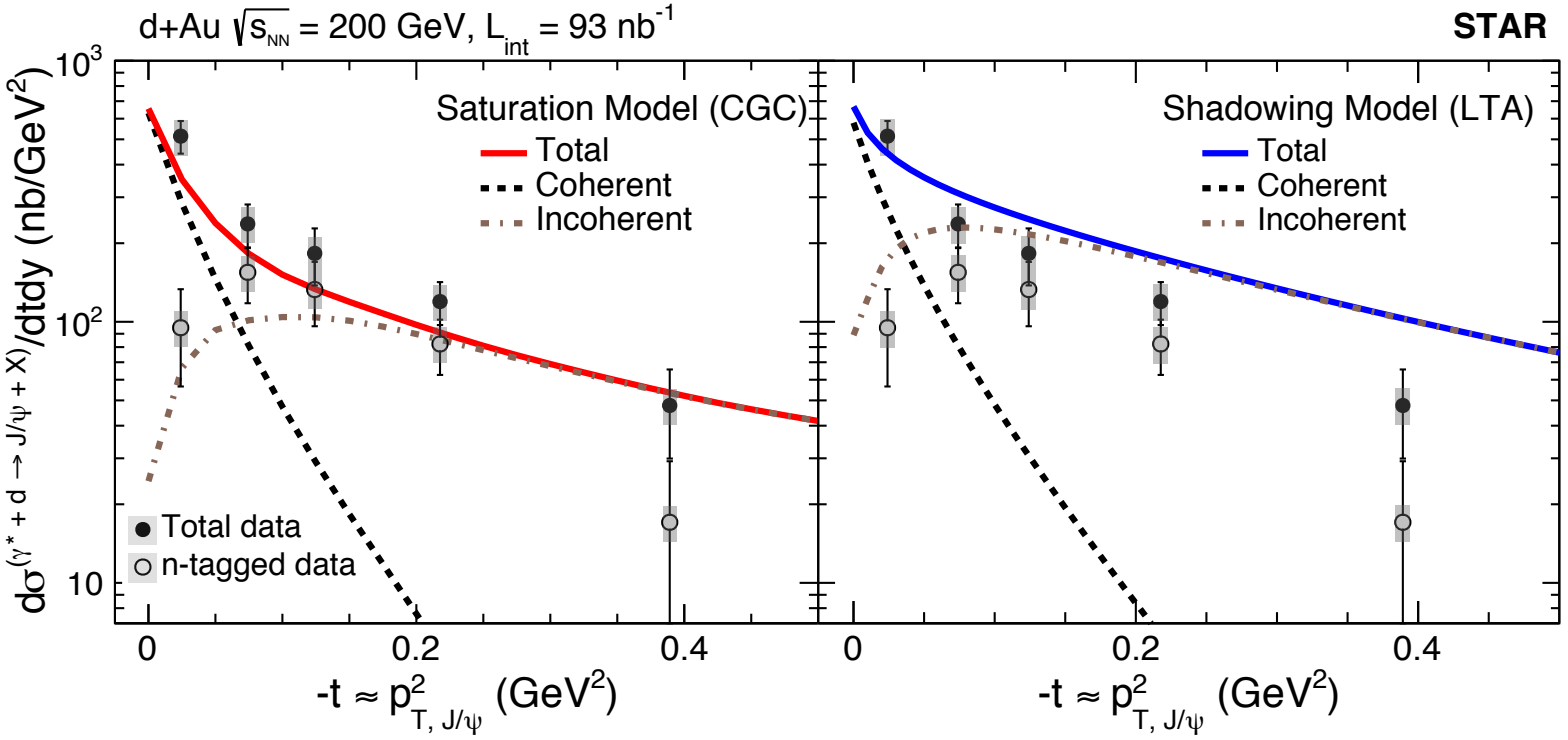


A breakdown view

Important baseline before going to heavy nucleus

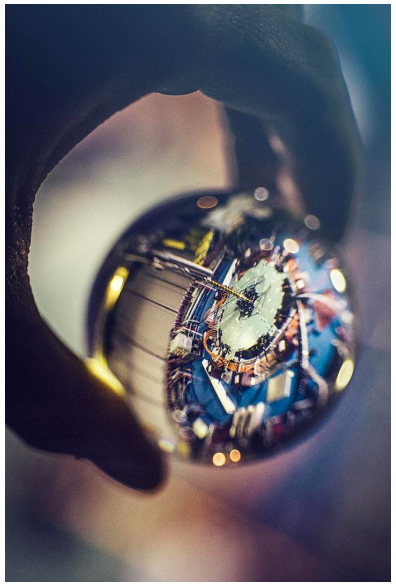
- CGC and LTA uses the same ***d*** wavefunction – AV18, with nucleon/cross section fluctuations.

✓ **CGC has a smaller χ^2/dof**

It is important to understand the differences between the two models/frameworks!
e.g., how much overlapped, where's the difference

Summary

- **STAR UPC dAu data has its unique position:**



✓Connecting between ep HERA data to AA UPC data;

We need to understand the full picture and baseline.

✓ZDC has shown excellent capability in tagging forward going neutron, and ~100% acceptance for spectator, but not for leading neutron. Important lessons for the EIC.

✓Close connection to tagging physics at the EIC.