What can we learn from UPCs ?

→ Physics perspectives from STAR d+Au preliminary results

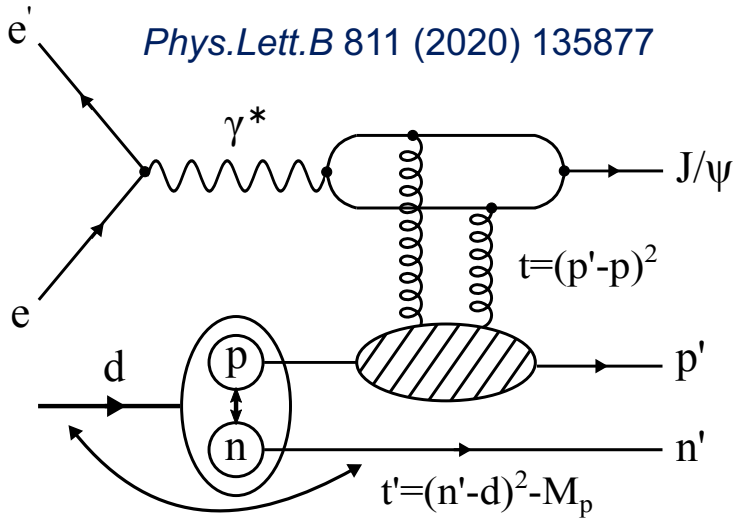
Kong Tu

BNL

01.14.2021

Motivation

- Nucleon and nuclear structure is a **big physics question.**
- EIC can provide an unprecedented opportunity to answer this question. However, ultra-peripheral collisions (UPCs) can provide some useful information before EIC.



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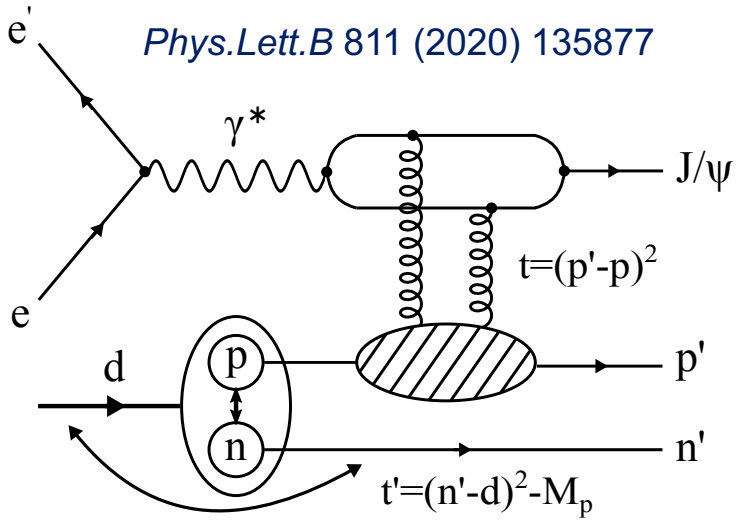

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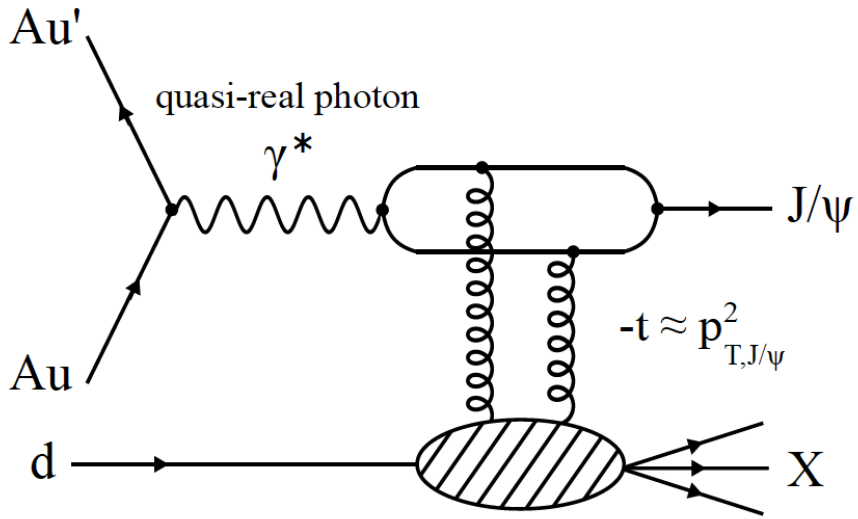
EIC

A similar physics problem



RHIC UPC

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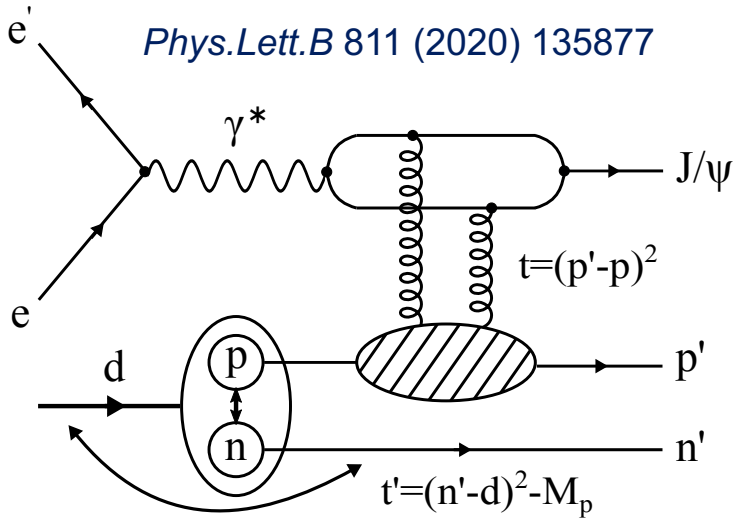

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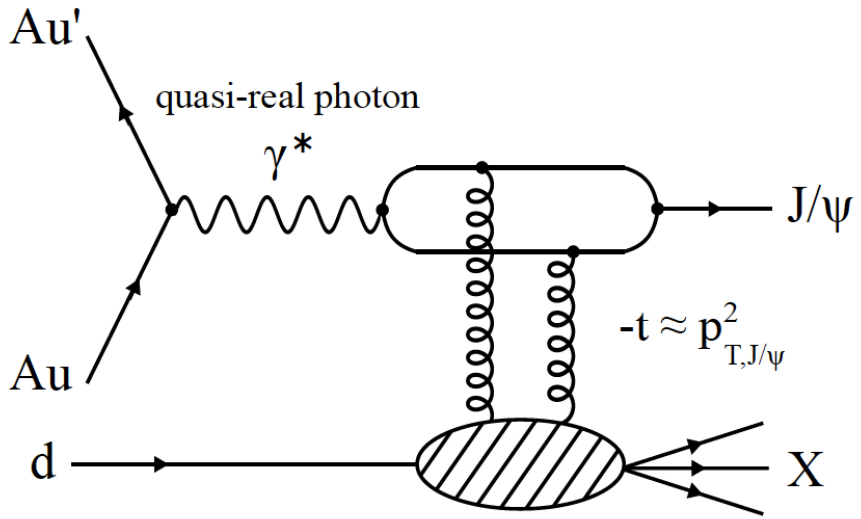


RHIC UPC

- Gluon density distribution and its modification in nucleus
  - Gluon shadowing effects
  - Saturation dynamics (EIC white paper: Q^2 dependence, VM productions, etc…)
  - Short-range nuclear correlation (NN potential, wave functions, repulsive core)

What STAR UPCs can measure?

✓Photoproduction of J/psi vector meson off **deuteron**
(no Q^2, EIC will have Q^2 level arm);

✓Momentum transfer t dependence cross section; x_P = 0.01 or W=25 GeV

✓Possible contributions:

- Coherent diffractive scattering, deuteron stays intact. d → d'

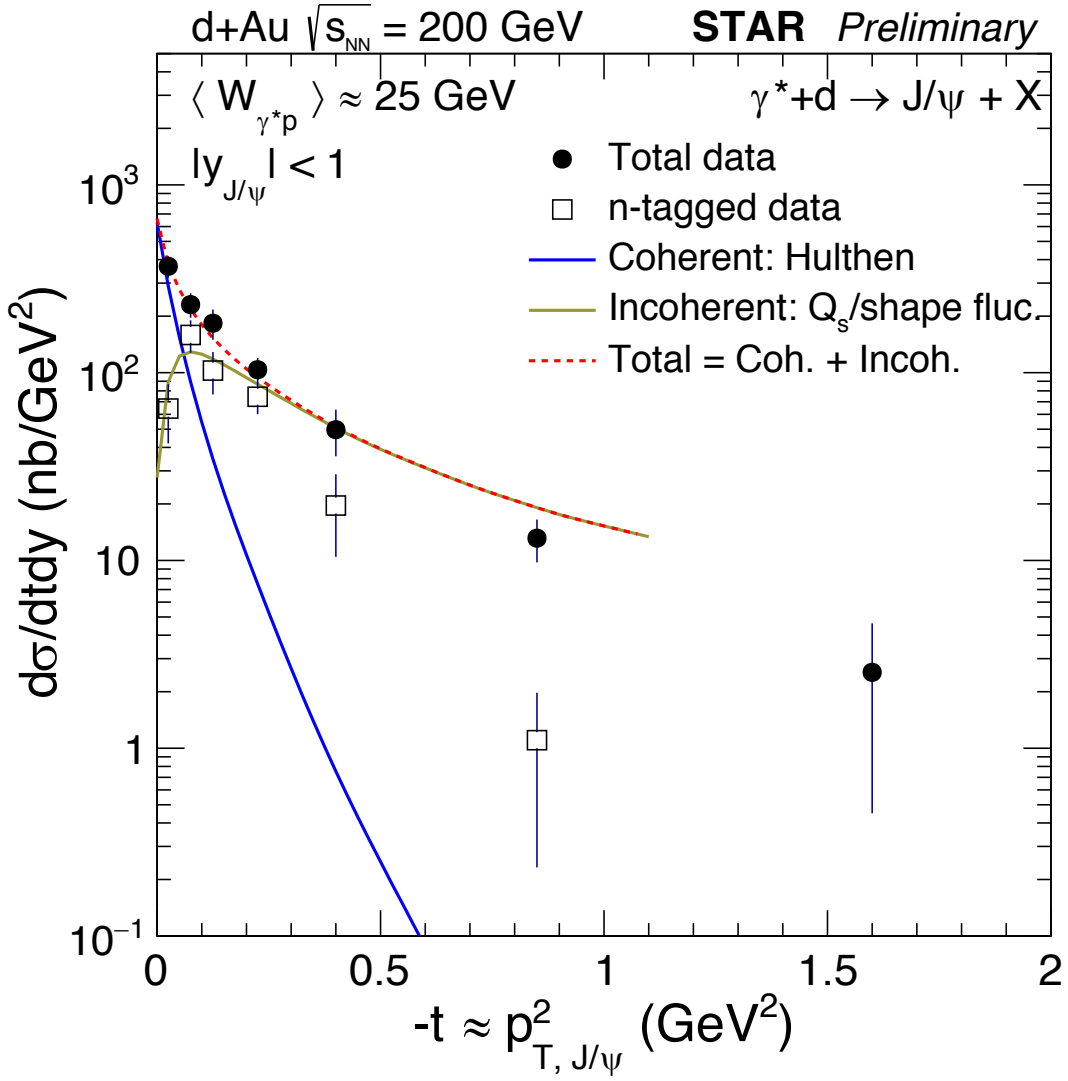
(sensitive to the deuteron wfs, SRC, low-x gluon dynamics)

- Incoherent, deuteron breaks up: d → p' + n'
- Incoherent with nucleon dissoc.: d → p' + X or d → n' + X

(sensitive to the bound nucleon distributions, parton modification, SRCs)

✓Coherent and incoherent both provide valuable physics, but the challenge is to separate them.

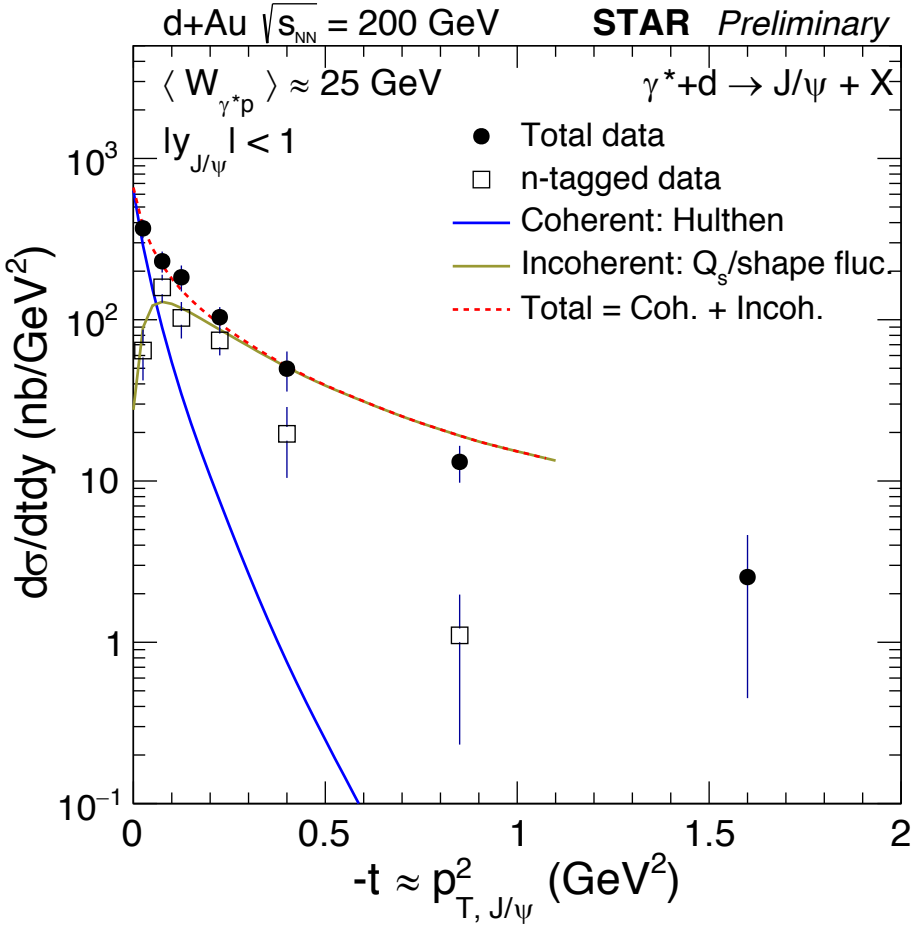
STAR preliminary data

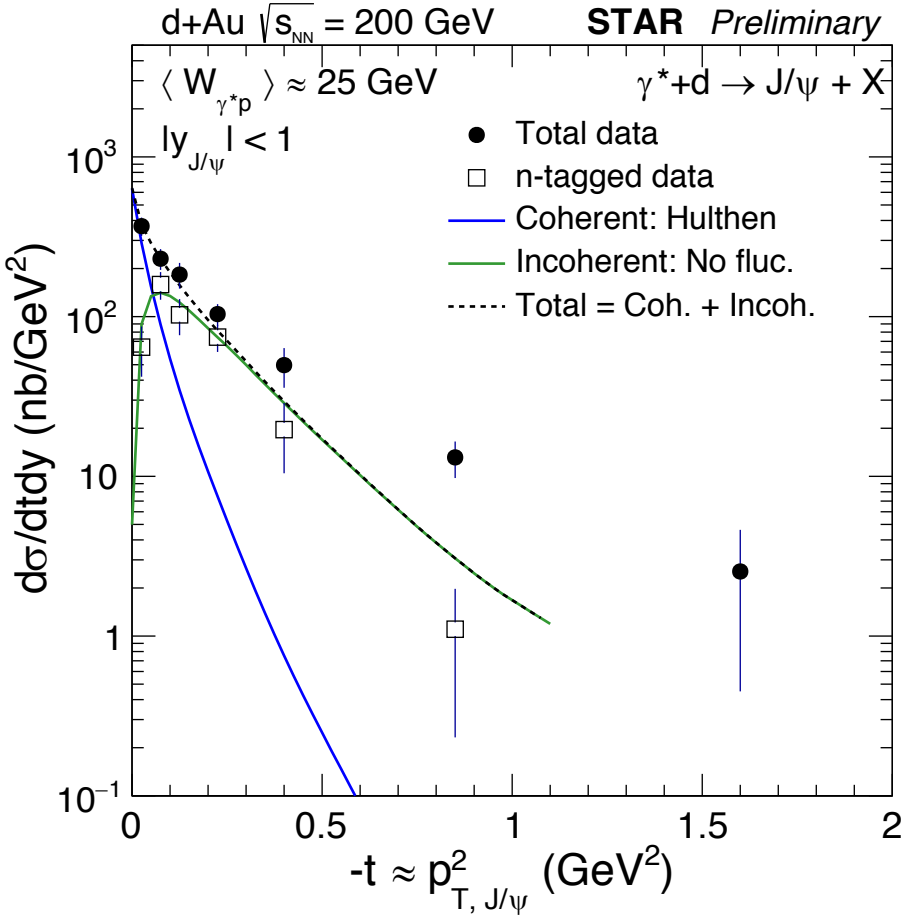


- **Total data:** inclusive for deuteron breakup with no activity in midrapidity
- **n-tagged data: Total data** + require 1 neutron in ZDC
  (nucleon forward tagging in collider)
- Experimentally with only ZDC, it is *impossible* to disentangle coherent and incoherent contributions…
- First observation:
  - Cross section is under expected. Steeper than proton but much wider than gold/lead.
  - We can only compare to theory to know more

STAR preliminary data

CGC prediction





Data favors ✓ Coherent: Hulthen
Incoherent: with fluctuations

Coherent: Hulthen
Incoherent: without fluctuations

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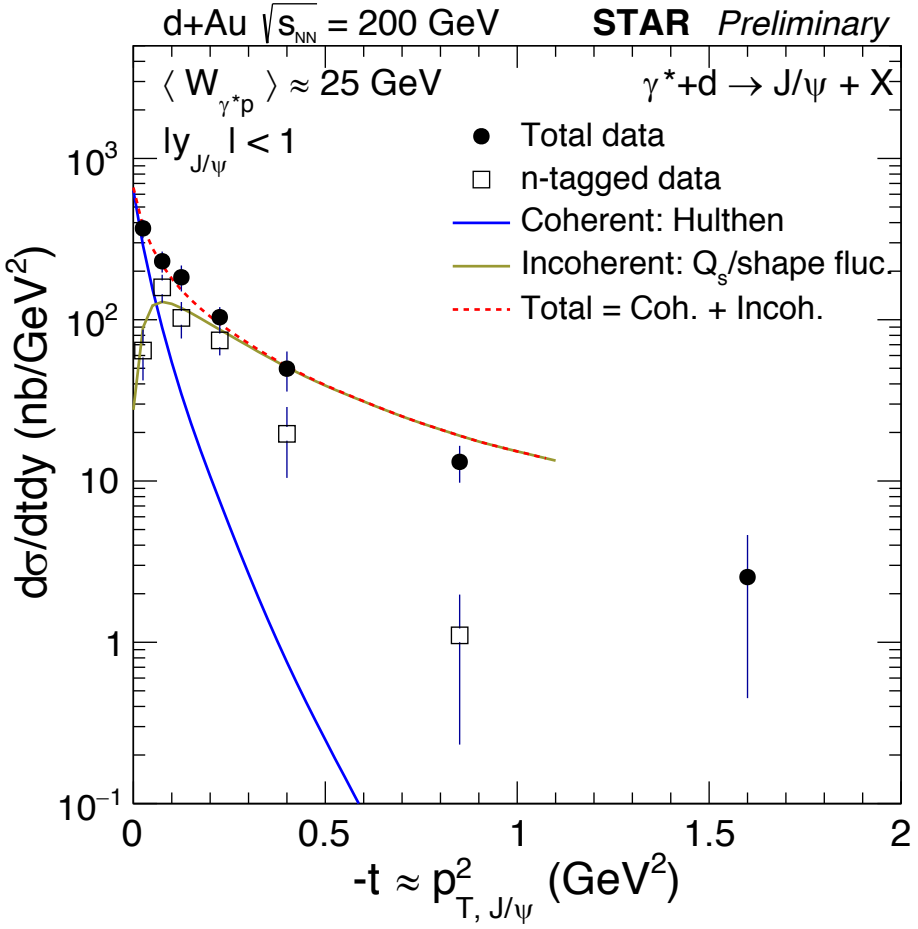

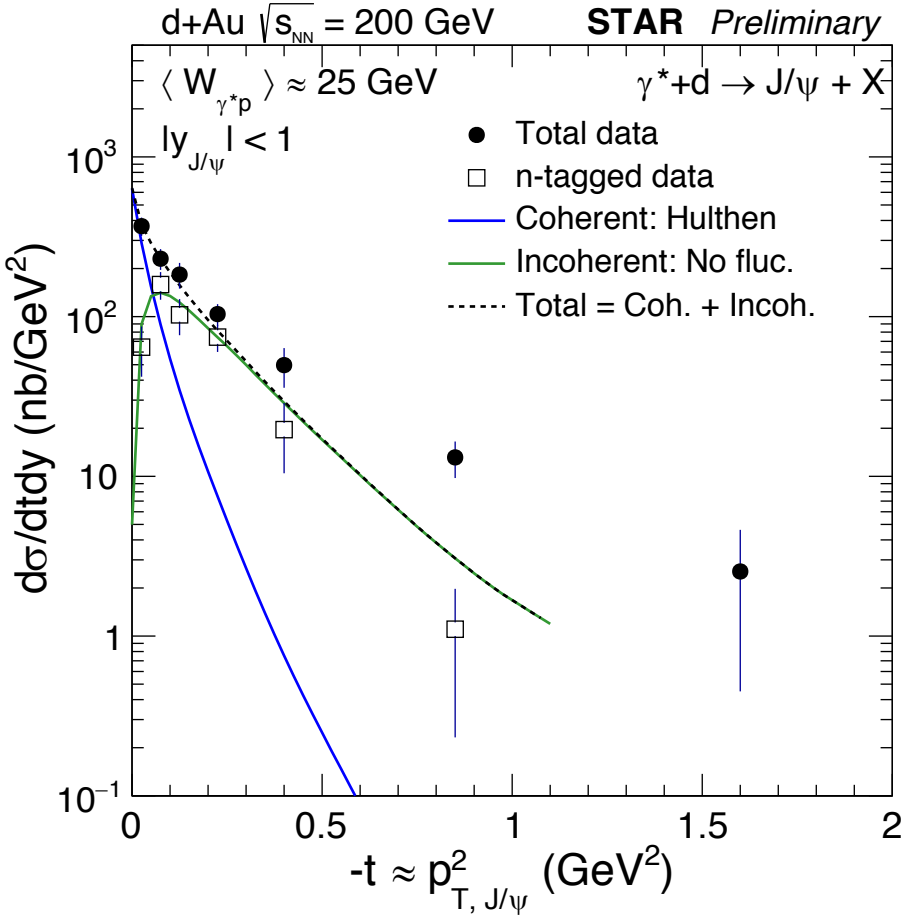

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What about other WFs?

Coherent: Hulthen
Incoherent: without fluctuations

Deuteron wfs

Fig. from Phys. Rev. C 101, 015203 (2020)

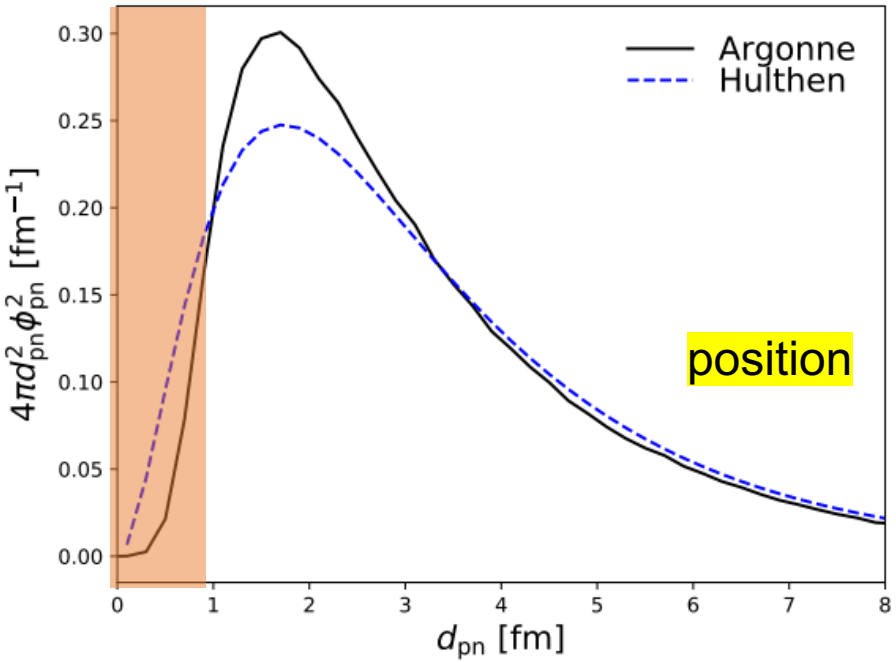
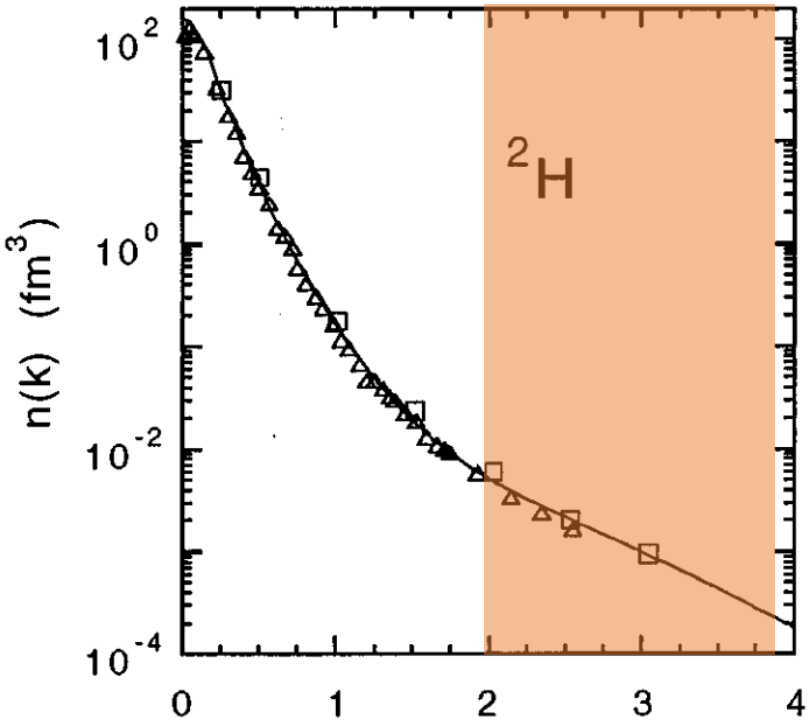


FIG. 1: Deuteron size distribution from the Hulthen and Argonne potential wave functions.

Nucleon momentum distribution k.



momentum

The NN interaction at short-distance or high momentum are predicted to be different

- Both wfs give about the same RMS or size of deuteron
- This region is usually regarded as the “repulsive core”

WFs: Coherent – high *t* is the key

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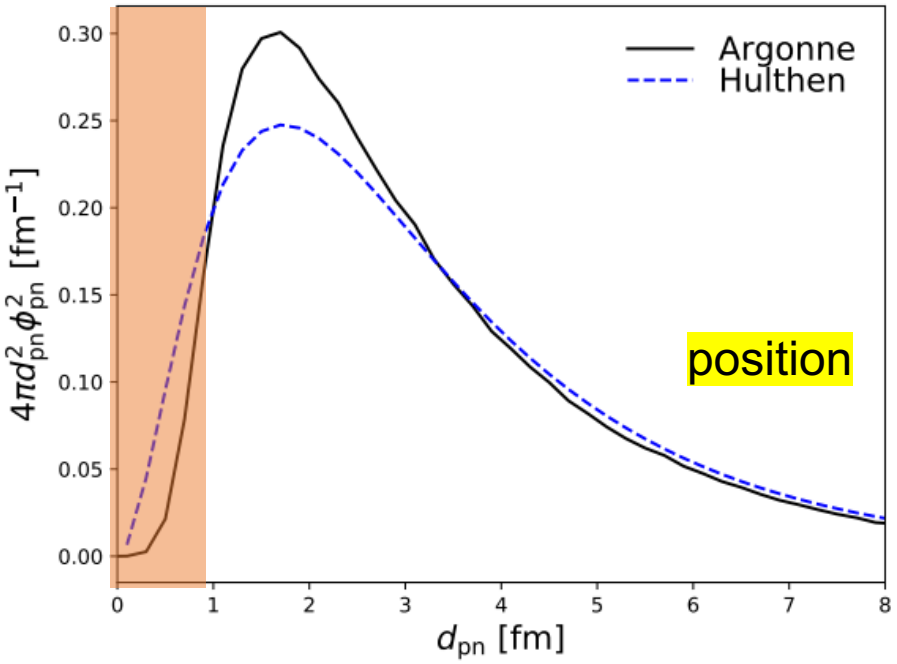

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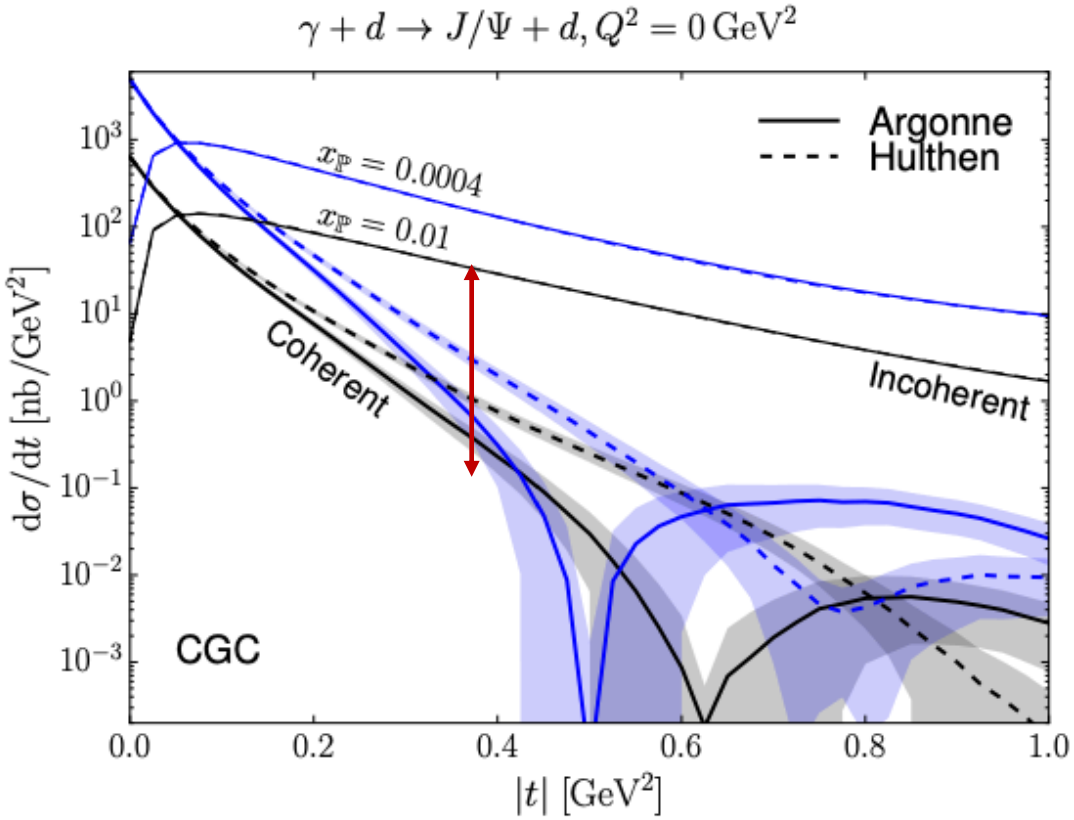
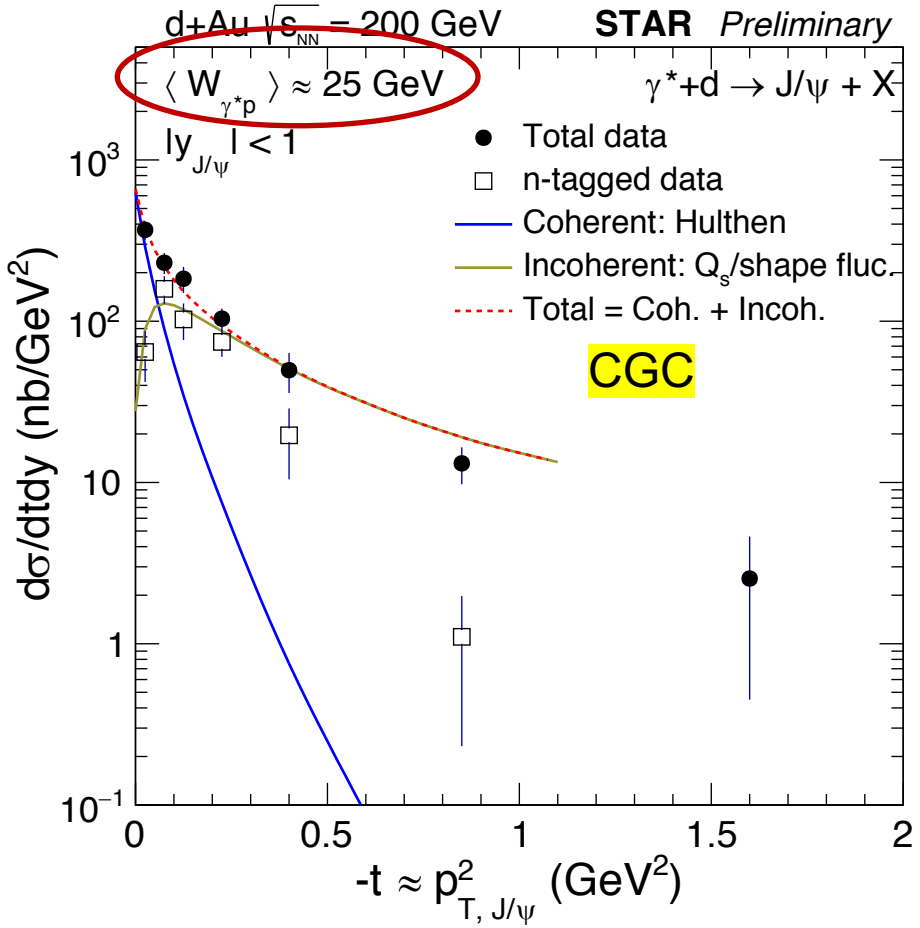
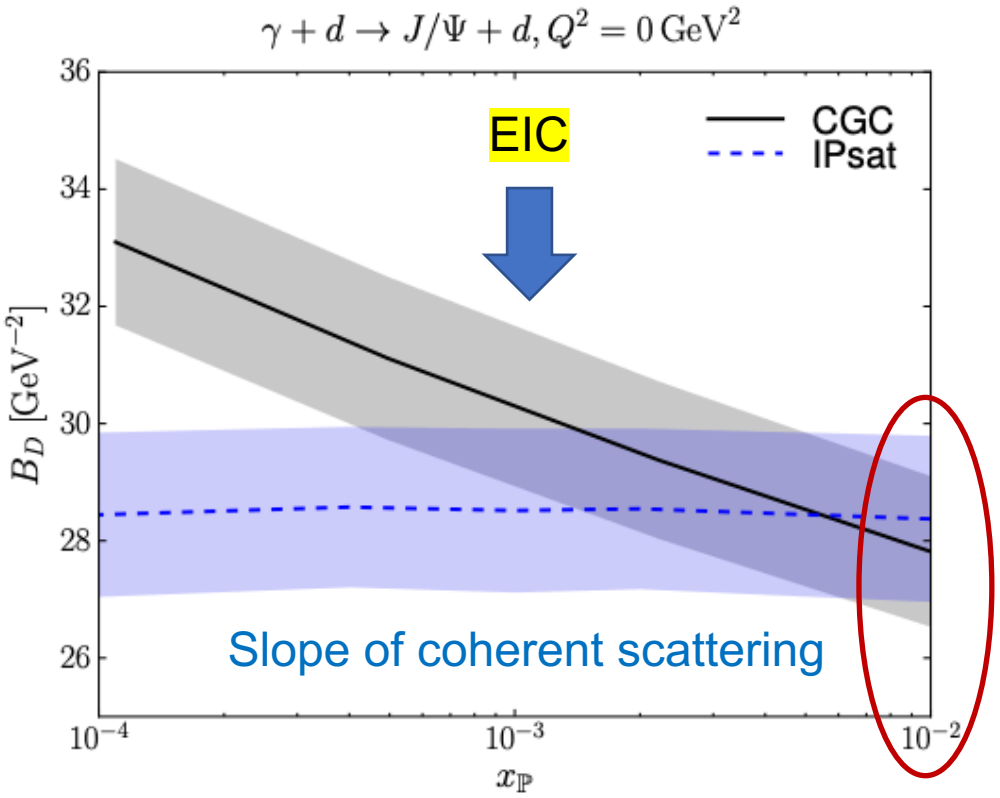


- Low *t* is large *d*, **high *t* is small *d***
- Challenge: high t → incoherent
e.g., t=0.4, need 500-1000 times reduction!

Model: Coherent – low x is the key

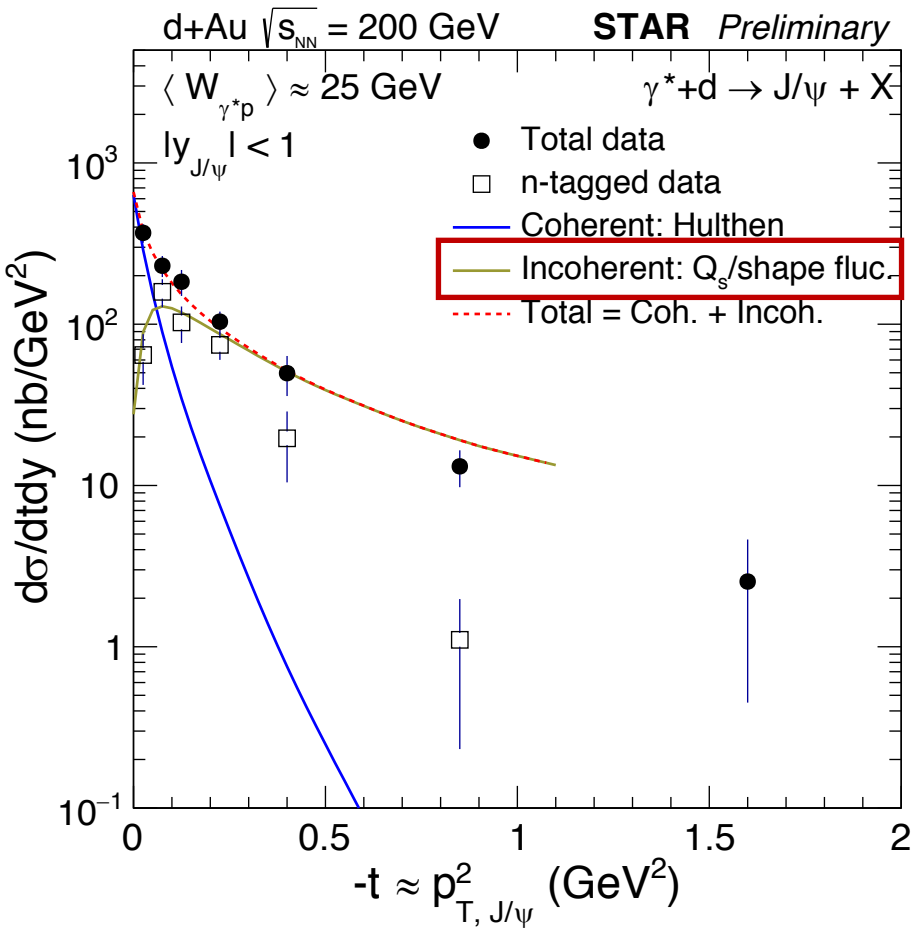


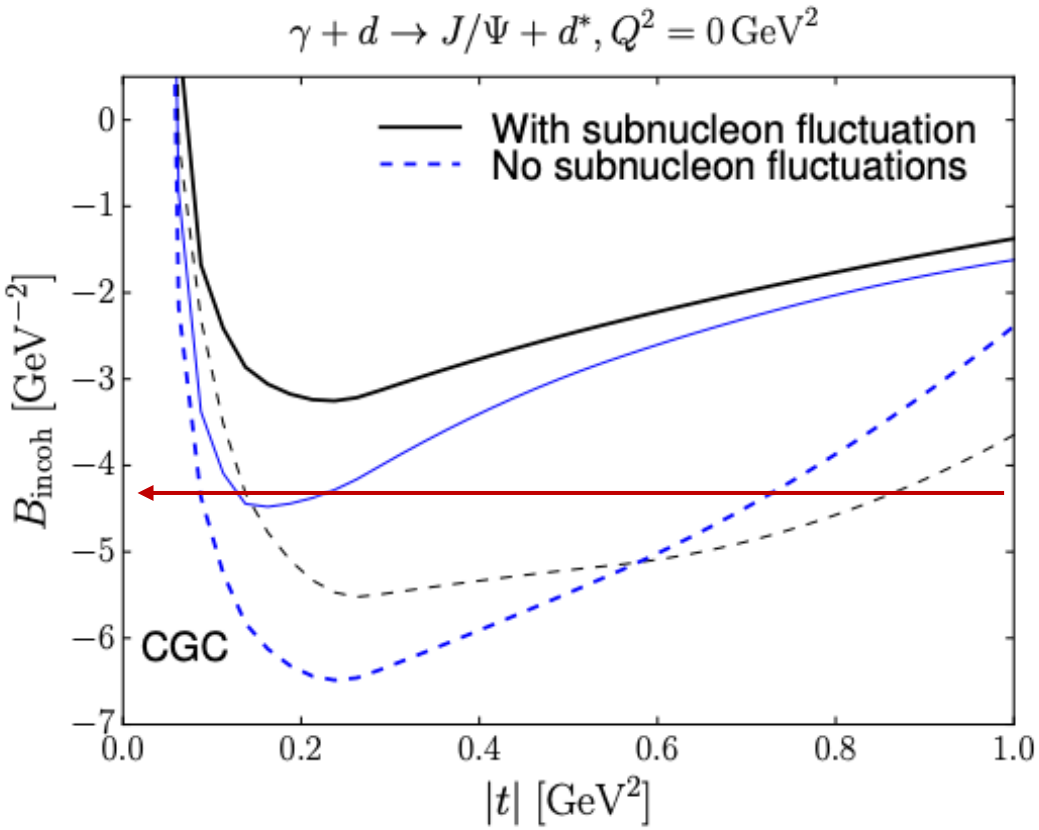


Low-x data should distinguish models!

- EIC top energy can probe down to x_P ~ 10^{-3}, not to 10^{-4}
- Maybe theory error can go down by then?

Incoherent perspective



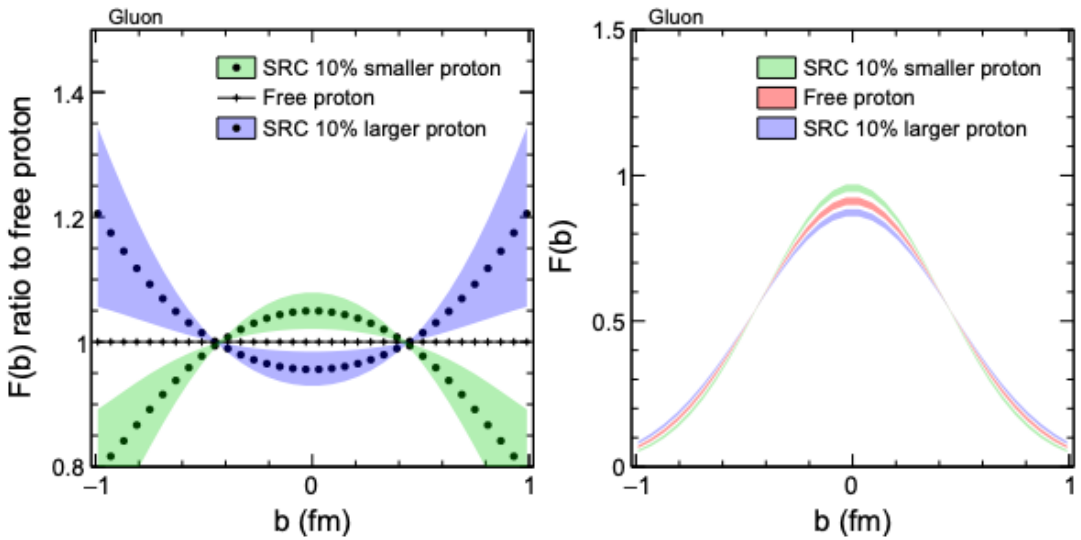


Free proton @HERA

Incoherent includes nucleon dissoc. Be careful.

Incoherent perspective

Different size of bounded proton w/o SRC at EIC



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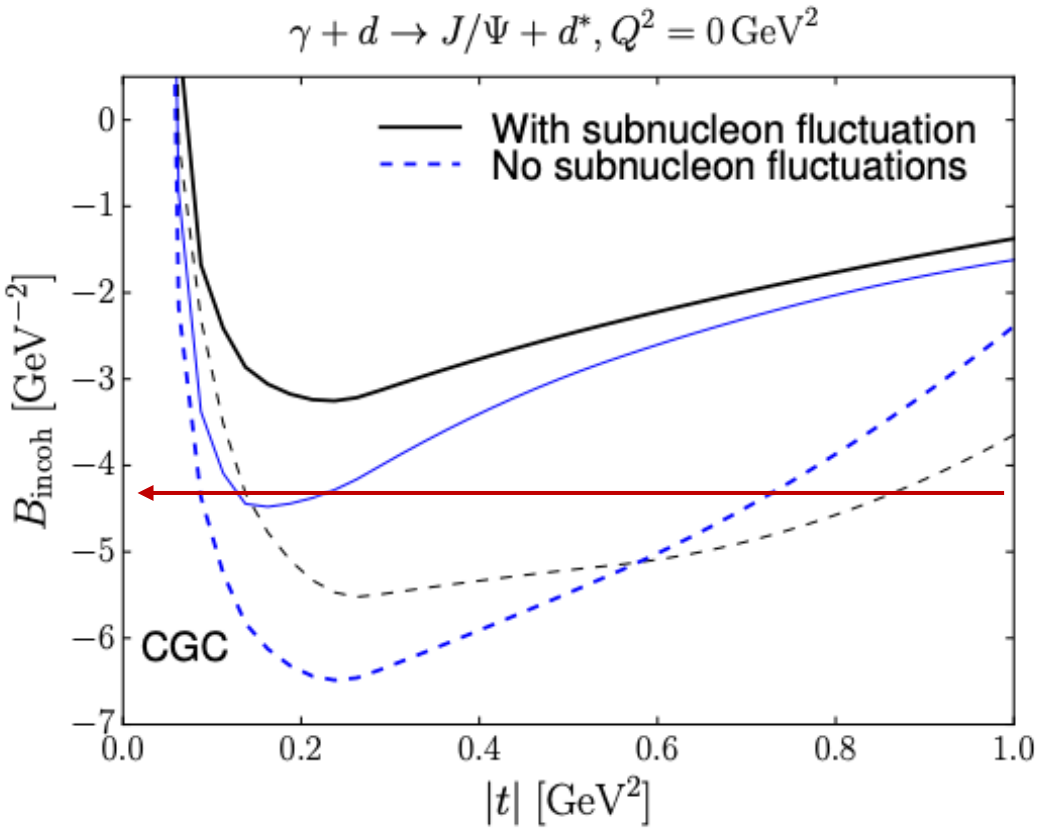
Incoherent slope provides us the clue to gluon modification.



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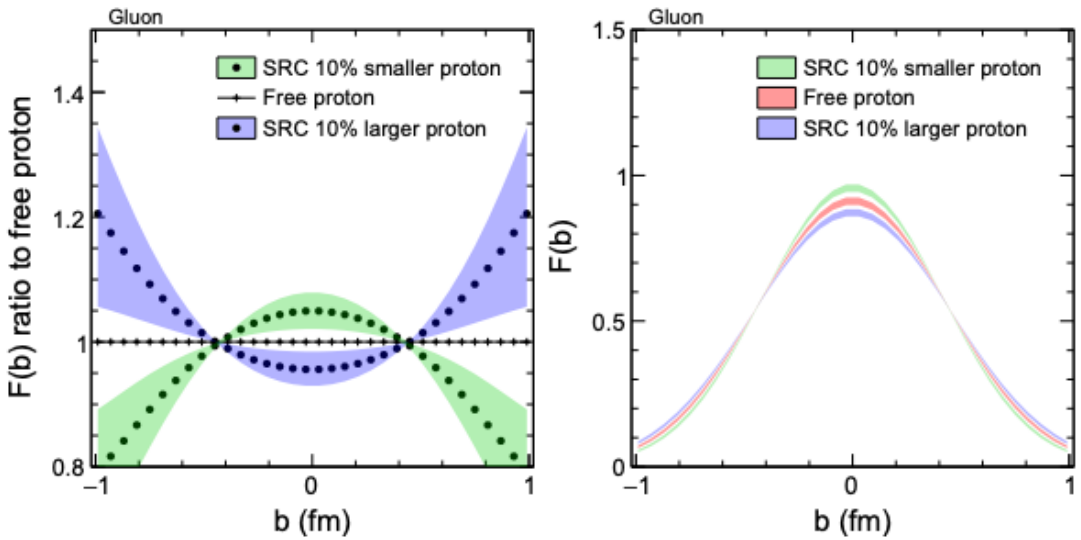

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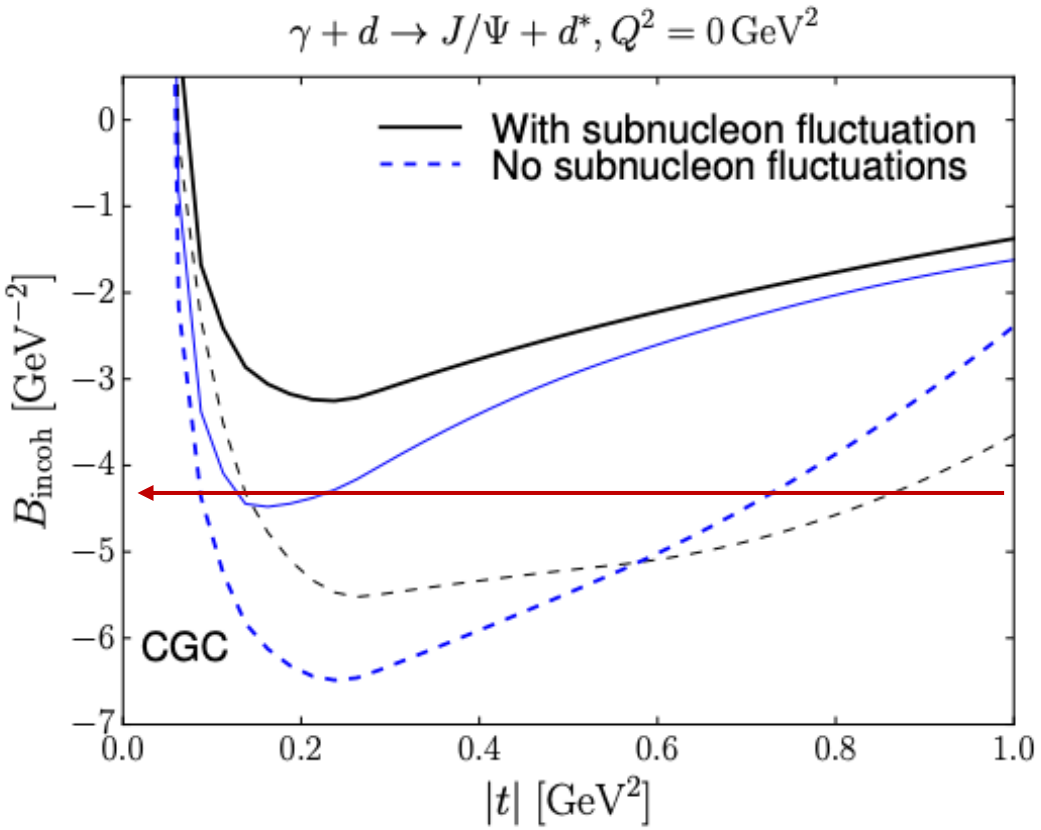
Incoherent slope provides us the clue to gluon modification.

This measurement replies on spectator tagging



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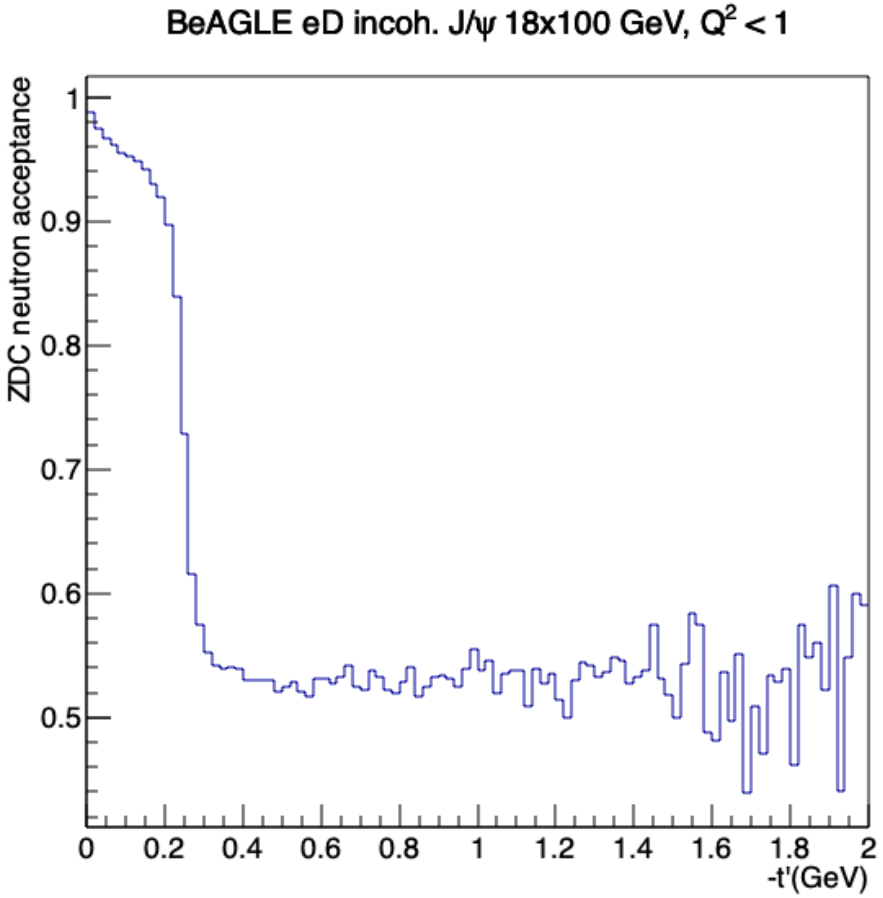
STAR ZDC data

- ZDC n-tagged data:
  - n-tagged data means incoherent only at small t.
  - A simple BeAGLE simulation shows that with ZDC acceptance < 5mrad, incoherent+dissoc. events can be tagged only above 90% at low t, and 50% for high t

Both incoherent and dissoc.



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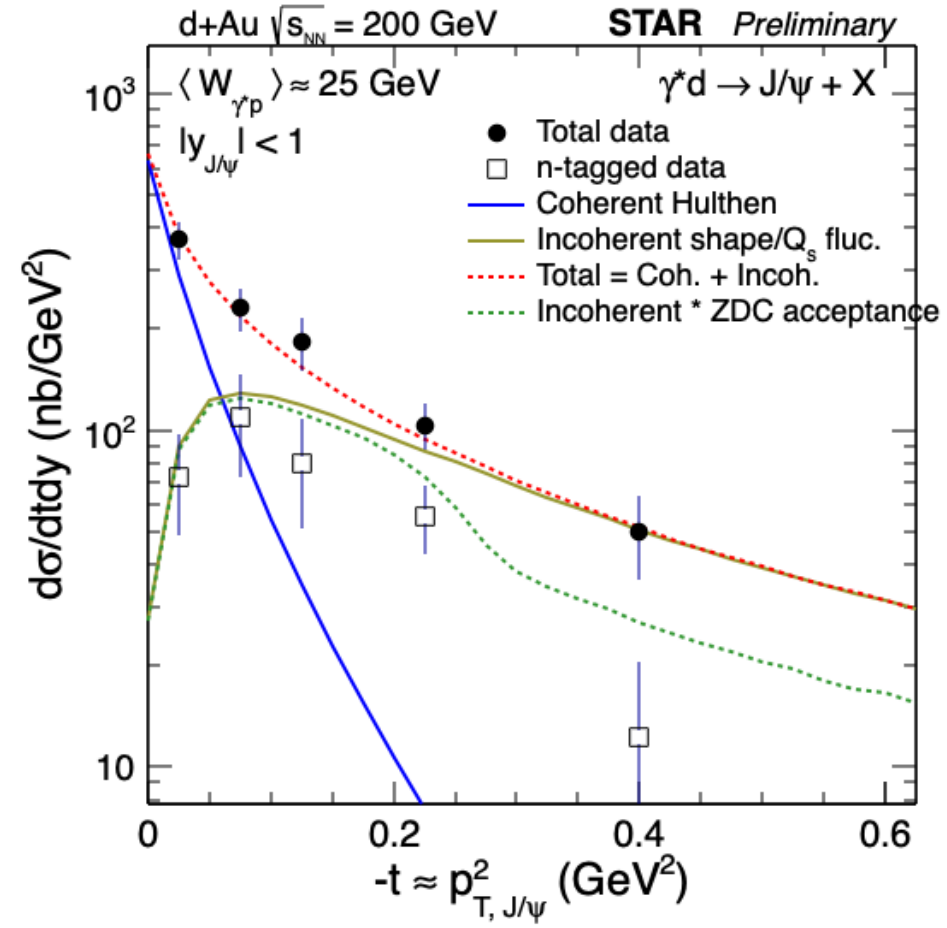
This shows that the forward detector acceptance is extremely important.



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Deuteron summary

- Deuteron is the simplest nuclei, 1 proton + 1 neutron;
- Question:
  1) a good baseline for nuclear effects (nuclear effect free) ?
  2) a good nuclear target for nuclear effects ?

Mostly we think it is 1). but not necessarily.

Under what condition deuteron behaves like 1). and when it behaves like 2).

→a big step forward in our understanding of nuclear physics.

This measurement could be essential and reveal the nature of deuteron from both sides!

Technical Summary

- CGC vs IPSat - low x is the key (energy, rapidity, kinematics…)
- Hulthen vs AV18 of D wfs - high *t* is the key (coh. separation)
- Incoherent diffraction – acceptance is the key
  - Incoherent high *t* measurement (mean-filed part)
  - SRC pairs (more acceptance)
- Statistics is important, but EIC will have no problem…
  (Question will be can we have more at RHIC?)
- Resolution is important but not so critical…

- STAR paper will be in “paper proposal” - PRL