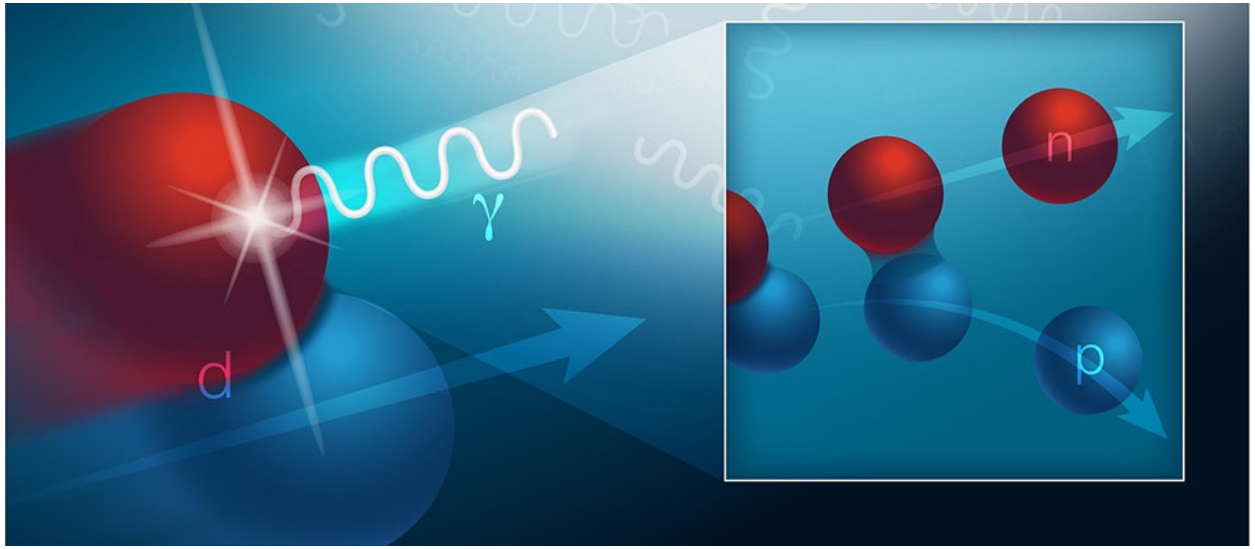
Brookhaven National Laboratory

# Exploring the origin of the EMC effect with electron-deuteron DIS at the EIC




(Image made by BNL)

Kong Tu
BNL
06.07.2022

Collaborators: Alexander Jentsch (BNL), Mark Strikman (PSU), Christian Weiss (Jlab)

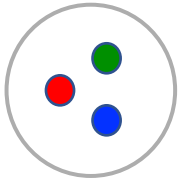
# Two sides of the same coin

- Two big questions in nuclear physics

(1) Free nucleon structure

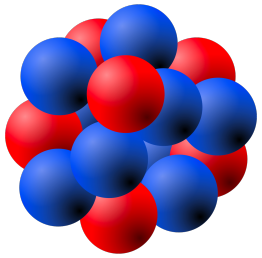
(2) The EMC effect.

Nucleon



Free nucleon structure

Nucleus



EMC effect

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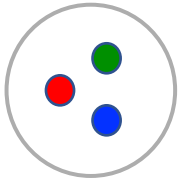
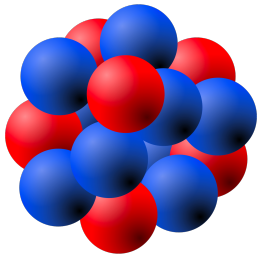


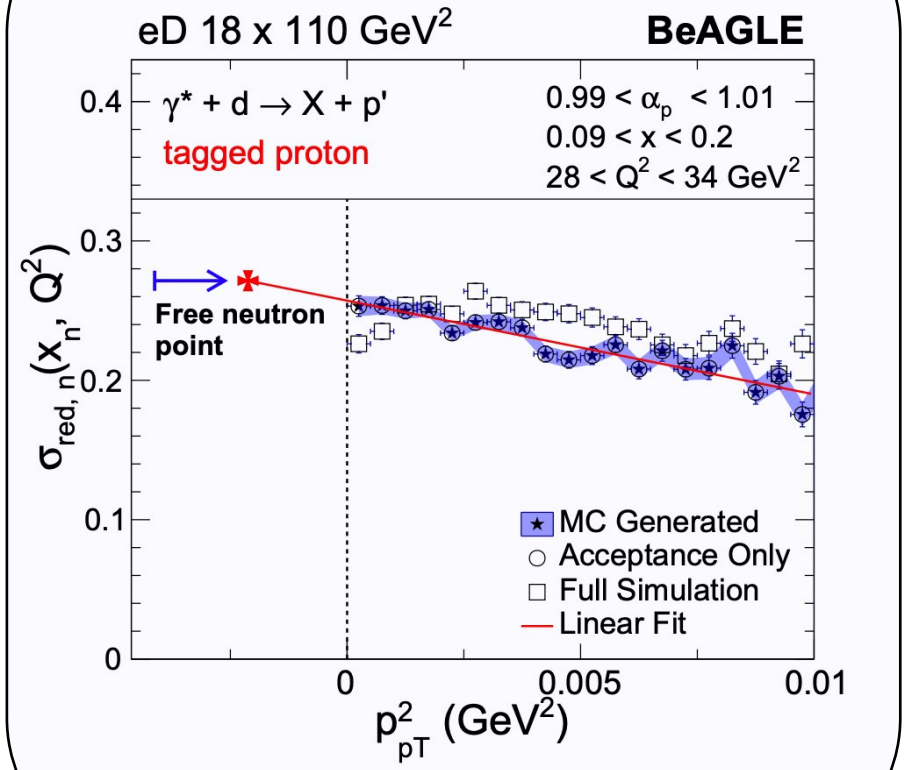
Nucleus



Free nucleon structure

EMC effect

2021




*Phys. Rev. C* 104 (2021) 6, 065205

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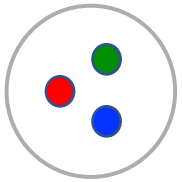
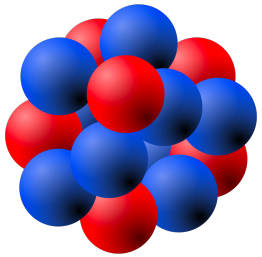
Nucleon



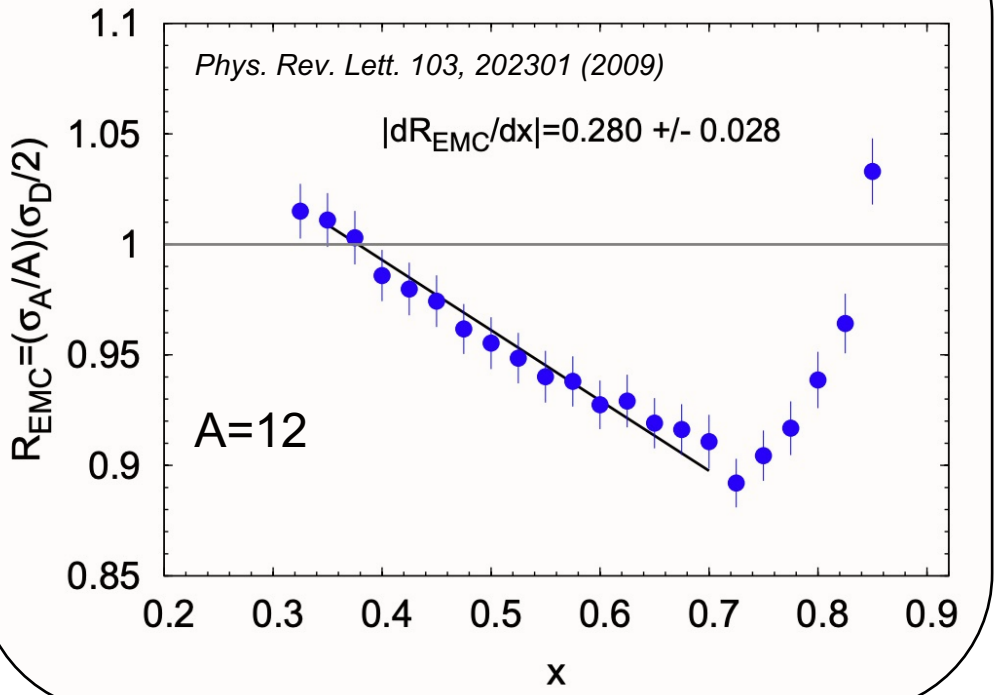
Free nucleon structure

Nucleus



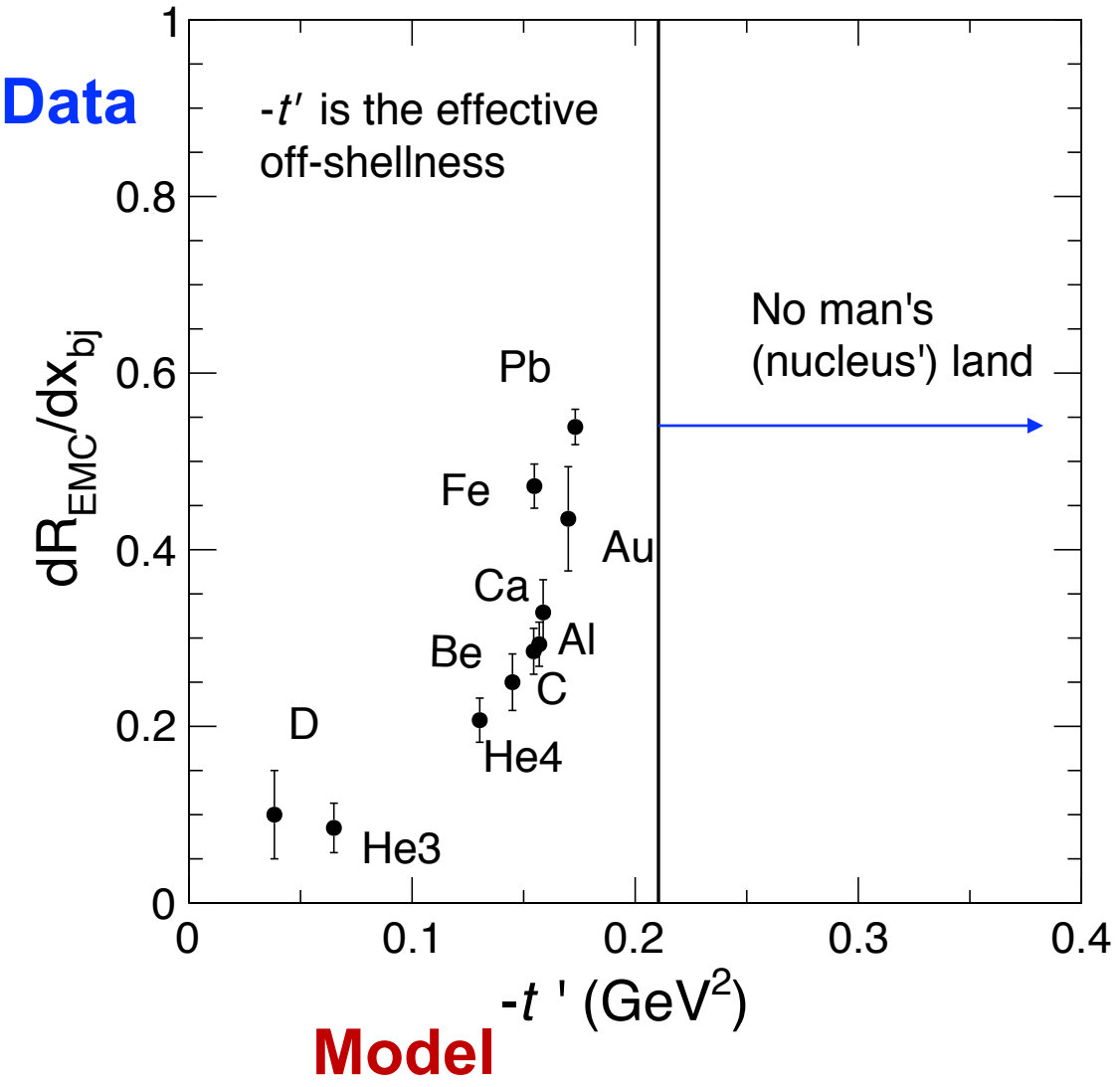
EMC effect

This talk focuses on the EMC effect




**What's the origin of the EMC effect? ~ 40-year puzzle.**

# One hypothesis - nucleon offshell effect




- $dR_{EMC}/dx_{bj}$ is the EMC slope – how strong the EMC effect is.
- $-t' \sim \nu_{NR}$ is the active nucleon virtuality based on model calculations

$$\upsilon_{NR}(|\mathbf{p}|, E) \approx -2m_N \left( \frac{A}{A-1} \frac{\mathbf{p}^2}{2m_N} + E \right)$$

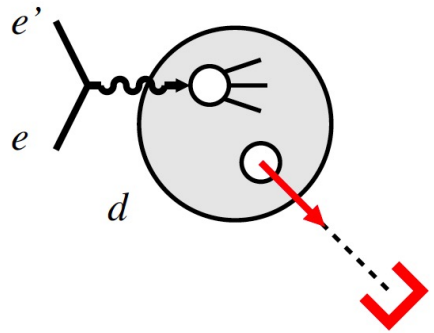
(*Phys.Rev.C76 055206,2007*)

- If the virtuality is indeed the cause, can the EMC effect be reproducible without changing the system, but rather only varying –*t'*?

# Proposal – *ed* tagged DIS

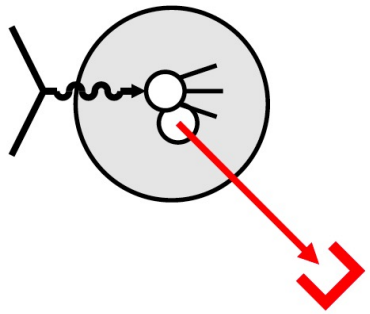
- **Goal:** Prove the direct relation between nucleon off-shell effect and the EMC effect.
- **System:** Deuteron, the simplest nuclear system with one proton and neutron
- **Method:** Tagging spectator in electron-deuteron (*ed*) DIS to control initial-state configuration → to vary nucleon virtuality event-by-event and *compare different configs.*
- **Experiment:** Electron-Ion Collider with Far-Forward detectors.

Low off-shellness

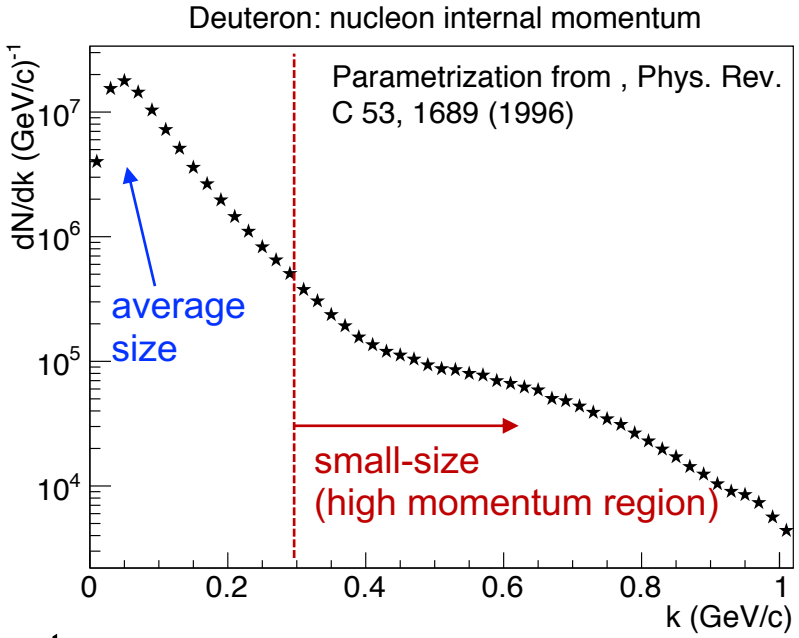



average–size

High off-shellness



small–size



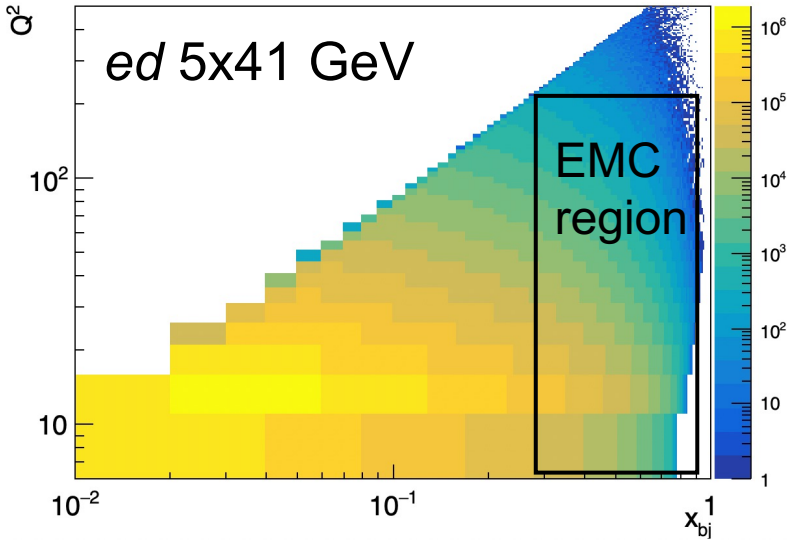

Tagged DIS Process: e + d → e' + X + p' or n'

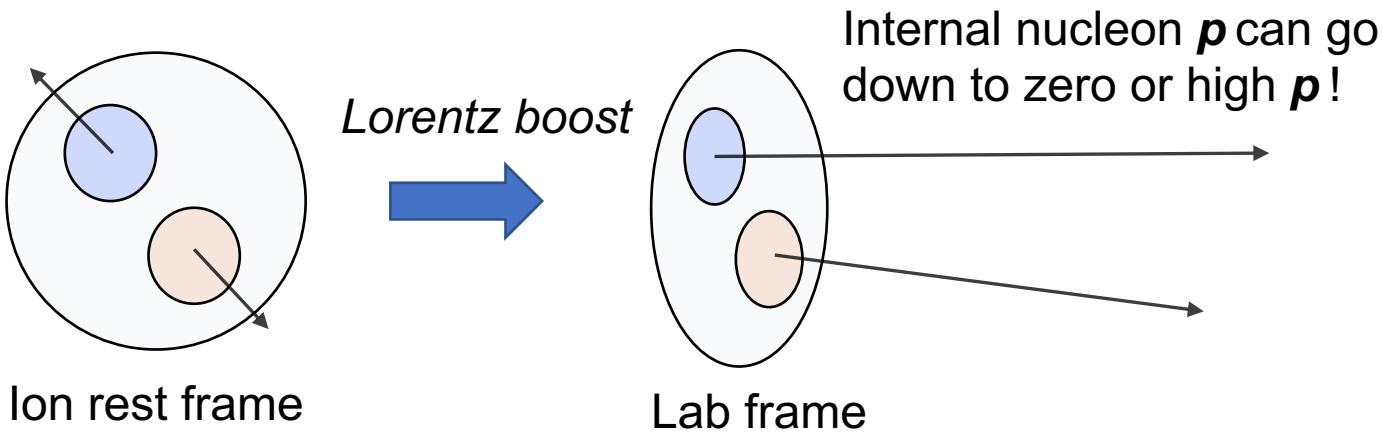
$-t^2 = M_N^2 - (p_d - p_p)^2$ virtuality/off-shellness in deuteron

# EMC studies at the EIC

- Electron-Ion Collider has a wide range of center-of-mass energy.
  e.g., 5x41 lowest *ed* energy can easily reach the EMC region.

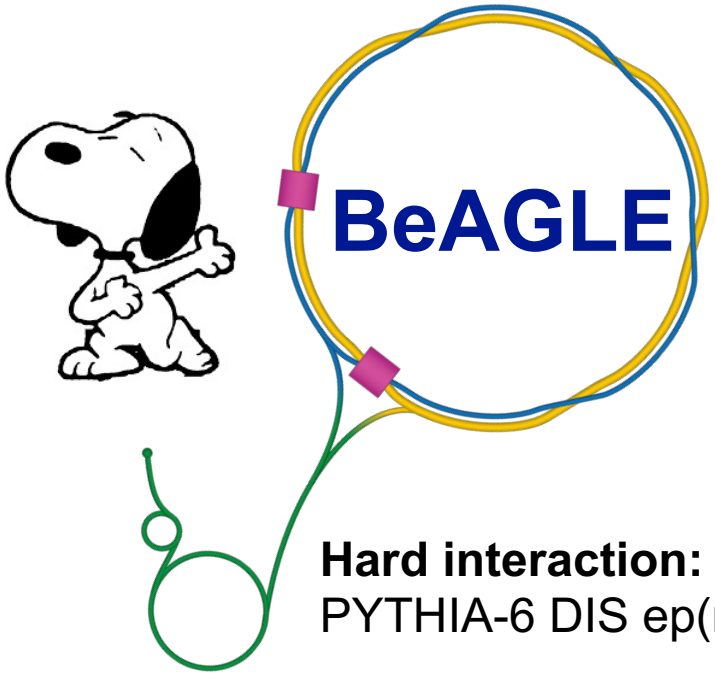
- **Advantages** of studying the EMC effect at the EIC:
  - Lepton side - Wide kinematic range in x and $Q^2$ (e.g., high $Q^2$).
  - Deuteron side - Lorentz boost provides wide range in spectator kinematics, in terms of spectator $p_T$ and light-cone momentum fraction $\alpha$.



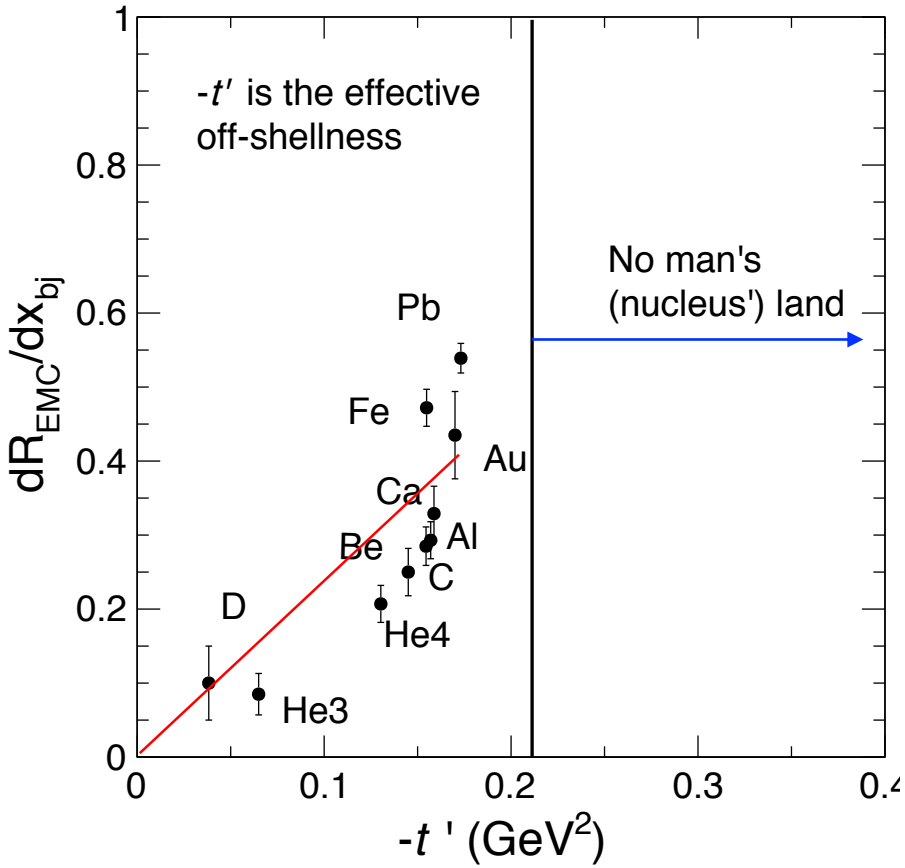
# Analysis - simulation and parametrization

General-purpose eA DIS MC generator
https://eic.github.io/software/beagle.html




**Hard interaction:**
PYTHIA-6 DIS ep(n) + nPDFs

Recent comprehensive overview of BeAGLE, (arXiv:2204.11998)




**Minimal parametrization (linear)**
Linear offshell dependence on the EMC effect.
(Frankfurt, Strikman 80', Weiss)

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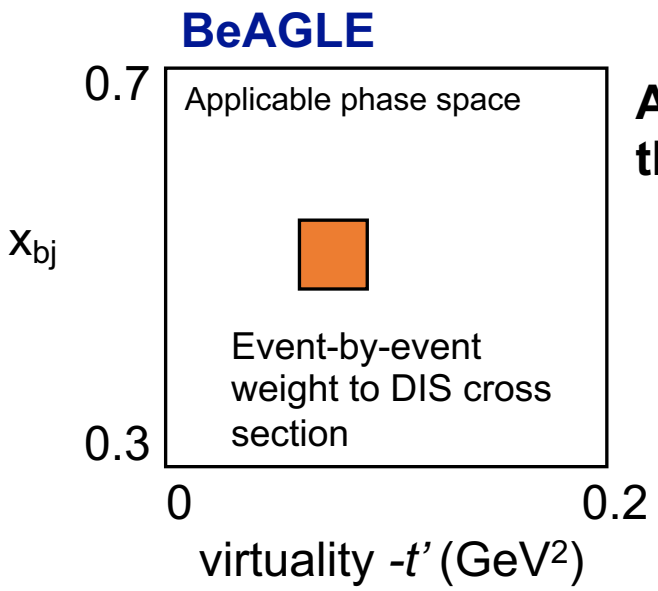
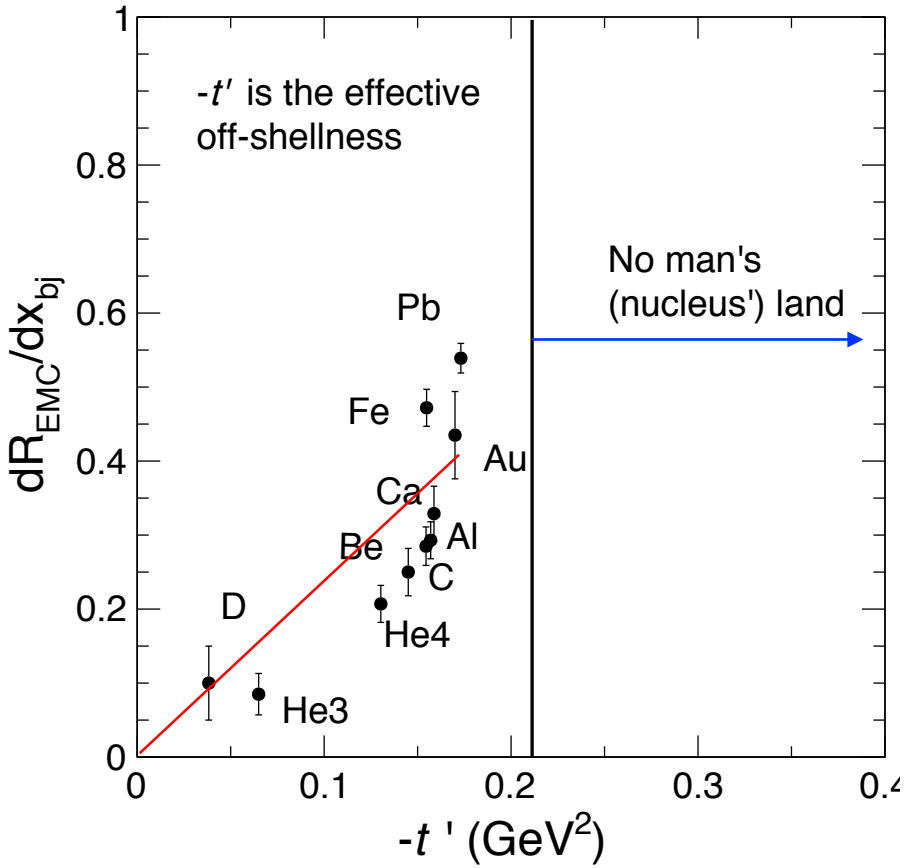



**Add EMC effect according to the linear parametrization**




- Only apply to $0.3 < x_{bj} < 0.7$
- $Q^2$ independent
- Weight = $F_2$ (bound)/ $F_2$ (free)

**Minimal parametrization (linear)**
Linear offshell dependence on the EMC effect.
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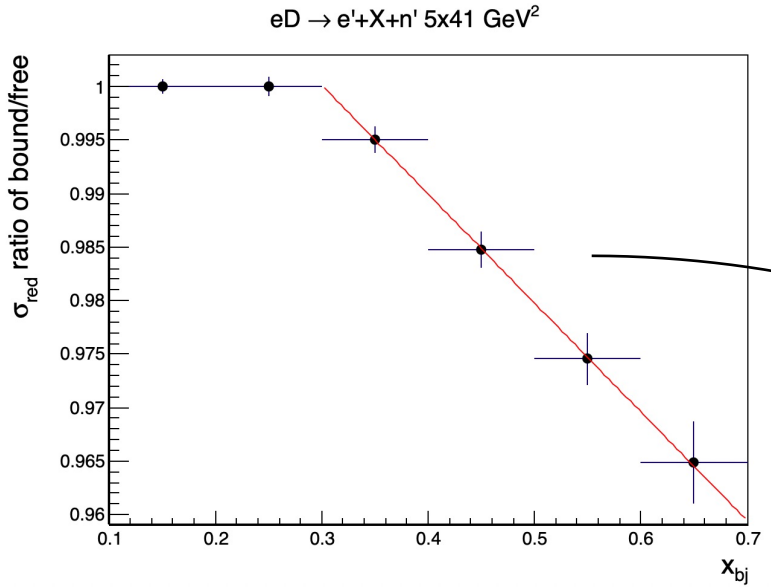
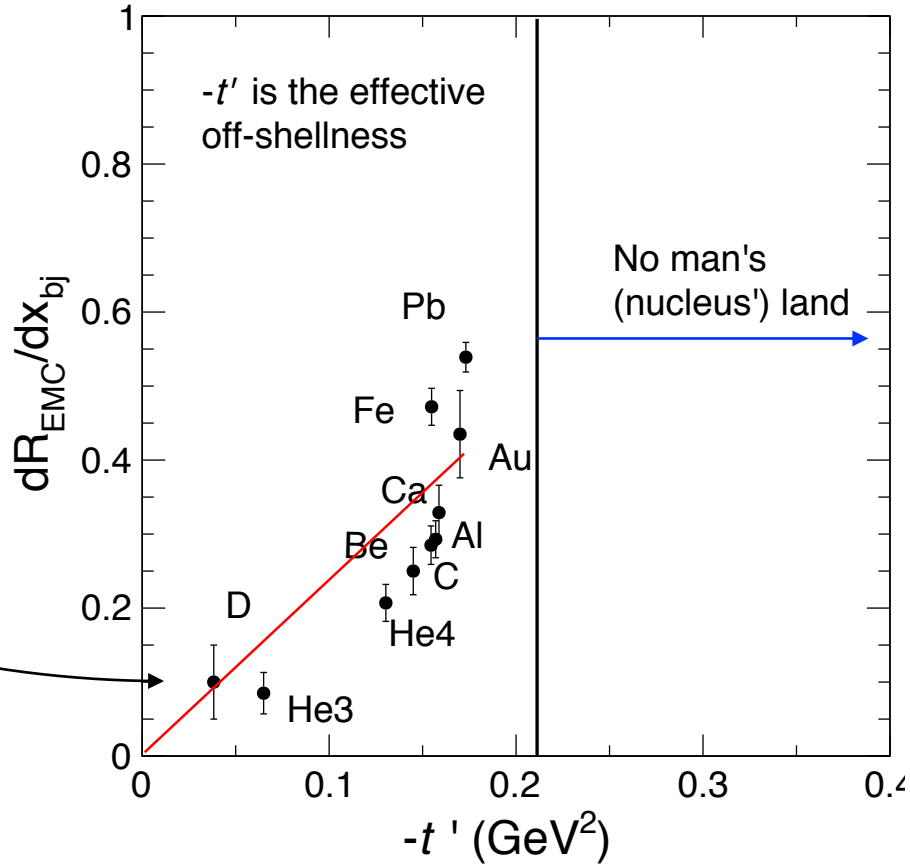
# Analysis - simulation and parametrization

A **closure-test in BeAGLE** on inclusive *ed* DIS without selecting configuration




The EMC slope is fitted to ~ 0.1

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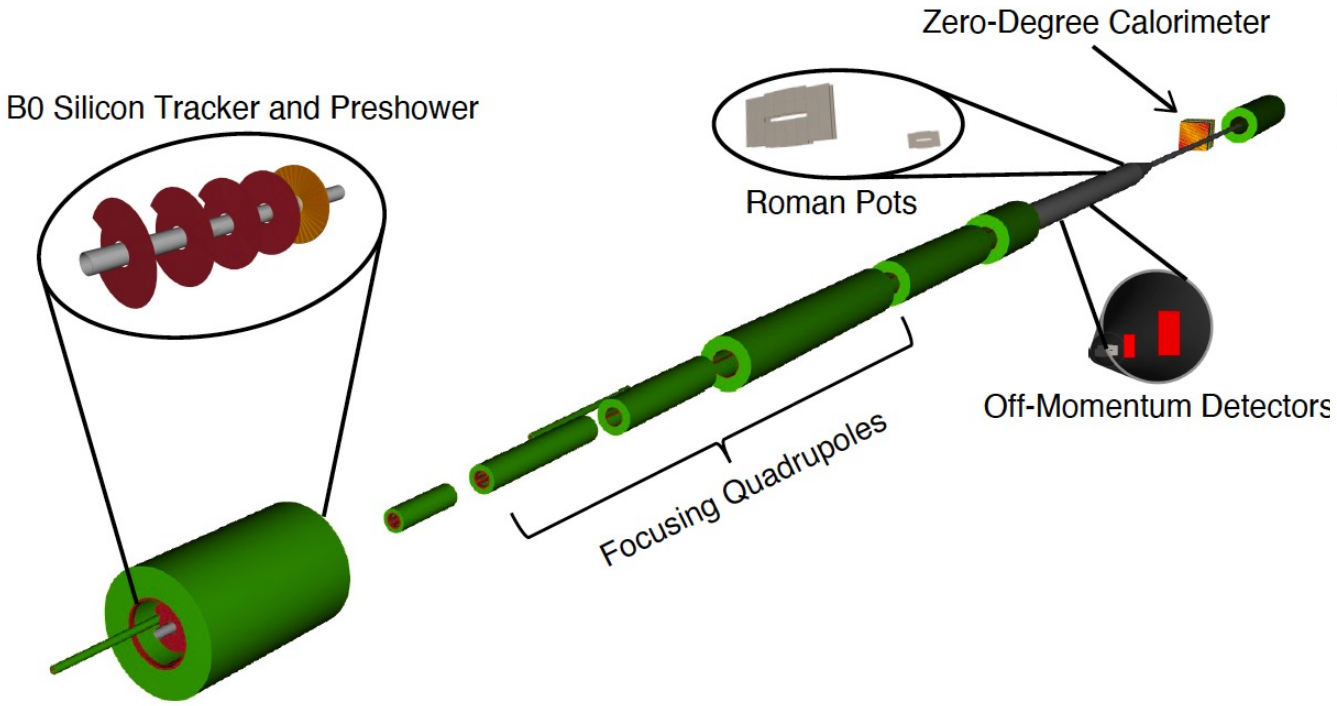
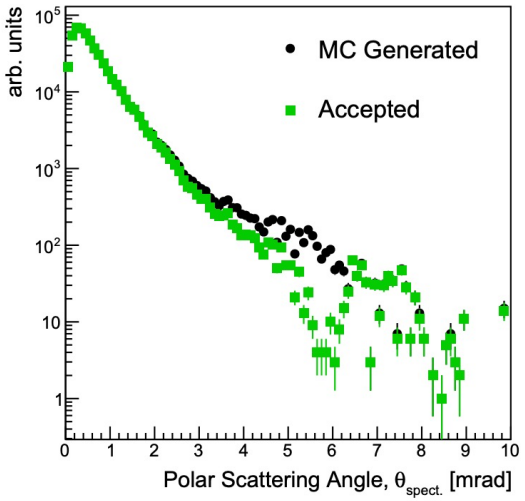
# Detector at the EIC – FF region

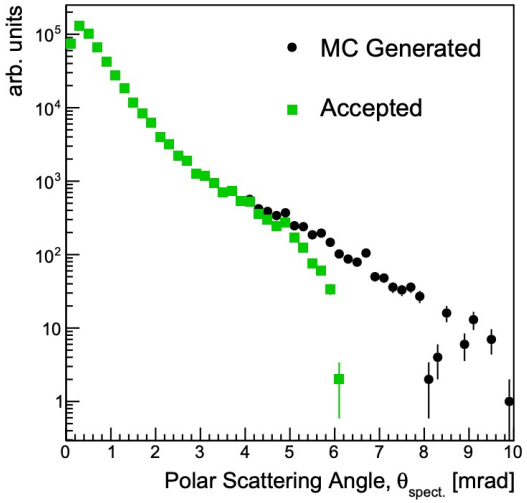



## Acceptance in scattering angle

*(Phys. Rev. C* 104 (2021) 6, 065205)




Proton spectator




Neutron spectator

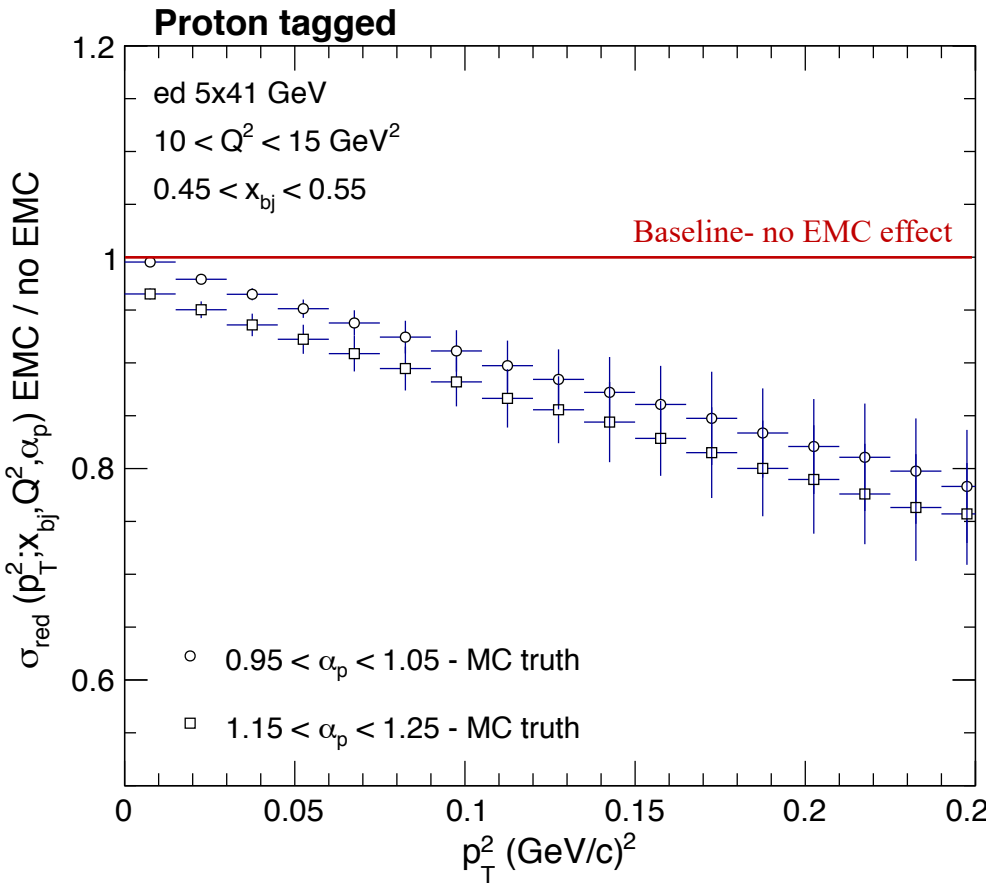
[Great spectator acceptance in general at the EIC]

- Spectator tagging based on these 4 detectors:

Roman Pots, Off-Momentum Detectors, B0 tracker, and ZDC

# Results - 1

- BeAGLE simulation 1B events ~ 25 $fb^{-1}$, ed 5x41 GeV
- The EMC effect in bins of $\alpha_p = 1$ and $\alpha_p = 1.2$




**At the MC level:**

What's plotted:

- Relative EMC effect at fixed bins of $x_{bj}$, $Q^2$
- Compare $\alpha_p = 1$ and $\alpha_p = 1.2$
- No Final-State Interaction.

Observations:

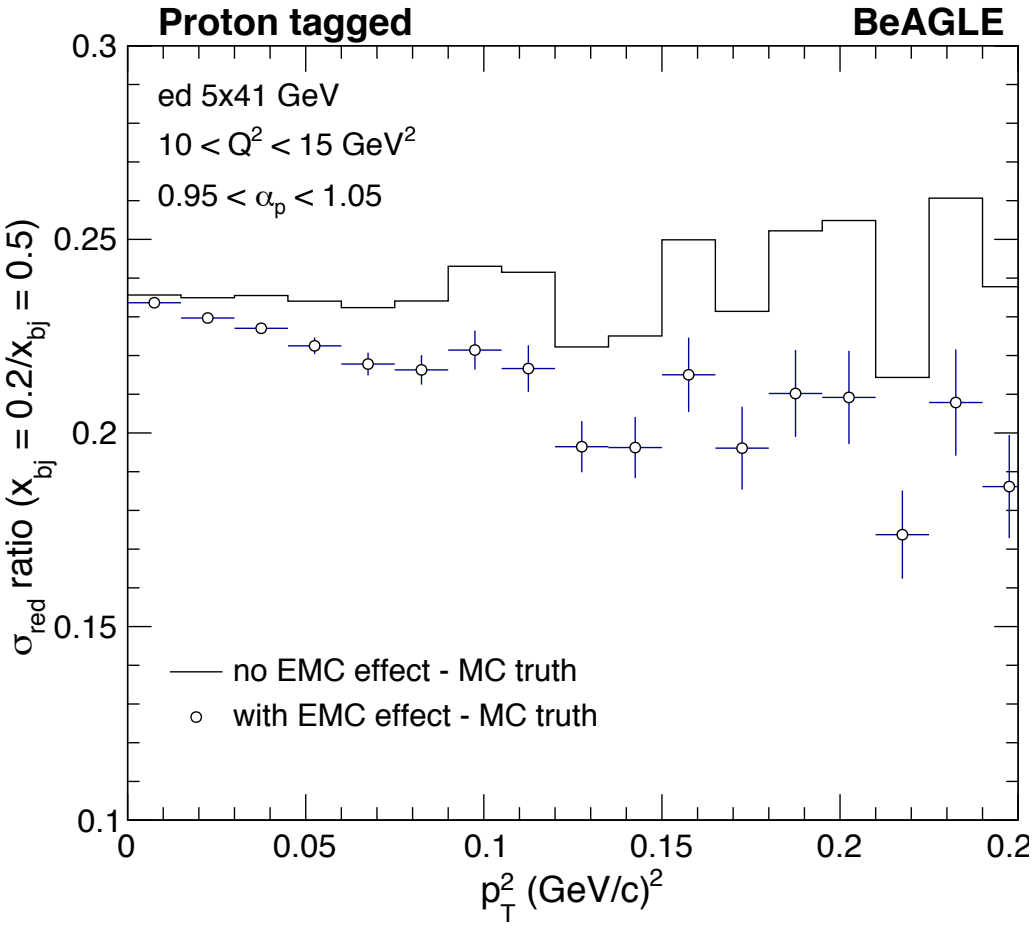
- Self-consistent at $p_T^2 = 0$ for $\alpha_p = 1$
- Linear dependence is consistent with input parametrization.

Messages:

- For high $p_T^2$, the measurement is sensitive to the EMC effect.
- Different $\alpha_p$ suppression is expected.

# Results - 2

- BeAGLE simulation 1B events ~ 25 $fb^{-1}$, ed 5x41 GeV
- Reduced cross section ratio between $x_{bj}$ = 0.2 and $x_{bj}$ = 0.5

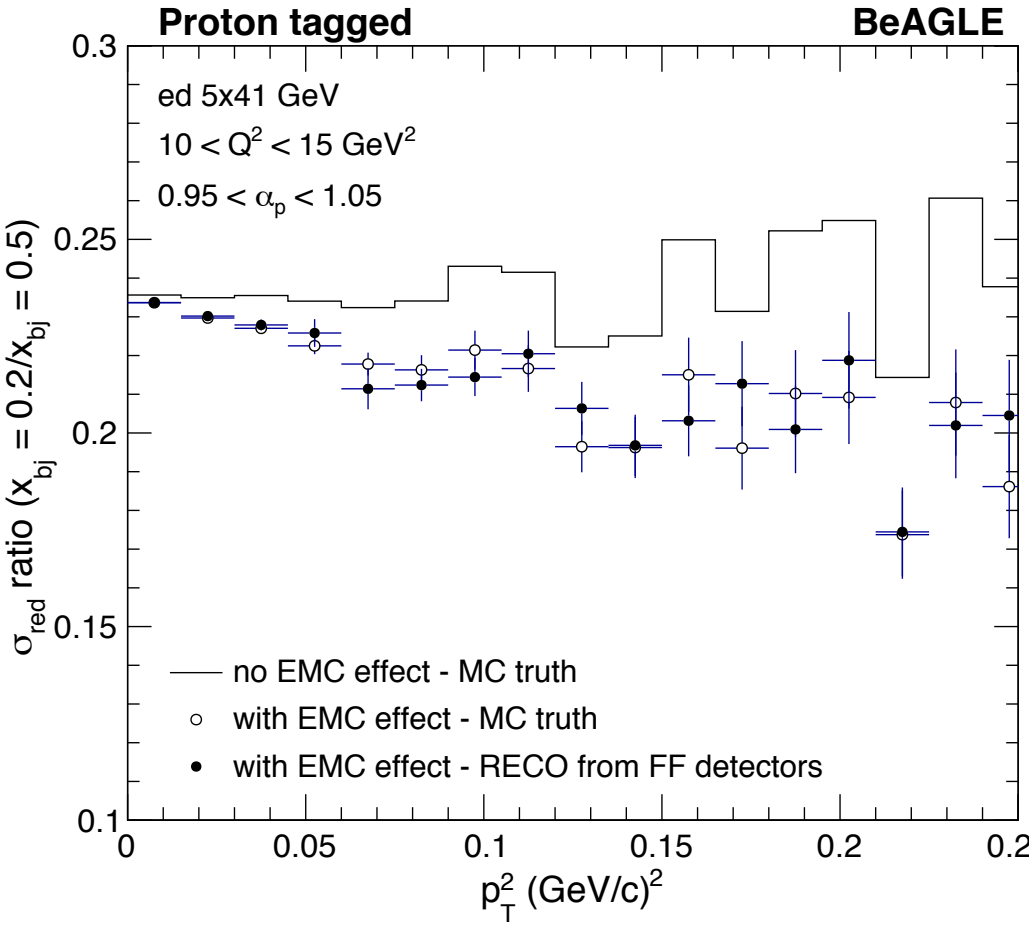



**At the MC level:**

- With and without EMC effect can be separated.
- No Final-State Interaction.
- With fixed $\alpha_p$ , virtuality is proportional to spectator $p_T^2$
- Self-consistent at $p_T^2$ = 0 for $\alpha_p$ = 1

# Results - 2

- BeAGLE simulation 1B events ~ 25 $fb^{-1}$, ed 5x41 GeV
- Reduced cross section ratio between $x_{bj}$ = 0.2 and $x_{bj}$ = 0.5

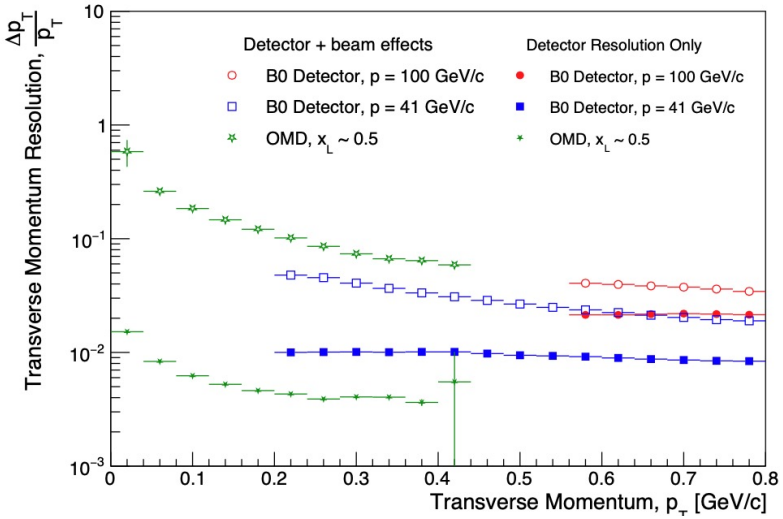



**At the RECO level:**

- Very well reconstructed with good acceptance and momentum resolution.
- $p_T^2$ < ~ 0.04 $GeV^2$ (Off Momentum Detector)
- $p_T^2$ > ~ 0.04 $GeV^2$ (**B0 tracker)** dominated

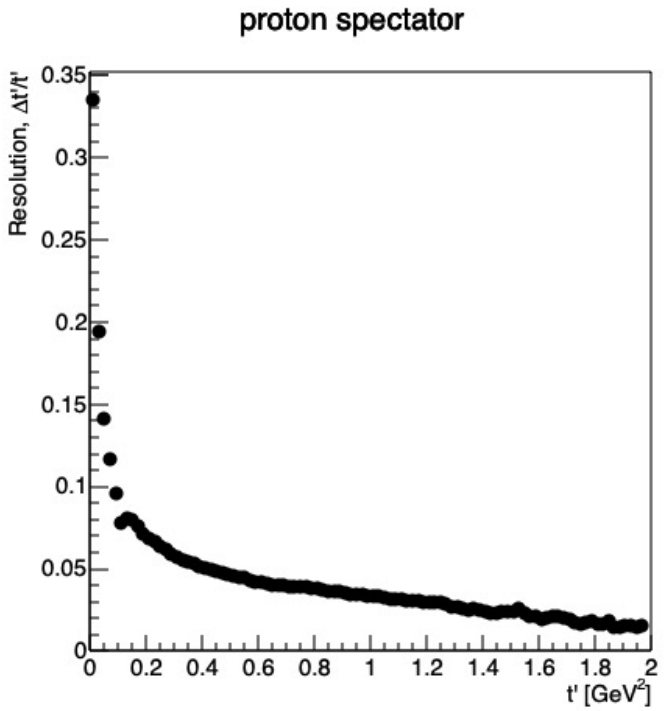
$p_T$ resolution ~ 25 MeV/c

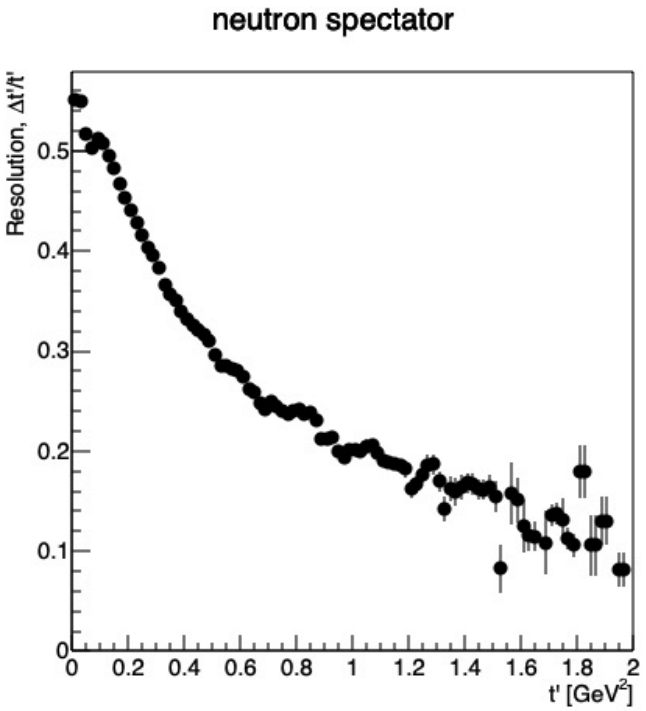
Dominated by beam effects not detectors!



# Measuring virtuality in deuteron

- Virtuality dependence in deuteron can be controlled by $-t'$, which is based on spectator tagging.
- Equivalently, it can be ($\alpha_p$, $p_T$)
- Proton spectator is found to be better than neutron in resolution, as expected.
- Neutron spectator EMC results are not shown in this talk - more challenging and smaller acceptance. (Stay tuned!)




$-t^2 = M_N^2 - \left(p_d - p_p\right)^2$ in deuteron

**Precise determination of $-t'$ or ($\alpha_p$, $p_T$) is the key to this measurement**

# Summary

**Conclusions:**

a) Experimental proposal to measure the electron-deuteron tagged DIS with spectator tagging – explore virtuality/off-shell dependence of the EMC effect.

b) Linear parametrization of the virtuality dependence based on data;

c) Simulations are based on BeAGLE event generator and EIC Far-Forward detectors.

d) Results show good sensitivity to cross section observables and their ratios.

**Open question**:

How to model higher virtuality dependence above $-t' > 0.2$ GeV$^2$ ? Will the EMC effect be saturated?

**Outlook:**

Theoretical studies are followed with different modeling of virtuality dependence, Final-State Interactions, etc.