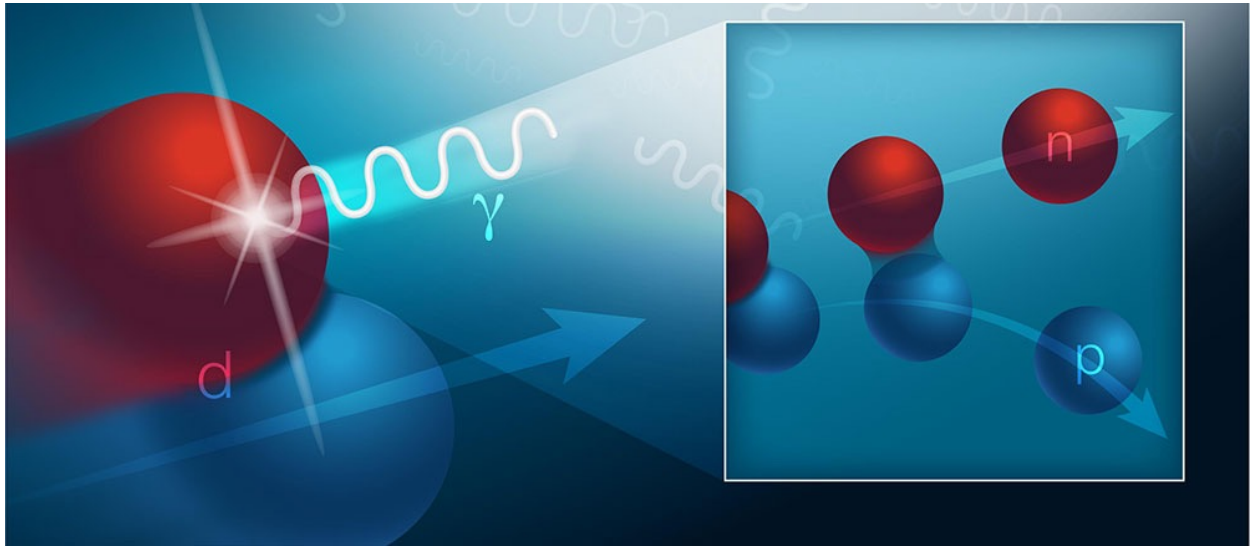
Brookhaven National Laboratory

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



(Image made by BNL)

Kong Tu
BNL
05.05.2022

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

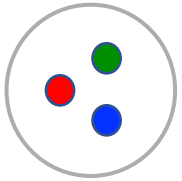
Two sides of the same coin

- Two big questions in nuclear physics

(1) Free nucleon structure

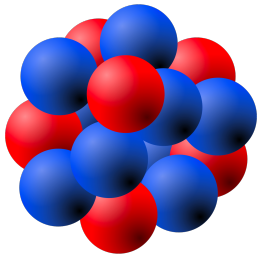
(2) The EMC effect.

Nucleon



Free nucleon structure

Nucleus



EMC effect

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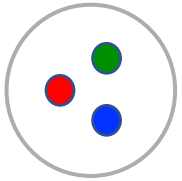
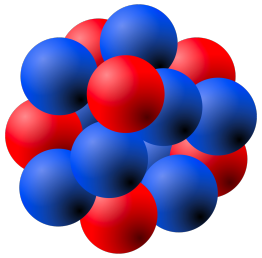


Nucleus

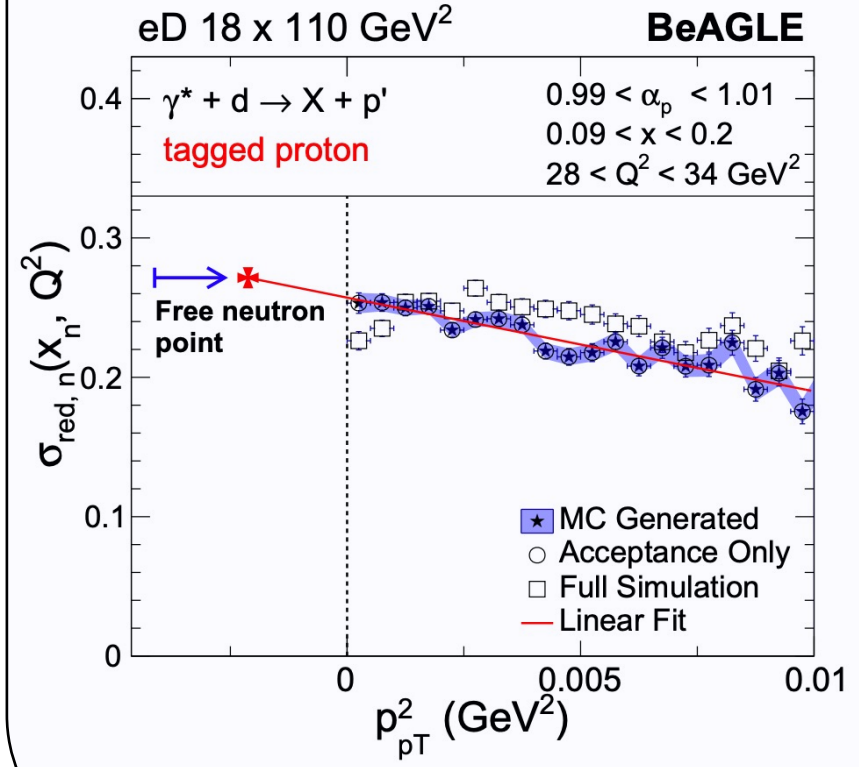


Free nucleon structure

EMC effect

Given by A. Jentsch at

DIS 2021 conference



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

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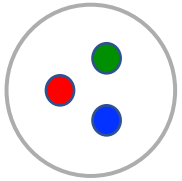
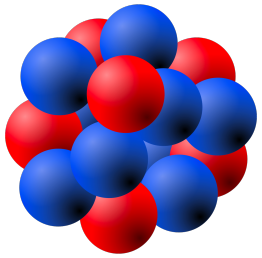
Nucleon



Free nucleon structure

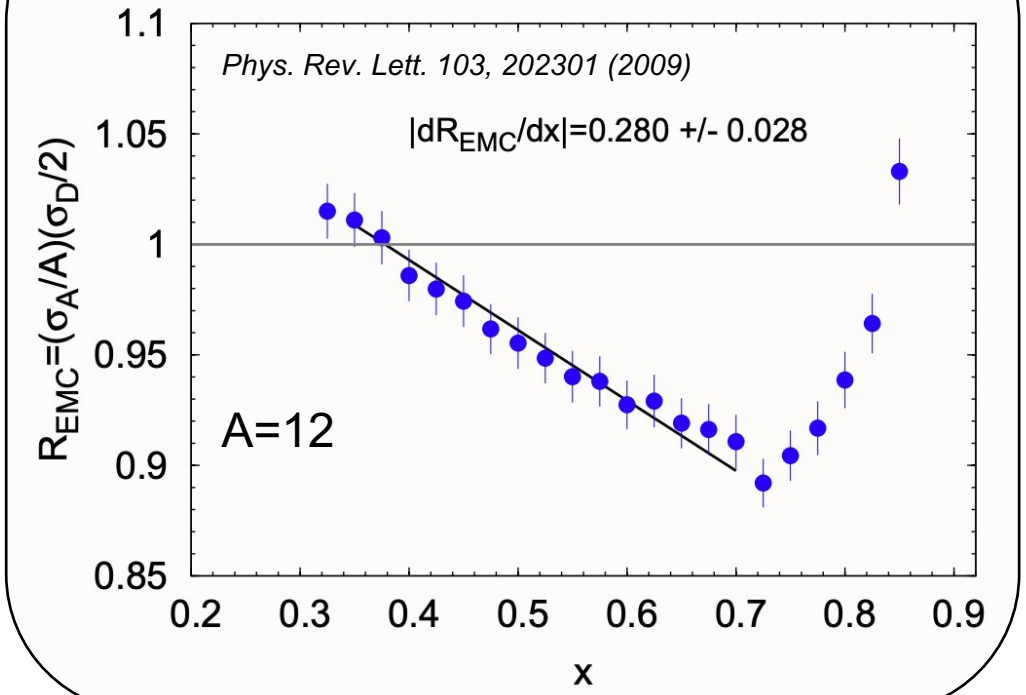
Nucleus



EMC effect

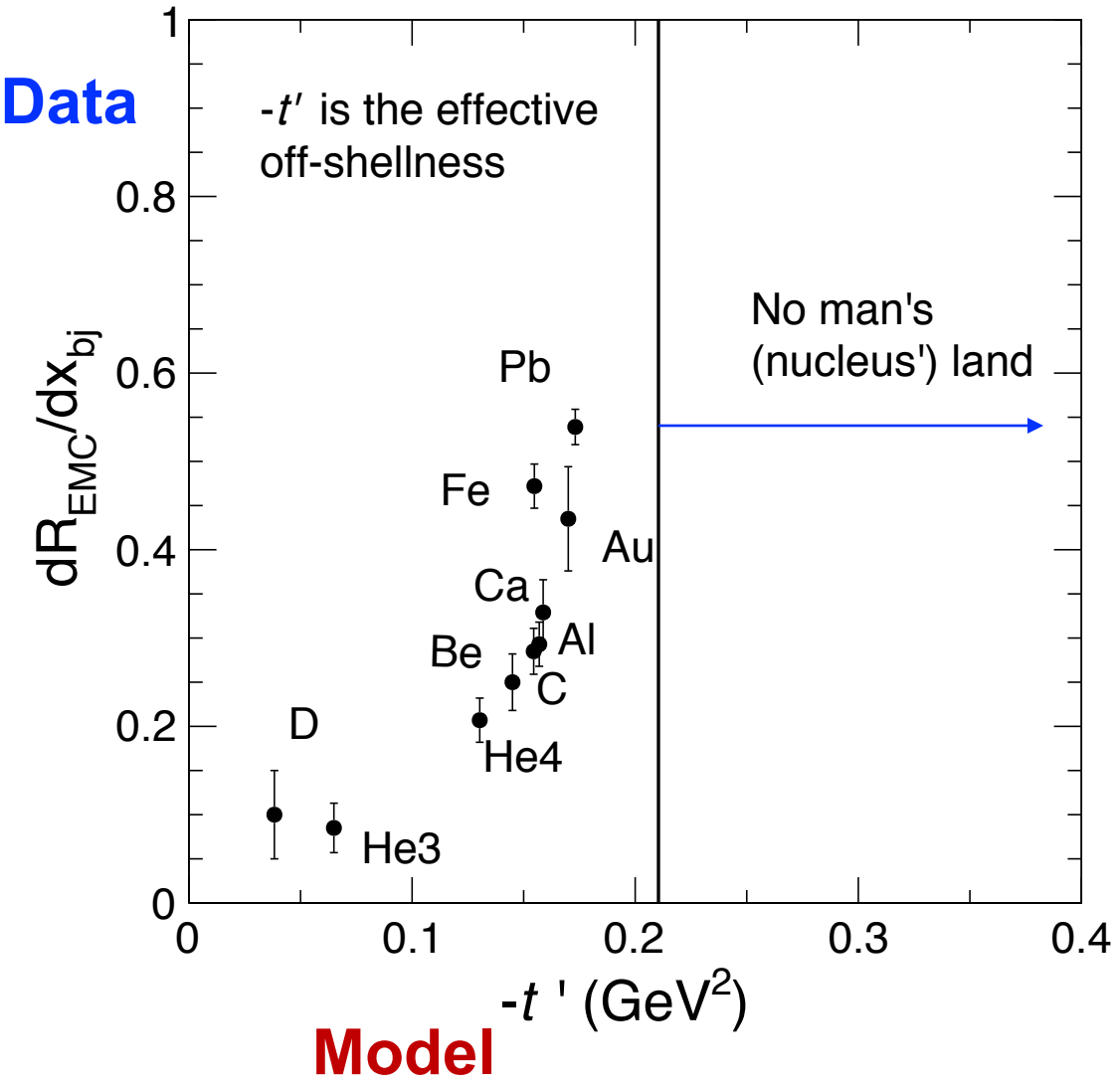
This talk focuses on

DIS 2022 – 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

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

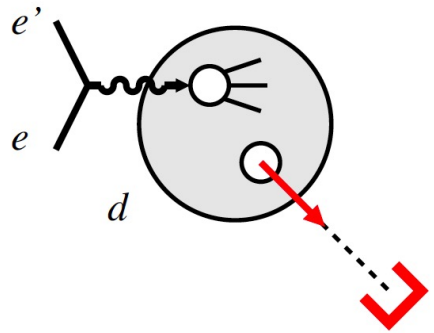
(*Phys.Rev.C76 055206,2007*)

- 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

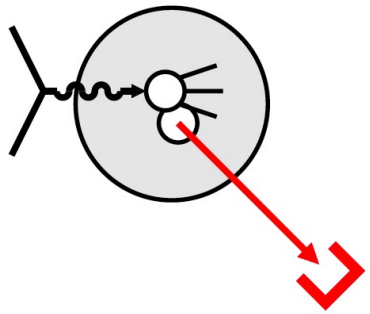
- **Goal:** Prove the direct relation between nucleon off-shell effect and the EMC effect.
- **System:** Deuteron, the simplest nuclear system with one proton and neutron
- **Method:** Tagging spectator in electron-deuteron (*ed*) DIS to control initial-state configuration → to vary nucleon virtuality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

Low off-shellness

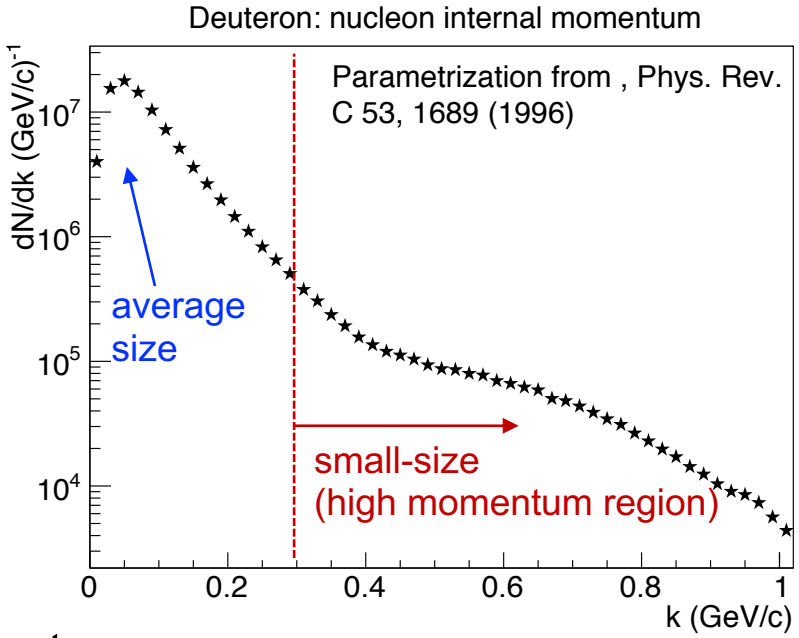


average–size

High off-shellness



small–size



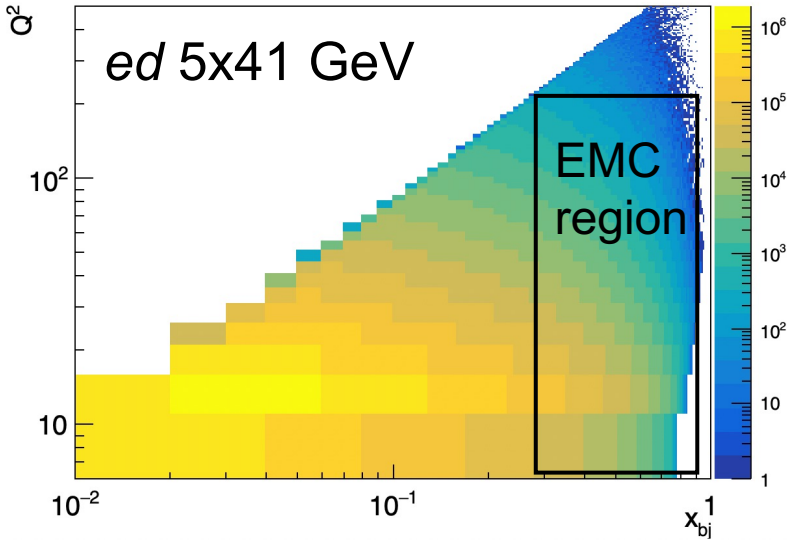
Tagged DIS Process: e + d → e' + X + p' or n'

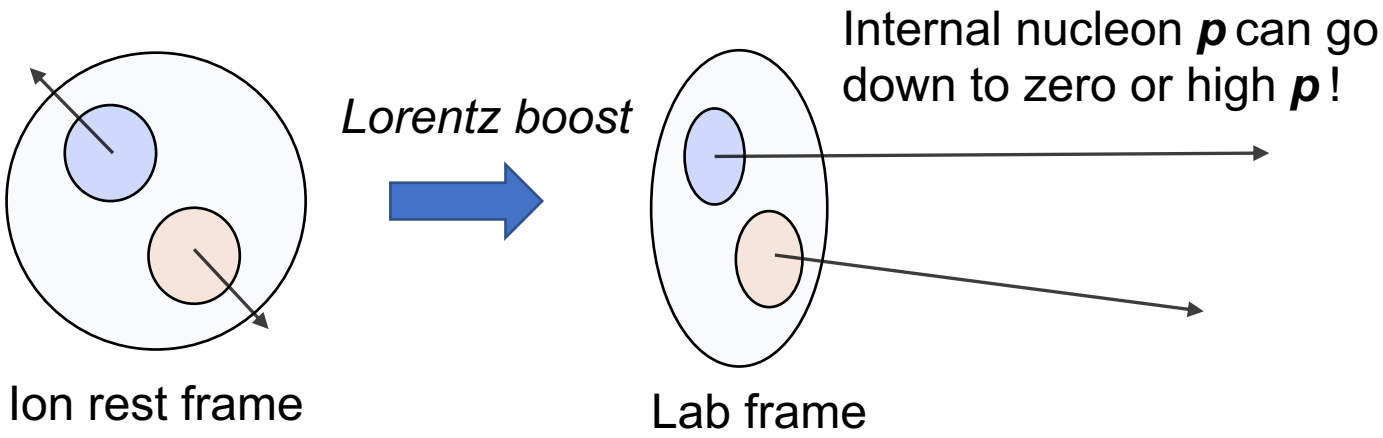
$-t^2 = M_N^2 - (p_d - p_p)^2$ virtuality/off-shellness in deuteron

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.

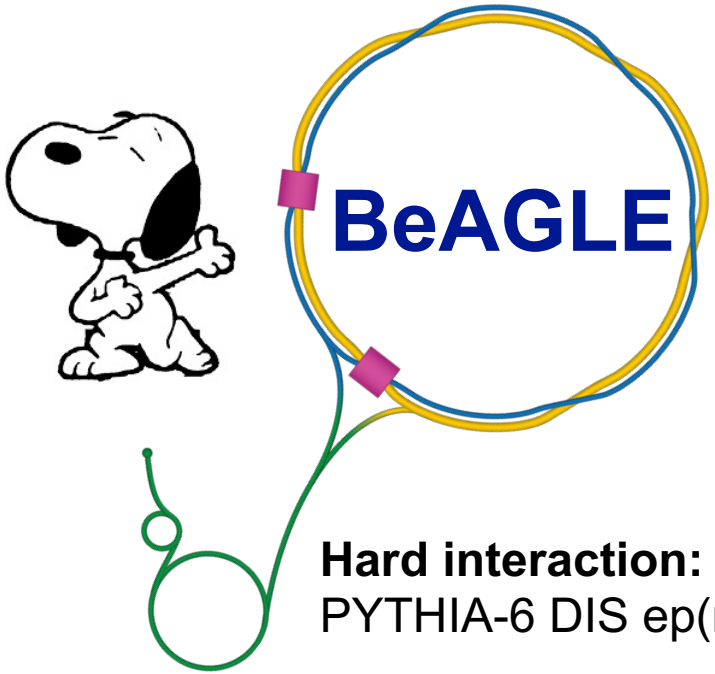
- **Advantages** of studying the EMC effect at the EIC:
  - Lepton side - Wide kinematic range in x and Q^2 (e.g., high Q^2).
  - Deuteron side - Lorentz boost provides wide range in spectator kinematics, in terms of spectator p_T and light-cone momentum fraction α.





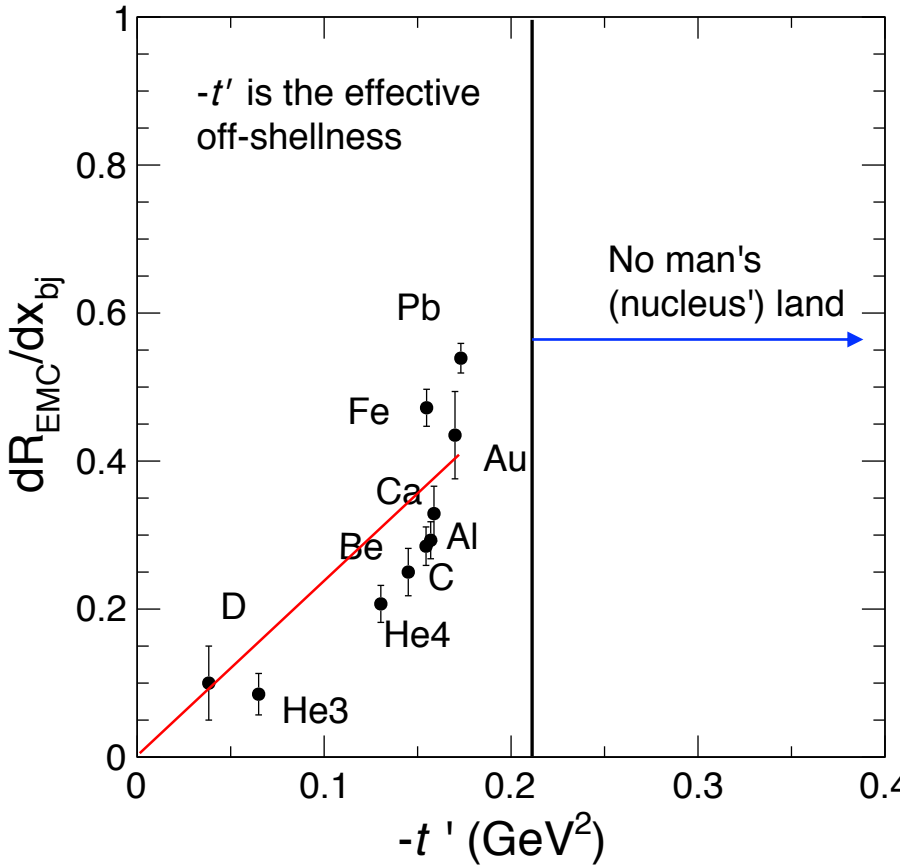
Analysis - simulation and parametrization

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)

Analysis - simulation and parametrization

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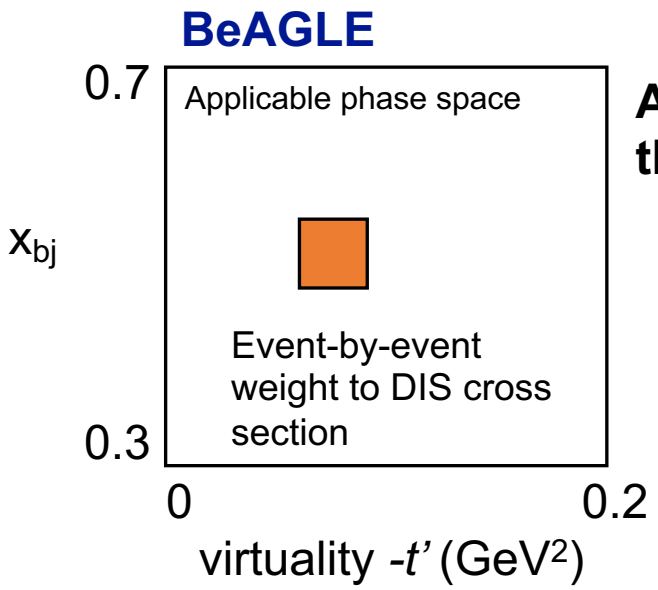
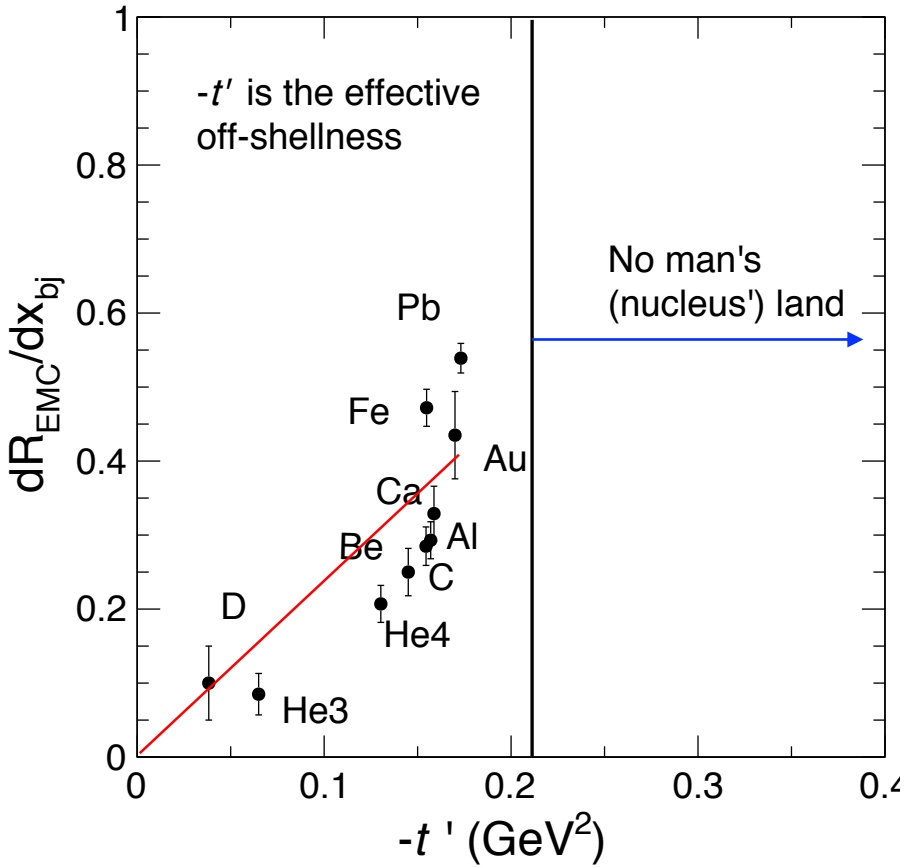


Add EMC effect according to the linear parametrization

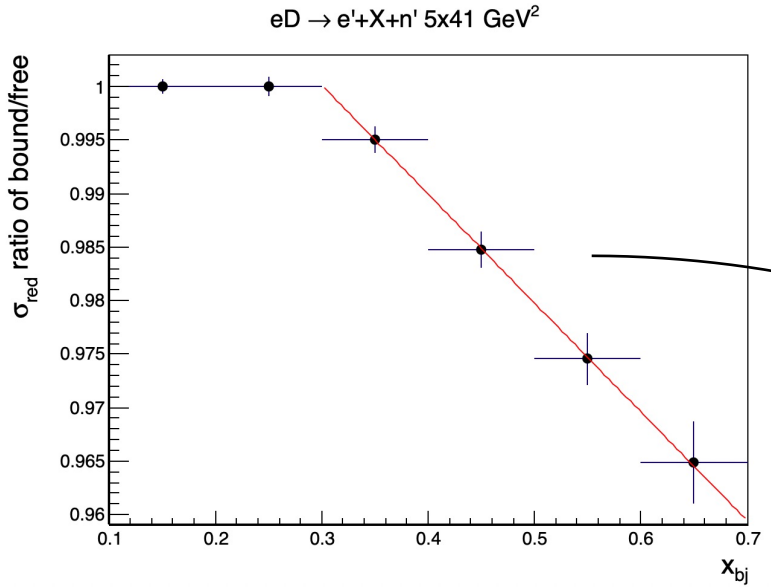


- Only apply to $0.3 < x_{bj} < 0.7$
- Q^2 independent
- Weight = F_2 (bound)/ F_2 (free)

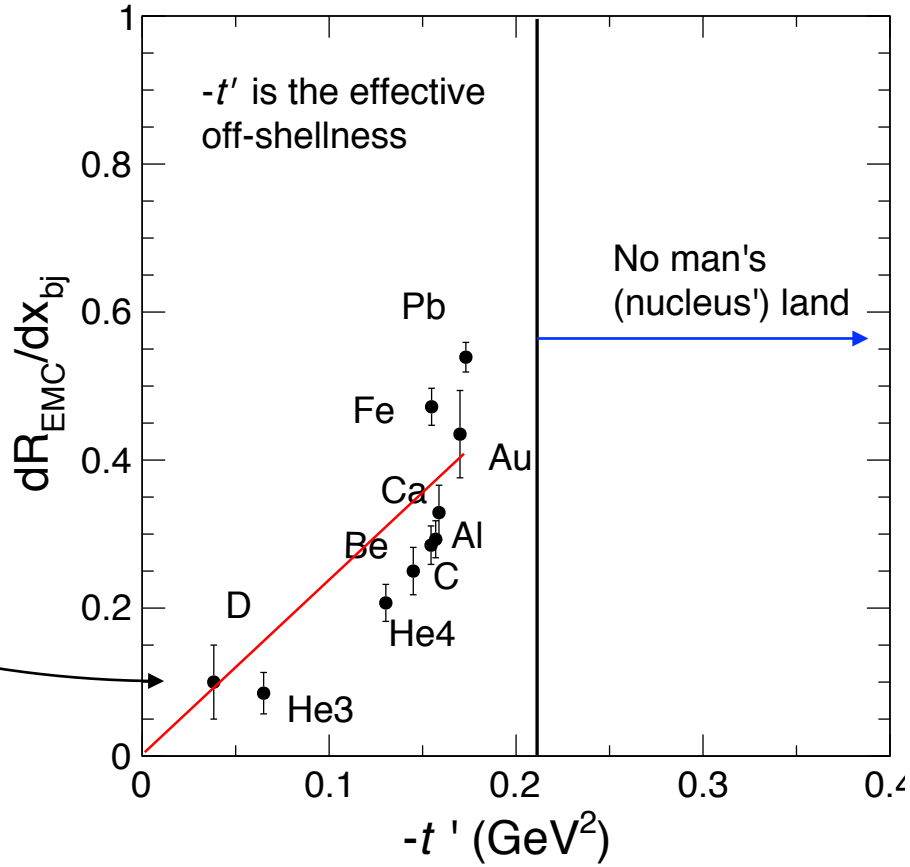
Minimal parametrization (linear)
Linear offshell dependence on the EMC effect.
(Frankfurt, Strikman 80', Weiss)

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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- Weight = F_2 (bound)/ F_2 (free)

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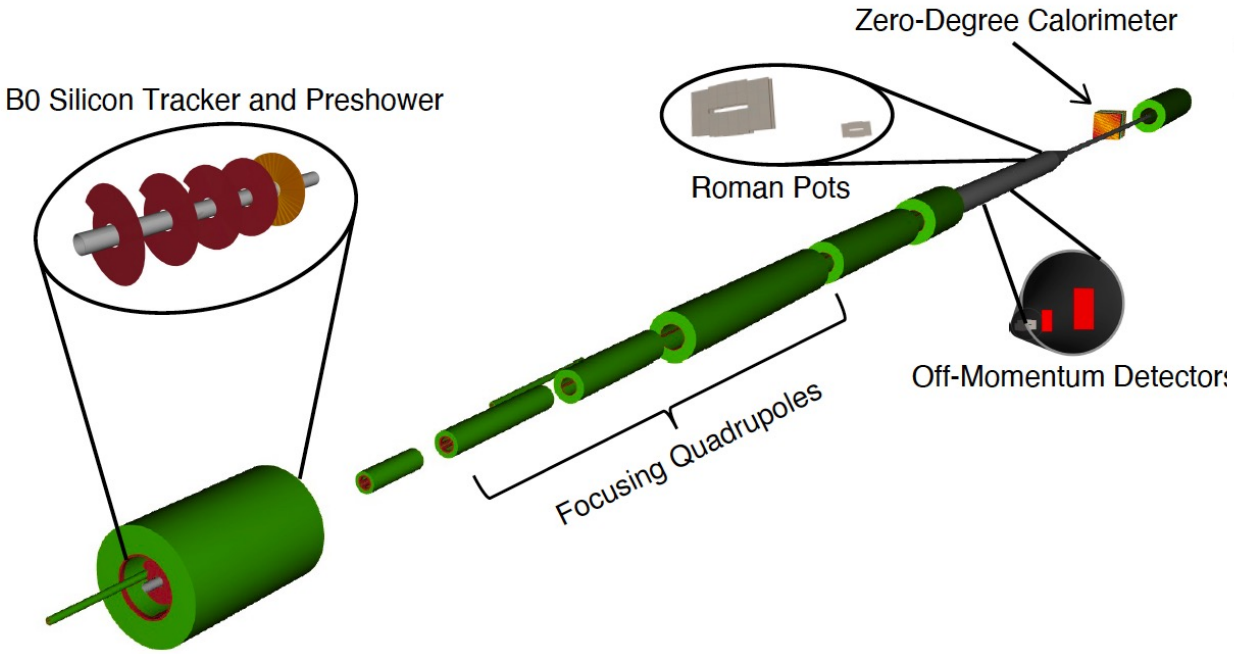
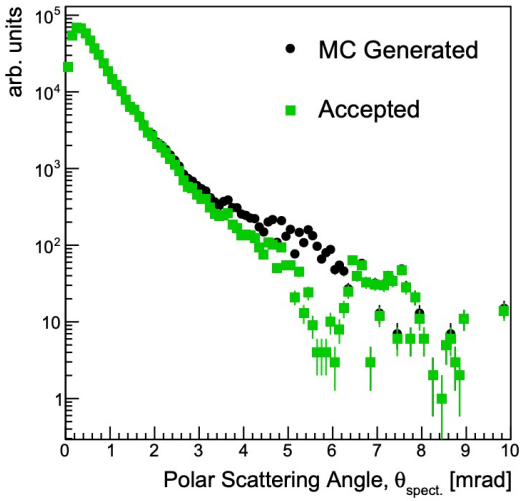
Detector at the EIC – FF region

(See A. Jentsch's talk for details, **5/4/22, 11:50 AM, WG6)**

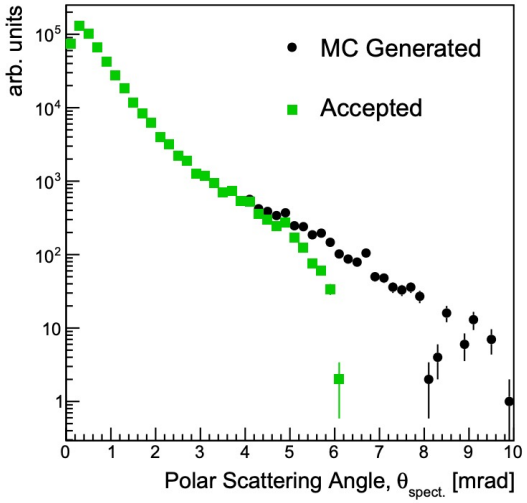


Acceptance in scattering angle

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



Proton spectator



Neutron spectator

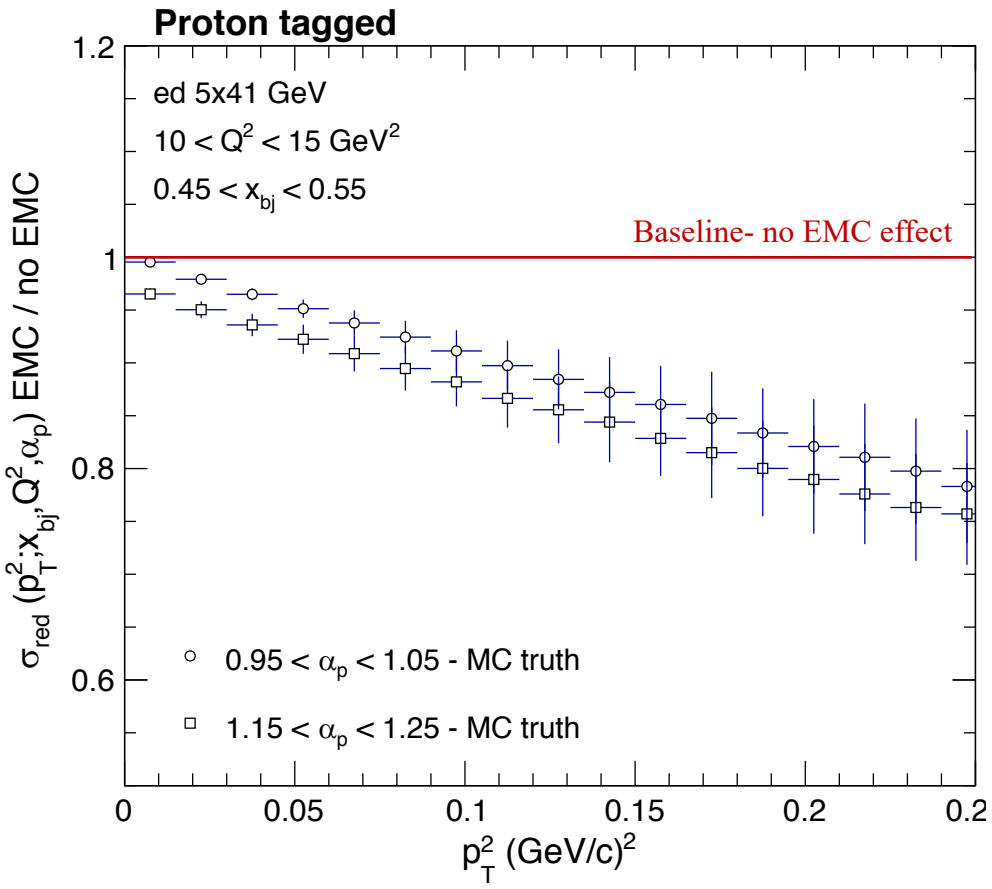
[Great spectator acceptance in general at the EIC]

- 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:

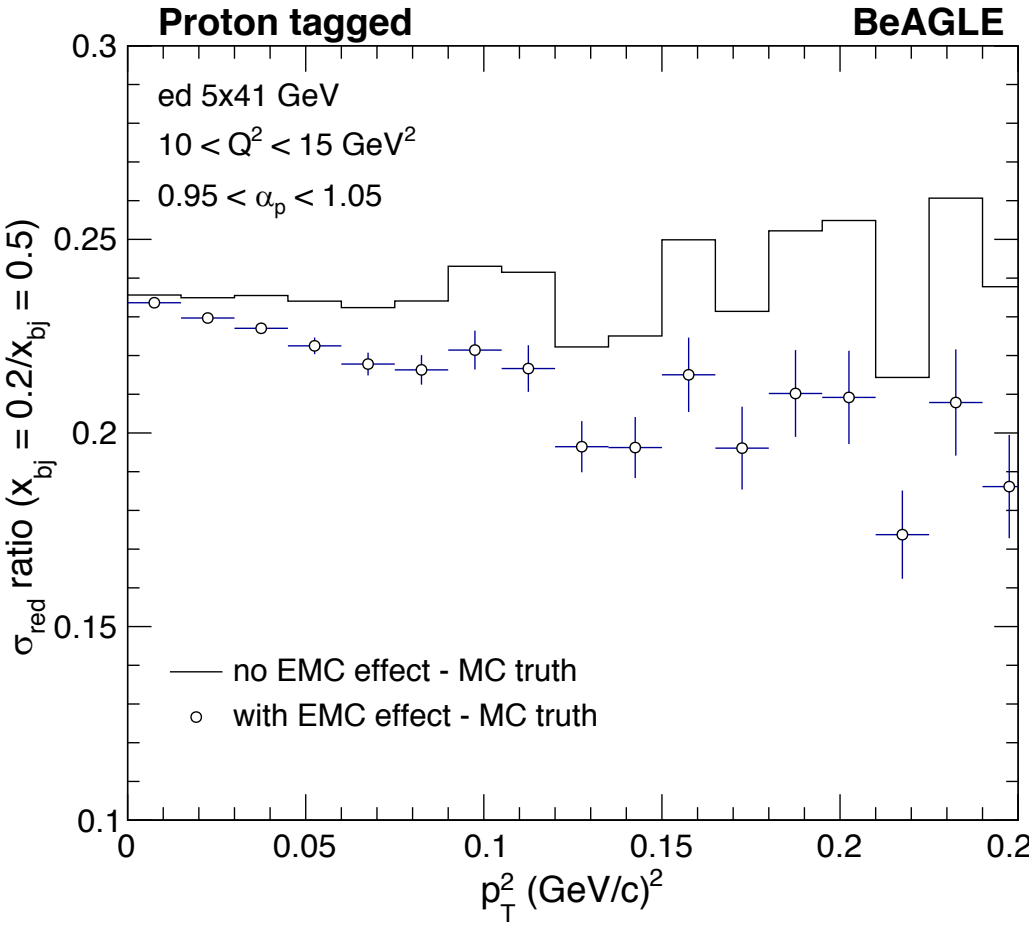
- Self-consistent at $p_T^2 = 0$ for $\alpha_p = 1$
- Linear dependence is consistent with input parametrization.

Messages:

- For high p_T^2, the measurement is sensitive to the EMC effect.
- Different α_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 α_p , virtuality is proportional to spectator p_T^2
- Self-consistent at p_T^2 = 0 for α_p = 1

Results - 2

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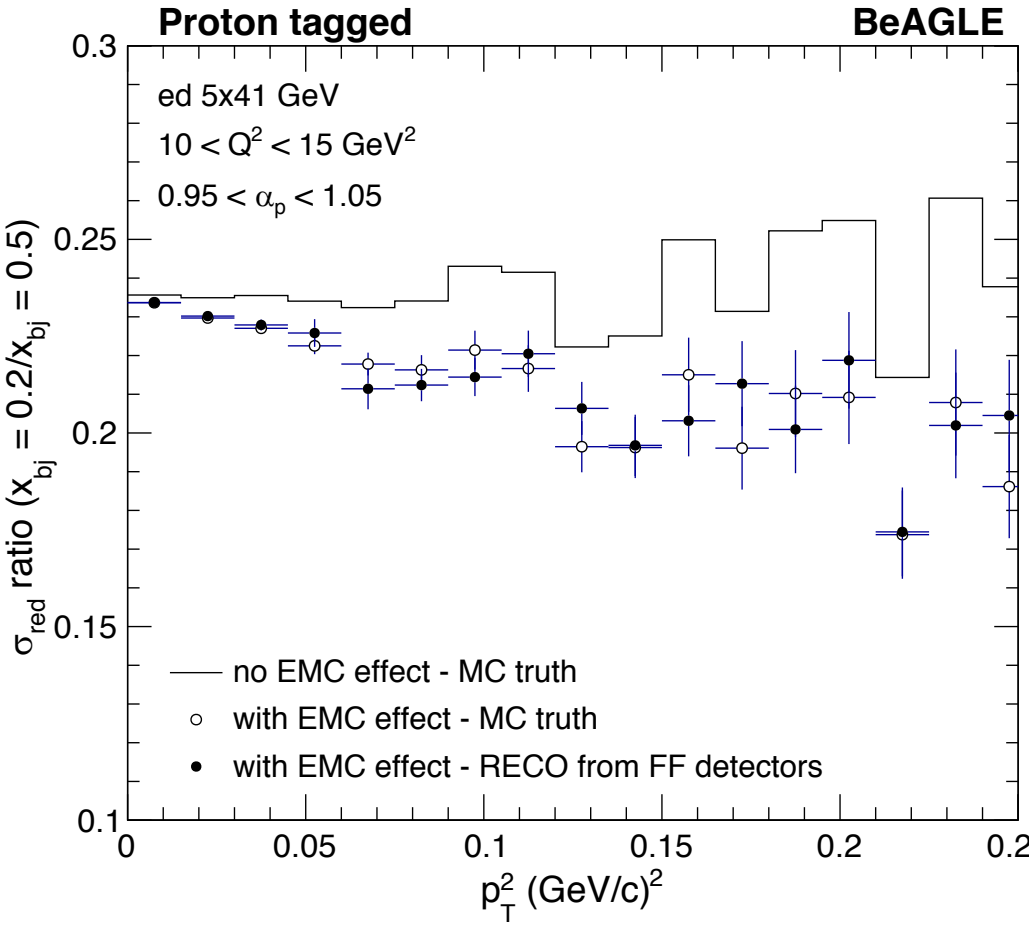
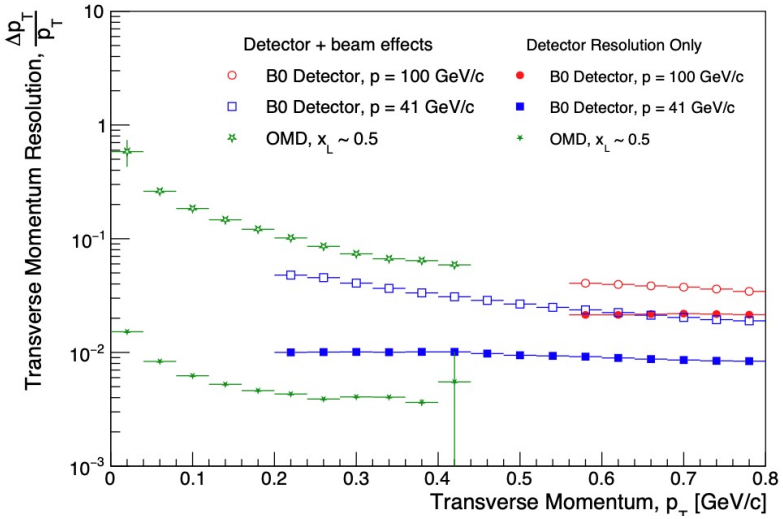


At the RECO level:

- 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

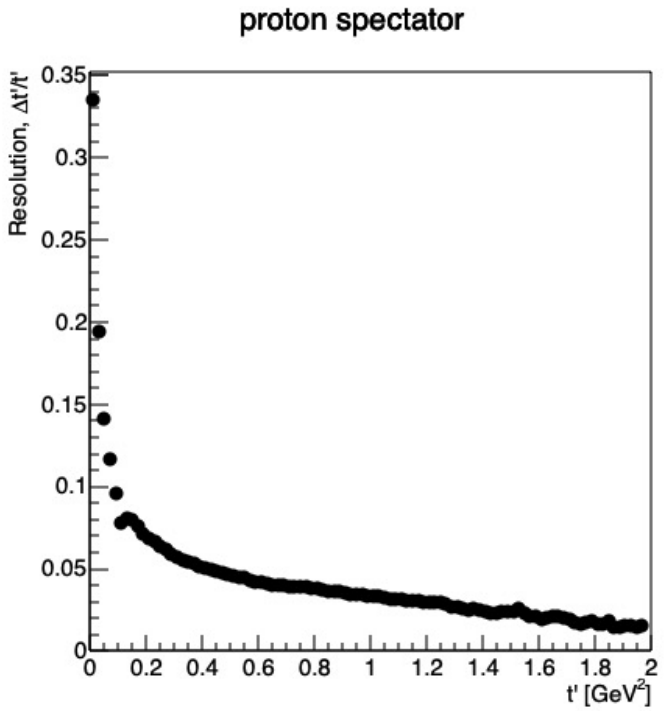
p_T resolution ~ 25 MeV/c

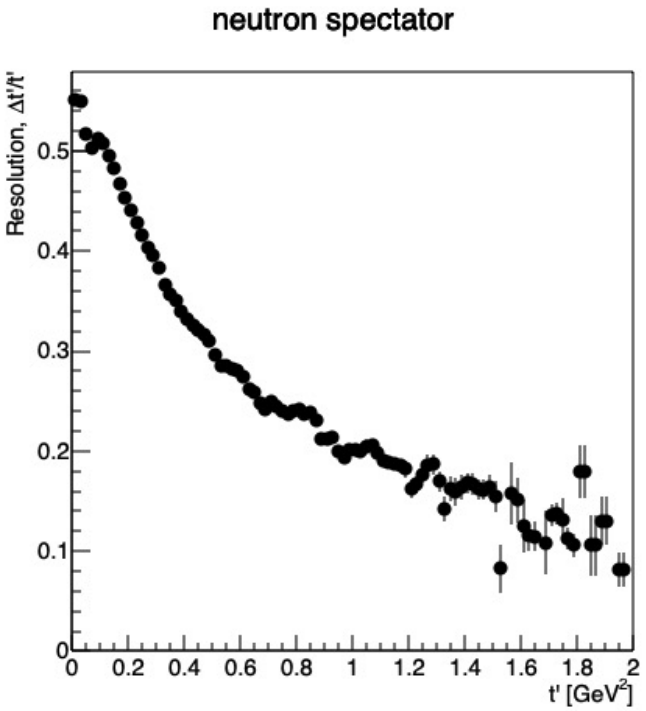
Dominated by beam effects not detectors!



Measuring virtuality in deuteron

- Virtuality dependence in deuteron can be controlled by $-t'$, which is based on spectator tagging.
- Equivalently, it can be (α_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 (α_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.

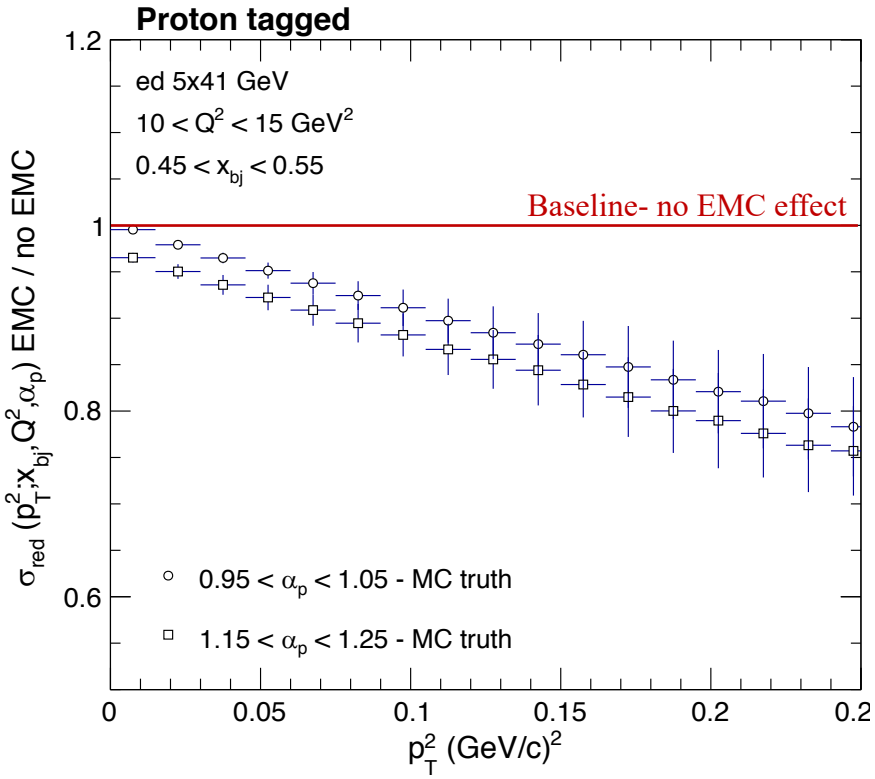
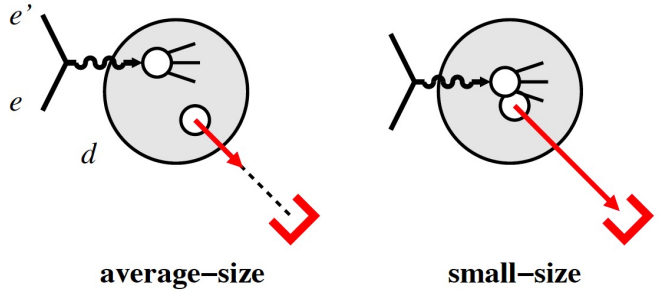
b) Linear parametrization of the virtuality dependence based on data;

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.