ALERT Run Group

Tagged EMC

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On behalf of the CLAS Collaboration

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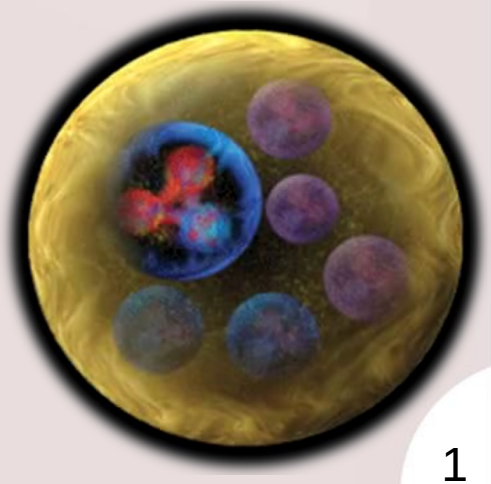
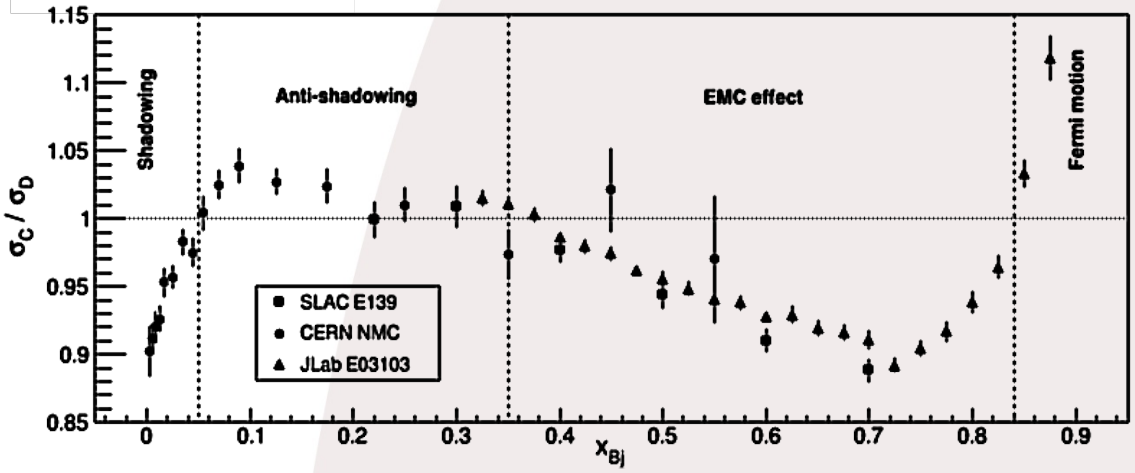
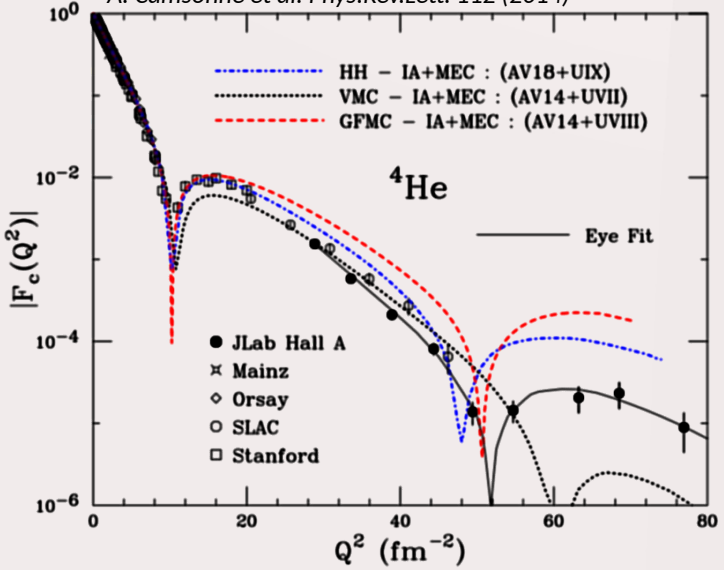


Lessons from the Past

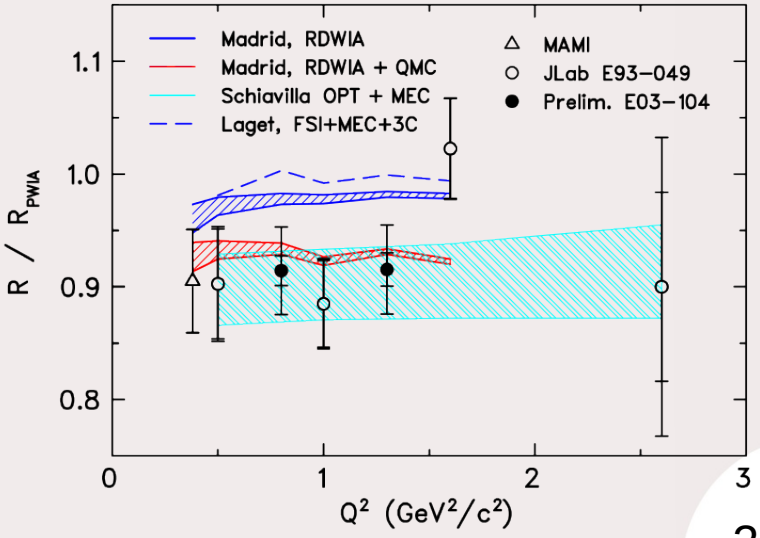


A. Camsonne et al. Phys.Rev.Lett. 112 (2014)



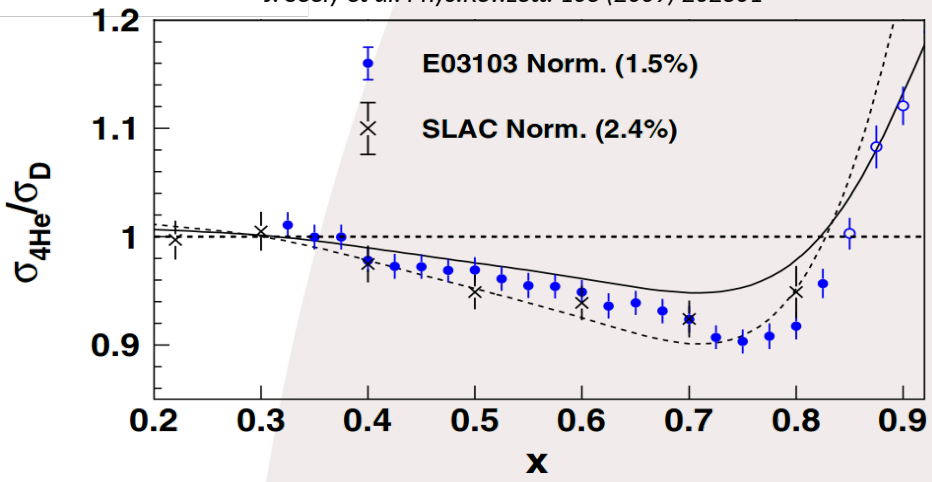
- **Nuclear Parton Distribution Functions (PDFs)**
  - We did not expect a significant effect
    - Binding is only at the level of MeVs
    - Several effects were discovered: shadowing, EMC…
- **Nuclear Form Factors (FFs)**
  - Reveal the transverse structure of nuclei
  - Mostly interpreted in term of nucleons
- **Bound nucleon FFs**
  - Quasi-elastic scattering on a bound nucleon
  - Attempt to reveal the modification of nucleon structure in the nuclear medium
  - Final State Interactions (FSI) could play a significant role

S. Strauch et al. Phys.Rev.Lett. 91 (2003) 052301

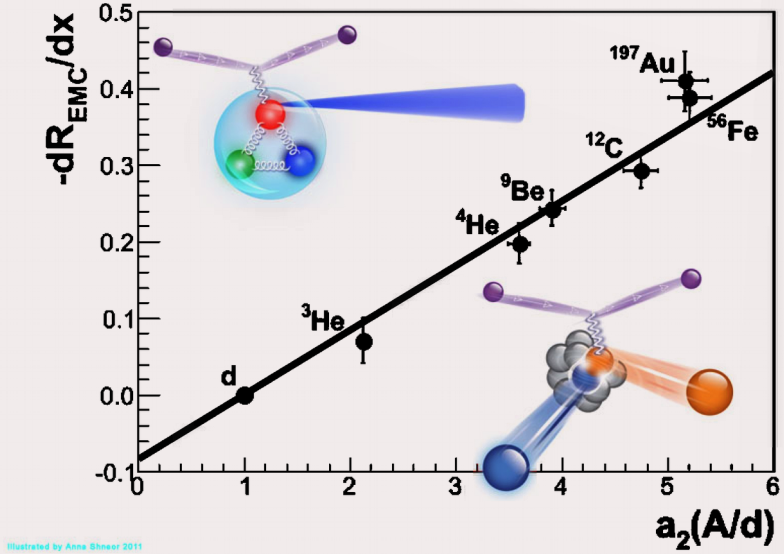


EMC: The Most Prominent Nuclear Effect

J. Seely et al. Phys.Rev.Lett. 103 (2009) 202301

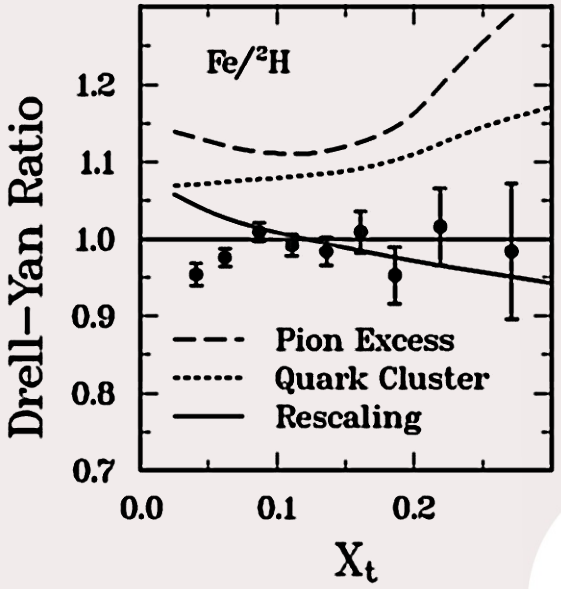


L.B. Weinstein et al., Phys.Rev.Lett. 106, 52301 (2011)



- **Do nuclear pions play a role?**
  - Drell-Yan experiment showed otherwise…
- **Is it x or Q^2-rescaling?**
  - Q^2-rescaling by modifying QCD in medium
  - x-rescaling due to the binding
- **Is there a dependence on nucleon virtuality?**
  - Hint from nucleon-nucleon Short Range Correlations (SRC)
  - Tagging the spectator of the reaction might help with the answer

D.M. Alde et al. Phys. Rev. Lett. 64, 2479 (1990)



The EMC Effect @ JLab

- **Direct precision measurements**
  - Concentrate on light nuclei, with well known nuclear structure
    - *Detailed studies of the nuclear dependence of F2 in light nuclei* (E-12-10-008) in Hall C
    - *Measurement of the F2n/F2p, d/u Ratios and A=3 EMC Effect in Deep Inelastic Scattering off the Tritium and Helium Mirror Nuclei* (E-12-10-103) in Hall A

- **Separating the different components of the cross section**
  - Looking at spin structure functions or longitudinal versus transverse cross sections
    - *The EMC Effect in Spin Structure Functions* (E-12-14-001) in Hall B
    - *Precision Measurements and Studies of a Possible Nuclear Dependence of $R=\sigma L/\sigma T$* (E-12-14-002) in Hall C

- **Search for a link between EMC effect and short range correlations (SRC)**
  - Explore the link between EMC and SRC on an event by event basis
    - *In Medium Nucleon Structure Functions, SRC, and the EMC effect* (E-12-11-107) in Hall C
    - *In Medium Proton Structure Functions, SRC, and the EMC effect* (E-12-11-003A) in Hall B
  - Other SRC proposals are not directly linked to the EMC effect studies

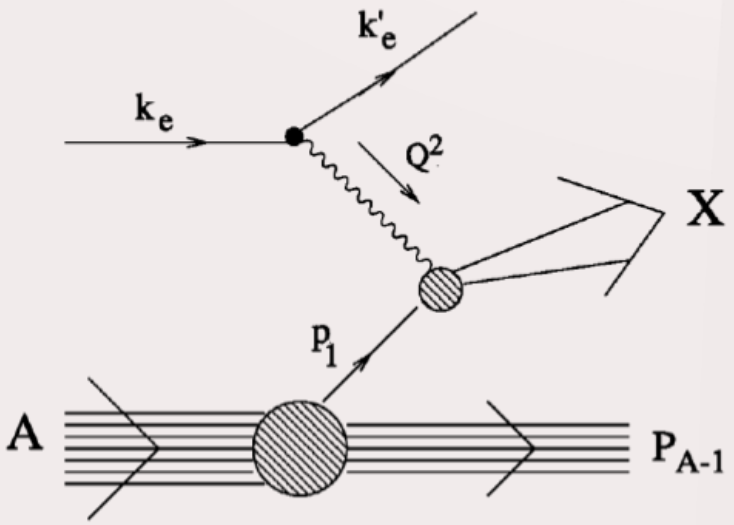
Why Tagged Measurements

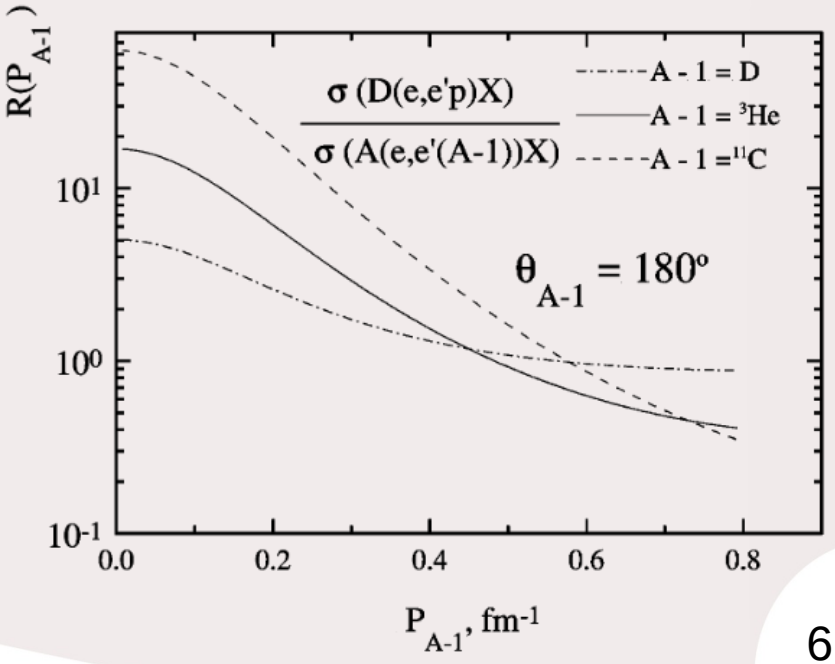
- **The EMC effect remains a mystery**
  - To solve it we need new observables
- **We propose to measure tagged DIS**
  - To explore possible links between the EMC effect and the intra nuclear dynamic
  - As was just shown, this aspect is not covered by other projects
  - Our data is of interest to the experiments that can be prone to FSI
- **Tagged measurements give access to virtuality**
  - The virtuality or off-shellness of the struck nucleon is linked to its momentum in the nucleus
  - It is the way to make a direct link between the nucleus configuration and its modification
- **Nuclear measurements are often plagued with FSI effects**
  - Tagging of low momentum backward fragments is the safest measurement in this regard

The Spectator Mechanism

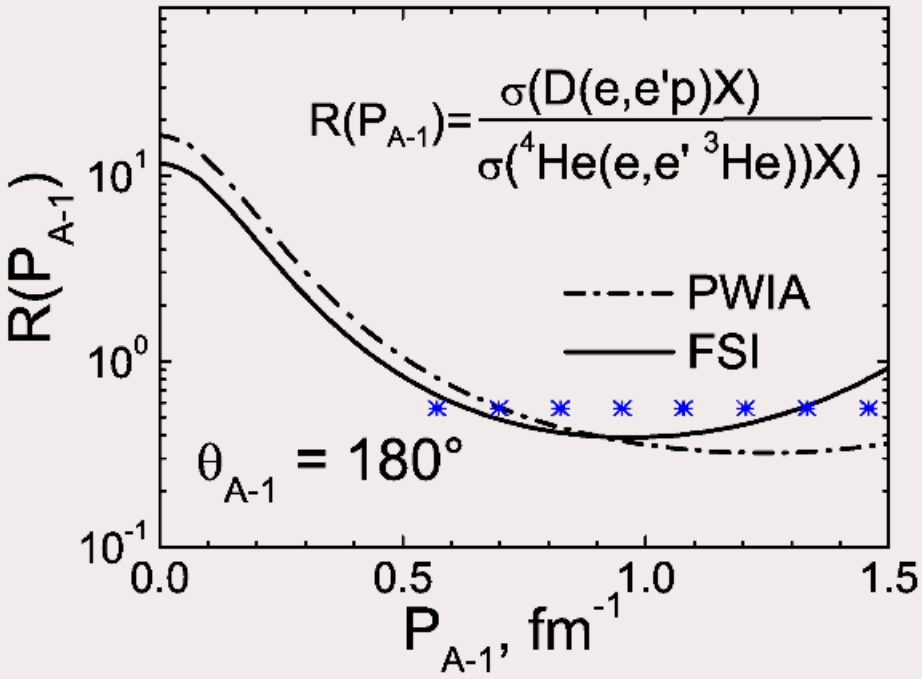
- **Spectator recoil for deuterium target**
  - The nucleon inside the nucleus does not interact with the virtual photon and other hadronic products of the reaction
  - The spectator kinematics can be used to control FSIs
  - Used by CLAS successfully for neutron structure function measurement (Bonus)

- **Spectator recoil for ^{4}He target**
  - The detection of the recoil nucleus (A-1) intact gives an extra indication that FSI is small
  - The Fermi distribution extends to higher momentum giving more reach than deuterium





Testing the Spectator Model

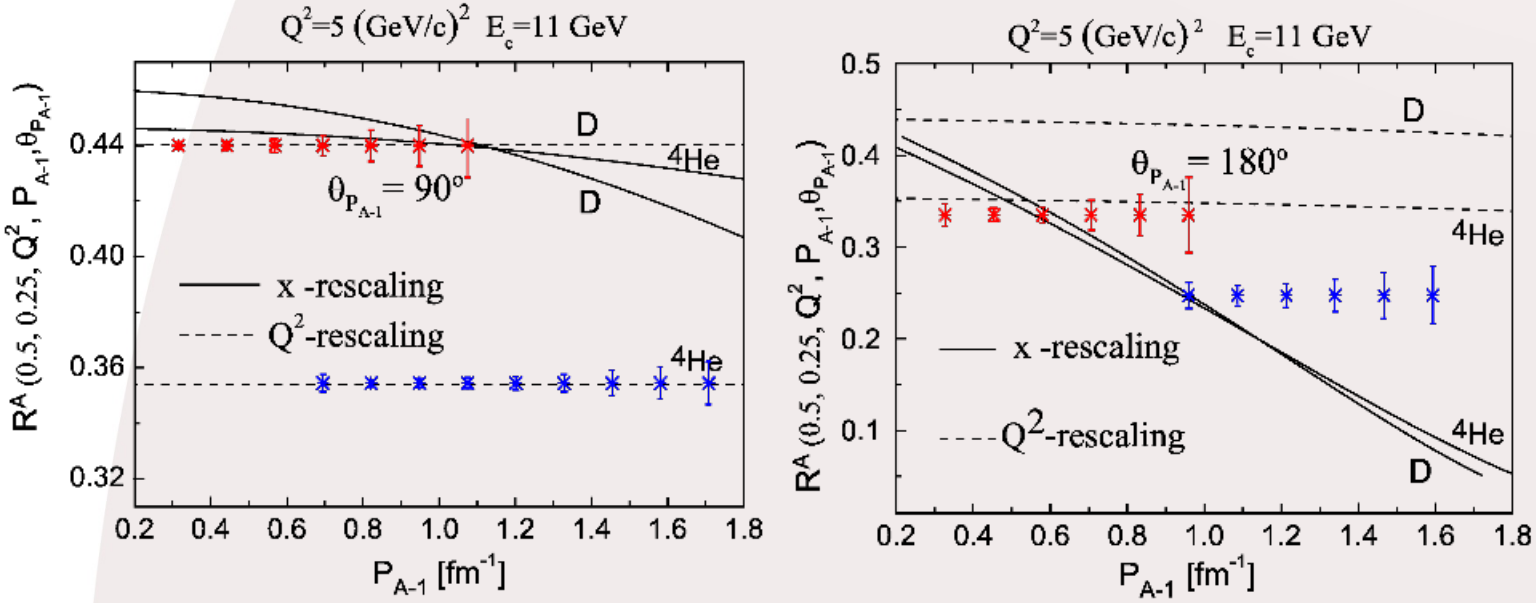


- **First step is to test FSI models**
  - Can be tested in large momentum and angle range with very good precision
    - This measurement will provide great constraints for theoretical calculations

    see M. Strikman, C. Weiss, arXiv:1706.02244 or recent review and references therein W. Cosyn, M. Sargsian, arXiv:1704.06117
  - Comparison of Helium and Deuterium targets
  - First measurement of its kind on ^{4}He

    C. Ciofi degli Atti, L. P. Kaptari, and S. Scopetta, Eur. Phys. J. A5, 191 (1999)

x or Q^2-Rescaling ?

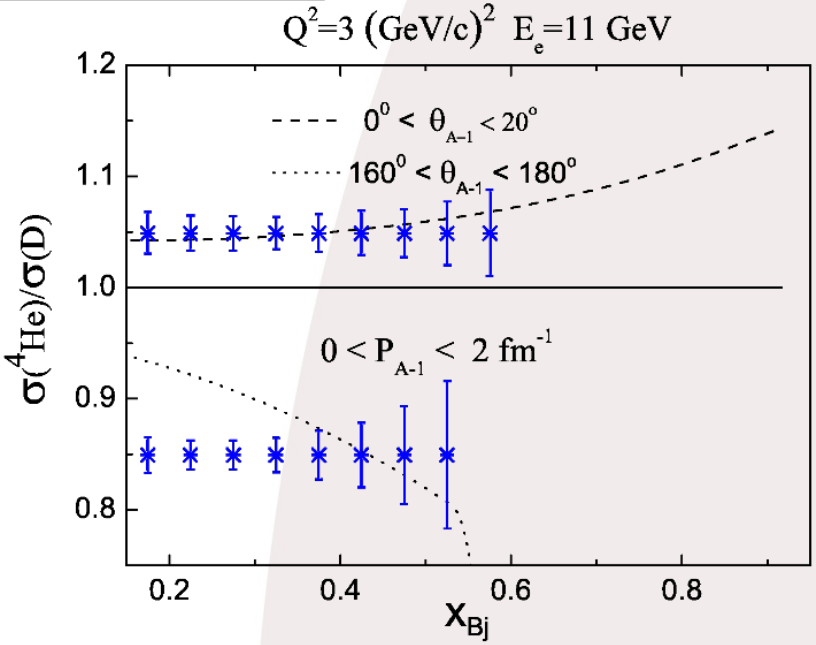


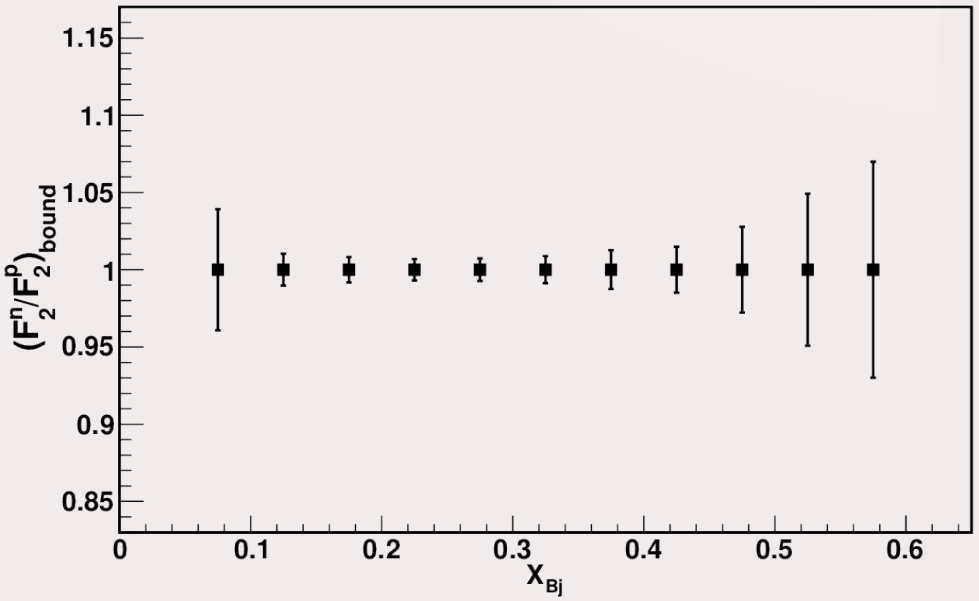
- **The nucleon virtuality is directly linked to the spectator momentum**
- **Rescaling models behave differently with tagged measurements**
  - It is impossible to differentiate x and Q^2 rescaling with inclusive measurements but they give very different signature in tagged measurements
  - Comparison of ^{2}H to ^{4}He is particularly interesting
    - It conserves the nucleus isospin symmetry
    - ^{4}He is a light nuclei with a sizable EMC effect
    - The two rescaling effects are cleanly separated by the comparison between the two nuclei
    - They complement each other in spectator momentum coverage

C. Ciofi degli Atti et al. Eur. Phys. J., vol. A5 (1999) 191

C. Ciofi degli Atti et al. Phys.Rev. C76 (2007) 055206

More Tests of the EMC Models



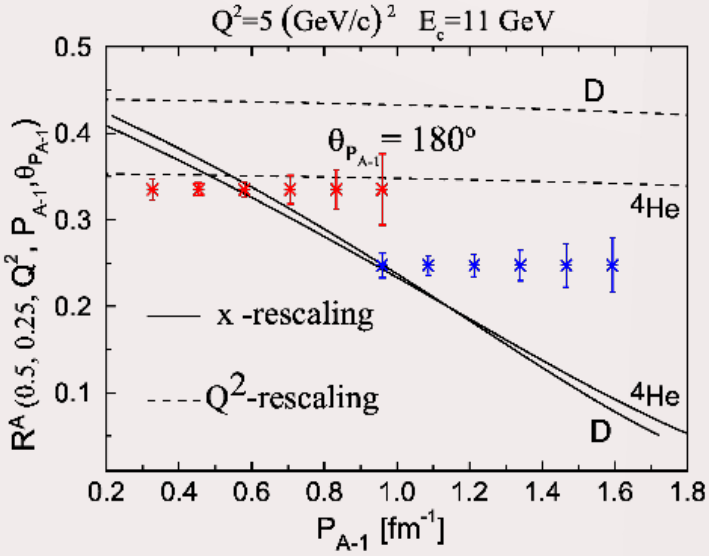


- **Tagged DIS gives many other opportunities to test the EMC models**
  - In binding model, the EMC effect is due to the cancellation of much larger effects that can be separated with spectator detection
- **Tagged DIS can also be used for flavor selection**
  - We can test how the d/u ratio changes in the nuclear medium

Summary and Beam Time Request

- **We are proposing to use tagging methods to study the EMC effect**
  - We will test the spectator model on a wide kinematic range and verify its applicability to complex nuclei
  - We will separate the contributions to the EMC effect from the nucleus density and the hit nucleon momentum
  - We will be sensitive to flavor effects in the nuclear medium
- **Tagged measurements are a key element of the future EIC**
  - We can perform the first measurements in JLab
  - Reinforce EIC physics program by proving their usefulness in the valence region

  See https://www.jlab.org/theory/tag/ for a summary of the local effort on the topic
- **ALERT run group will need 55 days of beam time**
  - The request driven by the Tagged EMC measurement is 35 days (Commissioning and config. B & C)



Configurations	Proposals	Targets	Beam time request	Beam current	Luminosity*
			days	nA	$n/cm^2/s$
Commissioning	All†	^1H, ^4He	5	Various	Various
A	Nuclear GPDs	^4He	10	1000	6×10^{34}
B	Tagged EMC & DVCS	^2H	20	500	3×10^{34}
C	All†	^4He	20	500	3×10^{34}
TOTAL			**55**		

Theory Report

PR12-17-012A ***Tagged EMC Measurements on Light Nuclei***

T. Rogers and C. Weiss

— Revised report —

This Run Group Proposal aims to use spectator-tagged deep-inelastic scattering (DIS) on light nuclei as a means to control the state of the active nucleon during the DIS process and explore the dynamical origin of the EMC effect. The targets and breakup channels are $d(e,e'p)X$, $^4\mathrm{He}(e'e'^3\mathrm{H})X$, and $^4\mathrm{He}(e'e'^3\mathrm{He})X$, and the $A-1$ remnant would be detected at recoil momenta $P_{A-1} \sim$ 70–400 MeV/c. The proposed setup exploits the ALERT detector's capability to identify low-energy and wide-angle hadrons and the large acceptance of CLAS12.

Despite many years of effort the dynamical origin of the EMC effect observed in inclusive nuclear DIS $A(e,e')X$ remains poorly understood. Theoretical explanations rely on various assumptions about the modifications of partonic structure due to nuclear binding, such as a change of the average nucleon properties in nuclei, the suppression of point-like configurations, and a possible connection with short-range NN correlations. Inclusive measurements alone cannot distinguish between the different scenarios. Essential progress could come from measurements in which one controls the configuration of the active nucleon during the DIS process by detecting the nuclear breakup in the final state, as is the goal of the present experiment. By measuring the dependence of the tagged structure function on the recoil momentum one can vary the virtuality (off-shellness) of the active nucleon in the initial state, which is seen as the main variable controling the nuclear modifications. A challenge arises from the fact that the recoil momentum dependence is generally also affected by nuclear final-state interactions. It is expected that with theoretical models (to be tested and refined with the forthcoming data) and judicious choice of kinematics (angular dependence on recoil momentum, backward/sideways regions) one would be able to disentangle nuclear initial-state modifications and final-state interactions.

The proposed method is particularly effective in tagged DIS on the deuteron $d(e,e'p)X$, where detection of the recoiling proton completely fixes the virtuality of the active neutron in the PWIA. Furthermore, for the deuteron detailed model calculations of FSI effects are available, which could be tested further with the expected data and used to separate nuclear initial-state modifications and FSI. The proposed measurements could thus significanlty enhance the understanding of the EMC effect, and at the same time provide valuable information about nuclear FSI.

The interpretation of the proposed measurements on $A > 2$ nuclei with breakup into an $A-1$ system is generally more challenging. The present predictions shown in the proposal are based on the spectator mechanism, which assumes that the nuclear modification of the $A \to A-1$ "tagged" structure function is due to nuclear binding effects in the initial state and described by the nuclear momentum distribution. FSI arise mainly from "slow" hadrons produced in the DIS process on the active nucleon (with momenta $\sim<$ 1 GeV in the nuclear rest frame), which are fully formed inside the nucleus and interact with the spectators with hadronic cross sections. While it is correct that FSI are generally suppressed in events with recoil of a bound $A-1$ nucleus, and at backward recoil angles $\sim 180°$, their effects could still be of the same order as the expected initial-state modifications. The analysis should eventually be performed within a comprehensive theoretical framework that incorporates both effects. The development of such a framework requires data on nuclear breakup in DIS over a wide range of recoil momenta, as would be taken in the proposed experiment, including the measurements on the deuteron. The proposed experiment would thus enable and stimulate further theoretical research in this area. We note that DIS with detection of nuclear final states is also being studied as a next-generation measurement with a future Electron-Ion Collider, and that the theoretical development stimulated by this 12 GeV experiment would be synergistic with that effort.