Experiment and Physics Overview

Axel Schmidt

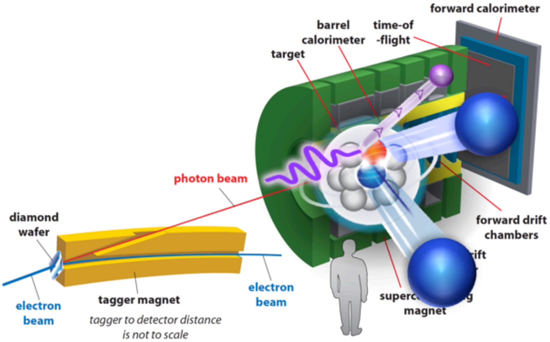
ERR: E12-19-003

May 7, 2020

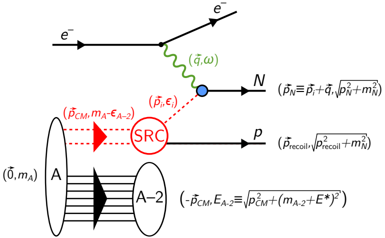
E12-19-003: Studying Short-Range Correlations with Real Photon Beams at GlueX

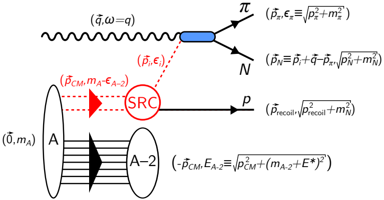
Spokespersons

- Or Hen (MIT)
- Eli Piazetsky (Tel Aviv)
- Maria Patsyuk (JINR)
- Axel Schmidt (GW)
- Alexander Somov (JLab)
- Lawrence Weinstein (ODU)



This experiment tests foundational assumptions about short-range correlations.





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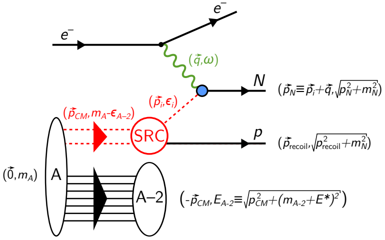
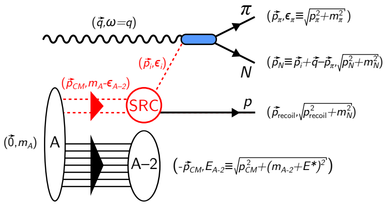
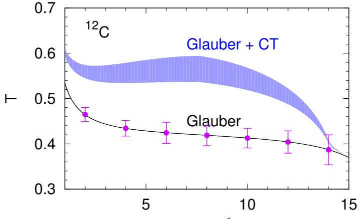


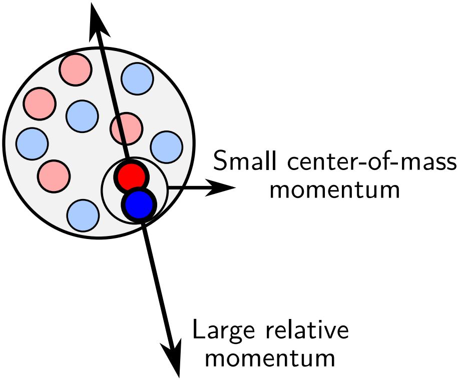


And lots of other physics too!

- Charged probes of neutrons
- BR Modification
- Color Transparency
- Photon structure



Short-range correlated (SRC) nucleons are found in all nuclei.



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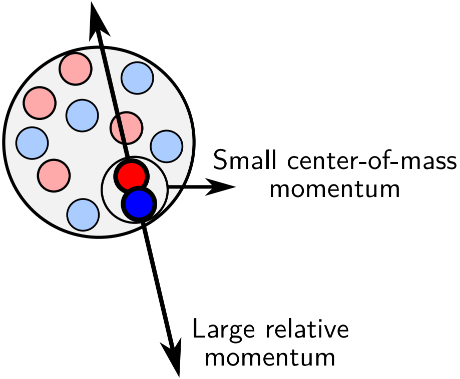

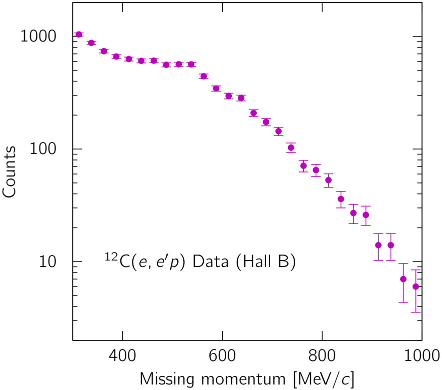

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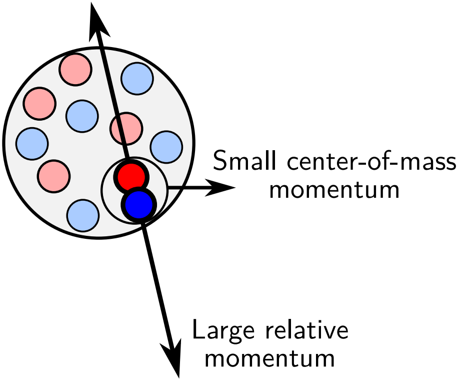
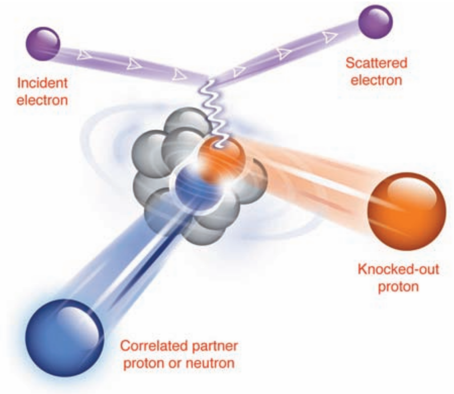
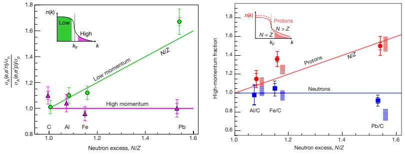


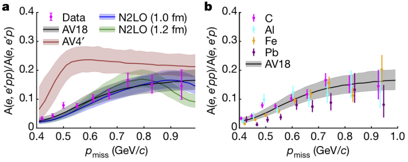


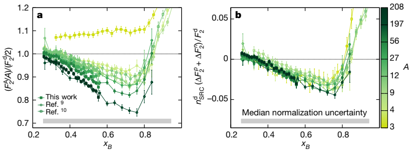
e^- scattering at Jefferson Lab has led to high-impact discoveries.

- Shneor et al., PRL 99, 072501 (2007)
- Subedi et al., Science 320, 1476 (2008)
- Hen et al., PLB 722, 63 (2013)
- Korover et al., PRL 113, 022501 (2014)
- Hen et al., Science 346, 614 (2014)
- Duer et al., Nature 560, 617 (2018)
- Cohen et al., PRL 121, 092501 (2018)
- Duer et al., PRL 122, 172502 (2019)
- Schmookler et al., Nature 566, 354 (2019)
- Duer et al., PLB 797, 134792 (2019)
- Cruz-Torres et al., PLB 797, 134890 (2019)
- Schmidt et al., Nature 578, 541 (2020)

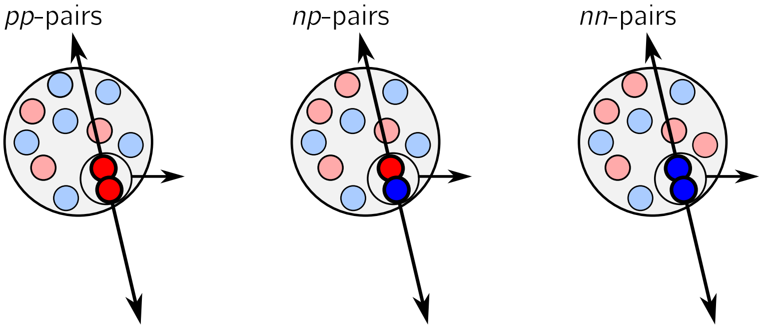
. . . and others!







Neutron-proton pairing dominates, even in asymmetric nuclei.



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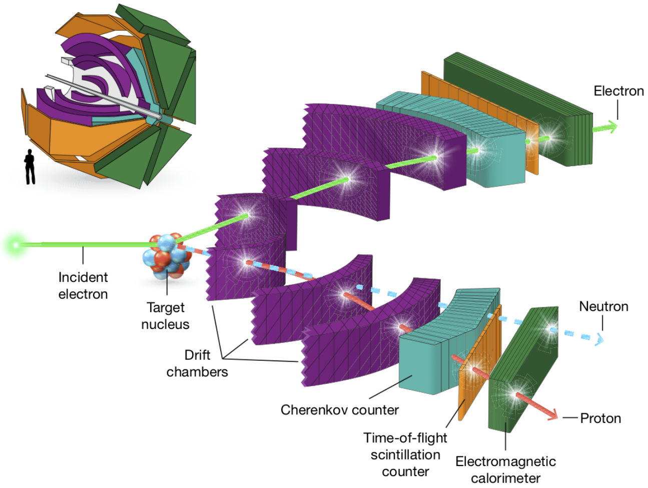

M. Duer et al, Nature 560 pp. 617–621 (2018)

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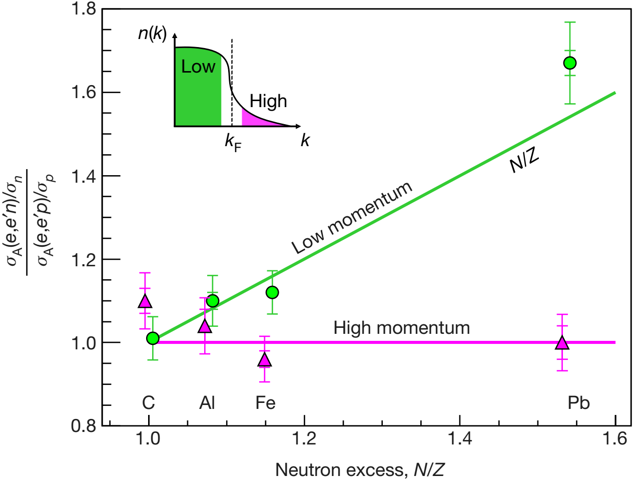

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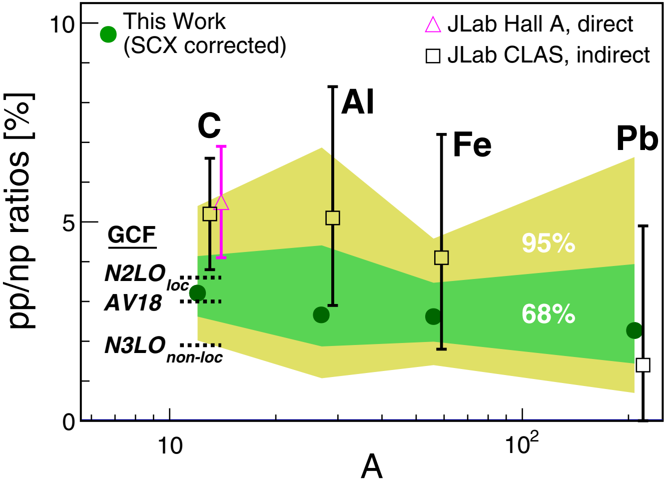
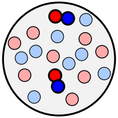
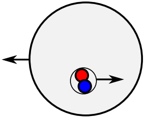


M. Duer et al, PRL 122, 172502 (2019)

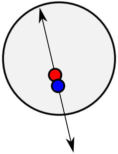
We can understand short-distance structure using scale separation.



Pair abundances



Pair CM motion



Pair relative motion

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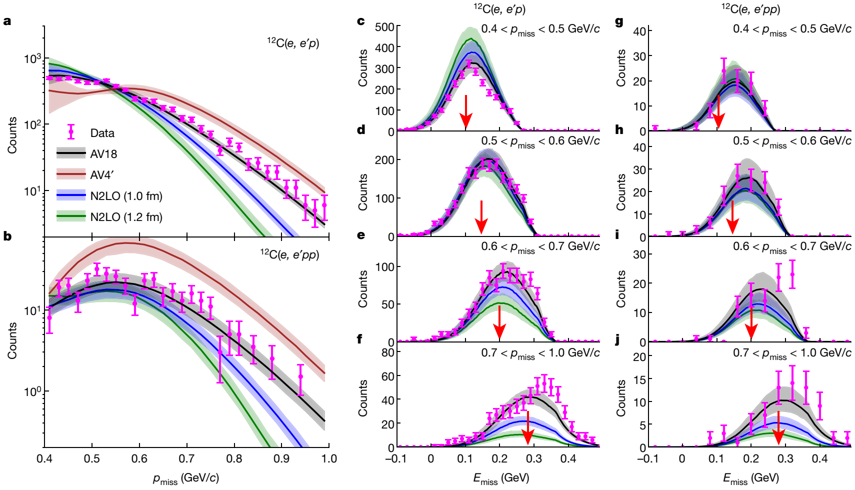

A. Schmidt et al, Nature 578 pp. 540–544 (2020)

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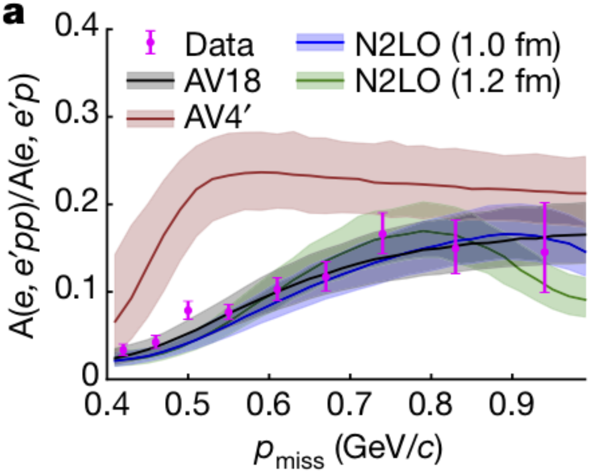

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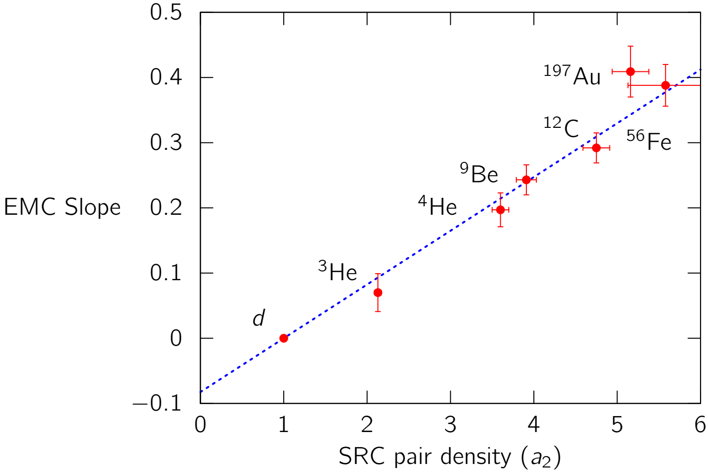
We have uncovered a connection between the EMC Effect and SRC nucleons.



Adapted from Hen et al., PRC 85, 047301 (2012)

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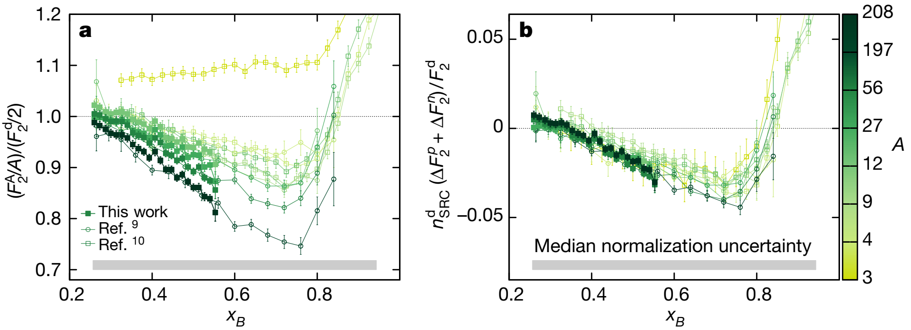
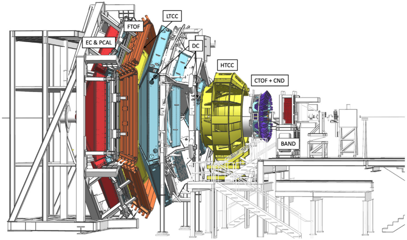


Schmookler et al., Nature 566 pp. 354–358 (2019)

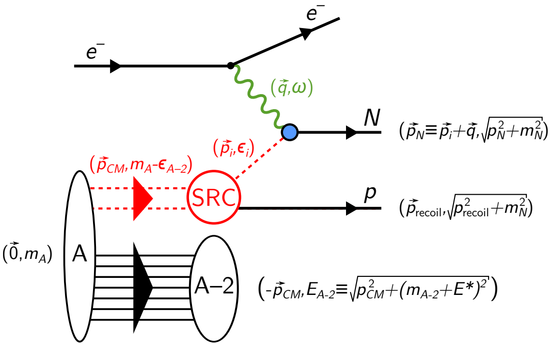
E12-17-006A: A new high-statistics campaign to study SRCs with CLAS-12

- 45 days, 'A'-rating from PAC 46
- CLAS-12 Run Group M
- 10 nuclei, multiple beam energies
- Size and asymmetry dependence
- 10×–100× statistics from 6 GeV Era



The e^--scattering program is built on a set of common assumptions.

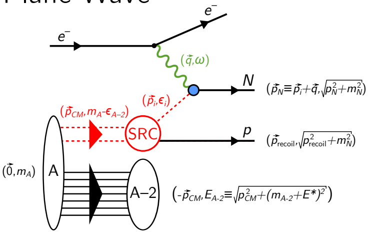
- Scale separation
- Relativistic effects
- Reaction mechanisms
- Final state interactions



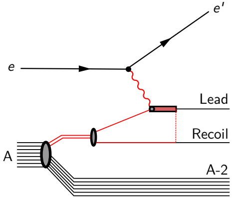
R. Weiss et al., PLB 791 pp. 242–248 (2019)
A. Schmidt et al., Nature 578 pp. 540–544 (2020)
J. R. Pybus et al., PLB 805 135429 (2020)
and others...

These assumptions need to be proven.

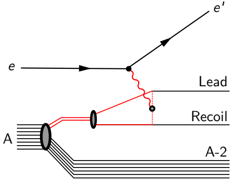
Plane-Wave



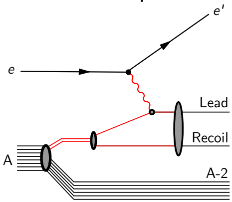
Isobar Config.



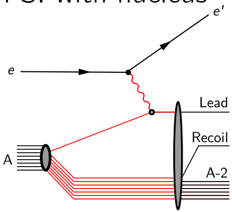
Meson-exchange curr.



FSI within pair



FSI with nucleus



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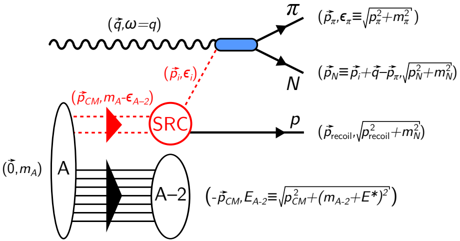
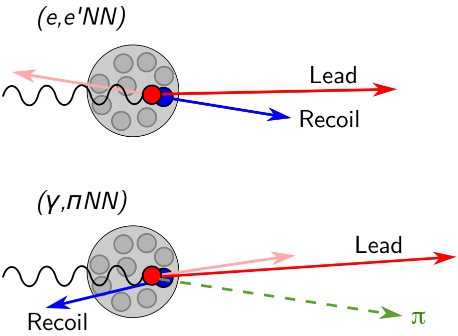


- Scale separation

These assumptions need to be proven.

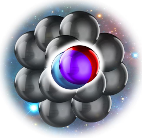


- Scale separation
- Reaction mechanisms
  - Final state interactions
  - Meson-exchange currents
  - Relativitistic effects

There's lots of other photon-nucleus physics too!

- Branching ratio modification

$$|p\rangle_{\text{free}} = \alpha_{PLC}|PLC\rangle + \alpha_{3qg}|3q+g\rangle + \alpha_{3q\pi}|3q+\pi\rangle + \ldots$$

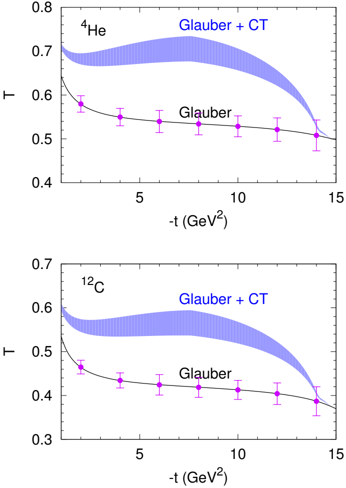


$$|p\rangle_{\text{bound}} = \alpha_{PLC}^{bound}|PLC\rangle + \alpha_{3qg}^{bound}|3q+g\rangle + \alpha_{3q\pi}^{bound}|3q+\pi\rangle + \ldots$$

There's lots of other photon-nucleus physics too!

- Branching ratio modification
- Probing color transparency

$$T \equiv \sigma(\gamma A \to \pi^- p)/\sigma(\gamma d \to \pi^- p)$$



There's lots of other photon-nucleus physics too!

- Branching ratio modification
- Probing color transparency
- Probing neutrons via charged final states
- Photon structure
- ...

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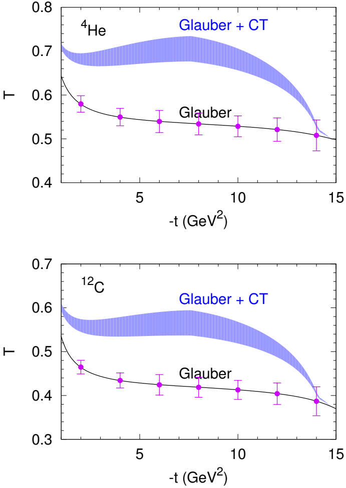

The plan for this experiment:

- Nuclear targets
- GlueX detector in standard configuration
- Measure many photo-production channels on SRC nucleons

p reactions	n reactions
$\gamma p \to \pi^0 p$	$\gamma n \to \pi^- p$
$\gamma p \to \pi^- \Delta^{++}$	$\gamma n \to \pi^- \Delta^+$
$\gamma p \to \rho^0 p$	$\gamma n \to \rho^- p$
$\gamma p \to K^+ \Lambda$	$\gamma n \to K^0 \Lambda$
$\gamma p \to K^+ \Sigma^0$	$\gamma n \to K^0 \Sigma^0$
$\gamma p \to \omega p$	$\gamma n \to K^+ \Sigma^-$
$\gamma p \to \phi p$	$\gamma n \to K^- \Sigma^+$
$\vdots$	$\vdots$

- Extract cross-section ratios
  - C/d
  - Channel 1 / Channel 2
  - Double ratios

Road to first publication

Demonstrating np-SRC dominance in the tensor region using photon probes

- $\gamma p(p) \longrightarrow \pi^0 p(p)$
- $\gamma n(p) \longrightarrow \pi^- p(p)$
- $\gamma p(p) \longrightarrow \rho^0 p(p)$
- $\gamma n(p) \longrightarrow \rho^- p(p)$

- ρ-production is the highest cross-section channel.
- The π/ρ double ratio can be used to reduce sensitivity to π^0 acceptance.

- *First publication anticipated within 1 year*

Our 12 GeV track record

Hall A Tritium Program

- April 12–30, 2018
  Data Taking

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Hall A Tritium Program

- April 12–30, 2018
  Data Taking
- Feb. 18, 2019
  arXiv:1902.06358

ELSEVIER

Physics Letters B
Volume 797, 10 October 2019, 134890

Comparing proton momentum distributions in A=2 and 3 nuclei via ^{2}H ^{3}H and ^{3}He $(e,e'p)$ measurements

Jefferson Lab Hall A Tritium Collaboration

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https://doi.org/10.1016/j.physletb.2019.134890
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Abstract

We report the first measurement of the $(e,e'p)$ reaction cross-section ratios for Helium-3 (^{3}He), Tritium (^{3}H), and Deuterium (d). The measurement covered a missing momentum range of $40 \leq p_{miss} \leq 550$ MeV/c, at large momentum transfer ($\langle Q^2 \rangle \approx 1.9$ (GeV/c)^2) and $x_B > 1$, which minimized contributions from non quasi-elastic (QE) reaction mechanisms. The data is

Our 12 GeV track record

Hall A Tritium Program

- April 12–30, 2018 Data Taking
- Feb. 18, 2019 arXiv:1902.06358
- Jan. 20, 2020 arXiv:2001.07230

Nuclear Experiment

[Submitted on 20 Jan 2020]

Probing few-body nuclear dynamics via 3H and 3He (e,e'p)pn cross-section measurements

R. Cruz-Torres, D. Nguyen, F. Hauenstein, A. Schmidt, S. Li, D. Abrams, H. Albataineh, S. Alsalmi, D. Androic, K. Aniol, W. Armstrong, J. Arrington, H. Atac, T. Averett, C. Ayerbe Gayoso, X. Bai, J. Bane, S. Barcus, A. Beck, V. Bellini, F. Benmokhtar, H. Bhatt, D. Bhetuwal, D. Biswas, D. Blyth, W. Boeglin, D. Bulumulla, A. Camsonne, J. Castellanos, J-P. Chen, E. O. Cohen, S. Covrig, K. Craycraft, B. Dongwi, M. Duer, B. Duran, D. Dutta, E. Fuchey, C. Gal, T. N. Gautam, S. Gilad, K. Gnanvo, T. Gogami, J. Golak, J. Gomez, C. Gu, A. Habarakada T. Hague, O. Hansen, M. Hattawy, O. Hen, D. W. Higinbotham, E. Hughes, C. Hyde, H. Ibrahim, S. Jian, S. Joosten, H. Kamada, A. Karki, B. Karki, A. T. Katramatou, C. Keppel, M. Khachatryan, V. Khachatryan, A. Khanal, D. King, P. King, I. Korover, T. Kutz, N. Lashley-Colthirst, G. Laskaris, W. Li, H. Liu, N. Liyanage, P. Markowitz, R. E. McClellan, D. Meekins, S. Mey-Tal Beck Z-E. Meziani, R. Michaels, M. Mihovilovic, V. Nelyubin, N. Nuruzzaman, M. Nycz, R. Obrecht, M. Olson, L. Ou, V. Owen, B. Pandey, V. Pandey, A. Papadopoulou, S. Park, M. Patsyuk, S. Paul, G. G. Petratos, E. Piasetzky, R. Pomatsalyuk, S. Premathilake, A. J. R. Puckett, V. Punjabi, R. Ransome, M. N. H. Rashad et al. (28 additional authors not shown)

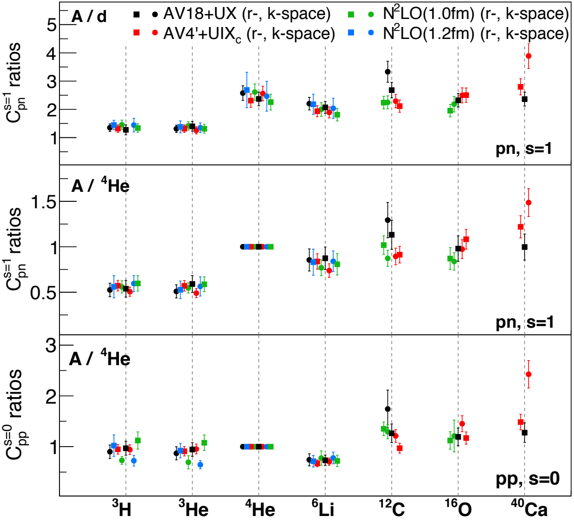
We report the first measurement of the (e,e'p) three-body breakup reaction cross sections in Helium-3 (^{3}He) and Tritium (^{3}H) at large momentum transfer ($\langle Q^2 \rangle$ 1.9 (GeV/c)^2) and $x_B > 1$ kinematics, covering a missing momentum range of $40 \le p_{miss} \le 500$ MeV/c. The measured cross sections are compared with different plane-wave impulse approximation (PWIA) calculations, as well as a generalized Eikonal-Approximation-based calculation that includes the final-state interaction (FSI) of the struck nucleon. Overall good agreement is observed between data and Faddeev-formulation-based PWIA calculations for the full p_{miss} range for ^{3}H and for $150 \le p_{miss} \le 350$ MeV/c for ^{3}He. This is a significant improvement over previous studies at lower Q^2 and $x_B \sim 1$ kinematics where PWIA calculations differ from the data by up to 400%. For $p_{miss} \ge 250$ MeV/c, the inclusion of FSI makes the calculation agree with the data to within about 10%. For both nuclei PWIA calculations that are based on off-shell electron-nucleon cross-sections and exact three-body spectral functions overestimate the cross-section by about 60% but well reproduce its p_{miss} dependence. These data are a crucial benchmark for few-body nuclear theory and are an essential test of theoretical calculations used in the study of heavier nuclear systems.

Experiment Readiness Review

- Run plan, conditions, configuration — H. Szumila-Vance
  - Addressing charges 1, 3, & 5
- Status of the target system — C. Keith
  - Addressing charge 2
- Radiation and Beamline Commissioning — A. Somov
  - Addressing charges 4 & 7
- Documentation — L. Pentchev
  - Addressing charge 9
- Responsibilities for the experiment and analysis — O. Hen
  - Addressing charges 6 & 8

Back-up

Scale/Scheme-independence and *k*-*r* equivalence



R. Cruz-Torres et al., arXiv:1907.03658

Competing reaction mechanisms in e^--scattering