SRC White Paper Forum

Introduction

- Many workshops over the years, some review papers, but no vision from the full community
- Nadia and Or decided to convene a group of (primarily) early career members to write a document that looks to the future, but is grounded in recent work
- We want a document that the SRC community (people that consider themselves part of it) signs onto
    - What we know
    - What we think we know
    - What does our data mean? → if we disagree about interpretation, what is needed for consensus?
        - This informs our future
    - What do we not know yet?

(key) Open questions

2N SRC

- Scale dependence (Q^2)
  - All observables
- Probe independence (*e,p,gamma*)
  - Confirm factorization
- Pairing mechanisms
- Precision of interpretation in terms of ground state properties (theory)
- Neutron rich systems

3N SRC

- (e,e’) high Q^2 x>2
- 3N KO (e,e’ppN)

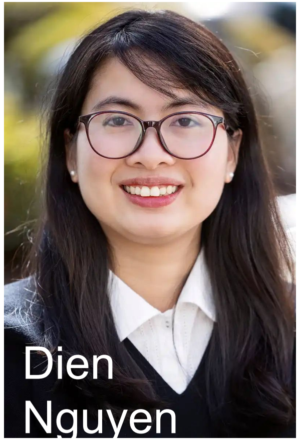
Theory guidance:

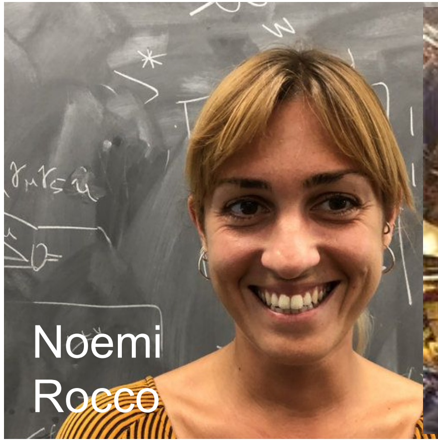
- Kinematics
- Ground state
- Factorization
- Phenomenology

What do we learn if we don’t see 3N SRC?

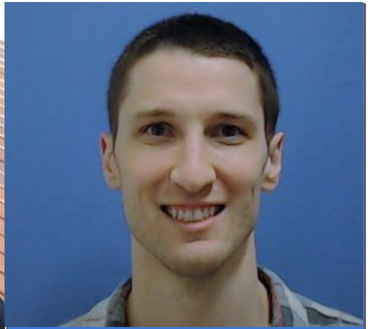
(at kinematics accessible to us)

Current Contributors





Jackson Pybus



Anthony Tropiano
(SRG text)

White Paper Organization

Section I - Introduction

- This is meant to be a little bit of a historical background, so that people new to the field realize that the SRC story didn't start in in the 1990s
- Will be fleshed out more

Section II - Probing Correlations (Theory and Experiment) 1980-2010ish

Section III - Modern Studies of SRCS

- Overview of Experimental Data and major conclusions

Section IV - Modern Theory of SRCs

Section V - Going Forward

- What do we need (theory and experiment wise) to make new progress?

Experimental: SRC using electron scattering

Tool:

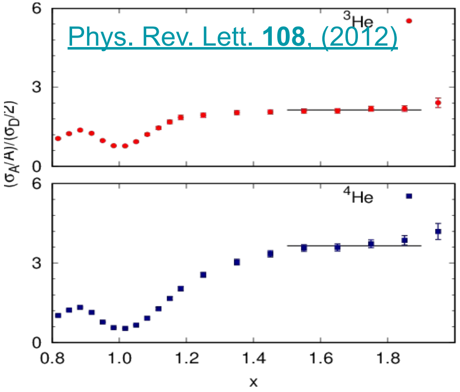
- Inclusive A(e,e’)
  - ***High-precision data***
  - ***2N SRC Probability***
  - *Interpretation uncertainties*
- Knock out proton A(e,e’p)
  - ***Discriminating between protons and neutrons***
  - ***Measure E_{miss} and P_{miss}***
  - *FSIs*
- Two-nucleon knock out A(e,e’NN)
  - ***pp to pn pair ratios***
  - ***Pair momentum distributions***

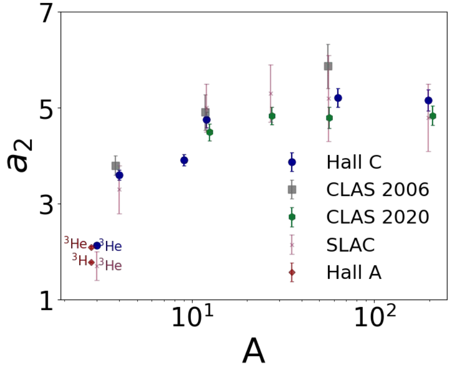
Experimental: A(e,e') Results

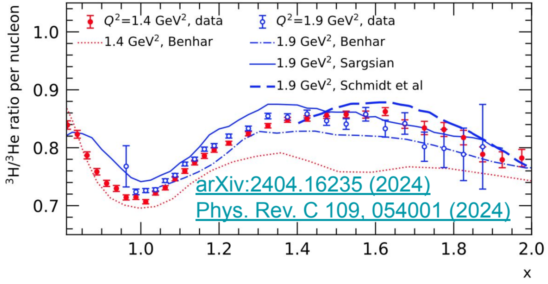
- Observed scaling in the 2N SRC-dominated region:

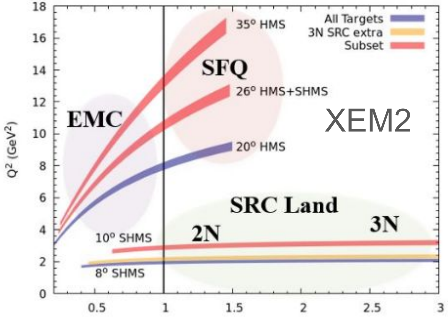
$$a_2(A,D) = \frac{2}{A}\frac{\sigma_A(x,Q^2)}{\sigma_D(x,Q^2)} \qquad Q^2 \gtrsim 1.5\ \mathrm{GeV}^2 \qquad 1.5 \lesssim x_B \lesssim 1.9$$

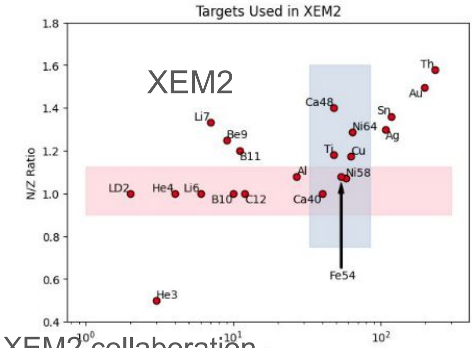
- Consistent a_2 measurements: SLAC, A, B, C ^{3}H, ^{3}He, ^{4}He, ^{9}Be, ^{12}C, ^{27}Al, ^{56}Fe, ^{63}Cu, ^{197}Au, ^{208}Pb
- State of the art calculations for high x data for light nuclei 2N-SRC region for light nuclei: Benhar, Sargsian, Ciofi
- Need of further exploration of the 3N SRC region











Courtesy of the XEM2 collaboration

Under Analysis

XEM2 Experiment (Hall C)

- Looking for 3N-SRC
- Understanding A dependence of a_2

Future:

Push to high Q^2 for 3N SRC observation

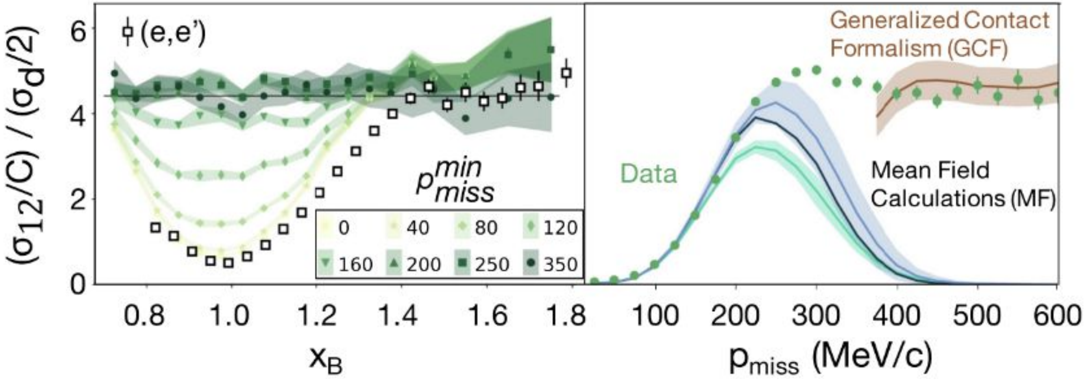
Experimental: A(e,e'p) Results

- Scaling was observed for 2N SRC:

$$Q^2 \gtrsim 1.5\ \mathrm{GeV}^2$$
$$1.5 \lesssim x_B \lesssim 1.9$$
$$250 < p_{\mathrm{miss}} < 600\mathrm{MeV/c}$$

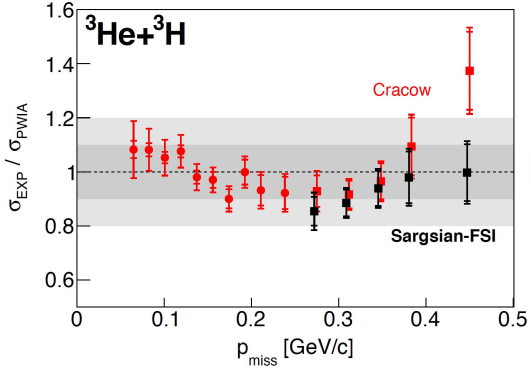
- Narrow transition from MF to SRC
  - $250 < p_{miss} < 350$ MeV/c

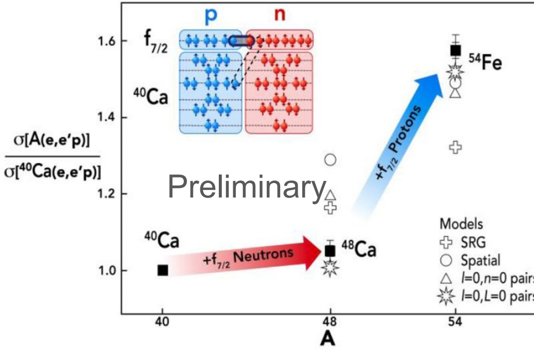
Phys. Rev. C Lett. 107, L061301 (2023).



R. Cruz-Torres PRL (2020)

- A=3 (e,e'p)
  - Isoscaler data agrees with full calculation up to 500 MeV/c
- A(e,e'p) pairing mechanisms (CaFe)
  - Intra-shell pairing dominant
  - Inter-shell pairing weak





- Future:
  - Extend ^{3}H,He(e,e'p) to Pmiss ~ 1 GeV
  - Test pairing with ^{40,48}Ca(e,e'pp) and (e,e'pn) [RGM]

Experimental: A(e,e'NN) results

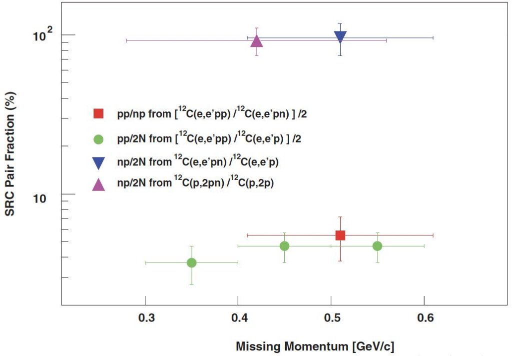
- Almost all high momentum nucleons (k > kf) belong to an SRC pair
  - pair is back-to-back with large relative momentum and smaller center of mass momentum
  - The p_rel distribution is universal
  - The p_cm distribution width is consistent with the sum of two MF nucleons

- About 25% of nucleons in medium to heavy nuclei belong to SRC pairs

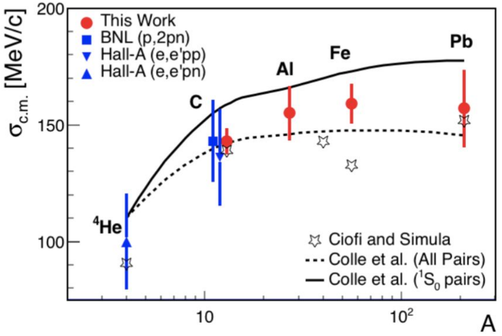
- SRCs pairs are predominantly np pairs (90% np, 5% each pp and nn)
  - np dominance is due to the tensor force around ~ 400 MeV/c
  - np dominance is A-independent
  - Scalar force dominance as p_rel → 1 GeV/c,

- Future:
  - Q2-independent
  - 3N knockout SRC

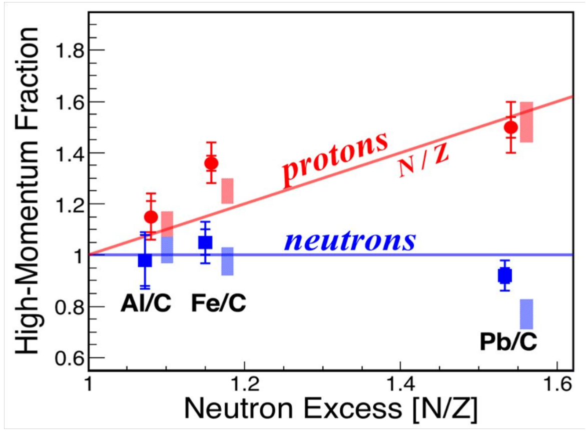
R. Subedi, Science (2008)



EO. Cohen, PRL (2018)



M. Duer, Nature (2018)



Experimental: SRC using electron scattering

Lessons

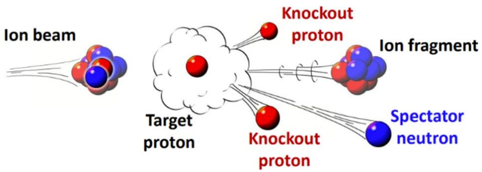
- Inclusive A(e,e’)
  - ***Shows SRC dominance at $k>k_{fermi}$***
    - ***Observed scaling of A/D cross sections at $x>1.5$, $Q^2>1.4$***
    - ***a_2 across many nuclei***
    - ***Proportional to SRC abundances***
- Two-nucleon knock-out A(e,e’NN)
  - ***pn pair dominance***
  - ***All* high momentum nucleons belong in SRC pairs***
  - ***pp/pn ratio increases with missing momentum***
    - ***Tensor → scalar transition***
- Single Nucleon knock-out A(e,e’p|n)
  - ***Direct comparison to theory for light nuclei***
  - ***Proportional to abundance of high-momentum of protons and neutrons***
    - ***Which nucleons pair (pairing mechanisms)***
  - ***Narrow transition region (mean field → SRC)***

Experimental: SRC studies using hadronic probes

Objectives

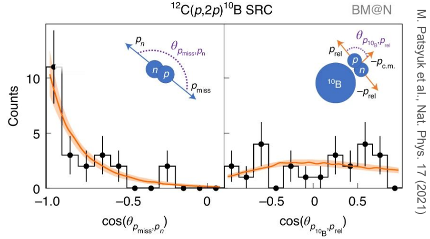
- Probe independence
- Fully exclusive measurements
- Neutron-rich systems

⇨ inverse kinematics
A(p,2pX)A-2

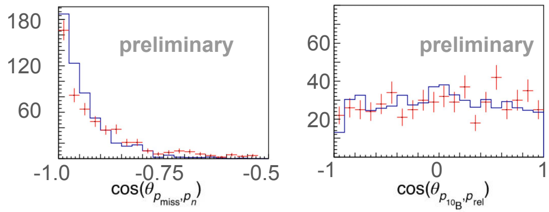


Results

- Pilot experiments at JINR and GSI-FAIR with ^{12}C (4+2 GeV/c/u) and ^{16}C (2 GeV/c/u)
- successful SRC identification
- confirmed pn dominance, low p_{cm}, indication for factorization A-2 vs pair

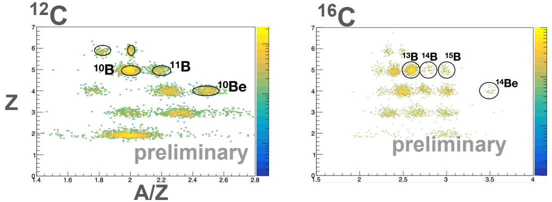


$^{12}C(p,2p)^{10}B$ @ GSI-FAIR

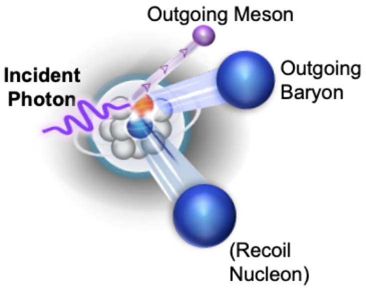


Future

- High-quality data (normal + inverse)
- Unique advantage: inverse kinematics
  - Radioactive-ion beams: chains of asymmetric nuclei
  - Fully-exclusive: factorization; 2N + 3N
  - Spectator final-state tagging: pair formation
- Many-body nuclear structure theory
- Reaction theory: new tools (p,pd)?



Experimental: SRC studies using photoproduction

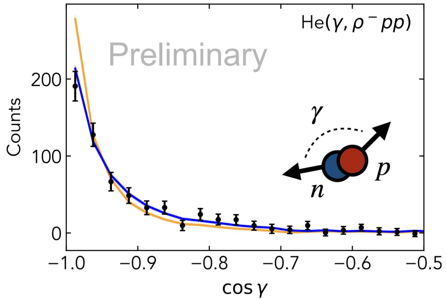


Objectives

- Establish probe-independence
- Explore unique kinematics
- Probe initial-state neutrons

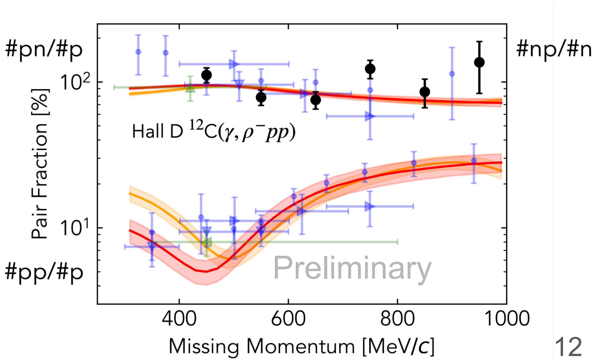
Results

- JLab Hall D; 6-10.8 GeV tagged photon beam; ^{2}H, ^{4}He, and ^{12}C targets
- First observation of SRC breakup in photoproduction using (γ, ϱ^-p) and (γ,ϱ^-pp)
- Measures initial-state neutrons using charge-exchange reactions; direct measure of NP-SRC pairs
- Consistency with electron- and hadron-scattering results



Future

- Finalize current ϱ^--channel analysis
- Analysis of complementary neutral channels (γ,ϱ^0p) and (γ,ϱ^0pp)
- Search for NPP-SRC triplets via (γ,m$^-$ppp) reactions



Open questions

2N SRC

- Scale dependence (Q^2)
    - All observables
- Probe independence (*e,p,gamma*)
    - Confirm factorization
- Pairing mechanisms
- Precision of interpretation in terms of ground state properties (theory)
- Neutron rich systems

3N SRC

- (e,e') high Q^2 x>2
- 3N KO (e,e'ppN)

Theory guidance

- Kinematics
- Ground state
- Factorization
- Phenomenology

What do we learn if we don't see 3N SRC?

(at kinematics accessible to us)

Discussion

- Is there missing content?
- Is there unclear/ambiguous content?
- What topics are unevenly covered?
- Where do we see ourselves in 5 years?

Some initial feedback -1

Strongly disagree with the statement around eq (1) that momentum distributions cannot be measured by experiments.

If this were the case, why do experiments? You shoot yourself in the foot.

The discussion ignores scale dependence, which is central to all rg analyses. You have to measure at the scale where you measure the right hand side of eq(1).

Furthermore Furntsahl's more recent work is aimed at proving that you can make such measurements. These points are made in the discussion in lines 48-56

There is something called ARPES in cm physics, in which electron momentum distributions are measured. NO one disputes that.

So my comment is about the writing, which needs to deemphasize eq(1) and not even mention that you can't do measurements. The way it is written now, people will get to eq(1) and the ensuing comment and stop reading.

Action item: Will reword. Momentum Distributions are not observations, but can be extracted from cross sections in a particular frame with particular operators.

General Feedback

- Inconsistent use of values for Q^2 and x for scaling throughout - will address
- Need general intro/overview of Quasielastic Scattering
- No mention of Drell-Yan data for SRC insight
-

Some initial feedback - Section II

- Inclusive and 2-body breakup paragraphs provide different levels of detail
- B - add some discussions of 2N, 3N forces and potentials, repulsive core v.s. tensor, and how those calculations are "ab initio”
-

Some initial feedback - Section III (Hall D experiments)

(A) What is the most suitable background model for describing the background in nuclear targets? Have different models been compared, and if so, which has shown the best agreement with experimental data?

(B) How well do your simulations perform at high values of $|t||t|$ and $|u||u|$? Are there any known limitations or discrepancies in the simulated distributions compared to experimental data?

(C) What is the reconstruction efficiency for the detected particles, and how is it normalized? Have there been studies on potential biases in the efficiency determination?

(D) How reliable is the particle identification in GlueX at high $|t|$ and $|u|$? Are there specific challenges in distinguishing particle species in this kinematic regime?

(E) Have systematic studies been conducted to evaluate the robustness of the results? If so, what sources of systematic uncertainty have been considered, and how have they been quantified?

(F) How do you justify that the selected events during the reconstruction process originate from the desired reaction rather than background contamination or misidentification? What selection criteria or validation methods have been employed to ensure signal purity?

(G) Background contamination can arise from misidentification of charged particles and electromagnetic showers. How is this background treated, and what methods are used to mitigate its impact on the results?

///////These are fundamental questions that must be thoroughly addressed before conducting the analysis.

Not sure what this refers to

To ensure a thorough analysis, it is essential to develop a robust theoretical background, improve background modeling, and enhance detector understanding. It has been noted that no prior high-quality simulations have been conducted. Once the experiment is performed, data handling appears to present challenges, potentially affecting the integrity of the results.

Additionally, Ph.D. students working on the analysis have limited time, and there is currently no dedicated individual responsible for continuing the analysis once data collection is completed. How will this issue be addressed?

Furthermore, what is the expected timeline for completing the analysis and publishing the results? Are there specific measures in place to ensure timely and efficient data processing and publication?

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Scale dependence (Q2)

All observables

Probe independence (e,p,gamma)

Confirm factorization

Precision of interpretation in terms of ground state properties (theory)

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Theory guidance

Kinematics

Ground state

Factorization

Phenomenology

What do we learn if we don’t see it?

Experimental: SRC studies using hadronic probes

Objectives

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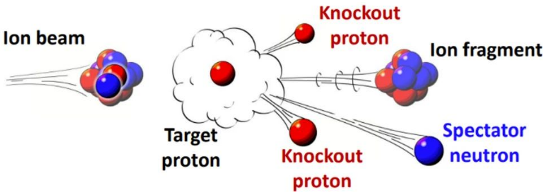
- Neutron-rich systems
- Fully exclusive measurements



Results

- First: (p,2pX) pair breakup in normal kinematics at BNL
- New: A(p,2pX)A-2 reactions in inverse kinematics [access p_{lead}, p_{recoil}, $p_{A\text{-}2}$]
- Pilot experiments at JINR and GSI-FAIR with ^{12}C (4+2 GeV/c/u) and ^{16}C (2 GeV/c/u):
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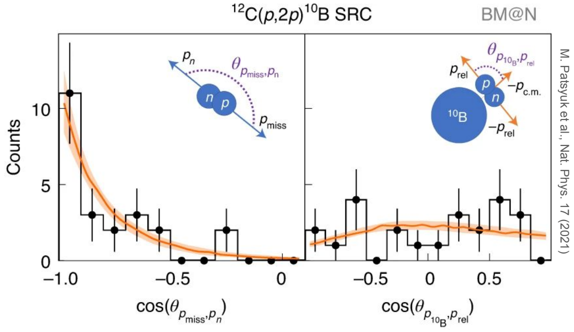

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- Reaction theory and FSI: new tools (p,pd)?