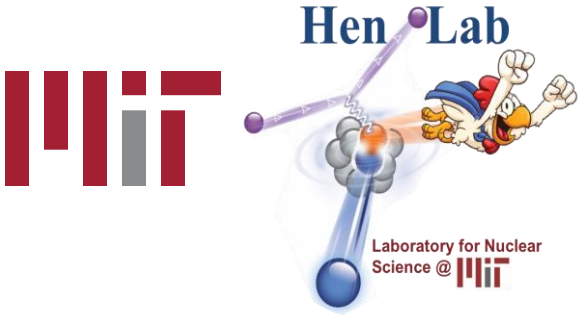
Towards the study of Short-Range Correlations in radioactive nuclei:

The transparent nucleus in inverse kinematics

Julian Kahlbow

International Workshop on Chiral Dynamics
Nov 16th, 2021

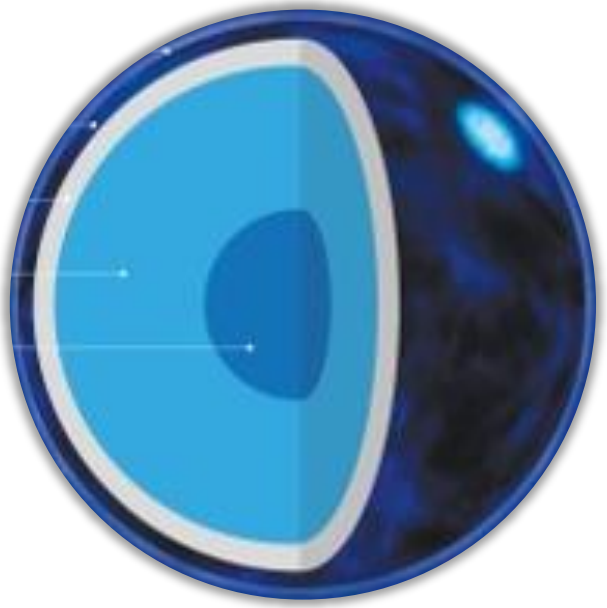


TEL AVIV UNIVERSITY

Neutron stars in the lab?

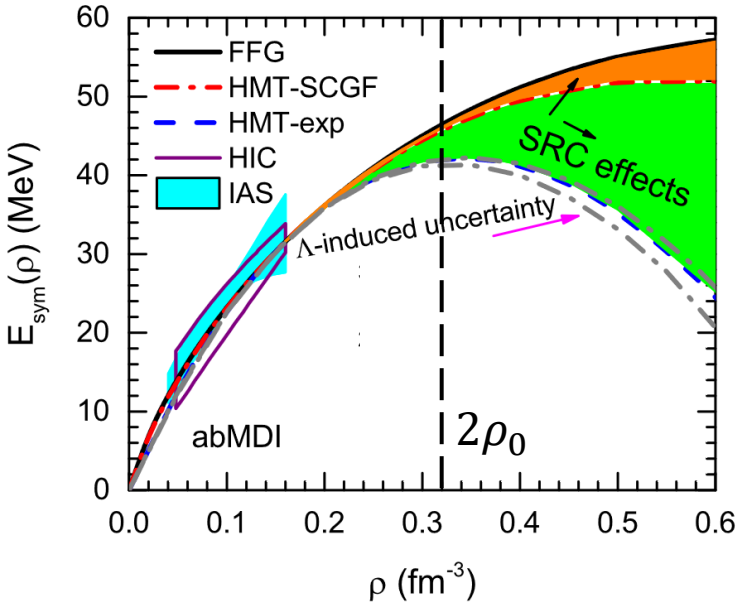
Neutron Star:

- **high density**
- **N/Z~20**



-> understand interactions in cold dense nuclear matter

Cold dense nuclear matter: Neutron stars and SRCs



adapted:
B.-J. Cai, B.A. Li, L.-W. Chen,
AIP Conf. Proc. 2038 (2018).

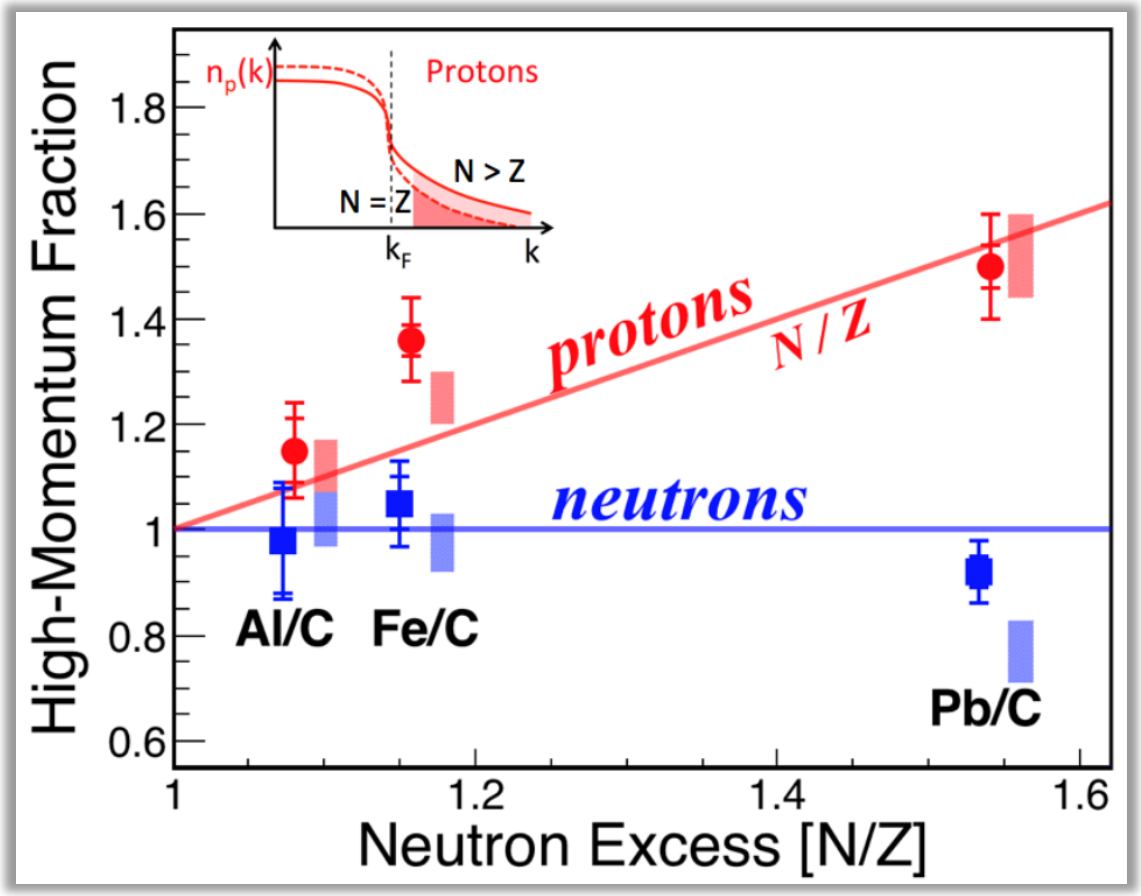
Nuclear structure and interaction in
- neutron-rich
- high-density
- cold

environment

→ Equation-of-State →

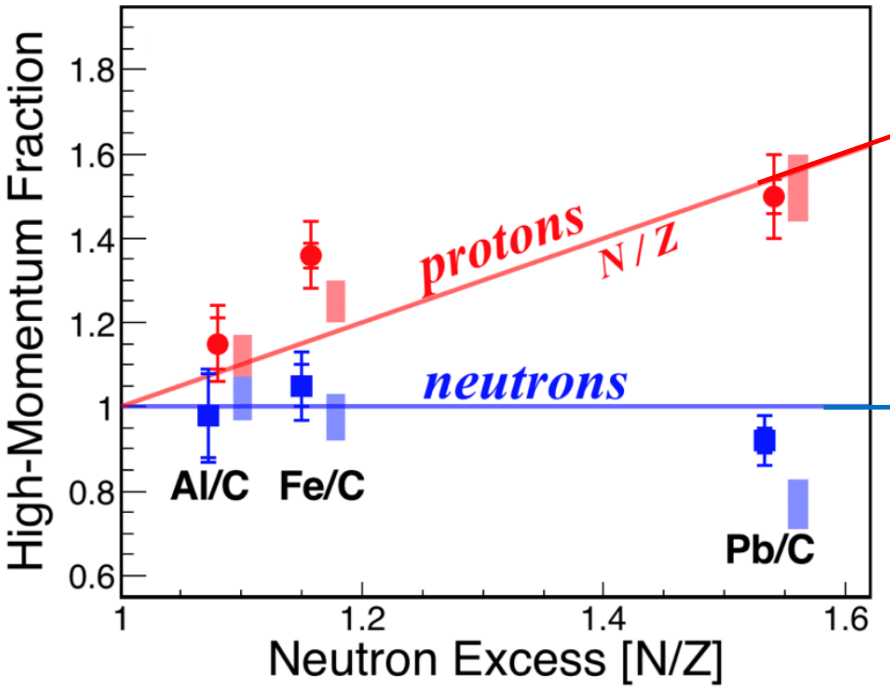
NN + 3N SRCs are crucial

SRC and nuclear many-body system:
Protons become more energetic in neutron-rich nuclei



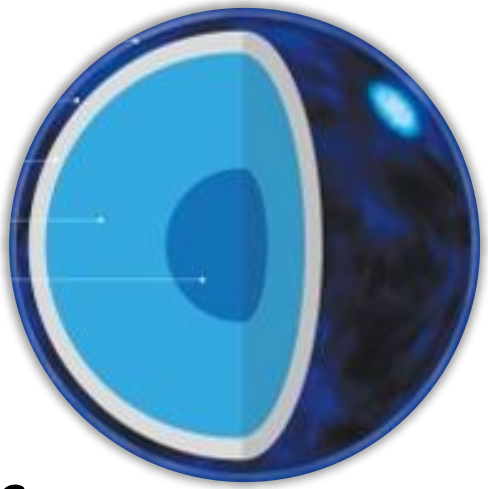
M. Duer et al. (CLAS), Nature 2018.

Neutron-rich nuclei: towards cold dense nuclear matter



?

Neutron Star:
- **high density**
- **N/Z~20**

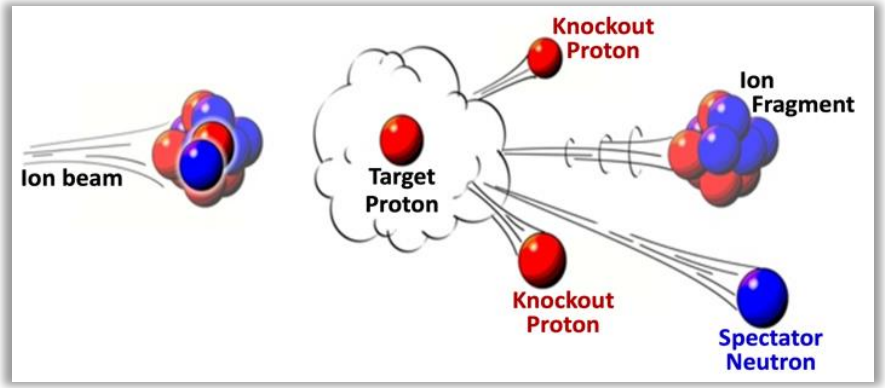


^{16}C ^{18}C ^{20}C
systematic studies
along isotopic chains:

Need radioactive-ion beams

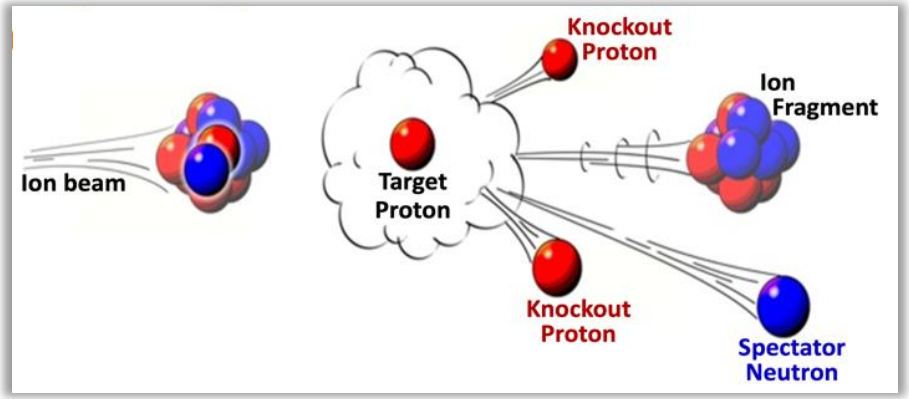
Nucleon-knockout experiments in inverse kinematics to study ground-state distributions

(radioactive) ion beam
hitting hadronic probe



fully exclusive measurement:
measure all emerging particles

Distortions due to initial and final state interactions overcome in inverse kinematics



incoming and
outgoing protons
interact with other nucleons

→ disturb initial momentum reconstruction

→ extra excitations of the nucleus (break fragment apart)

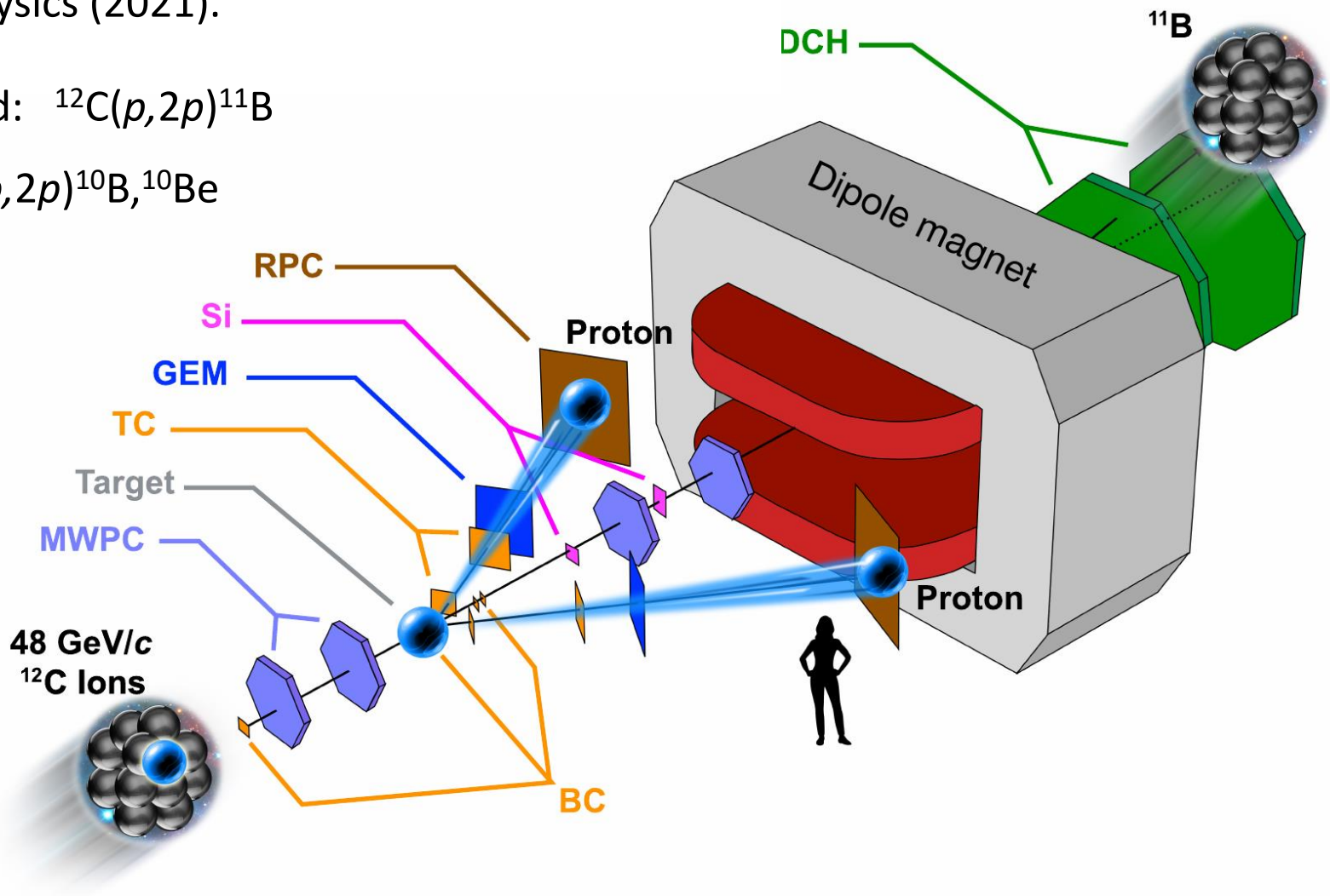
→ eject additional particles (pions, …)

Experiment at BM@N Setup (JINR, Russia)

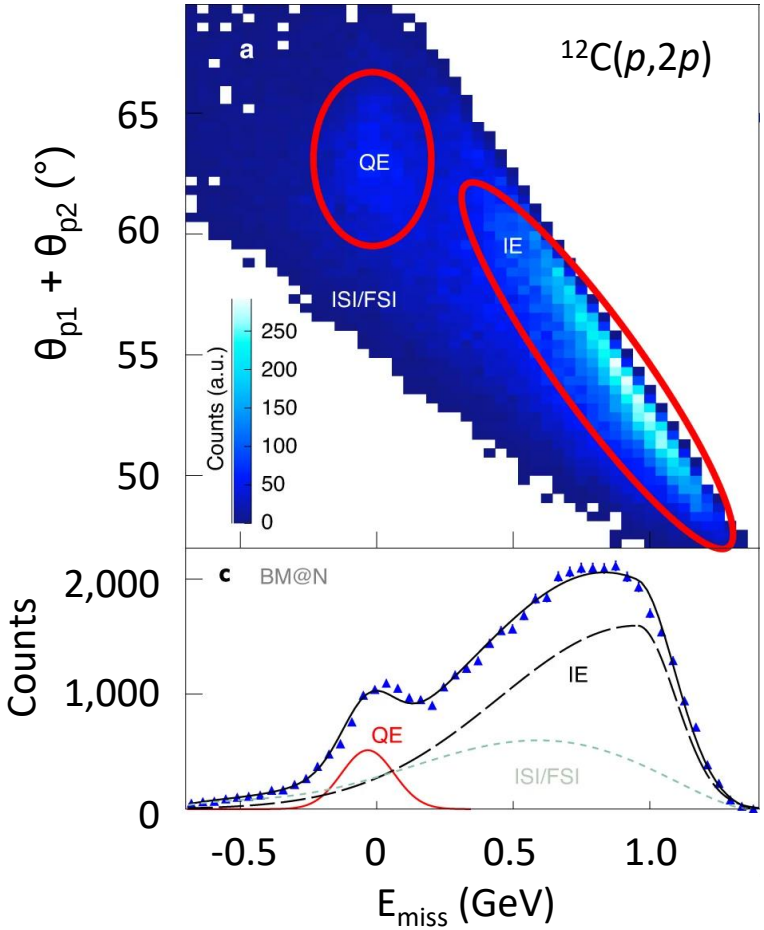
M. Patsyuk, JK et al. (BM@N),
Nature Physics (2021).

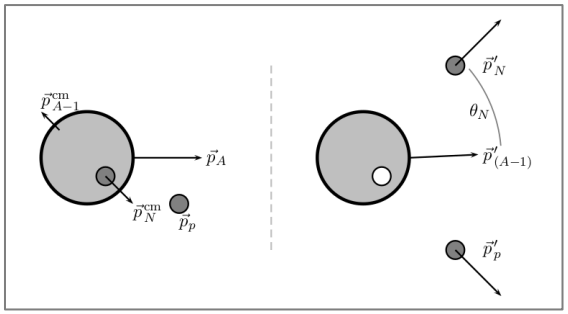
Mean-field: $^{12}C(p,2p)^{11}B$

SRC: $^{12}C(p,2p)^{10}B,^{10}Be$



$^{12}C(p,2p)$ inclusive scattering dominated by inelastic scattering and initial/final state interactions

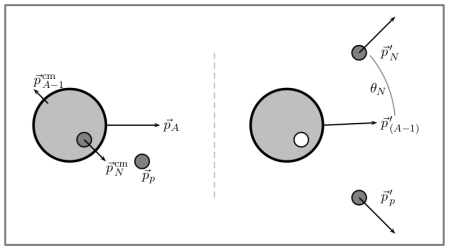


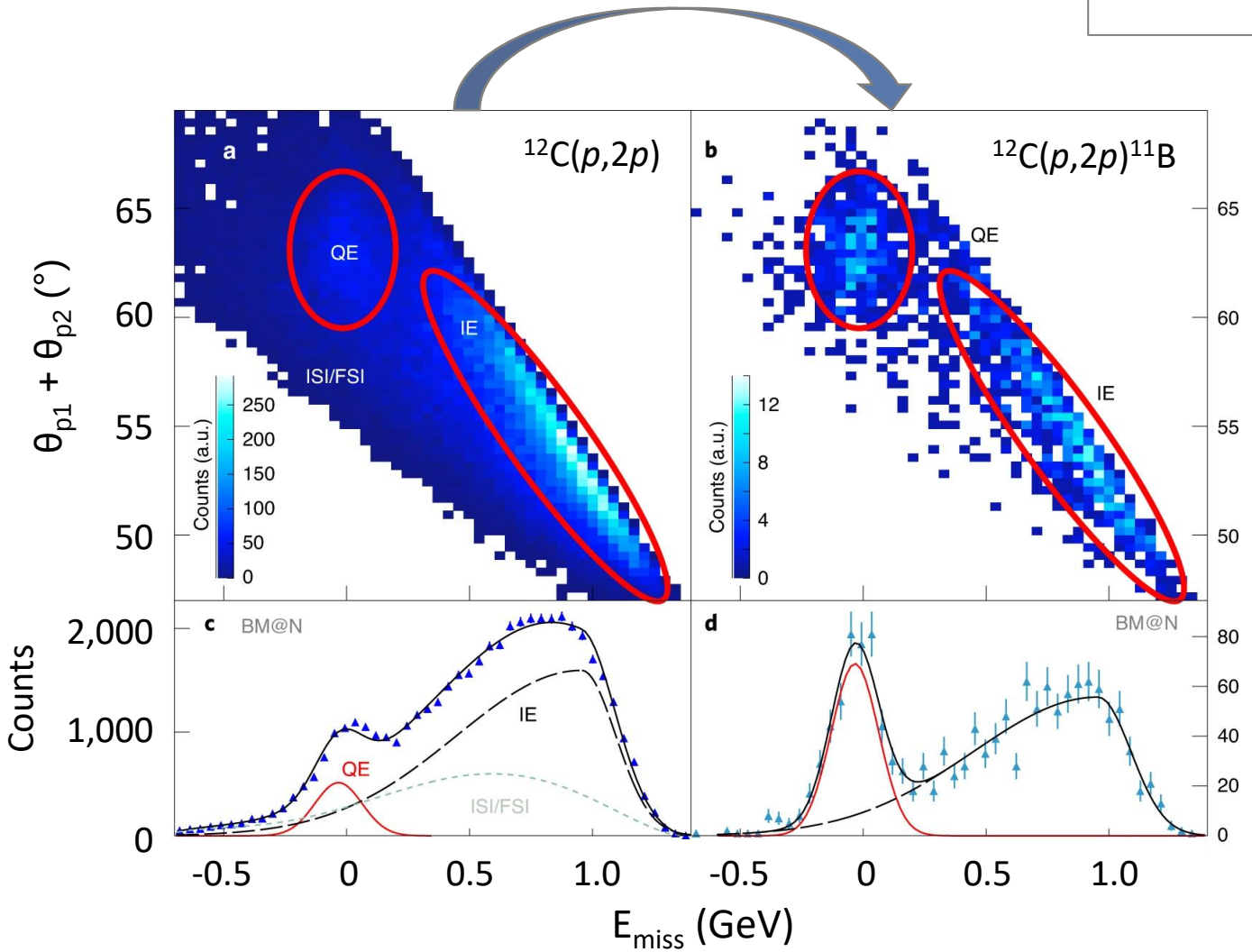


M. Patsyuk, JK et al. (BM@N), Nature Physics 17 (2021).

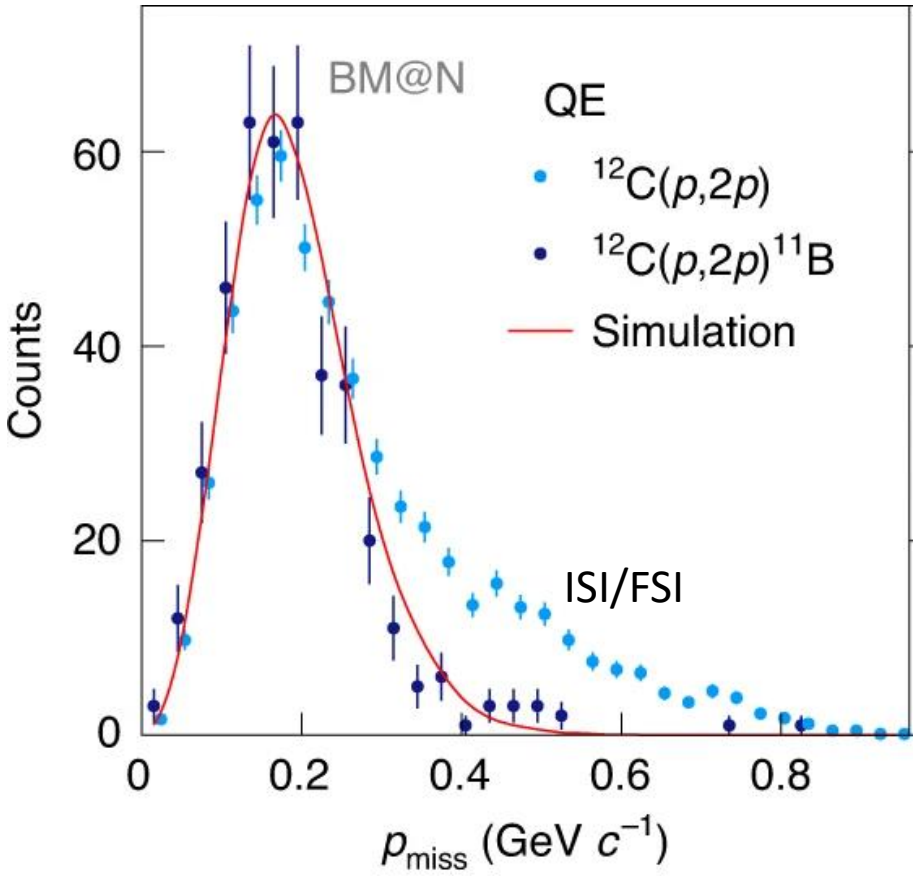
Reaction mechanism under control

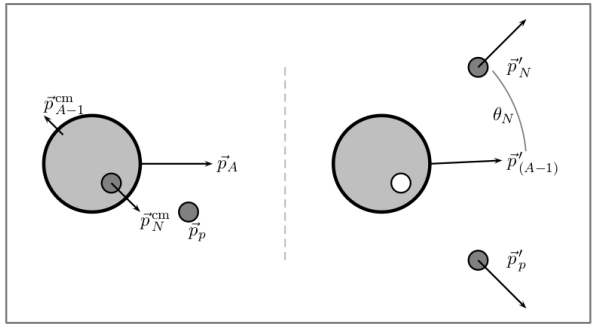
Fragment tagging suppresses initial/final state interactions





Single-step nucleon knockout proven: Access ground-state distributions





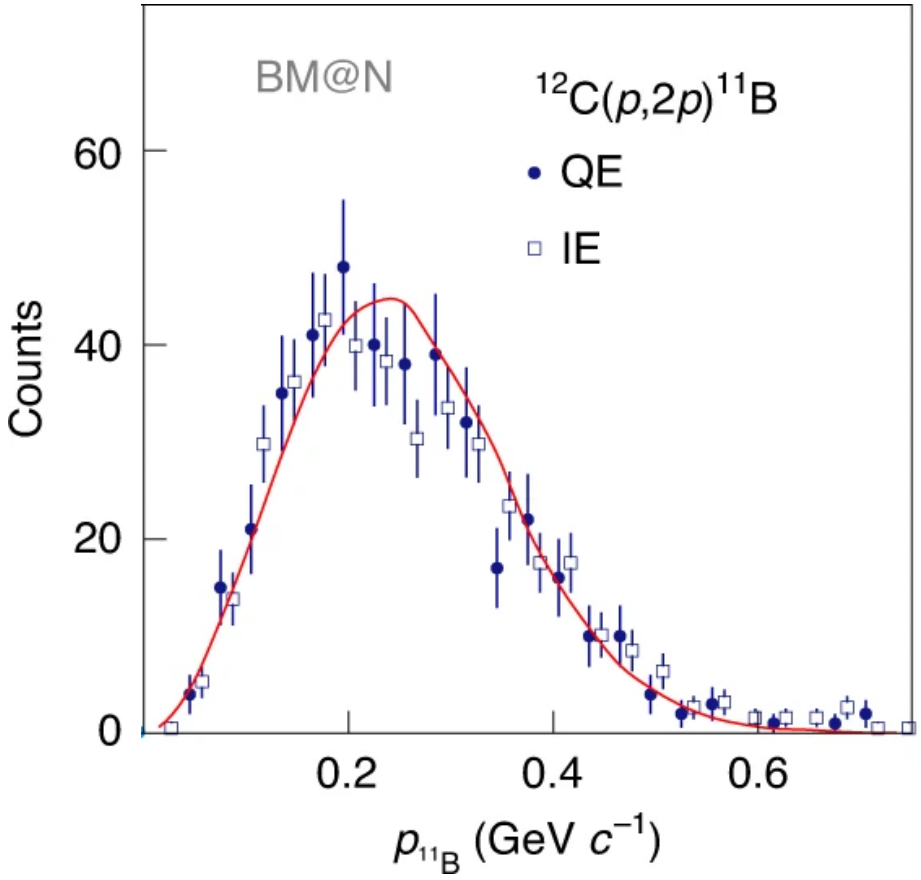
Calculation of QE (*p,2p*) scattering off *p*-shell nucleon in ^{12}C without ISI/FSI

[T. Aumann, C.A. Bertulani, J. Ryckebusch, PRC 88 (2013).]

M. Patsyuk, JK et al. (BM@N), Nature Physics 17 (2021).

Fragment recoil momentum

Fragment not impacted by inelastic scattering:
adiabatic approximation holds $p_{miss} = -p_{A-1}$



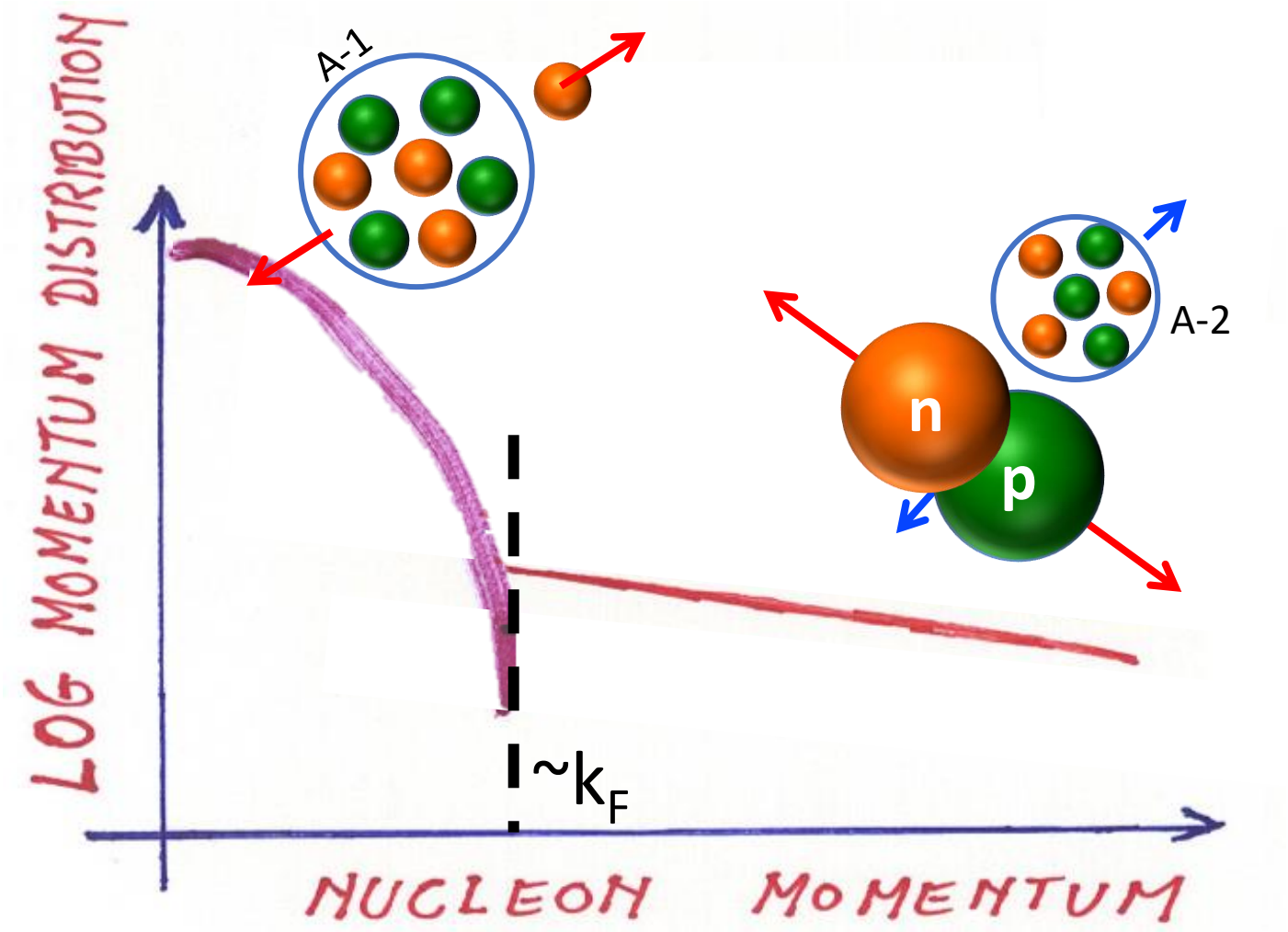
M. Patsyuk, JK et al. (BM@N), Nature Physics 17 (2021).

Experiment in inverse kinematics

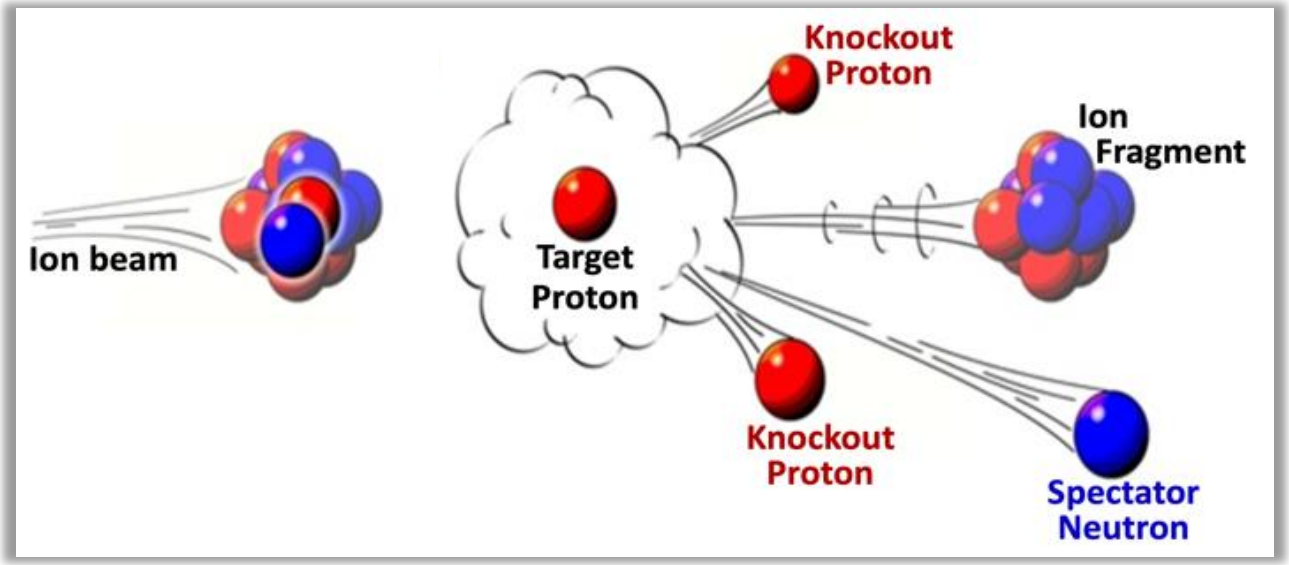
at high energy with hadronic probe

is a “clean” technique to study nuclear interactions

Short-range correlations studied in inverse kinematics



First study of SRCs in inverse kinematics



Hard breakup of SRC pairs

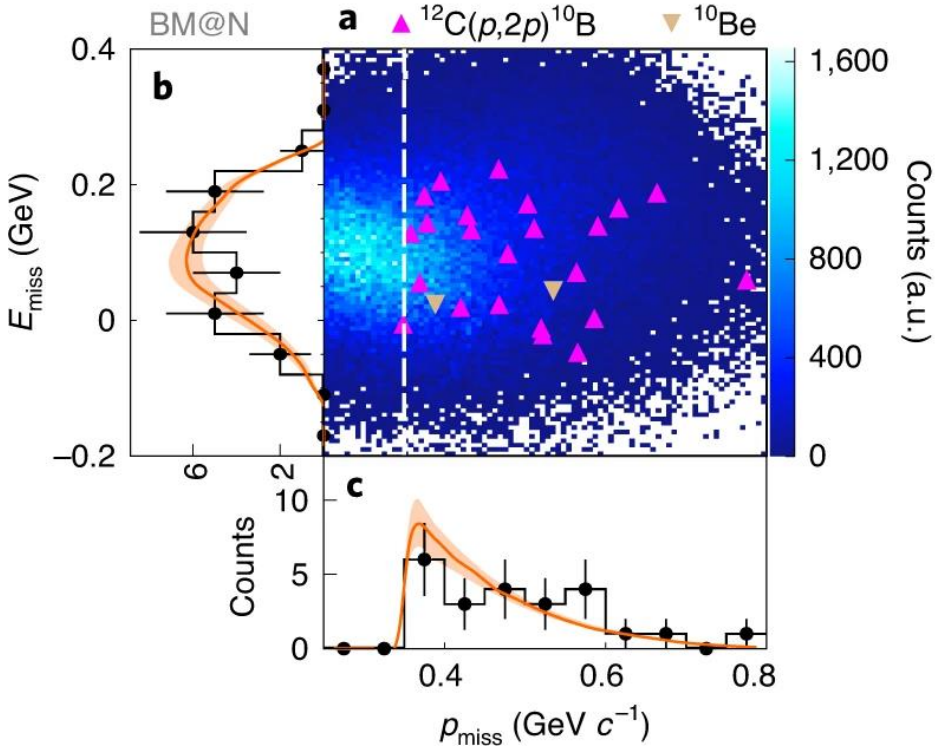
***np* pair**

$^{12}C(p,2p)\,^{10}\mathbf{B}$

***pp* pair**

$^{12}C(p,2p)\,^{10}\mathbf{Be}$

Identifying SRCs



23 *np* pairs
2 *pp* pairs
-> *np* dominance

+ proton-proton opening angle, guided by
Generalized Contact Formalism*

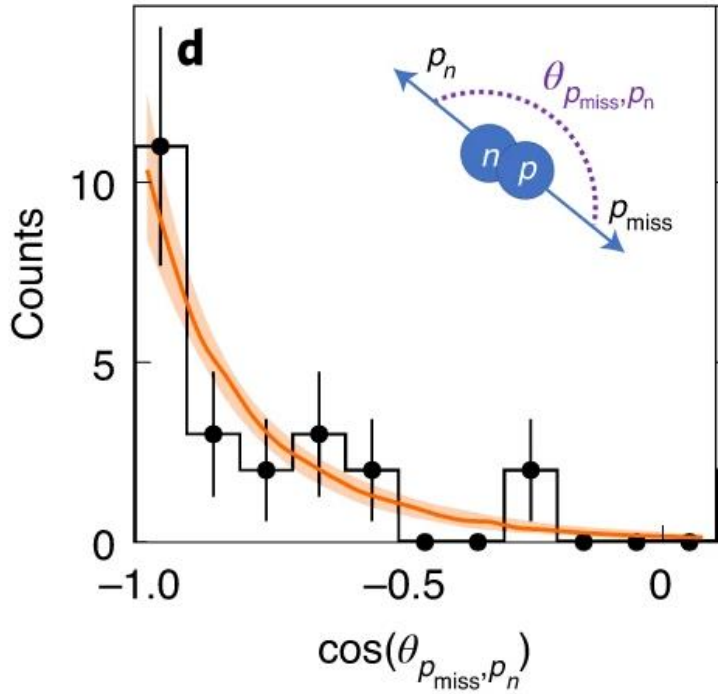
M. Patsyuk, JK et al. (BM@N),Nature Physics 17 (2021)

* A. Schmidt et al., Nature 578 (2020)
R. Cruz-Torres, D. Lonardoni et al., Nat. Phys. 17 (2021)
J.R. Pybus et al., PLB 805 (2020)

Pair correlations

strongly correlated pair:
nucleon momentum not
balanced by *A-1*

NN back-to-back emission



M. Patsyuk, JK et al. (BM@N),
Nature Physics 17 (2021).

Pair correlations

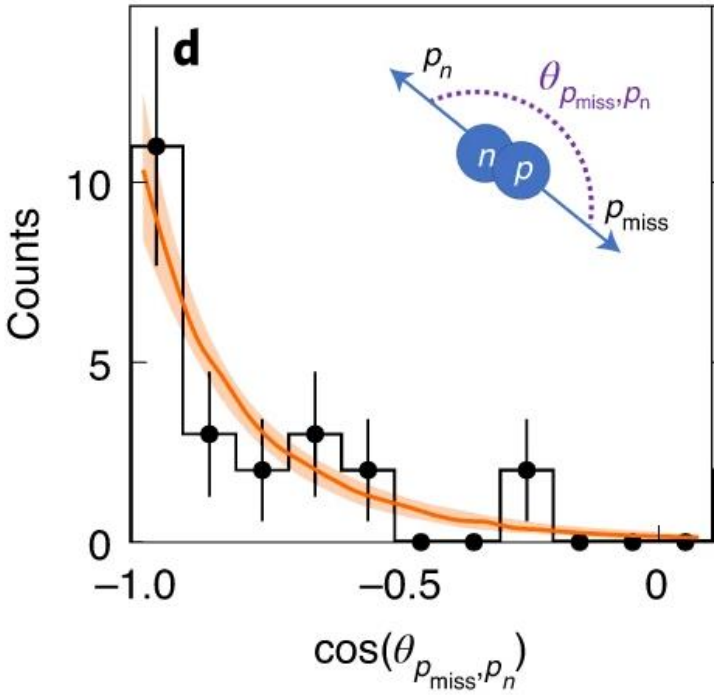
strongly correlated pair: nucleon momentum not balanced by *A-1*

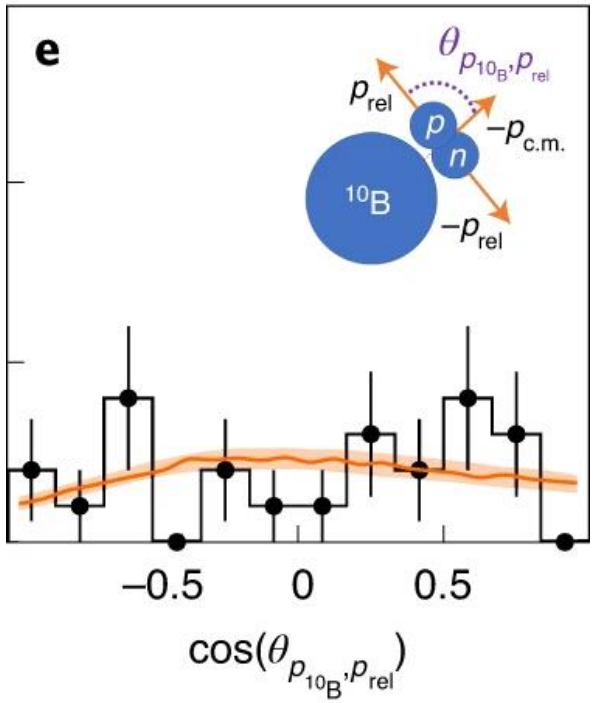
NN back-to-back emission

weak interaction between pair and A-2 spectator

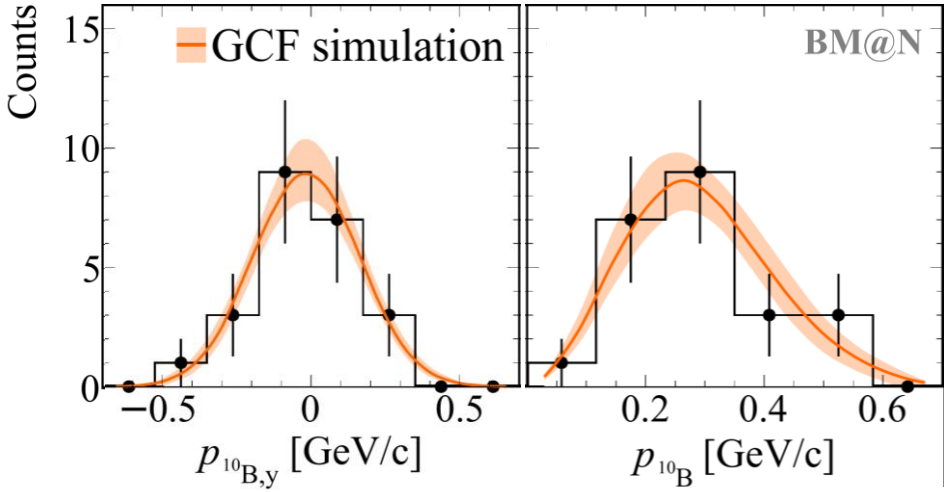
→ Factorization

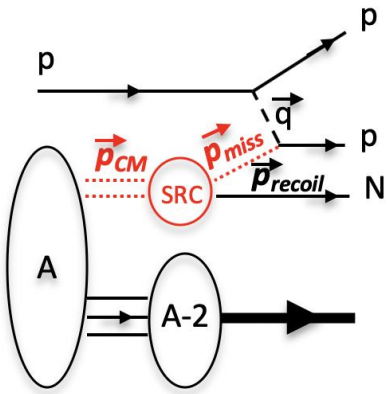
$$n^{A}_{\alpha,NN}(Q,q) = \tilde{C}^{A}_{\alpha,NN}(Q) \times |\tilde{\varphi}^{\alpha}_{NN}(q)|^2$$





Fragment momentum = pair c.m. motion

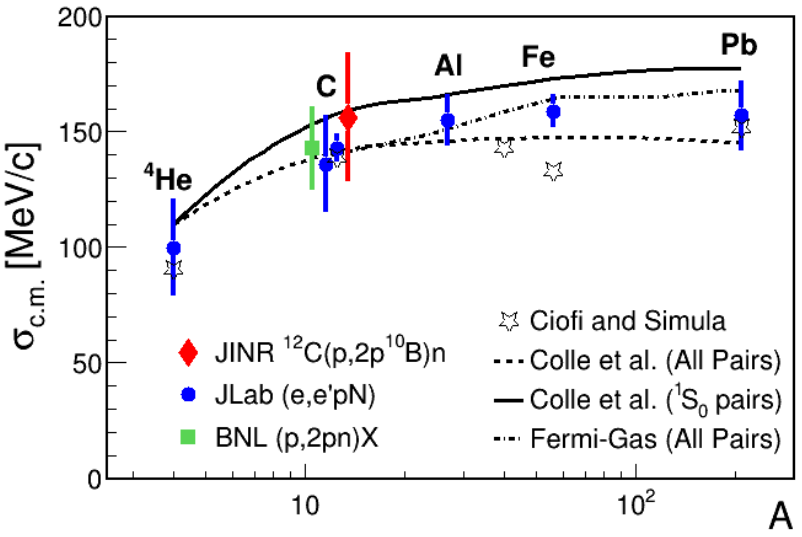




direct extraction:

σ = (156 ± 27) MeV/c

-> small c.m. momentum



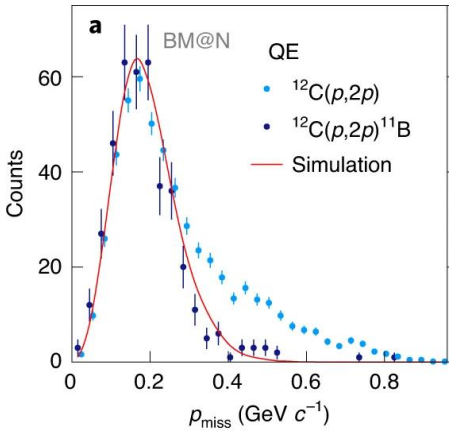
SRC studies in many-body dynamics entering new era:

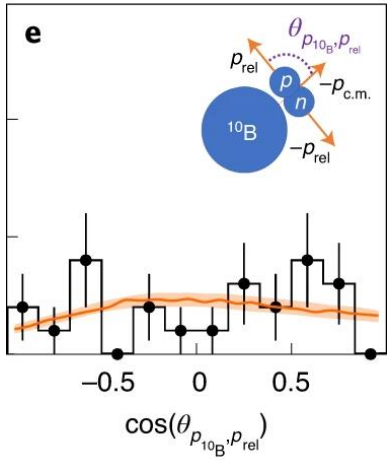
Experiments with hadronic probes in inverse kinematics
to study cold dense nuclear matter

- “Transparent“ nucleus:
  access ground-state distributions by
  fragment tagging (suppress ISI/FSI)
  -> neutron-rich nuclei

- 1st SRC experiment in inverse kinematics:
  evidence for factorization
  -> high-density

- building future experimental program at
  JINR and FAIR: high-energy and radioactive beams





Future Experiments: JINR

Quasi-elastic scattering

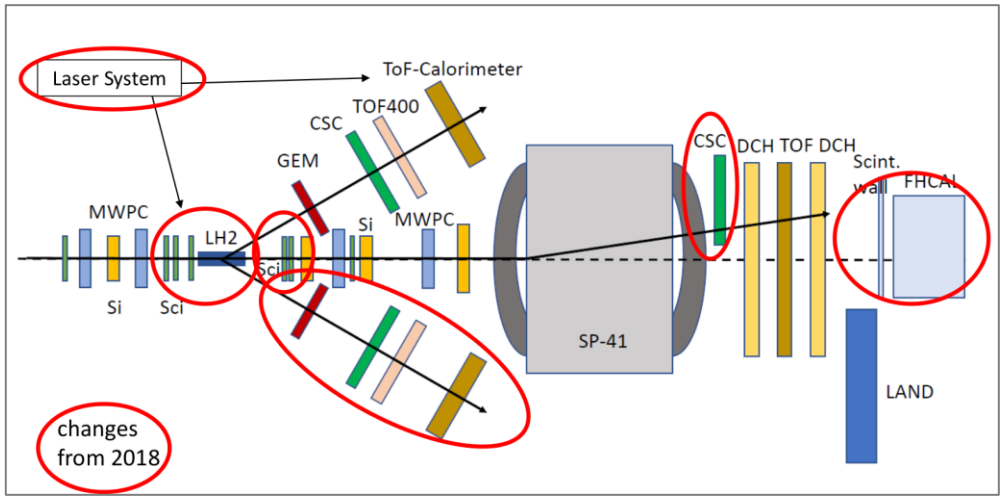
- quenching factor at large momentum transfer ($1 < |t| < 6$ GeV^2/c^2)
- momentum distribution for deeply bound s-shell states:

SRC

- fully exclusive measurement with recoil-neutron detection
- SRC formation mechanism: s- or p-shell?
- 3N SRC seacrch

Upgraded setup winter 2021 at BM@N:
improved momentum resolution,
increased acceptance,
proton-pion separation

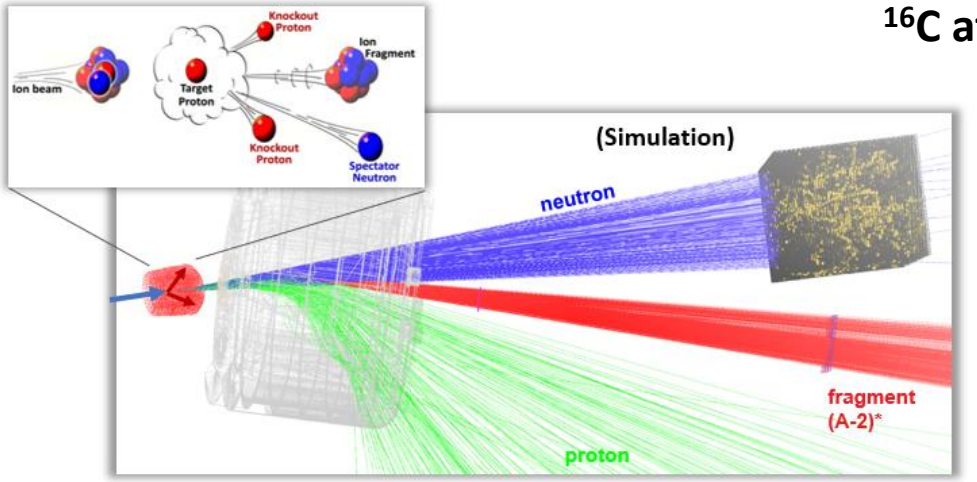
New beamline 2022 --



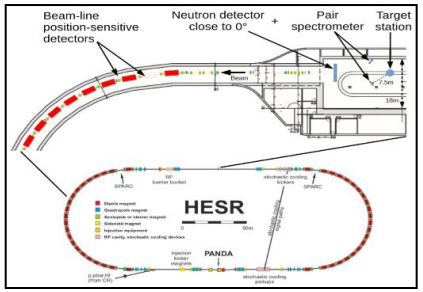
Future Experiments: GSI/FAIR

- Spring 2022: First SRC study with radioactive nucleus at R³B

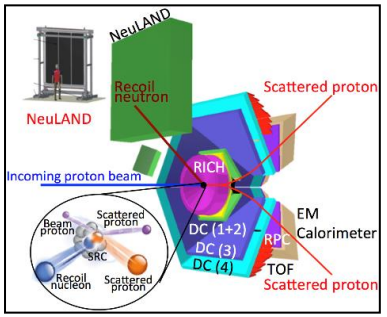
^{16}C at 1.2 GeV/u



- systematic studies along isotopic chains – ^{24}O, – ^{52}Ca, – ^{70}Ni, – ^{215}Pb



R³B + HESR at FAIR



HADES at GSI

Thank you.


Hen Lab
Laboratory for Nuclear Science @ MIT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