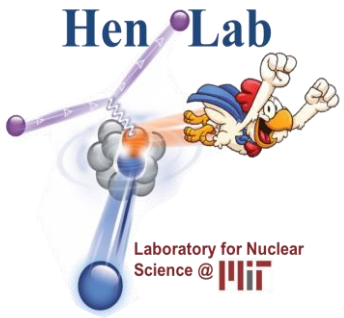
SRC studies in inverse kinematics

Julian Kahlbow

4th Intl. SRC-EMC Workshop
January 31, 2023

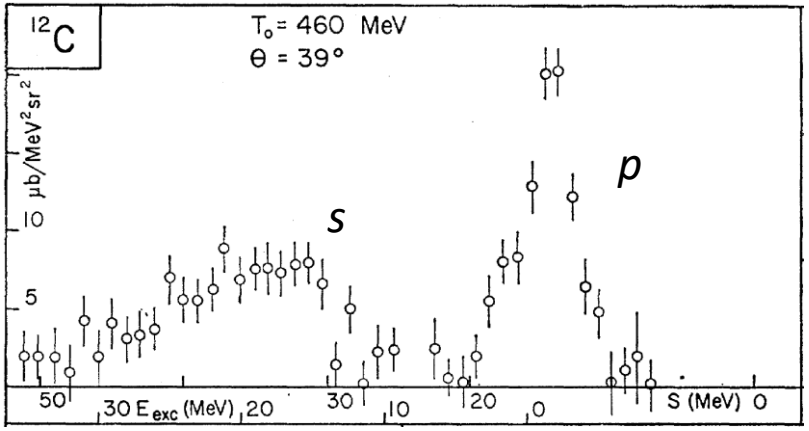


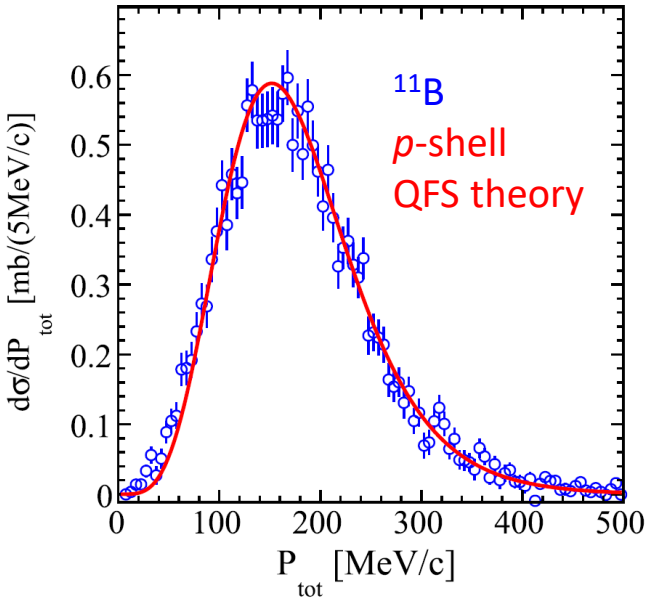
TEL AVIV UNIVERSITY

Quasi-free scattering to study nuclear structure

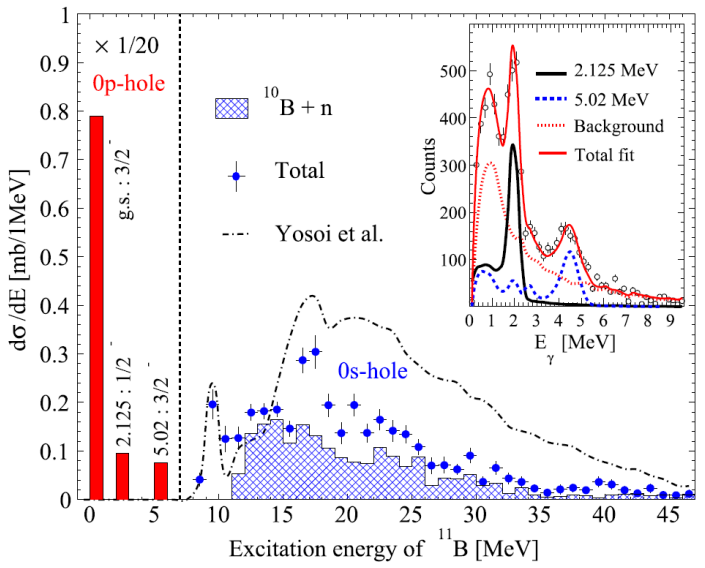
^{12}C(p,2p):
- shell structure
- momentum distributions

G. Jacob, Th. A. Maris, Rev. of Mod. Phys. 38 (1966)



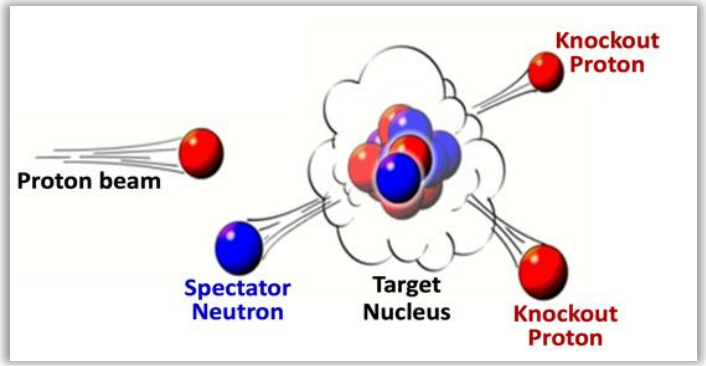


V. Panin et al., Phys. Lett. B 753 (2016)

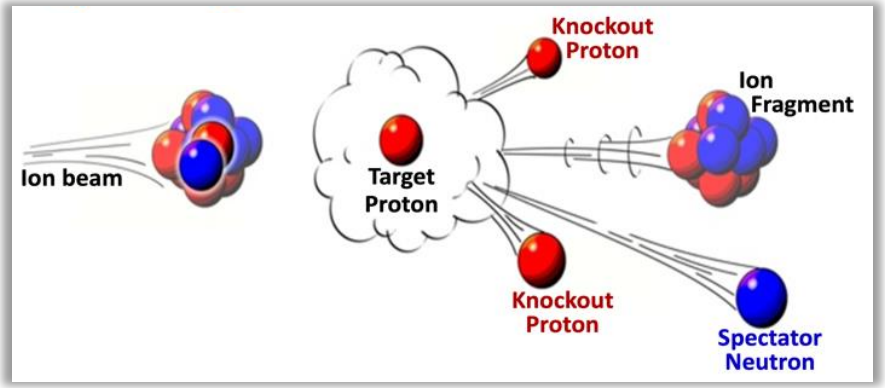


Advantages of inverse kinematics experiments for nuclear structure physics

nuclear target
and p or e^- beam



(radioactive) ion beam
hitting hadronic probe



fully exclusive measurement:
measure momenta of
all emerging particles

Disadvantages: In-medium effects

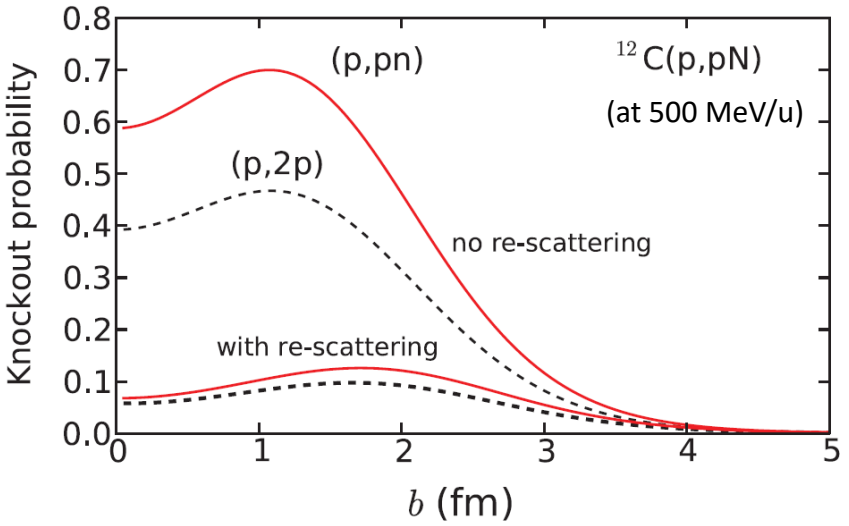
Incoming proton and outgoing protons interact with other nucleons (**initial and final state interactions**)

→ disturb initial momentum reconstruction

→ extra excitations of the nucleus (break fragment apart)

→ eject additional particles (pions, …)

T. Aumann, C.A. Bertulani, J. Ryckebusch, Phys. Rev. C 88 (2013)



L. Frankfurt, M. Strikman, M. Zhalov, PLB 503 (2001).
S. Stevens et al., PLB 777 (2018).

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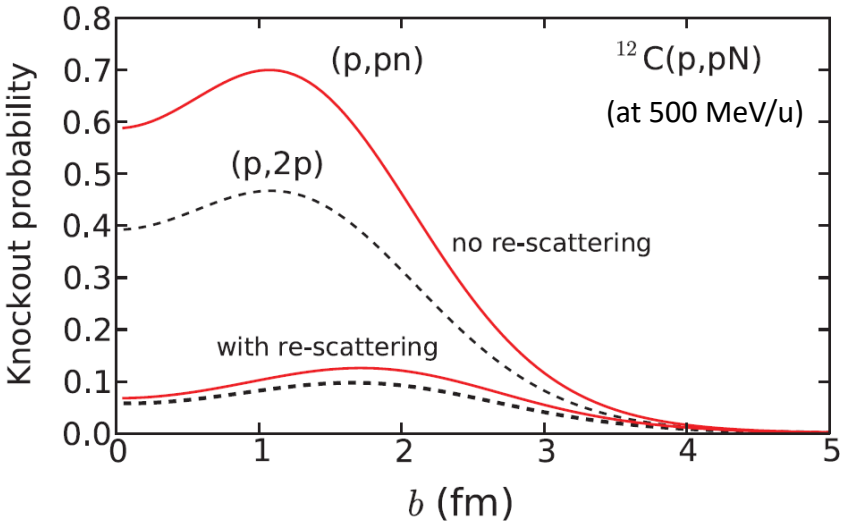
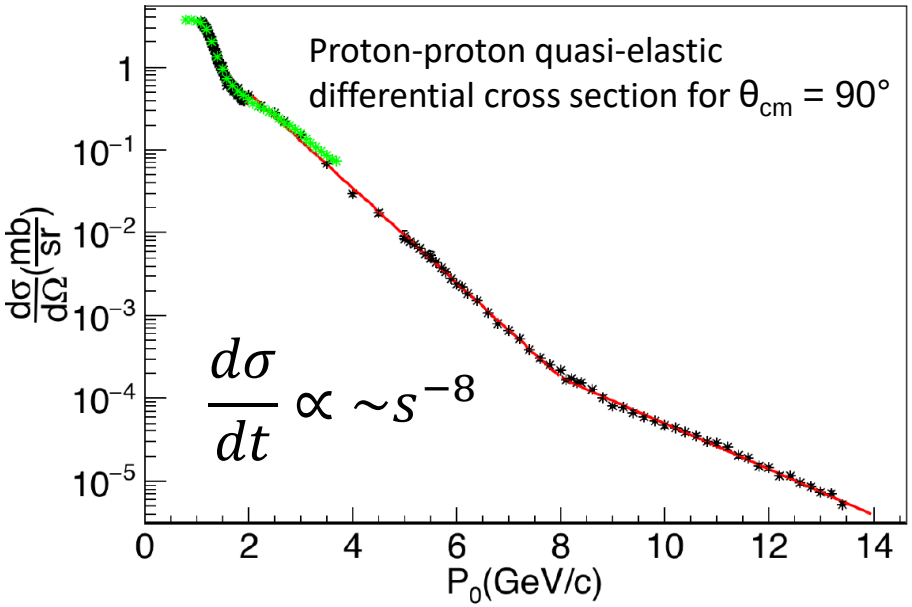


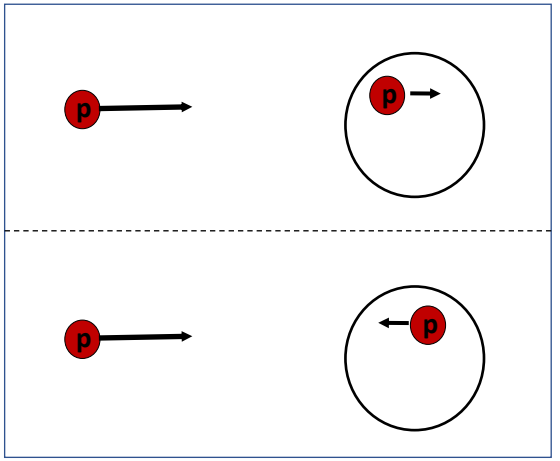
We proof in fully exclusive scattering experiment that fragment tagging suppresses ISI/FSI [Attenuation & Distortion]

L. Frankfurt, M. Strikman, M. Zhalov, PLB 503 (2001).
S. Stevens et al., PLB 777 (2018).

Quasi-free scattering at high energies



``Selective Attention``



$$\frac{d\sigma}{dt} \vee \frac{d\sigma}{dt}$$

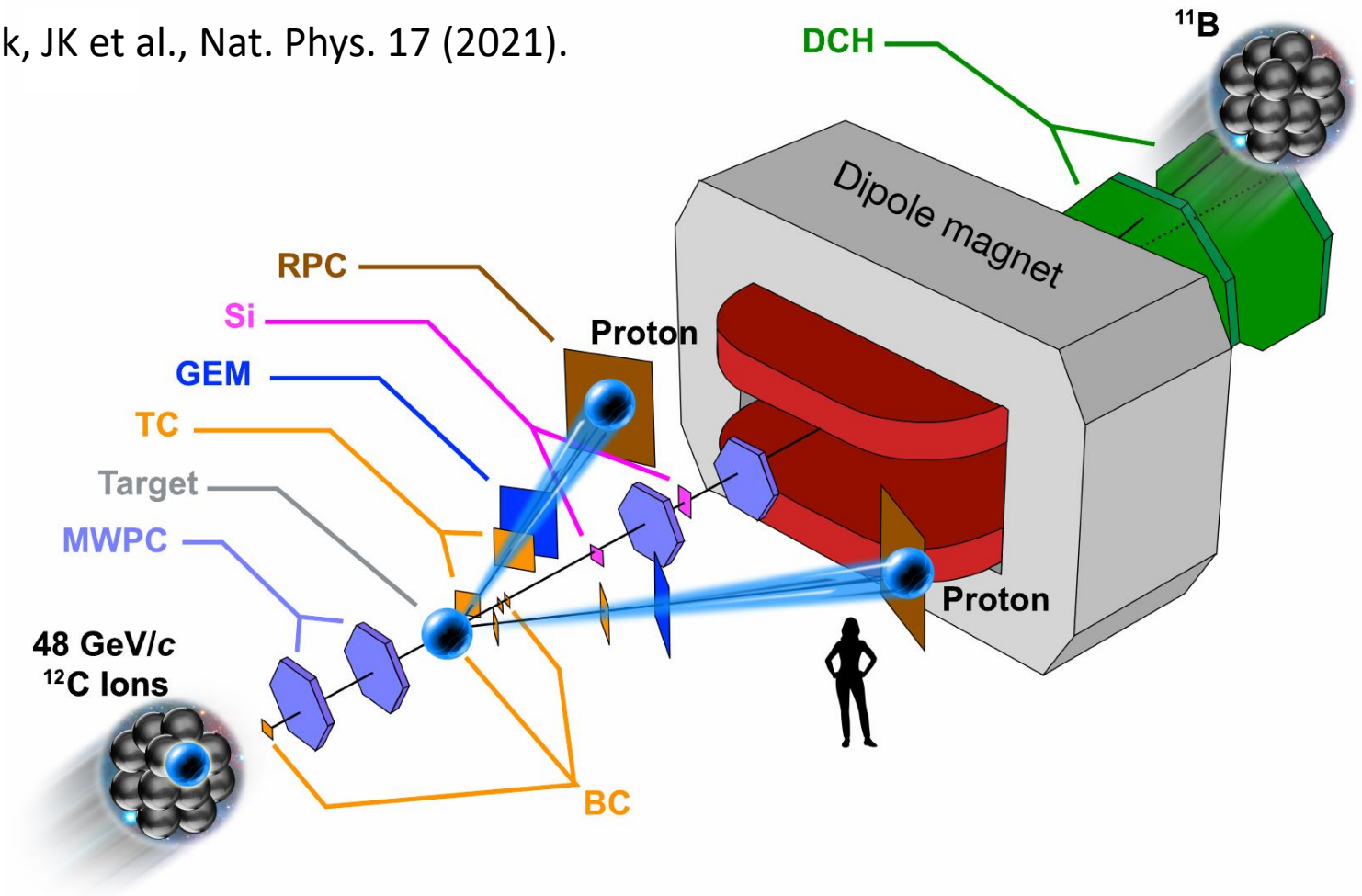
+ large energy and momentum transfer

→ impulse & spectator approximation (~ adiabatic process)
→ multi-scattering well described by Glauber theory

2018 Experiment at BM@N Setup / JINR

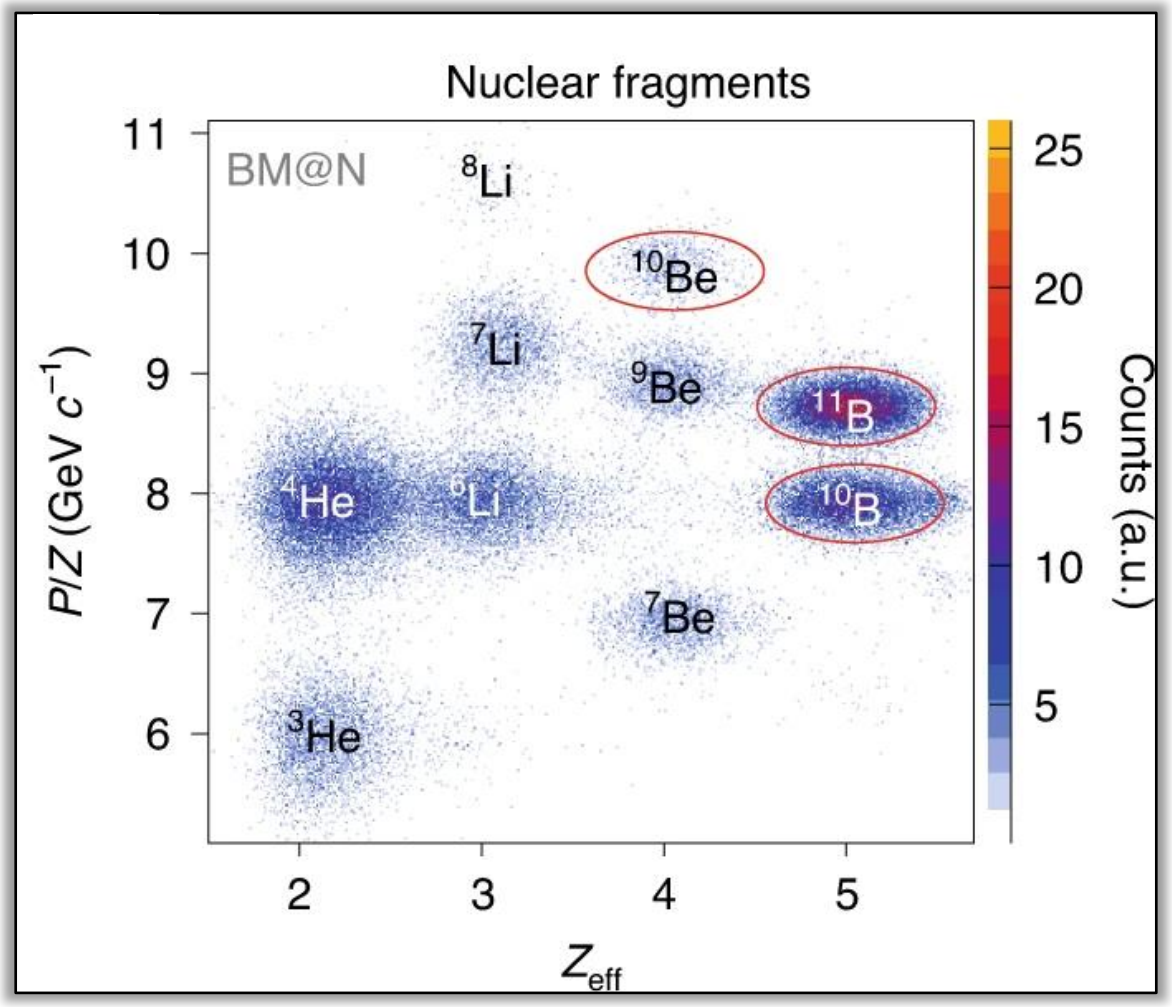
$^{12}C(p,2p)X$

M. Patsyuk, JK et al., Nat. Phys. 17 (2021).



Fragment Measurement

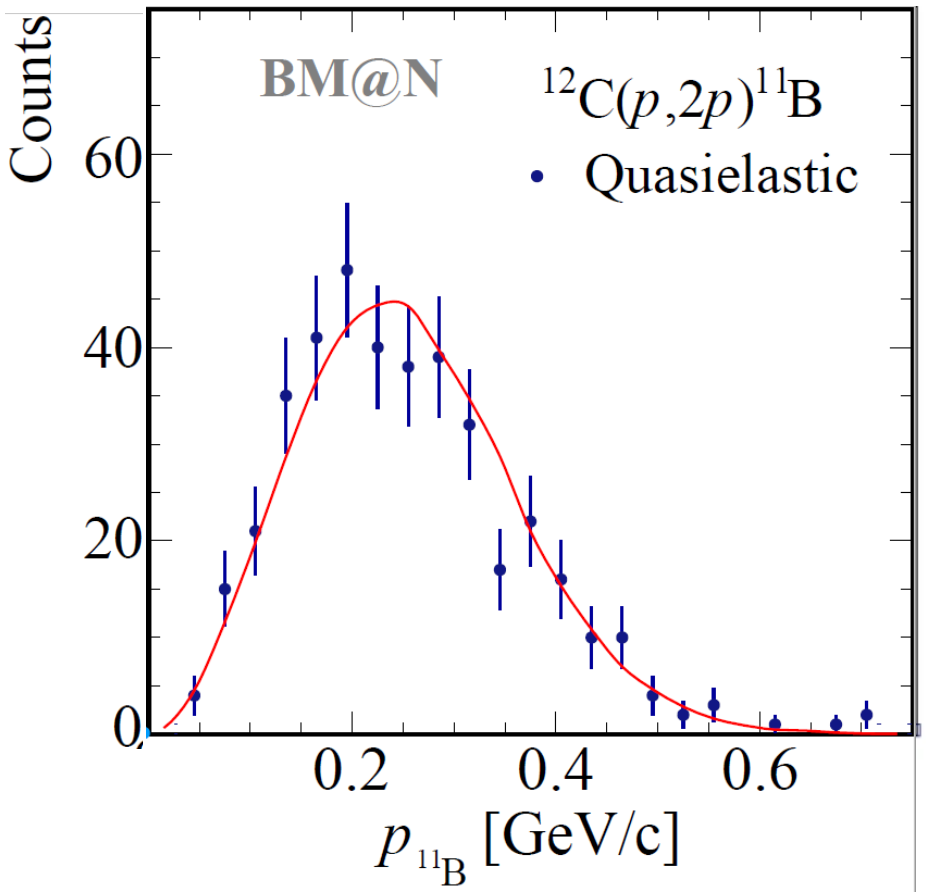
$^{12}C(p,2p)X$



M. Patsyuk, JK et al. (BM@N), Nat. Phys. 17 (2021).

Fragment recoil momentum

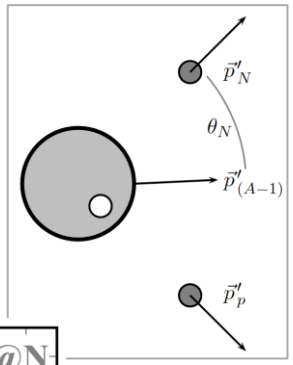
Does adiabatic approximation hold $\boldsymbol{p}_{miss} = -\boldsymbol{p}_{A-1}$?

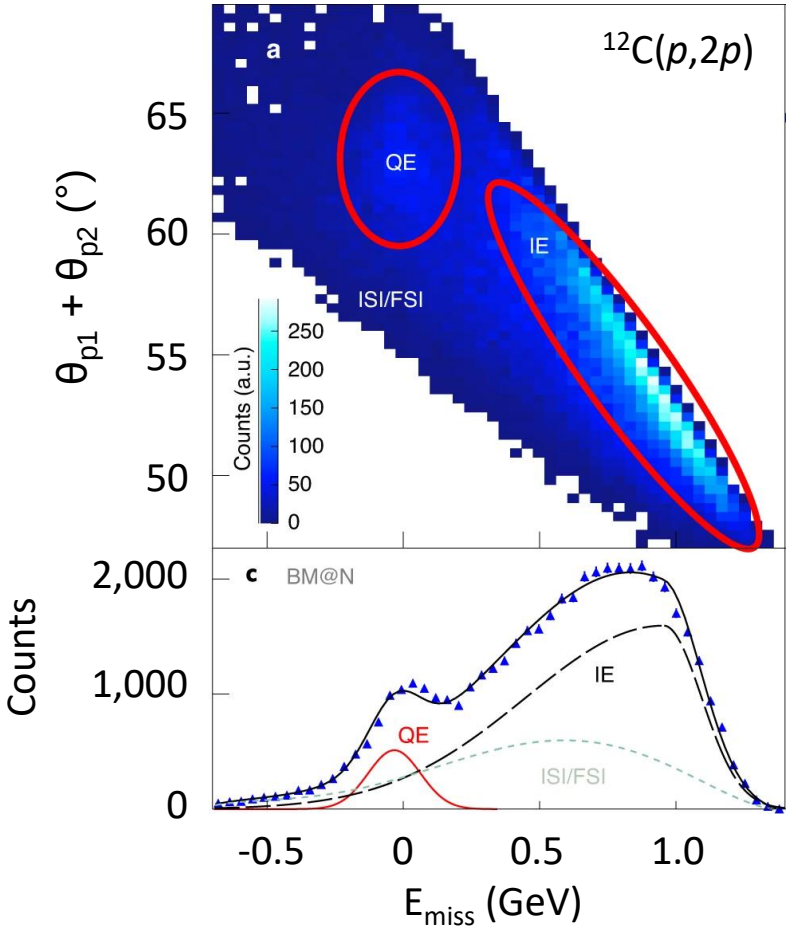


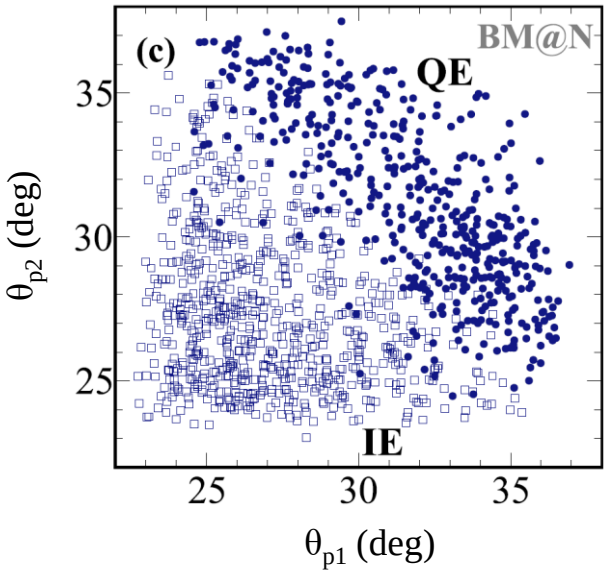
Calculation of QE (*p,2p*) scattering off *p*-shell nucleon
[T. Aumann, C.A. Bertulani, J. Ryckebusch, PRC 88 (2013).]

M. Patsyuk, JK et al. (BM@N), Nat. Phys. 17 (2021).

But: Is QE scattering free of FSI?



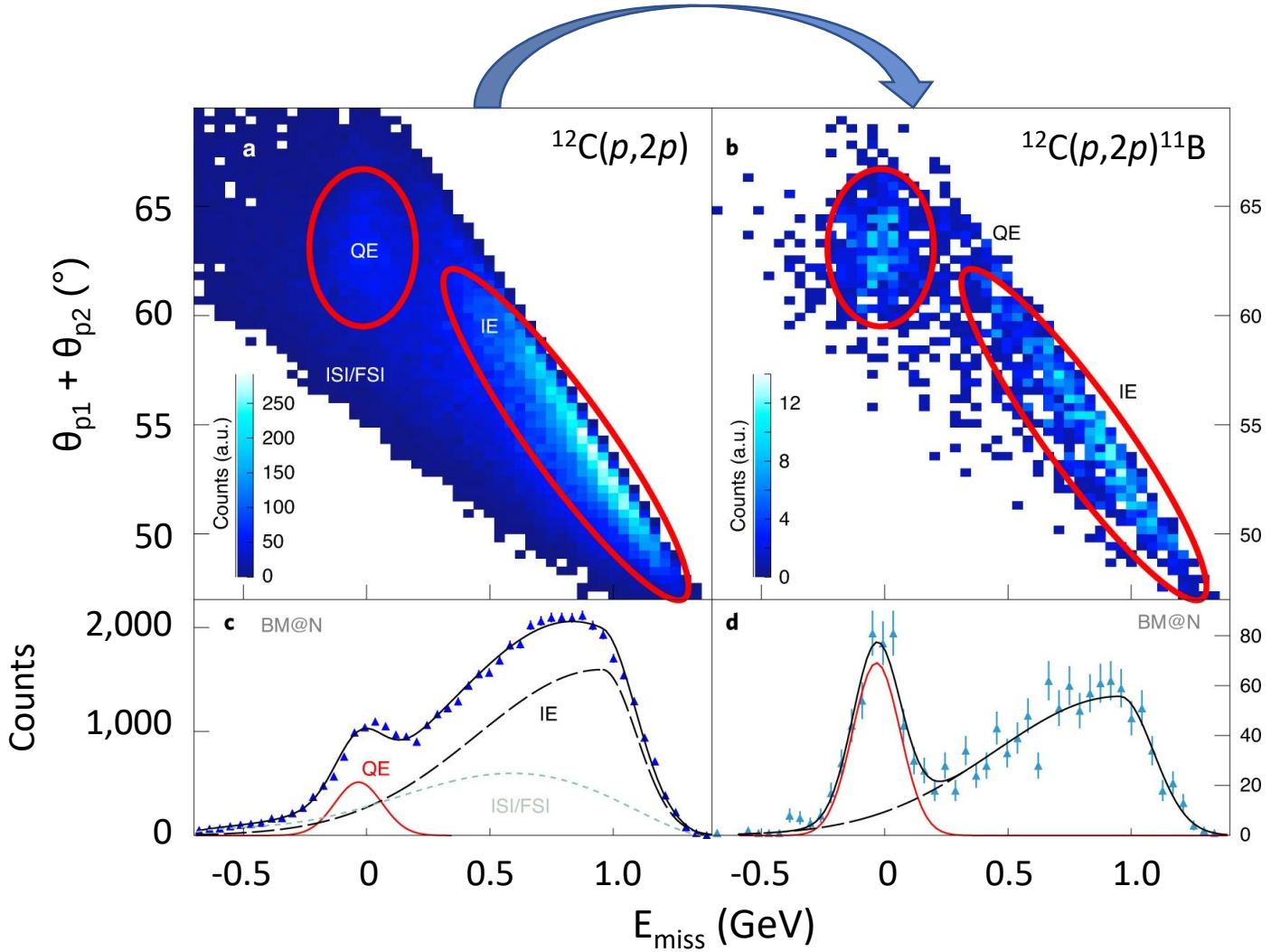




(*p*,2*p*) inclusive scattering dominated by inelastic scattering and initial/final state interactions

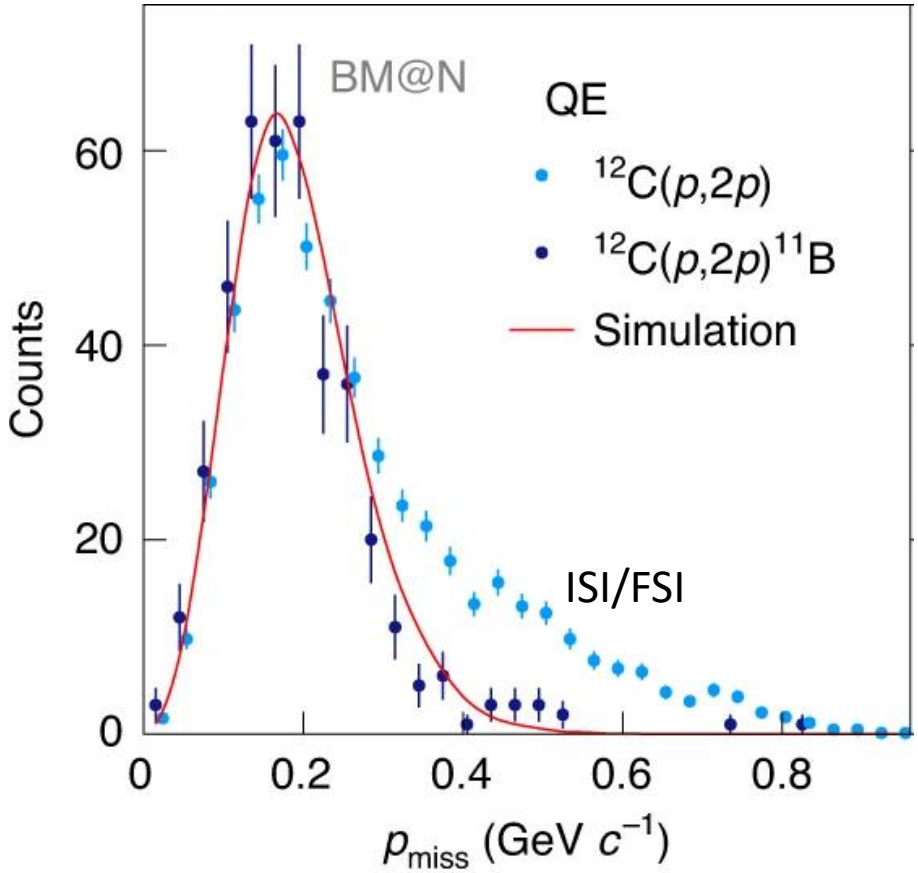
Reaction mechanism under control

Fragment tagging suppresses initial/final state interactions



Single-step nucleon knockout

Proton momentum distribution with fragment tagging to access ground-state distribution

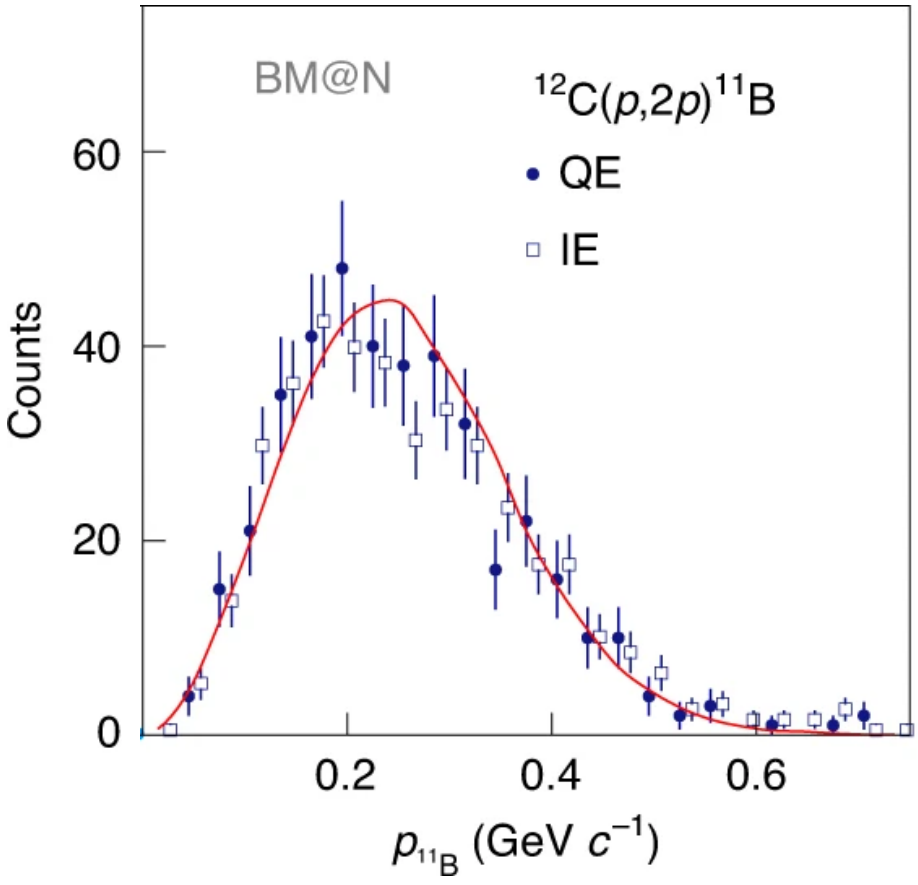


Calculation of QE (*p,2p*) scattering off *p*-shell nucleon in ^{12}C without ISI/FSI

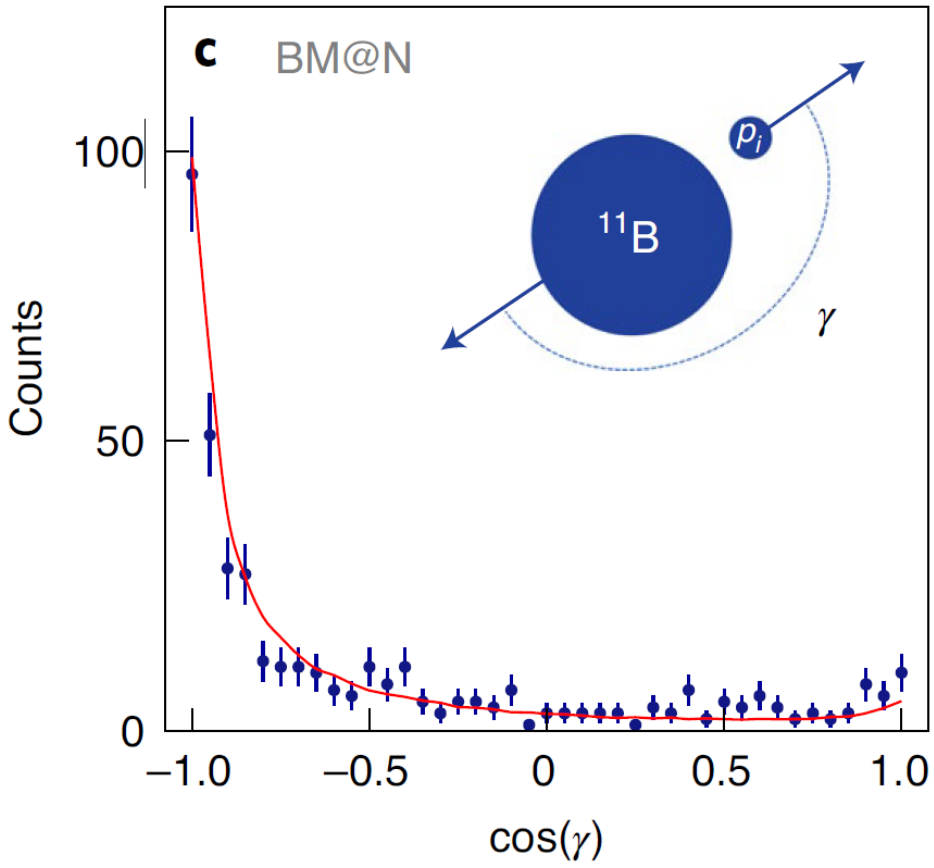
[T. Aumann, C.A. Bertulani, J. Ryckebusch, PRC 88 (2013).]

Fragment recoil momentum

Fragment not impacted by inelastic scattering: adiabatic approximation holds $\boldsymbol{p}_{miss} = -\boldsymbol{p}_{A-1}$



Fragment-proton correlation

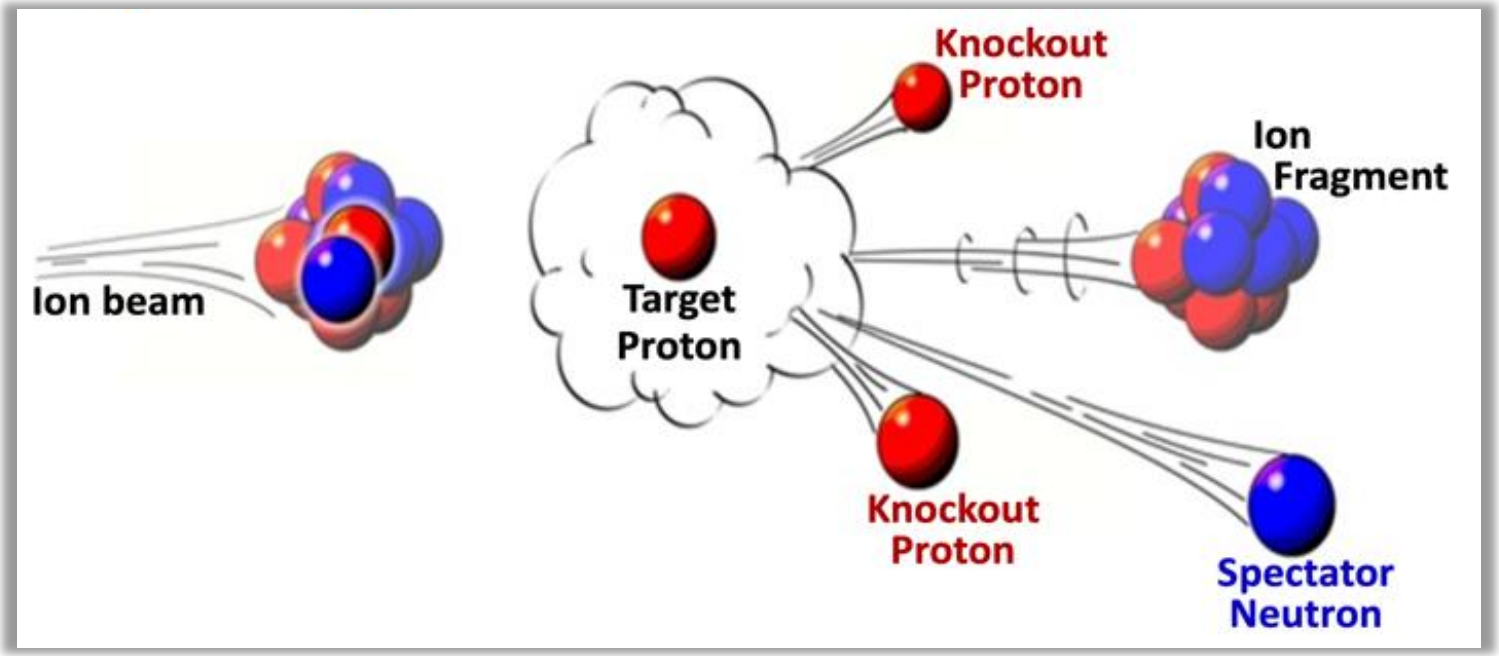


Experiment in inverse kinematics

at high energy with hadronic probe

is a “clean” technique to study nuclear structure

SRC study in inverse kinematics



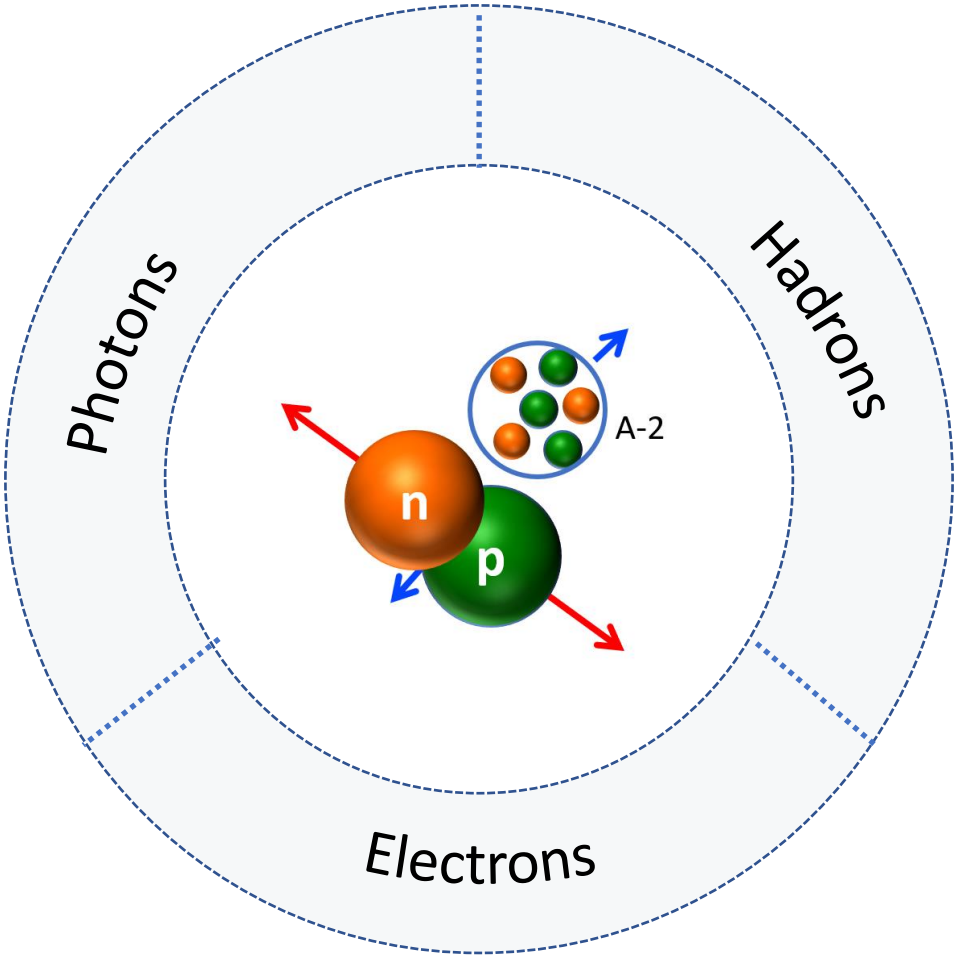
Measure:

- Scattered proton momentum
- Fragment momentum
- Recoil nucleon momentum
- Measure final state / energy

Extract:

p_{miss}
pair c.m.
factorization
spin, parity

Probe SRC universality using different probes

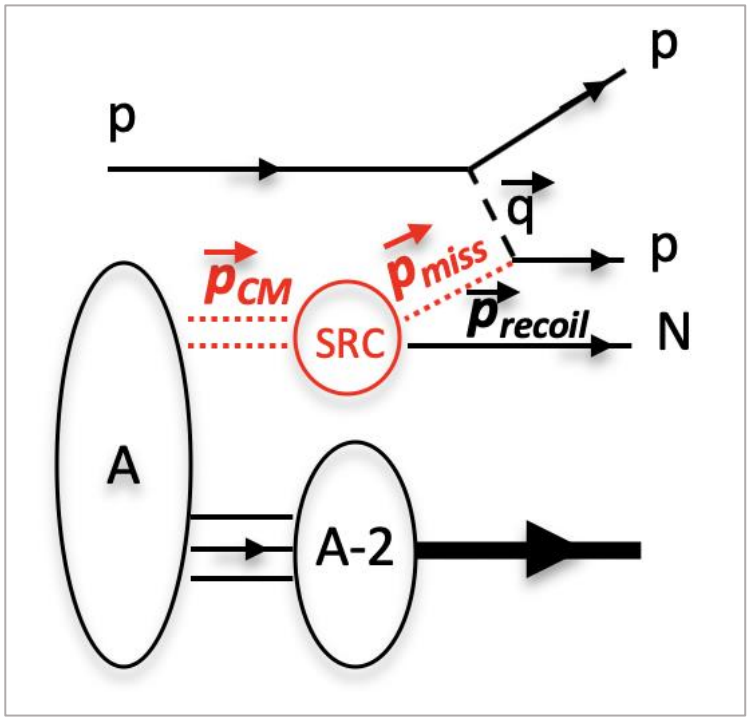


SRC breakup using hadronic probe

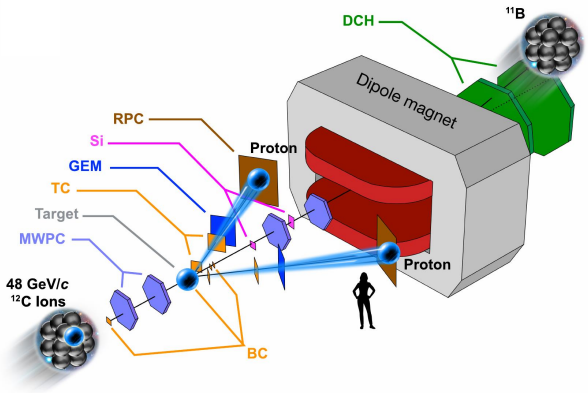
$$d\sigma \sim K \cdot \sigma_{eN} \cdot S(p_i, E_i)$$

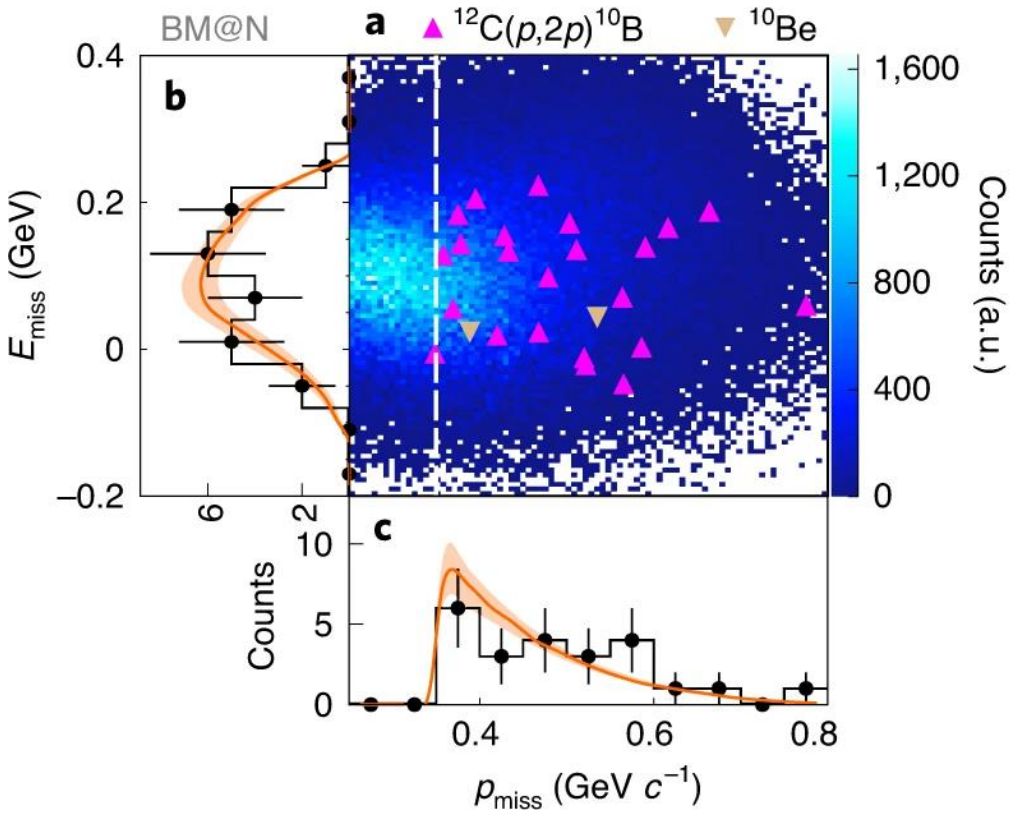
(σ_{pp} replaces σ_{eN})

$$S(p_i, E_i) \sim \sum_{\alpha} C^{A}_{\alpha,NN}(p_{cm}) \times |\tilde{\varphi}^{\alpha}_{NN}(|\vec{p}_{Rel}|)|^2$$



SRC identification



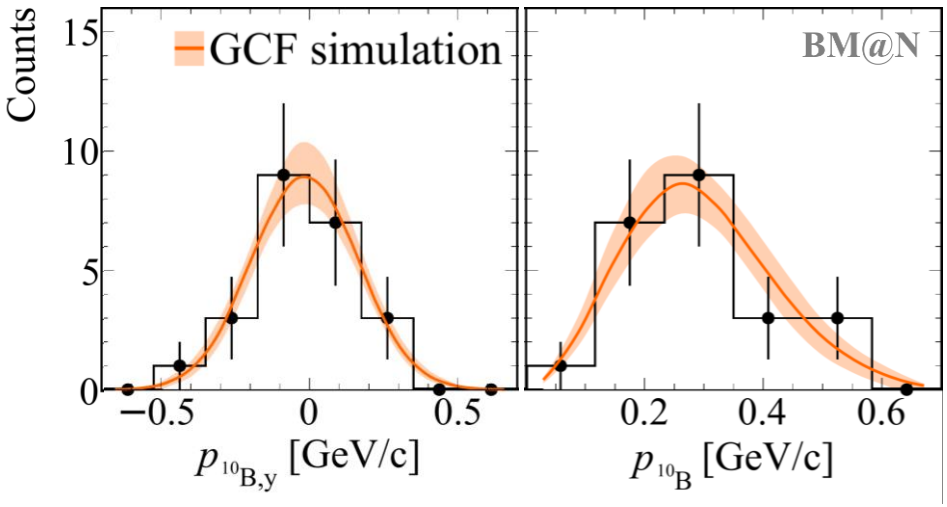


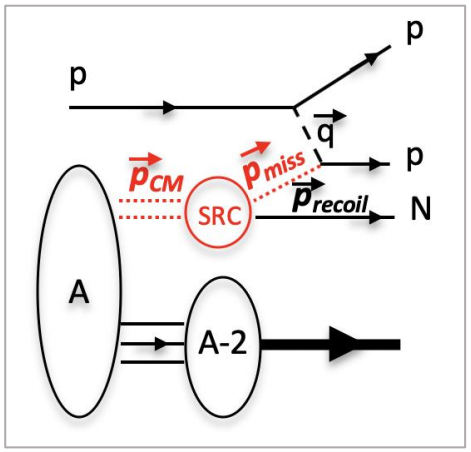
23 *np* pairs (^{10}B)
2 *pp* pairs (^{10}Be)
-> *np* dominance

(guided by GCF)

M. Patsyuk, JK et al. (BM@N), Nat. Phys. 17 (2021).

Fragment momentum = pair c.m. motion



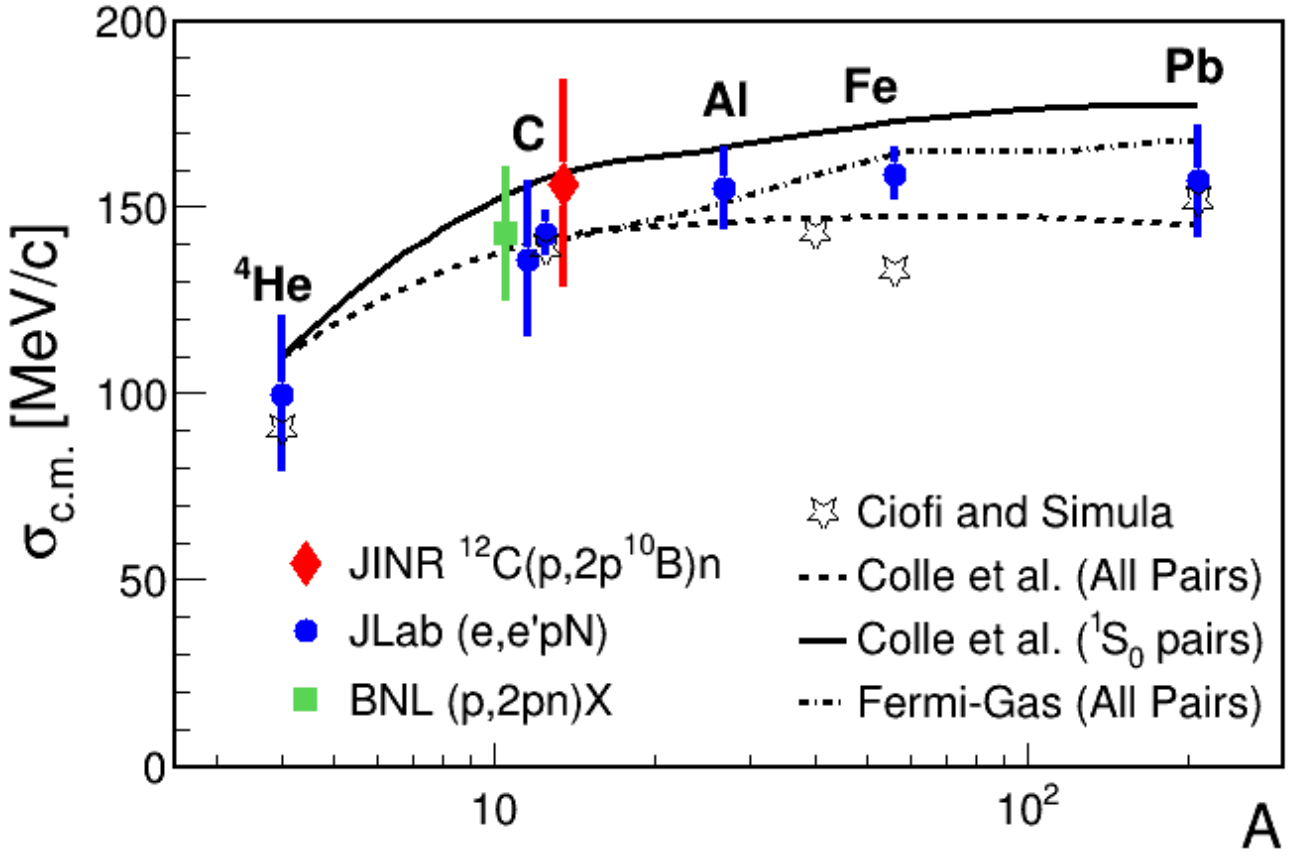


direct extraction:

σ = (156 ± 27) MeV/c

-> small c.m. momentum

Signature for universality: c.m. momentum comparison



Based on E.O. Cohen et al., Phys. Rev. Lett. 121 (2018).

SRC universality & scale separation

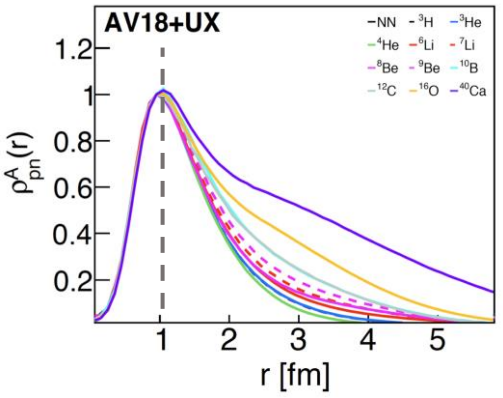
factorized **Generalized Contact Formalism** (GCF)

$$S(p_i, E_i) \sim \sum_{\alpha} C^{A}_{\alpha,NN}(p_{cm}) \times |\tilde{\varphi}^{\alpha}_{NN}(|\vec{p}_{Rel}|)|^2$$

universal

~ A-2 system [number of pairs small c.m. motion]

strongly correlated pair [universal 2-body]



R. Cruz-Torres, D. Lonardoni, R. Weiss et al., Nature Physics 17 (2021).

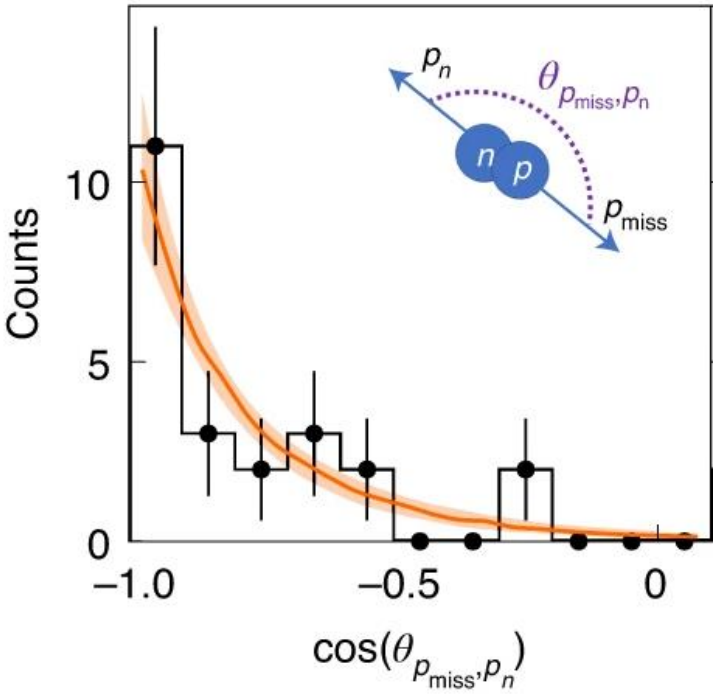
Pair correlations

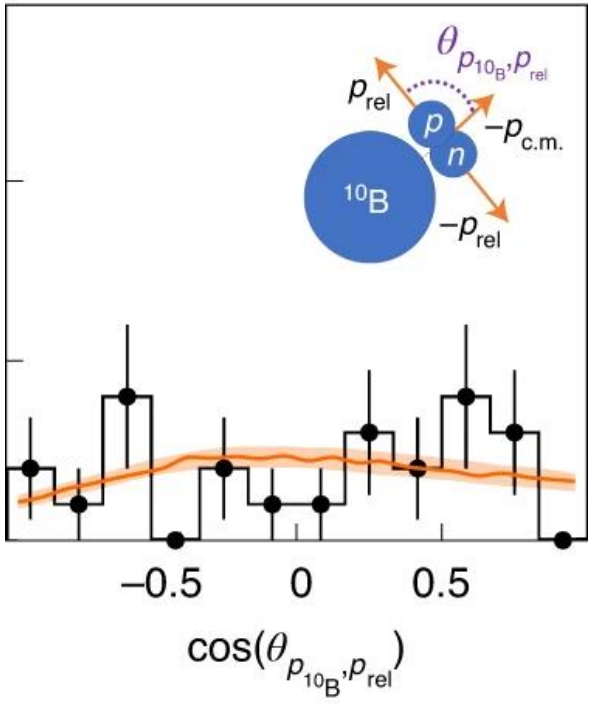
strongly correlated pair:
nucleon momentum not
balanced by *A-1*

NN back-to-back emission

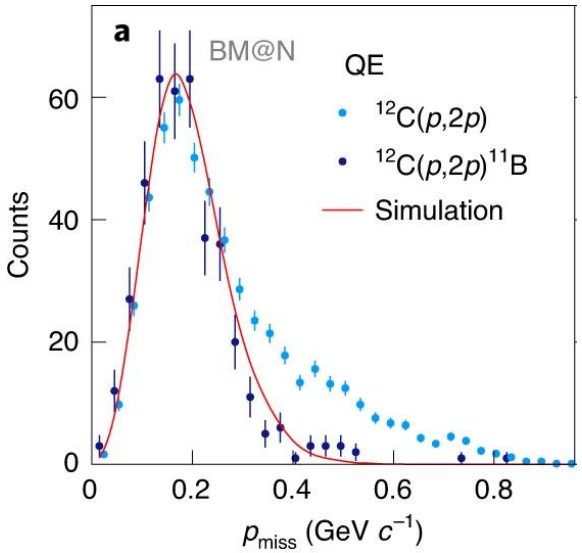
weak interaction between
pair and A-2 spectator

→ Factorization measured directly





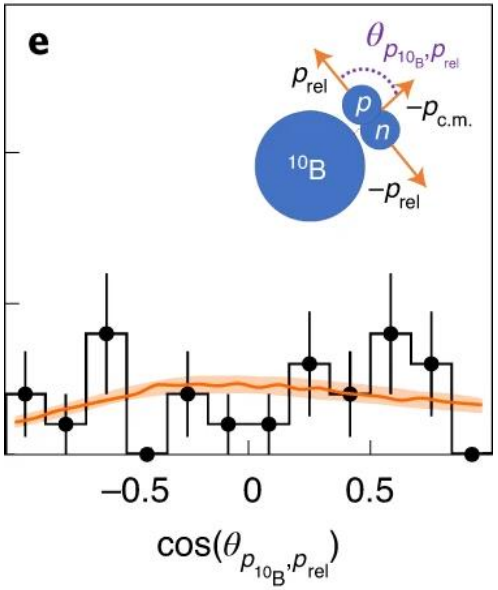
Summary



Quasi-free scattering in inverse kinematics is a clean reaction tool

1st SRC identification in inverse kinematics:

- access to new observables
- evidence for factorization and universality



Thank you.