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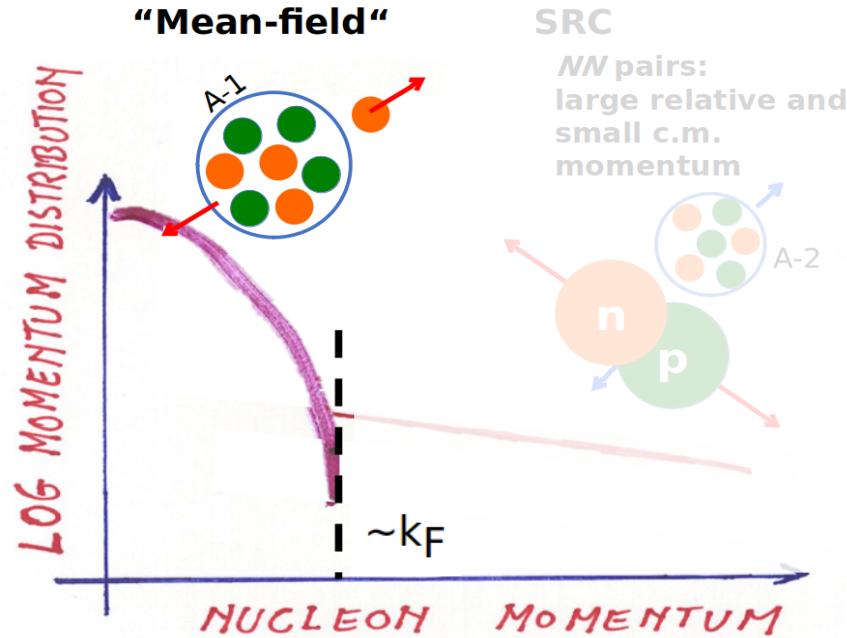
# **The Transparent Nucleus: Unperturbed inverse kinematics nucleon knockout measurements with a 48 GeV/c carbon beam**

Timur Atovullaev on behalf of the BM@N collaboration

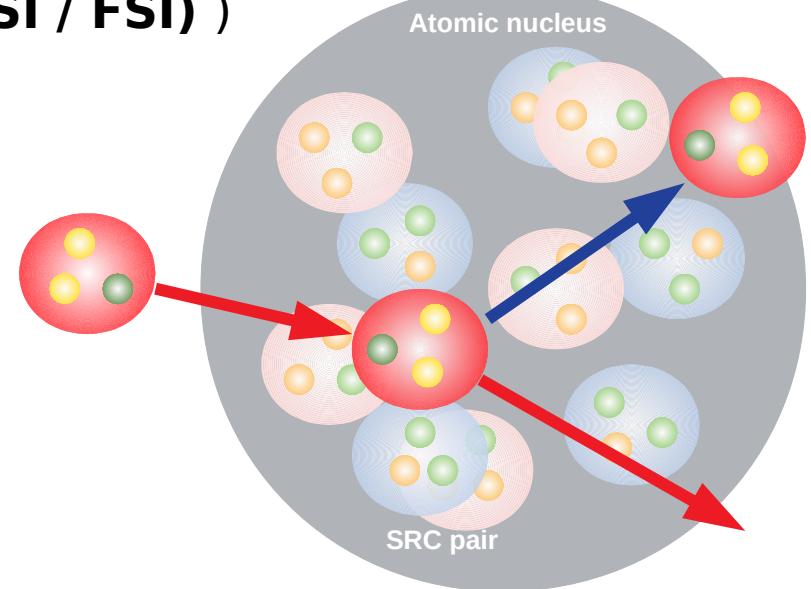


8th October 2020  
5th International Conference on Particle Physics and Astrophysics

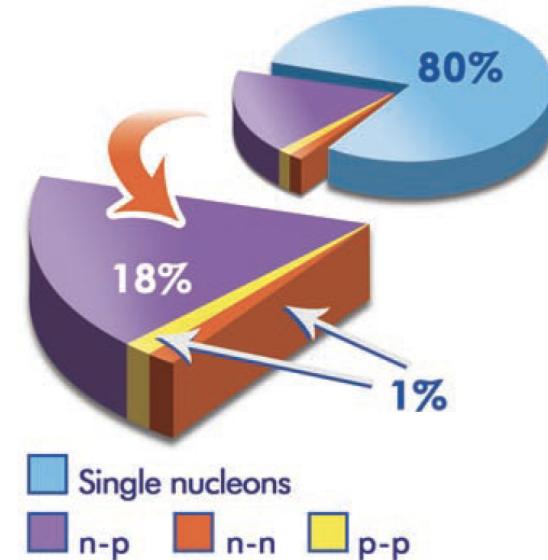
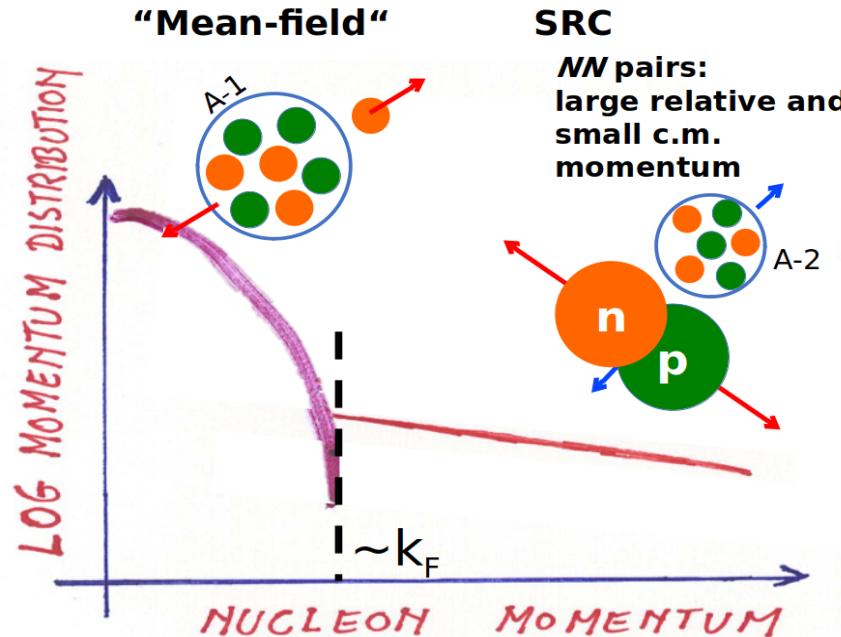
# Studying strongly interacting QM system



**Nucleon knockout reaction:**  
incoming proton and outgoing  
protons interact with other nucleons  
**(Initial / Final state interactions  
(ISI / FSI) )**



# Ground state distribution of nucleons



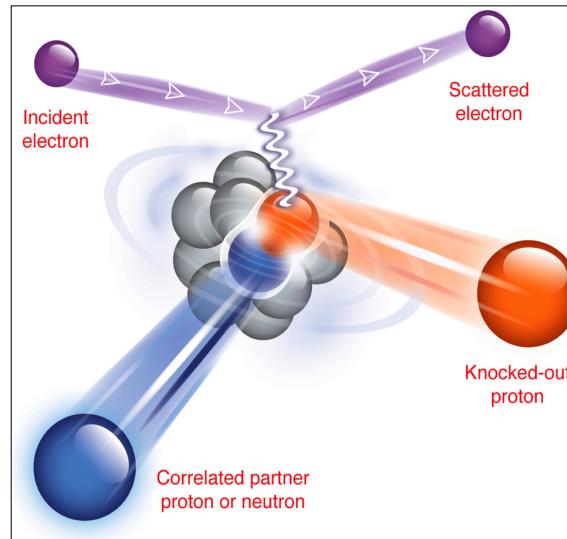
**SRC: n-p dominance**

- A. Tang et al., Phys. Rev. Letters (2003)  
E. Pisetsky et al., Phys. Rev. Letters (2006)  
R. Shneor et al., Phys. Rev. Letters (2007)  
R. Subedi et al., Science 320, 1476 (2008)

# SRC scattering experiments

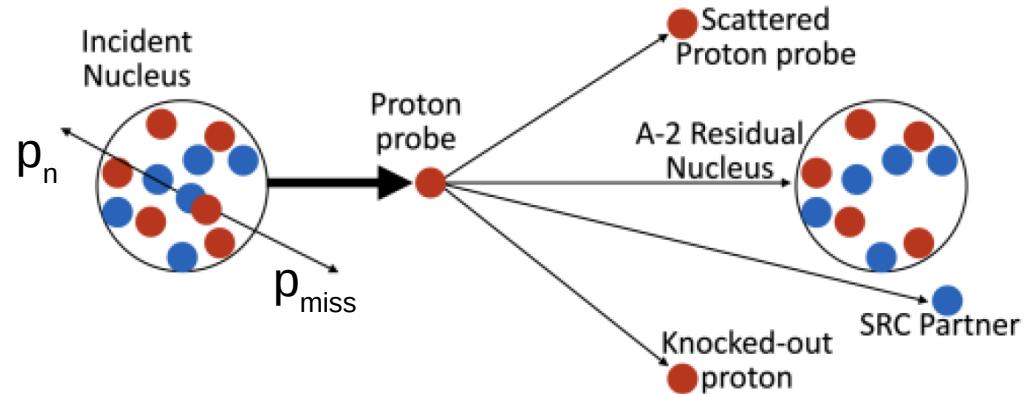
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**Previous studies limited to stable nuclei  
done in  $e^-$  and  $p^+$  scattering, normal kinematics**



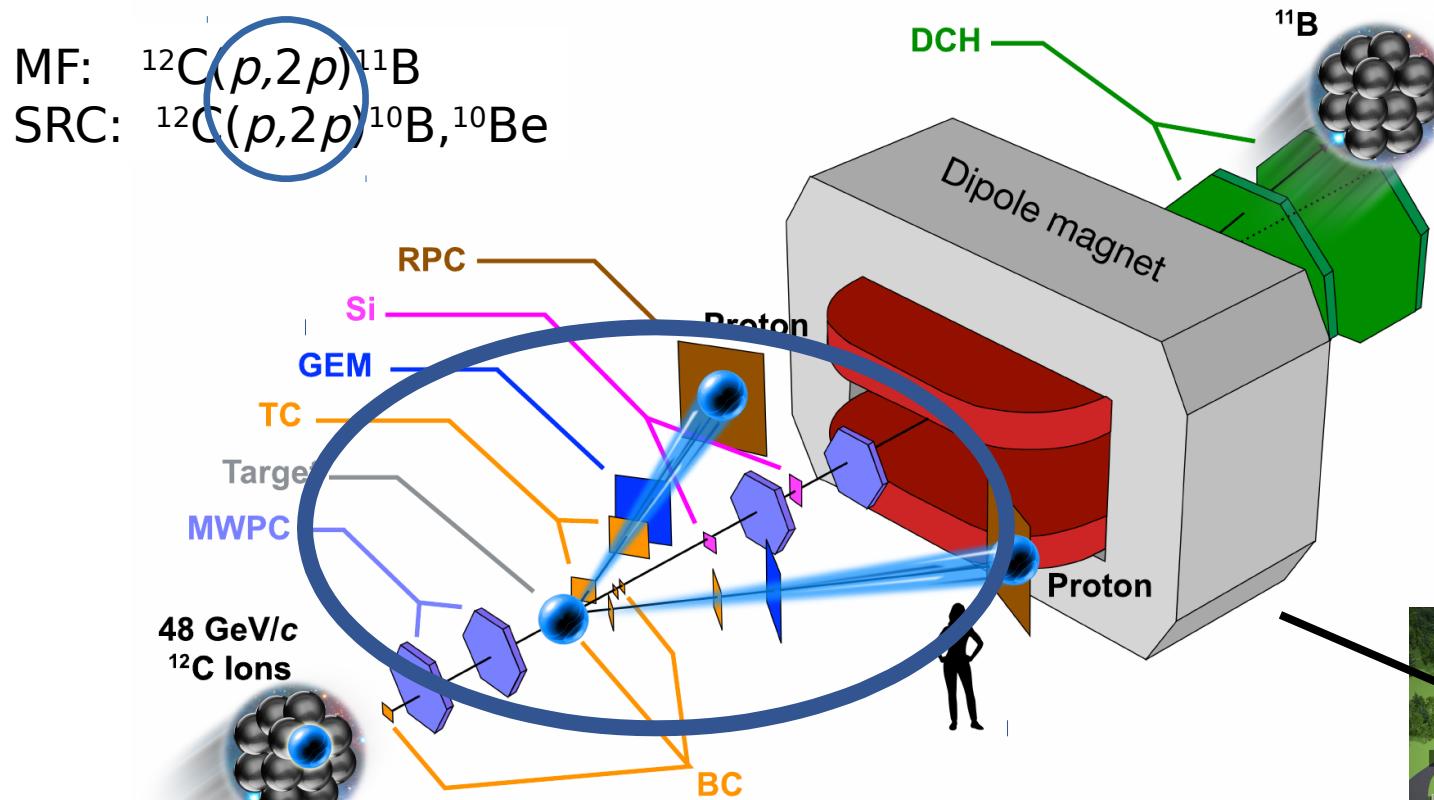
# Inverse kinematics

- ✓ unstable nuclei
- ✓  $p_{\text{miss}}$ ,  $p_n$
- ✓  $p$  probe:  
larger cross-section  
(compared to e-scattering)
- ✓ fragment ID +  $p_{A-2}$



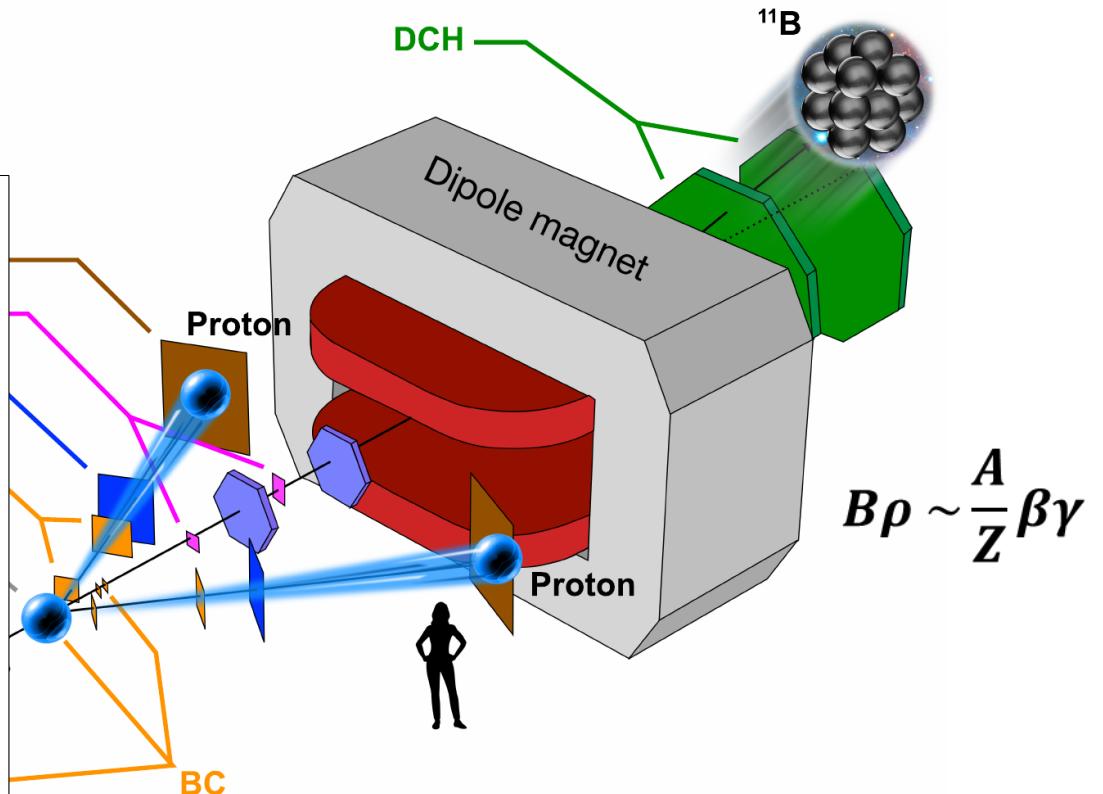
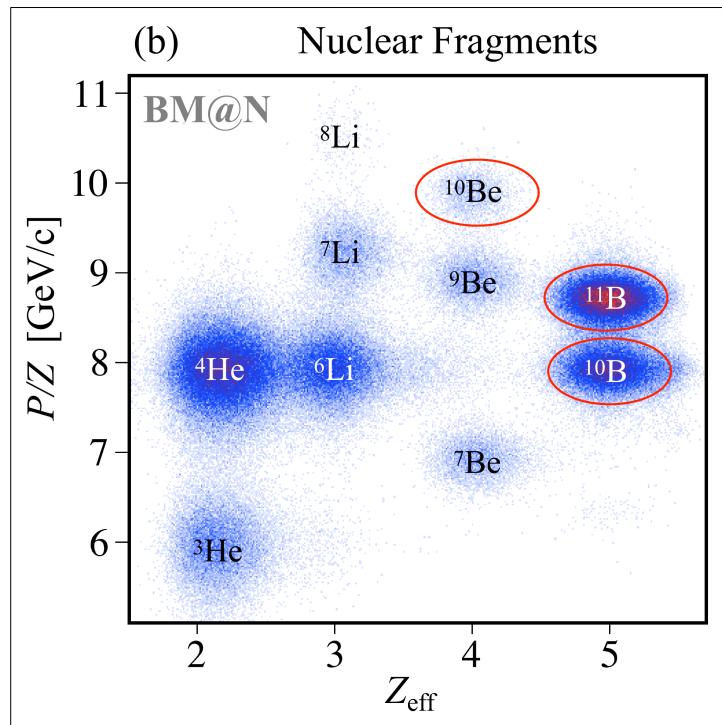
**Reaction:**  $A(p,2pN)A-2$

# Experimental setup at JINR

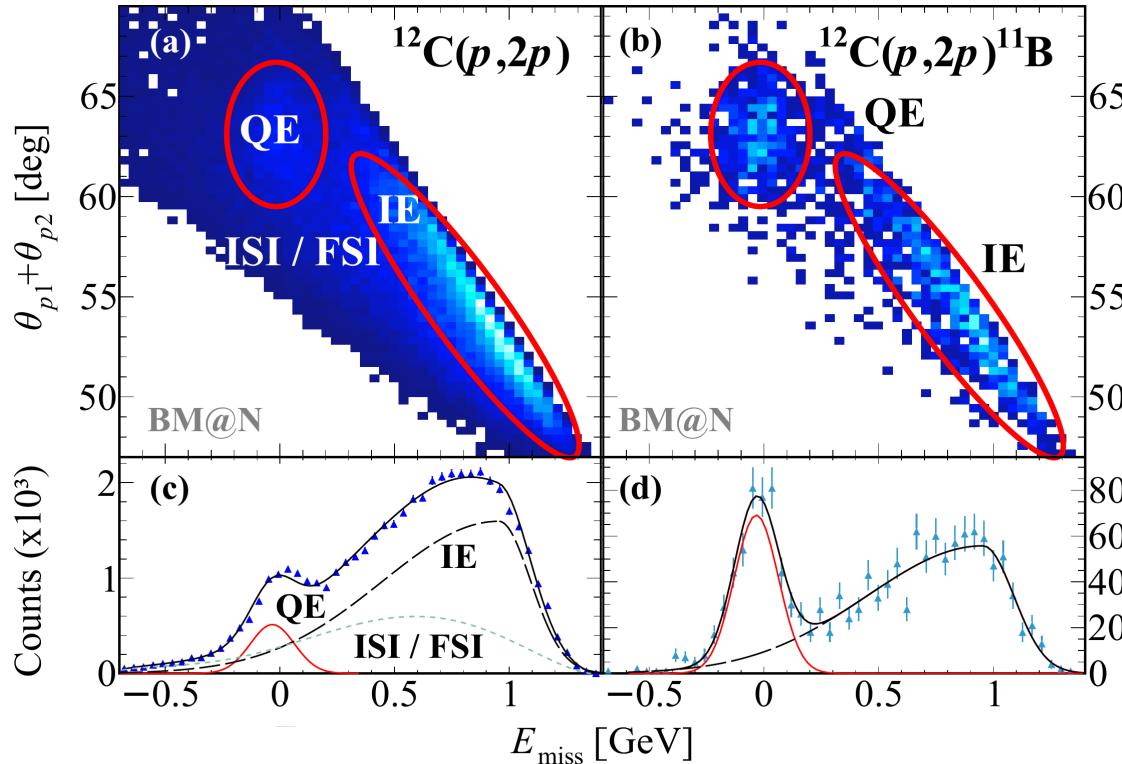


# Heavy-fragment identification

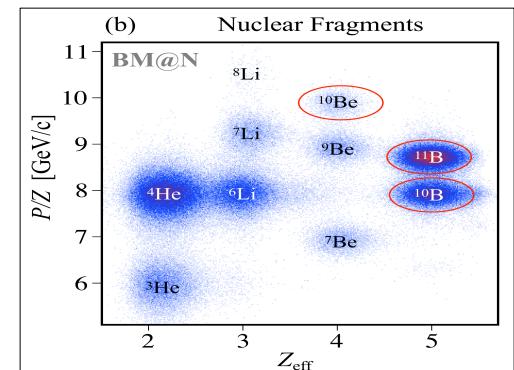
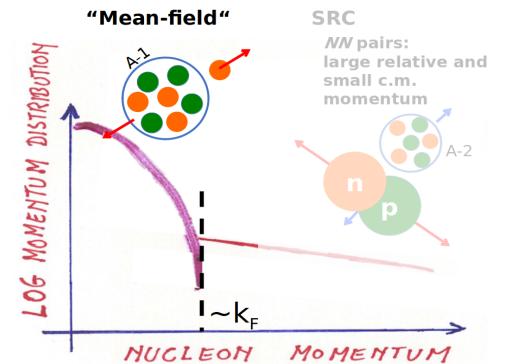
MF:  $^{12}\text{C}(p,2p)^{11}\text{B}$   
SRC:  $^{12}\text{C}(p,2p)^{10}\text{B}, ^{10}\text{Be}$



# Single proton knockout: Inclusive $^{12}\text{C}(p,2p)$ and Exclusive $^{12}\text{C}(p,2p)^{11}\text{B}$

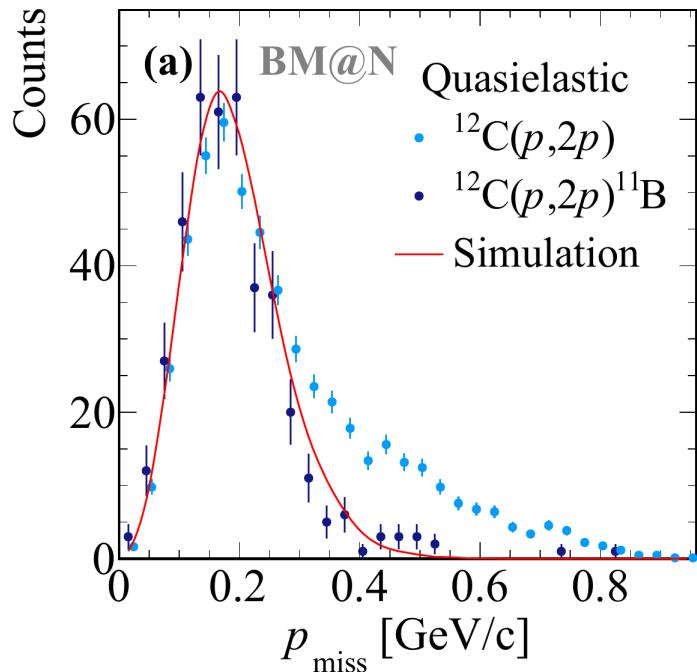


$^{11}\text{B}$  fragment tagging suppresses Initial/Final state interactions  
→ select quasi-elastic scattering

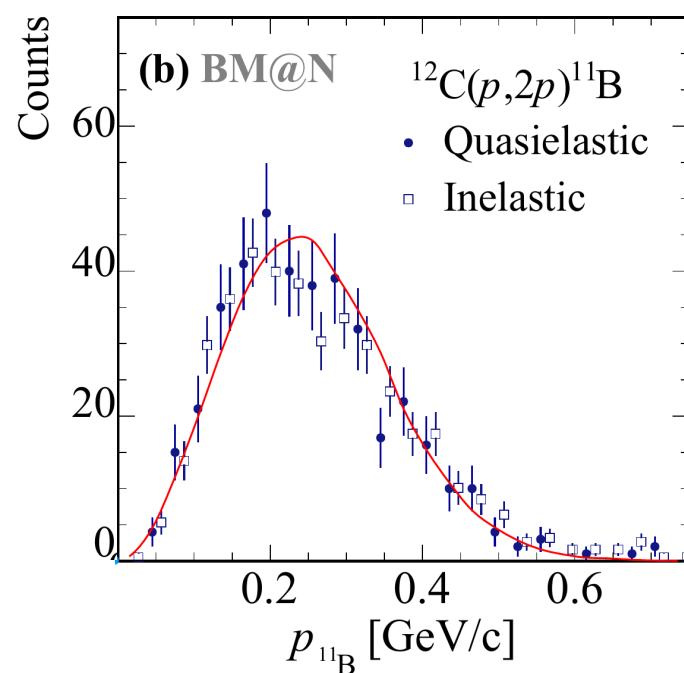


# Accessing nucleon momentum distribution

## Initial proton momentum

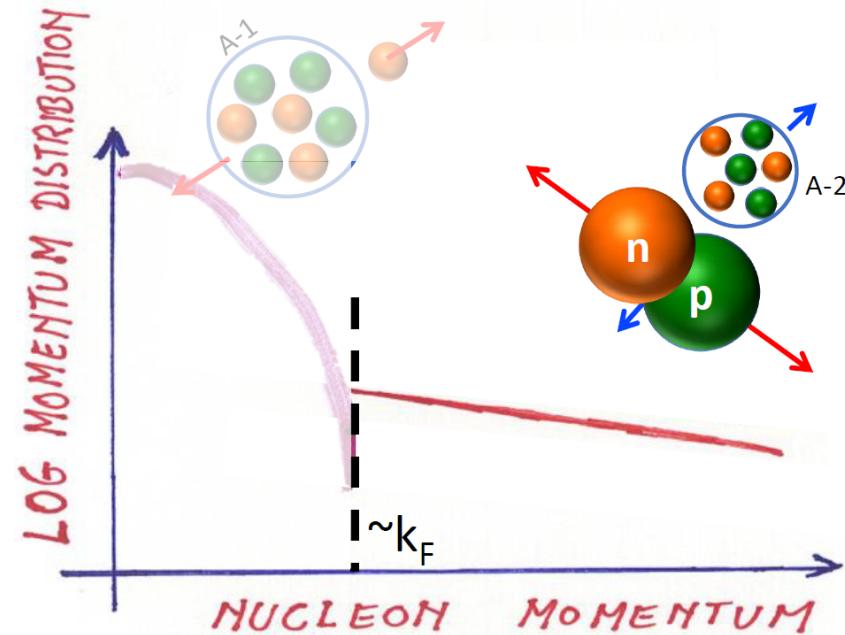


## Fragment recoil momentum

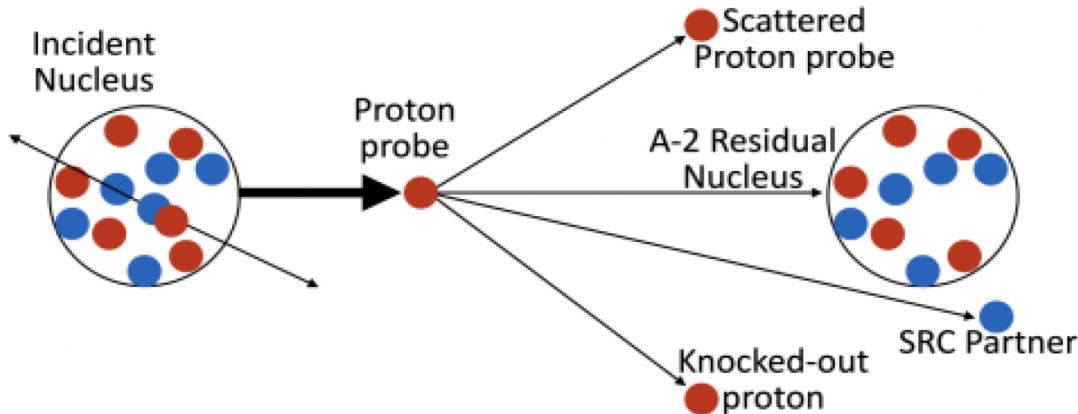


→ single step nucleon knockout process.  
Transparent part of reaction

# First study of SRCs in inverse kinematics



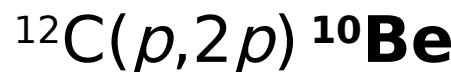
# Hard breakup of SRC pairs



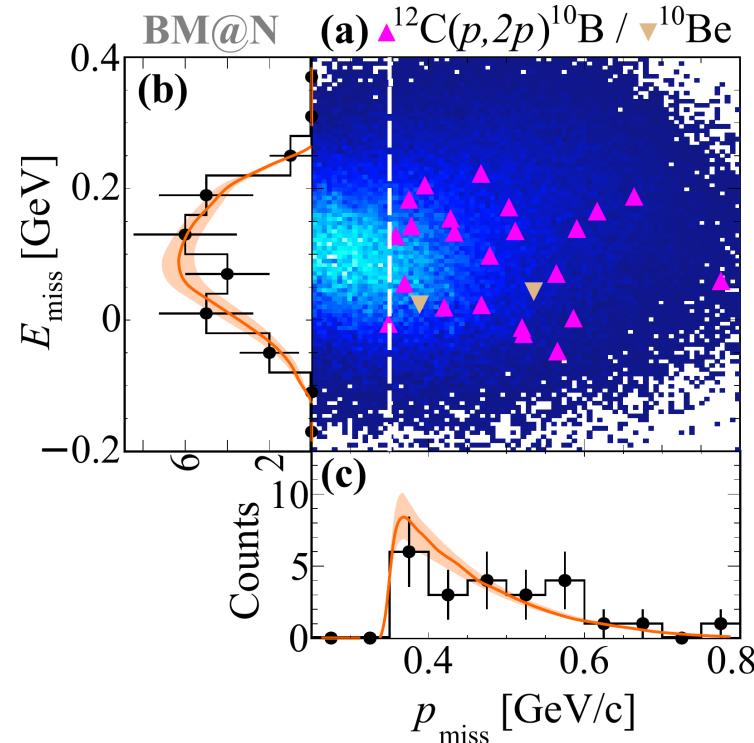
***np* pair**



***pp* pair**



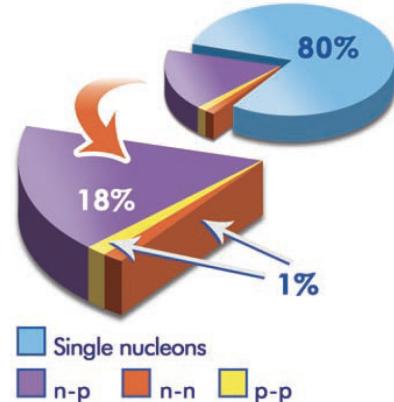
# Identifying SRCs



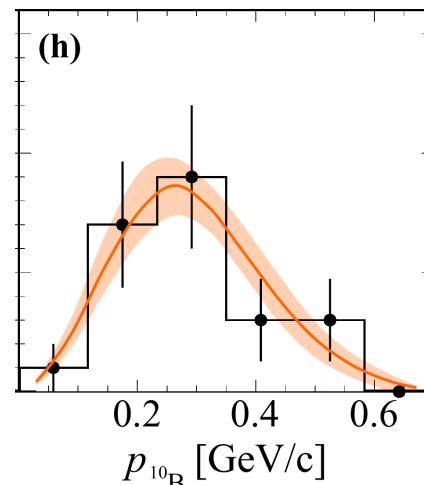
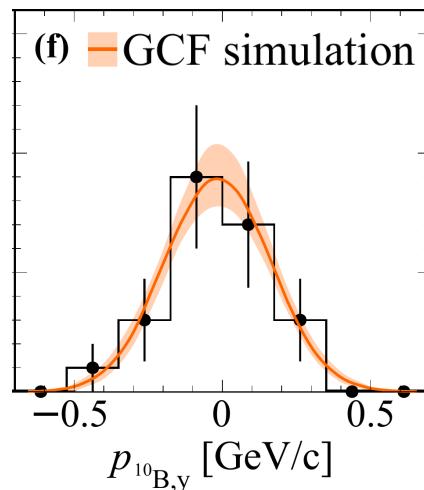
+ proton-proton opening angle  
(guided by simulation)

**23 np pairs  
2 pp pair**

-> *np dominance*

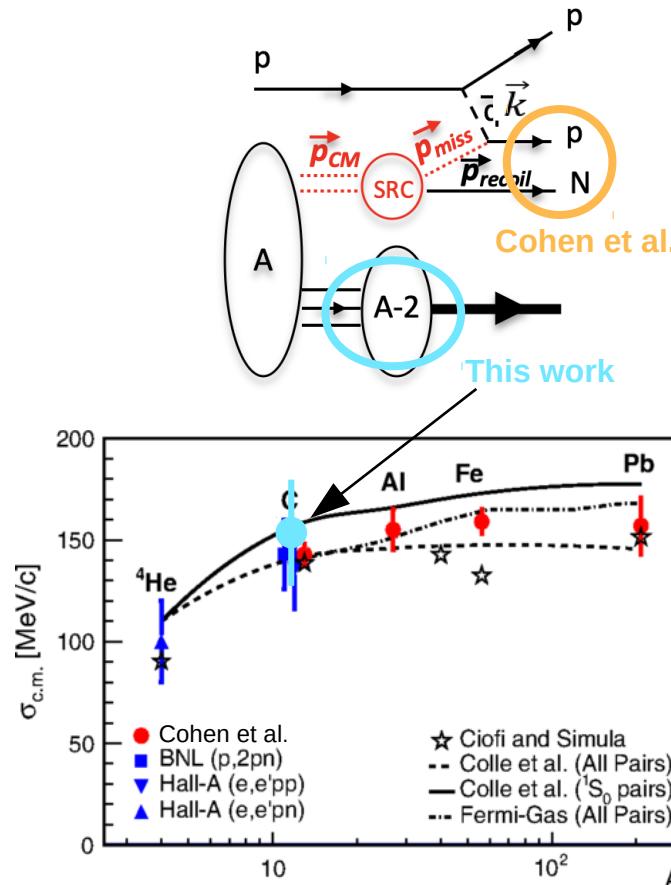


# New observable: Fragment momentum



direct extraction:  
 $\sigma = (156 \pm 27) \text{ MeV/c}$

-> small c.m. momentum



[E.O. Cohen et al., Phys. Rev. Lett 121 (2018)]

# Scale separation

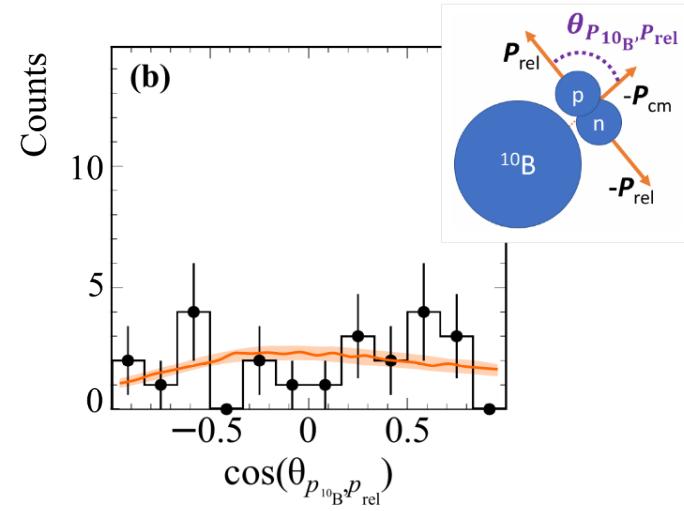
Factorization of nuclear many-body wave function:

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

**universal**

small c.m. motion  $\sim A^{-2}$

strongly correlated pair  
[universal 2-body]

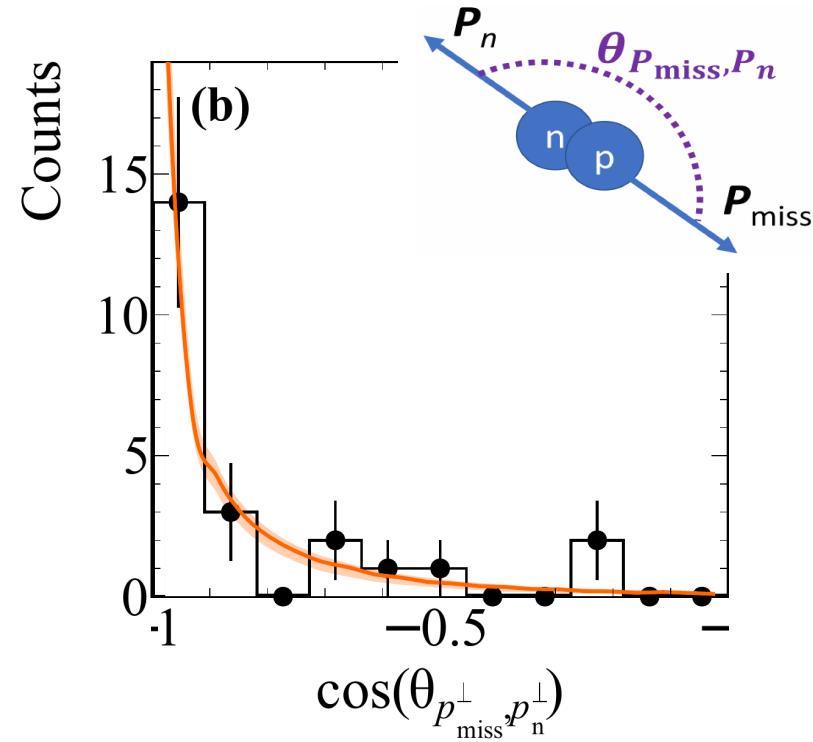


**Evidence for factorization between pair and  $A^{-2}$  !**

# Strong pair correlation

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

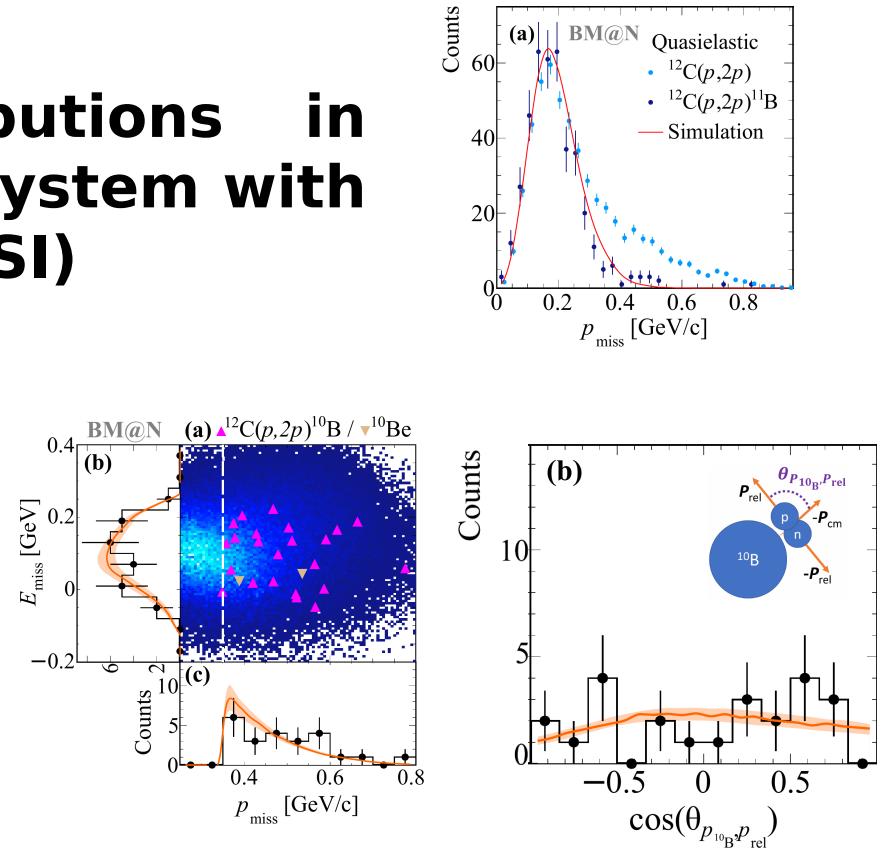
-> NN back-to-back  
emission

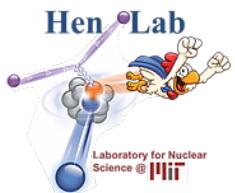
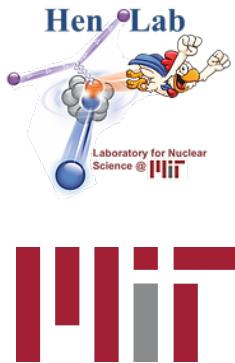


# Conclusion

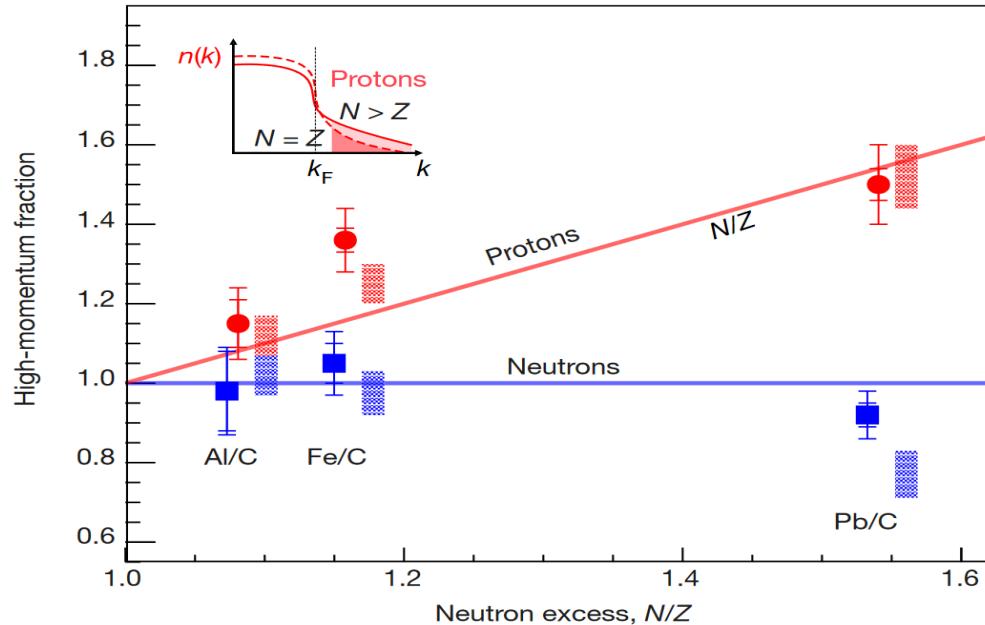
- “Transparent” nucleus:  
Extract ground-state distributions in  
strongly interacting many-body system with  
fragment tagging (suppress ISI/FSI)

- 1st SRC experiment in inverse  
kinematics:  
**evidence for scale separation**





# What happens in neutron-rich systems?



**Fraction of correlated  
protons / neutrons  
grow / saturate  
with neutron excess**

-> protons “speed up”

M. Duer (CLAS Collaboration ), Nature 560  
(2018)

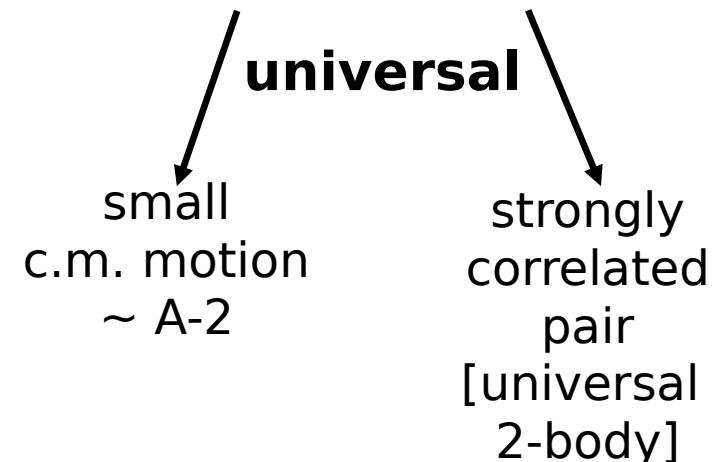
# Scale Separation

**Factorization of nuclear  
many-body wave function:**

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

A-2  $\leftrightarrow$  SRC pair

**Rooted in theories,  
e.g. Generalized Contact Formalism**



R. Cruz-Torres et al., Nature Physics (2020)

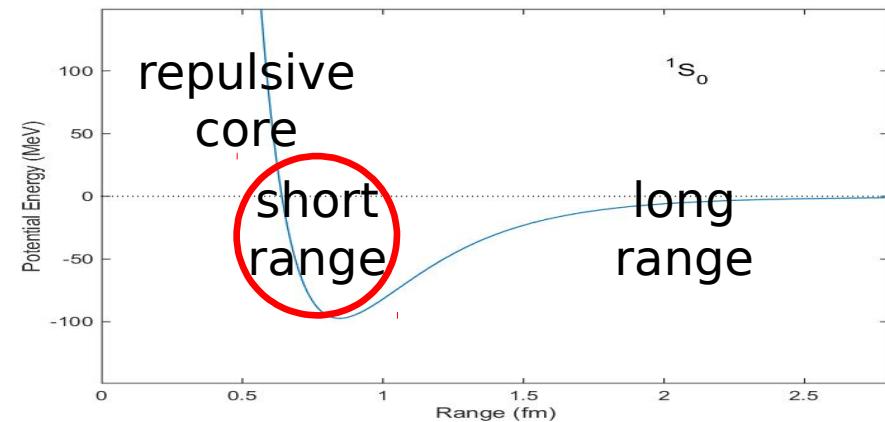
R. Weiss, B. Bazak, N. Barnea, Phys. Rev. C 92 (2015)

J.-W. Chen, W. Detmold, J. E. Lynn, A. Schwenk, PRL 119 (2017)

R. Weiss et al., Phys. Lett. B 780 (2018)

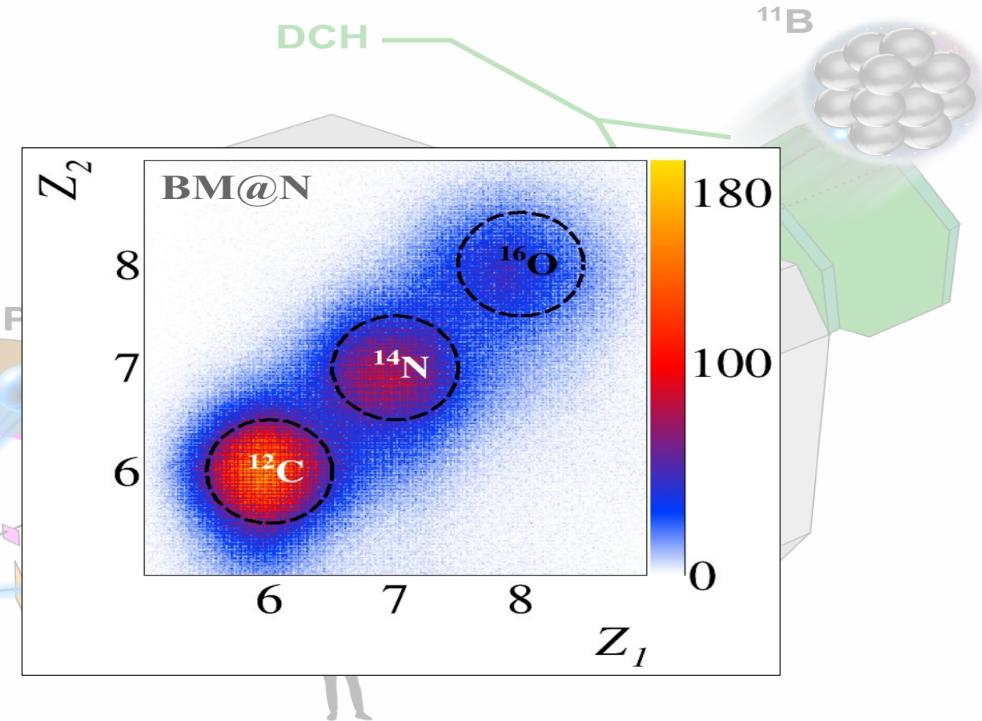
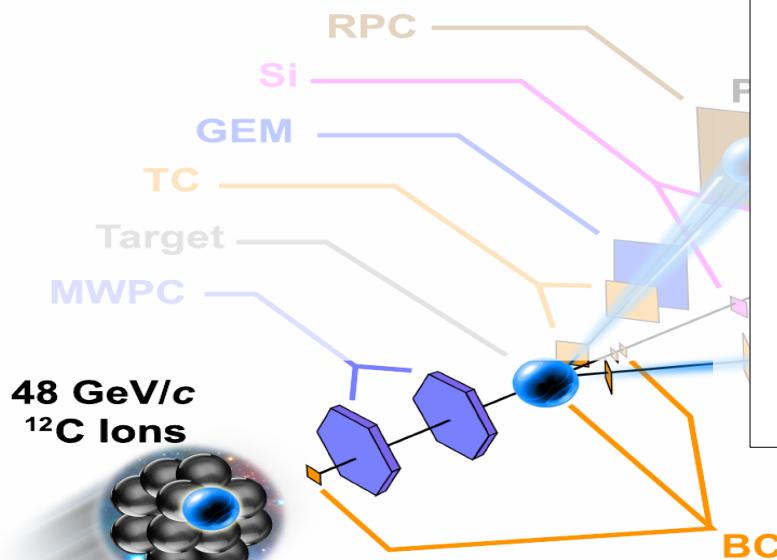
# Nuclear Many-Body Problem

$$\hat{H} |\psi_n\rangle = E_n |\psi_n\rangle$$
$$\hat{H} = \sum_{i=1}^A \hat{T}_i + \sum_{i < j}^A \hat{V}_{ij} + \dots$$

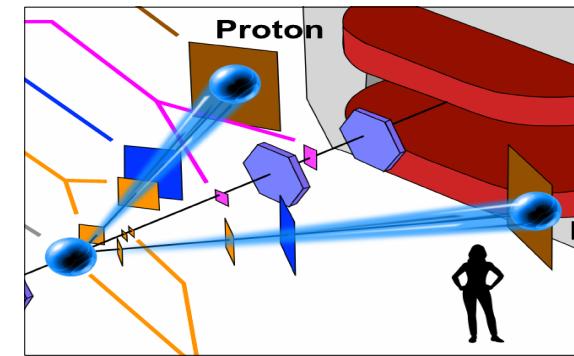
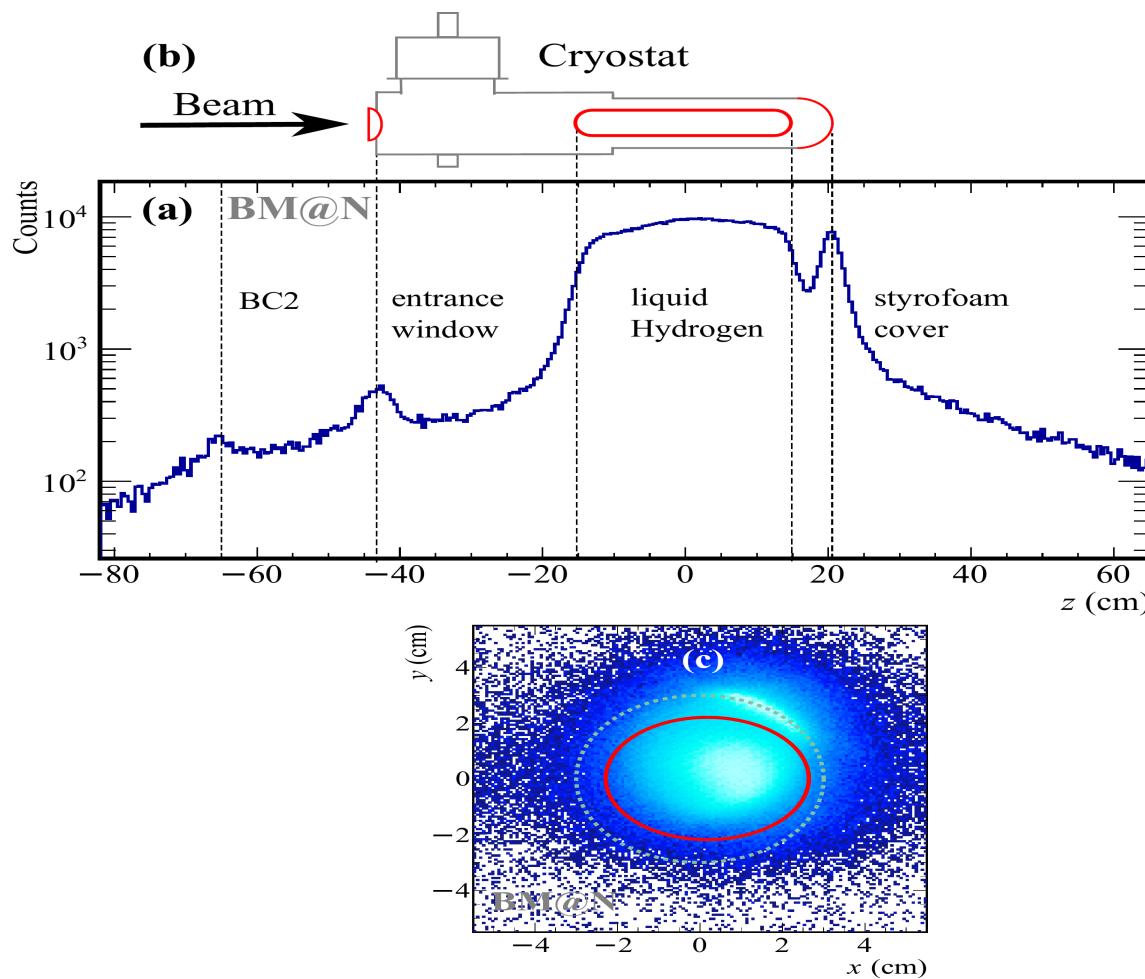


# Incoming-beam identification

MF:  $^{12}\text{C}(p,2p)^{11}\text{B}$   
SRC:  $^{12}\text{C}(p,2p)^{10}\text{B}, ^{10}\text{Be}$



# Proton vertex and Pion rejection



## Pion rejection

