Inverse Kinematics Nucleon Knockout Measurements with a 45 GeV/c Carbon Beam

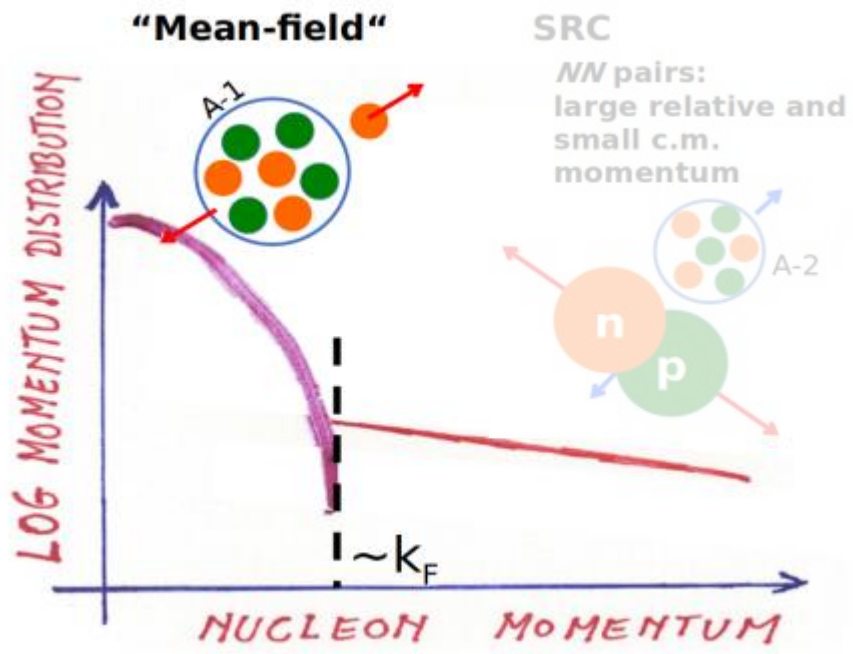
Timur Atovullaev

on behalf of the SRC collaboration

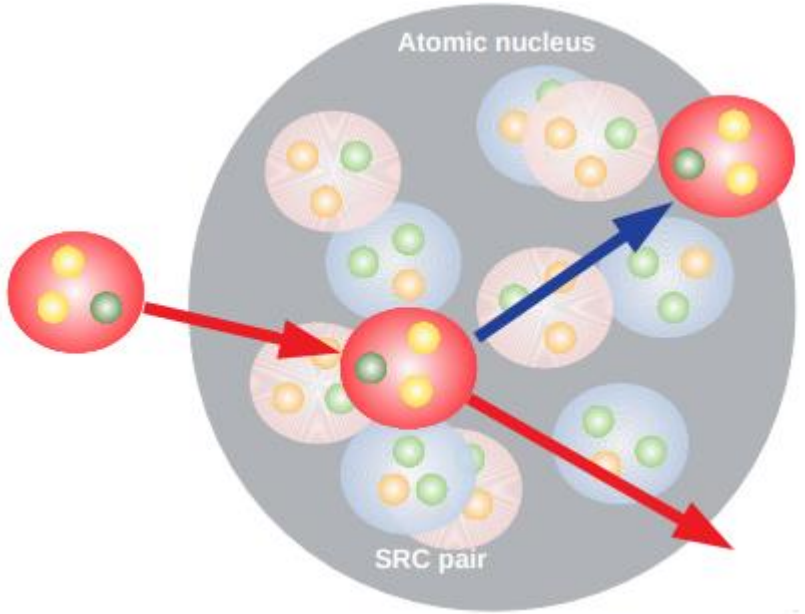
4th October 2024

20th *International Workshop on Hadron Structure and Spectroscopy, Yerevan, Armenia*

Studying strongly interacting quantum systems

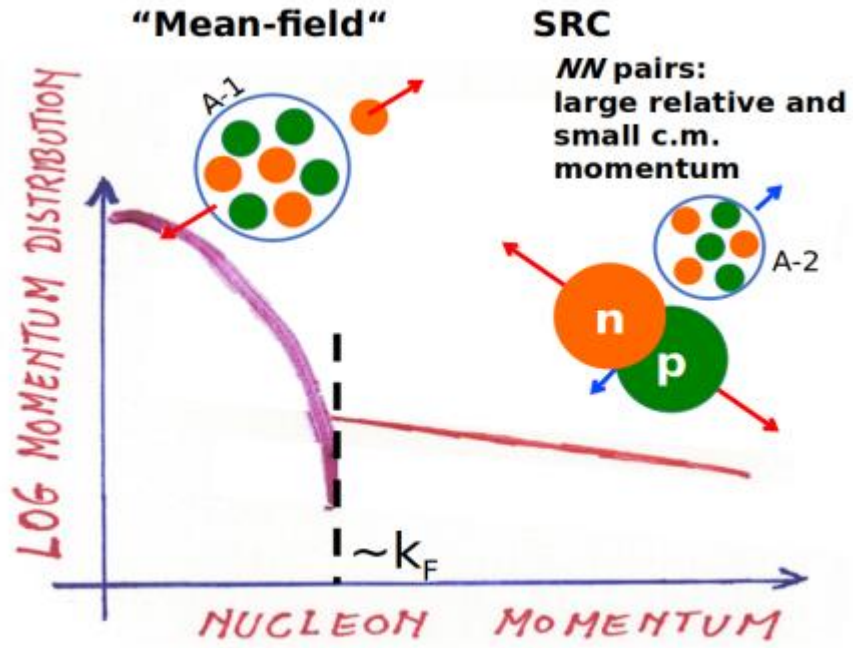


Nucleon knockout reaction: incoming proton and outgoing protons interact with other nucleons
(Initial / Final state interactions (ISI / FSI))

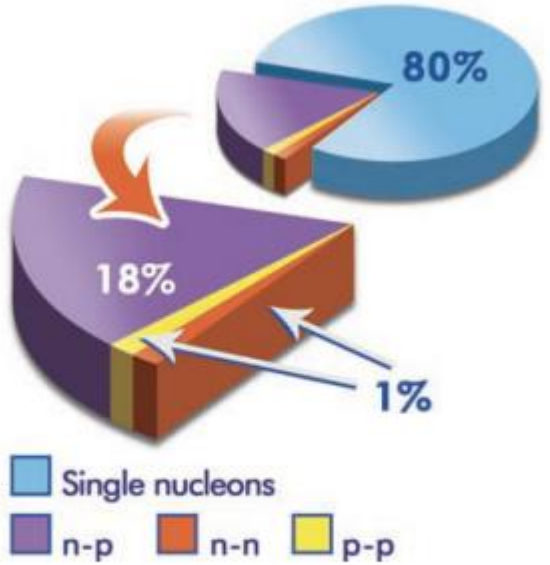


MF: $^{12}C(p,2p)^{11}B$

Ground state distribution of nucleons



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



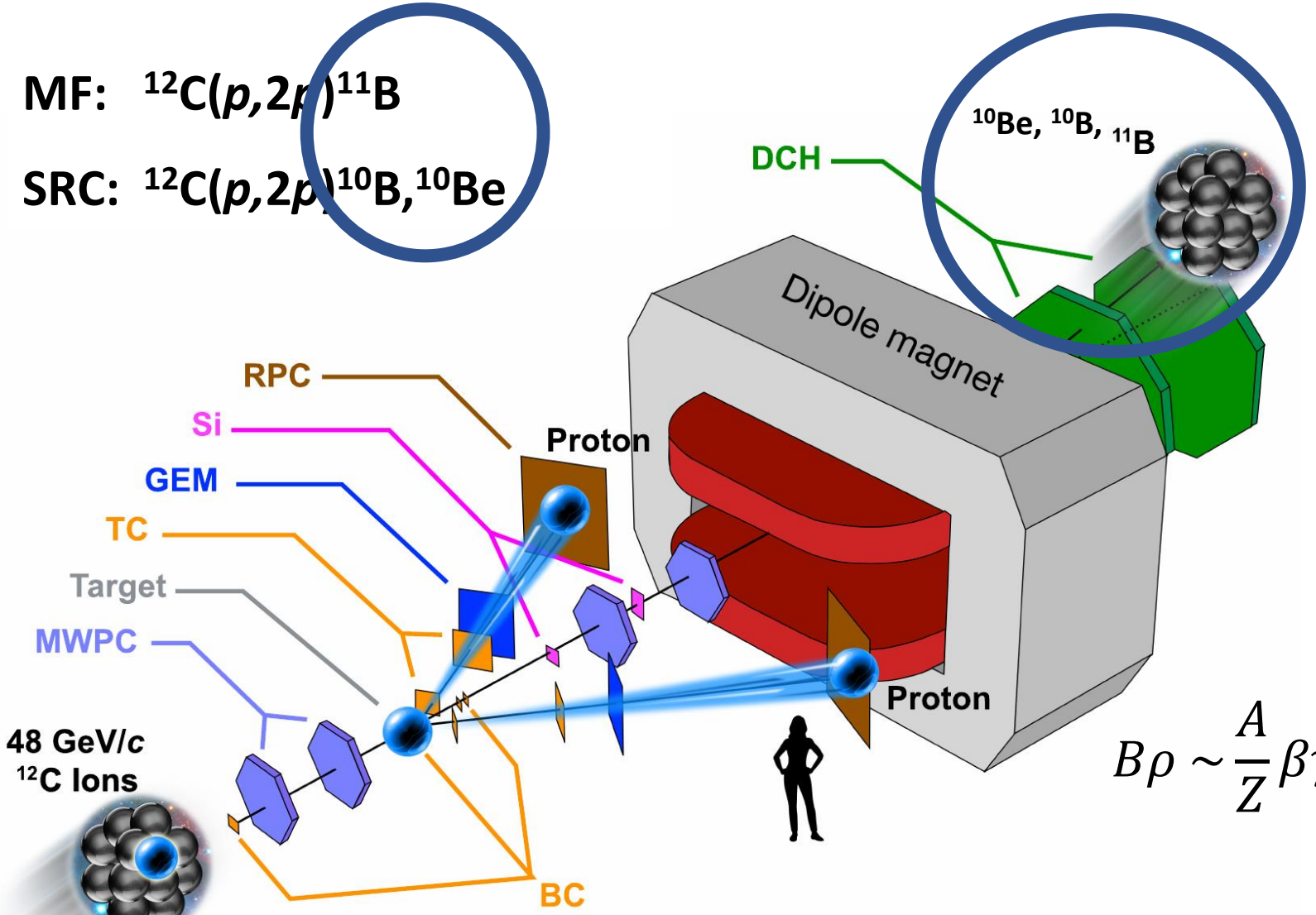
SRC: n-p dominance

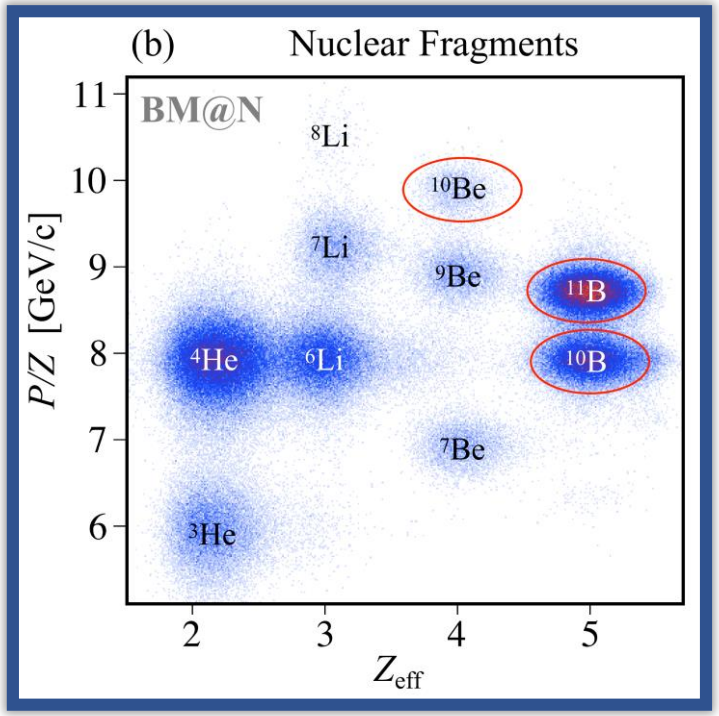
A. Tang et al., Phys. Rev. Letters (2003)
E. Piasetzky et al., Phys. Rev. Letters (2006)
R. Shneor et al., Phys. Rev. Letters (2007)
R. Subedi et al., Science 320, 1476 (2008)

JINR pilot experiment in 2018

MF: $^{12}C(p,2p)^{11}B$

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



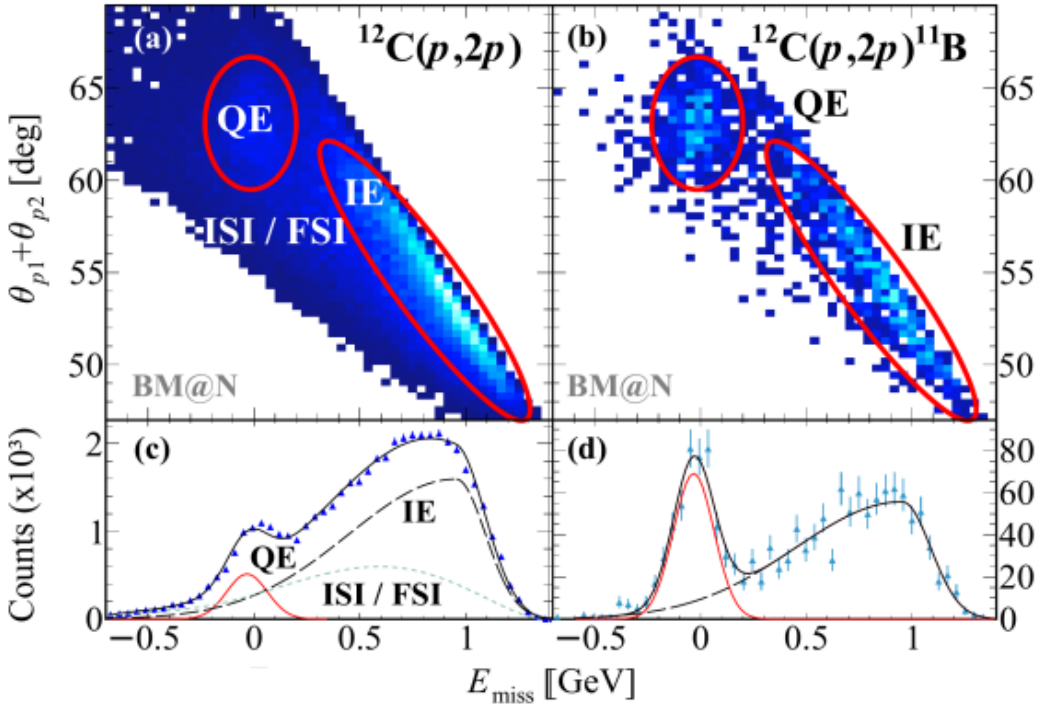


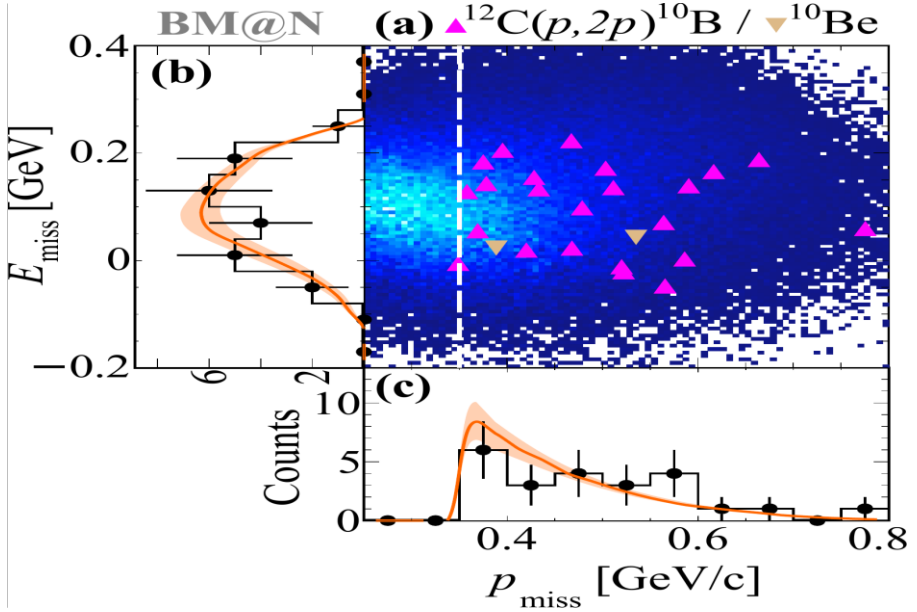
$$B\rho \sim \frac{A}{Z}\beta\gamma$$

Inverse kinematics:

- ✓unstable nuclei
- ✓pmiss, pn
- ✓p probe:
  - ✓larger cross-section
  - ✓(compared to e-scattering)
- ✓fragment ID + pA-2

Main results of 2018 experiment

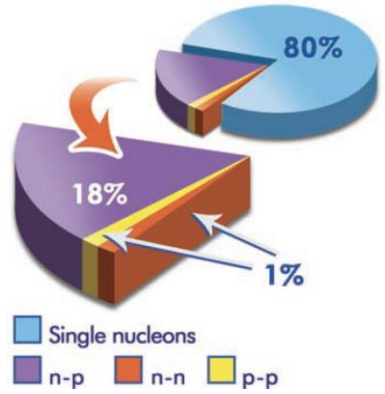




Fragment tagging suppress rescattering
(Initial/Final state interactions)
Select quasi-elastic scattering

23 np SRC pairs

2 pp SRC pairs



M. Patsyuk et al. Nature Physics 17, 693 (2021)

An important result of 2018 experiment: Factorization

Factorization of nuclear many-body wave function
Applied in Generalized Contact Formalism

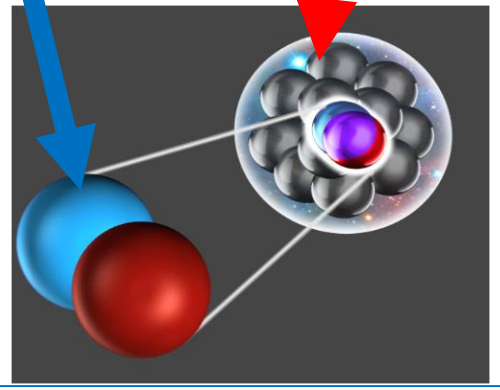
$$\Psi \xrightarrow{r_{ij\to 0}} \sum_{\alpha} \varphi_{ij}^{\alpha}(\boldsymbol{r}_{ij}) A_{ij}^{\alpha}(\boldsymbol{R}_{ij}, \{\boldsymbol{r}_k\}_{k\neq i,j})$$

~ A-2 system

Channels $\alpha = \pi_2 S_2 j_2 m_2$

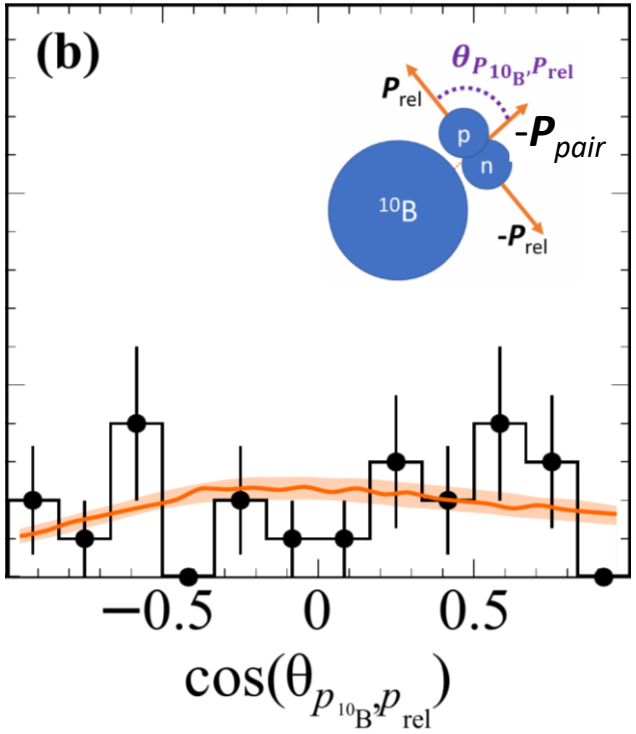
SRC pair "universal" function

The pair kind $ij \in \{pp, nn, pn\}$



Scale separation

$$\boldsymbol{p_{Rel} > p_{pair}}$$



M. Patsyuk et al.
Nature Physics 17, 693 (2021)

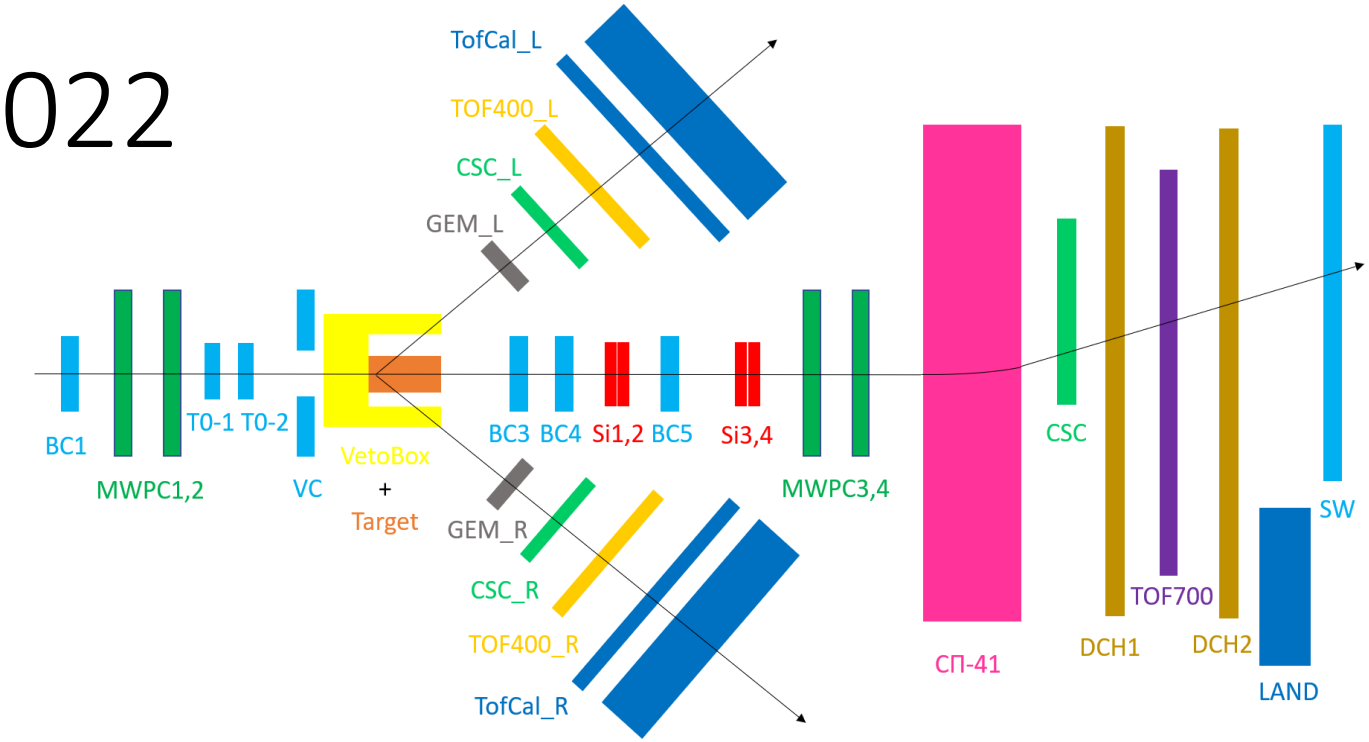
JINR experiment in 2022

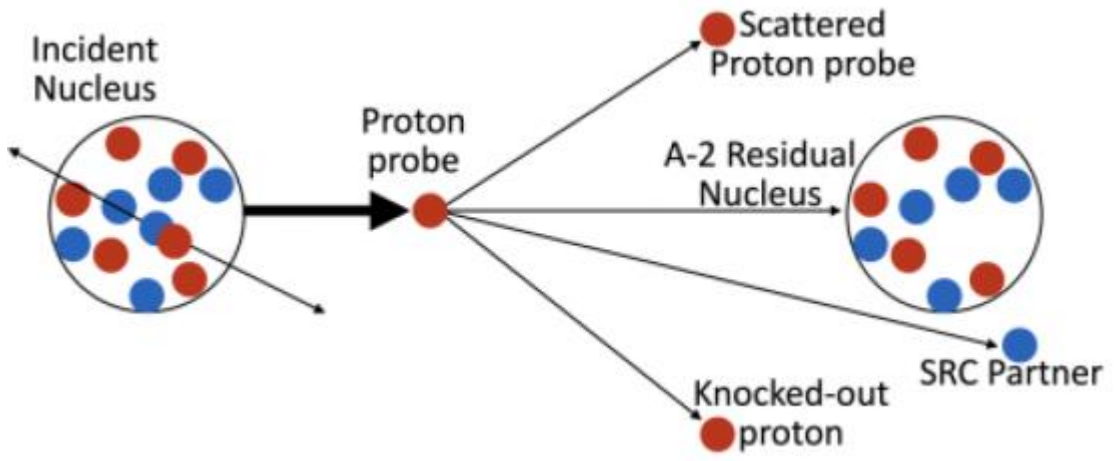
Main goal: reactions cross section measurements and studying fragment properties

45 GeV/c ^{12}C beam momentum
(3.7 GeV/c/nucleon)

Updated experimental setup:

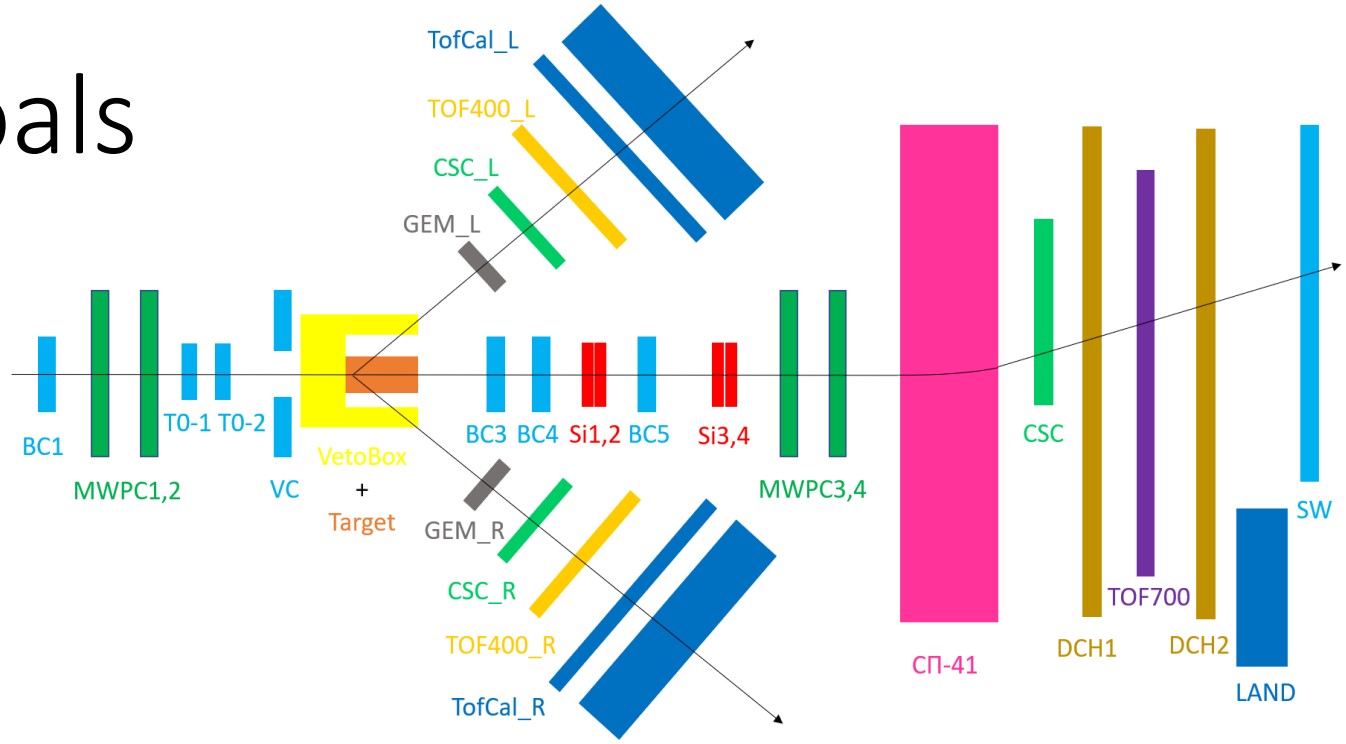
- New scintillator detectors T0 and BC and SW
- Two-arm calorimeter with TOF layer
- 2 pairs of Si detectors
- CSC
- Laser calibration system
- VetoBox detector





Experiment 2022 goals

10 times more statistics than 2018

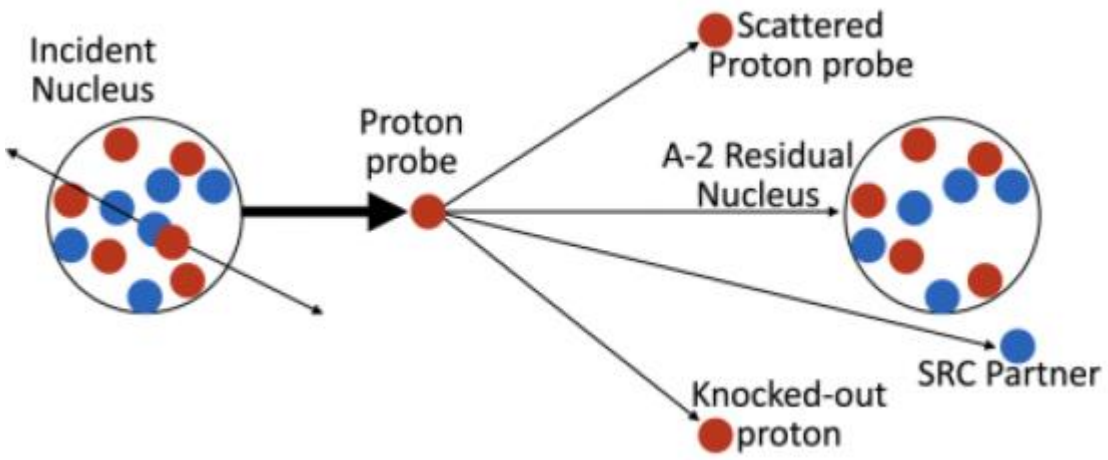


Single nucleon knockout:

- Absolute cross section
  - Quenching
  - Attenuation

SRC:

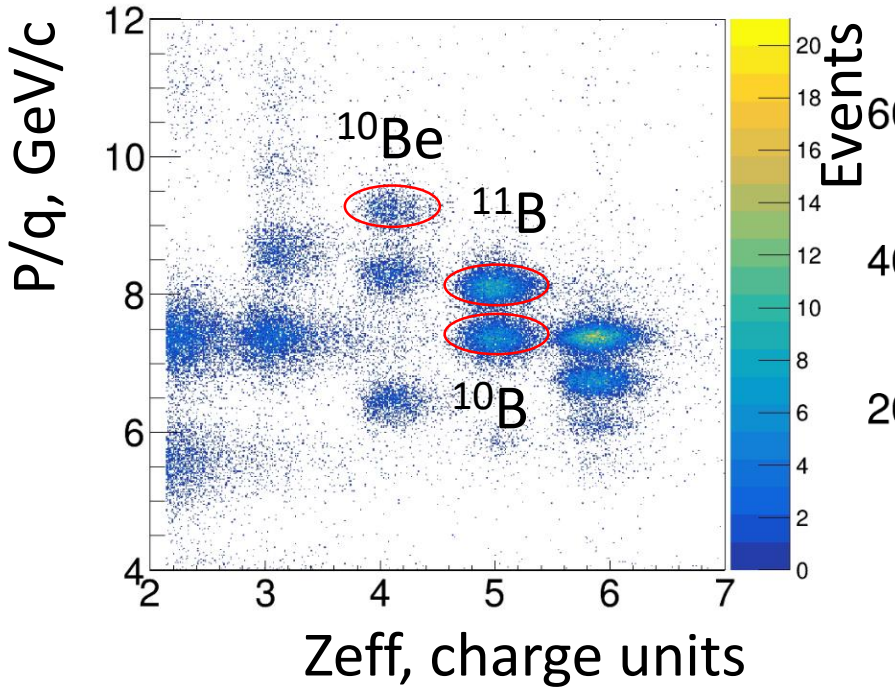
- Improve statistics
- Detect recoil n/p
- Multi-fragment reconstruction
- Fragment distribution → "SRC origin" → SRC pairs are $(2p)^{-1}$ $(1p1s)^{-1}$ $(2s)^{-1}$



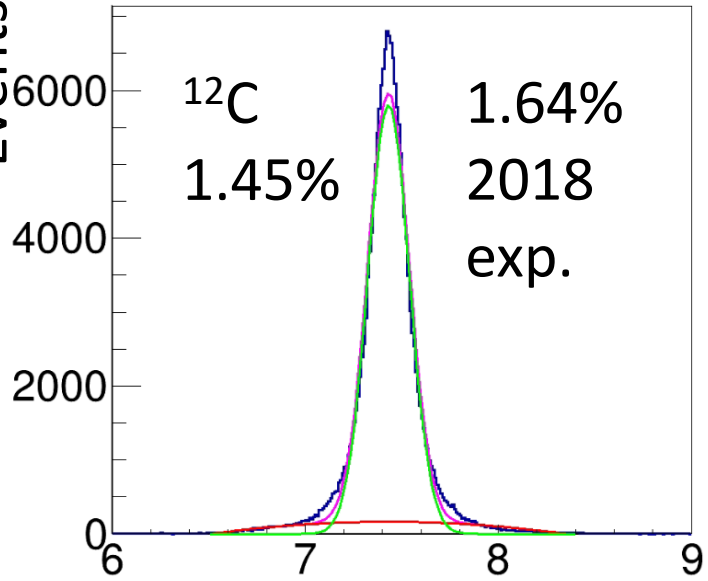
Heavy-fragment identification

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

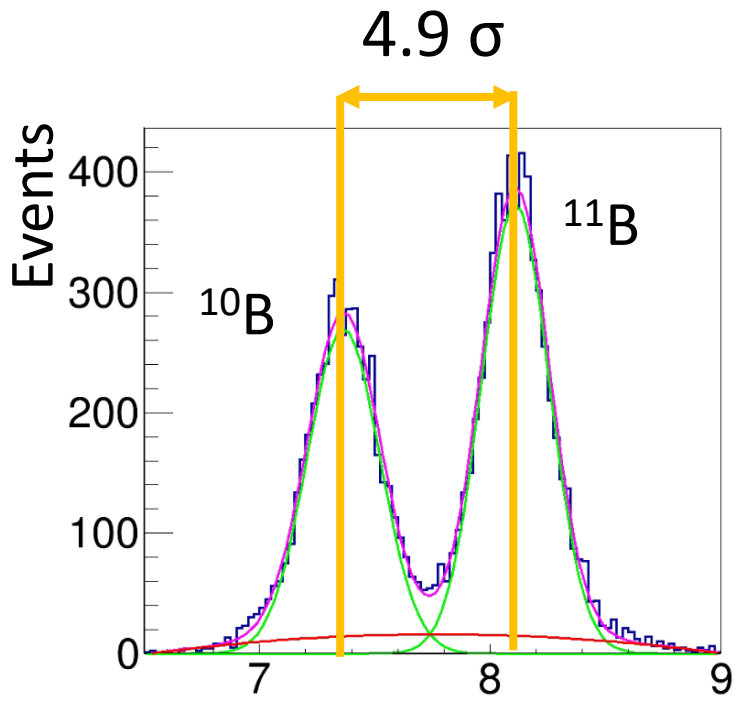
SRC: $^{12}C(p,2p)\ ^{10}B,^{10}Be$



Fragment identification

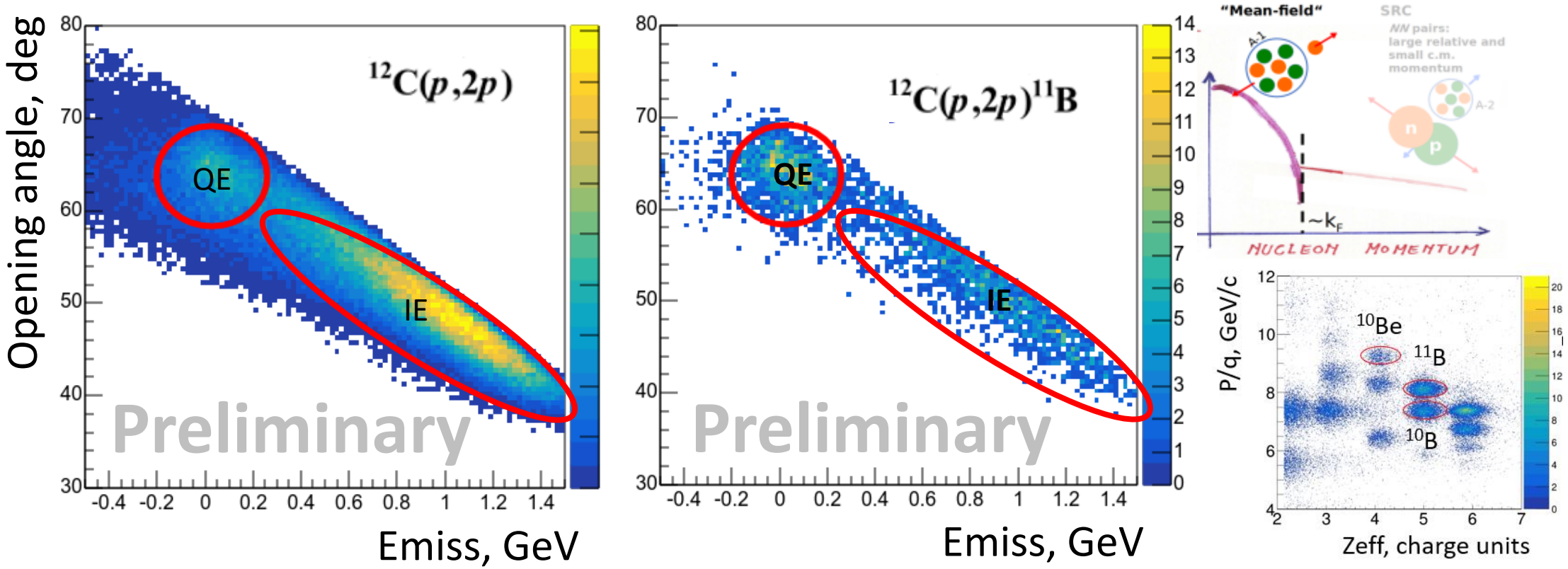


Beam momentum resolution



Boron isotopes separation

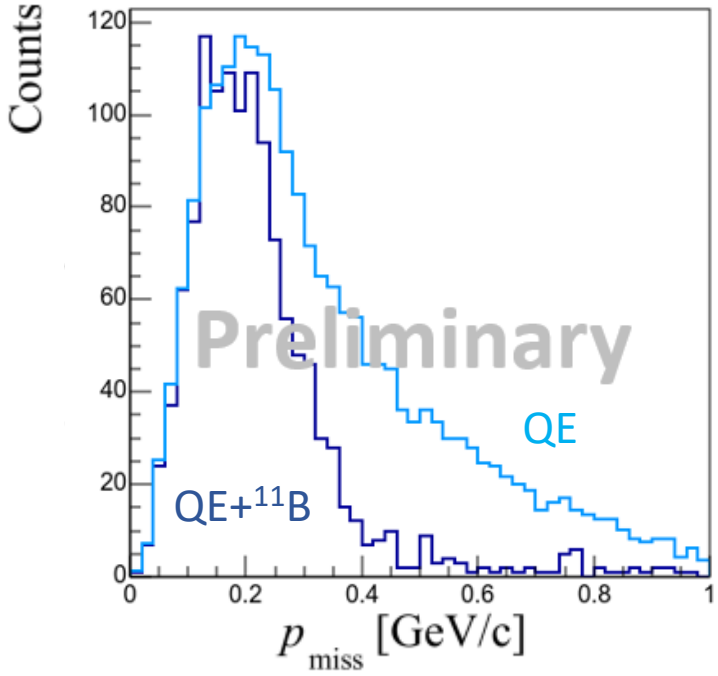
Single proton knockout: Inclusive $^{12}C(p,2p)$ and Exclusive $^{12}C(p,2p)^{11}B$



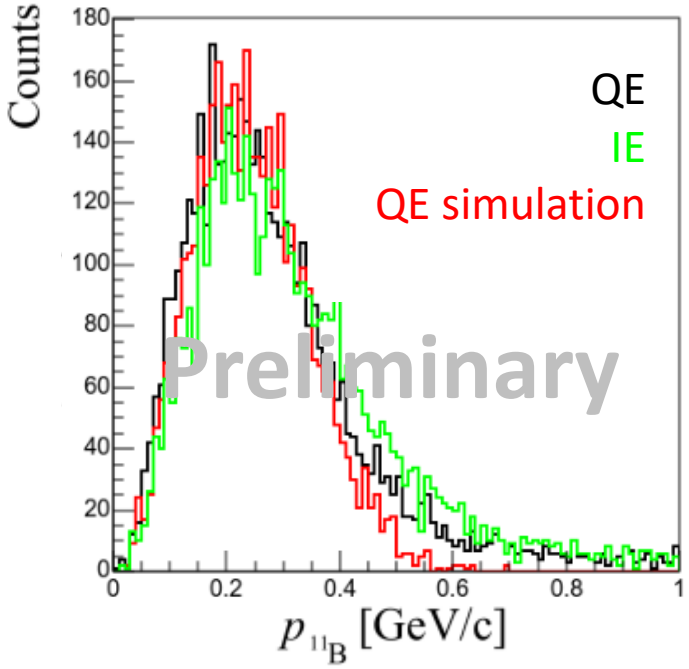
Fragment tagging suppresses rescattering
(Initial/Final state interactions)
Select quasi-elastic scattering

Accessing nucleon momentum distribution

Initial proton momentum

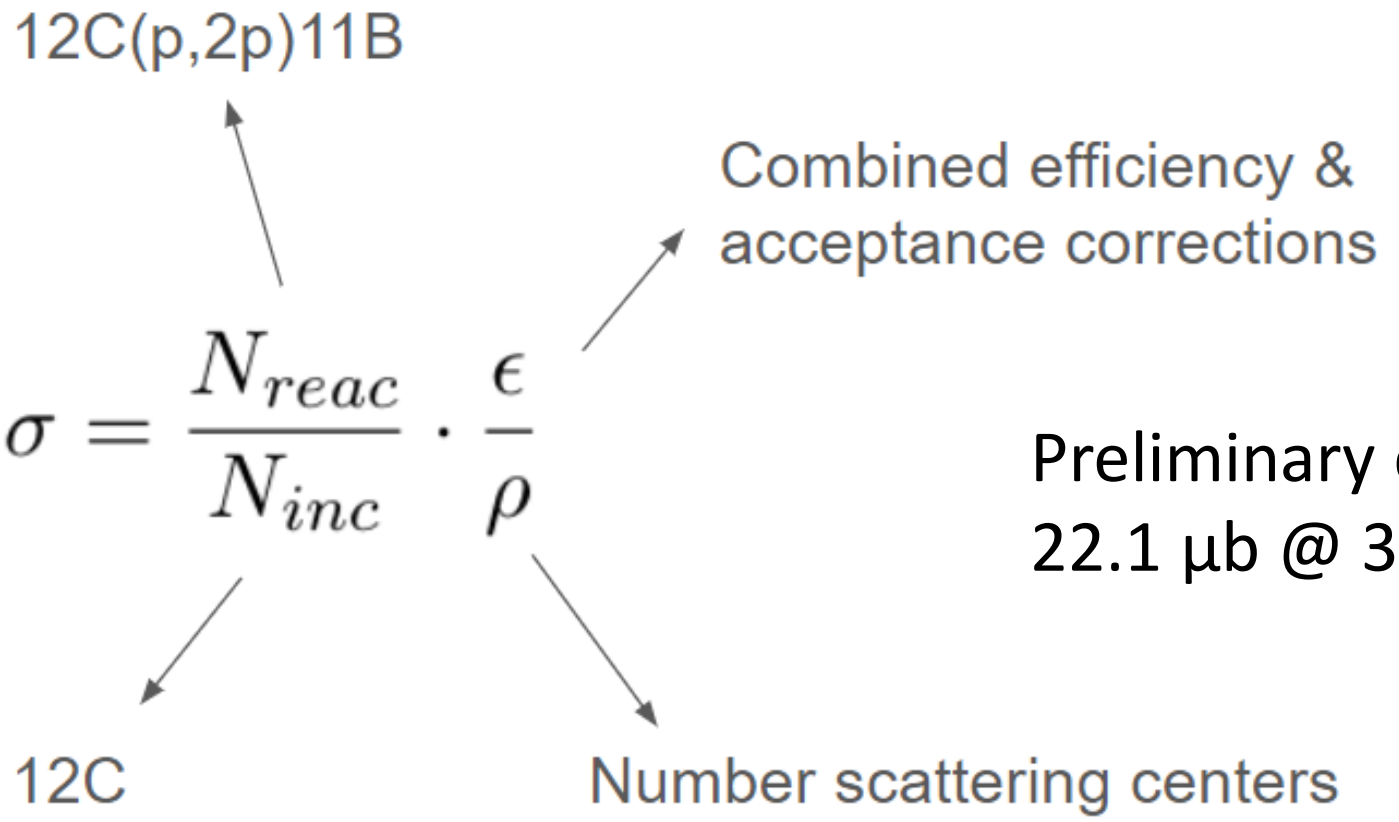


Fragment recoil momentum



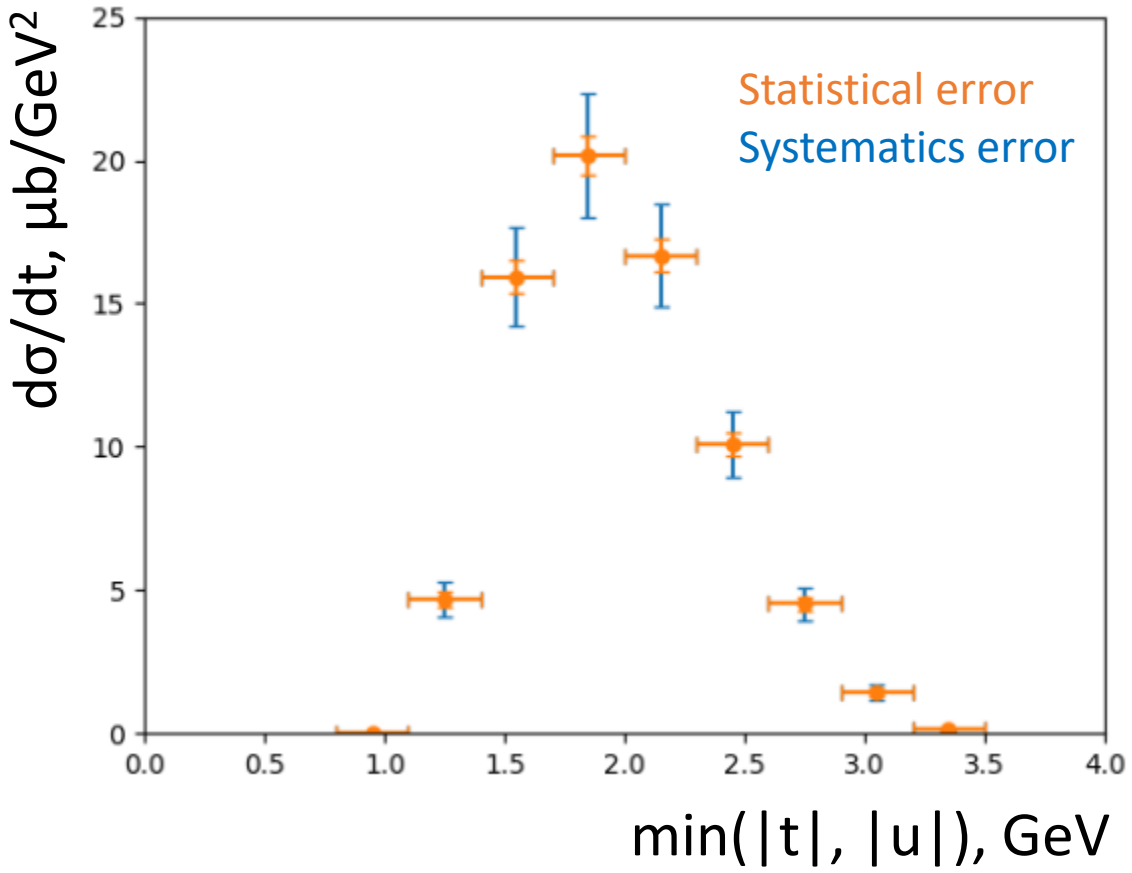
→ single step nucleon knockout process.
Transparent part of reaction

Cross section calculation



Preliminary cross section:
22.1 µb @ 3.75 GeV/c/nucleon

Preliminary QE cross section



This data is to be compared with calculations of A. Larionov (See talk at this conference)

Next steps

- Finish analyzing the full 2022 set of data
- Identify SRC pairs, extract SRC-pairs ratios
- Study events with more than one fragment

Expected results

- Ground-state **proton momentum distributions** with fragment tagging (suppress ISI/FSI)
- Single nucleon knockout **cross section**
- SRC pairs ratios
- Multi-fragment distributions

Thank you for attention!

Efficiency

	Effect	Value	Corr. factor ϵ_i	Uncertainty
1	Frag. P/Q cut	$[-1.8\sigma : 3\sigma]$	1.036	0.5%
2	Frag. bckgr.	3.5%	0.965	1.0%
3	Frag. charge cut	$[-2\sigma : 2\sigma]$	1.048	0.5%
4	Frag. tracking eff.	39.8%	2.513	3.0%
~~5~~	~~Frag. BC eff.~~	100%	1.000	0%
~~6~~	~~Frag. charge survive~~	73.3%	1.364	3.0%
~~7~~	~~Frag. neutral survive~~	100%		0%
8	Frag. tgt break	87%	1.149	1.5%
9	$(p, 2p)$ eff.	–	1.171	5.5%
10	TOF400 acc	65.5%	1.527	1.0%
11	Frag. acc	100%	1.000	0%
12	$(p, 2p)$ ϕ acc	13.75%	7.273	0%
13	$(p, 2p)$ vertex cut	3σ	1.000	0%
14	Inc. vertex cut	?	1.000	0%
15	Inc. charge cut	?	1.000	0%

Tgt breakup

$$p_{tgt} = \exp\left(-\rho\sigma_{tot}z\right) = 0.87, \tag{2}$$

with $\sigma_{tot} = 220 \pm 10\,\mathrm{mb}$ and $\rho = 4.267 \times 10^{22}\,\mathrm{protons/cm^3}$ and averaging over the target (i. e. $z = 15\,\mathrm{cm}$).

Number of scattering centers

$$\rho = \rho_{LH2} \cdot \frac{2 \cdot N_A}{M_{mol}} \cdot L$$

$$= 0.07085 \left[\frac{\mathrm{g}}{\mathrm{cm}^3}\right] \cdot \frac{2 \cdot 6.022 \times 10^{23} \left[\frac{1}{\mathrm{mol}}\right]}{2.016 \left[\frac{\mathrm{g}}{\mathrm{mol}}\right]} \cdot 30 \,[\mathrm{cm}]$$

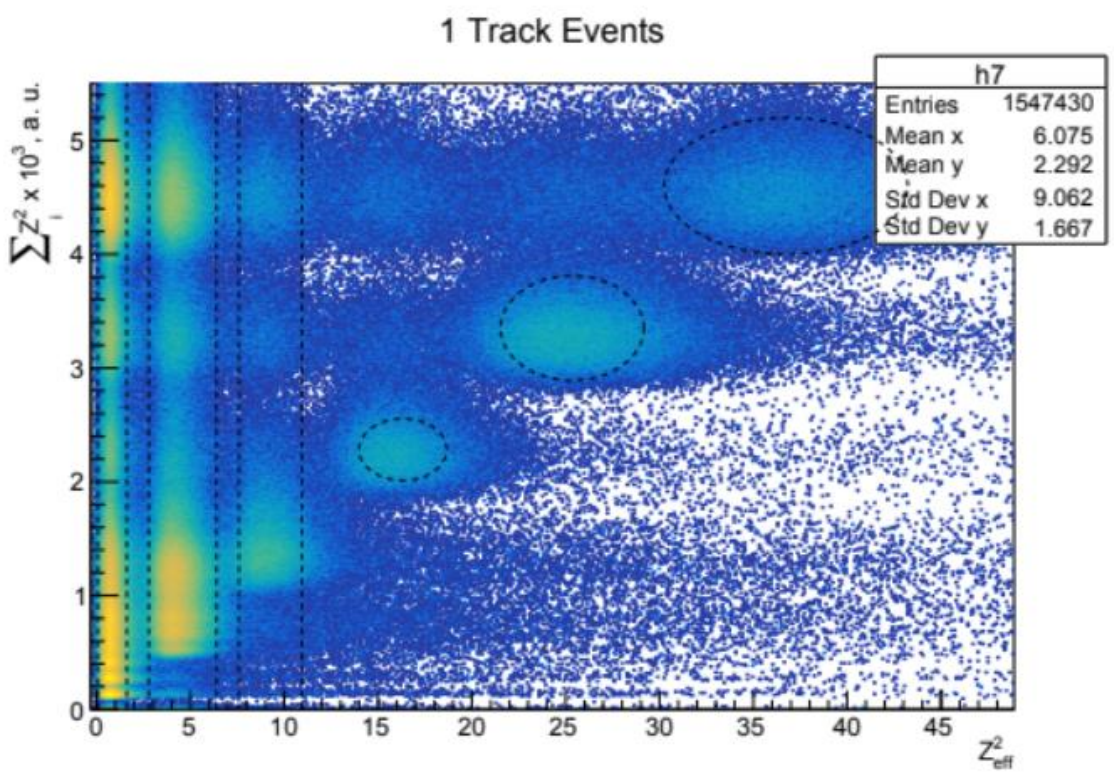
$$= 1.270 \times 10^{24} \frac{\mathrm{protons}}{\mathrm{cm}^2}.$$

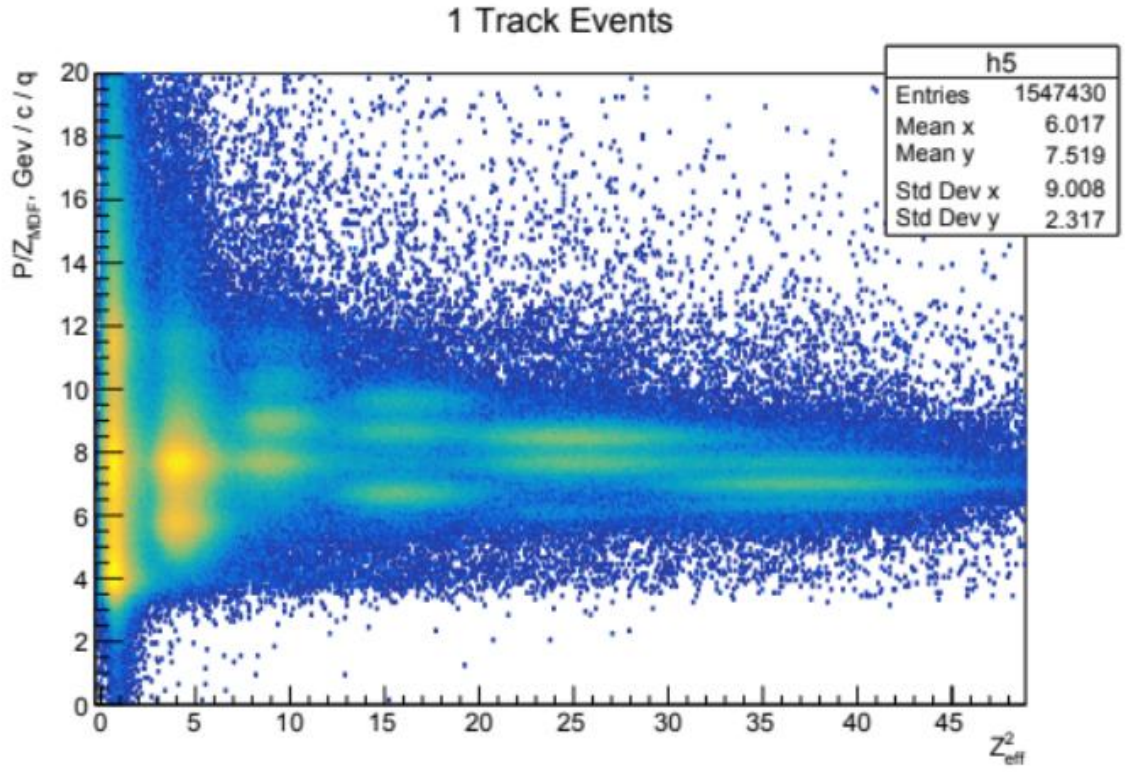
with 2% uncertainty

- fraction of Good-beam triggers relative to beam triggers because beam triggers were downscaled but Arm-And triggers come only with Good-beam triggers: ε = 1/1.018 (using MSC1 counts).
- DAQ readout itself is decoupled from the trigger logic/run control, and will not contribute to any additional bias when counting Arm-And versus beam trigger
- Sergey: add. Delay?

- $N_{inc} = DS_{eff} \cdot \#trig\,[\mathrm{BT}] \cdot \epsilon_{GB}$
- DS uncertainty?

Scintillator wall





Inverse kinematics

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- ✓pmiss, pn
- ✓p probe:
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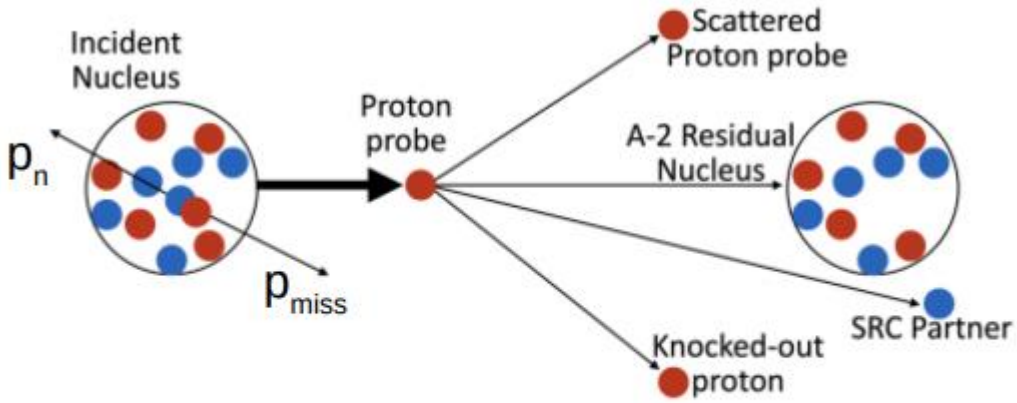
- ✓fragment ID + pA-2



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

Experiments at JINR

The 2018 experiment on the study of SRC on BM@N is the first experiment to study the properties of SRC in inverse kinematics.

Reactions:

MF: 12C(p,2p) 11B
SRC: 12C(p,2p) 10B,10Be