Status of the SRC experiment at NICA

Maria Patsyuk (JINR)

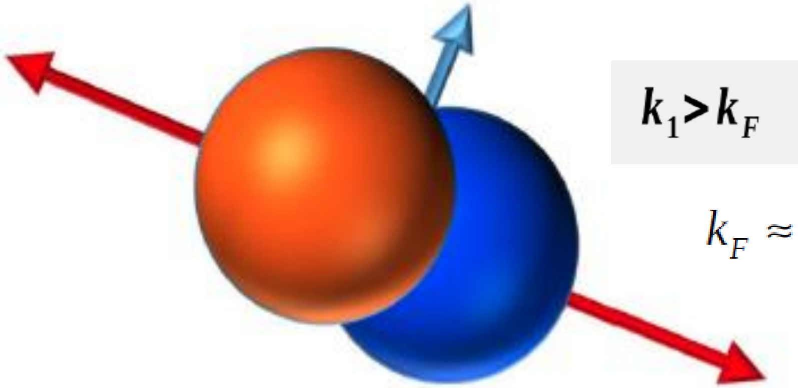
Short-Range Correlations (SRCs) – close proximity nucleon pairs

Short-range, short-lived,
highly correlated nucleon pairs

High momentum of correlated nucleons,
low pair momentum

r ~ R

Position-space



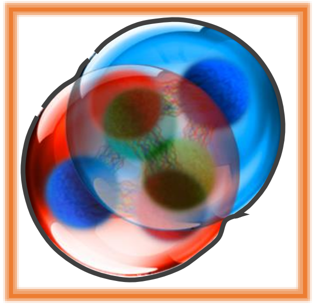
$k_1 > k_F \quad k_2 > k_F \quad k_1 \simeq k_2$

$k_F \approx 250$ MeV/c

Momentum-space

Why studying SRC is important?

Almost all nucleons above the Fermi sea level belong to SRC	**~80% of the kinetic energy in heavy nuclei is carried by SRC nucleons**



- Reveal properties of **dense nuclear matter** → essential for understanding neutron stars
- Key to understanding the microscopic origin of **intermediate- and short-range nuclear forces**
- Probes **new physics in nuclei** – beyond contributions from individual nucleons
- Bridge **nuclear structure, QCD**-based nuclear interactions, and astrophysical phenomena

SRC Experiments and results

2018:
Nature 560, 617 (2018)
Phys. Rev. Lett. 121, 092501 (2018)
Phys. Lett. B 785, 304 (2018)
Phys. Lett. B 780, 211 (2018)

2019:
Nature 566, 354 (2019)
Phys. Rev. Lett, 122, 172502 (2019)
Phys. Lett. B 797, 134890 (2019)
Phys. Lett. B 797, 134792 (2019)
Phys. Lett. B 793, 360 (2019)
Phys. Lett. B 791, 242 (2019)

2020:
Nature 578, 540 (2020)
Phys. Rev. Lett. 124, 212501 (2020)
Phys. Rev. Lett. 124, 092002 (2020)
Phys. Lett. B 805, 135429 (2020)
Phys. Lett. B 811, 135877 (2020)
Phys. Lett. B 800,135110 (2020)

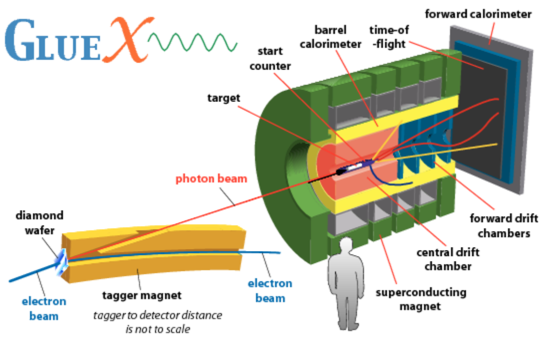
2021:
Nature Physics 17, 693 (2021)
Nature Physics 17, 306 (2021)
Phys. Lett. B 820, 136523 (2021)
Phys. Rev. Research 3, 023240 (2021)
Phys. Rev. C Lett. 103, L031301 (2021)

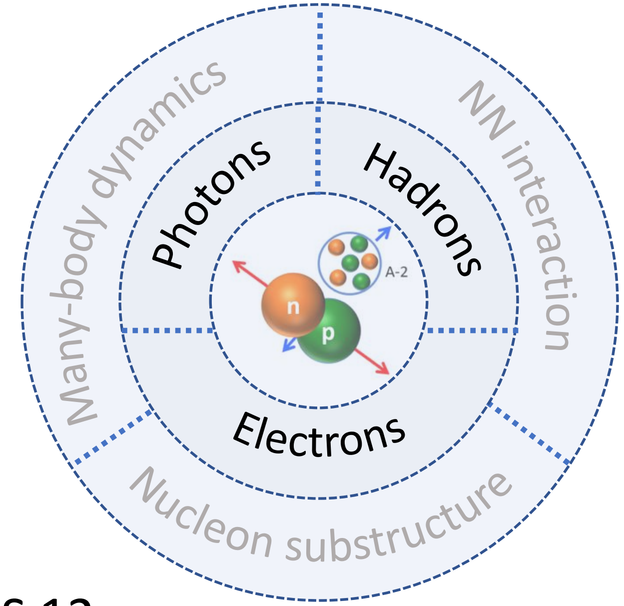
2022:
Phys. Rev. C 105, 034001 (2022)

2023:
Phys. Rev. C 107, L061301 (2023)
Nucl. Instrum. Meth. A 1052, 168238 (2023)

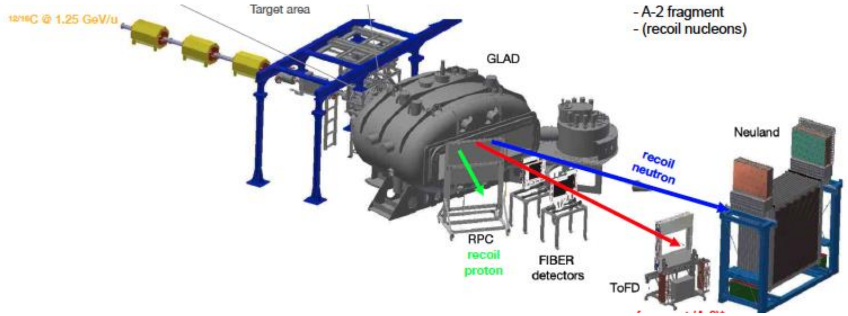
2024:
Nucl. Phys. A 1047, 122874 (2024)
JHEP 02, 123 (2024)
Phys. Rev. C 109, 054001 (2024)
Phys. Lett. B 855m 138790 (2024)

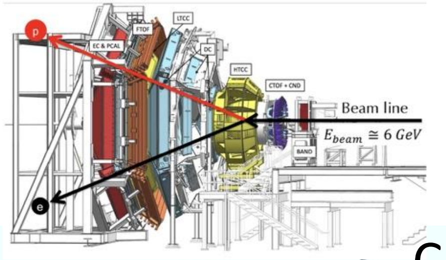
Jefferson Lab Hall D GlueX



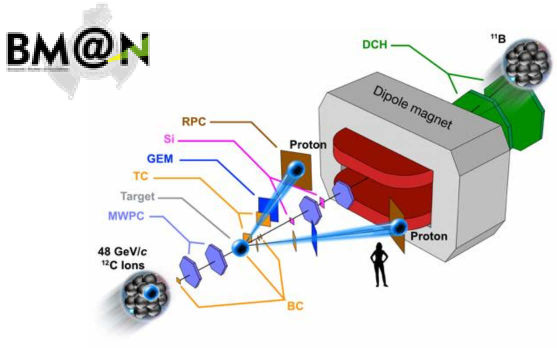


R3B

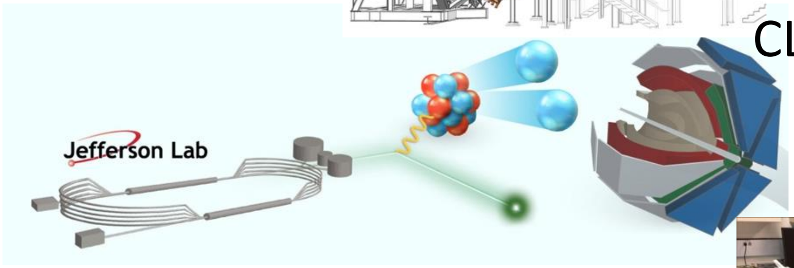




JINR

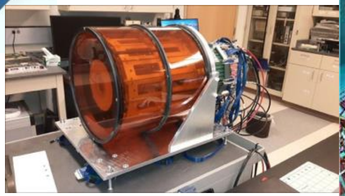


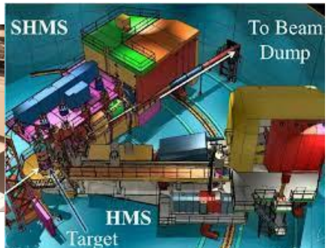
CLAS 12



Jefferson Lab Halls A, B, C

ALERT





State-of-the-art SRC studies

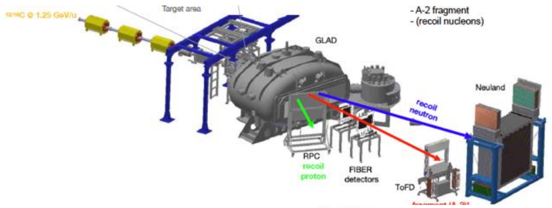
Fragmnets tagging
(R3B, **JINR**, HIAF, ALERT@CLAS12)

Neutron-rich nuclei / isotopic chains
(R3B, CLAS12, HIAF)

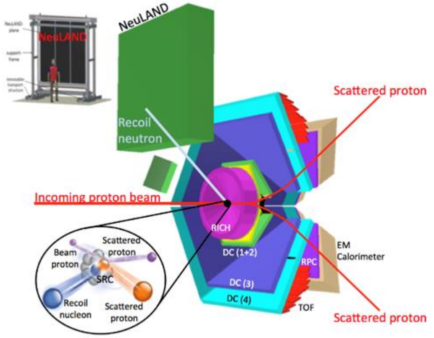
Polarized probes
(**JINR**)

High statistics
(HADES, **JINR**, HIAF)

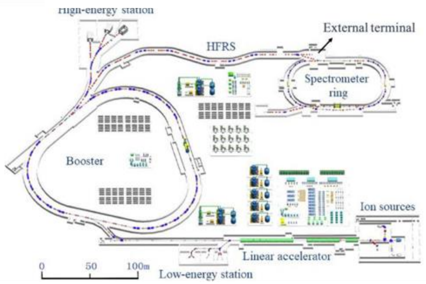
R3B



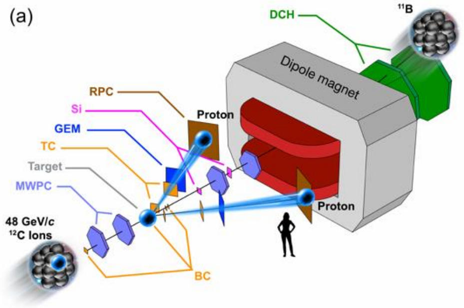
HADES



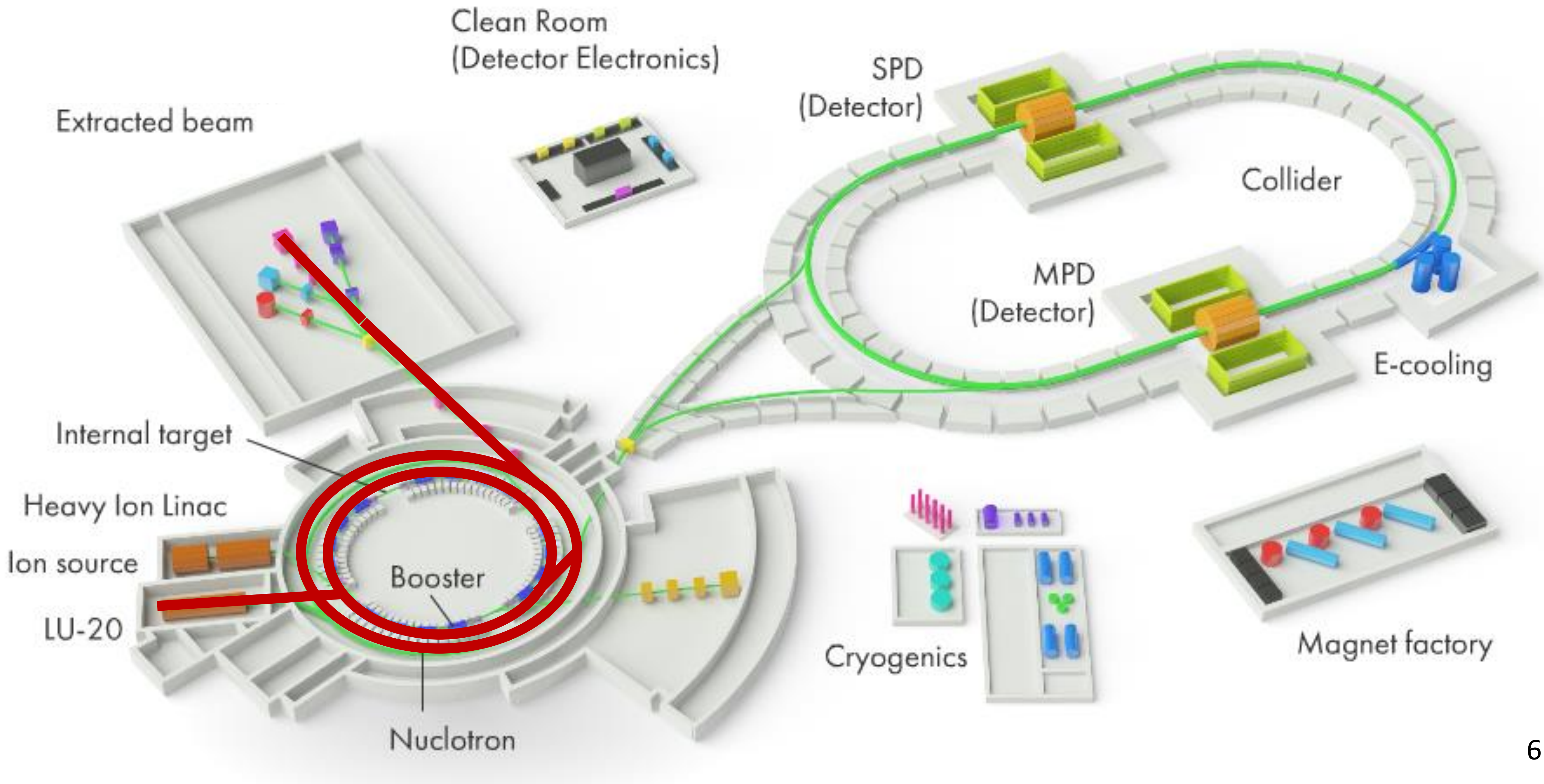
HIAF



JINR



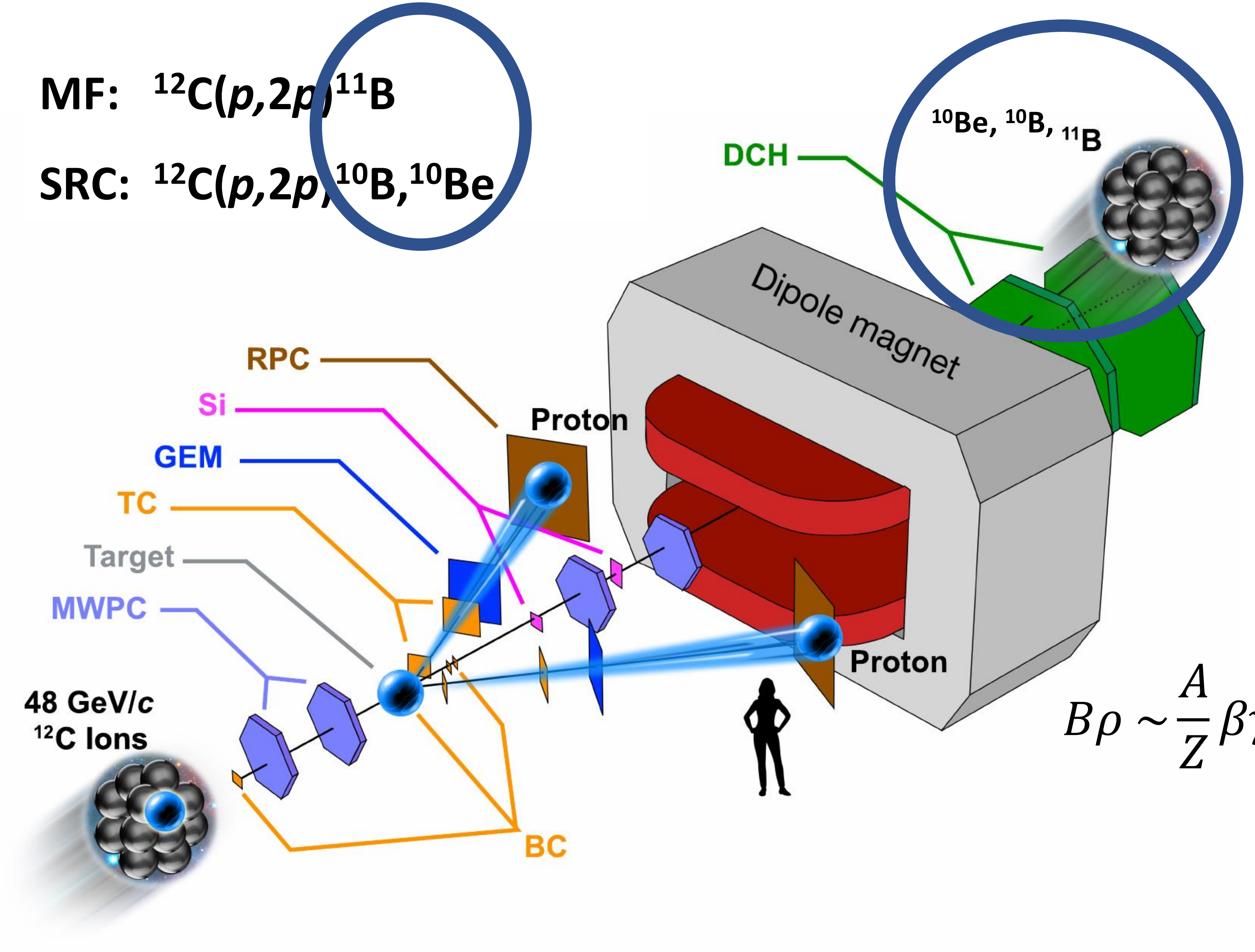
at Joint Institute for Nuclear Research (JINR)



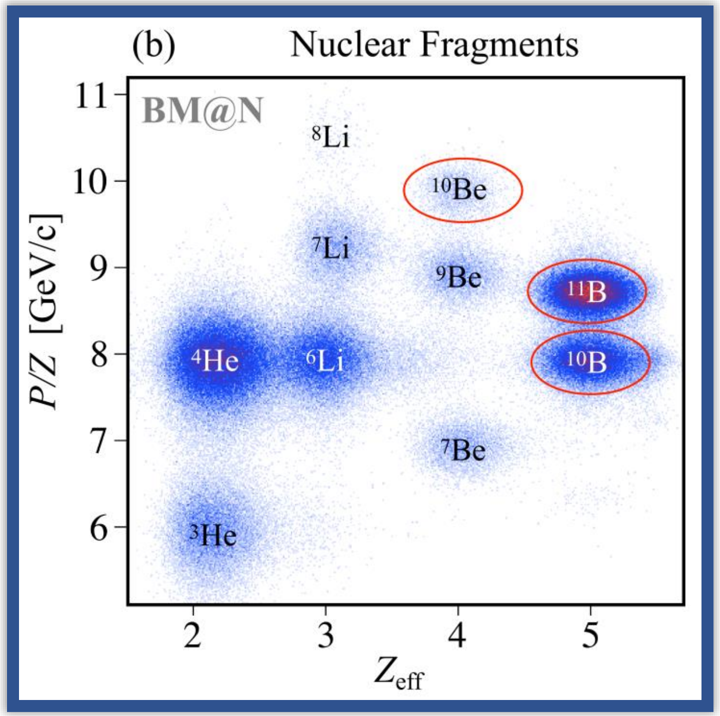
Pilot experiment in 2018

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

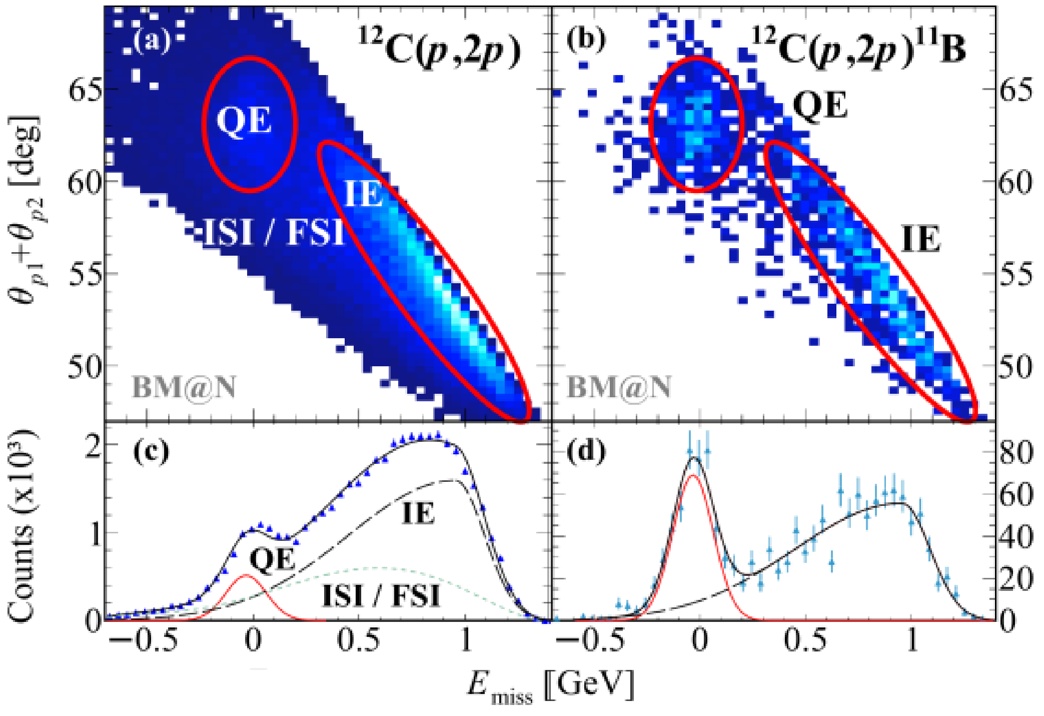
SRC: $^{12}C(p,2p)^{10}B, ^{10}Be$

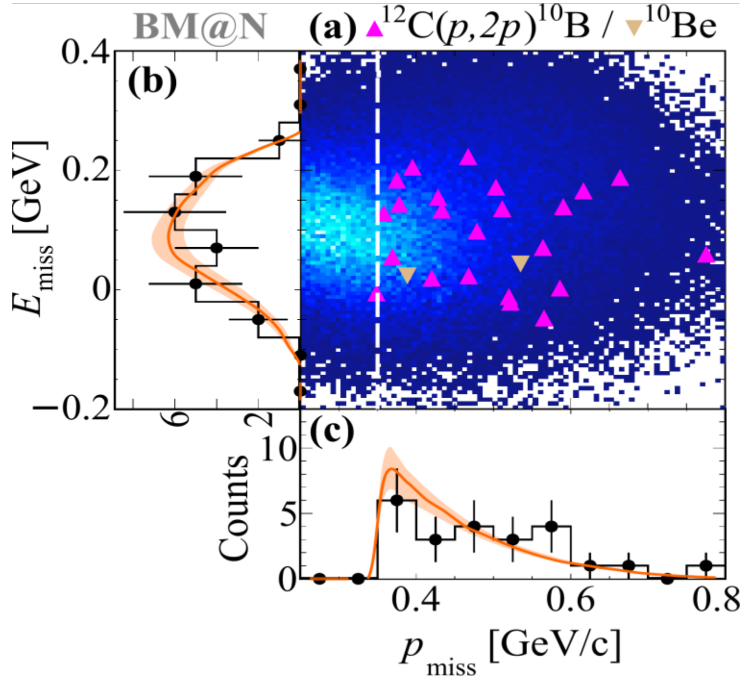


$$B\rho \sim \frac{A}{Z}\beta\gamma$$



Main results of 2018 experiment

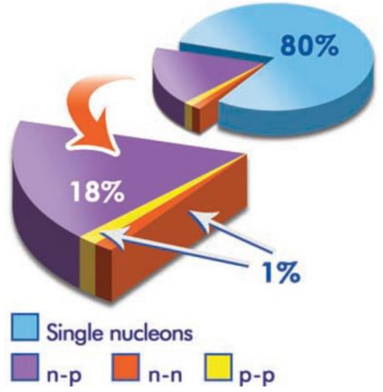




Fragment tagging suppresses rescattering
(Initial/Final state interactions)
Select quasi-elastic scattering

23 np SRC pairs

2 pp SRC pairs



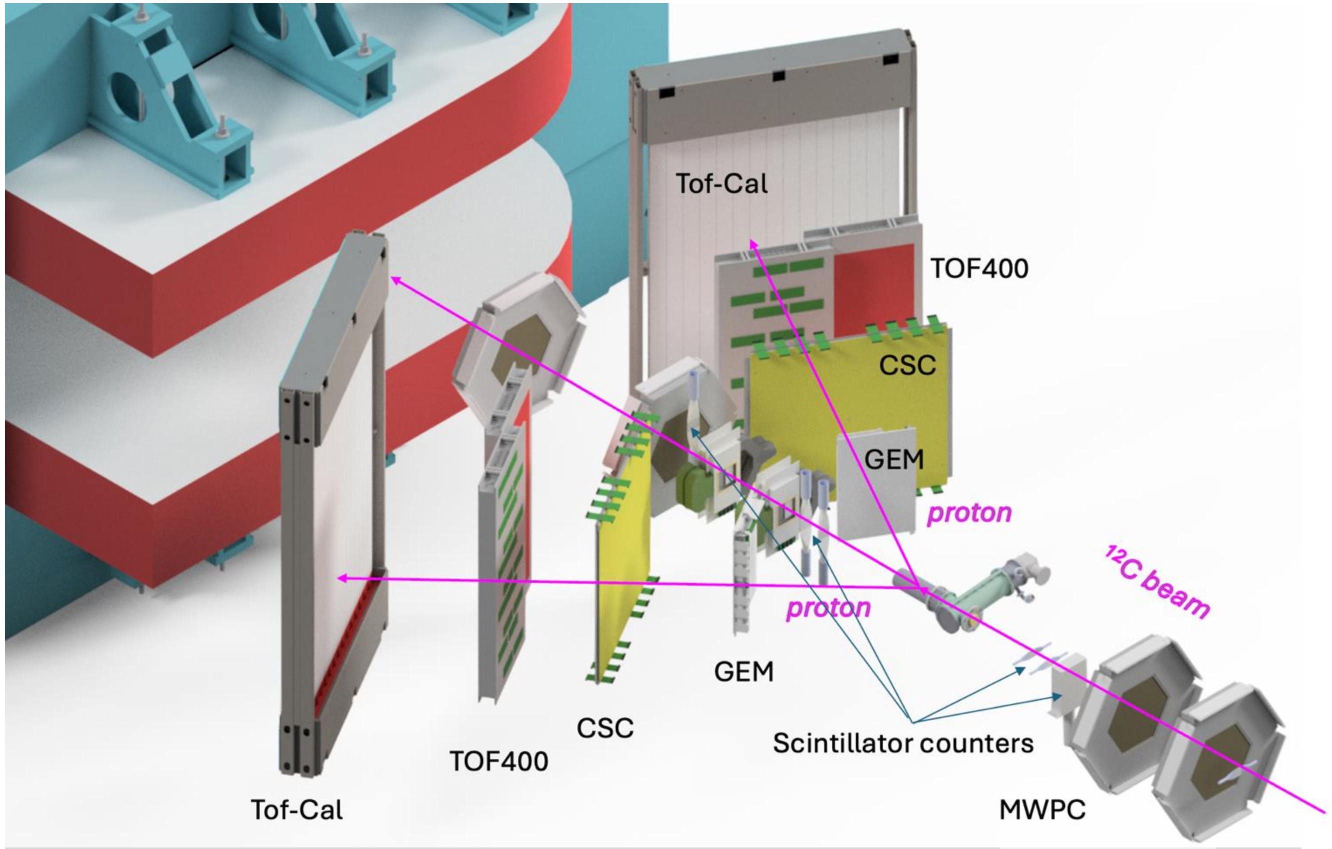
M. Patsyuk et al. Nature Physics 17, 693 (2021)

SRC experiment in 2022

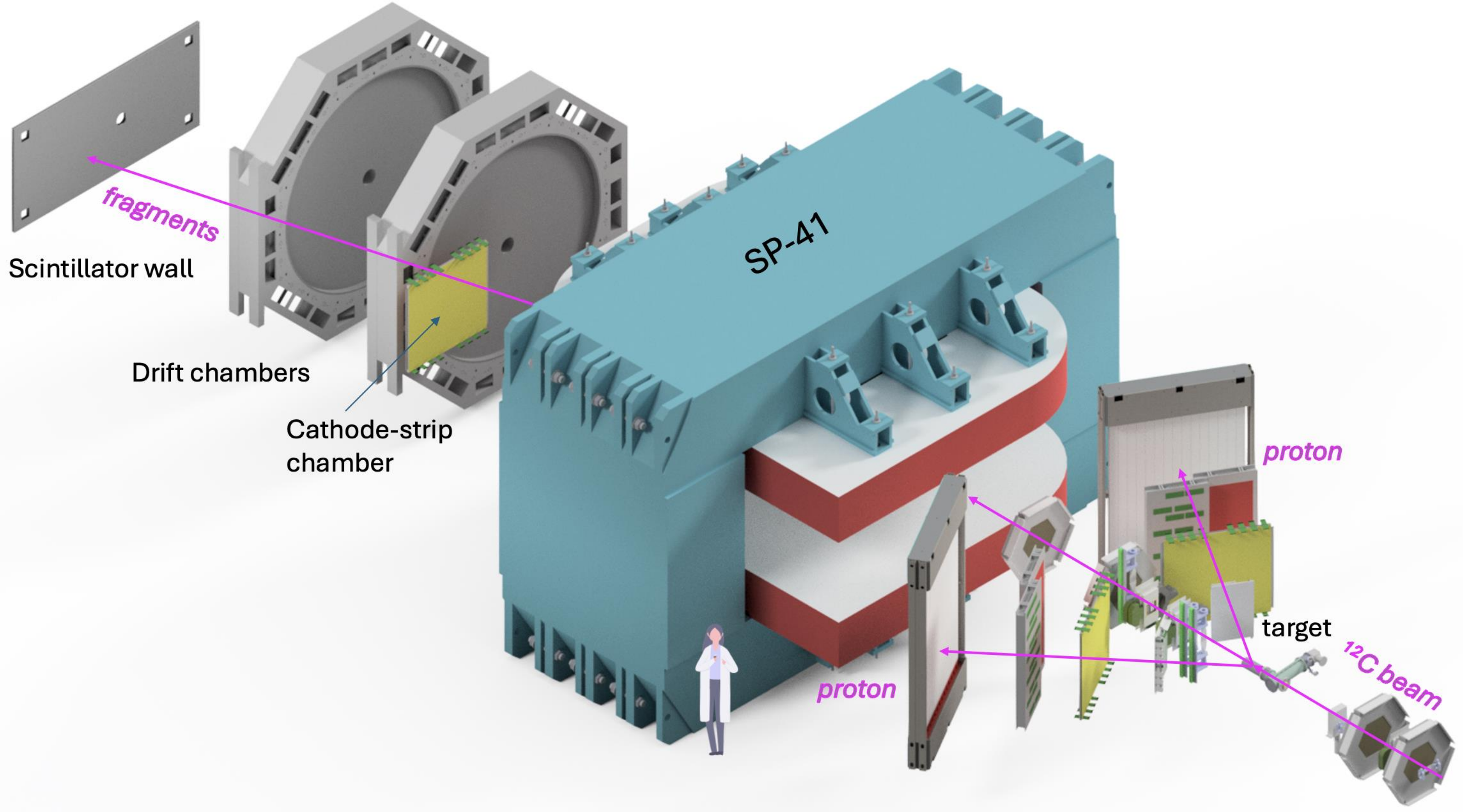
Main goal: reaction cross sections and fragmentation properties

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

Improved experimental setup:
- New scintillator detectors: T0, BC, and SW
- Two-arm calorimeter with TOF layer
- 2 pairs of Si detectors
- Cathode Strip Chambers
- Laser calibration system
- Veto Box detector



2022 experimental setup



Experiment 2022 goals

10 times more statistics than 2018

Single nucleon knockout

- Absolute cross section
- Quenching
- Attenuation

SRC

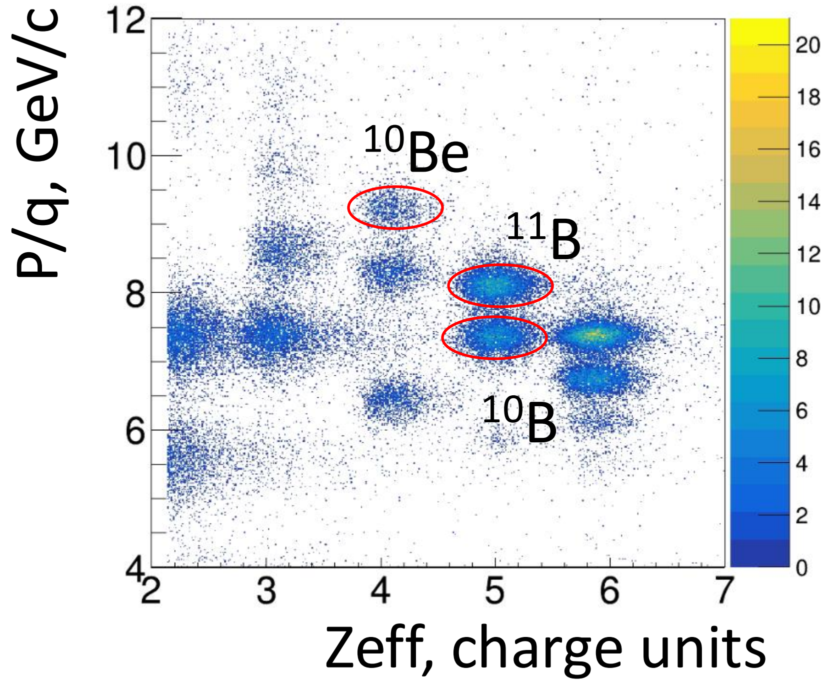
- Improve statistics
- Detect recoil n/p
- Multi-fragment reconstruction
- Fragment distribution → "SRC origin"



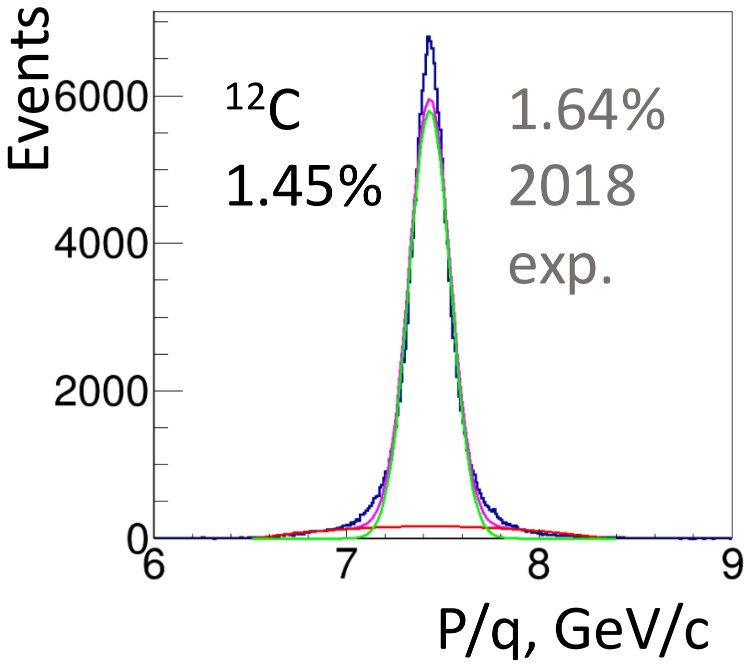

Heavy-fragment identification

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

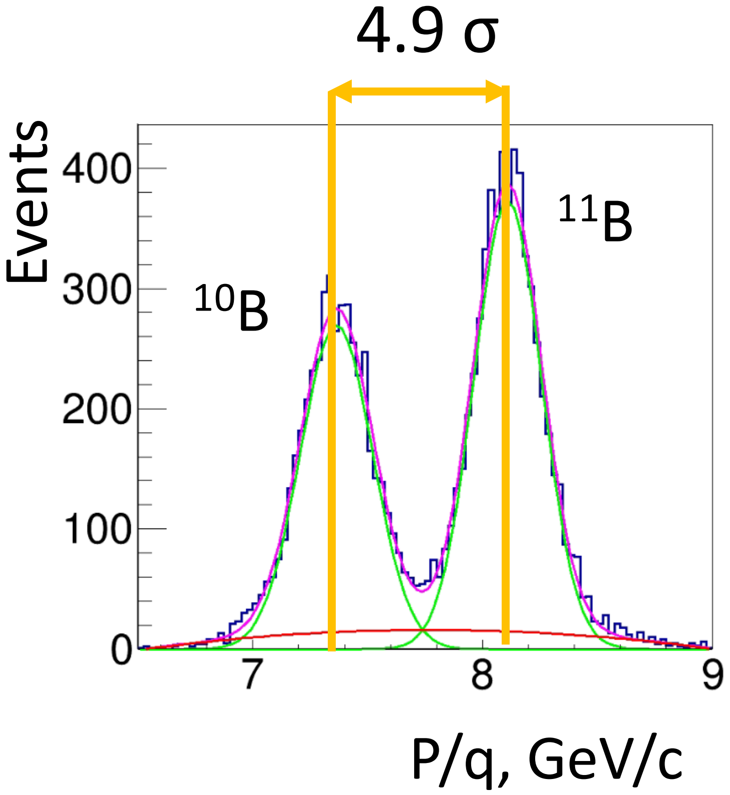
SRC: $^{12}C(p,2p)\ ^{10}B, ^{10}Be$



Fragment identification

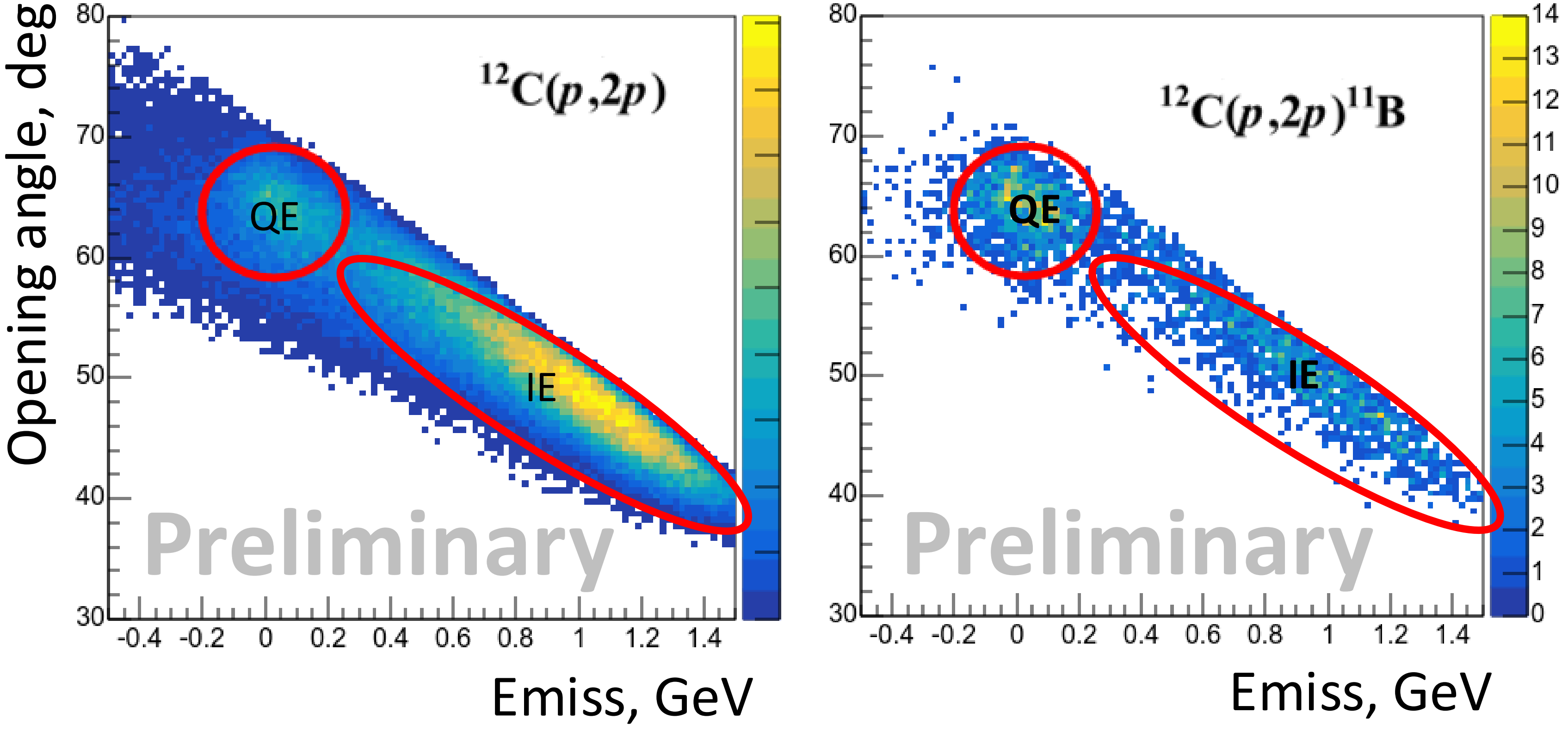


Beam
momentum resolution



Boron isotopes
separation

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

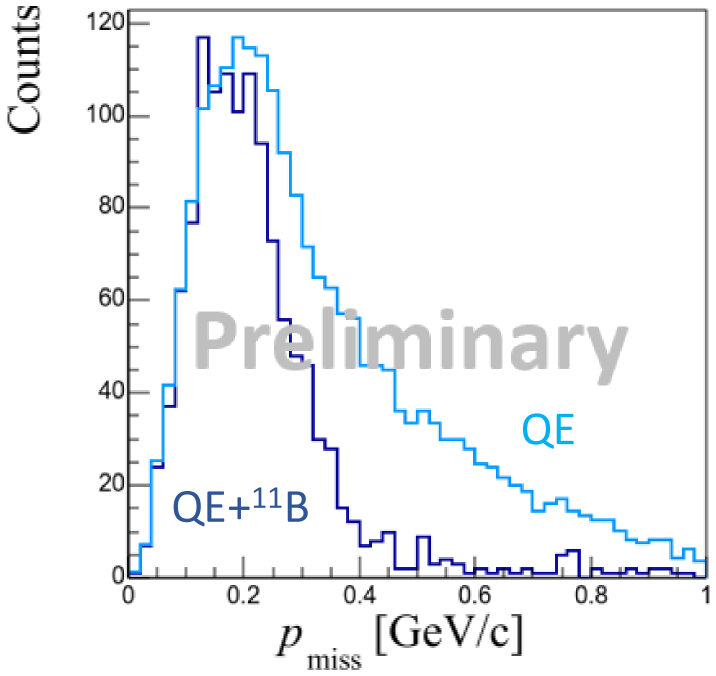


Fragment tagging suppresses rescattering (Initial/Final state interactions)

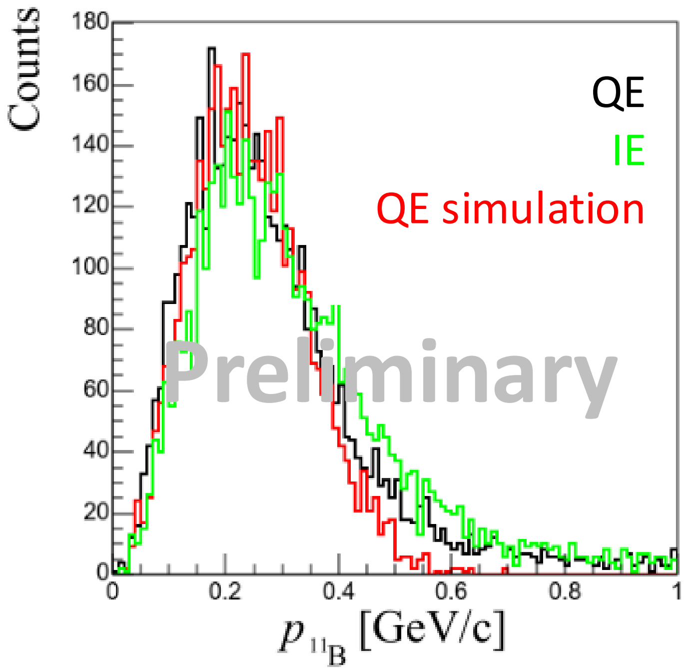
Select quasi-elastic scattering

Accessing nucleon momentum distribution

Initial proton momentum

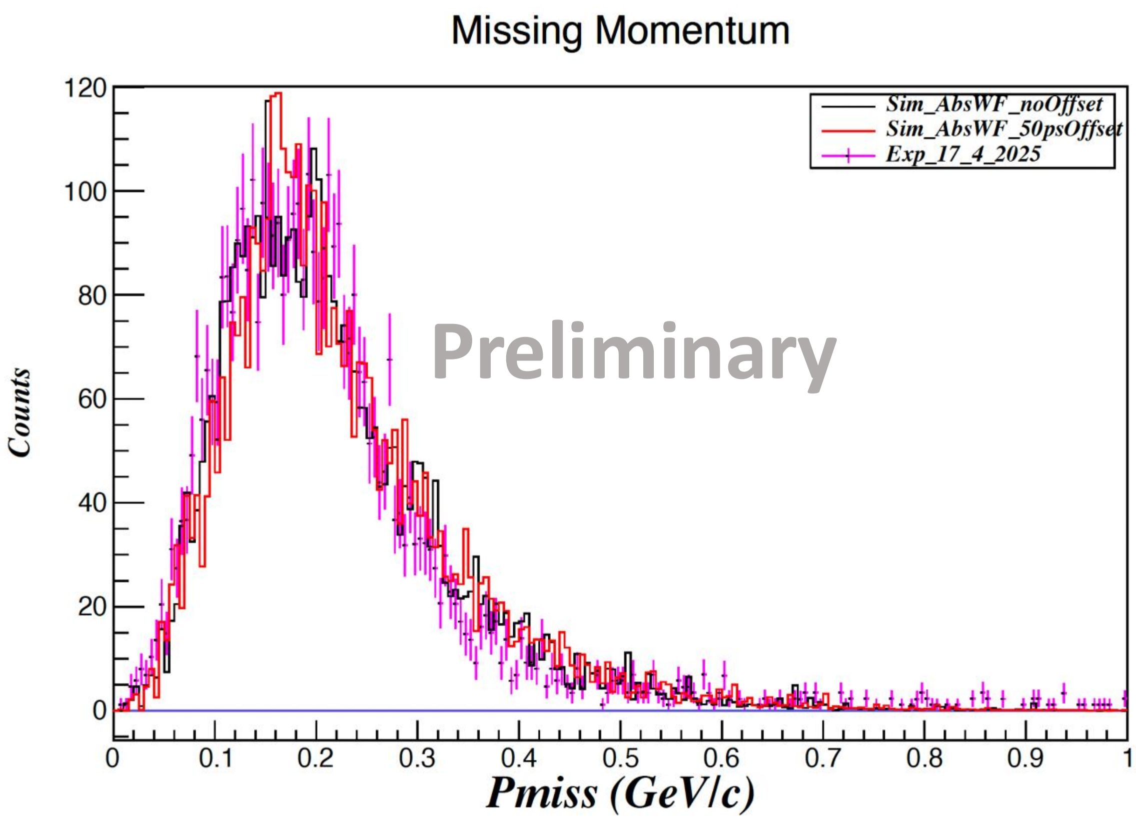


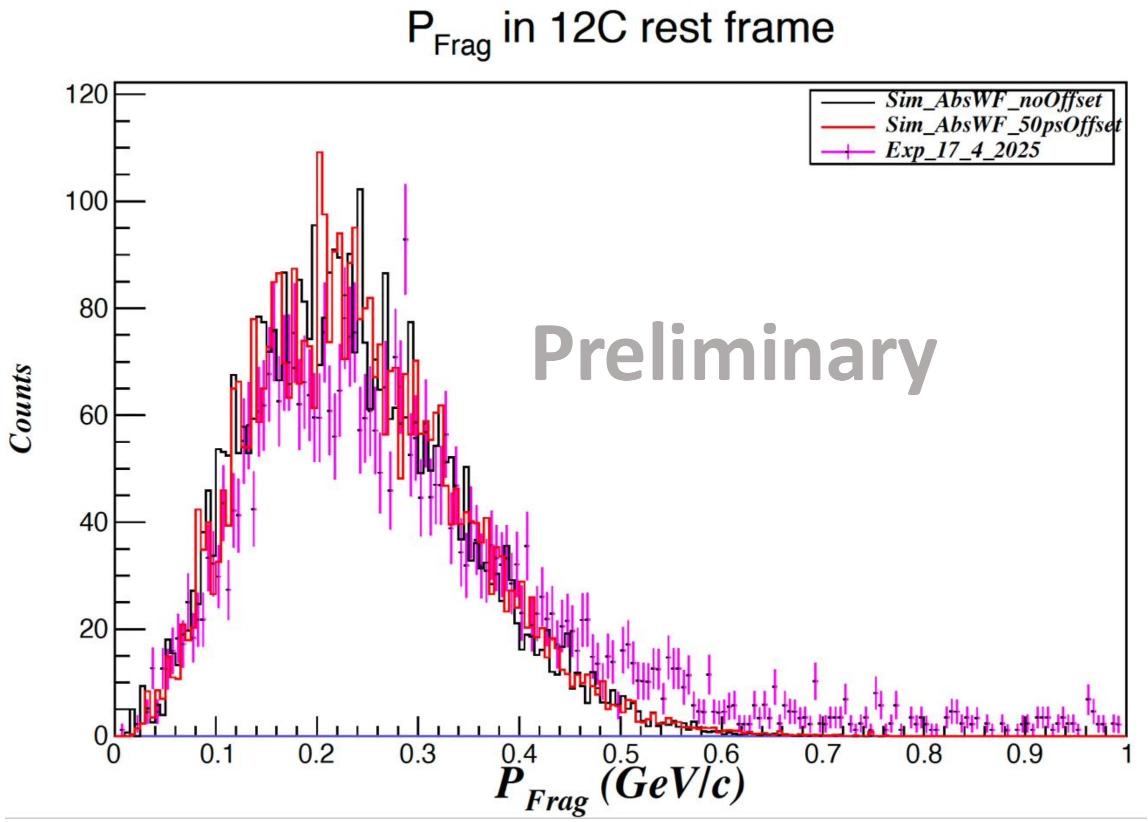
Fragment recoil momentum



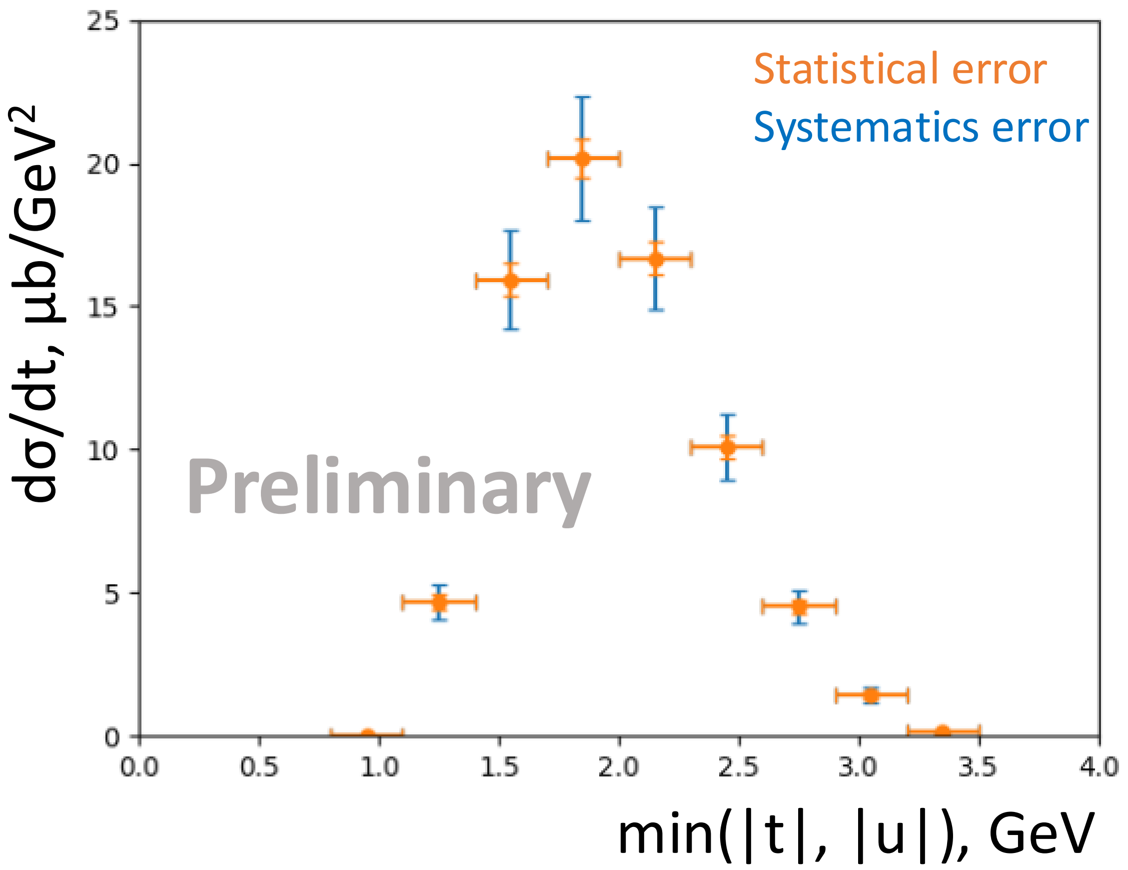
→ **single step nucleon knockout process.**
Transparent part of reaction

Simulation tuning to estimate the cross section





Preliminary QE cross section



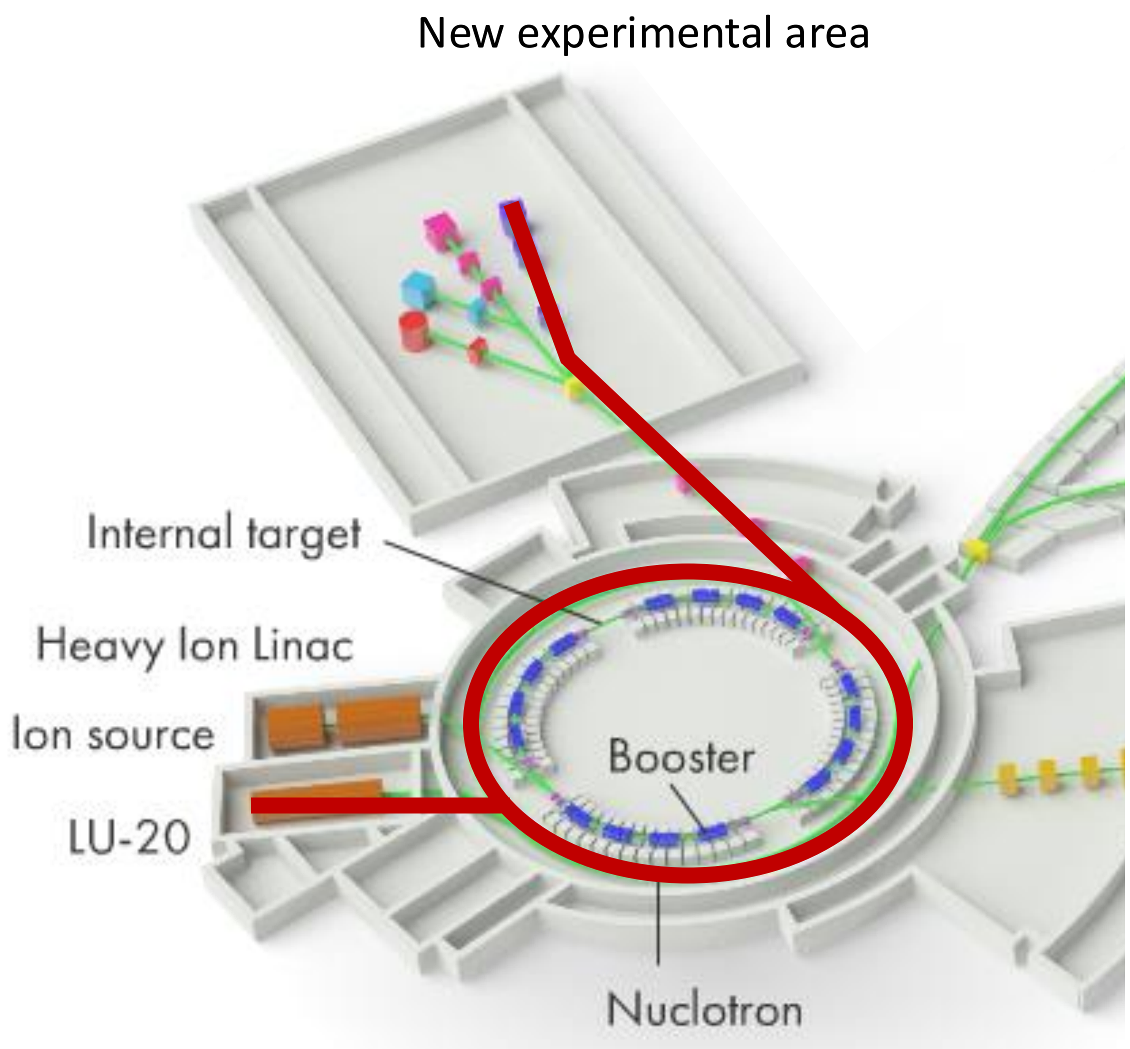
Preliminary cross section:
22.1 μb @ 3.75 GeV/c/nucleon

This data is in a good agreement with calculations of A. Larionov

Next steps

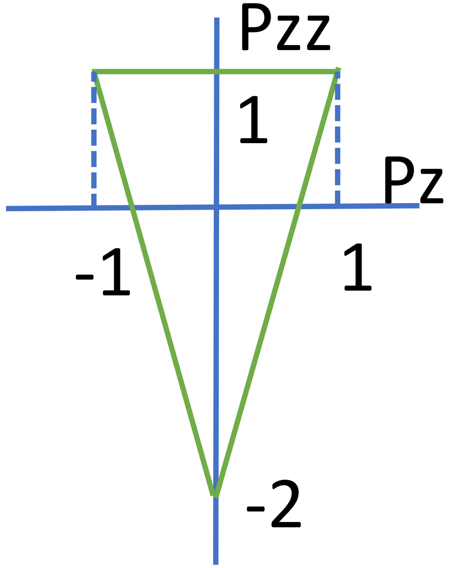
- Finish analyzing the full 2022 set of data
- Identify SRC pairs, extract SRC-pairs ratios
- Study events with more than one fragment

New SRC experiment with tensor-polarized deuteron beam



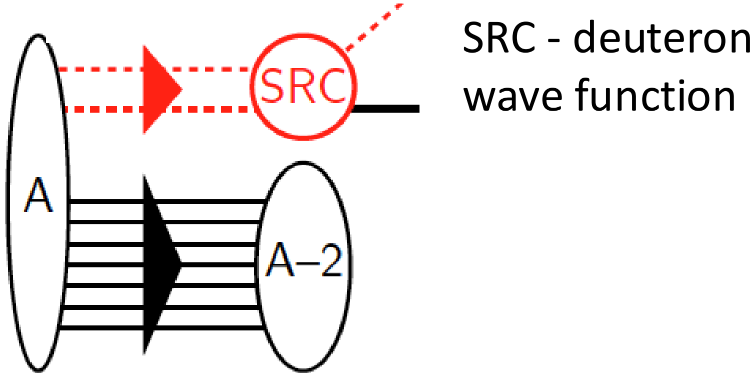
d beam
p < 5.5 GeV/c/nucleon
intensity 10^6 d/s

Various polarization configurations are available



Polarization can be changed every spill (σ_+, σ_-, σ_0)

Why polarized deuterons?



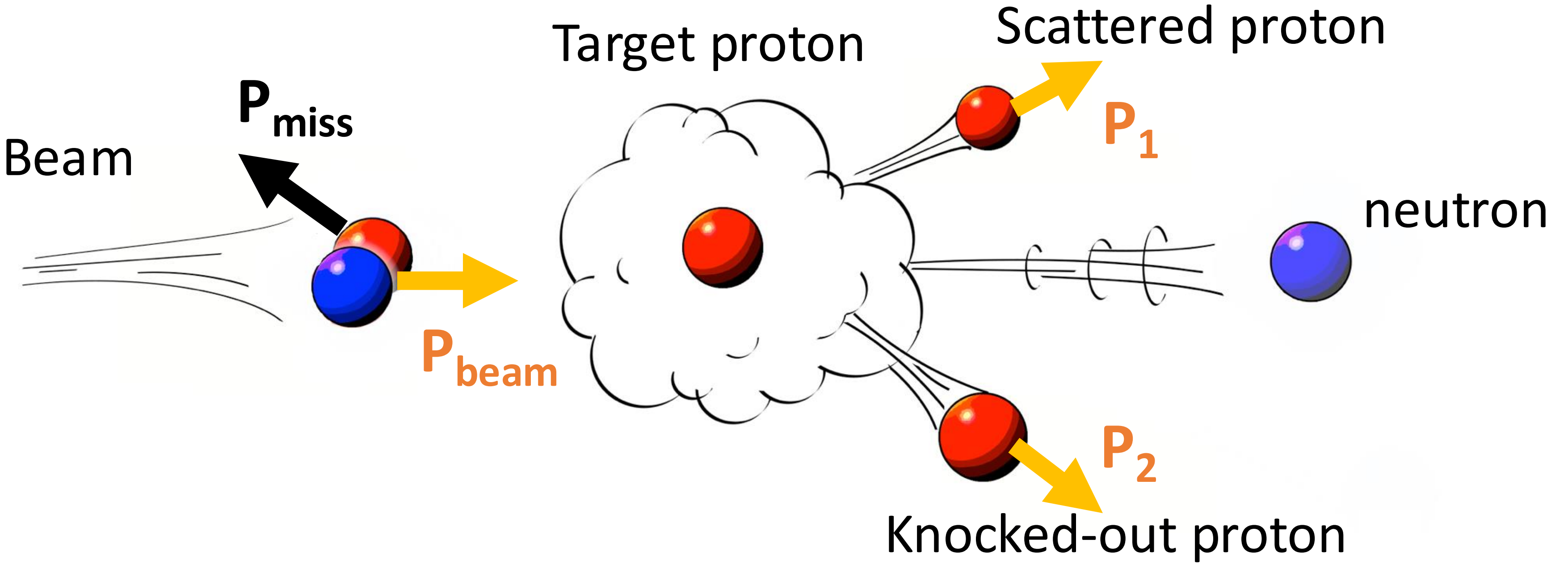
1. Relativistic description of the bound system

2. Final state interactions in the high-momentum region

3.Ratio between S- and D-waves of the deuteron

4. Non-nucleonic deuteron components in polarization measurements

Quasi-free **(p,2p)** scattering

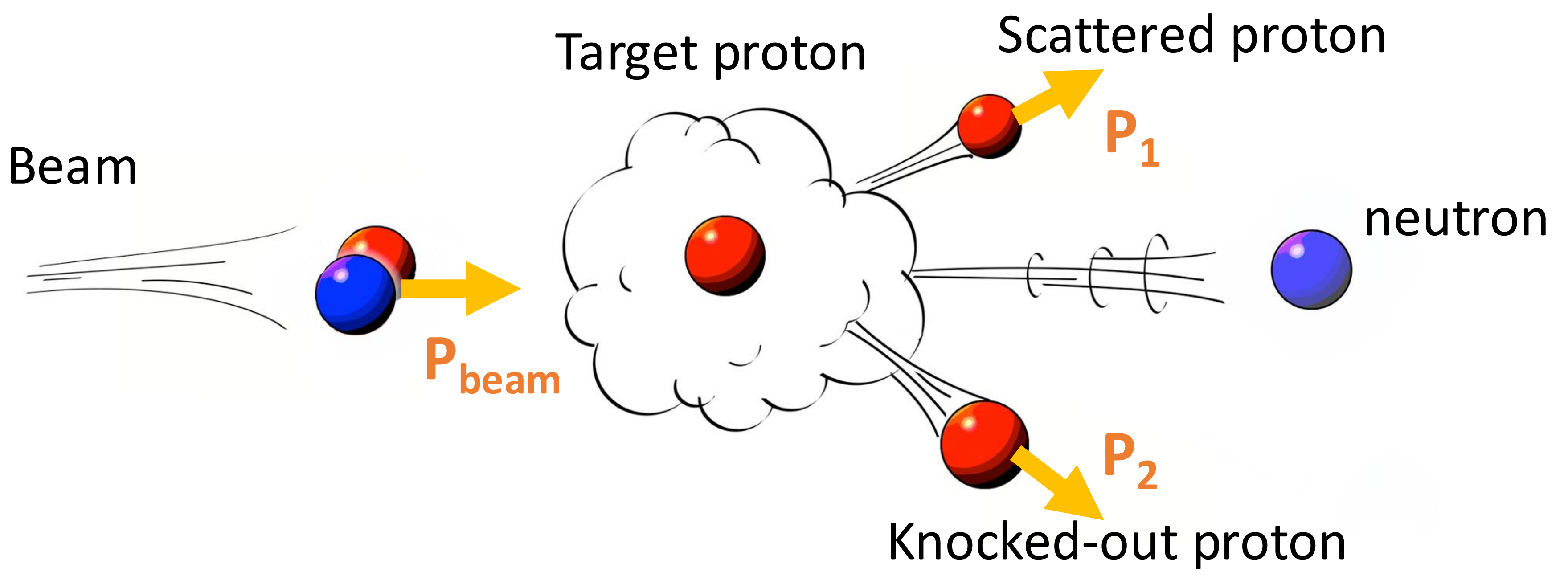


Reconstruct initial proton momentum $\mathbf{P}_{\mathbf{miss}}$ from scattered particles

$\mathbf{P}_{\mathbf{miss}} = P_1 + P_2 - P_{beam}$

~ 90° c.m. scattering

A_{zz} for hard quasi-free breakup of the deuteron: $\vec{d}$(p, 2p)n



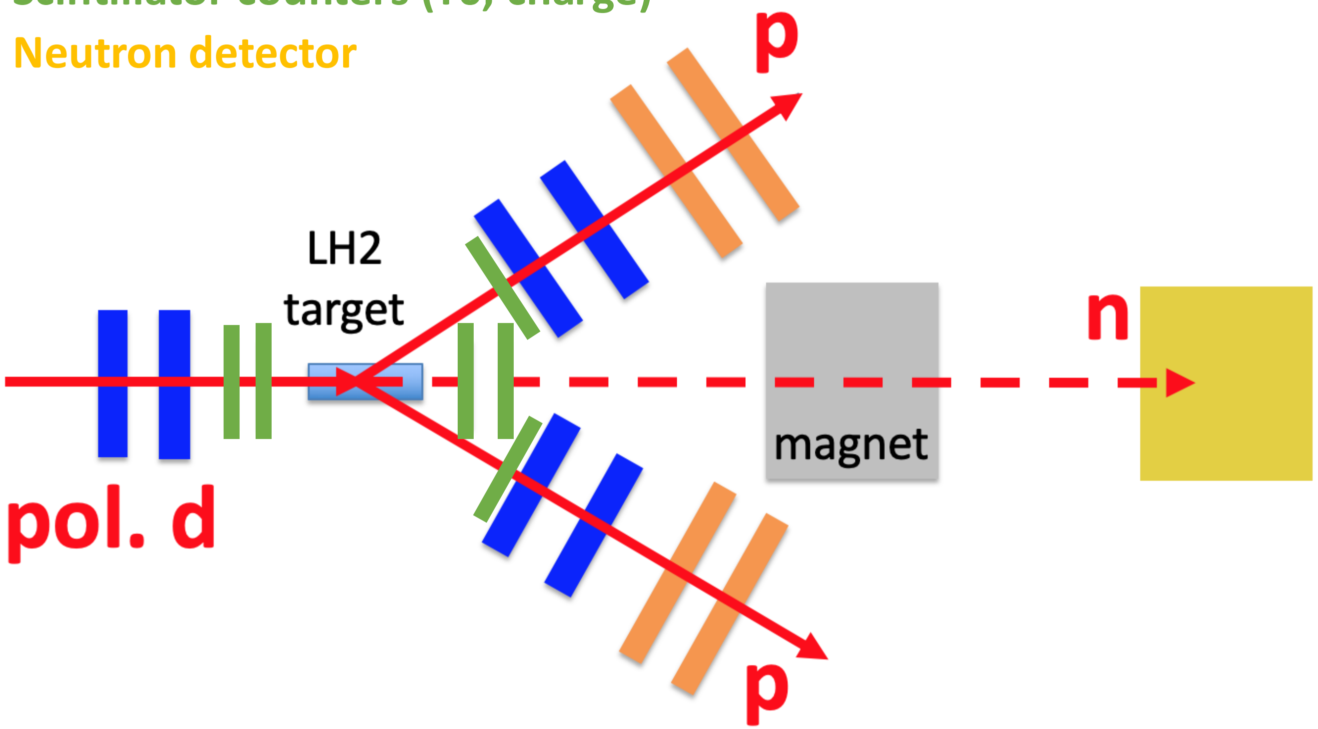
- |t| & |u| > 1 GeV^2
- $60^0 < \theta_{cm}$
- Two-arm acceptance: $20^0 < \theta_{lab} < 45^0$; $-20^0 <|\varphi_{lab}| < 20^0$
- $p_{miss} > 0.25$ GeV/c.

$$A_{zz} = \frac{(\sigma_- + \sigma_+ - 2\sigma_0)}{\sigma_{unpol}}$$

σ_- , σ_+ , σ_0 – cross sections for different tensor polarization states

Hard quasi-free breakup of the deuteron: $\vec{d}$(p, 2p)n

Time-of-flight detectors
Coordinate detectors
Scintillator counters (T0, charge)
Neutron detector



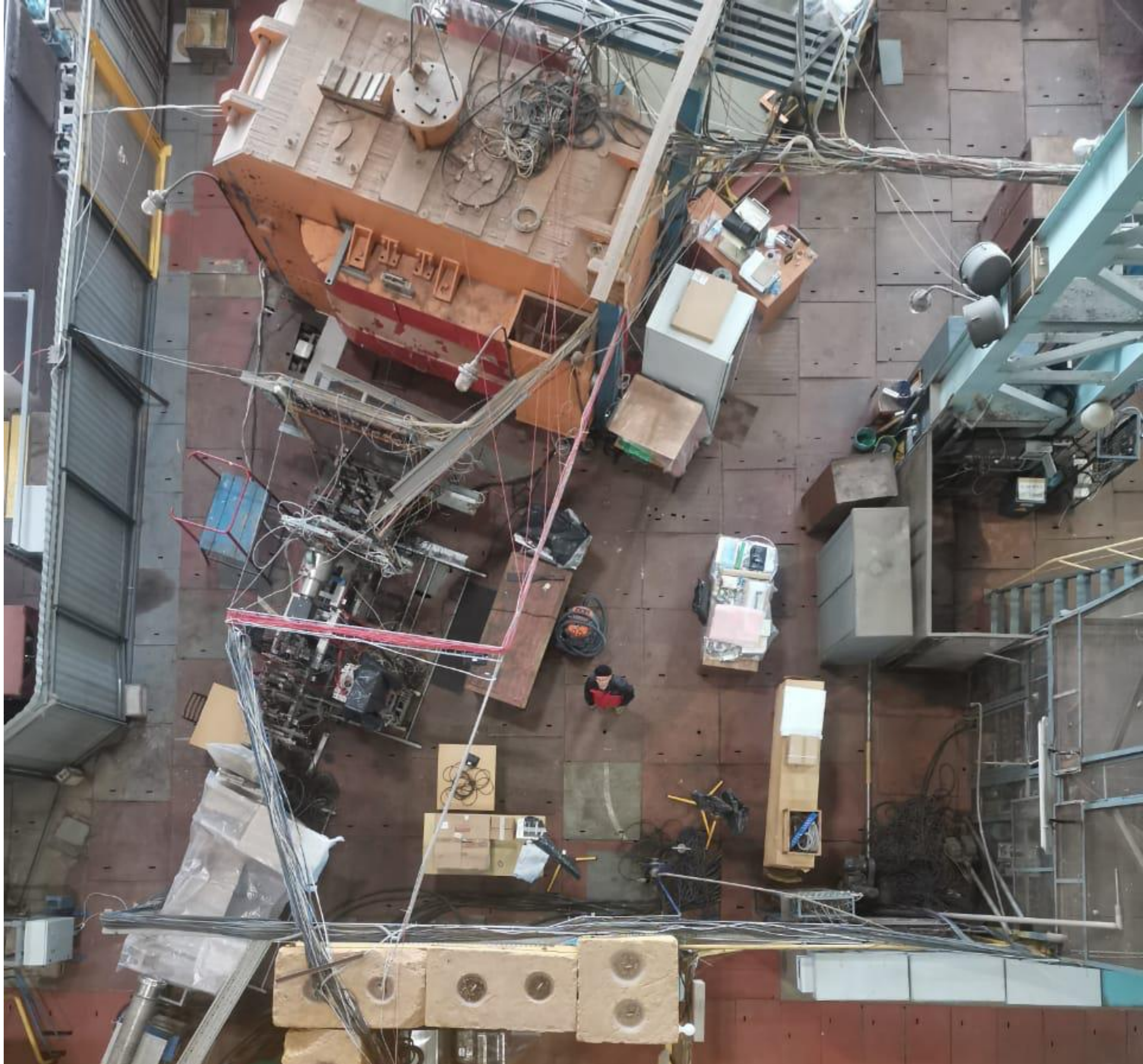
Two-arm spectrometer like 2022

A polarimeter separately or incorporated into the setup

Expected trigger rate < 5kHz based on single arm trigger

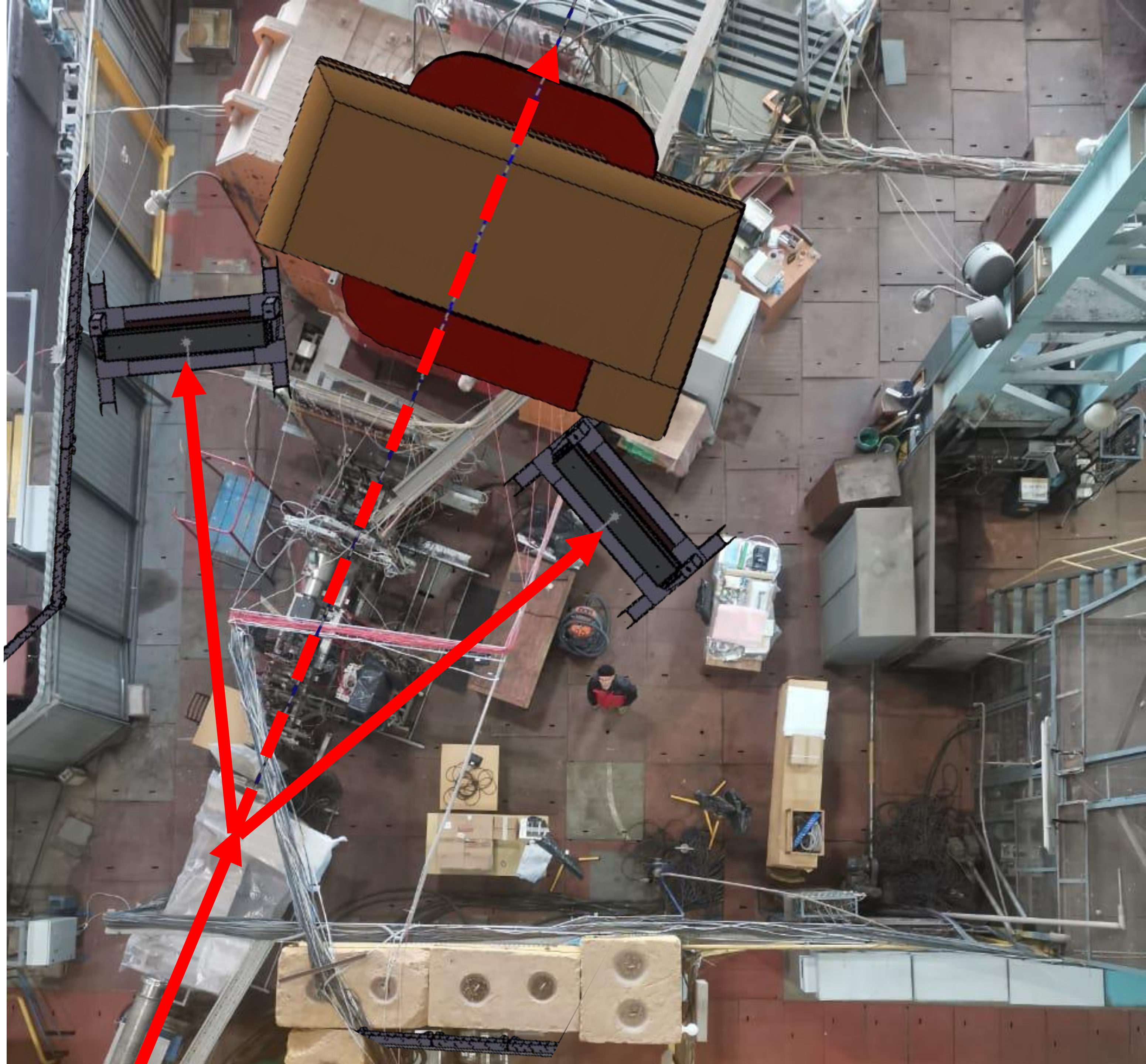
Experimental area

is hosting HyperNIS experiment

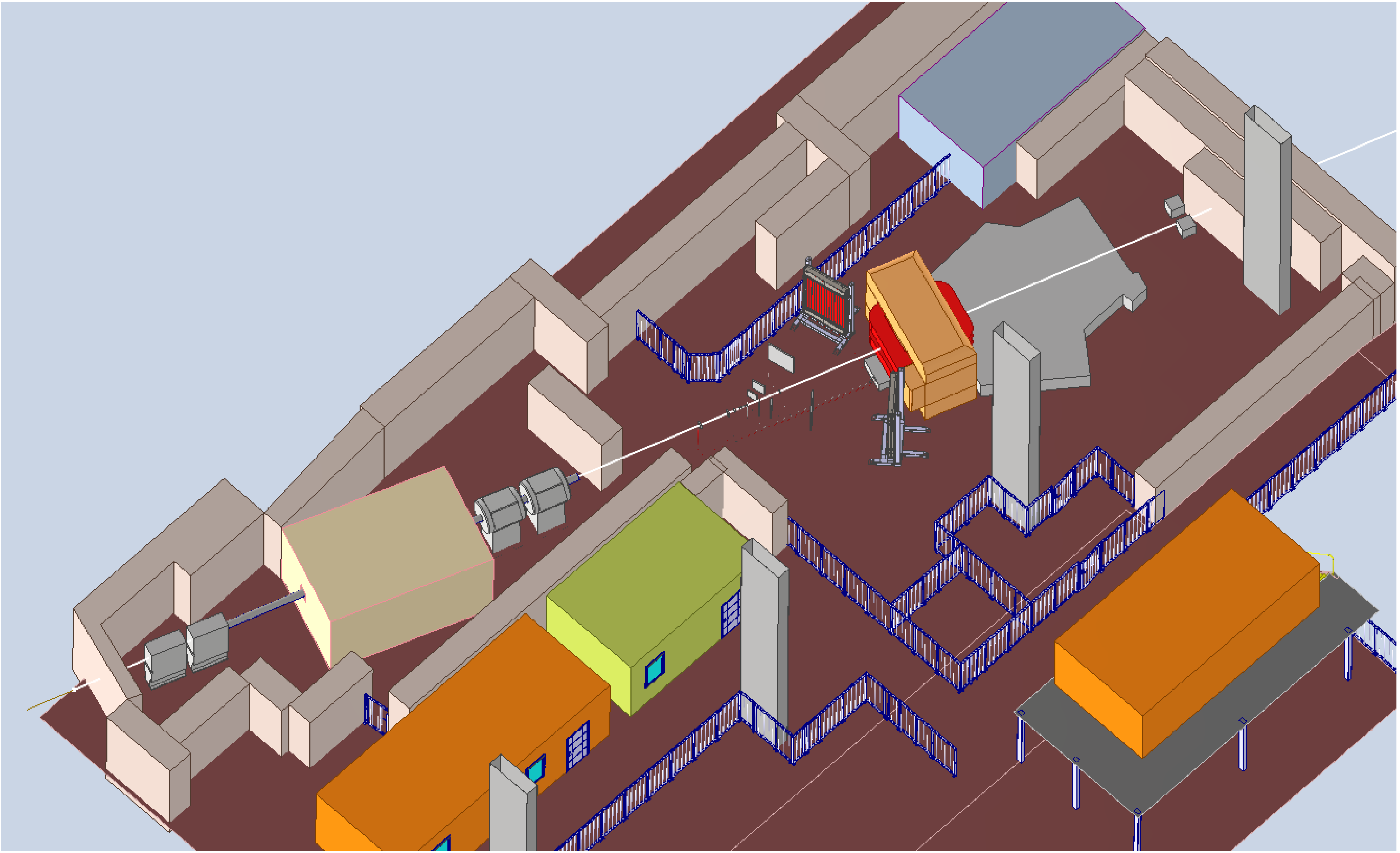


Current status

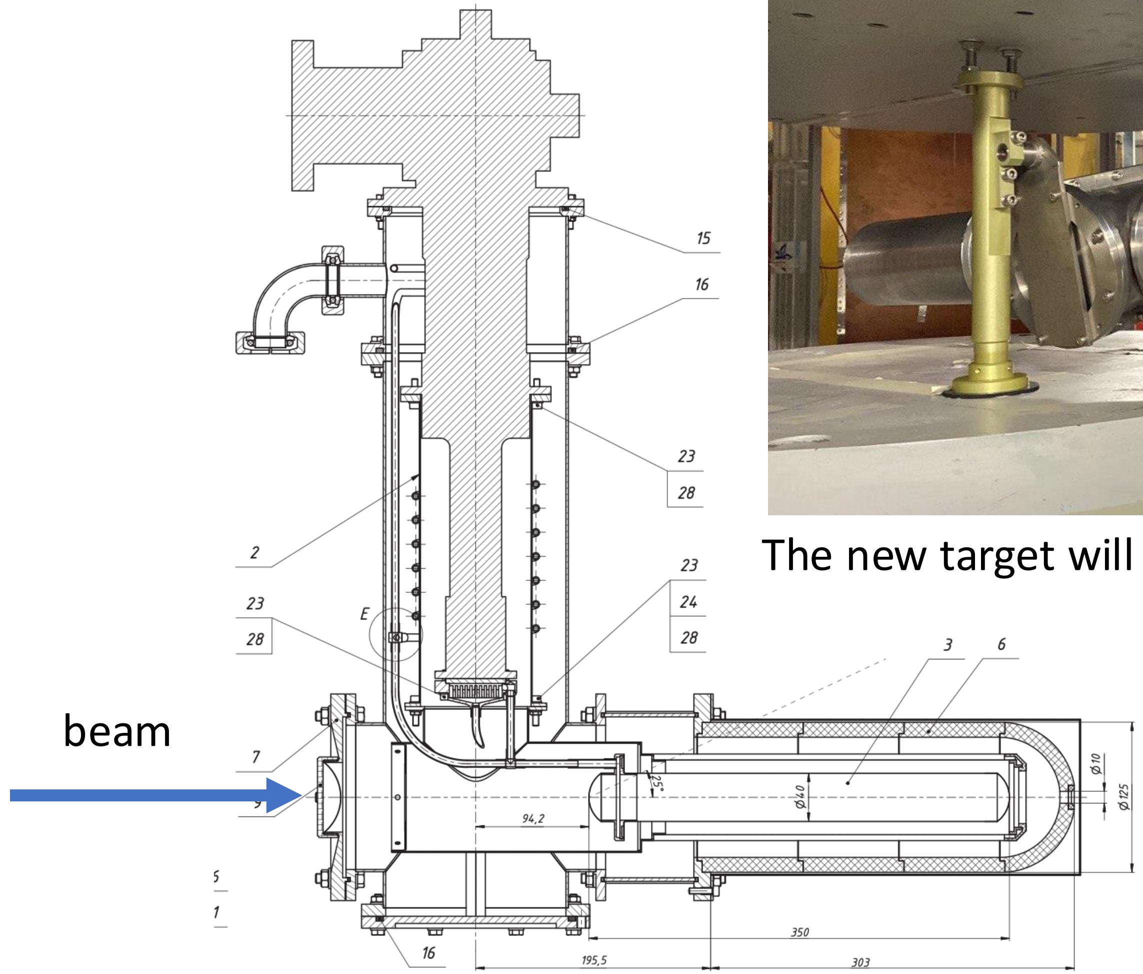
1. CSC chambers are going to be built at LHEP
2. Commissioning of the experimental area has been started - no clear procedures
3. Radiation estimations are done – need assessment to enforce the rad.protection (beam dump)
4. Counting house renovation is needed
5. New LH target is going to be produced at LHEP



Technical design parameters of the new SRC experiment are prepared



Target



beam

The new target will be a copy of the existing BM@N 2022 target

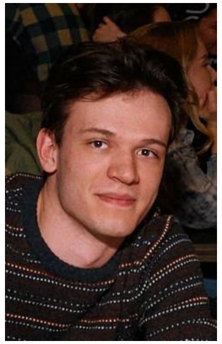
Cryo-refrigerator ($47 000)

Yu. Borzunov, D. Klimanskiy

Summary:

- JINR SRC program includes analysis of the 2022 data aiming at absolute cross sections, quenching, attenuation, SRC-pair ratios and analysis of fragmentation after SRC removal
- $\vec{d}$(p, 2p)n exclusive measurement in SRC kinematics aiming at A_{ZZ} at high P_{miss} with a new two-arm spectrometer, JINR LH target + DAQ, coordinate detectors
- Can be done in the next couple of years complementing the world-wide SRC effort

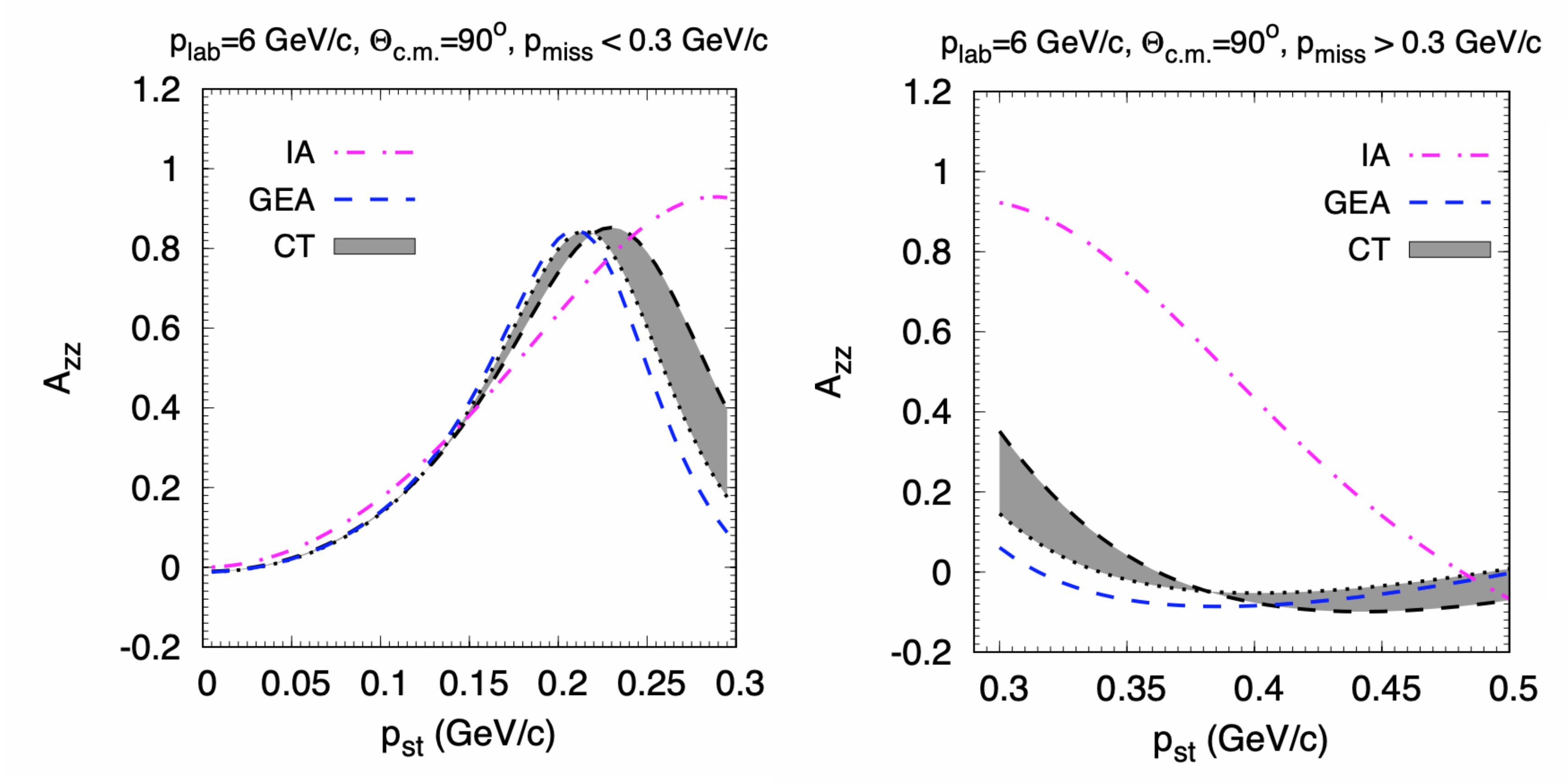


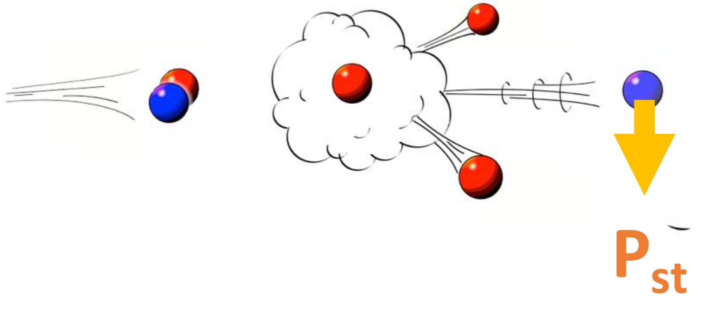



Thank you!

Impact of FSI

A. Larionov, JINR

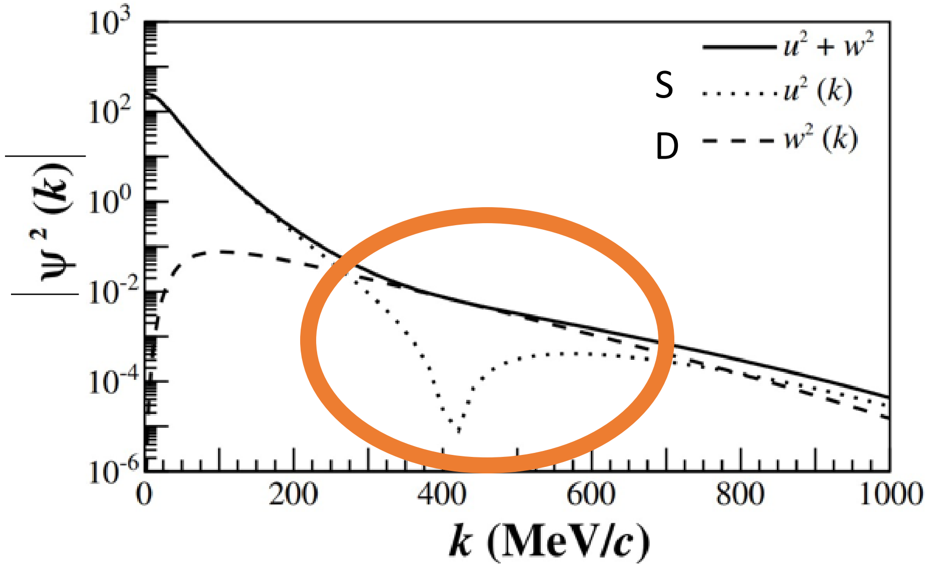




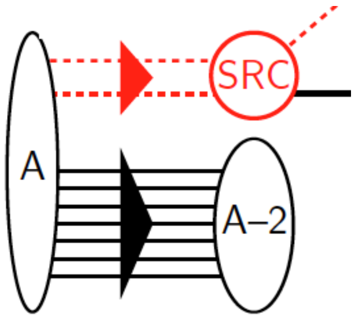
IA = Impulse Approximation

GEA = Generalized Eikonal Approximation

A_{zz} has a better sensitivity to admixture of small w.f. component than σ



u(k) – S-wave, w(k) – D-wave

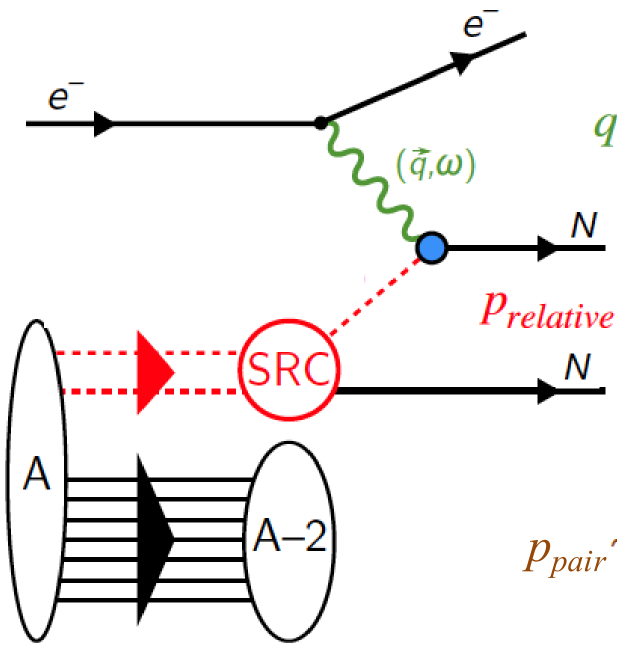


$$A_{zz} = \frac{(\sigma_- + \sigma_+ - 2\sigma_0)}{\sigma_{unpol}} \qquad \sigma \sim u(k)^2 + w(k)^2$$

$$A_{zz} \sim \frac{\frac{1}{2} w^2(k) - u(k)w(k)\sqrt{2}}{u^2(k) + w^2(k)}$$

L. Frankfurt and M. Strikman, Phys.Rept. 160, 235 (1988)
V. G. Ableev, E. Strokovsky et. al, Pis'ma Zh. Exp. Teor. Fiz. 47, 11 (1988)

Scale Separation: $q \gg p_{relative} \gg p_{cm}$



$q > 1.5$ GeV/c

$p_{relative} \sim$ 300-700 MeV/c

$p_{pair} \sim$ 100-150 MeV/c

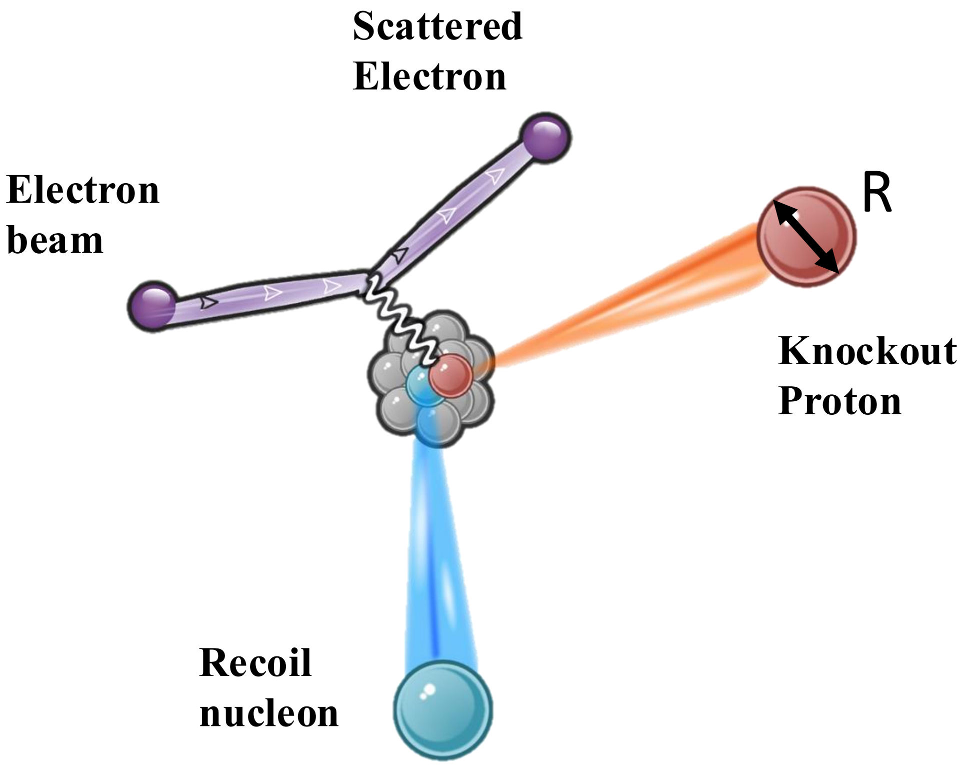
hard scattering

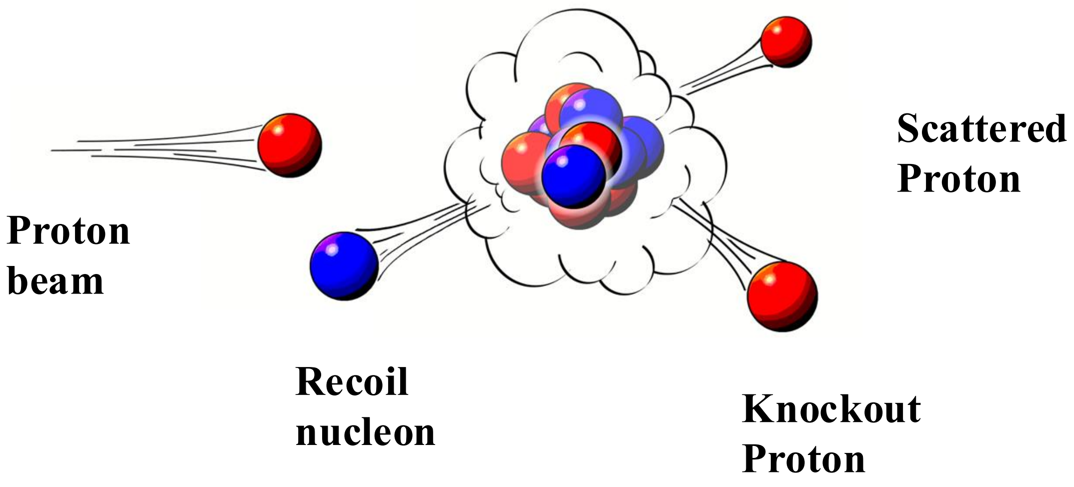
PRC 92 (2015), PLB 780 (2018), PLB 791 (2019), PLB 792 (2019), JPG 47 (2020), Nature Physics 17 (2021), PRC 104 (2021), PRC 53 (1996), PRL 119 (2017)

Elementary eN cross section	Nuclear Contacts	Two-body wave function	Center of mass motion

$$\sigma_{eA} = \sigma_{eN}(q) \cdot \sum_{NN-pairs} \cdot C_A^{NN} \cdot |\phi(p_{relative})|^2 \cdot n(p_{pair})$$

Study SRC with hard scattering





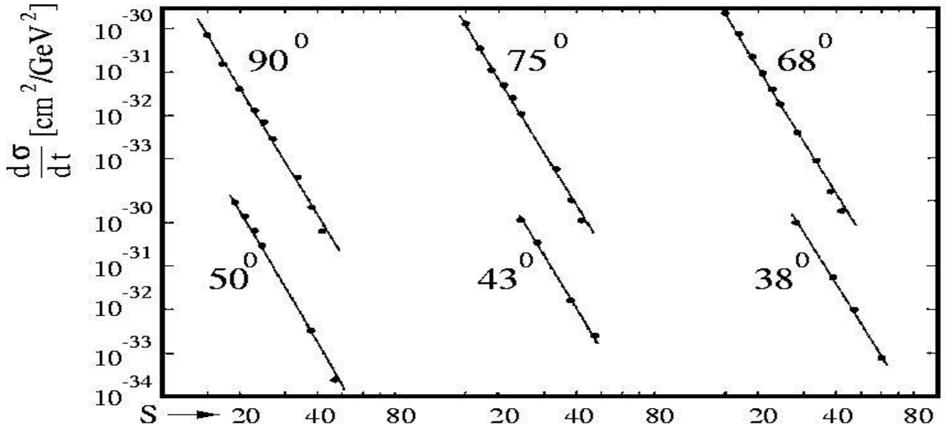
High energy: small de Broglie wavelength $\lambda < R$

Large momentum transfer q $q \cdot R < 1$

Advantage of hadronic probes

$$\frac{d\sigma}{dt} \propto s^{-10}$$

pp elastic scattering



QE pp scattering have a very strong preference for reacting with high-momentum nuclear protons (lower s)