SRC studies with hadronic probes

SRC Workshop, MIT
3 August 2022

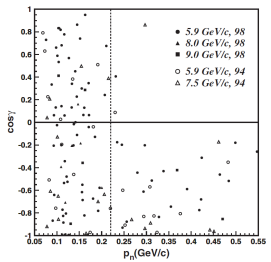
Julian Kahlbow

SRC = ground-state properties ?

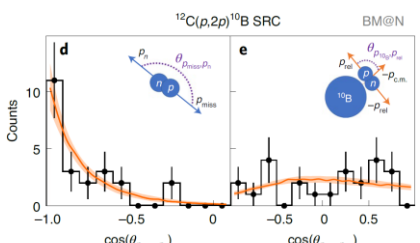
Studies with different probes

Protons / Nuclei

- BNL
- JINR
- GSI/FAIR



E. Piasetzky et al., PRL 97 (2006).

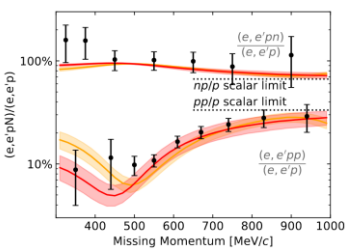


M. Patsyuk et al., Nature Phys. 17 (2021).

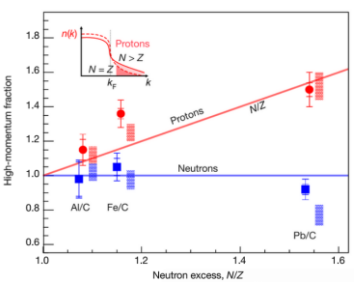
Electrons

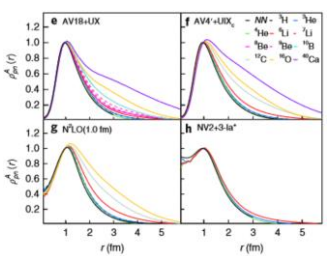
JLab

I. Korover et al., PLB 820 (2021).



M. Duer et al. (CLAS), Nature 560 (2018).

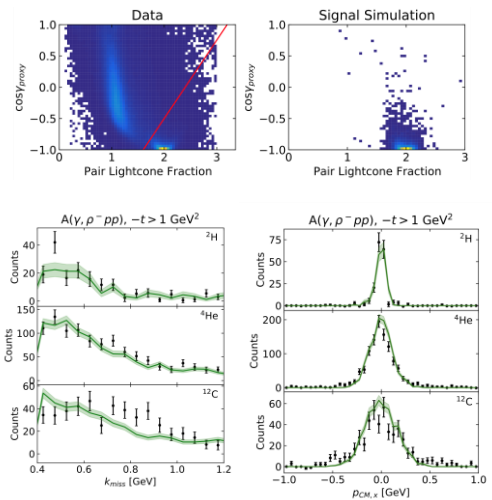




R. Cruz-Torres et al., Nature Phys. 17 (2021).

Real photons

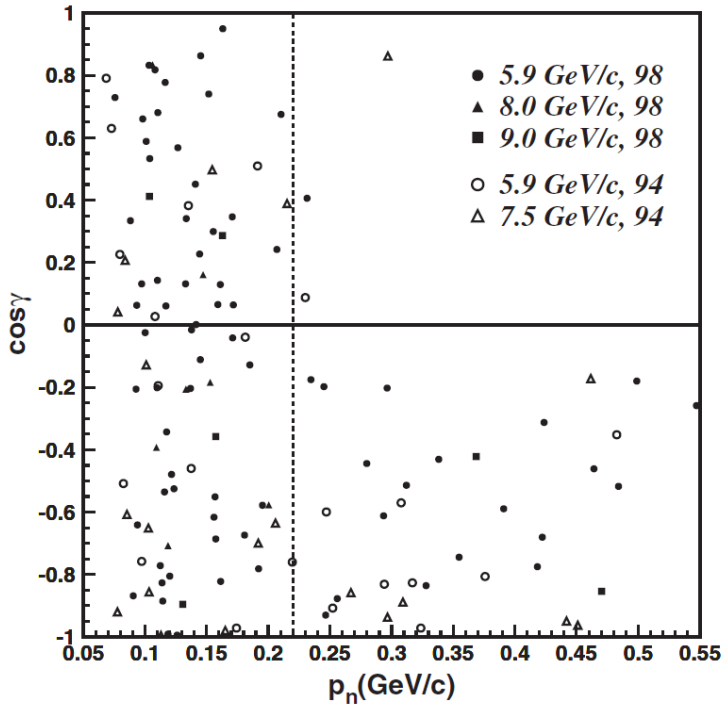
JLab/GlueX



J.R. Pybus, preliminary

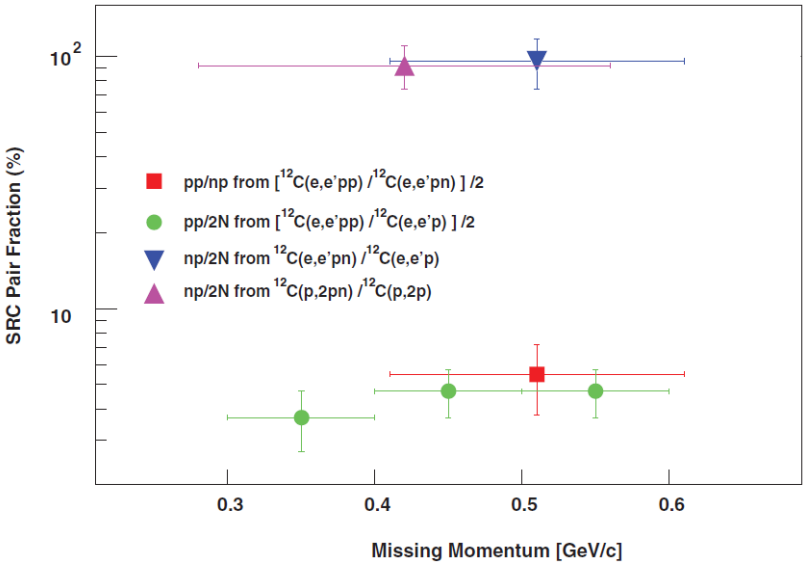
Proton scattering at BNL

np SRCs in ^{12}C(p,2p+n)



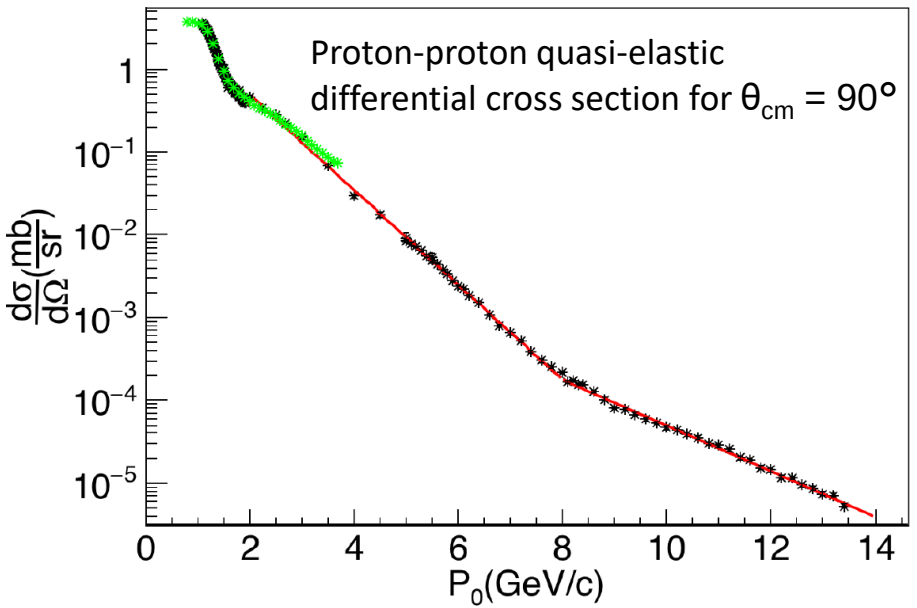
A. Tang et al., PRL 90 (2003).
E. Piasetzky et al., PRL 97 (2006).

in agreement with e$^-$ scattering



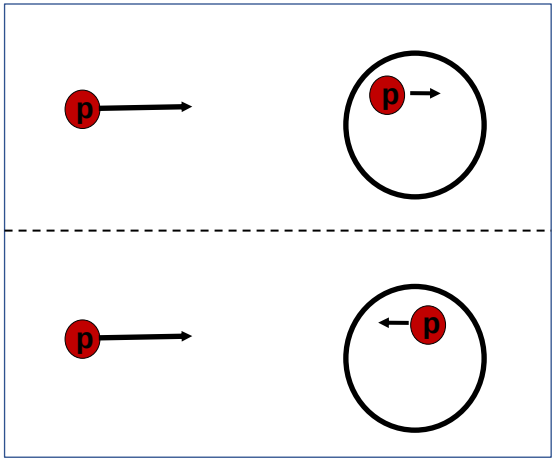
R. Subedi et al., Science 320 (2008).

Cross-section scaling



``Selective Attention``

$$\frac{d\sigma}{dt} \propto s^{-8}$$



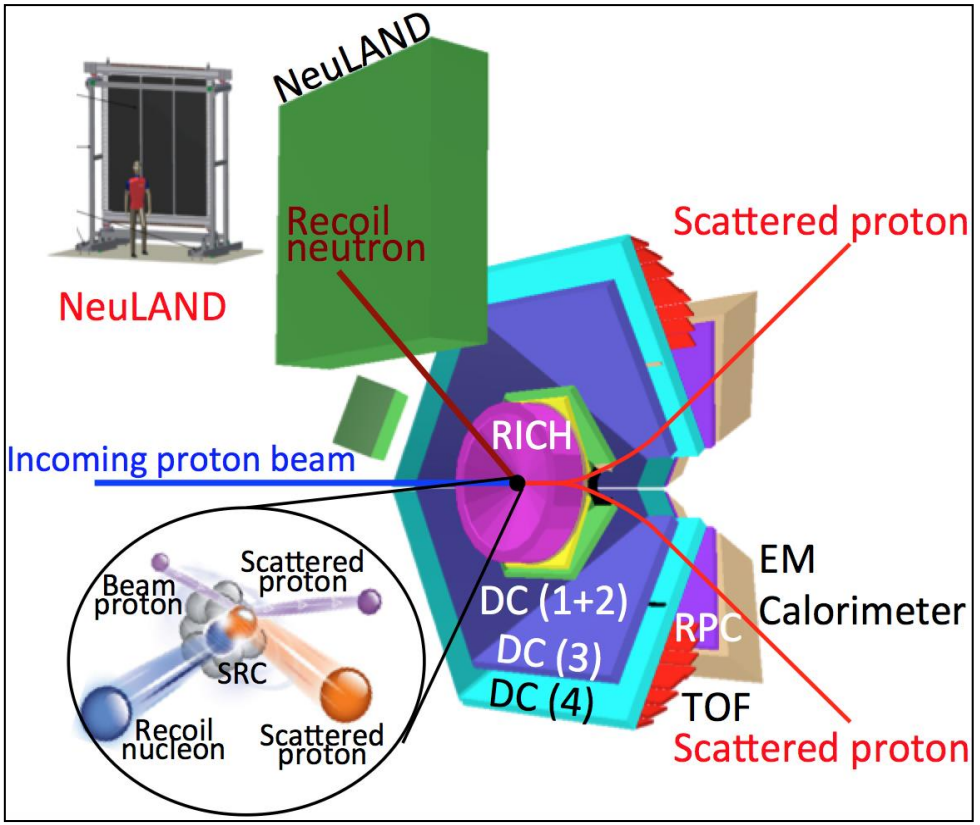
$$\frac{d\sigma}{dt} \vee \frac{d\sigma}{dt}$$

+ Large momentum transfer |t| & |u|

High-intensity proton beam at HADES/GSI

Open proposal:

- p + nuclear target at ~5 GeV/c/u
- intensity: 1×10^7 pps
- run 2025/26



High-intensity proton beam at HADES/GSI

Study:

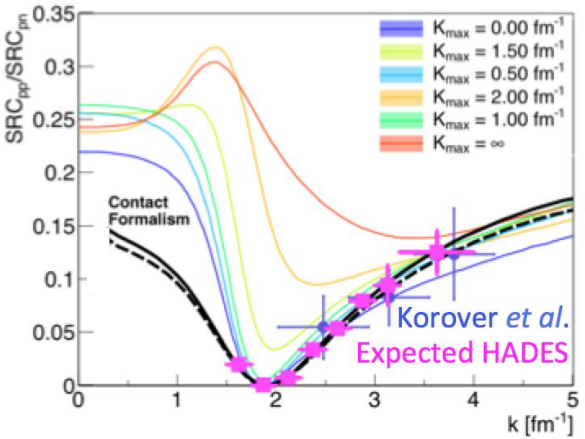
- MF to SRC transition
- NN interaction
- **3N SRCs**
- factorization

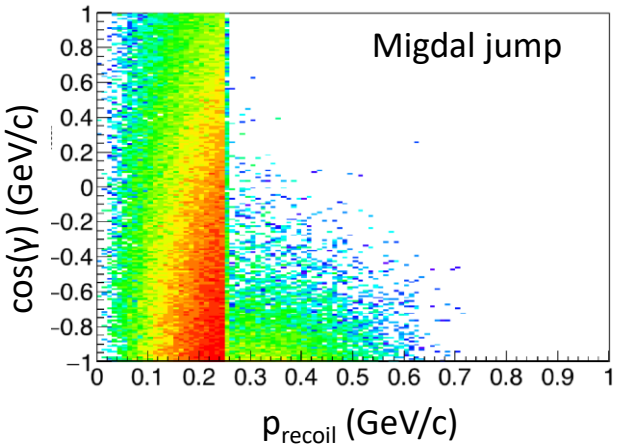
Statistics estimate:

A(p,2pn) ~ 10,000

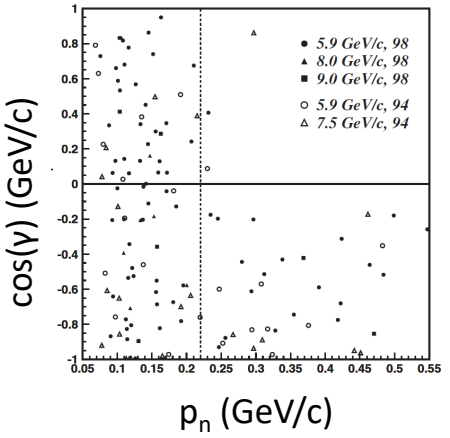
A(p,2pp) ~ 1,050

R. Weiss et al., PLB 2018



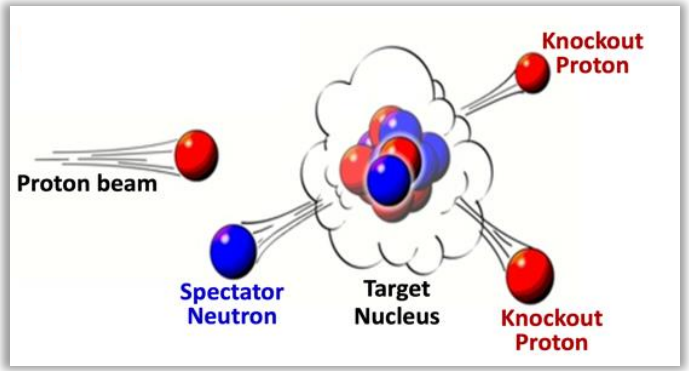


A. Tang et al., PRL 90 (2003).

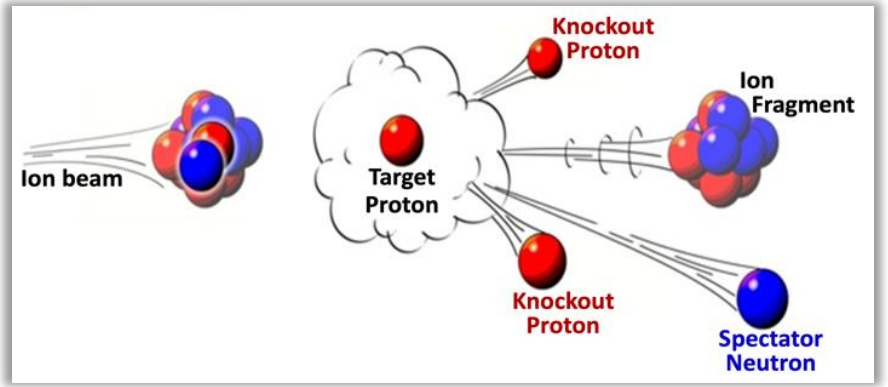


Proton beam -> Proton target
Inverse kinematics experiments

nuclear target
and p or e^- beam

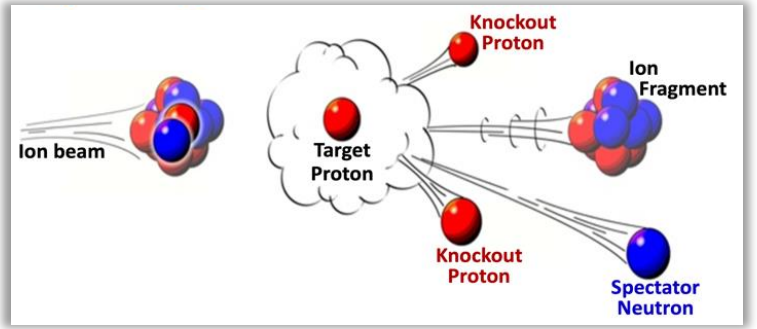


(radioactive) ion beam
hitting hadronic probe



fully exclusive measurement:
measure all emerging particles

Overcome distortions due to initial/final state interactions



incoming and
outgoing protons
interact with other nucleons

→ disturb initial momentum reconstruction

→ extra excitations of the nucleus (break fragment apart)

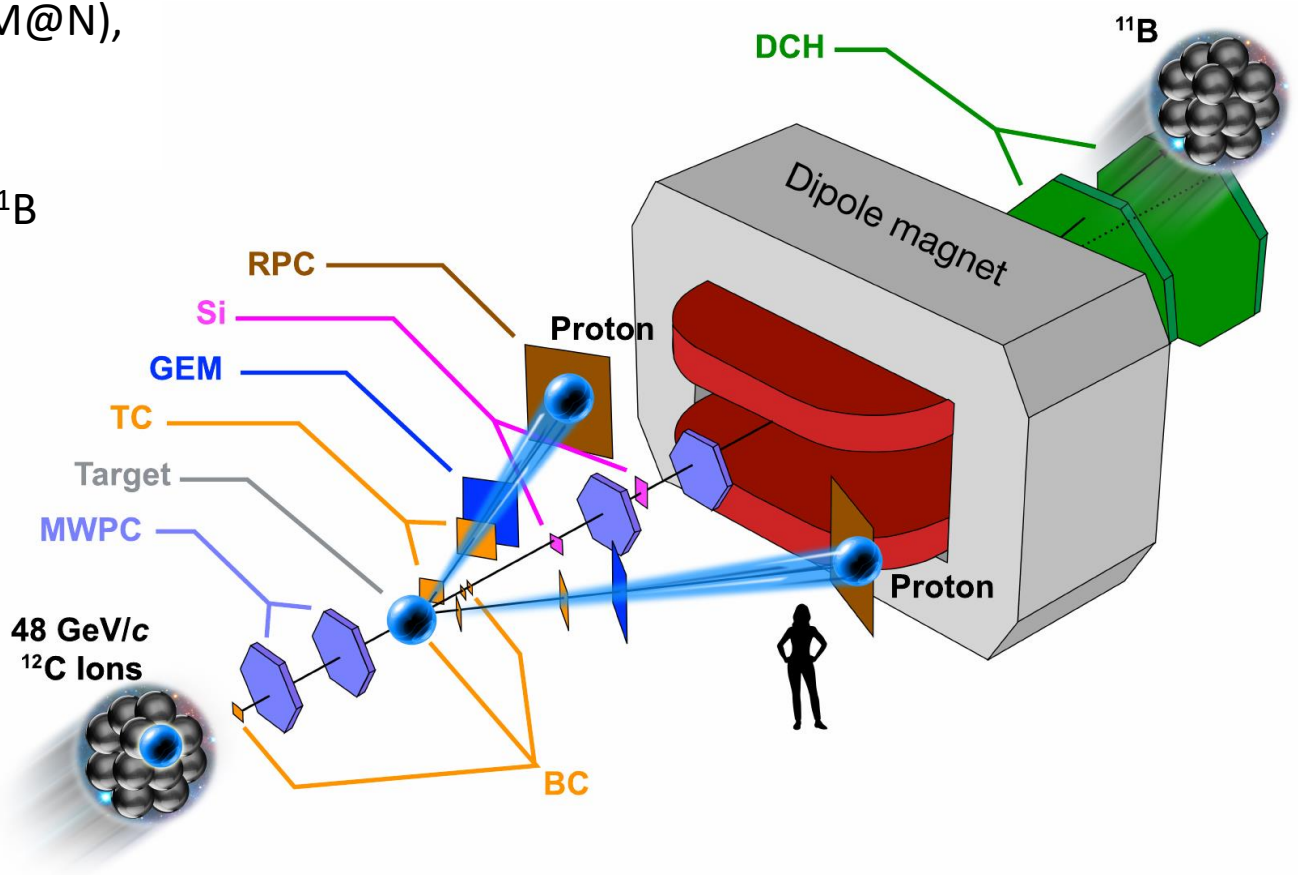
→ eject additional particles (pions, …)

2018 Experiment at BM@N Setup / JINR

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

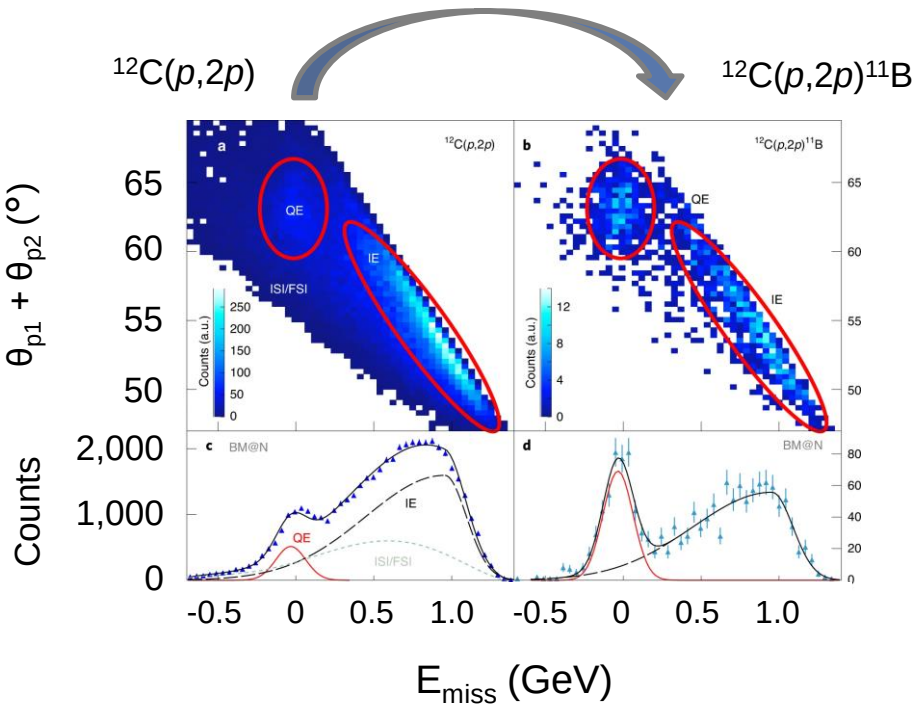
Mean-field: $^{12}C(p,2p)^{11}B$

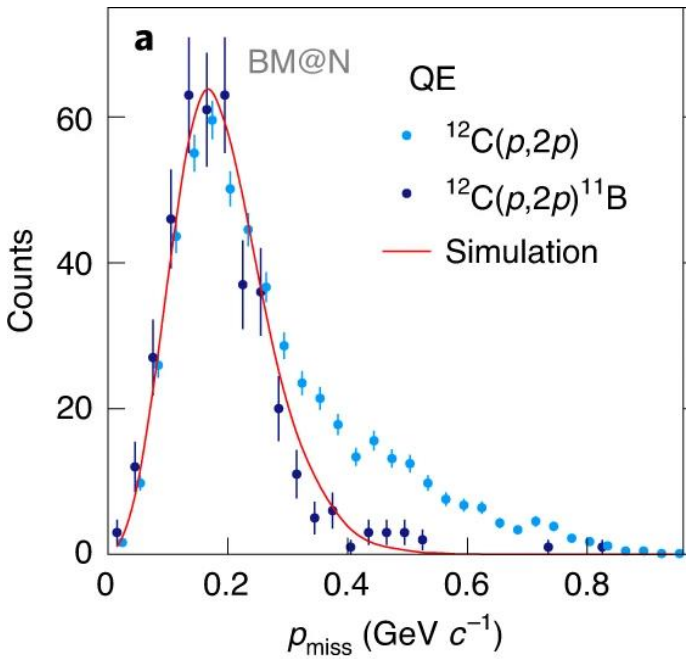
SRC: $^{12}C(p,2p)^{10}B,^{10}Be$



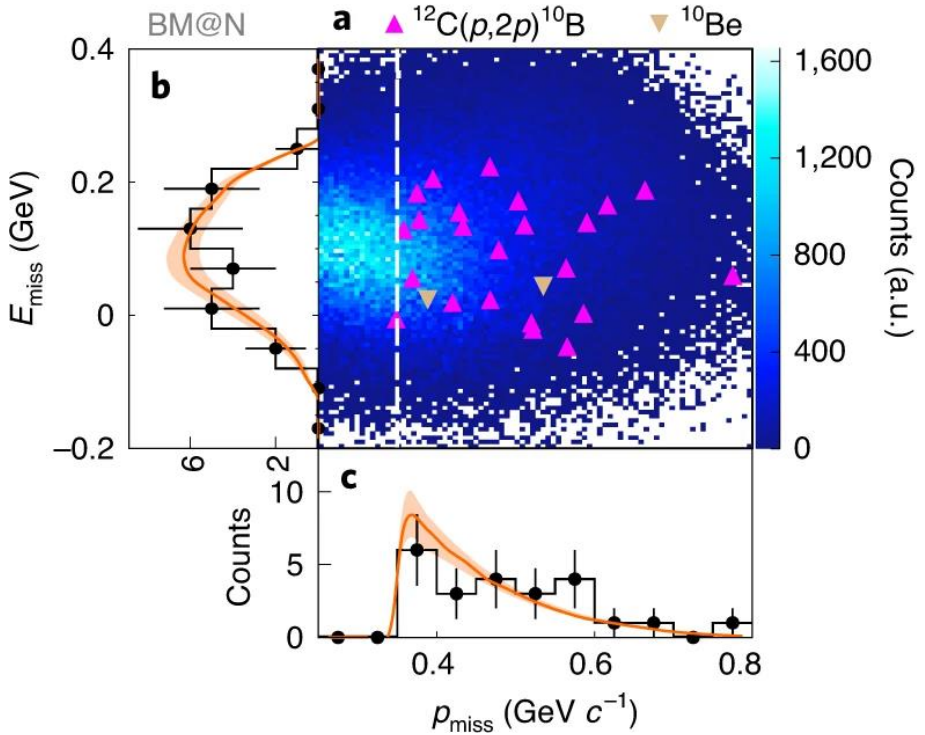
Single-step nucleon knockout proven: access ground-state distributions

Fragment tagging suppresses initial/final state interactions





Identified SRCs



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

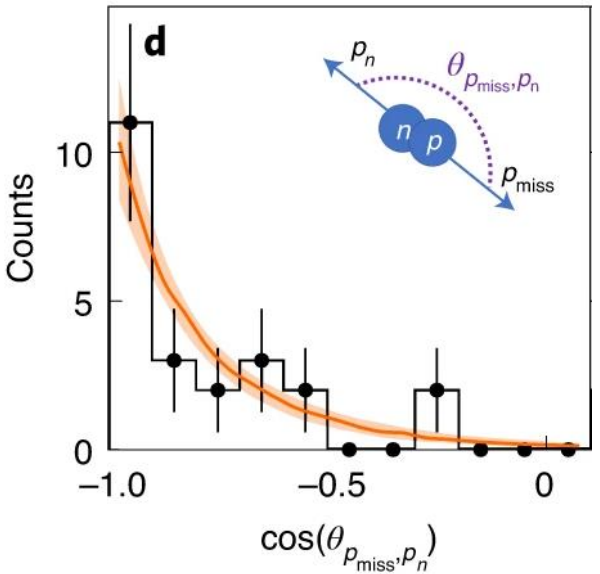
+ proton-proton opening angle,
guided by Generalized Contact Formalism*

* 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

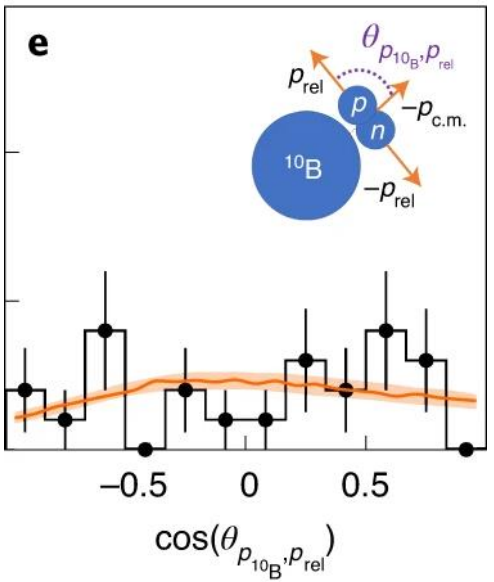
strongly correlated pair: nucleon momentum not balanced by *A-1*

NN back-to-back emission



weak interaction between pair and A-2 spectator

→ Factorization



Follow-up experiment in 2022

Goals:

- study nuclear structure in ^{12}C
- obtain absolute cross sections
- study SRC formation processes

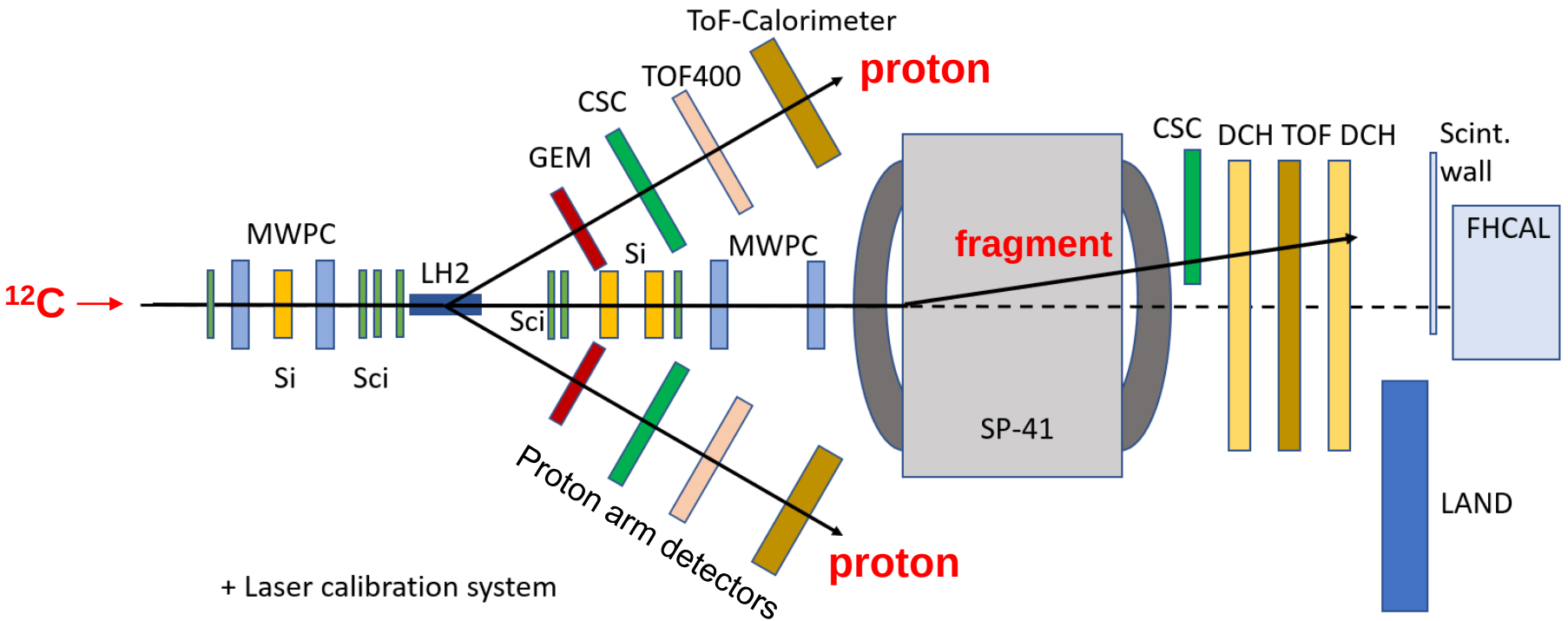
using quasi-elastic & hard knockout reactions

by

- longer run time
- better start-time resolution
- improved proton ToF measurement
- proton-pion separation
- improved fragment resolution
- multi-particle tracking

Experimental Setup at BM@N

2020/21: Building new detectors, new LH_2 target, ship equipment, set up experiment



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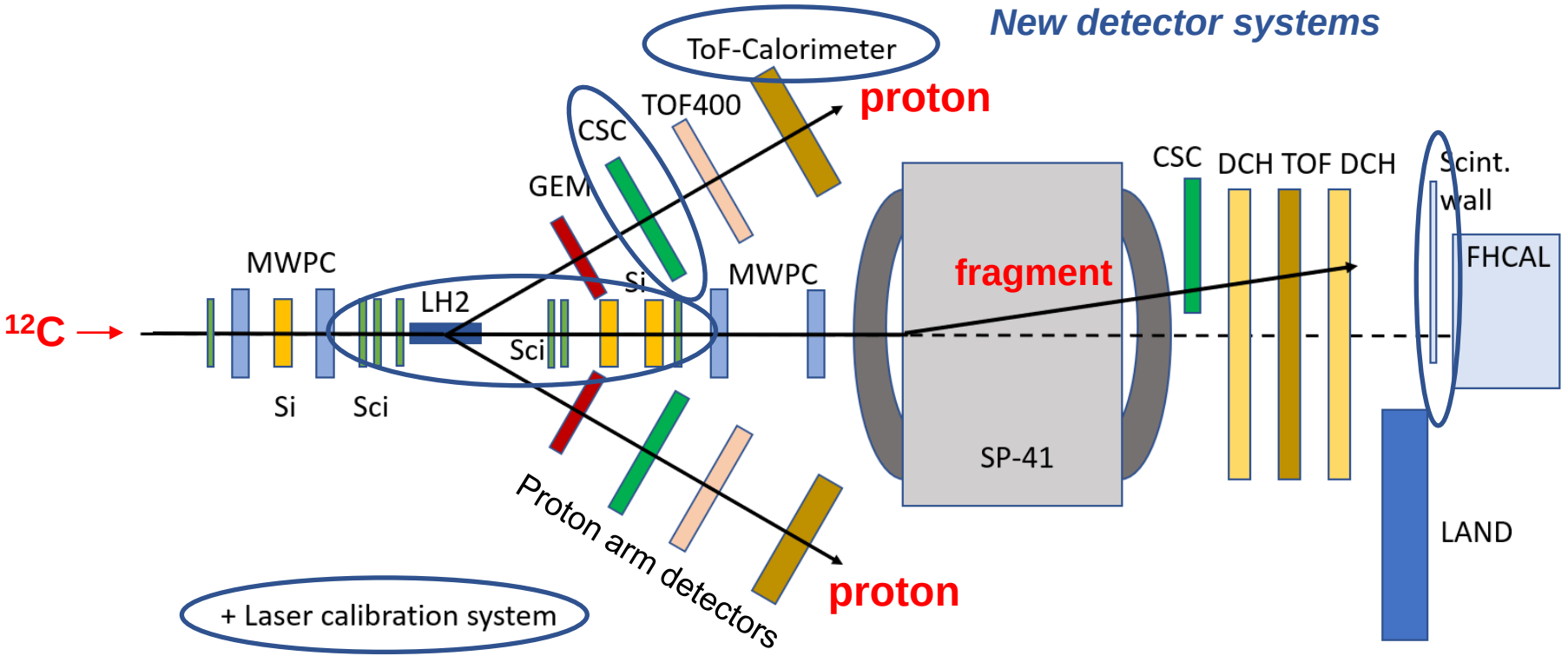
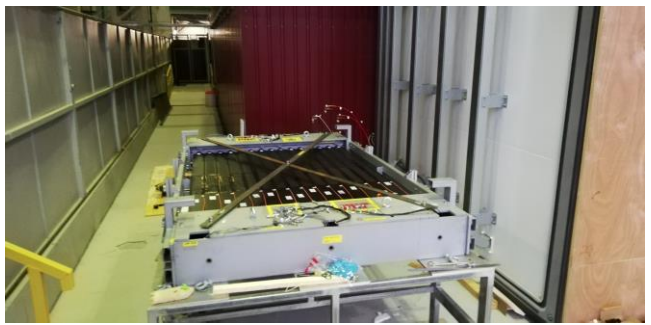
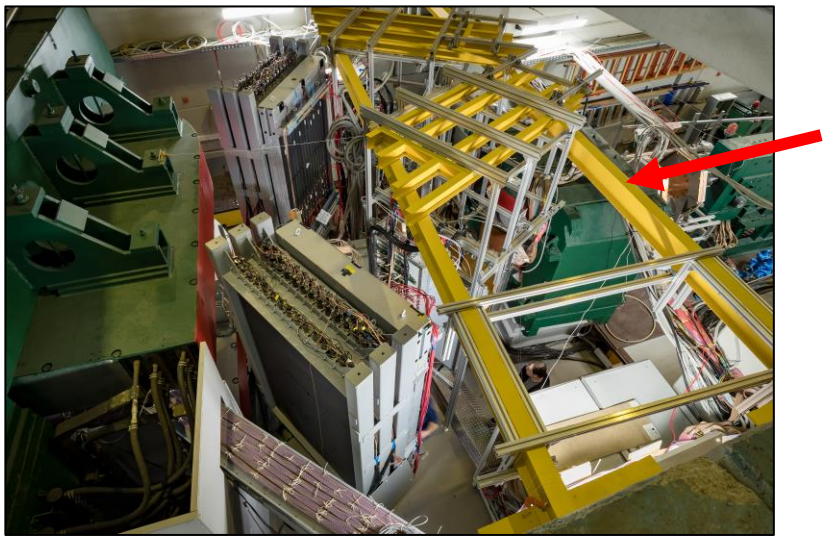


New ToF-Calorimeter

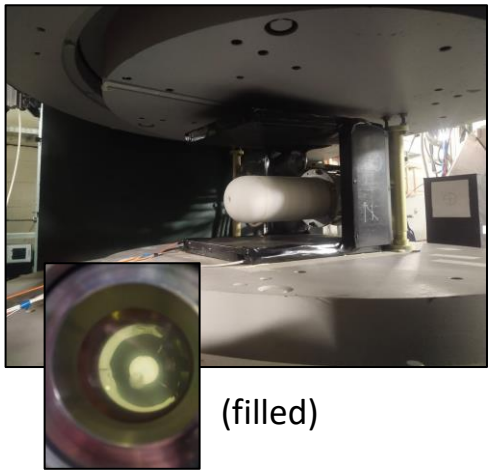


Arm detectors for (p,2p) measurement



New LH_2 target

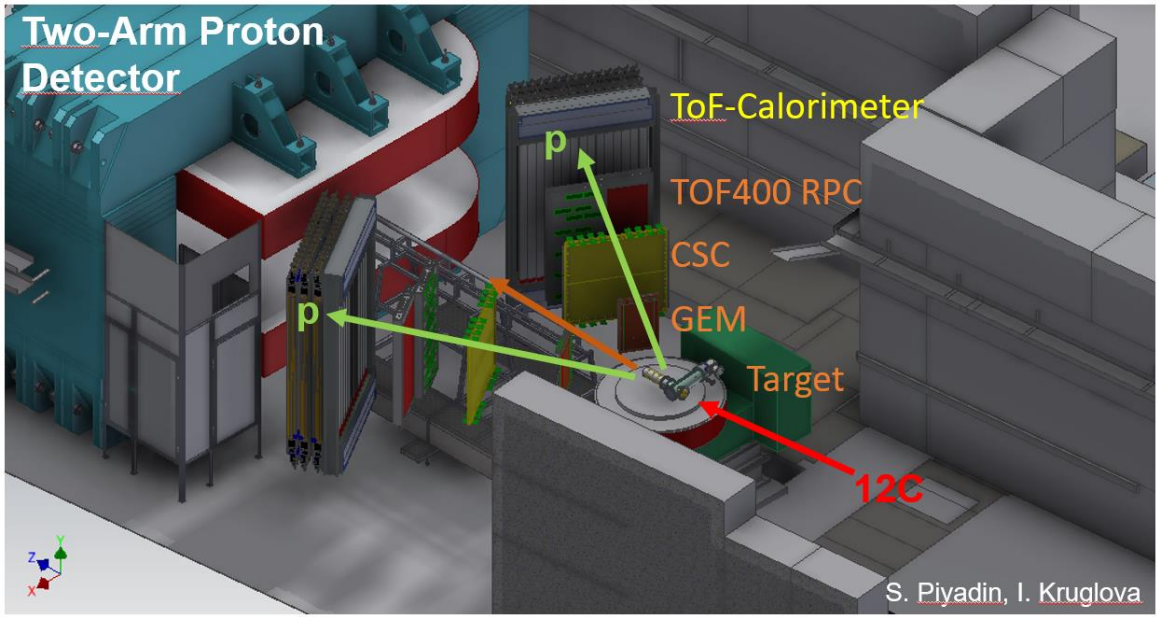
Dima Klimanskiy et al.



(filled)

Scintillator Wall

New ToF-Calorimeter



New ToF-Calorimeter

1 ToF layer:
- 15 scint. bars:
  - EJ200 + light guide
  - 200 cm x 10 cm x 6cm
- PMTs: Hamamatsu R13434
- GSI Tacquila electronics

3 Calorimeter layers, each:
- 15 bars: scint+iron sandwich
- PMT readout both ends

- weight ~5,000 kg

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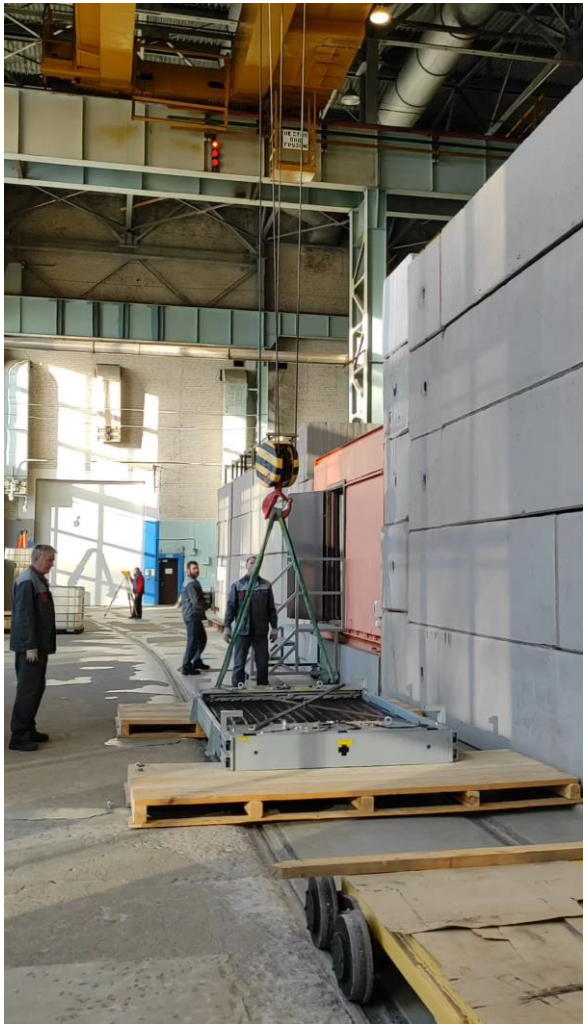
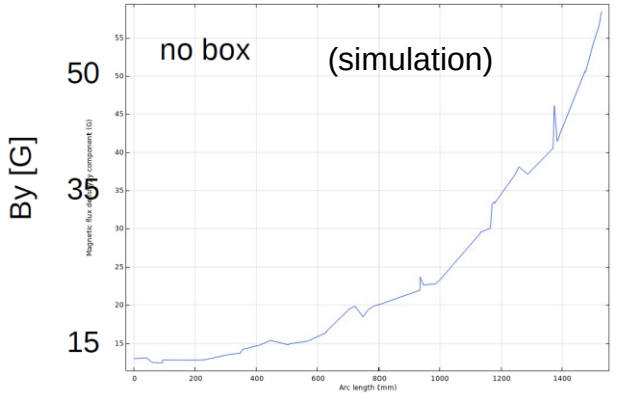


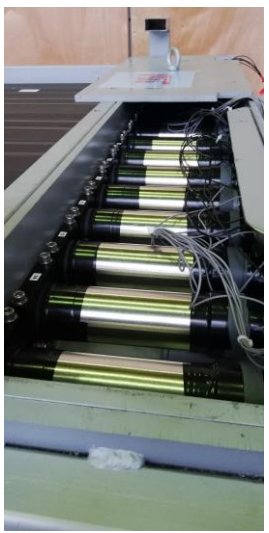
New ToF-Calorimeter: magnetic shielding

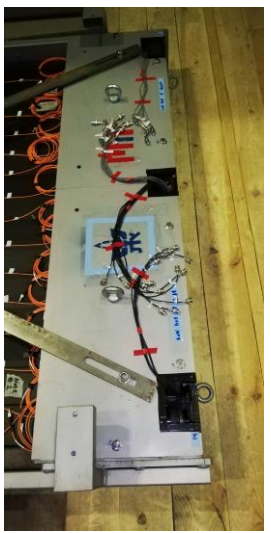
passive shielding from mag. field:

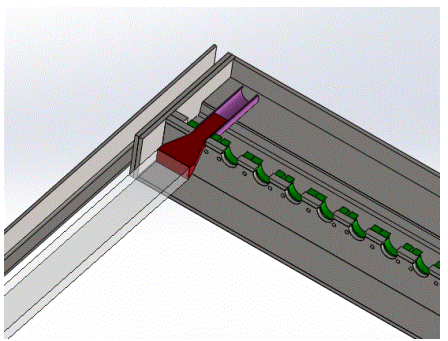
- iron box (1cm)
- mu-metal (ToF layer)

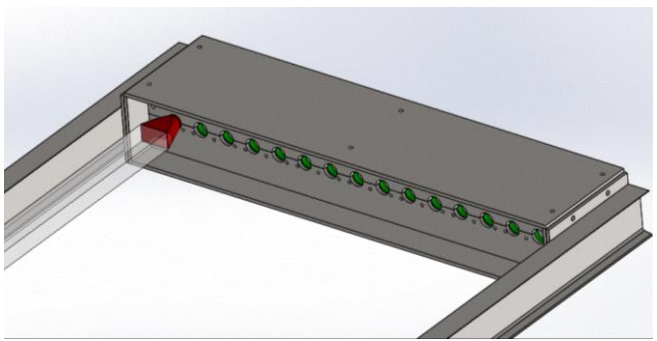


closer to the beamline →







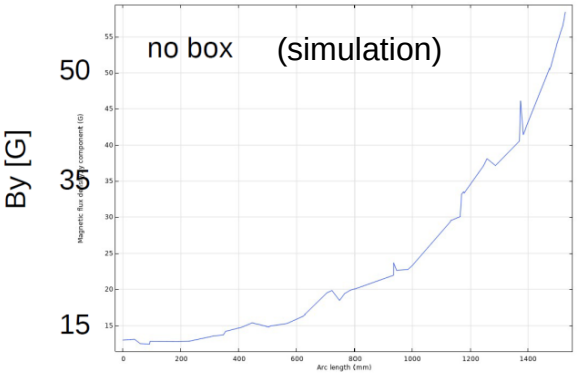


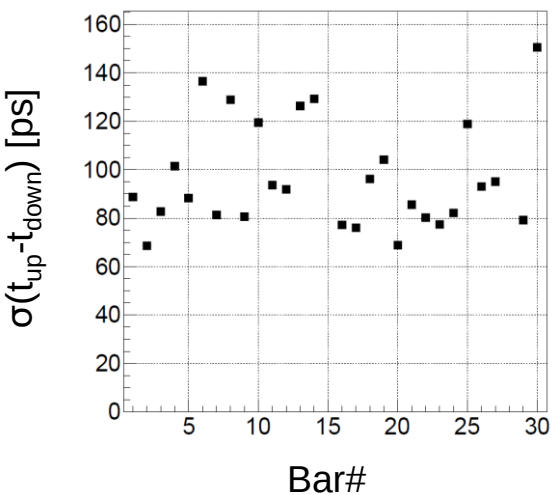
New ToF-Calorimeter: magnetic shielding

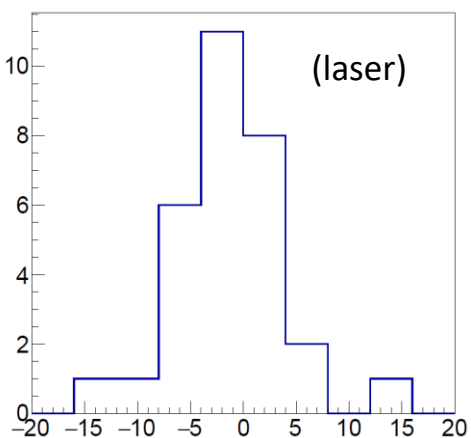
passive shielding from mag. field:

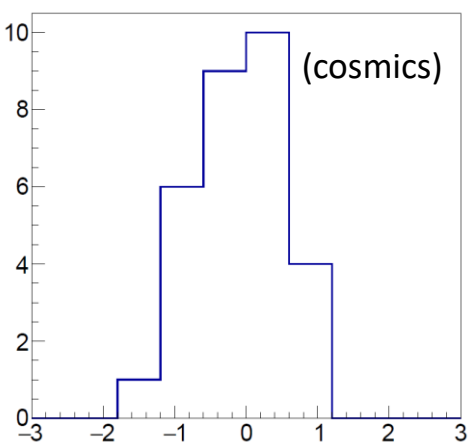
- iron box (1cm)
- mu-metal (ToF layer)

-> no distortions on ToF layer performance









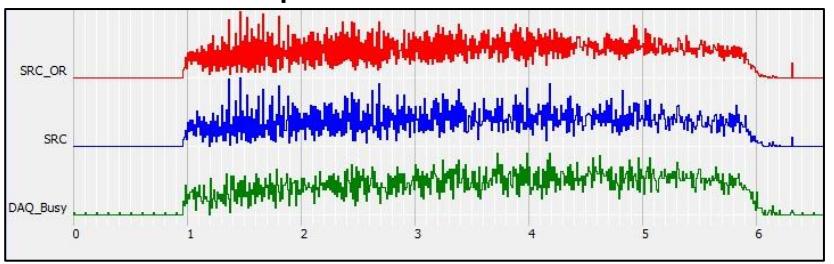
Experiment running conditions

- 7^{th} – 13^{th} March 2022: calibration with beam
- 14^{th} – 28^{th} March 2022: data taking with LH_2 target

Beam:

- ion: Carbon-12
- acceleration: **Booster** + Nuclotron
- intensity: ~ $4x10^5$ ions/spill, ~5s spill
- momenum: 3.75 GeV/c/u

Spill distribution



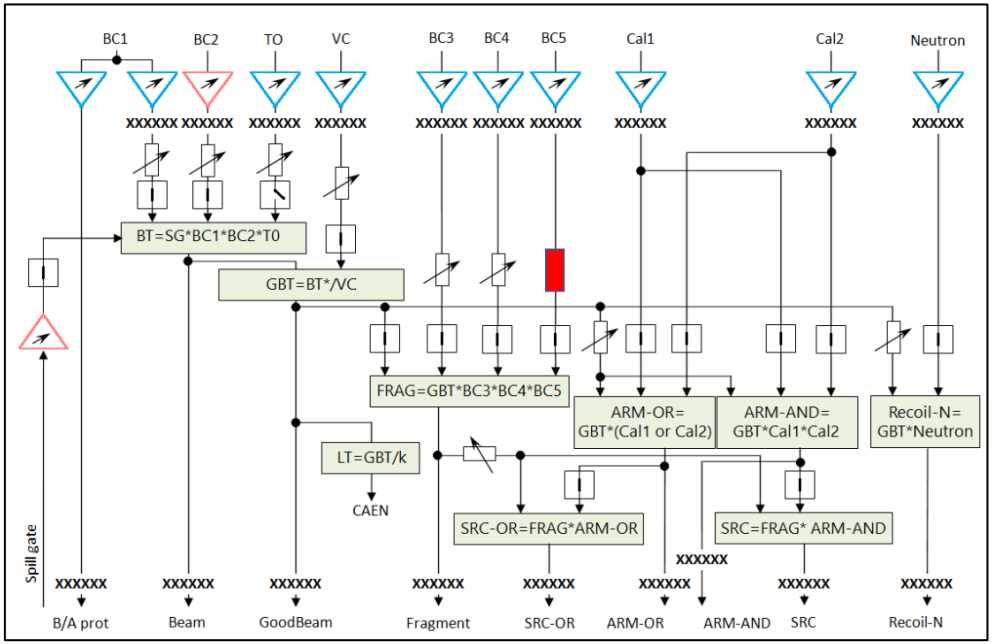
Experiment running

Run plan

- 1 Pb target (3 mm)
- No target
- 3 Pb targets (3 x 3 mm)
- LH_2 target (30 cm)

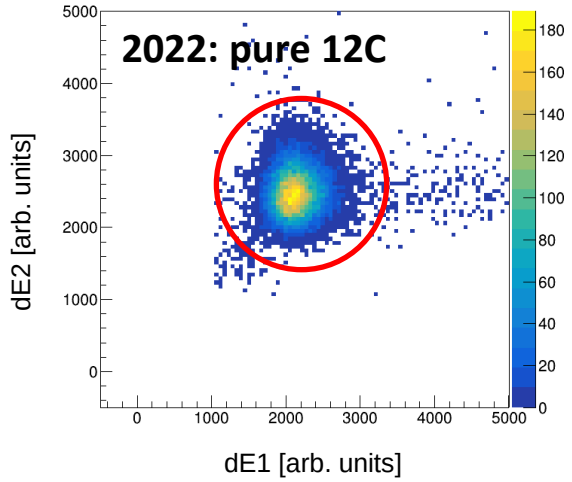
- main production trigger:
  Arm-And & Beam (DS 700) & Laser (10 Hz)
- accumulated physics triggers:
  ~ 3x statistics (2018)
  (140 Mio. triggers, 60 TB data)

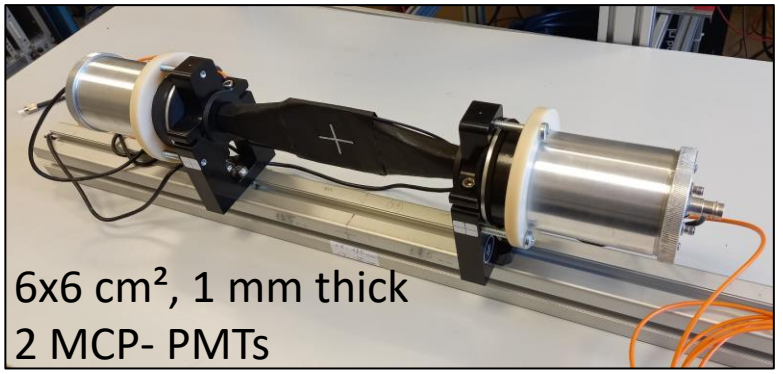
Trigger Bits



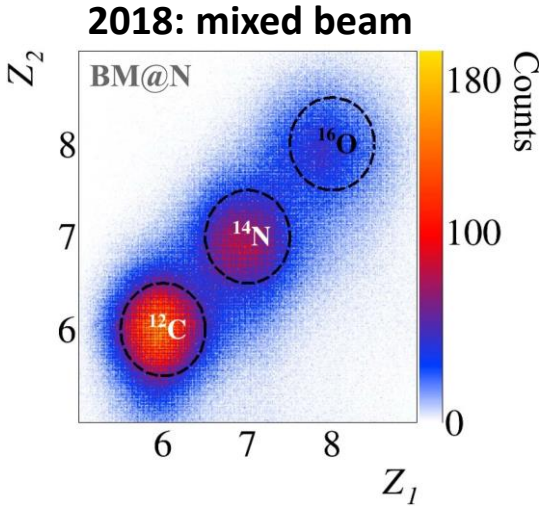
main DAQ + scalers

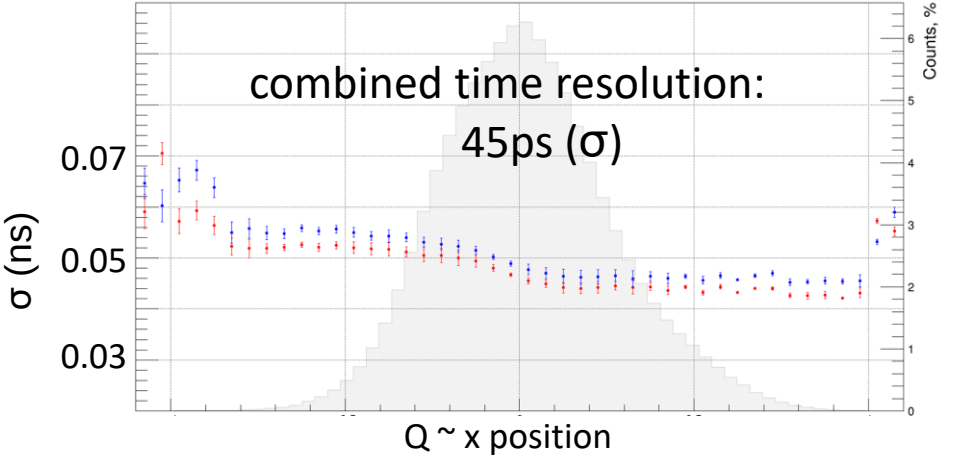
Incoming beam





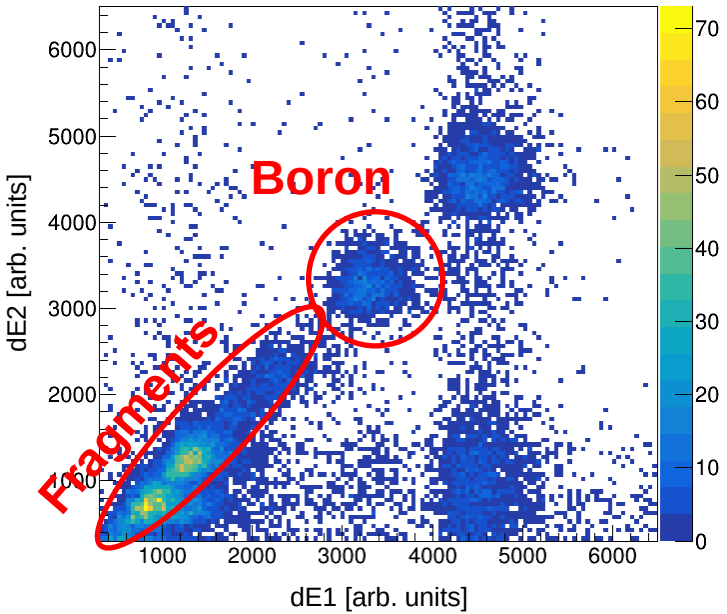
S. Sedykh



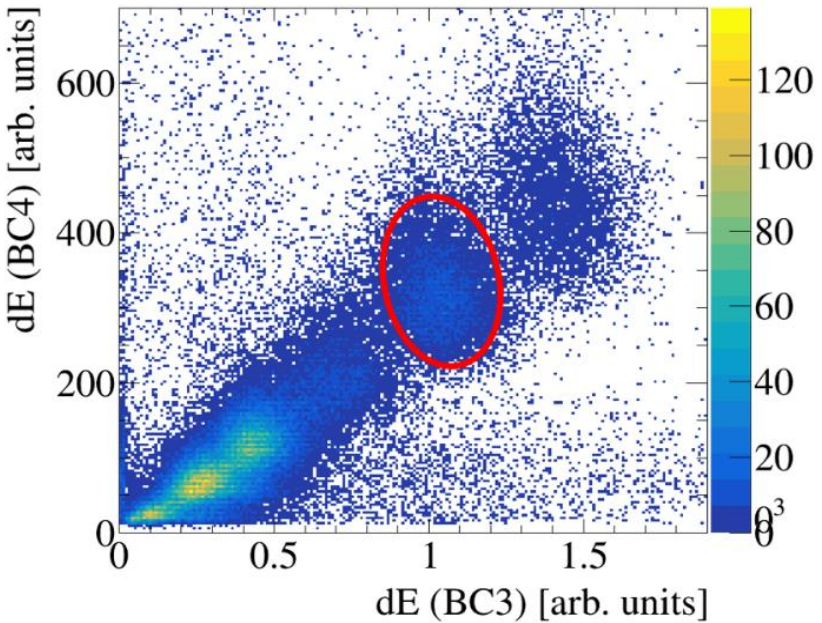


Fragment Charge ID

Clean charge ID after reaction



2018:

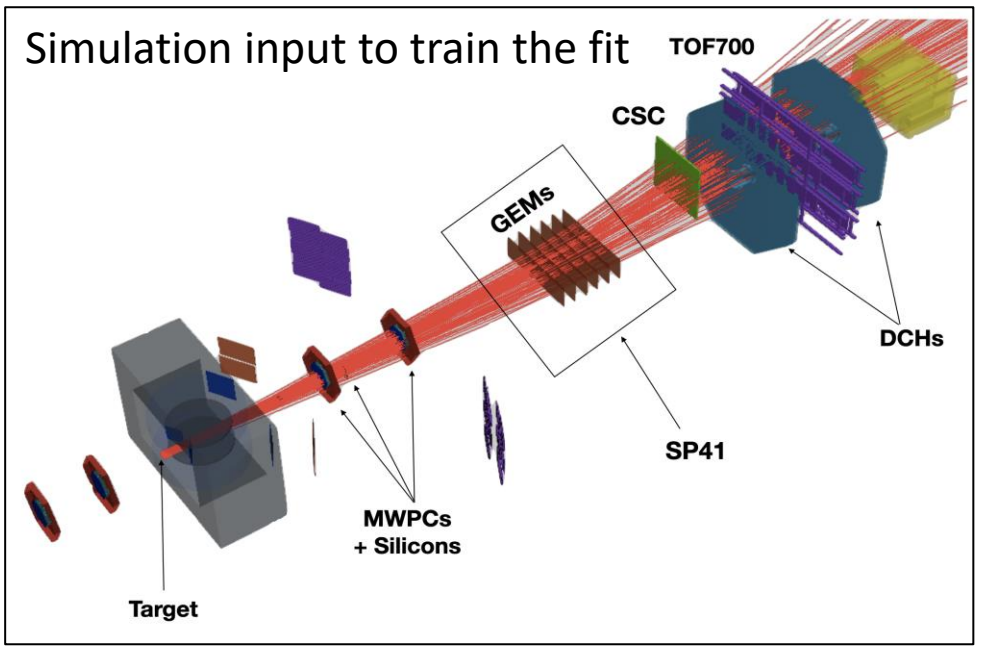


Fragment Momentum

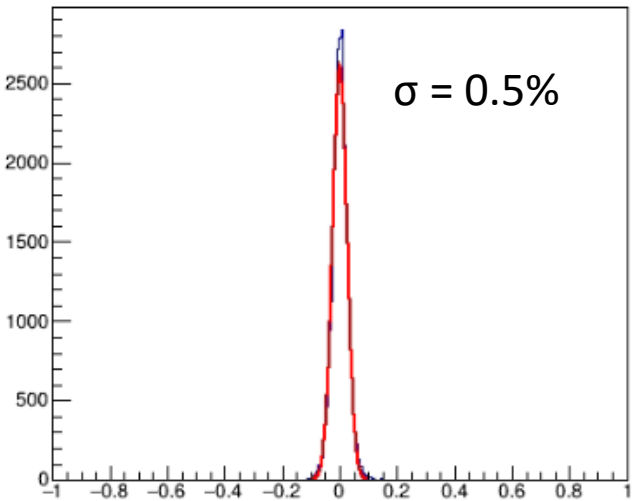
Momentum reconstruction based on multi-dimensional fit:

$$P/Z = f(X_0, Y_0, Z_0, TX_0, TY_0, X_{DCH}, Y_{DCH}, Z_{DCH}, TX_{DCH}, TY_{DCH})$$

Simulation input to train the fit



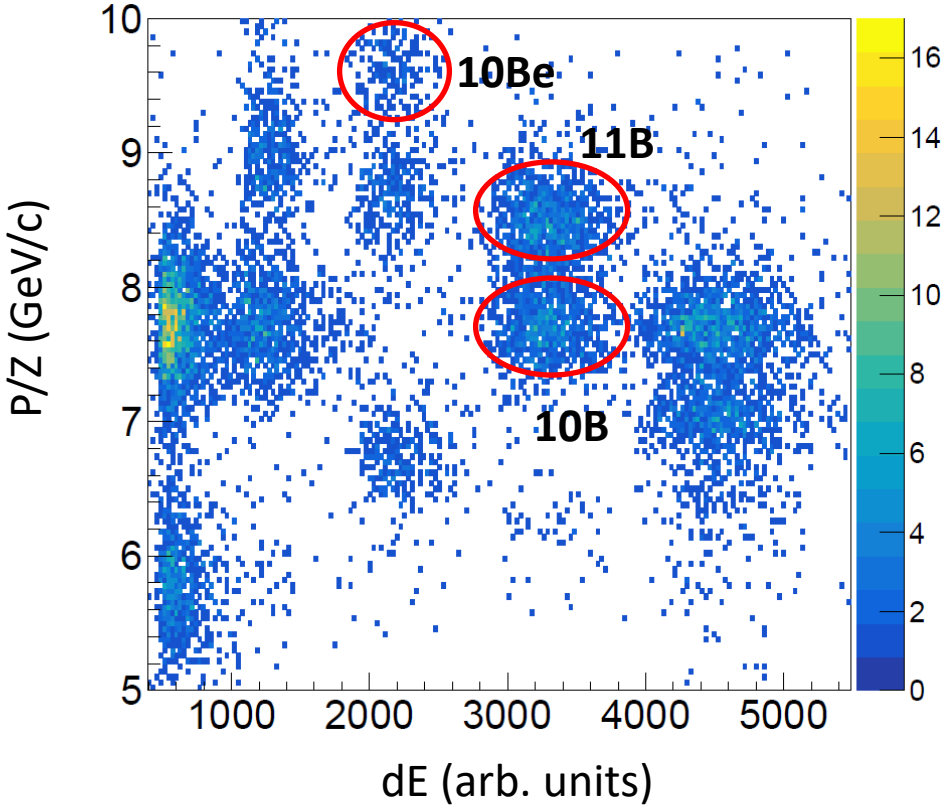
Simulation evaluation



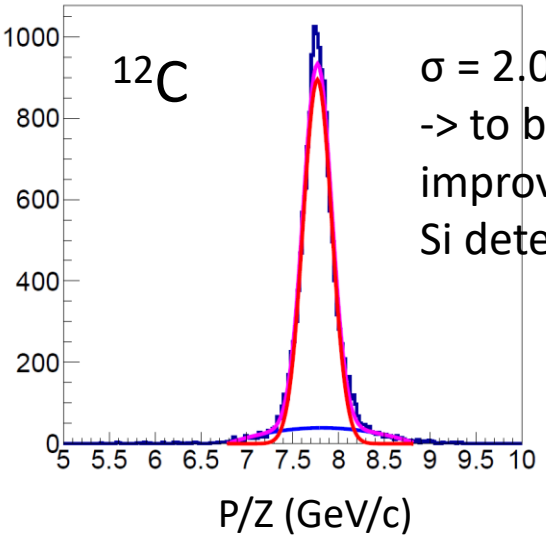
Fragment ID

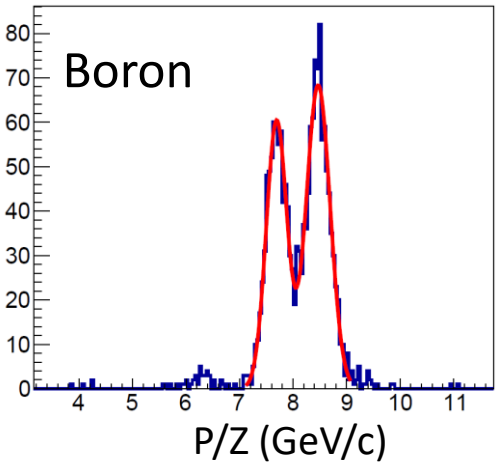
T. Atovullaev, V. Lenivenko

$^{12}C + p \rightarrow X$

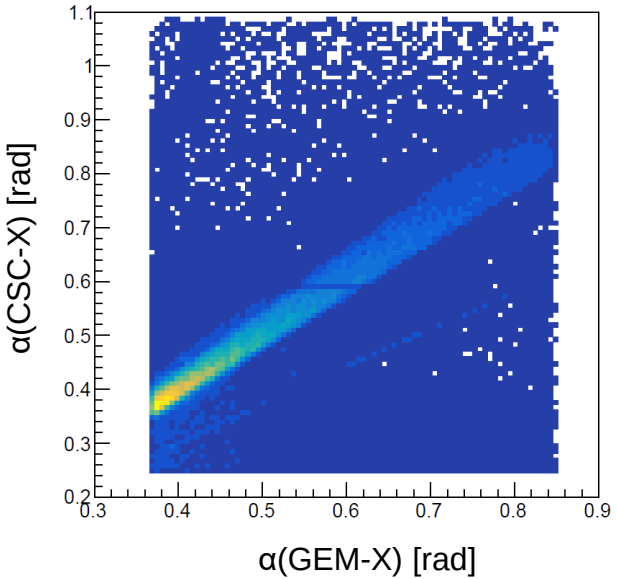


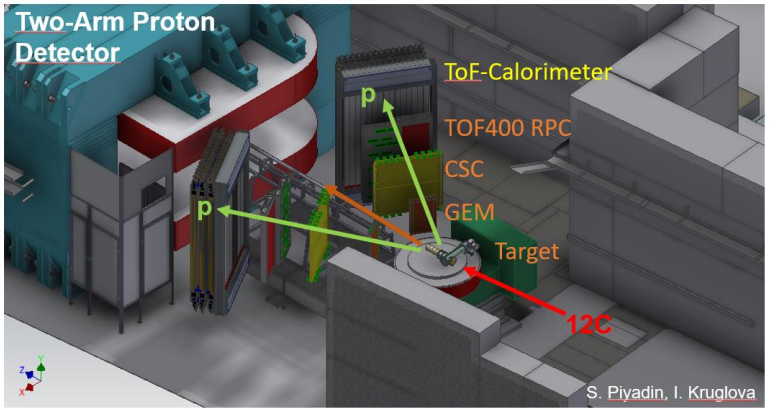
(noise to be reduced)

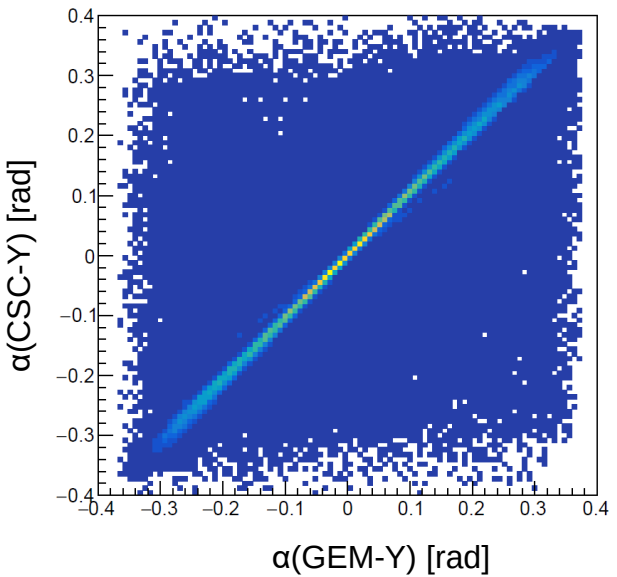




Tracking in Arms







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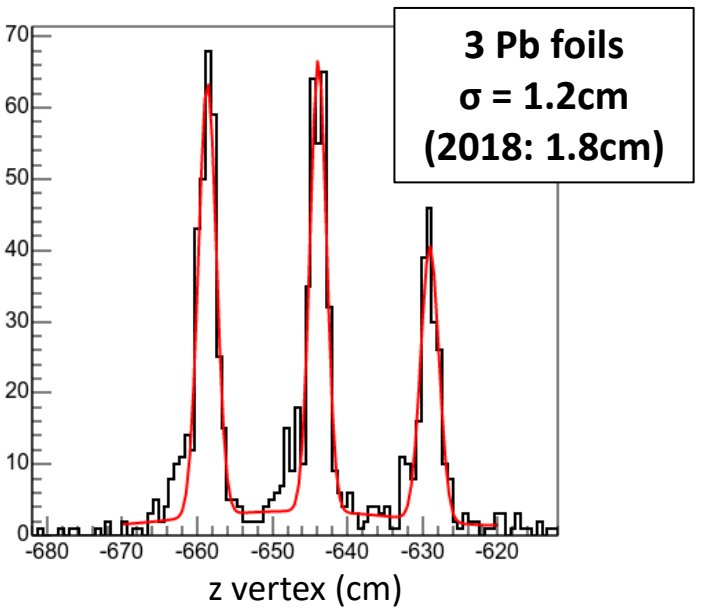
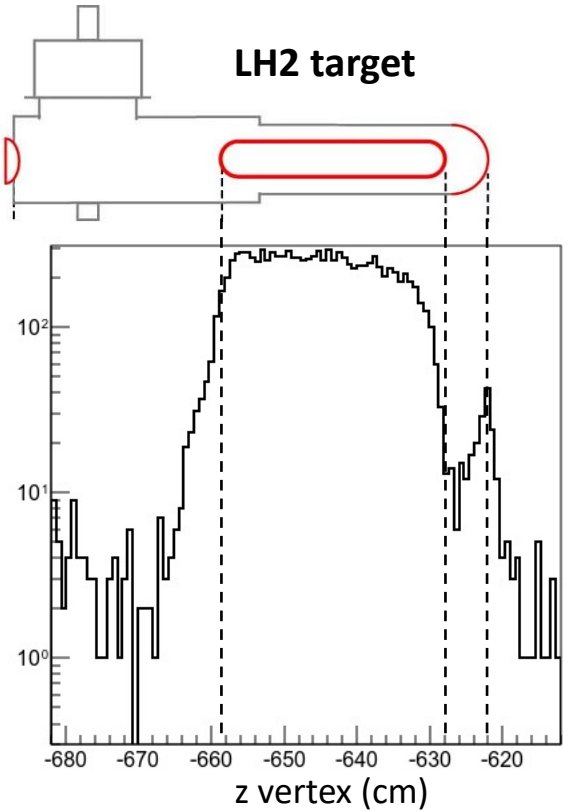
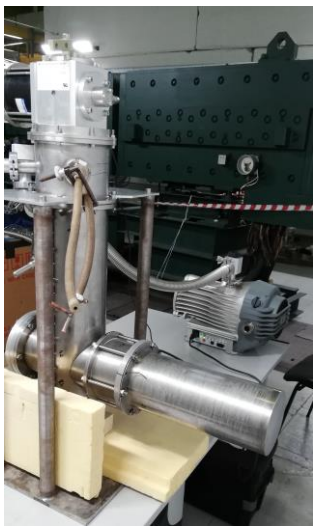
Göran Johansson

Tracking in Arms

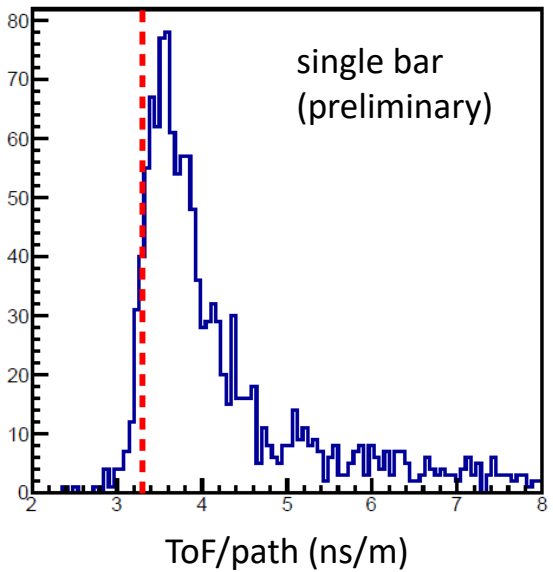
Reaction vertex reconstruction
GEM+CSC

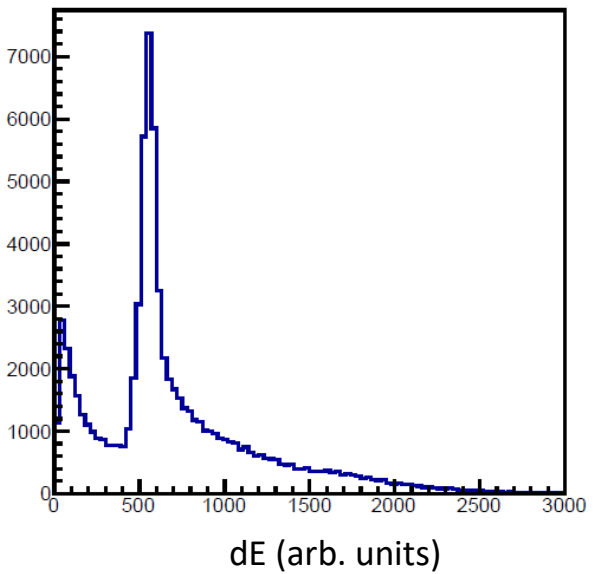






Timing in Arms





Working on time calibration with laser and Pb data → reconstruct momentum and PID

Göran Johansson

Summary and Outlook

April – June:

- Incoming beam selection
- Start time determination
- Fragment identification (charge + fragment tracking)

July:

- Vertex tracking with GEM+CSC
- Improving fragment tracking
- ToF – GEM/CSC correlation

Vasilisa Lenivenko, Timur Atovullaev,
Sergey Nepochatykh (JINR)
Göran Johansson (Tel Aviv U)

August – September:

- ToF calibration, timing w/ TOF400, identification leading protons
- Missing momentum / energy / mass reconstruction
- QE selection

Outlook

SRC studies with hadronic probes open a new pathway at European facilities

	BM@N @ JINR (March `22)	HADES @ GSI (2025/26)	R³B @ GSI/FAIR (May 2022 +)	HESR @ FAIR (2028 -)
High beam energy	✓	✓		✓
Inverse kinematics	✓		✓	✓
Radioactive beams			✓	✓

Next talk