Nucleon Correlation Studies in (p,pd) Knockout Reactions

Matthew Whitehead[1] for the R^{3}B Collaboration

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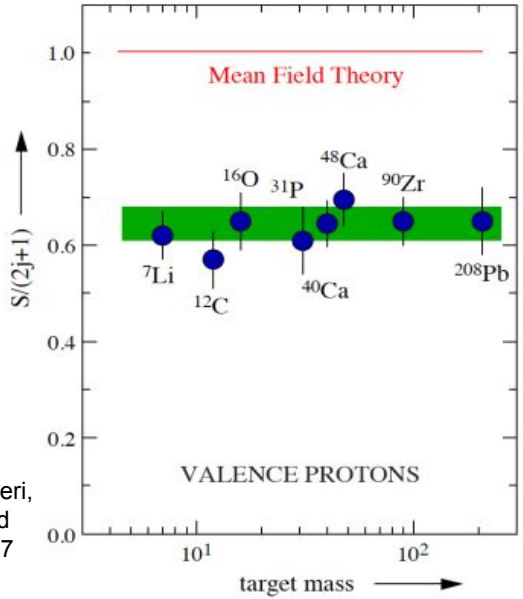
Nucleon-Nucleon Correlations

- The independent particle model describes many properties of the atomic nucleus very well.
- However the IPM does not account for all interactions between the nucleons.
- This has been observed experimentally through the reduction in spectroscopic factors.



W.H. Dickhoff, C. Barbieri, Progress in Particle and Nuclear Physics **52**, 377 (2004).

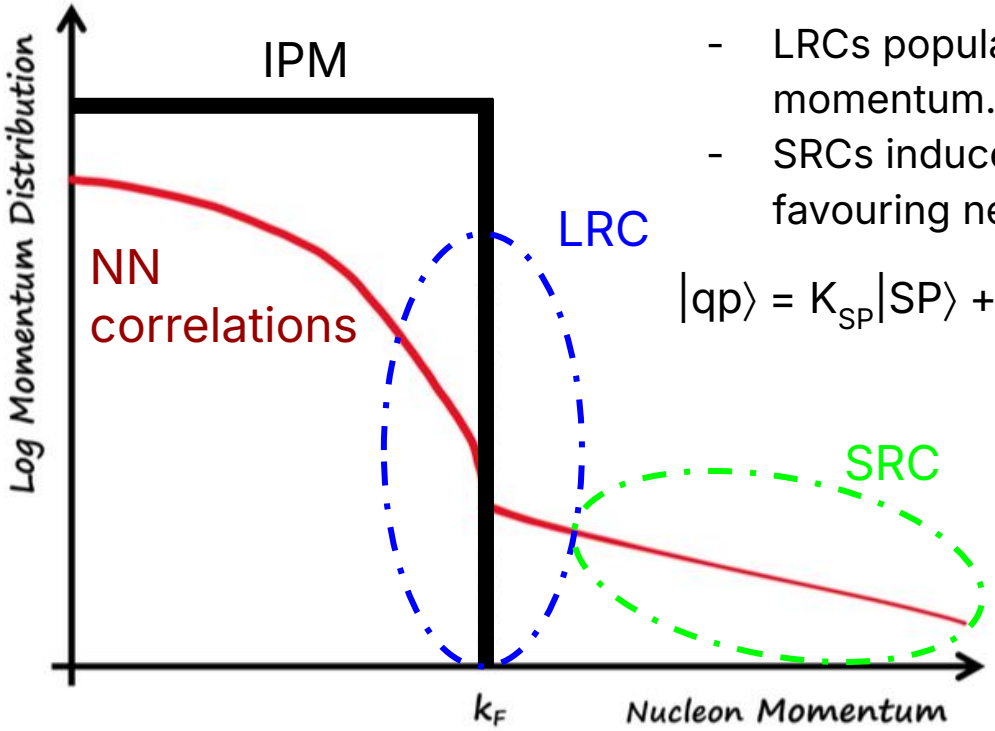
Attributed to **Nucleon-Nucleon correlations**, denoted Short (SRC) and Long Range Correlations (LRC).

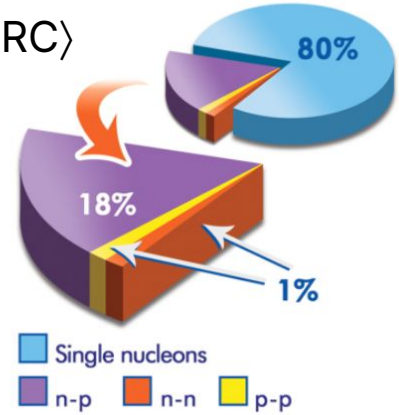
Nucleon-Nucleon Correlations

NN Correlations deplete 30-40% of single particle states.

- LRCs populate states close to the Fermi momentum.
- SRCs induce a high momentum tail well above k_F favouring neutron-proton pairs.

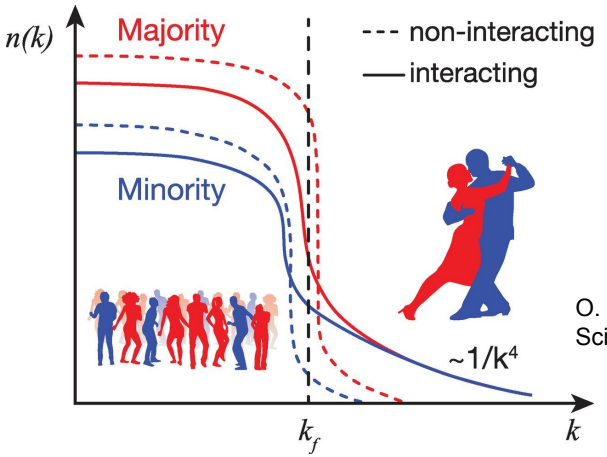
$$|qp\rangle = K_{SP}|SP\rangle + K_{LRC}|LRC\rangle + K_{SRC}|SRC\rangle$$





R. Subedi et al., Science **320**, 1476 (2008).

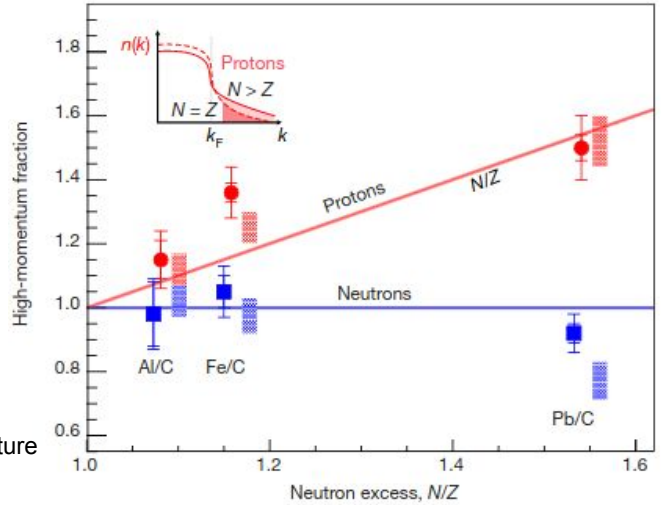
SRCs in Experiments



O. Hen et al., Science **346**, 614 (2014).

- Experimental effort at JLab to directly break up and tag the SRC pair, via (e,e'p) and (e,e'n) reactions.
- Results suggest fraction of high momentum (SRC) protons increases with neutron richness.
- Indication of SRC dependency on isospin.

Are there other ways to probe the SRC pair and isospin dependence?



M. Duer et al., Nature **560**, 617 (2018).

Motivation

We follow the seminal discussions of Brueckner:

*"The evidence is that for relative distances less than roughly 10^{-13}cm, **nucleon pairs in nuclei are correlated in the same way as they are in the deuteron** or in free scattering processes"*

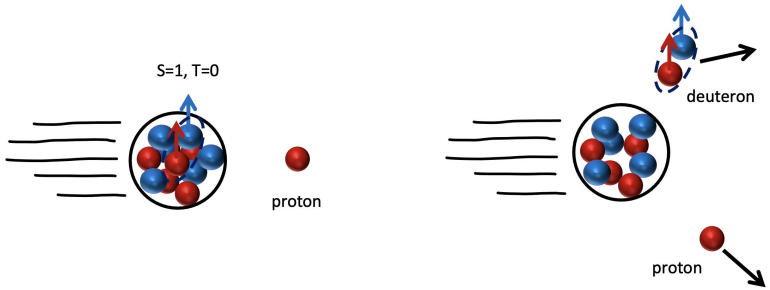
[from K.A. Brueckner, Proceedings of the Rutherford Jubilee Int. Conf. Manchester 1961, Ed. J.B.Birks, London, **1961**]

SRCs are a manifestation of the tensor part of the NN interaction which favours the S=1, T=0 (quasi-deuteron) channel.

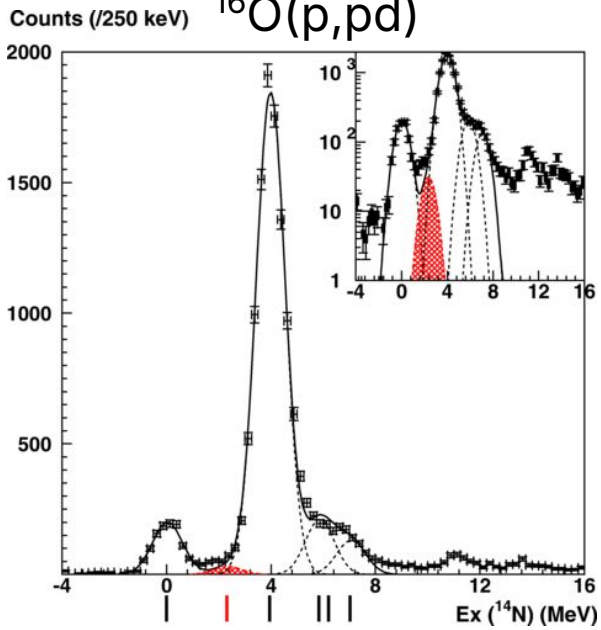
A "bare" nucleon in the presence of the SRC components of the NN interaction becomes "dressed" in a quasi-deuteron cloud, about 20% of the time with an **isospin dependence**.

$$|qp\rangle \sim 80\% \, |p\rangle + 20\% \, |h\rangle \otimes |qd\rangle$$

(p,pd) in experiments

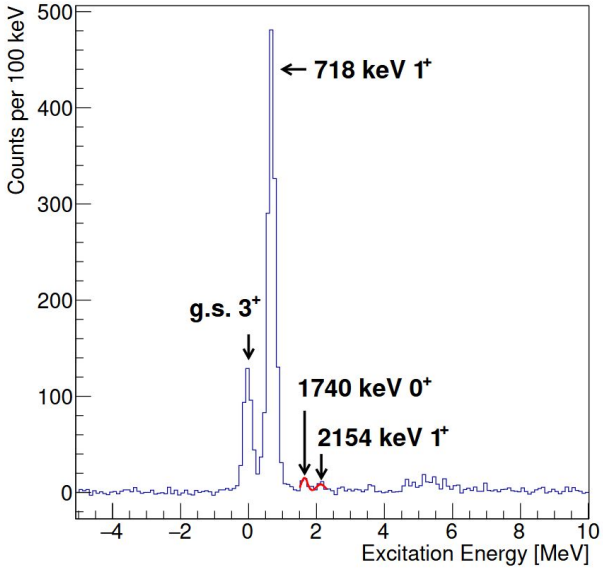


^{16}O(p,pd)



S. Terashima et al., Phys. Rev. Lett. **121**, 242501 (2018).

^{12}C(p,pd)

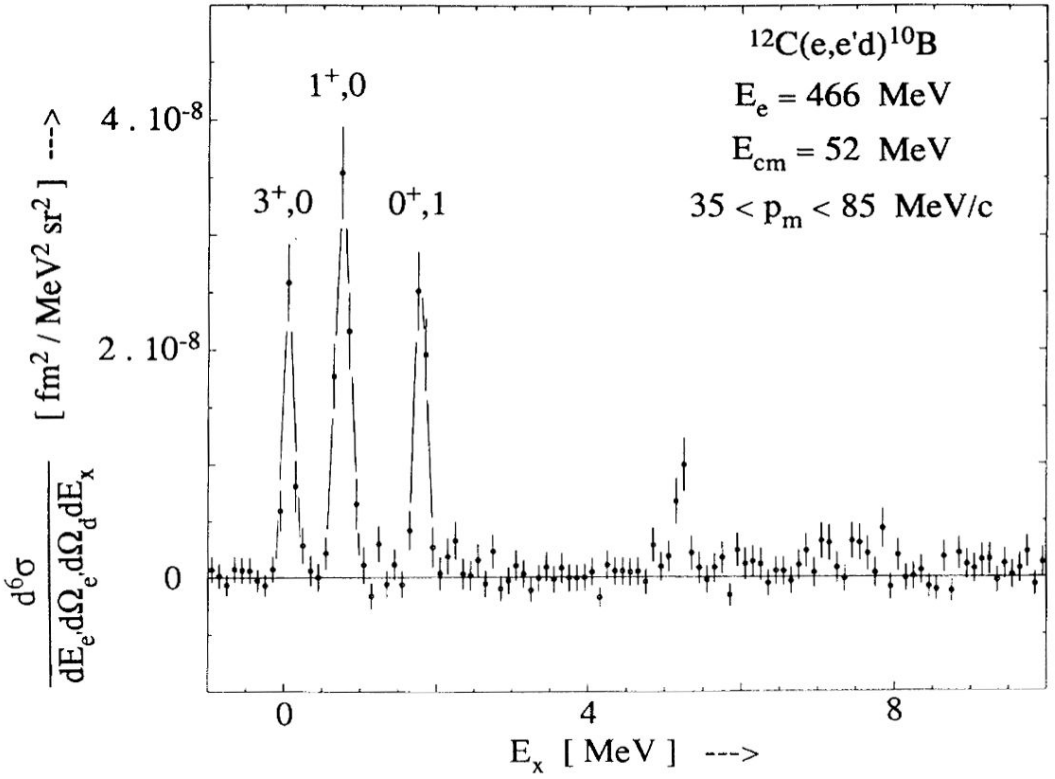


CheongSoo Lee et al., *Prog. Theor. Exp. Phys.*, **2026**, 053D01 (2026)

(p,pd) QFS in normal kinematics successfully carried out at RCNP.

Dominance of 1+ final state → Initial S=1, T=0 correlated n-p pair

(e,e'd) in experiments



Stronger contribution of isospin forbidden 0+ state in electron scattering → 'deuteron integration' of T=1 p-n pair into T=0 deuteron.

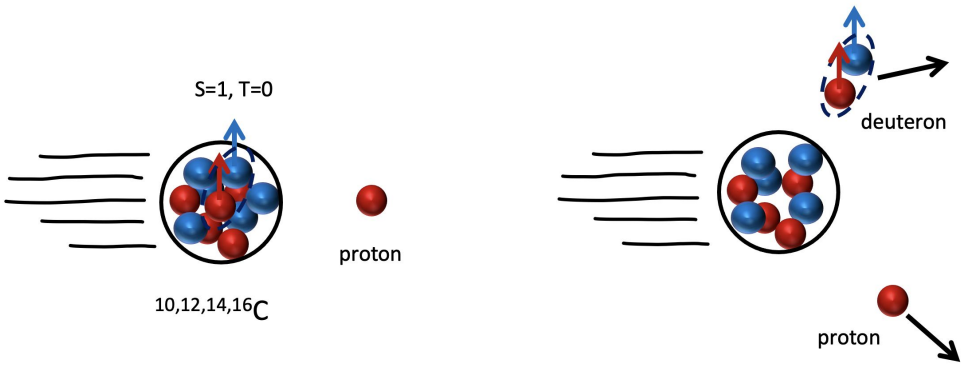
Suppressed in (p,pd) → hadronic probes more suitable for deuteron knockout?

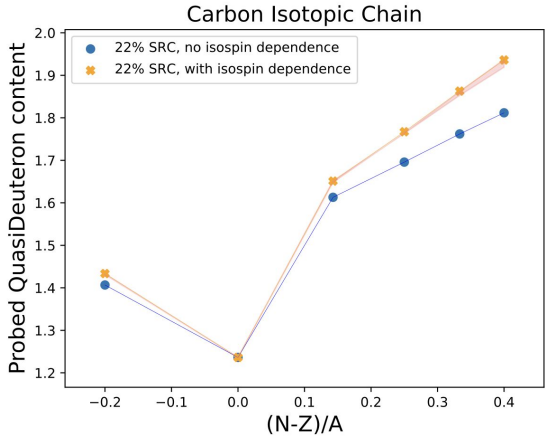
Probing Short Range Correlations via (p,pd) Quasi-Free Scattering Reactions

UNIVERSITY of York

Aims:

- Investigate the SRC dependence on isospin.
- Measure (p,pd) Quasi-Free Scattering cross sections of $^{10,14,16}C$ relative to ^{12}C at 400MeV/u.

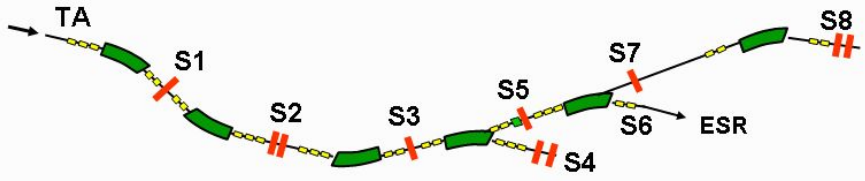


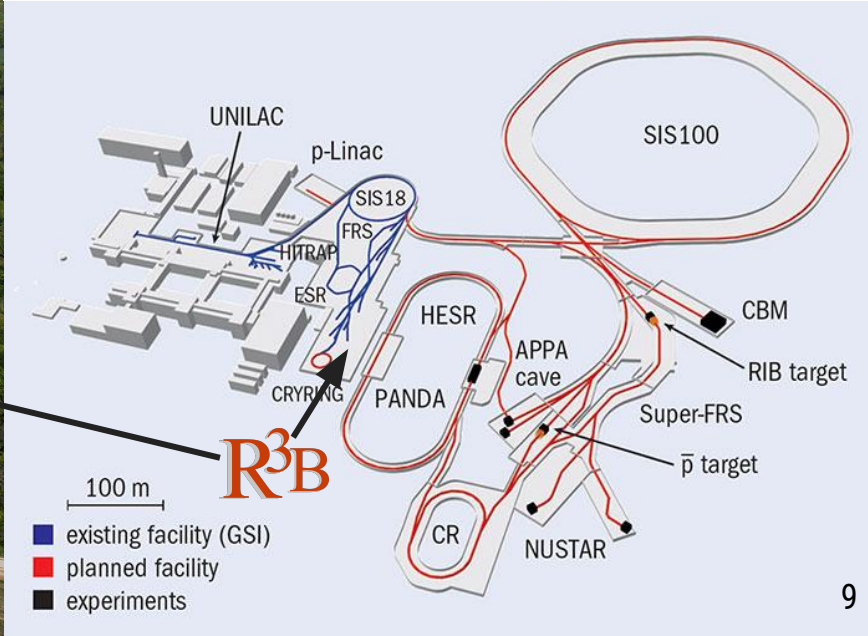


M. Petri, Private communication

R3B @ GSI-FAIR

Complete kinematical reconstruction of reaction. Fragment Separator (FRS) provides exotic beams to R3B.





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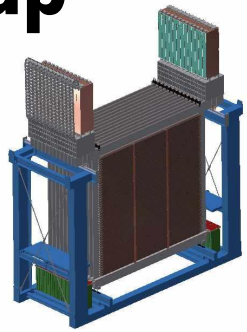

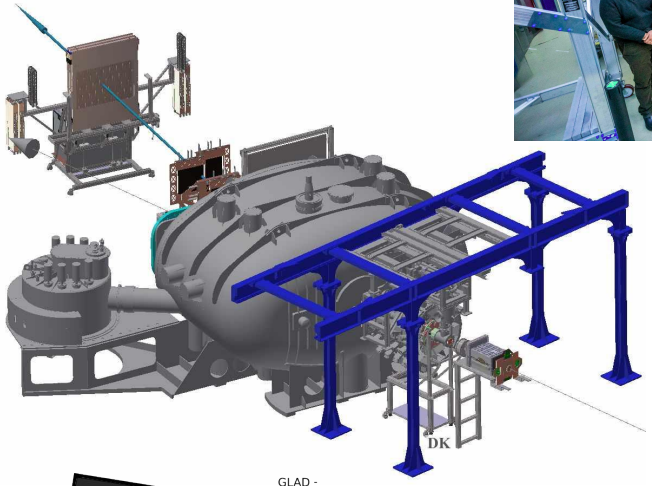

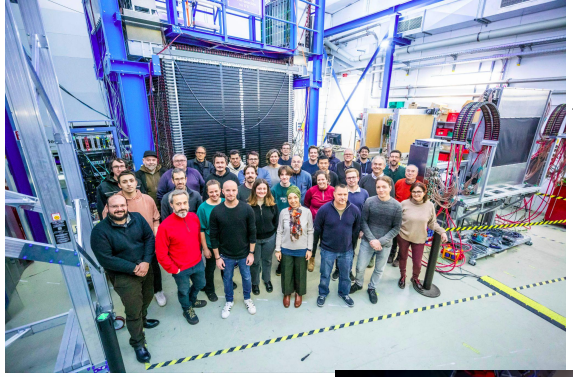

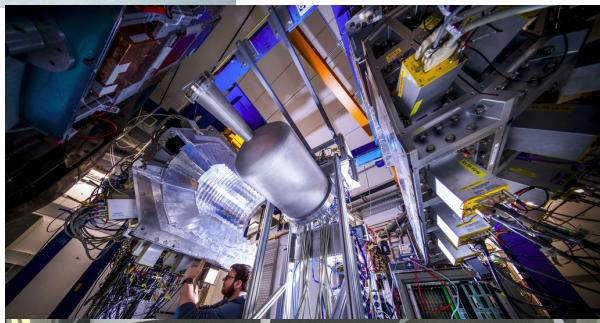

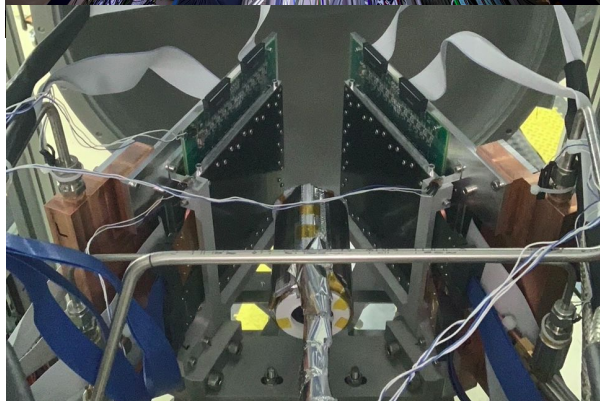

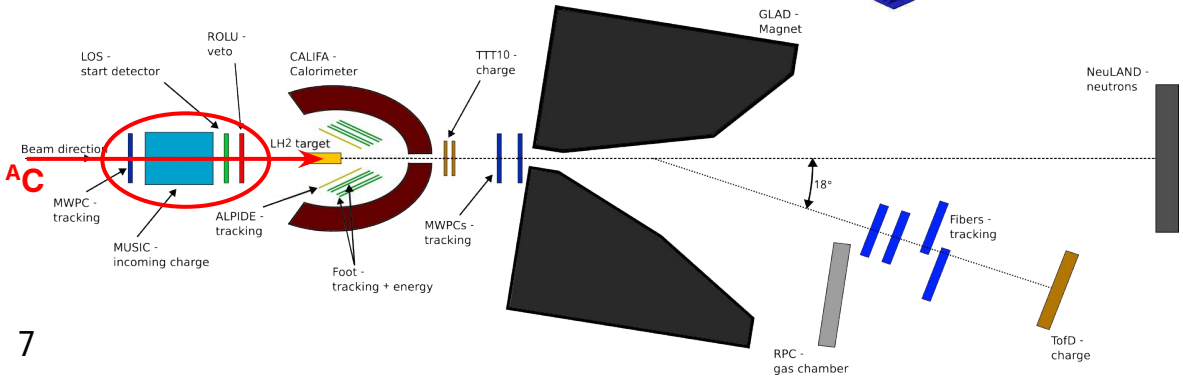

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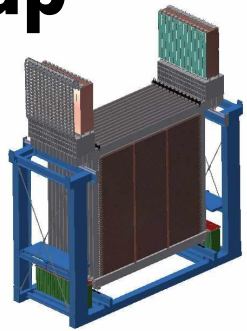

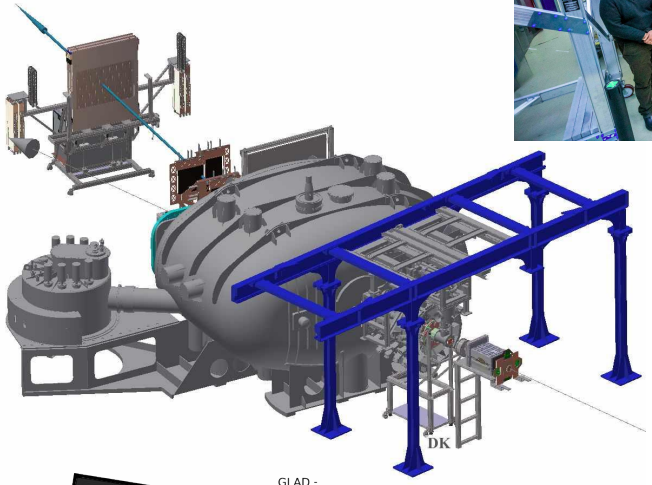

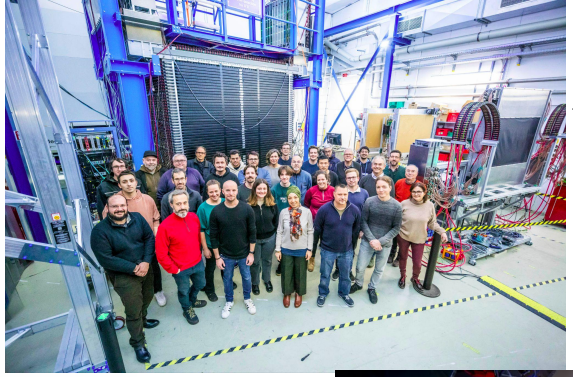

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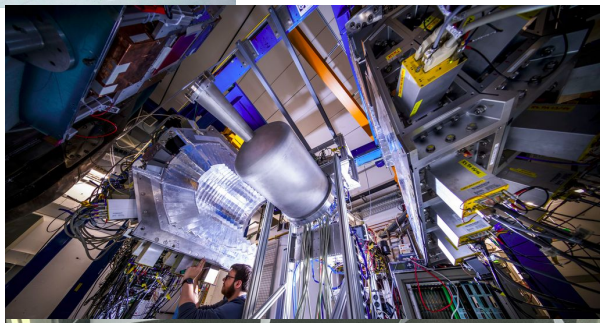

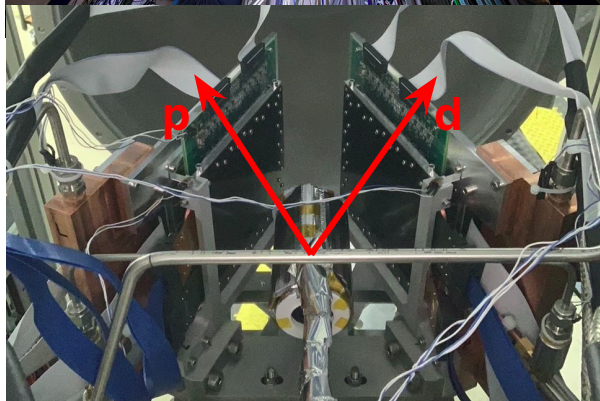

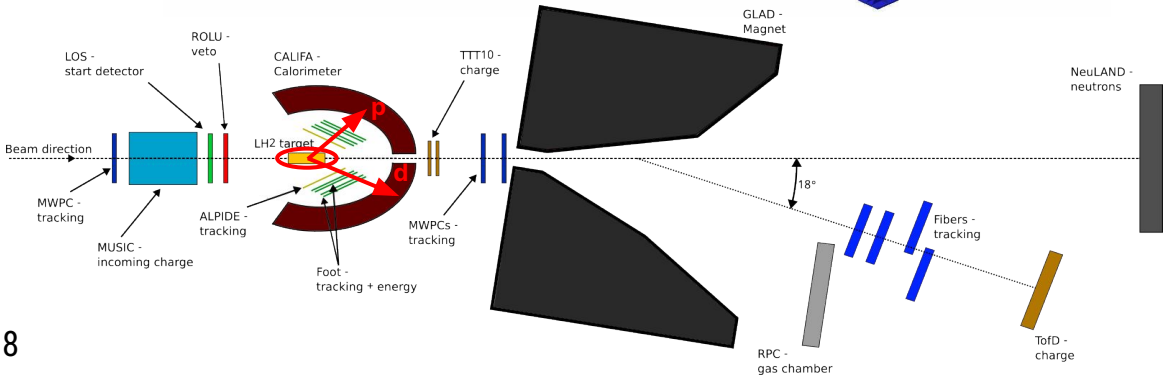

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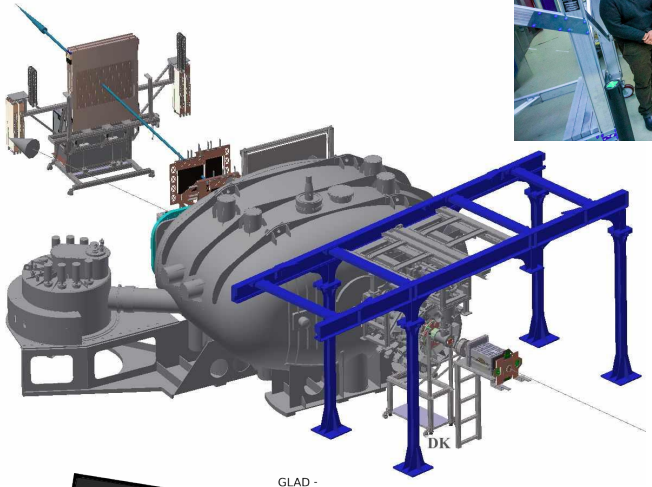

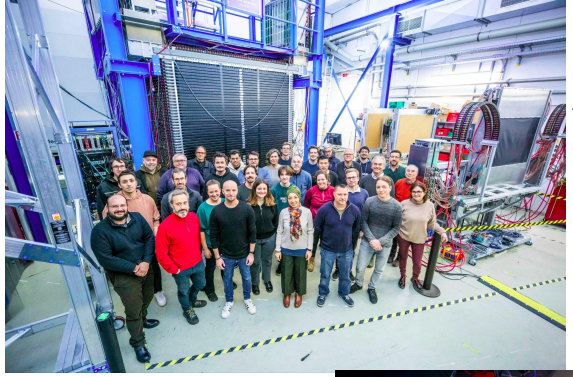

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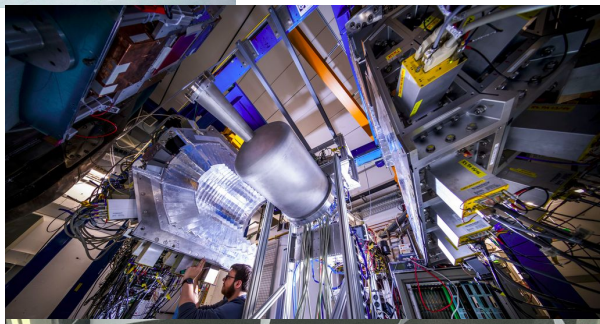
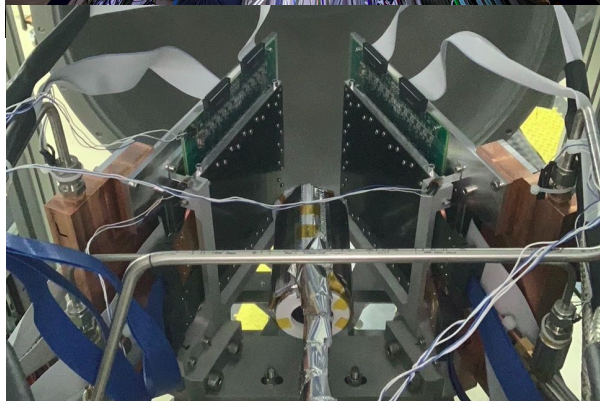
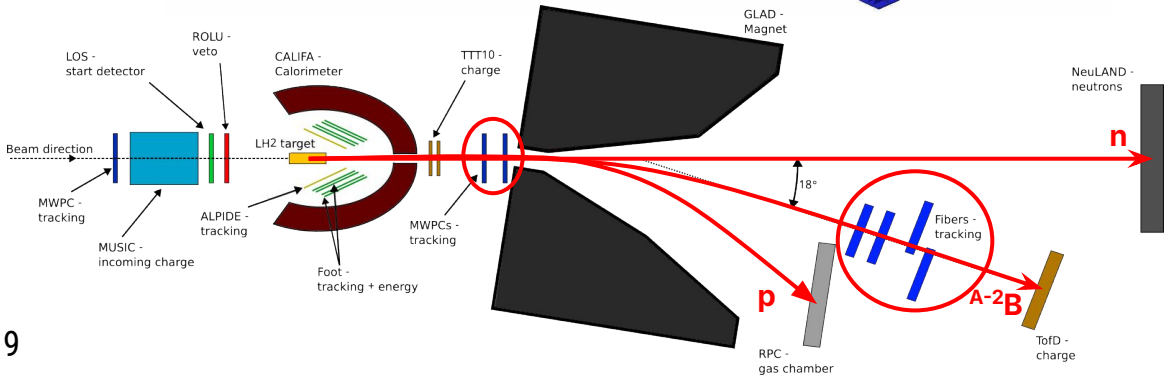
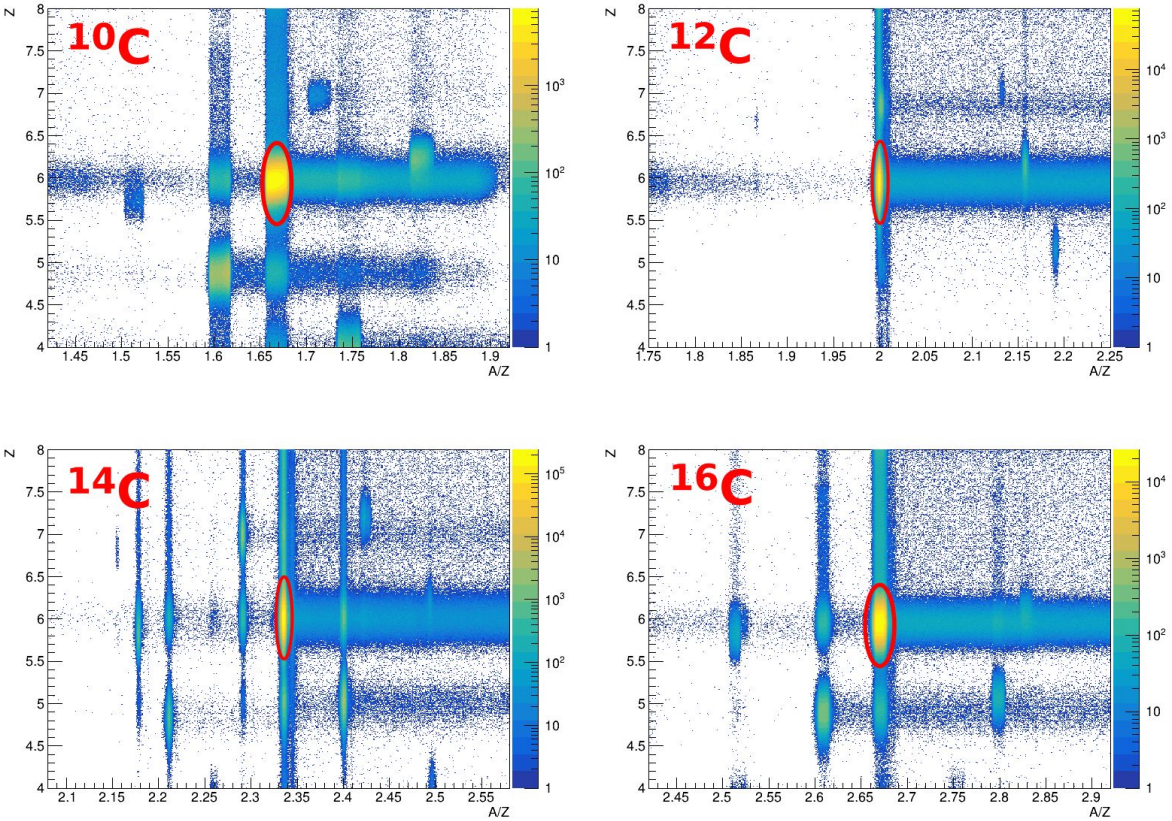




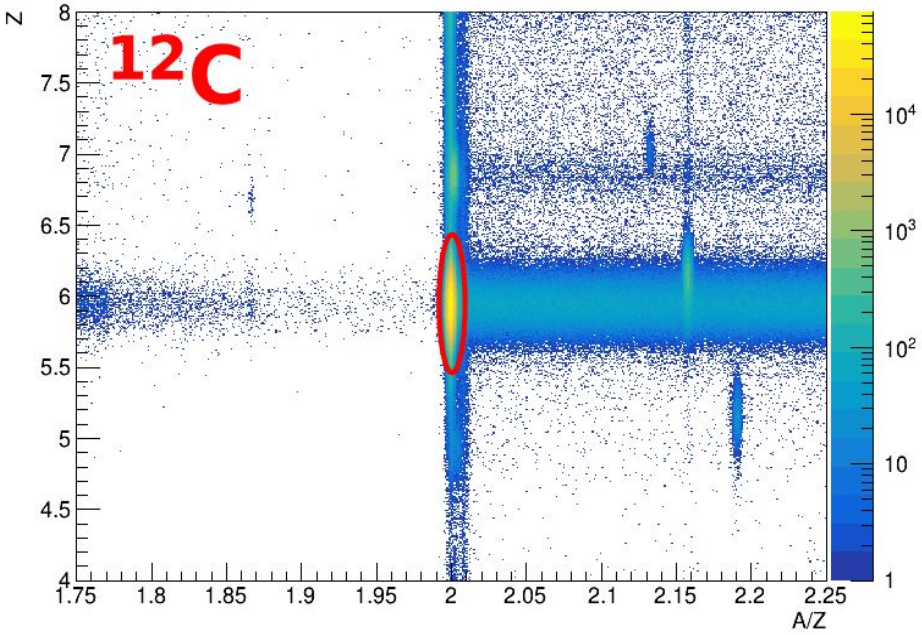


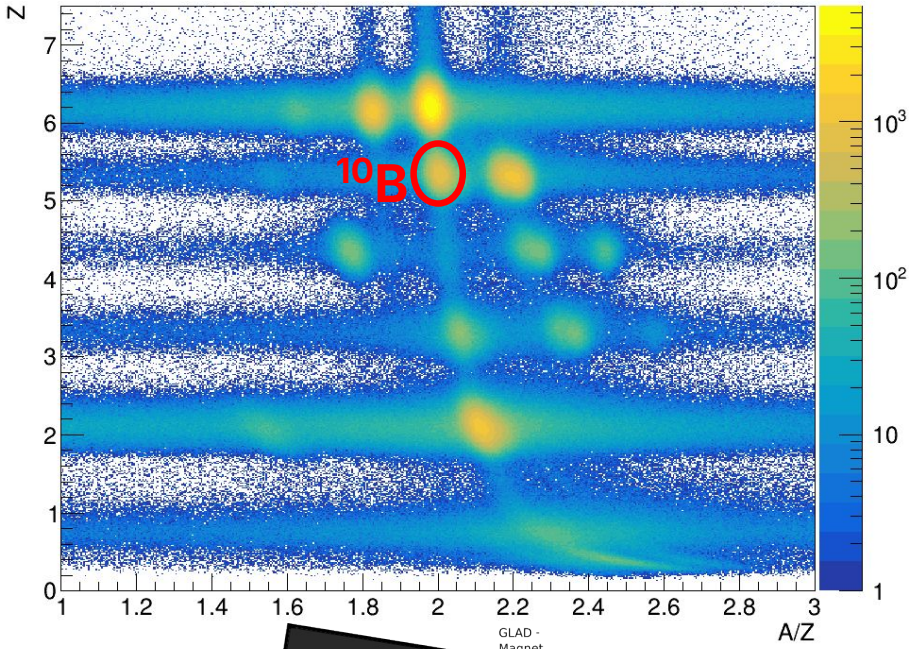
Incoming PID

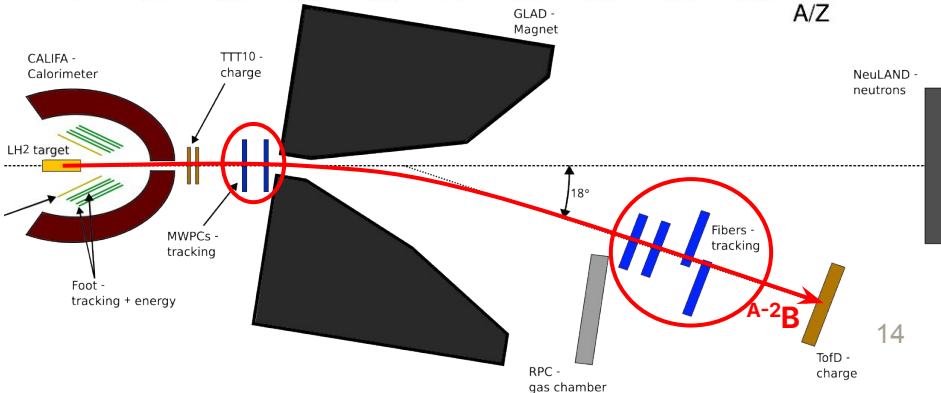


Achieved >95% purity for all beam settings.

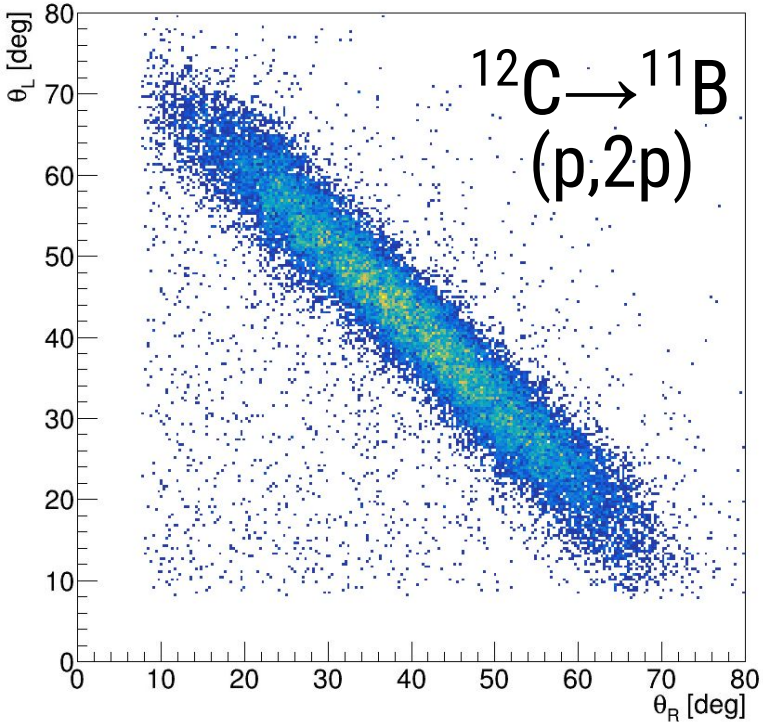
Incoming + Outgoing PID

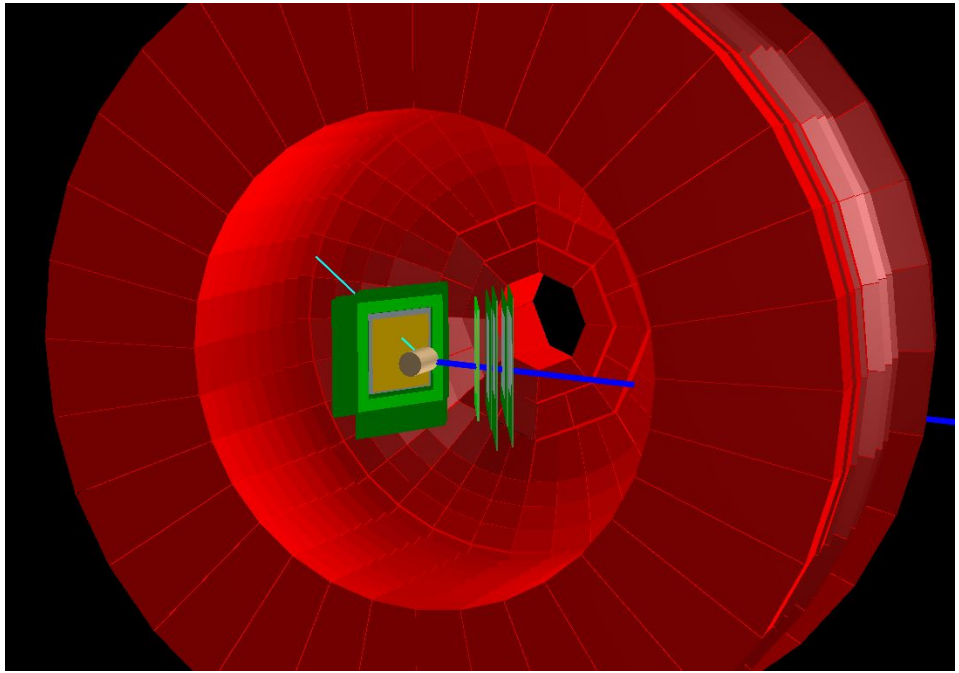






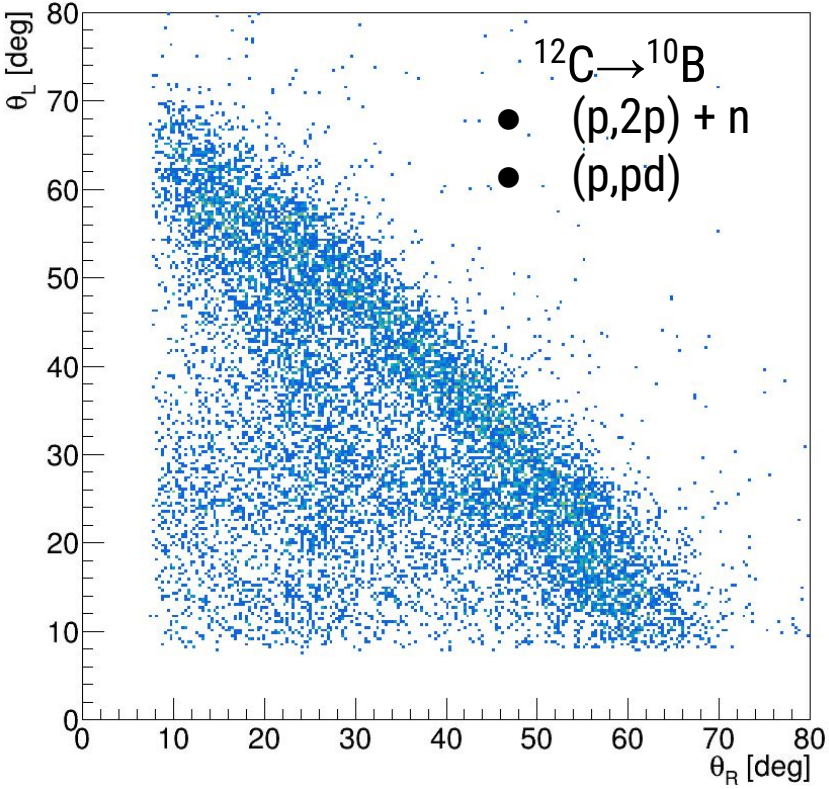
CALIFA kinematics

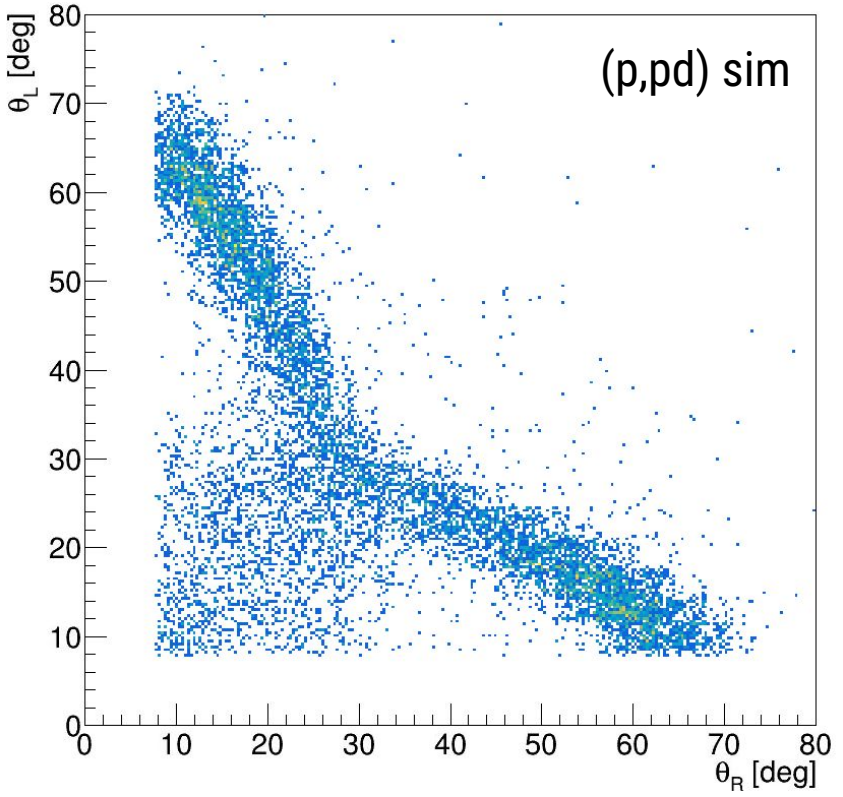




Two particles detected, one in each side of CALIFA.
Crystal Id → angular information

CALIFA kinematics

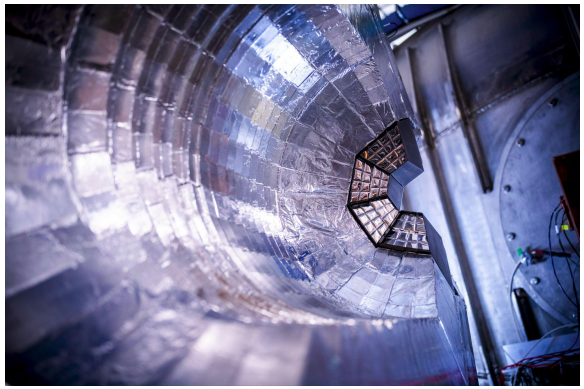


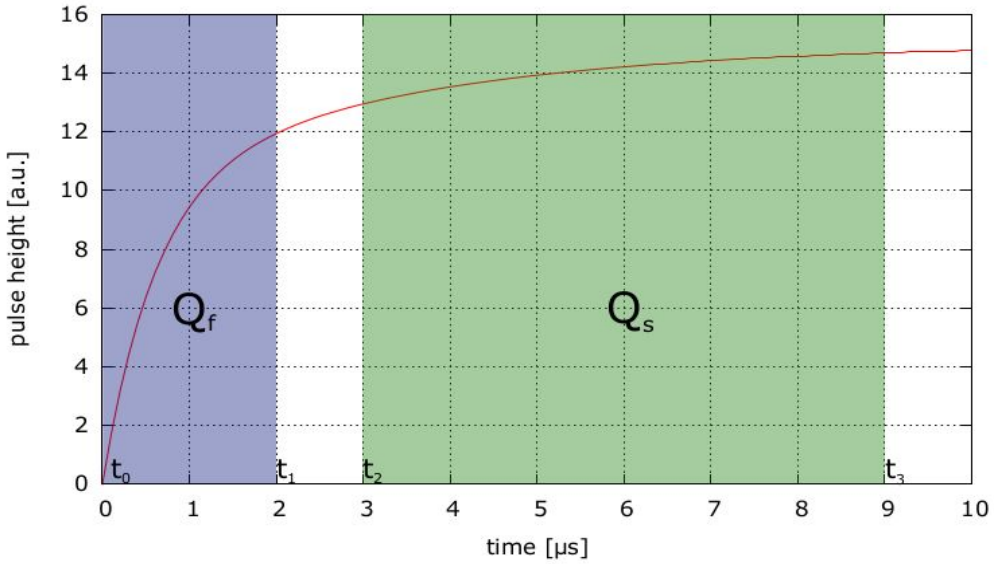


CALIFA QPID

Pulse signal from incident particle integrated in two separate time windows - ‘fast’ and ‘slow’.

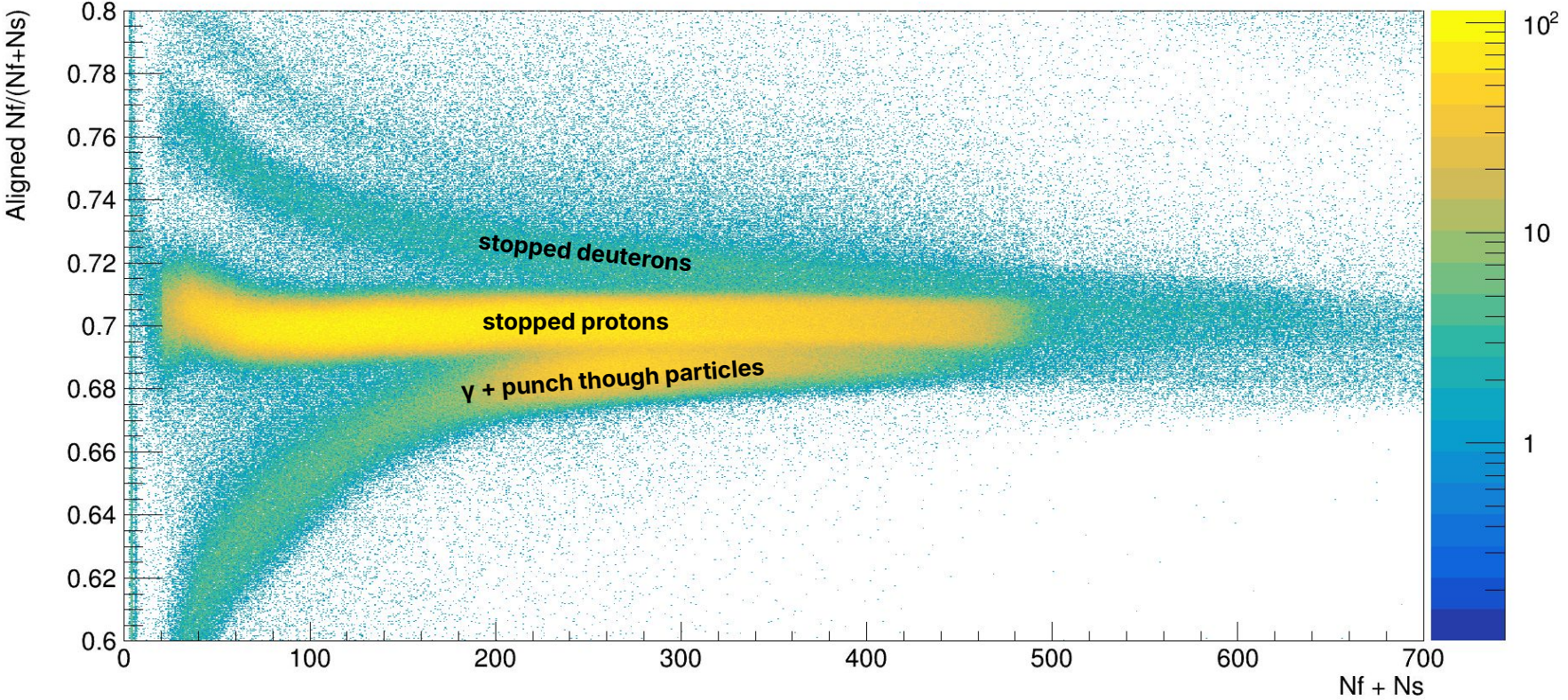
Different particles have a different fast and slow response, allowing for particle identification.





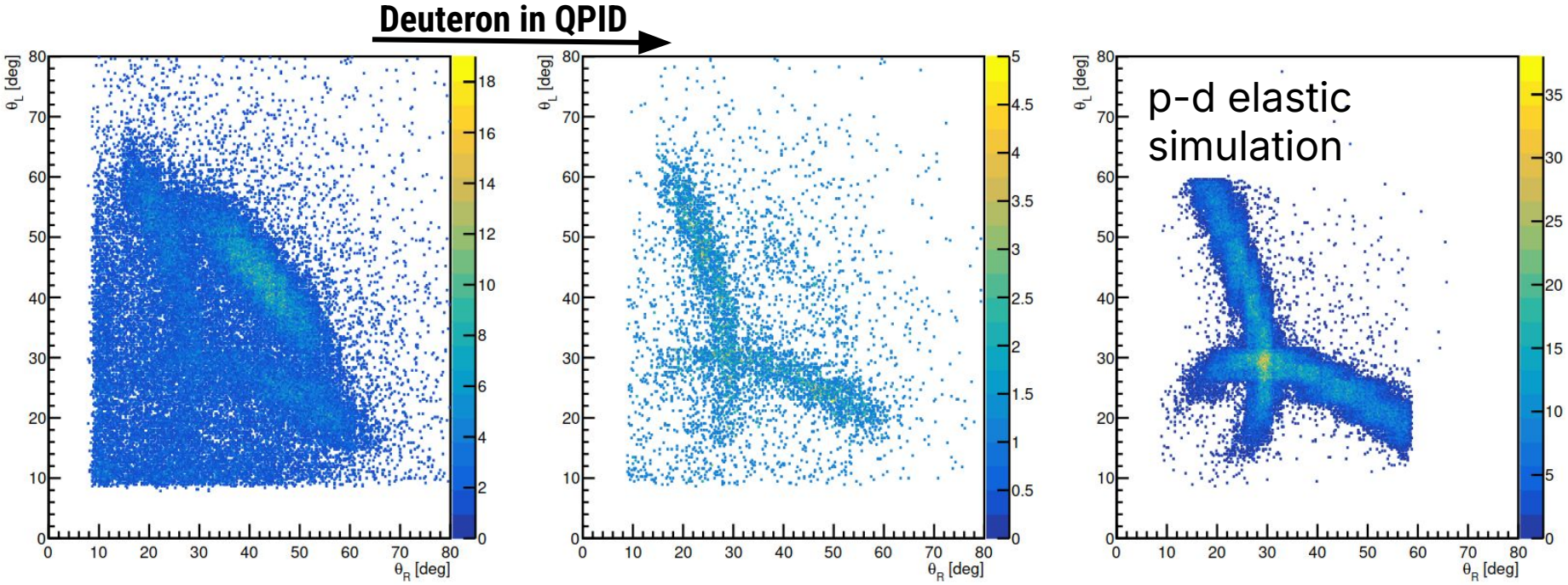
CALIFA QPID

Pulse-shape analysis of CsI(Tl) for particle identification.



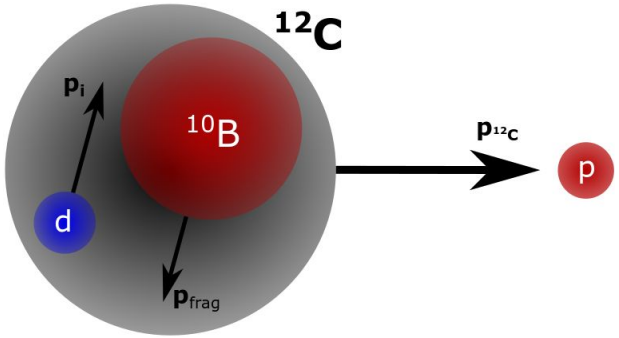
Deuteron beam

Deuteron beam prior to experiment shows the ability of CALIFA QPID to identify reactions involving a deuteron



(p,pd) QFS kinematics

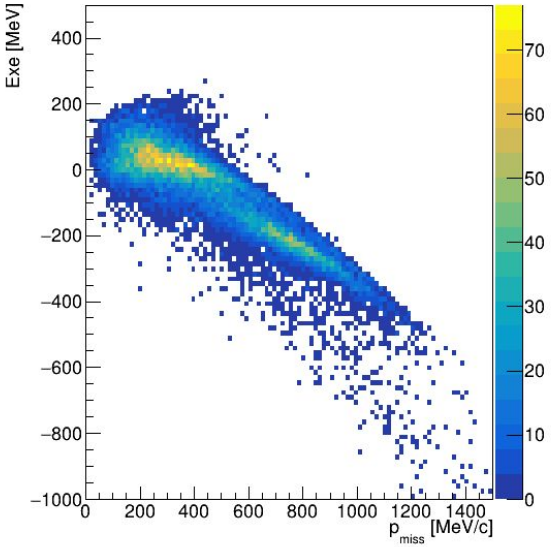
The information of a QFS reaction is carried entirely by the proton and deuteron.
QFS → fragment is a spectator

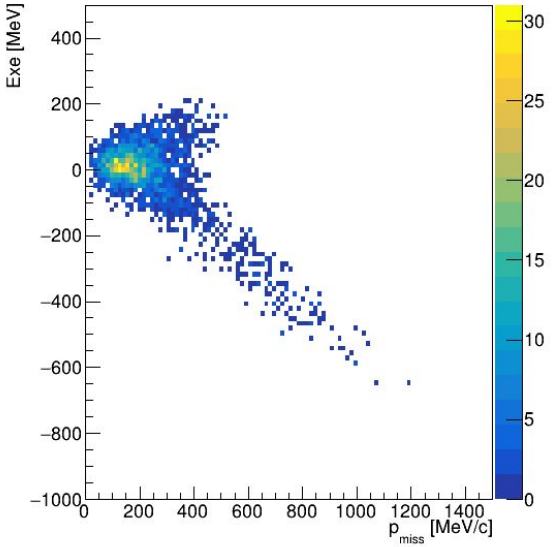


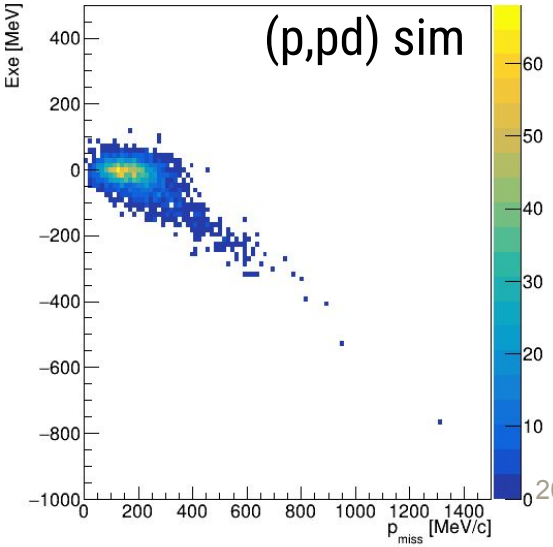
$$\mathbf{p}_{miss} = \mathbf{p}_i = \mathbf{p}_1 + \mathbf{p}_2 - \mathbf{p}_{\mathrm{tg}}$$

$$t = (p_1 - p_3)^2 c^2 = (p_4 - p_2)^2 c^2$$

High momentum transfer

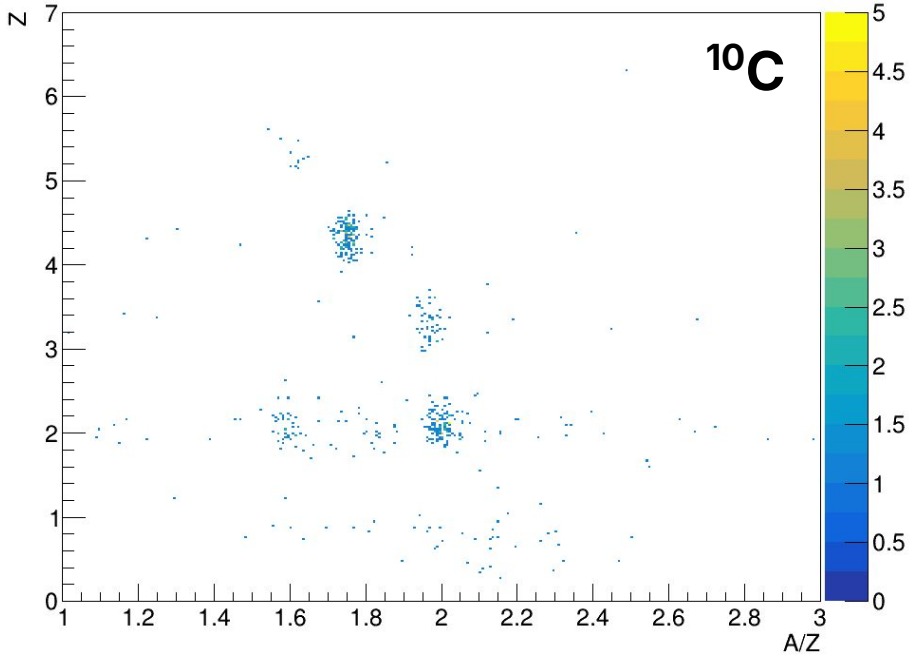


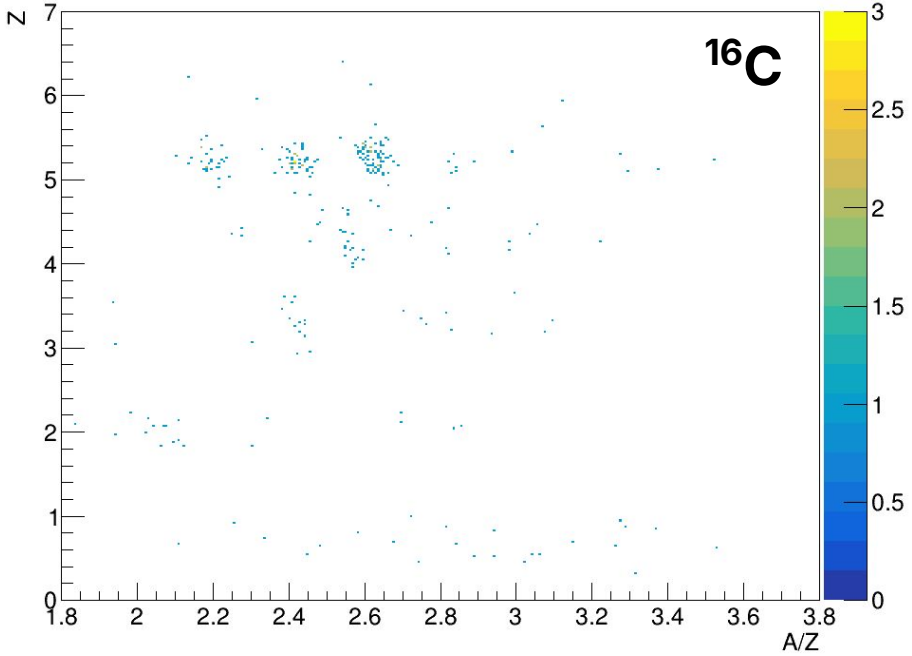




(p,pd) Fragment PID

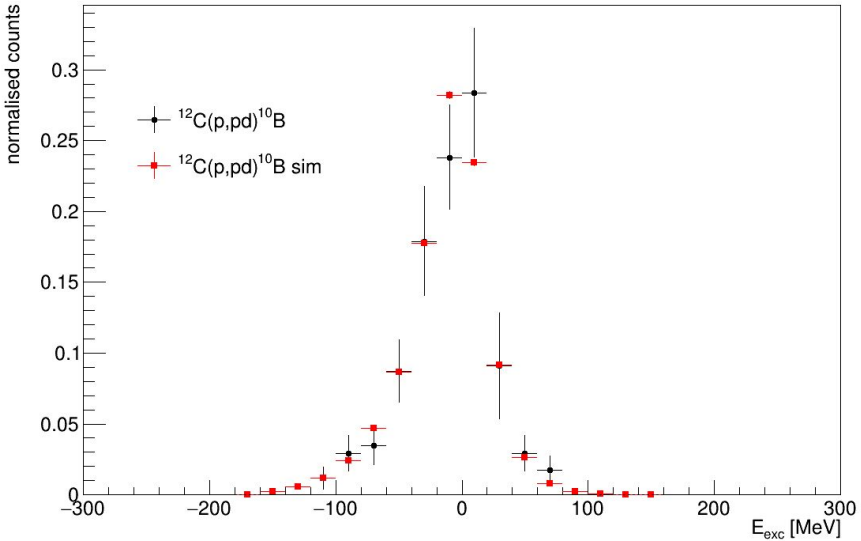
(p,pd) strength scattered across multiple channels →
Fragment condition would bias result



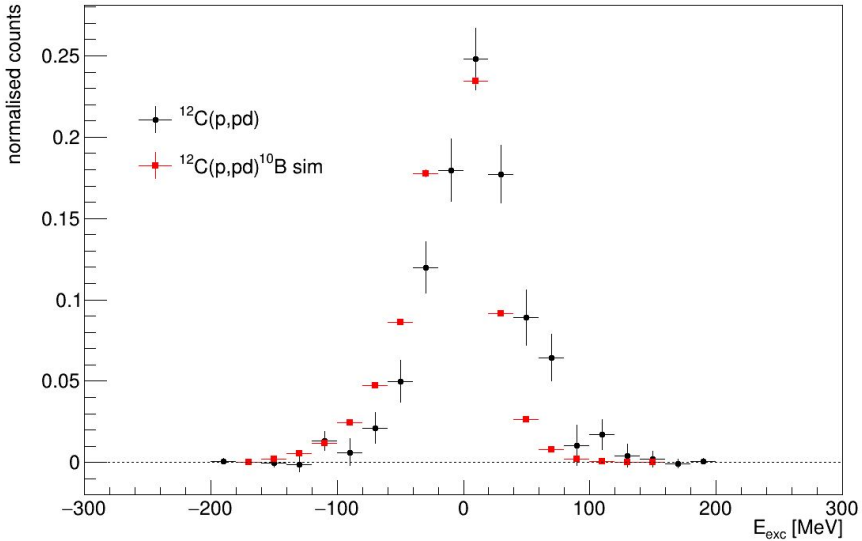


(p,pd) QFS kinematics

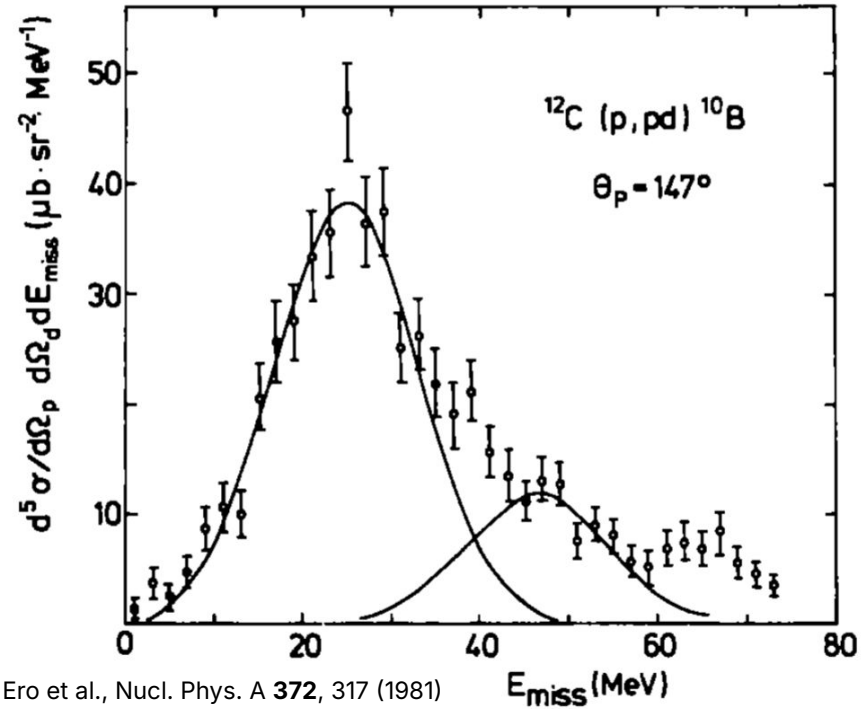
$^{12}C(p,pd)^{10}B$ excitation energy agrees well with simulation



No fragment selection → higher excitations → unbound states/FSI?

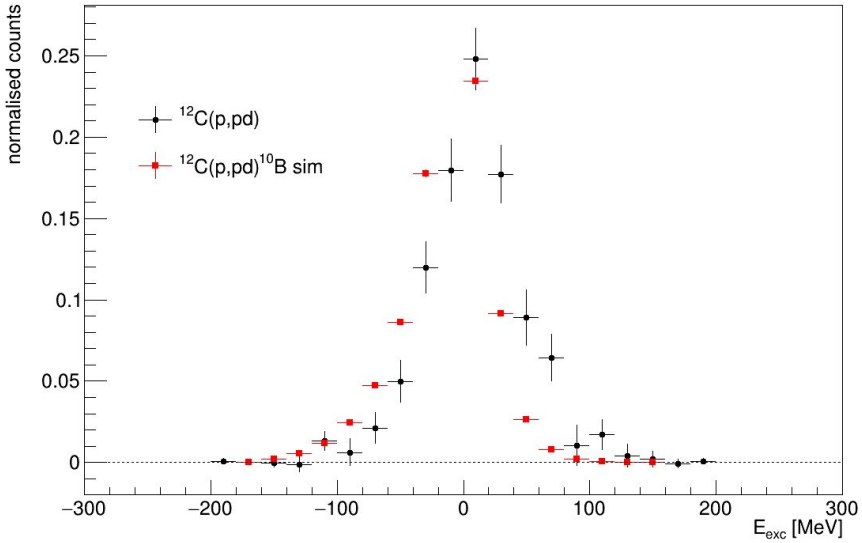


(p,pd) QFS kinematics



J. Ero et al., Nucl. Phys. A **372**, 317 (1981)

Previous ^{12}C(p,pd) experiment also suggested higher excitations → QFS of deuterons in the s shell?

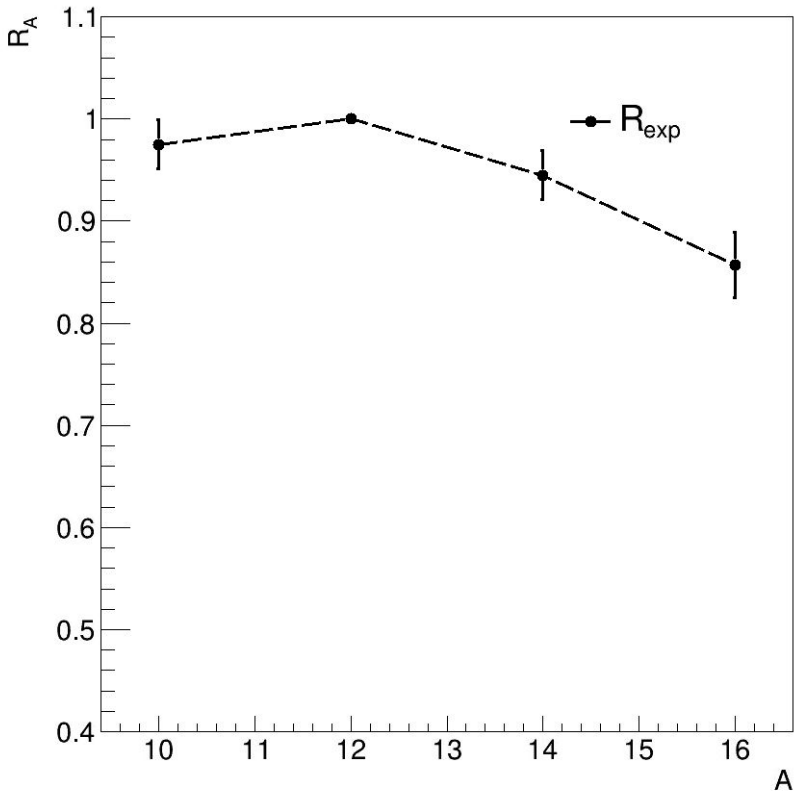


Results

^{A}C(p,pd) cross section relative to ^{12}C:

$$R_A = \frac{N_{(p,pd),^A C}}{N_{(p,pd),^{12}C}}$$

- (p,pd) cross section peaks at ^{12}C.
- Cross section falls gradually away from N=Z.



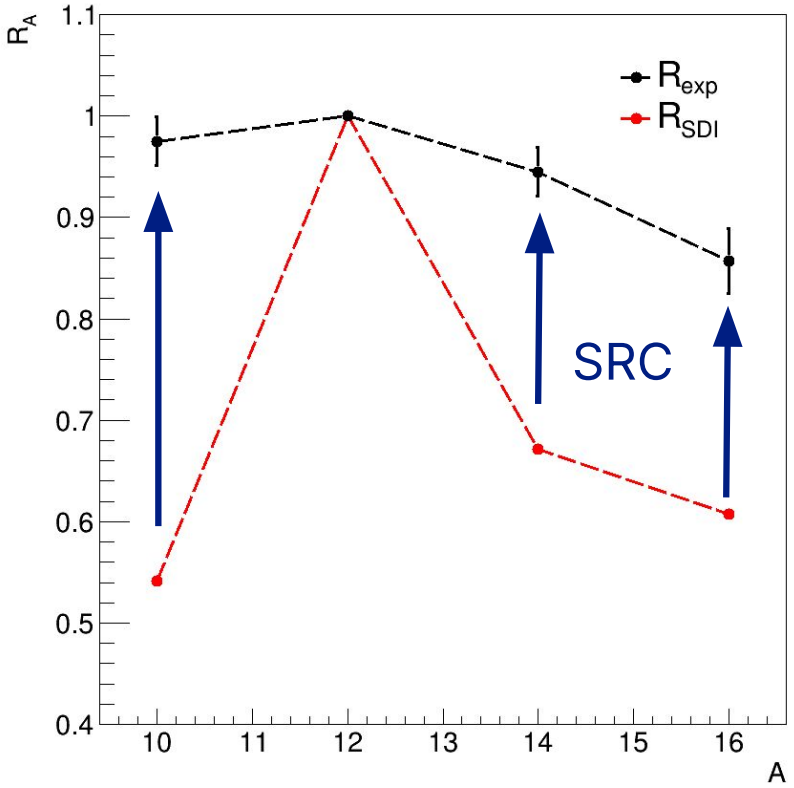
Results

^{A}C(p,pd) cross section relative to ^{12}C:

$$R_A = \frac{N_{(p,pd),^A C}}{N_{(p,pd),^{12}C}}$$

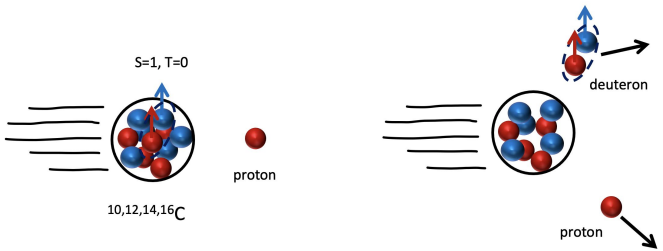
Theoretical comparison: “Mean Field” quasi-deuteron content using a Hamiltonian with a surface delta interaction (SDI)
Projection onto $^{3}S_{1}$ channel

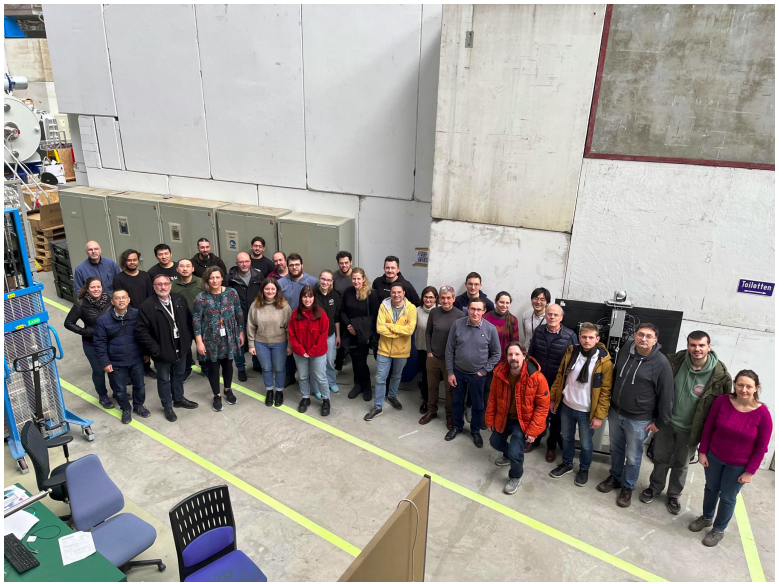
Experimental ratio much higher than mean field prediction → SRCs strongly amplify quasi deuteron content in asymmetric nuclei.



Conclusion

- Identified inclusive (p,pd) events at high momentum transfer using CALIFA QPID capabilities for stopped deuterons.
    - Results indicate SRC signature through increased quasi-deuteron content.
- This opens the way for new experiments at R3B with high resolution using the future ALPIDE Target Recoil Tracker device.





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