



Probing nucleon-nucleon correlations in atomic nuclei via (p,pd) QFS reactions

Matthew Whitehead¹ for the R³B Collaboration

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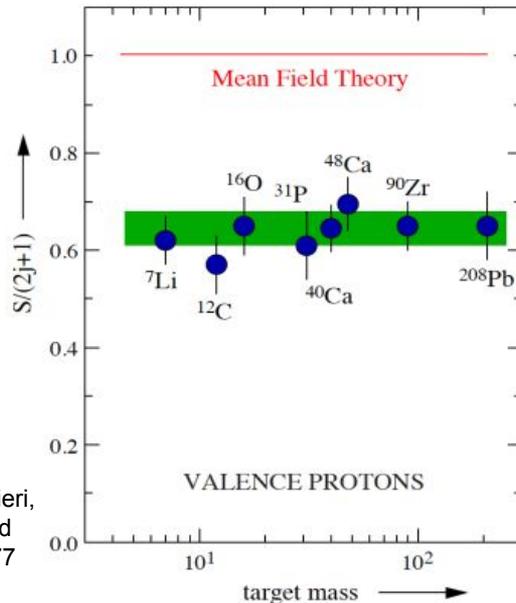
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Nucleon-Nucleon Correlations



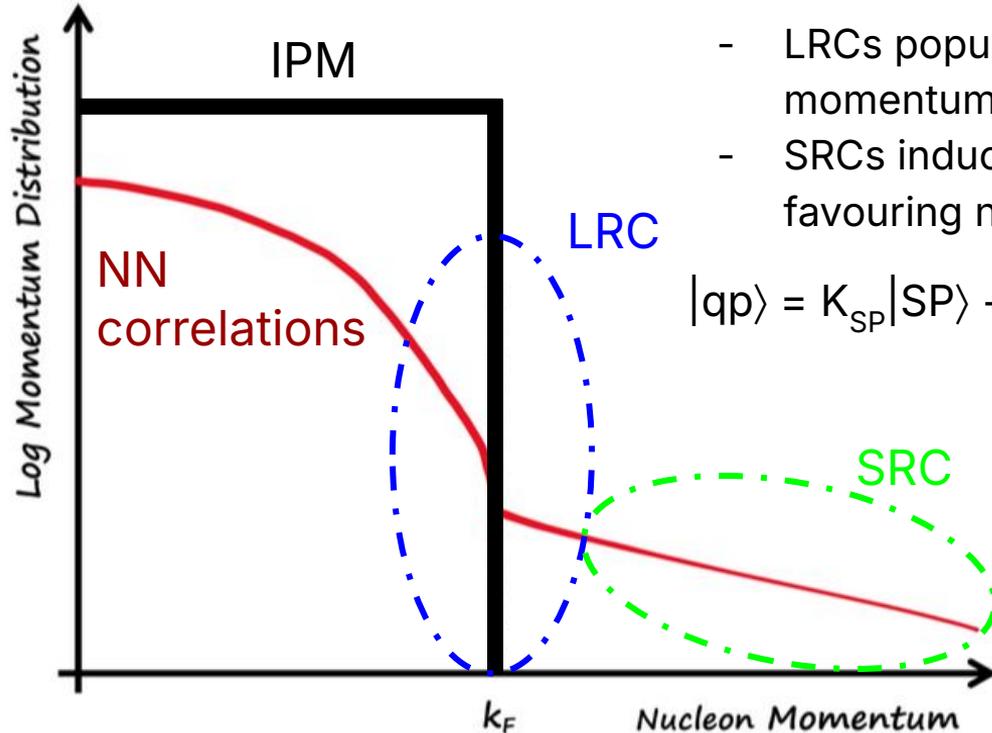
- The independent particle model describes many properties of the atomic nucleus very well.
- However the IPM does not account for all interactions between the nucleons.
- This has been observed experimentally through the reduction in spectroscopic factors.



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

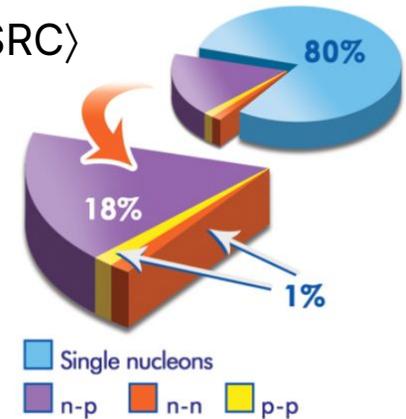
Nucleon-Nucleon Correlations

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.

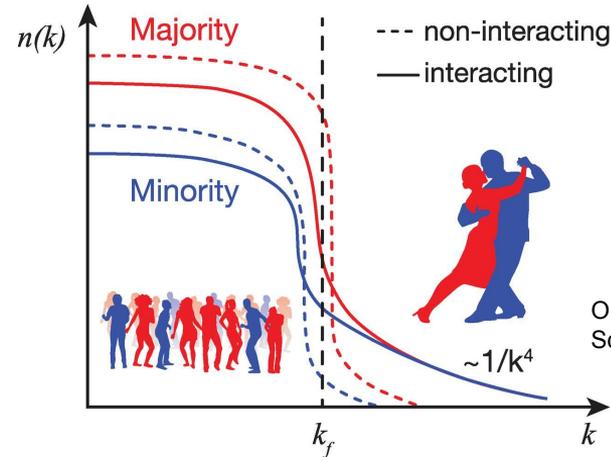
$$|qp\rangle = K_{SP}|SP\rangle + K_{LRC}|LRC\rangle + K_{SRC}|SRC\rangle$$



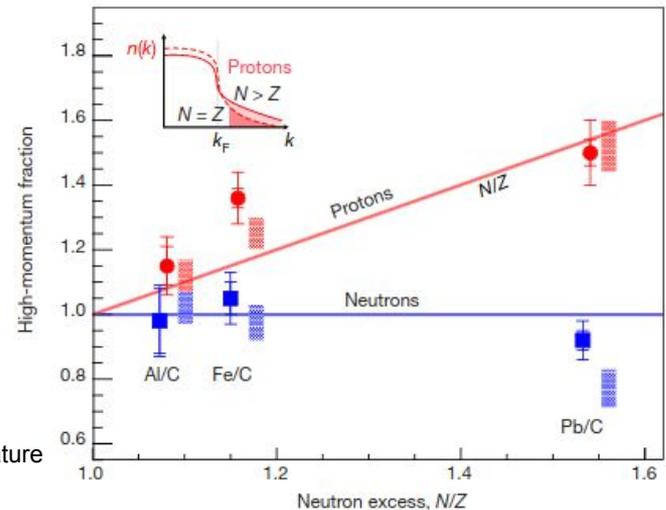
SRCs in Experiments

- 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?



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



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.

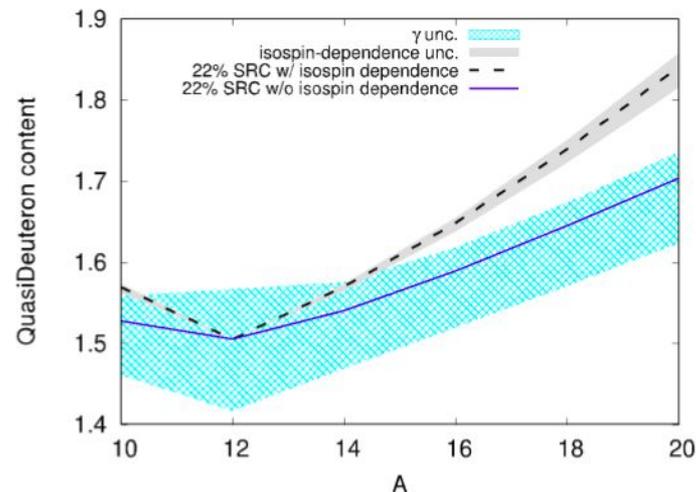
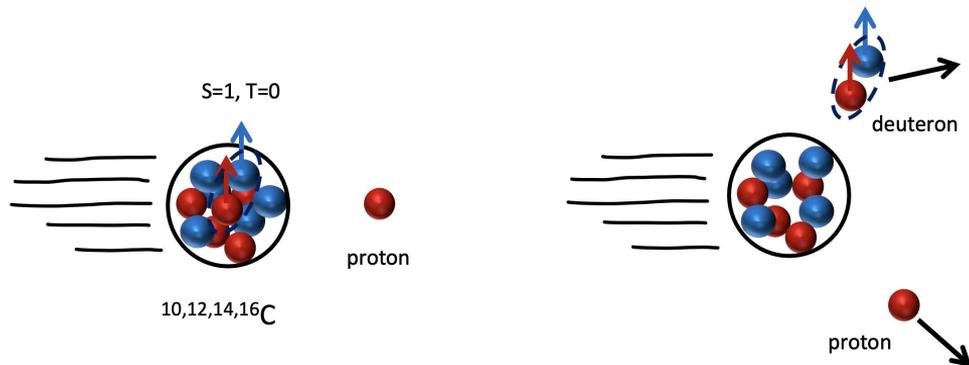
A "bare" nucleon in the presence of the SRC components of the NN interaction becomes "dressed" in a quasi-deuteron cloud, about 20% of the time with an **isospin dependence**.

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

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

Aims:

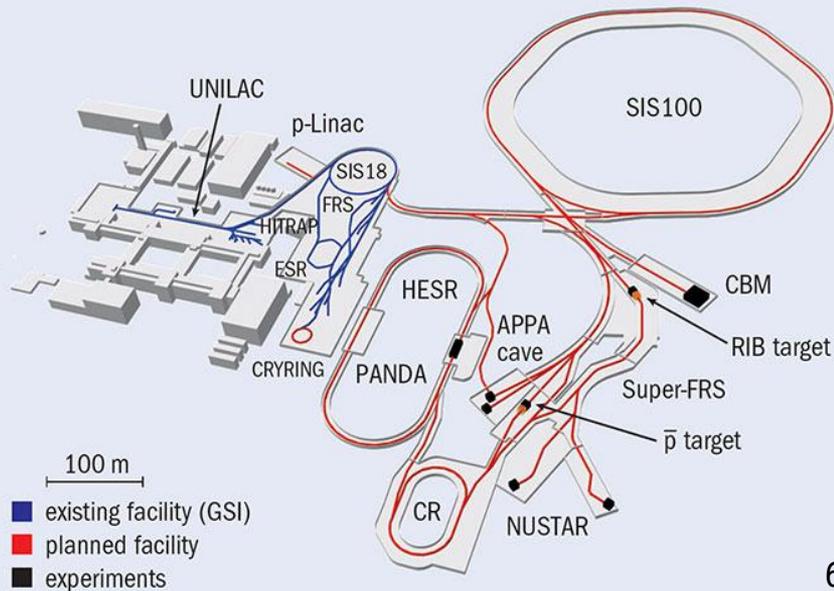
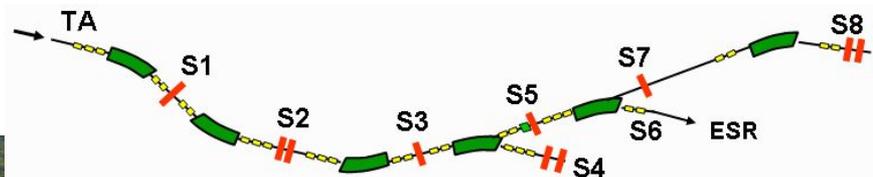
- Investigate the SRC dependence on isospin.
- Measure (p,pd) Quasi-Free Scattering cross sections of $^{10,14,16}\text{C}$ relative to ^{12}C at 400MeV/u.



R3B @ GSI-FAIR

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

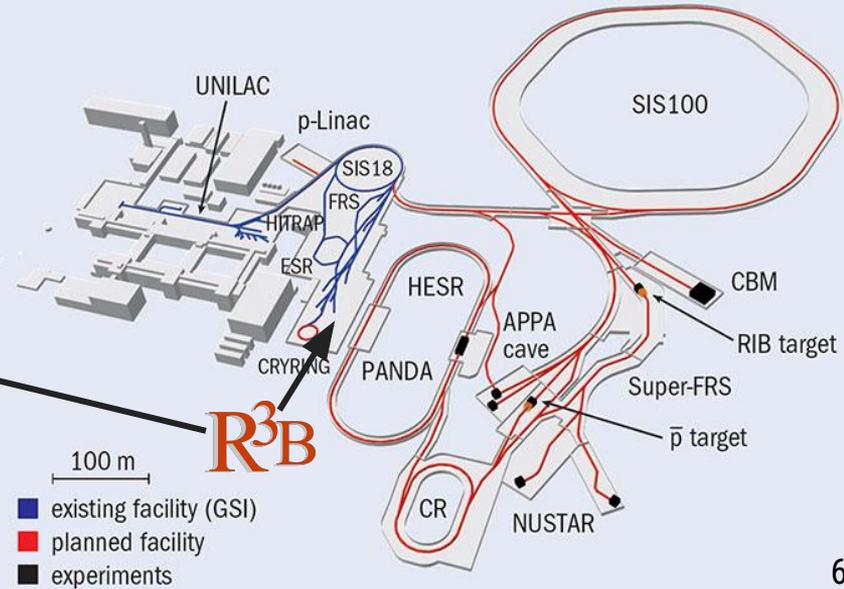
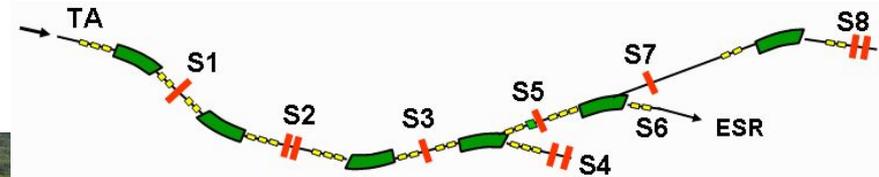
R³B



R3B @ GSI-FAIR

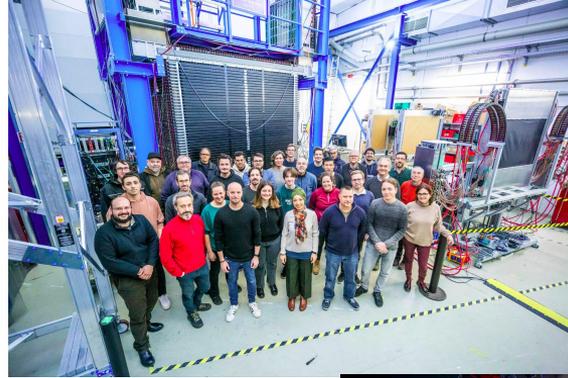
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R³B

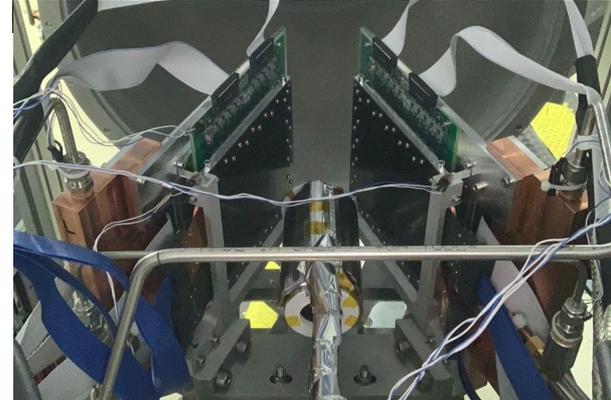
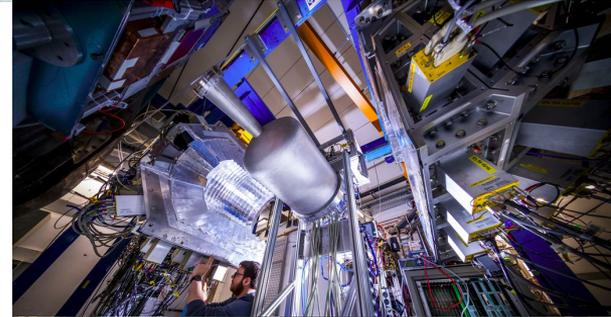
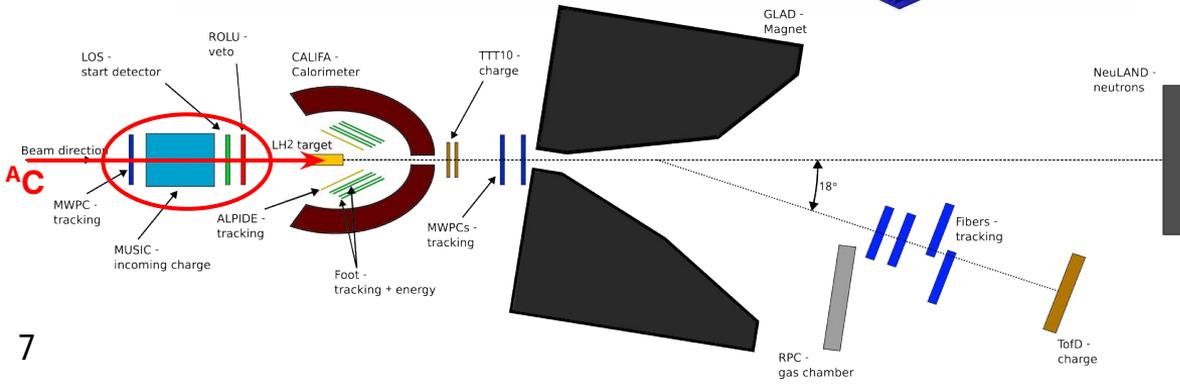
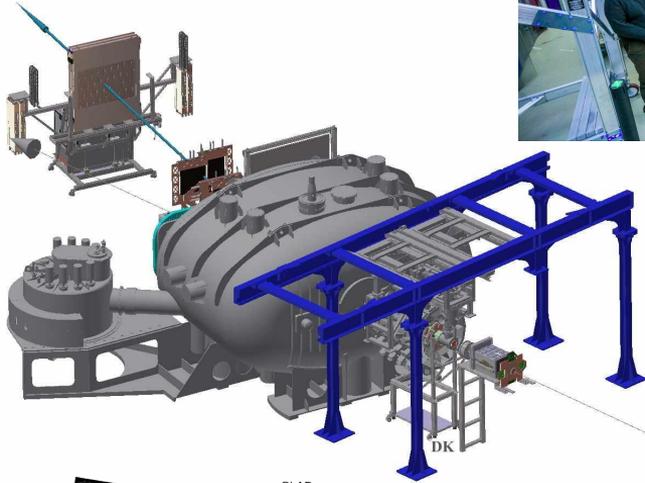
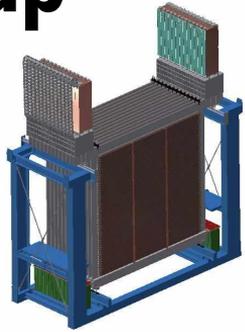


Setup

R³B



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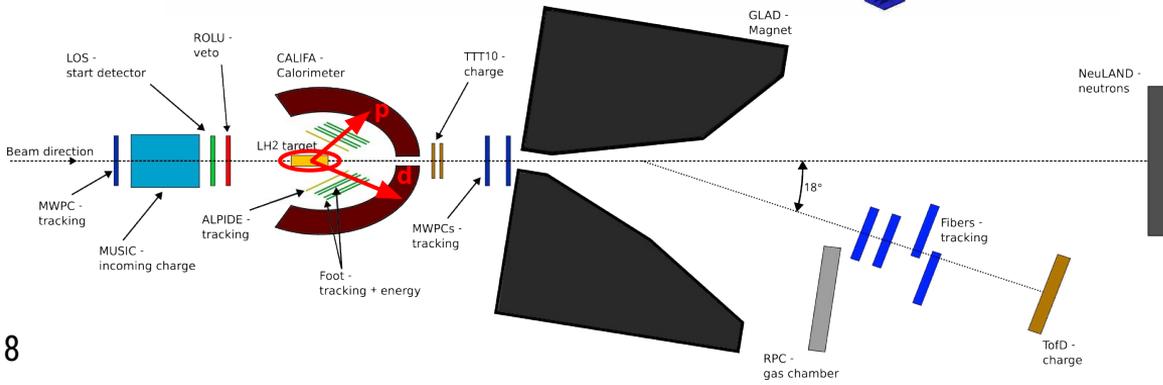
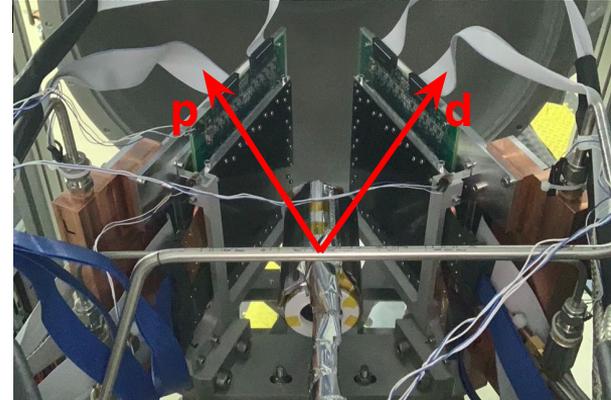
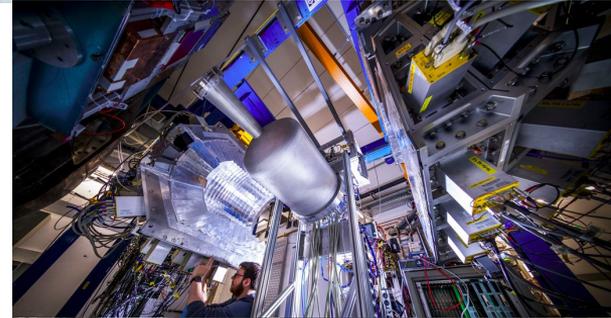
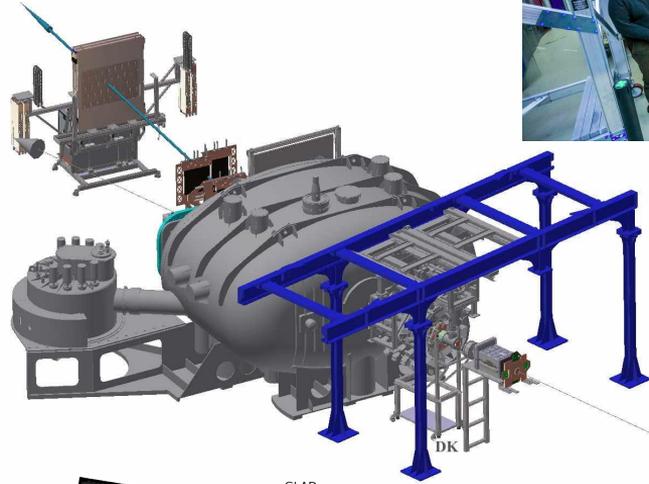
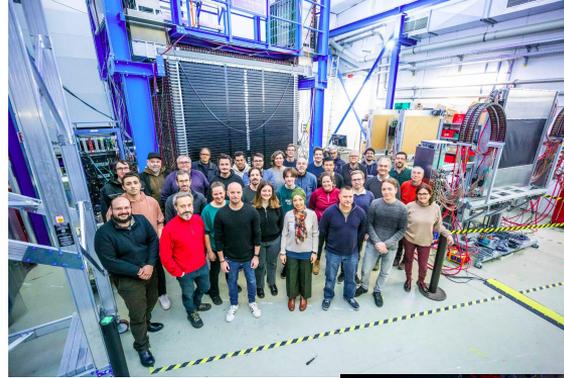


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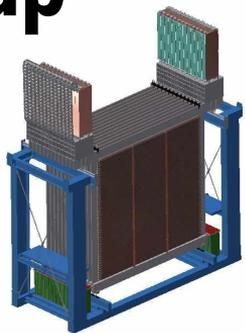
R³B



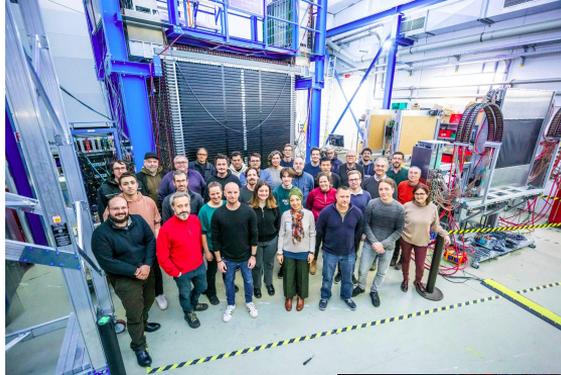
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Setup

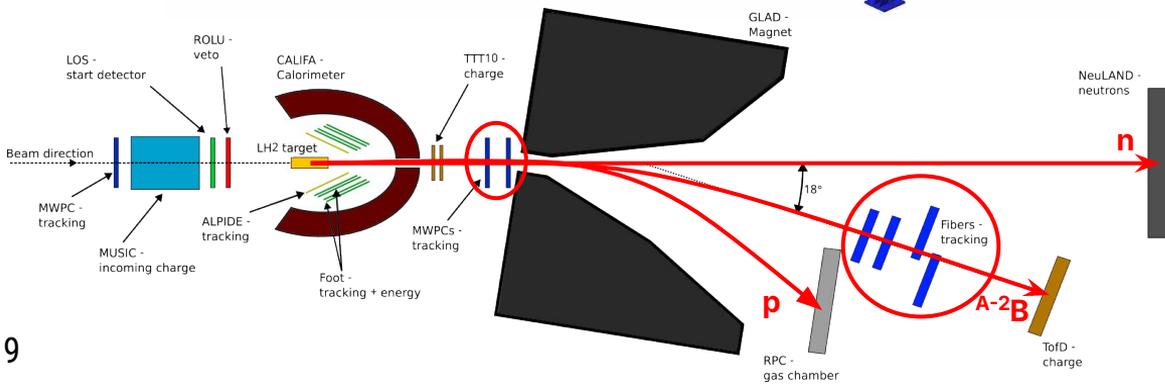
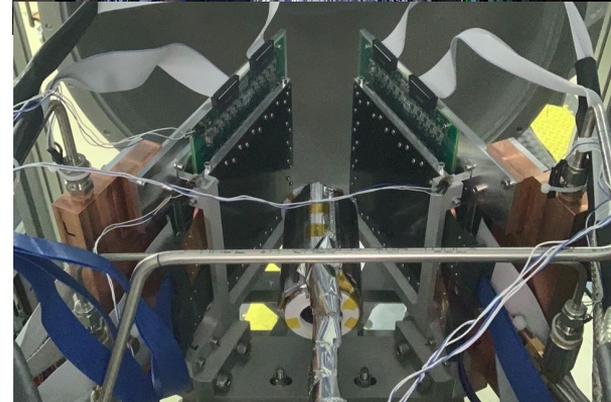
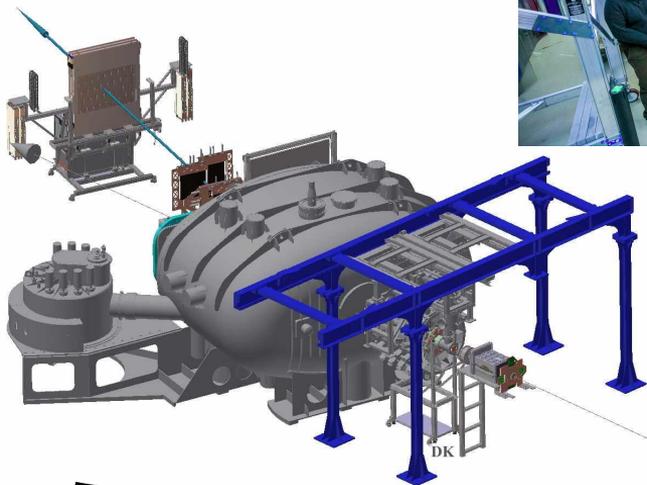


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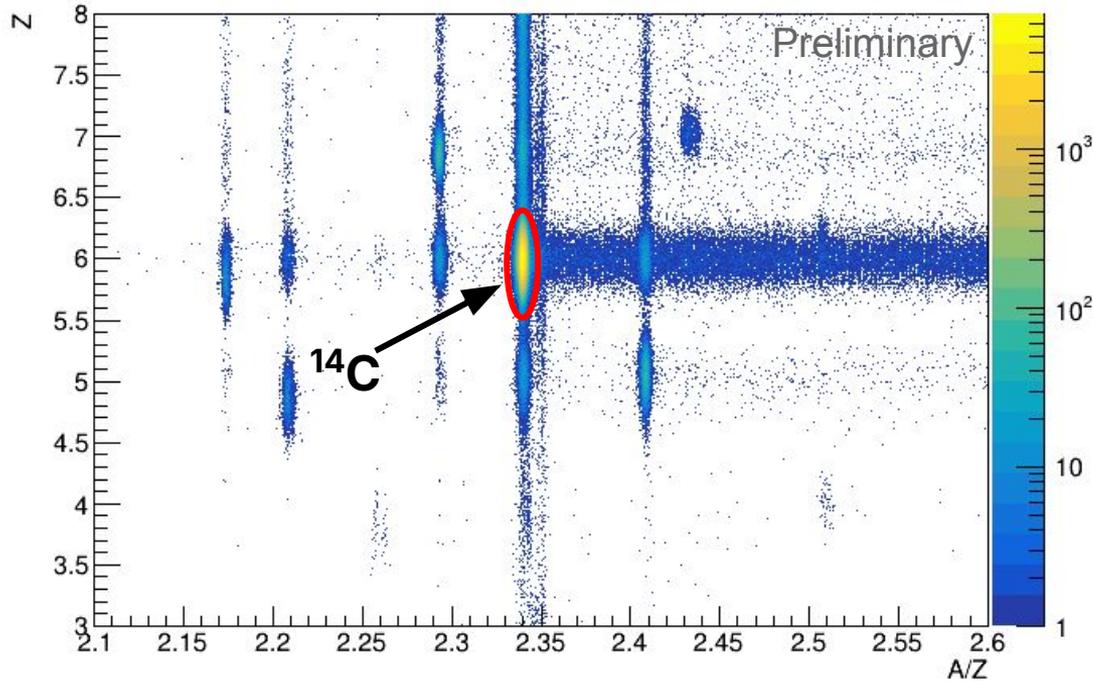
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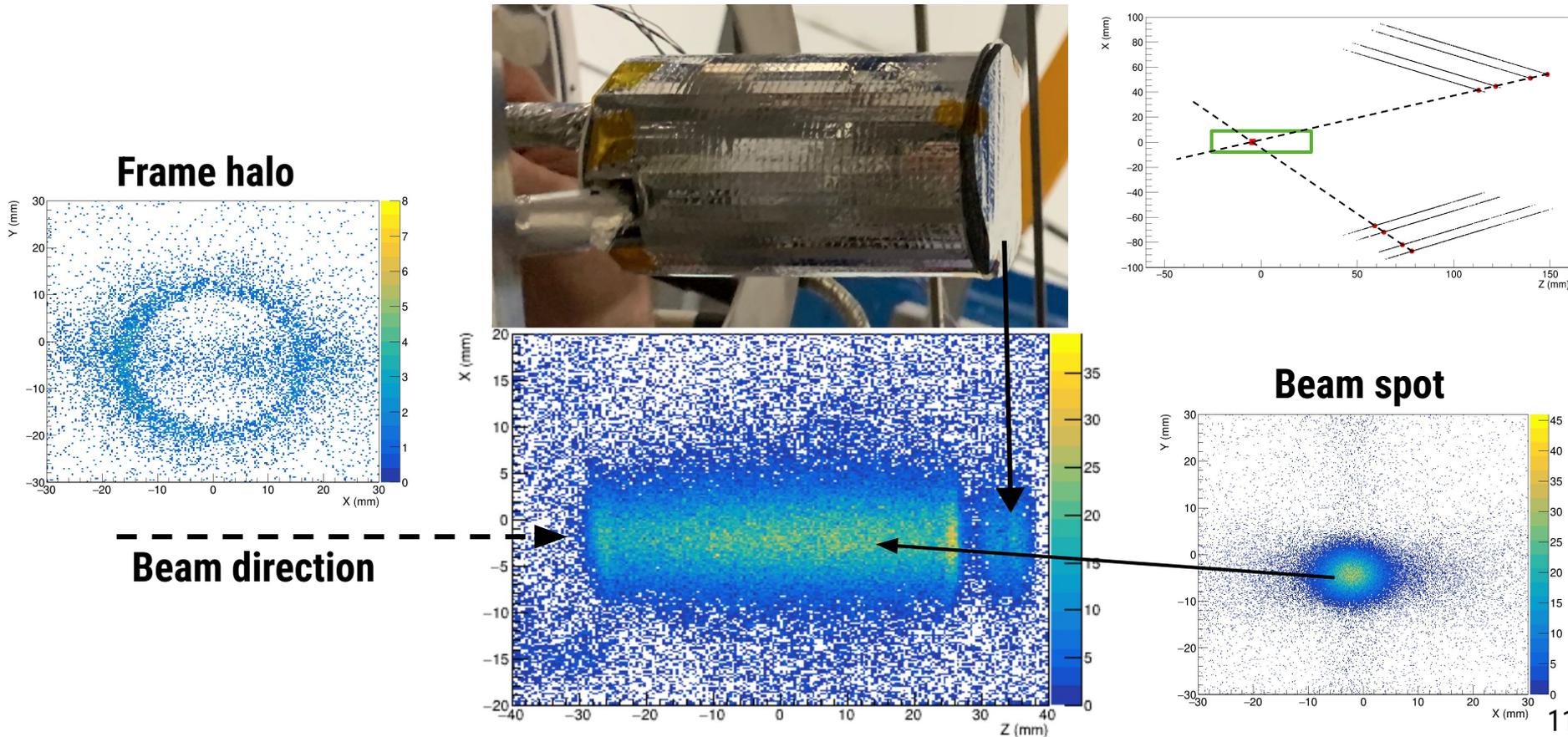
Incoming PID

^{18}O Primary - ^{14}C Secondary

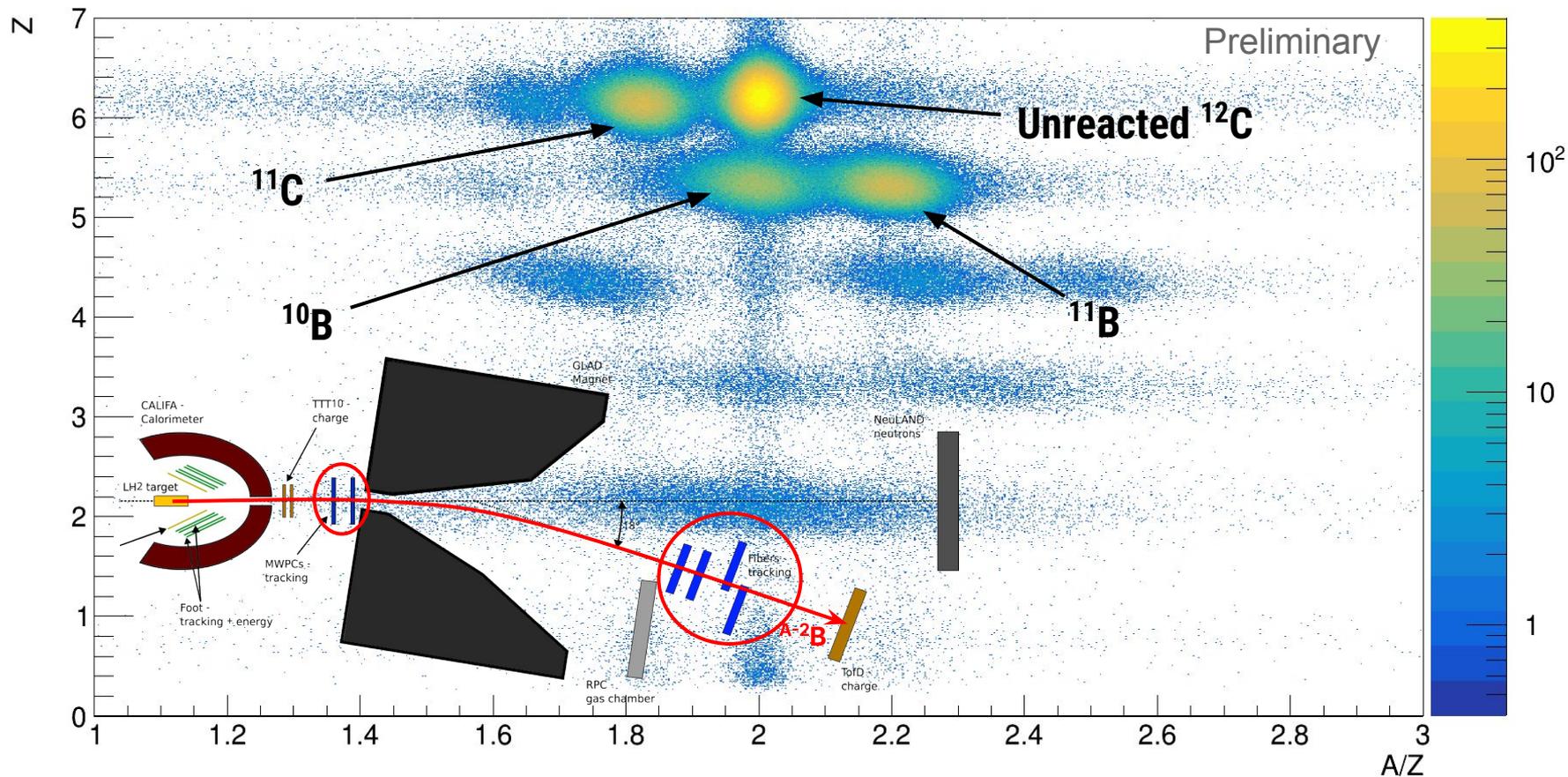


Isotope	Abundance
^{14}C	96.33%
^{12}B	1.64%
^{16}B	1.31%
^{11}B	0.20%
^{17}N	0.19%
^{13}C	0.18%
^{15}C	0.13%
^9Be	<0.01%

Vertex reconstruction

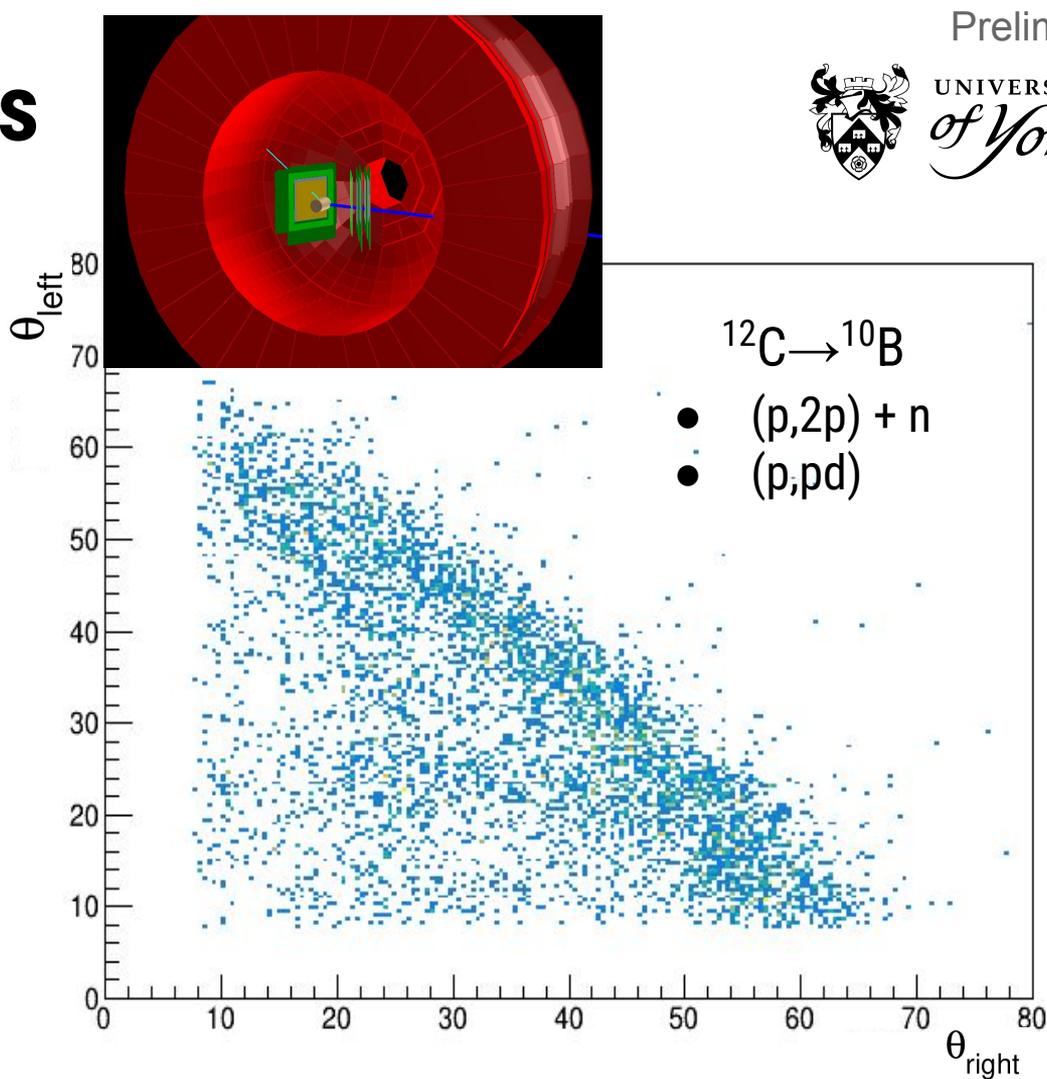
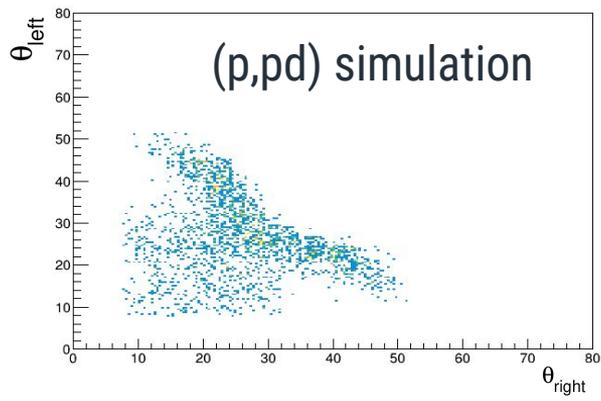
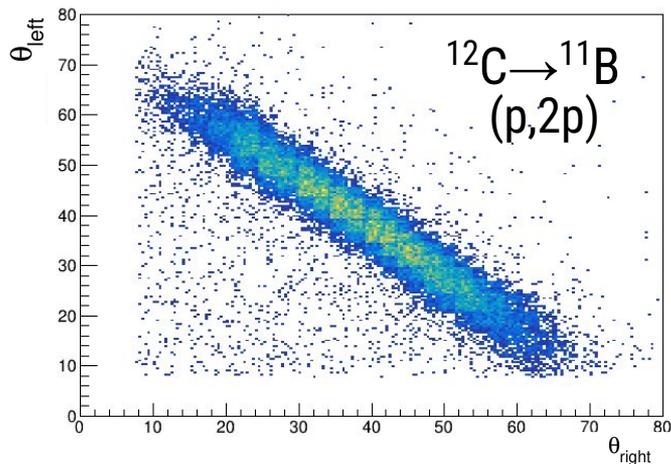


Fragment PID - ^{12}C Incoming



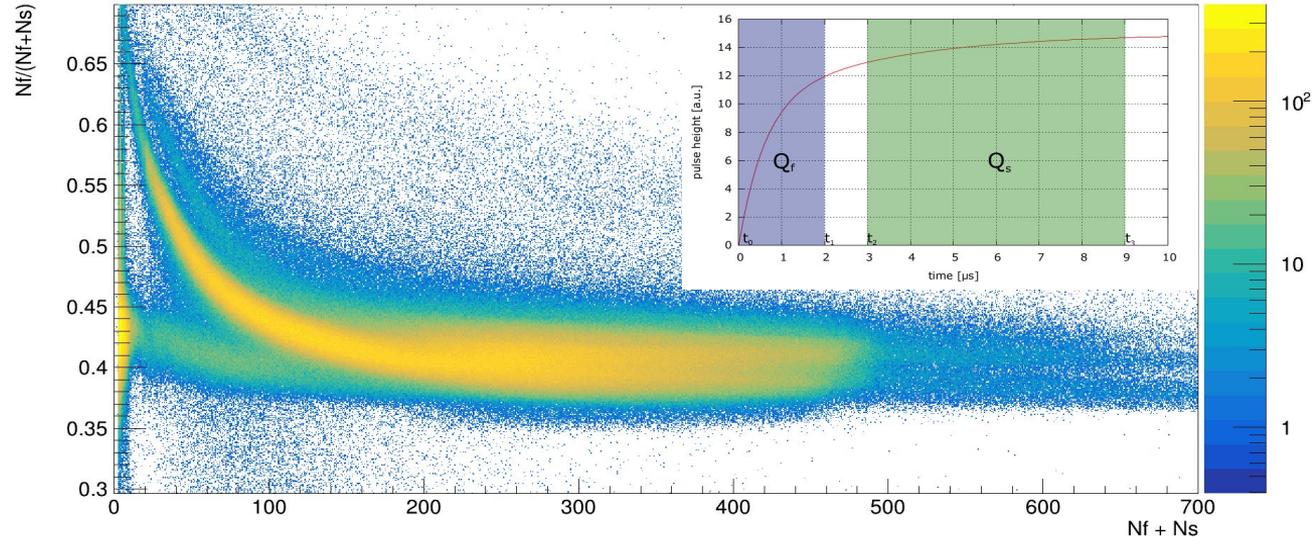


CALIFA kinematics



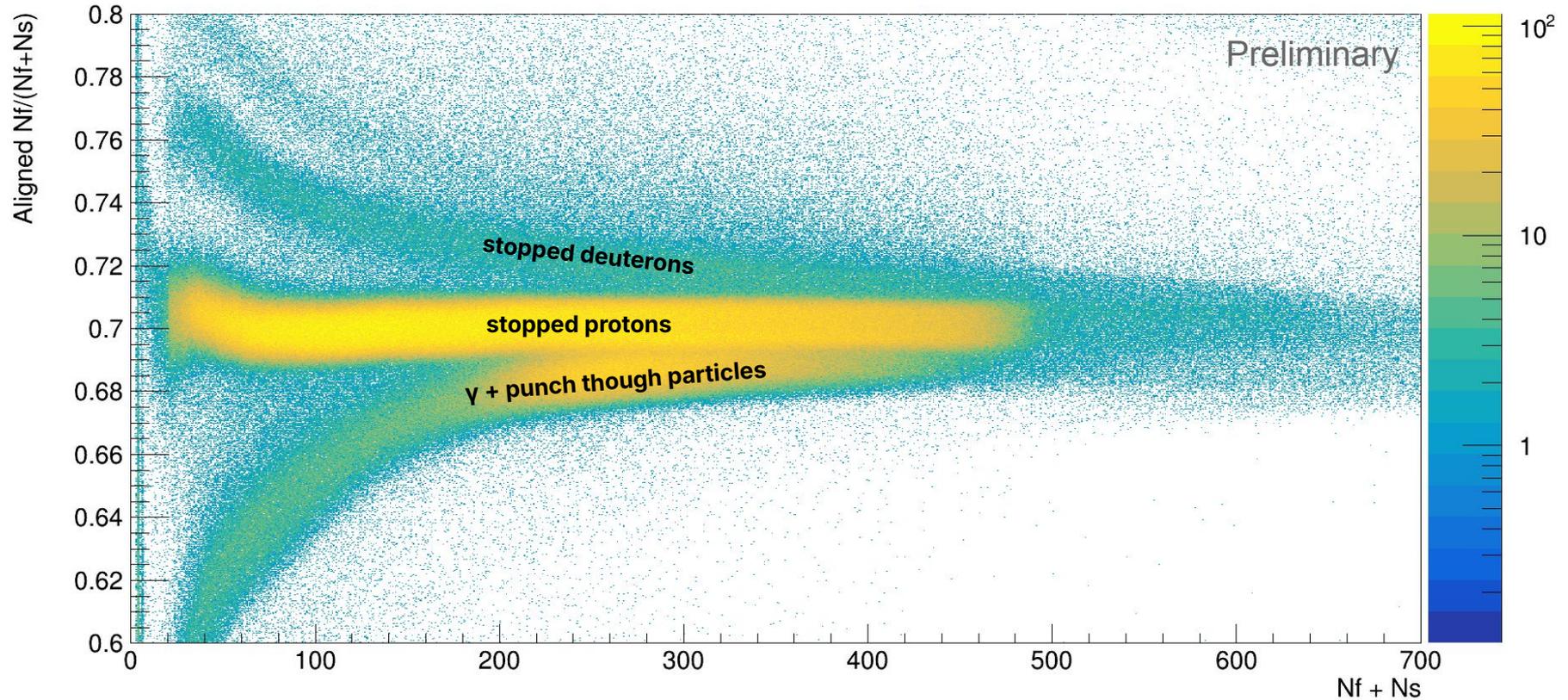
CALIFA QPID

- CsI(Tl) crystals have two scintillation decay components ($\tau_f \sim 900\text{ns}$, $\tau_s \sim 3.3\mu\text{s}$).
- The pulse signal is integrated over two time windows.
- The ratio of these two components is dependent on the type of incident particle.



2544 crystals with different responses - requires calibration.

CALIFA QPID

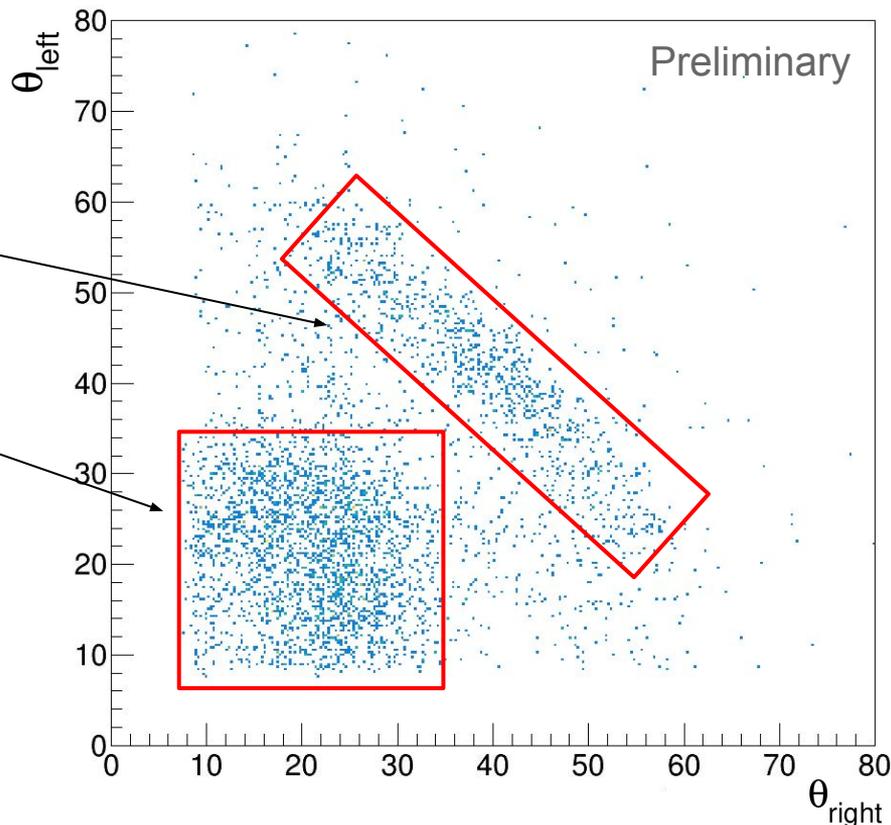
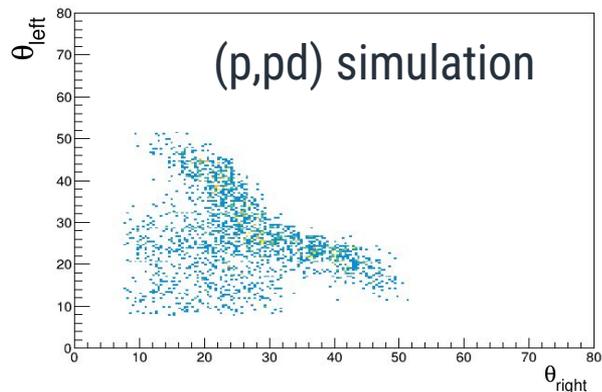


Inclusive $^A\text{C}(p, pd)$

Stopped deuteron in CALIFA QPID

- Two contributions:

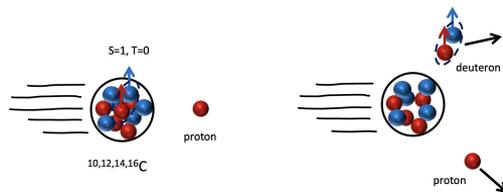
- $(p, 2p)$ where a deuteron was created inside the CALIFA crystal.
- Forward angle, high momentum transfer (p, pd) .



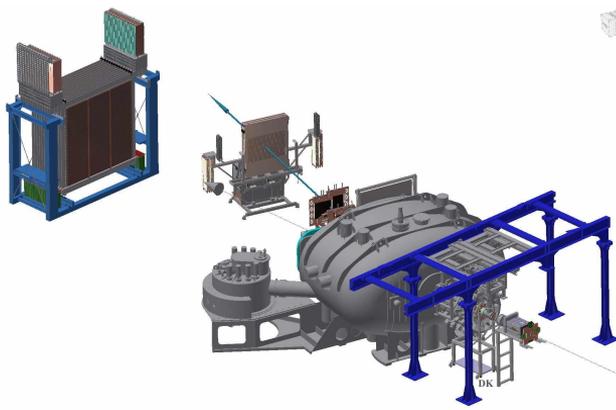
Conclusion

- Quasi-elastically knocking out deuterons to probe the number of quasi-deuterons in a nucleus and their isospin dependence:

- $^{16}\text{C}(p, pd)$
- $^{14}\text{C}(p, pd)$
- $^{12}\text{C}(p, pd)$
- $^{10}\text{C}(p, pd)$



- Analysis still ongoing - inclusive and exclusive $^A\text{C}(p, pd)$ events can already be identified.



R³B



Thank you to the R3B collaboration!

Acknowledgements



The results presented here are based on the experiment G-22-00091, which was performed at the FRS-HTC at the GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt (Germany) in the frame of FAIR Phase-0.

This project has received funding from the European Union's Horizon Europe Research and Innovation programme under Grant Agreement No 101057511.

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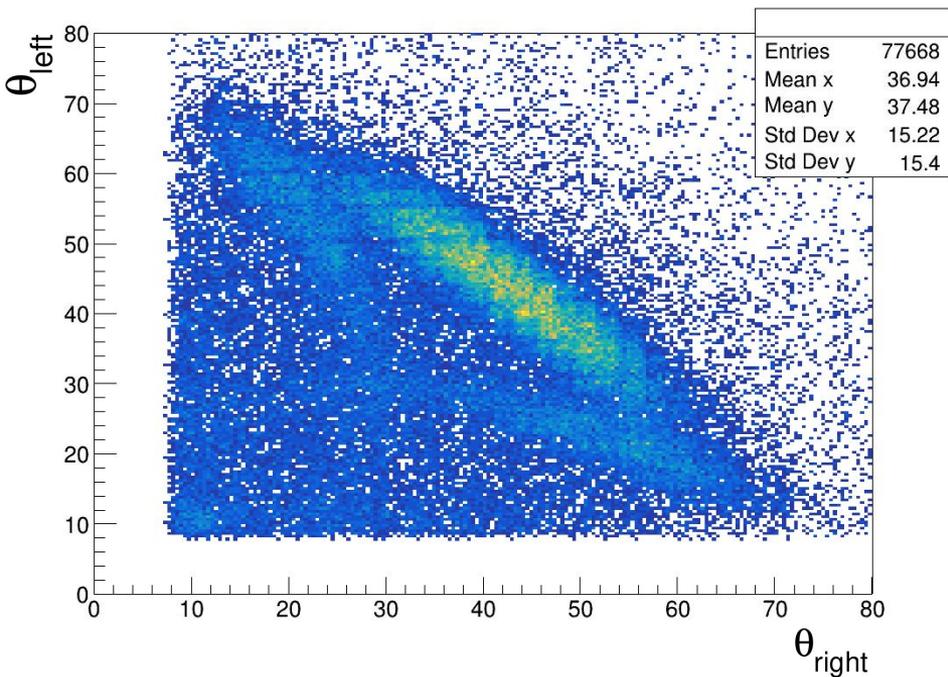
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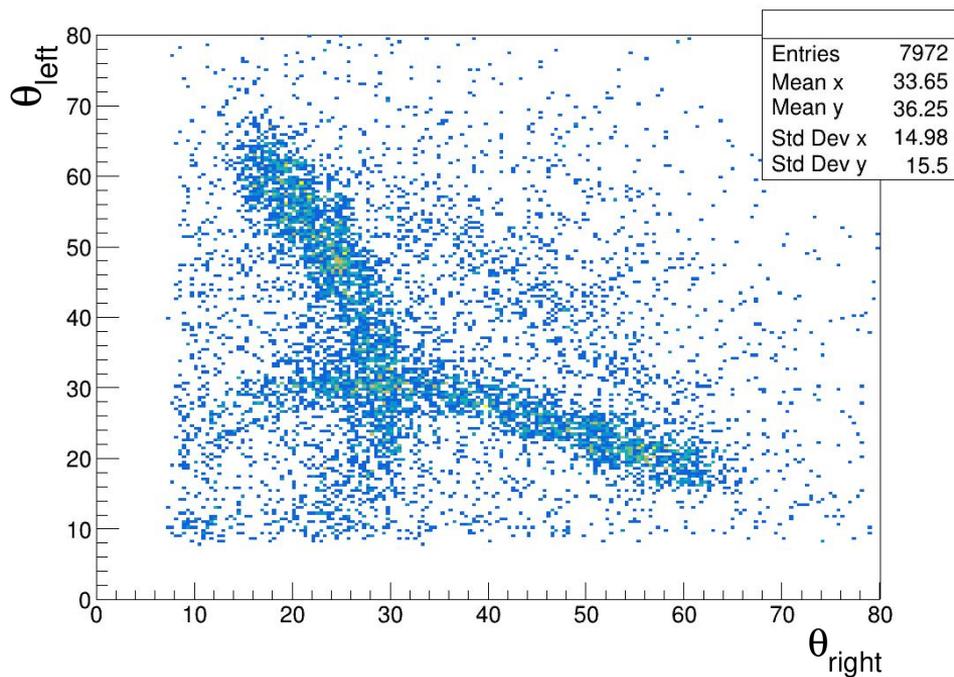
Science and
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Facilities Council

Deuteron beam 2H @ 285MeV/u

Before deuteron QPID selection

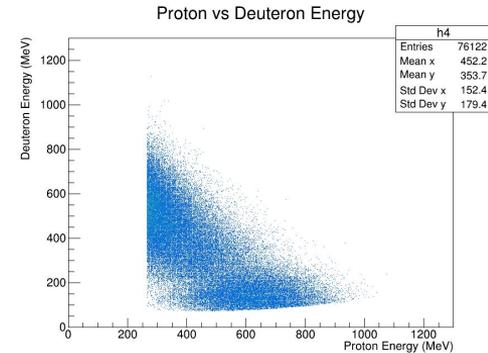
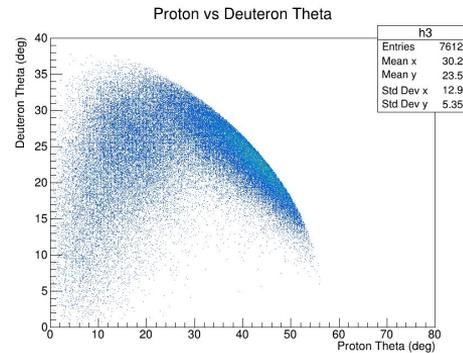
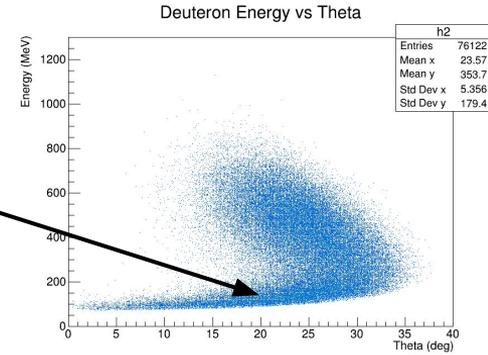
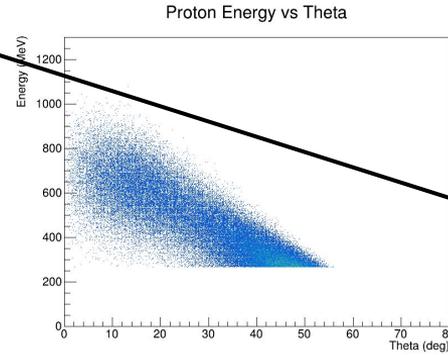
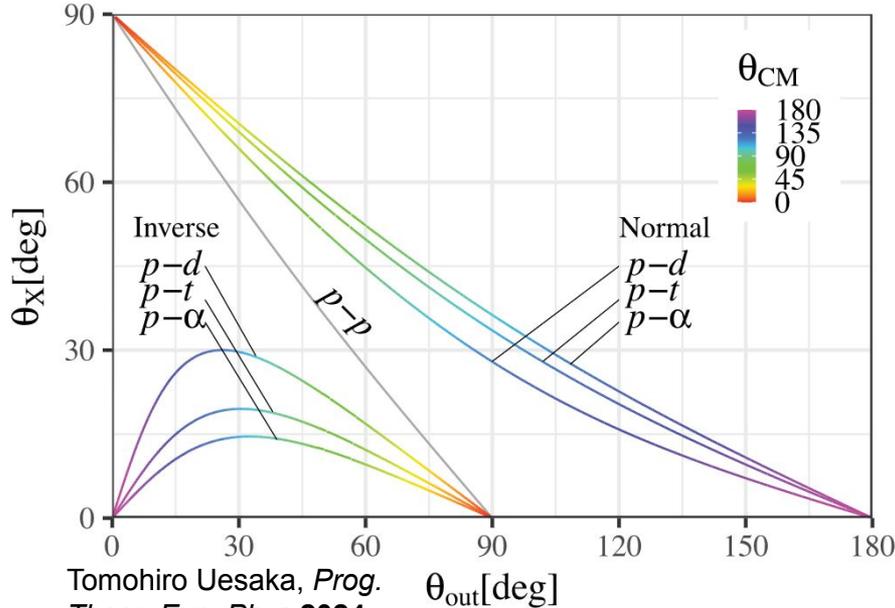


After deuteron QPID selection



(p,pd) in inverse kinematics

Low energy deuterons with high energy, forward angle proton

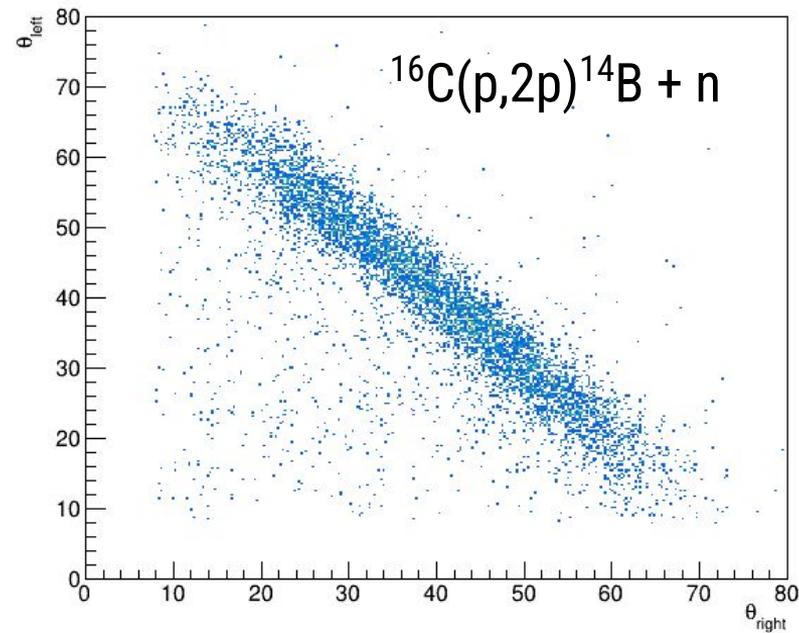
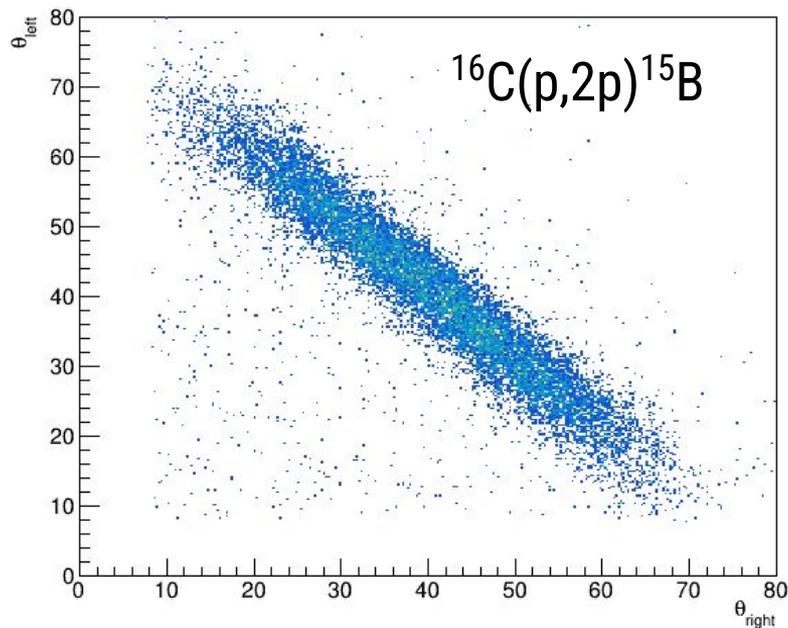
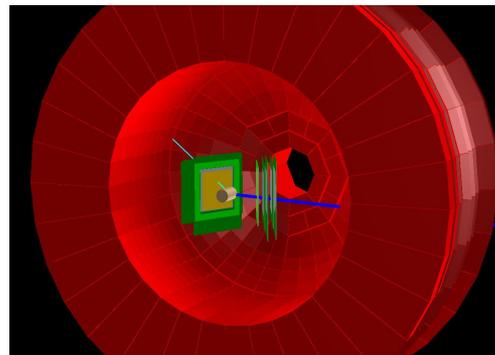


CALIFA kinematics

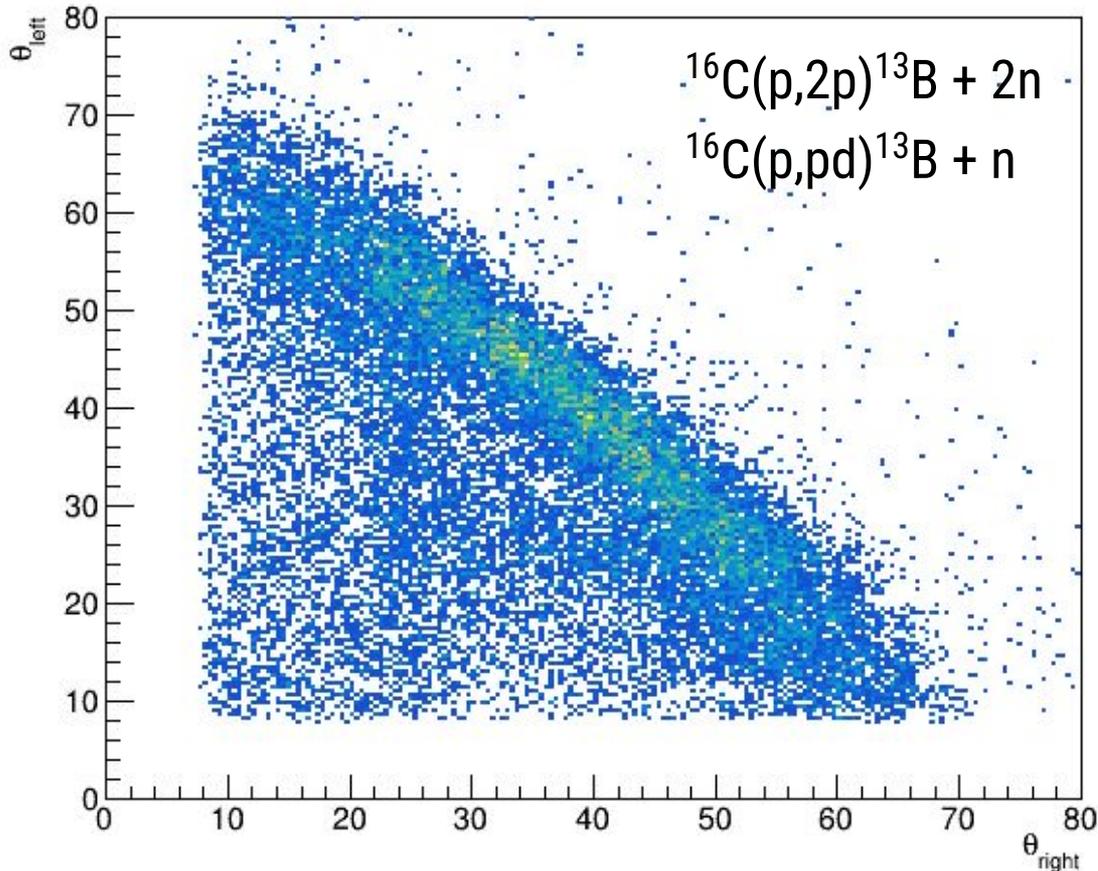
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CALIFA kinematics - ^{16}C



1+ state of ^{14}B populated in $^{16}\text{C}(p,pd)$. Decays via neutron evaporation to ^{13}B

^{14}B Levels

E(level)	J^π	Γ	L	Comments
1.27×10^3 2	1^+	160 keV 20	1	E(level): from $E(^{13}\text{B}+n)=304$ keV 4.
2.08×10^3	4^-		2	E(level): from (1973Ba34, 2000Ka21).
4.06×10^3 5	$(3^+, 3^-)$	1.2 MeV 5	(1,2)	Γ : for L=2. $\Gamma=1.0$ MeV 3 for L=1. E(level): from $E(^{13}\text{B}+n)=3090$ keV 50.