Opportunities with a cryogenic gas target at the ISS

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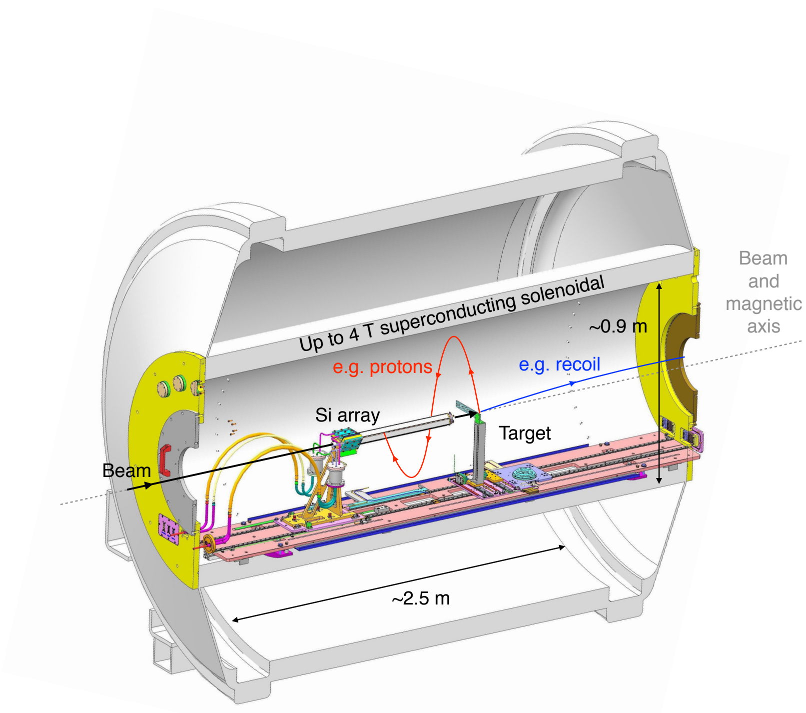
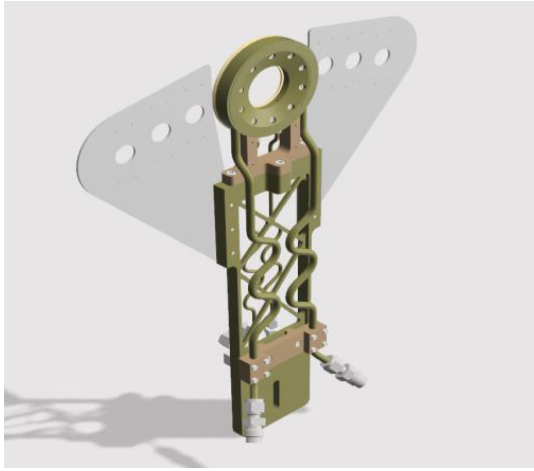
ISS Meeting, July 2020





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Motivation for a Cryogenic Gas Target

- A **unique tool** to maximise the physics possibilities of the ISS at ISOLDE.

- Primary motivations are direct measurements of astrophysical interest, such as (α,*p*) reactions, and transfer studies, e.g. (^{3}He,*d*), for both nuclear structure and astrophysics.

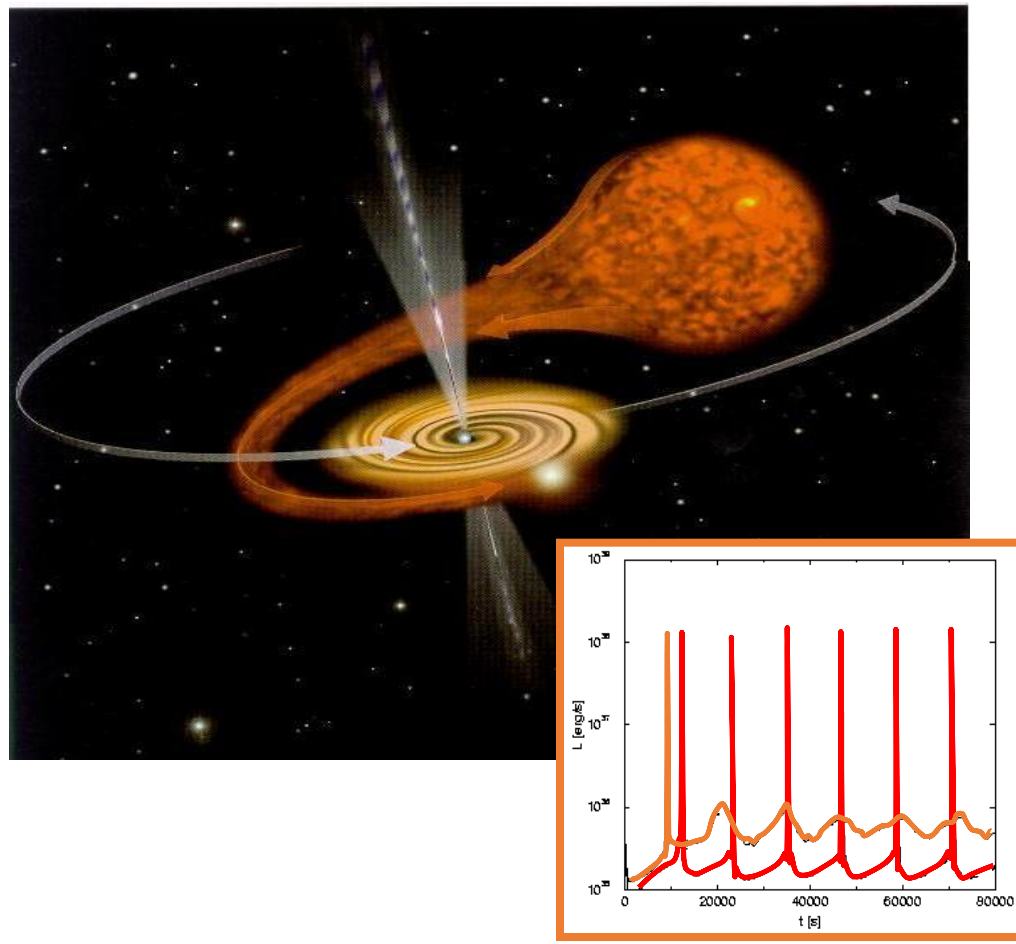
- Some precedent of direct measurements for nuclear astrophysics at ISOLDE, e.g.
  - **^{44}T(α,*p*)** [V. Margerin *et al.*, PLB 2014]
  - **^{17}F*(p,p')*** [J.J. He *et al.*, PRC 2009]

But unique advantages when using the ISS

Motivation

The observation of X-ray bursts is interpreted as thermonuclear explosions in the atmosphere of a neutron star in a close binary system.

As temperature and density at the surface of the neutron star increase, the CNO cycles breakout into the *rp* process.



Sensitivity studies highlight the key reactions for understanding these bursts

Energy Generation in X-ray Bursts

THE ASTROPHYSICAL JOURNAL, 872:84 (18pp), 2019 February 10

Influence of Nuclear Reaction Rate Uncertainties on Neutron Star Properties Extracted from X-Ray Burst Model–Observation Comparisons

Zach Meisel, Grant Merz, and Sophia Medvid

THE ASTROPHYSICAL JOURNAL, 830:55 (20pp), 2016 October 20

DEPENDENCE OF X-RAY BURST MODELS ON NUCLEAR REACTION RATES

R. H. CYBURT[1,2], A. M. AMTHOR[3], A. HEGER[2,4,5,6], E. JOHNSON[7], L. KEEK[1,2,7,9], Z. MEISEL[2,8], H. SCHATZ[1,2,7], AND K. SMITH[2,10]

Reactions that Impact the Burst Light Curve in the Multi-zone X-ray Burst Model

Rank	Reaction	Type[a]	Sensitivity[b]	Category
1	$^{15}O(\alpha,\gamma)^{19}Ne$	D	16	1
2	$^{56}Ni(\alpha,p)^{59}Cu$	U	6.4	1
3	$^{59}Cu(p,\gamma)^{60}Zn$	D	5.1	1
4	$^{61}Ga(p,\gamma)^{62}Ge$	D	3.7	1
5	$^{22}Mg(\alpha,p)^{25}Al$	D	2.3	1
6	$^{14}O(\alpha,p)^{17}F$	D	5.8	1
7	$^{23}Al(p,\gamma)^{24}Si$	D	4.6	1
8	$^{18}Ne(\alpha,p)^{21}Na$	U	1.8	1
9	$^{63}Ga(p,\gamma)^{64}Ge$	D	1.4	2
10	$^{19}F(p,\alpha)^{16}O$	U	1.3	2
11	$^{12}C(\alpha,\gamma)^{16}O$	U	2.1	2
12	$^{26}Si(\alpha,p)^{29}P$	U	1.8	2
13	$^{17}F(\alpha,p)^{20}Ne$	U	3.5	2
14	$^{24}Mg(\alpha,\gamma)^{28}Si$	U	1.2	2
15	$^{57}Cu(p,\gamma)^{58}Zn$	D	1.3	2
16	$^{60}Zn(\alpha,p)^{63}Ga$	U	1.1	2
17	$^{17}F(p,\gamma)^{18}Ne$	U	1.7	2
18	$^{40}Sc(p,\gamma)^{41}Ti$	D	1.1	2
19	$^{48}Cr(p,\gamma)^{49}Mn$	D	1.2	2

A variety of (p,γ) and (α,p) reactions have significant affect on the energy generated in X-ray bursts.

KEY REACTIONS

1. $^{61}Ga(p,\gamma)^{62}Ge$
2. $^{22}Mg(\alpha,p)^{25}Al$
3. $^{14}O(\alpha,p)^{17}F$
4. $^{17}F(\alpha,p)^{20}Ne$
5. $^{18}Ne(\alpha,p)^{21}Na$
6. $^{60}Zn(\alpha,p)^{63}Ga$
7. $^{57}Cu(p,\gamma)^{58}Zn$

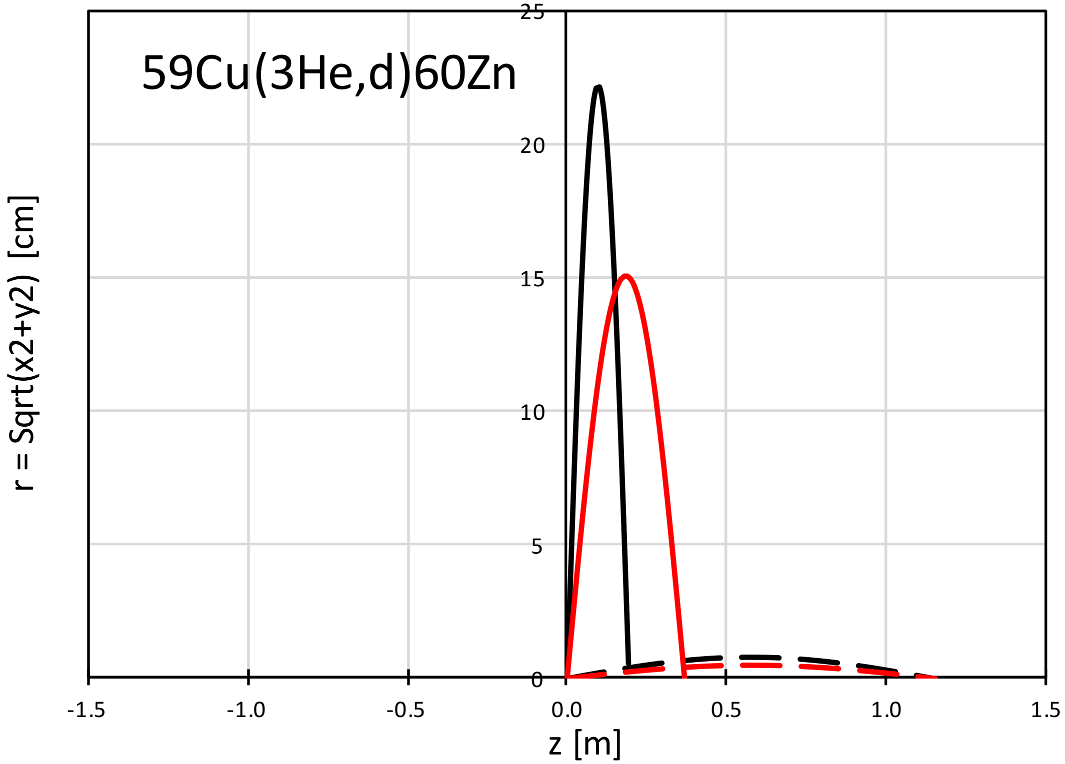
Examples - (^{3}He,*d*)

- Gas at ~90 K will have ~3 times the gas density compared to room temperature. At 500 Torr -> 50-100 μg/cm^2 solid target.

=> (^{3}He,*d*) measurements are feasible, direct analogue of proton-capture reaction.

E_B = 4.5 MeV/u
B = 2.85 Torr
Restrict to E_{CoM} > 30°, so that d energy is sufficient to escape target.

Ground state
Excited state (6 MeV)

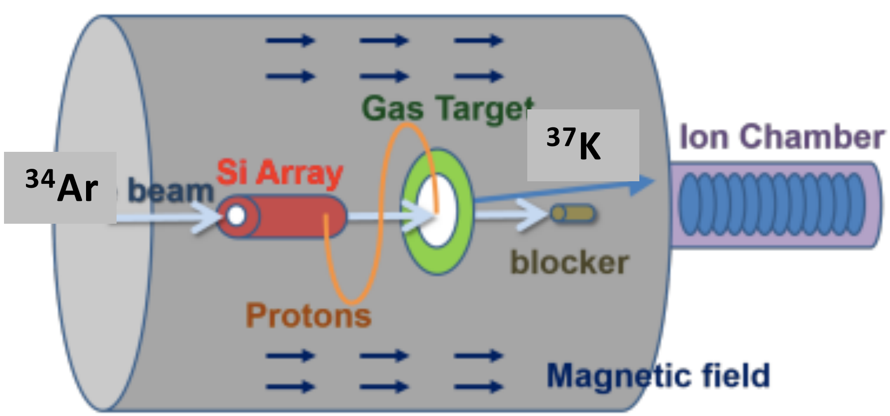


Examples – (^{4}He,*p*)

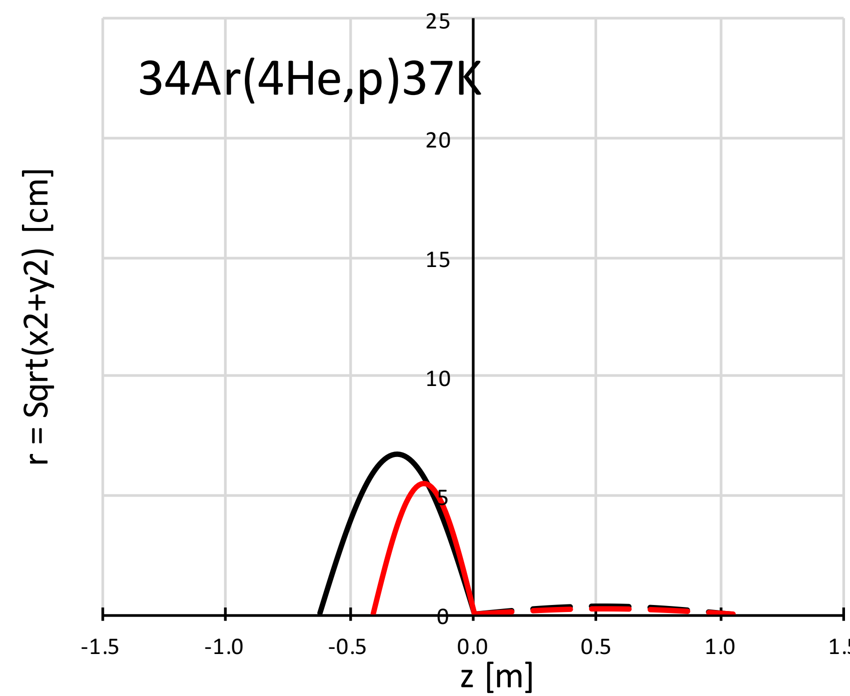
- Coincidence measurement exploiting ISS geometry, powerful way of reducing background. Excellent geometrical efficiency compared to more traditional methods.

   => Ion Chamber for detecting recoils

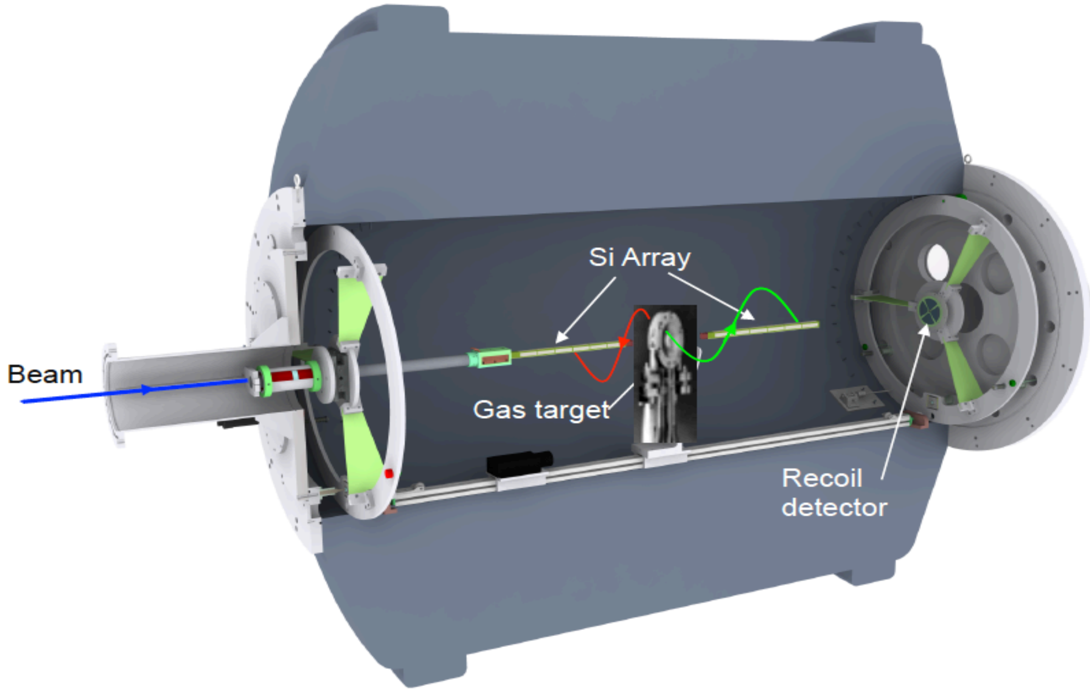
- Normalisation via (α,α')



Modified from J. Lai, PhD Thesis, LSU (2016)

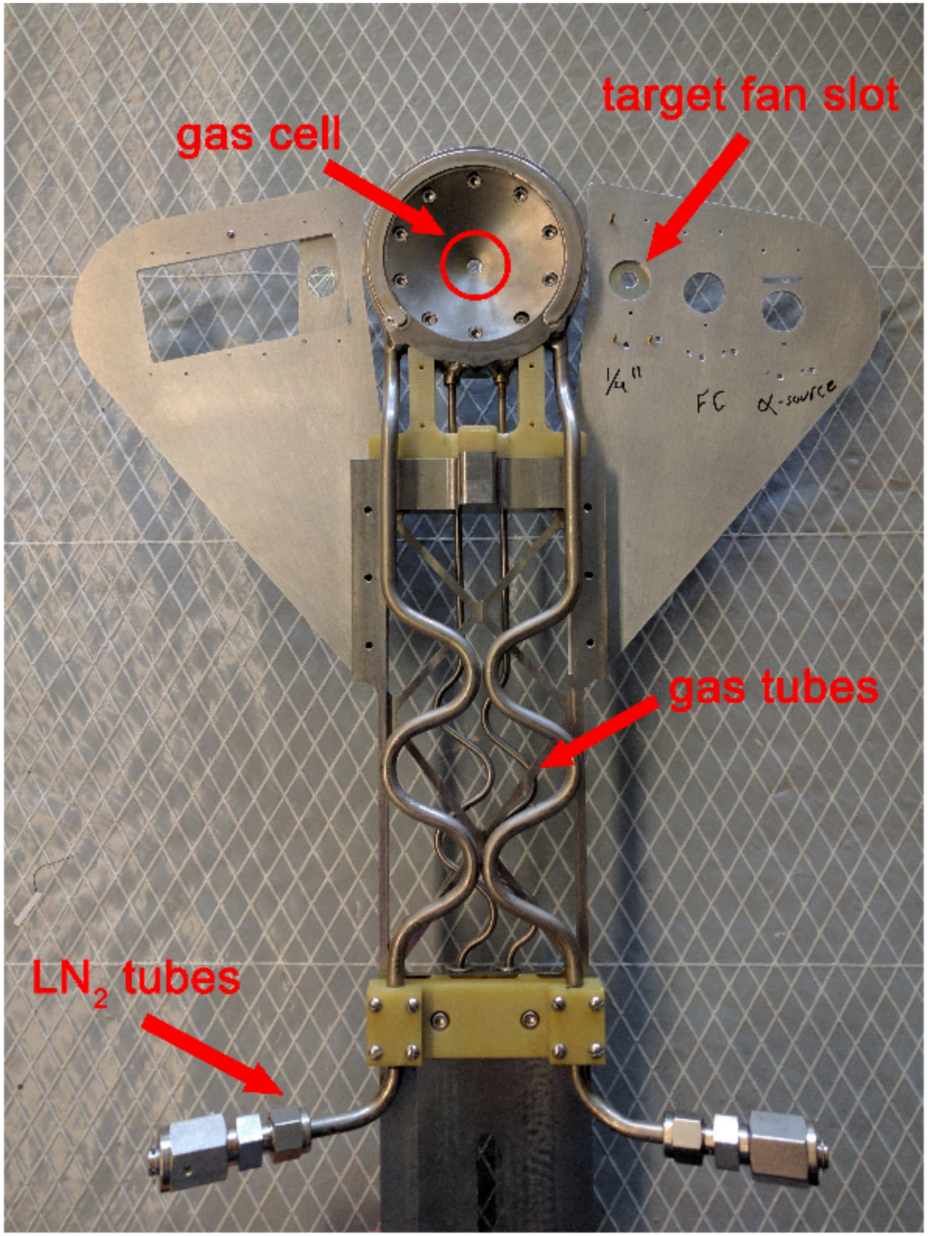


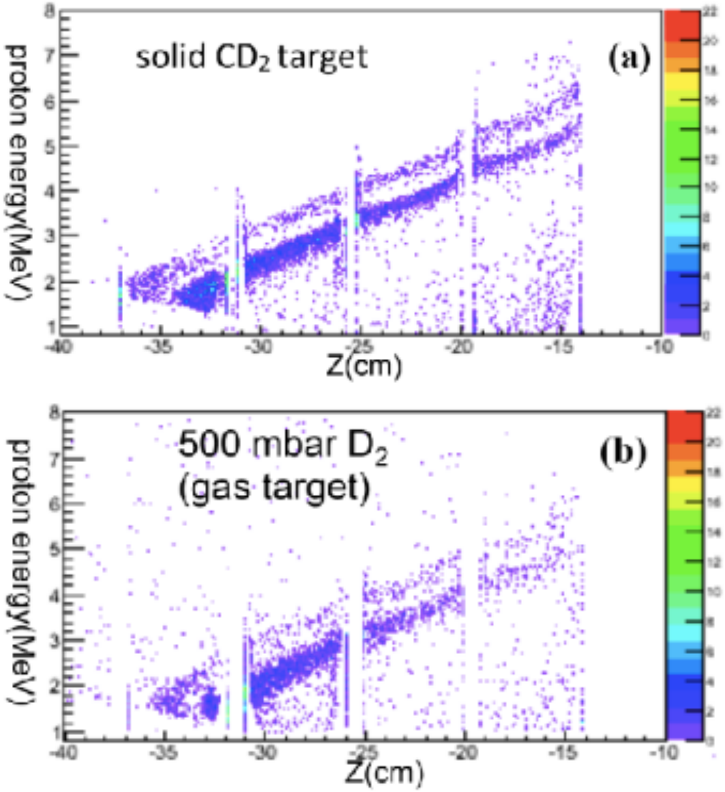
Cryogenic Gas Target with HELIOS @ ANL



- HELIOS design (previously used with Split-pole) shown above, target fan to allow for quick target changes.
- Currently uses Kapton windows
- Target thickness ~50 μg/cm^2
- Ability to accurately identify recoils is crucial (e.g. Ion Chamber)

HELIOS Cryogenic Target

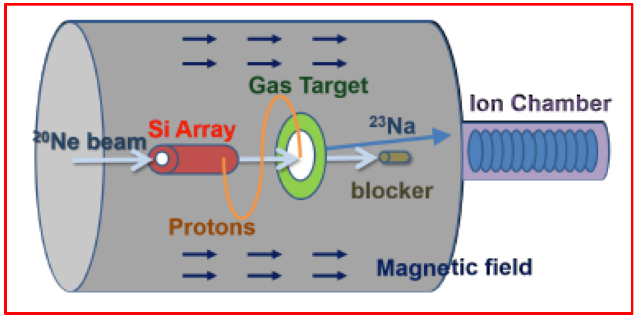


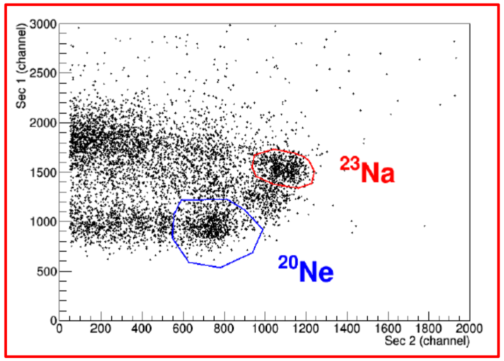


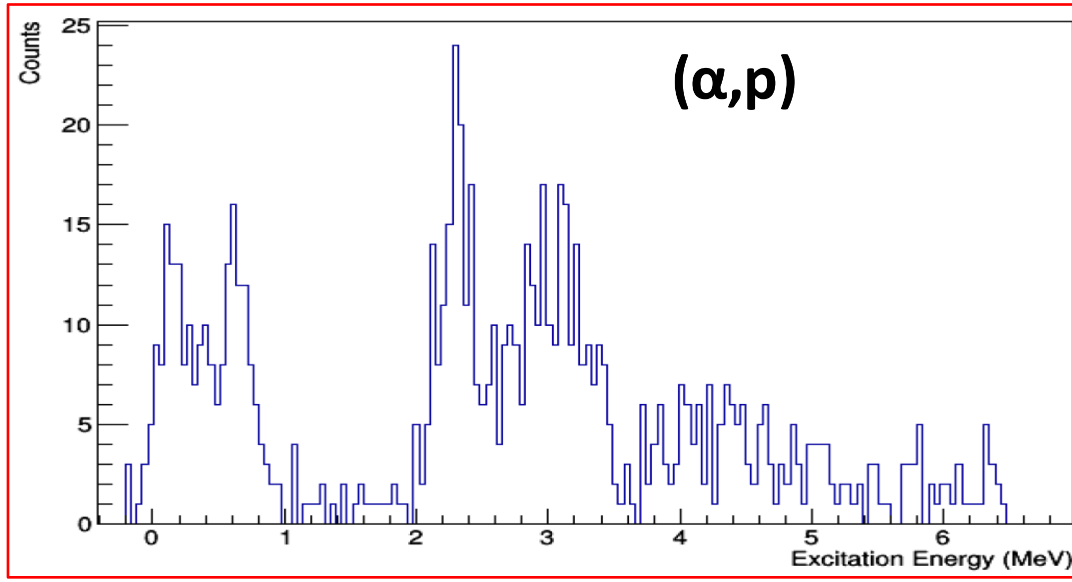
Proton spectra from $d(^{14}C, p)^{15}C$ reaction

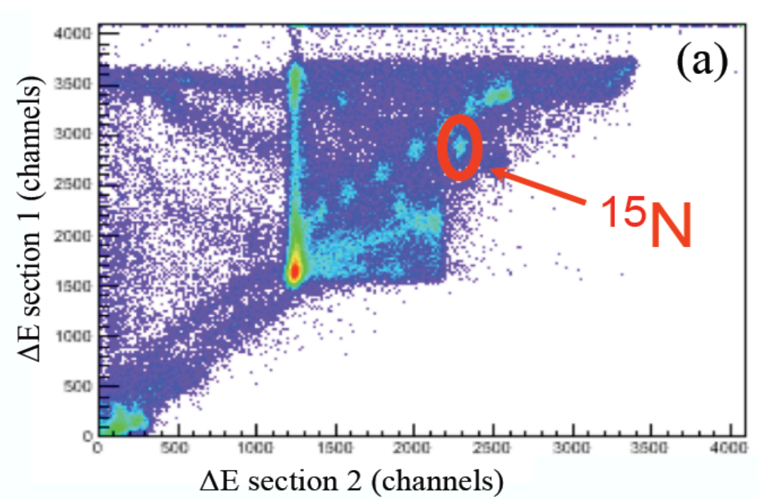
J. Lai, PhD Thesis, LSU (2016)

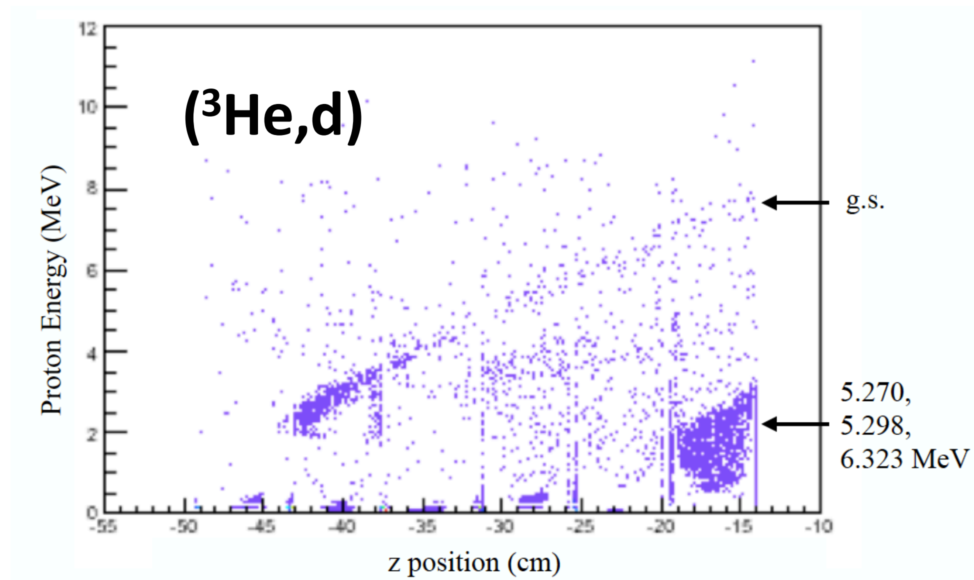
Previous Studies of $^{20}Ne(\alpha,p)$ and $^{14}C(^{3}He,d)$





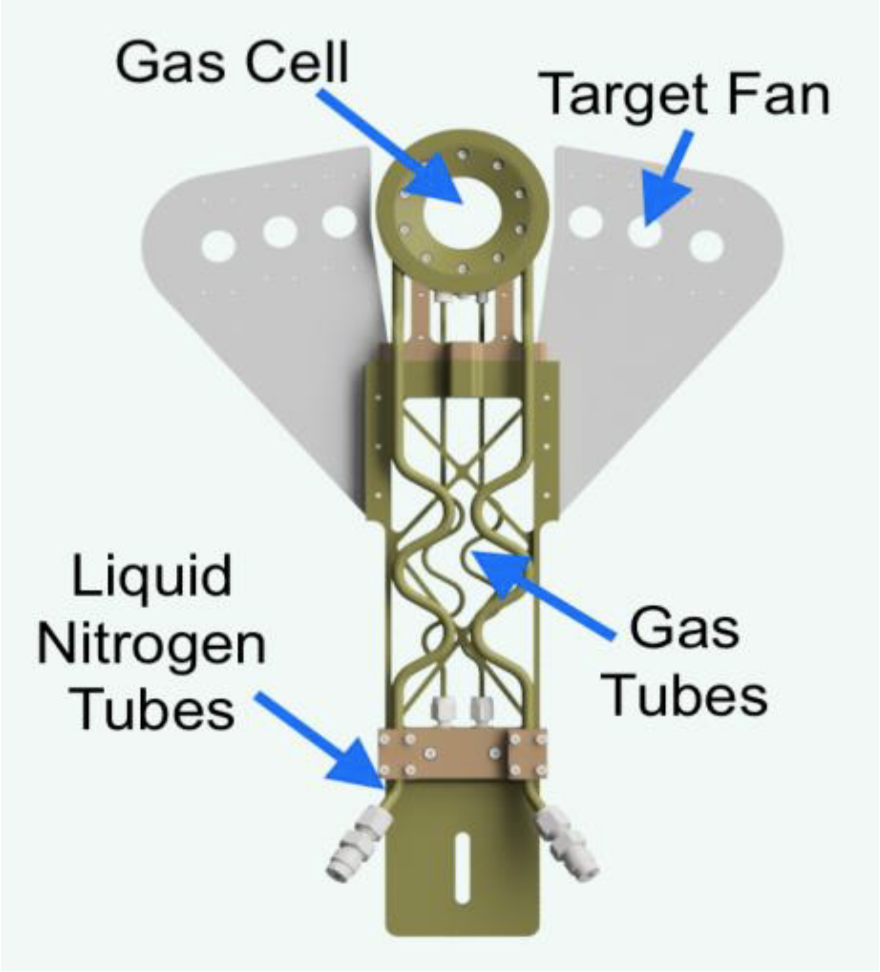






A Cryogenic Gas Target at the ISS

- Capital requested (**and matched**) as part of Surrey Consolidated Grant + cross-community support.
- We propose to build a copy of the University of Manchester IC gas-handling system (MKS Type 250 controller, 248 control valves and a baratron capacitance manometer).
- Larger gas cell windows to be explored (compared to HELIOS design).
- Construction and first experiments before long shut down (end of 2024).



Challenges and Discussion Points

- Gas targets are **extremely challenging** but the rewards are substantial and makes good use of the unique beam species available at HIE-ISOLDE.

- Optimum material and geometry of windows to be determined, some preliminary discussions at ISS meeting in 2019. **Windows are relatively thick.**

- Required beam energies relatively low for direct astrophysical measurements (down to < 2 Mev/u, REX-ISOLDE energies..)

- Need normalization for (α,p) measurements
  $\Rightarrow$ (α,α')

Thank you very much!