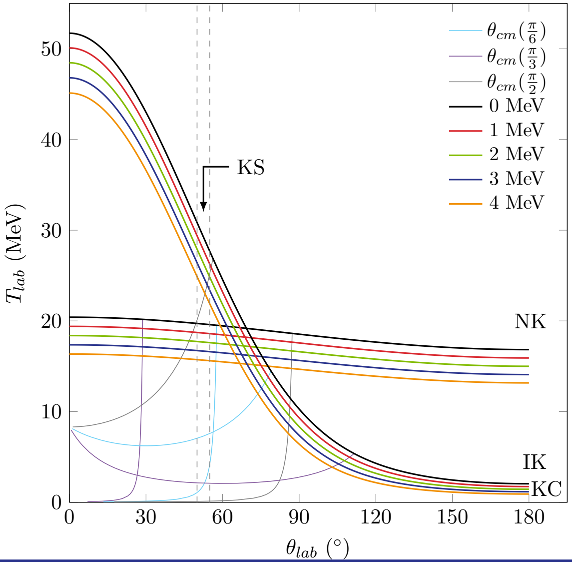
Overview of recent direct-reaction measurements in inverse kinematics at the ISOLDE Solenoidal Spectrometer, CERN

Patrick T. MacGregor

DREB 2024



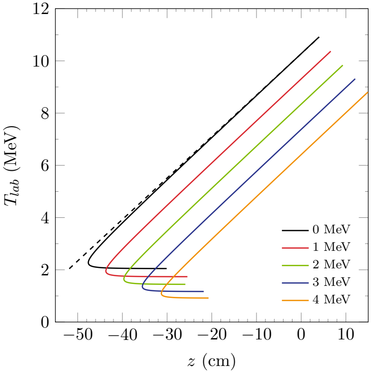
NK: Beam = *d*, Target = ^{A}X
IK: Beam = ^{A}X, Target = *d*

Kinematic shift (KS)
Broadens peaks in energy spectrum.

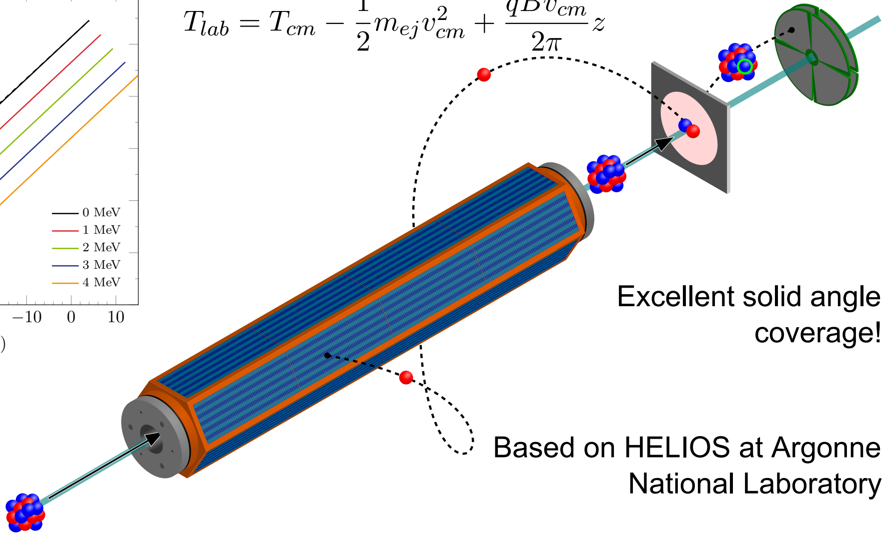
Kinematic compression (KC)
Reduces spacing between peaks in energy spectrum.

Result: lower-quality information on residual state populated using particle detection *alone*.

Transfer reactions in inverse kinematics in a solenoid



$$T_{lab} = T_{cm} - \frac{1}{2} m_{ej} v_{cm}^2 + \frac{qBv_{cm}}{2\pi} z$$

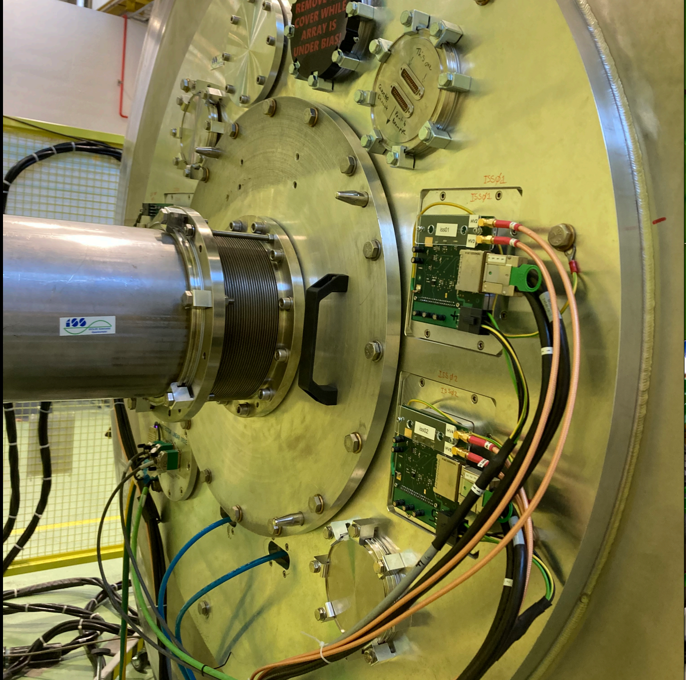


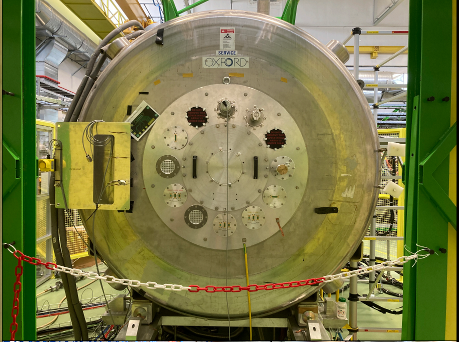
No kinematic compression!

Excellent solid angle coverage!

Based on HELIOS at Argonne National Laboratory


SOLARIS
HELIOS
ISOLDE Solenoidal Spectrometer
Greenland
Iceland
Canada
United States
Mexico
Hudson Bay
Labrador Sea
North Atlantic Ocean
Gulf of Mexico
Caribbean Sea
Mediterranean Sea
North Sea
Baltic Sea
Tyrrhenian Sea
Cuba
Puerto Rico
Guatemala
Nicaragua
Norway
Sweden
Finland
Denmark
Estonia
Latvia
Lithuania
Poland
Belarus
Germany
Czechia
Slovakia
Austria
Hungary
Moldova
Romania
Croatia
Serbia
Bulgaria
Greece
Italy
France
Belgium
Ireland
Spain
Portugal
Morocco
Algeria
Tunisia
Libya
Western Sahara
Mauritania
Mali
Niger
Chad
Senegal
The Gambia
Guinea-Bissau
Burkina Faso

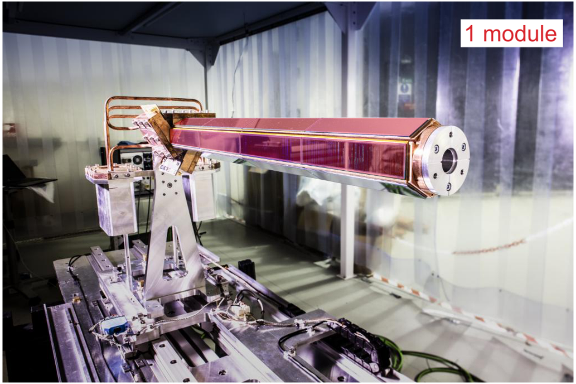

REMOVE
COVER WHILE
ARRAY IS
UNDER BIAS
ISSØ1
iss01
HV2
HV3
ISSØ2
iss02
HV4


SERVICE
OXFORD


Brun

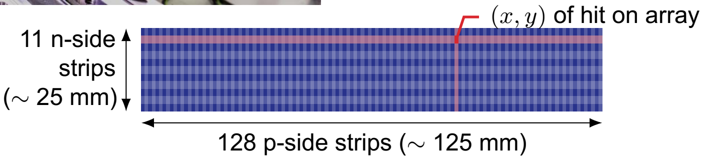
J. M. Ordan. General Photo. (2022). URL: https://cds.cern.ch/record/2800900

Detectors at ISS: silicon array



Technical details

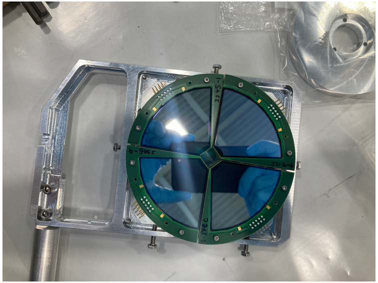
- Designed and built in Liverpool during LS2
- 3 modules of DSSDs = 2 sides of hexagonal array each
- Each module has 512 p-side channels and 88 n-side channels: total = 1800!
- Approx. 500 mm active silicon length
- Has ASIC readouts using chips designed for R^3B project
- NIM paper being written



Detectors at ISS: recoil detection

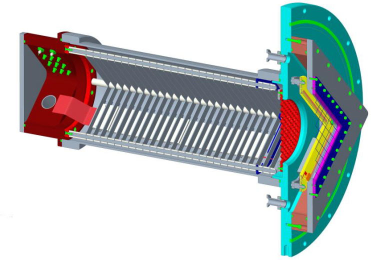
ISOLDE Solenoidal Spectrometer

Silicon mode



Used for reactions with lighter beams e.g. ^{49}Ca(d,p) (2023).

Recoil-gas mode



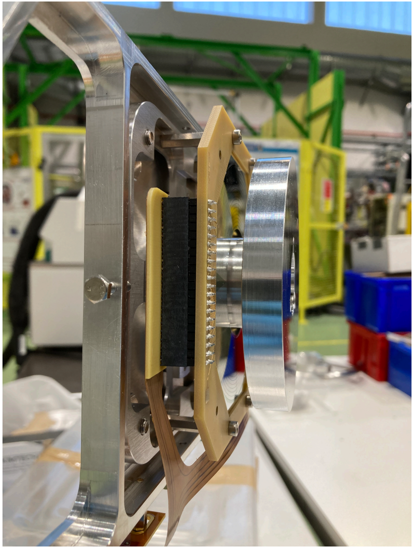
Used for heavier beams, but still being characterised (more later) e.g. ^{92,94}Kr(d,p) (2022)

Singles mode

- No direct recoil detection.
- Use EBIS pulse time, as well as other tricks, to clean the E v.s. z spectrum.
- Used where recoil detection difficult/impossible.

Necessary for reactions using heaviest beams e.g. ^{212}Rn(d,p) (2021)

Detectors at ISS: ancillary detectors

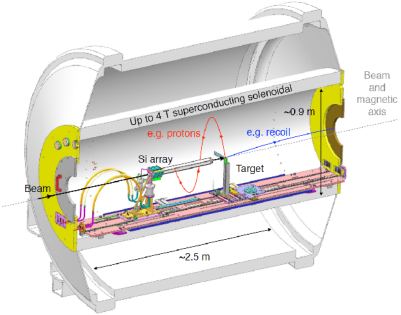


Can use additional ancillary detectors to complement measuring recoil + ejectile from (*d*,*p*) reaction:

- Luminosity detector for measuring elastically scattered deuterons (pictured)
- Zero-degree detector for measuring beam composition

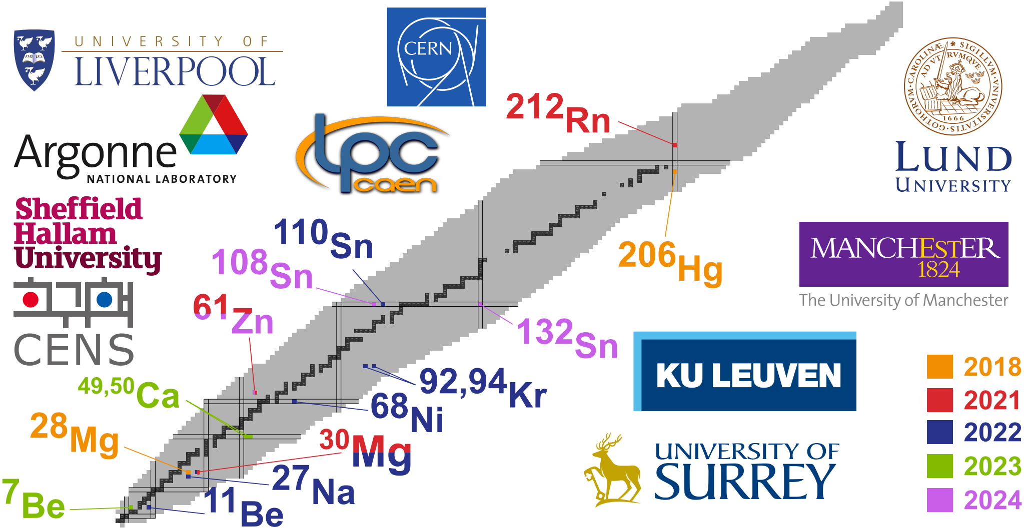
Multiple motors allow different configurations under vacuum.

Additional detector designs have been proposed for future experiments...



Beams from ISOLDE

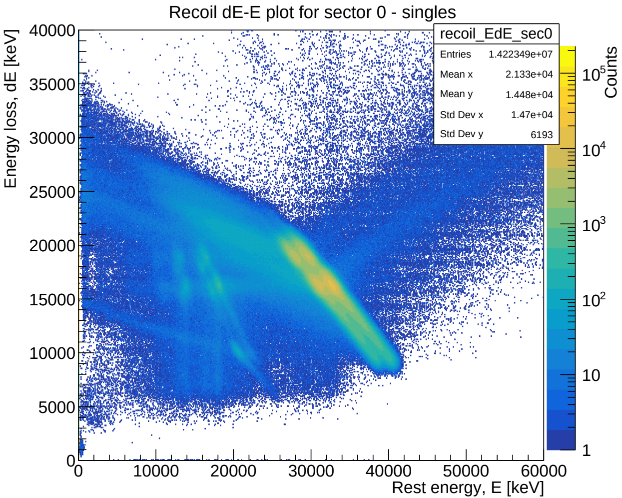
[1]

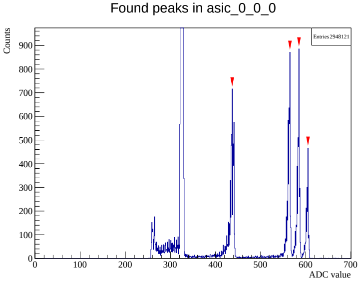


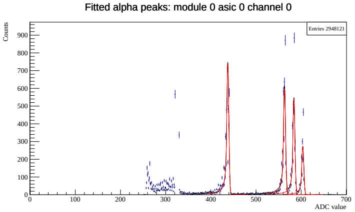
1 E. Simpson. 2023. URL: `https://people.physics.anu.edu.au/~ecs103/chart/` (Date accessed: 05/04/2023).

How are data processed - $^{30}Mg(d,p)$ reaction

ISSSort

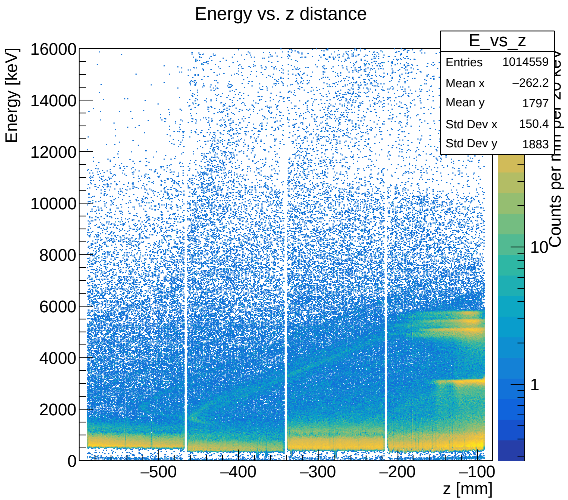


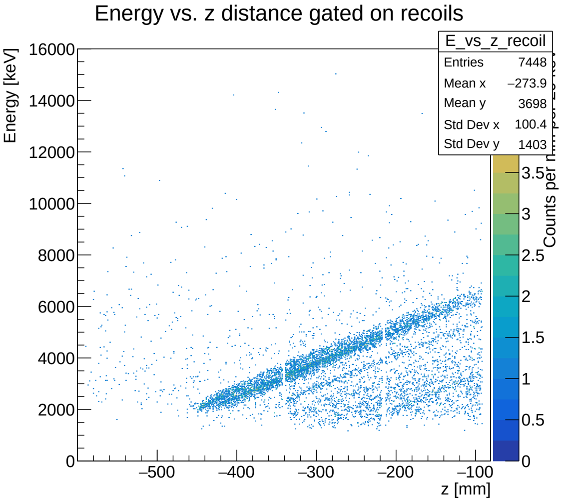




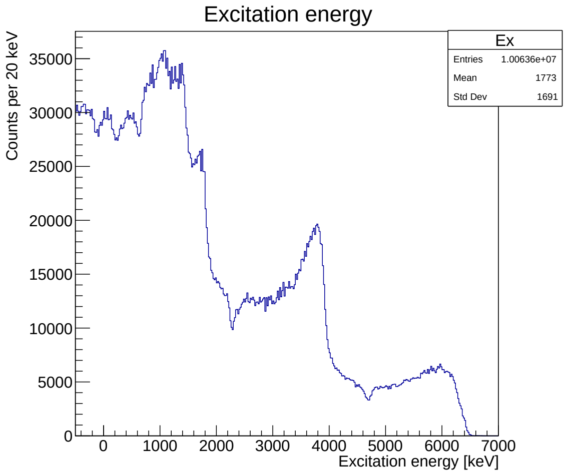
How are data processed - the ^{30}Mg(d,p) reaction

ISSSort

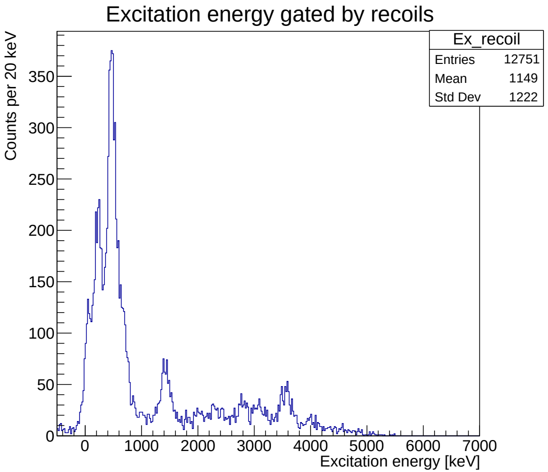




ISSSort

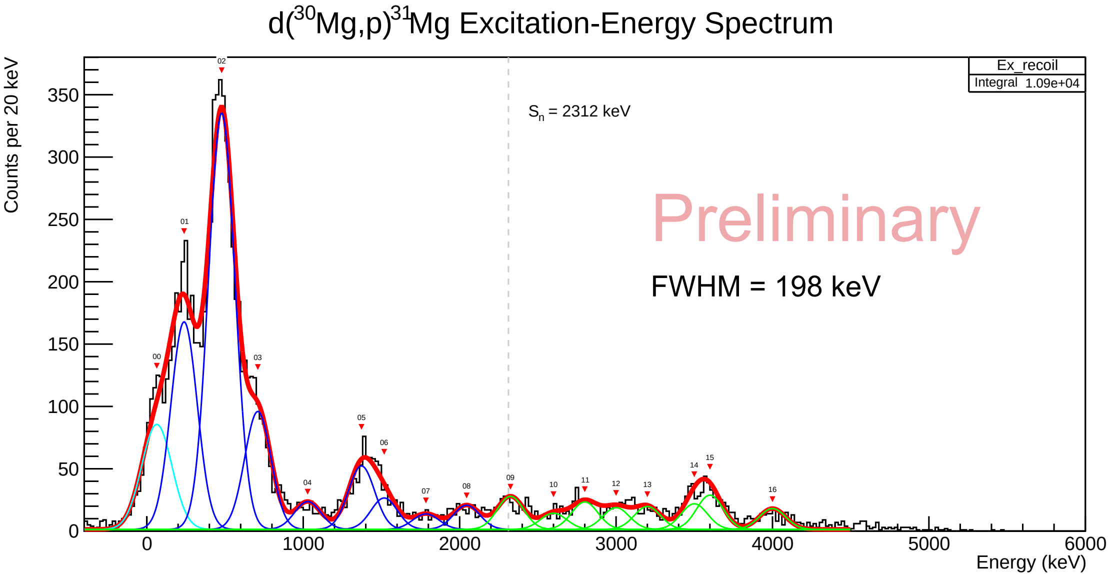


Excitation energy
Ex
Entries 1.00636e+07
Mean 1773
Std Dev 1691
Counts per 20 keV
Excitation energy [keV]

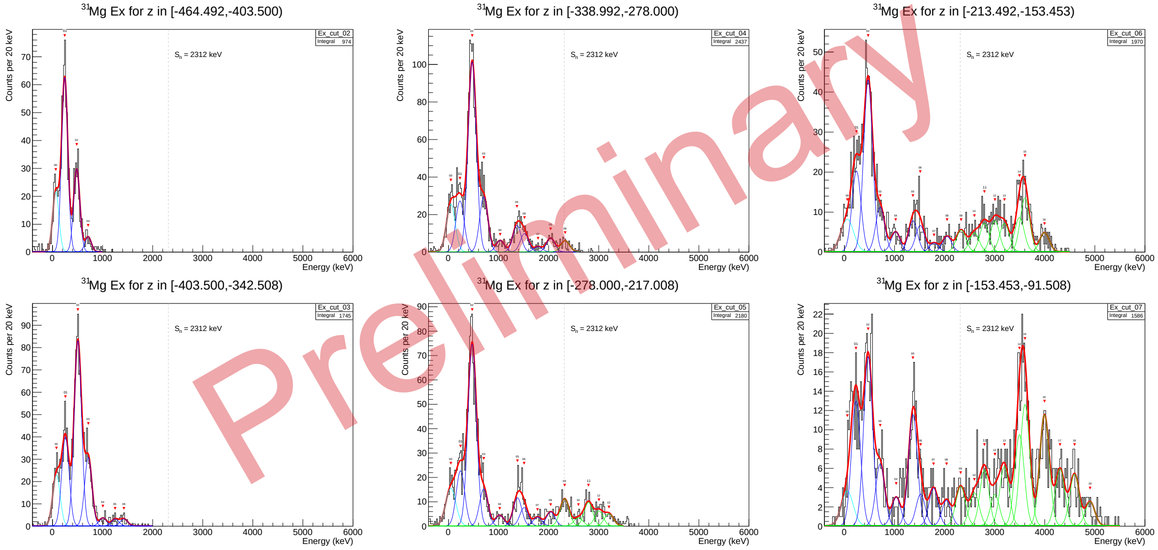


Excitation energy gated by recoils
Ex_recoil
Entries 12751
Mean 1149
Std Dev 1222
Counts per 20 keV
Excitation energy [keV]

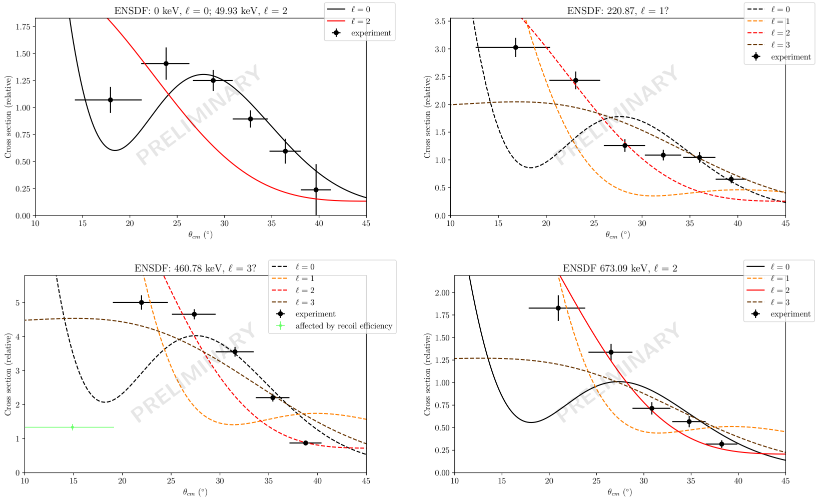
How are data processed - the $^{30}Mg(d,p)$ reaction



How are data processed - the ^{30}Mg(*d*,*p*) reaction

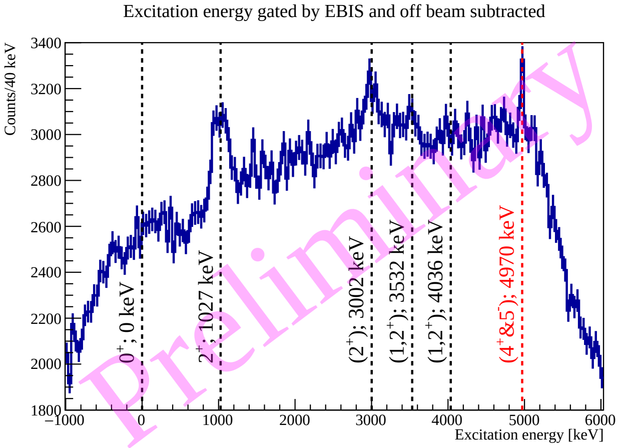


How data are analysed - the ^{30}Mg(d,p) reaction



Cross sections can be extracted, though caveats for what is here:

- Horizontal lines on each point correspond to angular range of detector used to calculate cross section.
- Not absolute cross sections (yet…) → (d,d) reaction on luminosity detector.
- Some points affected by recoil-detector efficiency e.g. 461-keV state.



[2]

Reactions: ^{49,50}Ca(d,p)
Motivation: Measure single-particle structure of neutron-rich calcium nuclei to better understand magicity of N = 32,34 shell closure.
Progress: Experiments in early stages on analysis. Image here is of theory predictions matched to experiment in the ^{49}Ca(d,p) reaction.

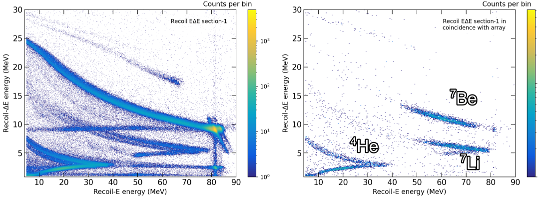
[2] F. Browne. Private communication.

2023 physics: winter ^{7}Be run

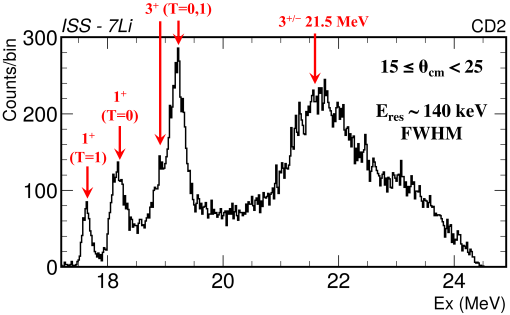
Reaction: ^{7}Be(d,p)

Motivation: Search for rotational bands built on p-h cluster states at high-excitation energy $\rightarrow$ low-energy protons in weaker (1.42 T) magnetic field.

Progress: Applied array-recoil timing and recoil-detector energy gates. Still need to remove ^{12}C background and account for random coincidences. Challenges still remain for nuclear reaction models and data interpretation.



[3]

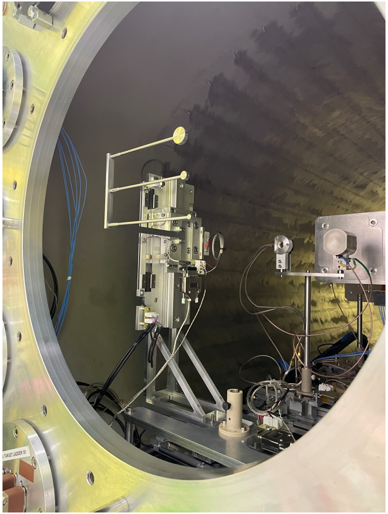


[4]

3 K. Haverson. Private communication.

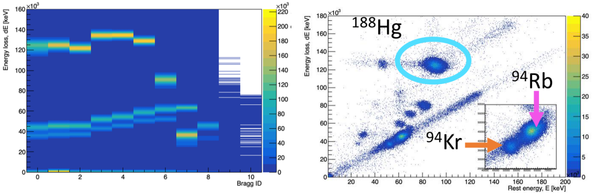
4 R. Smith. Private communication.

[5]



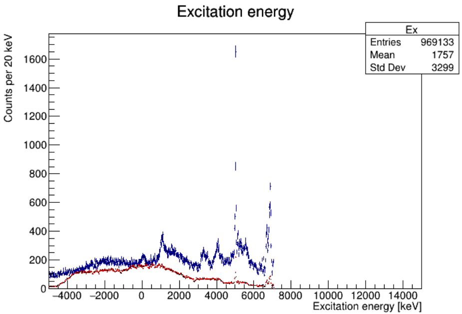
Gas recoil detector upgrade

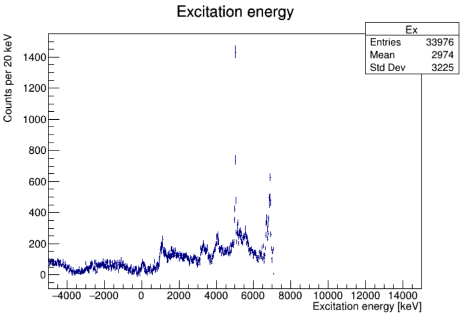
- 2D mechanism installed for placing beam blocker in front of the chamber, commissioning this year.
- Faster preamps used to improve detection with higher beam rates.
- Chamber being characterised and optimised right now by summer student from Chalmers University.



5 S. B. Reeve. Private communication.

Stable beam run completed





3 experiments scheduled:

CDS	Reaction	Spokesperson(s)
P-589	^{108}Sn(d,p)	J. Park/J. Cederkall
P-678	^{132}Sn(d,p)	B. P. Kay/S. J. Freeman
P-570	^{61}Zn(d,p)	G. Lotay/D. Doherty

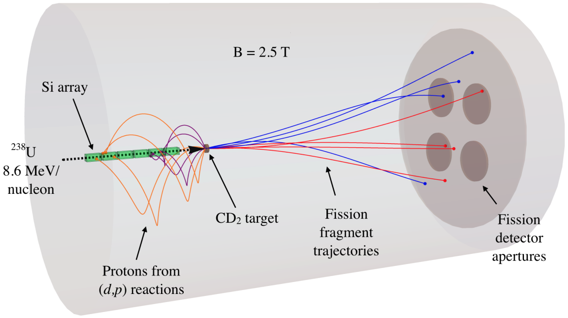
Argonne NATIONAL LABORATORY

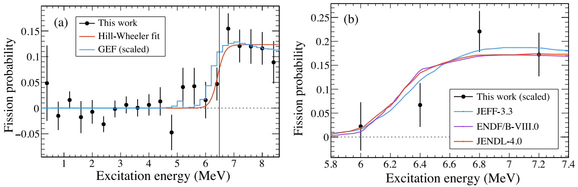
CENS

LUND UNIVERSITY

MANCHESTER 1824 The University of Manchester

UNIVERSITY OF SURREY





(d,pf) surrogate reaction has advantages over traditional fission measurements:

- Fission fragments focussed into small solid angle $\Rightarrow$ efficient detection
- Full Bragg peak spectroscopy possible at these energies
- ISOLDE gives access to short-lived actinides

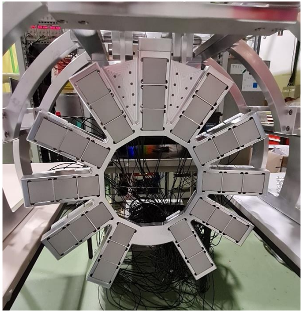
Can combine with scintillator array for $(n,\gamma)/(n,f)$…

Successful proof-of-principle ^{238}U(d,pf) experiment at HELIOS!

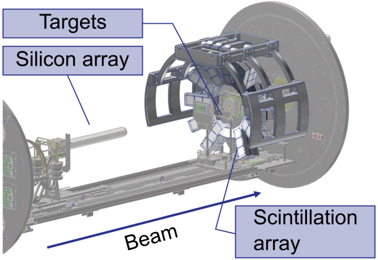
6 S. A. Bennett et al. Phys. Rev. Lett. **130**, 202501. (May 2023) .

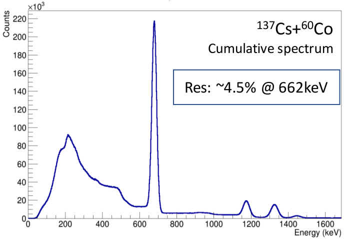
KU LEUVEN

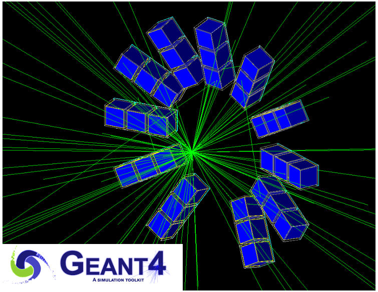
CHALMERS UNIVERSITY OF TECHNOLOGY

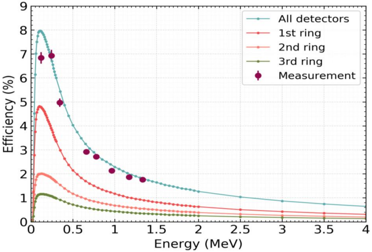


3 rings of 11 CeBr detectors from SpecMAT. Commissioned in Oct. 2022, further tests this summer... Can be used for (d,$p\gamma$) experiments for astrophysics[7].



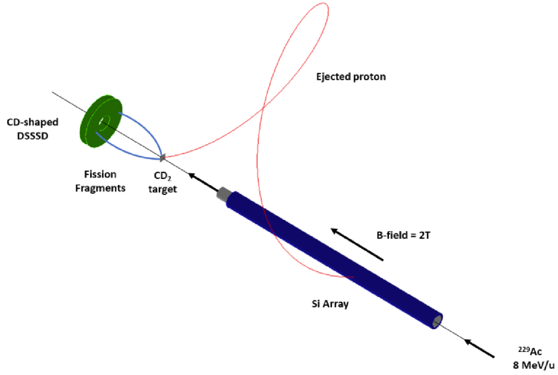




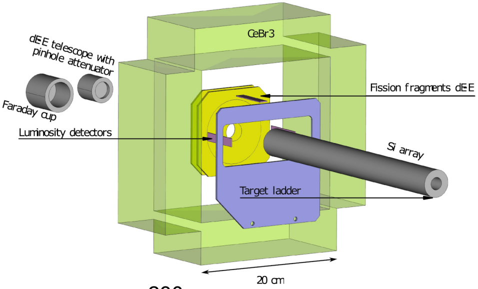


7 D. K. Sharp. Private communication.

Transfer-induced fission with scintillator array!



[8]



INTC P-668 ^{230}Ac(d,pf) proposal combines scintillator array with (d,pf) measurement. Detect fission fragments with CD detector. Geometrical efficiency of 82% for detecting both fission fragments. Initial tests of equipment planned this year.

8 A. Kawęcka, M. V. Managlia, and A. Heinz. Tech. rep. Geneva: CERN, 2023. URL: https://cds.cern.ch/record/2872247.

Poster!

ISOLDE Solenoidal Spectrometer

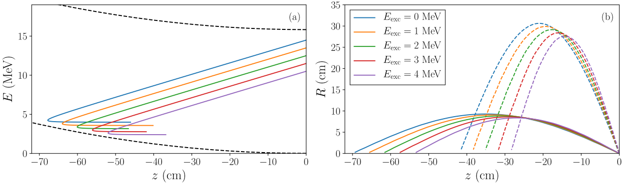
Advancements in fission studies: a novel approach for studying (d,pf) reactions at ISS *Maria Vittoria MANAGLIA*
Kurhaus Wiesbaden Tue 25/06 17:00-19:30

Looking to the future: new reactions

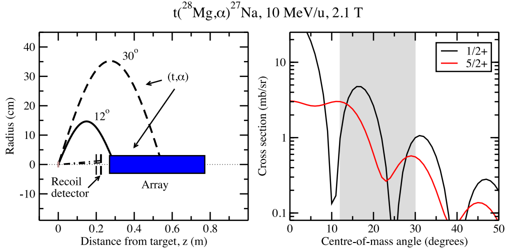
	INTC	Beam	Reaction	Spokesperson(s)
✓	P-582	^{9}Li	(t,p)	Y. Ayyad and E. Vigezzi
✓	P-599	^{134,136,138,140}Xe	(t,p)	A. O. Macchiavelli and K. Wimmer
?	P-679	^{78}Zn	(t,p)	S. Bottoni, F. Galtarossa
✓	P-609	^{146}Ce	(d,d')	L. P. Gaffney
?	P-660	^{28,30}Mg	(t,α)	D. K. Sharp and P. T. MacGregor

N.B. tritium target purchased for SEC and Miniball experiments

(t,p): protons travel backwards[9]



(t,α) + (d,d'): protons travel forwards[10]



[9] K. Wimmer and A. O. Macchiavelli. Tech. rep. Geneva: CERN, 2021. URL: https://cds.cern.ch/record/2766315.

[10] D. K. Sharp and P. T. MacGregor. Tech. rep. Geneva: CERN, 2023. URL: https://cds.cern.ch/record/2845991.

Thanks to all collaborators on experiments!