MANCHESTER 1824

The University of Manchester

ISOLDE Solenoidal Spectrometer

First results from the ISOLDE Solenoidal Spectrometer

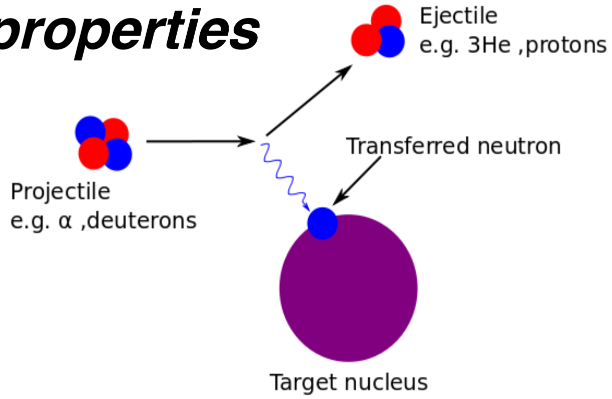
preliminary

D. K. Sharp
The University of Manchester, UK

ISOLDE Workshop
5th-7th December 2018

- *Introduction of solenoid technique for transfer reactions.*
- *Introduce ISS project.*
- *First results from IS621 and IS631.*

Transfer reactions as a probe of single-particle properties

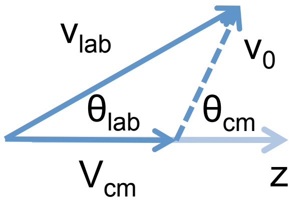


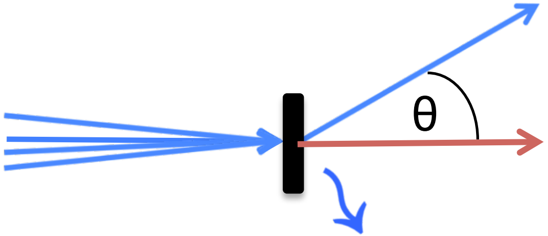
Transfer reactions are a direct reaction. Single-step transfer of one or more nucleons to or from a target of interest.

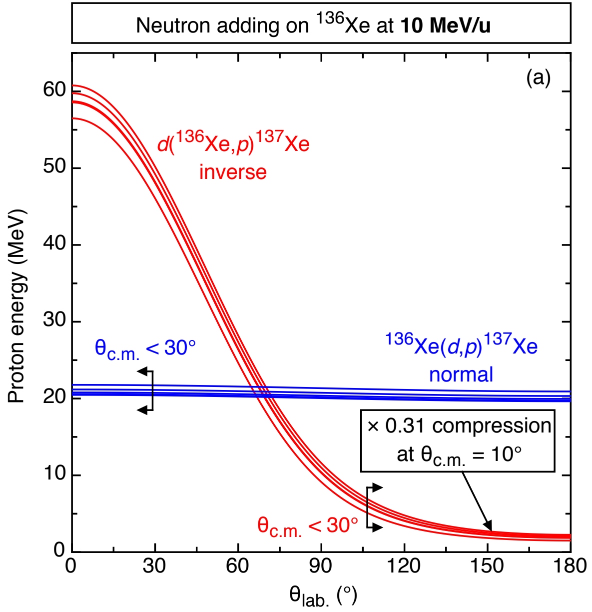
Single-nucleon transfer probes single-particle properties of nuclei.

- *Ejectile energy - > Excitation of residual nucleus.*
- *Yield -> cross section.*
- *Angular distributions -> ℓ.*

In inverse kinematics Q-value spectrum affected by kinematic compression of measured ejectile energies in lab frame - leading to poor resolution.

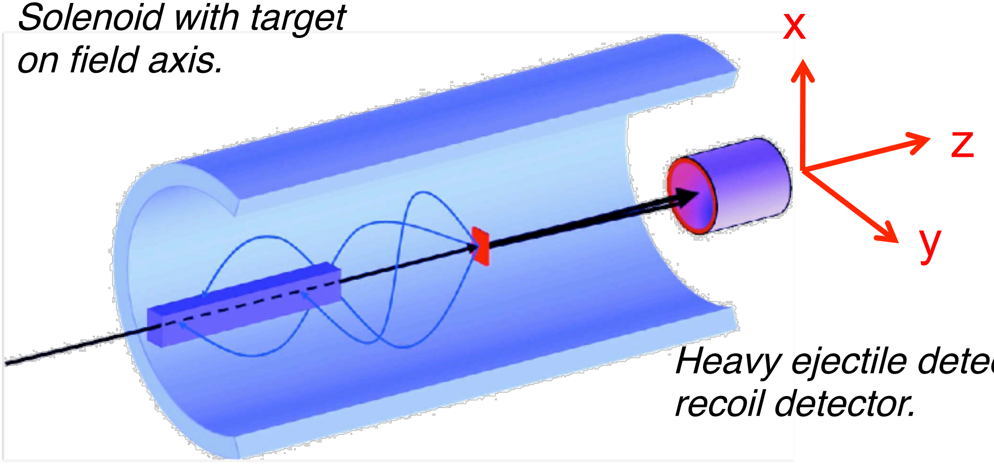






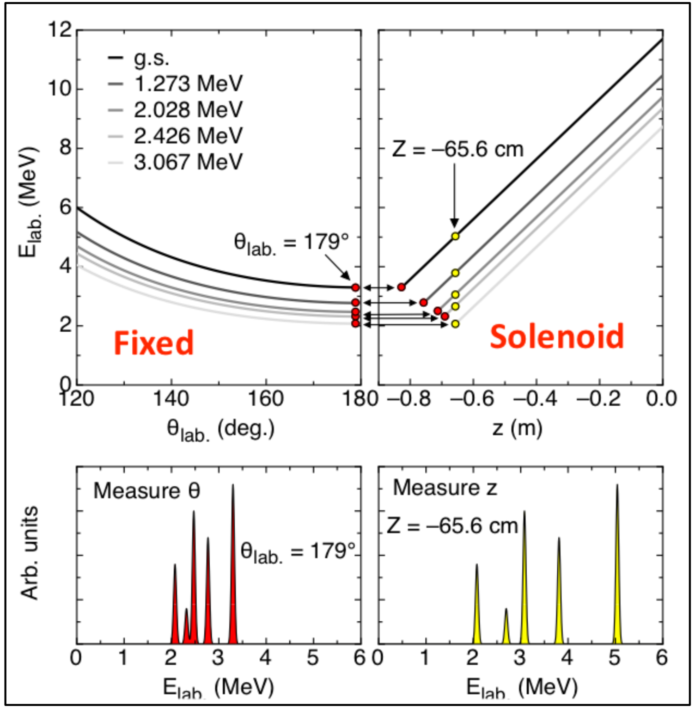
“New” Technique for Magnetic Spectrometers: Solenoid

Solenoid with target on field axis.



Heavy ejectile detected in recoil detector.

$$E_{\mathrm{cm}} = E_{\mathrm{lab}} + \frac{mV_{\mathrm{cm}}^2}{2} - \frac{mzV_{\mathrm{cm}}}{T_{\mathrm{cyc}}}$$



MEASURED QUANTITIES: position z, cyclotron period T_{cyc} and lab particle energy E_p

$$T_{\mathrm{cyc}} = \frac{2\pi}{B}\frac{m}{qe}$$

Suffers <u>no kinematic compression</u> of the Q-value spectrum

Linear relationship between E_{cm} and E_{lab}

Contribution from position resolution ~15-20 keV

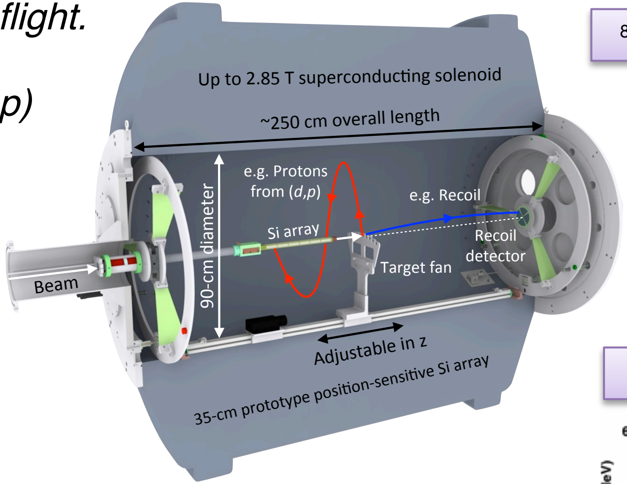
A. Wuosmaa *et al.* NIMA **580** (2007) 1290

HELIOS@ANL

Early experiments using stable beams of varying mass with intensity similar to strong ISOLDE RIBs ~1e^{7} pps.

Energy resolution of ~75 keV achieved.

Radioactive beams produced in-flight.



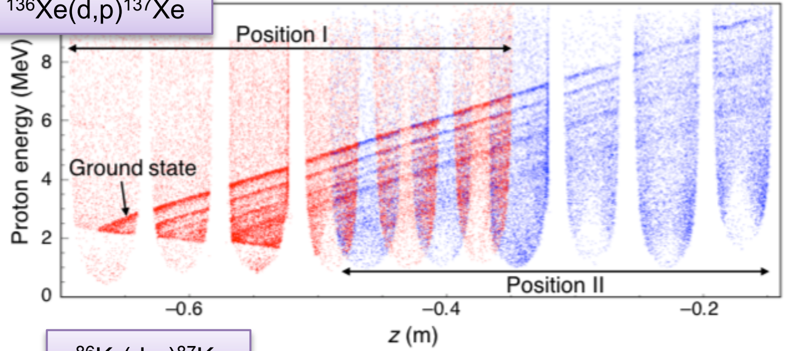
Many others – not limited to (d,p)

- $^{12,13}B$, ^{15}C, $^{18}N(d,p)$
- $^{14,15}C(d,^{3}He)$
- $^{14,15}C(d,\alpha)$

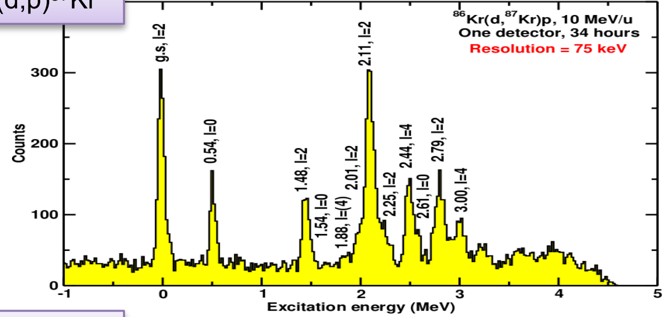
- $^{20}Ne(\alpha,p)$
- $^{10}B(p,p')$

Plan to exploit CARIBU beams and upgraded in-flight facility AIRIS.

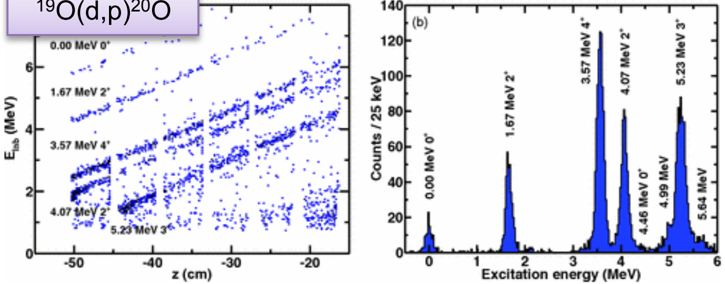
^{136}Xe(d,p)^{137}Xe



^{86}Kr(d,p)^{87}Kr



^{19}O(d,p)^{20}O



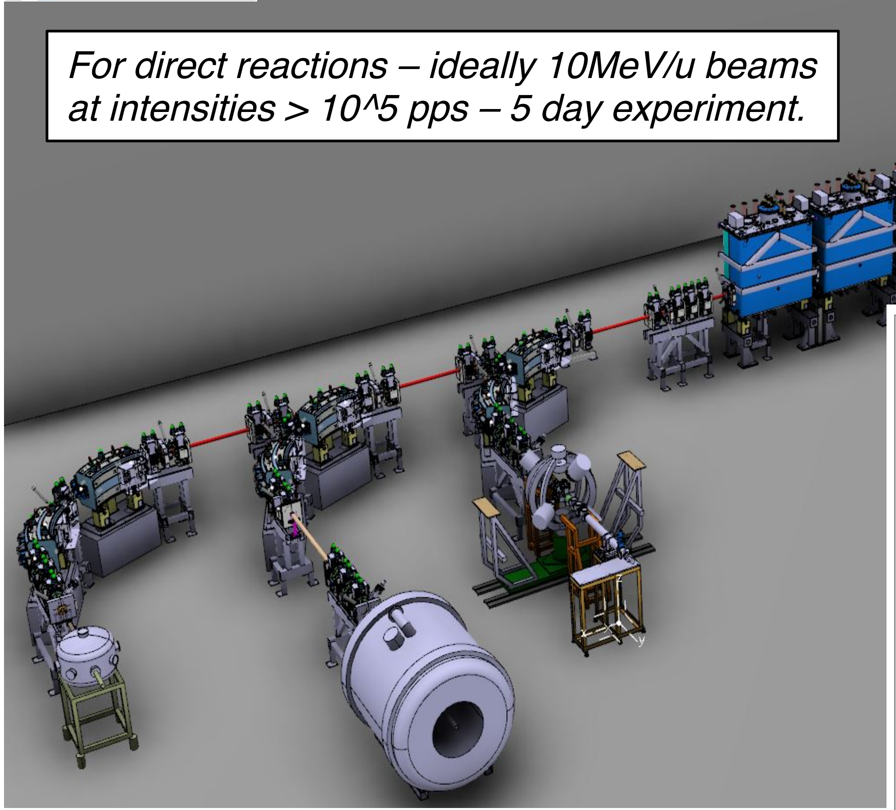
B. P. Kay *et al*, PRC **84** 024325 (2011)

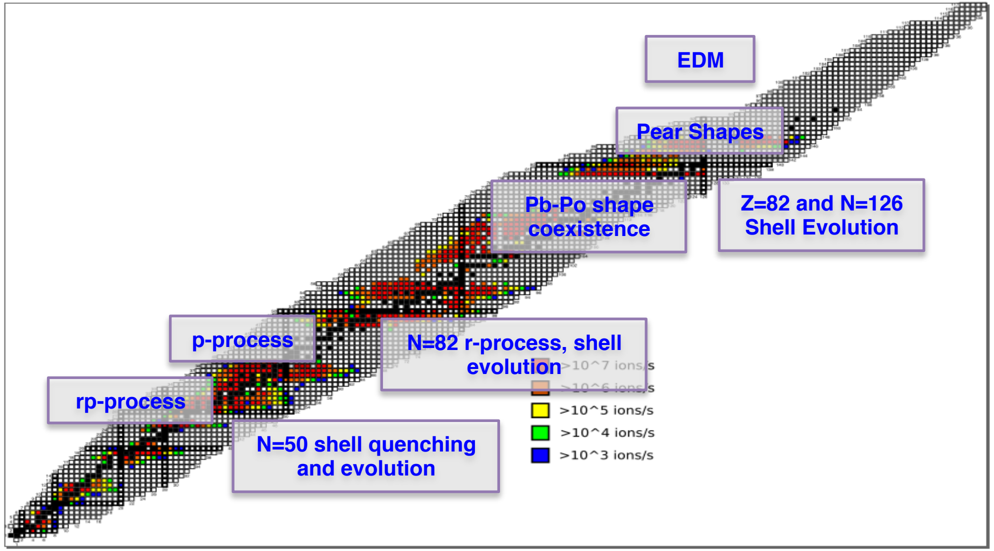
D.K. Sharp *et al*, PRC **87** 014312 (2013)

C. R. Hoffman *et. al.*, PRC **85**, 054318 (2012)

Physics at HIE-ISOLDE with a solenoid

For direct reactions – ideally 10MeV/u beams at intensities > 10^5 pps – 5 day experiment.





Getting a magnet

Magnet available from Brisbane (UQ)
OR66 4T ex-MRI magnet.

Only 10 ever made -> Argonne found three of them!
#2 SOLARIS -> FRIB
#10 ANL HEP
#5 ISS -> ISOLDE

Calicanto Bridge

Getting a magnet

Sarah

ISOLDE Solenoidal Spectrometer

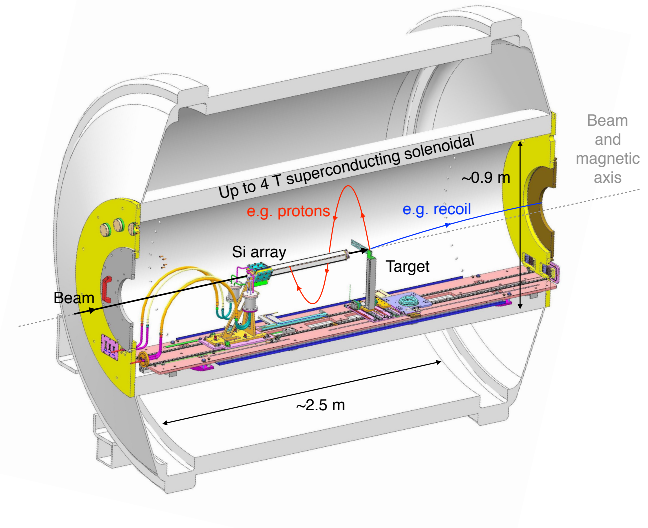
Delivered - April 2016

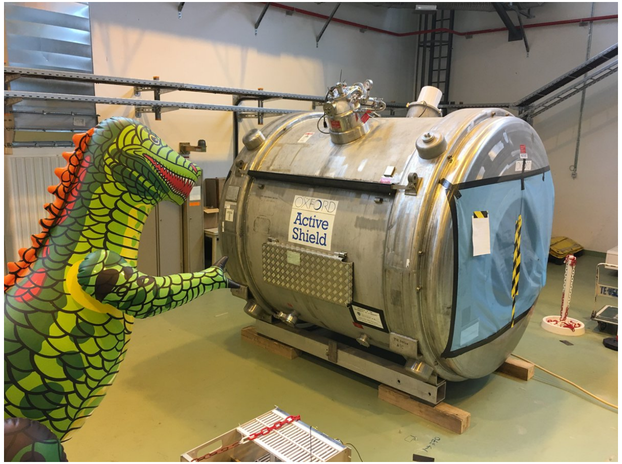
Cooled and energized - January 2017/ Feb 2017

Moved in to hall - March 2017

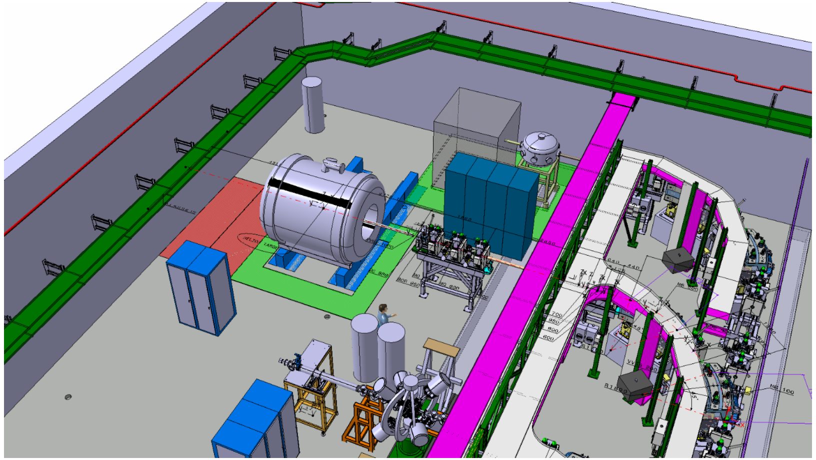
Field Mapping - November 2017

Stable beam tests - May 2018





Miniball's (and the SEC's) new neighbour



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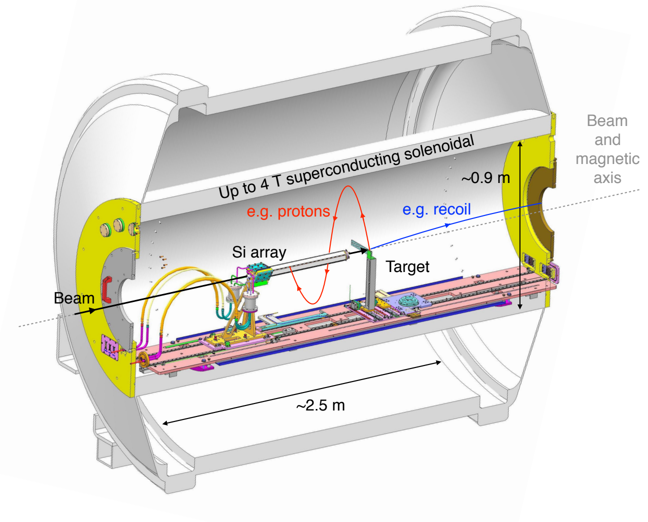
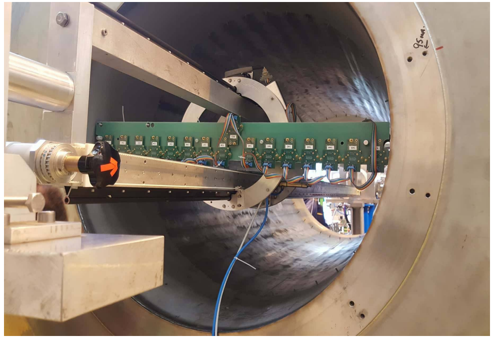
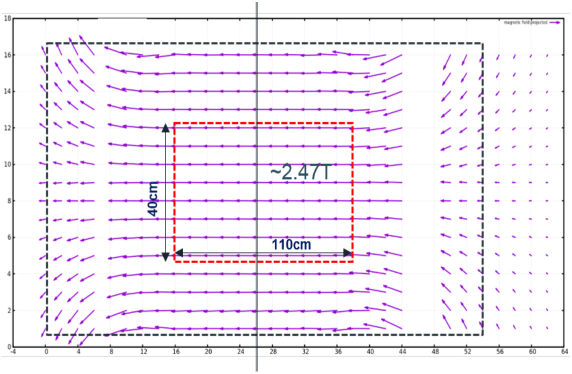


Uniformity and field pattern as expected.





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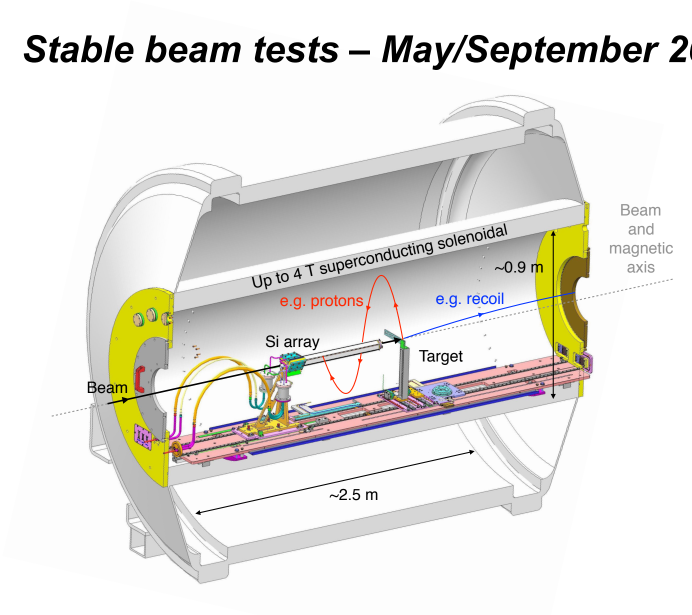
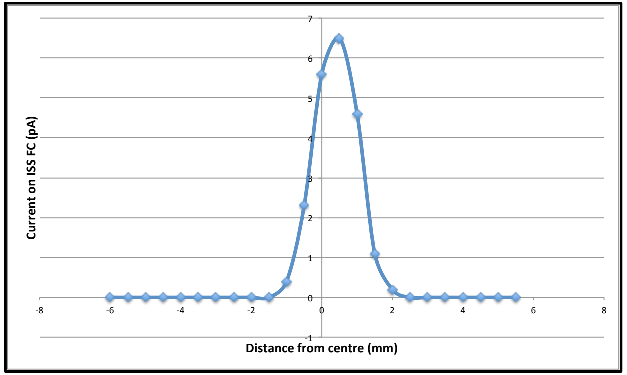
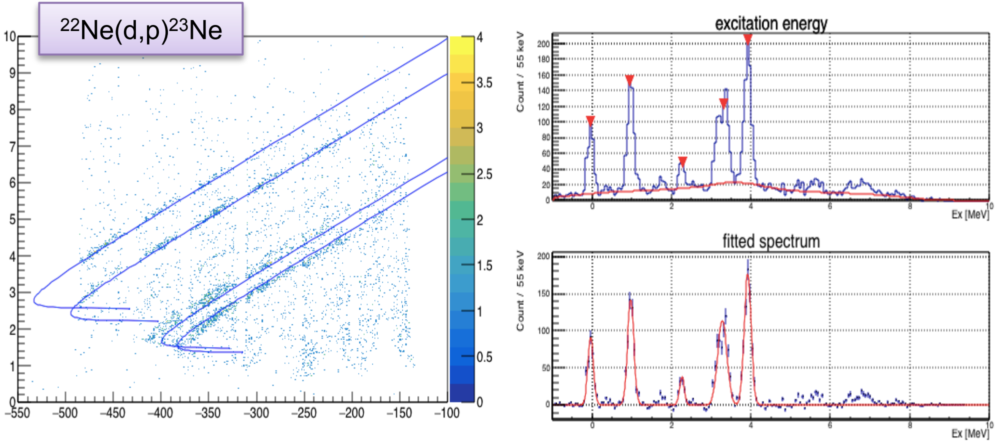




Beam profile scans – FWHM<1.5mm
Test of ANL array and DAQ - ~110keV FWHM (200ug target) – comparable with simulations.



EXP #1 IS621 – Changing shell structure near Island of Inversion

Ground states and low-lying excitations from intruder configurations have been observed.

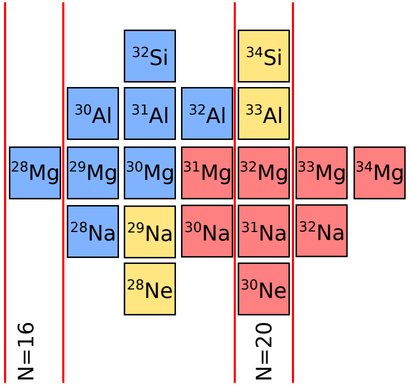
Prevalence of intruder orbitals is indicative of ***weakening N=20 shell closure****.*

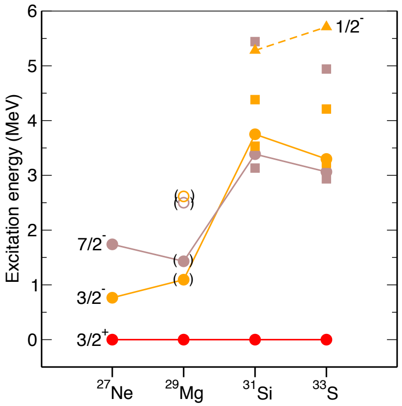
In the Ne, Al and Na isotopes there is a ***soft transition*** *to a deformed ground state.*

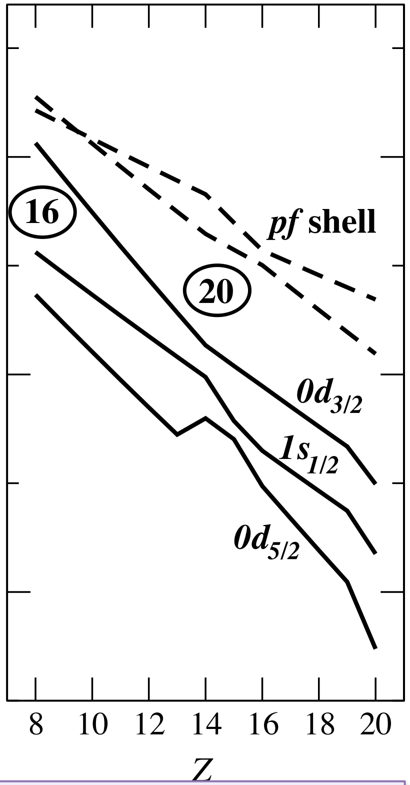
In Mg isotopes this transition is ***sharper*** *with ^{31}Mg inside the island and ^{30}Mg outside.*

Measurements of the ***single-particle properties*** *moving in to the island of inversion provide important systematic information on the behavior of the relevant orbitals and shell gaps.*

In particular the ***difference*** *between the d and s orbitals and fp -shell which define the N=20 shell gap.*







T. Otsuka *et. al.*, Eur. Phys. J. A 15, 151–155 (2002)

EXP #1 IS621– ^{28}Mg(d,p)^{29}Mg

10^6 pps 9.473 MeV/u (dE/E = 0.3%) beam – **highest HIE-ISOLDE RIB beam energy per nucleon**.

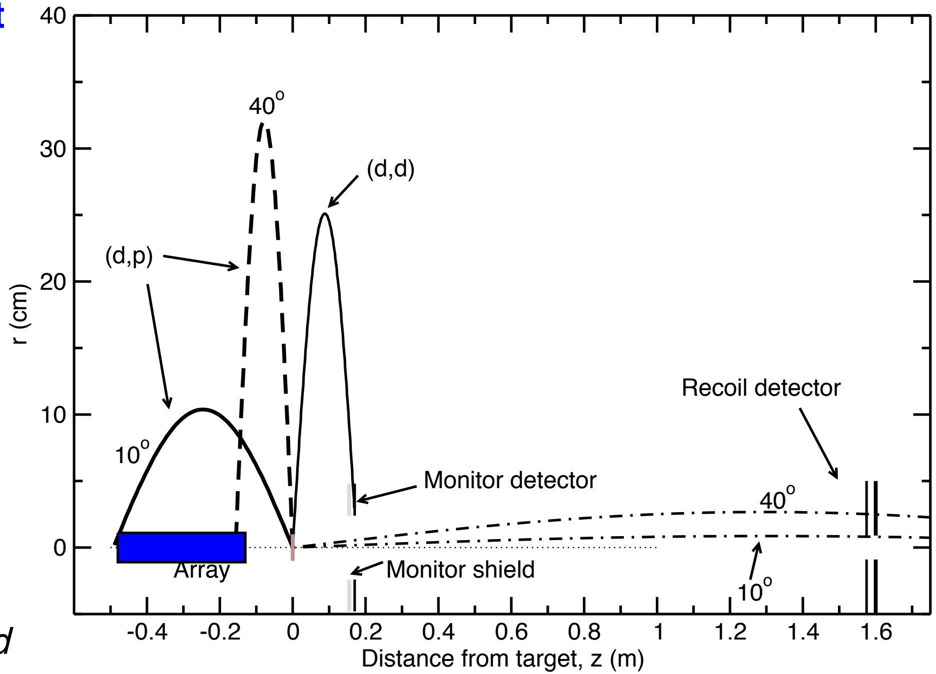
Annular detector *to monitor target thickness.*

ΔE-E recoil detector *(annular silicon) used to remove beam contamination.*

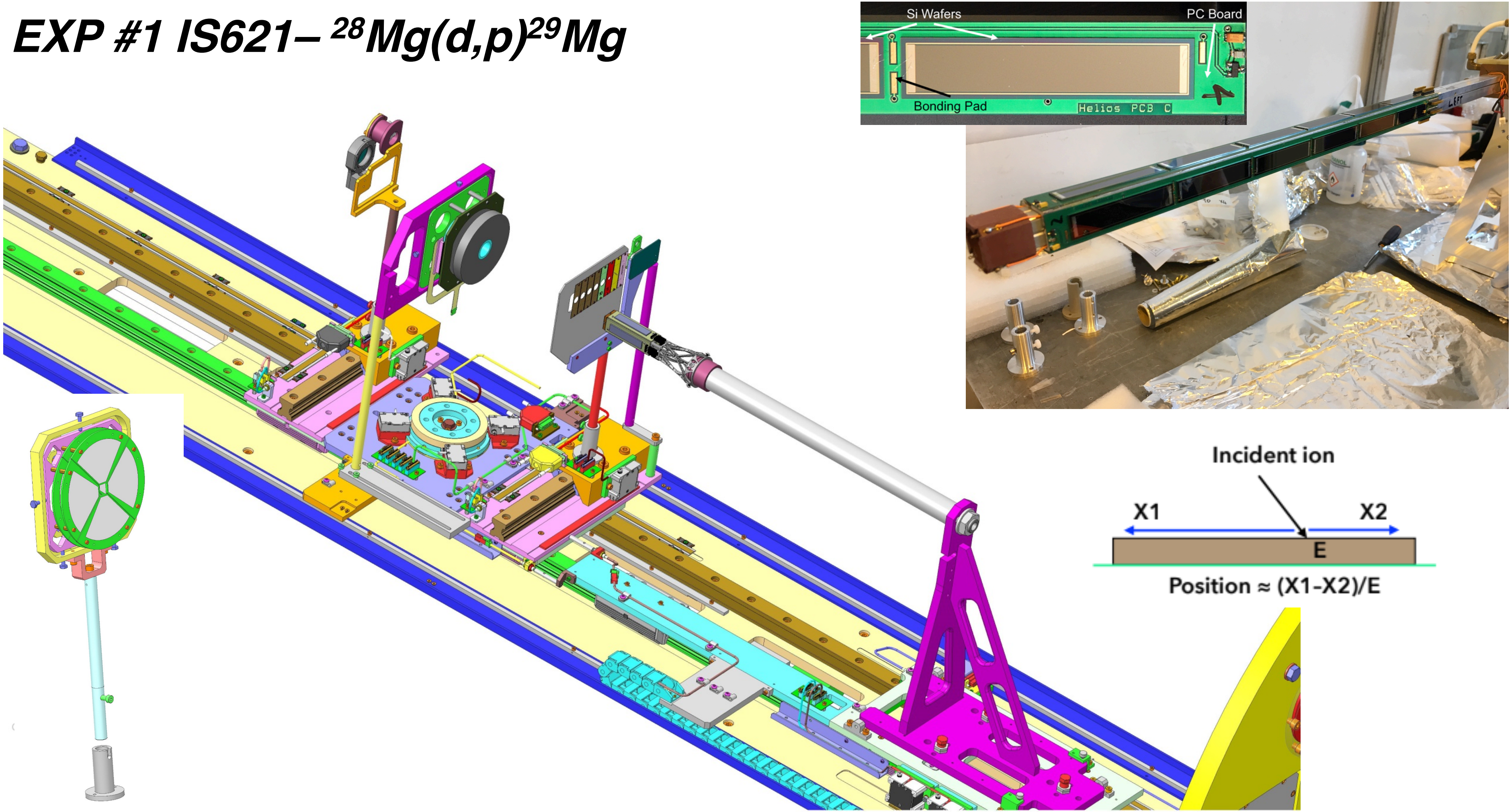
Zero-degree detector *to ascertain degree of contamination.*

Target ladder can hold ***multiple CD_2 targets (~90-150ug/cm^2)*** *and apertures.*

ISS set at a field of ***2.5T*** *– 2 target-array positions used to cover $10^o<\theta_{cm}40^o$ for states up to ~ 4MeV.*

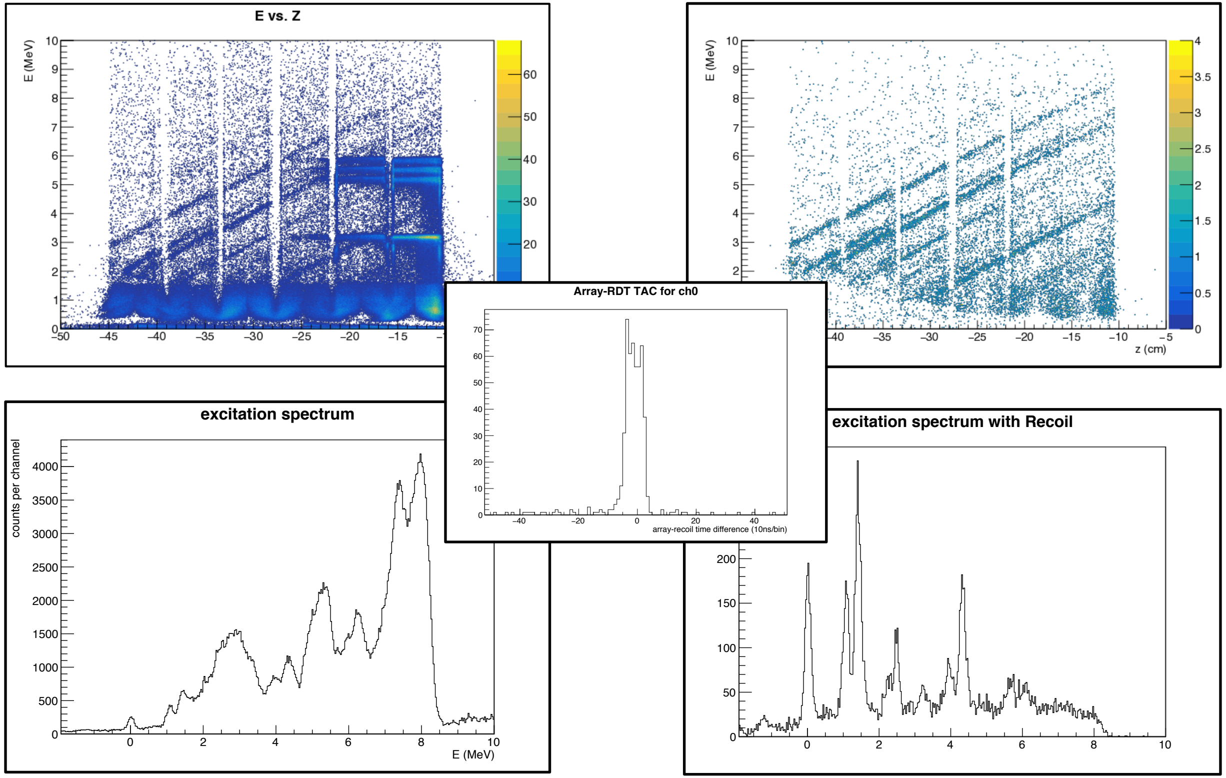


EXP #1 IS621– ^{28}Mg(d,p)^{29}Mg



EXP #1 IS621– ^{28}Mg(d,p)^{29}Mg reaction gating

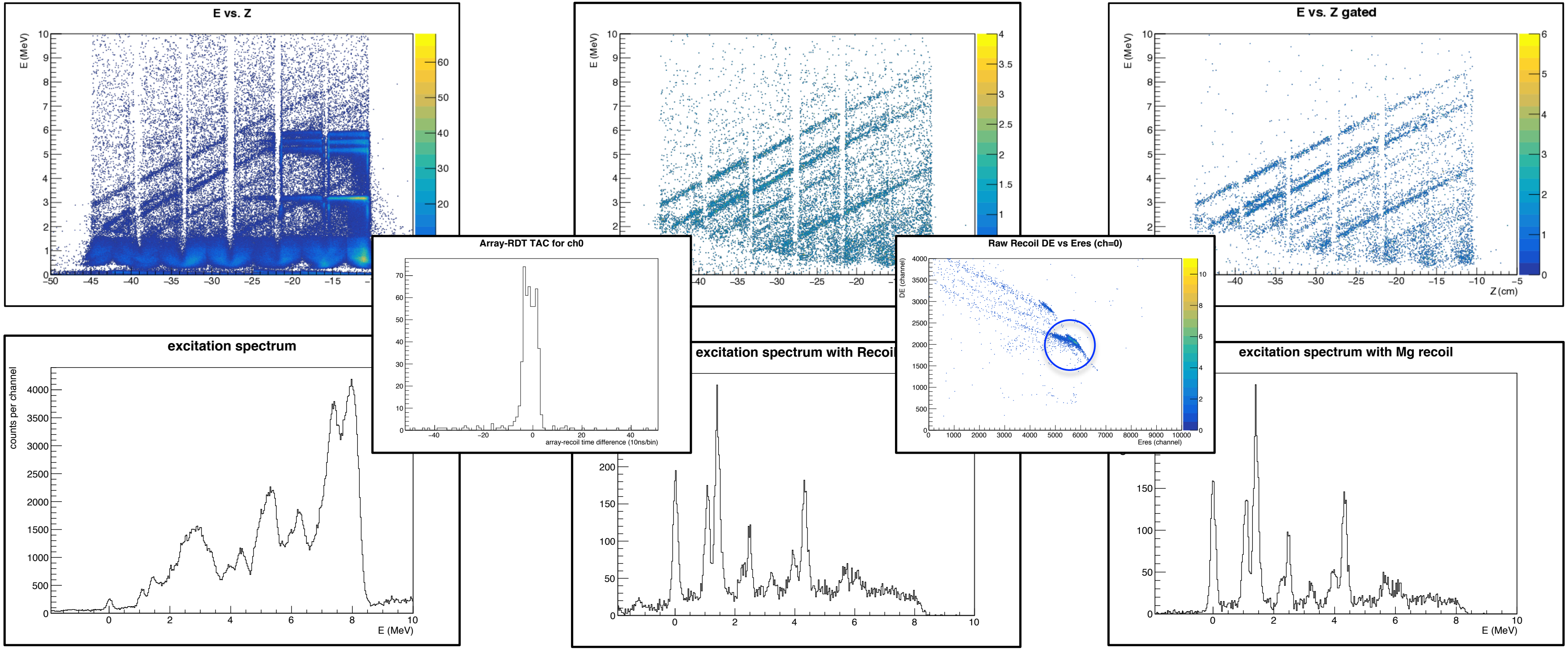
recoil-array timing



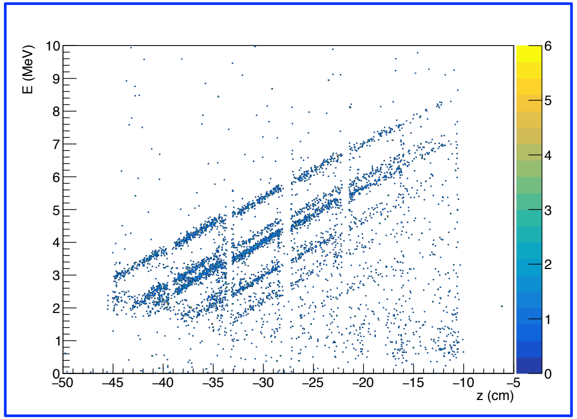
EXP #1 IS621– $^{28}Mg(d,p)^{29}Mg$ reaction gating

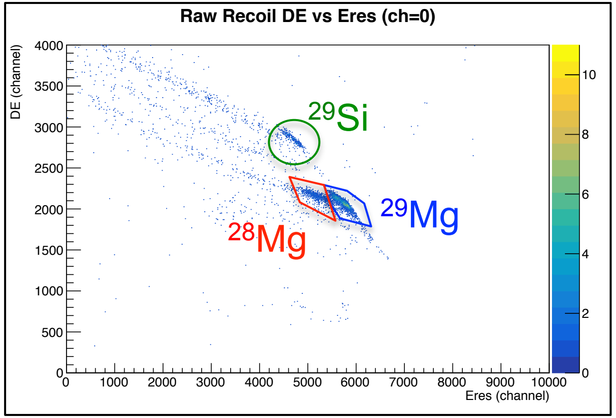
recoil-array timing

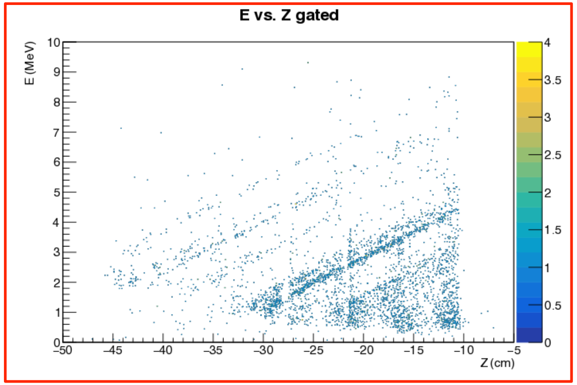
recoil energy gate

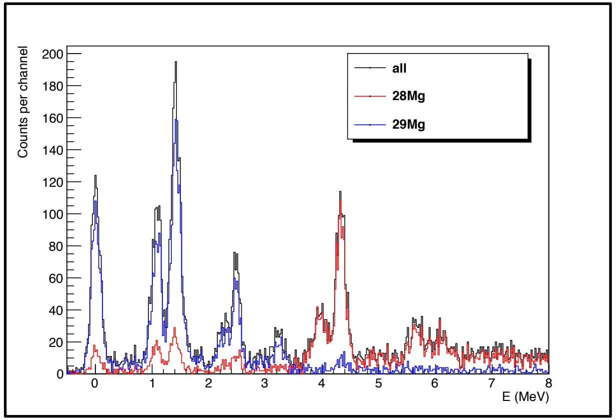


EXP #1 IS621– ^{28}Mg(d,p)^{29}Mg Bound/unbound comparison





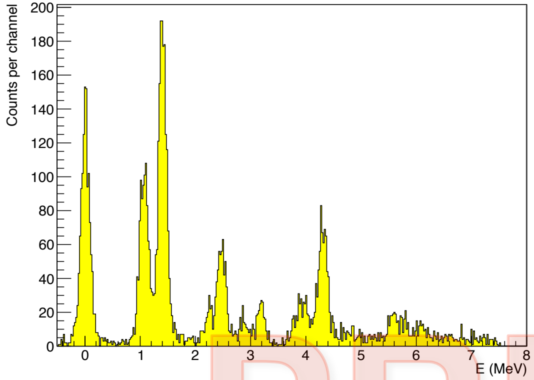




Ability to gate on ^{29}Mg recoil and ^{28}Mg component following neutron emission.

Further optimisation of gates required in order to put limits on potential gamma branches – some sign of 4.32 MeV gamma branch.

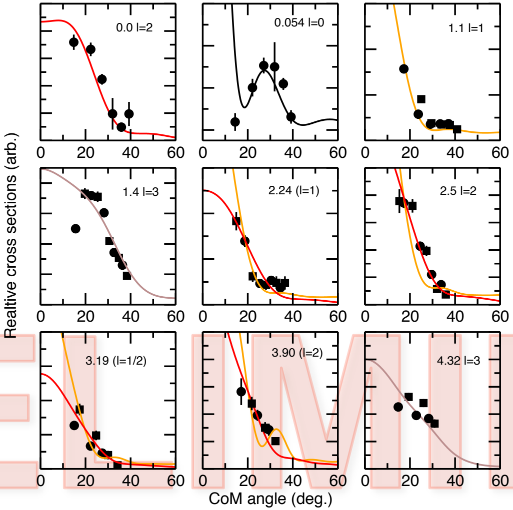
EXP #1 IS621– ^{28}Mg(d,p)^{29}Mg Angular distributions + Preliminary results

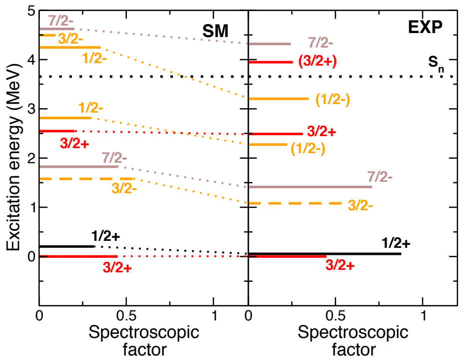


FWHM <115keV

*Angular distributions extracted for 9 states **up to 4.32 MeV** (2 unbound).*

*Compared to **DWBA** calculations to make **preliminary ℓ assignments** – calculations extrapolated for unbound states.*





*Comparison to SM calculations using the **SDPF-MU** interaction with **0p-0h** excitations only for the positive-parity states,**1p-1h** excitations for the negative-parity states, **N=20 shell closure smaller than predicted**?*

***Work still to be done** – optimise gates.*

Optimise detector calibrations.

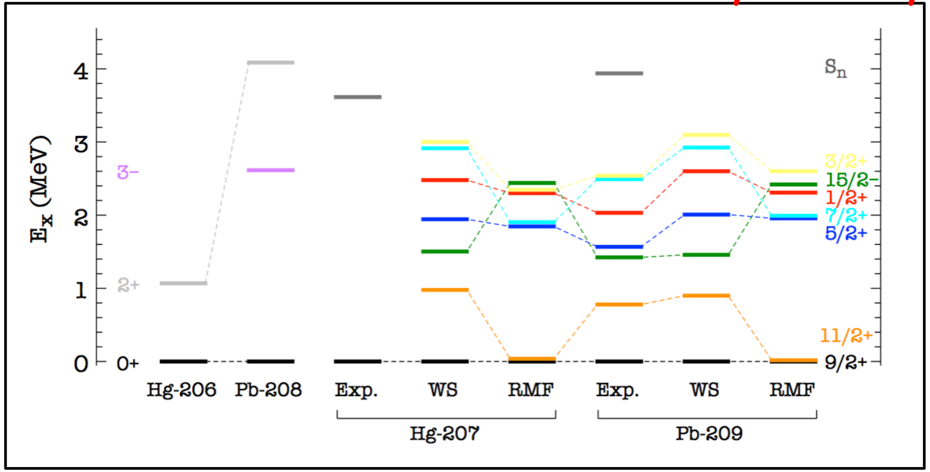
Treatment of reaction calculations for unbound states.

Comparison with new SM interaction.

PRELIMINARY

Slides courtesy of B Kay

EXP#2 IS631 - ^{206}Hg(d,p)^{207}Hg

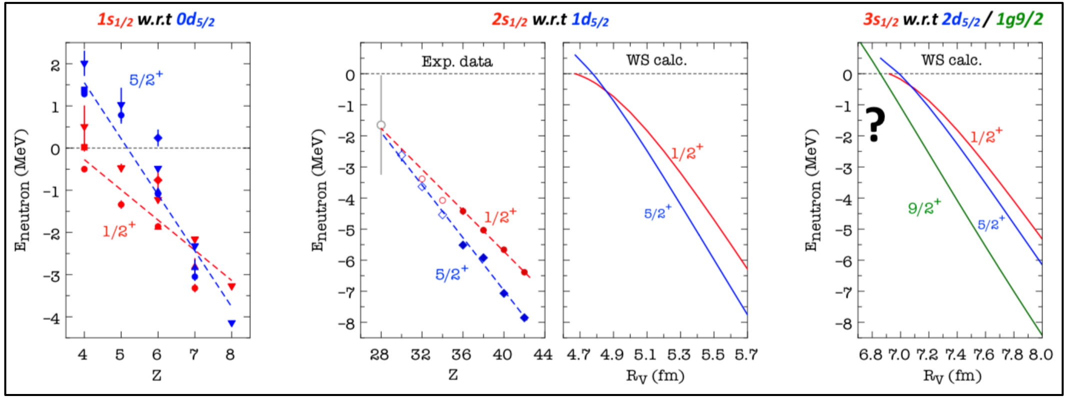


N=127 istones below Pb

Below Pb, around N=126 very little is known.

Evolution of single-particle structure not investigated in lead region – requires heavy RIB's which HIE-ISOLDE can provide

Few theoretical studies on single-particle excitations.

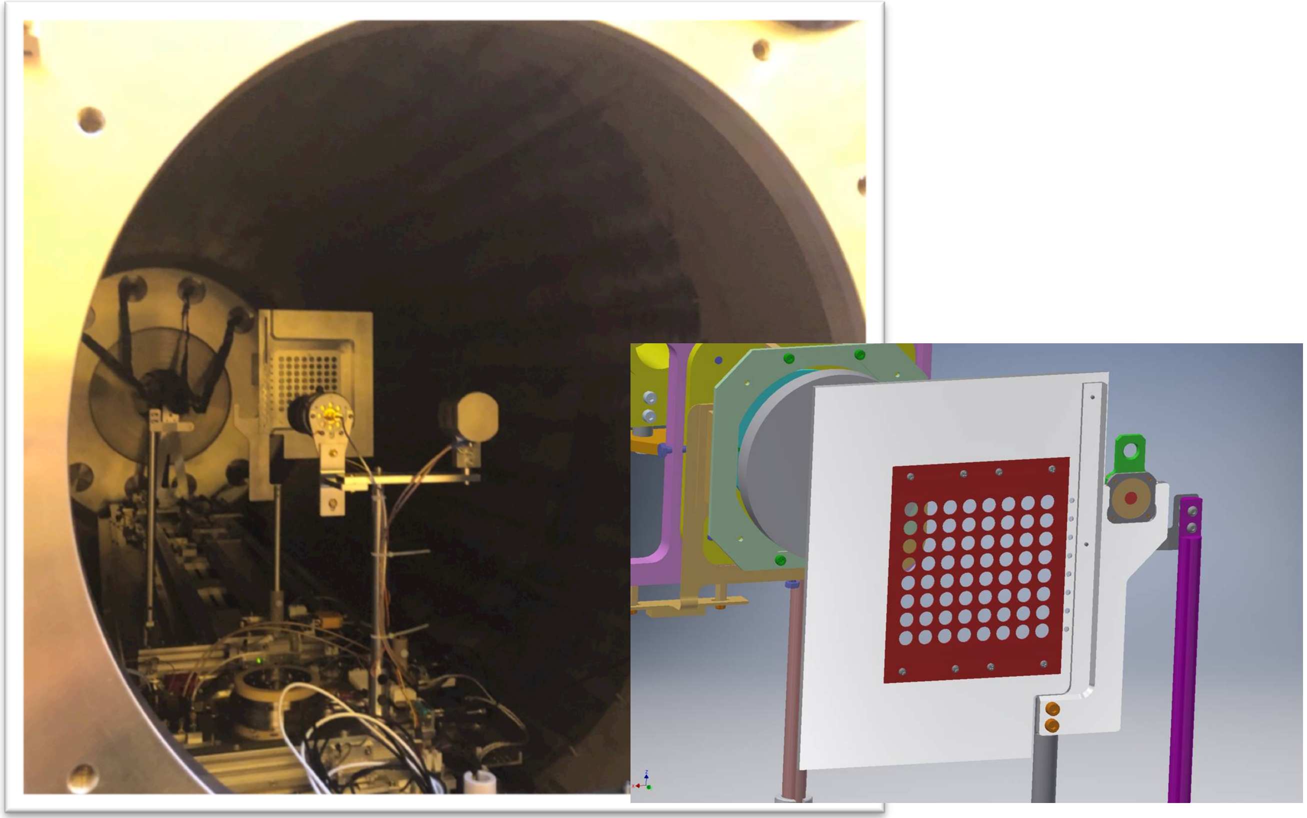


s-states in loosely bound systems *tend to linger below threshold—this feature seems to* ***dominate the structural changes in light nuclei****, and that results in* ***halo structures****. Does this characteristic of s-states play a role in loosely bound heavier systems?*

C. R. Hoffman, B. P. Kay, J. P. Schiffer, PRC **89**, 061305(R) (2014), C. R. Hoffman, B. P. Kay, J. P .Schiffer, PRC **94**, 024330 (2016), C. R. Hoffman, and B. P. Kay, Nuclear Physics News International Oct-Dec 2015. X. F. Yang et al., Phys. Rev. Le7. **116**, 182501 (2016)

EXP#2 IS631 - ^{206}Hg(d,p)^{207}Hg set up

Slides courtesy of B Kay



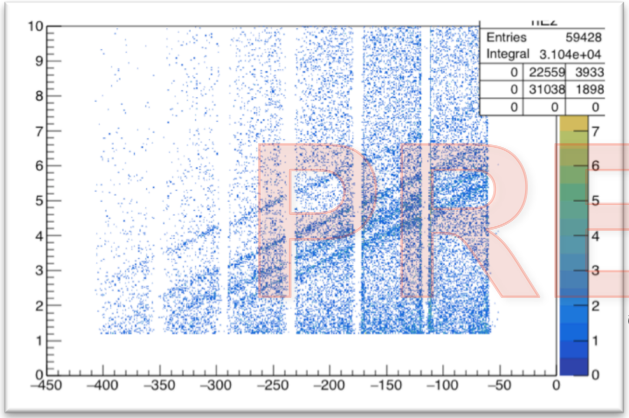
Experimental info:

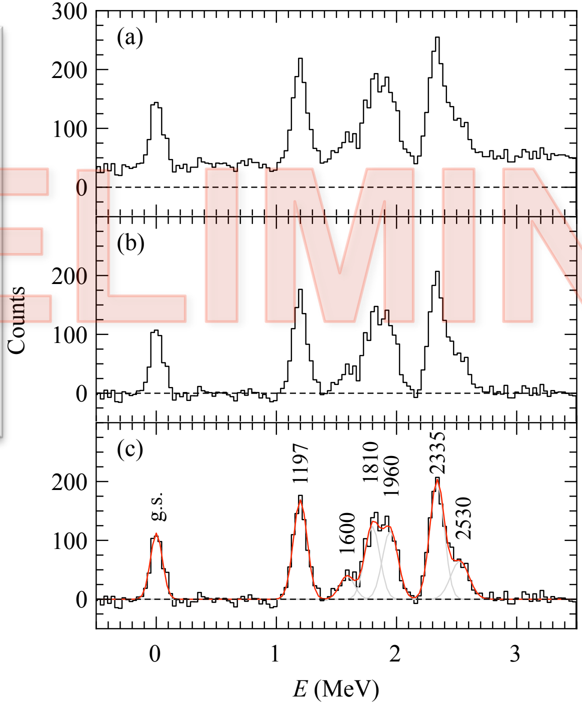
- ~***5×10^5 ions per second*** of ^{206}Hg for ~***82 hours***
- a ***7.4 MeV/u ^{206}Hg beam – highest total energy HIE-ISOLDE beam >1.5 GeV.***
- Beam ***purity of >98%***
- Measured in singles mode
- Using ***>30*** deuterated polyethylene ***targets*** of thickness around 165 μg/cm^2 (to deal with target degradation)
- ISS set to a B-field of 2.5 T

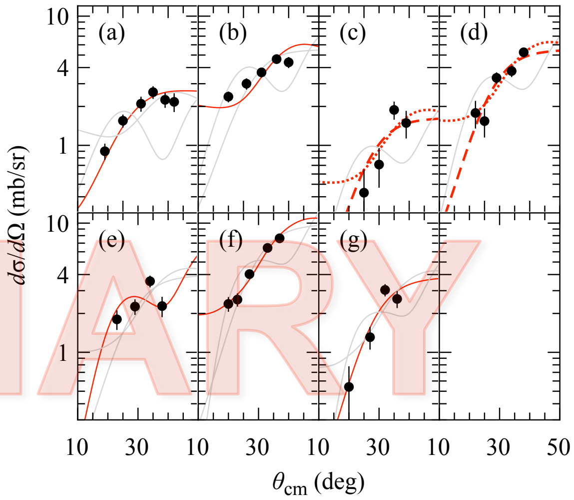
EXP#2 IS631 - ^{206}Hg(d,p)^{207}Hg preliminary results

Slides courtesy of B Kay

The bulk of the ***$0g_{9/2}$, $2d_{5/2}$, $3s_{1/2}$, $2d_{3/2}$, and $0g_{7/2}$ strength***, corresponding to l = 4, 2, 0, 2, and 4 transfer – beam energy limited cross section for higher ℓ transfer.





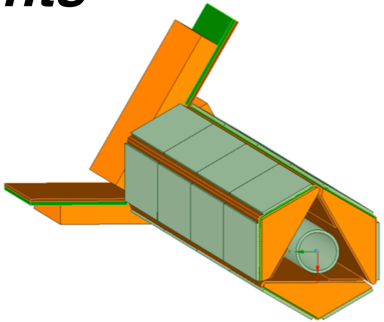


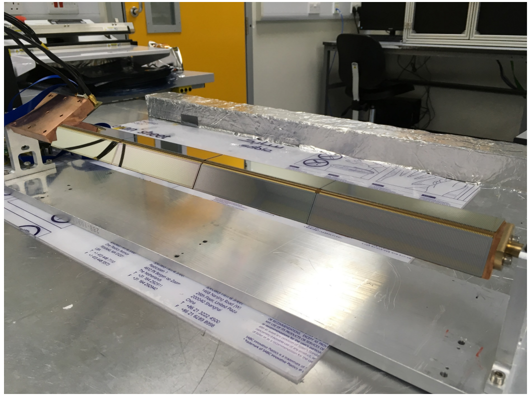
PRELIMINARY

E (keV)	ℓ	j^π	$n\ell s$	S
0	4	$9/2^+$	$1g_{9/2}$	0.82(5)
1197(5)	2	$5/2^+$	$2d_{5/2}$	0.47(6)
1600(45)	2	$5/2^+$	$2d_{5/2}$	0.13(1)
1810(20)	2	$5/2^+$	$2d_{5/2}$	0.42(3)
1960(30)	0	$1/2^+$	$3s_{1/2}$	1.00(13)
2335(6)	2	$3/2^+$	$2d_{3/2}$	1.00(7)
2530(20)	4	$7/2^+$	$1g_{7/2}$	0.62(6)

Outstanding tasks include: refining the analysis of the background and of the angular distributions, then interpreting the findings. ***All data presented are preliminary and subject to change***

Conclusions and future developments





First two experiments *with ISS have both been successful.*

Also for HIE-ISOLDE operating ***at new extremes of energy****.*

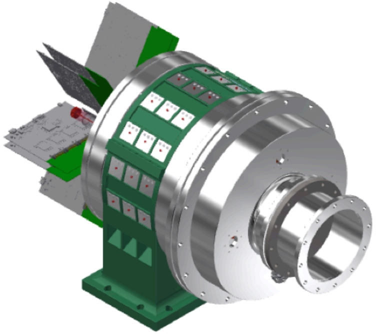
Operation of ISS in ***two different mass regions*** *demonstrated.*

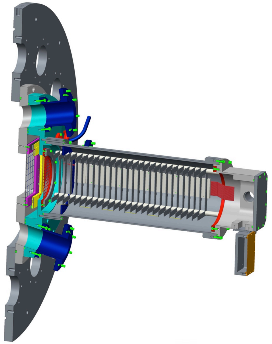
New array *(alpha tests to start in new year – commissioning during LS2).*

New fast counting recoil detector *– ready for after LS2.*

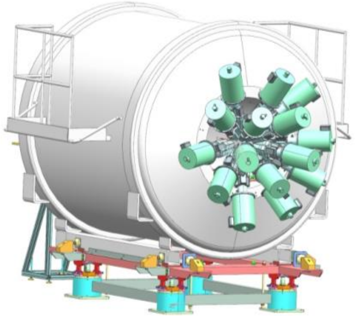
SpecMat *– time projection chamber with gamma ray detection. Full system characterized March 2019 – move to ISOLDE by end of 2019.*

Recoil spectrometer tests *in the solenoid field.*





Riccardo Raabe



Francesco Recchia

ISS collaboration

MANCHESTER 1824
The University of Manchester

Argonne NATIONAL LABORATORY

ISS ISOLDE Solenoidal Spectrometer

UNIVERSITY OF LIVERPOOL

ISOLDE

UNIVERSITY OF SURREY

UNIVERSITY OF THE WEST of SCOTLAND UWS

KU LEUVEN

UNIVERSITY OF CONNECTICUT 1881

CSIC
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

INFN Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Legnaro

Universidad de Huelva

THE UNIVERSITY of EDINBURGH

LSU
LOUISIANA STATE UNIVERSITY

TECHNISCHE UNIVERSITÄT DARMSTADT

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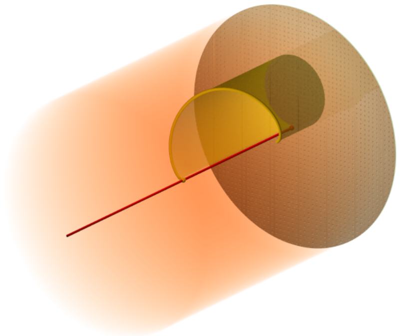
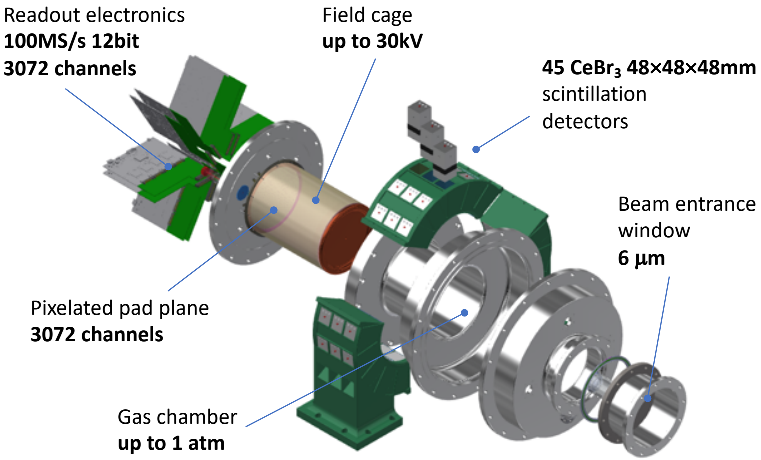
Science & Technology Facilities Council

JYVÄSKYLÄN YLIOPISTO
UNIVERSITY OF JYVÄSKYLÄ

UiO : University of Oslo

SpecMat




Readout electronics
100MS/s 12bit
3072 channels
Field cage
up to 30kV
45 $CeBr_3$ 48×48×48mm
scintillation
detectors
Beam entrance
window
6 μm
Pixelated pad plane
3072 channels
Gas chamber
up to 1 atm