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Single-particle structure study in neutron-rich Ca through ^{50}Ca(d,p)

ISOLDE Solenoidal Spectrometer

Andreas Ceulemans

72nd INTC meeting

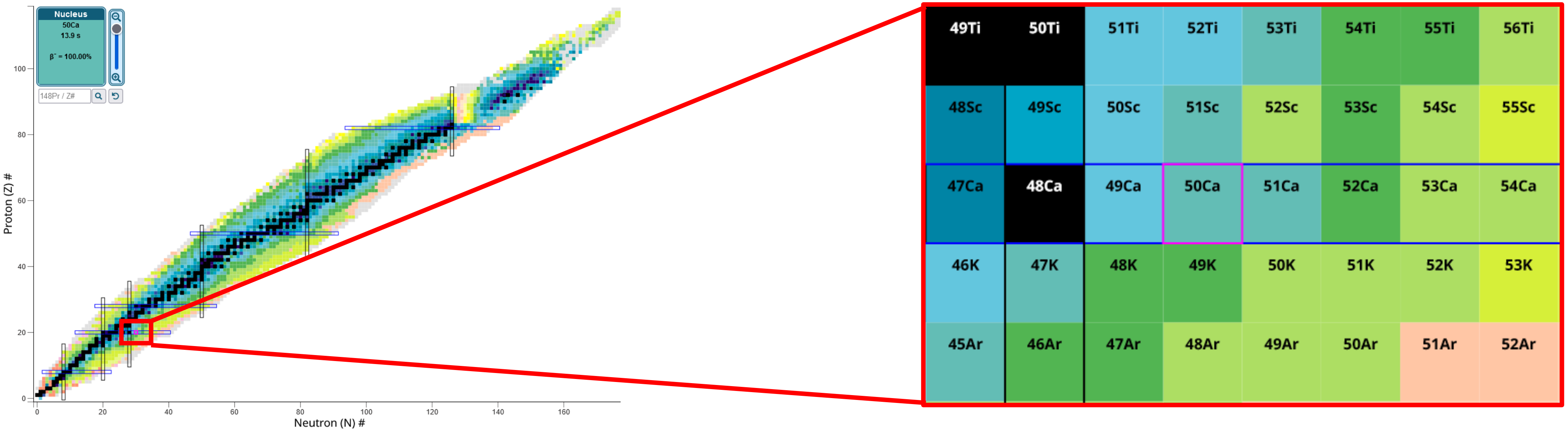
8 February 2023

Link to proposal INTC-P-652

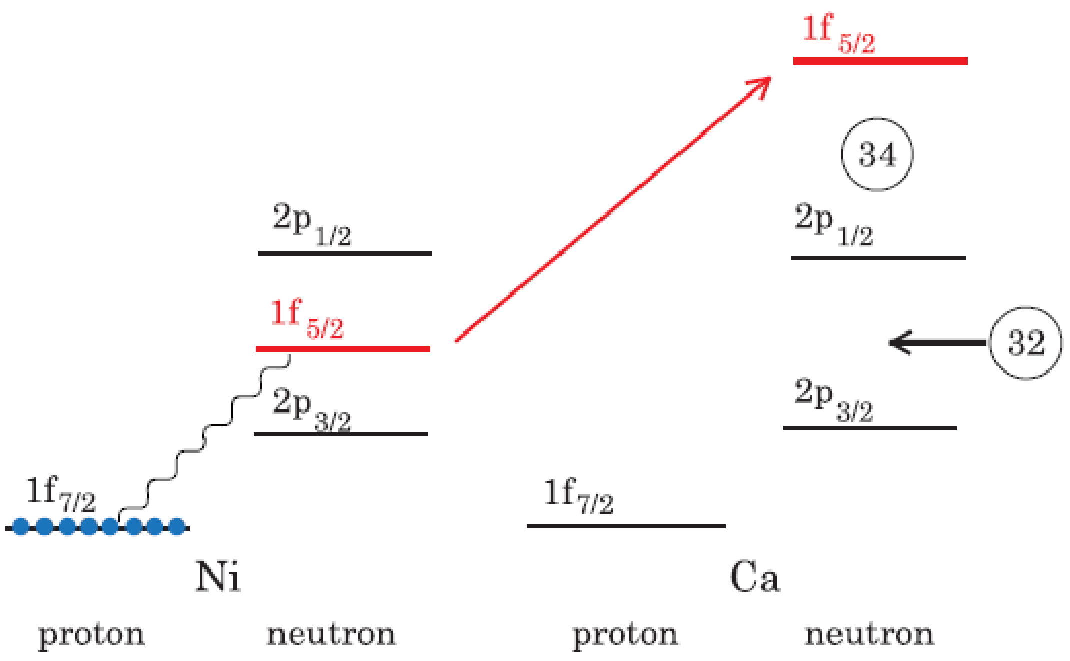
Physics case

- ^{40}Ca and ^{48}Ca: stable doubly magic isotopes
- Evidence for new neutron magic numbers N = 32,34

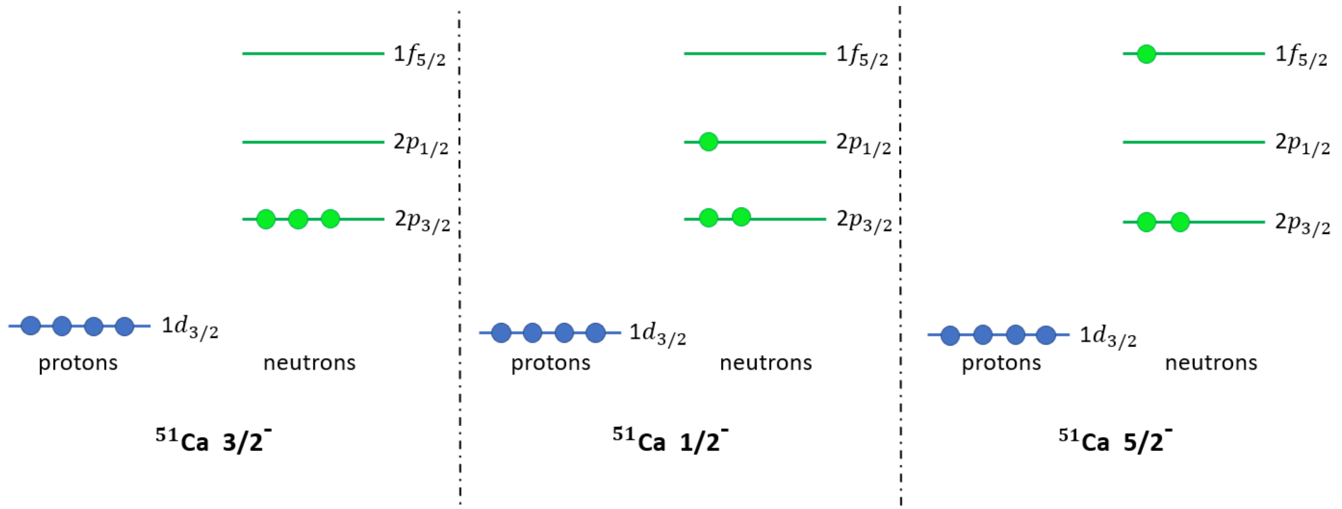
by measurements of mass, 2^{+}energy, charge radius



New magic numbers



[1]



- attractive interaction between $\pi 1f_{7/2}$ and $\nu 1f_{5/2}$
- Ca has full $\pi 1d_{3/2}$ but empty $\pi 1f_{7/2}$
- Single neutron transfer can be used to investigate N=32,34 gaps

[1] T. Otsuka and Y. Tsunoda. The role of shell evolution in shape coexistence. Journal of Physics G: Nuclear and Particle Physics, 43(2):024009, 2016

Current status of ^{51}Ca

E(level) (keV)	XREF	J^{π}(level)	$T_{1/2}$(level)	E(γ) (keV)	I(γ)	Final Levels	
0.0	AB DEFG	3/2(-)	10.0 s *8* % β^- = 100 % β^-n = ?				
1240 *40*	D						
1718.0 *10*	B F	(1/2-)		1718 *1*	100	0.0	3/2(-)
1940 *40*	D						
2378.06 *20*	B FG	(5/2-)		2378.0 *2*	100	0.0	3/2(-)
2934.1 *10*	B F	(3/2-)		2934 *1*	100	0.0	3/2(-)
3462.13 *20*	AB FG	(7/2-)		3462.0 *2*	100	0.0	3/2(-)
3477.5 *23*	F	(5/2-)		3479 *4*	100	0.0	3/2(-)
3500.9 *9*	B			1123 *1* 3500 *2*	11 *2* 100 *11*	2378.06 0.0	(5/2-) 3/2(-)
3580 *40*	D						
3844.1 *3*	FG	(7/2+)		1466.0 *2*	100	2378.06	(5/2-)

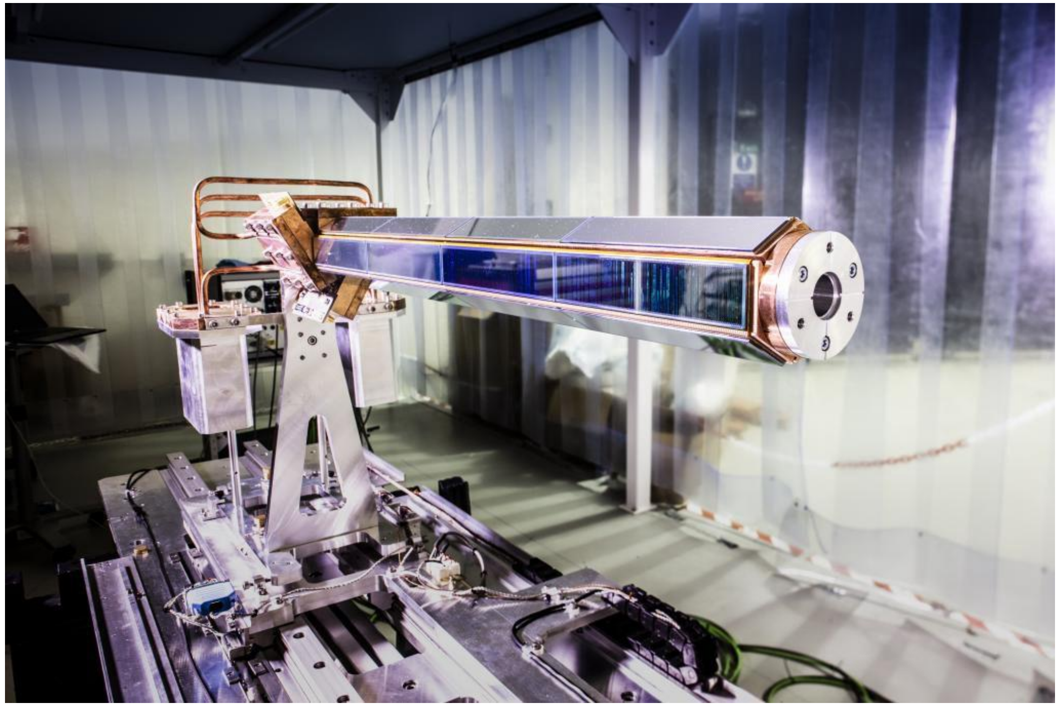
Spin assignments from beta-decay (A,B) and deep-inelastic reactions (F,G)

+ info from one-neutron knockout (Enciu, 2022):

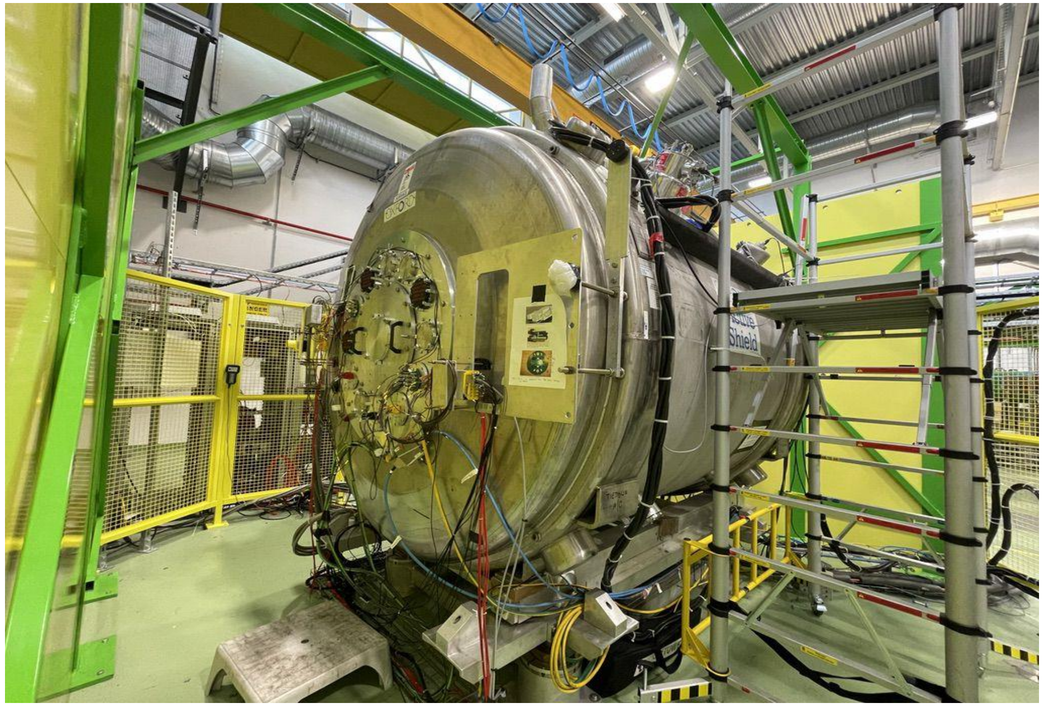
- Firm assignment ($7/2^-$ for 3.46 MeV state)
- tentative $1/2^-$ for 1.72 MeV + detection of other states

Table from: National nuclear data center, NuDat 3 , https://www.nndc.bnl.gov/nudat3/getdataset.jsp?nucleus=51Ca&unc=NDS, retrieved 30/01/2023
M. Enciu et al., Phys. Rev. Lett, 129(26), 2022

^{50}Ca(d,p) using the ISS detector



Solenoid can produce magnetic field up to 2.5T

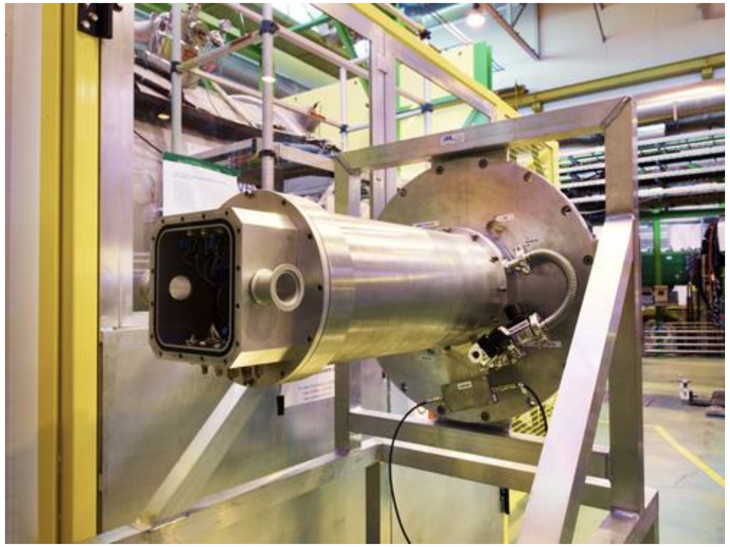


Si-array consists of DSSD's for detecting protons

Auxilary detectors

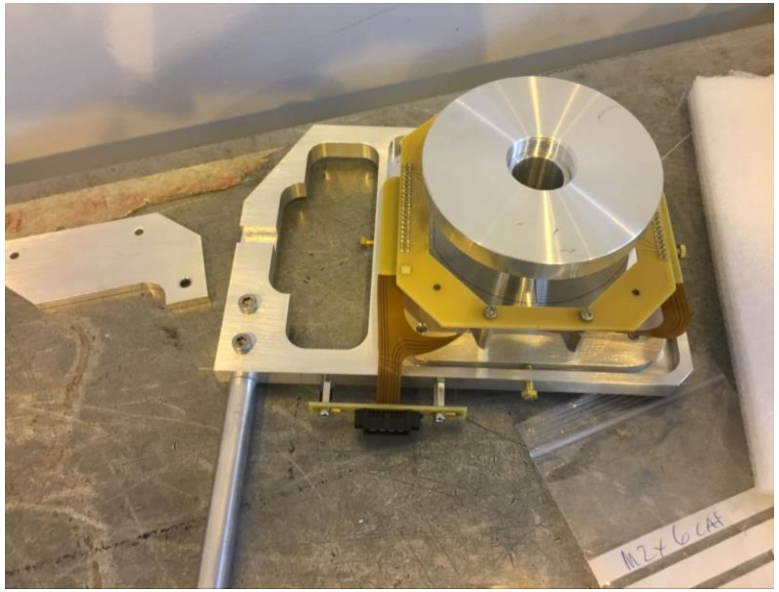
Gas filled recoil detector

- MWPC chamber
- Bragg chamber



Elastic scattering detector

- Micron S1 double-side silicon detector
- Shielded by aluminum plate

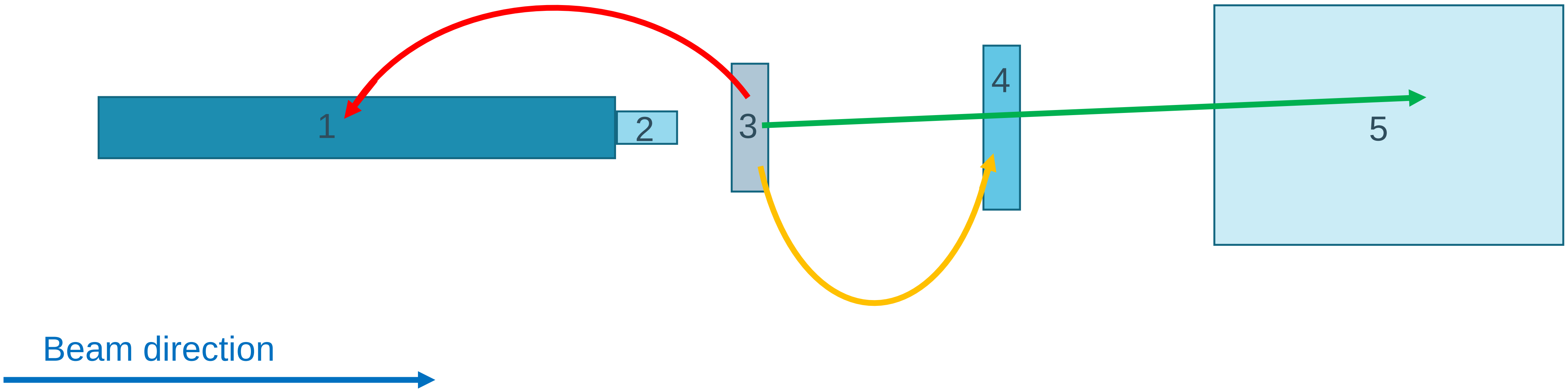


Schematic Setup

<u>Legend</u>

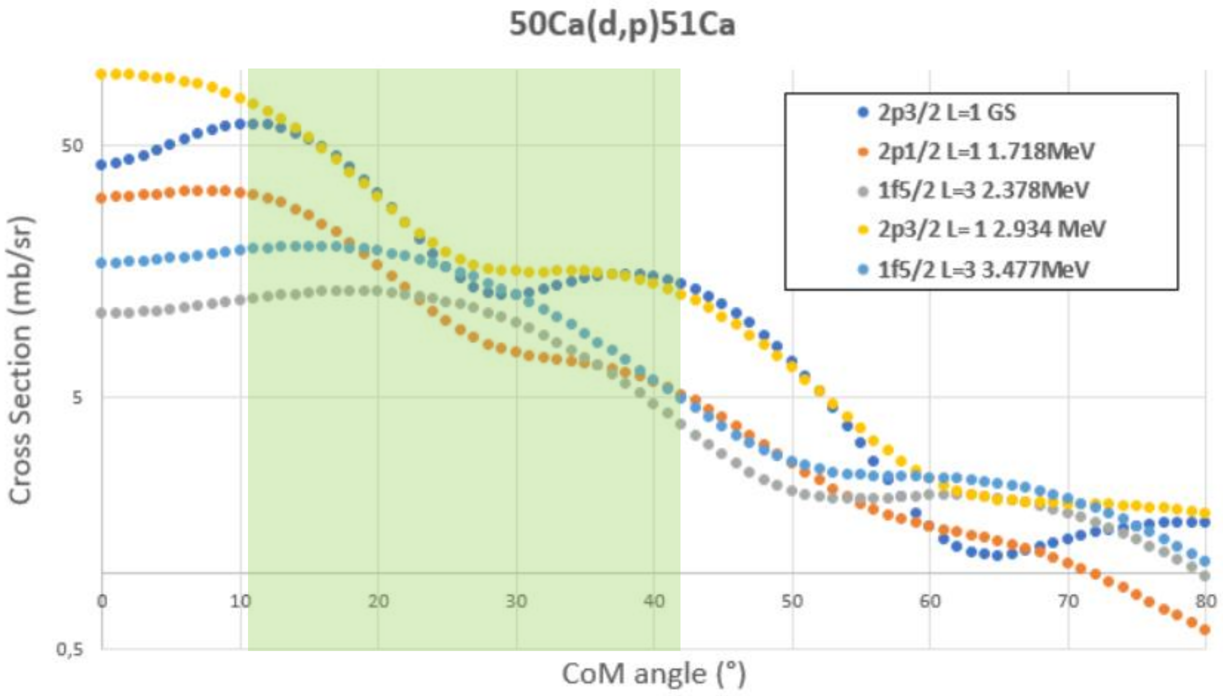
1) Si array
2) Array blocker
3) Target
4) Scattering detector
5) Gaseous recoil detector

Proton
Deuteron
^{51}Ca Recoil

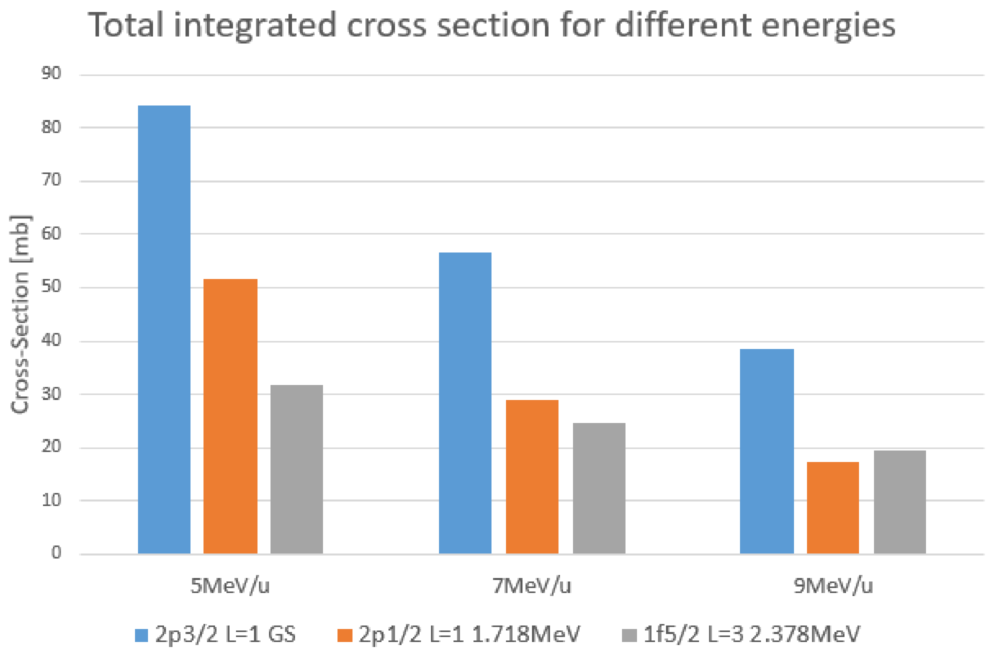


Cross sections

- Balance between max excitation energy and q-value matching



Protons incident on array



DWBA calculations performed using Fresco: . J. Thompson. Coupled reaction channels calculations in nuclear physics. Computer physics reports, 7(4):167–212, 1988.

Treshold information

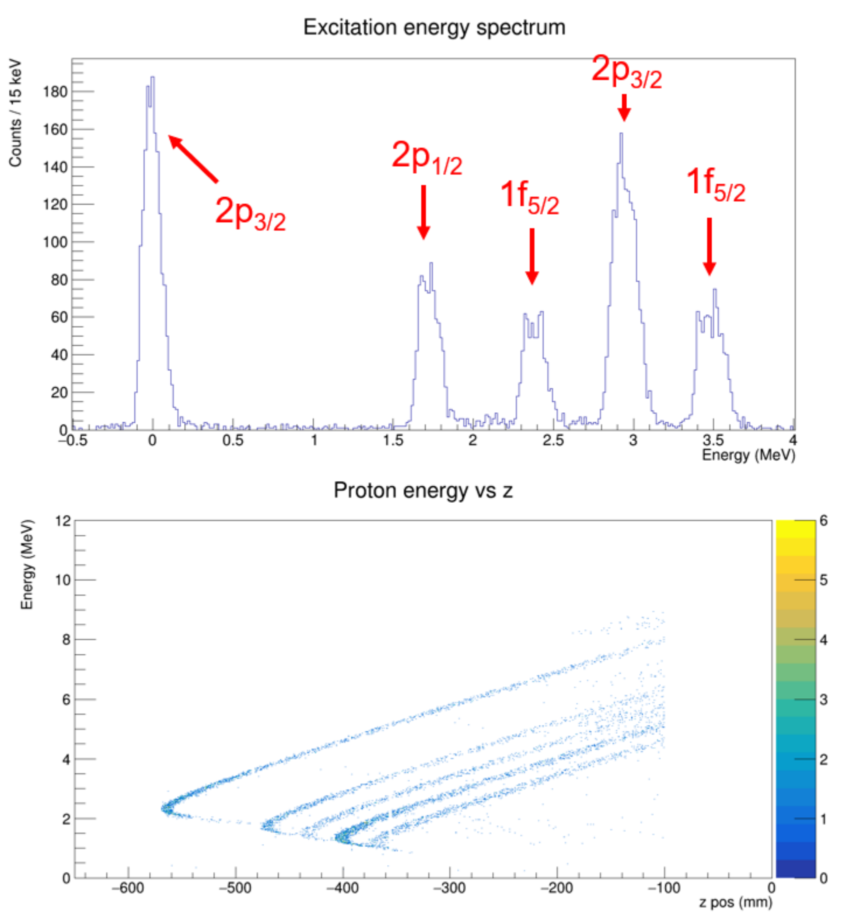
Neutron separation energy ^{51}Ca
S_n = 4.814 MeV

- Proton detection treshold ~1MeV
- Lower CM angle = lower energy

States of interest [MeV]	Spin
GS	$3/2^-$
1.72	$(1/2^-)$
3.48	$(5/2^-)$

Beam Energy	Highest Ex with E_{proton} > 1 MeV @ 10°
6 MeV	3.4 MeV
7 MeV	4.2 MeV
8 MeV	5.0 MeV
9 MeV	5.7 MeV

Simulation in nptool



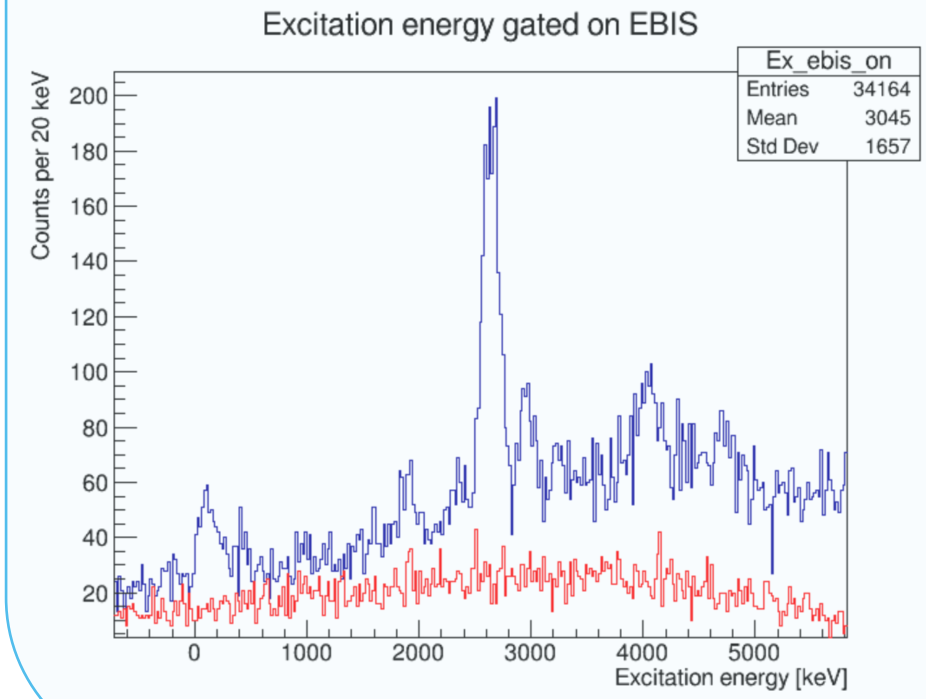
For 7MeV/u and 200µg/cm^2 CD_2 target

State	Counts on Array (SF=1)
$2p_{3/2}$ GS	1617
$2p_{1/2}$ 1.7 MeV	876
$1f_{5/2}$ 2.4 MeV	673
$2p_{3/2}$ 2.9 MeV	1761
$1f_{5/2}$ 3.5 MeV	841

Simulation made using nptool software
A Matta, P Morfouace, N de Séréville, F Flavigny, M Labiche, and R Shearman. Nptool: a simulation and analysis framework for low-energy nuclear physics experiments. Journal of physics. G, Nuclear and particle physics, 43(4):45113–, 2016

^{50}Ca production yield

Previous IS587 experiment
(estimated yield of ~3E4/μC)



Information Source	Production Yield (1/μC)	Yield at setup (1/μC)
ISOLDE Yield Database	2.5E5	1.25E4
Communication with target team	4.0E5	2.0E4

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Overview of experiments

Non-exhaustive list

Type of experiment	Isotopes	Date	Location
β-decay	^{52}K -> ^{52}Ca , ^{52}Ca -> ^{52}Sc , ^{52}Sc -> ^{52}Ti	A. Huck et al., Phys. Rev. C, 31:2226–2237, 1985	ISOLDE
β-decay	$^{51-53}$K -> $^{50-53}$Ca	F. Perrot et al., Phys. Rev. C, 74:014313, 2006	ISOLDE
Deep inelastic transfer	^{238}U on ^{48}Ca (1.31 GeV)	M. Rejmund et al., Phys. Rev. C, 76:021304, 2007	GANIL
One-neutron knockout	^{52}Ca (p, pn)	M. Enciu et al., Phys. Rev. Lett, 129(26), 2022	RIKEN
Transfer	^{50}Ca (d,p)	Not published yet, performed end 2022	RIBF

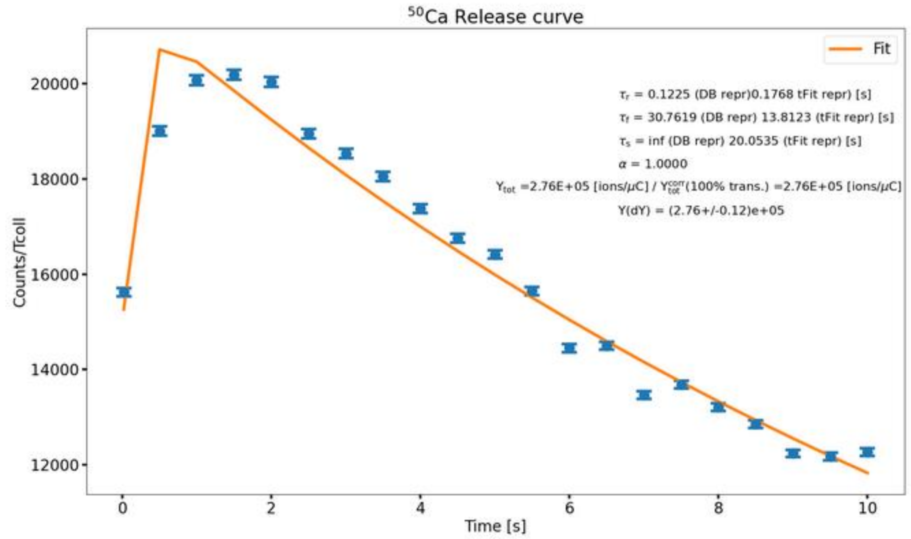
Thanks for listening

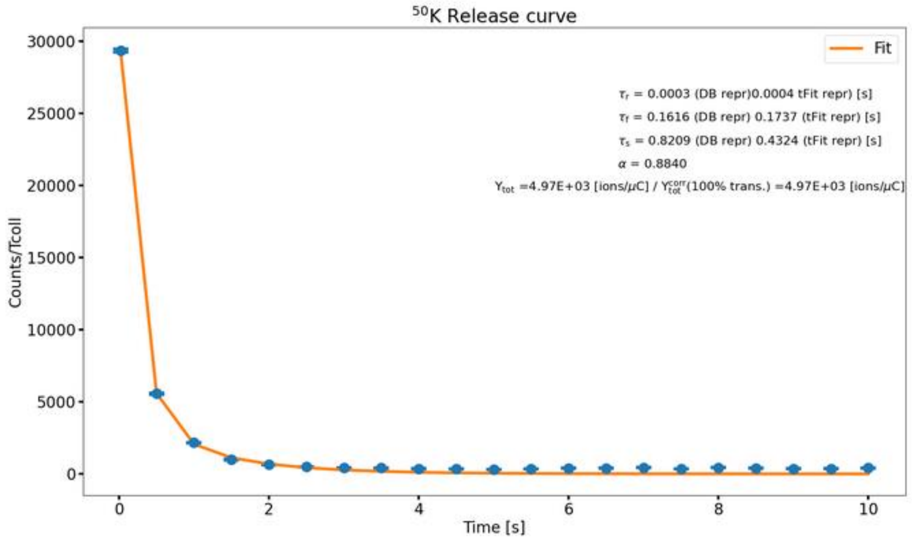
Backup Slides

Beam contaminants

- ^{50}Ca releases much slower than ^{50}K
- $T_{1/2}(^{50}Ca)$ = 14 s vs $T_{1/2}(^{50}Ca)$ = 0.5 s
- ^{50}Ti should be controllable
- Beam gate technique can be used
- 17+ charge state does not yield any significant

EBIS contaminants

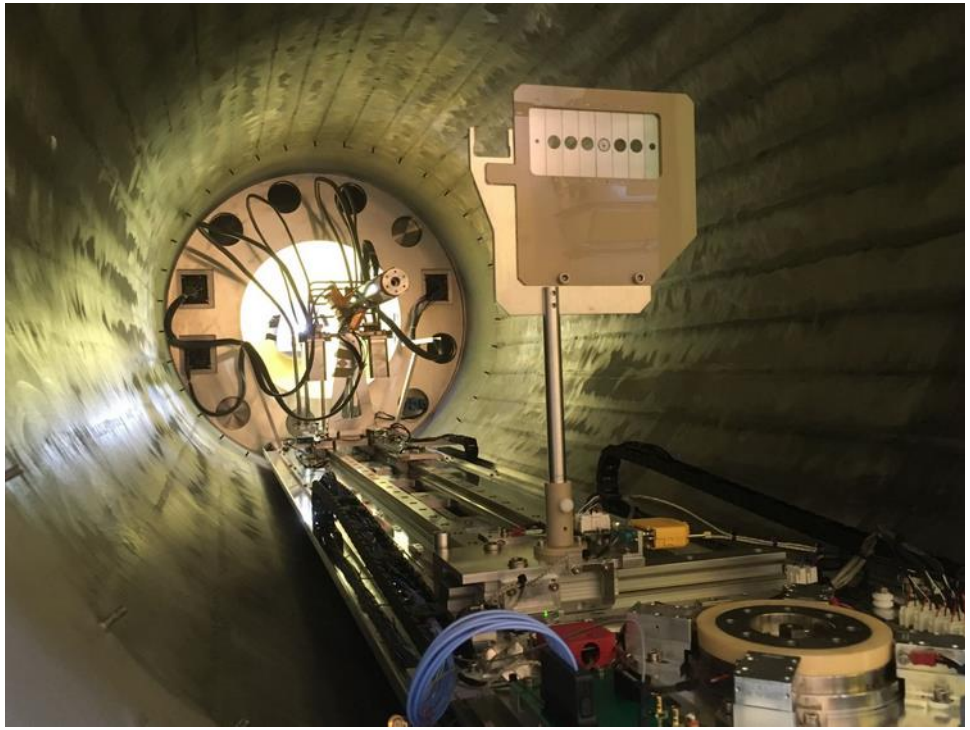




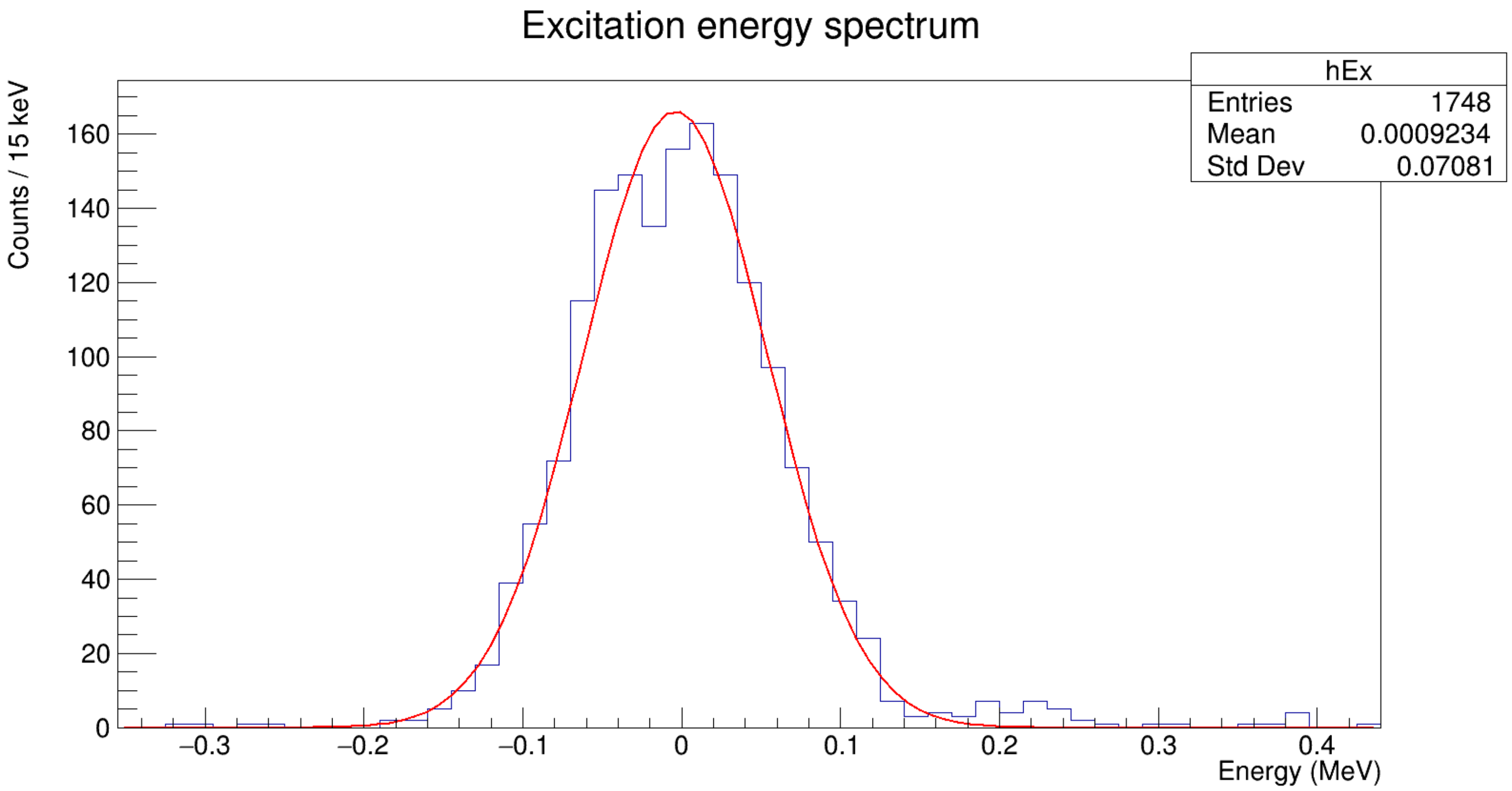
Private communication with S. Stegemann and S. Rothe

Targets

- Targets exist in different thicknesses (70 to 400µg/cm^2)
- Switchable during experiment
- New design for 2023

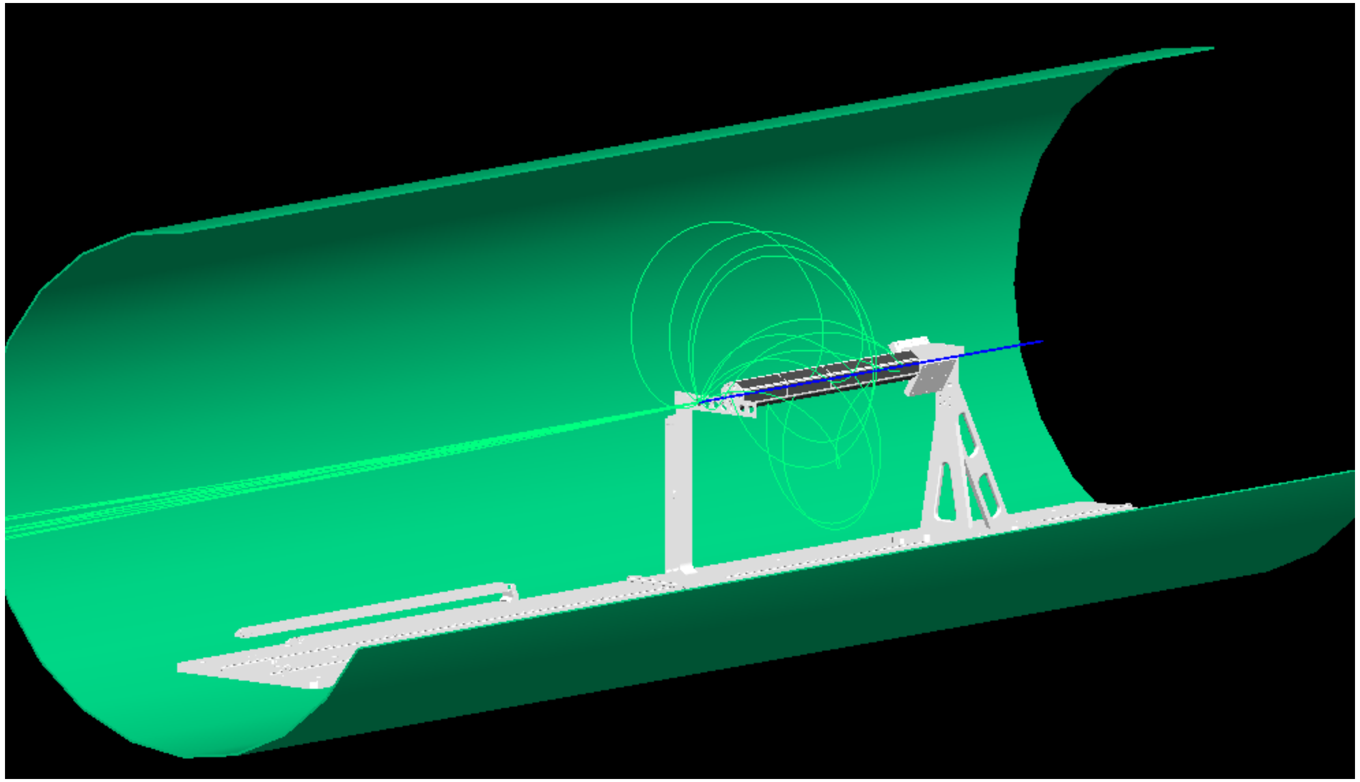


Simulated energy resolution (GS)



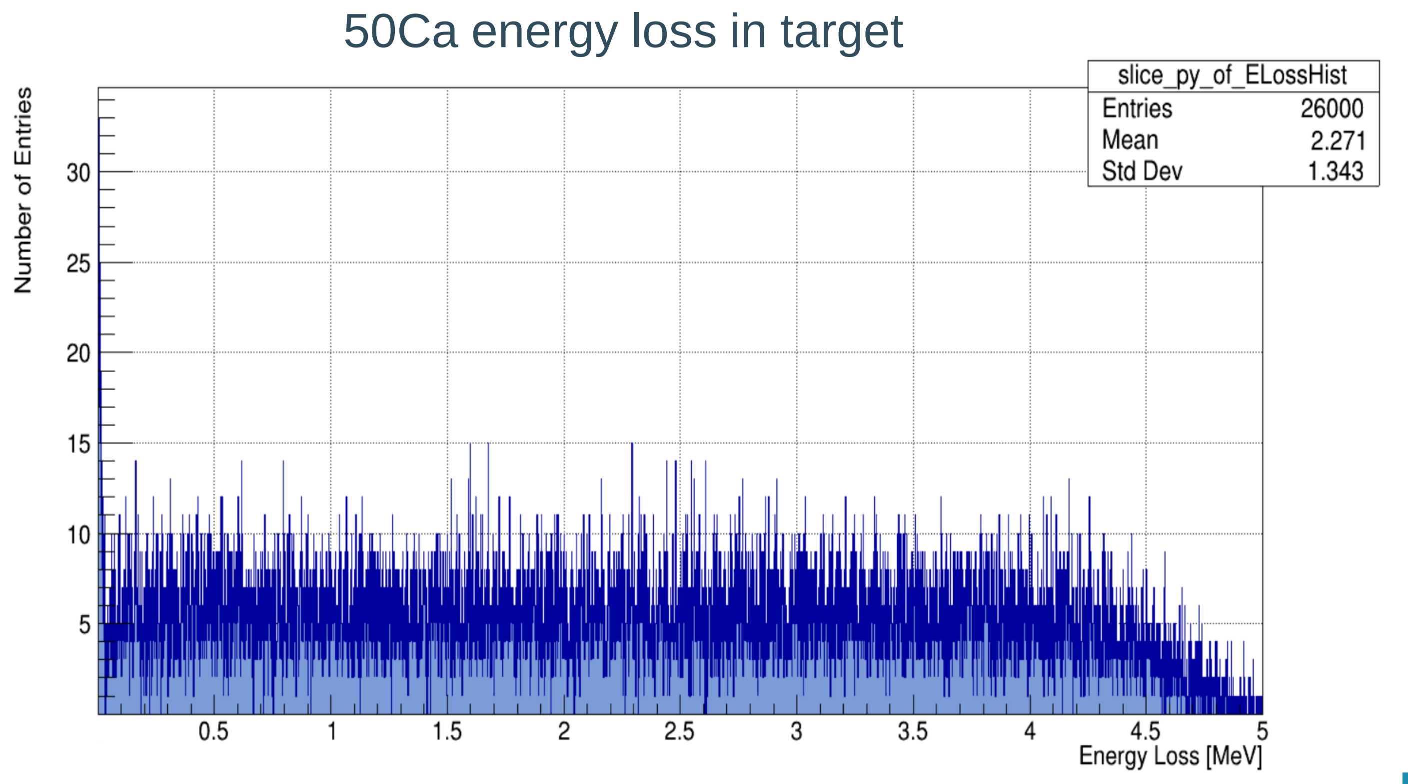
136keV FWHM

NPTool simulation



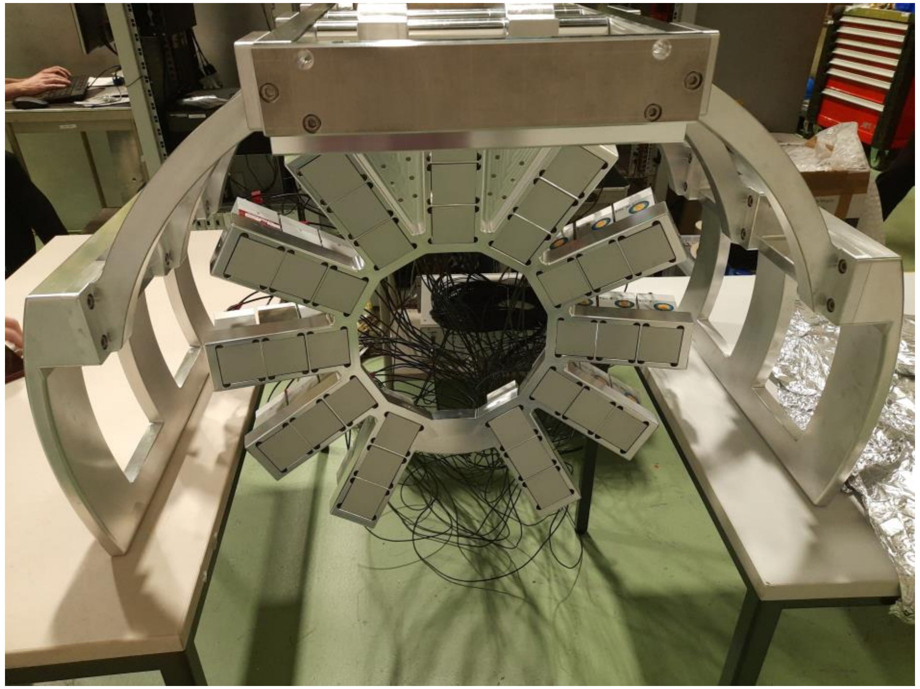
Energy loss

- Beam energy loss in target, assuming uniform vertex distribution in target

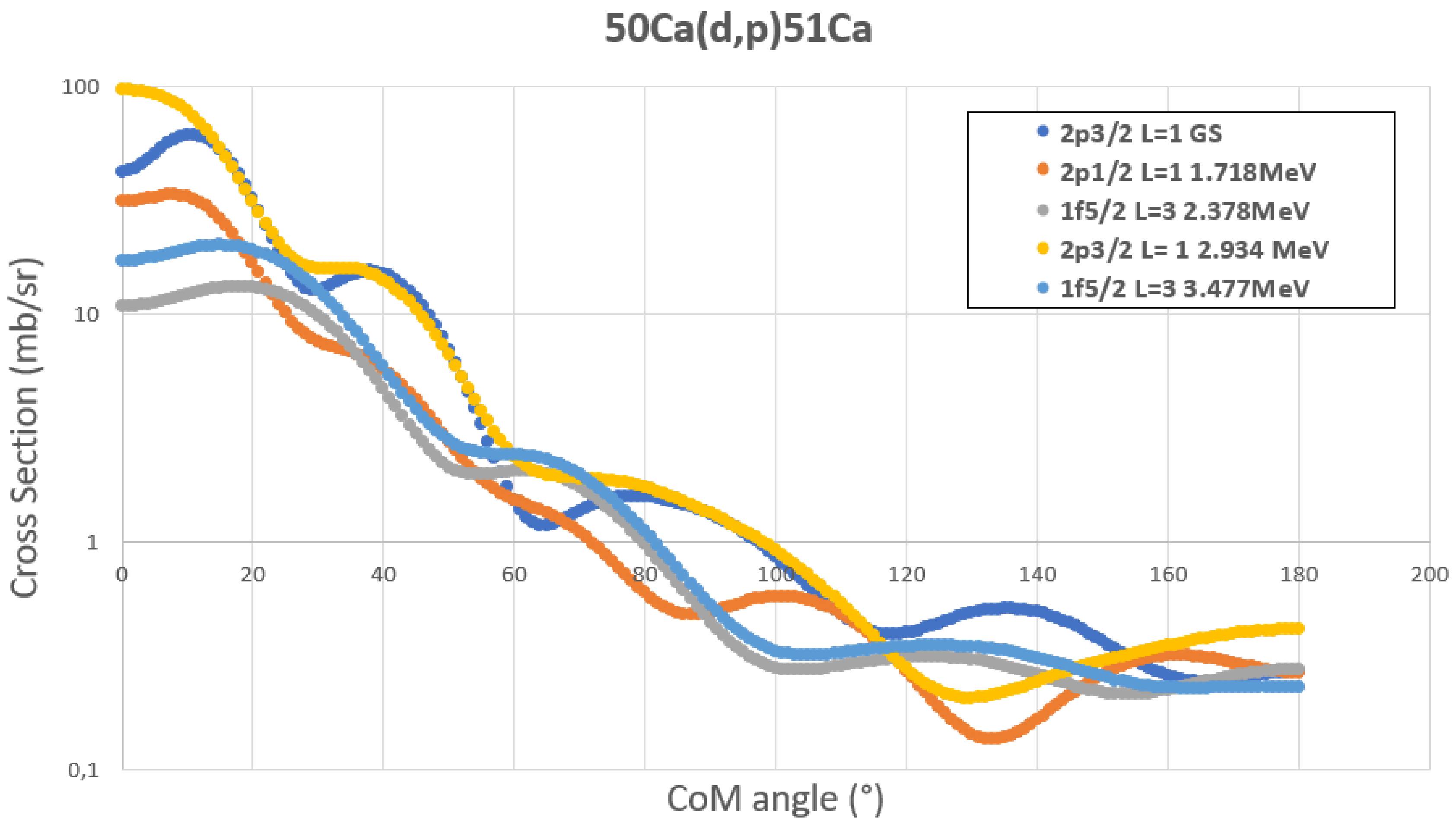


SpecMAT scintillator array

- Assembled + tested offline in November 2022
- Could improve energy resolution, but low count rate expected (~20 per peak)
- Possible to use experiment for commissioning

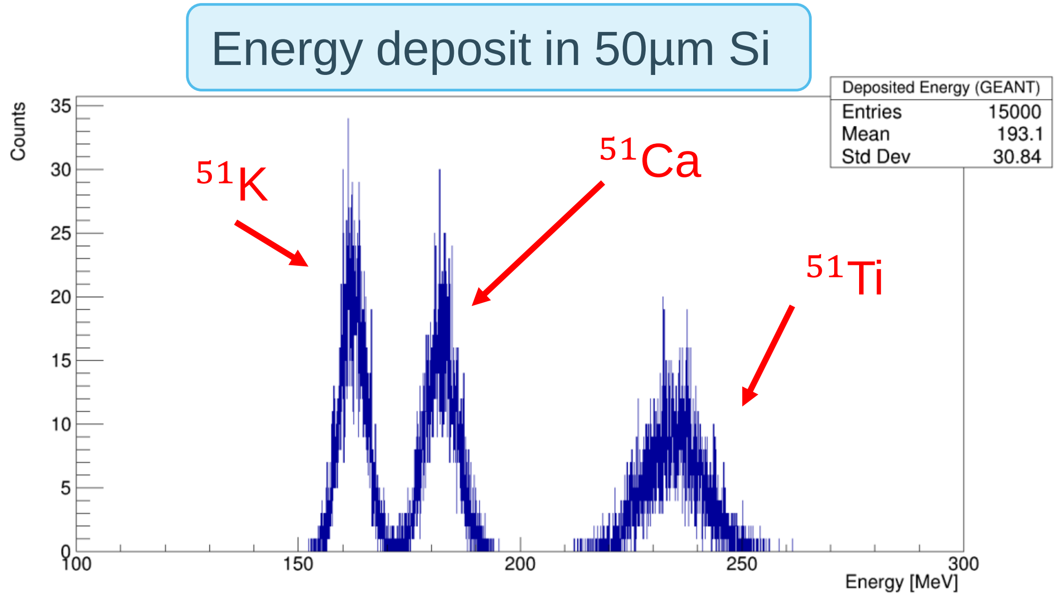


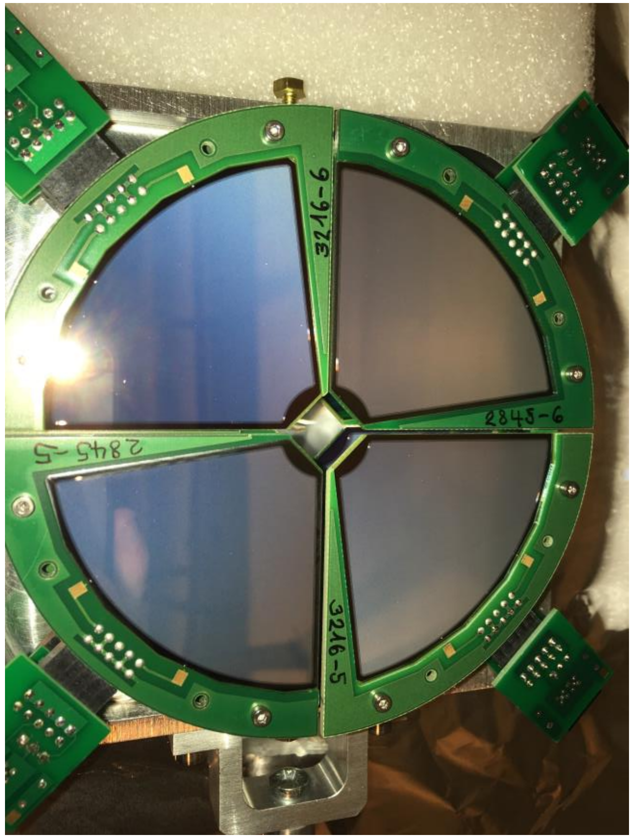
Fresco cross section



Si ΔE-E detector

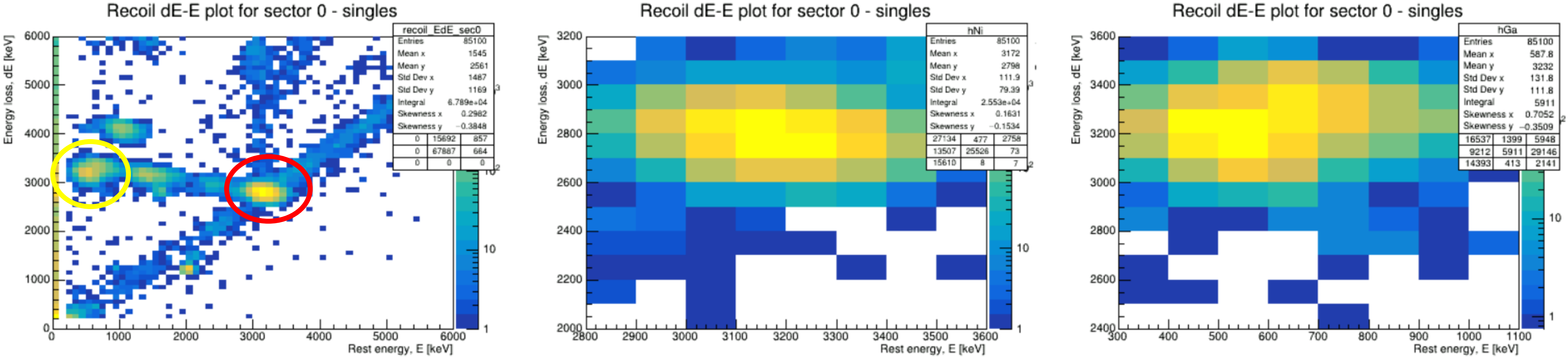
- In current thickness 65µm, recoils stop in ΔE part (according to GEANT4 simulation, according to SRIM range = 86µm)
- Thinner ΔE would work (50µm)





Identification of recoils in Bragg chamber

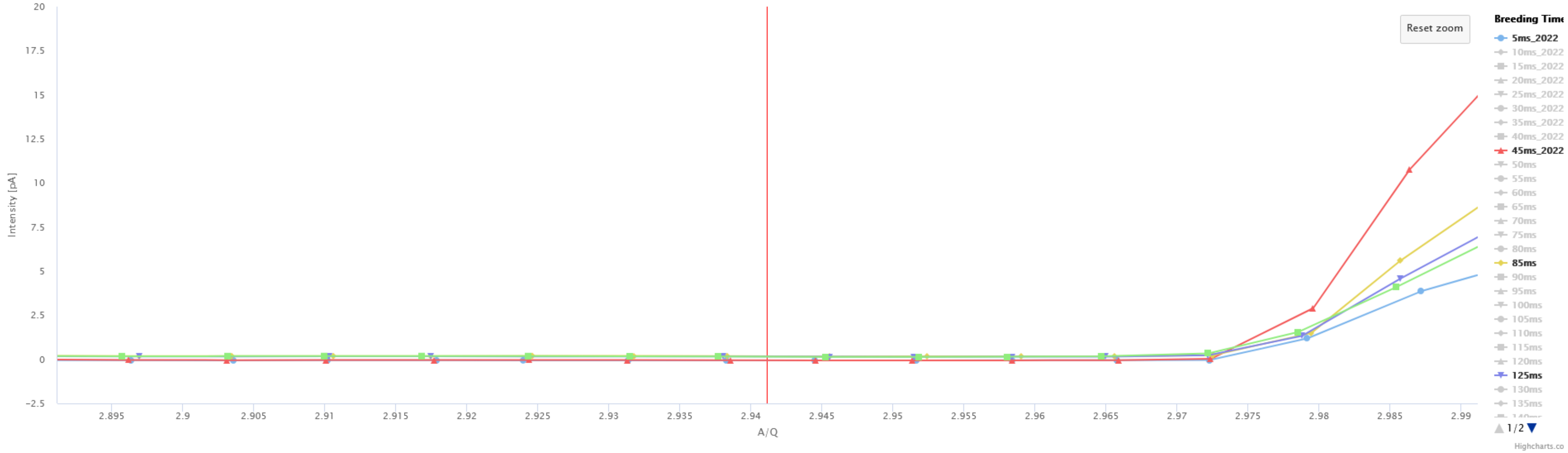
- Bragg chamber shows clear separation between Ni and Ga, so we can get ratio of the two



Red = Ni, Yellow = Ga

Ebis contaminants

50 / 17 = 2.94118 ± 0.02 ☑ **Stable Only** Found 1856 Elements, 126 Stable



$^{38}Ar^{13+}$ Argon Atomic Number: 18 Abundance: 0.0629 % A/Q: 2.92308	$^{41}K^{14+}$ Potassium Atomic Number: 19 Abundance: 6.7302 % A/Q: 2.92857	$^{44}Ca^{15+}$ Calcium Atomic Number: 20 Abundance: 2.09 % A/Q: 2.93333	$^{47}Ti^{16+}$ Titanium Atomic Number: 22 Abundance: 7.44 % A/Q: 2.93750
$^{50}Ti^{17+}$ Titanium Atomic Number: 22 Abundance: 5.18 % A/Q: 2.94118	$^{50}Cr^{17+}$ Chromium Atomic Number: 24 Abundance: 4.345 % A/Q: 2.94118	$^{53}Cr^{18+}$ Chromium Atomic Number: 24 Abundance: 9.501 % A/Q: 2.94444	$^{56}Fe^{19+}$ Iron Atomic Number: 26 Abundance: 91.754 % A/Q: 2.94737
$^{59}Co^{20+}$ Cobalt Atomic Number: 27 Abundance: 100 % A/Q: 2.95000	$^{62}Ni^{21+}$ Nickel Atomic Number: 28 Abundance: 3.6346 % A/Q: 2.95238	$^{65}Cu^{22+}$ Copper Atomic Number: 29 Abundance: 30.85 % A/Q: 2.95455	$^{68}Zn^{23+}$ Zinc Atomic Number: 30 Abundance: 18.45 % A/Q: 2.95652
$^{71}Ga^{24+}$ Gallium Atomic Number: 31 Abundance: 39.892 % A/Q: 2.95833	$^{74}Ge^{25+}$ Germanium Atomic Number: 32 Abundance: 36.5 % A/Q: 2.96000	$^{74}Se^{25+}$ Selenium Atomic Number: 34 Abundance: 0.89 % A/Q: 2.96000	$^{76}Se^{26+}$ Selenium Atomic Number: 34 Abundance: 9.37 % A/Q: 2.92308

Taken from: https://op-webtools.web.cern.ch/isolde/#/Contaminants, visited 01/02/23

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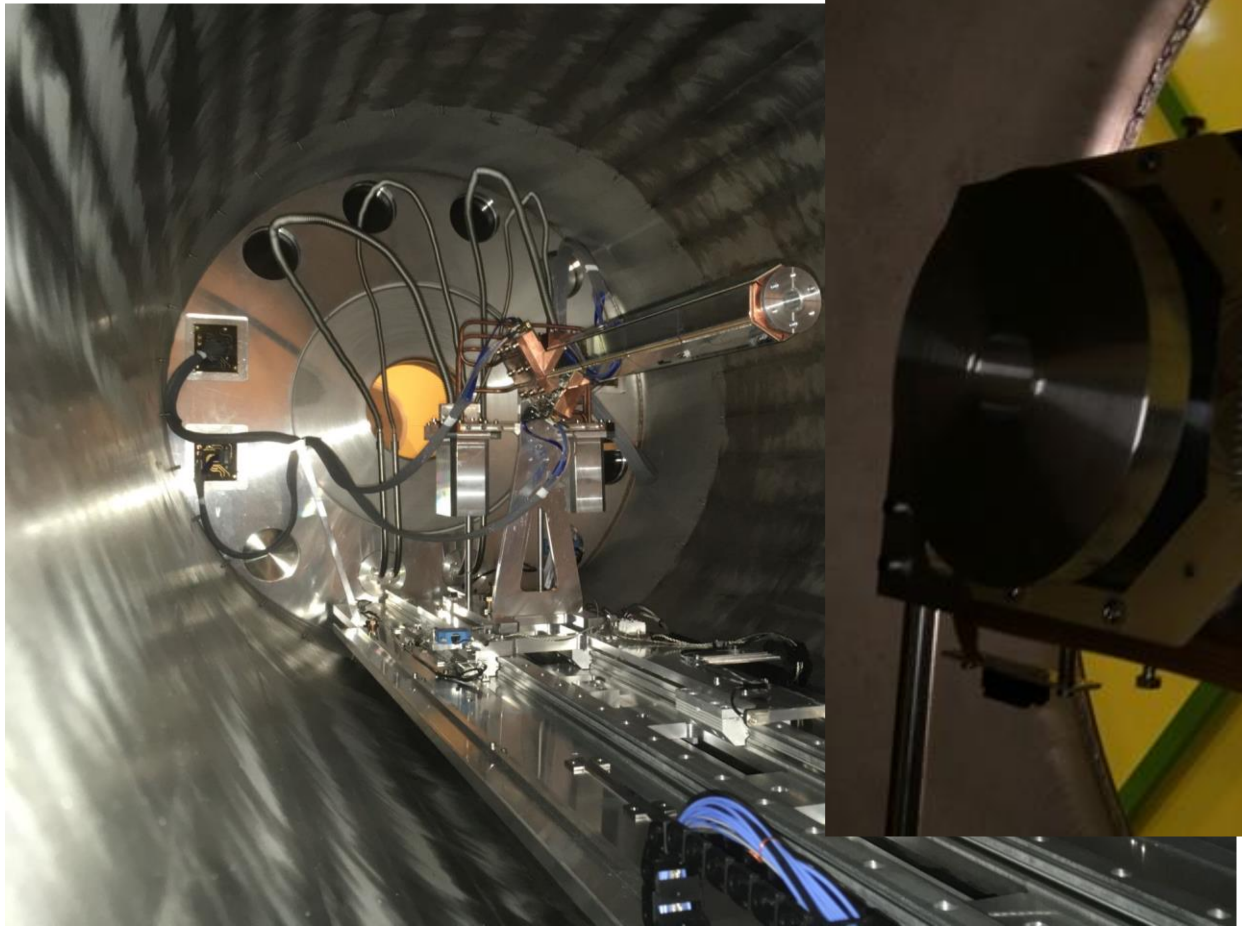

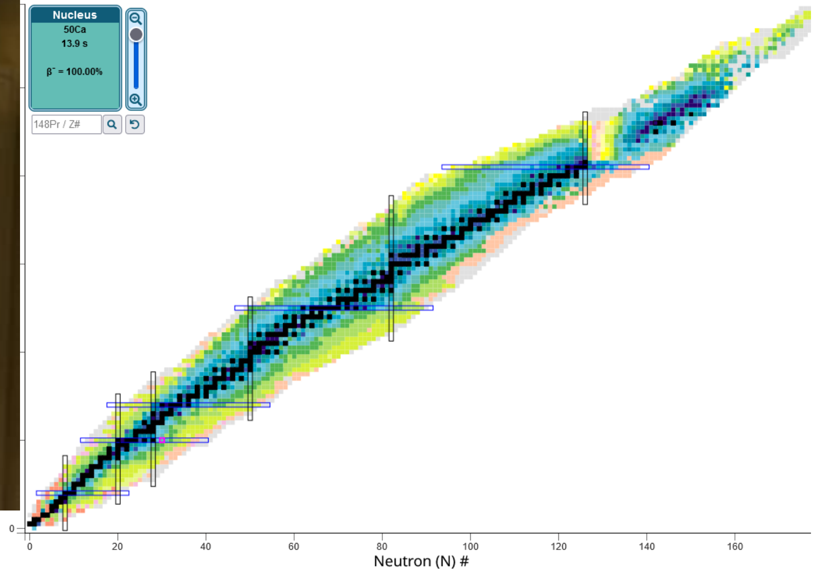
Nucleus
50Ca
13.9 s
β⁻ = 100.00%
148Pr / Z#
0
0 20 40 60 80 100 120 140 160
Neutron (N) #