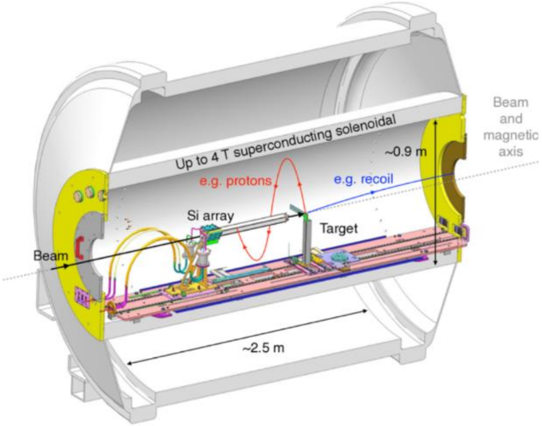
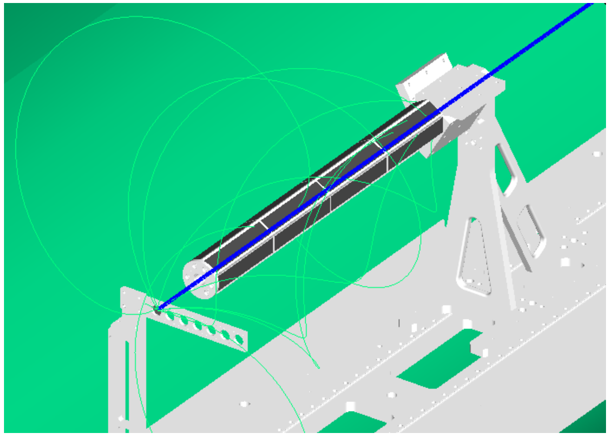




Investigating single-particle states in ^{111}Sn through d(^{110}Sn,p) with ISS

Joochun (Jason) Park

Focused workshop on rare isotope physics

Nov. 26, 2022

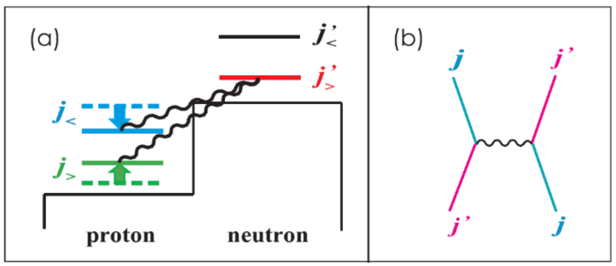
CENS
CENTER FOR EXOTIC NUCLEAR STUDIES

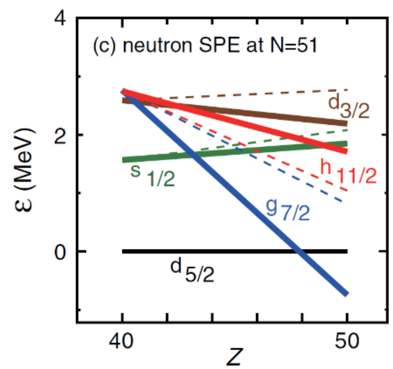
ISS
ISOLDE Solenoidal Spectrometer

Uncovering structural evolution towards ^{100}Sn

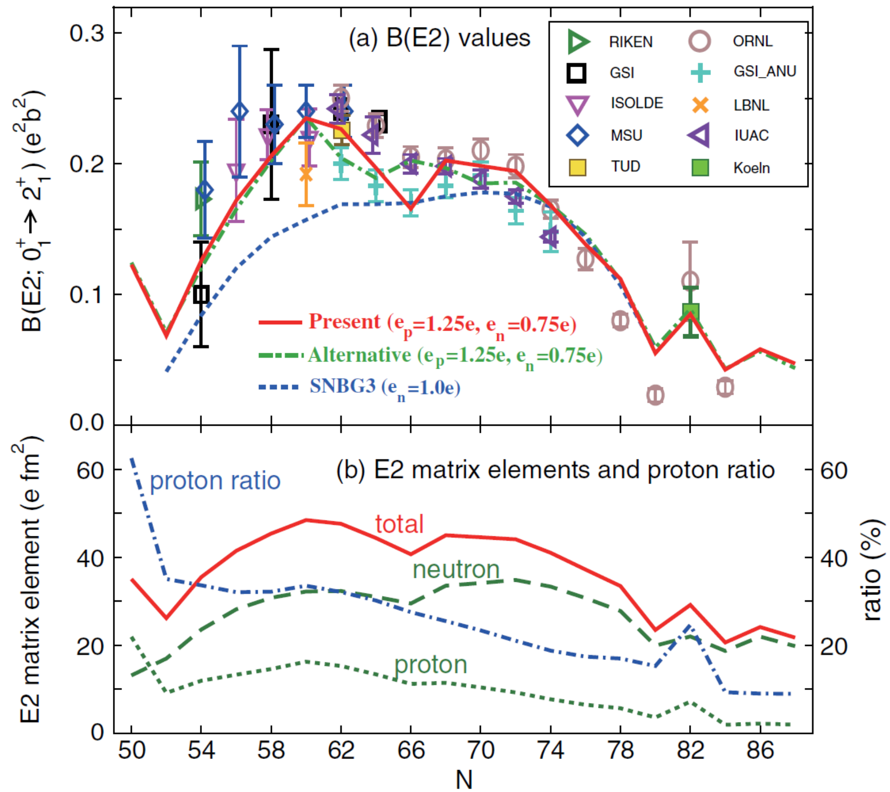
One of few double shell closures without direct spectroscopy results yet, must characterize single-particle vs collective phenomena along the isotopic chain

Proton-neutron tensor monopole interaction as an explanation for decreasing E(5/2$^+$)-E(7/2$^+$) gap observed in *N* = 51 isotones



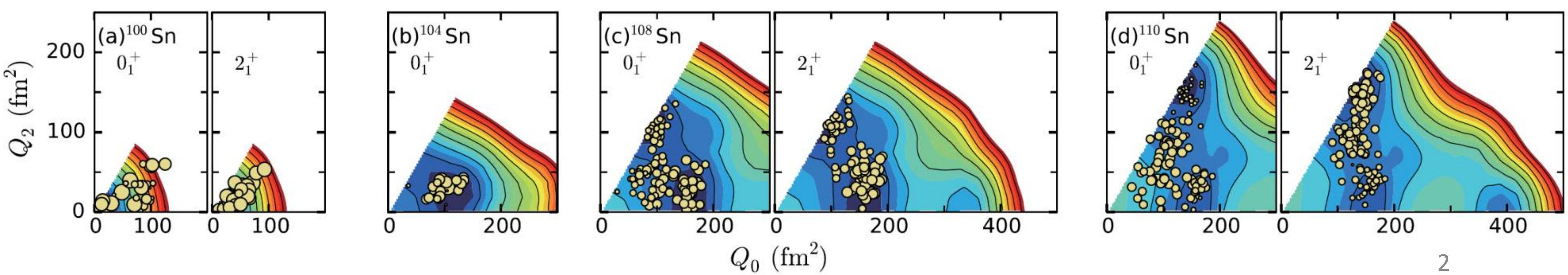


T. Otsuka et al., PRL 95, 232502 (2005)
and PRL 104, 012501 (2010)

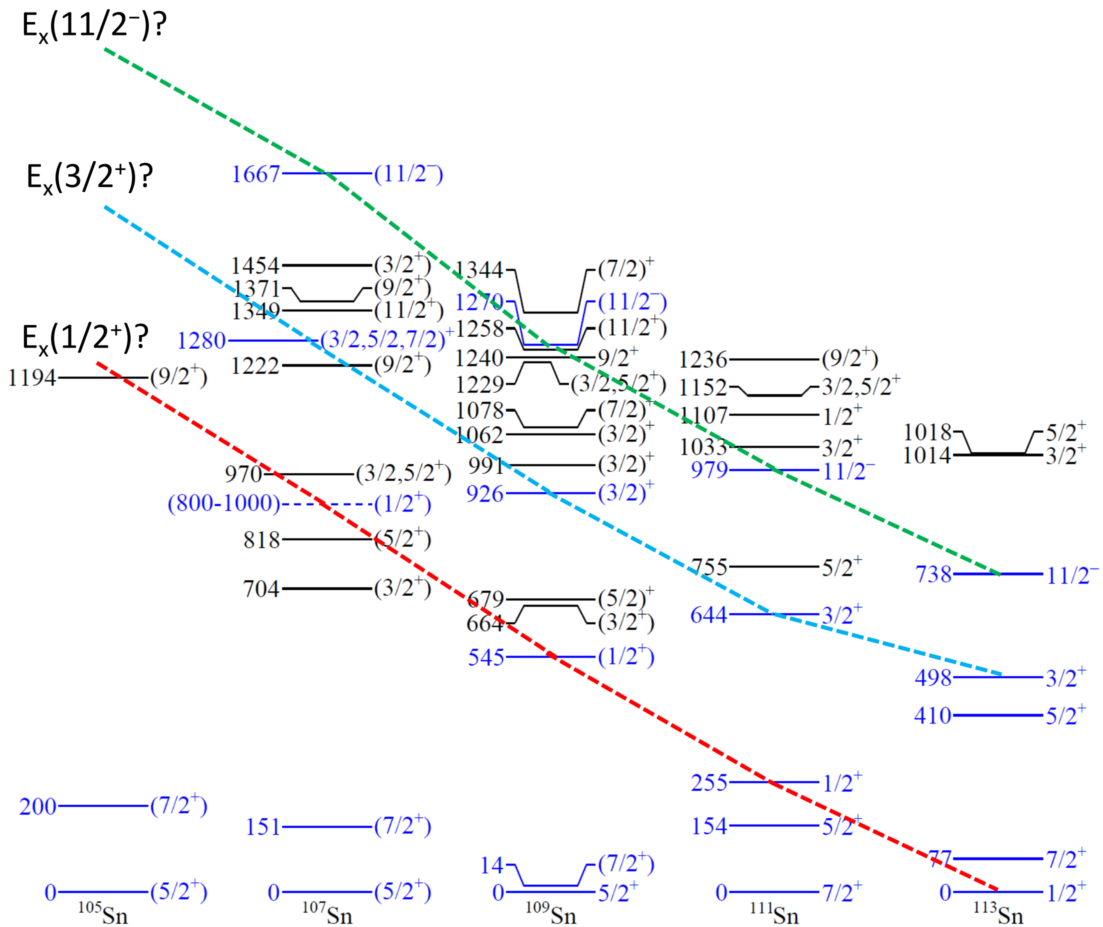


Deformation as a possible explanation for large B(E2) values in light Sn isotopes, reaching maximum at ^{110}Sn (*N* = 60)

T. Togashi et al., PRL 121, 062501 (2018)



Single-particle state candidates and energy trends in $^{105\text{-}113}$Sn



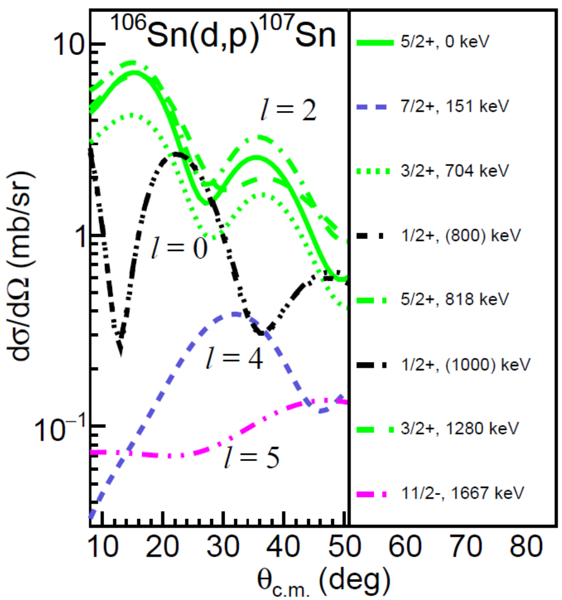
Tentative spin assignments based on beta-decay studies with γγ coincidences

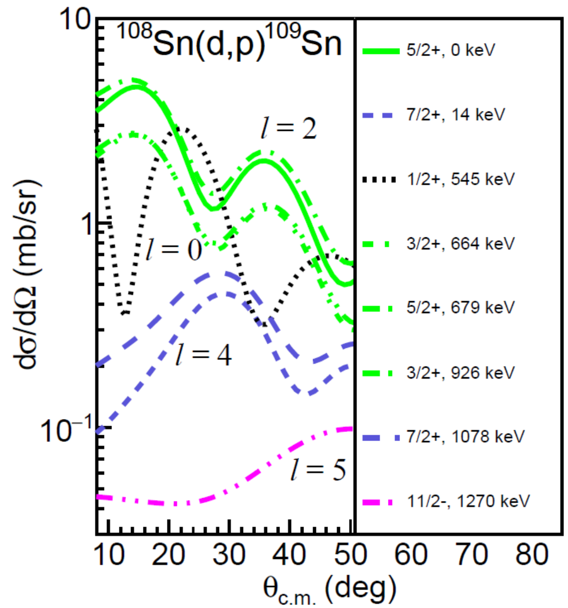
Previously suggested single-particle states in blue, to be clearly determined through (d,p)

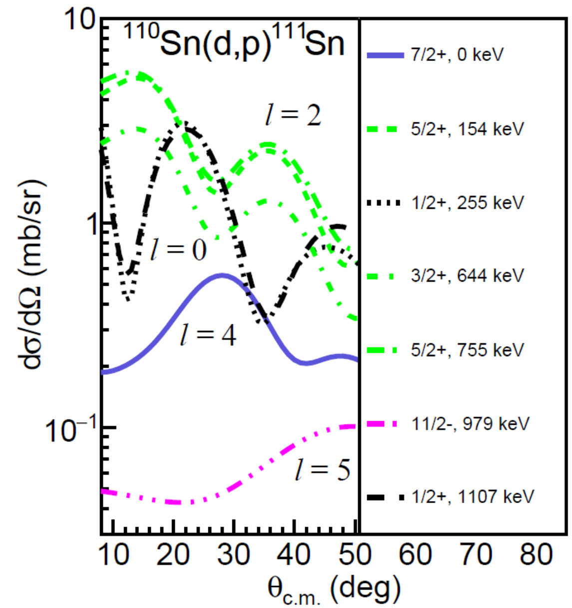
Energy of the unknown 1/2$^+$ state in ^{107}Sn and identification of 11/2$^-$ states (intruder orbit) particularly interesting, in addition to the S-factors

(d,p) cross section calculations with DWBA

Relevant neutron orbitals above N = 50: $1g_{7/2}$, $2d_{5/2}$, $2d_{3/2}$, $3s_{1/2}$, $1h_{11/2}$







Entrance channel parameters:
H. An and C. Cai, PRC 73, 054605 (2006)

Exit channel parameters:
A.J. Koning and J.P. Delaroche, NPA 713, 231 (2003)

Automatic binding potential depth adjustment in FRESCO
I. Thompson, Compt. Phys. Rep. 7, 167 (1988)

Priority on measuring l = 5 transfers to $11/2^-$ states with sufficient statistics

Angular distribution trends well separated as a function of l for spin assignments

Beam time requests and expected statistics/spectra

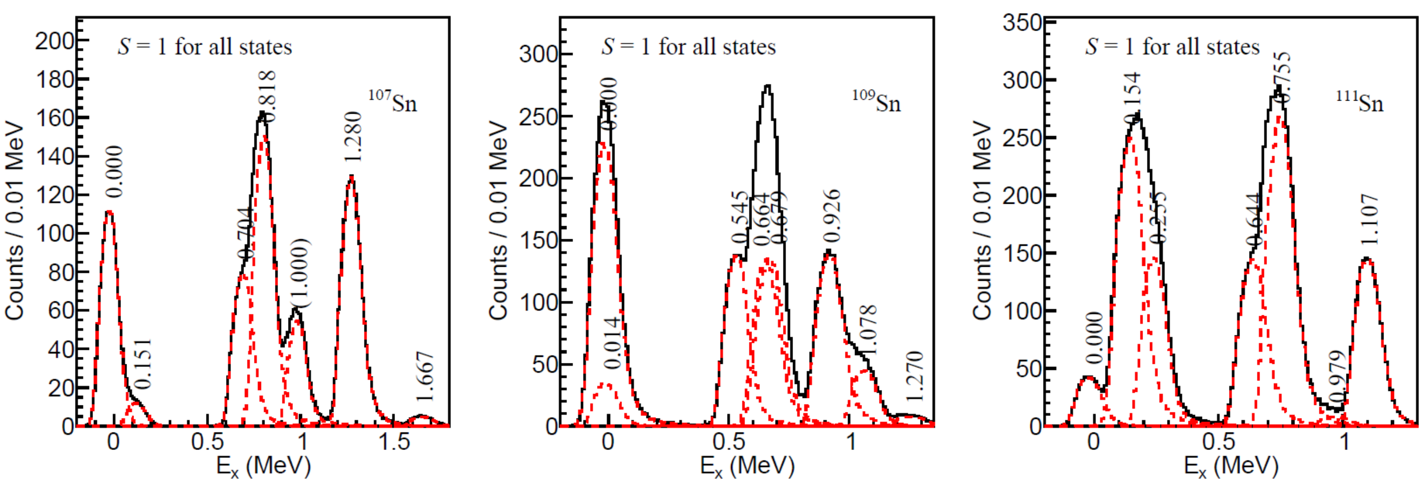
Reaction/ target	Intensity and beam time	E_x (keV)	J^π	ΔL	σ (mb)	Proton counts
^{106}Sn$(d,p)^{107}$Sn at 8 MeV/u on 165-μg/cm^2 CD$_2$	1×10^5/s for 24 shifts	0	$5/2^+$	2	4.436	1378
		151	$(7/2^+)$	4	0.461	143
		704	$(3/2^+)$	2	3.444	1070
		818	$(5/2^+)$	2	6.576	2043
		(800-1000)	$(1/2^+)$	0	2.031-2.072	631-644
		1280	$(3/2^+)$	2	5.641	1753
		1667	$(11/2^-)$	5	0.220	68
^{108}Sn$(d,p)^{109}$Sn at 8 MeV/u on 165-μg/cm^2 CD$_2$	5×10^5/s for 12 shifts	0	$5/2^+$	2	3.893	3018
		14	$(7/2^+)$	4	0.547	424
		545	$(1/2^+)$	0	2.220	1722
		664	$(3/2^+)$	2	2.357	1828
		679	$(5/2^+)$	2	2.411	1869
		926	$(3/2^+)$	2	2.463	1910
		1078	$(7/2^+)$	4	0.750	581
		1270	$(11/2^-)$	5	0.141	109
^{110}Sn$(d,p)^{111}$Sn at 8 MeV/u on 165-μg/cm^2 CD$_2$	5×10^5/s for 12 shifts	0	$7/2^+$	4	0.685	532
		154	$5/2^+$	2	4.378	3401
		255	$1/2^+$	0	2.346	1822
		644	$3/2^+$	2	2.553	1983
		755	$5/2^+$	2	4.813	3738
		979	$11/2^-$	5	0.147	114
		1107	$1/2^+$	0	2.458	1909

Transfer reaction quenching by 0.55 applied
[B. P. Kay, J. P. Shiffer, S. J. Freeman, PRL 111, 042502 (2013)]

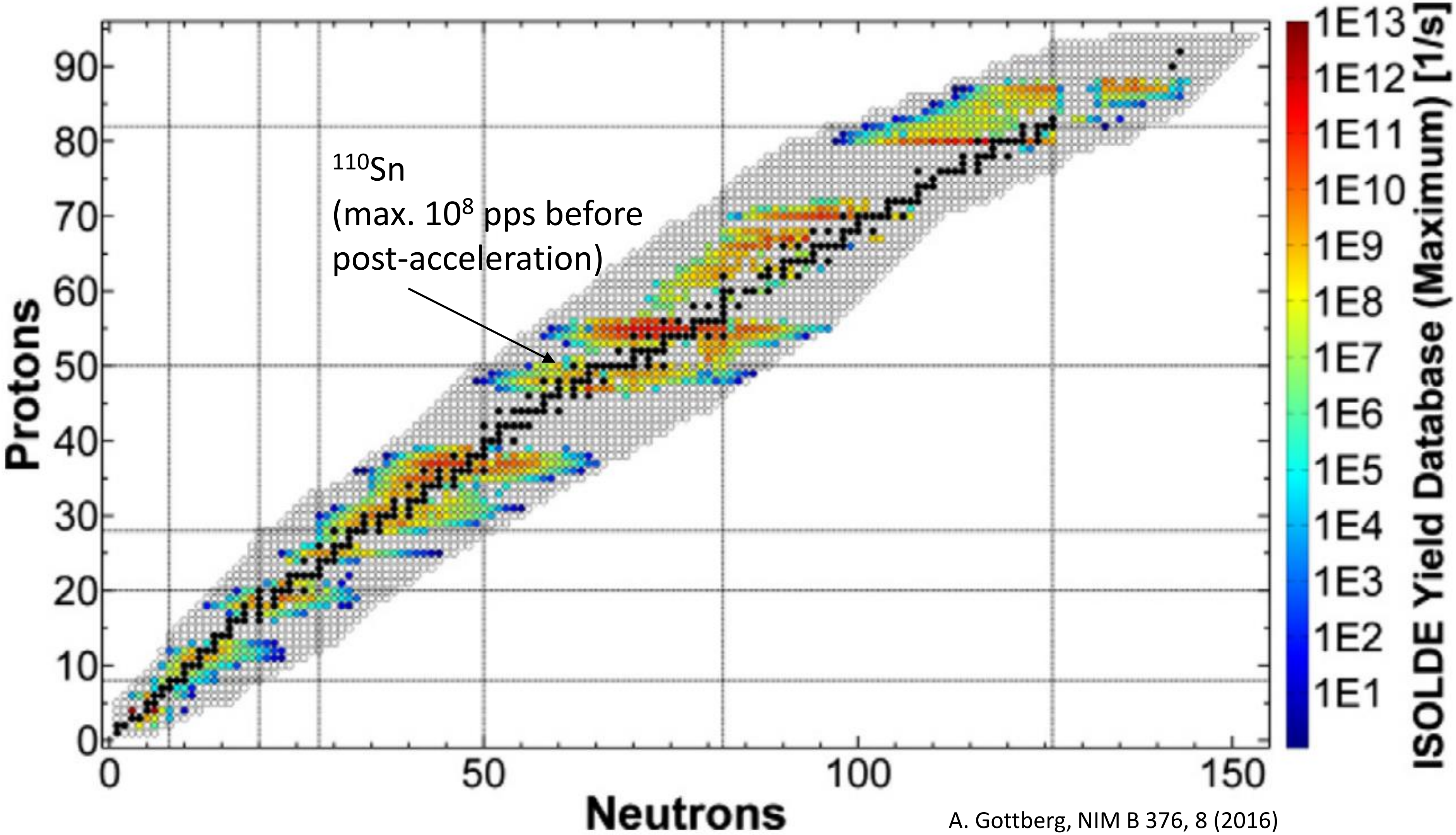
Statistics comparable to d(^{206}Hg,p)^{207}Hg results

Beam time set to measure transfers to $11/2^-$ states with ~10^2 counts at nominal RIB intensities, updated cross sections and lower E_{beam} can improve these numbers by 70-100%

Search for $1/2^+$ single-particle state in ^{107}Sn in E_x range 800-1000 keV with little dependence on cross section



CERN-ISOLDE yields

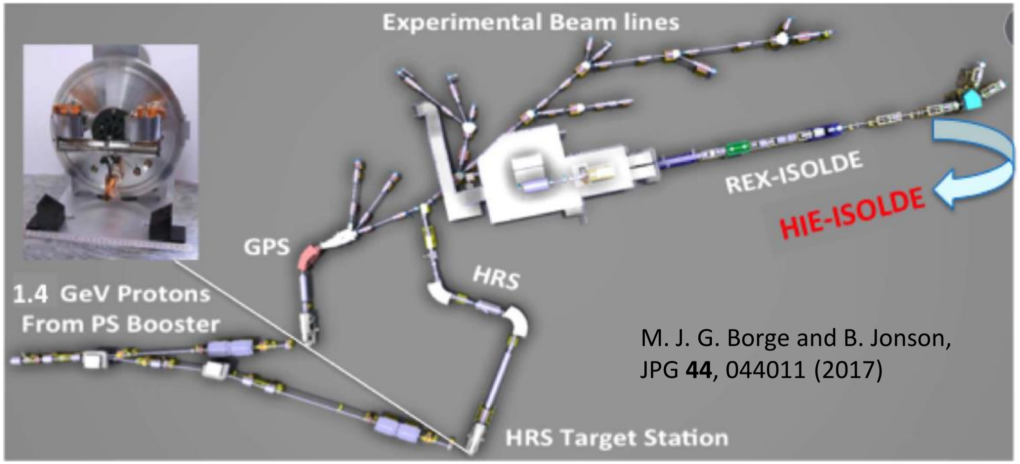


A. Gottberg, NIM B 376, 8 (2016)

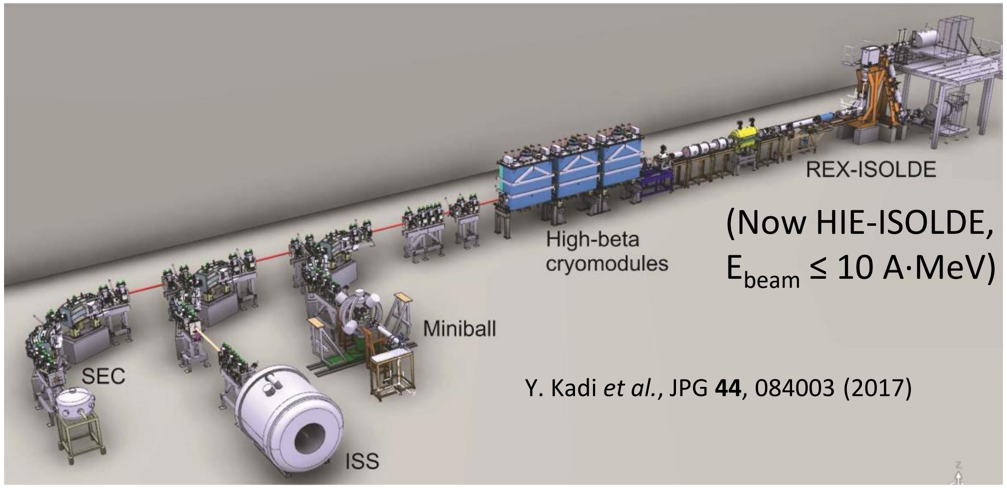
1.4-GeV proton synchrotron booster (PSB) for RIB production through spallation
Various primary targets with elements' atomic number from 6 (C) to 92 (U)

Radioactive ^{110}Sn beam production at CERN HIE-ISOLDE

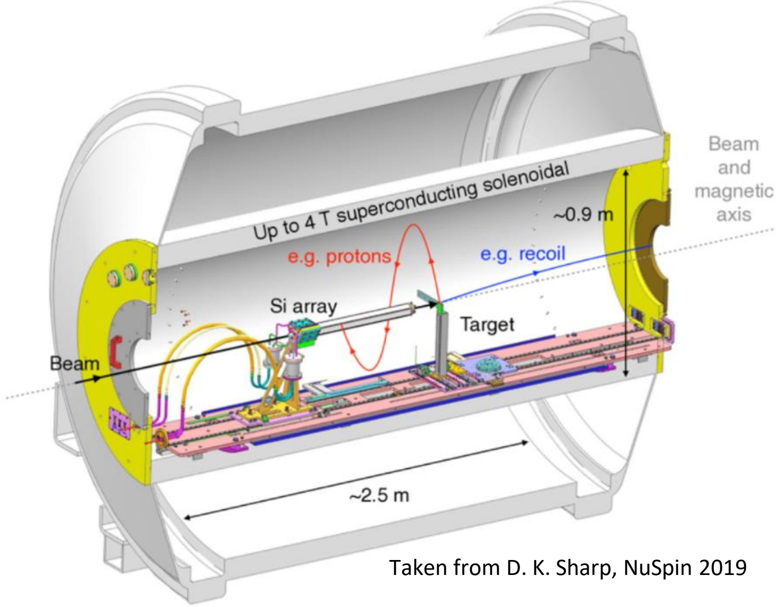
Proton from PS booster on LaC_x target
^{110}In isobaric contamination suppressed with extraction scheme and Resonance Ionization Laser Ion Source (RILIS)



Post-accelerated beam through GPS to HIE-ISOLDE,
towards ISS among multiple experiment stations

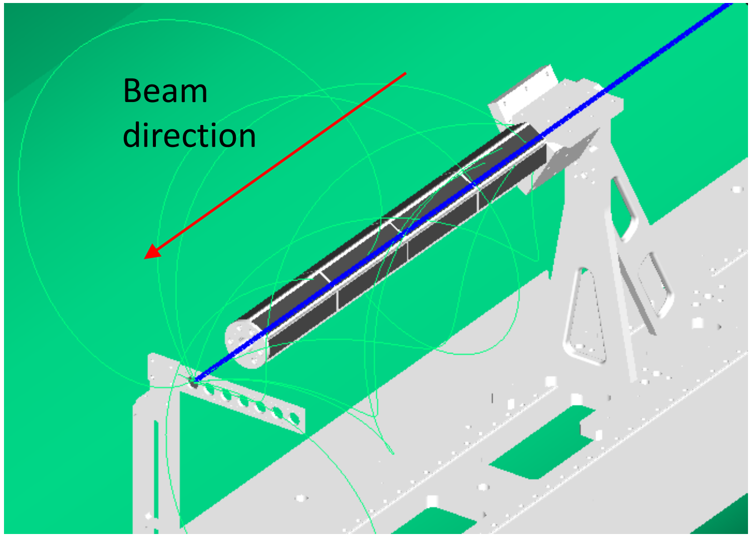


ISS spectrometer for (d,p) in inverse kinematics



Taken from D. K. Sharp, NuSpin 2019

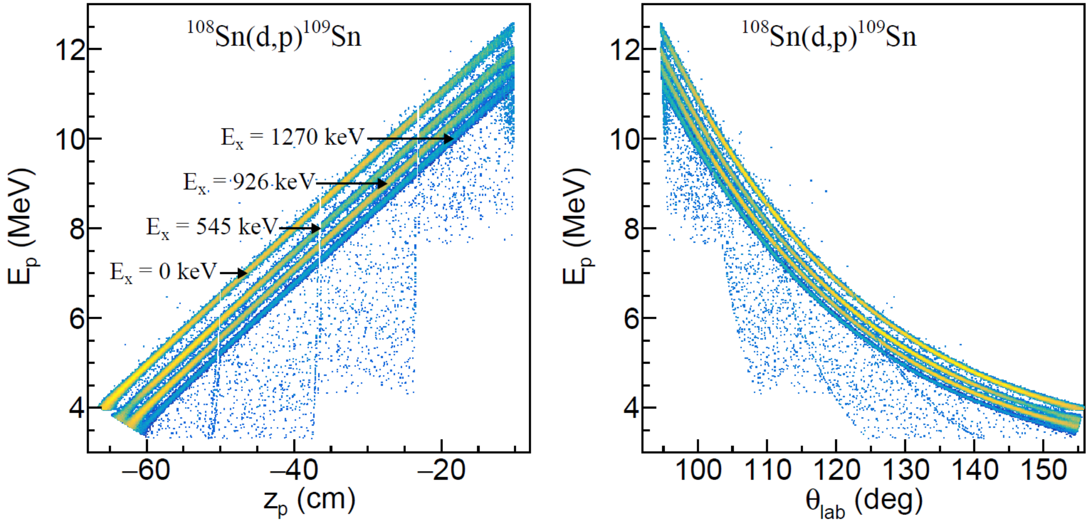
Proposed B-field strength: 2.5 T



1-mm thick DSSDs arranged in hexagonal tube
94% Si strip/70% ϕ coverage
z-coverage: (-61 cm, -11 cm) from the target
At E_{beam} = 8 A·MeV, ISS array covers $10° < \theta_{c.m.} < 45°$

NPTool simulation of ISS

A. Matta et al. J. Phys. G 43, 045113 (2016) and M. Labiche



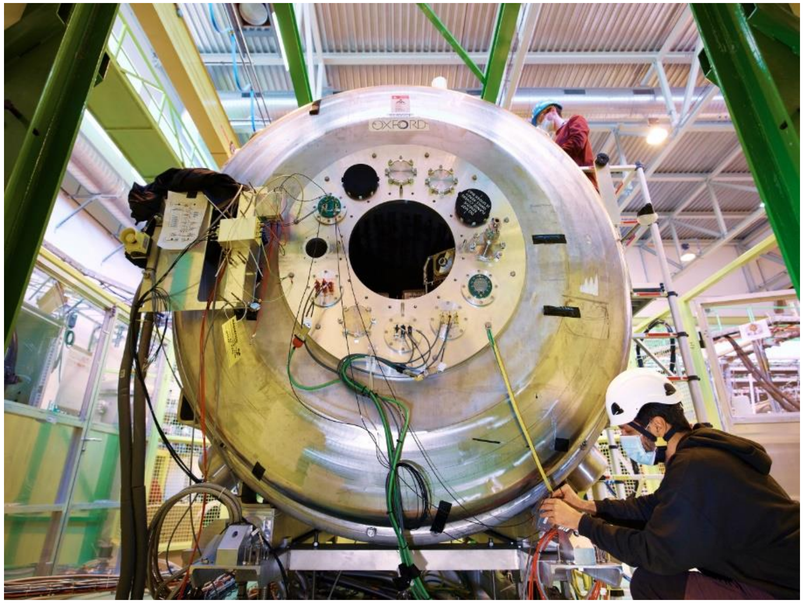
Particle kinematics in solenoidal magnetic field

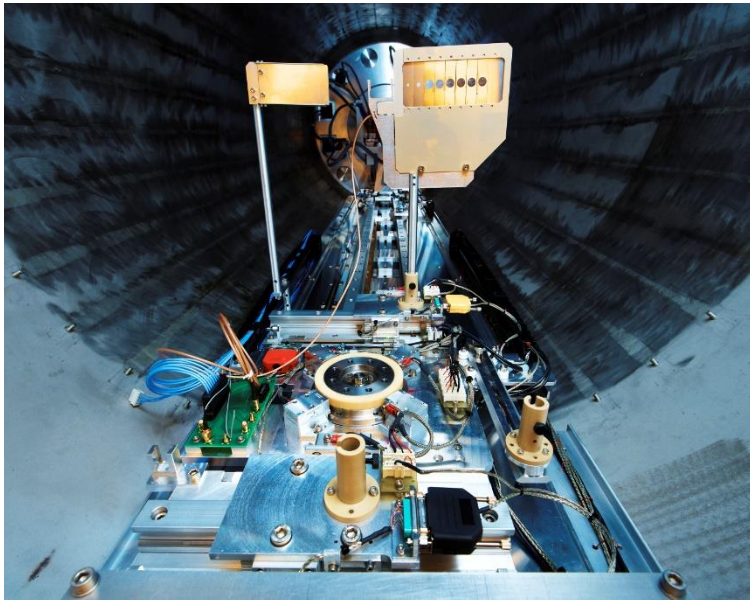
$$E_{lab} = E_{cm} - \frac{1}{2} m V_{cm}^2 + \left(\frac{mV_{cm}}{T_{cyc}}\right) z$$

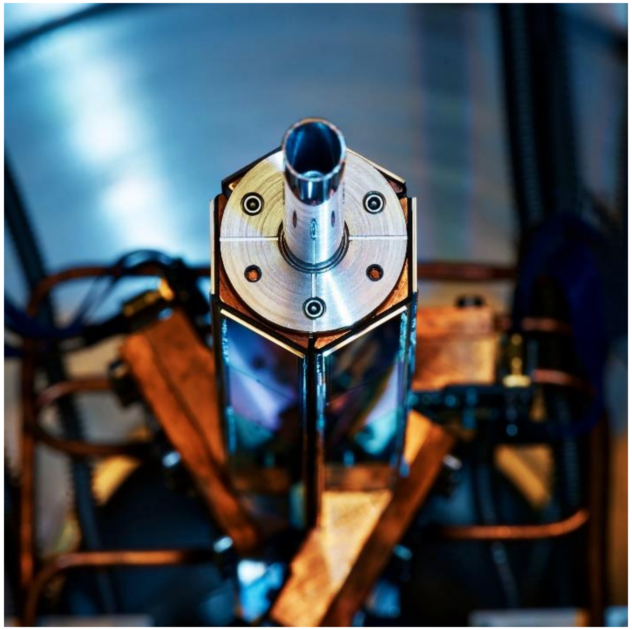
$$T_{cyc} = (2\pi/\mathcal{B})(m/qe)$$

$$z = (v_0 \cos(\theta_{cm}) + V_{cm}) \frac{r\left[2\pi - 2\arcsin\left(\frac{r_0}{2r}\right)\right]}{v_0 \sin(\theta_{cm})}$$

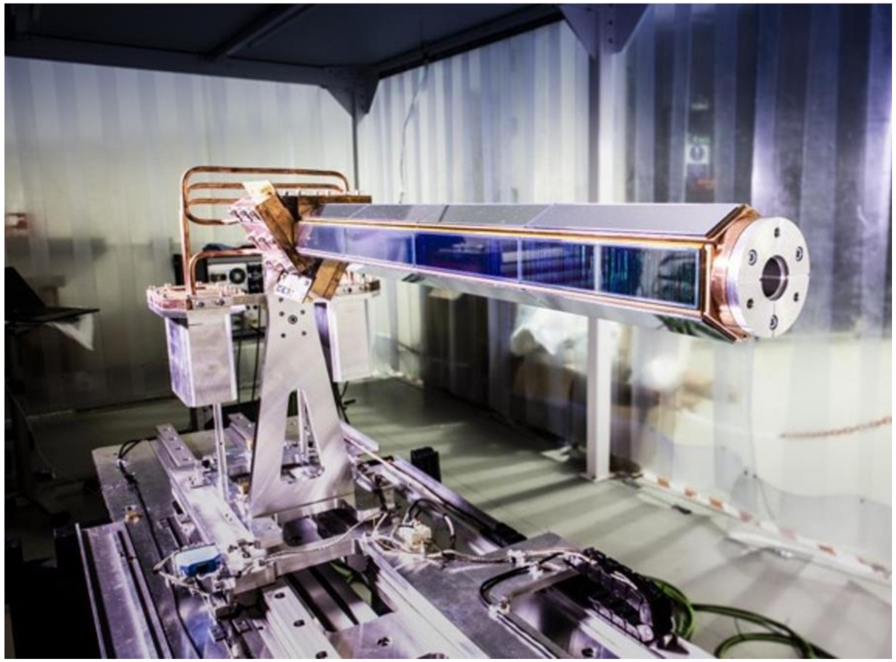
ISS spectrometer photos

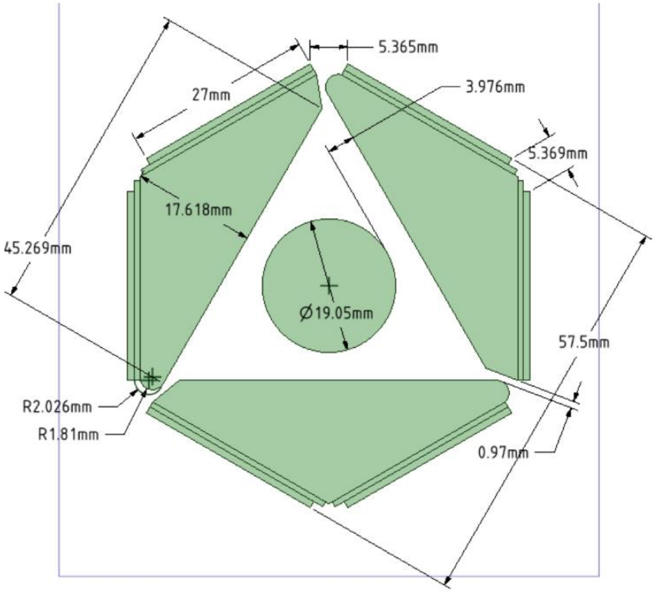






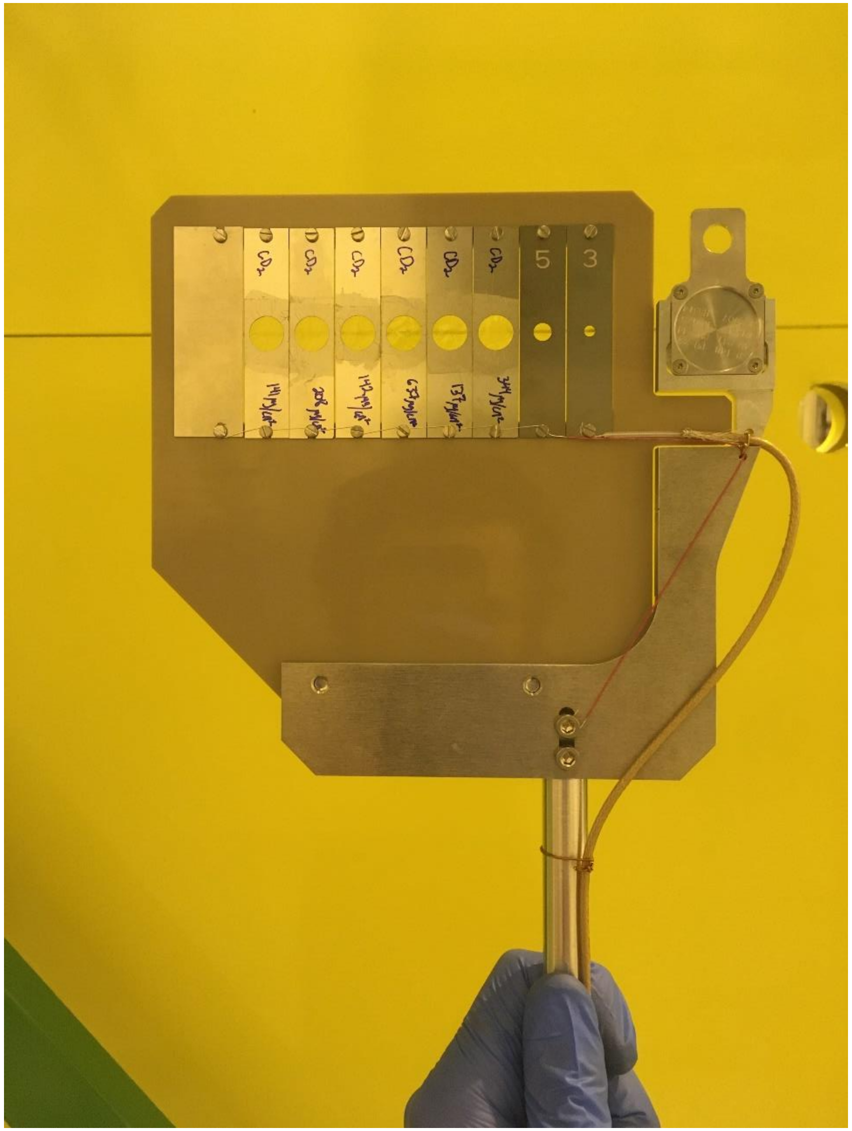
Si barrel array for ISS





- Micron BB21: DSSSD of 128 p-side strips, 11 n-side strips
- DSSSD dimensions: 125 x 27 x 1 mm^2
- 3 modules, ~70% coverage in ϕ accounting for gaps
- 4 sections (z coverage), 0.5-mm gaps in between for 94% coverage
- ASIC on-chip ADC serial readout (no PSA)
- Distance to target adjustable depending on kinematics

Target ladder + alpha source holder

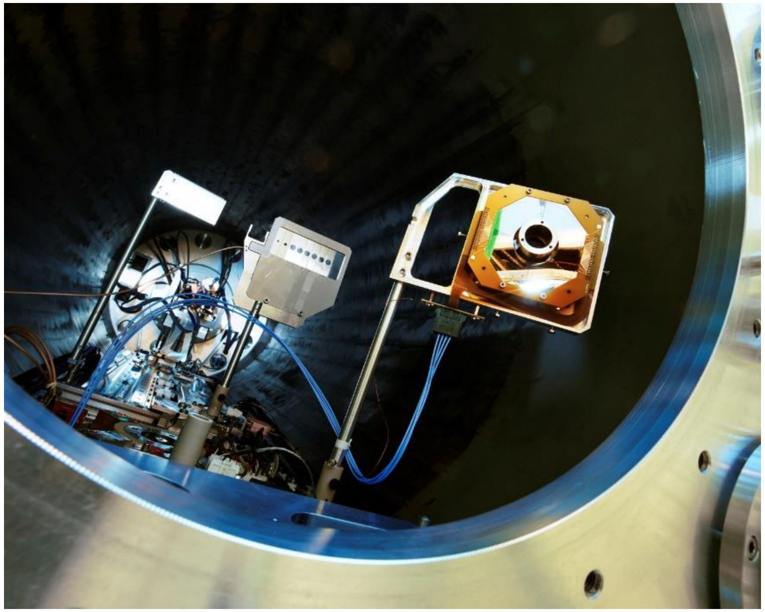


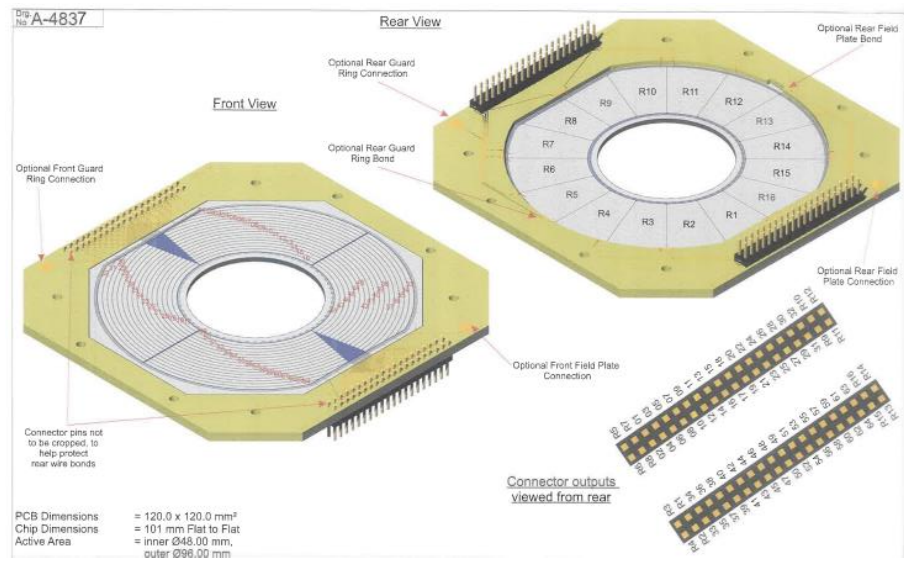
- 6 targets + 2 apertures for beam tuning
- Reversible alpha source holder
- Connected to drive motor that is turned on only when switching targets (eliminate noise)

- CD_2 targets used (not same as photo):
  - 97 µg/cm^2
  - 103 µg/cm^2
  - 108 µg/cm^2
  - 117 µg/cm^2
  - 129 µm^2
  - 209 µg/cm^2

5/6 targets thinner than the proposed thickness of 165 µg/cm^2 for better ΔE/E

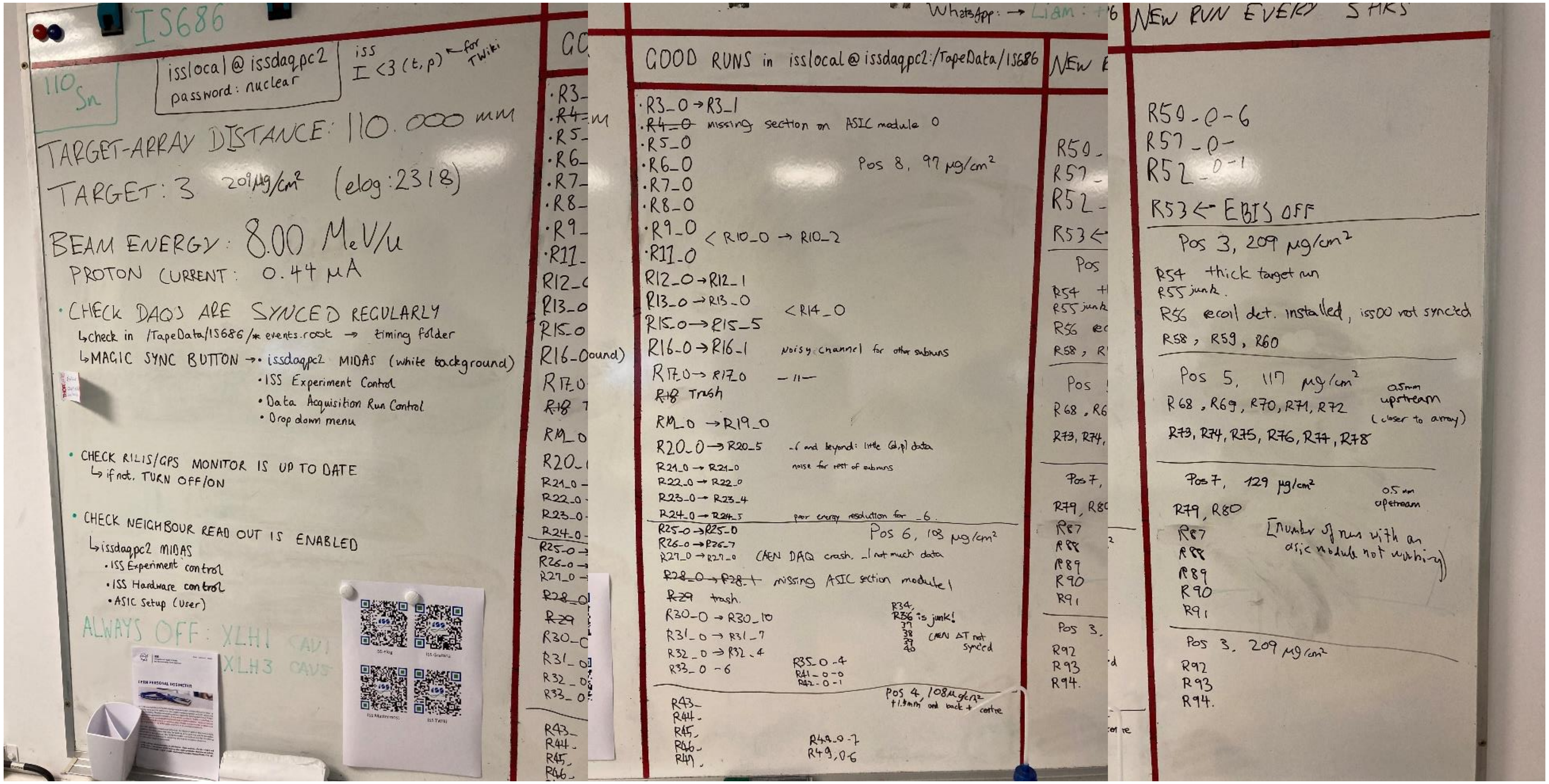
Elastic Luminosity (ELUM) detector





- Detect elastically scattered particles for beam intensity normalization
- Micron S1 DSSSD
- Signals summed together for each quadrant, data from 4 quadrants
- Blocker to control event rate (only a fraction of θ_{lab} accepted)

Run summary

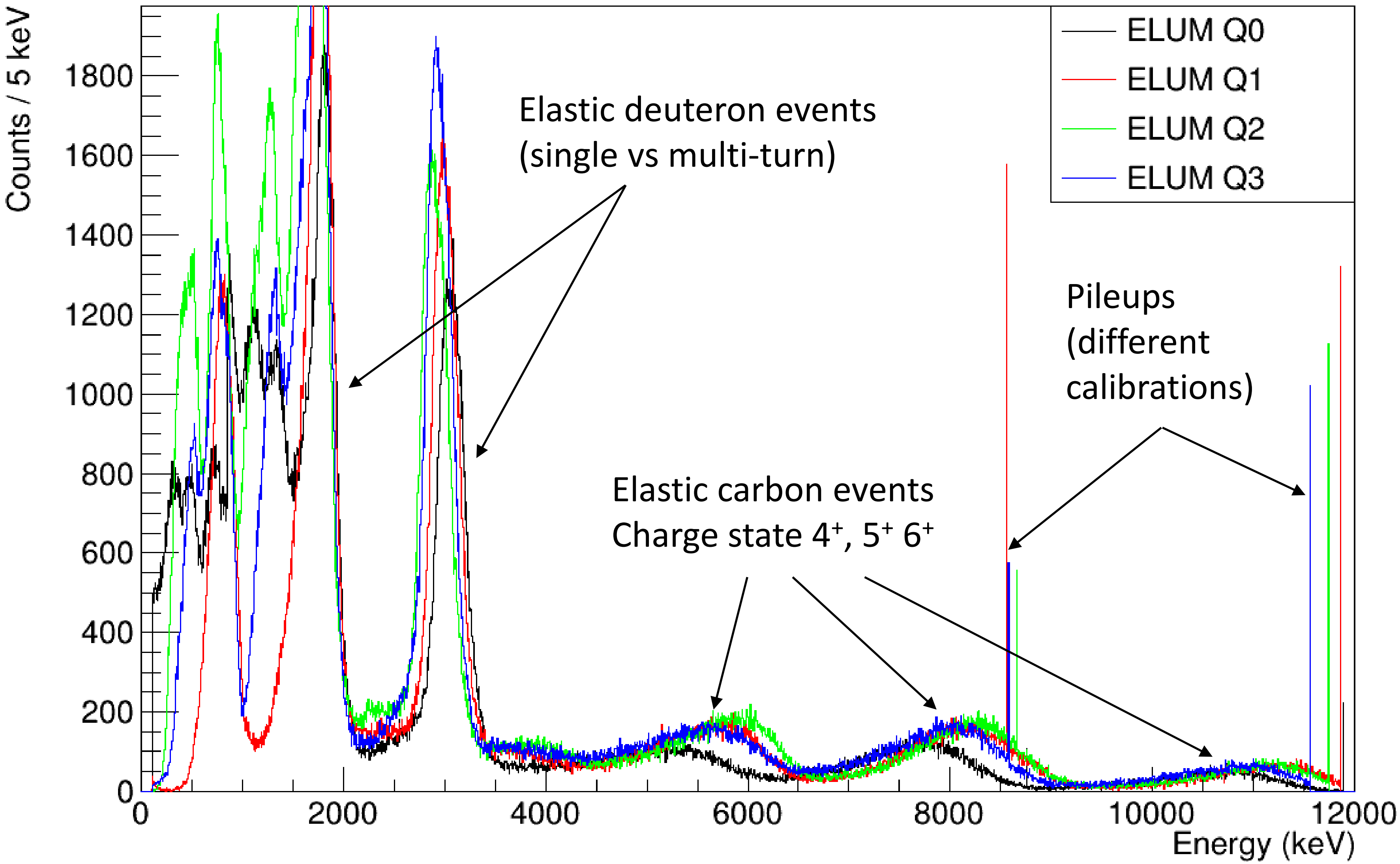


- E(^{110}Sn) = 8.00 A·MeV (±0.3%), very pure – R(^{110}In/^{110}Sn) ~ 0.1%
- Beam start/end: Sep. 29, 13:00 – Oct. 5 07:30

  ~6 days > 4 days assigned!
- Beam intensities: 0.30-0.5 μA protons, ~10^7 ^{110}Sn pps

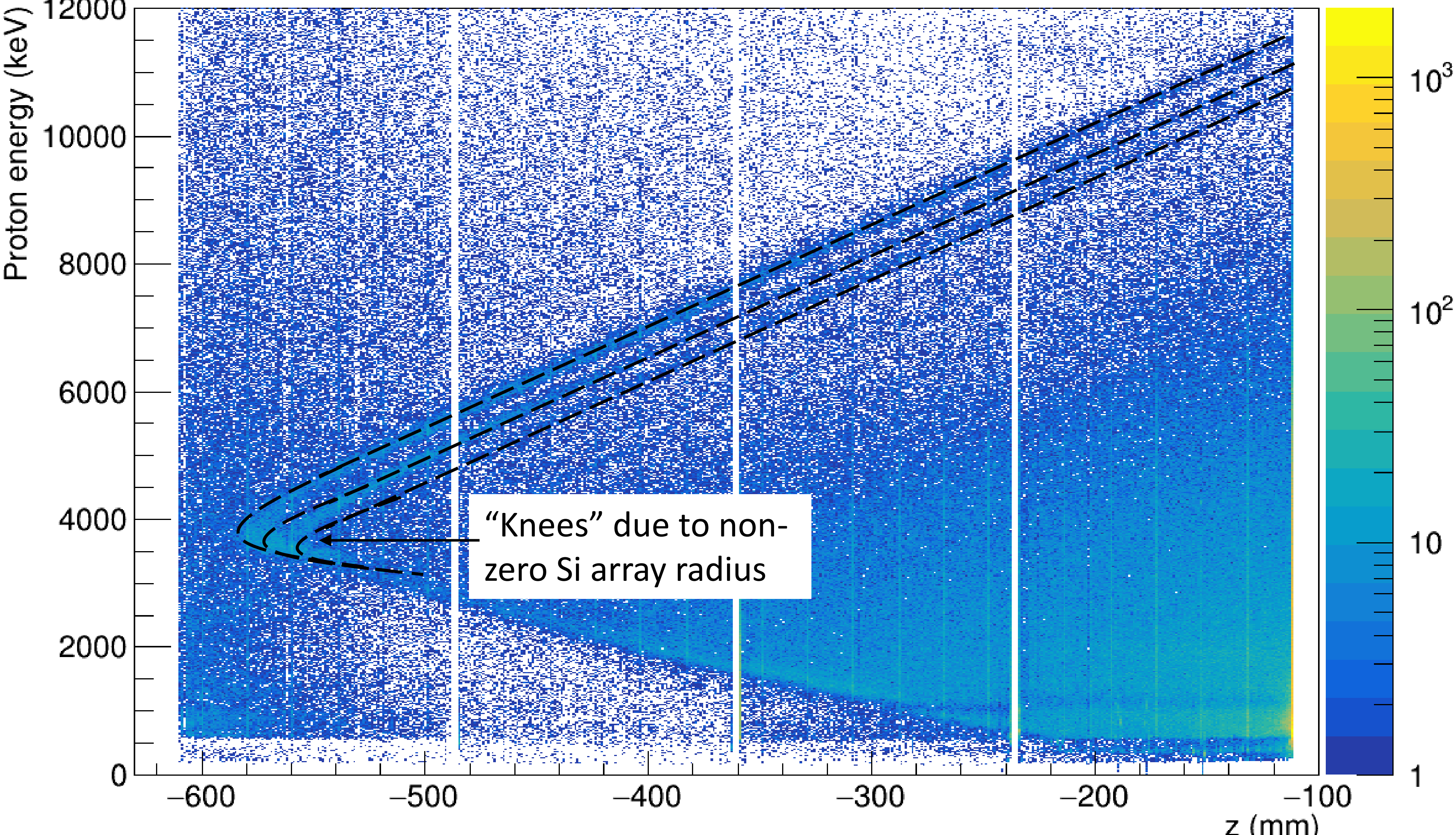
  [0.03 μA protons during recoil detector test, down to ~5 × 10^5 pps]

Preliminary spectra



Preliminary spectra

ISS Si array data, rough calibration

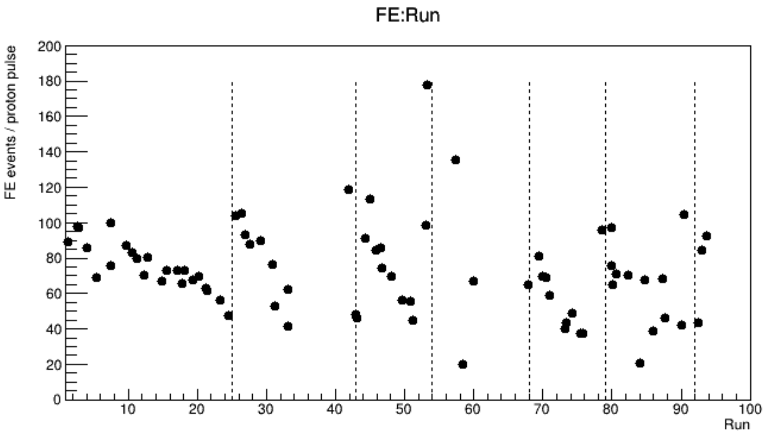


CoM angle cut needed to remove background

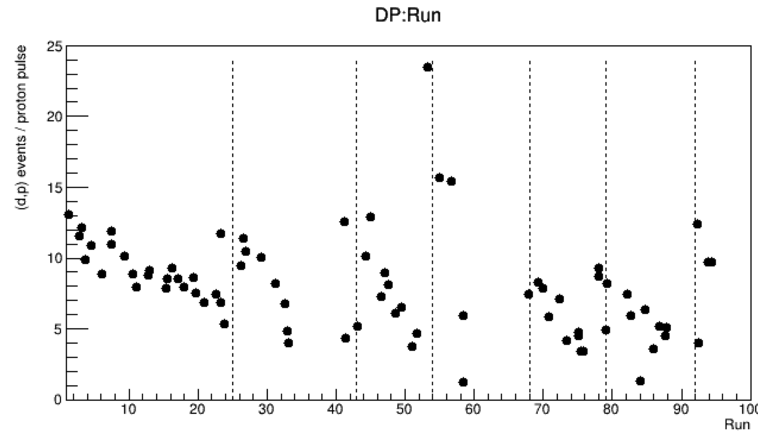
Decreasing event rates

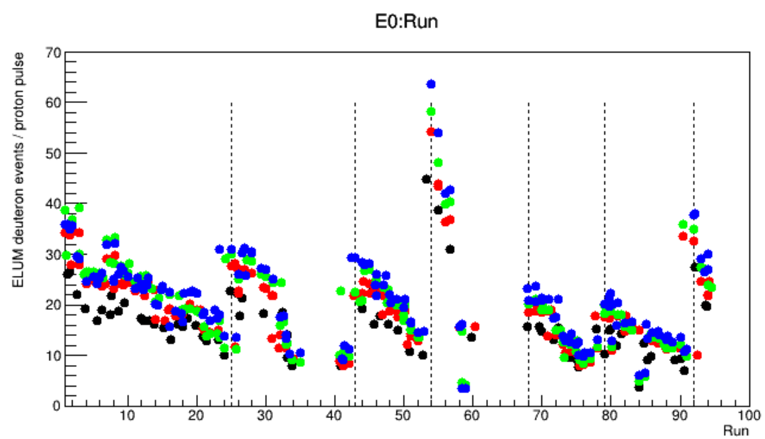
Counts divided by proton pulse → normalized event rate (intensity not considered)

Gated on high-excitation energy bump

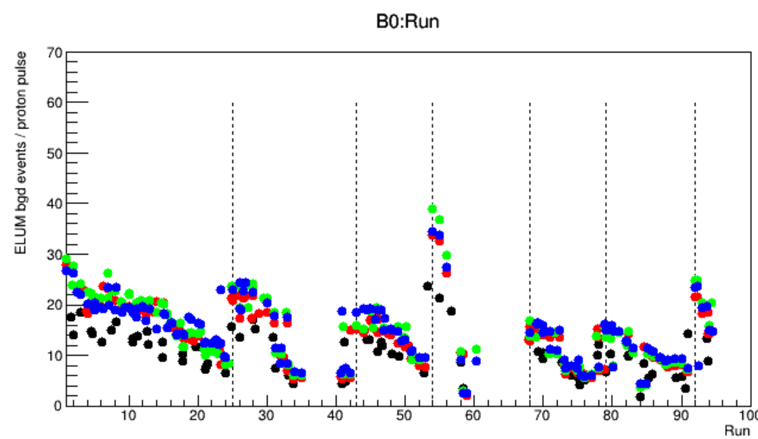


Counts under expected (d,p) peaks



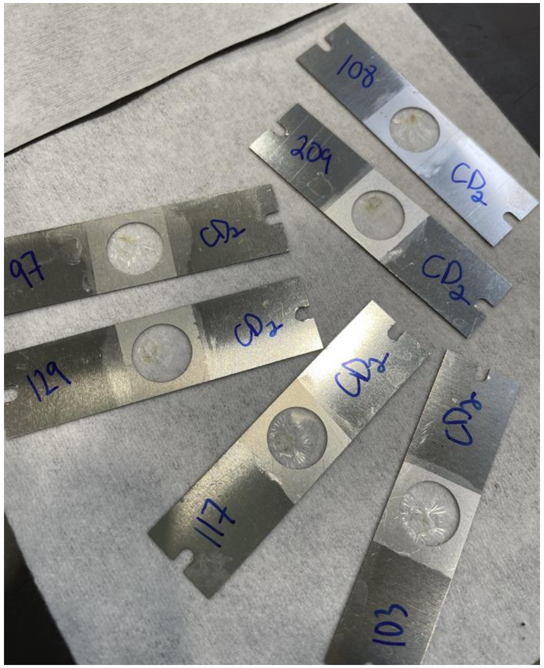


ELUM deuteron signal

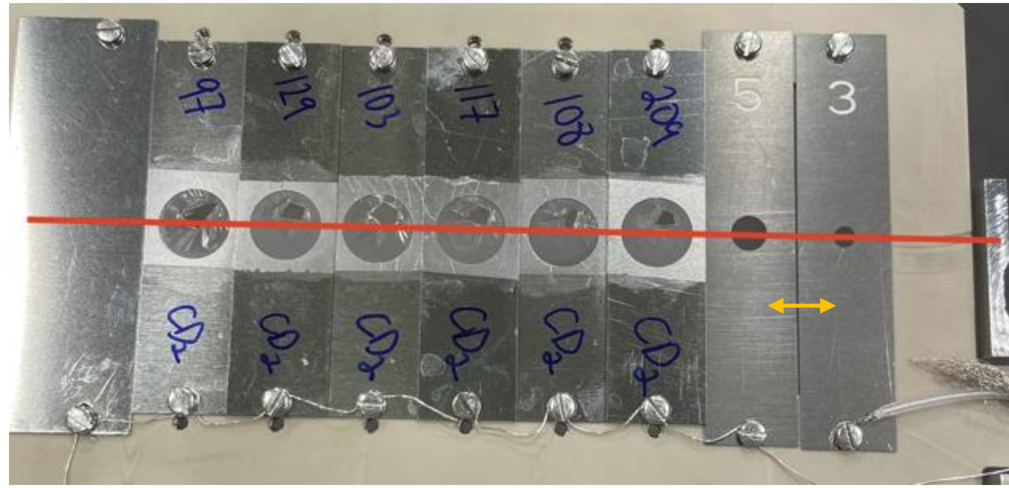


ELUM carbon signal

Postmortem analysis



All 6 CD_2 targets with holes!



- Hole shapes are irregular
- Hole positions rather consistent; little beam drift
- Small gap between 3-mm/5-mm apertures
  → To be considered in beam offset calculations
- Pure carbon target unavailable then

Cross section should be analyzed carefully with ELUM data

Summary

- $d(^{110}Sn,p)^{111}Sn$ experiment with ISS successful, more beam time than asked
- Beam intensity too high for recoil detector and CD_2 secondary target
  → much more statistics, but dependence on reliable beam composition
- Refined calibrations, channel diagnostics to be carried out

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Anna Kawecka	Chalmers University of Technology
Ben Kim	Sungkyunkwan University
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Experiment participants

Many thanks!