Spectroscopic factors in the r-process nucleus ^{135}Sn

CERN-INTC-2024-012, INTC-P-694

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HIE-ISOLDE

ISOLDE Solenoidal Spectrometer

Region of Interest

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Nuclei around doubly-magic shell closure in ^{132}Sn
- Letter of Intent: CERN-INTC-2010-045; INTC-I-111

Higher energies from HIE-ISOLDE …
… promote Coulex programme, e.g. IS548, IS551, IS702, ...
… enable nucleon transfer. e.g. ^{134}Sn(d,p)^{135}Sn … IS654

^{135}Sn – r-process nucleus

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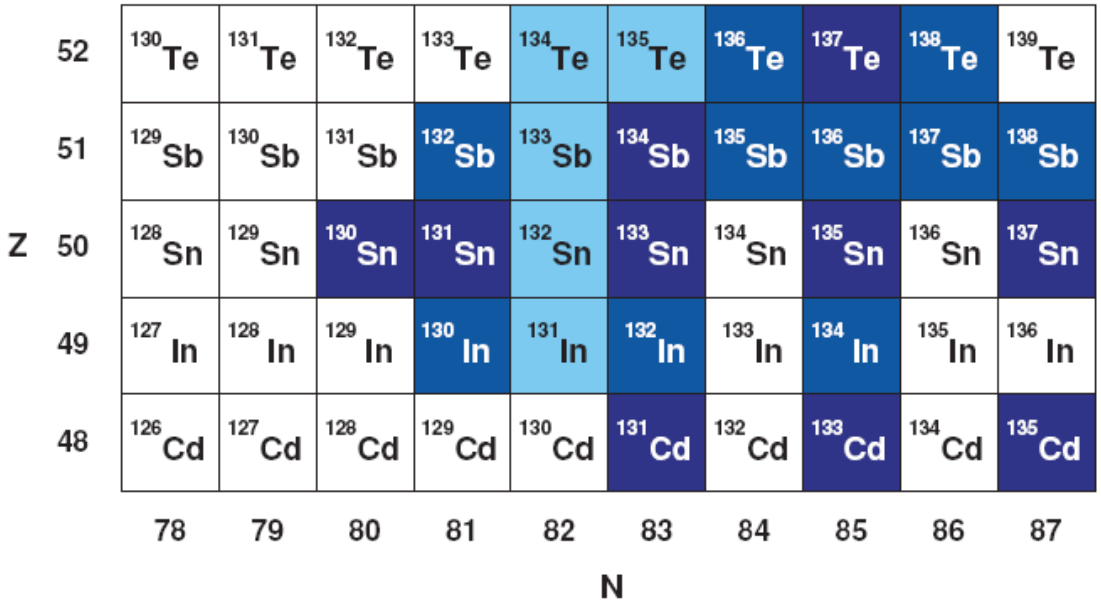
- r-process passes region around ^{132}Sn
- abundance pattern depends on both nuclear structure (m, β-$T_{1/2}$, σ(n), etc.) and astrophysical conditions
  ... August 2017: neutron star merger identified as (one) astrophysical site
- (d,p) is surrogate reaction for (n,γ)

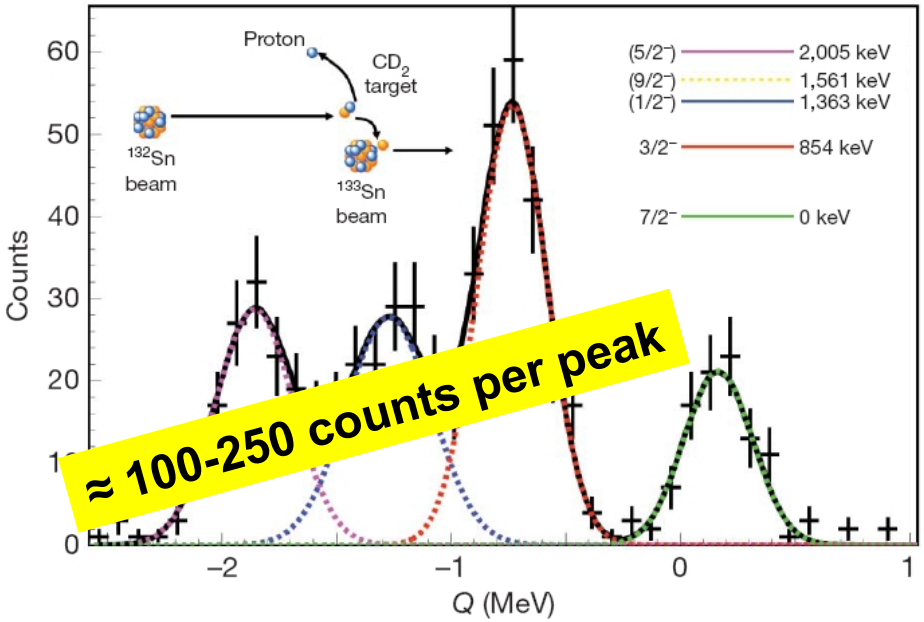
Neutron capture rates can change average abundances by up to 43%

^{134}Sn(n,γ) has no impact (^{134}Sb or ^{133}Sn have!!!)
... but transfer to an even-even nucleus is theoretically easier
... contributes to the overall understanding of (d,p) in this region

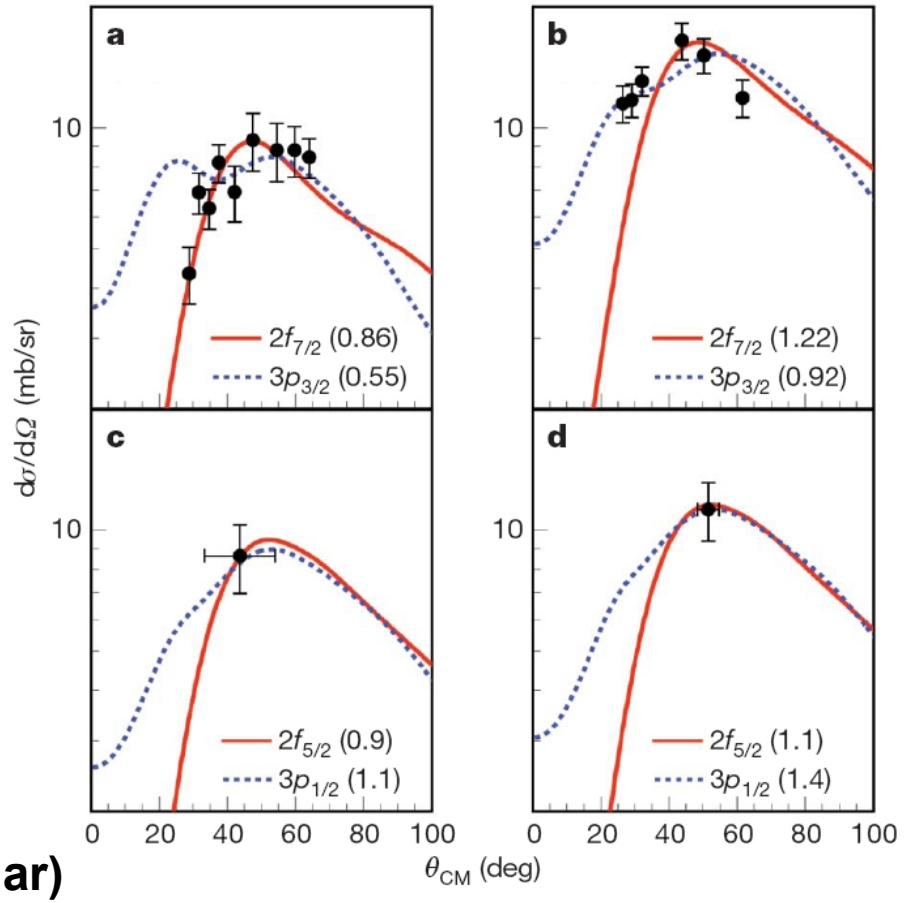


R. Surman et al., Phys. Rev. C 79, 045809 (2009)

^{133}Sn … what has been done?



^{132}Sn(d,p) @ 4.77 MeV/u



- particle spectroscopy only
- transferred Δℓ determined
  (angular distributions are quite similar)
- SFs extracted

K. Jones et al., Nature 465, 454 (2010)

… new experiment IS742 with ISS approved to repeat at HIE-ISOLDE energies

^{135}Sn – … knowledge and prediction (I)

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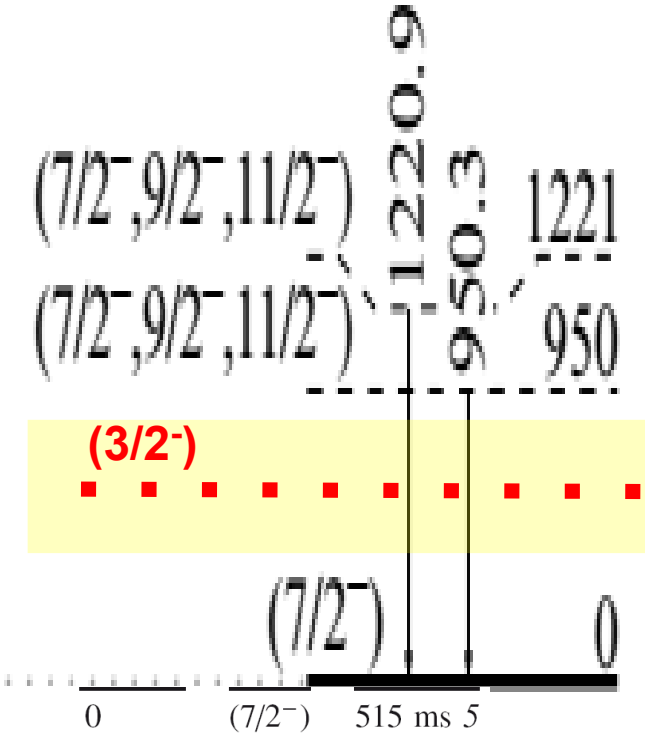
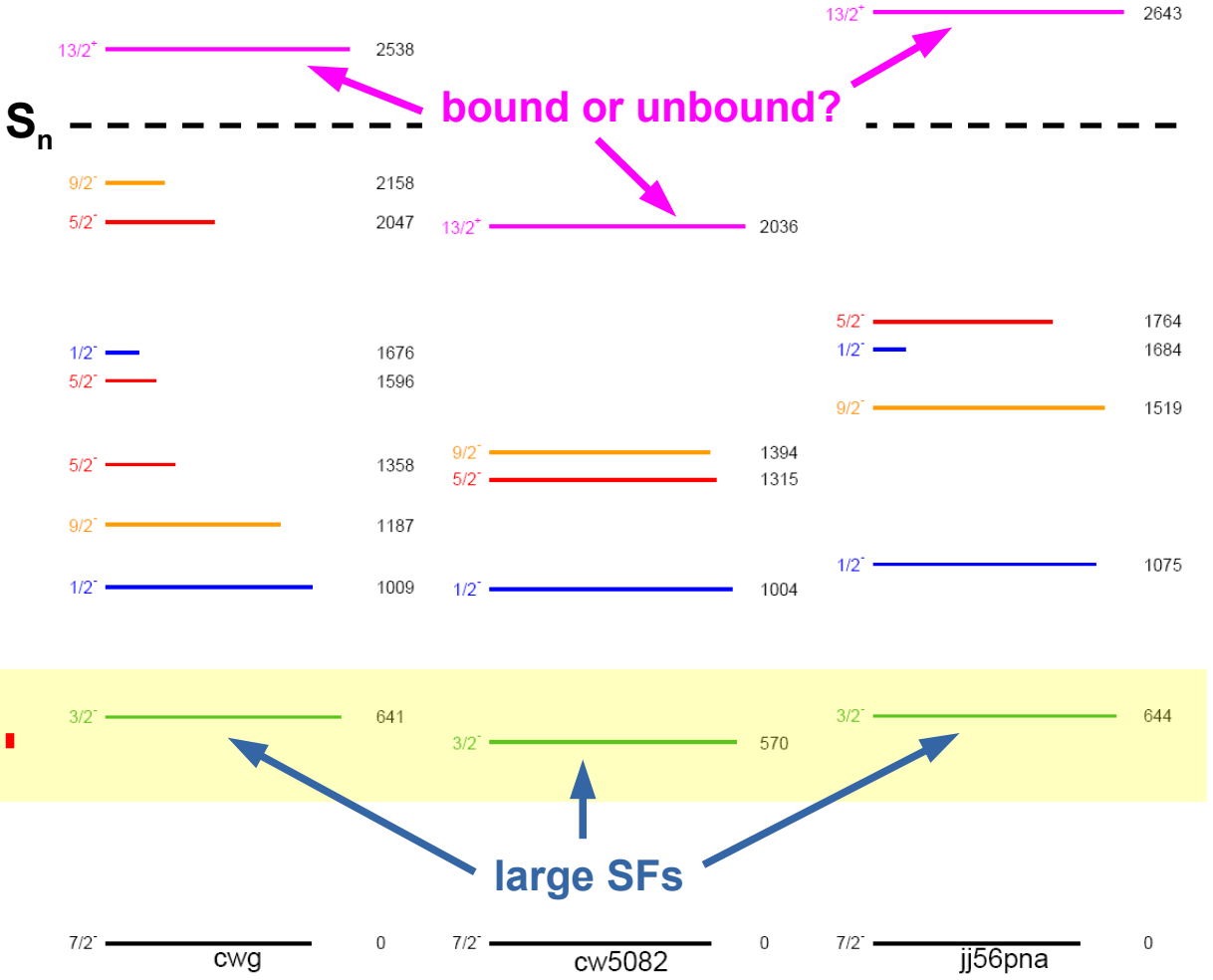
IDS: M. Piersa-Siłkowska et al. PRC 104, 044328 (2021)

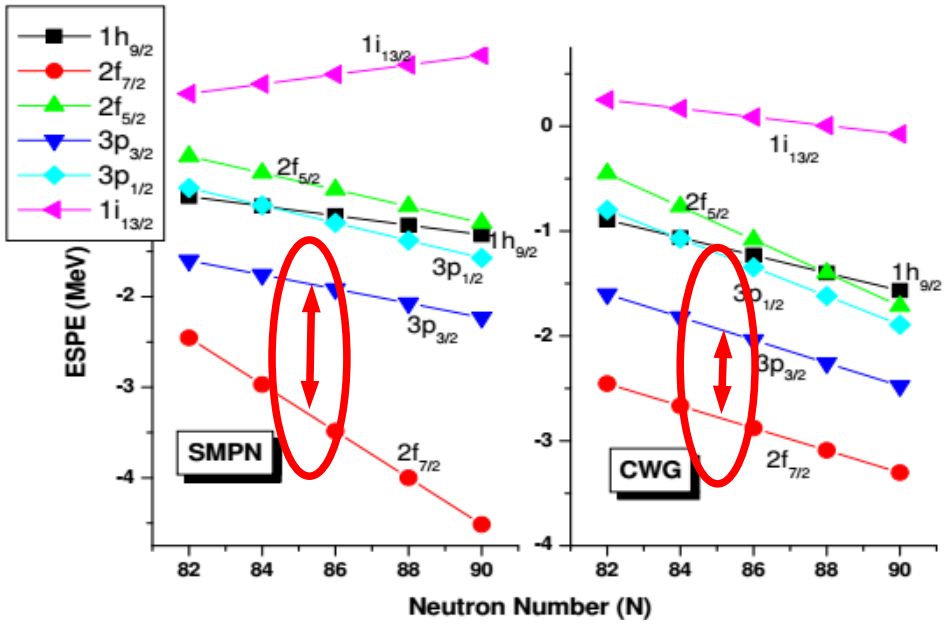
RIKEN: A. Jungclaus et al., submitted

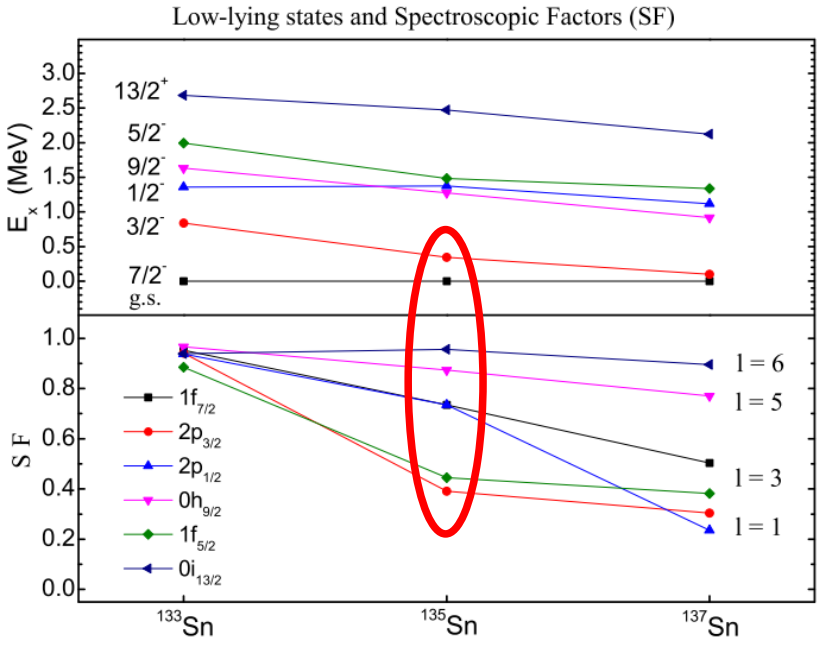


Shell model predictions



^{135}Sn – … knowledge and prediction (II)





3/2$^-$ state in ^{135}Sn
… higher excitation energy expected

S. Sarkar, M. Saha Sarkar,
J. Phys.: Conf. Ser. 267, 012440 (2011)

3/2$^-$ state in ^{135}Sn
… smaller SF predicted

H. K. Wang et al.,
Phys. Rev. C 107, 064305 (2023)

ISS vs. Miniball + T-REX … or both!

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- **Physics case already approved by INTC (IS654) … exactly 6 years ago**
  CERN-INTC-2018-008; INTC-P-539
- **Experiment with Miniball + T-REX in 2019 failed because of no beam**
  CERN-INTC-2019-006; INTC-SR-065

Why now proposed for ISS?

IS654 becomes obsolet?? No!

ISS	Miniball + T-REX
ΔE (FWHM) ≈ 200 keV for protons ground state can be measured NO kinematical compression	ΔE (FWHM) ≈ 6 keV for γ BUT: statistics about a factor of 10 lower (efficiency of Miniball) for γ-tagged protons BUT: kinematical compression
limited angular coverage only backward hemisphere	near to 4π coverage allows also for elastic scattering particle identification

Differential cross section at 7.5 MeV/u

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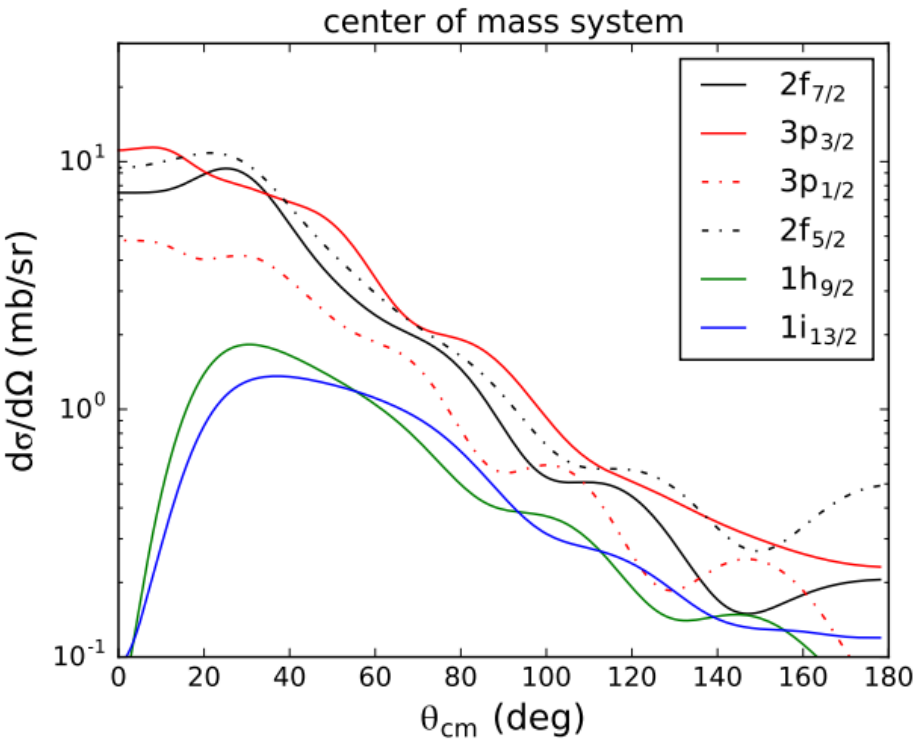

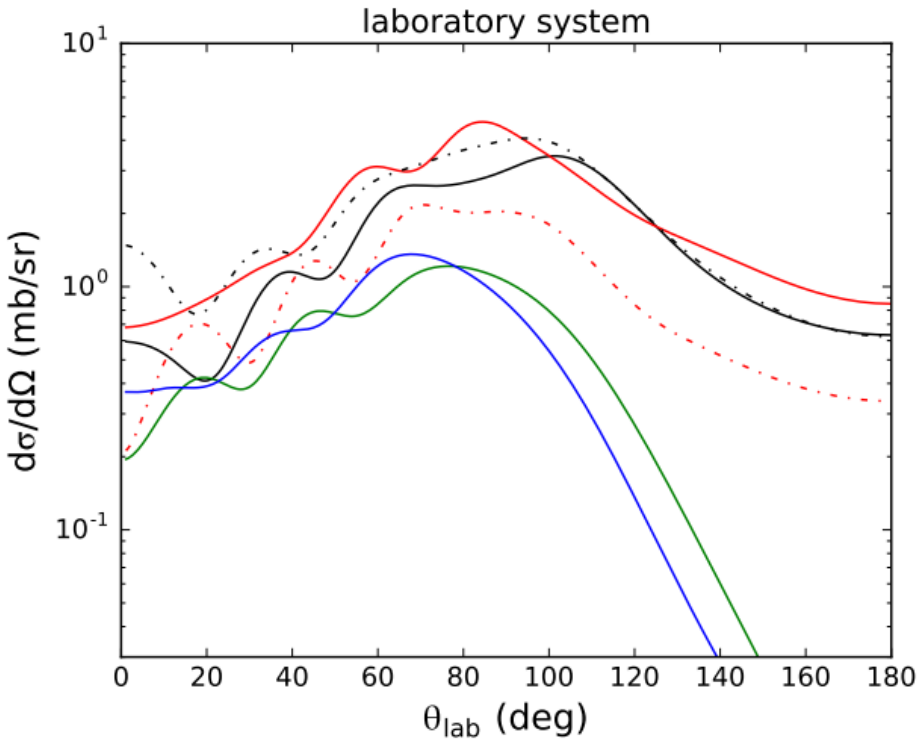

Optical potentials used:
Lohr/Haeberli (Nucl. Phys. A 232, 381) for deuterons
Becchetti/Greenlees (Phys. Rev. C 182, 1190) for protons

ISS – ISOLDE Solenoidal Spectrometer

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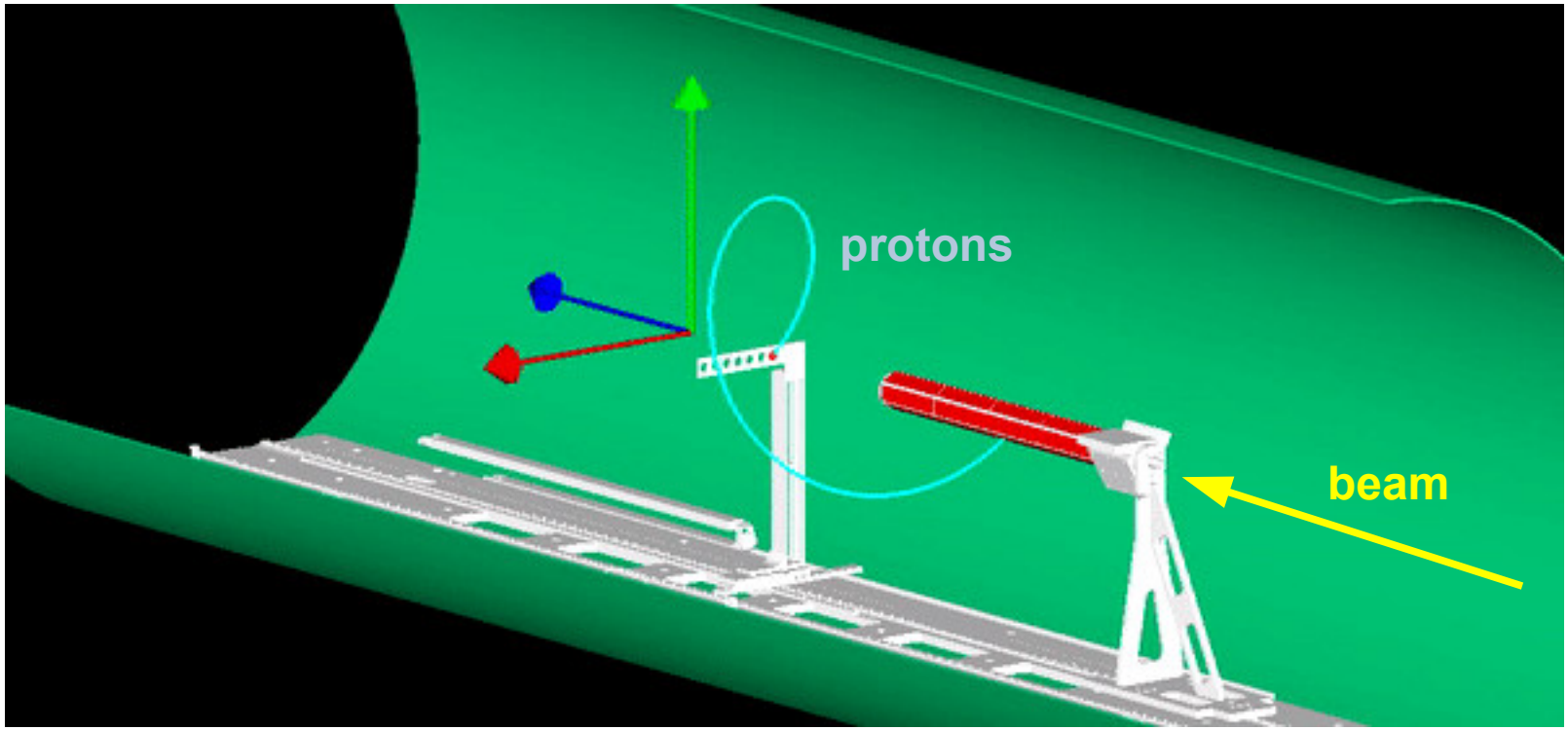
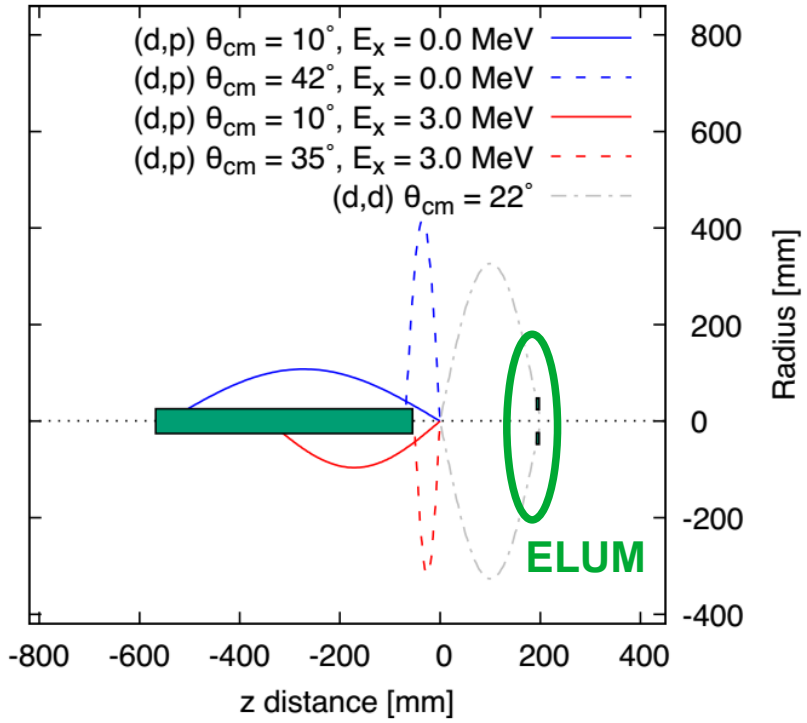
ISS (1.8 T) with ELUM and ionisation chamber



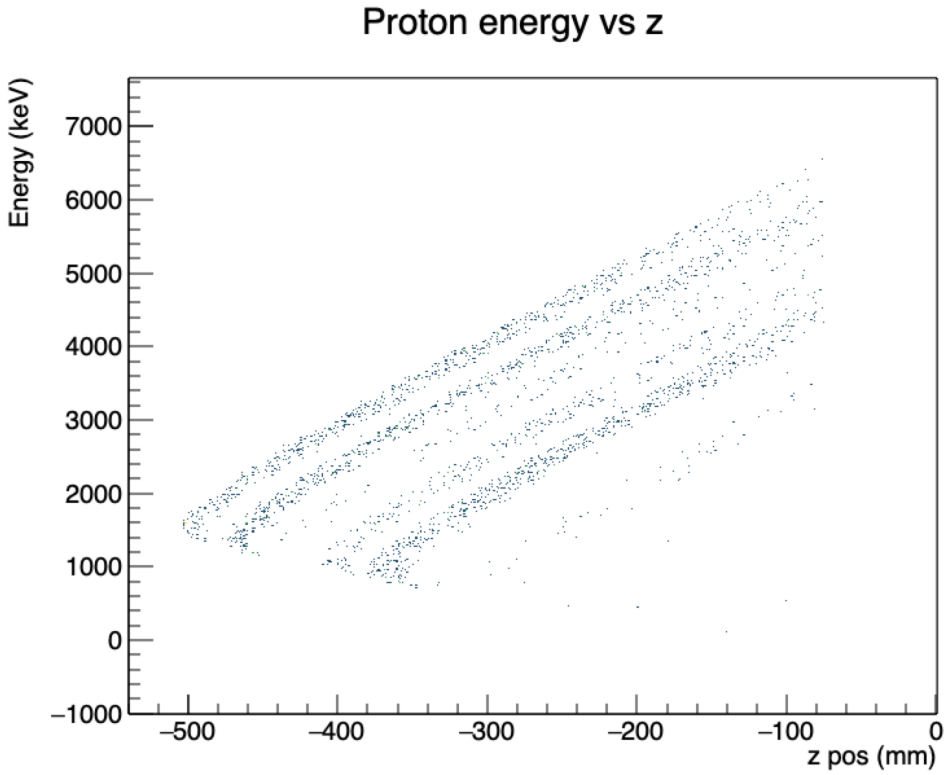
- protons from (d,p) in inverse kinematics emitted in backward direction
- linear motion parallel to beam axis
- cyclotron motion perpendicular to beam axis

Simulation (I)

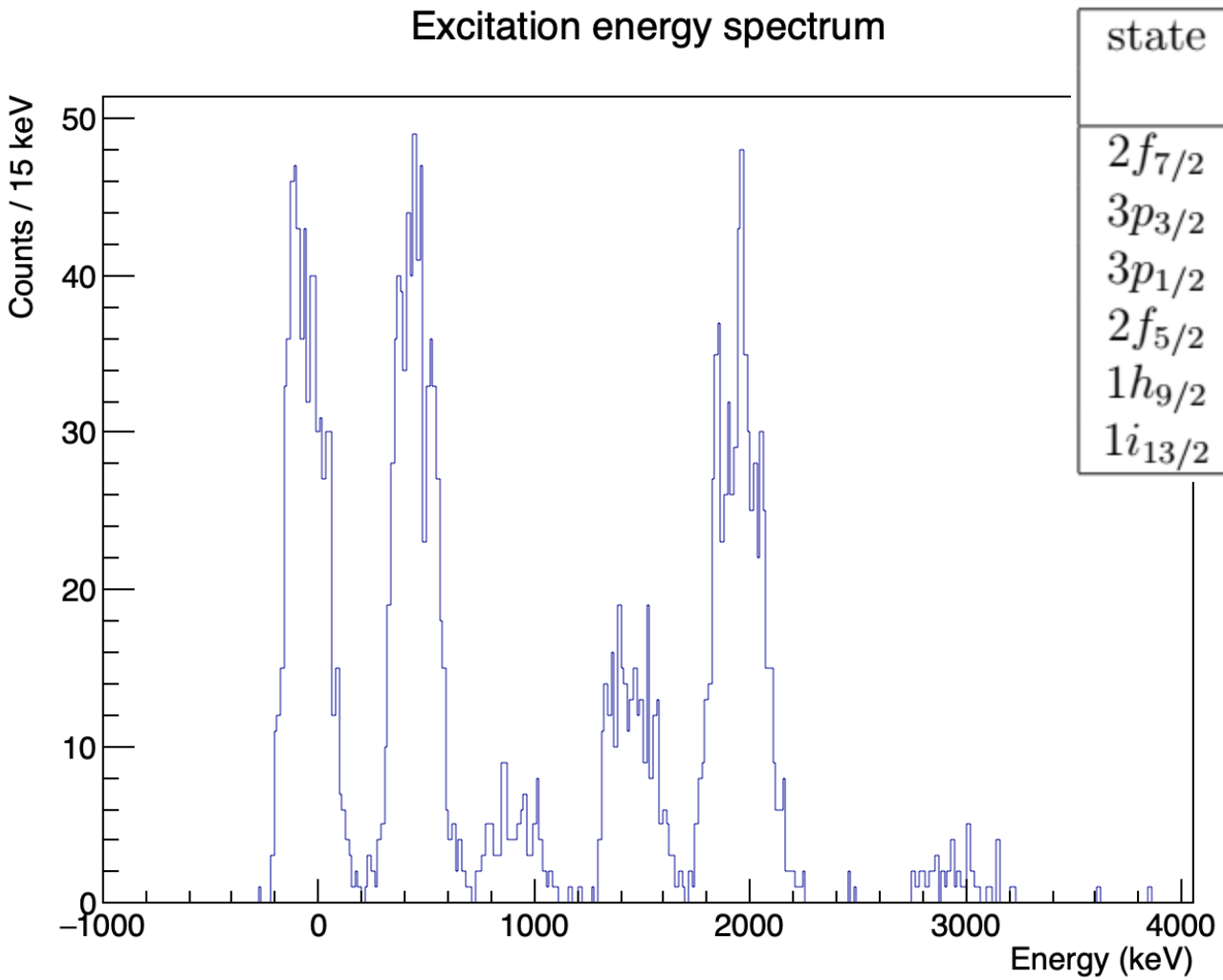


Kinematical acceptance of ISS

Detected protons in ISS Si array (threshold ≈ 1 MeV)



Simulation (II)



state	E_x [keV]	σ [mb]	rate [/shift]
$2f_{7/2}$	0	11.2	32
$3p_{3/2}$	500	11.6	33
$3p_{1/2}$	1500	5.6	16
$2f_{5/2}$	2000	13.1	37
$1h_{9/2}$	950	2.1	6
$1i_{13/2}$	3000	1.5	4

Resolution:
ΔE(FWHM) = 200 keV
… simulated for
- 200 µg/cm² CD_2 target
- realistic beam spot
- Si detector segmentation

Beam / rate estimate

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- **Beam**
  - molecular beam $^{134}Sn^{34}S^{+}$ from ISOLDE
  - beam energy from HIE-ISOLDE: 7.5 MeV/u
  - intensity on target 10^4/s
  - contamination with ^{134}Sb (A=168 contaminations?) … other Q value for (d,p)

→ no problems foreseen following the TAC comments

- **Rate (200 µg/cm² CD_2 target)**
  - rate per level: 4-37 protons/shift, ≈0.5/shift in total spectrum from fusion on C
  - split in 3-6 angular bins (5°-10°)
    → conservatively: 15 counts/shift, 6 angular bins, 24 shifts: **60 protons/bin**

(factor 2 more compared to ^{133}Sn
K. Jones et al., Nature 465, 454 (2010))

- **Main physics aims**
  - **ΔI and SFs for the strongly populated states**
  - excitation energies (possible also with lower statistics)

We request 24 shifts (8 days) of beam time