SpecMAT
Magnetic Active Target for the spectroscopy of exotic nuclei

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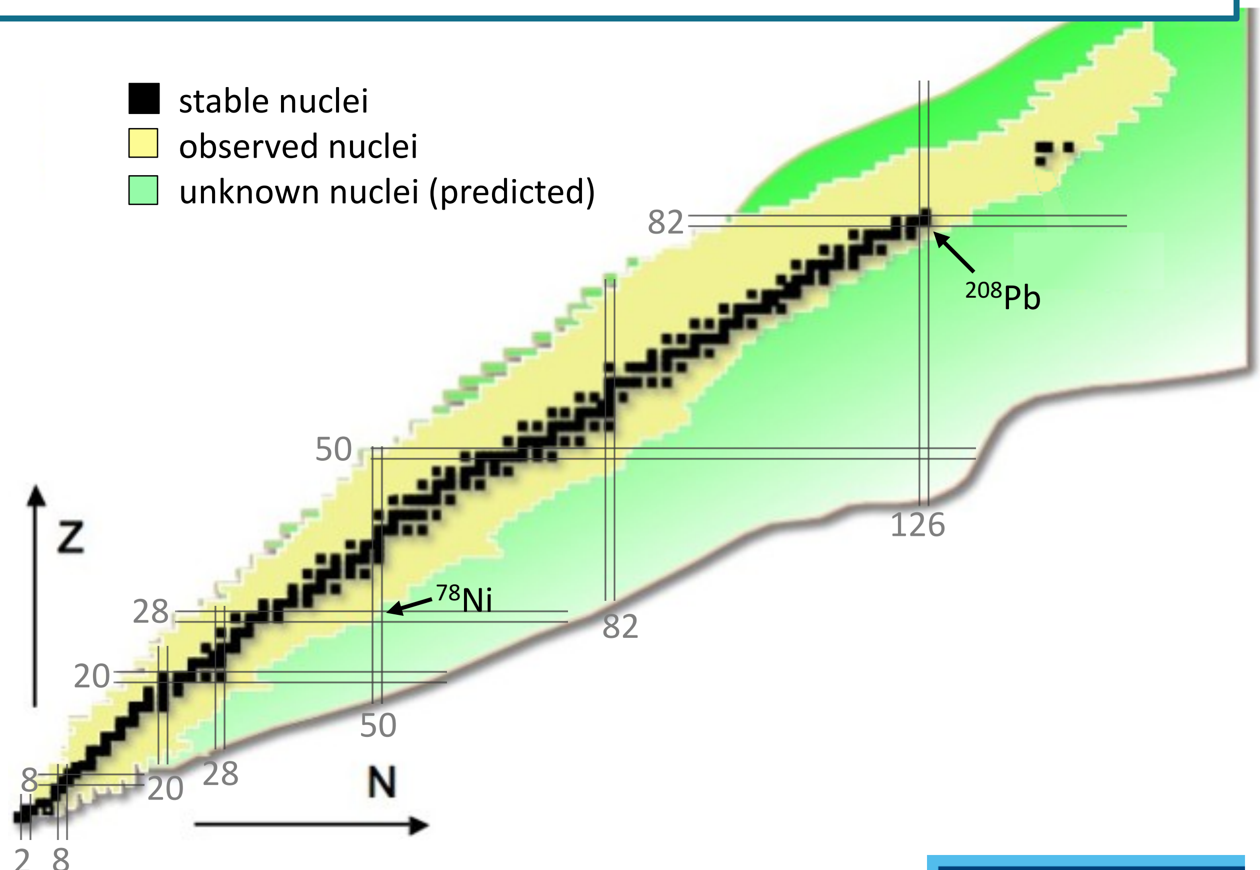
GDS Topical Meeting:
GDS for high-intensity and heavy-ion beams

Physics goals

- What are the **forces driving the shell structure in nuclei and how do they change** in nuclei far from stability?
- What remains of the **Z = 28 and N = 50 "magic numbers"** in ^{78}Ni?
- Do we understand **shape coexistence in nuclei**, and what are the mechanisms controlling its appearance?

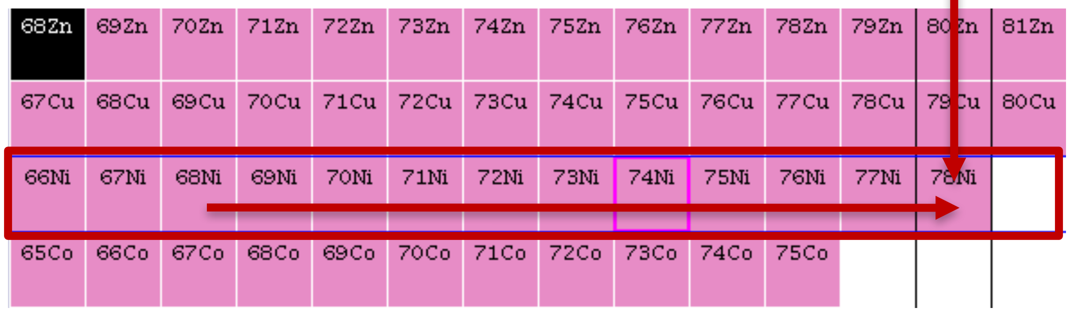
Changes in nuclear structure far from stability

- Shell evolution towards ^{78}Ni
- Shape coexistence "west" of ^{208}Pb



Shell evolution towards ^{78}Ni

- Migration of $\pi f_{7/2}$, $\pi f_{5/2}$ as $\nu g_{9/2}$ is filled (tensor interaction)



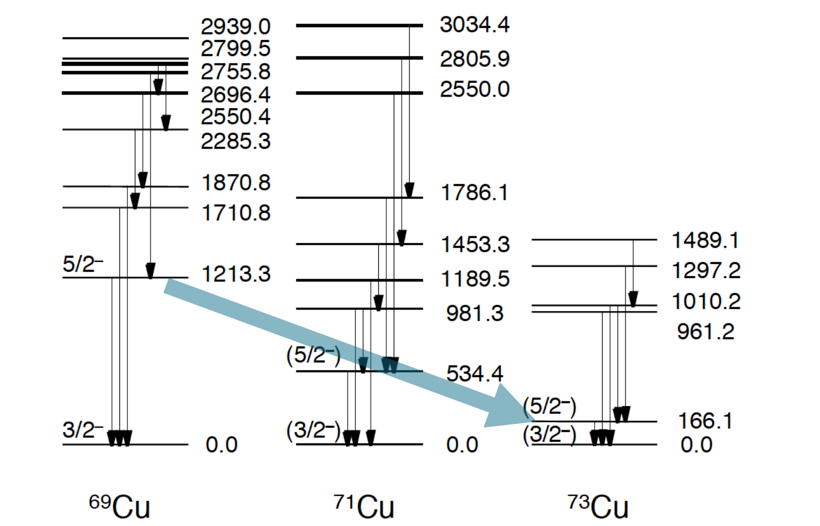


FIG. 4. Energy level systematics for ^{69,71,73}Cu. Energies are given in keV. The data for ^{69}Cu are taken from Ref. [18].

S. Franchoo et al., PRL 81 (1998) 3100

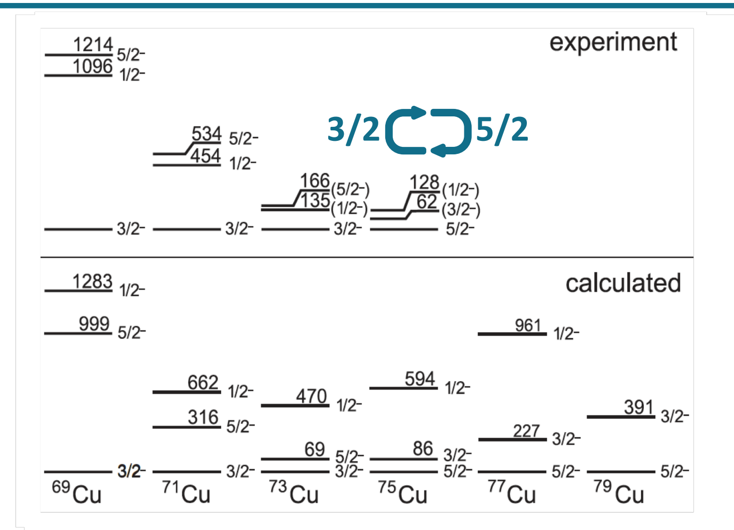


FIG. 3. Energy of the lowest levels from experiment [2,5,6] compared to large-scale shell-model calculation [25].

K. Flanagan et al., PRL 103 (2009) 142501

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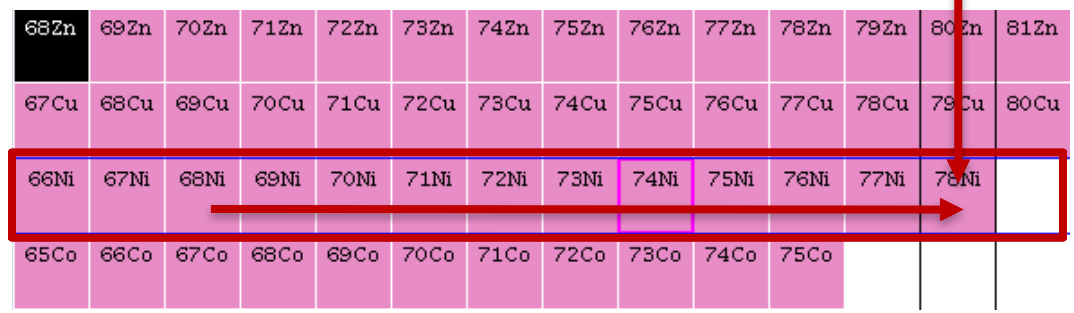
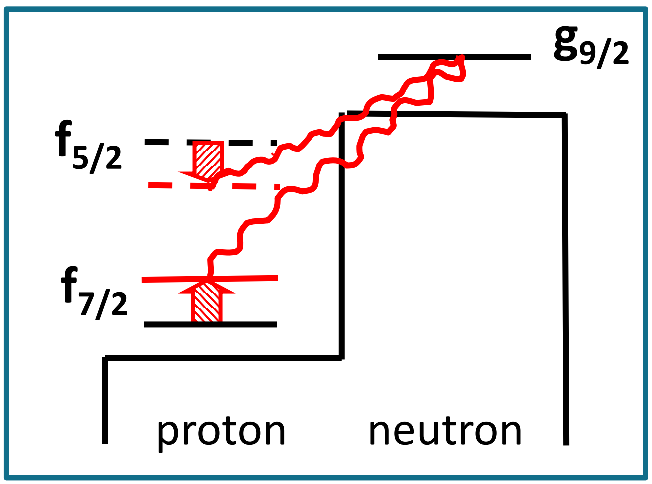
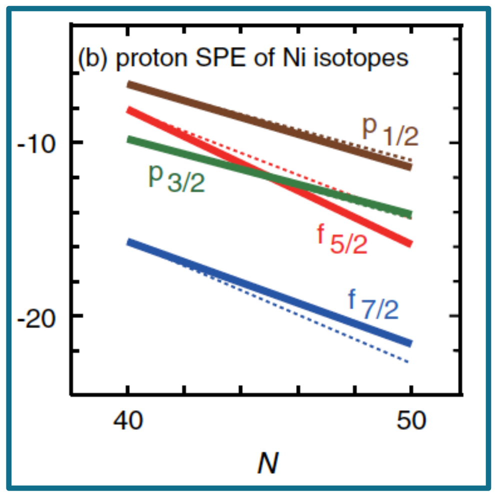
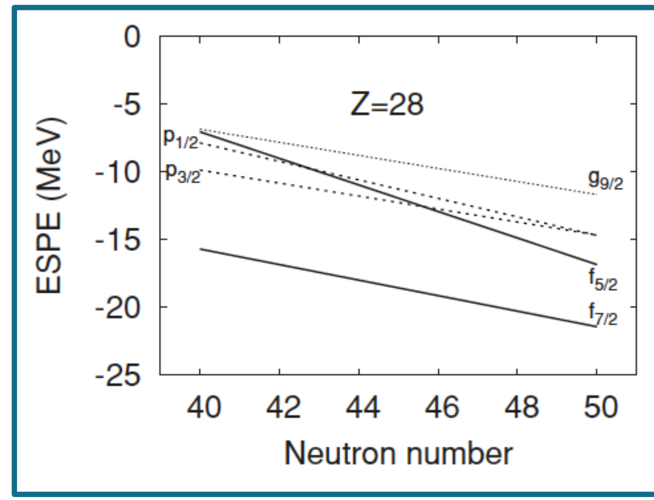






T. Otsuka, et al.,
PRL 104 (2010) 012501



K. Sieja, F. Nowacki,
PRC 81 (2010) 061303(R)

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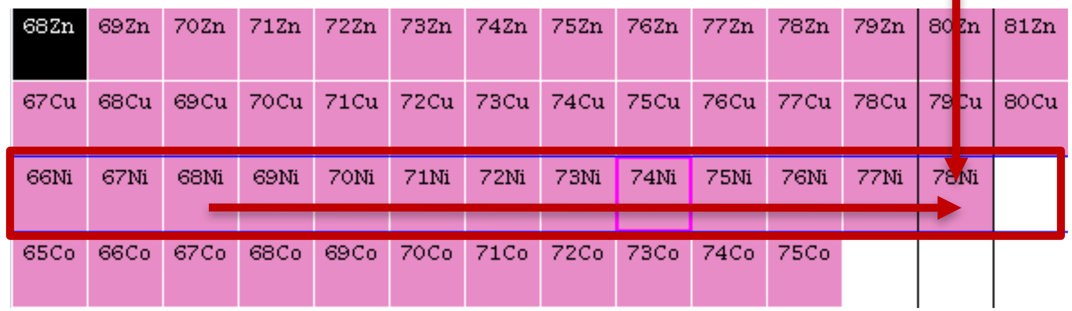
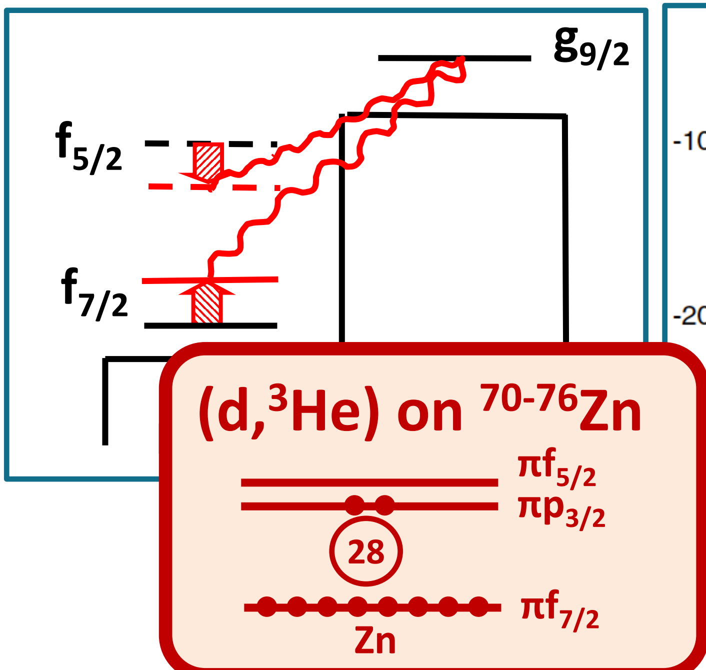
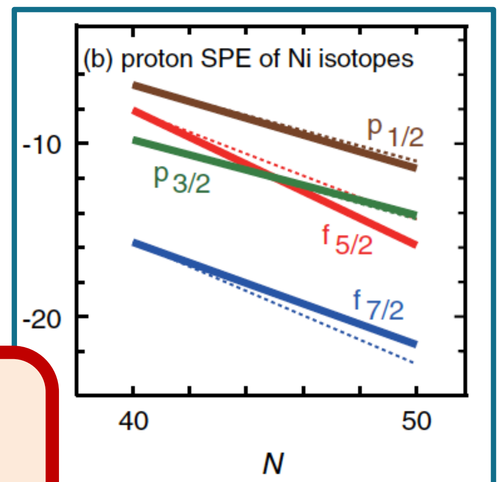
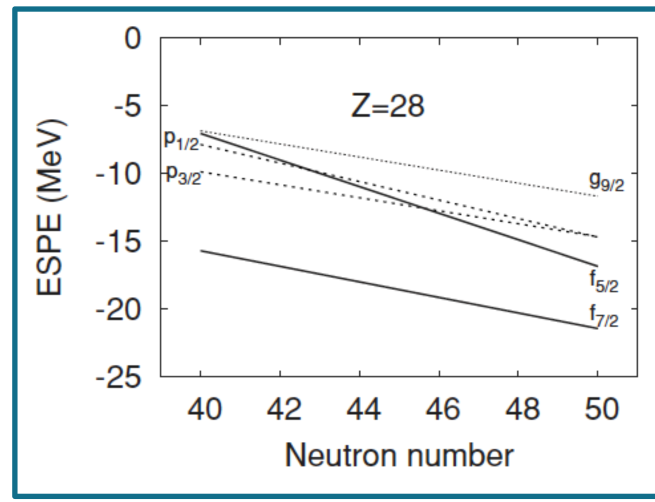






T. Otsuka, et al.,
PRL 104 (2010) 012501



K. Sieja, F. Nowacki,
PRC 81 (2010) 061303(R)

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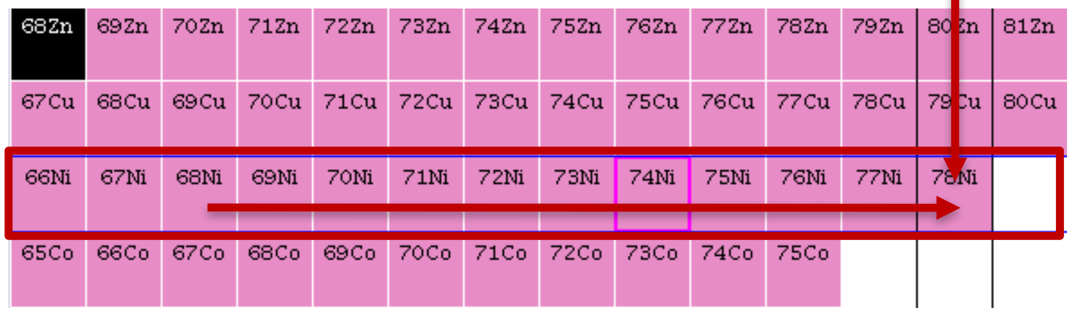
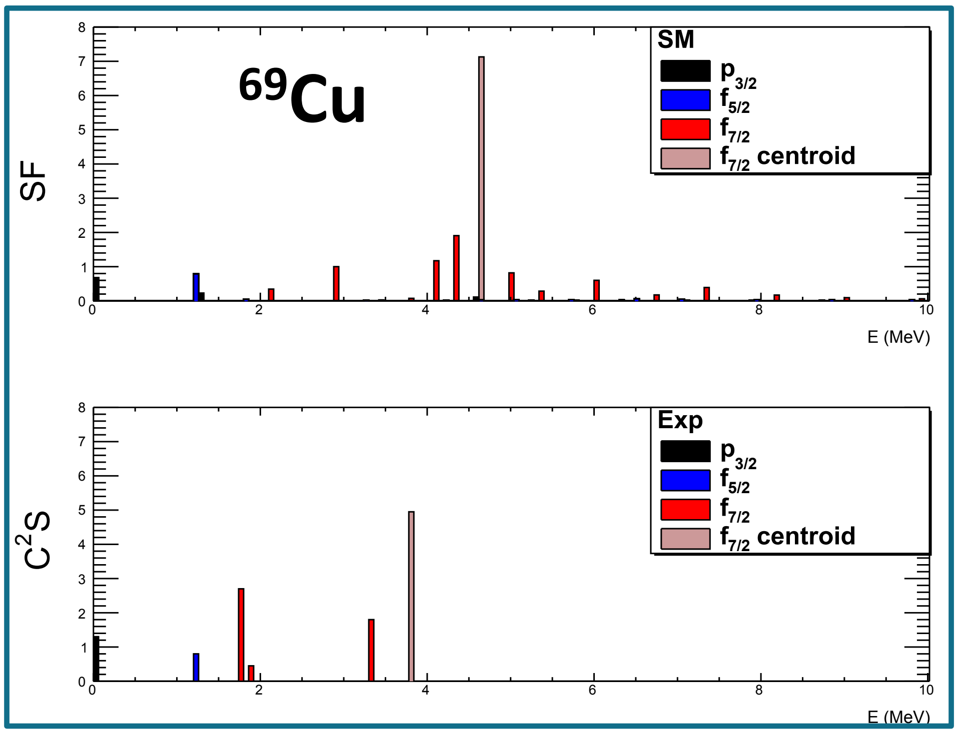
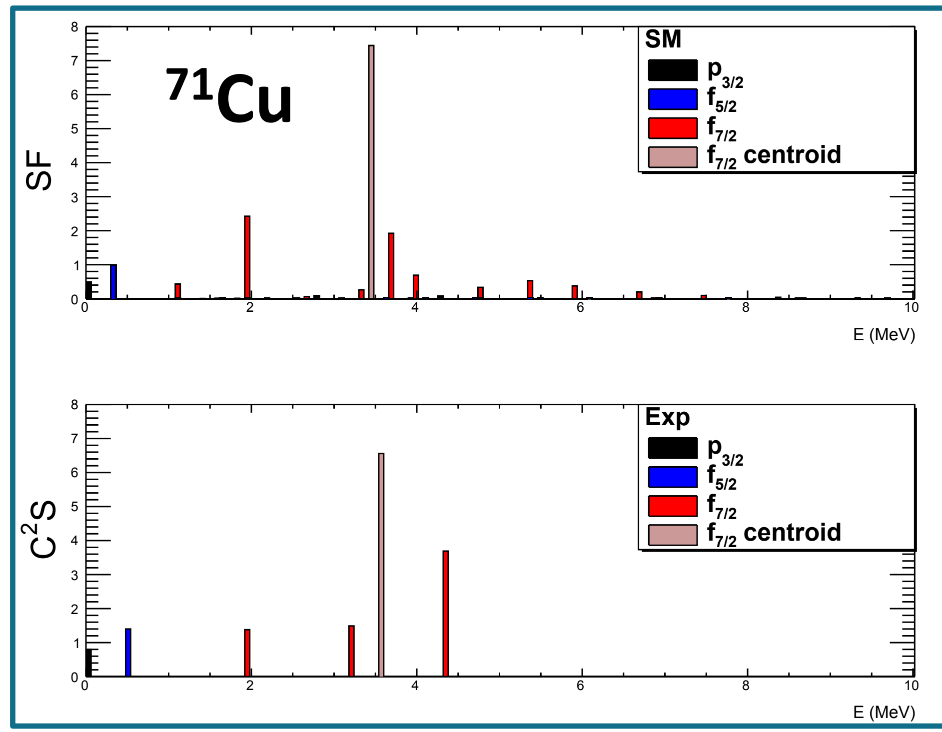






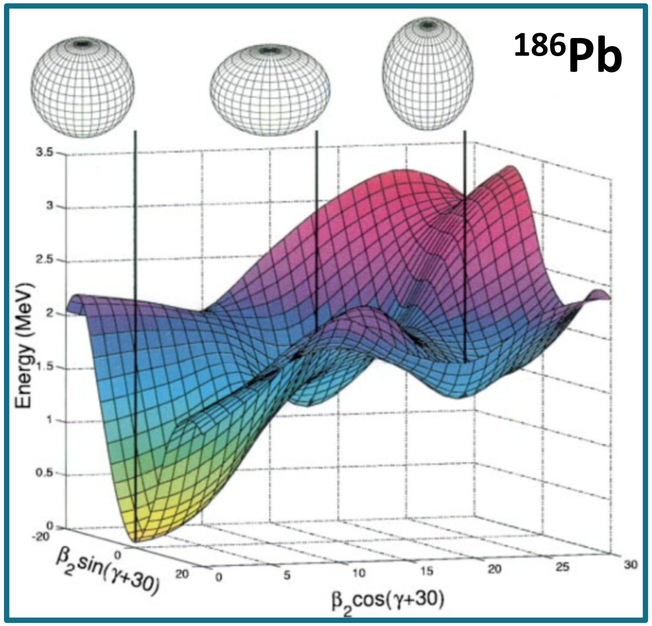
P. Morfouace et al., PRC 93 (2016) 064308

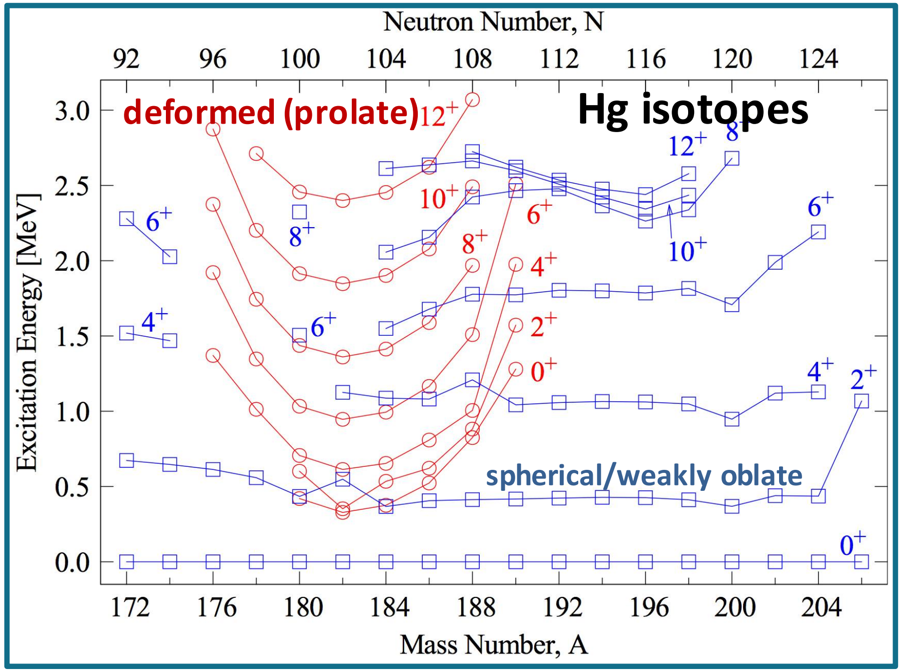
P. Morfouace et al., PLB 751 (2015) 306

Shape coexistence

- States characterised by different shapes appear at low excitation energy
- Example: n-deficient Pb region
  ^{186}Pb triple-shape coexistence
  Hg nuclei: "parabolic intrusion" at mid-shell

A. Andreyev et al., Nature 405 (2000) 430





Data: NNDC, figure courtesy of Liam Gaffney
Original figure in R. Julin et al., J. Phys. G 27 (2001) R109

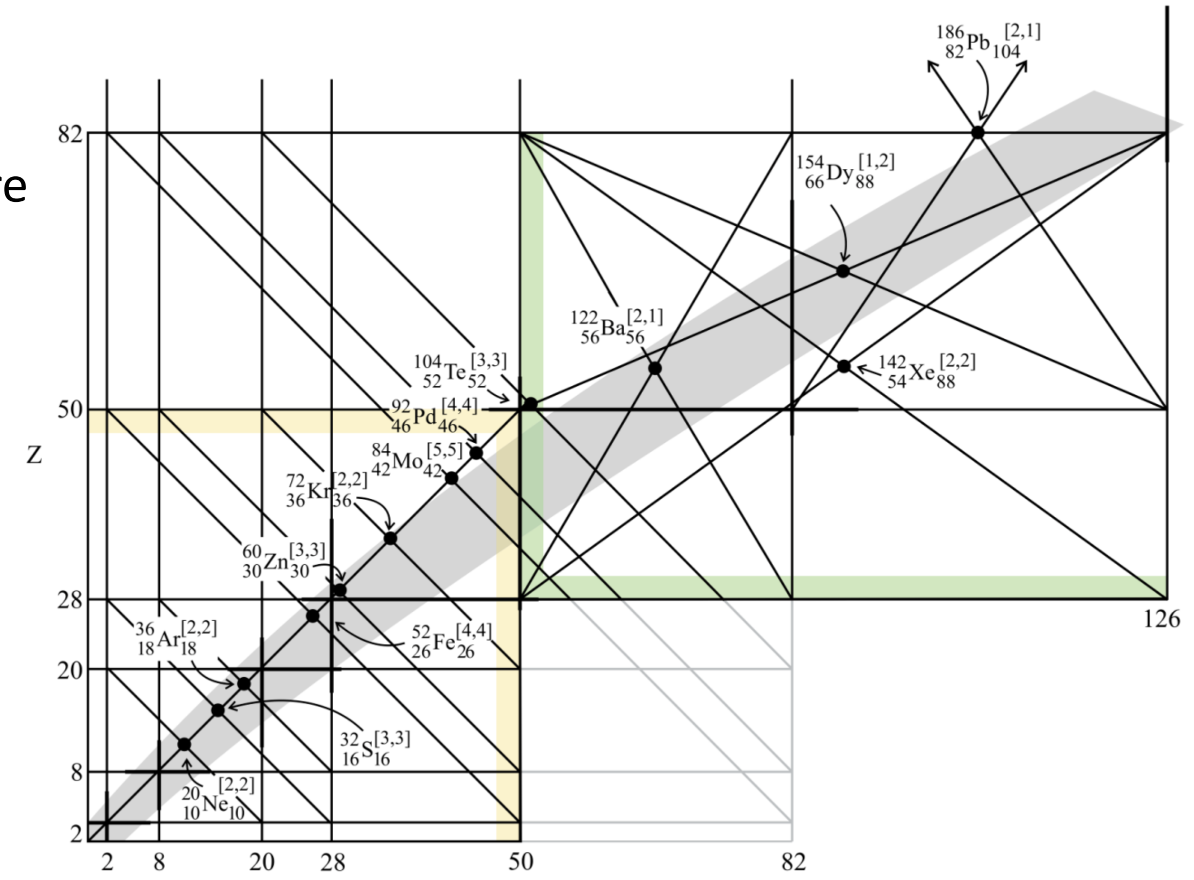
Which observables
to characterise these states?

Figure: T. Cocolios (2010)

Shape coexistence: a general occurrence?

K. Heyde and J. L. Wood, Rev. Mod. Phys. 83, 1467 (2011)

- Link collective properties with single-particle structure
- Shell-model picture: position of shells is crucial
- Far from stability: monopole migration from underlying NN forces
- We need both collective and single-particle probes



Single-particle structure and collectivity

PHYSICAL REVIEW C **89**, 031301(R) (2014)

Novel shape evolution in exotic Ni isotopes and configuration-dependent shell structure

Yusuke Tsunoda,[1] Takaharu Otsuka,[1,2,3] Noritaka Shimizu,[2] Michio Honma,[4] and Yutaka Utsuno[5]
[1]*Department of Physics, University of Tokyo, Hongo, Bunkyo-ku, Tokyo 113-0033, Japan*
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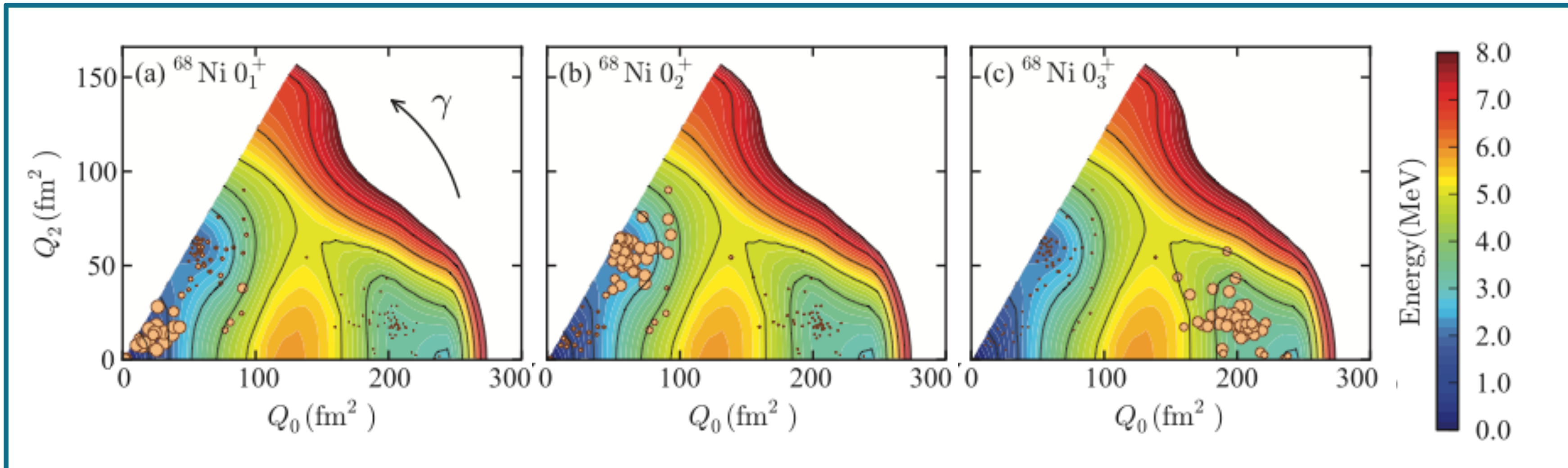
[3]*National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, Michigan 48824, USA*
[4]*Center for Mathematical Sciences, University of Aizu, Ikki-machi, Aizu-Wakamatsu, Fukushima 965-8580, Japan*
[5]*Advanced Science Research Center, Japan Atomic Energy Agency, Tokai, Ibaraki 319-1195, Japan*
(Received 19 September 2013; revised manuscript received 25 November 2013; published 17 March 2014)



^{68}Ni

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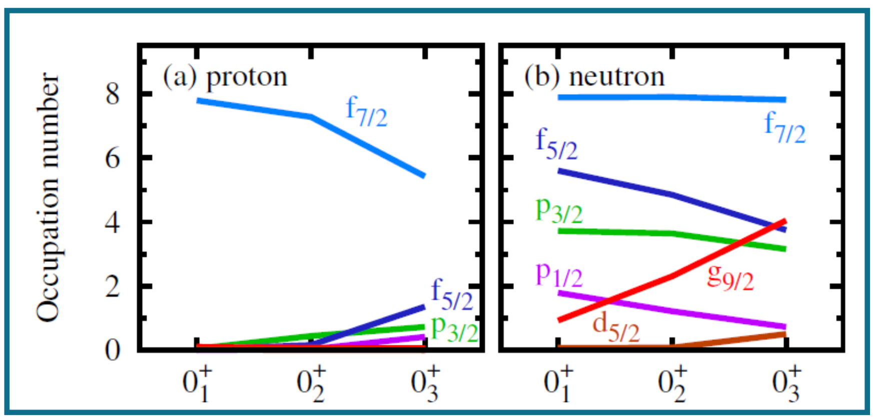


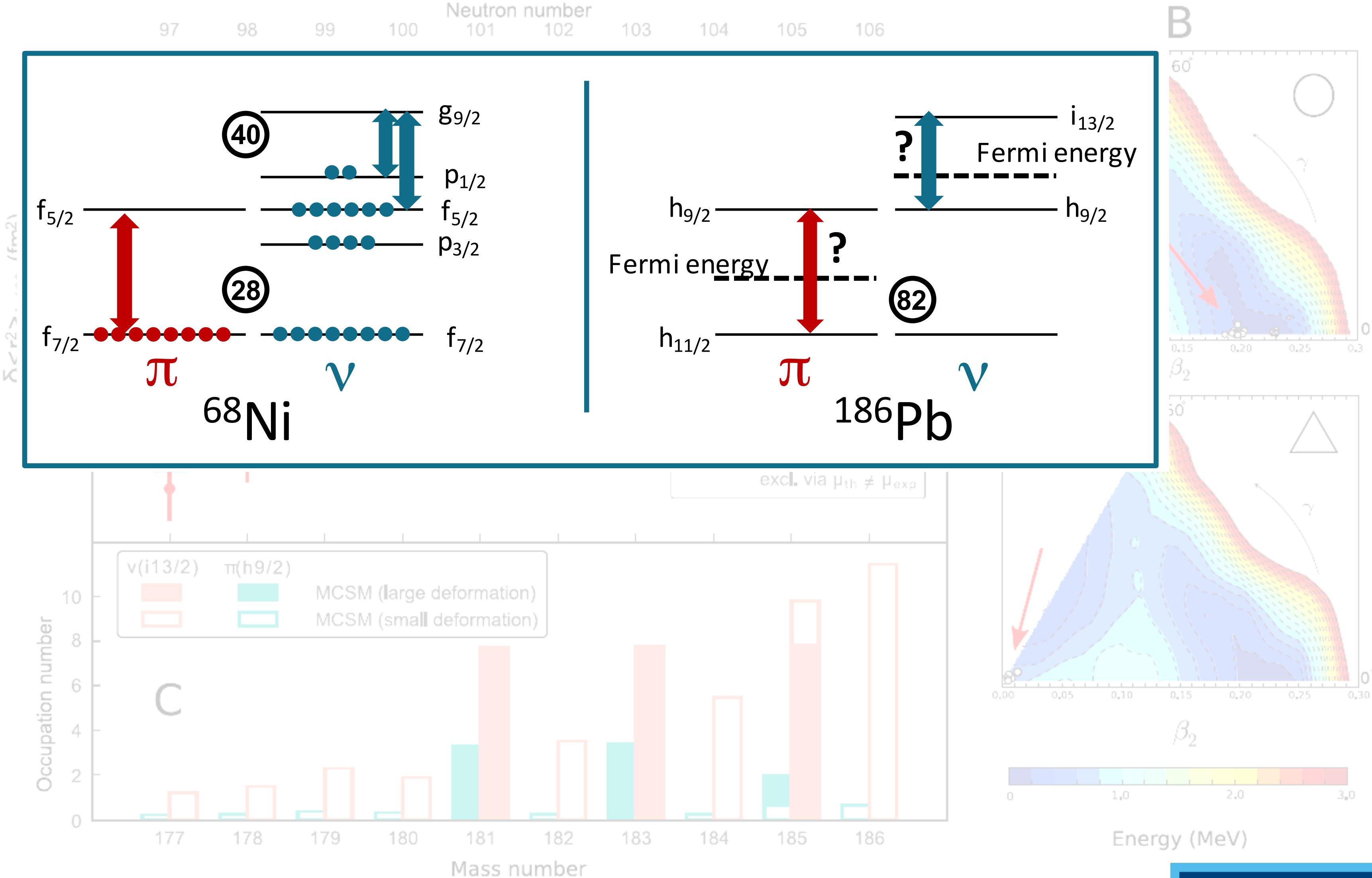
^{68}Ni

"Type II" shell evolution

- In excited states, the different occupancies drive the variations in the shell gaps…
- which may favour collectivity…
- which modifies energy levels even further

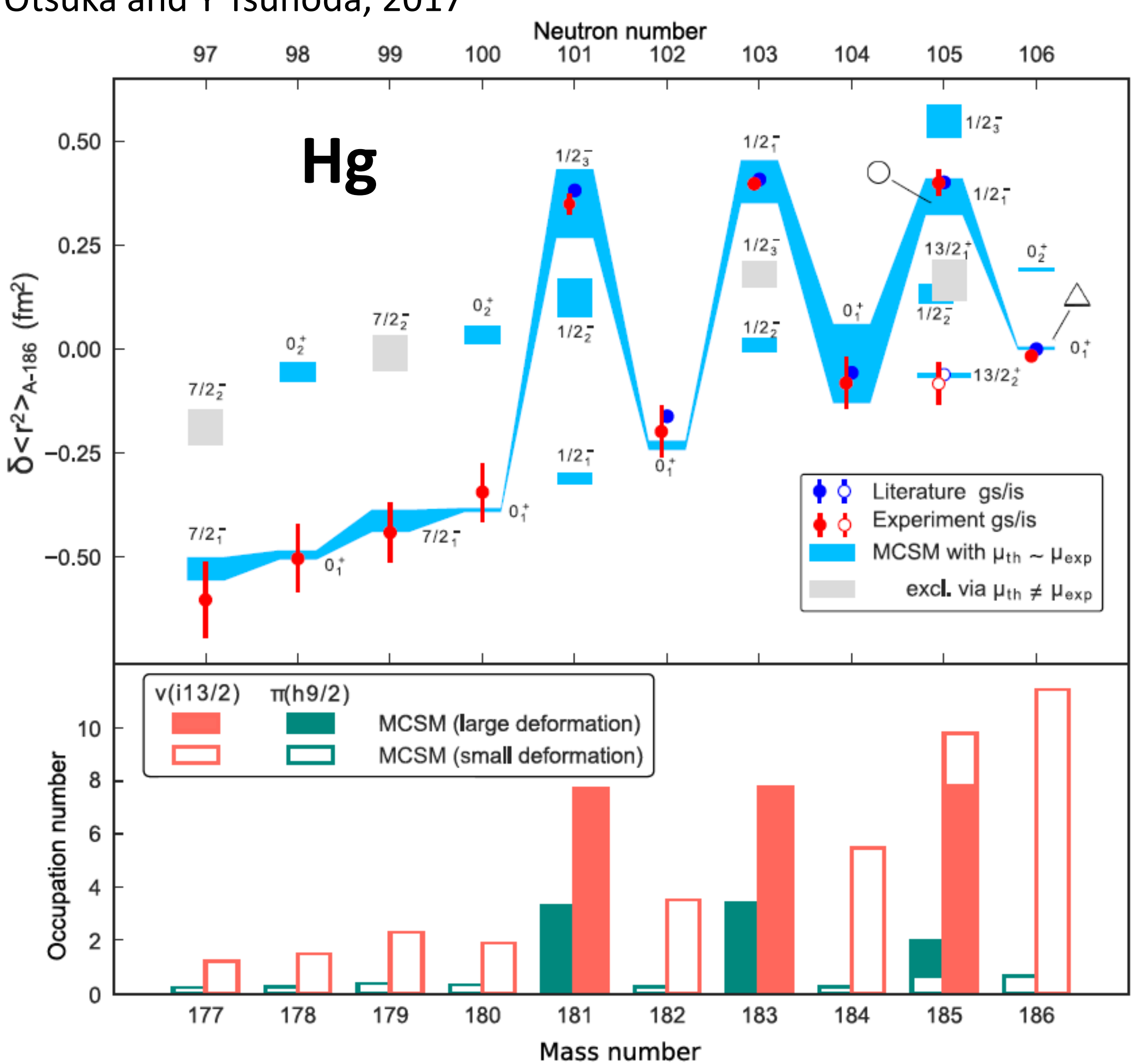
The n-deficient Pb region

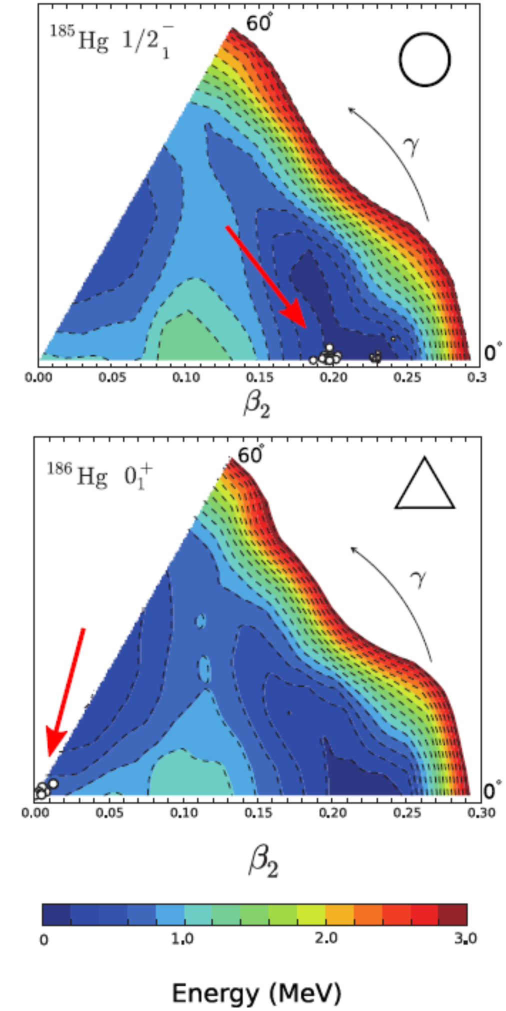
T Otsuka and Y Tsunoda, JPG 43 (2016) 024009



The n-deficient Pb region

T Otsuka and Y Tsunoda, 2017

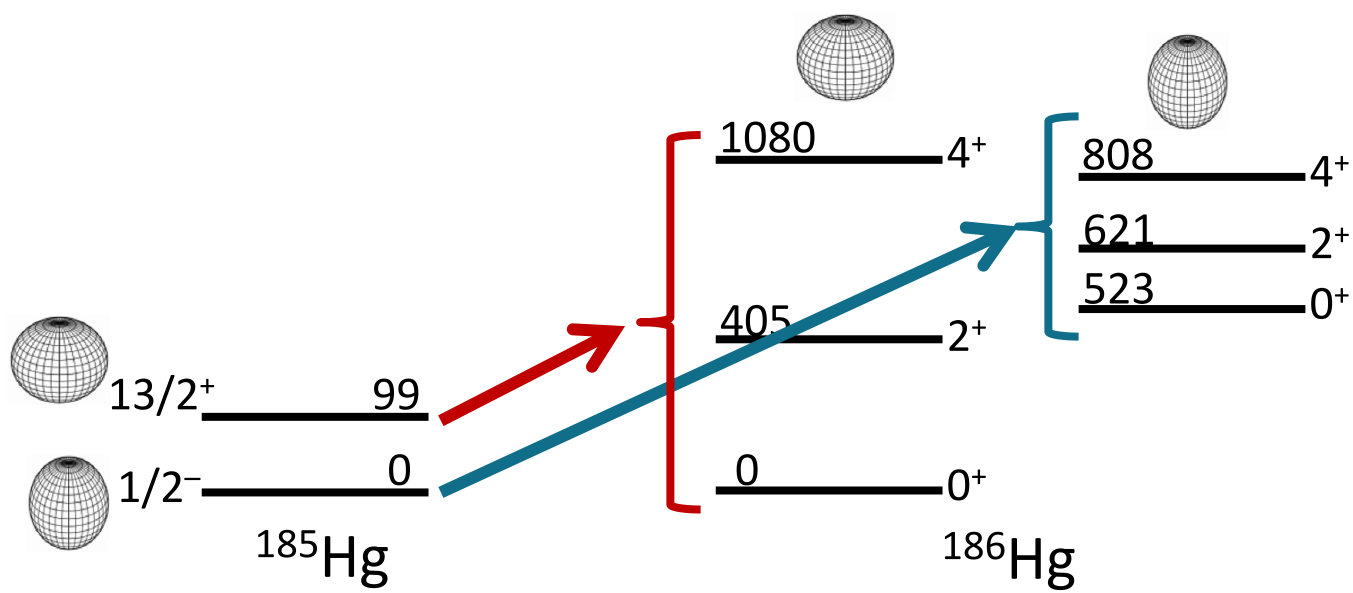




The n-deficient Pb region

1-n transfer in Hg

- ^{185g,m}Hg (d,p) and (p,d)
- Beam intensity ≈ 10^5 pps → feasible!



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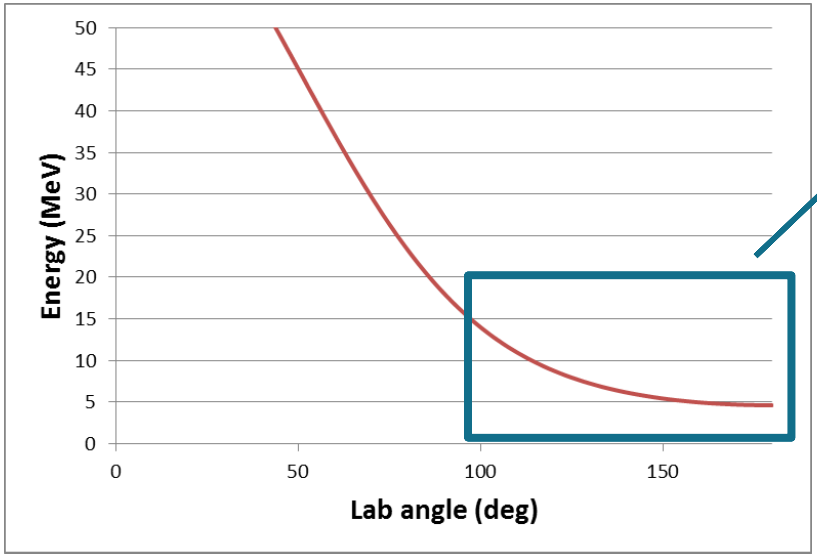
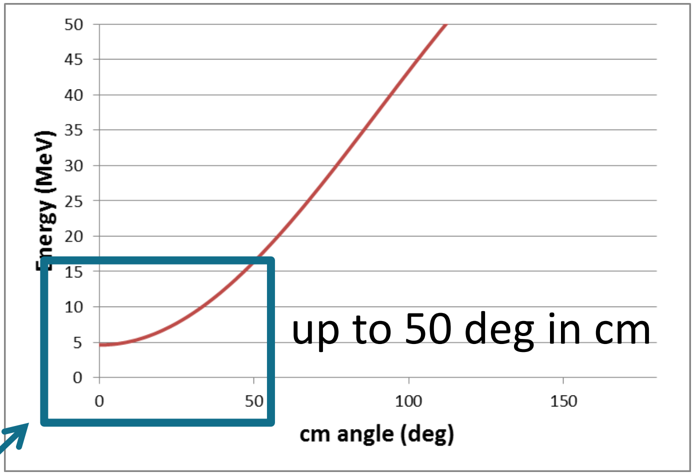
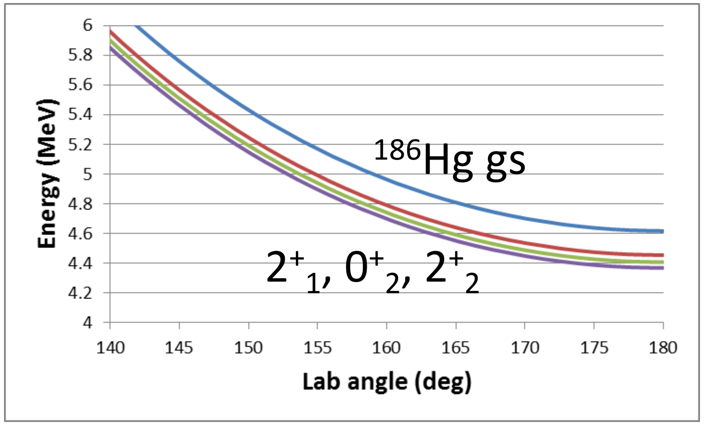
1-n transfer in Hg

- ^{185g,m}Hg (d,p) and (p,d)
- Beam intensity ≈ 10^5 pps → feasible!

(d,p)^{186}Hg 10 MeV/nucleon, *Q*-value +8.2 MeV





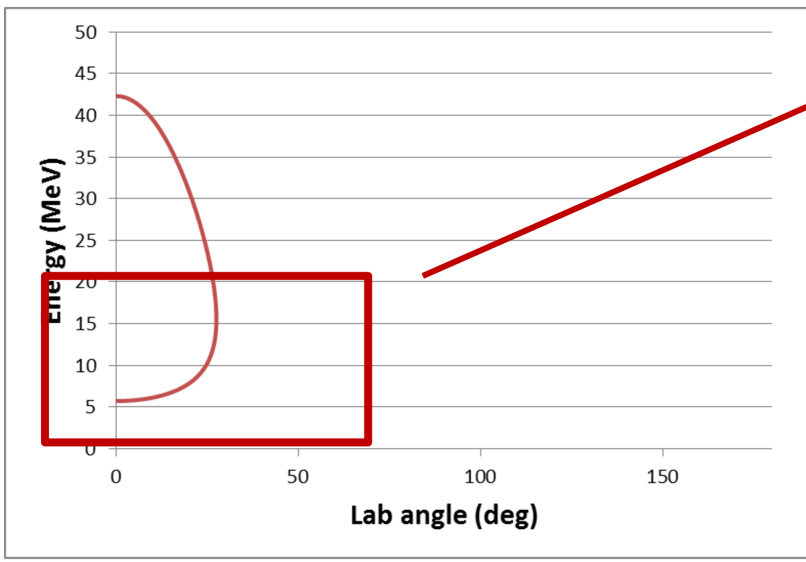


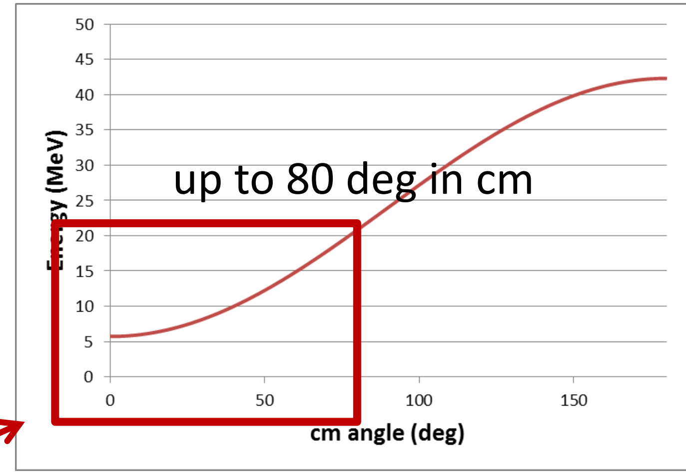
The n-deficient Pb region

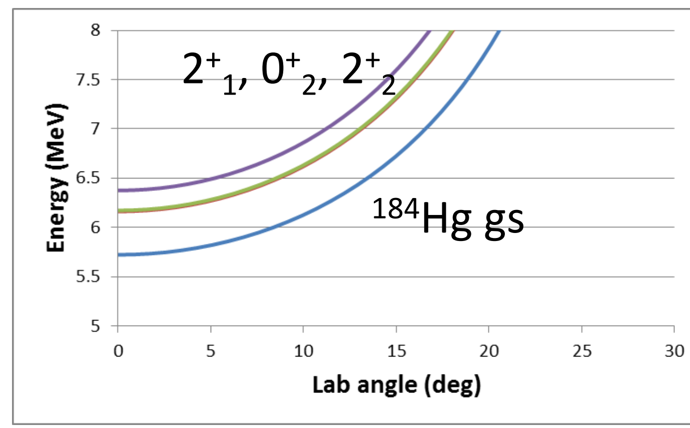
1-n transfer in Hg

- ^{185g,m}Hg (d,p) and (p,d)
- Beam intensity ≈ 10^5 pps → feasible!

(p,d)^{184}Hg 10 MeV/nucleon, Q-value –5.7 MeV



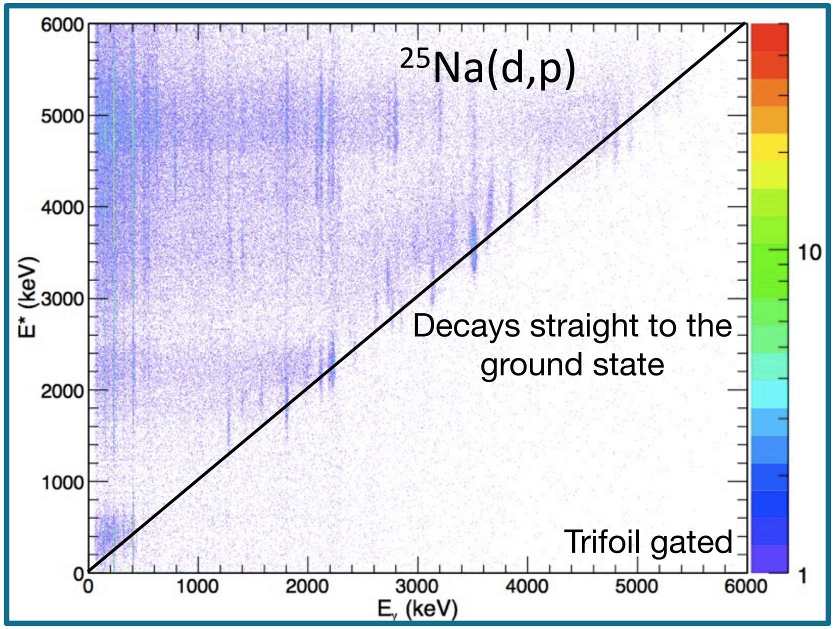




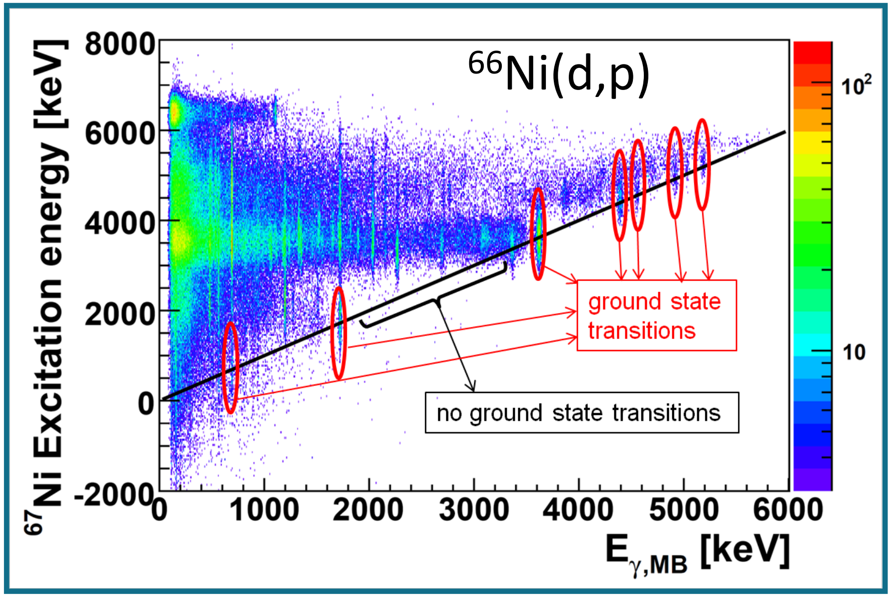
Problem: density of states

Importance of γ-ray detection

- Transition probabilities
- Energy resolution from coincidences
- Build the decay scheme



G. Wilson et al., PLB 759, 417 (2016)

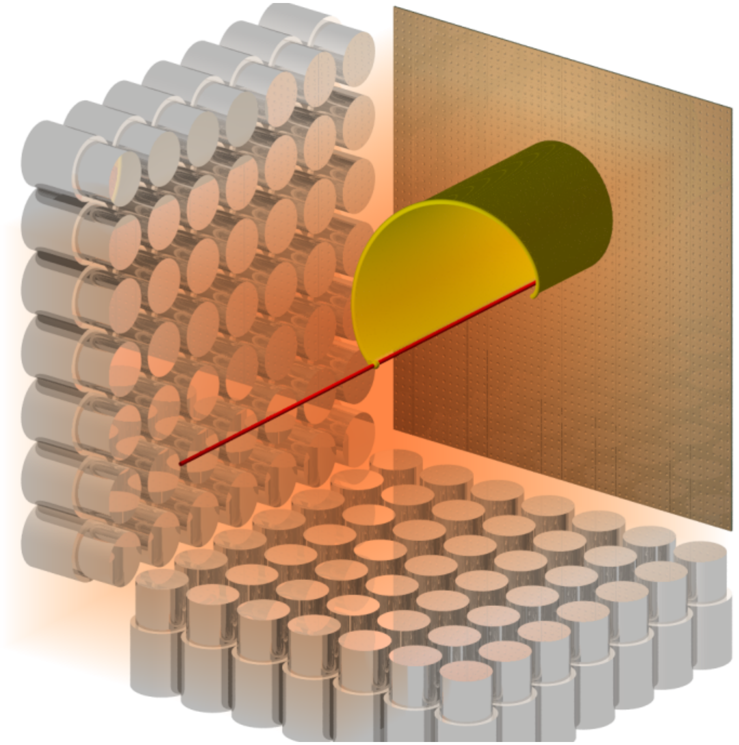


J. Diriken et al., PLB 736, 533 (2014)
J. Diriken et al., PRC 91, 054321 (2015)

Method: active target + γ-ray array

Challenges

- Good efficiency…
- …keeping a sufficient resolution
- Integration of detectors



→ Choices

- Active target
- Magnetic field parallel
  to beam direction
  to confine emitted particles
  and minimize absorbing material
- γ-ray detection: scintillators
  $CeBr_3$ with SiPM
  GET electronics (?)

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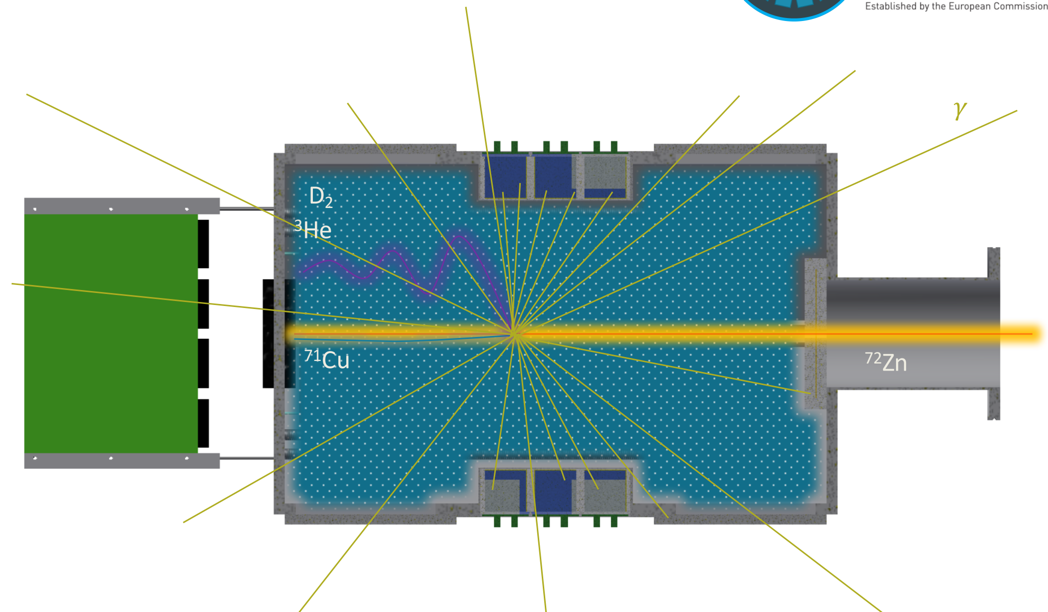
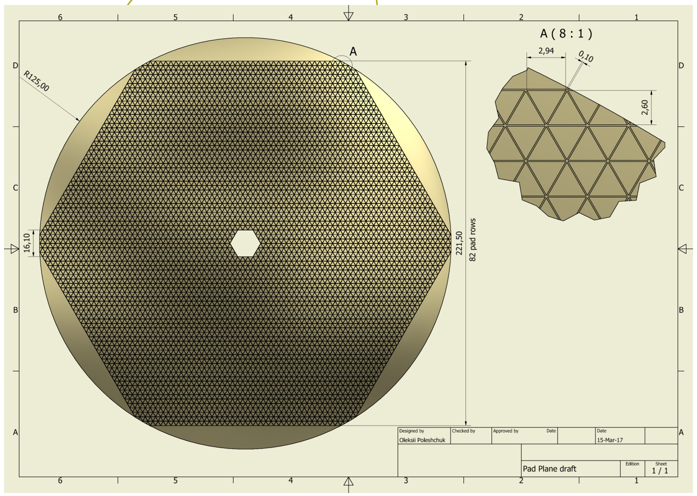
Figures by O. Poleshchuk

Features

- Parallel-field configuration → attenuation of problems related to the heavy beams
- Beam should NOT be stopped
- (d,^{3}He) better efficiency





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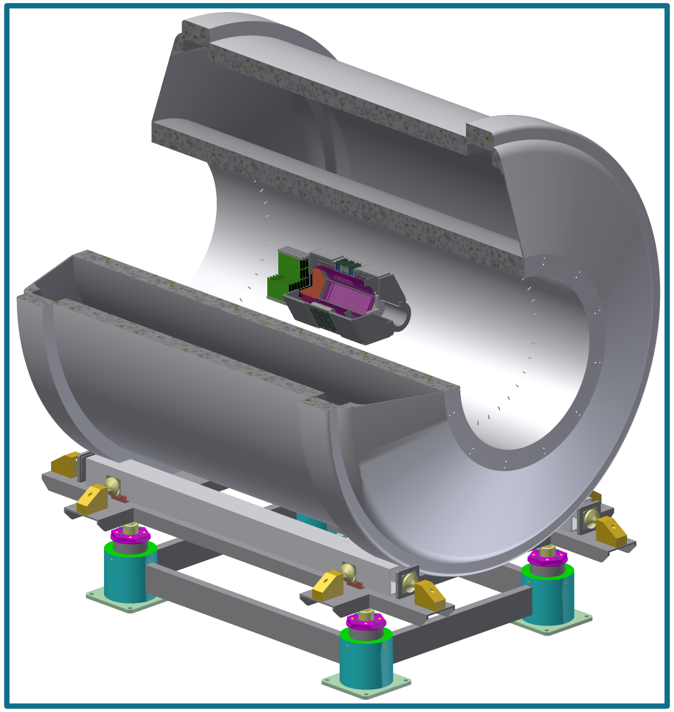
Development and status

- See Oleksii's talk today 17:45

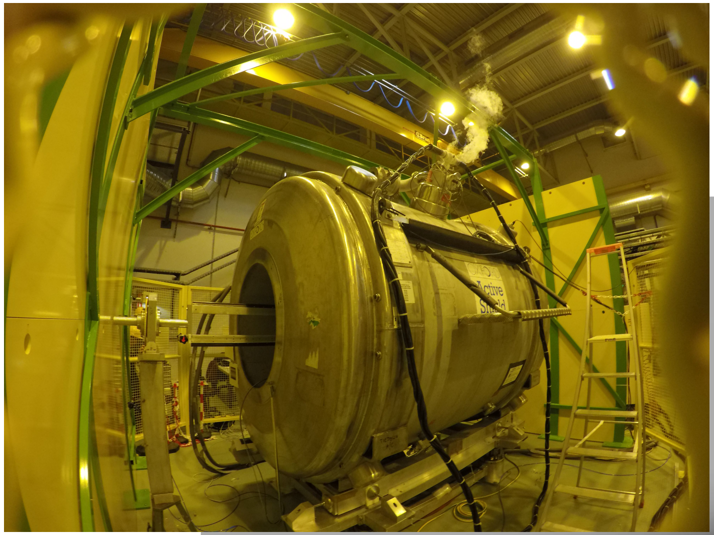
- The magnet: a long story…

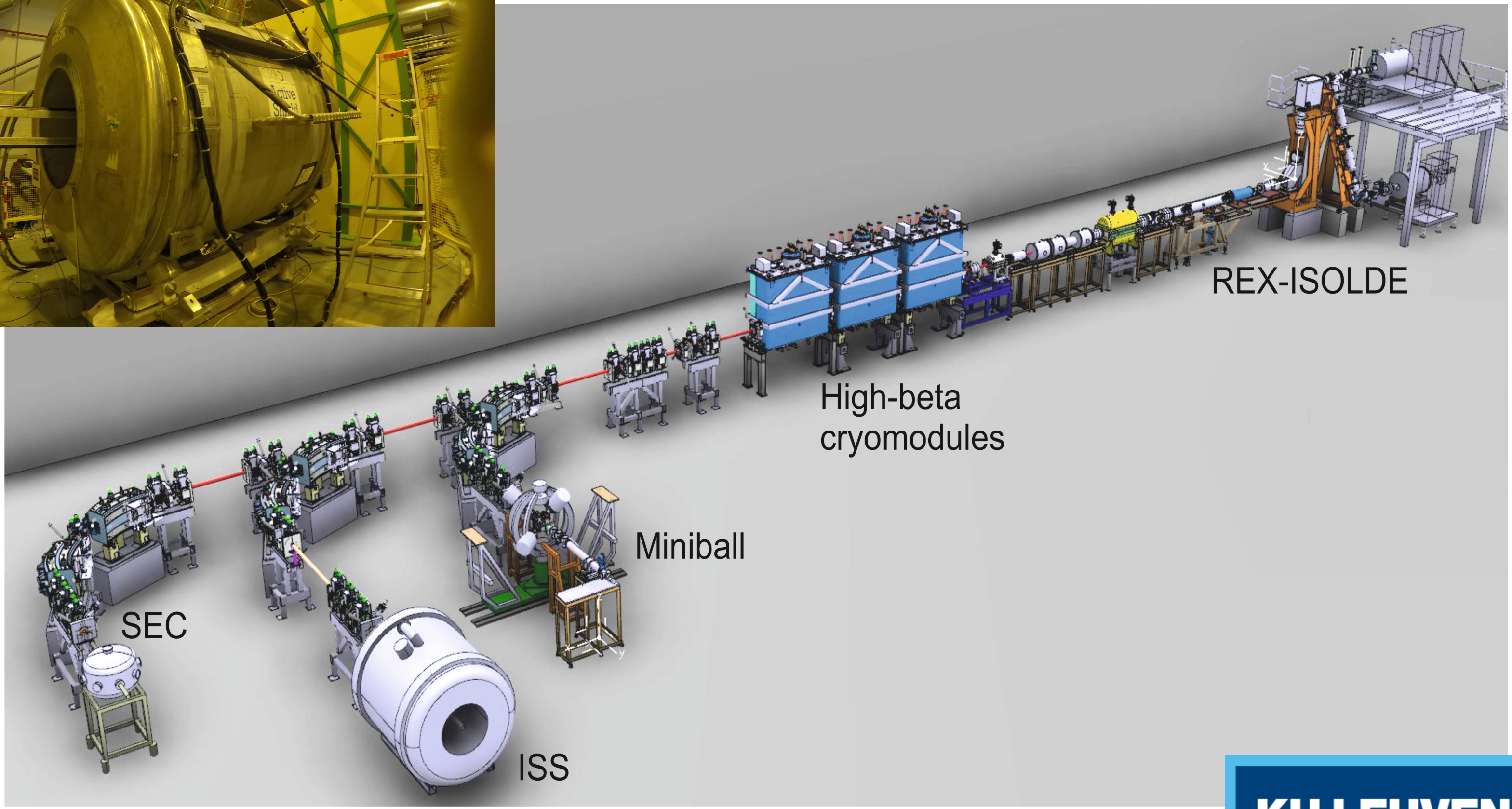


SpecMAT: ISS

- …with a happy end

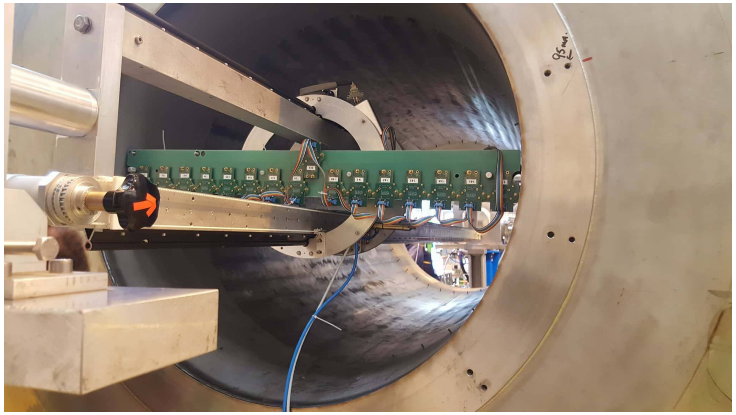
P Butler, S Freeman, R Page, RR
Liverpool, Manchester, Daresbury, Leuven

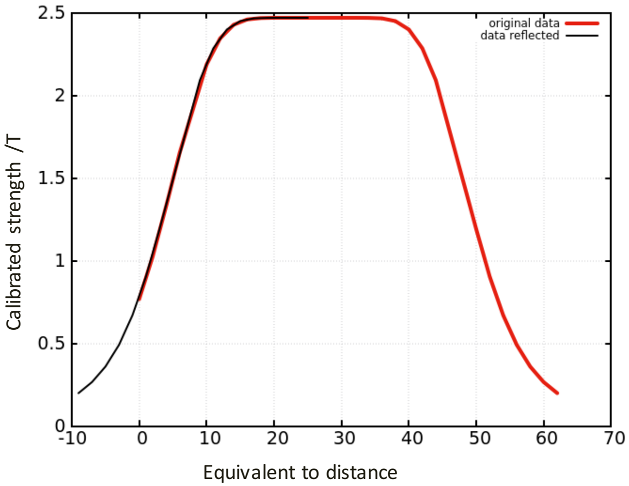


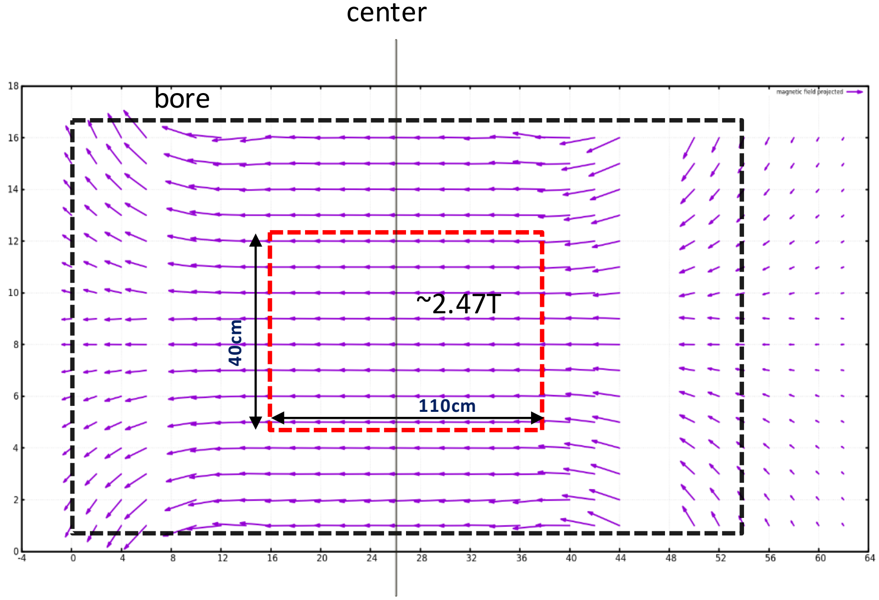


SpecMAT: ISS

- Field mapping and beam tests successfully completed







Magnetic field vector projection on x-y plane
(view from top of the solenoid)

Summary

- Exciting physics with heavy beams
  - shell evolution towards ^{78}Ni
  - shape coexistence in n-deficient Pb region
- Scintillation detectors purchased, prototype delivered
- Chamber design in progress
- GET electronics (2000 channels) acquired

Thanks to the SpecMAT team!

A. Arokja Raj, S. Ceruti, H. De Witte, O. Poleshchuk, M. Renaud, J. Yang

With us in the past: M. Babo, T. Marchi, C. Swartz

The research leading to these results has received funding from the European Research Council under the European Union's Seventh Framework Programme (FP/2007-2013) / ERC Grant Agreement n. 617156