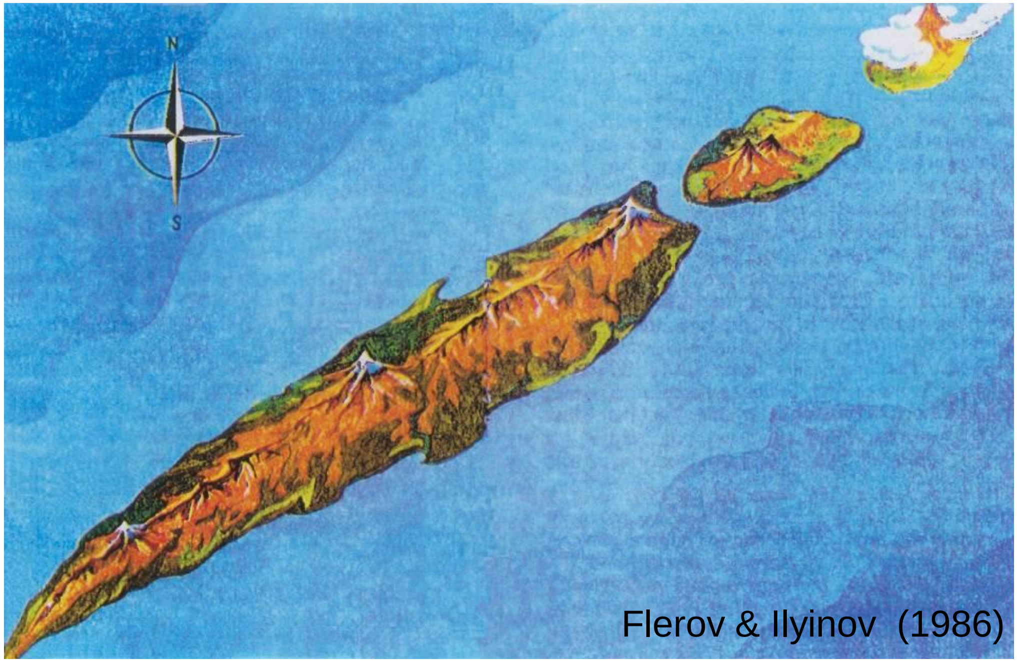
Super heavy element studies: Lessons learnt from Dubna and ALTO and plans with S3

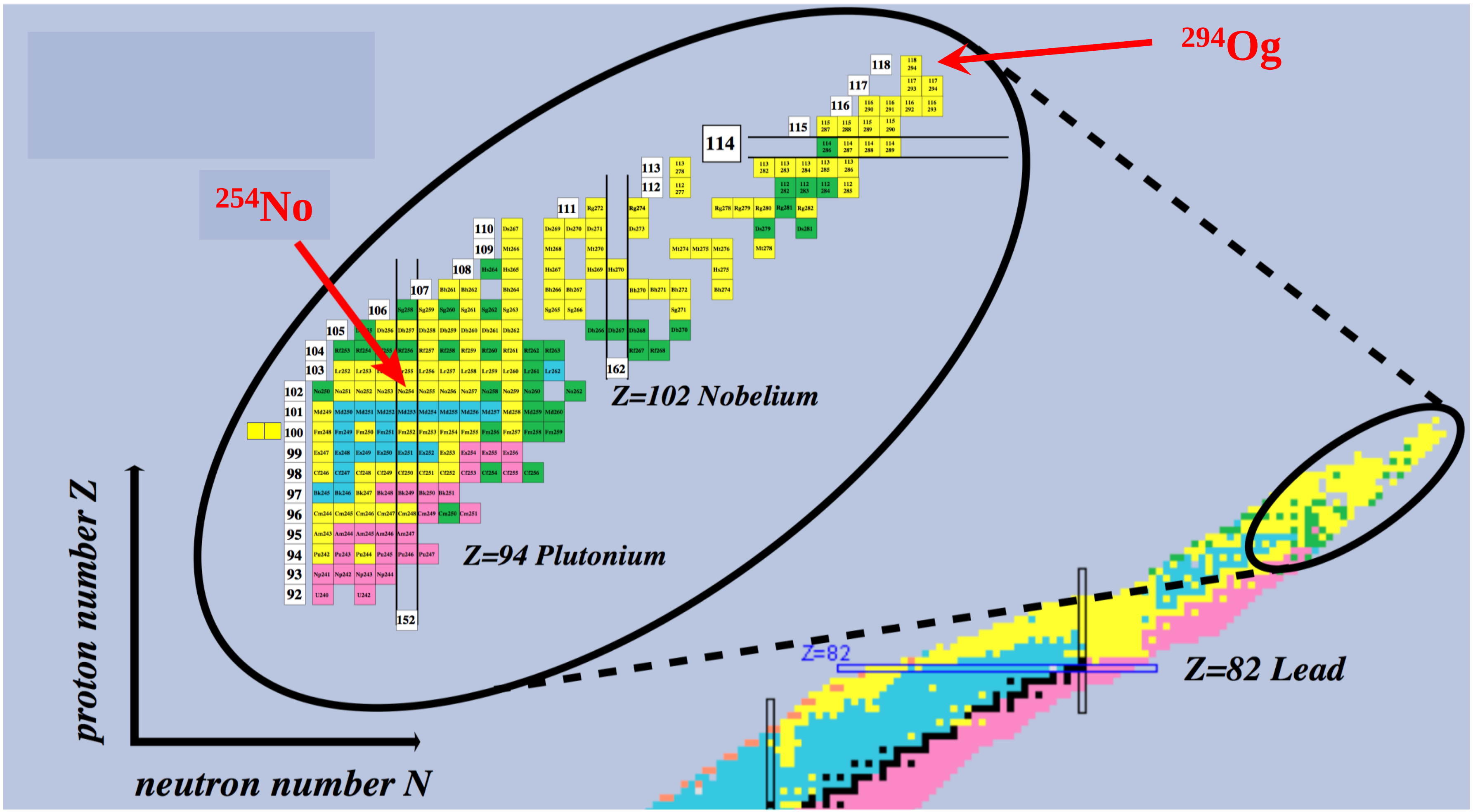


A. Lopez-Martens, P. Chauveau, K. Hauschild
GABRIELA & Charting Terra Incognita collaborations

Outline

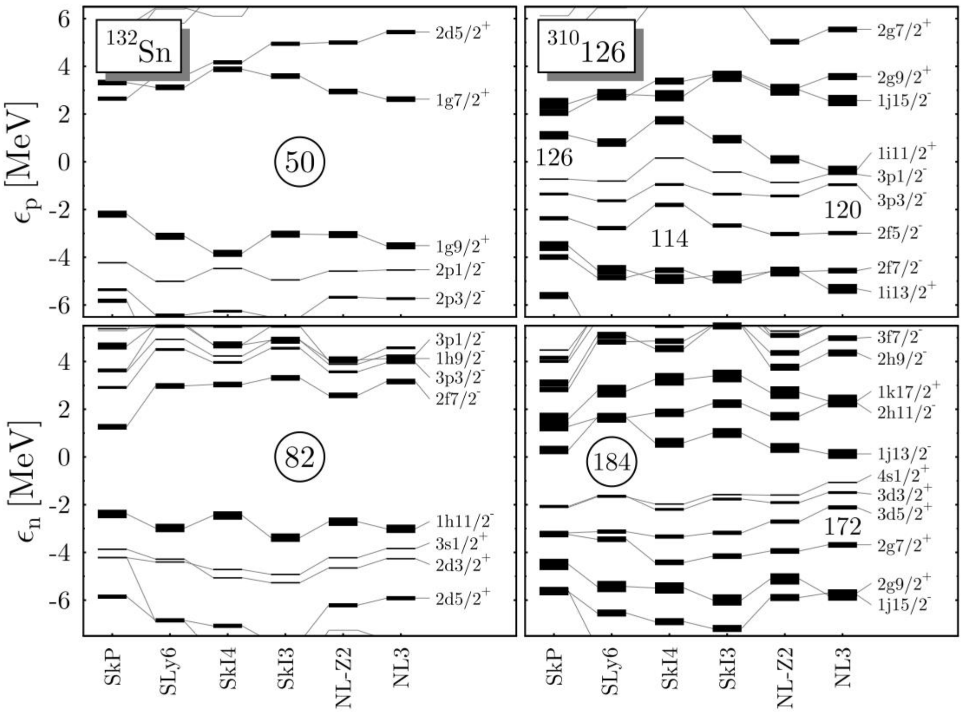
- Introduction
- Decay spectroscopy with GABRIELA@SHELS
- R&D on in-trap spectroscopy at MLLTrap @ ALTO
- Conclusions & Perspectives @ S3

Region of Interest

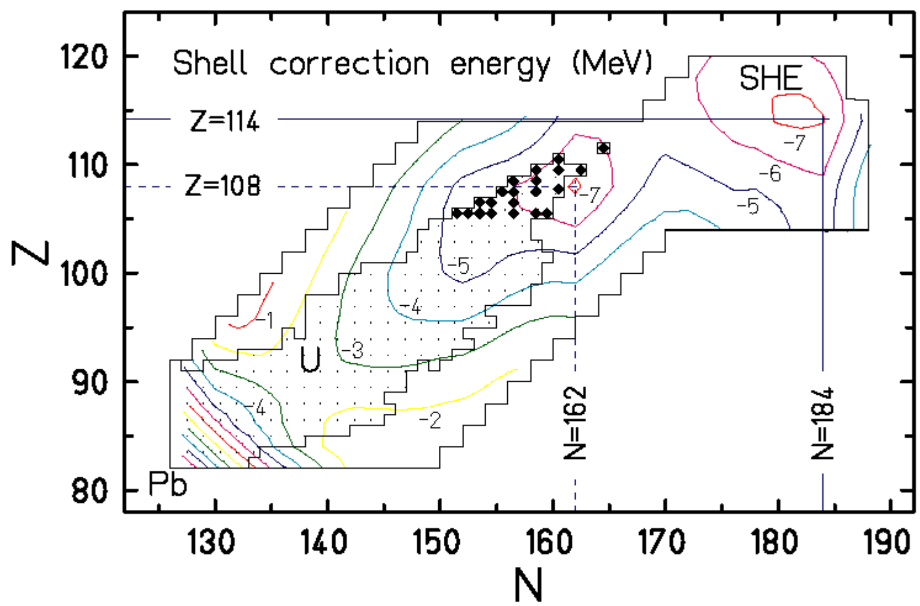


Special Nuclei

Super heavy nuclei owe their stability against spontaneous fission to quantum shell effects

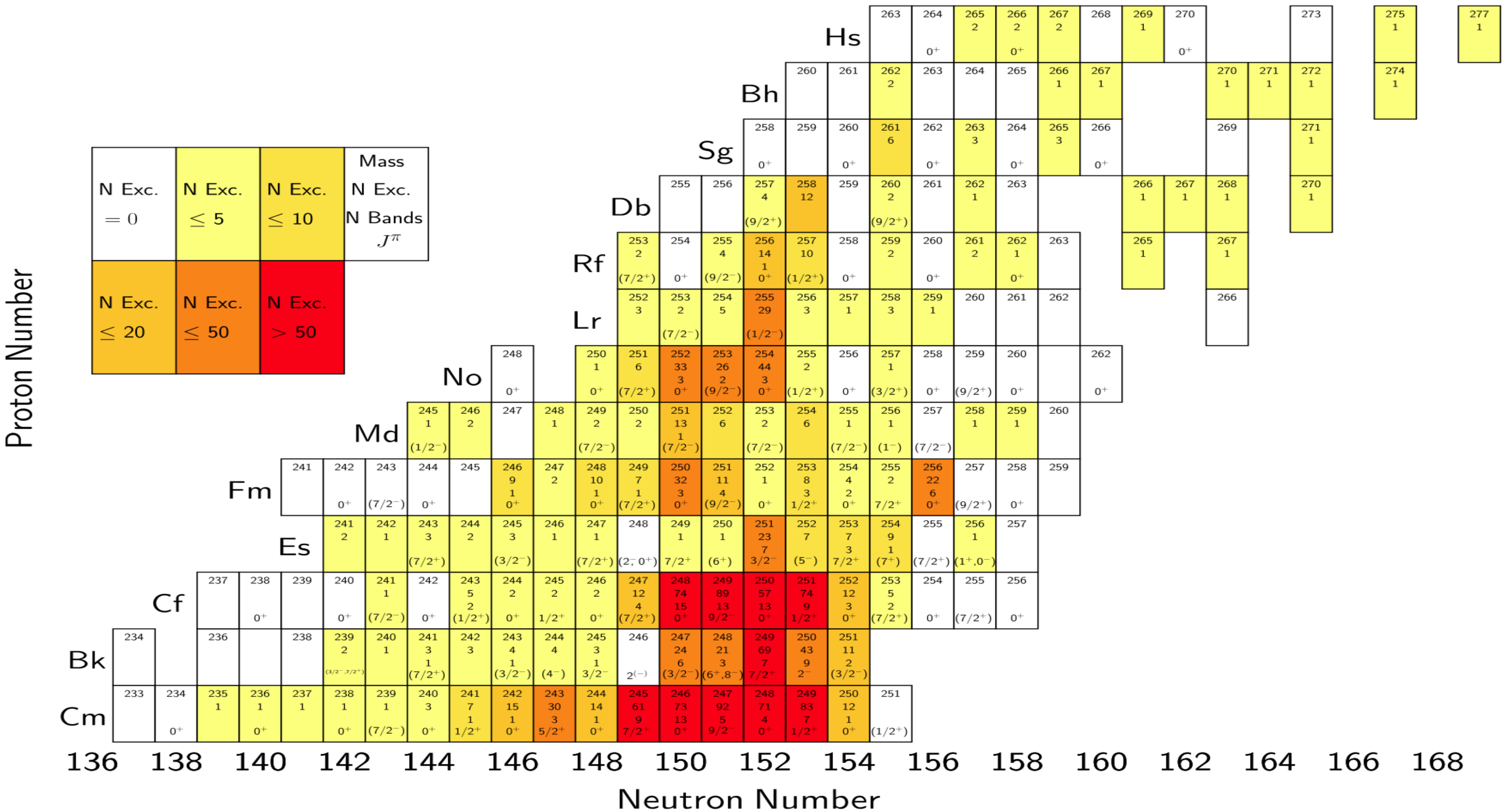


R. Smolanczuk, Phys. Rev. C56 (1997) 812



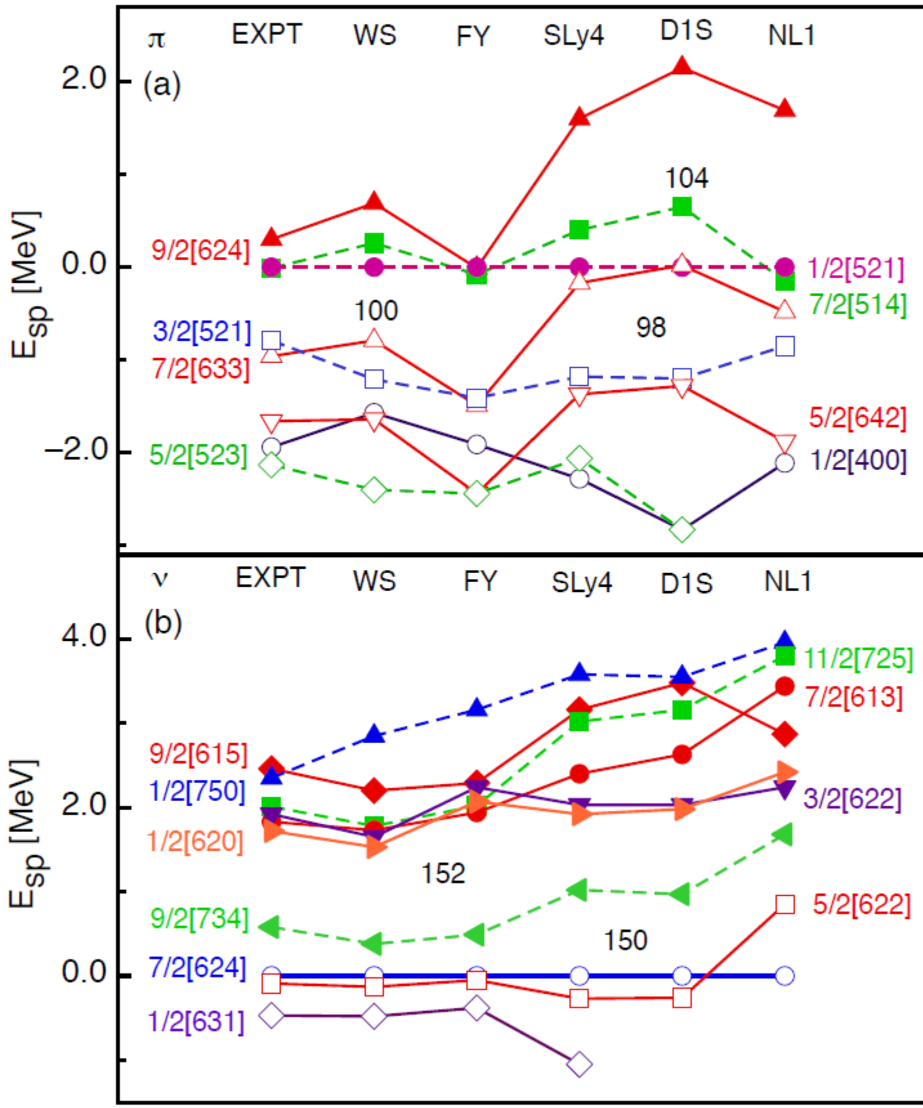
M. Bender and P.H. Heenen, J. Phys.: Conf. Ser. 420 (2013) 012002

Available spectroscopic data



Ch. Theisen et al., Nucl. Phys. A 944 (2015) 333

Comparison to theory



T.L. Khoo, private comm.

Single particle energies extracted from experimental energies in ^{247,249}Bk, ^{251}Es & ^{247}Cm, ^{251}Cf

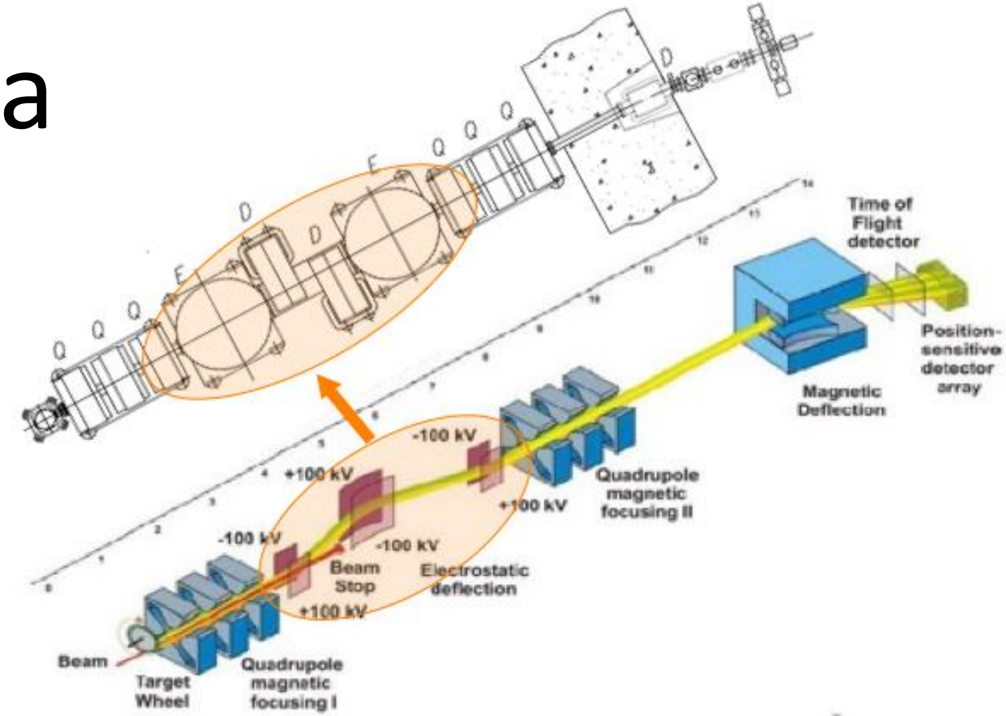
SHELS@Dubna

VASSILISSA (Energy filter)

➔SHELS (velocity filter)

Gain in transmission, especially for asymmetric reactions

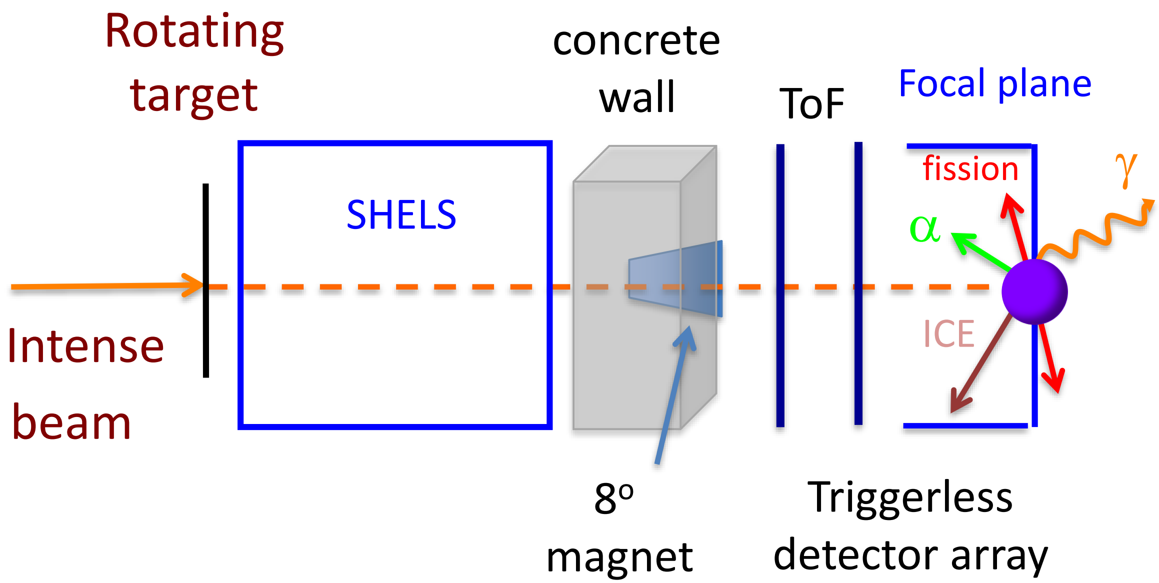
A. Popeko et al., Nucl. Instr. Meth. B 376 (2016) 140

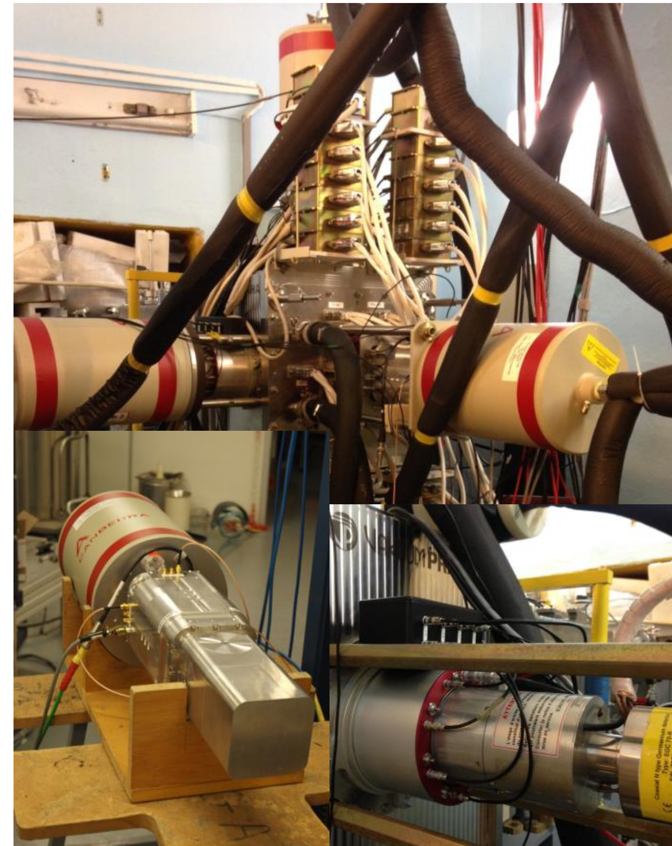


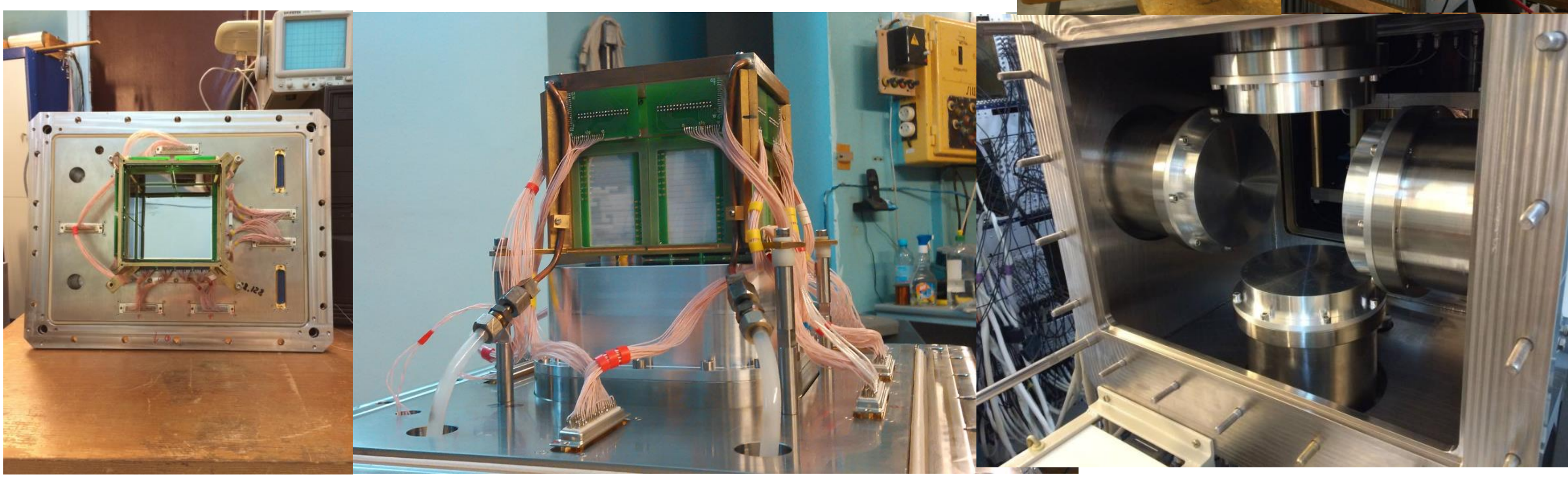
ANR-SHELS (2006-2010) & Russian Foundation for Basic Research

GABRIELA@SHELS

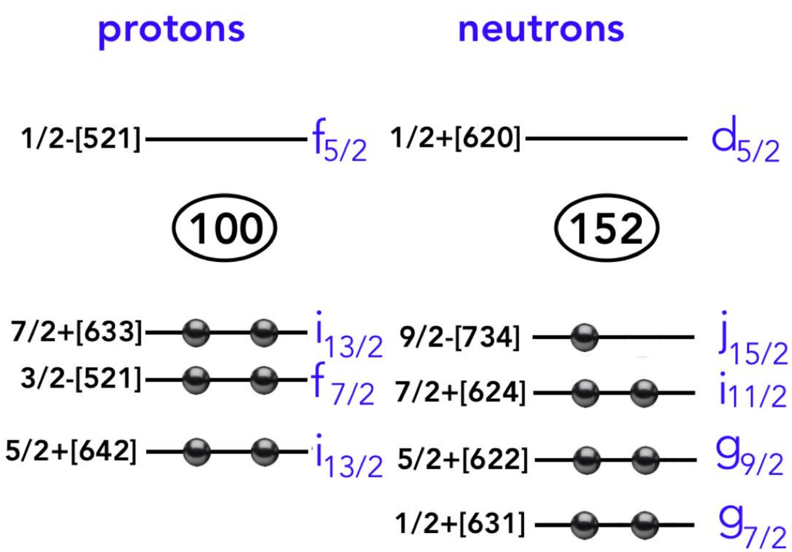
ANR-CLODETTE (2013-2017) & RFBR

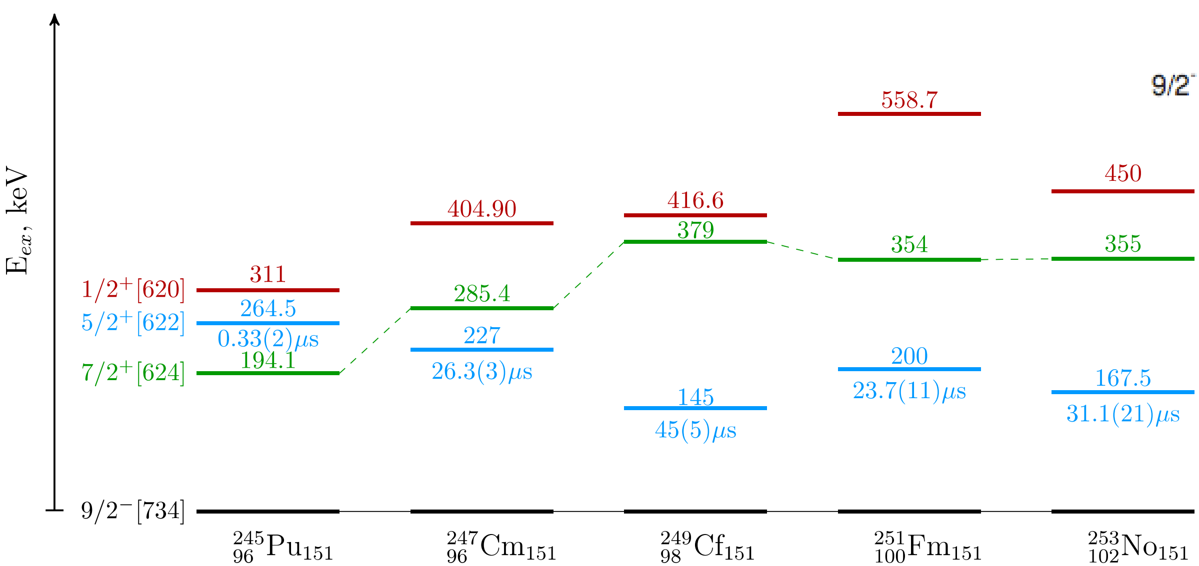


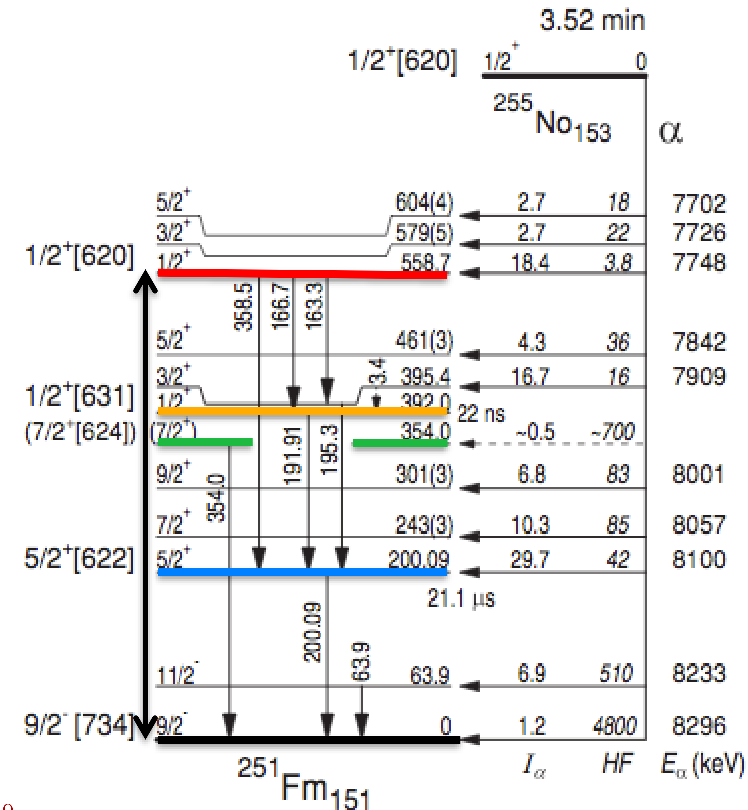




Spectroscopy of ^{251}Fm







^{248}Cm(^{12}C,5n)^{255}No, gas-jet technique

M. Asai et al., Phys. Rev. C 83 (2011) 014315

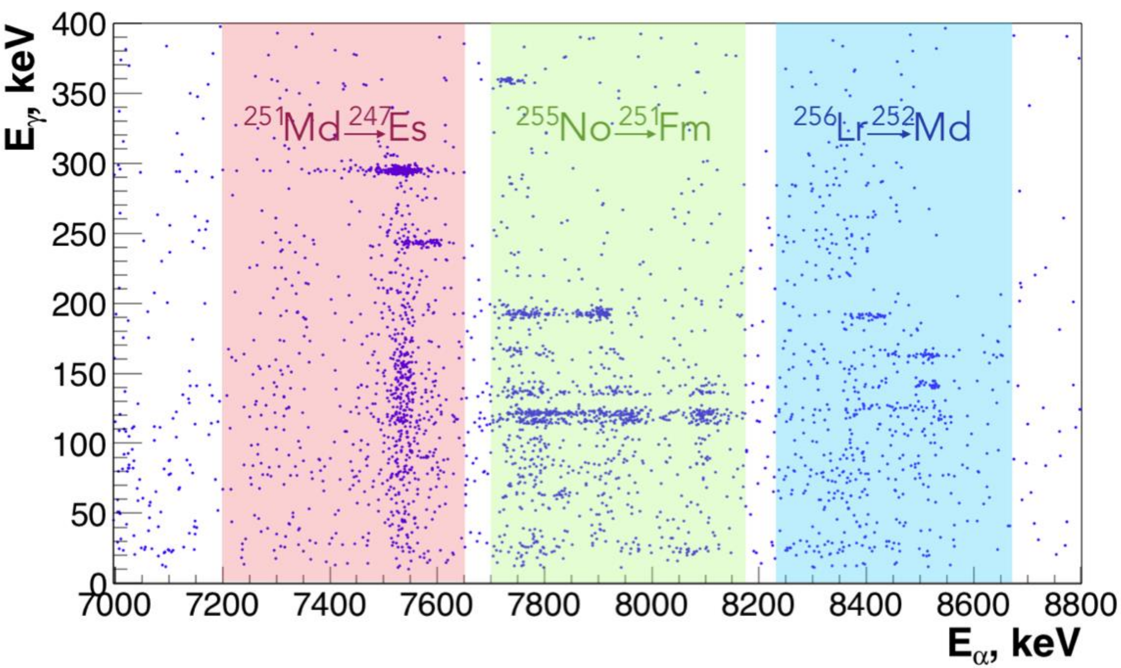
Spectroscopy of ^{251}Fm

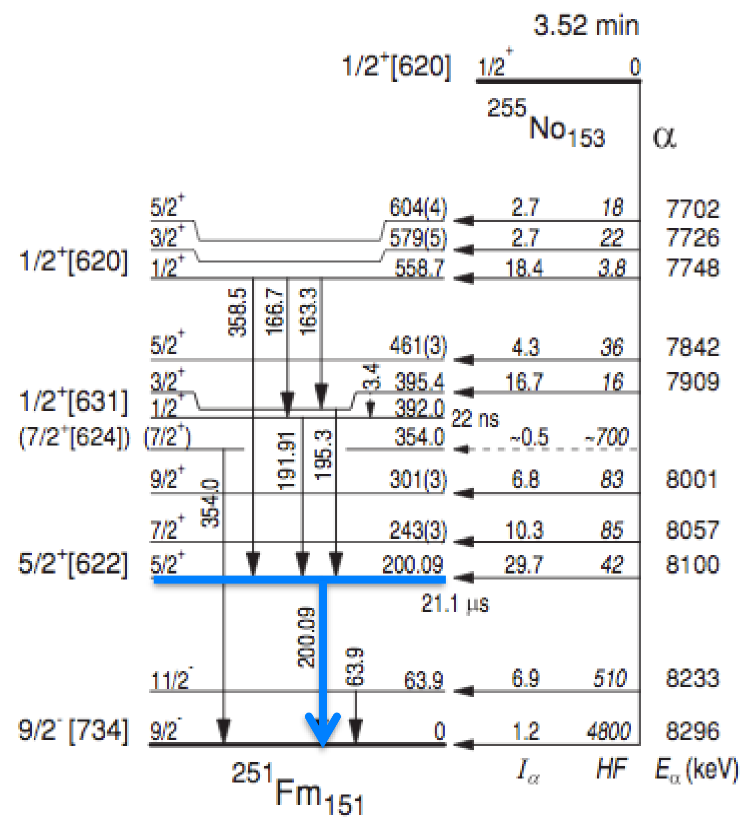
M. Asai et al., Phys. Rev. C 83 (2011) 014315

$$^{48}\mathrm{Ca}+^{209}\mathrm{Bi} \rightarrow {}^{257}\mathrm{Lr}^* \rightarrow {}^{255}\mathrm{Lr} + 2\mathrm{n} \xrightarrow[EC]{15\%} {}^{255}\mathrm{No}$$

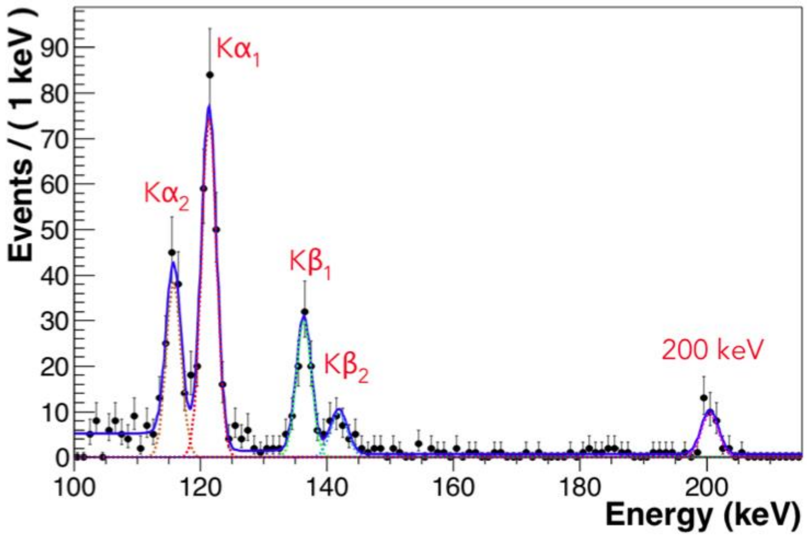
σ ~ 400 nb, E_{beam} = 220 MeV mid-target

K. Rezynkina, PhD thesis (2016)

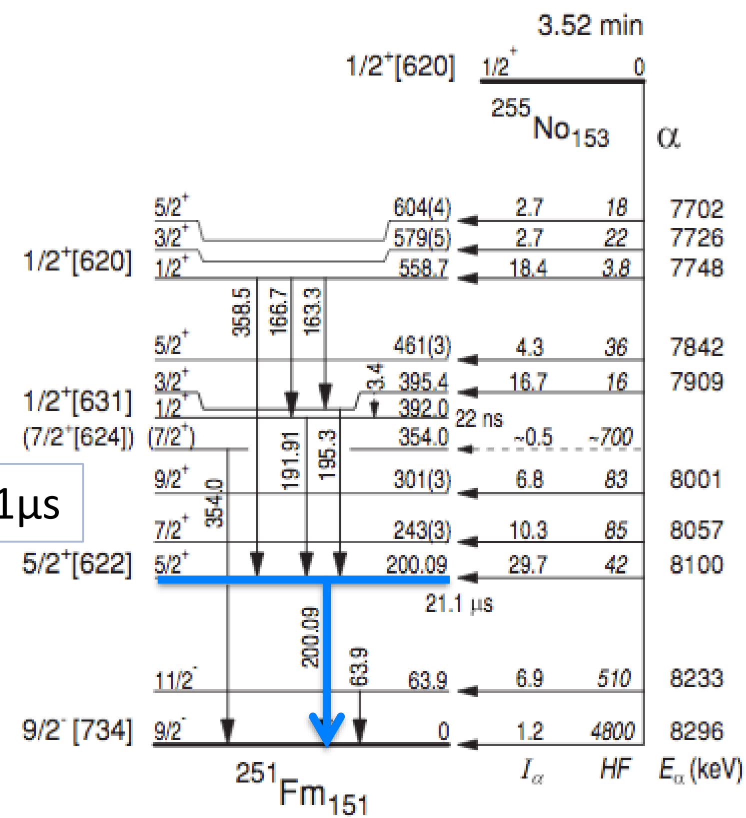


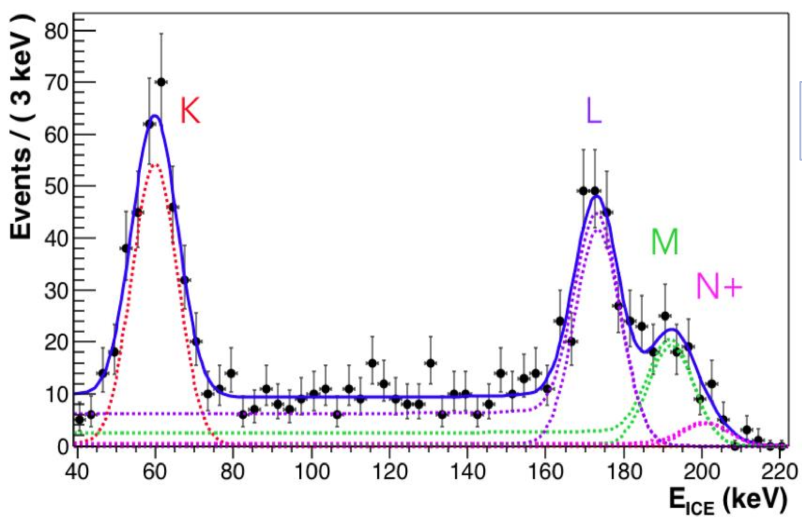


Spectroscopy of ^{251}Fm



M. Asai et al., Phys. Rev. C 83 (2011) 014315





$T_{1/2}$= 23.7 ± 1.1μs

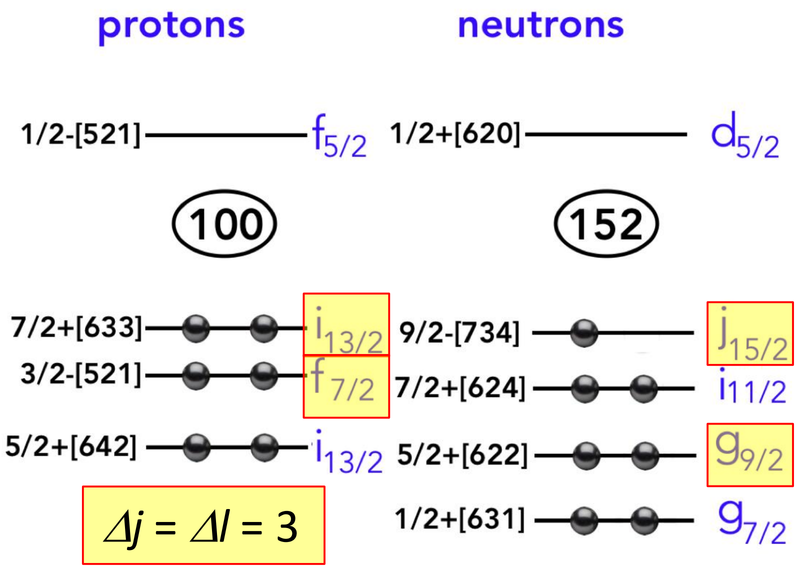
$\delta(E3/M2) = 0.76^{+0.20}_{-0.19}$

B(E3) = 18(6) W.u

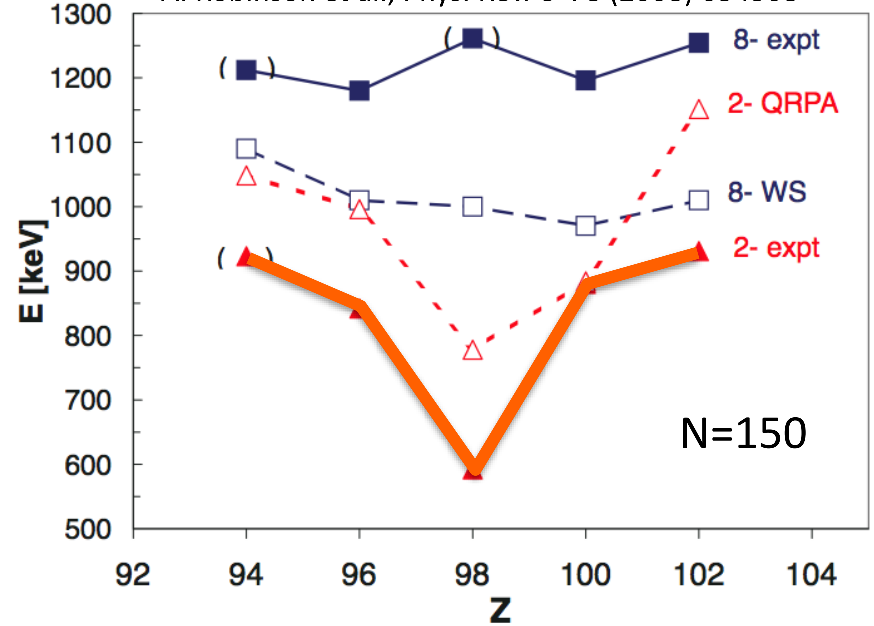
B(M2)=3.0(6) 10^{-3} W.u

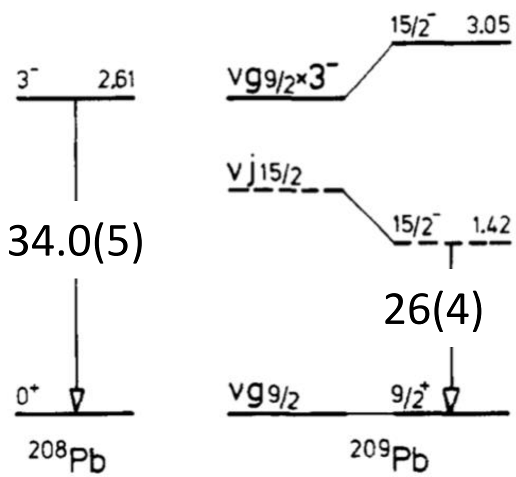
K. Rezynkina et al., Nucl. Instr. Meth. A 844 (2017) 96

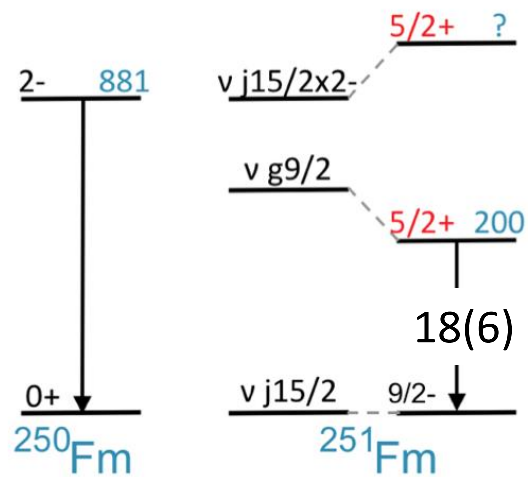
Origin of octupole collectivity



A. Robinson et al., Phys. Rev. C 78 (2008) 034308



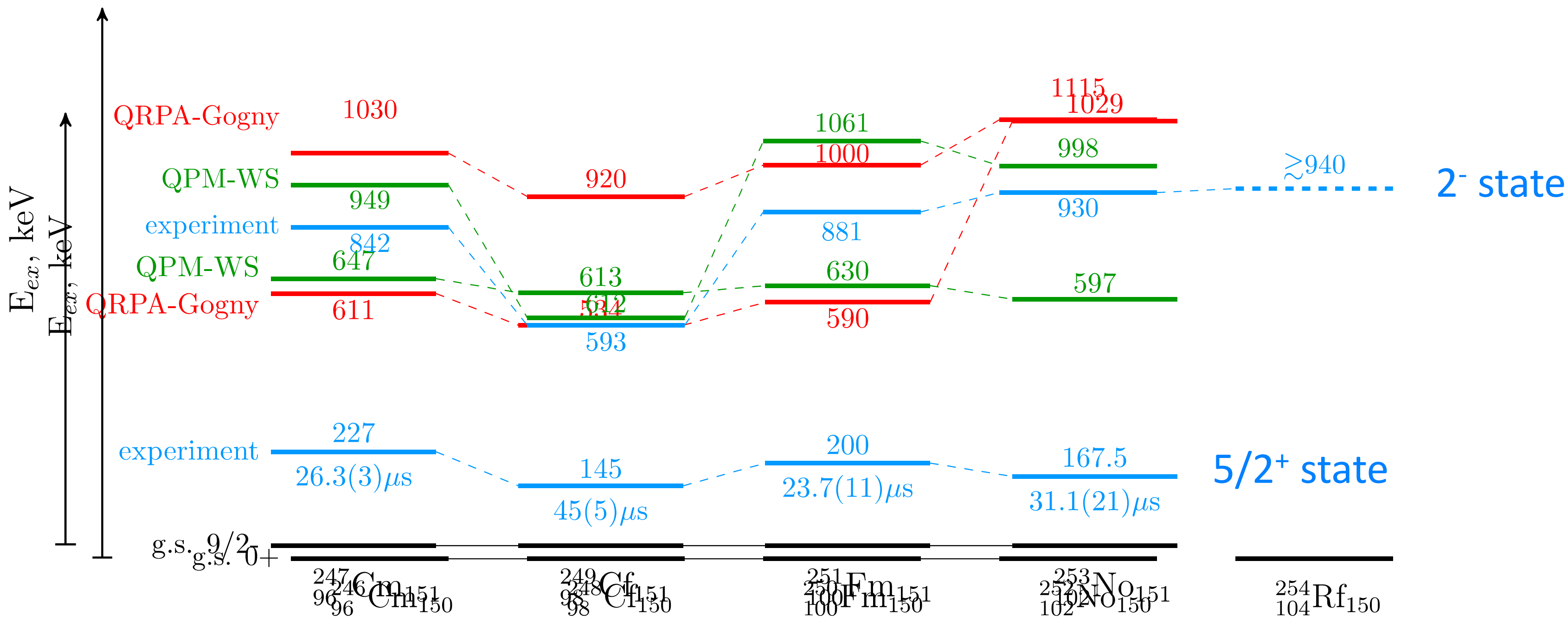




P. Kleinheinz. Physica Scripta, 24 (1981) 236
M. Rejmund et al., Eur. Phys. J. A 8 (2000) 161

K. Rezynkina, PhD thesis (2016) and article in prep.

Comparison to theory



Quasiparticle-phonon model + Woods-Saxon N. Yu. Shirikova et al., Eur. Phys. J. A (2015) 51: 21

QRPA + GOGNY I. Deloncle and S. Peru, private comm.

➔ Inclusion of particle-phonon coupling is necessary to describe states in the region around ^{254}No

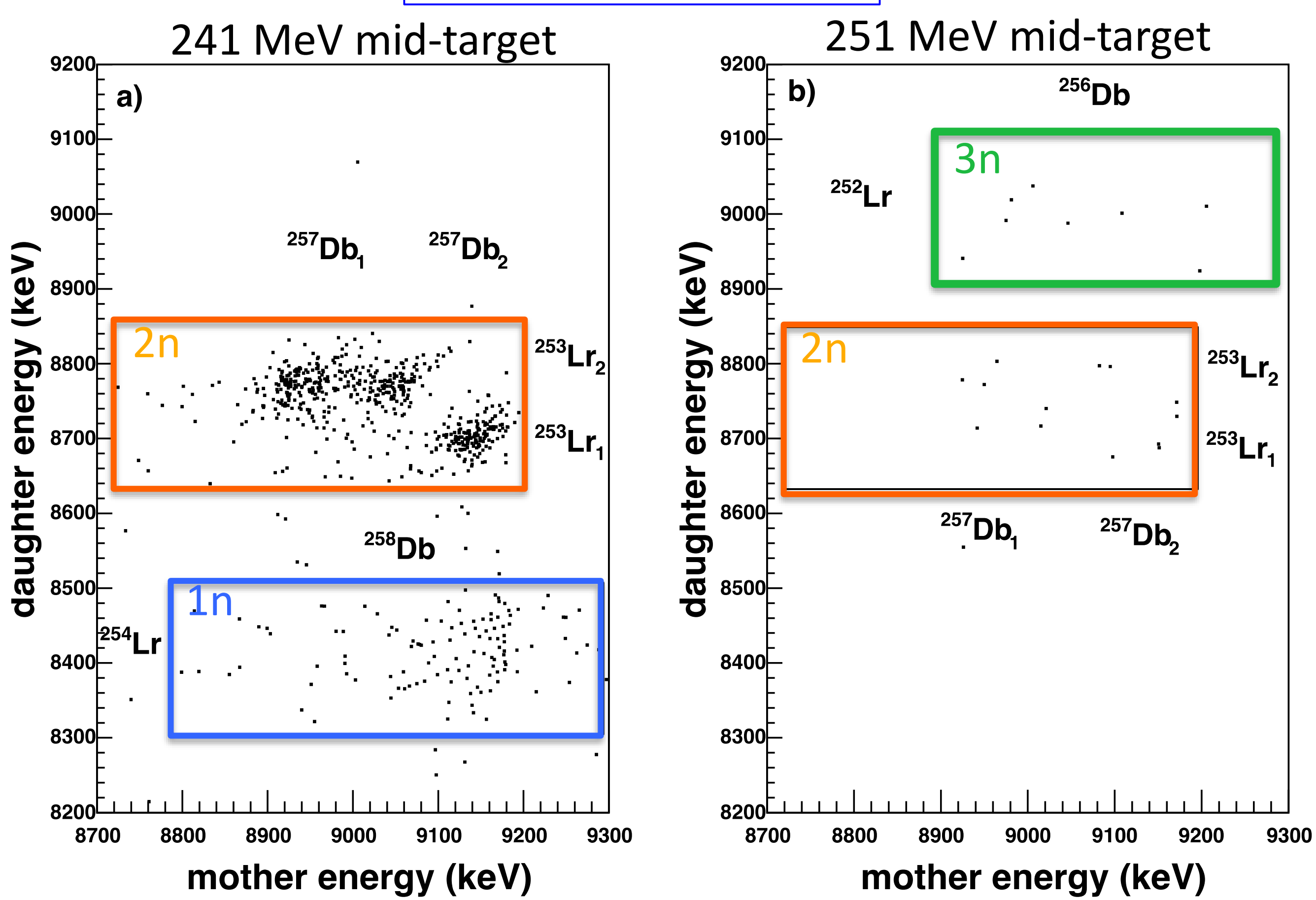
Next steps: ^{255}Rf, currently running (thesis of R. Chakma)

Particle evaporation from $^{259}Db^*$

$^{50}Ti + ^{209}Bi \longrightarrow ^{259}Db^*$ @ 255,265 and 275 MeV, 4.8 10^{18} p

^{50}Ti mivoc compound synthesized by IPHC and accelerated at 3 different energies by U400 in Dubna J. Rubert et al., Nucl Instr and Meth B 276 (2011) 33

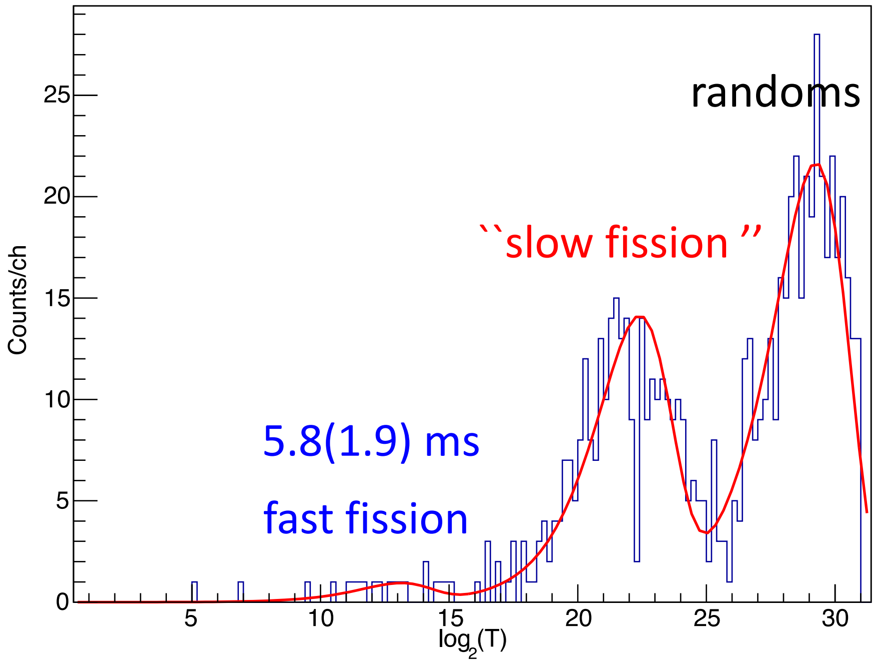
α–α correlations



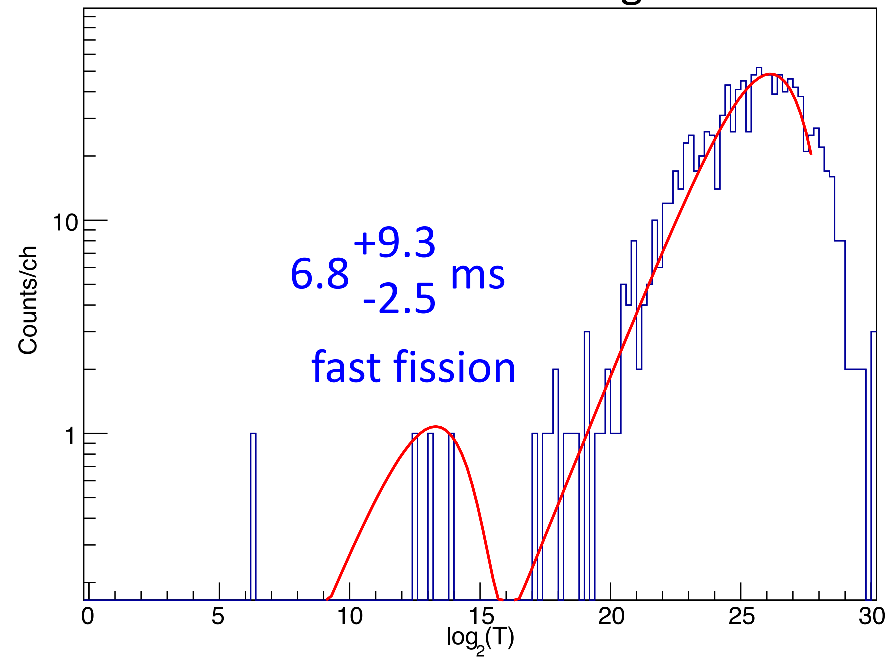
P. Brionnet, PhD (2017)

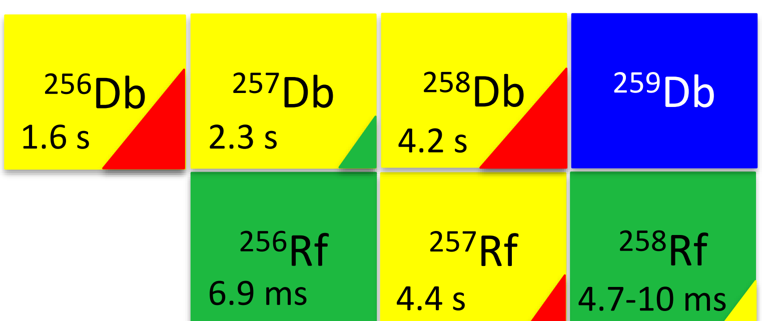
Observation of fission events

241 MeV mid-target



261 MeV mid-target





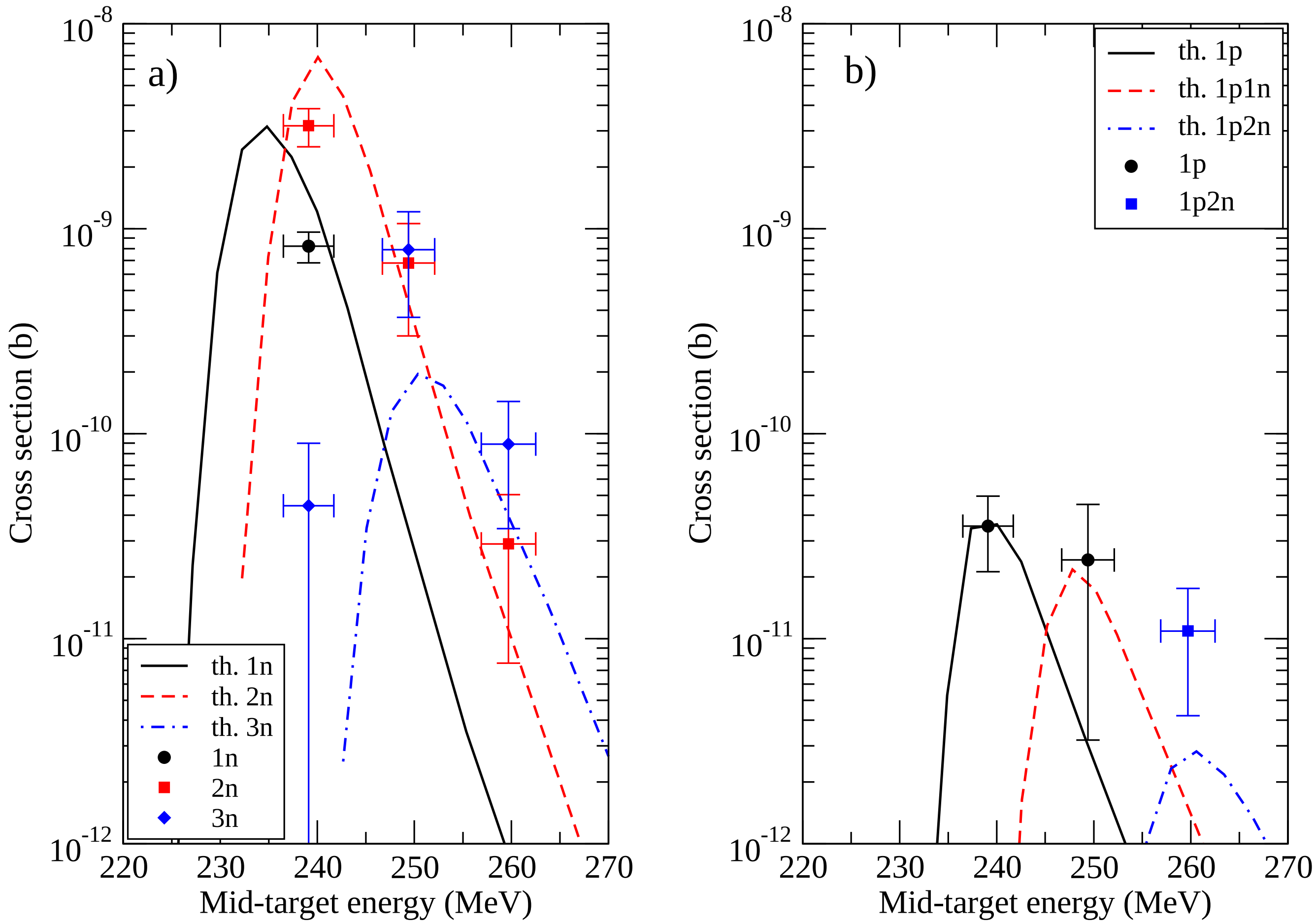
fast (ms) fission = **unambiguous** pxn signature

F. Hessberger et al., Eur. Phys. J. A 53 (2017) 75

Cross sections

Theoretical calculations:
V.I. Zagrebaev et al., http://www.nrv.ru
A.V. Karpov, priv. comm.

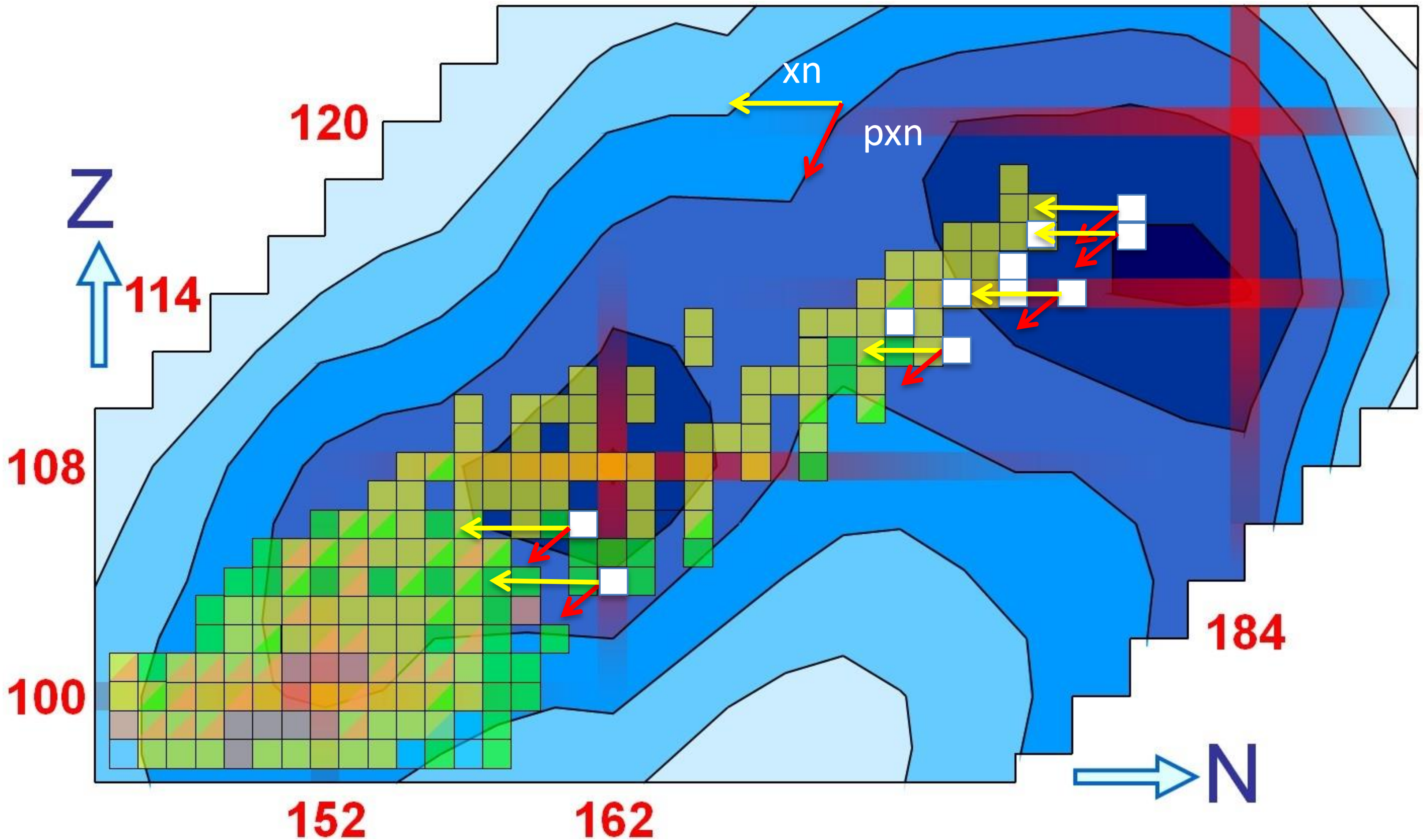
A. Lopez-Martens et al.



Next step in nov. 2017: search of p4n

pxn channels open new perspectives

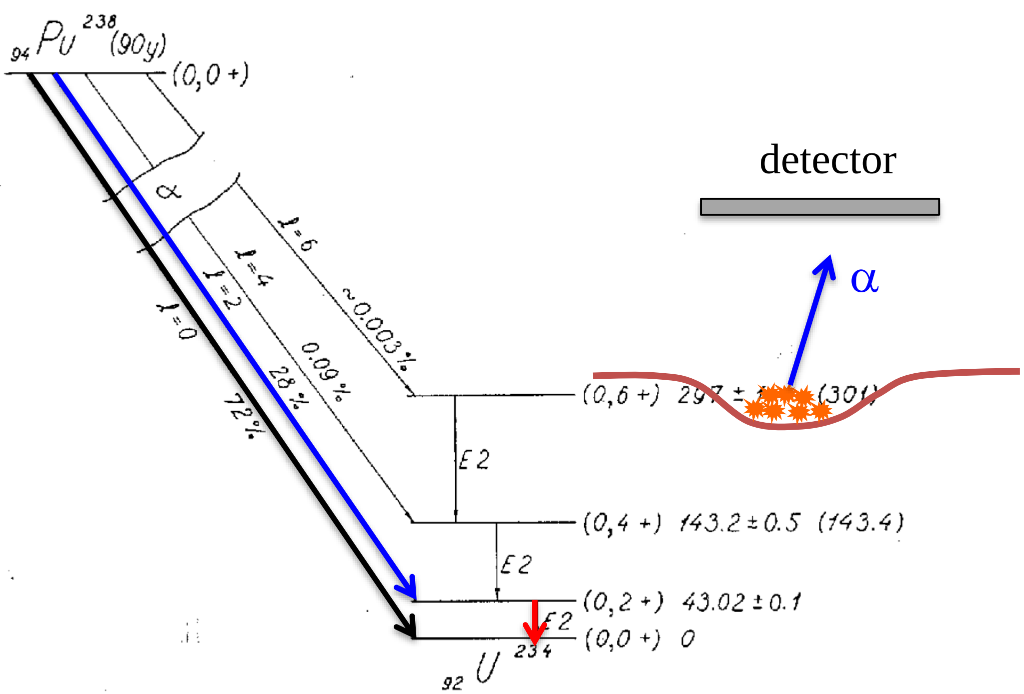
https://www-win.gsi.de/tasca



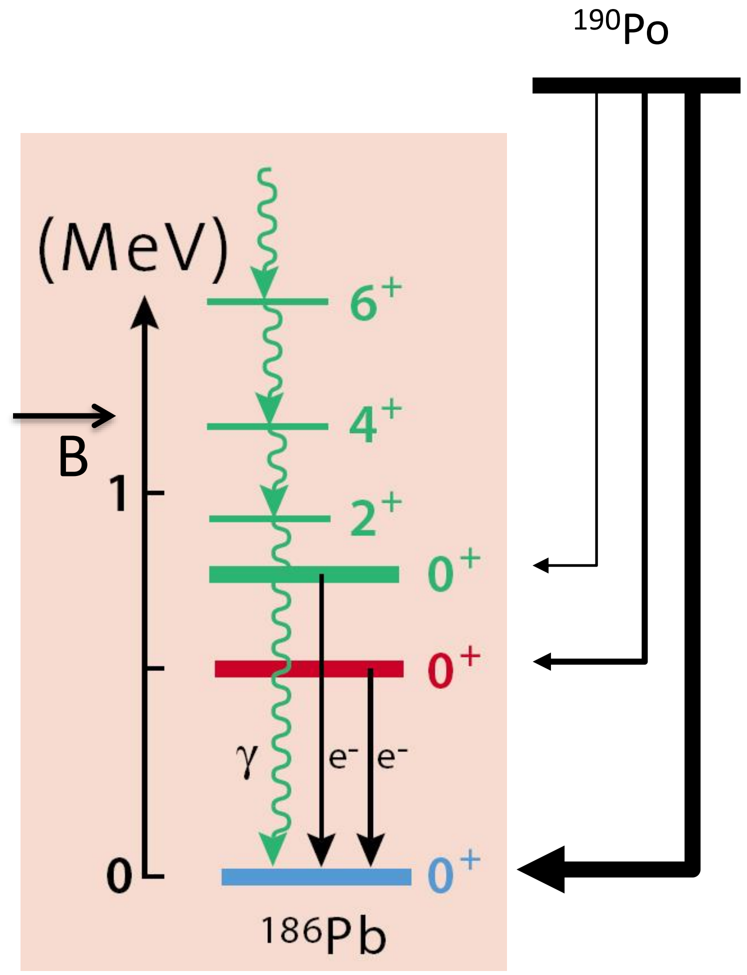
With 10 times or more beam intensity & efficient set-ups, one may:

- Synthesize more neutron rich isotopes closer to the « island of stability »
- Study lighter unknown nuclei

Can one measure lifetimes of states populated by alpha decay in a penning trap ?



On the Fine Structure of Alpha Decay, Bohr, Fröman and Mottelson (1955)



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

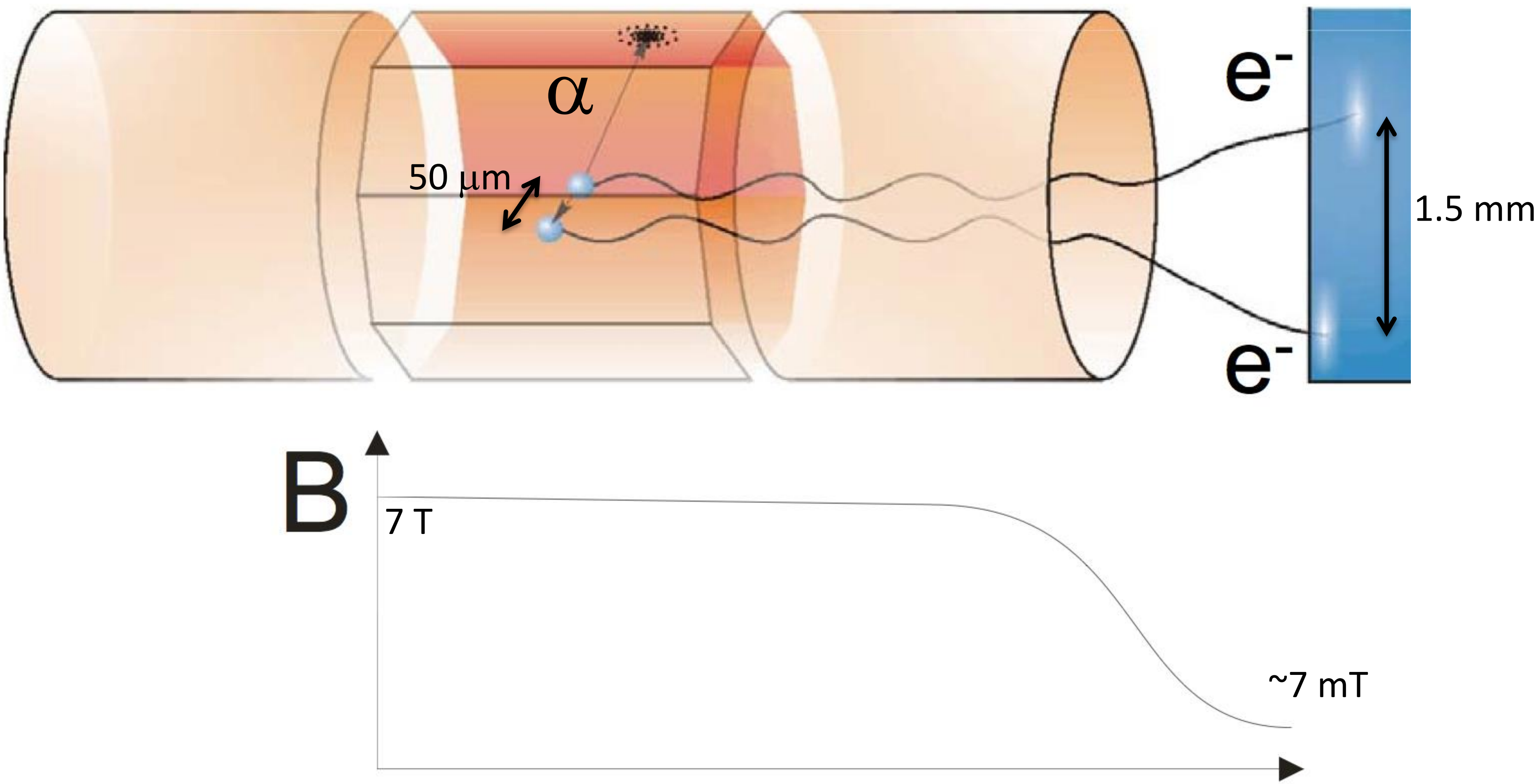
τ(2+) gives acces to the intrinsic quadrupole moment Q_0

τ(0+) gives acces to the monopole strength $\rho^2(E_0)$

Novel recoil-distance method

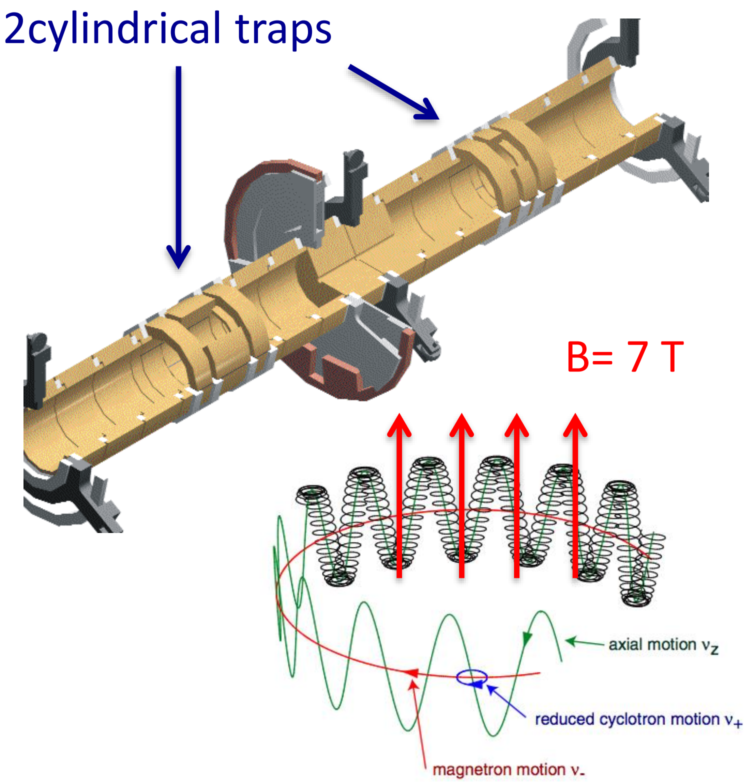
C. Weber et al., International Journal of Mass Spectrometry 349–350 (2013) 270–276

Image by F. Herfurth



➔ Maier Leibnitz Laboratory Penning trap

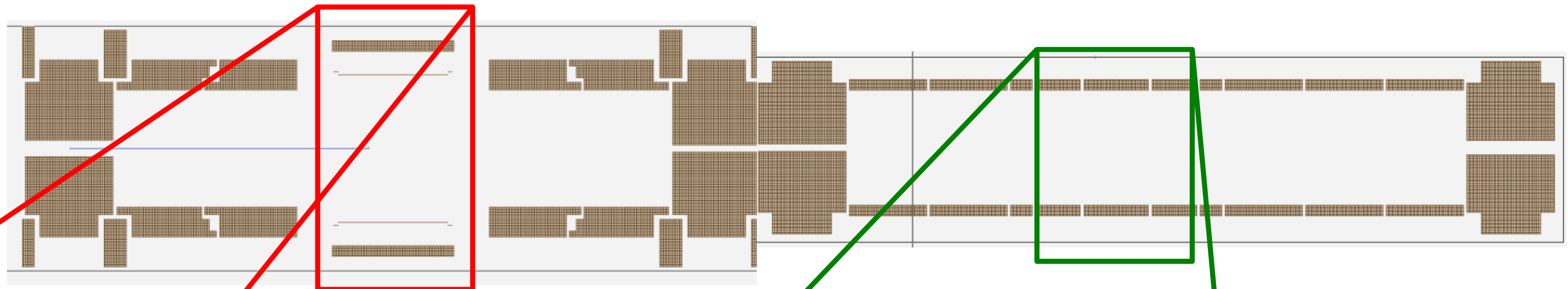
MLL trap – Mass measurement tower

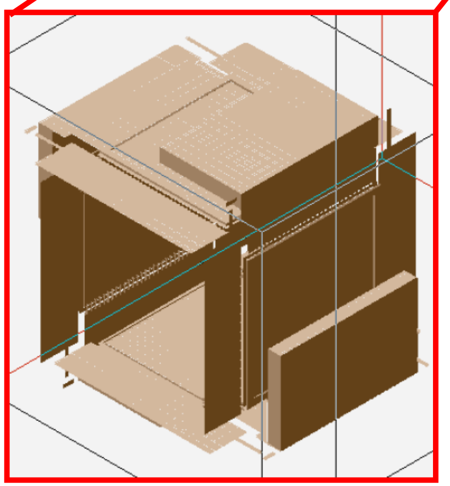


$$f_c = \frac{1}{2p} \times \frac{q}{m} \times B$$

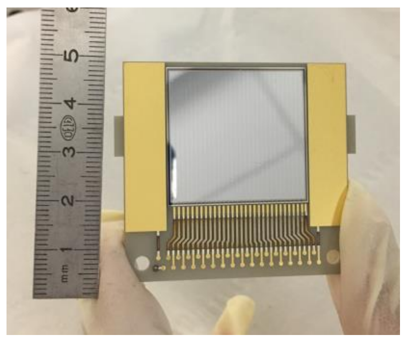
V.S. Kolhinen et al., Nucl. Instr. Meth. A 600 (2009) 391

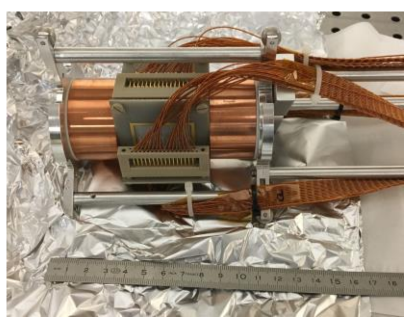
Spectroscopy tower

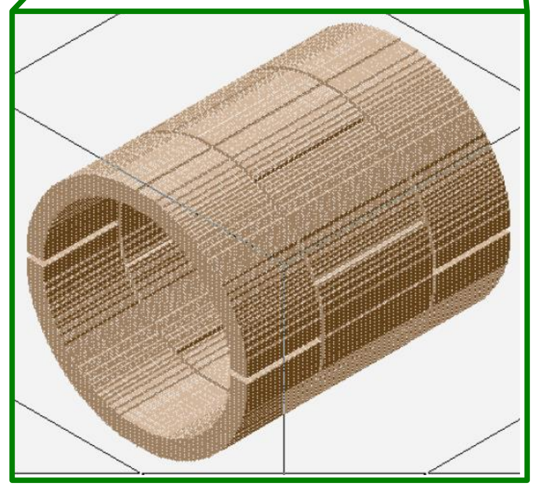




- Second Trap:
  - HV-UHV
  - For mass and half-life measurements



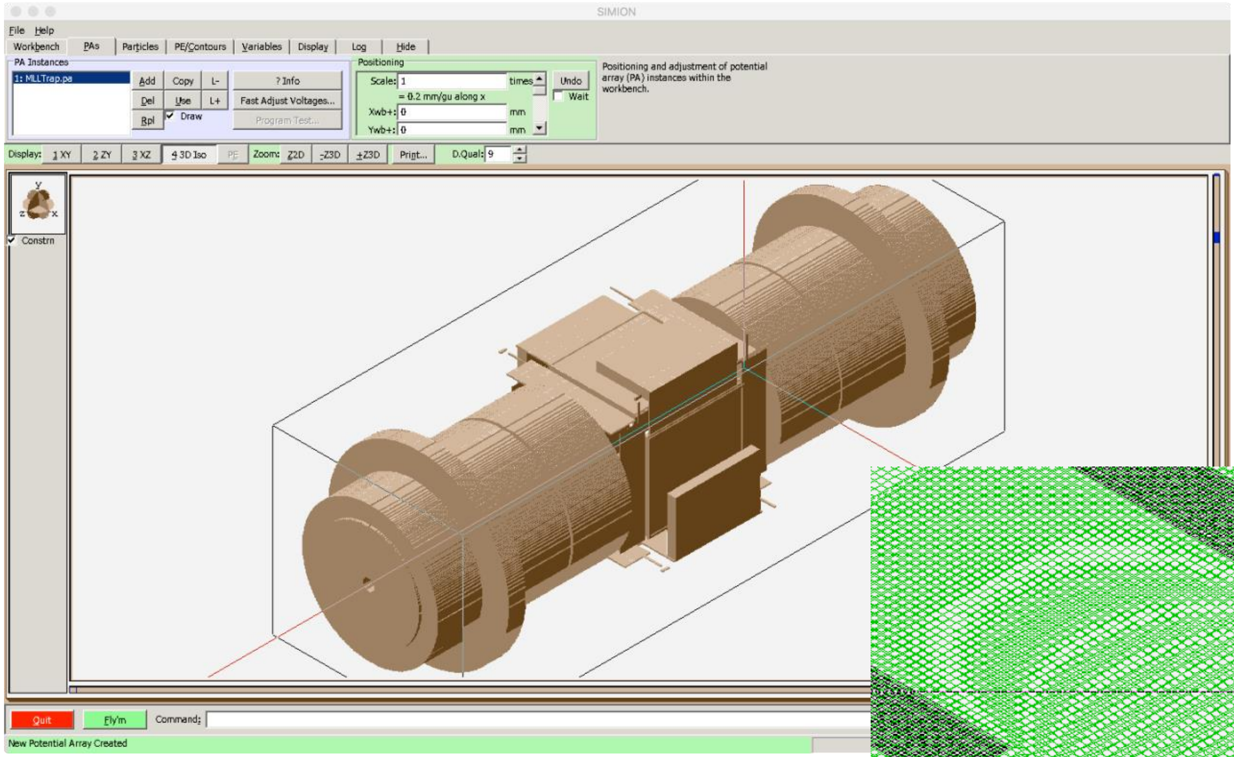


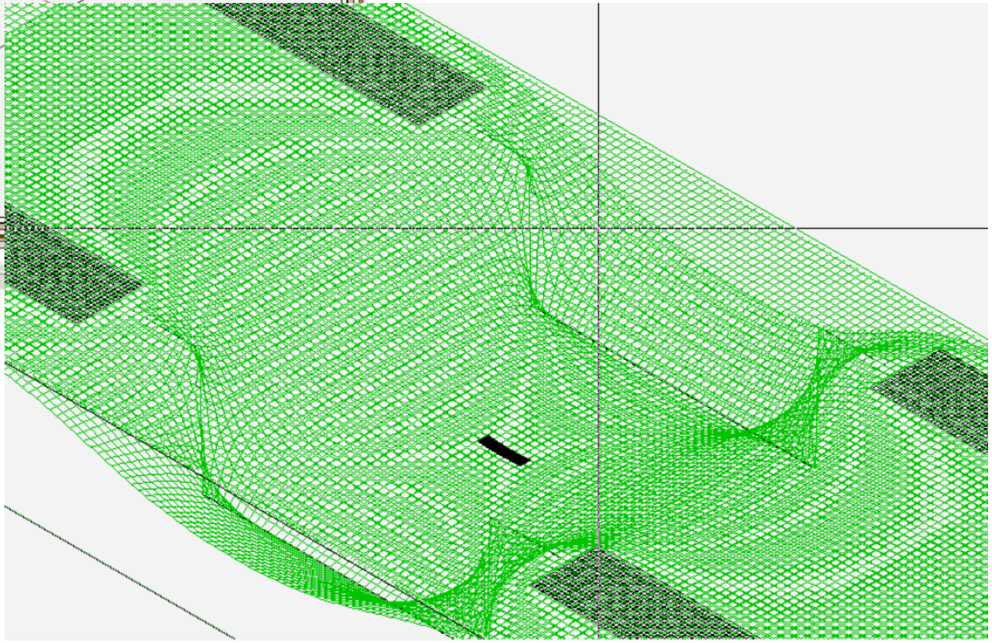


- First Trap:
  - Gas filed
  - For mass-selective cooling
  - Built

P. Chauveau

Detailed simulations

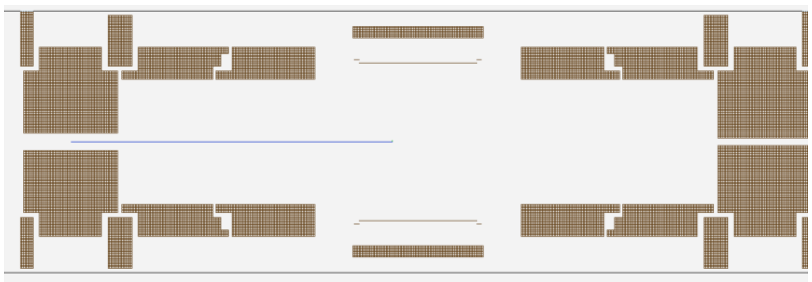




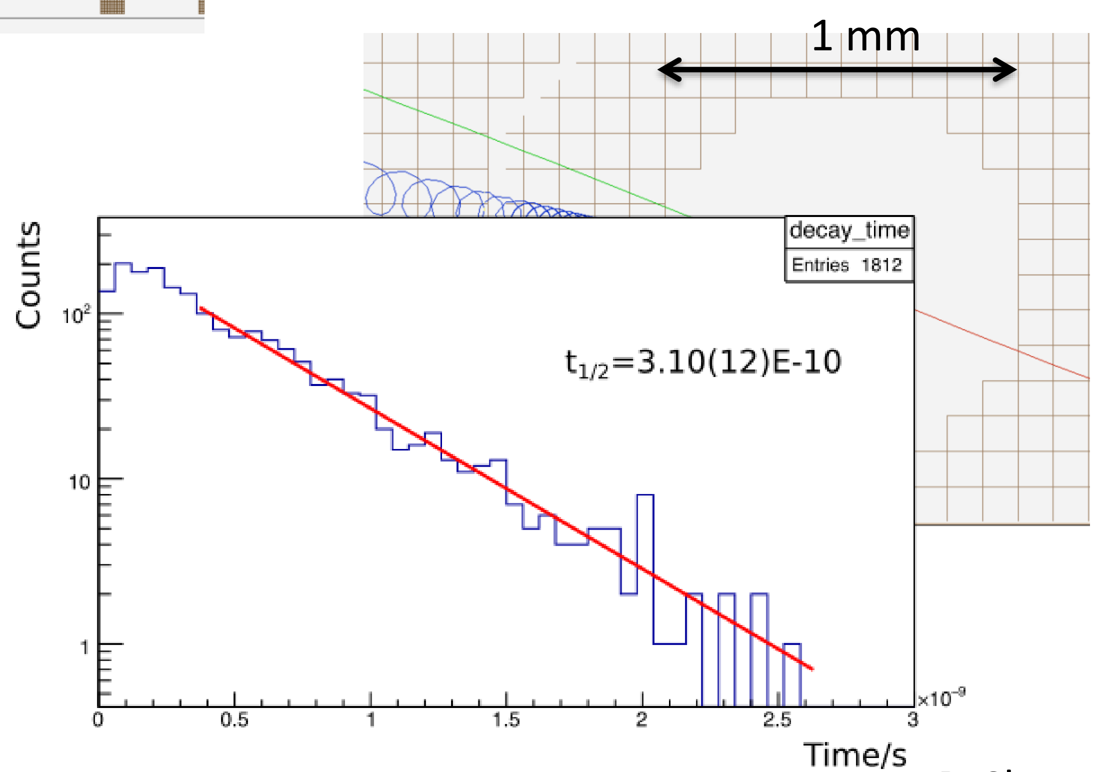
Goal: simulations of ions and decay in the trap to validate the concept

P. Chauveau

First results…



- Data:
  - In-trap detector: strip number, α energy, time
  - Electron detector in fringe field: pixels (also can use ToF)



- Conditions:
  - beam from first trap, accelerated at 10eV (~30V trap)
  - ~14mm total axial amplitude
  - 1ms, 4MeV α decay
  - 300 ps 2^+ decay time
  - 0.5mm pixel (electron detector)
  - two 200 eV electrons (random direction)

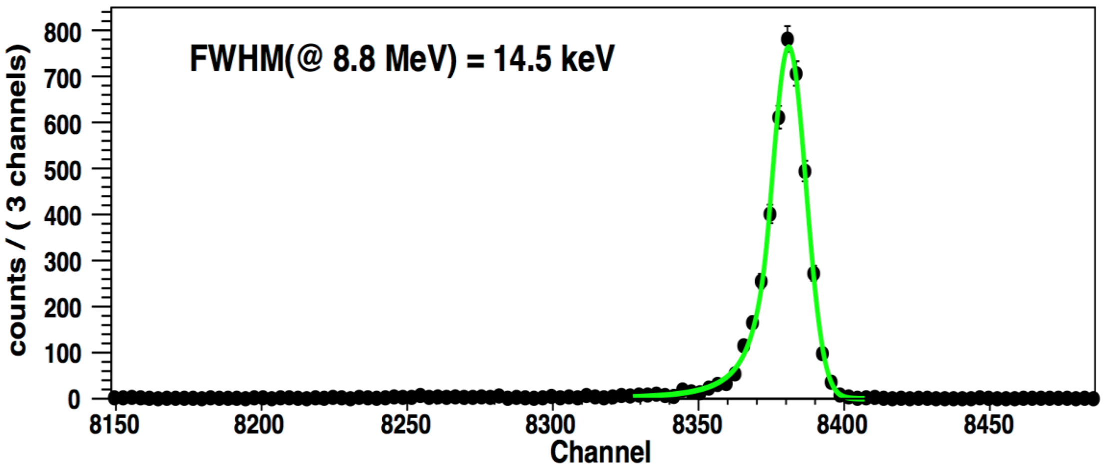
P. Chauveau

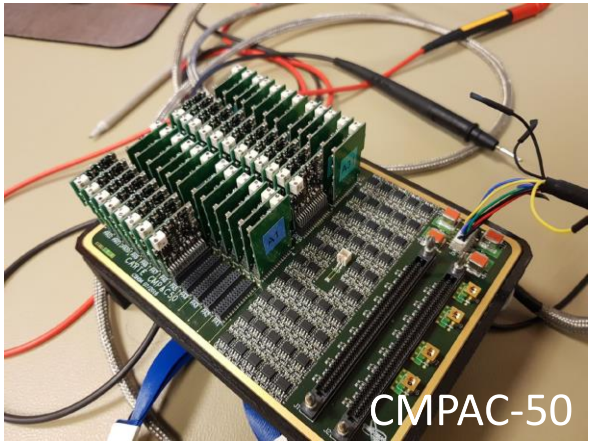
Conclusions & Perspectives

- Combined γ and ICE spectroscopy is necessay in the heavy-element region

- Dedicated low-noise & fast front-end electronics with reduced capacitance is required to disentangle complex ICE spectra and distinguish escape alphas from ICE's

Tests @ IPHC with S3 SIRIUS tunnel detector & prototype CSNSM-GANIL "CMPAC-16" (12.5x12.5 mm^2 pad on a 100x100 mm^2 detector)

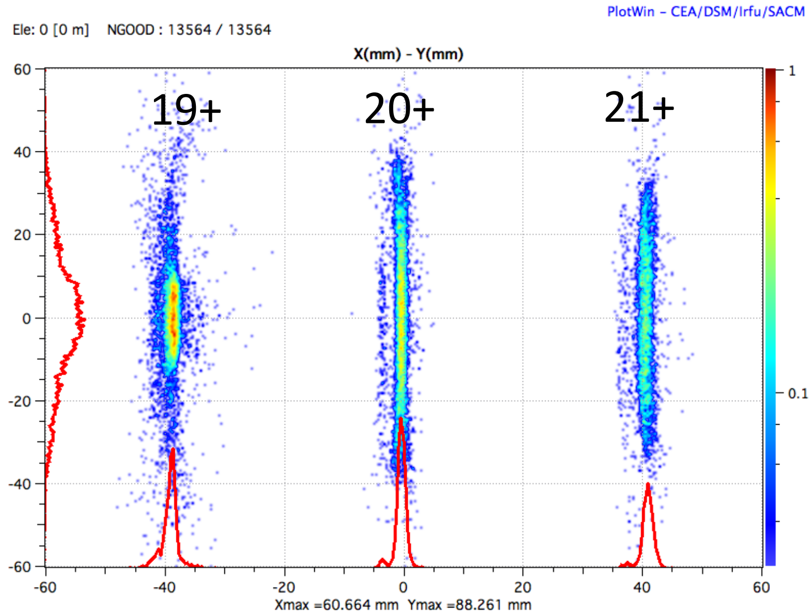




- One should be careful extracting spe from low-energy spectra in the ^{254}No region as vibrational modes are active

Conclusions & Perspectives

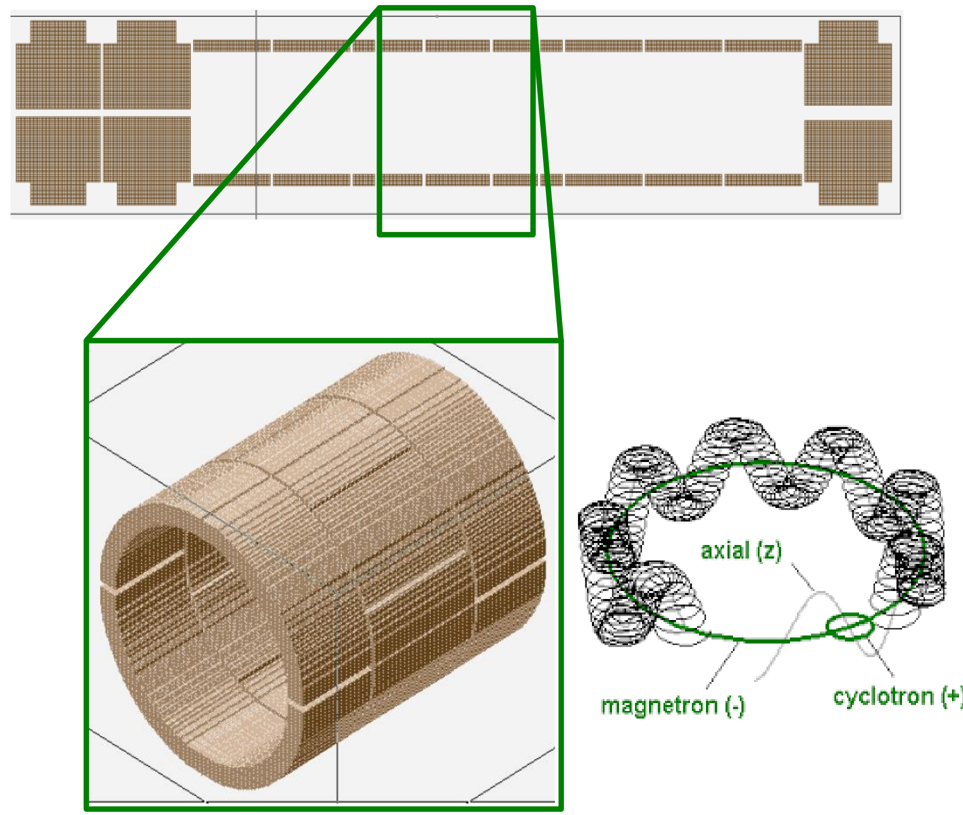
- p-evaporation channels are a way to go more neutron rich and there is a potential for discovery at S3 with its foreseen in-flight mass resolution & subsequent decay-chain identification with SIRIUS



^{208}Pb(^{48}Ca,1-3n) @ E_{lab}=216 MeV
σ(255No) = 180nb
σ(254No) = 3390nb
σ(253No) ~10nb

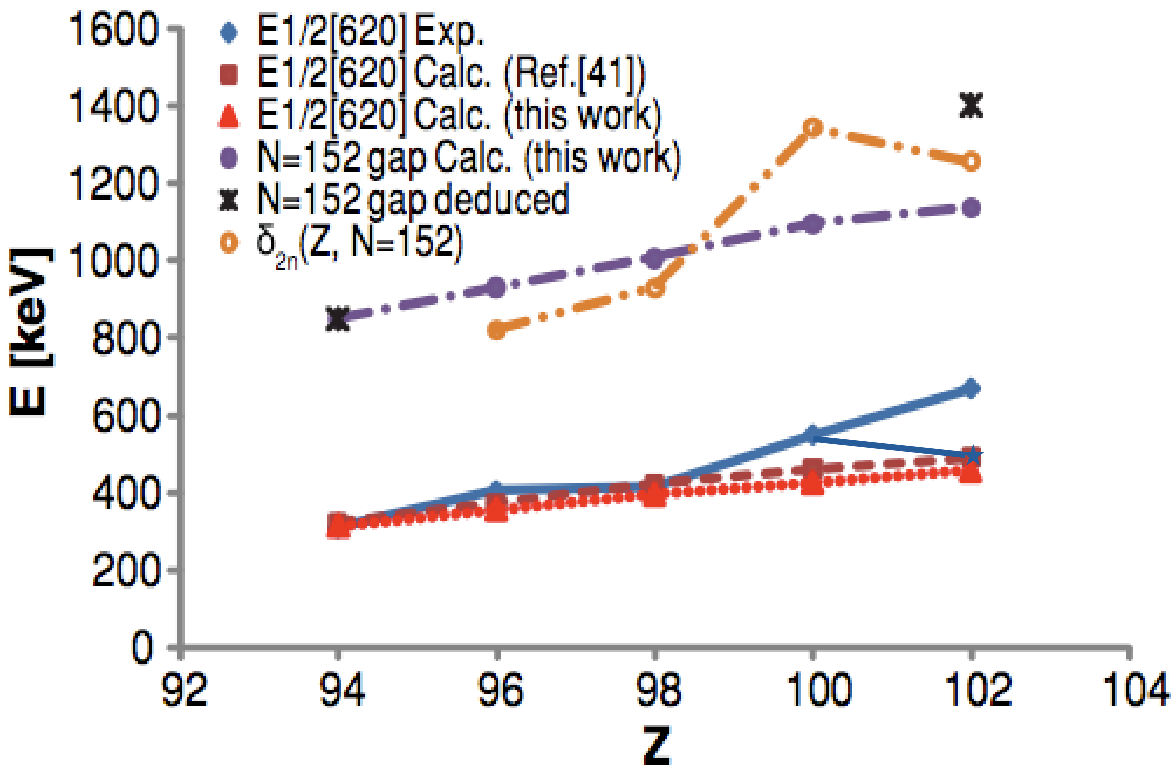
- In-trap spectroscopy of heavy & super heavy nuclei @ DESIR can give precious complementary information on fine structure alpha decay and nuclear lifetimes, inaccessible in standard recoil-implantation experiments or prompt spectroscopy experiments

First trap: simulations



- Pressure: 3E-4 mbar of He
- Timing (200 ms total):
  - 50 ms wait (cyclotron damping)
  - 20 ms dipol. exc. at f_{mag} (magnetron blow up)
  - 10 ms wait
  - 120 ms quad. exc. at f_c (selective centering)
- Centering results:
  - viscous damping: sigma ~ 20um, but no limit
  - hard sphere: sigma ~ 100-200um

N=152 gap



J.Qian et al., Phys. Rev. C79 (2009) 064319

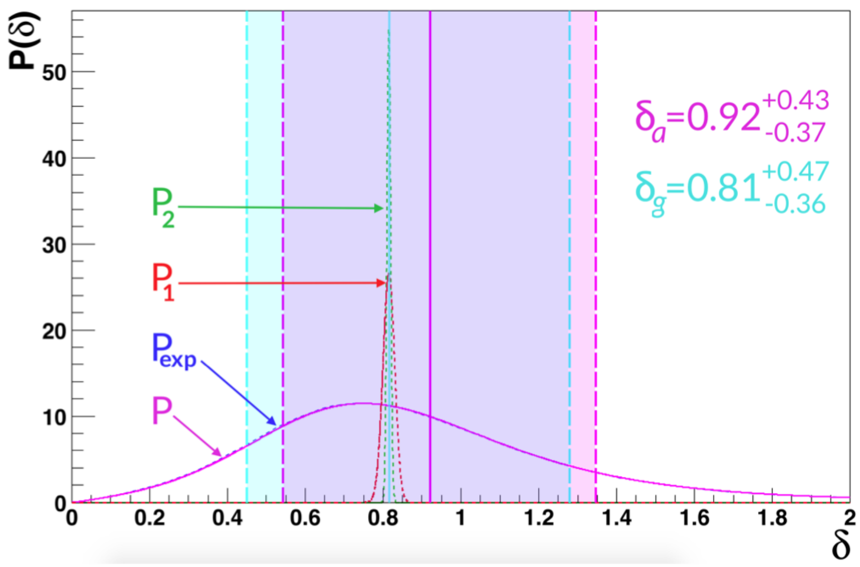
[41] A. Parkhomenko and A. Sobiczewski, Acta Phys. Pol. B **36**, 3115 (2005).

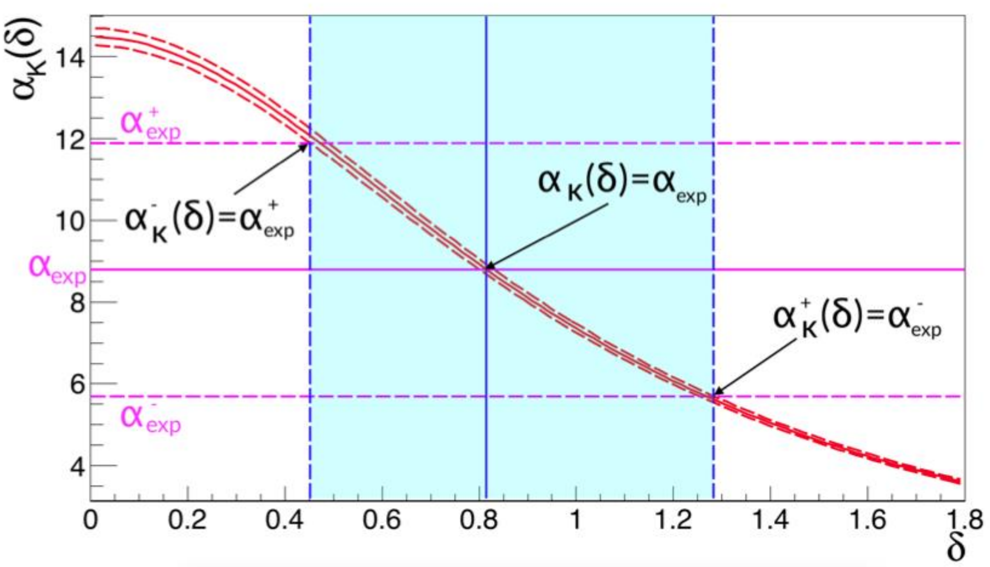
B. Streicher et al. .,Eur. Phys. J. A 45 3 (2010) 275

Extraction of δ

K. Rezynkina et al., Nucl. Instr. Meth. A 844 (2017) 96

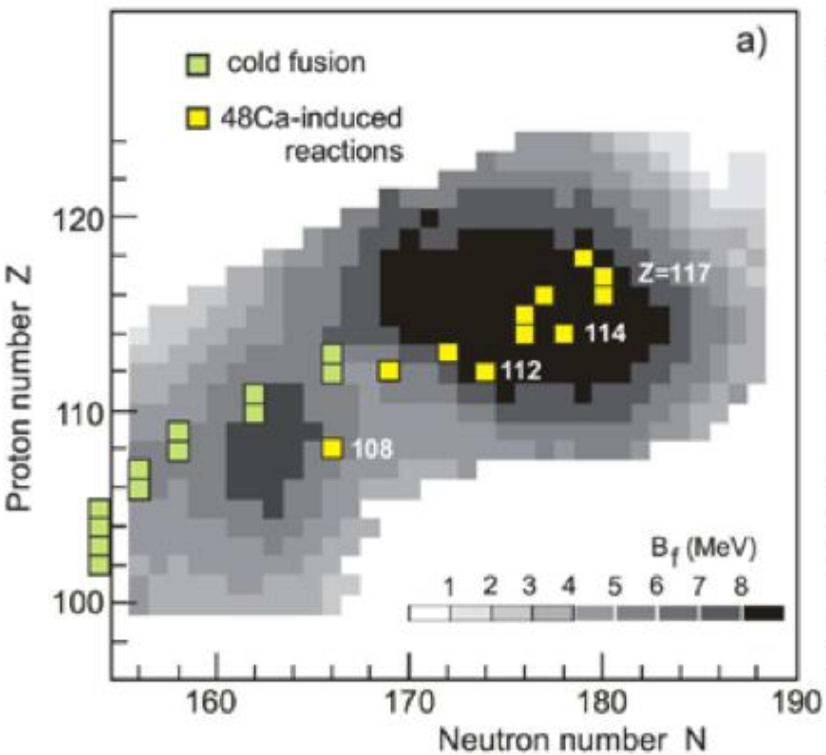
$$\delta = \sqrt{\frac{\alpha(\sigma L) - \alpha_{exp}}{\alpha_{exp} - \alpha(\sigma' L')}}$$

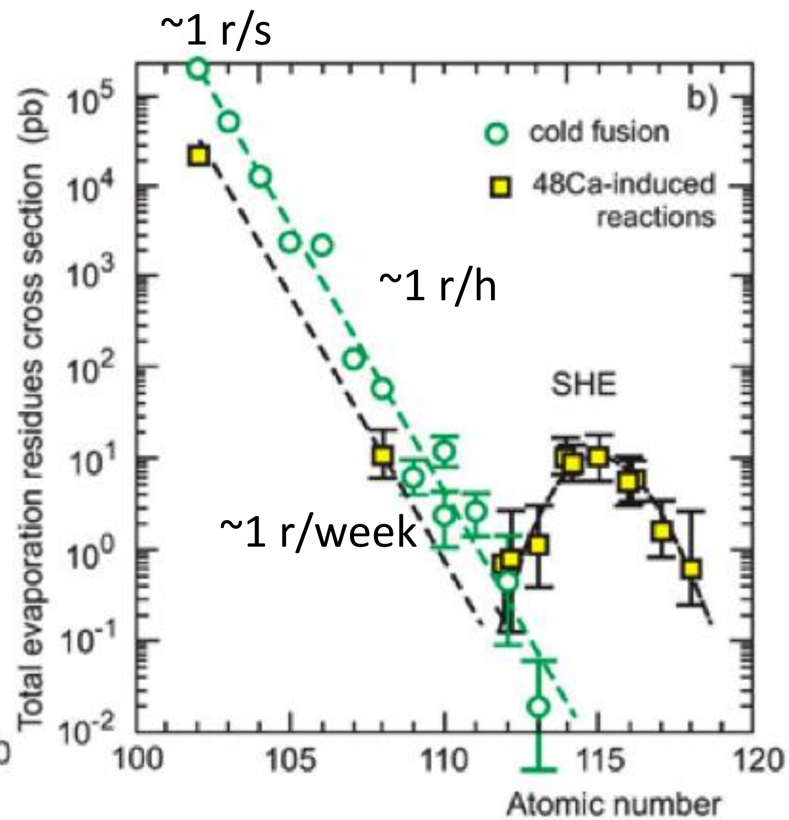




Experimental challenge

P. Möller et al., Phys. Rev C **79**, 064304 (2009)

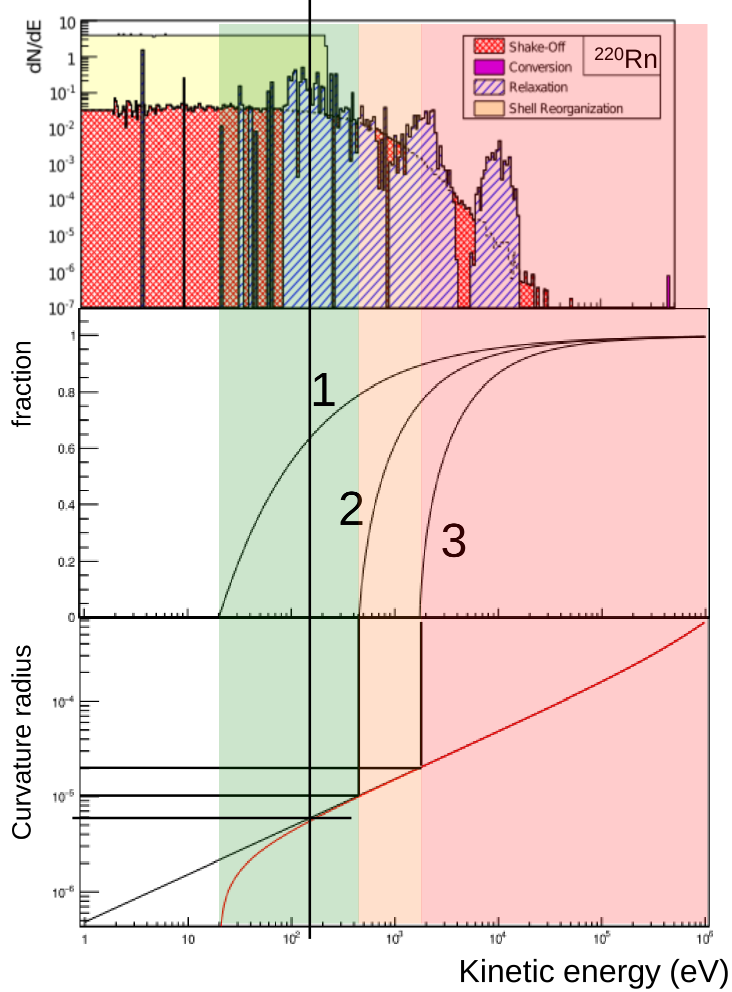




Y. Oganessian, Nuclear Physics News, Vol. 23 (2013)

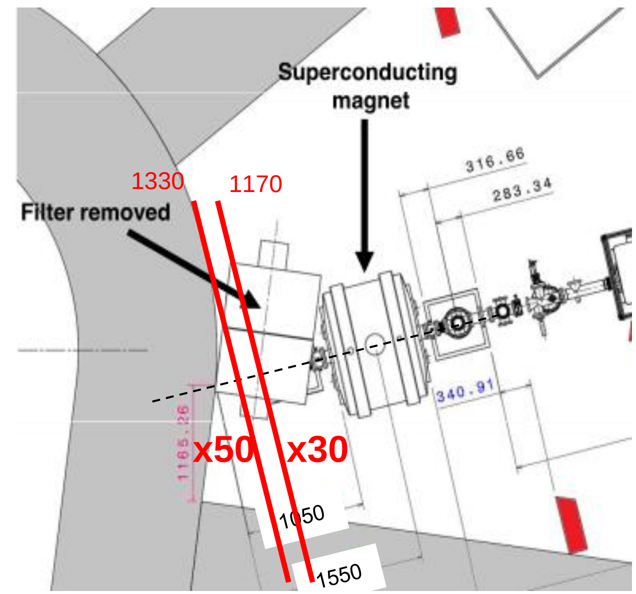
Second trap

Wandkowsky, et al.



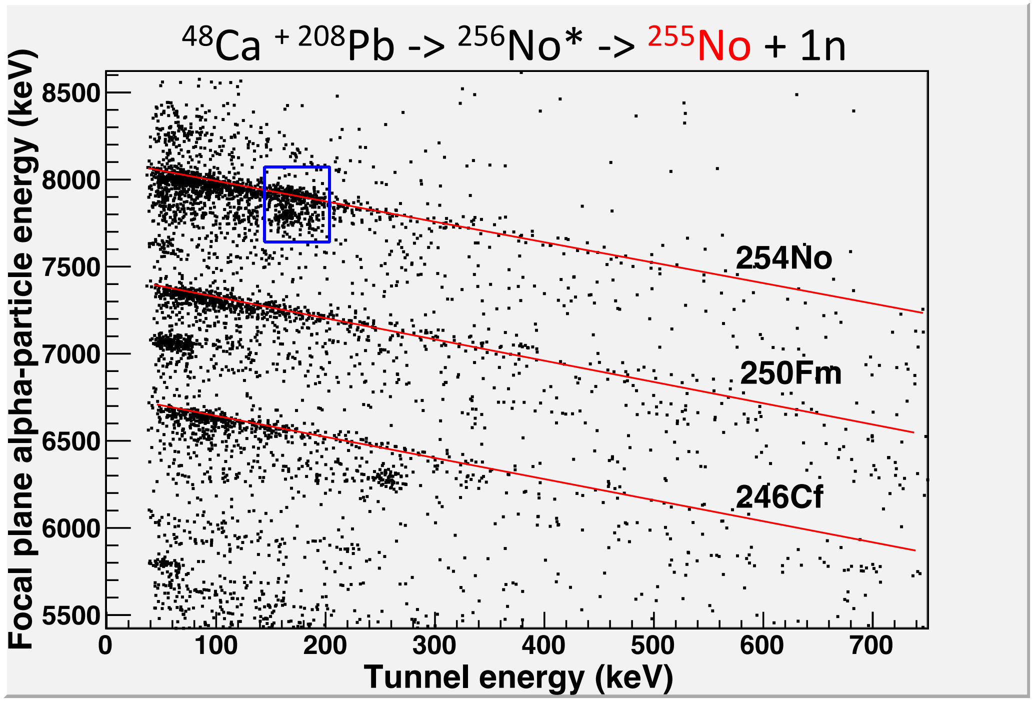
1) Out of the trap
2) Out of the trap & R>1e-5m
3) Out of the trap & R>2e-5

Black: max radius in the trap
Red: max radius outside the trap

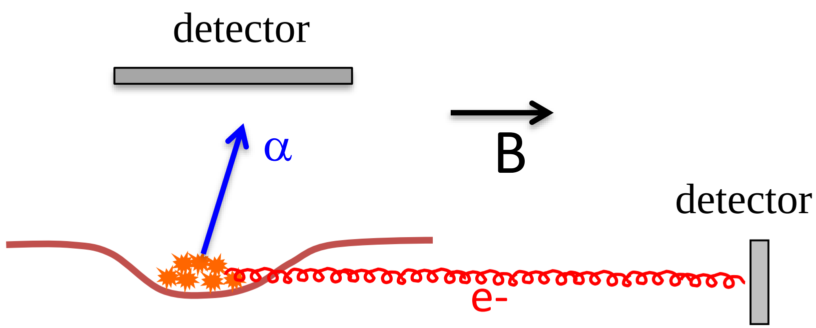


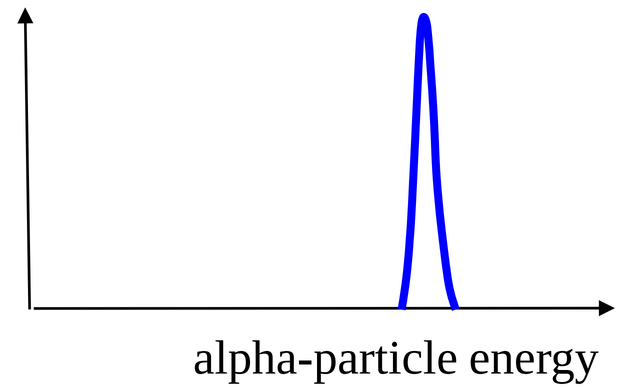
2e-5 ⇔ 6e-4(x30) ⇔ 1e-3(x50)
1e-5 ⇔ 3e-4(x30) ⇔ 5e-4(x50)
6e-6 ⇔ 1.8e-4(x30) ⇔ 3e-4(x50)

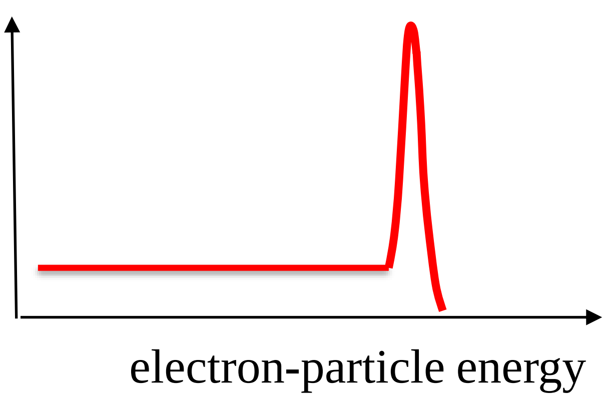
Contamination of electron-alpha coincidences



In-trap spectroscopy of heavy elements







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