Nuclear structure of N>150 Pu-Cf nuclei and outlook with AGFA

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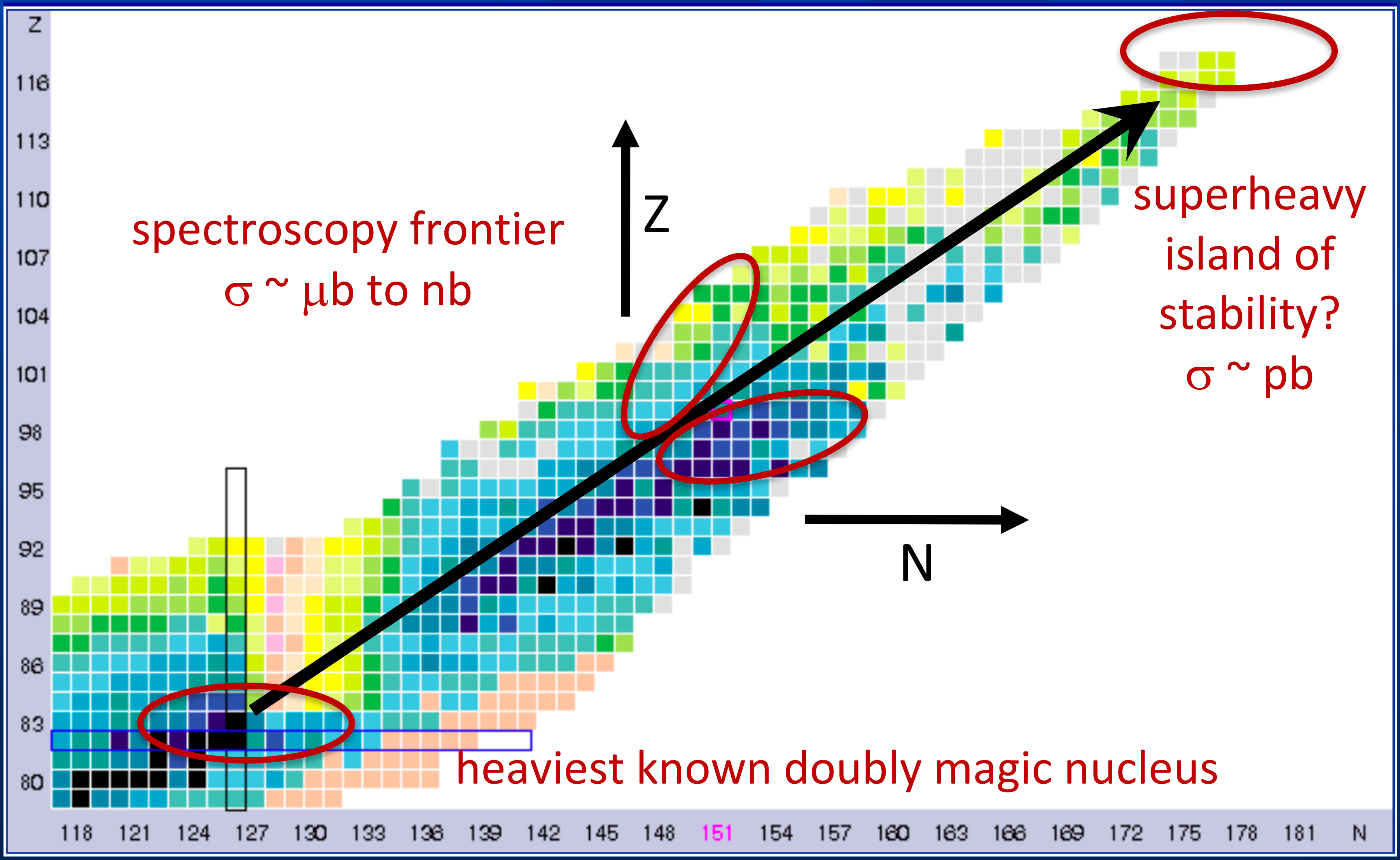
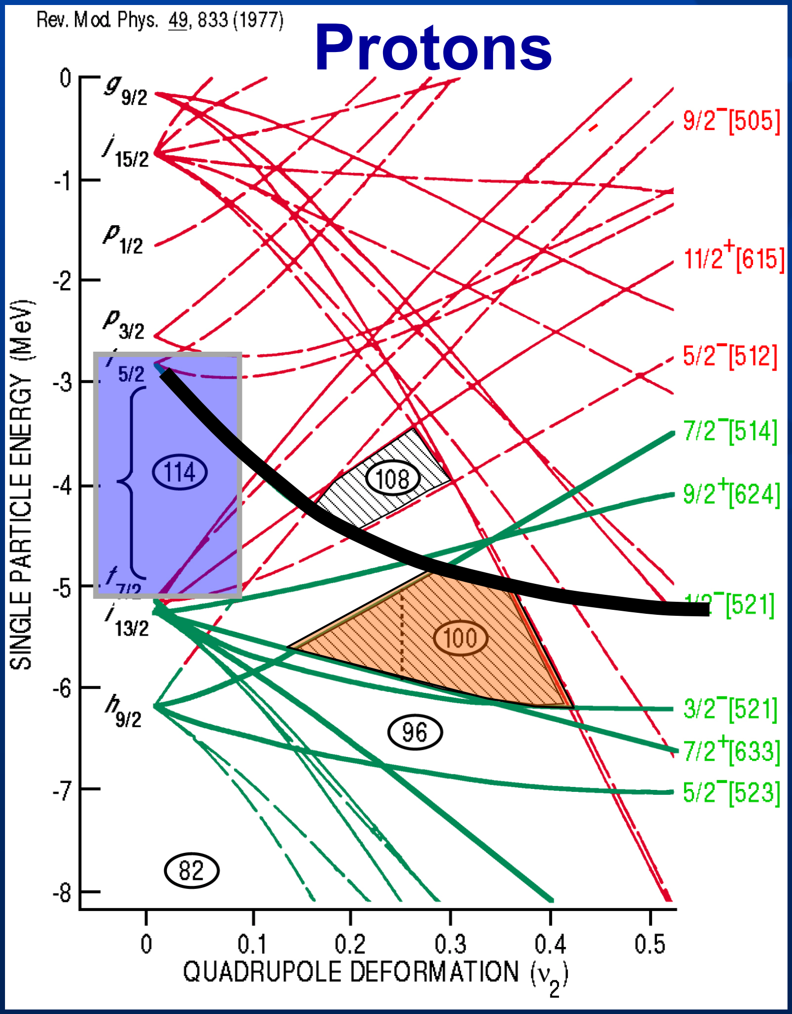
Work supported by U.S. Department of Energy

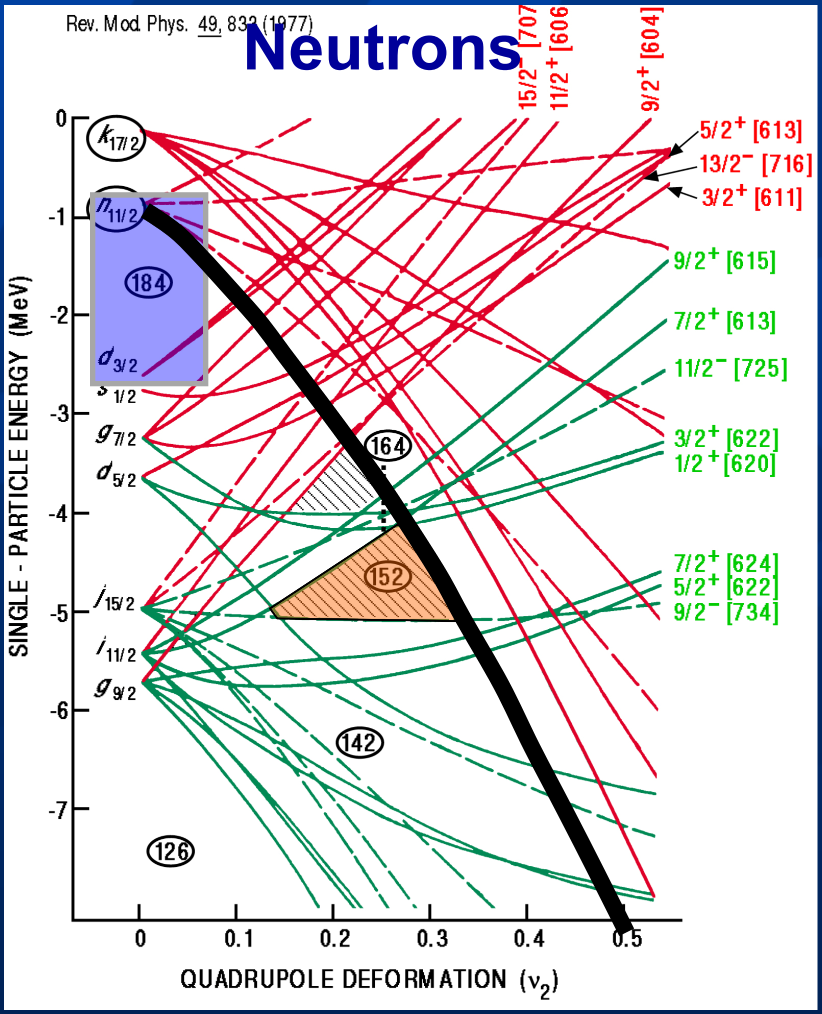
Learning with Purpose

towards superheavies



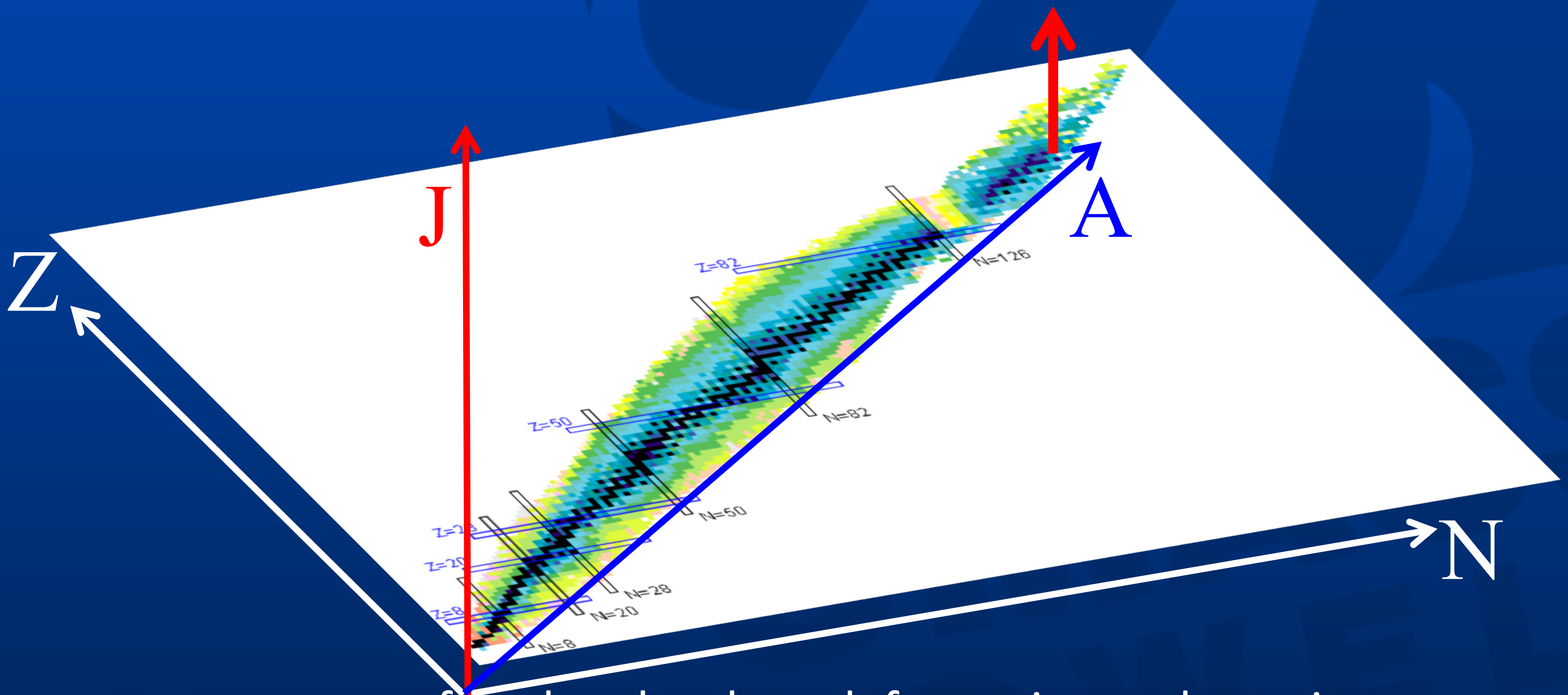
deform potential: lift degeneracy, rearrange gaps





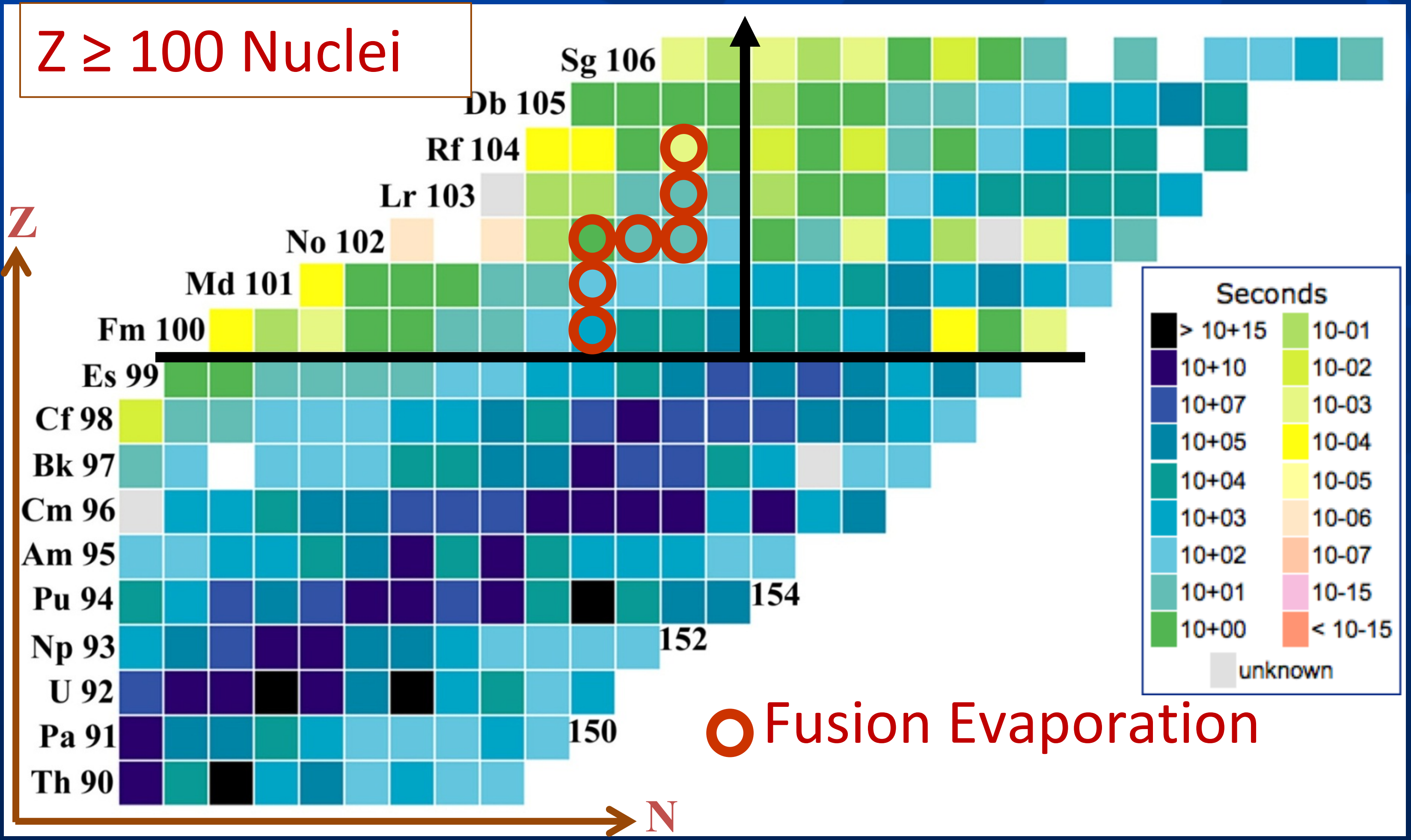
R.R. Chasman and I. Ahmad, Rev. Mod. Phys. 49, 833 (1977) Woods-Saxon

then rotate deformed potential

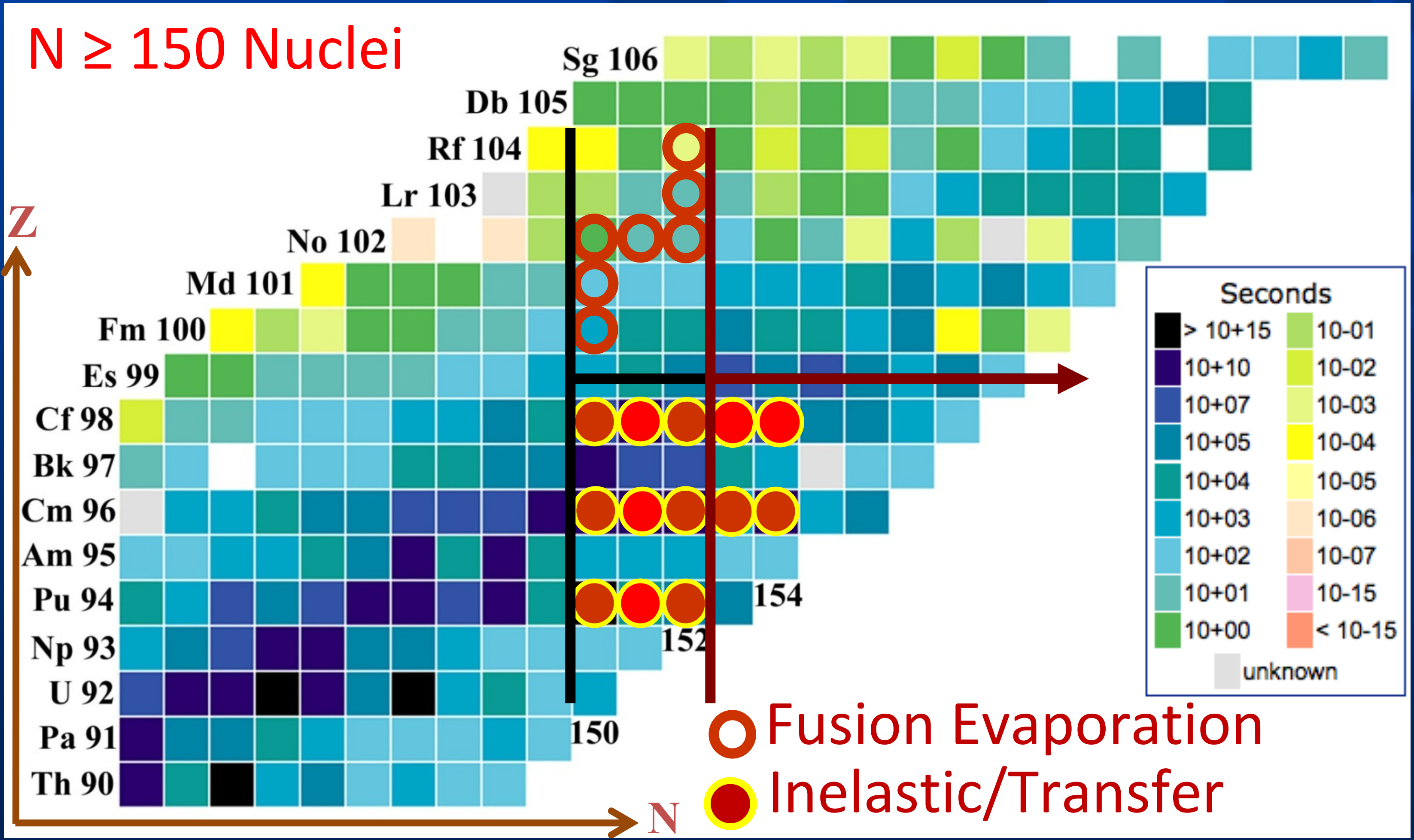


- response of nuclear levels to deformation and rotation
- deduce structure, extract single particle energy spectrum
- quantum shell gaps critical for superheavy stability
- superheavy theories must reproduce all observables

Z ≥ 100 : the highest proton orbitals



N ≥ 150 : the highest neutron orbitals



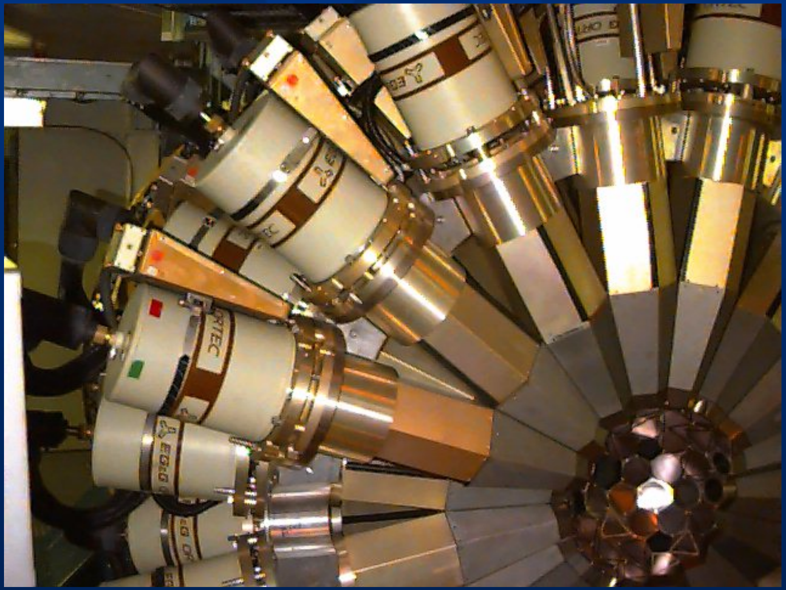
experiments

Inelastic and transfer reactions with radioactive targets
Complement fusion-evaporation studies of Z>100 nuclei
Access the highest neutron orbitals

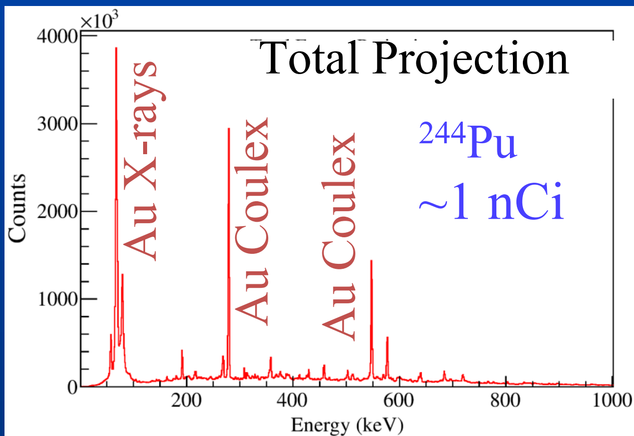
^{208}Pb on ^{244}Pu
^{209}Bi on ^{248}Cm
^{207}Pb on ^{249}Cf
^{208}Pb on ^{249}Cf
^{208}Pb on $^{249,250,251}Cf$

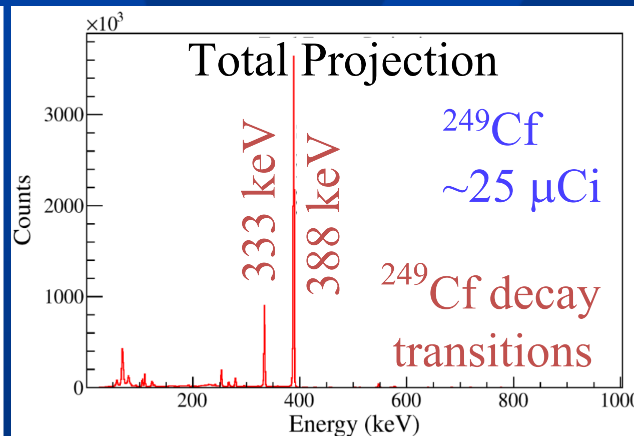
Unique capabilities of ATLAS stable-beam facility

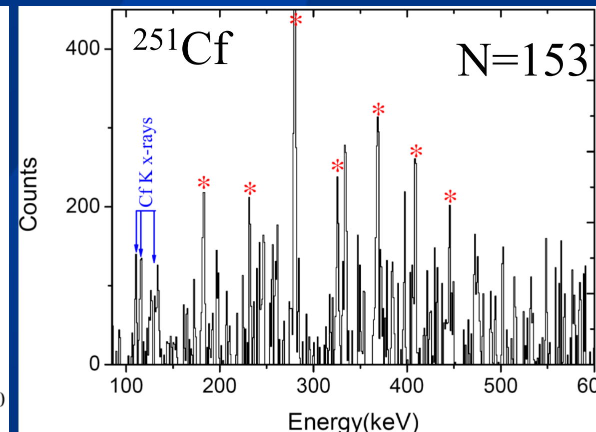
~15% above Coulomb barrier
ATLAS + Gammasphere



radioactive targets: challenges and techniques



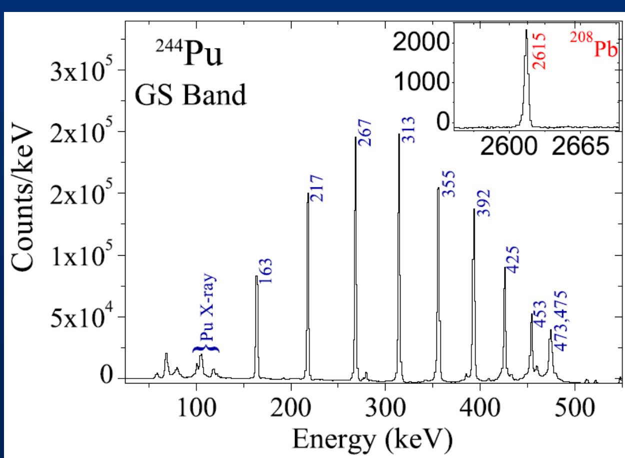


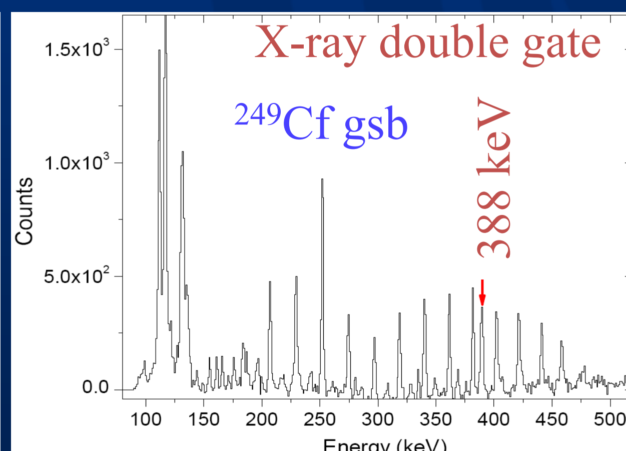


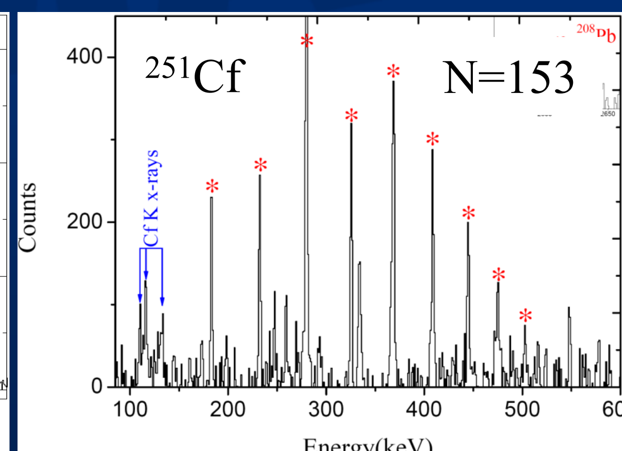
γ-ray double-gated

X-ray double-gated

H-K + double-gated

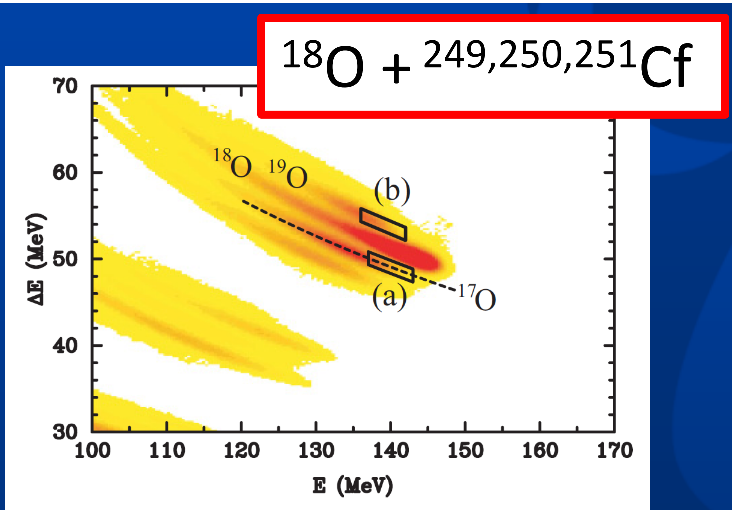


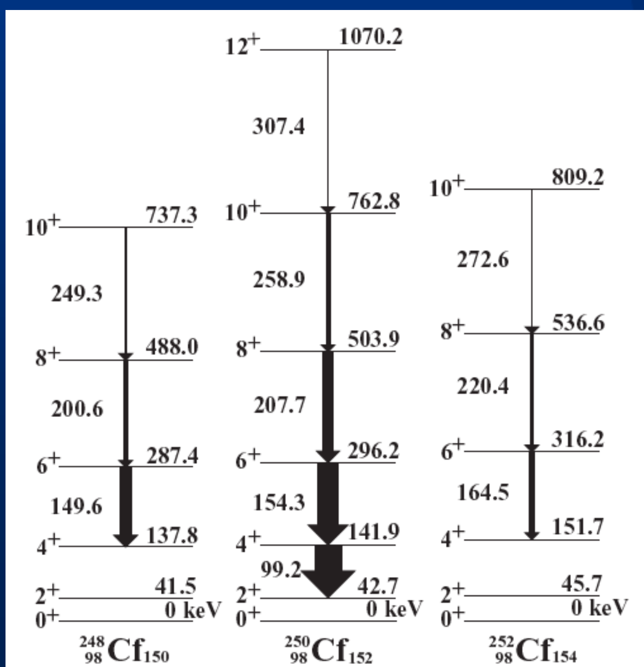


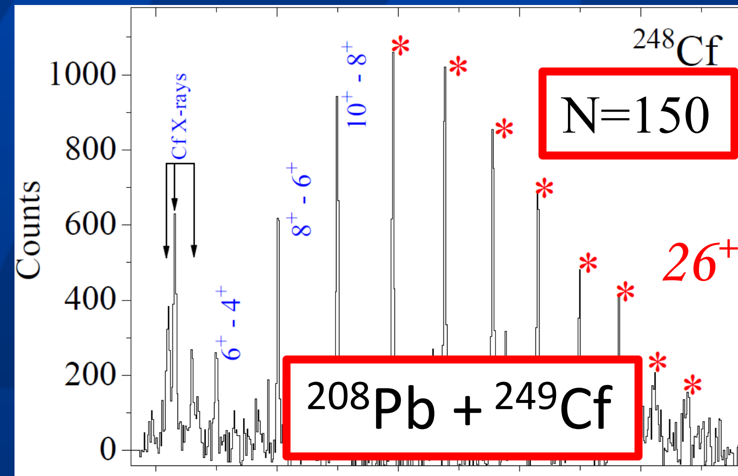


gsb in even-even nuclei : 1n transfer

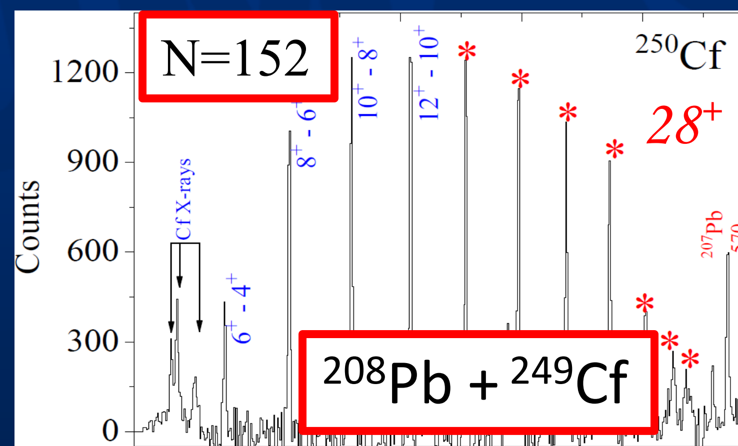
R. Takahashi et al., PRC 81, 057303(2010)







Sum of triple gates in a hypercube

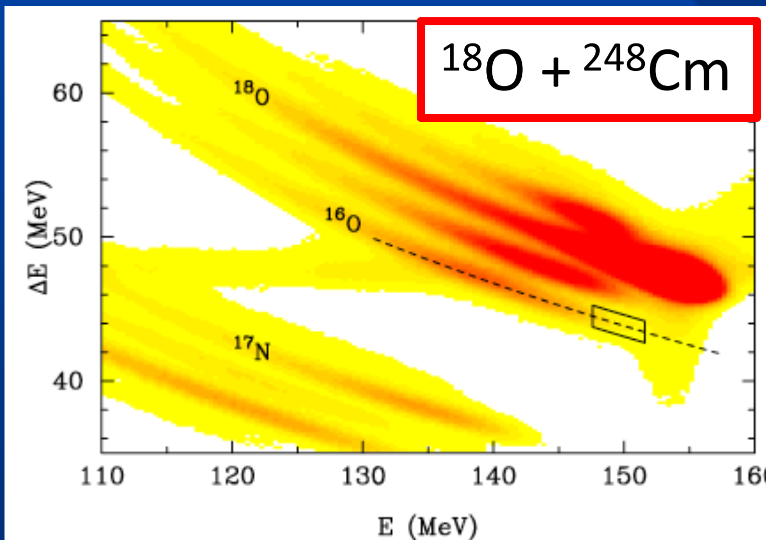


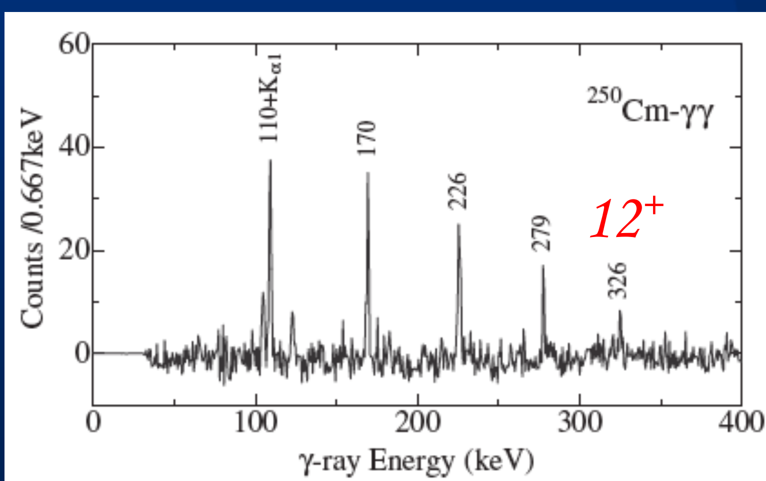
Sum of triple gates in a hypercube

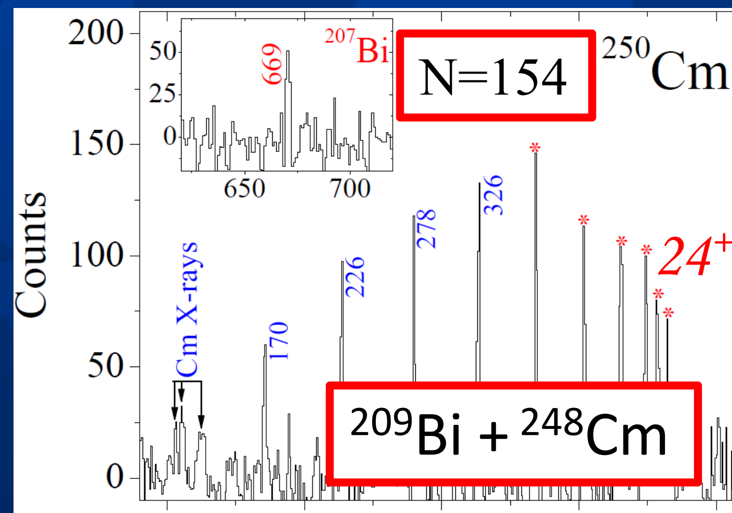
S.S. Hota (Ph.D. thesis, 2012)

gsb in even-even nuclei : 2n transfer

T. Ishii et al., J. Phys. Soc. Japan. 75, 043201 (2006)





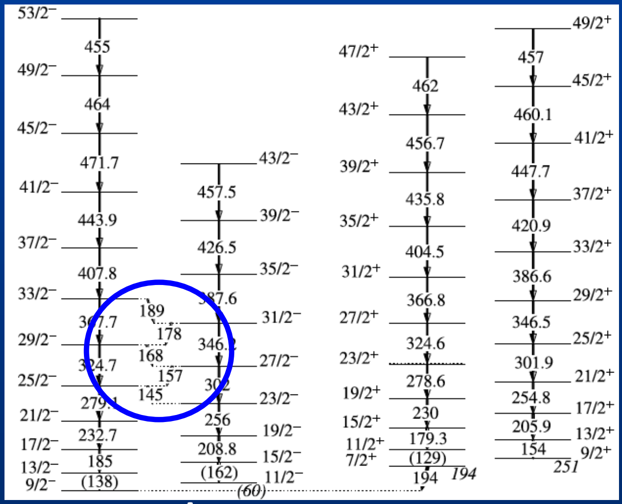


Sum of triple gates in a hypercube

S.S. Hota (Ph.D. thesis, 2012)

N=151 Pu (Z=94), Cm (Z=96) and Cf (Z=98)

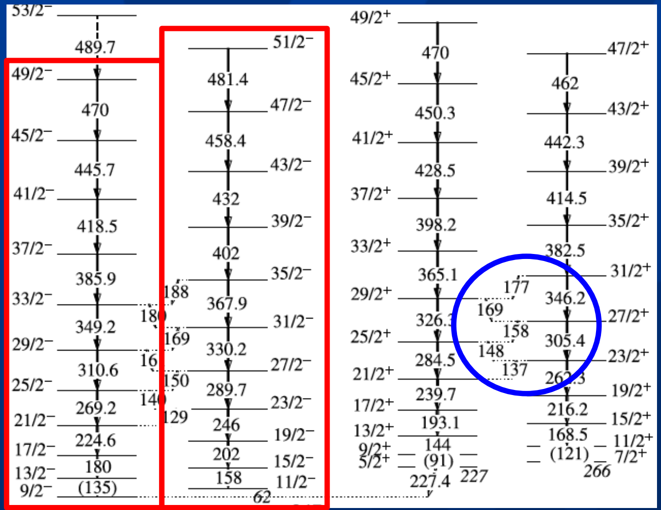
[734] 9/2 ⁻ [624] 7/2 ⁺



ground state

^{245}Pu

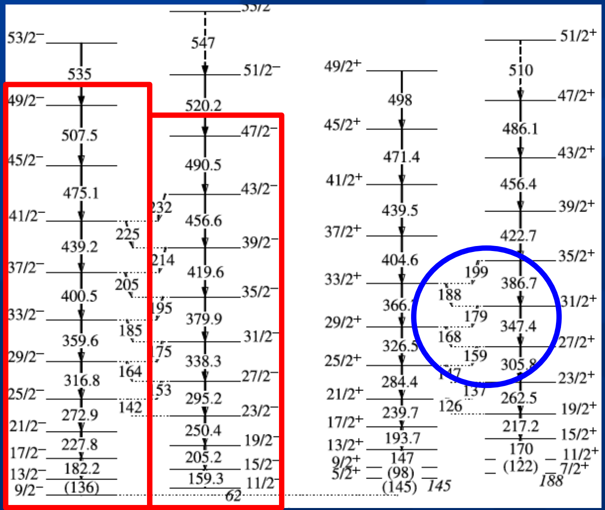
[734] 9/2 ⁻ [622] 5/2 ⁺



ground state

^{247}Cm

[734] 9/2 ⁻ [622] 5/2 ⁺



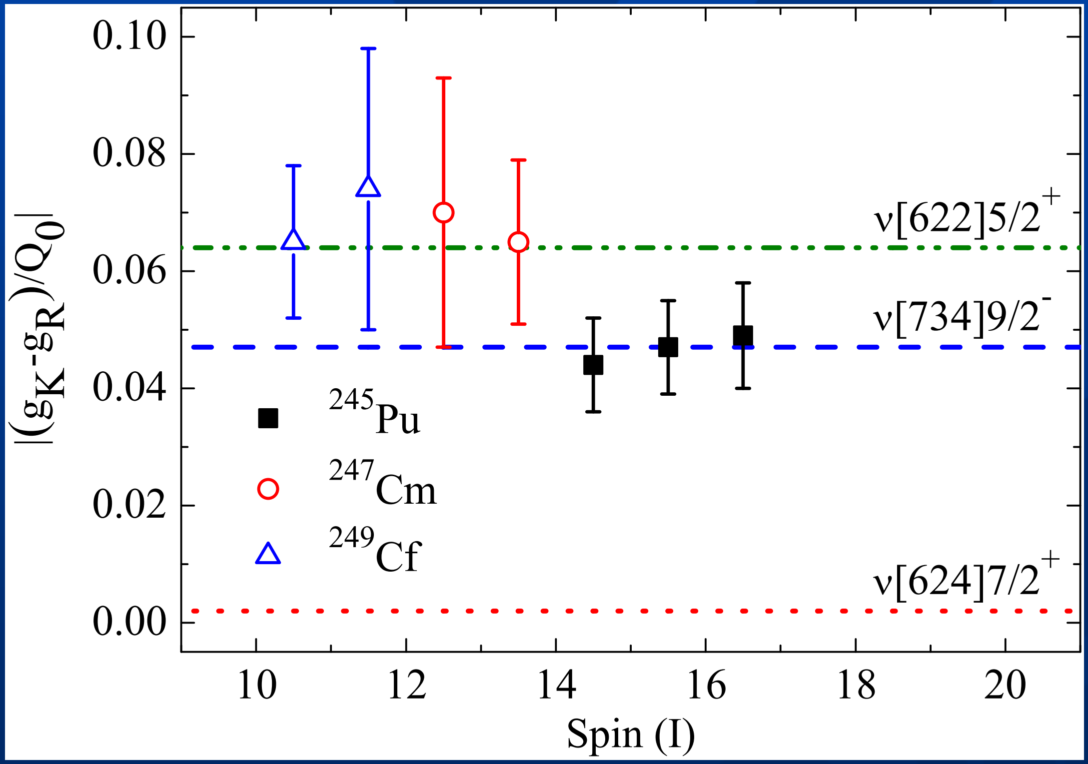
ground state

^{249}Cf

Initial work : S.K. Tandel et al., PRC 82, 041301 (R) (2010)

Subsequent work : S.S. Hota et al., Phys. Lett. B739, 13 (2014)

excited bands in odd-A nuclei



$\nu g_{9/2} + \nu i_{11/2}$

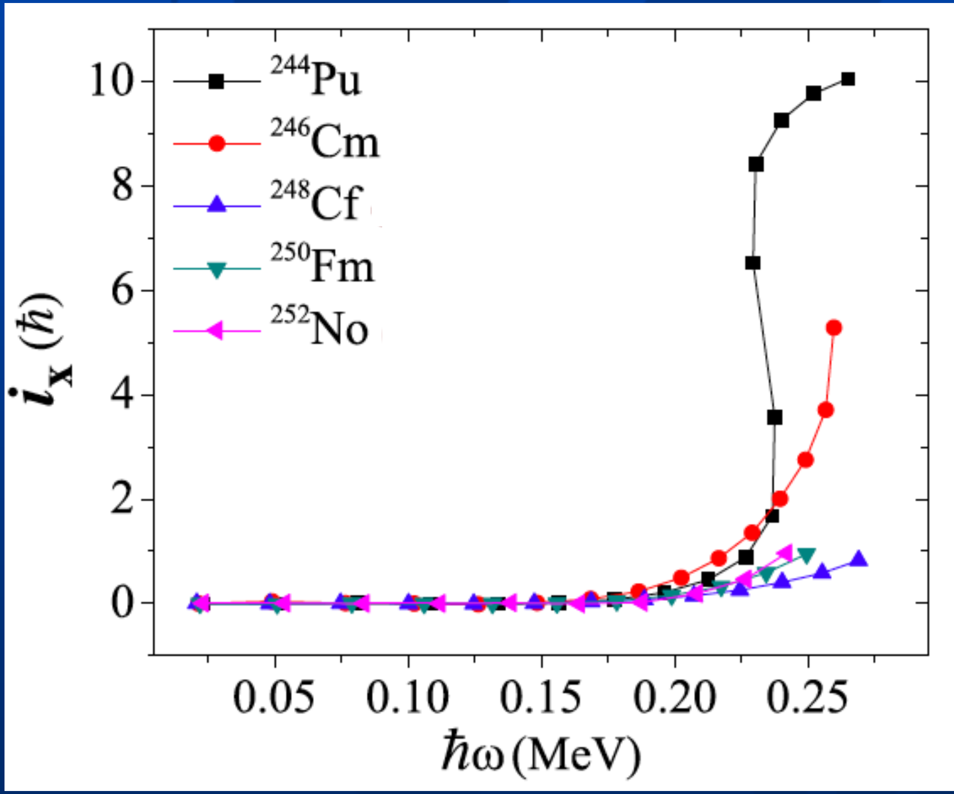
$\nu j_{15/2}$

configuration assignments via B(M1)/B(E2) branching ratios

S.S. Hota et al., Phys. Lett. B739, 13 (2014)

new physics?

Nucleon alignments in N=150 isotones



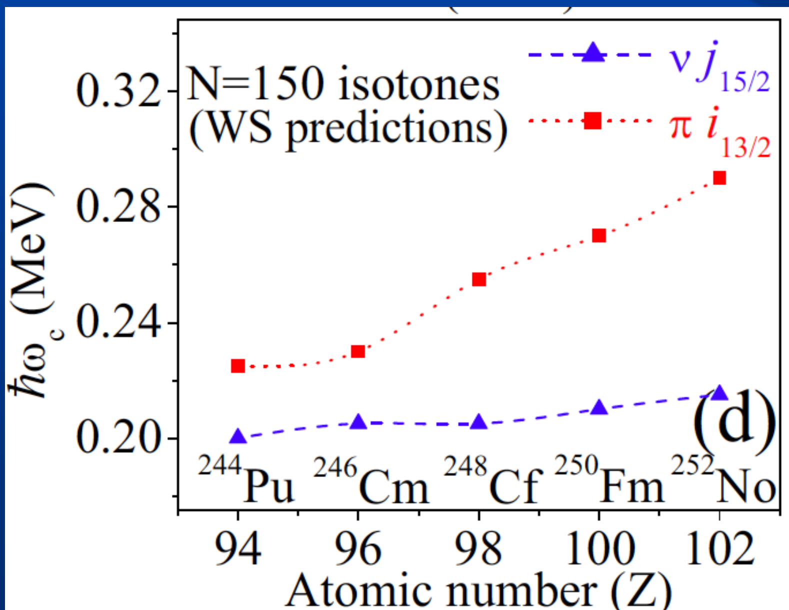
complete alignment observed only in ^{244}Pu

attributed to $i_{13/2}$ protons

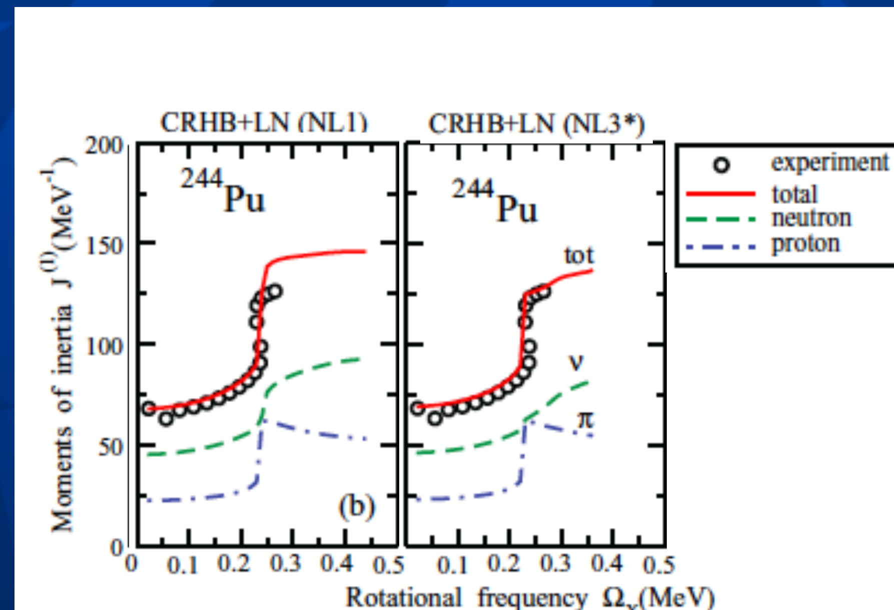
long-standing puzzle: $j_{15/2}$ neutron alignment?

alignment predictions : selected models

S.K. Tandel et al., PRC 82, 041301 (R) (2010)



A. Afanasjev and O. Abdurazakov PRC 88, 014230 (2013)



$i_{13/2}$ protons and $j_{15/2}$ neutrons

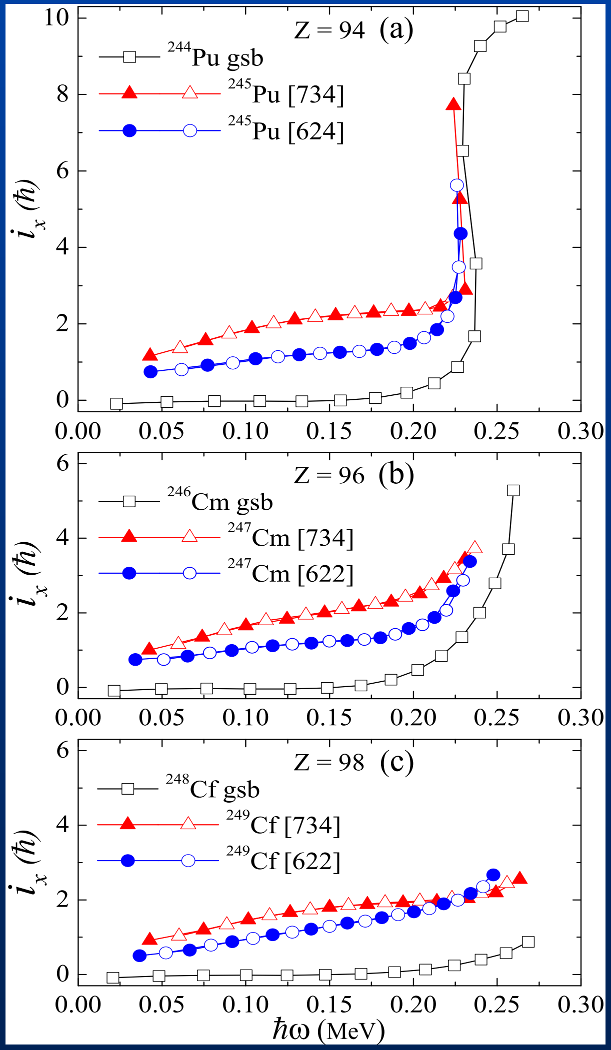
both predicted to align at comparable frequencies

WS predicts neutrons to align first

CRHB predicts simultaneous alignment

expt and theory do not match

odd-A blocking : N=151 nuclei



Two bands in each N=151 nucleus

$j_{15/2}$ neutron alignment is :

Blocked in [734] band (red)

Allowed in [624] band (blue)

Both bands align with even-even core ^{244}Pu

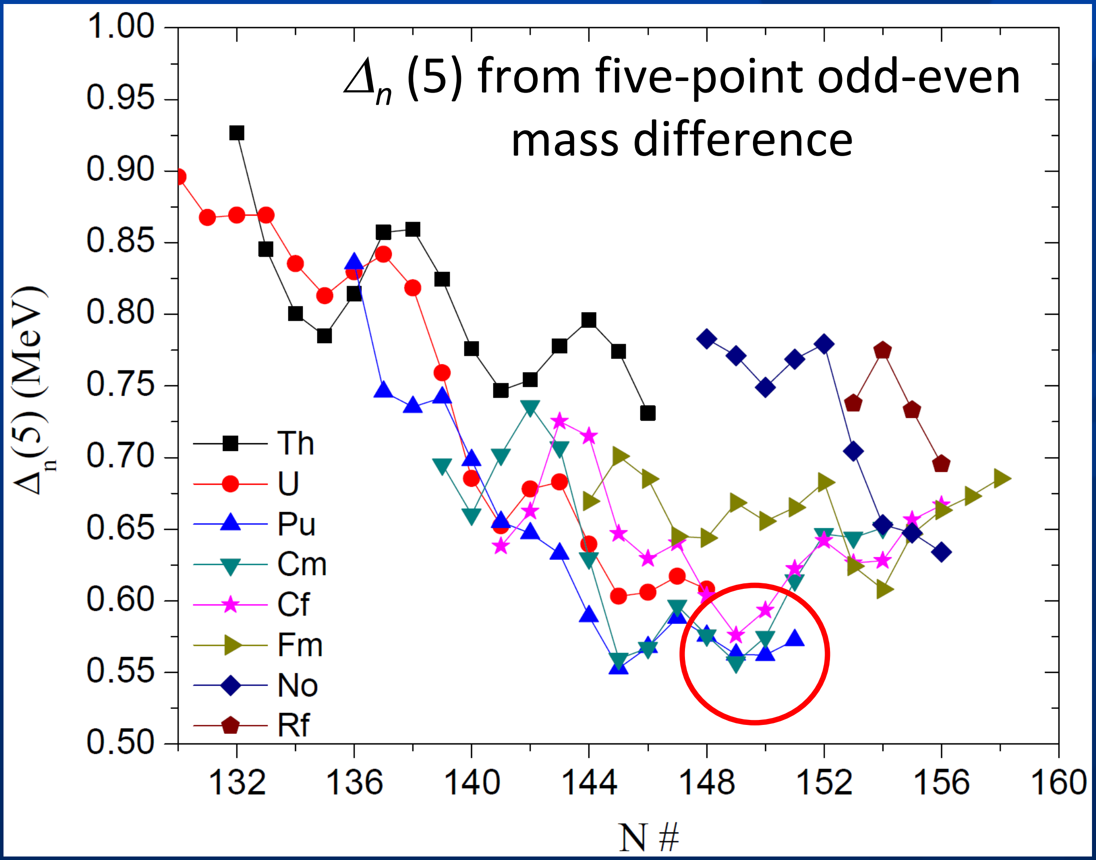
$i_{13/2}$ proton alignment confirmed !

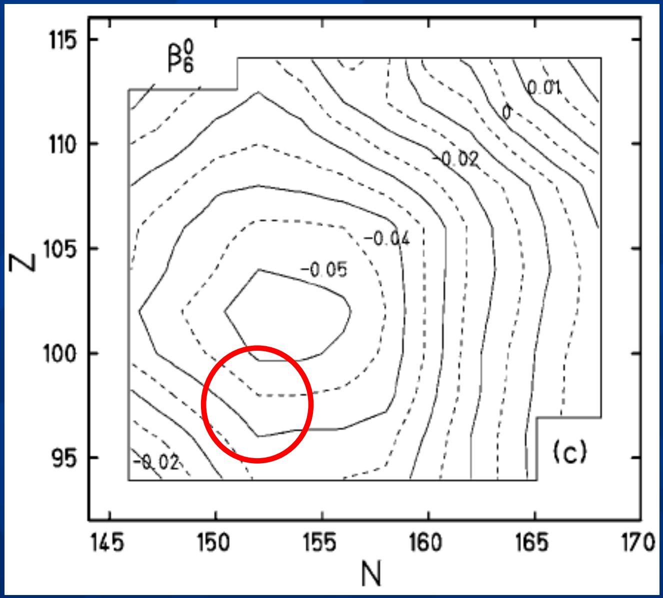
For neutron alignment,

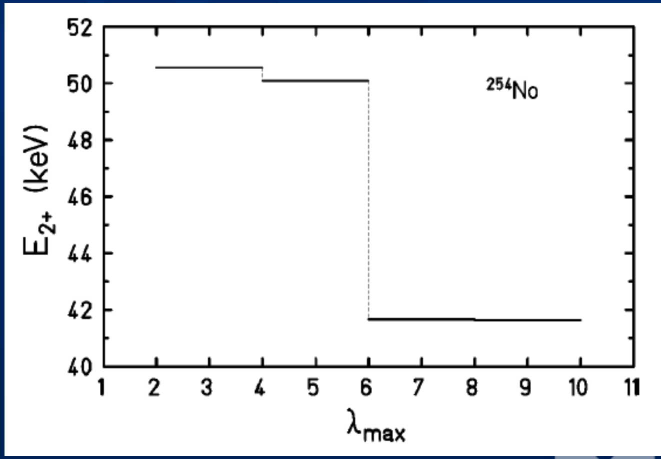
Blue should overtake red (a hint in ^{249}Cf ?)

(need alignment mapping to higher spins)

reduced pairing and higher order deformations

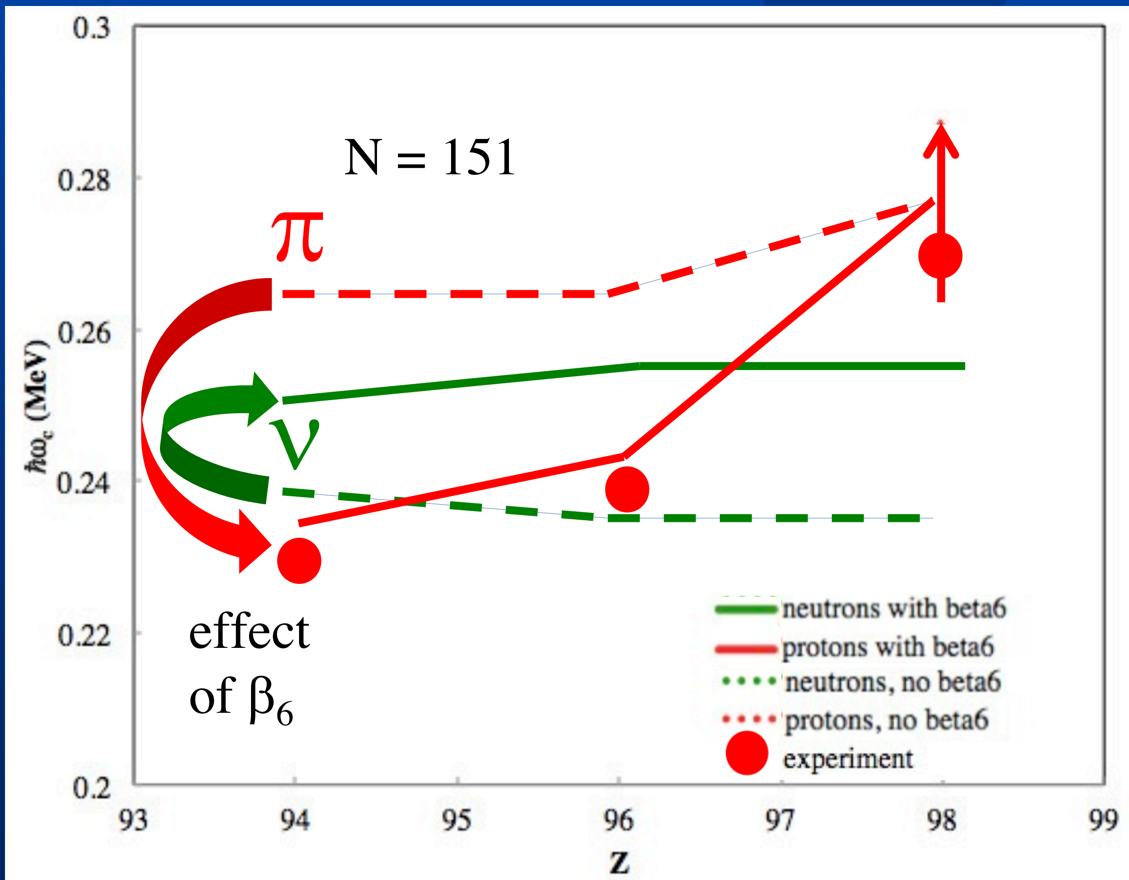






A. Sobiczewski et al., PRC 63, 034306 (2001)

effect of higher order deformations in WS



S.S. Hota et al., Phys. Lett. B739, 13 (2014)

Pairing Δ fixed at 5-point odd-even mass difference

Results not very sensitive to small variations in Δ

β_6 from calculated ground-state values

β_6 switches order of nucleon alignment !

the team

Physics Letters B 739 (2014) 13–18

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

$N = 151$ Pu, Cm and Cf nuclei under rotational stress: Role of higher-order deformations

S.S. Hota [a,1], P. Chowdhury [a,*], T.L. Khoo [b], M.P. Carpenter [b], R.V.F. Janssens [b], Y. Qiu [a], I. Ahmad [b], J.P. Greene [b], S.K. Tandel [a,2], D. Seweryniak [b], S. Zhu [b], P.F. Bertone [b,3], C.J. Chiara [b,c], A.Y. Deo [a,4], N. D'Olympia [a], S. Gros [b,5], C.J. Guess [a,6], T. Harrington [a], D.J. Hartley [d], G. Henning [b,7], C.R. Hoffman [b], E.G. Jackson [a], F.G. Kondev [b], S. Lakshmi [a,8], T. Lauritsen [b], C.J. Lister [a], E.A. McCutchan [b,9], K. Moran [a], C. Nair [b], D. Peterson [b], U. Shirwadkar [a,8], I. Stefanescu [b,c,10]

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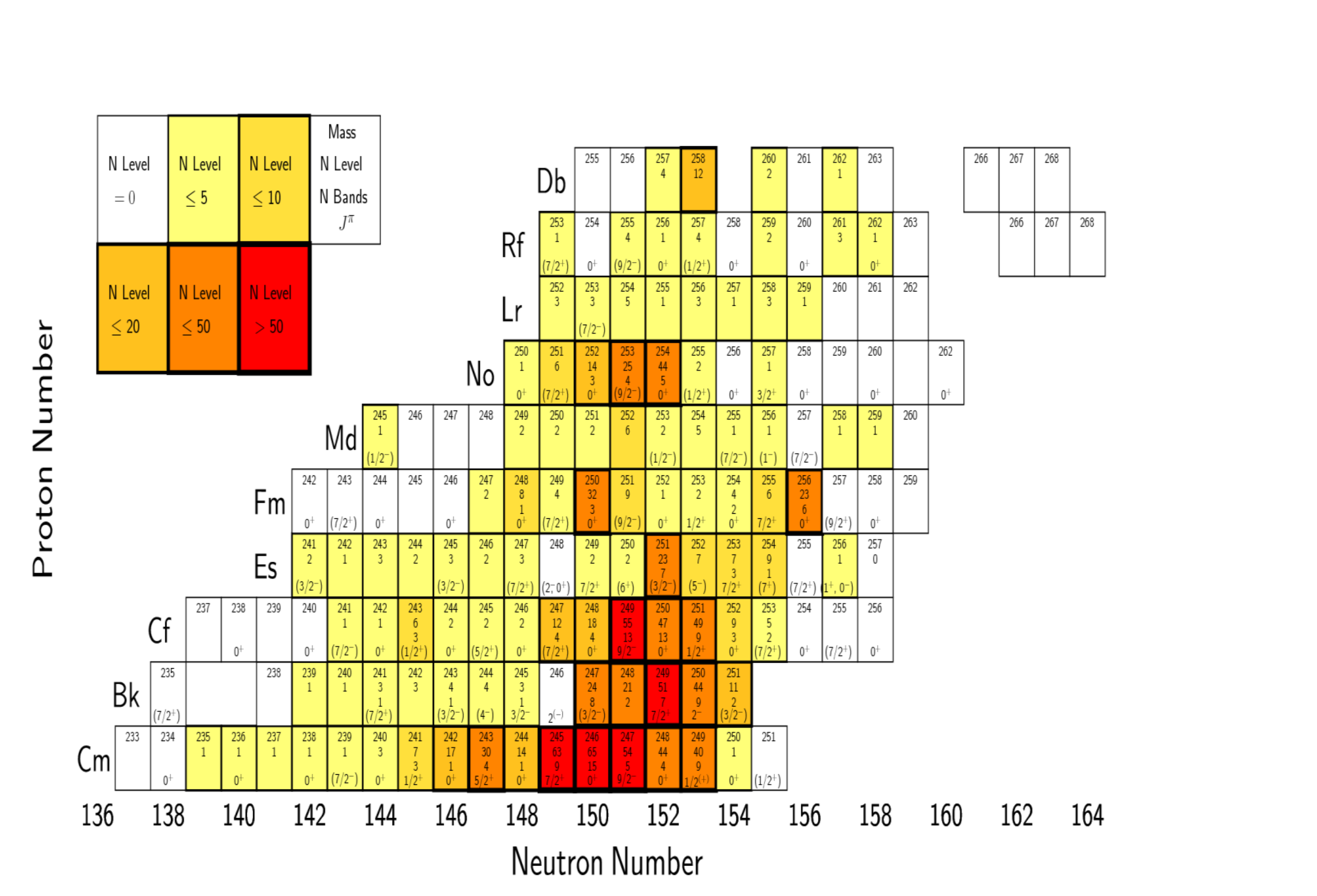
[c] Department of Chemistry and Biochemistry, University of Maryland, College Park, MD 20742, USA
[d] Department of Physics, US Naval Academy, Annapolis, MD 21402, USA

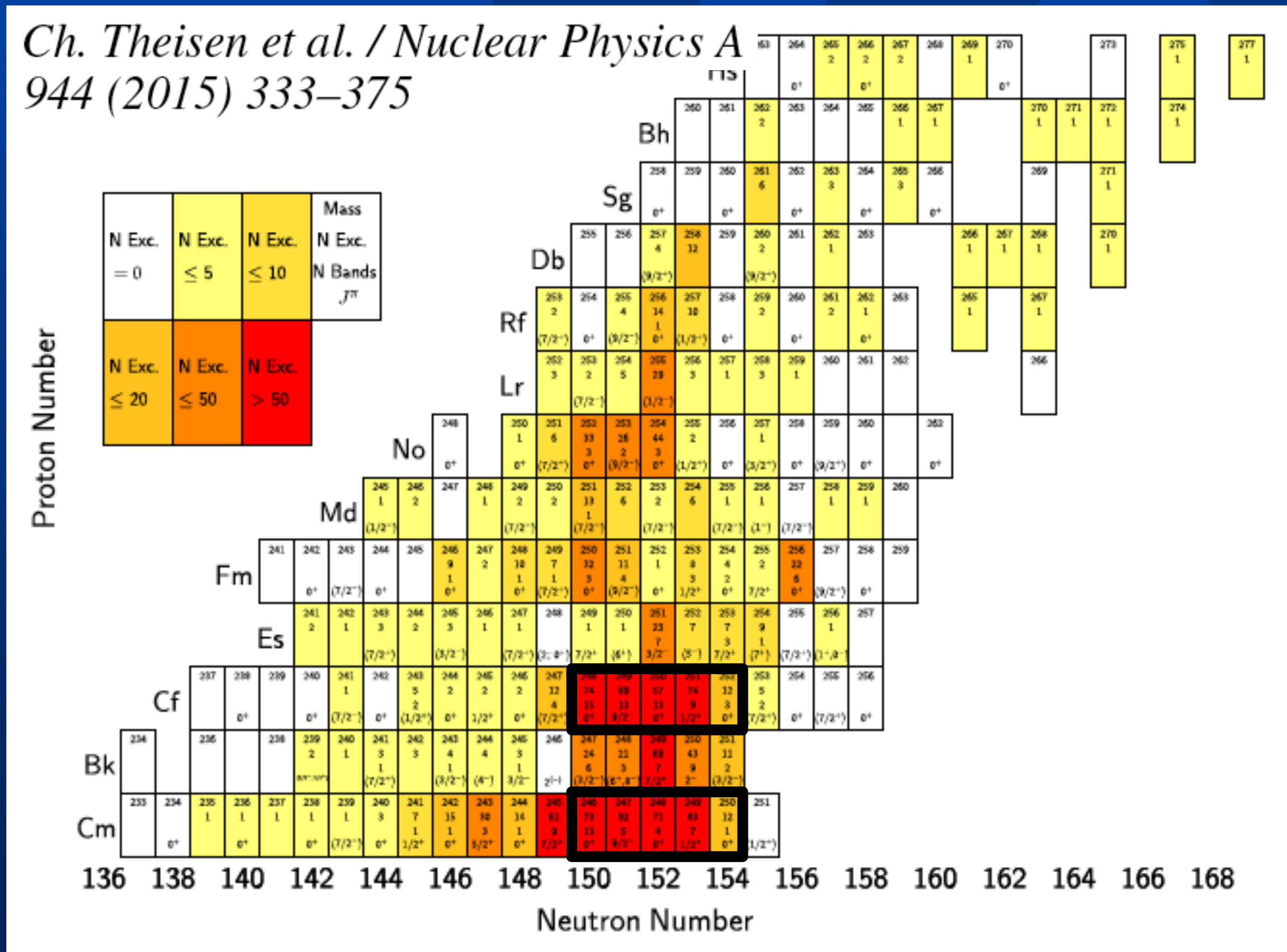
N=152-154 manuscripts under preparation, stay tuned !

evolving landscape

R.-D. Herzberg, P.T. Greenlees / Progress in Particle and Nuclear Physics 61 (2008) 674–720



evolving landscape



AGFA: Argonne Gas-Filled Analyzer collaboration

AGFA slides/content courtesy Darek Seweryniak (ANL)

Argonne National Laboratory

B.B. Back, R.V.F. Janssens, W.F. Henning, T.L. Khoo, J.A. Nolen,

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Lawrence Berkeley National Laboratory

K. Gregorich

Oregon State University

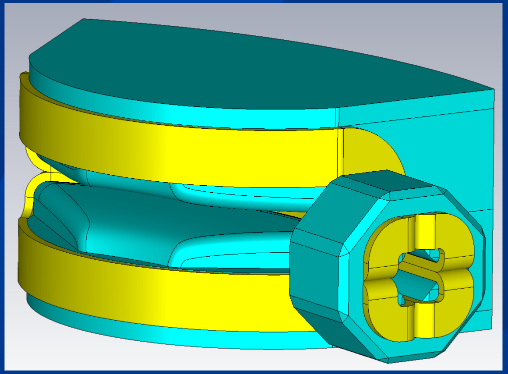
W. Loveland

AGFA concept (D. Potterveld, ANL)

AGFA slides/content courtesy Darek Seweryniak (ANL)

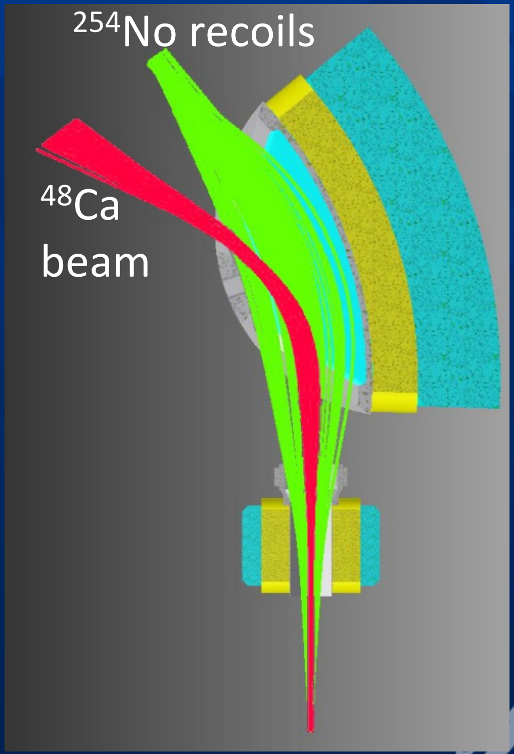
Combined Function bending magnet
Overlapping bending, focusing fields
Fewer magnets, ultra-compact design

Q_vD_m design   2.5 Tm max Bρ   38° bend
22.5 msr @ 80 cm (44 msr @ 40 cm)
4.2 m total path @ 80 cm. (3.9 m @ 40 cm)

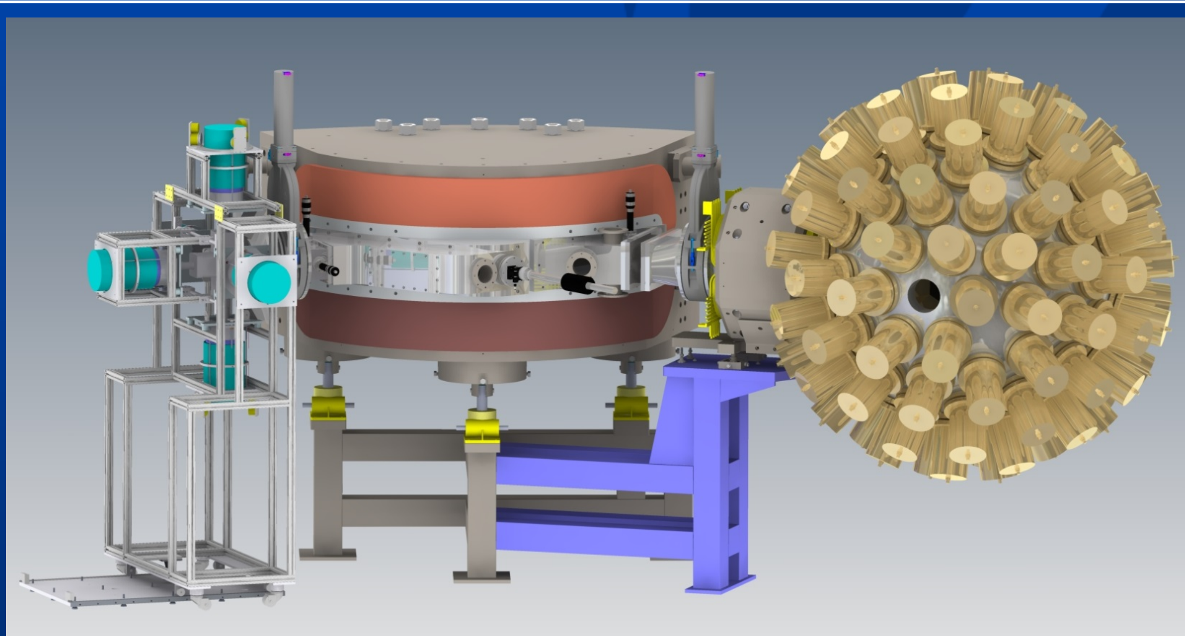
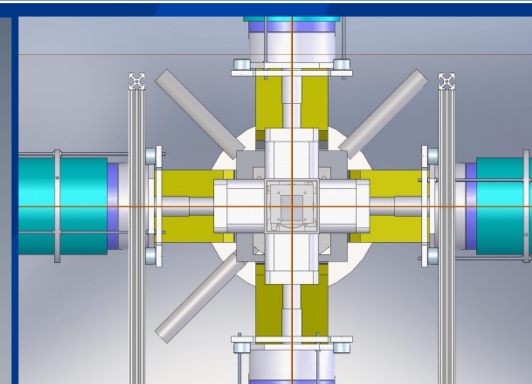
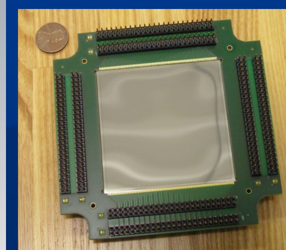
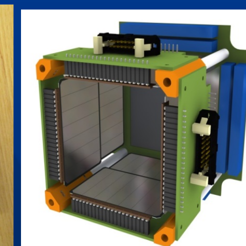


Monte-Carlo simulations

$^{48}Ca + ^{208}Pb \rightarrow ^{254}No + 2n$ E_{beam} = 220 MeV
1 Torr He
5 x 2 mm beam spot
^{254}No angular distribution: σ = 51 mrad
^{48}Ca stripped in C foil: <q> = 17.1
89% of ^{254}No transported to focal plane
71% fall within a 64 x 64 mm^2 DSSD
Beam well separated from residues



AGFA detection systems

Large target-separator distance

prompt γ-ray spectroscopy with 4π Ge array (Gammasphere)

High-granularity fast-implantation decay station

(160X160, 64mmX64mm DSSD, Si tunnel 8 SSSD

Compact focal plane, digital DAQ

efficient decay spectroscopy (X-Array, 5 clovers, box geometry)

Short flight path for short-lived activities

AGFA slides/content courtesy Darek Seweryniak (ANL)

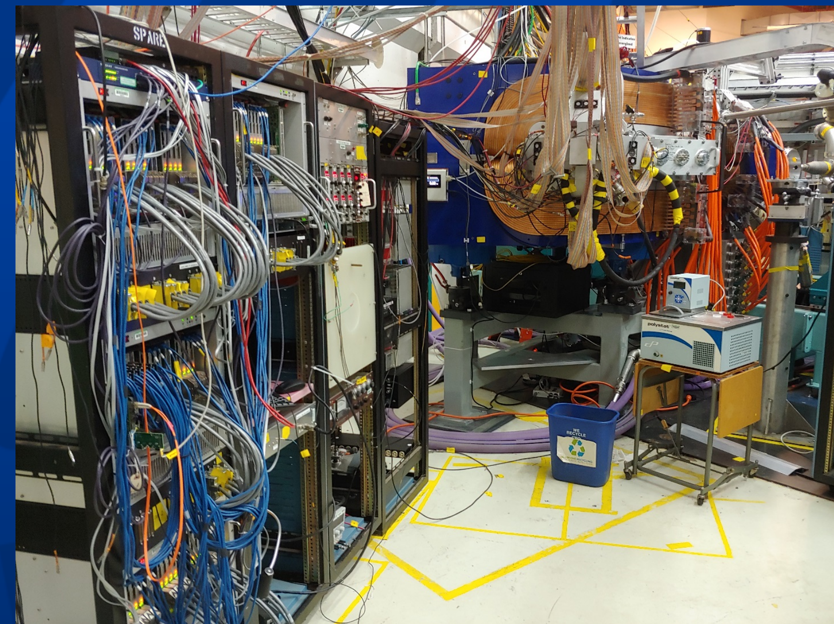
Spectroscopy at Z > 100 (Gammasphere/AGFA)

AGFA slides/content courtesy Darek Seweryniak (ANL)

- In-beam spectroscopy
  - Moments of inertia – deformation landscape, pairing
  - Backbending – high-j orbitals
  - Odd-A, odd-odd nuclei
  - High-K bands (bands feeding K-isomers)
- Entry-point distributions
  - Fission barriers
- K-isomers
  - Single-particle energies
  - Fission hindrance in K-isomers
- Decay spectroscopy
- Precise mass measurements
- Laser spectroscopy
- …

AGFA+Gammasphere

AGFA focal plane



AGFA slides/content courtesy Darek Seweryniak (ANL)

AGFA commissioning

Argonne National Laboratory

K. Auranen, B.B. Back, M.P. Carpenter, B. DiGiovine, T.L. Khoo, A. Korichi, T. Lauritsen, D.H. Potterveld, J. Rohrer, G. Savard, D. Seweryniak, S. Zhu

University of Massachusetts Lowell

P. Chowdhury

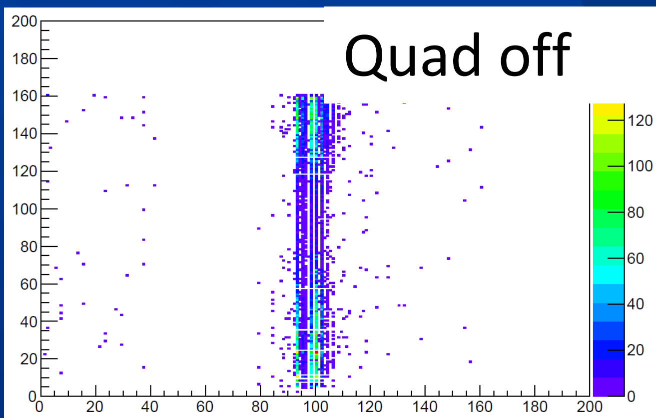
Beam bending/focusing

Effective solid angle

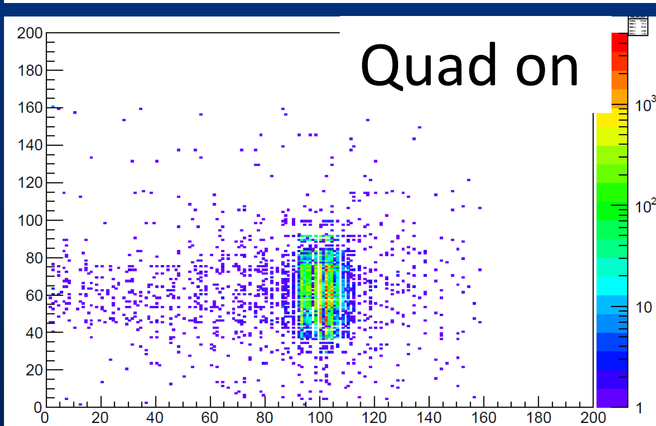
AGFA slides/content courtesy Darek Seweryniak (ANL)

150 MeV $^{48}Ca^{+10}$
Bρ = 1.21 Tm

DSSD Y strip

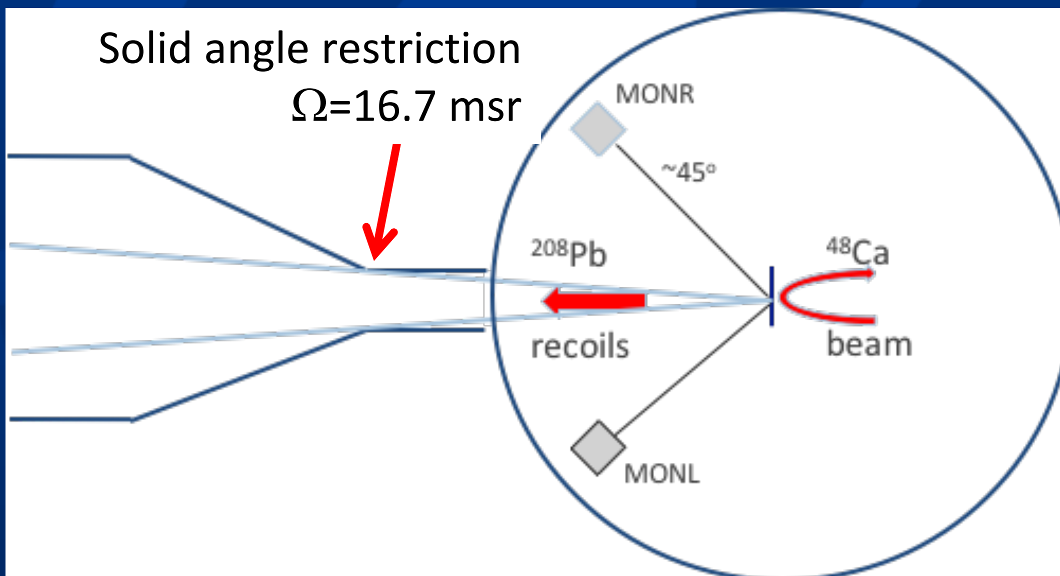


DSSD Y strip



DSSD X strip

150 MeV ^{48}Ca + ^{208}Pb
elastic backscattering

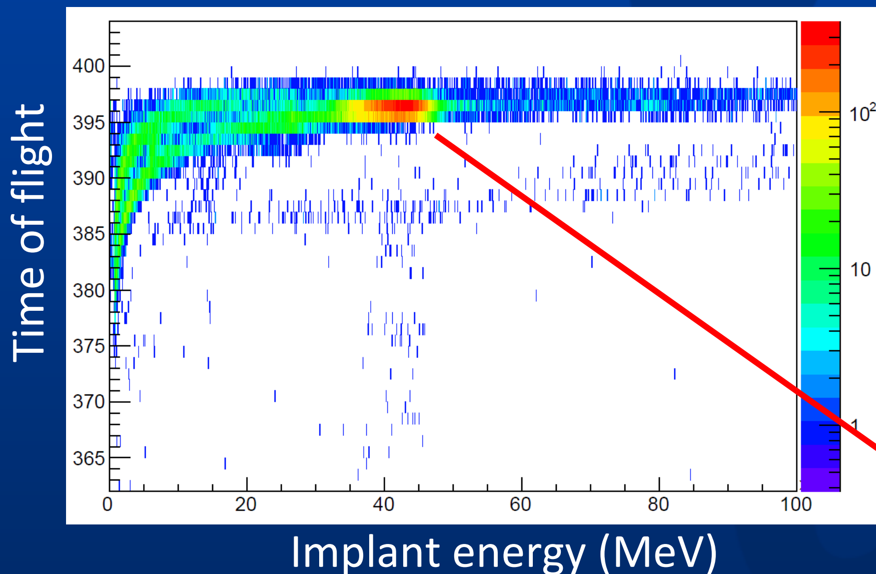


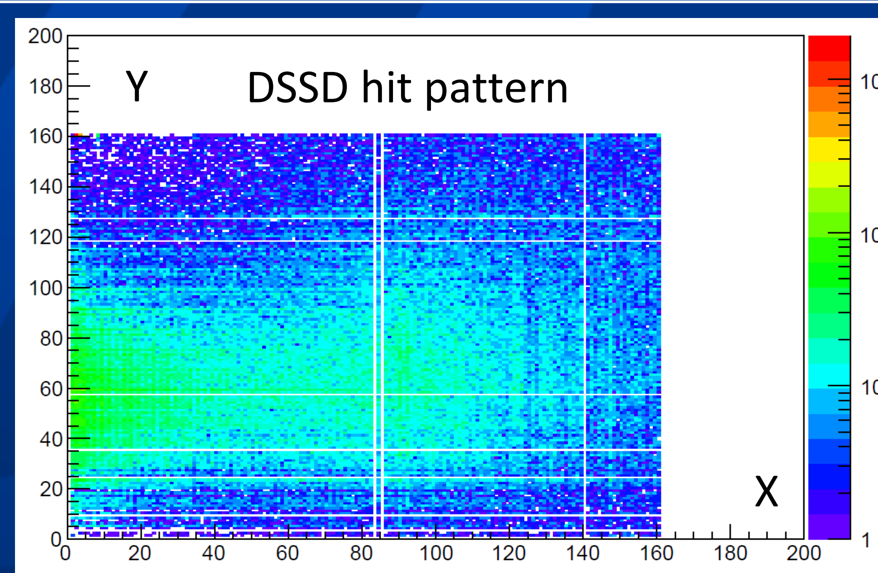
$$\Omega_{AGFA} = \Omega_{mon} \frac{d\sigma_{Ruth}(Ca, \theta_{mon})}{d\sigma_{Ruth}(Pb, \theta_{AGFA})} \frac{N_{DSSD}}{N_{mon}}$$

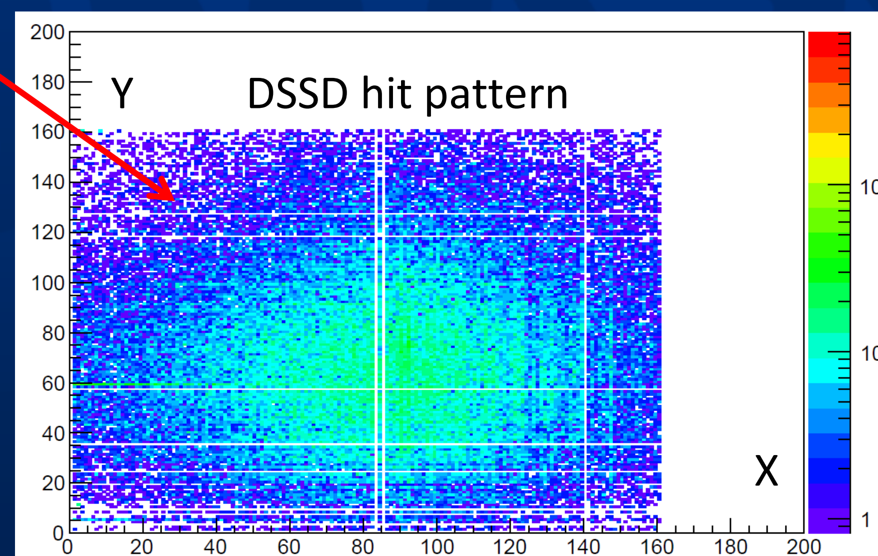
^{208}Pb recoils at the focal plane

AGFA slides/content courtesy Darek Seweryniak (ANL)

p = 0.5 Torr







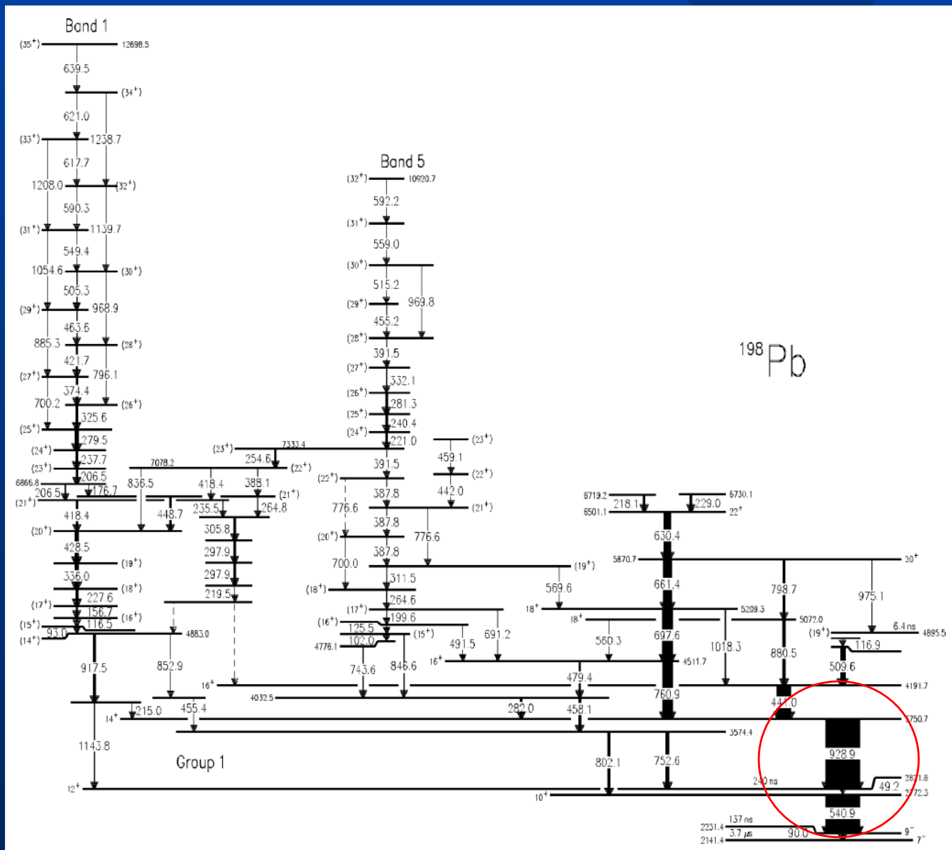
Solid angle ~ 12 msr

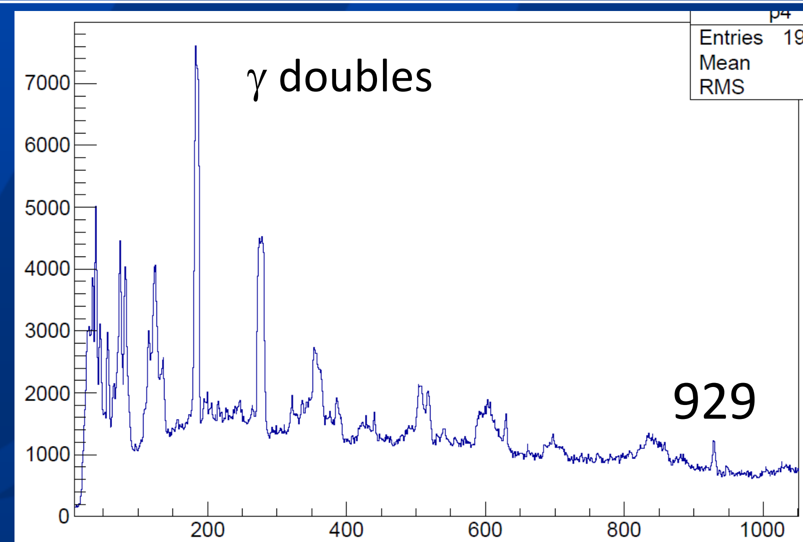
Beam suppression < 10^{-11}

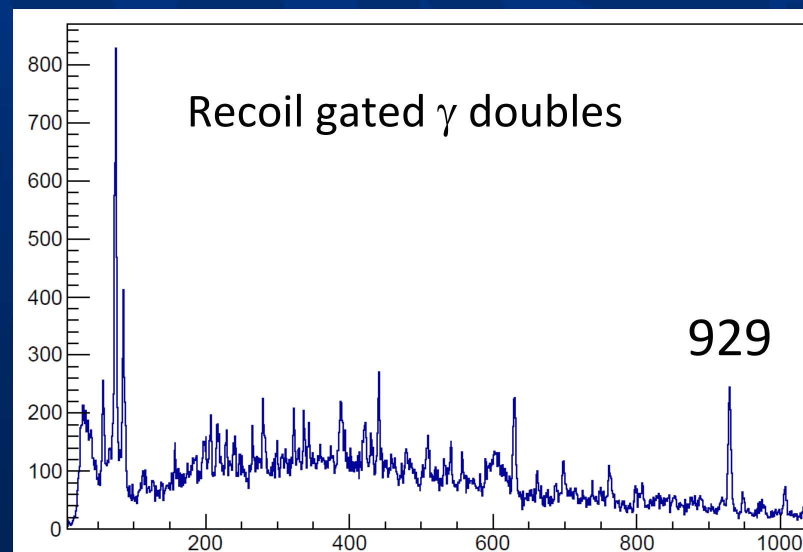
AGFA efficiency from recoil-γ vs γ measurement

AGFA slides/content courtesy Darek Seweryniak (ANL)

$^{154}Sm(^{48}Ca,4n)^{198}Pb$





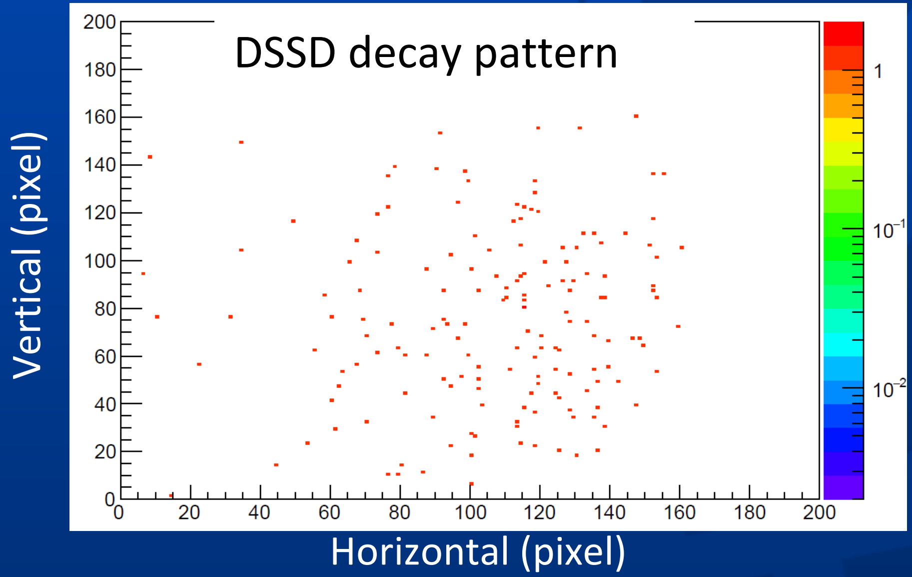


Eγ

Efficiency~40%

Simulation=45%

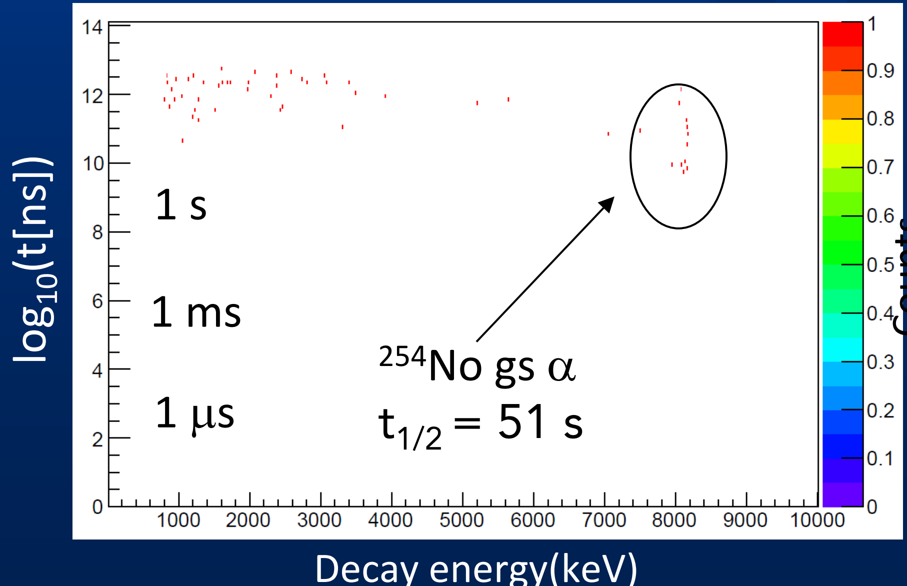
^{254}No α decays

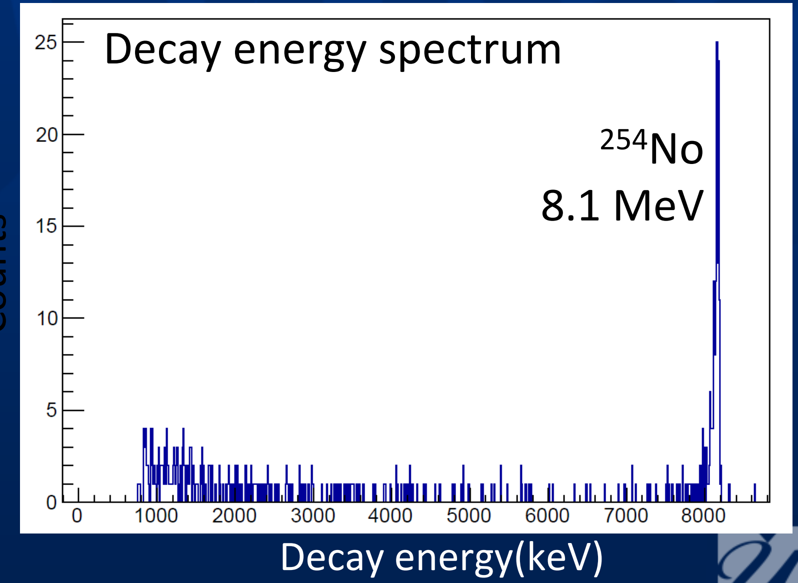


220 MeV ^{48}Ca on ^{208}Pb

Bρ = 2.09 Tm

Simulated transmission (including DSSD mount) = 59%





AGFA slides/content courtesy Darek Seweryniak (ANL)

AGFA approved expts for heavy element spectroscopy

AGFA slides/content courtesy Darek Seweryniak (ANL)

- AGFA Commissioning (Seweryniak, ANL) (50% done)
  - *Remaining tests (Target dist 40 cm; symmetric reactions)*
- ^{254}No spectroscopy (Clark, LBNL) (50% done)
- ^{255}Lr high spin spectroscopy (Korichi, Orsay)
- ^{251}Md spectroscopy (Clark, LBNL)
- ^{254}Rf rotation (Seweryniak, ANL) (Dec 2018)
- ^{255}Lr HK distribution (Khoo, ANL)
- ^{254}No isomer decay (Chowdhury, UMass Lowell)
- ^{255}Lr HK distribution (Khoo, ANL)

Stay tuned!

Thank you!