Proposal RIKEN (I)
Mass region A=110-125

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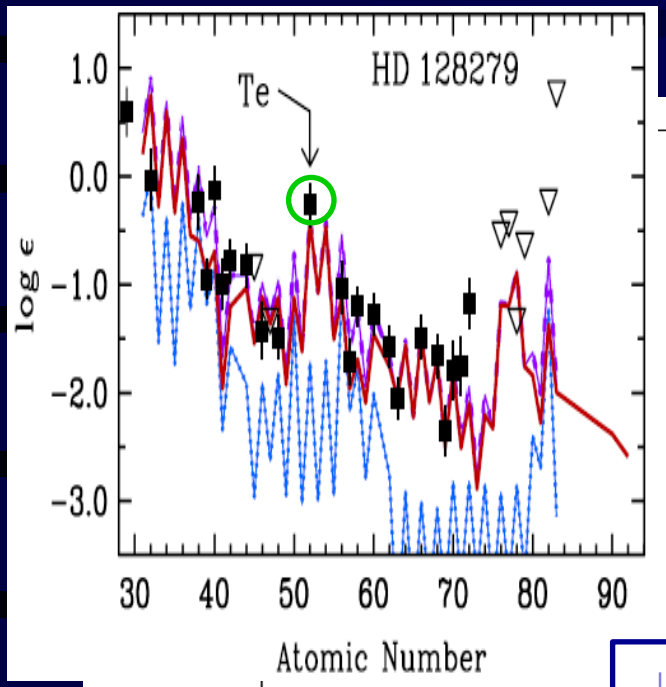
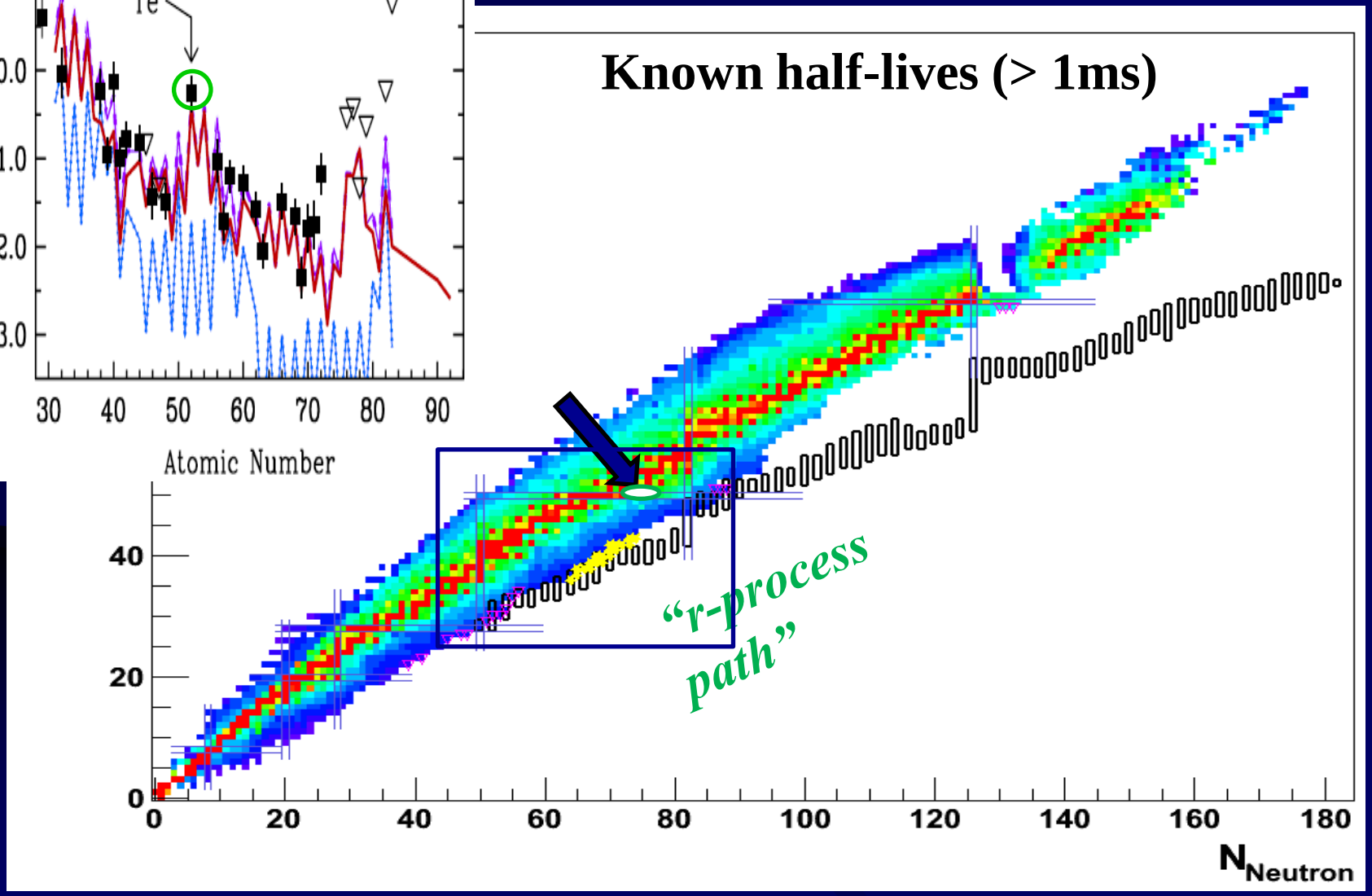
(RIKEN Nishina Center)

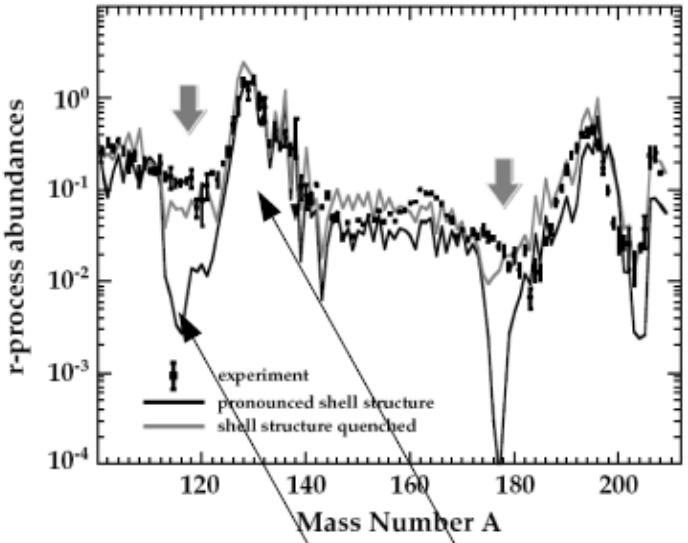
Motivation

I.U.Roederer, ApJ 747, L8 (2012)





2nd r-process peak and path around Z = 38~46

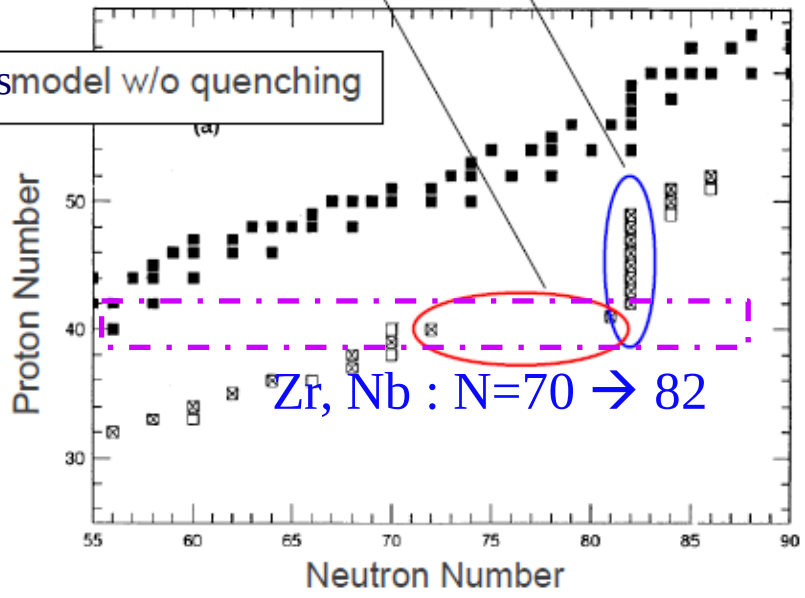


Profound astrophysical impact of:

- Quenching of the N=82 shell gap
  (need to study region around $^{128}Pd_{82}$)
- appearance of the a N=70 sub-shell closure
  (need to study region around $^{110}Zr_{70}$)

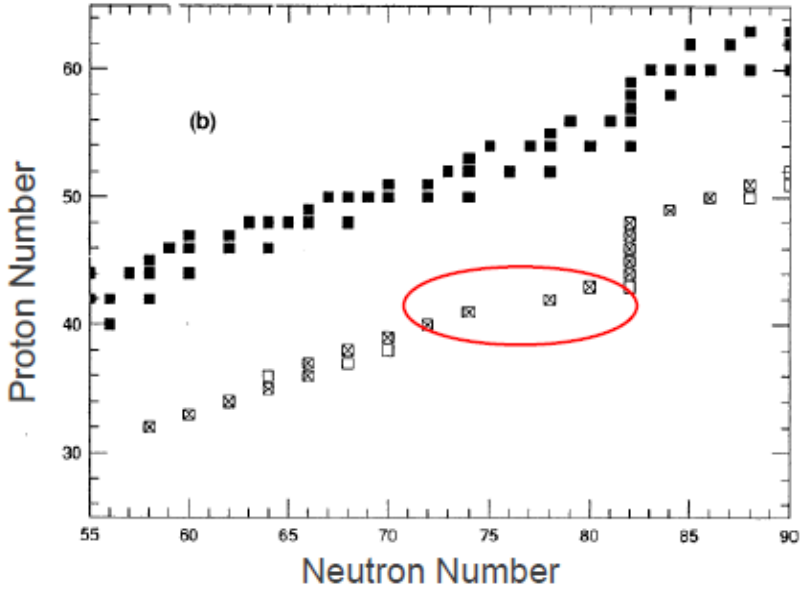
K.-L.Kratz (1993)

Massmodel w/o quenching



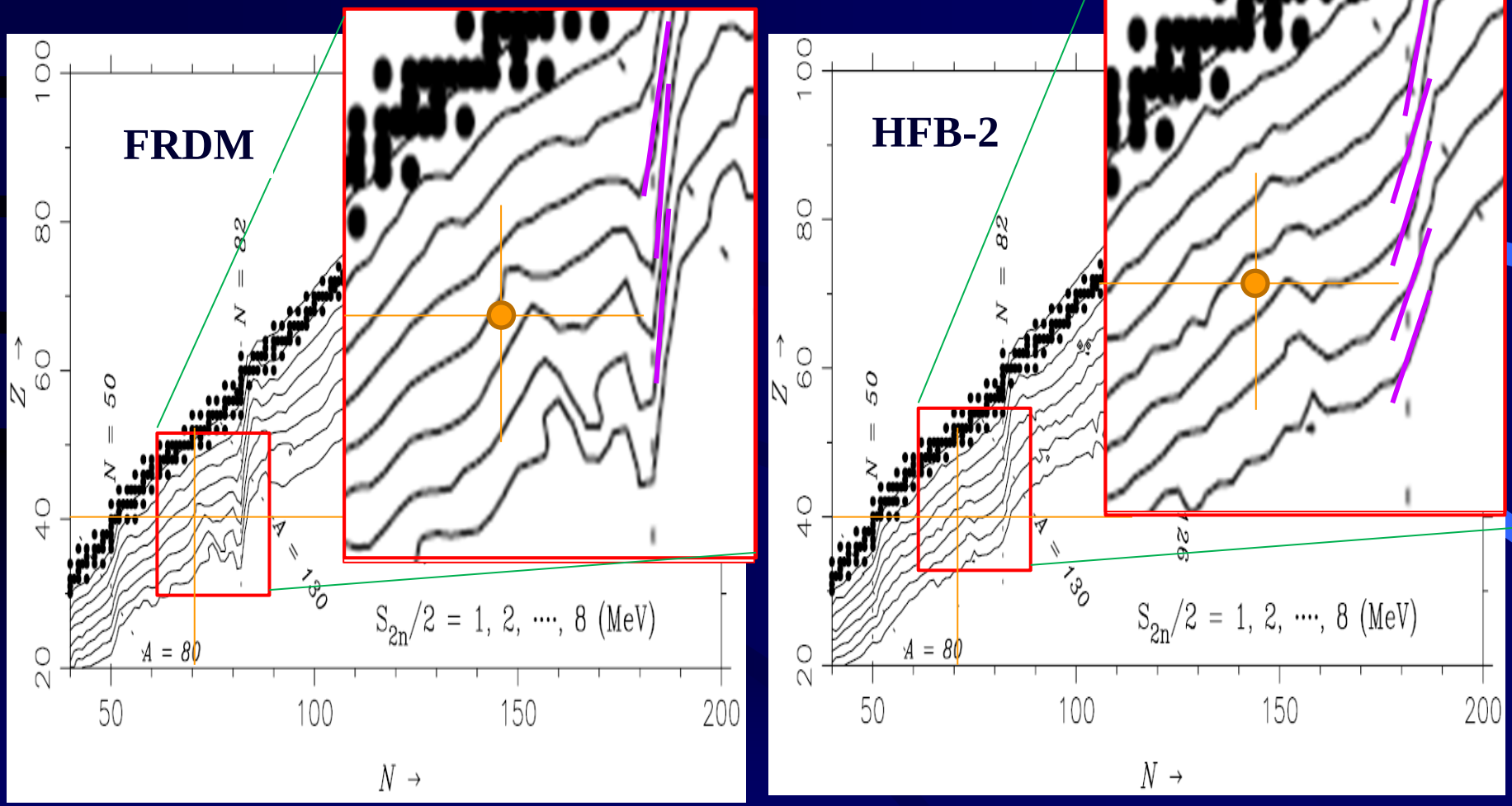
Zr, Nb : N=70 → 82

Mass model w/ quenching



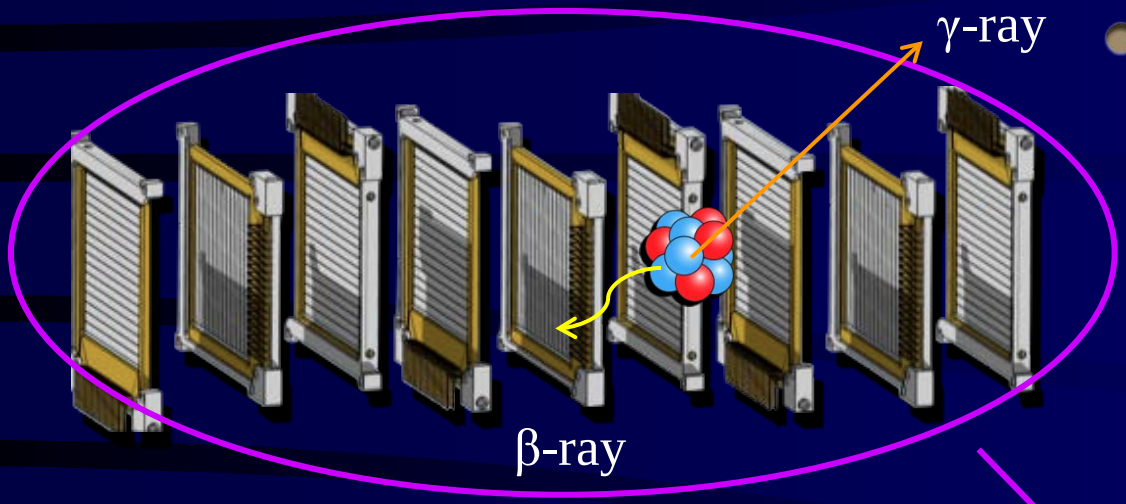
Neutron separation energies around Mass A=110-125

Location of r-process path depends on S_n (2 – 3 MeV)
(n,γ)-(γ,n) competition

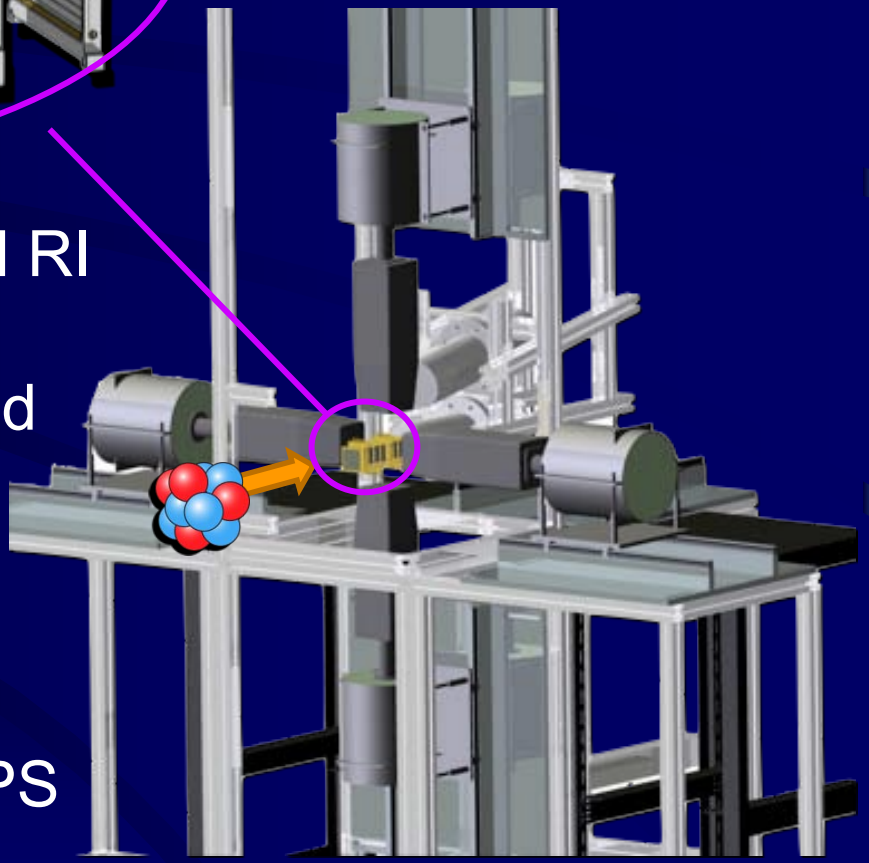


S.Wanajo, S.Goriely, M.Samyn, N.Itoh, Astro.J 606 (2004).

Experimental Setup in 2009



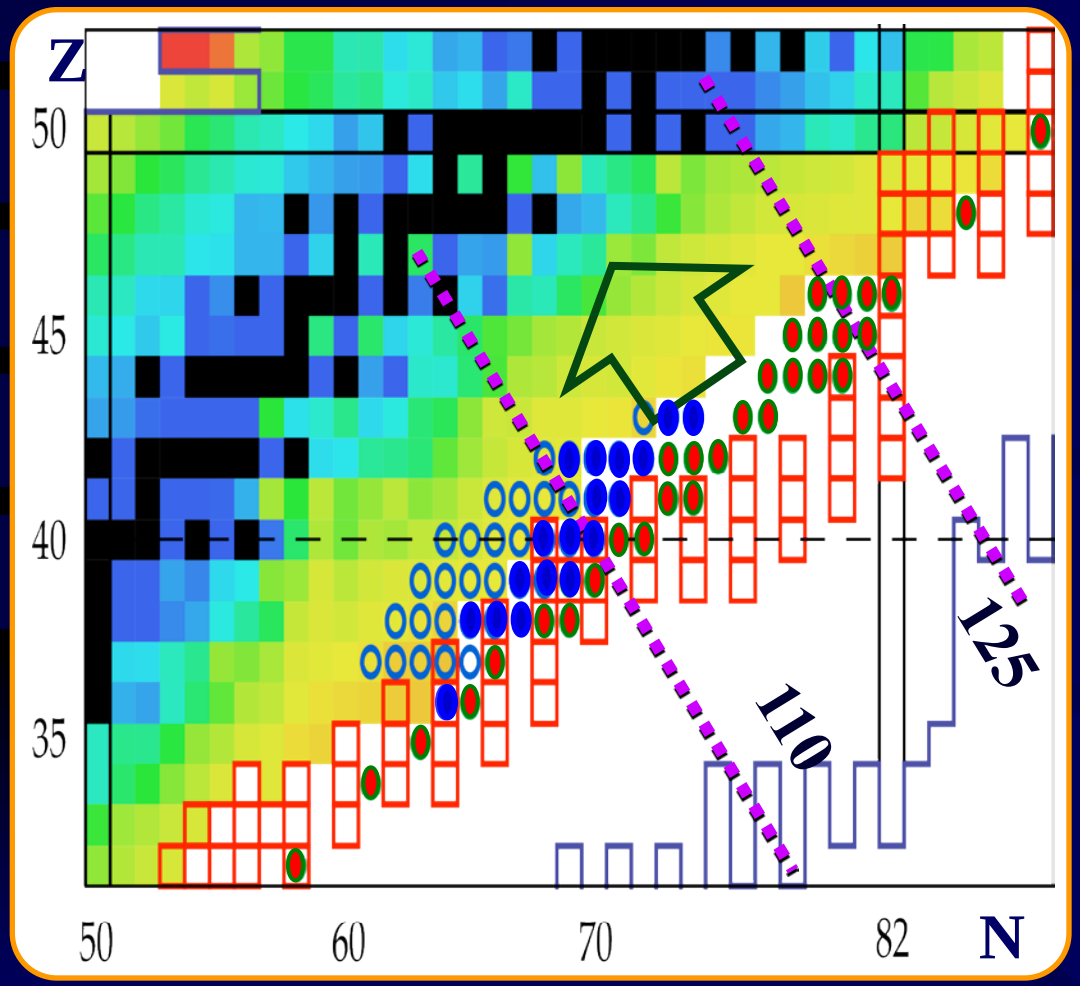
- **RI & β-ray detection**
  - **9 DSSDs (50 x 50 x 1 mm^3)**
  - **16 x 16 strips**
  - **~ 2000 pixels in total**

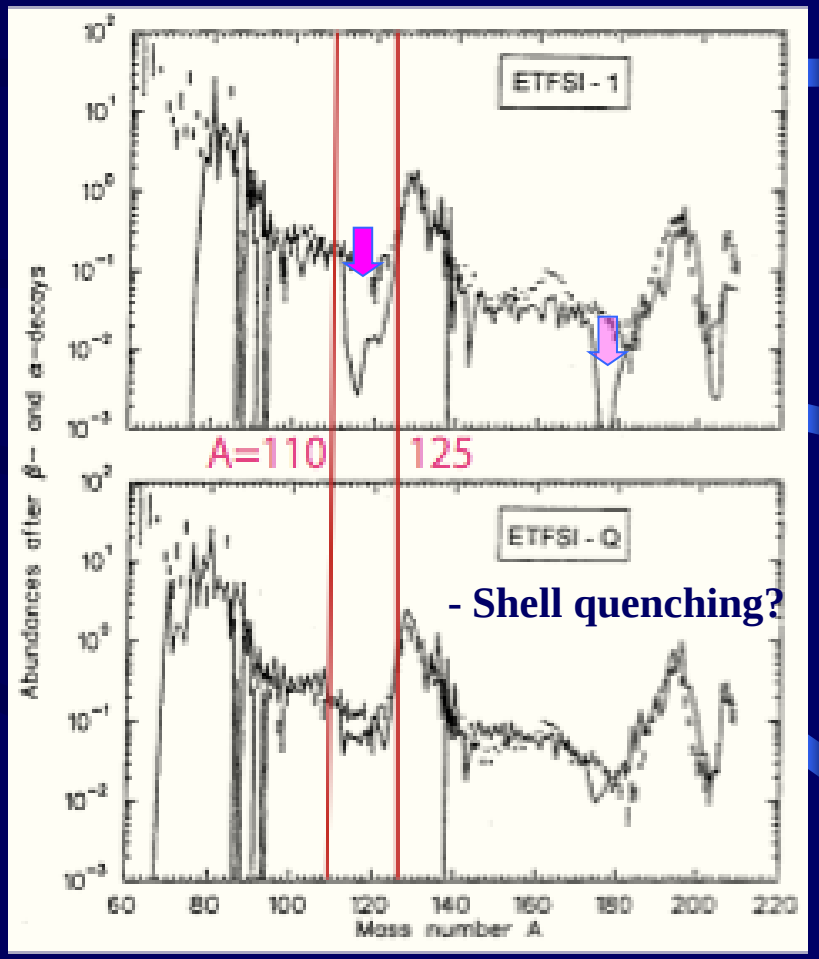


- The implantation of an identified RI is associated with the following β-decay events that are detected in the same DSSSD pixel

- ΔE-TOF-Bρ method using the focal plane detectors in BigRIPS

R-process Abundance around 2nd peak





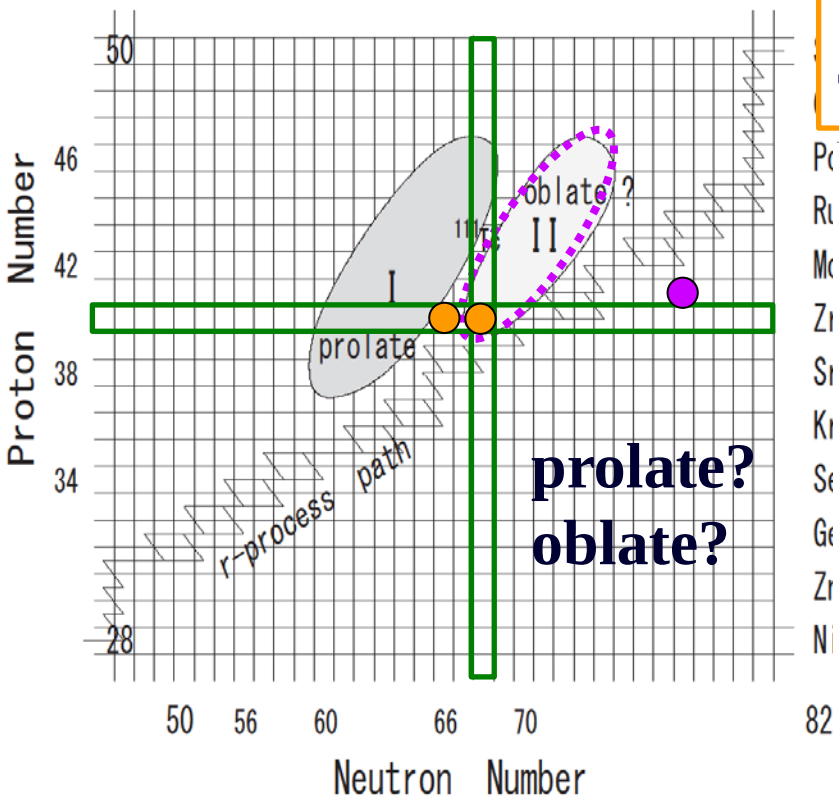
$$1/T_{1/2} = \sum_{E_i \geq 0}^{E_i \leq Q_\beta} S_\beta(E_i) \times f(Z, Q_\beta - E_i);$$

$$f \sim (Q_\beta - E_i)^5$$

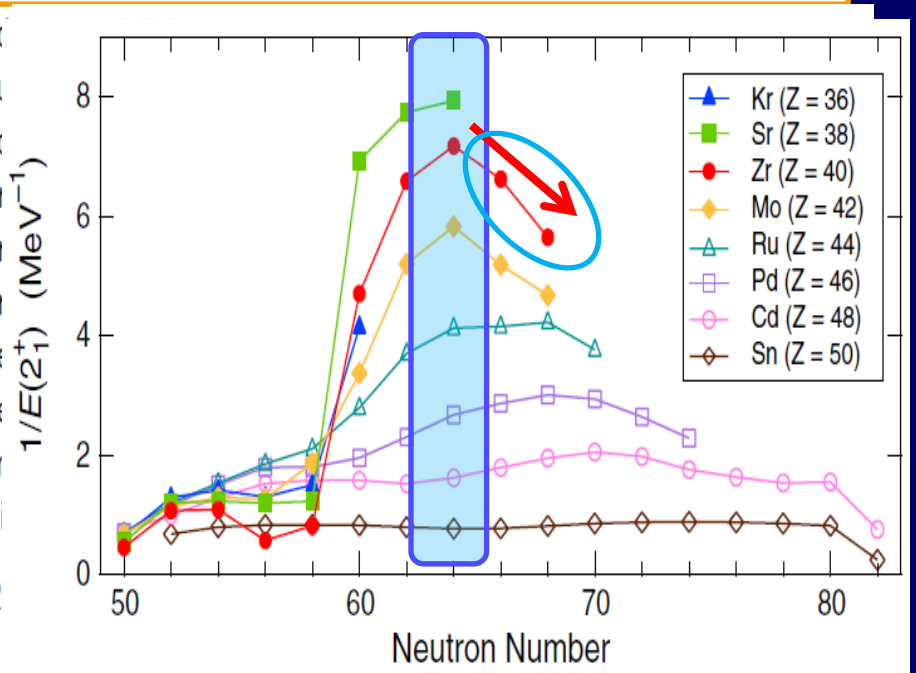
Deformation

- Phys. Lett. B 696 (2011) H.Watanabe
  Oblate shape isomer for ^{109}Nb?

W.Urban, et al., EPJA 20 (2004), EPJA24 (2005)



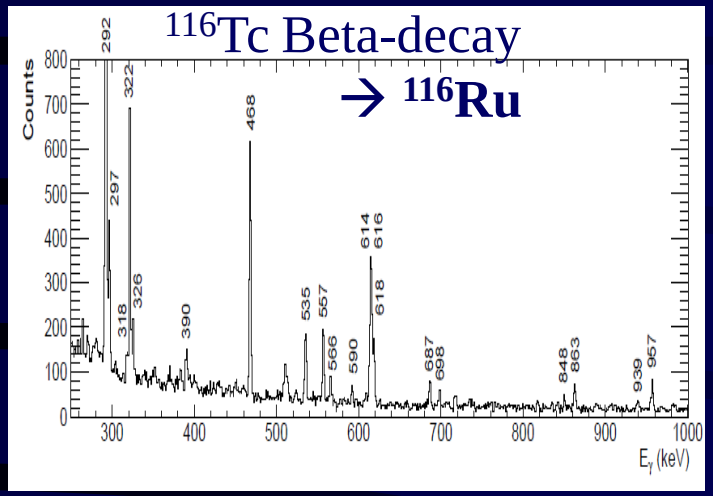
Structural Evolution in ^{106}Zr and ^{108}Zr
T.Sumikama, et al., PRL 106 (2011)

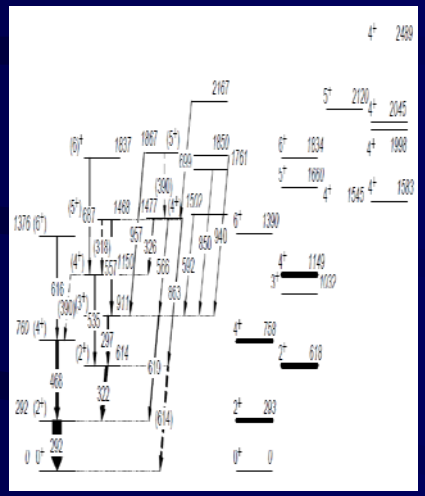


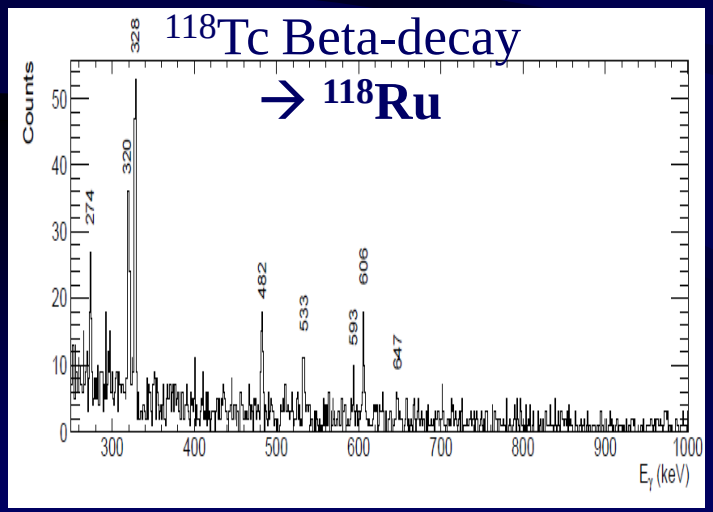
- Beta-delayed gamma : ^{106}Y → ^{106}Zr
- Isomeric states : ^{108}Zr

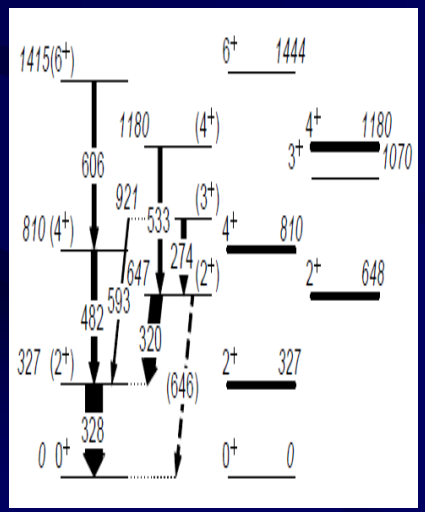
Shape evolution in $^{116,\ 118}$Ru (EURICA)

Spokesperson: G.Lorusso,H,Watanabe

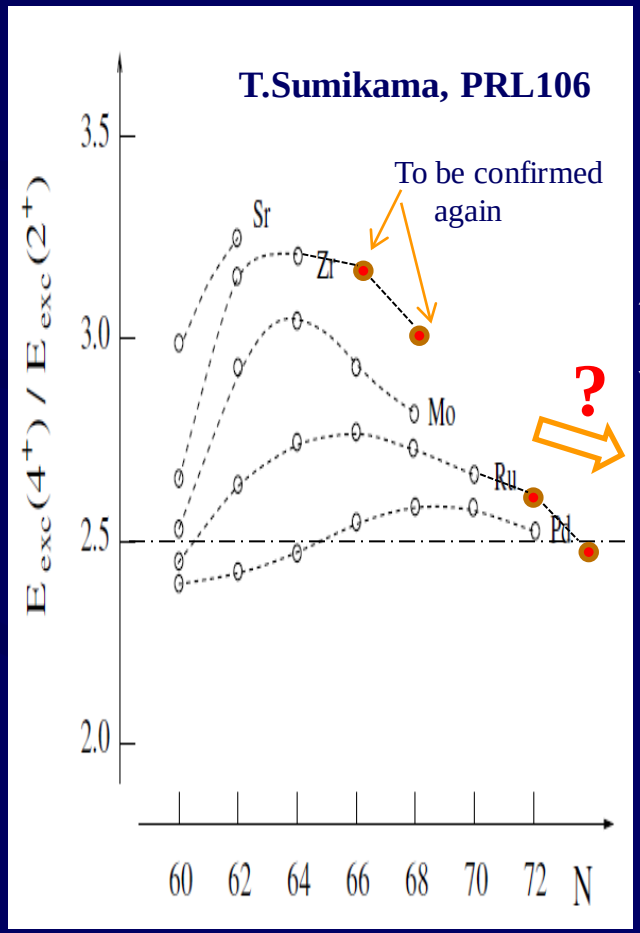








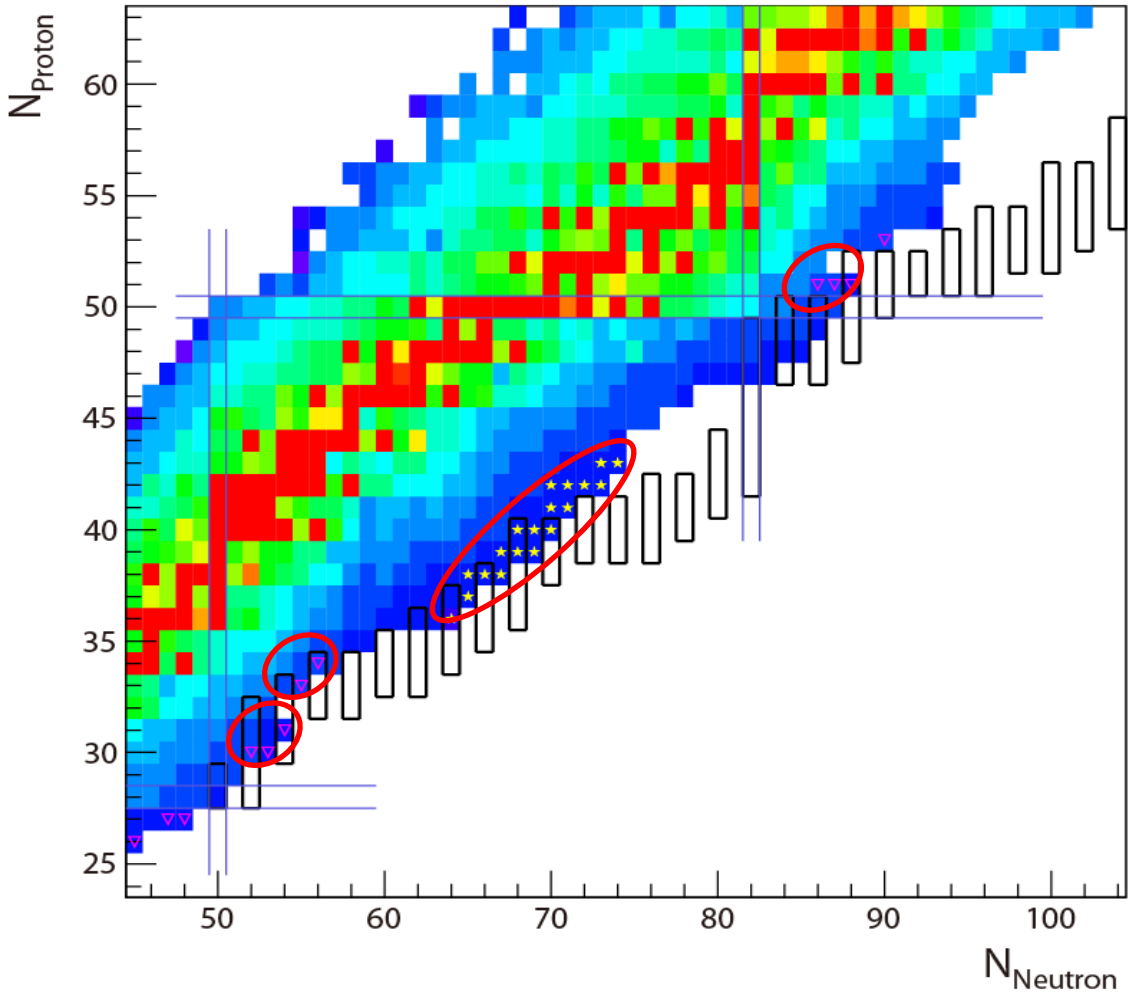
P.-A. Söderström, et al.
Phys. Rev. C, accepted.



Urban, EPJ A 20, 381 (2004)

Analysis is in progress in other isotopes around ^{110}Zr region

Beta-decay half-lives since 2007



2011 .. O.Arndt,
PRC 84,
3$T_{1/2}$ (ISOLDE)

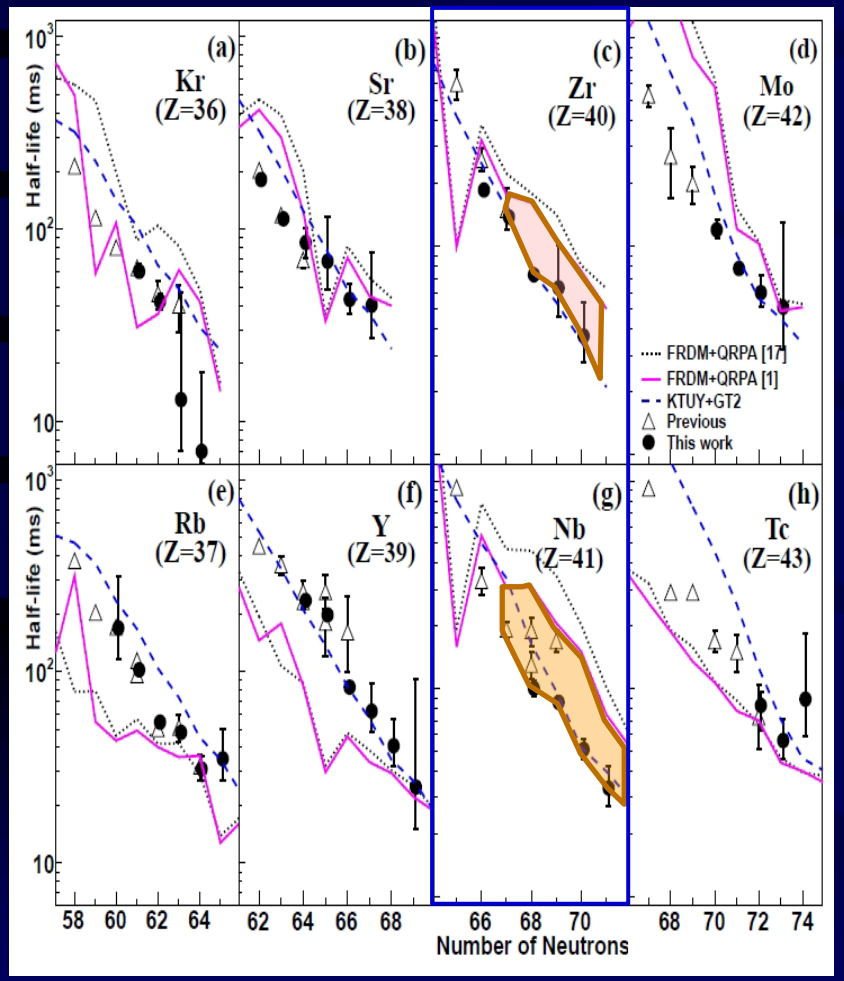
2011 .. SN,
PRL 106,
18 $T_{1/2}$ (RIBF)

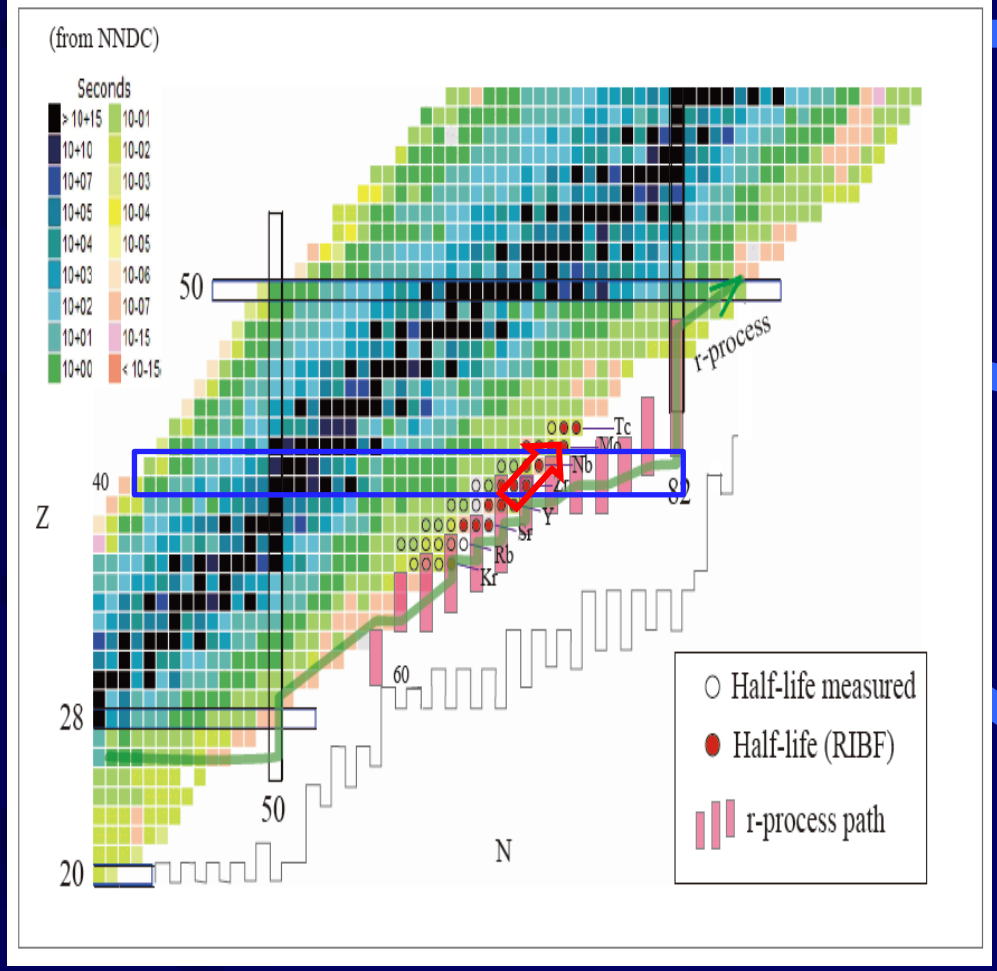
2012 .. M.Quinn,
PRC 85,
2 $T_{1/2}$ (MSU)

2012 .. M.Madurga,
PRL 109 ,
3 $T_{1/2}$ (ORNL)

2013 … C.Mazzocchi
1 $T_{1/2}$ PRC (ORNL)

Decay Experiment in 2009

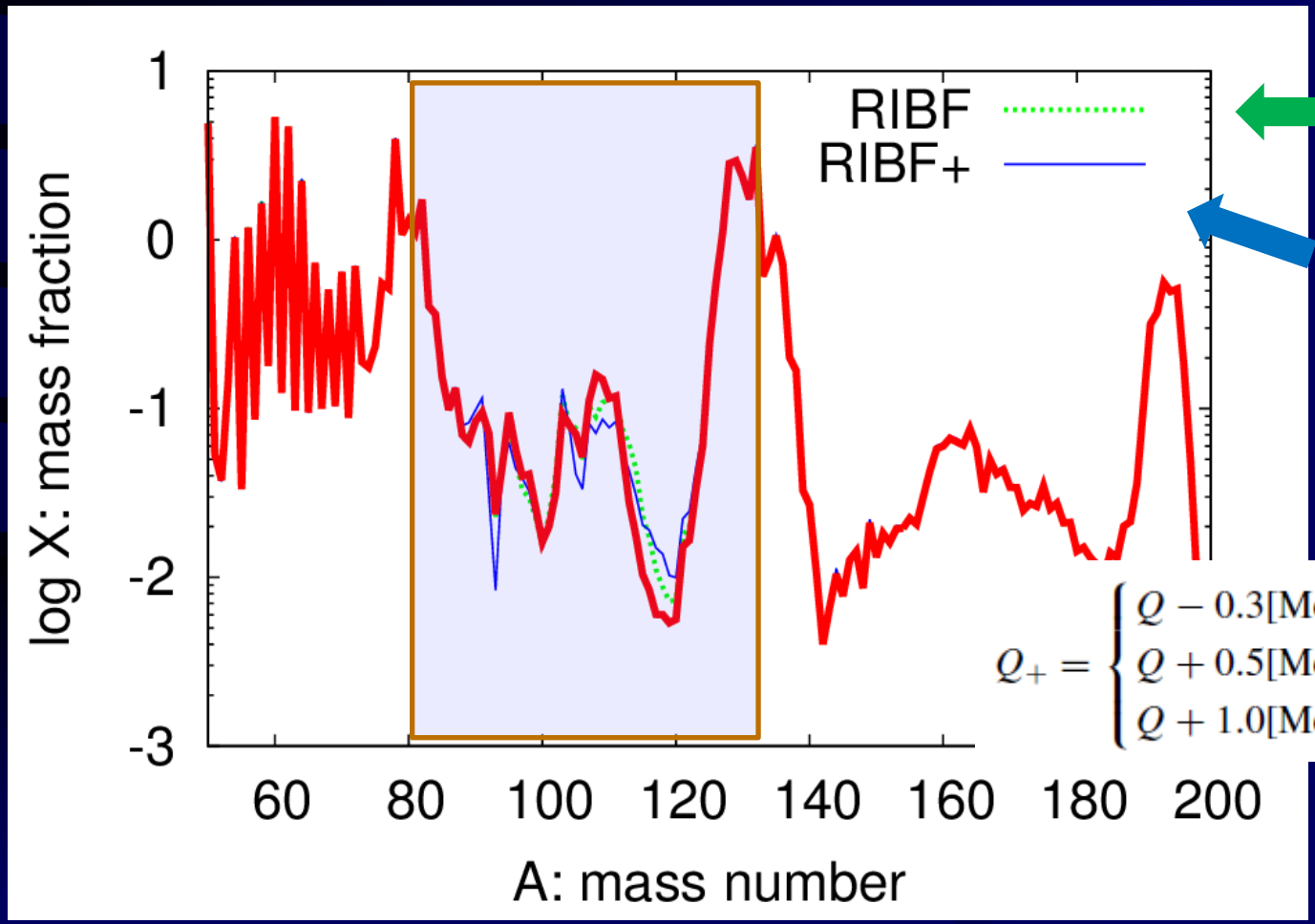




Zr and Nb decay faster than expected by FRDM+QRPA ($T_{1/2}$: 1/2 ~ 1/3)

RIBF data → Impact to r-process abundance

Nobuya Nishimura, T.Kajino, G.Mathew, SN, T.Suzuki, PRC 85 (2012)



38 Half-lives from RIBF

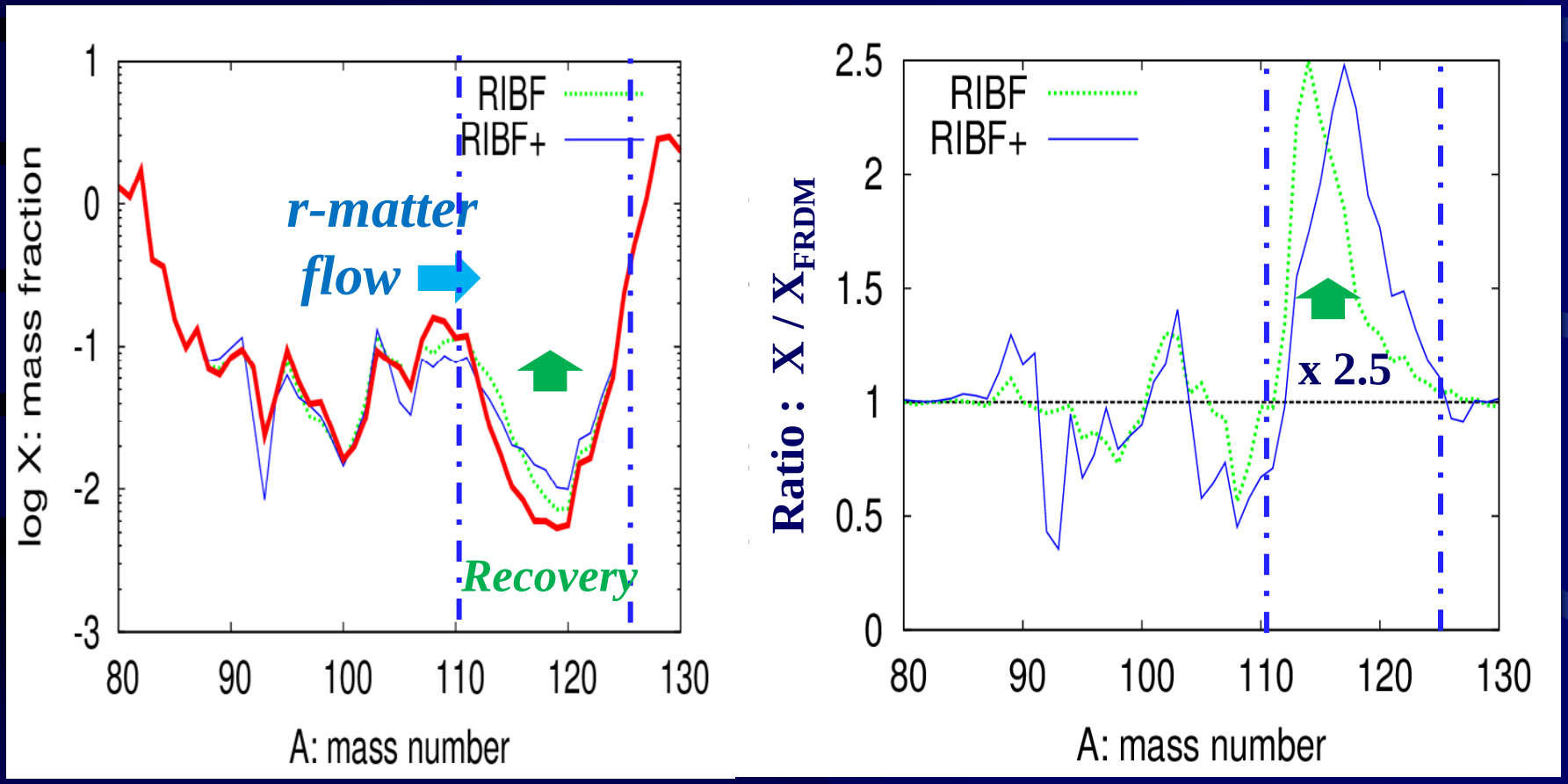
38 Half-lives + ΔQbeta from RIBF

$$Q_+ = \begin{cases} Q - 0.3[\mathrm{MeV}] & (97 \leqslant A \leqslant 103) \\ Q + 0.5[\mathrm{MeV}] & (104 \leqslant A \leqslant 107) \\ Q + 1.0[\mathrm{MeV}] & (108 \leqslant A \leqslant 115) \end{cases}$$

MHD supernova explosion model

RIBF data → Impact to r-process abundance

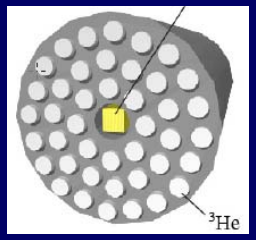
Nobuya Nishimura, T.Kajino, G.Mathew, SN, T.Suzuki, PRC 85 (2012)



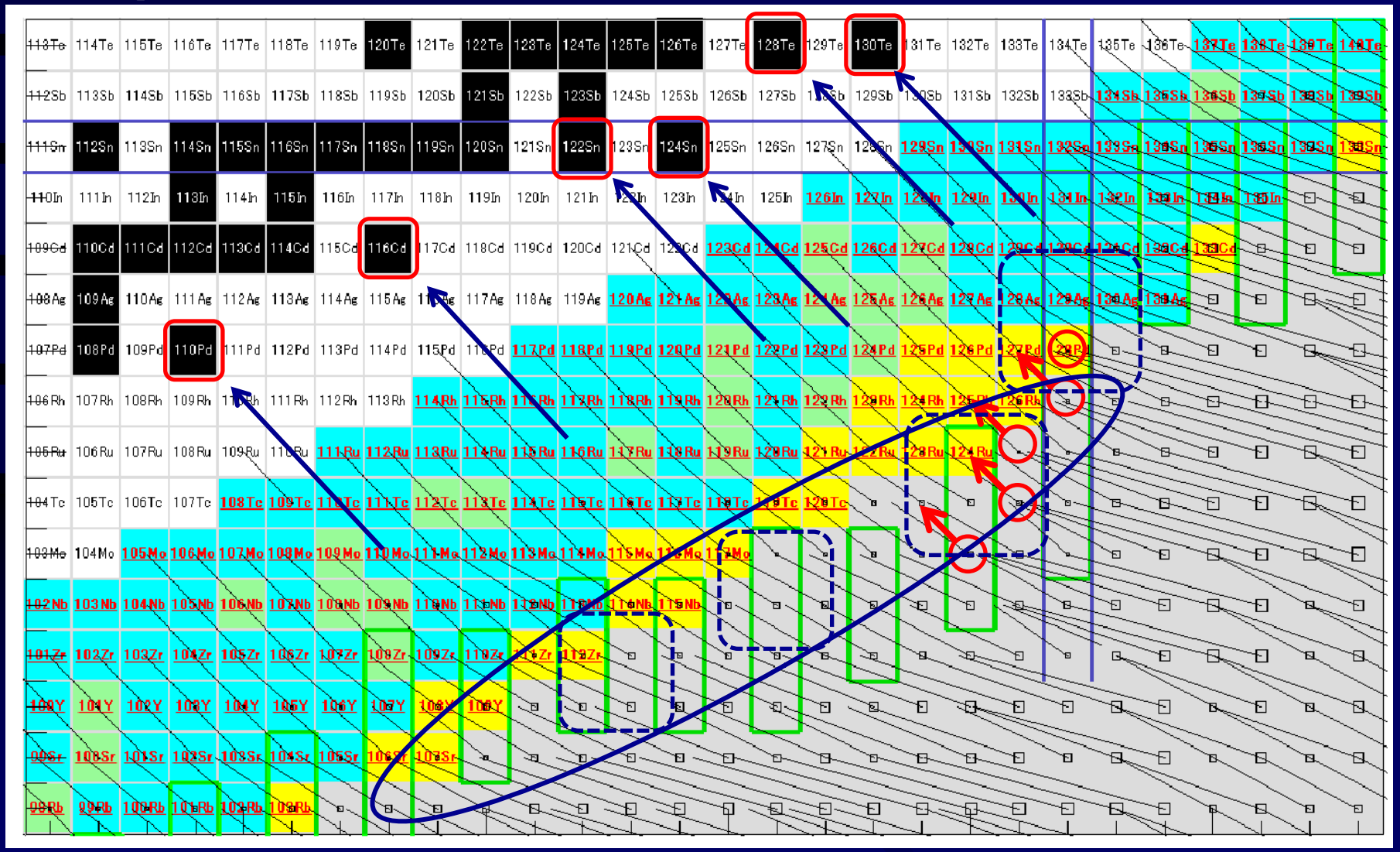
The calculated r-process abundance is improved by factor of x 2.5.
But, there is still issue remaining in mass A=110 – 125!

Expected Beta-decay Flow

(Beta-delayed Neutron Emission)



For example, FRDM+QRPA (P.Moller)



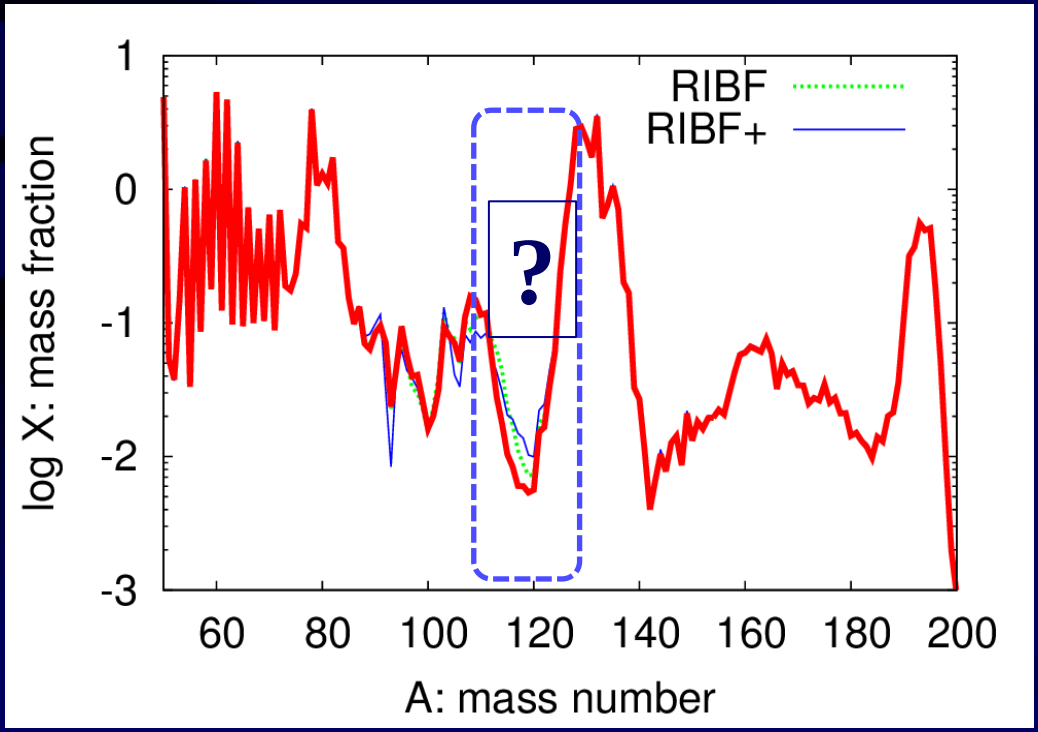
Summary

- Mysteries of the r-process abundance around 2nd peak.
  - Mass A = 110-125

  → Influence of Larger / smaller neutron emission ?

  → Multi neutron emission Pn,P2n,.. ?

  → Mass ? and Half-lives?



Do we have problems in

Nuclear theory?

or

Nuclear astrophysics

(or both…)