Production and β half lives of heavy neutron-rich nuclei approaching the r-process path at N=126

Pre-SPEC decay physics workshop
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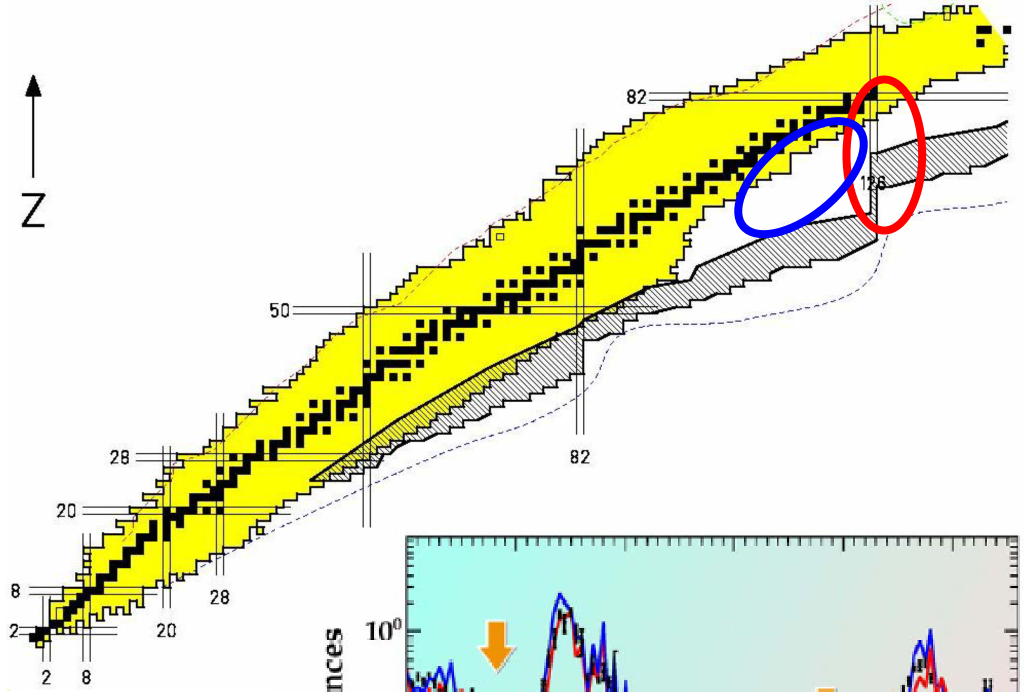
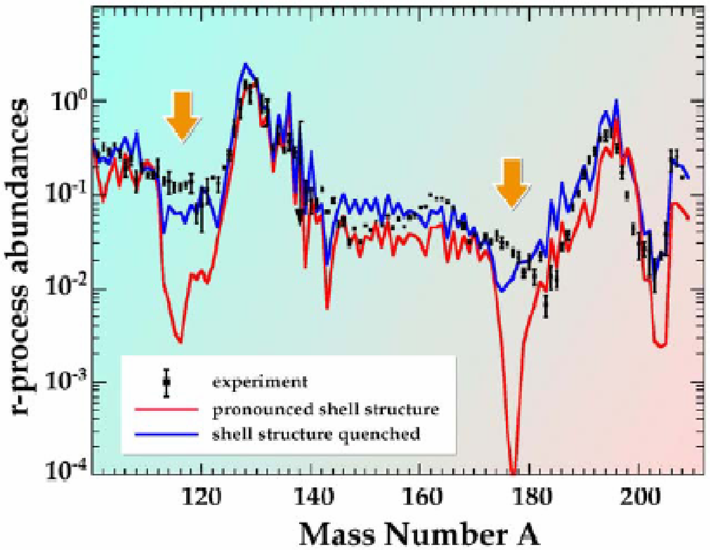
Nuclear data for the r process

Ground state properties of nuclei involved in the r pocess such us β half lives or masses are required for the full understanding of this nucleoshynthesis mechanism.

Present RIB facilities made possible to produce light and medium-mass neutron-rich nuclei at the r-process path. However, the region around the A~195 waiting point is out of our reach.

The waiting point at A~195 defines the abundance of the heaviest elements in the Universe. But this is also an interesting region for nuclear structure because of the interplay between shell closure and deformation effects.



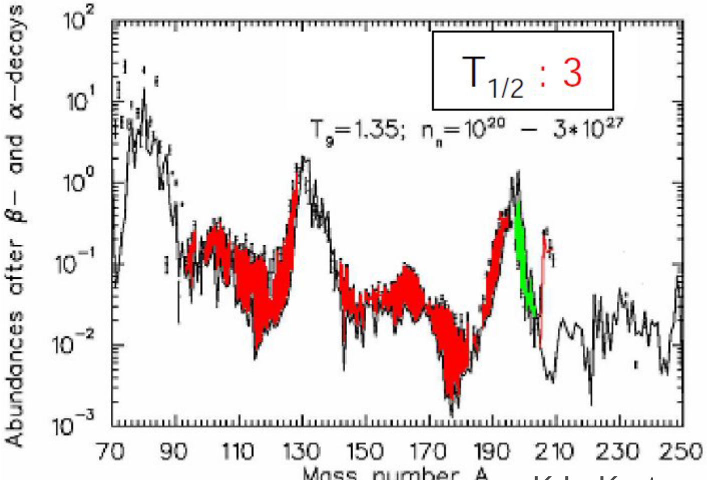


Nucler data for the r process

The β half lives of r-process nuclei along the N=126 shell define the role of the A~195 waiting point in the r process:

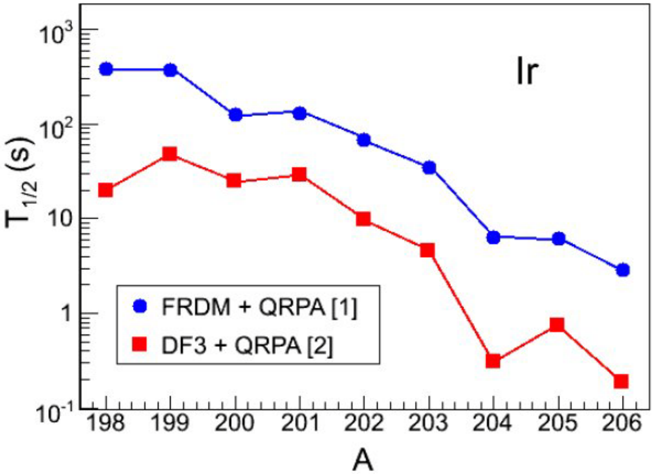
✓ Matter flow through the N=126 bottleneck region fixing the abundance pattern of the heaviest elements in the Universe.

✓ The velocity of synthesis of these heavy elements: r-process end point, r-process cycling.



K.L. Kratz

Present theoretical predictions of the β half lives of r process nuclei close or at N=126 are rather discordant.



[1] P. Möller, et al. PRC 67, 055802 (2003)
[2] I. N. Borzov PRC 67, 025802 (2003)

It is our goal to investigate:

- the production of heavy neutron-rich nuclei
- determine their β half lives

Outline

Pre-RISING S227 (2001-2003):

- production of heavy neutron-rich nuclei in fragmentation reactions induced by ^{238}U and ^{208}Pb projectiles

- first half-lives measurements using ion-β position-time correlations with an active stopper

RISING S312 (2007):

- half-lives measurements using ion-$\beta-\gamma$ position-time correlations with an active stopper+RISING

- low lying excited states

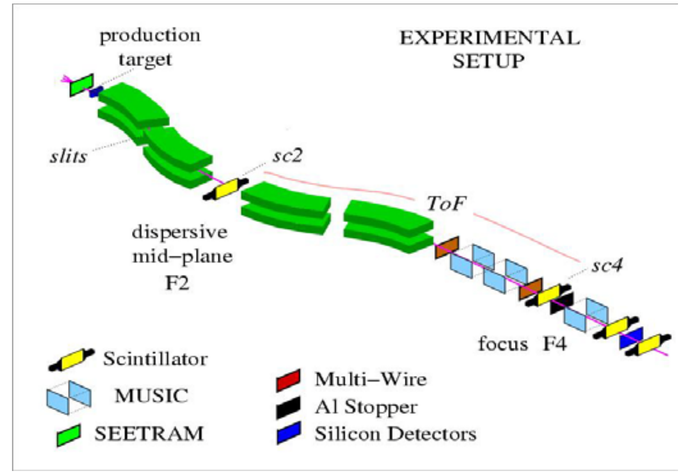
Pre-SPEC:

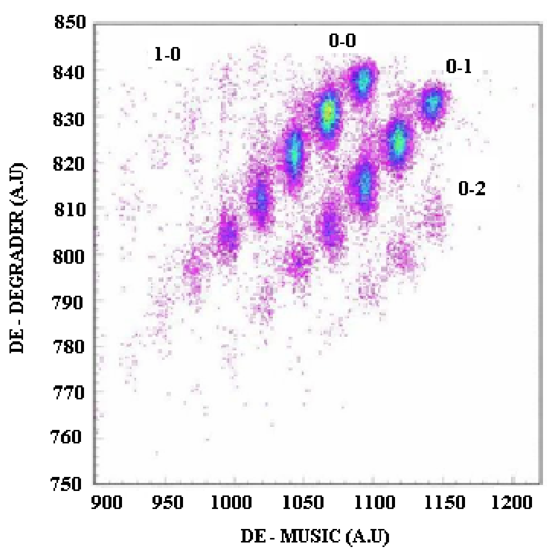
- few ideas on new half lives measurements and characterization of β-decays.

Production of heavy neutron-rich nuclei

Experimental technique: SIS18+FRS (GSI)

^{238}U, ^{208}Pb(1 A GeV)+Be (10^7 ions/s)

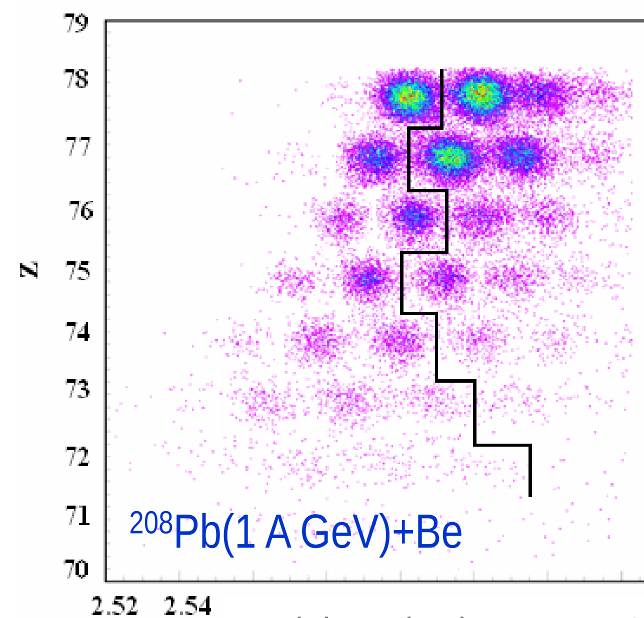




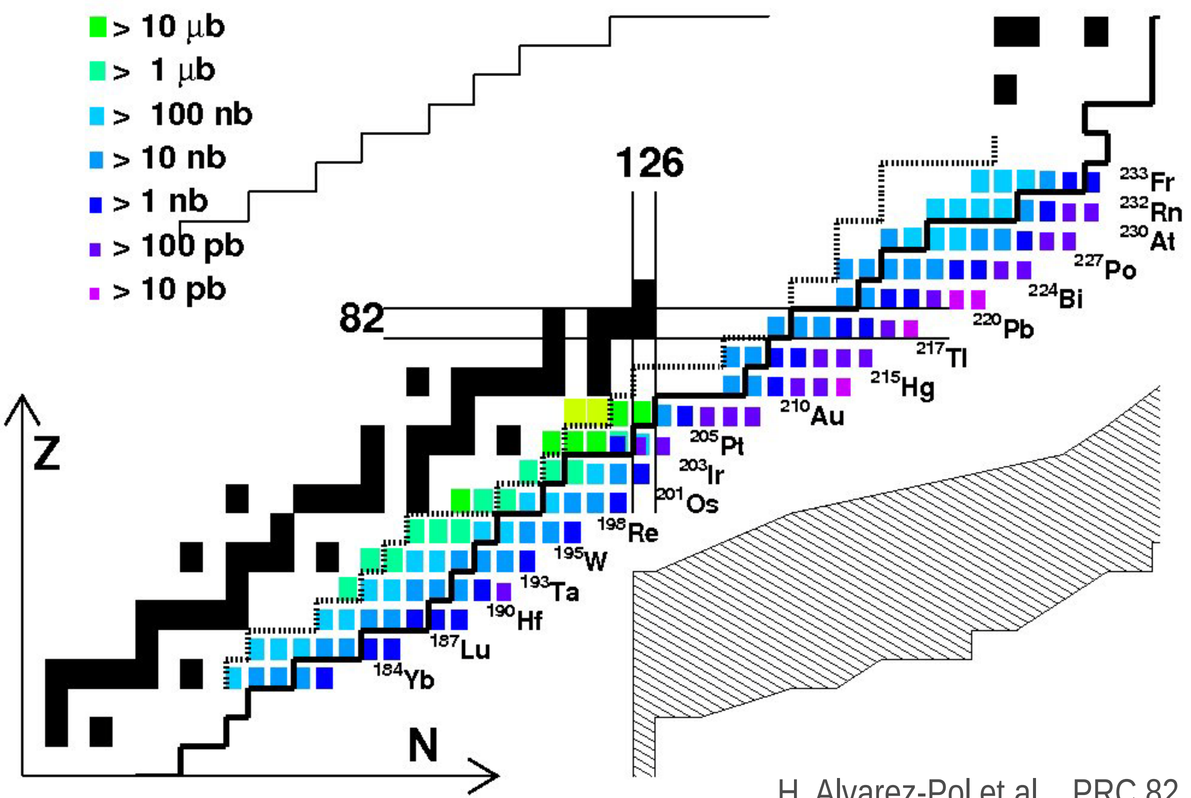
✓ One of the challenges of the experiment was the identification of charge states

→ Beam energy (< 700 A MeV)

→ FRS+energy degrader



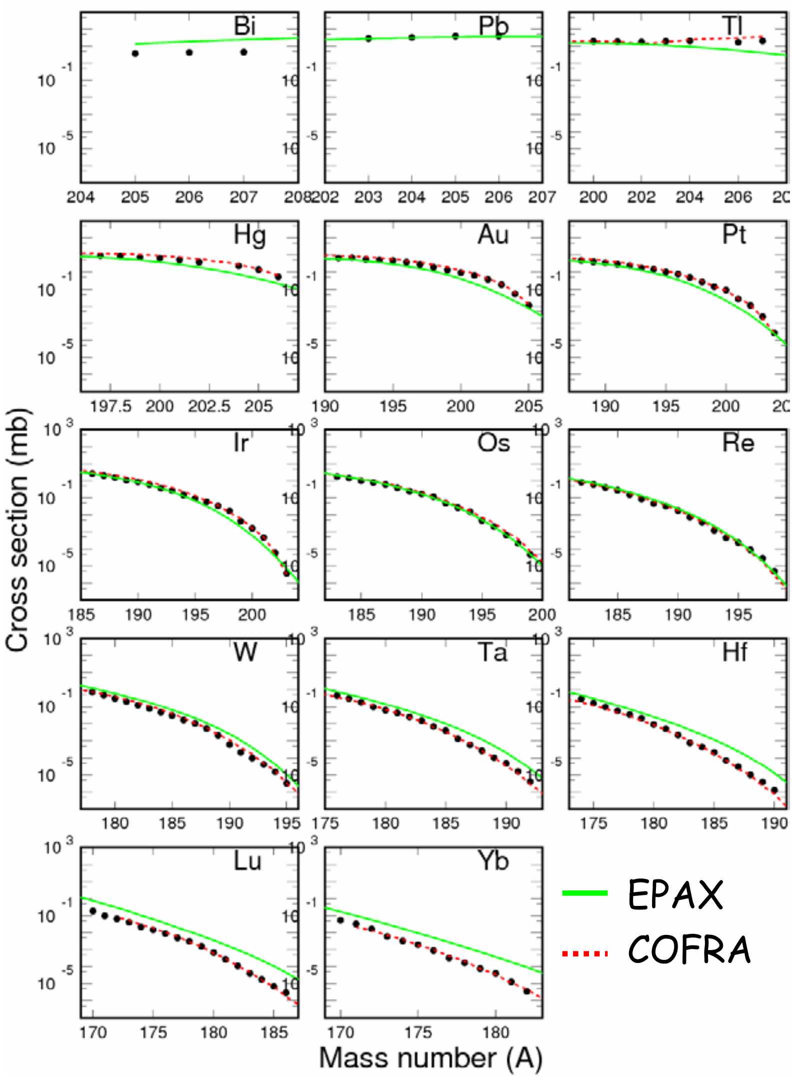
Production of heavy neutron-rich nuclei

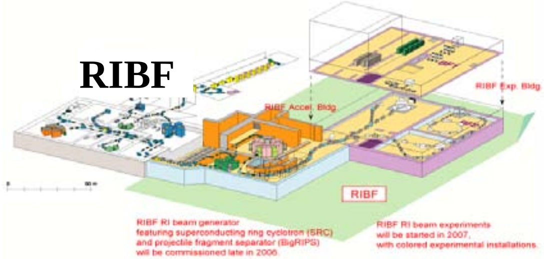


H. Alvarez-Pol et al.., PRC 82, 041602 (2010)

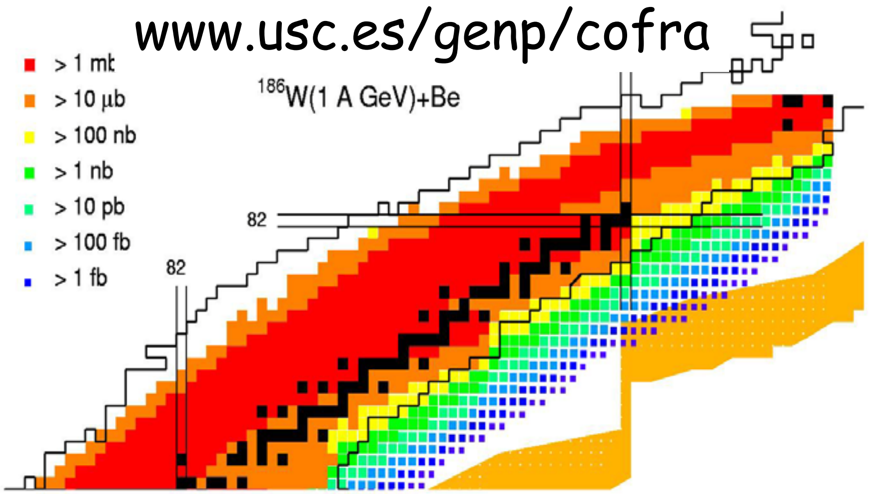
75 heavy neutron-rich nuclei have been identified for the first time.

Production of heavy neutron-rich nuclei



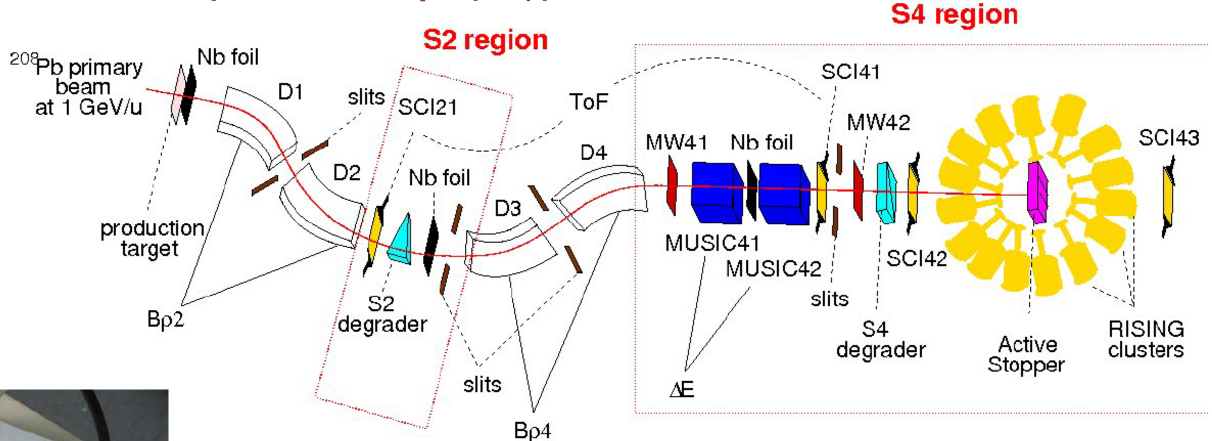


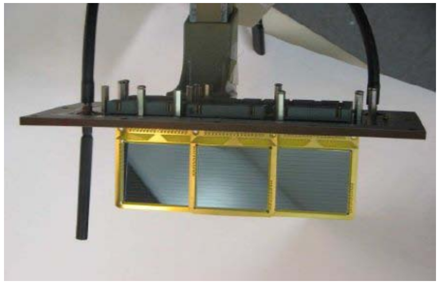
www.usc.es/genp/cofra



β half lives

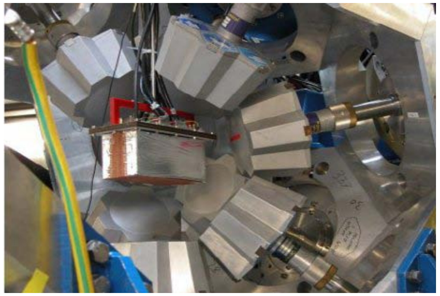
Experimental technique: ion – β (– γ) correlations





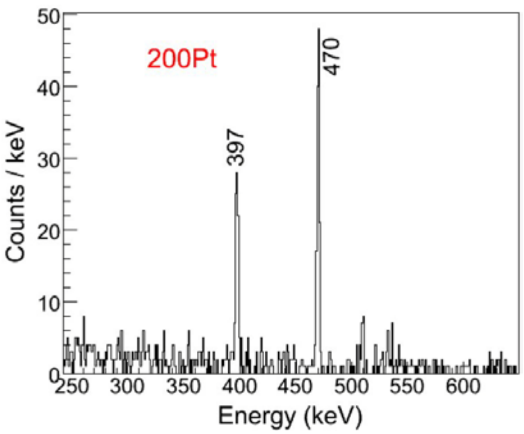
Active stopper: highly segmented DSSSD

ion-β time-position correlation



RISING γ-ray spectrometer

β–γ prompt correlation



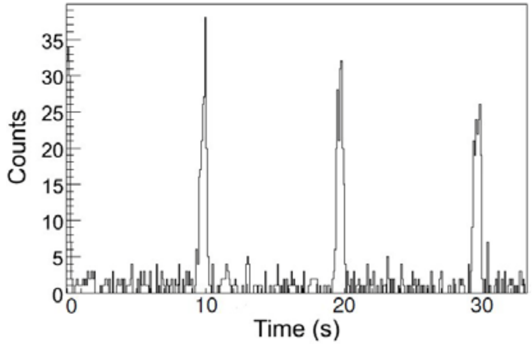
β half lives

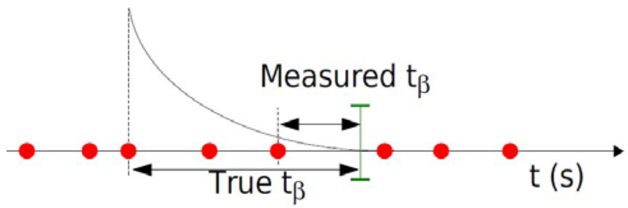
Time correlations evaluation

Standard exponential fits of time correlations are not applicable in general

✓ pulsed beam: time-modulated δ-electron background

✓ half lives (~ 10 s) are longer than the production/implantation rate: multiple implantations



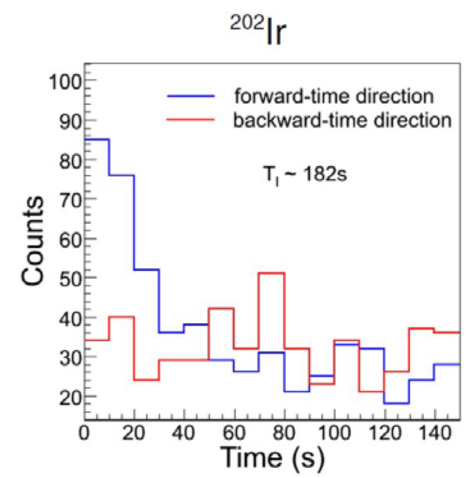


New proposed method:

✓ β–γ prompt correlations: δ-electron suppresion

✓ backward-time ion-β correlations: remaining background evaluation

✓ numerical fitting fuction based on Monte Carlo simulations of the implantation-decay process including experimental implantation rates and having as free parameters the β decay half life and the β detection efficiency

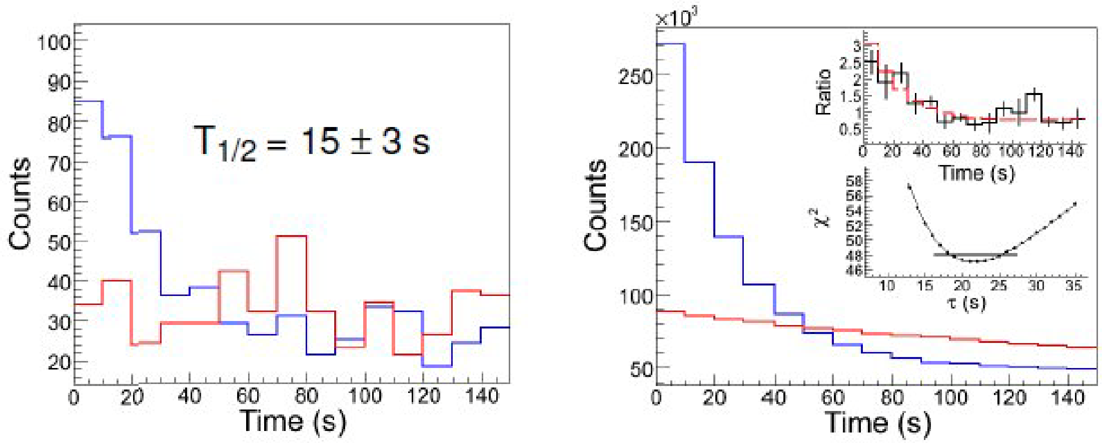


T. Kurtukian-Nieto et al.., NIMA 67, 055802 (2008)

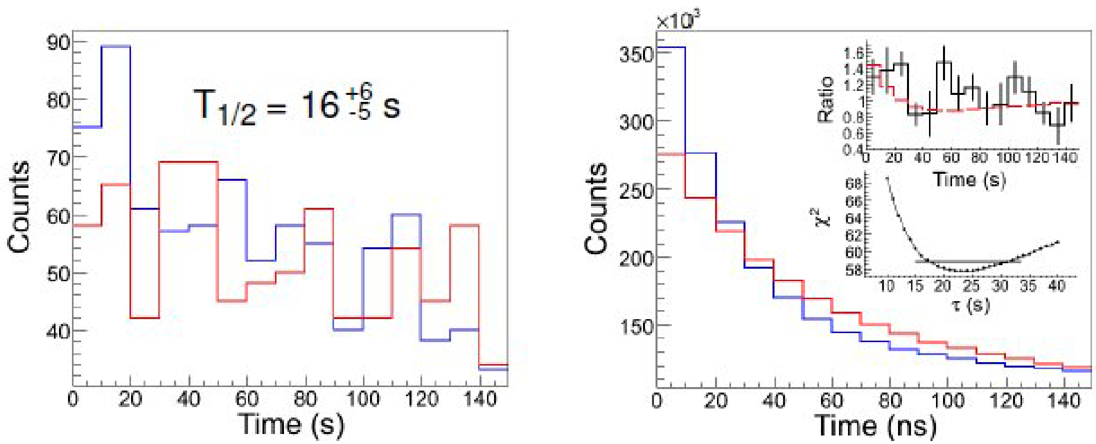
β half lives

Time correlations evaluation

^{202}Ir

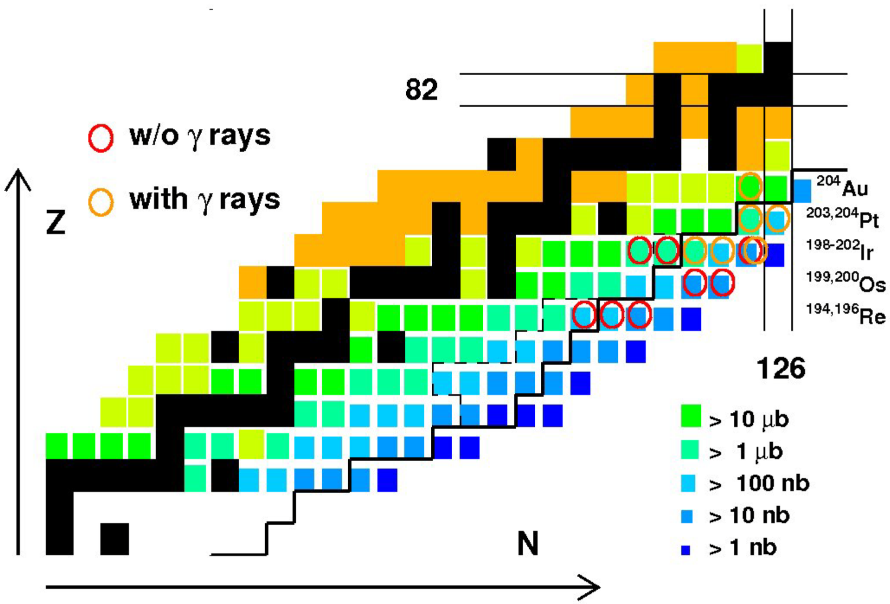


^{204}Pt



β half lives

Results



The β half lives of 13 heavy neutron-rich nuclei have been determined, 11 of them for the first time.

Nuclei	w/o γ	with γ	other works	FRDM+ QRPA[1]	DF3+ QRPA[2]
^{204}Au		37 ± 0.8 s	39.8 ± 0.9 s		
^{204}Pt		16^{+6}_{-5} s		321.8 s	7.4 s
^{203}Pt		22 ± 4 s		654.0 s	12.7 s
^{202}Ir	11 ± 3 s	15 ± 3 s		68.4 s	9.8 s
^{201}Ir		21 ± 5 s		130.0 s	28.4 s
^{200}Ir		43^{+6}_{-5} s		124.1 s	25.0 s
^{199}Ir	6^{+5}_{-4} s			370.6 s	46.7 s
^{198}Ir	8 ± 2 s		8 ± 1s	377.1 s	19.1 s
^{200}Os	6^{+4}_{-3} s			187.1 s	6.9 s
^{199}Os	5^{+4}_{-2} s			106.8 s	6.6 s
^{196}Re	3^{+1}_{-2} s			3.6 s	1.4 s
^{195}Re	6 ± 1s			3.3 s	8.5 s
^{194}Re	1 ± 0.5 s			70.8 s	2.1 s

[1] P. Möller, et al. PRC 67, 055802 (2003)
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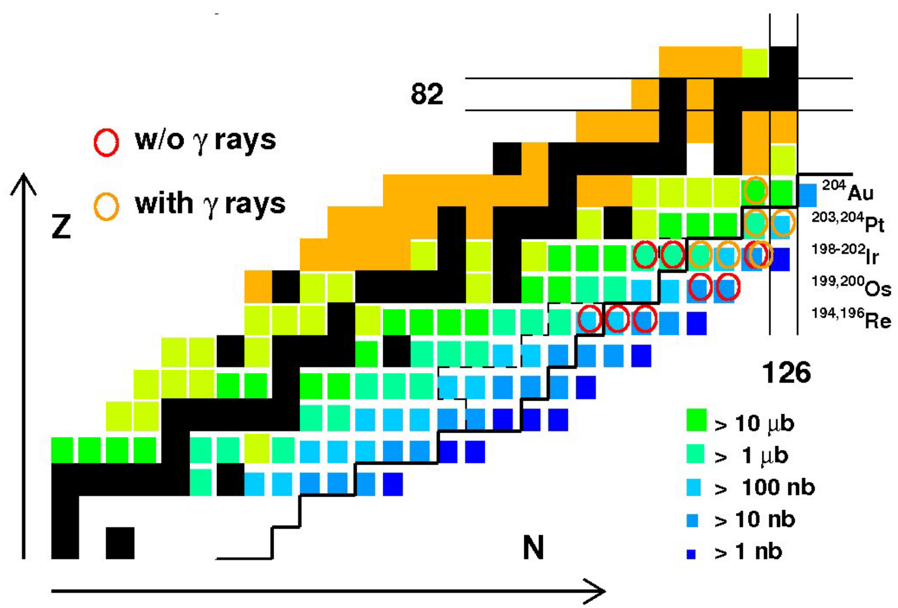
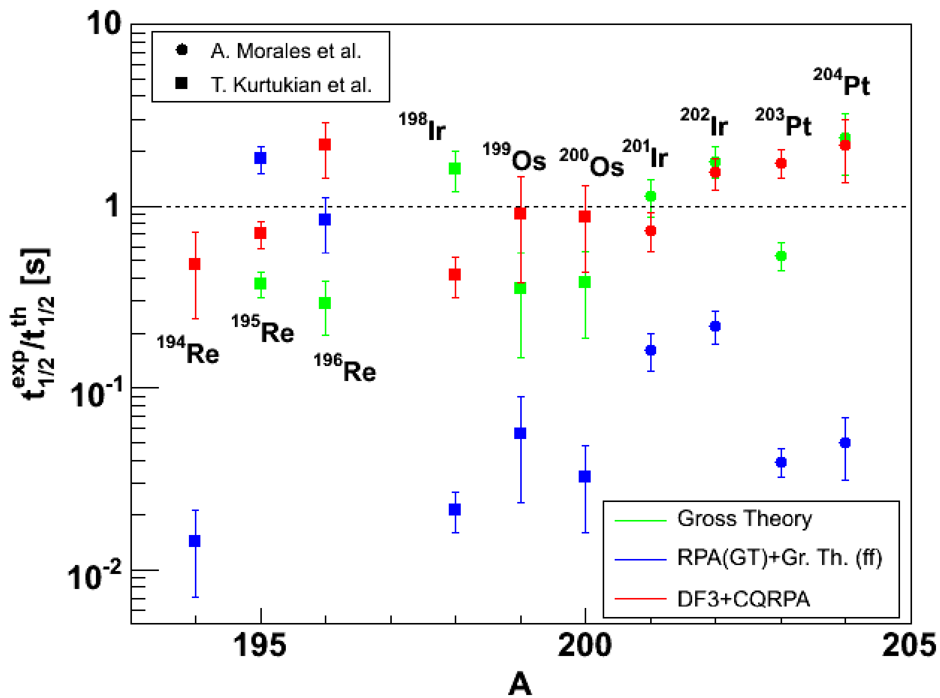
β half lives

Results





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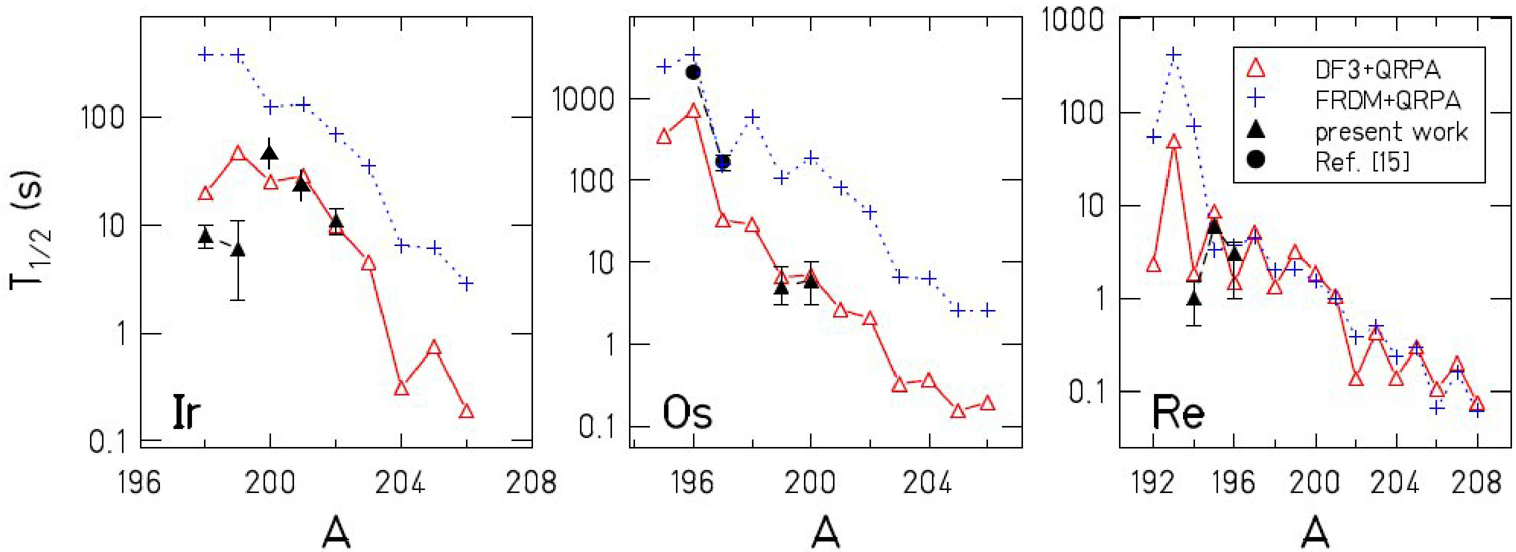
β half lives

Results



T. Kurtukian et al., submitted to PLB

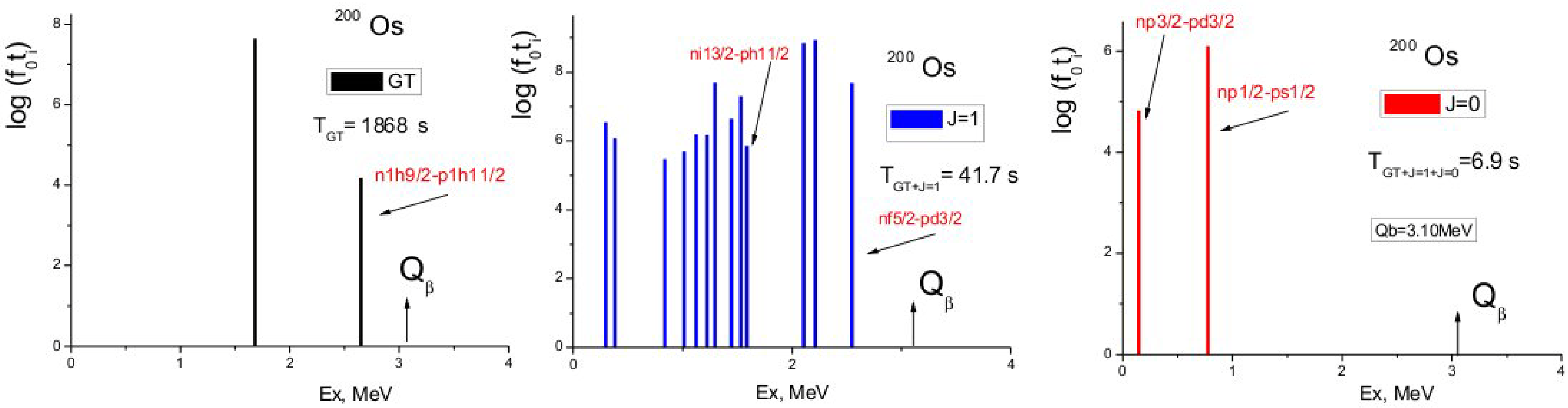
✓ FRDM calculations overestimate the measured half lives

✓ DF3 calculations provides a better description of the data: role of first forbidden transitions

✓ These results may suggest that the r process matter flow to the heavier fissioning nuclei could be faster than expected

β half lives

Role of first forbidden transitions

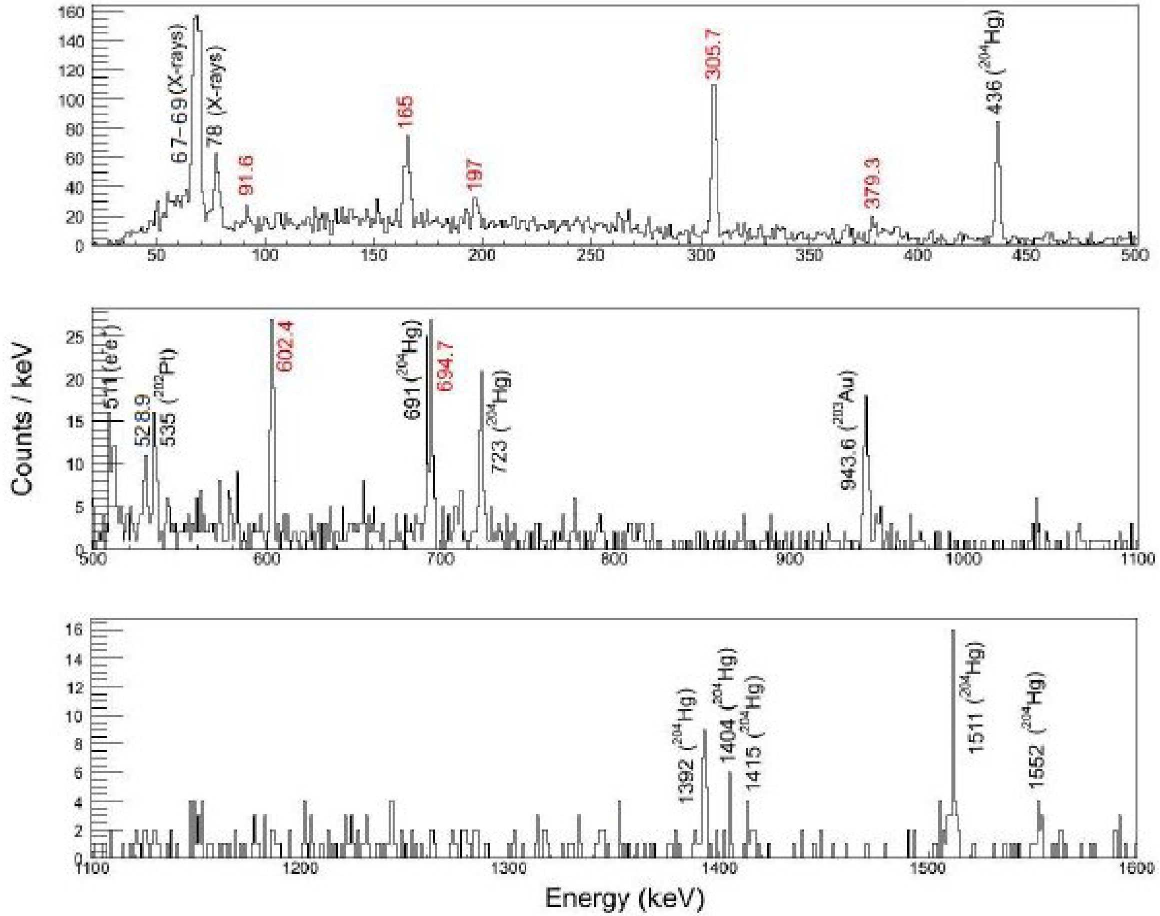


According to I. Borzov calculations, in this region of the chart of nuclides FF transitions appear at lower excitation energies than GT transitions. Because of the larger phase space, FF decays are then favored.

Borzov calculations do not include deformation effects

β-delayed gamma spectroscopy

Characterization of low-lying excited states

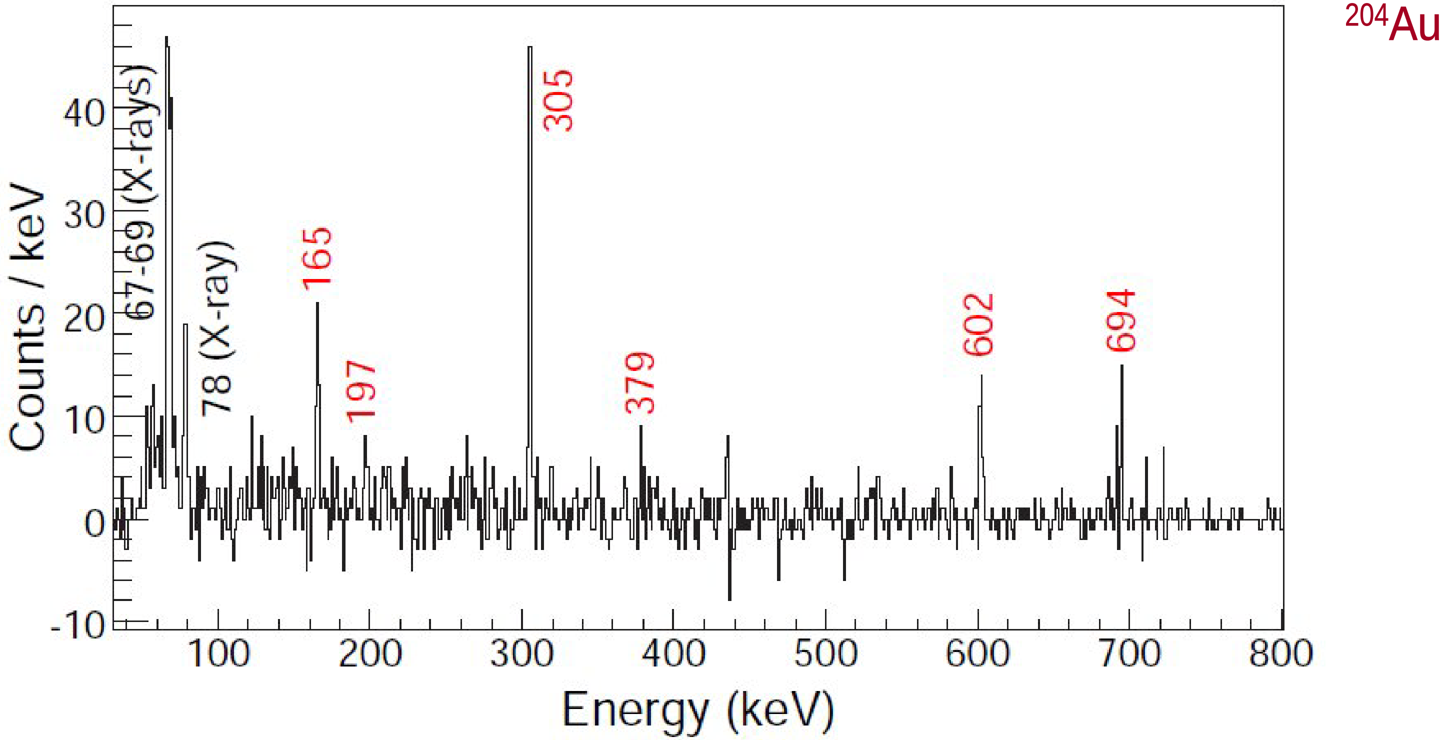


^{204}Au

The production/implantation technique at RISING produces rather complex gamma spectra

β-delayed gamma spectroscopy

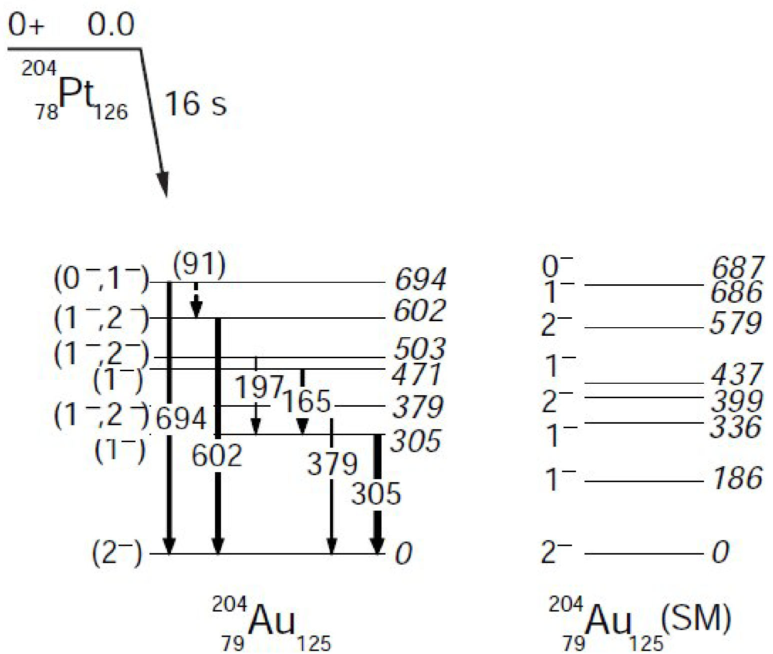
Characterization of low-lying excited states



Selecting areas in the DSSSD detectors where different contaminants are preferably implated and determining uncorrelated decays from backward-time β-ion correlations, the gamma spectra can be cleaned.

β-delayed gamma spectroscopy

Characterization of low-lying excited states



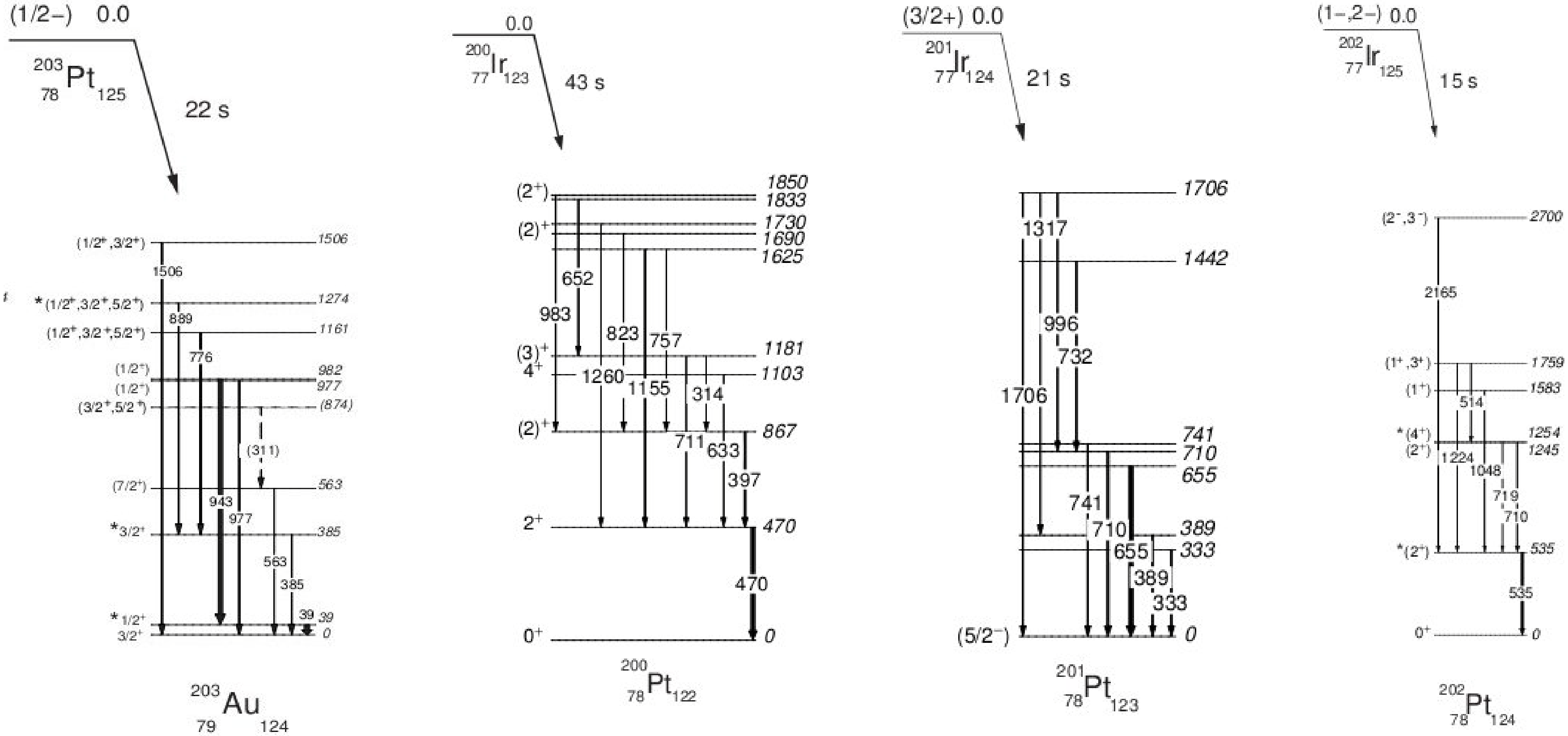
Nuclide	E_s (keV)	E_γ (keV)	I_γ(%)	F_γ(%)
^{204}Au	305.7(1.1)	305.7(1.1)	100(8)	17(6)
	379.3(1.9)	379.3(1.9)	18(2)	7.2(1.9)
	471(2)	165(2)	46(4)	19(5)
	503(2)	197.0(1.7)	11.7(1.3)	4.7(1.2)
	602.4(1.9)	602.4(1.9)	65(6)	7(9)
	694(2)	91.6(1.0)	47(18)	45(11)
		694.7(0.9)	63(6)	

OXBASH calculations by M. Gorska and H. Grawe

The feading of the lowest lying excited states together with spin-parity values based on shell model calculations would support the role of FF transitions in this decay.

β-delayed gamma spectroscopy

Characterization of low-lying excited states



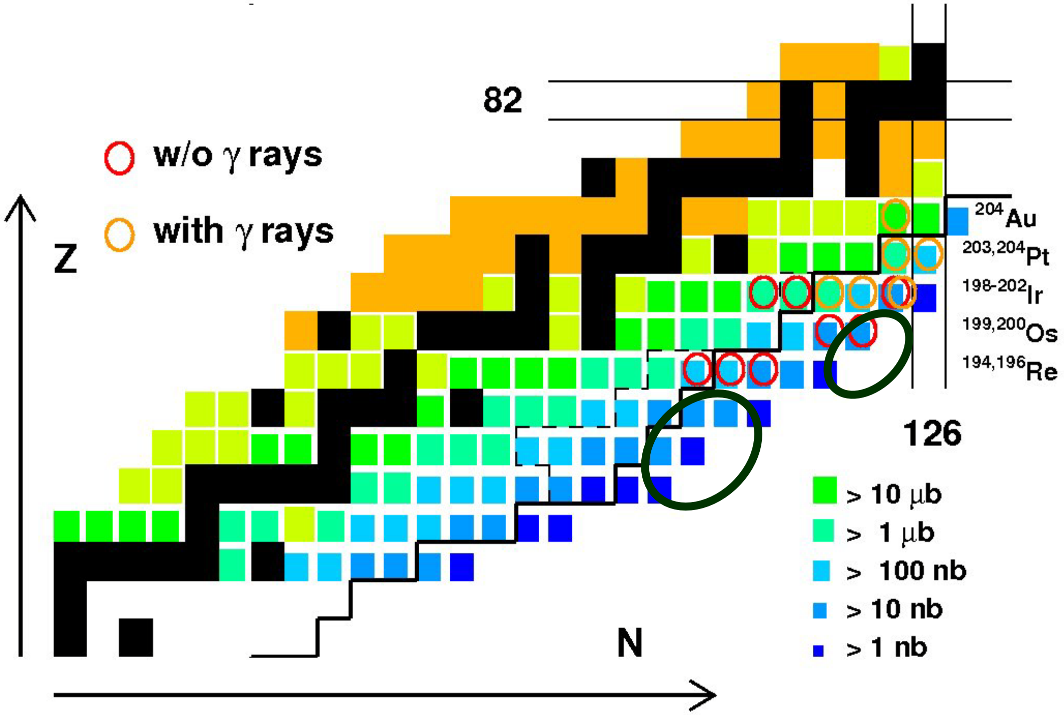
The interpretation of these level schemes based on shell model calculations is more difficult because of the valence space configuration and possible deformation effects.

Calculations are in progress.

Future measurements

Key issues:

- role of first forbidden transitions
- role of deformation



✓ Complete the systematics close to N=126

✓ Accurate half lives for nuclei approaching the deformation region

✓ Combined measurements with fast timing arrays

✓ Complementary measurements of the β strength with TAS

Summary

- We can not yet produce r-process nuclei at the N=126 shell, but.
  - ✓ Tremendous progress has been done at the FRS expanding the north-est frontier of the chart of nuclides
  - ✓ Present (GSI) and future (FAIR) production rates can be reliably estimated

- β half lives were determined using ion – β (-γ) correlations
  - ✓ A new method to determine β half lives under complex background conditions was introduced
  - ✓ The half lives of 13 heavy neutron-rich nuclei were determined.
  - ✓ The measured half lives better describe when FF transitions are considered.
  - ✓ The confirmation of this result for r process nuclei would indicate a faster r process matter flow towards the heavier fissioning nuclei.

- Future possibilities are:
  - ✓ Complete the systematics close to N=126
  - ✓ Investigate the role of FF transitions and deformation

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Collaborators

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