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

HEIDELBERG
NIC XI
JULY 19 - 23, 2010

José Benlliure

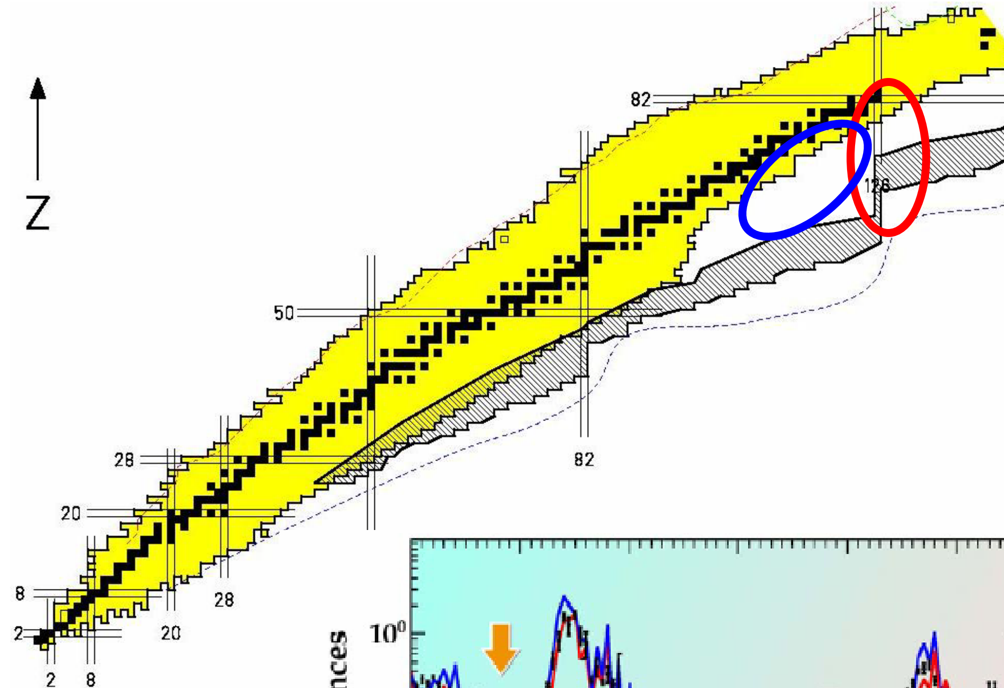
Universidad of Santiago de Compostela
Spain

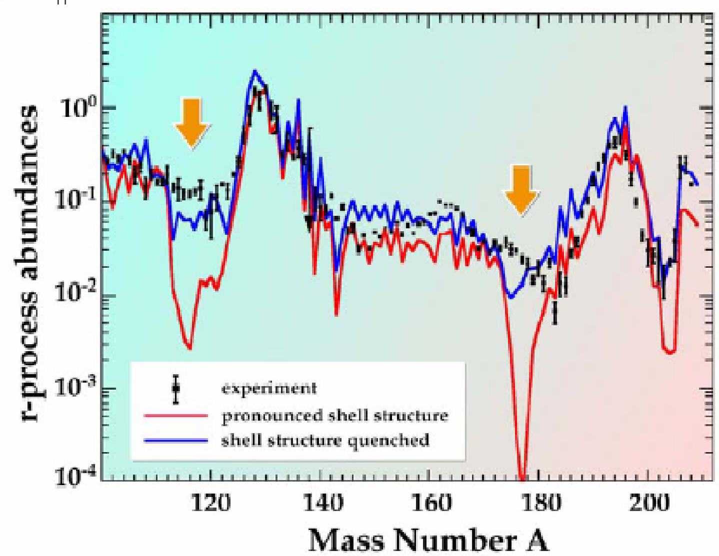
Nuclear data for the r process

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 nucleosynthesis 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.



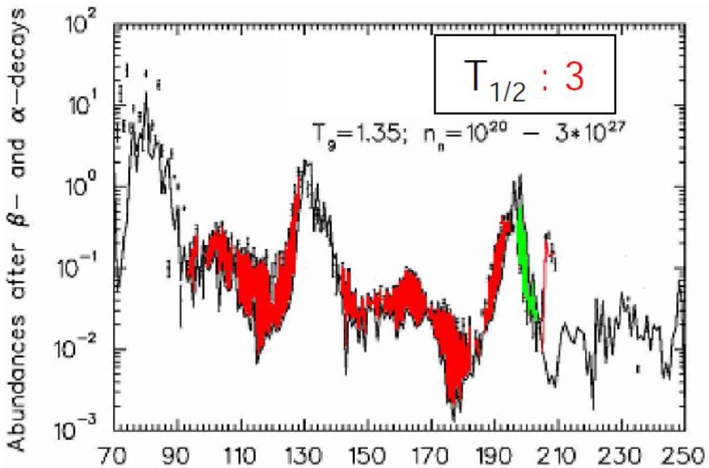


Nucler data for the r process

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:

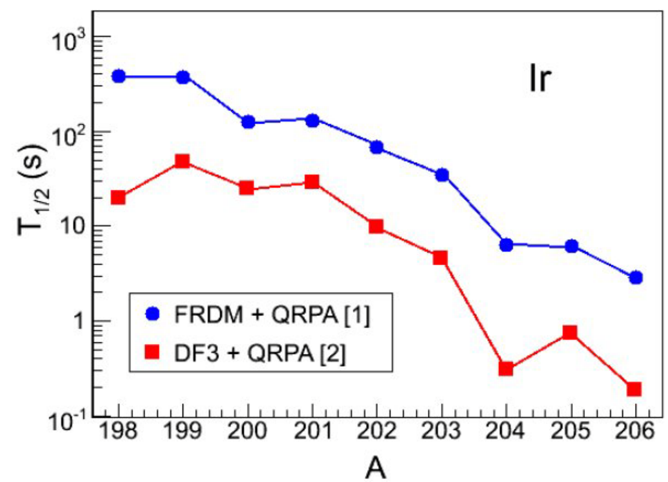
✓ Matter flow through the N=126 bottleneck region fixing the abundance pattern of the heaviest elements in the Universe.

✓ 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.



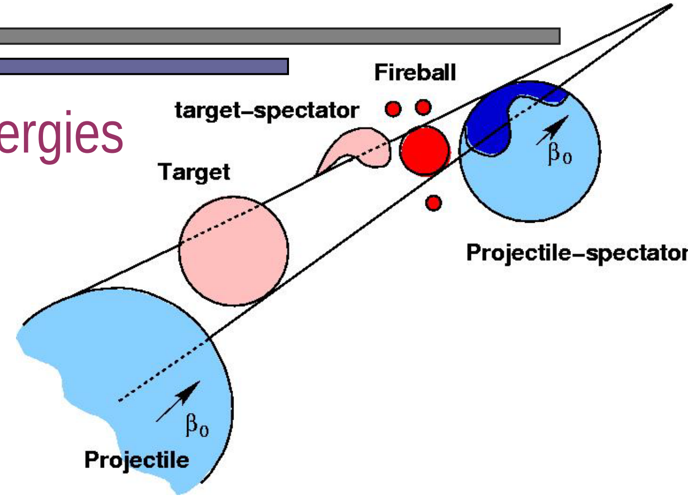
It is our goal to investigate:

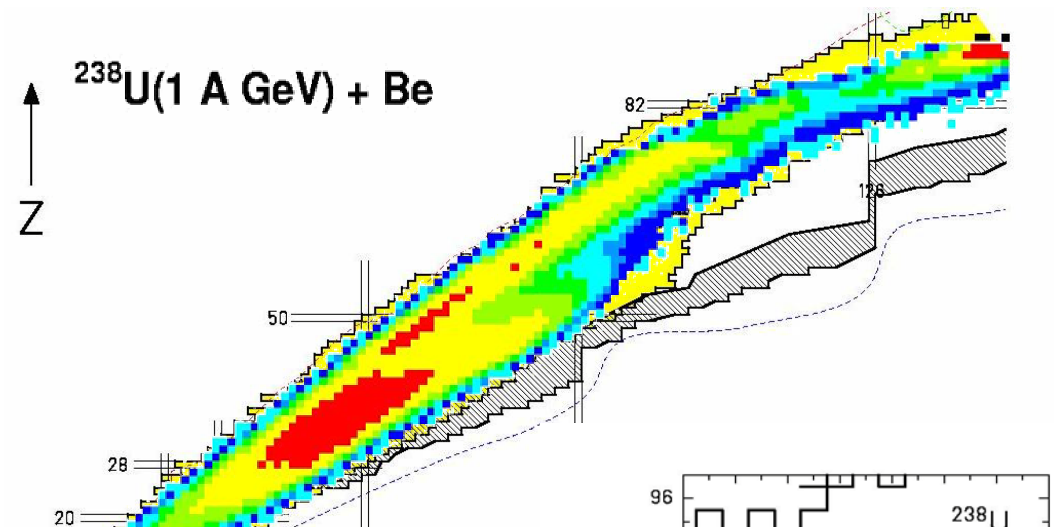
- the production of heavy neutron-rich nuclei
- determine their β half lives

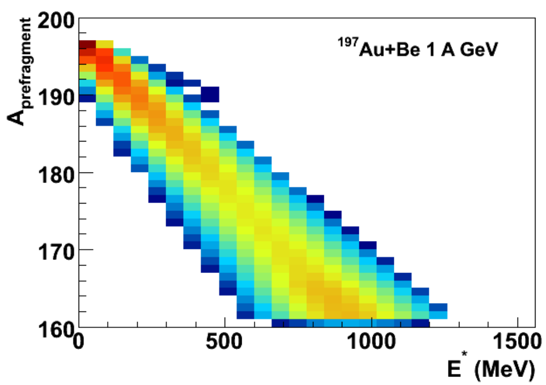
[1] P. Möller, et al. PRC 67, 055802 (2003)
[2] I. N. Borzov PRC 67, 025802 (2003)

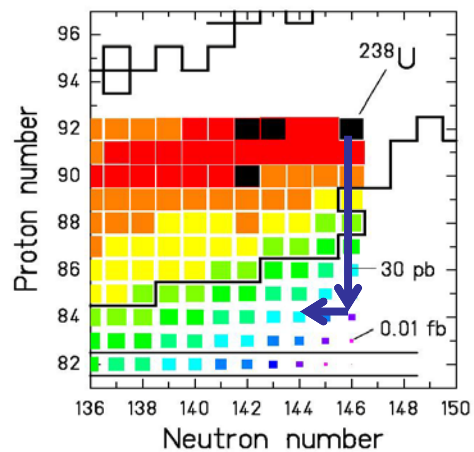
Production of heavy neutron-rich nuclei

Reaction mechanism: fragmentation at relativistic energies









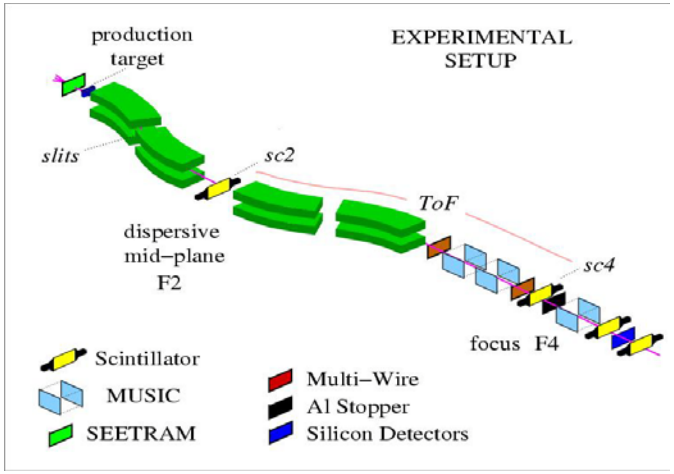
Fragmentation is an optimum reaction mechanism for exploring the nuclide chart:

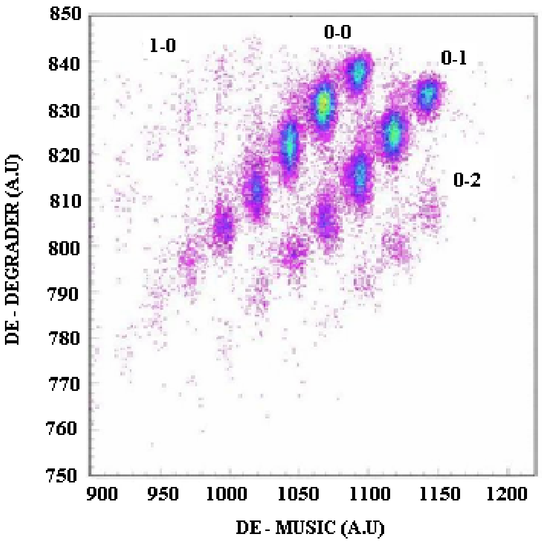
- neutron-deficient nuclei are highly populated up to the drip-line
- the in-flight fragmentation of heavy nuclei leading to fission produces medium-mass neutron-rich nuclei
- the large fluctuation in isospin (abrasion) and excitation energy (ablation) give access to cold **fragmentation** processes where neutron-rich nuclei are produced.

Production of heavy neutron-rich nuclei

Experimental technique: SIS18+FRS (GSI)

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

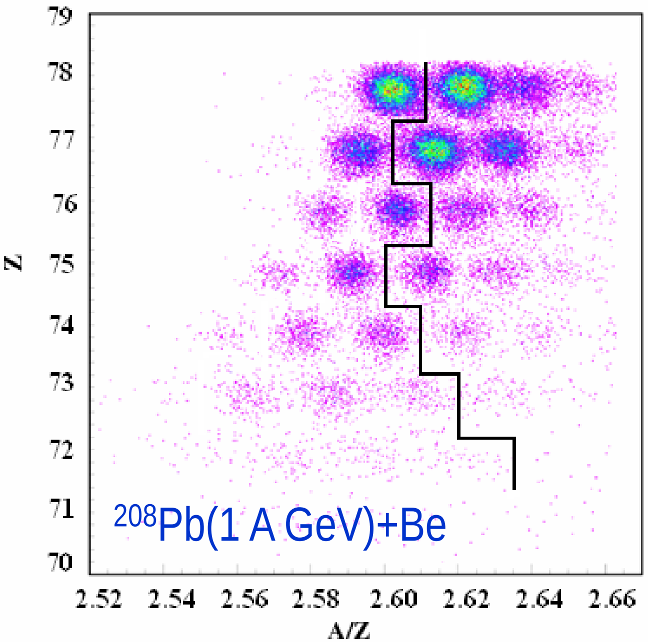




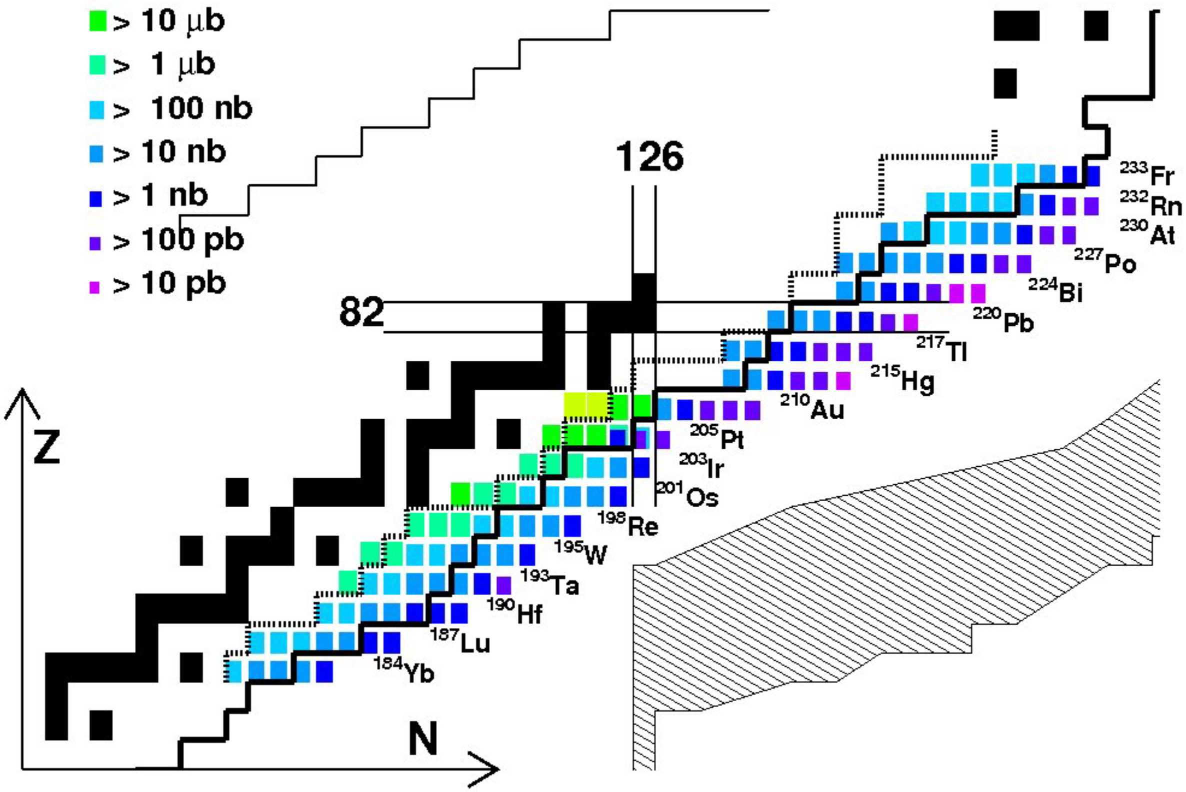
✓ One of the challenges of the experiment was the identification of charge states

→ Beam energy (< 700 A MeV)

→ FRS+energy degrader

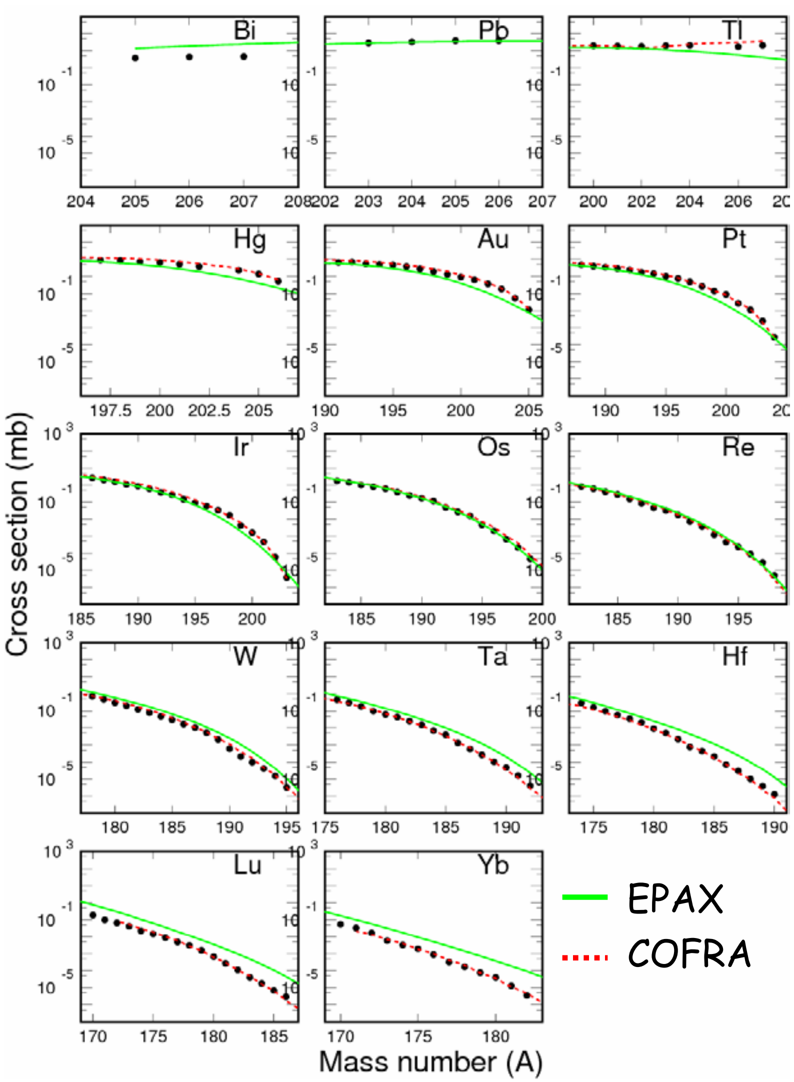


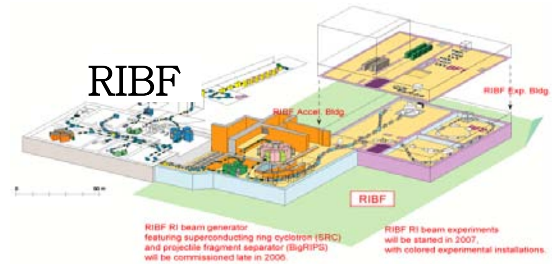
Production of heavy neutron-rich nuclei



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

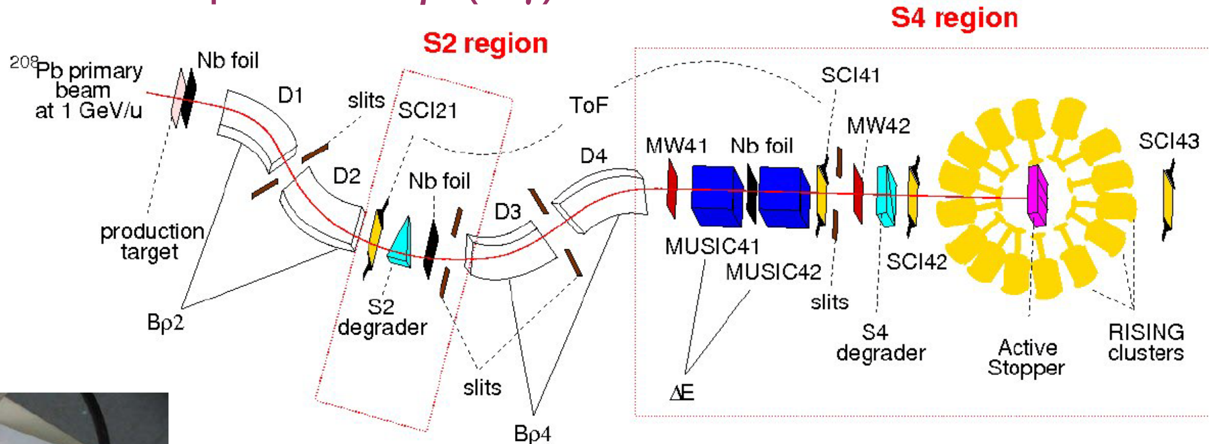
Production of heavy neutron-rich nuclei

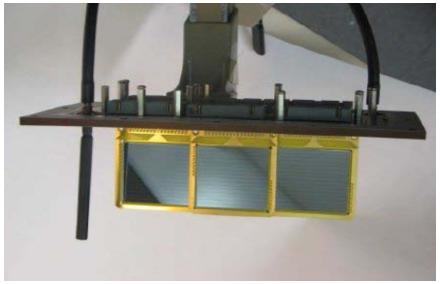




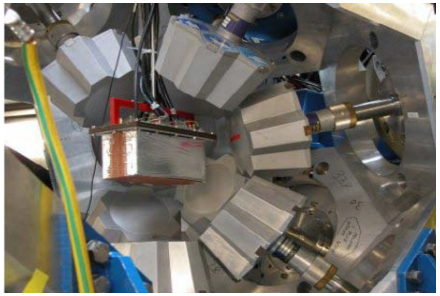
β half lives

Experimental technique: ion – β (– γ) correlations

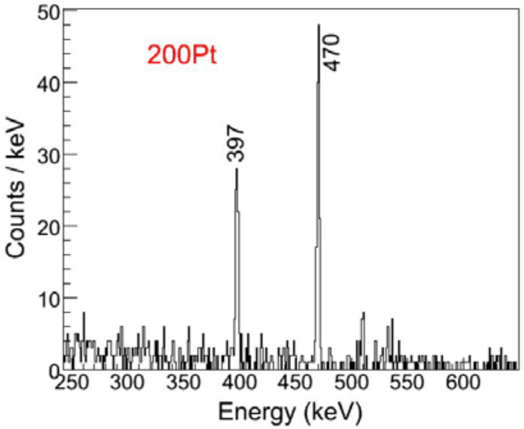




Active stopper: highly segmented DSSSD
ion-β time-position correlation



RISING γ-ray spectrometer
β–γ prompt correlation



USC
UNIVERSIDADE DE SANTIAGO DE COMPOSTELA

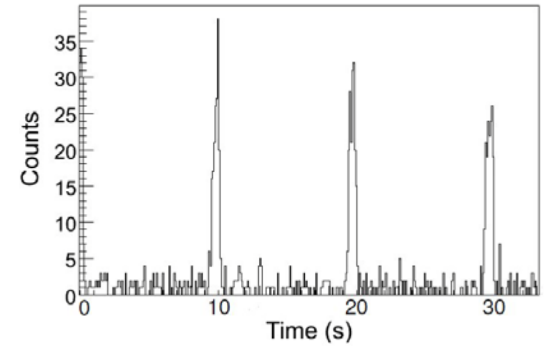
β half lives

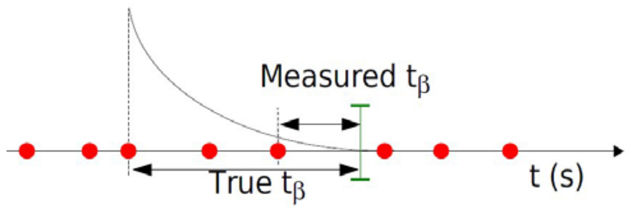
Time correlations evaluation

Standard exponential fits of time correlations not applicable

✓ pulsed beam: time-modulated δ-electron background

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



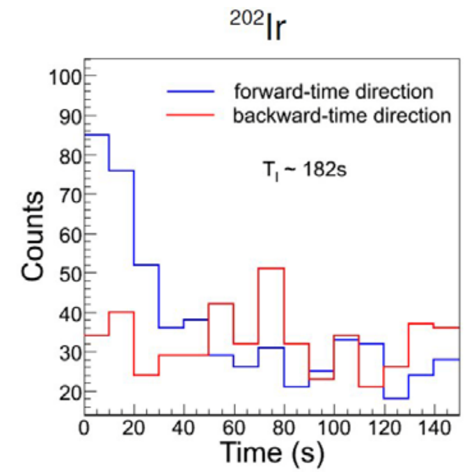


New proposed method:

✓ β–γ prompt correlations: δ-electron suppresion

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

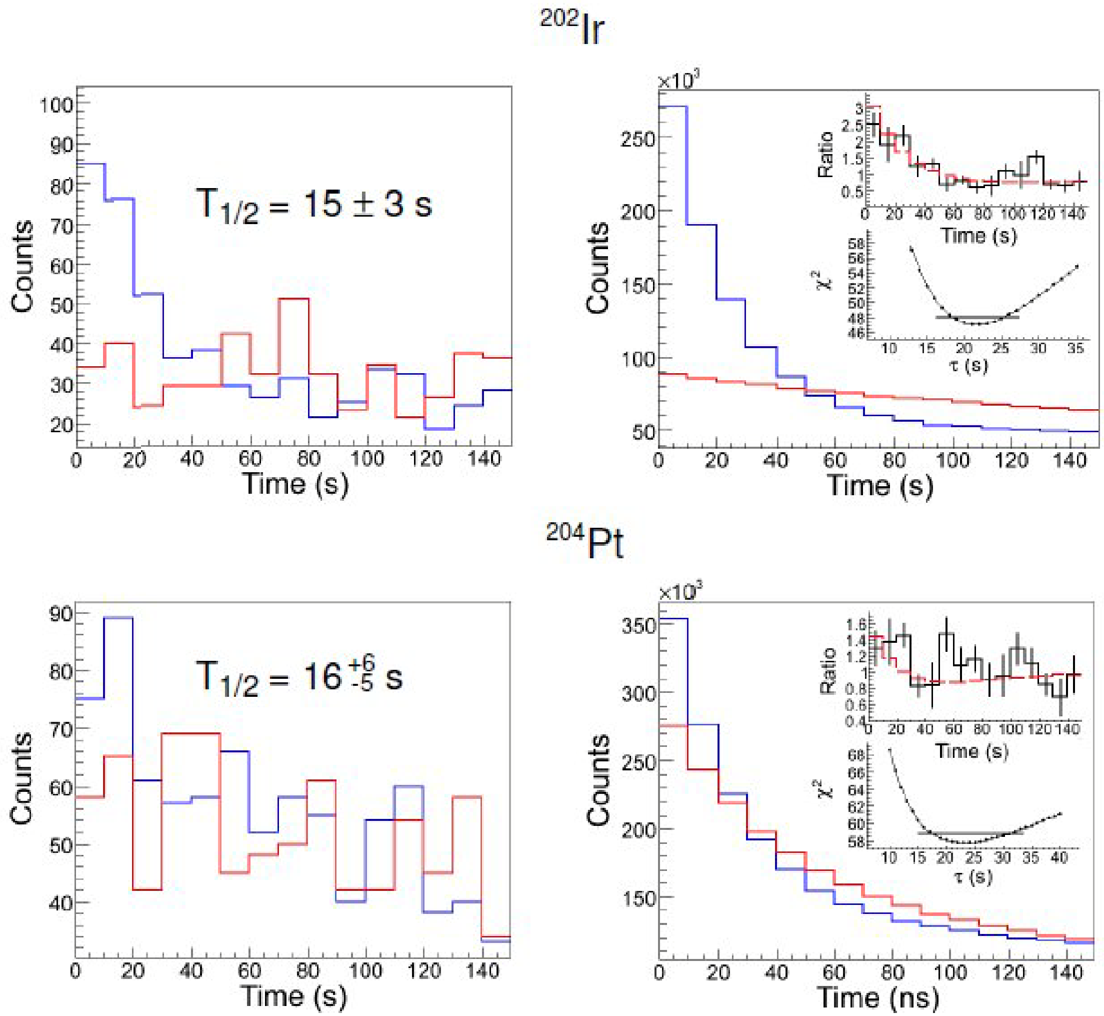
✓ numerical fitting fuction based on Monte Carlo simulations of the implantation-decay process including experimental implantation rates and having as free parameters the β decay half life and the β detection efficiency



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

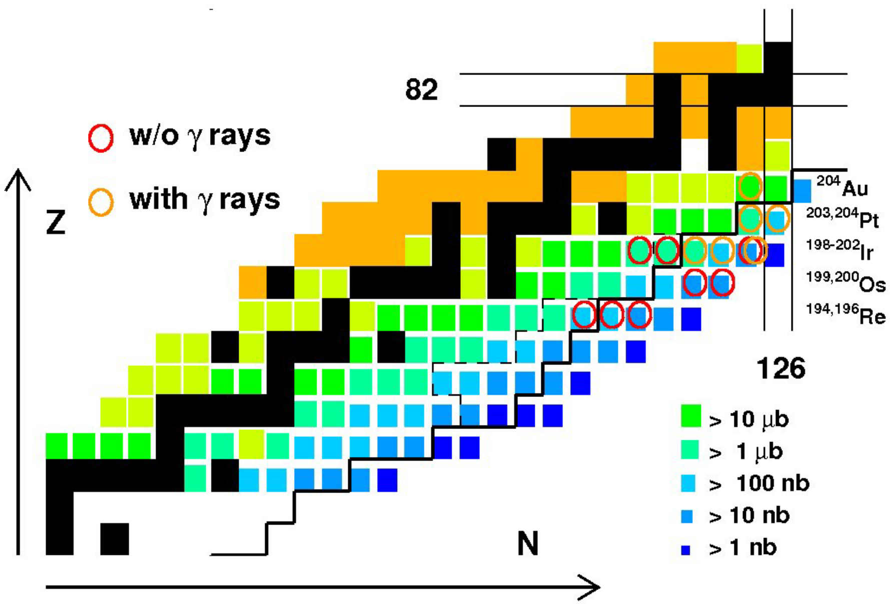
β half lives

Time correlations evaluation



β half lives

Results



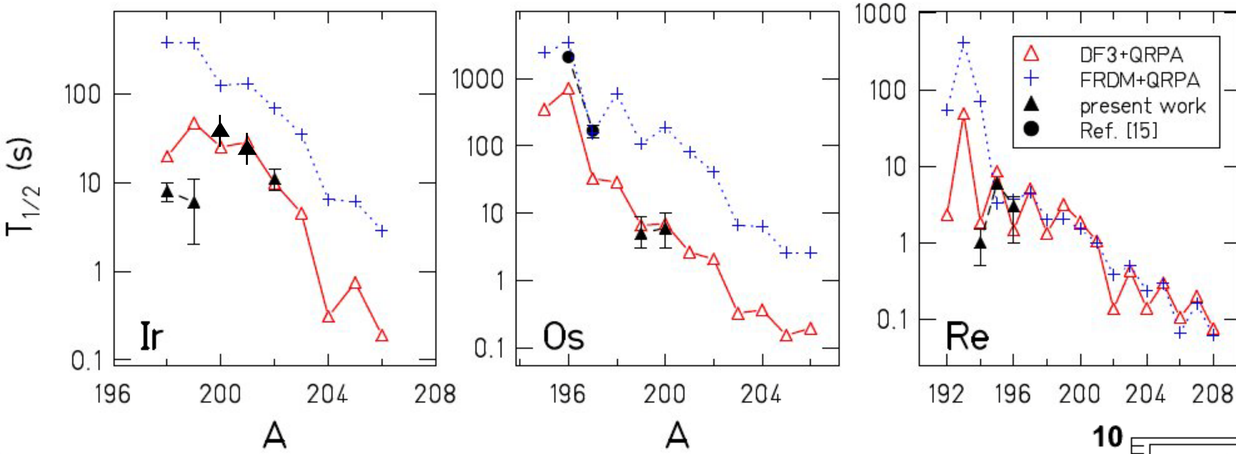
The β half lives of 13 heavy neutron-rich nuclei have been determined, 11 of them for the first time.

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)
[2] I. N. Borzov PRC 67, 025802 (2003)

β half lives

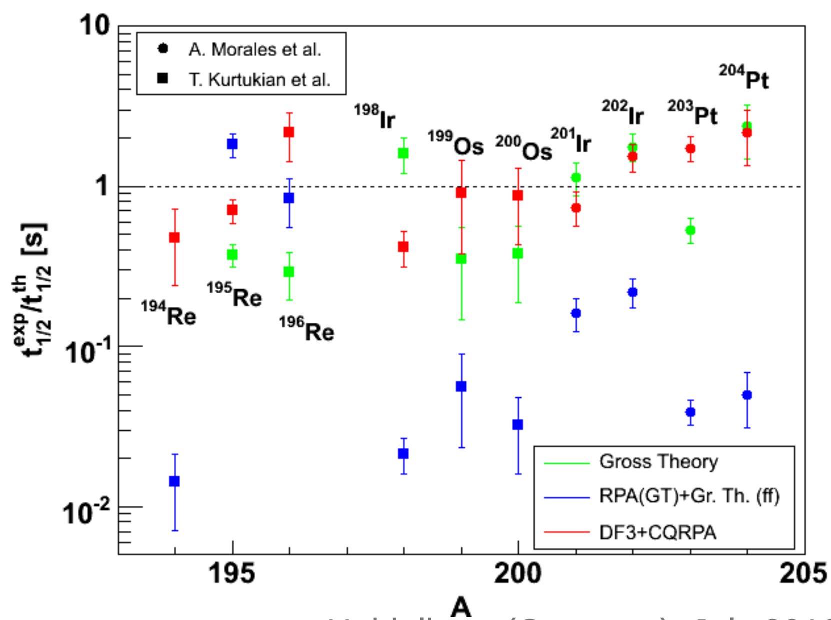
Results



✓ 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



Summary

- The production of heavy neutron-rich nuclei close to the A~195 r process waiting point was investigated using fragmentation reactions of ^{238}U and ^{208}Pb beams at relativistic energies.
  - ✓ 75 neutron-rich isotopes of elements between Yb and Fr were identified for the first time
  - ✓ Their production cross sections were determined and used to benchmark model calculations

- 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 are overestimated by FRDM+QRPA calculations and rather well described by DF3+QRPA.
  - ✓ The confirmation of this result for r process nuclei would indicate a faster r process matter flow towards the heavier fissioning nuclei.

Collaborators

J. Benlliure[1], **A.I. Morales[1], T. Kurtukian-Nieto[1,a] , H. Alvarez-Pol[1]**, I.N. Borzov[2], L. Audouin[3], B. Blank[4], F. Becker[2], E. Casarejos[1], D. Cortina-Gil[1], T. Enqvist[2,b], B. Fernández[5], M. Fernández-Ordóñez[1,c], J. Giovinazzo[4], D. Henzlova[2,d], A.R. Junghans[6], B. Jurado[4], k. Langanke[2], G. Martinez-Pinedo[2], P. Napolitani[3], J. Pereira[1,d], F. Rejmund[5], K.-H. Schmidt[2], O. Yordanov[2,e]

[1] Departamento de Física de Partículas, Universidade de Santiago de Compostela, Spain
[2] GSI Darmstadt, Germany
[3] Institut de Physique Nucleaire d'Orsay, France
[4] Centre d'Etudes Nucleaires Bordeaux-Gradignan, France
[5] GANIL, Caen, France
[6] Forschungszentrum Dresden-Rossendorf, Germany

and the RISING collaboration