



Lifetime measurement on fission fragments in the $A \sim 100$ region

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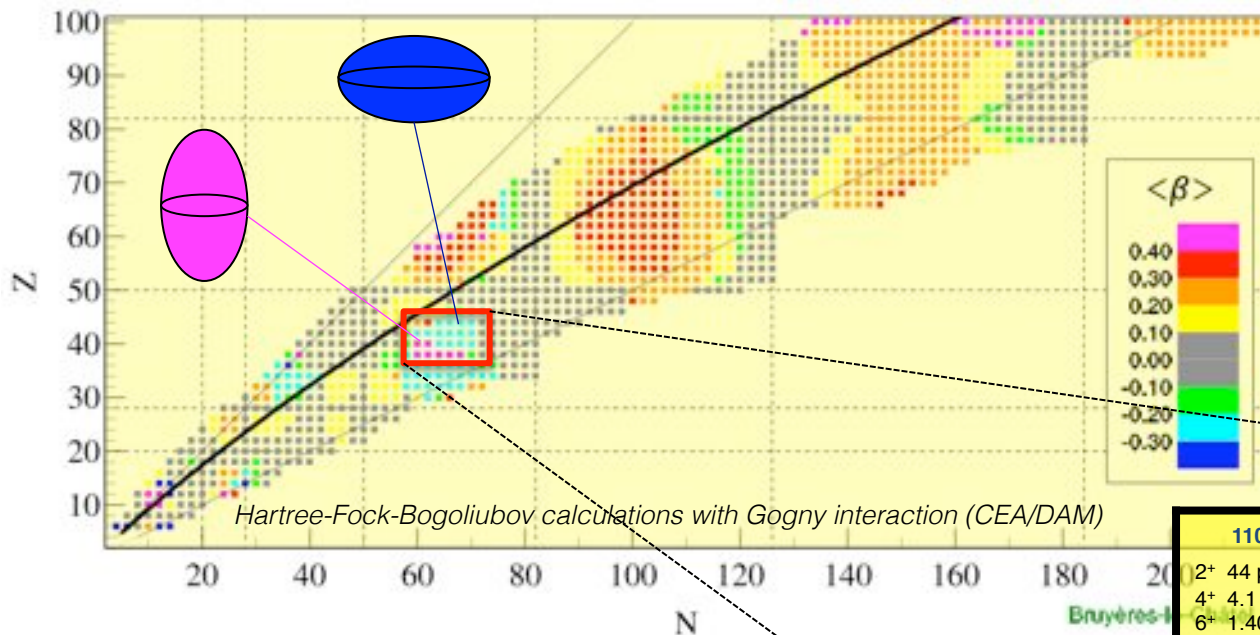
DSM/IRFU/SPhN

Nuclear Structure Physics with advanced
 γ -Detector Arrays

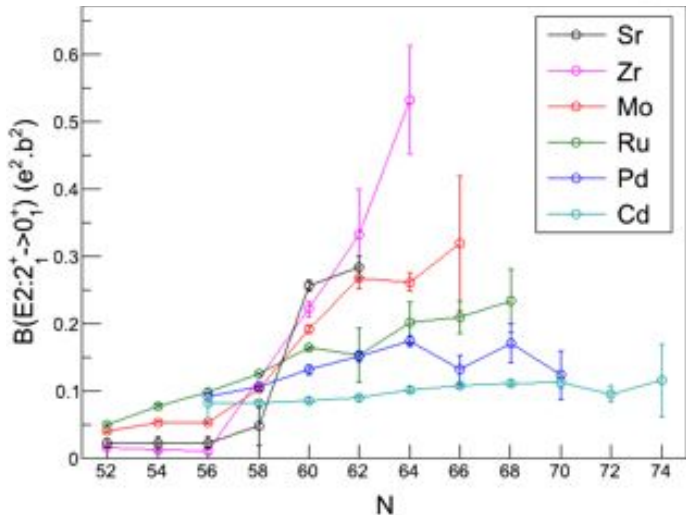
June 12th 2013

Motivation

Shape evolution and collectivity in the region of $A \sim 100$



Prolates and oblates shapes in the region of $A \sim 100$



		¹¹⁰Pd 2 ⁺ 44 ps(7) 4 ⁺ 4.1 ps(3) 6 ⁺ 1.40 ps(14)	¹¹²Pd 2 ⁺ 84 ps(14) 4 ⁺ ??? 6 ⁺ ???	¹¹⁴Pd 2 ⁺ 82 ps(14) 4 ⁺ ??? 6 ⁺ ???	¹¹⁶Pd 2 ⁺ 0.11 ns(3) 4 ⁺ ??? 6 ⁺ ???
	¹⁰⁴Ru 2 ⁺ 56.4 ps(10) 4 ⁺ 5.6 ps(6) 6 ⁺ 1.33 ps(12)	¹⁰⁶Ru 2 ⁺ 0.20 ns(3) 4 ⁺ ??? 6 ⁺ ???	¹⁰⁸Ru 2 ⁺ 0.36 ns(3) 4 ⁺ 13.4 ps(10) 6 ⁺ ???	¹¹⁰Ru 2 ⁺ 0.32 ns(2) 4 ⁺ 15.4 ps(17) 6 ⁺ 2.4 ps(10)	¹¹²Ru 2 ⁺ 0.32 ns(3) 4 ⁺ ??? 6 ⁺ ???
	¹⁰²Mo 2 ⁺ 0.125 ns(4) 4 ⁺ 12.5 ps(25) 6 ⁺ ???	¹⁰⁴Mo 2 ⁺ 0.97 ns(8) 4 ⁺ 26.1 ps(3) 6 ⁺ 4.73 ps(15)	¹⁰⁶Mo 2 ⁺ 1.25 ns(3) 4 ⁺ 25.4 ps(51) 6 ⁺ 4.2 ps(18)	¹⁰⁸Mo 2 ⁺ 0.5 ns(3) 4 ⁺ ??? 6 ⁺ ???	
	¹⁰⁰Zr 2 ⁺ 0.59 ns(3) 4 ⁺ 37 ps(3) 6 ⁺ 4.9 ps(11)	¹⁰²Zr 2 ⁺ 1.8 ns(4) 4 ⁺ ??? 6 ⁺ ???	¹⁰⁴Zr 2 ⁺ 2.0 ns(3) 4 ⁺ ??? 6 ⁺ ???		

Lifetime of the first excited states

Objective : extend $B(E2)$ data to higher spin

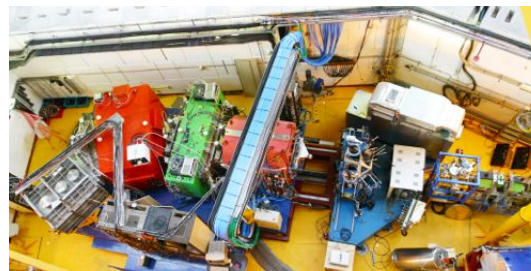
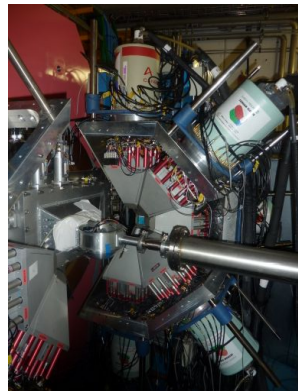
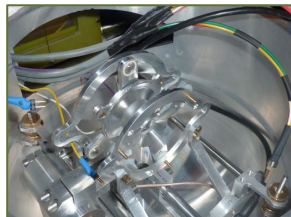
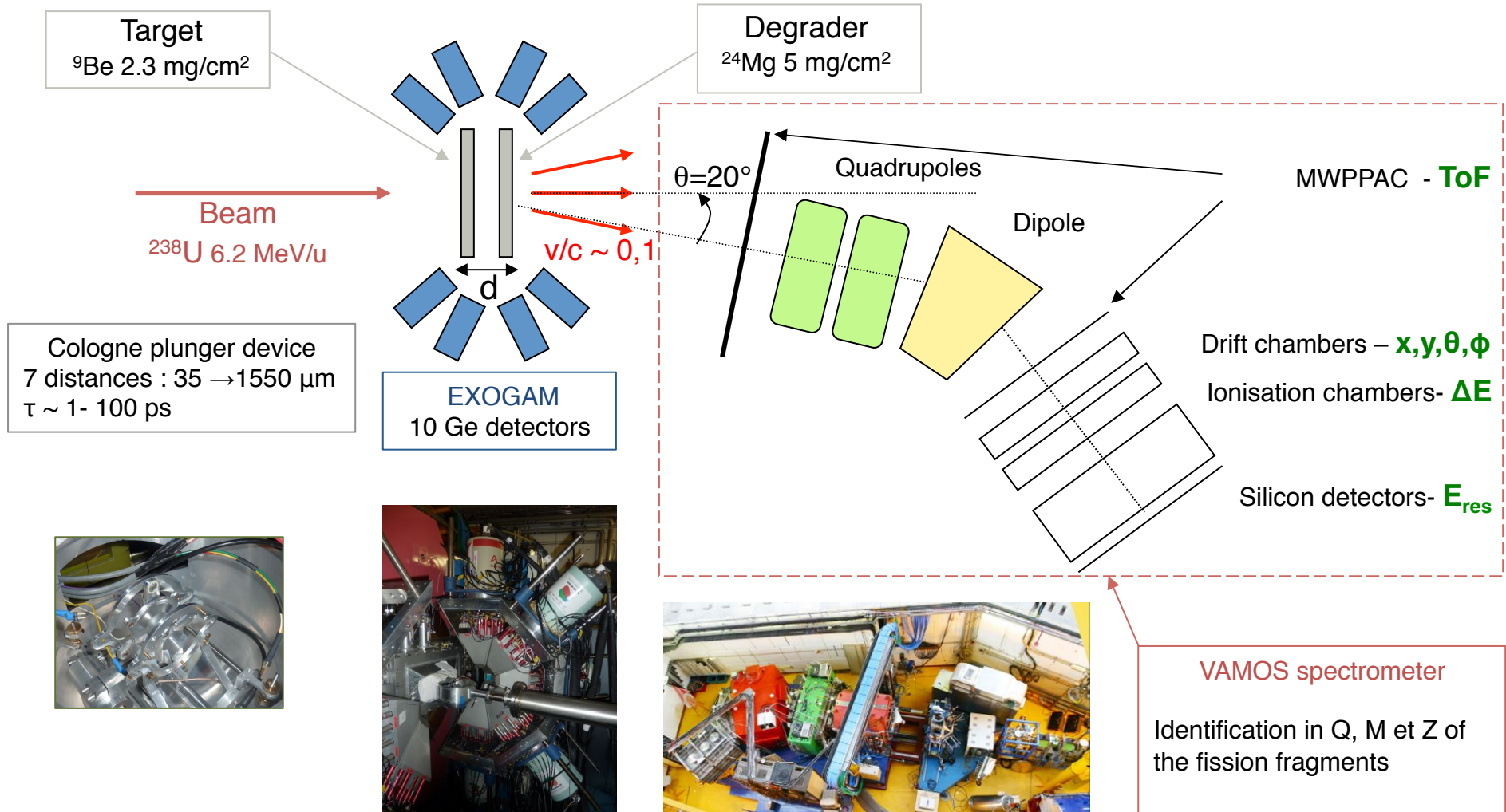
➔ Lifetime measurement in neutron rich Zr, Mo, Ru and Pd isotopes

Experimental method

Set up

Experiment performed at GANIL (E604, April 2011)

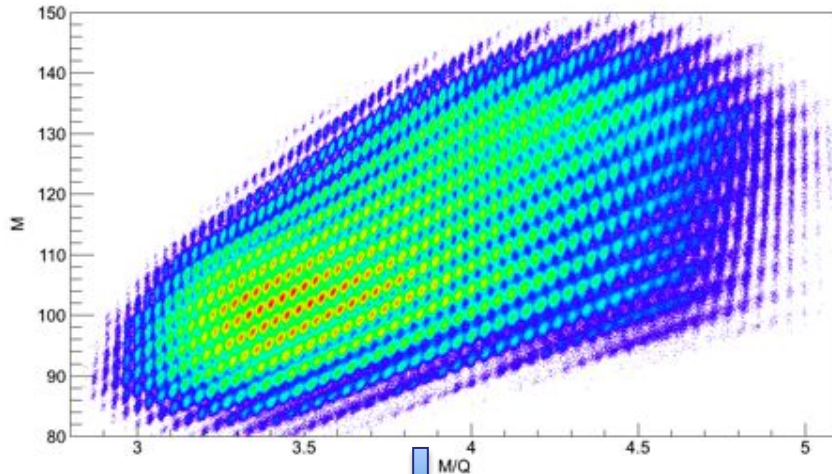
- ◆ Fusion-fission reaction $^{238}\text{U} + ^9\text{Be}$
- ◆ Inverse kinematics
- ◆ Excitation energy ~ 45 MeV



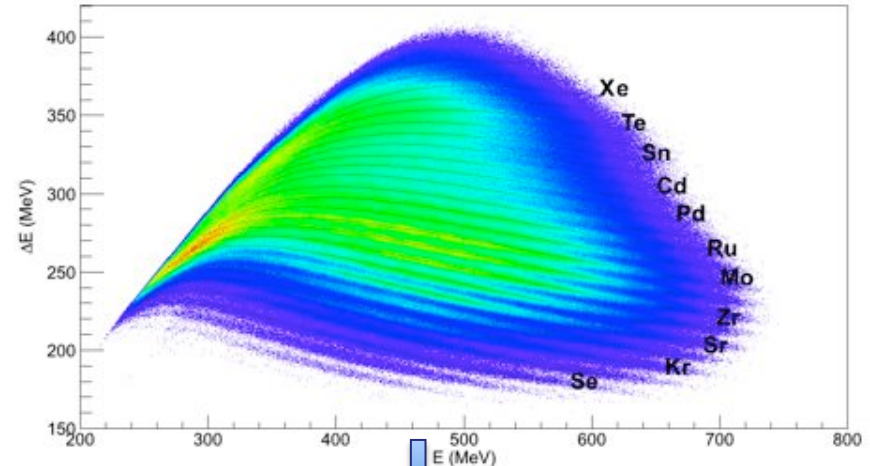
Analysis

The VAMOS spectrometer

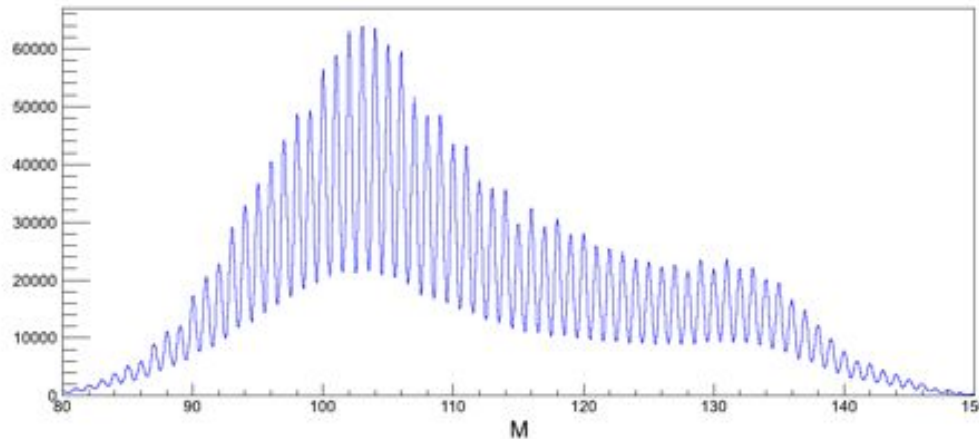
◆ Identification matrices from VAMOS focal plane



↓
Mass



↓
Atomic number



Total mass distribution of the detected fission fragments

Resolution

$$\frac{\Delta Z}{Z} = \frac{1}{60}$$

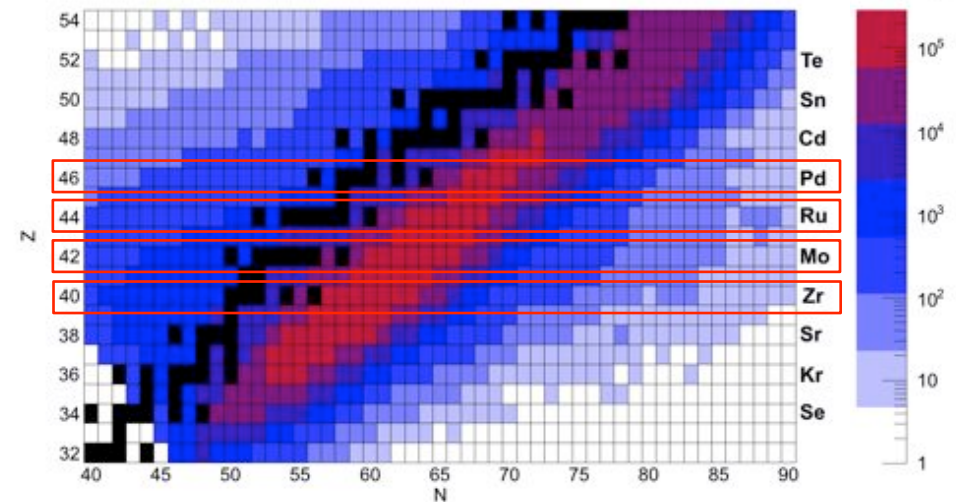
$$\frac{\Delta M}{M} = \frac{1}{200}$$

Analysis

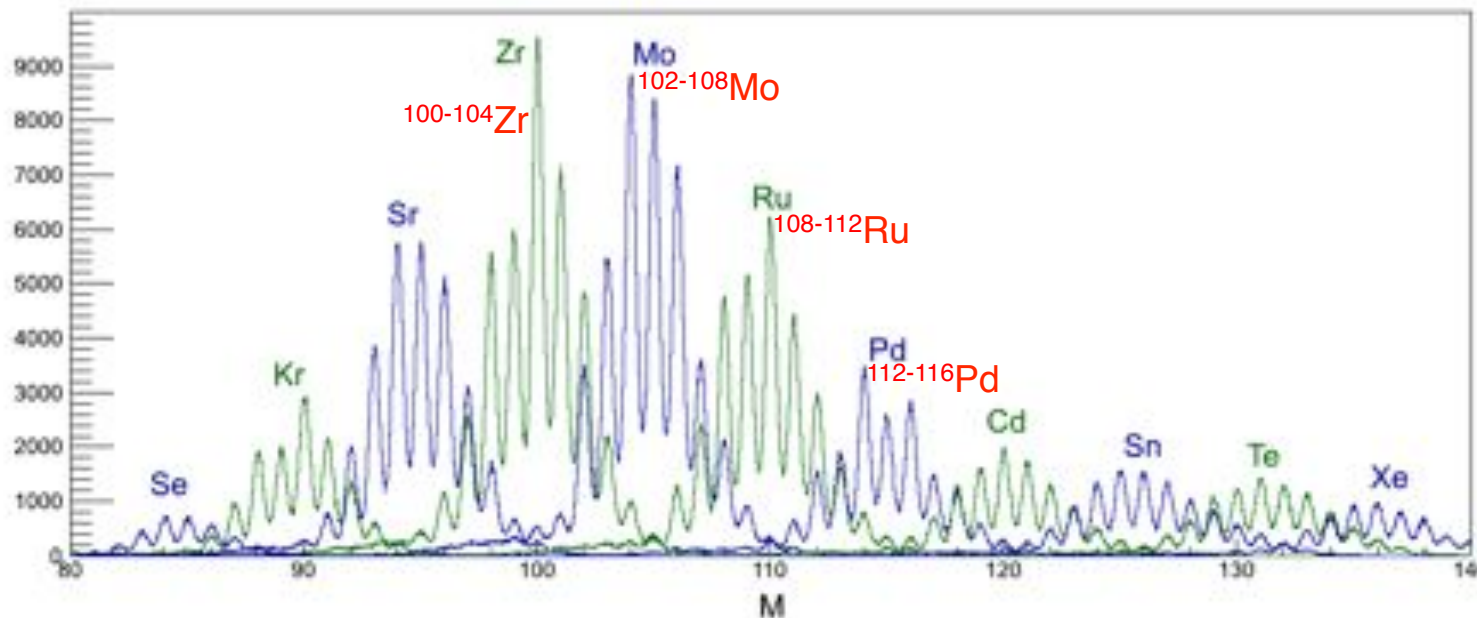
The VAMOS spectrometer

- ◆ Isotopic identification of +100 nuclei, from Se (Z=34) to Xe (Z=54)
- ◆ Exotic nuclei: up to 10 neutrons above stability

Measured relative yields of the detected fission fragments



Mass distribution of even-Z nuclei

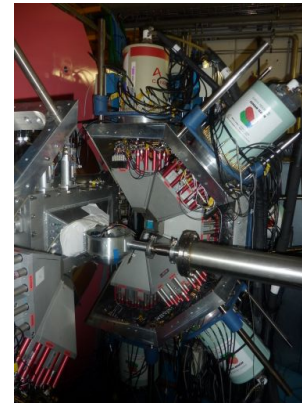
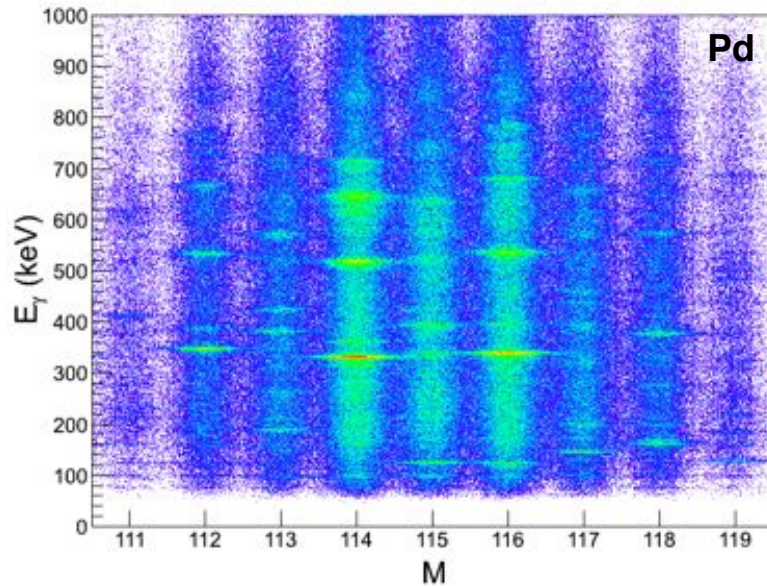


Lifetimes in neutron rich Zr, Mo, Ru and Pd isotopes

Analysis

EXOGRAM

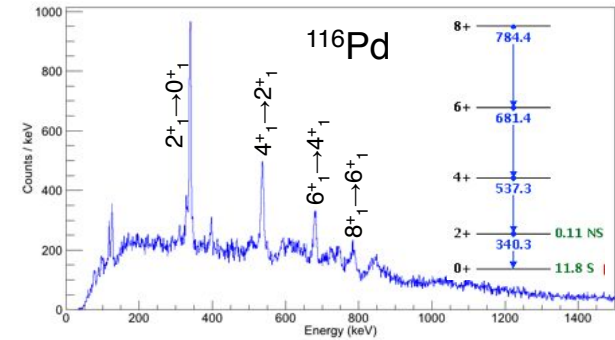
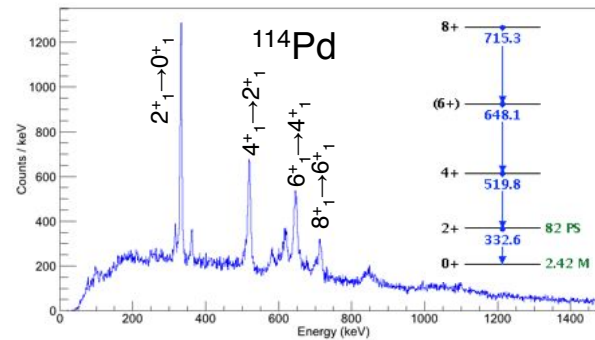
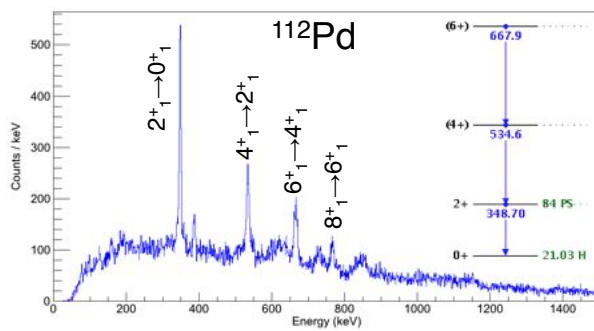
Prompt γ -spectroscopy with **EXOGRAM** in coincidence with selection in Z in VAMOS



EXOGRAM

- ◆ 10 clovers with full anti-Compton shielding: 3 at 135° and 7 at 90°
- ◆ Segmented crystals for Doppler correction and add-back procedure

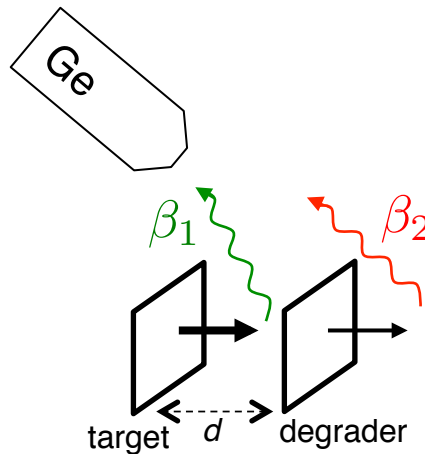
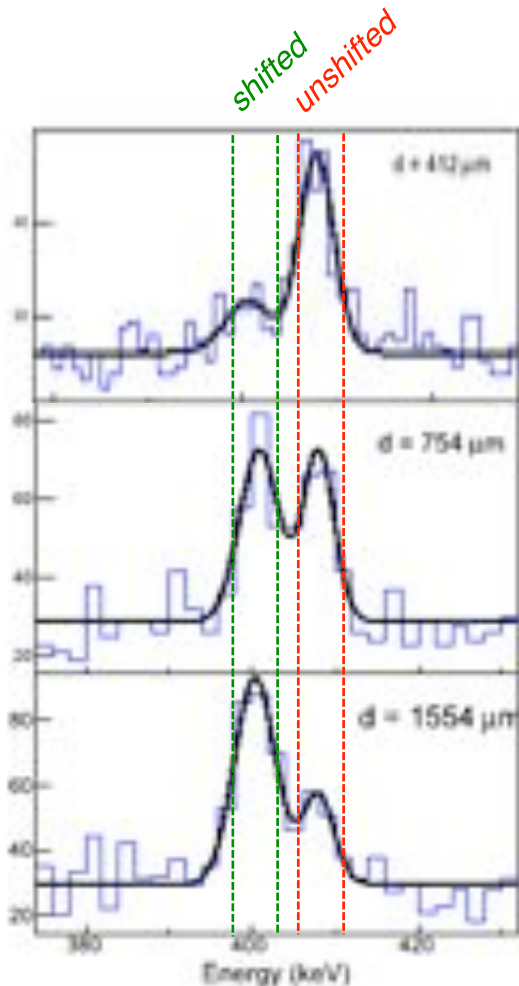
Projected spectra for the most neutron-rich Pd even isotopes



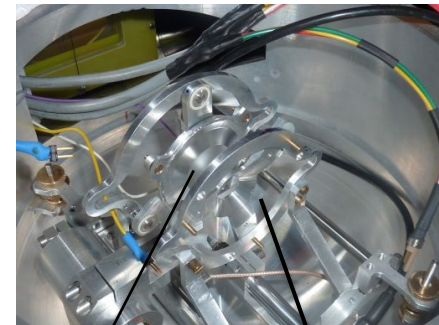
Analysis

The Recoil Distance Doppler Shift method

- RDDS method :
- Measurements of lifetimes $\tau \sim 10^{-12} - 10^{-9}$ s
 - Doppler shift of γ detected at backward angles



The Cologne plunger set up



Target Degrader

- 3 Exogam clovers at $\theta = 135^\circ$
- 7 distances from 35 μm to 1550 μm , 24h per distance
- $\beta_1 \approx 0.11$, $\beta_2 \approx 0.09$

Measure of the relative intensity of the 2 peaks
decay curve of the level :

$$Q_i(x) = \frac{I_i^u(x)}{I_i^u(x) + I_i^s(x)}$$

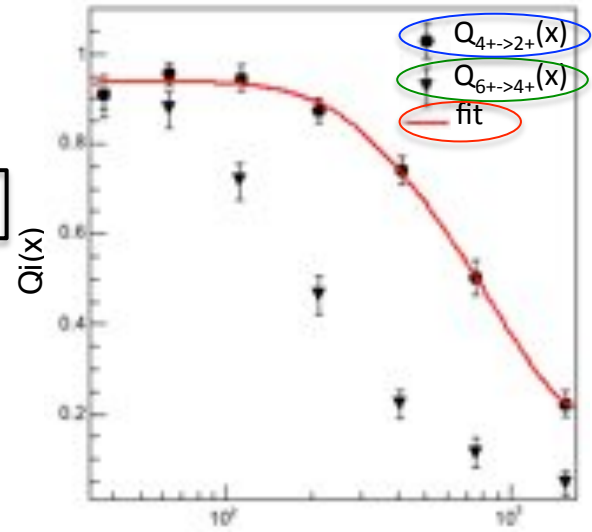
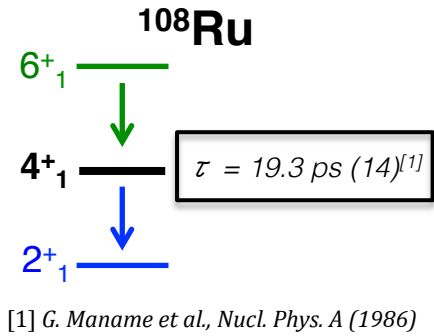
Results

Extraction of the lifetime: DDCM analysis

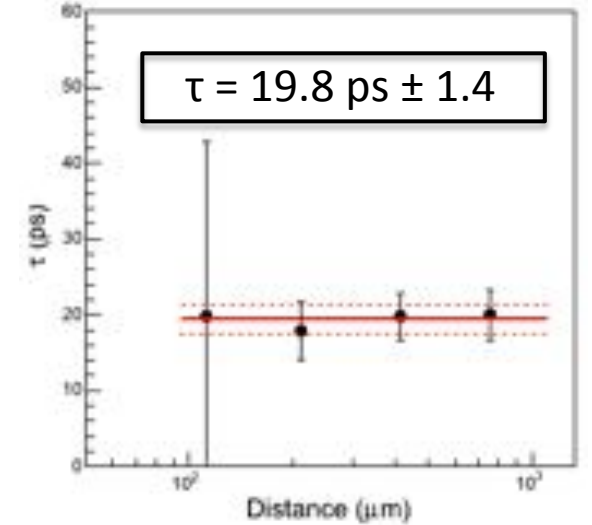
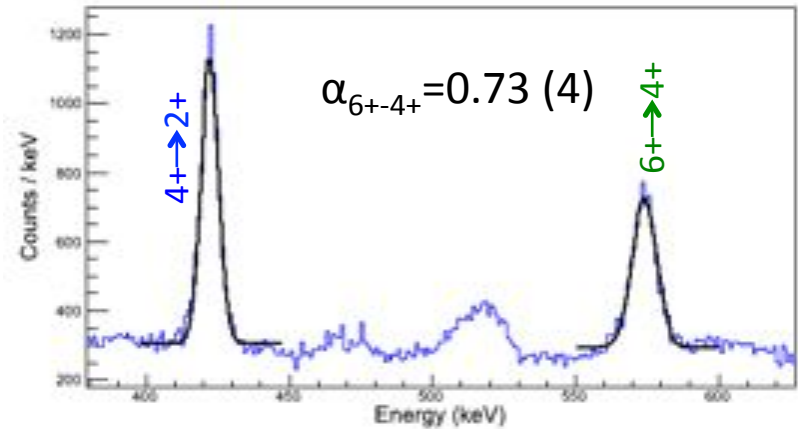
Differential Decay Curve Method

$$\tau_i(x) = \frac{Q_i(x) - \sum_j \alpha_{ij} Q_j(x)}{v \frac{dQ_i}{dx}(x)}$$

A. Dewald, Z. Phys.A Atomic Nuclei 334,(1989)



Nuclei velocity before the degrader:
 $v \approx 33 \text{ } \mu\text{m/ps}$



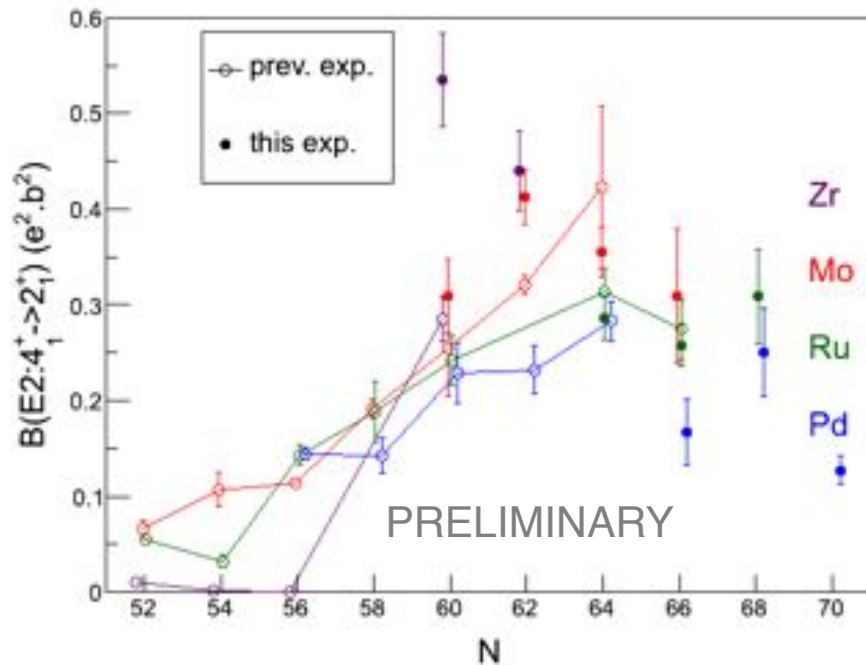
➡ agreement with the previous value

Results

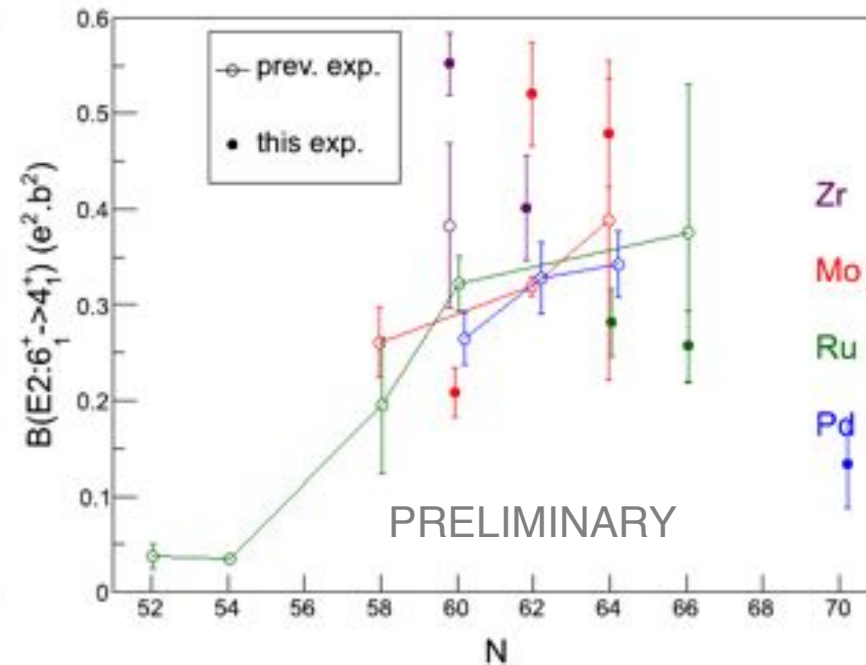
Lifetimes and B(E2)

- ◆ Extraction of 20 lifetimes among which 10 for the first time
- ◆ Deduced reduced transition probabilities :

$4^+ \rightarrow 2^+$ transition



$6^+ \rightarrow 4^+$ transition



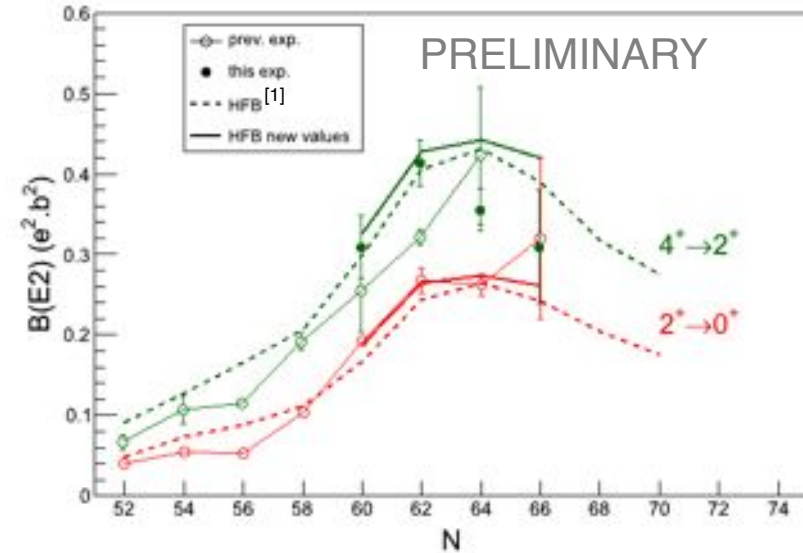
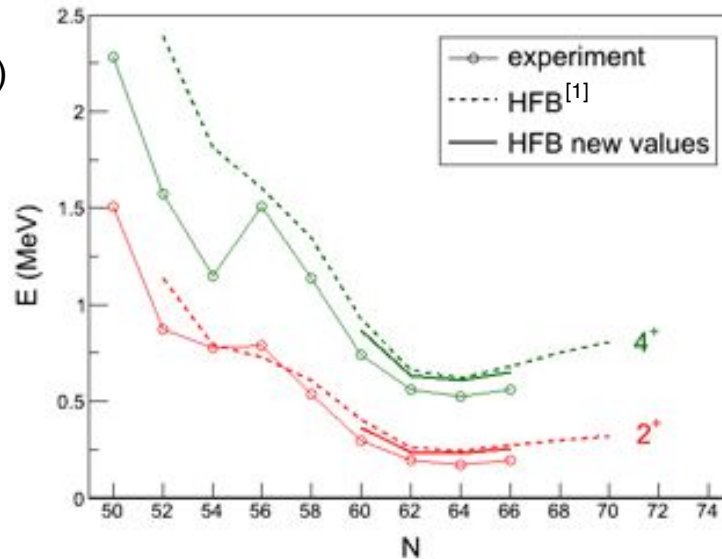
Results

Comparison with HFB+GCM predictions

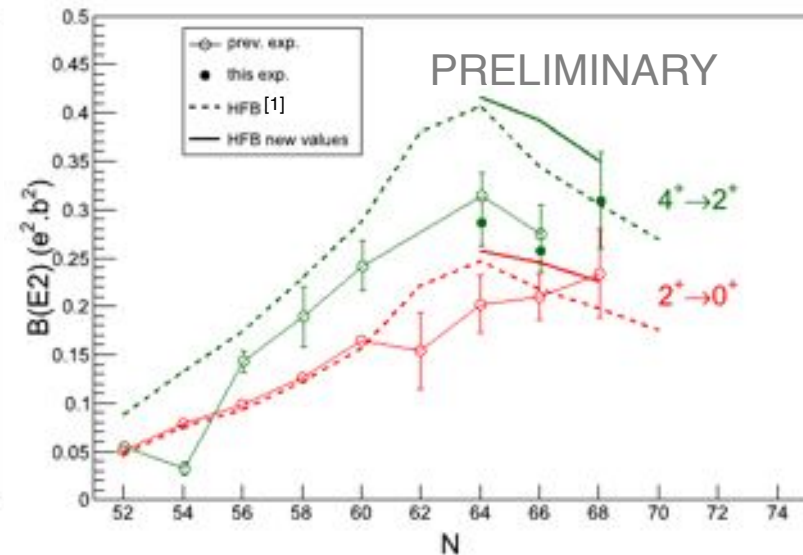
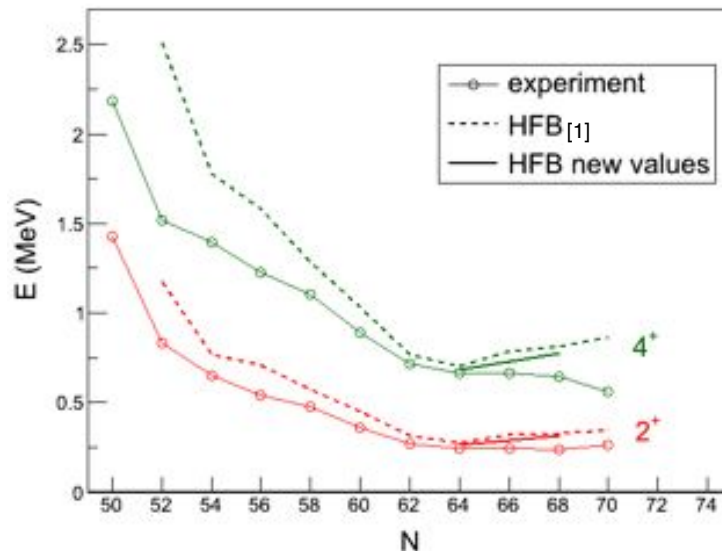
HFB+GCM calculations with Gogny D1S interaction^[1] (N. Pillet, CEA/DAM)

^[1] : J.-P. Delaroche et al., Phys. Rev. C 81, 014303 (2010)

Mo (Z=42)



Ru (Z=44)



Conclusion

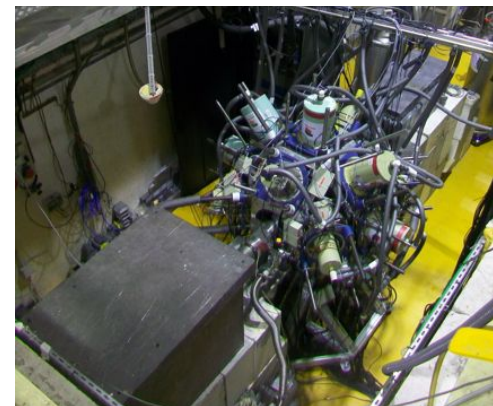
- ◆ **First RDDS experiment on fission fragments identified in A and Z**
 - Identification of nuclei, from Se (Z=34) to Xe (Z=54) with good resolution of $\Delta A/A=1/200$ and $\Delta Z/Z=1/60$
 - **More neutron rich nuclei** studied : up to 10 neutrons above stability
 - **High spin** : observed transitions up to 10^+
- ◆ **New experimental data on the collectivity in the mass 100 region**
 - 20 lifetimes measured of 4^+ and 6^+ levels, among which **10 measured for the first time**
- ◆ **Comparison with HFB+GCM calculation :**
 - agreement between experimental and theoretical data
 - maximum of collectivity at $N \approx 64/66$

Perspectives for the study of the mass 100 region

Two other lifetime measurement experiments :

- ◆ **EXILL-FATIMA campaign** (performed in march 2013)

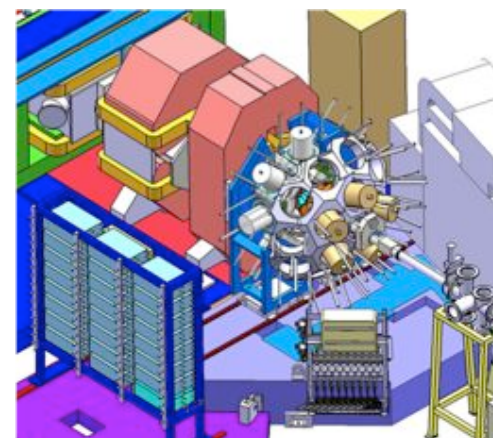
- Neutrons induced fission at ILL on ^{235}U and ^{241}Pu targets
- fast-timing set up (LaBr₃ detectors + EXOGAM)
→ **longer lifetimes** ($\tau \rightarrow 10^{-9}$ s)



EXOGAM at ILL

- ◆ **AGATA campaign at GANIL** (intended in 2014-2015)

- Set-up: VAMOS spectrometer, AGATA and plunger
- Fusion-fission in inverse kinematics
- Study of more neutron-rich nuclei and γ -bands,
 γ - γ coincidences



AGATA at GANIL

Collaborators

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