Nuclear shape evolution through lifetime measurement in neutron rich nuclei

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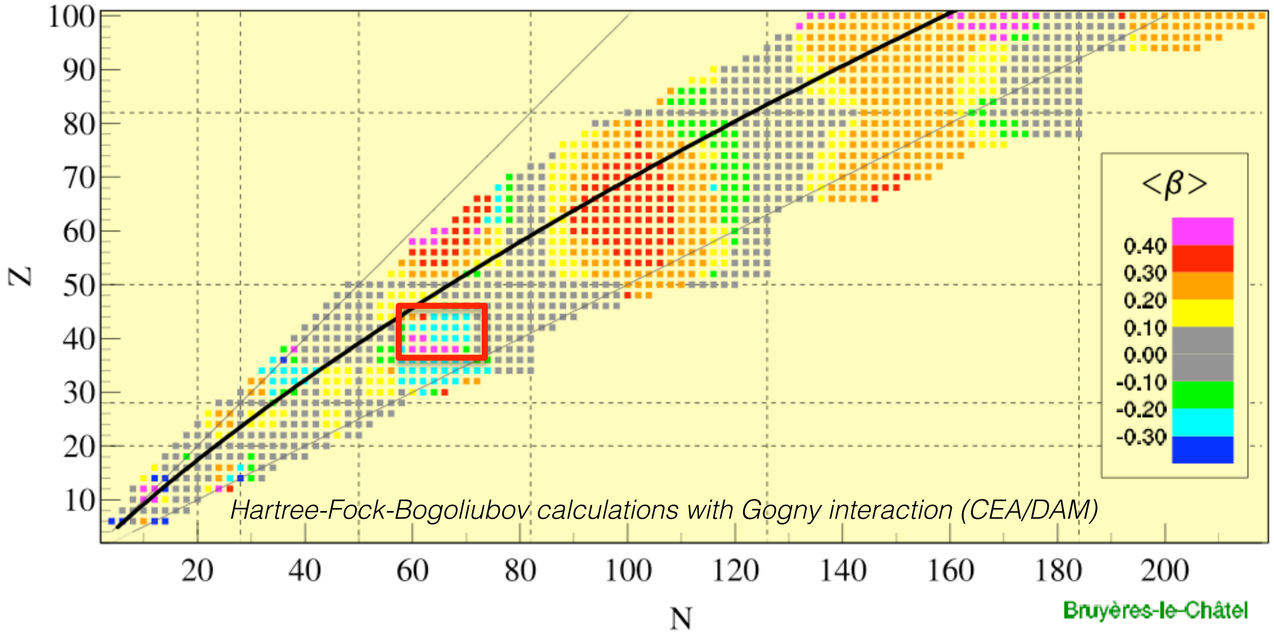
Motivation

Shape evolution and collectivity in the region of A~100



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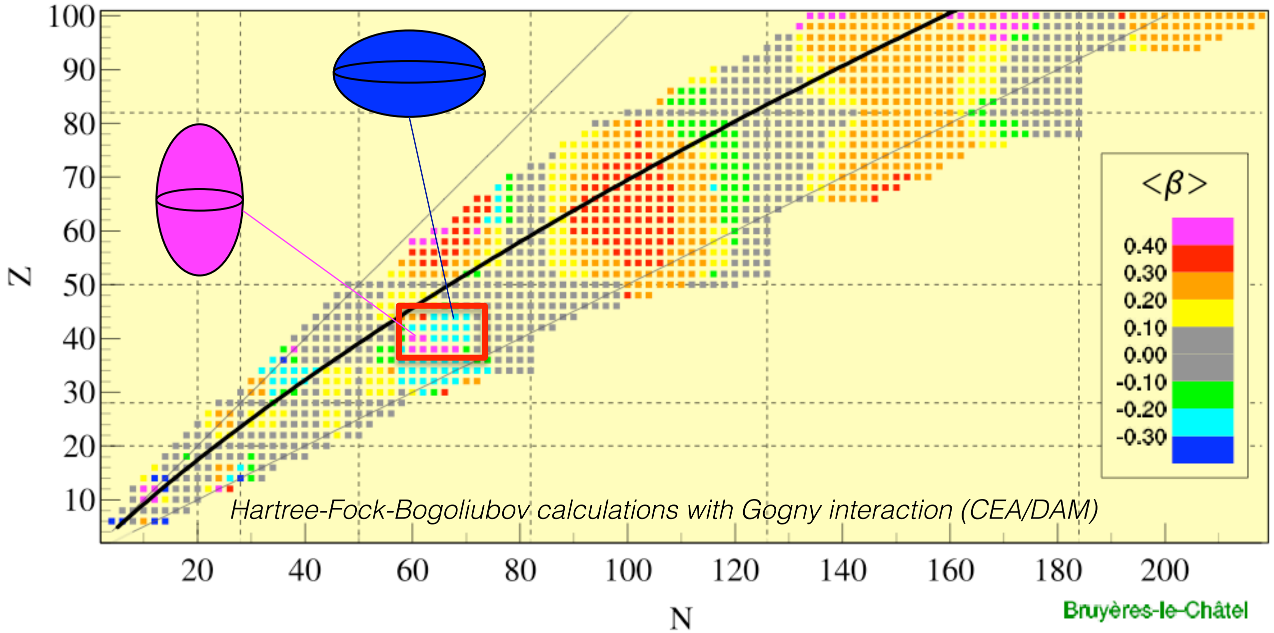

Prolates and oblates shapes in the region of A~100

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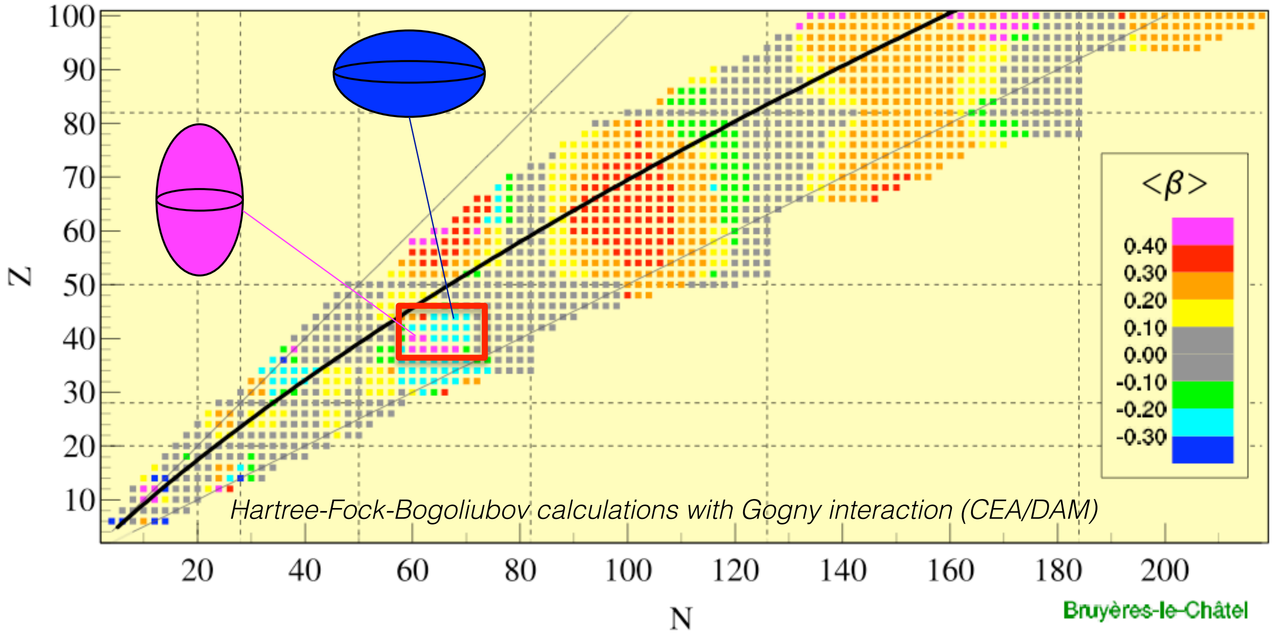

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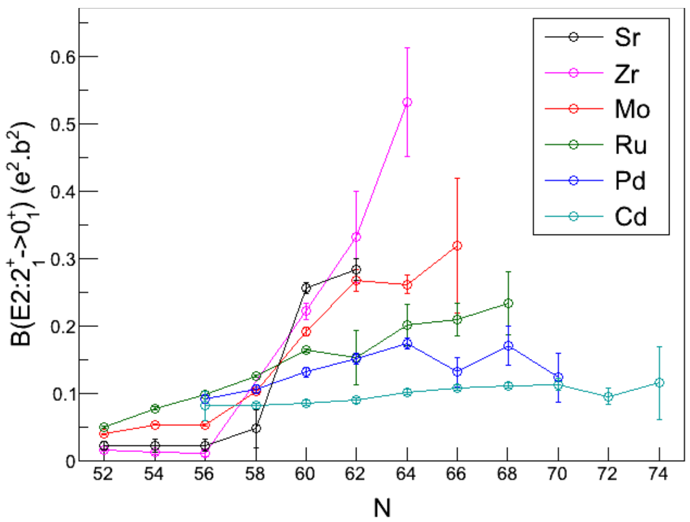

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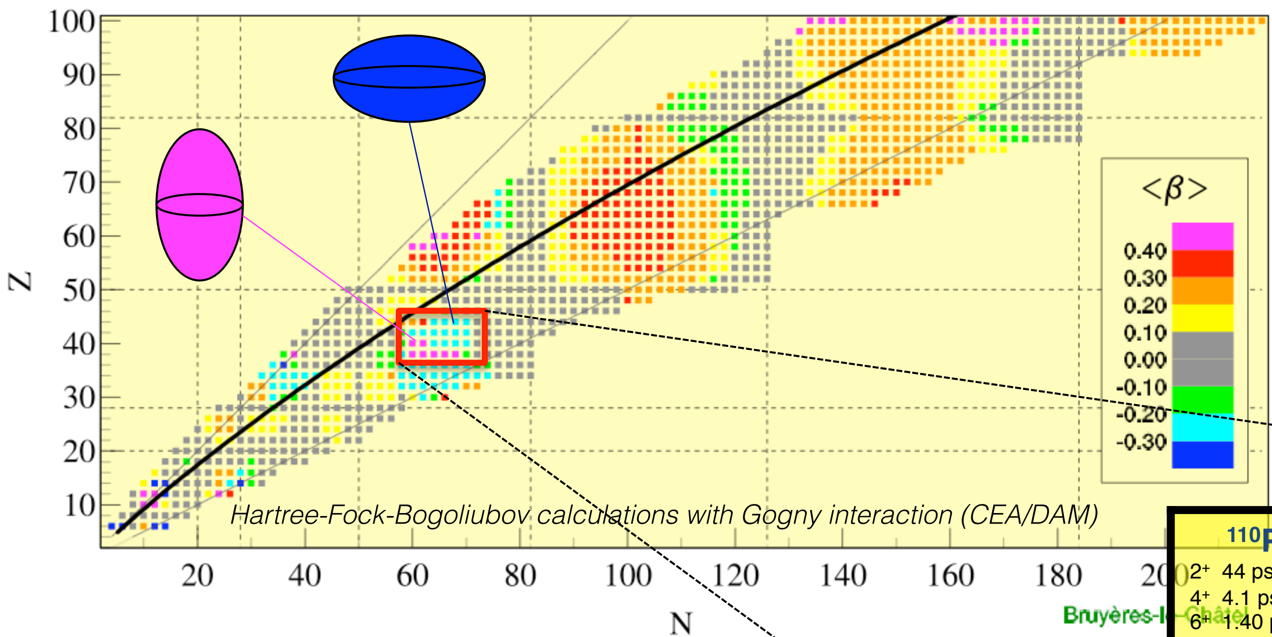
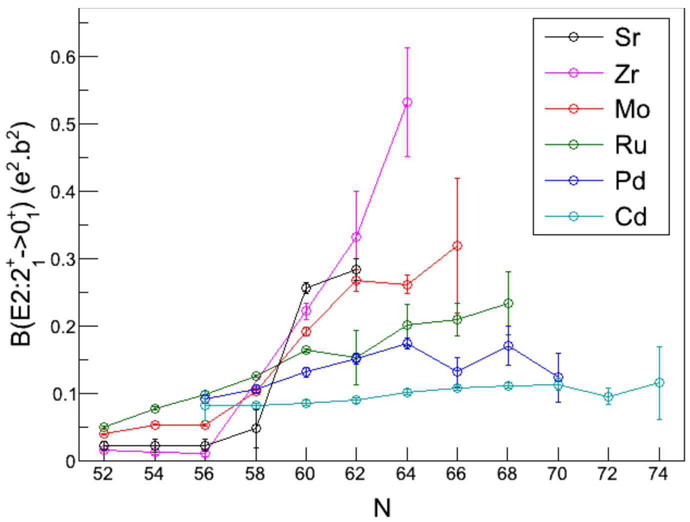
Shape evolution and collectivity in the region of A~100



Prolates and oblates shapes in the region of A~100

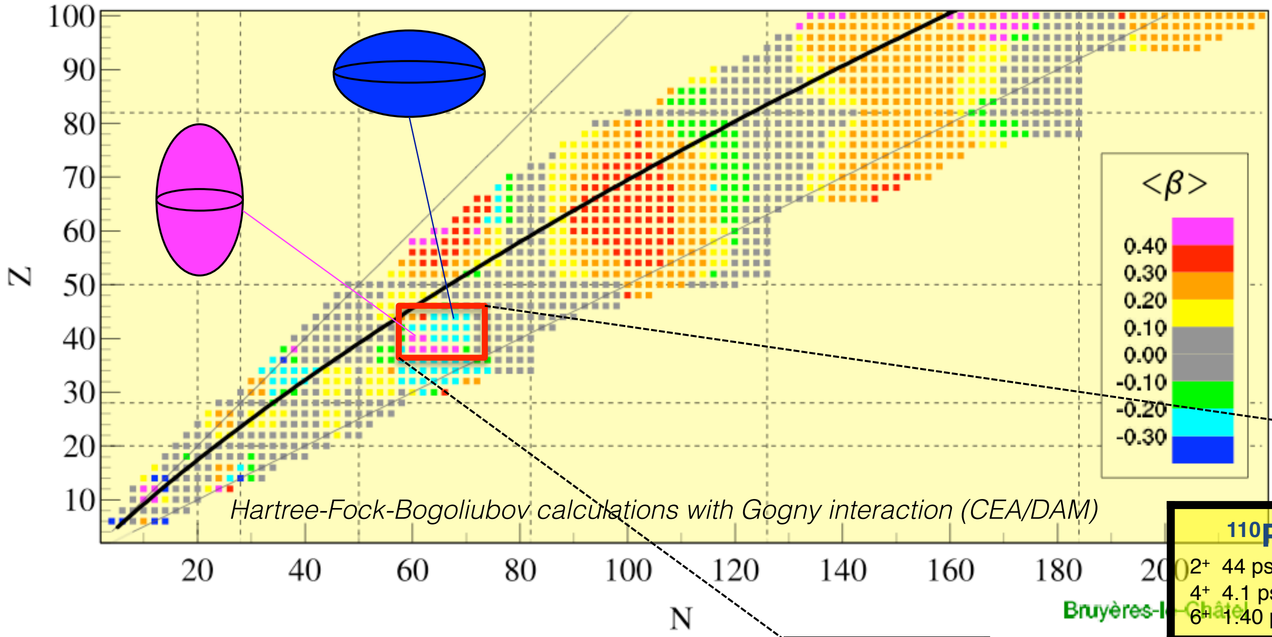


		^{110}Pd 2+ 44 ps(7) 4+ 4.1 ps(3) 6+ 1.40 ps(14)	**^{112}Pd** 2+ 84 ps(14) 4+ ??? 6+ ???	**^{114}Pd** 2+ 82 ps(14) 4+ ??? 6+ ???	**^{116}Pd** 2+ 0.11 ns(3) 4+ ??? 6+ ???
^{104}Ru 2+ 56.4 ps(10) 4+ 5.6 ps(6) 6+ 1.33 ps(12)	**^{106}Ru** 2+ 0.20 ns(3) 4+ ??? 6+ ???	**^{108}Ru** 2+ 0.36 ns(3) 4+ 13.4 ps(10)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

Lifetime of the first excited states

Motivation

Shape evolution and collectivity in the region of A~100



Prolates and oblates shapes in the region of A~100

		^{110}Pd 2+ 44 ps(7) 4+ 4.1 ps(3) 6+ 1.40 ps(14)	^{112}Pd 2+ 84 ps(14) 4+ ??? 6+ ???	^{114}Pd 2+ 82 ps(14) 4+ ??? 6+ ???	^{116}Pd 2+ 0.11 ns(3) 4+ ??? 6+ ???
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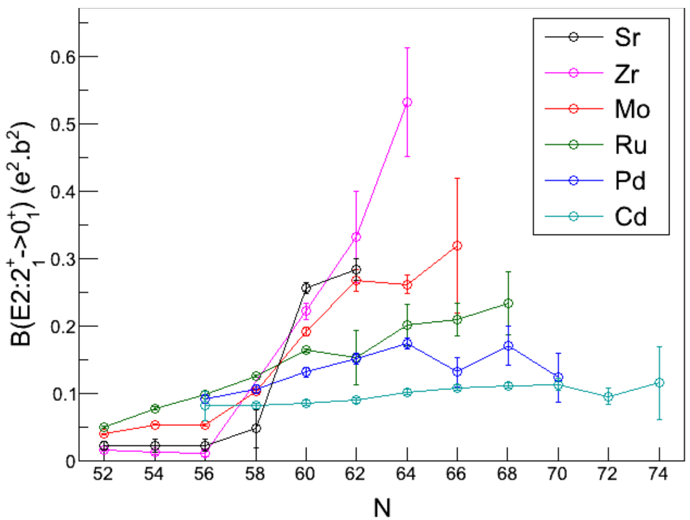
Lifetime of the first excited states



Objective : extend B(E2) data to higher spin

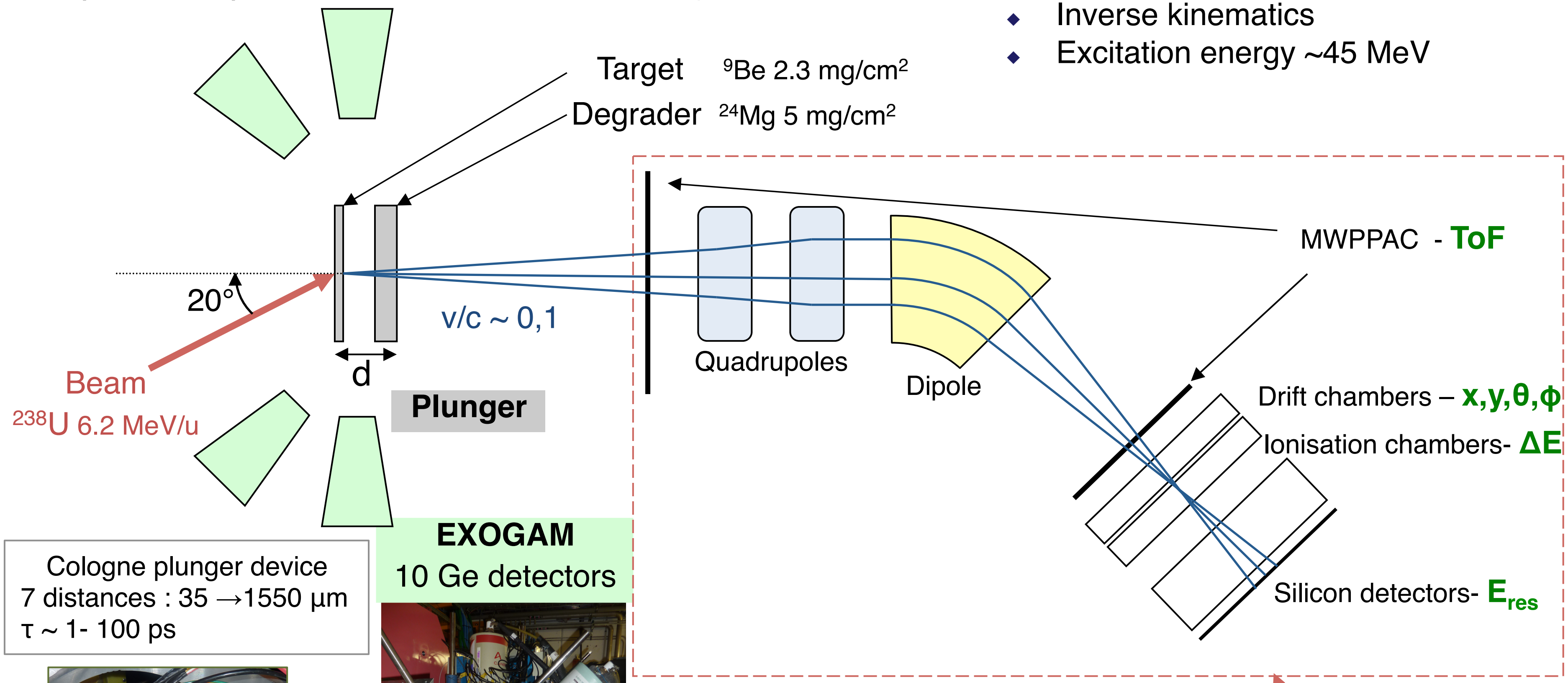
➡ **Lifetime measurement in neutron rich Zr, Mo, Ru and Pd isotopes**

Experimental method

Set up

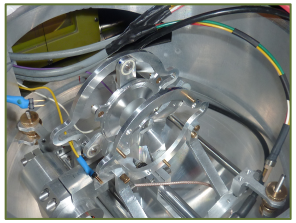
Experiment performed at GANIL (E604, April 2011)

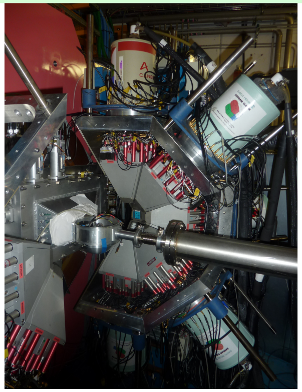
- Fusion-fission reaction $^{238}U + {}^{9}Be$
- Inverse kinematics
- Excitation energy ~45 MeV

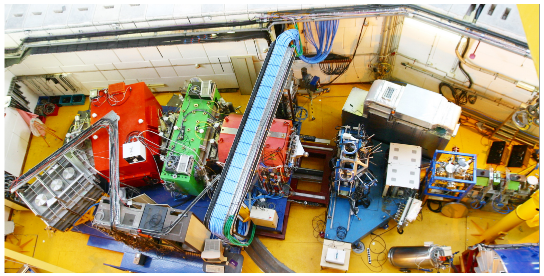


Cologne plunger device
7 distances : 35 →1550 µm
τ ~ 1- 100 ps

EXOGAM
10 Ge detectors







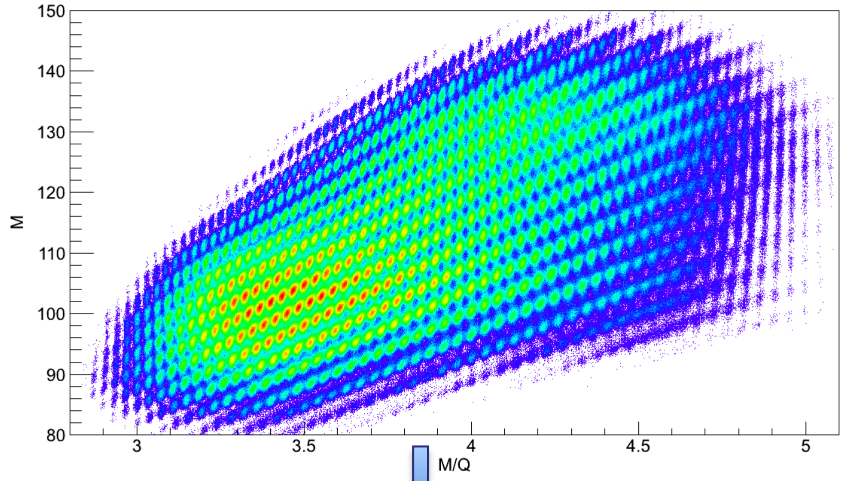
VAMOS spectrometer

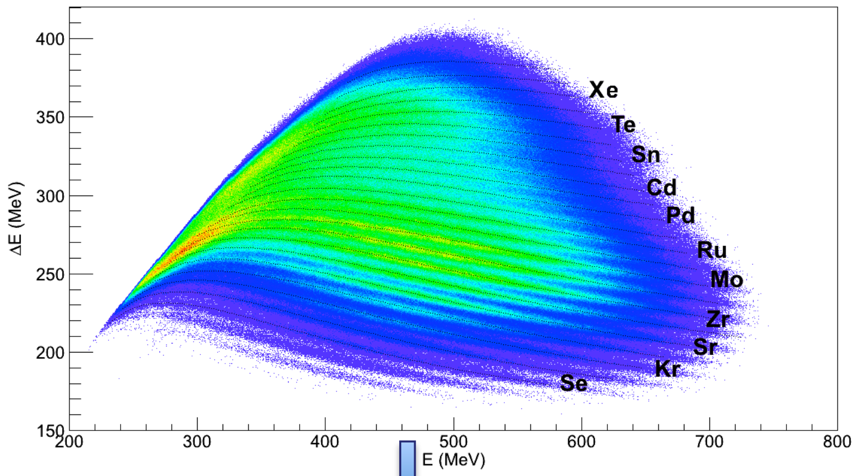
Identification in Q, M et Z of the fission fragments

Analysis

The VAMOS spectrometer

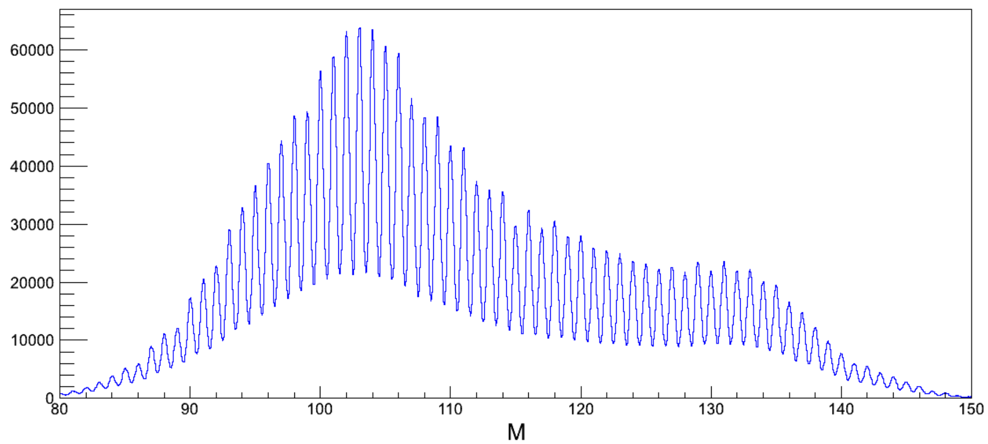
- Identification matrices from VAMOS focal plane





Mass

Atomic number



Total mass distribution of the detected fission fragments

Resolution

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

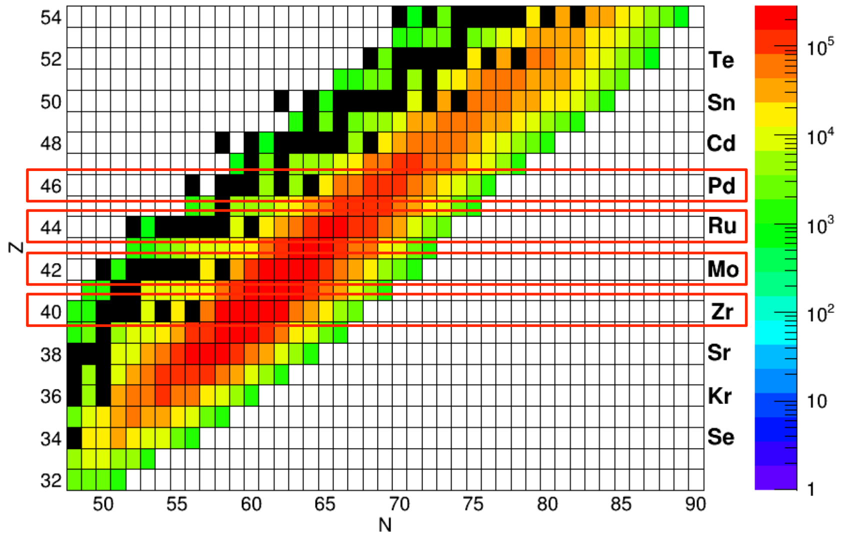
$$\frac{\Delta M}{M} = \frac{1}{200}$$

Analysis

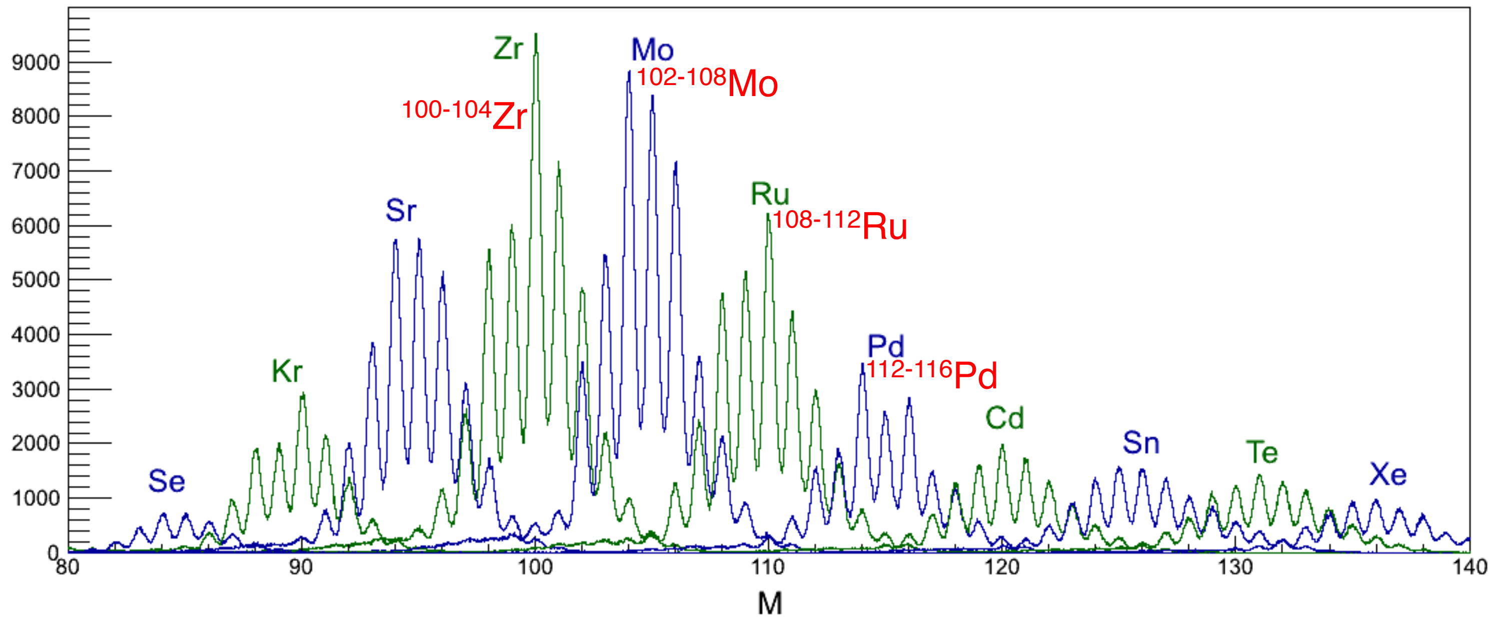
The VAMOS spectrometer

- 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

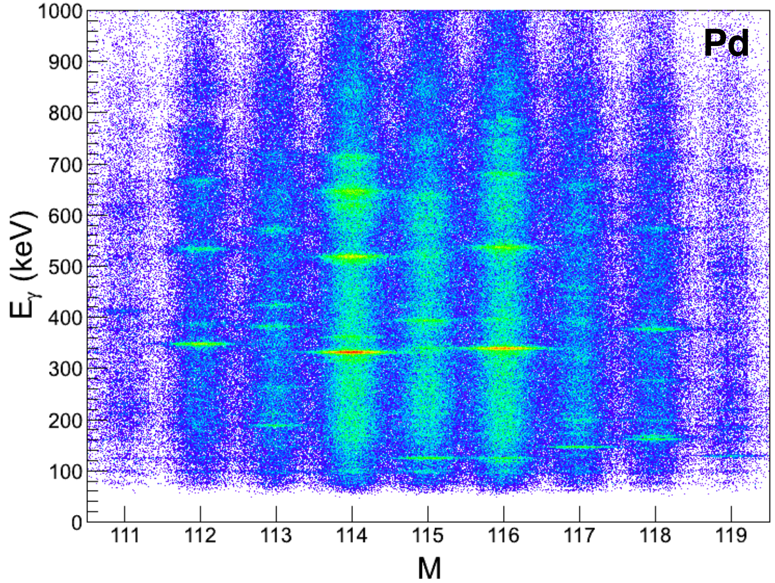


Lifetimes in neutron rich Zr, Mo, Ru and Pd isotopes

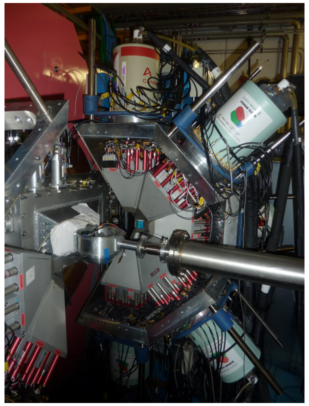
Analysis

EXOGAM

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

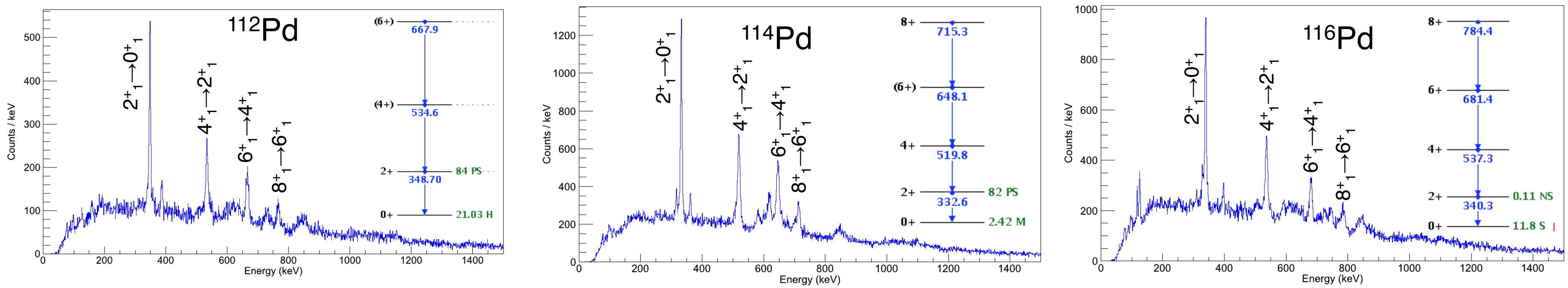


EXOGAM



- 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

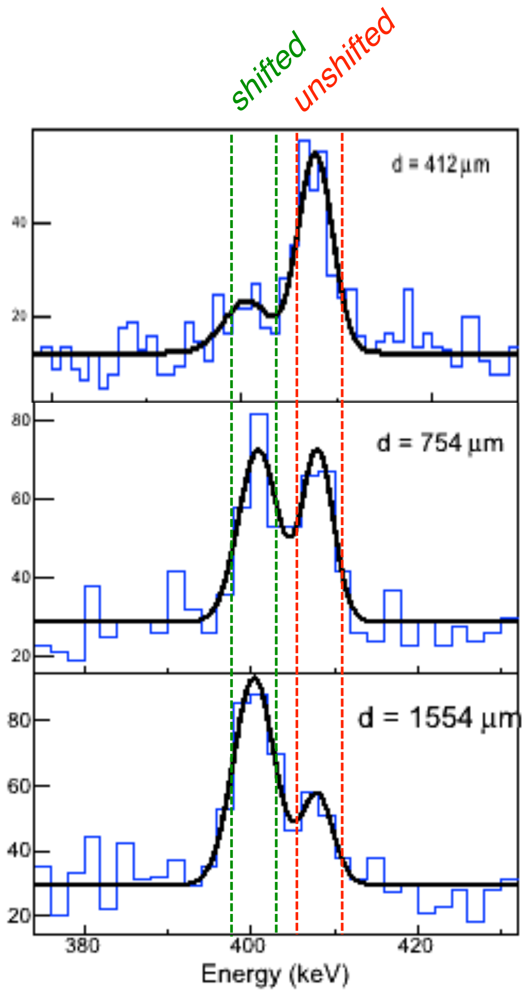


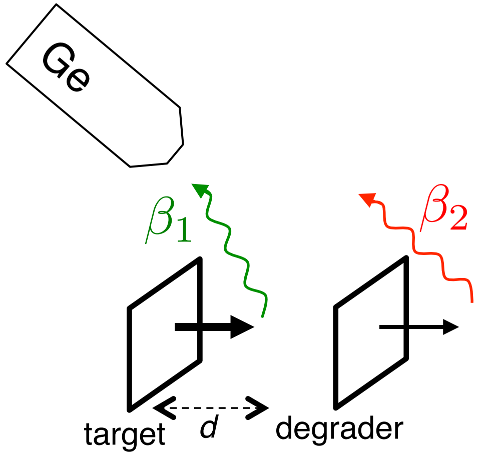
Analysis

The Recoil Distance Doppler Shift method

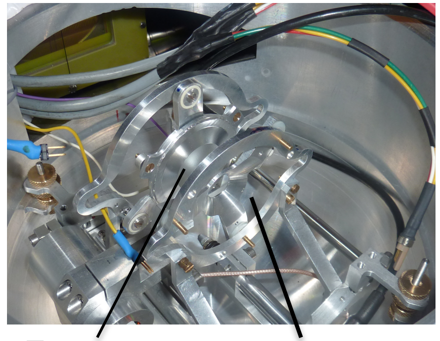
RDDS method :

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





The Cologne plunger set up



- 3 Exogam clovers at θ =135°
- 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

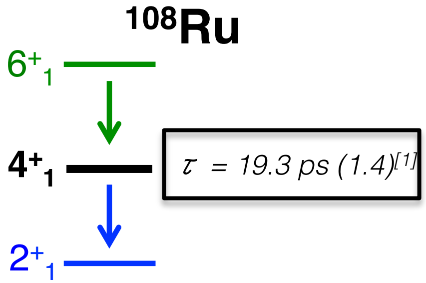
Extraction of the lifetime: DDCM analysis

Differential Decay Curve Method

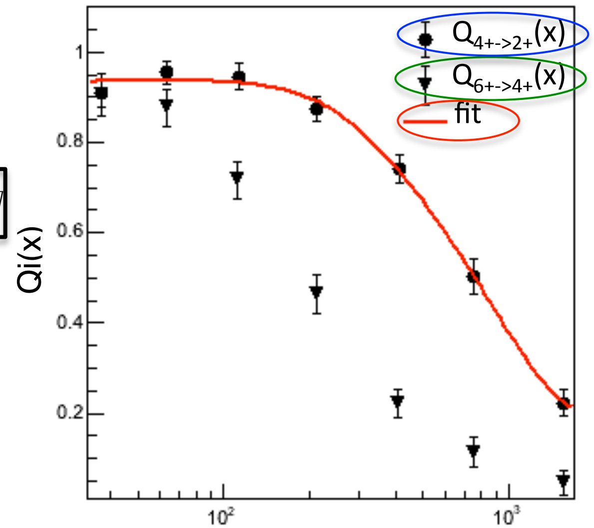
$$\tau_i(x) = -\frac{Q_i(x) - \sum_j \alpha_{ij} Q_j(x)}{v \frac{dQ_i}{dx}(x)}$$

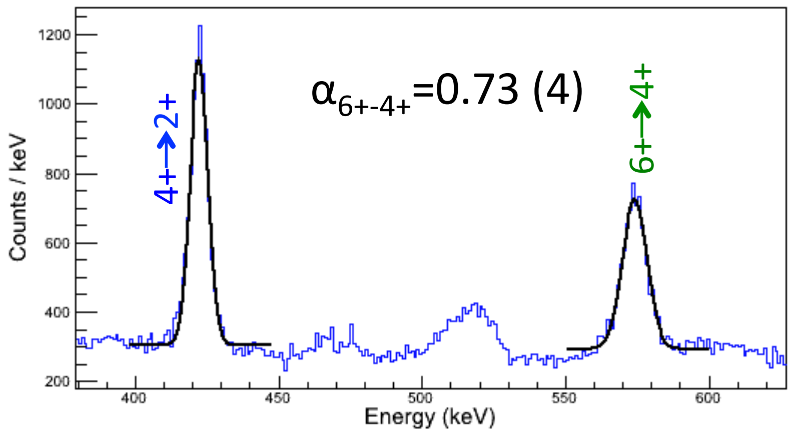
A. Dewald, Z. Phys.A Atomic Nuclei 334,(1989)

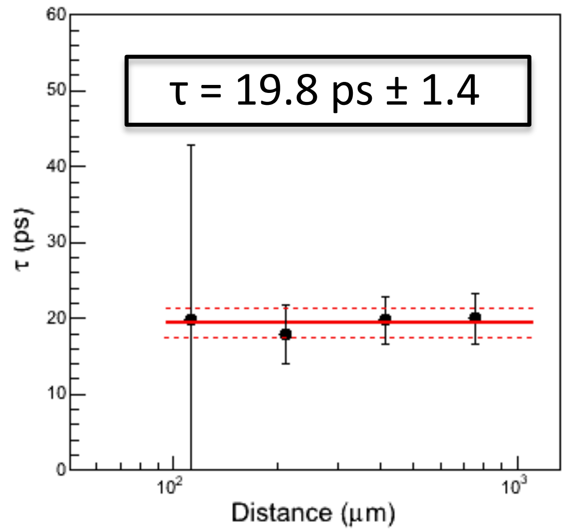
Nuclei velocity
before the degrader:
v ≈ 33 µm/ps



[1] *G. Mamane et al., Nucl. Phys. A (1986)*







➡ agreement with the previous value

Results

Lifetimes

- Extraction of 20 lifetimes among which 10 for the first time

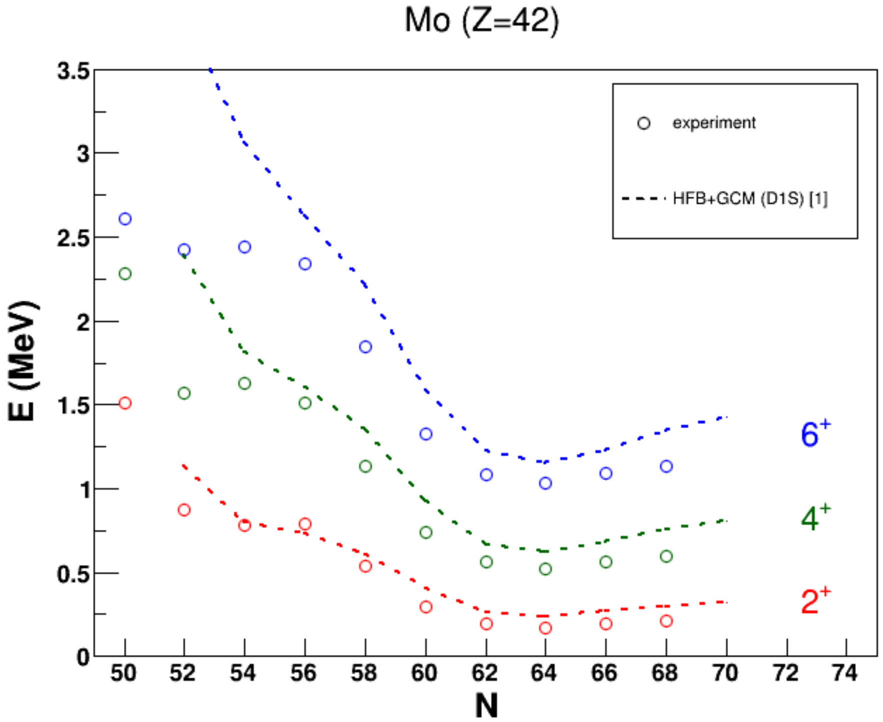
- Comparison with previous measures

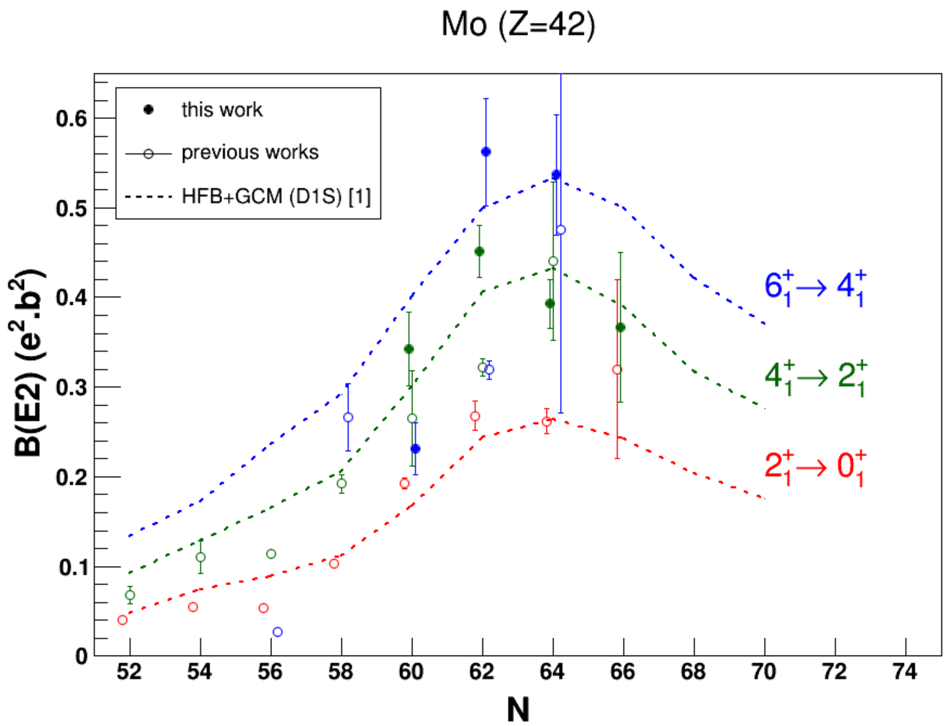
PRELIMINARY

			^{110}Pd 2^+ 44 ps(7) 4^+ 4.1 ps(0.3) 6^+ 1.40 ps(0.14)	**^{112}Pd** 2^+ 84 ps(14) 4^+ **5.4 ps (1.7)**	**^{114}Pd** 2^+ 82 ps(14) 4^+ **5.4 ps (1.0)** 6^+	**^{116}Pd** 2^+ 0.11 ns(0.03) 4^+ **8.7 ps (1.3)** 6^+ **2.6 ps (0.9)**
	^{104}Ru 2^+ 56.4 ps(1.0) 4^+ 5.6 ps(0.6) 6^+ 1.33 ps(1.2)	**^{106}Ru** 2^+ 0.20 ns(0.03) 4^+ 6^+	**^{108}Ru** 2^+ 0.36 ns(0.03) 4^+ 13.4 ps(1.0) **13.4 ps (1.0)** 6^+ **2.9 ps (0.3)**	**^{110}Ru** 2^+ 0.32 ns(0.02) 4^+ 15.4 ps(1.7) **14.9 ps (1.2)** 6^+ 2.4 ps(1.0) **3.2 ps (0.5)**	**^{112}Ru** 2^+ 0.32 ns(0.03) 4^+ **14.4 ps (2.2)** 6^+	
	^{102}Mo 2^+ 125 ps (4) 4^+ 12.5 ps (2.5) **9.4 ps (1.1)** 6^+ **3.5 ps (0.7)**	**^{104}Mo** 2^+ 0.97 ns(0.08) 4^+ 26.1 ps(0.3) **18.6 ps (1.2)** 6^+ 4.73 ps(15) **2.7 ps (0.3)**	**^{106}Mo** 2^+ 1.25 ns(0.03) 4^+ 25.4 ps(5.1) **27.5 ps (1.9)** 6^+ 4.2 ps(1.8) **3.1 ps (0.4)**	**^{108}Mo** 2^+ 0.5 ns(0.3) 4^+ **23.3 ps (5.3)** 6^+		
^{98}Zr 2^+ <11ps **7.1 ps $^{+1.0}_{-4.0}$** 4^+ 28 ps(3)	**^{100}Zr** 2^+ 0.59 ns(0.03) 4^+ 37 ps(3) **18.1 ps (1.6)** 6^+ 4.9 ps(1.1) **3.0 ps (0.4)**	**^{102}Zr** 2^+ 1.8 ns(0.4) 4^+ **32.0 ps (3.3)** 6^+ **4.7 ps (0.6)**	**^{104}Zr** 2^+ 2.0 ns(0.3) 4^+ 6^+			

Experimental half-life values:
previous measures
this experiment

Collectivity evolution in Mo isotopes

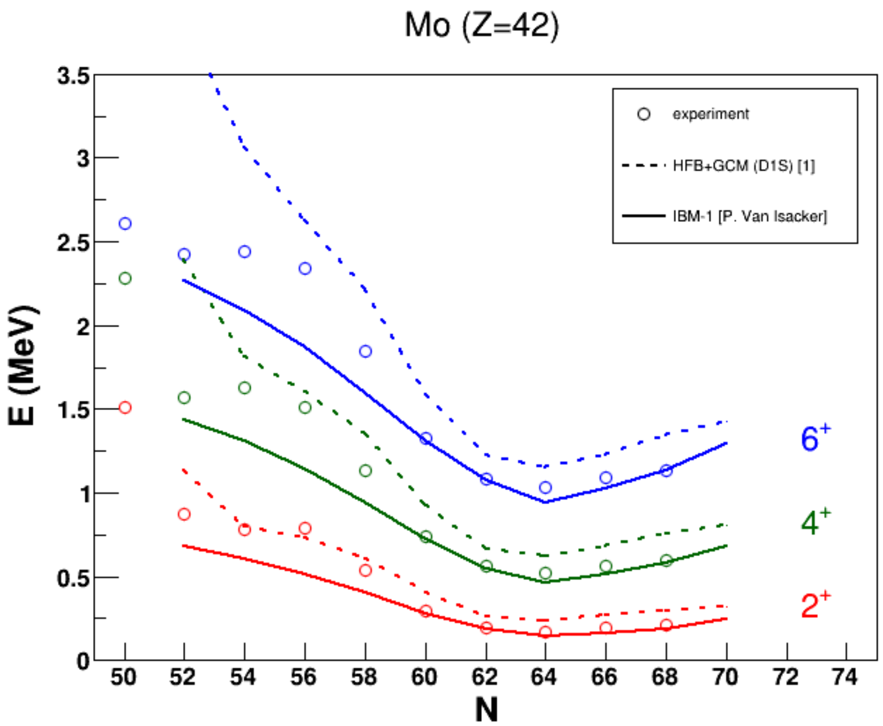


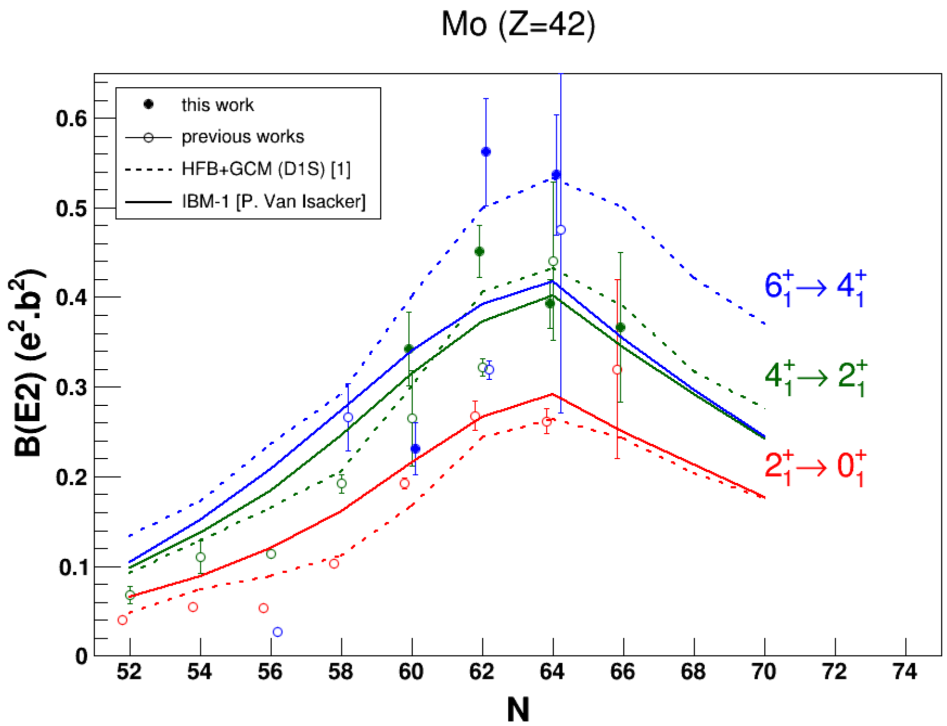


- Comparison with beyond mean field HFB + GCM calculations

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

Collectivity evolution in Mo isotopes





- Comparison with beyond mean field HFB + GCM calculations
- Comparison with IBM-I calculations

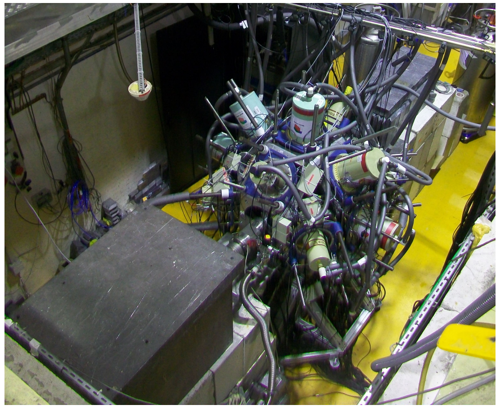
[1] : *J.-P. Delaroche et al., Phys. Rev. C 81, 014303 (2010)*

Conclusion

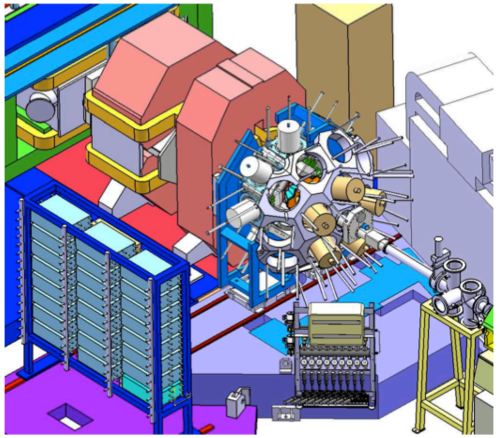
- **First RDDS experiment on fission fragments identified in A and Z**
  - Identification of nuclei, from Se (Z=34) to Xe (Z=54) with good resolution of $\Delta A/A=1/200$ and $\Delta Z/Z=1/60$
  - More neutron rich nuclei studied : up to 10 neutrons above stability
  - High spin : observed transitions 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 (D1S) calculation and IBM calculations :**
  - Maximum of collectivity at $N \approx 64/66$

Perspectives for the experimental study of the mass 100 region

- **EXILL-FATIMA campaign** (performed in 2013)
  - Neutrons induced fission at ILL on ^{235}U and ^{241}Pu targets
  - fast-timing set up ($LaBr_3$ detectors + EXOGAM)
    → longer lifetimes ($\tau \rightarrow 10^{-9}$ s)
- **Coulex of ^{100}Zr at Argonne** (planned for 2014)
  - CARIBU beams and Gammasphere
  - measurement of static quadupole moments in the ground state band
- **AGATA campaign at GANIL**
  - Set-up: VAMOS spectrometer, AGATA and plunger; fusion-fission in inverse kinematics
  - Study of more neutron-rich nuclei and γ-bands,
    γ-γ coincidences



EXOGAM at ILL



AGATA at GANIL

Collaborators

L. Grente[1], M.-D. Salsac[1], W. Korten[1], A. Görgen[2], T. W. Hagen[2], T. Braunroth[3], B. Bruyneel[1], I. Celikovic[4] , E. Clément[4], O. Delaune[4], J.P. Delaroche[5], A. Dijon[4], A. Drouart[1], S. Ertürk[6], F. Farget[4], G. de France[4], A. Gottardo[7], M. Hackstein[3], B. Jacquot[4], J. Libert[5], J. Litzinger[3], J. Ljungvall[8], C. Louchart[1], C. Michelagnoli[7], D. R. Napoli[7], A. Navin[4], N. Pillet[5], A. Pipidis[7], F. Recchia[7], M. Rejmund[4], W. Rother[3], E. Sahin[7], C. Schmitt[4], S. Siem[2], B. Sulignano[1], J. J. Valiente-Dobon[7], K. O. Zell[3], the VAMOS team and the EXOGAM team

[1] CEA Saclay, IRFU/SPhN; [2] University of Oslo ; [3] IKP, University of Köln ; [4] GANIL ; [5]CEA Bruyères-le-Châtel DAM ; [6]Nidge University ; [7]INFN, Laboratori Nazionali di Legnaro ; [8]CSNSM Orsay