Advancements of γ-ray spectroscopy of isotopically identified fission fragments with AGATA and VAMOS++

Jérémie Dudouet
on behalf of the AGATA/VAMOS collaborations

Institut de Physique des deux infinis de Lyon (IP2I)

17th International Symposium on Capture Gamma-Ray Spectroscopy and Related Topics

➡ The presented work is part of the recently published **AGATA Topical Issue in EPJA**:

➥ List of articles covering the different AGATA facets (physics, detectors, electronics, softwares…)

EPJ A — 2021 Impact factor **3.131**

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The European Physical Journal A

AGATA: Advancements in Science and Technology

Nicolas Alamanos, Maria Jose Garcia Borge, Angela Bracco, Emmanuel Clement, Andres Gadea, Wolfram Korten, Silvia Leoni and John Simpson

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THE EUROPEAN PHYSICAL JOURNAL A

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Regular Article - Experimental Physics

Advancements of γ-ray spectroscopy of isotopically identified fission fragments with AGATA and VAMOS++

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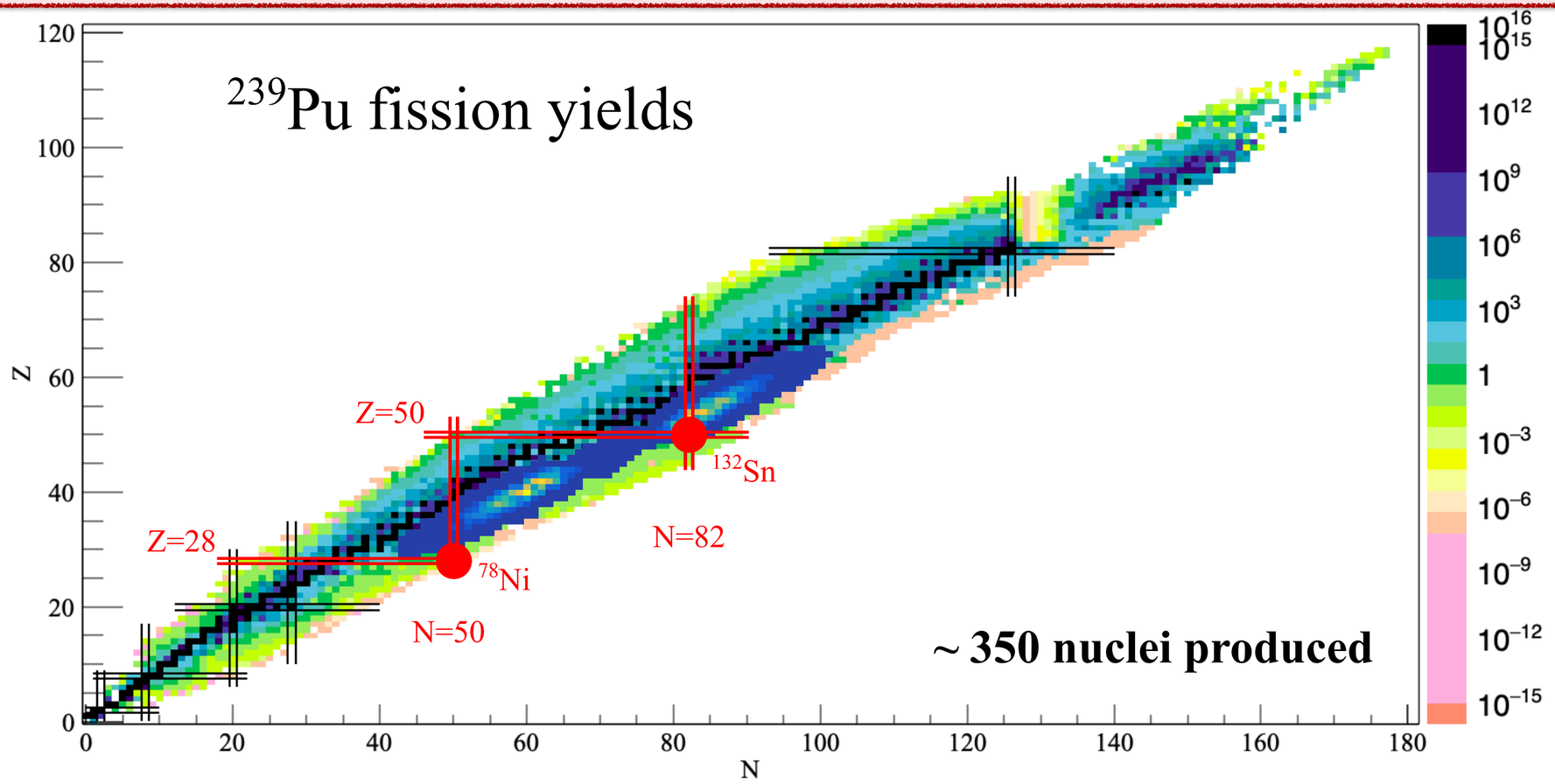
The nuclear fission process

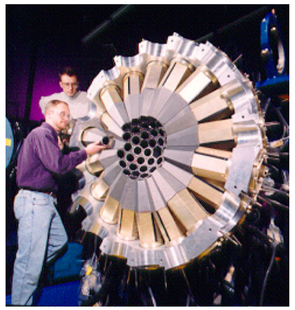
- Powerful and efficient way to produce neutron rich nuclei
- Covering a wide range of key nuclei in the nuclear structure understanding



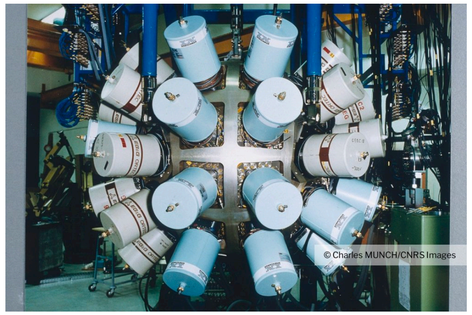
Nuclear fission fragments spectroscopy

➡ Two schools: **High fold studies / fission fragments identification**

GAMMASPHERE

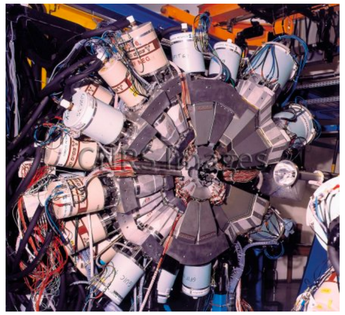


EUROGAM II



NUBALL

EUROBALL IV



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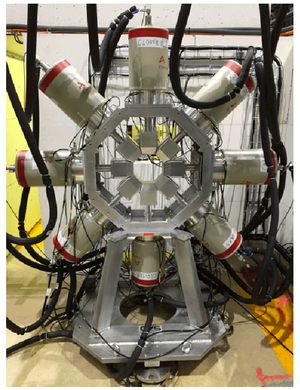
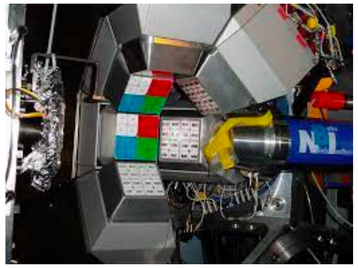
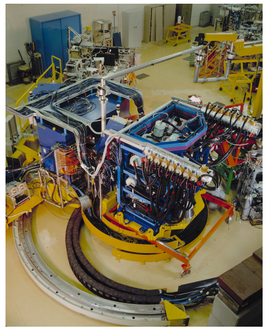


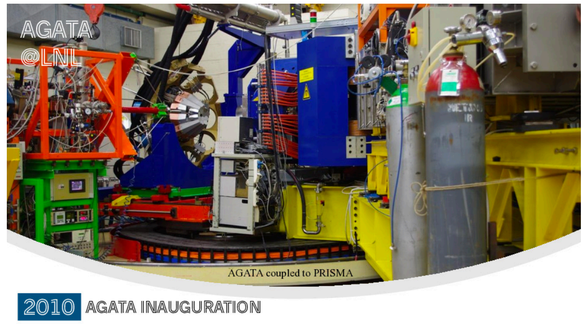
EXOGAM



PRISMA/CLARA

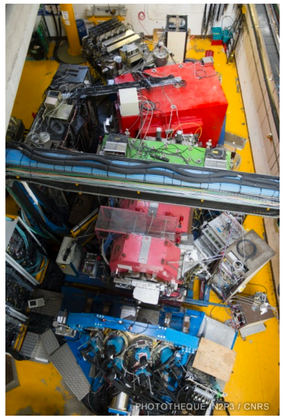


PRISMA/AGATA



VAMOS/EXOGAM

VAMOS++/AGATA



Nuclear fission fragments spectroscopy

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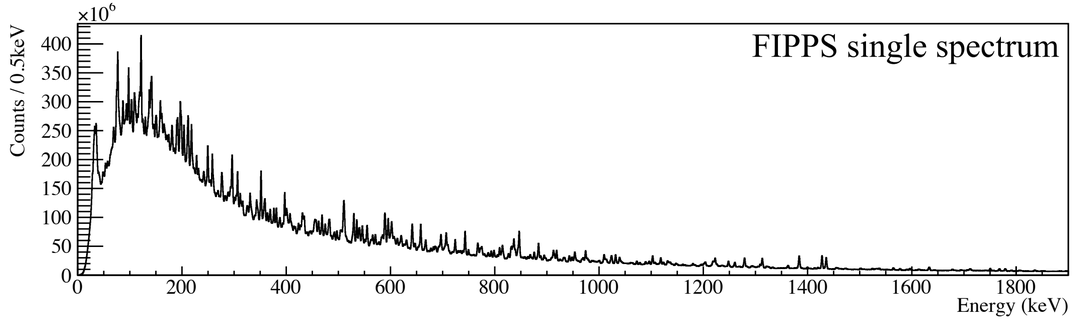
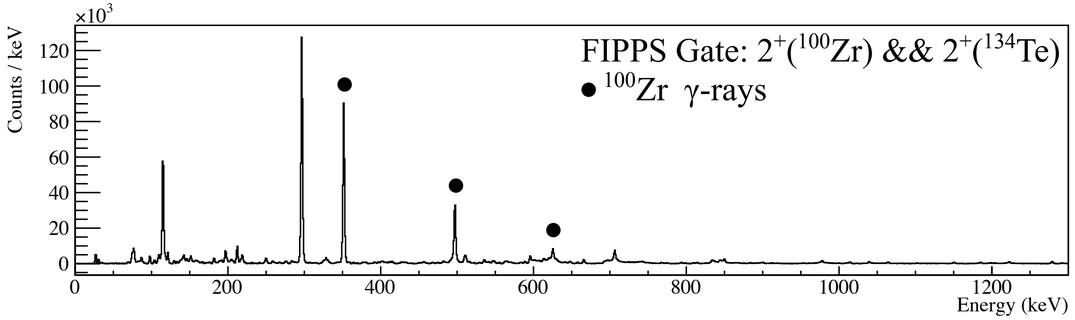
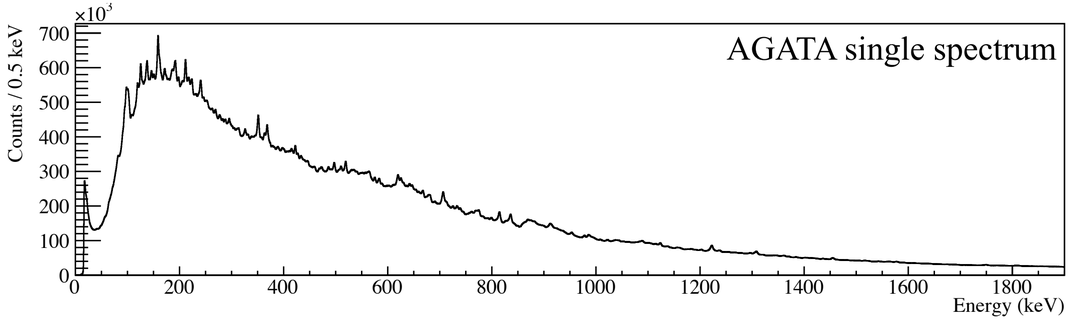
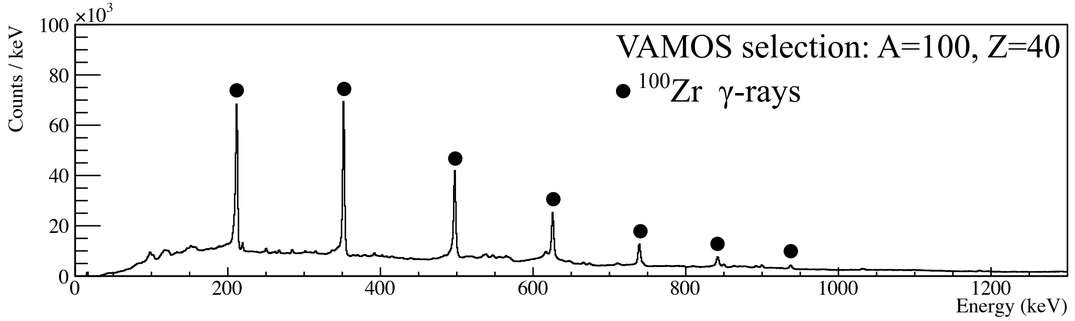




- ✅ Lot of statistics available with high folds (fold ≥ 3)
- ❌ Require a minimal knowledge of the nucleus
- ❌ Complicated analysis to avoid bad γ-ray attribution

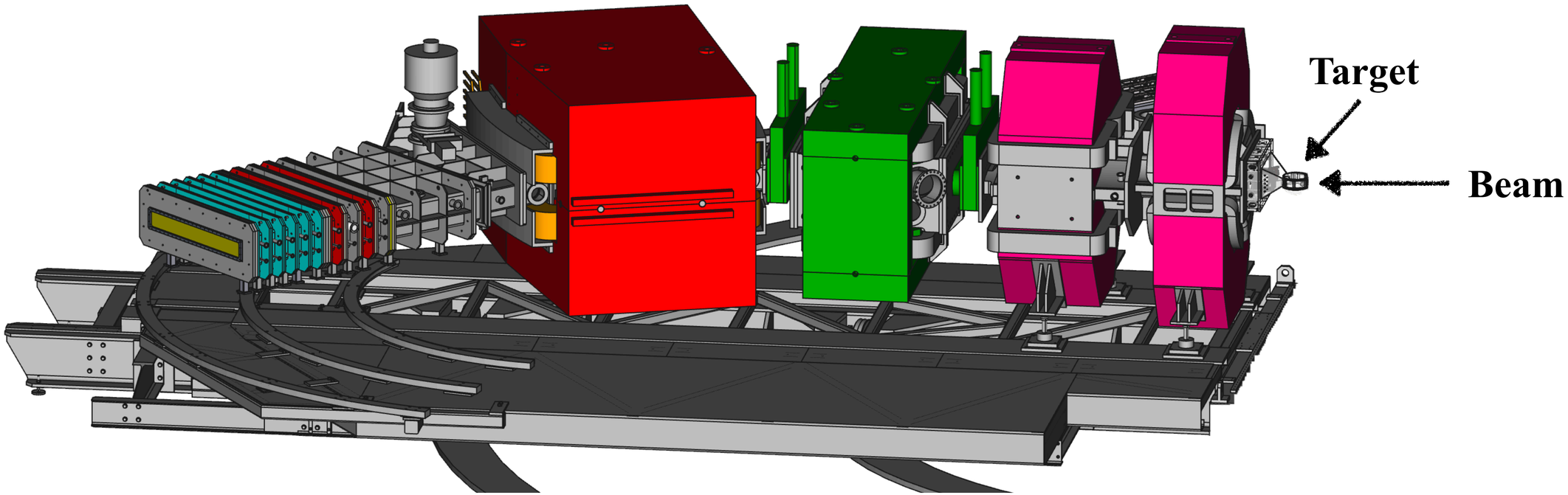




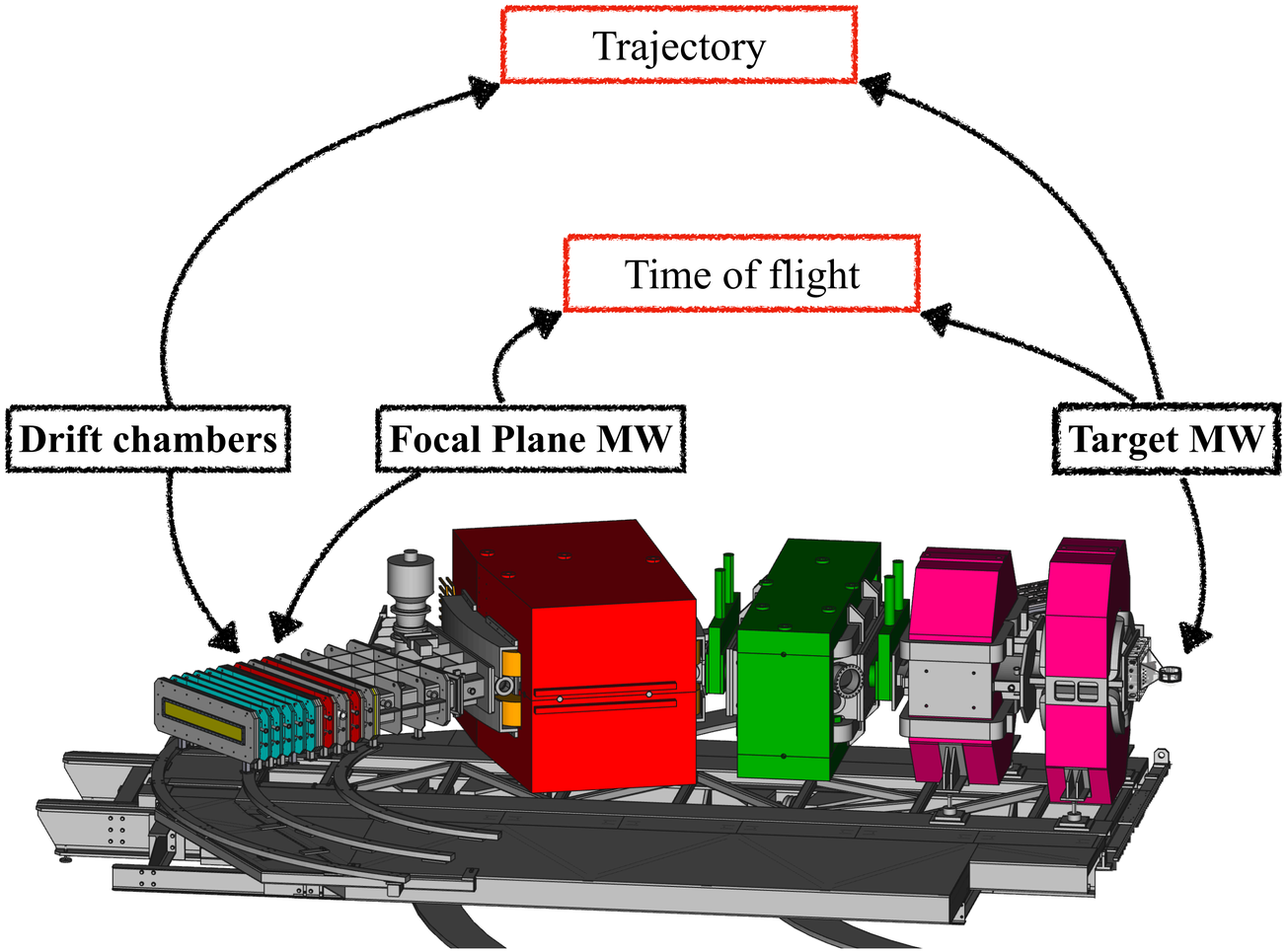
- ❌ Experimental setup much more complicated
- ❌ No statistics for fold ≥ 2 (γ-γ analysis only)
- ✅ Can be used on unknown nuclei
- ✅ Much simpler analysis

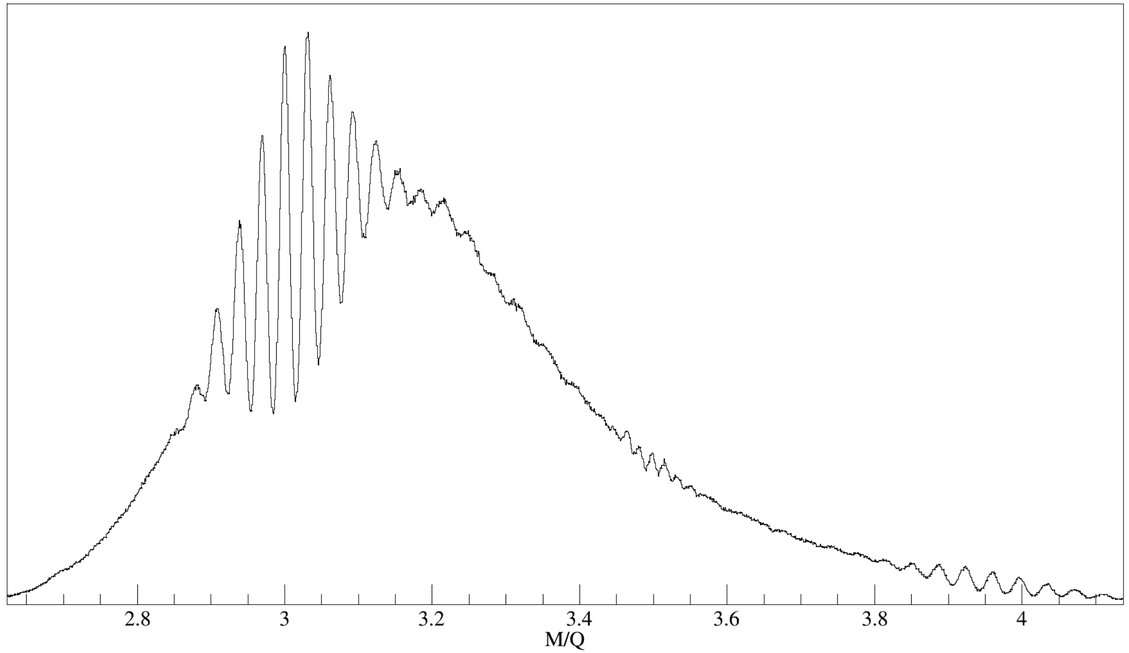
The VAMOS++ spectrometer

- Beam: ^{238}U @ 6.2 MeV/u, I~30enA
- Target: ^{9}Be ~10µm
- Detection angle: 19° < θ < 28°
- Recoil velocities: β ~ 0.1
- Validation rate: ~ 1.5 kHz



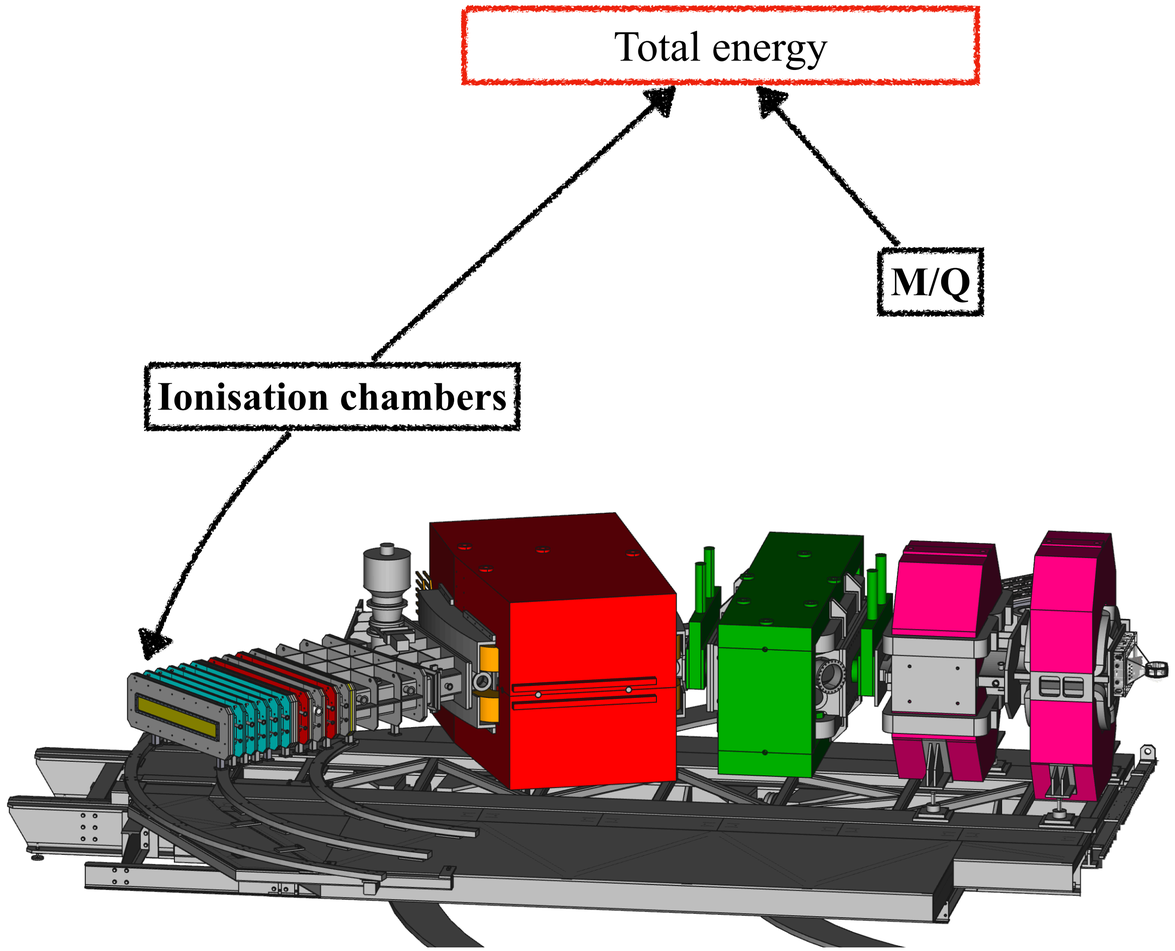
The VAMOS++ spectrometer: Mass identification

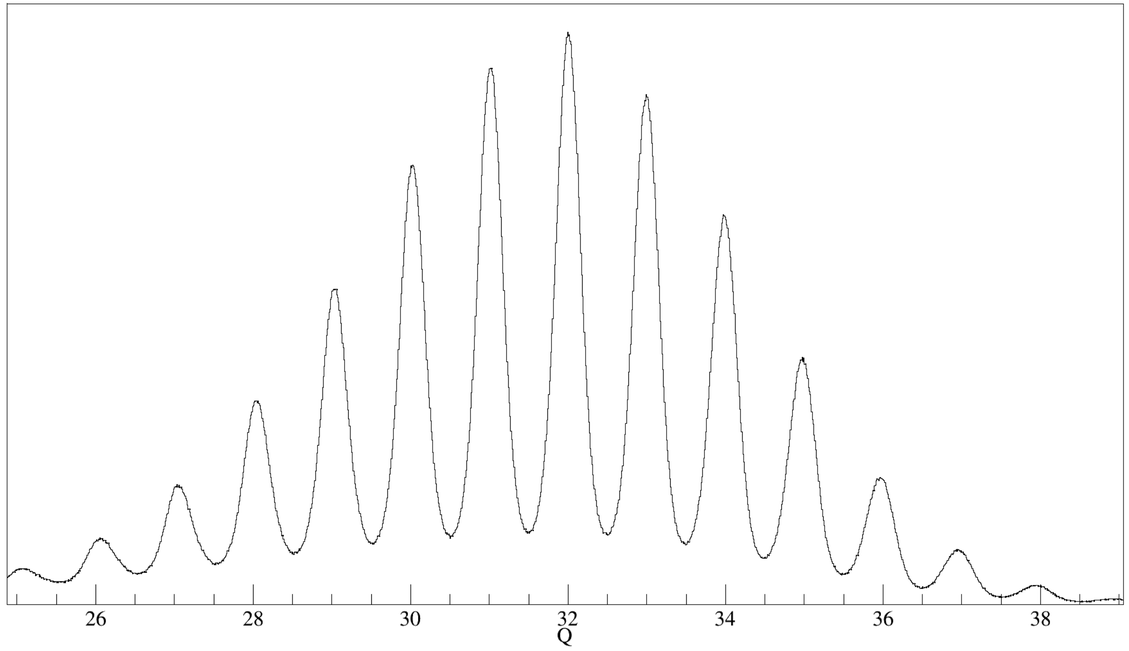




$$\frac{M}{Q} = \frac{B\rho}{3.105 \times \beta}$$

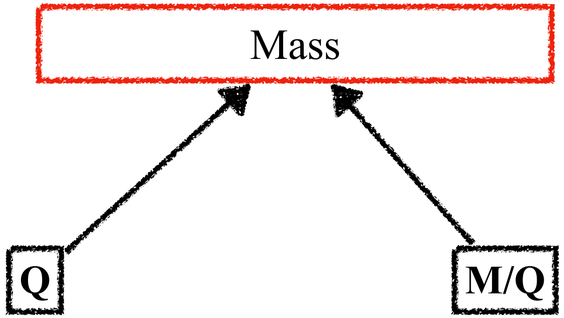
The VAMOS++ spectrometer: Mass identification

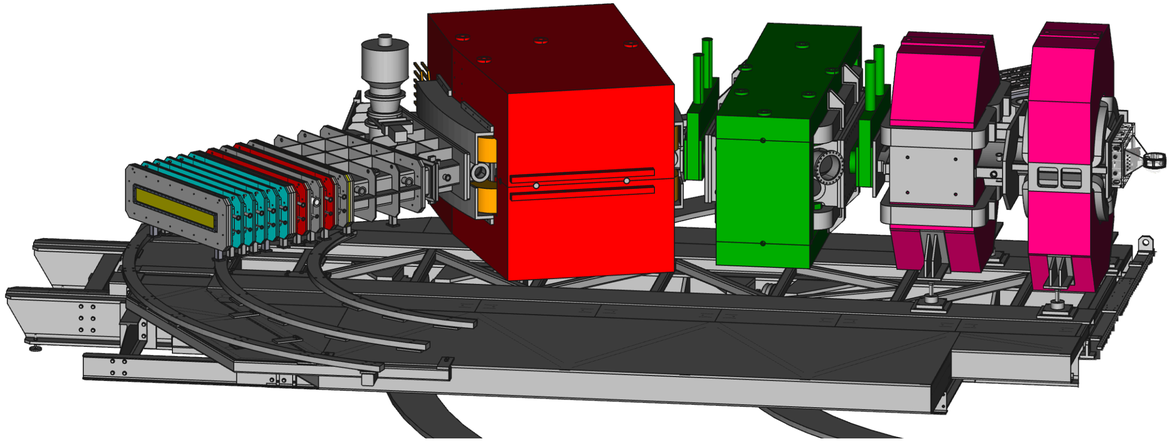


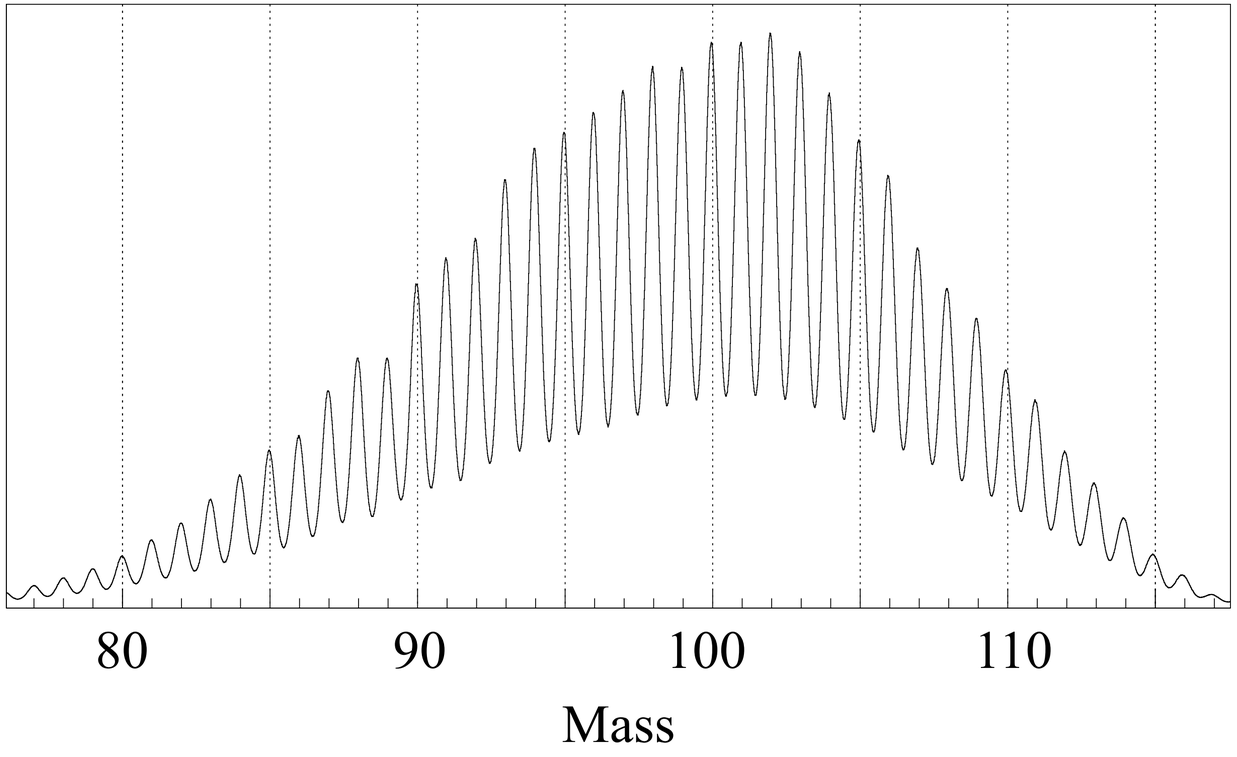


$$Q = \frac{2 \times E_{tot}}{931.5 \times \beta^2} \times \frac{Q}{M}$$

The VAMOS++ spectrometer: Mass identification

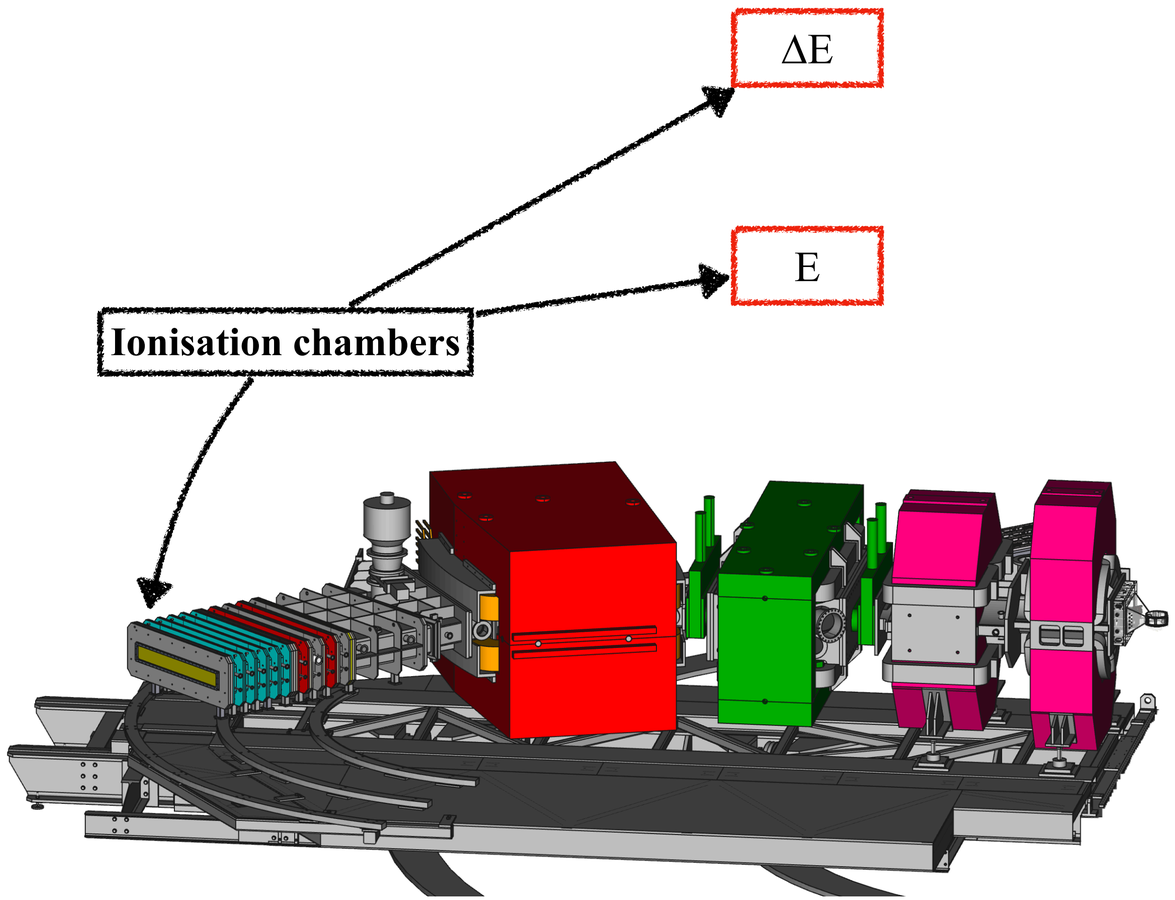


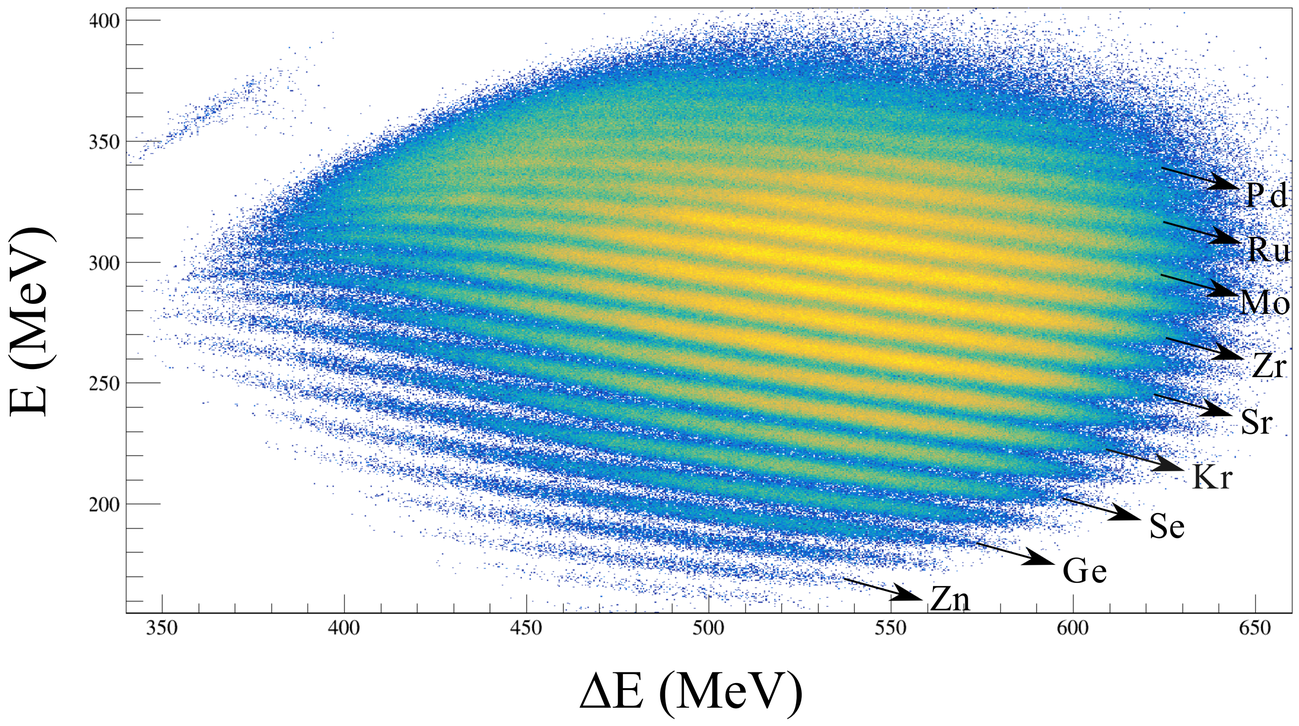




$$\frac{\Delta M}{M} \sim 0.6\%$$

The VAMOS++ spectrometer: Z identification





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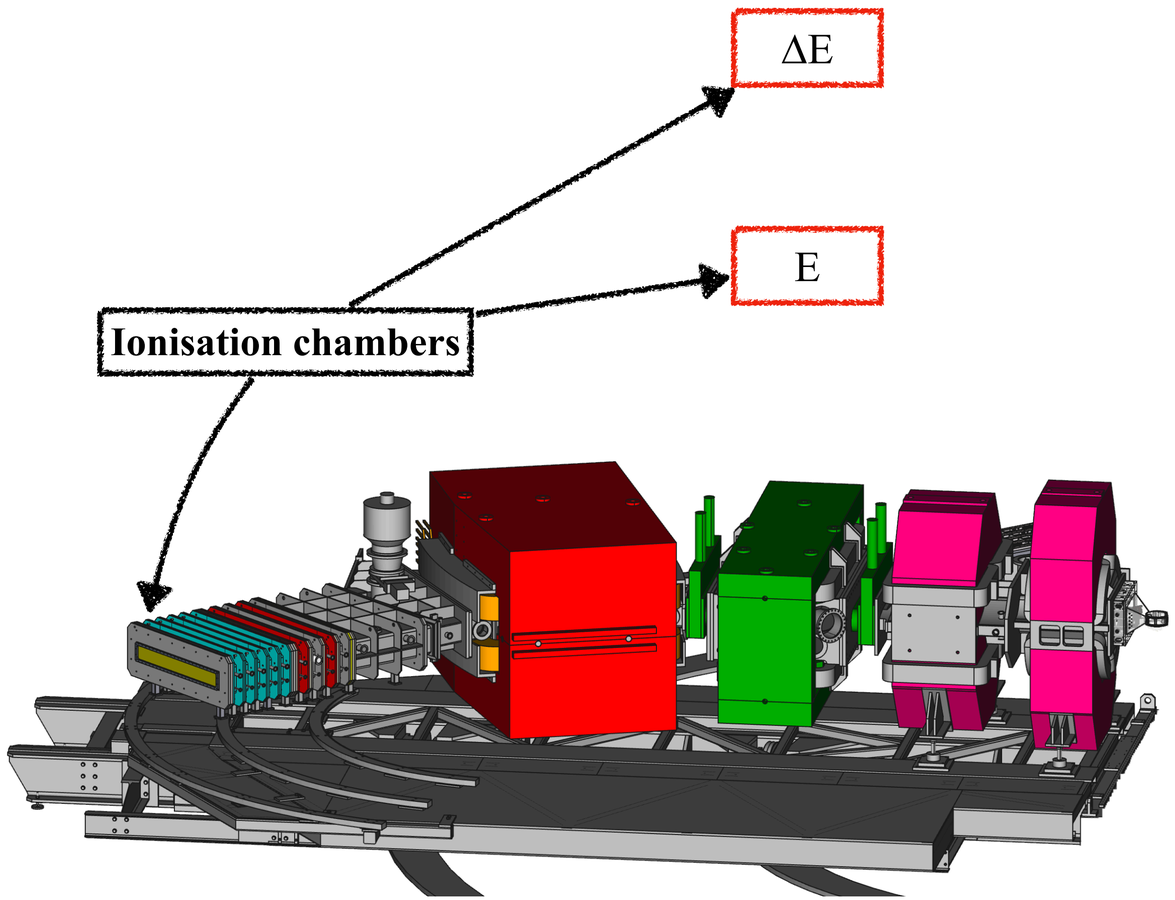
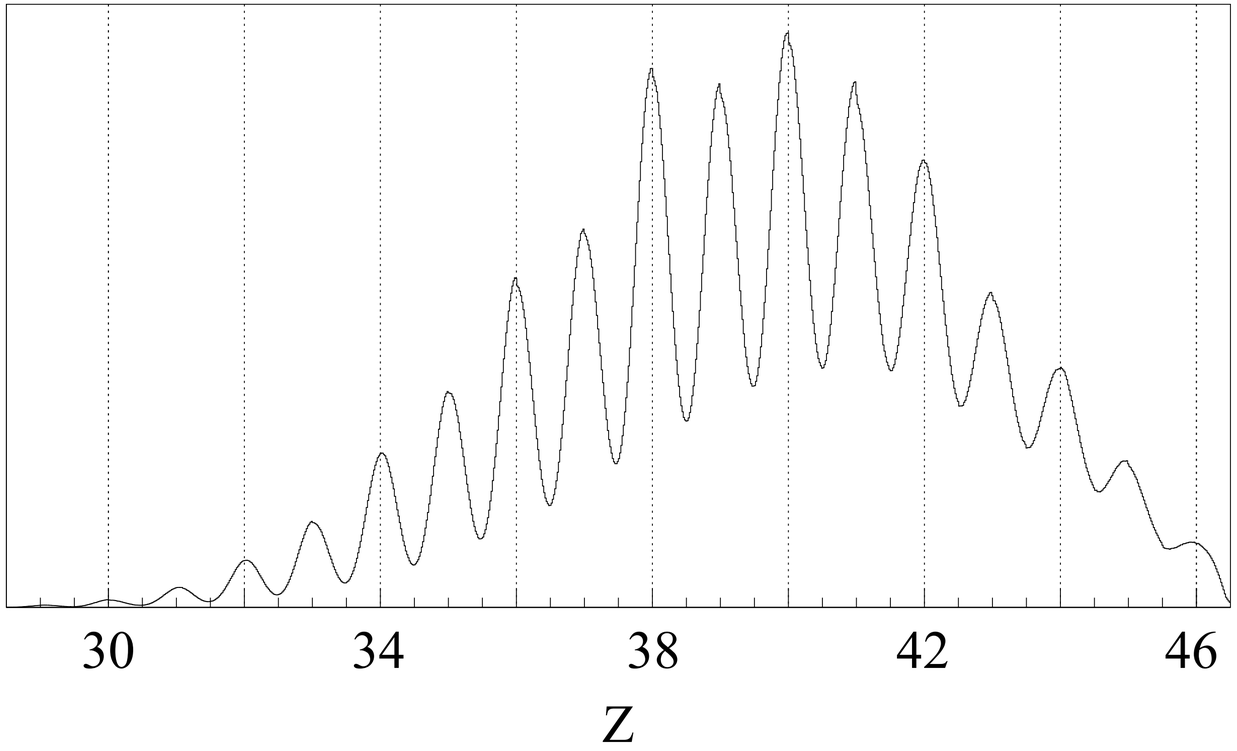
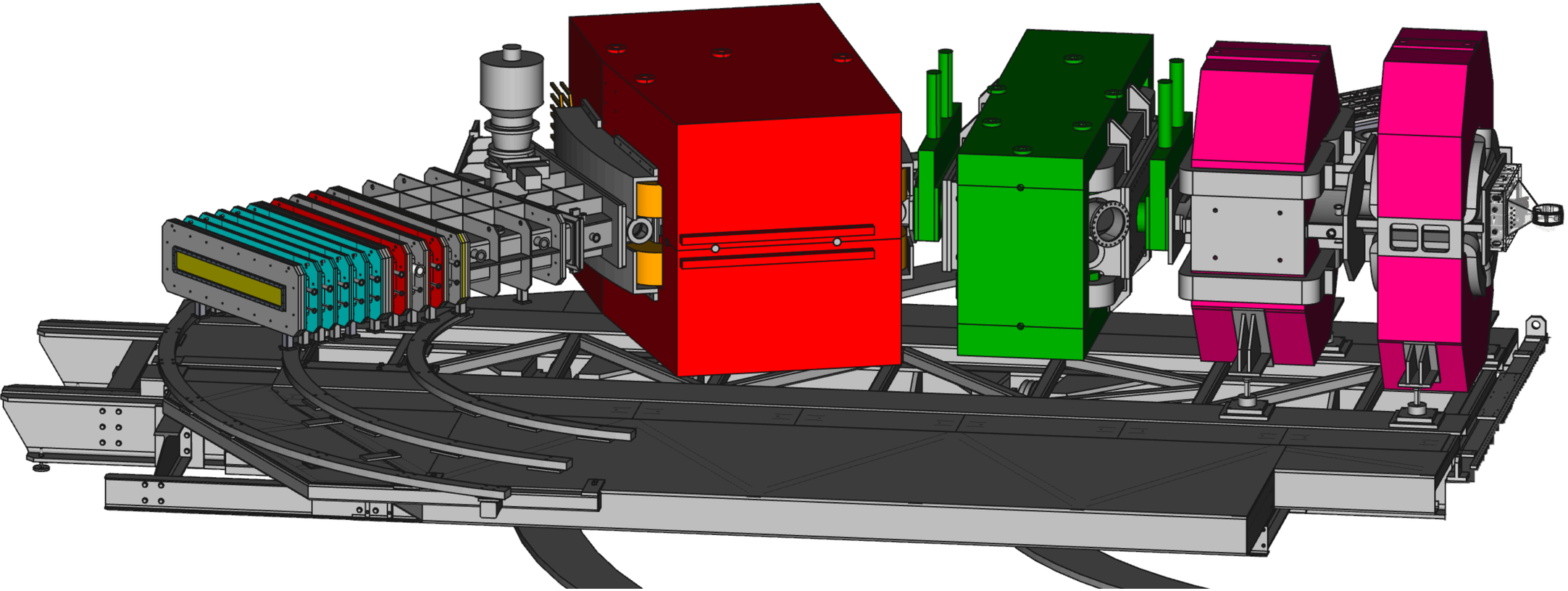


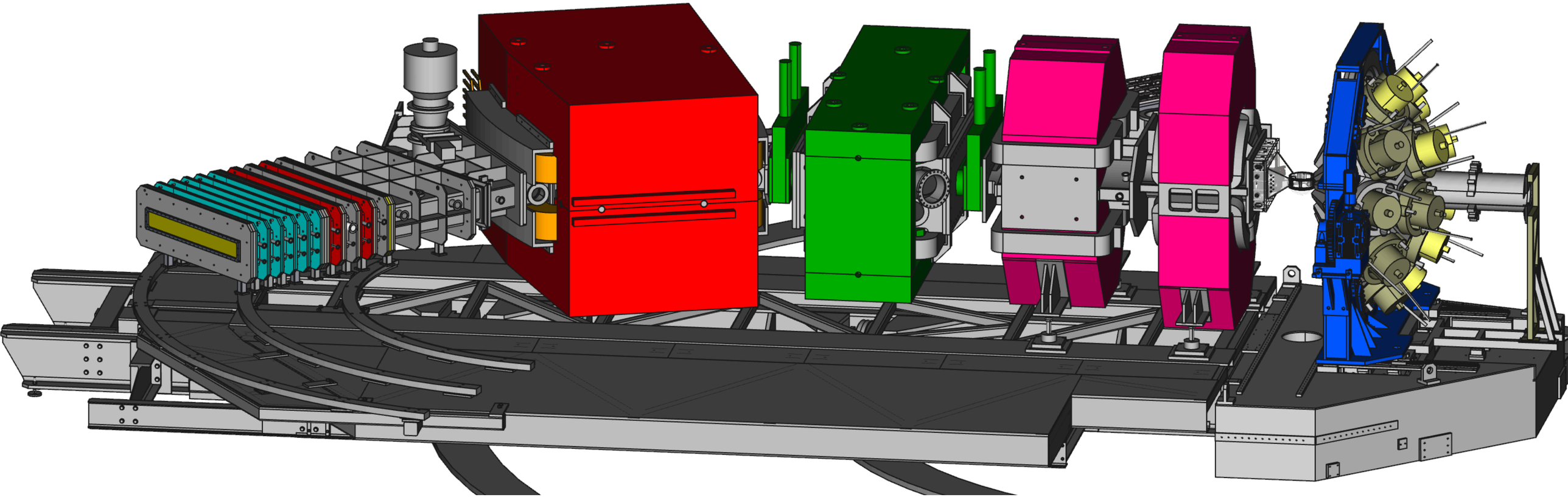


$$\frac{\Delta Z}{Z} \sim 1.5\%$$

The VAMOS++ spectrometer

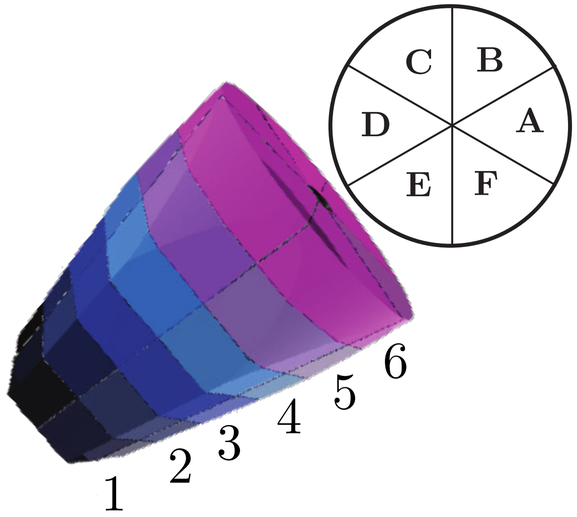


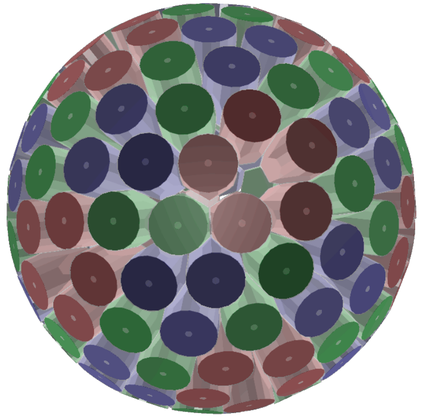
The AGATA Gamma Tracking Array

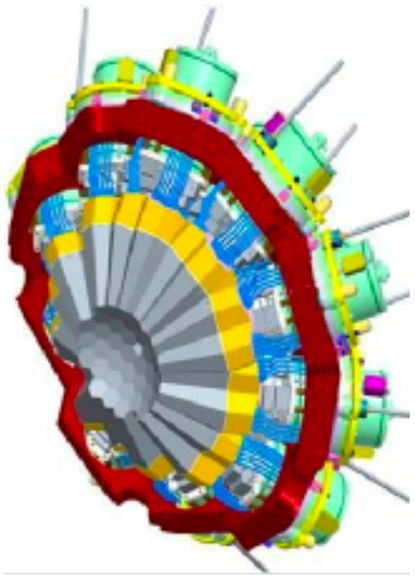


The AGATA Gamma Tracking Array

- Continuous sphere of segmented HPGe crystals
  - High energy resolution
  - High efficiency
- Full digital electronic:
  - High counting rates capabilities
  - Position resolution of interaction points ~ 5mm
- Tracking of the γ-ray path in the crystals
  - Increased peak to background ratio
  - Very precise Doppler Correction







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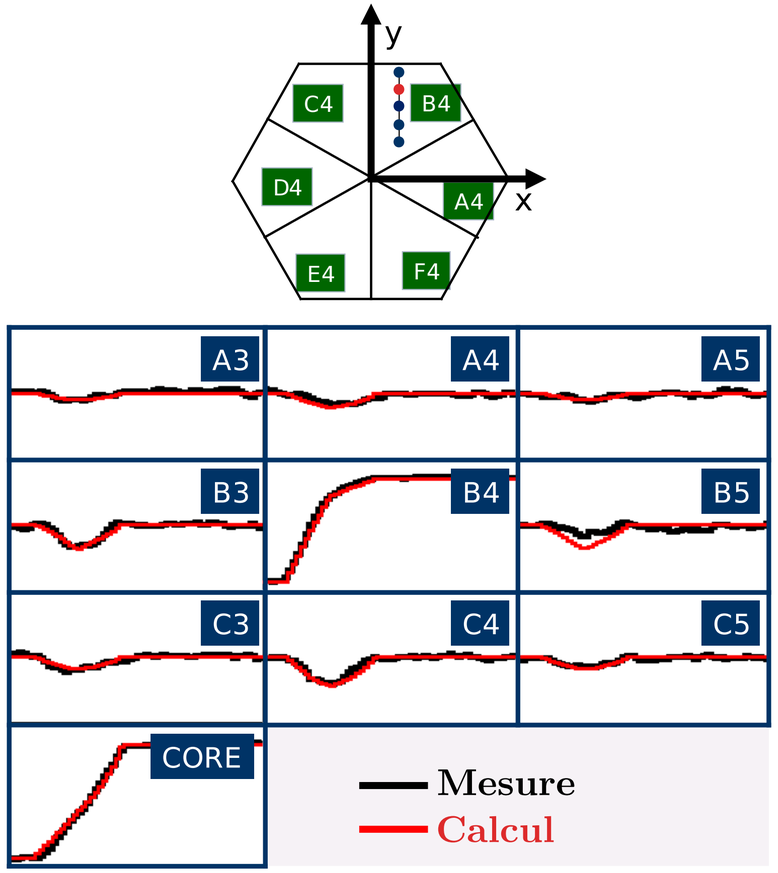
The Pulse Shape Analysis method (PSA)



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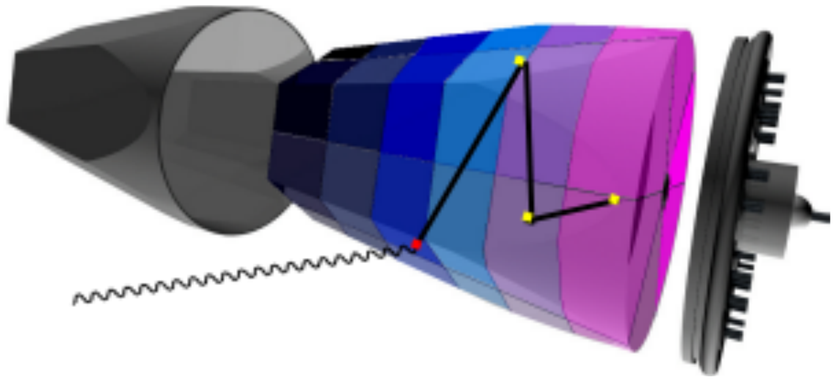

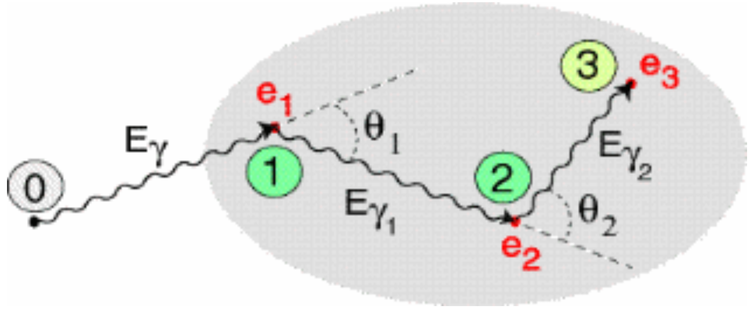

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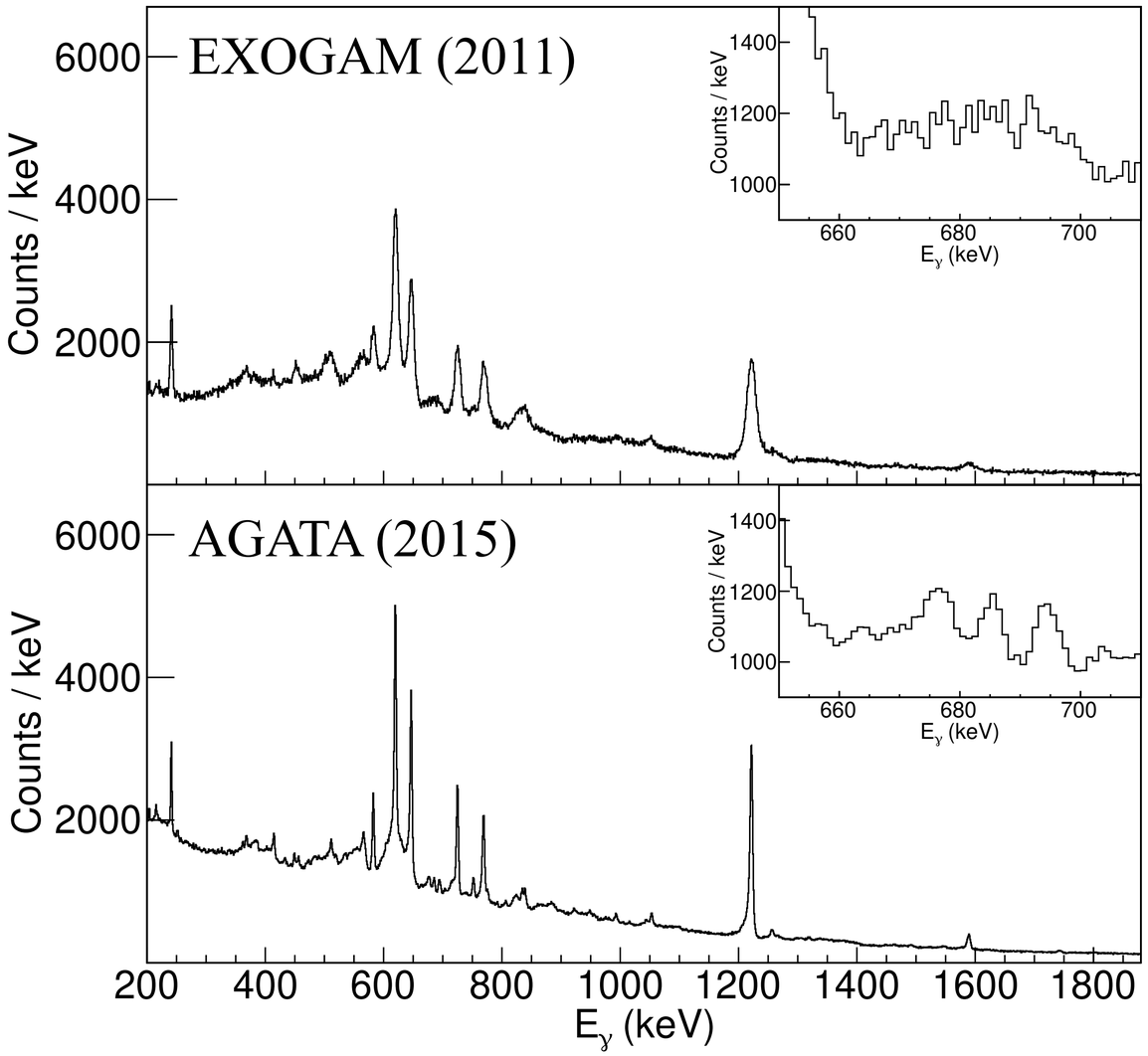

The AGATA / VAMOS++ fission campaigns @ GANIL (2015-2021)

Exp	Duration (days)	VAMOS-γ events	VAMOS			AGATA
			VAMOS angle	Z range	Plunger	Crystals
1	14	6×10^8	28	~ [30 ; 45]	✗	24
2	10	2×10^8	28	~ [30 ; 45]	✓	24
3	14	4×10^8	20	~ [35 ; 60]	✗	32
4	10	4×10^8	19	~ [35 ; 60]	✓	35

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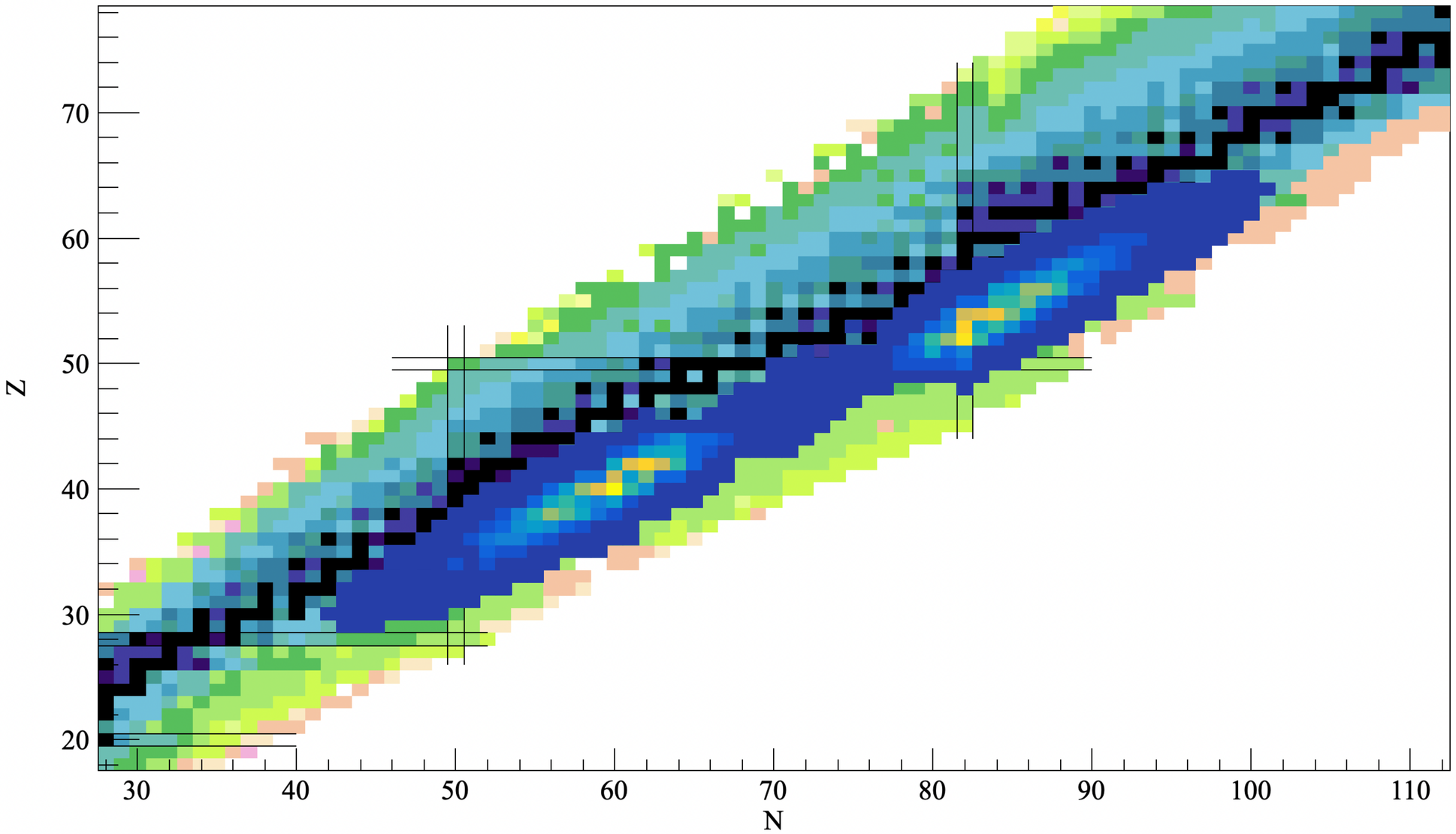

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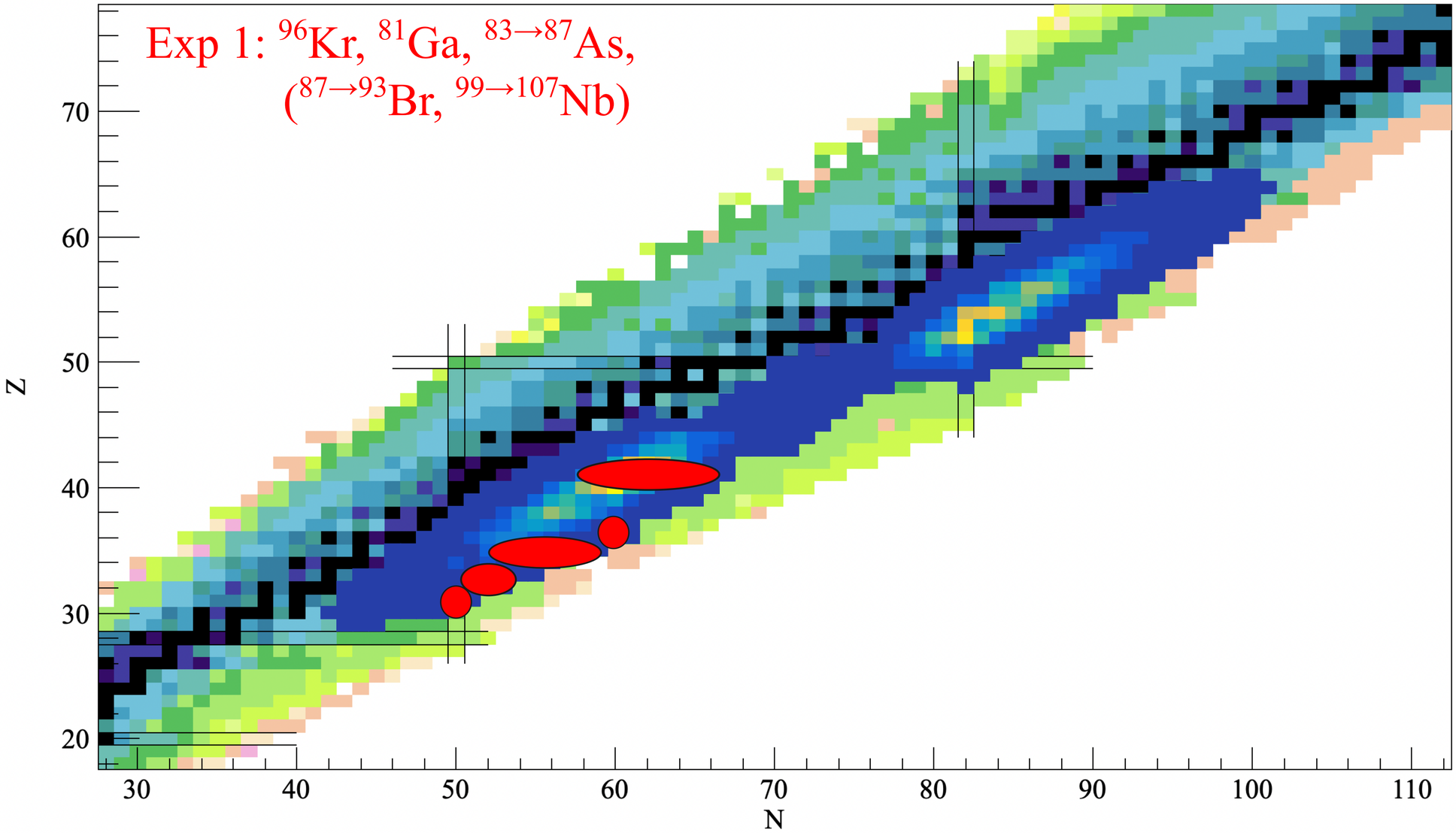

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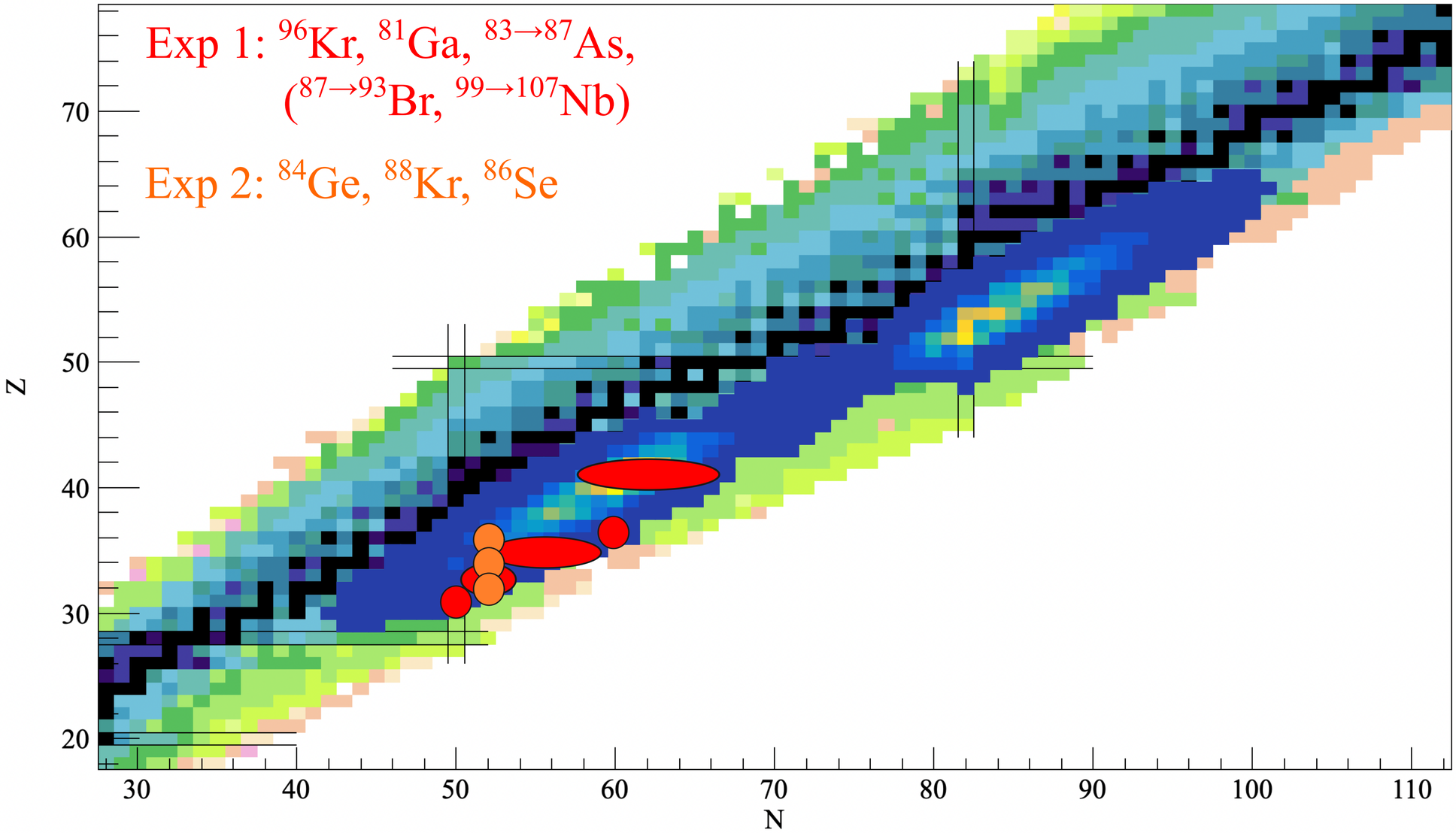

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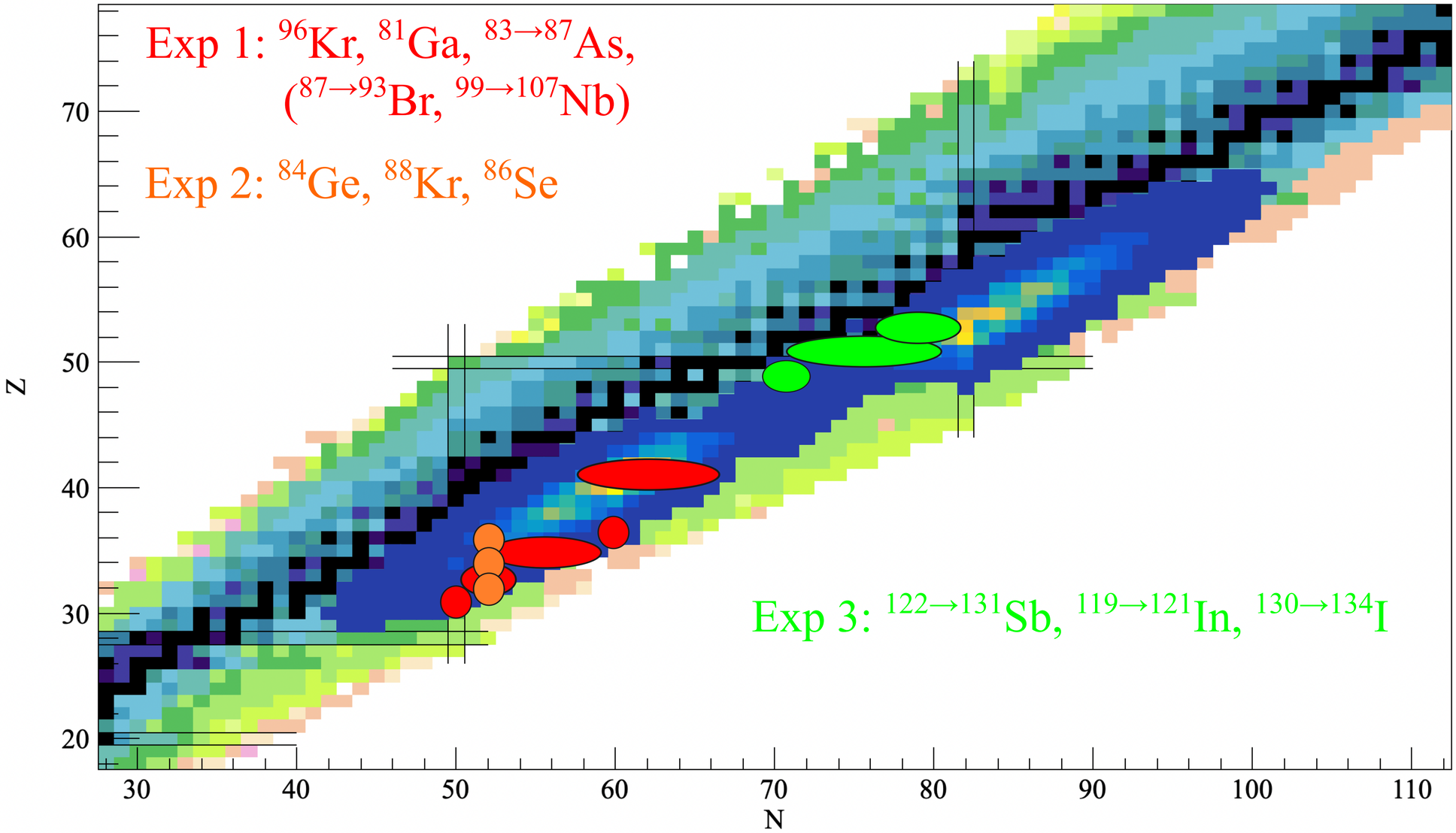

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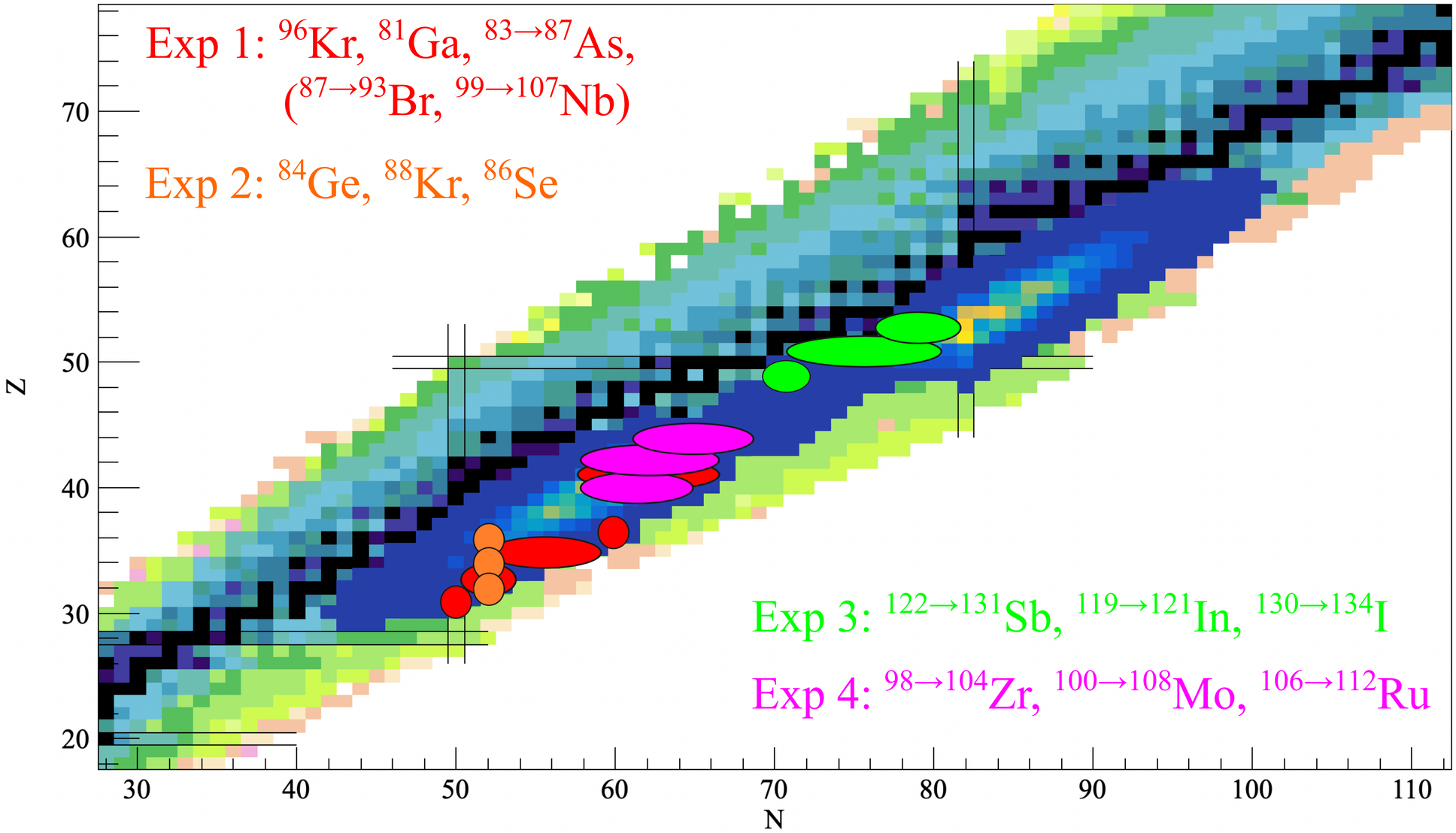
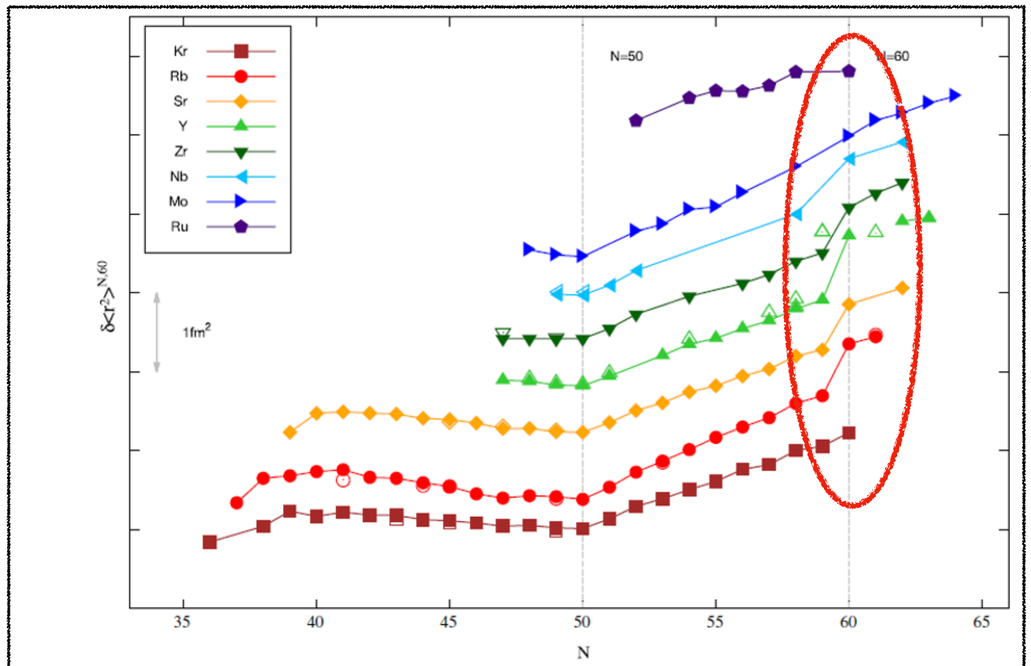
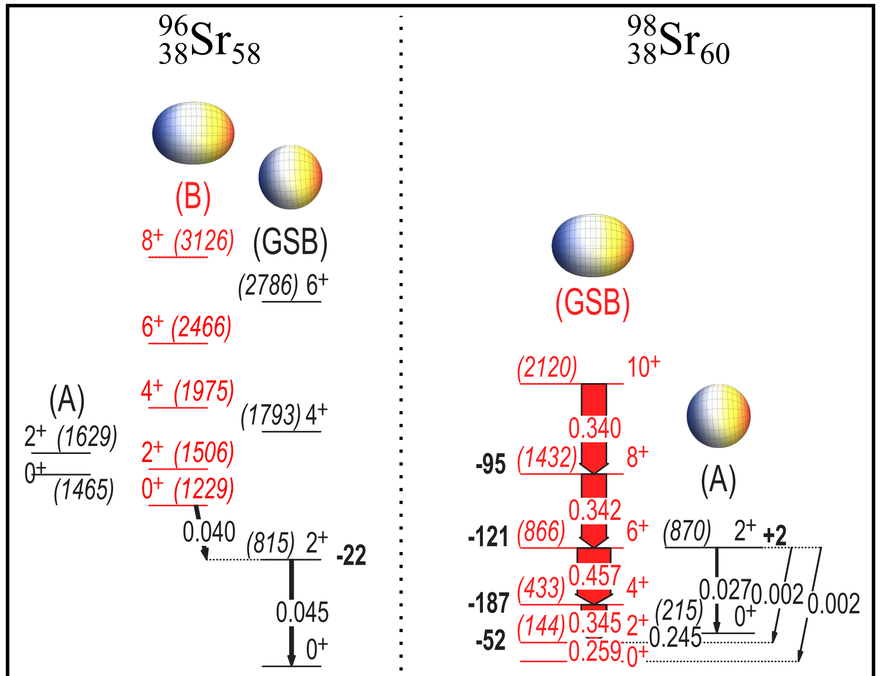


Some physics cases: The ^{96}Kr spectroscopy

- Spectacular shape transition at N=60 due to a shape coexistence phenomenon
- Well described theoretically by Monte-Carlo Shell Model calculation at Z=40
  - but still challenging to describe the limits of this region theoretically



P. Campbell et al., Prog. Part. Nucl. 86 (2016)



E. Clément et al., PRL 116, 022701 (2016)

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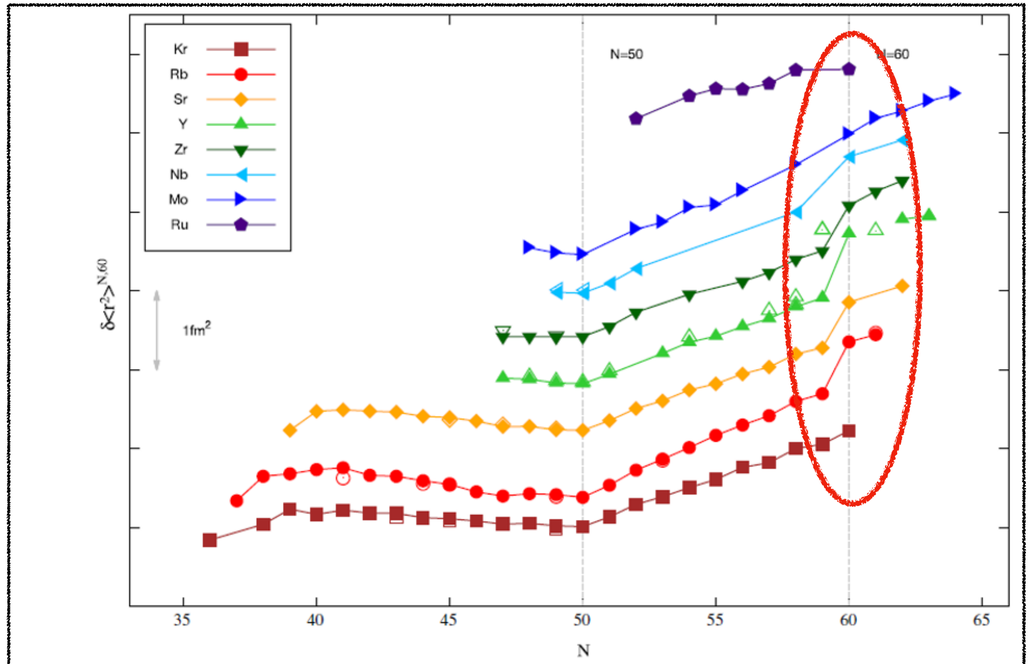

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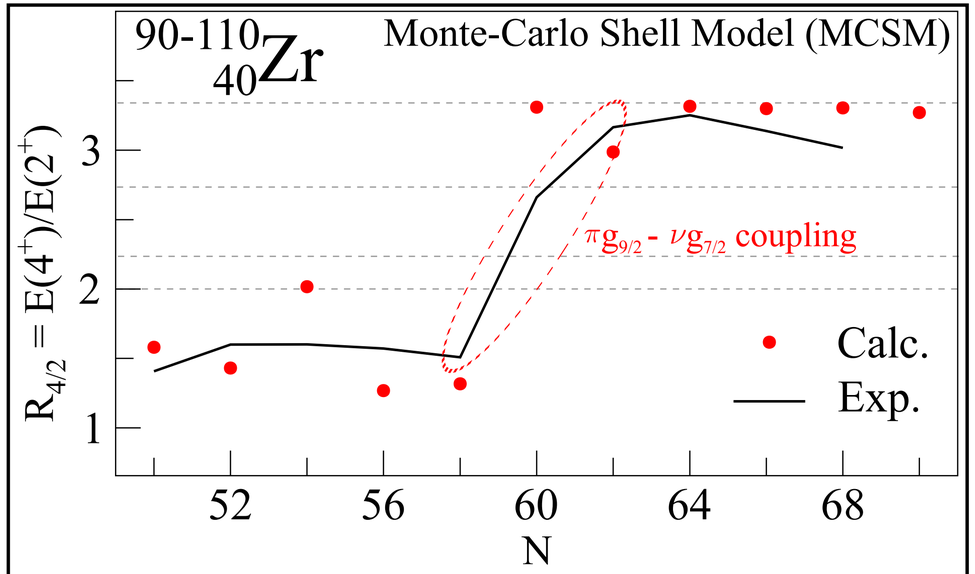
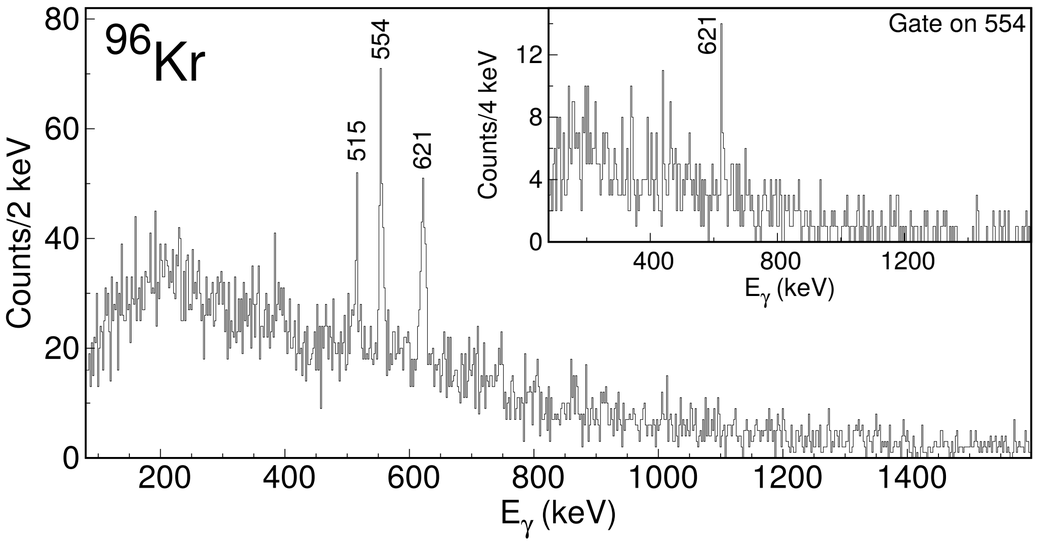


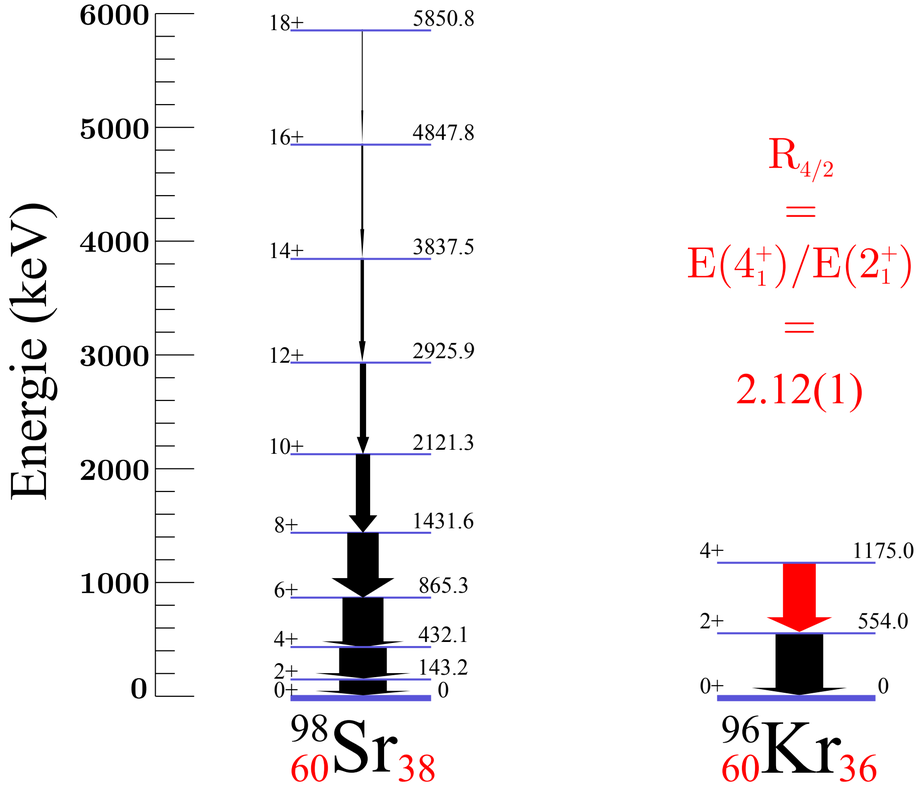
T. Togashi et al., PRL 117, 172502 (2016)

Some physics cases: The ^{96}Kr spectroscopy

- First result from the fission campaigns at GANIL: **^{96}Kr, as the low Z-boundary of this deformation region**
  - First measurement of the 4^+ level in ^{96}Kr
  - Kr follows an unexpected trend between $R_{4/2}$ and B(E2): hints of oblate/prolate shape coexistence ?



J. Dudouet et al., Phys. Rev. Lett 118, 162501 (2017)



$$R_{4/2} = E(4_1^+)/E(2_1^+) = 2.12(1)$$

Some physics cases: The ^{96}Kr spectroscopy

- First result from the fission campaigns at GANIL: **^{96}Kr, as the low Z-boundary of this deformation region**
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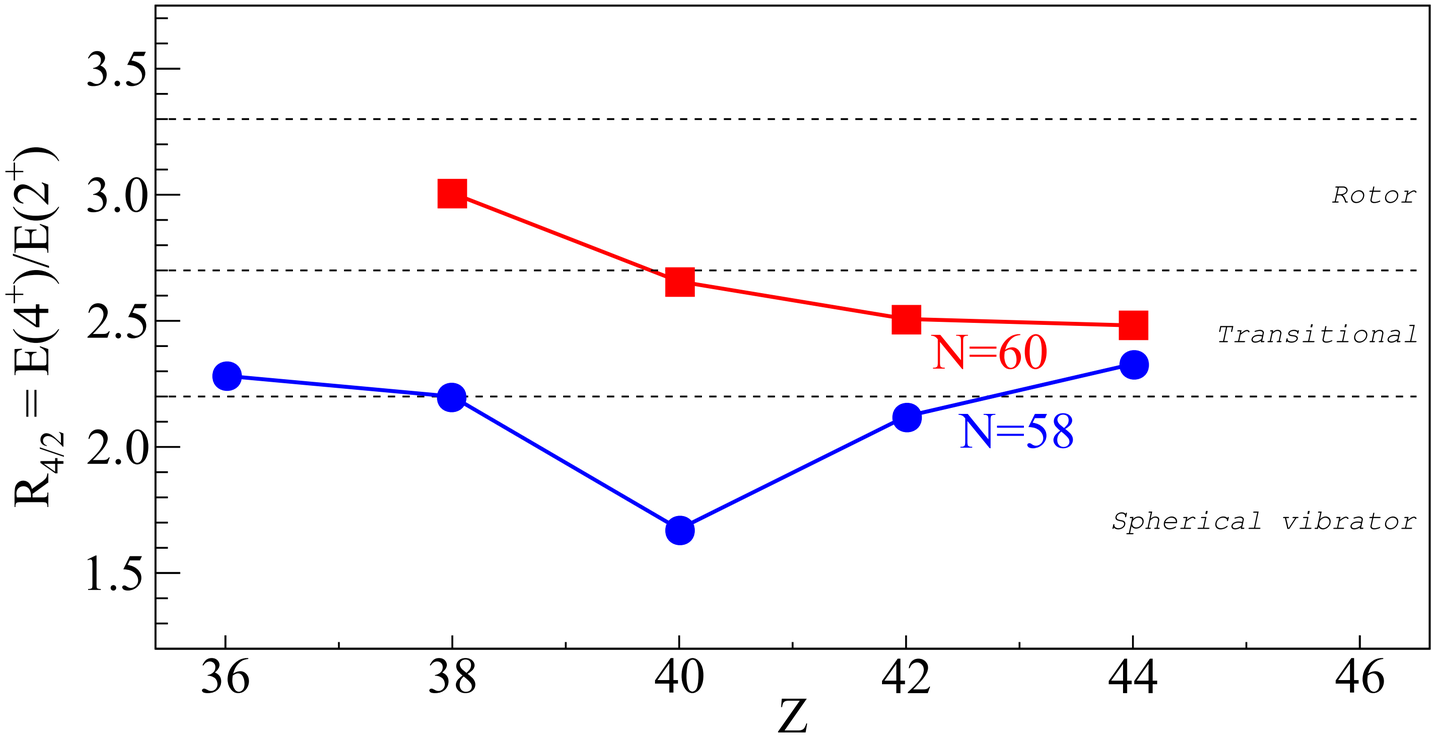

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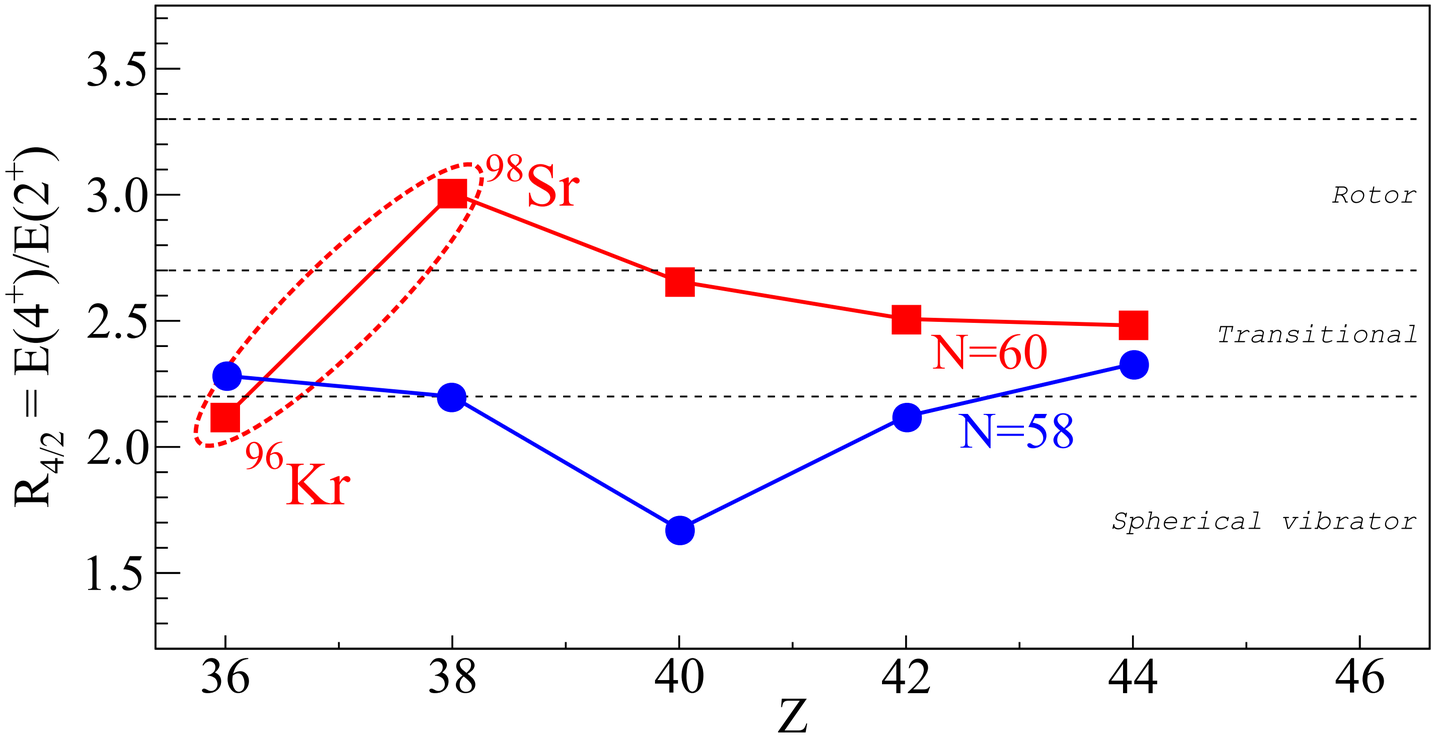

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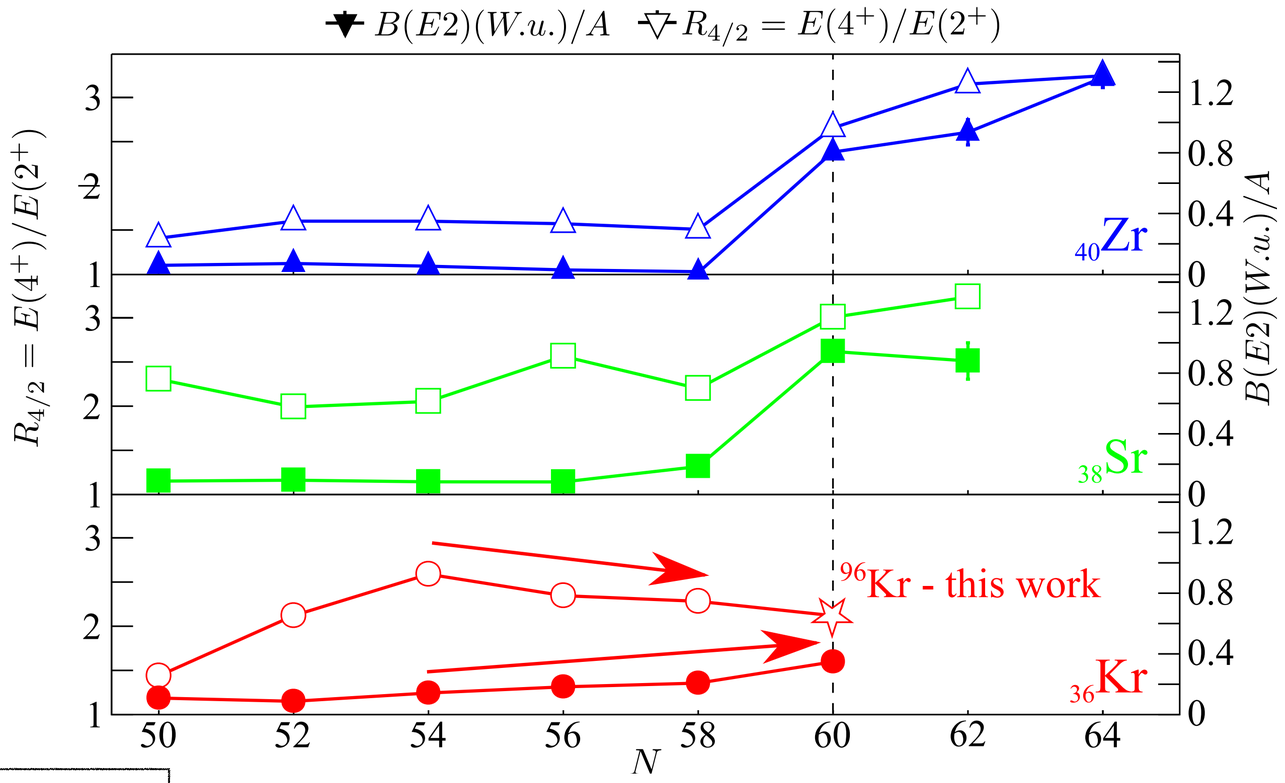

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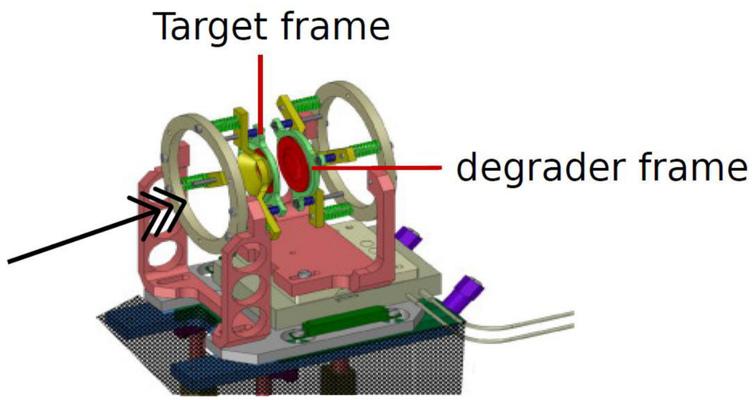
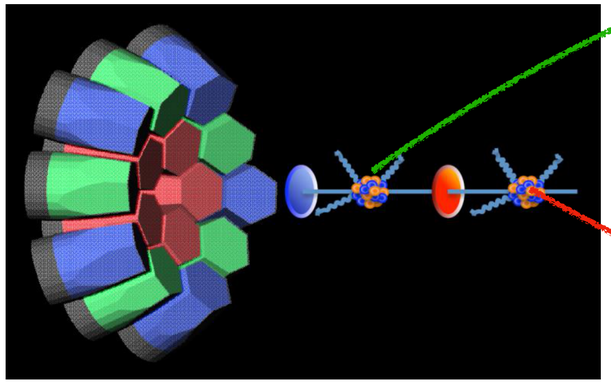
Some physics cases: Lifetimes in neutron rich Zr, Mo and Ru

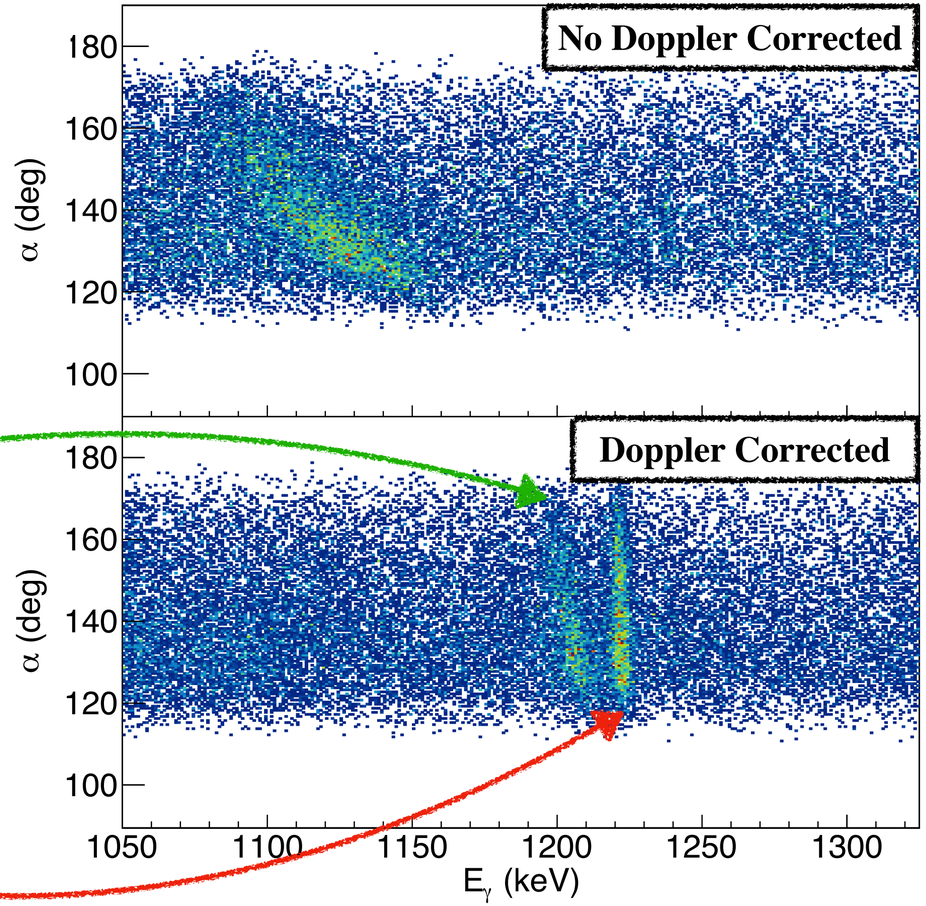
➡ Lifetime measurements in the Zr, Mo, Ru nuclei using RDDS* method

* Recoil Distance Doppler Shift



The OUPS Plunger: adapted from S. Ansari PhD thesis





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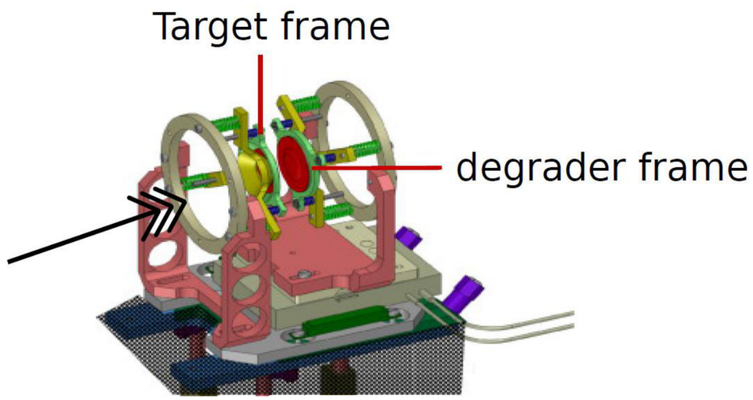

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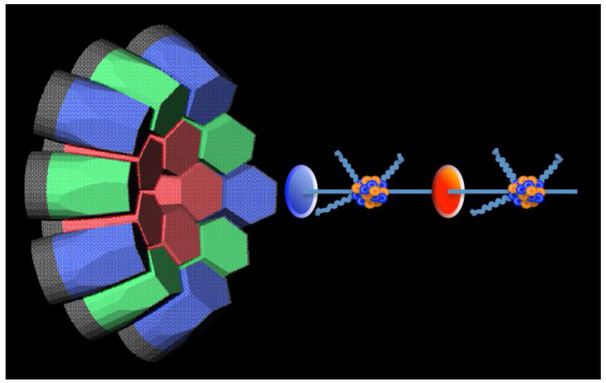
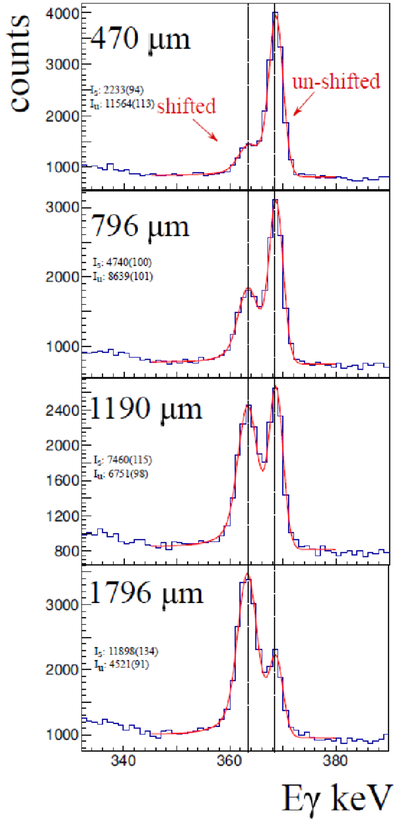
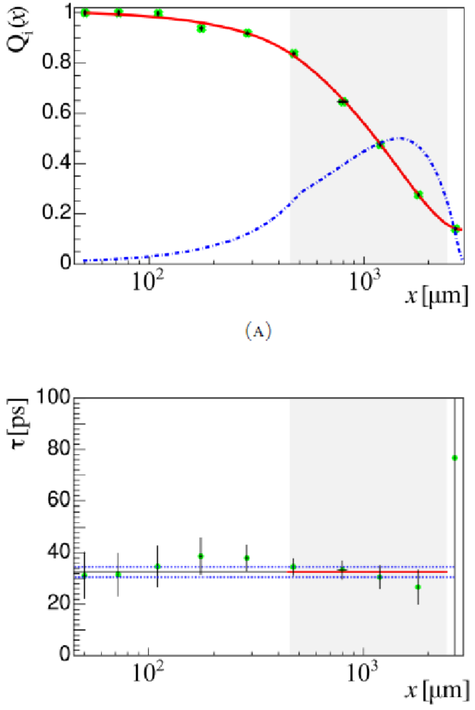


^{104}Mo: 4^{+} state

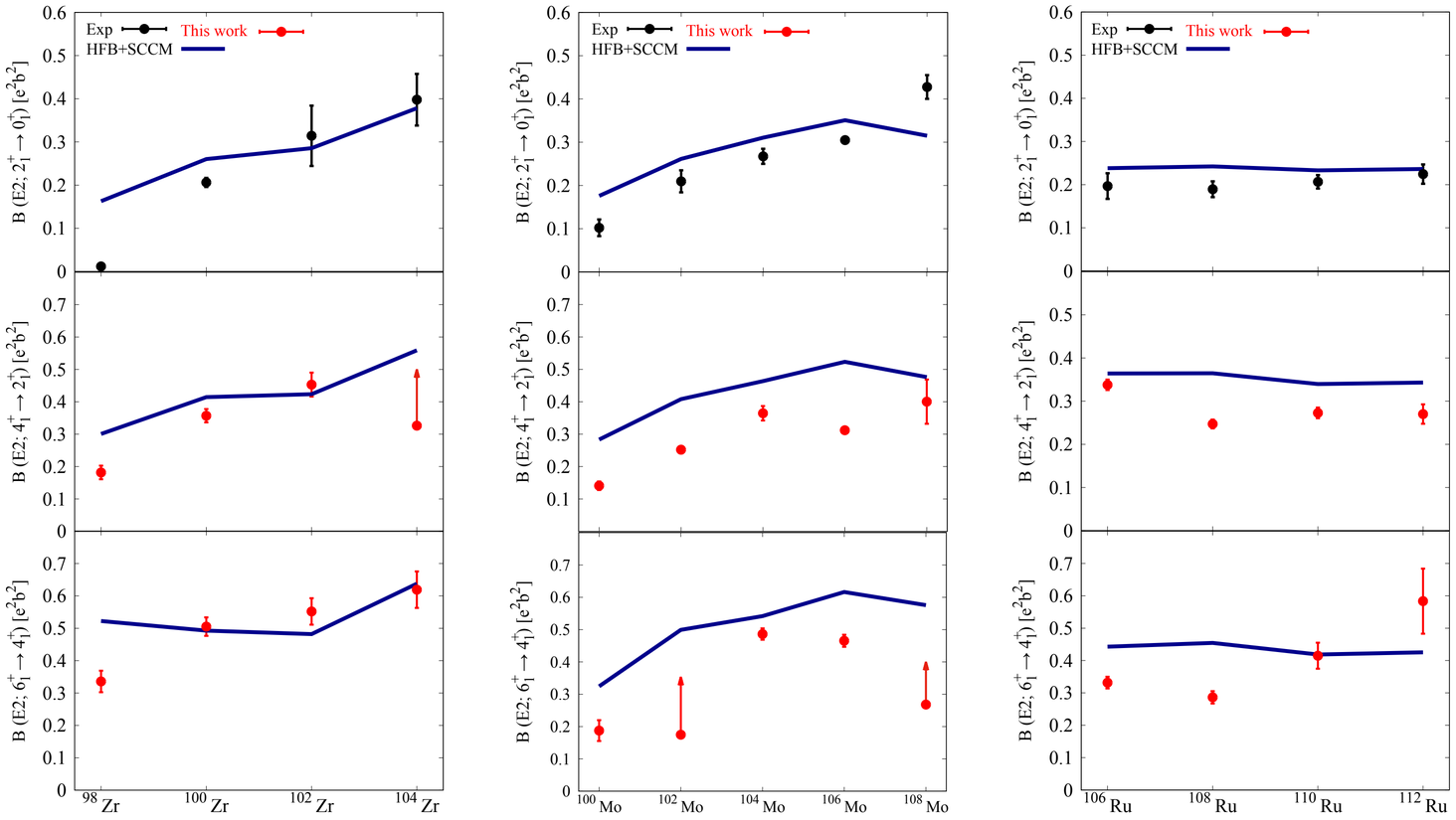




τ (4^{+}) = 32.6(20) ps

Some physics cases: Lifetimes in neutron rich Zr, Mo and Ru

- Lifetime measurements in the Zr, Mo, Ru nuclei using RDDS
  - A lot of new lifetimes measured in this region to constrain nuclear models



Adapted from S. Ansari PhD thesis

Some physics cases: Spectroscopy of neutron rich Nb isotopes

Nuclear structure of the neutron rich Nb isotopes: new insights into the sudden onset of deformation of the A∼100 and N=60 region.

M. Abushawish, E. H. Wang, J. Dudouet, O. Stezowski, A. Navin, S. Bhattacharyya, J. H. Hamilton *et al.*

See talk of **M. Abushawish** this afternoon in the parallel session

Conclusions and perspectives

Conclusions

- A large amount of fission data has been taken at GANIL using AGATA and VAMOS++
- 10 publications on various physics cases (and more to come)

Perspectives

- New gap in exoticity needs a factor 10 in statistics
- Will be investigated at LNL using the AGATA/PRISMA

Merci !