Nuclear Structure of Exotic Kr and Br Isotopes Using FIPPS

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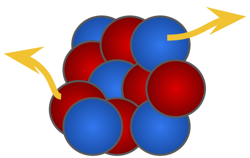
Nucleus: many body quantum system



Size ≈ 5 x 10 $^{-15}$ m

Nuclear structure → studies properties of nuclei:

- ➔ Mass
- ➔ Shape
- ➔ Characteristic energy levels
- ➔ Radioactive decay

“Exotic” = far from stability

Krypton, Z =36
Bromine, Z =35

FIPPS:

FIssion Product Prompt γ-ray Spectrometer

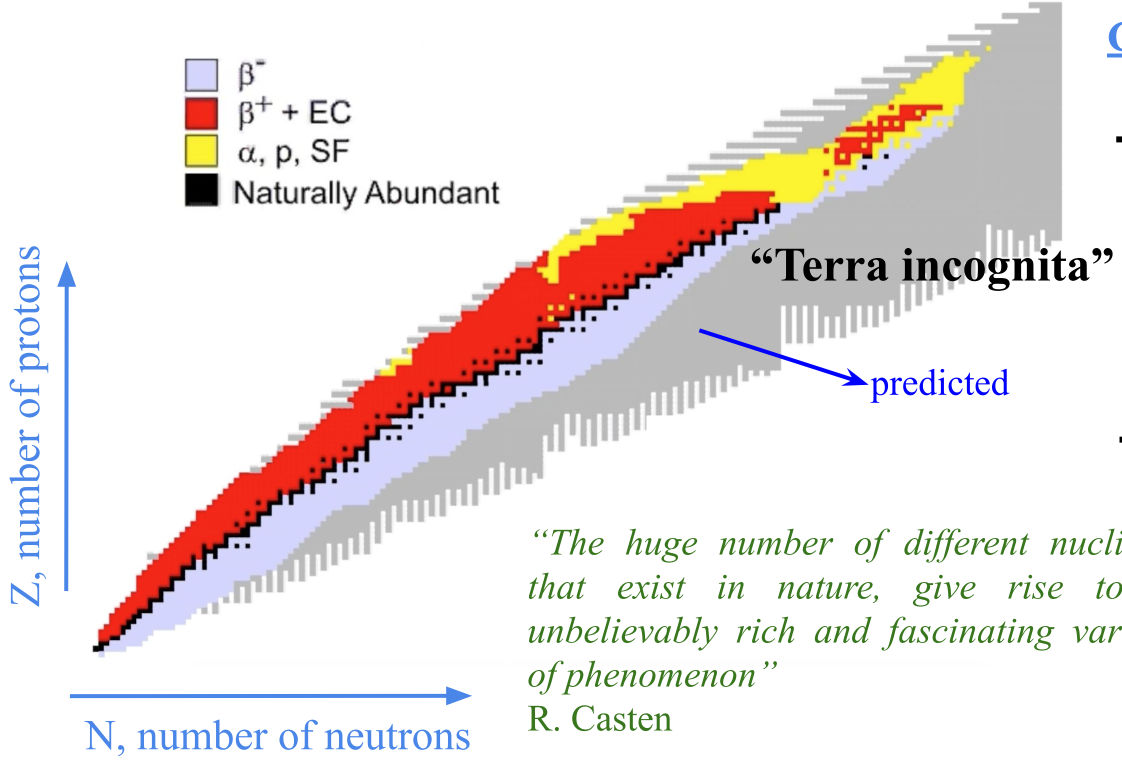
Permanent instrument at the ILL

FIPPS detectors

Outline:

1. Current challenges in nuclear structure
2. Why Kr? The A ~ 100 region
3. Fission experimental campaign at the FIPPS instrument
4. Data analysis and results
5. Future perspectives
6. Summary

The nuclear landscape: expanding frontiers



"The huge number of different nuclides that exist in nature, give rise to a unbelievably rich and fascinating variety of phenomenon"
R. Casten

Current challenges in nuclear physics:

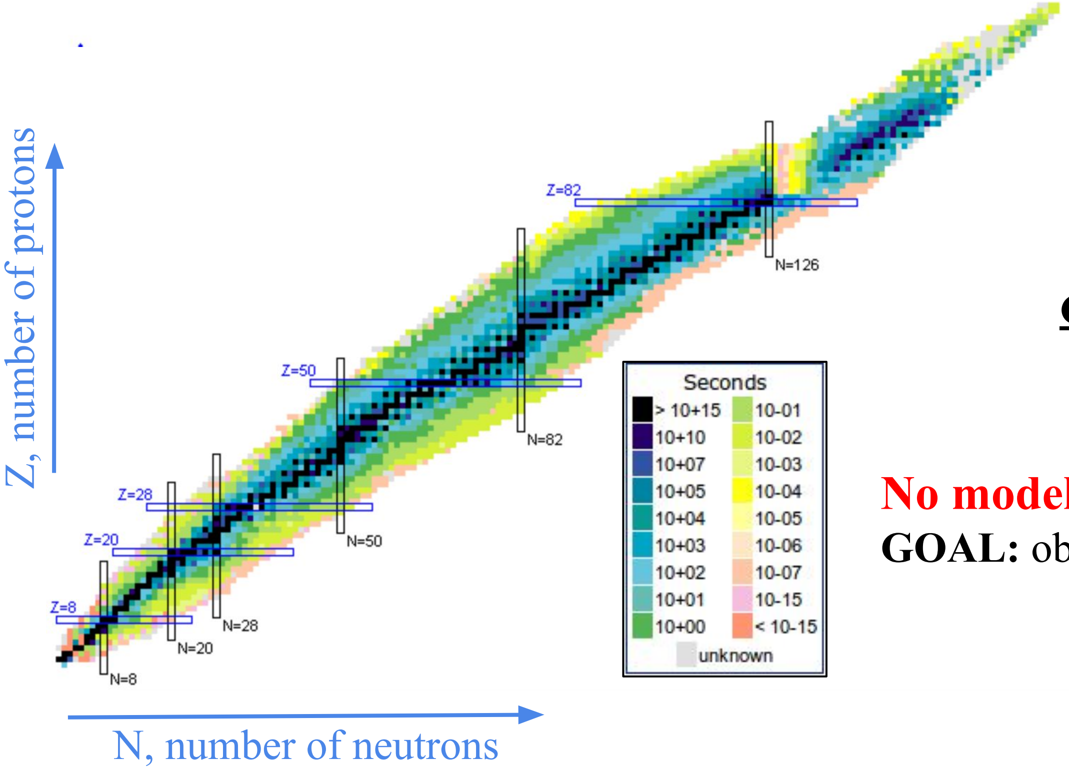
➔ **Expand the limits** of known isotopes (~3000).
Theoretical models predict the existence of an additional 4000 isotopes.

➔ Explain **characteristics** of nuclei and their **evolution** across the nuclear chart.

↓

NUCLEAR MODELS

Nuclear models



<u>The nuclear shell model:</u>

- Analogous to atomic model
- Protons and neutrons occupy energy levels grouped in shells
- **Magic numbers:** 2, 8, 20, 28, 50, 82, 126

<u>Collective properties</u> (deformation, vibration)

No model explains all!

GOAL: obtain unified description of the nucleus

Nuclear shapes

Shape is a fundamental property of the nucleus

- Few nuclei have spherical shape, variety of shapes can be observed
- Deformation is a consequence of collectivity

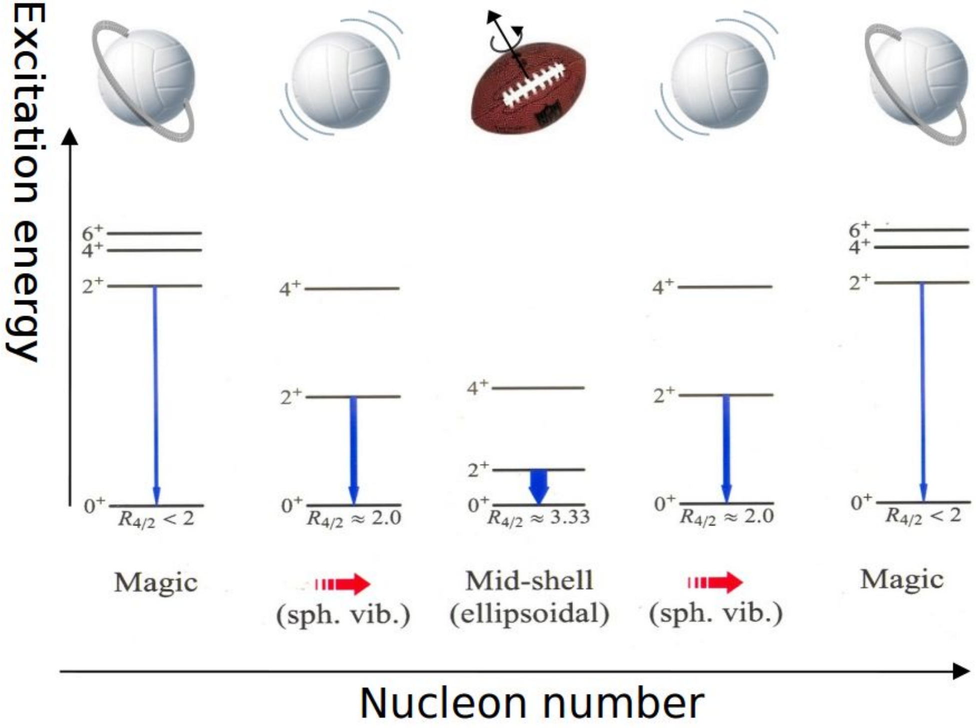
How can we experimentally determine the nuclear shape?

For even-even nuclei can use:

$$\boxed{R_{4/2} = E_{4_1^+}/E_{2_1^+}}$$

Vibrator: $E = \hbar\omega n$

Rotor: $E_{rot} = \frac{\hbar^2}{2\mathscr{I}} J(J+1)$



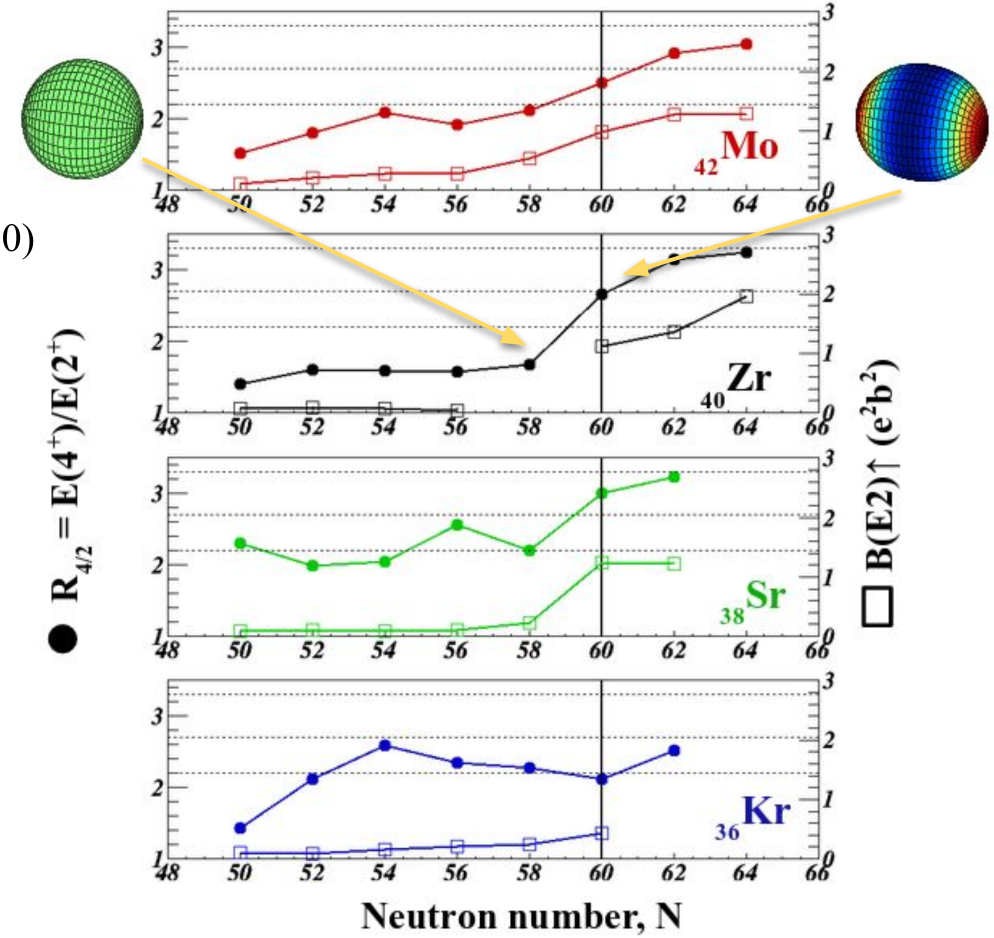
The A~100 island of deformation

- Neutron rich nuclei in this region (N~60, Z~40) exhibit a drastic **nuclear shape transition**: from nearly spherical (N=58) to strongly prolate (N=60)
- First observed for Zr (1970)

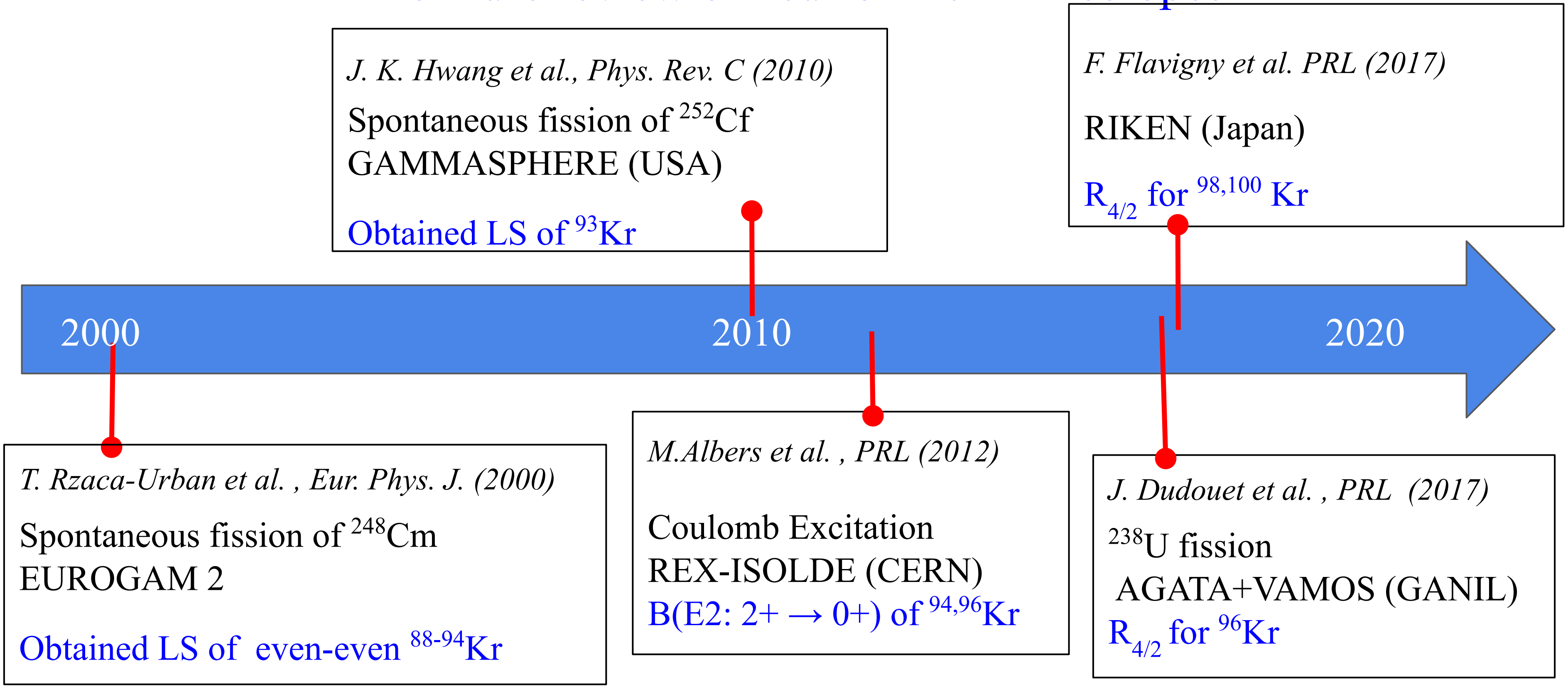
Where is the low Z limit of this island?

- No drastic transition in Kr isotopic chain? Delayed?
- Contradictory trend between $R_{4/2}$ ratio and the transition probability, B(E2)

Motivation for my thesis:
More experimental information is needed on Kr chain to test state of the art theoretical models .
Beyond mean field *T.R. Rodriguez PRC (2014)*
Monte Carlo Shell Model *T. Togashi,PRL (2016))*



Literature review of neutron rich Kr isotopes



T. Rzaca-Urban et al. , Eur. Phys. J. (2000)

Spontaneous fission of ^{248}Cm
EUROGAM 2

Obtained LS of even-even $^{88\text{-}94}$Kr

J. K. Hwang et al., Phys. Rev. C (2010)

Spontaneous fission of ^{252}Cf
GAMMASPHERE (USA)

Obtained LS of ^{93}Kr

M.Albers et al. , PRL (2012)

Coulomb Excitation
REX-ISOLDE (CERN)
$B(E2: 2+ \rightarrow 0+)$ of ^{94,96}Kr

F. Flavigny et al. PRL (2017)

RIKEN (Japan)

$R_{4/2}$ for ^{98,100} Kr

J. Dudouet et al. , PRL (2017)

^{238}U fission
AGATA+VAMOS (GANIL)
$R_{4/2}$ for ^{96}Kr

Experimental technique

How do we produce exotic Kr isotopes?

↓

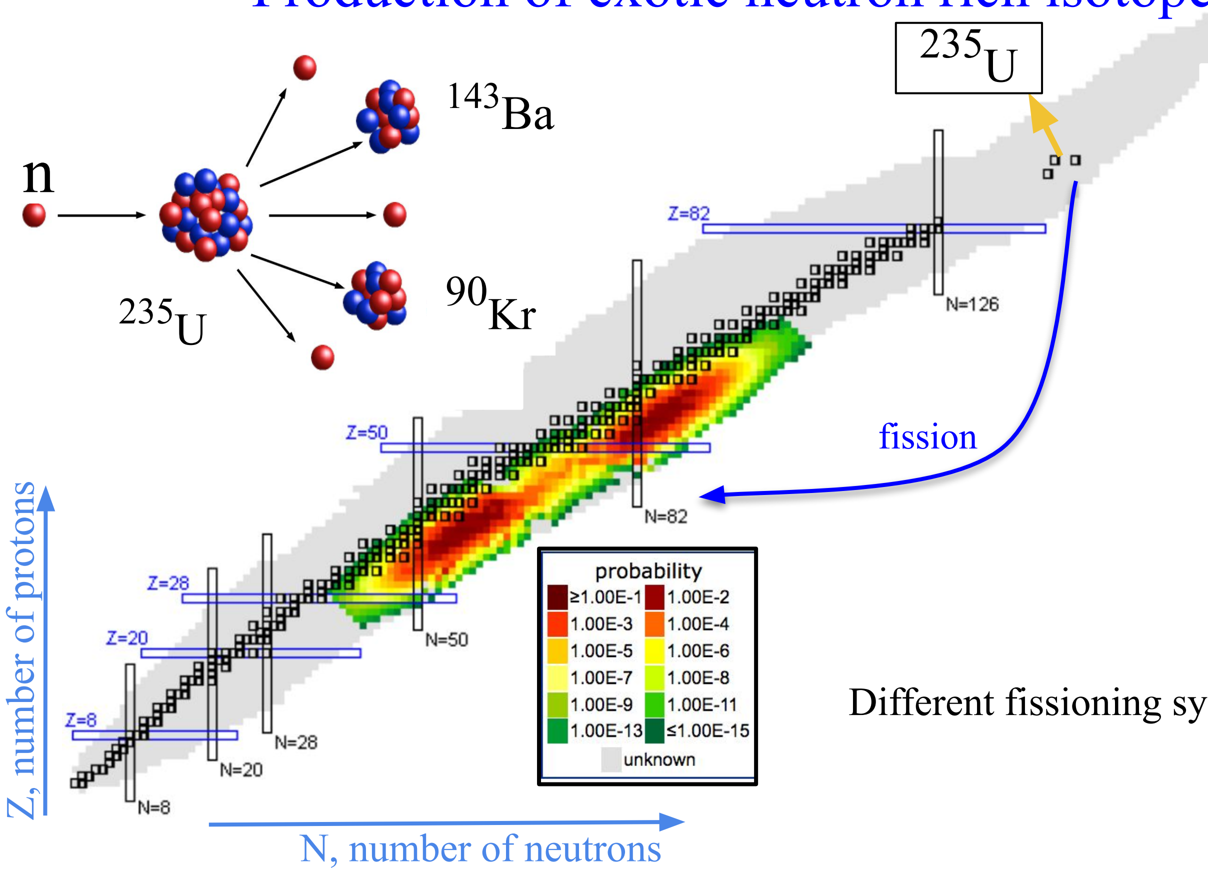
Fission reaction

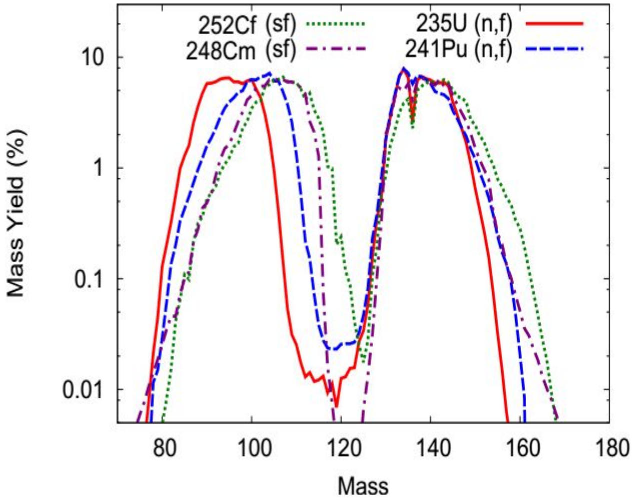
How do we experimentally measure Kr structure?

↓

γ-ray spectroscopy with the FIPPS Array

Production of exotic neutron rich isotopes: Nuclear fission



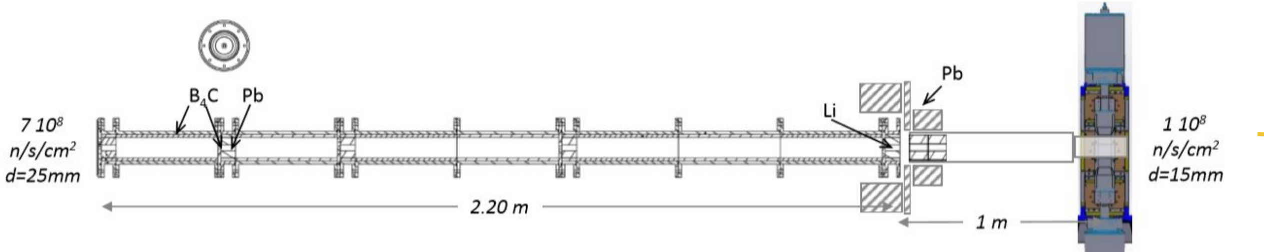


M. Jentschel et al 2017 JINST12 P11003

Different fissioning systems give access to different isotopes

The FIPPS Instrument

FIssion Product Prompt γ-ray Spectrometer: "pencil-like" neutron beam + HPGe array



Smaller than
1 cent coin

Collimation

- Thermal neutron beam
- Flux at target position: 10^8 n/s/cm^2
- Collimation: d=15 mm

FIPPS HPGe detectors

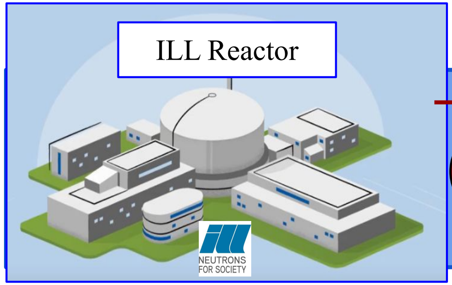
➔ 8 high resolution HPGe clover detectors (4 crystals) + anti-Compton shields

➔ Ring around target position

➔ Can be coupled to ancillary detectors

The ^{235}U fission campaign

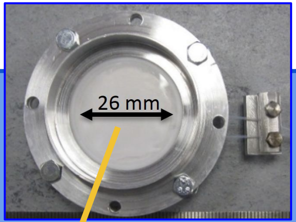
50 days of beam time in 2018



Thermal neutron beam

n

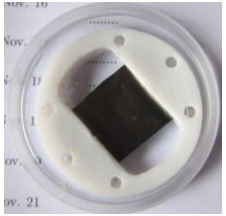
Neutrons reach FIPPS target position



Active target

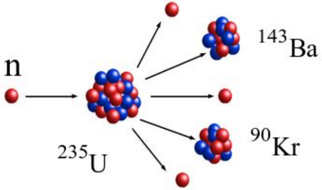
^{235}U diluted in liquid scintillator

F. Kandzia et al.

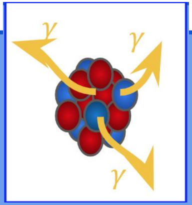


EXILL target

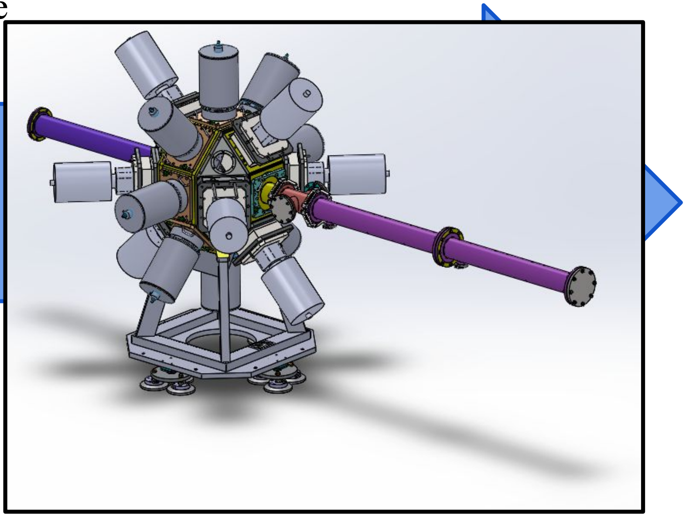
235U nuclei fission



Fission fragments deexcite via γ-emision



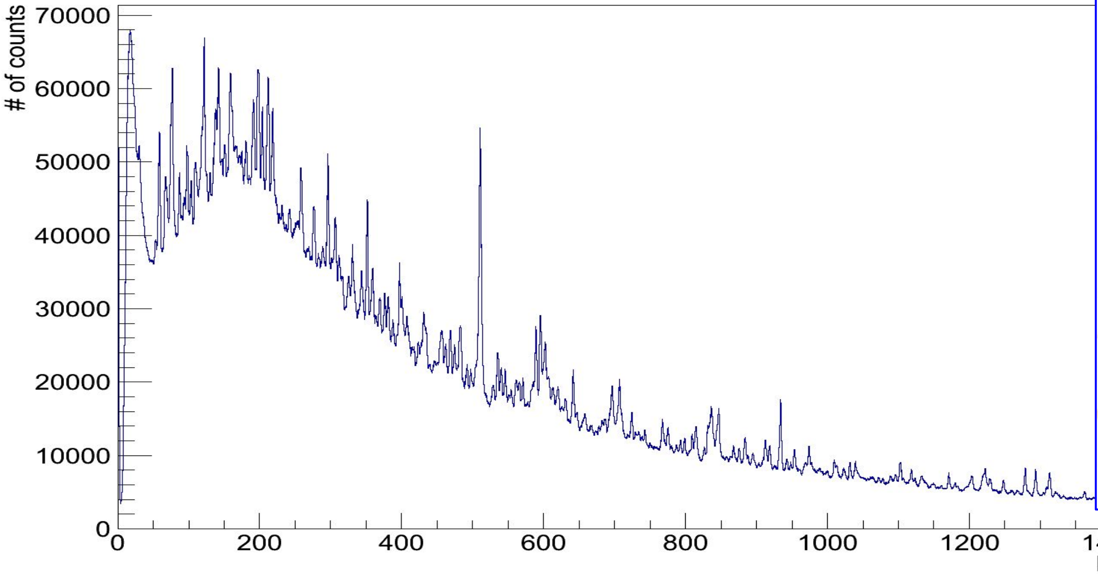
γ rays measured in HPGe detectors



➔ 8 FIPPS + 8 IFIN detectors

Total γ-ray energy spectrum after fission

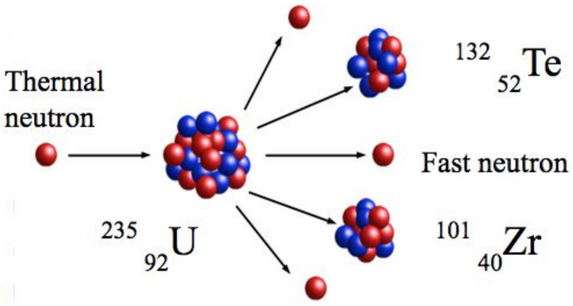
More than 100 different nuclei being populated in fission and emitting γ rays.



How do we get the data that we are interested in?
What gamma ray comes from what nucleus?

- γ coincidence technique (300ns window)
- Active target

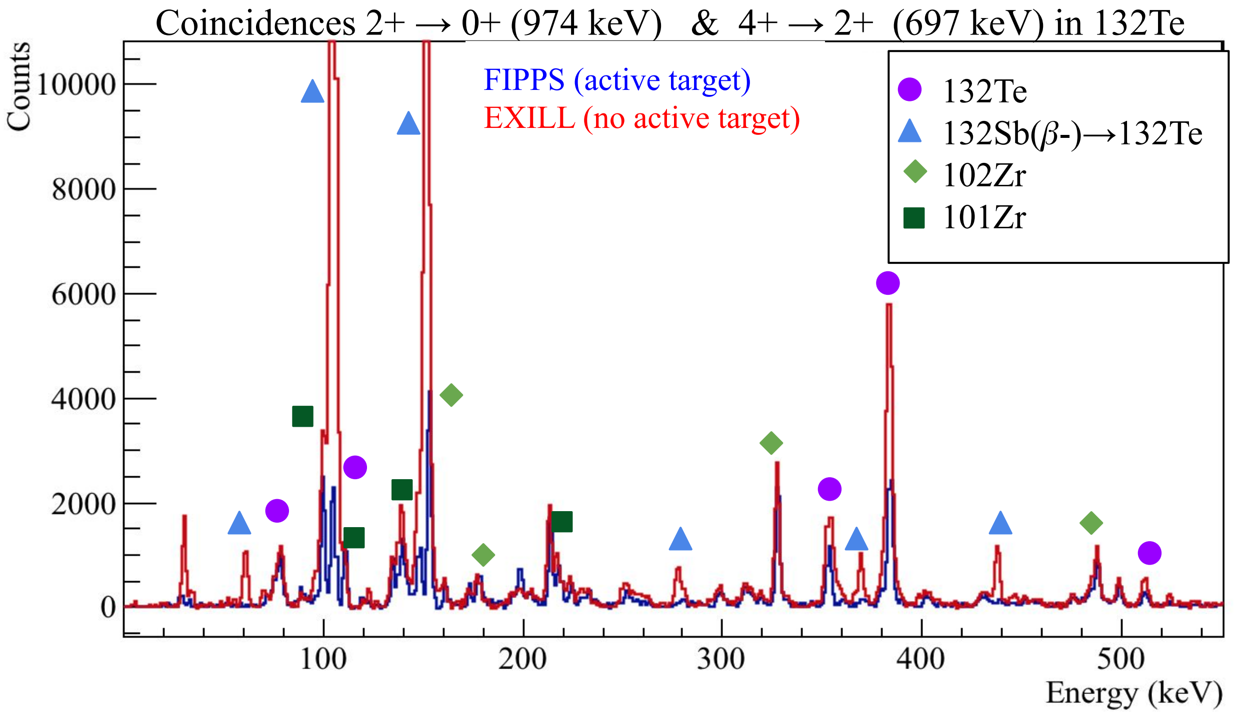
Active target performance



The fission fragments are populated in excited states and deexcite via γ-ray emission.

As they are very neutron rich they undergo a series of beta decays. The beta-decay daughter will also emit γ rays

The active targets allows identification of fission events
→ **Suppression of beta-decay background**



Efficiency calibration of FIPPS + IFIN array

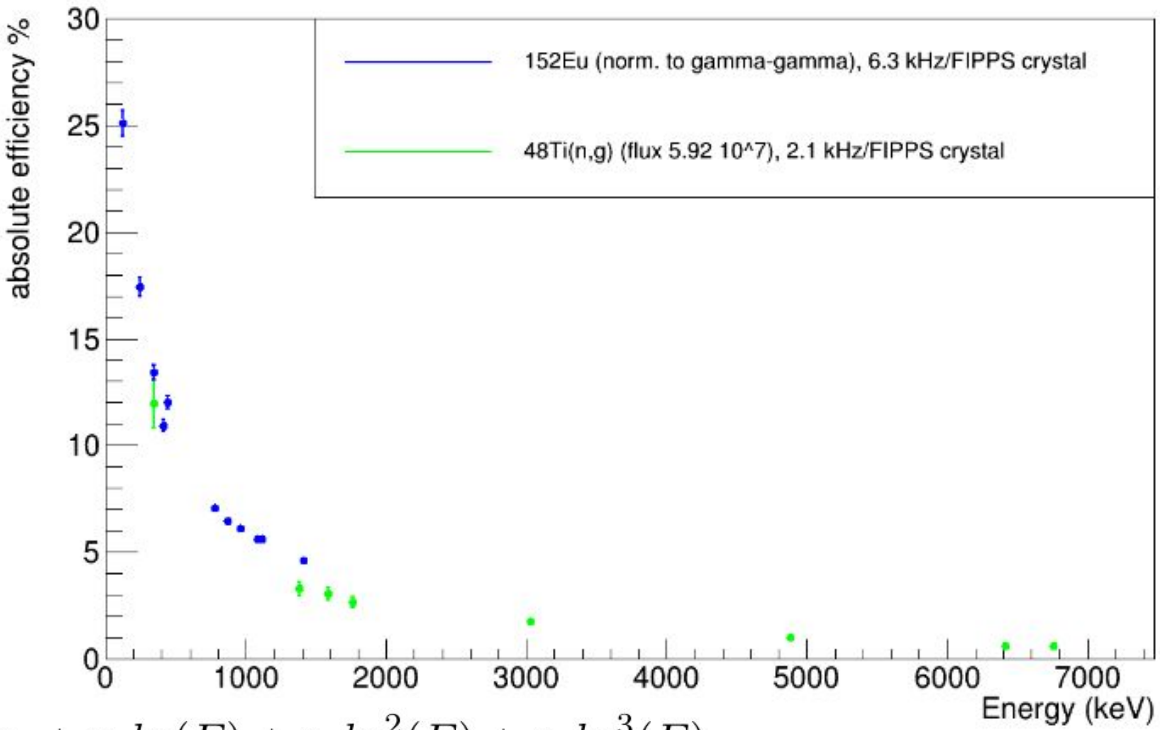
Known γ-ray energies and their intensities can be used to calibrate the response of the array:

^{152}Eu source

- ☐ Using activity of source
- ☐ Using γ-γ coincidences (→ independent of dead time)

^{48}Ti(n,γ) reaction

- ☐ Using neutron flux and reaction cross section.

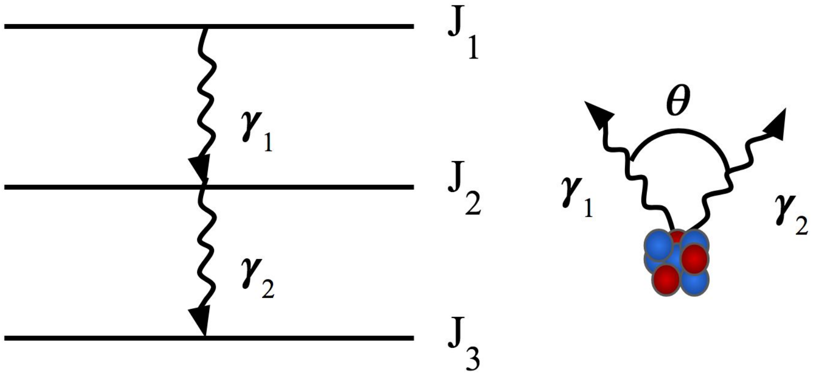


$$ln(\epsilon) = p_0 + p_1 ln(E) + p_2 ln^2(E) + p_3 ln^3(E)$$

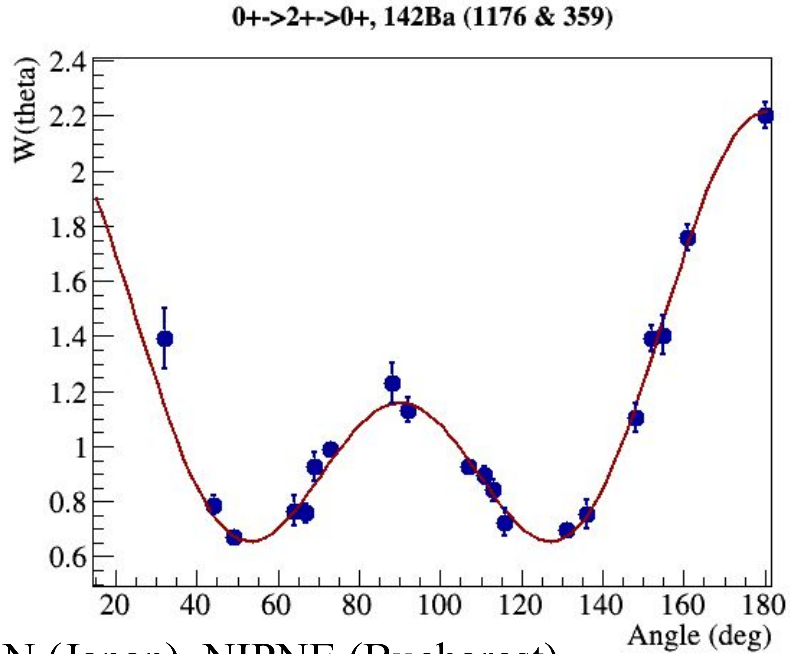
Results to be published, not included in this version of the presentation

Future perspectives

- ➔ Complete analysis on Br isotopic chain.
- ➔ Spin assignment of excited states in Kr and Br using **angular correlations:**



$$W(\theta) = 1 + a_2 P_2(cos(\theta)) + a_4 P_4(cos(\theta))$$



- ➔ Comparison with **theoretical calculations**: RIKEN (Japan), NIPNE (Bucharest),...

Conclusion

- Nowadays a model that can describe all observed properties of nuclei across the nuclear chart does not exist: → experimental nuclear data is required.
- The neutron rich Kr and Br isotopes lie at the boundary of an area of rapid shape change, providing an ideal testing ground for theoretical models.
- The isotopes of interest were produced using the ^{235}U fission reaction at the FIPPS instrument of the ILL.
- Gamma-ray spectroscopy was used to obtain new excited levels in Kr and Br isotopic chains.

Acknowledgements

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Y.H. Kim *et al.* NIM B (2019), *in press*