Fission-Fragment Spectroscopy @ the I.L.L.

Gary Simpson LPSC, Grenoble

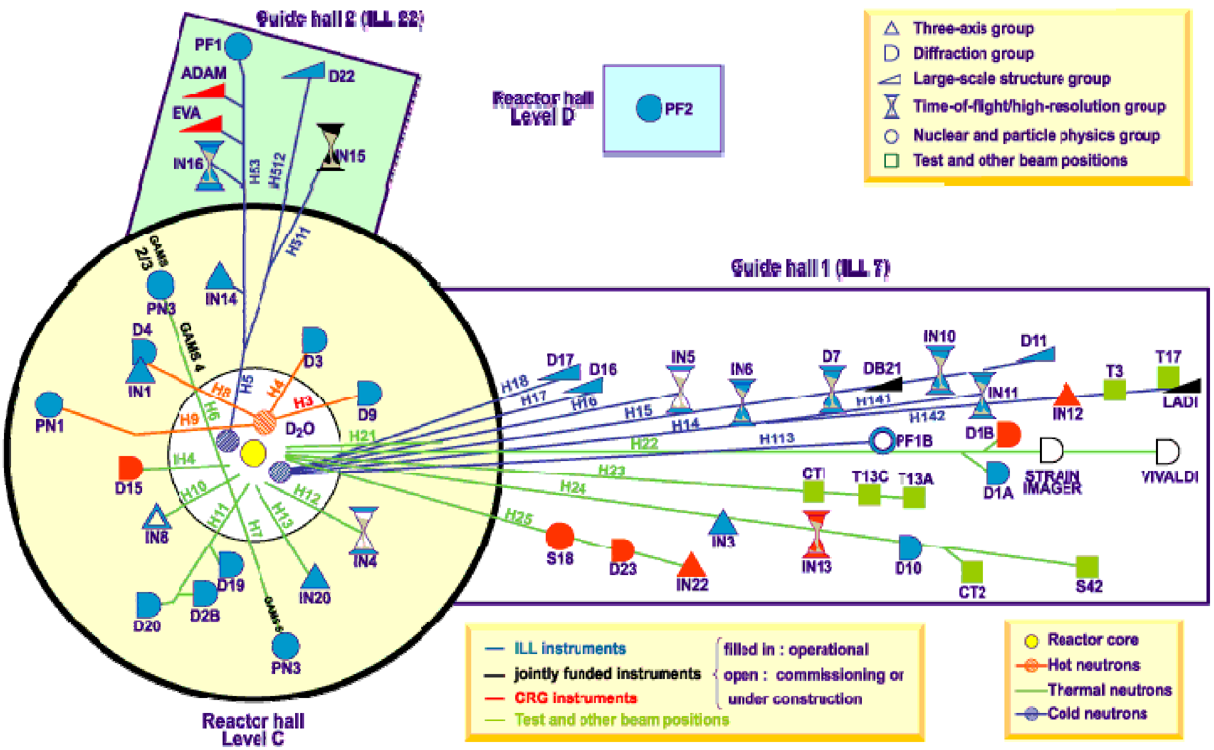
Recent Studies

Stopped-Beams pool

A large Ge array on a thermal neutron guide?

The ILL

- Operates the world's most intense neutron source (1.5×10^{15} n/s/cm^2)
- International lab (12 member countries)
- Houses ~45 instruments
- 430 staff members
- Budget ~90 M Euro
- ~225 days of beam per year



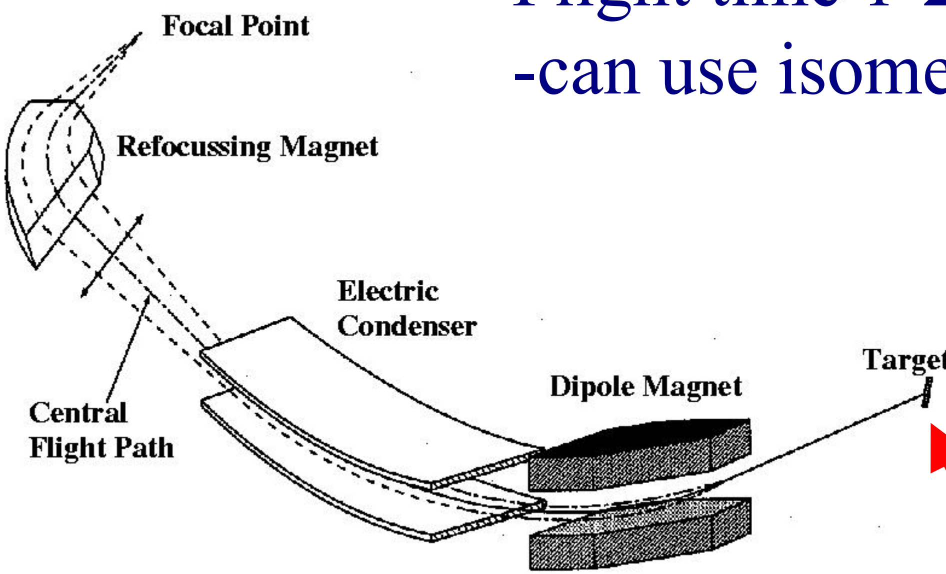
800 experiments per year

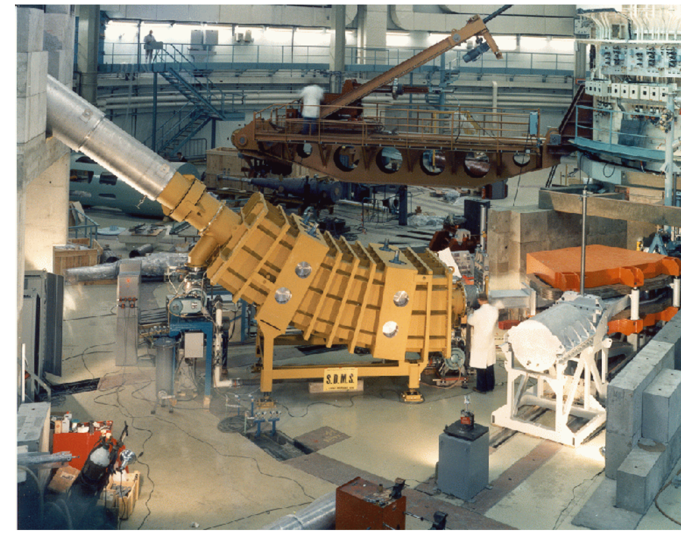
1500 visiting scientists per year

The Lohengrin Fission-Product Spectrometer

(Radioactive beam Facility)

Flight time 1-2 μs
-can use isomers





Separates according to A/q and v/q

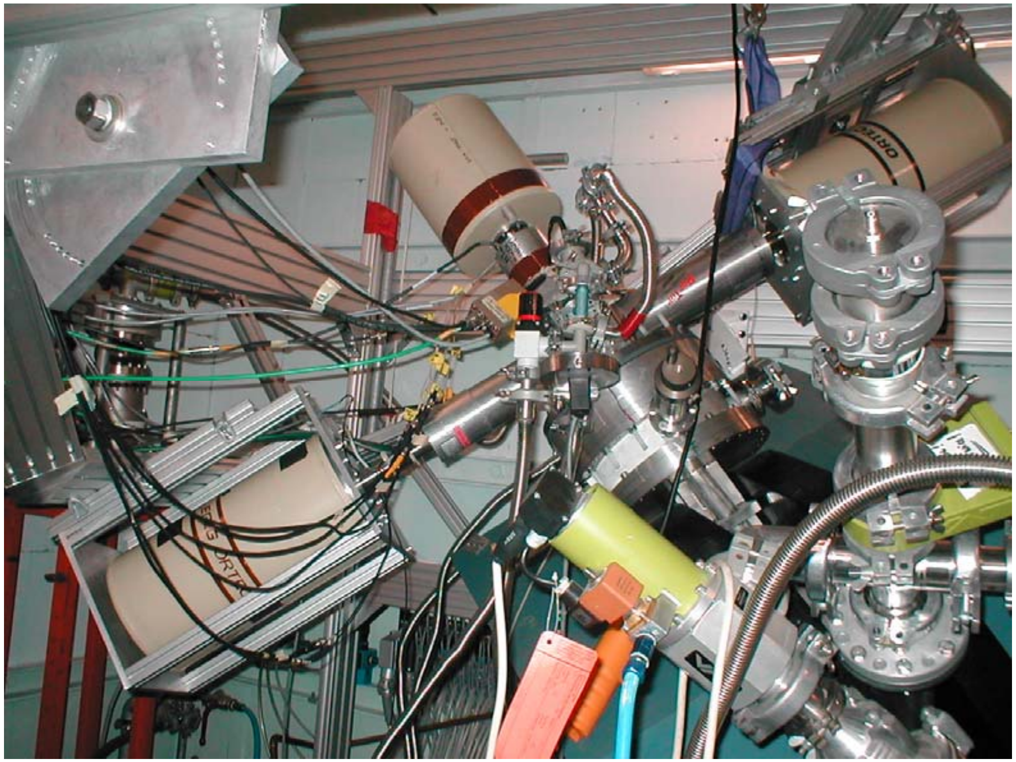
No ion source - no chemical selectivity

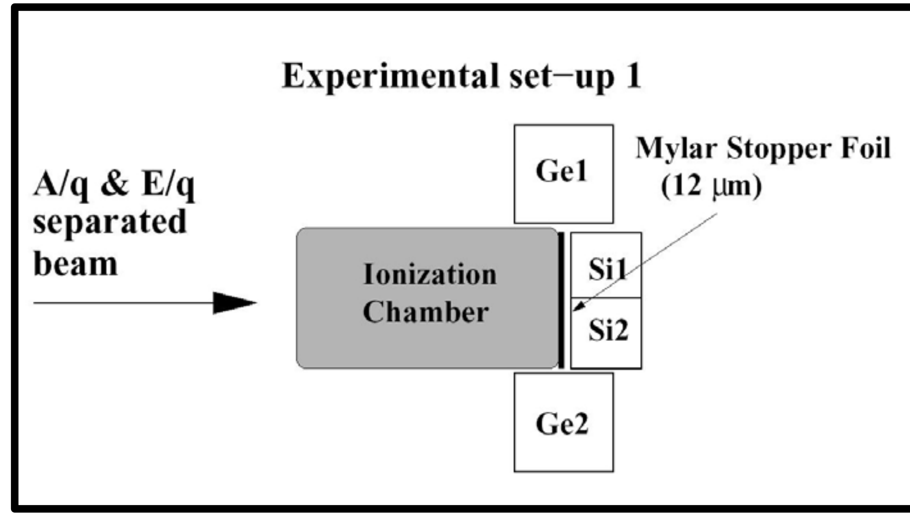
Rates at focal point
~ 1500 ions of ^{132}Sn /s

A/δA~250

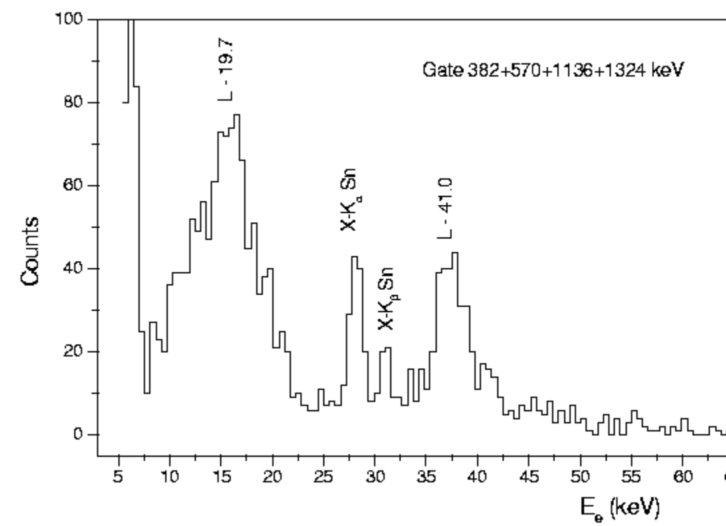
~2☟10^{12} fissions per second at target
(3.5 mg of ^{239}Pu 742 b)

Experimental Setup





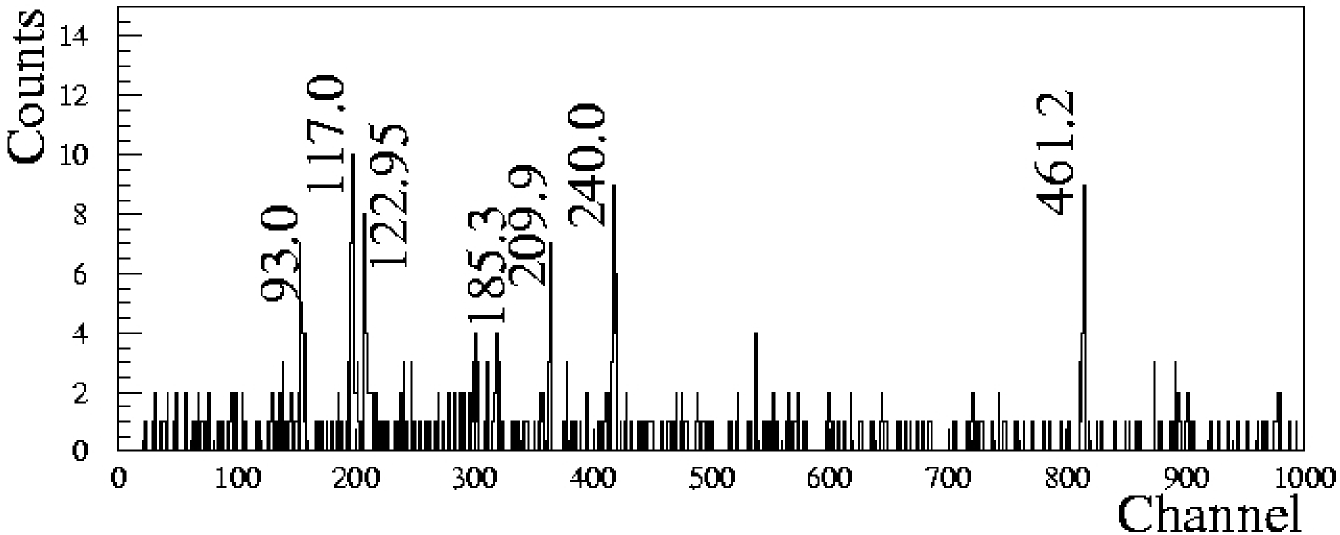
^{129}Sn

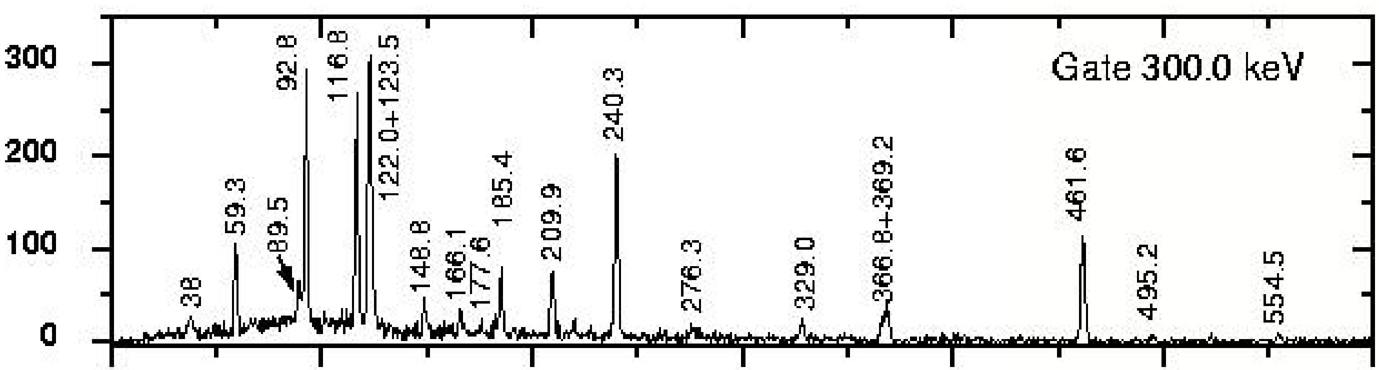


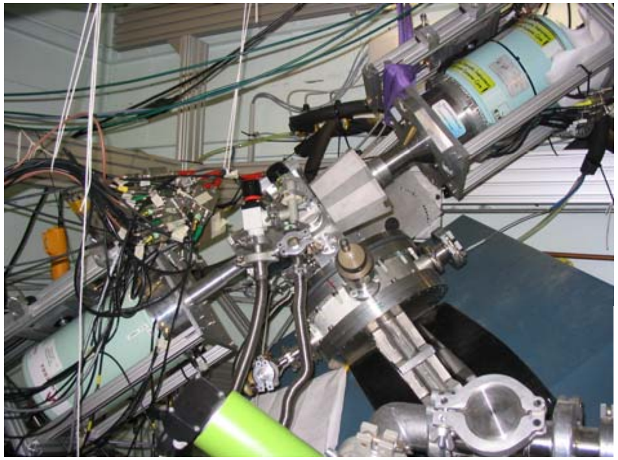
Conversion-electron detection efficiency ~25%.

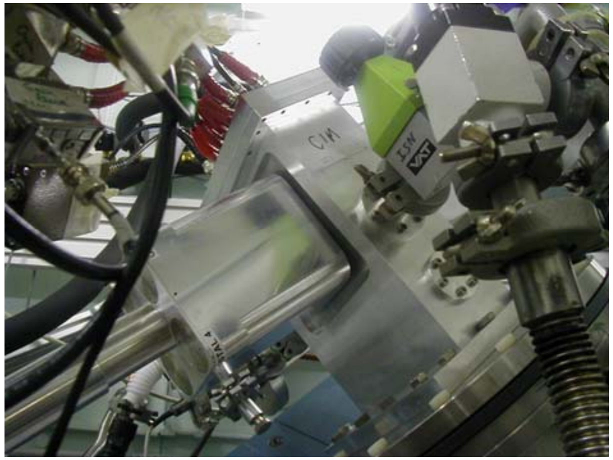
Detect conversion electrons > 15 keV

Big improvements in Gamma-ray detection efficiency









Pool for stopped beams? (β-decay, Isomers)
Would give big improvements at GANIL, ALTO, ISOLDE, ILL ....

Stopped-Beams Pool

Factor of ~3 improvement for isomer experiments at Lohengrin (~order of magnitude for γ–γ coincidences)

Factor of ~2 improvement for fast-timing experiments at ISOLDE

Easier improvement than increased beam intensity

Optimal use of resources?

Swap 4-6 Clovers from and array of ~25 Clovers with phase-1 s

4-6 Clovers factor of 2-3 gain for stopped beam experiments

Only 16 channels -easy to integrate into existing DAQs

Already made bids for funding
:French ANR: G. Simpson, G. Georgiev, F. Ibrahim
:Belgium: G. Neyens

Deformation and Shape Coexistence in the A~100 region
(LPSC, ILL, Warsaw, Manchester)

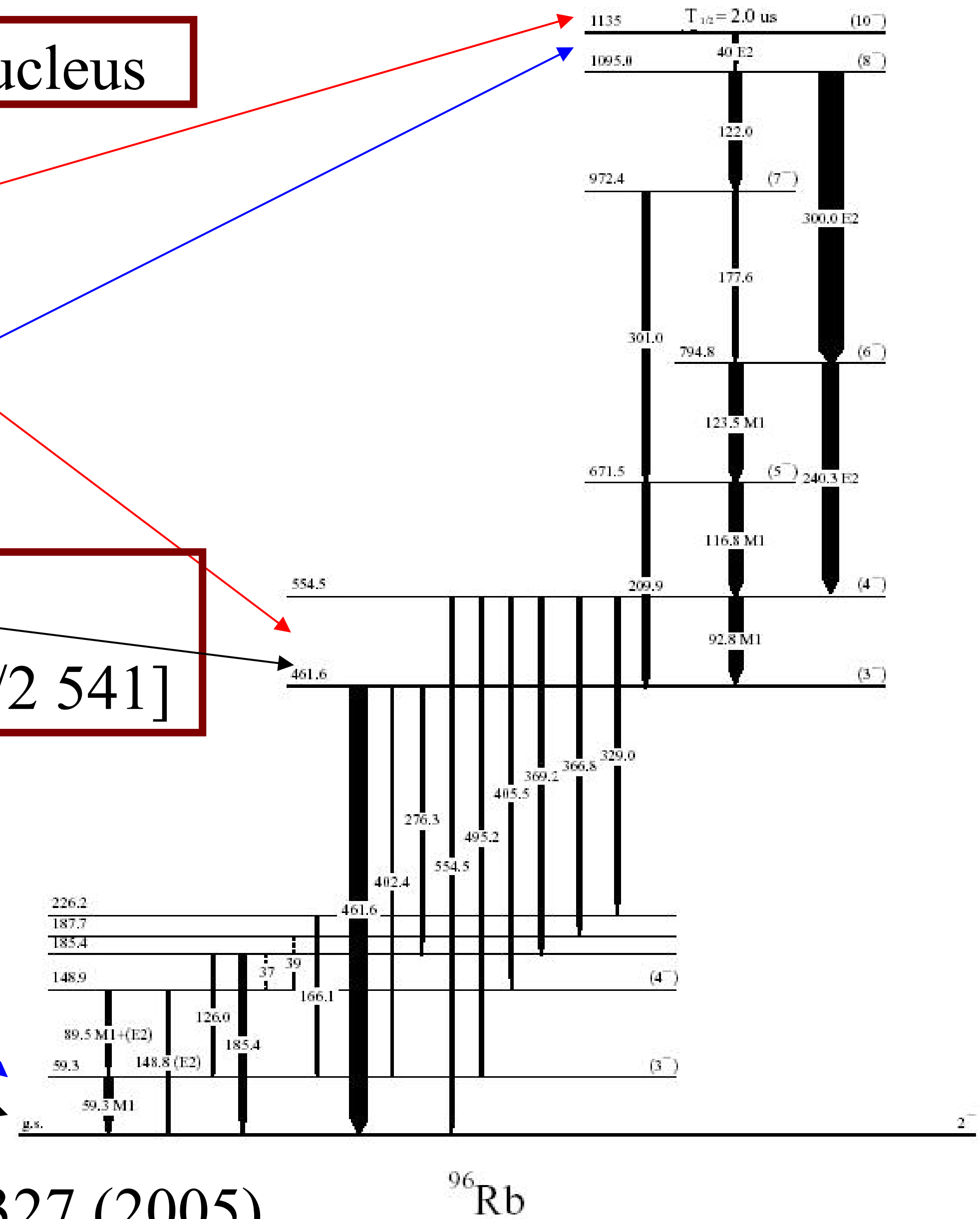
Only observation of any gammas in this nucleus

$\pi(g_{9/2})$
$\nu(h_{11/2})$

Spherical

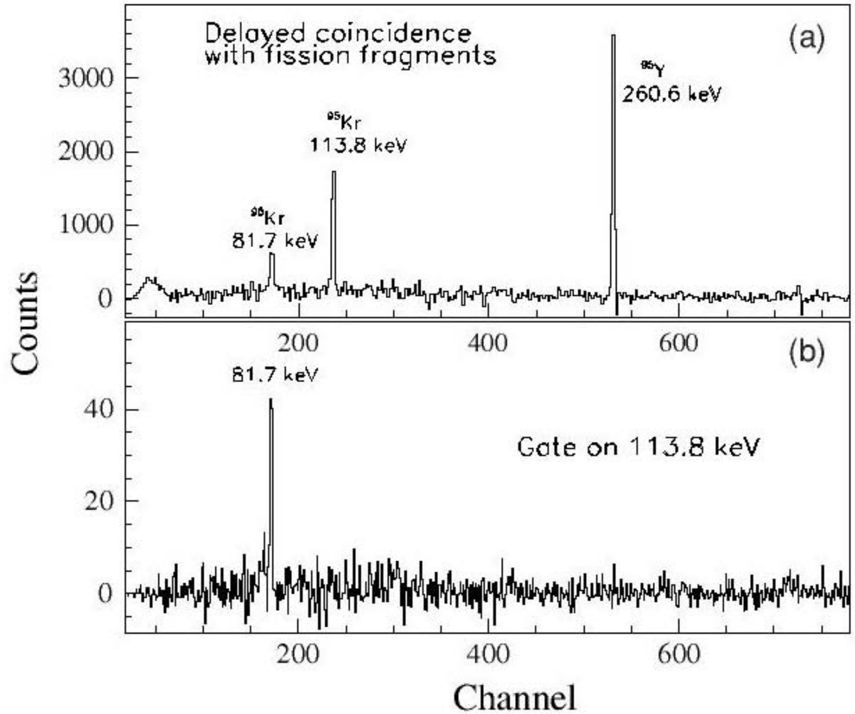
Deformed
$\pi[3/2\ 431]\ \nu[3/2\ 541]$

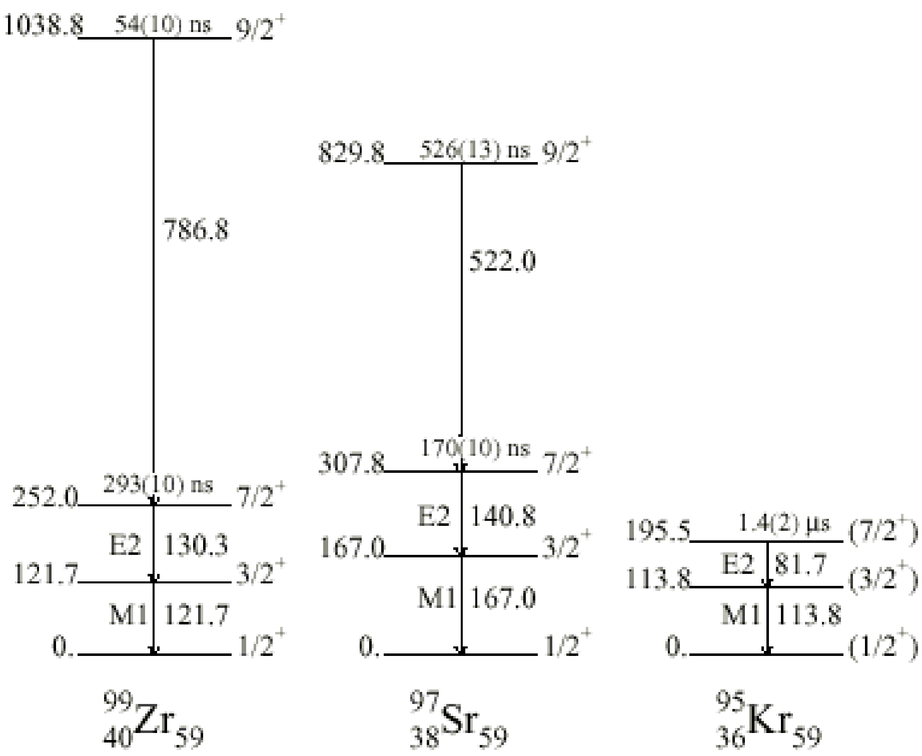
Quadrupole moment of 2^- ground state measured



J. Genevey et al. Phys. Rev. C 71, 064327 (2005)

First observation of any gamma rays in ^{95}Kr





Structure does not seem to change far from stability!

J. Genevey et al. Phys. Rev. C 73, 037308 (2006)

^{132}Sn region
(LPSC, ILL, Napoli, Warsaw)

µs isomers in the vicinity of the magic ^{132}Sn

						^{134}Xe		^{136}Xe			
									^{136}I		^{138}I
		^{128}Te		^{130}Te		^{132}Te			^{135}Te		
		^{127}Sb		^{129}Sb	^{130}Sb	^{131}Sb		^{133}Sb			^{136}Sb
^{124}Sn	^{125}Sn	^{126}Sn	^{127}Sn	^{128}Sn	^{129}Sn	^{130}Sn		^{132}Sn			
^{123}In		^{125}In	^{126}In	^{127}In	^{128}In	^{129}In	^{130}In				
			^{125}Cd								

-These nuclei are very difficult to measure

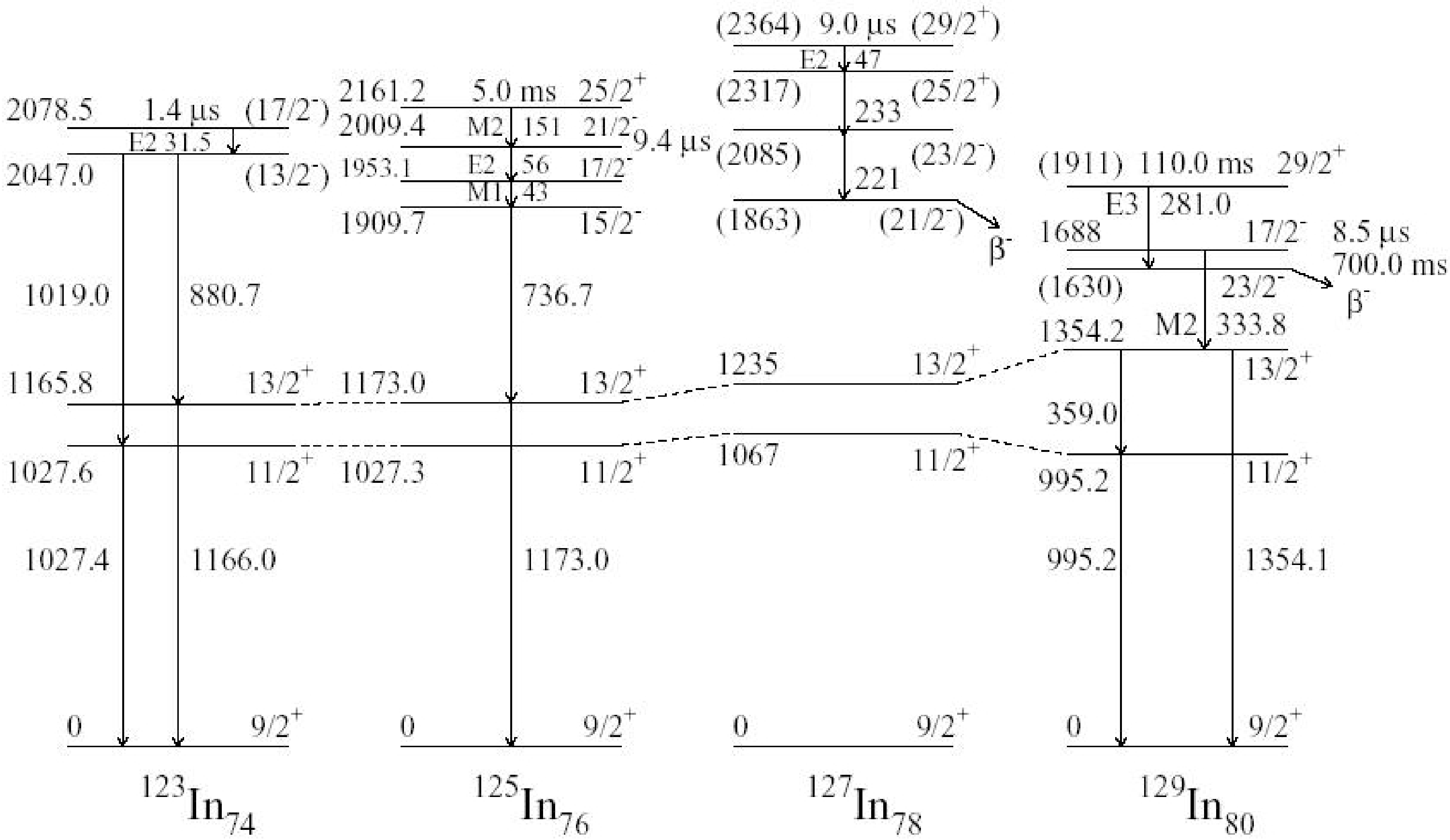
-symmetric fission region

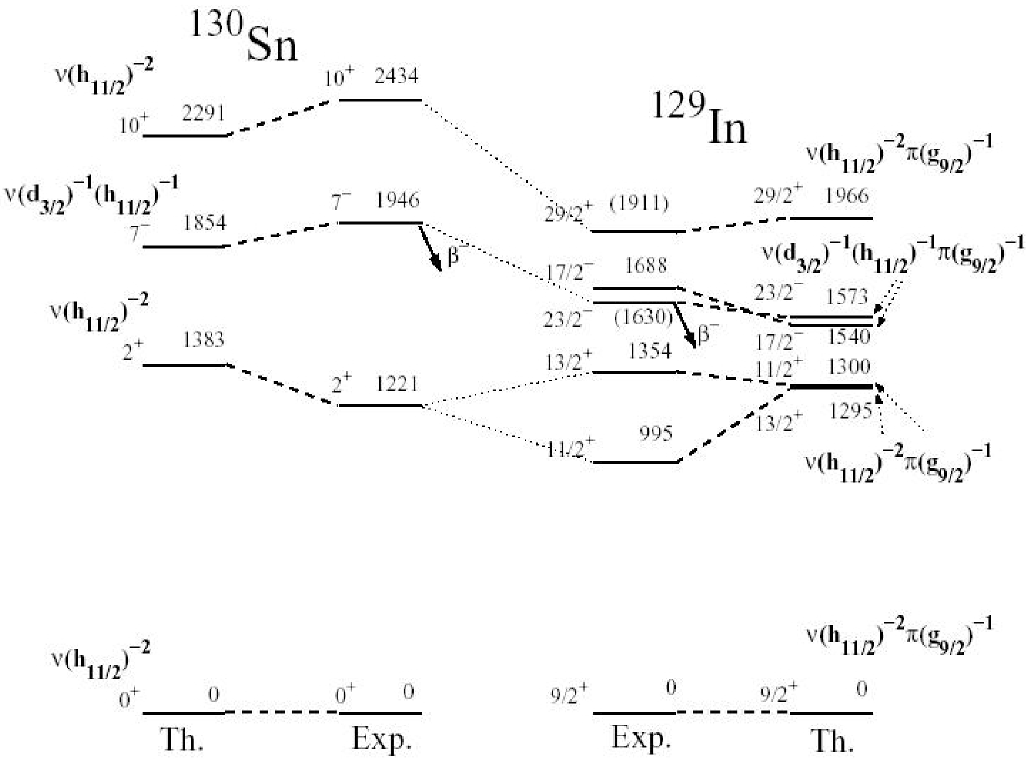
J. Genevey *et al*. Phys. Rev. C 67, 054312 (2003)

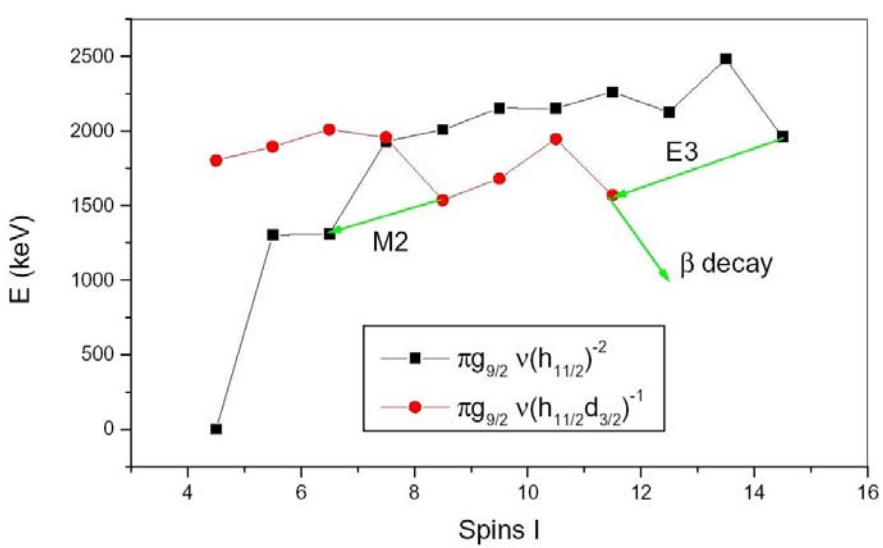
First substantial spectroscopic information in ^{129}In

A. Scherillo *et al*. Phys. Rev. C 70, 054318 (2004)

Complements previous beta-decay studies

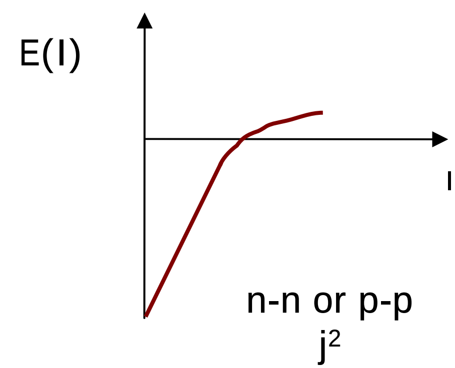






Calculation by Napoli Group effective n-n interaction deduced from CD-Bonn potential. Correctly reproduces the observed level scheme.

Simplistically yrast states in ^{129}In are from $\nu h_{11/2}^{-2}$ coupled to $\pi g_{9/2}^{-1}$



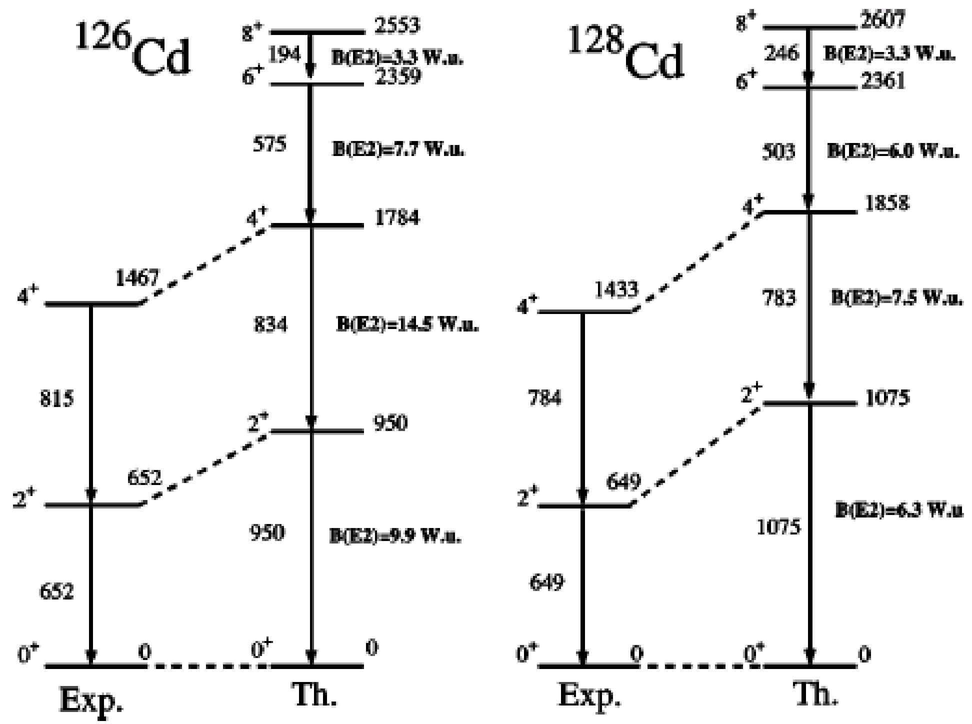
unique parity states + effective interaction

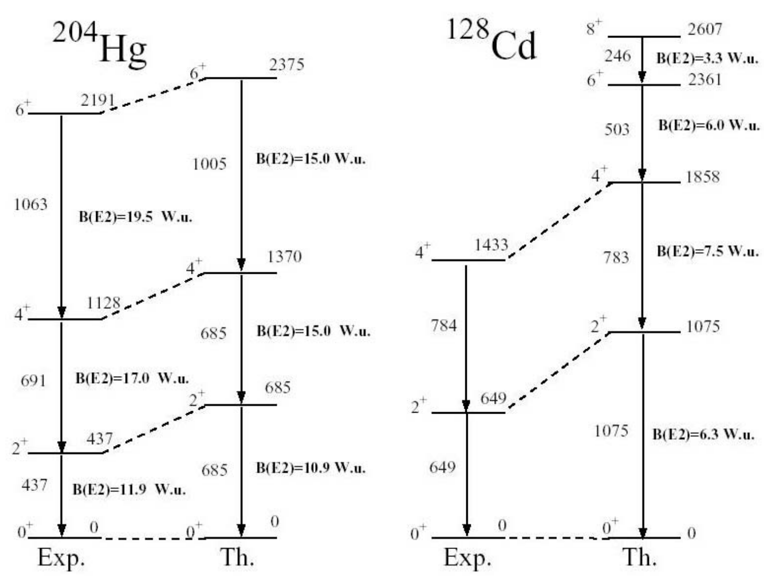
States are lower in energy due to attractive ν−π interaction

Cd and In nuclei close to ^{132}Sn

A. Scherillo *et al*, Phys. Rev. C 70 (2004) 054318.

- Collectivity in Cd nuclei? (shell quenching?)
- Why are 2^+ states systematically higher in calculations?
- Need lifetime measurements (or Coulex)



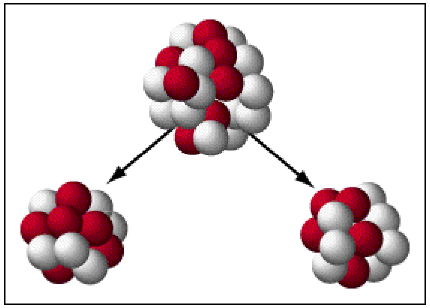


Similar phenomena observed in equivalent nuclei near ^{208}Pb.

Isomer Collaboration

LPSC Grenoble	-J. Genevey, J.A. Pinston, G. Simpson
ILL	-R. Orlandi, A. Scherillo, I. Tsekhanovich
Napoli	-A. Covello, A. Gargano
Cologne	-N. Warr, J. Jolie

Spontaneous Fission

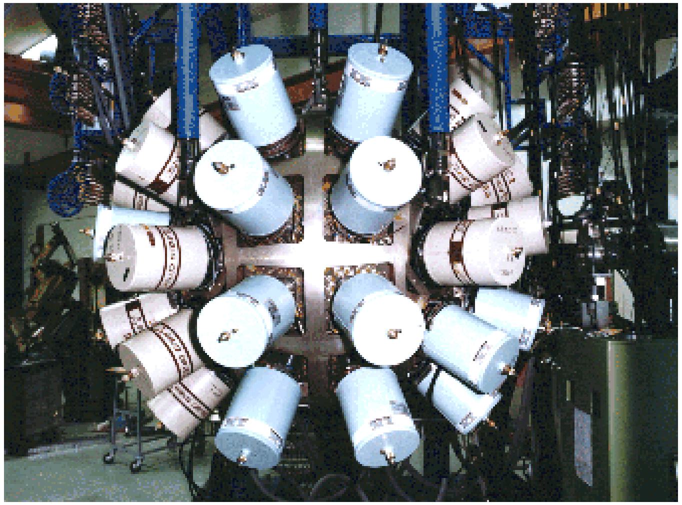


Nuclei produced in mass range ~70-160

~4 neutrons per fission -secondary fragments remain very neutron rich!

6-8 $\hbar$ mean spin (observed spins up to ~20 $\hbar$) -reaction multiplicity ~10

~100 nuclei available for prompt fission study per fissioning system -with current technology e.g. Euroball/Gammasphere (Normally use γ–γ–γ coincidences. To build level schemes).



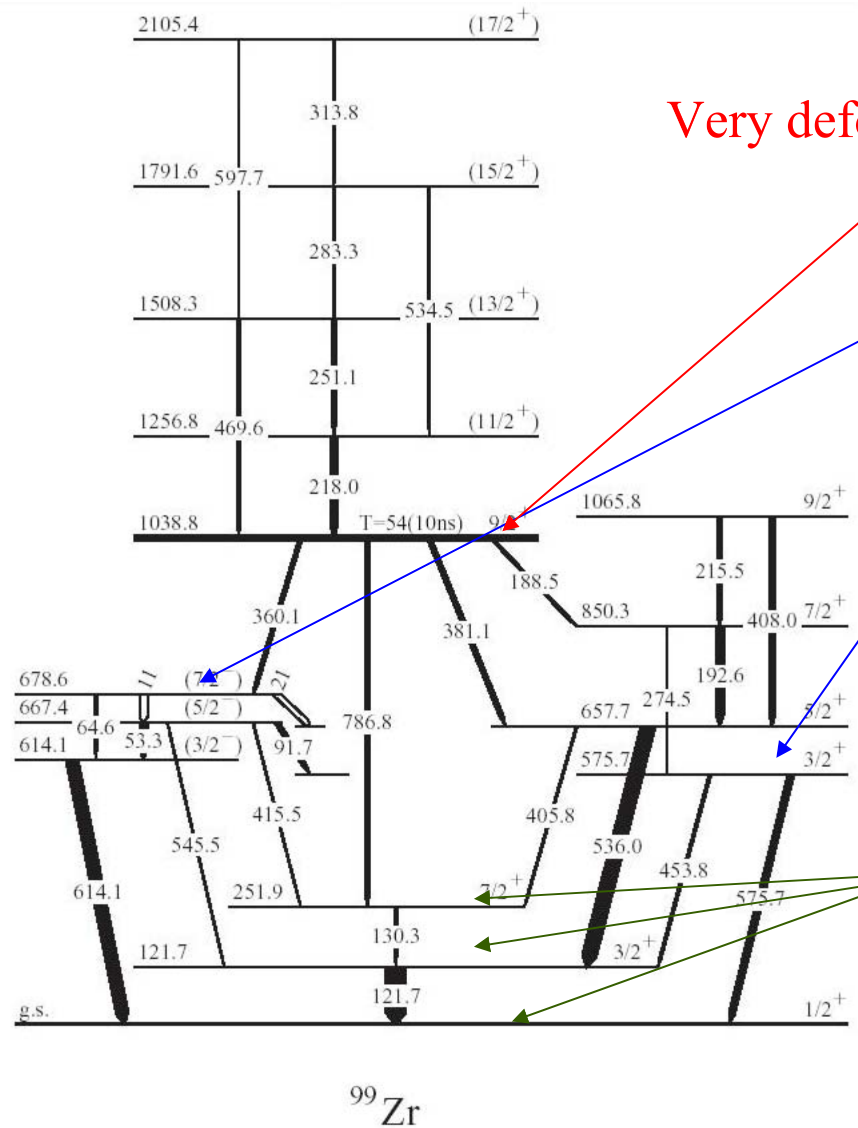
One experiment published ~60 articles including several PRLs (^{248}Cm + EurogamII) -optimal use of resources?

Can also measure
lifetimes (ps DPM, ps-ns plunger) -A.G. Smith
g-factors -A.G. Smith

Example of Physics

Combination of Eurogam II and Lohengrin data

Observation of 3 different shapes in $^{99,101}Zr$ and ^{97}Sr

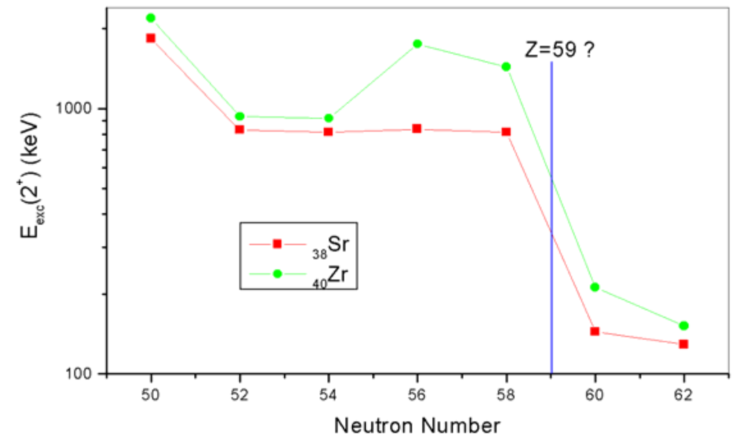


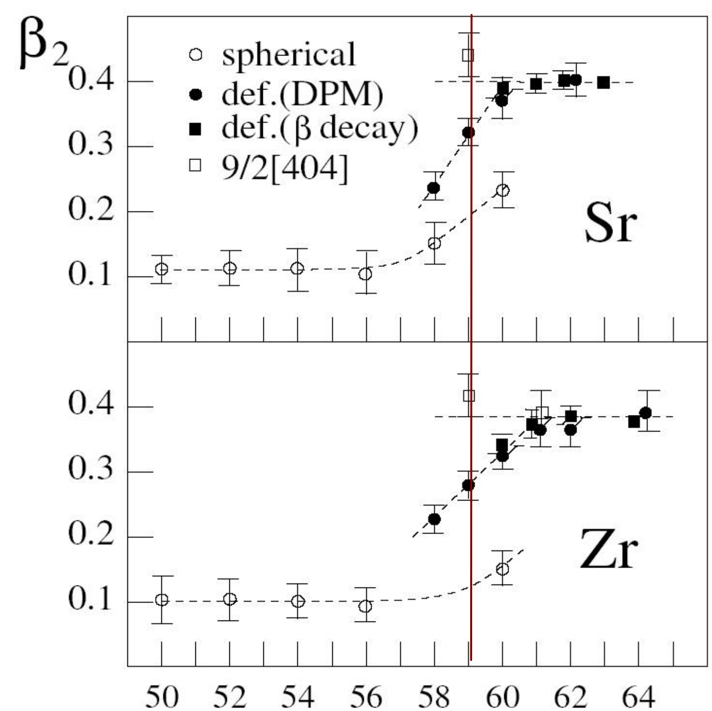
Very deformed $\beta_2=0.41$

Intermediate deformation $\beta_2=0.32$

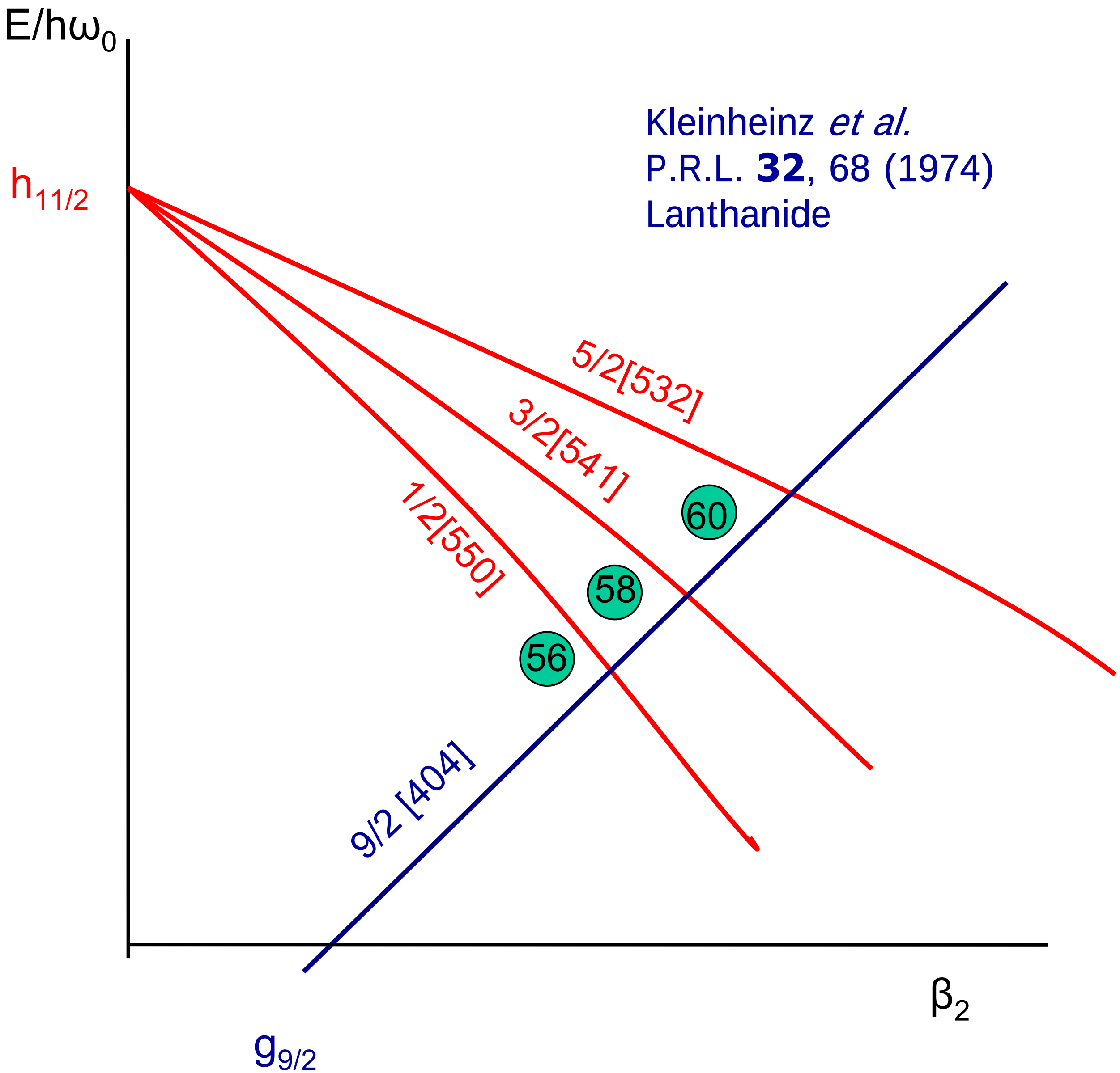
Spherical

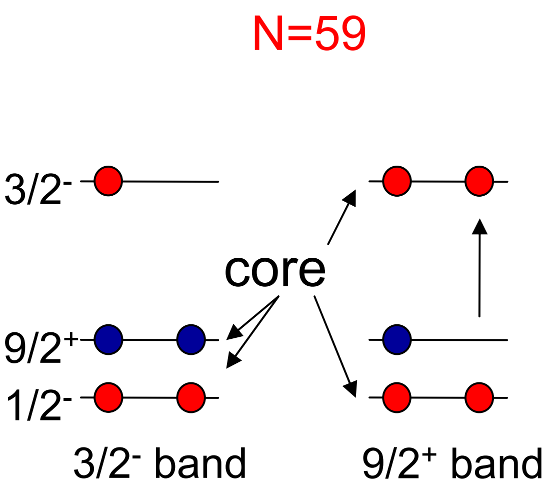
W. Urban, J.A. Pinston *et al.* Eur. Phys. J. A **16**, 11 (2003)





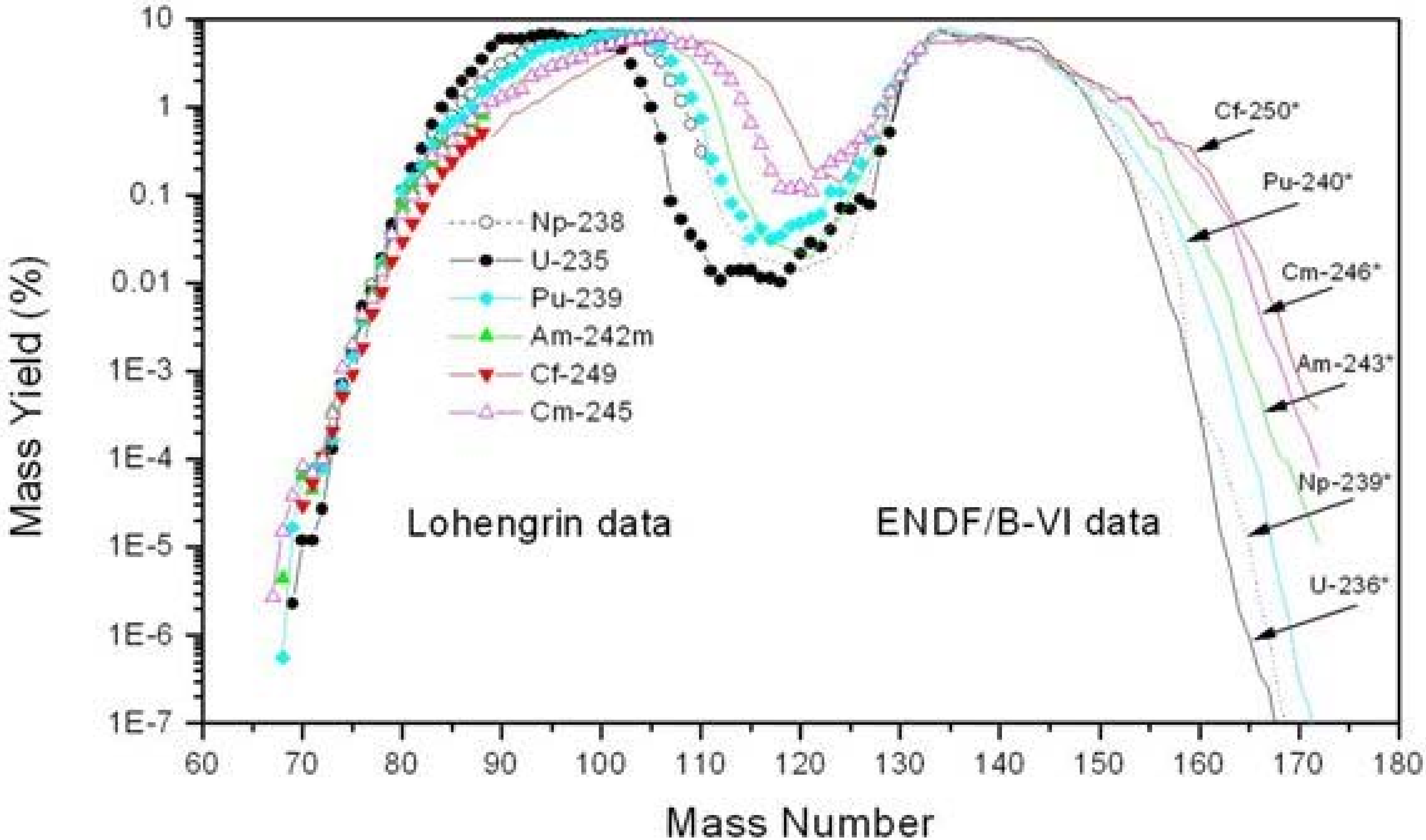
Schematic representations of deformed configurations in Sr and Zr isotones





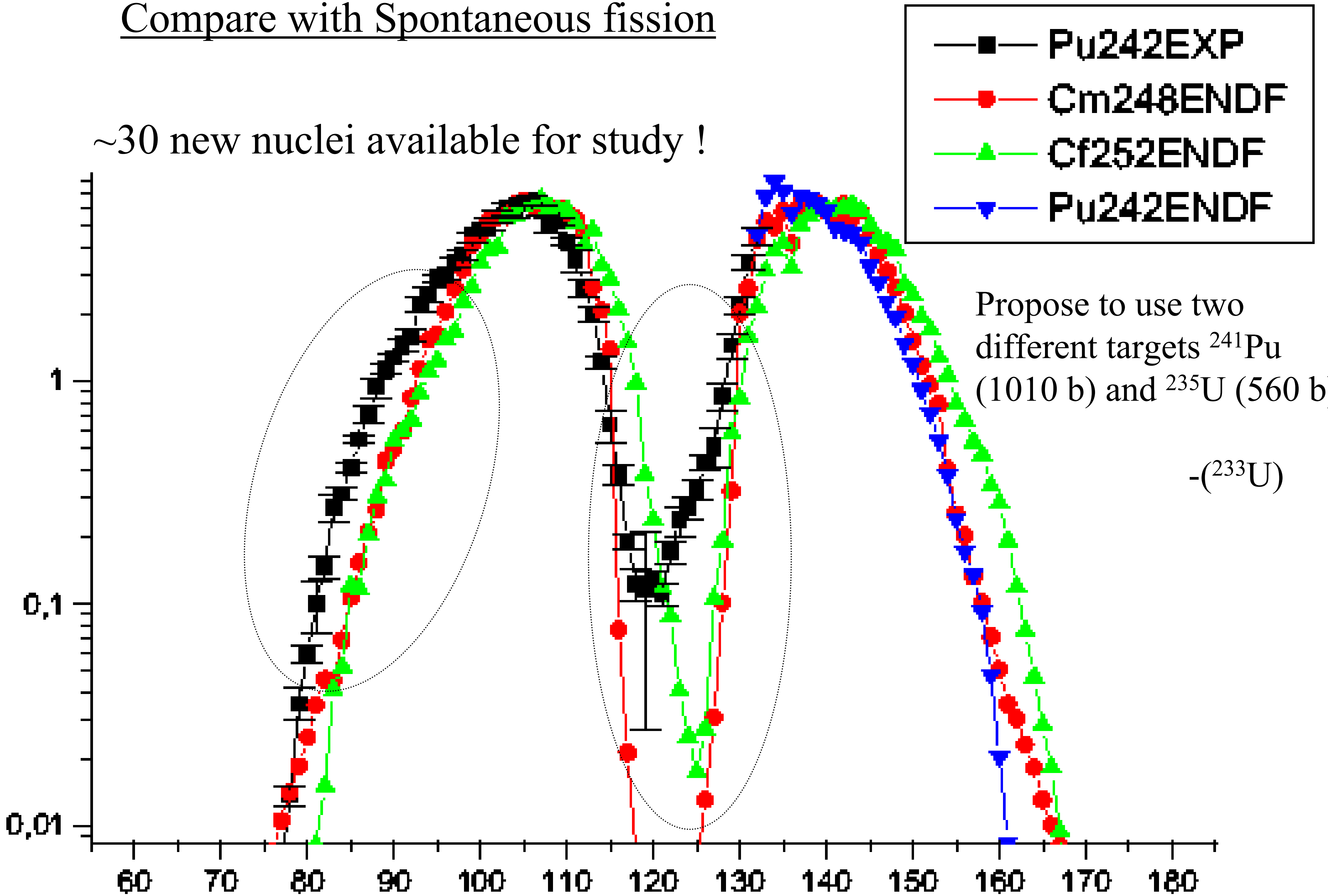
Disadvantage of s.f. -limited to two sources (^{252}Cf, ^{248}Cm)
Solution -use thermal-neutron-induced fission
(tried early 1990's W.R. Philips, J.L. Durell & co TESSA Brookhaven)

Change mass distribution by changing target



Compare with Spontaneous fission

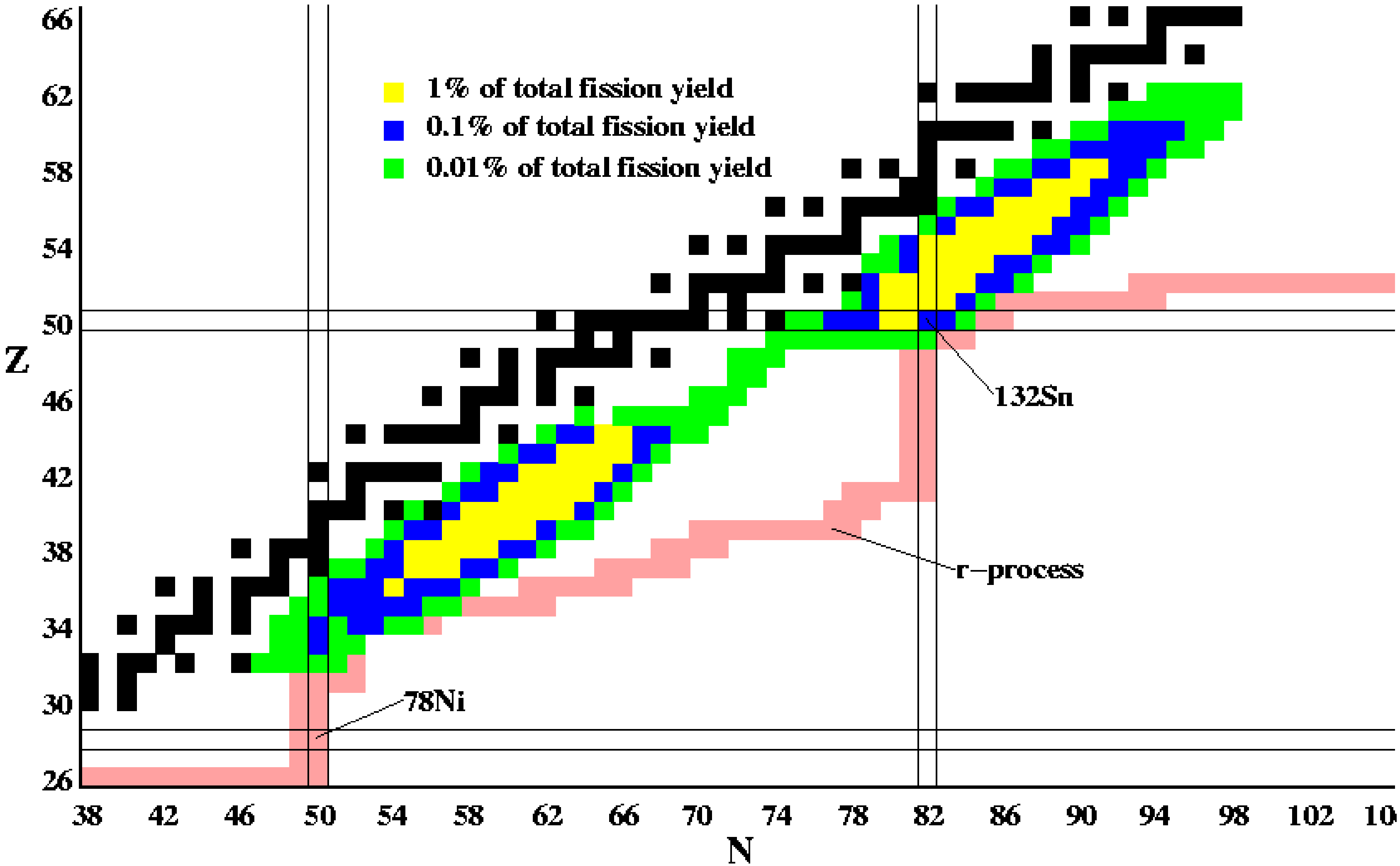
~30 new nuclei available for study !



Propose to use two different targets ^{241}Pu (1010 b) and ^{235}U (560 b)

-(^{233}U)

Thermal neutrons on ^{241}Pu



Mass 85 region

See properties of nuclei close to ^{78}Ni (r-process nuclei).
Few orbits play important roles in deformation

^{132}Sn region

Nuclei have a simple structure -good for testing the shell model far from stability.
Shell model calculations work quite well for In nuclei close to ^{132}Sn -but less well away from it.

Neutron Guides

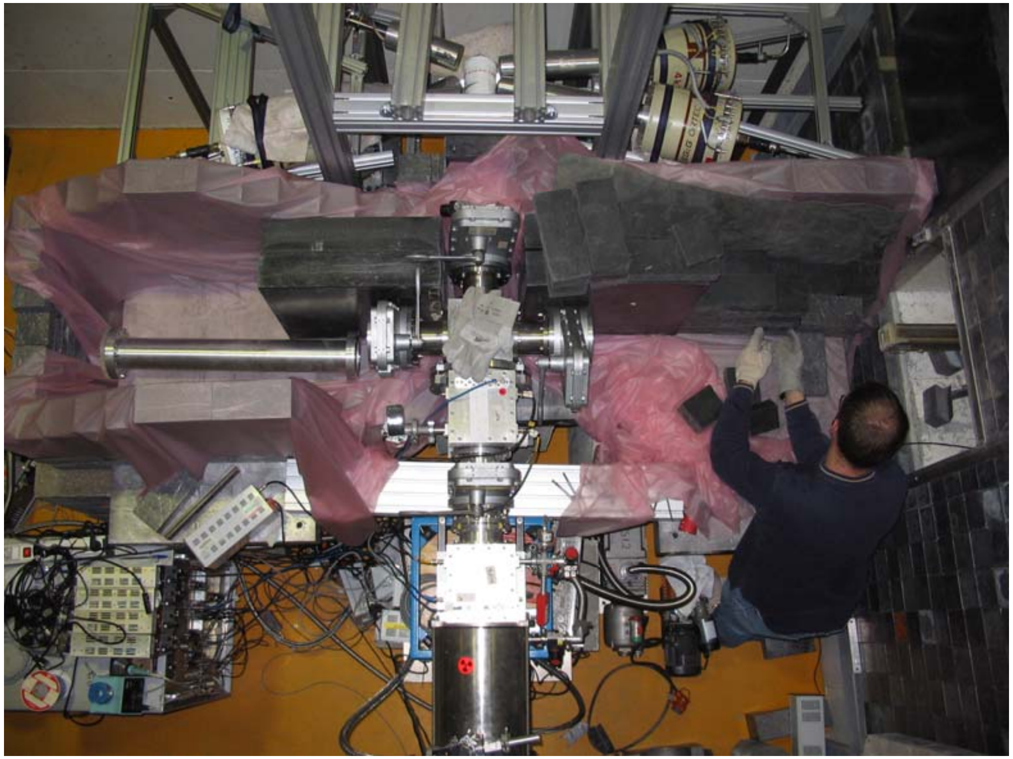
Reflect neutrons!

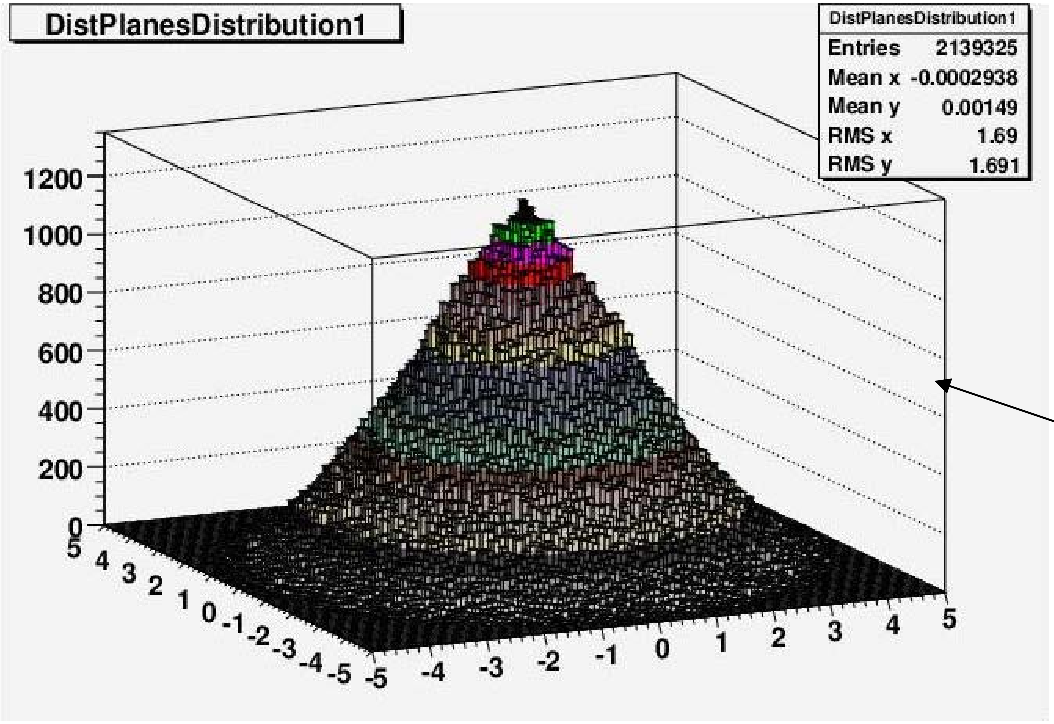
No fast neutrons

No gamma-ray background

Flux up to 1.3 x 10^{10} n/s/cm^2 (PF1B)

Thermal neutrons have meV energy





Beam profile on target

Key Measurements and Nuclei

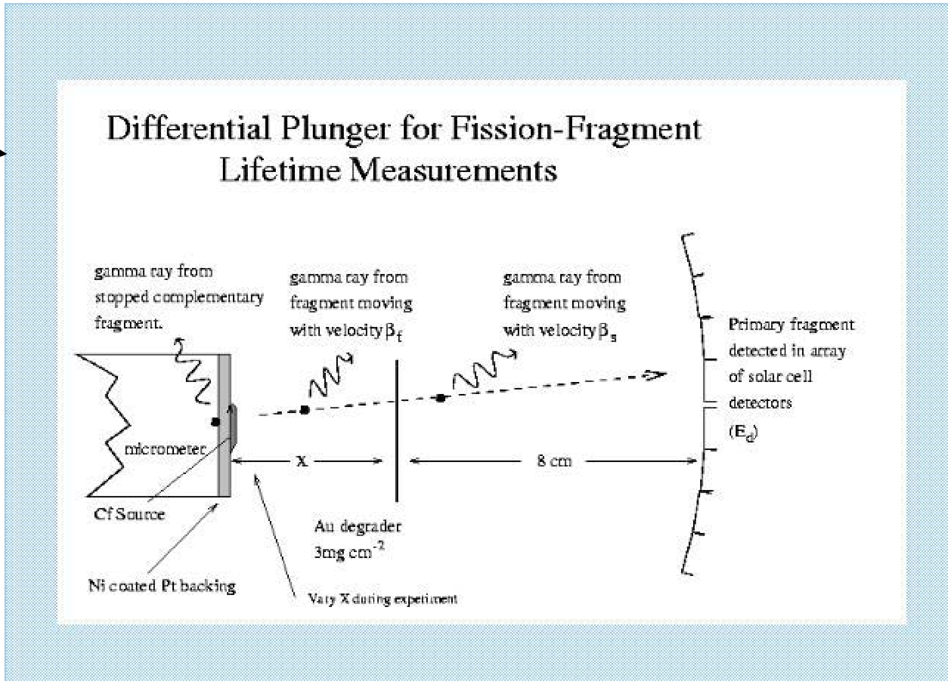
Spectroscopy (γ–γ–γ)

In and Cd nuclei close to ^{132}Sn

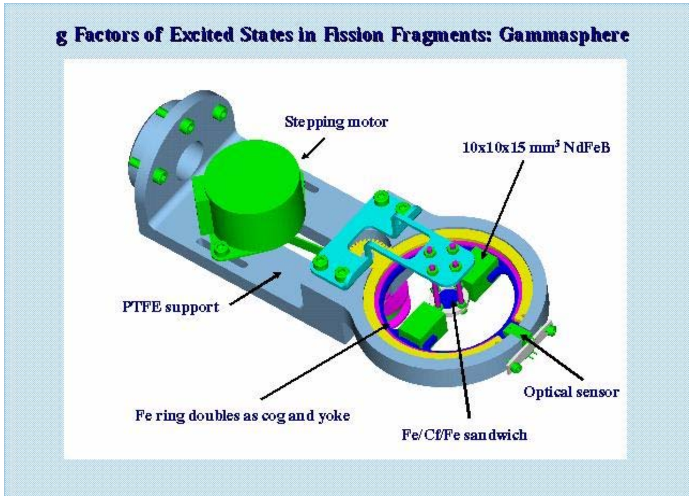
Neutron-rich mass 80-95 region

Yield measurements for reactors (heavy region not well measured -current reactors are operating at 40 % of their current theoretical efficiency!)

Lifetimes (DPM, plunger)



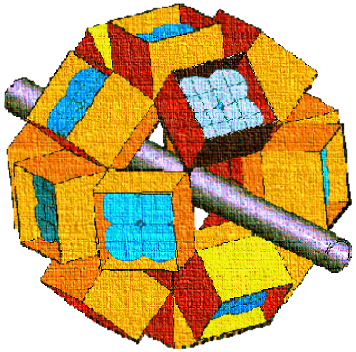
g-factors (Missing g_R values in several regions!)



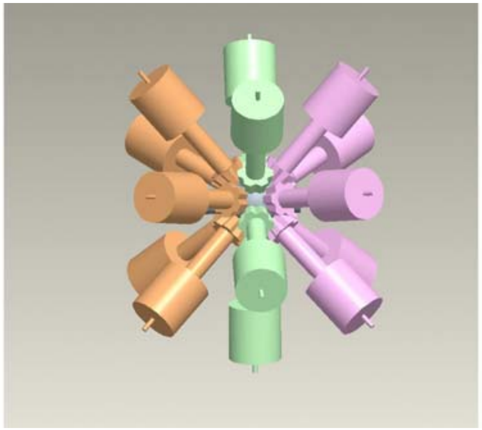
What kind of array do we need?

Need γ–γ or γ–γ–γ coincidences to build level schemes -strong function of array efficiency.

~10 % efficiency(at 1.3 MeV) needed, but must be able to handle multiplicity 10.



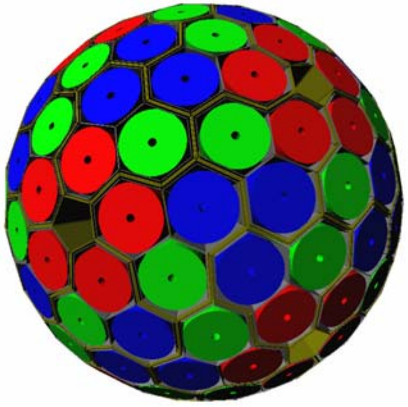
What is available?



Winter shutdown for most accelerators - but ILL still runs

ILL direction are willing to write a letter of support

Welcome collaborators



Far future AGATA 201? even s.f. (γ–γ–γ)

Facts and figures about fast neutrons in proposed experiment

2×10^5 fissions/s
2.5 neutrons/fission (^{241}Pu)
detectors at 15 cm
x2 weeks = 2.1×10^8 n/cm^2 on detectors

detectors at 20 cm
x2 weeks = 4.7×10^7 n/cm^2 on detector

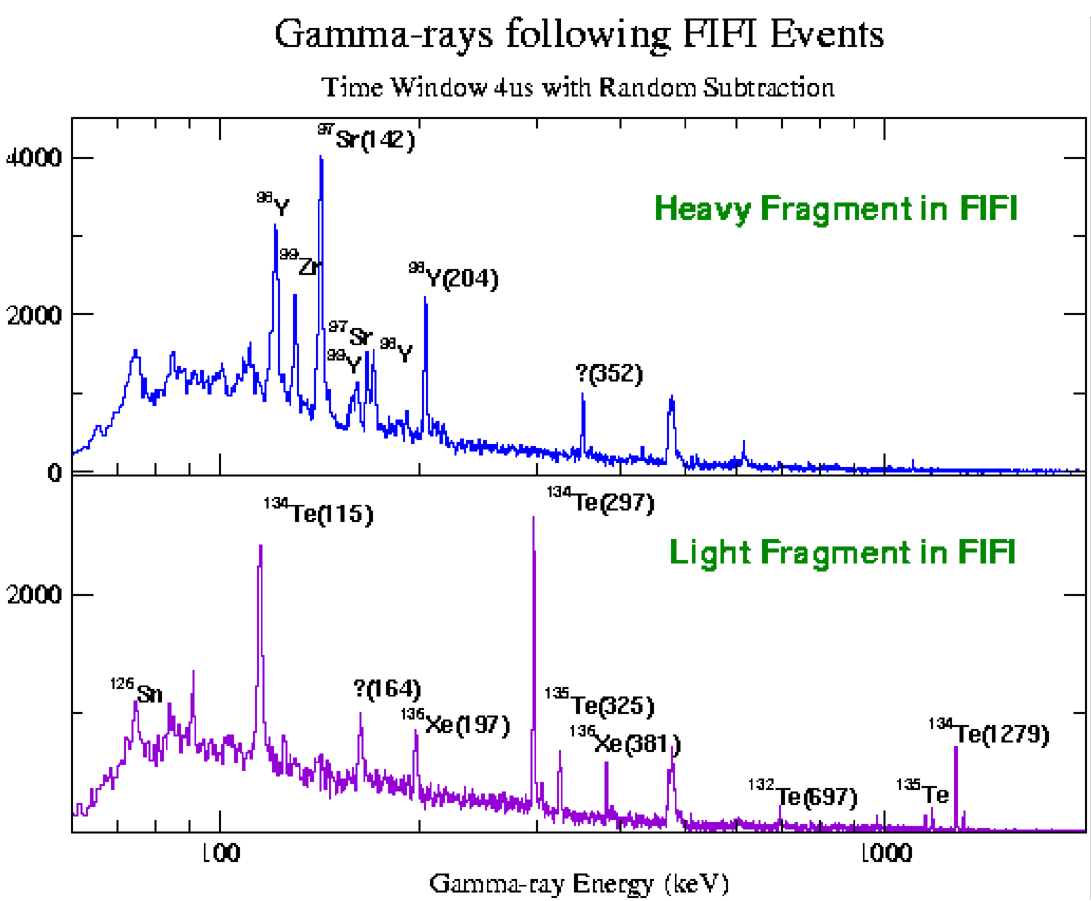
Limit Euroball 1.5×10^8 per detector
Limit ORTEC = 1×10^9 /cm^2

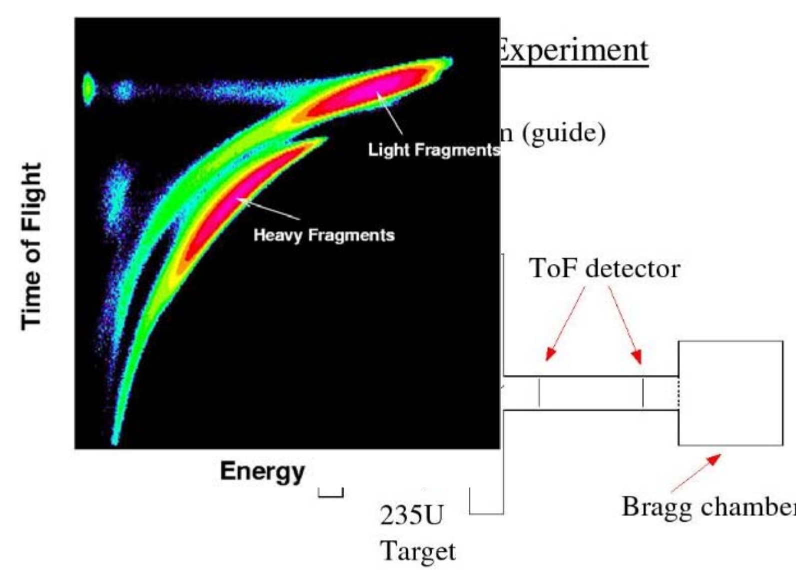
Compare with spontaneous fission experiments at Gammasphere
e.g. J. K. Hwang, Phys. Rev C 73, 044316 (2006)
^{252}Cf ~28 μCi (3% fission)

3.1×10^5 fissions/s
3.76 neutrons/fission (^{252}Cf)
detectors at 25.4 cm
x 2 weeks = 1.7×10^7 n/cm^2 on detectors
=8.5×10^8 per detector

Experiments using Neutron Guides

-Search for isomers 30 ns> $t_{1/2}$>1 μs
FiFi -ILL, LPSC, Manchester, Cologne, Warsaw





Collaboration

LPSC Grenoble	-J. Genevey, J.A. Pinston, G. Simpson
Univ. Warsaw	-W. Urban, A. Zlomaniac
ILL	-R. Orlandi, A. Scherillo, I. Tsekhanovich
Manchester Uni	-J.L. Durell, A.G. Smith, A. Thallon, B.J. Varley
Uni. of Cologne	-J. Jolie, N. Warr
Napoli	-A. Covello, A. Gargano

Other members of Lohengrin Community

ILL	-Ulli Koster
University of Uppsala	-H. Mach
Unversity of Camerino	-D. Balabanski
IPN Orsay	-G. Georgiev
Bruyeres-Le-Chatel	-J.M. Daugas