# Recent Measurements of Spherical and Deformed Fission fragments using the Lohengrin Spectrometer and large Ge arrays

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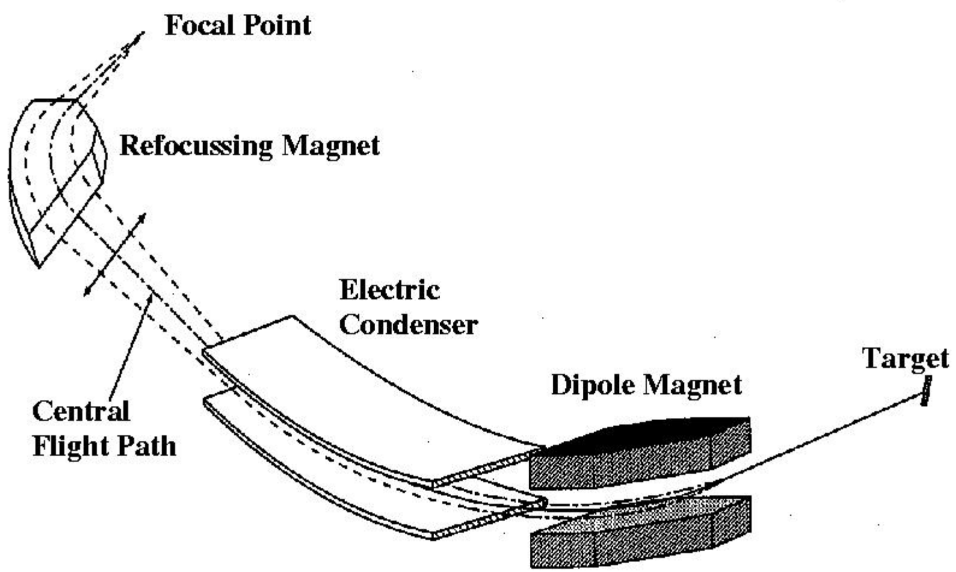
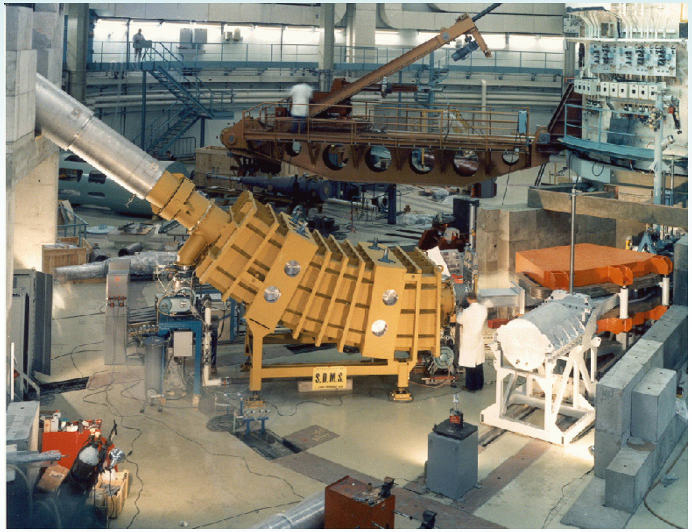
**LPSC(IN2P3-CNRS, UJF, IPG), Grenoble**

- $^{136}$Sb
- Fast timing
- $^{105,107}$Mo, $^{107}$Tc
- Future prospects

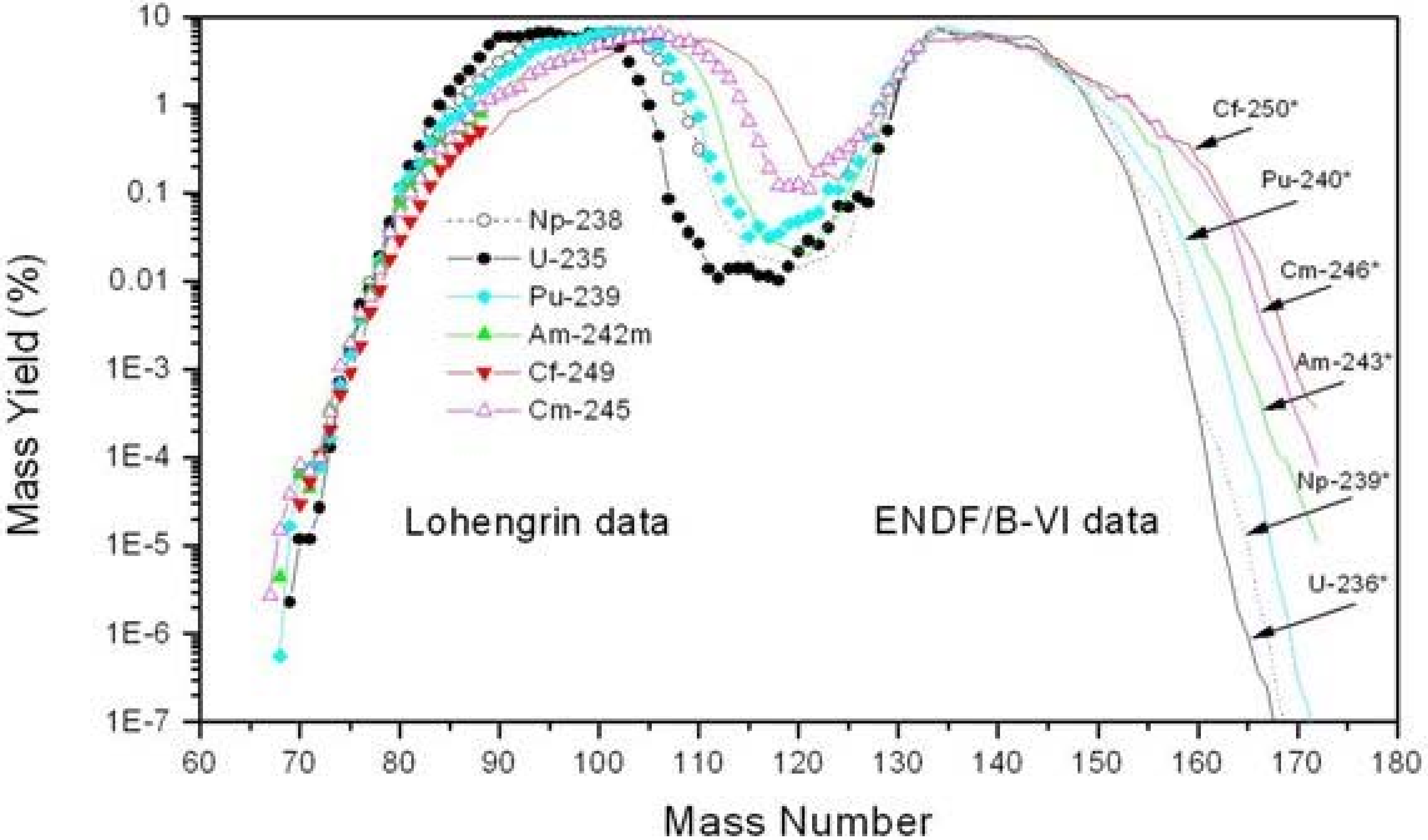
# The Lohengrin Fission Product Spectrometer @ ILL



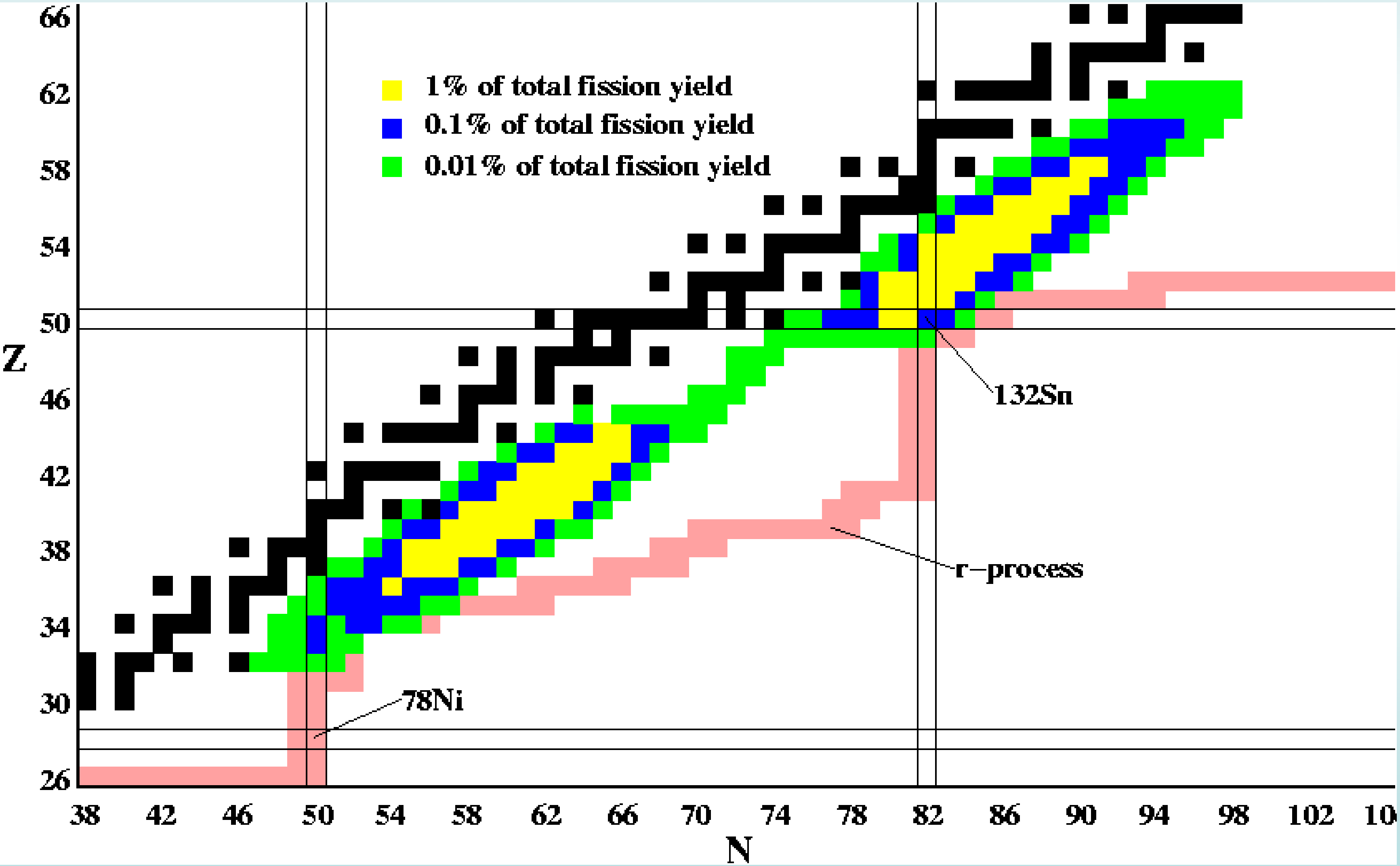



- Separates according to Av/q and K.E./q
- No ion source - no chemical selectivity
- $A/\delta A \sim 250$
- Solid angle $<2 \times 10^{-5}$
- $\sim 2\times10^{12}$ fissions/s (3.5 mg of $^{239}Pu$ 742 b) $\rightarrow \sim 1500$ $^{132}Sn$/s

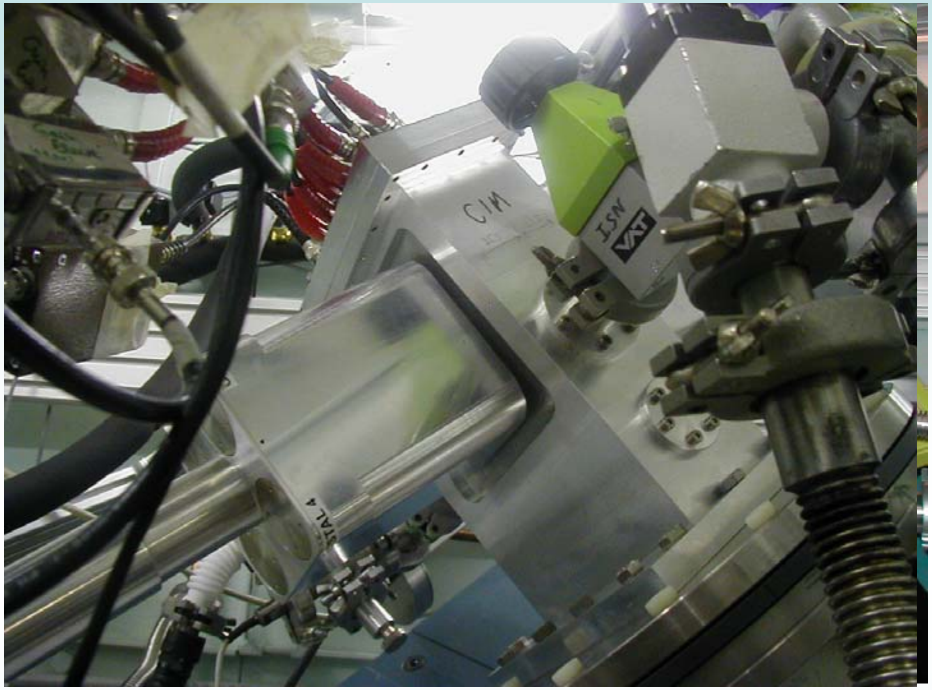
# Change *A, Z, N/Z* distributions by changing target

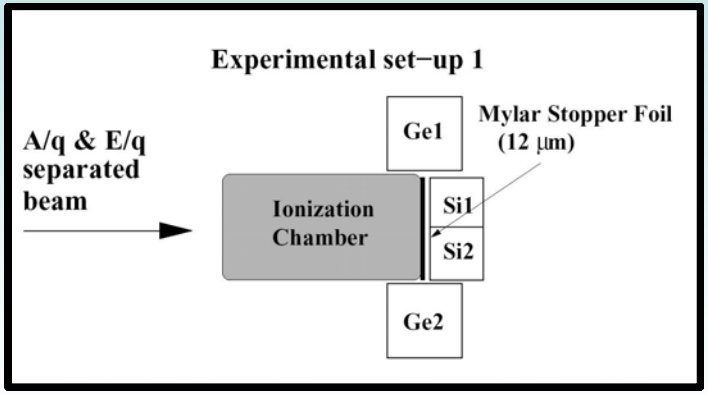


# Nuclei available for study with $^{241}Pu$ target

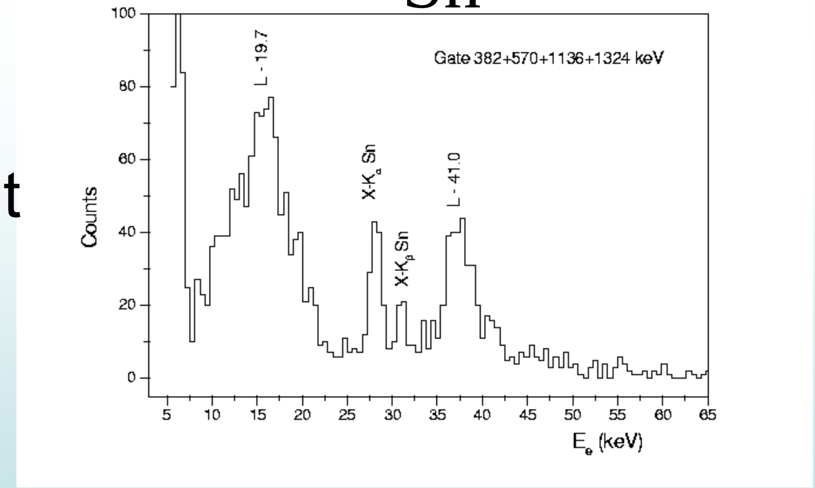


# Experimental Setup






$^{129}$Sn



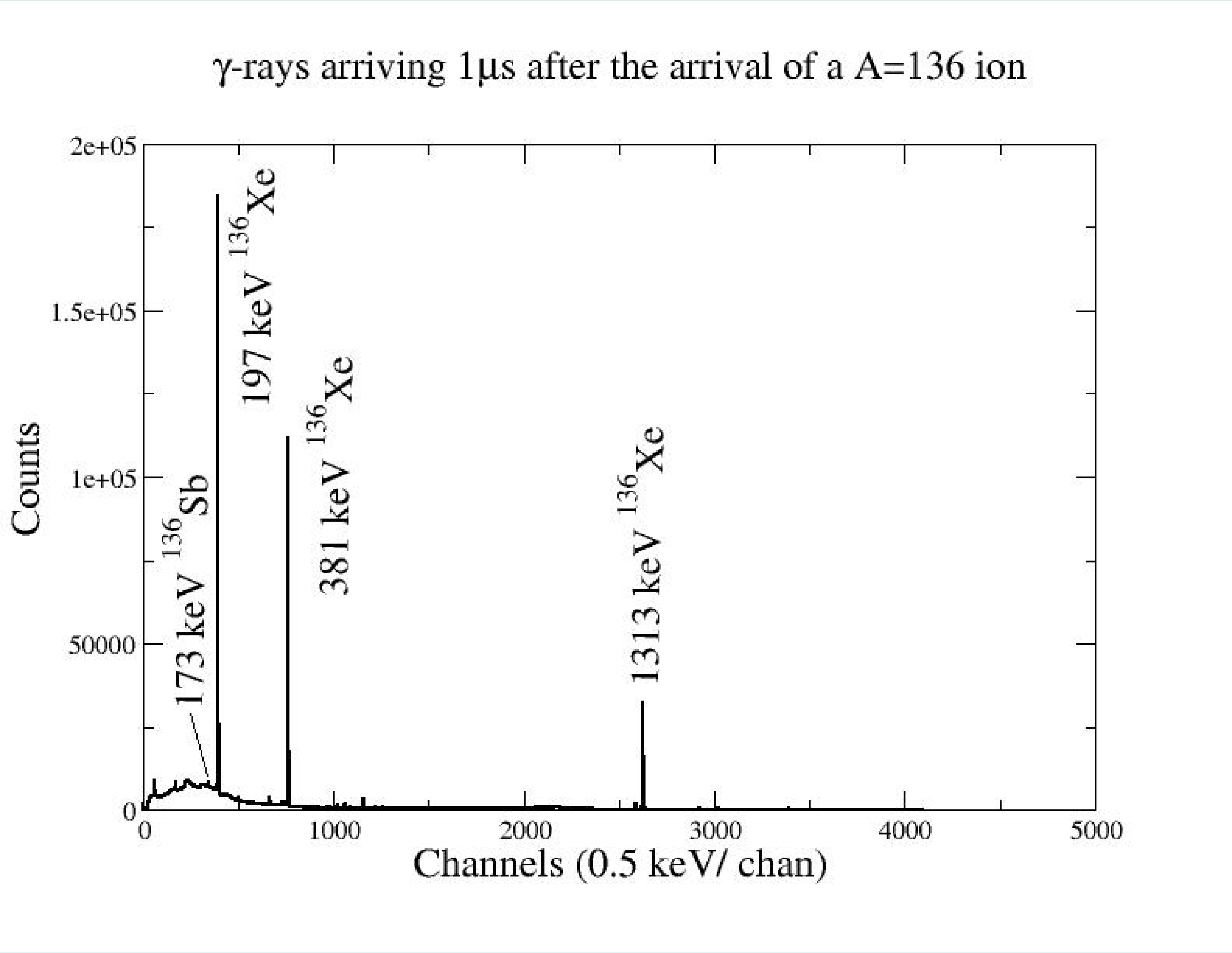

- Gamma detection efficiency ~4 % at 1 MeV and ~20 % at 100 keV
- Conversion-electron detection

efficiency ~25%.

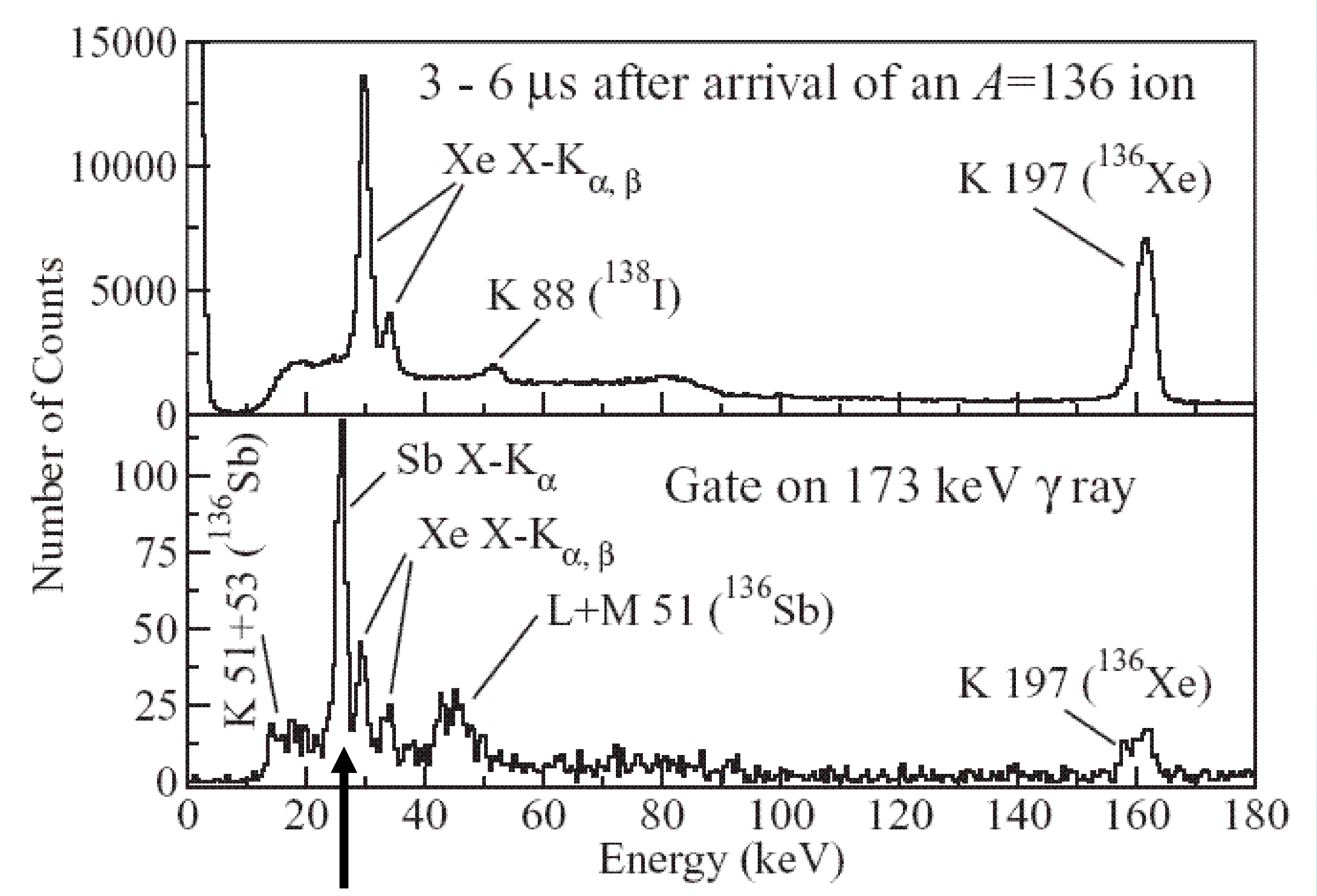
- Detect conversion electrons > 15 keV

# $^{136}$Sb

- Isomer observed at GSI (M. Mineva *et al*. Eur. Phys. J. A 11 (2001) 9)
- Only one γ-ray transition seen (173 keV) -alone does not explain isomer

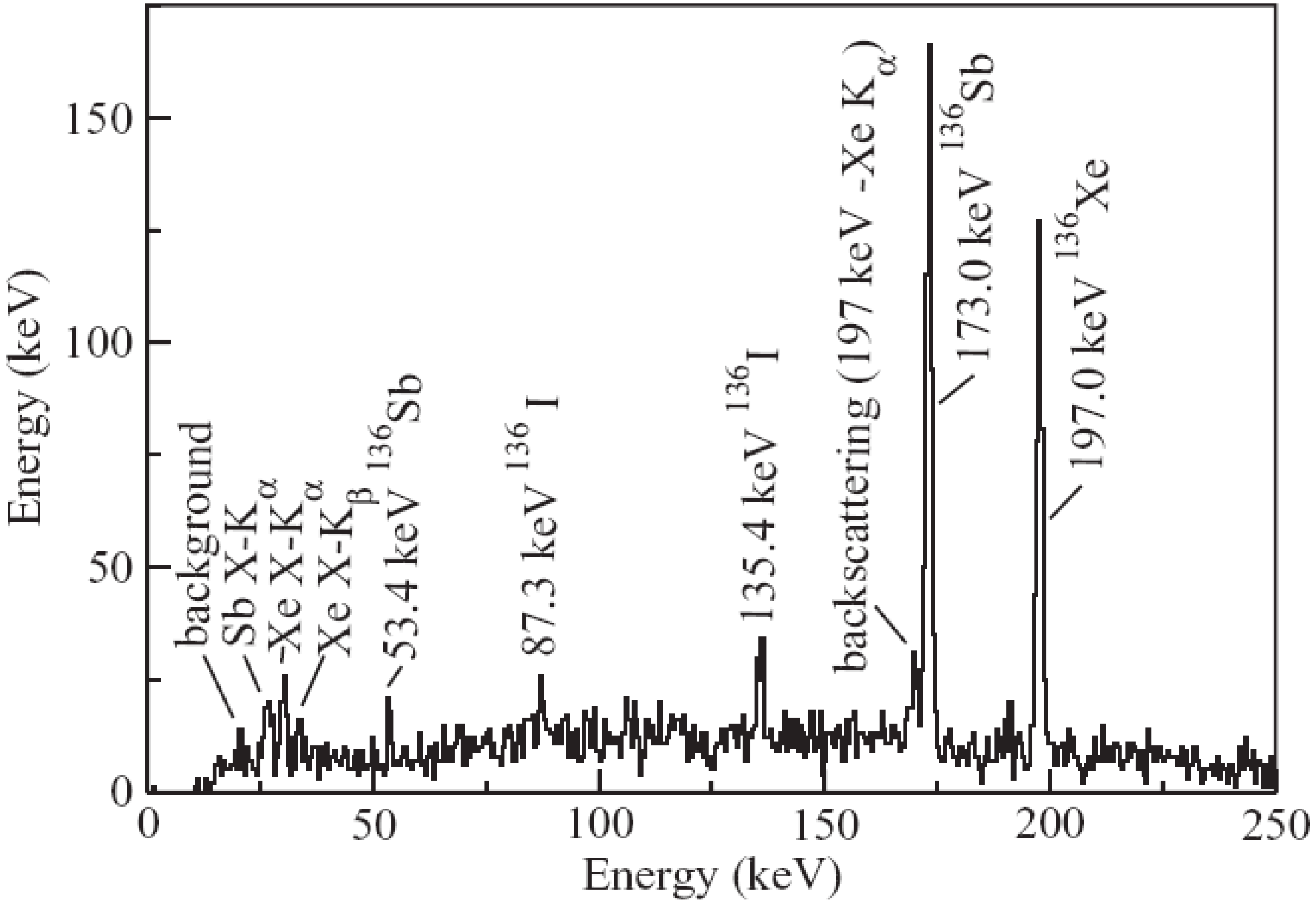


# Conversion-electron Spectra

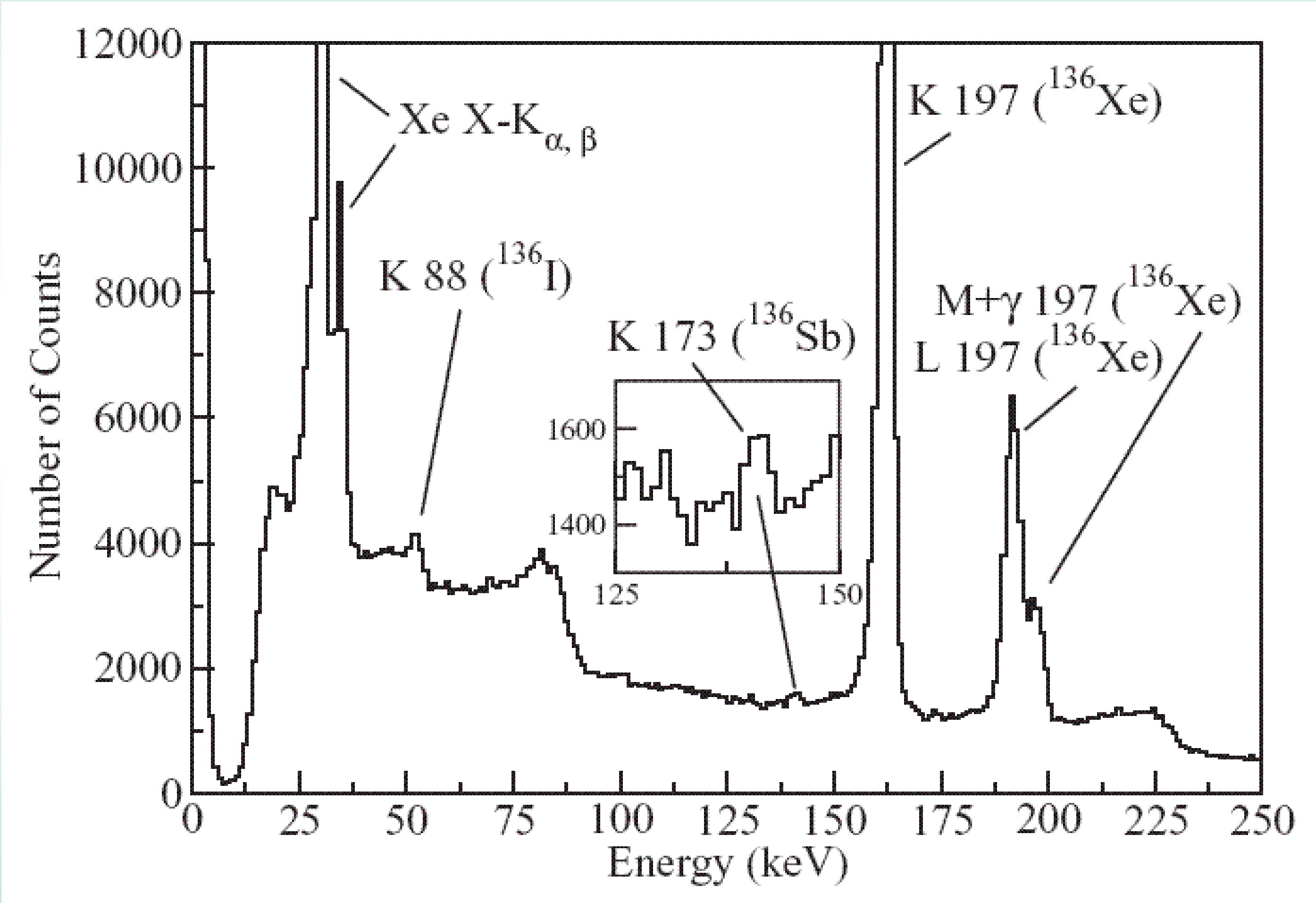



Too many Sb $K_{\alpha}$ for just one 51 keV E2 (~x2)

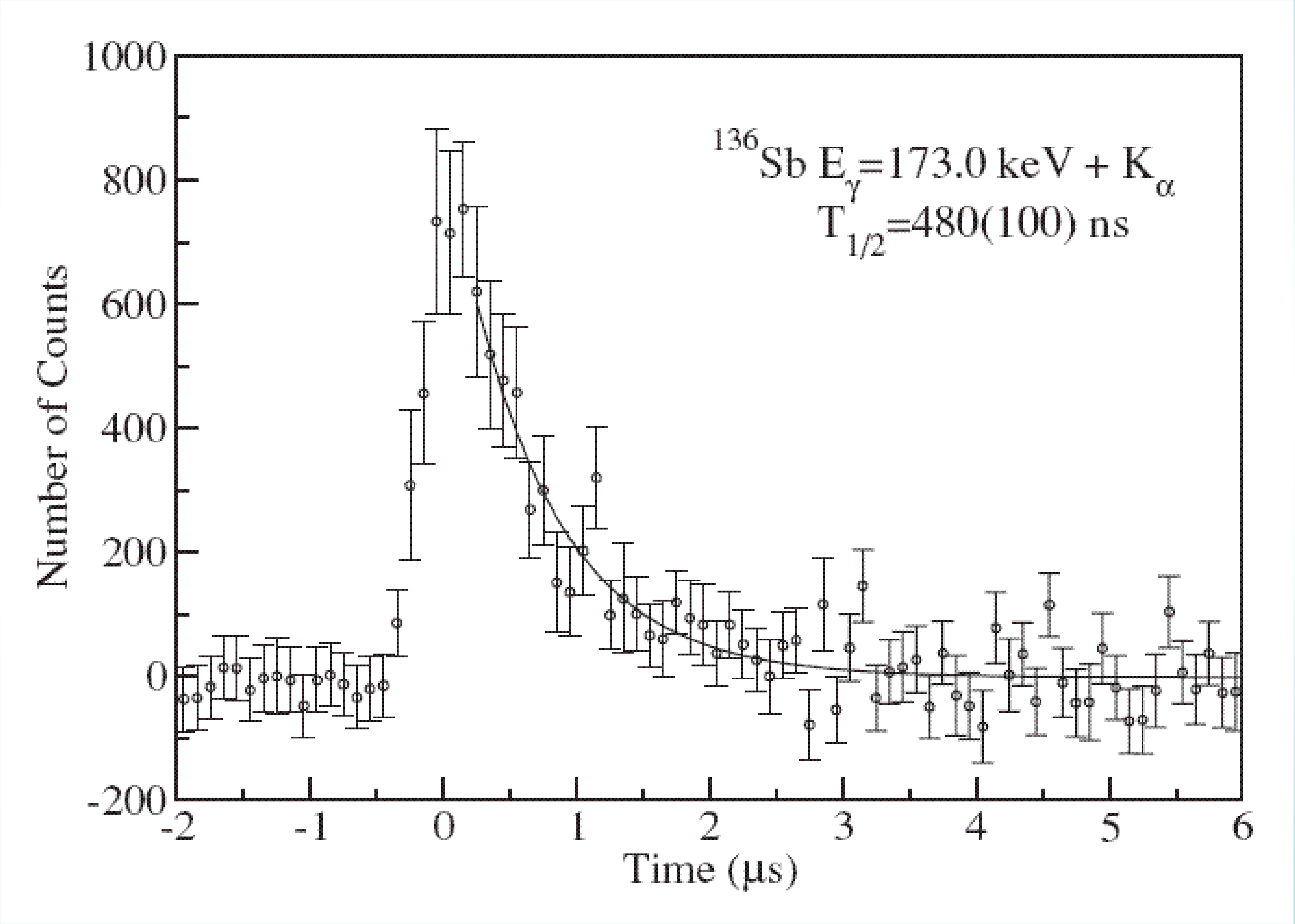
# Gamma rays in coincidence with Sb X rays



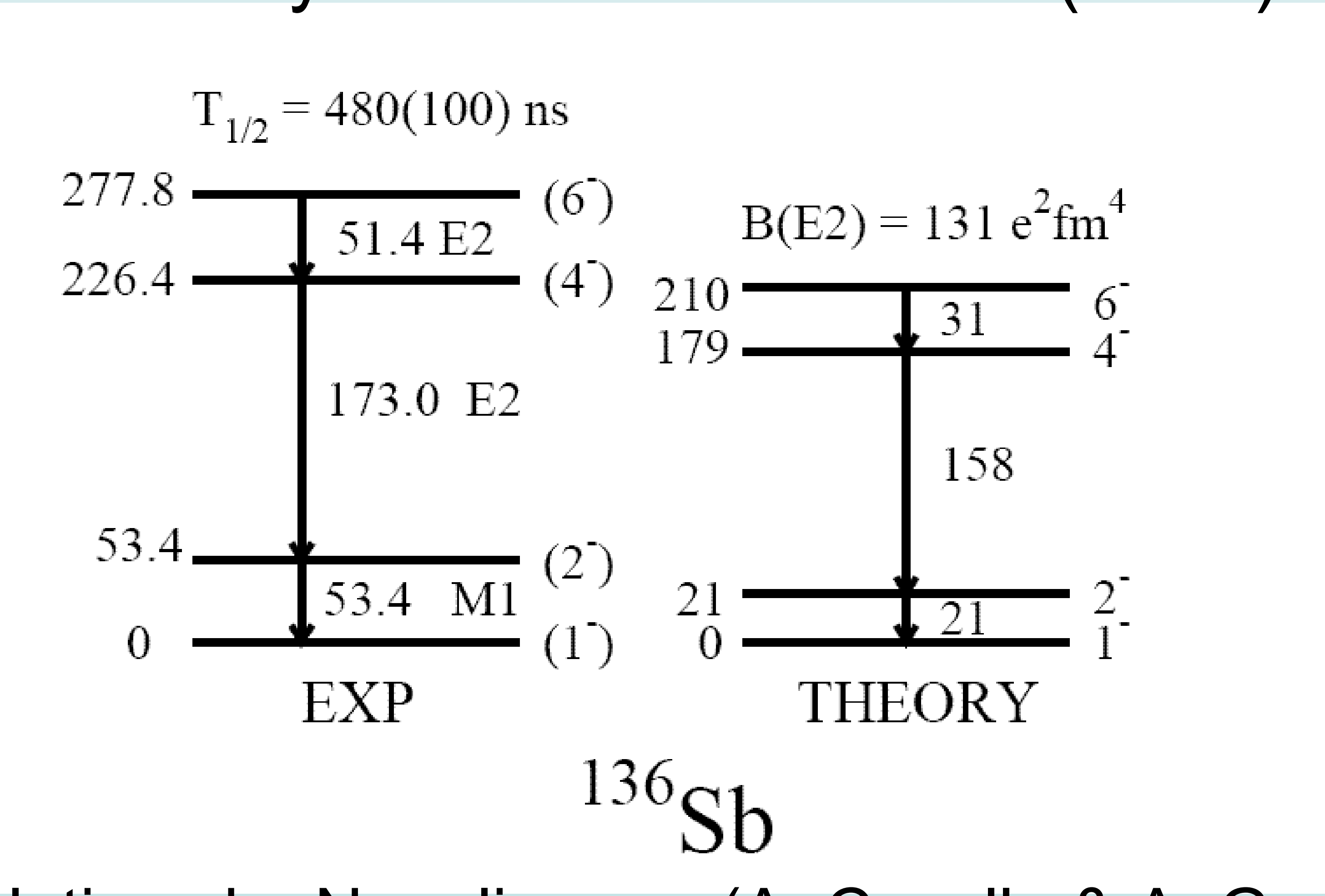
# 173 keV transition is E2



# Combined time Spectra

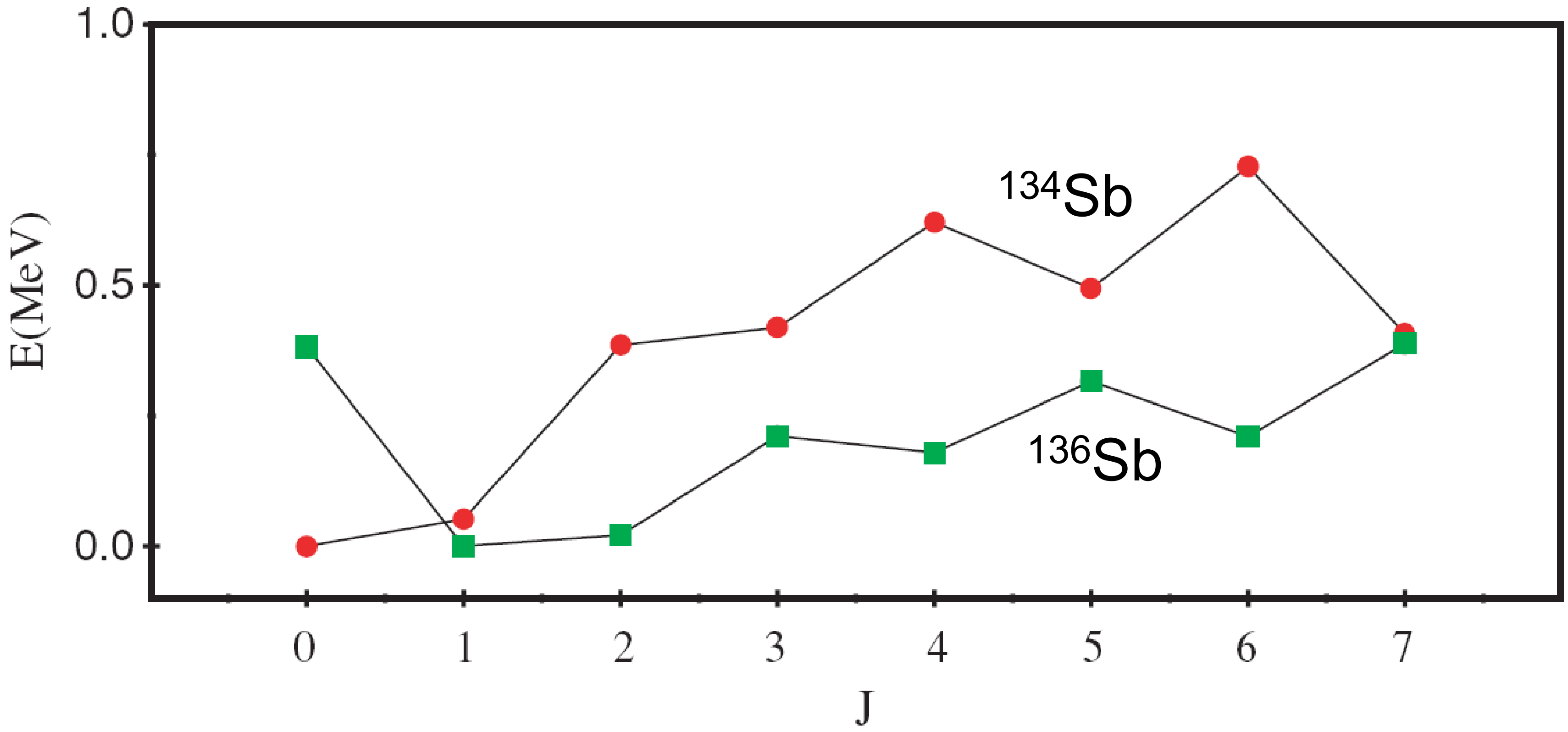


# Calculations compare very well with experimental measurements see Phys. Rev. C 76 041303 (2007)

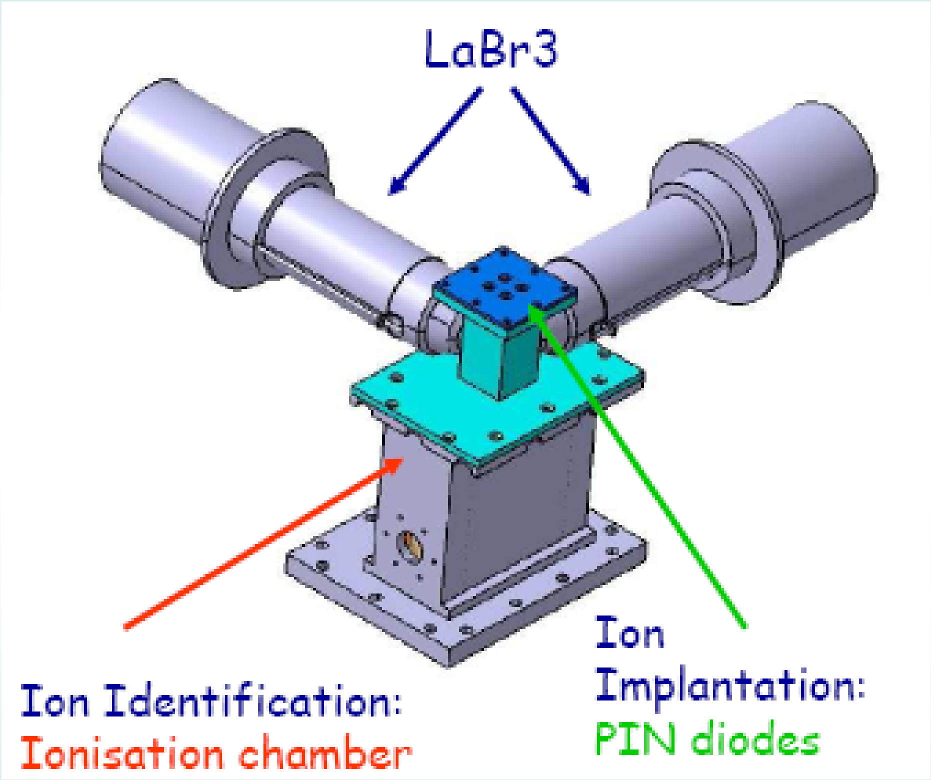



Calculations by Napoli group (A. Covello & A. Gargano)

# Theoretically predicted energies of the $\pi g_{7/2}(\nu f_{7/2})^{1,3}$ multiplet

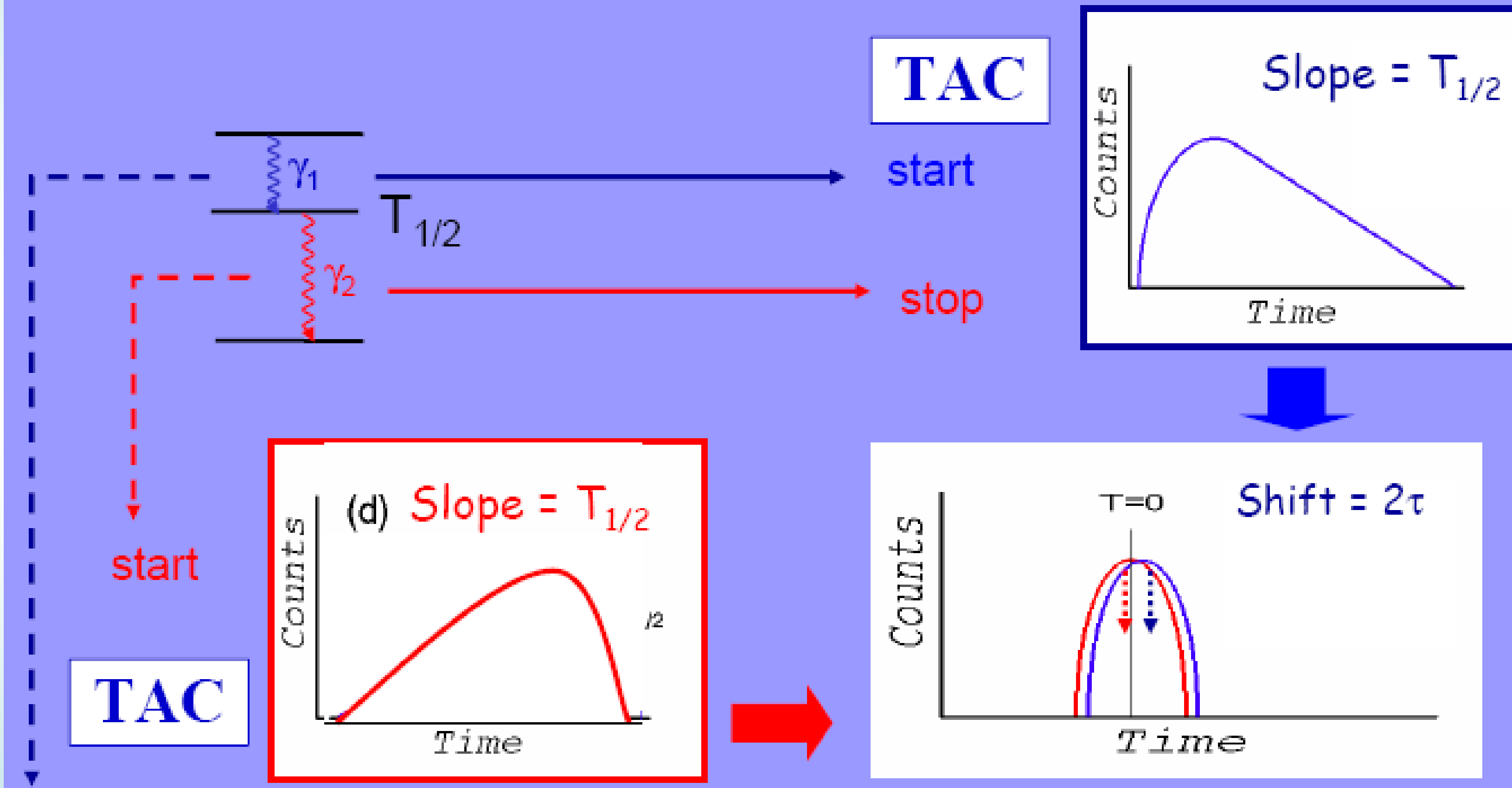


# Fast-timing with $LaBr_3$s and Lohengrin




# γγ(t) technique

$BaF_2$-$BaF_2$ / $LaBr_3$ -$LaBr_3$: lifetime measurements



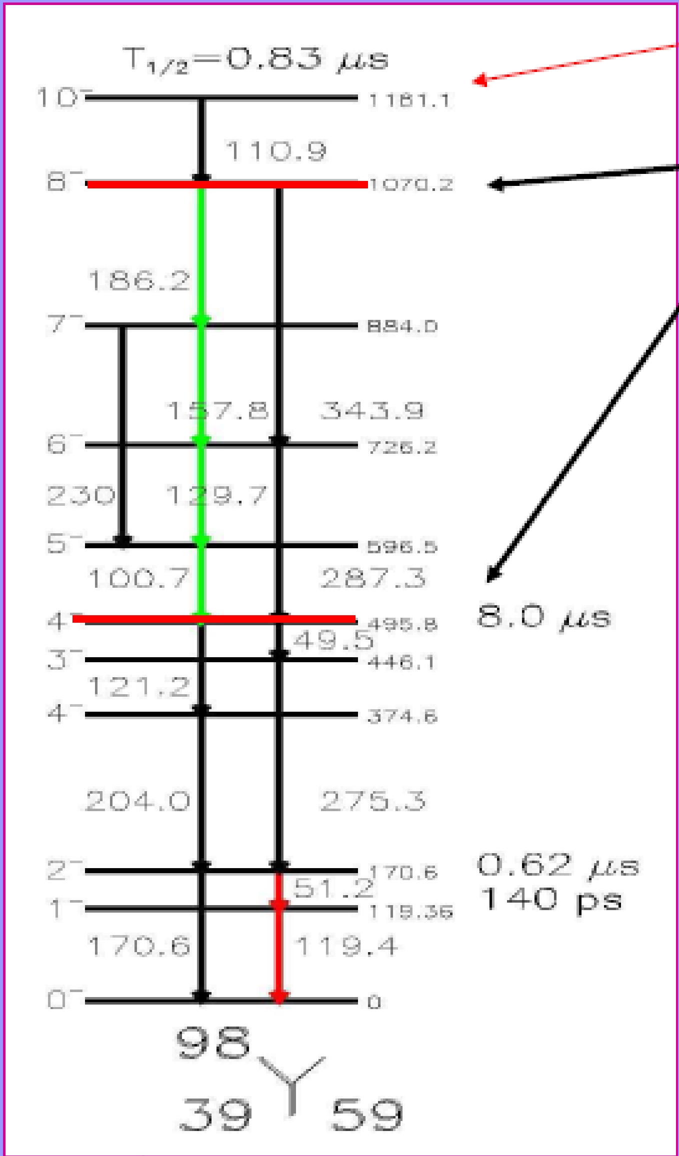

✓ De-convolution of slope

- Range: 30 ps to 30 ns (or longer)

✓Centroid shift

- Range: down to ~5-10 ps

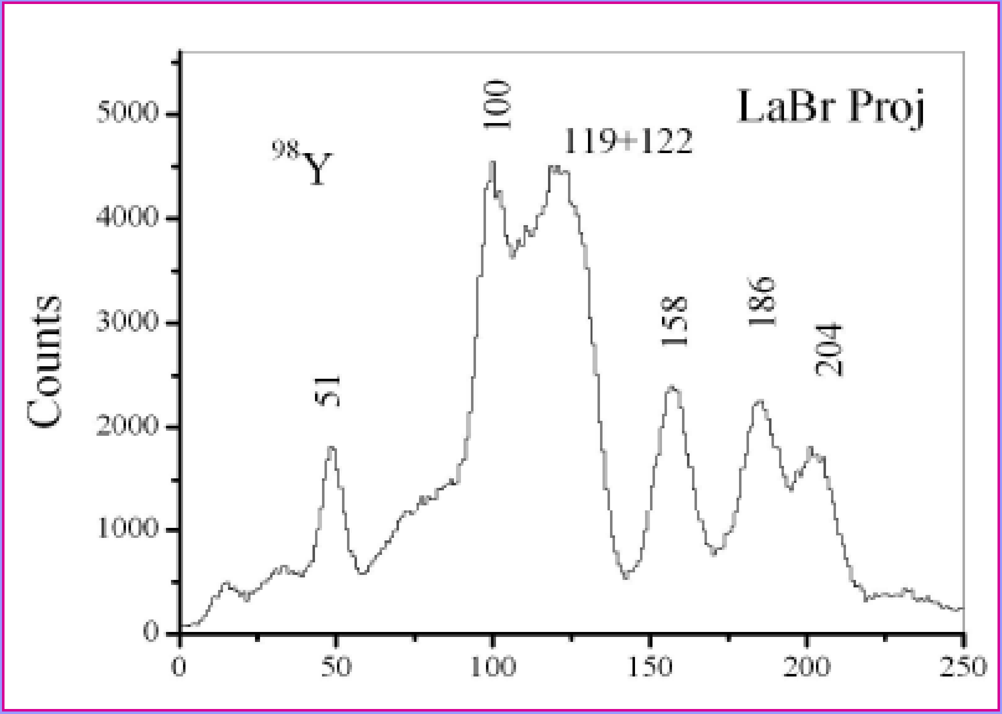
## $^{98}$Y ion of interest




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

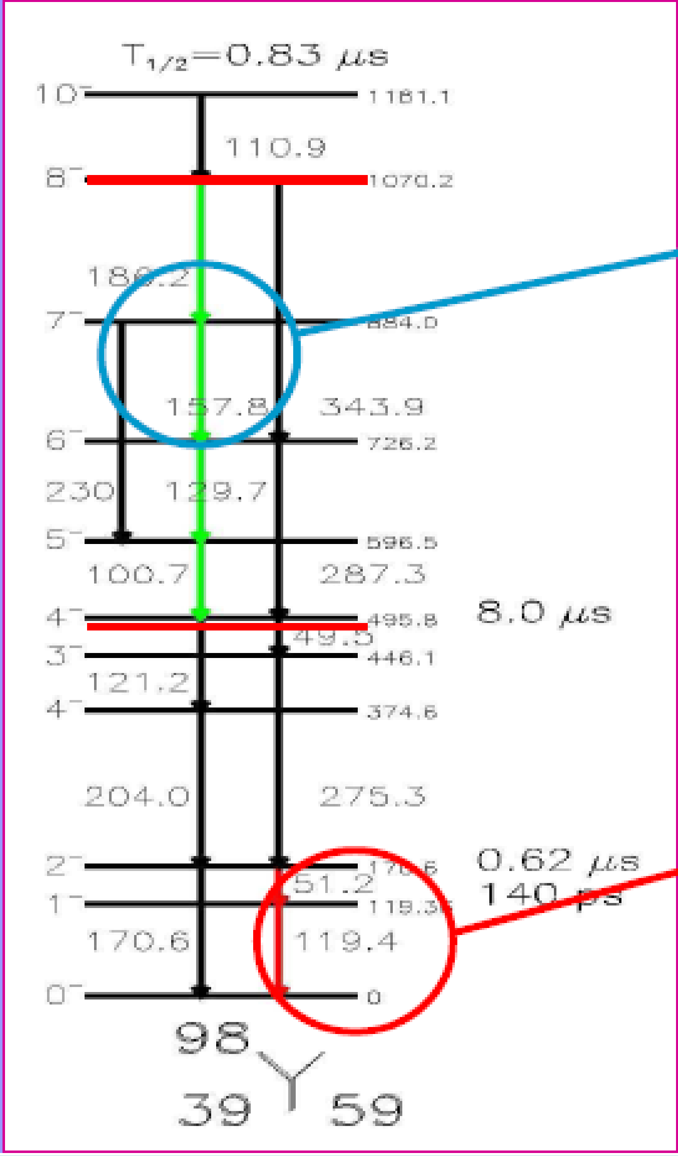
$\pi[422]5/2\ \nu[541]3/2$

## LaBr spectrum

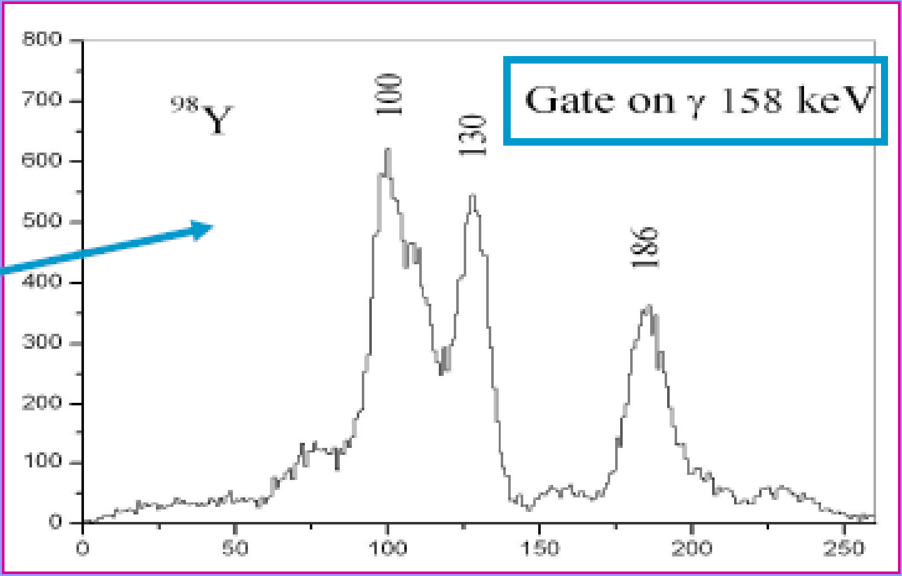


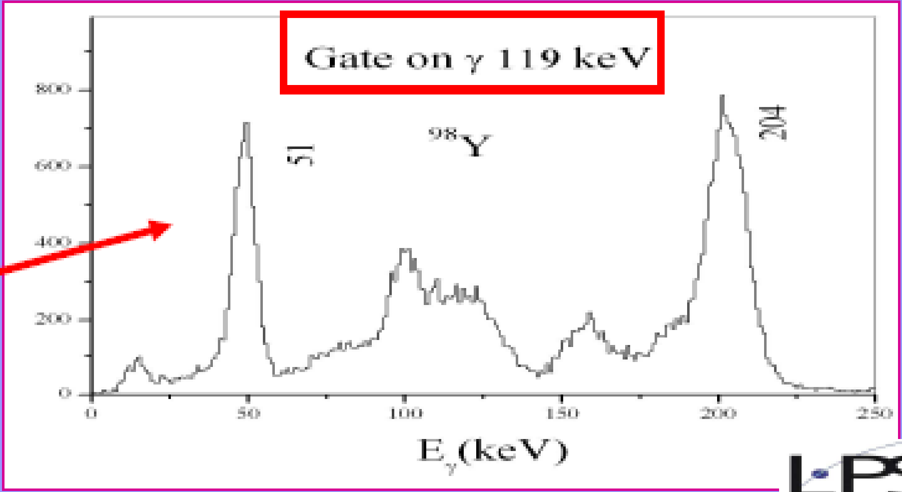

Brant *et al.*, Phys. Rev. C 69 034327 (2004)

## $^{98}$Y ion of interest




## LaBr coïncidence spectra



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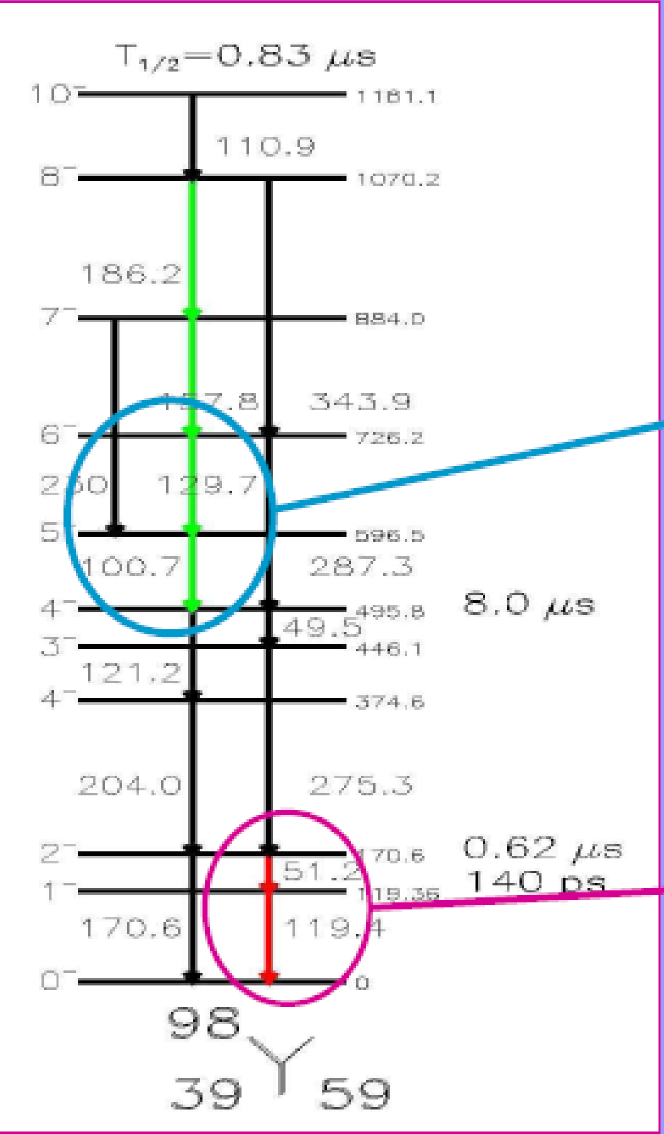
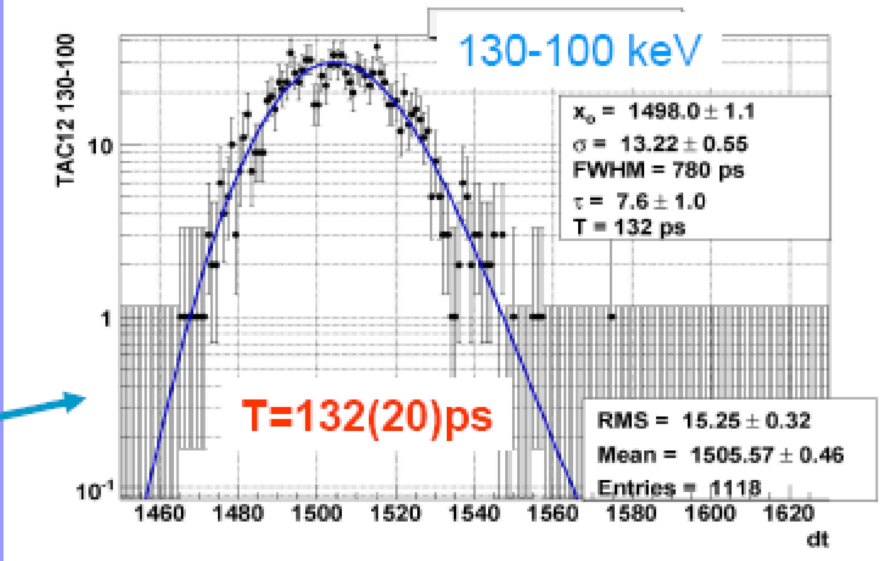
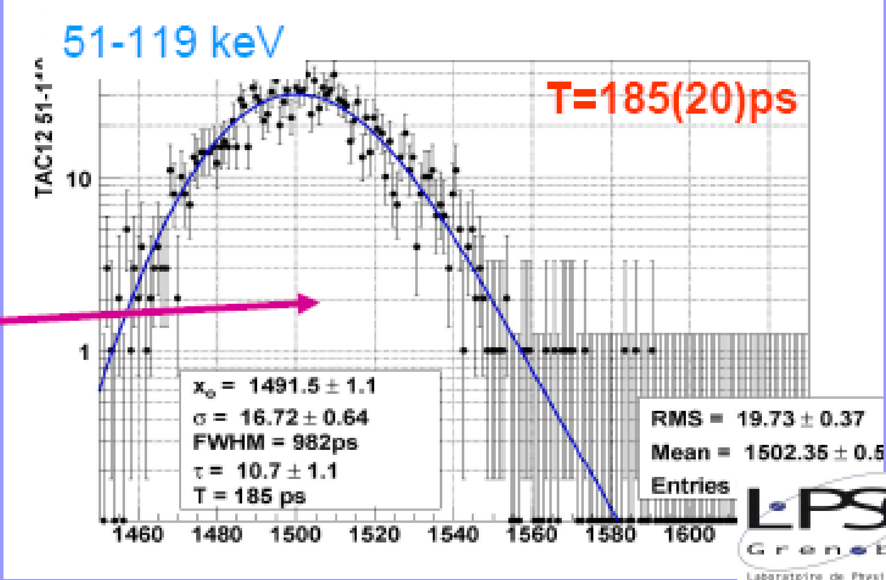



## lifetime measurements



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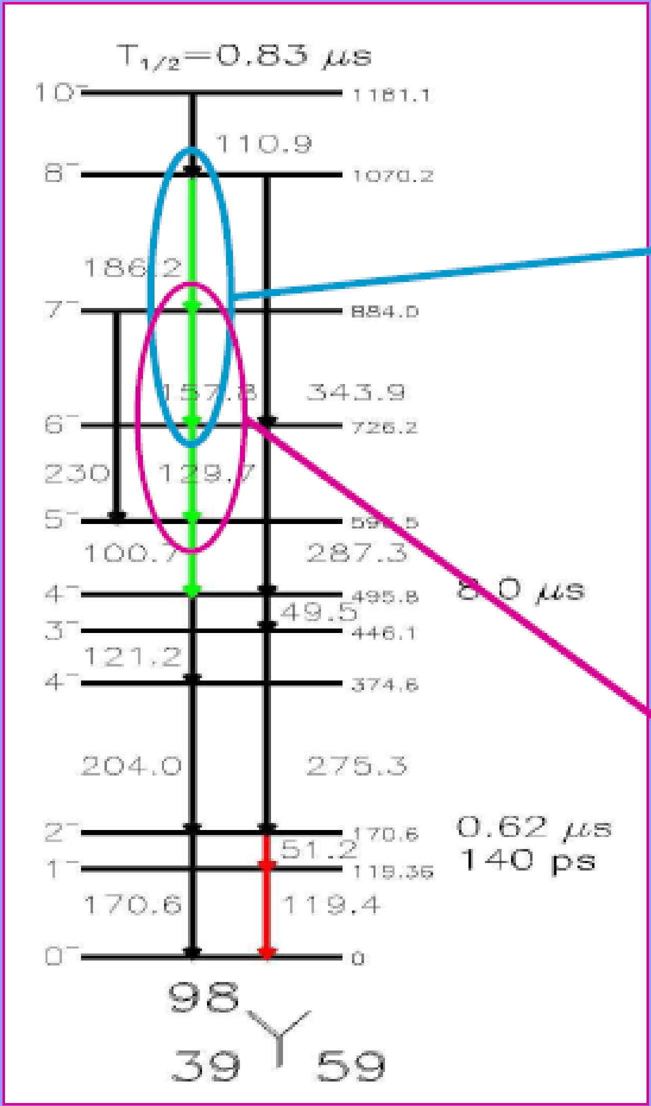
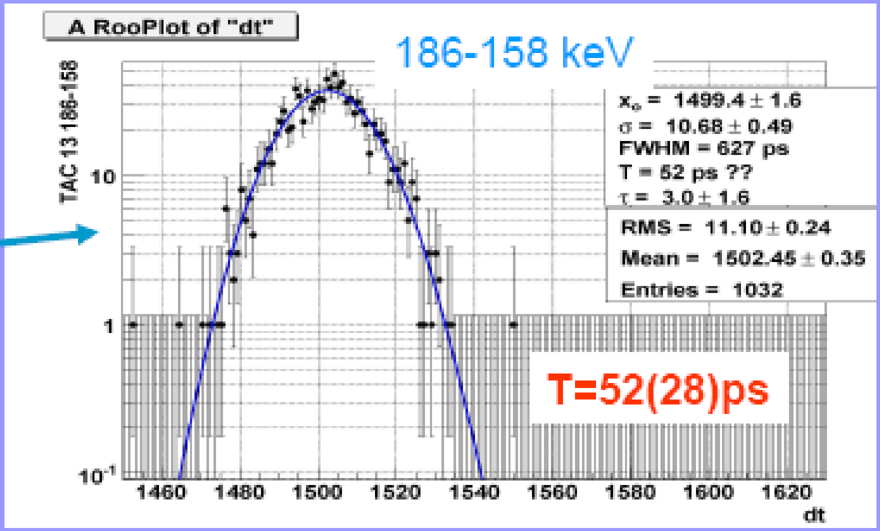
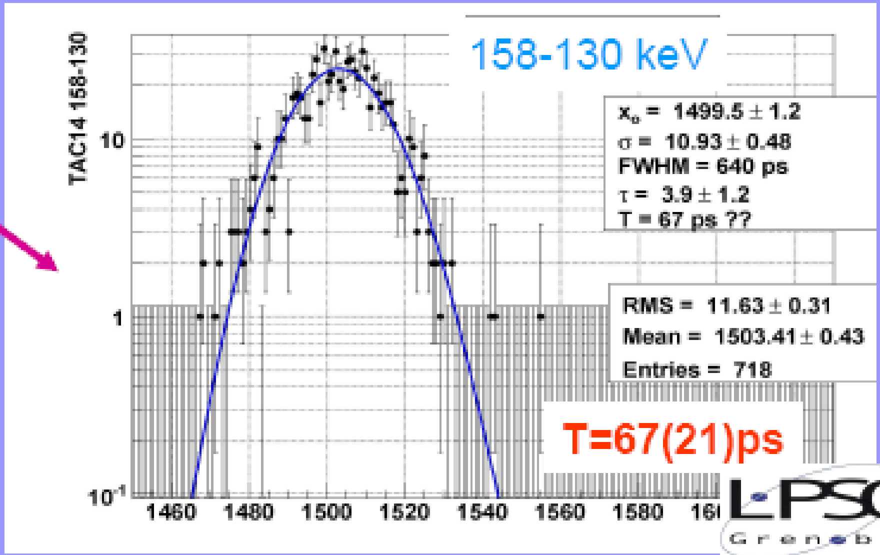



## lifetime measurements

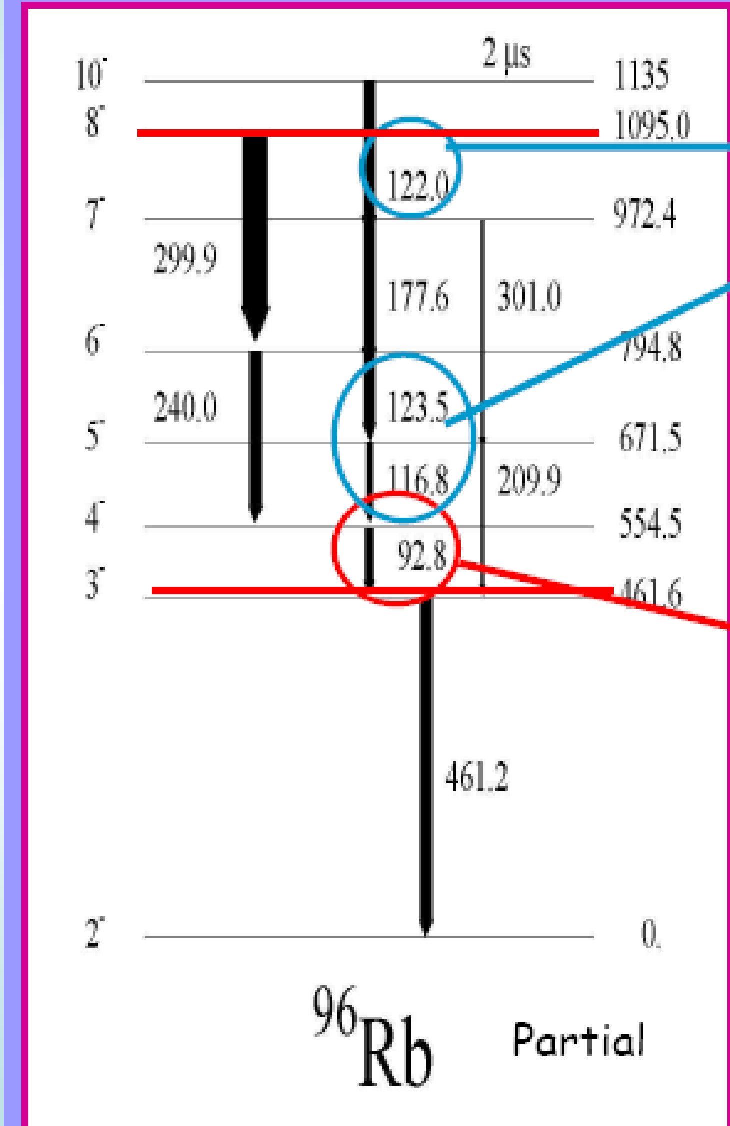


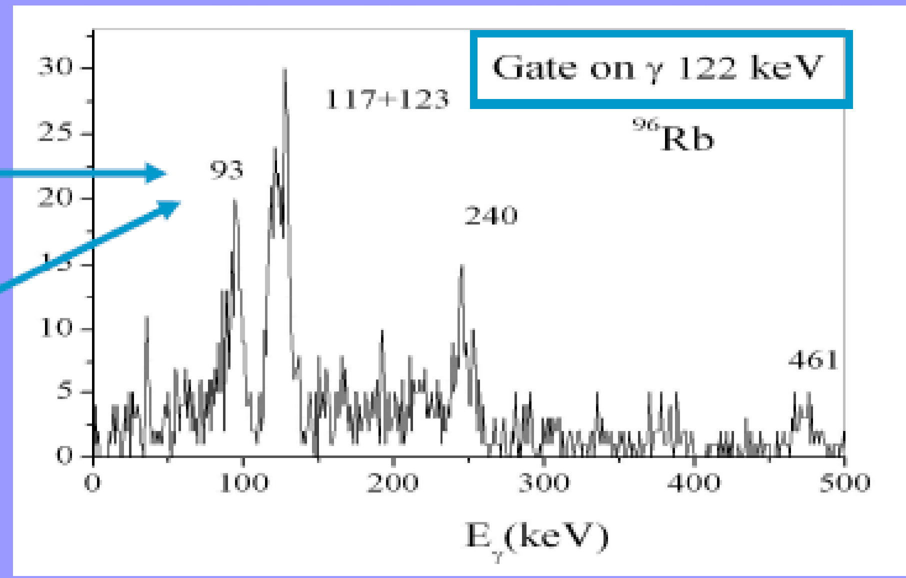



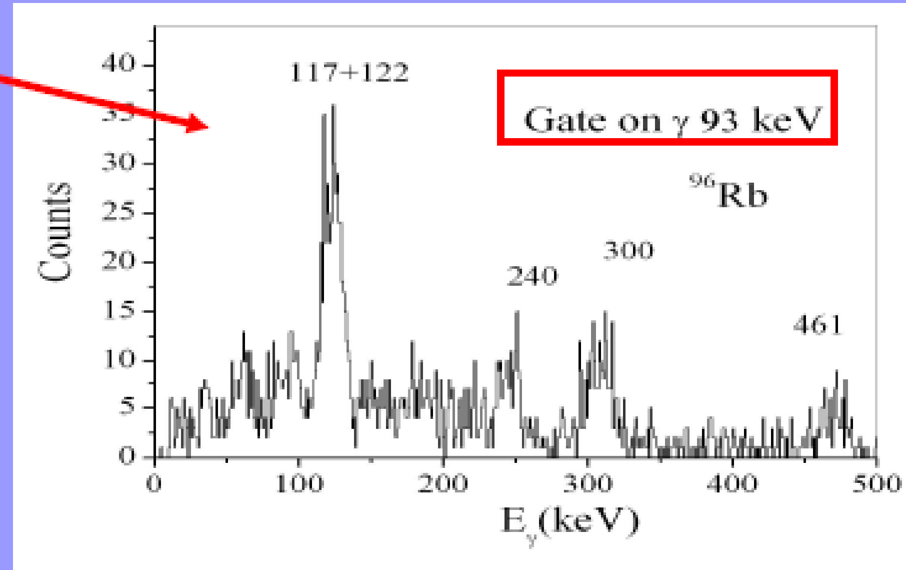

LPSC Grenoble
Laboratoire de Physique Subatomique et de Cosmologie

## $^{96}$Rb ion of interest

## LaBr coïncidence spectra

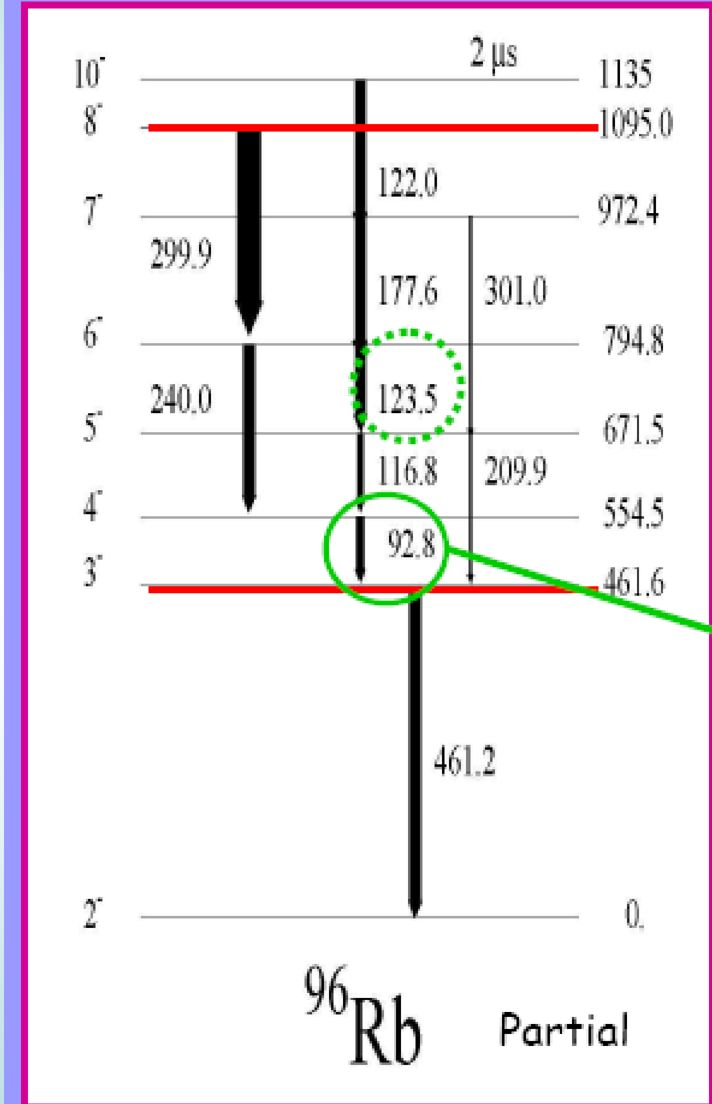


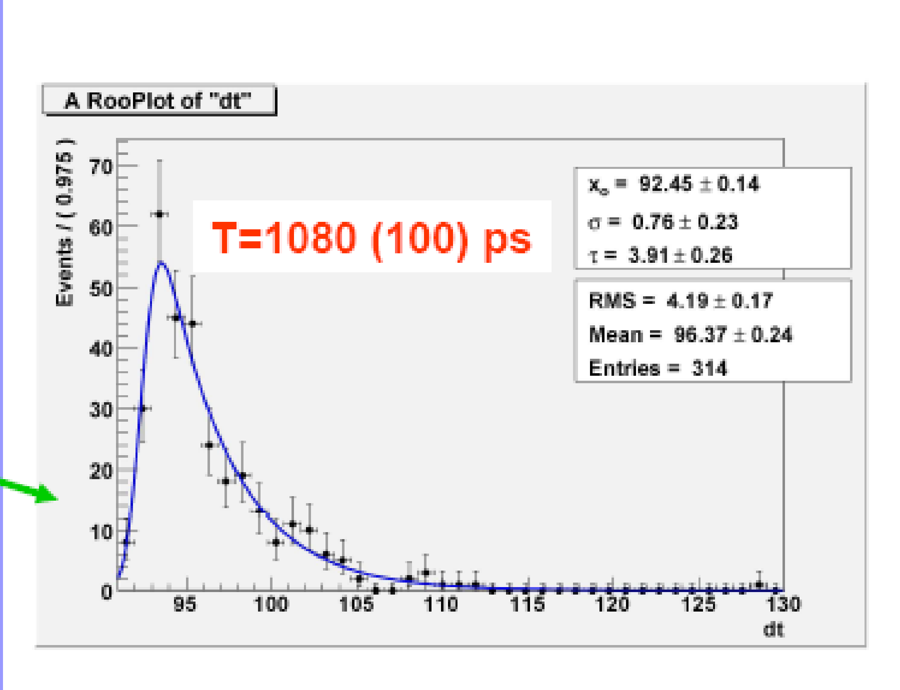



## $^{96}$Rb ion of interest

## lifetime measurements

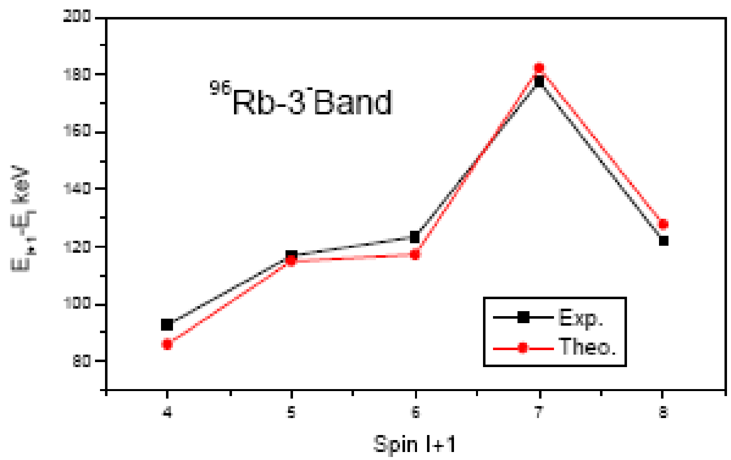



123-93 keV



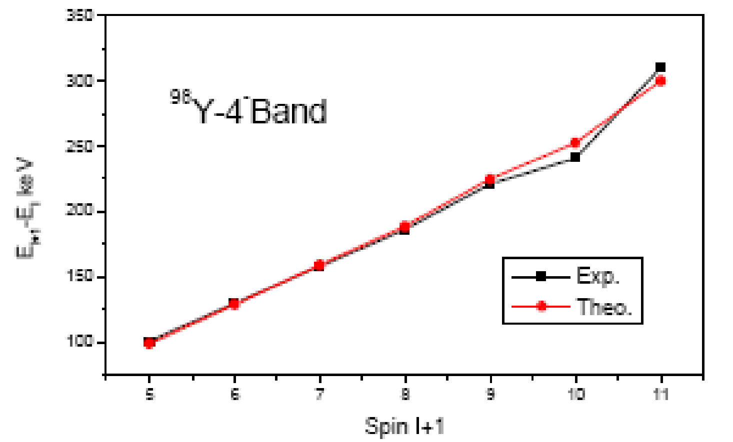
# Particle-Rotor Calculations in $^{96}Rb$ and $^{98}Y$

$B_2=0.38$, $Q_0=3.2$ b, $\mu=1.40$ μN ($3^-$)




$T_{1/2}$ $4^-$ Exp. =850(250) ps
Theo=704 ps

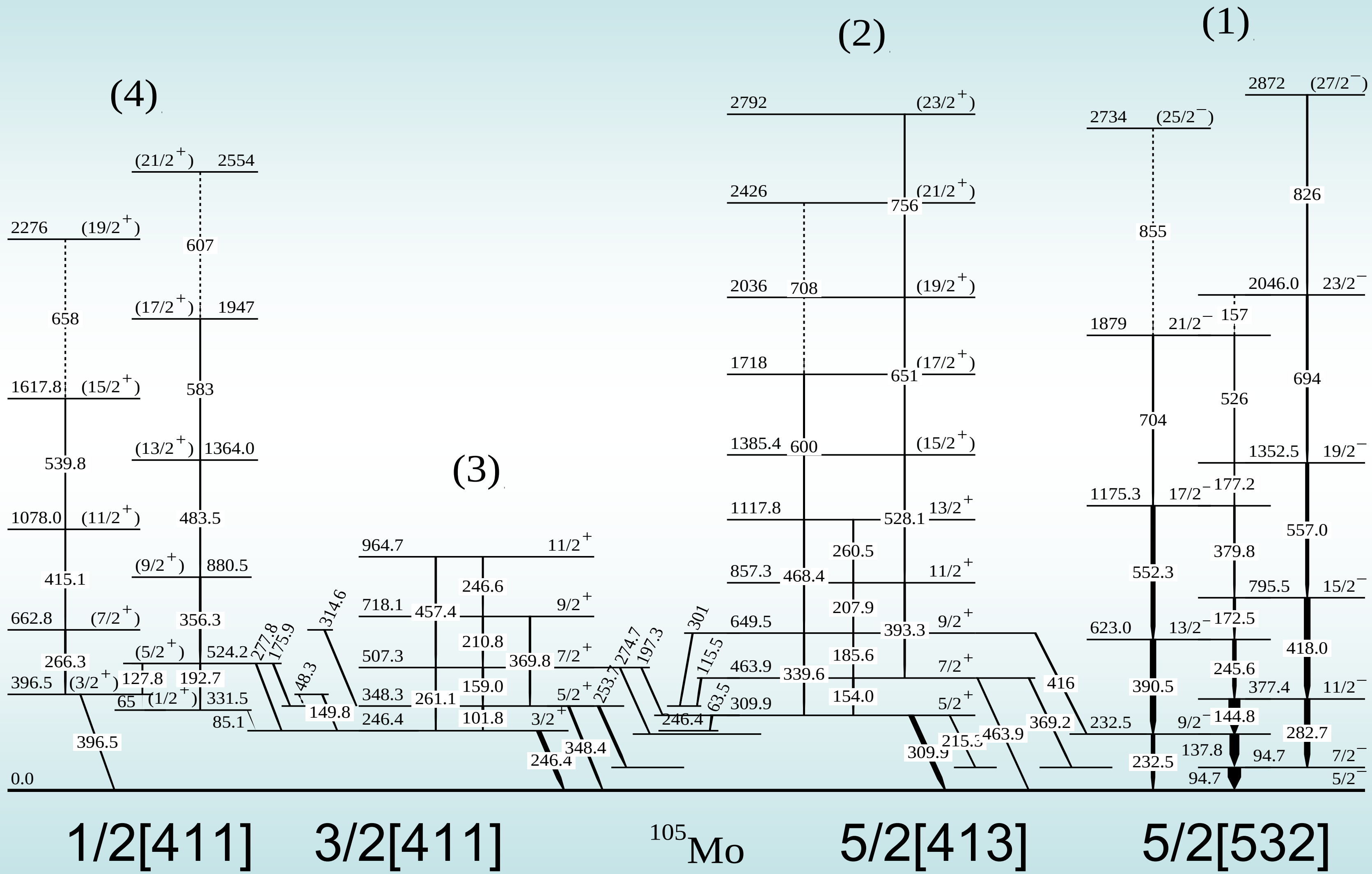
$B_2=0.38$, $Q_0=3.4$ b, $\mu=2.16$ μN ($4^-$)




$T_{1/2}$ $5^-$ Exp. =120(20) ps
Theo=157 ps

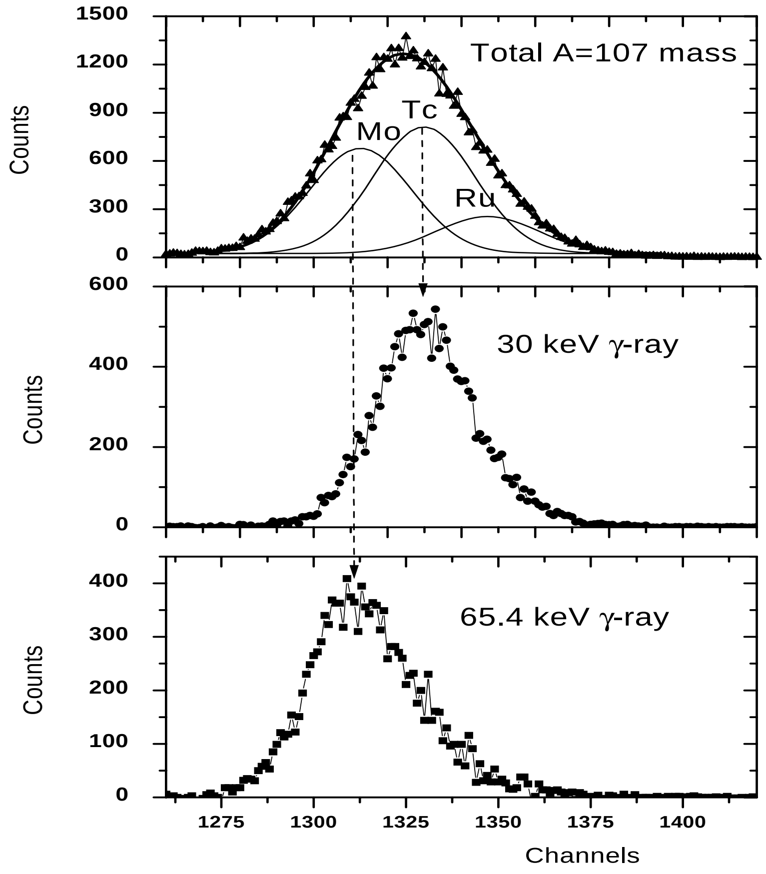
Energy-levels, staggering, branching-ratios and half-lives are well reproduced by the model

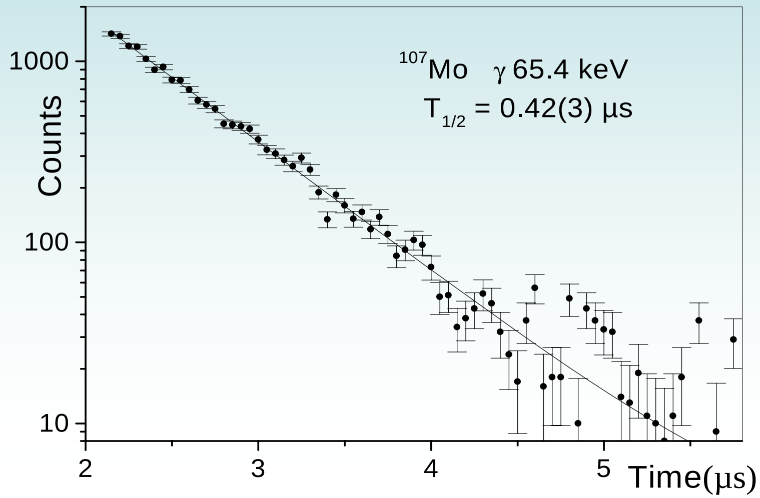
# Level scheme of $^{105}$Mo obtained with the EUROGAM2 experiment

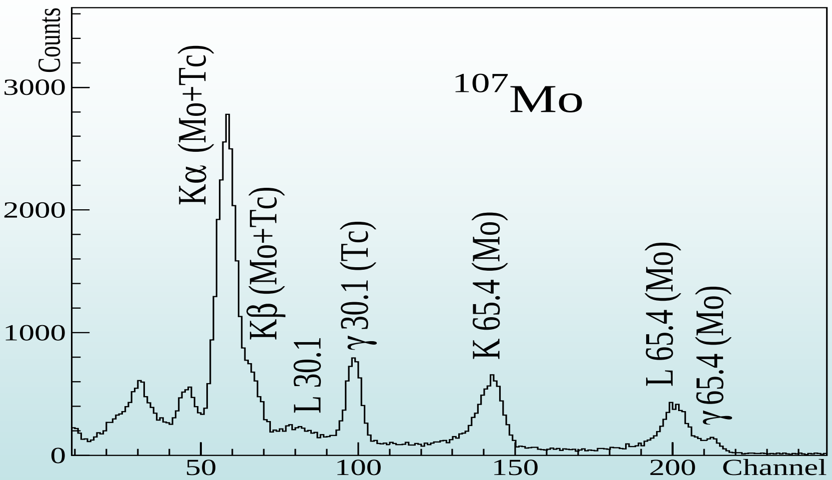



J.A. Pinston, W. Urban *et al.*, Phys. Rev. C 74 064304 (2006)

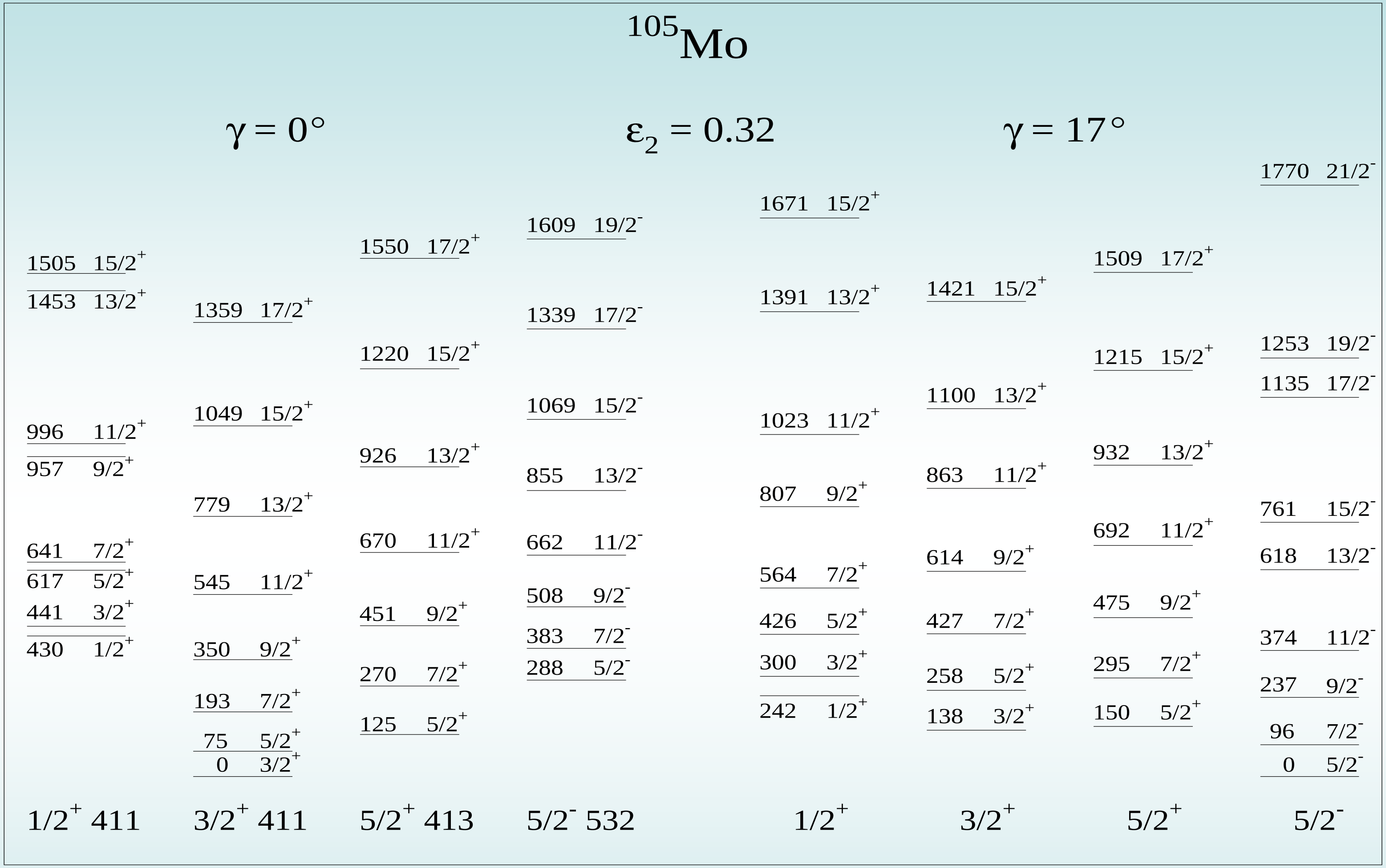
# Lohengrin experiment



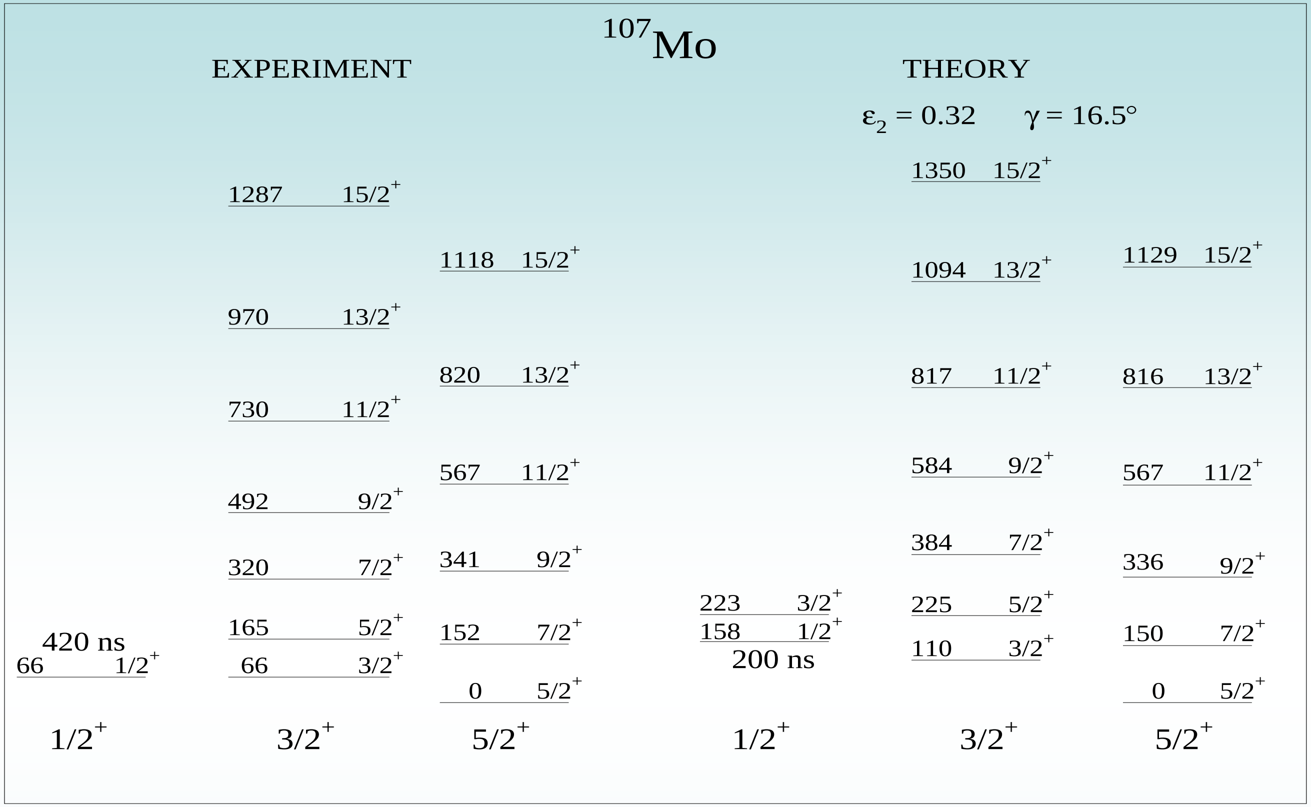




Si(Li) spectrum of delayed e/X in coinc with A=107




- The experimental levels are well reproduced at the deformation $\gamma = 17°$.
- The $5/2^-$ level is now the ground state of the $^{105}Mo$ nucleus, as seen in the experiment.

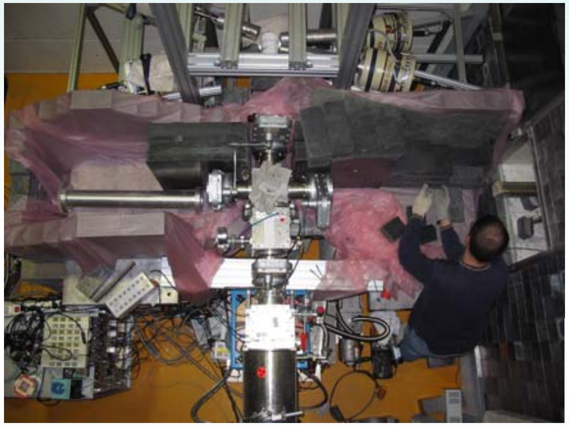



- Satisfactory fit to the experimental data has been obtained for $^{107}$Mo using the same paramaters as for $^{105}$Mo. The theoretical half-life of the $1/2^+$ state is not far from the experimental value.
- The four bands of same origin observed in $^{105}$Mo and $^{107}$Mo are well reproduced by the same parameters
- For even-even $^{104-108}$ Mo, the parameters of $\gamma$ and quadrupole deformation, can be deduced from the experimental data.
- These values are comparable to the ones observed in the odd Mo.

# Idea to put a large Ge array at a thermal neutron guide

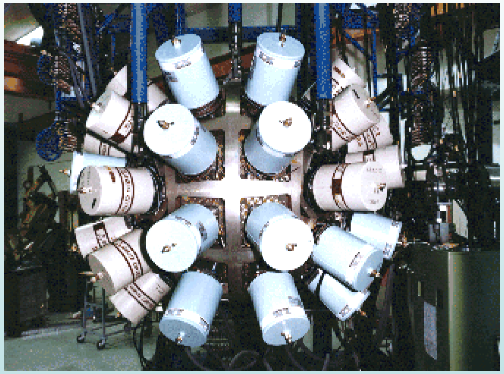
- Observe prompt gamma rays from fission (also lifetimes ps-ns and g factors –A.G. Smith)

- Thermal-neutron induced fission populates different nuclei to spontaneous fission



- Neutron guides delivery thermal neutrons cleanly (no $\gamma$-ray or fast-neutron background)

- Need a large Ge array to cope with multiplicity 10 reaction and high efficiency (≥10 %, Clusters, Clovers+Phase1s, EXOGAM)

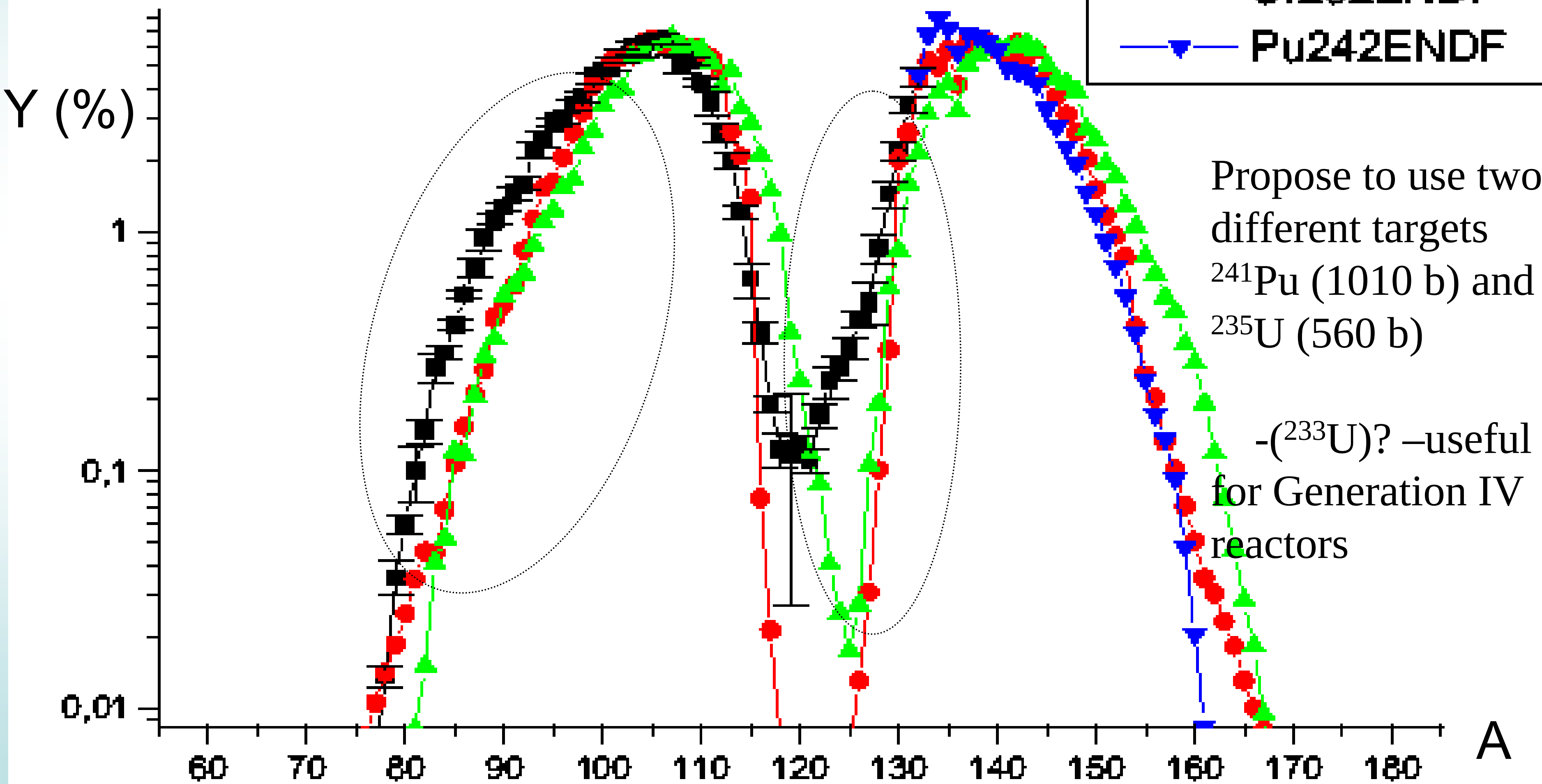


- Experimental conditions similar to the spont. fission experiments performed with EUROGAM/BALL, Gammasphere

# Compare with Spontaneous fission

~30 new nuclei available for study !

Different fission systems populate different states



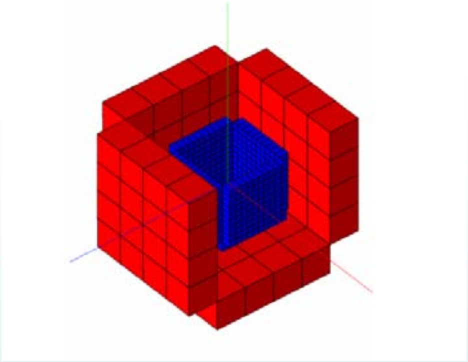

Propose to use two different targets $^{241}$Pu (1010 b) and $^{235}$U (560 b)

-($^{233}$U)? –useful for Generation IV reactors

Options for a $4\pi$ hybrid array

- LEPS-Coaxial array for odd-even and odd-odd nuclei (LEPS are cheap!)

- Ge-$LaBr_3$ array for lifetime measurements ($4\pi$ fast-timing array or PARIS?)
$\gamma(E)$-$\gamma(E)$-$\gamma(\sim E,t)$-$\gamma(\sim E,t)$



- Ge array plus particle detectors

# Letter of support from the ILL direction

INSTITUT MAX VON LAUE - PAUL LANGEVIN

NEUTRONS FOR SCIENCE

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*Fax: + 33 (0) 4.76.96.11.95*
*e-mail: vettier@ill.fr*

Thursday, 29 June 2006 DIR-DS CV/cg 06-99

Dear Gammapool Committee,

The Institut Laue-Langevin (ILL) would be proud to host an array of germanium Cluster detectors at the PF1B neutron guide, where they would be used for the prompt gamma-ray spectroscopy of fission fragments produced in thermal neutron-induced fission. The ILL promises to provide the necessary infrastructure to allow this experiment to take place (liquid nitrogen, electricity and access to the computer network). In addition, space will be made available where the detectors can be assembled, tested and maintained.

The scientific case for this experiment has already been submitted to the ILL's scientific council, in the form of a letter of intent. The scientific council's response to this letter was enthusiastically supportive.

The ILL strongly supports such initiatives to develop scientific partnerships for the mutual benefit of the different partners.

Yours sincerely,

Christian Vettier

The ILL will have a ~1 year shutdown (preliminarily scheduled for) summer 2011
-good opportunity for this project?

Would like to make a large, open collaboration

Gives <u>complementary</u> information to RIBs and will generate many ideas for studies with RIBs