Neutron capture γ-ray simulation of Eu and experimental initiatives

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Outline

- Brief overview
- Capture γ-ray simulation of ^{152}Eu and ^{154}Eu isotopes
  - Input file for statistical code DICEBOX
  - Analysis and
  - Preliminary Results
- Experimental activity
- Conclusions

Brief overview

- Elements related to nuclear technology
- Europium is a candidate material for control rod in the nuclear Reactor
- It has high neutron capture cross section
- Experimental cross sections are available
- Main interest:

$$\sigma_0 = \sum \sigma_\gamma^{\exp}(GS) + \sum \sigma_\gamma^{sim}(GS)$$

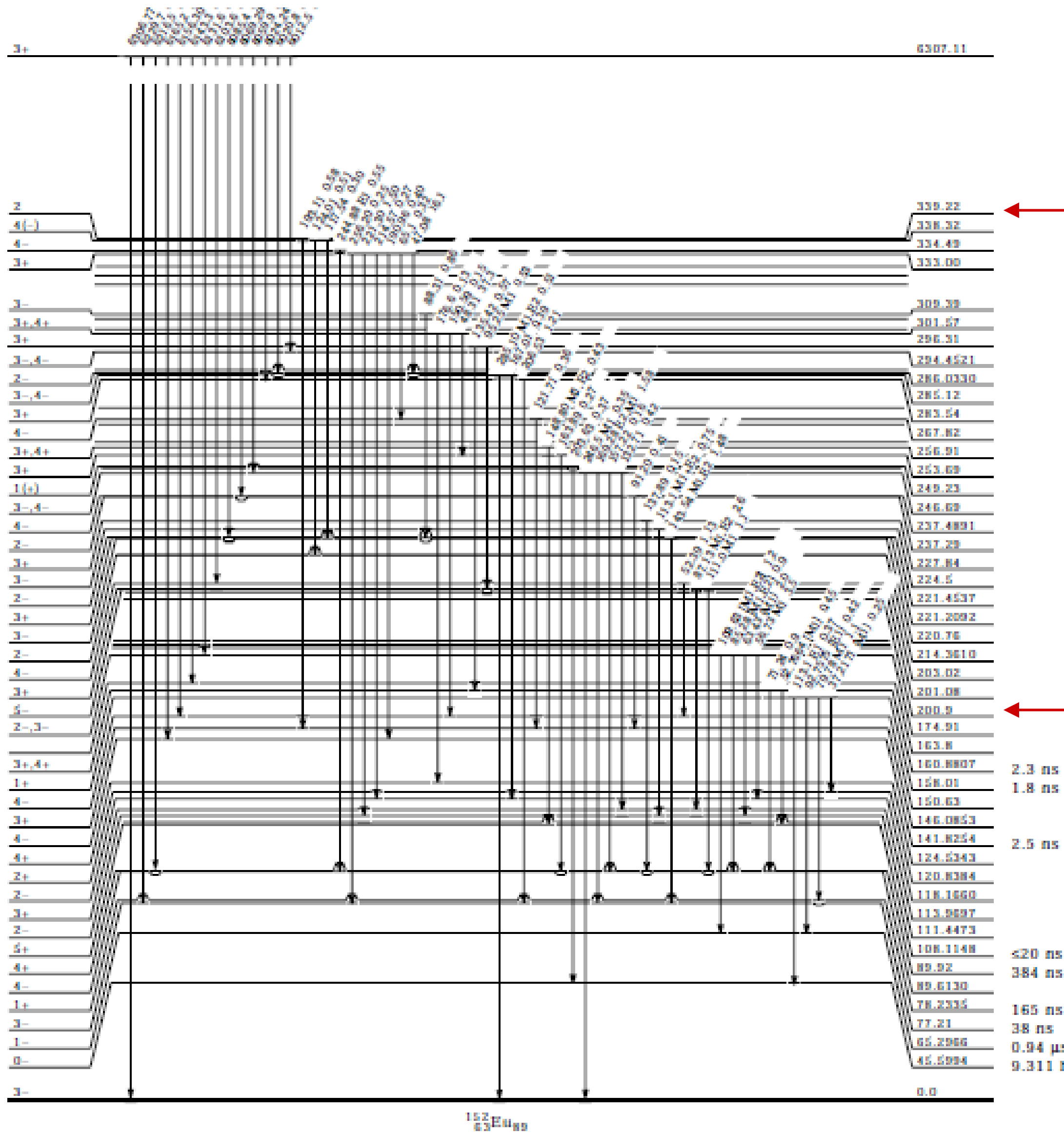
- Calculation process leads to extensive check of related structure data and sometimes yield experimental initiative

Input and Output

- Isotopes: ^{151}Eu and ^{153}Eu
- Reactions:
  - $^{151}Eu(n,g)^{152}Eu$
  - $^{153}Eu(n,g)^{154}Eu$
- Inputs from RIPL-3, EGAF, and ENSDF
- Target Spin: 5/2+

- Checks of output:
  - Radiative capture width
  - Average spacing of resonance width
  - Depopulation vs. Population plots

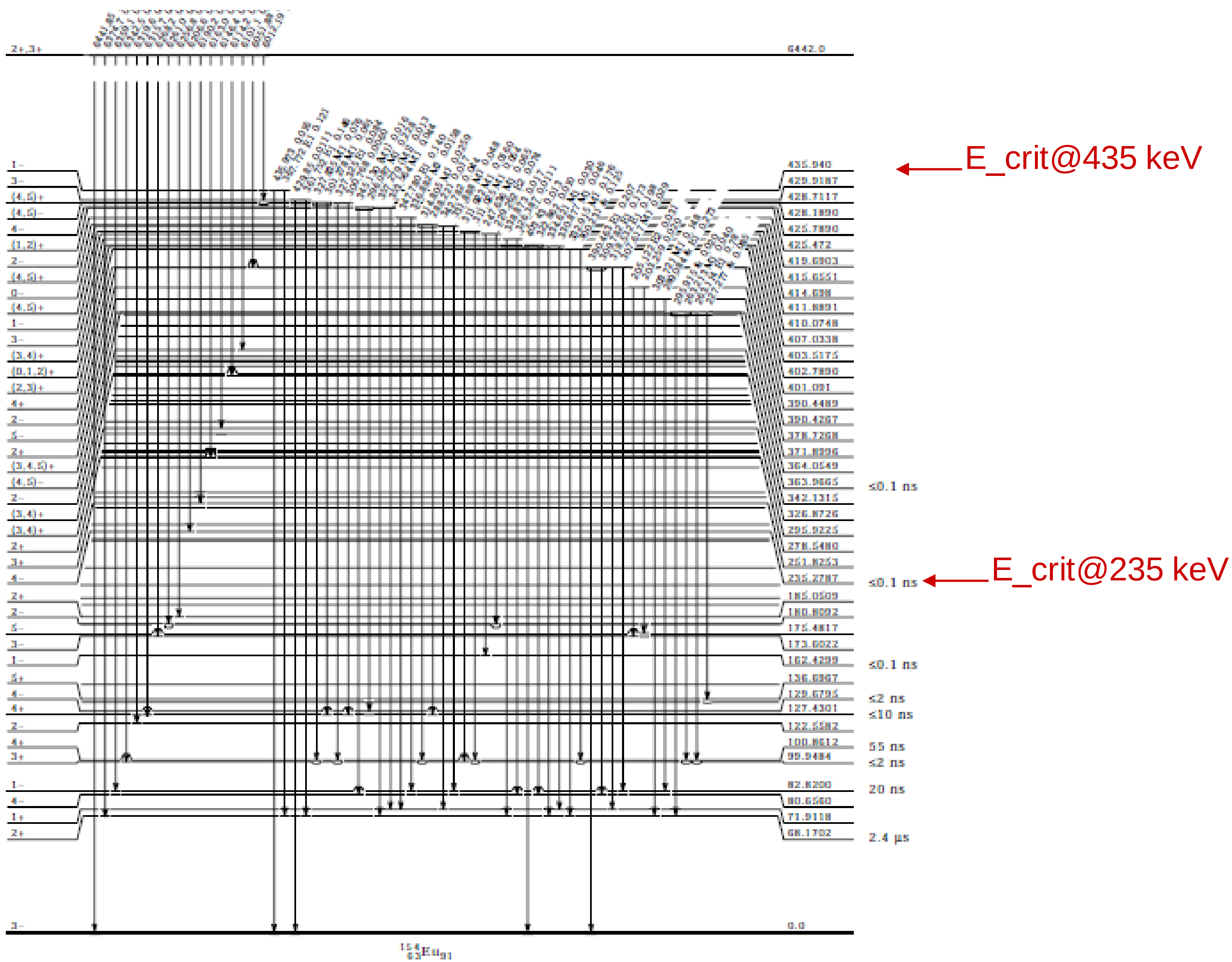
^{152}Eu



E_crit@339 keV

E_crit@200 keV

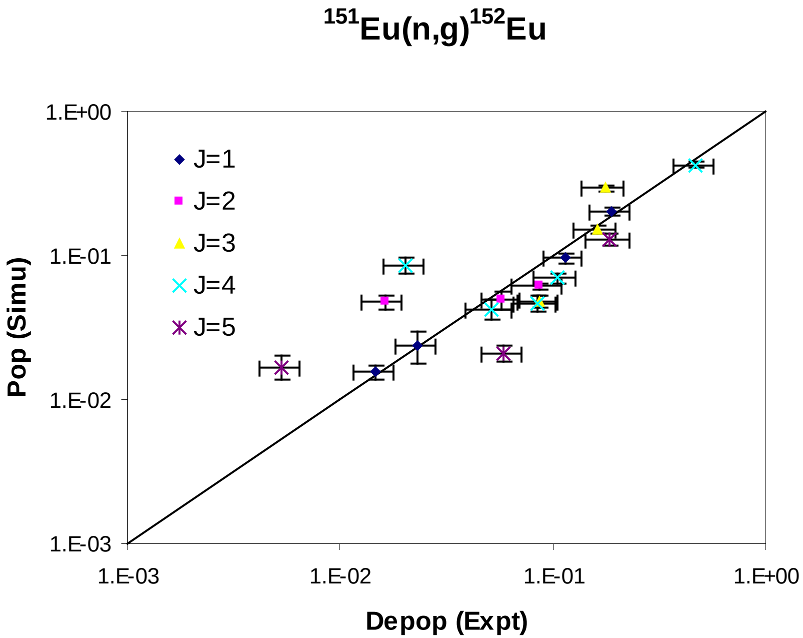
^{154}Eu

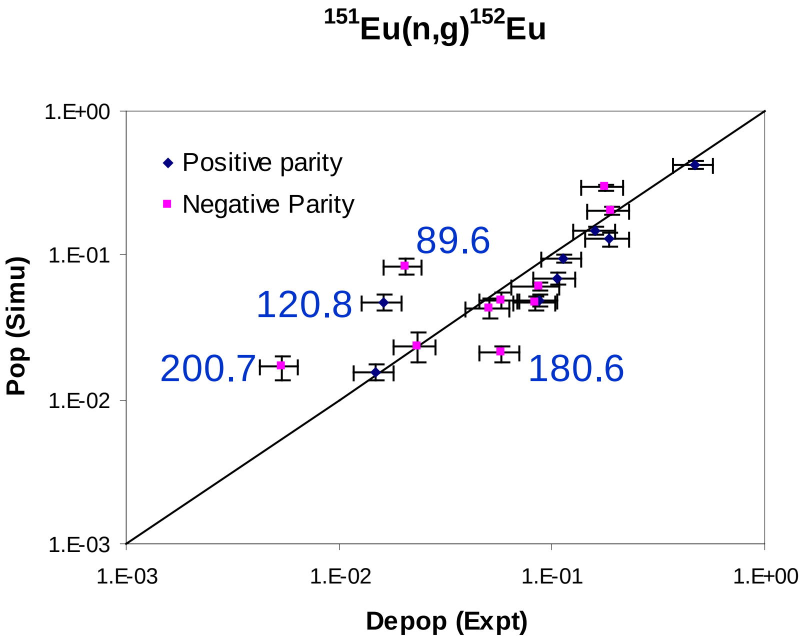

E_crit@435 keV
E_crit@235 keV
435.940
235.2787
0.0
≤0.1 ns
≤0.1 ns
≤0.1 ns
≤2 ns
≤10 ns
55 ns
≤2 ns
20 ns
2.4 µs

Check sheet (^{154}Eu)

LD Model	E1 Model	M1 Model	D_0 (eV)		Γ_γ^{tot} (meV)	
			LD Mod	Expt.	Simula	Expt.
CTF(0)	BA(1)	SP(0)	1.0	1.14 (8)	140	93 (3)
CTF(0)	BA(1)	SP(0)	1.0		136 (1)	
CTF(0)	C-H(6)	SP(0)	1.0		94 (1)	
CTF(0)	KMF(4)	SP(0)	1.0		64 (1)	
BSFG (6)	C-H(6)	SP(0)	0.42		161	
BSFG (8)	C-H(6)	SP(0)	1.1		167	
BSFG (8)	BA(1)	SP(0)	1.1		246	
BSFG (8)	EGLO(3)	SP(0)	1.1		340	
CTF(0)	C-H(6)	SP(0)	1.0		88 (1)*	
BSFG (8)	KMF(4)	MDR(1)	1.1		62	
BSFG (8)	C-H(6)	MDR(1)	1.1		99 (1)	

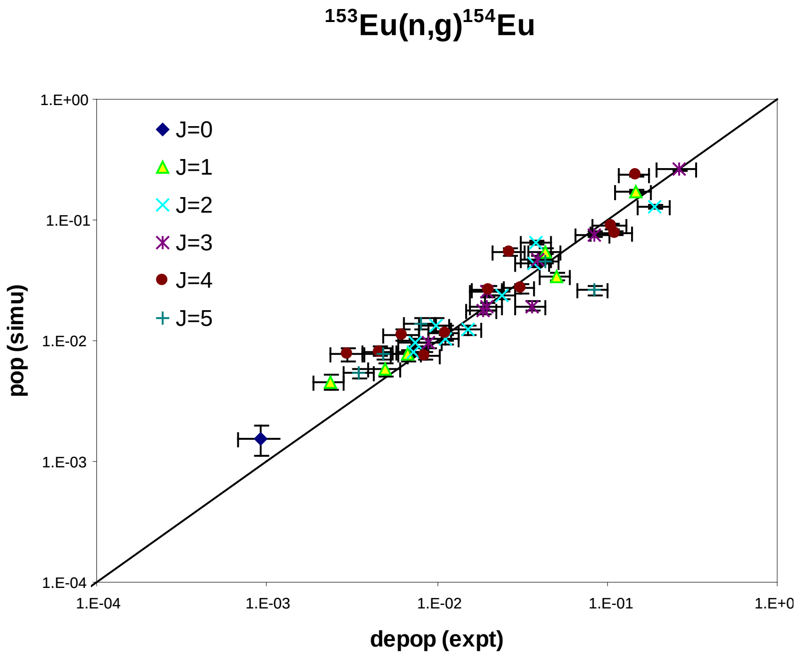
De_pop vs. Pop plot

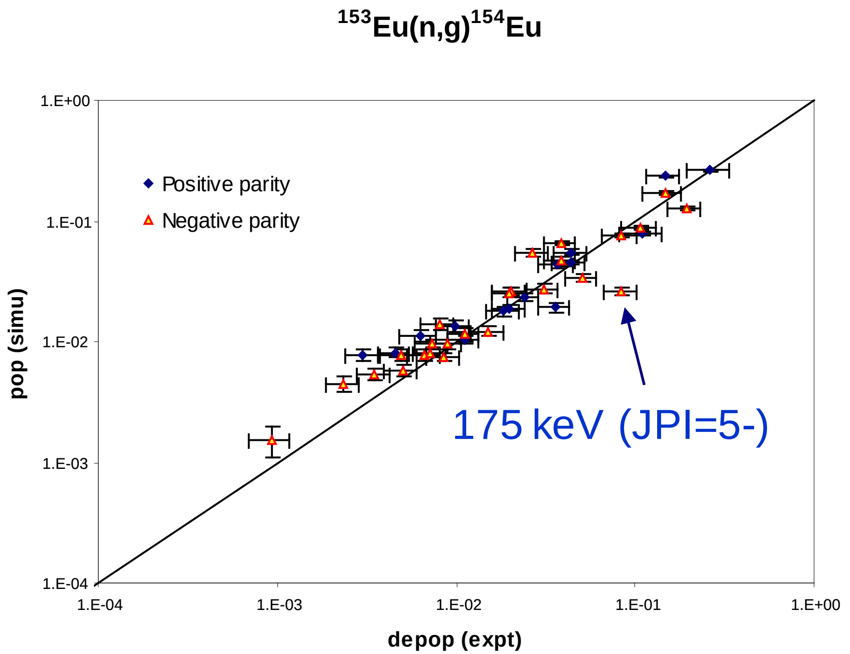




D_0 (eV)		Γ_γ^{tot} (meV)	
LD Mod	Expt.	Simula	Expt.
0.81	**0.73(7)**	**93(1)**	**91(9)**

De_pop vs. Pop plot





G-rays from 175 – 38.8, 45.8 and 74.6 keV

D_0 (eV)		Γ_γ^{tot} (meV)	
LD Mod	Expt.	Simula	Expt.
1.0 **1.1**	**1.14 (8)**	**94 (1) EGAF** **99 (1) ENSDF**	**93 (3)**

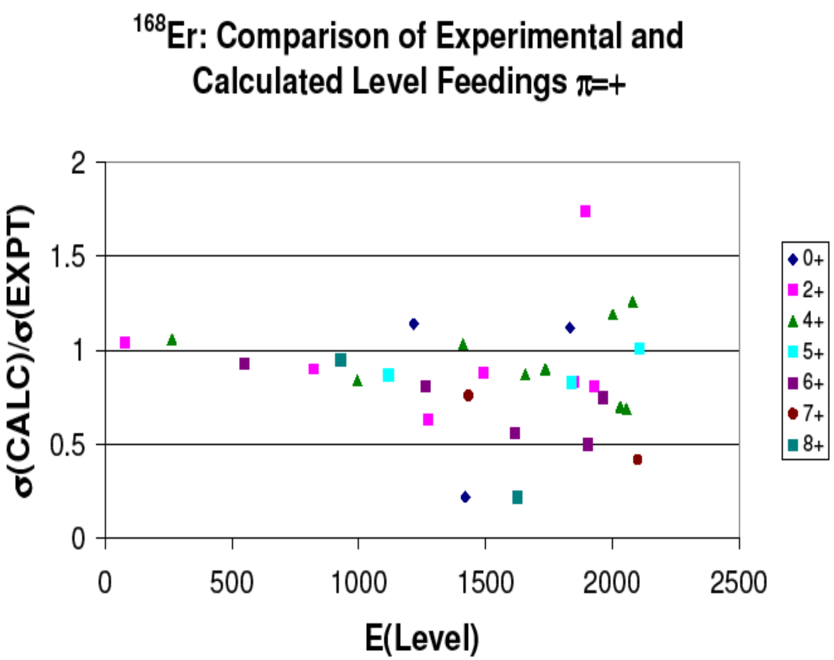
Preliminary Results

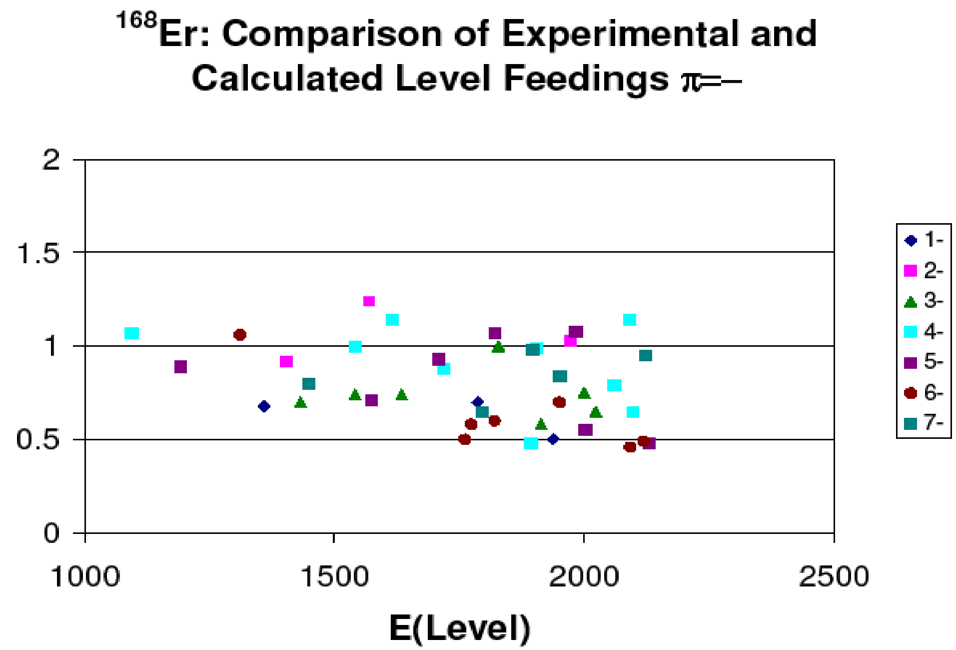
$^{151}Eu(n,g)^{152}Eu$			
	CS (EGAF) (b)	CS (SIM) (b)	Mugabgab (b)
G.S. ($T_{1/2}$=13 y)	6636 (300)	7230 (300)	5900 (200)
M.S. ($T_{1/2}$=9.3 h)	3378 (300)	3410 (300)	3300 (200)

$^{153}Eu(n,g)^{154}Eu$			
	CS (EGAF) (b)	CS (SIM) (barn)	Mugabgab (b)
G.S. ($T_{1/2}$)=8.6 y)	270 (12)	292 (12)	312 (7)

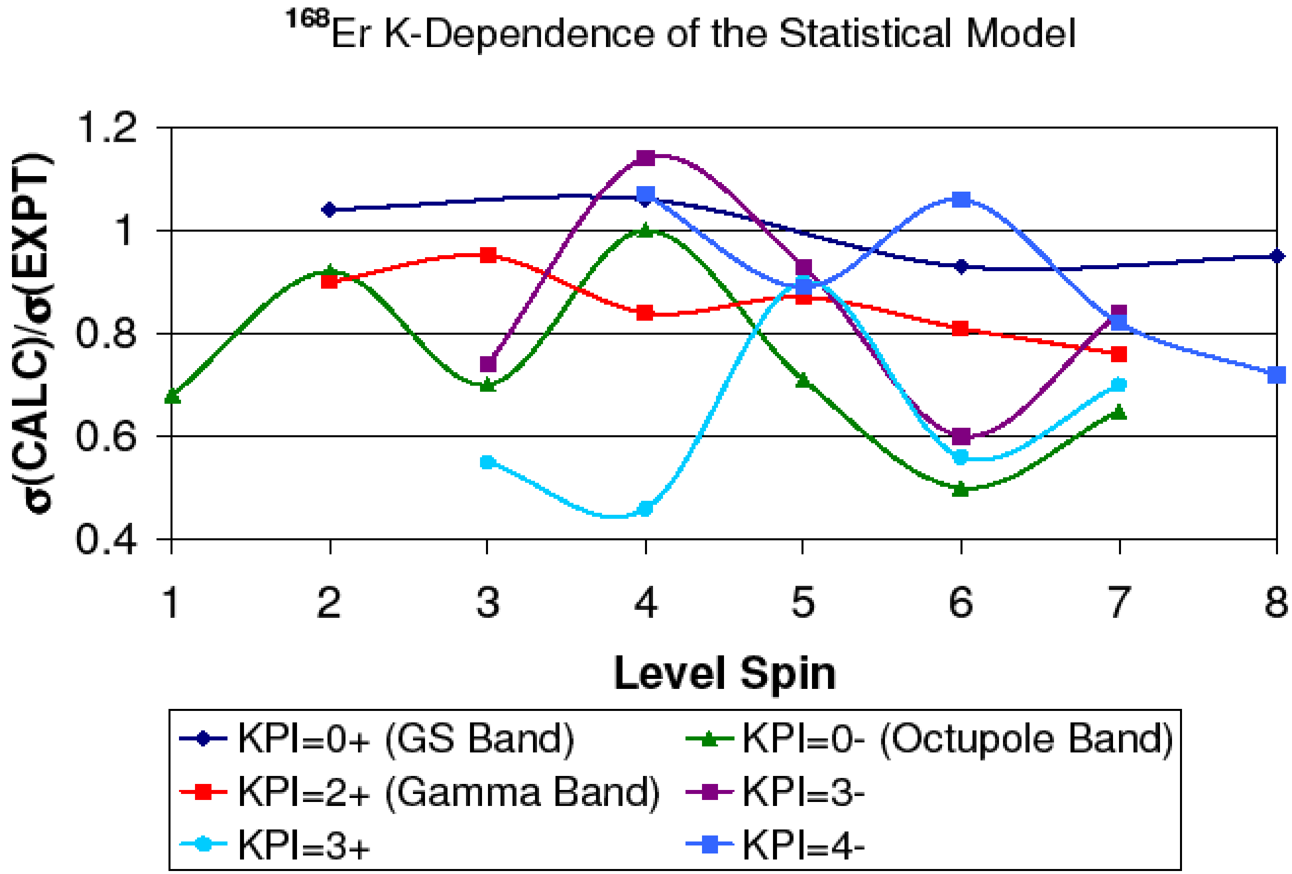
Experimental initiative

- The $^{167}Er(n,g)^{168}Er$ reaction was studied at Budapest nuclear reactor, Hungary
- Ratio of calculated and experimental CS plots show no dependence for spin and parity of the lower energy levels





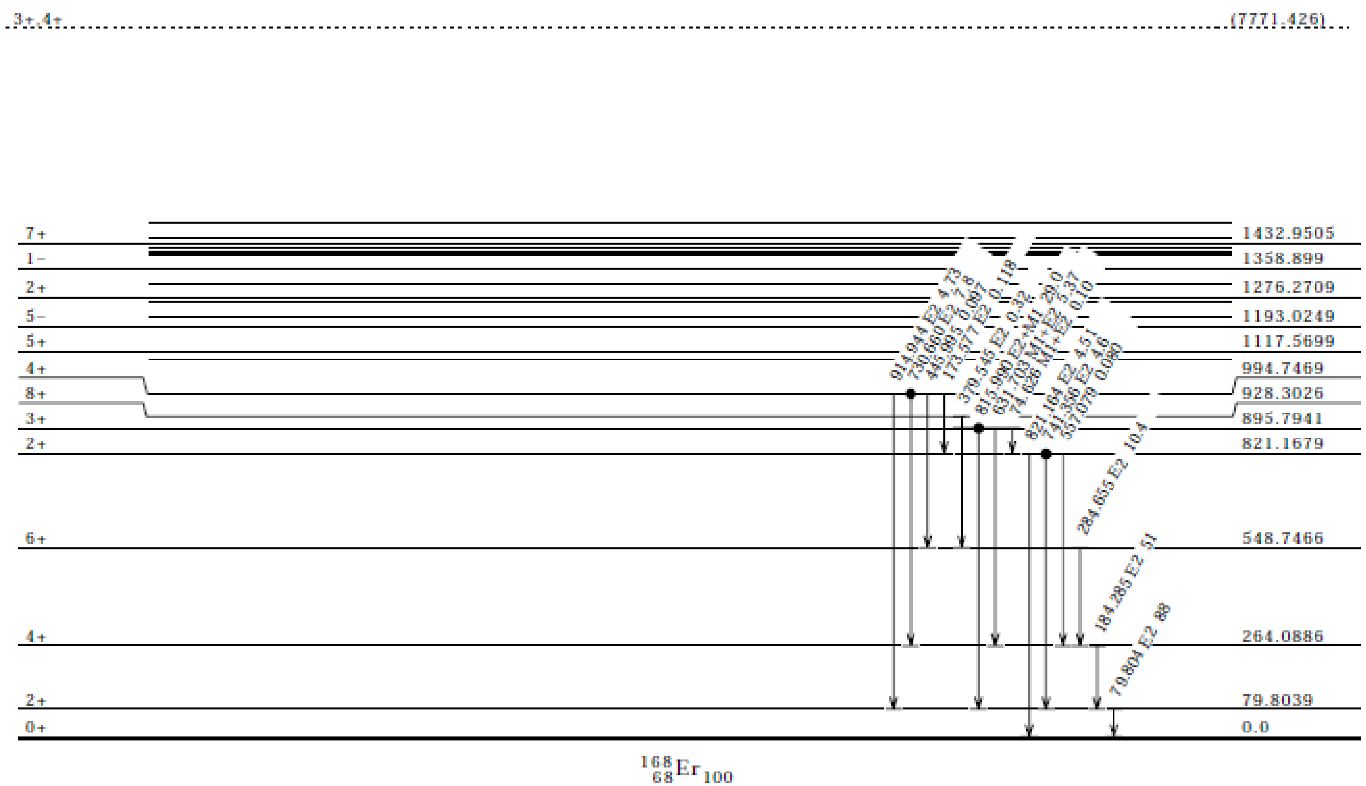
However, a K-dependence of statistical decay to the lower energy levels is visible



Experiment at 88-Inch cyclotron

- Reaction of interest: $^{167}Er(d,p\gamma)^{168}Er$
  - Q value: 5.5 MeV
  - Study $^{168}Er^*$ at different excitation energies between E_{crit} and S_n
  - S_n=7.77 MeV
  - Coulomb potential for ^{168}Er+p is 10 MeV
  - Beam energy 15 MeV

Goal

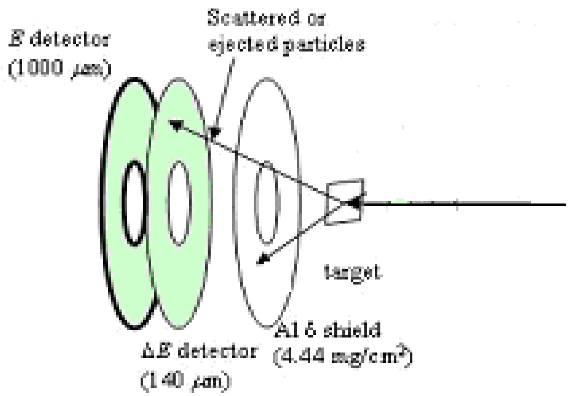


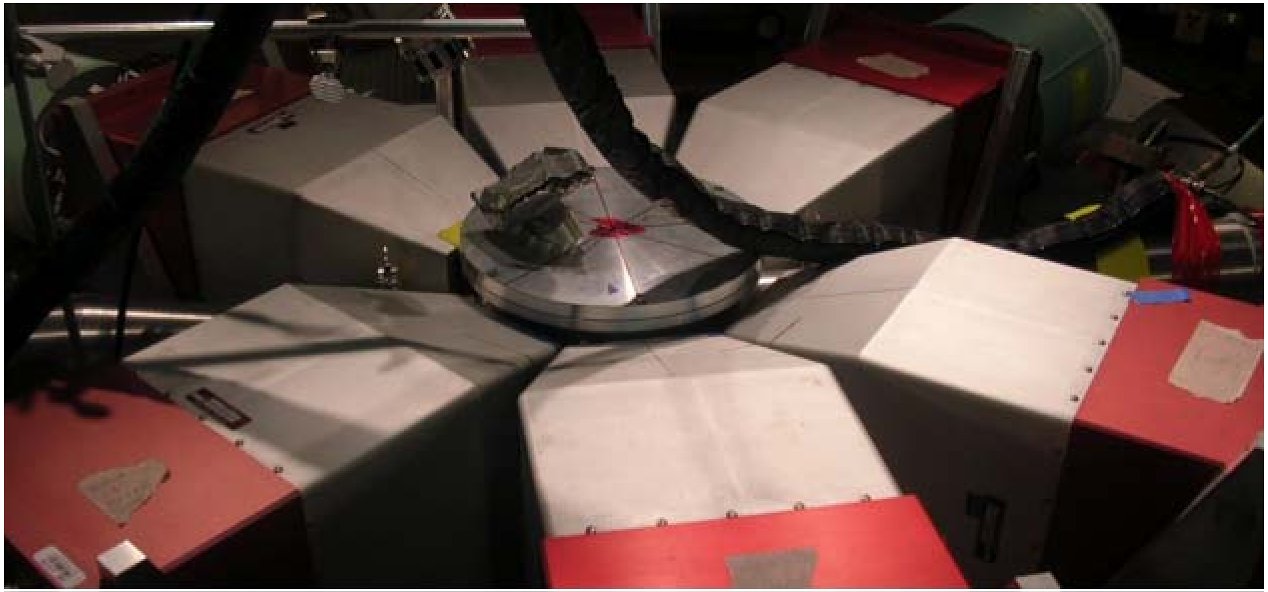
Testing of hypotheses:

- ❖ K is a good quantum number at all excitation energies
- ❖ The K quantum number disappears between E_crit and S_n
- ❖ K quantum number is conserved for thermal neutron capture

Experimental approach

- Deuteron beam from the 88-cyclotron, LBNL
- Proton detection of (d,pγ) reaction by silicon telescope
- γ-ray measurements by 6 suppressed HPGe clovers





Conclusions

- Neutron capture G-ray simulation work on Eu isotopes points out a few inconsistencies in the depop/pop plots
- These will be reviewed further, but sometimes solutions are not obvious
- Calculated and experimental CS for Eu isotopes are mostly consistent, except the ^{151}Eu(n,g)^{152}Eu (G.S.)
- Experiments at Budapest will be repeated with isotopic Eu targets
- Overall, DICEBOX work is found to be useful, it provides opportunity to check or re-evaluate related nuclear structure data and yields plan for experiments