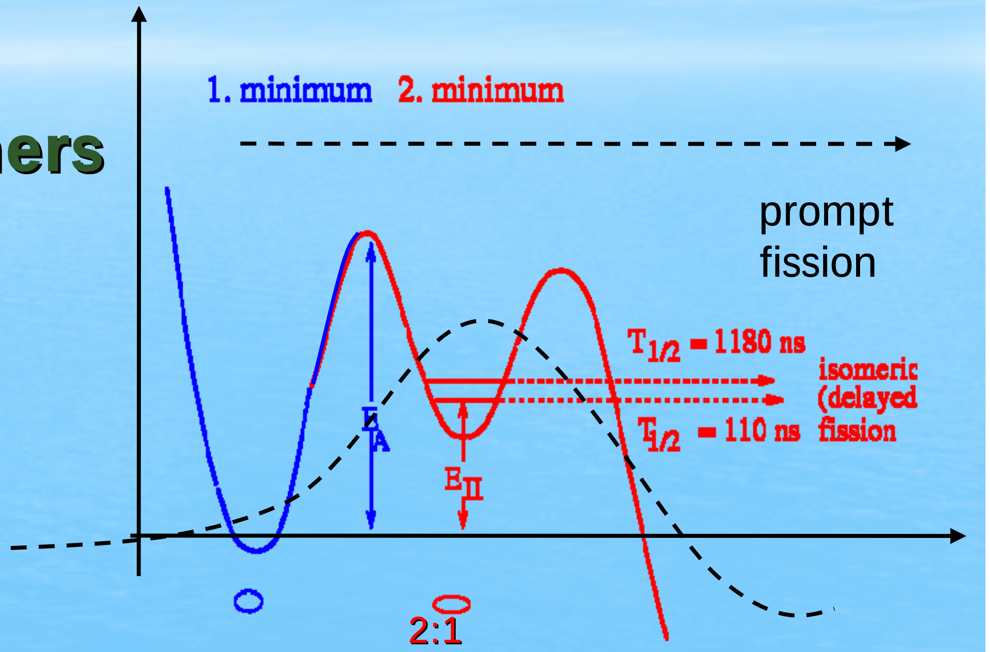
g-Spectroscopy of superdeformed ^{237}Pu

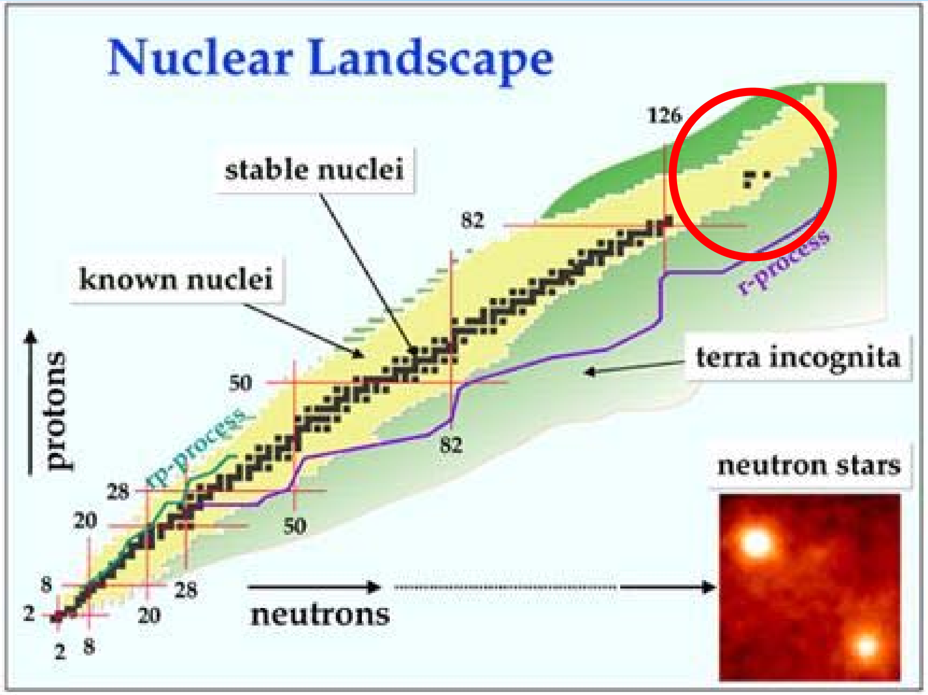
OUTLINE

- **Motivation: fission isomers**
- **Spectroscopy of ^{237f}Pu:**
  - **measurement**
  - **results**
- **Outlook**



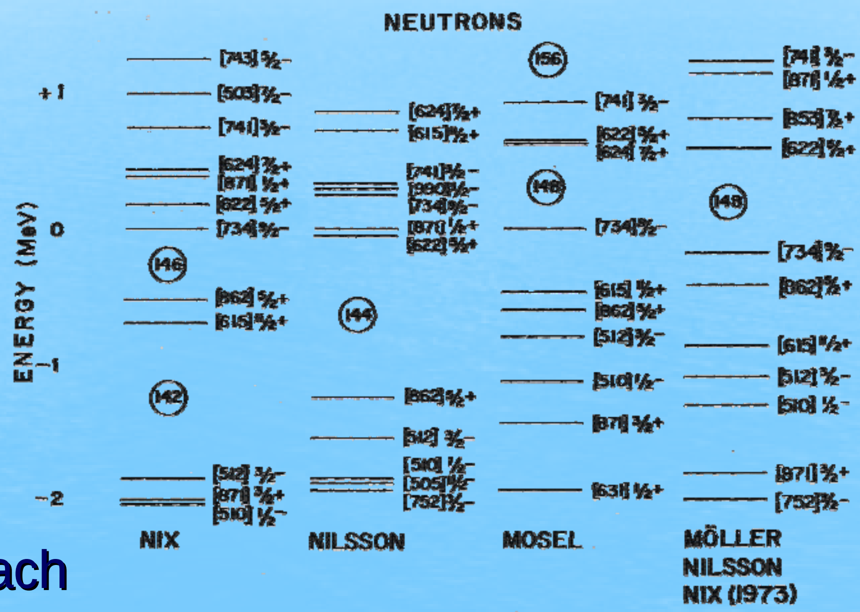
experimental goal: - first experimental identification of single-particle states in largely deformed actinides
-> determination of fission barrier from level density

r-Process Path in Heavy Element Region



no experimental data

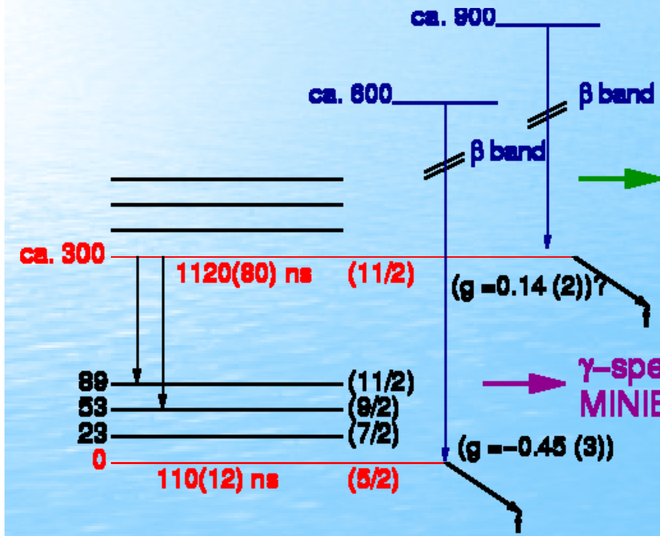
-> contradicting theoretical predictions:



- direct access to r-process path out of reach
- extrapolations of nuclear models require experimental data
- knowledge of fission barriers is crucial
- fission barriers: - determine end of chart of nuclides
  - change of shell correction energy by 1 MeV: fission lifetime changed by 10^5

Spectroscopy of the first Odd-N fission isomer

- Present Knowledge



Conversion electron spectroscopy
MINI ORANGES
(Future)

γ–spectroscopy
MINIBALL

^{237f}Pu

^{237f}Pu: rigid rotor

=> regular rotational band structure

^{240f}Pu (even-even) (3.8 ns)	^{237f}Pu (odd-even) (110 ns)
^{238}U(a, 2n) 24 MeV	^{235}U(a, 2n) 24 MeV
s_{delay} = 10 mb	s_{delay} ~1 - 2 mb
$\frac{\sigma_{delay}}{\sigma_{prompt}} = 1.2\times10^{-4}$	$\frac{\sigma_{delay}}{\sigma_{prompt}} = 1.2\times10^{-5}$

⇒ in spite of low cross section comparable yields expected

- D. Pansegrau et al. *Phys. Lett*. B 484 (2000) 1
- D. Gaßmann et al. *Phys. Lett* B. 497 (2001) 181

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Experimental Procedure

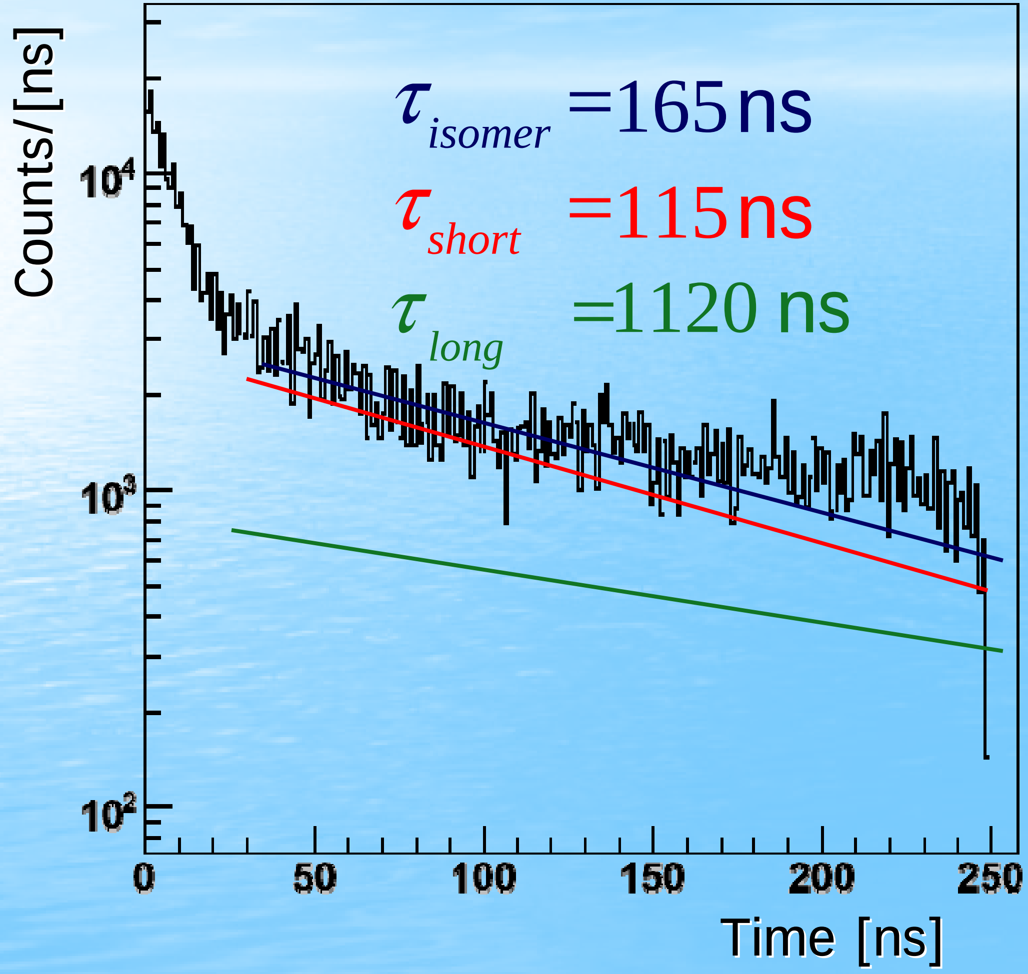
- Reaction: $^{235}U(a,2n)^{237f}Pu$;
- Beam: E_a = 24 MeV:
  pulsed, Dt = 400ns, width ~ 4 ns,
  Cologne Tandem
- Target: thick (rolled) ^{235}U; ≤ 3.7 mg/cm^2 → g-emission at rest
  metallic: low reaction background from e.g. oxygen and carbon
  but: highly oxidising, all handling under vacuum or Ar atmosphere

Detectors:

- fission fragments: compact PPAC array - 8 trapezoidal modules
  - 13 fold segmented anode
  - position sensitive for time of flight
  - large solid angle (73 %)
- g-rays: MINIBALL
  - 8 triple cryostats, distance to target ~10 cm
  - high resolution 2.3 keV (1.3 MeV)
  - high efficiency e_{ph} ~ 9% (1.3 MeV)
  - trigger: fission fragment & g-ray
  - 3 weeks beamtime

  ~ 2×10^4 delayed fission events (N_g = 1 ~ 90 %; N_g = 2 ~10 %)

Isomeric Lifetime



- theoretical expectation:

$$\frac{\sigma_{isomer}}{\sigma_{prompt}} \approx 1.2 \bullet 10^{-5}$$

- experimental finding:

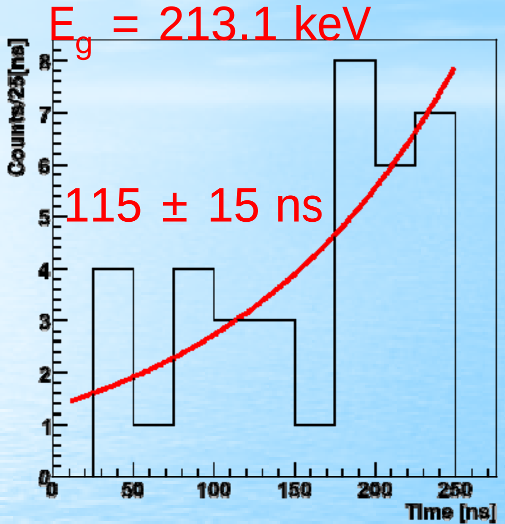
$$\frac{\sigma_{isomer}}{\sigma_{prompt}} \approx 1.2 \bullet 10^{-5} \sim 2\text{mb}$$

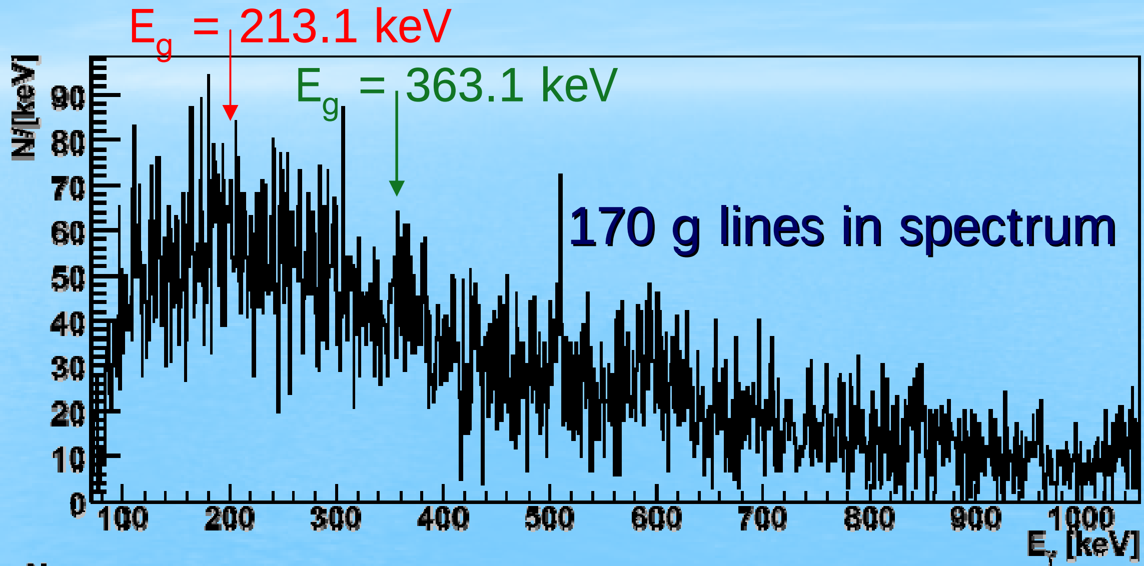
- relative isomeric population

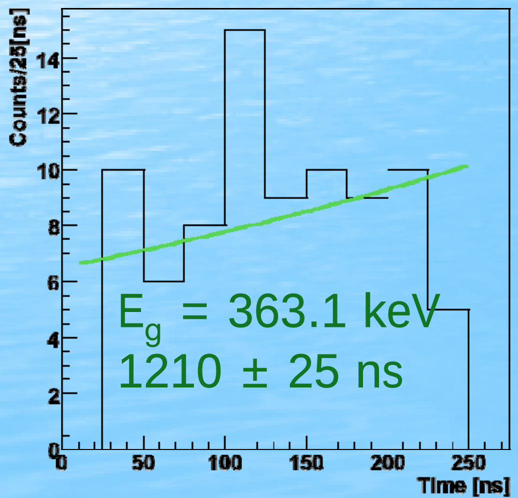
$$\frac{\sigma_{short}}{\sigma_{long}} \sim \frac{2}{1}$$

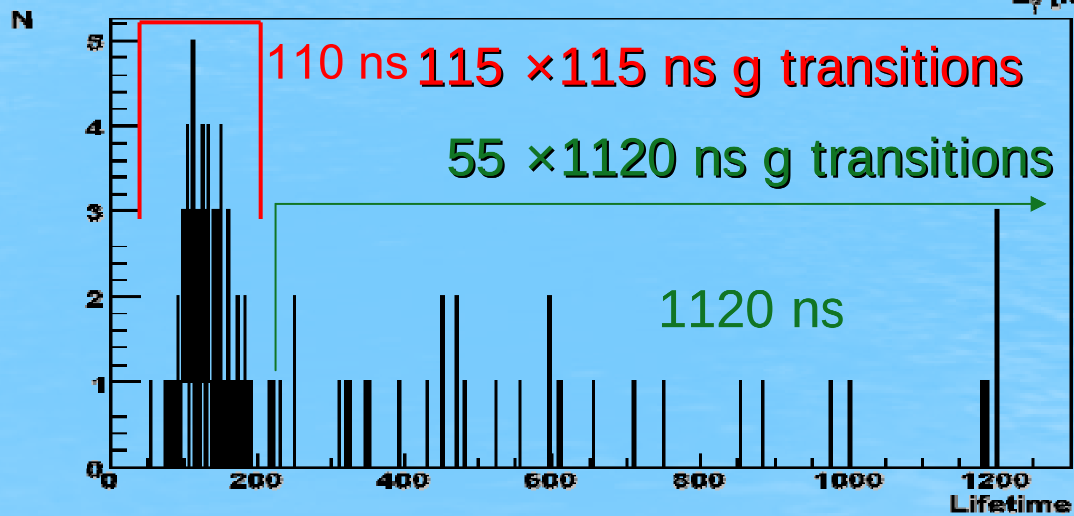
=> consistent with literature

Disentanglement of isomeric g-rays









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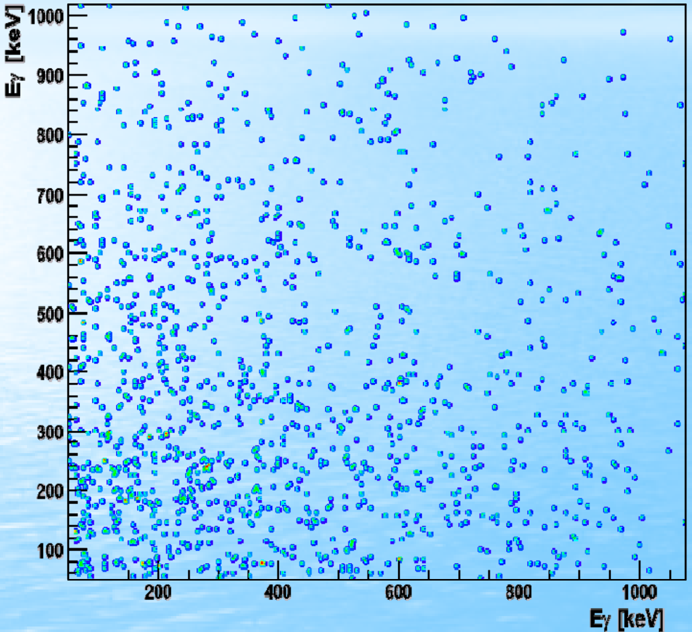
Identification of rotational bands

g-g correlation (2000 N_g = 2 events):



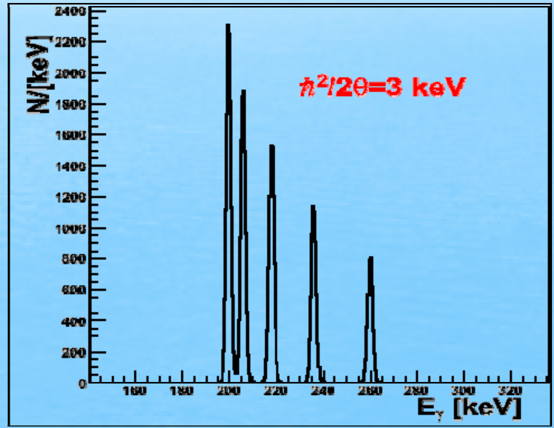
→ No obvious correlations

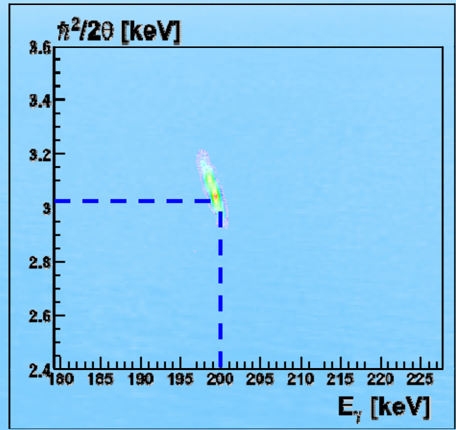
→ automatic search via peak correlation

^{237f}Pu: rigid rotor $$E_{\gamma} = J(J+1) \cdot \frac{\hbar^2}{2\theta}$$

=> regular rotational band structure

test case for peak correlation algorithm:





Variation of rotational parameter $\frac{\hbar^2}{2\theta}$

=> result:

- 9 rotational bands
- $\frac{\hbar^2}{2\theta} = 3.28\ [20]$ keV

(SD axis ratio 2:1 ~ 3.3 keV)

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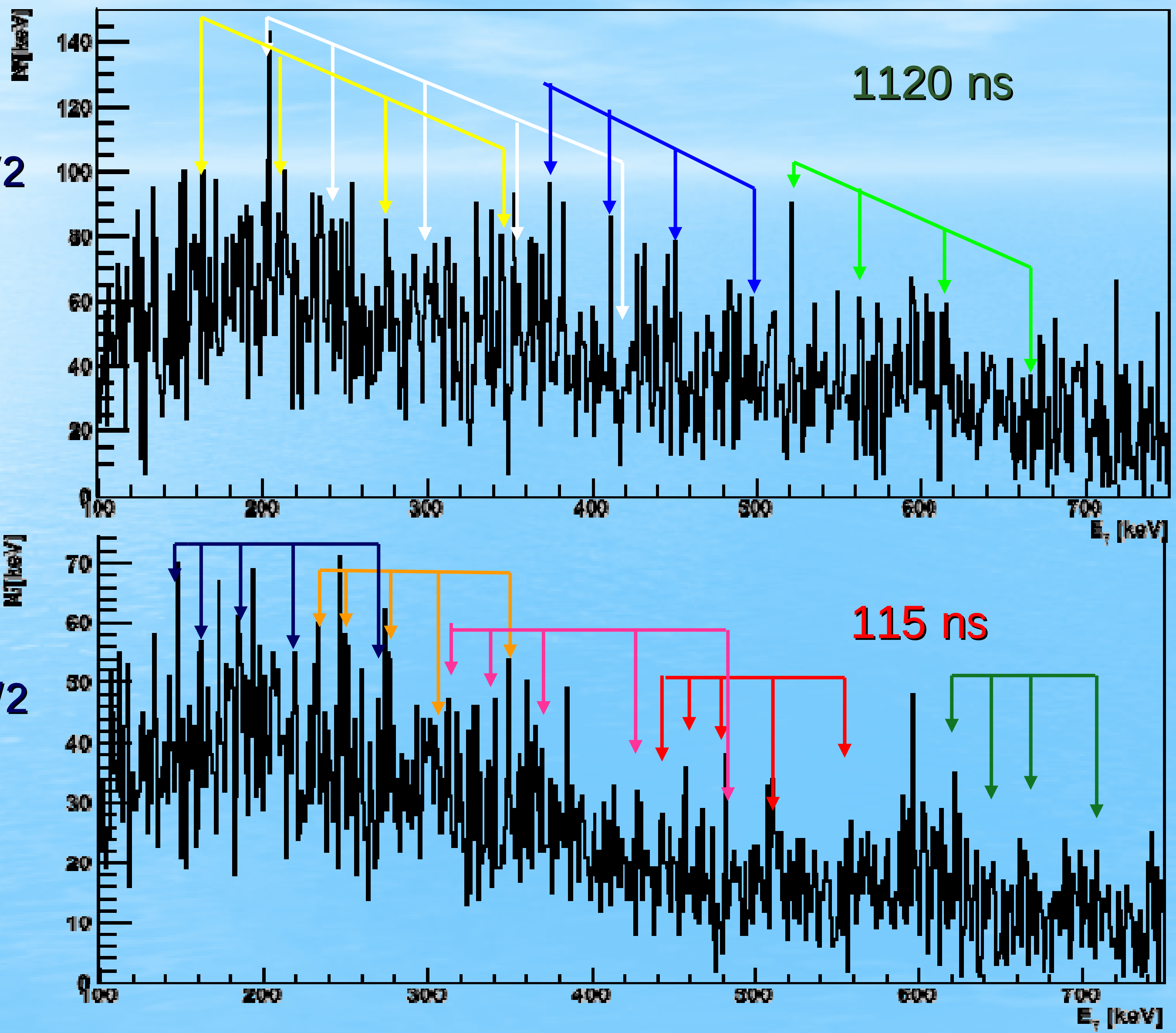
Isomeric rotational bands

9/2 and 11/2

3/2 and 5/2



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Construction of isomeric level scheme(s)

ground state rotational bands:

$$E_J = J(J+1)\cdot\frac{\hbar^2}{2\theta}$$

$$E_{J+1} - E_J = 2\cdot(J+1)\cdot\frac{\hbar^2}{2\theta}$$

$$\frac{\hbar^2}{2\theta} = 3.28\,[20]\ \text{keV}$$

→ Ritz combinatorial search program used (courtesy of T. v. Egidy, E18 TU München):

ground state bands + 170 g transitions

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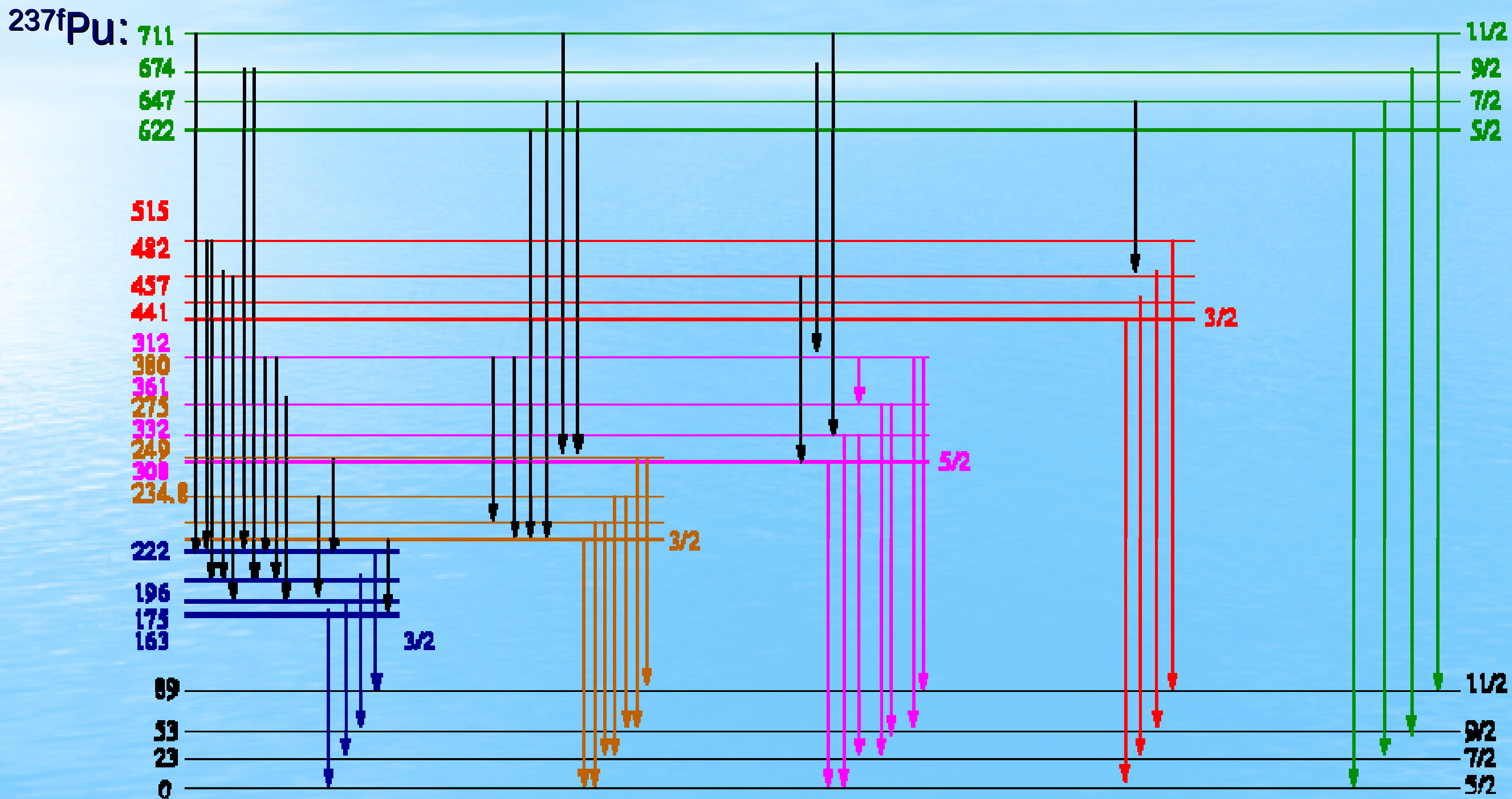
Rotational level scheme for short lived isomer (115 ns)



connecting inter-band transitions identified

-> consistent picture

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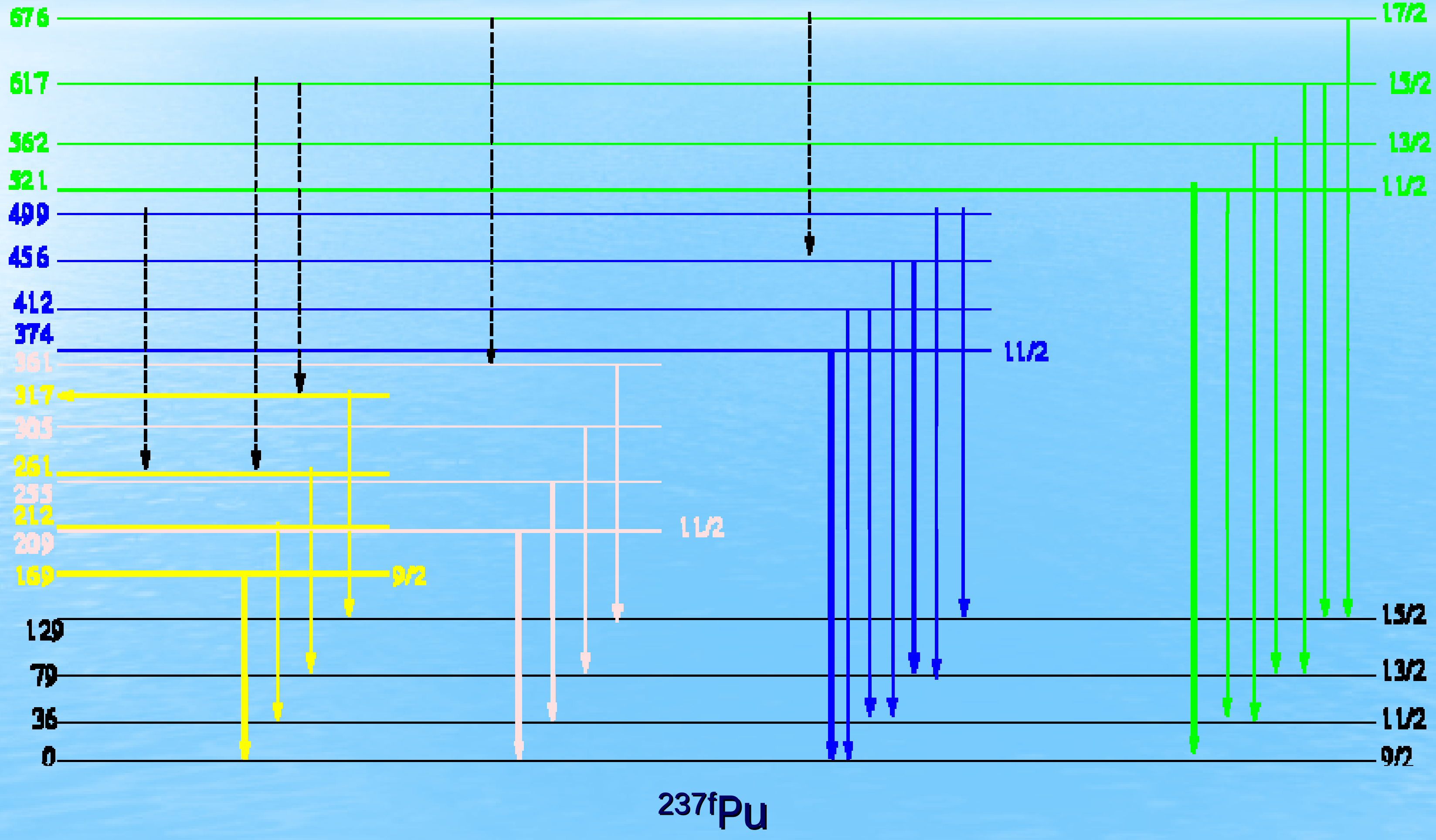
Rotational level scheme for long lived isomer (1120 ns)

work in progress:



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Summary and Outlook

Summary:

- first high resolution g-spectroscopy in Odd-N fission isomers
- regular rigid rotor pattern allows to interpret low-statistics spectra
- 9 rotational bands identified with SD moment of inertia
- g-spectra disentangled into contributions from 2 fission isomers
- level schemes constructed with Ritz combination (gs-band and interband transitions)

Outlook:

- finalise analysis
- complementary conversion electron spectroscopy (Mini Oranges)
  => b-vibration, E0 transitions
- g-spectroscopy of ^{239f}Pu
  – conversion electron data already available
  – identification of Nilsson orbitals
  – localisation of r-process path via fission barriers (theory)

Collaboration

T. Morgan[1], A. Blazhev[2], S. Becker[1], B. Bruyneel[2], L. Csige[3], F. Finke[2], D. Habs[1], H. Hess[2], A. Holler[2], H. Hübel[4], A. Imig[2], M. Kalkühler[2], R. Lutter[1], H. J. Maier[1], P. Reiter[2], O. Schaile[1], C. Schürmann[1], W. Schwerdtfeger[1], M. Seidlitz[2], T. Kotthaus[2], P. G. Thirolf[1], N. Warr[2], A. Wiens[2], K. Wimmer[1]
and the MINIBALL Collaboration

1. Ludwig Maximilians Universität München
   and MLL Garching
2. Universität zu Köln
3. Inst. of Nucl. Research of the Hungarian
   Academy of Sciences (Atomki) Debrecen
4. Rheinische Friedrich Wilhelms Universität Bonn