Highly deformed states, clusterization and fission in the actinide region

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Recent Results on High-Spin Hyperdeformation

ENS'05

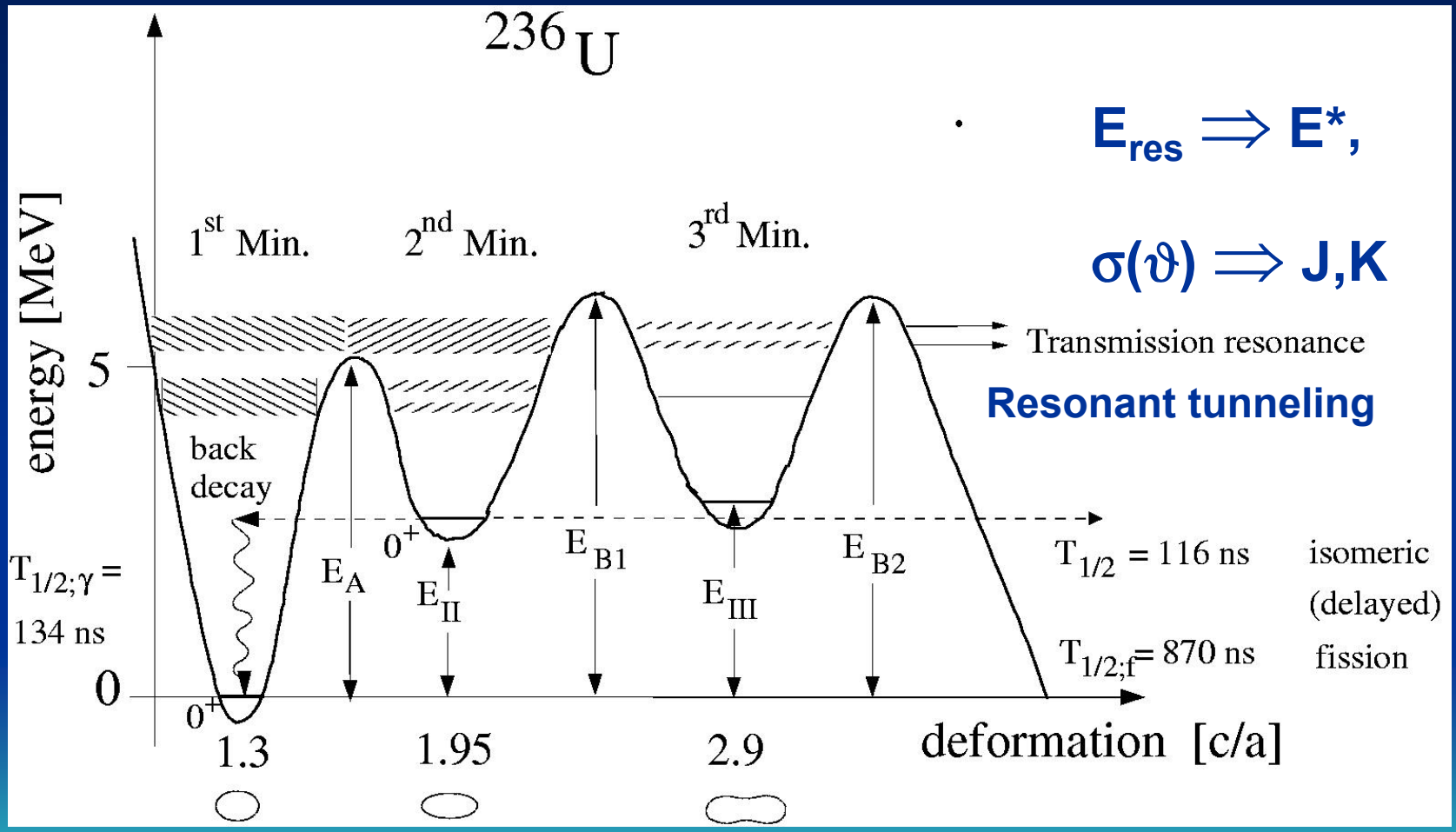
Debrecen 20. – 25. June 2005

Herbert Hübel

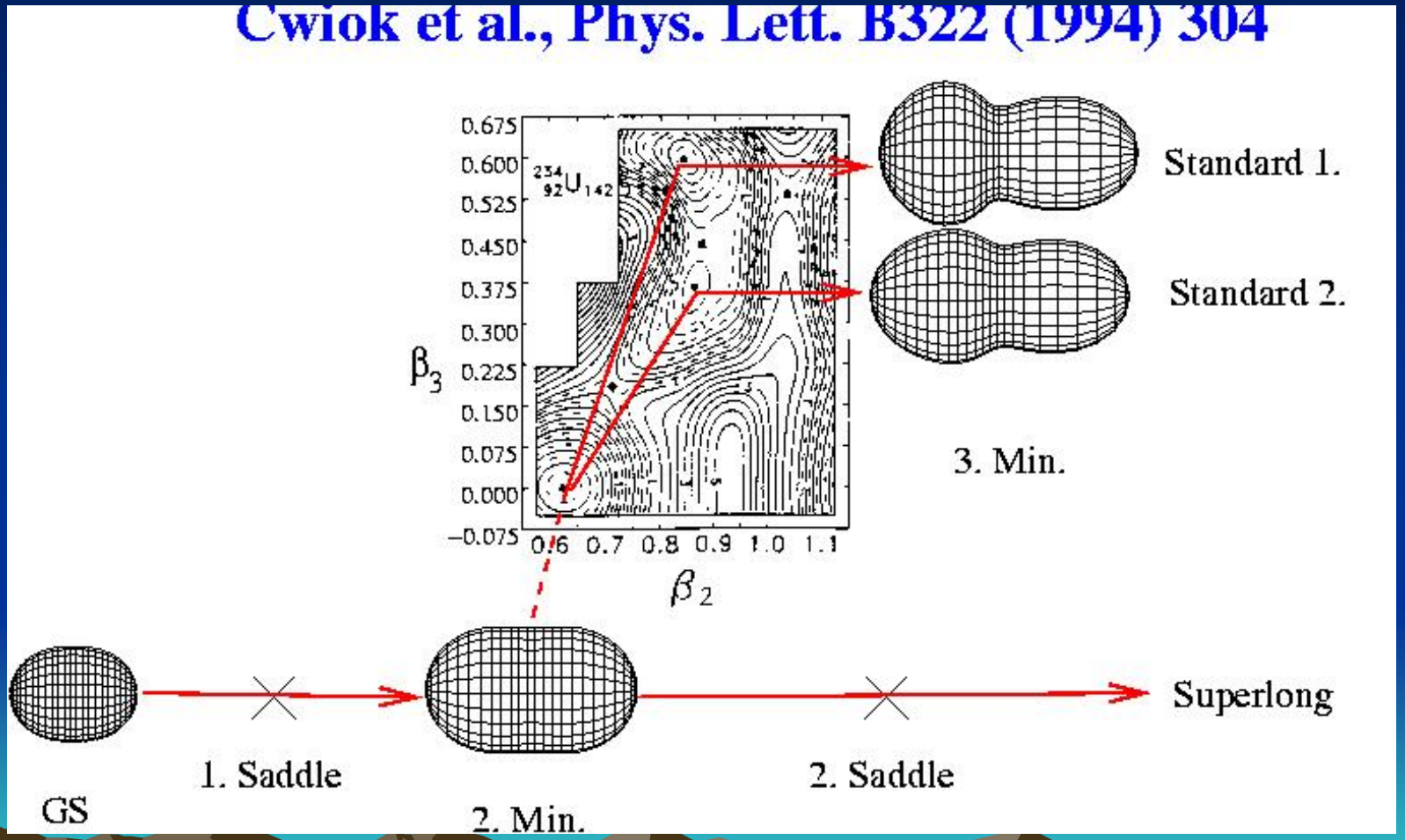
- Four compound systems were investigated (^{174}Hf*, ^{144}Nd*, ^{130}Xe*, ^{128}Ba*) with Euroball and Gammasphere
- 'Overshoot' beam energy by ~10 MeV
- HD searches
  - No convincing discrete-line spectra
  - Continuum ridges with ΔE between 32 and 56 keV corresponding to moments of inertia of 71 to 125 $\hbar^2$/MeV
- Moments of inertia in agreement with calculation for several nuclei
- 'HD' ridge structures with intensities of ~5 x 10^{-5} of reaction channel are composed >10 bands: individual bands below detection limit of EB and GS
- Data contain a wealth information on ND and SD structures. Examples: TSD in ^{170}Hf, SD in ^{140}Nd, high-spin bands in ^{125,126}Xe

1. Introduction
2. Resonant tunneling
3. Experimental methods
4. Experimental results:
   - Superdeformed bands in ^{240}Pu
   - Hyperdeformed bands in ^{234}U and in ^{236}U
   - On the shape of the potential barriers
   - Mass distributions
   - Clustering effects
5. Summary and conclusion, Future plans

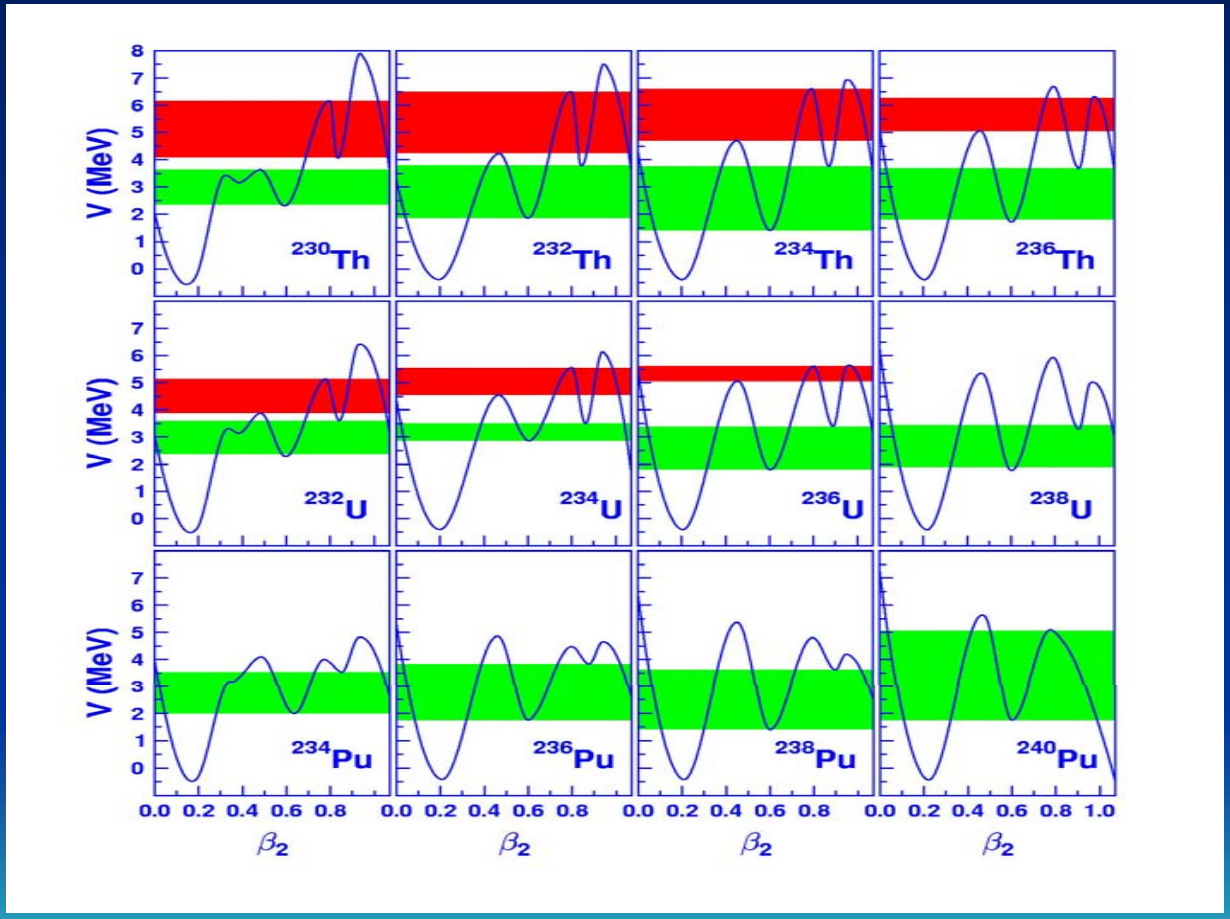
Triple humped fission barrier



Nuclear fission paths



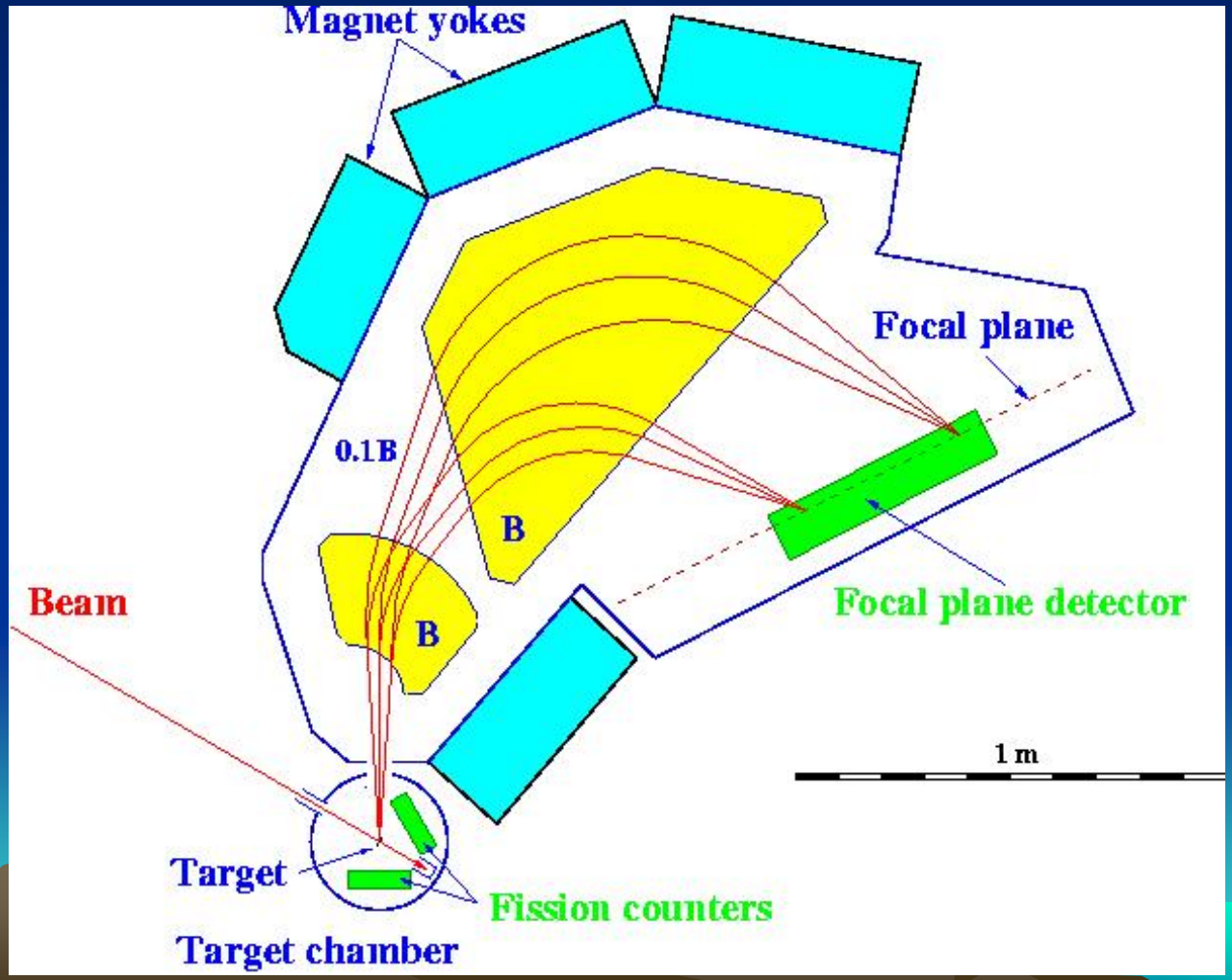
The best energy regions for studying the SD and HD states



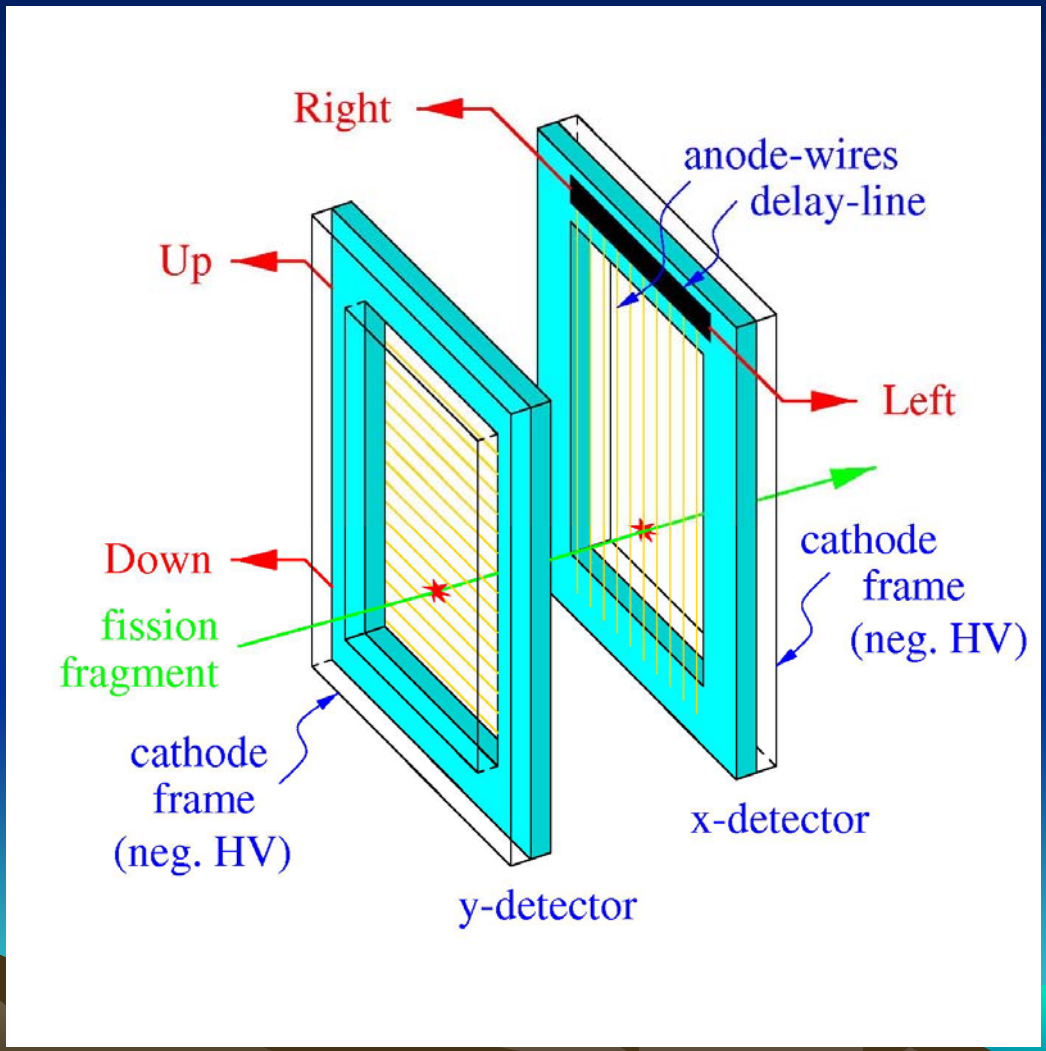
Howard, Möller, ADNDT 25 (1980) 218

Cwiok et al., PLB 322 (1994) 304

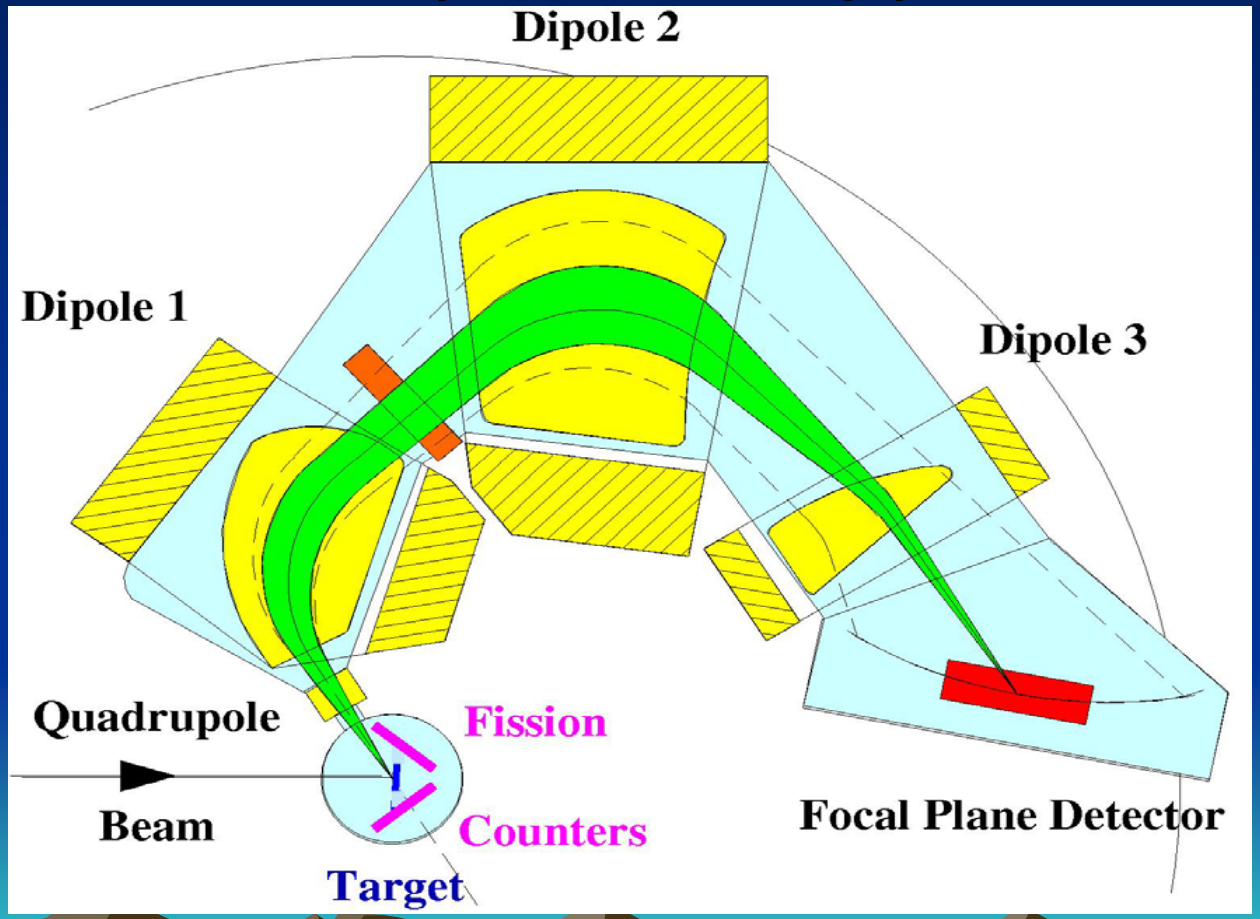
Experimental setup for studying fission (transmission) resonances in ATOMKI (Debrecen)



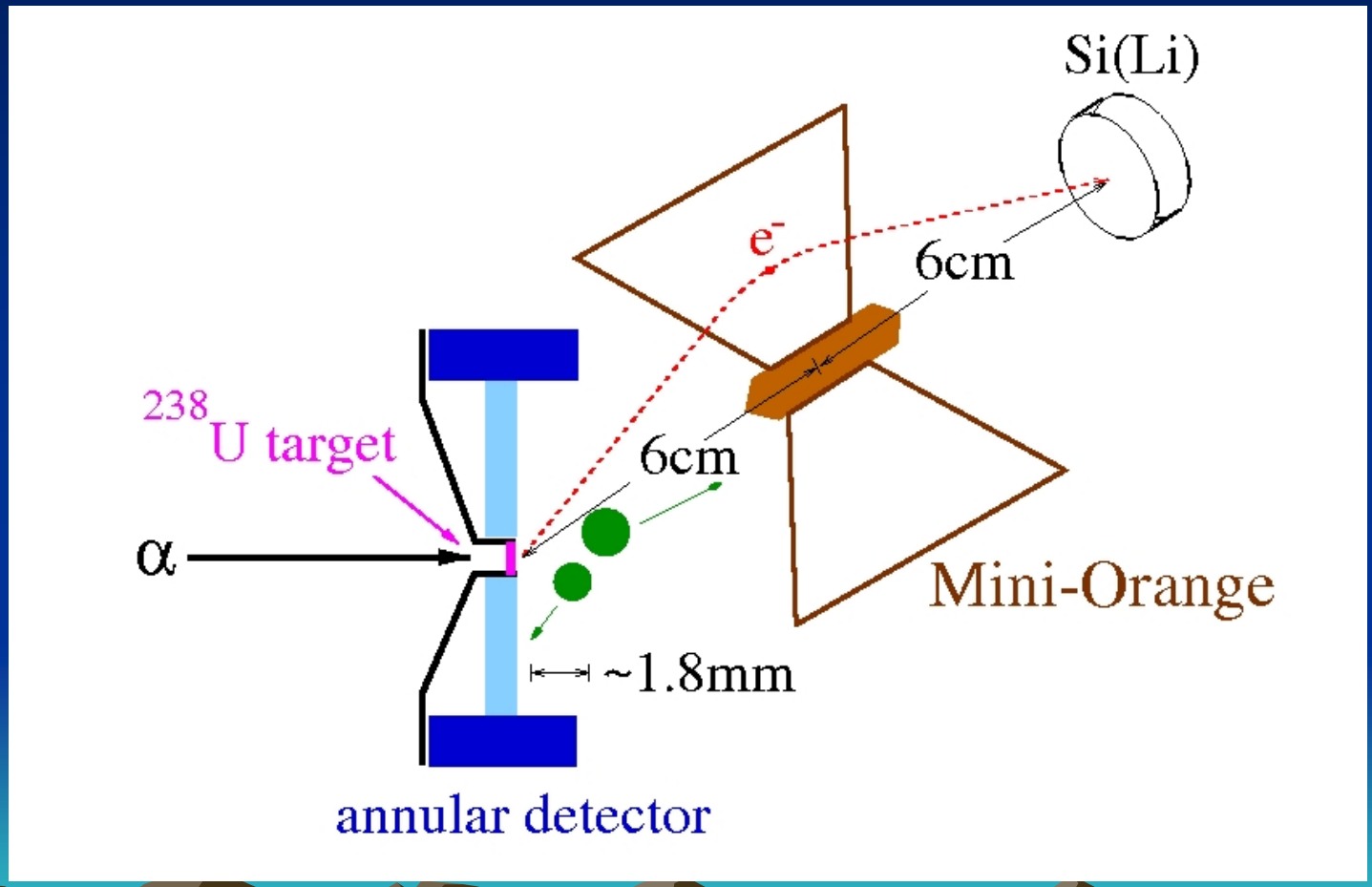
Low-pressure position sensitive avalanche counters



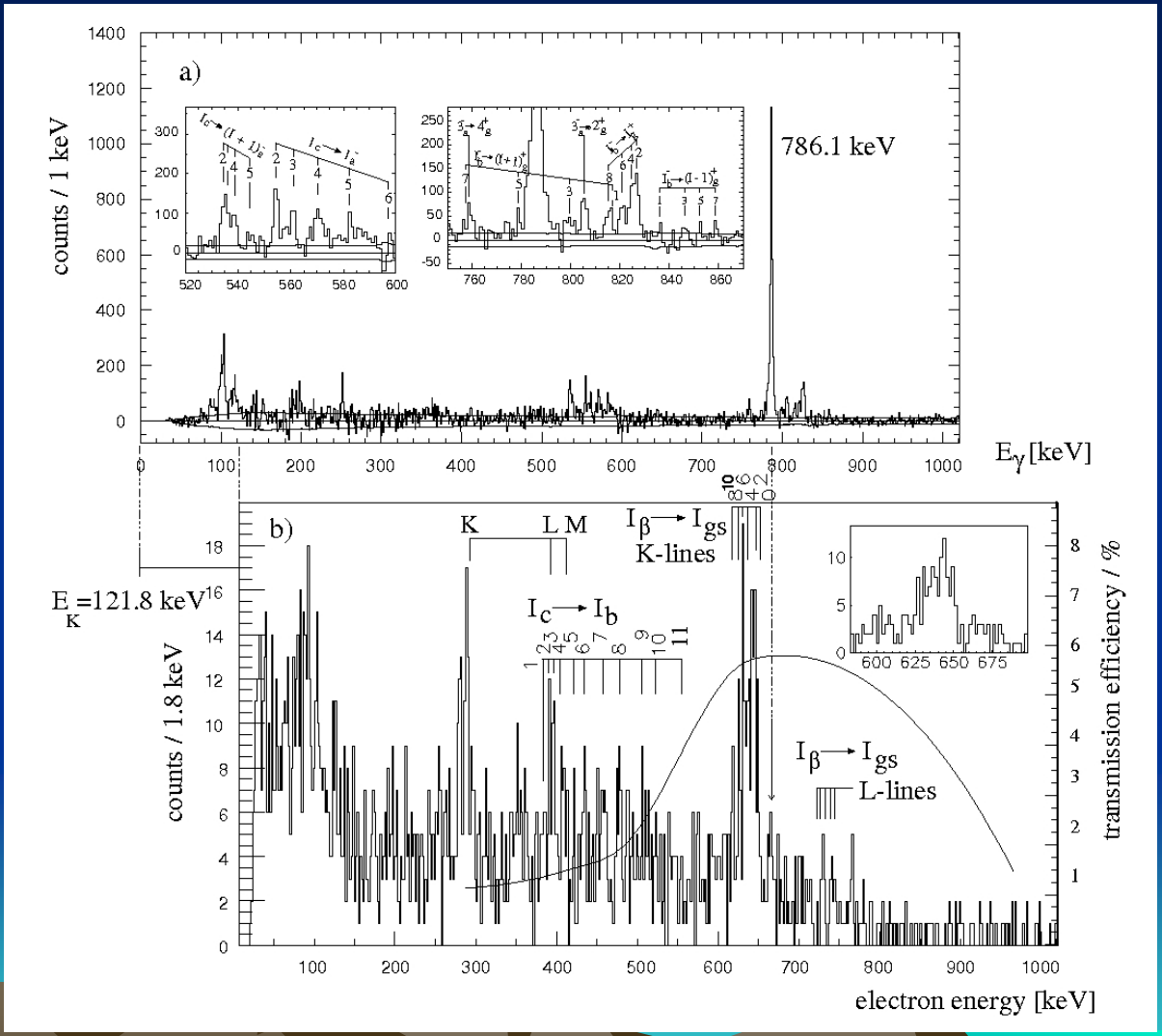
Experimental setup for studying fission resonances in Garching (Germany)



Conversion electron spectroscopy

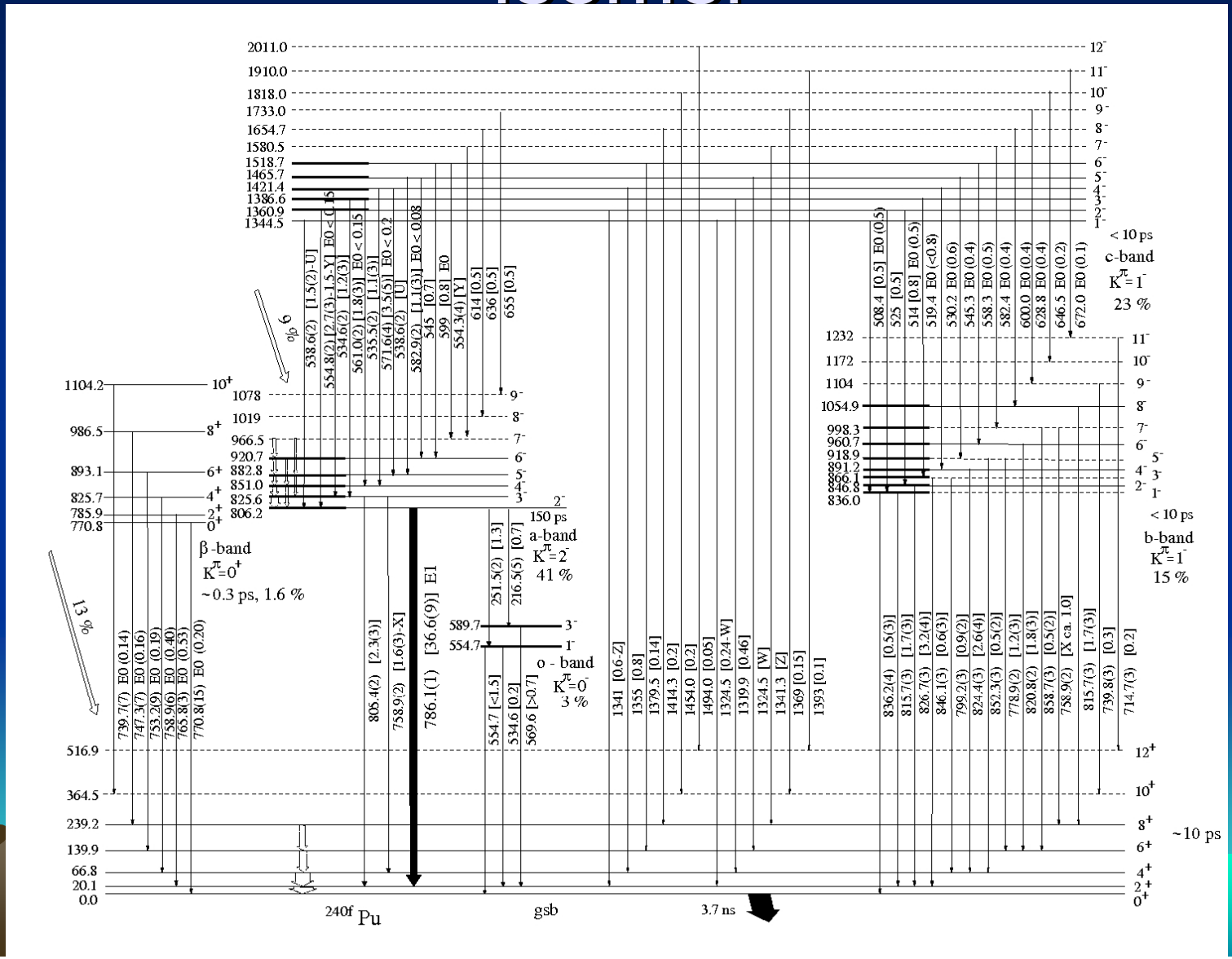


γ and conversion electron spectra

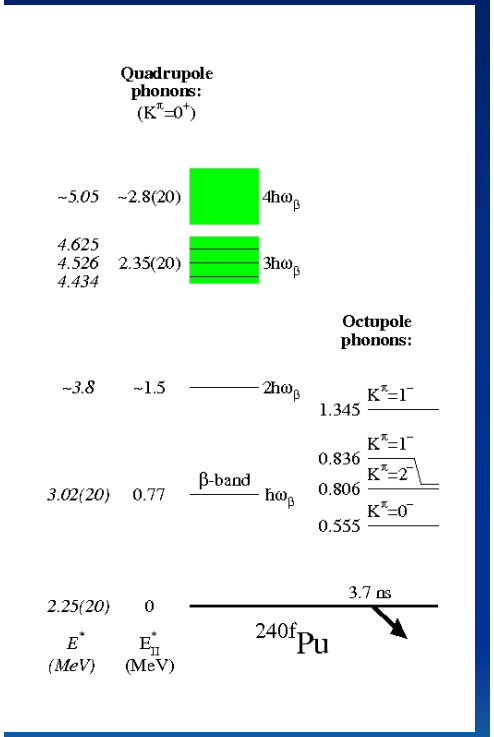


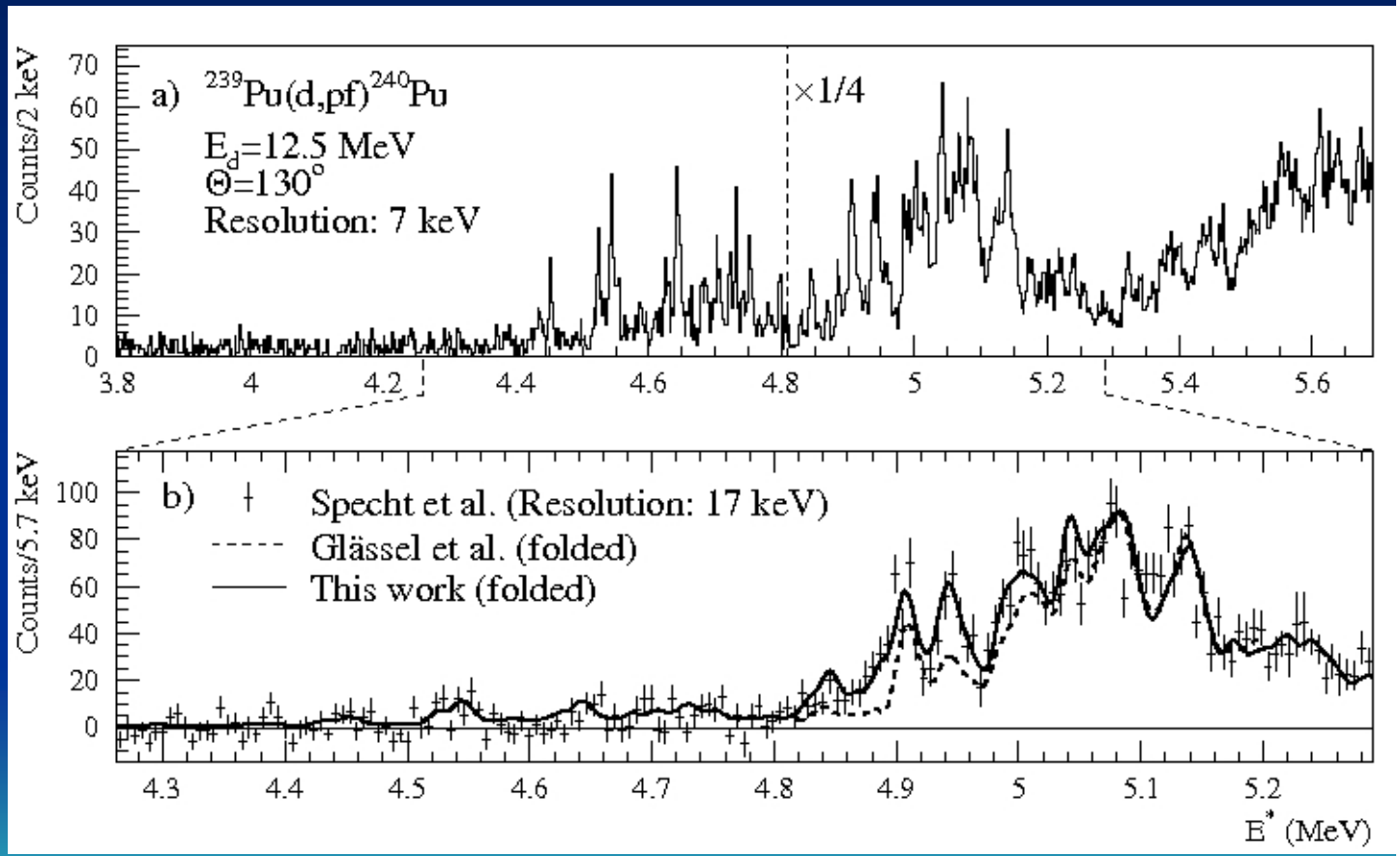
D. Gassmann et al., PLB 497 (2001) 181.

Level scheme built on the fission isomer



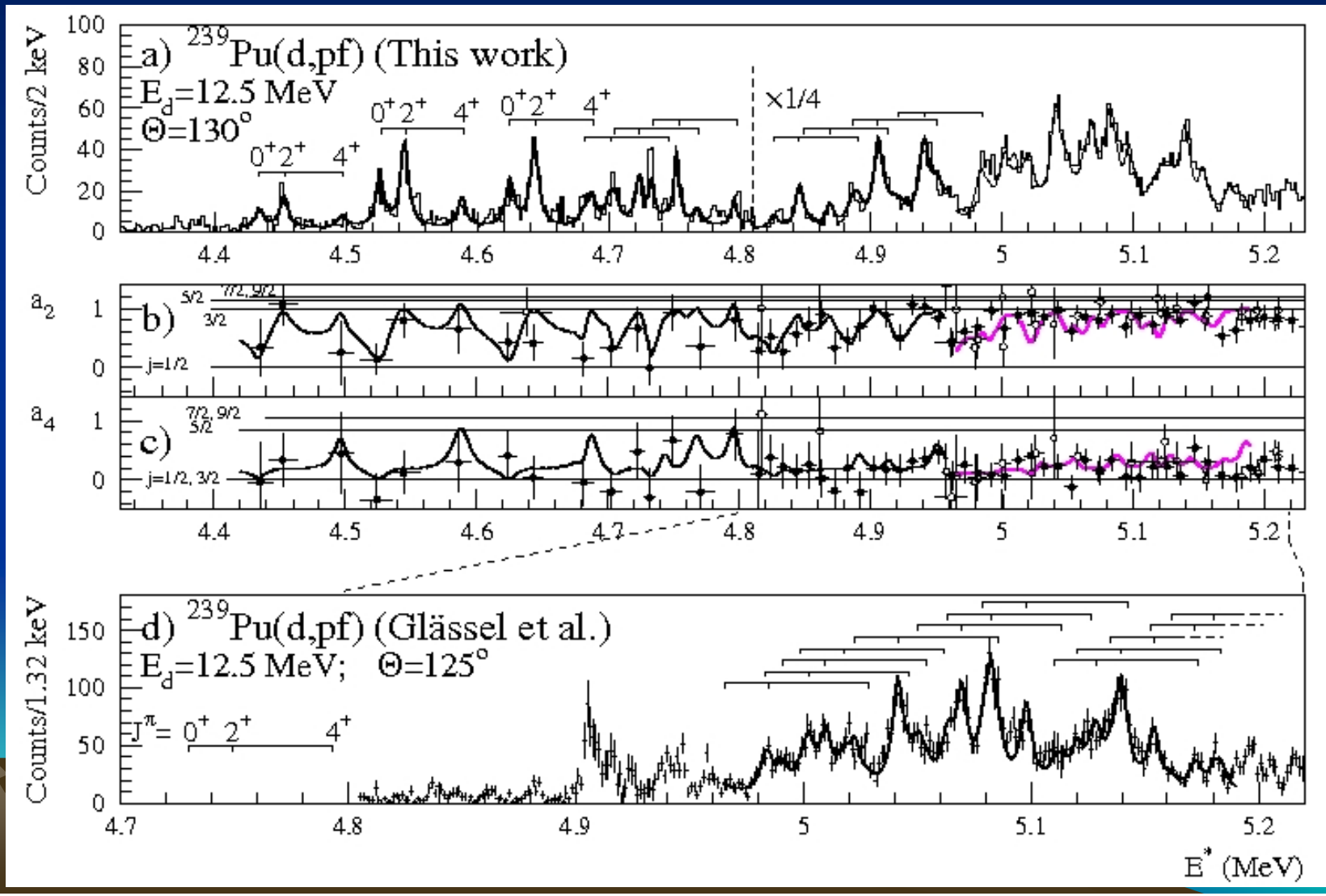
Higher excited states in the second minimum



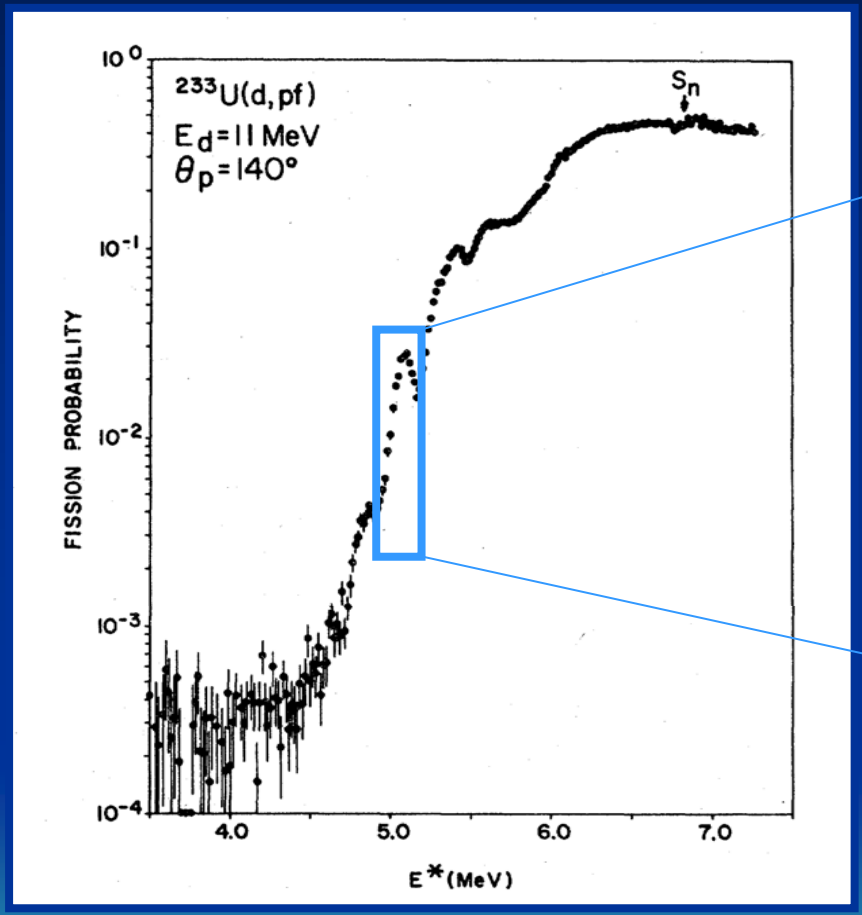


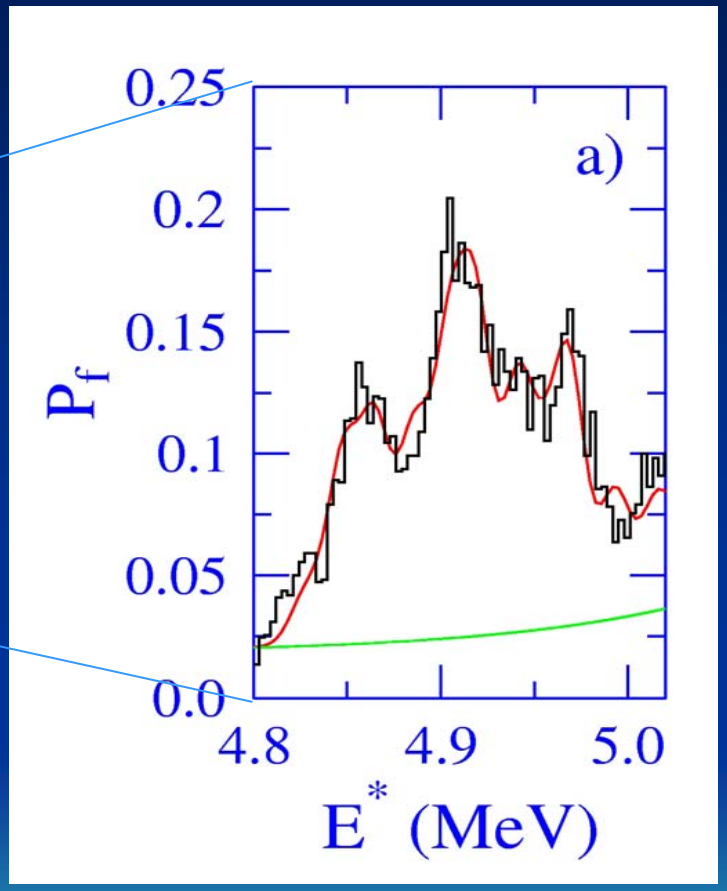
M. Hunyadi et al., PLB 505 (2001) 27.

Fitting the rotational bands



Previous results for ^{234}U



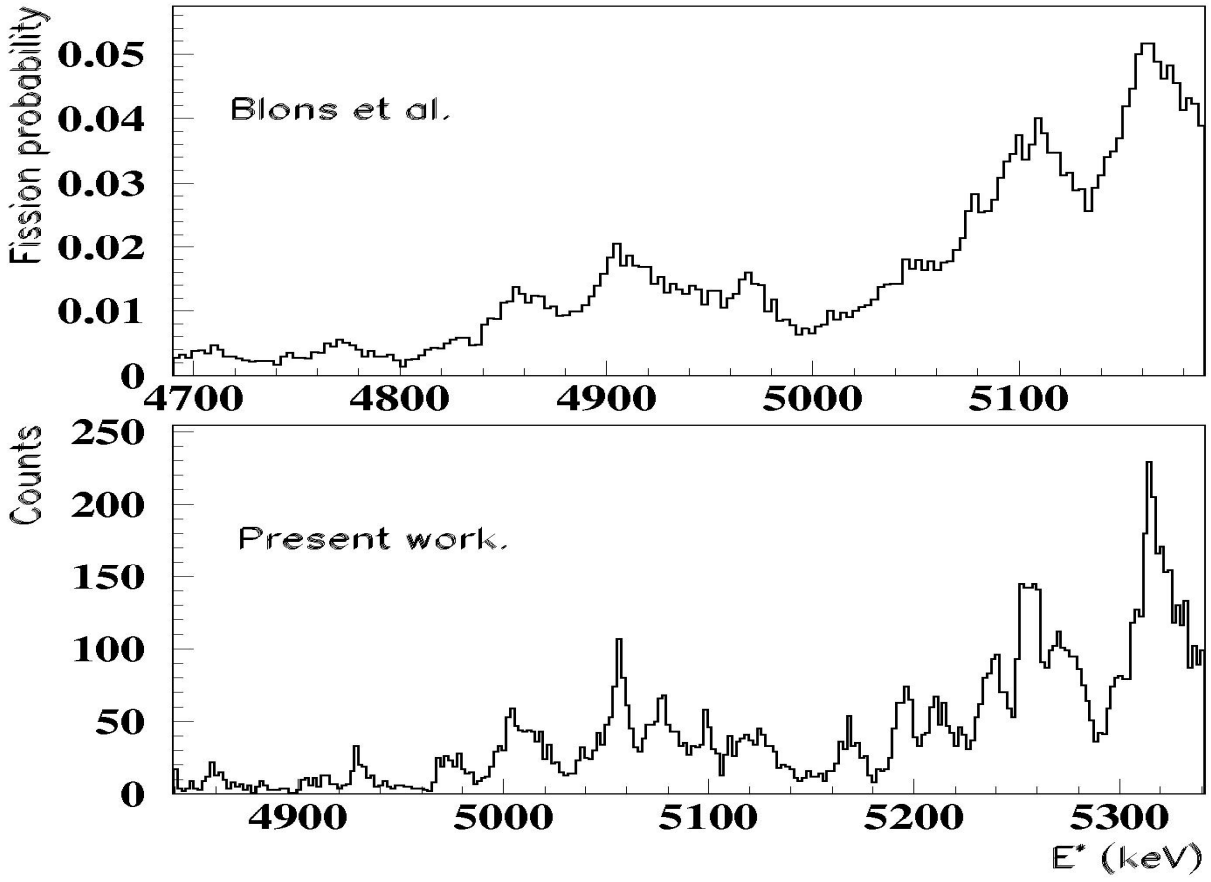


P.G. Goldstone et al., PRC 18 (1978) 1706

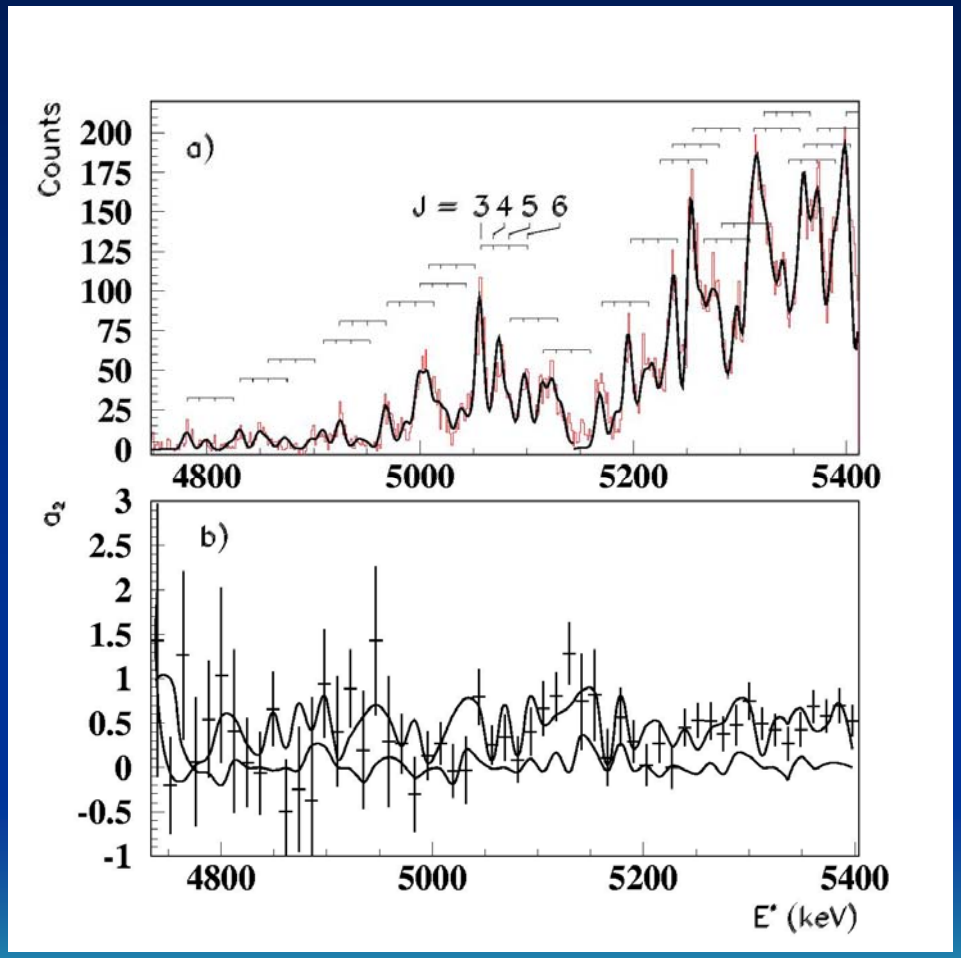
J. Blons et al., NP A477 (1988) 21

A. Krasznahorkay et al., PRL 80 (1998) 2073

Comparison of the results obtained for ^{234}U



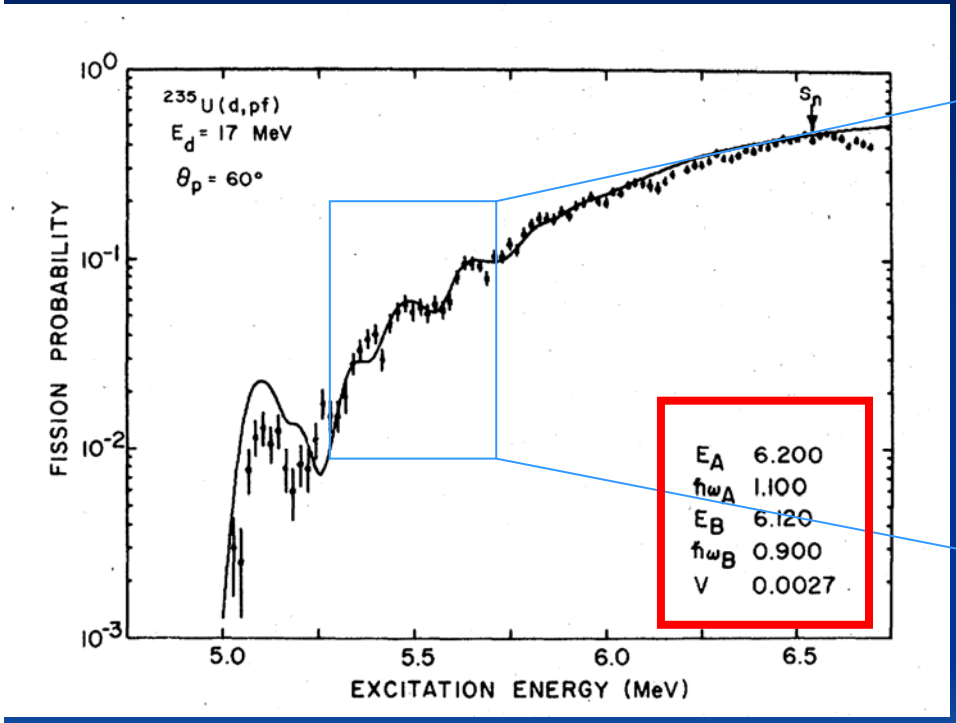
Results for ^{234}U

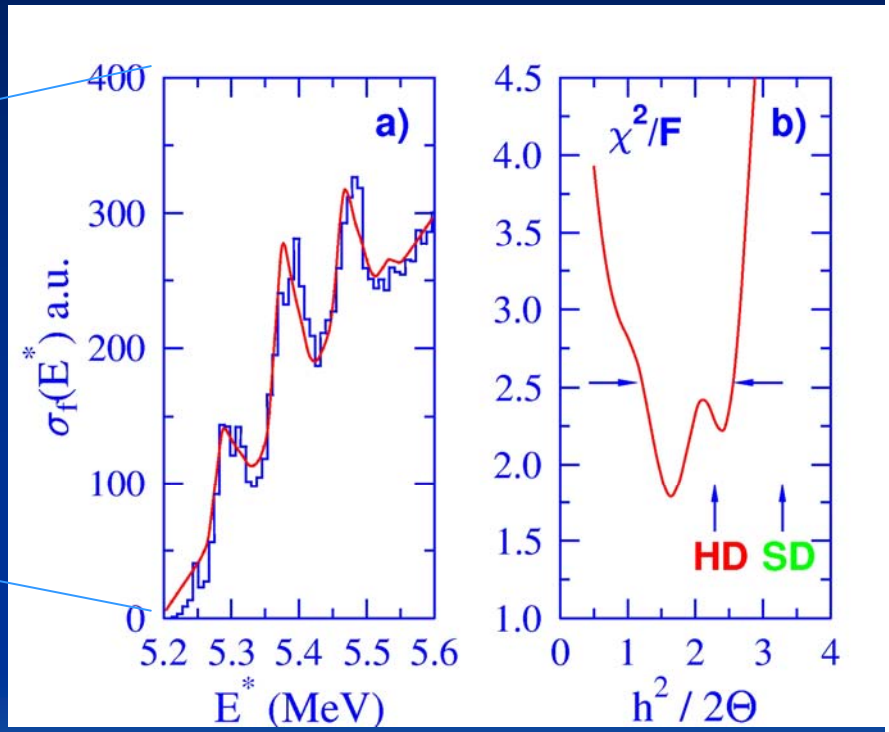


24 rotational bands !!!

A. Krasznahorkay et al., Phys. Lett B 461 (1999) 15

Previous results for ^{236}U

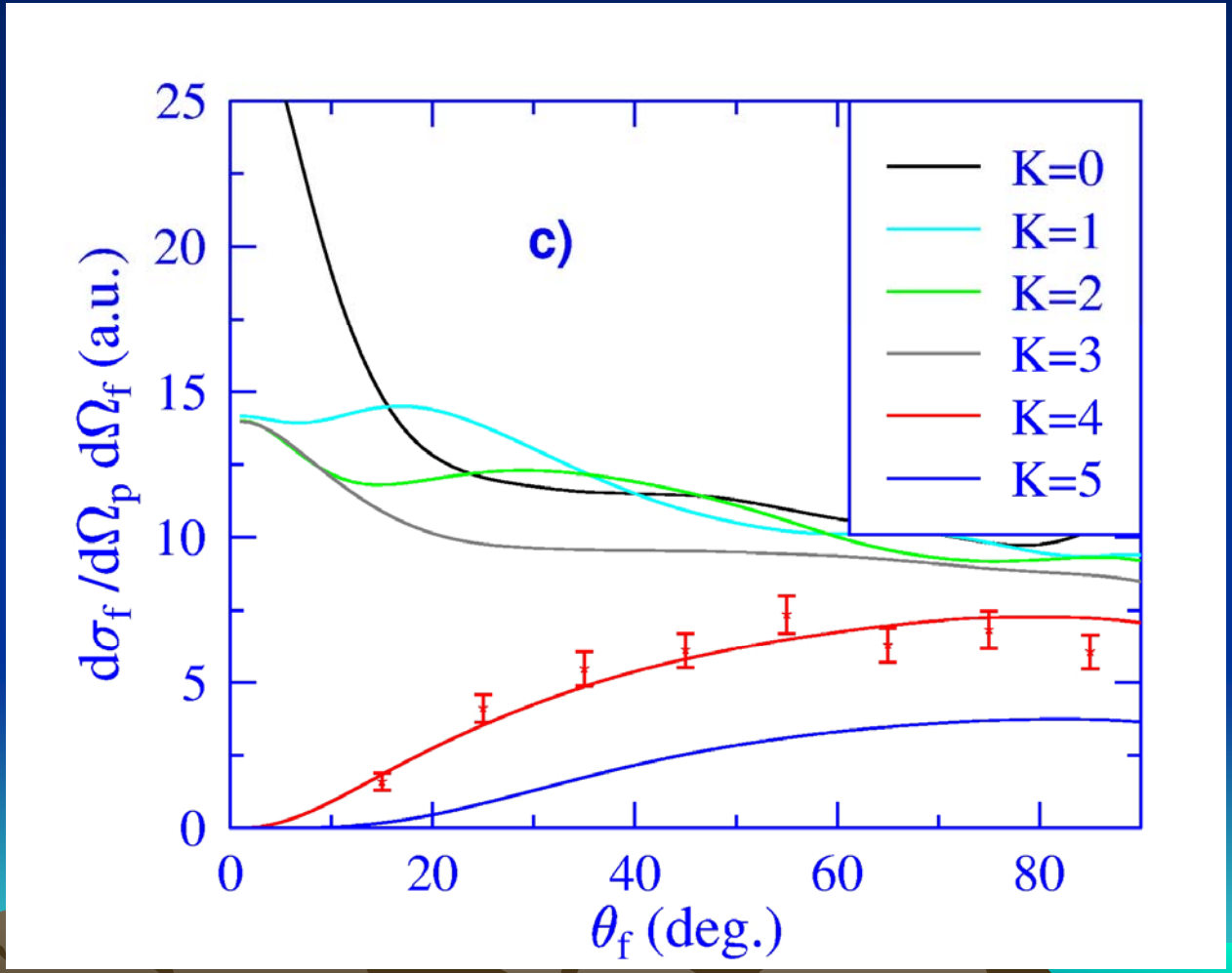




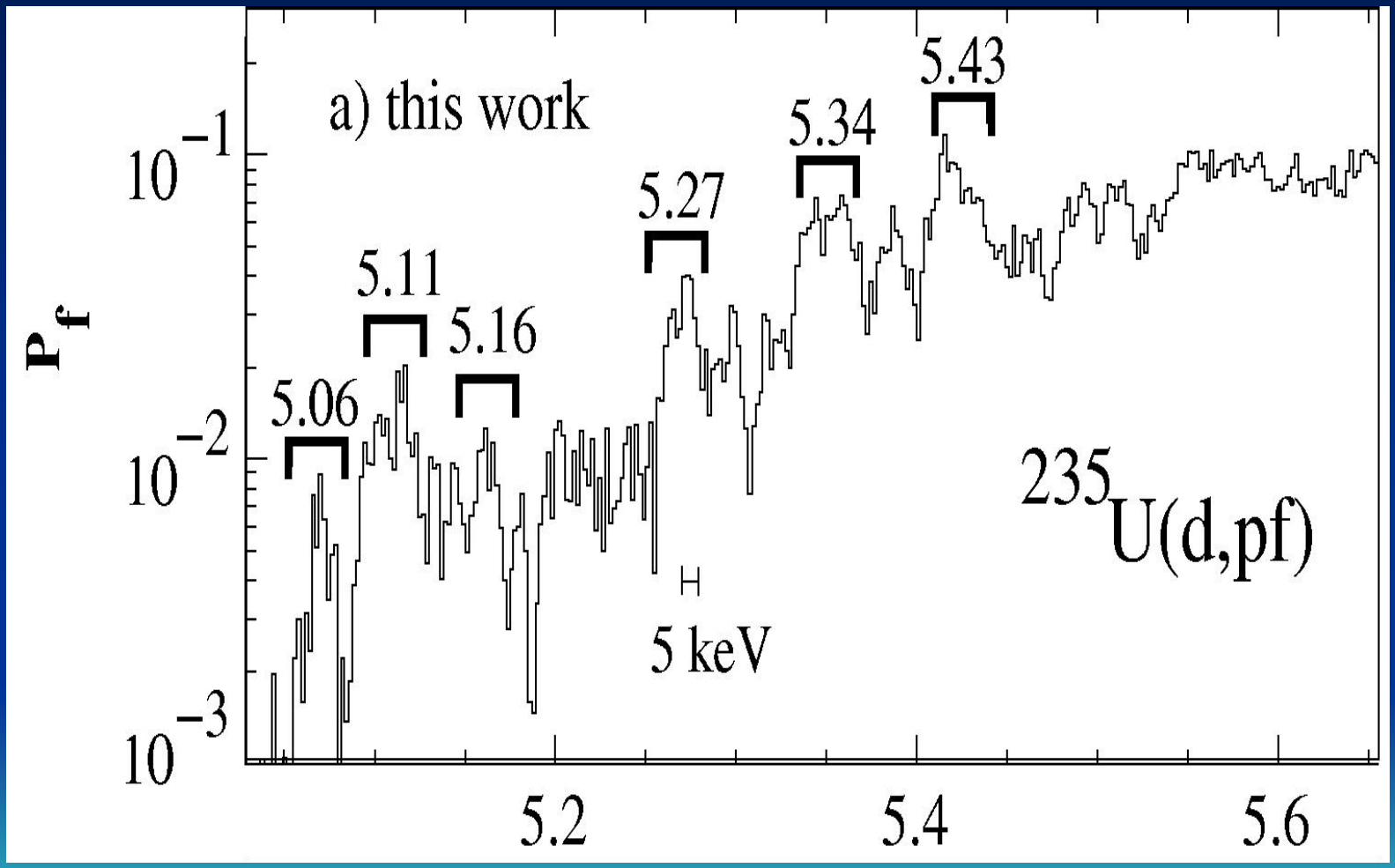
P.G. Goldstone et al., PRC 18 (1978) 1706

A. Krasznahorkay et al., PRL 80 (1998) 2073

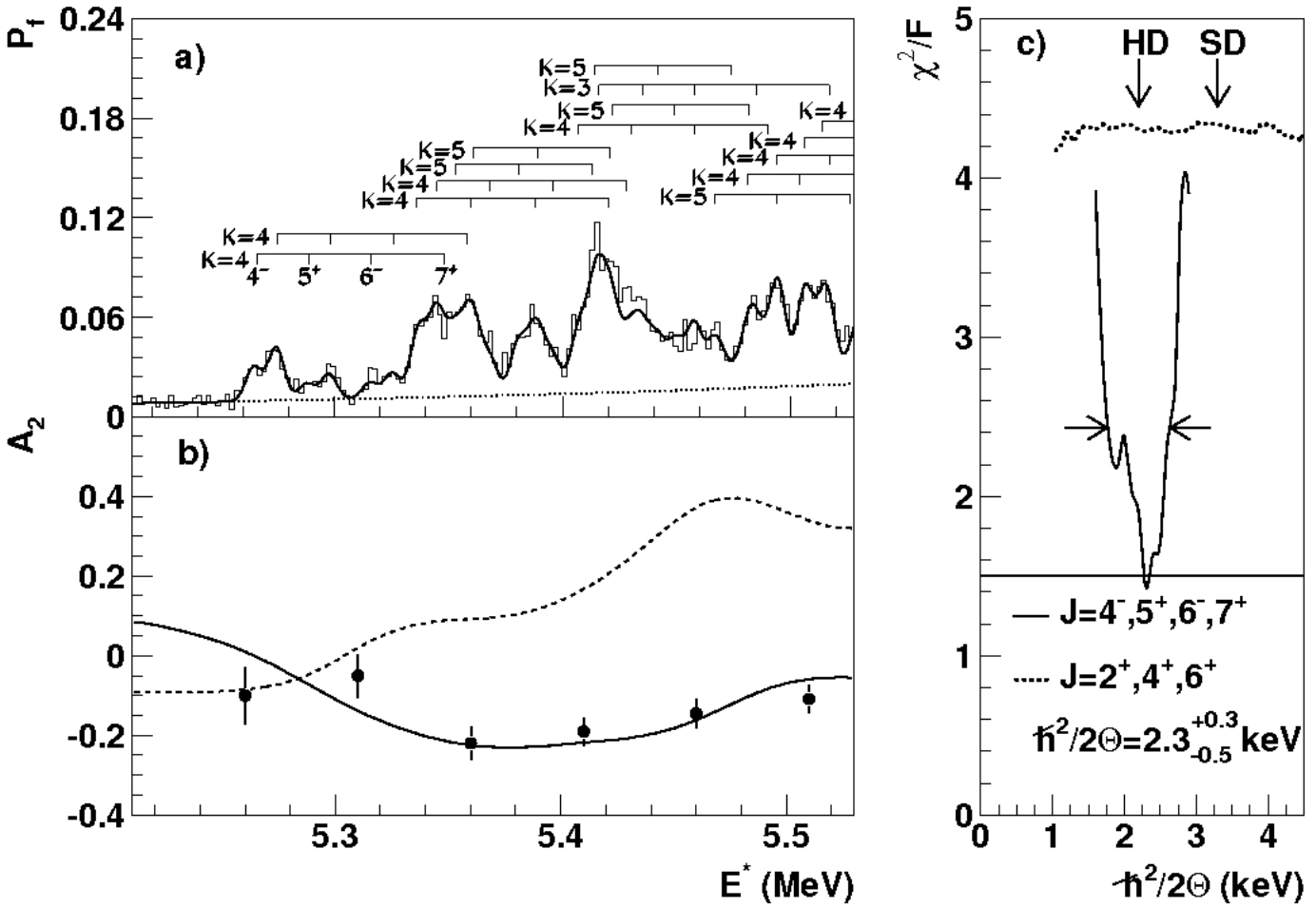
Angular distribution of the 5.4 MeV band in ^{236}U



Recent results for ^{236}U

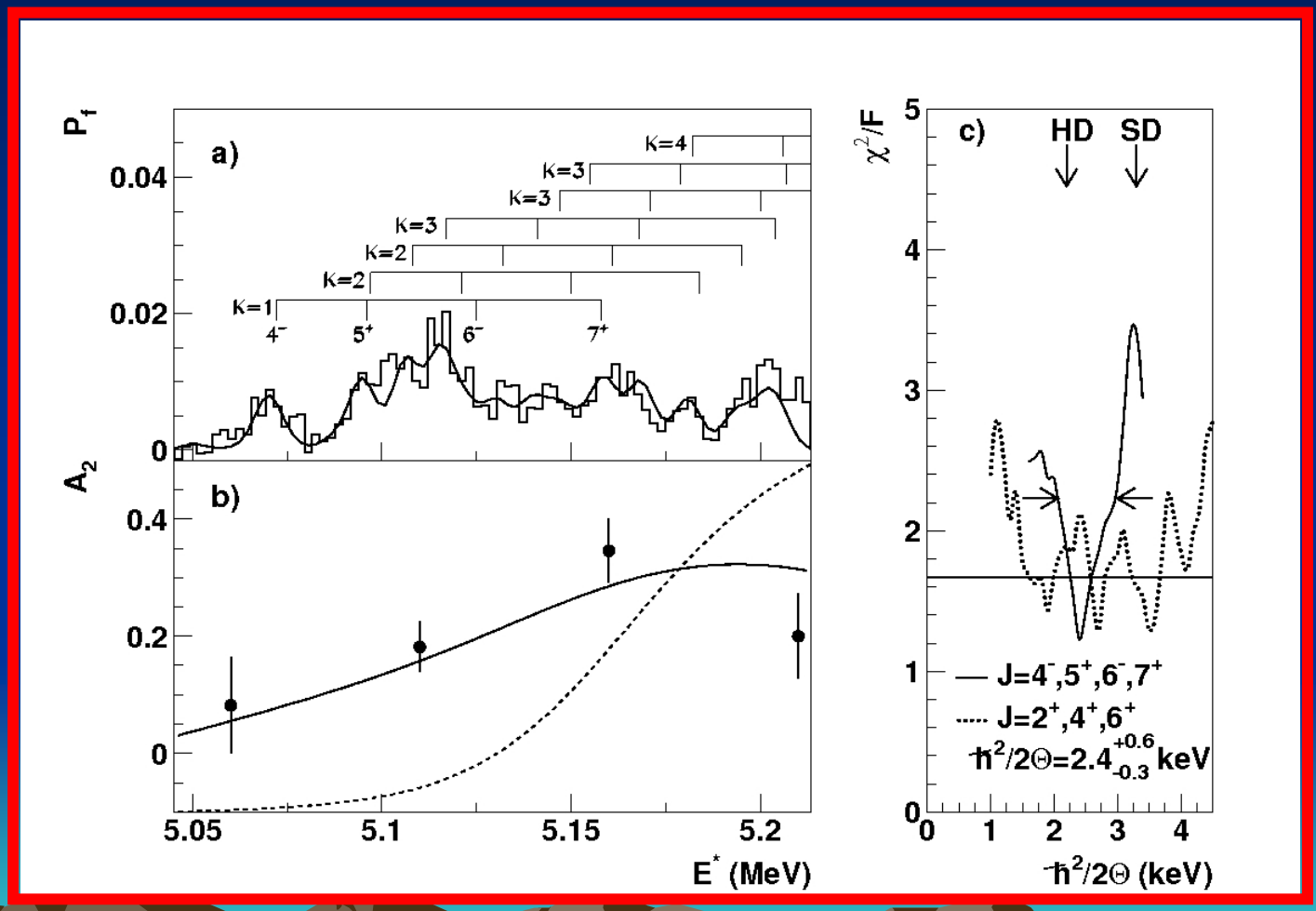


Fitting the fission resonances in ^{236}U



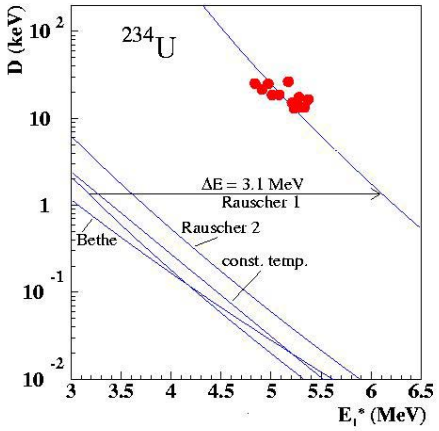
Csatlós et al., Phys. Lett. B615 (2005) 175

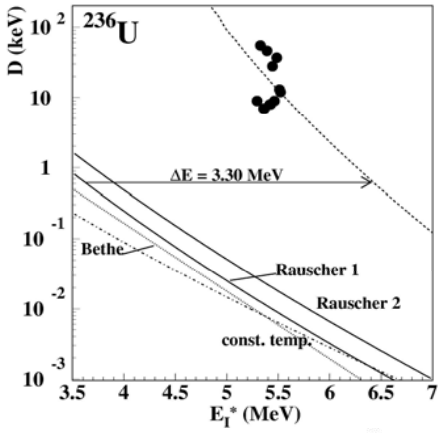
Fitting the fission resonances in ^{236}U around the 5.1 SD resonance

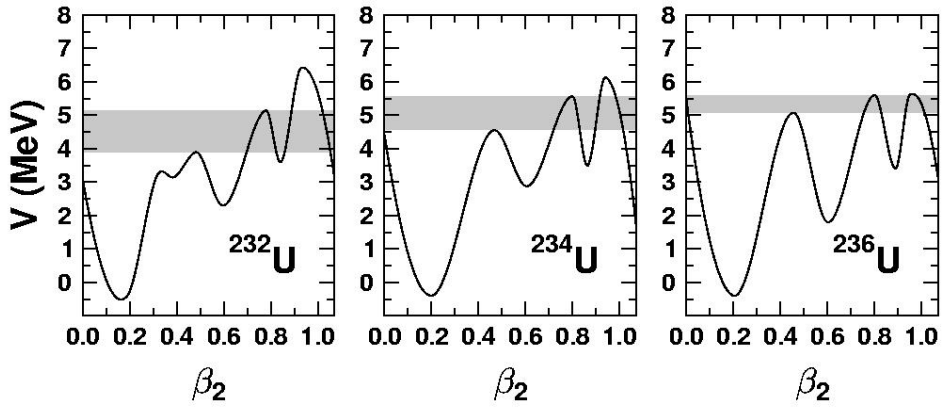


Not SD but HD bands !!!

On the depth of the third minimum

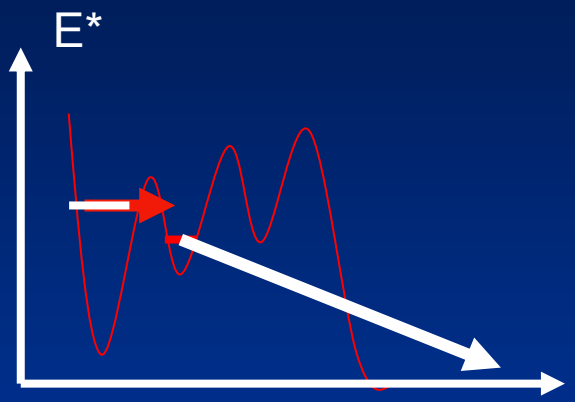






Calculations with the back shifted Fermi-gas model

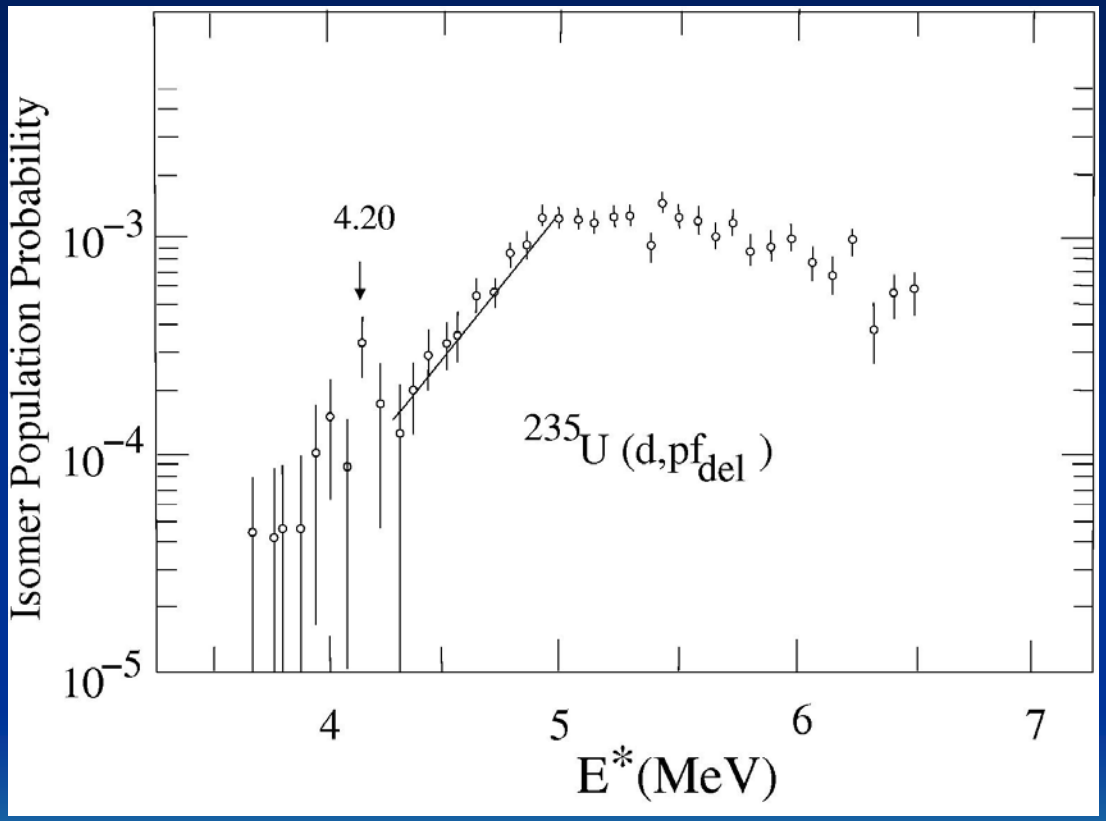
Determination of the height of the inner barrier



Lower and higher limits ⇒

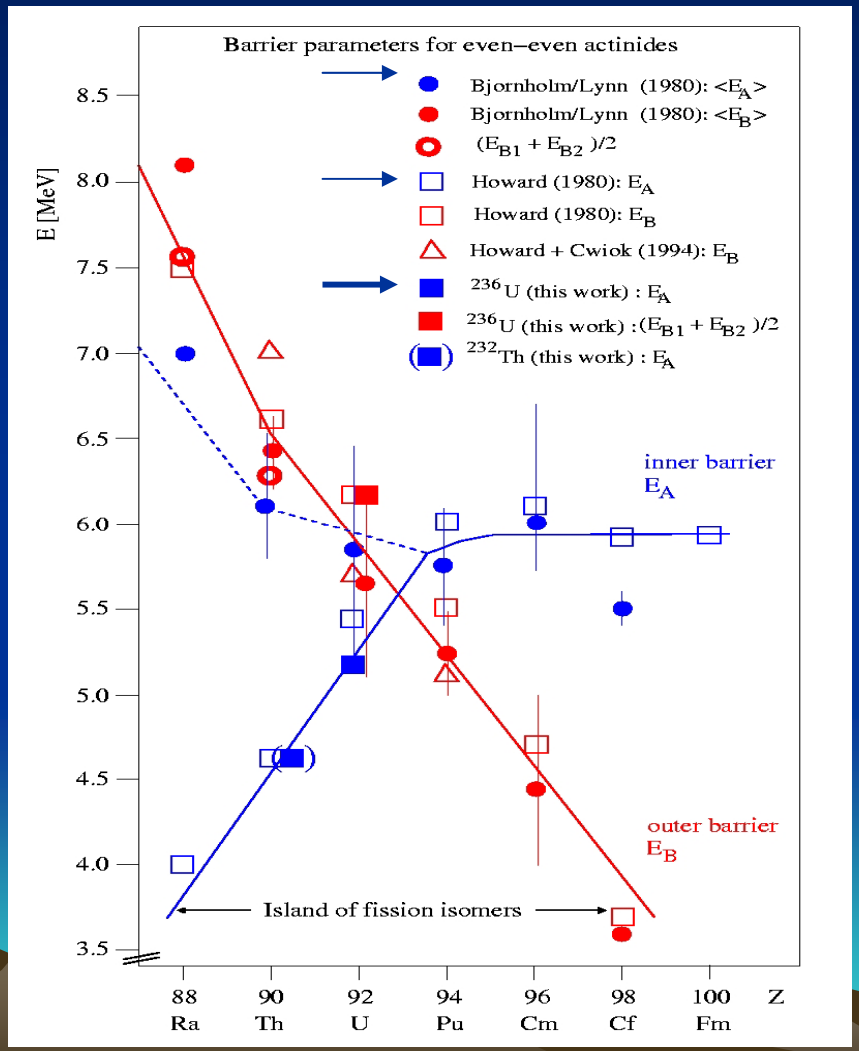
E_A= 5.05 ± 0.20 MeV

$h\omega_A$ = 1.2 MeV



Exp. Data from Goerlach diploma thesis, Univ. MPI Heidelberg (1978), unpublished

On the height of the fission barriers



History of the 3. Minimum

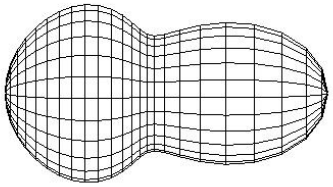
Möller … PLB 40 (1972) 329

Blons … PRL 41 (1978) 1282

(Howard, Möller, ADNDT 25 (1980) 218)

Cwiok … PLB 322 (1994) 304

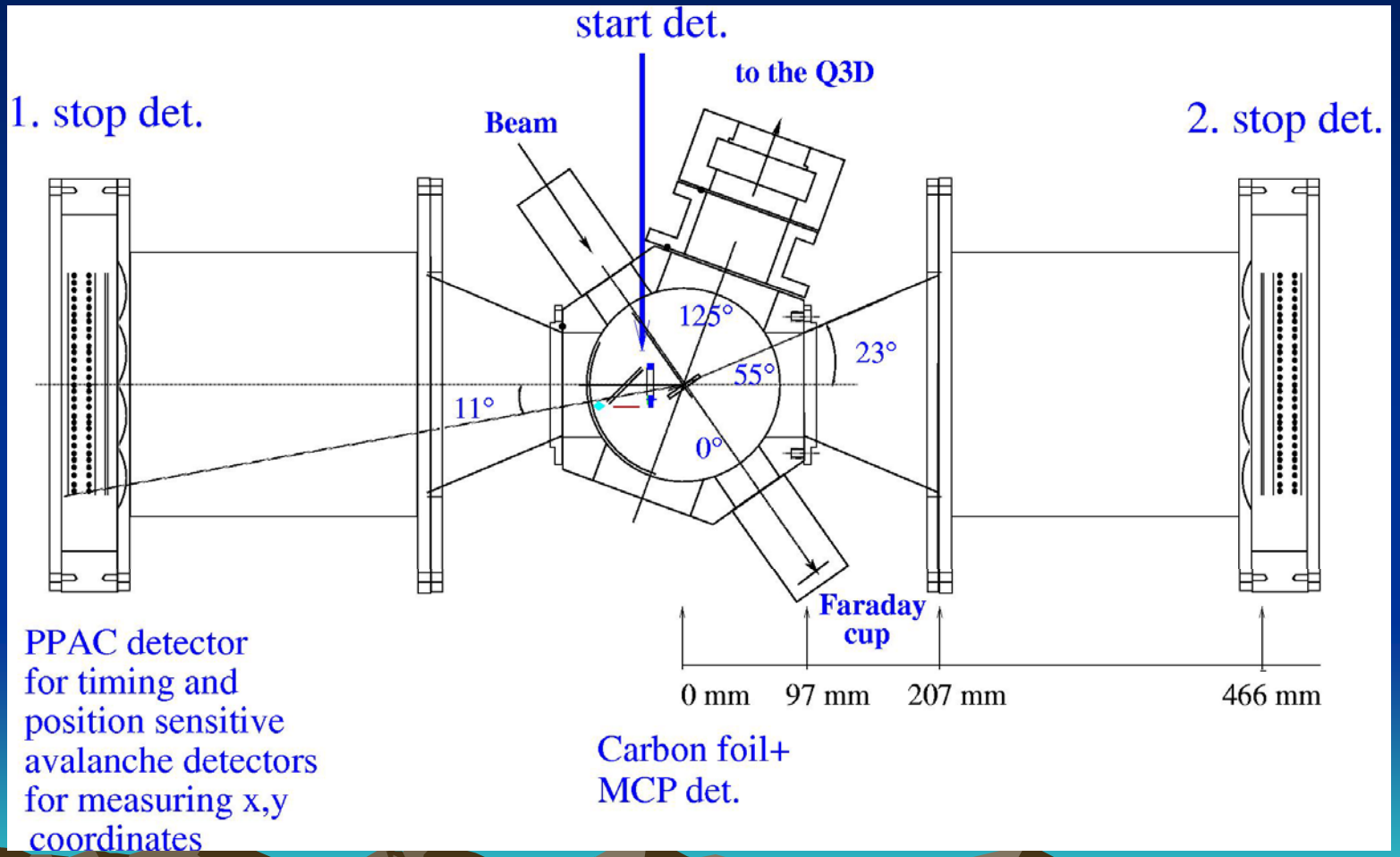
Nuclear molecules

		θ ($\hbar^2$/MeV)
^{232}Th	Experimental value:	183 (7)
Cwiok et al., PLB 322 (1994) 304		
Shneidman et al., NPA 671 (2000) 119	^{132}Sn + ^{100}Zr	235
Predicted	^{150}Ce + ^{82}Ge	249
	^{204}Pt + ^{28}Mg	94
	^{206}Hg + ^{26}Ne	82

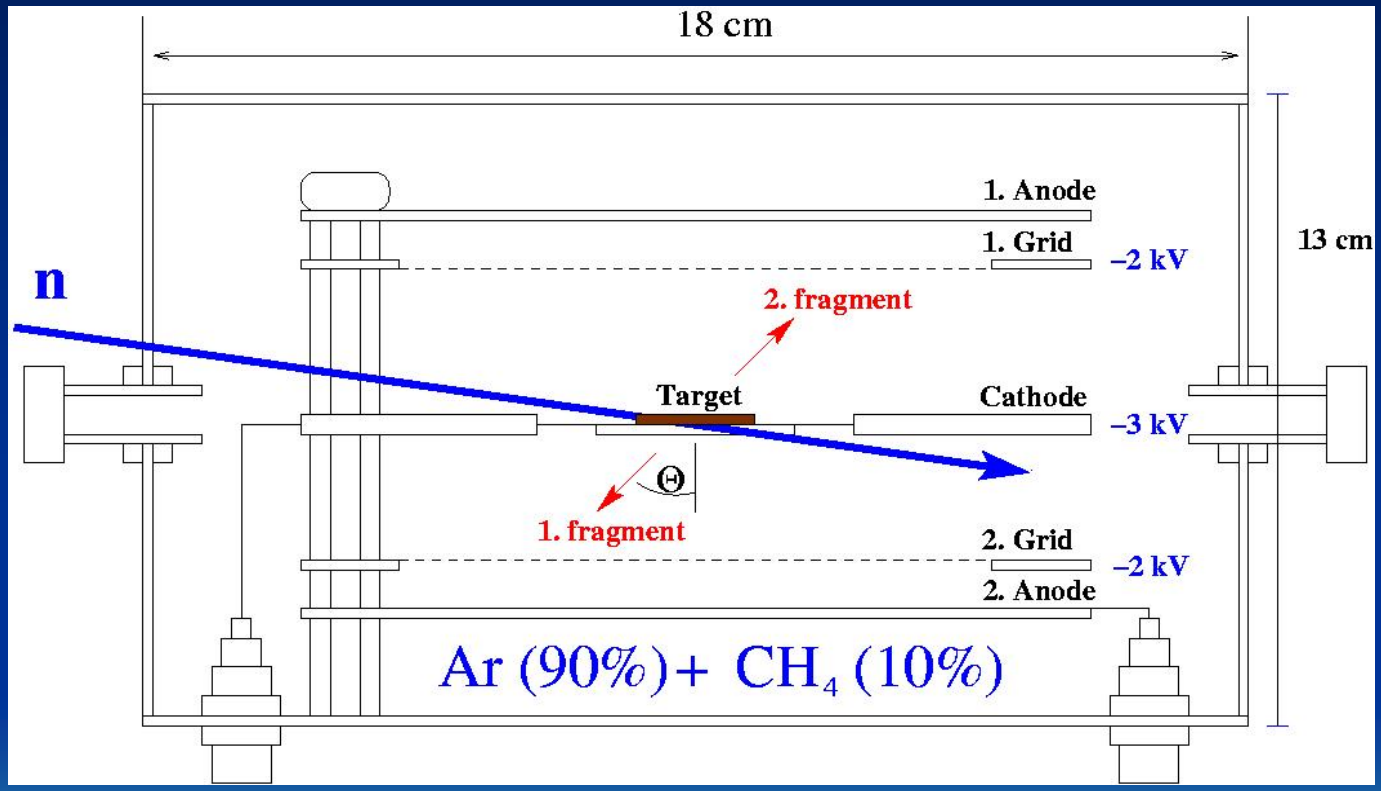
Clusterization in ^{234}U

^{234}U			
	Experimental value:		227 (21)
Predicted	^{134}Te	^{100}Zr	258
	^{152}Nd	^{82}Ge	257
	^{206}Hg	^{28}Mg	91

Setup for TOF measurements



Mass distribution measurements with a double ionization chamber

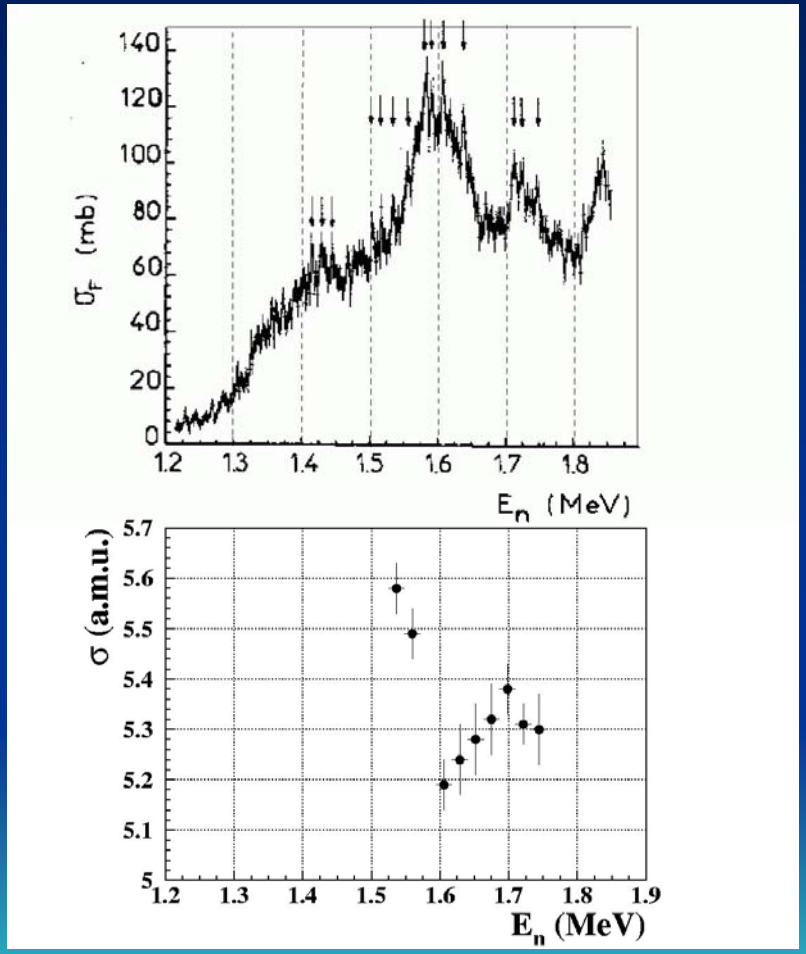


C. Budtz-Jörgensen et al., NIM A258 (1987) 209

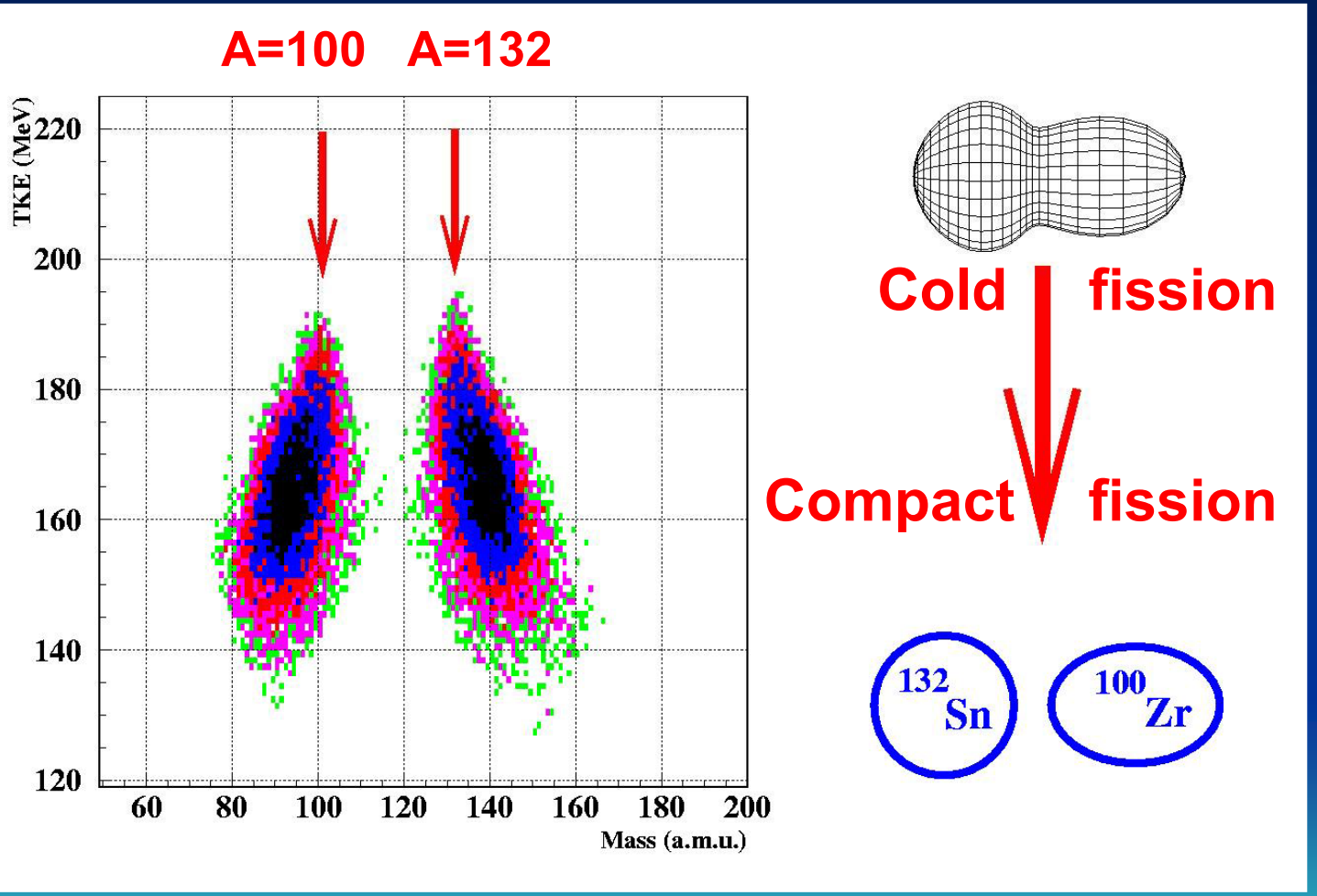
On the width of the mass distributions of ^{233}Th

Target: ThO_2 0.1 mg/cm^2, diameter 4 cm

Neutrons from ^{7}Li(p,n) at ATOMKI then in Karlsruhe, Φ=1.8*10^6 n/cm^2, one week exp.



TKE-mass distribution correlations



Summary and conclusions

- Fission resonances $\Rightarrow$ SD and HD states
- Density of the HD states $\Rightarrow$ depth of the 3rd minimum
- Appearance of the HD resonances + isomer population probability $\Rightarrow$ E_A
- The ″Th anomaly″ has been solved.
- Mass distribution from the decay of the HD states $\Rightarrow$ heavy clusterization
- Future plans $\Rightarrow$

Future plans

- Terra incognita in the actinide region
- The phenomena of hyperdeformation develops in that region
- REX ISOLDE with 10 MeV/nucleon would give novel possibilities to do experiments in inverse kinematics
- Clusterization, (n,f) reaction NTOF facility
- (5 double ionization chamber with ^{232}Th)

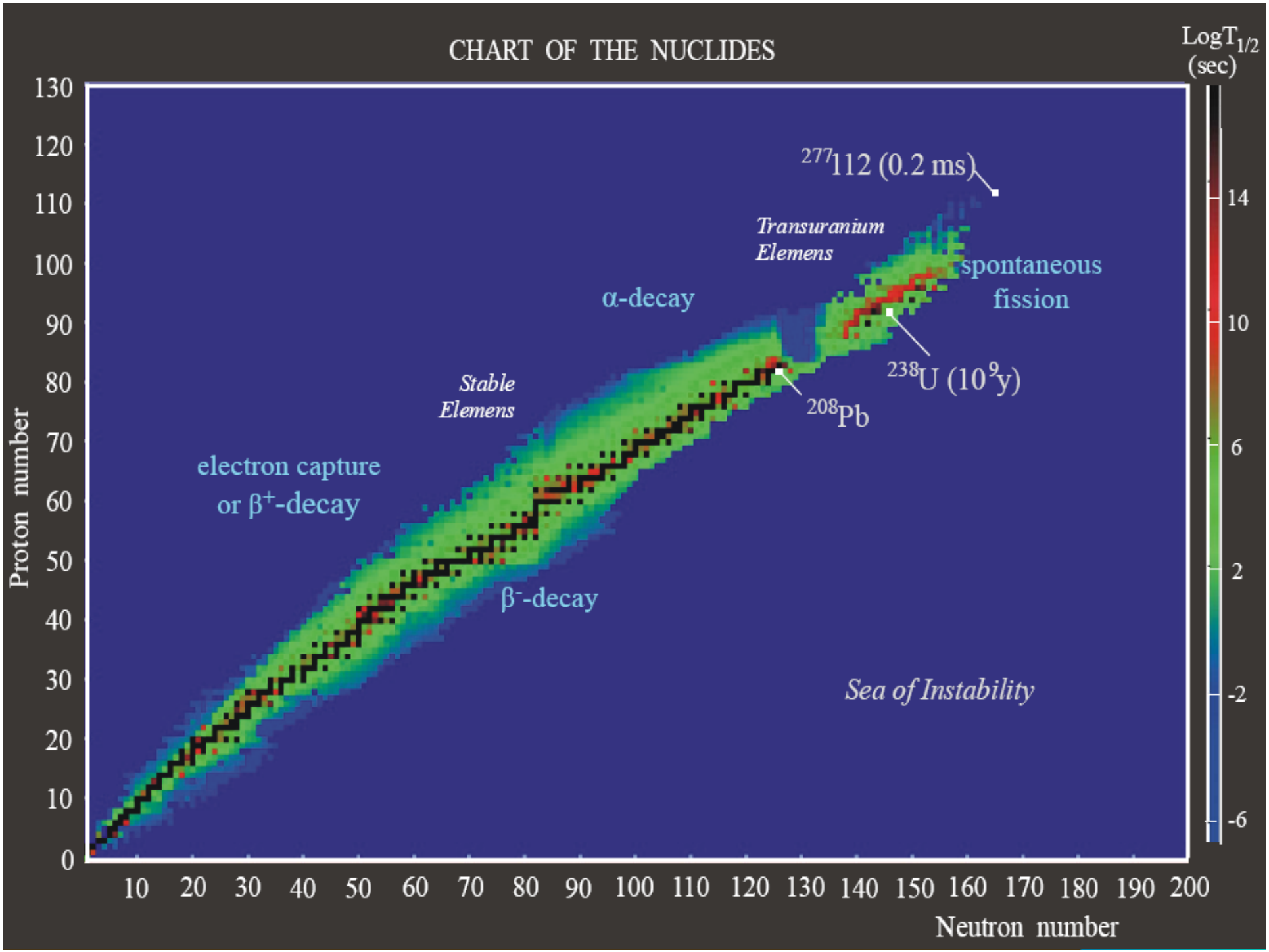
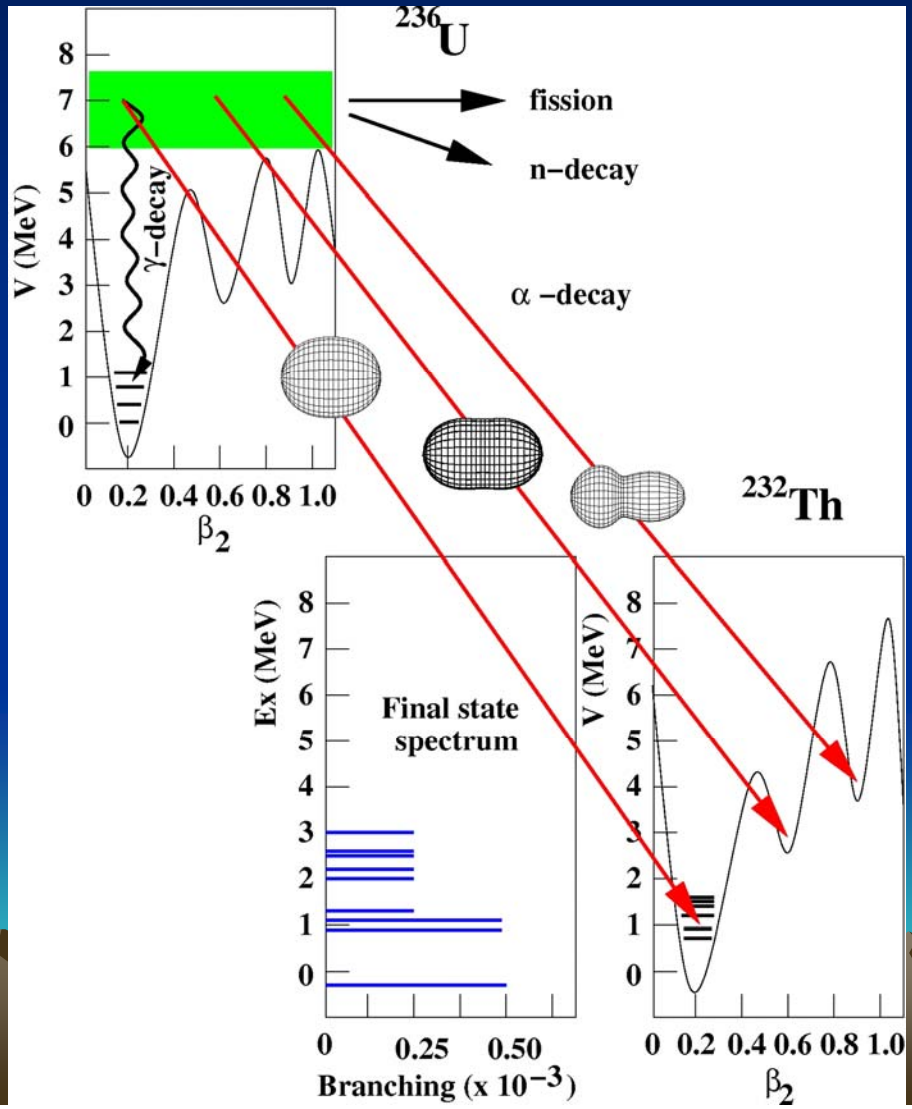


CHART OF THE NUCLIDES
LogT1/2 (sec)
14
10
6
2
-2
-6
277112 (0.2 ms)
Transuranium Elemens
spontaneous fission
α-decay
238U (10^9y)
Stable Elemens
208Pb
electron capture or β+-decay
β--decay
Sea of Instability
Proton number
Neutron number
0
10
20
30
40
50
60
70
80
90
100
110
120
130
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200

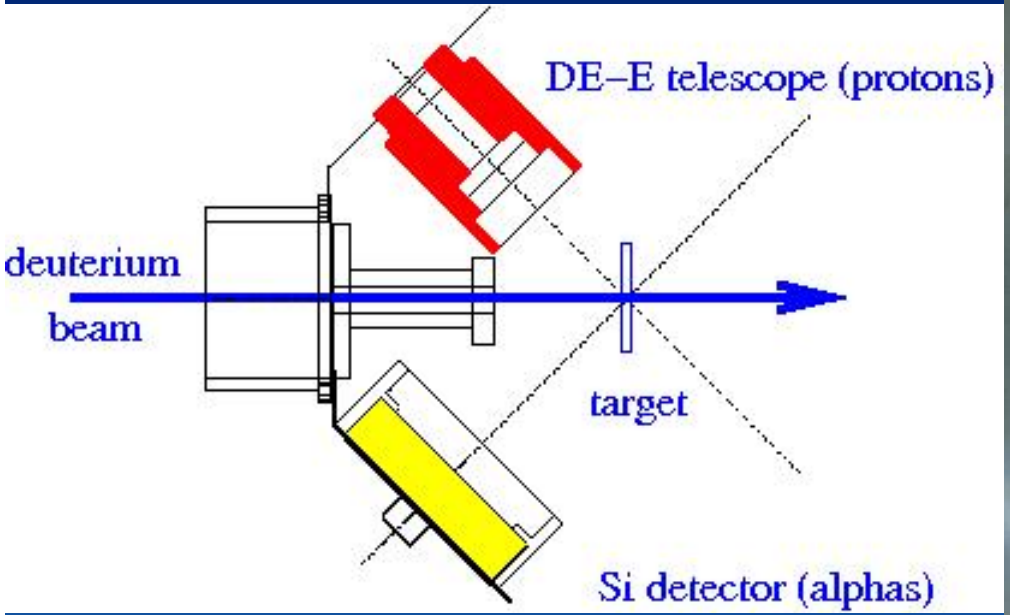
α-decay of the deformed states

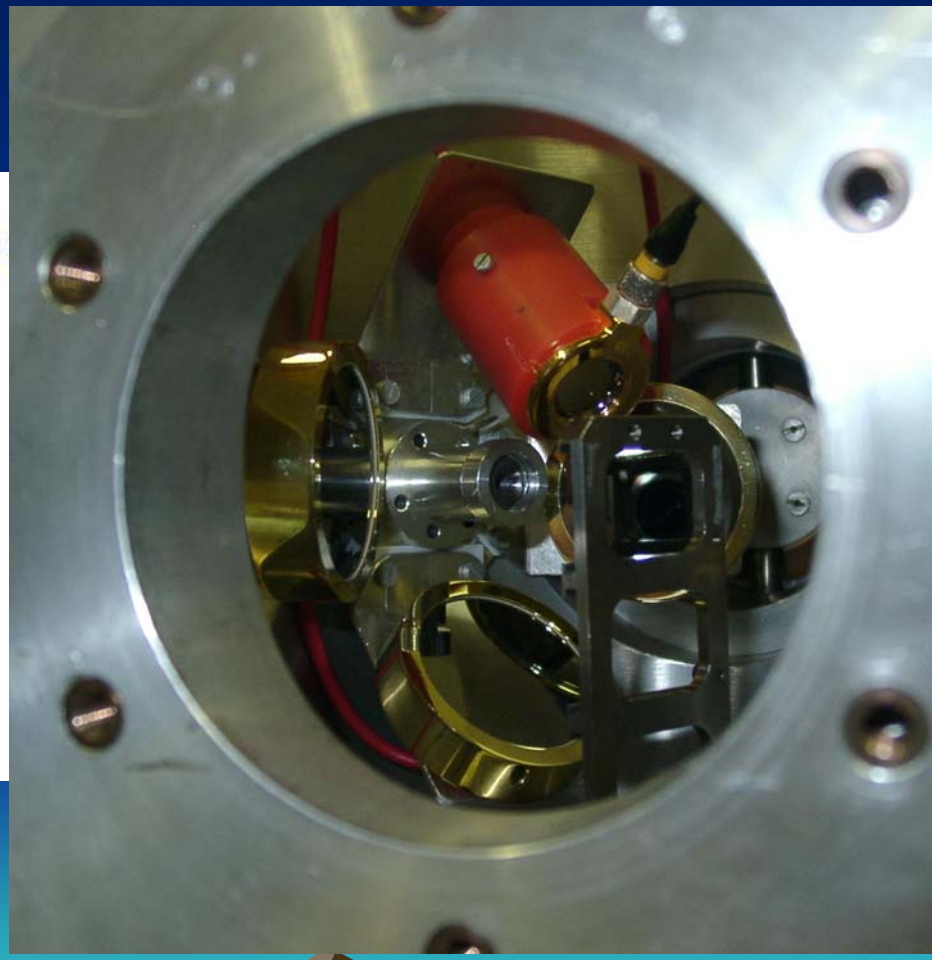


Motivated by the works of

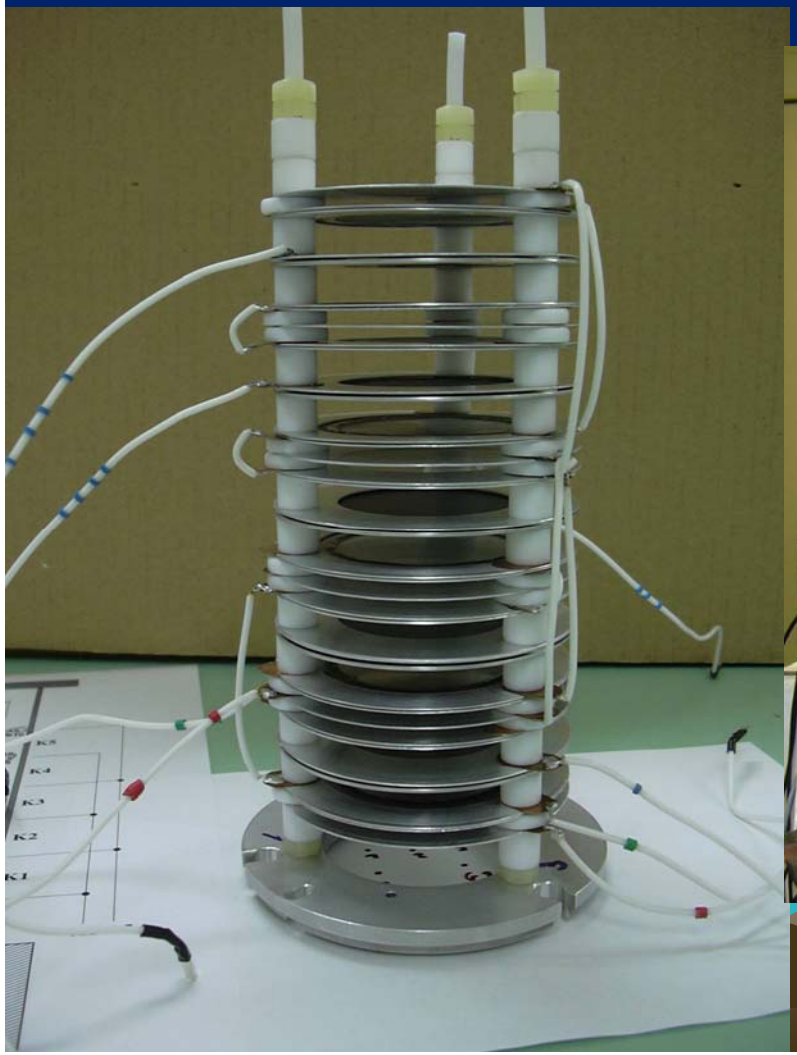
A. Marinov et al.

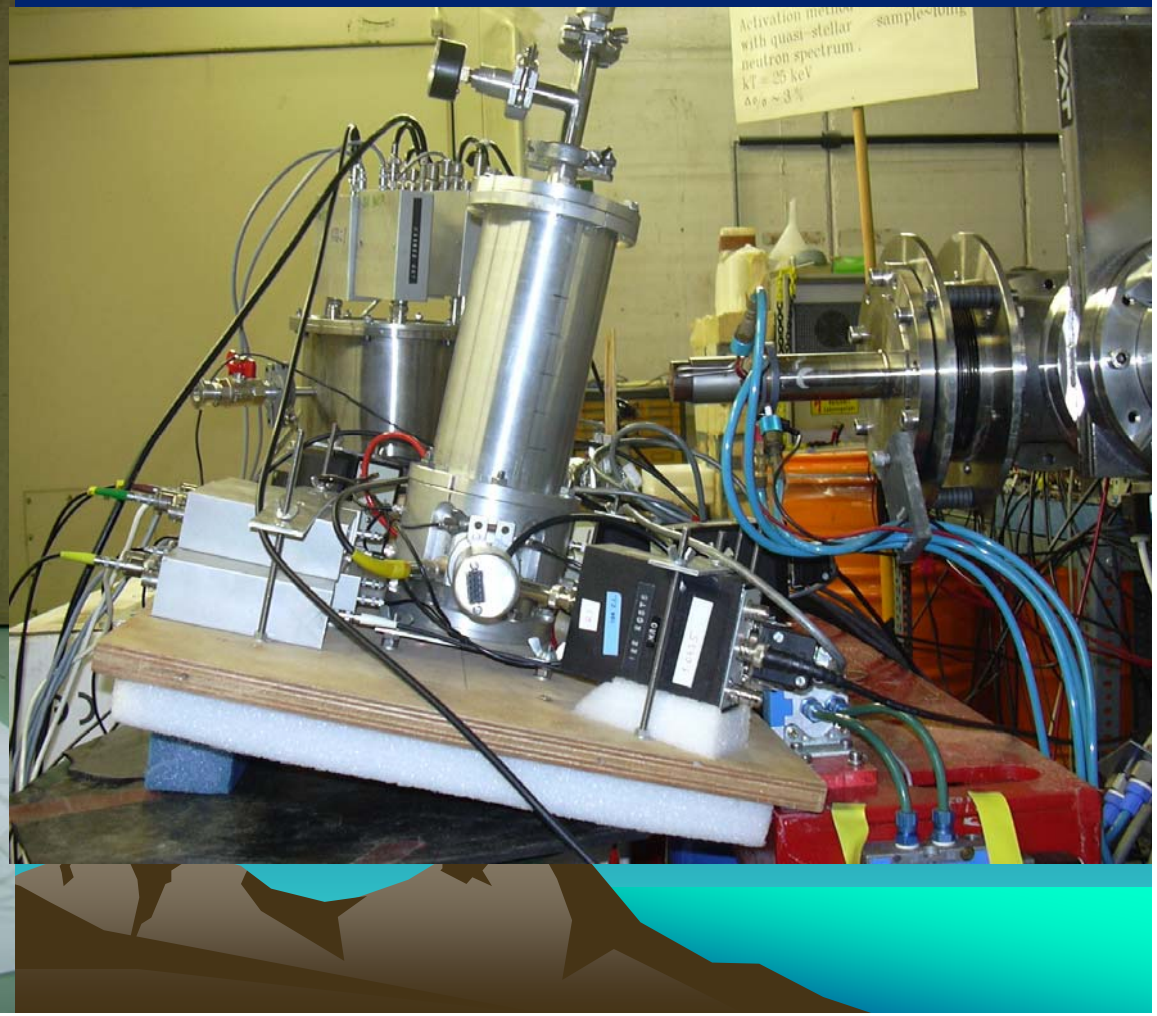
Experimental setup





Mass distribution measurements with higher efficiency (nTOF)





Triggering a nuclear transition