Evidence for inertial dynamics in fission

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Invited talk

Layout

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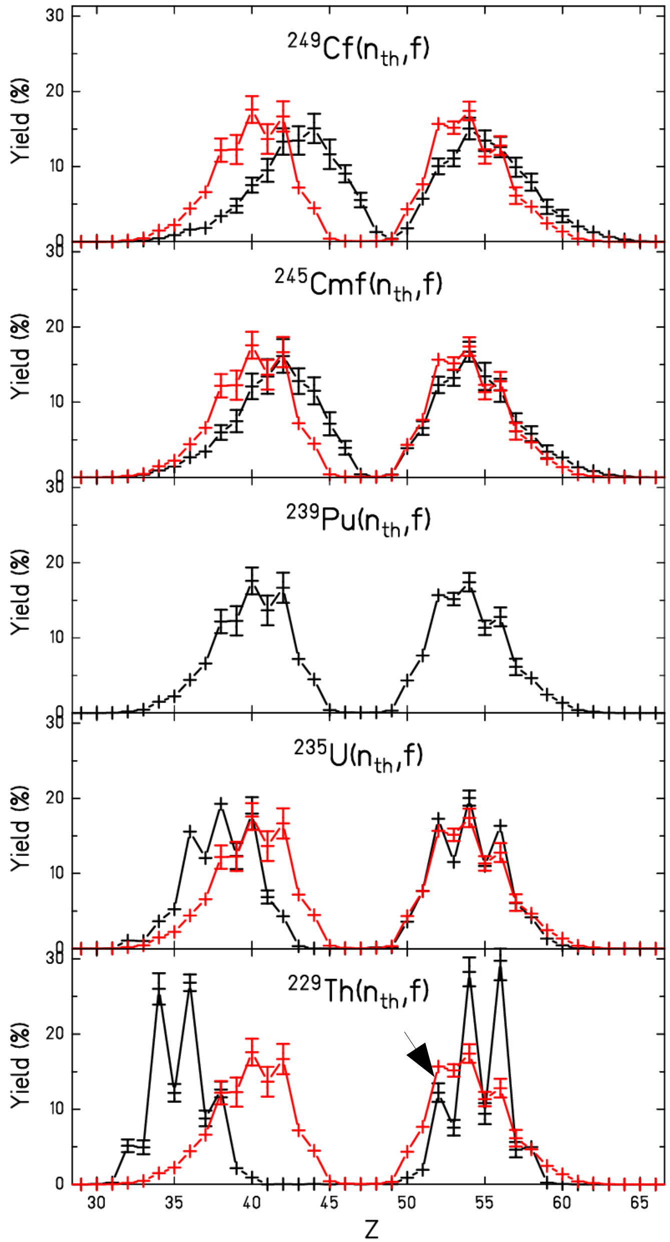
- Observed anomalies in the FF yields for light actinides
- Our hypothesis: Evidence for inertial dynamics
- Implementation in GEF
- Ideas for advanced model calculations
- Conclusion

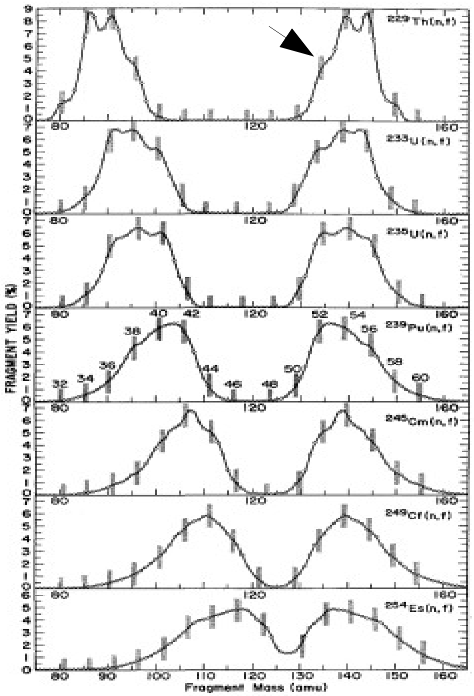
Introduction

- Anomalies in **fission excitation functions** and **FF angular distributions** in the light actinides have been observed since the 1970th.
- P. Möller and R. Nix made a connection between these anomalies and the appearance of a **triple-humped fission barrier** in 1973.
- Indications for the influence of a triple-humped barrier on the **FF yields** has not yet been reported. **→ This work**

Anomalies

Anomalies 1: nth,f





←
FF A yields Unik et al. (1973)

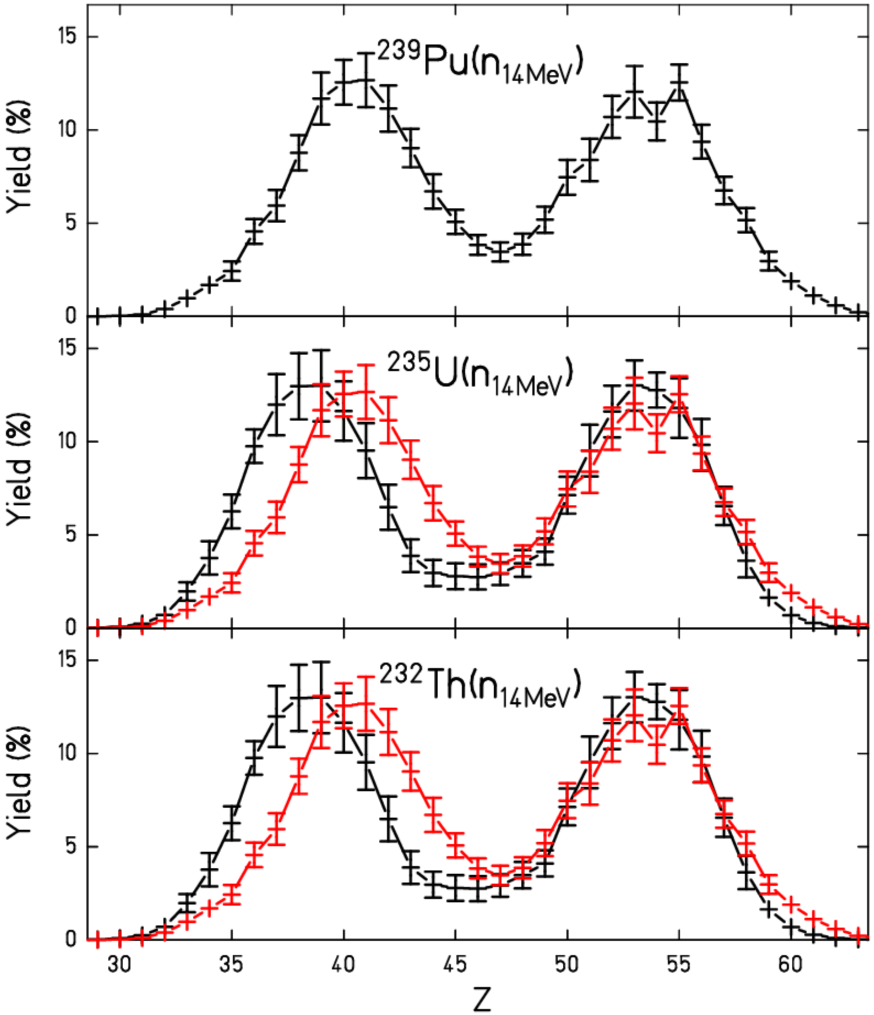
Known for $<A_{heavy}>$= 140.

Reduction of Y(A=135) in 233U, 229Th; not yet further investgated.´

←

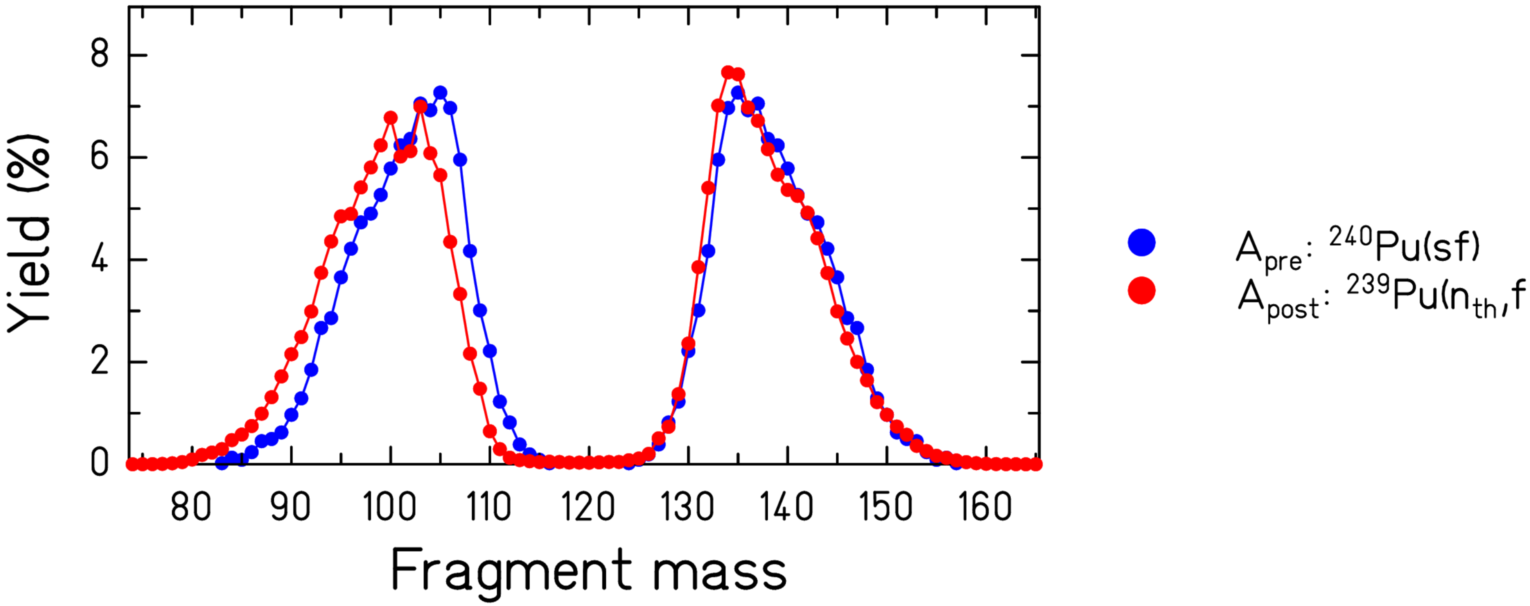
- FF Z yields from ENDF-B/VII
- Red: Yields from 239Pu(nth,f) repeated
- Clear shift of heavy peak to higher Z for 229Th(nth,f)

Anomalies 2: n(14 MeV),f

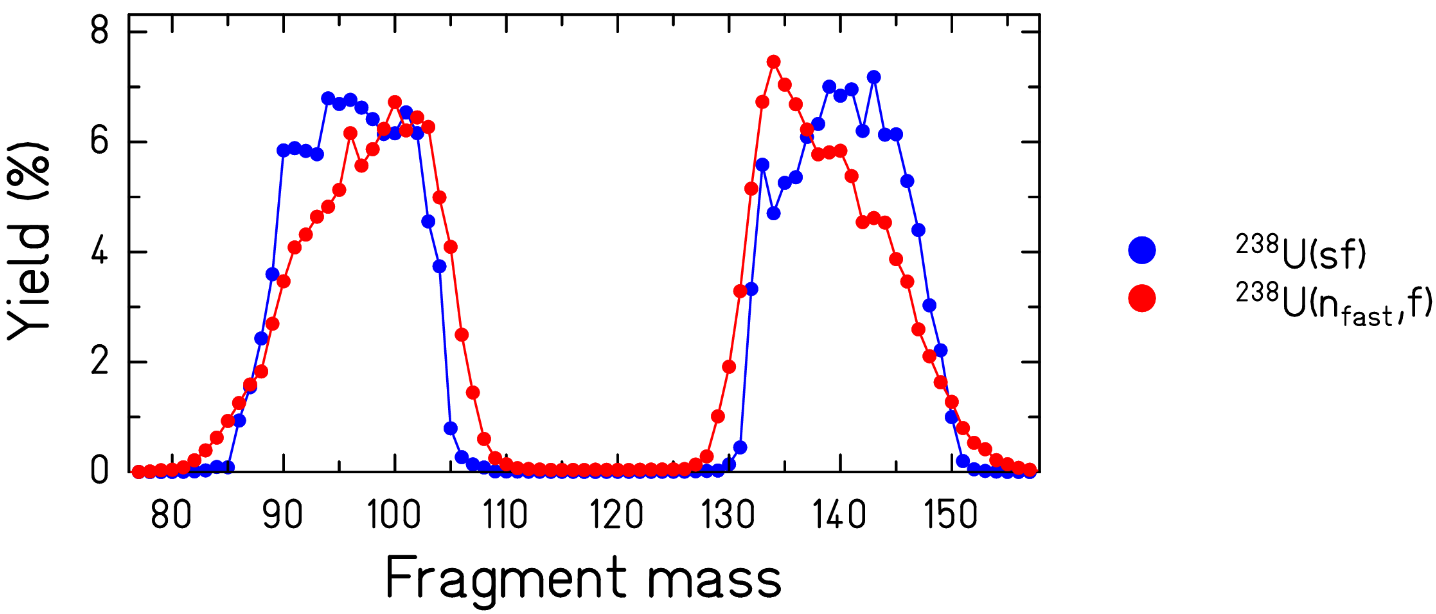


- FF Z yields from ENDF-B/VII
- Red: Yields from 239Pu(n,f) repeated
- No shift of heavy peak to higher Z for **232**Th(n,f)
- → Shift vanishes at higher E*!

Anomalies 3: n(th,fast) vs sf



239Pu: no shift



238U: strong shift

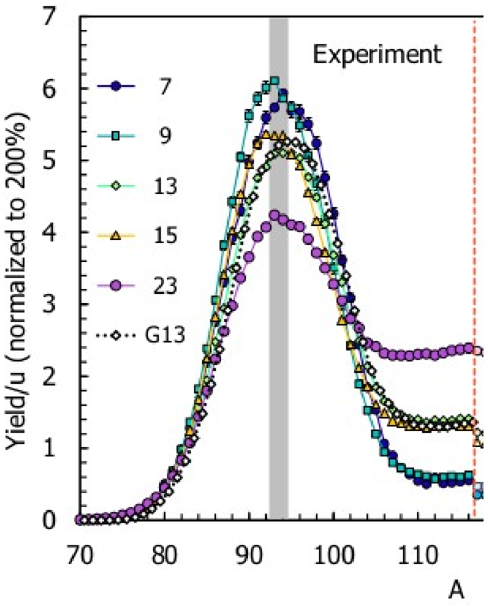
E* depencence of shift in 238U confirmed!

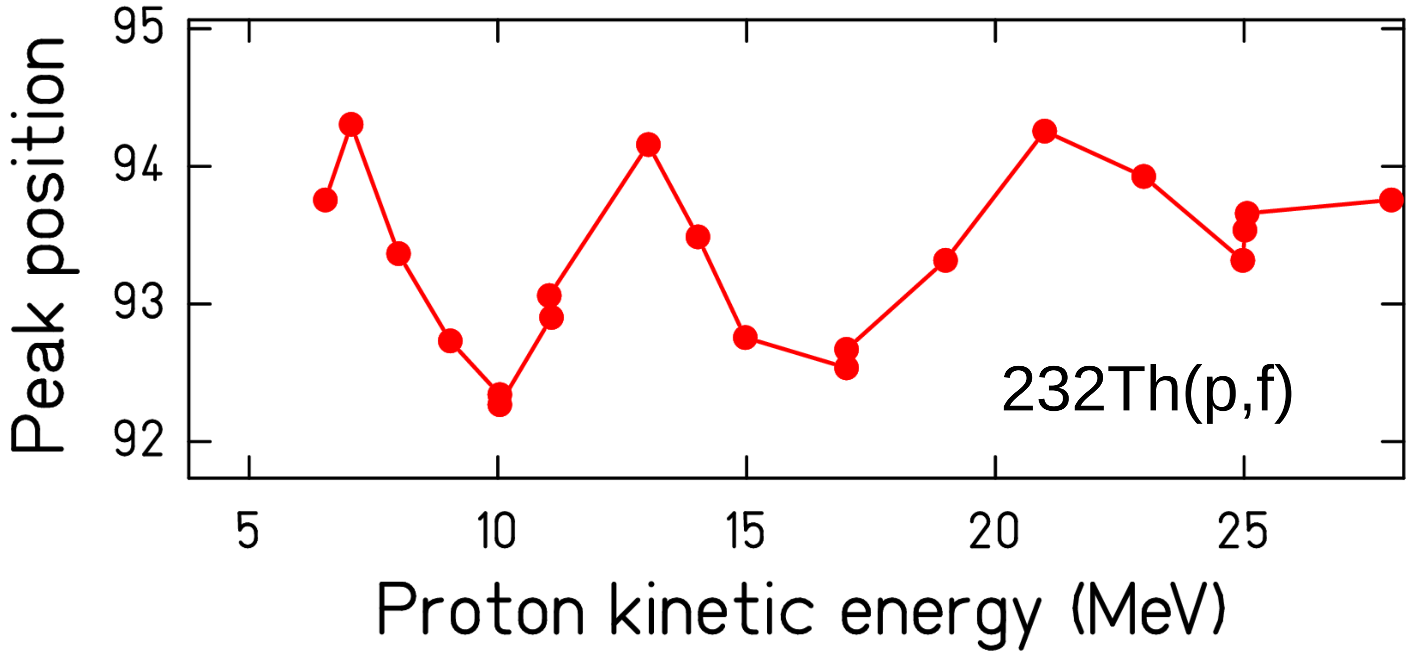
Summary of energies

- Spontaneous fission: $E^* = 0$ MeV
- (nth,f): $E^* = 0.0253\text{E-}6$ MeV + Sn $\approx$ 6 MeV
- (nfast,f): $E^* = 0.2 \ldots 2$ MeV + Sn $\approx$ 7 MeV
- (n-14 MeV,f): $E^* = 14$ MeV + Sn $\approx$ 20 MeV

Chosen on the basis of the limited availability of suited data.

Anomalies 4: E* dependence



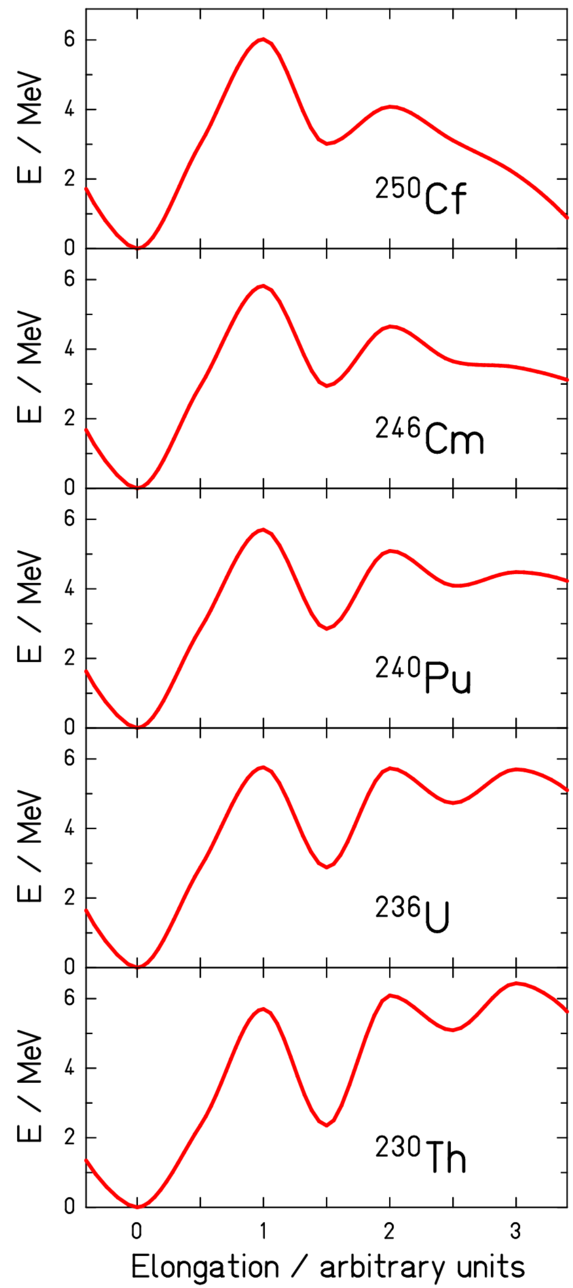


- 232Th(p,f):
- Position of the light peak:
  Oscillations at the thresholds for multi-chance fission
  (contribution of fission at low E*)

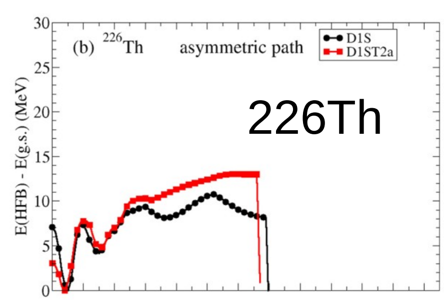
A. C. Berriman et al., Phys. Rev. C 105 (2022) 064614

Our hypothesis

Our hypothesis 1: Anomalies are caused by the third barrier.



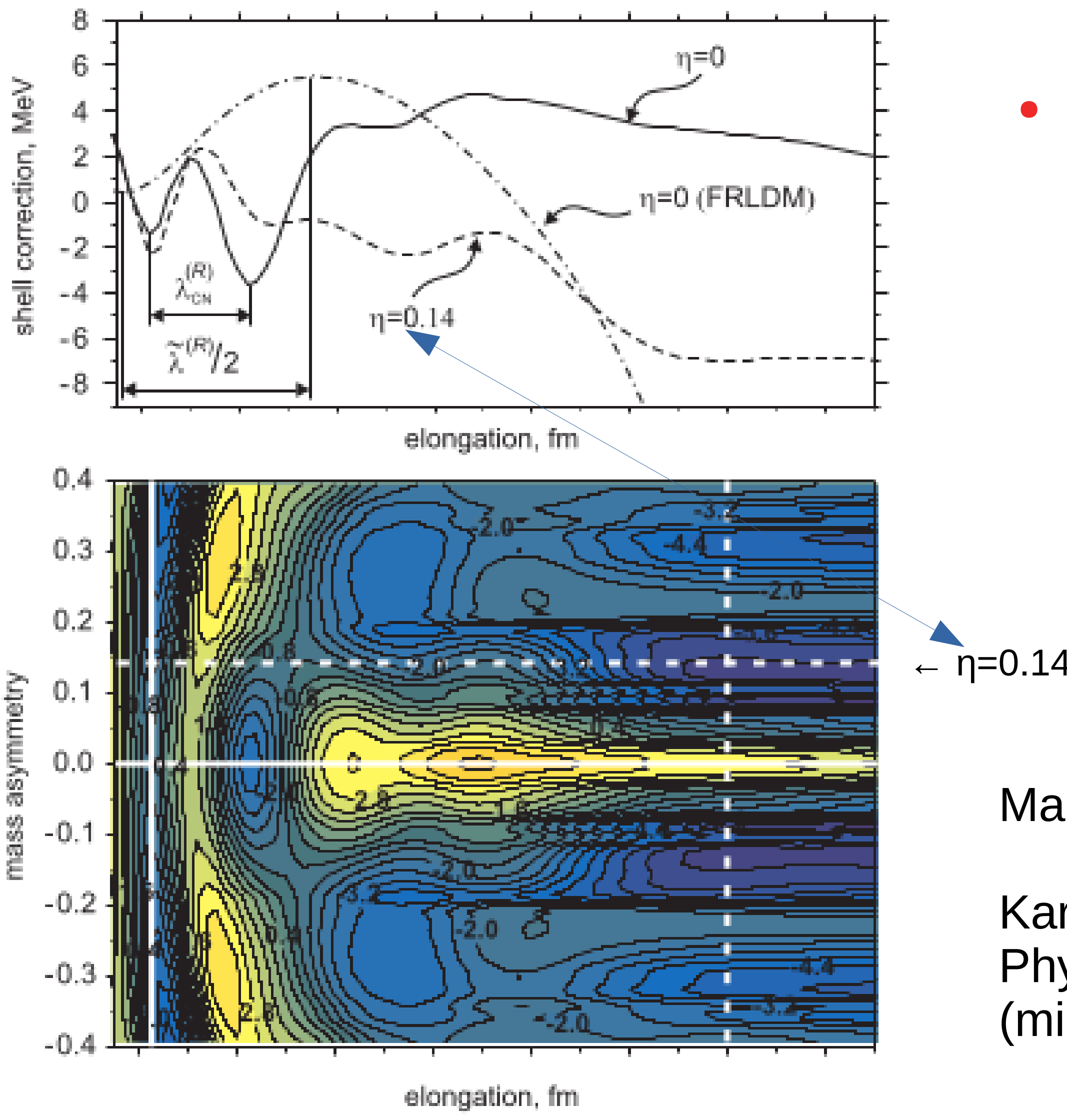
- Figure: educated guess of the pot. energy along the fission path
- Appearance of a triple-humped barrier in the light actinides
- Heavy actinides: 2nd barrier determines the FF yields
- Light actinides: 3rd barrier is the origin of the observed anomalies



Elongation

HFB calculation
R. N. Bernard et al.,
Phys. Rev. C 101 (2020) 044615

Our hypothesis 2:
At low E*, the mass distribution reveals the potential at 3rd barrier.



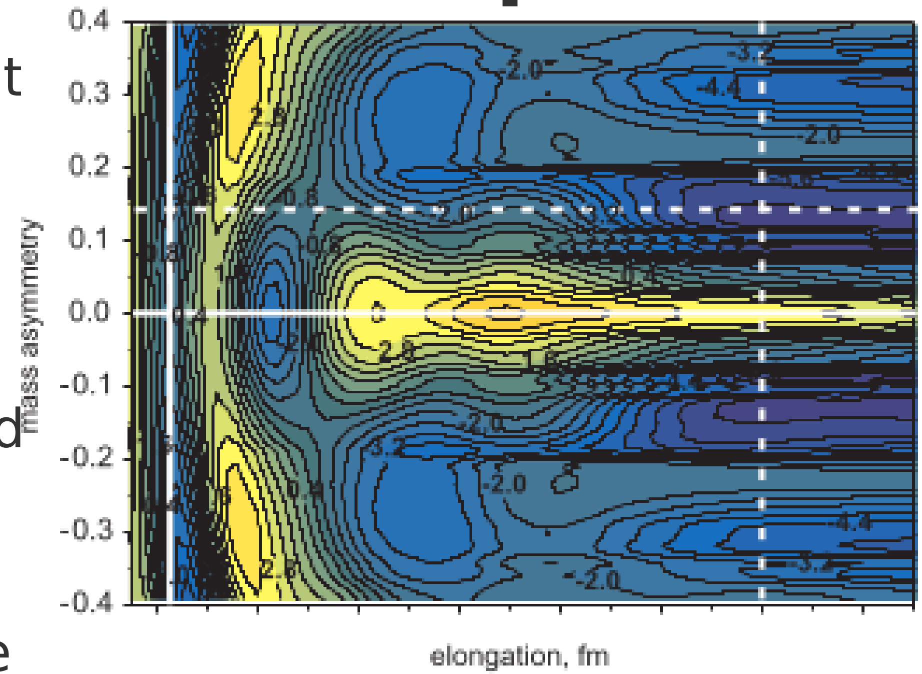
- When E* falls below the height of the 3rd barrier for specific unfavourable shapes (e.g. elongation, mass asymmetry) some flux is reflected at the 3rd barrier due to low transmission coefficient.

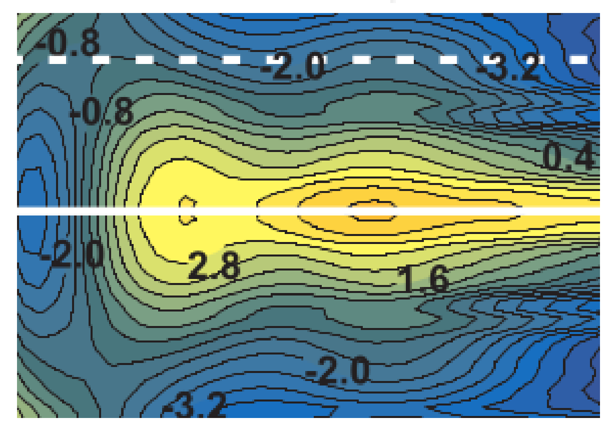
Map of Shell effects for 238U from:

Karpov et al., J. Phys. G: Nucl. Part. Phys. 35 (2008) 035104
(mic.-mac. 2-center shell model)

Our hypothesis 3:
At high E*, the inertial force prevails

- The mass asymmetry, established at the 2nd barrier is kept up to scission, because the driving force near the 3rd barrier does not overcome the inertial force in mass asymmetry.
- The system keeps a memory beyond the second barrier up to scission.
- The memory time in mass asymmetry is large compared to the dynamical time from 2nd barrier to scission.
- This is in severe conflict with the wide-spread claim, which often alleges that the role of collective inertia in fission dynamics is irrelevant.





← η=0.14

↑ 2nd ↑ 3rd barrier

Our hypothesis 4:

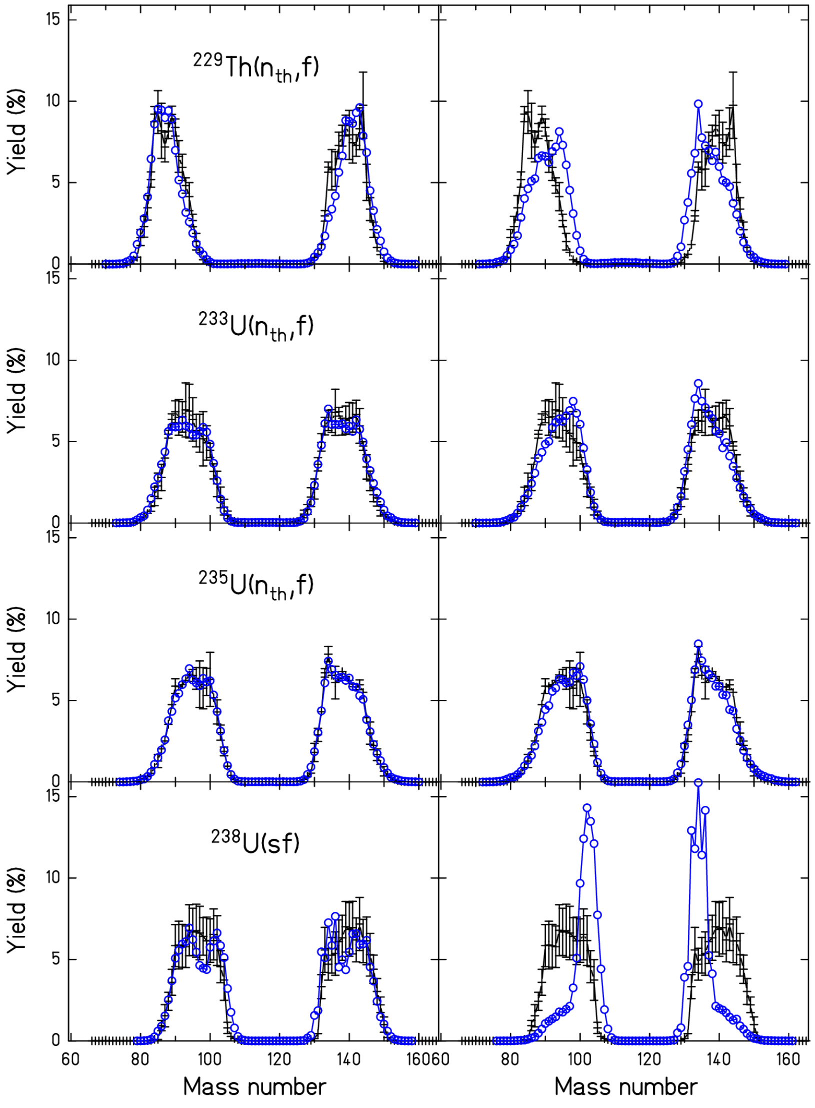
A simple model is implemented in the GEF code. All observations are quantitatively reproduced.

Idea: Reduction of flux by the transmission through the „local“ 3rd barrier (Hill-Wheeler).
(FF mass-dependence of the 3rd barrier adjusted to the data.)

- The new GEF code can be used to
  - estimate the consequences of the suppression effects for applications in nuclear technology*) and
  - as an orientation for new experiments that aim to check our hypothesis.

*) See K.-H. Schmidt et al., Ann. Nucl. Energy 208 (2024) 110784

GEF: Sample calculations

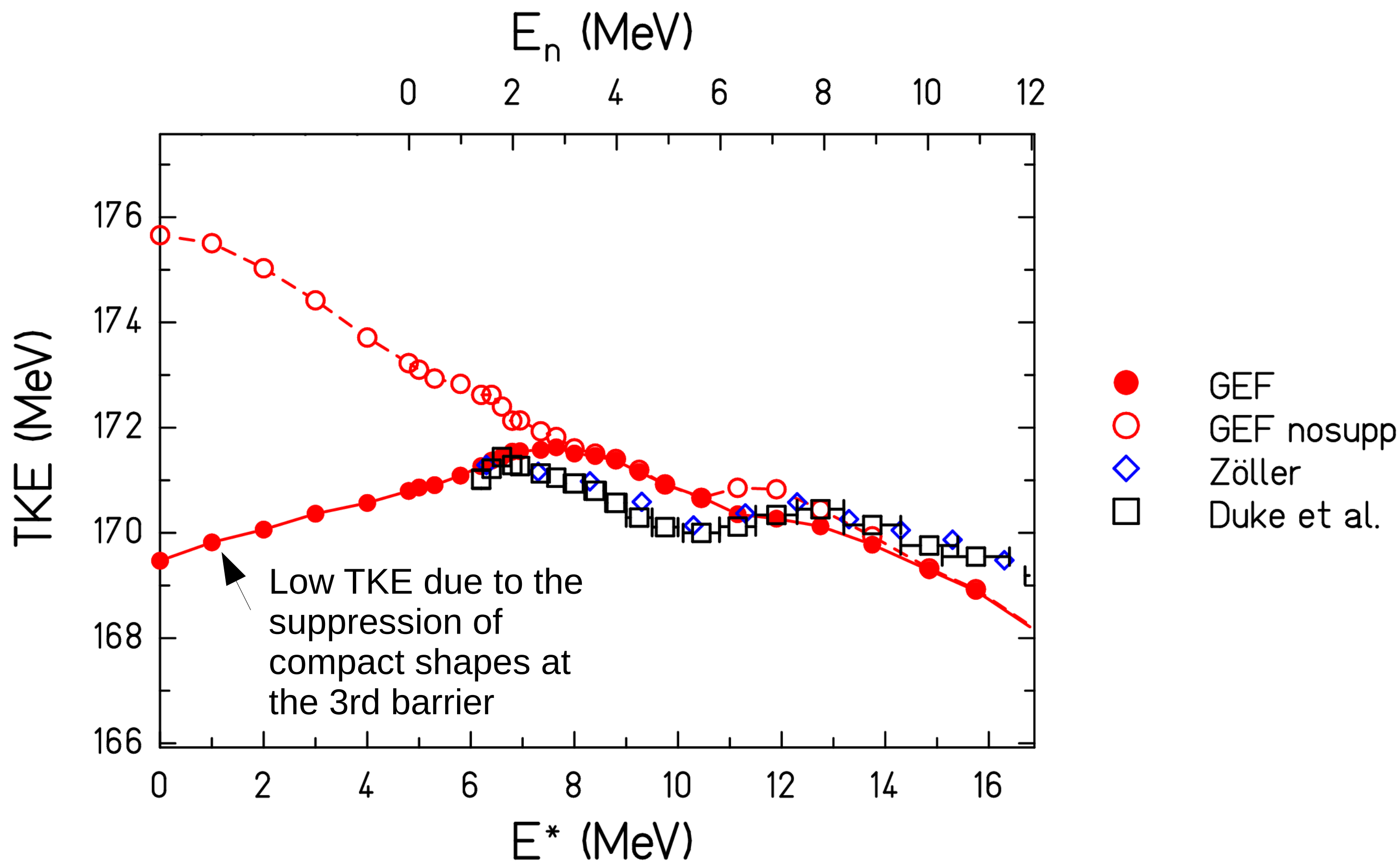


Effect of third barrier

- Compact shapes suppressed for Z_{CN} <= 92!
- Drastic effect for spont. fission of ^{238}U.

Black: ENDF-B/VII
Blue: GEF
Left: with suppression effect
Right: without suppression effect

Our hypothesis 5:
Idea for a crucial experiment on TKE



238U(n,f)

- Data at lower E* would be helpful.
- TKE for spont. fission fits to the FF yields (low S1)!

Ideas for advanced model calculations

- Calculation of the multi-dimensional potential-energy landscape
- Dynamical calculation of the fission process (e.g. with the Langevin equations) for positive energies.
- Transmission calculations through regions with negative energies (see Sadhukan et al. Phys. Rev. C 93 (2016) 011304R)
- Attempt to reproduce the data by varying the transport coefficients.

Conclusion

- Abnormal features in the FF mass distributions in the light actinides were demonstrated.
- Plausible arguments were given that these features are caused by the third fission barrier.
- Our explanation of the observations implies a strong influence of the inertial force on the fission dynamics.
- Fission models that disregard the inertial forces (e.g. scission models, use of the Smoluchowsky equation) are in conflict with our hypothesis and (as we expect) also with the data shown in this talk.