Anomalies in the fission of light actinides

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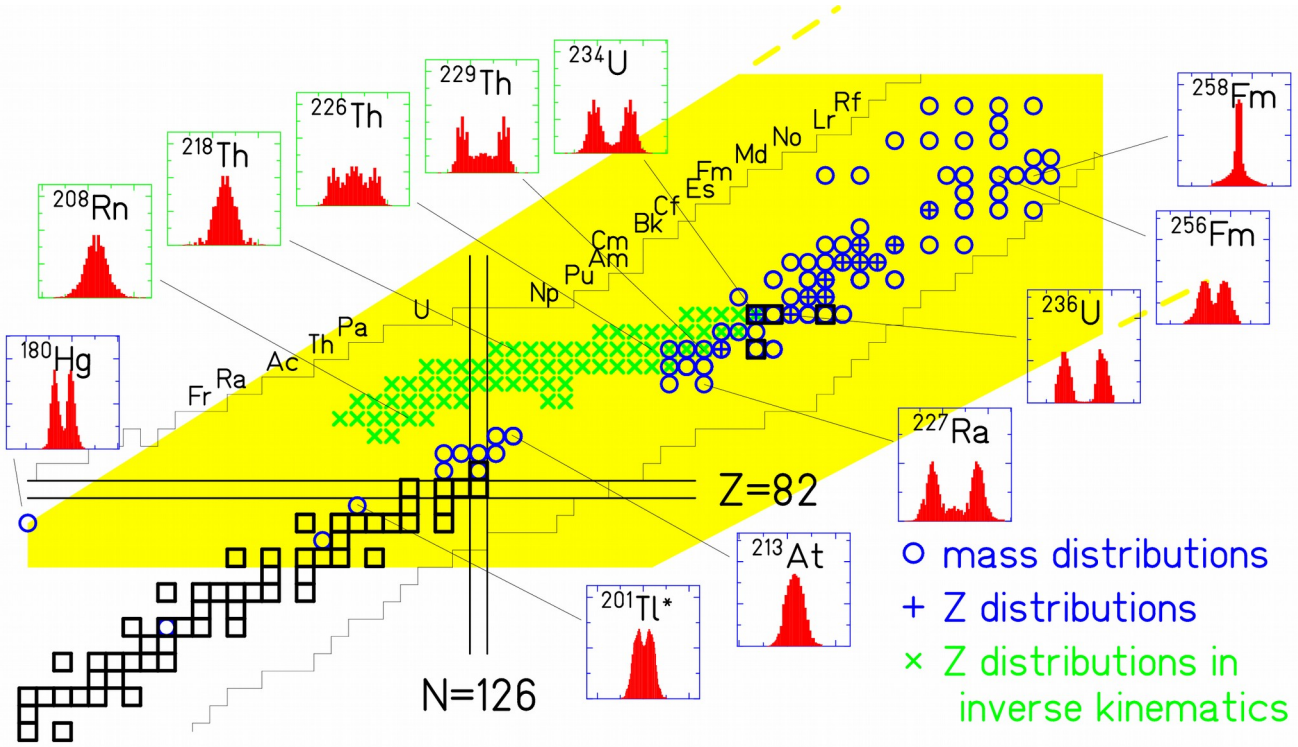
Contribution to Wonder 2026: 7th edition of the
International Workshop On Nuclear Data Evaluation for Reactor Applications

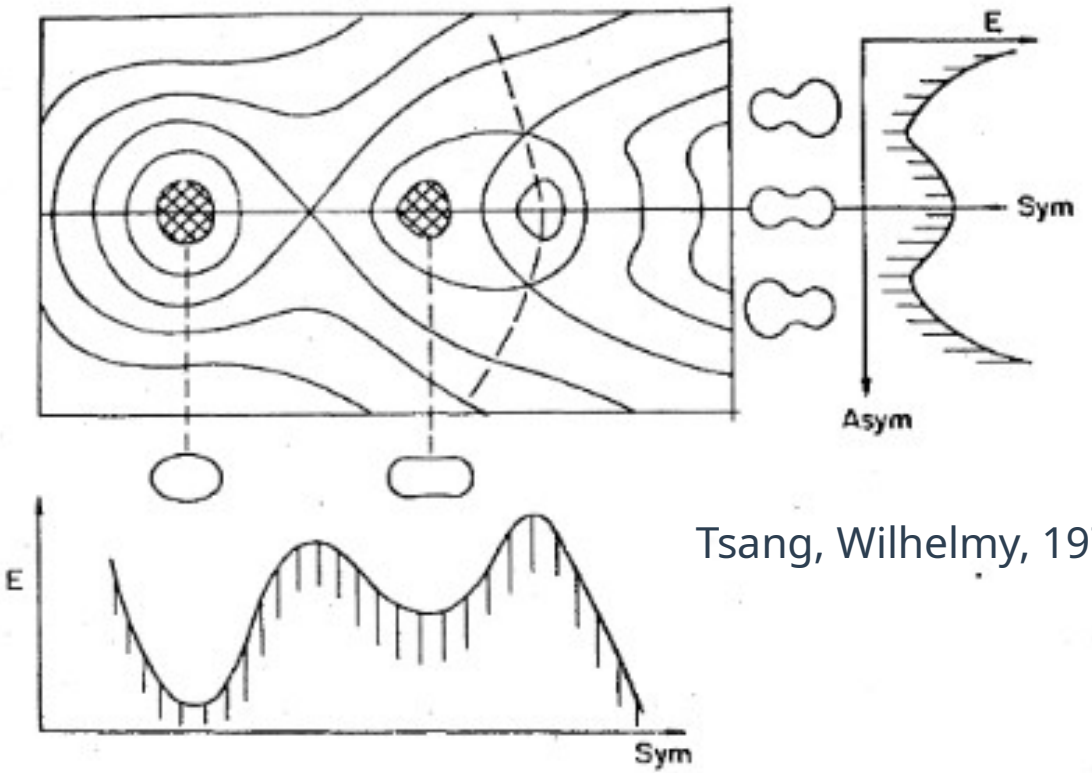
Complexity of mass yields



- Status of experiments: year 2013.
- Complex variation on the nuclear chart.
- nth,f in evaluations
- Less information on the variation with E*.

See also update in
Phil. Trans. R. Soc. A 382: 20230121.

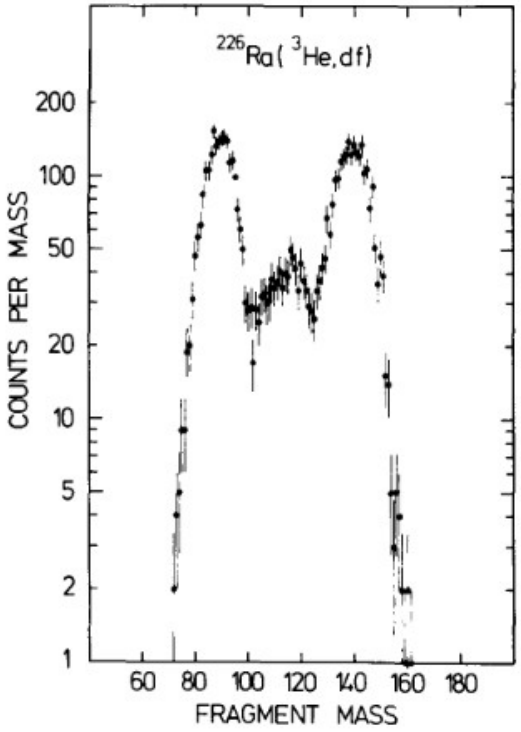
Competition of asymmetric and symmetric fission

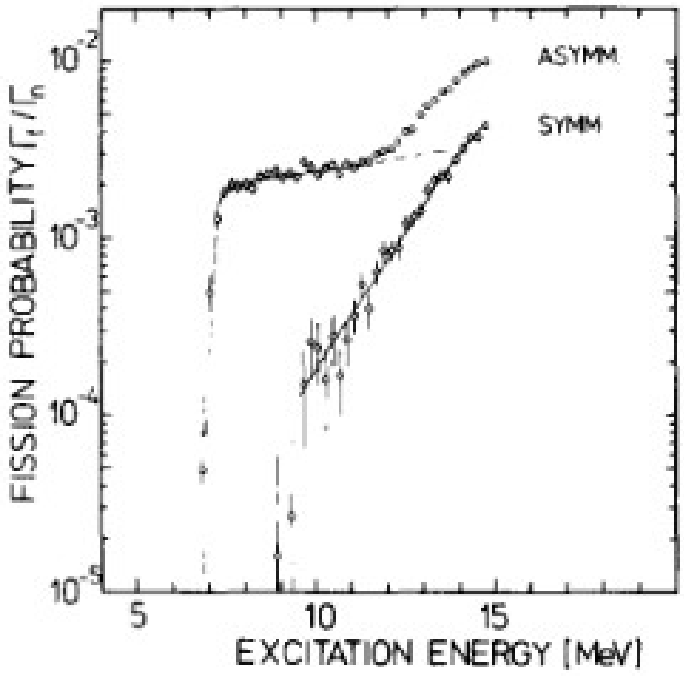


Tsang, Wilhelmy, 1972

- **Potential-energy landscape in the light actinides.**
- **(elongation - mass asymmetry)**
- **Basis for stochastic and statistical models.**
- **Lower barrier for asymmetric fission**

Energy dependence of mass yields

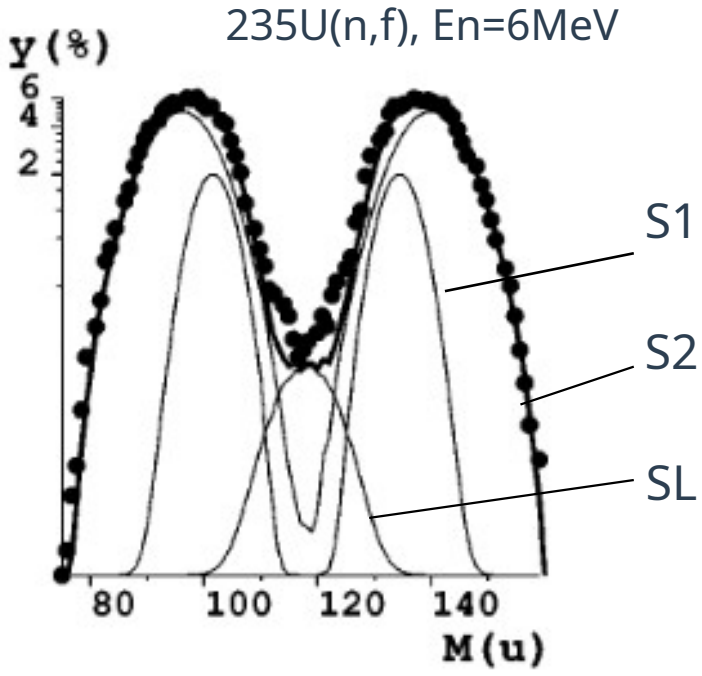




Specht, 1973

- **Fragment-mass-dependent fission barrier.**
- **Fission probabilities (sym - asym) explained by phase space.**

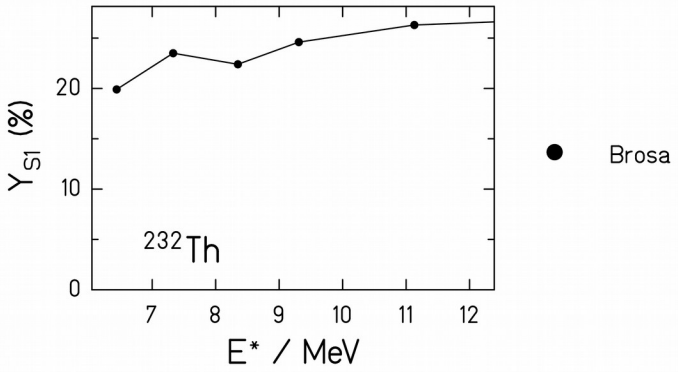
Brosa's fission channels (splitting of asymmetry)

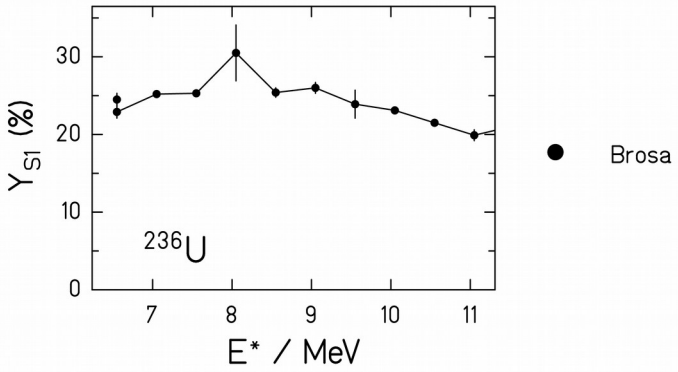


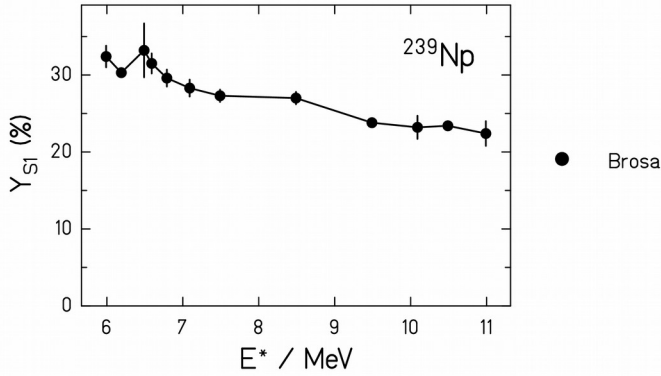
Brosa, 1999

- **S1: heavy fragment is spherical (near 132Sn), high TKE**
- **S2: heavy fragment is deformed, lower TKE**
- **SL: both fragments are strongly deformed, low TKE**

Competition of fission channels (analysis by Brosa, 1999)

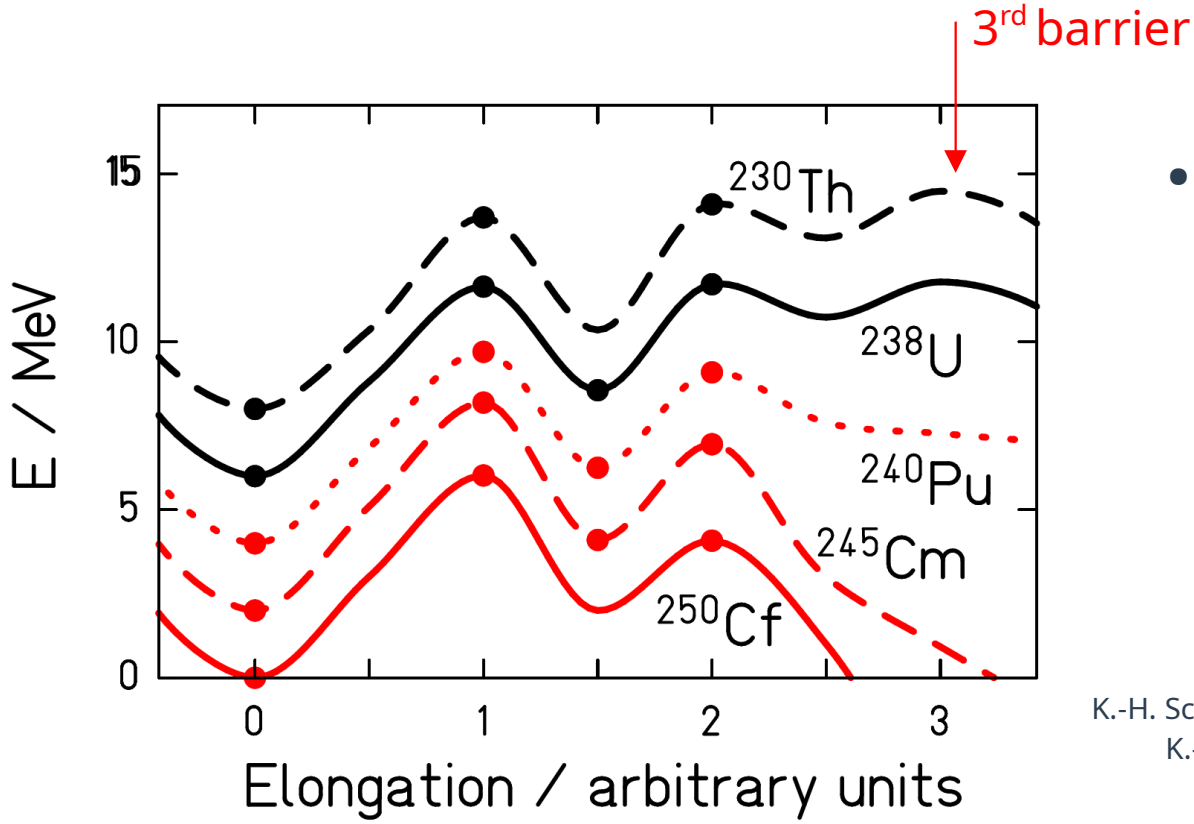






- **Our interpretation:**
  - 239Np: slight decrease of Y(S1), explained by phase space.
  - 236U: yield suppressed below E*=8 MeV.
  - 232Th: overall yield suppression.
- **Suppression of Y(S1) by a kind of obstacle for E* below a certain threshold.**

Our hypothesis: suppression of events with high TKE



- **Tunneling through 3rd fission barrier.**
  - Threshold behaviour
  - Similarity to Hill-Wheeler formula

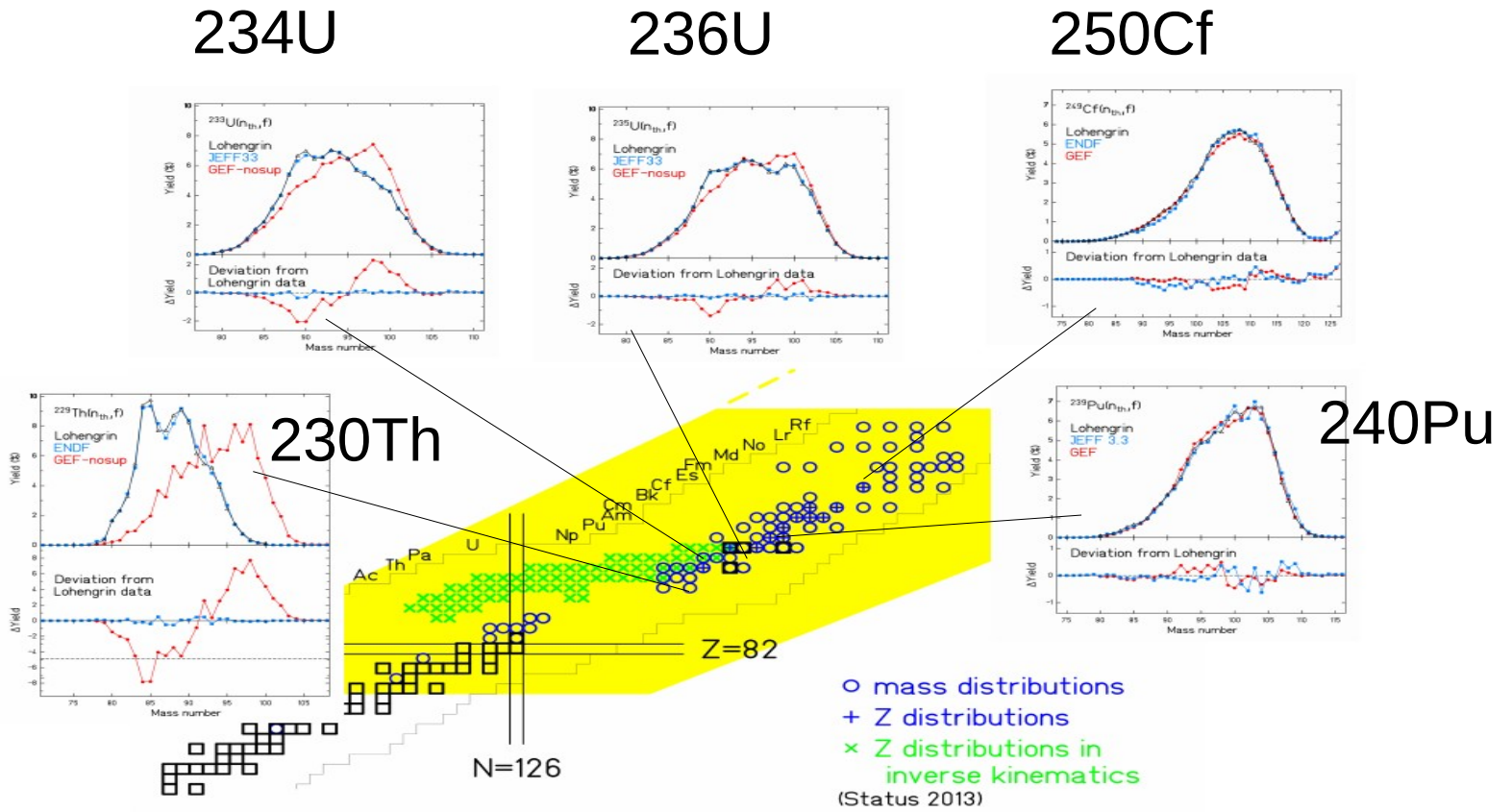
K.-H. Schmidt et al., Annals of Nuclear Energy 208 (2024) 110784
K.-H. Schmidt et al., https://arxiv.org/abs/2509.24590

Comparison exp. - GEF(until 2024/1.1)

Mass Distributions of the light fragments (**exp** and **GEF**).

Fission of indicated CN by (n_{th},f).

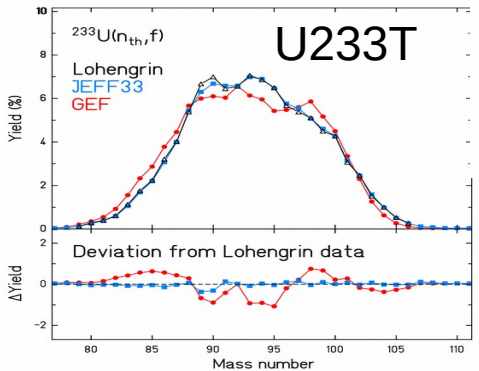
High-quality data from Lohengrin



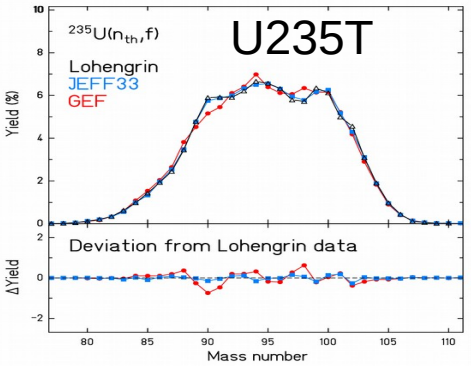
Large deviations for lighter CN.

Exp. - GEF(GEF-2025/1.2)

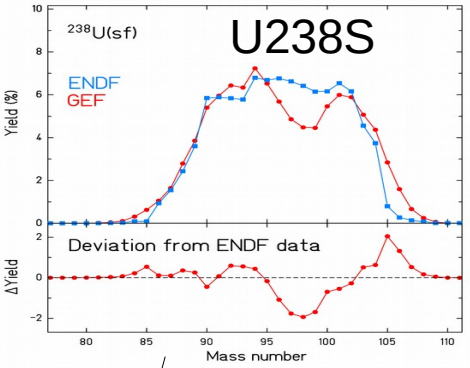
T = (nth,f)
S = (sf)
Light fragments



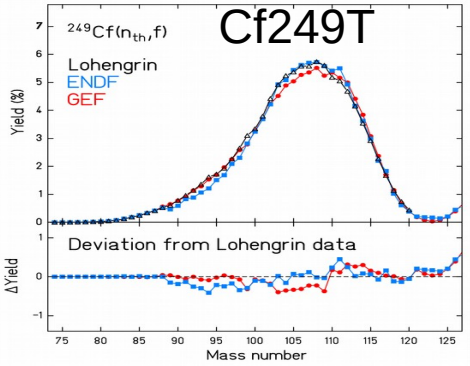
U233T



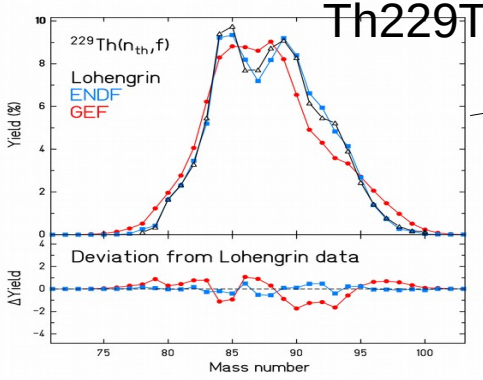
U235T



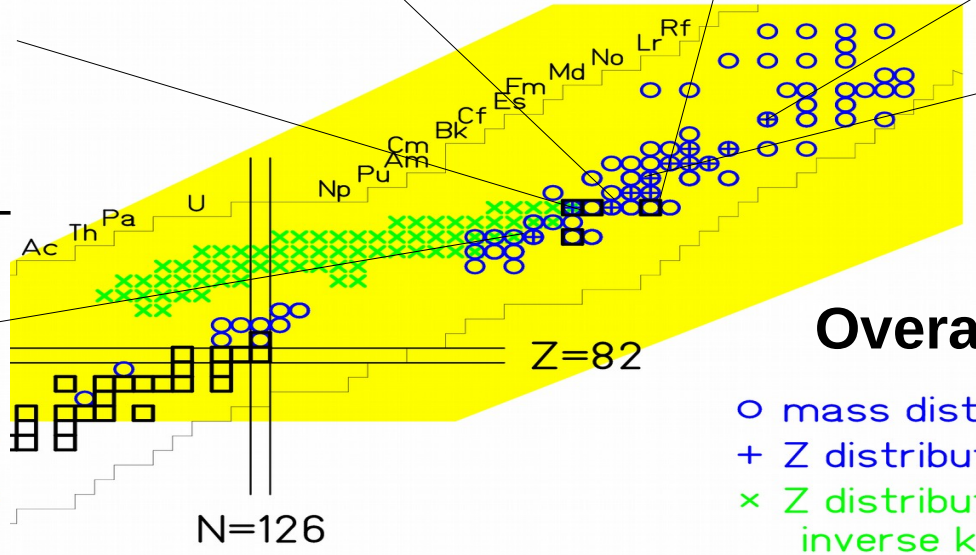
U238S

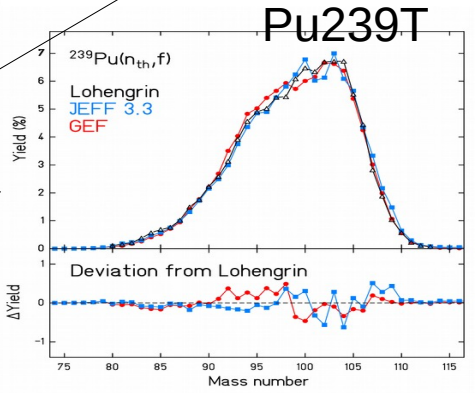


Cf249T



Th229T





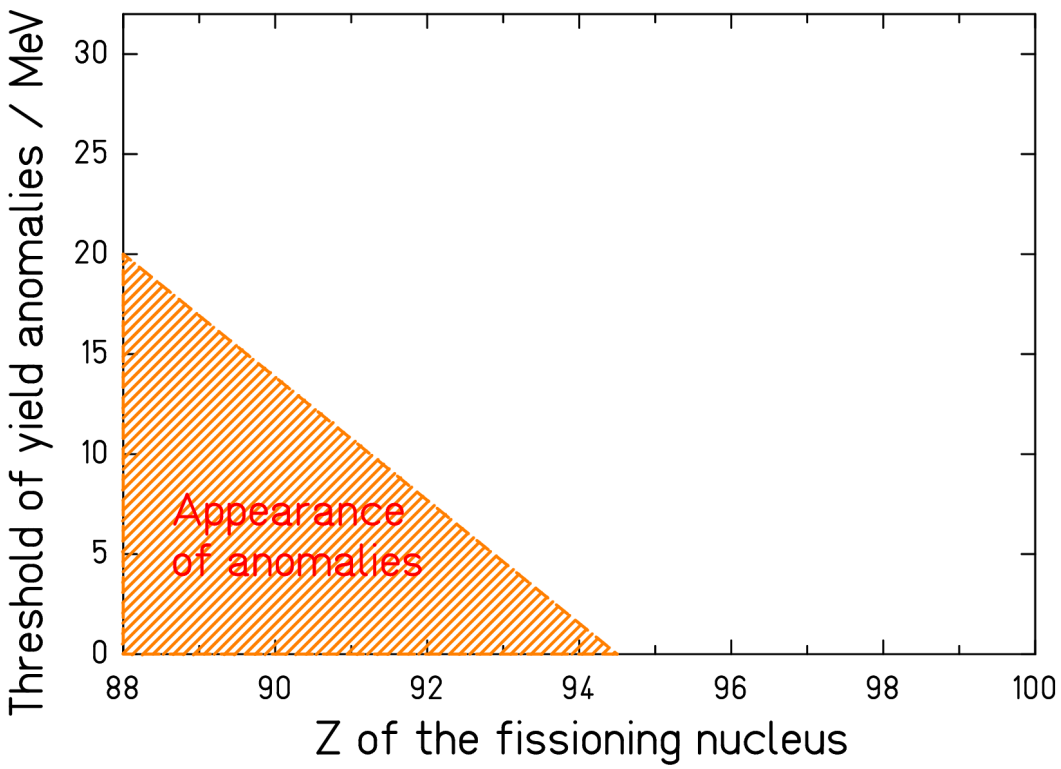
Pu239T

Overall good agreement.

○ mass distributions
\+ Z distributions
× Z distributions in inverse kinematics

(Status 2013)

Take-home message



- **For a given CN: Threshold depends on the fission channel.**
- **Highest threshold for the S1 channel (shown in the figure).**
- **No anomaly above the threshold (!)**

Unexpected observations, advancing the understanding of fission

- **Discovery of fission (Hahn, Strassman, Meitner 1939)**
- **Shell effects in mass asymmetry (Goeppert-Mayer 1948)**
- **Discovery of shape isomers (Polikanov 1964)**
- **„Thorium anomaly“: 3rd minimum (Back et al. 1972)**
- **Fission channels (Brosa 1986-1990)**
- **…**
- **Universal fragment shells (Schmidt et al. 2016)**
  - **GEF: FY for all systems with 4 universal fragment shells**
- **Revival of the thorium anomaly: (Schmidt et al. 2024)**
  - **First in-depth analysis of E*-dependent FY in low-energy fission**

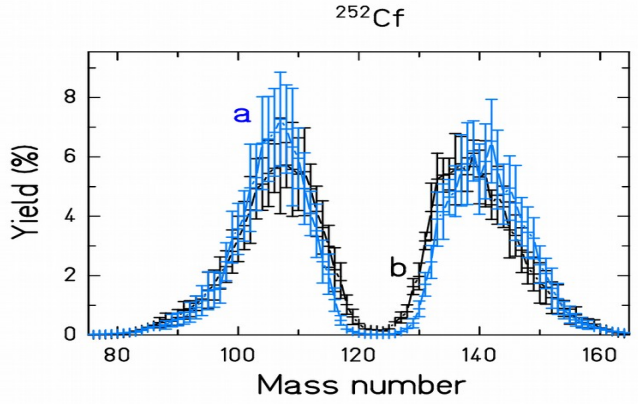
Conclusion and outlook

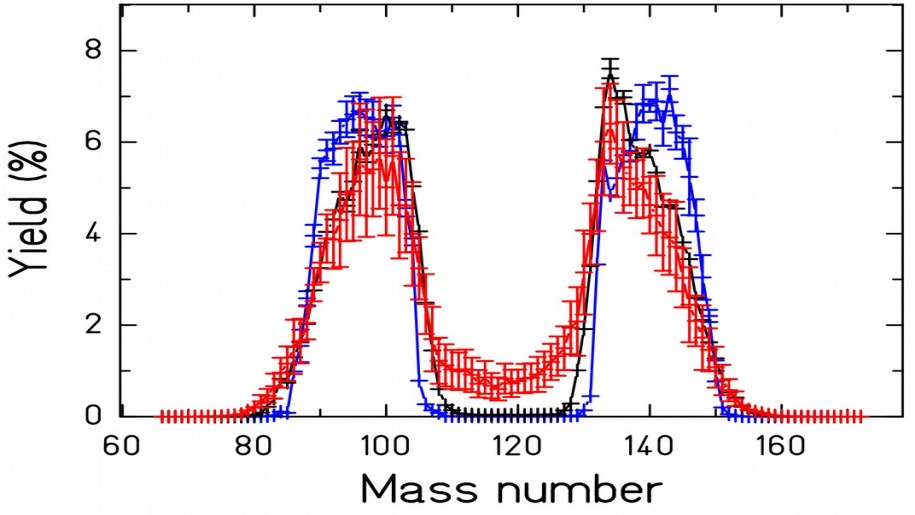
- Suppression of events with high TKE in light actinides.
- Anomalies are present in uranium and lighter elements.
  → Importance for the application of fast neutrons.
  (Yields measured with thermal neutrons cannot be used.)
- Threshold character: no anomaly above the threshold.
  → Information on transport properties of nuclear matter.
- Phenomenological description implemented in GEF.
- More and better data required.

Anomaly in sf

Mass yields from ENDF/VII-B

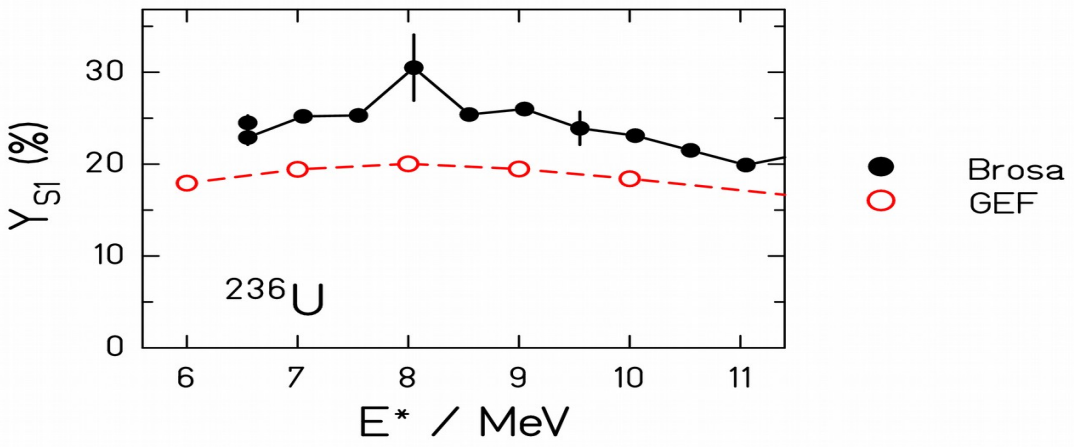
Best data available for 3 energies:
a) Spontaneous fission (E* = 0 MeV),
b) low-energy neutrons (E* ≈ 6 MeV),





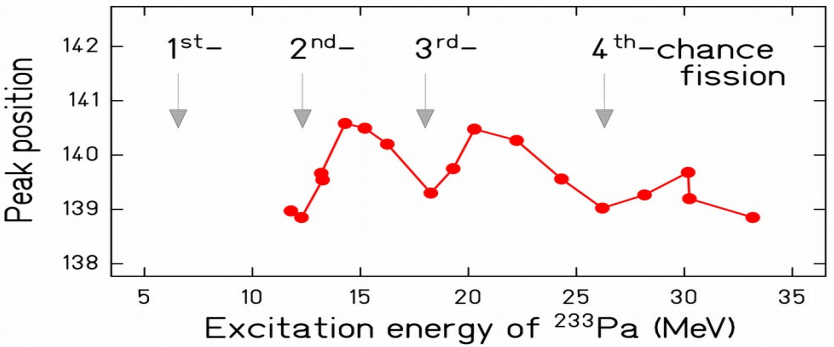
- Anomaly in 238U(sf):
  - Suppression of events with high TKE (S1 fission mode)

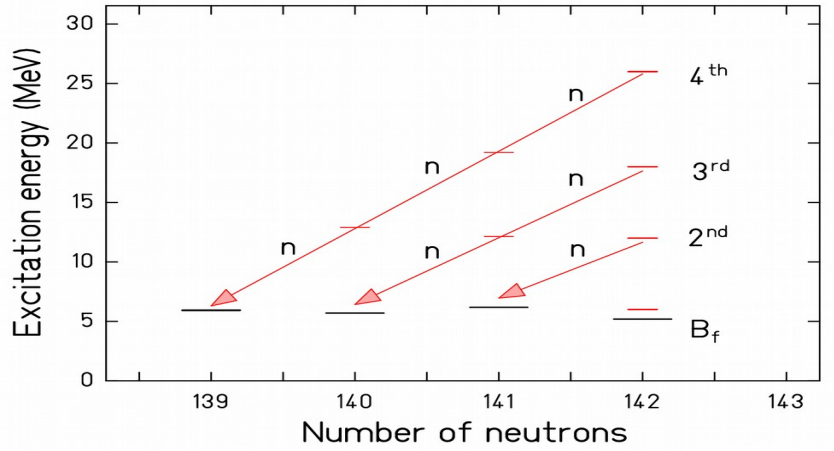
Test on energy dependence



- Slope inversion of Y(S1) in agreement with Brosa's analysis.
- Offset due to different shape of fission modes.

Anomaly in multi-chance fission





232Th(p,f)
Peak of heavy component.
Berriman et al.
Phys. Rev. C 105 (2022) 064614

- **Regular appearance of the anomaly just above the threshold of the next-chance fission.**
- **Anomaly has a strong influence also at higher initial excitation energies.**