Extensive study of the quality of fission yields from experiment, evaluation and GEF for anti-neutrino studies and applications

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Fission yields are basic data for calculating the anti-neutrino production with the summation method

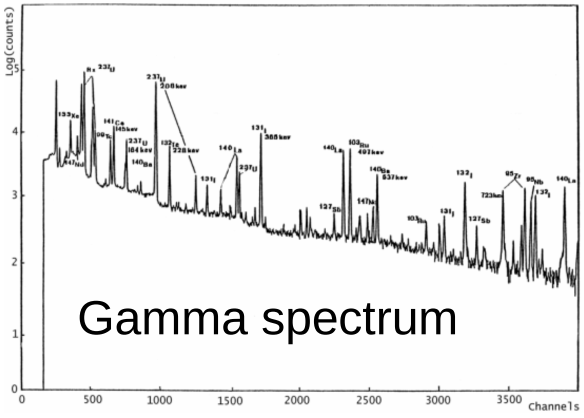
Experimental methods for FYs

Radiochemical
(Irratiation,
chemical separation +
gamma spectroscopy)

Strenghts:
Identification in Z and A
High sensitivity

Weaknesses:
Slow method
Limited to suitable targets
Mostly applied to (n,f)
En=thermal, fast, 14 MeV
Spectroscopy-dependent

Application:
Full use for evaluation



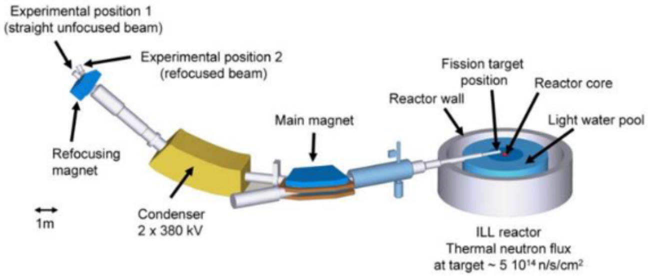
Kinematical (direct)
(Particle detectors +
spectrometer)

Strengths:
Excellent A resolution
Fair Z resolution
Direct particle counting
High accuracy

Weaknesses:
Only (nth,f) of few targets

Application:
Rare use for evaluation

LOHENGRIN (ILL)



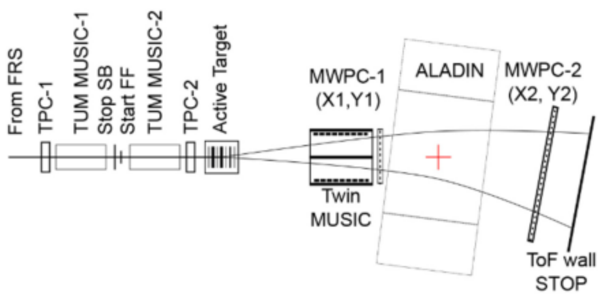
A. Chebbouhi et al.,
EPJ WoC 111, 08003

Kinematical (inverse)
(Particle detectors +
spectrometer)

Strengths:
Excellent A,Z resolution
Exotic systems

Weaknesses:
E* broad and restricted

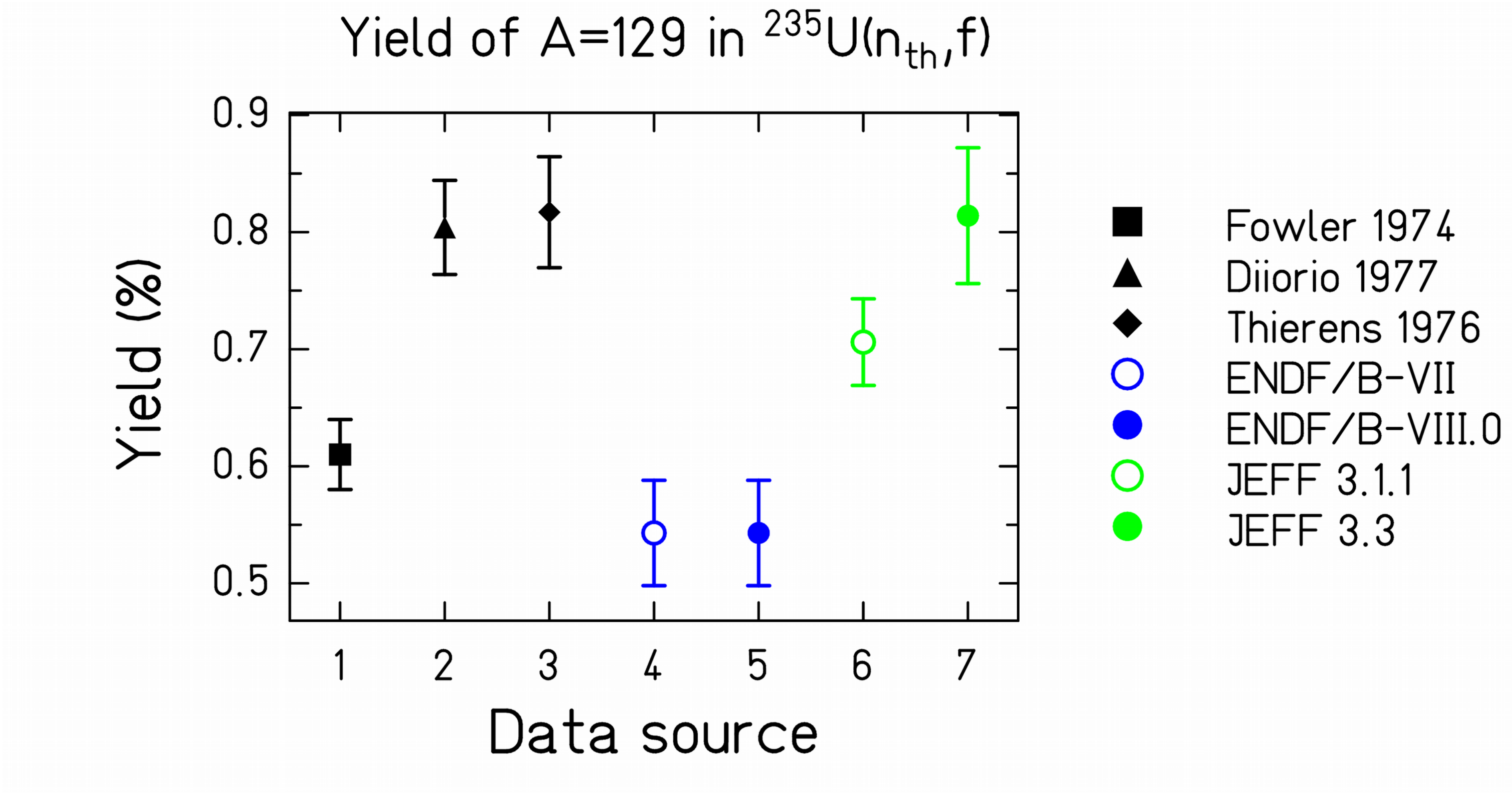
Application:
Not used for evaluation



SOFIA @ GSI

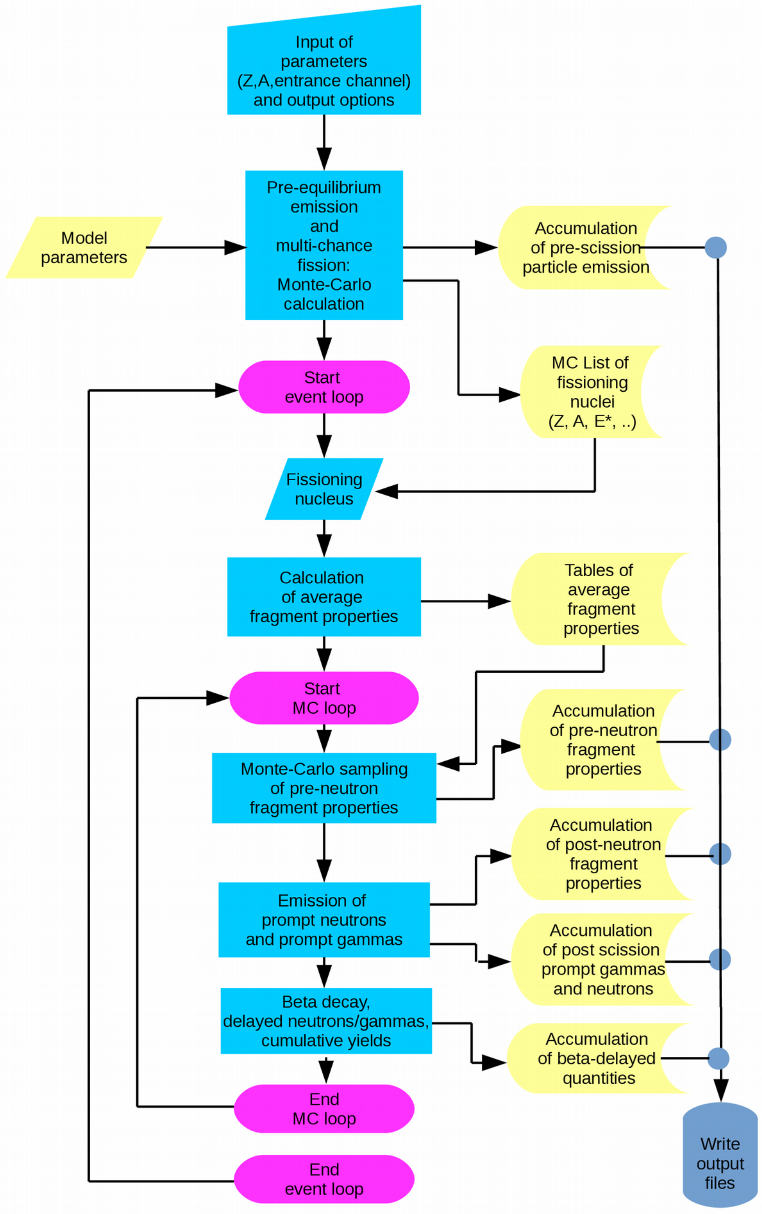
J. Taieb et al.

Problems of evaluations: data uncertainties



- Scatter of experimental data and evaluations.
- Clarification by Theory?

The semi-empirical GEF model



Description of the whole fission process from the excited compound nucleus to the radioactive decay of the fragments towards beta stability.

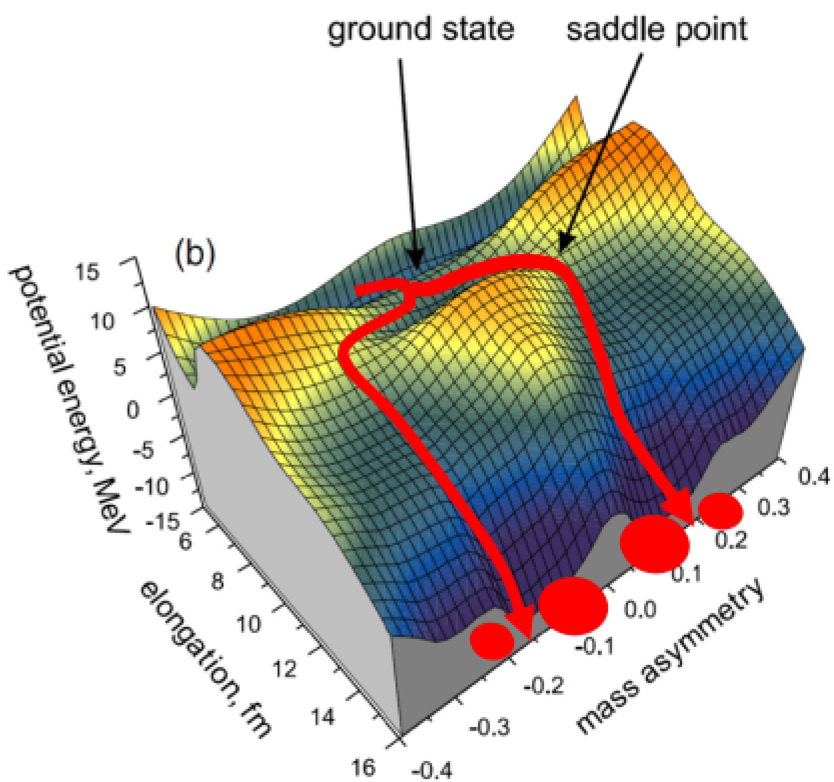
Covering almost all fission observables.

Based on theoretical concepts and laws of general validity.

Empirically adjusted parameters to FY and other data of about 100 systems (Z,A,E*).

Basic idea of GEF for FYs

- Structures in potential-energy landscape are caused by fragment shells (the same for all fissioning systems).
- Dependence on *Z* (and *N*) of fragment (not on CN!)
- Fragment shells determined by fit to *A* yields. (Avoids uncertainties of theoretical calculations.)



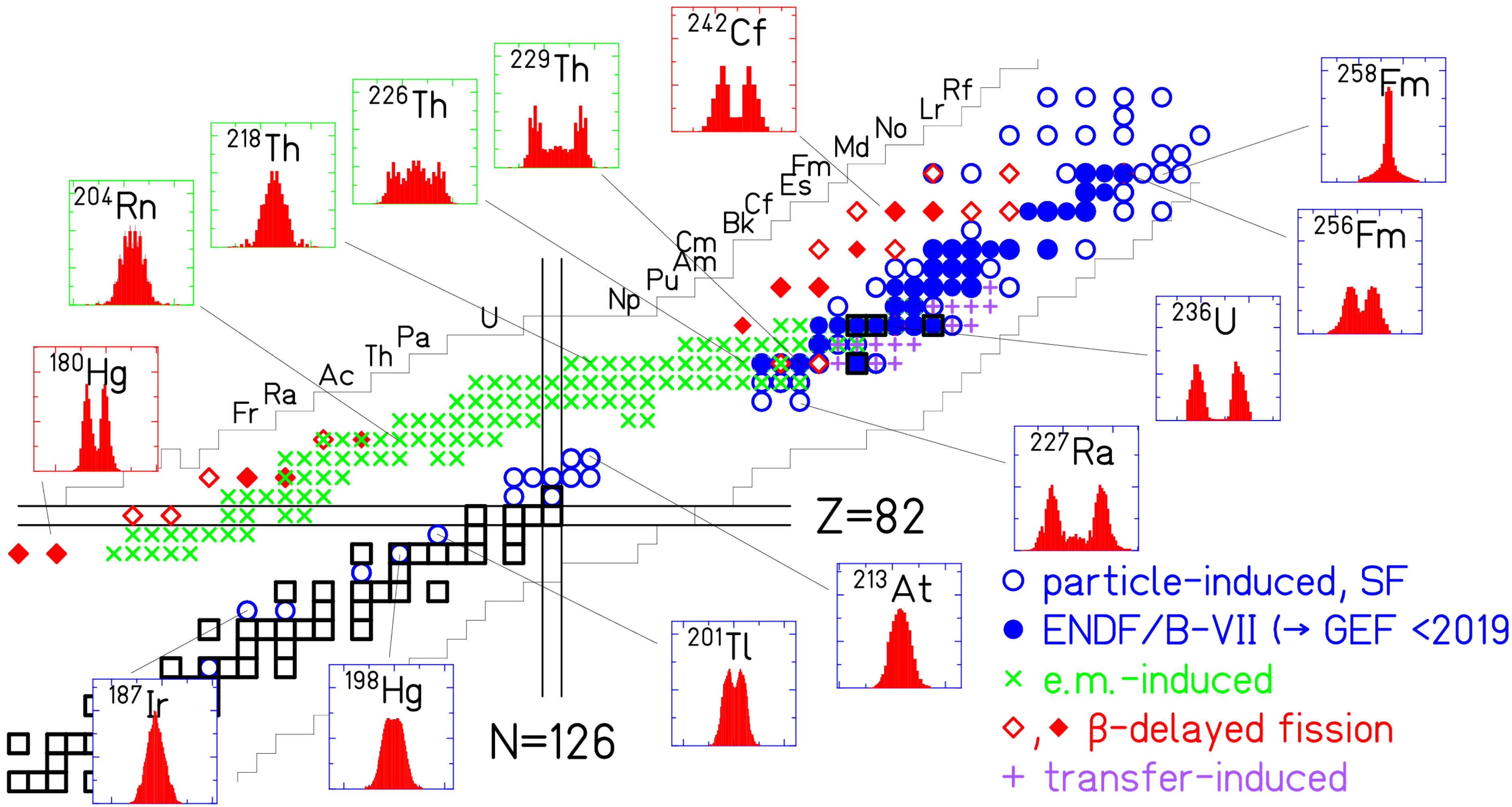
GEF needs experimental *A* yields.

Enables good reproduction of experimental fission yields.

But:

Erroneous data spoil the model.

FYs experimental knowledge



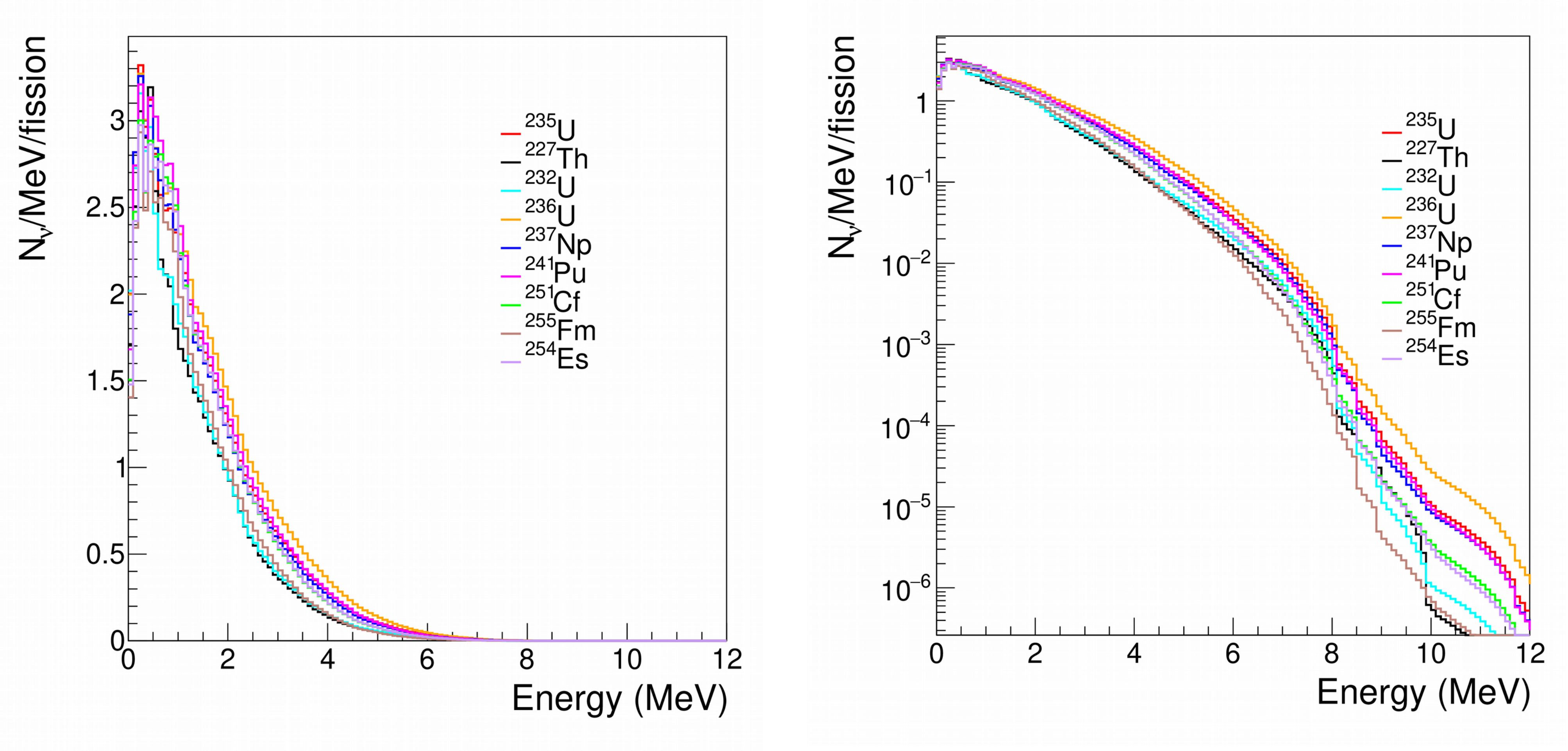
ENDF/B-VII has the widest coverage of FY for low-energy fission.

Recipe for GEF-parameter fit until 2018:

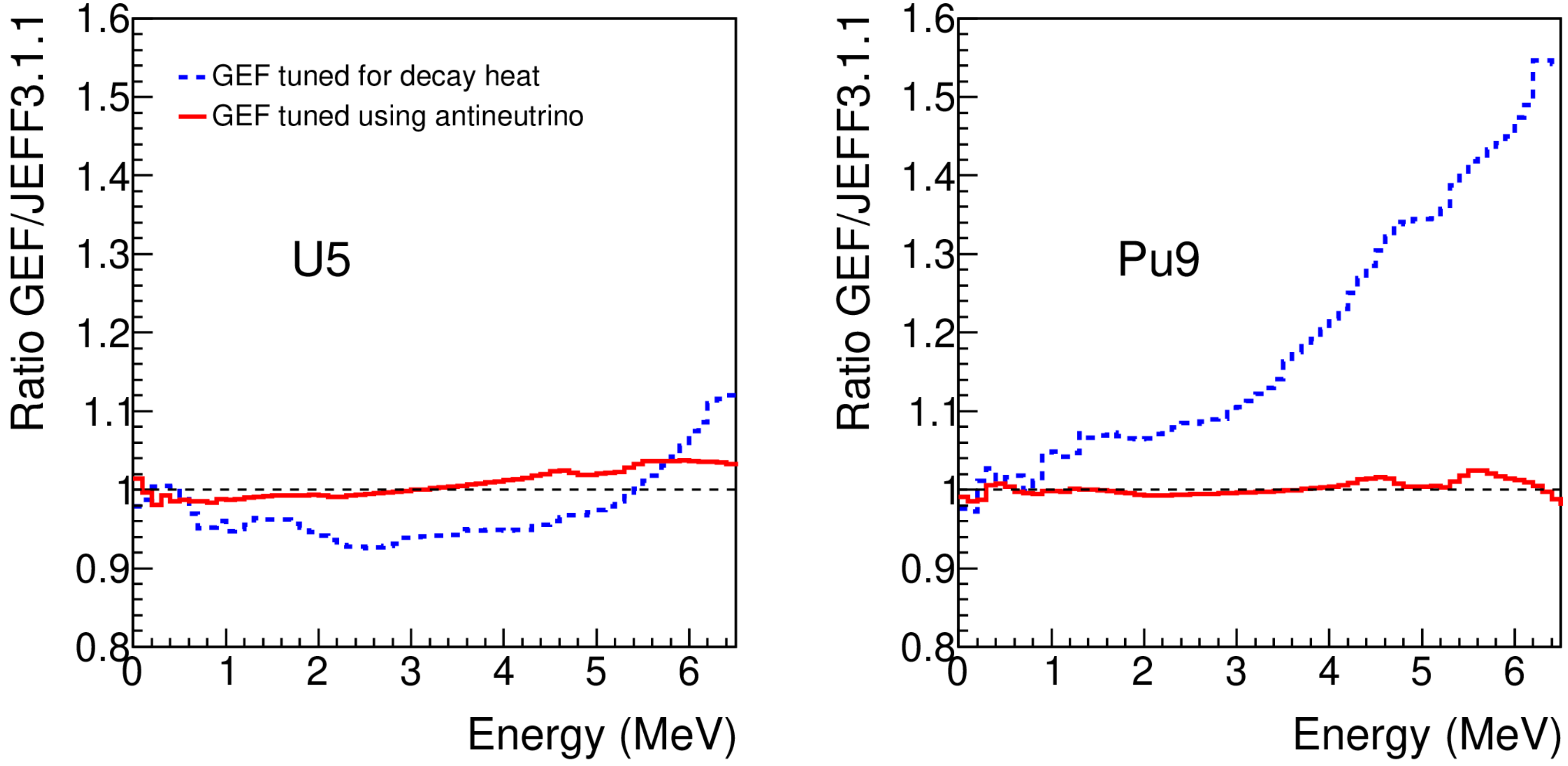
- Use the mass yields from ENDF/B-VII, because it provides the widest coverage of fissioning systems.
- Good information on the overall variation of the fission yields.
- Unique data source ensures consistency.

Calculation of anti-neutrino spectra

- Cumulative FYs from GEF (decay table from JEFF 3.1.1)
- Beta energies calculated by Subatech group (Nantes)



Unsatisfactory anti-neutrino spectra

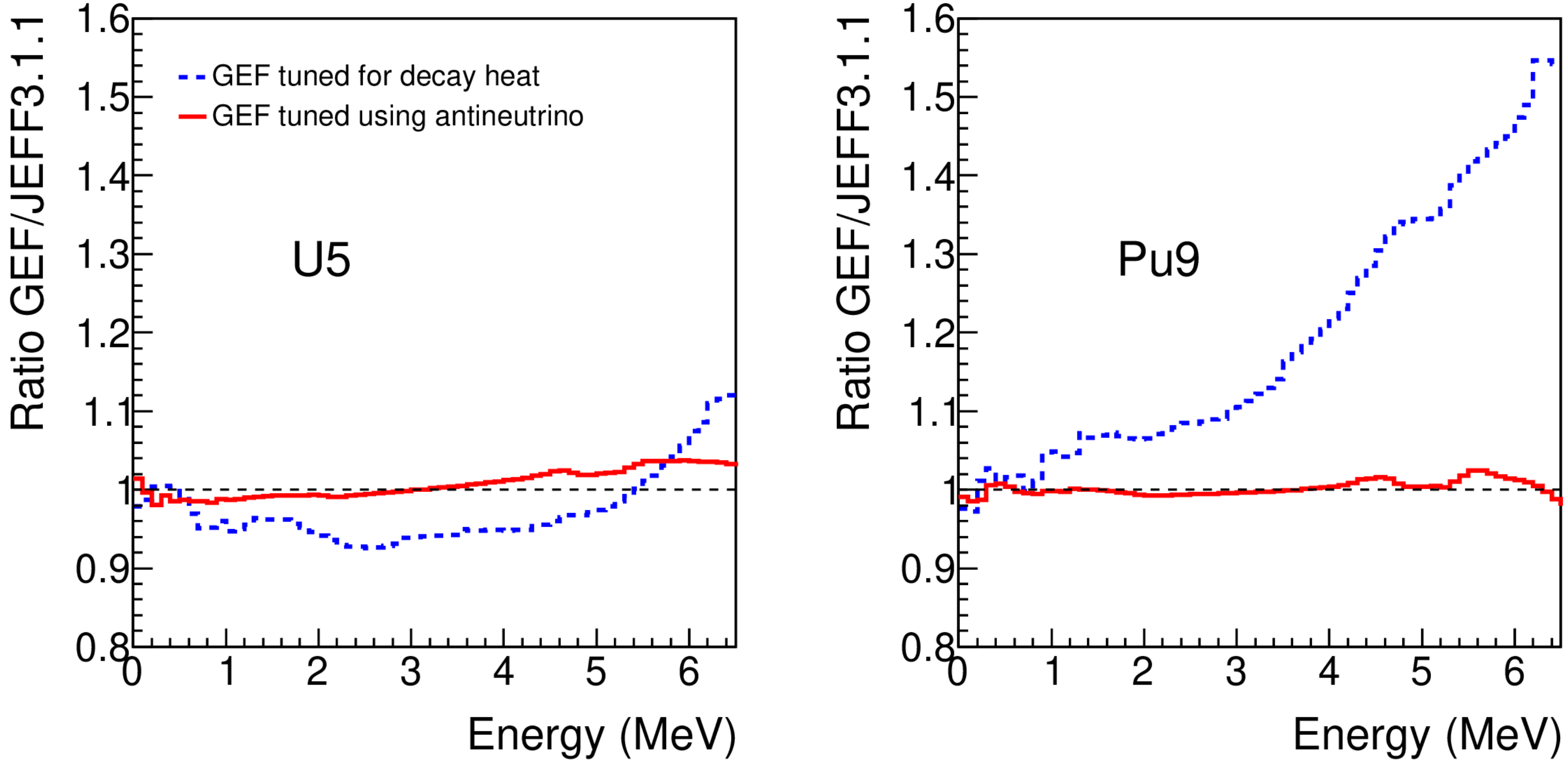


GEF vs JEFF 3.1.1

New rules for GEF-parameter fit (2019)

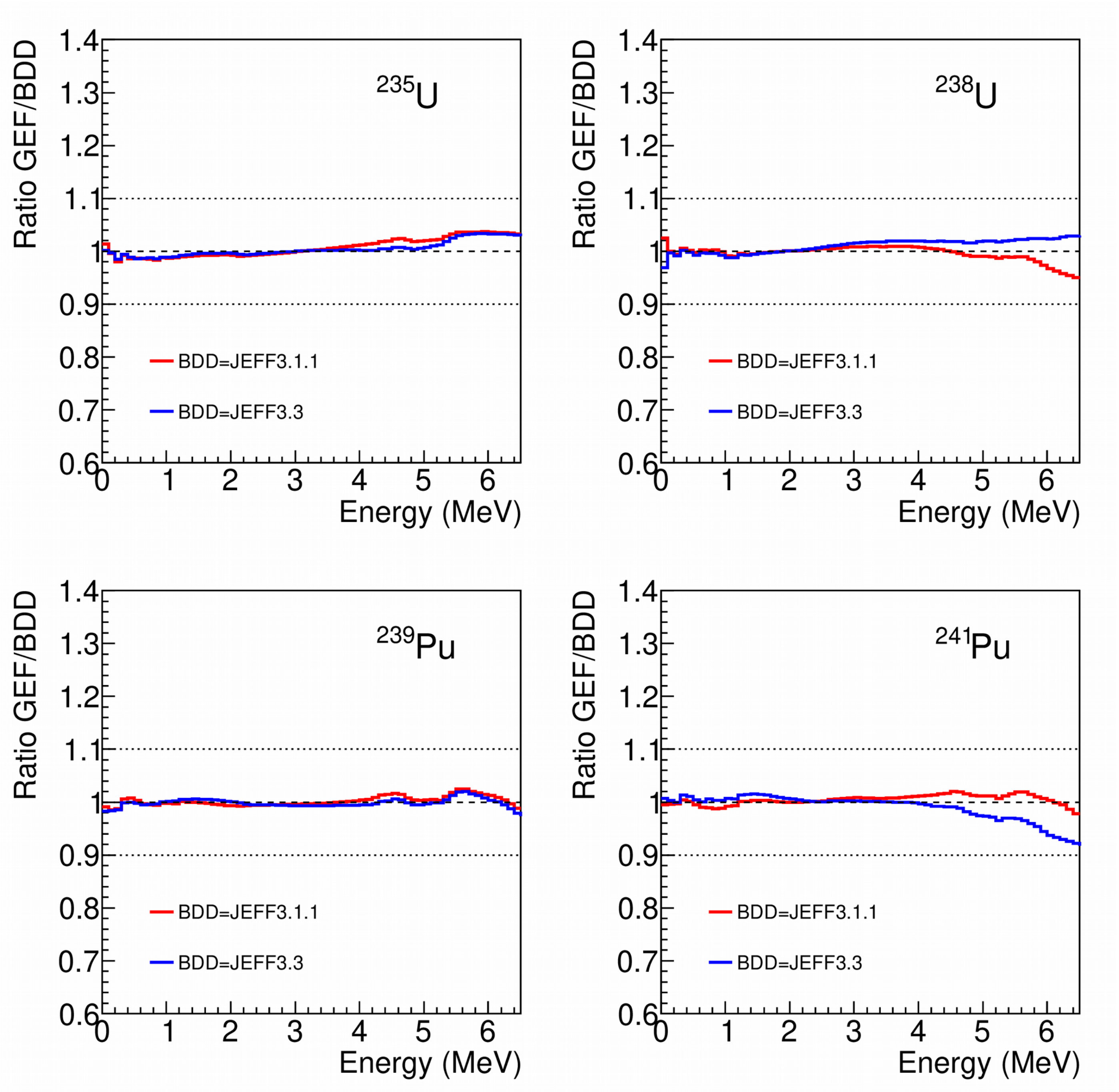
- Radiochemical data have very different quality.
  - Sequence: 235U(nth,f), 239Pu(nth,f) others ...
  - The quality is not always reflected by the error bars.
- Mass yields from LOHENGRIN experiments are exceptionally accurate (but not much used).
- Indirect information on FY (anti-neutrino spectrum, decay heat etc.) are very sensitive probes.
- First adjust the parameters of GEF to the most trustworthy data. The theoretical regularities of GEF help to recognize faulty data and to eliminate them from the fit.

Improved anti-neutrino spectra



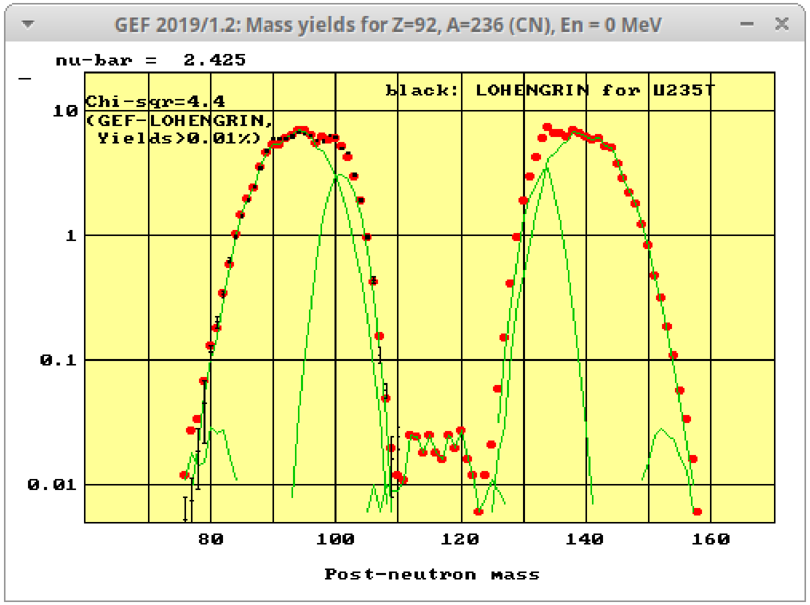
GEF vs JEFF 3.1.1

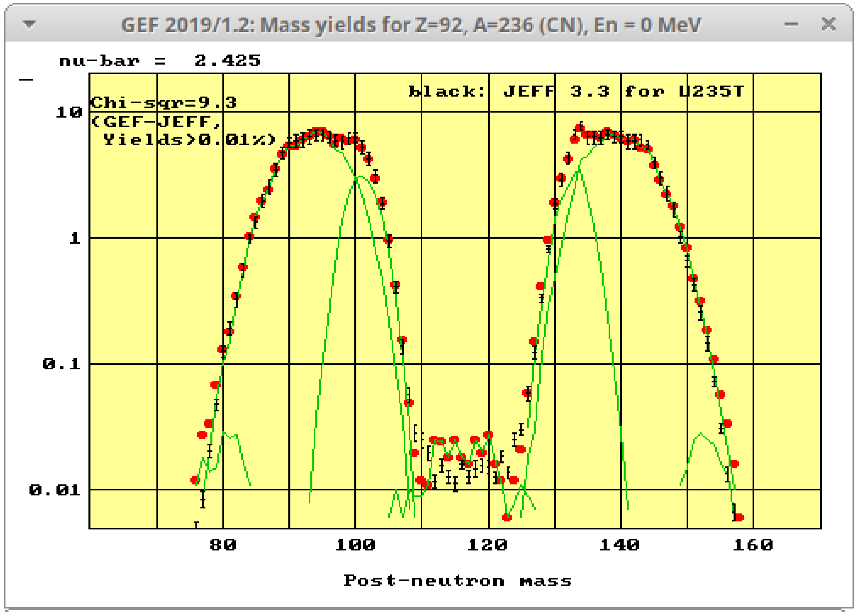
Improved anti-neutrino spectra

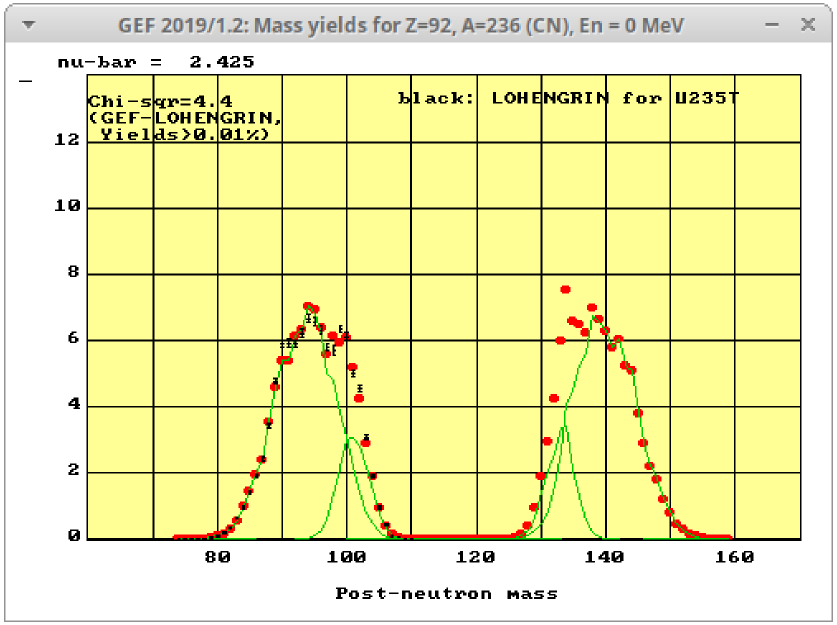


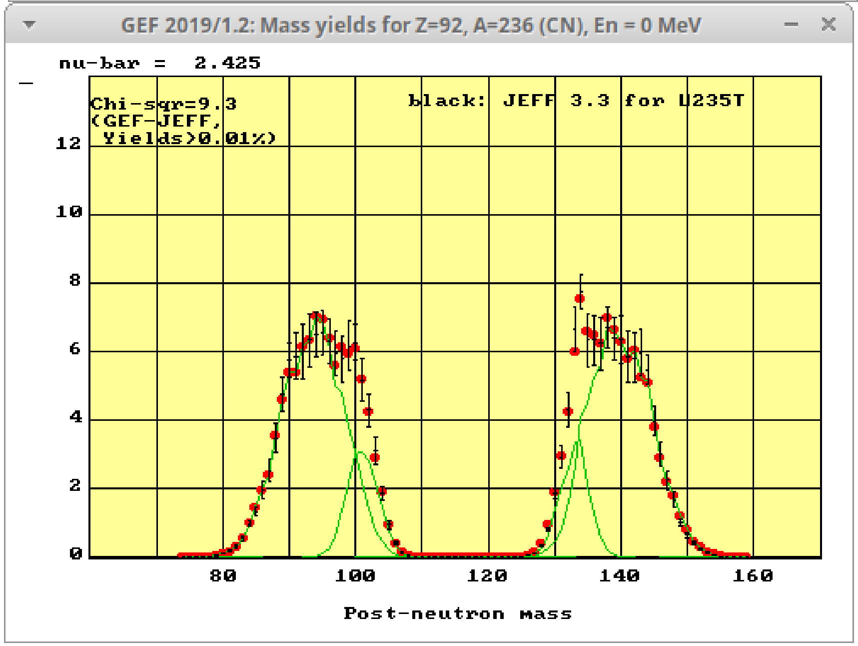
Systematic comparison of measured and evaluated fission yields with GEF 2019/1.2

Best case: A yields of U235T





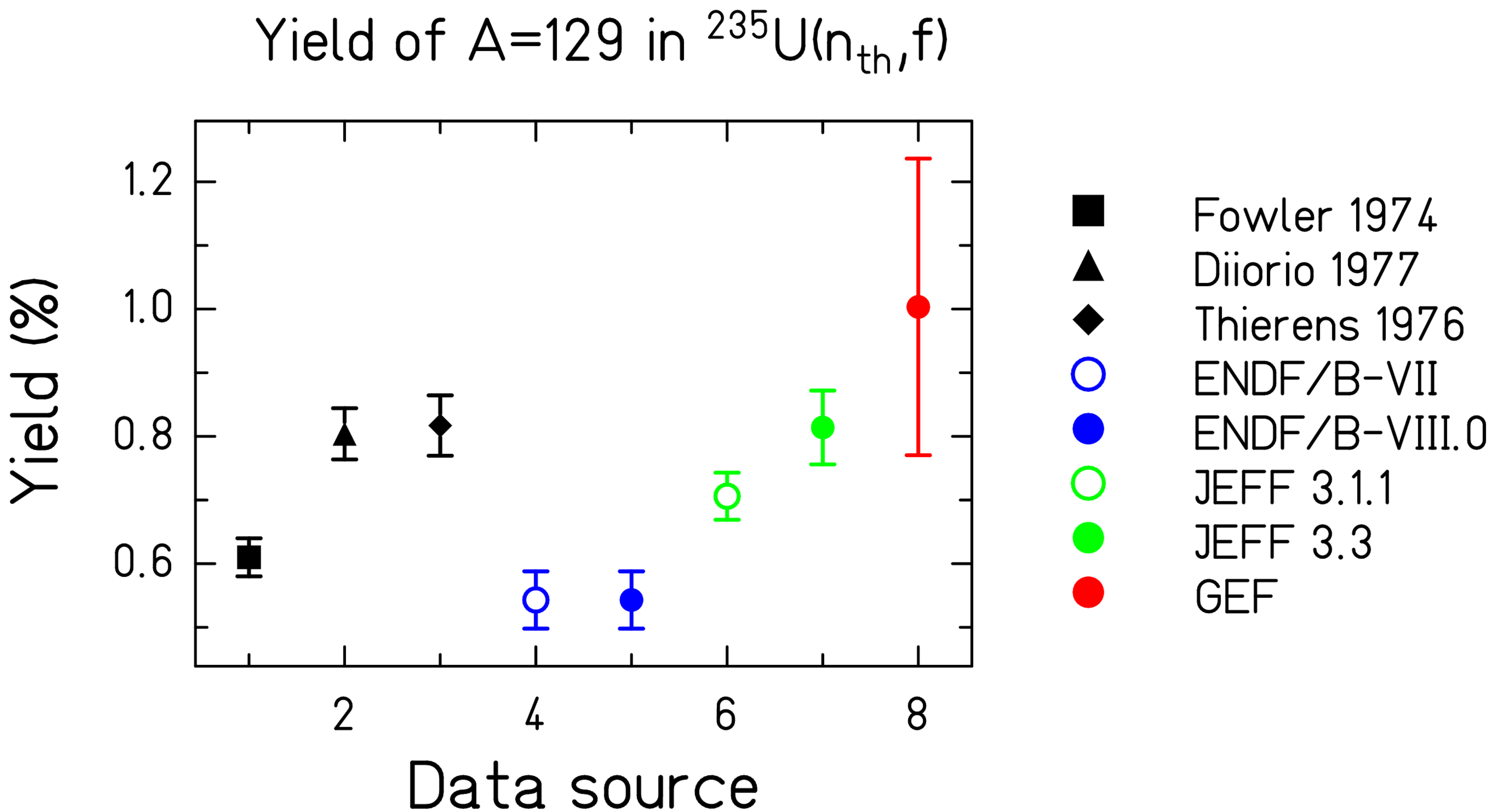




LOHENGRIN / GEF

JEFF 3.3 / GEF

Evaluations

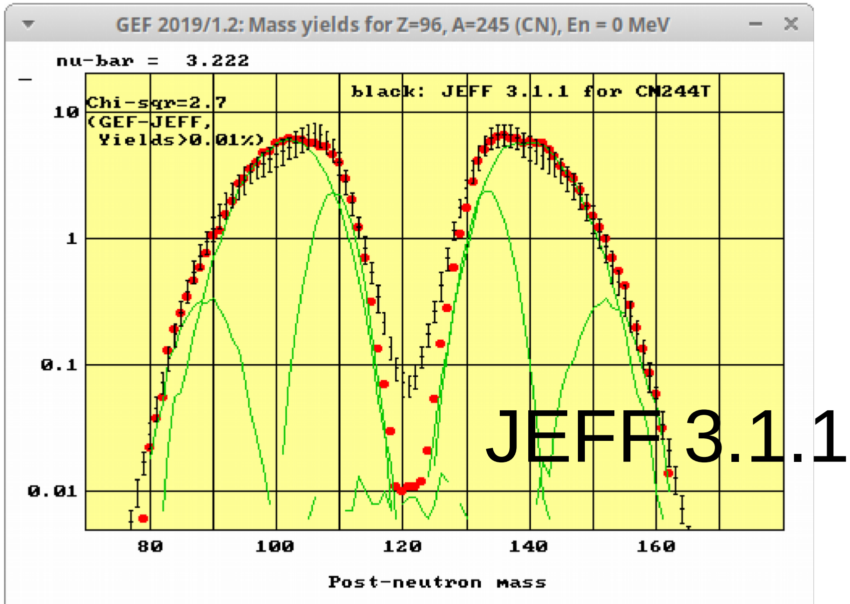


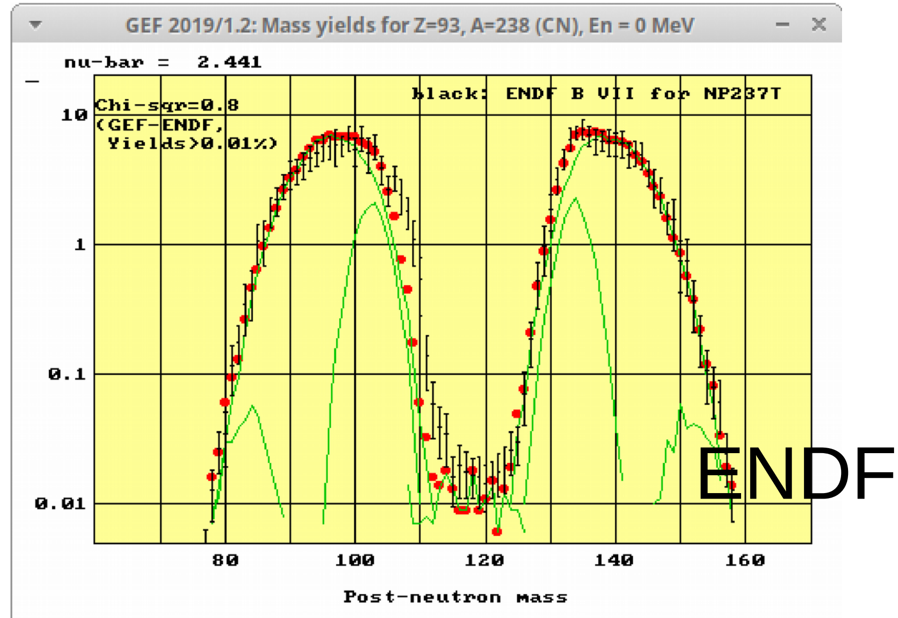
Scatter of experimental data and evaluations

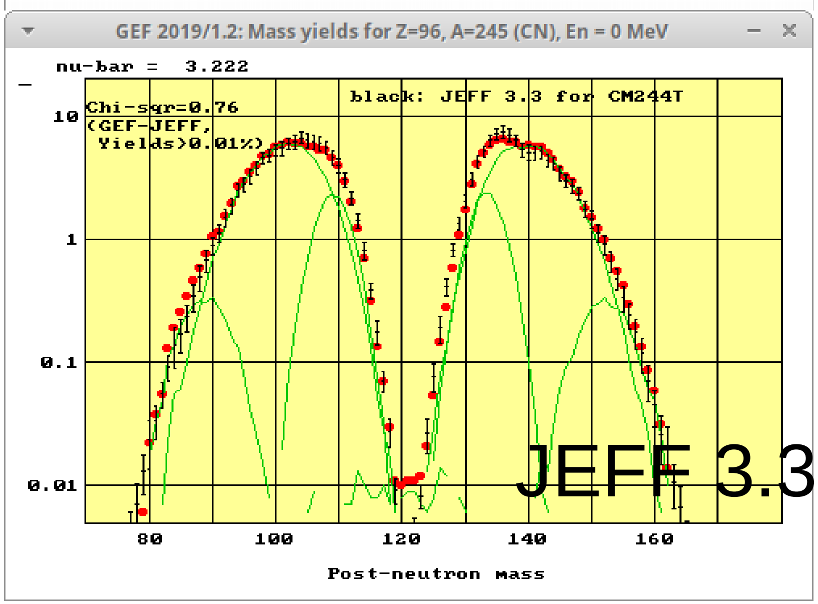
Evaluations

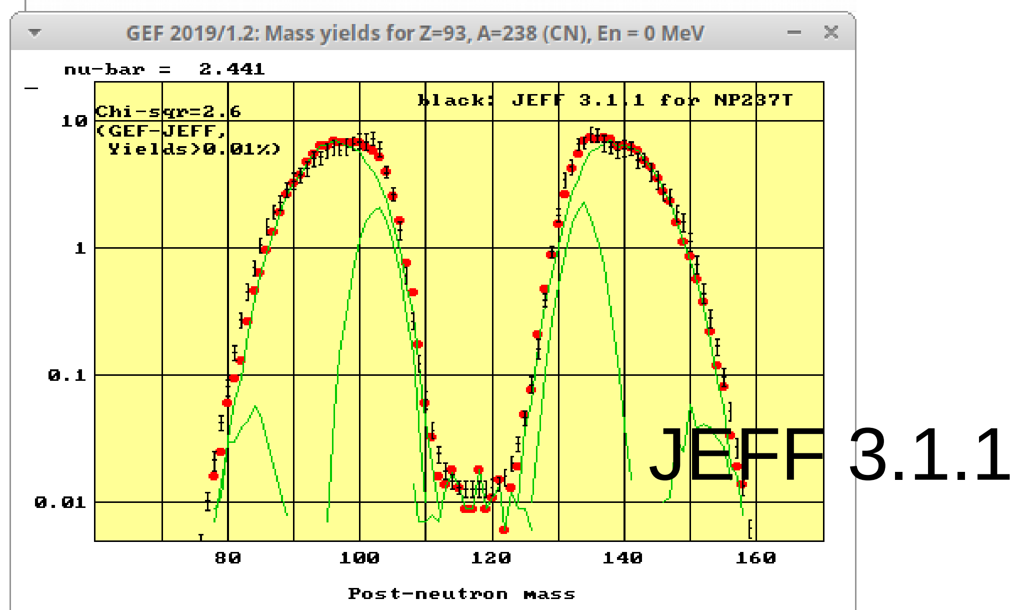
Cm244T

Np237T









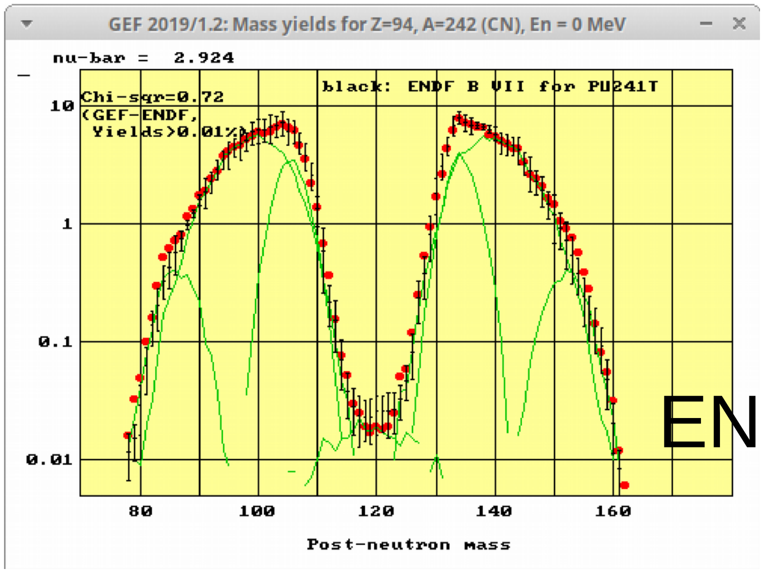
Improvements with time

GEF as reference

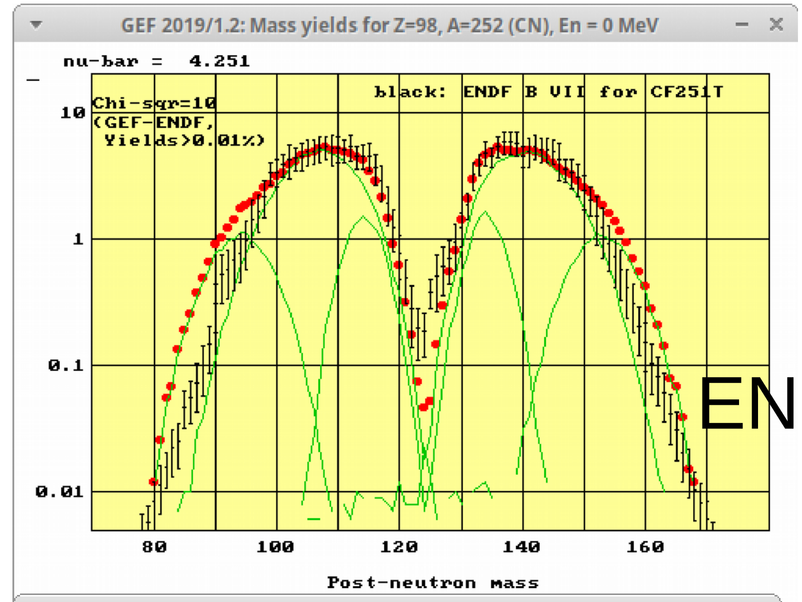
Evaluations / experiments

Pu241T

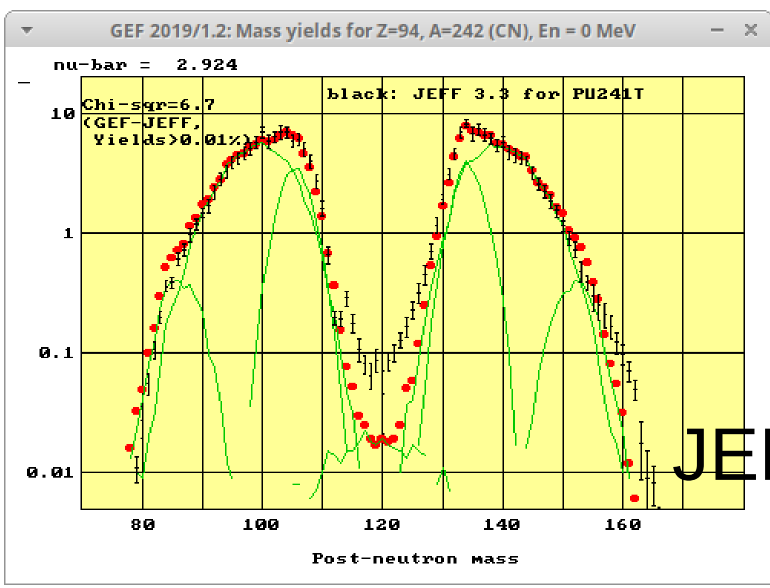
Cf251T



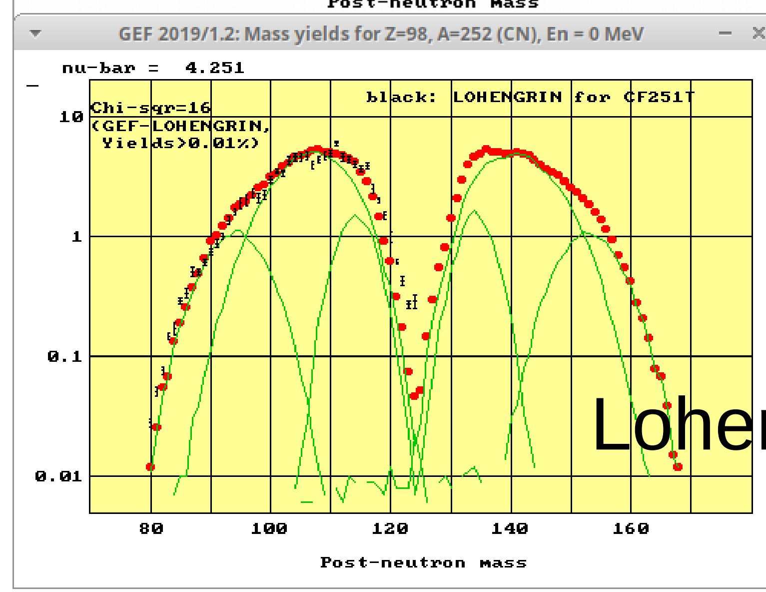
ENDF



ENDF



JEFF

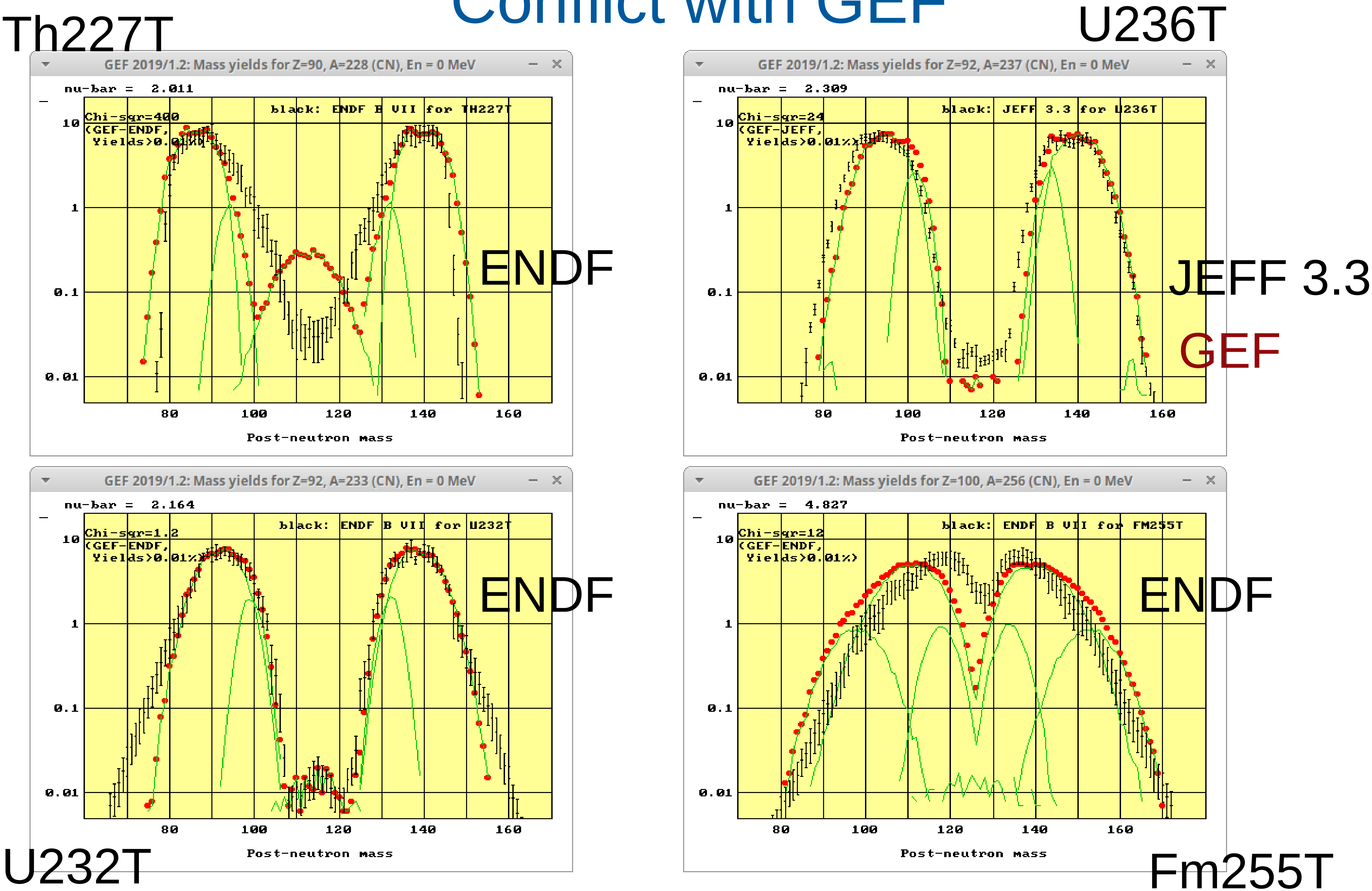


Lohengrin

Inconsistent mass distributions

GEF as reference

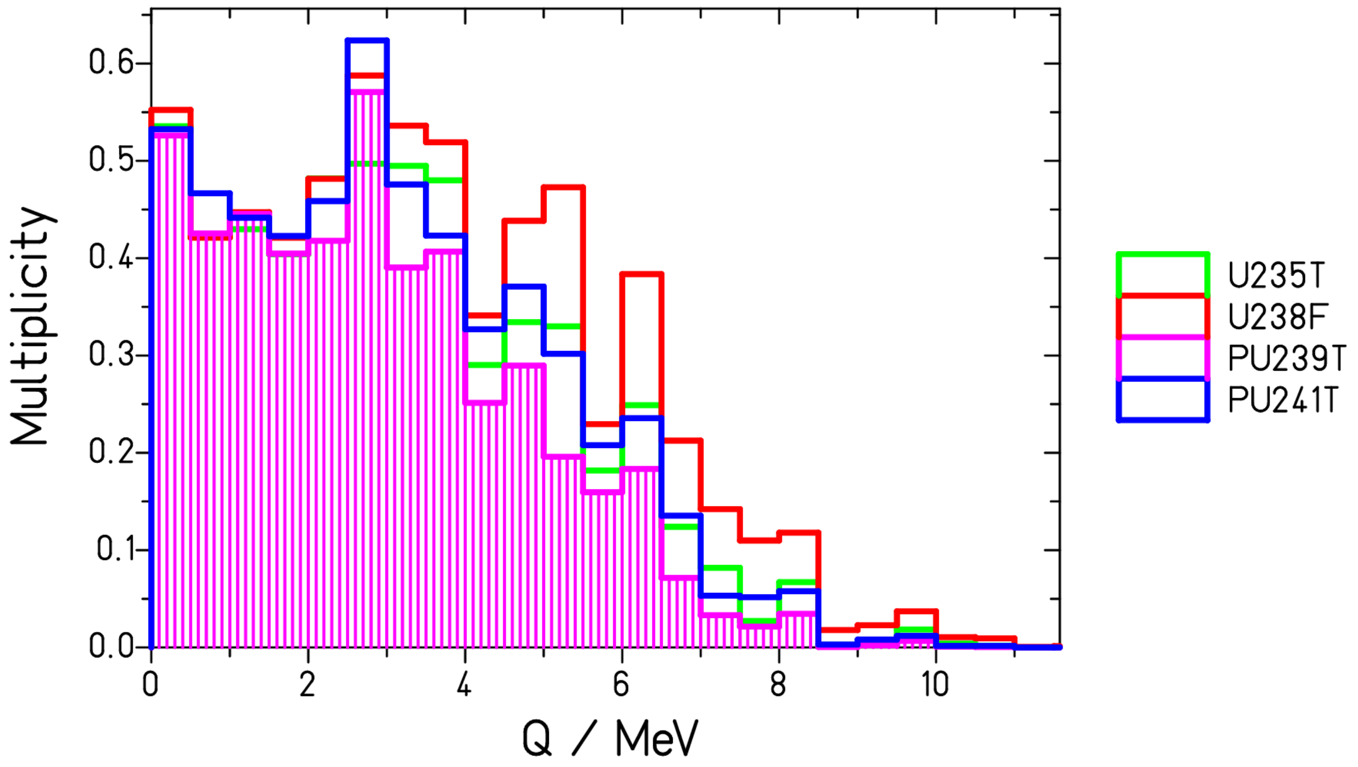
Conflict with GEF



Severe discrepancies

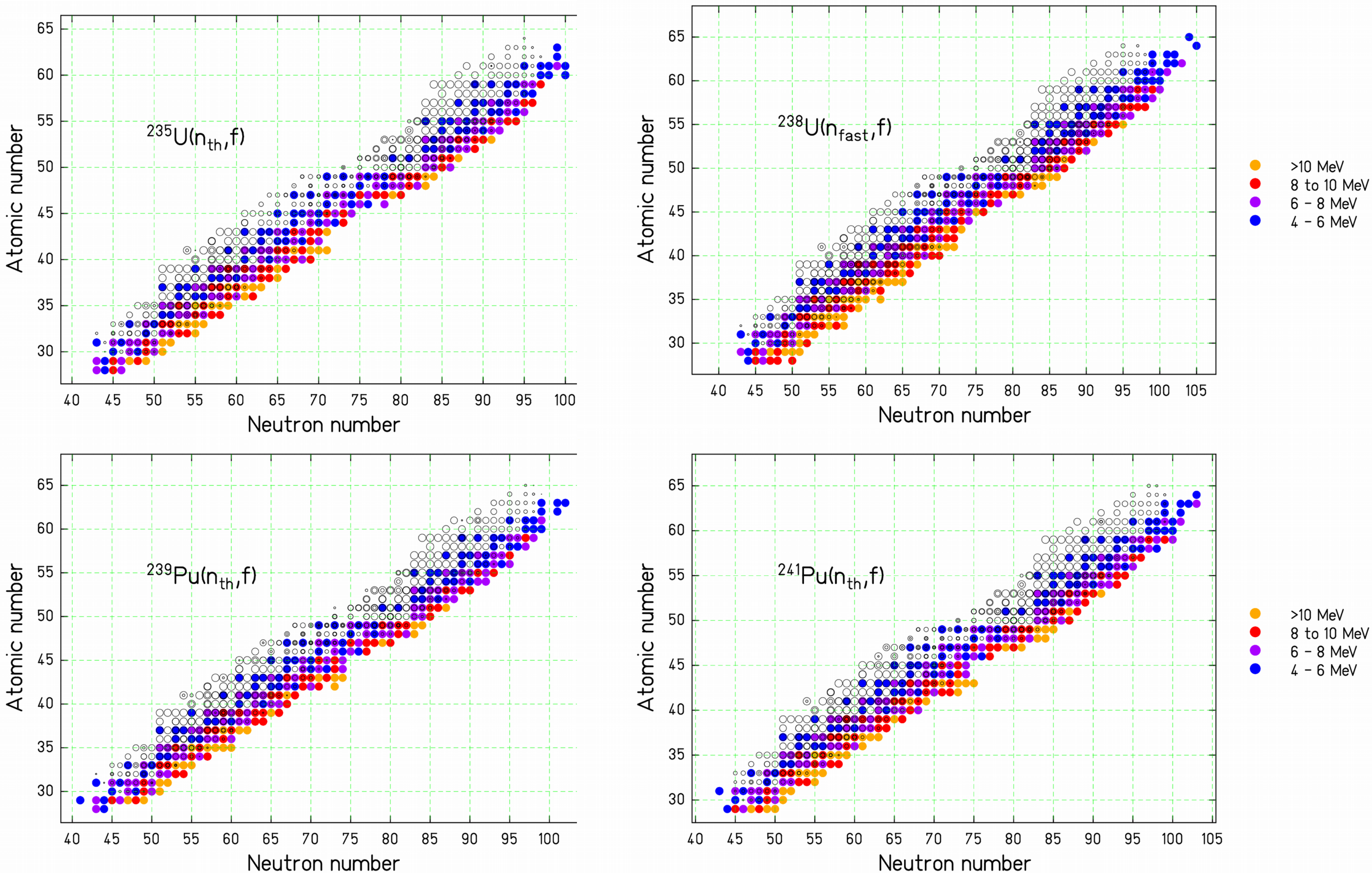
Some GEF calculations
on anti-neutrino production in fission

Spectrum of beta Q values from GEF



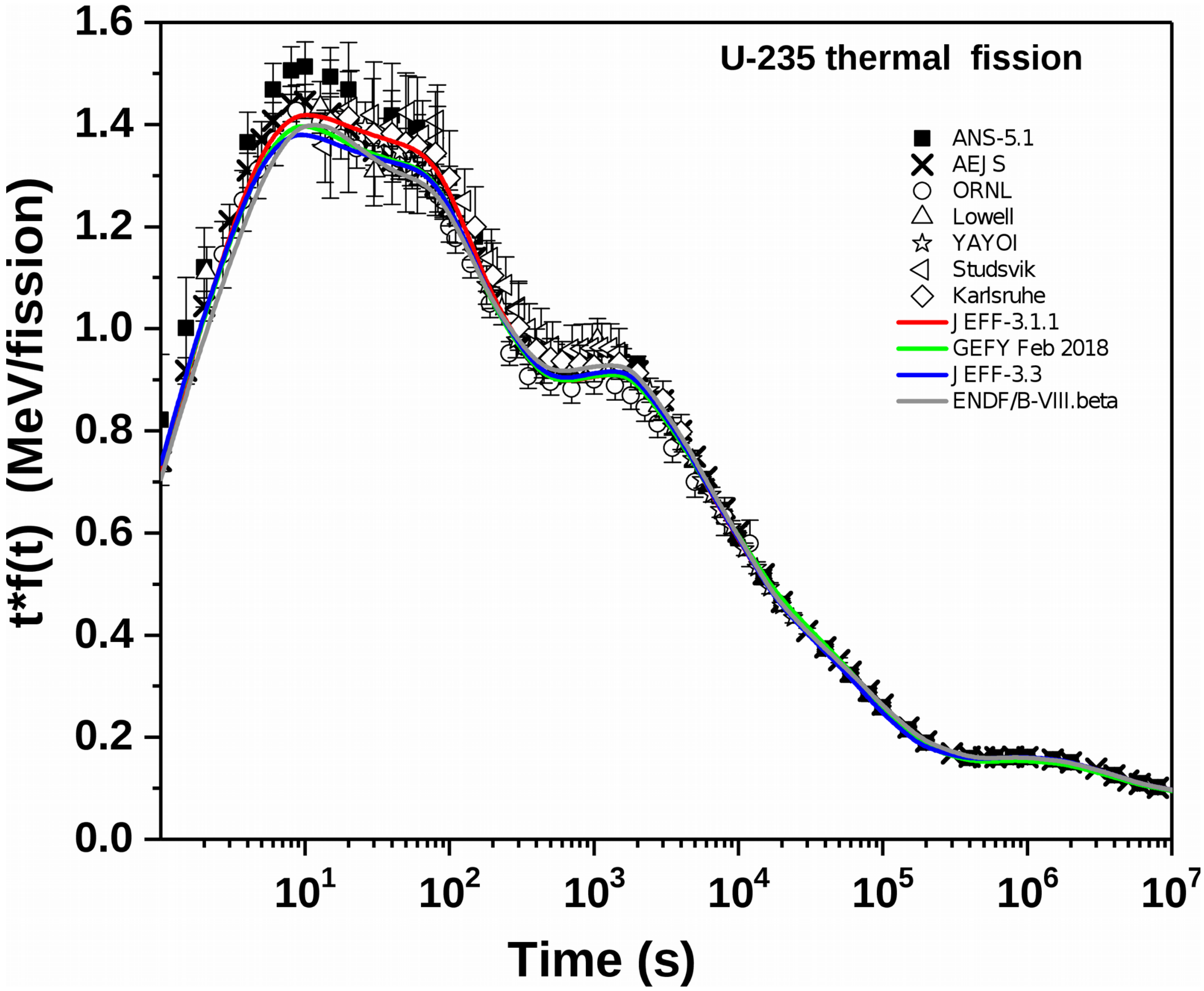
The four main contributors to the anti-neutrino production in a fission reactor.
Different shapes of the beta-Q-value spectra.
Key role of the *N/Z* ratio.
Important for reactor monitoring.

Anti-neutrino emitters from GEF



Q values (colours) and intensities (size of black circles) for orientation and further studies.

Decay heat



Alexey Stankovskiy 2018

Summary

- Evaluations mostly based on radiochemical data. Unambiguous nuclide identification, but only partial coverage. Many restrictions & sources of uncertainties and errors.
- Discrepant FYs from different experiments & evaluations.
- New rules for adjustment of GEF parameters (2019).
- GEF identifies wrong data & predicts unmeasured FYs.
- Many FY from evaluations are clearly wrong. Recommendations are given in the detailed report.
- Improved FYs by inclusion of very accurate kinematical experiments (backbone of new GEF!) and GEF directly.
- GEF provides correlations due to inherent regularities.
- Intensities & Q values of anti-neutrino emitters from GEF.

References

- **"Nuclear fission:
  a review of experimental advances and phenomenology"**
  A. N. Andreyev, K. Nishio, K.-H. Schmidt
  Rep. Progr. Phys. 81 (2018) 016301
- **"Review on the progress in nuclear fission -
  experimental methods and theoretical descriptions"**
  K.-H. Schmidt, B. Jurado
  Rep. Progr. Phys. 81 (2018) 106301
- **"General description of fission observables:
  GEF model code"**
  K.-H. Schmidt, B. Jurado, C. Amouroux, C. Schmitt
  Nucl. Data Sheets 131 (2016) 107

- The **GEF code** is available from
  http://www.khs-erzhausen.de/ and
  http://www.cenbg.in2p3.fr/GEF .