Experimental and Modeling Uncertainties in Cross Section Measurements Utilizing Discrete Gammas

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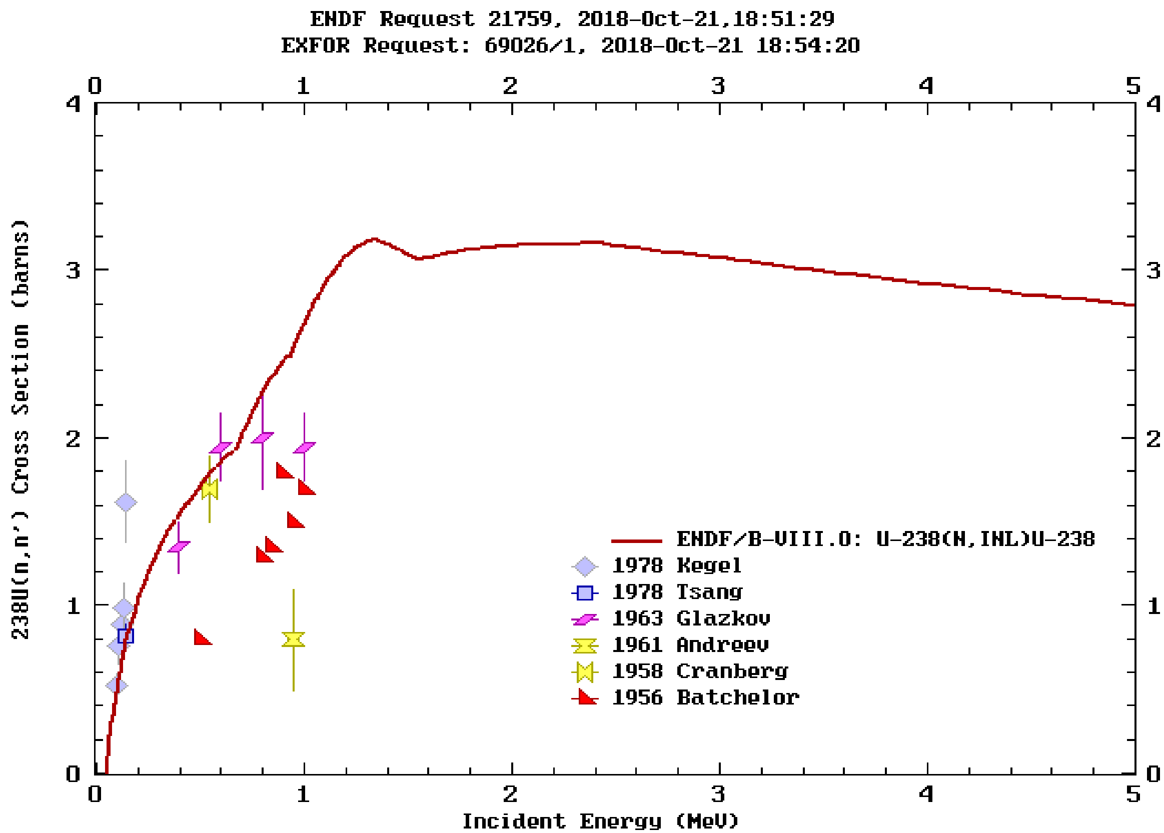
Evaluations often deal with discrepant data sets for the same reaction

- It is important that the data sets are **weighted fairly**, and that the correlations between the data sets are incorporated

- Inconsistent uncertainty analysis between different data sets can lead to biased evaluations



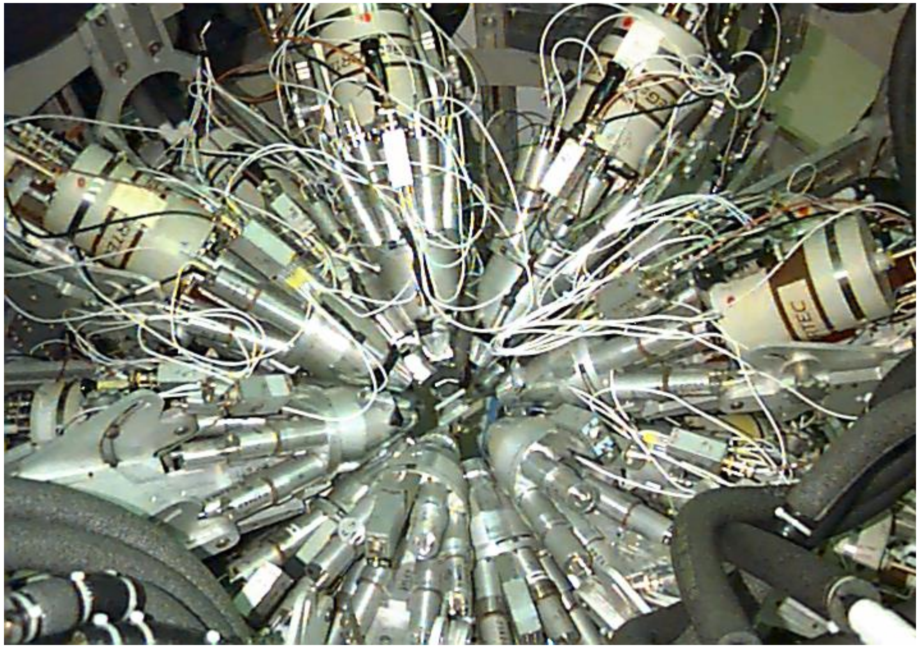
To assist in this process, a template of uncertainties was created for fission cross section measurements

- D. Neudecker, B. Henjal, F. Tovesson, et. al. EPJ. In press.
- This template identifies **all typical sources of uncertainty** and provides reasonable values and correlations within one and between experiments
- The template is then used to:
  - Check provided uncertainty values
  - Fill in missing uncertainty values
  - Fill in missing correlations

- Similar work has been done for
  - RRR – F. C. S. Gunsing, P. Schillebeeckx, V. Semkova, EXFOR Data in Resonance Region and Spectrometer Response Function, Tech. Rep. March 2012, IAEA (2012).
  - Thermal (n,α) reactions - P. Helgesson, Experimental data and Total Monte Carlo, Ph.D. thesis, Uppsala University (2015).

This work focuses on another subset of cross section measurements

- Experiments that measure characteristic discrete gammas to identify the product nucleus
  - Activation
  - GEANIE
- The measurements have been split into six types:
  - Gamma type: prompt, isomer, decay
  - Flux measurement type: monitor, absolute



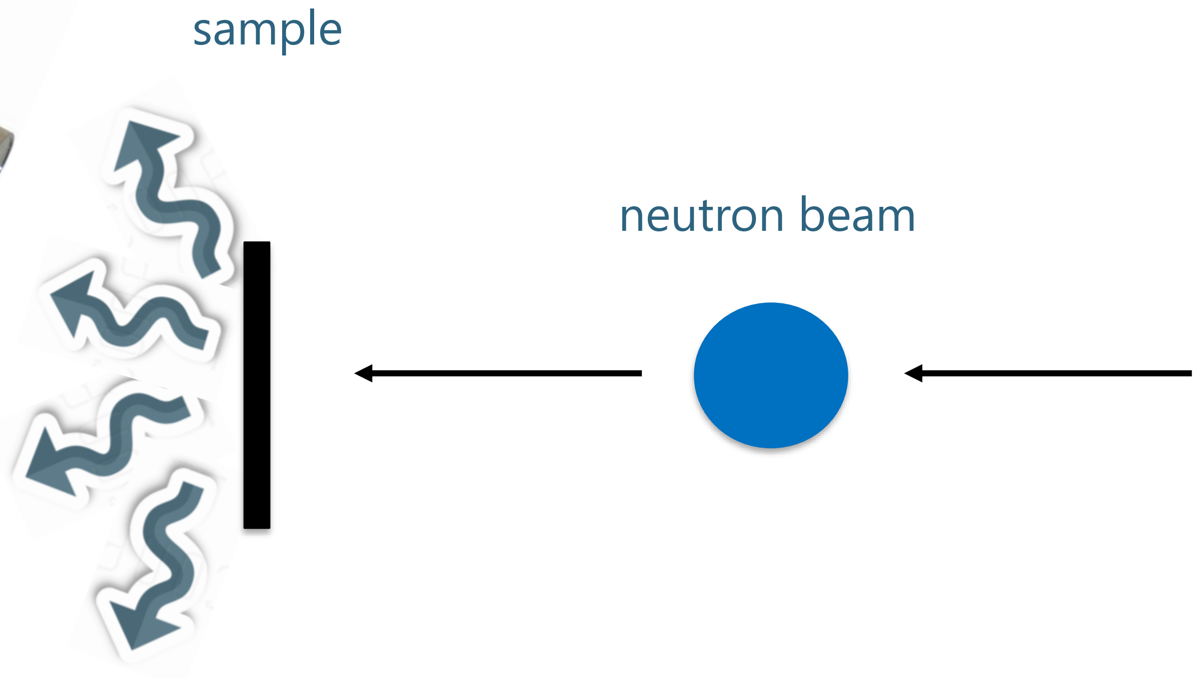
GEANIE detector at WNR-LANSCE

http://lansce.lanl.gov/facilities/wnr/flight-paths/geanie/about.php

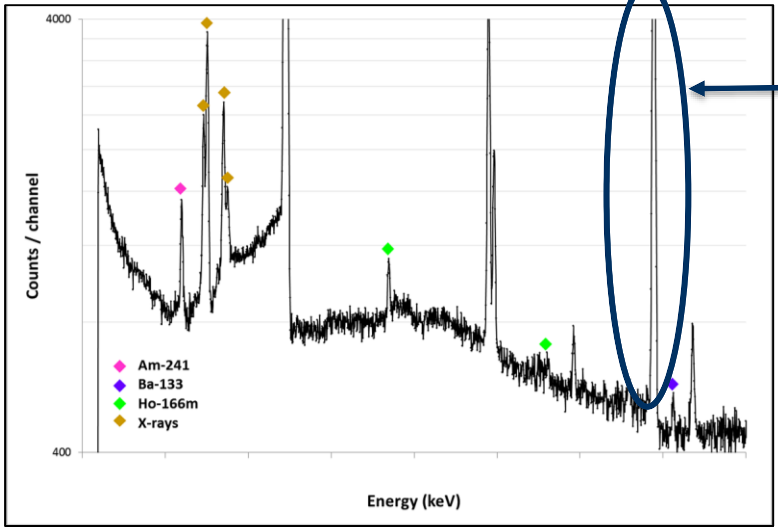
Gammas from the product nucleus are measured

https://caensys.com/hpge_portable/

gamma detector



The detector signal is converted into the number of gammas from which a cross section is calculated

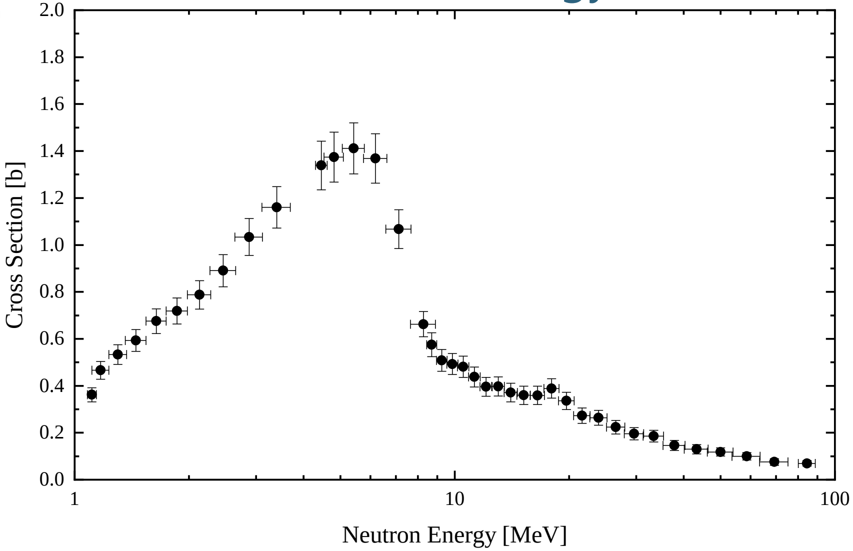


counts of the gamma at one neutron energy

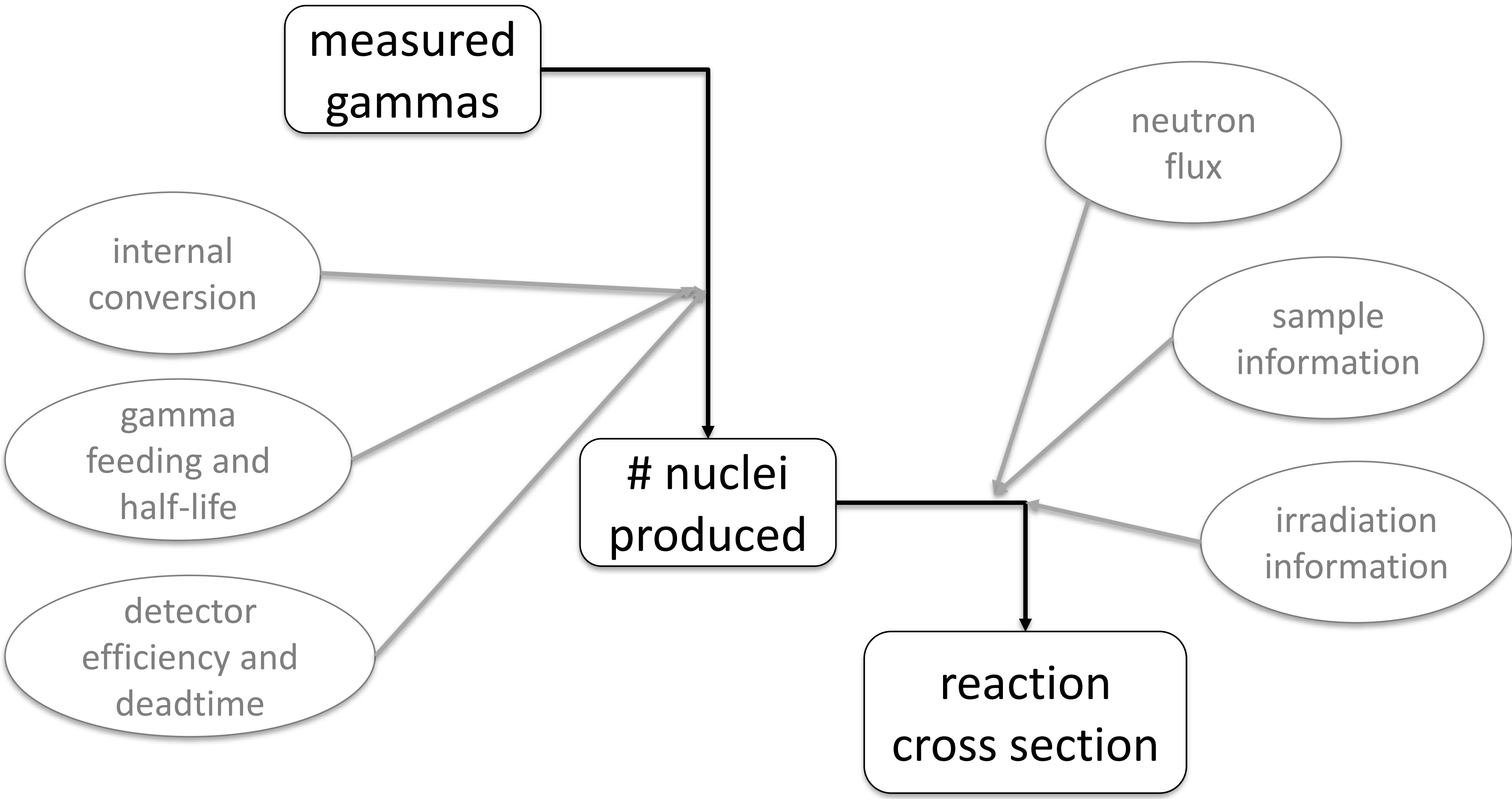
detector signal - gamma spectrum

https://carlwillis.wordpress.com/2012/08/19/gamma-analysis-of-chagan-atomsite/0_400kev_small/

cross section of the gamma line as a function of neutron energy



A lot of information is needed to get from the number of gammas to a cross section



The most important sources of uncertainty in this analysis process were determined

- Sample Uncertainties
  - Mass
  - Isotopic composition
  - Gamma attenuation
- Gamma Detector
  - Efficiency
  - Deadtime Correction
  - Counts
- Neutron Source Uncertainties
  - Flux
  - Energy, Resolution
  - Irradiation Geometry
- Nuclear Data
- Gamma Fractional Feeding Intensity

The template presents reasonable values for the uncertainties in tables

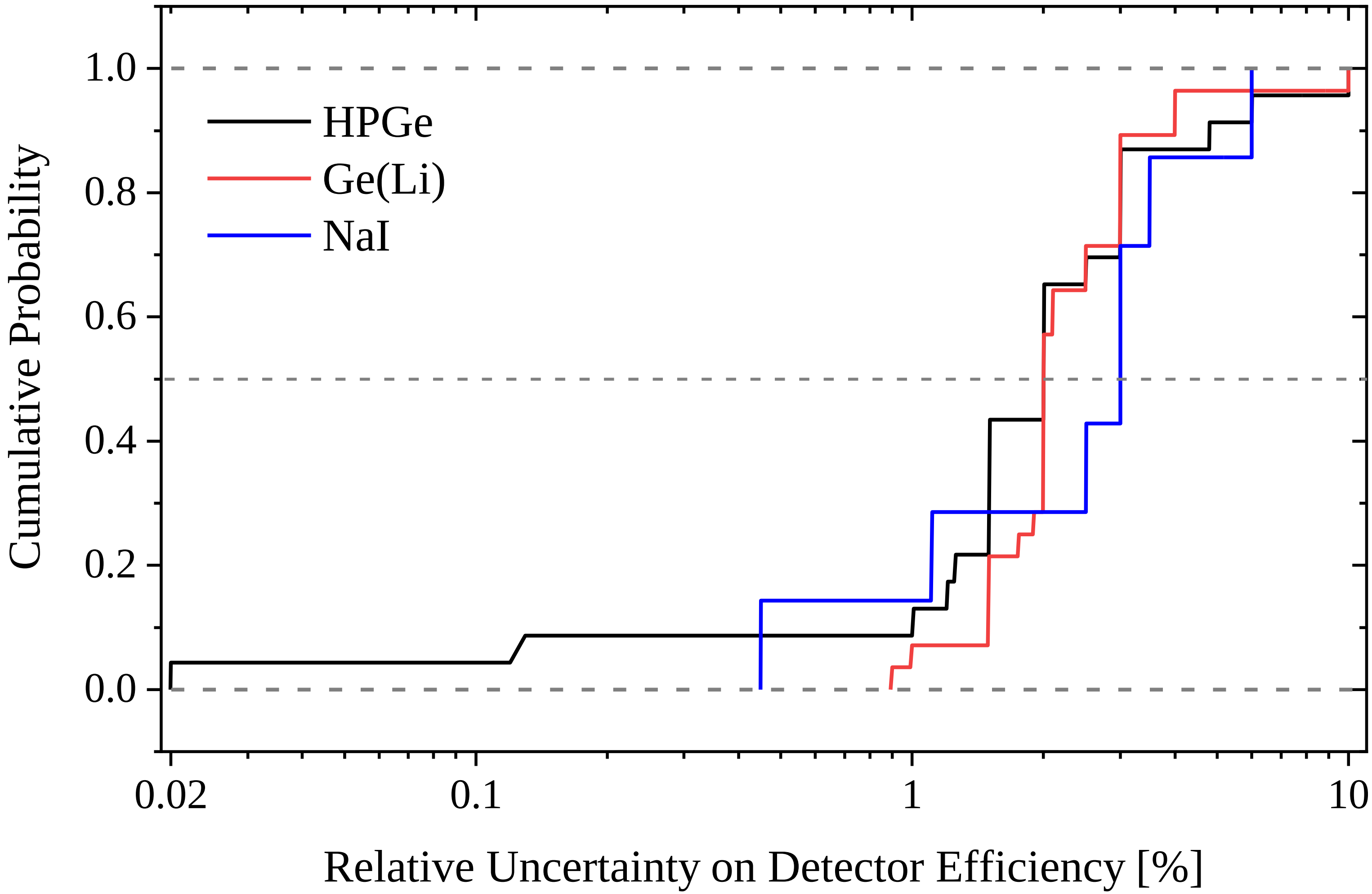
- Distributions of uncertainties were compiled from EXFOR

Sample type	Mass (m)	Isotopic Abundance (w)	Self-Absorption (ξ)
Stable Metal	0.3 (21)	0.2 (10)	0.7 (17)

Detector type	Efficiency (ε)
HPGe	2.0 (23)
Ge(Li)	2.0 (28)
NaI	3.0 (7)

Source type	Flux (ϕ)	Energy (E_n)	Resolution
Associated Particle	1.0 (8)	1.3 87)	0.7 (10)
Gas Target Generator	3.0 (9)	1.0 (9)	2.3 (6)
Solid Target Generator	2.6 (18)	0.7 (26)	1.7 (11)
Time-of-flight	2.0 (28)	2.9 (22)	5.7 (20)

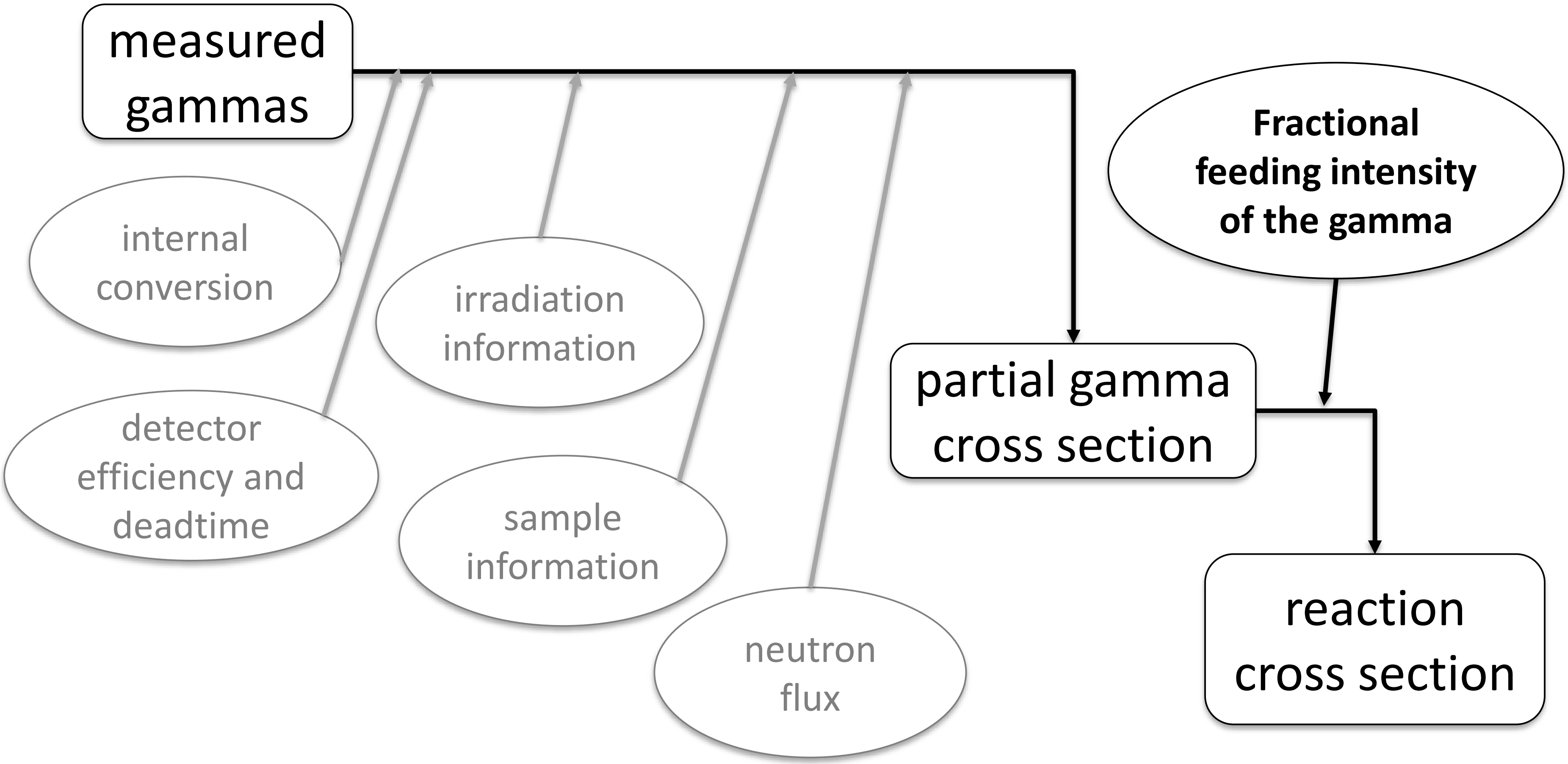
Distributions of uncertainty values have been compiled from EXFOR



Correlations between the data points have been estimated for each source

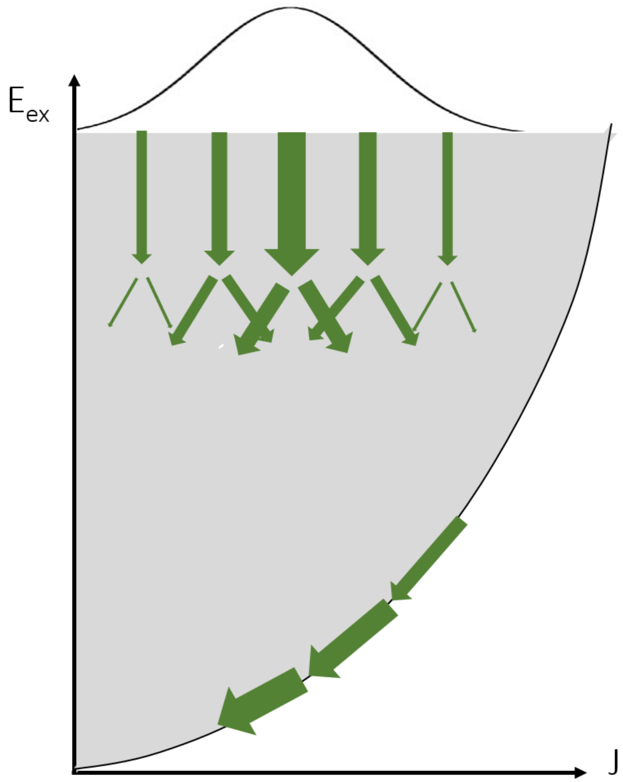
- Many sources were **fully correlated**
  - Sample uncertainties
  - Detector uncertainties
- Neutron source uncertainties were **gaussian**
- In the case of monitor experiments, there are correlations between the sample and monitor sources of uncertainty

In the case of prompt gammas, the data analysis steps are different – a partial gamma cross section is calculated first



The fractional feeding intensity must be calculated by a gamma cascade model

- Knowing the intensity of the gamma requires modeling
  - Angular momentum brought in
  - Spin distribution of level density
  - Gamma strength function
  - Discrete level branching ratios
- These factors determine feeding of the yrast band

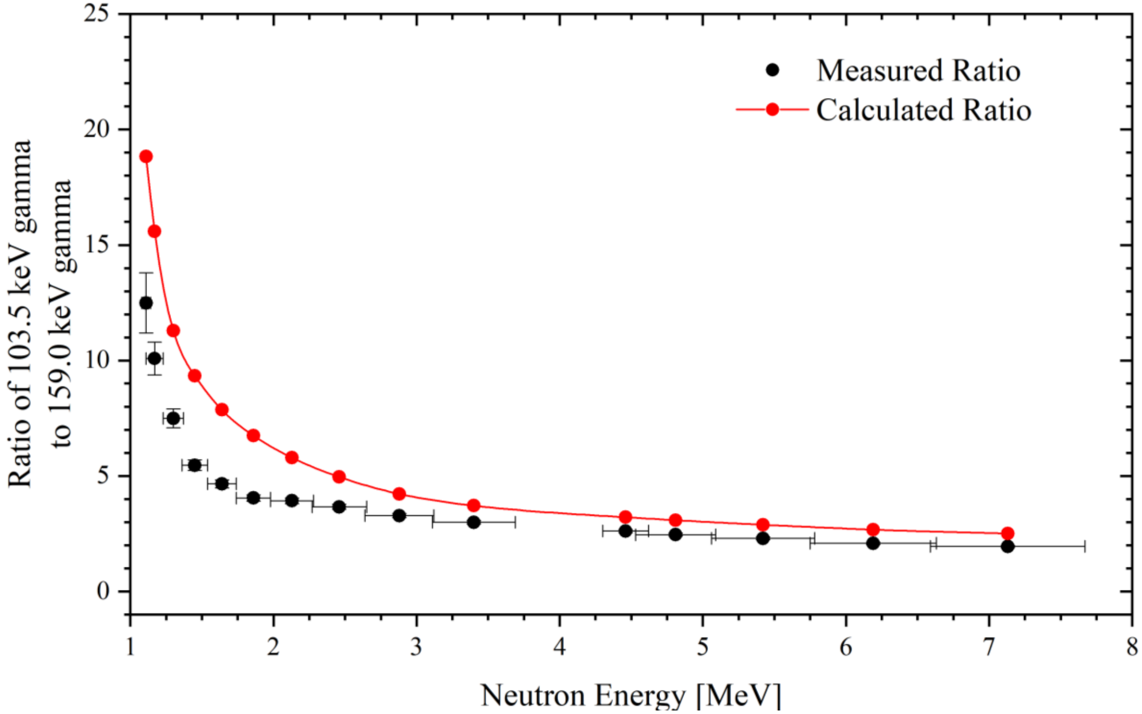


The uncertainty put on the fractional feeding intensity should represent how well the model matches the data overall

- Rather than a "model deficiency" this uncertainty represents the **inconsistency between the model and data**

- The average inconsistency is calculated as a **weighted average** of differences between calculated and measured ratios

N.Fotiades, PRC 69, 2004



This method has been applied to a GEANIE ^{238}U(n,inl) data set from 2004

PHYSICAL REVIEW C **69**, 024601 (2004)

Measurements and calculations of ^{238}U$(n, xn\gamma)$ partial γ-ray cross sections

N. Fotiades, G. D. Johns, R. O. Nelson, M. B. Chadwick, M. Devlin, M. S. Wilburn, and P. G. Young
Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA

J. A. Becker, D. E. Archer, L. A. Bernstein, P. E. Garrett, C. A. McGrath,* D. P. McNabb, and W. Younes
Lawrence Livermore National Laboratory, Livermore, California 94550, USA
(Received 18 June 2003; published 6 February 2004)

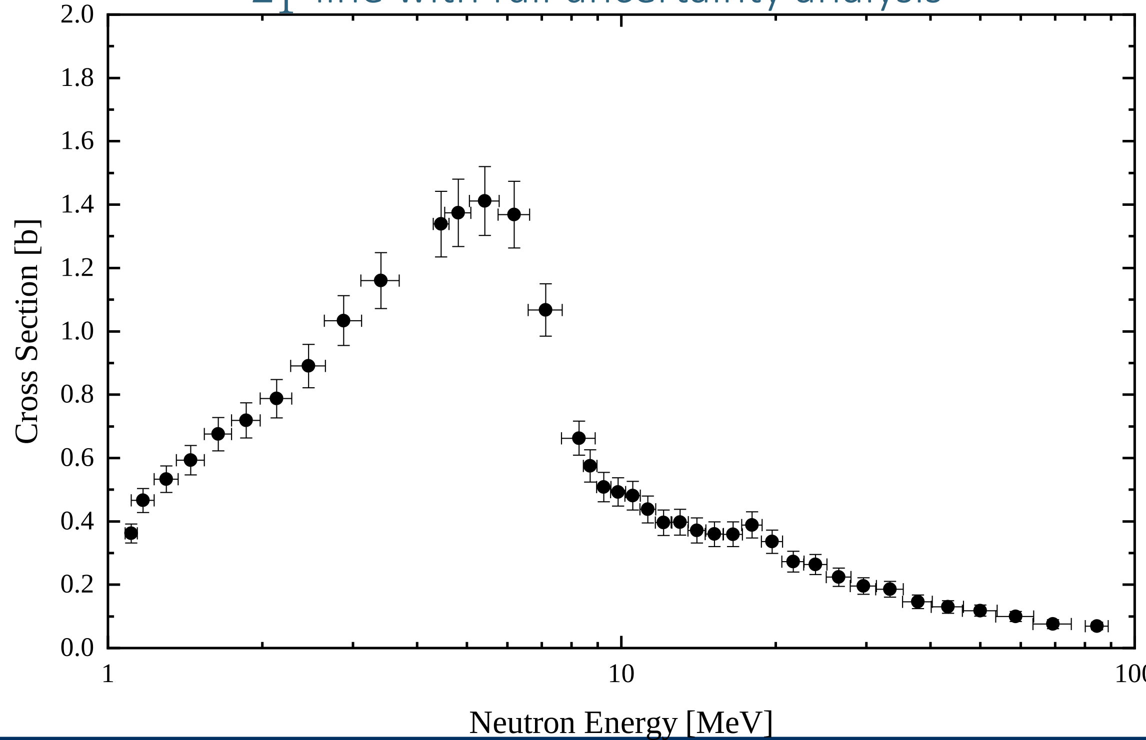
Absolute partial cross sections for production of 45 discrete γ rays in the ^{238}U$(n, xn\gamma)$ reactions with $x \leqslant 4$ are reported for incident-neutron energies in the range 1 MeV $< E_n <$ 100 MeV. A germanium-detector array for γ-ray detection and the "white"-neutron source at LANSCE/WNR were used for the measurement. The energy of the incident neutrons was determined using the time-of-flight technique. The data are compared with previous measurements and with theoretical predictions up to E_n=30 MeV from the GNASH reaction model. The combination of experimental results with theoretical calculations provides a means to deduce the ^{238}U(n, n') reaction cross section.

DOI: 10.1103/PhysRevC.69.024601 PACS number(s): 25.40.Fq, 28.20.−v, 21.10.−k

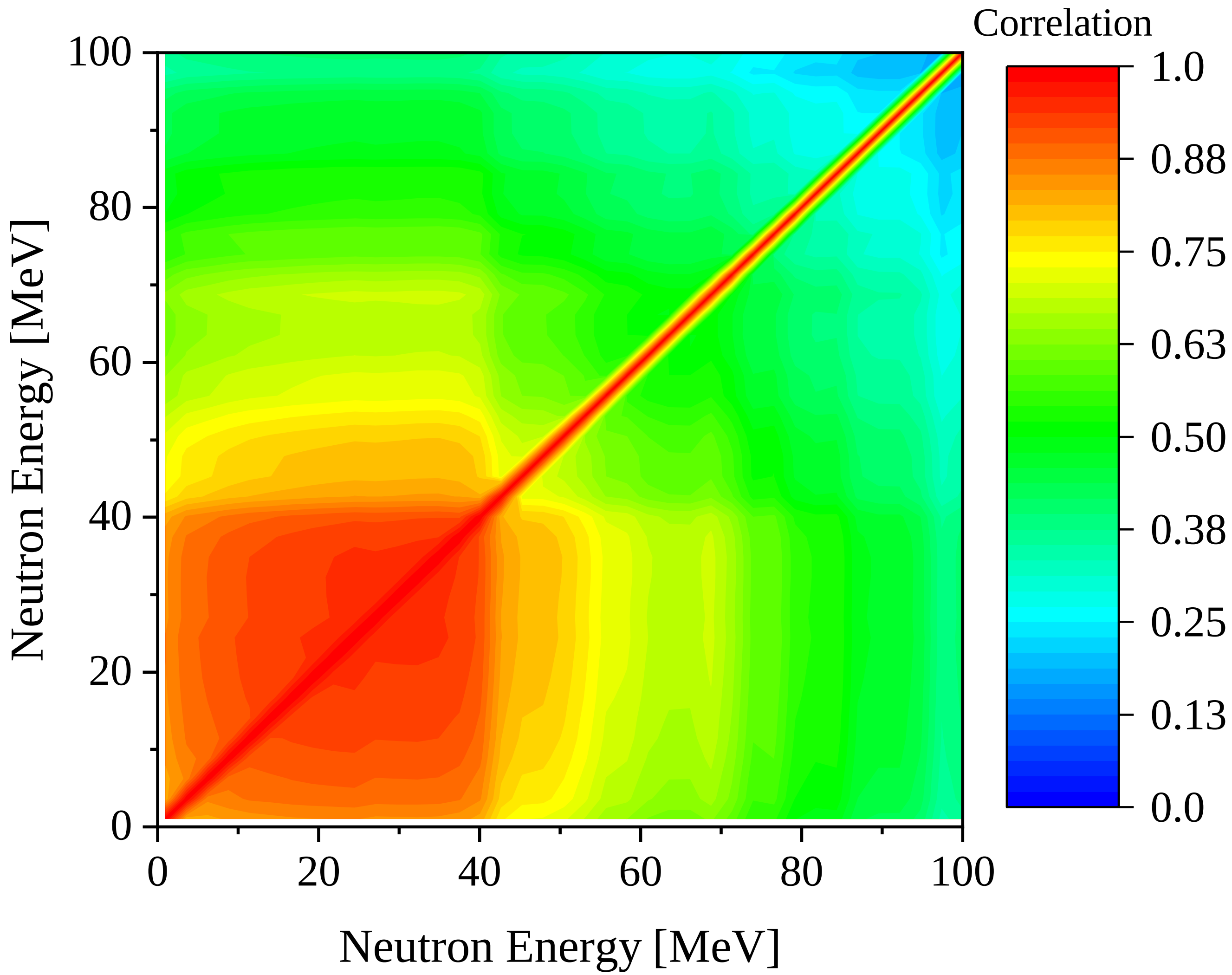
The measured partial gamma cross sections were combined to determine the total inelastic scattering cross section

- The final step was to use **16 of the lines** and their calculated cross sections to determine the total inelastic cross section
- All sources of uncertainty were given except
  - Internal conversion coefficients
  - Sample isotopic composition
  - Gamma fractional feeding intensities

Partial cross section for the 103.5 keV $4_1^+ \rightarrow 2_1^+$ line with full uncertainty analysis

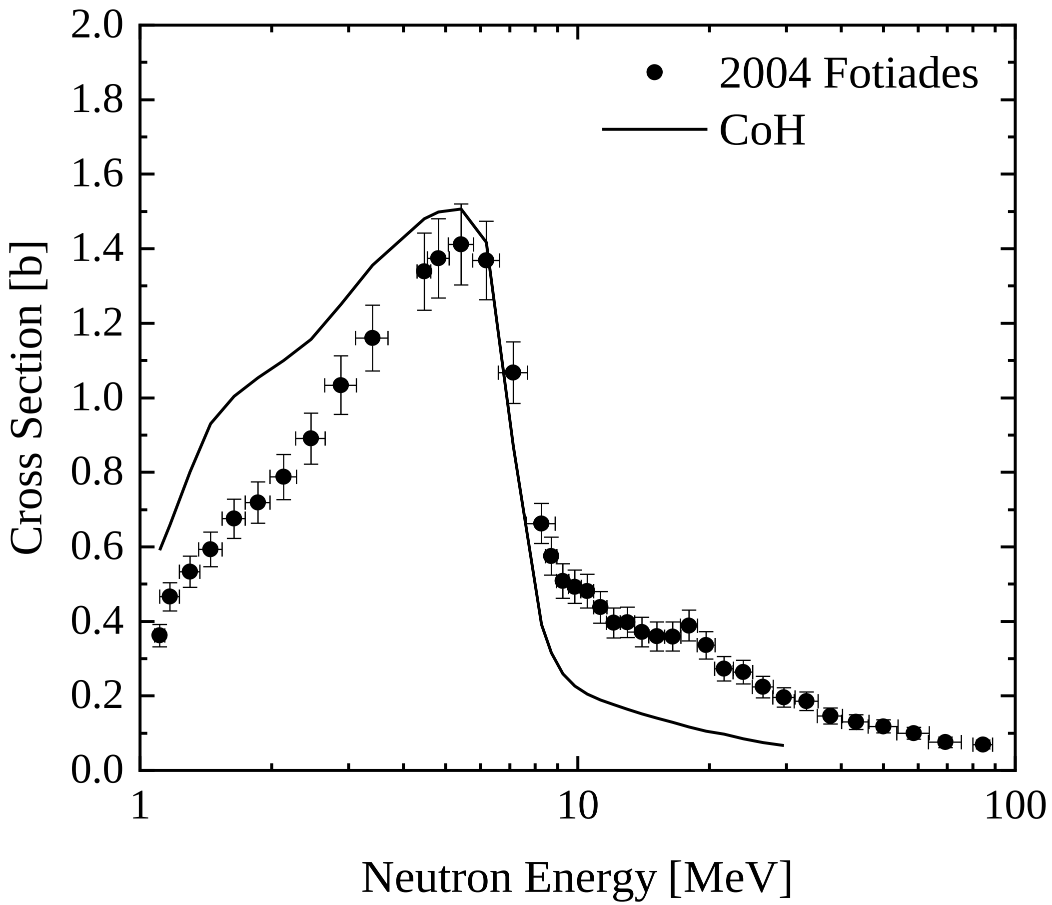


Correlations between data points for the 103.5 keV gamma

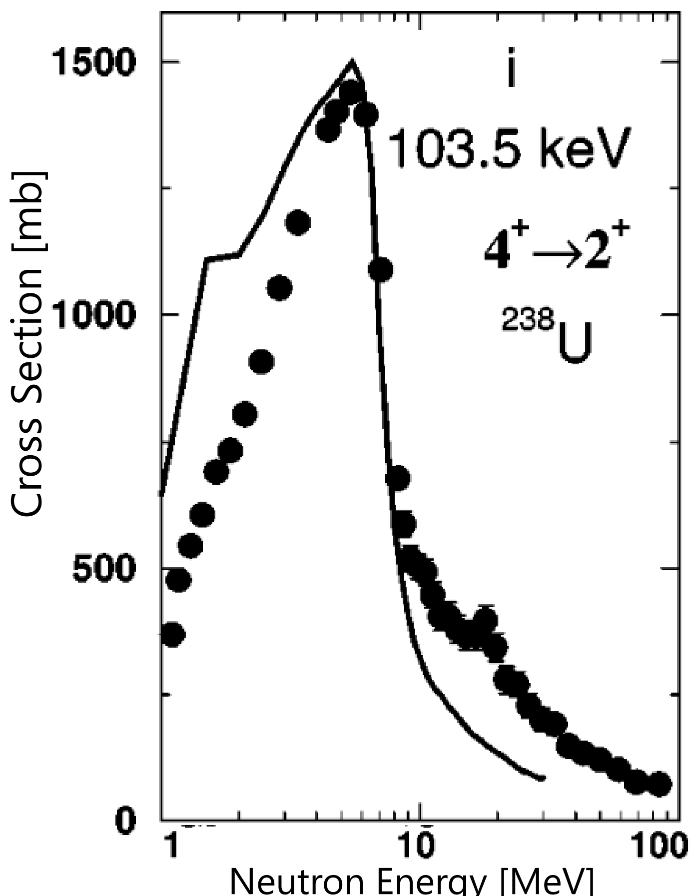


There are large inconsistencies in the shape and magnitude of the 103.5 keV gamma

2018 CoH calculation



2004 GNASH calculation

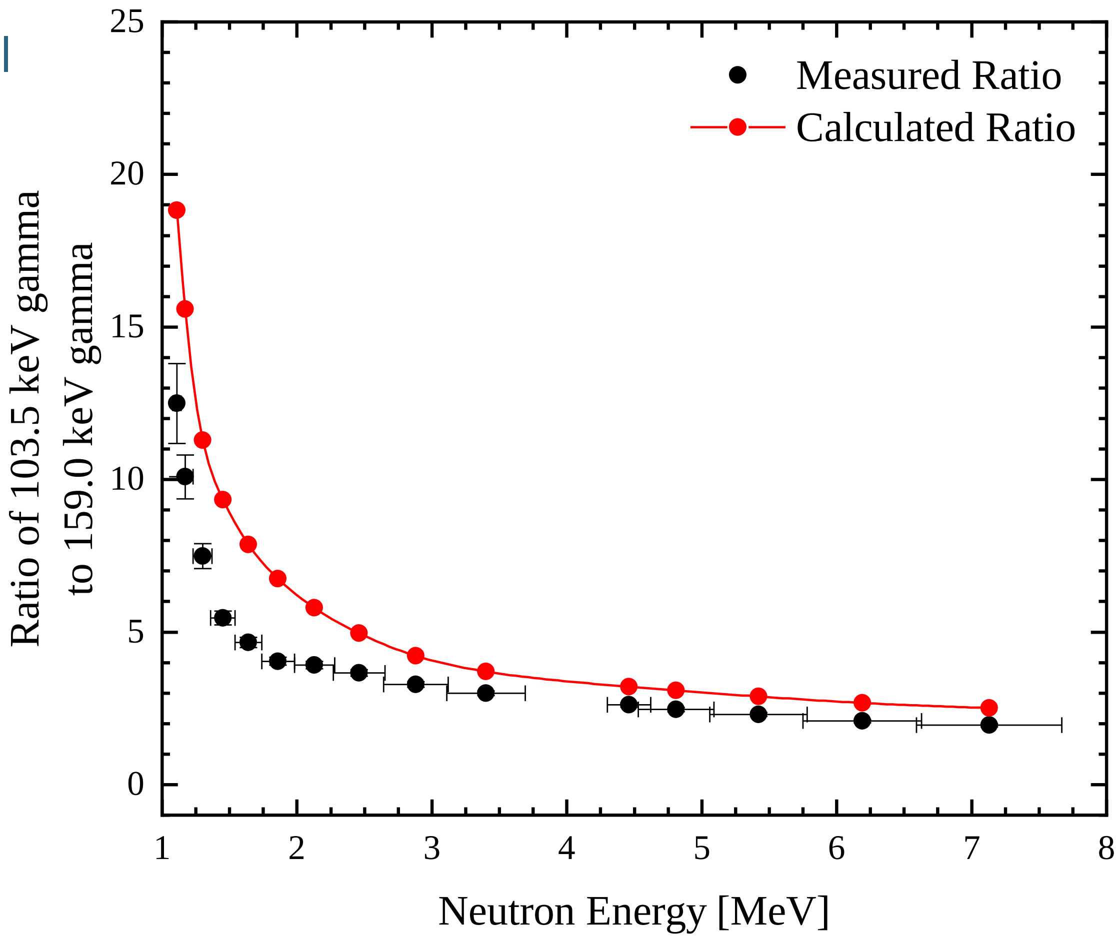


N.Fotiades, PRC 69, 2004

The inconsistency has been measured in three forms

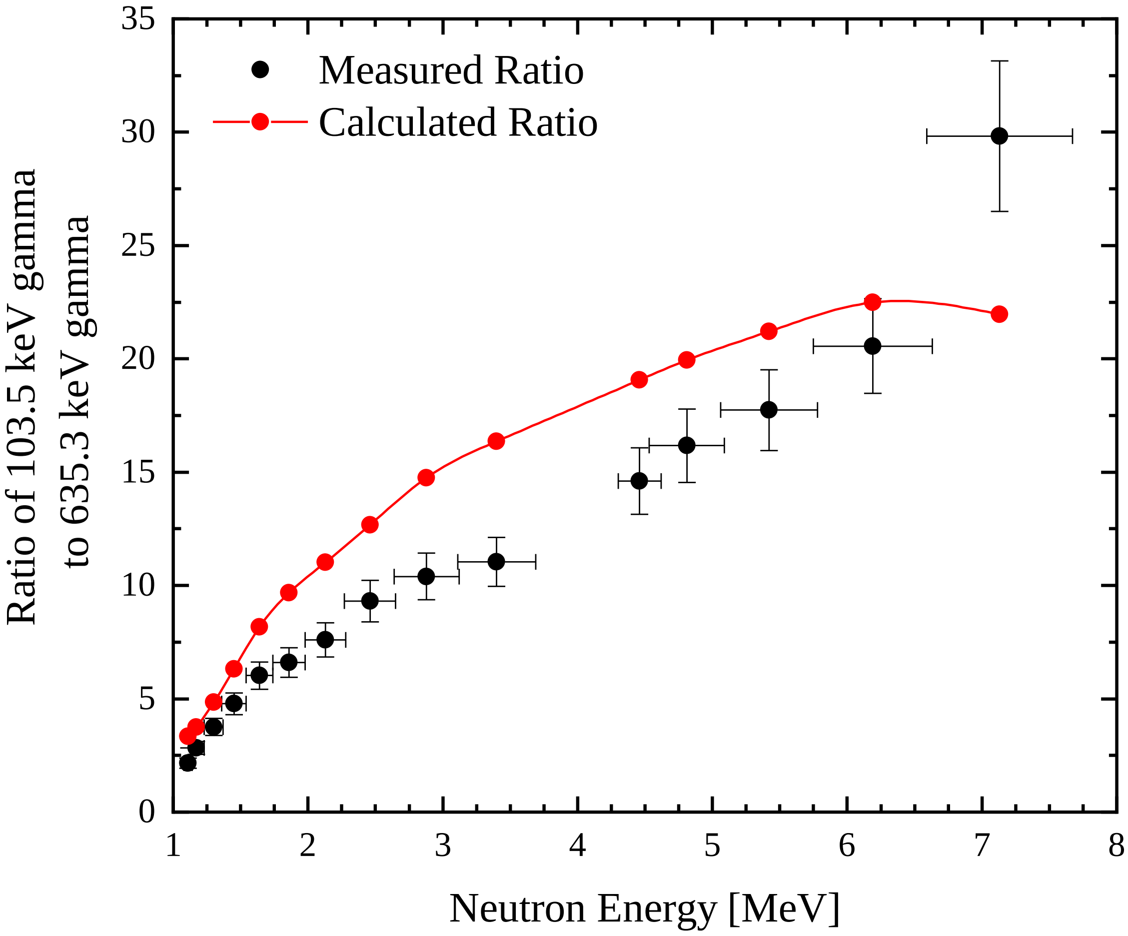
- All weighted by the experimental uncertainty, with correlations accounted for

- **The ratio of the yrast 4_1^+ - 2_1^+ transition to the yrast 6_1^+ - 4_1^+ transistion**



The inconsistency has been measured in three forms

- All weighted by the Fotiades uncertainty, with correlations accounted for
- The ratio of the yrast 4_1^+- 2_1^+ transition to the yrast 6_1^+- 4_1^+transistion
- **The ratio of the yrast 4_1^+- 2_1^+ transition to the 1_1^- - 2_1^+ transition**



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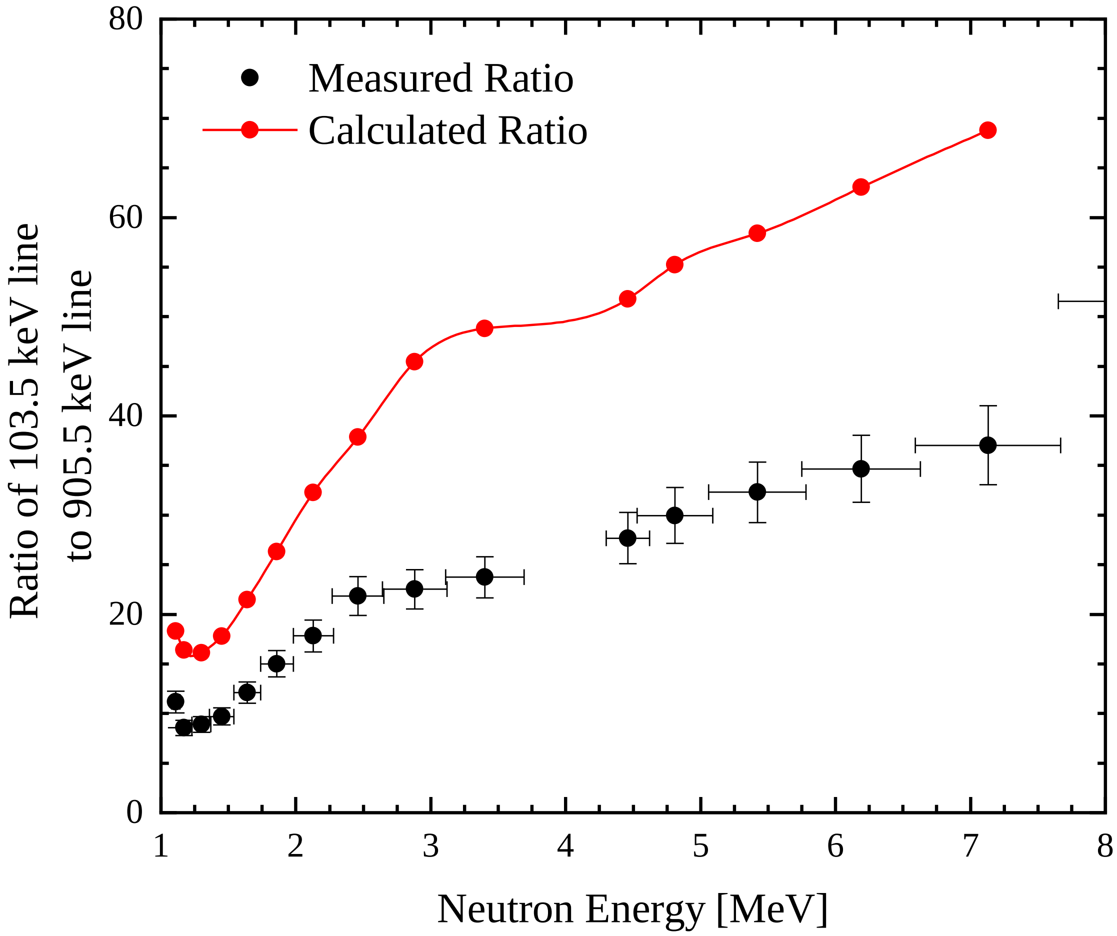
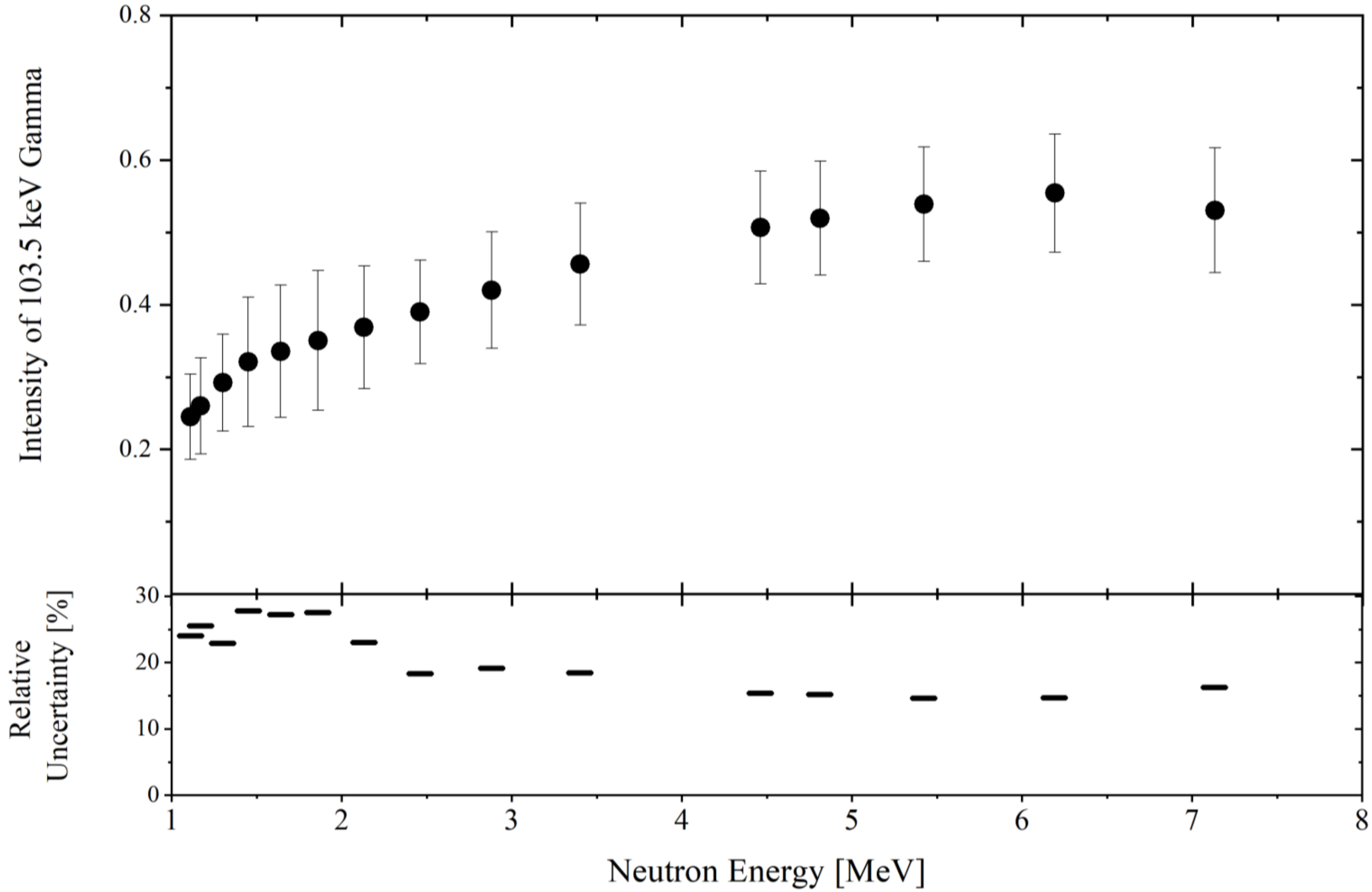
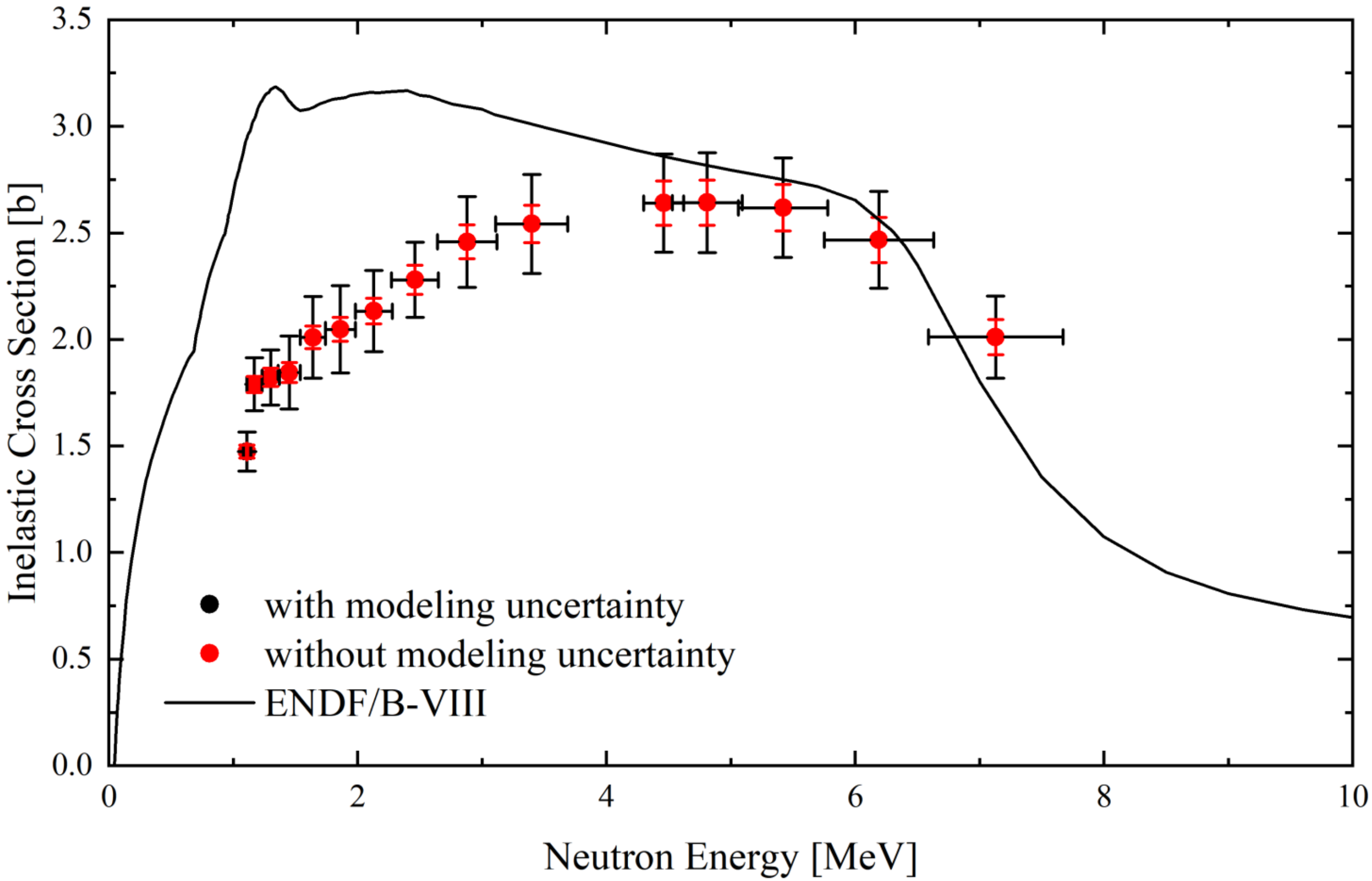
- The ratio of the yrast 4_1^+- 2_1^+ transition to the yrast 6_1^+- 4_1^+transistion
- The ratio of the yrast 4_1^+- 2_1^+ transition to the 1_1^- - 2^+ transition
- **The ratio of the yrast 4_1^+- 2_1^+ transition to the 2_1^- - 2_1^+ transition**



This lead to large uncertainties on the gamma feeding intensity



Using just this one gamma gives a channel cross section with a large uncertainty – but still smaller than the discrepancy with the evaluation



Summary

- A template has been created for cross section experiments that measure characteristic discrete gammas
- A method has been developed to incorporate model-data inconsistency into the channel cross section uncertainty
- The template and modeling uncertainties should be used to ensure consistent treatment of datasets
- This method has been applied to a GEANIE dataset, showing how to estimate uncertainty on the fractional feeding intensity of one gamma

Acknowledgements

- Denise Neudecker, Toshihiko Kawano for hosting me and providing guidance and help
- Matthew Devlin, Lee Bernstein, Eric Matthews, Jon Morrell for answering questions

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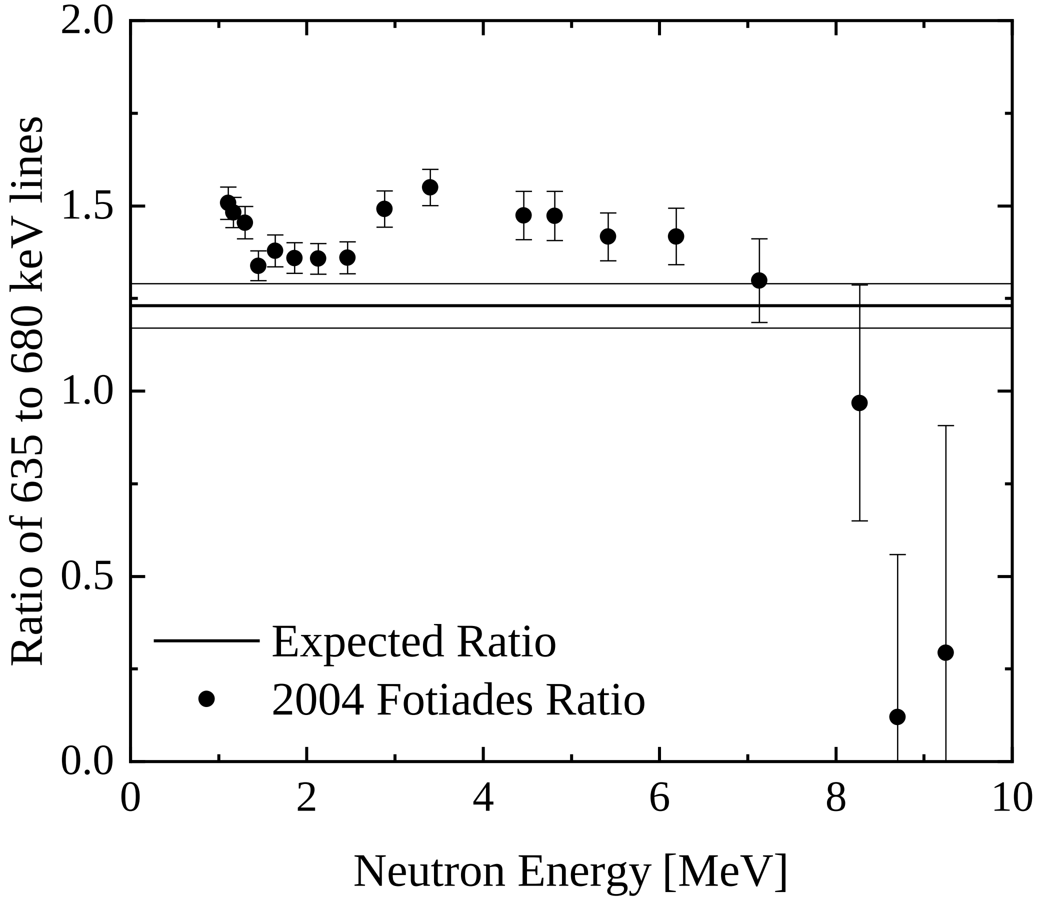
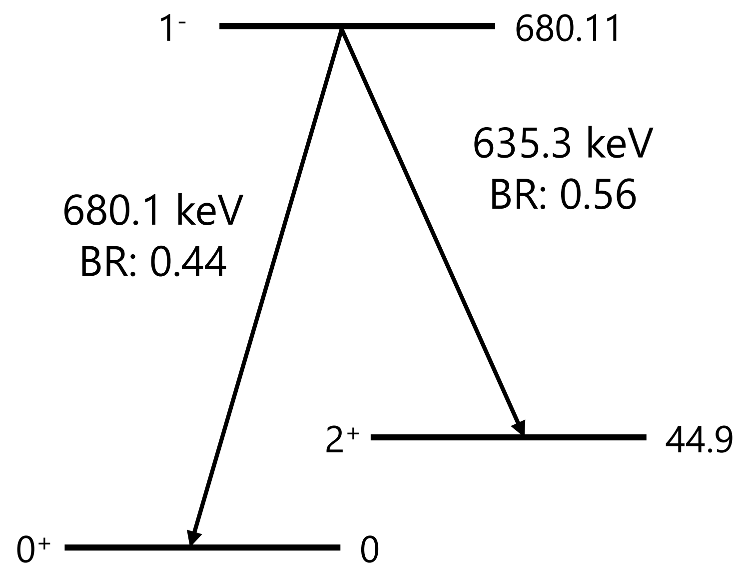
Extra Slides

Measured branching ratios are an example of "data deficiency"





The gamma feeding intensity uncertainty is calculated by a weighted average of the differences between the calculated and measured ratios

$$\bar{\Delta}(E_n) = \sum_{i=1}^{3} \frac{|\Delta_i(E_n)|}{R_i^{exp}(E_n)} w_i(E_n)$$

$$w_i(E_n) = \frac{\frac{R_i^{exp}(E_n)}{\delta_i(E_n)}}{\sum_{j=1}^{3} \frac{R_j^{exp}(E_n)}{\delta_j(E_n)}}$$

$R_i^{\mathrm{exp}} =$ experimental value of ratio i

$\delta_i =$ experimental unc of ratio i

$$\bar{\Delta}(E_n) = \sum_{i=1}^{3} \frac{|\Delta_i(E_n)|}{R_i^{exp}(E_n)} \frac{\frac{R_i^{exp}(E_n)}{\delta_i(E_n)}}{\sum_{j=1}^{3} \frac{R_j^{exp}(E_n)}{\delta_j(E_n)}}$$

$$\bar{\Delta}(E_n) = \frac{\sum_{i=1}^{3} \frac{|\Delta_i(E_n)|}{\delta_i(E_n)}}{\sum_{j=1}^{3} \frac{R_j^{exp}(E_n)}{\delta_j(E_n)}}$$

The covariance matrix is calculated using the sandwich formula

- This is a first-order linear approximation

$$\mathrm{cov}_{x,y}(\sigma_i, \sigma_j) = \left.\frac{\partial \sigma}{\partial x}\right|_{x_i} \delta x_i \; \mathrm{cor}(x_i, y_j) \; \delta y_j \left.\frac{\partial \sigma}{\partial y}\right|_{y_j}$$

The correlations between uncertainties in different experiments have also been estimated

- Sample uncertainties were **highly correlated**
- Detector and neutron source uncertainties depend on the type of facility and group
- Nuclear data depends on the library used
- Counts were treated as **independent**

The updated uncertainties are slightly larger than the given uncertainty