Oak Ridge National Laboratory
1 Bethel Valley Road
Oak Ridge, Tennessee 37830

Subject: Report on Foreign Travel to Vienna IAEA (virtual meeting)

Date: 01/10/2022

To: Dr. Angela Chambers, Nuclear Criticality Safety Program Manager, National Nuclear Security Administration / NA-511

From: Marco T. Pigni

Meeting Title: Consultancy Meeting of the International Nuclear Data Evaluation Network (INDEN) on Actinide Evaluation in the Resonance Region

Meeting Location: Vienna (Vritually)

Meeting Date: 1-4 November 2021

Attendees on behalf of NCSP:

Meeting Purpose:
The purpose of the event is to discuss and exchange evaluation methodologies in the resonance region, and further coordinate the activities in different laboratories with the final goal of obtaining consistent evaluated data files of fissile actinides that respect the differential data (particularly the thermal constants of Standards-2017, softer PFNS and new cross section measurements) and preserve good performance in criticality benchmarks.

Meeting Benefits to the NCSP:
U233,235U and 239Pu RRR evaluations are listed in the APPENDIX B and part of the milestones in the NCSP.

Purpose of Travel:

To present latest results on fissile actinides. RES ID 169852. (See attached)

Persons Contacted at Meeting:

Presentations, Chair Responsibilities, Etc.

Distribution:
Angela Chambers, anagela.chambers@nnsa.doe.gov
Doug Bowen, bowendg@ornl.gov
Marsha Henley, henleym@ornl.gov

Evaluated Data for Fissile Actinides in the Resolved and Unresolved Resonance Region and their Coupling to Neutron Multiplicities

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(1) Nuclear Data Group, Oak Ridge National Laboratory, Oak Ridge, TN, USA
(2) Nuclear Data Section, International Atomic Energy Agency, Vienna, Austria
(3) Jozef Stefan Institute, Slovenia

Technical Meeting of the International Nuclear Data Evaluation Network (INDEN) on Actinide Evaluations in the Resonance Region
International Atomic Energy Agency (IAEA), November 2021, Vienna, Austria

OVERVIEW

- **^{233}U**
  - Motivation: underestimated reactivity for critical assemblies
  - Status: updates to PFNS, thermal constants, *R*-matrix improved subset of benchmarks[1]
  - RRR: extension up to 2 keV and inclusion of possible newly measured capture data
  - URR: relevant to assess impact on benchmark calculations in the energy range 2–40 keV
- **^{235}U**
  - Motivation: investigation on reactivity rates related to depletion calculations
  - Status: ^{238}U evaluation (see Capote/Trkov presentation) affecting the burn-up trend
  - URR: updated evaluation by including recently measured fission data
- **^{239}Pu**
  - Motivation: *R*-matrix analysis to include TNC values (STD 2017) and PFNS (IAEA+LANL)
  - Status: partial work to extend RRR up to 5 keV
  - Neutron multiplicities: updated evaluation with fluctuations and related covariances in progress

[1] Annals Nuclear Energy **163** (2021) 108595.

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U(nresolved) R(esonance) R(egion) ANALYSIS OF ^{235}U

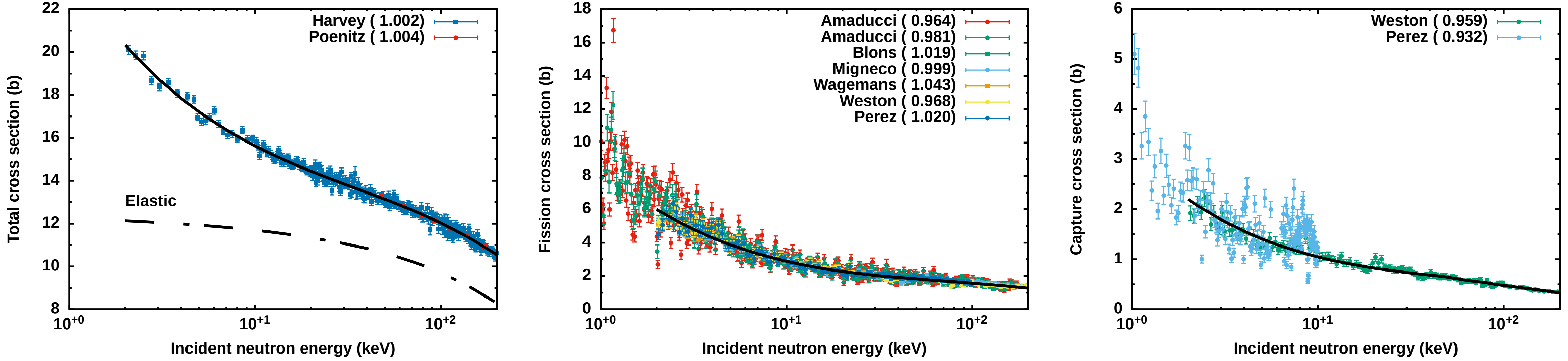

Figure 1: Preliminary SAMMY/FITACS fit of available total, fission, and capture data sets. Elastic channel computed by difference and inelastic channel parameterized by neutron strength functions and energy scaled penetrability factors.

- Except for the inelastic channel (11%), scaling factors ranging up to 6%
- Except for fluctuations, reasonable agreement with ENDF/B-VIII.0 (file 3)
- 20 keV is an acceptable upper energy limit for URR fit to account for self shielding effects

U(nresolved) R(esonance) R(egion) ANALYSIS OF ^{235}U

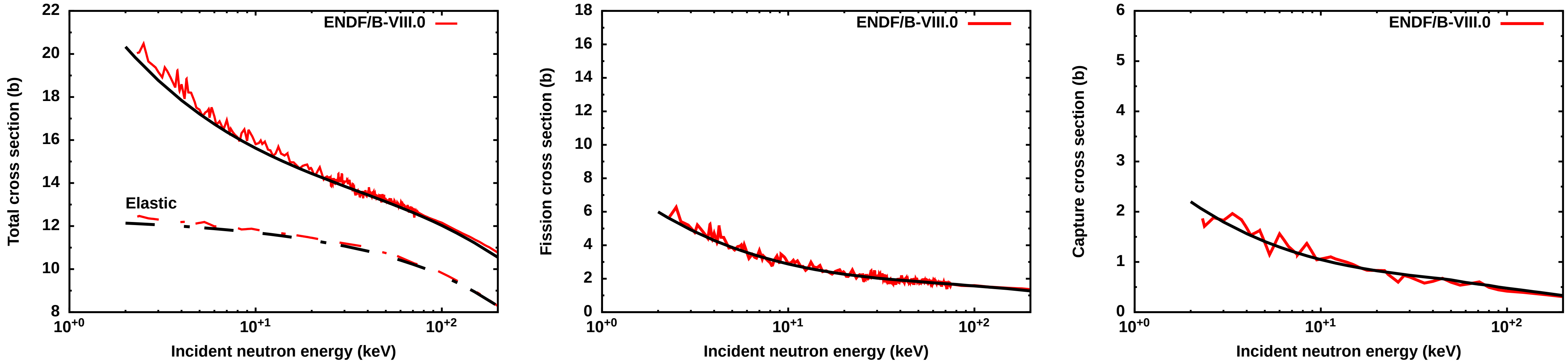

Figure 2: Preliminary SAMMY/FITACS fit compared to ENDF/B-VIII.0 evaluated data (file 3).

- ENDF/B-VIII.0 evaluated data show fluctuating behavior (to be checked if there is formal consistency between file 2 and file 3)

U(nresolved) R(esonance) R(egion) ANALYSIS OF ^{235}U

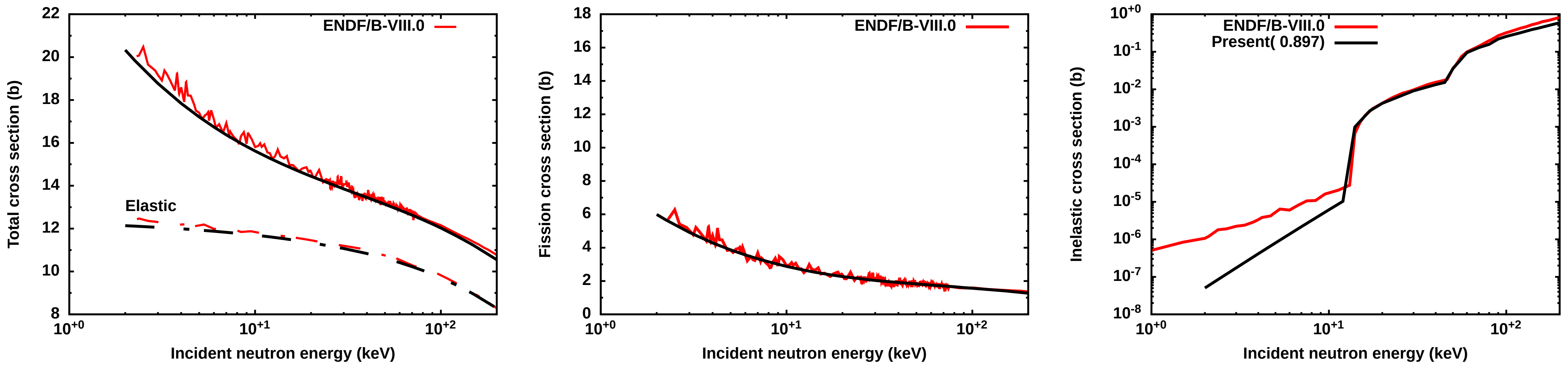

Figure 3: Preliminary SAMMY/FITACS fit compared to ENDF/B-VIII.0 evaluated data (file 3).

- Inelastic channel deviates from ENDF/B-VIII.0 below $\approx$10 keV
- μbarn should have no impact on criticality!
- Next step is the inclusion of fluctuations! (Resonance parameters $\Rightarrow$ fit $\Rightarrow$ effective/theoretical cross sections)

NEUTRON MULTIPLICITIES: On the $(n,\gamma f)$ reaction

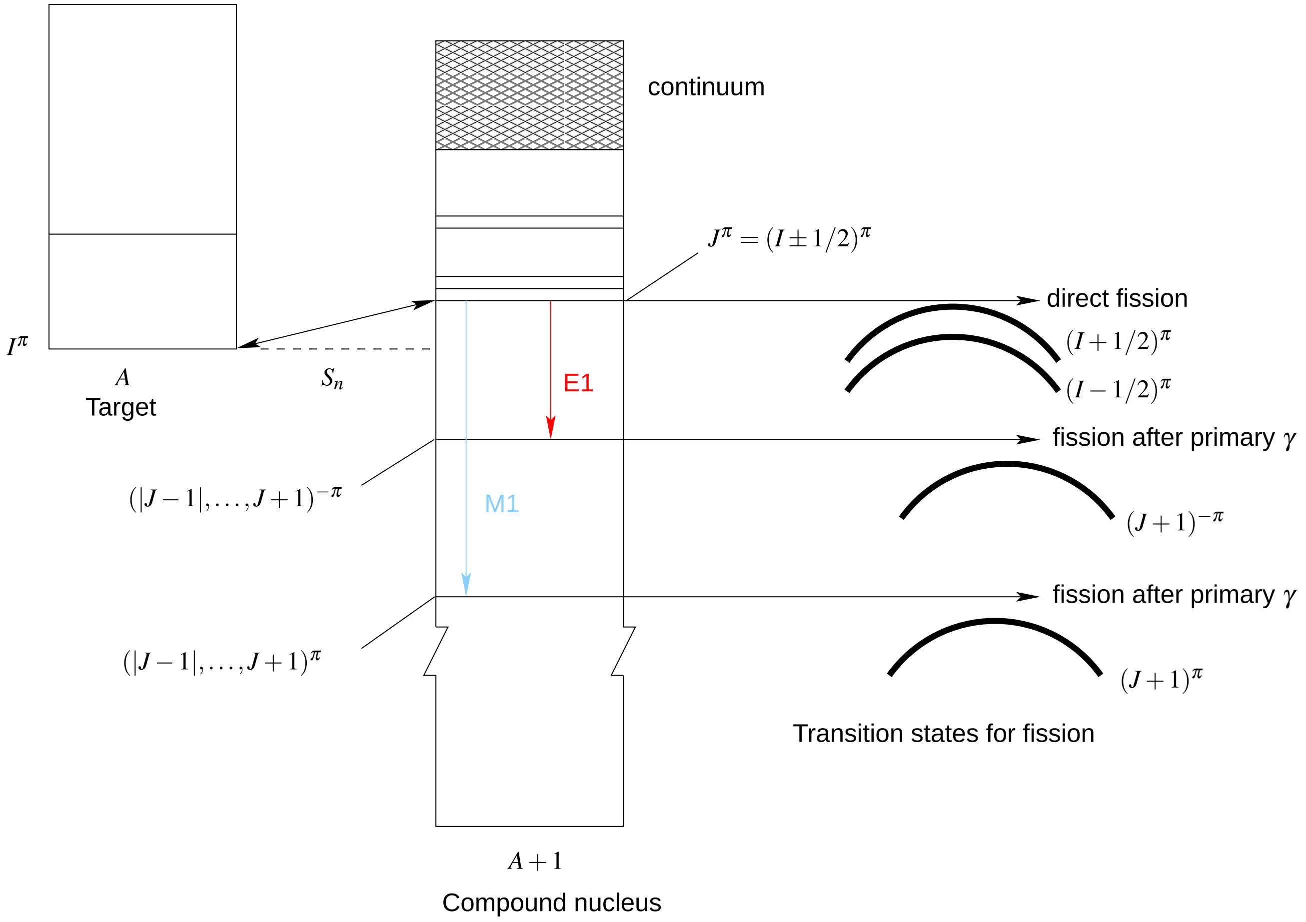

Figure 4: Schematic diagram of the $(n,\gamma f)$ reaction (Lynn 1965). After the emission of a primary γ-ray (e.g. E1, M1,..), the compound nucleus may still be in a highly excited state that may decay by fission as an alternative to secondary γ-ray emission. In the two-stage decay, the compound nucleus can be in an intermediate state that differs from the initial state depending on the multi-polarity of the transition.

NEUTRON MULTIPLICITIES: Calculating spin effect and $(n,\gamma f)$

- Fluctuating behavior of prompt neutrons based on the competition of $(n,\gamma f)$ and direct fission (n,f) processes[3]
- Neutron multiplicity $\bar{\nu}_p(E) = \nu^{\text{spin}}(E) - \Delta\nu^{(n,\gamma f)}(E)$ defined by

$$\nu^{\text{spin}}(E) = \left[\sum_J \nu_{c,J} \sum_{k_J} \sigma_{f,k_J}(E)\right] / \sigma_f(E) \quad (1)$$

$$\Delta\nu^{(n,\gamma f)}(E) = \left[\sum_J C_J \sum_{k_J} \sigma_{f,k_J}(E)/\Gamma_{f,k_J}\right] / \sigma_f(E)\,, \quad (2)$$

where the quantities $\nu_{c,J}$ and C_J are deduced by a least-squares of the measured data.

- The resonance fission widths Γ_{f,k_J} for each level E_λ are used to calculate the partial energy-dependent fission cross section $\sigma_{f,k_J}(E)$:
  - The coefficients $C_J = (\partial\nu_J/\partial E)\,\Gamma_{\gamma,f}\cdot E_{\gamma,f}$ are deduced from the linear dependence of $\bar{\nu}_p$ for the direct process, assuming that $\Gamma_{\gamma,f}$, $E_{\gamma,f}$ are constant due to the large number of independent channels involved.
  - For ^{239}Pu (having spins $J = 0^+, 1^+$), the parameters used in the calculations are four $\nu_{c,0^+}$, C_{0^+} and $\nu_{c,1^+}$, C_{1^+}

[3]Fort et al., NSE 99,375 (1988).

NEUTRON MULTIPLICITIES OF ^{239}Pu

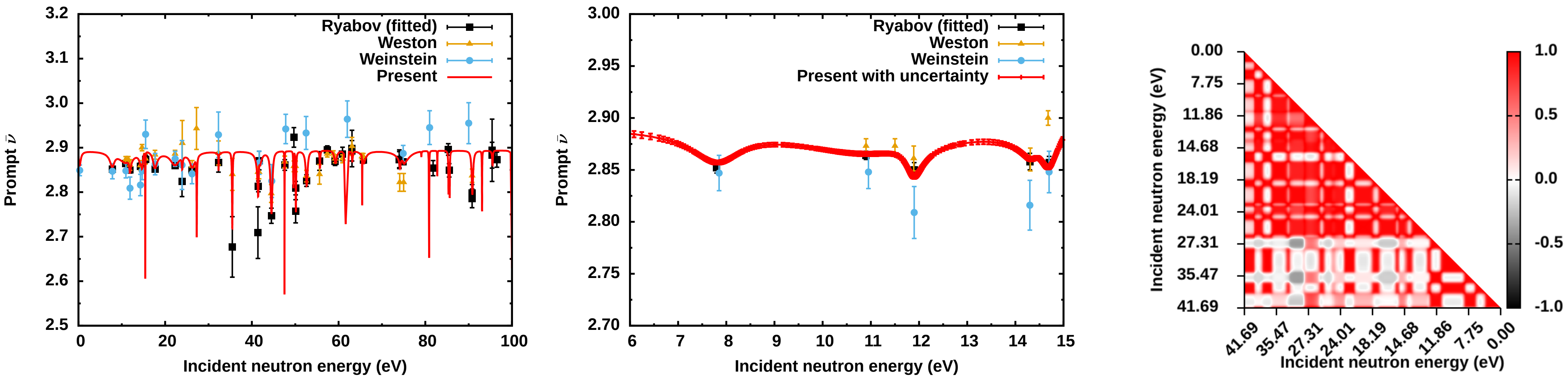

Figure 5: Preliminary fit of neutron multiplicities with available measured data and related covariance matrix.

- Measured data with different resolutions. Ryabov seems the most consistent
- As expected the correlation matrix reflects the $\bar{\nu}$ fluctuating behavior
- To reduce size of covariance matrix, energy grid properly defined around each energy level
- Calculated uncertainty is about $\leq$0.3%

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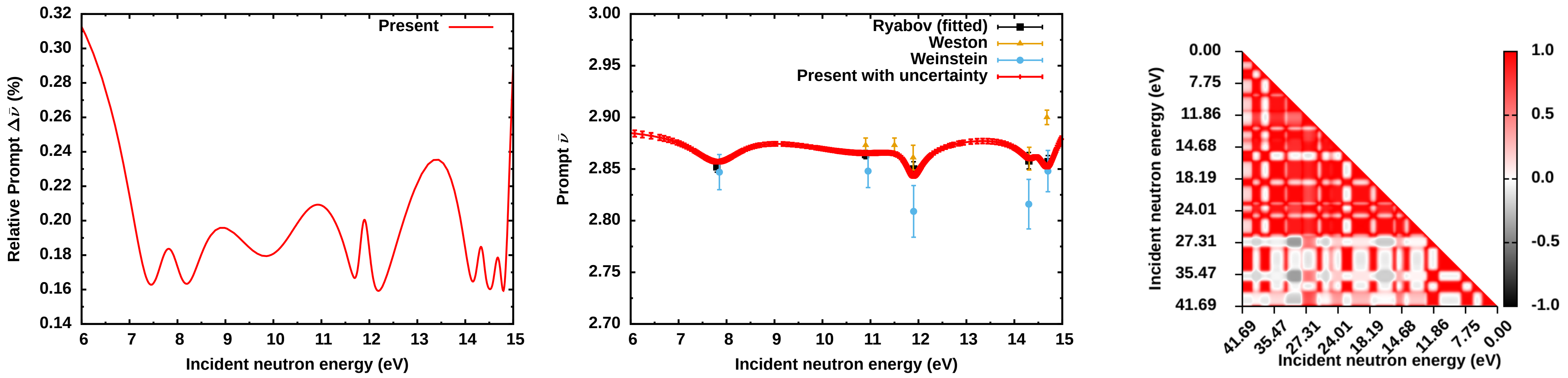

Figure 6: Preliminary fit of neutron multiplicities with available measured data and related covariance matrix.

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Acknowledgments

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Collaborators: D. Wiarda, J. McDonnell, C. Chapman, J. Brown, A. Holcomb, G. Arbanas, K. Guber, K. S. Kim.

Questions?