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Evaluated ^{238}U PFNS with Chi-Nu data

Denise Neudecker, Keegan Kelly, **Matt Devlin (speaker)**

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This work shows progress towards fulfilling an NCSP milestone of LANL ND1 (Nuclear Data Evaluation and Testing).

Thanks to: M.B. Chadwick,
T. Kawano, R.C. Little, A.E. Lovell,
P. Talou.

This talk shows work towards milestone:
^{238}U: “Finalize prompt fission neutron spectra based on LANSCE Chi-Nu Data” (FY24 Q4).

It makes use of ^{238}U PFNS measured by LANL/ LLNL Chi-Nu team for NCSP and delivered on time to evaluators.

It includes validation of evaluated PFNS by evaluator.

Evaluation algorithm and input

We get evaluated data and covariances with GLLS using model data as a prior and updating with exp. info.

GLLS combines:

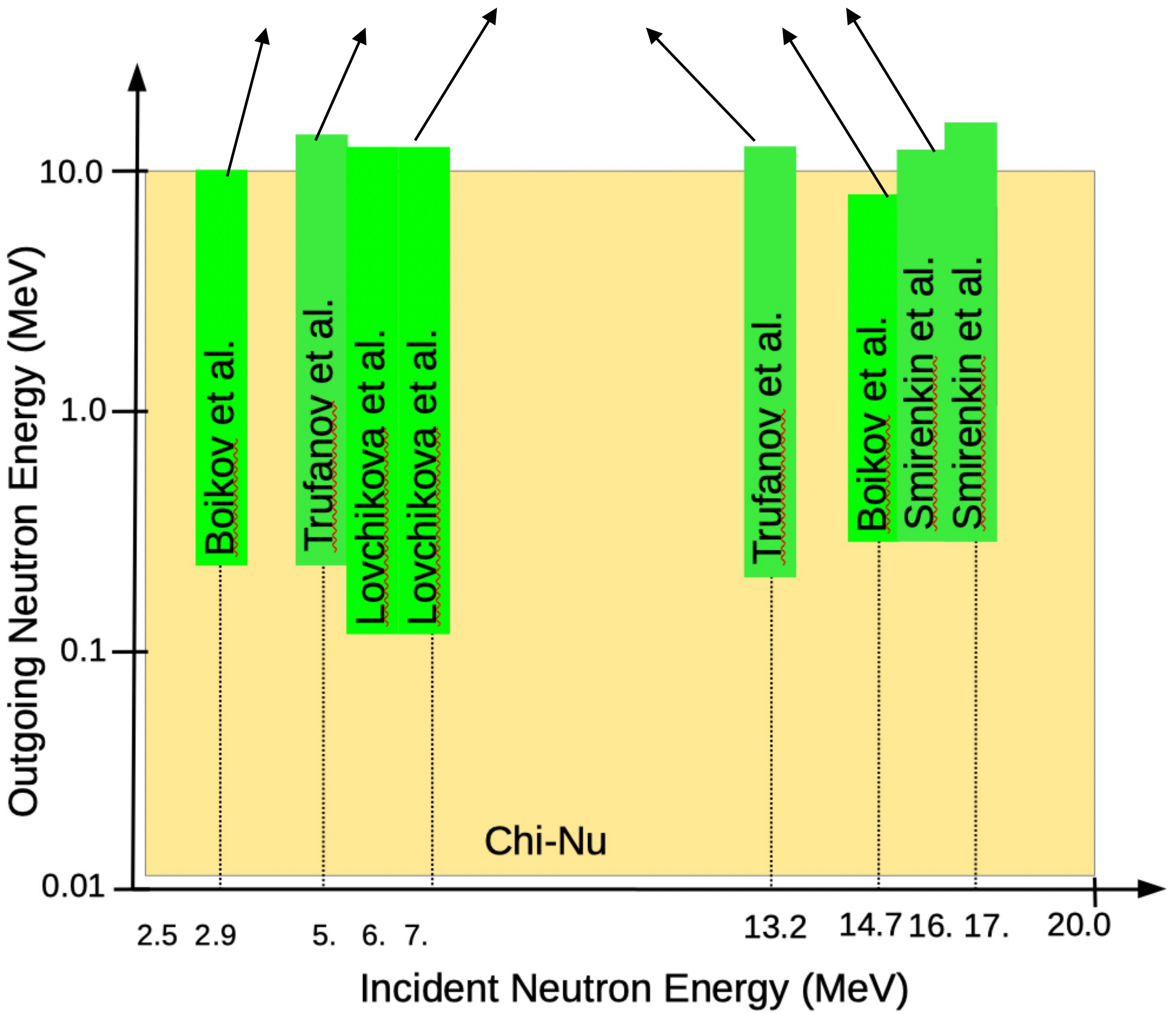
- **Model calculated ("M") PFNS mean values and covariances,**
- **Experimental PFNS mean values ("x")** and covariances,
- **To evaluated PFNS mean values and covariances ("post") for a ND file** using,
- The design matrix S that transforms PFNS from energy lattice of the model to exp. one.

$$\underline{\phi}^{post} = \underline{\phi}^{M} + \mathbf{Cov}^{post}\mathbf{S}^{+}\left(\mathbf{Cov}^{x}\right)^{-1}\left(\underline{\phi}^{x} - \mathbf{S}\underline{\phi}^{M}\right) ,$$

$$\mathbf{Cov}^{post} = \mathbf{Cov}^{M} - \mathbf{Cov}^{M}\mathbf{S}^{+}\left(\mathbf{S}\mathbf{Cov}^{M}\mathbf{S}^{+} + \mathbf{Cov}^{x}\right)^{-1}\mathbf{S}\mathbf{Cov}^{M}$$

Accepted experimental ^{238}U PFNS cover a broad E_{inc} and E_{out} range:

By the same group and correlated through joint equipment and similar analysis technique.



<u>LANL/ LLNL Chi-Nu data:</u>

- Cover broader Einc and E_{out} ranges than previously available.
- Have carefully assessed uncertainties.

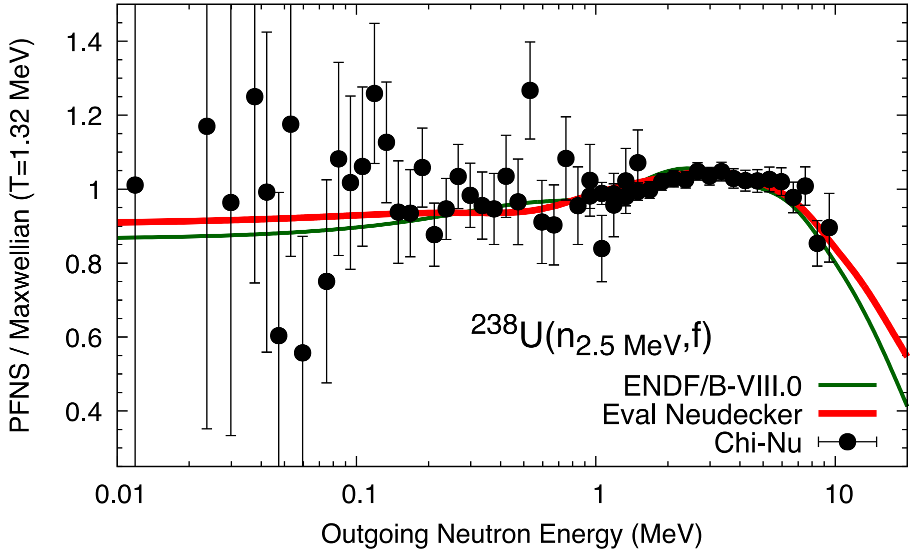
→ Chi-Nu data are key to map evaluated PFNS more completely out.

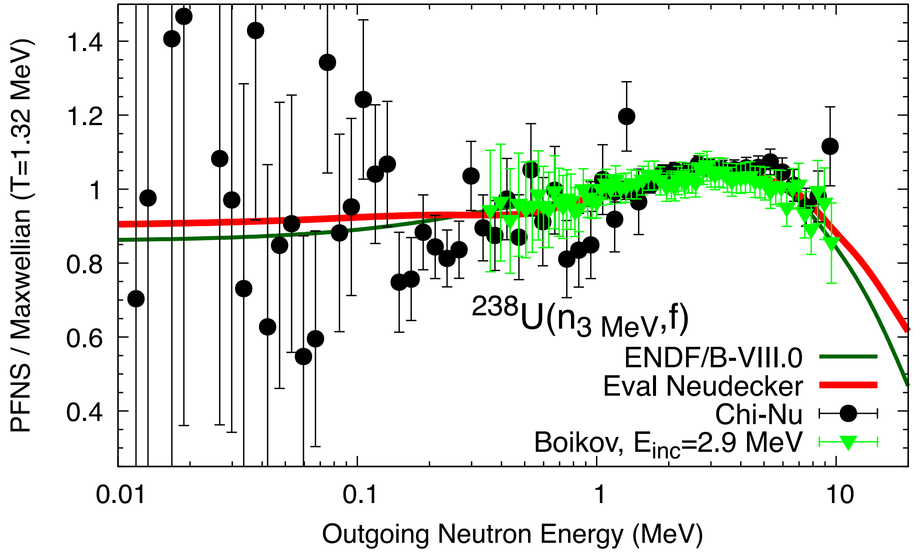
Model PFNS were obtained with an extended Los Alamos model implemented in CoH.

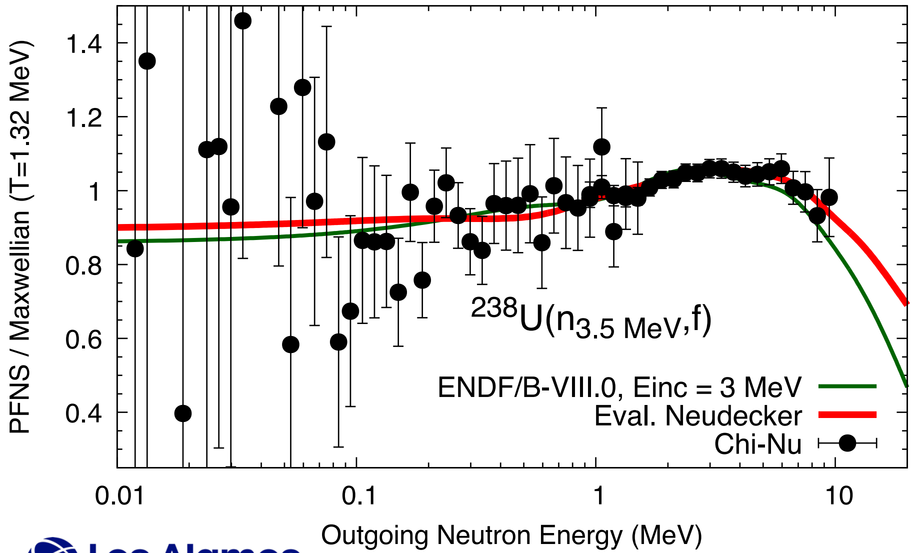
- Model PFNS provide prior for GLS evaluation. We have precise experimental data from E_{inc} = 2-20 MeV and E_{out}=0.8-10 MeV. The prior helps to extrapolate to high and low E_{out}, and below E_{inc} = 2 MeV (^{238}U fission threshold is between 1-2 MeV).
- Used CoH code and ^{238}U input deck by Toshihiko Kawano for level scheme, fission barriers, etc.
- Used extended Los Alamos model as described in D. Neudecker et al., Nucl. Data Sheets 148, 293 (2018); D. Neudecker et al., NIMA 791, 80 (2015).
- Parametrized TKE, energy release, etc., as a function of E_{inc}.
- Exciton model used to describe pre-equilibrium component.

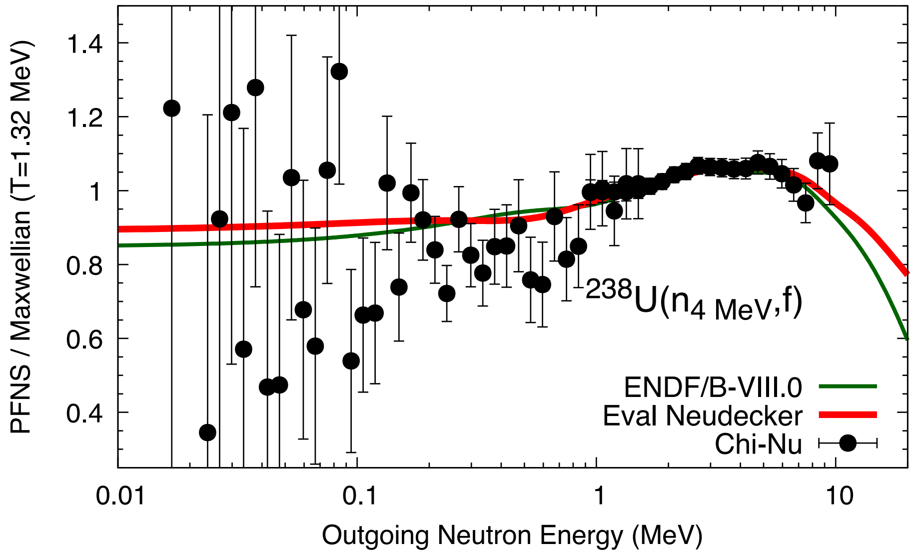
Evaluated results

New eval. PFNS gets reasonably close to Chi-Nu PFNS at E_{inc} = 2.5-4 MeV and differs in the wings from VIII.0.

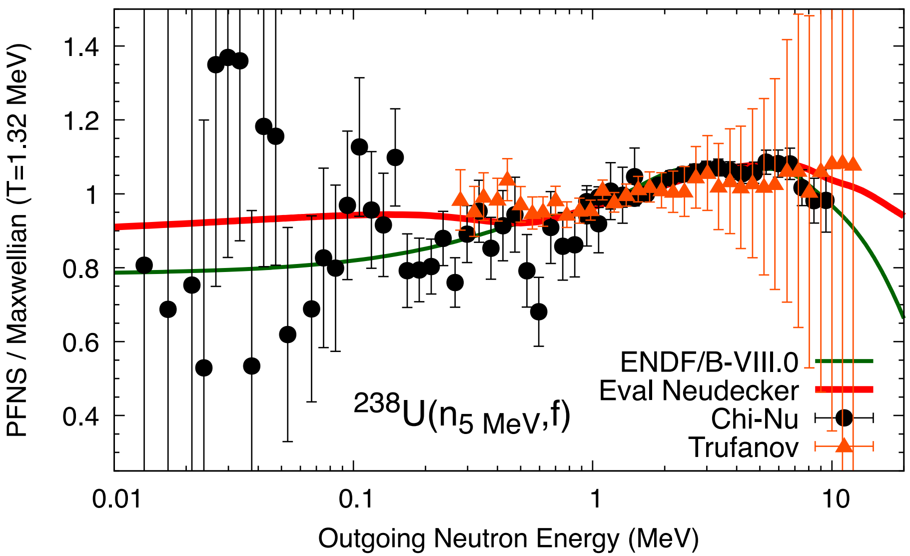


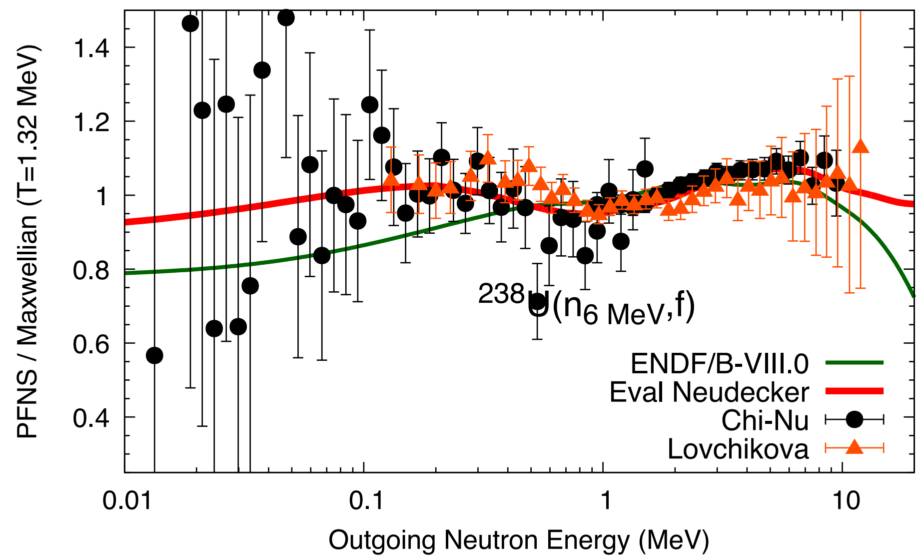


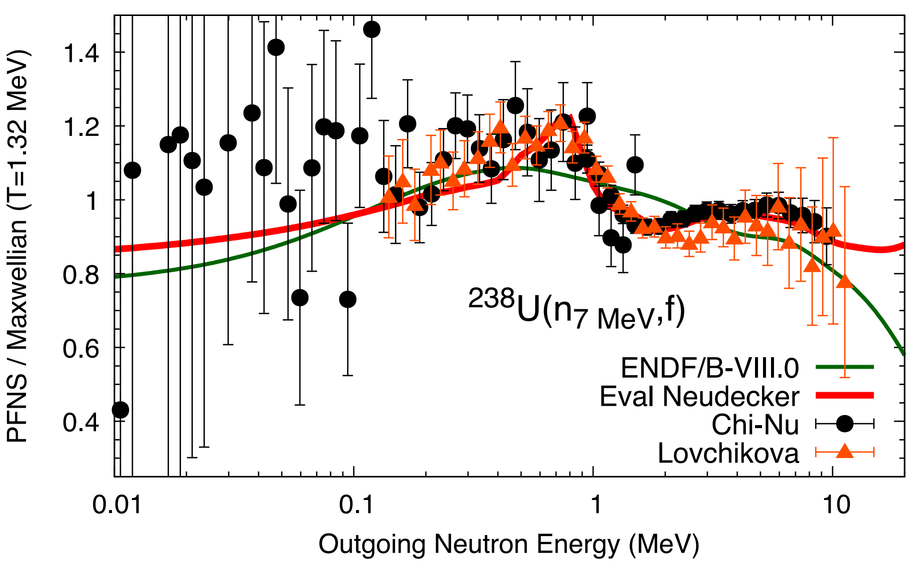




Eval. PFNS gets reasonably close to Chi-Nu PFNS and other experimental PFNS around second-chance fission.

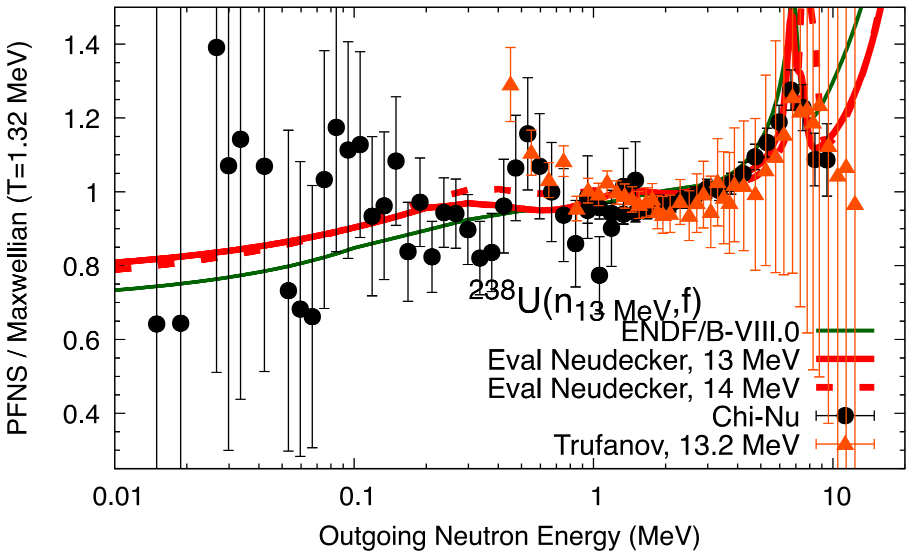


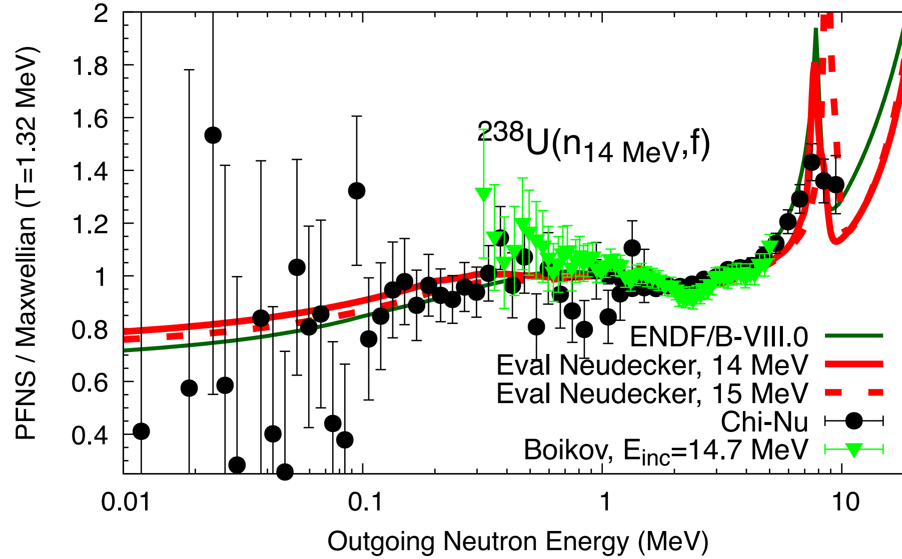


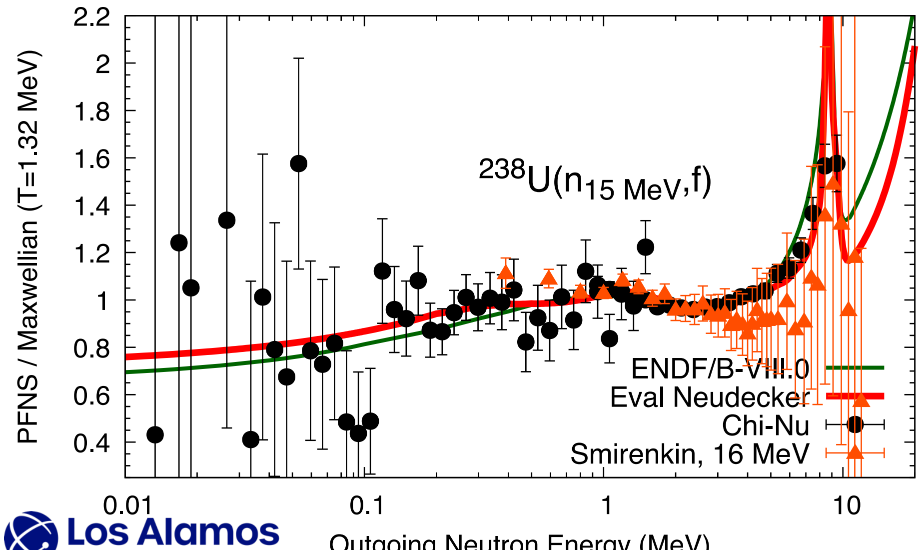


- Increase of PFNS around a few 100 keV caused by second-chance fission.
- More pronounced shape at E_{inc} = 7 MeV due to large angular anisotropy of FF emission compared to ^{235}U/^{239}Pu.

Eval. PFNS gets reasonably close to Chi-Nu PFNS for third-chance fission and pre-equilibrium component.

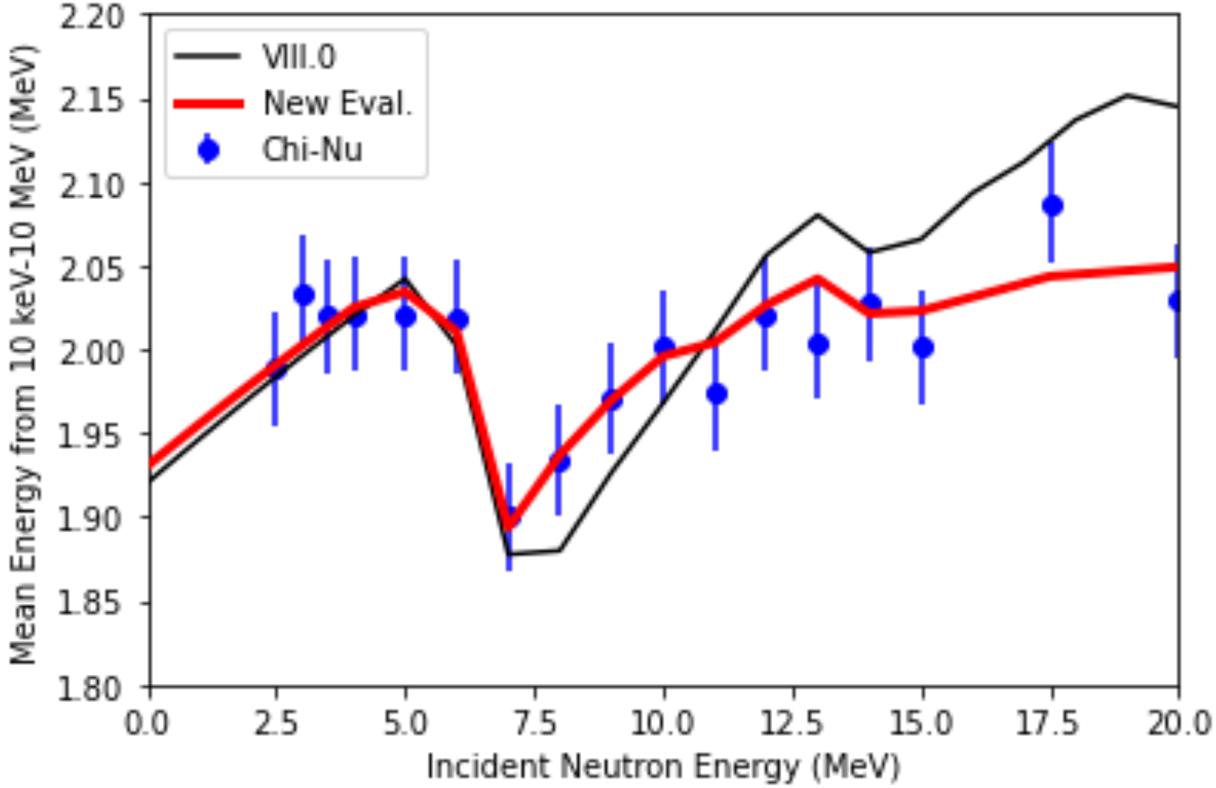






- Third-chance fission component to the PFNS more subtle.
- More pronounced shape at high E_{out} caused by neutrons emitted in pre-equilibrium process.

Mean energy of the PFNS shows that new eval. and Chi-Nu are close to ENDF/B-VIII.0 for E_{inc} < 6 MeV.



Given how close the new eval. is to VIII.0 for E_{inc} < 6 MeV, little impact on k_{eff} of ICSBEP benchmarks expected. Larger change for E_{inc} ~ 14 MeV could impact LLNL pulsed spheres simulations.

Validation results

- Uses DECE by T. Kawano to produce ENDF-6 formatted data.
- NJOY for processing.
- MCNP-6.2 for neutron-transport simulations.
- Thanks to S. Frankle and S. Kahler for input decks.

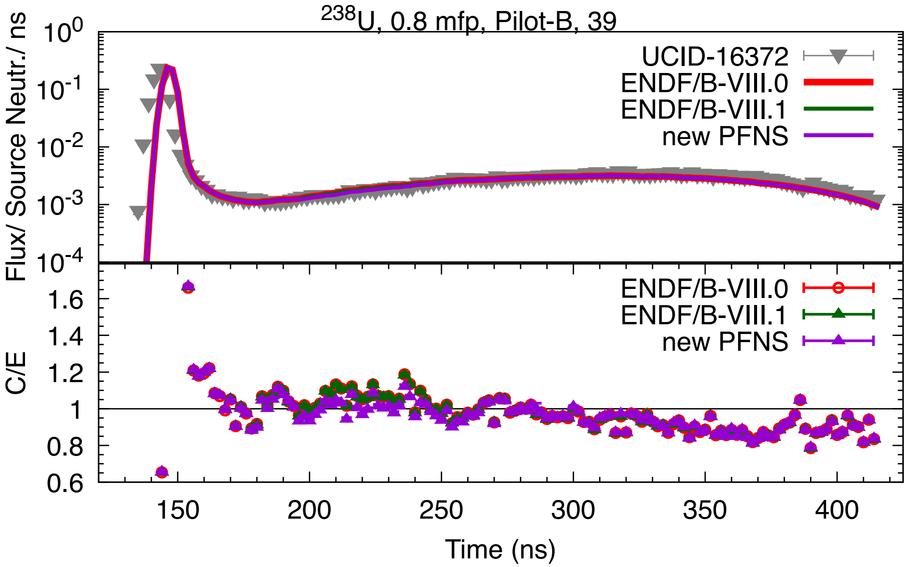
Crit testing: Changes are within 1-2 sigma of MC statistics.

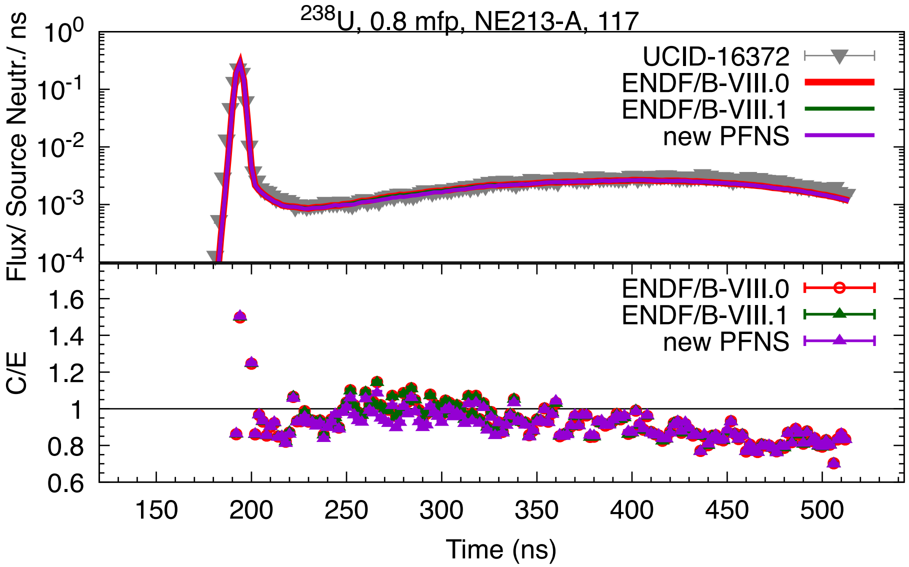
Assembly	VIII.0	VIII.1beta3	VIII.1beta3+PF NS	Experiment
Flattop-Pu (PMF006)	0.99970(10)	0.99989(10)	1.00009(10)	1.00000(300)
Flattop-U (HMF028)	1.00093(9)	1.00065(9)	1.00073(9)	1.00000(300)
BigTen (IMF007d)	1.00414(8)	1.00471(8)	1.00494(8)	1.00460(200)

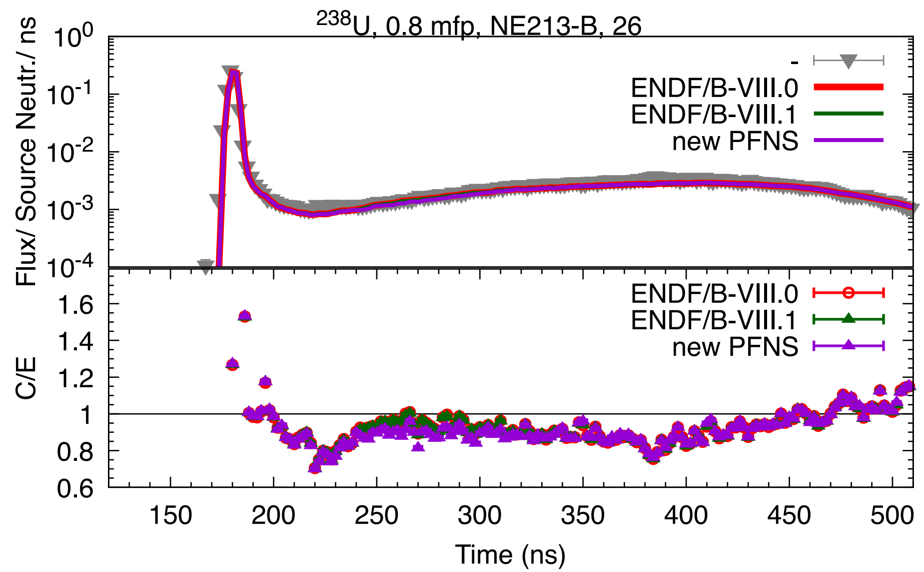
Assembly	C/E VIII.0	C/E VIII.1beta3	C/E VIII.1beta3+PF NS
Flattop-Pu (PMF006)	0.99970	0.99989	1.00009 Within 2s unc.
Flattop-U (HMF028)	1.00093	1.00065	1.00073 Within 1s unc.
BigTen (IMF007d)	0.99954	1.00011	1.00034 Within 2s unc.

All three benchmarks have thick reflectors with a high percentage of ^{238}U.

Thin ^{238}U LLNL Pulsed Spheres: two better, one worse after the inelastic valley, but within exp. uncertainty.







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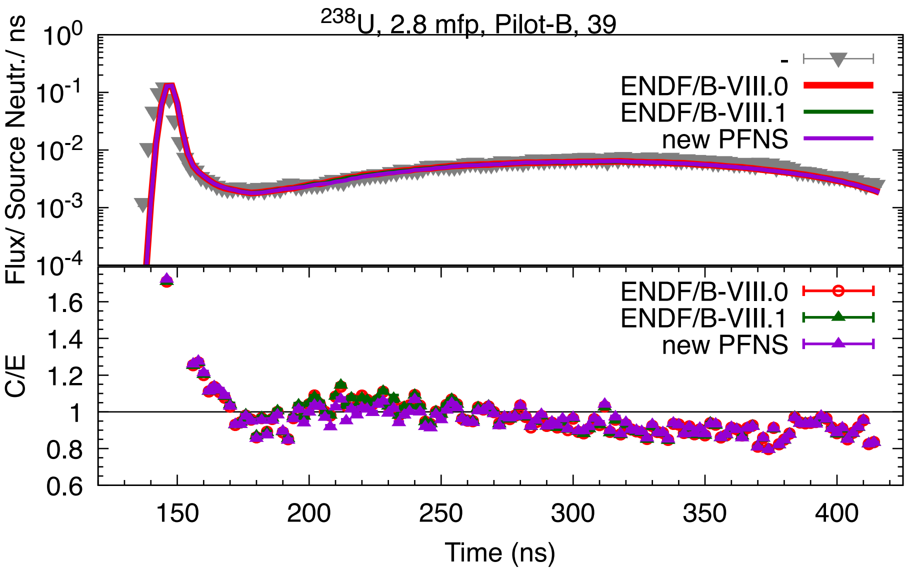
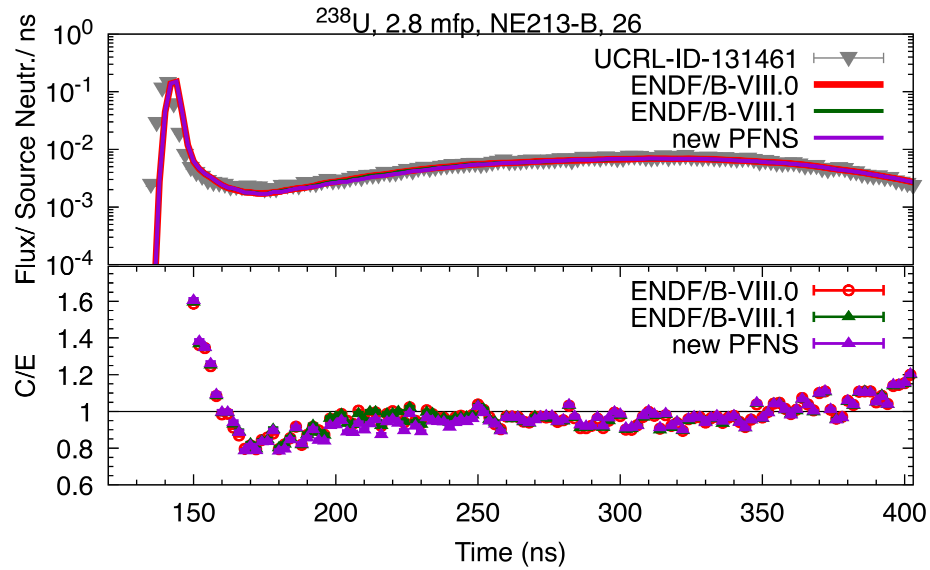
Thick ^{238}U LLNL Pulsed spheres: one better, one slightly worse after the inelastic valley but within exp. uncertainty,





- Over all five pulsed spheres, we are getting slightly better results after the inelastic valley.
- The spheres with 26 degree perform slightly worse, while the 39- and 117-degree spheres perform better but well with exp. unc.
- 26 degree queries slightly higher E_{inc} (more of E_{inc} = 15 MeV) compared to 39 and 117 degree.

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Summary:

- New evaluated ^{238}U PFNS make use of LANL/LLNL Chi-Nu high-precision experimental data paid for by NCSP.
- Extended Los Alamos and exciton models (CoH) used.
- New evaluated PFNS differ noticeably from VIII.0, but mean energy close for E_{inc} < 6 MeV.
- k_{eff} of crits with thick ^{238}U-containing reflectors are within 1-2 sigma of MC statistics.
- Changes in LLNL pulsed spheres are noticeable after inelastic peak and are within exp. unc.
- We are close to completing the milestone.

To-Do:

- Provide data to INDEN collaboration (in charge of current ^{238}U VIII.1 file).
- Provide evaluated covariances.
- Write end report.

Thank you for your attention!

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We gratefully acknowledge the support of the Advanced Simulation and Computing (ASC) program at Los Alamos National Laboratory.

5 out of 10 available ^{238}U PFNS data sets had to be rejected.

Rejected data:

- Desai 2015: The data have very large scatter and uncertainties. Multiple scattering was not corrected, no time resolution found, etc.
- Kornilov 1980: The data are described as absolute quantity in EXFOR, but it is indicated that the detector efficiency is given by measuring the ^{252}Cf PFNS and assuming a Maxwellian of T=1.42 MeV. When I divide through that Maxwellian function times Mannhart's ^{252}Cf PFNS evaluation, the experimental data becomes unphysical. So, it is not clear in what form, that is as what quantity, the data in EXFOR are given.
- Sardet 2013: The data have very large scatter and uncertainties. The data are marked as preliminary in EXFOR and are only described in a conference proceeding. Among other things, the detector efficiency is not final.
- Baba 1989: 2 MeV, unphysical shape.
- Baryba 1979: 14.3 MeV, disagreeing shape with other data, only limited information in EXFOR. Cannot find journal article. So, hard to judge if we can trust the data.