Chi-Nu Measurement of the ^{235}U and ^{239}Pu Prompt Fission Neutron Spectra

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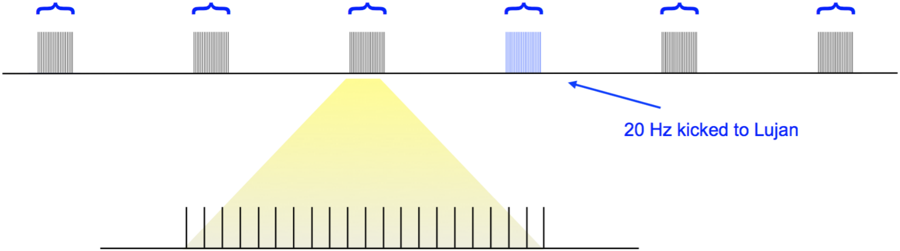
LA-UR-17-XXXXX (DC Reviewed)

LANSCE Beam Structure

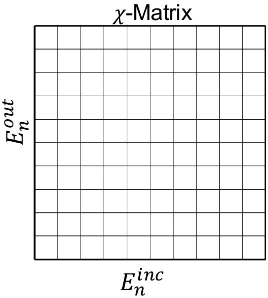
Macro-pulses are typically ~625 μs wide and occur at 120 Hz

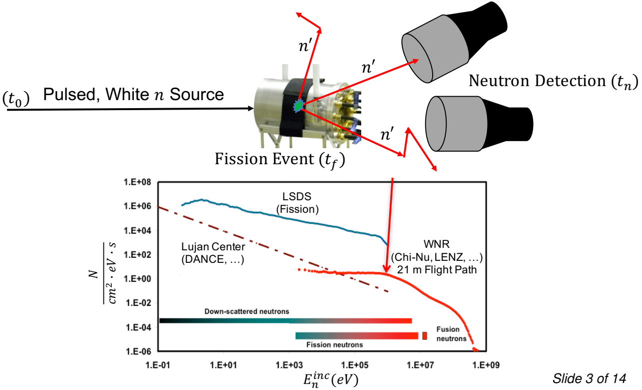


Macro-pulses are comprised of micro-pulses, each ~150 ps wide, separated usually by ~1.8 μs

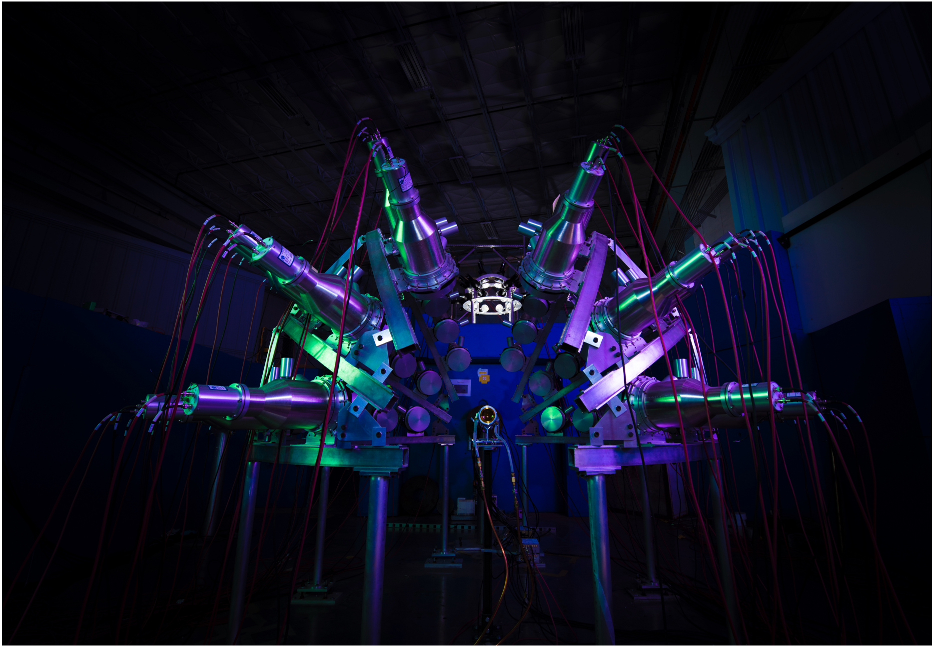
Chi-Nu Goals, Method, and Challenges

- Goals
  - Measure the neutron χ-matrix
  - ^{252}Cf, ^{235}U, ^{239}Pu
  - PFNS for ranges of E_n^{inc}
- Method
  - Double TOF
  - PPAC for fission
  - $E_n^{out} < 2$ MeV
    - 22 ^{6}Li-glass
  - $E_n^{out} > 800$ keV
    - 54 Liquid Scint.
- Challenges
  - E_n^{inc} $\geq$0.7 MeV $\leq$20 MeV
  - E_n^{out} $\geq$0.01 MeV $\leq$10 MeV
  - Detailed Uncertainties



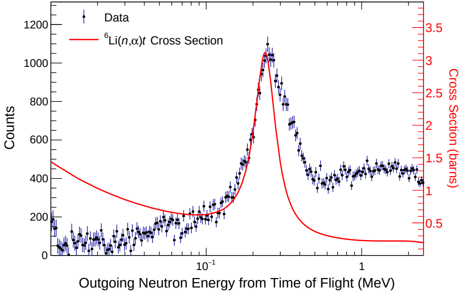


The Chi-Nu Arrays



Characterizing the ^{6}Li-glass Detector Response

^{6}Li-glass Fission Neutron Spectrum



- ^{235}U: 1.0 MeV $\leq E_n^{inc} \leq$ 1.5 MeV
- Large peak in data
  - 240-keV ^{6}Li$(n,\alpha)t$ resonance
- Background subtracted†

$$E = \text{Initial } n \text{ Energy}$$
$$E' = n \text{ Energy upon Detection}$$
$$E_t = \text{Measured } n \text{ Energy via TOF}$$

$$C(p(E)\,,E_t) = \text{Counts measured at } E_t$$
$$= \int_{E_t}^{\infty} p(E) \int_0^{\infty} \mathcal{S}(E, E', E_t)\,\epsilon(E')\,dE'dE$$

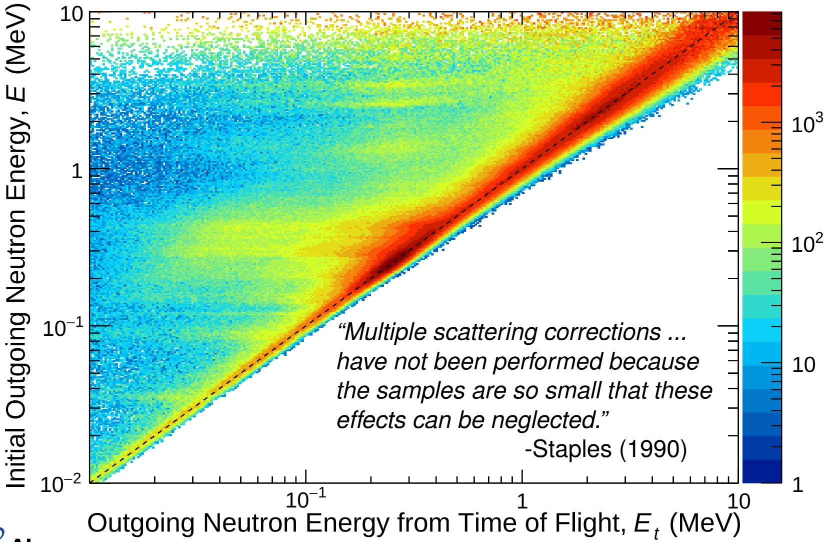
$$\mathcal{S}(E, E', E_t) = \text{Scattering Matrix}$$
$$p(E) = \text{PFNS}$$
$$\epsilon(E') = \text{Detector Efficiency at } E'$$
$$\mathcal{R}(E, E_t) = \text{Response Matrix}$$

$$\boxed{\mathcal{R}(E, E_t) = \int_0^{\infty} \mathcal{S}(E, E', E_t)\,\epsilon(E')\,dE'}$$

†J.M. O'Donnell, Nucl. Instrum. and Methods A, **805** (2016) 87

MCNP® ^{6}Li-glass Detector Response Matrix, $\mathcal{R}(E, E_t)$

Detector Response Changes with Experimental Environment



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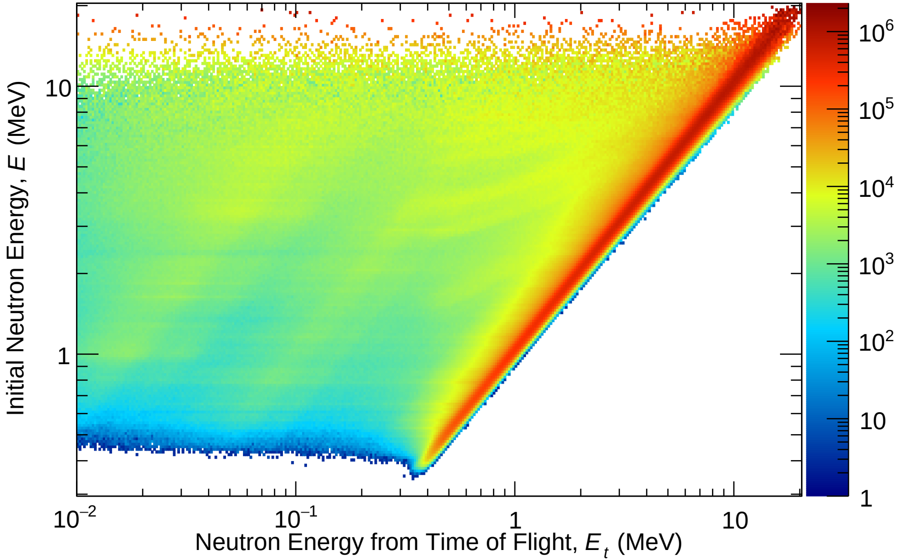
MCNP® Liquid Scintillator Response Matrix

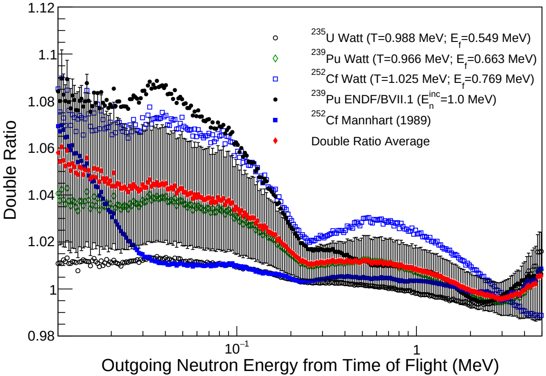


Method of PFNS Extraction: Ratio-of-Ratios Method†

- Based on the approximate equality of

$$\frac{C(p_\alpha(E), E_t)}{p_\alpha(E_t)} \approx \frac{C(p_\beta(E), E_t)}{p_\beta(E_t)}$$

- True within ∼5–10% for a typical PFNS



$$D_\alpha = \text{Double Ratio} = \frac{C(p_\alpha(E), E_t)/p_\alpha(E_t)}{C(p_{maxw}(E), E_t)/p_{maxw}(E_t)}$$

Average over reasonable PFNS range and set equal to the experimental ratio

$$\frac{1}{\kappa}\sum_{\alpha=1}^{\kappa}\frac{C(p_\alpha, E_t)}{p_\alpha(E_t)} = \frac{C(p_{exp}, E_t)}{p_{exp}(E_t)}$$

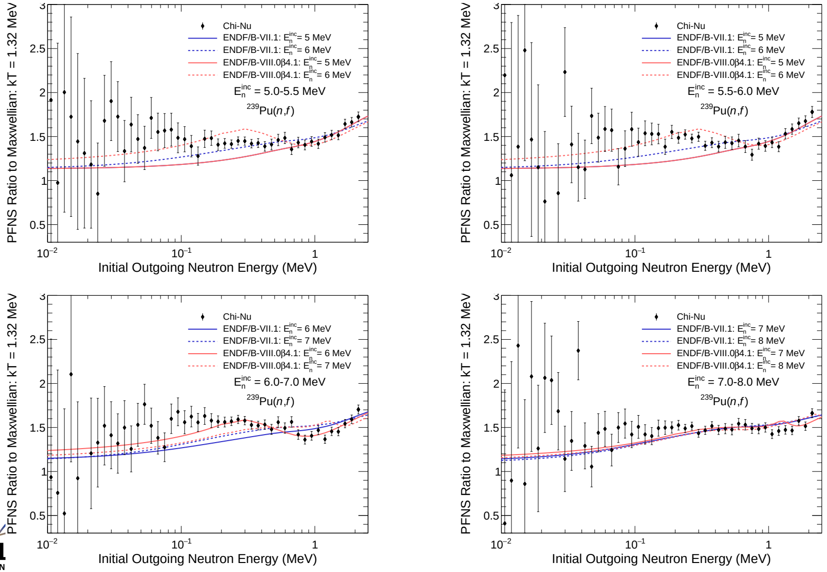
$$\Rightarrow \boxed{p_{exp}(E) = \frac{C(p_{exp}, E_t)}{\frac{1}{\kappa}\sum_{\alpha=1}^{\kappa}\frac{C(p_\alpha, E_t)}{p_\alpha(E_t)}}}$$

→ Quickly extracts PFNS

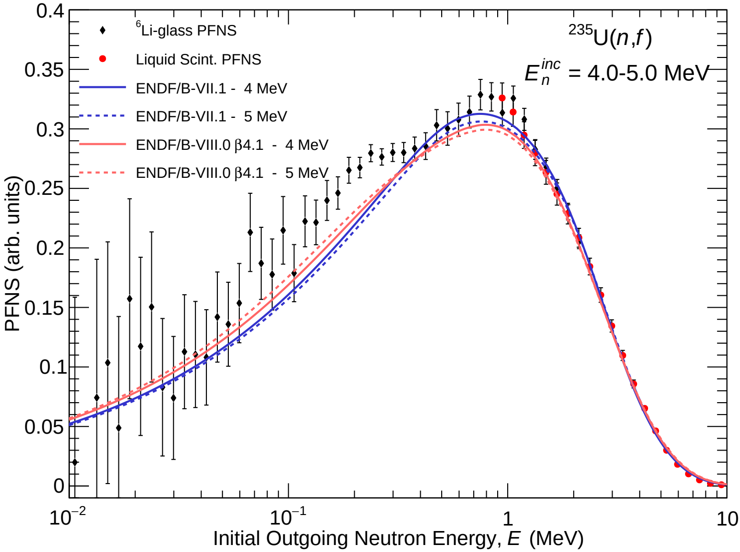
→ Uncertainties are increased to account for bias towards average PFNS

†T.N. Taddeucci *et al.*, Nucl. Data Sheets, **1232** (2015) 135

Preliminary ^{239}Pu PFNS: 2nd-Chance Fission Region



^{235}U Combined HE (preliminary) and LE Results

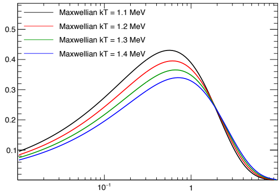


Data processed by J.A. Gomez

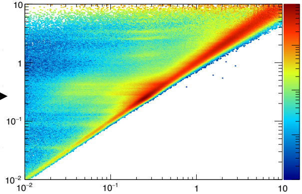
Future Analyses: Forward Analysis

1) Create Input Model PFNS

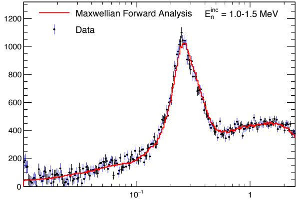
Maxwellian, Watt, Los Alamos Model



2) Create MCNP Output from Response Matrix



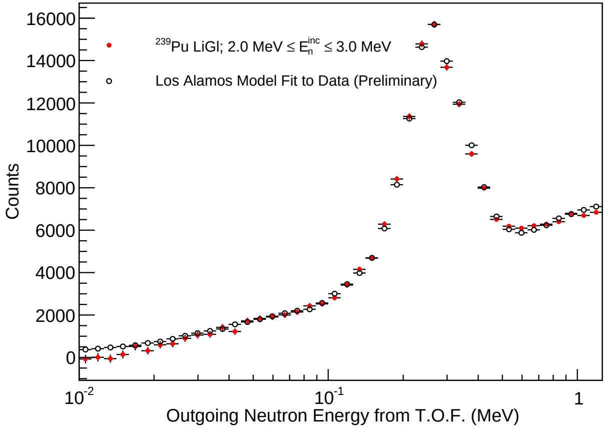
3) Compare to Data, Calculate Fit Metric, and Iterate



- Require *entire* PFNS for fit
  - Issue using just LE data
  - Require simultaneous fit to LE and HE data
- Simple models
  - Maxwellian or Watt
- $CoH_3^\dagger$ Los Alamos Model††

†Kawano *et al.* (2010); ††Madland & Nix (1982)

CoH_3 Los Alamos Model Forward Analysis Progress

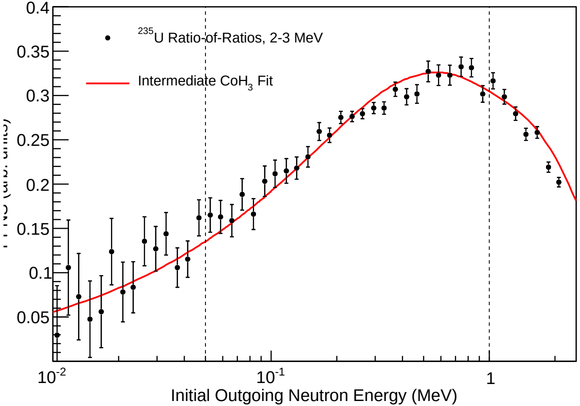


- LAM Parameters Varied:
  - $\langle \mathrm{TKE} \rangle$, $\langle E_\gamma^{tot} \rangle$, & $\langle S_n \rangle$
  - $\langle E_r \rangle$ calculated, not fit
  - s, $R_{\bar{\nu}}$, b, a_L, a_H
- Fission Barriers *not* fit yet
- Parameters chosen according to Neudecker *et al.* (2016)†

- Within each iteration of a ROOT TF1:
  - Run CoH_3, read in PFNS, Convert PFNS with $\mathcal{R}(E, E_t)$, compare to data
- Fission barrier heights will be varied in multi-chance fission regions

† D. Neudecker *et al.*, Nucl. Instrum. and Methods A, **791** 80

CoH_3 Los Alamos Model Forward Analysis Progress



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Future Directions

- Systematic Uncertainties:
  - MCNP® nuclear physics
  - Background normalization
  - Other sources
- More sophisticated analyses
  - Forward Analysis
  - Unfolding
- Finalize HE analysis of ^{235}U
- Finalize LE analysis of ^{239}Pu
- Analyze HE ^{239}Pu data