Chi-Nu PFNS Covariances

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on behalf of the Chi-Nu Collaboration

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Outline

- Brief Chi-Nu Description
- PFNS Correlations/Covariances
- $\langle E \rangle$ Correlations/Covariances

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Measurement of the ^{239}Pu(n, f) prompt fission neutron spectrum from 10 keV to 10 MeV induced by neutrons of energy 1–20 MeV

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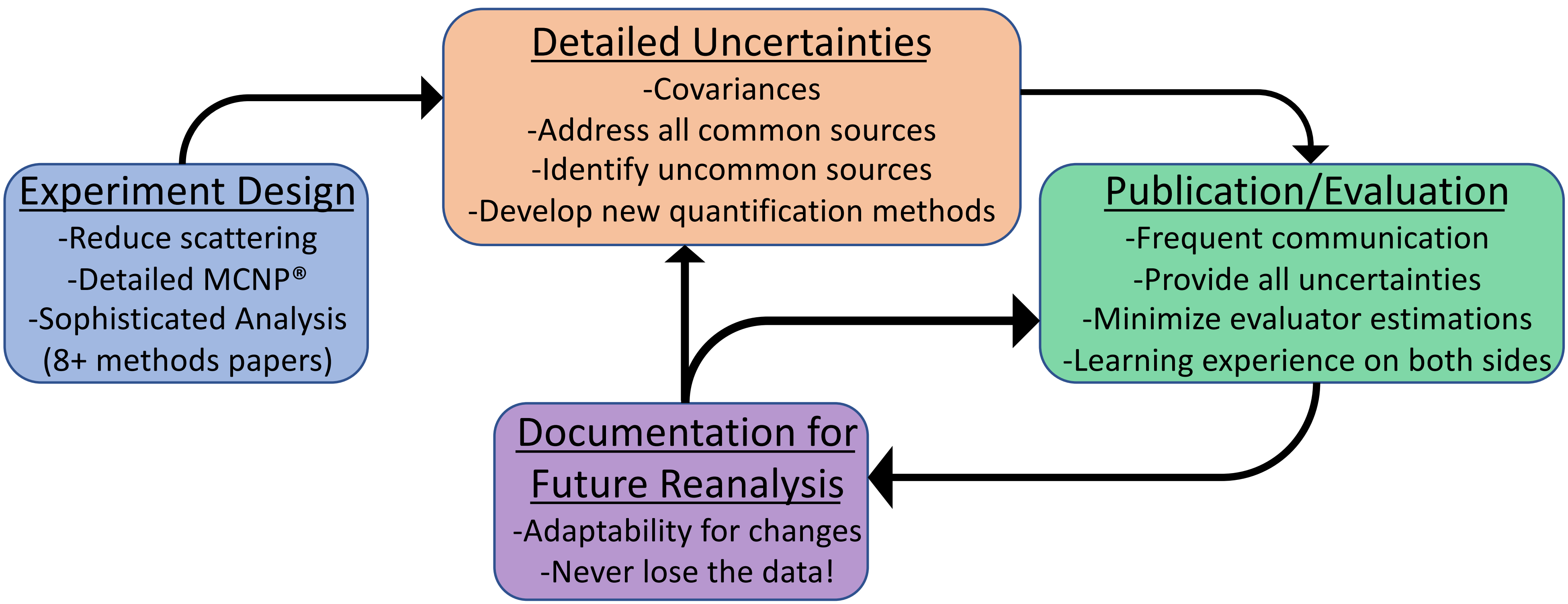
The Overall Purpose of Chi-Nu

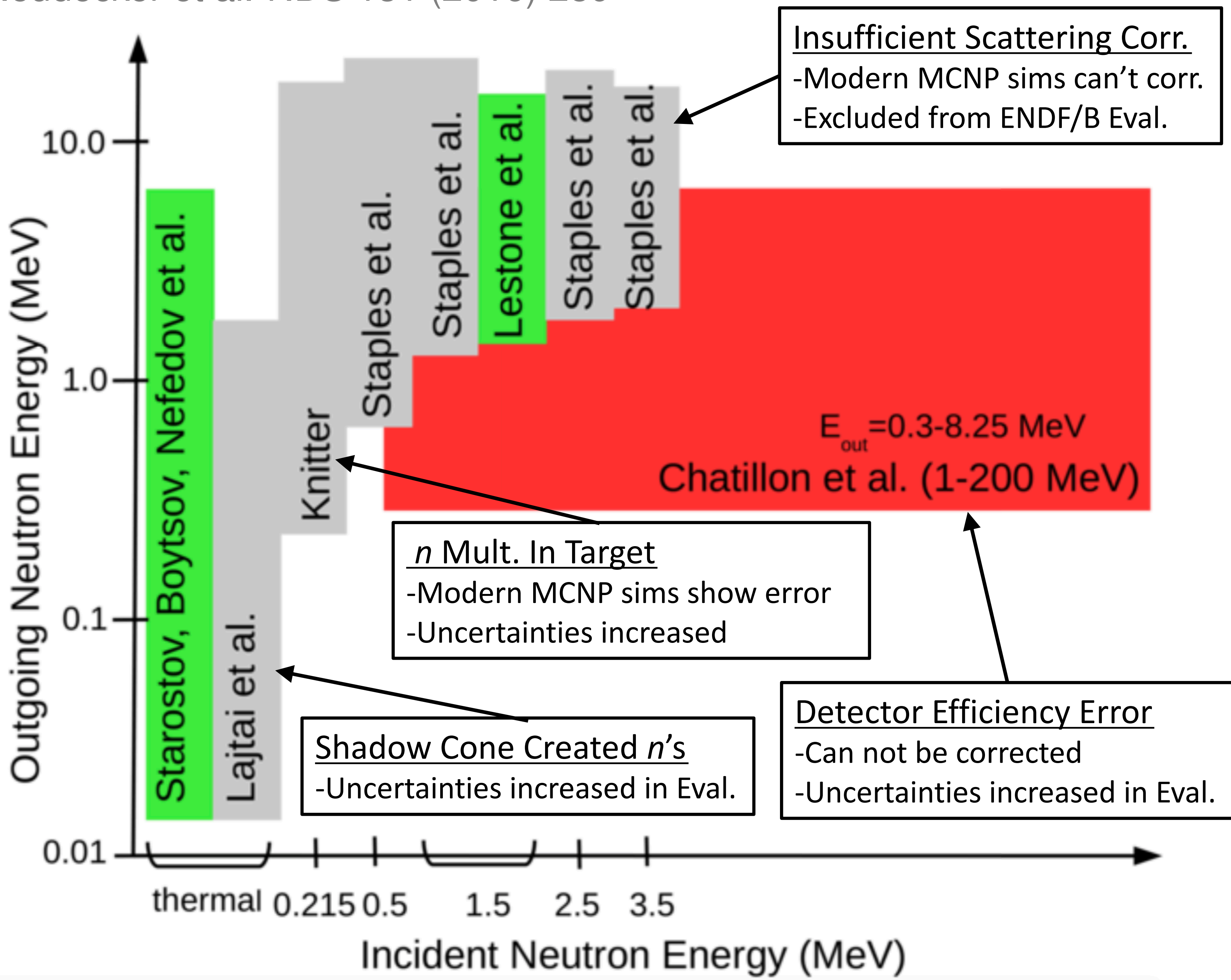
- Literature actinide PFNS measurements frequently have issues
  - No covariance matrices, and many uncertainty sources missing or ignored
  - Sometimes not possible to know how to accurately correct old data
  - Potentially unknown correlations within and between experiments

Chi-Nu is an experiment to measure the major actinide PFNS for as much of the incident and outgoing range of interest as possible with a thorough analysis of systematic uncertainties and covariances



Status of Previously Available ^{239}Pu PFNS Data

Fig: Neudecker et al. NDS 131 (2016) 289



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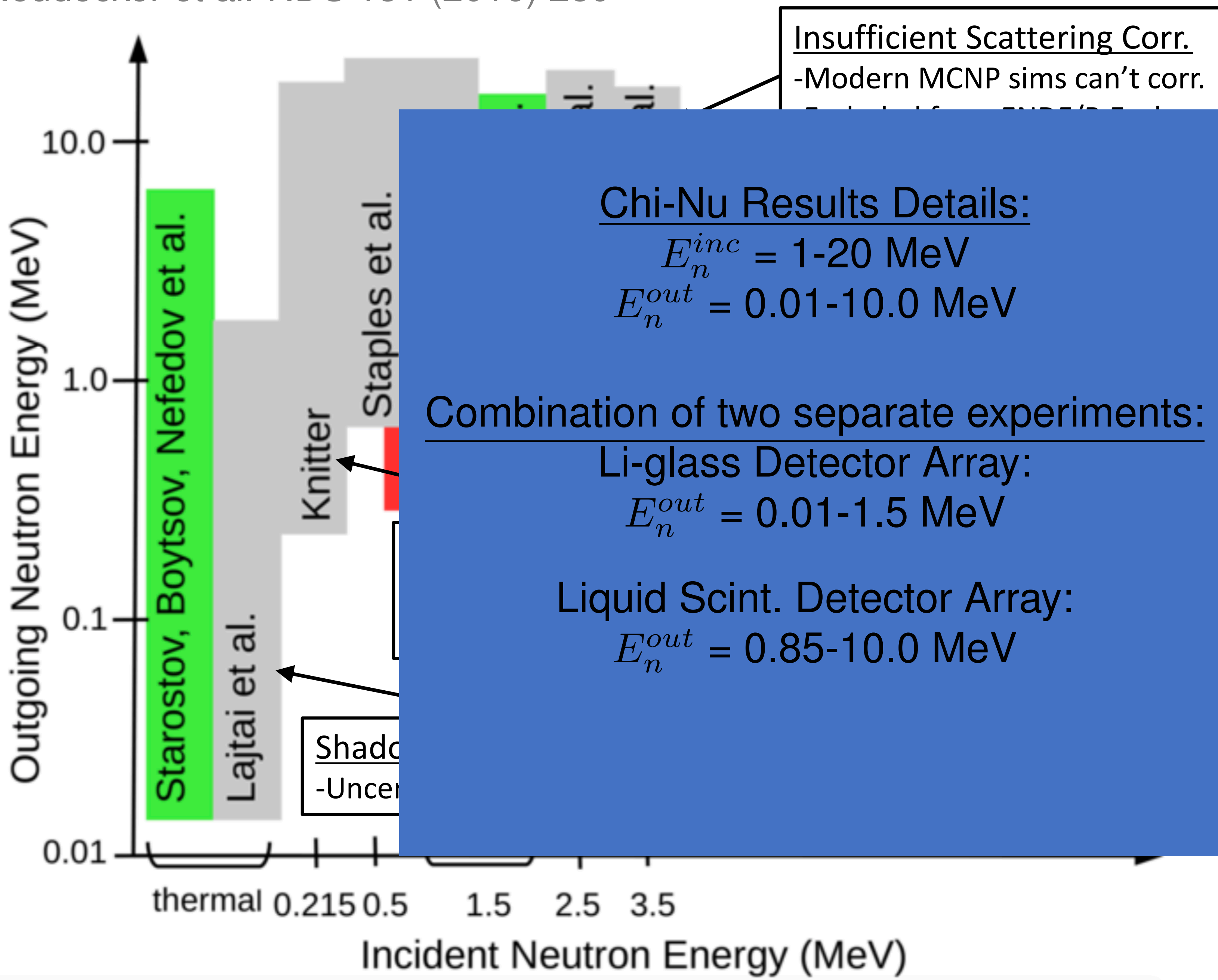


Chi-Nu Results Details:

E_n^{inc} = 1-20 MeV

E_n^{out} = 0.01-10.0 MeV

Combination of two separate experiments:

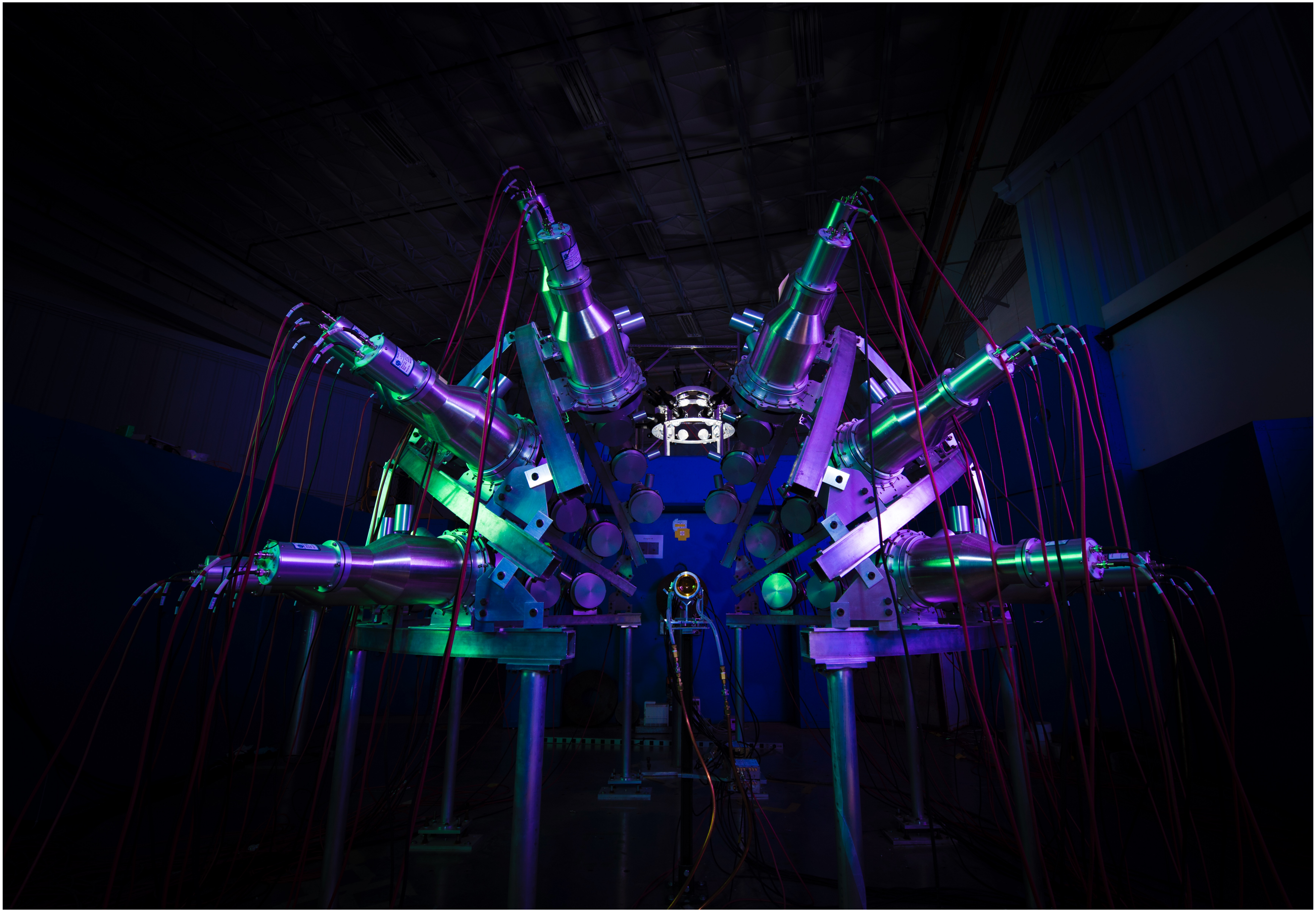
Li-glass Detector Array:

E_n^{out} = 0.01-1.5 MeV

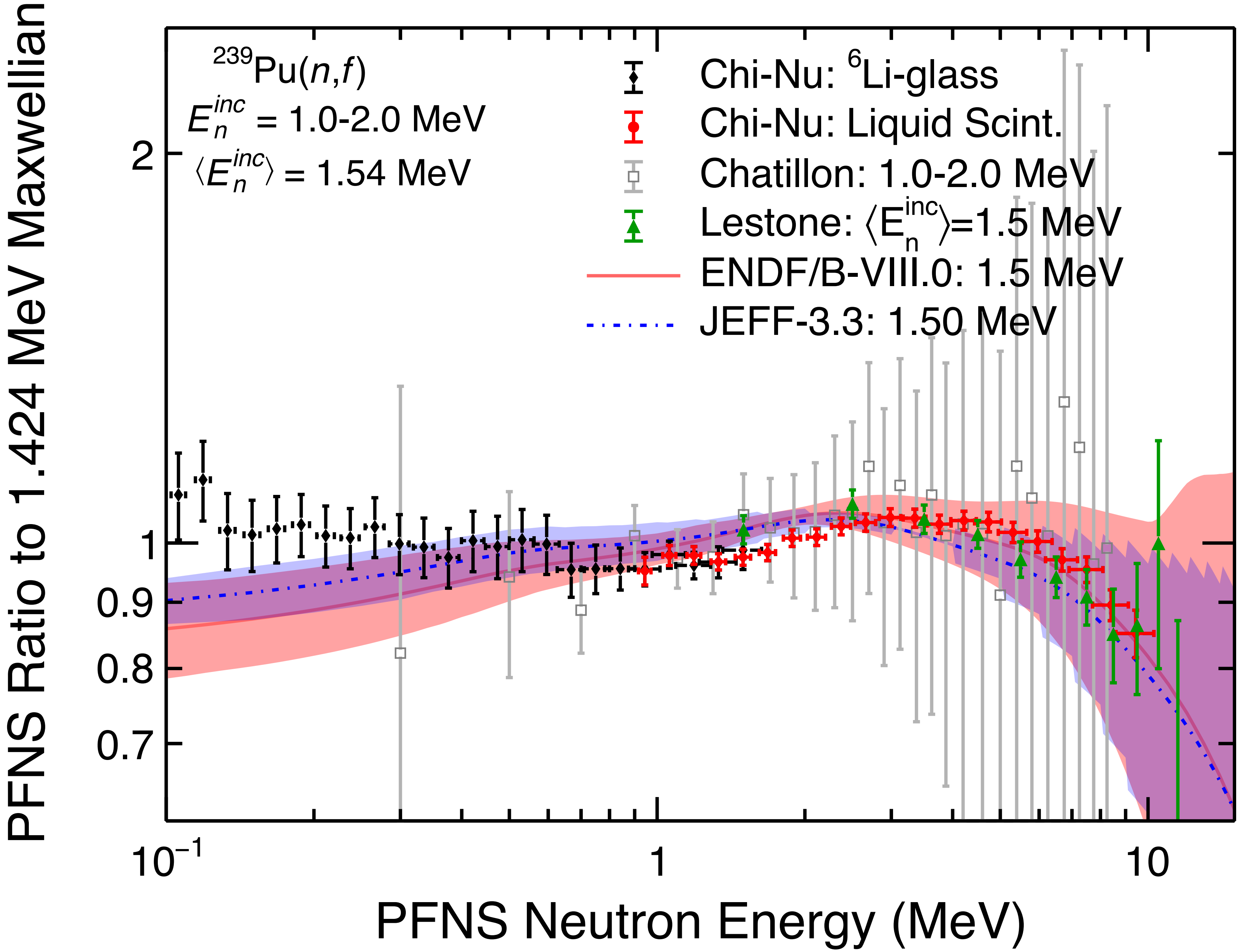
Liquid Scint. Detector Array:

E_n^{out} = 0.85-10.0 MeV

The Chi-Nu Arrays



Example PFNS Result at $\langle E_n^{inc} \rangle$ = 1.5 MeV



Covariances Separately Calculated for Each Detector

PFNS Calculated by $p_i = \dfrac{d_i - b_i}{F_i}$, for PFNS energy E_i and a single E_n^{inc}

With covariances defined by:

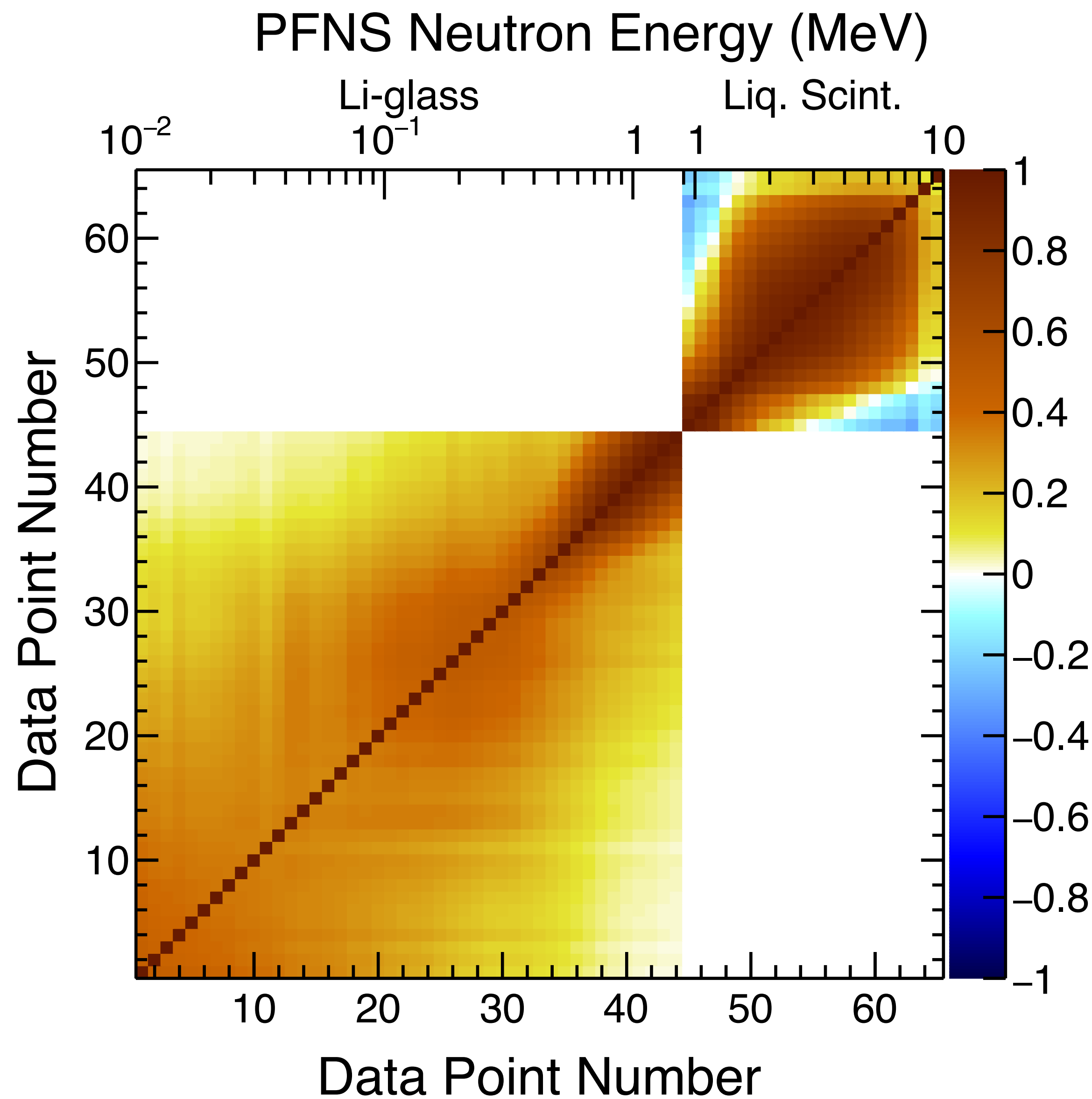
$$
\begin{aligned}
\text{cov}[d]_{ij} &= \delta_{ij} d_i, \\
\text{cov}[b]_{ij} &= \delta_{ij}\left[\frac{d_u + d_d}{4}\right] + \sigma_{b,r}^2\left[b_{o,i}b_{o,j} + \sigma_{b,l}^2\left(\frac{b_{u,i}b_{u,j} + b_{d,i}b_{d,j}}{4}\right)\right], \\
\text{cov}[F]_{ij,stat} &= \frac{\delta_{ij}}{\nu^2}\sum_{\alpha}^{\nu}\sum_{\beta}^{\nu}\sum_{k=1}^{n}\frac{R_{ik}p_{\alpha k}p_{\beta k}}{p_{ok}^2 p_{\alpha i}p_{\beta i}}, \\
\text{cov}[F]_{ij,syst} &= \frac{1}{\nu - 1}\sum_{\alpha}^{\nu}\left(\frac{c_{\alpha i}}{p_{\alpha i}} - F_i\right)\left(\frac{c_{\alpha j}}{p_{\alpha j}} - F_j\right),
\end{aligned}
$$

and, $\text{cov}[m]_{ij}$, $\text{cov}[r]_{ij}$, $\text{cov}[\epsilon]_{ij}$ applied to PFNS result.

Finally, the wraparound correction alters measured PFNS to $p_i' = \frac{p_i - \bar{x}W_i}{1-\bar{x}}$, with $\text{cov}[W]_{ij}$ and $\text{cov}[\bar{x}]_{ij}$ propagated to the result.

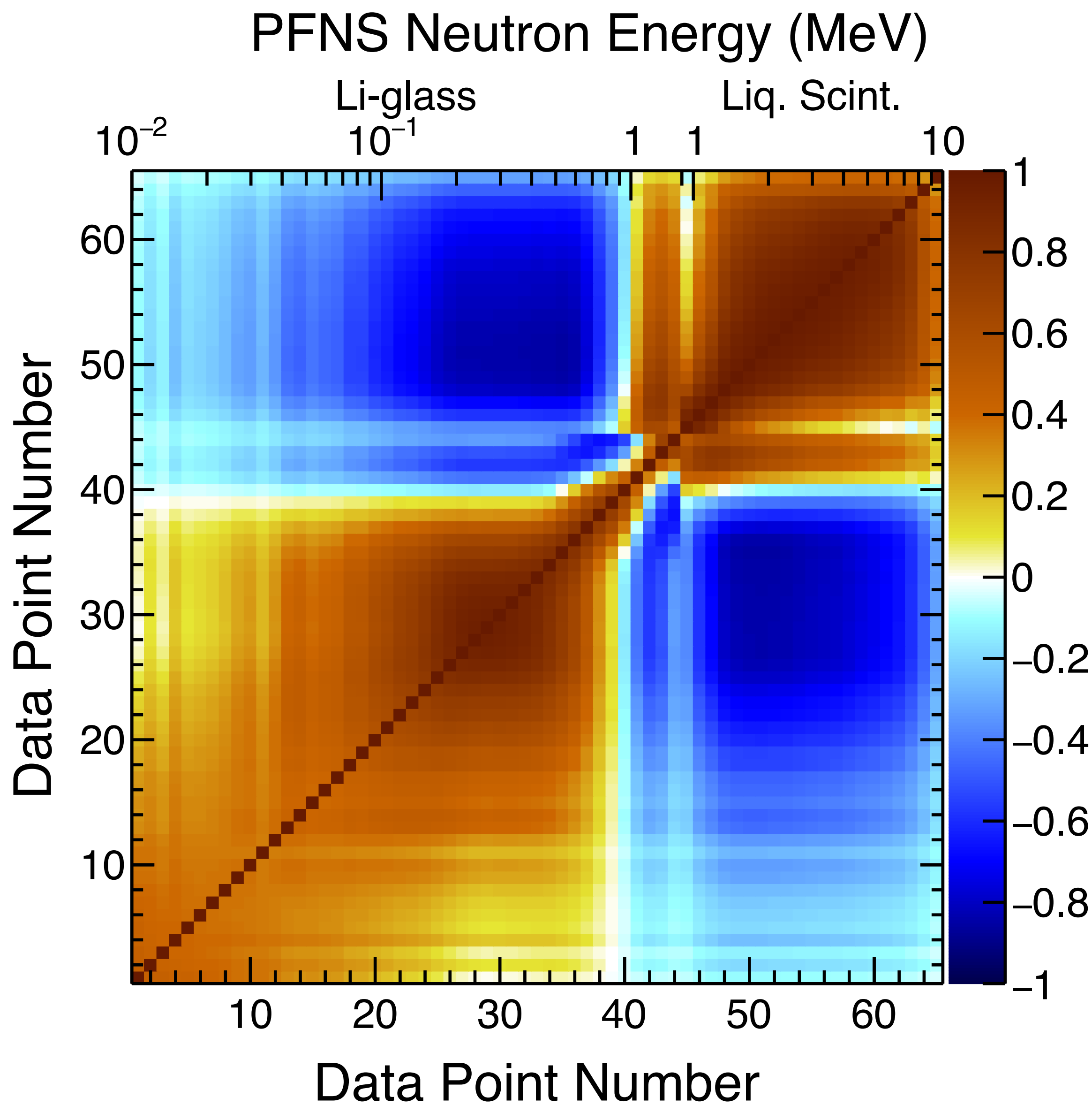
Initial Result is Two (almost) Uncorrelated Shapes

- Wraparound correction correlated between detector type and E_n^{inc}
- Complicated correlations result from correlated exp. environments
- Step 1: combine based on the overlap E_n^{out} overlap region
- Step 2: Normalize the entire shape to unit area
  - See 2019 CSEWG talk



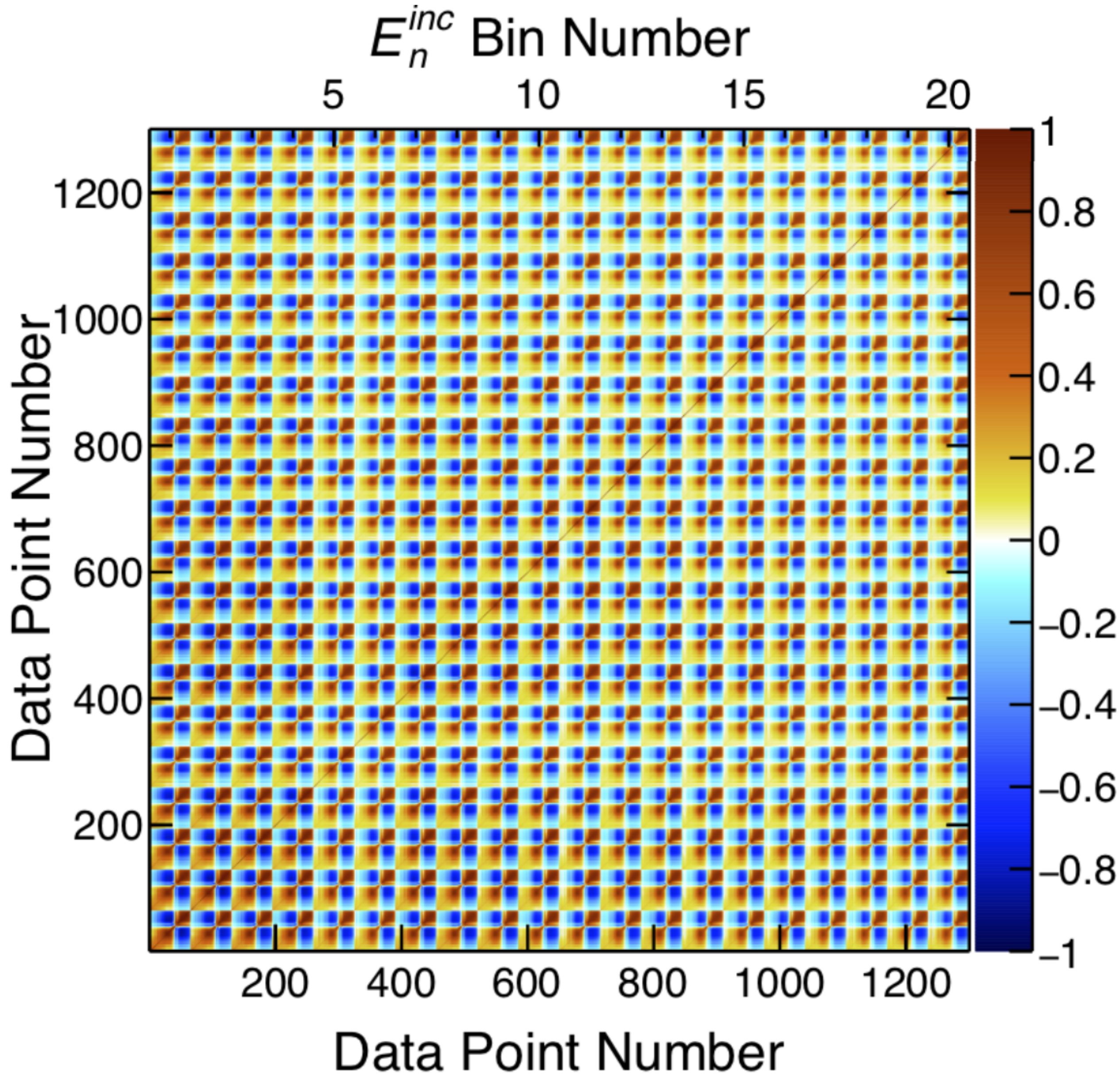
Overlap and Total Normalizations Yield Final Result

- Fully-correlated covariances drop out (none)
- Strongly-positive covariances reduce/alter impact
- Covariances are redistributed according to shape impact
- Notable correlations between points of a single detector, and anticorrelation between opposite detectors



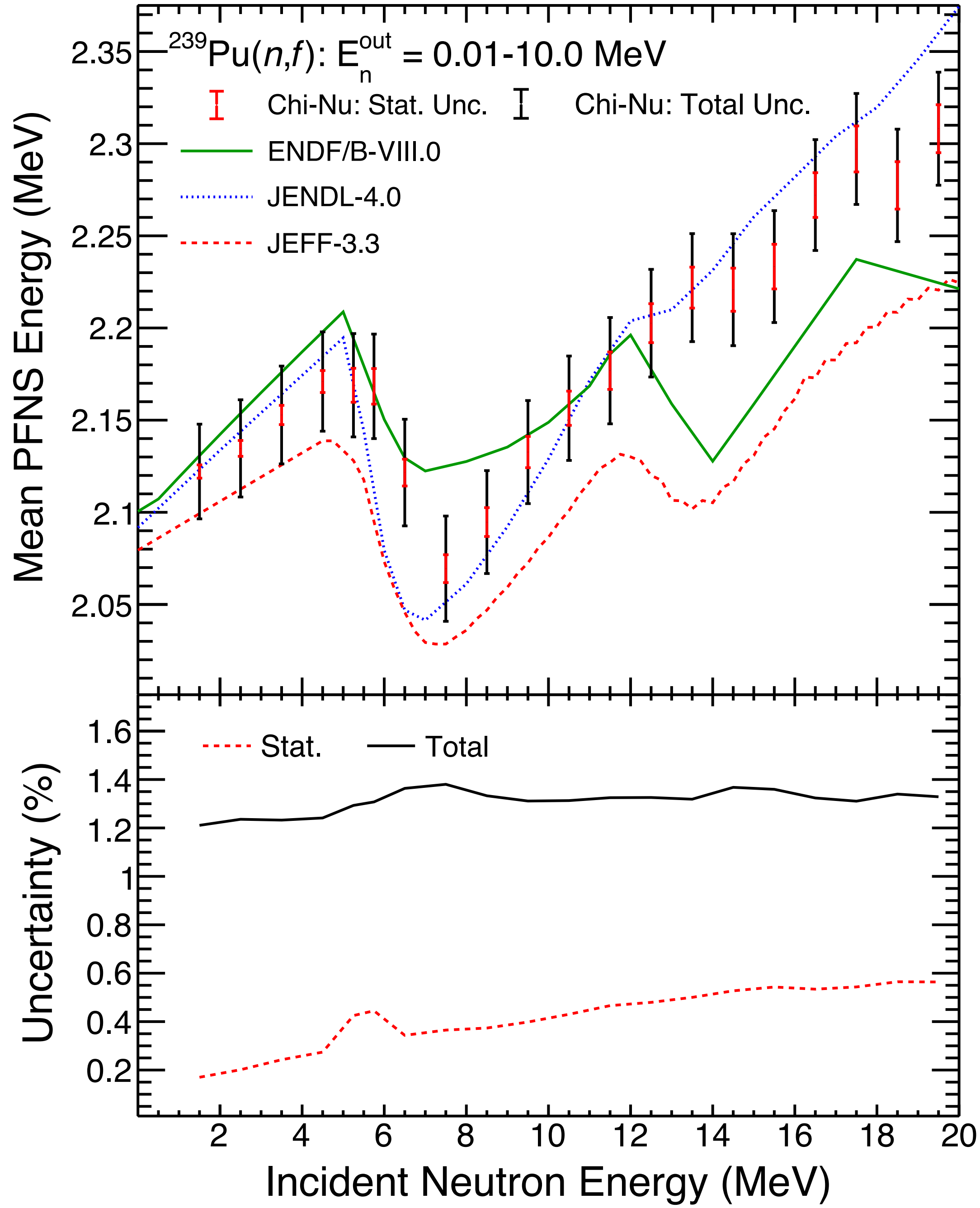
Strong E_n^{inc} Correlations from Identical Analyses

- Same ratio-of-ratios method applied to all E_n^{inc}
  - Similarly true for ratio to Cf
- Every data point has an experimentally-derived correlation to every other data point
- These details are essential for accurate representation of the acquired results
- E_n^{inc} correlations allow for $\langle E \rangle$ correlation calculations



Mean PFNS Energy, $\langle E \rangle$

- Never been calculated for a PFNS measurement
- $\langle E \rangle$ points are *highly* correlated
- Implies that the relative value of the $\langle E \rangle$ points is fairly well know
  - More well known than the total uncertainty would suggest



Mean PFNS Energies, $\langle E \rangle$, are Highly Correlated

Correlations between E_n^{inc} allows for calculation of $\langle E \rangle$ covariance matrix

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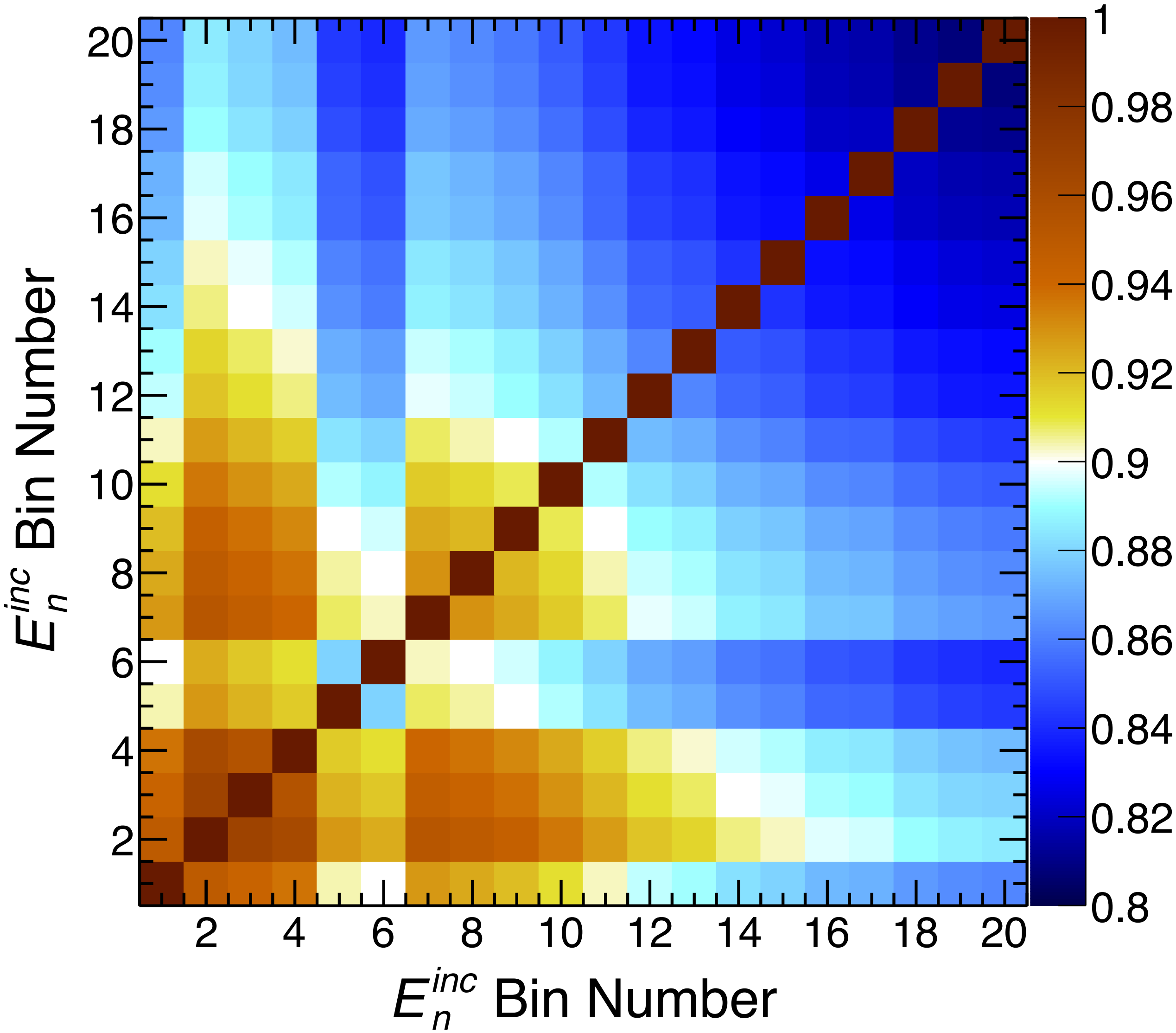

Conclusions and Future Work

- The covariances reported here are necessary for accurate usage of these data
- Similar correlations likely exist for other measurements across multiple E_n^{inc} values, but they were never reported
- The mean energy centroids have been fairly well measured, but the shape is well-known
  - Informative for relative contributions of multichance fission to PFNS
- Same, or improved, Chi-Nu analysis procedure will be applied to future results publications