LA-UR-20-29477
Approved for public release; distribution is unlimited.

Title: Neutron-Induced Fission and Scattering Measurements at LANSCE

Author(s): Kelly, Keegan John

Intended for: Discussion of LANL with CENTAUR students, for advertising purposes and informing them about work/life at LANL.

Issued: 2020-11-18

Neutron-Induced Fission and Scattering Measurements at LANSCE

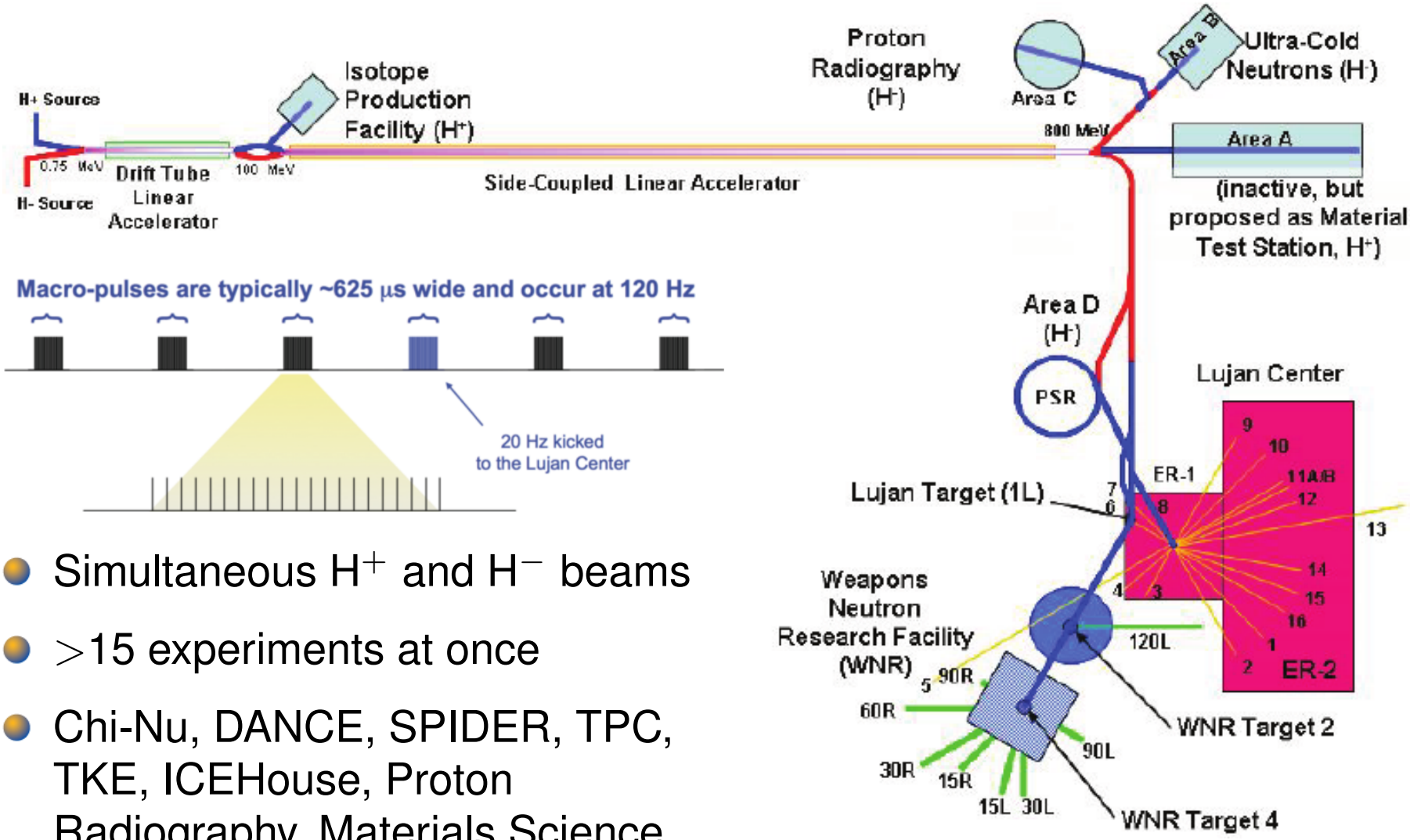
CENTAUR Meets LANL
11/10/2020

Keegan J. Kelly,
on behalf of P-27 and the Chi-Nu collaboration

Outline

- The Los Alamos Neutron Science Center (LANSCE)
- The Chi-Nu Experiment: Prompt Fission Neutron Spectra
- Neutron Scattering Measurements
- Collaborations with T and X Divisions at LANL
- Future Work

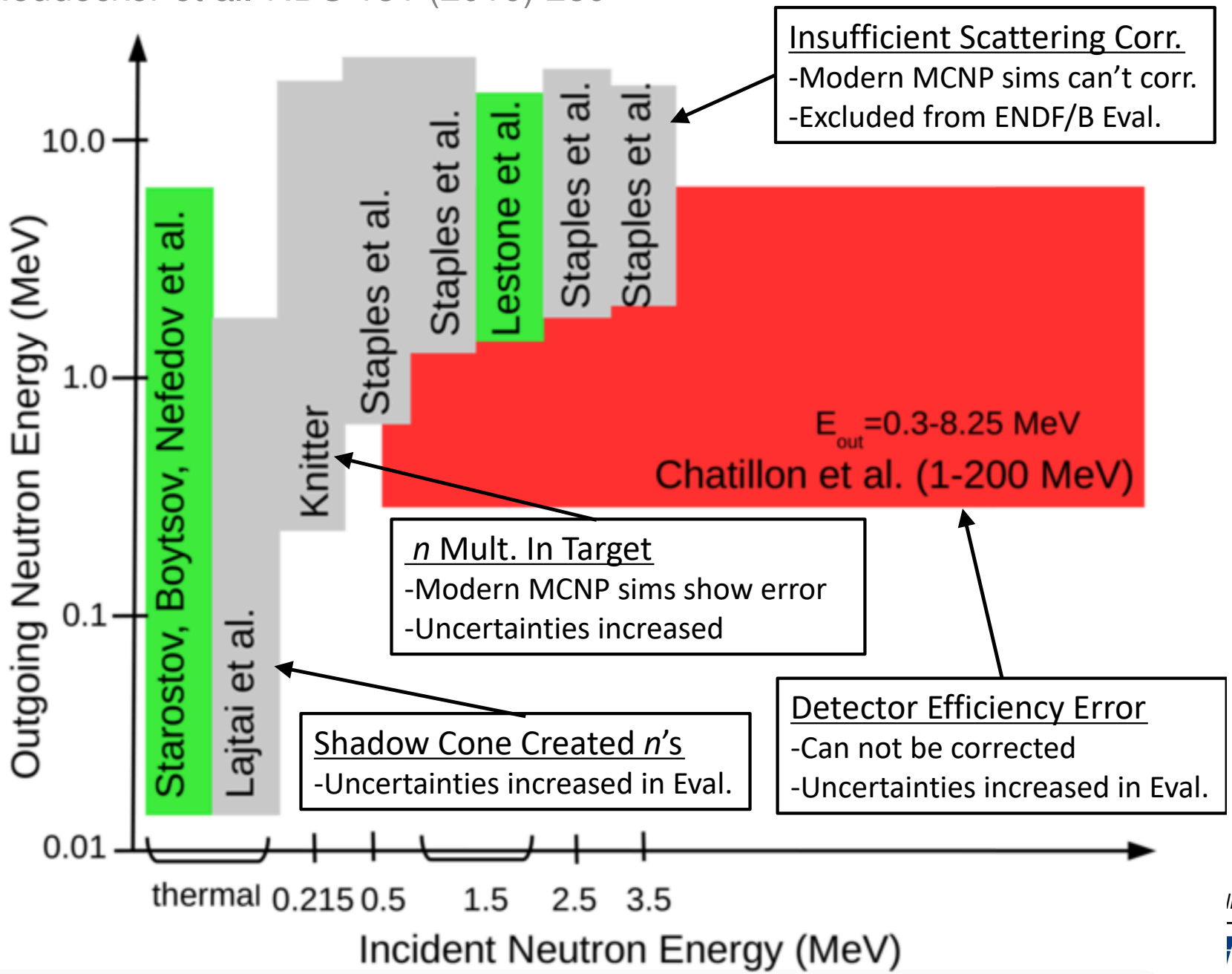
LANSCE Layout and Experimental Areas



- Simultaneous H^+ and H^- beams
- >15 experiments at once
- Chi-Nu, DANCE, SPIDER, TPC, TKE, ICEHouse, Proton Radiography, Materials Science, UCN, IPF, and more

Chi-Nu Goal: Measure PFNS χ Matrix for Actinides

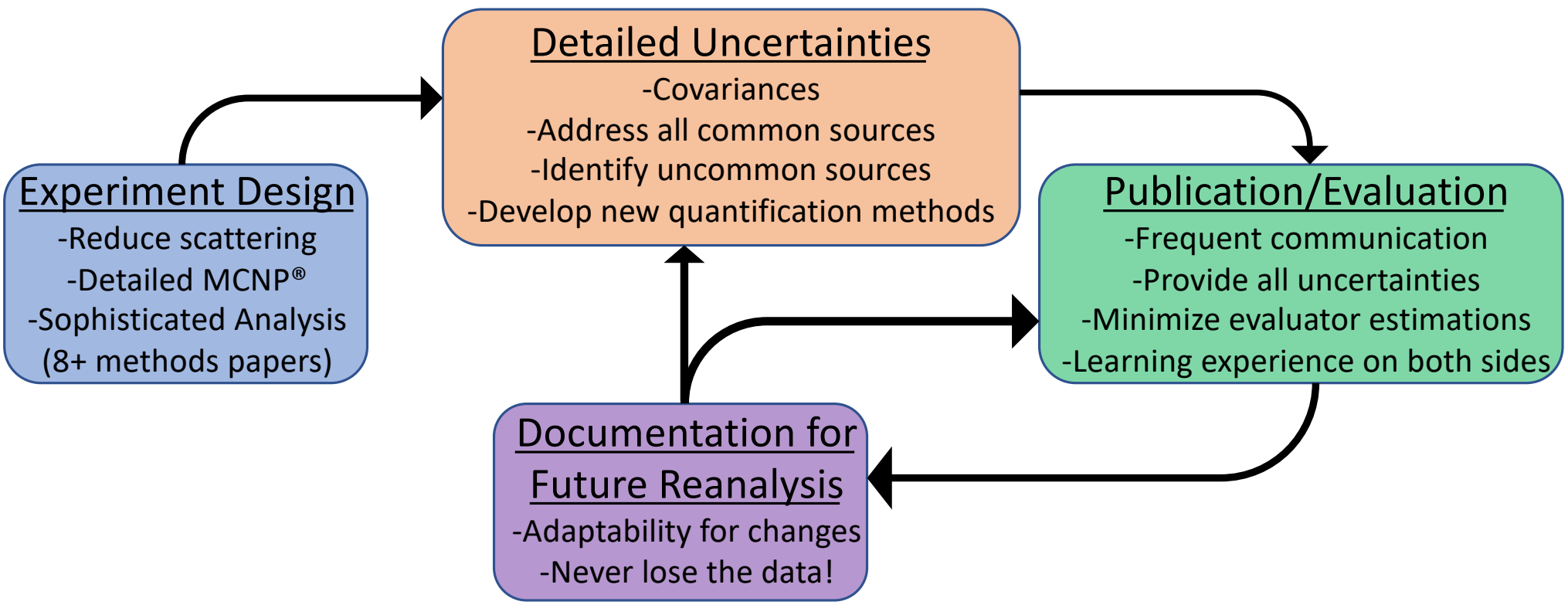
Fig: Neudecker et al. NDS 131 (2016) 289



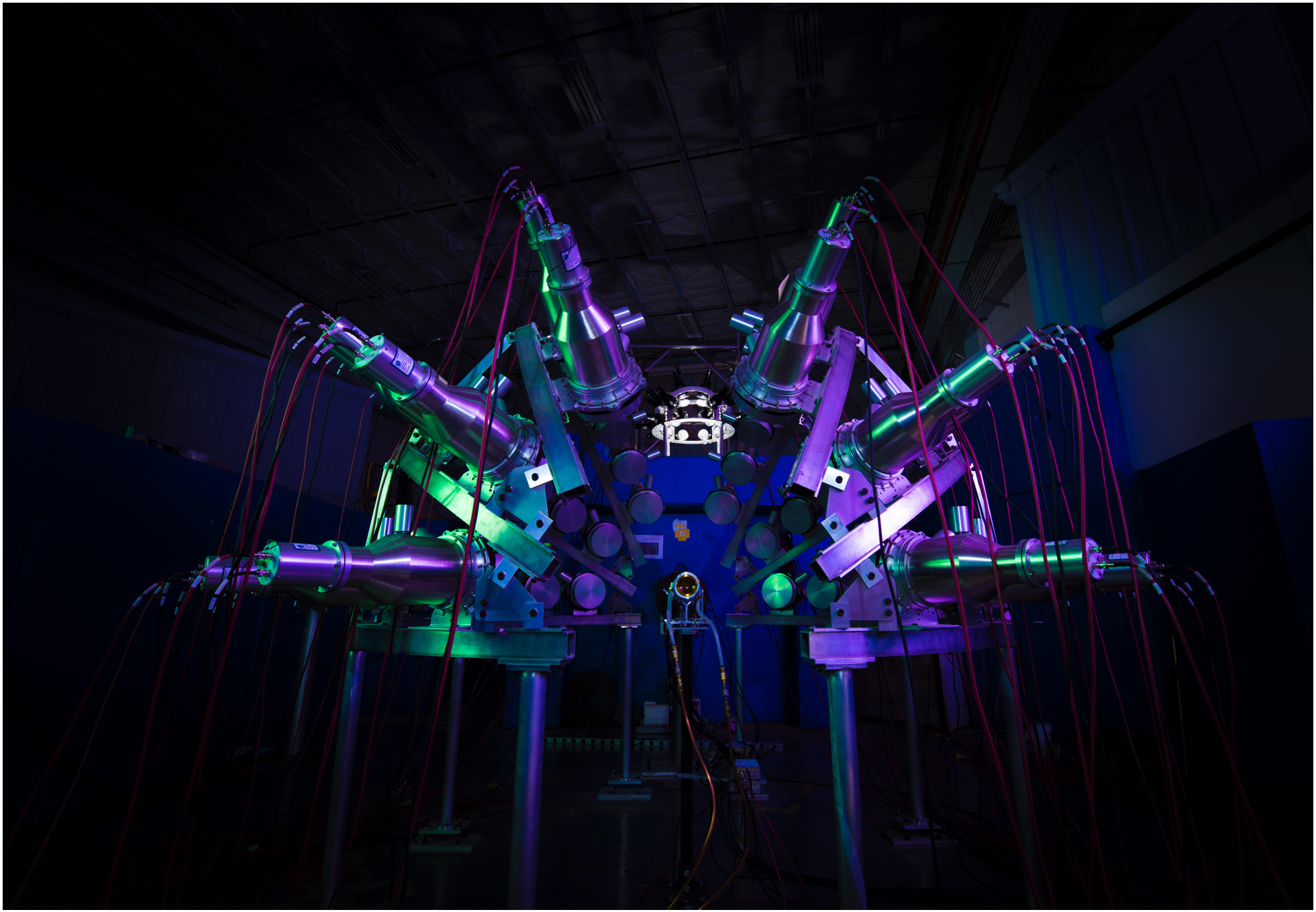
Ultimate Goal: Stand the Test of Time

- Repeated mistakes in experiments with regard to uncertainties:
  - Frequently no covariance matrices, 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 a single experiment to measure the major actinide PFNS for all incident and outgoing energies of interest with a thorough analysis of systematic uncertainties and covariances

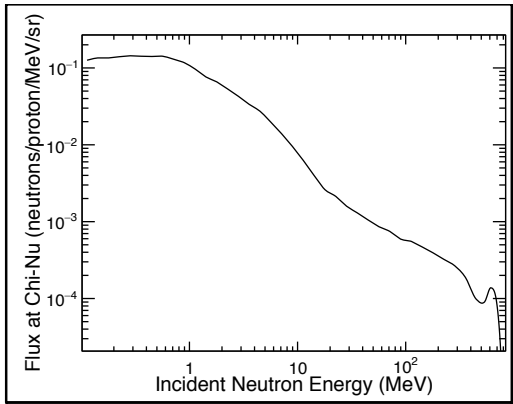


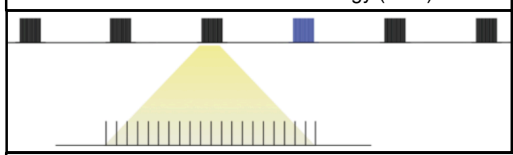
The Chi-Nu Arrays

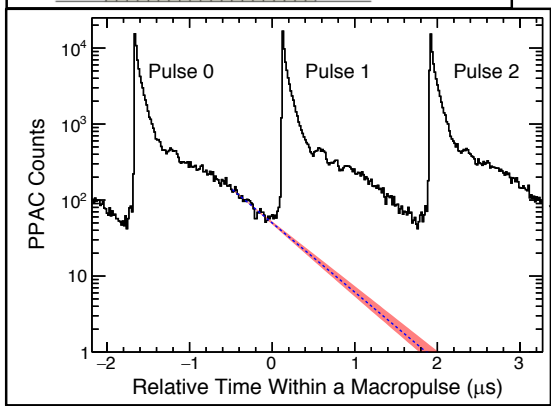


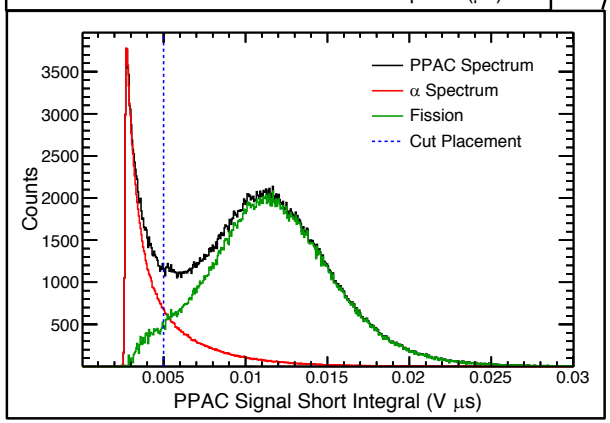
The Chi-Nu Experiment

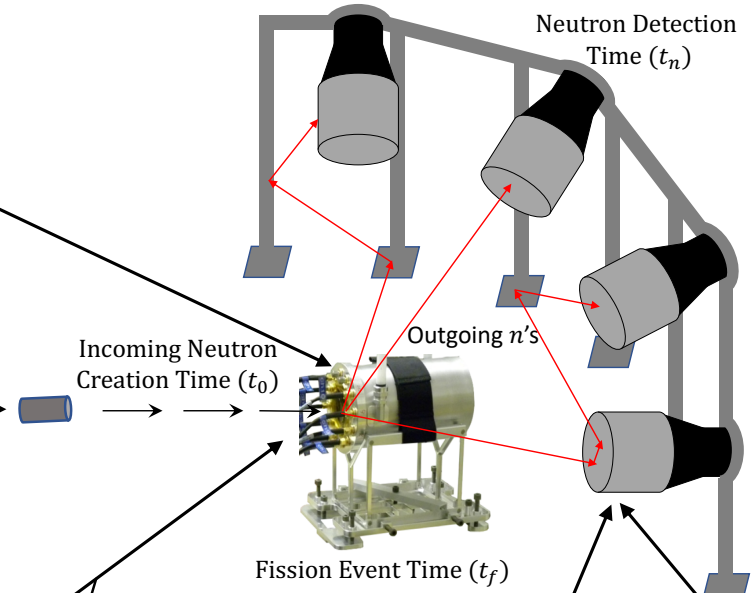
Devlin *et al.* NDS **148** 322 (2018)
Haight *et al.* NDS **123** 130 (2015)





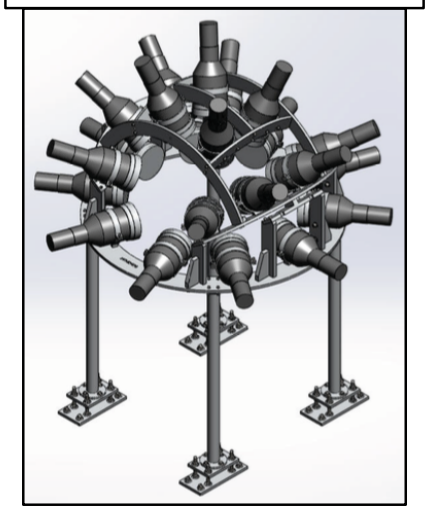






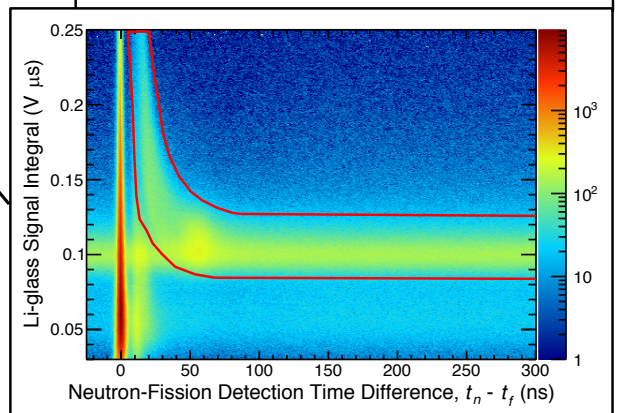
22 Li-glass Detectors

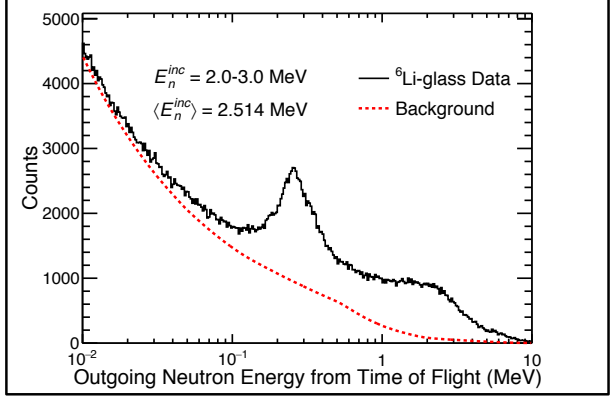
- ~0.4 m *n* flight path
- $E_n^{out} \approx$ 0.01-1.5 MeV



Chi-Nu is a double time-of-flight experiment

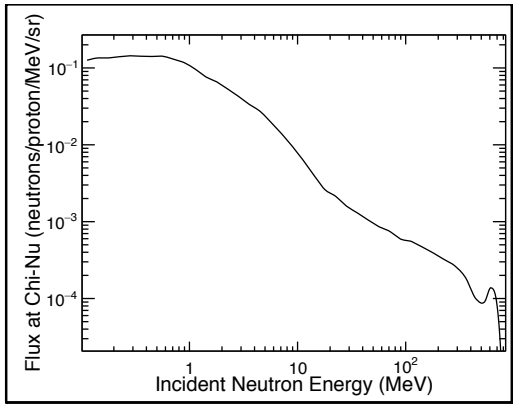
- $t_f - t_0 \rightarrow E_n^{inc}$
- $t_n - t_f \rightarrow E_n^{inc}$
- PPAC fission counter
- Two *n*-detector arrays used separately
- Combined to form single PFNS shape

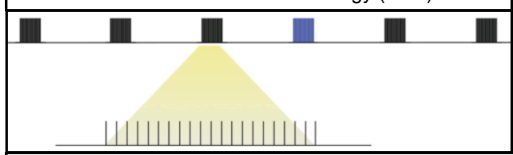


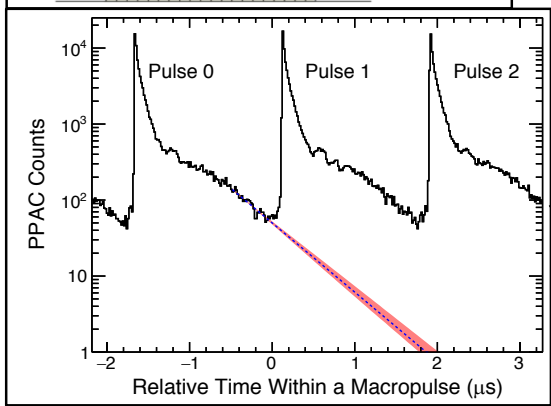


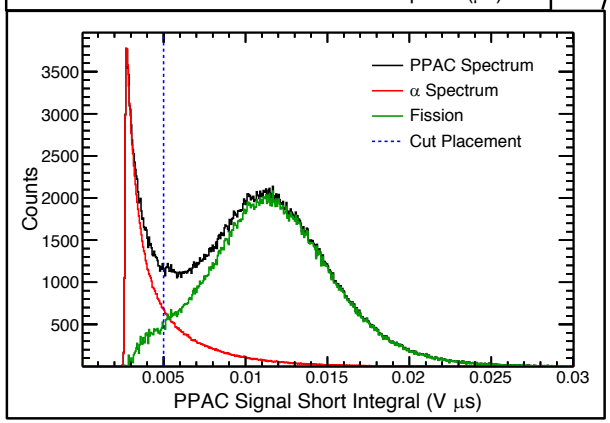
The Chi-Nu Experiment

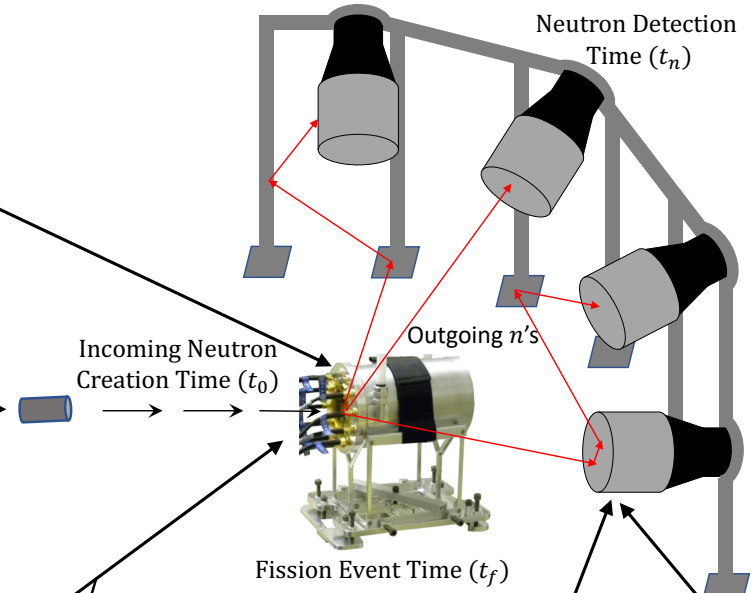
Devlin *et al.* NDS **148** 322 (2018)
Haight *et al.* NDS **123** 130 (2015)





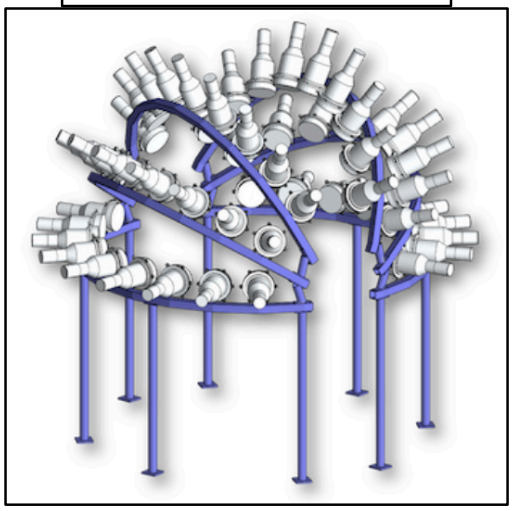






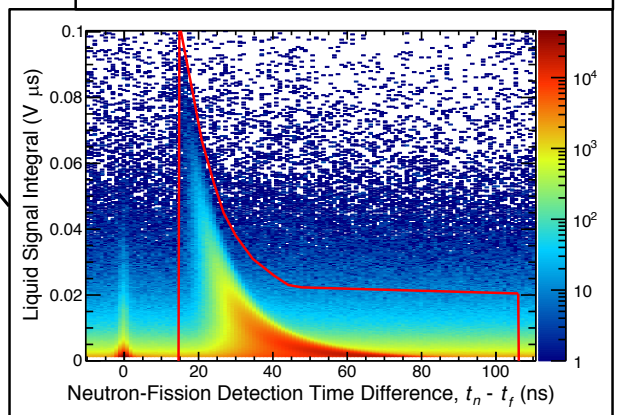
54 Liquid Scintillators

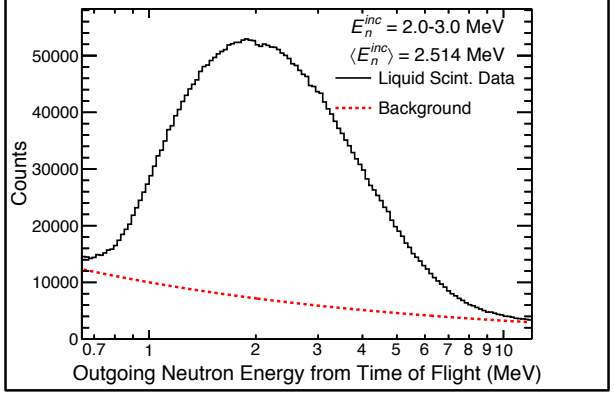
- ~1 m *n* flight path
- $E_n^{out} \approx$ 0.8-10 MeV



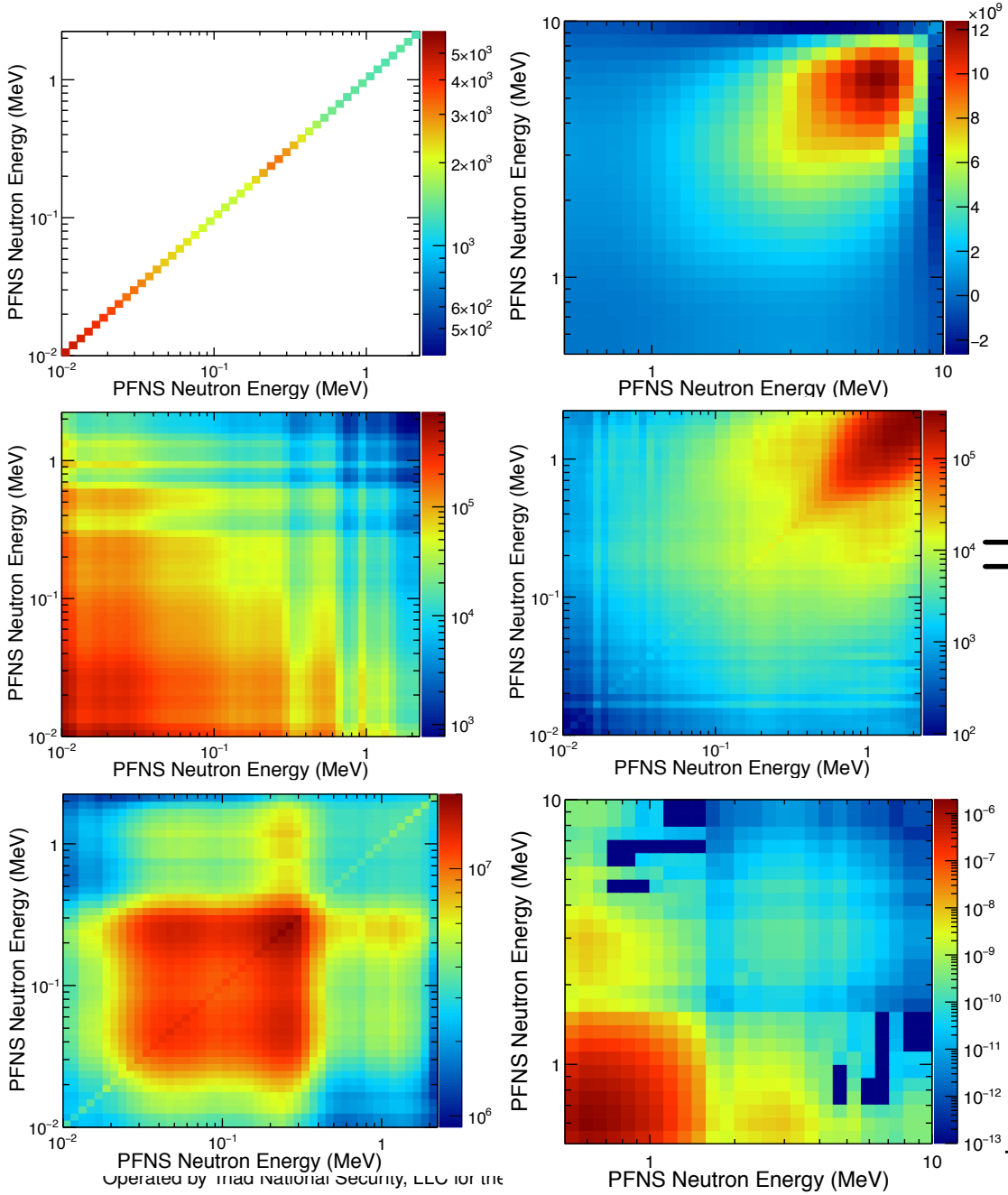
Chi-Nu is a double time-of-flight experiment

- $t_f - t_0 \rightarrow E_n^{inc}$
- $t_n - t_f \rightarrow E_n^{inc}$
- PPAC fission counter
- Two *n*-detector arrays used separately
- Combined to form single PFNS shape

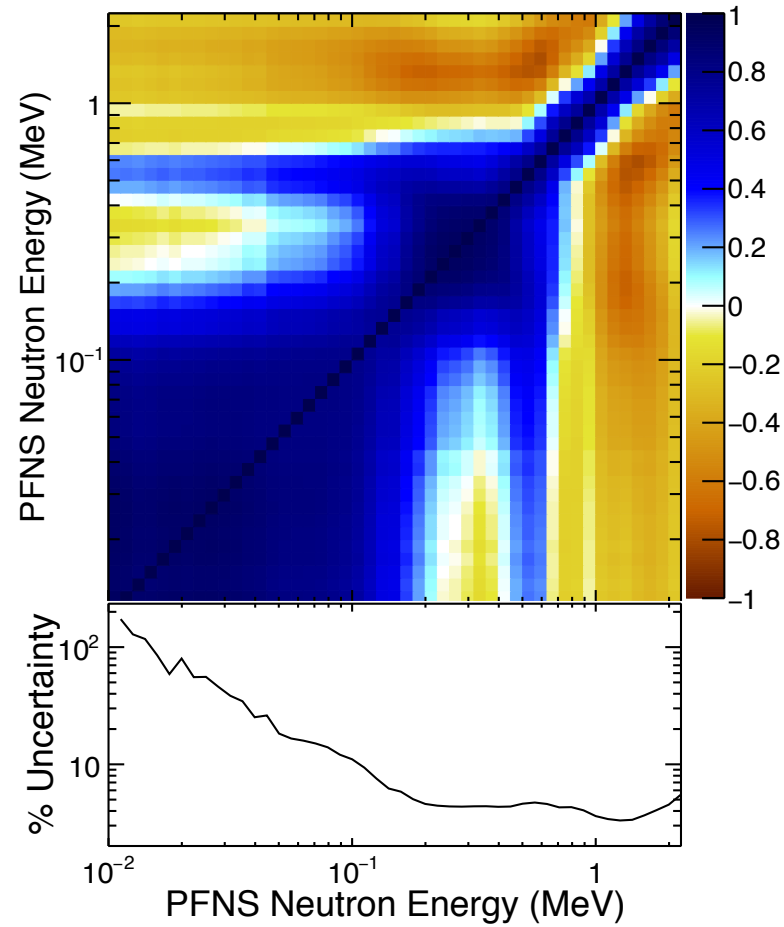




Covariances from Chi-Nu to Evaluations



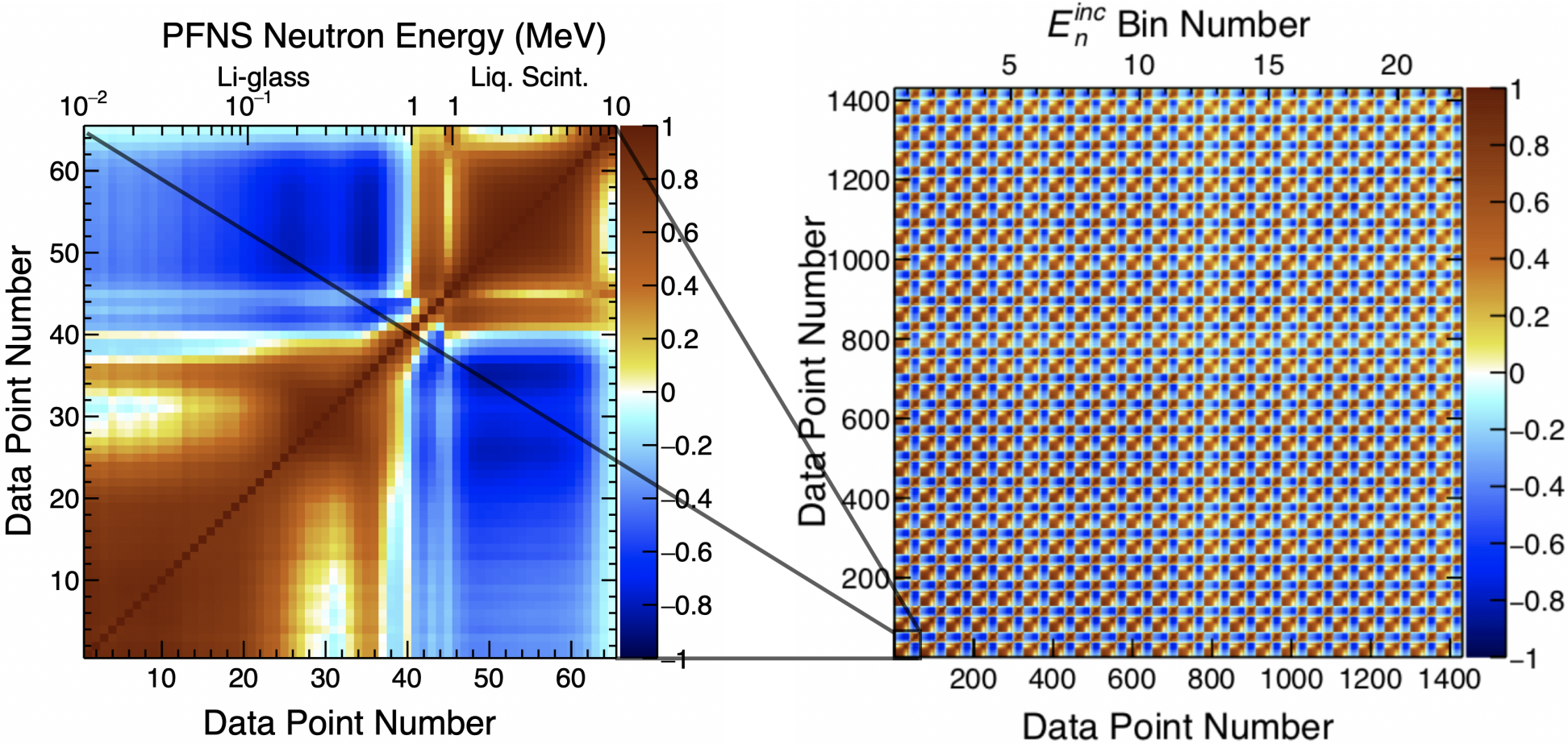
- Well-documented partial and full covariance matrices
- Thorough assessment of systematic effects



Correlations Between All E_{out} and All E_{inc} Points

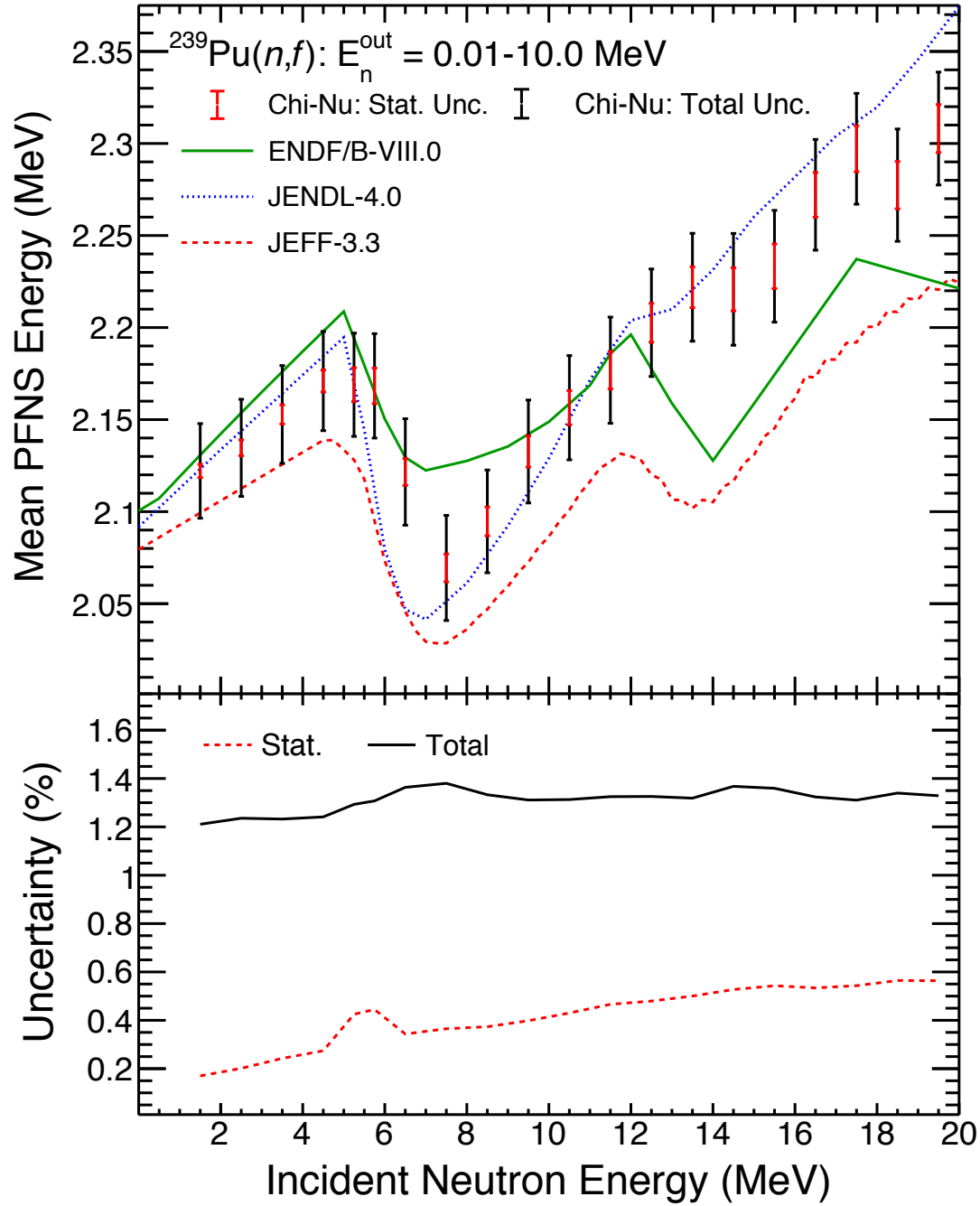
- Li-glass and liquid data combined to form single shape result for each E_{inc}
- Correlations between PFNS points within each detector array
- Correlations between PFNS points across detector arrays
- Correlations between PFNS points from each E_{inc} bin and E_{out}

Required for accurate representation of Chi-Nu data in evaluations



Mean PFNS Energy, $\langle E \rangle$; Observing New Physics

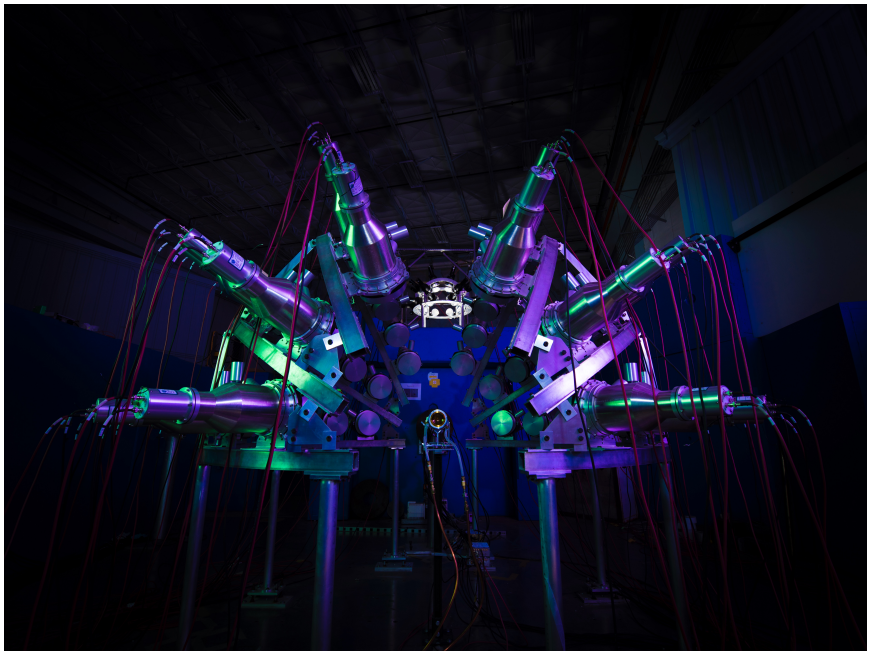
- Never been calculated for a PFNS measurement
- $\langle E \rangle$ points are *highly* correlated
- Implies that the <u>relative</u> value of the $\langle E \rangle$ points is fairly well know
  - More well known than the total uncertainty would suggest

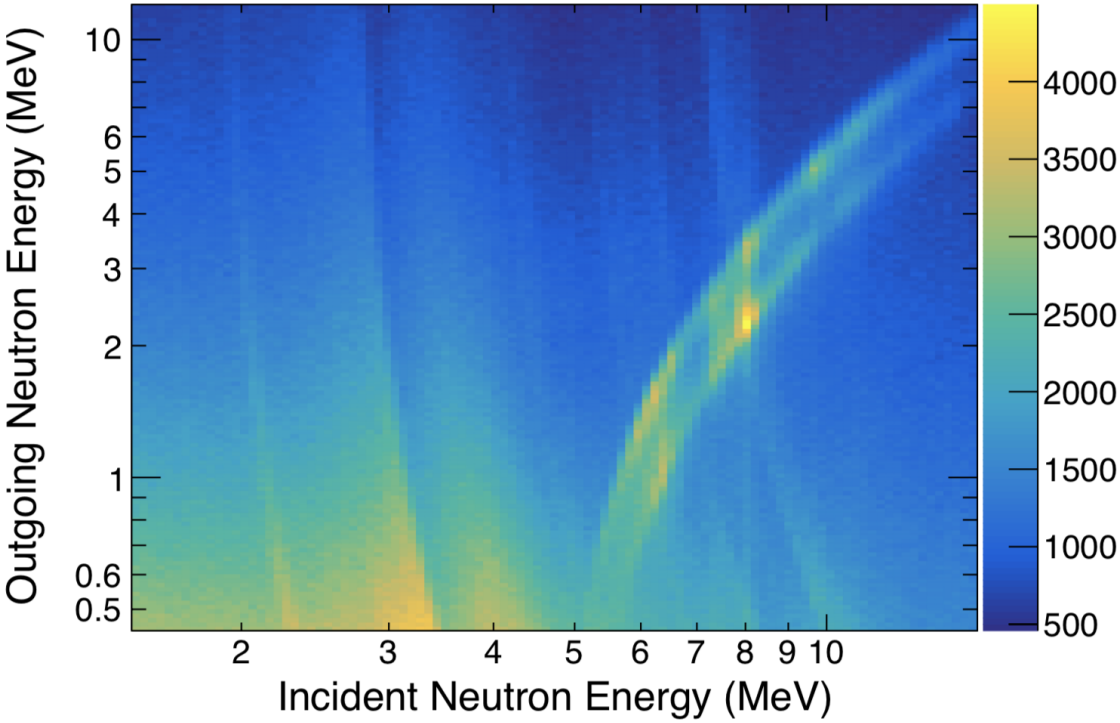


Repurposing Liq. Scints. for Dual n-γ Analysis

- Able to leverage data collected from other experiments using the Chi-Nu liquid scintillator array
  - High statistics, to better guide data analysis
  - Difficult to obtain high statistics with trial detector purchases
- Start with easy case: natural carbon

<u>Begin by simply looking for n-γ coincidence in post-processing analysis</u>





Random Coincidence Background Technique

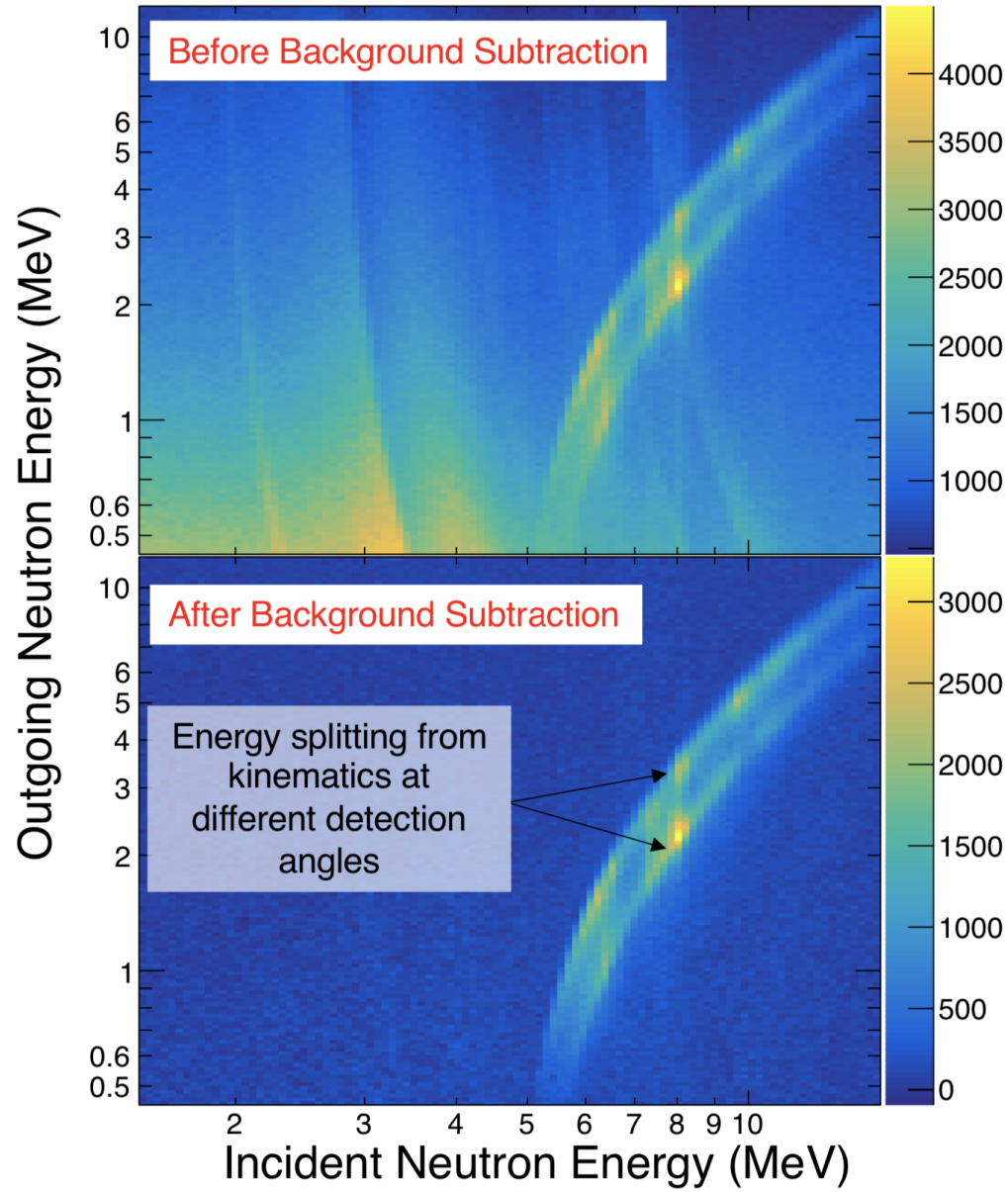
- Random coincidence rates derived form Poisson probabilities for *uncorrelated* detection rates †
  - true coincidence rate must be low

- Calculate the total probability for:
  1. Detecting a γ at time t_γ
  2. Not detecting n over coinc. time $t_n - t_\gamma$
  3. Detecting n at time t_n

$$\text{Coinc. Rate} = r_b = r_\gamma r_n \Delta_t$$

$$\Rightarrow \quad b = \frac{\gamma n}{N_{t_0}}$$

$$\text{with} \quad \gamma, n = \text{counts}$$

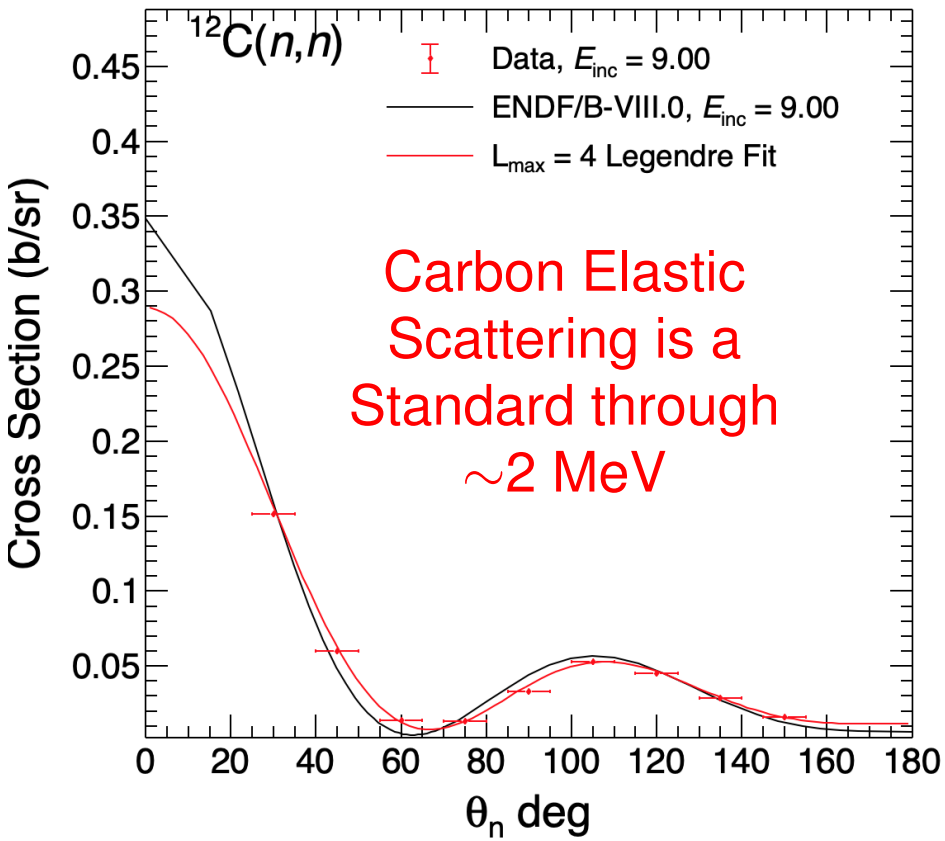


† O'Donnell, NIMA **805** (2016) 87

Correlated n-γ Distributions Collected as Well

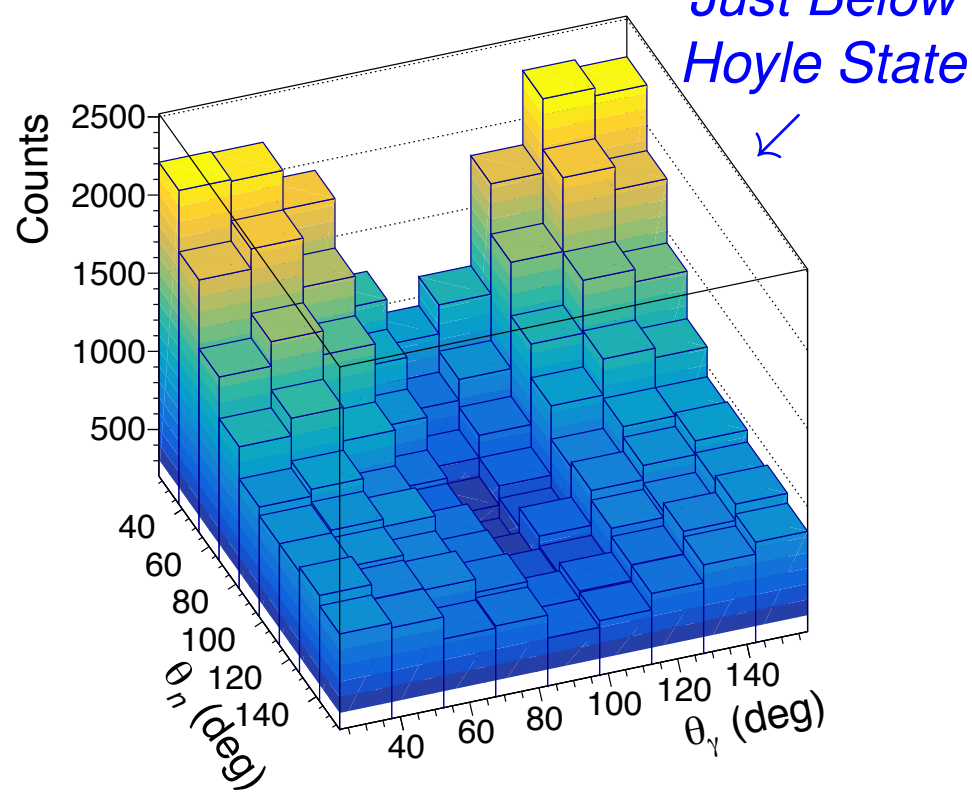
Extract n angular distributions from elastic scattering and correlated n-γ distributions from inelastic scattering

Elastic Scattering



Carbon Elastic Scattering is a Standard through ~2 MeV

Inelastic Scattering



Just Below Hoyle State

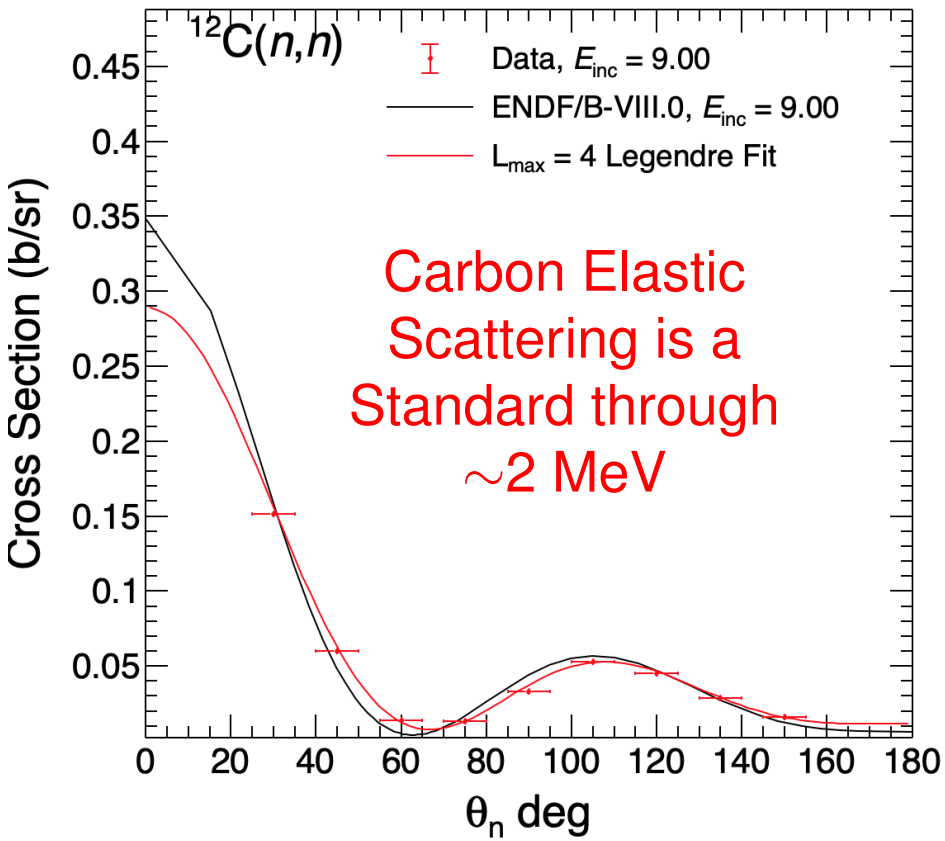
Very few experiments have measured n-γ distributions

$\rightarrow$ Measured at limited energies and angles

Even "Simple" Angular Dists. Can Be Complicated!

Extract n angular distributions from elastic scattering and correlated n-γ distributions from inelastic scattering

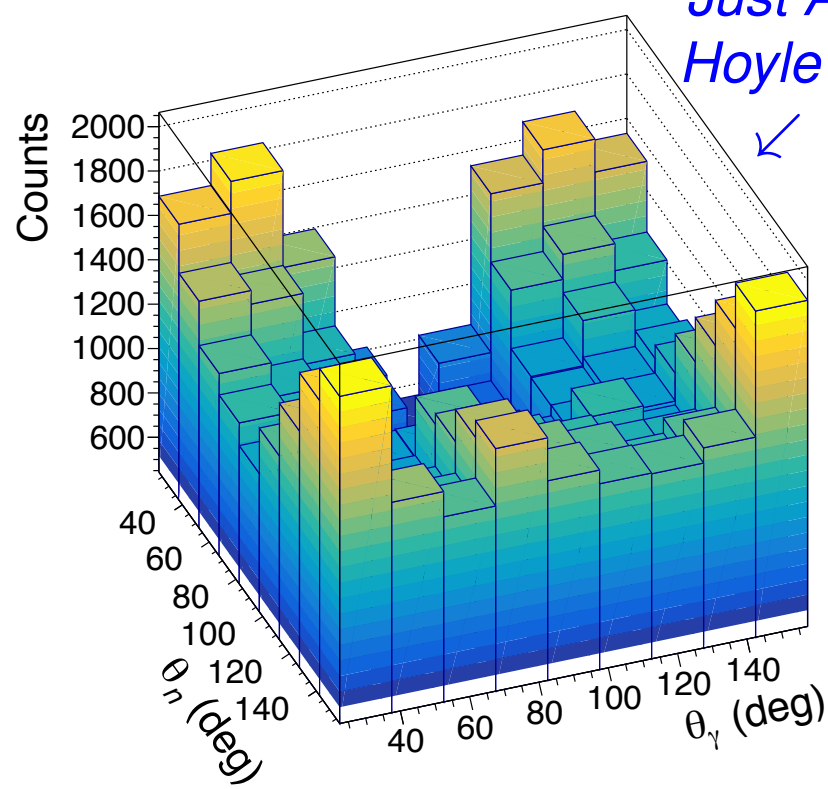
Elastic Scattering



Carbon Elastic Scattering is a Standard through ~2 MeV

Inelastic Scattering

Just Above Hoyle State

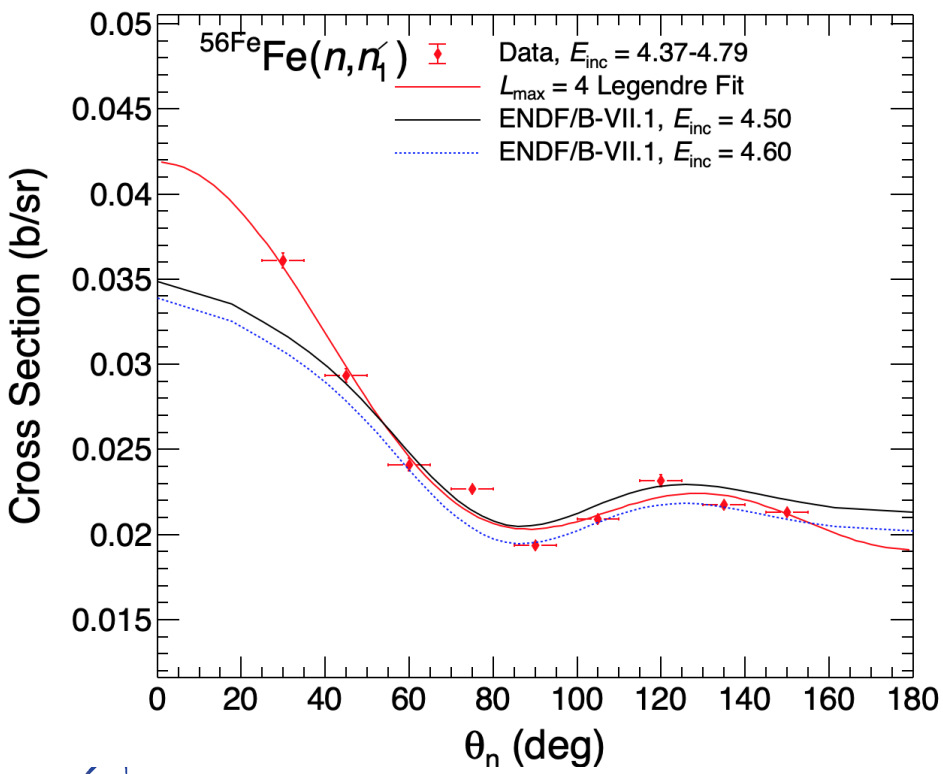


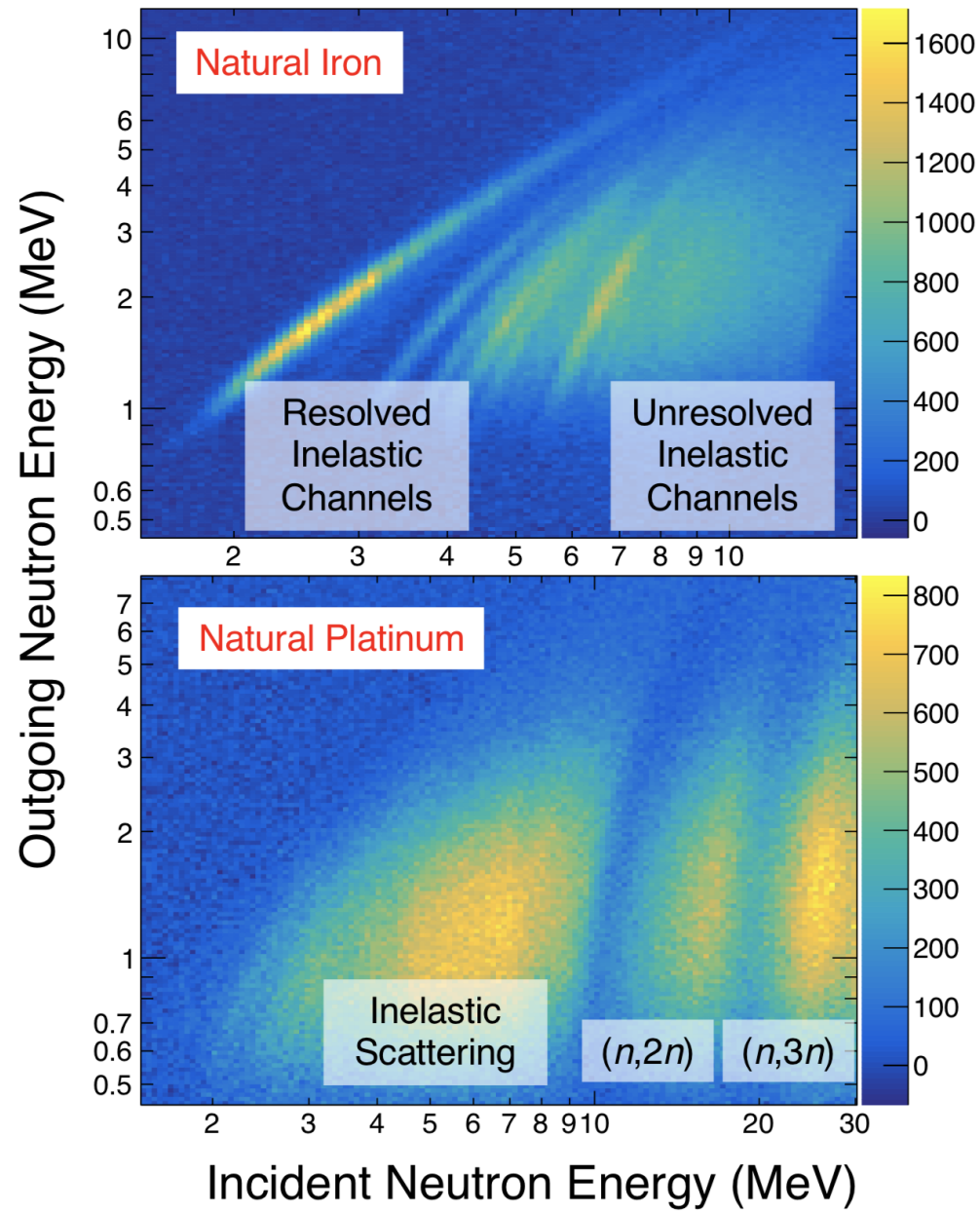
Distributions change with changing angular momentum distributions

$\Rightarrow$ Need to measure the entire distribution

Fe Levels Can Be Resolved

- Fe levels are reasonably dense
- The liquid scint. time resolution allows for low-lying state separation



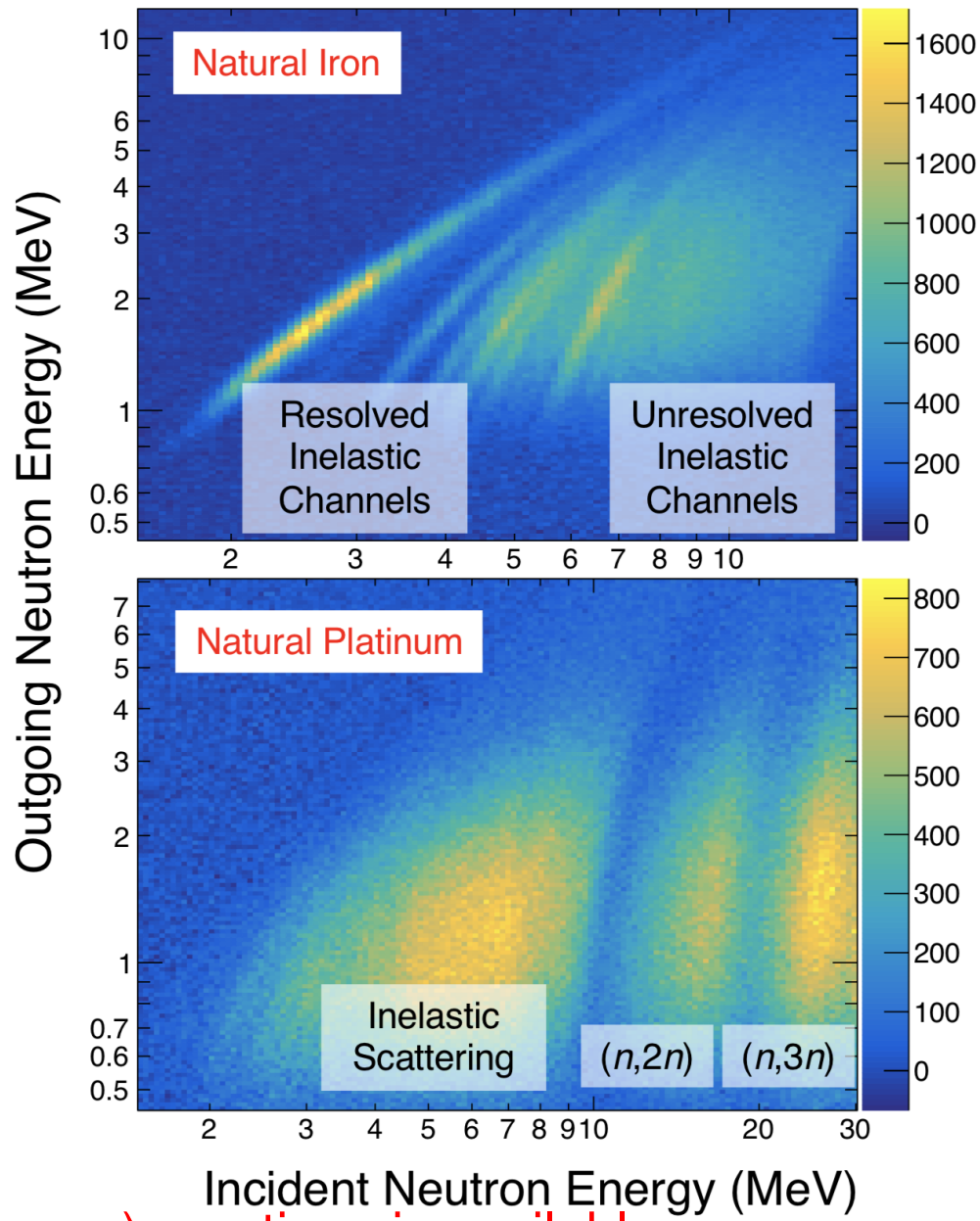


$(n,2n)$ and $(n,3n)$ Reactions Observed in Pt Data

- Fe levels are reasonably dense
- The liquid scint. time resolution allows for low-lying state separation

---

- Natural Pt contains 5 isotopes
  - ^{190}Pt: 0.01%
  - ^{192}Pt: 0.79%
  - ^{194}Pt: 32.97%
  - ^{195}Pt: 33.83%
  - ^{196}Pt: 25.24%
  - ^{198}Pt: 7.16%
- Regions of high counts can be understood as inelastic scattering, $(n,2n)$, and $(n,3n)$ reactions



Information about *all* $(n,xn\gamma)$ reactions is available

Collaboration Across the Wide World of LANL

- Direct communication with evaluators (T and X division)
  - Work with ENDF evaluators to get data correctly incorporated into evaluations
  - Assist with interpretation of other data including in evaluation
  - Extremely informative and rewarding process
- MCNP developers up the road (X Division)
  - Direct inclusion of models and theories into calculations
  - Able to influence the direction of development for MCNP
- Opportunities for collaboration and experiment hosting from ISR and NEN
  - LANSCE is a key experimental resource for LANL, and divisions all over LANL utilize it
  - Cross-group and cross-division mobility is a feature of LANL
- Working with experimenters from all over the world
  - When you're an experimental hub, you get the opportunity to be involved in many different experiments