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Title: FY24 Project Update for “Designing Nuclear-data Measurements that Resolve Discrepancies in Existing Data”

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FY24 Project Update for “Designing Nuclear-data Measurements that Resolve Discrepancies in Existing Data”

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2/29/24

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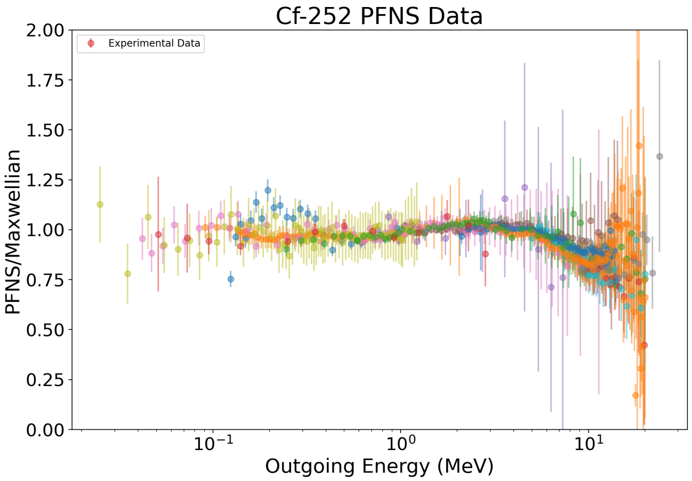
The main question of this project:

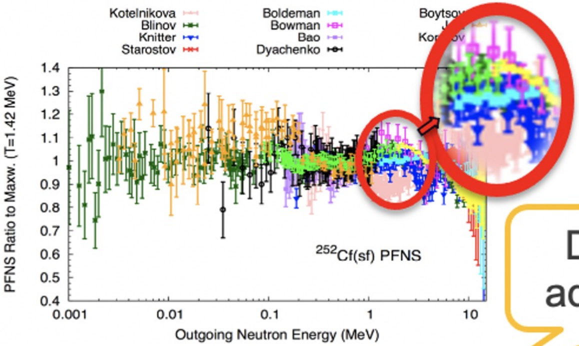
How can we design an experiment such that we credibly reduce unknown systematic uncertainties in a bulk of existing measurements (and thus reduce application uncertainties)?

i.e., how to turn unknown sources of exp. uncertainties into KNOWN ones and reduce them.



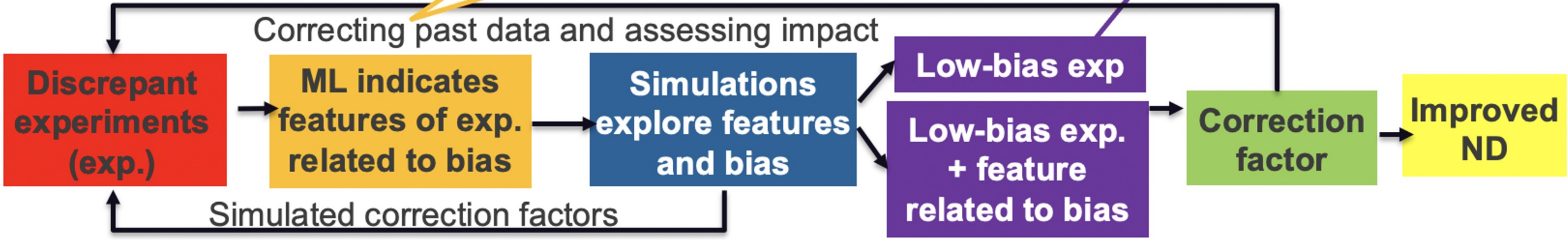
… at the example of the ^{252}Cf PFNS.

We will create and validate a ML capability to design ^{252}Cf(sf) PFNS exp. maximally reducing discrepancies in past exp.



Developing advanced ML

Using state-of-the-art LANSCE equipment



To that end, we used a ML capability to pin-point measurement features likely related to bias and choose most impactful experiments based on MCNP studies.

Why ^{252}Cf(sf) PFNS: It is a Neutron Data Standard and will thus impact many other PFNS, we have equipment available at LANL.

- ^{252}Cf(sf) PFNS is a standard: many PFNS measured in ratio to it -> if we correct ^{252}Cf(sf) PFNS or its uncertainties, this will impact nuclear data of other PFNS in libraries.
- Input to the current ^{252}Cf(sf) PFNS standard evaluation is lost. By re-doing it, we render it reproducible.

Isotope	^{232}Th	^{233}U	^{235}U	^{238}U	^{237}Np	^{239}Pu	^{240}Pu
% of data sets measured using/ relative to ^{252}Cf(sf) PFNS	100%	88%	70%*	100%	75%	70%*	67%
# data sets	3	8	16	7	4	10	3

- We have equipment at LANSCE (^{252}Cf(sf) PPAC, 3 neutron detector arrays, etc.).

Bottom line: If you care about the fission source term for your application, you want an accurate evaluated ^{252}Cf PFNS and low uncertainties.

* Only accepted data sets are counted.

AIACHNE has a team from BNL and LANL; it connects strongly to the Neutron Data Standards project.

Brookhaven National Laboratory

D. Brown
ND expert

B. Pritychenko
EXFOR

Los Alamos NATIONAL LABORATORY

M. Grosskopf
AI/ ML

R. Haight
Experiment

K. Kelly
Experiment

D. Neudecker
ND evaluation

S. Vander Wiel
AI/ ML

EXFOR database and literature database

ENDF/B libraries

Chi-Nu array

^{252}Cf(sf) PPAC

ARIADNE UQ evaluation tool

ML tool to find features related to outliers

EUCLID AI/ML experiment design

Neutron Data Standards database

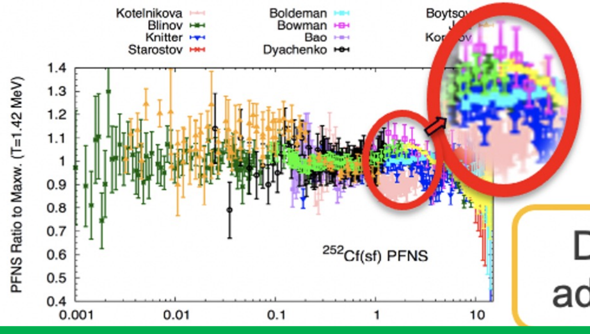
GMA evaluation code

N. Walton
Student (ML/ ND)

NIST

A. Carlson
Standards lead

FY23, we focused on using ML to identify which experiment features lead to bias and which one of those we will resolve.



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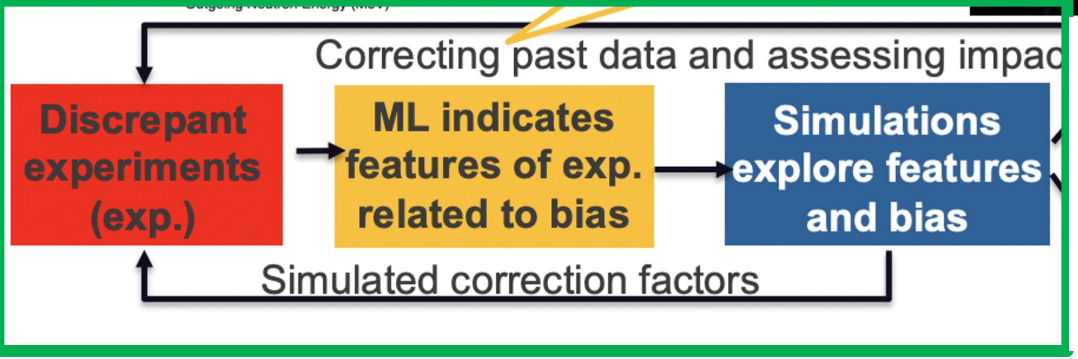


Correcting past data and assessing impac

Discrepant experiments (exp.)

ML indicates features of exp. related to bias

Simulations explore features and bias

Simulated correction factors

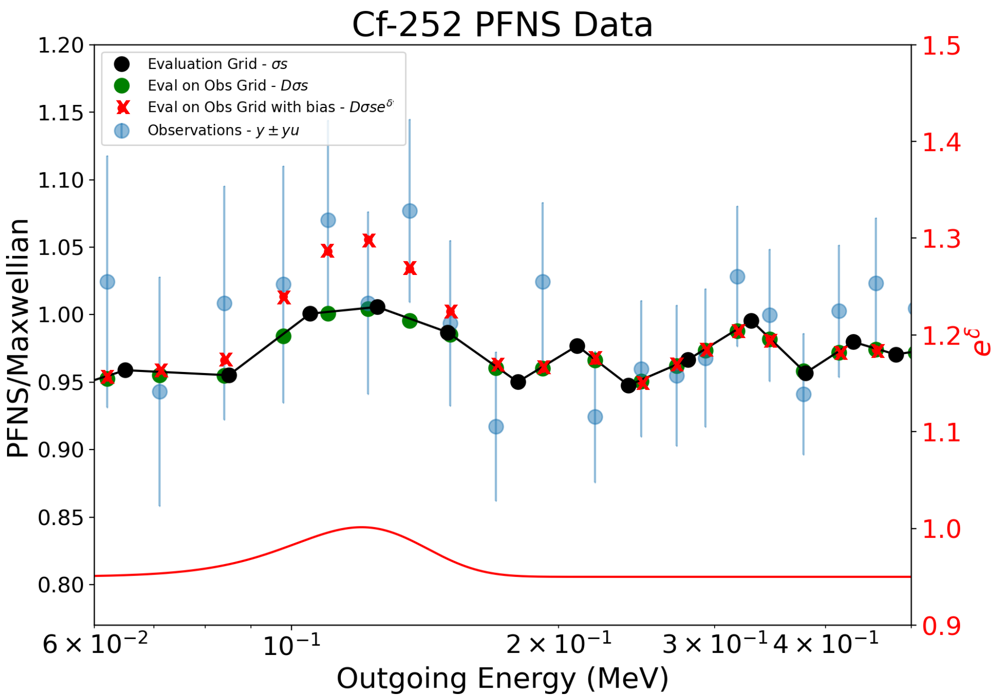
Milestone of FY23: Algorithm and process developed that successfully identifies features related to discrepant data.

AIACHNE is using a sparse Bayesian model to identify potential sources of bias in ^{252}Cf PFNS data.

We are extending the Bayesian model with an energy-dependent, multiplicative bias. Sparsity ensures no bias for most energies but the term is active when the data indicate the need. A sparsity-enducing prior reduces the number of potential biases.

$$y = D\sigma \cdot e^{\delta} + \varepsilon$$

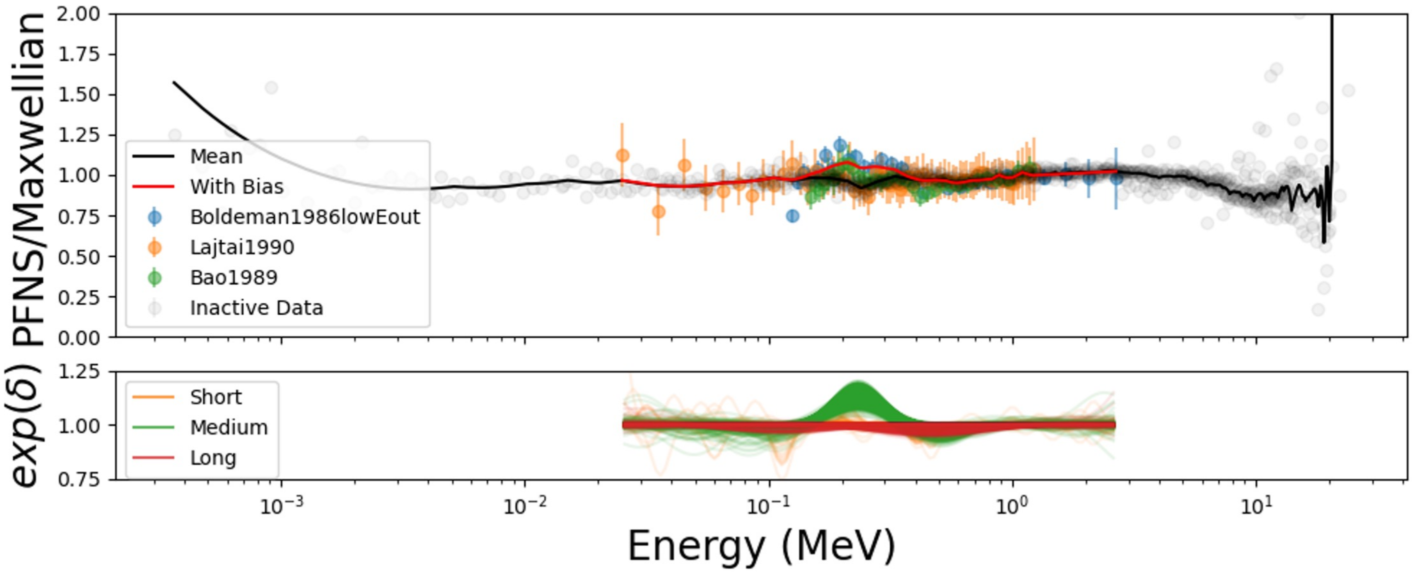
$\delta =$ $B\gamma =$ **relative bias**
$\mathbf{B} =$ **bias basis matrix**
$\gamma =$ **bias coefficients**
$\cdot =$ **element-wise product**



The algorithm deals well with a large number of correlated features compared to experimental data.

Validation example: does the algorithm correctly identify expected bias due to ^{6}Li peak? – Yes, it does!

Neutron Detector: ^{6}Li*



Advantage of algorithm: Enables to more quantitatively identify bias in exp. data as a function of energy to be included in Y2 evaluation algorithm.

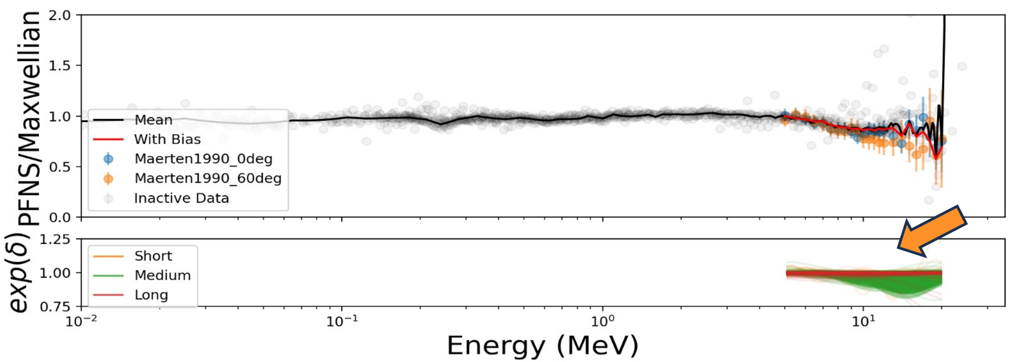
*We plan to correct Boldeman data for ^{6}Li bias in Y3. We explore that bias via experiment & simulations.

Another example: High-E bias identified across several feature groups, less obvious but experimentally explainable.

Effect at high energies was attributed to many features. Detailed expert discussion and analysis of data pointed to fission detection (angular dependence of fission fragments).

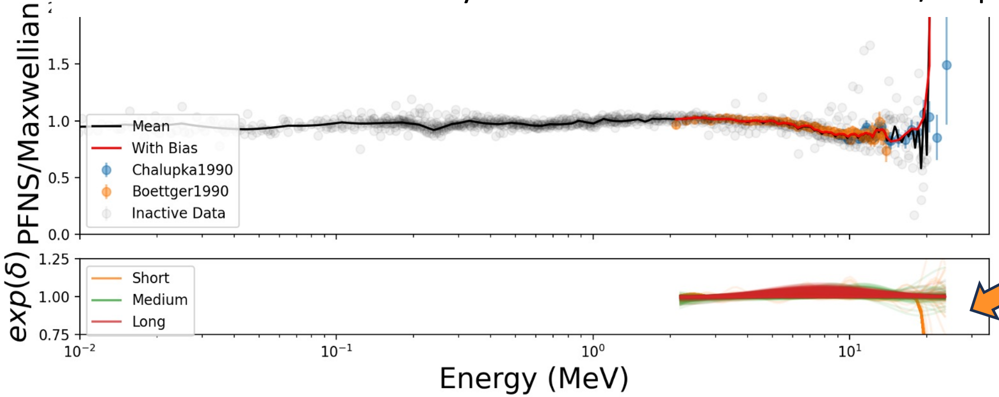
The algorithm finds features related to bias experts might have otherwise overlooked. The algorithm results require expert interpretation.

Fission Detection Efficiency Correction Method: Calculated/Measured



~30% of samples

Fission Detection Efficiency Correction Method: Calculated/Stapre



~10% of samples

Summary: AIACHNE ML algorithm allows us to explore sources of previously unknown systematic exp. uncertainties.

Other project output:

- 1 published publication (EPJ-N), 3 in progress.
- 3 invited talks at IAEA standards meeting.
- Training future workforce (Noah Walton from UTK),
- New ^{252}Cf PFNS eval. to be shared with Neutron Data Standards.
- Database of features will be shared with WPEC SG-50 & EXFOR.
- Code: feature-selection code is planned to be open-sourced for design of other experiments.

Current work: undertaking ^{252}Cf(sf) PFNS experiment and the evaluation.

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Templates of Expected Measurement Uncertainties: a CSEWG Effort, Cyrille De Saint Jean and Denise Neudecker (Guest editors)

REGULAR ARTICLE

Templates of expected measurement uncertaintie
fission neutron spectra

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Abstract. In this paper, we provide templates of uncertainty sources expected to ap
surement types of prompt fission neutron spectra (PFNS): (1) shape measurements, (
that is the monitor PFNS are measured in nearly exactly the same surrounding as th
and (3) indirect ratios, where the detector efficiency is backed out from PFNS mo
Information is also listed that is needed to faithfully include PFNS in nuclear data
experimenters on how to best report data and metadata for their measurements. T
suggest a typical range of pertinent uncertainty values and their correlations in case r
cannot be estimated from information on the measurement itself. The templates were
review, information found in EXFOR for ^{252}Cf, ^{235,238}U, and ^{239}Pu PFNS, and enhanced by expertise from experimenters contributing to these PFNS templates.

1 Introduction

A prompt-fission neutron spectrum (PFNS) describes the energy distribution of neutrons emitted from fission fragments from an actinide in a time window promptly after fission and before the onset of beta decay [1]. The fission reaction can be induced by neutrons, as e.g., for neutron-induced ^{235}U(n,f) PFNS, or be spontaneous, as, e.g., for the case of the PFNS standard, namely the ^{252}Cf spontaneous fission spectrum [2–4] that is shown in Figure 1. A PFNS gives a probability distribution of neutrons to be emitted at a specific outgoing-neutron energy, E_{out}. Thus, the evaluated data are normalized such that the integral over the PFNS gives unity [5]. The maximum of this distribution is usually in the low-MeV range–dependent on the isotope at hand. At higher E_{out}, the spectrum falls off, such that there can be a few orders of magnitude difference in the PFNS between its peak and, e.g., at $E_{\mathrm{out}} = 10$ MeV (see left-hand side of Fig. 1). It is very difficult to detect neutrons of the PFNS to high statistical precision for $E_{\mathrm{out}} > 10$ MeV due to the paucity of emitted neutrons in this energy range and cosmic backgrounds. Special background-reduced environments must be sought for measurements at $E_{\mathrm{out}} > 20$ MeV (a former lead mine under a 1000 m mountain was used, for instance, for Ref. [6]). It is equally difficult to precisely measure the PFNS at low E_{out}, e.g., below 10 keV in even favorable experimental conditions, because of the prevalence of background and multiple-scattered neutrons that can be larger in numbers than the desired prompt-fission neutrons. This limitation in measuring the PFNS at high and low E_{out} can be observed by the higher uncertainties and scatter among data points in the right-hand side of Figure 1. In these energy ranges, below 10 keV and above 10 MeV, nuclear model forms or integral information help to define evaluated PFNS, even if sufficient experimental data are available for other E_{out} ranges.

Below, a template of expected measurement uncertainties is provided for PFNS. These templates were developed for obtaining PFNS via the time-of-flight (TOF) technique to determine E_{out} of the PFNS as this is the most frequently employed technique. If other techniques are used (like measuring the E_{out} directly, using n–p scattering and a proton recoil spectrometer) recourse should be taken to other templates that describe these techniques.

The template described here was established based on (a) the uncertainty procedure developed within the IAEA Coordinated Research Project on PFNS documented in

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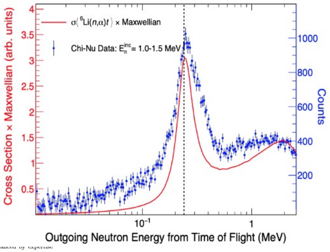

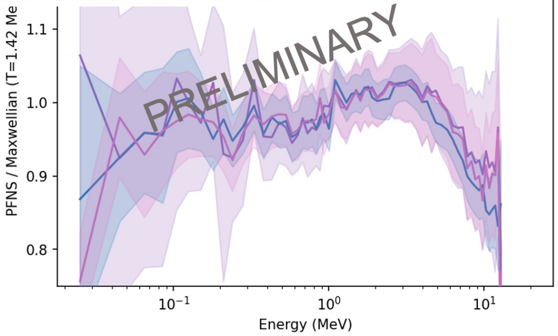

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