Preliminary Analysis of Hafnium Quasi-Differential High-Energy Neutron Scattering Measurement

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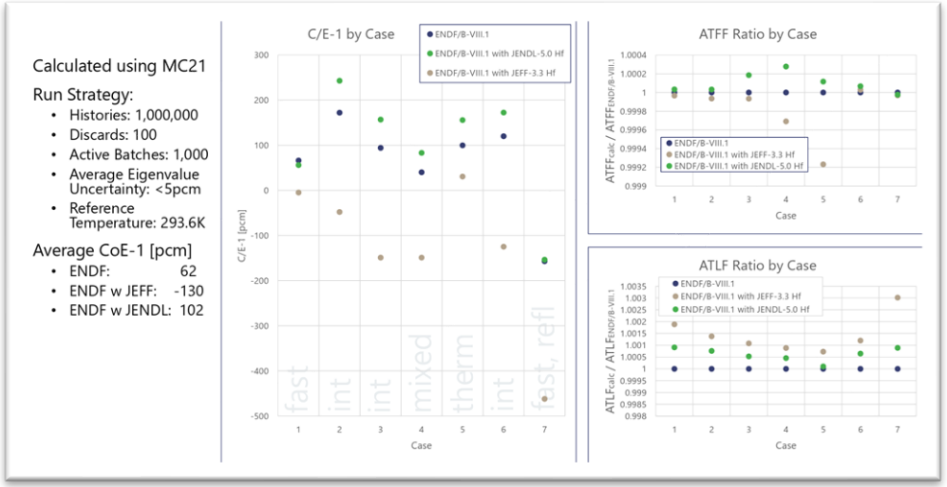
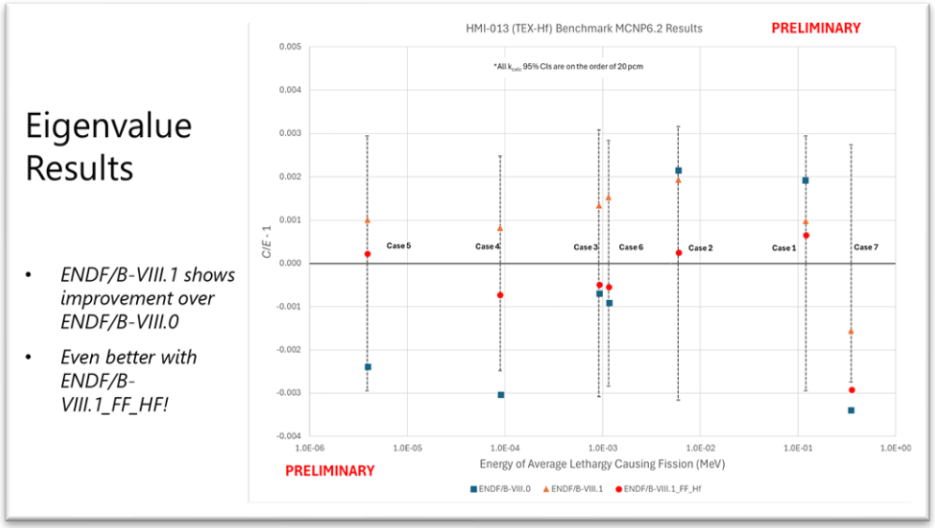
Motivation and Overview

- TEX-Hf results presented by Cotchen and Trumbull at CSEWG 2024 highlighted discrepancies between data and evaluations for Case 7 (fast spectrum, Hf reflected)
- Initial hypothesis was that this could be from problems with high-energy scattering (elastic and inelastic)
- NNL decided to run a high-energy quasi-differential scattering measurement on hafnium to test hypothesis



Cotchen, NNL Validation Testing using ENDF/B-VIII.1, Nuclear Data Week 2024



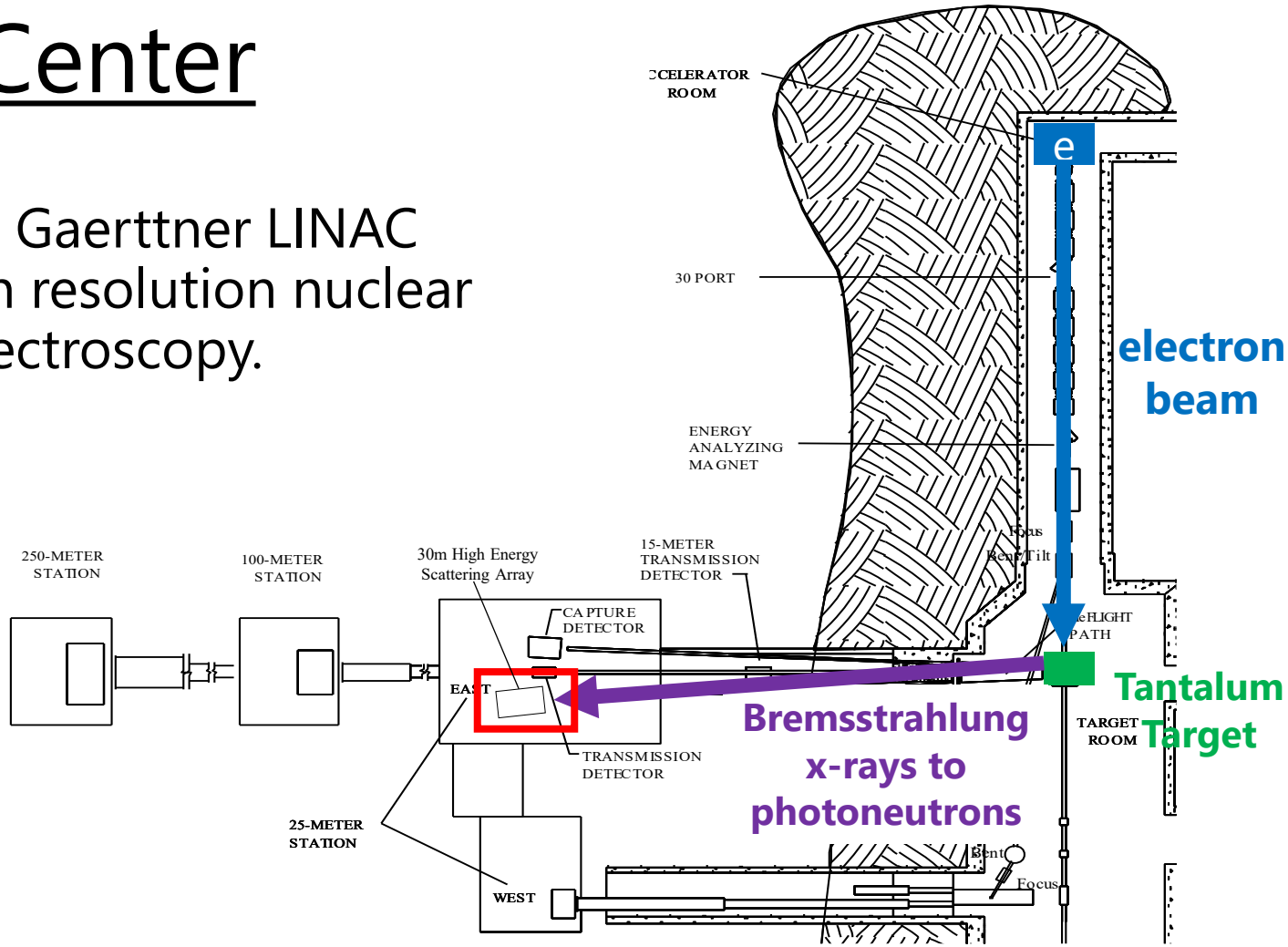
Trumbull, NNL Data Testing Results using TEX-Hf, Nuclear Data Week 2024

RPI Gaerttner LINAC Center

The electron linear accelerator at the Gaerttner LINAC Center at RPI is used to produce high resolution nuclear data using neutron time-of-flight spectroscopy.

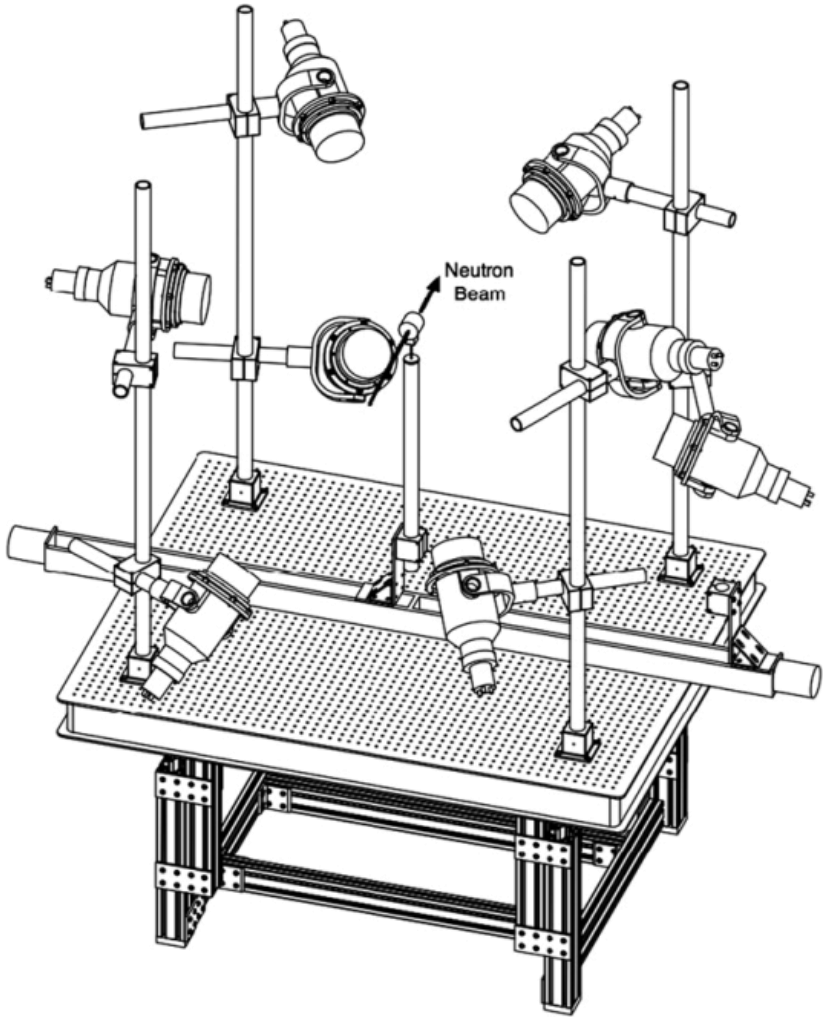
The high-energy electrons interact with a tantalum neutron target, producing Bremsstrahlung X-rays that then interact with the tantalum to eject neutrons with a continuous energy distribution.

The time-of-flight method is used to determine incident neutron energy



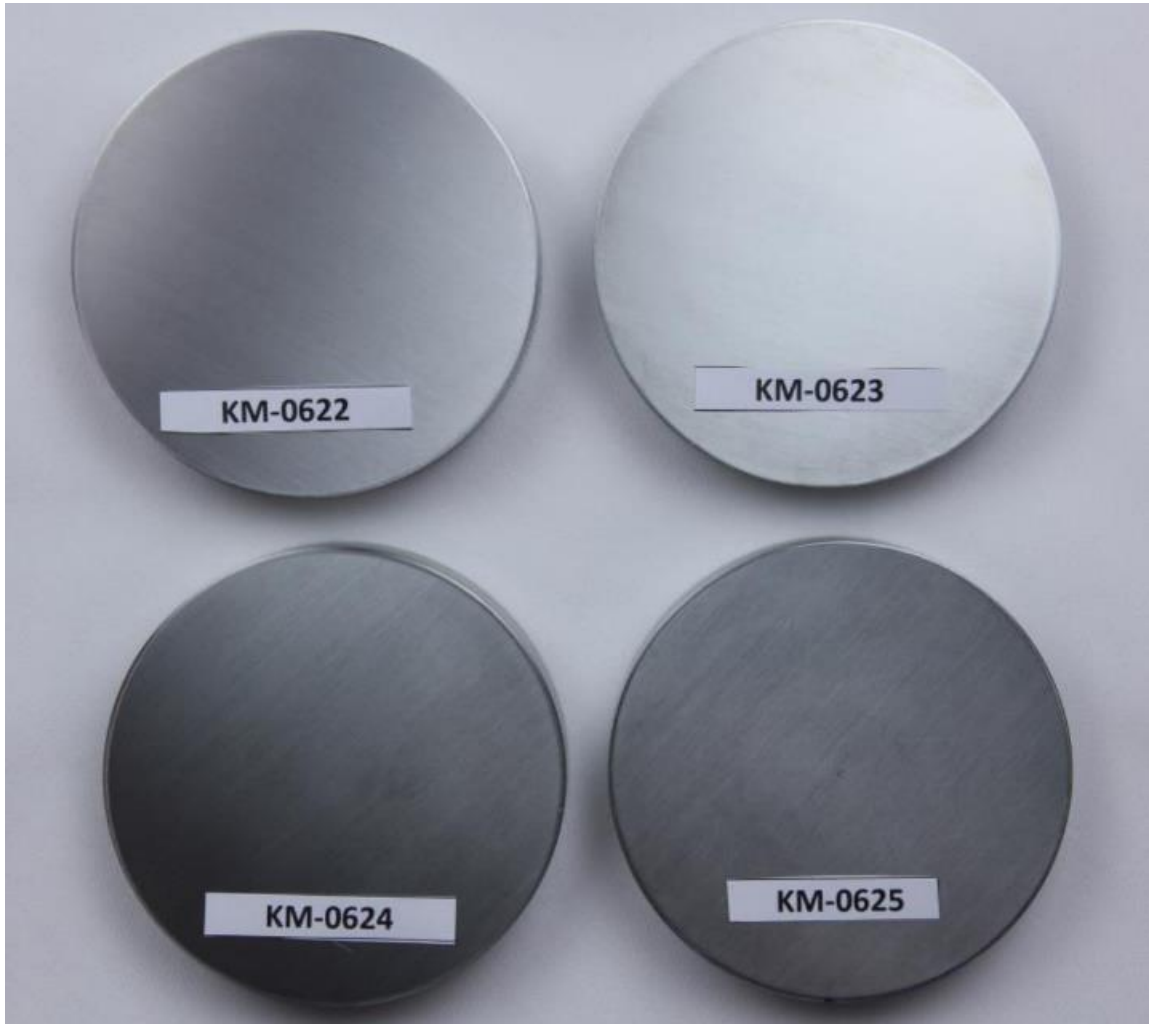
RPI High-Energy Scattering System

- RPI HES System was designed to be highly sensitive to fast neutron scattering (>0.5 MeV)
  - 8 EJ-301 liquid scintillator detectors that measure 5-inch diameter by 3-inch thick
  - Detector position(s) and sample characteristics are determined a priori to measure an enhanced scattering signal
  - Both detector efficiencies and neutron flux were quantified in independent measurements
- Measurements and Monte Carlo transport calculations are performed on a graphite reference sample to validate system geometry and to quantify uncertainties
  - Several calculations are then performed with different sets of nuclear data evaluations, and differences present between them are compared to a sample-of-interest experimental data to validate performance or show needs for improvement
- Previous measurements and Monte Carlo analyses include:
  - 8-bit DAQ: Be, C*, Mo, ^{238}U, Fe, Pb, Cu
  - 10-bit DAQ: Ta, C*, and CF_2 (Teflon)



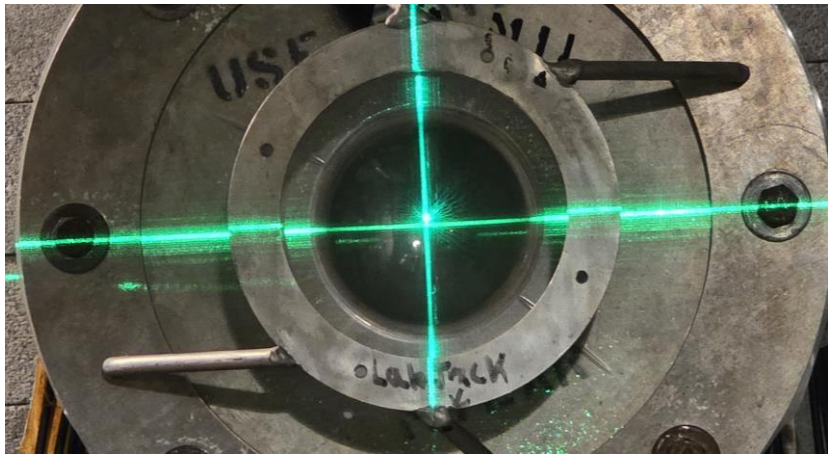
Hafnium Sample(s)

- Estimated 3 to 4-cm thick by 7.62-cm diameter cylindrical sample needed for HES measurements
- Four hafnium cylindrical samples were manufactured from natural wrought hafnium
  - 7.620 ± 0.010-cm diameter
  - 1.803 ± 0.127-cm thick
  - 1037.264 ± 0.517 grams
- Samples contain < 2.5 wt.% Zirconium
- Optimal thickness obtained by stacking two 1.8 cm-thick hafnium samples together

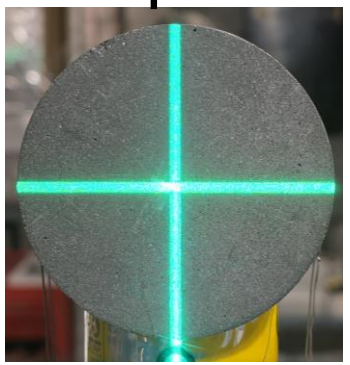


Measurement Setup

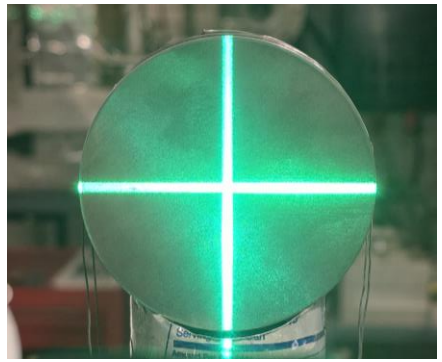
- Laser alignment used to position samples in the neutron beam
- Detector locations
  - 30, 45, 60, 95, 110, 125, 150 (x2)
  - All detectors are ≈50 cm from in-beam scattering sample(s)
- Samples were situated on low mass aluminum holders
  - Thin wire were used to secure the samples in place throughout the measurement

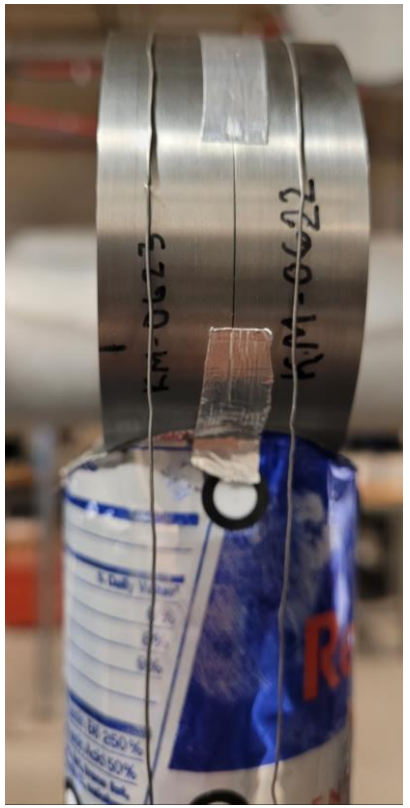


Graphite



Hafnium

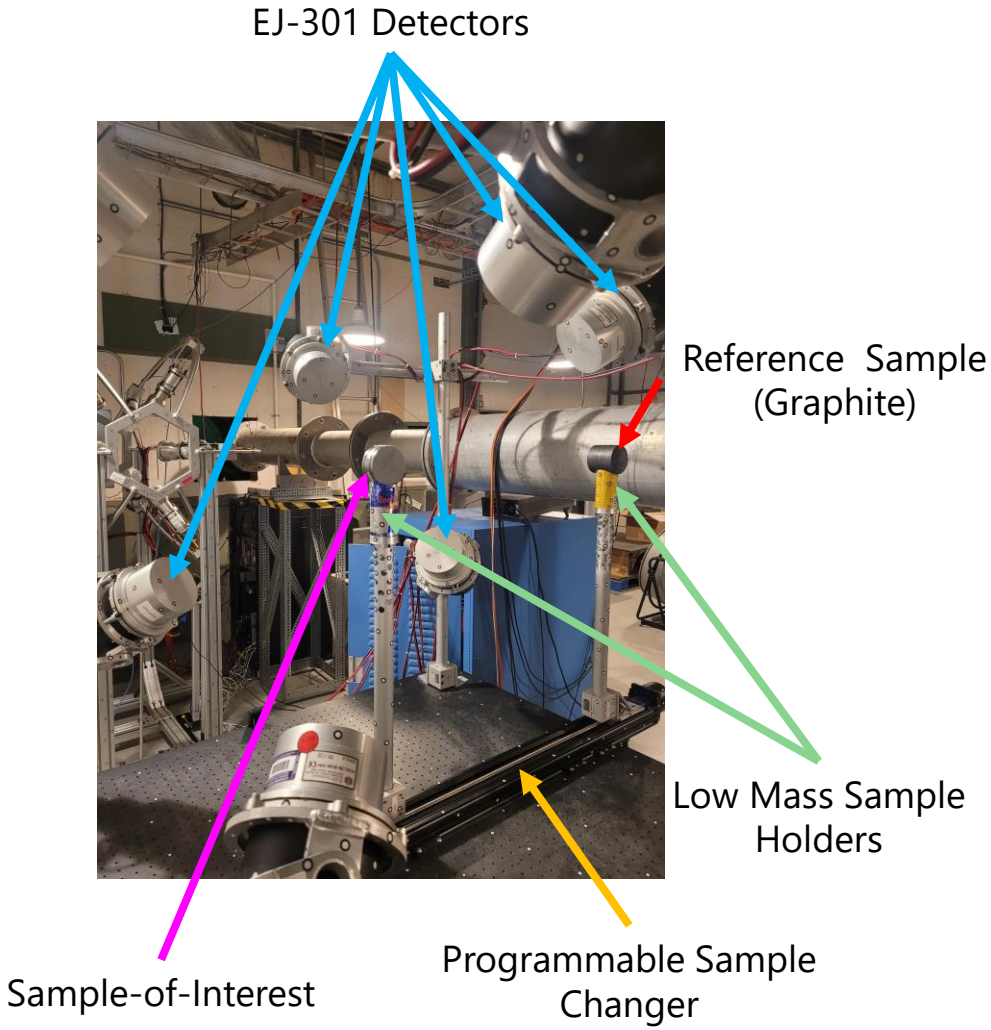




Measurement Overview

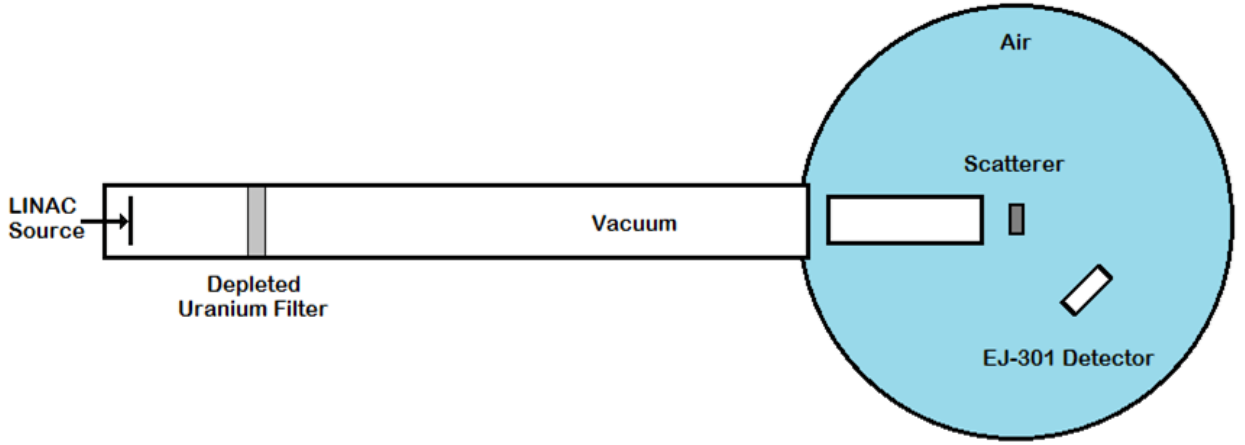
- LINAC operated at 400 Hz, ≈48 MeV, 8.7 μA, and 8 ns pulse width
- Neutron beam monitors recorded fluctuations in LINAC output throughout the measurement
- ≈100 hrs. of data collected
  - 177 cycles that consisted of:

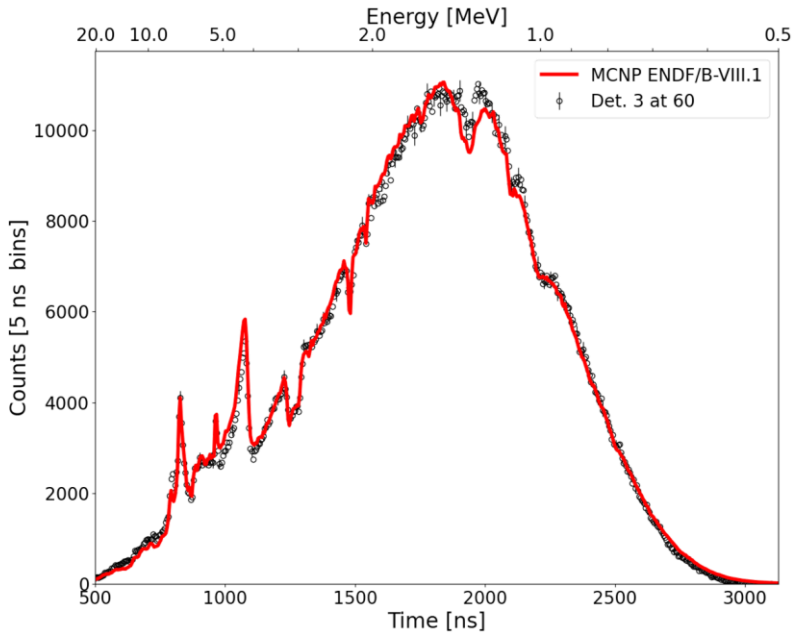
Sample	Duration
Sample-of-Interest (Hafnium)	15 min.
Reference Sample (Graphite)	8 min.
Open Beam (Background)	5 min.

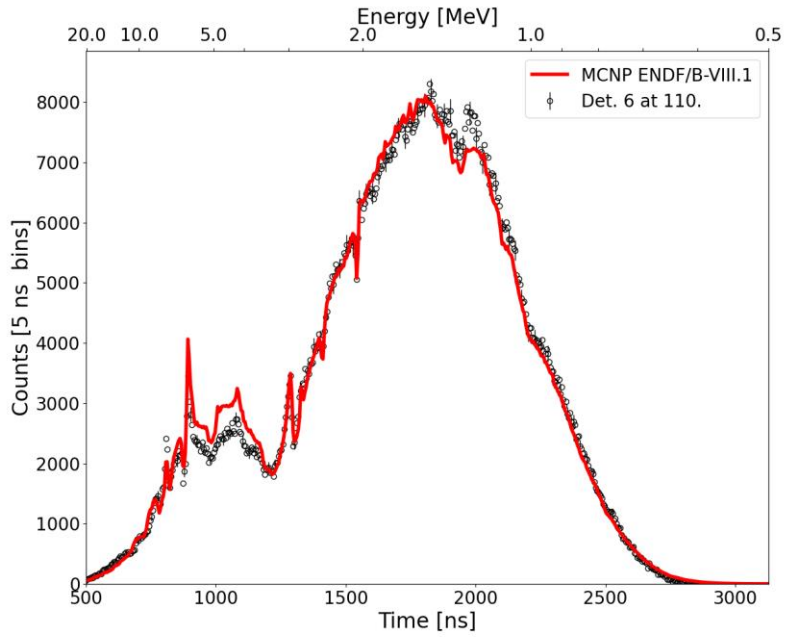


MCNP Model, Normalization, and Uncertainty

- Simple MCNP model used for this study
  - Scattering sample(s), vacuum pipes, table, floor, and in-beam materials
- Data collected from a graphite reference sample is used to calculate a normalization factor and estimate systematic uncertainty

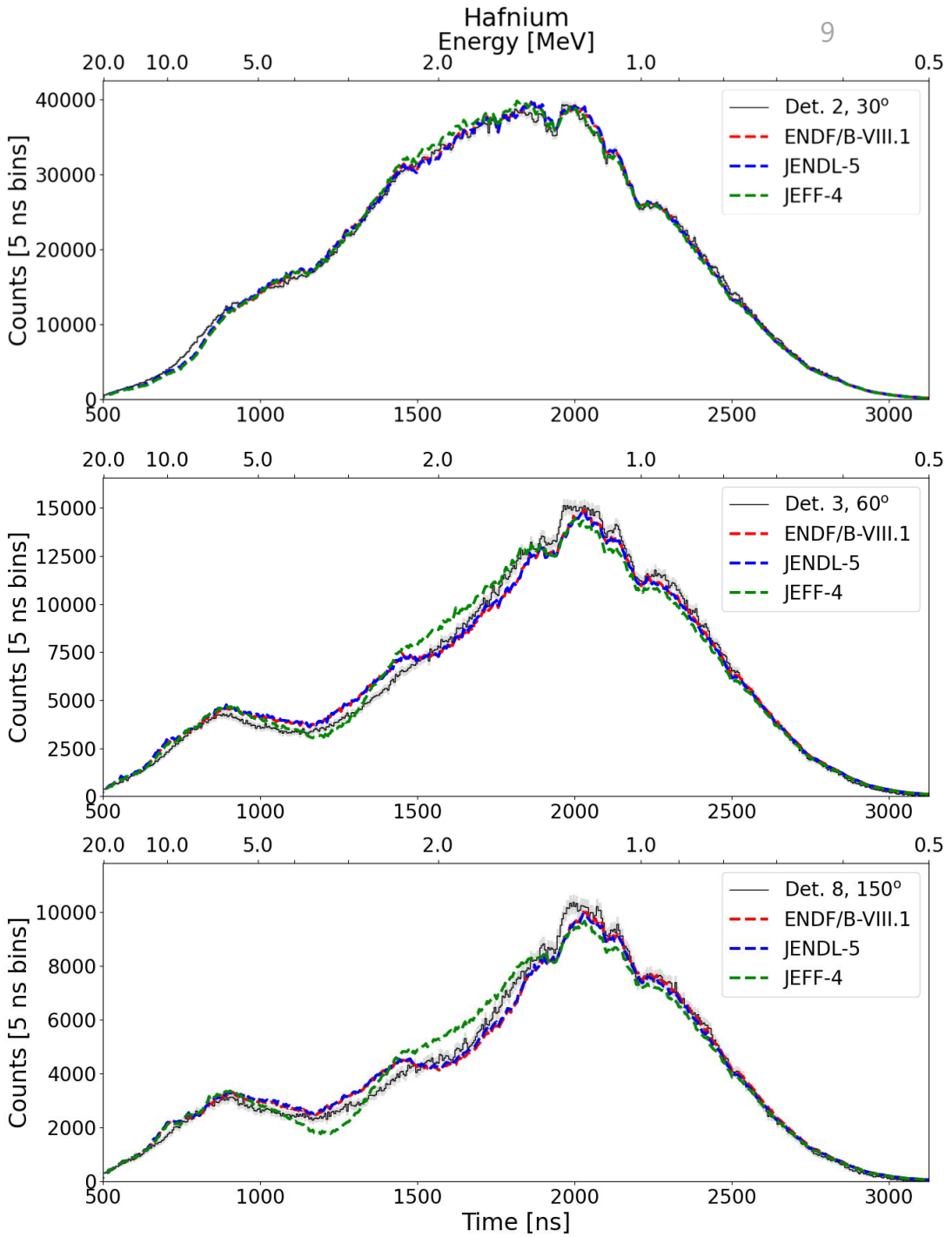






Preliminary Hafnium Results

- Discrepancies between experimental data and all Monte Carlo calculations begin at ≈1.2 MeV and continues through 5 MeV.
- JENDL-5 and ENDF/B-VIII.1 have very close agreement with each other at all measured energies and angles; however, notable differences with JEFF-4 occurs above 1.2 MeV



Moving Forward

- Monte Carlo
  - Finalize model (detailed model used by Siemers)
  - Incorporate sample impurities and isotopic concentrations
- Examine additional hafnium evaluations
- Data Analysis
  - Extract and examine pulse-height distribution in TOF
- Validate graphite and open beam
  - Compare with prior measurements (Ta and CF_2)