LA-UR-17-28521

Approved for public release; distribution is unlimited.

Title: Progress Towards an Indirect Neutron Capture Capability at LANSCE

Author(s): Koehler, Paul E.
Ullmann, John Leonard
Couture, Aaron Joseph
Mosby, Shea Morgan

Intended for: Report

Issued: 2017-09-20

Progress Towards an Indirect Neutron Capture Capability at LANSCE

P. E. Koehler, J. L. Ullmann, A. Couture, and S. Mosby

P-27, Los Alamos National Laboratory

Abstract: There are many neutron-capture cross sections of importance to radiochemical diagnostics and nuclear forensics which are beyond the reach of direct measurements. Hence, we have been developing an apparatus on flight path (FP) 13 at target 1 at LANSCE for tightly constraining these cross sections via determination of the underlying physical quantities. FP-13 was initially a cold-neutron beam line for materials science and therefore required substantial modification for use for nuclear physics. In FY17, we made several improvements to FP-13, demonstrated improved performance due to these changes via measurements on a variety of samples, identified a few more needed improvements, and reconfigured the beam line to implement the most important of these. New measurements to assess the impact of the most recent improvement will commence when beam is restored to LANSCE. Although FP-13 has not yet reached the performance required for small radioactive samples, measurements on a gold sample have led to an important science result which we are preparing for publication.

I. Introduction

Reducing uncertainties for neutron-capture cross sections on very rare stable and radioactive nuclides is vitally important for radiochemical diagnostics of nuclear devices, nuclear forensics, nuclear astrophysics, and nuclear criticality safety. Direct measurements on these nuclides have proven to be exceptionally difficult or impossible with current techniques [1]. However, it has been shown [2] that resonance total-cross-section measurements should be possible on these same nuclides and that these data should yield tight constraints on the needed neutron-capture cross sections. Hence, we are developing this indirect measurement technique on FP-13 at LANSCE. FP-13 was an underutilized FP at the Lujan Center, where the pulse spacing is well matched to the experiment needs. While it was initially developed as a cold-neutron beam line for material science, there are still significant numbers of neutrons between 1 eV and 1 keV, the energy region of interest. That being said, significant optimization has been required to isolate and transport the neutrons of interest in the absence of undesired backgrounds. As an additional benefit, FP-13 is located on the upper tier moderator of the Lujan Center. A target redesign is being investigated, independent of this project, which would improve both the resolution and intensity of neutrons in the relevant energy range. These gains will only be available to upper-tier flight paths.

In FY17, we made several improvements to FP-13, demonstrated improved performance due to these changes via measurements on a variety of samples, identified several more needed improvements, and reconfigured the beam line to implement the most important of these. New measurements to assess the impact of the most recent improvement will commence when beam is restored to LANSCE. Although FP-13 has not yet reached the performance required for small radioactive samples, measurements on a gold sample have led to an important science result which we are preparing for publication.

II. Apparatus Improvements

First test measurements in February 2016 revealed that the background needed to be reduced substantially. Potential improvements were identified and made to the apparatus to this end; new collimation was added at several locations, the flight path was lengthened to accommodate an improved beam stop further from the detector, beam-line components were realigned, and an improved detector was fielded. Fig. 1 is a photograph of the detector location near the end of the beam line before the changes were made, and illustrates one of the main problems with the original FP-13; residual beam passing through the detector is “dumped” into the back wall of the FP-13 cave less than two meters from the detector. This resulted in an intense neutron and γ-ray background source very close to the detector. Fig. 2 is a photograph of the new beam stop under construction. The beam line was extended several meters and a re-entrant beam stop (orange barrel in the picture) was installed. The completed improvements included a large concrete block behind the beam stop, a roof, hand-stacked shielding around the new beam stop, and an evacuated pipe between the detector and the new beam stop.

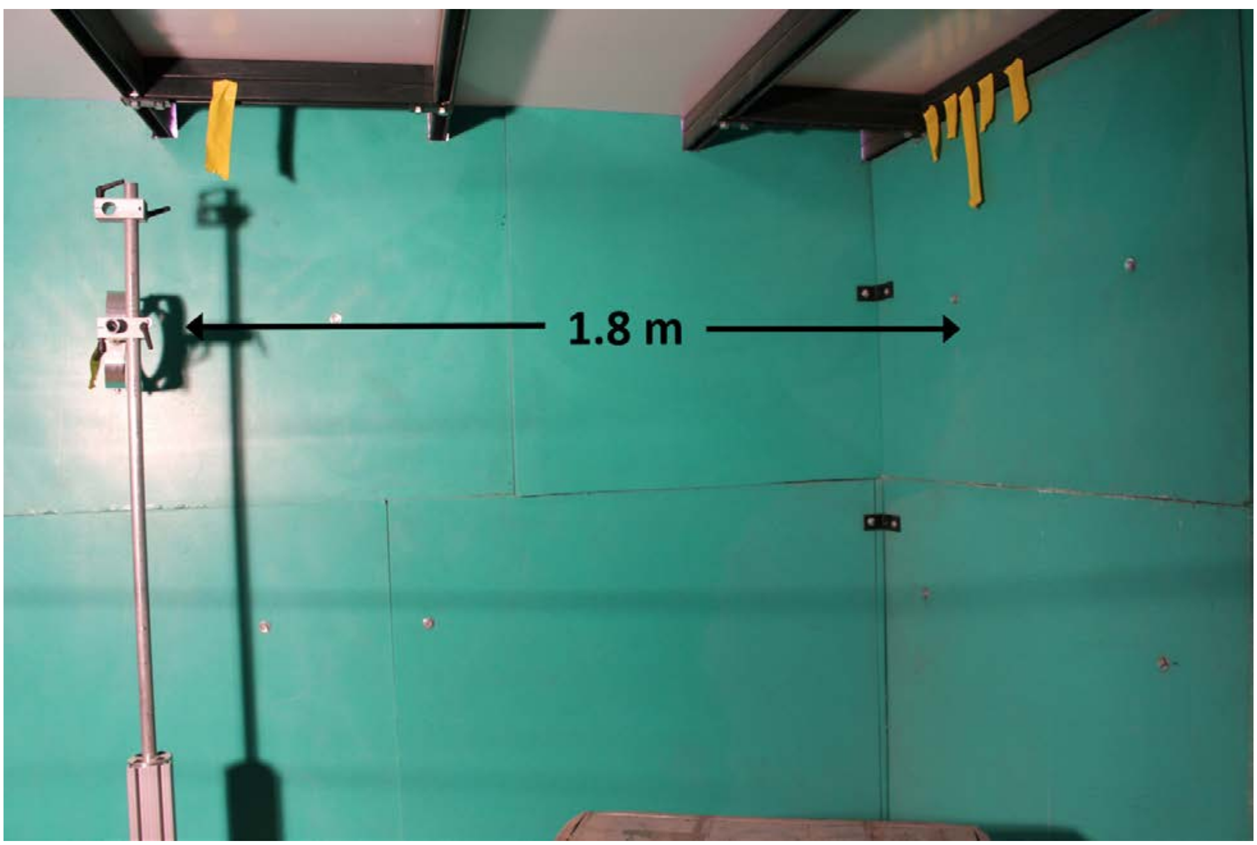

Figure 1. Original FP-13 "cave" near the detector location. The aluminum pole served as a detector stand (detector not shown). There was no beam stop. Instead the beam "dumped" on the back cave wall less than two meters from the detector.

Figure 2. Picture of the new FP-13 beam stop while it was under construction. See text for details.

Resulting reduction in the background at several energies due to these changes is demonstrated in Fig. 3. Shown in this figure are transmission spectra (transmission T is related to the total cross section $\sigma_t$via, $T = e^{-n\sigma_t}$ where n is the sample thickness) over three different energy regions taken with a 90 mg/cm^2 thulium sample. Blue circles and red X's depict data taken before and after, respectively, the improvements mentioned above. The solid curve shows the expected transmission calculated with the *R*-matrix program SAMMY [4] using resonance parameters from the latest ENDF evaluation. The top third of the figure shows data near the bottom of a "black" resonance. As can be seen, the recent improvements have lowered the background to the point where there is very good agreement with expectations. The middle and bottom thirds of Fig. 3 show regions near smaller resonances. The reduction in background after the improvements to FP-13 is evident by the better agreement between data and predictions as well as by the enhanced ability to detect small resonances. Success of the proposed technique [2] depends on the ability to accurately determine parameters for as many resonances as possible. The data in Fig. 3 demonstrate that the recent improvements to FP-13 greatly enhance our capabilities in this regard.

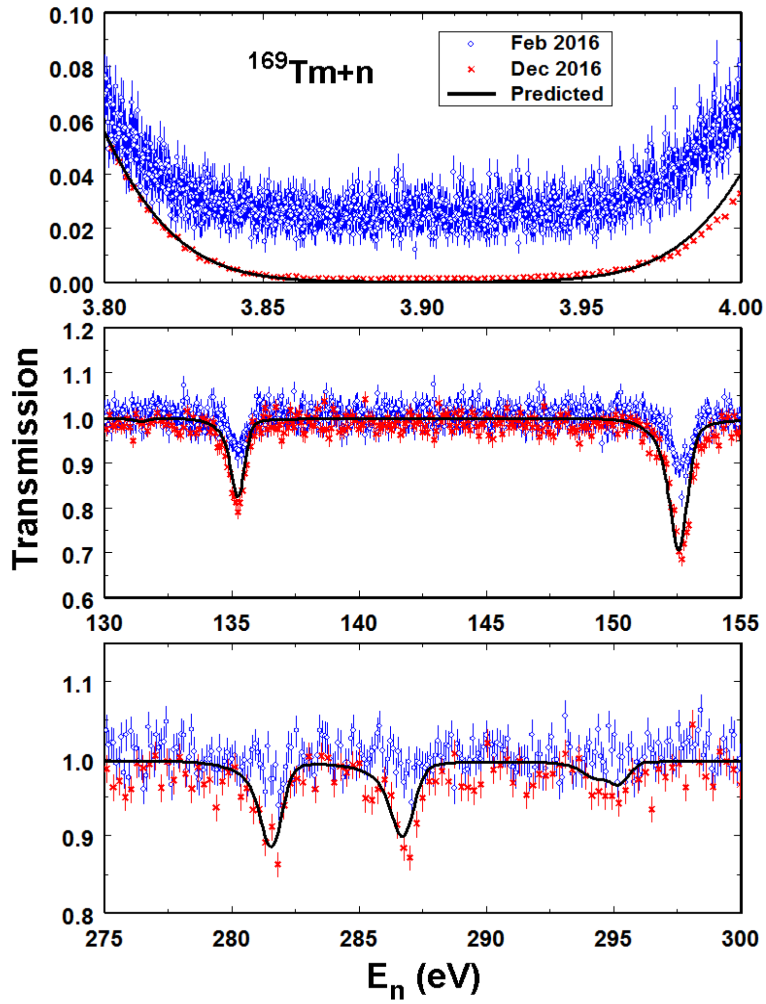

Figure 3. Transmission spectra over three different energy ranges taken with a 90 mg/cm^2 thulium sample, demonstrating improved performance after changes to FP-13. See text for details.

III. Need for Further Improvements

Although the data in Fig. 3 demonstrate that we have reduced the background considerably, data taken on additional samples indicate that further improvements are needed, especially at higher energies. For example, Fig. 4 shows measured and predicted transmissions for a bismuth sample in the region of a black resonance near 800 eV. Experience gained through many years of measurements at the (now closed) ORELA facility indicates that we should be able to reduce the background shown in Fig. 4 by a factor of five to 10.

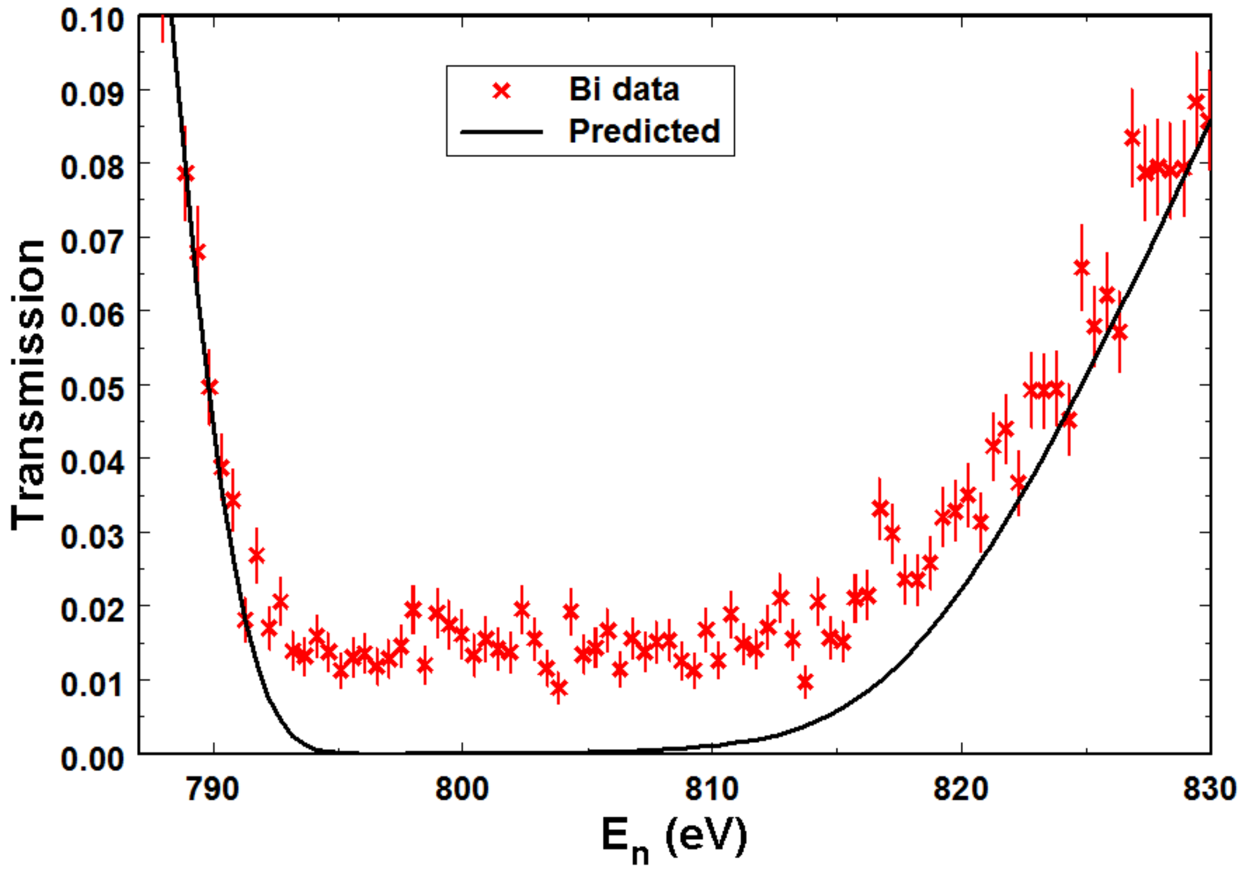

Figure 4. Measured and predicted transmissions in the region of a black resonance in Bi near 800 eV. Predicted transmissions were calculated using the most recent ENDF resonance parameters with the R-matrix code SAMMY. The fact that the predicted transmission is below the data indicates that further improvements to FP-13 are needed to reduce background at these higher energies.

The two main contributors to the remaining background are being addressed. First, as shown in Fig. 1, the cave wall and ceiling are very close to the detector. This results in in a sizeable sample-dependent background from neutrons which are scattered by the detector and subsequently scattered back into the detector. The massive cave wall and ceiling have been replaced by a low-mass Morgan building centered on the detector position. We will assess the effectiveness of this change when beam returns.

A second change to FP-13 to reduce background is in progress. Currently, we are using the neutron guide left over from the previous material-science instrument as the beam line between about eight and 30 meters. This guide scatters neutrons above thermal energies along almost its entire length and some of this scattered beam reaches the detector. A new beam pipe and collimators to replace this guide currently is being fabricated and is scheduled to be installed in November or December 2017. If installed in time, we plan measurements to test its effectiveness before the end of the run cycle.

IV. First Science Result from FP-13

Measurements were made on a gold sample to help diagnose performance. While comparing these data to R-matrix calculations we discovered that the latest [4] resonance parameters needed substantial improvement. This was surprising because gold is considered an unofficial standard by many. To obtain the best resonance parameters, we undertook a simultaneous R-matrix analysis of the best data available; our new data and the most recent capture [4] and transmission data [5], respectively. We also included firm resonance spin assignments from previous analyses [6]. Examples of the data and R-matrix fits, representing about 1/50 of the data fitted are shown in Fig. 5.

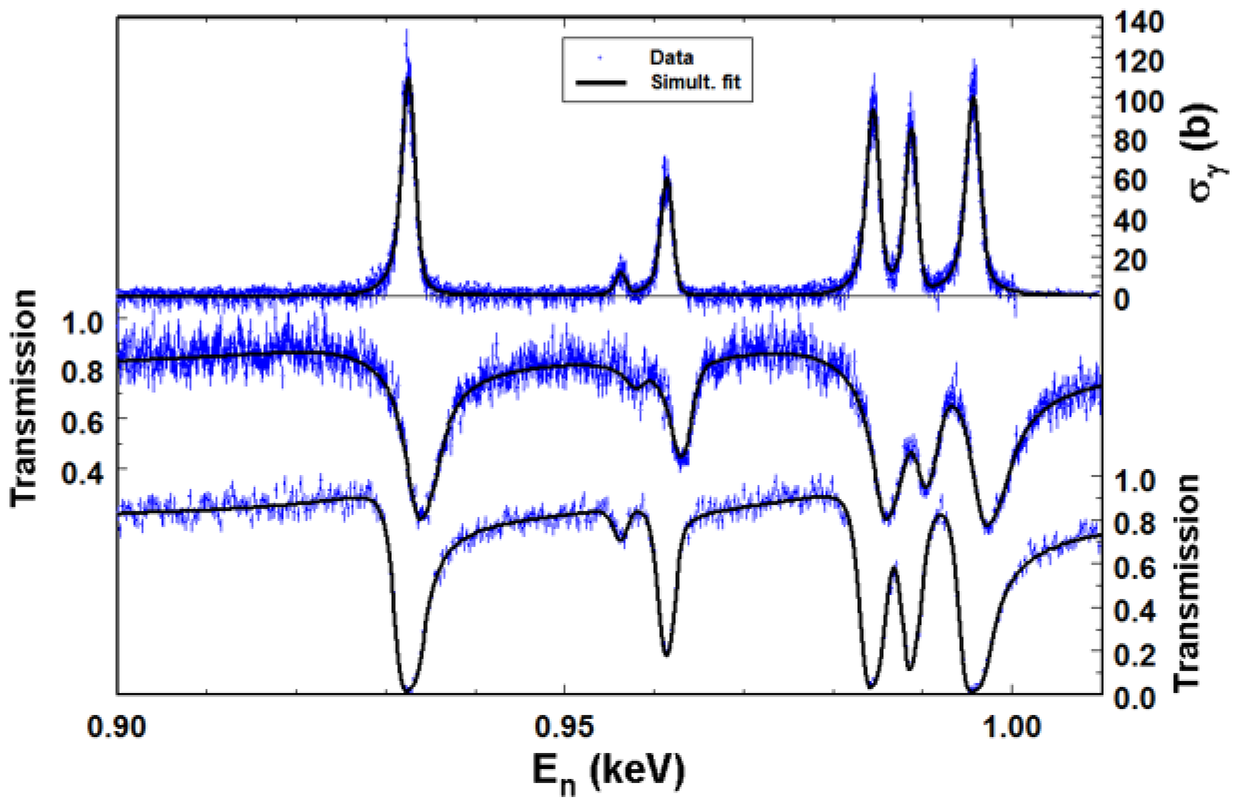

Figure 5. A small part of the gold data and R-matrix fits. On top are the neutron-capture data from Ref. [4] (scale on the top right). In the middle are our new FP-13 transmission data (scale on the left). On bottom are the transmission data from Ref. [5] (scale on bottom right). The measurements of Ref. [5] were made with a sample almost 50 times larger than the one we used on FP-13.

These new resonance parameters are useful for testing and improving nuclear models. This is important for applications such as radiochemical diagnostics and nuclear forensics because nuclear models currently are used to predict the neutron cross sections for almost all nuclides needed for these applications. Gold is potentially a particularly interesting case because resonances with two different spins, J, can be studied at the same time. Having two spins allows more important aspects of the models to be studied. Analysis of previous data [6] had identified a large number of J=1 (33) and 2 (44) resonances. However, the neutron and gamma widths (Γ_γ) of these resonances were too poorly determined to allow useful model tests. With our new FP-13 data and analysis, we are now able to perform detailed tests of the models.

One example of the tests possible is shown in Fig. 6, where cumulative distributions of Γ_γ values for resonances of the two different spins are compared to theory simulations. Plotted are the fraction of resonance having a Γ_γ value larger than given size versus that size. Blue circles and red X's with error bars represent our new data for J=1 and 2 resonances, respectively. The data clearly show that the average Γ_γ value for J=1 is significantly larger than for J=2. A maximum-likelihood analysis of the data yield average Γ_γ values of 154±4.3 and 132.2±2.4 meV for J=1 and 2, respectively, or a difference of 21.8±4.9 meV. In contrast, nuclear-statistical-model simulations of the expected distributions (using the default theoretical nuclear level density and photon strength function in the code Talys, normalized to our new average resonance parameters) predict a much smaller value for this difference, as well as much narrower distributions than observed. These simulations are shown as solid blue and red dashed curves in Fig 6.

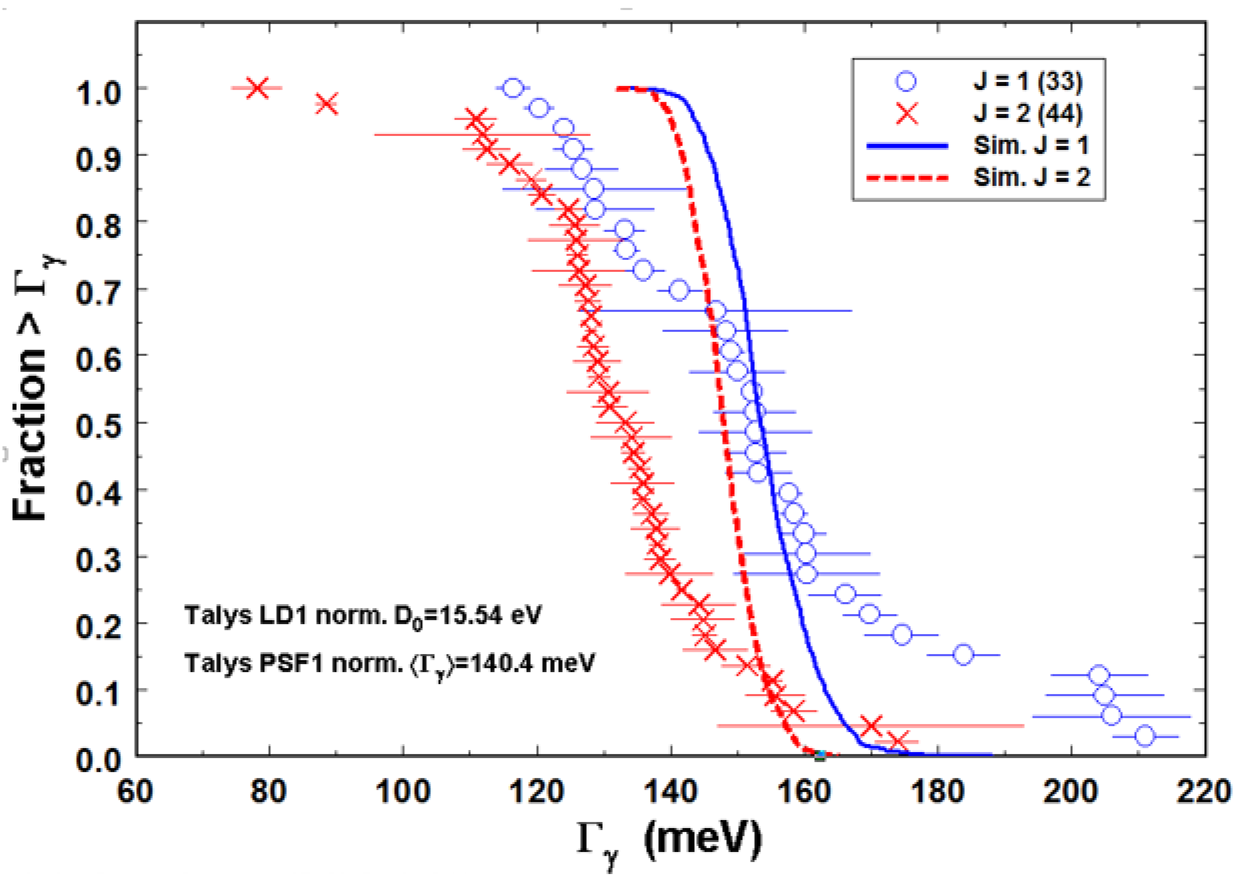

Figure 6. Γ_γ **value for 33 firm J=1 (blue circles) and 44 J=2 (red X's) neutron resonances in gold resulting from our new data and R-matrix analysis. Distributions predicted by the nuclear statistical model are shown as sold blue and red dashed curves. See text for details.**

As shown in Fig. 7, agreement between data and theory can be improved by using the nuclear level density and photon strength function for gold recently measured using the Oslo technique [7], rather than models for these two ingredients. However, the predicted difference between average values for the two spins is still too small and the predicted distributions still too narrow.

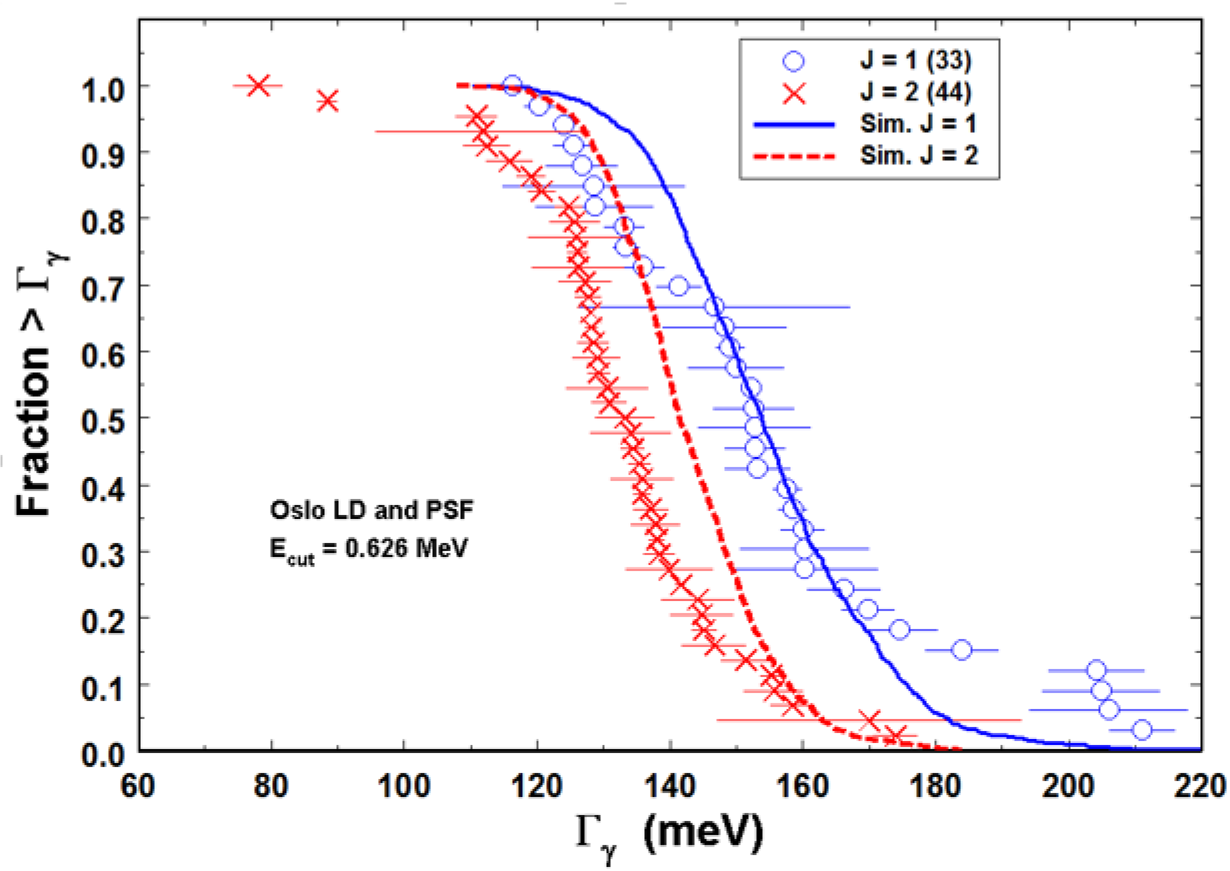

Figure 7. Comparison of the measured Γ_γ distributions for neutron resonances in gold, to those simulated using the recently measured [7] nuclear level density and photon strength function for gold. See text for details.

As shown in Fig. 8, we can improve agreement between the data and simulations by making two rather drastic changes to the theory. First, we changed the distribution of spins of nuclear levels in ^{198}Au so that there are fewer levels of high spin. Second, we assumed that the distribution of primary gamma widths is much broader than in the canonical model. The first change appears to be larger than conventional wisdom allows, but is needed to bring the difference in the average Γ_γ values for the two spins in closer agreement with the data. The second change is again at odds with conventional wisdom but in line with fairly recent data on platinum isotopes [8].

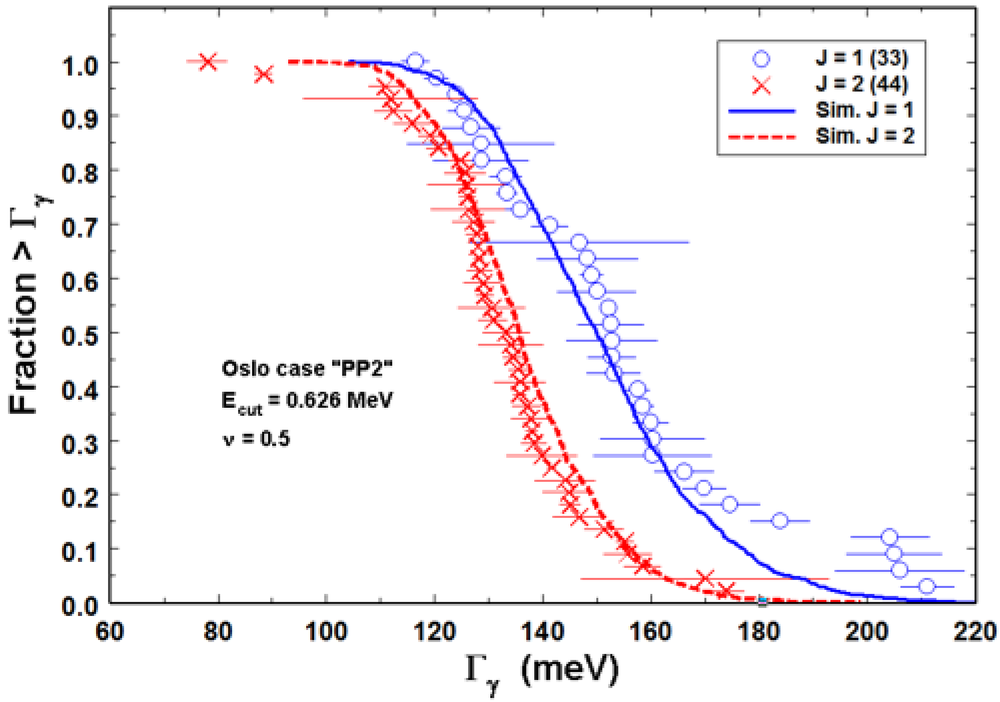

Figure 8. Comparison of measured Γ_γ distributions for neutron resonances in gold to those simulated using the recently measured [7] nuclear level density and photon strength function for gold, after adjustment of the nuclear-level spin distribution and the distribution of primary gamma widths in the model. See text for details.

V. Conclusions and Outlook

We continue to improve our capability for tightly constraining neutron-capture cross sections of importance to programmatic and basic science via total-cross-section measurements on FP-13. Changes to the apparatus and subsequent measurements during FY17 have demonstrated substantially improved performance.

Although the apparatus is not yet capable of measurements on very small, highly radioactive samples, our scoping measurements have resulted in an interesting science result. In addition, these initial studies have begun exercising the analysis tools that will be required for planned programmatic measurements, ensuring that all of the pieces are in place when radioactive material measurements are begun. Combining these data with complimentary data from the Oslo technique in our nuclear-statistical-model simulation code uncovered a problem in the model and/or the Oslo normalization. This result hints at the large impact a fully functioning capability on FP-13 could have for not only providing nuclear data for specific high-impact cases, but also for improving nuclear models and for leveraging and improving relevant data from other facilities. These first results could be further leveraged by combining them with analysis of complimentary data already obtained with the DANCE detector at LANSCE.

References

[1]] A. Couture and R. Reifarth, Atomic Data and Nucl. Data Tables **93**,803 (2007).

[2] P. E. Koehler, “Total Cross Sections as a Surrogate for Neutron Capture: An Opportunity to Accurately Constrain (n,γ) Cross Sections for Nuclides Beyond the Reach of Direct Measurements”, LA-UR-14-21466.

[3] N. M. Larson, Oak Ridge National Laboratory Technical Report No. ORNL/TM-9179/R8, 2008.

[4] C. Massimi *et al*., Phys. Rev. C **81**, 044616 (2010).

[5] I. Sirakov *et al*., Eur. Phys. J. A **49**, 144 (2013).

[6] J. S. Desjardins *et al*., Phys. Rev. **120**, 2214 (1960).

[7] F. Giacoppo *et al*., Phys. Rev. C **91**, 054327 (2015).

[8] P. E. Koehler *et al*., Phys. Rev. Lett. **105**, 072502 (2010).