Fluorescence Detection Needed to Improve X-Ray Raman Scattering

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Abstract: This work describes developments in an effort to improve X-ray Raman scattering by introducing fluorescence detection. A key step is to perform fast detection of inner shell X-ray fluorescence. Here we show promising signs of such signals.

Introduction:

Non Resonant inelastic X-ray scattering (also known as X-ray Raman scattering) is a powerful means to probe dynamic structures in quantum matter with an Achilles heel: spectral overlap between for various initial states. Here we are developing a detection system to select a particular initial state, namely electrons in the K shell of sulfur. Our proposed special signal in this case is K-shell fluorescence. Once it can be observed we can integrate it into a detection system for Raman scattering that requires coincidence between scattered and fluorescence photons. This paper discusses our efforts to perform such detection with sufficient speed. We have a promising signal that could very well be K-shell fluorescence.

Experiment Setup/ Procedure:

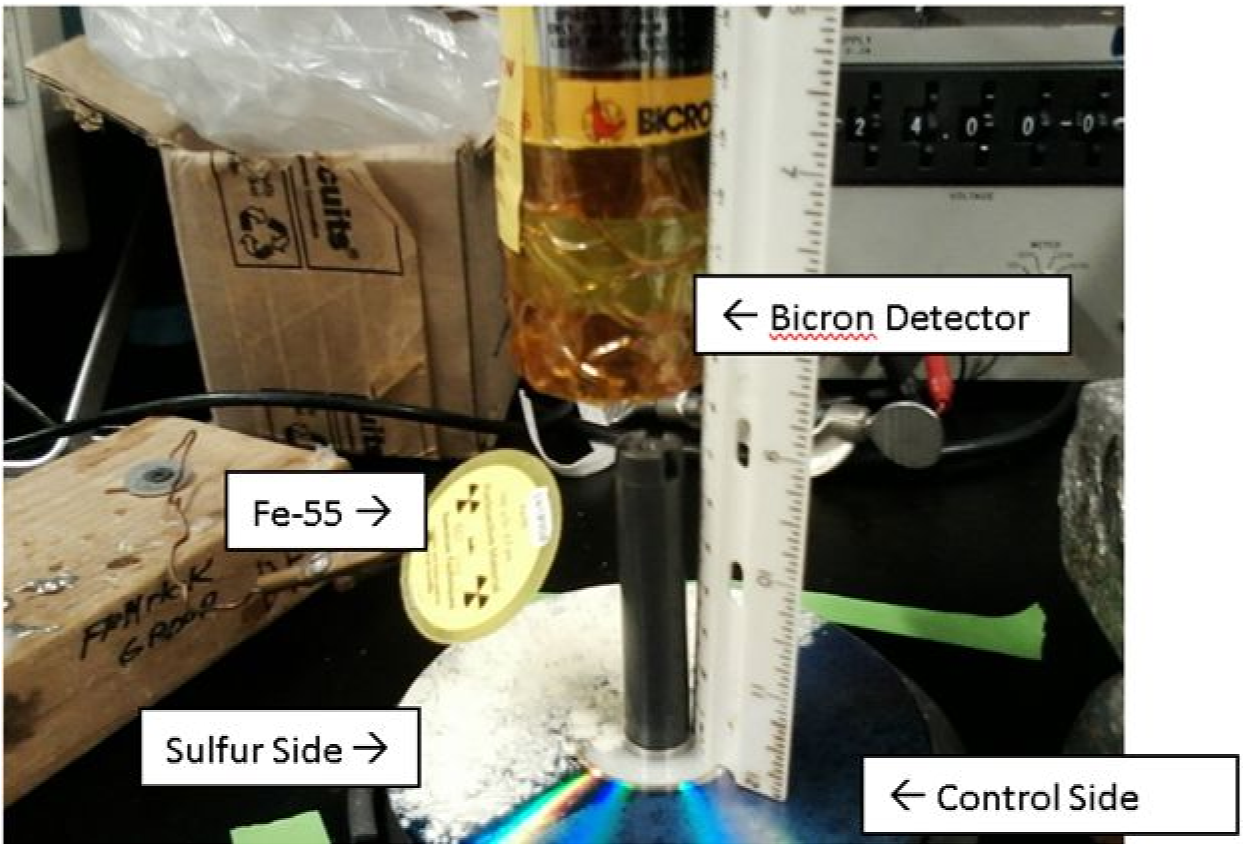

Figure 1: Experimental Set-up showing our means of testing for a signal from a substrate with both a target and a control made available by rotation

In our test, 6 keV photons from an Fe-55 source were incident on a sulfur target. A Bicron NaI(Tl) detector was used to observe the resultant radiation. In order to guard against extraneous background signals, we performed a control sample/ no sample experiment as follows using a CD as a substrate. On the bottom of Figure 1 of our setup is a disc holder with the CD placed upon it. There are two halves to the CD. One half had a spray on-glue applied with sulfur sprinkled to cover the surface (experimental side). The other half is just the glue alone on the CD surface itself acting as the control. Held at an angle as shown in the figure is the radioactive photon source, the yellow circular object with the radiation symbol. On the hidden side of the source, facing the CD, is a small amount of Fe-55. Held 3 inches above the CD is the Bicron detector. What makes this detector so special for this application is that it is capable of detecting low energy X-rays, as low as 2 keV. This is due to the beryllium window located on the detector's bottom facing towards the CD. In order to perform X-ray spectroscopy, the output of the Bicron detector is connected to a computer-based pulse height analysis system (Spectech UCS-30). Three of the several runs that were performed are presented here. One with the sulfur then the control each for five minutes of livetime (time that the detection system was sensitive to incoming photons). Then just the iron 55 itself aimed at the detector in order to establish the energy calibration of the system. In order to isolate the probable fluorescence signals from the background signals the spectra for the control experiment was subtracted from the spectra for the sulfur side.

Observations:

In Figure 2, the Fe-55 source spectrum (channel number is proportional to energy) indicates that the peak in the Fe-55 spectrum (corresponding to 6 keV) is at channel 128. This feature is very broad. These plots represent pulse height distribution of the photons that penetrated the NaI(Tl) in the detector. Below is the graph for Fe-55 photons hitting the detector directly:

These plots were taken using a Universal Computer Spectrometer[1].

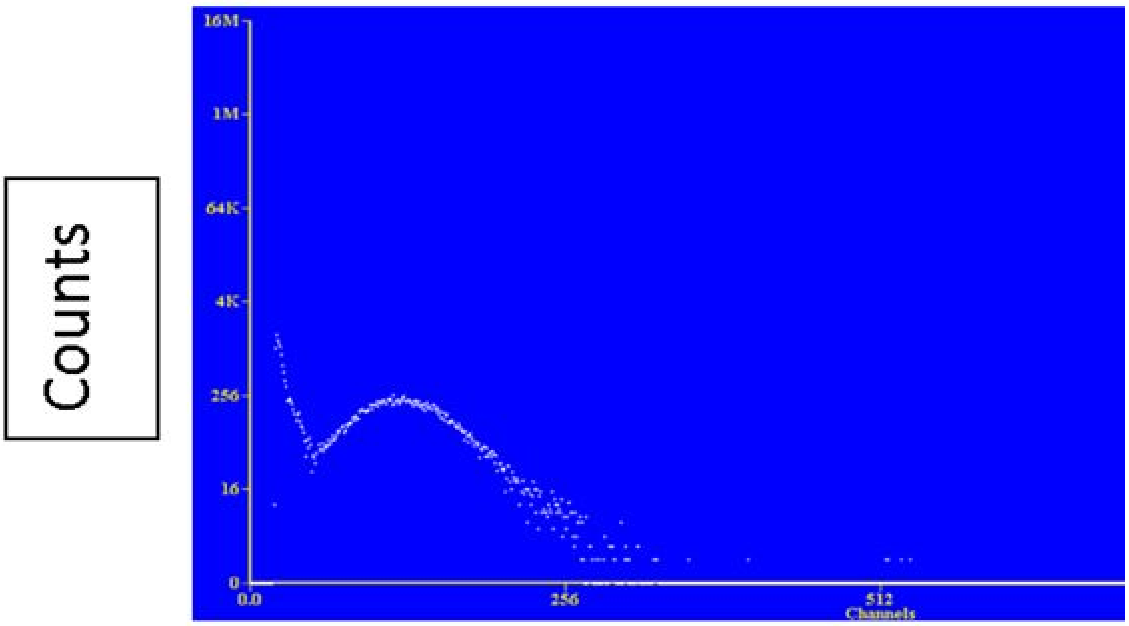

Figure 2: Signals from Radioactive Fe-55 Source. We conclude that 6 keV is at approximately channel 128

Since we know that the photons emitted from Fe-55 are around 6 keV. This plot proves to us that about channel 128 is 6 keV portrayed by the bump. This lets us know that we are at the right energy scale.

[1] Universal Computer Spectrometer manufactured by Spectech, model UCS30

On the following page the plots of the sulfur and then the control before the background signals were subtracted are provided

This plot was created during the sulfur side in the experiment:

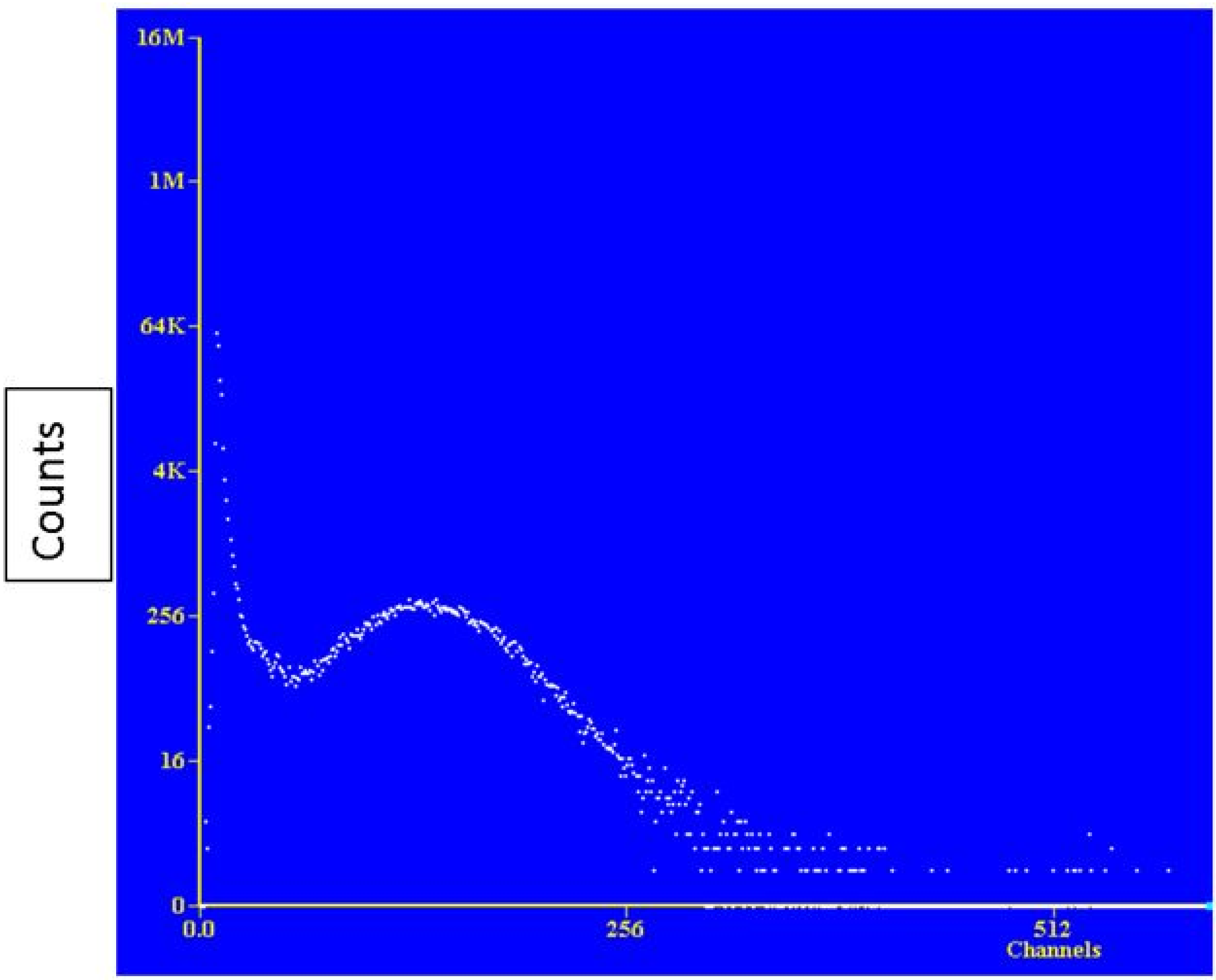

Figure 3: Spectrum Signals Created By Sulfur Target

This plot represents the raw data created from the independent variable. After photons were emitted from sulfur and hit the detector these energy pulses were detected. Since the bump is around 128 at 6 keV, we still know that we are in the right energy scale.

This plot represents the regular side of the CD acting as the control

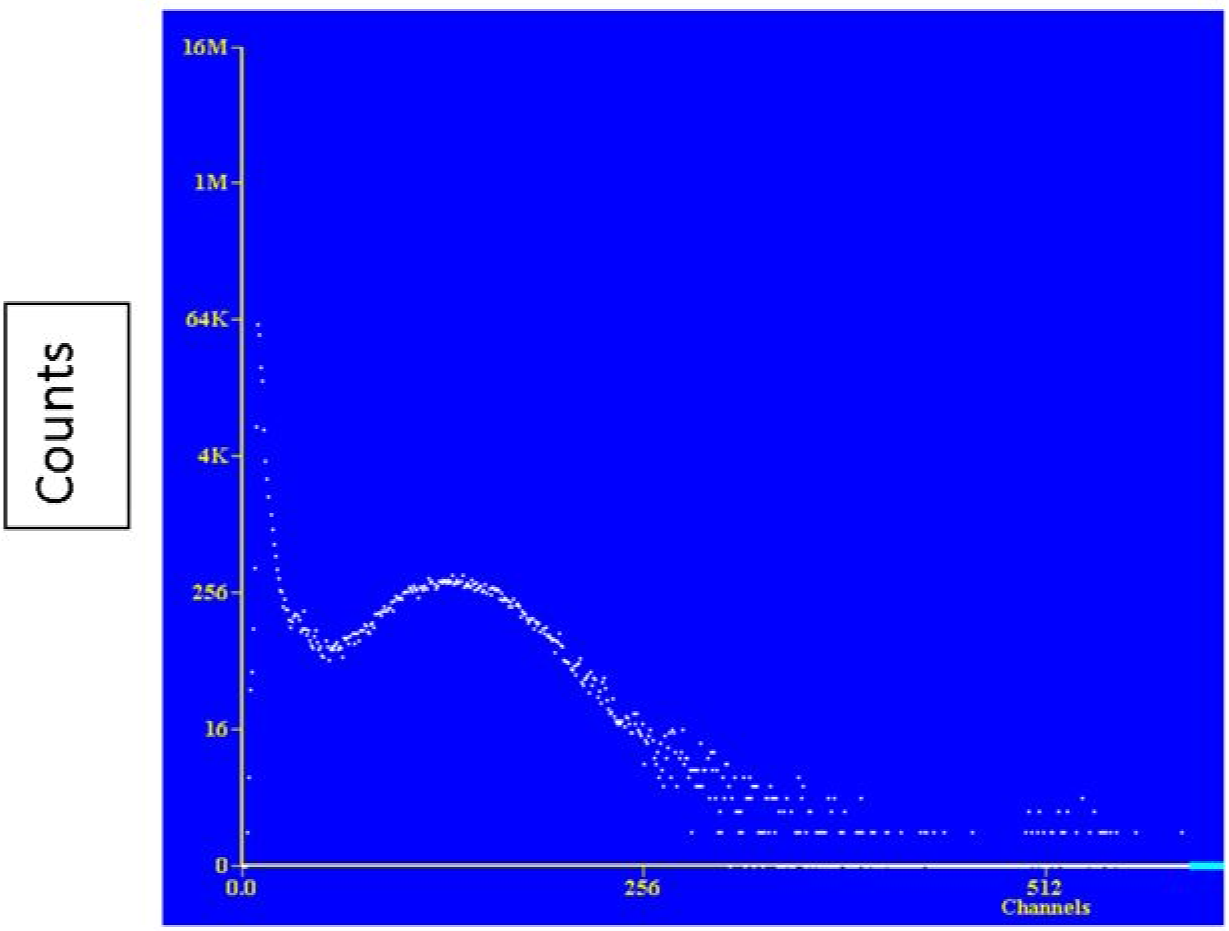

Figure 4: Signals created from the CD side (control)

This plot represents the signal created after photons from Fe-55 penetrated the CD and then hit the Bicron detector after being remitted. Overall this plot represents the signals created by the control. Again, Since the bump is around 128 at 6 keV, we still know that we are in the right energy scale.

Although both plots from the experiment and the control look very similar, subtracting the background signals will give us the possible fluorescence signal we are homing in on.

Background Subtracted Results:

The final graph had the background signals stripped by first, loading up the sulfur plot (figure 3). Second, the plot from the control (figure 4) was added to the plot with the sulfur. Then background signals were stripped, giving us the probable fluorescence signals as shown in figure 5

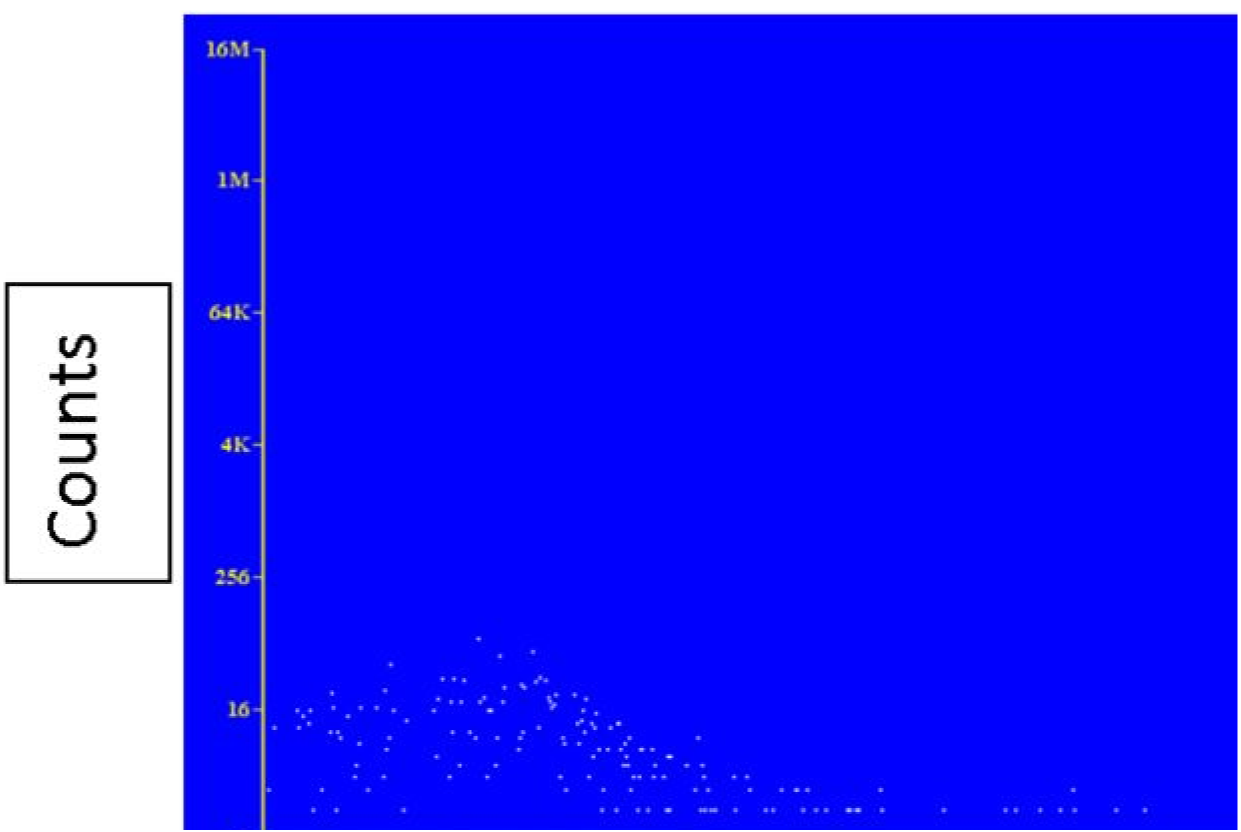

Figure 5: Probable Sulfur Fluorescence Signals

After the background signals were removed, these were the only signals that remained. Although all these signals don't directly indicate K-shell fluorescence, they are probable candidates. The reason we can't directly tell if these are fluorescence signals is because we do not see a shift to lower energy in the reemitted photons. Further research can be done to perfectly isolate actual signals of K-shell fluorescence. We have provided the suspects to stand in a line-up.

Application of Our System: X-Ray Raman Spectroscopy

Raman X-ray scattering lets us see two things very well. First it gives us an impression of how excited matter behaves both in space and time. It's much like a movie, but instead of using time we use frequencies. The aim of our fluorescence detection experiments is to provide a means of isolating a particular initial state from the multitude of initial states that can be excited in a Raman scattering experiment. We propose to accomplish this by placing our Bicron detector at the location indicated in Figure 6, the Raman scattering apparatus Ref. (2) (named LERIX) at the Argonne National Laboratory's synchrotron radiation facility, the Advanced Photon Source.

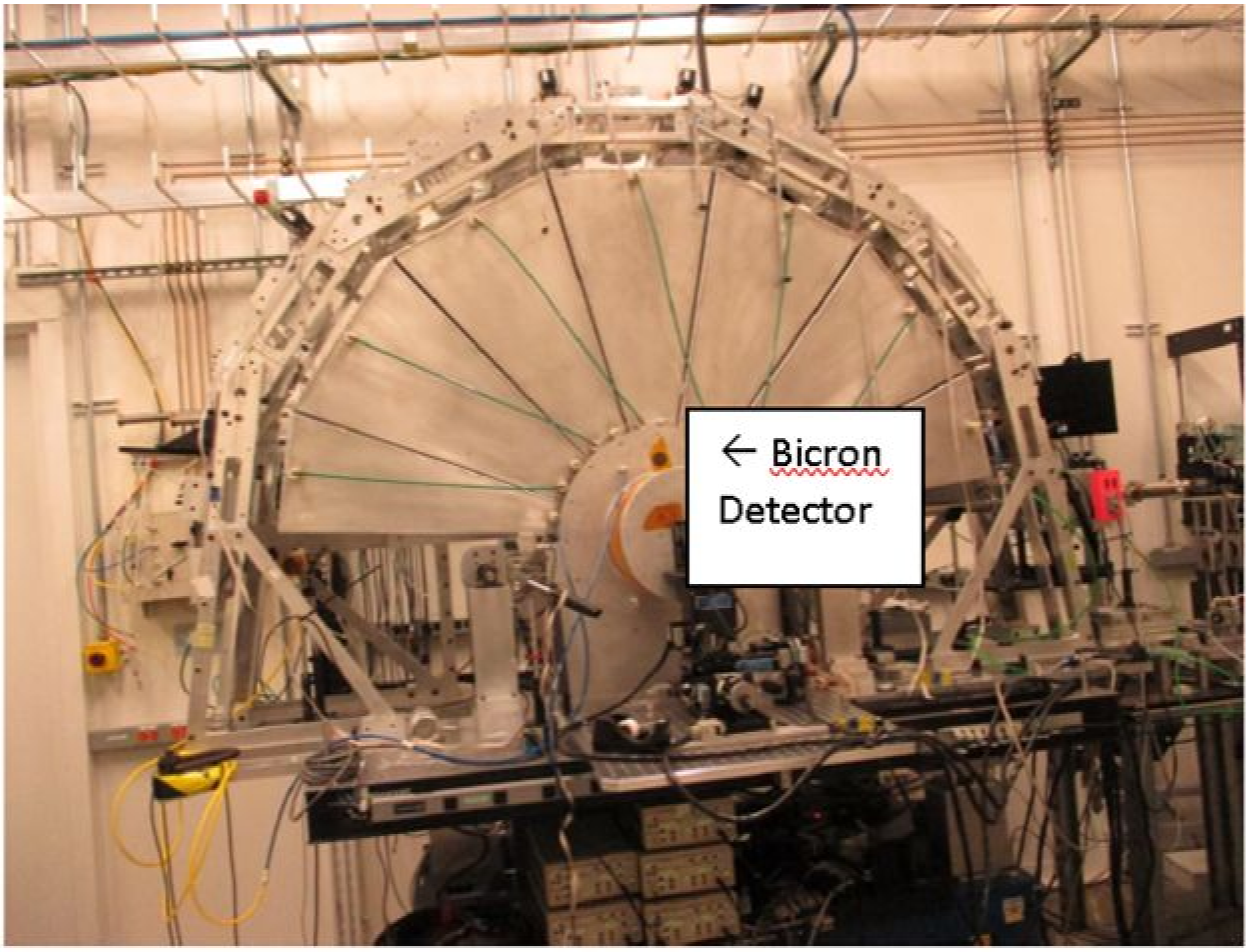

Figure 6: LERIX Facility at the Advanced Photon Source at the Argonne National Lab (where the detector used our experiment would be placed is marked)

Acknowledgments:

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References:

1) Universal Computer Spectrometer manufactured by Spectech, model UCS30

2) T.T Fisher et.al. Multielement spectrometer for efficient measurement of the momentum transfer dependence of inelastic x-ray scattering. From the journal of Review of Scientific Instruments, Volume 77, Issue 6, Page 063901 (2006)