

Introduction

A research program in ion-beam analysis (IBA) of atmospheric aerosols is being developed to study pollution in the Capitol District and Adirondack Mountains of New York. The IBA techniques applied in this project include proton induced X-ray emission (PIXE), proton induced gamma-ray emission (PIGE), Rutherford backscattering (RBS), and proton elastic scattering analysis (PESA). These methods are well suited for studying air pollution because they are quick, non-destructive, require little to no sample preparation, and capable of investigating microscopic samples. While PIXE spectrometry is used to analyze most elements from Si to U, the other techniques are being applied to measure some of the lighter elements and complement PIXE in the study of aerosols.

Ion-Beam Analysis

The IBA techniques are all based on the same basic principles. The sample of interest is bombarded with a beam of ions with energies of a few MeV, produced in an accelerator. As the projectiles penetrate the sample some of them interact with electrons and nuclei. The products of these interactions are emitted from the sample and are measured with detectors. The energy spectra of the interaction products provide information on the elemental composition of the sample.

Particle Accelerator

At the Union College Ion-Beam Analysis Laboratory (UCIBAL), ions are provided by a 1.1-MV pelletron accelerator shown in Figure 1. The ions are produced in the source, then accelerated through the accelerator tank to energies of up to 2.2 MeV for protons. The quadrupole and switcher magnets focus and steer the beam, respectively.

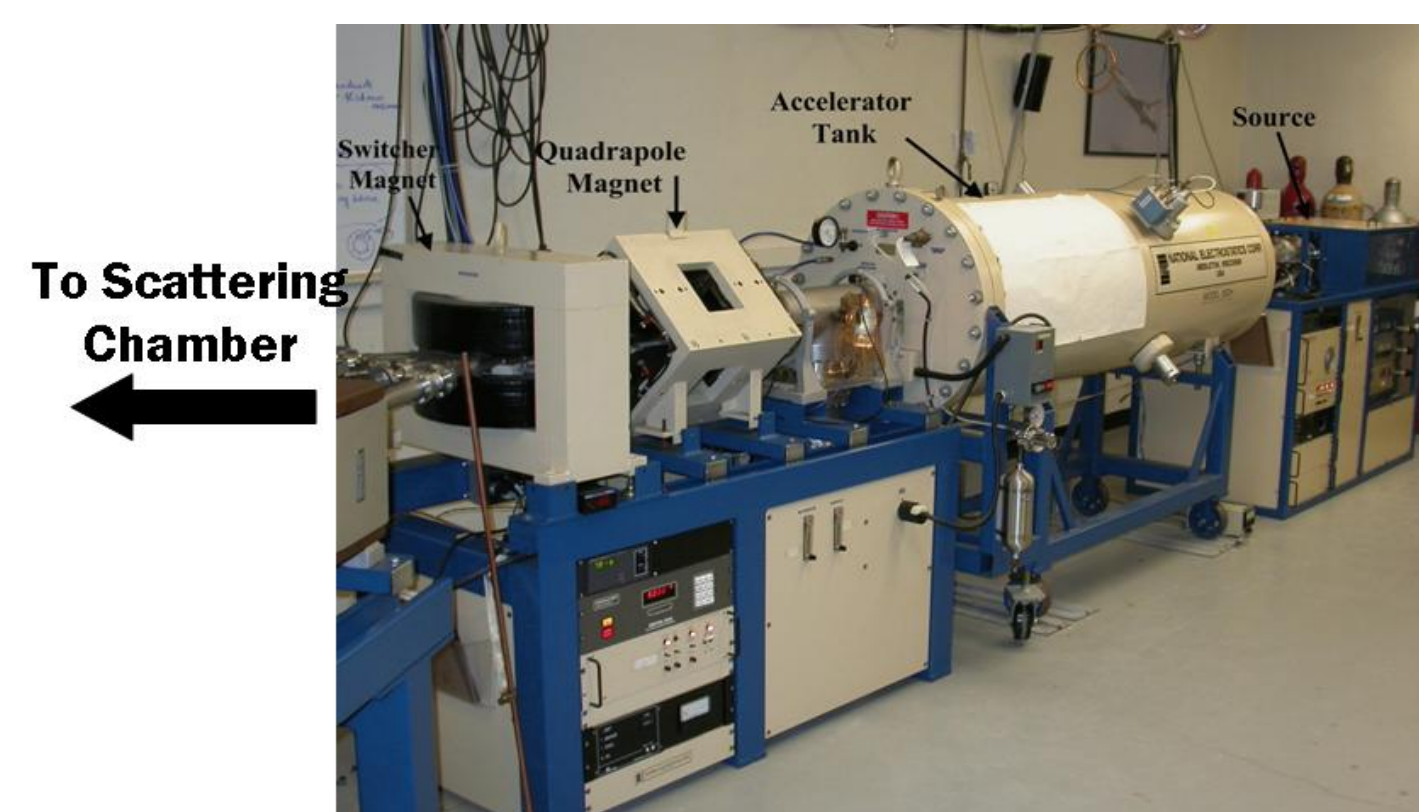


Figure 1: A photograph of Union College's 1.1-MV pelletron accelerator showing the main components.

Aerosol Sampling

The aerosol samples are collected using a nine stage cascade impactor [1] that separates particles according to their size. The particulate matter is impacted on thin Kapton films at each stage. The impactor and the sampling apparatus are shown in Figure 2. The pump pulls air through the impactor and the valve controls the flow rate which is monitored by the flow meter. The impactor is designed for a flow rate of 1 L/min.

PIXE

In the case of PIXE, the ion knocks an inner-shell electron out of the atom and an X-ray is emitted as the vacancy is filled by an outer-shell electron. The energies of the X-rays are characteristic of the elements in the sample and the intensities of the X-ray lines can be used to calculate the concentration of the elements. This technique provides information on selected elements from Si to U with good sensitivity. Minimum detectable limits for PIXE analysis of aerosol samples are typically on the order of a few ng/m³ [2].

The experimental apparatus for the PIXE measurements is shown in Figure 3. The samples are positioned at the center of the scattering chamber at an angle of 45° to the beam. The X-rays are detected with an Amptek Si drift detector positioned at 90° to the beam and 45° to the sample. The beam current is measured in the Faraday cup behind the scattering chamber.

Shown in Figure 4 are PIXE spectra taken on an aerosol sample (blue) and a blank Kapton film (red) with a 2.2-MeV proton beam. The sample contains particles between 4 and 8 μm in diameter and was obtained at the Vale Cemetery Crematorium in Schenectady, NY. The spectrum taken on the aerosol sample shows peaks for a broad range of elements from Si to Zn.

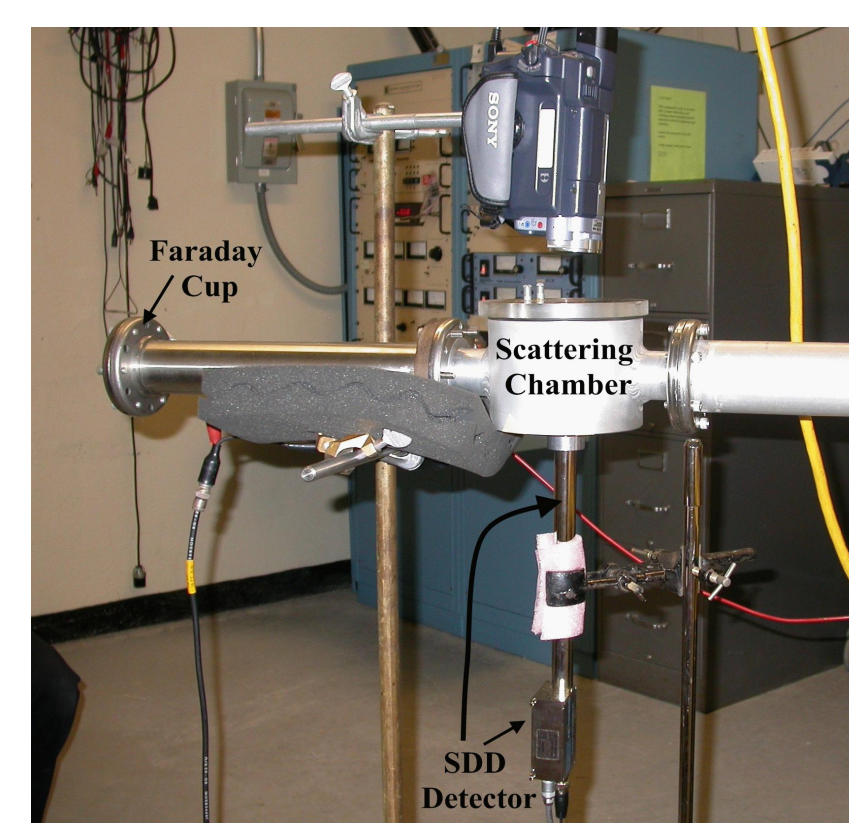


Figure 3: A picture of the experimental apparatus for the PIXE measurements.

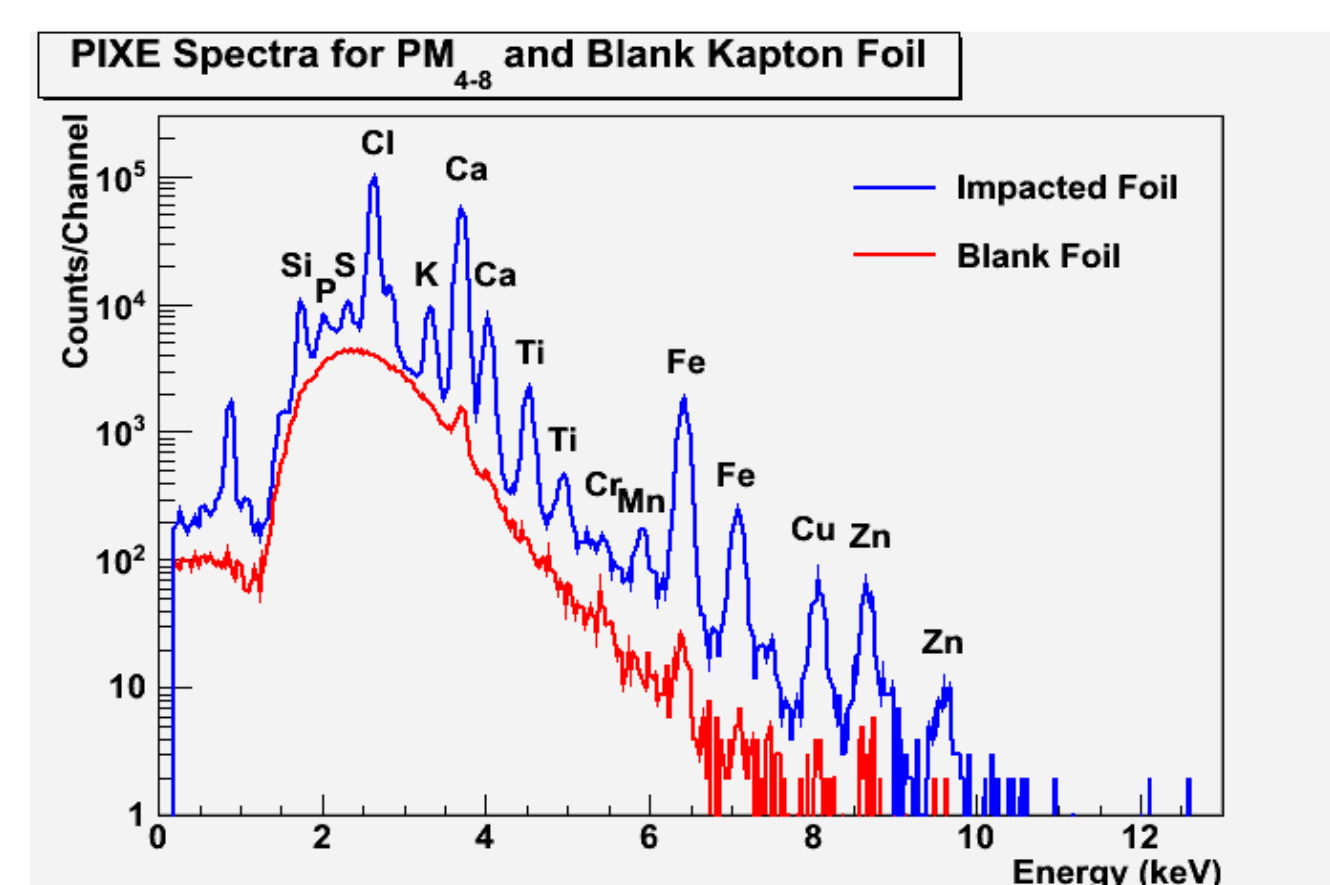


Figure 4: PIXE spectra of an aerosol sample (blue) and a blank Kapton foil (red) taken with a 2.2-MeV proton beam. The sample was for particulate matter between 4 and 8 μm, and a total charge of 15 μC was collected for each spectrum.

PIGE

PIGE involves a nuclear excitation with the emission of a γ-ray. Since the excitation is nuclear, the process has a lower probability of occurring than PIXE and hence is less sensitive. This technique has been used in the analysis of aerosol samples to measure concentrations of sodium and fluorine with minimum detectable limits of around 100 ng/m³ [3].

The experimental configuration for the PIGE measurements is shown in Figure 5. It was the same as in the PIXE measurements except that the X-ray detector was replaced with a Ge γ-ray detector.

Shown in Figure 6 is a PIGE spectrum taken on a GdF₃ standard with a 1.8-MeV proton beam. Peaks are clearly visible in the spectrum for F, Mg, and Al [4].

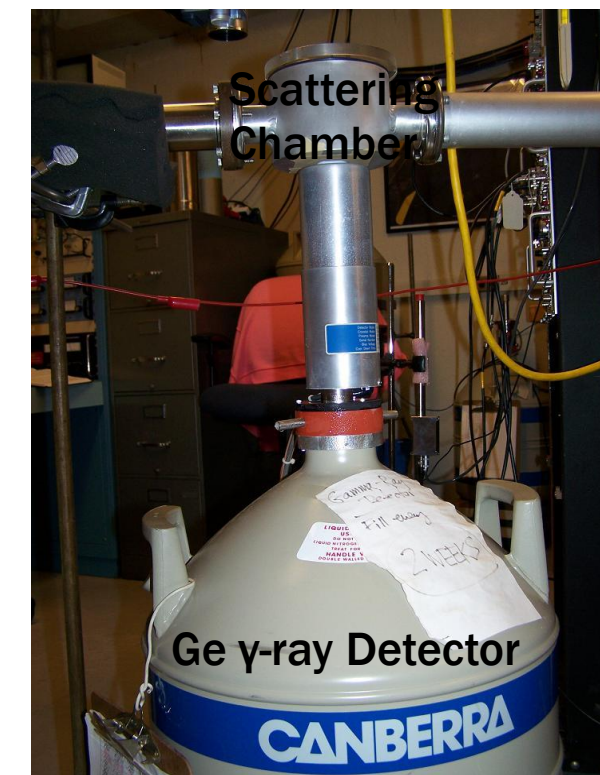


Figure 5: A picture of the experimental configuration for the PIGE measurements.

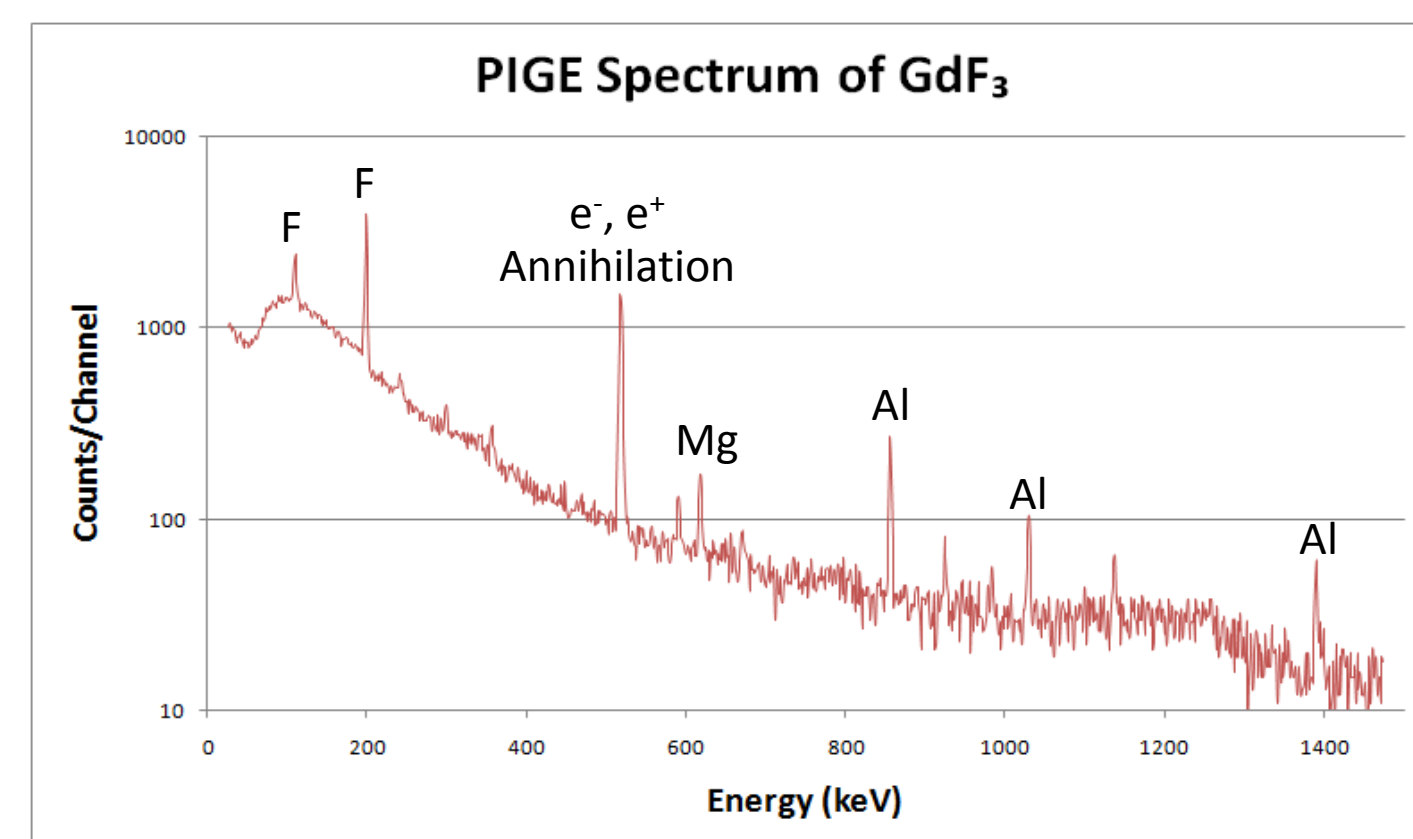


Figure 6: A PIGE spectrum taken on a GdF₃ standard with a 1.8-MeV proton beam. A total of 10 μC of charge was incident on the sample.

RBS

The energies of projectiles elastically backscattered from nuclei of atoms in the sample are measured in the RBS method. The mass of the target nucleus is determined from the energy of the scattered ions. Information on the concentration of elements (or isotopes) can be obtained from the number of scattered particles in the various peaks of the spectrum. The RBS technique has been applied to aerosol samples to determine concentrations of C, N, and O with typical minimum detection limits of 2-12 μg/cm² [3].

A photograph of the scattering chamber used in the RBS and PESA measurements is shown in Figure 7. The ion beam enters from the right and hits the target in the center. The vast majority of the ions pass through the target and are collected in the Faraday cup, but a small fraction are scattered to various angles. A Si surface barrier detector is used to detect the ions at large angle for RBS and small angles for PESA.

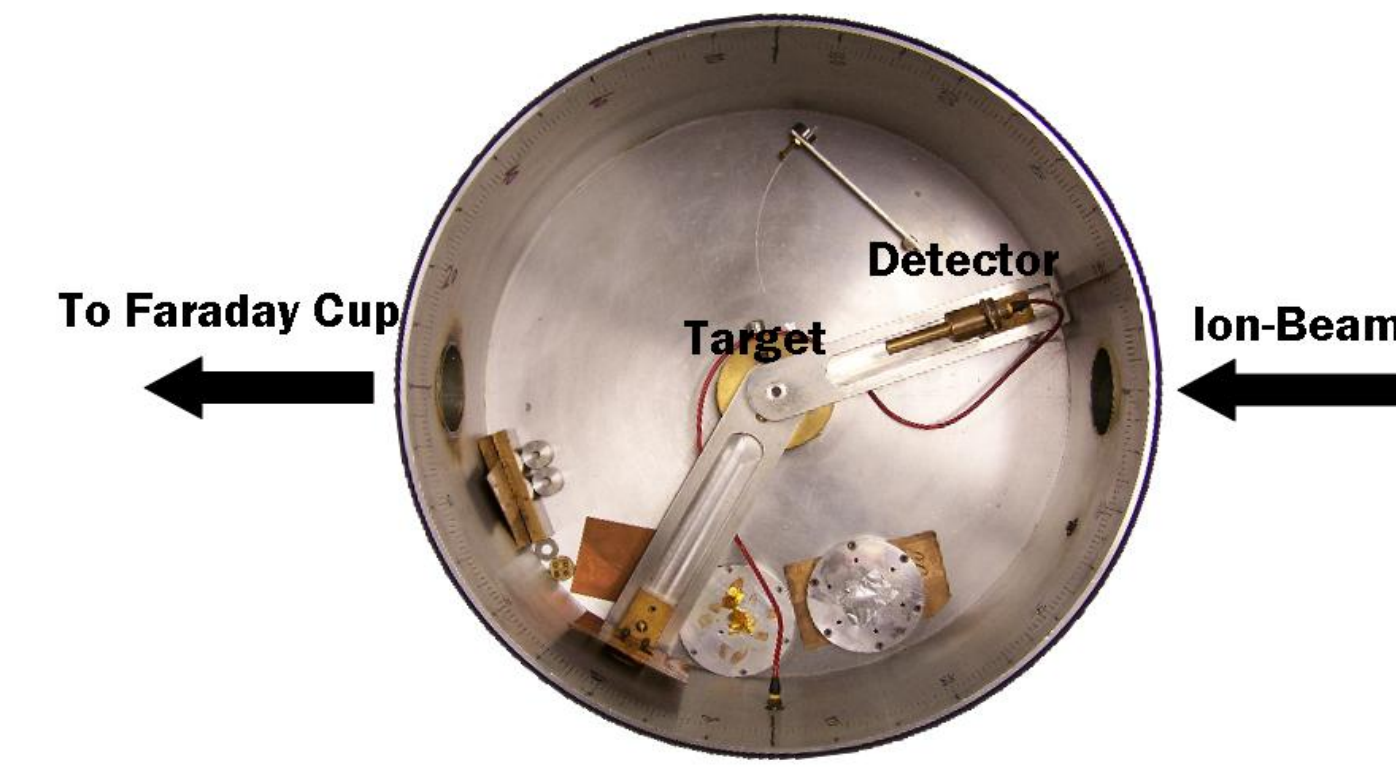


Figure 7: A photograph of the scattering chamber used in the RBS and PESA measurements. The target is positioned in the middle of the chamber and the Si surface barrier detector can be moved to measure scattered ions at various angles.

RBS with α-particle beams is a commonly used technique in materials analysis and provides good mass resolution for a broad range of elements. Shown in Figure 8 is an RBS spectrum taken with a 3.3-MeV α-particle beam taken at 140° on an Al target with a thin layer of Au. The red curve shown in the spectrum is a fit to the data using RUMP [5].

We are interested in making RBS measurements simultaneously with the other IBA techniques using proton beams. An RBS spectrum taken on an ErF₃ standard with a Mylar backing using a 1.8-MeV proton beam is shown in Figure 9. As can be seen, the mass resolution is not nearly as good as with α beams. We are currently working on fitting proton RBS spectra.

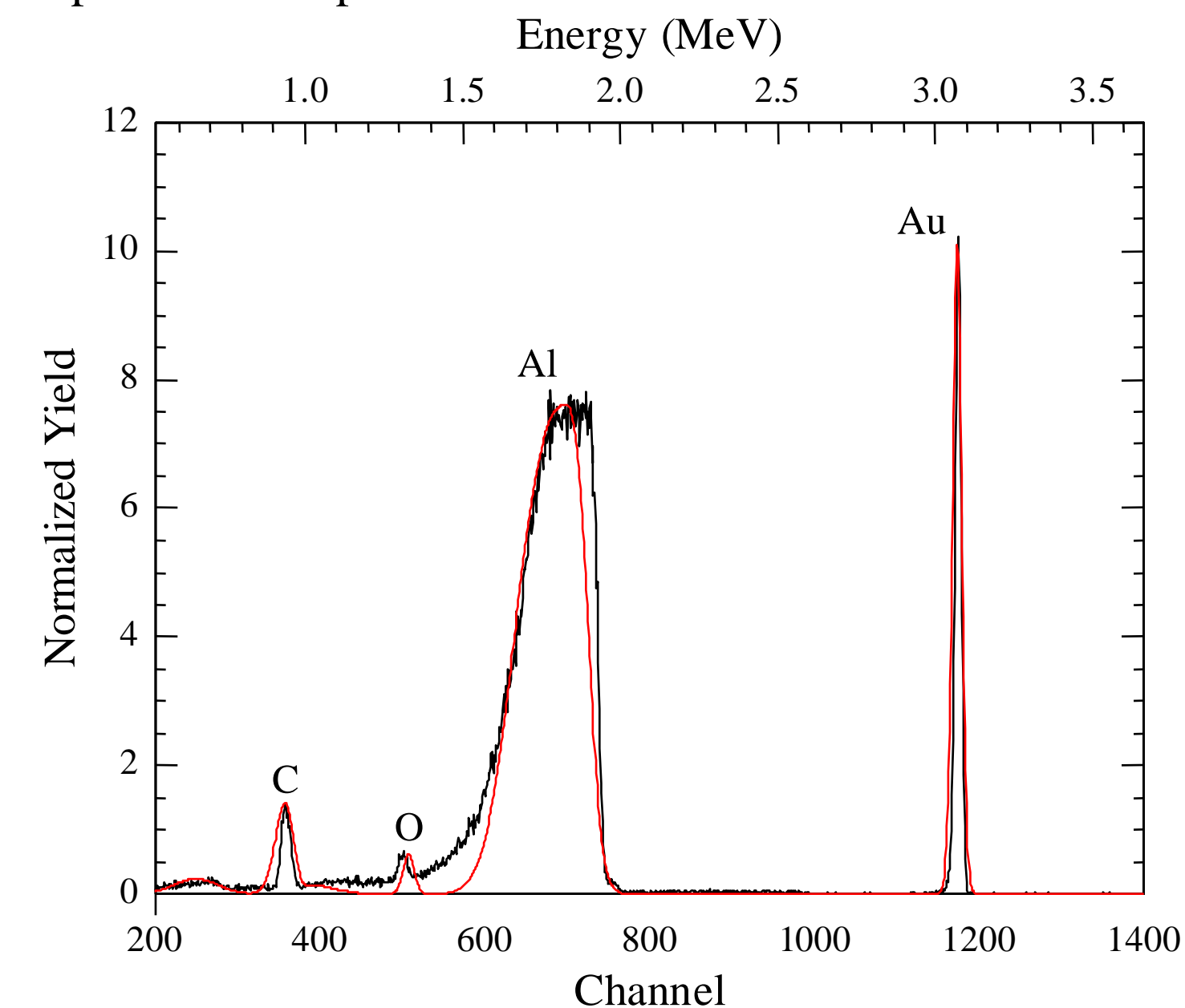


Figure 8: An RBS spectrum taken with a 3.3-MeV α-particle beam at 140° on an Al target with a thin layer of Au. The red curve is a fit to the data using RUMP [5].

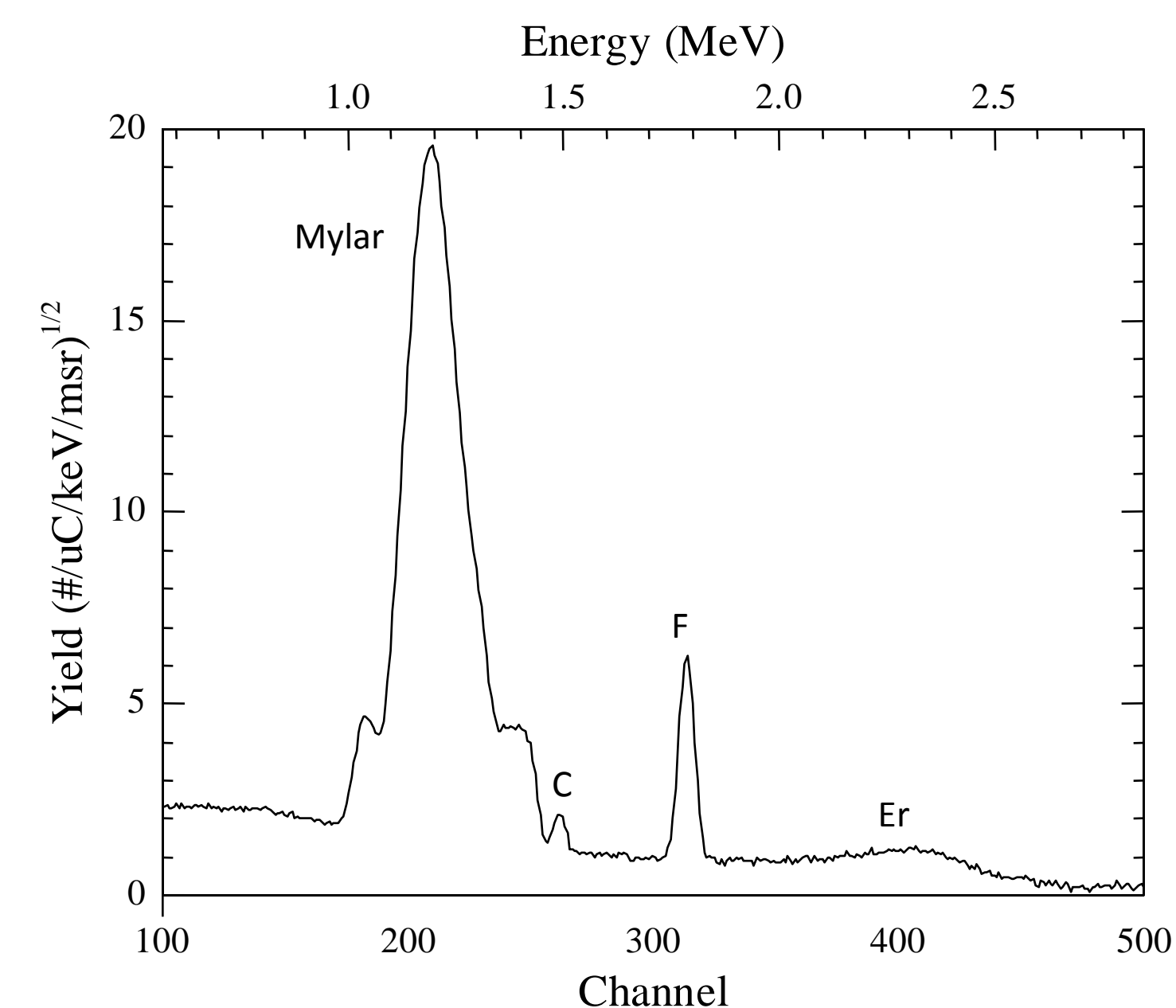


Figure 9: An RBS spectrum taken on an ErF₃ standard using a 1.8-MeV proton beam. A total charge of 10 μC was incident on the target.

PESA

In the PESA technique, protons scattered off light atoms like H and C are detected in the forward direction. This method has been used to measure the total hydrogen present in aerosol filters, but with lower sensitivity than PIXE or PIGE due to large backgrounds under the hydrogen peaks [3].

A PESA spectrum taken on a MoO₃ standard at a scattering angle of 40° using a 1.8-MeV proton beam is shown in Figure 10. The spectrum can be fitted to determine the concentration of hydrogen in the sample.

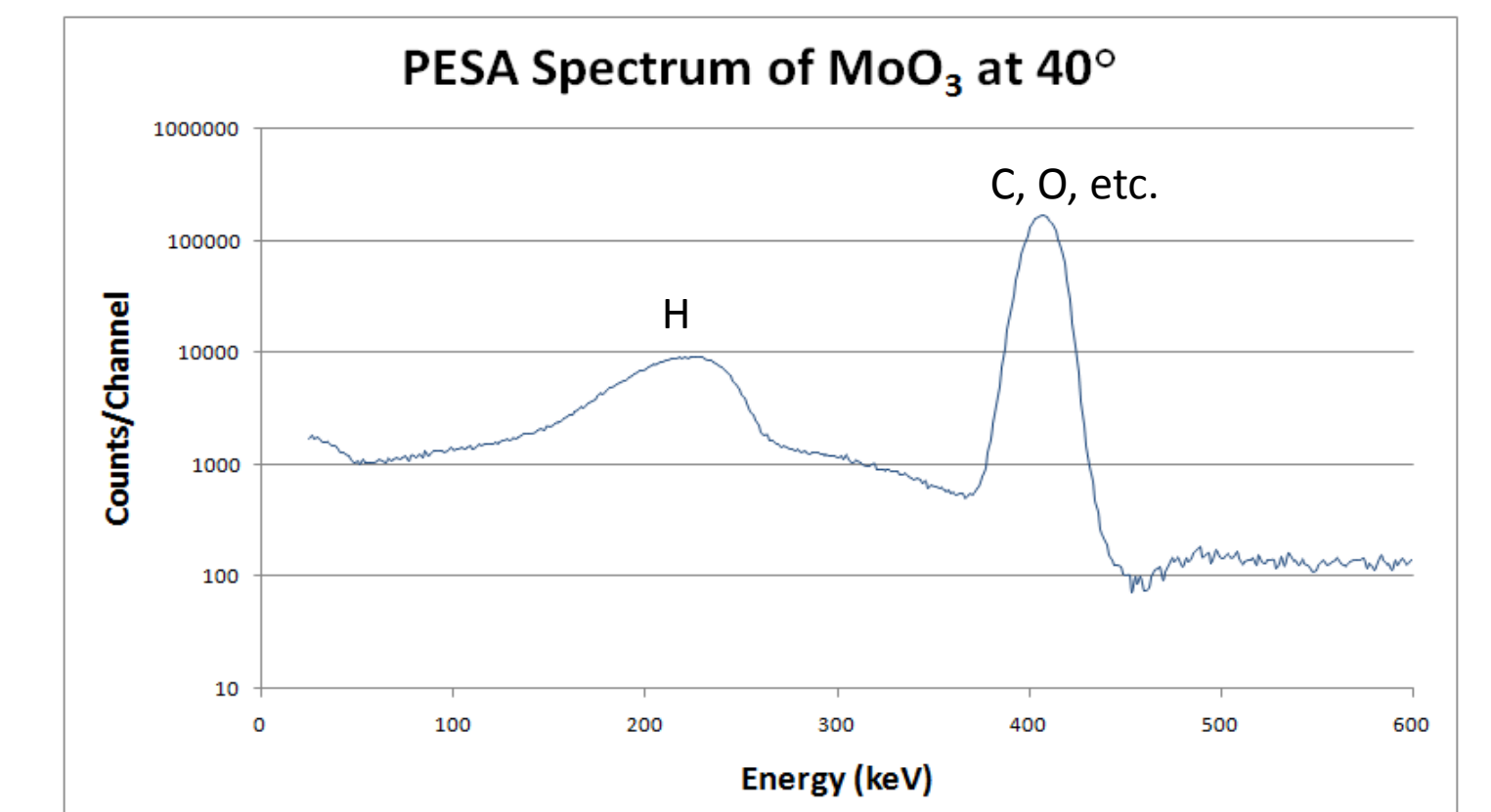


Figure 10: A PESA spectrum taken on a MoO₃ standard at a scattering angle of 40° using a 1.8-MeV proton beam. A total charge of 3 μC was incident on the target.

Future Work

We are constructing a new target chamber that will accommodate multiple targets and allow us to make all the IBA measurements simultaneously. The chamber is based on a 10-inch, multi-way, Conflat cross shown in Figure 11.



Figure 11: A photograph of the 10-inch, multi-way, Conflat cross that is the basis for the new scattering chamber at UCIBAL.

References

- [1] PIXE International Corporation, P.O. Box 2744, Tallahassee, FL 32316 USA, <http://pixeintl.com/>.
- [2] S.A.E. Johansson, J.L. Campbell, and K.G. Malmqvist, "Particle-Induced X-Ray Emission Spectrometry (PIXE)" (Wiley, New York, 1995).
- [3] D.D. Cohen *et al.*, "IBA methods for characterization of fine particulate atmospheric pollution: a local, regional and global research problem," Nuclear Instruments and Methods B **219-220**, 145 (2004); and references therein.
- [4] C. Bori *et al.*, "Prompt Gamma Emission Excitation Functions for PIGE Analysis of Li, B, F, Mg, Al, Si, and P in Thin Samples," Nuclear Instruments and Methods B **35**, 80-88 (1988).
- [5] GENPLOT and RUMP Documentation, <http://genplot.com/>.