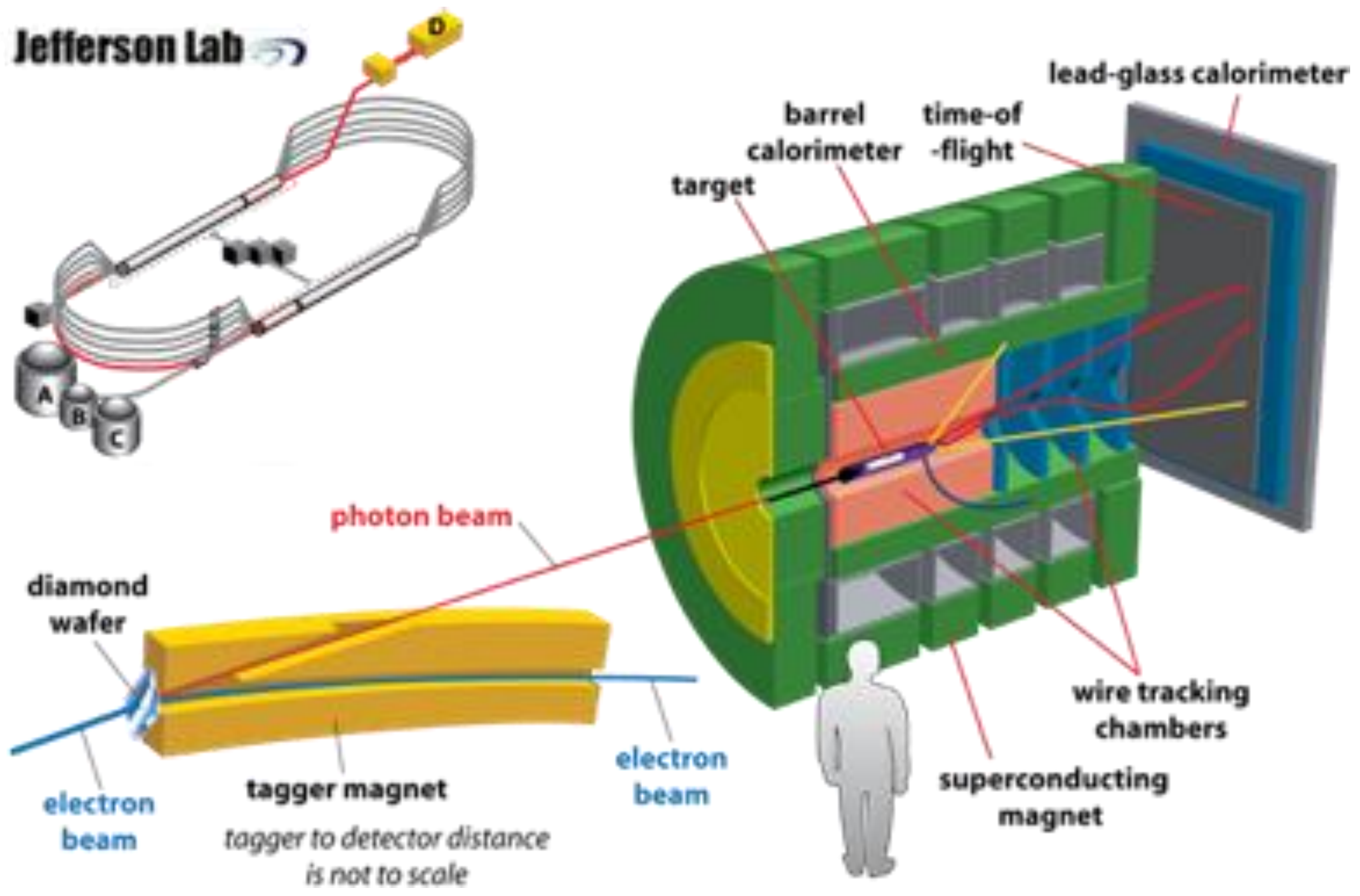


Abstract:
In the GlueX experiment at Jefferson Laboratory in Newport News, VA, a high-energy photon beam will be used to probe the forces that bind quarks together in the nucleus of an atom. The photon beam is produced by passing high-energy electrons through a thin sheet of diamond. In order for the experiment to succeed, the diamond must be precisely aligned. To guarantee this alignment, the diamond must be extremely flat. Our group has developed a laser interferometer that is capable of measuring this flatness to within twenty nanometers. To reduce cost, this interferometer incorporates a consumer camera with a non-specified fixed lens apparatus. However, in order to properly analyze the interference pattern that will be recorded, the specific workings of the lens assembly must be determined. As the lens is fixed and cannot be replaced, a mathematical model of the camera must be constructed instead. This model will then be used in tandem with data recorded by the camera in order to examine the light passing through the diamond wafer.

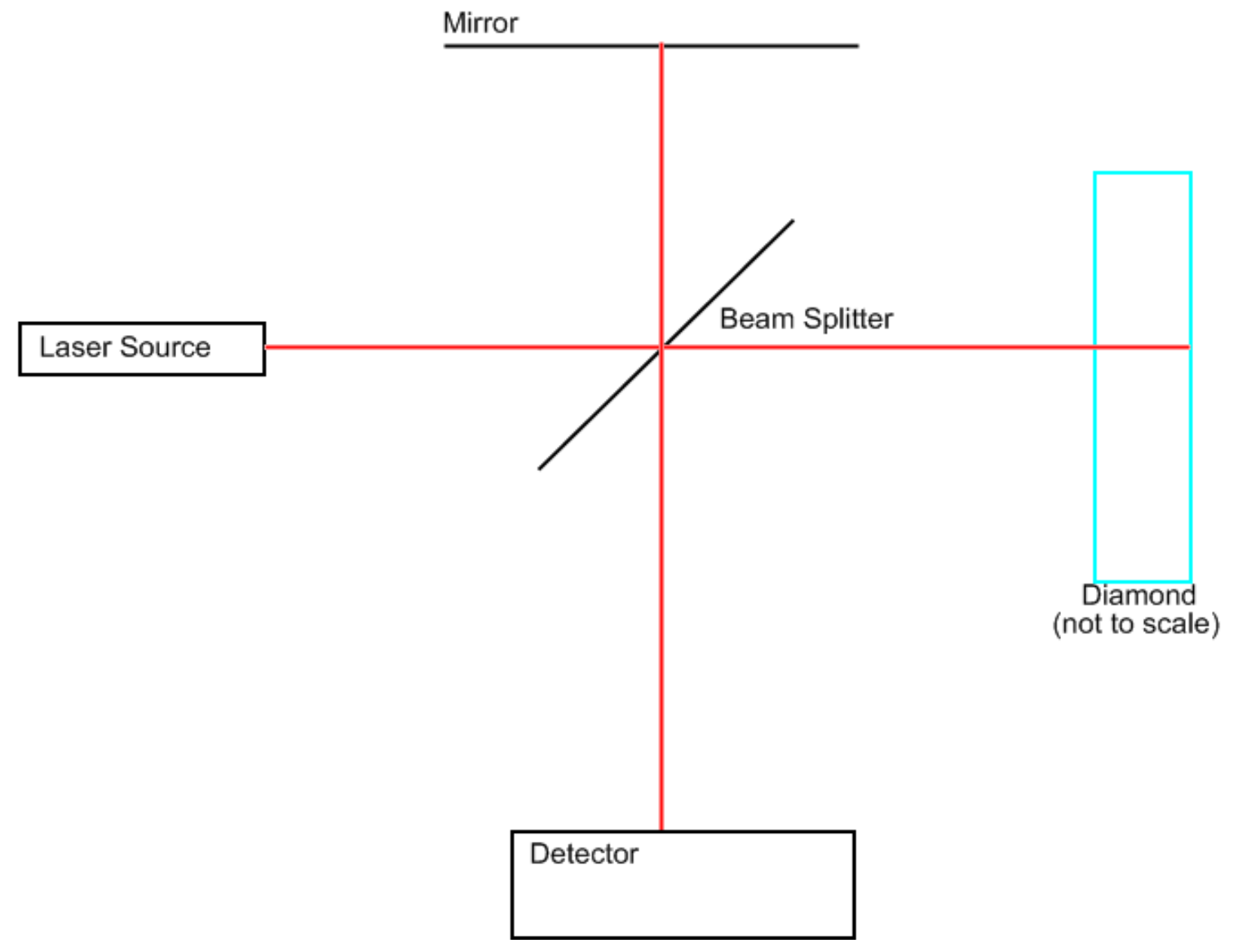
Casio Exilim Pro EX-F1
-12 lenses in 9 groups
-1200 frames per second
-6.6 million pixels

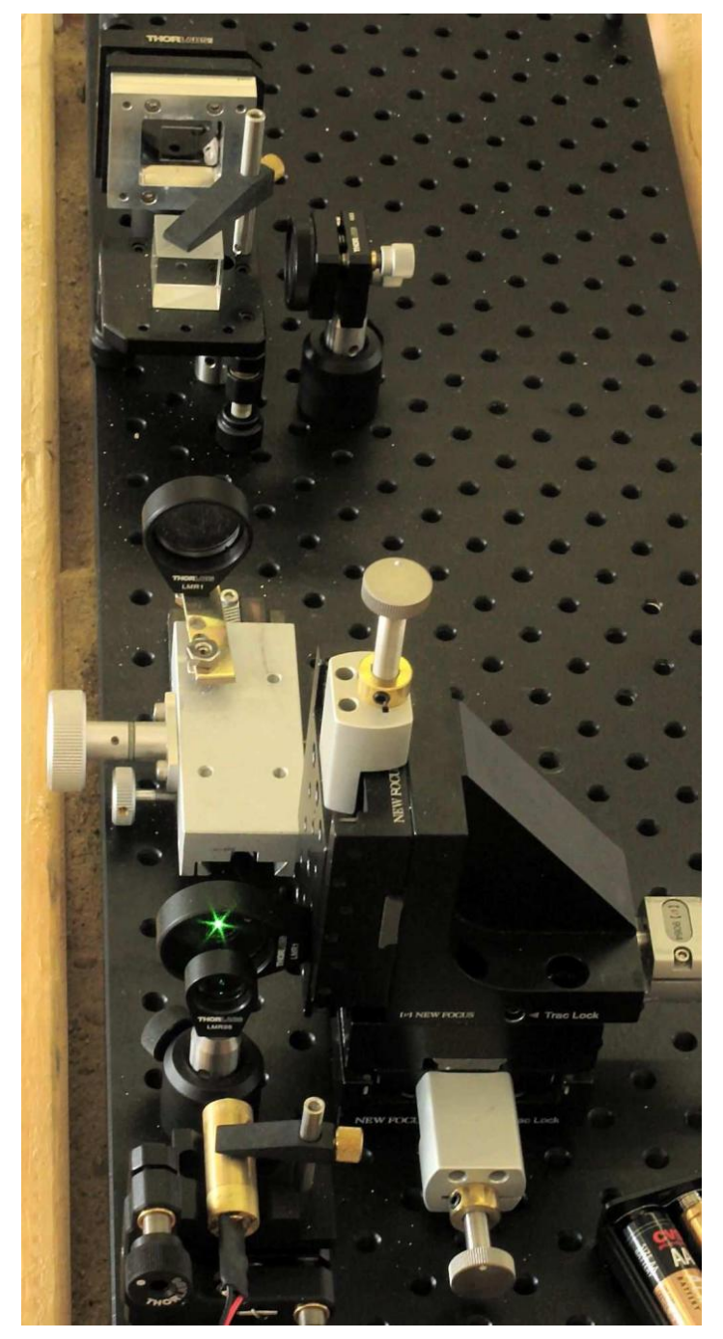
The internals of the lens assembly can be approximated by using the thin-lens approximation in order to simplify the mathematical model of the camera. Initially, a two-dimensional model of the lens system was created and used to generate an image of a one-dimensional object. Once the correct behavior of the basic model was verified, it was extended to a full three-dimensional model which generates two-dimensional images from three-dimensional objects, as an actual camera does. Using this model alongside data recorded experimentally, the precise arrangement of lenses in the camera can be calculated. With the lens assembly understood, any distortions in the received image can be corrected for, allowing us to determine the original object – the interference pattern – produced by the laser interferometer.

A simple mathematical model of the camera, calibrated to match its inputs and outputs with those of the actual camera, accurately reproduces the behavior and even the interior geometry of the lens assembly, to the extent permitted by the thin-lens approximation. Using this model, we can determine the precise interference pattern created by the laser interferometer, and using this we can precisely calculate the flatness and stability of the target diamond wafer.

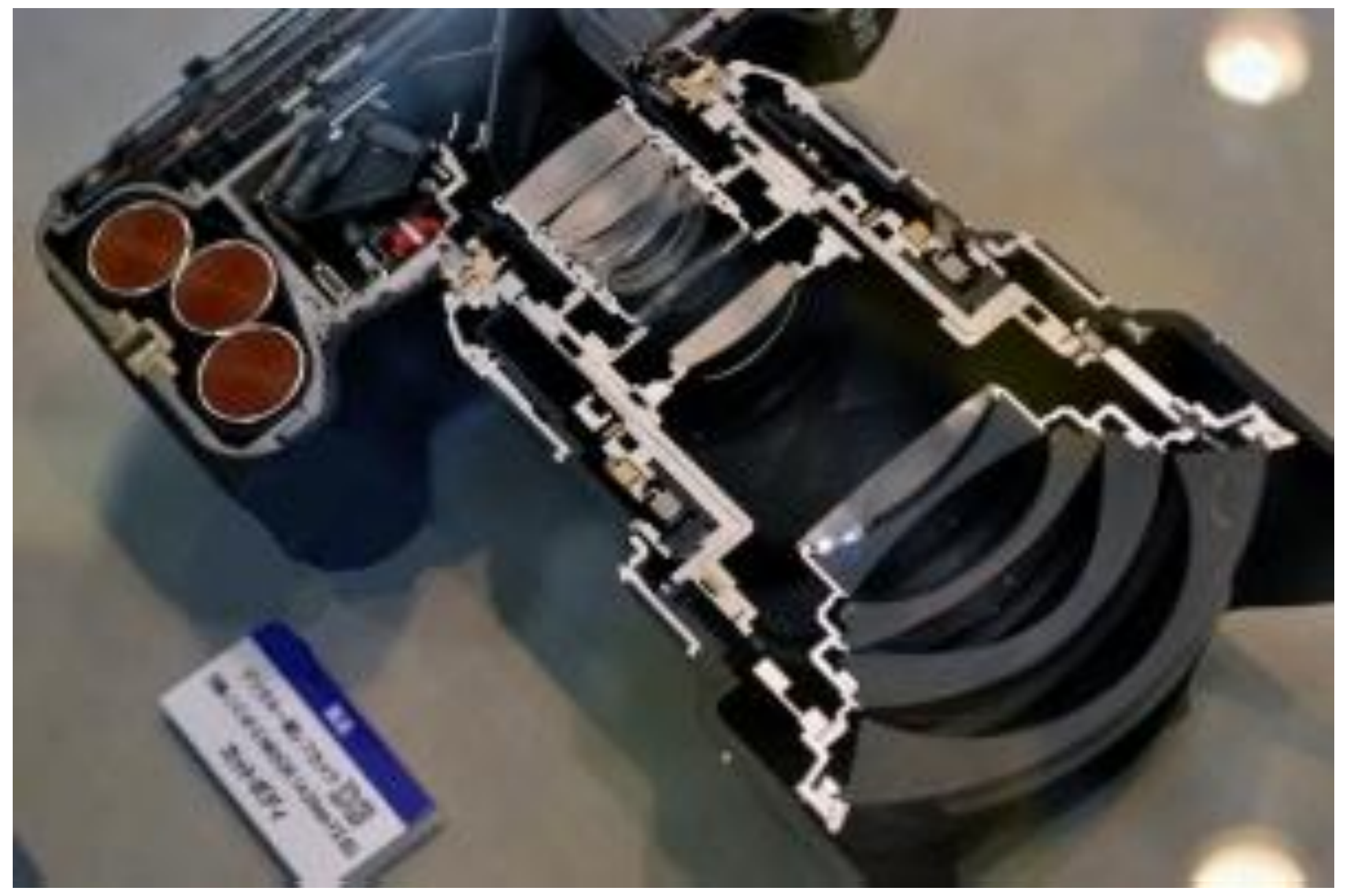
Internal Analysis of a Camera for a Laser Interferometer

Matthew Heiss
Advisor: Dr. Richard Jones, University of Connecticut





The laser interferometer is a very simple machine. A laser (left) projects a beam into a beam splitter (center). This splitter divides the beam, sending a beam with half the original amplitude towards a mirror (top) and a second identical halved beam towards the target diamond (right). When the beam reaches the diamond, it will be further split, with some of the wave reflecting towards the splitter and some of it passing through. We have calculated that the only significant beams returning from the diamond will be the reflections off of the front and back planes. Upon reaching the splitter, these beams will be reintegrated with the beam from the mirror, and the combined beam will be reflected into the detector (bottom). From this, we can calculate the shape and thickness of the diamond at any point.

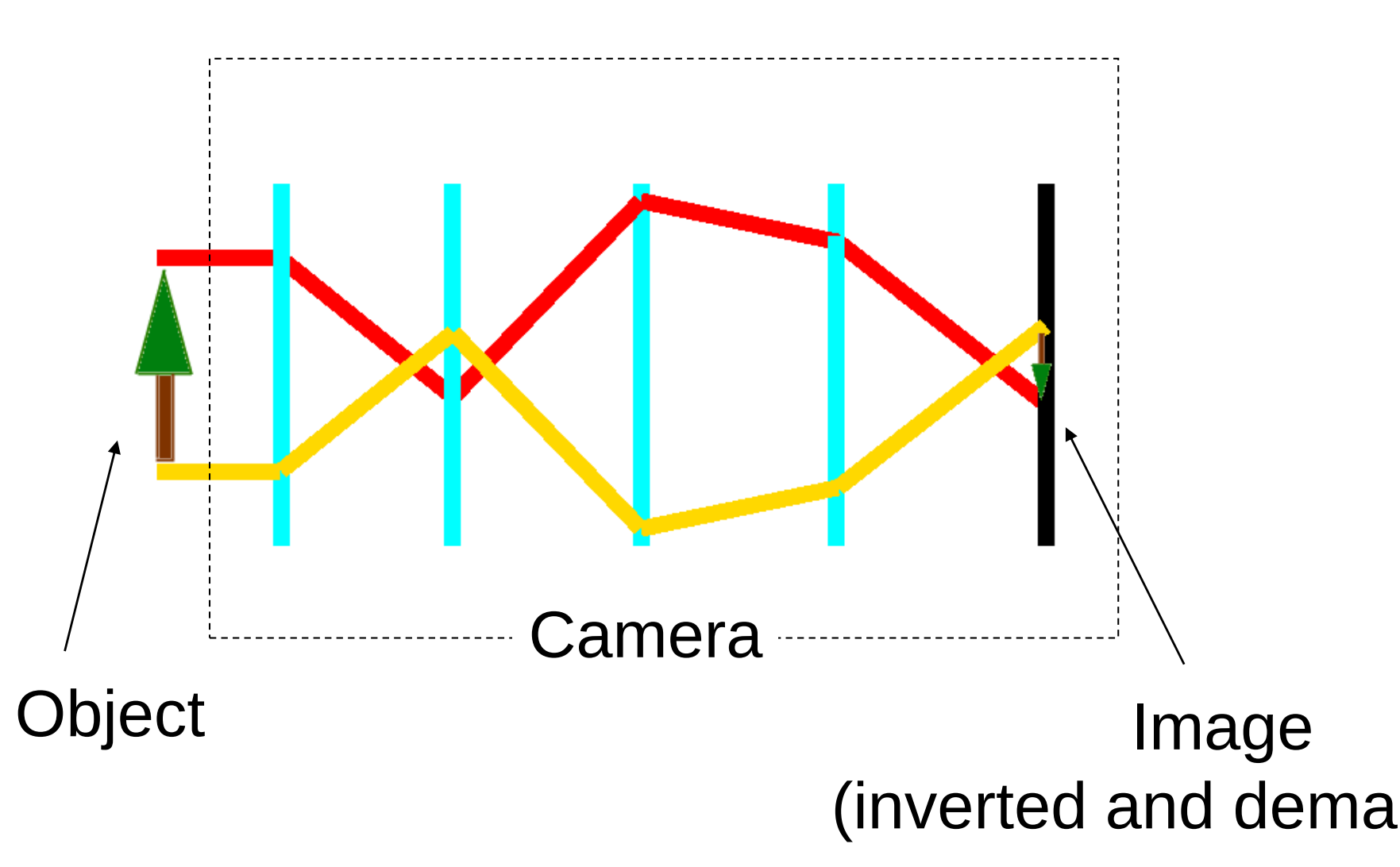


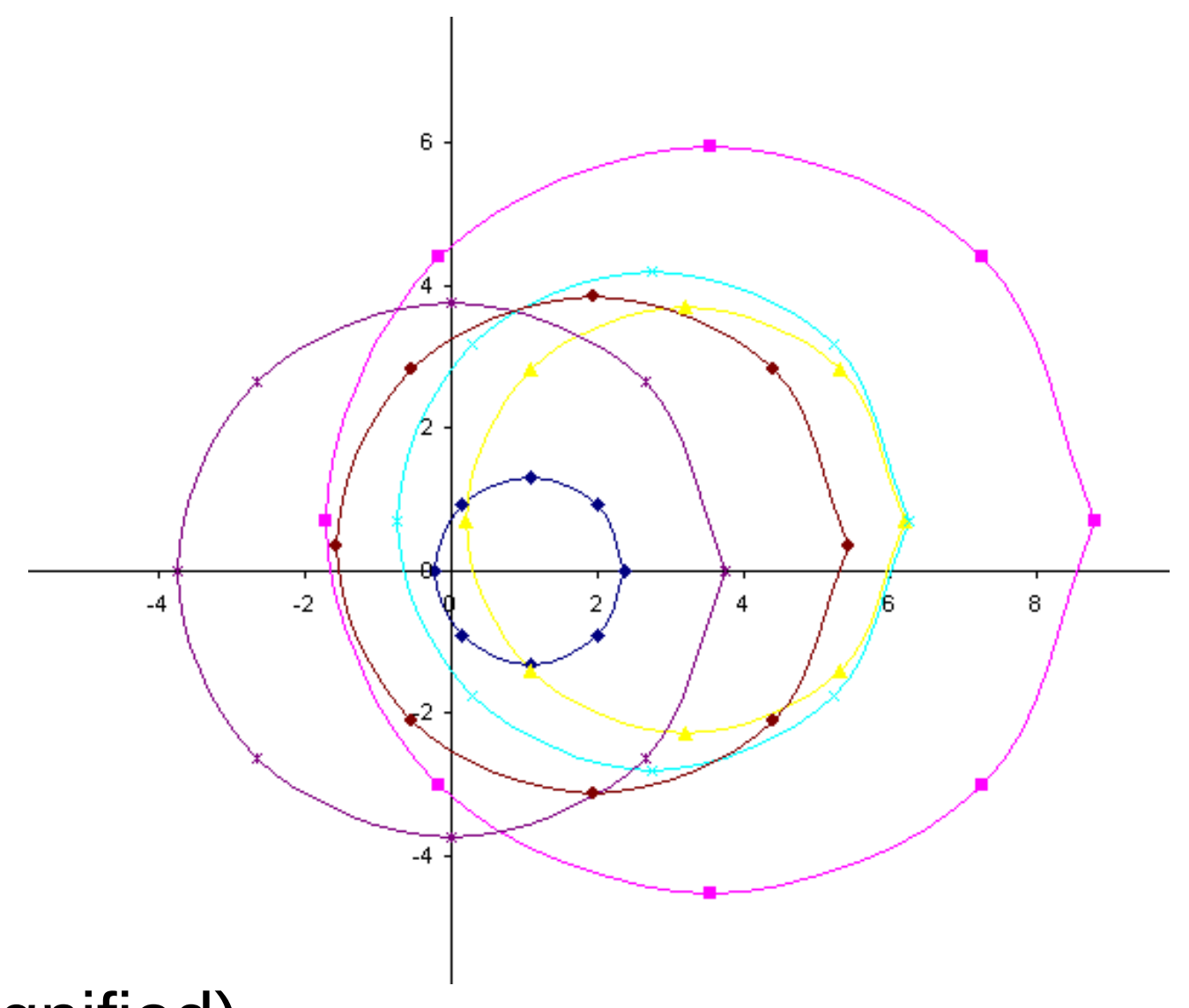
A lens assembly, bisected. Note the complicated lens arrangement within. Most if not all of these lenses move independently. This is extremely difficult to model but easy to approximate if generalizations are made. Generalizations are the heart of experimental physics.

In our lab experiments, we must measure and record the image of a collimated beam of laser light passing through the target diamond. This is done by shining the beam into a consumer camera (the Casio Exilim EX-F1) and photographing the results. In order to properly interpret the information, it is necessary to understand the effects of the lenses on the image; the lenses will necessarily change the size of the image, as well as trimming it. To understand the precise effects of the lenses is incredibly difficult because we have no way to directly measure the camera and acquire most of the information that we need. The lens assembly on the Exilim EX-F1 cannot be removed, so we cannot replace it with a custom- built lens assembly of known dimensions. All we can measure are a limited number of lengths, and we know the ranges of F-numbers and focal lengths. In order to solve this problem, a number of significant approximations and generalizations must be made.

While the actual lens assembly contains twelve lenses, our approximation has only four, and unlike the actual assembly, our approximation contains only perfect, idealized spherical lenses. This is a typical thing to do in research- it is standard practice to use generalized equipment and neglect all sources of error in initial calculations. The error is factored back in once the base math has been completed. Our approximations would certainly affect our final results, but most likely not enough to severely skew our results.

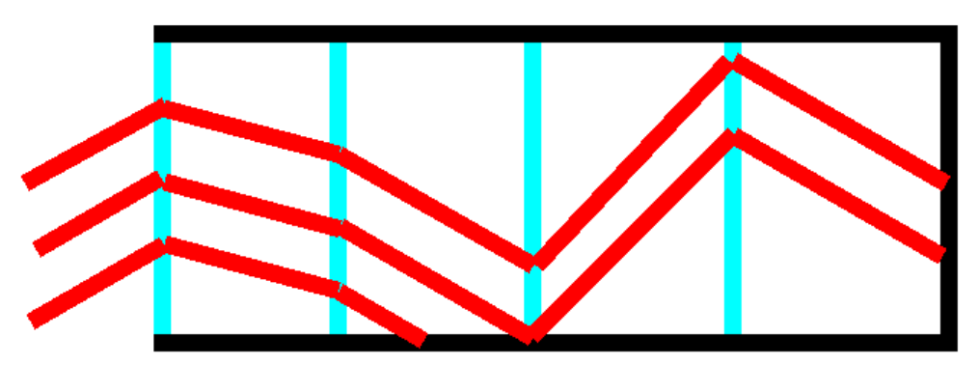
Hecht E: *Optics*, 4th ed. (Addison-Wesley, Reading, Mass., 2002)
The GlueX Experiment, WWW Document, (http://gluex.org)



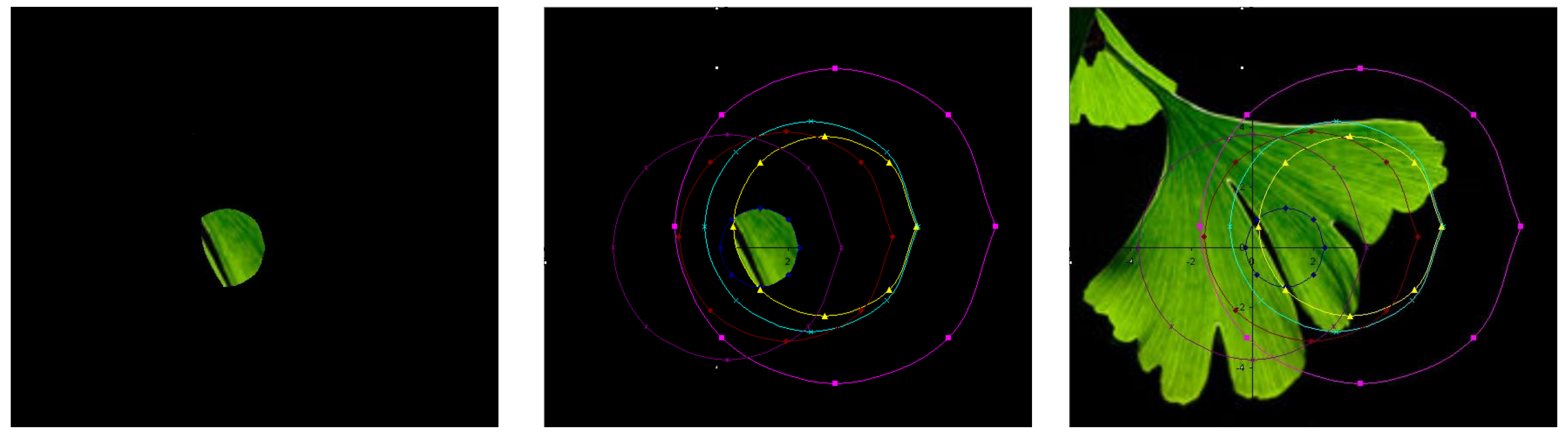


Above left: An image of light rays passing through the camera lenses, as seen from the side. This research aims to reconstruct the object (left) from the image (right).
Above right: An image of the camera lenses in the 3D model, from the perspective of the image. Notice that the lenses are not centered or aligned; this is because the rays entering the lens have a nonzero offset and entry angle.

The original model, seen here on the left, projected a one-dimensional image through a two-dimensional lens. The image is clearly shrunken and inverted. However, should the light enter at an angle, the beams could be cut off, as shown below, which would truncate the image. This two-dimensional model was used as a basis for the three-dimensional model, which projects a two-dimensional image through a three-dimensional camera. The results of this are shown above.



Left: Light paths colliding with the walls of the camera. In this case, the image is not inverted. More importantly, the bottom half of the image is cut off. With our equations, this can be reconstructed.



This is one possible image captured by the camera (right). Obviously, this image is severely cropped. For our research, it is necessary to reconstruct the original object. Using the lens diagram generated by our equations, we can calculate what parts of the object were trimmed. (center). This diagram displays the outlines of the camera lenses, as seen by the sensor and reconstructed by our model. Notice that the lenses do not align- this is because the light from the leaf is entering them at both an offset and an angle, both of which are known. Also notice that the leaf is only visible when contained within the perimeters of all the lenses. From this image and our known data, and with the orientation of the lenses known, the original object can be reconstructed (right).

Conclusions:

Appropriately enough, this research explains things in reverse. By receiving a cut image and analyzing the lenses through which it passed, the original object can be identified. This object can be retraced through the interferometer and broken into its three main component parts, and by this the structure of the target diamond can be confirmed. With the diamond analyzed, it can be used in the particle accelerator and make the GlueX experiment a success.

Above: An image of light rays passing through the camera lenses, as seen from the side. This research aims to reconstruct the object (left) from the image (right).

This is one possible image captured by the camera (right). Obviously, this image is severely cropped. For our research, it is necessary to reconstruct the original object. Using the lens diagram generated by our equations (far left), we can calculate what parts of the object were trimmed. (right center). This diagram displays the outlines of the camera lenses, as seen by the sensor and reconstructed by our model. Notice that the lenses do not align- this is because the light from the leaf is entering them at both an offset and an angle, both of which are known. Also notice that the leaf is only visible when contained within the perimeters of all the lenses. From this image and our known data, and with the orientation of the lenses known, the original object can be reconstructed (far right).

Our research, the GlueX experiment, intends to analyze the structure of the class of subatomic particles called hadrons. These particles, whose members include the protons and neutrons that compose matter, are made of quarks and gluons. The quarks are held together by the strong nuclear force, which is generated by the gluons. Hadrons are further divided into two classes, baryons and mesons. Baryons are composed of three quarks, while mesons are composed of two. Because mesons are simpler particles, it is them that our research studies.
The GlueX experiment intends to create mesons with gluonic excitation by colliding protons and photons. This is done by passing a high-energy electron beam, generated by the Department of Energy's Thomas Jefferson National Accelerator Facility, through a thin diamond wafer. This wafer must be precisely shaped, and this shape must be precisely measured. The measurements are found by use of a laser interferometer.

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This leads to a significant problem: How can we analyze the structure of something we cannot access? We contacted Casio, but the company was unwilling to divulge any detailed information about the lens assembly. Actually dismantling the lens assembly is out of the question, as it would permanently damage the apparatus. Acquiring a second camera to dismantle would be prohibitively expensive. Instead, we chose to geometrically approximate the light paths through the lens apparatus and compare these results with data we were able to acquire. This would prove difficult, but it would also prove to be a generally successful approximation.

By representing the lens assembly numerically, we will be able to calculate the effects of the lens experimentally. This would be done by taking photographs of the light beam and comparing the magnification of the final image with the size of the initial object. These values could be plugged into an Excel spreadsheet, and various values for the spacing of the lenses and their focal lengths could be entered appropriately. In addition, the few known and measurable values could be added as well.