Experimentally Determining Sources of Error in Reproducibility Measurements for DVCS

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BACKGROUND

DVCS, or Deeply Virtual Compton Scattering, is an experiment in which a 6 GeV electron beam impinges a liquid hydrogen target. When electrons come into contract with the target, the beam will emit an electron, a proton, and a photon. The scattered electron will be detected by a high resolution spectrometer, and the proton will be absorbed by a plastic scintillator. The emitted photon will be detected by a calorimeter composed of lead fluoride crystals.

While the experiment is in progress, the PbF2 crystals are exposed to massive amounts of radiation. After the lead fluoride blocks are exposed to this radiation for a length of time, their molecular crystal structure will become damaged, causing the block to become cloudy. This makes the transmission of the block decrease over time, as light will not be able to easily pass through and will be absorbed by the blocks. Our ability to measure the photons entering the calorimeter will decrease dramatically. In an attempt to cure the blocks of radiation damage we expose them to a blue light that will restore their molecular structure and improve the transparency of the blocks.

I.) Stability and Reproducibility Measurement

Before attributing any transparency changes to the blue light, we need to ensure that taking transmission measurements will be stable after moving the blocks on and off the holder. It is important that any significant improvements in transmission can be attributed to the exposure of the blue light. We want to prove that consistent measurements of transmission are possible to reproduce. Additionally, we want to calculate the error in the relative transmission of the blocks in order to analyze specific sources of error in an attempt to make our measurements more accurate.

II.)Minor Misalignment Measurements

In our transmission measurements, the DT-MINI-2-GS uses deuterium and halogen gases to emit light through a fiber cable. Because the field of view of the fiber is 25.4 degrees, the light will create a cone-shape as it leaves the cable and travels through air. This means that in relation to the central ray which will have no angle when leaving the fiber, the outermost rays will have an angle of $\pm$ 12.7 degrees. Light traveling from one medium to another with an incident angle will be deflected as described by Snell's law. In the case of the lead fluoride blocks with a refractive index of 1.82, light traveling with an incident angle will be deflected when the light beam travels from the air to the block, and then again from the block to the air.

A concern involving the transmission measurements is the orientation of the blocks and the fiber. Because there is a possibility for the block or fiber holder to move a few degrees in relation to one another, we were concerned that light may be deflected from the receiving fiber enough to drastically change the measurement of the spectra. We needed to determine if very slight angles of the fiber holder or lead fluoride blocks could be a major cause of the error in our stability measurements. The magnitude of the changes in the beam path due to the position of the blocks and holder needed to be determined.

PROCEDURE

I.) Determining Error in Data Collecting

In total, eight separate lead fluoride blocks were measured. During the day I took two sets of measurements for each block. One was in the morning and one was in the afternoon. Between the measurements I removed each block from the support and put it away. This assures that removing and replacing the block have no affect on the reproducibility of the data.

For each individual block, I took a total of seven separate measurements during data collecting. After placing a block on the holder, I first saved the spectrum with the shutter on the light source closed in order to find the signal produced by the background. The background consists of a combination of elements, such as noise in the optical high resolution spectrometer and light entering the fiber cable from the room. The value of the background must be subtracted from the lamp and signal measurements as they are not associated with the transmission percentage we are calculating. For the second measurement I opened the shutter to allow light to travel directly into the optic fiber without going through the block. This gives the signal of the lamp with no light being absorbed. All relative counts will be based on this spectrum. The next four measurements allow the light to pass through the block at four designated positions along the crystal. These positions are marked clearly on the support block. To do this I simply slide the fiber holder along the block and save the data at the appropriate locations. For the last set of data, I remove the block from the path of the light and remeasure the signal of the lamp directly to ensure that the lamp intensity is stable.

After completing the above procedure, I removed the block and put it away, replacing it with a new block. I repeated this until all blocks were accurately measured. This was repeated for three days, allowing the blocks to be moved on and off the support and to be measured at different times during the day. For most of the lead fluoride blocks, a total of 4 sets of data were taken at each position on the block, but for blocks 120, 18, and 55, five measurements were completed.

II.)Measuring the Effect of Small Angles In System

To measure the effect, we needed to simulate the misalignment of the light rays and fiber cables by intentionally placing the fiber holder at a slight angle. We then rotated the fiber holder about 2.5 degrees around its center and measured the effect on the path of the light beam. By drawing a diagram, an accurate calculation of how the light behaves can be completed. For the circumstance when the fiber holder is perpendicular to the crystal, the calculation was relatively simple with standard geometry. However, the mathematics became complicated in the case with the angled fiber holder, and the precise locations of the intersection of the three beams and the receiving plane were left undetermined. Rather than struggling to continually complete calculations by hand for numerous individual angles, I created an program that completes calculations based on the original angle of the fiber holder.

DATA ANALYSIS

I.) Normalizing Transmission to Calculate Stability Error

After recording the transmissions I calculated the average transmission of each particular position for all three days. With that, the normalized values for the positions on each block are determined by dividing the individual transmissions by their respective averages. The normalized values will be centered around one for all measurements. This allows measurements of all blocks at all positions to be easily correlated. The total average and standard deviation of the normalized transmission measurements can then be calculated. All normalized values can be represented visually in a histogram.

II.) Analyzing Effect of Angles with Software

The file uses a standard coordinate plane in which the entrance face of the block is at -1.5 cm and the exit face of the block is at 1.5 cm. The program describes the behavior of the central ray emitted by the fiber, as well as the two outermost rays. The equations of the individual rays as they travel from one fiber to the other are computed, allowing precise intersection coordinates to be determined. The coordinates of where the light enters and exits the block are given, as well at the intersection of the rays and the plane of the receiving fiber. By knowing these exact coordinates, we can compute the diameter of the laser that is projected on the plane of the receiving fiber. This distance is defined at *d*. Additionally, we can measure the distance that the central ray is deflected from the middle of the receiving fiber, defined as *s*. This information can be used to determine the magnitude of effects produced by slight misalignments between the blocks and the fibers.

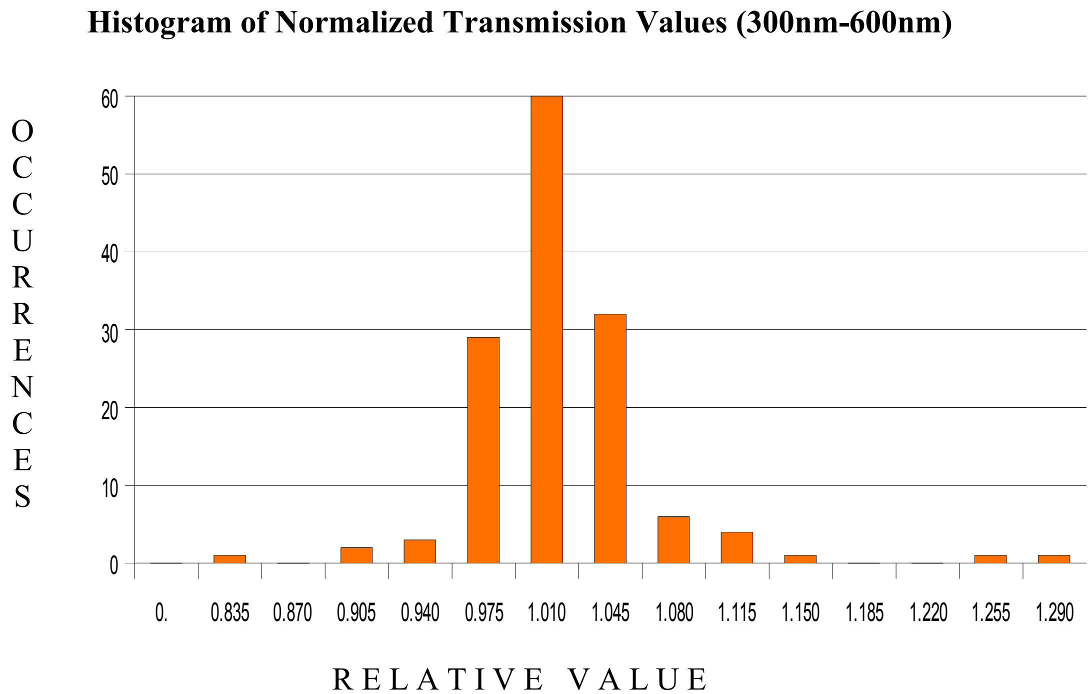
RESULTS

I.) Calculated Error

Results were completed over the wavelength range of 300 nanometers to 600 nanometers. After mathematically determining the average normalized value and standard deviation, we concluded that the average was approximately 0.999 with a standard deviation of 0.050, as shown in Figure 1.

FIGURE 1:

This graph shows the relationship between the normalized transmission measurements and the number of occurrences. The histogram is centered around 1.00 since each individual measurement was divided by the average.



The histogram clearly represents all normalized measurements taken over the course of three days. It is apparent that the histogram is evenly distributed around the average value of one.

In addition to taking the general measurement over the entire range (300nm-600nm) of wavelengths, I broke the spectrum in half. This gave all of the same calculations over a smaller range. The two sets of data were analyzed from 300nm-450nm, and 450nm-600nm.

From 300nm-450nm, the average transmission was 1.003 with a standard deviation of 0.053. From 450nm-600nm, the average transmission was 0.997 with a standard deviation of 0.052. Both of these outcomes show that the overall measurement from 300nm-600nm is consistent even when examined in smaller increments.

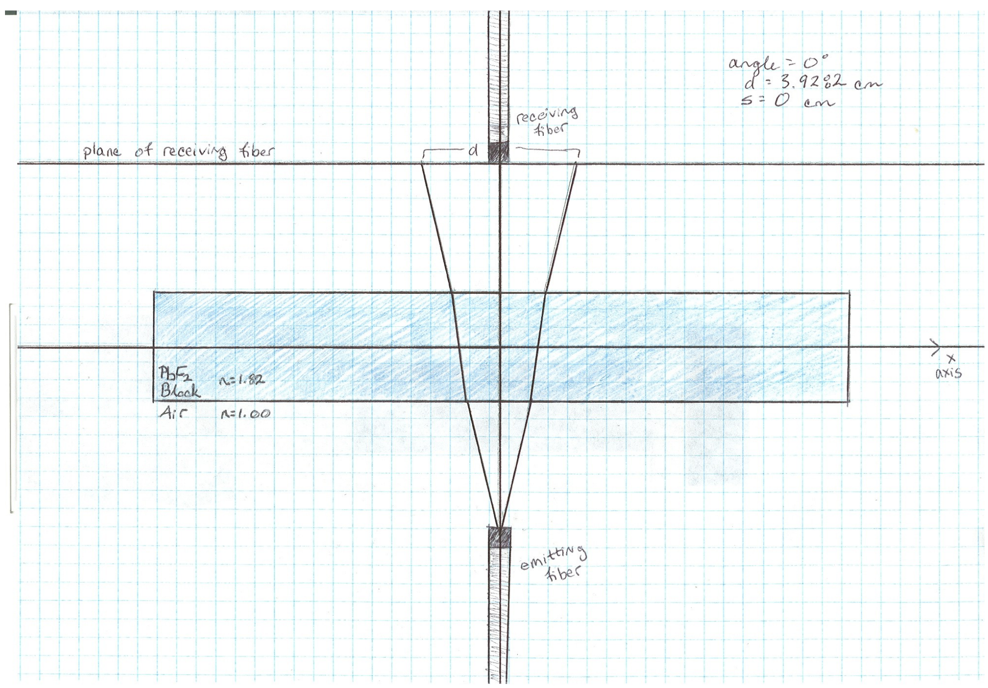
The percent error for reproducibility measurements is 5%.

II.) Angle as a Source of Error

In the program, we first calculated the path of light as with the holder perpendicular to the crystal. In this measurement, *d,* the diameter of light on the receiving plane, is 3.928 cm. Because the central ray has no incident angle the light is not deflected. This means that the distance between the central ray and the middle of the receiving fiber is 0 cm, as shown in Figure 2. The outermost rays will have an incident angle of ± 12.7 degrees, which is half of the field of view for the fibers. These rays will be slightly deflected when traveling from one medium to another. The crystal acts as a thick lens and focuses the light. Figure 2 shows the path of the three light rays.

FIGURE 2:

This is a drawing that displayed the effect of the PbF2 crystal acting as a thick lens. The light rays are slightly deflected when it enters and exits the block. Due to the deflection of the light as it changes mediums, the light is focused and diameter *d* is 3.928 cm. The measurement of *s* is 0 cm because the central ray is not deflected.

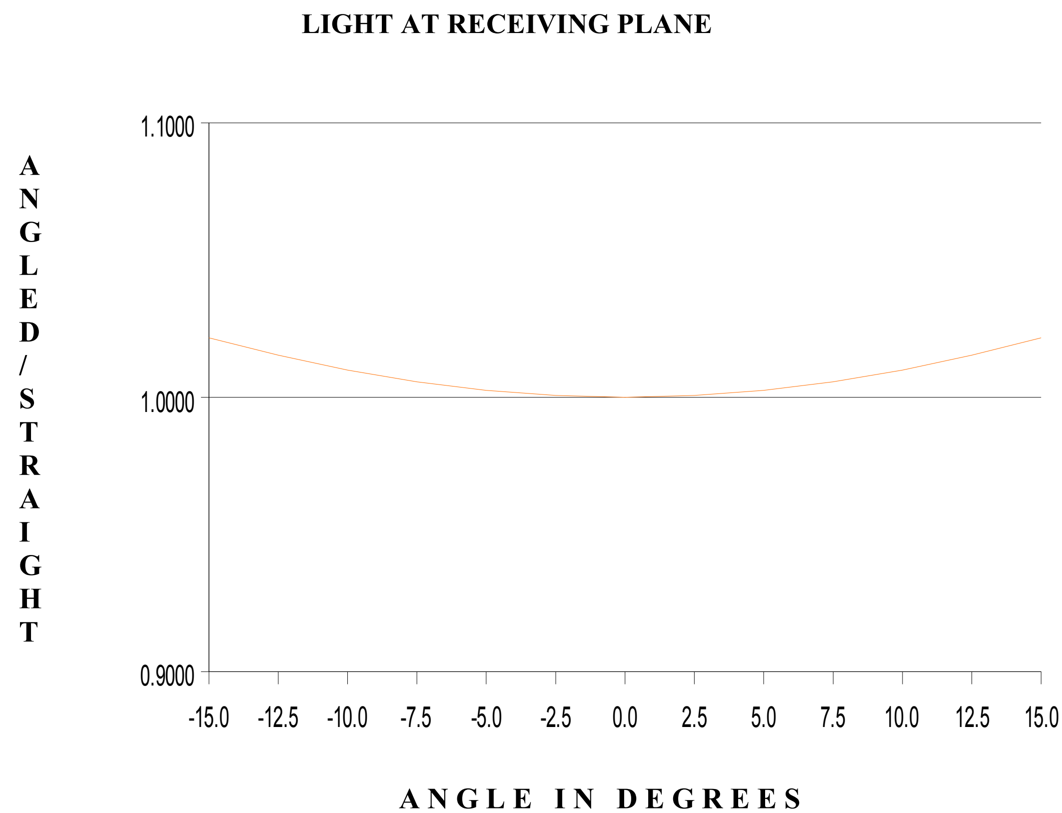


Using the program, we computed *d* and *s* with a beginning angle of 2.5 degrees. When the fiber holder is angled so that the incident angles are altered by 2.5 degrees, *d* is equal to 3.9294 cm. Therefore *d* only has a change of 12 micrometers. With the same angle, *s* is calculated to be only about half of a millimeter.

Although the path of the light changes with a 2.5 degree angle, it is too small to accurately show in a drawing. To describe the behavior of the light with an angled fiber holder, we increased the incident angle to 15 degrees. As with the smaller angle, the positive and negative angles will give results that are mirrored images of each other. To demonstrate this property of Snell's law, Figure 2 shows the relationship between the diameter of light projected on the receiving plane and the incident angle. The graph is perfectly symmetrical, showing that the sign of the incident angle has no effect on *d.*

FIGURE 3:

This figure shows the relationship between the size of the diameter of light and the angle at which the fiber holder is placed. The y axis is the diameter of light at the associated angle divided by the diameter of light with no angle. The graph shows that the diameter of the laser is symmetrical, regardless of which direction the fiber holder is rotated.

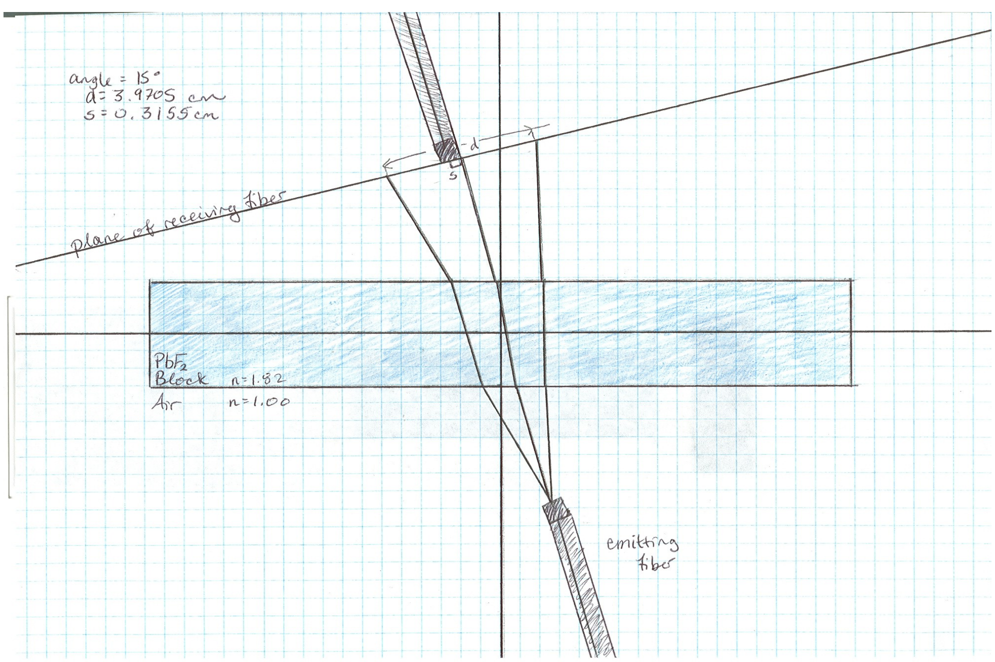


The y axis on the above chart does not directly represent *d* at the associated angles. It is a ratio of the *d* in the angled cases divided by the *d* in the perpendicular case.

Although only minor misalignments can occur in our equipment setup, we used to program to measure the light effect on all angles. Additionally, the drawings would have observable effects. When running the program, the case of 15 degrees which is entirely too big of an angle to exist in our experiment, *d* is still only 3.905 cm. This is a change of less than half a millimeter. The measurement of *s* is 3.2 millimeters, as shown in Figure 4. It is obvious that the incident angle causes the light to change paths, however, the effect on *d* and *s* are not as significant as we expected.

FIGURE 4:

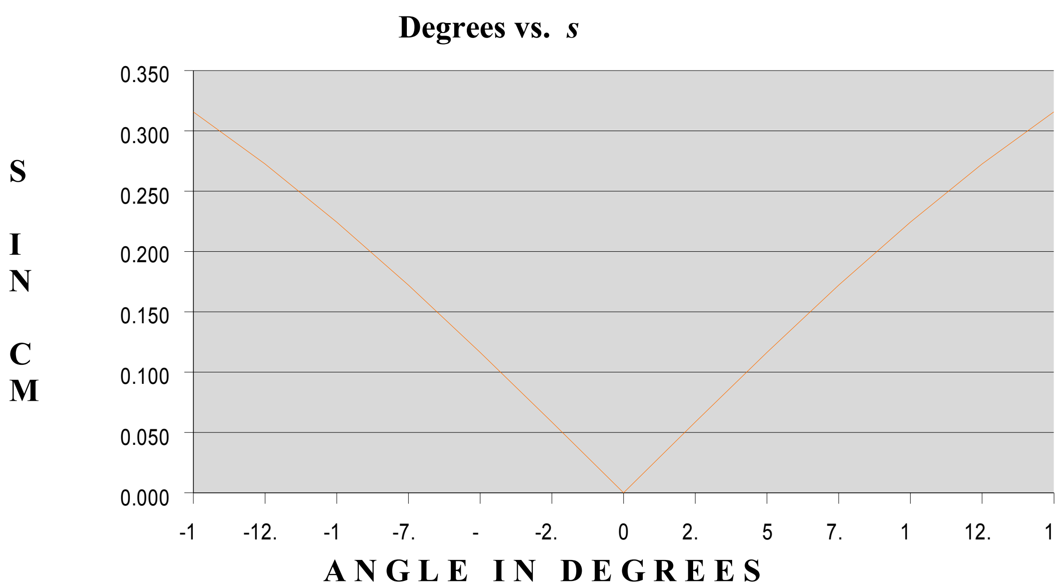
This drawing represents the paths of the light traveling through the block. Because all of the rays are initially at an angle, they will all be deflected according to Snell's law. The receiving plane now has a slope so that it is orthogonal to the emitting and receiving cables. A small but noticeable displacement in the coordinate of the receiving plane and the emitted laser can be seen.



The intensity of the light emitted from the fiber is not uniform for the whole area that is projected on the receiving plane. The central ray has the highest intensity of the light, and as the rays become more diverged from the central ray they become dimmer. Even though *d* changes less than a millimeter when the angle is relatively large, the most import aspect of taking precise transmission measurements depends on the direction of the central ray. For the spectra to be measured correctly, the central ray should be intercepted by the receiving fiber. This means that *s* in relation to the angle of the fiber holder is important. Figure 5 shows the distance that the central beam is deflected from the middle of the receiving fiber.

FIGURE 5:

This figure shows the change in the position of the central ray, where the emitted light is the brightest. The x axis is in degrees and the y axis is in centimeters. This graph demonstrates that the sign of the angle is arbitrary in the measurement of *s*.



The small misalignments that may occur in our setup are not causing the light to be significantly deflected. Our original prediction that perhaps the position of *d* was shifting enough to not be intercepted by the fiber is not correct. The position of *d* changes slightly, even at larger angles. Therefore, the small angles created by the placement of the holder and crystals are not changing the position of *d* enough to see variances of the transmission. Also, the central ray, where light is the brightest, is not changing direction enough to contribute significantly to our 5% error. With the block at larger angles, such as 15 degrees, a few millimeter would noticeably change the spectra. But angles created in our experiment are less than half a millimeter. Although the central ray may shift, an angle less than 5 degrees should have a negligible effect on the transmission of light through the block with the the fibers are correctly aligned.

CONCLUSION

By examining the traits of the transmission measurements, we see that individual sets of data may slightly drift when moving the block on and off the holder. However, all of the variances of the measurements are statistically distributed around one. This histogram shows that although a few sets of data are beyond the calculated value of the standard deviation, the transmission is stable regardless of the removing and replacing of the lead fluoride blocks.

Because the error is measured to be approximately 5.0%, we can conclude that any dramatic increase in transmission will be attributed to the curing by exposure to blue light.

Additionally, the program used to compute all of the data shows that having the block and fibers perfectly perpendicular is not a necessity in achieving fairly accurate transmission measurements. Even with angles larger than possible with our experimental setup, the variation of *s* and *d* are too small to account for a majority of our 5% error.

All of these calculations were completed with the assumption that the fiber holder was steady enough to keep the cables level. It is clear that the cables are extremely sensitive to misalignments. Even one cable being offset by a minuscule distance can cause the emitted light of the central ray to miss the receiving cable. This will drastically changed the measured transmission, causing the spectra to be inaccurate. Tests need to be completed that will determine the reliability of the fiber holder and its sensitivity to being moved.

Additionally, because the paths of light enter the block at an angle, reflection occurs at the faces of the block. Transmission is only a part of the total light traveling through the crystal. Light is lost through absorption, but light is also lost in reflection. More light will be reflected if the light hits the faces of the block at an angle. Some of the light will be reflected outside and within the block. Some transmission error may be the cause of this principle.

Our 5% error is not a result of the change in path of the light through the crystal.