Vibration characteristics of simulated diamond wafer

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Abstract

All atoms are made up of protons and neutrons, which are in turn comprised of quarks. The particles "gluing" the quarks together are known as gluons. The interaction of quarks and gluons is still not entirely understood, specifically how they are confined in the nucleus such that lone quarks are never seen. The nuclear physics group at the University of Connecticut is part of the GlueX Experiment, which hopes to probe directly the gluon bond and understand its mechanical properties. The probe used by GlueX is a high energy (small wavelength), polarized photon (particle of light) generated by a technique known as coherent bremsstrahlung . This technique involves radiation of photons as a high energy electron beam passes through a carefully oriented diamond wafer. Because of the potential for contamination, it is necessary to suspend the diamond wafer rather than mount on a ridged mount. The diamond is currently suspended on thin tungsten wires. Proper orientation ensures a high degree of polarization, which requires stable mounting of the diamond. The goal of my research is to investigate the mechanical properties of the mount and eliminate the possibility of vibration of the crystal.

Looking at the "glue"

Unlike quarks, gluons are charge-neutral, meaning that they can not be detected using conventional microscopes, such as the widely-used electron microscope. To image the gluons binding quarks, a different kind of technique must be used in which researchers attempt to excite the gluon fields and make them resonate.

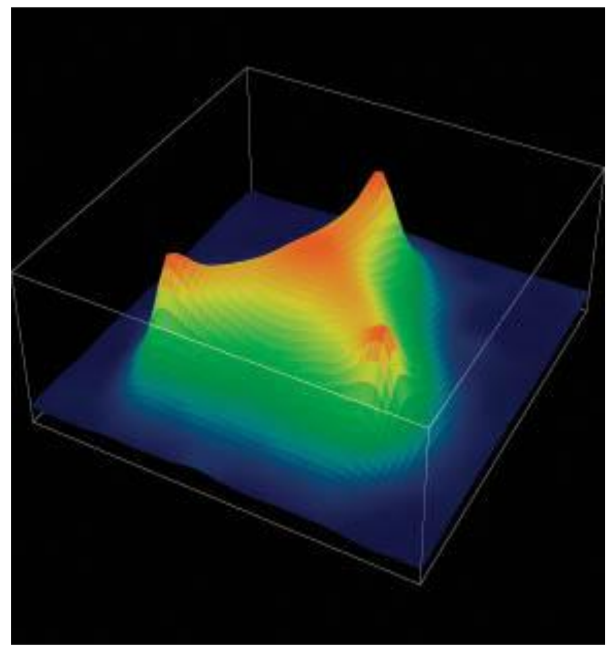

Fig. 1 Structure of gluon field in the proton, a three-quark flux-tube formation

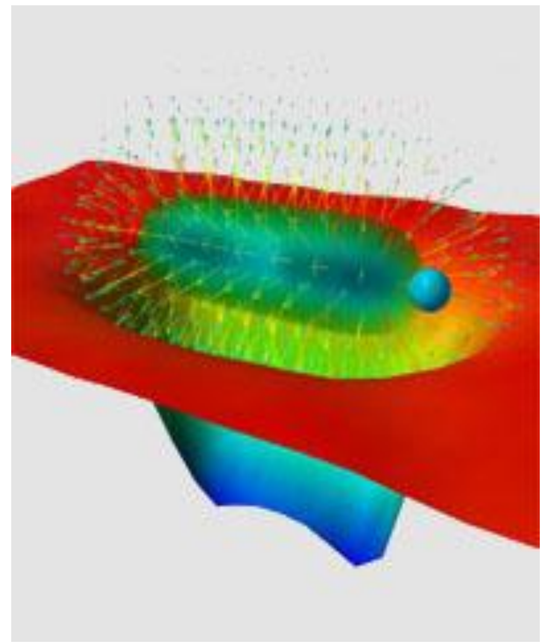

Fig. 2 Lattice QCD image of flux tube separating quarks in a meson

Figure 1 shows an image of the structure of the gluon field inside a proton, generated by a computer model, where the quarks appear on the ends of three arms known as "flux tubes." The aim of the GlueX experiment is to test the validity of this picture in a somewhat simpler configuration of only two quarks and one flux tube, shown in figure 2. Researchers hypothesize that the gluon field could be made to vibrate like a guitar string, by exciting it using a beam of light of a very short wavelength. Observation of gluonic resonances will be a major breakthrough in nuclear physics and open the door to a deeper understanding of confinement.

The Problem

The purpose of the GlueX experiment is to investigate one of the fundamental challenges in physics: how quarks are confined in the nucleus. To do this, we will use high-energy photons to excite the gluonic bond between the quarks. These photons are produced when high-energy electrons collide with the atoms in a diamond crystal lattice. These high-energy electrons are produced in a linear accelerator located at the Thomas Jefferson National Accelerator Facility in Newport News, Virginia where the GlueX experiment is located. Once a high-energy electron has emitted some of its energy in the form of a photon, the electron continues on with reduced energy and is deflected in a magnet through an angle that depends on how much energy it has left. If it produces a photon with enough energy to be useful to the experiment, it is deflected into a special detector known as a "tagger" which sends an electronic signal to the detector telling it to watch for the ensuing collision. Bremsstrahlung will occur when electrons interact with any matter. Since we want only those photons which come from the diamond wafer, we require a mount with as little material in contact with the wafer as possible. It is necessary to suspend the diamond from wires to reducing the potential contamination due to the mounting material. Because of the very small divergence of the photon beam, the vibration response of this mount is of particular interest Currently, the diamond mount has too high of a vibration amplitude, leading to a decrease in the number of useful (proper energy) photons. It is the goal of this research to find ways to reduce or eliminate this vibration.

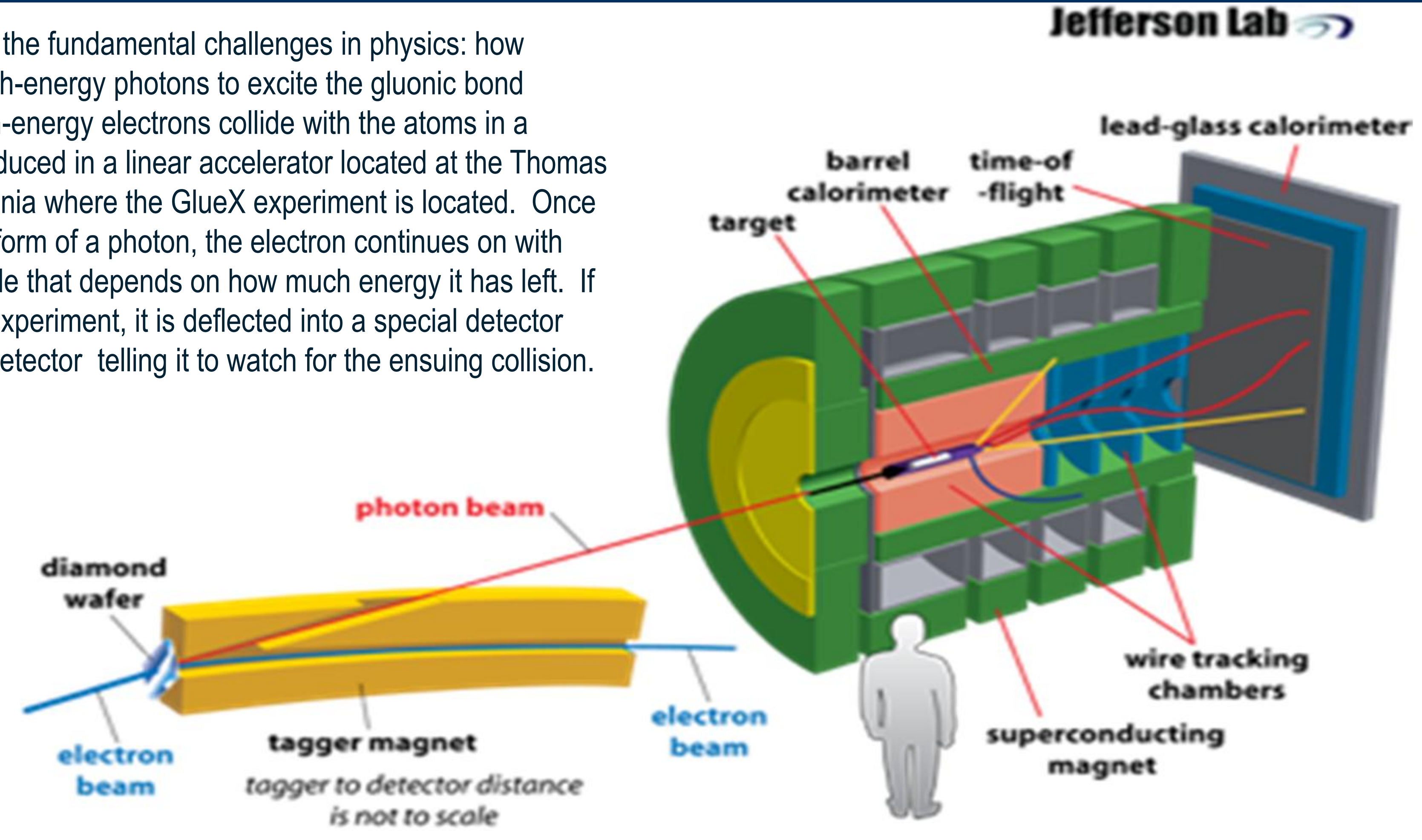

Fig. 3. Images of the beam line and apparatus for the GlueX experiment

Method

To the right is an image of the imaging device used to detect motion of the diamond surface. For this experiment, a "simulated" diamond(glass) is used. Once the characteristics of the glass are known, they can be re-scaled to fit the true diamond. The wires were carefully strung using 5 gram weights, ensuring that the tensions on each wire were equal To measure the vibration of the diamond wafer, a high speed imaging technique is used. The surface of the wafer(Fig 4. (1)) is illuminated with a green laser Fig 4 (2)). Reflected light (is redirected to an imaging device, taking advantage of the long path length of the beam to amplify the motion. The imaging device which is used in this experiment is a Casio EX-F1 consumer camera (Fig 4. (3)) The beam spot entering the lens of the camera creates an artifact known as a "lens flare". As the crystal rocks, the position of this artifact changes relative to a fixed reference point. This change is recorded using the camera's high speed (1200 frames per second) video mode. The videos are processed by programs that identify and record the spot locations as it evolves in time. This information is used to determine the angular displacement of the crystal surface about both the x and y axis. Using techniques of Fourier Analysis, the frequencies of the vibration can also be determined from the position data. To the left is a TurboCAD rendering of the mount which is used to hold the suspended diamond wafer. Currently, the wafer is being suspended from tungsten wires, and the diamond is mounted to the wires using an acrylic glue.

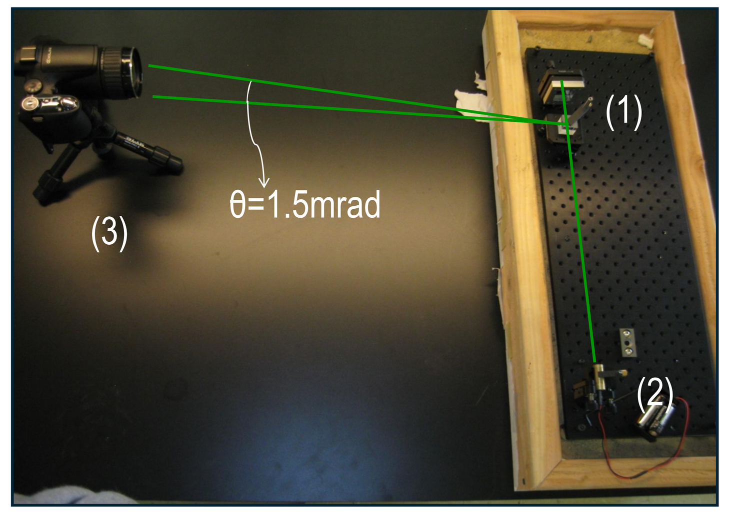

Fig. 4 Photo of the imaging device showing the beam path (green)

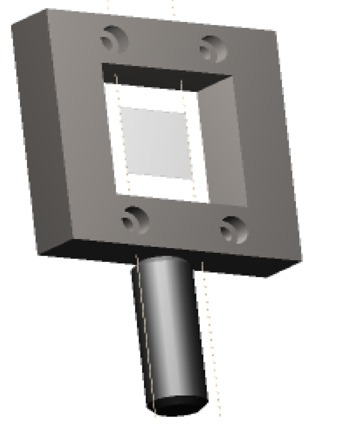

Fig. 5 TurboCAD rendering of diamond radiator mount

Results

These two graphs are the results compiled from the position versus time analysis (Fig. 6. a) and the Fourier analysis performed on the position data (Fig. 6. b). Preliminary theoretical calculations indicated that the fundamental frequency would occur at around 40 Hz. The fundamental frequency of the diamond radiator determined from testing was found to be 8.096 Hz, five times lower than originally estimated. This result is most likely due to a poor estimate for the wire tension in our original calculation.
The maximum amplitude of vibration was found to be ±1.5mrad (.086 degrees) from center. This amplitude is 150 greater than the maximum specification allowable, meaning the mount will need to be redesigned.

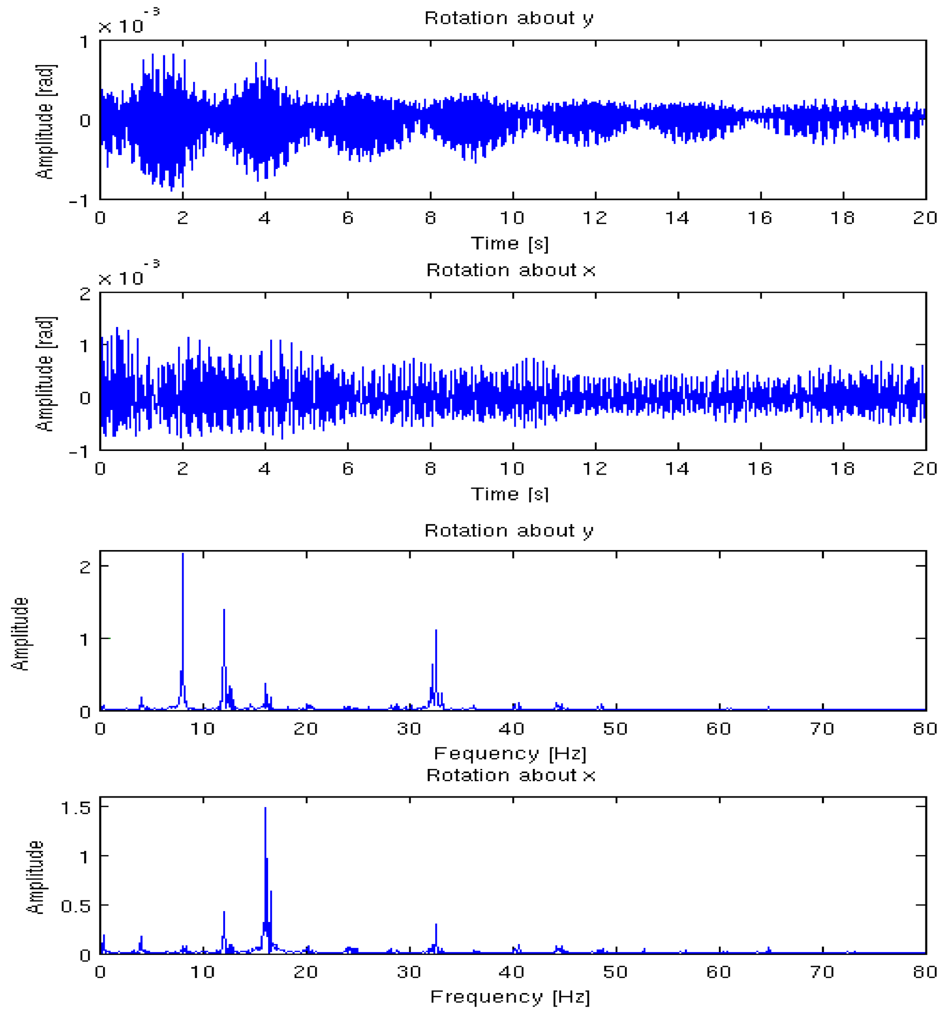

Fig. 6 Position and Fourier Transform for video of diamond vibration

Impact of vibration

This graph shows the effect of increased vibration amplitude. The solid line is the operating range spectrum for the 10microradians vibration. The dashed line is what the spectrum looks like when the amplitude is three times this specification. As you can see, there is a widening of the peak for higher vibration amplitude. Since the current mount has a vibration amplitude 150 times the required there would be a complete blurring of this peak. This is significant, since the photons which are used for the experiment are those produced at or near the peak at 9GeV. A blurred peak would lead to a decrease in the number of useful photons, and therefore a decrease in the accuracy of the GlueX experiment.

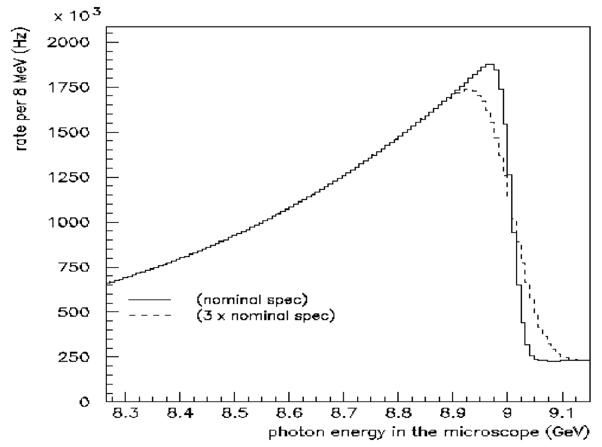

Fig. 7 Spectrum for operating range of the GlueX experiment

Ongoing work

Ultimately, the goal of this work is to produce a mount which permits diamond vibration below 10 microradians. This requires the tension on the suspension wires to be much higher than the current set-up. Because of temperature requirements during the experiment itself, tungsten wires will not be able to sustain the necessary tension. Ongoing work will examine the suitability of other materials such as 7μm diameter carbon wire. Operating temperature has less of an effect on carbon than tungsten, so the material properties of the carbon wire should be more consistent throughout the experiment. This material change presents new challenges, including how to mount the diamond to the wire.

Because of the low amplitude of vibration and low resolution of the camera, direct imaging of the rotation may not be possible for higher frequencies. In this case, a technique known as interferometry will be used to determine the frequency and amplitude of vibration. This technique uses the principle of interference to detect small changes in the position of the reflected beam spot. We are attempting to create a mount which has 150 times less vibration amplitude than the current set-up.

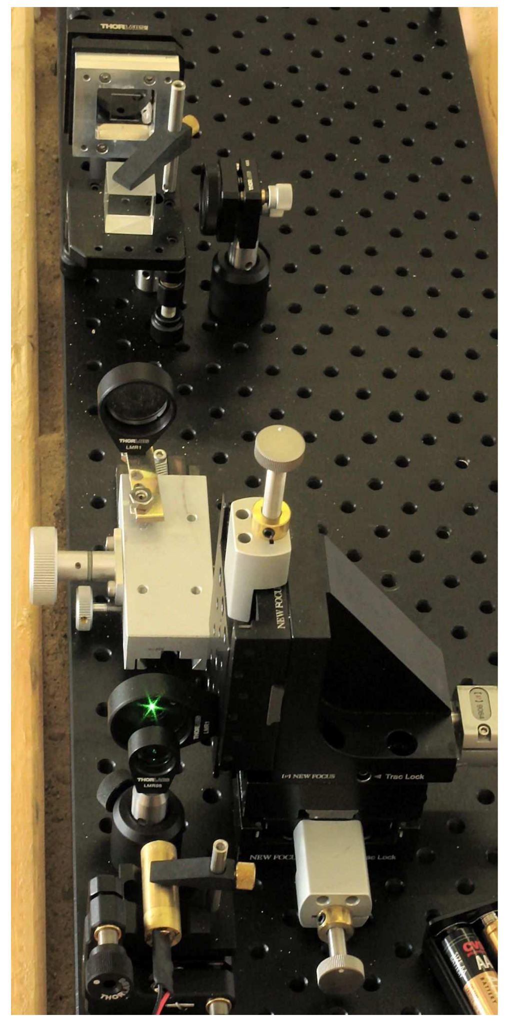

Fig. 8. Michelson Interferometer which will be used to determine the vibration frequency and amplitude for higher frequency mounts

Citations

[1] *The GlueX Experiment*, WWW Document, (http://www.gluex.org).

[2] Senderovich, Igor., *Diamond Radiator Thinning and Mounting*., (http://www.jlab.org/Hall-D/software/wiki/index.php/GlueX-Collaboration-Meetings).

[3] H. Ichie, V. Bornyakov, T. Streuer and G. Schierholz, *Color Confinement and Hadrons in Quantum Chromodynamics*., (http://www.th.phys.titech.ac.jp/~conf2003/main.html).