Technical Proposal

A UV Laser Setup for Thinning Radiator Diamonds for GlueX

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August 10, 2009

Executive Summary

The GlueX experiment at Jefferson lab is a driving motivation for the CEBAF 12 GeV upgrade. The experiment uses a 9 GeV polarized photon beam to produce excited mesons whose spectrum is expected to reveal important new information about the way that the strong force binds quarks inside hadrons and nuclei. The polarized photon beam is produced when the 12 GeV electron beam passes through an oriented diamond crystal radiator and undergoes coherent bremsstrahlung. To meet the requirements for GlueX, the diamond radiator must be sliced as thin as possible from a large single crystal (several hundred microns is achievable) and then thinned down to a thickness of 20 microns. Element Six, the world leader in production of high-quality synthetic diamonds has demonstrated ability to thin these diamonds down to about 50 microns, but below that they claim that the lapping method that they use is unreliable. However, within the last two years the Instrumentation Group at BNL has demonstrated a laser ablation technique for thinning these diamonds that is capable of achieving the 20 micron thickness required for GlueX. The PI has met with the BNL group and discussed with them what would be required to replicate the BNL setup at UConn. This proposal requests funds to refurbish an existing excimer laser setup within the Physics Department at UConn, and equip it with optics and control system for laser ablation of diamond radiators.

Introduction

The GlueX experiment is a primary scientific motivation for the upgrade of the CEBAF electron accelerator at Jefferson Lab from 6 to 12 GeV. The purpose of the GlueX experiment is to reveal the role played by gluonic degrees of freedom in hadrons by discovering and mapping the spectrum of excited mesons with exotic (non-qq) quantum numbers. To accomplish this, the experiment requires the generation of an intense beam of linearly polarized 9 GeV photons, which are produced by coherent bremsstrahlung of 12 GeV electrons in a diamond radiator. Optimal performance of this source requires a supply of very thin diamonds with near-perfect crystalline quality. The basic technique is the same as that used by the existing coherent bremsstrahlung source in Hall B and elsewhere, but its extension to higher energies places tighter limits on the maximum allowable thickness of the diamond, and also on its mosaic spread.

The mosaic spread of a diamond describes the deviation of a monocrystal from perfect planarity of its crystal lattice. As the energy scale increases in the coherent bremsstrahlung process, all of the angles are more forward-focused and the effects of misalignment in both the beam and crystal lattice vectors become exaggerated. The characteristic scale for this sensitivity is set by the characteristic bremsstrahlung angle *m/E* where *m* is the electron mass and *E* is the electron beam energy. At 12 GeV this corresponds to about 40 μr. Synthetic diamonds with mosaic spreads at this level and somewhat better, as determined using X-ray diffraction measurements, have been obtained for use in the Hall B source. Recently the P.I. and other members of the GlueX photon beam group have tested a sample of a new so-called type-III synthetic CVD diamond from the diamond specialty firm Element Six which and measured its whole-crystal X-ray mosaic spread to be less than 20 μr. These measurements, which the P.I. and collaborators pioneered at the CHESS synchrotron source at CESR, represent a major step forward in the technology for mapping the mosaic structure of large-area diamonds. These techniques will be described in more detail in the following section on evaluation.

The 40 μr alignment scale mentioned above applies not to the crystal alone, but to the angle between the beam direction and the crystal planes. Fortunately, the upgraded CEBAF machine is capable of producing a 12 GeV beam with an angular divergence much less than this, so the only remaining concern is multiple scattering. To keep multiple-scattering effects at the level of 20 mr, it is necessary to limit the thickness of the diamond crystal to about 20 microns.

Technology for Thinning Diamonds

The high-quality synthetic monocrystals that are available from vendors are grown as large three-dimensional crystals from which slices are cut using a diamond saw. Once they are sliced off, the manufacturer polishes the slices to remove the damaged surface from the saw cuts, and they are sold as planar wafers typically a few mm on a side and a few hundred microns thick. If desired, the Element Six has the capability to continue the polishing process until the diamond thickness is reduced to less than 100 microns, with an ultimate limit of about 50 microns. Below this thickness, there is serious risk of breakage from the mechanical stresses of the process. Several attempts have been made, and the Hall B group was able to obtain one whole 20 micron sample, but it turned out to be badly warped and in the end proved to be unusable. The thinnest usable samples that have been produced using the well-known lapping technique have been close to 50 microns in thickness, more than a factor 2 thicker than the goal of 20 microns for GlueX.

Within the last two years, researchers at Brookhaven National Lab have been actively working on development of a diamond amplifier for use in a high-current source for an energy-recovery linac. Although the reasons are very different, this application has many of the same requirements for diamond crystal quality and thickness as GlueX. In fact, their goal is also to produce a self-supporting diamond monocrystal with an area approaching a square cm and a thickness of 20 microns. To achieve this goal, the BNL group has developed capability and techniques in-house for thinning diamonds using laser ablation. Much of this work is too new to have been published yet. The P.I. has made a series of visits to Brookhaven to speak with the diamond development group there and to see their setup. The sample is mounted in a computer-controlled *XY* translation stage which holds the diamond in a precise position with respect to the beam. The laser produces a beam of 192 nm light (excimer ArF source) which is focused using a fused silica lens down to a spot on the diamond that is approximately 200 microns x 50 microns. The power in each laser pulse is monitored using a sensor and fed back to the power supply to maintain the desired power level for ablation. The translation stage moves the sample in a raster pattern across the beam, with a step size much smaller than the beam spot in order to ensure as flat as possible a cut surface.

The BNL group has carefully optimized the parameters of the ablation procedure to minimize the roughness of the final cut surface and maximize the cutting rate. They found that the power required to attain a given cutting rate is somewhat lower for the polycrystalline samples that they first tested than for the monocrystals that they tested more recently. All of these results have been reported internally, and will eventually be published for the benefit of other groups such as GlueX.

Synergies at the University of Connecticut

There is significant experience with high-power UV lasers within the experimental groups in the Physics Department at the University of Connecticut. The Condensed Matter research group of Prof. Barry Wells operates a large KrF excimer laser for electronic studies of superconductors. Although this laser could be reconfigured to work at the shorter 192 nm wavelength, it is in active use for the on-going condensed matter research program of the lab. However, there is space and infrastructure in the lab to support a second excimer laser setup. The fluorine gas used in excimer lasers is extremely reactive, and their setup requires capability for both storage and distribution and for venting of waste gases from the laser. Prof. Wells has offered to the P.I. sufficient space in his lab and connections to his gas handling and ventilation systems for the setup presented in this proposal. There is a strong possibility that his group may wish to have access to the 192 nm beam from this setup for certain experiments that they plan to carry out in the future. This shared use of the laser makes sense, given the need by GlueX to have only intermittent access to it in order to produce new radiators as needed throughout the lifetime of the source.

For the laser itself, the Atomic and Molecular Optics research group of Prof. Ed Eyler has an excimer laser that is configured for use at the 192 nm wavelength that he is willing to provide to the P.I. on an indefinite loan basis. This laser has been used by his group in the past, but has been idle for about 10 years, as his research has not required it. The laser is still configured as it was when it was last used. Its gas connections were flushed with dry nitrogen after its last use to prevent corrosion due to long-term exposure to fluorine gas. Some degradation of the vacuum seals is expected after so long a period without use, but the primary components are expected to be in working order. Once it passes an initial checkout in its present location, it will be dismantled and moved to its new location in Prof. Wells' lab where the diamond ablation work will be carried out.

Other Funding Sources

Diamond crystals of sufficient area for use as coherent bremsstrahlung radiators are currently available from Element Six at a cost on the order of $1K apiece. Funding for a handful of these radiators is already present in the construction budget for the Hall D beam line, but there is no additional allowance for the cost of thinning them ourselves. The budget in this proposal covers only the optics and translation stage for the diamond ablation facility, together with refurbishment of the existing excimer laser and its integration with the existing infrastructure in the excimer laser lab at the University of Connecticut. JSA funding is sought for this project because the scale of JSA grants matches the project budget, and because of the immediate opportunities that exist to take advantage of synergies at the University of Connecticut.

Risk Assessment and Evaluation Plan

Installation of major instrumentation related to the photon beam in Hall D is scheduled to begin in 2011 and continue into 2013 with the commissioning of the GlueX experiment. By the time that commissioning begins, it is important that basic radiator production issues have been resolved, and that the Hall D beam group be able to devote its resources to supporting operations. It makes sense in the year 2010 to devote resources to working out radiator production methods that will guarantee a reliable supply of radiators throughout the lifetime of the GlueX experiment. A reliable source for the raw diamond material has been found in Element Six, and reliable methods for assessing the quality of individual samples using X-rays has already been demonstrated. What is missing in the procurement pipeline for diamond radiators is the capability to thin them all the way down to 20 microns from the starting thickness of 200 – 300 microns. Without this capability, the experiment risks having to run at substantially decreased beam polarization, leading to reduced power to resolve small resonant signals in the excited meson mass spectrum and to distinguish them from background.

BNL researchers have demonstrated a timely and cost-effective thinning technique based on laser ablation. They are unable to commit to providing GlueX with a diamond thinning service that can meet our needs over the long run, but in the near term they are willing to cooperate with GlueX in helping us to reproduce their capabilities. In this context, it is not likely that unforeseen technical obstacles will emerge that will prevent this technique from producing usable radiators.

Furthermore, unlike the lapping technique which can only produce radiators with nominally uniform thickness, laser ablation can be used to produce radiators with an arbitrary thickness profile. This might be exploited to produce diamonds that are thicker along the edges than in the middle, which might be more stiff and less susceptible to the kind of warping strains that ruined the usefulness of the Hall B 20 micron radiator. Thus, the use of the laser ablation thinning technique reduces the risk that a 20 micron diamond will be difficult to mount on a free-standing fixture without distorting its natural shape.

Access by the GlueX photon beam group to the X-ray beam line C at CHESS that is configured for crystal diffraction is essential to the success of this project. X-ray rocking curve measurements of the diamonds before and after thinning are the only reliable way known to determine whether the quality of a diamond has changed during a processing step. The GlueX group is presently working with the BNL diamond R&D group to measure the quality of a diamond monocrystal before and after it is subjected to thinning by ablation. Demonstration of successful thinning of diamond radiators will only be complete when rocking curves of the thinned radiator show that it has essentially the same mosaic spread as had the original raw sample.