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Proposal Number FS ____________

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FEASIBILITY STUDY PROPOSAL FORM

PLEASE TYPE ALL INFORMATION
SUBMIT ORIGINAL AND 3 COPIES OF PROPOSAL

COLLABORATORS AND AFFILIATIONS: Name (First and Last), Affiliation with complete address, telephone and Fax number. Please list Principal Investigator first. The Principal Investigator will be the group's primary contact with CHESS. (Collaborators, for example, include all authors of the paper that would describe the use of the CHESS data.)

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PROPOSAL TITLE:
Assessing single-crystal diamond quality by rocking curve and topography measurements

ABSTRACT (1/2 PAGE ONLY)

The proposed GlueX experiment at Jefferson Lab requires high-quality diamond crystals to generate a highly polarized high-energy photon beam from an electron beam via the process of coherent bremsstrahlung. The polarization of coherent bremsstrahlung is very sensitive to the presence of defects in the radiator, therefore very high quality diamond crystals are needed. Some imperfections are present in the diamond due to the synthetic growth process. Others may be generated by the cutting and thinning process, and still others by radiation damage during the operation of the beam. It is essential for the reliable operation of the polarized beam for the GlueX experiment that these effects be understood and procedures developed for their mitigation. To this end, we plan to examine diamond samples from different stages in the life-cycle of a radiator and assess their crystal structure using X-ray rocking curve and topograph measurements. These measurements require a highly collimated X-ray beam, a good performance monochromator, a 4-circle goniometer and a good detector. After a visit to the Wilson Synchrotron Lab, we found that the CHESS facilities are suitable for doing such measurements and request an opportunity to do feasibility measurements in the near future.

FEASIBILITY STUDY FORM (page 2)

1) Based on the existing CHESS facilities, indicate which station/s you think will satisfy your needs please visit: **http://www.chess.cornell.edu/aboutus/index.htm** or call a staff member. See contact numbers at: **http://www.chess.cornell.edu/staff/index.htm**

The C-1 beamline.

2) Estimate how much beam-time you will require to perform your experiment. (Maximum 4 days).

4 days

3) What equipment will you require that is available at the facility? Be specific.

Asymmetric monochromator, 4-circle goniometer, single-crystal detector for fast scans, 2D pixel detector.

4) What equipment do you expect to bring with you?

None.

5) **HAZARDOUS MATERIALS:** Are HAZARDOUS MATERIALS involved in this experiment? This includes any radioactive materials, radiation producing sources, toxic and explosive substances. See **http://www.chess.cornell.edu/onlnquiz/pages/hzrdmts.htm**

YES__________________ NO____No_________

If YES you must complete a "DECLARATION OF HAZARDOUS MATERIALS" form
http://www.chess.cornell.edu/prposals/forms/hzrdmtv7.doc

IF NO you must complete a "DECLARATION OF NON-HAZARDOUS" form
http://www.chess.cornell.edu/prposals/forms/nhzrdsv7.doc

6) If your experiment requires special equipment for hazardous or especially sensitive materials, please list type of equipment.

N/A

7) ATTACH A SHORT DESCRIPTION OF PROPOSED WORK. (Please limit to 2 pages)

The proposed GlueX project at Jefferson Lab (Jlab) requires a highly polarized high-energy photon beam, which will be created by the coherent bremsstrahlung process[1] which occurs when a beam of high-energy electrons passes through a carefully oriented diamond crystal. The GlueX project requires that the photon beam linear polarization should be as high as possible[2]. Diamond is chosen as the radiator material because of its combination of low atomic number, high crystal packing density, and very high Debye temperature, all of which contribute to the efficiency of the coherent bremsstrahlung process[3]. The diamond crystal quality has a vital effect on the polarization of the photon beam. Because diamond specimens always suffer from imperfections and the lattice regularity is disturbed by these imperfections, diamond crystal quality varies from sample to sample. Only those crystals that are of very high quality are suitable to be used as a photon radiator. These crystals must be of order 30-50 mm^2 in area but relatively thin, roughly 20 μm or less under Jlab conditions, to prevent multiplescattering from destroying the excellent emittance properties of the beam. Single-crystal diamond wafers of these dimensions are available from industry, but when they are first produced they roughly an order of magnitude thicker than this, and must be thinned after initial selection. Preliminary experience at Jefferson Lab with one 20 μm diamond has suggested that deformations may be present that were not seen before the thinning step, but very little is known about the exact nature of this deformation. The nature of the defects generated by radiation damage during the use of the diamond as a radiator and the rates at which they appear must also be understood, as it impacts the rate at which they must be replaced during the running of the GlueX experiment. Therefore, we need a simple and efficient method to select diamond crystals and track their changes throughout their life-cycle. The assessment technique should focus on measuring features of the crystals which determine how well the diamond will perform as a radiator.

According to our previous experience at the Daresbury SRS, rocking curve and topograph measurements are particular useful for selecting diamond radiators. The X-ray measurements were taken at an experimental station located at the end of an 80m beam line, ensuring that with adequate collimation the beam is sufficiently parallel. The X-rays wavelengths we used were 1.0 and 1.3 Å. X-rays are scattered by atomic electrons whose density peaks at the nuclear sites in the crystal lattice, whereas in coherent bremsstrahlung the high-energy electrons scatter from the total charge distribution of the lattice, but both processes are governed by the same crystal form factor. Therefore, from the X-ray rocking curve width we can estimate the performance of the diamond crystal in the coherent bremsstrahlung process. Our recent NIM publication contains more details of the diamond selection process[4].

For a perfect crystal, the rocking curve is not infinitely sharp but has a finite width. For example, the natural width of diamond is 5 μr for the (001) plane and 1 Å X-ray wavelength. Deviations from an imperfect crystal lattice, whether from defects and dislocations or from bending of the lattice and variation in lattice parameter, result in the rocking curve becoming broader than the theoretical value for a perfect crystal. The best crystals have rocking curve widths just a little bit larger than the theoretical value over the entire surface. A bad one may be 50 or 100 μr wide or have several peaks spanning this range. Such narrow widths are difficult to resolve with conventional laboratory X-ray diffractometers, therefore we need a highly-collimated synchrotron X-ray beam line. The second reason why we need a synchrotron X-ray source is that we need to measure a large crystal over the whole surface. The typical size of the diamond radiators for the GlueX project is 6mm x 6mm. Scanning this large area would require an excessive amount of time with a typical 10kW copper K-alpha source. A synchrotron beam has very high intensity, which facilitates the assessment of these large samples.

The diamond rocking curve measurements require a highly collimated X-ray beam, a good performance monochromator, a 4 circle goniometer and a good detector. During a visit to the CHESS facility on 15th of August, we found that all necessary equipment for a feasibility study is already available at CHESS. We believe that CHESS will be a good place to carry out the diamond assessment studies required for GlueX. The CHESS C-1 beam line is equipped with a 4-circle goniometer which can be used to align and rotate the diamond crystal with few-μr resolution. If an asymmetric crystal is used in the X-ray beam line, the vertical beam divergence will be dramatically reduced and also the beam size will be increased, making the X-ray beam suitable for diamond rocking curve measurements. We propose to use a single detector with fast readout as a starting point to align the crystal for rocking curve measurements, and then use a pixel detector to scan through the rocking curve peak and image the crystal with 100 μm spatial resolution. The CHESS staff have a high resolution homemade pixel detector that would be suitable for this measurement. The benefit of using a pixel detector is that it produces a two-dimensional rocking map in a short time period, compared with using a single detector and scanning the whole crystal using a pin-hole beam [5]. This two-dimensional map measures precisely the diamond quality at each point across the crystal. This map can be compared with high-resolution topographs taken of the crystals using a photographic emulsion and an unmonochromated beam.

We will use transmission geometry to do the rocking curve and topograph measurements of the 220 reflection. The diamond crystal samples have (001) surface orientation and the X-ray wavelength can be chosen by the CHESS staff depending on what kind of monochromator is available. We prefer the X-ray wavelength to be close to 1 Å, for the reason that we can get the best topograph contrast for diamond samples at around 1 Å. At around 1 Å, the X-ray absorption depth is about 700 µm and therefore photoelectric absorption is not significant for our samples which have thicknesses of order 100 µm. As a result, the measurements probe the whole diamond sample. We will not use reflection geometry, because the penetration depth of the X-rays into a perfect crystal is given by the extinction distance which is of order 10 µm.

The diamond crystals are obtained from a company called Element Six (formerly the Drukkers Synthetics Laboratory, a division of DeBeers). These crystals are grown from a small seed to an ingot of cm-scale dimensions. We are able to obtain samples from a number of these ingots, from which we select the few (perhaps 10-20%) of the ingots whose uniformity and rocking curve width are sufficiently small for our purposes. After final machining, these wafers will be examined again for crystal quality, and those that pass all tests will be mounted in a beam line at Jefferson Lab and used to generate highly monochomatic and polarized gamma ray beams in the multi-GeV energy region by the process of coherent bremsstrahlung. These beams provide unique opportunities for high-energy nuclear physics experiments.

In summary, the GlueX project needs high quality diamond crystals as radiators and the diamond crystals can be assessed and selected by using rocking curve and topograph measurements. All necessary facilities for diamond rocking curve and topograph measurements can be found at CHESS. We request that we be granted four days on beam line C1 in order to carry out feasibility measurements at CHESS in Fall 2006.

We want to thank Ken and other members of the CHESS staff for the helpful discussions that we had during our visit to CHESS.

References

[1] RT Jones, Jefferson Lab Hall D Conceptual Design Report, v4.0 September 25 2002.
[2] RT Jones, JLab Hall D note, GlueX-doc-646-v5.
[3] U. Timm, Fortschr. Phys. 17 (1969) 765.
[4] JD Kellie, PJM Clive, GL Yang, RT Jones, et al. Nucl. Instr. And Meth. A 545 (1-2): 164-180 JUN 11 2005.
[5] T. Albert Macrander, Szczesny Krasnicki, Yucheng Zhong, et al. Appl. Phys. Lett. 87(2005) 194113.

8) There are no charges for non-proprietary access to CHESS. However, we do have to justify your productivity to our sponsors. Please list all publications involving CHESS data that have not previously been reported to CHESS, even if you forgot to acknowledge CHESS. Don't worry if you can't recall if a paper has already been reported – we can easily cull duplications.

None.

NOTE: A **Feasibility** Study is a request for a limited amount of beam-time (maximum 4 days) to test whether a longer ranged experiment will work. Time will be granted, if possible, in a way that will not conflict with standard CHESS proposals.