Topography of Diamonds at CHESS helps Nuclear Physics Program at JLAB

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Our group at the University of Connecticut, with collaborators from Catholic University of America and Glasgow University, is in charge of construction of the photon source for Hall D at Jefferson Laboratory (JLAB). This source of polarized high-energy photons is an essential part of the GlueX experiment [1] – a key scientific motivation for the 12 GeV Upgrade of CEBAF at JLAB and the highest priority in the 2007 NSAC Long Range Plan for Nuclear Science. GlueX requires a 9 GeV photon beam with a high degree of linear polarization that will be produced by passing 12 GeV electrons through a thin oriented diamond crystal radiator, using the process of coherent bremsstrahlung (CB).

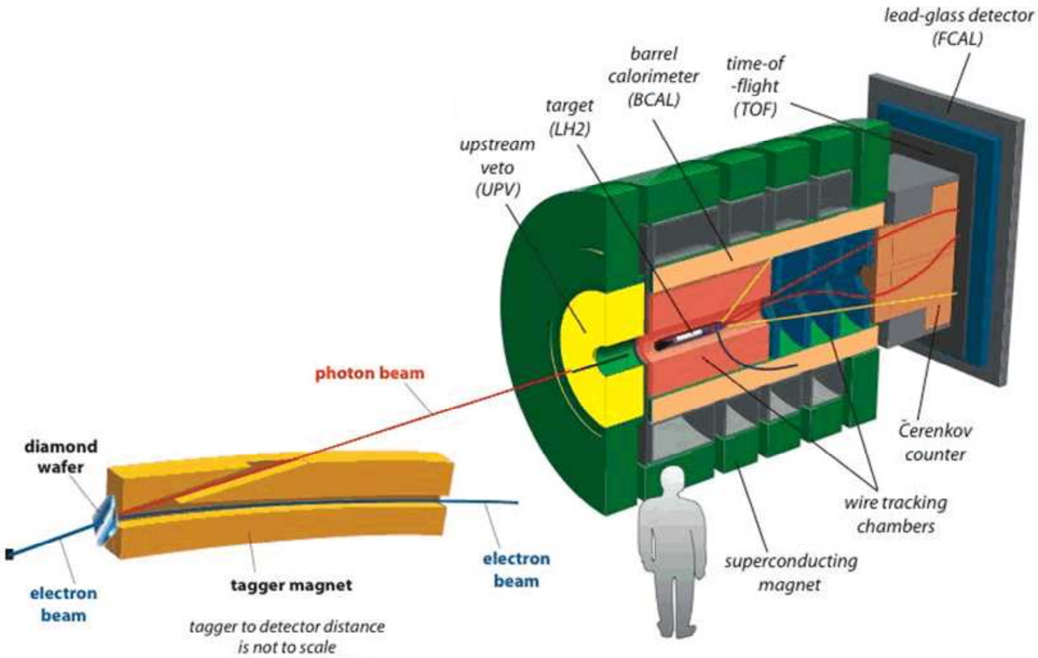
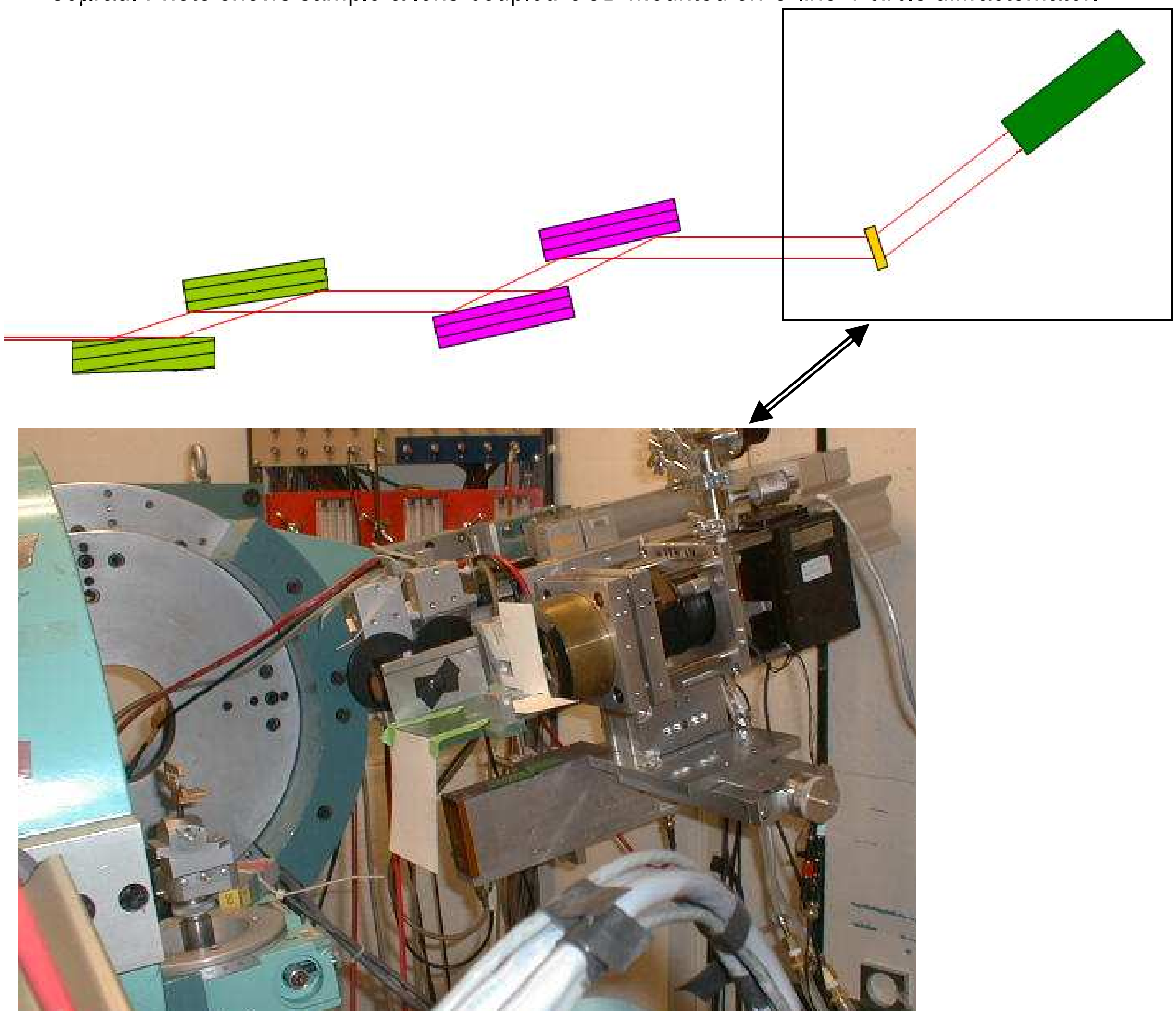


Figure 1 illustrates the relative position of the source of polarized photons (diamond wafer), GlueX target , and surrounding components making up the high energy physics detector.

The creation of CB makes very stringent demands on the thickness and mosaic spread of the diamonds. We start with the very best monocrystals available from the diamond industry and thin them to the required thickness while subjecting them to a thorough quality control process. The unprecedented intensity of the GlueX source demands a better understanding of radiation damage rates in diamond than is currently available. Because the "coherent scattering vertex" (scattering process) in CB has the same form as elastic scattering in x-ray diffraction, the later method is an essential tool for diamond radiator diagnostics.

The ability to do whole-crystal rocking curves with arc-second angular resolution is essential to raw material selection for diamond radiators. We were unable to identify any x-ray diffraction end station at major US facilities with the capability to do whole-crystal rocking curves on samples of dimensions 10 mm with arc-second resolution, but we were advised to contact CHESS to discuss our specialized requirements. CHESS staff member Ken Finkelstein agreed to collaborate with us on a feasibility study; first measurements of diamond radiators took place at CHESS in November 2006. During that run we obtained rocking curves images of several used diamond radiators. These whole-crystal rocking curves were taken with 100 micron spatial resolution using a CCD detector - the first time these whole crystals had been examined with such high spatial resolution.

Figure 2 illustrates our first topographic rocking curve setup that provided ~100 micron spatial resolution. The asymmetric Si(111) monochromator (green) operating at 15KeV (b = 8) expanded the beam and gave sample (gold) rocking curve angle resolution not better than 150μrad (FWHM). Adding a second, symmetric Si(220) mono (pink) improved resolution to 30μrad. Photo shows sample & lens-coupled CCD mounted on C-line 4-circle diffractomator.



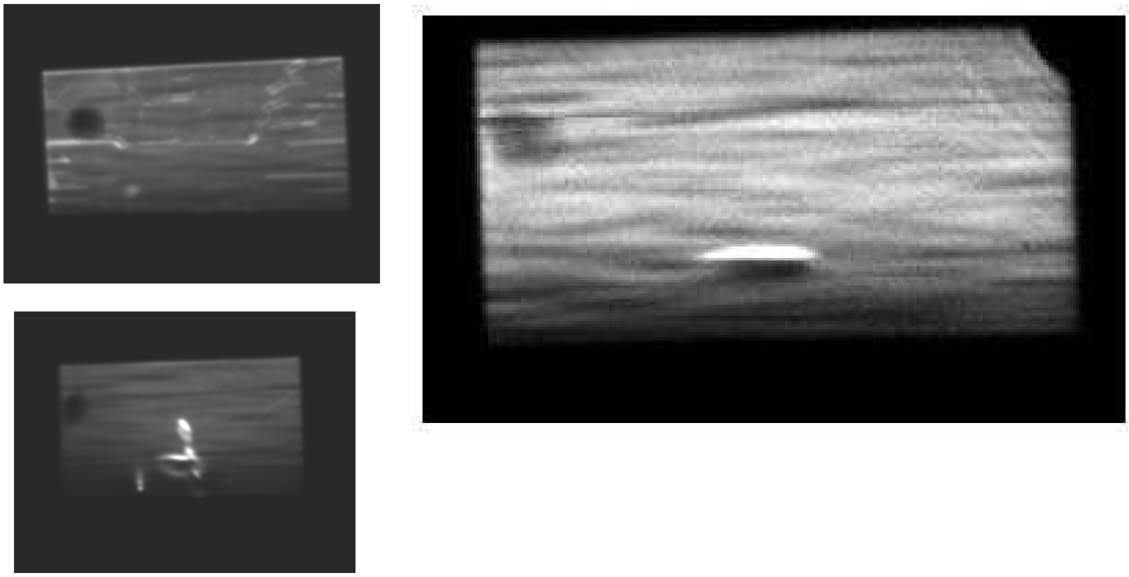


Figure 3 displays transmission topographs of several diamond samples. Localized light regions near the center in two images show damage caused by exposure to high energy electron beams at JLab. Near upper left corner are ink spots added by the manufacturer for identification.

GlueX requires diamond radiators of thickness no more than 20 microns - the thinnest ever used in a CB source. The diamond we studied during this visit had been produced for use in Hall B, but never put into production because it appeared to be unstable in alignment. The measurements at CHESS provided an explanation for this instability: the rocking curves demonstrated that the diamond was severely warped. This result was very significant because it pointed to a problem with the thinning and mounting techniques used for past CB sources. Uncovering this problem early in the R&D phase of the GlueX experiment has enabled us to put in place a mitigation plan that will help avoid project delays and additional costs that would result if not uncovered until beamline commissioning.

Following this initial success, we returned for a second run in 2007. The purpose was primarily to help in the upgrade and testing of new C-line optics designed to obtain arc-second resolution in the rocking curves. This was an essential element of the original feasibility proposal, and would yield an order of magnitude improvement over what was obtained in 2006. The improvement was made possible by fabrication of a custom asymmetric silicon (311) mono crystal pair that provided nearly perfect dispersion matching to the diamond (220) reflection. The optics were designed and simulated by our group, and machined, etched & installed at C-line by CHESS specifically for our measurements. Subsequent measurements demonstrated the customization meets all requirements put forward for CB diamond radiator diagnostics.

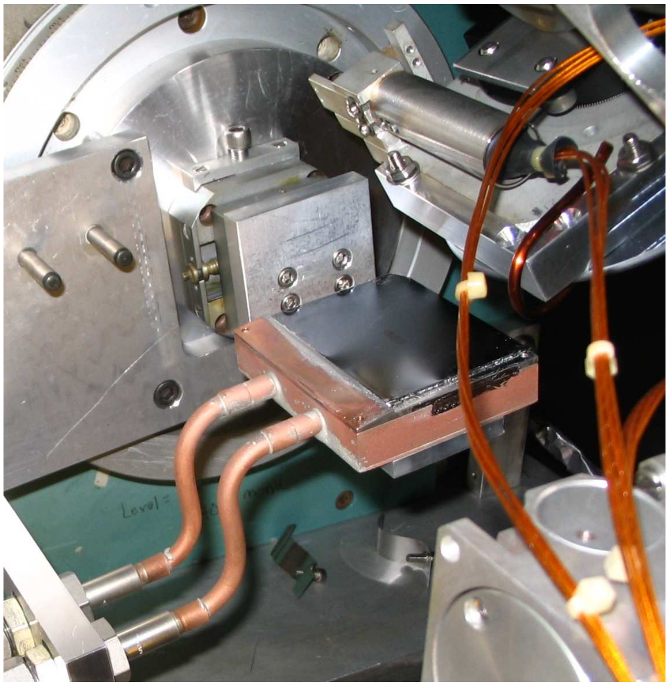


Figure 4, a photo taken in Nov. 2007, shows the new C-line asymmetric monochromator. It uses two asymmetric Si (331) reflections with b=14 at 15KeV, provides a large beam that is dispersion matched to diamond 220 planes so dispersion broadening under 10μrads was expected.

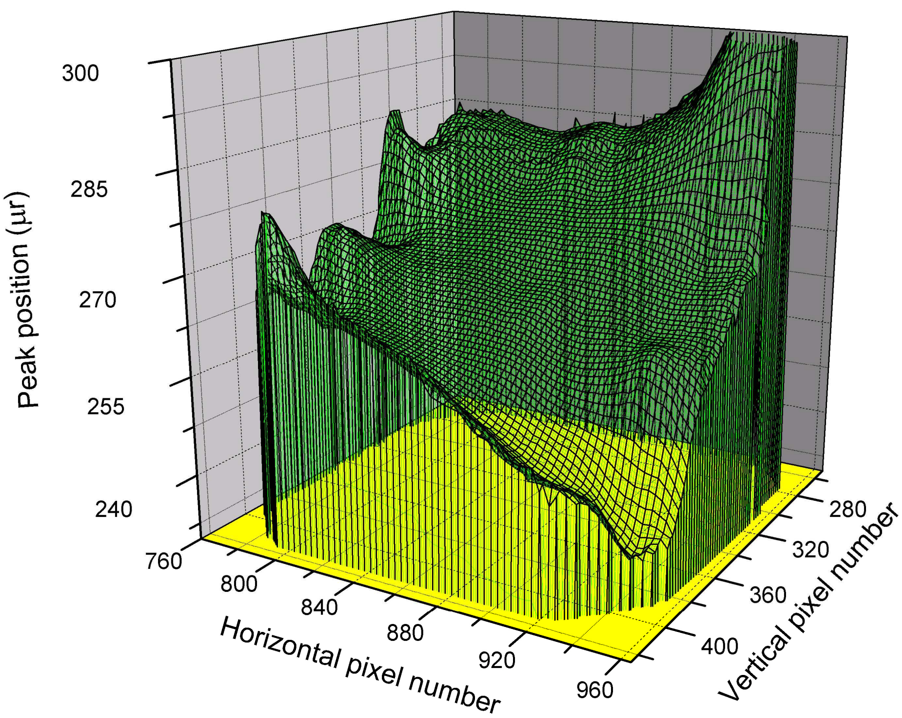


Figure 5 shows results from a quantitative analysis of a series of topographs from a nearly perfect diamond. The indicated pixel range corresponds to a 3 square mm area. Vertical surface height variation shows the range of angle required for peak rocking curve intensity. The angular resolution obtained shows the new monochromator is working as expected.

A follow-up run was postponed until May 2009 to take advantage of instrument upgrades at C-line [see Ernie's article] that will enable switchover to our custom monochromator more quickly and efficiently. In a related development, our group has benefited from parallel developments in thin diamond monocrystal fabrication and mounting taking place at the Instrumentation Division of Brookhaven National Lab. From this group, we obtained, on loan, a diamond monocrystal produced using the latest CVD diamond technology. We plan to characterize the mosaic structure at CHESS in May.

Access to unique facilities at CHESS is essential to carry out diamond thinning and mounting studies for GlueX during the next three years. Once those goals have been met, we anticipate there will be an ongoing need for radiator diagnostics that will enable us to provide a continuous source of top-quality radiators to guarantee continuous operation of the source throughout the data-taking lifetime of GlueX. CHESS occupies a unique place among X-ray user facilities in the US as a place where specialized needs can be accommodated. As non-specialists in the techniques of X-ray optics and measurements, our group has greatly benefited and learned from our collaboration with CHESS staff. Our experience demonstrates how CHESS has a critical impact in other areas of scientific exploration.

[1] A goal of the GlueX experiment is to provide critical data needed to address one of the outstanding and fundamental challenges in physics – the quantitative understanding of the confinement of quarks and gluons in quantum chromodynamics (QCD).For more information see http://portal.gluex.org/ .