Research and Development of a Prototype Tagger Microscope

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Abstract

At the Thomas Jefferson National Accelerator Facility in Newport News, Virginia, a team of nuclear physicists has come up with a way to probe the nuclear "glue" that binds quarks together inside protons and neutrons. The probe to be used in this experiment consists of a beam of polarized particles of light called photons with a specific energy close to 10 billion electron-Volts. The University of Connecticut Nuclear Physics group has designed a detector to "tag" the amount energy the photons will have. This detector consists of a large array of closely-packed optical fibers made of a special plastic called "scintillator" that produces a brief flash of light whenever struck by a high-energy particle. These scintillating fibers are coupled to individual photodiodes, which convert the flashes of light into electrical pulses that are recorded during the course of an experiment. Methods and tooling for the construction of the fiber detectors is under development by undergraduate researchers in the Physics Department at Storrs. The immediate goal of this project is to construct a scaled-down prototype of the tagging detector. This prototype will be taken to Jefferson Lab and tested under realistic conditions in a photon beam prior to launching construction of the full-scale model.

Introduction

The prototype detector has three main components that must be integrated and tested together: scintillating fibers, photodiode readout electronics, and the optical coupling between them. The schematic design for the prototype is shown in Figure 1 below. A scintillating fiber emits a fast pulse of visible light when a high energy electron passes through it, indicated by the blue arrow in the figure. Some of the scintillation light is trapped inside the fiber, and passes through the clear light fiber into the silicon photomultiplier (SiPM) photodiode, where it is detected. The clear light fibers are glued to the scintillating fibers on one end, and on the other end they are mechanically fixed to the SiPM photodiode entrance window. To couple the scintillators to the clear light fibers, an optical-grade epoxy with an index of refraction approximately equal to that of water is used. For coupling the clear light fiber to the photodiode, a special device called a *chimney* has been developed .

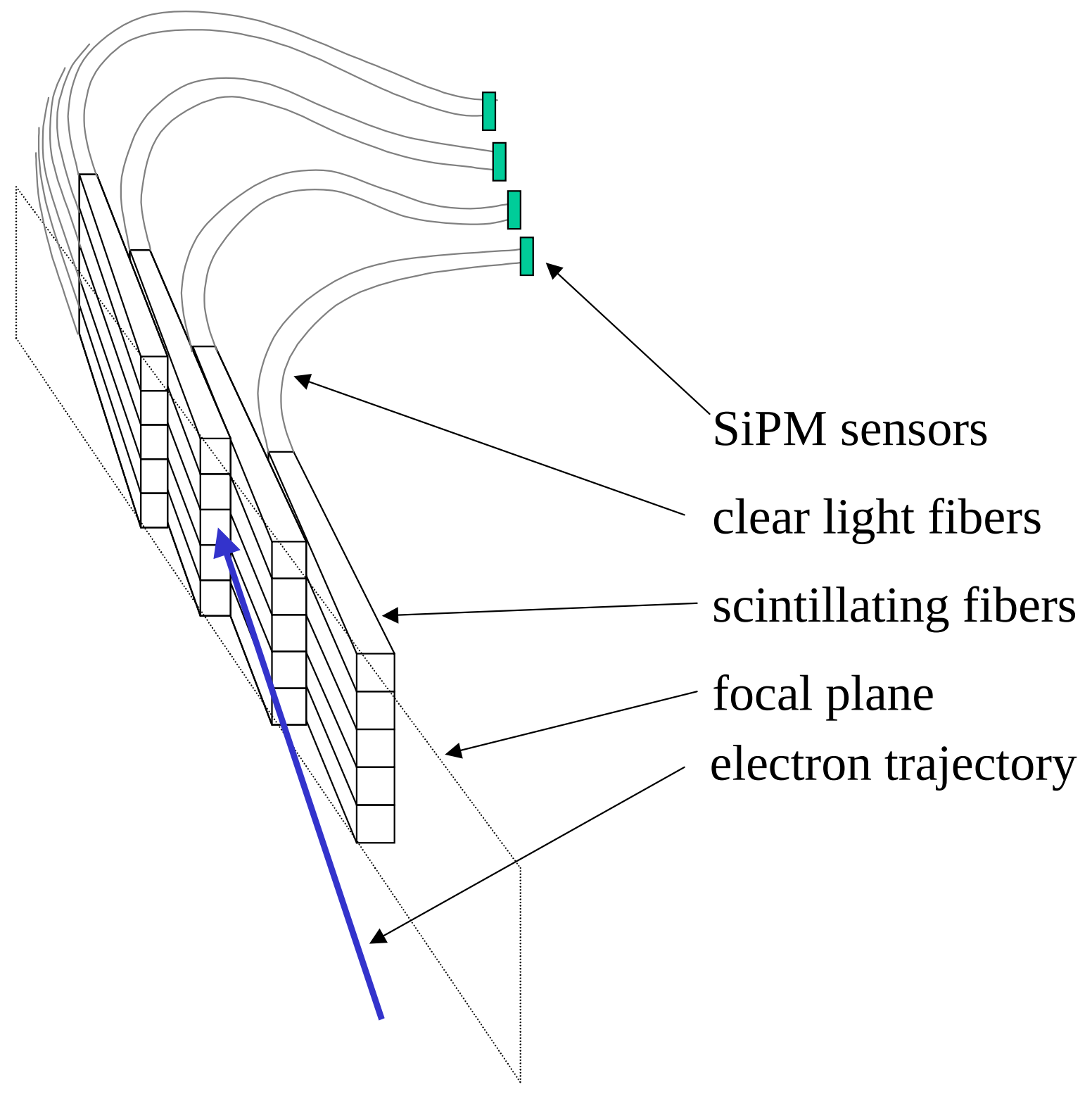

Figure 1: Schematic diagram of the prototype tagger microscope design, showing the path of high-energy electrons being detected and the means employed for collecting and detecting the scintillation light produced. The square optical fibers in the figure have a 2mm x 2mm square cross section.

Fibers

The scintillating and clear light fiber fibers are delivered by the manufacturer on spools containing one continuous fiber several meters in length. The first fabrication step is to cut the fiber into segments of the desired length and polish the cut ends to the desired optical quality. A special apparatus, labeled *work stand* in Figure 2, was created to facilitate both cleaving and polishing the optical fibers of the desired length.

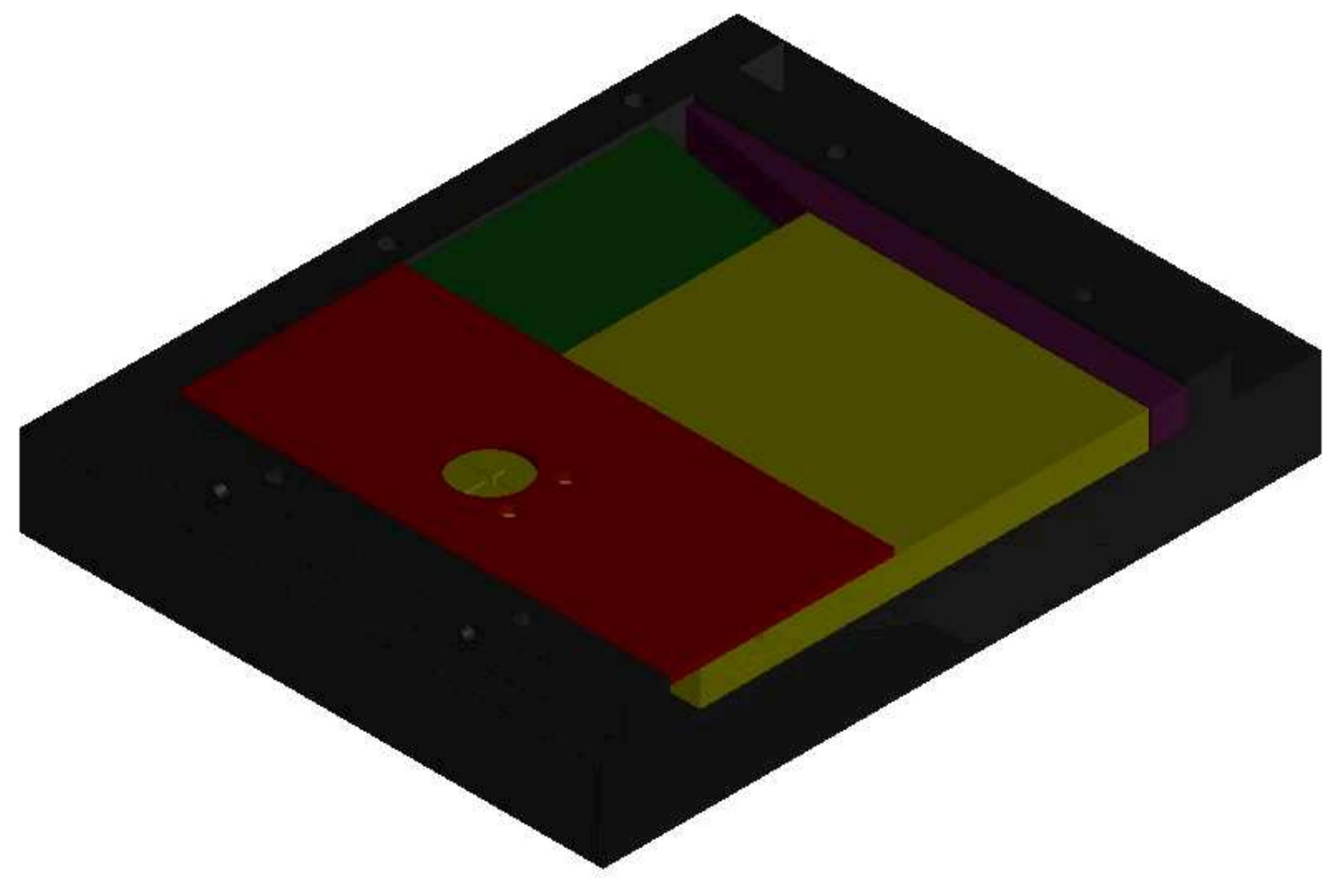

Figure 2: *Work Stand*
There is a channel in the yellow piece for the fiber to lay in. The red piece clamps down the fiber so that it will not move. The far side of the yellow block is where the fibers are held for gluing into columns. The red piece slides down and holds the glued fibers in place while the epoxy cures.

Polishing the cut fibers requires special care. This involves sanding down the ends of the fiber to make a flat, smooth, and optically clean surface. The ends have to be flat and clean so that when the fibers are glued together, each end lies flush against the other. The optically clean surface is needed in to obtain maximum transmission through the bond. The polishing process that we developed has three main stages. The first is stripping the cladding, which is a thin outer layer of the fiber (see Figure 3). This is done so that the rest of the polishing process does not peel back the cladding around the fiber. The next stage is sanding the exposed end of the fiber with medium-grit sandpaper, until the core and the cladding are practically flush (see Figure 4). The last stage is to use a series of increasingly finer grit sandpaper to remove any abrasions left by the coarse sandpaper (see Figure 5).

Figure 3: The first step: trimming back the cladding and exposing the core.

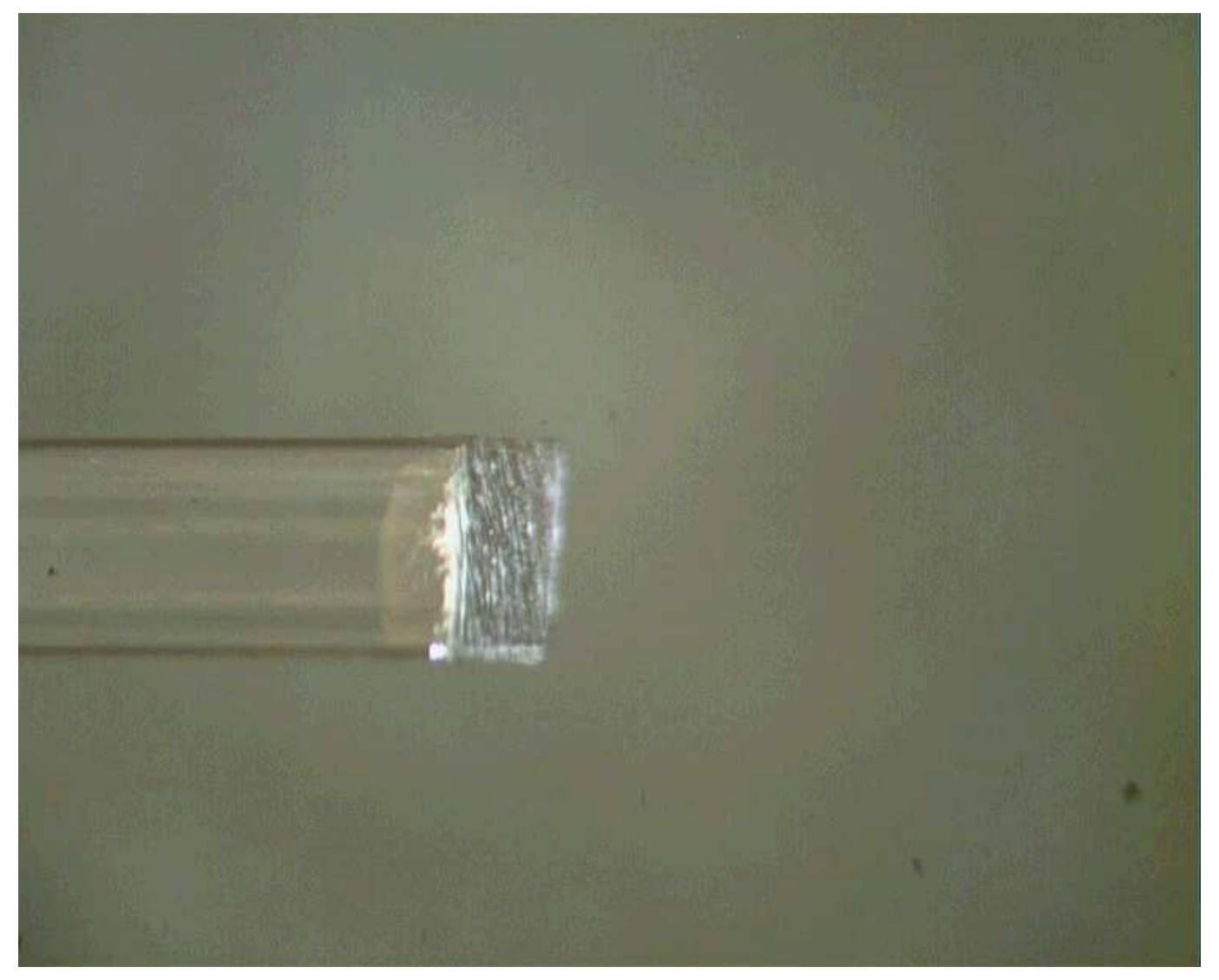

Figure 4: The second step: grinding the exposed core until it is flush with the cladding.

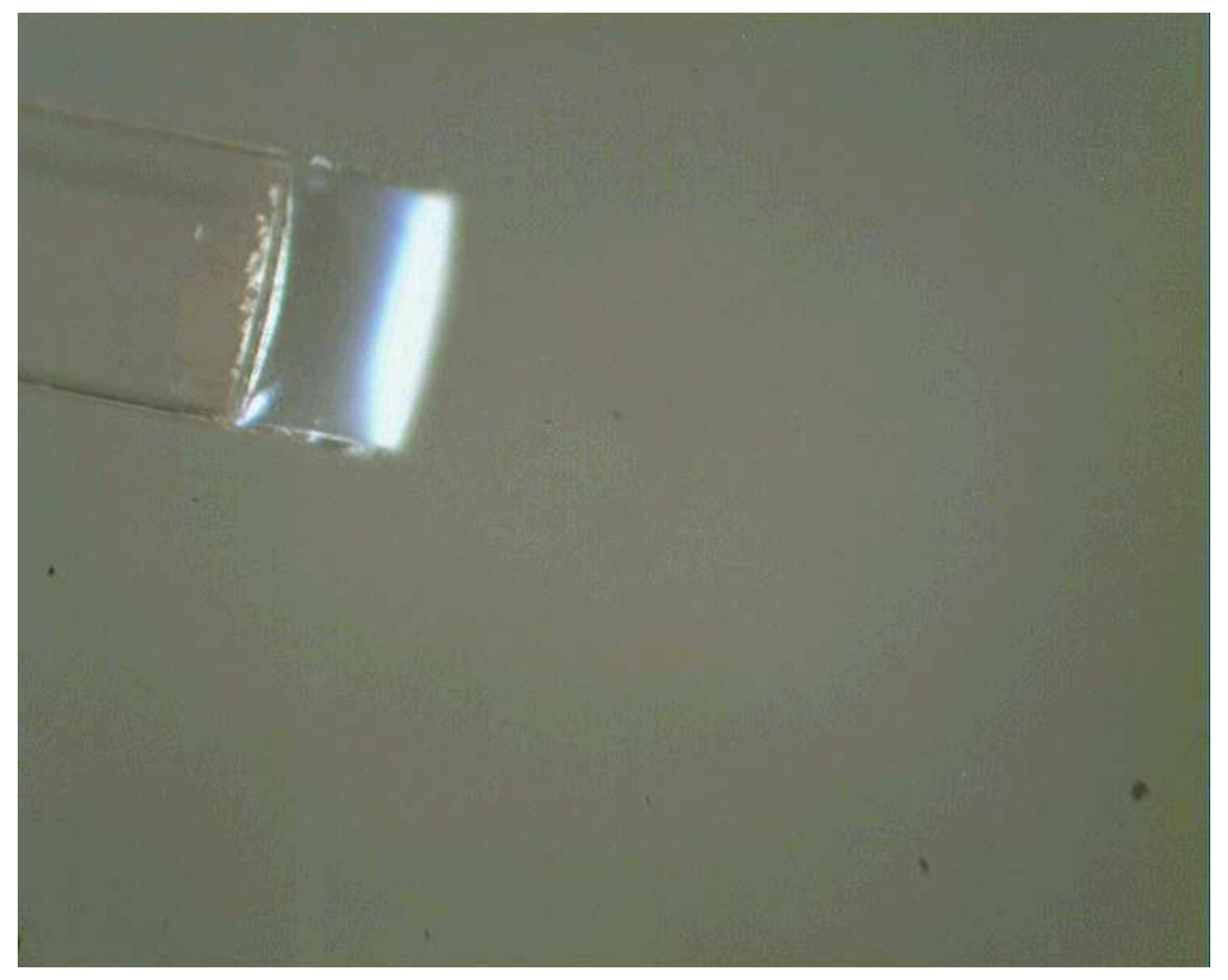

Figure 5: The last step: polishing the end of the fiber with finer grit until it is optically clean.

Epoxy

The scintillating and clear fibers both have square cross sections of dimensions 2mm x 2mm. The joint between them is made using a two-component *water-clear* optical grade epoxy from the manufacturer Epoxies, Etc. The components of the two-part epoxy have to be measured precisely to produce a joint that is mechanically strong and optically clear. When the epoxy is mixed and cured properly, the result is a strong, water clear optical bond between the scintillator and clear fibers, as shown in Figure 6.. Application of the epoxy to the fibers is done with a precision pipette that allows the volume of epoxy to be controlled to within 0.01 μl.

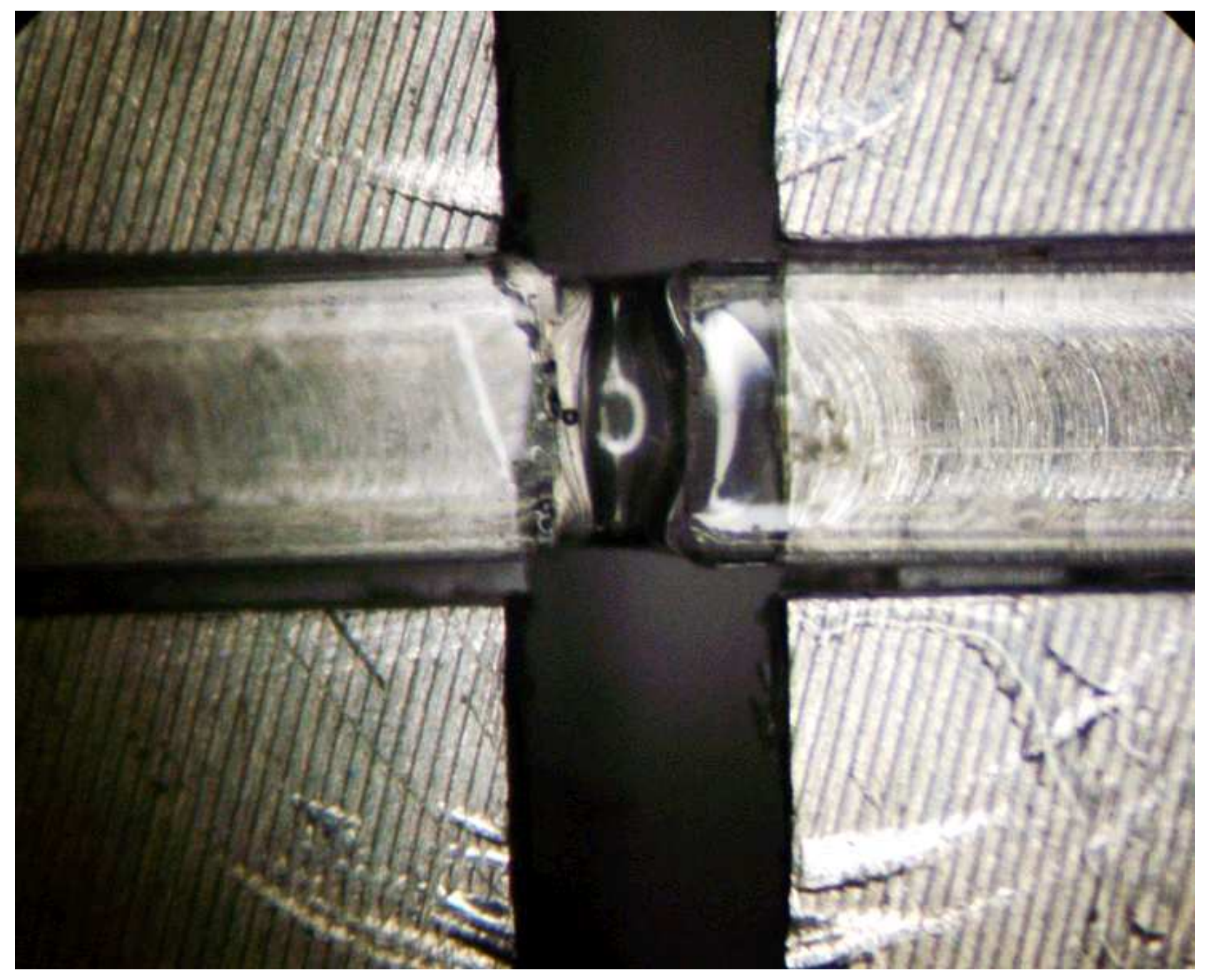

Figure 6. Fibers after the epoxy has been applied

Proto-Chimney

In Figure 7 is shown a photograph of the prototype chimney. The two groves on the sides of the interior walls hold the circuit board on which the photodiode is mounted. Figure 8 shows the same chimney viewed from the back, where the clear fiber enters and is fed through to the photodiode. The larger screw on the top is to clamp the fiber in place.

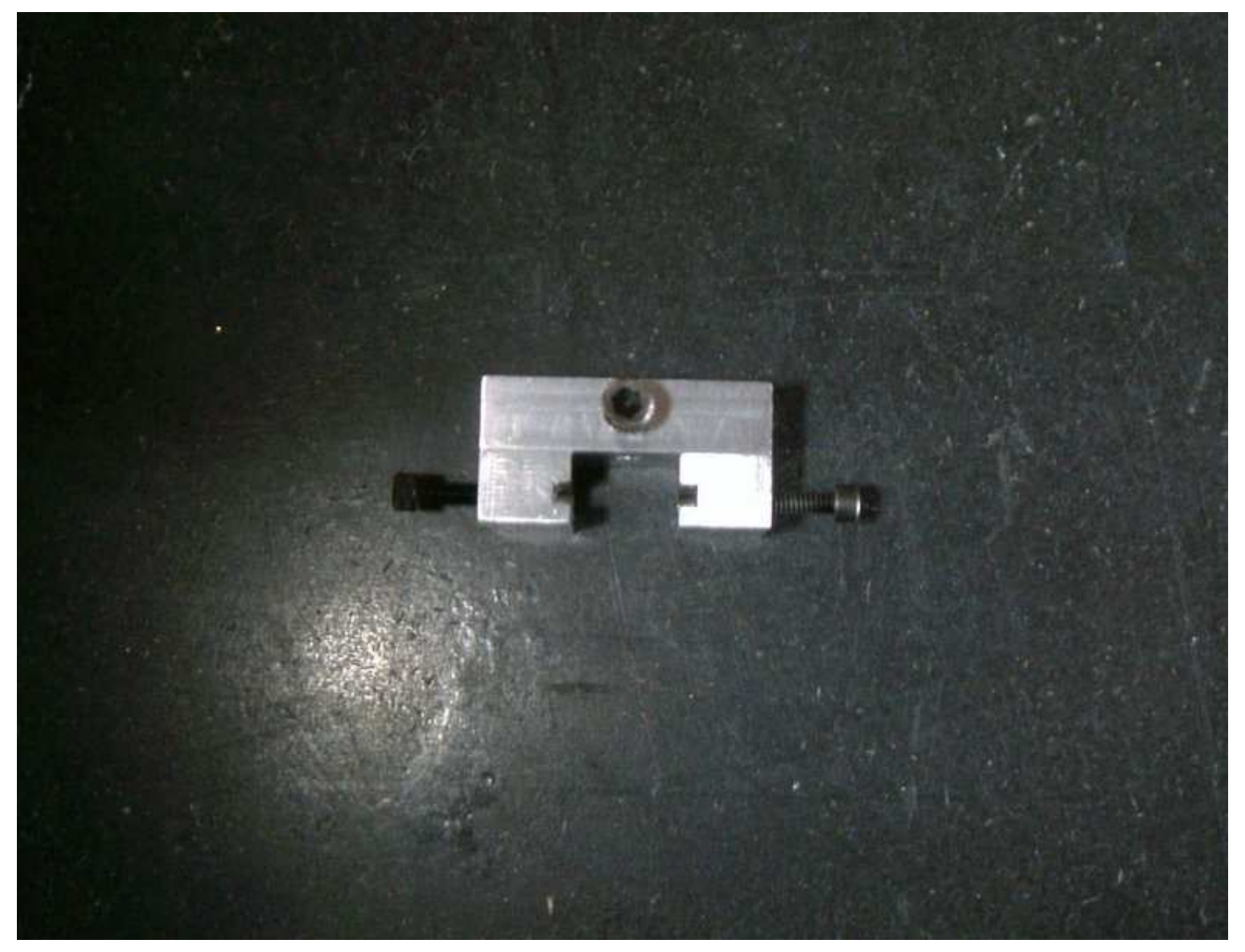

Figure 7. Top-down view of prototype chimney. The fiber enters from the top of the image.

Figure 8. Back view of prototype chimney, where the clear fiber enters.

Conclusions and Outlook

Step 3 in the polishing procedure is by far the most time-consuming. Currently we are measuring the transmission of the fibers after each step in grit size, to see if it might be possible to reduce the number of steps, or even eliminate step 3 altogether. Eliminating step 3 would enable us to cleave, polish, and glue the scintillator/clear light fiber pairs in about one third the time it takes using the present procedure. Once this question is answered, a set of 25 fiber detectors will be constructed and assembled in a 5 x 5 array, and taken to Jefferson Lab to be tested in the high-energy electron beam.