Engineering Design of a Photon-Tagging Detector for GlueX

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Abstract

The GlueX experiment is designed to probe the mechanisms of confinement of quarks and gluons inside hadrons. Quantum chromodynamics (QCD) is the accepted theory of the nuclear strong force, which explains the interactions of the quarks and gluons that compose hadrons. Quarks and gluons are subatomic particles which never live in isolation, but are always bound inside composite objects called hadrons. Gluons create the force that holds quarks together inside hadrons. Hadrons come in two types: mesons, existing in their simple state of bound quark/antiquark pairs, and baryons, in their simplest form of three quarks. Mesons consist of only two fermions, and provide a unique opportunity for studying strong-interacting nuclear physics. Such an opportunity is analogous to the hydrogen atom in traditional atomic physics.

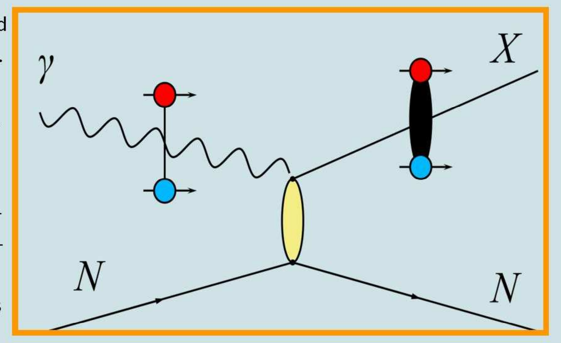
One fundamental hypothesis in the field of nuclear physics is confinement, which explains how quarks and gluons are the elementary particles of which the nucleus is made, even though isolated quarks and gluons have never been observed in an experiment. Confinement implies that an infinite amount of energy is required to isolate a quark outside of a hadron. One of the predictions of QCD is that the gluonic field inside hadrons has an independent degree of freedom from the quarks, and is capable of being independently excited. The energy and mode structure of the excitations give important information regarding the configuration of the gluonic fields, which ultimately lead to confinement.

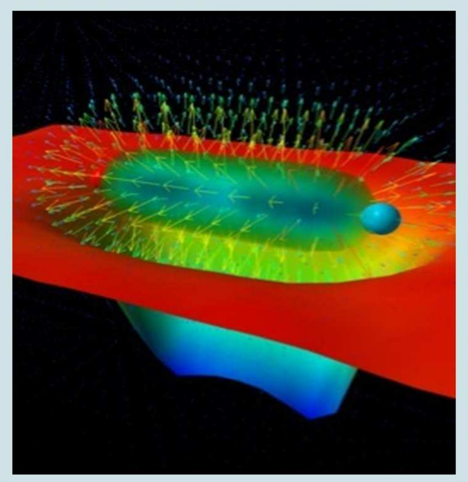
The GlueX experiment searches for mesons with internal gluon excitations, called "exotic mesons." The experiment will map these mesons by producing them with photon-proton collisions and subsequently measuring their quantum numbers by studying the angular distribution of their decay particles. The GlueX experiment will generate a photon beam beginning with a high-energy electron beam from the US Department of Energy's Thomas Jefferson National Accelerator Facility, using the process of coherent bremsstrahlung. Coherent bremsstrahlung refers to electromagnetic radiation produced by the deceleration of electrons inside a diamond crystal. After the electrons emerge from the diamond, their energies are measured in a magnetic spectrometer called the "tagger", which "tags" the energy of the photons produced in the diamond as the difference between the pre- and post-bremsstrahlung electron energies.

Atomic & Subatomic Structure

At a basic level, atoms are composed of protons, neutrons, and electrons. But what do these terms really mean?

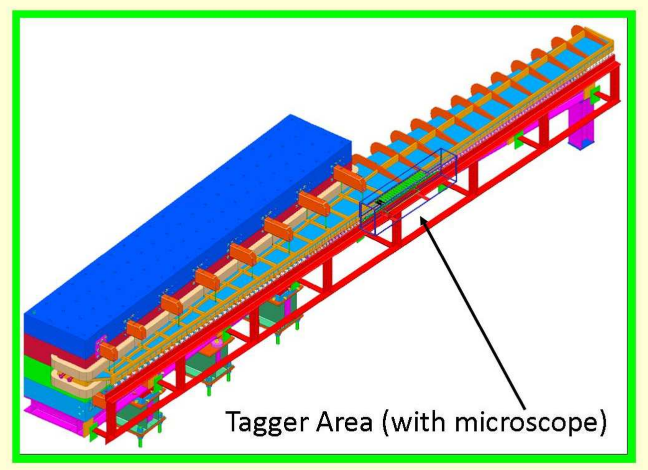
A normal meson is a bound state of quarks and gluons. An exotic meson is a meson with vibrating glue. Exotic mesons can be produced by exciting the gluon field surrounding ordinary mesons. This excitation is done using a beam of high-energy photons, as is illustrated in this Feynman diagram, to the right.

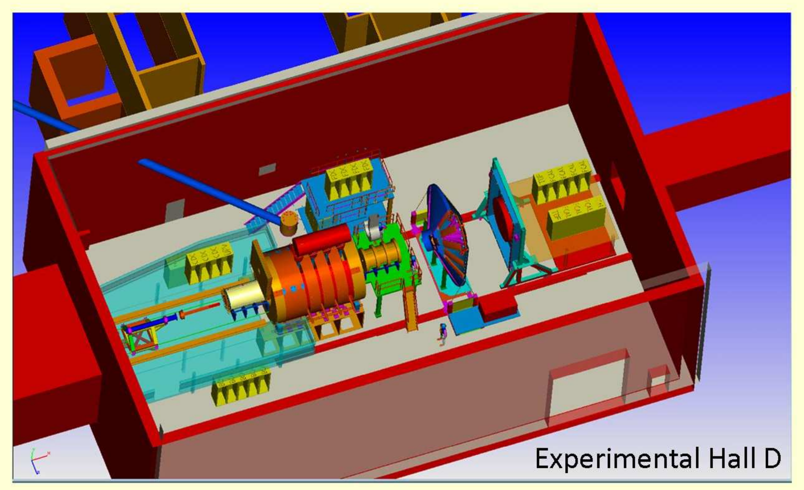


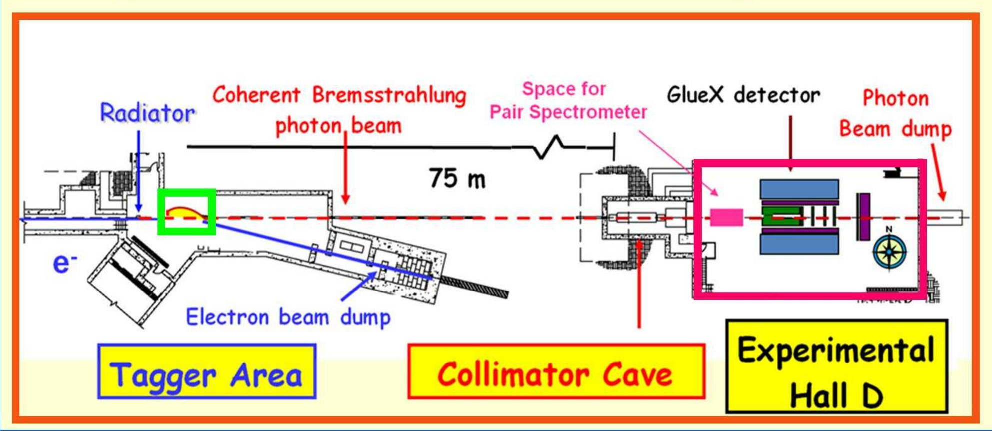


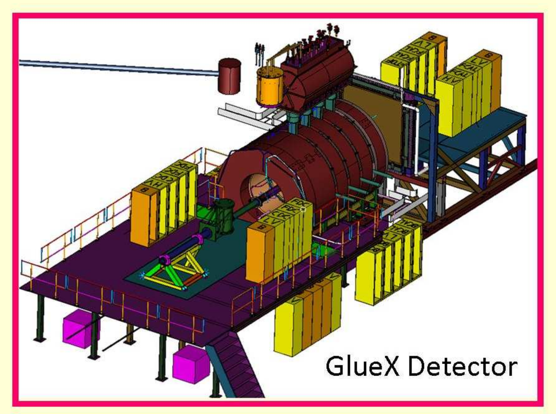
This picture illustrates a meson as a quark and anti-quark connected by a gluonic string. Excitations of the gluonic field binding the quarks can give rise to so-called hybrid mesons that can be viewed as bound states of a quark, anti-quark and valence gluon. An alternative picture of hybrid mesons, one supported by lattice QCD, is one in which a gluonic flux tube forms between the quark and anti-quark and the excitations of this flux tube lead to so-called hybrid mesons.

What is the GlueX Experiment?





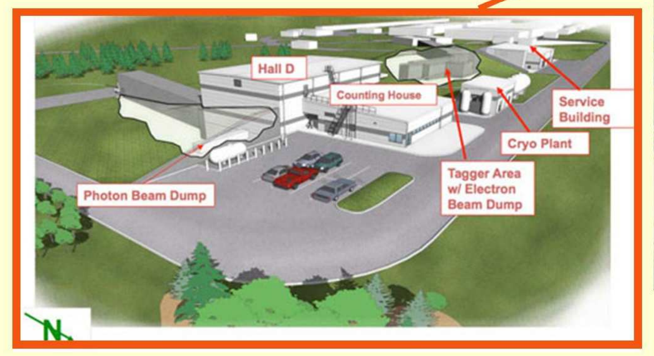


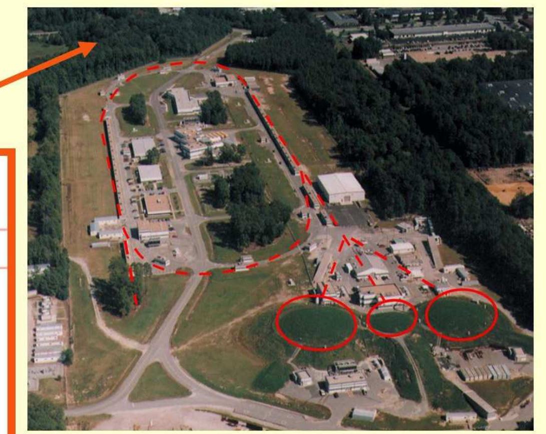


The Physics of GlueX

The GlueX experiment [1-3] is designed to probe the mechanisms of confinement of quarks and gluons inside hadrons. The GlueX experiment will be conducted in the new "Hall D" at Jefferson Lab in Virginia. The experiment consists of colliding a high-energy photon beam with protons in a liquid hydrogen target to produce excited mesons. The photon beam is produced by decelerating a high-energy electron beam inside a thin diamond crystal. After the electrons emerge from the diamond, their energy is measured in the tagger.

Below: This image is an architectural rendering of the new Hall D that will be built at the Jefferson Lab facility specifically for the GlueX project. Construction on Hall D started 15 April 2009.





^^ Above: This image is an aerial view of the Thomas Jefferson National Particle Accelerator Facility in Virginia.

Terminology: A Quick Reference

Fermion: A quantum particle with half-integer spin.

Boson: An quantum particle with full-integer spin.

Quarks & Leptons: The two elementary types of fermions.

Gluons: The quanta of the force field that binds quarks together.

Hadron: A bound state of quarks and gluons.

Exotic Meson: A hadron whose gluonic force field is excited.

GlueX Experiment: A nuclear physics experiment to investigate the nature of quark confinement by mapping the spectrum of exotic mesons.

Jefferson National Lab: The Thomas Jefferson National Accelerator Facility is located in Virginia, and is run by the US Department of Energy.

Scintillator: A special fiber optic composed of a plastic that emits light when a high-energy particle passes through it.

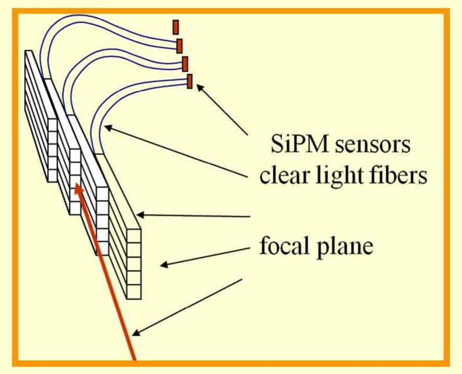
Wave Guide: A plastic tube that conducts physical light from the detector to the sensor, using total internal reflection.

Optics: Gluing & Polishing Procedures for Fiber Arrays

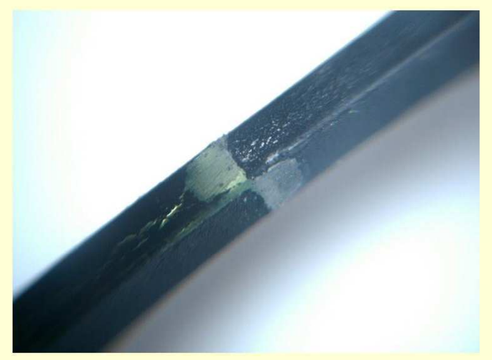
Fiber optics plays a critical role in the function of the photon-tagging detector in GlueX. Two types of fibers are currently being studied and tested, and will be used in both the prototype and the final detector. They are the Scintillating Fibers and the Wave Guides.

The method of gluing the scintillators and wave guides to each other and then into 5x5 arrays is outlined:

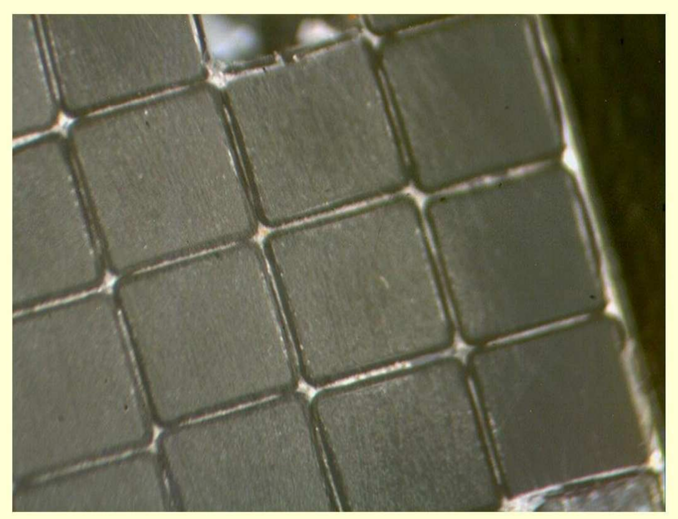
- Cut the fibers to an appropriate length, and polish the ends thoroughly.
- Align the scintillators to the wave guides in the gluing apparatus.
- Mix the optical epoxy using a ratio of ten parts resin to three parts epoxy.
- Apply the epoxy to the fibers in a precise amount, using a micropipette.
- Allow the epoxy to cure (takes 2+ hours) at a controlled temperature of 70°C.
- Re-polish the ends of the glued fibers using fine sand paper and emery boards.
- Spray black paint on the exterior of the fibers to prevent light coupling.



A new gluing apparatus was recently designed in TurboCad and machined using CNC technology in the UConn Physics machine shop. This apparatus has yet to be tested , but it is anticipated that it will yield gluing session results which are more accurate, precise, and replicable.

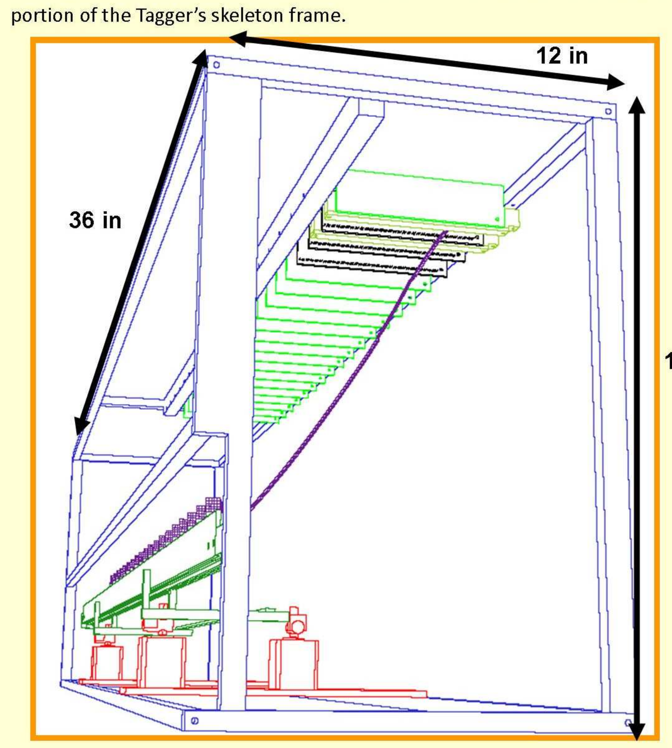


^^ Above: The images above are photographs of two stages of fiber preparation. The left image shows a waveguide fiber with its cladding stripped away, and the right image shows one pair of fibers—a waveguide and a scintillating fiber—that have been glued and painted successfully.



<< Left: The image at left is a photograph of a glued array of fibers that has been fly-cut but not yet polished. One finished array

Below: This image shows one array of fibers, and how it will connect to the electronics of the Tagger microscope detector. The 5x5 array of fibers will connect to an Analog circuit board, which will in turn connect to a control board reading out to a computer. The control boards will be mounted to a backplane portion of the Tagger's skeleton frame.

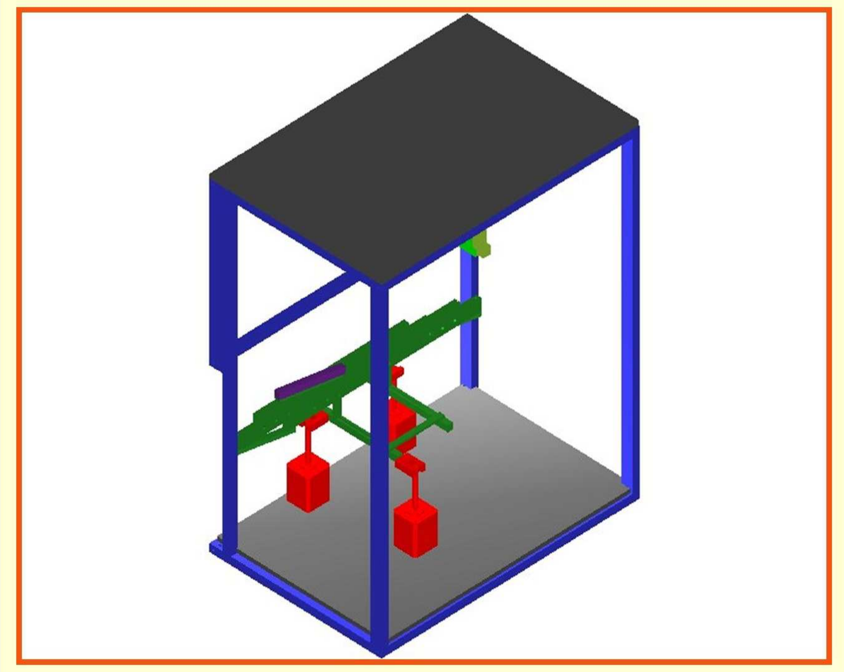


CAD Rendering: Designing the Tagger Structure

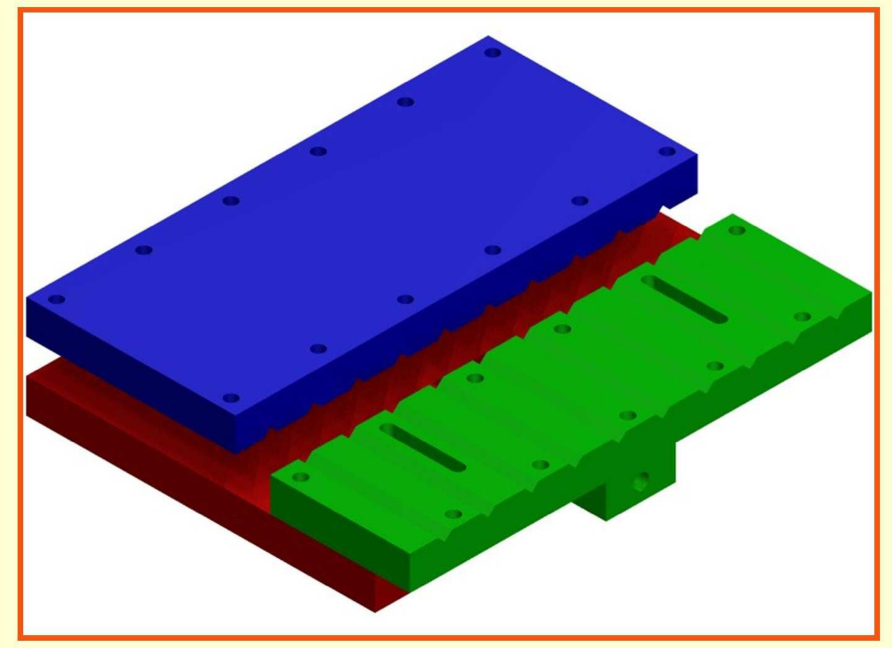
The rendering for the prototype microscope structure was done using TurboCad software Version 12, run on Windows XP. TurboCad is capable of modeling both 2d and 3d objects, and final ANSI-standard prints can be generated.

The following objectives were critical to the research and design of the structure:

- The structure must be completely sealed to outside light sources.
- The structure must allow ample room to safely bend the final, glued fiber arrays.
- The design must be able to interface flawlessly with all electronics components and SiPM detectors.
- The structure must incorporate attachments for motors, rails, and other mechanical parts contained inside.
- The design should ideally allow for adaptation to particle beams of all energies.



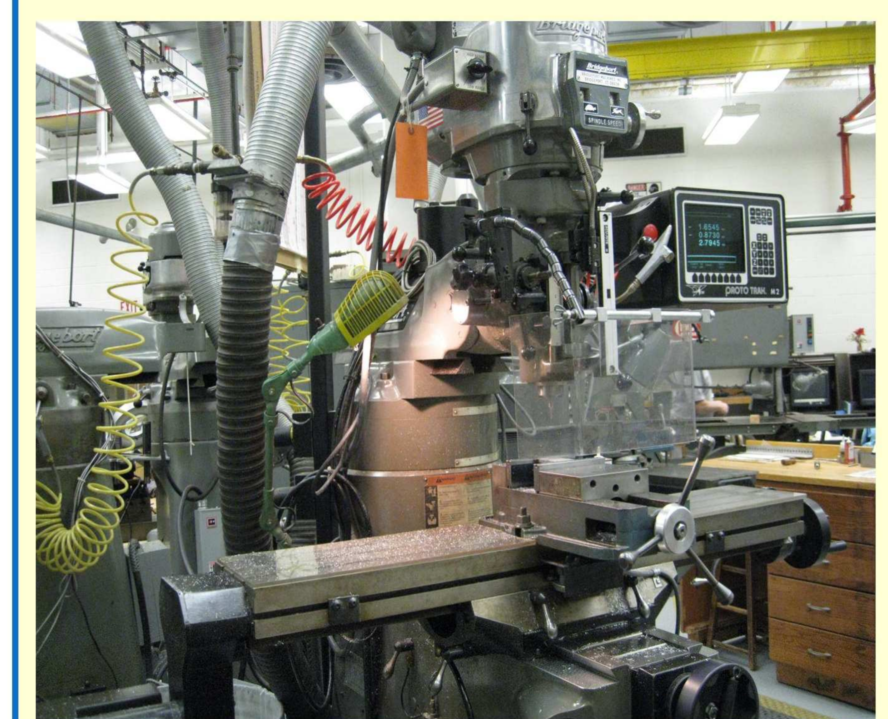
^^ Isometric cutaway view of the prototype microscope skeleton assembly. The three motors, as well as the alignment rails they control, are shown in red and green.

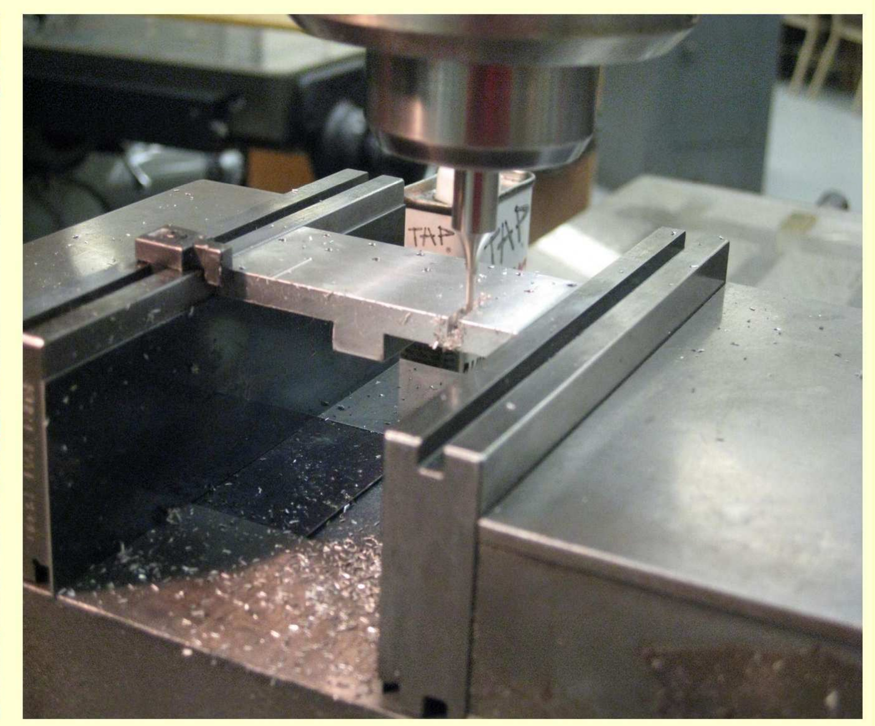


^^ Isometric assembly rendering of the new apparatus for gluing fibers. Notice that the channels in each piece are designed to hold the 2mm square fibers—wave guides on one side and scintillators on the other—and they will be aligned as close to perfectly as possible for the gluing process.

Putting it All Together: The Art of CNC Machining

CNC Machining stands for "Computer Numerical Control", and it is used to manufacture material components in a machine shop. The components are first drafted in two and three dimensions using CAD software, and CNC machining brings these renderings to be reality.





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1. GlueX Conceptual Design Report: Authored by GlueX collaborators worldwide. Routinely updated at <http://www.gluex.org>.
2. American Scientist Article: "Jefferson Lab Starts its 12GeV Upgrade". Allison Lung and Claus Rode. 1 April 2009. <http://cerncourier.com/cws/article/cern/38296>.
3. CERN Courier Article: "The Search for QCD Exotics". Alex Dzierba, Curtis Meyer, and Eric Swanson. <http://www.americanscientist.org/issues/num2/2000/5/the-search-for-qcd-exotics/1>.