Flash Tracks

Building an 'eyepiece' for a particle accelerator

By IVARS PETERSON

Step by step, a new particle accelerator is taking shape on a flat, sandy, water-logged site in Newport News, Va. Office buildings, laboratories and test facilities already crowd the grounds, while construction workers busily prepare the tunnel – along which electrons will eventually race – and the three cavernous halls to which these high-energy particles will be delivered.

All this activity, at a cost of roughly $550 million, focuses on what one can describe as an immense electron microscope, called the Continuous Electron Beam Accelerator Facility (CEBAF). Designed to produce an intense beam of electrons with an energy of at least 4 billion electron-volts, this accelerator will allow nuclear and particle physicists to use electrons as sensitive probes for elucidating the complex structure of protons, neutrons and nuclei (SN: 8/9/86, p.90).

Without suitable detectors, however, a particle accelerator is about as useful as a microscope without an eyepiece. This lesson isn't lost on Paul Stoler of Rensselaer Polytechnic Institute (RPI) in Troy, N.Y., who has spent more than enough time around particle accelerators to know firsthand the crucial importance of a properly functioning, well-designed detector to an experimental physicist.

Hundreds of miles away from the rumble of heavy construction equipment in Newport News, Stoler and his colleagues have taken on the task of designing and building one of the detectors that will go into the smallest of the three experimental halls where high-energy electrons meet their targets. Although this project's modest $1 million budget constitutes only a tiny fraction of CEBAF's total cost, it represents a major, long-term commitment for the RPI team, which includes physicists, engineers and graduate and undergraduate students.

Developing the detector, required for distinguishing electrons from other types of particles that may pass through, has challenged the ingenuity of the researchers at every stage of the design phase. "At first, we thought it was going to be straightforward, but the project just got more and more complex – and more interesting," Stoler says.

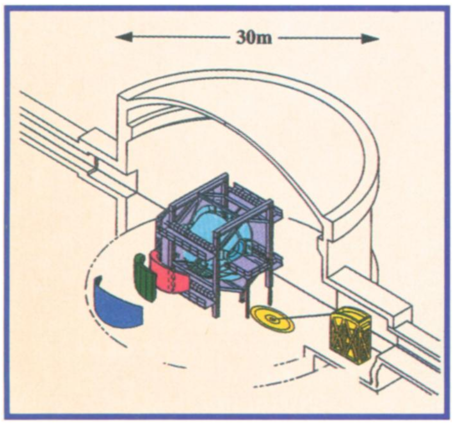
The concept underlying the RPI detector appears reasonably simple. A charged particle traveling at a rate greater than the characteristic speed of light in a gas generates a shock wave of light. Thus, a sufficiently fast, charged particle racing through the gas would produce a string of photons, which can be detected by photomultiplier tubes.

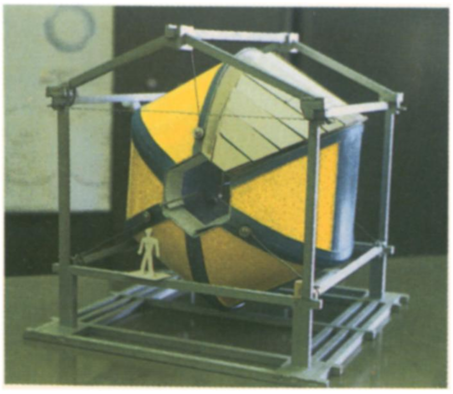
At CEBAF, such signals would allow researchers to distinguish between electrons – which are deflected by a target's protons or nuclei – and particles known as pions, which can be created in high-energy interactions between electrons and protons. Because deflected electrons would typically travel faster than any pions present, flashes of light in a detector in which the gas density has been properly adjusted would reveal the passage of electrons but not pions.

"It's a very delicate way of doing immediate particle identification," Stoler notes.

Known as Čerenkov detectors, such devices have been used for many years to identify high-velocity particles in accelerator experiments. "It's a known technology, and we had previous experience with it," Stoler says.

But because the new detector and all the paraphernalia required for its operation must fit into a severely confined space with a very odd geometry, the project proved far





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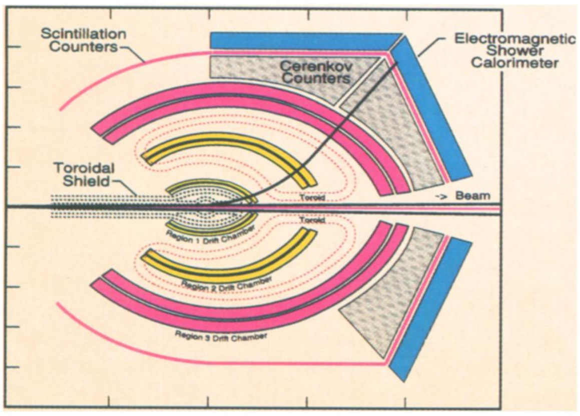
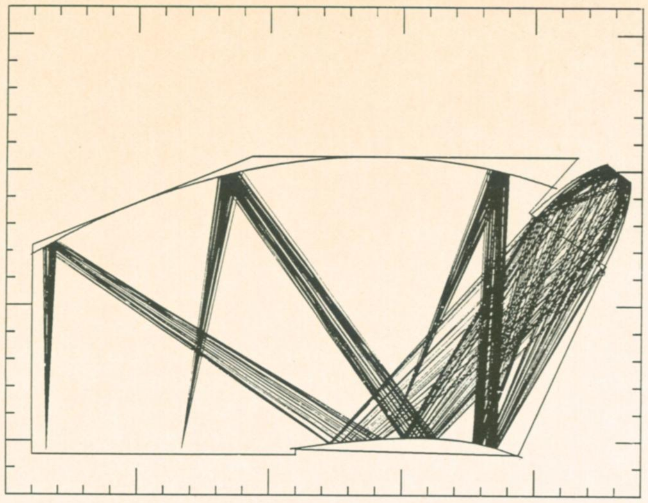


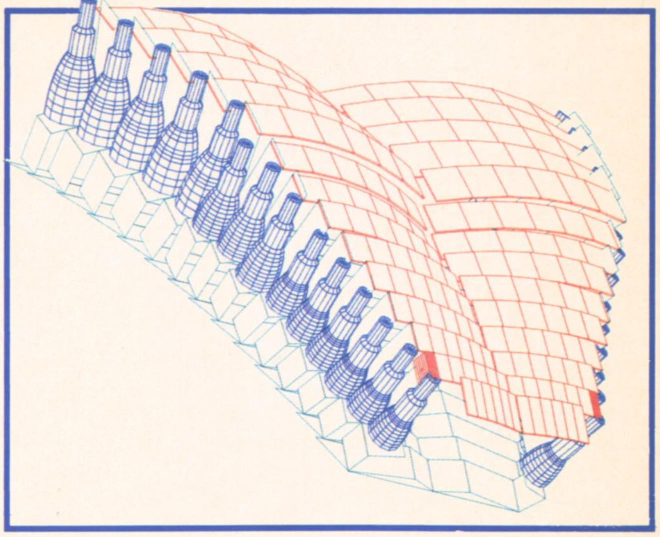
Diagrams: CEBAF

CEBAF's Hall B houses a specially designed spectrometer (top left). Electrons interact with a target surrounded by a magnetic field created by six superconducting coils (red dashed lines in bottom diagram). Four different types of detectors lie in layers that fit snugly between the coils and surround the target area. Most high-energy electrons (entering from left in bottom diagram) will pass unaffected right through the target, but a few will be deflected, traveling in succession through a drift chamber, a Čerenkov detector, a scintillation counter and an electromagnetic shower calorimeter. A scale model at RPI (top right photo) shows how the mirrored units that make up the Čerenkov detector in one of the six open areas between adjacent coils will fit into the spectrometer.



RPI

Left: In a typical, mirrored section of RPI's Čerenkov detector, high-speed electrons traveling from bottom to top will generate a cascade of photons that propagate in roughly the same direction as the electrons. Curved mirrors reflect these photons into a photomultiplier tube. This computer simulation illustrates the paths followed by photons resulting from the passage of three electrons through the chamber.



RPI

Above: This illustration shows one of the six units that make up RPI's Čerenkov detector. Electrons enter from the flat-mirror side (green) and generate photons. Curved mirrors (red), acting in combination with the flat mirrors, reflect these photons into photomultiplier tubes (blue). Although the diagram shows segments (red), each strip will actually consist of a single, smoothly curved mirror.

more difficult than anyone had anticipated.

Hall B, where the RPI detector will go, houses the so-called "large acceptance spectrometer." Its core consists of a specially designed set of six superconducting coils that generate a magnetic field to bend the paths of any electrons scattered by a target. Widely and equally spaced, these coils allow even electrons deflected by large angles to reach a series of detectors arranged in concentric shells around the target area.

Each type of detector provides somewhat different but complementary information about the particles that come through, says Bernhard A. Mecking, Hall B program manager at CEBAF.

But the spectrometer's open structure also leaves very little room for the groups responsible for the four types of detectors in Hall B to hide the cables and electronics necessary to operate the equipment. Moreover, because the detectors must be tucked between the coils and surround a large portion of the spectrometer, they can't have a simple, flat geometry.

And everything has to fit together, Mecking notes. Any slight change in configuration to accommodate, for example, an extra cable requires negotiations among the participating groups.

"That's what makes ours the most unusual gas Čerenkov detector ever built," Stoler says.

Computer simulations at RPI showed that an electron would typically generate about 100 photons of ultraviolet light in the brief interval during which it passes through a Čerenkov detector. Of that tiny output, researchers could expect to capture from six to 10 photons. But to have a reasonable safety factor built into the system, even one photon from an electron's track had to be sufficient to trigger a response.

"We had to design a system to somehow collect these photons as efficiently as possible, given the experimental situation," Stoler says. "That brought in the need for careful mirror design and high-quality photomultiplier tubes."

To meet these constraints, optics specialist Paul F. Yergin and his coworkers spent many months using computers to design an arrangement of elliptical and flat mirrors for efficiently reflecting and focusing the available light into photomultiplier tubes.

The tubes themselves, however, presented a more serious problem. To keep the open regions of the Hall B spectrometer free of obstructions, the arrays of photomultiplier tubes for actually detecting the photons had to fit into the narrow spaces behind the coils where no electrons would penetrate anyway. But this put the tubes into much higher magnetic fields than they can cope with and meant that the tubes required shielding in some way.

"We never thought that this would be a problem until we started the project, and it gradually dawned on us that it was the biggest one we had," Stoler says. "It looked pretty bleak for a while."

In the end, says Gary S. Adams, "We used a fairly standard approach, but we had to do it in a very small space. Nobody had ever faced those constraints before." That still leaves the problem of actually fabricating the complicated shielding system for each of the dozens of photomultiplier tubes required for the detector.

As the design phase winds down, a group of engineering students has started investigating techniques and materials for fabricating the high-quality curved and flat mirrors required for the detector. They face the challenging task of finding a rigid but moldable, lightweight, tough, reflective material that poses virtually no barrier to high-speed electrons on their way to the next detector in line. And the RPI group has to do it at a reasonable price.

"It's a very good experience for the engineering students," Stoler says. "They are now actually building prototype mirrors. They're also learning a lot about what goes on in the real world when they start negotiating with companies and find that the companies are willing to do things you need for about four times what you can afford to pay."

RPI's agreement with CEBAF calls for delivery of the first Čerenkov detector to CEBAF in early 1995. That seems a long way off, but given the scope and intricacy of the project — just one small, though important piece of the entire CEBAF jigsaw puzzle — it may barely suffice.

"Ultimately, the most important function we have here [at RPI] is the involvement of students in new kinds of experiences," Stoler says. "We're trying to educate our students to be knowledgeable about new materials, new techniques. When they go out into the industrial world, they'll carry these kinds of skills with them." ☐