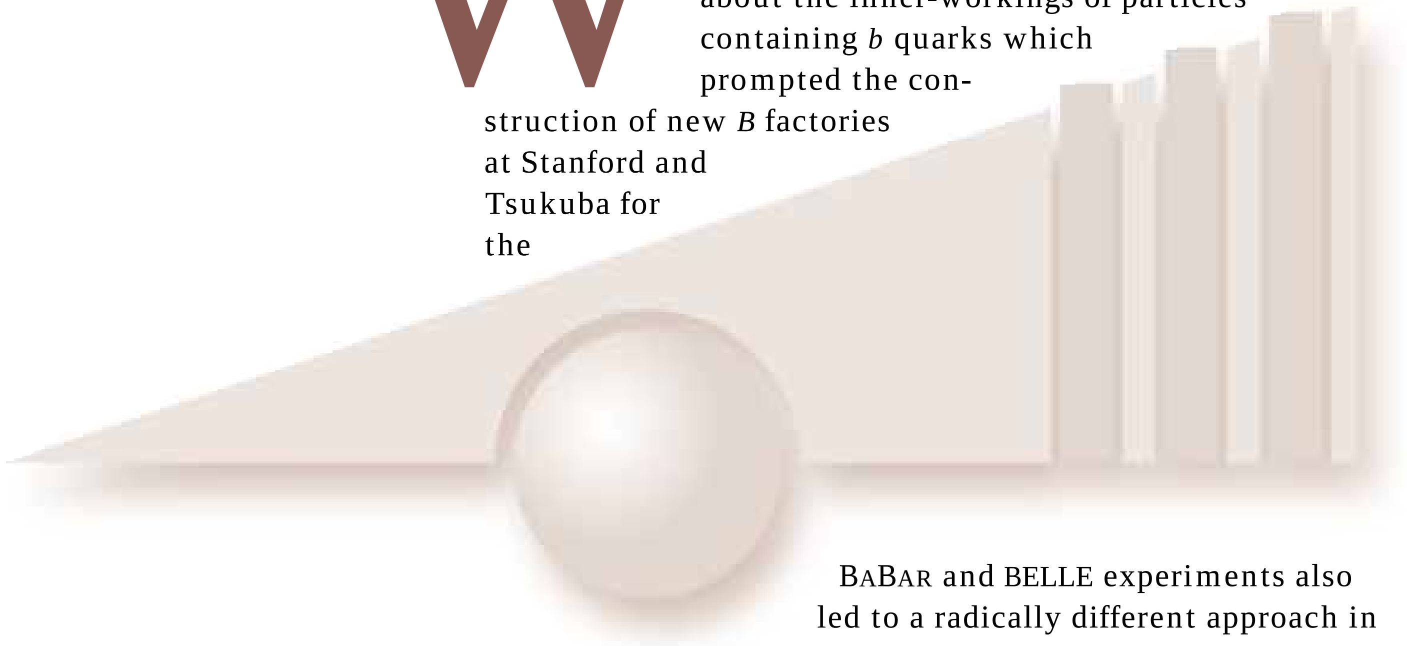
# HERA-B

## Variations on a Standard Model Theme

by ROY SCHWITTERS



WORLDWIDE INTEREST in learning more about the inner-workings of particles containing *b* quarks which prompted the construction of new *B* factories at Stanford and Tsukuba for the BaBar and BELLE experiments also led to a radically different approach in Hamburg called HERA-B. The scientific goals of HERA-B are similar to those of the new electron-positron collider experiments—searching for new phenomena beyond the realm of the Standard Model of particle physics by testing whether its ideas can explain subtle asymmetries among electric charge, space, and time on the subatomic level—but the experimental techniques employed are very different.

HERA-B uses protons from the 920 GeV HERA proton storage ring* at the Deutsches Elektronen Synchrotron (DESY) in Hamburg, Germany. Protons hit stationary nuclei in fine wire

---

**HERA is an electron-proton collider, but the electrons are not used by HERA-B.*

targets surrounding the beam producing hosts of subatomic particles, among which are particles containing *b* quarks that are detected and measured by the HERA-B apparatus.

***One of the advantages of the proton-wire approach is that sufficient collision rates are relatively easy to obtain and have already been demonstrated at HERA.***

## ACCELERATORS & DETECTORS CHOICES, CHOICES!

HERA-B, BaBar, and BELLE offer textbook examples of the diverse choices possible between types of beam and target particles, accelerators, and detectors for pursuing outstanding physics questions. These choices involve technical and financial tradeoffs of many kinds, but ultimately come down to judgments that are the art of experimental science.

HERA-B grew out of the pioneering studies of the *b*-quark system by the ARGUS group working on the DORIS electron-positron collider at DESY. In the early 1990s physicists associated with ARGUS also sought a higher-intensity collider to compete with new machines then being proposed at SLAC, KEK, and Cornell. DESY chose not to construct a *B* factory because of the cost and effort required, but as is so often the case, compelling science became the "mother of invention." ARGUS physicists recognized that *b* quarks could be produced in proton-nucleus collisions using the *existing* HERA ring. The choice puts severe demands on detector technology but eliminates the need to build two new storage rings.

The key new idea was ingenious: place a fine wire beside the beam stored in HERA and protons moving relatively far from the center of the beam will preferentially strike it because there are no other obstructions nearby. The proton-nucleus collisions are energetic enough to produce pairs of particles containing *b* and anti-*b* quarks that can be measured in an experiment. The fine wire would also precisely locate the point of collision, a significant technical advantage for experiments.

Protons behave quite differently than electrons in high energy storage rings because of their two thousand times larger rest-mass. Synchrotron radiation dominates the performance of high energy electron-positron storage rings but plays essentially no role in even our highest energy proton accelerators, the Fermilab Tevatron and HERA. Minor errors in the fields that guide electrons around storage rings can be completely masked by the ebb and flow of synchrotron radiation and the radiofrequency power needed to compensate for it. This is not the case with protons—their motion feels the sum of all minor perturbing influences over the millions and millions of miles they travel around a storage ring in the hours they are captured. The mechanics of chaos come into play and individual protons gradually migrate outward from ideal paths at the center of the beam, forming the "halo" of particles which hit the HERA-B target wires, while not affecting the other collider experiments; HERA-B runs simultaneously with them with little or no interference.

A critical factor in the success of the next-generation *b*-particle experiments will be the yield of "gold-plated" events, events displaying certain decay modes like $B^0 \rightarrow J/\psi K^0_S$ that are expected to manifest the particle-antiparticle asymmetries most eagerly sought. One of the great challenges to the accelerator physicists of the electron-positron *B* factories is achieving unprecedented luminosities required to produce sufficient numbers of events. One of the advantages of the proton-wire approach is that sufficient collision rates are relatively easy to obtain and have already been demonstrated in HERA.

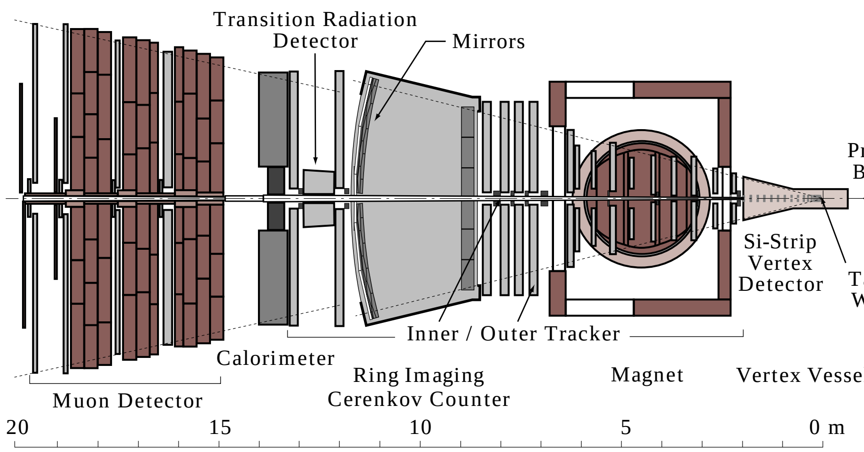
On the other hand, producing *b* quarks through collisions of protons and nuclei (or other protons) is considerably "messier" than by electron-positron annihilation—the strong interaction produces them frequently in many forms, but, unfortunately, at the HERA-B energy only about one pair of *b* quarks is produced for every *million* collisions. When one seeks particular gold-plated examples of *b*-quark events of most interest, *one-hundred billion* proton-wire collisions take place for every nugget found! The central challenge for HERA-B is how to find the desired events while rejecting enormous backgrounds. To do this, new levels of speed and complexity in the digital processing and selection of detector information—called "triggering"—will be required. It is interesting that, on paper, the projected capabilities of HERA-B, BABAR, and BELLE are quite similar even though the accelerator and detector challenges are vastly different. Our confidence in the proton approach is strengthened by the pioneering work of the Collider Detector at Fermilab (CDF) group who have published the best measurements to date on asymmetries involving the gold-plated events; CDF becomes a strong competitor after improvements to their detector and accelerator are completed next year.

HERA-B target wires present a "fixed-target" to HERA's protons. Kinematic rules dictate that the *b* quarks and all others produced in a collision are thrown forward into a relatively small range of angles about the proton beam direction. This has important implications for the design of the detector: one need only instrument a relatively small range of angles, but the number of particles passing through detector components is large, imposing severe requirements on detector element size and performance. In addition, components must stand up to all the other proton-wire collisions taking place. To collect enough gold-plated events in a reasonable period of time, the rate of ordinary collisions will be in the range 10–40 million per second. These particle rates are comparable to what will be encountered at CERN's Large Hadron Collider (LHC). Our ability to design and build detector components suitable for the formidable HERA-B environment rests on detector R&D carried out in anticipation of the LHC and the Superconducting Super Collider.

## COLLABORATION & DETECTOR—STATUS AND PLANS

HERA-B is being built and commissioned by an international collaboration comprising approximately 280 physicists from institutes in China, Denmark, Germany, Italy, Netherlands, Norway, Portugal, Russia, Slovenia, Spain, Sweden, Switzerland, Ukraine, and the United States. The collaboration formed in the early 1990s to design a detector optimized for *b*-quark physics. HERA-B was formally approved by DESY management in 1995. In spring 1999, major parts of the detector were commissioned with HERA beams while other components are still being built and installed during pauses in the program. The apparatus is expected to be completed by the end of 1999, and initial physics running is planned for winter/spring 2000.

*HERA-B collaboration members in front of the electromagnetic calorimeter. Parts of the muon detector can be seen in the left background.*



*Plan view of HERA-B indicating the major detector components and scale. The proton beam passes through the apparatus from right to left.*

A basic principle underlying the design of HERA-B is to record events exhibiting highly distinctive decays of *B* particles such as $J/\psi K^0_S$ mentioned previously, and to "tag" whether the trigger particles come from decays of *B* particles or anti-*B* particles by observing properties of the *other* particles in the same event. The decision to record an event is made by means of a specialized trigger processor that examines information from several detector subsystems within the 96 nanosecond period of time between collisions, followed by subsequent levels of processors using successively more computation and more time to reach a decision. Tagging is achieved by examining all the data recorded for the event from a multiplicity of detector types that respond differently to various kinds of particles. The choice of detector components and layout follows from these considerations.

Eight remotely positioned target wires surround the HERA proton beam. During a run, one or more wires are moved into the beam halo; a feedback system makes fine adjustments to wire positions to maintain the desired rate of proton-target-wire collisions. Downstream from the target wires, in the beam vacuum, are 136,000 channels of silicon detectors for accurately measuring trajectories of charged particles. The silicon detectors determine the proton-wire collision point and detect secondary vertices arising from decays of *B* particles. Decay vertices occur over distances of millimeters to centimeters from the wires because of the high energy kinematics involved, making them easily recognizable in the silicon detectors. Products of *B*-particle decays and other particles produced in the target wires next pass through a ten-meter-long system of tracking detectors and a dipole magnet for determining momenta. There are nearly 300,000 channels in the tracking system. Finally, a large ring-imaging Cerenkov detector, electron/photon calorimeter, and muon absorber/tracker aid in particle identification and photon detection. In total, HERA-B is about twenty meters in length and comprises roughly one-half million detector channels.

To date, the most vexing technical problem has been aging of tracking chambers—degradation in performance when exposed to the large fluxes of particles expected in the actual experiment. Extensive tests involving new fabrication techniques and operating procedures indicate that aging problems can be mitigated, but the effort has resulted in delays. The knowledge gained in these studies, however, is of great utility to future high-intensity hadron collider experiments such as those planned for the LHC.

## OUTLOOK

The next few years promise to be landmarks in the study of the building blocks of matter with the new experiments HERA-B, BaBar, and BELLE starting up and joining ongoing and upgraded efforts at other laboratories. The multiplicity of approaches will ensure full exploration of today's open questions and will provide road maps to future inquiries which become imperative in the happy event that the *b*-quark system reveals new mysteries not anticipated by the Standard Model. HERA-B plays a central role in this process both scientifically and in lessons to be learned about detecting *B* particles in intense proton collisions, the likely future path for this physics because of the superior numbers of *B* particles that can be produced in high energy proton collisions.

The technical challenges of building a new kind of detector system within tight constraints of time and resources, and the future promise of the proton approach make HERA-B a demanding, yet rewarding experience for the relatively small group of people creating this interesting variation among modern detectors.