BROOKHAVEN BULLETIN
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BROOKHAVEN NATIONAL LABORATORY

BNL Strives for Basic Truths With High Energy & Nuclear Physics

If someone had told Sir J.J. Thompson that his identification of the electron 100 years ago would lead to greater understanding of electricity and, thus, to huge and tangible benefits, he likely would have been pleased. But that wasn't his motivation for seeking the electron in the first place.

No, Thompson's motivation — like that of most high energy and nuclear physicists — was to discover a fundamental truth. That, after all, is what basic research is all about: striving to learn all there is to know about how the world and the universe work.

And that, after all, is what being human is all about. Robert Browning was a poet, not a physicist, but he understood this passion when he wrote, in 1855, "Ah, but a man's reach should exceed his grasp,/Or what's a heaven for?"

The heavens, as it turns out, are where most of the great physics questions were born. But it is here on Earth that most of them will be answered — by physicists, often using tools like particle accelerators or underground detectors to help them reach beyond their grasp.

In the past century, theorists and experimentalists have worked closely together, defining directions for basic research, proving them valid or invalid and revising the theories accordingly. And out of this fundamental quest has come much priceless knowledge and practical application — from the invention of the transistor and lasers in the 1940s and '50s to current advances in medical technologies, such as radiation therapies for cancer, and CAT and MRI scanners, and other diagnostic equipment.

When Brookhaven National Laboratory was founded in 1947 to explore peaceful uses of the atom, high energy and nuclear physicists flocked here to use the Lab's unique state-of-the-art facilities and to reap the benefits of working side by side with other innovative scientists.

This combination proved productive: Much that has been added to the world's basic understanding of the universe in the last 48 years has come from work done at BNL. This special edition of the Brookhaven Bulletin details some of those singular achievements, describes the Lab's current quests in high energy and nuclear physics, and shows how BNL physicists' reach is still exceeding their grasp as the Lab looks to the future.

"I have been fortunate to be part of this amazing quest since coming to Brookhaven as a summer student in 1952," said BNL Director Nicholas Samios. "It has been a thrilling, fruitful adventure — not just for physicists, but for all those who have profited from our discoveries and their spin-offs. It has also been my experience that each new discovery raises new questions, opening new avenues of inquiry.

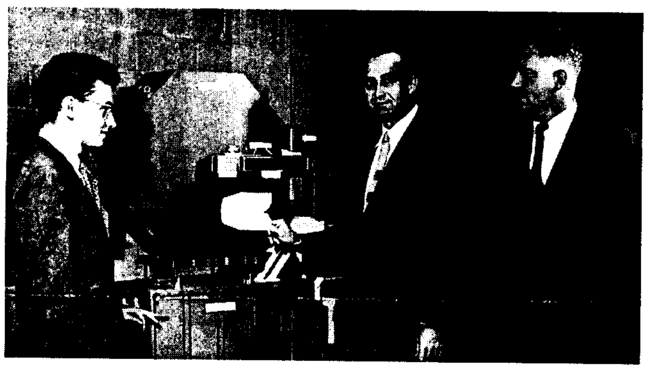
"We physicists are aware that the discoveries that excite us are often mysterious to non-physicists, and we know that we must do a better job of communicating our excitement and the reasons for it," continued Samios. "Nonetheless, we who do physics are grateful for the funding and other support that we have received from those who value it, and I look forward to this productive relationship continuing as we reach out to the 21st Century."

Accelerator Expertise — Almost 50 Years of Revolutionary Advances

In December 1946, the Subcommittee on Electronuclear Machines, which was formulating plans for construction of particle accelerators at the proposed Brookhaven National Laboratory, included these comments in its Initial Program Report:

"The most promising means of learning more about the nature of matter and of energy is the study of high energy particles and their interaction with atomic nuclei. . . . It is, therefore, natural that a major part of the Brookhaven Laboratory program should be devoted to the design, construction, and use of gigantic electronuclear machines that can produce such very high energy 'bullets' . . ."

Accelerators are devices that increase the energy of electrically charged particles, then smash them into targets where detectors record the results. And, in terms of accelerators, "gigantic" is a relative term. When the above report was written, no accelerator had yet produced particles in the billion electron volt, or GeV, region. Since meeting that initial challenge with the Cosmotron, BNL's accelerator physicists have continuously pushed the energy and intensity frontier of accelerators into uncharted territory.



Gathered around a quarter-scale model of the Cosmotron magnet in 1952 are the scientists who discovered strong focusing at BNL: (from left) Ernest Courant, M. Stanley Livingston and Hartland Snyder. Livingston holds a cardboard cutout of a quarter-scale strong-focusing magnet to illustrate the great reduction in size the principle made possible.

So named because its proton beam was to be comparable to cosmic rays, the Cosmotron became the world's first operating proton synchrotron in June 1952. In January 1953, it reached its full design energy — an astounding 3.3 GeV. Besides being the world's highest energy accelerator, the Cosmotron was the first synchrotron from which a beam of particles was extracted for use by experimenters and the first to produce all the types of negative and positive mesons known to exist in cosmic rays.

Though the Cosmotron ceased operating in 1966, one of its C-shaped electromagnets stands today outside Bldg. 911. With their gaps pointed outwards, the 288 magnets collectively held the beam together, but in a less than perfect orbit and in a less than tightly focused beam. So, to increase a particle beam's energy, intensity and collimation, while reducing the size and expense of a new accelerator, another principle of acceleration was needed.

That principle, called strong focusing, was discovered at BNL in the summer of 1952, by Ernest Courant, M. Stanley Livingston and Hartland Snyder, who proposed the alternating gradient scheme, which provides a strong focusing by alternating the way the magnet gaps face from one magnet to the next in the accelerator ring. This principle has been used in every major circular particle accelerator built since its discovery at BNL and, independently, in Greece.

Among the first was the aptly named Alternating Gradient Synchrotron (AGS), the Lab's second accelerator. The AGS reached its design energy of 33 GeV in July 1960. Ten times more powerful than the Cosmotron, the AGS was the highest energy accelerator in the world until 1968.

Today, the AGS is the world's most intense proton accelerator, delivering 6.3 x 10^{13} protons per pulse (ppp), or about 63 trillion protons to AGS experiments every 3.2 seconds — a factor of 63,000 greater than the 1 x 10^{10} ppp intensity that the AGS was originally designed to deliver.

Finally, the AGS is probably the world's most versatile accelerator: In addition to protons, since 1984, it has accelerated polarized protons, whose spins are all aligned

(continued in box on page 4)

Nobel Prizes and Other Major Discoveries at Brookhaven

The coveted Nobel Prize in Physics has been awarded to eight scientists for their work at Brookhaven. Also, a host of new elementary particles has been found as a result of research performed at BNL's proton accelerators — first the Cosmotron and then the AGS.

The Nobel Prizes

⚛**Theoretical breakthrough on parity violation** — In the summer of 1956, theoretical physicists T.D. Lee of Columbia University and C.N. Yang, of the Institute for Advanced Study and BNL, were intrigued by results of experiments at the Cosmotron. These experiments indicated that two particles — the tau and the theta — were identical in lifetime, scattering, behavior and mass. But their decay modes were different, meaning they had opposite parity and must, therefore, be two different particles.

T.D. Lee

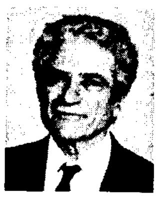
C.N. Yang

In physics theory, the rule of parity conservation — which states that the mirror image of a reaction is equally probable — was considered unbreakable. But Lee and Yang believed that the tau and theta particles might actually be the same particle if parity conservation is violated in the weak interaction — the force responsible for radioactivity and nuclear decay. Subsequent experiments performed at other institutions proved they were correct, and, for their insight, they were awarded the Nobel Prize in 1957.

⚛**Discovery of the muon-neutrino** —

Leon Lederman

Melvin Schwartz



Jack Steinberger

Leon Lederman, Melvin Schwartz and Jack Steinberger, who in 1962 were all associated with Columbia University, used the first neutrino beam in a high energy physics experiment at the then two-year-old AGS — and subsequently discovered the muon-neutrino.

Although not completely recognized until later, the muon-neutrino established the existence of different particle families. This first neutrino experiment also opened up a new area of experimental physics, and, in 1988, it garnered the Nobel Prize for the three pioneering scientists.

⚛**Discovery of CP violation** — In 1963, James Cronin and Val Fitch, both then Princeton physicists, began an experiment at the AGS to set strict limits on the validity of the CP symmetry principle. According to this principle, the laws of physics would stay the same if all particles were to be replaced by their antiparticles (charge conjugation, or C) while all their motions were replaced by their mirror images (parity, or P). In effect, physics would be the same even if time were reversed.

Val Fitch

James Cronin

The two physicists discovered that one kind of neutral K meson occasionally decays to two pi mesons — which meant that the CP symmetry principle was violated. So, in finding this violation of CP invariance in 1964, Cronin and Fitch placed a very stringent limit on symmetry and showed that the direction of time does affect the laws of physics.

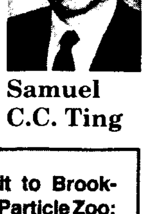
For finding this flaw in one tiny corner of the subatomic world, they were awarded the 1980 Nobel Prize.

⚛**Discovery of the J/psi particle** — In 1974, Samuel C.C. Ting of the Massachusetts Institute of Technology headed a team at the AGS, which was searching for new unstable particles, or resonances, formed in collisions between a proton beam and a stationary target.

The researchers found a sharp peak in the data, indicating that electron-positron pairs were originating from a single, huge parent particle with a mass of 3.1 GeV and a lifetime 1,000 times longer than that of other massive particles. The group called this new entity the J particle.

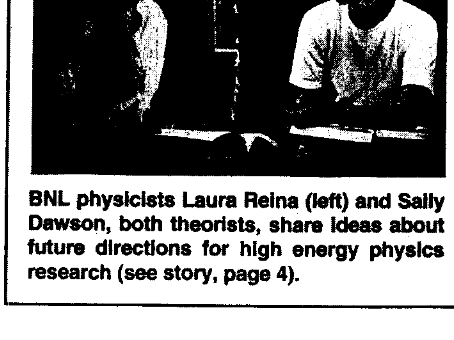
Meanwhile, a group led by Burton Richter at the Stanford Linear Accelera-

(continued on page 4)



Samuel C.C. Ting

The Inside Stories . . .



BNL physicists Laura Reina (left) and Sally Dawson, both theorists, share ideas about future directions for high energy physics research (see story, page 4).

A Visit to Brookhaven's Particle Zoo

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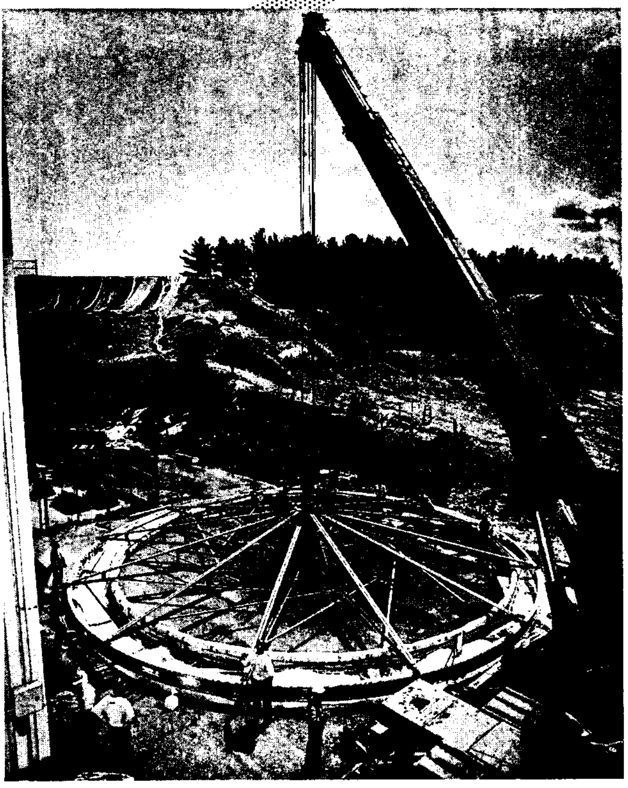
MUONS — World's Largest Superconducting Coil Takes Minute Muon Measure

Using the world's largest superconducting magnet coils, one of the world's smallest measurements — the magnetism of the muon particle — will be made at Experiment 821 (E821) at the AGS, starting in January. Scientists from 11 institutions in Germany, Japan, Russia and the U.S. have joined the BNL team in this venture.

The three BNL-built coils form a precision storage-ring magnet that will be used to refine the muon's g-2 measurement. Muons are electrically charged particles that spin on their own axes, acting like tiny magnets. When a muon travels in a magnetic field, it moves in a circle. Its spin axis rotates slightly faster than its momentum, so that its spin advances about 12 degrees each time the muon completes a circular orbit. The weak force is also carried by the muon, and virtual W particles, which carry the weak force, are part of the muon's electrical field of photons that it constantly emits and reabsorbs.

The muons emit Ws very seldom, but the magnetic field then "sees" or reacts to, the W rather than the muon. This is predicted to cause an increase in the 12-degree shift by 40 millionths of a degree — the measurement known as g-2. As any force felt by the muon would affect this spin advance, measuring the advance is a powerful way to determine if we understand how forces are carried, and whether there might be unknown forces at work.

Said the AGS's Gerry Bunce, E821 Project Manager, "We'll measure 30 billion muons, each orbiting about 1,000 times. We'll need to know the magnetic field exquisitely well within the region that the muons travel — a donut nine centimeters thick and 45 meters around. Our goal is to be sensitive to g-2 at 10 percent of the expected contribution from the W, or 0.4 millionths of a degree per orbit."



In 1992, "the coil on a string" — the completed outer coil of the 15-meter-in-diameter superconducting magnet for AGS experiment 821 — was being placed with two inner coils.

At CERN, the European particle physics laboratory, during the 1960s and '70s, g-2 was measured to a precision of eight millionths of a degree per orbit.

In the 1990s, however, the new technology being used at the AGS experiment promises an even better result. For example, with the Booster on line at the AGS, a much greater intensity of muons is available. Also, a new beam line and magnetic kicker inside the g-2 ring will make collecting muons ten times more efficient.

In addition, the magnetic field will be 20 times more uniform than before, a key to detecting this minuscule effect. A new field-measuring system is now on a trolley, able to be moved without turning the field off. Another enhancement to uniformity will be the mammoth, continuous-coil magnet, which replaces 40 separate, non-superconducting magnets used at CERN. Designed and built at BNL with special winding and milling machinery and unique expertise in welding and machining, final coil variations were only about 0.3048 of a millimeter over seven meters of radius.

This January saw the successful first test to cool the coils down to operating temperature, five degrees above absolute zero. The next milestones are to complete the cooling system, turn on the magnet, incorporate collaborators' components, then prepare for taking data in January 1996. — Liz S[illegible]rt

LEPTONS — In the lepton section of the zoo, the weakly-interacting particles *electron*, *muon*** and *tau* can be found with their respective associated neutrinos*** — *electron neutrino*, *muon neutrino** and *tau neutrino*.

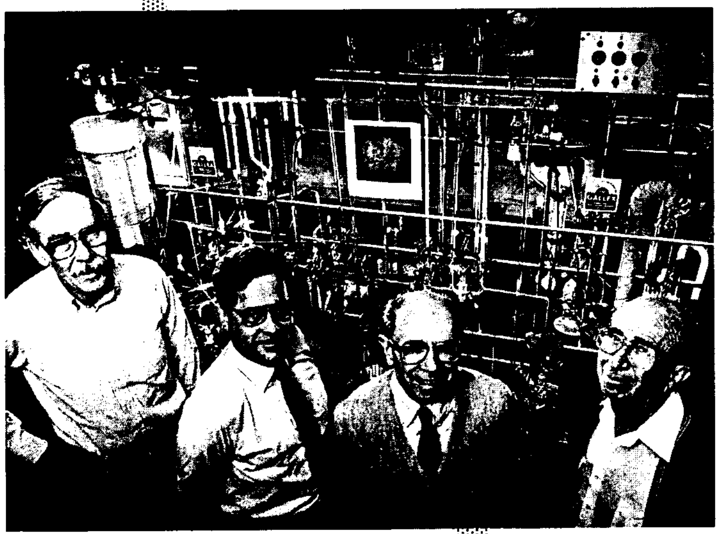
****Discovered at BNL in 1962; Nobel Prize in 1988 (see story on page 1).***

***See story above. ***See story below.*

NEUTRINOS — GALLEX Deepens Solar Puzzle

Solar neutrinos are the elusive quarry of the Italy-based gallium experiment known as GALLEX, a collaboration of chemists and physicists from BNL and nine other international institutions. Theory predicts that 65 billion of these ghostlike particles, produced in the burning core of the sun, pass through each square centimeter of the Earth's surface every second.

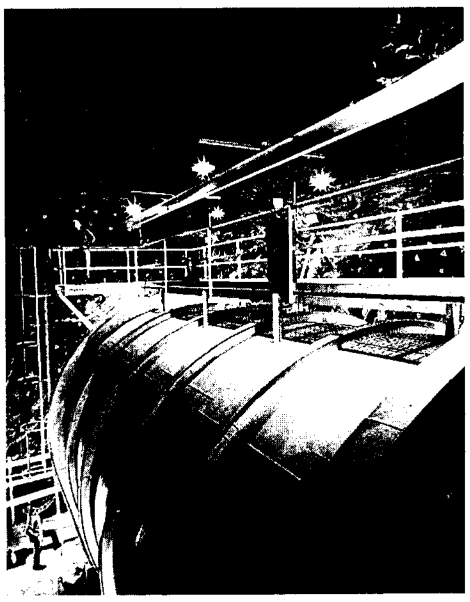
But of the total of solar neutrinos predicted to arrive on Earth, only about 60 percent are actually observed.



In their laboratory are the BNL scientists in the GALLEX collaboration: (from left) Keith Rowley, Richard Hahn, Joseph Weneser and Raymond Stoenner. Not shown: John Boger.

GALLEX's findings were first reported in 1992. They deepened the "solar neutrino puzzle" — a mystifying deficit observed first in the chlorine-based detector run by BNL's Ray Davis in the 1970s; and again in the water-based Kamiokande study in Japan in 1990.

Too few neutrinos indicate that either the solar model of theory should be revised or that new neutrino properties — new physics — might exist.



The solar neutrino puzzle came to light 1.6 kilometers underground, in this BNL experiment, which ran from 1967 to 1985, in the Homestake Gold Mine in Lead, South Dakota.

Both earlier experiments detected neutrinos produced in *secondary* solar fusion processes. But the GALLEX experiment is sensitive to a *broad* spectrum of solar neutrinos, especially those of low energy produced in the sun's *primary* nuclear reaction.

Yet GALLEX confirmed the deficit. Located deep underground in the Italian Gran Sasso Physics Laboratory, the GALLEX tank contains 30 metric tons of gallium in 101 metric tons of a solution of gallium chloride, water and hydrochloric acid. A neutrino entering the tank can transform the isotope gallium-71 into radioactive germanium-71 (Ge-71). Approximately each 28 days since 1991, the Ge has been removed and purified chemically and its radioactive decay counted to reveal the very small number of reactions caused by neutrinos.

In November 1994, preliminary results of a second major GALLEX experiment validated their solar neutrino findings. Using an "artificial sun" of chromium-51 (Cr-51) to provide a known number of "substitute solar neutrinos," the new test proved that, to within a 10 percent error margin, *all* of the solar neutrinos arriving on Earth should have been detected. "So, the solar-neutrino deficit we observed was not caused by an artifact," said Richard Hahn, leader of the present BNL GALLEX team.

Interestingly, neutrino energies from the Cr-51 source are close to those from one of the sun's secondary reactions, with beryllium-7 (Be-7). Thus, GALLEX should also detect the Be-7 solar neutrinos. Yet its result is essentially the value expected from the sun's primary reaction only, implying an extra puzzle: The Be-7 neutrinos seem to missing. — Liz Seubert

IN SEARCH OF THE PARTICLE ZOO

When BNL researchers are not tending particles on the Lab site, they might be found at another of the world's laboratories that house the particle zoo. Two labs that are frequently mentioned in this publication are:

- **Fermi National Accelerator Laboratory (Fermilab)** — The DOE laboratory near Chicago, where particles are housed in the ring of the Tevatron, in which protons and antiprotons collide at energies of almost 2 trillion electron volts (TeV).
- **CERN, the European Particle Physics Laboratory** — Now building the Large Hadron Collider (LHC), in which protons will ultimately collide at energies of about 14 TeV (see page 4).

HEAVY IONS — Exploi

After BNL's RHIC comes on line in 19
smashed into each other at six points ar
in hopes of recreating quark-gluon plasma, a
high-density phase of matter that is though
shortly after the Big Bang.

The Big Bang, cosmologists believe, was th
universe. Before it, the universe was compres
Immediately after this explosion, the unive
made of a plasma of elementary particles cal
But instants later, as the newborn universe
the quarks combined and were held togeth
particles called hadrons, which included pro

Because the ultrahigh pressures and tempe
it only lasted a moment, such a plasma of qua
been seen in the natural universe since the
unstable quark-gluon plasma can now only
these conditions in a high-energy particle acc
the collision of heavy ions at very high energies within RHIC.

While no living creatures were around at the time of the Big Bang, the "mini bang" that will take place within RHIC will have two major witnesses.

At the 8 o'clock position around the RHIC ring, will be a detector called PHENIX, which is short for Pioneering High Energy Nuclear Interaction Experiment. This collaboration of 355 scientists is led by spokesman

Surveying plans for
tor: (from left) Wa
Project; Shoji Nagan
versity; Glenn Young
Laboratory; Sam Ar
Department; and L
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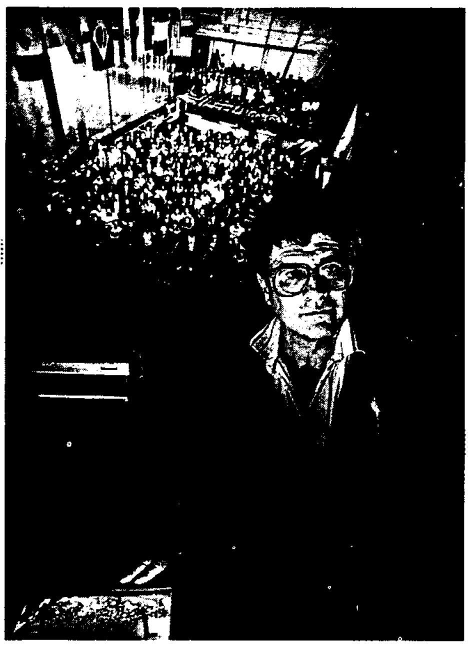
FERMIONS — Any visit to
ı particle zoo begins with the funda-
ıtal *fermions*. Physicists believe that two
of fermions are fundamental particles:
cannot be broken down into anything
and all other particles are formed from
ıem. These two kinds of fermions
: *quarks* and *leptons*.

TOP QUARK — D-Zero Finds It's There and It's Massive



BNL's Serban Protopopescu, who led D-Zero's top-quark analysis group, displays a photo of the detector and many of those who worked on it.

QUARKS — Like the animals in Noah's Ark, these elementary inhabitants of the particle zoo come in pairs: *up* and *down* quarks make up all ordinary matter; the other two pairs — *strange* and *charm*, and *bottom* and *top** quarks — are progressively more massive and can only be observed in particle accelerators.

**See story below.*

A worldwide search that began in 1977 ended on March 2, 1995, when the discovery of the top quark was announced by two rival experiments at the Tevatron collider at Fermilab. While one of the discoverers is a collaboration known as the Collider Detector at Fermilab (CDF), the other is a 42-institution collaboration called D-Zero, which, since its inception in 1983, has included members of the Omega Group, led by BNL Senior Physicist Howard Gordon, in BNL's Physics Department.

As predicted by a particle-physics theory called the Standard Model, the top is one of six "flavors" of quarks, which are paired in three generations: up and down, charm and strange, and top and bottom. While these elementary particles were all present at the birth of the universe, only the up and down quarks exist today in ordinary matter, making up the protons and neutrons found within atomic nuclei.

The other two generations of quarks have not occurred naturally since the Big Bang, so these four quarks have to be created by high-energy accelerators. Since the 1977 discovery of the bottom quark, also at Fermilab, physicists around the world had hunted for the last holdout — the top — at higher and higher energies, ultimately finding it using the Tevatron, which is the world's highest energy collider at present.

r witnessing hundreds of thousands of proton-antiproton collisions a second and having seen its first top-quark candidate produced by one of these collisions two years ago, D-Zero made its announcement based upon the analysis of 17 events, 11 of which provided enough information to measure the quark's mass.

Its massive size is the reason why the top quark eluded physicists for nearly 20 years: D-Zero found that the top tips the scale at 199 billion electron volts (GeV) — making it heavier than many atoms. This finding is consistent with the top-quark mass of 176 GeV reported by CDF.

The Omega Group contributed expertise, hardware and software to the D-Zero experiment and, hence, to the top-quark discovery: BNL Physicist Bruce Gibbard heads D-Zero's on-line data acquisition, and BNL Physicist Serban Protopopescu led the top-quark analysis group and continues as leader of D-Zero's off-line data reconstruction and analysis.

As it turned out, the discovery-yielding analysis relies heavily upon measurements made by one of the D-Zero detector's four major systems: the central calorimeter, which was designed, engineered and built by the Omega Group. — Marsha Belford

MESONS — Every quark has an *antiquark*, identical except that all of its charge-like properties are opposite to the quark's charge-like properties. However, it's not possible to put them in the same cage for a very long time: When quarks and antiquarks get together, they don't get along very well; in fact, they eventually annihilate each other or decay. Still, quarks and antiquarks can live together briefly, and when together they are called *mesons*. Mesons include *pions* and *kaons**.

**See story below.*

ing the Mini Bang With RHIC

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Ceremoniously beginning construction of the STAR detector on March 17, 1995, are: (from left) RHIC Project Head Satoshi Ozaki; STAR Project Director Jay Marx, Lawrence Berkeley National Laboratory; BNL Director Nicholas Samios; and RHIC Project Manager Jim Yeck of DOE's Brookhaven Group.

the PHENIX detec-
lter Kehoe, RHIC
ıiya, Columbia Uni-
Oak Ridge National
nson, BNL Physics
eo Paffrath, RHIC

Shoji Nagamiya of Columbia University. The other major detector is named STAR, for Solenoidal Tracker at RHIC; to be found at 6 o'clock, it is being built by 350 scientists led by spokesman John Harris of Lawrence Berkeley Laboratory.

While both will be looking for evidence of quark-gluon plasma, each detector will go about it in a different, but complementary way.

In addition to looking at hadrons, PHENIX will study photons and leptons, which are produced directly, as a plasma is formed in the gold-on-gold collisions at the center of the collision volume. PHENIX will be able to conclude that quark-gluon plasma was formed if several of the expected "signatures" of a plasma are found in the spectra of these particles.

Meanwhile, STAR will concentrate on the hadrons produced relatively late in the collision process and found at the surface of the collision volume, through a detailed, event-by-event analysis. The collective properties of thousands of hadrons produced in each collision will hold clues as to whether or not they resulted from the "freeze-out" of a quark-gluon plasma. — Marsha Belford

KAONS — Forbidden Violations, or . . . Searching for Rare K Decays

Some people climb mountains because they are there. And some scientists — particularly at the AGS — search for rare kaon decays, because, supposedly, they are *not* there!

As members of the meson family, kaons, or K particles, are unstable. Depending on their type, they decay after only 50, 12 or one-tenth nanoseconds into lighter mesons, usually pions. But, once every several billion times, K particles can decay in ways "forbidden" or unpredicted by theory, disintegrating in processes called rare K decays.

One form of K particle, the neutral K-long, was discovered at BNL's Cosmotron in 1956 — identified by the way it decayed into three pions as the Standard Model had predicted. Then, in 1963 in the AGS, a neutral K-long was shown to decay sometimes into only two pions. This evidence of CP violation (see story, page 1) was the first known rare K decay.

The discovery was of such interest for physics that, in 1980, it won the Nobel Physics Prize. That same physics interest — the compulsion to open windows beyond the standard model — continues to inspire experiments on forbidden or highly suppressed K decays.

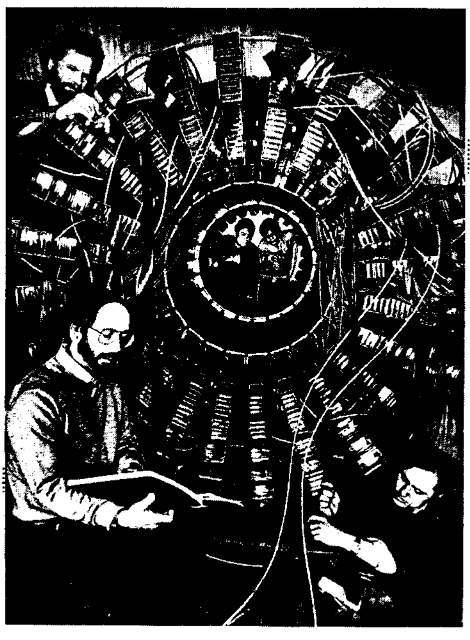
Since the world's best source of K particles is now the AGS, many rare K experiments take place at BNL. Over the years, not only the kaon beams, but also the technology for detecting and tracking kaons has been improved to extraordinary sensitivity.

For example, the upgraded detector for Experiment 787 (E787) can now make a trigger decision on an interesting event in just 12 microseconds instead of the 250 microseconds needed in 1992. The team's BNL, Princeton University, Canadian and Japanese scientists search mainly for a positively charged K (K^+) decaying into a positively charged pion (π^+), a neutrino and an antineutrino, an event predicted to occur only about once in 10 billion decays.

In E865, a collaboration of Russian, Swiss and U.S. physicists is looking for a K^+ decaying to a π^+, an electron and a muon. In a third major AGS experiment, E871, the University of California, Irvine; the University of Richmond; Stanford University; the University of Texas at Austin; and the College of William and Mary hope to see K-long decay to a muon and an electron.

If no unusual findings result, these experiments are still a valuable confirmation of the Standard Model. But if an experiment reveals a K decay that is forbidden — it would be a gateway to new physics.

— Liz Seubert



Checking the connections within the detector for AGS Experiment 787 are BNL physicists: (top) Steven Kettell, (bottom, from left) Laurence Littenberg, Steven Adler, (center, from left) Kelvin Li and I-Hung Chiang.

ONS — Quarks really like to hang out with each
strongly that a single quark has never been detected. Up
exa , gang up in triplet combinations to form *protons* and
oin forces as *nucleons* to form the *nuclei* of *atoms*. Most atoms
electrons orbiting their nuclei. If some electrons are stripped
tor, the atom becomes an *ion*. When it's one of the heavier
*heavy ion**.

**See story above.*

Into the Future — Experiments Slated for 1999 and Beyond

BNL physicists plan to explore the mysteries of matter in the 21st century through several major areas of experimentation, including: the search for quark-gluon plasma at RHIC and the search for the Higgs particle at the LHC.

In the RHIC tunnel where two rings of superconducting magnets are now being assembled: (from left) BNL Director Nicholas Samios, RHIC Project Head Satoshi Ozaki and Thomas Kirk, BNL Associate Director for High Energy & Nuclear Physics.

RHIC — Back to the Beginning

RHIC is expected to recreate the conditions and matter that existed at the beginning of the universe. In this world-class accelerator at Brookhaven, two beams of heavy ions will whirl in opposite directions around a 3.8-kilometer (2.5-mile) circular tunnel at nearly the speed of light, and collide with an energy of 100 billion electron volts for each nucleon contained in the ion. Under these hot, dense conditions, ordinary nuclear matter is expected to be transformed to a quark-gluon plasma — the matter that was created just moments after the Big Bang.

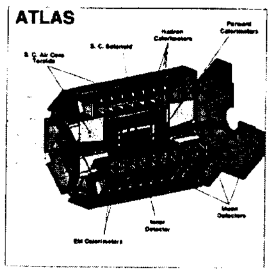
Begun in 1991, construction of the $500 million collider is past the halfway mark, with completion slated for 1999. RHIC will use the AGS and other existing facilities on the Laboratory site to preaccelerate and inject heavy ions into the collider.

Over 700 researchers from 81 institutions in 15 countries will perform experiments at RHIC based on two giant detectors, known as STAR and PHENIX (see story, page 2), and two smaller ones whose acronyms are PHOBOS and BRAHMS.

Large Hadron Collider (LHC) — A U.S./European Collaboration?

Now under construction at CERN, the LHC will be the world's highest energy proton accelerator and the only one at which the massive and elusive Higgs particle might be found. But the accelerator's completion date is still undetermined.

If the U.S. does not share the $2 billion cost of building the LHC, the 19-member European community that sponsors it may have to settle for a two-stage construction plan. By the year 2004, the accelerator would function at an energy of 10 trillion electron volts (TeV), or 5 TeV in each ring, and it would be upgraded to 14 TeV, or 7 TeV in each ring, in 2008. Though 14 TeV is considerably lower than the 40 TeV collisions that were anticipated in the now canceled U.S. effort for the Superconducting Super Collider (SSC), it is much higher than the 1.8 TeV attained by the Tevatron at Fermilab, currently the world's highest-energy accelerator. And physicists worldwide believe that the LHC could answer many of the questions they had hoped would be answered by the SSC.



Schematic for ATLAS, a detector proposed for the LHC.

Thus, said Thomas Kirk, BNL's Associate Director for High Energy and Nuclear Physics, "It's desirable for the U.S. physics community to bring the LHC to full fruition by 2004. In fiscal year 1996, DOE is committing $6 million to the project. In April 1995, DOE and CERN began discussions aimed at identifying U.S. involvement at the $400 to $500 million level. The U.S. Congress would have to vote on the proposed spending plan."

Two DOE labs — BNL and Fermilab — would likely take a lead role in building the two large LHC detectors, known as ATLAS and CMS. Kirk explained, "Brookhaven would have expertise in building ATLAS because we had already developed similar detectors for the SSC." — Diane Greenberg

Brookhaven's Theorists — Seekers of Symmetry

Scientific discovery comes from observation, but, while some scientists are mainly involved with actual physical observation in experiments, others prefer looking at various results to see how they could connect — might there be some pattern indicating where to look for more data? These symmetry seekers are the theorists, who spin webs of ideas to span and then reach beyond experimental results.

The ideas of high energy theorists, who are mainly concerned with the interactions of particles at very high energies, are linked at a fundamental level with the ideas of nuclear theorists, who focus on the nuclei of atoms. In BNL's Physics Department, the High Energy Theory Group (HETG), headed by William Marciano, and the Nuclear Theory Group (NTG), led by Carl Dover, work closely together at the forefront of theoretical physics, stimulated by the visits of distinguished scientists from all over the world.

BNL was put on the theoretical physics map as early as 1954, when C.N. Yang, the Institute for Advanced Study and BNL, and R.L. Mills, a doctoral student from Columbia University, wrote the Yang-Mills theory, a paper that became the foundation of all particle theory — "perhaps the most important piece of theory in the last 50 years," according to Marciano.

Because office space was limited, Mills had a desk in Yang's office. "So, I've never minded asking our postdocs to share offices with visitors," observed Marciano. "You never know what may come of it."

Two years later came another landmark paper — the Nobel Prize-winning treatise on parity violation by Yang and T.D. Lee, Columbia University (see story, page 1), which was inspired by experimental results from BNL's Cosmotron.

Direct interaction with experiments at the Lab is characteristic of BNL theory. A recent example is A Relativistic Cascade (ARC), an innovative computer model that evaluates the hadronic content of heavy-ion data. Originated by Sidney Kahana, ARC was developed by him, Thomas Schlagel and Yang Pang, all of NTG. ARC uses experimental data as input to make predictions for nucleus-nucleus collisions.

Already, ARC has predicted significant experimental results: In the distribution of protons from central gold-on-gold collisions at a beam energy of 11.6 billion electron volts per particle, ARC predictions closely matched the data observed in Experiment 866 at the AGS.

When experiments start at RHIC, each collision will produce thousands of particles. "ARC should provide some reliable insight as to where to look first for events of interest," said Kahana.

The NTG has long been a world leader in hypernuclear and other strangeness-related physics. Recently, Carl Dover, John Millener of NTG, and Avraham Gal, Hebrew University, proposed new forms of nuclei containing many units of strangeness with even the rare cascade-minus playing a significant role. In the past, Dover and collaborators have led the design of experiments seeking the doubly-strange H-dibaryon, a particle of fundamental significance. Important work on solar neutrinos by NTG's Joseph Weneser and Tony Baltz has tied in with BNL's contribution to the GALLEX experiment (see story, page 2).

In 1979, Michael Creutz, HETG, thought of applying existing "Monte Carlo" or probabilistic computational methods, to relativistic quantum field theory, the primary tool of the elementary particle physicist. By applying Monte Carlo methods, in which statistical sampling is done over a three-dimensional lattice to get a probable approximation of the solution to a problem, a field can be described on a lattice. This allows theorists to demonstrate aspects of quantum chromodynamics (QCD), the theory proposed to explain the interactions of quarks. Today, Creutz and Amarjit Soni, continue to develop this technique.

The HETG program also includes work by Robert Pisarski and Laurence Trueman, on field theory with emphasis on finite temperature and density effects — important for investigating the possible properties of the quark-gluon plasma expected to be formed in RHIC experiments.

Theorists Sally Dawson and Frank Paige study perturbative quantum chromodynamics and collider phenomenology, to solve problems in particle production and new physics signatures at, for example, the Tevatron at Fermilab, the LHC at CERN and the muon collider proposed for BNL (see story at left).

Electroweak physics, in which the weak and electromagnetic forces are combined into a single theoretical framework, is the focus of a fourth HETG interest. Marciano and Laura Reina look, for example, at the possible properties of the postulated Higgs boson and ways to observe it. Electroweak physics is also the quarry of such precision experiments as the muon g-2 measurement ongoing at the AGS (see story, page 2).

As Peter Bond, Chairman of the Physics Department, summed up: "The synergism between theory and experiment is key to progress in understanding nature at a fundamental level." This synergism is alive and well at BNL. — Liz Seubert

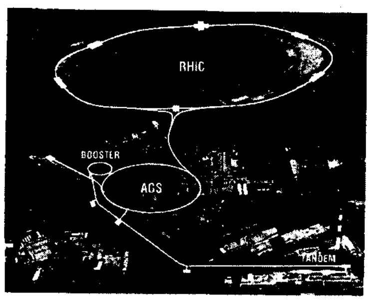
Seen behind the theorists' story is the doodle pad used by T.D. Lee during discussions with C.N. Yang that led to their Nobel Prize-winning work at BNL during the summer of 1956.

Accelerator Expertise (cont'd)

in the same direction, and, in 1986, a transfer line between BNL's Tandem Van de Graaff Accelerator and the AGS made it possible for physicists to experiment with heavy ions at the AGS.

All three AGS physics programs have been enhanced by both the 1992 addition of the Booster, a small-but-mighty intermediate accelerator, and extensive upgrades to the AGS over the years.

This year, for example, polarized proton acceleration reached 25 GeV.



The chain of accelerators that makes possible the Relativistic Heavy Ion Collider.

And researchers are experimenting with heavy ions as heavy as gold to see what happens to nuclear matter under conditions of extreme temperature and density. Ultimately, these physicists are looking for quark-gluon plasma — so they are looking forward to the completion of RHIC, BNL's Relativistic Heavy Ion Collider, by 1999 (see story at top).

While RHIC will take experimentalists into the future of nuclear physics, physicists at BNL's Center for Accelerator Physics (CAP) are looking into the future of particle physics.

Strong focusing has made possible truly "gigantic" accelerators — the LHC under construction at CERN has a design energy of 14 trillion electron volts (TeV). But LHC will also be 27.2 km (17miles) in circumference — nearly 300 times as big as the Cosmotron. Clearly, if new frontiers of high energy physics are to be explored, novel methods of accelerating particles are again required.

That's where CAP comes in. Established in 1987, CAP is now exploring the concept of colliding muons.

In a muon collider, one positively charged and one negatively charged beam would smash into each other at energies up to 4 TeV. Unlike protons, which are made up of quarks, muons are point-like particles, so they do not split the energy load at the point of collision.

Therefore, a 1.4-TeV muon collider might be comparable to the 14 TeV LHC — but it would be about ten times smaller and much less expensive. And it would continue BNL's almost 50-year tradition of truly revolutionary advances in accelerator design. —Marsha Belford

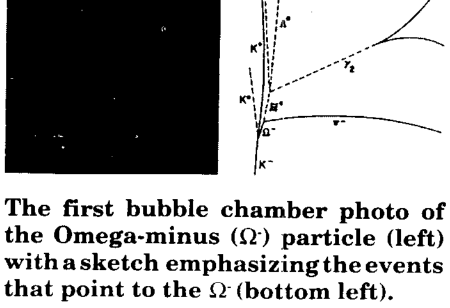
Prizes & Discoveries (cont'd)

tor Center, found the same particle, which they called psi. Ultimately, the J/psi particle was found to be composed of a new so-called "charmed" quark bound to its antiquark. Not only was this the first experimental indication of the charmed quark, it also made it clear that quarks are real entities, not just mathematical inventions. For this discovery, Ting and Richter shared the Nobel Prize in 1976.

Numerous Discoveries

Another significant physics discovery came from the Cosmotron's unprecedented energy of 3.3 GeV, which enabled scientists to provide experimental confirmation of the theory of associated production of strange particles. Strangeness, a particle characteristic related to the strong interaction that keeps quarks bound together, is now fundamental to an understanding of particle physics.

Among the host of new particles discovered at the Cosmotron was the K meson, which later led researchers to CP violation.



The first bubble chamber photo of the Omega-minus (Ω^-) particle (left) with a sketch emphasizing the events that point to the Ω^- (bottom left).

At the AGS, the Omega-minus and the charmed baryon were among the most important particles found, and both discoveries were made by teams led by Nicholas Samios, now BNL Director.

In 1964, a BNL/Rochester/Syracuse group was the first to use the 203-centimeter (80-inch) bubble chamber, a device in which particles interact in liquid hydrogen, leaving tracks that can be photographed and analyzed. The group found the Omega-minus within two weeks, a particle that formed the foundation for the development of quark theory.

In 1975, using the 2.13-meter (7-foot) bubble chamber at the AGS, a BNL group discovered the charmed baryon, a particle made of three quarks. This finding reinforced the interpretation of the J particle and was crucial in establishing that there was a new member of the quark family — the charmed quark. — Diane Greenberg

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