Brookhaven National Laboratories is home of the Relativistic Heavy Ion Collision (RHIC) Experiment where hundreds of physicists from several countries and various universities collaborate in an effort to better understand our Universe. Theorists believe that in addition to the familiar solid, liquid and gas, there is a fourth state of matter, called quark gluon plasma, QGP. The atom together with its cloud of electrons was thought to be the most basic unit of matter until Rutherford’s alpha particle scattering experiments on thin gold foils led to the discovery of the nucleus. Electrons, protons and neutrons were then thought to be elemental units. However, around 1970 AD physicists learned that protons and neutrons have a substructure made of quarks that are held together by gluons. Based on Rutherford’s discovery, accelerator physicists conducted nuclei collisions and found particles within the nucleus. Study of elementary particle scattering and theoretical considerations led physicists to believe that under the proper temperatures and pressures, quarks and gluons could be released from protons and generate a high energy state called quark gluon plasma.

The Universe is thought to have existed in a quark gluon plasma state in the first microseconds after the Big Bang. Following the Big Bang, as the Universe expanded and cooled down, the quarks went on to form protons. As the Universe cooled further, protons combined with electrons to form neutral atoms that eventually formed large gaseous aggregates, which coalesced into the formation of stars. Stars are extremely hot and dense in their core where hydrogen atoms are dislocated. Protons have very large velocities and collide
with one another at very high rates. A large fraction of the collisions lead to the fusion of hydrogen into deuteron and helium nuclei. This process of nuclear fusion continues throughout the life of stars and leads to the production of all elements lighter than iron. At the end of their lives, massive stars burst in a so-called supernovae explosion. These explosions are so violent and rapid that they are believed to have produced elements heavier than iron, which combine into the atoms and elements that make up the Universe, as we know it today. Consequently, a working knowledge of quark gluon plasma will yield an understanding into the early stages of the Universe and possible future applications as well.

**Solenoidal Tracker at RHIC, STAR**

The Relativistic Heavy Ion Collision (RHIC) Experiment consists of accelerating gold ions to nearly the speed of light and colliding them in order to determine if quark gluon plasma results from the collision. During the experiment, two gold ion beams that transverse a circular ring in opposite directions are forced to intersect at four locations where experiments STAR, PHENIX, PHOBES AND BRAHMS are designed to study the particles produced by the gold collisions. During a typical run of the experiment, the gold ionic beams circle the three-mile ring approximately 80,000-times per second for ten hours. The diameters of the beams are so small until a collision actually takes place about one-tenth of time the beams are set to intersect. Nonetheless, the collisions generate a tremendous amount of data that is later analyzed and published in scientific journals such as Physical Review and Journal of Physics and posted on the Internet.

Detectors placed at each of the aforementioned locations around the ring are designed to collect certain data during a collision. The Solenoidal Tracker at RHIC, STAR, which is the approximately the size of a two-story, two bedroom apartment, is essentially a gaseous Time-Projection Chamber, TPC, surrounded by a magnetic field. After a collision, charged particles travel along helicoidal
trajectories within the chamber. An intricate network of about twenty-five detectors records various aspects of a collision. Included among the many devices at STAR is the Photon Multiplicity Detector, PMD, which counts the gamma rays that are emitted from an ionic collision. During the analysis of the 2004 run of the experiment, engineers speculated that spark damage to portions of the diode network mounted on the gassiplex boards might have contributed to some PMD technical difficulties. The Research Experience for Teachers for the summer of 2004 centered on learning the composition and analysis of the Photon Multiplicity Detector including testing the resistance of diode boards to minimize future voltage overloads.

The STAR
(Solenoidal Tracker at RHIC)
Physicist Tapan Nayak noticed STAR did not have a method to record and analysis data related to the photons or gamma rays (commonly known as light rays) that resulted from collisions. Dr. Nayak and his colleagues reasoned that various theoretical considerations seem to suggest that nuclear matter can undergo a so-called chiral transformation under the proper conditions, which means the chiral symmetry can be restored. Theorists further suggest that chiral symmetry restoration may lead to production of disoriented chiral condensates, DCC, in heavy ion collisions. The production of DCC, however, is expected to lead to fluctuations in the relative production of neutral and charged pions. Dr. Nayak and his team are interested in finding evidence for the formation of DCCs in heavy ion collisions. Since neutral pions were readily measurable with other STAR detectors, Dr. Nayak and his colleagues designed, obtained funding from the Indian government, and built a Photon Multiplicity Detector to perform measurements of neutral pion decays into two gamma rays. The search for DCC thereby amounted to a search for anomalous fluctuations in the ratio of produced
gamma measured by the PMD and charged particles measured in the TPC and other detectors.

The STAR Photon Multiplicity Detector uses a gassiplex as front-end electrons readout system that has sixteen inputs and one multiplexed output. Each of the sixteen channels consists of a charge sensitive amplifier, a deconvolutions with a switch able filter, a stage amplifier and a track and hold stage to store charge. The Gas-Four Board contains four gassiplex chips with necessary passive components that sit on the detector connected to a zone consisting of sixty-four cells.

The Photon Multiplicity Detector is made up of about 85,000 hexagonal cells. Each cell is a gas chamber surrounded by a small electro-magnetic field with a copper floor and a lead frontier. The lead wall acts as a converter that divides incoming gamma rays into constituent positrons and electrons. The charged particles interact with the argon and carbon dioxide in the chambers and are caught in the electro-magnetic field and counted. This relatively recent addition to the STAR Experiment offers insight and data regarding pions resulting from heavy ionic collisions that would otherwise be lost. During their research experience, the teachers took into consideration whether positrons and electrons interact with the gas differently.
Scientists, engineers and students who work on the Solenoidal Tracker at RHIC Detector in diverse capacities came to Brookhaven National Laboratories for a weeklong conference to confer regarding data analyses and to provide updates on the functions of various detectors. The conference was interesting and informative. Many collaborators, including graduate students in physics, gave presentations on the work they were doing with STAR. Experts questioned each other on how best to interpret data generated from previous runs of the Experiment. A healthy exchange of ideas ensued as collaborators tried to reach a consensus on the publishable results from the analyses.

Interviews with Physicists at Brookhaven National Laboratories

Jim Thomas, PhD.

Dr. Thomas gave an overview of the type of physics done at Brookhaven National Laboratories with particular emphasis on the STAR contribution to RHIC. The STAR main detector consists of a Time-Projection Chamber or TPC. The TPC is essentially a gas chamber containing a mixture of argon and methane. Charged particles traversing the TPC deposit energy and form an ionized trail. This trail is measured and its shape, orientation and position provide information about the momentum and particle type produced. The TPC is surrounded by a large magnet and is accompanied by an array of smaller detectors, most of which measure charged particles. Dr. Thomas mentioned that quarks are understood to be strictly confined inside hadrons inside cold matter, or may be produced as de-confined particles in dense, high temperature matter. For example, pions have two quarks and are classified as mesons whereas protons contain three quarks and are classified as baryons. Since quarks are the building blocks of the Universe, by reproducing quark-gluon plasma via the RHIC
Experiment, the information derived will help in understanding the fundamentals of all basic structures.

Aihong Tang, PhD.

Dr. Tang’s research at RHIC is centered on studying the elliptic flow resulting from nonhead-on collisions. When two gold ions collide off center, they overlap in an almond shaped region which gives rise to an ellipsoid-like arrangement of matter in the reaction plane of the collision. Since particles have a tendency to move in the direction of the momentum supplied by the colliding ions, this ellipsoid-like structure can be described azimuthally with respect to the centermost point of the collision and the reaction plane. However, since particles emit anisotropically, the reaction plane’s orientation is usually unknown, and anisotropic flow is commonly reconstructed from two-particle azimuthal correlations. Yet, there are several possible sources of azimuthal corrections that are not related to elliptic flow, which complicates calculations. Dr. Tang noted some theorists argue that since this ellipsoid-like flow of matter resemble hydrodynamic models, that maybe hydrodynamics can be used to predict behavior of quark-gluon plasma. However, should the original distortion plotted as a function of particle density reveal a phase shift from normal nuclear matter to quark-gluon plasma, the question remains unanswered as to whether or not pure fluid-like conditions would be satisfied during the phase transition.

Akio Ogawa, PhD

Akio Ogawa’s research at RHIC deals primarily with Spin Physics, which asks: What happens inside the proton and neutron? Dr. Ogawa explained that the mass of a proton is about one GeV, and the mass of a quark is about one KeV. Therefore, approximately ninety percent of the proton’s mass is due to the interactions of quarks and gluons, which spin around each other at the speed of light. Nuclear physicists are trying to better understand how the spin of the
quarks and gluons contribute to the overall spin of the proton. Initially, theorists believed that the up and down quarks within a proton balanced each other and the spin of the remaining quark determined the spin of the proton, and that half of the momentum of the proton was carried by quarks and half by gluons. However, researchers learned from experiments in the mid-1980’s that the quark spin only accounts for about twenty percent of the proton’s spin. Physicists now believe that the remaining eighty percent of the proton’s spin comes from the gluon spin and the angular momentum generated from the interactions among quarks, antiquarks and gluons. Dr. Ogawa explained that the Spin Physics Group at RHIC is trying to determine the gluon contribution to the proton’s spin. Dr. Ogawa also mentioned that quarks and gluons have not been observed in isolation primarily because of the strong force that holds them together. This phenomenon is known as confinement. One challenge to both theoretical and experimental physicists is to overcome confinement in order to study the quantum chromodynamic properties of quarks and gluons directly.

Bill Christie, PhD, Jerome Lauret, PhD and Claude Pruneau, PhD

Bill Christie, Jerome Lauret and Claude Pruneau served as mentors for persons participating in the Research Experience for Teacher, RET, Program coordinated through Wayne State University. Drs. Christie and Lauret availed themselves to answer questions and to acclimate the teachers to the BNL environment. Their assistance in working with STAR equipment together with their introductions to BNL computer technologies and their arrangements of interviews with STAR personnel made the transition to becoming a member of the Brookhaven Community amicable. Dr. Pruneau served as a liaison between Wayne State University and Brookhaven National Laboratories. In addition to making accommodations for high school teachers to serve as BNL guest scientists, Dr. Pruneau helped make the BNL experiences meaningful by providing valuable insight regarding the physics studied via the RHIC Experiment.
**General Environment at Brookhaven National Laboratories**

Brookhaven National Laboratories comes very highly recommended as a place where high school mathematics, science and computer technology teachers can have a meaningful research experience. The entire facility is dedicated to science. At BNL, teachers have an opportunity to interact with leading scientists and to learn of current research in physics, chemistry, biology and material science. The BNL research experience for teachers could well be the catalyst that sparks the next generation of internationally renowned scientists.