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INTRODUCTION

Stony Brook University is proud to host the Research Experiences for Undergraduates (REU) Program in Physics. Sponsored by the National Science Foundation (NSF), this program gives undergraduate students an intensive hands-on research experience and involves them in all phases of the research process. This year, twelve summer researchers from colleges and universities throughout the country were selected from a select pool of over two hundred applicants. In carrying out their projects, REU participants worked alongside Stony Brook's faculty, post-docs, graduate students and other undergraduates. The summer activities culminated in a presentation of the students' work in a research symposium and in a written report.

As you read this collection of their abstracts, you will see evidence of their hard work, keen insight and enthusiasm, and be impressed at what they have accomplished in only eight weeks. I have no doubt that these individuals will continue on with successful academic and research careers.

—Erlend Graf, NSF REU Physics Site Director, Stony Brook University

Matthew Captaine
St. Norbert College

DEVELOPMENT OF MARIACHI GROUND-BASED SCINTILLATOR PARTICLE DETECTOR ARRAY FOR ANALYSIS OF COSMIC RAY SHOWERS

Matthew Captaine, *St. Norbert College*; Matthew Lucia, *University of Notre Dame*; Dima Vavilov, Michael Marx, *Department of Physics and Astronomy, Stony Brook University*

Ultra-high energy cosmic rays remain a mystery to scientists. Mixed Apparatus for Radar Investigation of Cosmic-rays of High Ionization, or MARIACHI, is a project dedicated to the study of such phenomena using antennae to detect television signals from transmitters of a great distance and scintillator detectors arranged on the ground to validate these findings. By simply arranging a few antennae and using local high schools to collect data with the particle detectors, this new cost-effective method will cover a much larger area than before.

We focused on development of the ground array. After calibrating a number of scintillator counters by selecting optimum operating voltages with high efficiencies and low noise levels, we installed a five-fold array in the Nuclear Structure Lab to complement the upstairs set up. Using the LabView software, we were able to collect oscilloscope data as well as counts data, and the installed GPS allowed for data time stamping as well for multiple (four or five) fold coincidences. From the oscilloscope data, we analyzed the difference in pulse heights between two-fold and multi-fold coincidences, noting a shift. We believe the larger pulse heights for multi-fold coincidences mean that more particles are passing through the detectors. The multi-fold coincidences are thus most likely showers produced by higher energy cosmic rays. It is hoped that further analysis of such changes in pulse heights could lead to more quantitative information regarding the cosmic ray energies. Stacking five counters, we calibrated the counters for time, adjusting for delays. With some further calibration testing, it will be possible to calculate the direction of the shower front and look for patterns. The counts data allowed us to compare the rates of the upstairs and downstairs arrays as well as a setup on top of the roof. We noted a sharp (factor of three) decline in multifold coincidence rates downstairs for the same dimensions. The two-fold coincidences also saw a 20% decrease downstairs as well. Early indications would lead one to believe that the thickness of the ceiling caused the lower energy particles to stop, thus dropping the rate. A grid with the counters arranged in the corners of a square of varying lengths gave us an idea of how rates are affected by a given separation distance. Analysis of this information will be imperative when installing the arrays in the area high schools as planned in order to translate measured rates into primary cosmic ray energies. This work was supported by grants from the National Science Foundation (PHY-0552521, OCI-0537403, and OCI-0636194).

Christina Chu
Embry-Riddle Aeronautical University

REBUILD AND UPGRADE OF THE HADRON BLIND DETECTOR

Christina Chu, *Embry-Riddle Aeronautical University*; Matt Durham, Jason Kamin, Thomas K. Hemmick, Greg Wille, Thomas Videbaek, *Department of Physics and Astronomy, Stony Brook Univeristy*

The Hadron Blind Detector (HBD) is an upgrade of the Pioneering High Energy Nuclear Interaction eXperiment (PHENIX) at the Relativistic Heavy Ion Collider (RHIC). The HBD is a windowless, unfocused Cherenkov detector that uses a triple stack of gas electron multipliers (GEMs) in a purified carbon tetrafluoride (CF4) atmosphere to detect e+e- pairs created during particle collisions at RHIC. Cherenkov photons radiated by the e+e- pairs hit the top GEM in a stack, which is coated with ~350 nm of cesium iodide. The Cesium iodide acts as a photocathode that emits an electron when it absorbs a photon. These photoelectrons are accelerated through holes in the GEM by a potential difference. CF4 molecules are ionized through collisions which produce more free electrons. These electrons are in turn accelerated and avalanche through the second and third copper GEMs before striking a readout pad.

Maintenance and upgrades are being performed on the HBD to prepare for Run 8 of RHIC. Data collected during Run 7 indicated that scintillation light was being detected. Shades are being installed in the HBD to reduce this background signal. The HBD is also currently being fitted with new GEMs since several of the original GEMs were damaged by high voltage discharges. These discharges may have been related to dust on the GEMs in some cases. Since the GEMs have 80 μm holes all over their surface they are sensitive to dust, and it is imperative to keep and work with them in a dust free environment. I worked throughout the clean tent and improved the dust conditions by factors ranging from 4X to 10X by systematically locating dust sources and improving clean procedures. The clean room now operates at class 100-200, and the glovebox operates at class 50 or better. At Stony Brook University, evaporations are done of high purity cesium iodide onto new GEMs in a high vacuum, the quantum efficiency of these cesium iodide coated GEMs is measured, and gain testing of the GEM stacks is done. Old GEMs are being studied as well. Those with a non-linear current draw are subjected to a trial cleaning with ultrasound. This work was funded by NSF Grant Phy-0552521.

Daniel D'Orazio
Juniata College

SCHAEFER-BERGMANN PATTERNS IN ACOUSTO-OPTIC DEVICES

Daniel J. D'Orazio, *Juniata College*; Marty Cohen, John Noé, *Laser Teaching Center, Department of Physics and Astronomy, Stony Brook University*

Acousto-optic devices utilize acoustic waves launched into crystals to Bragg diffract a percentage of the incident laser light for applications such as modulation, deflection, and frequency shifting. This project has been motivated by the unexpected observation of complex spatial patterns in laser light diffracted by commercial acousto-optic devices. These patterns, which are called Schaefer-Bergmann patterns, were first observed many years ago (1934) but were not expected to be seen in the commercial devices that we used.

Commercial acousto-optic devices utilize a traveling acoustic wave. Typically, a combination of acoustic absorption and redirection (away from the Bragg angle) at the crystal face opposite the transducer is used to reduce normal-incidence reflections that would produce a standing wave in the crystal. We have concluded that this redirection unintentionally fills the crystal with very low amplitude longitudinal and shear waves traveling in all directions. The diffraction of incident light from these low level acoustic waves results in the generation of the Schaefer-Bergmann patterns we have observed in two different crystals, TeO_2 and $PbMoO_4$. We have analyzed the acoustic wave behavior in each crystal by deriving acoustic wave velocities as a function of propagation direction from measurements of beam displacements observed in traces of the Schaefer-Bergmann patterns. We will suggest ways to reduce beam deflection into these patterns (which could be useful in commercial applications) and to further investigate the observed intensity variations within the Schaefer Bergmann patterns.

This work was supported by a grant from the National Science Foundation (Phy-055251).

Scott Feister
University of Notre Dame

CYBER-CONTROL AT STONY BROOK: DIGITIZING STONY BROOK'S TANDEM VAN DE GRAAFF ACCELERATOR CONTROL SYSTEM

Scott Feister, *University of Notre Dame*; Thomas K. Hemmick, Rich Lefferts, Andrzej Lipski, *Department of Physics and Astronomy, Stony Brook University*; Greg Wille, *Stony Brook University*; Leila Makdisi, *Bard College*; Brad Turow, *Solomon Schechter HS, Glen Cove*

The aim of this project was to prepare Stony Brook's Tandem Van de Graaff accelerator for use as a remote teaching facility educating in cyber-control and Accelerator Mass Spectrometry (AMS) carbon dating. This has involved a complete overhaul of the accelerator's analog control system so that selected controls can be exported digitally through the internet via HTML. National Instruments Data Acquisition (DAQ) PCI cards were installed in four computers sitting at different electrical potentials throughout the complex. Output and input control through these cards was programmed using the Labview 8.2.1 G programming language. Remote access to these computers through a local network and exported HTML controls using the Labview Web Publishing tool were shown to allow all controls wired to these computers' cards to be accessible from a single control console. It was also demonstrated that when properly configured selected controls and interfaces could be exported over the internet using HTML. Full control of two computers at the accelerator's ion source was achieved from a remote networked computer and smoothly maintained as the ion source was raised to a potential of 300 kV. All controls at the ion source were then rewired to the computers' DAQ cards and successfully controlled wirelessly over the network. The successful implementation of ion source digital controls over a network indicates that further replacement of the accelerator's analog controls using the same method will be successful. This work was funded by NSF Grant Phy-0552521.

Mallory Fischer
Eastern Michigan University

OPERATING CHARACTERISTICS OF HELIUM-NEON LASERS

Mallory Fischer, *Eastern Michigan University*; John Noé, *Laser Teaching Center, Stony Brook University*

Helium neon (HeNe) lasers can be found in labs and classrooms everywhere. They provide highly collimated beams with excellent quality at modest power levels up to tens of milliWatts. The most common wavelength is 632.8 nm (red), but several other visible wavelengths are also available. In the laser, an electrical discharge excites helium atoms to long-lived states which then transfer their energy to the neon atoms through collisions, thus maintaining the population inversion needed for stimulated emission. Each laser requires a power supply that is able to provide both the proper operating current and a starting voltage, which can be up to five times the operating voltage. Operating voltage scales roughly with tube length, while operating current depends mostly on the bore diameter of the capillary tube that contains the excited plasma.

The Laser Teaching Center currently has a family of thirteen HeNe laser heads and seven power supplies, most of which were obtained as surplus at very low cost. The power supplies each contain a sealed "brick" which provides a regulated current over a range of voltages. In some of the units the current is fixed and in others it can be adjusted with a screwdriver trimpot. While all lasers are physically compatible with all power supplies (all have the same Alden-type high-voltage connectors) only some combinations are electrically compatible.

In the first part of this project all available information on each laser and power supply was collected and compiled in a spreadsheet. Lasers and supplies were assigned reference numbers and letters respectively, and a compatibility matrix was created to provide a quick reference for recommended combinations. More recent work has concentrated on measuring the V-I characteristic of each laser, and the dependence of laser output power P on current I. Digital meters can be damaged by high voltage transients, so two analog meters obtained from surplus equipment were configured to read 0-10 kV and 0-10 mA, respectively. These meters can easily be inserted between the laser and power supply using Alden patch cables. The output power of each laser peaks at an optimum current that can be found from the P-I curve; operating at a higher current just shortens tube life. V-I curves are expected to display the negative resistance phenomenon characteristic of a gas discharge.

This work was supported by a grant from the National Science Foundation (PHY-0552521).

Ian Goyette
University of Vermont

INVESTIGATION OF A DOUGHNUT-SHAPED BEAM FROM AN OPEN-CAVITY HeNe LASER

Ian Goyette, *University of Vermont*; John Noé, *Laser Teaching Center, Department of Physics and Astronomy, Stony Brook University*

This project was motivated by a chance observation while studying the transverse modes produced by an open-cavity helium-neon laser. The modes of a laser are the specific ways that the light field oscillates within the resonant cavity that contains the amplifying medium. Longitudinal modes are the equally spaced frequencies of light that "fit" within the cavity, while transverse modes are the spatial intensity patterns allowed by the paraxial wave equation. Hermite-Gaussian (HG) and Laguerre-Gaussian (LG) transverse modes are solutions of the paraxial wave equation in rectangular or cylindrical coordinates, respectively. Certain types of LG modes have a spiral phase pattern (phase depends on azimuthal angle) and consequently a doughnut-shaped intensity distribution with one or more bright rings around a dark center. These optical vortex modes are intrinsically interesting and can be used to trap and manipulate atoms and small particles.

An open-cavity laser like ours can be coaxed into producing TEM_{01} or TEM_{10} (HG) modes by very careful adjustments of the output coupler mirror. There are several methods for producing pure LG modes, but these are generally not obtained directly from a laser. In the course of demonstrating various HG modes it was observed however that a doughnut-shaped beam appeared midway between the two mirror positions that produced the TEM_{01} and TEM_{10} modes. While this beam visually resembles a first-order LG mode, one cannot draw conclusions about the phase structure of the beam with the eye alone.

To determine if the observed doughnut-shaped pattern is a true LG (optical vortex) mode, its phase structure was investigated with a Mach-Zehnder interferometer with a Dove prism inserted in one arm to create a mirror image of the beam. The prism would have the effect of reversing the helicity of the beam if it were indeed an optical vortex. The resulting interference pattern would resemble a flower with two petals (a first-order HG mode) that would smoothly rotate about the beam axis with changing relative phase. What was observed was deceptively similar to this expectation, but on closer examination was actually distinctly different: a cyclic pattern of first-order HG modes with doughnut beams appearing in between.

Based on these observations and computational models created with Mathematica, we have tentatively concluded that the doughnut-shaped beam we are seeing is actually a superposition of the TEM_{01} and TEM_{10} modes lasing on adjacent longitudinal modes, a phenomenon described in the literature as a TEM_{01}^{*} mode. (This mode can be thought of as a beam rapidly switching between a right-handed and a left-handed vortex.) Additional experiments now underway will further test this hypothesis.

This work was supported by NSF grant Phy-0552521.

Michael Heinz
Cornell University

MEASUREMENT OF ULTRAFAST FEMTOSECOND LASER PULSES

Michael Heinz, *Cornell University*; Thomas Weinacht, *Department of Physics and Astronomy, Stony Brook University*

Creating a pulse of light that's only a few femtoseconds in duration is no easy task, and measuring it has proven to be just as difficult. The fastest computers complete with terahertz processors can sample events on the order of picoseconds, however femtosecond pulses exist for one-thousandth of that time. Since electronics simply are not fast enough, these ultrafast pulses of laser light must be measured using crystals with nonlinear optical properties. The current methods of measuring pulse duration employed in our lab are FROG (Frequency Resolved Optical Gating) and GRENOUILLE (GRating-Eliminated No-nonsense Observation of Ultrafast Incident Laser Light E-fields) which both require high precision alignment of various optics, including a very expensive non-linear crystal (second harmonic generation crystal in our case). Because these two methods need to be precisely aligned, they are fixed in one location of our optical table, making it impossible to measure the duration of the laser pulse at other locations around the table. This is why we have started to implement another method of measuring pulse duration that uses small, inexpensive photodiodes that easily move around the optical table. The photodiodes we are using can sense blue photons because a blue photon has enough energy to excite the electrons in the diode to state where they become mobile, thus allowing current to flow between the two terminals of the diode. The photodiode cannot sense a red photon because it has less energy than a blue photon, however, if and only if a very compressed pulse of red photons is incident on the photodiode, an electron can accept the energy of two red photons simultaneously, giving it that required amount of energy to become mobile. Since our pulsed laser light is only made up of red and infrared light, we know that the photodiode measures the compression of our pulse, which is correlated to pulse duration. This method differs from FROG and GRENOUILLE which use nonlinear crystals to turn two red photons into one blue photon because with the new method, blue photons are never actually produced. One electron in the photodiode simply accepts the energy of two red photons simultaneously because the red photons are highly compressed in time. The photodiode, however, only gives us a relative measurement of pulse duration and is therefore not meant to replace FROG and GRENOUILLE, which yield absolute measurements of pulse duration. In addition, FROG and GRENOUILLE can also measure other pulse characteristics that the photodiode cannot. Although it is not a replacement, the photodiode is a great addition to our many laser analyzation techniques. We simply integrate a photodiode, a battery (to reverse bias the diode) and an RC circuit together, and we get a cheap and easy way to measure the duration of femtosecond pulses. This work was supported by a grant from the National Science Foundation (PHY–0552521).

Matthew Lucia
University of Notre Dame

IMPLEMENTATION OF GROUND-BASED SCINTILLATION DETECTORS AS A TOOL FOR STUDYING COSMIC RAY ACTIVITY

Matthew Lucia, *University of Notre Dame*; Matthew Captaine, *St. Norbert College*; Dima Vavilov, Michael Marx, *Department of Physics and Astronomy, Stony Brook University*

The Mixed Apparatus for Radar Investigation of Atmospheric Cosmic-rays of High Ionization (MARIACHI) Project is an experiment designed to study ultra high energy cosmic rays (UHECRs) incident on Earth's atmosphere. When these extremely energetic particles enter and interact with the gas molecules in the upper atmosphere, they create a large trail of ionization. The eventual goal of MARIACHI is to locate this ionization trail by observing the reflection of radio waves over the horizon. However, radio waves can be reflected by numerous atmospheric phenomena, including lightning, meteors, and even jet airplanes. Thus, MARIACHI uses the so-called mixed apparatus of radar and ground-based scintillation detectors; the ground-based detectors serve as confirmation for potential UHECRs seen by radar.

The main focus of this work was to better understand the ground-based scintillation detectors. These detectors are being installed in high schools across Long Island, so a calibration method must be determined as soon as possible. MARIACHI's ground-based detectors come in sets of five detectors, and at the start of this work, only one such fivefold array was running. The first task of the project was thus to duplicate this setup, getting a second fivefold array working in a different part of the building. This involved two main steps: Preparation of the detectors (operational plateau search, efficiency test, etc.) and the installation of the fivefold array's infrastructure.

With the second fivefold detector array installed and running, the project moved on to actual analysis of the data coming from the detectors. The ground-based arrays are currently configured to acquire two types of data, coincidence counts and oscilloscope traces. The primary use of the coincidence count data was the development of a "grid", where count rates are determined for varying distances between detectors. Here it was observed that rates drop off rapidly as the fivefold array's detectors are spread further apart; this decrease was expected because coincidences at larger separations are indicative of higher energy primary UHECR, the flux of which decreases rapidly with increasing energy. Work is currently underway to develop a direct connection between the data and simulated UHECR showers. Coincidence count data was also used to demonstrate the effect of shielding on cosmic ray flux, where count rates of fivefold arrays varied widely by location, depending on the amount of material overhead.
The primary use of the oscilloscope trace data was an analysis of photomultiplier tube (PMT) output pulse heights (suggesting larger numbers of particles hitting the counters). Increasingly higher levels of coincidence were shown to have increasingly large PMT pulses. In addition, analysis of pulse heights helped to show that the density of particles in cosmic ray showers is rather low.

Work on this project has been spread across a wide range of topics; while progress was made in all areas, much remains to be done. Each small segment of our work easily could be expanded into its own project. This work was supported by grants from the National Science Foundation (PHY-0552521, OCI-0537403, and OCI-0636194).

Samuel Meehan
University of New Hampshire

THE RELATIVE CALIBRATION OF THE ELECTROMAGNETIC CALORIMETERS OF THE ATLAS EXPERIMENT WITH ELECTRONS FROM W-BOSON DECAYS

Samuel Meehan, *University of New Hampshire*; and Michael Rijssenbeek,
Department of Physics and Astronomy, Stony Brook University

Scheduled to start taking data in 2008, the ATLAS detector at CERN will be one of two highest energy accelerator-collider experiments. Although many new observations are expected at this new high energy regime (14 TeV), the main focus of the detector is to search for the Higgs boson, the particle involved in the Higgs mechanism that is theorized to give all other particles mass. This search and most other topics require great precision and so a well-designed calibration of energy measurements is crucial.

The main component for energy measurement is the electromagnetic calorimeter, responsible for the measurement of high energy photons and electrons.

The goal of the project described here is to investigate the feasibility and performance of a *relative* calibration of calorimeter "cells" with electrons from the well-known W boson decays. Such a program of relative calibration, i.e. equalization of response, would then be followed by an absolute calibration, not described here, based on electrons from the well-known, but less-frequently occurring Z-boson, the mass of which is known to 1 part in 50,000.

The study is done by performing Monte-Carlo simulations of the production and subsequent decay of a W into an electron and an unobservable neutrino. The resulting motion of the electron in the laboratory is calculated and the calorimeter cell impacted by the electron determined. The simulated transverse energy (E_t) is smeared by an arbitrary a-priori injected "measurement mis-calibration factor" for that particular cell, and is recorded with the cell number. Using data from many simulated events, E_t distributions for all calorimeter cells are created. These distributions show a characteristic peak at around 40GeV, half the W mass, and so provide curves for the cell calibration. Because the distributions vary somewhat with the polar angle of the cells, but not with azimuth, the relative calibrations are done between cells which have approximately the same polar angle (i.e. "rings" of cells located at the same "pseudo-rapidity"). Choosing a ring, a relative calibration is performed using a χ^2 minimization to determine the optimum scale factor α_i for each cell i in the ring. In principle, these factors α_i should correct for the a-priori systematic mis-calibration error applied in the beginning, and scale the E_t distributions for the individual cells in a ring such that they become all alike. Thus, applying these calibration factors to experimental data of electrons and photons should correct the a-priori systematic errors and assure that all cells in a ring have an identical response.

In the following, we describe the procedure in detail, and give results of the simulation and show how well the scale factors determined from the use of W-electrons recover the injected mis-calibration factors.

This research was supported by the National Science Foundation (NSF Grant Phy-0552521).

Yancey Sechrest
University of Arizona

BOSE-EINSTEIN CONDENSATION OF RUBIDIUM

Yancey Sechrest, *University of Arizona*; Rebekah Schiller, Daniel Greif, Daniel Pertot, and Dominik Schneble, *Department of Physics and Astronomy, Stony Brook University*

I will report on Bose-Einstein condensation experiments in a dilute ultracold gas of rubidium atoms. Our group effort during my stay has been focused on obtaining the first Bose-Einstein Condensate(BEC) with a new apparatus. Atoms are first collected and laser-cooled to temperatures below 100 microK in a Magneto-optical trap (MOT). For laser cooling we use an all-diode laser system that is locked to an atomic transition using a modulation-free polarization spectroscopy locking technique. Our apparatus features a novel TOP trap design that incorporates a movable coil quadrupole magnetic trap with which the atom cloud is moved into a 10^{-12} torr science cell after laser cooling. Once in the cell, evaporative cooling is performed in a Time-averaged Orbiting Potential(TOP) trap to reach temperatures on the order of 100 nK. We then use absorption imaging to image the cloud.

We report the first BEC achieved at Stony Brook! We have created a BEC with atom numbers on the order of 10^5 atoms. Recently, we have been characterizing the shot-to-shot stability of the TOP trap by checking the reproducibility of BEC position and atom number, we also have measured the TOP trap frequencies. We find that the atom number is stable to within 11%, and that the horizontal position (perpendicular to the axis of observation) of the BEC is stable to within a standard deviation of 2.48 microns (not accounting for a slow drift) and the vertical position has a standard deviation of 3.04 microns. The TOP trap frequencies were measured to be 34.2 Hz in the horizontal direction and 96.4 Hz in the vertical direction. We believe that the already satisfactory position stability and atom number of the BEC can easily be improved through optimization of the apparatus. Looking forward, we plan to install an infrared laser system for optical trapping of the BEC, with the prospect of simulating condensed-matter systems with quantum gases in optical lattices. The project was funded through Stony Brook University and The SUNY Research Foundation/Office of the Vice President for Research. My position was supported by NSF Grant Phy-0552521.

Robert Steinman
Indiana University of PA

THE BINARY SPECTRA OF SIGMA-ORI

Robert Steinman, *Indiana University of Pennsylvania*; and Deane Peterson,
Department of Physics and Astronomy, Stony Brook University

This project involves the analysis of the spectra of a double-lined spectroscopic binary star, the term used when the spectra from both components are visible. In some phases of the orbit the spectral lines might be cleanly separated, allowing a measurement of the projected difference in velocity between the two components through the Doppler Effect. At other phases, where the lines overlap, we would also like to recover velocity difference measurements. To accomplish this, we wrote a C program that creates a synthetic binary spectrum allowing for an arbitrary brightness ratio and velocity difference. We can see how well the synthetic spectrum matches the observed one by calculating the sum (over wavelength) of the squared differences between the two, after allowing for the systemic velocity. Minimizing this quantity by simultaneously varying the brightness ratio and velocity difference allows us to determine the latter even when the lines overlap. We show examples of these various steps.

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