Assessing the Effects of Magnetic Fields on the Photomultiplier Tubes in the SANE

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As nuclear physicists work to understand the behavior of the quarks and gluons that comprise nucleons, polarization has become increasingly important. The Spin Asymmetries of the Nucleon Experiment (SANE) at Jefferson Lab used polarization of both beam and target in electron-proton scattering. While the beam can be produced in a polarized state, the target was polarized by way of a strong magnet. This magnet's field was non-negligible outside of the intended region, and this study examined the field and assessed its effect on photomultiplier tubes (PMTs) used in SANE. The magnetic field was mapped with reference to the location of the PMTs, and a statistical analysis of run data from SANE was done using the physics analysis framework developed ROOT. It was concluded that the magnetic field caused, on average, a 3.3% ± 1.8% loss in PMT signal due to the bending of electrons. This minor, but statistically significant, effect is consistent with prior, cursory estimates and solidifies the viability of coming results from SANE. These results also provide a good characterization for the PMTs' performance in a magnetic field and will benefit future experiments in which they are used.

Effect of Temperature on the Surface Morphology of Niobium during Buffered Electropolishing

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In order to achieve high acceleration gradients for particle accelerators based on niobium (Nb) superconducting radiofrequency (SRF) technology, Nb cavity surfaces need to be as smooth and as free from impurities and defects as possible. In cavity production, removal of damaged surface layers typically occurs as the final step before rinsing and RF testing. Presently, this is performed by either buffered chemical polishing (BCP) or electropolishing (EP). Buffered electropolishing (BEP), a method developed at Jefferson Laboratory, has been shown to outperform both BCP and EP in terms of surface smoothness and polishing rate. BEP utilizes a mixture of hydrofluoric, sulfuric, and lactic acids to etch away the damaged layer of Nb surfaces. The aim of this research was to study how the surface topography of the Nb changed with varying temperatures during BEP and to better understand the mechanism for the removal of Nb from the surface. BEP was performed on Nb flat samples at temperatures between 7 °C and 44 °C. The smoothness of the Nb surfaces was evaluated via profilometry and atomic force microscopy. To investigate the role of lactic acid in BEP, soluble Nb complexes with lactic acid were proposed. To verify the possibility of these complexes, an electrolyte consisting of only sulfuric and lactic acids was also used to electropolish Nb flat samples. This research indicates that a higher temperature during BEP yields faster polishing rates, maximizing near 32 °C, and that a smoother Nb surface can be obtained via polishing between 21 °C and 32 °C. In addition, this research suggests that lactic acid may form soluble coordination compounds with niobium, aiding hydrofluoric acid in the removal of niobium oxides from the material surface. Coordination of lactic acid with niobium oxides may explain the higher polishing rate of BEP when compared with conventional EP, which contains hydrofluoric and sulfuric acids, but not lactic acid. Further research into the exact surface conditions present during BEP and EP have

yet to be explored, but a better understanding of the BEP's temperature dependence and mechanism could advance BEP treatments on Nb SRF cavities.

Software for an Automated Bead-Pull System for the Production of Superconducting Radiofrequency Cavities

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The propagation of electromagnetic (EM) waves depends on the material through which they pass. The introduction of a small dielectric sphere into a superconducting radiofrequency(SRF) cavity, such as those used at the Continuous Electron Beam Accelerator Facility (CEBAF)at Jefferson Lab, alters the relative phases of the resonating EM fields in the cavity. These phase changes can be used to find the field flatness of the resonant EM modes in a cavity, which is critical to the operation of CEBAF. This measurement is called bead-pulling and is performed several times on each cavity during tuning at Jefferson Lab. The purpose of this project was to write data acquisition software for a preexisting, manual bead-pull system as part of the development of a fully automated bead-pull system. The preexisting bead-pull system consists of a pulley system controlled by an electric motor for moving a dielectric sphere through the cavity being measured and a network analyzer for generating and measuring radio waves in the cavity. The software was developed in the Microsoft .NET framework, runs from a desktop computer and controls and receives data from the network analyzer. The data acquisition software has been successfully implemented. Previously, bead-pull measurements were taken manually and took between half an hour and four hours; with the new software these same measurements take approximately ten minutes. This project shows that a cost-effective automated bead-pull system is feasible and that the cavity tuning facility at Jefferson Lab could save hundreds of hours of labor by implementing this software. The next step in this project will be to automate the mechanical apparatus of the bead-pull system.

Beam. Dynamics studies of 11 GeV Normal Conducting Radio Frequency Separator for 12 GeV Upgrade of Continuous Electron Beam Accelerator Facility

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In recent years, deflecting/crabbing RF cavities have received significant popularity; applications include beam splitting, luminosity upgrade, light source, emittance exchange and beam diagnostics etc. In this paper, we report the beam dynamics studies of parallel-rod type deflecting structures both superconducting and normal conducting. The excited transverse electromagnetic (TEM) π-mode provides deflecting/crabbing kick to the beam. In the deflecting mode of operation, bunch center experiences net force, however, the head and tail are kicked oppositely in crabbing application. This cavity has advantages over the conventional cylindrical cavity operating in TM_{110}-mode particularly at low frequency. Numerical simulations of beam dynamics show significantly small increase in the emittance which is consistent with the analytical estimates. Moreover, the strong concentration of EM fields between the rods make the arrangement of normal conducting cavities insensitive to the mechanical vibrations causing misalignment.

Electron Spin Dynamics in ELIC Spin Rotators and its Visualization Tool

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The Electron-Ion Collider or ELIC is a proposed upgrade to the Continuous Electron Beam Accelerator Facility (CEBAF) in which high-energy polarized electrons will be collided with positively charged polarized ions. Important to the device's role in many nuclear physics experiments is an intrinsic property of particles known as spin, which must be oriented or polarized according to the electron beam's position in the collider. The geometry of the ELIC is important to its spin dynamics, consisting of two circular arcs connected by two linear intersection regions where the collisions are to occur. Effective operation of the ELIC will require longitudinal polarization of spin at the interaction points and vertical polarization in the circular arcs in order to exploit the Sokolov-Ternov effect of electron self-polarization. The redirection of the particle spin between each of these regions is achieved by special devices called spin rotators, each consisting of two solenoids and two horizontal bending magnets. The focus of this project is to develop a tool which will help physicists and accelerator operators to visualize the spin rotation dynamics of an electron beam in the ELIC. For this study, the numerical computing software MATLAB was used to produce a computer-graphics representation of the effect of ELIC spin rotators on electron spin. A Graphical User Interface was developed which accepts user inputs, uses existing theory to compute desired quantities and uses Matlab's graphical capabilities to display the results. The outcome of this project is an easy-to-use tool which allows users to visualize the precession of electron spin in the ELIC spin rotators for any beam energy at which the machine is designed to operate. Physicists will be able to use this software as a convenient means of computing required field strengths for the rotators and obtaining graphical verification of solutions. In addition, it allows for investigation into the effects of changing the physical parameters of the rotators themselves. The theory of spin rotation dynamics is crucial to the design of ELIC, and it is hoped that this study will contribute to a better understanding of the spin dynamics of rotators as plans for the Electron-Ion Collider continue to develop.

Error and Background Radiation Analysis for the Compton Polarimeter

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Many of the experiments that run in Hall C at Thomas Jefferson National Accelerator Facility require a precise measurement of the electron-beam polarization. Along with the current Moller Polarimeter, a Compton Polarimeter is going to be added, which is non-destructive to the beam, allowing the polarization to be measured at the same time that data is taken. Current simulations for the Compton Polarimeter, which track the properties of the particles as they go through the magnetic chicane and into the detectors, neglect the background radiation that is created, especially when the beam passes through a focusing aperture before it enters the optical cavity of the polarimeter. When the beam goes through this aperture, some of the electrons in the beam

halo will collide with the metal, thus creating background radiation. The focus of this project was to adapt the current Monte-Carlo-based Compton simulation to determine the perimeters as to when the background radiation produced by the beam halo will cause significant errors in the data taken in the detectors. Using Fortran, the aperture was created in the Geant3 Monte-Carlo simulation. Then, simulations of the beam halo background radiation were run, and the rates of the particles detected for both backscattering and the beam halo were analyzed. It was found that the halo will not be a significant problem in the detectors, but it will be more of a problem in the photon detector than the electron detector. For the backscattering and halo events to differ by a factor of ten, the fraction of the beam in the halo needs to be smaller than 2E-10, which is 20 times smaller than expected. This means that as long as the beam is focused, the back scattering events will dominate. Setting certain hardware thresholds and software cuts on the detectors, which will cause them to only read a certain energy range, can also improve the ratio of back scattering to halo events. These findings will allow the scientists using the Compton Polarimeter to reduce and estimate the relative size of the contamination coming from the beam halo background radiation. The simulation will also be useful for the design of the 12GeV Compton Polarimeter, allowing scientists to see if the size of the aperture must change as the beam's energy increases and the halo becomes worse.

Maximizing Collider Luminosity through Genetic Optimization of Beam Tunes

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In designing a particle collider, one goal is to achieve the maximum feasible luminosity, a measure of the rate of collision events. Luminosity depends, in part, on a set of parameters known as the betatron tune working points (oscillation frequencies) of the beam. The relationship is complicated and nonlinear, making optimization extremely difficult. Researchers have long sought viable algorithms for solving this problem. Here, a massively parallel genetic algorithm was developed and used to locate high-luminosity working points for the proposed Medium Energy Ion Collider currently being designed at Jefferson Lab. The algorithm made use of the BeamBeam3D package to perform beam-beam simulations and to then calculate the luminosity of each working point. It was found that after five or more generations, the algorithm successfully located working points with luminosities exceeding the proposed design luminosity of the collider. These results demonstrate that such algorithms provide a feasible solution to this type of problem. Owing to the parallel evaluation of working points, a large subset of tune space can be covered relatively quickly (one or two days). It is hoped that such methods may prove useful for various other difficult optimization problems in accelerator design.

Betatron Tunes in the Proposed Medium-Energy Electron-Ion Collider at Jefferson Lab

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The future of Jefferson Lab lies within the construction of a Medium-Energy Electron-Ion Collider (MEIC), which is currently in the proposal stage. In a synchrotron collider storage ring, the orbiting beams oscillate transversely in both the horizontal and vertical directions. The frequency of these oscillations is called the betatron tune. Depending on the design tune of the collider, non-linear beam-beam effects can cause rapid degradation of the beam quality, thus yielding poor luminosity, which is the figure of merit in the MEIC. The non-linear nature of the beam-beam effects poses a serious obstacle to the efficient analysis of potential design tunes. The goal of this research was to find an X and Y betatron tune, or working point, which optimizes luminosity performance. Using code developed at Lawrence Berkeley National Lab, particle interactions were numerically simulated. Beginning with a previously known working point, systematic simulations were run to scan the adjacent tune space. A subsequent working point was discovered that provides a 33 percent increase in theoretical peak luminosity over the current MEIC design.

Using a CO2 Laser to Heat a Gallium Arsenide Wafer

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Polarized electron beams have a wide application in studies that range from materials science to nuclear and high-energy physics. The Continuous Electron Beam Accelerator Facility of the Thomas Jefferson National Accelerator Facility requires a highly polarized electron beam that is produced by photoemission from a gallium arsenide (GaAs) semiconductor photocathode. Before the photocathode can emit electrons, it must first be heated to near 550°C in a vacuum chamber to remove any oxide from the surface. Currently, the wafer-heating is done by placing a large molybdenum puck, holding the GaAs, on a ceramic heater in the vacuum chamber. The focus of this project was to test if a CO2 laser is a viable alternative to the ceramic heater and capable of heating the GaAs photocathode to 550°C by varying the metal to which the GaAs is mounted. Pucks made both of stainless steel and molybdenum, either bare or coated with a layer of Aerodag vacuum-compatible carbon coating, were placed in a vacuum chamber with a thermocouple attached to the front face, where the GaAs would normally be placed. A 40W CO2 laser, at the infrared wavelength of 10.6 microns, was aimed at the puck within the vacuum chamber through a zinc selenide window, and the temperature on the front surface was recorded as the laser heated the puck. A block of anodized aluminum was also placed in the chamber with a thermocouple attached to it and a 10W CO2 laser was shone at it, while the temperature was recorded. The maximum temperature achieved was 420 °C with the carbon coated stainless steel puck, which is insufficient to remove oxides from a GaAs photocathode. The coated molybdenum reached a temperature near 300 °C, while the uncoated metals only reached temperatures near 200°C. The anodized aluminum was only able to reach a temperature near 120°C. These results indicate that the radiation absorbed by large bare or coated pucks, of either molybdenum or stainless steel, is insufficient to heat the puck face to 550°C. Smaller pucks, a higher power laser, more absorptive coatings or less reflective materials should be investigated in order to heat a GaAs wafer sufficiently using an infrared laser. If such a material is found, then it can be used in a side puck chamber design.

Whenever possible, we look for additional opportunities to enhance the research experience for the students. In 2010, 4 of our accelerator physics REU students participated in the Beam Physics Symposium in honor of the 70th birthday of a prominent Accelerator Physicist, Yarosalv Derbenev. This was an opportunity for students to listen to and meet pre-eminent accelerator physicist from around the world. The students not only participated but assisted in the logistics of execution of the symposium.