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Searching for a Betatron Tune Working Point for the Proposed Electron-Ion Collider at Jefferson Laboratory
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The mechanics of relativistic particles in storage rings are well understood. The particles oscillate around the intended orbit in the transverse X and Y directions--called the betatron oscillations. The number of oscillations per orbit is known as the betatron tune. If the betatron tune is an integer or a special resonance value, the oscillations will build in amplitude due to constructive interference and the beam will become less focused. This becomes complicated in the proposed ELectron-Ion Collider at Thomas Jefferson National Accelerator Facility (ELIC). The ELIC will be similar to a storage ring except that there will be beams of particles in both directions through each other several times every turn around the ring. When the beams pass through one another, they give each other a 'kick' which alters the betatron tune often causing it to become one of the resonance values and degrading the beam quality and luminosity, which is a measure of the number of collisions per turn around the ring. This narrows down the range of betatron tunes that are available to operate the collider with a well focused beam. The purpose of this research was to find a betatron tune working point, or a set of betatron tunes in both transverse directions, which optimize the luminosity for both beams. A tune map shows which areas of the tune space are far from resonance values. The tune map was used to choose some betatron tune working points far from resonance. The region that was used was near half integer, because there was a large space on the tune map that was far from the regions of resonance. Simulations were run that broke down the collider rings into a series of linear maps around the ring and elementary forces at the point where the two beams interact. The goal was to find a betatron tune point where the beams stayed focused after many turns. An effort was made to separate the different tunes to find out how each one affected the luminosity but due to the highly nonlinear nature of the forces involved, this was ineffective. A stable working point has been found in the half integer region of the tune map. The point maintained about 65% of its peak luminosity after 30000 turns. This compares well with some of the best working points that have been found which top out at around 70% of the peak luminosity. It was found that there are certainly stable working points in the half integer region, and more points should be explored in this promising region of values. With a good working point, it will be possible to build a high luminosity collider allowing new experiments involving quantum chromo dynamics.

Laser System for Hall C Compton Polarimeter
Student: ***Eric Holland***, Saint Anselm College, Manchester, NH
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At Thomas Jefferson National Accelerator Facility a polarized electron beam is used to study the properties of nuclei. Currently, in Hall C a Møller Polarimeter is used to measure the electron beam polarization. This process is accurate but during measurements, the experiment is interrupted (destructive measurement). Since Møller measurements can only be done at low beam current < 1 microAmp and the experiments typically run near 100 microAmps, one has to

assume that the polarization remains constant between measurements. To supplement the Møller Polarimeter, Hall C is constructing a Compton Polarimeter, which performs non-destructive electron beam polarization measurement by Compton scattering. The purpose of this research is to optimize the laser component of the Compton Polarimeter. A fiber optic pulsed laser, with the same radio frequency as the electron beam (499MHz), was chosen to improve the luminosity and thus the number of Compton events. The current choice of laser alone would be adequate for Hall C; however, a higher power system would provide two obvious benefits: the time needed for a measurement would decrease, and the signal to background ratio would increase. A Fabry-Perot optical cavity was proposed to achieve a gain in the laser power. Due to cavity conditions and geometrical restraints, it was determined that a cavity of length 1.2 meters would best satisfy the needs of the Compton Polarimeter.

Our results strongly suggest that a gain switched pulsed laser cannot be coupled to an external optical cavity. A possible explanation is that the process of gain switching does not produce a mode-locked pulse train. Within each pulse it is possible that the Gaussian may be coherent but from pulse to pulse the coherence does not held. Mode locking is necessary for realizing a successful optical cavity.

Separating the Spin States of a Free Electron Beam

Student: ***Neil Rifkin***, University of Connecticut, Storrs, CT
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In 1922, Otto Stern and Walther Gerlach set out to test the spacial quantization of the electron by passing a beam of neutral silver atoms through a transverse magnetic field. The interaction of the two projections of the electron's magnetic moment with the magnetic field resulted in a splitting of the beam. However, for some 60 years it was generally accepted that the spin of free electrons, and thus their magnetic moment, could not be measured with an experiment similar to that of Stern and Gerlach. The reason being that the Lorentz force on charged particles is far greater than the force due to the magnetic moment of the electron, thus blurring any desired results. The purpose of this research is to determine the feasibility of splitting the spin states of free electrons. To reduce the Lorentz force, the electrons are passed through a magnetic field whose gradient is in the direction of the electrons' momentum. This eliminates the Lorentz force with the exception of the stray velocities associated with imperfect beam preparation. It was shown with computer simulation that constructing a longitudinal Stern - Gerlach device with a superconducting solenoid results in a measurable separation of the two spin states. A polarization of one half was shown in the tails of the beam with a 10 Tesla meter magnet and a beam with 0.1% velocity uncertainties. The splitting is approximately linear in both the strength of the magnet and the perfection of the beam, therefore a complete splitting is certainly within the realm of possibility. In addition, a polarization booster could be built on the Jefferson Lab beam line to help increase beam polarization. These results show that it is physically possible, and even experimentally achievable, to separate a beam of free electrons with a set-up similar to that of Stern and Gerlach.

Fowler-Nordheim Equation Derived, Explained and Calculated

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Working within the field of superconducting accelerators the problem of field emissions is a common problem diminishing the performance of the accelerator. In order to study this problem and find ways to prevent it and or detect it before large sums of money are wasted because the niobium used in the production of the superconducting radio frequency cavities had a field emitting impurity, an understanding of the theory of field emissions is a prerequisite. There is no better way to gain an understanding of abstract physical functions then by derivative from first hand. Therefore it is the aim of this article to examine the origin of field emitted electrons or the Fowler-Nordheim (FN) equation, illuminate its origins using first principle, evaluate it at several steps throughout the derivative using Mathematica, to provide a solid foundation for anyone working with superconducting radio frequency (SRF) cavities, especially to those involved with work function measurements and calculations. Furthermore it is the aim of this paper to establish an approximation to the transmission current that can easily be evaluated on a pocket calculator. In an effort to derive the FN equation from first principle, the image force, the Fermi-Dirac distribution (F.D.D) and density of states (D.o.S.), and quantum tunneling will be introduced. The results given here agree with Russel D. Young and Erwin W. Müller as well as W. W. Dolan, and the model given is accurate within one one hundreth of a numerically evaluated result. Not only does this paper provide the necessary tools to study work functions, field emission and a basis for all work involving superconducting accelerators however it also provides an approximation that can be evaluated on the spot with a pocket calculator.

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Electropolishing Copper Substrates for Niobium Thin-Film in SRF Technologies

Student: ***Andrea S. Carlini***, Virginia Tech, Blacksburg, VA
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Electropolishing, the electrochemical removal of surface contaminants and microscopic smoothing of metallic surfaces, has been extensively used as a surface preparation technique for niobium/copper (Nb/Cu) and bulk-Nb superconducting radio frequency (SRF) cavities. Electropolishing of Cu is particularly useful to prepare substrates for Nb thin-film coatings in SRF technology at Jefferson Lab. However, surface roughness and impurities on Cu substrates can negatively influence the efficiency of Nb-Coated superconductors. During the electropolishing process, a current is applied ot the Cu substrate which is submerged in an electrolyte bath; Cu atoms on the highest peaks of the surface oxidize to form ions that travel away from the substrate, resulting in a smoothing of the surface. The focus of this project was to improve the electropolishing of Cu by optimization of various parameters. Test samples were polished in a phosphoric acid and n-butanol bath, and later observed with profilometry and scanning electron microscopy (SEM). Here it is shown that a high and low current density (J8), electric current per unit area, was identified for optimum polishing. Variables such as bath age, previous mechanical polishing (MP), time, electrode distance, and J8 combinations were tested to analyze the effect on Cu samples. The results indicate that significant leveling of the Cu surface was achievable through optimization of the parameters considered in this paper. Significant improvements in the efficiency and maximum accelerating field of Cu/Nb cavities may be achievable through this improved electropolishing process at Jefferson Lab.

Development of the SRF Cavity Optical Inspection System

Student: ***Alan Chen***, Virginia Tech, Blacksburg, VA
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Superconducting radio frequency (SRF) waves are used to accelerate the particles in the accelerator beam through niobium cavities. Thousands of these niobium cavities must be utilized in the construction of the International Linear Collider (ILC) in the near future. However, given the precise nature of SRF technology, even the smallest defects on the inner surface of the niobium cavities can decrease the maximum acceleration gradient well below its theoretical limit. The optical cavity inspection process for locating these defects is a tiring manual process that proves tedious when inspecting multiple cavities. The focus of this project was to increase the efficiency of the scanning of the cavities through the automation of the inspection process. Through the use of basic materials such pulse motors, basic aluminum metal stock and a telescope coupled with a charged couple device (CCD) digital camera for hardware and Visual Basic express 2008 to program the software, the SRF optical cavity inspection system was automated with features including an automated rotational system and a program that automatically scans the cavity for defects. A polar coordinate system was also implemented maping the inner surface of niobium cavity allowing a reference point for locating inner defects that adversely affect the cavity's performance. Upon the project's completion, the cavity inspection process should be far more efficient with automated features and a user-friendly interface that allows more precision in locating the defects. The program will allow each cavity's defects to be repaired through a pinpoint chemical wash technique rather than replacing the entire cell on which the defect is located. The automation of the cavity inspection system will improve the data acquisition efficiently and increase the reliability of the findings as well. The automation of the cavity system will also greatly improve the cost efficiency in which the cavities can be processed and repaired and is a major step in preparing for the construction of the new ILC in the near future.

The Parameterization of SRF Niobium Cavities

Student: ***Filis Coba***, Central Connecticut State University, New Britain, CT Mentor: Andrew Hutton, Thomas Jefferson National Accelerator Facility, Newport News, VA

The Continuous Electron Beam Accelerator Facility (CEBAF) at Jefferson Laboratory uses elliptically-shaped Superconducting Radio Frequency (SRF) cavities to accelerate electrons to energies approaching 6 GV. These cavities are made from sheets of fine-grain niobium that are forged and rolled from a niobium ingot. CEBAF created the so-called 'C-50_ program to refurbish inefficient cavities and increase the accelerator gradient Eacc', while reducing Radio Frequency (RF) losses. The C-50 cavities were treated with Buffered Chemical Polishing (BCP) and High Pressure Rinsing (HPR) to remove any impurities found on the cavity surface. Prior to going into the accelerator, the cavities then were tested using high RF power represented graphically as the quality factor Q0 against the Eacc (MV/m). The focus of this research was to emphasize specific changes commonly ignored in C-50 cavities by linearly plotting the Surface Resistance (nΩ) against the Eacc and by analyzing and parameterizing the middle field of C-50 as well as ILC and DESY cavity plots. The primary step in analyzing the middle field was to convert the Q0 value into the surface resistance. Data was taken for many C-50, ILC and DESY cavities plotted linearly and fitted with various difference parameterization techniques in order to extract a common fit for all cavities. The 4th order polynomial fit equation was the best fit for all cavities, yielding five constants. After numerous manipulations, difference programming and graphing techniques, the results indicate that the following parameterization equation:

$$R = T + S \times E + (R0 - T) \times [1-(E/U)2 \times [1-(E/V)]2$$

fits the data, not only for all of the C-50 cavities, but also for the ILC cavities from JLab and DESY. Furthermore, the middle field 'bump' is always present regardless of the difference cleaning methods performed on the cavities. This study makes no attempt to explain the significance of this parameterization, but it does provide an indication of the underlying physics which will be followed in future studies.

Controlling Electron Bunch Spacing with a New Beat Frequency Modulator

Student: ***Heather Graffius***, West Virginia Wesleyan College, Buckhannon, WV
Mentor: Joseph Grames, Thomas Jefferson National Accelerator Facility, Newport News, VA

The Continuous Electron Beam Accelerator Facility (CEBAF) at Jefferson Laboratory uses a DC high-voltage GaAs photogun to supply a continuous train of electron bunches known as the electron 'beam'. The electron bunches are generated by drive lasers pulsing at 499 MHz synchronous with the radio-frequency cavities of the accelerator, consequently the bunch spacing for typical experiments is 2 ns. Experiments at CEBAF can sometimes benefit from the bunch spacing being longer (>10 ns) to allow the detectors to better distinguish time-dependent signal from background, however, the drive laser does nto have sufficient band-width for such low repetition rates (<100 MHz). The focus of this experiment is to implement a device that will use the existing drive lasers, yet allow the electron bunch spacing at the experiment to increase. To achieve this, a new radio-frequency electronic device called the Beat Frequency Modulator (BFM) was constructed. The BFM lowers the repetition rate of the drive laser to a sub-harmonic frequency within an acceptable range (400-500 MHz) so that this new train of electron bunches 'beat' against a fixed 499 MHz radio-frequency chopping cavity, allowing only bunches at the difference in frequencies to pass. The BFM was fabricated and bench tested with a spectrum analyzer. The BFM will be tested with the electron gun and used in an experiment to limit background at the injector Mott polarimeter detectors, by operating with bunch spacing greater than 10 ns. The successful design construction and installation of the BFM will allow physicists at Jefferson Lab to obtain more precise data by going them a range of electron bunch spacing than can dependent on their experiment.

New Wien Filter at the Continuous Electron Beam Accelerator Facility CEBAF)

Student: ***Robert A. Powell, Jr***., West Virginia Wesleyan College, Buckhannon,WV
Mentor: Joseph Grames, Thomas Jefferson National Accelerator Facility, Newport News, VA

A new beam line containing a Wien filter will be installed at the Continuous Electron Beam Accelerator Facility (CEBAF) injector as part of an upgraded 4π spin manipulation system for the PREX experiment. The spin of each of the beam electrons process along the journey from the polarized electron source to the end-station experiment. A Wien filter, a device possessing both an electric and magnetic field, rotates the spin direction to precisely compensate the accelerator journey and control the ultimate orientation at the target. The optically asymmetric nature of the Wien filter, however, must be accounted for and is done so with quadrupole magnets. The focus of this project is to characterize the new Wien filter and beam line. The required magnetic was determined by calculation and compared with measurement. Optimization of the quadrupole magnets is done by defining the beam size and divergence using the code Elegant. It is shown that the analysis and modeling support the beam line design with the intended goal of injecting into the accelerator an electron beam with control over the final spin orientation at the experimental target. This control over the final spin orientation allows for more precise and efficient measurements in each of the experimental halls.

Hydrogen Outgassing in Stainless Steel Gun Chambers
Student: ***Melissa Ricketts***, Merced Community College, Merced, CA
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Vacuum quality is an important aspect in electron guns. The hydrogen outgassing rate is a determinant of the vacuum quality in stainless steel gun chambers. A low outgassing rate allows for a better vacuum and therefore a longer photocathode lifetime. Low outgassing rates depend on thermal treatments of the chamber. The purpose of this project is to put together a gun chamber, and assess the hydrogen outgassing rate after an administered thermal treatment. To determine the hydrogen outgassing rate, pressure measurements of the vacuum chamber must be taken. Once these measurements have been obtained, they can be used along with the known volume and surface area of the chamber to calculate the outgassing rate. A thermal treatment of 400o C for nine days achieved an outgassing rate of 1.12 x 10**-13 Torr L/s cm2. The value obtained for the hydrogen outgassing rate is one order of magnitude better than previous outgassing rates. This is because in the past, this specific thermal treatment has never been used. This improvement illustrates the success of the project.

RTPC for Low-Energy α-Particle Detection in the Experimental Search for Hybrid Mesons
Student: ***Nicholas Sharp***, Frostburg State University, Frostburg, MD
Mentor: Stepan Stepanyan, Thomas Jefferson National Accelerator Facility, Newport News, VA

The theory governing the strong interaction between partons (quarks, q and gluons, g) in the standard model of particle physics, quantum chromodynamics (QCD), allows a large variety of bound states, known as hadrons. Any combination of quarks and/or gluons can exist as long as their respective color charges negate to zero. Nearly every hadron observed however is in a qqq (baryonic) or q (mesonic) configuration. These are the particles predicted by the well-known quark model, however so-called exotic states are also allowed by QCD, such as glueballs (gg), pentaquarks (qqqq), hybrid mesons (gq), etc. Some of these short-lived exotic states can be identified by their unique quantum numbers, but others are indistinguishable from ordinary hadrons. The detection of exotic hadrons has so far been shrouded in controversy, and as such we are seeking evidence of the ground state hybrid meson π1 with quantum numbers JPC = 1–+ via photoproduction utilizing the 6-GeV electron beam off of 4He nuclei. A key factor in our experiment is the use of 4He nucleons due to the 4He nuclei being spin- & isospinless, thus greatly simplifying the partial-wave analysis (PWA) thanks to the resulting coherent photoproduction process and subsequent elimination of noise from nucleon-resonance production. The foundation of the experiment however is in the use of a radial time-projection chamber (RTPC) to detect the low-energy recoiling 4He nuclei. The RTPC has cylindrical gas electron multipliers (GEMs) with almost 360° cover- age for detection, similar to the successful barely off-shell nucleon structure (BoNuS) experiment. Two mass-energies have tentatively been detected for the ground-state $\pi 1$, though there can only be one: 1.4 GeV & 1.6 GeV (theory predicts ≈ 2 GeV/c2). Detection of the $\pi 1$ at Jefferson Laboratory will be a big step towards ending the controversy surrounding exotic hadrons and furthering our knowledge of the still-elusive quark-gluon behavior and the strong force.

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Assessing the Effects of Magnetic Fields on the Photomultiplier Tubes in the SANE
Student: ***Forrest Smith***, State University of New York, Geneseo, NY
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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
Student: ***Jennifer Beveridge***, Indiana University of Pennsylvania, Indiana, PA
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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

Student: ***Stephen Lowery***, Harvey Mudd College, Claremont, CA
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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

Student: ***Kirsten Dietrick***, Rensselaer Polytechnic Institute,Troy, NY
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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
Student: ***James Kotary***, State University of New York at Buffalo, Buffalo, NY
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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
Student: ***Amber McCreary***, University of Pittsburgh, Pittsburgh, PA
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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

Student: ***Matthew Kramer***, University of California, Berkeley, CA
Mentor: Balsa Teraic, Thomas Jefferson National Accelerator Facility, Newport News, VA

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

Student: ***Colin Jarvis***, Macalester College, St. Paul,MN
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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

Student: ***Allison Mitchell***, Juniata College, Huntington, PA
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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.

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Abstract

The genetic algorithm is a relatively new optimization tool that uses the ideas implemented in biological processes of evolution to arrive at the best solution for a given optimization problem. The algorithm works especially well for problems with a big quantity of local optima and has been shown to provide good results in a short amount of time for optimization of accelerator processes such as beam-beam collision. The success of genetic algorithm motivates an attempt to implement it for another problem – in the case of this project, minimizing the electron beam coupling, which is essential to prevent degradation of the beam quality. The genetic algorithm was set to work with electron beam code Elegant, first for a model case to work out the best parameters and strategy, and then for a more realistic case. The parameters studied included a number of individuals per generation and variables that control the size of mutation and recombination. It was shown that the traditional genetic algorithm is able to converge to an optimal solution on average in 320 iterations, which takes around 15-20 minutes. The algorithm was shown to be robust and able to find a very good local optimum. A novel enhancement to the genetic algorithm has been devised to improve convergence to the optimal point: narrowing down the area of search as soon as the individuals start to converge to some smaller region, which allows the parameters to keep working efficiently and not miss the optimum due to large mutation jumps. The devised strategy decreased the average optimization time to around 240 iterations. The results have shown the viability of genetic algorithm in electron beam decoupling. The algorithm's success should motivate its usage in various other processes that require optimization. The developed strategy and the analysis of the best parameters improved the efficiency of the algorithm. The improved algorithm can prove useful in solving other optimization problems.

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The Testing of Hall D Beam Position Monitors For Operation On a Low Current Beam.

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Efficient accelerator operation requires the determination of the electron beam position at various locations along the beam path. The Jefferson Lab Beam Position Monitors (BPMs) are superheterodyne receivers that utilize analog and digital components. The BPMs measure the voltage and phase of the beam and utilize these measurements to determine the position and change in position of the beam, respectively. Hall D requires more sensitive stripline BPMs, which can detect low-current beams. The focus of this project was to test stripline BPMs, before installation. Furthermore, the BPM firmware and new methods of BPM calibrations, including phase measurement calculations and Y-factor calibration, will be tested before utilization in the beam tunnel. To test the BPMs, a Goubau Line system was used to simulate an electron beam. The BPMs were attached to Stac6Si stepper motors, which were used to scan a 1 cm^2 area around the BPM center. The stepper motor position was compared with the BPM data to measure BPM sensitivity. Finally, the BPMs' circuitry and Y-factor calibration methods were tested. It was found that BPM voltage measurements can determine the beam's position with a sensitivity of 1.9 dBm/mm. Furthermore, Y-factor analysis provided real-time measurements of BPM gain and noise factor. The BPM circuitry was found to have an acceptable gain, isolation, and

saturation point. It was determined that a 1 mm change in position results in a 4.2° change in phase. It was found that the new BPMs are twice as sensitive as previous models, and, with the use of a perceptron, phase measurements can determine change in beam position, providing feedback for beam operators during BPM calibration. More sensitive position measurements allow researchers to conduct experiments requiring low-current beams, and allow for more accurate electron beam positioning.

Target Mass Corrections to Nucleon Structure Functions. **MATTHEW D. BROWN** (Arizona State University, Tempe, AZ 85287) WALLY MELNITCHOUK (Thomas Jefferson National Accelerator Facility, Newport News, VA 23606).

A nucleon (a proton or a neutron) can be described simply as a bound state of three quarks. However, in reality, the structure of the nucleon is complicated by the gluons which bind the quarks together and quark-antiquark virtual pairs popping in and out of the vacuum. This structure is often parameterized by quantities known as structure functions. Structure functions are measured in deep inelastic scattering experiments with nucleon targets, such as the ones conducted here at Jefferson Lab, and then fitted to theoretical conjectures. Because of the high energies involved in the experiments, one may typically assume when postulating theoretical parameterizations that the nucleon mass is negligible compared to the interaction energy. However, in order to obtain a more accurate and complete picture of the internal structure of nucleons, we considered the effects of target mass corrections to nucleon structure functions. Using the operator product expansion of quantum field theory, along with several other mathematical tools, we obtained elegant new formulas for the target mass corrections to all of the usual spin-averaged nucleon structure functions. We also determined the Cornwall-Norton moments of each target mass corrected structure function, quantities which are convenient for numerical studies. Our results are consistent with previous work. However, we have found interesting behavior of the target mass corrected structure functions in what is referred to as the large-x regime. This suggests a relationship between our work and what is known as the threshold problem, one of the most important outstanding questions about the limitations of the operator product expansion.

Slow Controls LabVIEW Program for the Silicon Vertex Tracker. **MINNAE P. CHABWERA** (Hampton University, Hampton, VA 23668) AMRIT YEGNESWARAN (Thomas Jefferson National Accelerator Facility, Newport News, VA 23606).

The focus of this project was to create a LabVIEW slow controls program for the Silicon Vertex Tracker, SVT, slow controls system. The program will be used to test the modules of the SVT at Fermi National Accelerator Laboratory, Fermilab. The LabVIEW Virtual Instrument, VI, in which the program was created and is currently stored, will run a 72-hour burn-in test on each of the 66 modules of the SVT, while retaining the ability to run shorter, more specific tests. The slow controls VI has been designed for both novice and expert LabVIEW users, while allowing them the freedom to adjust the parameters specifically to their needs. The VI was created with the capability to run with voltage and current as its parameters. The graphical user interface, GUI, of the LabVIEW slow controls program is designed with a user-friendly interface, where each parameter control is labeled and easy to accurately adjust. The main result from the LabVIEW program is the creation of the monitoring program for the detector modules. The VI has been programmed to communicate with the MPOD hardware, make a strip chart of the voltage and current levels, and automatically record data. It has been specifically wired in the block diagram for the computer to communicate with the MPOD crates and resultantly the SVT. The LabVIEW slow controls program reads back the voltage and current from each channel, as well as signals the voltage and current relation to the programs' threshold settings. The results have been a VI that uses voltage and current as its primary parameters and communicates directly to the MPOD hardware. The next steps for the LabVIEW program to be used in Hall B will be the conduction of the burn-in test and expansion to include more parameters such as humidity and temperature.

Development of a Slow Controls Program for the Silicon Vertex Tracker. KALEE M. HAMMERTON (Christopher Newport University, Newport News, VA 23606) AMRIT YEGNESARWAN (Thomas Jefferson National Accelerator Facility, Newport News, VA, 23606).

As part of the 12 GeV Upgrade to the Continuous Electron Beam Accelerator Facility (CEBAF) Large Acceptance Spectrometer (CLAS) in Hall B of Thomas Jefferson National Accelerator Facility, the Hall B Instrumentation group is developing a silicon vertex tracker (SVT). The SVT requires that each of its 66 modules be connected to four low-voltage and two high-voltage channels. The voltage will be provided to the SVT by Wiener MPOD mainframes. These mainframes hold low- and high-voltage cards, which have eight and 16 channels, respectively. The objective of this work was to develop a LabVIEW program to set and adjust the voltages and to monitor the set voltages and the current drawn by the detector. The program was built up from the simple network management protocol (SNMP) virtual instruments (VI) provided by Weiner for LabVIEW. A graphical user interface was designed to allow novices and experts to operate the program. The initial program is capable of setting the voltages and reading back the voltages and currents from eight low-voltage channels and 16 high-voltage channels. The program is communicating with the MPOD mainframe and is running error free. The program will be used for the burn-in tests that will be conducted on the modules at Fermi National Accelerator Facility in the fall of 2012. Now that one card worth of low-voltage and of high-voltage channels can be set, changed and monitored, the program can be easily expanded to set and monitor the 264 low-voltage channels and the 132 high-voltage channels needed for the SVT.

Electromagnetic Field Distribution Measurements in a New Deflecting/Crabbing SRF Cavity Using a "Bead Pull" Test. YOAV LEVINE (Tel Aviv University, Tel Aviv, Israel 69978) JEAN DELAYEN (Thomas Jefferson National Accelerator Facility, Newport News VA).

The Continuous Electron Beam Accelerator Facility (CEBAF) at Jefferson Laboratory and the Large Hadron Collider (LHC) at Conseil Européen pour la Recherche Nucléaire (CERN), present a need for a deflecting/crabbing cavity. At LHC, this cavity will rotate the beam bunches just prior to collision in order to enhance the luminosity, and at CEBAF this cavity will deflect each bunch to its corresponding experimental hall. A superconducting radio frequency (SRF) deflecting/crabbing cavity was designed and two niobium models were manufactured, one for each facility. Their geometry is designed to allow an optimal electro-magnetic (EM) field distribution, most importantly a horizontal electric field and vertical magnetic field on the main axis. The focus of this project was to measure the actual EM field distribution inside the cavity intended for CEBAF and to track deviations from the numerical simulations conducted prior to its manufacturing. A "bead pull" measurement was conducted, based on the principle stating that when a dielectric or metallic small bead is inserted into a cavity, it perturbs the EM field, causing the resonance frequency of the cavity to shift. A designated LabVIEW program was modified to coordinate measurements of the cavity's phase shift as beads of different materials and shapes were pulled through it. It was found that the measured on-axis horizontal electric field distribution is satisfactorily consistent with the simulations, exhibiting a symmetric peak of the expected width and magnitude. The on-axis magnetic field measurement demonstrates peaks at the expected positions, but was influenced by the bead over-perturbing the field and needs to be retaken. The off-axis longitudinal electric field measurement demonstrates peaks positioned further away from the center than predicted. Overall, it is shown that the CEBAF cavity exhibits the expected horizontal electric field response to radio frequency excitation, but needs further testing before ready to operate successfully at its intended facility.

Simulating Pressure Profiles for the Free-Electron Laser Photoemission Gun Using Molflow+. **DIEGO MIONG SU SONG CHO** (Wesleyan University at Middletown, CT 06459) CARLOS HERNANDEZ-GARCIA (Thomas Jefferson National Accelerator Facility, Newport News, VA).

The Jefferson Lab Free-Electron Laser (FEL) is capable of generating tunable infrared or ultraviolet laser light by passing a relativistic electron beam through a magnetic undulator. The electron beam is generated in a high-voltage DC electron gun with a semiconducting photocathode, which must be placed in stringent vacuum conditions, an imperative requirement in order to guarantee photocathode longevity. In prospect of an upcoming upgrade of the electron gun, this project consists of simulating pressure profiles to determine if the novel design meets the electron gun vacuum requirements. The method of simulation employs the software Molflow+, developed by R. Kersevan at the Organisation Européene pour la Recherche Nucléaire (CERN), which uses the test-particle Monte Carlo (TPMC) method to simulate molecular flows in three-dimensional structures. Using Molflow+, pressure profiles are obtained along specified chamber axes in the form of linear plots and color-mapped texture graphics. Molflow+ pressure profiles are then compared to measured pressure values in existing electron guns for validation. Outgassing rates, surface area, and pressure were found to be proportionally related. The simulations make evident that the upgraded gun vacuum chamber requires more pumping compared to the existing FEL electron gun vacuum chamber. Since experimental data correlates well with simulation results, the simulations predict that the new electron gun should have similar vacuum conditions to the existing one, with pressures ranging from 4.0×10^{-12} Torr to 4.5×10^{-11} Torr, depending on the outgassing rate after vacuum bake-out. The ability to simulate pressure profiles through validated tools like Molflow+ allows researchers to optimize complex vacuum systems during the engineering design process.

Simulation of the Hall C Compton Polarimeter Electron Detector. **ERIK G. URBAN (Hendrix College in Conway, AR 72034) DAVID GASKELL** (Thomas Jefferson National Accelerator Facility, Newport News, VA 23606).

Experiments at Thomas Jefferson National Accelerator Facility (TJNAF) use a polarized electron beam to make high-precision, electron helicity-dependant measurements in order to probe the fundamental properties of particles. In such experiments, knowledge of the electron beam polarization is required to extract the physics of interest and therefore needs to be tracked precisely. The Hall C Compton polarimeter serves this need by measuring the scattering asymmetry observed between helicity states in polarized Compton scattering. The primary objectives of this project are to update a simulation and analysis package for the electron detector used in the Compton polarimeter in order to better understand the processes influencing the beam polarization measurement, to test the validity of the current analysis methods, and to test for various systematic sensitivities within the apparatus. First, the simulation package was modified to include the current electron detector configuration and to output the necessary information from each event to a data file. Secondly, the analysis package was redesigned to receive this data and analyze it as if it were from a real experimental run. Once both systems were operational, slight systematic changes were made to the simulation but analyzed without accounting for them in order to gauge the systematic uncertainties associated with the beam polarization measurement as a whole. Both systems are currently functional and it is now possible to gauge the systematic uncertainties associated with the polarimeter. Once all of the tests on the simulation are complete, it will be known which method of analysis is most appropriate and which parameters have the largest impact on the overall uncertainty associated with the polarization measurement. With the uncertainty associated with the beam polarization determined, its overall impact on the final precision achievable by the Hall C experiments will be known.

Cresting Algorithm Using Fourier Analysis of Beam Position. RYAN ROUSSEL (Rensselaer Polytechnic Institute, Troy,NY,12180) YVES ROBLIN (Center for Advanced Studies of Accelerators, Thomas Jefferson National Accelerator Facility, Newport News,VA, 23606)

The Continuous Electron Beam Accelerator Facility (CEBAF) accelerator contains two linear accelerators with superconducting radio frequency (SRF) cavities to accelerate electrons. Sinusoidal electric fields are created inside the cavities, such that electrons see a constant potential accelerating them forward. For this to happen, the maxima of the electric fields in each cavity must be precisely matched to the timing of the particles trajectories. Unfortunately, when first starting the beam, imperfections in the accelerator prevent this from happening. Optimization is achieved by modulating the phase of cavities one at a time

until the electrons are observed to have the maximum energy. The focus of this project is to improve the process of finding the crest (maxima) phase of multiple cavities by modulating a large number of cavities simultaneously. This was done by modulating the phase of each cavity at a different frequency and observing the position of the beam at a point of high dispersion. The position of the beam over the period of modulation was then Fourier transformed, producing spikes at the frequencies that corresponded to the different cavities. This was repeated with different amplitudes of modulation to fit a relationship between the amplitude of modulation and the Fourier transform spike amplitude, which contained phase information. This algorithm was used to determine the phase of cavities in a simulation of the North CEBAF Linac with an error of 100 microns in beam position measurement. The improved algorithm successfully predicted the correct phase of eight cavities simultaneously to within an error of two degrees. It has been shown that multiple cavities can be crested at the same time through the phase modulation of cavities at different frequencies and Fourier transforming the positions of the resulting beam. This has ramifications for accelerator operation, because it dramatically decreases tuning time needed for beam optimization.