

Precision, absolute proton polarization measurements at 200MeV

G.Atoian^{a*}, A.Bogdanov^b, B. Briscoe^a, D.Raparia^a, M.Runtso^b,
E.Stephenson^c, D.Steski^a, V.Zajic^a, A.Zelenski^a

^aBrookhaven National Laboratory, Upton, NY, 11973, USA

^bMoscow Engineering Physical Institute (MEPHI), Moscow 115409, Russia

^cIUCF, Bloomington, 47408, USA

atoian@bnl.gov

A polarimeter for absolute proton beam polarization measurements at 200 MeV with accuracy better than $\pm 0.5\%$ has been developed as a part of the RHIC polarized source upgrade.

The polarimeter is based on elastic proton-carbon scattering at 16.2° where the analyzing power is close to 100% and known with high accuracy. The elastically and inelastically scattered protons are clearly identified by the difference in their propagation through a variable-thickness copper absorber and their energy deposition in the detectors. The 16.2° elastic scattering polarimeter was used for the calibration of a high-rate inclusive 12° polarimeter for on-line polarization tuning and monitoring. This technique can be used for accurate polarization measurements in the energy range between 160 and 250 MeV.

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Polarization optimization studying in the polarization

G. Atoian^{a*}, J. Alessi^a, V. Davydenko^b, A. Ivanov^b, V. Klenov^c, A. Kolmogorov^b, T. Lehn^a, D. Raparia^a,
J. Ritter^a, D. Steski^a, A. Zelenski^a, V. Zubets^c

^aBrookhaven National Laboratory, Upton, NY 11973, USA

^bBudker Institute of Nuclear Physics, Novosibirsk, Russia

^cInstitute of Nuclear Researches, Novosibirsk, Russia

atoian@bnl.gov

A novel polarization technique had been successfully implemented in the RHIC polarized H⁻ ion source upgrade to higher intensity and polarization for use in the RHIC polarization physics program at enhanced luminosity RHIC operation.

Limitations of the polarized H⁻ ion current, suitable for application at RHIC and other high-energy accelerators and colliders can be overcome in pulsed operation source by using instead of ECR a high brightness Fast Atomic Beam Source (FABS) outside the magnetic field. A high current and low divergence primary proton of ~5.0-8.0keV energy is neutralized in the pulsed hydrogen neutralizer cell. The H atomic beam is injected into a superconductive solenoid containing a pulsed-gaseous He-cell ionizer and the optically pumped polarized Rb vapor cell. The injected H atoms are ionized in the He with 80% efficiency and then enter the polarized Rb-cell. The protons pick-up polarized electrons from the Rb atoms to become a beam of electron-spin polarized H atoms then passes through a magnetic field reversal region, where the polarization is transferred to the nucleus via hyperfine interaction (Sona-transition technique). The negative bias voltage of ~2.0-5.0kV applied to the He-cell decelerate proton beam to allow energy separation of the polarized hydrogen atoms and residual hydrogen atoms of primary beam.

Higher polarization of the FABS source is achieved by: a) the separation and neutralization of residual hydrogen due to bending magnet and collimators more than 25-30 times, b) better efficiency Sona-shield transition for the smaller beam diameter of ~ 1.5 cm, c) of the optimized magnetic field and the frequency of the pump laser. All these factors combine to make it possible to increase the polarization in pulsed OPPIS to ~90%, and the source intensity to over 10 mA.

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Møller Polarimetry with Polarized Atomic Hydrogen at MESA

Patricia Aguar Bartolome
Institut für Kernphysik Mainz, Germany

Abstract

A new generation of parity violation electron scattering experiments are planned to be carried out at the Institut für Kernphysik in Mainz. These experiments will be performed at low energies of 100-200 MeV using the new accelerator MESA (Mainz Energy recovering Superconducting Accelerator). One of the main challenges of such experiments is to achieve an accuracy in beam polarization measurements that must be below 0.5%. This very high accuracy can be reached using polarized atomic hydrogen gas, stored in an ultra-cold magnetic trap, as the target for electron beam polarimetry based on Møller scattering. Electron spin-polarized atomic hydrogen can be stored at high densities of 10^{16} cm^{-2} , over relatively long time periods, in a high magnetic field (8T) and at low temperatures (0.3K). The gradient force splits the ground state of the hydrogen into four states with different energies. Atoms in the low energy states are trapped in the strong magnetic field region whereas the high energy states are repelled and pumped away. The physics of ultra-cold atomic hydrogen in magnetic traps and the status of the Mainz Hydro-Møller project will be presented.

Polarized ion sources with nearly resonant charge-exchange plasma ionizer: parameters and possibilities for improvements.

A. S. Belov

*Institute for Nuclear Research of Russian Academy of Sciences,
Moscow, 117312, Russia.*

Abstract. Parameters of polarized ion sources with nearly resonant charge-exchange plasma ionizer are summarized. Pulsed beams of polarized protons with peak intensity up to 11 mA and polarization of 80% and polarized negative hydrogen ions with peak current of 4 mA and polarization of 91% have been obtained. While no progress of parameters during recent past years has been obtained, possibilities for further improvements still exist. Both atomic beam part of the sources can be improved as well as efficiency of conversion of polarized atoms into polarized ions. The possibilities are discussed in the paper.

A Helium-3 polarimeter using electromagnetic interference

N. H. Buttimore

School of Mathematics
Trinity College, Dublin 2, Ireland
nigel.buttimore@tcd.ie

Measuring polarization levels of a high energy beam of polarized He-3 ions will be required for studies of many spin dependent hadronic processes. In particular, this will facilitate investigations involving the spin of a down quark as the spin properties of helium-3 are not unlike those of a neutron [1].

The successful use of electromagnetic hadronic interference in proton high energy polarimetry [2] is examined in the context of a helium-3 beam. The carbon nuclei recoiling both left and right from elastic scattering off a very thin carbon target provide a sensitive indication of the polarization of incident fermions. More stringent kinematic cuts are necessary in the case of helium to ensure that elastic collisions have taken place, thus excluding helium break-up and carbon nuclear excitation events.

Though the greater hadronic total cross section of helium-3 carbon scattering reduces the optimal analyzing power by comparison with the proton case, the large anomalous magnetic moment of He-3 nuclei is helpful. The doubling of the electric charge and the more prominent Coulomb phase arising from two photon exchange effects also serve to enhance the analyzing power. Against this, the finite nuclear size of helium reduces it for momentum transfers outside the interference region [3].

Hadronic spin-flip effects need to be known as they influence the accuracy of interference polarimetry [4]. Such effects have recently been shown to be small for high energy proton elastic collisions [5]. Nevertheless, a polarized helium-3 jet should be made available to fully calibrate the helium polarimeter.

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Spin-exchange polarized ^3He for electron scattering

Gordon D. Cates

University of Virginia, Charlottesville, VA 22903, U.S.A.

Polarized ^3He targets based on spin-exchange optical pumping (SEOP) have been successfully used to measure spin-dependent neutron observables in electron scattering for over two decades. Examples of the physics that has been studied include the spin structure of the neutron in deep inelastic scattering, the Q^2 dependence of the generalized Gerasimov-Drell-Hearn (GDH) integral, the electric form factor of the neutron, and single-spin asymmetries in semi-inclusive deep inelastic scattering (SIDIS). The expanding scope of the physics that has been studied with these targets has only been possible because of dramatic increases performance. The advances in the polarized ^3He target technology has been due to both an improved understanding of the underlying physics as well as technological advances.

In this talk, I will first summarize the work that has resulted in over an increase in the effective luminosity of these targets by well over an order of magnitude. This includes the use of alkali-hybrid SEOP and the use of high-power spectrally-narrowed lasers. Substantial gains have been made in the quantity of ^3He gas that can be polarized, the maximum polarizations achieved, and the rate at which the gas can be polarized. The rate at which polarization is achieved is particularly important for tolerating high electron-beam currents. I will also describe our measurements of the so-called X-factors, that characterize an as yet unidentified relaxation mechanism that limits the maximum polarizations that can be achieved.

Also discussed will be the development of next-generation polarized ^3He targets that will be used in upcoming experiments following the JLab energy upgrade. Among the new features incorporated into these targets is the use of convection to rapidly circulate the polarized ^3He gas between the chambers in which the SEOP takes place and the target chamber, through which the electron beam passes. We have shown that convection, unlike diffusion, results in a much smaller polarization gradient between the two chambers without significant loss of polarization. It appears that significant increases in the performance of polarized ^3He targets can be expected to continue for many years.

Upgrade of the PAX H and D polarized internal target for precision measurements at COSY

G. Ciullo^a, M. Statera^a, L. Barion^a, P. Lenisa^a, G. Tagliente^b, and A. Nass^c.

^a Dipartimento di Fisica e Scienze della Terra
Università degli Studi di Ferrara ed INFN
Via Saragat 1, I-44122 Ferrara - Italy
ciullo@fe.infn.it

^bINFN - Bari
Via E. Orabona 4, I-70125 Bari -Italy

^cInstitut für Kernphysik
Forschungszentrum - Leo-Brand-Straße D-52425 - Jülich - Germany

In order to accomplish to the needing of future experiments, the PAX collaboration ¹ is performing an upgrade of the polarized internal target presently installed at the COSY ring in Jülich (Germany).

The implementation of a new dual cavity will allow to switch from H to D and to measure the gas polarization without hardware change in a daily time. The introduction of an openable storage cell will increase the ring acceptance at injection and the intensity of the stored beam.

The new setup will be adopted in spin-filtering ² measurements as a mechanism to produce polarized antiprotons and in a recently proposed test of Time Reversal Invariance³ foreseen at the COSY ring.

In the report, the status of the development of the apparatus and the plans of the Collaboration will be illustrated.

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Demands on polarized electron sources by future experiments in Parity Violating Electron Scattering

Mark Macrae Dalton

^aJefferson Lab, Newport News, VA (dalton@jlab.org)

Parity Violating Electron Scattering (PVES) is a very clean way to probe the neutral weak-current. The observable of interest is an asymmetry in the electron-scattering cross-section, measured under reversal of the longitudinally polarization of the electron beam. Such a polarization reversal is a parity transformation, which leaves all known forces invariant except the weak interaction.

The technique was originally used to verify the nature of the weak neutral-current, and more recently has been used to bound the size of the strange quark contribution to the nucleon form factor, verify the existence of a “neutron-skin” in ^{208}Pb , and to do precision tests of the Standard Model of particle physics. Asymmetries measured in experiments so far have ranged from ~ 200 parts-per-million (ppm) down to ~ 0.2 ppm, depending on the physical process and kinematics. The polarization is reversed at between 30 and 960 times per second.

Production of the polarized electrons and particularly their rapid reversal in the polarized source can produce effects on the beam that lead to measured “false” asymmetries, which then require complex corrections and increase the uncertainties. The classic source of false asymmetry is a change in the angle, position or energy of the beam that is correlated with the polarization direction. Another potential source of false asymmetry is a charge asymmetry in a small portion of the beam phase space which has an proportionally much larger signal in the detectors.

Future PVES experiments will need to make measurements with uncertainties smaller in both absolute and relative terms than what has been achieved to date. They will therefore be much less able to make corrections and will need to control potential sources of false asymmetries to a higher degree. In addition, for reasons related to the very high luminosity of future experiments, even faster reversal rates will be required.

This presentation will present polarized-source related issues encountered in recent PVES experiments. The beam requirements for some major future experiments will be reviewed and potential bottlenecks and solutions will be discussed.

PERSPECTIVE FOR DEVELOPMENT OF A UNIVERSAL SOURCE OF HIGHLY POLARIZED IONS

Vadim Dudnikov, *Muons, Inc., Batavia, IL USA;*

High beam polarization degree is essential to the scientific productivity of colliders. If there is no depolarization during acceleration and storage, the final beam polarization is determined by the initial polarization at extraction from the ion source. Therefore, ion sources with performances exceeding those achieved today is a key requirement for the development of the next generation high-luminosity high-polarization colliders.

We present a single universal H-/D-/He⁺⁺ ion source design combining the most advanced developments in the field of polarized ion sources and targets to provide high-current high-brightness ion beams with >90% polarization and improved lifetime, reliability, and low ownership cost. The new source is an advanced version of the atomic beam polarized ion source (ABPIS) with resonant charge-exchange ionization of polarized neutral atoms by negative (or positive) ions generated by surface-plasma interactions with cesiation. The main innovation of this approach is the strong suppression of parasitic generation of unpolarized H-/D- ions by using novel designs of the dissociator, plasma generator, and surface-plasma ionizer, which prevent adsorption and depolarization of particles from the polarized atomic beam. The same system with some modifications is capable of producing positive and negative ion beams of different species including polarized and unpolarized H⁻, D⁻, H⁺, D⁺, 3He⁺⁺, and Li⁺, Li⁺⁺⁺. Computer simulations of the formation, extraction, and transport of the polarized atomic and ion beam in the new source are presented. Manufacturing techniques are discussed.

Neutron spin filter based on dynamically polarized protons using photo-excited triplet states

T.R. Eichhorn^{a,b}, B. van den Brandt^a, M. Haag^a, P. Hautle^a and W.Th. Wenckebach^a

^aPaul Scherrer Institute
CH - 5232 Villigen PSI, Switzerland

^bLaboratory of Functional and Metabolic Imaging, EPFL
CH - 1015 Lausanne, Switzerland

The use of polarized protons as a spin filter is an attractive alternative to the well-established neutron polarization techniques such as super mirrors and polarized helium-3 gases, as the large spin dependent neutron scattering cross section for protons is useful up to the sub-MeV region.

Nuclear spin order can be obtained by standard methods using dynamic nuclear polarization (DNP) through a coupling to highly polarized electron spins being at thermal equilibrium. This requires both low temperatures (ca. 1 K) and strong magnetic fields (2.5 to 5 T) in order to obtain a significant Boltzmann factor for the electron spin system. These rather strict conditions can be relieved by a more recent and very promising DNP method that uses short-lived electron triplet states in organic pentacene:naphthalene crystals. Photo-excitation of the triplet states provides a large electron spin order far beyond the thermal equilibrium. As a consequence the requirements for the cryogenic equipment and the magnetic field are relaxed significantly and technically simpler systems with open geometries are possible.

We have recently proven that the triplet DNP method can be used to build a reliably working neutron spin filter. It is operated in 0.3 T and about 100 K and has performed stably over periods of several weeks [1,2]. So far we can report on high proton spin polarization values of up to 0.5 corresponding to an analyzing power of ca. 0.5 obtained with a sample of typical 4 mm thickness [3].

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E-mail of the corresponding author: tim.eichhorn@psi.ch

Polarized Fusion

Can polarization help to increase the energy output of fusion reactors?

R. Engels

Institute for Nuclear Physics, Research Center Jülich
Wilhelm-Johnen-Str. 1, 52425 Jülich, Germany
r.w.engels@fz-juelich.de

The option to use polarized fuel for coming fusion reactors is discussed since many years [1]. For example, the total cross section of the fusion reactions $d + t \rightarrow {}^4\text{He} + n$ or ${}^3\text{He} + d \rightarrow {}^4\text{He} + n$ is increased by a factor of about 1.5, if the spins of both incoming particles are aligned. This can be used to increase the energy gain up to a factor 10, depending on the design of the different reactor types. In addition, the differential cross section is not uniform any more which allows a more simpler design of the plasma cooling. But before polarized fuel can be used for energy production, a number of questions must be answered. In this talk an overview on various activities in this field of research will be given:

1. Compared to the above mentioned reactions the d-d fusion reactions are more complicated. Up to now the influence on the differential and the total cross section for the double-polarized case is theoretically predicted but never proofed. In a collaboration between the PNPI in Gatchina, Russia, the University of Ferrara, Italy, and the FZ Jülich, Germany, the spin-dependence of the d-d fusion reactions will be measured with a polarized deuteron beam at energies below 100 keV on a polarized deuterium jet target.
2. Beside the magnetic confinement fusion inertial fusion with laser heating is tested at several experiments. One of the important questions here is the lifetime of the polarization of the primary particles in the induced laser plasma. In collaboration between the University of Düsseldorf and the FZ Jülich it will be tested to accelerate polarized ${}^3\text{He}^{2+}$ ions from a polarized ${}^3\text{He}$ gas jet with the laser beam. If the polarization of the ${}^3\text{He}$ atoms will survive in the ions the feasibility of ongoing experiments is shown.
3. When polarized fusion might be a reasonable option for energy production than the question of polarized fuel production will become important. This problem is solved for ${}^3\text{He}$ and seems to be within reach for tritium. But for deuterium the situation is unclear. One option might be the production and storage of polarized D_2 molecules which was investigated in the last years in FZ Jülich.

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Polarized Hydrogen/Deuterium Molecules - A new option for polarized targets?

R. Engels^a, R. Gorski^a, K. Grigoryev^{a,b}, L. Kochenda^b, P. Kravtsov^b,
M. Mikirtychiants^{a,b}, F. Rathmann^a, H. Paetz gen. Schieck^c, H. Ströher^a,
V. Trofimov^b, A. Vasilyev^b, and M. Vznuzdaev^b

^a Institut für Kernphysik, Forschungszentrum Jülich
Wilhelm-Johnen-Str. 1, 52425 Jülich, Germany
r.w.engels@fz-juelich.de

^b Laboratory of Cryogenic and Superconductive Technique, Petersburg Nuclear Physics Institute
Orlova Rosha 1, 188300 Gatchina, Russia

^c Institute for Nuclear Physics, University of Cologne
Zùlpicher Str. 77, 50937 Köln, Germany

Since 50 years different types of storage cells have been used to increase the target density of polarized internal targets in storage rings, fed with atoms from an atomic beam source. Most of these cells are optimized to avoid recombination of the polarized hydrogen or deuterium atoms into molecules and to preserve the nuclear polarization at a high level between 0.75 and 0.9. Independently, groups at AmPS[1], IUCF[2], and HERMES[3] have shown that nucleons of recombined molecules can still be polarized. In a collaboration between the Petersburg Nuclear Physics Institute, the University of Cologne and the Forschungszentrum Jülich we have built a dedicated apparatus to measure the polarization of hydrogen(deuterium) atoms and molecules in cells of different surface materials for temperatures between 45 and 120 K and in magnetic fields up to 1 T. In addition, the recombination probability of atoms and the amount of wall bounces of molecules inside the cells have been measured with good precision. First measurements on a gold surface, on fused quartz and on FOMBLIN oil will be presented.

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Investigation of pulsed spin polarized electron beams at the S-DALINAC

M. Espig^a, J. Enders^a, Y. Fritzsche^a and M. Wagner^a

^aInstitut für Kernphysik
Schlossgartenstr. 9, 64289 Darmstadt
mespig@ikp.tu-darmstadt.de

A source of polarized electrons has been implemented at the superconducting Darmstadt electron linac S-DALINAC. It uses photo-emission from strained-layer superlattice-GaAs (SSL) and bulk-GaAs photocathodes, driven by either 3 GHz modulated diode lasers at 780 nm (high polarization) and 405 nm (unpolarized, high quantum efficiency) or a short-pulse Ti:Sapphire laser system at 780 nm.

We present results from measurements with varying laser pulse lengths, yielding electron bunch lengths between 40 ps and 90 ps using a pulse stretcher system and a single-mode optical fiber. The electron bunch length was determined using a chopper rf cavity and a slit system. The dependence of the electron polarization from the rf phase was studied over the electron bunch both for SSL and bulk cathodes. The extracted data at low quantum efficiency require an extension of the model description for photo-emission from semiconductor cathodes.

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STATUS OF THE NEW SOURCE OF POLARIZED IONS FOR THE JINR ACCELERATOR COMPLEX

V.V. Fimushkin^a, A.D. Kovalenko^a, L.V. Kutuzova^a, Yu.V. Prokofichev^a, A.S. Belov^b, V.N. Zubets^b, A.V. Turbabin^b

^a*Joint Institute for Nuclear Research, Joliot-Curie 6, 141980 Dubna, Moscow region,
Russia*

^b*Institute for Nuclear Research of Russian Academy of Sciences, 60th October Anniversary
Prospect 7A, 117312 Moscow, Russia*

fimushkin@jinr.ru

The project assumes the design and construction of a universal high-intensity source of polarized deuterons (protons) using a charge-exchange plasma ionizer. The output $\uparrow D^+$ ($\uparrow H^+$) current of the source is expected to be at a level of 10 mA. The polarization will be up to 90% of the maximal vector (± 1) for $\uparrow D^+$ ($\uparrow H^+$) and tensor (+1, -2) for $\uparrow D^+$ polarization. Realization of the project is carried out in close cooperation with INR of RAS (Moscow). The equipment available from the CIPIOS ion source (IUCF, Bloomington, USA) is partially used for the Dubna device. The new source at the JINR NUCLOTRON accelerator facility will make it possible to increase the polarized deuteron beam intensity up to the level of 10^{10} d/pulse. The status of development and testing is discussed.

Long term performance of the COSY/Jülich polarized ion source

R. Gebel, O. Felden, R. Maier and S. Mey

Forschungszentrum Jülich
Institute for Nuclear Physics (IKP-4)
52425 Jülich, Germany
r.gebel@fz-juelich.de

The COoler SYnchrotron and storage ring COSY [1] located at the Institute for Nuclear Physics (IKP) of the Forschungszentrum Jülich provides routinely polarized protons and deuterons with momenta between 0.3 GeV/c and 3.8 GeV/c for experiments at several internal and external target places. Since January 1996, the cyclotron JULIC operates as the injector of H⁻ or D⁻ beams for stripping injection into the COSY ring with polarized beams delivered by the colliding beams source [2, 3]. The original source has been designed and set in operation by groups from the universities Bonn, Cologne and Erlangen as a colliding beams source in continuous operation [5]. In parallel to beam delivery to the synchrotron the atomic beam part, the cesium ionizer, neutralizer and the ion extraction have been optimized continuously for pulsed operation. By advancing the components of the polarized ion source the number of polarized particles for injection into the cyclotron has reached about 5×10^{12} protons, delivered in a 20 ms pulse with a repetition rate of 2 seconds [6]. The polarization of the circulating beam in COSY is measured routinely during acceleration and at maximum momentum with the internal EDDA detector and exceeds 70 % after compensation of depolarizing resonances for highest beam energies [4]. The polarization of the source is optimized with Breit Rabi techniques and a Lambshift polarimeter behind the ion source. High analyzing powers for elastic scattering of the beams on carbon targets enable efficient determination of the nuclear vector polarization behind the cyclotron. In order to provide polarized beams with the highest possible intensity and polarization routinely, components of the source and diagnostic tools for neutral beams and polarization measurements have been optimized over the last years. An important long term activity has been the controlled, local production of dispenser ionizers for the cesium beam part, because the source's over all performance is correlated to the cesium ionizer's performance and depends strongly on the availability and quality of dispenser ionizers with a porous tungsten button. Within the last two years the production process at the Forschungszentrum has been improved substantially and a new generation of tungsten dispensers is now available. In parallel laser cleaning and production methods have been applied for dispensers. The production process, the start performance and also recovery of used dispensers benefited significantly from laser application. This report describes briefly the characteristics of the ion source in its present mode of operation, the achievements and programs towards higher beam intensities for polarized H⁻ and D⁻ beams with high reliability.

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Polarized ^3He spin filters for neutron science

T.R. Gentile

Stop 8461, National Institute of Standards and Technology
Gaithersburg, Maryland 20899
thomas.gentile@nist.gov

The large spin dependence of the absorption cross section for neutrons by ^3He gas provides a method to polarize neutron beams. For certain applications, such polarized ^3He -based neutron "spin filters" have advantages over conventional neutron optical polarizing methods. Spin filters operate at all neutron wavelengths, can cover a large angular range and/or a large energy range, and decouple neutron polarization from energy selection. Both spin-exchange optical pumping (SEOP) and metastability-exchange optical pumping (MEOP) are currently being employed to polarize ^3He spin filters at various neutron facilities worldwide. I will focus on the development and application of SEOP-based neutron spin filters at the National Institute of Standards and Technology, Center for Neutron Research (NCNR) [1]. The combination of long relaxation time spin filter cells, high power spectrally narrowed diode lasers, and the use of Rb/K mixtures have allowed us to reach ^3He polarizations up to 85 % in spin filter cells ≈ 1 liter in volume. Studies have revealed limits to the achievable polarization from temperature-dependent relaxation [2] and unexplained magnetic field dependence for relaxation in SEOP cells [3]. Applications include neutron scattering methods such as triple-axis spectrometry and small angle neutron scattering, and fundamental neutron physics. In most neutron scattering applications, cells are transported to the beam line and stored in a magnetically shielded solenoid or box. A recent focus has been apparatus for wide-angle neutron polarization analysis. A measurement of the spin-dependence of the neutron- ^3He scattering length was performed with a small, polarized ^3He cell in a neutron interferometer and a ^3He spin filter for accurate neutron polarimetry [4]. Use of spin filters in high flux neutron beams have revealed beam-induced alkali-metal relaxation and long term effects on SEOP spin filter cells [5].

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Polarimetry for the polarized deuterium target at ANKE/COSY

B. Gou^{a,b} for the ANKE collaboration

^aInstitute of Modern Physics, Chinese Academy of Sciences
Lanzhou, 730000, China

^bInstitut für Kernphysik, Forschungszentrum Jülich
D-52425 Jülich, Germany
b.gou@fz-juelich.de

The understanding of the NN interaction is fundamental to the whole of nuclear and hadronic physics. The scattering amplitudes for the complete description of NN interactions can be reconstructed from phase-shift analyses (PSA), which require measurements with polarized beam and polarized target. Very little is known about the np system above 800 MeV nucleon energy. The ANKE collaboration at COSY-Jülich has proposed to extract np scattering amplitudes using deuterons as a source of quasi-free neutrons. The first part of the program with a polarized deuteron beam and a hydrogen target allowed successful determination of np amplitudes up to 1.1 GeV nucleon energy. Use of a polarized deuterium target and a proton beam will allow to increase the np study up to 2.8 GeV, the highest energy available at COSY. In order to compensate the low density of the atomic beam source (ABS), polarized deuterium gas will be injected into a storage cell, placed along the beam direction. Commissioning of the polarized deuterium target was carried out in June 2012. Nuclear reactions with large and well-known cross sections and analyzing powers were selected to measure the target vector and tensor polarization (Q_y and Q_{yy}).

The talk will present the results of polarimetry studies of polarized deuterium gas target at ANKE, as well as first results for the np charge-exchange reaction.

Research is supported by CSC program.

PEPPo: Using a Polarized Electron Beam to Produce Polarized Positrons

J. Grames for the PEPPo Collaboration

*Thomas Jefferson National Accelerator Facility
600 Kelvin Drive Suite 3
Newport News, VA 23606
(grames@jlab.org)*

Polarized positron beams are identified as either an essential or significant ingredient for the experimental program at present or next generation lepton accelerators (JLab, Super KEK B, ILC, CLIC). A proof-of-principle experiment for a new method to produce polarized positrons has recently been performed at the Continuous Electron Beam Accelerator Facility at Jefferson Lab. The PEPPo (Polarized Electrons for Polarized Positrons) concept relies on the production of polarized electron/positron pairs from the bremsstrahlung radiation of a longitudinally polarized electron beam interacting within a high Z conversion target. The experiment was performed at the injector of the CEBAF accelerator at Jefferson Lab and investigated the polarization transfer of an 8.2 MeV/c polarized electron beam to positrons produced in varying thickness tungsten production targets, and collected and measured in the range of 3.1 to 6.2 MeV/c. This technique potentially opens a new pathway for both high energy and thermal polarized positron beams. This presentation will discuss the PEPPo concept, the motivations of the experiment and the experimental results so far obtained.

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Using Polarimetry To Determine The CEBAF Beam Energy

Douglas W. Higinbotham

Jefferson Lab
12000 Jefferson Avenue, Suite 4
Newport News, VA 23606
doug@jlab.org

As the Lab heads into the 12 GeV era, the lab once again needs to determine the absolute beam energy of the machine. Previously, the beam energy was determined using precision measurements of the bending ARC integral fields along with the beam position. This result was confirmed with elastic scattering from hydrogen where with knowledge of the scattering angles of the electron and proton the energy can be determined. While the ARC integral method will still work at 11 GeV, the elastic cross sections become rather small to try to make precision measurement; so a new second technique for energy determination has been sought. It will be shown that by making use of the world class polarimetry that has been developed at the lab, one can use spin precession, as illustrated in Fig. 1, to determine the absolute beam energy of an 11 GeV beam to the few MeV level. This can be done in a single hall if the parameters of the machine, such as the injector energy and linac imbalance, are known or in two halls without any knowledge of the machine parameters though with a loss of absolute precision.

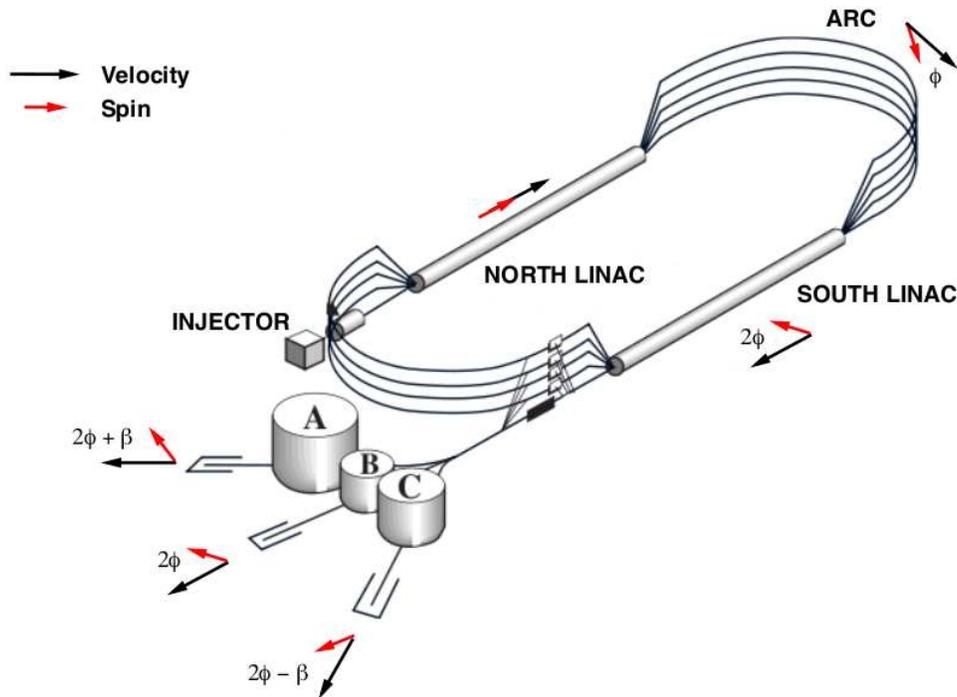


Figure 1: Diagram of first pass beam being sent from the injector to the three experimental hall showing how the spin direction changes with respect to the velocity. As the magnitude of the spin precession is energy dependent, it can be used to determine the beam energy.

High performance spin-polarized photocathode using GaAs/GaAsP strain-compensated superlattice

X.G. Jin^{1,2}, N. Yamamoto², A. Mano², M. Yamamoto³, Y. Takeda^{4,5}

¹*Institute for Advanced Research, Nagoya University, Nagoya 464-8603, Japan*

²*Synchrotron Radiation Research Center, Nagoya University, Nagoya 464-8602, Japan*

³*High Energy Accelerator Research Organization (KEK), Tsukuba, 305-0801, Japan*

⁴*Aichi Synchrotron Radiation Center, Aichi Science and Technology Foundation, Seto 489-0965, Japan*

⁵*Nagoya Industrial Science Research Institute, Nagoya 464-0819, Japan*

Email: jinxg@nagoya-u.jp

We have successfully developed a transmission-type GaAs/GaAsP strained superlattice (SL) photocathode, and a high spin-polarization (SP) (90%) with a super-high brightness ($\sim 10^7$ A \cdot cm $^{-2}$ \cdot sr $^{-1}$) of electron beam was achieved [1]. In this study, we report the design and fabrication of an optimized transmission-type photocathode with strain-compensated SL for higher quantum efficiency (QE).

In the GaAs/GaAsP strained SL, a compressive strain was introduced in the GaAs well layers to obtain a large band-splitting between heavy-hole and light-hole mini-bands. The increasing SL pair-number causes strain relaxation with resultant SP degradation. A smaller SL layer thickness is one reason behind the limited value of the QE. To overcome this problem by increasing the SL layer thickness without degradation, the use of strain-compensated SL was proposed [2]. In this structure, a strain is introduced in the SL barrier layers to the opposite direction to compensate the strain in the SL well layers. Figure 1 shows the GaAs/GaAsP strain-compensated SL structure. The maximum pair of the prepared SL is 90.

X-ray diffraction revealed that the strain relaxation by thickness increase was effectively controlled. Figure 2 shows the change of maximal spin-polarization with the SL pair number. The superlattice photocathodes up to 36-pair maintain high SP of about 90%. Then, the SP obviously decreased. During the transport, the spin-polarized electrons should flip by scattering with holes. The scattering effect becomes stronger in the thicker SL photocathodes. The thickness effect on the QE and transport time will be investigated.

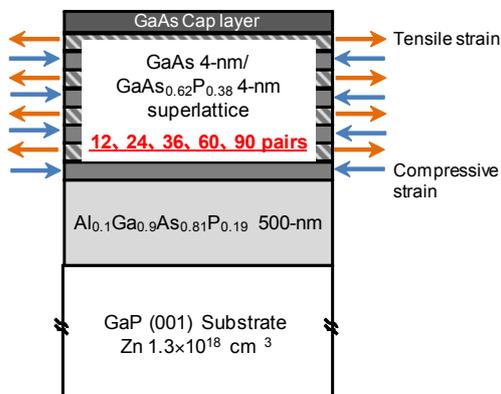


Figure 1. Strain-compensated superlattice structure

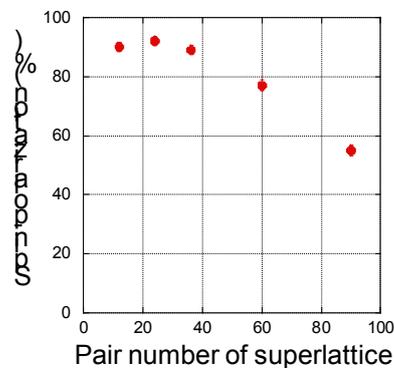


Figure 2. Maximum spin-polarization with increasing superlattice pair number

Precision Compton polarimetry for Hall C at Jefferson Lab

Donald Jones for the Hall C polarimetry group

Department of Physics, UVA
Charlottesville, VA
dcj4v@virginia.com

A new Compton polarimeter was recently built in Hall C at Jefferson Lab in order to meet the tight constraints on polarimetry needed for the Qweak experiment. This polarimeter, modelled after the Hall A design, utilizes a circularly polarized green laser locked to a Fabry-Perot optical cavity intersecting the electron beam at small angles ($\approx 1.3^\circ$). Both the scattered electrons and the back-scattered photons are detected separately downstream of the interaction point, providing in principle, two semi-independent measurements of the electron beam polarization.

I will demonstrate the recent performance of the Compton polarimeter with special emphasis on the electron detector analysis. I will also discuss a novel technique used to determine the polarization of the light inside the Fabry-Perot cavity with very small systematic uncertainty.

Investigation into polarization uncertainty minimization of solid polarized targets

D. Keller

Department of Physics
382 McCormick rd. Charlottesville, VA 22904-4714
dustin@jlab.org

A discussion of uncertainty minimization in the polarization produced by Dynamic Nuclear Polarization is presented. Techniques of error estimation and minimization are outlined for the use in polarized data analysis. Procedures for minimizing uncertainty in a setting such as the Jefferson Lab solid polarized target experiments are described with examples using recent experiments. Both the proton and deuteron targets are considered. Techniques in the deuteron tensor polarization enhancement and enhanced tensor polarization measurement uncertainty are also discussed in the interest and preparation of future experiments.

Search for Electric Dipole Moments with Polarized Beams in Storage Rings.

P. Lenisa

Università di Ferrara and INFN, 44122 Ferrara, Italy

An electric dipole aligned along the spin axis of a fundamental particle, nucleus, or atomic system violates both parity conservation and time reversal invariance. The observation of such a phenomenon would, at present or proposed levels of experimental sensitivity, signal new physics beyond the Standard Model.

The usual method for identifying an electric dipole moment (EDM) in such searches is to observe the rotation of the spin axis or polarization under the influence of a strong electric field. The use of a storage ring opens the search to charged, polarized particles such as the proton, deuteron, ^3He , etc. that would otherwise not be manageable in such a field. The best procedure begins with the alignment of the beam polarization along the velocity of the beam followed by the observation of any slow rotation of that polarization into the vertical direction perpendicular to the ring. Electric ring fields of the right strength or the correct combination of electric and magnetic ring fields are needed to ensure that the polarization does not rotate relative to the velocity (“frozen” spin).

This imposes several feasibility requirements. First, the ring must utilize a special combination of higher order fields to ensure that the usually unstable polarization along the direction of the velocity remains for times up to 1000 s to allow any EDM effect to accumulate to a measurable level. Second, the beam must be slowly sampled during the storage time by a polarimeter capable of detecting a change in the vertical polarization of several μrad over the 1000 s storage time. The required large polarimeter efficiency and polarization sensitivity may be achieved by continuously extracting the beam onto a carbon target several cm thick. In combination with an array of calorimeter detectors that emphasize elastic scattering events at forward angles, it has been shown to be possible to meet these requirements for an EDM search [1]. In addition, when the sensitivity of the polarimeter to systematic rate and geometric errors is calibrated, it becomes possible to correct the measurements in real time using only the online data itself to levels approaching or exceeding 1 ppm. This demonstration was made using the EDDA detector [2,3] located on the Cooler Synchrotron (COSY) at the Forschungszentrum-Jülich [4]. First results covering the contribution of synchrotron oscillations to RF-solenoid induced spin resonances may be found in Ref. 5.

At present, dedicated studies are being performed at COSY to examine the use of higher-order (sextupole) fields in the storage ring to lengthen the coherence time of the stored, horizontal beam polarization. To support these studies, a novel polarimeter system has been developed that is capable of monitoring the horizontal polarization of the beam circulating in the ring as it precesses at ~ 120 kHz. So far, the sextupole fields have been tuned to produce horizontal polarization lifetimes in excess of 200 s.

This presentation is meant to provide a general introduction to the EDM search by means of polarized beams in storage rings and to highlight the developments in the polarimeter system accomplished at the COSY ring at FZ-Jülich

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Title: **Photocathode materials able to sustain high currents**

Authors: Zhaozhu Li¹, Kaida Yang², Jose M. Riso¹ and R. Ale

Lukaszew¹

¹ Department of Physics, The College of William and Mary, Williamsburg, VA, 23187

² Department of Applied Science, The College of William and Mary, Williamsburg, VA, 23187

We will present preliminary work on photocathode materials able to sustain high currents, pertinent to the technology of accelerators and associated systems and essential to develop strategies and technologies for next generation nuclear physics accelerator capabilities. To this end, metallic photocathodes offer several clear advantages over semiconductor photocathodes because they are robust against degradation due to surface contamination and against damage resulting from conditioning or heating and can withstand high electric surface fields present at the cathode in RF accelerators. Other advantages include their very short response time (less than picoseconds) and their very long lifetime (years or longer), which is much longer than of other types of photocathodes (hours to months). However, the main problem with metallic photocathodes is the rather low quantum efficiency (QE), even for UV radiation. A possibility to improve the QE of metallic photocathodes is to exploit surface Plasmon resonance using adequate geometries for the intended application, as well as possible cap layers able to lower the metal work function. In this way, metal photocathodes designed to support surface Plasmons could produce high electron yields by enhancing their QE. We will show design criteria for such platform for this application as well as our preliminary results.

Title

Polarized Electron Beams In The MEIC Collider Ring At JLab*

Authors

F. Lin, Ya.S. Derbenev, V.S. Morozov, Y. Zhang, Jefferson Lab, Newport News, VA, USA
D. P. Barber, Deutsches Elektronen-Synchrotron (DESY), 22607 Hamburg, Germany

Abstract

The nuclear physics program of the Medium-energy Electron-Ion Collider (MEIC) at the JLab requires a highly-polarized (over 80%) electron beam with longitudinal polarization at the collision points. This can be achieved by arranging the equilibrium polarization direction to be vertical in the arcs of the figure-8 shape ring and longitudinal at collision points. The rotation of the polarization is accomplished by using energy-independent universal spin rotators, each of which consists of a set of solenoids and dipoles placed at the end of each arc. To reduce the spin-orbit depolarization effect due to the synchrotron radiation, spin matching to make the rotators and interaction regions spin transparent must be applied. We present the current universal spin rotator design and its layout, address various coupling compensation schemes for the solenoids, estimate the beam polarization lifetime from spin tracking simulation using the code SLICK and explore how issues related to spin matching influence the design of the ring.

Acknowledgements

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JLab Polarized ^3He Target

Jie Liu^a

(For the JLab Polarized ^3He Target Group)

^aDepartment of Physics
University of Virginia, VA, 22904
jl5uj@virginia.edu

The polarized ^3He target was successfully used as an effective polarized neutron target for thirteen electron scattering experiments at JLab. It is based on the optical pumping of alkali atoms in vapour and the subsequent spin exchange between the polarized alkali atoms and the ^3He nuclei. There were significant improvements for this target during recent years by using the hybrid cell (a Rb-K mixture) and newly available high-power narrow-width diode lasers. The maximum target polarization reached over 60% with up to 15 uA electron beam on a high density target, a world record for the high luminosity ($10^{36}/\text{cm}^2/\text{s}$) polarized ^3He target. For the 12 GeV program at JLab, there are already seven polarized ^3He target related experiments approved with high scientific rating. Upgrade of the target is underway to meet the requirements of the experiments. Progress will be reported in this talk.

Polarized Protons in the Fermilab Main Injector

W. Lorenzon^a and **C.A. Aidala^a** (for the E1027 collaboration)

^aPhysics Department, University of Michigan
450 Church St., Ann Arbor, Michigan 48109-1040, USA
lorenz@umich.edu

The Main Injector at Fermilab currently produces high-intensity beams of protons at energies up to 120 GeV for a variety of physics experiments. Polarizing the protons in the Main Injector will open up opportunities for a rich spin physics program at Fermilab. To achieve polarized proton beams in the Main Injector accelerator complex, detailed design and costing studies using a novel single Siberian snake approach are needed. In particular, detailed spin tracking simulations with realistic parameters based on the existing facility will be required to demonstrate that the present conceptual design can preserve beam polarization throughout the acceleration chain. The spin tracking further needs to investigate the tolerance of various machine and beam errors for preserving beam polarization. We will report on the present status and plans to develop polarized beams at Fermilab.

Electrons on the HDice Target: Results and Analysis of Test Runs at JLab in 2012

M. M. Lowry^a for the HDice Collaboration

^aThomas Jefferson National Accelerator Laboratory
12000 Jefferson Ave., Newport News, VA 23606
mlowry@jlab.org

During the Jefferson Laboratory E06-101 (g14) experiment [1] of photons on solid HD, performed in Hall B, two opportunities arose for targets to be subjected to multi-GeV electron beams in week-long campaigns of dose accumulation and NMR polarization measurements. Besides the important thermal effects from energy deposit, evidence consistent with screening of the NMR and with decay of the target polarization were observed during bombardment and for a time afterwards. The solid hydrogens have also been the subject of previous radiation damage studies, both for possible polarized DT fusion [2] and for production of dynamically polarized nuclear targets [3]. An attempt will be made to synthesize all this information into an overall picture that can guide on-going development of the HDice target system for use in future electron experiments after the 12 GeV JLab upgrade [4].

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Sub-percent Precision Møller Polarimetry in Experimental Hall C

Joshua Magee

The College of William and Mary

August 20, 2013

Modern experiments in Jefferson Lab Hall C require precise knowledge of the electron beam polarization. This knowledge comes from two complementary polarimeter devices (Møller and Compton). Unlike typical Møller devices, the Hall C Møller polarimeter uses a pure iron foil that is brute-force polarized out-of-plane by a superconducting solenoid. A system of quadrupole magnets focuses the scattered and recoil electrons onto an asymmetric detector array. This design offers several improvements compared to previous devices, enabling sub-percent systematic uncertainties. This talk will introduce the Hall C Møller polarimeter and discuss the necessary work to determine $< 1\%$ precision, using the Q_{weak} experiment as an example.

^3He polarimetry for RHIC

Yousef Makdisi

Brookhaven National Laboratory, Collider-Accelerator Department

Upton, NY 11973

Makdisi@bnl.gov

The Relativistic Heavy Ions Collider (RHIC) has accelerated polarized proton beams for physics since 2001. As part of the future eRHIC program and in order to enhance access to the down quark, a program to accelerate polarized ^3He in the AGS and RHIC is envisioned. To that end, a polarized ^3He source is being built at MIT. This will be installed on the BNL EBIS source in preparation for injection into the booster and AGS. As an early exercise, in June 2012, unpolarized ^3He beams have been accelerated in the AGS. I will present some ideas for ^3He polarimetry and calibration that could be utilized at the AGS as well as RHIC.

High average brightness electron beam production at Cornell University

J. Maxson^{a,b}, B. Dunham^a and I. Bazarov^a

^aCornell Laboratory For Accelerator-based Sciences and Education
161 Synchrotron Drive, Ithaca, NY 14853

^b jmm586@cornell.edu

Cornell University operates a high average brightness electron photoinjector, using a 350kV DC photogun and a 1.3 GHz, 5 - 15MeV booster linac, as a prototype injector for a proposed 5 GeV Energy Recovery Linac based light source. In this talk, some of our most recent achievements will be described, including the production of world record high-average current from a photoinjector [ref], and demonstration of low emittance². Both GaAs and multialkali photocathodes are used, and the talk will describe our experience with photocathode growth, lifetime in high current conditions, and thermal emittance for each cathode type.

Also, a new photoelectron gun has been constructed and is currently in commissioning. The segmented insulator design, construction, and high voltage processing results will be described. Furthermore, a full 6D brightness measurement beamline has been constructed for use with the new photogun, and measurements to characterize fundamental brightness limits from photoguns, including the onset of the virtual cathode instability for dense beams, will be detailed.

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Polarized ^3He Source Development for RHIC

J. Maxwell^a, C. Epstein^a, R. Milner^a, J. Alessi^b, E. Beebe^b, J. Farrell^b,
A. Pikin^b, J. Ritter^b, and A. Zelenski^b

^aLaboratory for Nuclear Science, MIT, Cambridge, MA 02139

^bBrookhaven National Laboratory, Upton, NY 11973

The addition of a polarized neutron beam source to the Relativistic Heavy Ion Collider at Brookhaven National Laboratory would present promising opportunities for the study of nucleon structure. Polarized neutron collision measurements of transverse spin asymmetries in Drell-Yan scattering would allow a search of the predicted sign switch for u and d quark flavors in the Sivers function[1]. In a future electron-ion collider, precision tests of the Bjorken sum rule[2] could be carried out with both proton and neutron beams.

Polarized ^3He offers an effective polarized neutron beam which is accessible with RHIC spin manipulation. We are developing such a source leveraging metastability exchange optical pumping of ^3He [4] and utilizing the existing Electron Beam Ionization Source at RHIC[3]. We aim to deliver approximately 1.5×10^{11} doubly ionized ^3He atoms per pulse at 70% polarization. The source is under development at MIT and an initial test of the principle at BNL is planned for the fall. The source design will be described and the status of the test summarized.

The research is supported by the United States Department of Energy Office of Nuclear Physics under the program of Research and Development for Next Generation Nuclear Physics Accelerator Facilities.

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Two Novel Approaches for Electron Beam Polarization from Unstrained GaAs

J L McCarter^{1,2}, N B Clayburn³, A Afanasev⁴, J M Dreiling³, T J Gay³, J Hansknecht⁵, A Kechiantz^{4,6}, M Poelker⁵, D M Ryan³

¹ Department of Physics, University of Virginia, Charlottesville, VA 22901

² Laser and Plasma Technologies, Hampton, VA 23666

³ Department of Physics, University of Nebraska, Lincoln, NE, 68588

⁴ Department of Physics, The George Washington University, Washington, DC 20052

⁵ Thomas Jefferson National Accelerator Facility, 12050 Jefferson Ave. Suite 500, Newport News, VA 23606

⁶ On leave from Institute of Radiophysics and Electronics, NAS of Armenia, Ashtarak 0203, Armenia

Abstract. Two novel approaches to producing highly-polarized electron beams from unstrained GaAs were tested using a micro-Mott polarimeter. Based on a suggestion by Nakanishi [1], two-photon photoemission with 1560 nm light was used with photocathodes of varying thickness: 625 μm , 0.32 μm , and 0.18 μm . For each of these photocathodes, the degree of spin polarization of the photoemitted beam was less than 50%. Polarization via two-photon absorption was highest from the thinnest photocathode sample and close to that obtained from one-photon absorption (using 778 nm light), with values 40.3 \pm 1.0% and 42.6 \pm 1.0%, respectively. The second attempt to produce highly-polarized electrons used one-photon emission with 778 nm light in Laguerre-Gaussian modes with different amounts of orbital angular momentum. The degree of electron spin polarization was consistent with zero, with an upper limit of \sim 3% for light with up to $\pm 5\hbar$ of orbital angular momentum. In contrast, the degree of spin polarization was 32.3 \pm 1.4% using circularly-polarized laser light at the same wavelength, which is typical for thick, unstrained GaAs photocathodes.

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Mott Polarimeter Upgrade at Jefferson Lab

**M.J. McHugh^a, J. Grames^b, C. Horowitz^c, M.W. Melnitchouk^b, A.K. Opper^a,
M. Poelker^b, S. Rhodes^d, X. Roca Maza^e, C. Sinclair^f, and R. Suleiman^b**

^aDepartment of Physics
The George Washington University
Washington, DC 20052
mjmchugh@gwu.edu

^bThomas Jefferson National Accelerator Facility
Newport News, VA 23606

^cDepartment of Physics
Indiana University
Bloomington, IN 47408

^dDepartment of Physics
Lycoming College
Williamsport, PA 17701

^eDepartment of Physics
Università degli Studi di Milano and INFN
20133 Milano, Italy

^fDepartment of Physics
Cornell University
Ithaca, NY 14853

A Mott polarimeter with a design optimized for 5.5 MeV/c has been in routine use at the CEBAF accelerator for well over a decade, providing polarization measurements approaching 1% accuracy. Measurements with different target elements (Au, Ag, Cu) over decades of target thicknesses (100 – 10,000 angstroms), and beam energies between 2 and 8 MeV allow us to determine the effective analyzing power with a high degree of certainty. Recent and planned improvements in our polarimeter configuration, detectors and data acquisition system, coupled with a low 31 MHz repetition rate beam allow us to distinguish and suppress electrons that do not originate from the target foil. This work coupled with a significant effort to produce a detailed GEANT4 model of the polarimeter is part of an effort to determine systematic uncertainties at the level of the theoretically calculated analyzing power. We describe our activities and a series of planned measurements that will allow us to demonstrate and possibly improve the precision and accuracy of polarization measurements at JLab, as required for future parity violation experiments.

A Spin-Light Polarimeter for Multi-GeV Longitudinally Polarized Electron Beams

P. Mohanmurthy^a and D. Dutta^a

^aDepartment of Physics and Astronomy
Mississippi State University, Mississippi State, MS 39762
d.dutta@msstate.edu

The physics program at the upgraded Jefferson Lab (JLab) and the physics program envisioned for the proposed electron-ion collider (EIC) include large efforts to search for interactions beyond the Standard Model (SM) using parity violation in electroweak interactions. These experiments require precision electron polarimetry with an uncertainty of $< 0.5\%$. The spin dependent Synchrotron radiation, called "spin-light," can be used to monitor the electron beam polarization. In this presentation we discuss a conceptual design for a "spin-light" polarimeter that can be used at a high intensity, multi-GeV electron accelerator. We have also built a Geant4 based simulation for a prototype device and report some of the results from these simulations.

Title

Ion Polarization Control in MEIC Rings Using Small Magnetic Fields Integrals

Authors

Ya.S. Derbenev, F. Lin, V.S. Morozov, Y. Zhang, Jefferson Lab, Newport News, VA, USA
A.M. Kondratenko, M.A. Kondratenko, Sci. & Tech. Laboratory Zaryad, Novosibirsk, Russia
Yu.N. Filatov, MIPT, Dolgoprudny, Russia & JINR, Dubna, Russia

Abstract

The Electron-Ion Collider (EIC) proposed by Jefferson Lab is designed to provide high polarization of both colliding beams. In comparison to conventional colliders, its figure-8 shaped rings provide a unique capability to control the polarization of any particle species including deuterons by using small magnetic field integrals. This expands the experimental opportunities at EIC. We present schemes for preserving the particle polarization during acceleration in the pre-booster and large booster. We also present schemes for controlling the ion polarization up to the energy of 100 GeV in the collider ring that allow one to adjust the beam polarization in any orientation in its experimental straights. The deuteron polarization is controlled by weak solenoids while the proton polarization is controlled by weak radial fields. The components of these schemes are optically transparent to the orbital motion when integrated into the magnetic structure of the rings. We use the spin response function formalism to evaluate the zeroth harmonic of the spin perturbation and investigate the possibility of its compensation. For control of the proton polarization in the high-energy stage at energies above 100 GeV, we plan to use the conventional approach of Siberian snakes and spin rotators.

Acknowledgements

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DSMC simulations of polarized atomic beam sources including magnetic fields

M. Gaisser, A. Nass and H. Ströher

Institut für Kernphysik, Forschungszentrum Jülich
Leo-Brandt-Str.1, 52425 Jülich, Germany
m.gaisser@fz-juelich.de

In recent decades a lot of work has been done to understand and optimize the output of polarized atomic beam sources mainly with tracking calculations of atoms moving through the field of the sextupole magnet system with the measured parameters of the supersonic atomic beam as starting conditions. Besides of these simple calculations attempts were made to achieve an analytical description of the processes in an atomic beam source [1]. However, there are many effects which prevent a complete analytic description of the system. A new DSMC (Direct Simulation Monte Carlo) simulation based on OpenFOAM 1.7.1 using Birds [2] algorithm has been developed which calculates the output intensity including all major processes occurring in the atomic beam source, e.g., influence of magnetic fields, high frequency transitions, rest gas scattering, recombination, intra-beam scattering, and spin exchange collisions.

So far, the simulated particles have been given spin and a generic utility to include arbitrary magnetic fields has been created. The equation of motion in every timestep is solved by a fourth order Runge-Kutta scheme. Additionally, high frequency transition units are included as well as recombination on the walls and spin exchange collisions. Additionally, a generic interface for optimization algorithms was built and Adaptive Simulated Annealing (formerly Very Fast Simulated Re-Annealing [3]) was put into this framework to optimize the output of DSMC simulations. Last but not least, a tool to measure the collision age of particles in a storage cell has been created and first tests of the program are promising.

This development is in particular important for the PAX project (Polarized Antiproton eXperiments [4]) since a high-density highly polarized target is necessary in order to polarize a stored antiproton beam.

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PHYSICS OF POLARIZED TARGETS

Tapio Niinikoski

CERN, Geneva, Switzerland (retired)

ABSTRACT

For developing, building and operating solid polarized targets we need to understand several fields of physics that have seen dramatic advances during the last 50 years. In this talk we shall review a selection of those that are most important today. These are: 1) quantum statistical methods to describe saturation and relaxation in magnetic resonance; 2) equal spin temperature model for dynamic nuclear polarization; 3) magnetic resonance and relaxation in glassy and crystalline solids at low temperatures; 4) radiolytic paramagnetic impurities usable for DNP; 5) weak saturation during NMR polarization measurement; 6) refrigeration using the quantum fluid properties of helium isotopes. These, combined with superconducting magnet technologies, permit today to reach nearly complete polarization of almost any nuclear spins. Targets can be operated in frozen spin mode in rather low and inhomogeneous field of any orientation, and in DNP mode in beams of high intensity. Beyond such experiments of nuclear and particle physics, applications are also emerging in macromolecular chemistry and in magnetic resonance imaging.

This talk is a tribute to Michel Borghini, whom we remember for his work on the equal spin temperature model at CERN, and to Franz Lehar, who promoted the frozen spin target techniques and applied it in a long series of nucleon-nucleon scattering experiments in Saclay.

The Cathode Preparation Chamber for the DC High Current High Polarization Gun (The Gatling gun)

Omer Rahman^{1,2}, Ilan Ben-Zvi^{1,2}, Eric Riehn¹, David Gassner¹, Alexander Pikin¹, Triveni Rao³, Brian Sheehy¹, John Skaritka¹, Erdong Wang¹.

¹Collider-Accelerator Department, Brookhaven National Lab, Upton, NY- 11973

²Department of Physics and Astronomy, Stony Brook University, Stony Brook, NY - 11740

³Instrumentation Division, Brookhaven National Lab, Upton, NY – 11973

A very compact cathode preparation chamber for the high current high polarization gun for the proposed eRHIC project has been designed and assembled at the Brookhaven National Laboratory. This preparation chamber will be used to activate GaAs photocathodes to be used in the Gatling gun. The chamber is capable of achieving XHV in a consistent basis. Bulk GaAs samples were activated in this chamber with standard QE for the respective wavelength. In this paper, we discuss the design of this vacuum system, the heat cleaning and the activation procedure for the GaAs sample which will eventually be followed for the Gatling gun.

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High Precision Compton Polarimetry at 11 GeV Jefferson Lab

K.D. Paschke

Department of Physics
University of Virginia
Charlottesville, Virginia 22903
paschke@virginia.edu

Two major new experimental efforts for the 11 GeV Jefferson Lab, SOLID-PVDIS and MOLLER, seek high precision measurements of polarization-dependent, parity-violating asymmetries in electron scattering, and require an unprecedented 0.4% precision on knowledge of the electron beam polarization. To meet the challenge, a robust cross-check will be provided by two independent techniques: one based on Moller scattering and the other on Compton scattering. For both systems, previous operation at Jefferson Lab suggest the feasibility of 0.4% precision. For the Moller polarimeter, scattering is measured from an iron foil in a high applied magnetic field, with the saturated magnetization assumed to correspond to a known electron spin-polarization. While this system has been quoted with a precision near to the final desired goal, development of a similar polarimeter based on an atomic hydrogen vapor target would improve knowledge of the spin polarization as well as provide continuous operability at high current. For the Compton polarimeter, a Fabry-Perot optical cavity will provide at least 10 kW optical power, and recent improvements in techniques to control the polarization of laser light injected into the cavity promise knowledge of the target photon polarization at the level of 0.1%. The Compton polarimeter will be upgraded to provide 0.4% precision by controlling potential systematic errors in the measurement of the scattering asymmetry, normalization of the experimental analyzing power, and determination of the target photon polarization, with a high degree of independence between analysis of Compton-scattered photons and electrons. This presentation will review the polarimetry strategy for the future 11 GeV Jefferson Lab parity-violation program, with a focus on the Compton polarimeter upgrade.

The Recoil Polarization Experiments at Jefferson Lab

C.F. Perdrisat^a, V. Punjabi^b and M.K. Jones^c

^aDepartment of Physics
College of William and Mary
perdrisa@jlab.org

^bDepartment of Physics
Norfolk State University
punjabi@jlab.org

^cPhysics Division
Thomas Jefferson National Accelerator Facility
jones@jlab.org

The use of polarization observables to obtain the form factors of the nucleon, has resulted in a drastic change in the way we understand the structure of both proton and neutron. In particular, the results for the two non-zero components of the recoil proton polarization in the elastic $\vec{e}p \rightarrow e'\vec{p}$ reaction in 3 experiments at JLab, have resulted in determining the ratio G_{Ep}/G_{Mp} up to a Q^2 of 8.5 GeV². These experiments were done with two different proton polarimeters, capable of good performance from a few GeV/c to 5.5 GeV/c proton momentum [1,2,3,4,5,6]. A planned future experiment, which will become possible with 11 GeV electrons in Hall A after the JLab energy upgrade, is being designed and should reach proton momentum of 8 GeV/c, corresponding to $Q^2=15$ GeV² [7]. It will require a new polarimeter to be added to the super bigbite spectrometer facility (SBS). The evolution of the design and performance of the 3 polarimeters will be discussed in some details.

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COMPASS polarized target for Drell-Yan

M. Peseck, CERN

Unpolarized pion beam with momentum of 190 GeV/c and intensity up to 10^8 pions/s interacts with transversely polarized proton target producing muon pair via Drell-Yan process. The solid NH_3 is polarized by DNP. Maximum polarization reached during data taking is expected to be up to 90 %. Non-interacting beam and other particles produced inside the target will be stopped in the hadron absorber after the polarized target. This absorber will worsen the vertex resolution. The pion beam will increase substantially the heat load to the target material. Two target cells with gap of 20 cm, each 55 cm long and 4 cm in diameter give target cell volume about 690 cm^3 . The target platform needs to be moved 2.3 m in upstream direction from SIDIS position for placing the absorber. The microwave cavity has one central microwave stopper.

During the beam time radiation of about $3.6 \mu\text{Sv/h}$ is expected in the area of the control room. Thus a new target remote control system must be used. The magnet will have substantial upgrade with new control system.

Drell-Yan data taking is expected to start in 2014 - 2015 for period of approximately 180 days. Current status of the target, the required modifications and future plans will be presented.

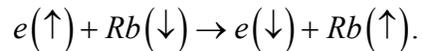
Optically-Pumped Spin-Exchange Polarized Electron Source

M. Pirbhai¹, J. Knepper¹, E.T.Litaker¹, D. Tupa², and T. J. Gay¹

¹ *Department of Physics and Astronomy, University of Nebraska, Lincoln, NE 68588-0299*

² *Physics Division, Los Alamos National Laboratory, Los Alamos, NM 87545*

Polarized electron beams are an indispensable probe of spin-dependent phenomena in fields of atomic and molecular physics, magnetic materials and biophysics. While their uses have become widespread, the standard source, based on NEA GaAs, remains technically complicated [1]. We are thus seeking other ways to make beams of polarized electrons. In this talk, we discuss one alternative involving spin-exchange collisions with oriented rubidium atoms:



In such a scheme, free, unpolarized electrons are transported into a collision cell where they encounter a mixture of oriented rubidium vapor and quenching gas. They undergo spin-exchange collisions with the former while drifting through the gases under the influence of an electric field. Building on previous work in our lab [2], we have devised a robust system capable of operating at ambient background pressures of ~1 mTorr, and generating ~4 μ A of current with 24% electron polarization. This system takes us a step closer towards the realization of a “turn-key” polarized electron source. We will discuss the role of secondary processes, such as spin transfer associated with secondary electrons or incident electrons that have lost significant energy.

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(talk to be given by Munir Pirbhai)

Polarimetry at the AGS.

A. Poblaguev^{a*}, I. Alekseev^b, E. Aschenauer^a, G. Atoian^a, A. Basilevsky^a, K. O. Eyser^a,
H. Huang^a, W. Schmidke^a, D. Smirnov^a, D. Svirida^b, K. Yip^a, A. Zelenski^a

^aBrookhaven National Laboratory,
Upton, NY 11973, USA

^bInstitute for Theoretical and Experimental Physics,
Moscow, 117218, Russia

Proton beam polarization measurement is essential for the Relativistic Heavy-Ion Collider (RHIC) spin program at Brookhaven National Laboratory (BNL) [1]. A proton-Carbon polarimeter is used to monitor beam polarization at Alternative Graduate Synchrotron (AGS) which injects 24 GeV/c protons into the RHIC. Polarization measurement is based on observing asymmetry of elastic beam proton scattering with low momentum transfer (Coulomb nuclear interference region) on a very thin carbon ribbon target. A few minute exposure provides a polarization measurement with statistical accuracy of about 2–3%. Since the carbon target width is much smaller than the beam size, polarization profile can be also measured. Performance of the AGS polarimeter in the RHIC Run 13 will be discussed.

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*Corresponding author. *E-mail address:* poblaguev@bnl.gov

The polarized hydrogen jet target measurements at RHIC.

A. Poblaguev^{a*}, I. Alekseev^b, E. Aschenauer^a, G. Atoian^a, A. Basilevsky^a, A. Dion^{a†},
K. O. Eyser^a, H. Huang^a, D. Kalinkin^c, W. Schmidke^a, D. Smirnov^a, D. Svirida^b,
K. Yip^a, A. Zelenski^a

^aBrookhaven National Laboratory,
Upton, NY 11973, USA

^bInstitute for Theoretical and Experimental Physics,
Moscow, 117218, Russia

^cMoscow Institute of Physics and Technology,
Dolgoprudny, Moscow region, 141700, Russia

The polarized hydrogen jet polarimeter (HJet) [1] at the Relativistic Heavy Ion Collider (RHIC) polarized proton complex [2] is employed for the absolute polarization measurement in each of the Blue and Yellow beams. The beam asymmetry is determined by measuring of the asymmetry of low energy (1–5 MeV) recoil proton production in the Coulomb nuclear interference region. With analyzing power of such a process of about 4%, the average beam polarization is measured with statistical accuracy of about $\delta P \sim 3\%$ during 8-hour store in RHIC. The results of the polarization measurements in the Run13 will be reported. Systematic errors of the measurements will be discussed.

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*Corresponding author. *E-mail address*: poblaguev@bnl.gov

†Present address: Department of Physics and Astronomy, Stony Brook University, Stony Brook, NY 11794, USA

Recent research activities and results of the Bochum/Bonn Polarized Target Group

G. Reicherz^a

^aExperimentalphysik I AG I, Ruhr-Universität Bochum
Universitätsstr. 150, D44780 Bochum, Germany
gerhard.reicherz@rub.de

The Bochum/Bonn polarized target group is involved in the fixed target experiments COMPASS at CERN and baryon spectroscopy at ELSA and MAMI. The experiments at Bonn and Mainz are focused on the study of the nucleon resonance region with polarized beam and target with 4π detection system. The focus of the COMPASS experiment is the study of hadron structure and hadron spectroscopy with high intensity muon and hadron beams.

In this talk technical achievements and the operation experience of the Bonn Frozen Spin Target will be highlighted. New developments to produce an internal superconducting polarizing coil for continuous DNP will be shown. In addition the setup and measurements with the new Bochum NMR system and recent material investigation will be presented.

Pil-Neyo Seo for HIFROST collaboration

Department of Physics
University of Virginia
414 TUNL Building, Science drive, Durham, NC 27708, USA

The UVa group in collaboration with the TUNL group is currently building a frozen spin target system for the high intensity gamma-ray source (HIgS) at the Duke Free Electron Laser Laboratory (HIFROST). The heart of the system is a dilution refrigerator which we rebuilt from the one originally designed by T. Niinikoski and used at CERN and subsequently at HZG, Germany. The use of a polarized target together with $\sim 100\%$ polarized beams available at HIgS make the HIgS facility ideal for double polarization experiments. The first experiment will utilize a polarized deuterium target with the $\sim 100\%$ circularly polarized gamma-ray beams to measure the Drell-Hearn-Gerasimov sum rule integrand for the deuteron below pion threshold. In this talk, I report the status of developing this system and describe the first experiment using HIFROST.

Overview of Electron Polarimetry

By Charles K. Sinclair

The 1956 discovery of parity non-conservation in weak interactions led directly and rather quickly to the development of electron polarimeters based on both Mott and Møller scattering. These early polarimeters appeared well before the first polarized beams were generated, almost two decades later. Compton scattering was initially used to generate polarized gamma beams in the late 1960s, before the technique was adapted to measuring the polarization of stored beams in storage rings in the 1970s. These three methods of measuring the polarization of electron beams are now all in wide general use, and have evolved considerably since the early polarimeter designs. Parity violation has now been developed into a tool for studying the detailed structure of nucleons, and has led directly to very demanding requirements for high precision polarimeters. We will briefly describe some of the recent developments in these polarimeters, mention their limitations, and briefly indicate where the field may move in the near future.

Novel Physics with Tensor Polarized Deuteron Targets

K. Slifer

University of New Hampshire

Durham, NH 03824, USA

Development of solid spin-1 polarized targets will open the study of tensor structure functions to precise measurement, and holds the promise to enable a new generation of polarized scattering experiments. In this talk we will discuss a measurement of the leading twist tensor structure function b_1 , along with prospects for future experiments with a solid tensor polarized target.

The recently approved JLab experiment E12-13-011 will measure the leading twist tensor structure function b_1 , which provides a unique tool to study partonic effects, while also being sensitive to coherent nuclear properties in the simplest nuclear system. At low x , shadowing effects are expected to dominate b_1 , while at larger values, b_1 provides a clean probe of exotic QCD effects, such as hidden color due to 6-quark configuration. Since the deuteron wave function is relatively well known, any non-standard effects are expected to be readily observable. All available models predict a small or vanishing value of b_1 at moderate x . However, the first pioneer measurement of b_1 at HERMES revealed a crossover to an anomalously large negative value in the region $0.2 < x < 0.5$, albeit with relatively large experimental uncertainty.

E12-13-011 will perform an inclusive measurement of the deuteron tensor asymmetry in the region $0.16 < x < 0.49$, for $0.8 < Q^2 < 5.0 \text{ GeV}^2$. The UVa solid polarized ND₃ target will be used, along with the Hall C spectrometers, and an unpolarized 115 nA beam. This measurement will provide access to the tensor quark polarization, and allow a test of the Close-Kumano sum rule, which vanishes in the absence of tensor polarization in the quark sea. Until now, tensor structure has been largely unexplored, so the study of these quantities holds the potential of initiating a new field of spin physics at Jefferson Lab.

Double Polarized Measurements with Frozen Spin Target at MAMI

A. Thomas^a

^a*Institut für Kernphysik, Universität Mainz, J.-J. Becherweg 45, D55128 Mainz, Germany,
(thomas@kph.uni-mainz.de)*

The A2-collaboration at the Mainz Microtron MAMI is measuring photon absorption cross section using circularly and linearly polarized photons up to energies of 1.5GeV. The photons are produced in the ‘Bremsstrahlungs’ process, the energy is determined by a dedicated tagging system. In the years 2005/2006 the Crystal Ball detector with its unique capability to cope with multi photon final states was set up in Mainz.

Since 2010 the experimental apparatus has been completed by a polarized target. The horizontal dilution refrigerator of the Frozen-Spin Target has been constructed and is operated in close cooperation with the Joint Institute for Nuclear Research in Dubna, Russia. The system includes longitudinal or transverse superconducting holding coils to allow for all directions of polarization. Due to the low base temperature of 25mK of the cryostat very long relaxation times in the order of 1000-2000 hours for protons and deuterons could be reached.

In this talk technical achievements and the operation experience of the Mainz Frozen Spin Target will be emphasized. New developments to produce an internal superconducting polarizing coil for continuous DNP will be shown. In addition, we are investigating the possibility to get ‘active’ polarized target material in the cryostat to allow for a new class of threshold meson production and Compton scattering experiments.

POLARIZED ATOMIC BEAM SOURCES: FROM THE VERY START UP TO PRESENT DAYS

D.K.Toporkov

Budker Institute of nuclear physics, Novosibirsk 630090, Russia

Novosibirsk State University, Novosibirsk 630090, Russia

The history of the creation of sources of polarized particles is considered. A comparative analysis of the parameters of different sources of polarized particles used for production of polarized ions or for polarized gas targets is given. The reasons for limiting of the atomic beam intensity in such kind of sources are analyzed. The parameters of polarized gas targets obtained with the use of these sources are presented. Other sources of polarized particles are discussed.

STATUS OF HIGH INTENSITY POLARIZED ELECTRON GUN PROJECT

E. Tsentalovich

MIT-Bates, 21 Manning Rd, Middleton, MA, 01949, USA

MIT-Bates in collaboration with BNL investigates the possibility to build a polarized electron gun with extremely high intensity. The design implements a separate preparation chamber, load lock, ring-shaped beam and active cathode cooling. Very good vacuum conditions have been achieved in both the gun chamber and the preparation chamber. Reliable cathode transfer between the load lock, the preparation chamber and the gun chamber has been demonstrated. The design of the beam line and the beam dump is completed, and the beam line fabrication is under way.

Funneling multiple bunches of high-charge polarized electrons

Erdong Wang, Ilan Ben-Zvi, David M Gassner, Wuzheng Meng, Alexander I. Pikin, Omer Habib Rahman, Triveni Rao, Eric Riehn, John Skaritka

The future electron ion collider (eRHIC) at Brookhaven national laboratory requires a polarized electron source with high average current, short bunch length and small emittance. The state of the art single GaAs based electron source is far from delivering the required 50mA current due to ion back-bombardment and surface charge limit. A high average polarized electron source based on the Gatling gun principle is being designed and currently under construction. In our funneling gun design, the electron bunches generated from 20 photocathodes in a 220 kV DC gun, funnel to a single common beam axis. This article details our design of a high-average-current polarized electron including mechanical design, cathode preparation, beam dynamics, laser system and beam diagnostic. We also report the recently progress of funneling gun construction.

**Boosting Deuteron Polarization in HD Targets: Experience of moving spins
between H and D with RF methods during the E06-101 experiment at Jefferson Lab**

X. Wei^a, C.D. Bass^a, A. D'Angelo^b, A. Deur^a, G. Dezern^a, T. Kageya^a,
V. Laine^{a,c}, M.M. Lowry^a, A.M. Sandorfi^a, R.W. Teachy^a and C.S. Whisnant^d

^aThomas Jefferson National Accelerator Facility
12000 Jefferson Ave., Newport News, VA 23606, USA
xwei@jlab.org

^bUniversita' di Roma2 "Tor Vergata"
and INFN Sezione di Roma, Roma, Italy

^cUniversite Blaise Pascal
Clermont-Ferrand, France

^dDepartment of Physics
James Madison University, Harrisonburg, VA 22807, USA

Solid HD targets are polarized by bringing the HD crystal to thermal equilibrium at low temperature and high magnetic field, typically 10~20 mK and 15 Tesla at Jefferson Lab. Due to its smaller magnetic moment, the resulting polarization for D is always much smaller than for H. The controlled amount of polarizing catalysts, ortho-H₂ and para-D₂, used in the process of reaching a frozen-spin state, further limit the maximum achievable D polarization. Nonetheless, H and D polarizations can be transferred from one to the other by connecting the H and D sub-states of the HD system with RF radiation. In a large target, the RF power needed for such transitions is effectively limited by non-uniformities in the RF field. High efficiency transfers can require substantial RF power levels, and a tuned-RF circuit is needed to prevent large temperature excursions of the holding cryostat. In this talk, we will compare the advantages and limitations of two different RF transfer methods to increase D polarization, *Forbidden Adiabatic* and *Saturated* RF Transitions. The experience with the *HDice* targets used during the recently completed E06-101 experiment[1] in Hall-B of Jefferson Lab will be discussed.

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HD gas purification for polarized HDice targets production at Jefferson Lab

C. S. Whisnant^a, A. D'Angelo^b, L. Colaneri^b, J. Devilbiss^a, T. Kageya^c,
D. A. Loving^a, M. Lowry^c, A. Rizzo^b, A. M. Sandorfi^c, C. Schaerf^b,
J. D. Storey^a, C. M. Wallace^a, X. Wei^c, and I. Zonta^b

^aDepartment of Physics and Astronomy
James Madison University, Harrisonburg, VA
whisnacs@jmu.edu

^b Università di Roma Tor Vergata and INFN Roma Tor Vergata
Via della Ricerca Scientifica, 1 00133 Rome, Italy
annalisa.dangelo@roma2.infn.it

^cThomas Jefferson National Accelerator Facility
12000 Jefferson Avenue, Newport News, VA
sandorfi@jlab.org

Solid, frozen-spin targets of molecular HD were first developed for nuclear physics by a collaboration between Syracuse University and Brookhaven National Lab. They have been successfully used in measurements with photon beams, first at the Laser-Electron-Gamma-Source [1] and most recently at Jefferson Lab during the running of the E06-101 (g14) experiment [2]. Preparations are underway to utilize the targets in future electron experiments after the completion of the 12 GeV JLab upgrade [3]. HD is an attractive target since all of the material is polarizable, of low Z , and requires only modest holding fields. At the same time, the small contributions from the target cell can be subtracted from direct measurements.

Reaching the frozen-spin state with both high polarization and a significant spin relaxation time requires careful control of H_2 and D_2 impurities. Commercially available HD contains 0.5 - 2% concentrations of H_2 and D_2 . Low-temperature distillation is required to reduce these concentrations to the 10^{-4} level to enable useful target production.

This distillation is done using a column filled with heli-pack C [4] to give good separation efficiency. Approximately 12 moles of commercial HD is condensed into the mechanically refrigerated system at the base temperature of 11K. The system is then isolated and the temperature stabilized at 18K producing liquid HD , which is boiled by a resistive heater. The circulation established by the boil-off condensing throughout the column then filtering back down produces a steady-state isotopic separation permitting the extraction of HD gas with very low H_2 and D_2 content.

A residual gas analyzer initially monitors distillation. Once the H_2 concentration falls below its useful operating range, samples are periodically collected for analysis using gas chromatography [5] and Raman scattering. Where the measurement techniques overlap, good agreement is obtained. The operation of the distillery and results of gas analysis will be discussed.

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Overview of High Intensity Gamma-ray Source at TUNL
- Capabilities and Future Upgrades

Y. K. Wu, wu@fel.duke.edu

DFELL/TUNL, Dept of Physics, Duke University, NC 27708-0319, USA

The High Intensity Gamma-ray Source (HIGS) at Triangle
Universities

Nuclear Laboratory is the world's most intense Compton gamma-ray
source in the energy range from 1 to 100 MeV. Driven by a
powerful storage ring FEL,

the HIGS produces exceptionally high intensity, polarized gamma-
ray beams

with a maximum total flux more than $2E10$ g/s and a spectral flux
of

more than $1E3$ g/s/eV (with a 5% FWHM energy resolution) around
10 MeV.

In the recent years, the polarized, high-brightness gamma-ray
beam at the HIGS

has been used by a large number of researchers in the US and
around the world

to conduct a wide range of research in nuclear physics and
astrophysics.

In this talk, we will describe the present gamma-ray
capabilities of the HIGS,

including new capabilities enabled by a recently completed FEL
wiggler

switchyard project. We will also outline the future development
and

upgrade projects at the HIGS facility on the energy front and
intensity front.

The future upgrade of the HIGS will extend its high-energy
operation

to about 158 MeV to enable photo-pion physics research. The
development

of a next-generation gamma-ray source at the HIGS facility
will produce gamma-ray beams with unprecedented brightness
or the spectral flux in the 2 to 12 MeV region.

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THE RHIC POLARIZED SOURCE UPGRADE

A.Zelenski, G.Atoian, J.Ritter, D.Steski.

Brookhaven National Laboratory, Upton, NY

F.Podolyako, I.Sorokin, I. Vizgalov, *MEPHI, Moscow*

V.Klenov, V.Zubets, *INR Moscow*

V.Davydenko, A.Ivanov, A.Kolmogorov

Budker Institute for Nuclear Physics, Novosibirsk

Abstract. A novel polarization technique had been successfully implemented in the RHIC polarized H⁻ ion source upgrade to higher intensity and polarization for use in the RHIC polarization physics program at enhanced luminosity RHIC operation. In this technique a primary proton beam inside the high magnetic field solenoid is produced by charge-exchange ionization of the atomic hydrogen beam in the He-gas ionizer cell. Further proton polarization is produced in the process of polarized electron capture from the optically-pumped Rb vapor. The atomic beam of a 6-8 keV energy and total (equivalent) current up to 3.5 A is produced by neutralization of proton beam in pulsed hydrogen gas target. Formation of the proton beam (from the surface of the plasma emitter with a low transverse ion temperature ~0.2 eV) is produced by four-electrode spherical multi-aperture ion-optical system with geometrical focusing. Polarized beam intensity produced in the source exceeds 4.0 mA. A strong space-charge effects cause significant beam losses in the LEBT (Low Energy Beam Transport, 35.0 keV beam energy) line. The LEBT was modified to reduce losses and 1.4 mA polarized beam was transported to the RFQ and maximum so far 0.7 mA was accelerated in linac to 200 MeV. Maximum polarization of 84% was measured at 0.3 mA beam intensity and 80% at 0.5 mA in 200 MeV polarimeter. This high beam intensity allowed reduction of the longitudinal and transverse beam emittances at injection to AGS to reduce polarization losses in AGS. The source reliably delivered beam for 2013 polarized run in RHIC at $\sqrt{s}=510$ GeV. This was a major contribution to the RHIC polarization increase to over 60 % for colliding beams. The high intensity polarized beam is also required for a planned RHIC luminosity upgrade by using the electron beam lens to compensate the beam-beam interaction at collision points.

POLARIZATION MEASUREMENTS AND ABSOLUTE POLARIZATION VALUES EVOLUTION DURING PROTON BEAM ACCELERATION IN THE RHIC ACCELERATOR COMPLEX

A.Zelenski, T.Roser

ABSTRACT

Absolute polarization measurements at different beam energies are very important for the understanding of the polarization evolution and polarization losses during acceleration and transport in the RHIC accelerator chain: Source-Linac-Booster-AGS-RHIC. In the RHIC complex there are two absolute proton polarimeters: the elastic proton-Carbon polarimeter at 200 MeV beam energy and the CNI H-jet polarimeter at 24-255 GeV in the RHIC ring. The polarization transport simulations show that depolarization occurs at the edge of the beam and that the polarization of the beam core at the center of the 2-dimensional beam intensity profile should be preserved during acceleration. Polarization profile measurements by the scanning p-Carbon CNI polarimeters in the AGS and RHIC provide experimental data that support these expectations. In addition, an estimate for the upper limit of depolarization at the edge of the beam distribution was deduced from the absolute polarization measurements at 200 MeV and at 100 and 255 GeV.