2024 Workshop on Polarized Sources, Targets, and Polarimetry

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Jefferson Lab

Book of Abstracts

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High-Precision Measurements of Asymmetry and Quantum Efficiency in Photocathodes for Polarised Electron Beam Experiments

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At the new, energy-recovering superconducting accelerator MESA in Mainz, spin-polarised electrons are required in the P2 experiment. Here the requirements increase considerably compared to the experiments at the micotron MAMI in Mainz.

A very sensitive part of the photocathodes lies in the specially prepared surface, characterised by its negative electron affinity. This surface is highly sensitive to residual gases in vacuum and subjected to ion back bombardment. Traditionally, this negative electron affinity is achieved through a preparation involving caesium and oxygen. Beam current losses induce a degradation of quantum efficiency and, in addition, the spin polarisation undergoes significant change. The exploration of the intricate relationship between asymmetry and quantum efficiency bears considerable importance, especially for the P2 experiment.

Our aim is to clarify this connection and its implications, offering insights into managing spin polarisation and quantum efficiency in photocathodes.

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Kicker Manget for the MESA 5 MeV Mott Polarimeter

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The Mainz Energy Recovering Superconducting Accelerator (MESA) requires for carry out of the high-precision measurements exactly measurement the long-term spin properties of the electron beam.
The chain of three Mott and Möller polarimeters at different beam energies is planed. Actual design of the 5.0 MeV beam section contained a kicker and a Mott polarimeter is presented

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Development of Polarized Lithium Sources for EIC

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In the next decades, the U.S.-based Electron-Ion Collider (EIC) will be one of the premier collider facilities for hadronic and nuclear physics. Among the crucial science goals of EIC beyond those articulated by the National Academy of Sciences report and EIC White paper is to explore the quark and gluon structure of nuclei. One essential knob in this investigation is the spin of the nucleus. The spin-dependent structure of the nucleus can only be accessed with polarized beams. The polarized light ion beams including H, D, and 3He are already part of the EIC project, and their science has been extensively discussed in those reports. However, making also polarized ion beams with A¿3 available will undoubtedly expand the scientific reach of EIC and benefit critical accelerator technologies.
A good example is the polarized lithium-6 and lithium-7 nuclei, ideal sources for spin-dependent studies since they allow to probe the nuclear medium modification of the spin-1/2 nucleon target or the scalar spin-1 deuteron target. Among the subjects that will be investigated are the polarized EMC effect and its A-dependence, hidden color and six-quarks contributions to the deuteron (embedded in lithium-6) through measurements of the $b1$ structure function and the gluon transversity. In this talk, we report the development progress for polarized lithium-6 and lithium-7 sources at Argonne National Laboratory. The potential physics programs with such sources at EIC will also be discussed.

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Search for Electric Dipole Moments and Axions/ALPS with Polarized Beams in Storage RIngs

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Two of the major scientific drivers of particle physics and cosmology are the faith of antimatter after the Big Bang and the origin of Dark Matter. The answers to these questions can be addressed by investigating permanent and oscillating Electric Dipole Moments (EDM) of fundamental particles. The experiments can be performed with polarized beams in a storage rings. Important milestones have been achieved by the JEDI Collaboration, using the magnetic storage ring COSY at Forschungszentrum Juelich (Germany). Among them the first ever measurement of the permanent and oscillating EDM of the Deuteron.

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The LHCspin project: a polarized target experiment at LHC

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A polarized gaseous target, operated in combination with the high-energy, high-intensity LHC beams and a highly performing LHC particle detector, has the potential to open new physics frontiers and to deepen our understanding of the intricacies of the strong interaction in the non-perturbative regime of QCD. Specifically, the LHCspin project aims to perform spin physics studies in high-energy polarized fixed-target collisions using the LHCb detector. Given its forward geometry (2¡¡5), the LHCb spectrometer is, in fact, perfectly suitable to cover the forward kinematics of these collisions. This ambitious task poses its basis on the recent installation and successfull operation of SMOG2, a storage-cell based unpolarized gas target in front of the LHCb spectrometer. With the installation of the proposed polarized target system, LHCb will become the first experiment delivering simultaneously unpolarized beam-beam collisions at 14 TeV and bot polarized and unpolarized beam-target collisions at center-of-mass energies of the order of 100 GeV. The status of the LHCspin project is presented.

6

Cooling Analyses of HV-MAPS detector for the Compton Polarimeter

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The Measurement Of a Lepton-Lepton Electroweak Reaction (MOLLER) experiment anticipates new dynamics beyond the Standard Model. The measurements are acquired by the scattering of longitudinally polarized electrons off unpolarized electrons in a liquid hydrogen target using a set of detectors in Hall A at the Thomas Jefferson National Accelerator Facility (JLab) in Newport News, Virginia, USA. MOLLER will use High Voltage-Monolithic Active Pixel Sensors (HV-MAPS) in the Hall A's Compton polarimeter to monitor the polarization. The detector contains a quad-planar geometry and each plane has three HV-MAPS chips attached. Compton polarimeter requires the HV-MAPS to be placed inside the vacuum to allow for the detection of low momentum particles at high rates. The chips generate heat during operation, and thus require an effective cooling system. The temperature measurement of the HV-MAPS in vacuum

is essential to understand the thermal properties of the pixel detector and cooling needs. This project reviews the efforts towards the cooling strategies, structure modification, and thermal simulations to achieve an in-vacuum operation. Further, the prototyping and successful testing of the electron detector's cooling system (using a test version of HV-MAPS chips with equivalent heat load) in a local lab was performed, and computational fluid dynamics studies are compared with the collected data.

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Progress on a Polarized 3He++ Ion Source at BNL

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A high intensity (2 x 10ˆ11 ions per pulse) polarized 3He++ ion source is being developed at BNL for use at the future Electron Ion Collider (EIC). The helium gas will be polarized using a novel technique based on metastability-exchange optical pumping (MEOP) in the 5T field of the existing Electron Beam Ion Source (EBIS), where it can be ionized and prepared for injection into the Alternating Gradient Synchrotron (AGS). An infrared laser system has been developed for optical pumping and measuring the polarization of the gas inside of the EBIS field. Previous results in a test setup have shown up to 80% polarization for ultra-pure 3He in an "open" cell configuration, with isolation valve and refilling tubes closed. Now, the setup has been moved into an exact copy of the EBIS magnet to prepare for final integration and injection into AGS. In this talk, the MEOP scheme used to polarize the 3He++ sample will be presented and the current state of the project at BNL will be discussed.

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New DAQ for the 200 MeV Polarimeter at BNL Linac

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A new DAQ system for the 200 MeV proton-carbon polarimeter at the BNL Linac has been commissioned during the polarized proton RHIC Run 2024. The polarimeter measures the asymmetry of the vertically polarized 200 MeV proton beam scattering off a thin carbon target at 12° and 16.2°. For the 16.2° elastic scattering, the analyzing power is close to 100%, allowing for precision absolute calibration of the beam polarization. To optimize the isolation of elastic events, a variable-thickness copper absorber is used. The new Data Acquisition system, based on 14-bit, 200 MHz Waveform Digitizers (WFDs), records full $\sim 300\,\mu$s beam bunch signal waveforms in the scintillator detectors. An exhaustive data analysis requires less than 50 ms and is performed between the beam bunches (typically repeated every 4.2 s). The dead-time-free measurements allow us to accurately control systematic errors (
$lesssim$0.1%) in the value of the elastic asymmetry for the 16.2° scattering, and consequently determine the beam polarization with systematic uncertainties better than 0.5%. For the combined data, including elastic and inelastic events at 12° and 16.2°, the statistical accuracy of the measured beam polarization is about 0.5% for a 1-hour measurement.

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Operation of the OPPIS H Ion Source during the RHIC Run-2024

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This work will provide an overview of the operation of the Optically Pumped Polarized Ion Source (OPPIS) during the polarized proton Run 24 of the Relativistic Heavy Ion Collider (RHIC).
The functionality of the source has been achieved by the upgrades focused on three key areas: performance, stability and safety
A 10 % enhancement of the beam transport efficiency was achieved by shortening the LEBT line and replacing electrostatic Einzel lenses with magnetic quadrupole lenses. Furthermore, optimization of the Rb and Na cells has mitigated the vapors dispersions in the beamline resulting in a significant reduction of Rb and Na consumption and enhanced source stability. Modifications in the plasmatron have led to a substantial increase source components lifetime (over 6 months of operation), thus ensuring a reduction of duty factor.
The upgrades confirmed the reliable operation through the whole Run 24 with a mean 350 µA / 300 µs current and an average 80 % polarization effectively provided at the end of the 200 MeV linac. The source development have also established the groundwork for remarkable achievements in view of future development.In this regard, we tested an extended 450 µs beam pulse width with minimal polarization losses (10%) and the successful injection of 1×10^{12} protons into the Booster.

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Proton beam polarimetry based on pe elastic scattering

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Fast and precise beam polarimeters are crucial for both accelerator tuning and spin-observable extraction. The statistical precision of a polarimeter is dominated by the figure-of-merit (FOM), i.e. the cross section multiplied by the physical asymmetry squared, of its reference reaction. The High Intensity heavy-ion Accelerator Facility (HIAF) and the polarized Electron Ion collider in China (EicC) are future large-scale scientific facilities being constructed and planned by the Chinese physics community. Spin-polarized physics programs are planned at both the facilities. The maximum proton beam energies at HIAF and EicC are 26 GeV/c and 9.3 GeV/c respectively. In this energy range, the FOM of the proton-electron (pe) elastic scattering is much larger than that of the proton-proton elastic scattering, which has been widely used for proton beam polarimetry. In addition, all observables of the pe scattering can be calculated exactly with QED. These two features make the pe elastic scattering perfect for beam polarimeters at the HIAF and EicC. This talk will report our feasibility study and design of a beam polarimeter based on double polarized pe elastic scattering.

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Far-forward neutral particle asymmetry measurements in the RHICf experiment

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The RHICf experiment installed an electromagnetic calorimeter in front of the Zero-Degree Calorimeter (ZDC) of the RHIC-STAR experiment in 2017 to measure the transverse-spin asymmetries of the far-forward neutral particles produced from transversely polarized proton collisions at RHIC. It is known that the far-forward neutrons produced in transversely polarized proton collisions have a large transverse-spin asymmetry, and the ZDC at RHIC serves as a polarimeter to monitor the polarization in the collision experiments. In particular, it is an important tool for tuning the polarization direction at the collision point. The electromagnetic calorimeter installed in the RHICf experiment was able to obtain high-precision position information, and furthermore, by moving the detector position, the kinematic region that can be measured was greatly extended and improving the precision of the measurement. In addition to neutrons, we also measured the far-forward asymmetry of neutral pions and collected new data on particle production in the far-forward region. Furthermore, we are conducting a combined analysis with the STAR detectors to advance our understanding of the particle production mechanism.

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Electron beam polarimetry at SuperKEKB

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The physics scope of the Belle II experiment currently acquiring data at the SuperKEKB collider will expand with a polarized electron beam upgrade, as recently proposed. Among the required elements for this upgrade, a real time diagnosis of the polarization is necessary to ensure it is large for all bunches in the accelerator during its regular operation. This will be realized by inserting a Compton polarimeter in the accelerator. Its conceptual design is described and no show-stopper for its integration has been identified. An estimation of the sensitivity of the polarimeter is made by means of toy Monte-Carlo studies. The proposed design accounts for the constraint to preserve the performance of the SuperKEKB accelerator and to cope with the short time separation of successive bunches. We show that the polarimeter will measure for each bunch the polarization within five minutes with a statistical precision below 1% and systematic uncertainties below 0.5%. It has the capability of providing this information online on a similar timescale. This work paves the way towards future implementation of real-time Compton polarimetry in several future projects.

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Practical Considerations when Using Low Carbon Steel for Extreme High Vacuum Applications

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The very low outgassing rate of low-carbon steel – of the order 1000 times smaller than degassed stainless steel - suggests this material could provide the means to routinely achieve significantly better vacuum, well into the extreme high vacuum range. At Jefferson Lab, low carbon steel will be used for the construction of a new spin-polarized electron source. The improved vacuum we expect to achieve will ensure reliable and long-lasting beam delivery at milliampere beam currents, which is roughly one hundred times more current than today's state-of-the-art spin polarized electron sources provide. But reaping the full benefit of low-carbon steel depends on practical matters, namely, limiting the surface area of all non-low-carbon steel materials required to build a functional photogun. For example, the pressure reduction expected in a photogun with surface area composed of just 10% stainless steel (e.g., the surface area contribution from of an all-metal gate valve leading to the accelerator beamline) would be just a factor of ten, and not the factor of 1000 suggested by the ratio of outgassing rates. This submission describes outgassing rate measurements of chambers built using low-carbon steel and stainless steel, and the ultimate pressures achieved for vacuum systems composed of low carbon steel and stainless steel and pumped using a non-evaporable getter and ion pump. A factor of ten pressure reduction was observed in the system with surface area dominated by low-carbon steel, consistent with MolFLow predictions based on measured outgsassing rates. Lower pressures are expected when more thoughtful steps are taken to limit the amount of surface area of non-low carbon steel material.

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Metastable exchange optical pumping to polarize ^{3}He at high magnetic fields

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Recent advancements in Metastability Exchange Optical Pumping (MEOP) techniques have enabled the investigation of ^{3}He nuclear spin polarization under high magnetic fields and varying gas pressures. At Jefferson Lab, we are employing MEOP of ^{3}He nuclei at varying pressures using a fillable cell under magnetic fields ranging from 2 to 5 T. The current development focuses on creating a double-cell, cryogenic polarized ^{3}He target for CLAS12 in Hall B at JLab, featuring a central solenoid that generates a magnetic field of 5T. We will present the polarization tests using current design for this target, and provide updates on progress so far in polarizing ^{3}He using MEOP at JLab.

This material is based on work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics under contract DEAC05-06OR23177.

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Polarized positrons at Ce+BAF

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A baseline concept for a continuous wave (CW) polarized positron injector was developed for the Continuous Electron Beam Accelerator Facility (CEBAF) at Jefferson Lab (Ce+BAF) [1]. This concept is based on positron beam generation by a high current polarized electron beam (1 mA, 120 MeV, ¿85% polarization) irradiating a 4 mm thick rotating water-cooled tungsten target or liquid metal target. The concept of the Ce+BAF injector including the concept of polarized electron source and simulations of polarized positron beam generation, positron beam capture and beam dynamics in the focusing solenoid, normal conducting standing wave capture cavities, magnetic chicane and SRF cavities are presented, as well as results of calculations of the energy deposited by the beams in the target, magnets, cavities and beam absorbers along the positron beam line.

[1] J. Grames et al., “Positron beams at Ce+BAF”, in Proc. IPAC’23, Venice, Italy, May 7-12, 2023, MOPL152.

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Polarization REsearch for Fusion Experiments and Reactors - The PREFER collaboration: aims, goals and present status

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The **PREFER** (olarization REsearch for Fusion Experiments and Reactors) collaboration was born to address the know-how in different fields and techniques to the challenging bet on fusion energy production with polarized fuel. Efforts are focused on a variety of tasks and objectives, which are under the responsibility of different institutes.
Starting from open questions in the fusion reaction physics, such as the study of d-d spin-dependent cross sections to measurements of nuclear polarization conservation in laser-induced fusion plasmas, there is still unexplored territory to discover. The collaboration aims to produce nuclear-spin polarized molecules, recombined from polarized atomic beams, and their condensation and transport, or explore new possibility by resonance ("Sona") transition technique which promises sufficient intensity for the feeding of fusion reactors.
Other options of production are investigated, like nuclear-spin polarization of molecules by laser or microwave excitation. The presentation provides the status of proposals and investigations in the European community.

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Amorphous Carbon-coated Storage Cell Tests for the Polarized Gas Target at LHCb

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The LHC beams cannot be polarized. Hence, the implementation of a dense polarized gas target at the LHCb experiment at CERN, to be operated simultaneously with beam-beam collisions, will enable fixed target interactions to explore a new energy range of spin physics measurements. Unfortunately, typical surface coatings like water, Teflon or aluminium, normally used to avoid polarization losses, are forbidden due to vacuum and beam policies.
Using the former ANKE atomic beam source at Forschungszentrum Jülich to provide a polarized atomic hydrogen beam, we investigated the properties of a storage cell coated with amorphous carbon. A notable recombination rate, lying between 93 and 100 %, and a preservation of

polarization during recombination exceeding 74 % was observed. We were able to generate H_2 molecules with a nuclear polarization of P ˜ 0.59. Remarkably, no water layer accumulated on the cooled storage cell surface, even over extended periods. Furthermore, we examined the influence of Lyman- radiation on the recombination rate on carbon, addressing a prominent question in the field of astrophysics.

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A facility for testing bulk superconducting hollow MgB_2 cylinders for the production and shielding of magnetic fields for polarized targets and nuclear fusion fuels

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The challenging magnetic problem of producing internal fields in compact spaces can be solved by high temperature superconducting bulk materials, such as MgB_2, which are promising tools for trapping fields around polarized substances, while shielding out external fields, as required for fundamental physics studies in scattering experiments.

They are also of great interests, as they allow to easily generate holding fields for accumulation and transport of polarized fuel in nuclear fusion tests.

A facility has been commissioned, which allows to control the bulk superconductor temperature down to 8 K, thanks to a cold head, driven by a helium compressor, thus satisfying also the requirement of eco-sustainability.

The facility has been tested on various superconducting hollow MgB_2 cylinders, each sintered starting from boron powders having different grain sizes, and it allows to measure the holding and shielding capabilities, together with the corresponding long-term stability.

The facility allows to map the trapped field along the symmetry axis and radially, as a function of both the temperature and the magnetic field. The measurements have been performed in transverse magnetic fields up to 1.2 T, due to the available magnet in our lab. And it can be moved for tests with higher transverse magnetic fields and also, after its preparation for transverse field generation, can be moved in longitudinal magnetic fields for shielding them.

In the context of an electron scattering experiment, such a solution minimizes beam deflection and the energy loss of reaction products, while also eliminating the heat load to the target cryostat from current leads that would be used with conventional electromagnets.
In the context of polarized fuel for fusion its use is straightforward, because the system can trap

the magnetic field required during fuel production, and then it can provide the holding field for its transfer in fusion test facilities.

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Further development of a Lamb-shift polarimeter

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The Lamb-shift polarimeter (LSP) is a useful detection apparatus to verify nuclear spin polarization for atoms, molecules and ions consisting of hydrogen and/or its isotopes. Its functionality relies on the creation of metastable hydrogen atoms via a charge exchange reaction that preserves the nuclear polarization in a strong magnetic field. The nuclear polarization is then determined by analyzing the relative occupation numbers between different metastable hyperfine states with different nuclear spin projection m_I. This makes the LSP a very rapid and cost efficient detection method for beams with a beam energy in the keV range as no pre-acceleration is needed. In the past it could be shown that many of the above mentioned candidates like H^+, D^+, HD etc. could be measured with success and in this work an additional ion, i.e. H^-, adds up to the list. Furthermore, the measurements of polarized H^- ions have been performed for pulsed beams as it was in use for long times at the cooler synchrotron COSY in Jülich. In a second part a theoretical outlook for possible adaptations on the spin filter are given, which is an important component of the LSP. This paves the way to realize experiments like the bound beta decay or parity violation in metastable hydrogen atoms. In addition, a small outlook for possible applications for a ^3He beam is given.

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Development of spherical neutron polarimetry at Oak Ridge National Laboratory

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Spherical neutron polarimetry is a unique and powerful tool to study certain complex magnetic structures. At the Oak Ridge National Laboratory (ORNL), we have developed a state-of-the-art

Spherical Neutron Polarimetry (SNP) system for neutron instruments at High Flux Isotope Reactor (HFIR), which is now in HFIR user program. This system, designed for high precision and versatility, offers a new dimension in polarized neutron scattering experiments. Our SNP system is characterized by its unique ability to manipulate and analyze the polarization state of neutrons in all three dimensions, unveiling new information otherwise inaccessible with conventional neutron polarimetry. This capability allows for a more comprehensive understanding of magnetic properties of materials. The control of neutron polarization is realized via a combination of adiabatic and non-adiabatic polarization transitions. The system's design includes utilizing high-Tc YBCO films and a range of advanced polarization manipulation devices, ensuring precise neutron polarization control and enabling a wide range of scattering angles. The development of the SNP system not only marks a significant milestone in polarized neutron scattering at ORNL but also opens up new possibilities for future research in physics, chemistry, and materials science. This talk presents an overview of the system's design, capabilities, and some of the online tests at HFIR.

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Enhanced durability NEA surface layer for GaAs photocathodes using Cs, O_2, and Li*

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Photocathodes based on GaAs are used as photo-electron sources to supply spin-polarized, high-current electron beams for accelerator applications. A thin surface layer, typically comprised of Cs and an oxidant, needs to be applied to such photocathodes during an activation process in order achieve negative electron affinity (NEA). The NEA layer and the associated quantum efficiency (QE) deteriorates over time. This decay is characterized by the so-called lifetime, a crucial parameter for photo-electron source operation. An increase of surface layer durability and, hence, lifetime by adding Li during activation has been successfully shown in previous studies. Recently, lifetime studies of bulk GaAs photocathodes activated with Cs, O_2, and Li have been conducted using the activation chamber of the Photo-CATCH setup at the Institut für Kernphysik of Technische Universität Darmstadt. We will present the results of these measurements as well as additional measurements planned in the future.

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22

Small Polarized Electron Storage Ring for Fundamental Physics Experiments

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We will present a new design of highly specialized small storage rings for low energy polarized electron beams. The new design is based on the transparent spin methodology that cancels the spin precession due to the magnetic dipole moment at any energy while allowing for spin precession induced by the fundamental physics of interest to accumulate. The buildup of the vertical component of beam polarization can be measured using standard Mott polarimetry that is optimal at low electron energy. These rings can be used to measure the permanent electric dipole moment of the electron, relevant to CP violation and matter-antimatter asymmetry in the universe, and to search for dark energy and ultra-light dark matter.

23

New Insights into Sona Transitions

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The Sona method, described in 1968 by Peter Sona, was used in polarized sources of the Lamb-shift type and is still important at optically pumped ion sources like at BNL. The trick of this method is that an electron polarization of a hydrogen beam, e.g. produced by charge exchange of a proton beam with optically pumped rubidium atoms, can be transferred into nuclear polarization. For this purpose, the electron-polarized hydrogen atoms have to pass a zero-crossing of a longitudinal magnetic field that acts as quantization axis. This non-adiabatic passage exchanges the occupation numbers of the "pure" hyperfine substates —1¿ and —3¿, but keeps the "mixed" states —2¿ and —4¿. Thus, the atoms in a hydrogen beam in the states —1¿ and —2¿, both have m_J =+1/2, will end up in the states —2¿ and —3¿ that have now both m_I =−1/2.

Like other groups before, we observed during operation of such a Sona unit for metastable hydrogen atoms strong oscillations of the occupation numbers of the involved hyperfine substates that depend on several parameters like the magnetic field shape and amplitude of the Sona unit or the velocity of the hydrogen beam. In this talk we will discuss the theoretical explanation of this effect and possible application for future polarized sources.

24

Record setting Compton polarimetry at 2 GeV

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A new level of accuracy in the measurement of electron beam polarization using Compton polarimetry was achieved during the CREX experiment. Conducted in experimental Hall A at Jefferson Lab in 2020, the back-scattered photons from the Compton scattering process were detected. A total uncertainty of dP/P=0.36% was achieved, surpassing even the measurement from the SLAC Large Detector (SLD) Compton polarimeter. The future Jefferson Lab flagship measurements to be made by the MOLLER and SoLID experiments will required polarization at this level. In this talk I will detail the steps required to achieve this high precision measurement.

25

SpinQuest Polarized Target System

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The SpinQuest experiment at Fermilab uses a solid-state polarized ammonia target held at a magnetic field of 5 T, immersed in liquid helium-4, which is held at approximately 1K by the evaporation refrigerator. The refrigerator provides the required cooling power during the dynamic nuclear polarization (DNP) process and the high intensity interaction with the 120 GeV proton beam from the Fermilab main injector. The refrigerator was designed in compliance with the American Society of Mechanical Engineers (ASME) to operate safely at Fermilab. The high pumping capacity ($17'000\, m^3/h$) roots stack provides the required pumping speed during DNP production data taking and a custom-made radiation hard flow control valve regulates the refrigerator temperature during the thermal equilibrium calibration measurements. The frequency of the microwave generator, an Extended Interaction Oscillator (EIO), is automated to keep the maximum polarization while the (Nuclear Magnetic Resonance) NMR system continuously measures the polarization of the target material. In this talk, an overview of the SpinQuest polarized target system will be presented as well as a brief report of recent commissioning activities and target performance during the early production runs in 2024.

26

Application of Deep Learning in Polarized Target Nuclear Magnetic Resonance Measurements

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Continuous wave Nuclear Magnetic Resonance (NMR) with constant current has been pivotal in solid-state polarized target experiments within Nuclear and High Energy Particle physics. Phase-sensitive detection using a Liverpool Q-meter is conventionally employed for monitoring polarization during scattering experiments. Yet, when operating outside of designed operational parameters, there are significant nonlinearities have not yet been well understood for high-fidelity running. Additionally under experimental conditions low signal to noise can lead to much larger experimental uncertainties reducing the overall figure of merit of the scattering experiments. This presentation discusses recent advancements aimed at enhancing data acquisitions in NMR-based polarization measurements and extending the operational capabilities of the Q-meter beyond its designated parameters using machine learning (ML) to analyze measurements with a low signal-to-noise ratio (SNR), corresponding to high noise levels. This innovative approach enables more effective real-time online polarization monitoring and offline data analysis, thereby enhancing the overall performance metrics in scattering experiments involving Spin-1 target material.

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Polarization behavior of fluorine-labeled glucose-water solution

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Magnetic resonance imaging using contrast agents is now an indispensable part of medical imaging. When these contrast agents, such as 3He gas, 13C in pyruvic acid or fluorine-labeled glucose (FDG), are used in the body, the sensitivity can be increased by 10,000 times or even more if the nuclei are dynamically polarized.
The results of the first dynamic polarization experiments of fluorine and hydrogen in a glucose solution doped with TEMPO are presented.

28

Precision Moller Polarimetry in Hall A at Jefferson Lab

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A M\o ller polarimeter has been active in Hall A at Jefferson Lab since the late 1990s. During the first decade of its use, it was limited to systematic errors of several percent due to its use of a low field tilted foil target whose polarization was the limiting uncertainty. Eventually, an upgrade in the target and measurement techniques allowed for uncertainties down to the 2\% level. Two

further upgrades to the target in 2010 and 2015 allowed for achievement of saturation polarization of the foil along the beam direction further reducing this systematic error and introducing an era of sub-percent level M\o ller polarimetry. This trajectory of increased precision is continuing with the approval of the MOLLER experiment and the proposal of the PVDIS experiment in Hall A initiating a program to reach ¡0.5\% uncertainty. The plan is to utilize the current apparatus with a few small upgrades, requiring a precise understanding of the spectrometer optics, validated models of Levchuk and radiative corrections and a careful examination of all contributions to the systematic uncertainty with an eye to minimizing each one. Key systematic errors under investigation are target polarization, DAQ dead time and accidental corrections and uncertainties arising from potential polarization differences between low and high current. I will discuss the plans to achieve this aggressive goal and the current status of those efforts.

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Correction of partial snake resonances with betatron coupling at the Brookhaven AGS

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Polarization of proton beam in the Brookhaven Alternating Gradient Synchrotron is preserved during acceleration by use of two helical dipole partial snake magnets. These magnets modify the spin tune to avoid strong intrinsic resonances associated with the vertical betatron motion, but in the process excite many weaker resonances associated with the horizontal betatron motion. Since these resonances occur at the same frequencies as resonances from betatron coupling, they may be corrected by introducing coupling resonances of equal and opposite amplitude. Fifteen pulsed skew quadrupoles have been added to the AGS lattice in order to implement such a correction scheme. We describe the correction principle, its implementation and commissioning results.

30

The pNab experiment and the quest for every better neutron beam polarization

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The pNab, a follow-up to the Nab experiment that is currently starting to take data at the Fundamental Physics Beamline of the Spallation Neutron Source at Oak Ridge National Lab,

aims to determine the beta asymmetry A in the beta decay of polarized free neutrons, and with high precision. In combination with others, this measurements will shed light on recent hints for a violation of the unitarity of the Cabbibo-Kobayashi-Maskawa matrix. I will discuss motivation and design, with a particular focus on the methods to provide very high polarization of cold neutrons, allowing for a precision measurement of it.

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Polarized ^{3}He ABS for an Absolute Polarimeter at the EIC

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Polarized ^{3}He beam is a crucial capability envisioned for EIC, whose development is underway. Measuring the polarization of the ^{3}He beam is thus critical for a productive scientific program. We plan to develop and commission an absolute ^{3}He polarimeter based on ^{3}He–^{3}He elastic scattering at RHIC, similar to the HJet based proton polarimeter currently in operation, which also uses an atomic beam source (ABS) of polarized H^-. This new hadron polarimeter would use a highly polarized ABS of ^{3}He as a target. The ABS initially was planned for the neutron electric dipole moment experiment at Oak Ridge National Laboratory. Re-purposing this ABS benefits not only the previous investment into its development, but also provides a far superior target with a high density.

The ABS produces a near-collinear beam of cold ^{3}He atoms at ~ 1 K, with the help of an etched multi-channel plate, and upon passing through a quadrupole magnetic field, polarizes the ^{3}He atoms. The upgraded atomic beam source can be mounted in the vertical orientation and has the capacity to actuate the initial direction of the beam of ^{3}He atoms. The performance parameters of, and the design challenges involved in upgrading the ^{3}He atomic beam source, along with the simulations used in vetting the design process, as well as the development of scattered particle detectors required for absolute polarimetry, will be presented.

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Beam Commissioning Result of Polarized Target at SpinQuest

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SpinQuest is a fixed-target experiment at Fermilab to measure the Drell-Yan process using transversely polarized NH_3 and ND_3 targets and unpolarized 120-GeV proton beam. In the Drell-Yan process, a quark in one scattering hadron and an anti-quark in the other hadron annihilate

into a virtual photon and then decay into a muon (lepton) pair. The angular distribution of final-state muon pairs with respect to the target polarization is sensitive to the Sivers function of light anti-quarks in the nucleon, which is one of the eight Transverse Momentum Dependent (TMD) parton distribution functions.

The intensity of the proton beam is as high as 10^{12} protons/second, in order to accumulate the required statistics of Drell-Yan events. The polarized target system at SpinQuest has been carefully designed to accommodate such a high beam intensity. It is equipped with an evaporation refrigerator with a cooling power of 3 W at ~1 K. The target temperature is maintained at 1 K even under heat load caused by the proton beam and the DNP microwave.

The target system and the spectrometer were commissioned with the proton beam from May through July 2024, where we studied, for example, the effects of the beam heating on the superconducting magnet. In this talk the experimental setup of SpinQuest and the performance of the target system during the beam commissioning will be presented.

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Development of a polarized Lanthanum target with perovskite crystals

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It is widely known that a solid polarized target is a powerful device for researches in spin physics, such as investigations of spin structure of nucleons, spin correlation in nuclear reactions, and precise measurements of discrete symmetries. In practical beam experiments, the solid polarized targets are limited to protons and deuterons since a relaxation time of nuclei with a large quadrupole moment is very short under a typical magnitude of external magnetic field. A possible method for overcoming such a problem is to perform the Dynamic Nuclear Polarization(DNP) with perovskite crystals, which is expected as a new tool for opening up further potential in spin physics. The NOPTREX collaboration applies this method for the development of a polarized lanthanum (139La) target, which is a core device for discovery of Time-reversal violating effects with a slow neutron. In this presentation, I will introduce a basic concept and some features of the method, and also show the current status on Research and Development(R&D) of the polarized 139La target in the NOPTREX project.

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The CERN FCCee Polarimeter Status

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The next CERN flagship project, named FCCee will be dedicated to precision physics measurements. To achieve a good knowledge of the collision energy (down to 100keV precision) a few hundreds pilot bunches will be polarized to use them for regular energy calibration by means of resonant depolarization (RDP) technique. Furthermore, a precise measurement of the residual longitudinal polarization of the physics bunches will be needed for the Z Mode runs to insure no physics bias. The FCCee polarimeter design is currently ongoing and the most updated status of this development will be presented at the workshop.

35

Polarized Photocathode R&D at BNL and spin consideration for the EIC

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Superlattice GaAs photocathodes are vital for producing polarized electron beams in key accelerator facilities, such as the Continuous Electron Beam Accelerator Facility (CEBAF) at Jefferson National Laboratory and the Electron-Ion Collider (EIC) at Brookhaven National Laboratory. The electron pre-injector at the EIC requires a 7 nC bunch with at least 85% spin polarization from a GaAs-based superlattice cathode. The doping density of the very surface layer of the cathode needs to be optimized to extract a high bunch charge beam from the high voltage DC gun. The polarization axis of the emitted beam is longitudinal, and it will be rotated to transverse direction using two Wien filters, each rotating the spin by 45 degrees. In this paper, we will report on our progress in recent R&D efforts for polarized photocathodes, and spin considerations for the EIC

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Developments of polarized ^{7}LiD target system for spin-dependent EMC effect experiments at CLAS12

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Experiment E12-14-001, "The EMC Effect in Spin Structure Functions", will be performed in Hall B at Jefferson Lab and compare the polarized quark distribution functions of bound and free protons using inclusive and quasi-elastic scattering scattering of electrons from dynamically polarized samples of solid ammonia (NH_3) and solid lithium deuteride (^{7}LiD). According to shell model calculations, about 87% of the ^{7}Li spin is carried by a single valence proton, making it an effective source of polarized, bound protons. In this talk I will describe our plans to fabricate target samples from commercially available LiD powder, irradiate them at the CEBAF injector, and test their polarization at 5 T and 1 K in the JLab Target Development Laboratory.

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Absolute hadron beam polarimetry at the EIC

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At RHIC, the calibration of the absolute beam polarization is based on the elastic proton-proton scattering from a polarized hydrogen gas jet target (HJET) in the CNI region. The nuclear polarization of the HJET itself is determined with a Breit-Rabi polarimeter. Electron and hadron beam polarizations of 70% with 1% absolute error are to be provided for the EIC (Electron Ion Collider). This represents a challenge and requires a more precise polarization determination and a higher polarization transfer in the accelerator chain leading to the hadron storage ring (HSR) than presently achieved. About ten times more and shorter beam bunches will be stored at the EIC, and the total beam current will also be larger compared to the one at RHIC. As a result, the depolarizing effect at the HJET must be re-evaluated and the target and detector systems must be optimized to meet the goals at the EIC. Consideration is being given to improving the polarimetry capabilities for the HSR, aiming to determine all Cartesian components of the polarization vector at the specific position of the polarized jet target in the HSR, and not just the vertical component of the beam polarization as has been done so far.

The injection of other polarized species, such as vector- or tensor-polarized deuterons and vector-polarized 3He ions, is not included in the base physics program for the EIC but is technically feasible. To enable absolute beam polarimetry for these target species, the successful concept of scattering identical particles to transfer the measured nuclear target polarization from an atomic polarimeter to calibrate the beam polarization will also be applied. For polarized 3He ions, a new source has been developed for this purpose [1], which will be used to address this problem. Although the magnetic moment of the deuteron is small (G = -0.1426) and would normally prevent longitudinal beam polarization in the HSR, it has been shown that imperfect spin resonances in the HSR can be overcome by using the detector magnets as partial coils [2]. This has the advantage of ensuring longitudinal polarization at —G— = 3×integer together with vertical orbit bumps. The HJET and the associated atomic polarimeter can be easily converted to generate polarized deuterium beams for determining the absolute polarization of deuterons.

The talk aims to highlight the challenges and the status regarding hadron beam polarimetry for the EIC.

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Generation of Polarized Electron Beams: Unveiling the First RF Electron Gun with GaAs Photocathode

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Polarized electron beams play critical role in fundamental physics research by providing additional observables and opening new channels of discoveries. This discovery potential is well-known and is frequently used in high-energy and nuclear physics research. Recently, more conventional branches of science, such as ultra-fact electron microcopy, started exploitation of unique features of matter interaction with polarized electrons. While there is an active search for efficient sources of polarized electrons, GaAs crystals illuminated by circular polarized IR lasers remain the main "work-horse" in polarized electron sources. All current GaAs polarized sources are limited to so-called DC – or electrostatic- electron guns with maximum voltage of few hundred kilovolts and accelerating gradients of few megavolts per meter. This technology is providing super-ultra-high vacuum conditions necessary for survival of GaAs photo-emissivity, i.e. its quantum efficiency. But this technology limits both the quality and quantity of available beams, and results in ion back-bombardment diminishing quantum efficiency of GaAs photocathodes. These are the reasons why accelerator community was and is attempting to extend this important technology to the realm of the RF (radio-frequency) electron guns, which are capable of accelerating beams to mega-electron-volts and accelerating gradients measured in tens if megavolts per meter. Unfortunately, all previous attempts of operating GaAs photocathodes in RF guns were unsuccessful and their QE was diminishing in few RF cycles. In this paper, we report on first successful operation of GaAs photocathode in superconducting RF gun. We describe in detail all critical steps necessary for this saucerful demonstration, parameters of the accelerator system and the generated electron beam, evolution of the GaAs quantum efficiency, as well as, lessons learned to further improve the systems.

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Spin-polarized photoemission from GaAs based superlattice structures

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Photocathodes capable of producing highly spin polarized electrons beams are required for both high energy and nuclear physics experiments. In this talk, we report on the commissioning of a new UHV vacuum system for photocathode characterization, which includes a retarding field Mott polarimeter for the measurement of electron spin polarization. We will illustrate the design of III-Vs superlattice structures equipped with Distributed Bragg Reflector and present the measurements of electron spin polarization and quantum efficiency of emitted electrons from these structures

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Polarized 3He Target Production and Performance in the JLab SBS GEn-II Experiment

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The JLab Super Bigbite Spectrometer (SBS) program's primary goal is to determine the elastic nucleon form factors at high momentum transfer. The SBS program includes a measurement of the neutron electric form factor, GEn, using the double-polarization technique with both a polarized electron beam and a polarized ^{3}He target (effective neutron target). In order to obtain adequate statistics in the high Q^2 region, the polarized ^{3}He target has operated with a polarization-weighted luminosity approximately a factor of two above any previous polarized ^{3}He target used in an electron-scattering experiment. The world-record-breaking target includes a double-chambered glass cell, filled to approximately 7 atm of ^{3}He at room temperature, with the long cylindrical "target chamber" measuring approximately 60 cm in length. In order to maintain high polarization with electron beam currents up to 60 μA, the target cells contain roughly 6 STP liters of ^{3}He, twice the quantity of ^{3}He used in previous targets at JLab. This target is polarized using alkali-hybrid spin-exchange optical pumping using up to 200W of near-infrared light from high-powered diode-laser arrays. This talk will cover the cell production process at UVA, an overview of the current polarimetry efforts, and a preliminary breakdown of individual cell performance for the entire GEn-II experiment.

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Methods in using a Novel 3He Target During Jefferson Lab's GEn-II Neutron Form Factor Experiment

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Nucleon electromagnetic form factors offer insight into the internal structure of those nucleons. The Super Bigbite Spectrometer (SBS) program at Jefferson Lab conducts experiments measuring nucleon form factors at high Q^2 values. With the neutron's electric form factor, G_E^n, previously measured to $Q^2 = 3.4$ GeV^2, GEn-II aimed to surpass this by up to roughly a factor of three. By colliding a polarized electron beam with a polarized ^{3}He target (with novel convection cell), GEn-II, measured the double spin asymmetry of the $e - n$ cross section in order to extract the form factor ratio G_E^n/G_M^n at Q^2 values of 2.9, 6.6, and 9.7 GeV^2.

The changes in the target cell's geometry, along with an innovative experimental setup, allowed for higher beam currents coupled with high SEOP (Spin Exchange Optical Pumping) polarizations. These effects helped lead to luminosities previously unattainable in polarized ^{3}He experiments.

This talk will cover target installation, the target system setup, as well as a general overview of the ^{3}He target performance during GEn-II.

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Holding Coil Advancements for Frozen Spin Experiments at the University of Bonn

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The University of Bonn has a long history of advancing polarized target technology. The first horizontal frozen spin dilution refrigerator with an internal holding field was pioneered there in 1993 and research in the field continues to this day. Currently, the next generation of frozen spin holding coils are being developed. This includes a paired longitudinal and transverse field arrangement which combines and extends the functionality of current holding coils while maintaining optimization for the frozen spin environment. I will present the status of those and other developments along with the performance of recent experimental runs at ELSA.

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Preparation of MOCVD-grown Photocathodes containing a Strained GaAs/GaAsP Superlattice

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In this work, we investigate multiple heat cleaning options for MOCVD-grown photocathodes containing a distributed Bragg reflector and a strained GaAs/GaAsP superlattice. This was done using a microMott polarimeter[1] at Jefferson Lab to optimize both quantum efficiency and polarization. Polarized photocathodes are essential to perform the physics programs planned at Jefferson Lab and Brookhaven National Lab. The fabrication process for MOCVD-grown photocathodes does not allow for the inclusion of an arsenic cap, contrarily to what is done in MBE-grown photocathodes[2]. Without proper preparation, photocathode performance is limited due to surface contamination which requires an optimized cleaning procedure. Here, we varied both duration and temperature of the heat cleaning process and observed increased quantum efficiency with negligible loss of polarization. Results of the optimized cleaning process in addition to upgrades to the testing apparatus will be presented.

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Compton Polarimetry for the MOLLER Experiment

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The MOLLER experiment at Jefferson Lab aims to measure the parity violating asymmetry(PV) in electron-electron(Møller) scattering. The prediction for PV in the current experimental design is 33parts per billion (ppb) and the goal is to measure this quantity with an overall uncertainty of 0.8 ppb. This measurement depends on the precise determination of the electron beam's polarization.

Compton polarimetry leverages the scattering of polarized photons from the electron beam to determine its polarization with high accuracy. To meet the stringent MOLLER requirements, we are developing a novel electron detector combining layered diamond microstrip detectors and high-voltage monolithic active pixel sensors (HVMAPS). Concurrently, robust laser polarization measurements and careful characterization of photon detector linearity provide accurate electron polarization determination. Along with hardware optimization, I will talk briefly on robust data analysis approaches under
study to achieve the sub-percent level precision required for the success of MOLLER.

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Polarized ^{3}He Double-Cell Target Utilizing Metastability Exchange Optical Pumping at High Pressure and Magnetic Fields

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The nuclear-spin polarized ^{3}He is a crucial instrument for investigating the neutron's spin structure, effectively acting as a polarized neutron target. The latest advancements in metastability exchange optical pumping (MEOP) techniques within high magnetic fields have enabled the use of polarized ^{3}He targets in strong magnetic field environments, such as Jefferson Lab's CLAS12 spectrometer. This work examines the polarization of ^{3}He nuclei through MEOP under varying pressures in a fillable cell, exposed to magnetic fields ranging from 1 to 5 T. The objective of this research is to develop a polarized ^{3}He double-cell target for incorporation into the CLAS12 detector's central solenoid, featuring a room temperature pumping cell and the diffusion of polarized ^{3}He to a cryogenically-cooled target cell. The design concepts, the present status, and the future implementation of this project are discussed.

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Electron polarimetry at EIC

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The Electron-Ion Collider will be the first collider to use both polarized electron beams and polarized protons and light ions. This will offer unique opportunities to study the structure of protons and nuclei and answer fundamental questions in QCD. The uncertainties on the polarization measurement translate directly into the uncertainties of final physics observables. Hence, a precise measurement of the electron and hadron beam polarization and a good control of the uncertainties are critical for the success of the spin program at the EIC. The requirements for electron beam polarimetry are non-destructive with uncertainty less than 1%. At the Electron Storage Ring (ESR) and the Rapid Cycling Synchrotron (RCS), the electron beam polarization will be measured using well-established Compton polarimetry techniques. However, the EIC Compton polarimeter will face unique challenges, demanding further developments. A Mott polarimeter will also be employed at the source for initial polarization measurements. Both longitudinal and transverse polarization will be measured, with the capability to monitor polarization on a bunch-by-bunch basis. Achieving these precise measurements will be critical to controlling systematic uncertainties and ensuring the overall success of the EIC's physics goals.

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New helium recapture and reliquefier system for Dynamic Nuclear Polarization at UNH.

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This talk concerns the installation of a new helium recapture and reliquefaction system, consisting of a gas bag, manifold, cooling chiller, purifier, high pressure compressor and cylinder banks, in the dynamic nuclear polarized target lab at University of New Hampshire. This new system has the capability to improve the efficiency of target polarizations runs by recycling our cryogenic helium which would otherwise be lost during polarization operations. Our helium liquefier is

rated to 40 L/Day under normal full-capacity operations with 800L capacity. I will explain the initial installation process followed by a discussion of the challenges with installation, including issues of impurities which appeared during the initial operation of the system. Then I will discuss how we overcame these difficulties. Finally, I will discuss the function of the system during normal operation and the present situation of the helium recapture and reliquification processing in our lab.

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Designing targets, from low to very high power with CFD

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Computational fluid dynamics (CFD) has played an essential role in designing high performance targets. I will review the experience accumulated at Jefferson Lab in designing polarized and unpolarized targets with CFD.

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Computational NMR Model for Deuteron Vector and Tensor Polarization

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Understanding the NMR lineshape of solid deuterated materials has become of interest due to upcoming measurements of the tensor polarized observables A_{zz} and b_1 at Jefferson Lab. This talk will describe a new computational model based on simple spin-flip transition calculations that accurately describes the NMR spectra of deuterated materials that have undergone both dynamic nuclear polarization (DNP) and semi-selective saturation radio frequency (ssRF) techniques to enhance the vector and tensor polarization. This model correctly predicted the imaginary portion of the deuteron lineshape, which can be utilized along with the typical real NMR signal to reduce systematic uncertainties in lineshape analysis due to mistuning of the NMR measurement tank circuit.

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Dynamic Nuclear Polarization Facility at the University of New Hampshire

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We describe the operation of a dynamically polarized nuclear (DNP) target facility and helium recapture system at the University of New Hampshire. Polarization enhancement is driven in a 5 Tesla superconducting magnet by a solid-state 140 GHz mm-wave source with quasi-optics transmission and a low-loss overmodal waveguide that is insensitive to magnetic fields. We have dynamically enhanced the vector and tensor polarization of deuterons in a variety of doped materials. A VME-based QMeter system is used to measure polarization, with the system normalization determined both by measuring the thermal equilibrium response and via line shape analysis of the NMR spectra. This facility supports the Jefferson Lab experimental program to explore tensor structure functions in DIS, and the tensor asymmetry in quasi-elastic and SIDIS experiments.

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Spin Transport for the PSI n2EDM Experiment

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The CP-violating neutron electric dipole moment (nEDM) is sensitive to physics beyond the Standard Model which is needed to explain the baryon asymmetry in our universe. The most precise measurement of the nEDM, carried out at Paul Scherrer Institute (PSI), is consistent with zero with an upper limit of 1.8×10^{26} e cm at the 90% confidence level. To reach an order of magnitude better sensitivity, the n2EDM experiment is being commissioned at PSI. In this completely redesigned apparatus, polarized ultracold neutrons from a 5 T superconducting solenoid are transported through six mu-metal layers of the Magnetic Shield Room into a uniform 1 uT precession field via a system a surface current spin transport coils. I will present the design, fabrication, and testing of these coils.

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Impact of the Crab Cavities on Polarization in EIC

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The Electron Ion Collider (EIC) represents a cutting-edge facility designed to explore the internal structure of protons and atomic nuclei at unprecedented levels. In this study, we focus on the investigation of the influence of crab cavities within the EIC setup on the polarization.
Crab cavities play a crucial role in achieving head-on collisions between particle bunches, enhancing luminosity. However, their influence on polarization spread remains an aspect yet to be understood. Through computational simulations and theoretical analysis, this study aims to analyze the effect of crab cavities on the polarization in the EIC. The findings will contribute to understanding beam dynamics and refining experimental methods, thereby optimizing collider performance.

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A Target Insert Design for the UNH Solid Polarized Target Lab

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The University of New Hampshire polarized target lab uses dynamic nuclear polarization to achieve high tensor polarization in solid deuterated target material, such as ND3 and deuterated alcohols. This system is comprised by a number of subsystems including a 1 K liquid helium refrigerator, a solid state microwave emitter, and a superconducting magnet. To mount the target material inside the uniform field region of the magnet we use a target insert which we design and assemble at UNH. The insert is placed from the top of a cryostat from above, down into the uniform field region. At the bottom of the target insert we mount a target ladder, which we design at UNH and 3D print using a resin plastic which can withstand 1 K temperatures. Inside the target cup we wrap a coil of wire to be used for a NMR measurements on the target sample. The target ladder also has an ss-RF coil for hole burning as well as an EPR coil for measurements of a sample's polarizability. Additionally the target ladder holds a thermometry, placed both above and below the target sample. Finally, the target insert must be engineered such that it is sufficiently vacuum-tight for a polarization operations, but still removable to swap out different materials. The target insert is used in concert with a NMR analyzer system, which can be used to extract the deuteron lineshape and from that a target polarization.

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RF techniques for enhancing tensor polarization in solid targets

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The use of tensor targets enables access to a set of observables that allow a deeper understanding of deuterium, the lightest composite nucleus. Currently, there is significant interest within the community in studying some of these observables, with experiments already approved and new physics proposals in development. The common technique for enhancing vector polarization is Dynamic Nuclear Polarization (DNP), while tensor polarization is enhanced through RF manipulation techniques applied after vector enhancement has been achieved. This talk summarizes the RF manipulation techniques and the efforts at the University of New Hampshire to achieve tensor polarizations suitable for physics experiments.

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The effect of superlattice pairs on MOCVD-grown strained GaAs/GaAsP spin polarized electron sources

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Electron sources capable of high polarization and quantum efficiency (QE) are critical to the operation of electron accelerators such as the Continuous Electron Beam Accelerator Facility (CEBAF) at Thomas Jefferson National Accelerator Facility. Strained superlattice photocathodes containing pairs of strained GaAs/GaAsP are currently the standard for beam production at CEBAF, capable of more than 80% polarization and 1.5% QE [1]. In order to increase the quantum efficiency, several devices were grown by MOCVD with varying number of superlattice pairs and the effects on quantum efficiency and polarization were studied. All devices were tested using a microMott polarimeter at Jefferson Lab using a heat clean at 550°C and a cesium/NF3 activation process. Our initial test results seem to indicate that increasing the number of pairs beyond 30 provides minimal benefits for the QE, while the polarization remained constant. A brief discussion of the MOCVD growth process will be presented along with the results of the parametric study.

References
[1] P. Adderley, J. Clark, J. Grames, J. Hansknecht, M. Poelker, M. Stutzman and R. Suleiman, "CEBAF 200kV Inverted Electron Gun," in Particle Accelerator Conference, New York, NY, 2011.

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Analysis of the Complex NMR Lineshape of the Deuteron

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To determine the spin polarization of deuterons, nuclear magnetic resonance (NMR) is used. This is necessary for polarized targets, such as for the upcoming Azz and b1 experiment at Jefferson Lab. NMR measures the impedance of a solenoid around a deuterated sample. Although the impedance is a complex value, conventionally only the real part of the impedance has been used for this purpose. However, often the tune is not precisely real, meaning the signal has at least some small imaginary portion. This has conventionally been dealt with by some sort of offset parameter, such as Dulya's false asymmetry method. For vector polarization, this suffices, as the tuning is factored into the overall error of the results, and for a small phase angle doesn't make much of a difference. However, for tensor polarization, the exact lineshape of the signal is quite significant. Treating the impedance as complex during analysis removes the need for an offset parameter, and also provides more accurate results. Recent results and analysis from the UNH DNP group will be presented on this subject.

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Characterizing the AFP Spin Flipper for the Nab Experiment

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The Nab experiment at the Spallation Neutron Source (SNS) at Oak Ridge National Laboratory (ORNL) aims to yield a precise measurement of the electron-neutrino correlation parameter, a, to a/a 3×10^4 from the beta-decay of the free neutron. To achieve Nab's precision goal, it is required that there is near-zero polarization of the neutron beam. To measure any residual polarization, a polarizer/analyzer combination, neutron monitors, and an Adiabatic Fast Passage (AFP) spin flipper will be used to determine a beam polarization effectively less than 2×10^5. Here, I will discuss the initial characterization efforts of the Nab spin flipper as well as the plans for further testing and its ultimate role once installed on the Fundamental neutron Physics Beamline (FnPB).

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The 200 keV CEBAF polarized source electrode design and implementation process

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The CEBAF injector, which generates continuous-wave spin-polarized electron beams for nuclear physics experiments at Jefferson Lab, has been upgraded with a polarized 200 keV photoemission electron source (photogun). We present the workflow involved in the development of this photogun with particular emphasis on the transverse match of the beam to the injector. Competing factors arise when optimizing electrode geometries for field-emission-free operation at a predetermined bias voltage, and matching the beam envelope to a pre-determined injector layout. As such an optimization is prohibitively complex when starting out with full 3D models of both the photogun and the subsequent injector, the challenge lies in choosing an adequate level of simplification of all components to capture all significant details. We discuss a systematic process involving particle tracking simulations verifiable with pencil-beam measurements for predicting the beam-optical properties of a given electrode geometry in order to optimize it for a desired set of beam parameters.

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Development of GaN as a Robust Spin-Polarized Photocathode at Cornell University

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The creation of a durable spin-polarized electron source that can maintain mA-scale average beam currents over an extended period in a photoinjector is essential for the success of future accelerator facilities like the International Linear Collider (ILC). In the Bright Beams Laboratory at Cornell University, photoemission of a spin-polarized electron beam from gallium nitride (GaN) photocathodes has been measured and characterized. In this proceeding, we overview the development, demonstration and current status of GaN as a robust spin polarized source.

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Preparations at Jefferson Lab for a Spin Polarized Fusion Program

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As part of a Spin Polarized Fusion (**SPF**) program, polarized ^{7}**LiD** pellets are being developed at Jefferson Lab (JLAB) for testing the survivability of nuclear polarization in a **100 million Kelvin** fusion plasma. With polarized fuels in a tokamak, the cross section can increase by **50%**, and the power gain of a large-scale fusion reactor, such as ITER, by **75%**. However, this power gain can only be realized if the fuel polarizations survive for periods comparable or longer than the particle confinement times (at least times in the order of seconds). Recently, the initial phase of an ***in-situ*** demonstration of polarization survivability in a tokamak plasma, proposed by the **SPF** collaboration, has been funded to answer this crucial question. In the next few years, we plan to prepare polarized ^{7}**LiD** pellets and ^{3}**He** capsules for injecting into the plasma at the

DIII-D tokamak of the DOE National Fusion Facility in San Diego, using the isospin-mirror reaction, $\boldsymbol{D+^3He \to a+p}$; this will mimic the standard $\boldsymbol{D+T \to a+n}$ fusion process without introducing tritium. For the next 2 years at JLAB, ^{7}**LiD** pellets made with fusion specifications will be irradiated with electron beams at the newly built Irradiation Beamline at the CEBAF Injector; irradiations will be carried out at 185K to induce paramagnetic centers, and then stored at 77K. A DNP polarizer, with a pellet handling system suitable to manipulate single ^{7}**LiD** cylinders of **2 mm** in size, and capable of polarizing many pellets simultaneously at 7 **Tesla** and **100 mK**, will be designed based on a commercial dry dilution refrigerator. A prototype polarizer will be tested at room temperature to verify the mechanical and electrical functionalities. In phaseII, the full device will be built at JLAB to produce polarized ^{7}**LiD** pellets for mating to a tokamak cryo-injection gun. The **SPF** experiment at DIII-D will be carried out in phaseIII. In parallel, efforts are also underway at UVA, ORNL, UC-Irvine and DIII-D to prepare for the **SPF** experiment. Details will be discussed.

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GaAs-based Spin-polarized photocathode research at Cornell

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GaAs-based photocathodes are currently the only viable technology for producing a spin-polarized electron beam at a high enough average current required for particle collider based nuclear and high energy physics experiments. In this work we give an overview on research carried out at Cornell University focused on improving the robustness of GaAs based photocathodes, including: the development of alternative Negative Electron Affinity (NEA) activation recipes, alkali-halide treatment of GaAs surface and gun tests at high average current in the High ElectRon Average Current for Lifetime ExperimentS (HERACLES) beamline.

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AI-Optimized Polarization at Jefferson Lab

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The AI-Optimized Polarization project seeks to develop experimental control applications for polarized targets and beams at Jefferson Lab using AI/ML. This talk will focus on two on-going efforts involving a cryogenic polarized target and a linearly-polarized photon beam. Firstly, cryogenic targets, such as those used in Halls B and C (and approved for Hall D), are complex systems that are sensitive to a number of factors, including the temperature, beam currents, and the microwave and NMR apparatus. Secondly, the Hall D photon beam polarization depends on the optimal orientation of a diamond radiator, which produces coherent bremsstrahlung radiation from the electron beam incident upon it. Manual operation of both systems is tedious and error prone; implementing well-designed, interpretable control systems that incorporate AI is expected to lead to improved real-time polarization. AI optimization of nuclear physics experiments will lead, not just to cost-savings, but also to more efficient and higher-quality data, and this project will help to lay the foundation for future autonomous experiments.

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Quantum Efficiency, Electron Spin Polarization and Lifetime Study for GaAs Based Truncated Nanocone Array Photocathodes

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GaAs based nanostructured photocathodes with truncated nano-cones were fabricated and studied at a low voltage test chamber. Quantum Efficiency (QE) enhancement due to dipole resonance mode excitation has been consistently observed throughout the waveband of 530-680 nm compared to the QE of flat bulk GaAs wafers. A modified photocathode activation recipe was followed for negative electron affinity (NEA) activation. In this report, we will present the experimental results from truncated nano-cone region and comparison with the flat region of the photocathode, and the recent study on other important properties of this type of photocathode including lifetime and electron spin polarization (ESP).

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Electron polarization in the RCS at EIC

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We review the status of the RCS polarization transport after the increase in energy to 3 GeV, the impact of several lattice changes, and the effect of the introduction of a radiative element to increase damping time.

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High polarization InAlGaAs/AlGaAs photocathodes grown using MBE

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Strained superlattices of GaAs/GaAsP grown using molecular beam epitaxy (MBE) have been used for more than 20 years to generate high polarization electron beams for nuclear physics. GaAs/GaAsP superlattices have several manufacturing challenges, including the thick graded layer required for the virtual GaAsP substrate, the significant difference in optimal growth temperatures for GaAs and GaAsP, and the scarcity of MBE systems using phosphorus. InAlGaAs/AlGaAs strained superlattice photocathode are an alternative structure that eliminates many of hurdles to growing GaAs/GaAsP in MBE systems. Measurements of quantum efficiency and polarization from InAlGaAs/AlGaAs will be presented. These include studies on a variety of growth parameters to optimize performance, including digital alloys, growth temperature variations, and variation in structure.

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The Dynamic Nuclear Polarization Program at ORNL

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The ORNL High Flux Isotope Reactor's IMAGINE instrument facilitates a wide array of biological structure and function studies. Notably, the neutron scattering experiments performed with this single-crystal diffractometer provide atomic-resolution insights into macromolecular protein crystals structure. The sensitivity of neutron macromolecular crystallography can be significantly enhanced by leveraging the spin dependence of the neutron scattering cross section of hydrogen. At ORNL, a proof-of-concept system employing Dynamic Nuclear Polarization (DNP) of samples has demonstrated a significant improvement in the signal-to-noise ratio of neutron diffraction data. Current efforts are focused on developing: 1) a neutron polarizer with spin flipper beamline infrastructure; 2) a next-generation SiPM-based neutron detector system; and 3) a DNP apparatus consisting of a 5T Helmholtz magnet and a dry 1K 4He refrigerator. The progress and future prospects of constructing a new DNP-enhanced beamline will be presented.

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Liquid metal-based polarized positron generation benchmark using the GEANT4 toolkit

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In this work, we report simulation results for the positron yield and polarization of polarized electron beams incident on GaInSn and PbBi liquid metal targets. One of the proposed upgrades to 12 GeV CEBAF is the use of a continuous wave polarized positron beam for physics experiments. Because of their heat dissipation capabilities, high-Z liquid metal jets are excellent candidates for positron production targets. Polarized positron beams can be generated from a primary electron beam incident on thick high-Z targets through circular polarized bremsstrahlung conversion to linearly polarized pair production. This polarization transfer from the primary electron beam has been previously demonstrated at JLab in the PEPPo experiment with a solid target and low energy. Here we report GEANT4 simulations for 10 and 120 MeV electron beams incident on GaInSn and PbBi liquid metal targets. These simulations are compared to simulations with a solid tungsten target, as well as with the PEPPo results and with unpolarized simulations using MCNP6.

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Polarized neutron pseudomagnetic precession in polarized 3He and (associated) precision NMR measurements in SEOP cells

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Three-nucleon (3N) interactions contribute ~5% of the binding energy of nuclei. Our ignorance of this major component of nucleon interactions limits the ability of nuclear theory to compute the properties of stable nuclei and predict the properties of the many new nuclei that radioactive beam facilities will create in the future. More accurate measurements in nuclear few body systems are needed. We have recently shown [ref] that it is possible to greatly improve our knowledge of the spin dependence of n-3He s-wave scattering by measuring the spin-dependent phase shift of a polarized neutron beam passing through polarized 3He gas using a neutron spin echo (NSE) spectroscopy. Polarized neutron optical birefringence through polarized 3He gas can help isolate the spin dependence of the 3N interaction in combination with nuclear theory calculations. The neutron-3He system is simple enough for the relevant theory calculations to be done, and the precision from exiting neutron instruments is high enough to be sensitive to 3N interactions.

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Summary talk - European Workshop on Photocathodes for Particle Accelerator Applciations

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The European Workshop on Photocathodes for Acclerator Applications (EWPAA 2024) took place in Dresden, Germany.
A summary of cathode work in Europe concerning photocathodes for spin-polarized electron beams will be presented. Topics include ,e.g., high QE cathodes for driving spin polarized positron sources for applied science, mechanisms to increase cathode lifetime and materials. Moreover, a new scheme for a high accuracy polarimeter will be presented.

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Development of Polarized Electron Sources in Japan

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Future particle accelerator projects in Japan such as the proposed International Linear Collider and an upgrade under consideration to the SuperKEKB collider plan to utilize spin-polarized lepton beams. Work is underway to create robust sources of polarized electrons for these projects, as well as solving issues related to beam transport and spin manipulation. This talk will describe the work being done to meet the challenges spin-polarized beams in current and future generation accelerators in Japan.

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Searching for Exotic Polarized-Electron Polarized-Neutron Interactions in Polycrystalline Terbium Iron Garnet Using Slow Neutron Polarimetry

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Rare-earth iron garnets are known examples of Néel ferrimagnetism. Polycrystalline terbium iron garnet (Tb¡sub¿3¡/sub¿Fe¡sub¿5¡/sub¿O¡sub¿12¡/sub¿, or TbIG) exhibits a net electron polarization and zero internal magnetization at its compensation temperature T_c, and the NSR-Ferrimagnets Collaboration has used this polarized electron target to search for exotic spin-dependent interactions between polarized electrons and polarized neutrons. We will describe

the development and initial characterization of the TbIG target as well as the neutron polarimetry techniques used in our ongoing search for these exotic interactions. The most recent efforts at the HFIR CG-1D MARS neutron imaging beamline in June 2024 will be discussed, including a description of the apparatus as well as data analysis of spin-state asymmetries in neutron imaging data and preliminary results.

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Polarization transmission to high energy at the EIC's HSR

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The EIC's Hadron Storage Ring will capture and accelerate spin-polarized hadron bunches from the injector chain comprising OPPIS/EBIS, Linac, Booster, and the AGS. If unaccounted for, polarized species will cross a vast number of depolarizing first-order spin-orbit resonances, which for ultra-relativistic particles occur every 523 MeV for protons, every 13.1 GeV for deuterons, every 336 MeV for helions, etc. Pairs of Siberian snakes, consisting of helical dipole magnets, are used to fix the closed-orbit spin tune at 1/2, thereby avoiding first-order spin-orbit resonances. Nevertheless, prominent higher-order spin resonances do arise in the vicinity of the strongest first-order resonances, and necessitate the use of multiple pairs of snakes for mitigation. The HSR is approximately three-fold super-periodic, and for such a ring we find that 12 snakes is a sufficient number for precisely cancelling first-order spin-orbit coupling independently of orbital tunes, using only these snakes. This number is too large, however, and we investigate how a smaller number of snakes can be optimally chosen by varying the betatron phase advance between the snakes to find an accelerator lattice configuration with the highest polarization transmission.

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Hadron Polarization in EIC

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Electron Ion Collider (EIC) requires high polarization for both ion and electron beams. To reach 70% proton polarization, six snakes will be used for EIC hadron storage ring (HSR). Extensive simulations have been done to make sure the polarization will be preserved through HSR. The simulations show that with pre-cooled beam size, the polarization can be preserved. In addition, polarized He3 acceleration has been simulated. Polarized deuteron has also been explored. This paper will summarize the overall strategy and status of the EIC hadron polarization.

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Electron Polarization in the EIC Storage Ring

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Summary of electron polarization in ESR.

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A Solid Polarized Target Development Facility at Jefferson Lab

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Solid polarized targets are a crucial tool used in scattering experiments to investigate different properties of the nucleon. The equipment used to produce, measure, and maintain conditions for the polarized material is complex in comparison to non polarized targets. This, in combination with the frequency of polarized experiments run at Jefferson Lab, limits the opportunity to refine and build upon experience gained from previously constructed targets. To address this, the Jefferson Lab Target Group has begun the construction of a permanent facility dedicated to creating and testing material for Dynamic Nuclear Polarization. The design elements and manufacture of the test cryostat along with the incorporation of other DNP associated equipment will be presented.

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UT Future Polarized Target Development

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The University of TN medium energy group will collaborate with ORNL to perform spin relaxation studies as well as study new materials with an ORNL DNP apparatus operated at UT. The details of the apparatus and modification/update plans will be discussed. Additionally, plans

for the development of a DNP target for Hall D's GDH sum rule experiment will be briefly described.