POL.A.R.I.S: POLarized target Advancements, Refinements, and InnovationS

Victoria Lagerquist, Stefan Goertz (Uni Bonn), Gerhard Reicherz (RUB), Andreas Thomas (KPH Mainz), Giuseppe Ciullo (INFN Ferrara), Dan Watts (York)

1. Research objectives

The Standard Model (SM) of strong and electroweak interactions has been a true success story in describing the microcosm over the last several decades. Many precision tests have verified the SM at the quantum level and set tight bounds for physics beyond it. Nevertheless, fundamental questions remain in the realm of low-energy quantum chromodynamics. Spin plays an important role in understanding these questions. An ambitious spin program is underway at accelerator centers in Europe (ELSA, MAMI, and CERN) and the United States (JLab and BNL). Polarized targets are an indispensable component for measuring polarization observables. Our goal is to establish principles necessary to ensure that the polarized target is a highly accurate and well-understood instrument for planned experiments at the aforementioned infrastructures.

The POLARIS consortium focuses on improving the figure of merit and luminosity of polarization experiments. We aim to enhance the polarization properties of solid-state targets and minimize systematic uncertainties in scattering experiments. Additionally, we plan to use high-temperature superconductor materials for field generation in the target. The third area of focus deals with further developing hyperpolarization technology into a method applicable to polarization experiments at high luminosities. These focal points are explored through five distinct research projects.

Polarized solid-state target materials:

(based on radiation-doped C_mH_n chains): For at least three decades, the question of whether polymers are suitable materials for use as polarizable solid-state targets has been debated. They offer unquestionable advantages in filling factor, handleability, and versatile geometry. Studies of polymer-foils doped with chemical radicals were conducted at PSI in Switzerland already in the 1990s. The key question arising from these investigations was whether these materials can be prepared or doped in such a way that high polarization values are achievable. This question can only be clarified if they are investigated under the realistic conditions of a particle physics experiment. This opportunity now exists at the University of Bonn. If the polymer materials show high proton polarization values (> 80%) under these conditions, it would represent another major step toward an ideal polarized solid-state target.

(based on fluorinated hydrocarbons): A high degree of nuclear polarization is an essential ingredient in some applications of nuclear physics: namely radiation detected NMR and conventional NMR spectroscopy and imaging. RD NMR combines asymmetric beta or gamma decay and, combined with high nuclear polarisation, increases the sensitivity of conventional NMR by up to 10 orders of magnitude. It can be used to measure nuclear magnetic moments of unstable nuclei with sub-ppm precision in order to determine the distribution of magnetic moment across the nuclear chart. In addition, if combined with biologically active nuclei (e.g., 18F, 11C) it could lead to new medical imaging applications. Additionally, there has been renewed interest in the NMR/MRI community in the technique of DNP that can greatly enhance the sensitivity and resolution of conventional NMR. The team of M. Kowalska currently explores this direction, with proven expertise in RD NMR and DNP. Several investigations have also been supported by CERN medical applications funding.

High-temperature superconductors for target applications:

(BISCO and YBCO): The current state of polarized targets with internal magnetic fields requires the delivery of electrical current to static coils within the cryostat. This significantly increases heat load and limits the flexibility of field shape. One of the projects of the CryPTA program was to investigate the use of bulk, high temperature superconductors (HTS) (BISCO and YBCO) to supplement traditional coils by shielding them from external fields. We would like to further develop these low mass HTS efforts by investigating their applicability for use as primary sources of frozen spin holding fields - removing the need for conventional coils altogether. Employing materials already developed at Mainz, we plan to utilize the University of Bonn's cryogenic and magnetic infrastructure to test the limits of this application.

(MgB2): Concurrently, in Ferrara, a facility for testing the HTS material MgB_2 has been commissioned. This facility is equipped to characterize the trapped fields as a function of both temperature and applied magnetic field. These measurements have been performed in transverse fields up to 1.2 T at temperatures of 8 K. The promising results have applications at JLab.

Hyperpolarization for a polarized target in scattering experiments:

Chemical hyperpolarisation (ChHP) is a novel method for spin polarising nuclei (p, 13C, 19F, etc.) in liquid target media. In ChHP, spin-order is transferred from dissolved parahydrogen (pH_2) to the nuclei, by means of a catalyst. It operates at room temperature and requires only small magnetic fields. Recent work to scale up this technology from the small volumes (sub mm^3) used in medical research (enhanced MRI) towards cm^3 have established feasibility. Similarly, prototype systems to continuously replenish polarisation, through pH_2 bubbling and methods to increase relaxation times of the polarised nuclei, have shown promise.

The research objectives are to inform the evolution of ChHP technology towards niche deployment in EU infrastructures and support access and collaboration with infrastructure facilities (and leading target and beam experts) as the ChHP technology and prototypes evolve. Key targets would use ChHP polarised target technologies that can operate at the frontiers of electron beam intensity at JLAB, MESA, MAMI and highly ionising environments (e.g., R3B beams, laser-plasma acceleration) where cryogenic technologies cannot operate effectively.

2. Connection to Transnational Access infrastructures (TAs) and / or Virtual Access projects (VAs)

ELSA (Bonn, Germany): The ELSA facility will be used for irradiation of target samples and the dilution cryostat will be used for polarization measurements. HTS materials will also be investigated using the cryogenic and magnetic infrastructure.
MAMI (Mainz, Germany): The A2 facility at the electron accelerator MAMI in Mainz will be crucial for testing the newly developed ChHP target.
CERN (Geneva, Switzerland): the ISOLDE facility will support testing of F18/F19 materials.
JLab (Newport News, USA): MgB_2 is being developed in Ferrara for use at JLab. Additionally, ChHP will be tested in the high intensity beam.

3. Estimated budget request

€200k broken into: €50k for conference organization and administration and €30k per project (€150k total) for purposes including: travel and materials transport between consortium institutions, personnel including undergraduate and graduate students, and consumable material investments.

4. Participating and partner institutions

University of Bonn (Uni Bonn), Ruhr-Universität Bochum (RUB), Johannes Gutenberg University, Mainz (KPH Mainz), INFN Ferrara, University of York (York)