PROCEEDINGS OF SCIENCE

CryPTA2022, Status Report from this year's annual Meeting

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The joint research activity CryPTA (Cryogenic Polarized Target Applications) is part of the European Research Association for Hadron Physics STRONG2020 and receives funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N^0 824093. CryPTA deals with developments in the field of polarized solid-state targets. Our focus is on the development of active polarized target technologies and the further development of superconducting coils for applications in the polarized target and beyond.

Here we will report on current developments and perspectives for polarized solid-state targets presented at the annual meeting CryPTA2022.

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1. Introduction

CryPTA (Cryogenic Polarized Target Applications) is part of the European research network STRONG-2020 [1], one of the 14 collaborative research projects within STRONG-2020, and is assigned to the area of instrumentation of new experiments in hadron physics. In addition to the instrumentation issues and research areas, the STRONG-2020 research network addresses fundamental issues and validity of hadron physics both at low energies and at the highest energies achievable at the moment. Beyond the collaborative research projects oriented to the concrete physics problem, the STRONG-2020 network promotes the virtual exchange of research activities and supports the transnational scientific exchange at the well-known European accelerator laboratories and knowledge centers on theoretical physics in the field of hadron physics. In total, 45 laboratories from 36 countries are involved in 32 work packages. The project is registered under grant agreement No 824093 since 01.07.2019 and ends on 30.11.2023.

CryPTA itself is a collaboration of four working groups from Ruder Boskovic Institute (RBI, Croatia), Ruhr-Universität Bochum (RUB), Rheinische Friedrich-Wilhelms-Universität Bonn (UBO) and Johannes-Gutenberg-Universität Mainz (UMainz) all Germany. In the past 3 years, 15 scientists have been working on the development of new technologies in the field of polarized solid-state target to improve experimental capabilities with the aim of enabling new and improved measurements of polarization observables in hadron physics in the future.

The vector polarization P_z of the nucleons in a polarized target in thermal equilibrium

$$P_z = \frac{N_\uparrow - N_\downarrow}{N_\uparrow + N_\downarrow} = \vec{P} \sim \tanh {}^{\mu\vec{B}}\!/_{kT}$$

is essentially determined by the external applied magnetic field (B) and the temperature (T) of the nucleons or the target material. Even with the dynamically polarized solid-state targets used today, with their high polarizations to be achieved, the magnetic field necessary to align the spins in the scattering plane is often the limiting factor in the choice of the desired polarization observable in an existing detector system. This is especially true in detectors with large solid angle acceptance and most especially in detectors operated in a strong magnetic field for particle detection.

In almost all particle physics scattering experiments for the measurement of polarization observables, one is therefore confronted with the two fundamental challenges that the intended observable cannot be measured with the existing magnetic field in the planned detector system or that the magnet enclosing the target makes particle detection more or less impossible.

The research activities of the groups involved in the collaborative research project CryPTA focus on the development and optimization of small, minimally invasive superconducting magnet systems to align the polarization in the polarized target and with the development of technologies to detect scattered particles within the target material and thus within the magnet structure. Consequently, the CryPTA project is divided into two tasks:

- CryPTA:ScM and CryPTA:ScS deal with magnetic field generation and shielding using LTSC-wires (ScM) or HTSC-materials (ScS). The key technology to improve the performance of polarized targets to increase luminosity, FoM, availability and enable the measurement of new polarization observables.

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- CryPTA:APT focuses on the detection of recoil particles in an active polarized target by developing active target materials and readout technologies at the lowest temperatures. The key technology to extend the kinematic range of polarized solid-state targets to lowest energies.

The goal of all CryPTA efforts is to develop breakthrough superconducting magnet structures and low-temperature detector techniques for new and innovative polarization experiments using polarized targets in 4π-detector systems for hadron physics experiments in Europe.

In order to re-intensify the scientific exchange in this field, 20 scientists from 10 laboratories met at the CryPTA2022 annual meeting in Boppard, Germany, from September 20-22, 2022, to exchange viewpoints and experiences and to present their scientific results and developments in the subject area of CryPTA. In the following, a selection of results and ideas from the annual meeting on the three topics of CryPTA are presented. Detailed information about the program and all presentations of the annual meeting can be found on the workshop web page [2].

2. Superconducting magnet systems using LTSC materials: CryPTA:ScM

2.1 Thin superconducting magnets for DNP

In the double polarization experiments at the large acceptance detector systems Crystal Barrel at ELSA and Crystal Ball at Mami, the target technology of the horizontal frozen spin target with an internal holding coil developed in Bonn [3] has been used very successfully for many years. Central part is a horizontal dilution refrigerator in which a thin superconducting magnet is integrated. The magnet maintains the polarization during data acquisition either longitudinally or transversely to the scattering plane in 'frozen spin mode'. This allows the large solid angle acceptance of the detectors to be fully utilized. A disadvantage of the frozen spin target principle is the continuous polarization decrease during data taking despite the very low temperatures in the dilution cryostat. To improve the figure of merit for future polarization experiments, the thin internal holding coil of the frozen spin target should be replaced by a coil of the same geometry but with a stronger magnetic field. Ideally, the magnet should provide the field of the external polarization magnet, typically 2.5 Tesla. The advantages of this scheme of an internal polarization magnet are obvious: the target polarization can be kept at a high level even during data acquisition by DNP, there is no more loss of time due to the otherwise usual post-polarization phases. We call this scheme '4π-continuous polarized target' [4].

However, the DNP process requires a high field homogeneity over the target volume and since the magnetic field volume of the planned internal polarization magnet is of the same order of magnitude, appropriate correction windings have to be placed on the solenoid. In addition to this necessary boundary condition, the solenoid must not exceed a total thickness of 2 mm to ensure particle detection of the reaction products. All this requires precise winding of thin superconducting wires on a thin-walled copper substrate using wet winding techniques [5].

In the target laboratory of the Physics Institute of the University of Bonn, a small superconducting solenoid with a nominal field of $B_P = 2.5$ T was successfully wound on the specially developed winding machine. The coil can be installed in the existing or in the future horizontal dilution cryostat. The coil was tested in a 1K ^{4}He evaporation refrigerator. We demonstrated that both butanol and ^{6}LiD can be dynamically polarized [6]. The next step is to install the coil in the new dilution refrigerator and use it in the Crystal Barrel experiment at ELSA.

In order to measure as many polarization observables as possible with one setting of detector system and polarized target, we are currently developing a coil system in which a solenoid is combined with a race-track coil pair in a cylinder carrier [6].

2.2 Superconducting correction coils for DNP in a spectrometer magnet

At JLab, the technique of internal superconducting coils is used at the CLAS12 experiment to correct for an external strong magnetic field. There, the 5 Tesla magnetic field of the large acceptance detector system is used to dynamically polarize the target material in a continuously operated horizontal 1 K evaporation refrigerator. In contrast to the frozen spin operation, the target material is also permanently dynamically polarized during data taking. In this sense, this is also a '4π continuous polarized target' [7]. However, since the homogeneity requirements for the DNP process must also be met here, superconducting correction coils were installed in the cryostat in the target area after prior precise measurement of the spectrometer magnetic field. The coil system was designed to not only correct the external field, but also to provide a significant field shift to reverse the polarization direction in the individual target cells and measurements for NMR calibration. Overall, then, a very elegant solution and use of internal coil technology [8].

3. Superconducting magnet systems using HTSC materials: CryPTA:ScS

In recent years, the development of high-temperature superconductors has progressed to such an extent that these materials are also suitable for special magnet applications. The special geometrical requirements of the thin magnet systems used in the polarized target suggest the use of tubes made of solid high-temperature superconductor material. In addition, tubes made of high-temperature superconductor open the possibility to induce and practically store or completely shield the magnetic field of an external magnet when passing through the critical parameters of the material.

3.1 Bi-2212 shielding tube

Within the framework of CryPTA:ScS, the working group from HIM (UMainz) has investigated the shielding properties of HTSC tubes consisting of bulk Bi-2212 ($Bi_2Sr_2CaCu_2O_8$). Background of this measurement is the planned use of this shielding in the Panda magnetic field to create a field-free space for a polarized target at the interaction point. The measurements on the shielding behavior of the Bi-2212 tube have shown that at a temperature of $T_{Bi\text{-}2012} = 4.2$ K a longitudinal external magnetic field of $B_{ext} = 1.4$ T can be almost completely shielded with a shielding factor of $SF = B_{ext}/B_{res} = 3*10^5$ (B_{res}: field inside the cylinder) [9]. Further measurements on shielding behavior at higher temperatures and magnetic fields are planned for the future. It is also planned to systematically investigate the high-temperature superconductor YBCO under the same conditions and to test its suitability as a shielding material [9].

3.2 Bulk MgB2 holding magnet

A really promising concept for field generation or field storage using a high-temperature superconductor as a holding coil for a polarized target was presented by G. Ciullo from INFN Ferrara [10]. There, one uses a tube of magnesium diboride (MgB_2) sintered in one's own laboratory. The tube is produced by the so-called magnesium 'reactive liquid infiltration' process. MgB_2 is an intermetallic compound that currently has the highest transition temperature (39.5 K) among metallic superconductors and is characterized by a high critical current density. To measure the properties of the MgB_2 tubes, the cylinder was cooled to T_{MgB2} = 13 K via a cold head and subjected to an external axial and longitudinal magnetic field of B_{ext} = 980 mT. Depending on the condition under which the temperature fell below the critical temperature, the external magnetic field could be trapped or shielded. This showed that the external magnetic field was almost completely trapped (B_{res} = 943 mT). The shielding behavior of MgB_2 is less pronounced than Bi-2212 at T_{MgB2} = 13 K, but a clear temperature dependence is evident. Thereafter, a much higher shielding factor can be expected at 4.2 K for MgB_2. The long-term stability measurements show a stable shielding behavior and a high stability of the trapped field. In further measurements in the near future, the temperature of the cylinder will be lowered further and exposed to higher external magnetic fields, thus testing its suitability for use in the polarized target. But already now it can be said that the concept of cylindrical high-temperature superconductors is a good alternative to the classical superconducting coils based on low-temperature superconductors. Thus, the high-temperature superconductors significantly expand the application and experimental range of the polarized solid-state targets in polarization experiments. Thus, the use of the concept is envisaged in the future at the CLAS12 experiment.

4. Low temperature detection techniques: CryPTA:APT

Naturally, the polarized solid-state target reaches its limits with respect to the detection probability of the reaction products when measuring threshold reactions or at generally low beam energies. The density of the target material and the large radiation length of the structural materials surrounding the target, and here in particular the internal holding coil, shadow the target material and shift the detection threshold for particle detection by about 100 MeV. Thus, among other things, the measurement of the 'Proton Spin Polarizabilities with Double-Polarized Compton Scattering' is planned at MAMI. Due to the reaction kinematics and the competing processes, the detection of the recoil proton is essential for the process. From this constraint for the experiment, the idea of the active polarized target has been developed in the working group at MAMI [11].

Typically, doped alcohols are used in polarization experiments with real photons because of their high content of polarizable nucleons. Since polystyrene also has this property and at the same time functions as a classical scintillation material, the obvious conclusion is to dope polystyrene, polarize it dynamically and read out the light from the recoil protons. However, all components, scintillator, light guide and first readout electronics are located in the dilution cryostat and are thus partially exposed to temperatures in the millikelvin range. This places high demands on the coupling of the light guide to the scintillator and the quality of the light guide itself. In the meantime, the concept has been used in a first scattering experiment and first data have been taken. The polystyrene used could be polarized to just under $P_p \sim 50\%$. The relaxation times reached $\tau \sim 80$h in the frozen spin mode of the target. The low relaxation times were due to the high thermal conductivity of the optical fiber and are not unusual for now. What was important was the successful detection of recoil protons, which were detected in the analysis process. The tests confirmed the concept, but a modified version of the active target will be used in the future. The idea of a semi-active target is being discussed. It is planned to embed a small classical alcohol target material (high polarization, significantly improved relaxation times) a cage of strongly segmented scintillators and to guide the light via thin fiber elements from the low temperature range to the medium temperature range of the cryostat. This significantly reduces the thermal load on the mixing chamber and improves the performance of the refrigerator [12].

Regardless of the difficulties, the concept has proven that the active target opens a new class of polarization experiments with the polarized solid-state target, offering a significant expansion of experimental possibilities in hadron physics.

5. Summary

In summary, the collaborative research project CryPTA addresses the current technological developments in the field of Polarized Solid-State Targets and opens the door for new experimental methods for double polarization experiments in hadron physics. Finally, I would like to thank all participants from the CryPTA2022 annual meeting for their contributions and fruitful discussions.

References

[1] B. Erazmus et al., *STRONG-2020*, [Online]. Available: `http://www.strong-2020.eu`.

[2] H. Dutz and A. Thomas, *CryPTA2022, Annual meeting of the STRONG2020 Joint Research Activity 'Cryogenic Polarized Target Applications' (WP28)*, [Online]. Available: `https://indico.hiskp.uni-bonn.de/event/84/`.

[3] Ch. Bradtke et al, *A new frozen-spin target for 4pi particle detection*, Nucl.Instrum.Meth.A 436 (1999) 430-442, p. 13.

[4] H. Dutz, *Summary of the 9th International Workshop on polarized solid state targets and techniques*, Proceedings of the 16th International Spin Physics Symposium, pp. 221–225, WORLD SCIENTIFIC, 2005.

[5] M. Bornstein, *Development of a thin, internal superconducting polarisation magnet for the Polarised Target*, PoS(PSTP2015)006, p. 6, 2015.

[6] H. Dutz, *Status of CryPTA:ScM*, CryPTA2022, 2022. [Online]. Available: `https://indico.hiskp.uni-bonn.de/event/84/contributions/896/`.

[7] C. Keith, *Activities of the Jefferson Lab Target Group*, CryPTA2022, 2022. [Online]. Available: `https://indico.hiskp.uni-bonn.de/event/84/contributions/887/`.

[8] V. Lagerquist, *Optimization and Implementation of Magnet Correction Coils for the Jefferson Lab Polarized Target*, CryPTA2022, 2022. [Online]. Available: `https://indico.hiskp.uni-bonn.de/event/84/contributions/892/`.

[9] F. Maas, *Experimental tests of the shielding tube BSCCO-2212*, CryPTA2022, 2022. [Online]. Available: `https://indico.hiskp.uni-bonn.de/event/84/contributions/899/`.

[10] G. Ciullo, *A versatile bulk superconducting MgB2 cylinder for the production of holding magnetic field for polarized targets and nuclear fusion fuels*, CryPTA2022, 2022. [Online]. Available: `https://indico.hiskp.uni-bonn.de/event/84/contributions/893/`.

[11] A. Thomas, *Status of the polarized target at MAMI*, CryPTA2022, 2022. [Online]. Available: `https://indico.hiskp.uni-bonn.de/event/84/contributions/883/`.

[12] M. Biroth, *The Mainz Active Polarized Proton Target - Review and Perspectives*, CryPTA2022, 2022. [Online]. Available: `https://indico.hiskp.uni-bonn.de/event/84/contributions/895/`.

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