PROCEEDINGS OF SCIENCE

Double polarized measurements with frozen spin target at MAMI

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

Since 2010 the experimental apparatus has been completed by a polarized target. The horizontal dilution refrigerator of the Frozen-Spin Target has been constructed and is operated in close cooperation with the Joint Institute for Nuclear Research in Dubna, Russia. The system includes longitudinal or transverse superconducting holding coils to allow for all directions of polarization.

Due to the low base temperature of 25mK of the cryostat very long relaxation times in the order of 1000-3600 hours for protons and deuterons could be reached.

Research and development is done to produce an internal superconducting polarizing coil for continuous DNP. In addition, we are investigating the possibility to get 'active' polarized target material in the cryostat to allow for a new class of threshold meson production and Compton scattering experiments.

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1. Introduction

Since more than 20 years the international A2 collaboration has been measuring photo absorption cross sections of linearly and circularly polarized photons on unpolarized and polarized protons and deuterons to determine the total cross section and partial reaction channels in a large kinematical range, which provides new information about the excitation spectrum of the nucleon. The A2-Glasgow-Mainz tagging facility stands out due to its high photon intensity. In the framework of the GDH-experiment there was used a longitudinally polarised Frozen-Spin Target [1] from the University Bonn in combination with the DAPHNE detector. In the year 2010 a new Frozen-Spin Target, produced in collaboration with the Joint Institute for Nuclear Research, Dubna, Russia, came into operation and was used with transverse polarized protons and deuteron for more than 5000 hours in beam. We have continued the series of double polarized measurement with a longitudinally polarized target in summer 2013.

2. The A2 Real Photon Facility

The A2 Real Photon Facility is one of the three major experiments using the electron beam from the MAMI accelerator, see figure 1. The experiments A1 and A4 use the direct electron beam, while in A2 the electron beam is converted in a beam of photons in the 'Bremsstrahlungs' process.

The MAMI accelerator with its source of polarized electrons, based on the photo-effect on a strained GaAs crystal, routinely delivers polarized beams with a maximum energy of 1608 MeV. We typically have a degree of polarization of about 85%. Details about the new machine type can be found in reference [2].

The electrons are used to produce a secondary beam of real photons in the 'Bremsstrahlungs' – process. The energy of these photons is detected in the Glasgow-Mainz tagging-system [3].

The resulting photons can be circularly polarized, with the application of a polarized electron beam, or linearly polarized, in the case of a crystalline radiator. The degree of polarization achieved is dependent on the energy of the incident photon beam E_0 and the energy range of interest, but currently peaks at ~75% for linear polarization and ~85% for circular polarization.

The Glasgow Photon Tagger provides energy tagging of the photons by detecting the post-radiating electrons and can determine the photon energy with a resolution of 2 to 4 MeV depending on the incident beam energy, with a single-counter time resolution of 0.117ns. Each counter can operate reliably to a rate of ~1 MHz, giving a photon flux of $2.5 \cdot 10^5$ photons per MeV. Photons can be tagged in the momentum range from 4.7 to 93.0% of E_0.

3. The detector system

The detector system is a typical setup with close to 4π angular acceptance. The detector is optimized for neutral final states. No magnetic field for charge separation is available. The central detector system consists of the Crystal Ball calorimeter combined with a barrel of scintillation counters for particle identification and two coaxial multi-wire proportional counters for charged particle tracking. This central system provides position, energy and timing information for both charged and neutral particles in the region between 21° and 159° in the polar angle and over almost the full azimuthal range. At forward angles, less than 21°, reaction products are detected in the TAPS forward wall. The full angular coverage of this detector system sets very rigorous condition for the construction of the polarized target.

The Crystal Ball detector (CB) is a highly segmented 672-element NaI(Tl), self triggering photon spectrometer constructed at SLAC in the 1970's. Each element is a truncated triangular pyramid, 41cm (15.7 radiation lengths) long. The readout electronics for the Crystal Ball were completely renewed in 2003, and it now is fully equipped with SADCs which allow for the full sampling of pulse-shape element by element. In normal operation, the onboard summing capacity of these ADCs is used to enable dynamic pedestal subtraction and the provision of pedestal, signal and tail values for each element event-by-event. Each CB element is also newly equipped with multi-hit CATCH TDCs. The readout of the CB is effected in such a way as to allow for flexible triggering algorithms. There is an analogue sum of all ADCs, allowing for a total energy trigger, and also an OR of groups of sixteen crystals to allow for a hit-multiplicity second-level trigger - ideal for use when searching for high multiplicity final states.

In order to distinguish between neutral and charged particles species detected by the Crystal Ball, the system is equipped with PID2, a barrel detector of twenty-four 50mm long, 4mm thick scintillators, arranged so that each PID2 scintillator subtends an angle of 15^0 in ϕ. By matching a hit in the PID2 with a corresponding hit in the CB, it is possible to use the locus of the ΔE, E combination to identify the particle species. This is primarily used for the separation of charged pions, electrons and protons.

4. The Polarized Target

The new Frozen-Spin target was designed to retain the high angular acceptance of the detector system. The main boundary condition for the outer diameter of the target cryostat was the most inner particle identification detector PID2 with a diameter of 104 mm. The internal holding coils had to be as thin as possible to allow particles to punch through. The core of the Frozen-Spin target for the Crystal Ball detector is a specially designed, large, roughly 2m long, horizontal $^3He/^4He$ dilution refrigerator (see figure 1) that was built in cooperation with the Joint Institute for Nuclear Research (JINR) Dubna.

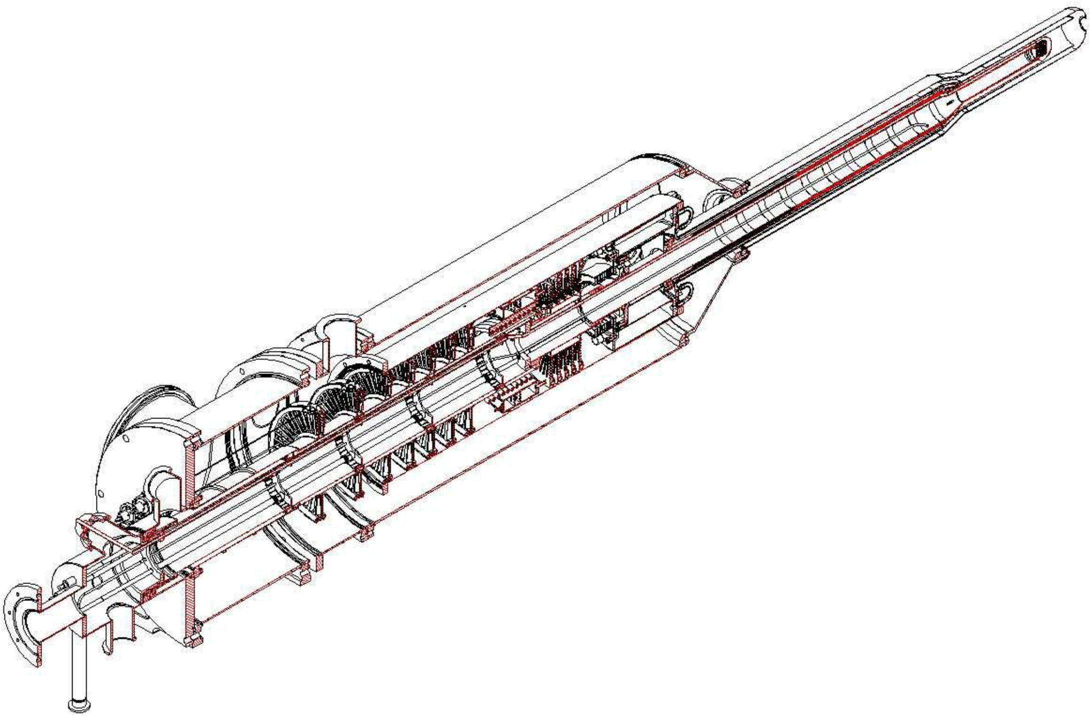

Figure 1. 3D-construction drawing of the dilution refrigerator.

The cryostat has a separator working at 3 K and an evaporator working at 1.2 K in the pre-cooling stages. These are pumped by rotary pumps with pumping speed of 60 m^3/h, 100 m^3/h and 250 m^3/h (company Busch). The beam axis is equal to the cryostat axis and the target material has to be loaded along the beam axis using a specially adapted, twofold target-insert. This target-insert needs to seal the cavity against the beam pipe vacuum. It has minimum limitations for the particle detection and fits into the central core of the inner Particle Identification Detector (PID2). This was achieved by using the Frozen-Spin technique in combination with the new concept of placing a thin superconducting holding coil on the thermal radiation protection shields of the refrigerator.

The cryostat could provide a very low operation temperature of 25mK in the target chamber. The butanol is filled into a PTFE-cylinder of 2cm length and diameter. A temperature stability of better than ±0.2mK over a time scale of a week was reached. This corresponds to very long relaxation times of the target nuclei in the order of some thousands of hours. Typically the target had to be re-polarized once a week. Longitudinal and transverse polarizations are possible.

4.1. Microwave apparatus

In the framework of a diploma thesis [4] a microwave apparatus was developed and successfully tested in the GDH experiment in 2003. Special features of this computer-controlled apparatus with a center frequency of 70 GHz are a tunability of frequency of 300MHz and a stability of better than 1 MHZ. In addition a motor driven attenuator can adopt the microwave power to the requirements of the target, see figure 2. A Labview program is used to stabilize the frequency.

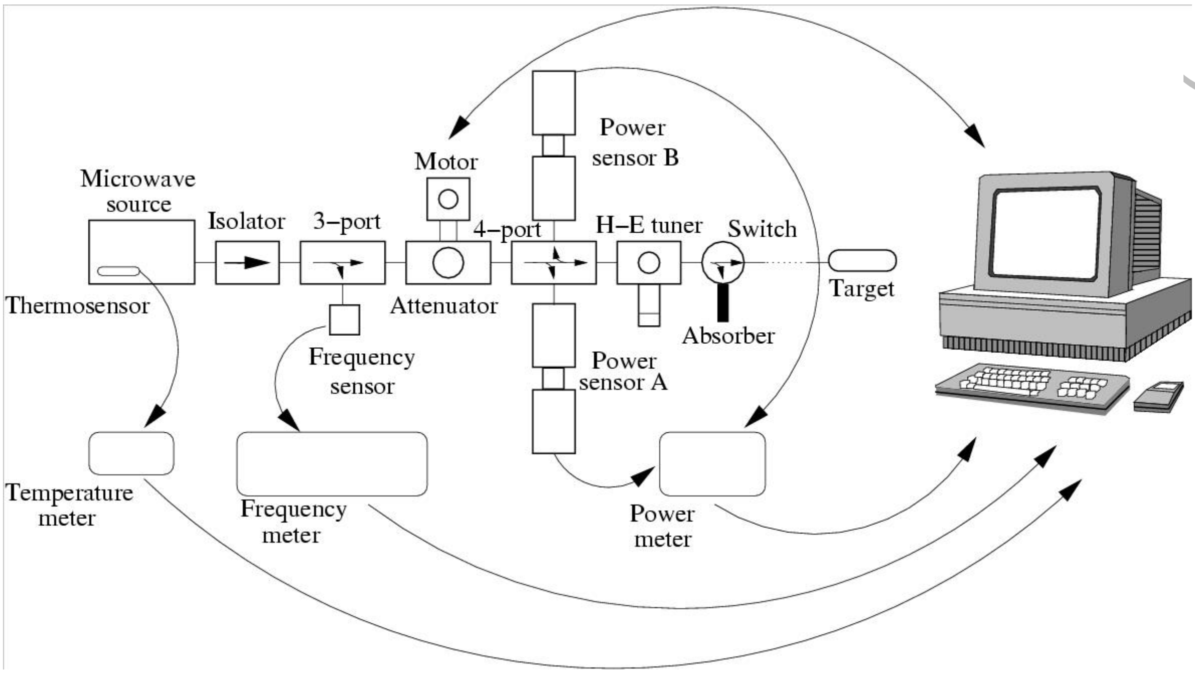

Figure 2. The Microwave system.

The cavity and microwave guide into the cryostat were optimized for minimum reflection. The 2cm long target is contained in a PTFE container. The vacuum window of the circular waveguide to the cavity was realized using a laminated Copper-Kapton foil (printed circuit), see on top of figure 3.

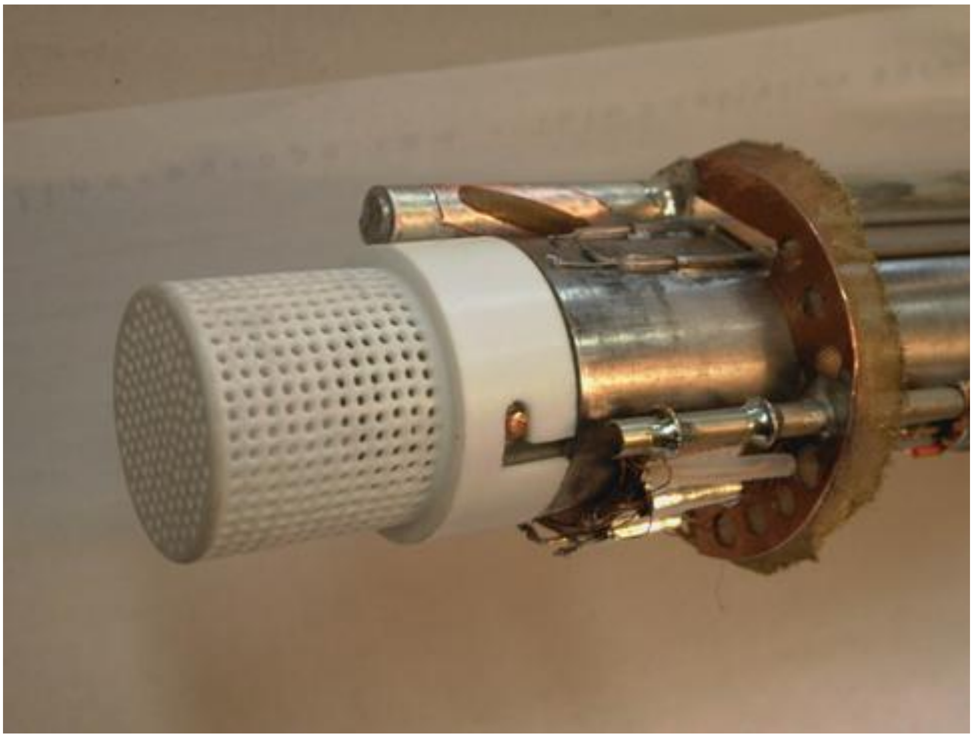

Figure 3. The cavity and the microwave guide.

Technical details: The waveguide consists of a Copper tube (l=300mm, 8×1 mm) and a vacuum window (30 μm mylar film). The cryogenic part is a Nickel silver tube (l = 1860 mm, 6×0.2 mm). The vaccum window (d=1.5 mm, l=15 mm, angle 30˚) is covered by Kapton (printed circuit). In addition an inner adjusting cylindrical piston was used with an angle of 30˚.

4.2. New Developments

4.2.1. Internal Polarizing Coil

State-of-the-art frozen spin targets at JLAB, ELSA and MAMI use a thin, superconducting coil inside the 3He/4He dilution refrigerator to hold the polarization with a relaxation time in the order of more than 1000 hours. The outgoing particles punch through this coil. After a measurement period of approximately one week the detector or the target has to be moved and the target material has to be re-polarized in a strong superconducting magnet. This leads to a loss in beam-time and overall efficiency. One should also consider secondary effects, that might introduce additional systematic errors using the ’frozen spin technique’ by performing the movement of target or detector. These could be: vibrations changing the target bead configuration, changes in the electromagnetic noise environment and non-reproducibility of the positioning. We plan to place a superconducting polarizing solenoid inside the cryostat (fig. 4).

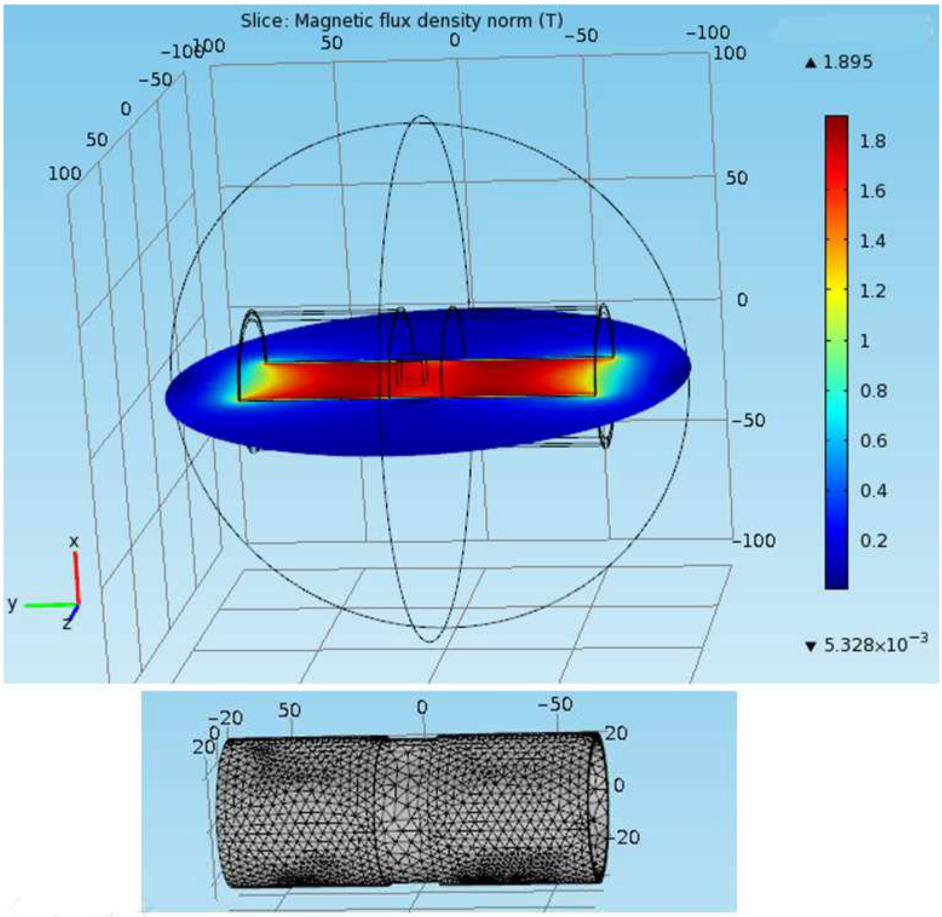

Figure 4. Calculations for a 10 layer notched solenoid.

A 10 layer notched solenoid should provide a polarizing field of 2.5 Tesla with sufficient homogeneity. Three dimensional finite element calculations were carried out. A first solenoid was produced by an industrial company and is being tested.

4.2.2. Active Polarized Target

For some experiments, it is important to keep the momentum threshold for the outgoing particles as low as possible. The standard solution is to make the materials surrounding the target as thin as possible, e.g. to use a sub-cooled superconducting wire at a temperature of 1.2 K to produce the magnetic holding field.

The best option for this requirement would be to detect the recoiling nucleon directly inside the target material itself, using a so called 'active target' [5]. We have placed a stack of 1 mm thick radical doped scintillating polystyrene plates into our target cell. The stack geometry ensures an effective cooling of the material in the liquid helium of the mixing chamber. The light is guided out of the cavity into the beam-line vacuum via optical fibers or a plexiglas-tube to silicon avalanche photo diodes, operating at temperatures of a few Kelvin.

First tests under cryogenic condition have been done to check the relaxation times and maximum polarization of the polystyrene target material provided by the University of Massachusetts, Amherst [6]. We could achieve first results for the relaxation times at 0.2 Tesla and 25mKelvin, depending on the radical spin density, see figure 5.

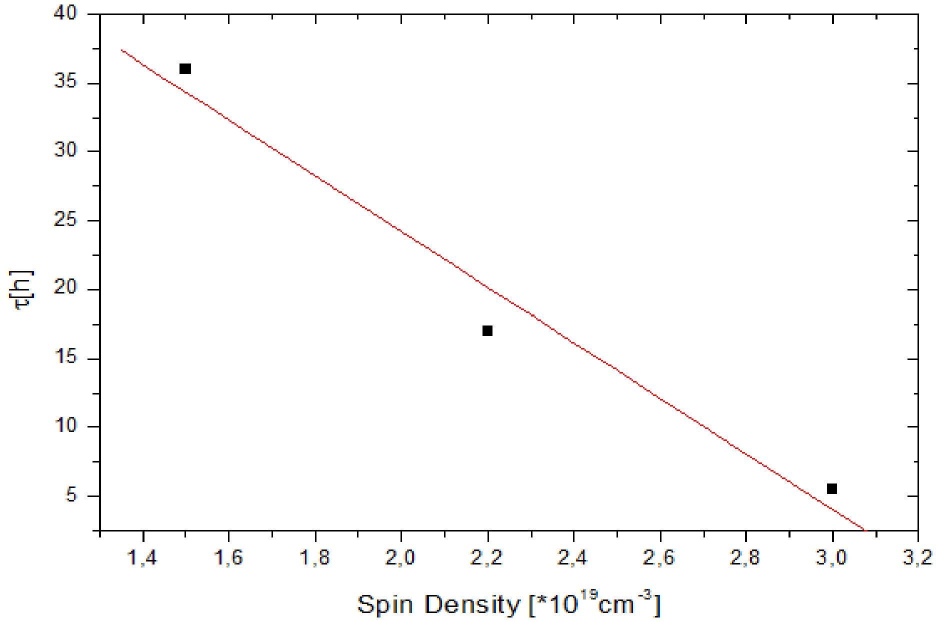

Figure 5. Relaxation times at a magnetic field of 0.2 Tesla and 25 mKelvin.

We have checked the magnetic field dependency of the relaxation times up to a field of 0.2 Tesla, see figure 6. The extrapolation to higher magnetic holding fields has to be done by using the quadratic approach (red line) proposed by [7] and a cubic fit (blue line), showing promising perspectives for future developments.

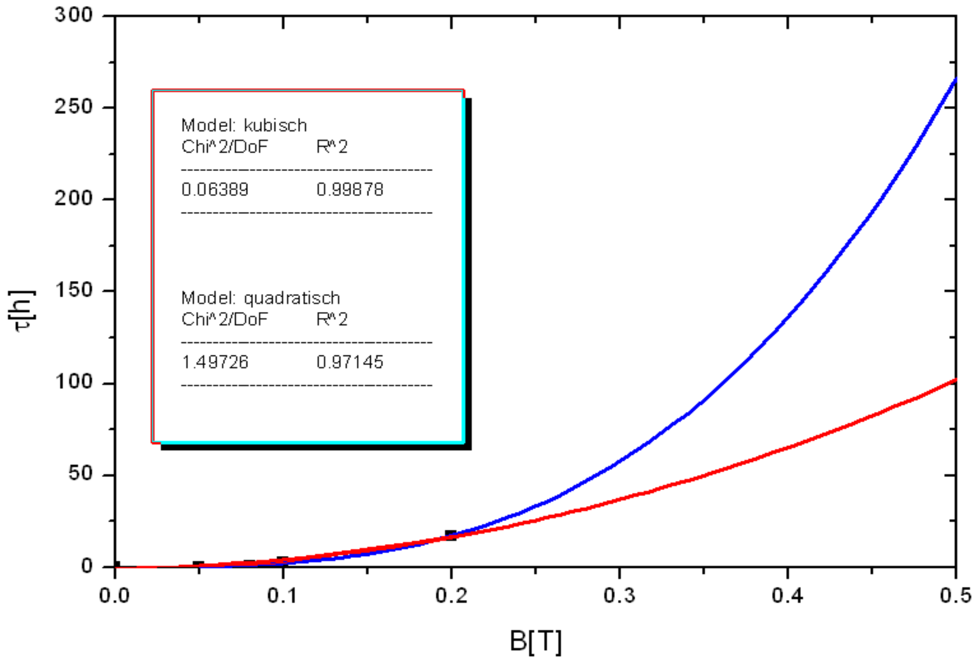

Figure 6. Extrapolation of the relaxation times of active polarized polystyrene materials at a temperature of 25 mKelvin.

A maximum degree of polarization in the order of 70% could be reached. Further investigation will have to be done under realistic condition, especially with respect to the combination with the new internal superconducting coils.

5. Conclusion and outlook

Polarized solid targets are an essential tool to investigate spin observable in several field of fundamental research. The Mainz Solid Polarized Target at MAMI is pushing the frozen spin technology to its limits. Further developments of thin superconducting magnets to provide a continuous polarization in the 'DNP'-mode are on the way. Another promising technology investigation is going in the direction of 'Active Polarized Targets' to use the target as an intrinsic part of the detector. This will hopefully allow an investigation of 'up to now' unmeasured kinematic regions.

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