Printed ISSN 1330–0016
Online ISSN 1333–9133
CD ISSN 1333–8390
CODEN FIZBE7

THE FROZEN SPIN TARGET AT MAMI

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Received 31 January 2011; Accepted 14 December 2011
Online 10 February 2012

The A2-collaboration at the Mainz Microtron MAMI measures photon absorption cross sections using circularly and linearly polarized photons up to an energy of 1.5 GeV. The photons are produced in the 'Bremsstrahlung' process. 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. In 2010, the experimental apparatus was completed by the installation of a polarized target. The horizontal dilution refrigerator of the Frozen Spin Target was constructed by and is operated in close cooperation with the Joint Institute for Nuclear Research in Dubna, Russia. The system offers both longitudinally and transversely polarised protons and deuterons.

PACS numbers: 29.25.Pj, 29.40.-n UDC 539.1.074, 539.171

Keywords: Mainz Microtron, Crystal Ball detector, polarized target, longitudinally and transversely polarised protons and deuterons

1. Introduction: the Crystal Ball detector setup

In the physics program for the MAMI C accelerator [1], the investigation of the spin-dependent excitation spectrum of the nucleon and fundamental properties, such as its spin polarizabilities, are an important goal. This will be tackled in the framework of the A2-collaboration by doing double-polarization experiments, using the linearly or circularly polarized marked photon beams in combination with a new solid-state polarized target. The main detector system will be the Crystal Ball, consisting of 672 NaI crystals, in combination with the TAPS detector for the forward angles, leading to an angular acceptance close to 4π. More details on the ongoing physics program are presented in Ref. [2].

The central detector system is completed by a barrel of scintillation counters for particle identification and two coaxial multiwire 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 (θ) and over almost the full azimuthal (ϕ) range. At forward angles, less than 21°, reaction products are detected in the TAPS forward wall. The full, almost hermetic, detector system is shown schematically in Fig. 1. The new frozen spin target was designed to retain the high angular acceptance of the detector system. The innermost dimension of the particle identification detector with a diameter of 104mm limits the outer diameter of the frozen spin target cryostat. The internal holding coils had to be as thin as possible to allow secondary particles to punch through. The main concept of this target is similar to that of the Bonn frozen spin target [3], which was used in 1998 and 2003 for the measurement of the GDH sum rule on the proton and neutron in Mainz [4], since the DAPHNE [5] detector had very similar inner geometry.

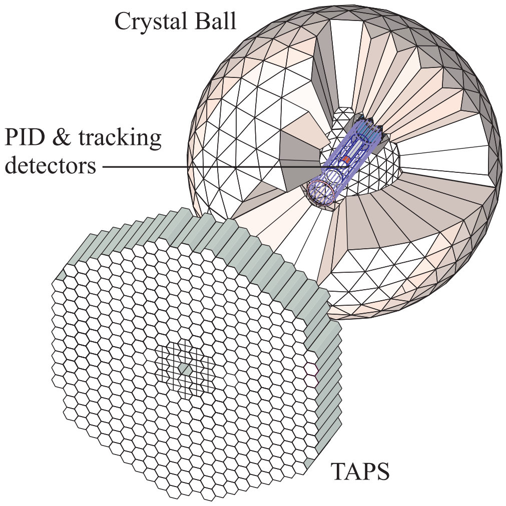

Fig. 1. The A2 detector setup: The Crystal Ball calorimeter, with cut-away section showing the inner detectors, and the TAPS forward wall.

2. *The frozen-spin target for Crystal Ball*

The operation of a solid-state polarized target requires various, technically complex subsystems, sketched in Fig. 2.

The knowledge of different polarized target groups around the world based on a more than 40 years history in developing polarized solid targets was used for realising the complex apparatus.

2.1. *The* ^{3}He/^{4}He *dilution refrigerator*

The core of the frozen spin target for the Crystal Ball detector is a specially designed, large horizontal ^{3}He/^{4}He dilution refrigerator that was built in cooperation

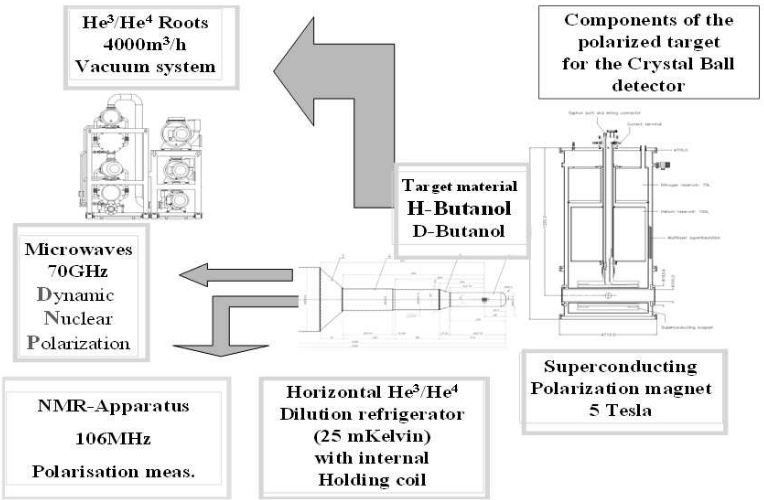

Fig. 2. Components of the polarized target for the Crystal Ball Detector.

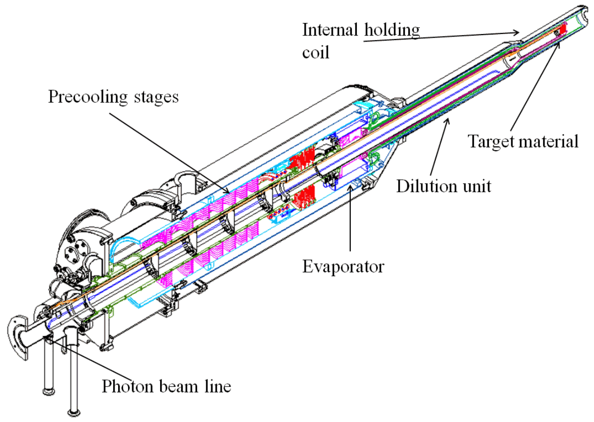

Fig. 3. 3D cut of the new dilution refrigerator.

with the Joint Institute for Nuclear Research (JINR) Dubna (see Figs 3 and 4).

The cryostat has a separator working at 3 K and an evaporator working at 1.2 K in the precooling 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 aligned with the cryostat axis and the target material has to be loaded along the beam axis using a specially adopted, twofold target insert. This target insert needs to seal the cavity against the beam pipe vacuum. It is designed to retain the geometrical acceptance and to fit into the central core of the inner particle identification detector (PID2). This was achieved by using the frozen spin technique with the new concept of placing a thin superconducting holding coil inside the polarisation refrigerator.

Fig. 4. The new dilution refrigerator for the Crystal Ball Frozen Spin Target.

Fig. 5. The transverse holding coil.

Longitudinal and transverse polarisations are possible. For this a solenoid or a 4-layer saddle coil has to be installed. In Fig. 5, the internal superconducting holding coils for transverse field operating at 1.2 K can be seen. The transverse coil has been in operation for more than 2000 hours in the year 2010 at a current of 35 A, producing the field of 0.45 Tesla. The current leads are optimized for low thermal input: As the first step we place into the cryostat a thick, normally conducting copperwire to cool to a temperature of 70 K. In the next step the high-temperature superconducting band is used. The helium consumption for stable operation of the complete cryostat (target material at 25 mK and holding coil at 0.45 T) was below 2 liters per hour, showing a very economic design of all heat exchangers.

2.2. The polarizing magnet

The polarizing magnet was bought from the company Cryo-Technics. The solenoid coils are cooled in a liquid He bath at 4 K. The outer thermal radiation shield is cooled by liquid nitrogen to minimize the helium consumption. The field axis is coincident with the beam axis, the maximum strength of the field is 5 T, and the uniformity was better than $\Delta B/B \leq 10^{-4}$ over the target volume of 6 cm^3. The warm bore of this magnet is 100 mm in diameter to allow the entrance of the target refrigerator.

2.3. The Roots pumping unit

The Roots blowers, with maximum pumping speed of 4000 m^3/h, were especially designed by the German company Pfeiffer to provide a very low leak rate ($\leq 10^{-5}$ (mBar·l)/s), which is very important to pump the expensive ^{3}He gas of the dilution refrigerator. The pumping system consists of a series of pumps as follows: 4000 m^3/h, 2000 m^3/h, 1000 m^3/h, 500 m^3/h and 250 m^3/h with two motors. Water-cooled heat exchangers are added to dissipate the heat of the compressed helium gas. The tuning of the different pumping stages was done in such a way, that it is possible to avoid an additional oil-sealed rotary pump in the main pumping circuit. This provides a long cryostat operation time and avoids blockage by dirt in the restrictions of the cold part of the ^{3}He circuit.

Two liquid nitrogen cooling traps are operated in parallel in the exit line of the roots blowers to trap gases from residual leaks. In the year 2010 the system was operated for more than 2500 hours without problem.

2.4. The microwave system

In the framework of a diploma thesis [6], a microwave apparatus (see Fig. 6) was developed and successfully tested in the GDH experiment in 2003. Special features

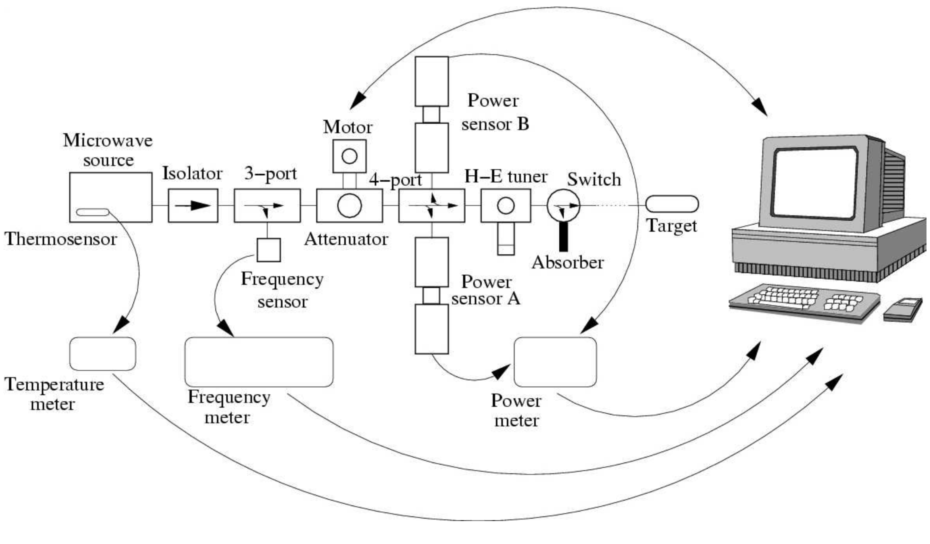

Fig. 6. The 70 GHz *microwave system.*

of this computer-controlled apparatus, with a central frequency of 70 GHz, are a tunability of frequency of 300 MHz 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 Fig. 6.

2.5. The NMR system

The NMR System is a serial resonance circuit with a coil within or around the target material. We have used tempo doped butanol and trityl doped deuterated butanol target substrates, provided by the Bochum polarised target group [7].

Figure 7 shows the Teflon target container with the integrated NMR coil. The arrows show the soldering points from the coil to the coaxial cable leading outside the cryostat.

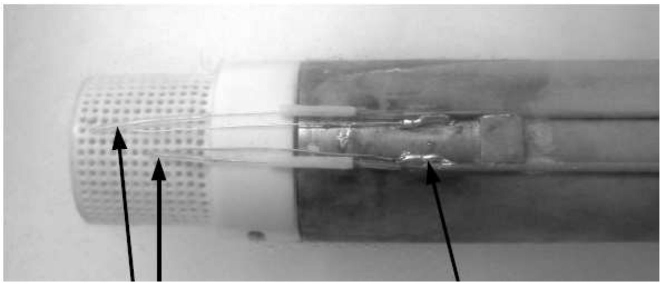

Fig. 7. Target container with NMR coil. The arrows indicate the solder joints of he NMR coils.

The coil is connected to the capacitor via a transition cable. A change in the polarization value induces a change in the magnetic susceptibility of the coil. This causes a variation of the Q factor of the circuit, which can be measured as an increase or a decrease of the voltage. This voltage is conditioned with RF- and LF-amplifiers. The signal is obtained by a frequency scan (sweep) over the resonance (Larmor) frequency. A PC with a Windows OS, running a LABVIEW control program, detects the adapted signal. In order to increase the signal to noise ratio, many signals are accumulated (the noise reduces by the square root of the number of sweeps). Since the commonly used Liverpool boxes are no longer commercially available, we have set up a new system consisting of individual high frequency components, see Fig. 8 [8]. Typical signals achieved with the new system for the protons and the 'Liverpool box' for the deuterons are shown in Fig. 9

3. Conclusion and outlook

The new Mainz frozen spin target has been in operation for more than 2000 beam hours in combination with the Crystal Ball detector system in the A2 Tagger hall in 2010 with transverse polarisation. We have achived polarisations of up to

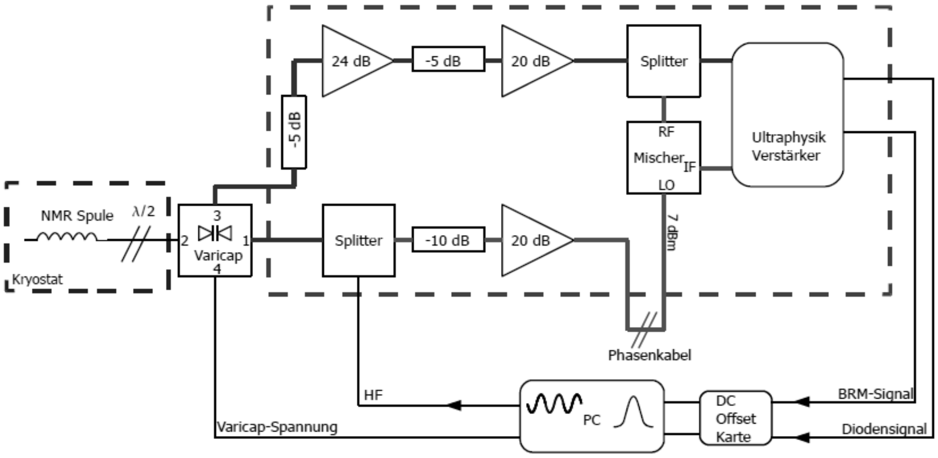

Fig. 8. The NMR apparatus.

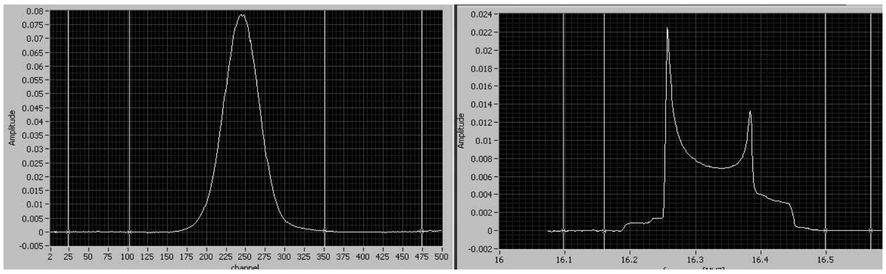

Fig. 9. Typical NMR signals at a proton polarization of 75% (left side) and a deuteron polarization of 53% (right side).

85% for protons and 55% for deuterons. The relaxation times were longer than 1000 hours at a magnetic field of 0.45 Tesla and 25 mK, allowing for continuous data taking periods of one week.

In 2011, we plan to exchange the saddle coil, which provides transverse polarization, by a solenoid to allow longitudinal polarization.

4. Acknowledgment

The author wishes to acknowledge the excellent support of the accelerator group and operators of MAMI. This work was supported by the Deutsche Forschungsgemeinschaft (SFB 443), DFG-RFBR (Grant No. 09-02-91330), the European Community-Research Infrastructure Activity under the FP6 "Structuring the European Research Area" programme (Hadron Physics, contract number RII3-CT-2004-506078).

References

[1] A. Jankowiak, Eur. Phys. J. A **28** Suppl. 1 (2006) 149.

[2] M. Ostrick, Fizika B **20** (2011) 179 (this volume).

[3] C. Bradtke et al., Nucl. Instr. Methods A **436** (1999) 430.

[4] A. Thomas et al.: Eur. Phys. J. A **28** (2006) 161.

[5] G. Audit et al.: Nucl. Instr. Meth. A **301** (1991) 473.

[6] M. Martinez: *Setup and test of a 70 GHz microwave apparatus for a polarized target*, Internal report, Mainz (2003).

[7] J.Heckmann et al., Appl. Magn. Reson. **34** (2008) 461.

[8] N. Frömmgen: *Aufbau und Test einer NMR-Apparatur zur Messung des Polarisationgrades hyperpolarisierter Targetnukleonen*, Internal report, Mainz (2009).

META ZAMRZNUTIH SPINOVA U MAMI

Suradnja A2 pri mikrotronu MAMI u Mainzu mjeri udarne presjeke za apsorpciju fotona rabeći cirkularno i linearno polarizirane fotone energije do 1.5 GeV. Fotoni se proizvode kočnim zračenjem elektrona. Tijekom 2005/2006 postavljen je u Mainzu Crystal Ball detektor sa svojim jedinstvenim mogućnostima za opažanje konačnih stanja s mnogo fotona. Mjerni uređaj je upotpunjen tijekom 2010 postavljanjem polarizirane mete. Taj 'Frozen Spin Target' rabi vodoravan hladnjak na razrjeđivanje koji je sagrađen i njime se upravlja u bliskoj suradnji sa Saveznim institutom za nuklearna istraživanja u Dubni, Rusija. Sustav daje uzdužno i poprečno polarizirane protone i deuterone.