INFN – Istituto Nazionale di Fisica Nucleare
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THE TARGET STICK OF THE POLARISED PROTON AND DEUTERON TARGET OF CLAS

M. Anghinolfi, P. Cocconi, R. DeVita, C. Pizzorno, F. Parodi, A. Rottura

INFN–Sezione di Genova, Via Dodecaneso 33, I–16146 Genova–Italy

Abstract

The description of the target stick for the polarised target of CLAS is presented. The choice of the materials, the position of the temperature sensors, the shape of the NMR coils are discussed while the results of quality checks performed before the assembling of the system are presented; these results indicate that the stick design matches the required performances.

1. – INTRODUCTION

Within the collaboration between the National Institute for Nuclear Physics (INFN) of Genova, the University of Virginia and TJNAF, a target to polarise protons and deuterons has been designed to be used in CLAS, the 4p detector in Hall B. The system includes a super conducting magnet to produce an highly uniform 5 T magnetic field and a 1K liquid helium (LHe) refrigerator to polarise via DNP[1] hydrogenated (NH3) or deuterated (ND3) samples. The Italian part of the collaboration contributes both to the fridge and to the target stick including the containers of the material and sensors.

Concerning the fridge, the principles and the technique are relatively well known and OXFORD Industries was charged to make it together with the super conducting magnet and cryostat.

The realisation of the stick, on the contrary, required a dedicated study including the design of the support for the containers of the material, the optimisation of the NMR read out and the choice and position of the various sensors.

In this paper a detailed description of the target stick is given and the result of some preliminary laboratory tests are also reported.

2. – GENERAL DESCRIPTION

To start with, in fig 1 a very general view of the system is presented including the two split coils super conducting magnet, the electron beam line along the horizontal axes, the vertical target access where the stick is located and maintained in the cold LHe bath, the large exit window (±55°) and the refrigerator positioned at 30° with respect to the beam line to fit the clearance of CLAS.

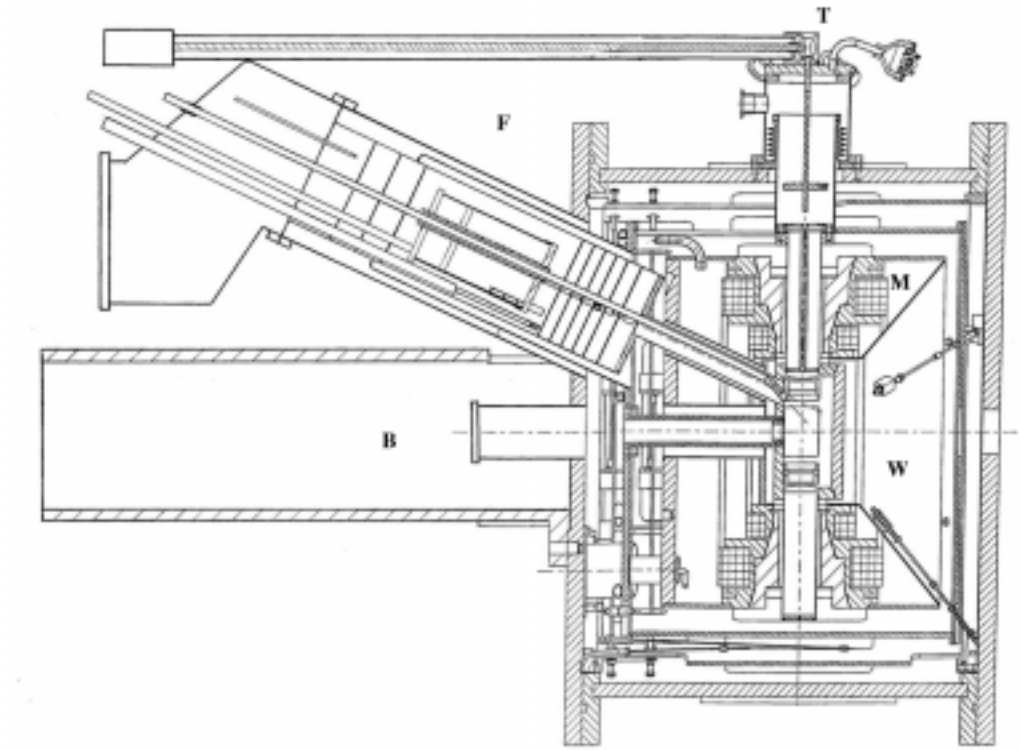


FIG. 1: The polarised target system for Hall B at TJNAF. B is the electron beam line, F the helium refrigerator, M the super conducting magnet, W the exit window and T the target access.

The target stick, shown in fig. 2 a) and b), holds four cylindrical containers: two for the polarizable material (NH3 and ND3), one for the ‘nuclear’ background (a disk of pure graphite) and an empty one for centring the electron beam.

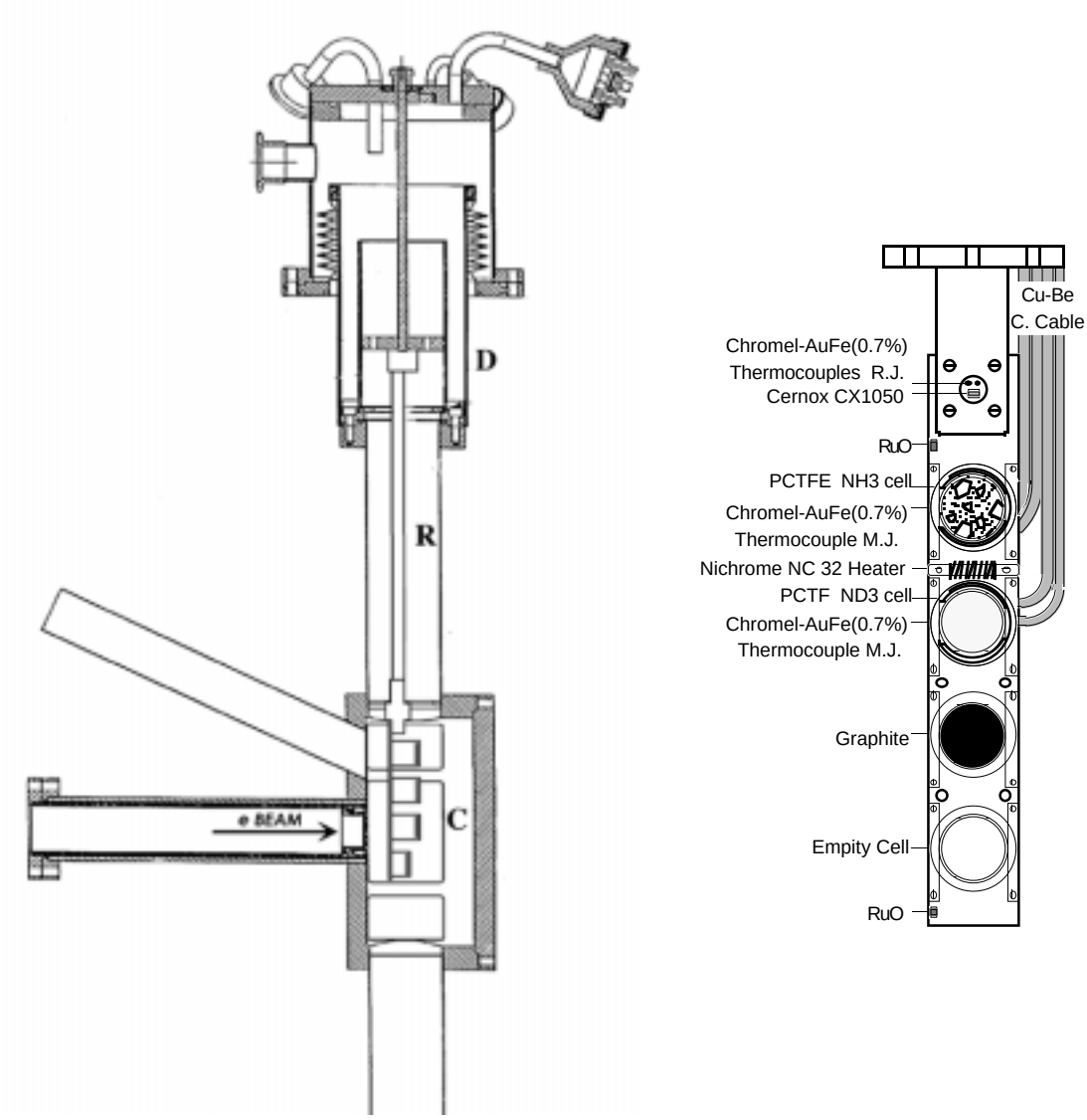
Each container (fig. 2b), 15 mm Δ and 10 mm length, was obtained from a 20 mm Δ PCTFE rod. PCTFE was selected because of:

a) easy machining

b) good mechanical resistance at LHe temperatures

c) low radiation damage

d) no presence of hydrogen



(a) **(b)**

FIG. 2: a) the detail of the target access where the stick is located. The stick includes the four material containers(C), the steel bar R, the brass disk D which fits into the threaded rod to allow the vertical movement. b) the support of the containers with the temperature sensors and the annealing system

In particular conditions c) and d) provide both a good resistance over time (order of months) in presence of intense electron beam and the absence of any external contamination to the proton signal in the NH3 target.

The thickness of the containers was largely reduced to minimise the energy loss of the scattered particles: 0.3 mm for the lateral PCTFE cylinder, .011 mm for the fixed aluminium entrance window and .05 mm for the exit Kapton window.

The Kapton window is removable to fill the containers with the target material.

The shape of the thin kapton foil is reported in fig.3: this particular design minimises the amount of material crossed by the scattered particles and allows the insertion of the foil within the two slots carved in the PCTFE container by the simple use of pliers (see also fig. 4). This operation, though manually performed under liquid nitrogen, is not particularly difficult.

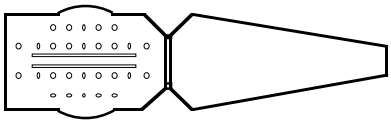


FIG. 3: the thin Kapton window design. The small holes allow the liquid helium to merge the target material while the circular shape fits into the slots of the container

To reduce the contribution of the background from hydrogenated material outside the NH3 target and possible distortions to the highly uniform magnetic field (1 part in 10^4) due to the presence of magnetic or paramagnetic materials, the containers have been fixed to the aluminium frame using small copper bars and screws: glues or similar products could in fact contain hydrogen and make not reversible the substitution of the container.

The aluminium frame is connected to a brass disk in thermal contact to the magnet shield (T=50–100K) through a 40 cm long bar made in stainless steel 316 L to strength the entire structure (see fig. 2a). The disk can move up and down through a threaded rod: the containers can be therefore alternatively located into the electron beam via an external stepping motor remotely controlled by an OXFORD SMC 4 unit.

3. – THE SENSORS

Different exclusive scattering experiments are planned to run with this system. To allow the detection of the scattered particles in the final state, the clearance close to the containers was optimised by the special design of the mechanical support and a proper choice of the various sensors which are needed both in the stick and in the target access region. Different parameters must be monitored during the experiments:

– the temperature and the level of the He bath

– the value of the polarisation of the protons, deuterons as well as the N15 nuclei
– the temperature of the target during the process of annealing where the material is heated to 80 K to restore the polarisation after beam irradiation.

Both the level and the temperature of the bath are monitored in the target access using respectively a standard level meter (40 cm. sensitive length) connected to an OXFORD ILM 220 unit and a precision manometer to determine the temperature from the vapour pressure. However, to provide an alternative in case of a possible malfunctioning of the level probe, simple sensors were located in the stick which give a similar information. Two RuO chips (fig 2b) represented the proper choice: their resistance, in fact, strongly increases at low temperatures and a measurement of the temperature within 0.05 K can be obtained in the 1K region using an high precision resistance bridge (OXFORD AVS 47). In these conditions the presence of the liquid bath in the target region can be deduced from the value of the temperature (below 4.2 K) and its fluctuations (within 0.1 K).

Though the target will operate with a low intensity electron beam (1 nA), a reduction of the polarisation due to radiation damage is expected[2] and a system for the annealing has been therefore implemented in the stick (fig 2b). In this process the temperature of the material inside the container (NH3,ND3) must be carefully monitored in order to prevent excessive heating (T>100 K) with possible recombination of the paramagnetic centres. The annealing system includes two Chromel–Au Fe (.07%) thermocouples located in the inner part of the container to detect the temperature. The thermocouples were selected due to their limited sensitivity to the magnet field and to their small dimension (@150 mm): the electron beam, during the experiment, is in fact rastered through almost the whole diameter of the container and any interaction with materials different than NH3 or ND3 should be avoided. Each thermocouple has two junctions: one located close to the material and one on the top of the target holder (see fig 2b) to be used as a reference. Here the absolute value of the temperature is measured by a calibrated Cernox 1050: the temperature in the container is then determined from the voltage difference at the two junctions (25 mVolts/K). To provide the heating for the annealing process a 50 Ohms Nichrome NC 32 wire resistance is located between the two containers; the heater is PID controlled via an OXFORD ITC 503 unit.

The measurement of the material polarisation is performed via the standard NMR technique. In our case, however, the limited target dimension and the necessity to locate the sensing coils outside the container gave severe constraints and an extensive study was performed to optimise the geometry of the NMR inductance as described in ref.[3]. The final deduced configuration for the proton consists of a single rectangular loop while for the deuteron or N15, due to the small detectable signal, two double–turns coils are required as shown in fig 4.

FIG. 4: The shape of the NMR coils for the NH3 target and ND3 target

In each container a proton and a deuteron NMR sensing coils are located: for the NH3 target, in fact, the proton and the N15 polarisation signals must be measured while for ND3 both the few % proton contamination and the deuteron polarisation value must be determined. The proton and the deuteron coils are placed on the external surface of the containers: to prevent electrical contact between them, the wires (a .5mm Cu/Ni capillary tube) have been insulated using a thin layer of FEP directly sprayed on their surface. To drive the NMR signal to the Q–meter, each inductance is welded to a cryogenic coaxial line: a Cu/Be cable (JT 50085) 40 cm. long up to the copper disk, a 20 cm long semi flexible SHUNER SM 86 to the top of the target access to allow the target movement, a 150 cm or more Cu/Be cable with fluffy FEP as insulator from the top flange of the target access to the Q–meter. Here the fluffy insulator minimises the effect of the thermal fluctuations.

4. - RESULTS FROM THE TESTS

Two target sticks have been machined and mounted in the machine shop of the Genova INFN Institute and quality checks have been accomplished to control the expected performances before installation on the complete system in CLAS.

To this purpose the experimental apparatus described in ref.[4] was used: with this apparatus we were able to thermally and dynamically polarise samples of hydrogenated and deuterated materials, to measure the absolute polarisation and to change the temperature of the samples from 1.25 to 4.2 K.

We have addressed our tests to verify:

– the sensitivity on the measurement of the TE proton polarisation in NH3
– the sensitivity on the measurement of the TE deuteron polarisation in ND3
– the contribution to the TE peak on the proton of the material surrounding the container including the Kapton window and the insulator on the NMR coils.
– the absolute value of the polarisation enhanced via DNP.

The calibration and measurement of the polarisation was done with the standard Q–meter technique. In fig 5 the TE signal of the proton in NH3 measured at 1.5 K is shown. Here a

LabView program is used to generate a triangle wave form to fed a frequency synthesiser connected to the Q–meter input and the corresponding Q–curve is digitised into 500 steps. The measurement is repeated 1000 times, averaged and finally base–line subtracted: though the amount of material is limited (1.5 gr. of NH3) and the proton NMR coil small, 1000 sweeps are sufficient to give the area of TE peak within 2% statistical error.

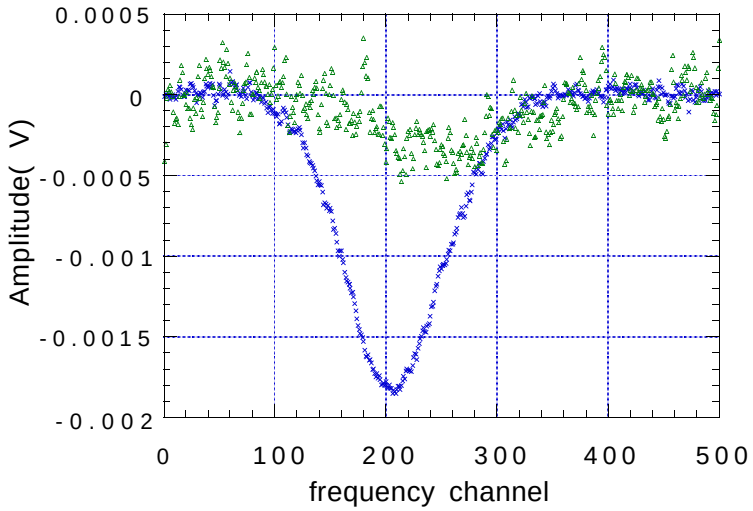


FIG. 5: The NMR TE peak in ammonia at 1.5 K (crosses) compared to the empty target measurement (open triangles). The amplitude of he signal in ammonia was divided by 10 to allow direct comparison. The small proton contamination (2%) in the empty target is essentially due to the Kapton window.

The detection of the TE peak of the deuteron required a more accurate measurement. Given the same circuit configuration, the area of this signal is, in fact, at least 50 times smaller with respect to the proton one. The performances of the coil configuration already discussed was tested on a deuterated buthanol sample to check whether the signal was detectable with acceptable uncertainly (better than 5%) within a reasonable time. Fig 6 shows the TE deuteron signal after the baseline subtraction in a 50000 sweeps measurement: a reproducibility of the peak inside 4.5 % standard deviation was obtained in these conditions as required during real data taking.

Once the measurement of the TE peak in deuteron and proton was proved to be consistent with the experimental requirements, we focused on the contribution of the residual proton background to the TE peak. This contribution, in fact, strongly depends not only on the quantity but also on the position of possible hydrogenated material with respect to the NMR coils: the lower the distance the higher the signal. The measurement was easily performed comparing the TE peak of the full to empty target: the result is shown in fig 5 where the contribution of the background (mainly from the thin Kapton window) is shown to be below 2%.

DNP was finally performed using a CPI EIO VKT 2438 tube to generate microwaves in the 140 GHz frequency region, a wave guide line to drive the power down to the material and a horn to irradiate the sample. Power was tuned from 600mW down to 100 mW at the target region and a maximum value of 60% polarisation at 1.4 K was found for NH3 independently from the power value. This results demonstrates that, due to the limited quantity of polarizable material, the amount of MW power to perform DNP is sufficient also for the system mounted in CLAS where a relatively long wave guide line is expected.

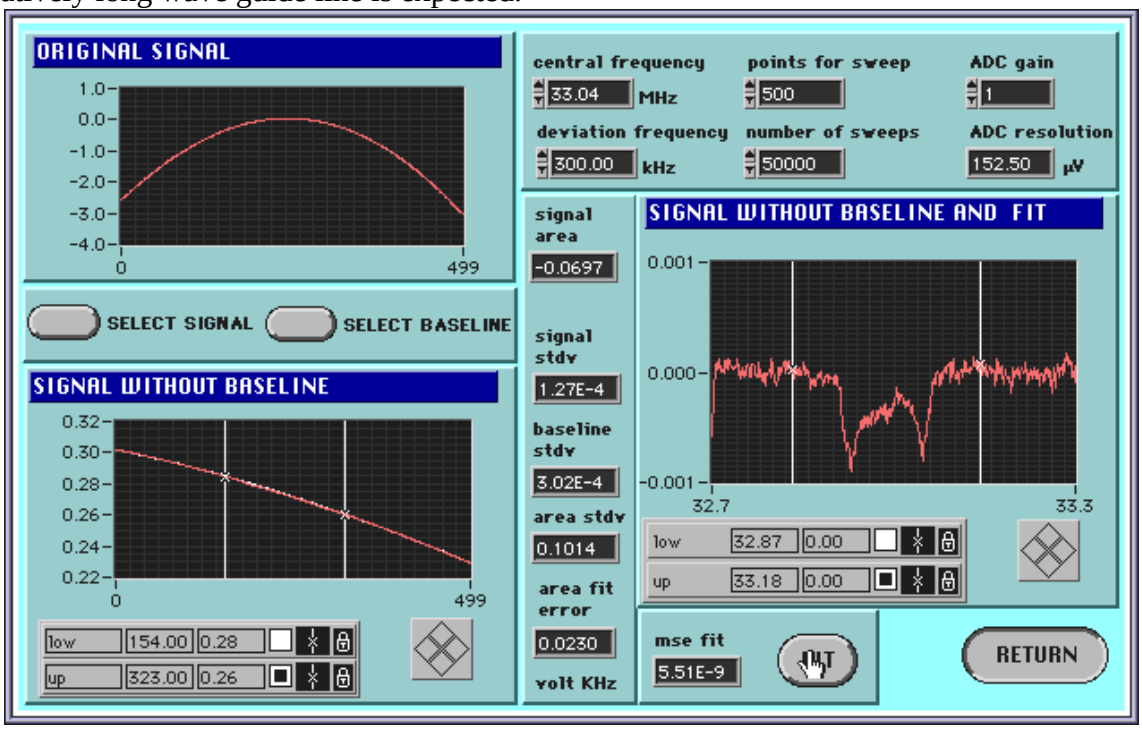


FIG 6: The TE peak on deuterated butanol (right) after a 50000 sweeps average. The signal was obtained after baseline subtraction and fitting (right)

5. – CONCLUSIONS

The Nuclear Physics Institute of Genova has provided the target stick for the polarised target to be locate in CLAS, the 4p detector in Hall B at TJNAF. The expected performances have been tested using a simplified experimental apparatus sufficient to reproduce the same temperature and B–field conditions in the target region. These tests demonstrated that the design of the stick was correct as well as the choice of the different material and sensors. To compensate for the small amount of polarizable material, the sensitivity to the absolute value of the polarisation was optimised using a special design of the NMR sense wires which fits both the geometrical constraints and the required accuracy. The test we performed confirmed that the configuration we have developed can be successfully used in the polarised target in Hall B at TJNAF.

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