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Polarized target at COMPASS

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The transversely polarized solid proton target was used in 2015 and 2018 for the polarized Drell-Yan experiment at the first in the world with a 10^8 /s intensity of 190 GeV pion beam at COMPASS. Because of the radiation damage, the deterioration of the proton relaxation time of NH_3 was observed over more than 6 months data taking period. The radiation also affected the cryogenics control system in 2015. The radiation shield was improved and any incidents on the radiation was not observed in 2018. The transversely polarized deuteron target will be applied in 2021 with a muon beam of 160 GeV for Transversity and Sivers parton distribution functions measurements. A cooling test of the polarized target system will be performed in 2020.

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1. Introduction

The COMPASS experiment (NA58) at CERN has been researching the nucleon structure with a polarized solid nucleon target system and various secondly beams. The COMPASS polarized target is an essential equipment for the polarized Drell-Yan and SIDIS (Semi-Inclusive Deep-Inelastic Scattering) program. The Drell-Yan program with a polarized proton target was done in 2015 and 2018. We are going to use a transversely polarized deuteron target for SIDIS program in 2021.

2. The polarized Drell-Yan program in 2015 and 2018

In 2018 we performed the polarized Drell-Yan program to measure Transvers-Momentum-Dependent (TMD) Parton-Distribution-Functions(PDFs) as well as in the 2015 run which was the first ever polarized Drell-Yan experiment with fixed target [1, 2]. To study the Drell-Yan reaction with 190 GeV/c pion beam and transversely polarized proton target is essential for our understanding of universality of the parton distribution function like Sivers function comparing to SIDIS case [3].

3. Polarized target for the polarized Drell-Yan

The CERN SPS M2 beam line stopped on Wednesday regularly due to Machine Development (MD) for 8 hours or more. The target polarization was built up during the MD in the same polarization direction or in opposite direction. We changed the polarization direction every two weeks to cancel geometrical difference between upstream and downstream cell. Once the polarization was enhanced with DNP technique at 2.5 T solenoid magnet in longitudinal direction, the polarization direction was rotated to transverse direction by using the solenoid magnet and 0.6 T dipole magnet (field rotation). Ammonia NH_3 was used as the proton target material. The ammonia granules were produced in 2011 in Bochum and irradiated with 20 MeV electrons at the LINAC of ELSA in Bonn [4]. When we changed the polarization directions we polarized for more than 24 hours. The polarizations in 26 hours were about +77 % and -79 %

We observed a polarization loss of 1 % during the field rotation in 2015 [5]. This effect can be explained by collective spontaneous spin transition, so-called supperradiance, at low magnetic field. The effect can be suppressed by non-homogeneity magnetic field during the field rotation. We modified the procedure of the field rotation to make a non-homogeneity magnetic field with 16 trim coils for the solenoid during the field rotation so that the polarization loss of 0.1 % during the operation was observed in 2018.

The relaxation time can be interpolated with two polarizations measured at 2.5 T before and after the transverse mode. The average relaxation time during the data taking period as a function of doses/cm^2 is shown in Figure 1. The unit of the relaxation time is hour. The radiation damage is considerable issue in the high intensity pion beam condition. The effect of the radiation damage on the reachable maximum proton polarization of NH_3 appeared from 10^{15} doses/cm^2 with electron beam [6]. However the doses in 2018 was below 10^{15} doses/cm^2, we could observe a deterioration of the proton polarization relaxation time. We monitored accumulated the number of the incoming

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beam particles. We simulated that the number of the secondly particles produced by scattering the beam particle with the target material, that is about five particles per one beam particle of the pion. The accumulated doses includes the factor of the five. And then the accumulated doses in 2018 was about 0.7×10^{14} /cm^2.

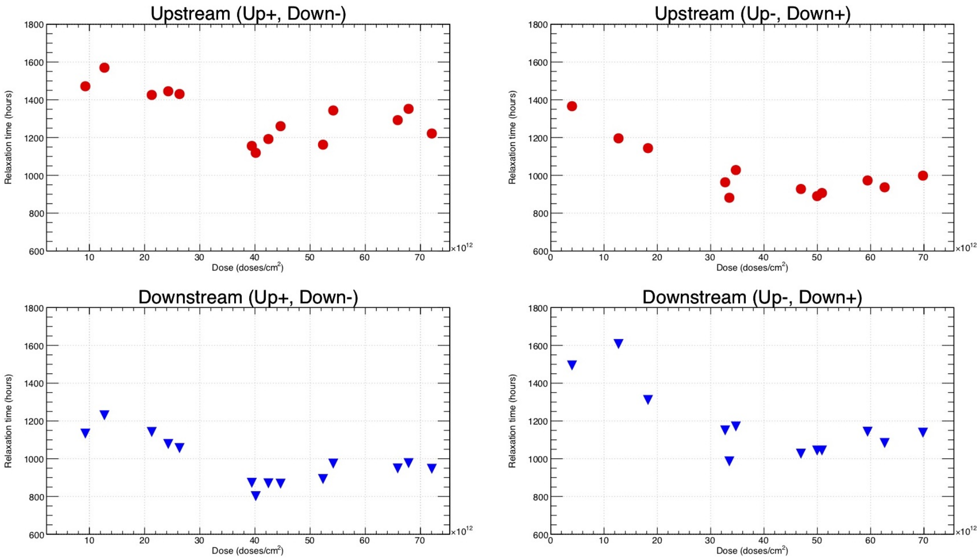

Figure 1: Proton relaxation time [h] as a function of doses/cm^2. Upper left : Positive polarization in upstream. Upper right : Negative polarization in upstream. Lower left : Negative polarization in downstream. Lower right : Positive polarization in downstream.

We also measured the relaxation time at 0 T followed as below.

1. Measured polarization at 2.5 T
2. Decreased the magnetic field to 0 T
3. Waited for 5 minutes
4. Increased the magnetic field to 2.5 T
5. Repeated from 1.

We obtained several data points and measured the relaxation times of 11 minutes for positive polarization and 7.5 minutes for negative polarization.

The cryogenics operation of the magnet and the diffusion pump operation for the isolation vacuum control systems were failed for several times in 2015 due to high radiation (neutron) level, even they were installed outside shielded experimental area, where is about 10 μSv/h condition. We protected those CPUs which were surrounded by a concrete of 60 cm thickness on the top and 30 cm side wall, a polyethylene of 2 cm thickness and a boron-carbid sheet (Figure 2). The concrete, which is outer layer, is for high energy neutrons, the polyethylene for lower energy and the boron-carbid installed in the inner place for thermal neutron. The CPU for helium liquefier control system was also protected with those materials in 2018. The shields made the systems running without any interruptions by the radiation during the 2018 run.

Figure 2: Protection of PLC CPU for the magnet system. Right side : The CPU is installed in the polyethylene box which is covered by the concrete blocks. The front concrete block, which is not shown in this picture, is movable to access the CPU easy. Left side : The top cover of the polyethylene box with the boron-carbid sheet.

4. SIDIS off transversely polarized deuteron program in 2021

TMD PDFs and Transversity are flavour dependent, so that both proton and deuteron transversely polarized targets data are important to provide constraints on the d-quark contribution. In 2007 and 2010 we had measured them with the proton target [7, 8]. In 2021 we will use transversely polarized deuteron target and the 160 GeV muon beam to measure SIDIS for Transversity and Sivers PDFs extraction.

5. Polarized target for SIDIS

^{6}LiD is considered as the deuteron target material because of our experience [10] and its higher figure of merit PT_{FoM} shown in Table 1. PT_{FoM} is described as $PT_{FoM} = f^2\ P_T^2 \rho\ F_f$, where P_T is the polarization, ρ is the target material density, f is the material dilution factor and F_f is the packing factor of the material in the target cell. 80 % deuteron polarization of D-butanol with trityl radical was reported in Ref. [11], that gives a high figure of merit. However, the polarization with DNP is extremely sensitive to the correct frequency of the microwave and power because it has narrow EPR spectrum of the peak-to-peak separation. Considering the difficulty of the adjustment of the microwave, it is hard for the COMPASS target system to use the material with the large size target cell and with limited polarization time for the transverse target program as same as the Drell-Yan program. Therefore, 50 % polarization reported in Ref. [12] is used for the D-butanol in the Table 1.

Table 1: Target figure of merit for polarized deuteron target

		ND3	D-butanol	^{6}LiD
P_T		0.40	0.50	0.55(D) 0.54(^{6}Li)
ρ	10^3[kg/m^3]	1.00	1.12	0.84
f		0.30	0.24	0.25 (D) 0.25(^{6}Li)
F_f		0.58	0.62	0.55
PT_{FoM}	[kg/m^3]	8.4	10.0	17.1

The deuteron data was already taken for short periods in the first years of COMPASS [9]. In addition we used the small-aperture SMC target magnet with 60-60 cm long target-cell so that the statistic uncertainties of the deuteron transverse spin asymmetries are considerably larger than those of the corresponding proton asymmetries taken in 2007 and 2010. The old magnet had a 69 mrad acceptance and the present magnet 180 mrad. The target cell has to be modified same as the set up in 2007 and 2010, that is 30-60-30 cm long with a 3 cm diameter. The gaps between each cells are 5 cm long. The 3-target-cells can be considered as two pairs of 2-target-cells which helps to reduce false asymmetry. The target operation will be same as in 2015 and 2018, that means we will have one or two days to polarize the target material each time and about 5 days for a data taking period with 0.6 T dipole.

The target material of ^{6}LiD was produced in Bochum and irradiated at LINAC at ELSA Bonn almost 20 years ago [10]. The material has been kept in liquid nitrogen. We measured the polarization of the small amount of sample at 1 K at Bochum in 2019. The polarization test showed almost same performance of the polarization and build up time as 20 years ago (Figure 3).

The deuteron polarization of ^{6}LiD at 2.5 T reached 55 % for one week in 2002. The microwave modulation was effective for the polarization [10]. It is planned to make a cooling test in 2020 in order to obtain reasonable polarization for 24 hours by optimization of microwave and the dilution refrigerator parameters for the 2021 run. The magnet safety system is also needed to adjust during the cooling test because of the change of the microwave cavity geometry inside the magnet bore.

6. Summary

We performed the long run operation of the polarized proton target without any major problems for the polarized Drell-Yan program in 2018 . However we observed the radiation damage on the relaxation time slightly, we could keep the target system in high performance. We also showed the preparation of the polarized deuteron target system for the SIDIS off transversely polarized deuteron target in 2021.

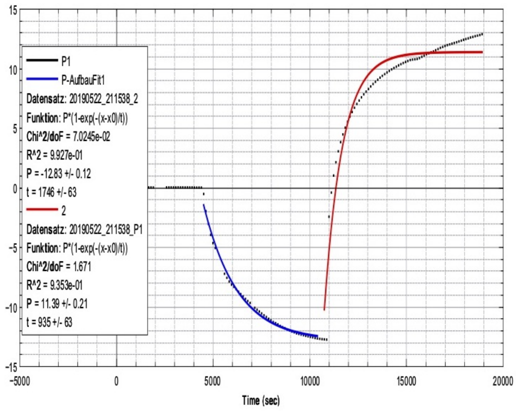

Figure 3: Deuteron polarization build up curve of ^{6}LiD at 1 K with 2.5 T. The blue (red) curve shows the negative (positive) polarization. The build up time of the negative (positive) polarization is 935 (1746) hours.

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