COMPASS polarized target in 2018 and 2021 on behalf of the COMPASS Collaboration

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- Introduction
- COMPASS Setup in 2018
- COMASS Polarized Target
- Target materials
- Summary/Outlook
fixed target experiment at the CERN SPS
COMPASS II
approved by CERN Research Board in 2010

• Polarized Drell-Yan measurement
  TMD PDFs \( \pi^- \) beam with polarized proton target

• GPD measurement
  Transverse imaging \( \mu^+ \mu^- \) beam with liquid hydrogen target

• Pion and Kaon polarizability
  Chiral perturbation theory \( \pi^- , K^- (\mu^-) \) beam with nucleus target

With a upgraded COMPASS spectrometer

2014  Test beam Drell-Yan process with \( \pi \) beam and T polarized proton target
2015  Drell-Yan process with \( \pi \) beam and T polarized proton target
2016  DVCS / SIDIS with \( \mu \) beam and unpolarized proton target
2017  DVCS / SIDIS with \( \mu \) beam and unpolarized proton target
2018  Drell-Yan process with \( \pi \) beam and T polarized proton target
Introduction

Structure of the nucleon

- 8 intrinsic transverse momentum dependent PDFs
- Asymmetries with different angular dependences on hadron and spin azimuthal angles, $\Phi_h$ and $\Phi_s$

<table>
<thead>
<tr>
<th></th>
<th>quark polarization</th>
<th>nucleon polarization</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>U</td>
<td>L</td>
</tr>
<tr>
<td>U</td>
<td>$f_1$ number density</td>
<td>$g_1$ helicity$\Delta q$</td>
</tr>
<tr>
<td>L</td>
<td>$h_{1L}$ - Boer Mulders</td>
<td></td>
</tr>
<tr>
<td>T</td>
<td>$h_{1T}$ transversity $\Delta_T q$</td>
<td></td>
</tr>
</tbody>
</table>

SIDIS gives access to all of them
Drell-Yan and SIDIS

Drell-Yan Process

- Quark-Antiquark annihilation with two leptons in the final state
- Small cross section
- Describe the cross section with convolution of two PDFs only

\[(PDF) \otimes (PDF)\]

Semi-Inclusive DIS process

- Describe the cross section with convolution between PDF and FF
- Higher cross section
- Uncertainty of FF

\[(PDF) \otimes (FF)\]
A new measurement of SIDIS on transversely polarized deuteron is proposed

TMD PDFs and Transversity $h_1(x)$ are flavor dependent.

- Flavour separation -> data on both proton and deuteron transversely polarized targets
- Proton data set is factor 4 compared to deuteron (see error bars for transversity $h_1(x)$ in the plot below)
- It’s logical to increase the deuteron data set (so far the only data sets available are COMPASS ($^6$LiD) and CLAS ($^3$He) target.

A. Martin, F.B., V. Barone PRD91 (2015) 014034
COMPASS setup in 2018

designed to
• use high energy beams
• have large angular acceptance
• cover a broad kinematical range

variety of tracking detectors
to cope with different particle flux from $\theta = 0$ to $\theta \approx 200$ mrad with a good azimuthal acceptance

Two stages spectrometer
• Large Angle Spectrometer (SM1)
• Small Angle Spectrometer (SM2)
COMPASS Polarized Target

First time hadron beam was used with the COMPASS PT system

- 2.5 T solenoid + 0.6 T dipole
- 50 mK dilution refrigerator
- 2 x 55 cm long target cells
- NH$_3$ as proton target (17% df)
- DNP by microwave of 70 GHz
- 10 NMR coils
- Frozen spin mode at 50mK
Target cells and NMR coils

Target cell
- 55 cm × Ø 4 cm
- made with $(\text{C}_2\text{F}_3\text{Cl})_n$ to reduce the effect on polarization measurement
- 2(3) outer coils and 3(2) inner coils for each cell
- Since high intensity hadron beam on PT is the first attempt in COMPASS, we installed inner coils which are more sensitive to the effect of the beam
- 2 cells were placed 20 cm apart
- in 2018 old SMC NH$_3$ material is added to fill up the cells
Microwave system

Equipment

- M.W. generator extended interaction oscillator, 20 W
- Power supplies
  - Varian VPW2838 and CPI VPW2827
- Power control
- Frequency counters
  - Phase Matrix EIP-548-B
- Power meter
  - Millitech DET-12-RPFW0
Protons in a solid ammonia (NH₃) are used as a polarized target. Paramagnetic centers were created by irradiating with electron beam. The NH₃ has typically 10⁻⁴ - 10⁻³ free radicals/nucleus.

Time after radiation:
- 1 week
- 2 weeks
- 7 months
- 4 years

2018 we will add a few grams from the old smc materials (1996) its still polarizable very high but slower build up and relaxation times.
Target loading April 17th
Polarization in 2015

Maximum Polarization

- upstream: 82.7%, -86.0%
- downstream: 79.3%, -77.8%

Typical polarization during phys. data taking

- upstream: 74.2%, -71.4%
- downstream: 69.2%, -67.0%
Polarization in 2018

Maximum Polarization
- upstream: 78.1%, -82.8%
- downstream: 81.3%, -80.5%

preliminary
Deuteron Targets for SIDIS

A new measurement of SIDIS on transversely polarized deuteron is proposed (2021)

Possible materials are

• $^6$LiD
• D-Butanol
• ND$_3$

About 900ccm are needed
Nucleon Polarization

Polarization = Orientation of Spins in a magnetic field

e-, p- and d-polarization vs temperature

\[ P = \frac{N^\uparrow - N^\downarrow}{N^\uparrow + N^\downarrow} \]

<table>
<thead>
<tr>
<th></th>
<th>T=1K</th>
<th>B=2.5 T</th>
<th>B=5T</th>
</tr>
</thead>
<tbody>
<tr>
<td>electron</td>
<td>93.3 %</td>
<td>99.8 %</td>
<td></td>
</tr>
<tr>
<td>proton</td>
<td>0.255 %</td>
<td>0.512 %</td>
<td></td>
</tr>
<tr>
<td>deuteron</td>
<td>0.052 %</td>
<td>0.105 %</td>
<td></td>
</tr>
</tbody>
</table>
Idea: Transfer the high $P(e^-)$ to nucleon

$B = 2.5T$

H-Propanediol with Trityl-Radical

$\mu$-wave frequency/MHz

$|P_{max}| < \frac{|P_{TE,e}|}{1 + f}$ mit $f = \frac{N_I t_{1e}}{N_e t_{1n}}$

$T_1^{e^-} = \text{ms to sec}$

$T_1^p = \text{min to hours}$

$B = 2.5T$ and $T=1K$
EPR spectra of dif. radicals in D-materials

TEMPO

irrad. 6LiD for comparison

trityl Width ≈ 0.22 mT

(C₄D₈)OD
Deuterated Target materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Radical</th>
<th>$\Delta g/g [10^{-3}]$</th>
<th>FWHM [mT]</th>
<th>$P_{D,max}(2T5)$ [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>D-Butanol</td>
<td>EDBA</td>
<td>5.98 ± 0.03</td>
<td>12.30 ± 0.20</td>
<td>26</td>
</tr>
<tr>
<td>D-Butanol</td>
<td>TEMPO</td>
<td>3.61 ± 0.13</td>
<td>5.25 ± 0.15</td>
<td>34</td>
</tr>
<tr>
<td>D-Butanol</td>
<td>Porphyrexide</td>
<td>4.01 ± 0.15</td>
<td>5.20 ± 0.23</td>
<td>32</td>
</tr>
<tr>
<td>$^{14}$ND$_3$</td>
<td>$^{14}$ND$_2$</td>
<td>$\approx 2...3$</td>
<td>4.80 ± 0.20</td>
<td>44</td>
</tr>
<tr>
<td>$^{15}$ND$_3$</td>
<td>$^{15}$ND$_2$</td>
<td>$\approx 2...3$</td>
<td>3.95 ± 0.15</td>
<td>-</td>
</tr>
<tr>
<td>D-Butanol</td>
<td>Hydroxyalkyl</td>
<td>1.25 ± 0.04</td>
<td>3.10 ± 0.20</td>
<td>55</td>
</tr>
<tr>
<td>$^6$LiD</td>
<td>F-center</td>
<td>0.0</td>
<td>1.80 ± 0.01</td>
<td>57</td>
</tr>
<tr>
<td>D-Butanol</td>
<td>Finland D36</td>
<td>0.50 ± 0.01</td>
<td>1.28 ± 0.03</td>
<td>79</td>
</tr>
<tr>
<td>D-Propanediol</td>
<td>Finland H36</td>
<td>0.47 ± 0.01</td>
<td>0.97 ± 0.04</td>
<td>-</td>
</tr>
<tr>
<td>D-Propanediol</td>
<td>OX063</td>
<td>0.28 ± 0.01</td>
<td>0.86 ± 0.03</td>
<td>81</td>
</tr>
</tbody>
</table>


**Result:** The smaller the EPR line width, the higher the deuteron polarization value.
Target material D-Butanol

Paramagnetic center induced chemically
- Porphyrexid nitroxyl
- FINLAND trityl
f = 20/84 = 0.238

D-Butanol doped with Porphyrexid and Tritayl radical

Deuteron Polarisation Fin II
Deuteron Polarisation Porphyrexid

GDH 2003
$\bar{P} \approx 65\%$
$\bar{P} \approx 29\%$
Target material D-Butanol

- Trityl radical density 2 to 2.5 weight%
- $\varnothing$ 4cm $\cdot$ 55cm $\cdot$ 2 cells $\cdot$ 0.6 $\approx$ 830ccm $\Rightarrow$ 16 to 21g of radical trityl

- the magnetic field homogeneity must be about $3 \cdot 10^{-5}$

The 900ml must be produced (Bochum, trityl radical exists) and it must be sure that the magnetic field homogeneity is about $3 \cdot 10^{-5}$
Target material $^6\text{LiD}$

Preparation by irradiation with electrons
$(E_e = 20 \text{ MeV}, T=190K)$
$f = \frac{4}{8} = 0.5$ ($^6\text{Li}: \alpha + D$)

COMPASS 2006
$P^+ = +56\%$
$P^- = -52\%$
Comparison in measurement time

Calculations are made for same target volume

### Proton materials

<table>
<thead>
<tr>
<th>Targetmaterial</th>
<th>P</th>
<th>$\rho$ [g/cm$^3$]</th>
<th>f</th>
<th>$F \times 10^{-2}$ g/cm$^3$</th>
<th>$t/t_{HD}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Butanol</td>
<td>90%</td>
<td>0.94</td>
<td>0.14</td>
<td>1.39</td>
<td>0.46</td>
</tr>
<tr>
<td>NH$_3$</td>
<td>90%</td>
<td>0.85</td>
<td>0.18</td>
<td>2.14</td>
<td>0.30</td>
</tr>
<tr>
<td>HD</td>
<td>63%</td>
<td>0.15</td>
<td>0.33</td>
<td>0.64</td>
<td>1.00</td>
</tr>
</tbody>
</table>

### Deuteron materials

<table>
<thead>
<tr>
<th>Targetmaterial</th>
<th>P</th>
<th>$\rho$ [g/cm$^3$]</th>
<th>f</th>
<th>$F \times 10^{-2}$ g/cm$^3$</th>
<th>$t/t_{HD}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>D-Butanol $\circ$</td>
<td>80%</td>
<td>1.07</td>
<td>0.24</td>
<td>3.88</td>
<td>0.42</td>
</tr>
<tr>
<td>ND$_3$ $\circ\circ$</td>
<td>44%</td>
<td>1.02</td>
<td>0.30</td>
<td>1.78</td>
<td>0.91</td>
</tr>
<tr>
<td>6Lid</td>
<td>50%</td>
<td>0.82</td>
<td>0.50</td>
<td>5.13</td>
<td>0.31</td>
</tr>
</tbody>
</table>
Summary / Outlook

• 2018 Target setup from 2015 is used
  o coils #3 and #8 are mounted also inside the cells
  o to fill up the lack of 2011 irradiated NH₃, material from SMC run 1996 is used

• 2021 SIDIS measurement Deuterated material will be used
  o ⁶LiD is available last use 2006
  o D-Butanol doped with trityl must be produced (Bochum)

  o Man power and target experts must be available!