Transverse Spin Asymmetries in the Drell-Yan Process from COMPASS

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The COMPASS Collaboration measured Transverse Spin Asymmetries in the Drell-Yan process. The measurement was done with a 190 GeV/c negative pion beam and a transversely polarized ammonia target. The data were taken during 2015 and 2018. The measured asymmetries, related to Transverse Momentum Dependent Parton Distribution Functions will be presented with a special focus on the Sivers asymmetry, which is related to the orbital angular momenta of the quarks inside the nucleon. The Sivers function was also accessed in COMPASS Semi-Inclusive Deep Inelastic Scattering measurement and is theoretically predicted to be of opposite sign compared to that in Drell-Yan. The results from the 2015 data analysis, which will be presented, favor the sign change scenario. The joint analysis of 2015 and 2018 Drell-Yan data will improve the experimental uncertainty.

KEYWORDS: Drell-Yan, TSAs, TMD PDFs, Sivers, COMPASS

1. Introduction

The description of the nucleon in terms of Parton Distributions Functions (PDFs) has been extensively addressed in the last decades. COMPASS studies the Transverse Momentum Dependent (TMD) PDFs, which in addition to the nucleon spin and the parton spin also take into account the intrinsic transverse momentum ($k_T$) of the partons. Eight TMD PDFs are needed to describe the nucleon at twist-2, which are shown in Fig. 1.

![Fig. 1. TMD PDFs in terms of nucleon polarization (red arrows), quark polarization (purple arrows) and quark intrinsic transverse momentum (orange arrows).](image-url)
These functions can be accessed through different processes, such like Drell-Yan (DY) and Semi-Inclusive Deep Inelastic Scattering (SIDIS). The spin-$k_T$ correlations generate experimentally accessible azimuthal asymmetries in the dimuon production in DY and in hadron production in SIDIS. The Sivers function is of particular interest, since it is process dependent and is predicted to have opposite sign when accessed from DY or SIDIS. Both processes can be described by different harmonic modulations of the corresponding cross section, each containing convolutions of two PDFs in the DY case and one PDF with one fragmentation function in the SIDIS case. Thus the same nucleon PDFs can be addressed in both measurements. COMPASS has preformed both of them and in this paper the result from 2015 DY data will be presented [1].

2. COMPASS Experiment

COMPASS is a fixed target experiment located at CERN, which has been taking data since 2002. It receives muon or pion beams from the SPS M2 beam line. It is a general purpose spectrometer with a complex target system based on dynamic nuclear polarization for the generation of polarized protons or deuterons. This versatility made possible the measurement of both SIDIS and DY. In the DY case the spectrometer is essentially the same as for SIDIS, with the addition of a hadron absorber immediately downstream of the polarized target allowing to detect DY dimuons with the downstream spectrometer while keeping the background under control. Its weak point is the introduction of multiple scattering to the penetrating muons, which degrades the experimental resolutions.

3. 2015 Drell-Yan Data

In 2015, the COMPASS experiment dedicated its data taking to the DY measurement using a negative pion beam with 190 GeV/$c$ and a transversely polarized proton target. It was a successful campaign which ended up in the collection of 35k good DY dimuons useful for the Transverse Spin Asymmetries (TSAs) extraction. The dimuon mass distribution for masses larger than 2 GeV/$c^2$ is shown in Fig. 2. The black points represent the 2015 data. The estimated combinatorial background, also extracted from the data sample, is shown by the dotted black line. The remaining curves represent the other sources of dimuons simulated by Monte-Carlo simulations. The total sample was fitted taking into account all the possible distributions. For the TSAs analysis a clean dimuon sample with masses between 4.3 and 8.5 GeV/$c^2$ was selected resulting in a background contamination smaller than 4%.

![Fig. 2. Dimuon mass distribution. The different colors represent the different dimuon sources. The two vertical dashed lines represent the mass region selected for the TSAs analysis.](image-url)
4. Results

The TSAs analysis consists in combining the events from the two target cells with opposite signs of polarization and in fitting these data to the harmonic modulations theoretically expected in the spin-dependent DY cross section. For the single-polarized DY case, the cross section is described by 5 fitting amplitudes, called TSAs, each one containing a convolution of a pion (beam) PDF and a proton (target) PDF. The results from 2015 DY data are shown in Fig. 3. The first value from top is the Sivers asymmetry, which is one sigma positive. The next two asymmetries are higher twist asymmetries, which are more difficult to interpret and have a larger statistical accuracy. The fourth asymmetry is the pretzelosity and shows a positive result as well. And finally the last one is the transversity, which is around two sigmas negative.

Fig. 3. TSAs extracted from the 2015 DY data.

The Sivers asymmetry for different kinematics is also shown in Fig. 4 selecting three equipopulated bins for each variable. It shows a positive trend. Due to the conventions chosen for the COMPASS Sivers asymmetries in DY and SIDIS, the same sign of the asymmetry corresponds to a sign change of the Sivers function. Therefore our result is compatible and favors the sign change scenario. In Fig. 5 the Sivers asymmetry is shown together with three different predictions DGLAP [2], TMD-1 [3] and TMD-2 [4]. Our result is compatible with all of them. The 2018 DY data are currently being analyzed and an improvement on the statistical accuracy is expected in the near future. The STAR experiment at BNL also studied the Sivers sign change in W/Z bosons production from pp collisions.
at 500 GeV, and their results are also compatible with the sign change scenario [5]. Nevertheless in their case the TMD evolution effects may play a substantial role. More STAR data are in the pipeline.

![Sivers asymmetry extracted from 2015 data together with three different predictions: DGLAP [2], TMD-1 [3] and TMD-2 [4]. They are all positive in the case of sign change, and negative with the same amplitude in the case of no sign change.](image)

**Fig. 5.** Sivers asymmetry extracted from 2015 data together with three different predictions: DGLAP [2], TMD-1 [3] and TMD-2 [4]. They are all positive in the case of sign change, and negative with the same amplitude in the case of no sign change.

## 5. Summary

The analysis of COMPASS 2015 DY data results in a Sivers asymmetry favoring the sign change scenario DY vs. SIDIS. The COMPASS 2018 data taking, again dedicated to the polarized DY measurement was successfully completed and the data are being analyzed. This will allow to better constrain the sign change study in the near future.

## References