

POLARIZED DRELL–YAN MEASUREMENTS AT COMPASS*

R. LONGO

on behalf of the COMPASS Collaboration

INFN — Sezione di Torino, Università di Torino, Torino, Italy
riccardo.longo@cern.ch

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COMPASS is a fixed-target experiment operating on north area of SPS (M2 beamline) at CERN. An important part of the physics programme of the experiment is the exploration of the transverse spin structure of the nucleon via measurements of spin-(in)dependent azimuthal asymmetries in the semi-inclusive DIS and, recently, also in Drell–Yan processes. Drell–Yan measurements with a 190 GeV/c π^- beam impinging on a transversely polarized NH_3 target started in the year 2015 (18 weeks data taking) and will be continued in 2018. The measurement of the Sivers and other azimuthal asymmetries in polarized SIDIS and Drell–Yan performed by COMPASS provides a unique possibility to test (pseudo-)universal features of transverse momentum-dependent parton distribution functions, predicted in QCD. In this review, results of the first ever measurements of the polarized Drell–Yan reaction performed by COMPASS are presented.

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1. Introduction

For a polarized nucleon, within the “twist-2” approximation of QCD parton model, there are eight transverse-momentum-dependent (TMD) parton distribution functions (PDFs) describing the distributions of longitudinal and transverse momenta of partons and their correlations with nucleon and quark polarizations. A powerful method used to access these TMD PDFs is the study of transverse spin-dependent azimuthal asymmetries (TSAs) arising in the Semi-Inclusive Deep Inelastic Scattering (SIDIS) and Drell–Yan (DY) cross sections. The TMD-factorization theorem has been proven for both cross sections [1], allowing to express the TSAs as convolutions of

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hard-scale-dependent TMD PDFs, and (in the case of SIDIS) parton fragmentation functions (FFs). For the SIDIS case, the hard scale Q is defined by the square root of the virtuality of the photon exchanged in the DIS process, while for the DY case, it is given by the invariant mass of the lepton pair.

Summing over the polarization of the produced leptons, at leading-twist the single-polarized Drell–Yan cross section can be written as

$$\begin{aligned} \frac{d\sigma^{\text{LO}}}{d\Omega} \propto & F_U^1 \left\{ 1 + \cos^2 \theta_{\text{CS}} + \sin^2 \theta_{\text{CS}} A_U^{\cos(2\varphi_{\text{CS}})} \cos(2\varphi_{\text{CS}}) \right. \\ & + S_T \left[(1 + \cos^2 \theta_{\text{CS}}) A_T^{\sin \phi_S} \sin \phi_S \right. \\ & + \sin^2 \theta_{\text{CS}} A_T^{\sin(2\varphi_{\text{CS}} - \varphi_S)} \sin(2\varphi_{\text{CS}} - \varphi_S) \\ & \left. \left. + \sin^2 \theta_{\text{CS}} A_T^{\sin(2\varphi_{\text{CS}} + \varphi_S)} \sin(2\varphi_{\text{CS}} + \phi_S) \right] \right\}. \quad (1) \end{aligned}$$

The φ_{CS} , θ_{CS} and Ω , the solid angle of the lepton, are defined in the Collins–Soper frame [2] and ϕ_S is the azimuthal angle of the direction of the nucleon polarization in the target rest frame, see Fig. 1.

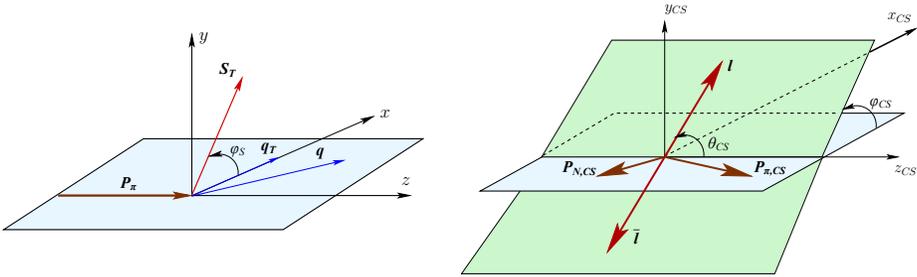


Fig. 1. The Collins–Soper frame (left) and the target rest frame (right).

At leading order, the Drell–Yan cross section contains three (one) polarization (in)dependent TSAs. Within the QCD parton model approach, the three Drell–Yan LO TSAs appearing in Eq. (1) are described by specific convolutions of the beam hadron (pion in the case of COMPASS) and the target nucleon TMD PDFs. For instance, the measurement of $A_T^{\sin \varphi_S}$ DY TSA gives access to the convolution of nucleon Sivers TMD PDF with unpolarized pion PDF, while $A_T^{\sin(2\varphi_{\text{CS}} - \varphi_S)}$ and $A_T^{\sin(2\varphi_{\text{CS}} + \varphi_S)}$ TSAs are related with the pion Boer–Mulders TMD PDF convoluted with the transversity and the pretzelosity nucleon TMD PDFs [3–5], respectively. All the three aforementioned TMD PDFs are associated to analogous twist-2 TSAs in the general expression of the cross section of unpolarized-hadron production in SIDIS of leptons on transversely polarized nucleons [4, 5]. These SIDIS TSAs were measured by both HERMES and COMPASS experiments (see for details [6–10] and references therein).

According to the TMD framework of QCD, the two naively time-reversal odd TMD PDFs, the Sivers (f_{1T}^\perp) and the Boer–Mulders (h_1^\perp) functions, are expected to have the opposite sign when measured in SIDIS or DY [11]. On the other hand, time-reversal even TMD PDFs, like the transversity and the pretzelocity functions, are expected to be genuinely universal (process-independent). The experimental test of these fundamental predictions is one of the major challenges in hadron physics. Another open issue is the estimation of TMD evolution effects of PDFs. Measurement of TSAs in different hard-scale regions within a single experimental environment is a way to access this information. Recently, COMPASS published the first multi-differential results of the SIDIS TSAs, which were extracted from SIDIS data at four different hard scales [7]. As for DY TSAs, the COMPASS experiment is presently the only place to explore the transverse spin structure of the nucleon studying the polarized Drell–Yan reactions. In addition, the experiment possesses the capability to measure TSAs both in SIDIS and DY at similar hard-scale using essentially the same experimental setup. Thus, COMPASS has the unprecedented and remarkable possibility to test, in a unique experimental environment, the universality and other key-features of TMDs.

2. Polarized Drell–Yan measurements

The polarized Drell–Yan measurements are one of the main topics of the COMPASS phase-II (2012–2018) physics programme. The data were collected in 2015 using high intensity ($6 \times 10^7 \text{ s}^{-1}$) 190 GeV/c π^- beam impinging on a transversely polarized NH_3 target with proton polarization $\langle P_T \rangle \sim 73\%$ and dilution factor¹ $\langle f \rangle \sim 0.18$. The polarized target consisted of two cells (55 cm long, 2 cm of radius) configuration, separated by a 20 cm gap. The target material was polarized along the vertical direction and the polarization was maintained in a magnetic field (0.6 T) generated by a dipole magnet. The cells were polarized in opposite directions, in order to collect data with both spin directions simultaneously. The polarization in both cells was reversed every two weeks, to minimize the acceptance effects. A hadron absorber, made mostly of alumina, was placed downstream of the NH_3 target. This structure had also a tungsten core, acting as a beam dump.

The mass spectrum resulting from reconstructed events passing all analysis requirements is shown in black in Fig. 2 (left panel). The J/ψ peak is clearly visible, showing a shoulder that is associated with the $\psi(2S)$ resonance. All the contributions to the mass spectrum are evaluated via Monte Carlo. The sum of all contributions is shown in black (violet). A good agreement between Monte Carlo and real data can be observed. The mass range

¹ The dilution factor f accounts for the fraction of polarizable nucleons in the target and the migration of reconstructed events from one target cell to the other.

$4.3 < M_{\mu\mu}/(\text{GeV}/c^2) < 8.5$ (hereafter referred as high mass range) contains mostly DY events (overall background contamination in this ranges is estimated to be below 4%) was selected for the analysis [12].

The two-dimensional distribution of the Bjorken variables of pion and nucleon, x_π and x_N , for the high mass range is presented in Fig. 2. The COMPASS measurements explore the valence region in x_π and x_N , where the DY cross section for a proton target is dominated by the contribution of nucleon u -quark and pion \bar{u} -quark TMD PDFs.

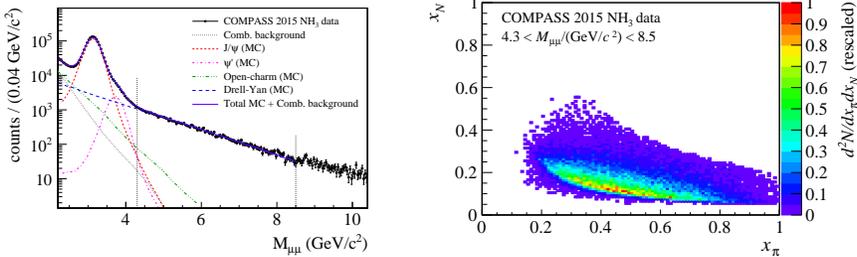


Fig. 2. The dimuon invariant mass distribution (left panel) and two-dimensional (x_π, x_N) distribution (right panel) of the selected high mass dimuons.

The distributions of the Feynman variable x_F and the dimuon transverse momentum q_T are presented in Fig. 3. The shaded parts (blue online) represent the regions selected for the analysis. The $q_T > 0.4 \text{ GeV}/c$ cut was applied to ensure a sufficient resolution in the angular variables. After all cuts, $\sim 35 \times 10^3$ events remain for the analysis.

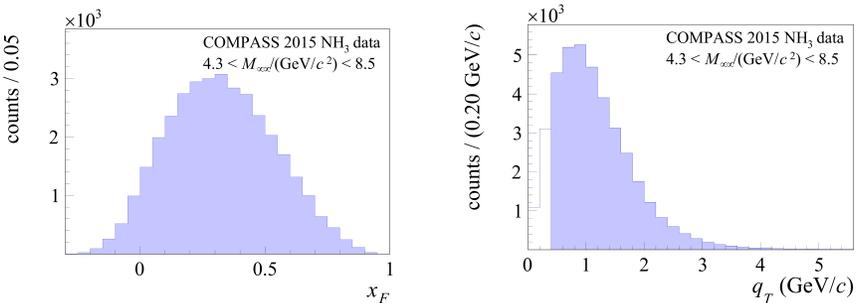


Fig. 3. The x_F distribution (left) and q_T distribution (right) of the selected high mass dimuons.

The asymmetries extracted as functions of the kinematic variables x_N , x_π , x_F , q_T are shown in Fig. 4. Because of a relatively large statistical uncertainty, no clear trend can be observed for any of the TSAs. A significant improvement from the statistical point of view is expected after the 2018 DY run. The three extracted TSAs integrated over the entire kinematic range are shown in the last column of Fig. 4.

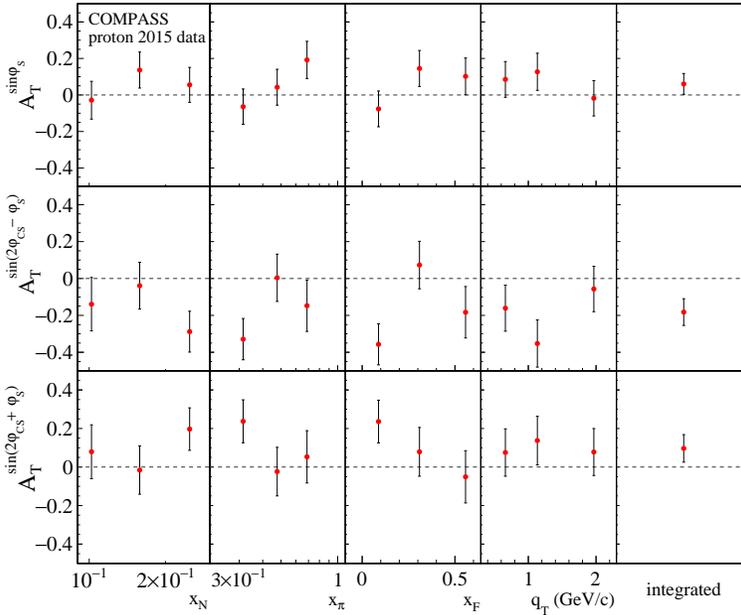


Fig. 4. Extracted Drell–Yan TSAs related to Siverts (top), transversity (middle) and pretzelosity (bottom) TMD PDFs. Error bars represent the statistical uncertainties. Systematic uncertainties (not shown) are 0.7 times the statistical ones.

The average Siverts asymmetry $A_T^{\sin\varphi_S}$ is found to be above zero at about one standard deviation of the total uncertainty. In Fig. 5, it is compared with recent predictions from Refs. [13–15] that are assuming different Q^2 evolution schemes. These predictions are based on numerical fit of SIDIS data for

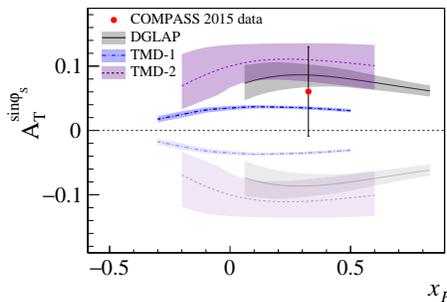


Fig. 5. The measured mean Siverts asymmetry and the theoretical predictions for different Q^2 evolution schemes from Refs. [13] (DGLAP), [15] (TMD1) and [14] (TMD2). The dark-shaded (light-shaded) predictions are evaluated with (without) the sign-change hypothesis. The error bar represents the total experimental uncertainty.

the Sivers TSA and are quoted for both sign-change (positive sign) and no sign-change assumption (negative sign). The figure shows that the first measurement of the Sivers asymmetry of the Drell–Yan process is compatible with the predicted change of sign of the Sivers function.

The $A_T^{\sin(\varphi_{CS}-\varphi_S)}$ TSA is found to be negative with a significance of about two standard deviations. The magnitude of the asymmetry is in agreement with the predictions made in [16] and will be a useful input to study the universality hypothesis for transversity TMD of the nucleon. The pretzelosity-related $A_T^{\sin(\varphi_{CS}+\varphi_S)}$ asymmetry was measured to be negative of about one standard deviation. Since both $A_T^{\sin(\varphi_{CS}-\varphi_S)}$ and $A_T^{\sin(\varphi_{CS}+\varphi_S)}$ TSAs are also related to the pion Boer–Mulder TMD PDF, these results may be also a useful input to increase the knowledge about the internal structure of the pion.

REFERENCES

- [1] J. Collins, *Foundations of Perturbative QCD*, Cambridge Univ. Press, 2011.
- [2] J.C. Collins, D.E. Soper, *Phys. Rev. D* **16**, 2219 (1977).
- [3] S. Arnold, A. Metz, M. Schlegel, *Phys. Rev. D* **79**, 034005 (2009) [arXiv:0809.2262 [hep-ph]].
- [4] A. Kotzinian, *Nucl. Phys. B* **441**, 234 (1995) [arXiv:hep-ph/9412283].
- [5] A. Bacchetta *et al.*, *J. High Energy Phys.* **0702**, 093 (2007) [arXiv:hep-ph/0611265].
- [6] A. Airapetian *et al.* [HERMES Collaboration], *Phys. Rev. Lett.* **103**, 152002 (2009) [arXiv:0906.3918 [hep-ex]].
- [7] C. Adolph *et al.* [COMPASS Collaboration], *Phys. Lett. B* **770**, 138 (2017) [arXiv:1609.07374 [hep-ex]].
- [8] C. Adolph *et al.* [COMPASS Collaboration], *Phys. Lett. B* **717**, 383 (2012) [arXiv:1205.5122 [hep-ex]].
- [9] C. Adolph *et al.* [COMPASS Collaboration], *Phys. Lett. B* **717**, 376 (2012) [arXiv:1205.5121 [hep-ex]].
- [10] B. Parsamyan [COMPASS Collaboration], *Phys. Part. Nucl.* **45**, 158 (2014) [arXiv:1301.6615 [hep-ex]].
- [11] J.C. Collins, *Phys. Lett. B* **536**, 43 (2002) [arXiv:hep-ph/0204004].
- [12] M. Aghasyan *et al.* [COMPASS Collaboration], *Phys. Rev. Lett.* **119**, 112002 (2017) [arXiv:1704.00488 [hep-ex]].
- [13] M. Anselmino *et al.*, *J. High Energy Phys.* **1704**, 046 (2017) [arXiv:1612.06413 [hep-ph]].
- [14] P. Sun, F. Yuan, *Phys. Rev. D* **88**, 034016 (2013) [arXiv:1304.5037 [hep-ph]].
- [15] M.G. Echevarria, A. Idilbi, Z.B. Kang, I. Vitev, *Phys. Rev. D* **89**, 074013 (2014) [arXiv:1401.5078 [hep-ph]].
- [16] A.N. Sissakian, O.Y. Shevchenko, A.P. Nagaitsev, O.N. Ivanov, *Phys. Part. Nucl.* **41**, 64 (2010).