Study of the Hadron Structure Using the Polarised Drell-Yan Process at COMPASS

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The COMPASS experiment at CERN is one of the leading experiments studying the nucleon structure. The Parton Distribution Functions and the Transverse Momentum Dependent Parton Distribution Functions were extensively studied at COMPASS using Semi-Inclusive Deep Inelastic Scattering measurements until 2012. In 2015 the data taking was dedicated to the study of the polarised Drell-Yan process. COMPASS scattered a negative pion beam of 190 GeV/c off a transversely polarised proton target, with the goal of accessing the TMD PDFs of both hadrons (pions and protons). This can be achieved by measuring the target polarisation (in)dependent azimuthal asymmetries of produced oppositely charged muons. Since the DY data cover the same kinematic region as the SIDIS data collected with a transversely polarised target, COMPASS has the unique opportunity to test the sign change predicted by QCD of the Sivers TMD at the same hard scale in both processes. Preliminary distributions of collected DY data and estimation of projected asymmetry uncertainties are presented.

KEYWORDS: COMPASS, Drell-Yan, TMDs

1. Introduction

The general purpose spectrometer of COMPASS experiment at CERN gives the possibility to measure both Semi Inclusive Deep Inelastic Scattering (SIDIS) and Drell-Yan (DY) processes using muon and pion beams, respectively, on a transversely polarised proton target. The spin (in)dependent azimuthal asymmetries extracted from these two measurements are related with the spin and the Transverse Momentum Dependent PDFs (TMDs). The latter describe the nucleon mapping in the momentum space, they are ingredients to understand the nucleon structure. COMPASS offers a unique opportunity to access these TMDs through two different processes and using essentially the same setup. One of the main results will be the test of the Sivers TMD sign change when extracted from SIDIS or from DY, as predicted by the QCD TMD approach [1].

2. TMDs from SIDIS and DY

The nucleon structure at leading twist QCD, which takes into account the polarisations of the nucleon and quark and the quark intrinsic transverse momentum (k_T) is described by eight TMDs for each quark flavour. Three of them survive the integration over k_T and the other five describe correlations between the quark's k_T, its spin and the spin of the nucleon. Most of these TMDs can be accessed in COMPASS from both SIDIS and DY on the transversely polarised target. In terms of leading twist asymmetries the Drell-Yan cross section is written as

$$\sigma^{DY} \propto 1 + \cos^2(\theta) + \sin^2(\theta) A_{UU}^{\cos(2\phi)} \cos(2\phi) + S_T \Big[(1 + \cos(\theta)) A_{UT}^{\sin(\phi_S)} \sin(\phi_S) + \sin^2(\theta) \Big(A_{UT}^{\sin(2\phi+\phi_S)} \sin(2\phi + \phi_S) + A_{UT}^{\sin(2\phi-\phi_S)} \sin(2\phi - \phi_S) \Big) \Big] \quad (1)$$

and the lepton polarisation-independent part of the SIDIS cross section on the transversely polarised target as

$$\sigma^{SIDIS} \propto 1 + \varepsilon \cos(2\phi_h) A_{UU}^{\cos(2\phi_h)} + S_T \Big[\sin(\phi_h - \phi_S) A_{UT}^{\sin(\phi_h-\phi_S)} + \varepsilon \sin(\phi_h + \phi_S) A_{UT}^{\sin(\phi_h+\phi_S)} + \varepsilon \sin(3\phi_h - \phi_S) A_{UT}^{\sin(3\phi_h-\phi_S)} \Big] \quad (2)$$

where the A's stand for the asymmetries, each being an amplitude of a specific angular modulation in the angles θ, ϕ and ϕ_S in the DY case, and in ϕ_h and ϕ_S in the SIDIS case. These angles are defined in Fig.1. The two subscripts of A correspond to the polarisation of the beam and of the target, "U" stands for polarisation independent and "T" for transverse polarisation.

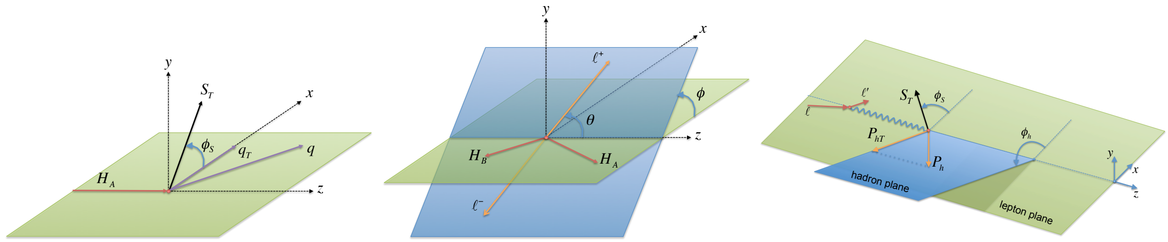

Fig. 1.: (Left) Target rest frame used to define the ϕ_S in DY case. (Middle) Collins-Soper rest frame used to define the θ and ϕ angles in the DY case. (Right) Definition of the angles ϕ_h and ϕ_S in the SIDIS case.

The above asymmetries are related to a convolution of pion and nucleon TMD PDFs in the DY case and with a nucleon TMD PDF and a TMD fragmentation function in the SIDIS case. Thus the same TMDs for the proton can be accessed in the two processes, namely, the Boer-Mulders, the Sivers, the transversity and the pretzelosity. The Sivers function is of great interest since it is predicted to differ in sign when extracted from the DY or from the SIDIS processes. In order to avoid possible Q^2 evolution effects it is important to extract the results in a same phase space. Indeed COMPASS SIDIS data and the collected DY data are analysed in the same Q^2 intervals [2].

3. Drell-Yan programme - 2015 data taking

The polarised DY data taking at COMPASS took place in 2015. A negative pion beam with 190 GeV/c and two oppositely transversely polarised ammonia target cells were used. Four months of stable data taking were performed. These data are now being analysed. Here we show preliminary distributions and asymmetry estimation obtained using 30% of collected data. These data can be divided in four dimuon mass ranges ($M_{\mu\mu}^2 \equiv Q^2$), as shown in Fig. 2, here x_N stands for the momentum fraction carried by the quark within the nucleon. The dimuon mass distribution is shown in Fig. 3.

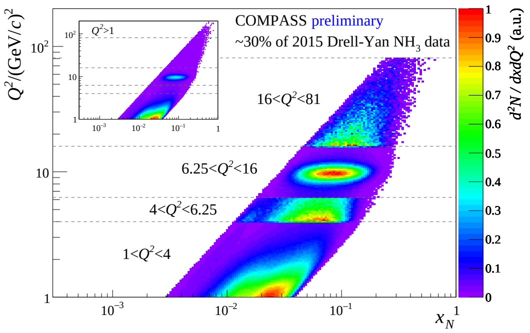

Fig. 2.: Q^2 versus x_N distribution. The distributions are normalised for each mass range. The insert shows the overall distribution without independent normalisation for the four ranges.

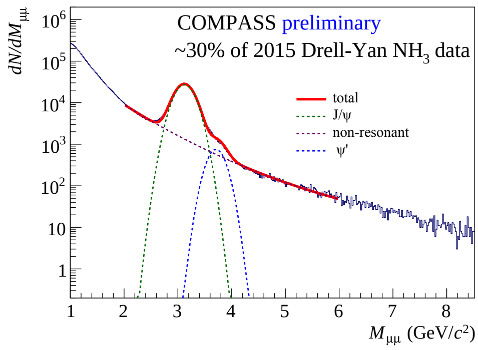

Fig. 3.: Dimuon mass distribution.

The distribution of dimuon production vertices along z is presented in Fig. 4 for events in the J/ψ mass region and in Fig. 5 for events in the high dimuon mass region. From left to right the shadowed areas identify the two ammonia target cells, the aluminium and the tungsten cells. As it can be seen the targets are rather well separated. The optimization of the event selection criteria for different targets regions is currently under study.

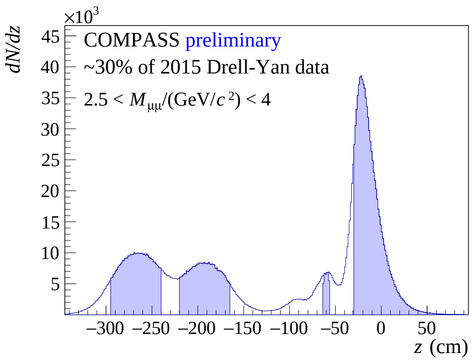

Fig. 4.: Vertex distribution along z for events from the J/ψ region.

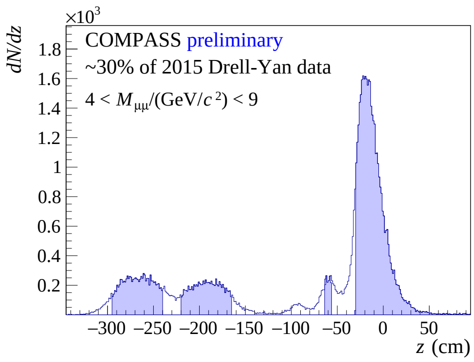

Fig. 5.: Vertex distribution along z for events from the high mass region.

In the above mentioned mass intervals the events mainly originate from the valence quarks region, as one can see in Fig. 6 for the J/ψ region and in the Fig. 7 for the high mass region.

The azimuthal asymmetries are being studied in the two cases. The J/ψ region has the advantage of a much larger statistics but with several physics processes contributing to it. See reference [3], where a significant Sivers asymmetry, around 20%, for COMPASS kinematics, is predicted for this region. In the high mass range the statistics is much lower, the statistical uncertainty calculated using 30% of currently analysed data are shown in Fig. 8 for Boer-Mulders, in Fig. 9 for transversity, in Fig. 10 for Sivers and in Fig. 11 for pretzelosity. Considering all 2015 data and a possible second year dedicated DY data taking the statistical uncertainty for Sivers asymmetry is predicted to be $\sim 2.3\%$. The projected uncertainty of Sivers asymmetry for two years of data taking and theoretical predictions are shown in Fig. 12.

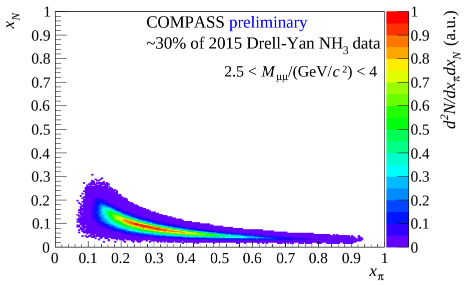

Fig. 6.: x_N versus x_π in the J/ψ region.

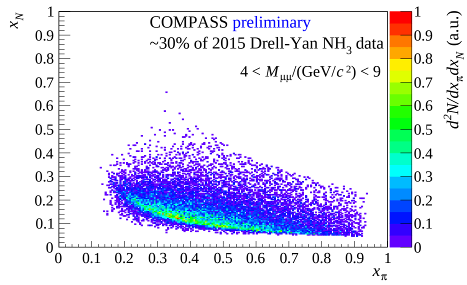

Fig. 7.: x_N versus x_π in the high mass region.

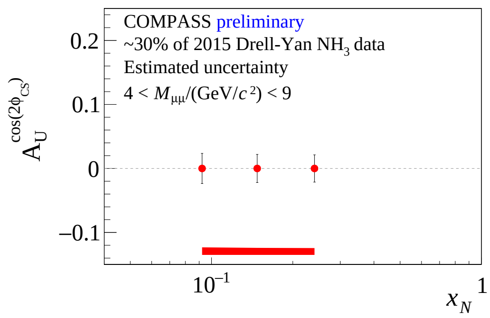

Fig. 8.: Boer-Mulders asymmetry uncertainties.

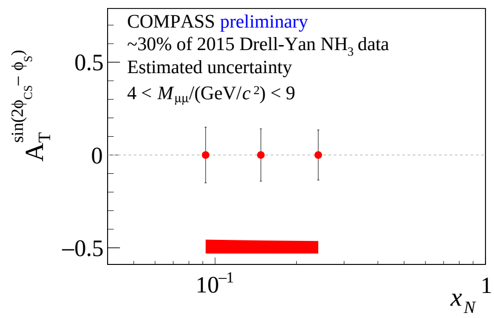

Fig. 9.: transversity asymmetry uncertainties.

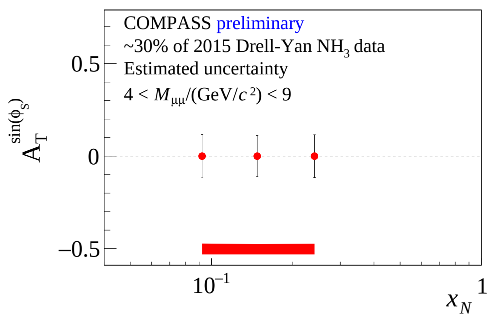

Fig. 10.: Sivers asymmetry uncertainties.

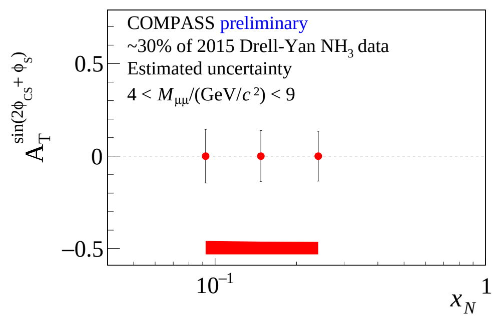

Fig. 11.: pretzelosity asymmetry uncertainties.

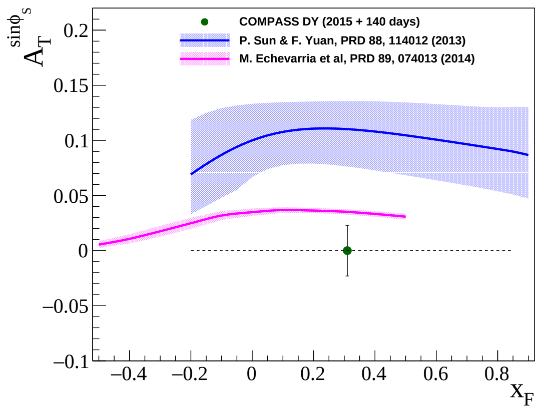

Fig. 12.: Projected Sivers asymmetry uncertainty for two years of data taking.

4. Summary

The first ever polarised DY measurement using a negative pion beam and a proton polarised target was done by COMPASS in 2015. These data are now being analysed. COMPASS has the unique opportunity to extract the TMD PDFs from both SIDIS and DY asymmetry measurements in the same experiment, and this is very important to test the Sivers function sign change prediction. The approval of the second year of polarised DY data taking by COMPASS would significantly improve the statistical precision of extracted asymmetries.

5. Acknowledgements

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References

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