**Polarised Drell-Yan measurements at COMPASS-II** [1]

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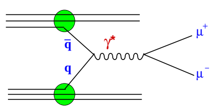
**Abstract**

The spin structure of the nucleon and its Parton Distribution Functions (PDFs) are important topics studied by the COMPASS experiment at CERN. So far, the transverse momentum dependent PDFs (TMD PDFs) of the proton and deuteron have been studied in Semi-Inclusive Deep Inelastic Scattering (SIDIS). The Drell-Yan (DY) process is a complementary way to access the TMD PDFs, using a transversely polarised target. Studying the angular distributions of dimuons from the DY events produced in the collisions of a $\pi^-$ beam with 190 GeV/$c$ momentum off a transversely polarised proton target ($NH_3$) we are able to extract the azimuthal spin asymmetries, which are generated by 4 out of the 8 TMD PDFs needed to describe the nucleon structure at leading order QCD. The expected sign change in Sivers and Boer-Mulders functions when accessed from DY and SIDIS will be checked [1]. The opportunity to study, in the same experiment, the TMD PDFs from both SIDIS and DY processes is unique at COMPASS. The COMPASS II Proposal [2] was approved by CERN including one year for polarised DY measurements; the beginning of the DY data taking is scheduled for 2014. The feasibility of the measurement was proven by several beam tests performed so far.

# 1 Introduction to the Drell-Yan process




The DY process is an electromagnetic annihilation of a quark-antiquark pair in the initial state with the production of two leptons. In COMPASS we will register two muons in the final state, the so-called dimuon events. Our goal is the study of the angular distribution of dimuons, which in the unpolarised case can be written as:

[1]Talk at the 20th INTERNATIONAL SYMPOSIUM on Spin Physics (SPIN2012), JINR, Dubna, September 17 - 22, 2012.

$$\frac{1}{\sigma}\frac{d\sigma}{d\Omega} = \frac{3}{4\pi}\frac{1}{\lambda+3}[1+\lambda\cos^2\theta+\mu\sin 2\theta\cos\phi+\frac{\nu}{2}\sin^2\theta\cos 2\phi] \quad (1)$$

If quarks do not have intrinsic transverse momentum ($k_T$) no azimuthal modulations are expected. But in fact two past experiments (NA10[3] and E615[4]) measured $\cos 2\phi$ modulations up to 30%, which point to the possible importance of $k_T$. The nucleon structure in first order QCD and taking into account $k_T$ is described by 8 PDFs. Using a transversely polarised proton target and a $\pi^-$ beam we are able to extract 4 azimuthal spin asymmetries, each containing a convolution of 2 TMD PDFs. In this way one can access 4 of the 8 leading twist TMD PDFs, namely $h_1(x, {k_T}^2)$ (which leads to transversity after integration in $k_T$), ${h_1}^{\perp}(x, {k_T}^2)$ (Boer-Mulders), ${f_{1T}}^{\perp}(x, {k_T}^2)$ (Sivers) and ${h_{1T}}^{\perp}(x, {k_T}^2)$ (Pretzelosity).

The Sivers and the Boer-Mulders functions are naïve time-reversal odd functions, which leads to the prediction that they must change sign when accessed from DY or SIDIS[1]. The experimental confirmation of this prediction is considered a crucial test of non-perturbative QCD. This TMDs universality check as well as the extraction of the asymmetries as a function of $x_F$ and $p_T$ are the main goals of the COMPASS-II DY program.

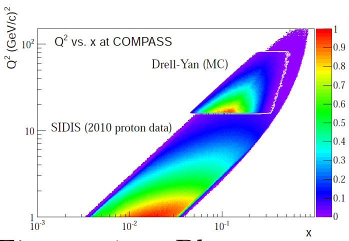


Figure 1: Phase space overlap between SIDIS and DY.

## 2 COMPASS experiment at CERN

COMPASS is a CERN fixed target experiment located in the M2 beam line, which provides either muon or hadron beams. The apparatus comprises a two stage spectrometer, giving the possibility to measure in a wide range of momenta and with wide angular acceptance. The spectrometer includes a large number of tracking detectors, 2 sets of calorimeters, one RICH and trigger hodoscopes. A complete description can be found in [5]. In the DY program a solid state polarised target will be used, with two ammonia cells with opposite polarisations transverse to the beam. In these conditions one can reach a polarisation up to 90% with a dilution factor of 22%. The spectrometer has a geometrical acceptance of ±180 mrad. A hadron absorber with a beam plug in the central part along the beam direction will be placed just downstream of the target. Its function is to stop the produced hadrons and also the non-interacting beam. The composition of the absorber is chosen in order to minimise the number of radiation lengths ($X_0$) crossed by the muons in order to minimise the multiple scattering, while maximising the number of pion interaction lengths ($\lambda^{\pi}_{int}$). The use of the absorber is mandatory, taking into account the small value of the DY cross-section in comparison with the hadronic one and the need of a high intensity beam. The contribution from the combinatorial background is high only in the low mass range ($M_{\mu\mu} < 2.5$ GeV/$c^2$), due to uncorrelated muon pairs from pion and kaon decays appears in the dimuon invariant mass spectrum, populating the low mass region. In the mass range below the $J/\psi$, a physics background from D meson decays must also be taken into account. Thus the most clean region to study DY is in the mass range between 4 and 9 GeV/$c^2$, the DY high mass region (HMR).

# 3 Feasibility of the measurement

The feasibility of the measurement was proved by several beam tests carried out so far, in which we verified the absorber effect and the spectrometer response, the radiation level and the J/$\psi$ yield. The last test was performed in 2009, using a hadron absorber prototype, made of concrete and stainless steel, and with a W beam plug inside the central part of absorber. A $\pi^-$ beam at 190 GeV/$c$ and two unpolarised target cells (polyethylene) with 40 cm length each, spaced by 20 cm were used. This absorber had 66.2 $X_0$ and 6.7 $\lambda^{\pi}_{int}$. A dimuon trigger was used based on coincidences in hodoscopes and in one of the hadronic calorimeters. Looking at the results of the test one can distinguish the events from each of the target cells, as well as a large number of events produced in the absorber due to the fact that the dimuon trigger had no target pointing capability. An optimised dimuon trigger is being developed based in coincidences of hodoscopes for the future measurement.

# 4 Acceptances, event rates and asymmetries

The setup for the future DY experiment is being optimised. If one considers two target cells ($NH_3$) 55 cm long each spaced by 20 cm and an absorber 236 cm long, made of $Al_2O_3$ which has 33.5 $X_0$ and 7.3 $\lambda^{\pi}_{int}$ then the z resolution is expected to be around 6 cm and the mass resolution 180 GeV/$c^2$ in HMR. The target cell contamination, i.e. number of events generated in one cell and reconstructed in the other is expected to be of the order of 1%. The

DY dimuons geometrical acceptance in the HMR is 39%. 22% of them are with both muons in the $1^{st}$ spectrometer, 2% with both muons in the $2^{nd}$ spectrometer and 18% with one muon in the $1^{st}$ spectrometer and one in the $2^{nd}$ one. Assuming a $\pi^-$ beam with 190 GeV/$c$, a beam intensity of $6 \times 10^7$ $\pi$/s and a luminosity of $1.2 \times 10^{32}$ cm$^{-2}$s$^{-1}$ one expects 900 DY events/day in the HMR. In two years of data taking ($\sim$ 280 days) we expect to reach the following statistical error on the corresponding asymmetries:

| Asymmetry | Uncertainty in HMR |
|---|---|
| $\delta A_U^{\cos 2\phi}$ | 0.0057 |
| $\delta A_T^{\sin \phi_S}$ | 0.0143 |
| $\delta A_T^{sin(2\phi+\phi_S)} = \delta A_T^{sin(2\phi-\phi_S)}$ | 0.0285 |

Taking into account the existing theoretical predictions for the asymmetries, we shall be able to make the study in several bins in $x_F$. A comparison of the amplitude and the shape of the Sivers function between DY and SIDIS, both studied in COMPASS, will be possible.

# 5 Summary

The opportunity to study in the same experiment the TMD PDFs from both SIDIS and the DY processes is unique. The predicted sign change in Sivers and Boer-Mulders functions when accessed from DY and SIDIS will be checked in the first year of data taking. The feasibility of the measurement was proved by the already performed beam tests. The COMPASS II Proposal was approved by CERN for a first period of 3 years including 1 year for polarised DY, which will start in 2014. A second year of data taking with polarised $NH_3$ is expected to happen in 2017 or 2018. COMPASS aims to perform the first polarised DY experiment in the world.

# References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