Drell-Yan measurements in COMPASS

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Abstract. The future polarized Drell-Yan measurement at COMPASS is presented. The Drell-Yan events produced by the collision of a pion beam with a transversely polarized NH_3 target will allow to access the transverse momentum dependent parton distribution functions of hadrons. Sivers, Boer-Mulders, pretzelosity and transversity functions will be studied. This measurement is complementary to the ones performed in COMPASS in semi-inclusive deep inelastic scattering of muons off a transversely polarized target, providing an important test of QCD in the non-perturbative regime.

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The COMPASS experiment has been studying the transverse momentum dependent parton distribution functions (TMD PDFs) of the proton and deuteron from semi-inclusive deep inelastic scattering (SIDIS) processes of a polarized muon beam off a transversely polarized target. By measuring the azimuthal asymmetries of produced hadrons originating from different target spin configurations one accesses the convolution of a target nucleon PDF with a fragmentation function of the produced hadron. In this way TMD related effects like Collins and Sivers are studied, providing us with information about the interplay between the spin of the nucleon, its momentum and intrinsic transverse momentum of its constituent quarks. Another way to access TMD PDFs is from the Drell-Yan process, with the difference that the measured azimuthal asymmetries are proportional to a convolution of 2 PDFs, corresponding to target and beam quarks intervening in the annihilation process. TMD PDFs which are time reversal odd, as is the case of Sivers and Boer-Mulders, are expected to change their sign when accessed from SIDIS or from Drell-Yan. This is considered to be a crucial test of the TMD factorization approach. The COMPASS experiment will do the Drell-Yan measurement in the dimuon channel with transversely polarized NH_3 target and a π^- beam, thus being able to check not only the sign change prediction, but also extract Sivers, Boer-Mulders, pretzelosity, and transversity [1].

COMPASS has a two-stage spectrometer, with two dipole magnets and a large number of tracking detectors, allowing for an angular coverage from 15 to 140 mrad [5]. Two target cells are installed inside a superconducting solenoid/dipole, at a temperature of 50 mK. The cells are oppositely polarized, and the spin configuration is periodically inverted, such that systematic effects are minimized. The system allows for either longitudinal or transverse polarization of the target nucleons with respect to the beam direction. With solid state ammonia (NH_3) as target material, one can reach a packing factor of 50%, with a fraction of polarizable material of 0.22, and the polarization reached is of the order of 90%.

COMPASS is located in the M2 beam line of the SPS/CERN, which provides either

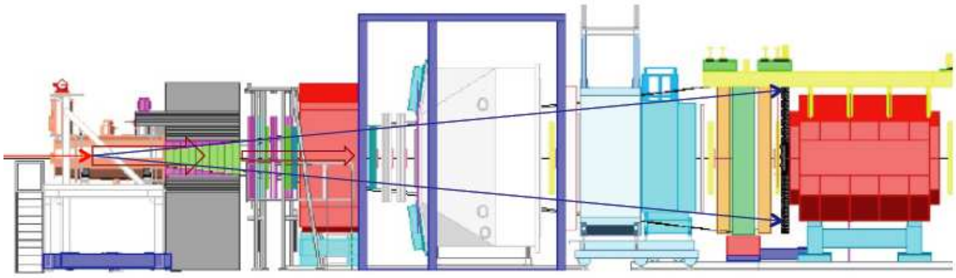

FIGURE 1. The target and first spectrometer regions of the Drell-Yan set-up: the alumina absorber is shown in green, surrounded by a steel (purple) and concrete (grey) shielding. The beam plug is not shown.

muon or hadron beams, in a momentum range of 50 to 280 GeV/c. The optimization studies indicate that a π^- beam at 190 GeV/c is a good choice for the Drell-Yan measurement. This beam has a small contamination of 4% kaons, and less than 1% antiprotons. The radiation safety conditions limit the beam intensity allowed in the experimental hall to 1×10^8 particles/second.

The hadro-production cross-section being much larger than the Drell-Yan one, it becomes mandatory to prevent these hadronic products to overflood the detectors. This goal is achieved by adding a thick hadron absorber immediately downstream of the target. The optimization of such an absorber is still ongoing, but in the preferred design it shall be made of aluminum oxide and be more than 2 meters long. Inside the absorber, along the beam line, a beam plug made of tungsten will be installed, in order to stop all the beam which do not interact in the target cells. Fig.1 presents one of the options for the target region configuration.

In such a measurement it is also very important to have a dimuon trigger. Such trigger will be based on two large area hodoscopes, with homothety and target pointing features.

In the polarized Drell-Yan measurement we are interested mostly in the so-called high mass region, of dimuons with invariant mass $4 \leq M_{\mu\mu} < 9$ GeV/c^2. This mass region has the advantage of being very clean from both combinatorial and physics backgrounds. The Drell-Yan cross-section is nevertheless low, amounting to only fractions of nanobarn. The intermediate mass region $2 \leq M_{\mu\mu} < 2.5$ GeV/c^2 has 5 times larger cross-section, but a non-negligible background contamination. In this mass range the open charm contamination is estimated at the level of 15%, and the combinatorial background is at least as large as the signal. The mass region of the J/ψ resonance is of special interest, not only because of the higher Drell-Yan cross-section as compared to the one in the high mass region, but also because of the so-called DY-J/ψ duality. The J/ψ and the γ being both vector particles, one can consider an analogy between Drell-Yan and the J/ψ production via $q\bar{q}$ annihilation, which is believed to dominate at the energies of this measurement. The possibility of varying the π beam energy may allow to study the J/ψ production mechanisms in addition to checking the duality hypothesis.

A detailed simulation for both the Drell-Yan and the background processes was performed, using PYTHIA LO generator, and a GEANT based simulation of the spectrometer. The geometrical acceptance for high mass dimuons is 35%. More than 50% of the accepted events are identified in the large angle spectrometer (LAS), while almost 40%

TABLE 1. Statistical errors expected in the azimuthal asymmetries, assuming two years of data taking.

	$2 \leq M_{\mu\mu} < 2.5$ **GeV/c^2**	**J/ψ region**	$4 \leq M_{\mu\mu} < 9$ **GeV/c^2**
$A_{UU}^{\cos 2\phi}$	0.0020	0.0013	0.0045
$A_{UT}^{\sin \phi_S}$	0.0062	0.0040	0.0142
$A_{UT}^{\sin(2\phi+\phi_S)}$	0.0123	0.0080	0.0285
$A_{UT}^{\sin(2\phi-\phi_S)}$	0.0123	0.0080	0.0285

have one of the muons identified in the small angles spectrometer (SAS).

Assuming a beam intensity of 6×10^7 particles per second, one expects an instantaneous luminosity of 1.2×10^{32} cm^{-2}s^{-}1, which means an event rate of high mass Drell-Yan events of 800 per day. In 280 days of data-taking the integrated luminosity will be 2900 pb^{-1} and one can collect 230 000 such events.

With an unpolarized or transversely polarized ammonia target, and a π^- beam, one can assume u-quark dominance annihilation, and study the four azimuthal asymmetries: $A_{UU}^{\cos 2\phi}$, $A_{UT}^{\sin \phi_S}$, $A_{UT}^{\sin(2\phi+\phi_S)}$ and $A_{UT}^{\sin(2\phi-\phi_S)}$, which are proportional to the following convolutions of PDFs, respectively: both Boer-Mulders of incoming hadrons, unpolarized of beam with Sivers of target nucleon, Boer-Mulders of beam pion with pretzelosity of target nucleon, and Boer-Mulders of beam pion with transversity of target nucleon. The COMPASS measurement will be probing $x_p > 0.1$, i.e. mostly valence quarks, and the theory predictions are for sizable asymmetries, in the order of 2 to 15%, in this case.

Table 1 presents the expected statistical errors in the asymmetries, assuming two years of Drell-Yan data-taking. Such statistical accuracy will allow to do a study in several x and dimuon p_T bins. In Fig.2 the expected statistical accuracy of the asymmetries is shown together with some theory predictions available for the Drell-Yan case at COMPASS, from [2], [3] and [4].

In order to study the feasibility of the measurement three beam tests were performed in 2007, 2008 and 2009. The radiation conditions in the COMPASS hall were monitored, showing no unexpected effects. The target temperature does not increase significantly with the incident pion beam at the proposed intensity. The relaxation time of the target polarization is measured to be in the order of thousands of hours. The beam tests have shown no problems with the detector occupancies, even for the planes closer to the hadron absorber, that still detect some amount of punch-through low momentum particles.

The J/ψ particles collected in the beam tests have shown a good agreement with the expected from Monte-Carlo, thus validating our simulations. The beam test of 2009 used a prototype hadron absorber and beam plug. The data collected in three days lead to more than 3000 J/ψ events reconstructed. The reconstructed vertexes clearly show the separation between the two target cells as well as the events originating from interactions in the hadron absorber. The combinatorial background resulting from pion decays is estimated using the sample of like-sign muon pairs. The presence of the hadron absorber reduces the combinatorial background by a factor 10 for dimuons of $M_{\mu\mu} = 2$ GeV/c^2.

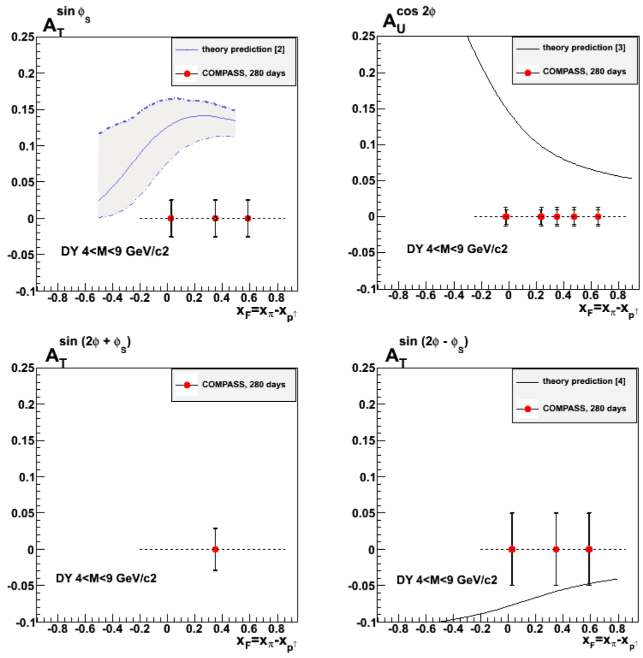

FIGURE 2. Statistical accuracy of the asymmetries in two years of data-taking, compared to several theory predictions ([2], [3] and [4]) for the Drell-Yan COMPASS case in the dimuons high mass region.

The Drell-Yan measurement with transversely polarized NH_3 target is part of the COMPASS-II physics program already approved by CERN to start in 2012.

To conclude, one should stress that the expected statistical accuracy will allow to check the theory prediction that the naive time reversal odd TMD PDFs Sivers and Boer-Mulders have opposite signs when measured in SIDIS and in Drell-Yan processes. Not only these two PDFs, but also the transversity and the pretzelosity will be studied as a function of x and dimuon p_T. COMPASS has the potential to become the first experiment to access these TMDs of the nucleon in a polarized Drell-Yan experiment.

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