FORTHCOMING DRELL-YAN MEASUREMENTS AT COMPASS

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Abstract

The COMPASS experiment at CERN is a universal facility which can operate with both muon and hadron beams as well as with unpolarized or longitudinally/transversely polarized liquid and solid targets. The availability of pion beam provides an access to the Drell-Yan physics, i.e. to the process where quark (target)-antiquark (beam) pair annihilates electromagnetically with a production of dilepton pair. The possibility to use in a future COMPASS Drell-Yan measurements a transversely polarized target together with negative pion beam will provide us unique opportunity to access a number of convolutions of transverse momentum dependent PDFs (TMDs), which can not be measured with unpolarized targets.

1 Transverse momentum dependent PDFs

At leading twist, the quark structure of the hadron is completely described by three Parton Distribution Functions (PDFs): the unpolarized distribution function $f_1(x)$, the helicity distribution $g_1(x)$ and transversity function $h_1(x)$. But there are several experimental observations of large azimuthal and spin asymmetries which perturbative QCD at leading twist in collinear approximation can not explain. In particular, large asymmetric azimuthal distributions of final-state leptons measured in high-energy collisions of pions and protons with nuclei [1] – [3] show a striking deviation from the so-called Lam-Tung sum rule [4], [5] that is based on collinear perturbative QCD, and seem to indicate the need to go beyond the collinear approximation. When considering non-zero quark transverse momentum k_T with respect to the hadron momentum, the nucleon structure is described at leading twist by eight PDFs. Two of five new functions: the Boer-Mulders function $h_1^\perp(x, k_T^2)$ describing the correlation between transverse spin and transverse momentum of the quark in an unpolarized nucleon and the Sivers function $f_{1T}^\perp(x, k_T^2)$ describing the influence of the transverse spin of the nucleon into the quark transverse momentum distribution, as well as transversity function h_1 are of great interest to further reveal the partonic (spin) structure of hadrons (see [6] for a review).

The Drell-Yan quark-antiquark annihilation process is an excellent tool to study transversity and k_T-dependent PDFs. In the DY process (Fig. 1) quark and antiquark annihilate into a lepton pair. Other kinds of hard processes can also access chirally odd PDFs, like semi-inclusive deep-inelastic scattering (SIDIS) where chirality is conserved through the convolution of PDFs with polarized quark fragmentation functions. There exist no fragmentation process in DY. In order to access spin structure information a high-intensity hadron beam and a large-acceptance setup as well as a high-performance polarized target are required. These features are provided by the multipurpose large-acceptance COMPASS spectrometer.

2 Future Drell-Yan measurement at COMPASS

COMPASS is a fixed target experiment at the secondary beams of Super Proton Synchrotron at CERN [7]. The purpose of the experiment is the study of hadron structure and hadron spectroscopy with high intensity muon and hadron beams [8]. The COMPASS detector consists of two spectrometers built around two dipole magnets in order to detect particles scattered at large and small angles, respectively. It is equipped with a large number of precise tracking detectors, two electromagnetic calorimeters, two hadron calorimeters and particle identification system including RICH and two muon walls. Layout of a target region of the experiment can be optimized for a particular measurement. COMPASS operates with muon and hadron beams with momentum up to 200 GeV/c. During the first phase (2002-2011) of the experiment the longitudinal and transverse nucleon spin structures were studied via deep inelastic scattering with muon beam of high intensity. Production of hadron resonances via diffractive scattering, central production and photon exchange using pion and proton beams and hydrogen, tungsten, lead and nickel targets were also studied.

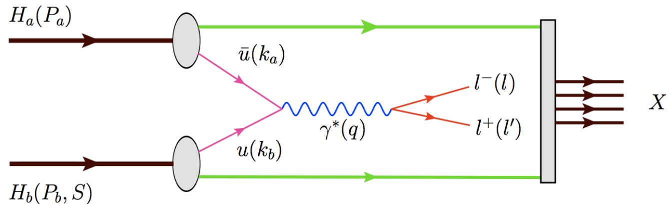
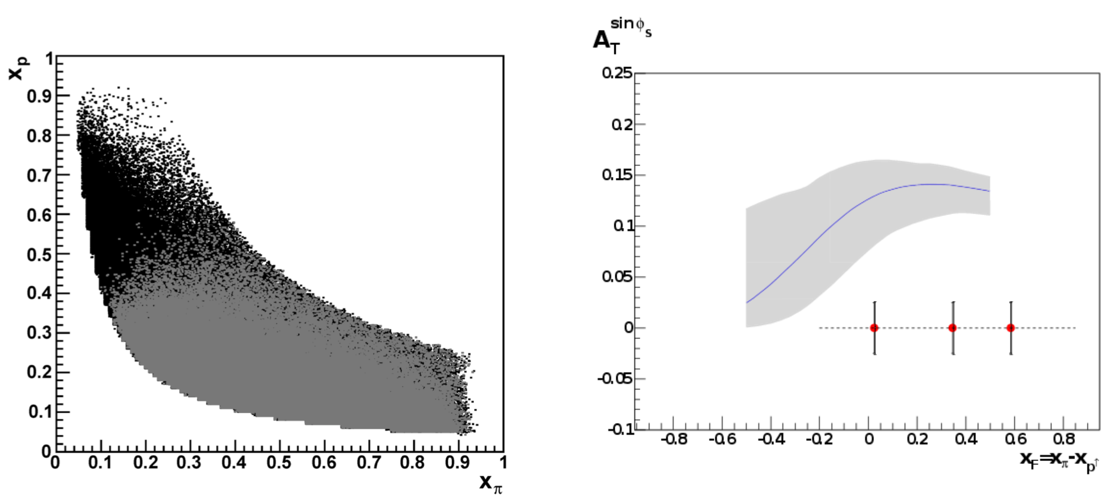


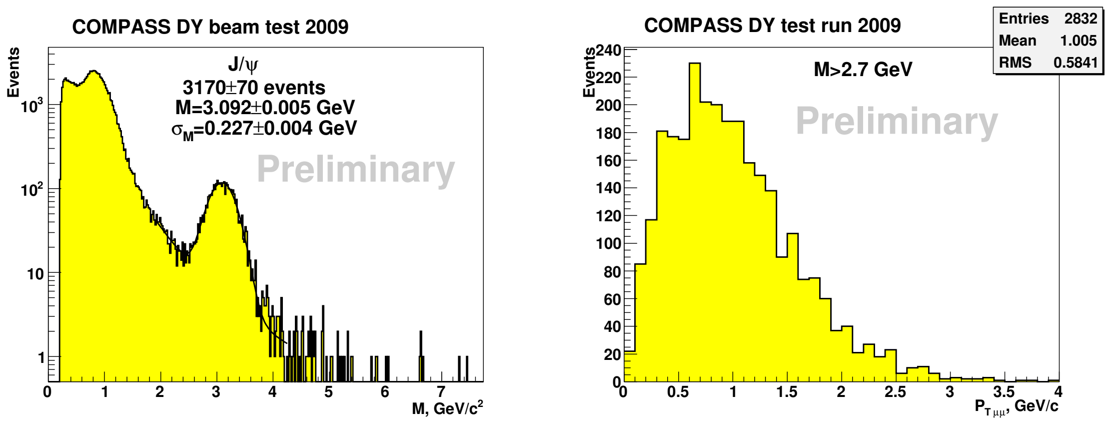
Figure 1: Feynman diagram of the Drell-Yan process.

Possible extension of COMPASS physic program is described in the COMPASS-II Proposal [10] which was approved by the CERN Research Board for the period of three



(a) (b)

Figure 2: **(a)** Kinematic range in x_π vs. x_p, covered by COMPASS (in grey) for $4\ GeV/c < M_{\mu\mu} < 9\ GeV/c$ (Monte-Carlo simulation). **(b)** Expected error of the Sivers asymmetry for a measurement in three bins of $x_F = x_p - x_\pi$. Two years of data taking (280 days) is assumed.



(a) **(b)**

Figure 3: **(a)** The measured $\mu^+\mu^-$ invariant mass distribution. The number of events is obtained from the fit in the J/ψ region. **(b)** P_T distribution for dileptons with $M_{\mu^+\mu^-} > 2.7\ GeV$

years starting since 2012. It consists of three general directions: tests of chiral perturbative theory, GPD program and Drell-Yan program.

Convolutions of PDFs of incoming pion and target proton can be accessed via the measurement of the lepton pair angular distributions in the final state. The Sivers and Boer-Mulders functions are T-odd objects. QCD predicts that the $f_{1T}^{\perp}$ and the $h_1^{\perp}$ functions extracted from DrellYan processes and those obtained from semi-inclusive DIS should have opposite sign [11], i.e.

$$f_{1T}^{\perp}\big|_{DY} = -\ f_{1T}^{\perp}\big|_{DIS}\,,\quad h_{1T}^{\perp}\big|_{DY} = -\ h_{1T}^{\perp}\big|_{DIS}\,. \tag{1}$$

COMPASS provides unique opportunity to test this QCD prediction because SIDIS and DY measurements can be done at the same setup and in overlapping kinematic ranges. The J/ψ-resonance production mechanism can also be studied in parallel.

For Drell-Yan studies COMPASS will operate with 190 GeV/c π^- beam of high intensity (up to $10^8\ s^{-1}$) and transversely polarized NH_3 target. Hadron absorber will be installed just downstream the target to stop both secondary hadrons and unscattered beam pions to prevent their decay into muons and reduce the combinatorial background and occupancy of tracking detectors . Construction of the absorber will be optimized to minimize multiple scattering in material for muons. Dedicated trigger for the selection of a pair of oppositely charged muons will be provided. A safe range for dimuon masses, separated from J/ψ and Υ peaks, is 4-9 GeV/c^2. Kinematic range of x_π and x_p variables which are the fractions of the momentum carried by the interacting parton in the incoming pion and proton respectively, covered by COMPASS is shown on Fig. 2(a). Main part of potentially observed DY events correspond to annihilation of valence quarks ($x_\pi,\ x_p > 0.1$). According to the performed Monte Carlo study the average value of the dilepton transverse momentum PT will stay at about 1 GeV. In this range the TMD-induced effects are expected to be dominant. Two years of data taking with the beam intensity of $6 \times 10^7\ s^{-1}$ will allow to collect enough statistics (more than 200 000 DY events) to extract TMD PDFs. Expected error of the Sivers asymmetry for a measurement in three bins of $x_F = x_p - x_\pi$ is shown on Fig. 2(b).

Feasibility of Drell-Yan measurements at COMPASS was studied during three short beam tests. The most important three-day-long test was performed in 2009. The polarized target was simulated by two cylinders of polyethylene. A prototype hadron absorber was installed downstream of the target. The beam intensity of 8×10^7 pions/spill (spill length of 9.6 s) was used except for two runs when the beam intensity was increased up to 1.5×10^8/spill (integrated beam flux was equal to 3.7×10^{11} pions). J/ψ peak was used as a monitoring signal (see Fig. 3(a)). The number of expected J/ψ events based on the cross section, accumulated luminosity, apparatus acceptance and trigger/reconstruction performance is 3600 ± 600, the number of expected DY events in the mass range $4\ GeV/c^2 < M_{\mu\mu} < 9\ GeV/c^2$ is 110 ± 22. The number of found J/ψ's (3170 ± 70) is in good agreement with the expected yield as well as the number of DY events of 84 ± 10. Events with dimuon mass below J/ψ peak were also studied. Distribution of P_T of dimuon with $M_{\mu\mu} > 2.7\ GeV$ is shown of Fig. 3(b) and it corresponds to our expectations from the Monte Carlo, that the typical P_T is about 1 GeV.

3 Conclusion

Polarized Drell-Yan measurement is a part of COMPASS-II proposal. This proposal was approved by CERN SPSC for a first period of 3 years (1 year of Drell-Yan data taking). Three DY beam test were performed so far and the feasibility of the measurement with the COMPASS spectrometer was demonstrated. According to our estimations 2 years of data taking with the beam intensity of $2 \times 10^8\ s^{-1}$ will allow to collect enough statistics for test theory predictions and extract TMD PDFs. After one year of data taking with the beam intensity up to $10^8\ s^{-1}$ we aim to measure the Sivers asymmetry with statistical accuracy about 1-2%. Comparison of Sivers and Boer-Mulders functions measured in DY and SIDIS also can be performed.

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