Future Drell-Yan measurement @ COMPASS

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The COMPASS experiment is investigating possible physics aspects connect with the use of the polarized target (PT) together with the secondary (CERN–SPS) hadron beams. The main purpose of this project is to study the Drell–Yan reactions as a clear tool to measure the parton distribution functions, in particular the Boer-Mulders, the Sivers and the transversity functions.

Keywords: COMPASS; Drell–Yan; PDF; Transversity; Sivers function, Boer–Mulders function.

1. Introduction

The interest on the parton distribution functions (PDFs) has developed a large variety of researches both on theoretical and on experimental side. Nowadays, a large source of data has been provided with the deep inelastic scattering inclusive (DIS) and semi-inclusive (SIDIS). A complementary tool to access the PDFs is through the Drell-Yan (DY) mechanism. In this way it is possible to measure directly the PDFs without any convolution with the fragmentation functions, as it is for example in the case of the SIDIS. The DY reaction consists of an electromagnetic annihilation of quark and antiquark of colliding hadrons into a lepton pair production. In this context the PDF of the quarks of the interacting hadrons can be extracted. Thanks to the large lepton pair mass ($M^2 = Q^2$), this electromagnetic process can be factorized into terms describing the soft physics convoluted with the elementary cross-section:

$$d\sigma^{DY} \propto \sum_q f_q(x_1, k_{\perp 1}, Q^2) \otimes f_{\overline{q}}(x_2, k_{\perp 2}, Q^2) \cdot d\sigma^{q\overline{q} \to l^+ l^-}, \tag{1}$$

where x_i is the Bjorken variable, $k_{\perp i}$ is the transverse momentum of the

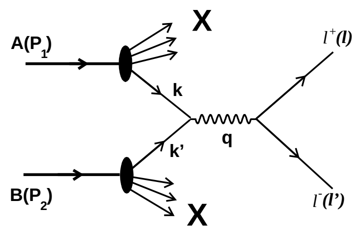

Fig. 1. Feynman diagram of the DY process

quark inside the hadron and Q^2 is the square of the four-momentum transferred, i. e. the square of invariant mass of the produced di-lepton pair. The introduction of the $k_\perp$ plays a fundamental role to explain the data on large p_T production of pions [1]. Without this inclusion the collinear model computation does not give results in agreement with the data. This fact open the way to many possible spin effect. For this purpose the COMPASS experiment [2] will perform a new generation of DY experiment with high intensity beam, large acceptance apparatus and a polarized target, not only to increase the statistics of the past experiment, limited by the low DY cross-section, but also to explore the effect due to the polarized target.

2. The PDFs

The complete knowledge of the nucleon spin structure at leading twist in case of perfect collinear quark is described by three distribution functions: the unpolarized PDF $f_1(x)$, that gives the probability to find an unpolarized quark with a fraction x of the longitudinal momentum of the unpolarized parent nucleon, the helicity PDF $g_1(x)$, that describes the difference between the number density of the quark with spin parallel and anti-parallel to the longitudinal polarized parent nucleon and the transversity PDF $h_1(x)$, that have the same meaning of $g_1(x)$, but in the case of transversely polarized nucleon. At the level of leading twist, if the partonic intrinsic motion $k_\perp$ inside the nucleon is considered, the nucleon is described by eight PDFs: $f_1(x, k_\perp^2)$, $g_{1L}(x, k_\perp^2)$, $h_1(x, k_\perp^2)$, $g_{1T}(x, k_\perp^2)$, $h_{1T}^\perp(x, k_\perp^2)$, $h_{1L}^\perp(x, k_\perp^2)$, $h_1^\perp(x, k_\perp^2)$, $f_{1T}^\perp(x, k_\perp^2)$, for a review see Ref. [3]. The first three ones are integrated on $k_\perp$ become the PDFs before cited $f_1(x)$, $g_1(x)$, $h_1(x)$ respectively. A possible way to measure the transversity $h_1(x)$, the Boer–Mulders $h_1^\perp(x, k_\perp^2)$, Sivers function $f_{1T}^\perp(x, k_\perp^2)$ is presented.

3. Drell–Yan physics with transversely polarized target

The COMPASS future program with intense pion beams, involving the valence quark ($x_B > 0.1$) spin dependent PDFs in the energy scale of $Q^2 >> 1(GeV/c)^2$ is presented.

In COMPASS both unpolarized ($\pi + p \rightarrow l^+ + l^- + X$) and single transverse spin polarized ($\pi + p^{\rightarrow} \rightarrow l^+ + l^- + X$) DY processes are available. Depending on the pion beam charge, the PDFs for the u and for the d quark can be studied separately. They are not mixed up as in the case of the $\overline{p}p$, because the $\overline{u}u$ annihilation takes place mainly with the π^- beam, while the $\overline{d}d$ annihilation is accessible with the π^+ beam, negletting the non–valence quark contributions.

The Collins–Soper frame [4] (see Fig. 2) is commonly used to describe the DY processes where θ and ϕ are the polar and the azimuthal angle

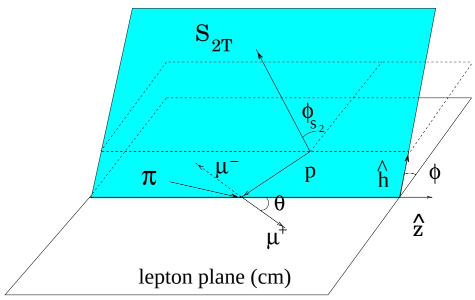

Fig. 2. The Collins-Soper frame.θ and Φ are the polar and the azimuthal

of the positive lepton produced in the reaction. The x-axis is chosen as the incoming hadron direction, the y-axis is perpendicular to the hadron plane, while the z-axis is chosen along the bisector between the μ^+ and the target hadron direction. The third angle ϕ_{S_2} is peculiar of the polarized DY reaction, in fact it represents the azimuthal spin vector of the polarized hadron target with respect to the di-lepton plane.
The effect of the transverse motion of the quark inside the nucleon can be studied through the Single Spin Asymmetry (SSA). In case of $\pi + p^{\rightarrow} \rightarrow l^+ + l^- + X$ the SSA can be expressed like:

$$A^{\sin(\Psi)} = \frac{\int d\Omega d\phi_{S_2} \int d^2 q_T (\frac{|q_T|}{M}) \sin\Psi [d\sigma(S_{2T}) - d\sigma(-S_{2T})]}{\int d\Omega d\phi_{S_2} \int d^2 q_T [d\sigma(S_{2T}) - d\sigma(-S_{2T})]} \qquad (2)$$

where q_T are the transverse component of the virtual gamma exchange in the interaction in the Collins–Soper frame and $\Psi = (\phi \pm \phi_{S_2})$. The asymmetry, shown in Eq. 2, is obtained using the q_T weighting approach as suggested in Ref. [5–8].

Therefore using the Ψ weight variable it is possible to disentangle the two contributions present in this asymmetry:

$$A^{\sin(\phi+\phi_{S_2})} \propto \frac{\overline{h}^{\perp(1)}_{1\overline{u}}(x_\pi)\cdot h_{1u}(x_p)}{\overline{f}_{1\overline{u}}(x_\pi)\cdot f_{1u}(x_p)};\ A^{\sin(\phi-\phi_{S_2})} \propto \frac{\overline{f}^{(1)}_{1\overline{u}}(x_\pi)\cdot f^{\perp(1)}_{1T}(x_p)}{\overline{f}_{1\overline{u}}(x_\pi)\cdot f_{1u}(x_p)} \quad (3)$$

The weighting approach can be also used in the unpolarized reaction $\pi + p \rightarrow l^+ + l^- + X$. In this case ratio R between the angular differential unpolarized cross-section and the unpolarized cross section can be constructed and its parameterization is:

$$\hat{R} = \frac{\int d^2q_T[\frac{|q_T|^2}{\mathbf{M_\pi M_p}}][\frac{d\sigma^0}{d\Omega}]}{\int d^2q_T\sigma^0} = \frac{3}{16\pi}(\gamma(1+\cos^2\theta) + \hat{k}\cos(2\phi)\sin^2\theta)) \quad (4)$$

in the coefficient $\hat{k}$ the PDFs appear as:

$$\hat{k} = 8\frac{\overline{h}^{\perp(1)}_{1\overline{u}}(x_\pi)\cdot h^{\perp(1)}_{1u}(x_p)}{\overline{f}^{\perp(1)}_{1\overline{u}}(x_\pi)\cdot f^{\perp(1)}_{1u}(x_p)} \quad (5)$$

where $\overline{h}^{\perp(1)}_{1\overline{u}}(x_\pi)$ and $h^{\perp(1)}_{1u}(x_p)$ are the Boer-Mulders functions for pion and proton respectively.

At this point there are three unknown functions to be extracted, but only two equations, nevertheless if one assume that [9, 10]:

$$\frac{\overline{h}^{\perp(1)}_{1u}(x_{\pi^-})}{h^{\perp(1)}_{1u}(x_p)} = C_u \cdot \frac{\overline{f}_{1u}(x_{\pi^-})}{f_{1u}(x_p)}; \qquad C_u \approx 1 \quad (6)$$

the system of three equations can be solved.

Studying the dependence on $sin(\phi + \phi_{S_2})$ in polarized measurement of SSA, as reported in Eq. 3, together with the unpolarized measurement, the transversity and the first moment of the Boer-Mulders functions can be extracted. Studying the $sin(\phi - \phi_{S_2})$ dependence in the polarized reaction $\pi + p^{\rightarrow} \rightarrow l^+ + l^- + X$, the Sivers function can be deduced.

The measurement of this T-odd parton distribution function is very interesting because of its peculiar property [11]:

$$f^{\perp}_{1T}|_{DY} = -f^{\perp}_{1T}|_{DIS} \quad (7)$$

the Sivers function measured via the DY reaction and via the SIDIS should show a reversed sign, if measured in the same kinematical range. An experimental proof of the Eq. 7 would provide an exhaustive test of the Sivers mechanism within the QCD. In particular it would be a crucial test of the factorization approach for the description of this kind of processes, sensitive to the transverse parton momenta. One of the theoretical prediction for the Sivers function [12] for the COMPASS kinematical range is illustrated in Fig. 3.

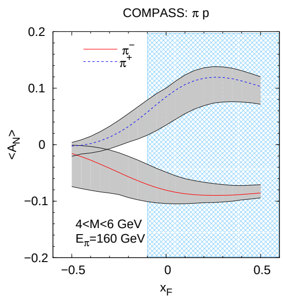

Fig. 3. Prediction [12] for the SSA contribution due to the Sivers function vs the x_F variable. In light-blue is highlighted the region covered by the COMPASS kinematical range

4. COMPASS apparatus and upgrade

To study the feasibility of the DY measurement with the COMPASS setup, a MonteCarlo (MC) event simulation, together with a beam test were performed in 2007. The MC simulations were done using the standard analysis COMPASS softwares [13]. To produce events dominated by the valence quark-antiquark annihilation in the reaction $\pi + p \to \mu^+ + \mu^- + X$ two event generators Pythia [14] and the DY-AB5 [15] were used. Then the acceptance of the COMPASS setup for DY pair $(\mu^+\mu^-)$ was studied. The events were generated in the invariant mass range of $4.0\ GeV/c^2 < M_{\mu^+\mu^-} < 9.0\ GeV/c^2$, to avoid the J/Ψ and Υ resonances, where the main production mechanism is not the quark-antiquark annihilation. Different pion beam momenta were tested in order to select events falling in the valence quark-antiquark region, but having cross-section large enough to provide a reasonable statistics in the dimuon mass region between $4.0\ GeV/c^2$ and $9.0\ GeV/c^2$. The target length and target material can to be optimized in order to maximize the rate of DY events together with the conditions to keep low the rate of background events and the effect multiple scattering in the target.

The very preliminary MC results together with the 2007 beam test shows the feasibility of this measurement. During this test a beam intensity of $2 \cdot 10^7 \pi$ per spill with the full COMPASS polarized target were used. The corrisponding luminosity reached was $L = 10^{31} cm^{-2} s{-}1$.
A new trigger system, to select the di-muon pair, based on two scintillating hodoscopes dectectors, is under study for the COMPASS DY future program.

5. Conclusion

The DY program at COMPASS can be started after the 2010. For the first time the SSA in a DY process will be measured with the COMPASS experimental setup, which is basically ready to reconstruct the di–lepton muon pair. The statistical error achievable mainly depends on the choice of the target material.

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