Transversity and inclusive two-pion production

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Abstract. A model for dihadron fragmentation functions is briefly outlined, that describes the fragmentation of a quark in two unpolarized hadrons. The parameters are tuned to the output of the PYTHIA event generator for two-hadron semi-inclusive production in deep inelastic scattering at HERMES. Then predictions are made for the unknown polarized fragmentation function and the related single-spin asymmetry in the azimuthal distribution of $\pi^+\pi^-$ pairs in semi-inclusive deep inelastic scattering on transversely polarized targets at HERMES and COMPASS. This asymmetry can be used to extract the quark transversity distribution.

Keywords: deep-inelastic scattering, transverse polarization, fragmentation, spin asymmetry

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Dihadron Fragmentation Functions (DiFF) describe the probability that a quark hadronizes into two hadrons plus anything else, i.e. the process $q \rightarrow h_1 h_2 X$ [1]. They can appear in lepton-lepton, lepton-hadron and hadron-hadron collisions producing final-state hadrons. DiFF can be used as analyzers of the spin of the fragmenting quark. At present, the most important application of polarized DiFF is the measurement of the quark transversity distribution $h_1$ in the nucleon, which represents the probabilistic distribution of transversely polarized partons inside transversely polarized hadrons.

Transversity is a missing cornerstone to complete the knowledge of the leading-order (spin) structure of the nucleon (for a review, see Ref. [2]). Its peculiar behavior under evolution represents a basic test of QCD in the nonperturbative domain. The most popular strategy to extract $h_1$ is to consider Deep Inelastic Scattering (DIS) of electrons on transversely polarized targets, and look for azimuthally asymmetric distributions of inclusively produced single pions when flipping the spin of the target (the so-called Collins effect [3]). But the cross section must explicitly depend on the transverse momentum of the pion [4].

Inclusive production of two pions offers an alternative and easier framework, where the chiral-odd partner of $h_1$ is represented by the DiFF $H^q_{\perp}$, which relates the transverse spin of the quark to the azimuthal orientation of the $(\pi\pi)$ plane. In fact, the leading-twist spin asymmetry is [5]

$$A_{UT}^{\sin(\phi_R+\phi_S)} = \frac{1}{\sin(\phi_R+\phi_S)} \frac{d\sigma^+ - d\sigma^-}{d\sigma^+ + d\sigma^-} \propto \frac{\sum_q e_q^2 (h_1^q(x)/x, M_{h_1}^2)}{\sum_q e_q^2 (f_1^q(x)/x, D_1^q(z, M_{h_1}^2)} \left(\frac{h_1^q(x)}{x}\right)^{\phi_R} \left(\frac{f_1^q(x)}{x}\right)^{\phi_S},$$

(1)

where $M_h$ is the invariant mass of the two pions carrying a total $z$ momentum fraction, and $\phi_R$ and $\phi_S$ are the azimuthal orientations with respect to the scattering plane of the $(\pi\pi)$ plane and target spin, respectively (see Fig. 1 left panel).
So far, in the literature only two papers addressing $A_{UT}$ were available: one predicting a sign change around $M_h \sim m_\rho = 770$ MeV [6], one predicting a stable small asymmetry [5]. In the right panel of Fig. 1, I show results for the latter one, adjusted to the Trento conventions [7] and compared with the recent preliminary data from HERMES [8]. The applicability range in $M_h$ was restricted around the $\rho$ mass, and a large uncertainty band was deriving from modelling $h_1$ in Eq. (1) as well as from the unavailability of constraints on the model parameters. Here, I present some results from a significant upgrade of this model [9], where in the same framework of the "spectator" approximation a $(\pi^+ \pi^-)$ pair can be produced via a background contribution, or via the $\rho$ resonance, or via the $\omega$ resonance decaying either directly in $(\pi^+ \pi^-)$ or in $(\pi^+ \pi^- \pi^0)$ (and then summing upon the unobserved $\pi^0$). The asymmetry is generated by the interference between the first channel, where the $(\pi^+ \pi^-)$ is assumed to be produced in a relative $s$ wave, and the other ones where the $(\pi^+ \pi^-)$ is assumed in a relative $p$ wave. At variance with Ref. [5], the parameters are fixed by reproducing the $M_h$ and $z$ dependences of $(\pi^+ \pi^-)$, as they come out from PYTHIA adjusted to HERMES kinematics. In other words, the $D_1$ in Eq. (1) is fitted and the calculation of $H_1^{\text{CS}}$ is a true predictions.

The results are shown in Fig. 2, left panel, for several models of $h_1$ in Eq. (1). The
statistical uncertainty on $H_{S}$, coming from the parameter fixing, is negligible \([9]\); the theoretical uncertainty comes entirely from modelling $h_1$. The shape of $A_{UT}$ is quite good, but the overall size is too big. There are mainly two reasons for that. In the calculations, the spectator was assumed the same in all channels, which maximizes the interference of pion pairs in different channels \([9]\). Moreover, it is known that the channel $\omega \rightarrow \pi^{+}\pi^{-}\pi^{0}$ contains a significant percentage of $(\pi^{+}\pi^{-})$ in relative $s$ waves; hence also this channel has been overestimated \([9]\). To have an idea of the size of the overestimation, in the right panel of Fig. 2 the lowest and the highest $A_{UT}$ of the left panel have been transformed in histograms, by averaging the theoretical result over each of the five experimental bins (see Ref. \([9]\) for details), and then the histograms have been fitted to the HERMES data. It turns out that it is necessary to reduce to 40% the number of $(\pi^{+}\pi^{-})$ pairs active in the $s-p$ interference; the number of pairs in $p$ wave, coming from the $\omega \rightarrow \pi^{+}\pi^{-}\pi^{0}$ channel, must be further reduced to 60%, which amounts to a total reduction of 24% of pairs active in this channel.

**FIGURE 3.** The same results as in Fig. 2 left panel, but in the COMPASS kinematics.

In Fig. 3 the same $A_{UT}$ is displayed in the COMPASS kinematics, where the lepton-proton scattering c.m. energy is now $s \sim 300$ GeV$^2$ and the phase space has been reduced to $0.03 < x < 0.4$.

**FIGURE 4.** Left panel: COMPASS data for the pion pair invariant mass dependence of the single-spin asymmetry for deep-inelastic scattering on a deuteron target \([14]\). Right panel: the same results as in Fig. 3 but for a deuteron target.

In Fig. 4 the COMPASS experimental data using deuteron targets (left panel) are compared with $A_{UT}$ from Eq. (1) adjusted to a deuteron target: the cancellation induced
by the isospin structure of the target is confirmed also for two-hadron inclusive production.

Finally, it is worth to mention that there is a valid alternative to extract $h_1$ via dihadron fragmentation functions, which is of interest for all the facilities devoted to hadronic collisions, like RHIC, GSI and, particularly, JPARC. Leaving the details for the interested reader to Ref. [15], here I just sketch the argument. In the $pp^{↑} \rightarrow (\pi \pi)X$ process, where a pion pair is detected in one jet, the polarized cross section is proportional to the convolution

$$d\sigma_{UT} \propto f_1^a \otimes h_1^b \otimes d\Delta\hat{\sigma}_{ab^{↑} \rightarrow c^{↑}d} \otimes H_1^{sc},$$

(2)

where $d\Delta\hat{\sigma}$ is the elementary cross section at the partonic level. There are two unknowns in this formula. But if in the same experiment also the $pp \rightarrow (\pi \pi)(\pi \pi)X$ process is considered where two pion pairs are detected each one in a separate jet, the cross section contains the convolution

$$f_1^a \otimes f_1^b \otimes d\Delta\hat{\sigma}_{ab \rightarrow c^{↑}d} \otimes H_1^s \otimes H_1^{sd}.$$  

(3)

Therefore, a combined measurement of the two processes makes it possible to self-consistently determine the unknowns, namely $H_1^s$ and $h_1$.

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