# Tracing the origin of the left-right asymmetries observed in inclusive single-spin hadron-hadron collisions

C. Boros, Z. Liang, T. Meng and R. Rittel (presented by Z. L.)

Institut für theoretische Physik der FU Berlin, Arnimallee 14, 14195 Berlin, Germany

**Abstract:** It is shown that the origin of the striking left-right asymmetries observed in single-spin inclusive hadron production processes in high energy hadron-hadron collisions can be traced by performing suitable experiments at HERA. The possible outcomes of these experiments are summarized. It is pointed out that the results of such a set of experiments will not only be able to differentiate between existing theoretical models, but also be helpful in locating the source(s) of the observed asymmetries.

Striking left-right asymmetries ($A_N$) have been observed [1-3] for hadron production in single-spin high energy hadron-hadron collisions. A number of mechanisms [4-11] have been proposed recently which can lead to non-zero $A_N$'s in the framework of quantum chromodynamics (QCD) and/or quark or quark-parton models. Among the competing theoretical models the following two classes of models enjoy the privilege of being simple — so simple that the basic ingredients of these models can be directly tested by performing suitable experiments: (1) perturbative QCD based hard scattering models [4-9] and (2) non-perturbative quark-fusion models [11].

In the pQCD based hard scattering models [4-9], the cross section for inclusively produced hadrons in hadron-hadron collisions is expressed as convolution of (i) the cross section for the relevant elementary hard scattering (ii) the momentum distribution functions of the constituents of the colliding hadrons; and (iii) the fragmentation function of the scattered constituent which describes its hadronization process. The asymmetry can originate from any one or more of these three factors.

In the second type of models [11], the basic elementary process is quark-antiquark fusion — which is a process that *cannot* be calculated by using perturbative QCD. The asymmetry originates from the orbital motion of the valence quarks in transversely polarized nucleons and the hadronic surface effect in single-spin hadron-hadron collisions.

Both kinds of model can give significant left-right asymmetry for inclusive hadron production in single-spin hadron-hadron collisions. It is impossible to tell which one is more appriciate to describe the abovementioned data[1-3]. In particular, it is impossible to tell which factor in the type one model is asymmetric since one observes always the convolution of all the three factors. In a recent paper [12], we proposed several new experiments and pointed out that the results of such experiments together with those of others [7,11] will not only be able to differentiate between the abovementioned models, but also be helpful in locating the source(s) of the observed asymmetries. The experiments we have proposed and/or chosen for this purpose are the following:

(A) Perform $l + p(\uparrow) \rightarrow l + \pi + X$ for large $x_B$ ($> 0.1$, say) and large $Q^2$ ($> 10$ GeV$^2$, say) and measure the left-right asymmetry in the current fragmentation region *with respect to the jet axis.* Here, $l$ stands for charged lepton $e^-$ or $\mu^-$; $x_B \equiv Q^2/(2P \cdot q)$ is the usual Bjorken-$x$, $Q^2 \equiv -q^2$, and $P, k, k', q \equiv k - k'$ are the four momenta of the proton, incoming lepton, outgoing lepton and the exchanged virtual photon respectively. The transverse momenta of the produced hadrons with respect to this axis come solely from the fragmentation of the quark. Hence, by measuring this transverse momentum distribution, we can directly find out whether the fragmentation function of this polarized quark is asymmetric.

(B) Perform the same kind of experiments as that mentioned in (A) and measure the left-right asymmetry of the produced pions in the current fragmentation region *with respect to the photon direction* in the rest frame of the proton, and examine those events where the lepton plane is perpendicular to the polarization axis of the proton. In such events, the obtained asymmetry should contain the contributions from the intrinsic transverse motion of quarks in the polarized proton and those from the fragmentation of polarized quarks, provided that they indeed exist.

(C) Perform the same kind of experiments as that in (A), but measure the left-right asymmetry *in the target fragmentation region* with respect to the moving direction of the proton in the collider (e.g. HERA) laboratory frame. By doing so, we are looking at the fragmentation products of "the rest of the proton" complementary to the struck quark (from the proton). Since there is no contribution from the elementary hard scattering processes and there is no hadronic surface effect, $A_N$ should be zero if the existence of left-right asymmetries is due to such effects. But, if such asymmetries originate from the fragmentation and/or from the intrinsic transverse motion of the quarks in the polarized proton, we should also be able to see them here.

(D) Measure the left-right asymmetry $A_N$ for $l\bar{l}$ and/or that for $W^{\pm}$ in $p(\uparrow) + p(0) \rightarrow l\bar{l}$ or $W^{\pm} + X$. Here, there is no contribution from the quark fragmentation. Hence, non-zero values for $A_N$ in such processes can only originate from asymmetric quark distributions — including those due to orbital motion of valence quarks and surface effect.

The results of different models for these experiments are summarized in the table.

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**Table:** Predictions for left-right asymmetries in the discussed experiments if the asymmetries observed in inclusive hadron production in hadron-hadron collisions originate from the different kinds of effects mentioned in the text.

| process | If the $A_N$ observed in $p(\uparrow) + p(0) \to \pi + X$ originates from ... | | | |
|---|---|---|---|---|
| | quark distribution function | elementary scattering process | quark fragmentation function | orbital motion of valence quarks & surface effect |
| $l + p(\uparrow) \to l + \begin{pmatrix} \pi^\pm \\ K^+ \end{pmatrix} + X$ in the current fragmentation region for large $Q^2$ and large $x_B$ | $A_N = 0$ wrt jet axis | $A_N = 0$ wrt jet axis | $A_N \neq 0$ wrt jet axis | $A_N = 0$ wrt jet axis |
| | $A_N \neq 0$ wrt $\gamma^\star$ axis | $A_N = 0$ wrt $\gamma^\star$ axis | $A_N \neq 0$ wrt $\gamma^\star$ axis | $A_N = 0$ wrt $\gamma^\star$ axis |
| $l + p(\uparrow) \to l + \begin{pmatrix} \pi^\pm \\ K^+ \end{pmatrix} + X$ in the target fragmentation region for large $Q^2$ and large $x_B$ | $A_N \neq 0$ | $A_N = 0$ | $A_N \neq 0$ | $A_N = 0$ |
| $p + p(\uparrow) \to \begin{pmatrix} l\bar{l} \\ W^\pm \end{pmatrix} + X$ in the fragmentation region of $p(\uparrow)$ | $A_N \neq 0$ | $A_N \approx 0$ | $A_N = 0$ | $A_N \neq 0$ |