Evidence for a Transverse Single-Spin Asymmetry in Leptoproduction of $\pi^+\pi^-$ Pairs

One of the fundamental properties of every particle is its *spin*. It could be viewed as its *intrinsic rotation* much like a spinning ball. Depending on the value one has two classes of particles: Fermions and Bosons. Most of the matter as we know it consists of Fermions, which are particles with spin that is an odd multiple of $\frac{1}{2}\hbar$ (in contrary to Bosons whose spin is an even multiple of $\frac{1}{2}\hbar$). In particular, atoms are made of a hard core consisting of protons and most of the time also neutrons, surrounded by a cloud of electrons, which are much lighter (about 1/2000) than protons and neutrons. All the evidence we have up-to-date is that electrons are indeed elementary particles, i.e., they are point-like without any substructure. On the other hand, protons and neutrons (subsequently denoted as nucleons) were found to be made of even smaller, probably point-like partons: quarks and gluons. Naturally the question then arises how these partons interplay to give the nucleon the properties it has. Especially intriguing to theorists and experimentalists alike, is the question of how these various constituents conspire to yield the spin of the nucleon.

The HERMES experiment at DESY was built to shed light on exactly that question. It uses the (polarized) electron beam of HERA, a storage ring for electrons and protons. HERMES also has polarized targets which are bombarded by the electrons of the beam. The energy of the beam electrons is large enough to break up a target nucleon. The fragments of the nucleon will then form new particles, mostly pions, which can be detected with the HERMES spectrometer. In some way one could compare this to a huge microscope: The HERA storage ring – a particle accelerator – provides "light" that is energetic enough to resolve objects of the size of the nucleon (and smaller), e.g., sizes of less then 1fm (10^{-15}m) – about 1/100000 the size of a hydrogen atom! The target is the object we want to study under the microscope, and the HERMES spectrometer is the eye.

With such an apparatus one is indeed able to look at the inner structure of the nucleons. This structure can be described in terms of parton distribution functions (PDFs), which tell you how often one will find partons in a certain state. These functions are usually given as functions of x, the fraction of the nucleon's longitudinal momentum carried by that parton. If one only worries about the quark structure and ignores the transverse motion of these quarks (which means one just does not study the transverse motion and thus averages over all the possible transverse directions), then there are three PDFs that fully describe the structure of the nucleon. One describes the total number of quarks in the fast-moving nucleon.

Another one describes the number of quarks with their spin pointing in the same direction as the nucleon's spin when the nucleon is longitudinally polarized, and the third one measures the number of quarks with their spin pointing along the nucleon's spin when it is transversely polarized. These different views of the nucleon are illustrated in Fig. 1.

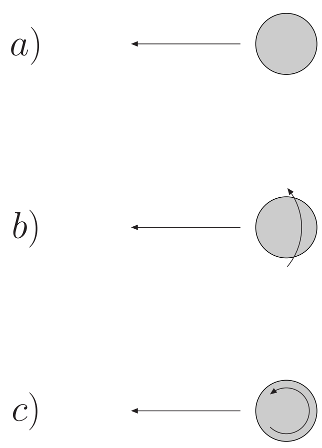

FIG. 1: Different views of nucleons that move very fast in the z direction: a) unpolarized nucleon, b) longitudinally polarized, and c) transversely polarized nucleon.

It turns out that the first two PDFs are relatively easy to measure. However, transversity escaped attention as no practical way of measuring the transverse polarization of quarks had been known. Of course, that did not satisfy physicists' curiosity and so various ways of studying transverse quark polarization became available. One such 'quark polarimeter' is the so-called *Collins* function, which became subject to an earlier HERMES publication. Here, another 'quark polarimeter' is utilized: the orientation of the plane defined by two pions produced from a transversely polarized quark, compared to the direction of the quark 's transverse spin. Without going into details one of the hadrons produced prefers to go – on average – to one side of the quark spin, while the other hadron goes into the opposite direction.

The HERMES experiment took an extensive data set for which the nucleon, in this case a proton, was polarized in a direction transverse to the incoming lepton beam. The interesting question was thus: Do the quarks in this nucleon have their spin preferentially in the same direction as the proton? And, did the distribution of hadron pairs produced from such quarks exhibit an dependence on the direction of the quark spin? Fig. 2 gives the answer: It basically shows the preferred orientation of $\pi^+\pi^-$-pairs (denoted by $A_{UT}^{\sin(\phi_{R\perp}+\phi_S)\sin\theta}$) as a function of the invariant mass of this pion pair. In particular, in this case the pion pair's π^+ prefers to go to the left of the transverse spin of the quark. Also this direction does not change at higher invariant mass ($> m_{\rho^0}$), in contrast to some earlier speculations that predicted a sign change. In any case the result shows that transversity is nonzero and that the orientation of the pion pair's plane can be used to measure transversity.

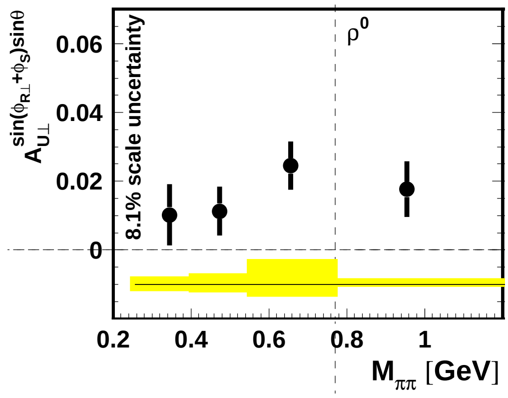

FIG. 2: "Left-right asymmetry" of the pion pair as function of the invariant mass of the pair.