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Review

Polarized structure functions

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Abstract

We discuss the spin structure of quarks in hadrons, in particular the transverse spin polarization or transversity. The most direct way to probe transversity appears to be via azimuthal spin asymmetries. This brings in the role of intrinsic transverse momenta of quarks in hadrons and the study of T-odd phenomena, which are connected to single spin asymmetries.

Keywords: Polarized leptoproduction; Single spin asymmetries; Transversity; Deep inelastic scattering; Distribution functions; Fragmentation functions; Parton intrinsic transverse momentum; Azimuthal asymmetries

1. Introduction

The topic of this lecture is the spin structure of hadrons and the way it is probed in high-energy scattering processes. We specifically study electroweak scattering processes. One specific process, namely lepton–hadron scattering will be dealt with in detail. A signal for an electroweak process is the presence of leptons which do not feel strong interactions. They allow a separation of the scattering amplitude for the process into a leptonic part and a hadronic part, where the leptonic part, involving elementary particles is known. The structure of the hadronic part is constrained by its (Lorentz) structure and fundamental symmetries and can be parametrized in terms of a number of structure functions. The emerging expression for the scattering amplitude can be used to calculate the cross sections

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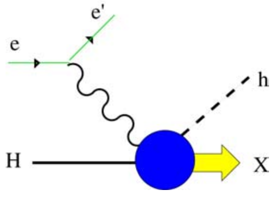
in terms of these structure functions. In turn one can make a theoretical study of the structure functions. Part of this can be done rigorously with as only input (assumption if one wants) the known interactions of the hadronic constituents, quarks and gluons, within the standard model. For this both the electroweak couplings of the quarks needed to describe the interactions with the leptonic part via the exchange of photon, Z^0 or $W^{\pm}$ bosons as well as the strong interactions of the quarks among themselves via the exchange of gluons described in the QCD part of the standard model are important. For a general reference we refer to the book of Roberts [1].

2. Leptoproduction

In this section we discuss the basic kinematics of particular hard electroweak processes, namely the scattering of a high-energy lepton, e.g. an electron, muon or neutrino from a hadronic target, $\ell(k)H(P) \rightarrow \ell'(k')X$. In this process at least one hadron is involved. If one does not care about the final state, counting every event irrespective of what is happening in the scattering process, one talks about an inclusive measurement. If one detects specific hadrons in coincidence with the scattered lepton one talks about semi-inclusive measurements or more specifically 1-particle inclusive, 2-particle inclusive, depending on the number of particles that are detected.



$$q^2 = (k - k')^2 \equiv -Q^2 \leq 0$$
$$2P \cdot q \equiv 2M\,\nu \equiv \frac{Q^2}{x_B}$$
$$2P_h \cdot q \equiv -z_h\, Q^2$$
$$P \cdot k = \frac{P \cdot q}{y} = \frac{Q^2}{2x_B y}$$

The variable x_B is the Bjorken scaling variable, by the kinematics constrained to $0 \leq x_B \leq 1$, and $x_B = 1$ corresponding to elastic scattering. In this scattering process a hadron is probed with a spacelike (virtual) photon, for which one could consider a frame in which the momentum only has a spatial component. This shows that the spatial resolving power of the probing photon is of the order $\lambda \approx 1/Q$. Roughly speaking one probes a nucleus (1–10 fm) with $Q \approx$ 10–100 MeV, baryon or meson structure (with sizes in the order of 1 fm) with $Q \approx$ 0.1–1 GeV and one probes deep into the nucleon (<0.1 fm) with $Q > 2$ GeV. Leptoproduction is characteristic for a large number of other processes involving particles (leptons) for which the interactions are fully known together with hadrons. The electroweak interactions with the constituents of the hadrons (quarks), however, are also known. This opens the way to study how quarks are embedded in the hadrons (e.g. in leptoproduction or in the Drell–Yan process, $A(P_A)B(P_B) \rightarrow \ell(k)\bar{\ell}(k')X$) or to study how quarks fragment into hadrons (in leptoproduction and e^+e^- annihilation into hadrons).

For inclusive unpolarized electron scattering the cross section, assuming one-photon exchange, is given by

$$E' \frac{d\sigma}{d^3k'} = \frac{1}{s - M^2} \frac{\alpha^2}{Q^4} L^{(S)}_{\mu\nu}\, 2MW^{\mu\nu}, \tag{1}$$