Transverse Spin Physics with CLAS12

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The CLAS12 project and the related physics program for a comprehensive study of the transverse hadron structure are here reviewed.

Deep inelastic scattering (DIS) has been used extensively as an important testing ground for QCD. So far studies have been concentrated toward a better determination of parton distribution functions (PDFs) describing the longitudinal momentum fraction of partons in the infinite momentum frame. In recent years, the interest has been extended to the partonic transverse degrees of freedom, and two complementary descriptions of the nucleon structure are being investigated. Transverse Momentum dependent Distribution functions (TMDs) describe correlations between spin and quark transverse momentum, which are recognized as essential ingredients of the structure of hadrons [1, 2]. Generalized Parton Distributions (GPDs) provide a join description of the longitudinal momentum fraction and the transverse spatial distribution (impact parameter space) of quarks [3]. Large single spin asymmetries have been recognized among the most difficult phenomena to understand from first principles in QCD and can be related to TMDs. The increasing interest on GPDs is triggered by their potential to help unraveling the spin structure of the nucleon, as they contain information not only on the helicity carried by partons, but also on their orbital angular momentum. Model-dependent relations among TMDs and GPDs have been found and already used to gather predictions or phenomenological informations. Although challenging, such novel investigation could lead to a 3D description of the nucleon structure.

TMDs investigation is possible in semi-inclusive DIS (SIDIS). It promises to give new insights into the nucleon structure, at the price of a much more involved phenomenology. When the transverse momentum is small with respect the hard scale Q (photon virtuality) TMDs factorization holds in SIDIS [4]. The observables can then be interpreted as the convolution of parton distribution and fragmentation functions in terms of their transverse momentum dependence. The interpretation is not trivial and involve issues on TMDs universality, evolution and twist expansion of the cross-section terms. Since up to now evidences of non-zero signals related to TMDs are reported by only a few SIDIS experiments [5− 12], and in some cases the different measurements are barely in agreement, new measurements are needed. However, in order to contribute significantly, new measurements should be as much comprehensive as possible. In particular, the coverage of a wide kinematic range and a high statistic power are required to allow multidimensional analyses in order to resolve all the dependencies. Moreover, the use of different targets (hydrogen and deuterium) and an efficient hadron identification should be envisaged to achieve flavor tagging. A high luminosity electron-ion collider can ideally meet such requirements. There exist predictions that TMDs should undergo Sudakov suppression at large Q due to soft gluon radiation broadening transverse momentum effects [13]. Therefore high luminosity is more crucial than high energy for such an investigation. In a medium term range, JLAB 12 GeV upgrade could meet the requirements to study TMDs in the valence region, at the same time covering a complementary kinematic region with respect to currently running experiments.

The CLAS12 experiment in Hall-B is designed to achieve a very broad kinematic coverage while increasing by a factor 10 the luminosity with respect to the current 6 GeV setup [14]. In particular, the forward spectrometer comprises a 2T toroid with improved geometry to minimize the not-active azimuthal coverage (coil blind region) and a RICH detector is under study to extend the hadron identification over the full energy range of the experiment. The spectrometer is complemented by a central detector embedded in a 5T solenoid. The strong longitudinal field allows momentum measurements in the target fragmentation region and provides the holding field for longitudinally polarized targets. Moreover, it confines the large Moller background in the safe region inside the beam pipe and thus allows to reach the maximum luminosity (exceeding 10^{35} cm^{-2}s^{-1}). Thanks to the high statistics collected, a detailed multidimensional study of the azimuthal modulations of the unpolarized cross-section (related to spin-orbit effects within the nucleon) and of the helicity dependence of the quark transverse momentum distribution will be possible. In addition, it would be possible to study sub-leading twist effects by probing their Q^{-1} dependence, and to explore the transition from non-perturbative (at small transverse momentum, typically lower than 1 GeV/c) to perturbative regime (at large transverse momentum). This is crucial to achieve a complete phenomenology and to test the connection between TMDs and twist-3 collinear [15] approaches, which should hold in the two different transverse momentum regimes, respectively. The multidimensional analysis allows to test factorization by disentangling distribution and fragmentation function dependencies. As a consequence, the investigation of novel type of fragmentation functions, like the Collins function [16], becomes possible in SIDIS. This would help to solve issues related to TMDs evolution by comparing the results with measurements made at e^+e^- colliders at much larger center-of-mass energy [17].

An innovative HD-ice transverse target is under construction at JLab [18]. Such a target offers the possibility to independently polarize hydrogen and deuterium nuclei to high degrees (90% H and 70% D) with small dilution and minimized nuclear effects (both affecting the systematic error). The HD-ice target was proven to work with a photon beam and will be tested with an electron beam at the beginning of next year. As a backup solution, a traditional ammonia target is foreseen with similar performances but different systematics. The transverse target requires a dedicated shielding for Moller background, thus a 10 times smaller luminosity is assumed as a conservative estimate. Measurements with transverse target give access to the transversity distribution [19, 20] which is, together with the unpolarized and helicity distributions, one of the three leading-twist distributions which survive transverse-momentum integration. The CLAS12 measurements will cover the valence region, where transversity is largely unconstrained, and lead to a precise determination of the tensor charge. Moreover they will give access to the Sivers function [21] which is an indirect probe of the orbital motion of the partons. In addition, transverse targets provide access to observables with unsuppressed contributions of the GPD E, which enters the Ji sum rule about quark orbital motion [22]. This would allow to experimentally test the model-dependent relations between the two approaches for a 3D study of the nucleon and to eventually pin down the elusive partonic orbital motion.

In conclusion, CLAS12 provides a medium-term powerful setup for TMDs investigation in the valence region at relatively small Q. In the long-term range, a high-luminosity electron-ion collider with center-of-mass energy of few tenths of GeV will be able to cover the valence region at much higher Q^2 (addressing issues related to higher-twist contributions and evolution) and at the same time exploring in detail for the first time the sea region.

References:

1. P.J. Mulders and R.D. Tangerman, Nucl. Phys. **B 461**, (1996) 197.
2. A. Bacchetta et al., JHEP **02**, (2007) 093.
3. A.V. Radyushkin, Phys. Lett. **B 280**, (1996) 417; Phys. Rev. **D 56**, (1997) 2982.
4. J.C. Collins, D.E. Soper and G. Sterman, Adv. Ser. Dir. High Energy Phys. **5**, (1988) 1.
5. A. Airapetian et al., Phys. Rev. Lett. **94**, (2005) 012002.
6. A. Airapetian et al., Phys. Lett. **B 622**, (2005) 14.

7. A. Airapetian et al., Phys. Lett. **B 648**, (2007) 164.
8. A. Airapetian et al., Phys. Rev. Lett. **103**, (2009) 152002.
9. V.Y. Alexakhin et al., Phys. Rev. Lett. **94**, (2005) 202002.
10. M. Alekseev et al., Phys. Lett. **B 673**, (2009) 127.
11. H. Avakian et al., Phys. Rev. **D 69**, (2004) 112004.
12. M. Osipenko et al., Phys. Rev. **D 80**, (2009) 032004.
13. D. Boer, Nucl. Phys. **B 603**, (2001) 195.
14. http://www.jlab.org/Hall-B/clas12/Documentation.
15. J. Qiu and G. Sterman, Phys. Rev. **D 59**, (1999) 032011.
16. J. Collins, Nucl. Phys. **B 396**, (1993) 161.
17. R. Seidl, Phys. Rev. **D 78**, (2008) 032011.
18. X. Wei et al., Nucl. Instrum. Methods **A 526**, (2004) 157.
19. J. Ralston and D. Soper, Nucl. Phys. **B 152**, (1979) 109.
20. R.L. Jaffe and X. Ji, Nucl. Phys. **B 375**, (1992) 527.
21. D. Sivers, Phys. Rev. **D 43**, (1991) 261.
22. X. Ji, Phys. Rev. Lett. **78**, (1997) 610.