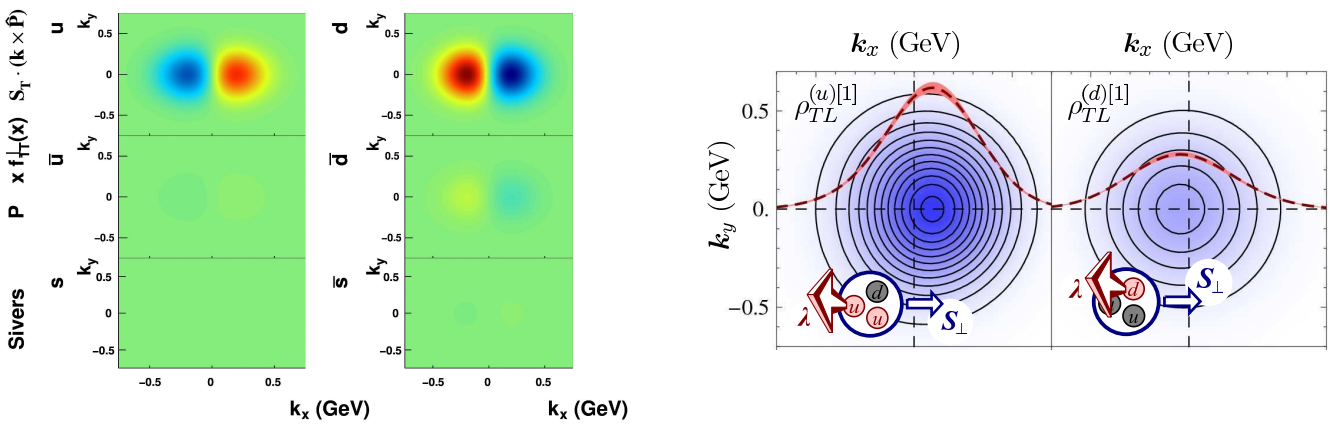
Transverse Momentum Dependent Distributions

In a head-on collision of a proton (or neutron) and an electron, the transverse (sideways) motion of the quarks inside the proton leads to an asymmetric distribution of the scattered fragments. The intriguing properties of the strong force holding the quarks together lead to additional asymmetries that cannot be explained in the classical picture, such as the Sivers asymmetry shown in Fig. 1a. These effects, encoded in Transverse Momentum dependent parton Distributions (TMD) and fragmentation functions, and measured experimentally in processes such as Semi-Inclusive Deep Inelastic Scattering (SIDIS), allow us to draw three-dimensional pictures of the dynamics inside the proton and to study fundamental aspects of the strong force.



(a) (b)

Figure 1: (a): Slice through the three dimensional momentum distribution from the Sivers function at $x = 0.1$. (b): x-integrated momentum densities exhibiting deformations from the worm gear function g_{1T}, as obtained from a straight-link lattice calculation at a pion mass of 500 MeV [2]. The insets show the spin direction of the nucleon (blue arrow) and the quark (red arrow).

Experimental advances, including the JLab 12 GeV program and the prospect of an Electron Ion Collider (EIC), have triggered new interest in TMDs world wide and particularly within the theory group of Jefferson Lab. Phenomenological analyses of existing data from the HERMES and COMPASS experiments have allowed us to extract the Sivers function [1]. From such studies emerges a picture of a dipole shaped deformation of transverse momentum densities inside the transversely polarized proton as displayed in Fig. 1a. Complementary to this, we are establishing methods to calculate transverse momentum distributions purely theoretically, from the basic principles of Quantum ChromoDynamics, using lattice techniques [2] and relying on the computing resources at the Jefferson Lab cluster. First results of such calculations corroborate model predictions for the relative size of the so-called worm gear TMDs, see Fig. 1b. Precision SIDIS data for these and other TMDs will become available from approved experiments at JLab 12 GeV and from a potential EIC, mapping the internal structure of the proton/neutron at different spin-orientations. In this way, the Jefferson Lab theory group actively contributes to optimizing the design goals for a future EIC facility.

References

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[2] Ph. Hägler, B. U. Musch, J. W. Negele and A. Schäfer, Europhys. Lett. **88**, 61001 (2009). B. U. Musch, P. Hägler, J. W. Negele and A. Schäfer, arXiv:1011.1213 [hep-lat] (2010).