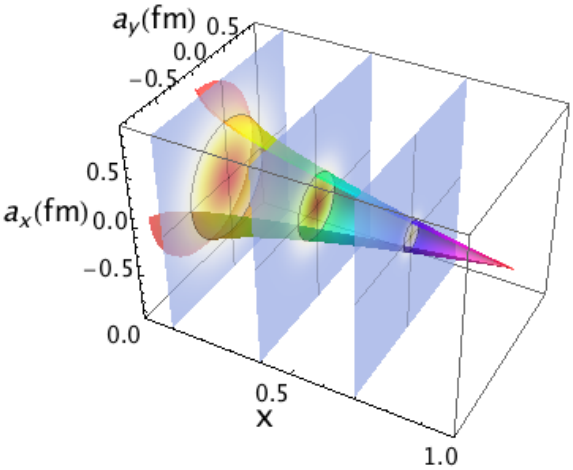
A Snapshot of the Proton [1]

Quarks, the fundamental constituents of matter, remain confined within hadrons (such as the protons and neutrons), even when struck in very high energy collisions, such as at the large hadron collider at CERN. What does a proton look like under such circumstances? What determines the quark distributions within a proton? These are difficult questions to answer, since the theory of the strong interactions, Quantum Chromodynamics (QCD), has no simple answers in the realm of the strong dynamics which determine the confinement of quarks. Furthermore, comprehensive predictions for the quark distributions obtained from current lattice QCD computation are still beyond reasonable reach, even using state-of-the-art supercomputers. This paper provides a new structural framework for examining these complex issues, based on QCD/gravity duality in the light-front – "light front holography" [2]. For example, when an electron collides with the quarks in the proton, as in the classic SLAC deep inelastic experiments, it interacts with the proton at a single light-front time –at the front of a light-wave, as in a flash photograph. Although the framework used is not derived directly from QCD, it has an attractive simplicity and predictive power hardly achieved before. It predicts masses and form factors of hadrons and also leads to new connections between the masses of hadrons and the proton quark distributions from global data fits. It also describes with high precision the quark distributions observed in a recent data analysis of quark distributions in the pion [3]. The framework incorporates the structure of the Veneziano amplitude, a model of the strong interactions established before the advent of QCD, which gave rise to the birth of string theory. These connections are quite intriguing and can provide further insights into hadron dynamics and structure.

[1] G. F. de Teramond, T. Liu, R. S. Sufian, H. G. Dosch, S. J. Brodsky, A. Deur, ``Universality of generalized parton distributions in light-front holographic QCD (Accepted for publication in PRL).

[2] S. J. Brodsky, G. F. de Teramond, H. G. Dosch and J. Erlich, ''Light-front holographic QCD and emerging confinement,'' Phys. Rept. **584**, 1 (2015).

[3] P. C. Barry et al. (JAM Collaboration), "First Monte Carlo global QCD analysis of pion parton distributions," arXiv:1804.01965 [hep-ph].



3-dimensional image of a proton: This light-front view of the quark distribution in the proton is computed from the holographic model discussed in the article. The average transverse size a, the transverse distance of the quark's momentum relative to the proton's momentum, shrinks to a point at the maximum longitudinal momentum fraction x. Also shown in the vertical figure slices are the impact-space distributions for the up quark.