be desirable to know much more about $s\bar{s}$ spectroscopy. Given that the photon often fluctuates into an $s\bar{s}$ pair, a great deal of data will automatically be available from this sector as part of the planned exotic meson program, creating the opportunity to correct this situation. Mapping out the $s\bar{s}$ spectrum presents some challenges. Given that the intrinsic $s\bar{s}$ content of the proton is expected to be small, photon-initiated $s\bar{s}$ spectroscopy will strongly favor the production of diffractive-type $C = -1$ states. The exception will be channels where OZI-violating t-channel exchanges (like those of the $\eta - \eta'$ system) can occur. These effects will result in an uneven population of the spectrum. The very high data rates anticipated should nevertheless lead to a data set of sufficient quality that the weakly excited states will still be identifiable.

1.A.2 The Fundamental Structure of the Nuclear Building Blocks

The nucleons are the basic building blocks of atomic nuclei. Their internal structure, which arises from their quark and gluon constituents, determines their mass, spin, and interactions. These, in turn, determine the fundamental properties of the nuclei. To make further progress in our understanding of nuclei, it is crucial that we understand in detail how the nucleon's basic properties are derived from the theory of strong interactions: quantum chromodynamics (QCD).

Over the past half century much progress has been made toward unraveling the structure of the nucleon. However, our understanding is fragmented and incomplete, and many puzzles remain. For example, we only partially understand how the nucleon's spin is "assembled" from the quark spins and the quark and gluon angular momenta, and we don't know the details of the spatial and momentum distributions of the quarks and gluons within the nucleon. Our understanding of nucleon structure is, quite simply, very far from the level of our understanding of atomic structure.

The JLab 12 GeV Upgrade will support a great leap forward in our knowledge of hadron structure through major programs in three areas: nucleon form factors at large Q^2, valence quark structure, and deep exclusive scattering. It will also support important initiatives in a number of other areas of hadron structure. These data can be understood and interpreted coherently, using the theoretical framework of the recently-discovered Generalized Parton Distributions (GPDs), to provide truly remarkable and revealing images of the proton's structure that will enable us to understand these fundamental "building blocks" of nuclear physics.

Nucleon Form Factors at Large Q^2. The internal structure of the nucleons was first studied by using elastic electron-proton scattering in which a proton at rest is struck by a virtual photon of mass Q^2, and the probability that the proton remains intact is measured. This elastic form factor can be directly related to the nucleon's spatial electric charge and current distributions. The first measurements of the proton's electric form factor taught us that the nucleon has a finite size of about one femtometer (10^{-15}m); Robert Hofstadter was awarded the Nobel prize for this discovery. Form factors at large Q^2 are difficult to measure because they require very high luminosity. For many years after Hofstadter's initial measurements there were no further fundamental breakthroughs in our understanding of the nucleon because no appropriate facility was available.

The theoretical understanding of the form factors has expanded significantly. It was realized that they can be interpreted as the Fourier transformations of charge and current (or quark) density distributions in the transverse plane. This is similar to the Feynman parton distribution, which can be interpreted in a frame of reference in which the nucleon travels with the speed of light.

Parton Distributions at Large x. A second window on nucleon structure came with the development of deep inelastic lepton-nucleon scattering (DIS) in the 1970s at SLAC. In these experiments the hadronic reaction products are not detected. DIS data led to the experimental confirmation of the existence of quarks and helped to establish QCD as the fundamental theory governing all strongly interacting (*i.e.*, nuclear) matter. Friedman, Kendall, and Taylor won the Nobel prize for pioneering this research.

What one infers from DIS data are the quark distributions in momentum space. In frames of reference in which the nucleon travels with speed approaching the velocity of light, the DIS cross sections determine the probability of the struck quark having a fraction, x, of the nucleon's longitudinal momentum. In such situations the elastic form factors and the deep-inelastic structure functions provide complementary information. The former gives the coordinate space distribution in the transverse direction, and the latter yields the momentum space distribution in the longitudinal direction. Together, they provide parts of a 3-dimensional picture of nucleon structure.

Even though DIS experiments have been pursued vigorously for over 30 years, it is remarkable that there has never been an experimental facility that could measure the DIS cross sections throughout the kinematic regime where the three basic ("valence") quarks of the proton and neutron dominate the wavefunction. The contribution of the valence quarks peaks at $x \simeq 0.2$. However, if one is in the conventionally defined deep inelastic regime, the probability of finding a quark in the high-x "valence quark region" is small, and becomes smaller and smaller as $x \to 1$. Moreover, with "pollution" from gluons and quark-antiquark pairs, it is only for $x > 0.5$ that the valence quarks dominate the wavefunction. The 12 GeV Upgrade will allow us to map out the quark distribution functions in this "clean" valence quark region with high precision. Such measurements will have a profound impact on our understanding of the structure of the proton and neutron.

Deep Exclusive Scattering and the Generalized Parton Distributions While the elastic form factors and parton distributions provide the distributions of quarks in the transverse coordinate and longitudinal momentum spaces, respectively, they do not yield a complete picture. To have this, one would need a joint distribution representing the density of quarks having a fixed longitudinal momentum and *simultaneously* a fixed transverse position. Such a distribution has been discovered recently: the Generalized Parton Distribution (GPD) [Mu94, Ji97, Ra96].

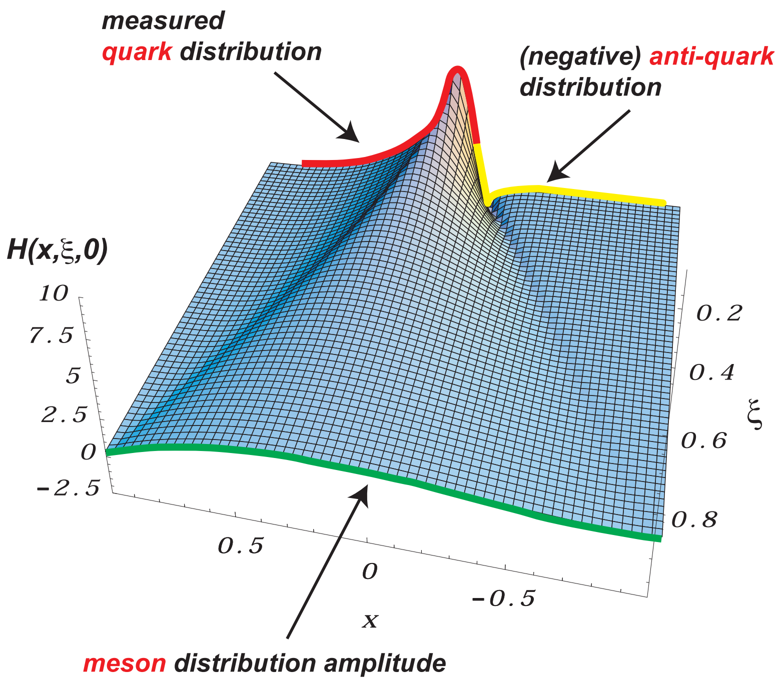

Figure 6: Model representation of the Generalized Parton Distribution (GPD) $H(x, \xi, t = 0)$ in two dimensions. The known parton momentum densities constrain the distribution at $\xi = 0$. The new physics is contained in the ξ- and t-dependence of this surface, which can currently only be modeled. The dramatic change in the shape of the surface reflects changes in the underlying physics. As ξ increases, the correlations between the quarks and anti-quarks increase leading to meson-like distributions at large ξ.

A GPD depends on three kinematic variables: x, which specifies the fraction of the nucleon momentum carried by partons (as in the Feynman distribution); t, which characterizes the momentum transfer to the nucleon (as in the elastic form factors); and ξ, which measures the difference in momentum fraction between the initial and final parton. When $t = \xi = 0$, a GPD reduces to a regular Feynman parton distribution; when integrated over x the GPD gives an ordinary electromagnetic form factor. There are four leading-order GPDs for each quark flavor. For example, $H(x, \xi, t)$ and $E(x, \xi, t)$ are quark helicity-independent distributions, and $\tilde{H}(x, \xi, t)$ and $\tilde{E}(x, \xi, t)$ are helicity-dependent distributions. A model of the H distribution with factorized t-dependence is shown in Fig. 6. At $\xi = 0$, the physical interpretation of $H(x, 0, t)$ is very simple [Be02], as illustrated in Fig. 7. Its Fourier transformation in t gives the joint probability distribution for a quark with longitudinal momentum x and transverse position $b_\perp$.

These remarkable functions capture the full richness of the nucleon's structure. In addition to providing a consistent theoretical framework for interpreting a broad variety of available data probing nucleon structure, they provide critically needed access to essential, but almost unknown aspects of nucleon structure such as the correlations among the quarks and the quarks' contribution to the nucleon's spin. In the remainder of this section we discuss the advances anticipated in each of the important areas of nucleon structure studies that will be supported by the 12 GeV Upgrade.

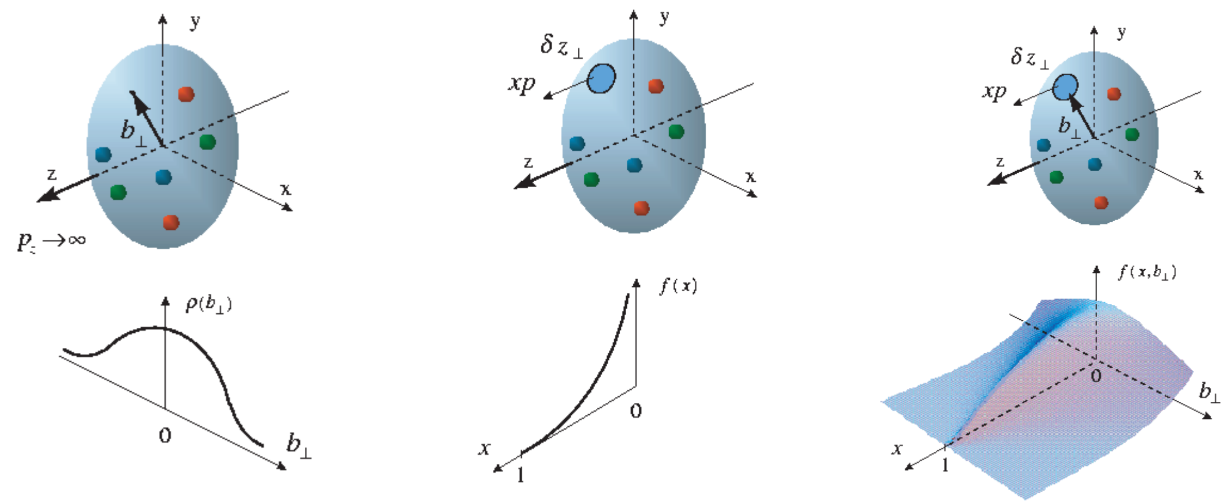

Figure 7: Representations of the proton properties probed in elastic scattering (left), deeply inelastic scattering (center), and deeply exclusive scattering (right). Elastic scattering measures the charge density $\rho(b_\perp)$ as a function of the transverse coordinate $b_\perp$. DIS measures the longitudinal parton momentum fraction density $f(x)$. GPDs measure the full correlation function $H(x, b_\perp)$.

Form Factors - Constraints on the Generalized Parton Distributions The hadronic form factors are moments of the GPDs; they provide precise information on the distribution of charge and magnetization in protons, neutrons and nuclei, and are essential tests of our understanding of nucleon structure. Using the formalism of the GPDs outlined above (and discussed below), elastic and transition form factors can be connected directly to the parton structure of the hadrons. They are complementary to deeply virtual exclusive (DVE) reactions (discussed below), which probe the GPDs more directly; the form factors uniquely access the GPD moments. Another important consideration is that while DVE reactions access GPDs only at relatively low $|t|$, the form factors connect at high $|t|$ ($=Q^2$ for elastic scattering). High-Q^2 data are required to obtain the small $b_\perp$ structure of the hadron.

For nucleon elastic scattering there are four form factors – two for the proton (G_E^p and G_M^p), and two for the neutron (G_E^n and G_M^n); taken together they determine the charge and current distributions of the nucleon. They are the first moments of the GPDs. It is important to extend the measurement of the four nucleon form factors to the highest possible Q^2 and to express all four in terms of common GPDs. Only the magnetic form factor of the proton, G_M^p, has been measured to high $Q^2(\sim 30\ (\mathrm{GeV}/c)^2)$ with relatively good accuracy. With the 12 GeV upgrade, G_E^p/G_M^p can be measured up to 14 $(\mathrm{GeV}/c)^2$. Knowledge of neutron form factors at high Q^2 is equally important. For the neutron, G_M^n would be extended up to about 14 $(\mathrm{GeV}/c)^2$, and for G_E^n to 5 $(\mathrm{GeV}/c)^2$.

Recent JLab results (Fig. 8) show the potential for discovery with increasing Q^2; before this