Some thoughts on unifying the language of LCSR and GPDs

The question is how can the N* program contribute to the priority CLAS12 physics goals. To answer this we must cast the language of resonance electroproduction as much as possible with the global program and language of the CLAS12 program.

Where does N* physics fit in with the primary focus of CLAS12? At high Q^2 and low $-t$ (off - forward) the flagship is the exclusive DVCS and also DVMP experiment. The primary language in these programs relating nucleon structure to experiment has been in terms of GPDs. Although baryon resonance production can have a role to play in the DVCS program, the evidence so far is that isolating resonances in these experiments may be very difficult (except maybe the S_{11} via eta production) and should not be a focus of the N* proposal. Then, there are the semi- inclusive meson production experiments, which are very complicated to interpret, but appear to have the potential for telling us something about the quark flavors and spins.

This brings us to the question of exclusive form factors (or equivalently, helicity amplitudes), which involve high Q^2 and high $-t$, which *is* the subject of this proposal. The treatment of form factors so far has proceeded via several different calculation tracks, and as I see it, these must somehow be related to the language of deeply virtual exclusive reactions.

The pQCD method was developed in the 1980's (Brodsky, et al.). This involves factorization of the valence quark distribution amplitudes (DA), and the perturbative transition amplitude (TA). The DAs, which are the result of complicated soft processes in the nucleon, are obtained via SVC sum rules (e.g. Chernyak et al.), and the TA is written in terms of the exchange of two high virtuality gluons.

Since pQCD, or hard, physics is a limiting process for asymptotic values of Q^2, it will contribute only a part of the experimental form factors at accessible Q^2, other techniques have been used to obtain parameterizations (Radyushkin et al) which contain both hard and much more complicated soft processes. Foremost, for our present consideration, is the light cone sum rule approach.

Then, GPDs. The form factors are the first moments of GPDs. The relationship of form factors and GPDs for elastic, $N \to N$, $N \to \Delta$ and $N \to S_{11}$ are illustrated below. With respect to resonances they were discussed by Goeke et al, and Frankfurt et al (among others). These GPDs must contain all the information about both the hard (pQCD) and soft processes which contribute to the form factors.

In principle, the best way of getting the moments of the GPDs or the DAs is via the direct Lattice QCD method. In practice this seems to be stymied to smaller Q^2 by the practical limitations of how smallness are lattice sizes which can be handled by currently available computers. Still, lattice there is progress, at least for the N→Δ.

Since the local duality sum rule, the lattice and the GPDs contain all the same information buried in them, one should be able to relate their main ingredients to each other. That is, the GPDs contain overlaps of initial and final wave functions, which we are after, and these should be directly related to the DAs used in the sum rules approach, and the moments obtained in the lattice calculations. In fact, the they should even contain the DAs which are contained in the pQCD SVC sum rules.

V. Braun and others (QCDSF Collaboration) have made what I think is an important advance in the goal of employing the power of the different approaches. They claim using lattice to directly calculate these form factors is unlikely to go beyond Q2 ~ 3 GeV2. Alternatively, they used lattice to calculate the moments of the DAs. These DAs are then used in the light cone sum rule approach (LCSR) to obtain the transition matrix elements. A large systematic error (~30%) comes from the lattice calculation of matrix elements. I think this has to significantly improve over time. The new large super-large computers (e.g. BlueGene @RPI) have got to permit calculations of ever smaller lattice spacing. In all, this seems like a promising direction.

I think the lattice folks know how to calculate moments of GPDs. Once again, to close the circle one should be able to show how the lattice based light cone sum rule obtained matrix elements cononnect directly to the GPDs/

This brings me to relationship of form factors and GPDs. In addition to non-strange ones we know from Maxim et al already in 2001, in principle how to attack the transitions to strangeness containing excitations, e.g. N→Λ,Σ.

ep → ep:

$$\Gamma_\mu = F_1(q^2)\gamma_\mu + \frac{\kappa}{2M} F_2(q^2) i\sigma_{\mu\nu}q_\nu \quad \Rightarrow \quad H^q \gamma \bullet n + \frac{1}{2M_N} E^q i\sigma^{\mu\nu} n_\mu q_\nu$$

$$F_1^q(t) = \int H^q(x,\xi,t)dx \quad F_2^q(t) = \int E^q(x,\xi,t)dx$$

ep → eΔ:

$$\Gamma_{\nu\mu} = G_M^*(q^2)\mathrm{K}_{\nu\mu}^M(q^2) + G_E^*(q^2)\mathrm{K}_{\nu\mu}^E(q^2) + G_C^*(q^2)\mathrm{K}_{\nu\mu}^C(q^2)$$

$$\Rightarrow H_M \mathrm{K}_{\nu\mu}^M n^\mu + H_E \mathrm{K}_{\nu\mu}^E n^\mu + H_C \mathrm{K}_{\nu\mu}^C n^\mu$$

$$\int_{-1}^{1} dx\, H_{M,E,C}\left(x,\xi,Q^2\right) = 2G_{M,E,C}^*\left(Q^2\right)$$

p → S11

$$\Gamma_\mu^{S11} = F_1^{S11}(q^2)\left(\gamma_\mu - \not{q} q_\mu\right)\gamma_5 + \frac{\kappa_{S11}}{2M_{S11}} F_2^{S11}(q^2) i\sigma_{\mu\nu}q_\nu\gamma_5$$

$$\Rightarrow H_{S_{11}}^q \bar{u}(p')\left(\gamma\bullet n - \not{q} q\bullet n\right)\gamma_5 u(p) + E_{1S_{11}}^q \bar{u}(p') i\sigma^{\mu\nu}\gamma_5 \frac{n_\mu q_\nu}{2M_N} u(p)$$

$$F_{1S_{11}}^q(t) = \int \tilde{H}_{S_{11}}^q(x,\xi,t)dx \quad F_{2S_{11}}^q(t) = \int \tilde{E}_{S_{11}}^q(x,\xi,t)dx$$

P → Y

$$\Gamma_\mu^{N\to Y} \sim F_1^{N\to Y}\left(q^2\right)\bar{s}\gamma^+ + \frac{\Delta_\kappa}{2m_N} F_2^{N\to Y}\left(q^2\right)\bar{s} i\sigma^{+\kappa}$$

$$\Rightarrow (\gamma^-)_{\alpha\beta}\left[H^{N\to Y}(x,\ \xi,\ t)\,\gamma^+ + E^{N\to Y}(x,\ \xi,\ t)\, i\sigma^{+\kappa}\frac{\Delta_\kappa}{2m_N}\right]\bar{s}_\beta$$