Nucleon Elastic and Transition Form Factors at High Q^2 at JLAB at Higher Energies

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A fundamental issue in hadron physics is which degrees of freedom are appropriate to describe exclusive reactions at experimentally accessible momentum transfers, and how are models at low, medium and high Q^2 related? Constituent quark models (CQM) appear to work well at the low Q^2 limit, and it is widely believed that valance pQCD will be valid in the limit of high Q^2. How far the validity of these models extend in Q^2 is still an open question.

Many exclusive reactions exhibit constituent scaling behavior at moderate Q^2 (few $\mathrm{GeV}^2/\mathrm{c}^2$) which is interpreted by some [1] as the onset of perturbative QCD. Others [2] argue that the observed scaling is not a manifestation of pQCD, and that at the experimentally accessible range of Q^2 exclusive reactions are explained primarily by soft Feynman mechanism. Recently[3][4], there have been promising developments in bridging the high and low Q^2 extremes for exclusive reactions in terms of a quark-parton description of exclusive reactions In this approach the perturbative hard part of the reaction, which is calculable, is isolated from the non-perturbative soft, physics which is parameterized in terms of *non-forward parton distributions* (NFPD). These NFPD's are generalizatons of the the usual parton non-spin and spin distribution functions obtained in unpolarized and polarized deep inelastic inclusive scattering, and in fact reduce to them in the limit of forward scattering.

An attractive aspect of this approach is that the same NFPD can be carried over to a variety of exclusive reactions which involve the same set of hadrons, and can be constrained in a number of different experiments which are discussed in these proceedings.

Figure 1. schematically shows some examples of exclusive reactions and their connection to each other and DIS in terms the NFPD's. Figure 2. illustrates the pQCD valence quark discription of these same reactions, which presumably are obtain in the asymptotic limit of momentum transfer.

Elastic and transition form factors are the simplest limit of the NFPD's (they are the first moment of the NFPD's), and therefore are among the most important tests for the theory. Thus, carefully characterizing them to the highest possible Q^2 will be one of the most important future JLAB programs. In this submission I would like to concentrate on the status and prognosis for the future JLAB program of measurements of nucleon elastic and transition form factors.

The various models for exclusive reactions make very definite predictions. For example, valance pQCD predicts $1/Q^4$ scaling for the leading helicity conserving form factors, and $1/Q^5$ and $1/Q^6$ dependence for next to leading helicity *non*-conserving form factors, which asymptotically vanish relative to the helicity

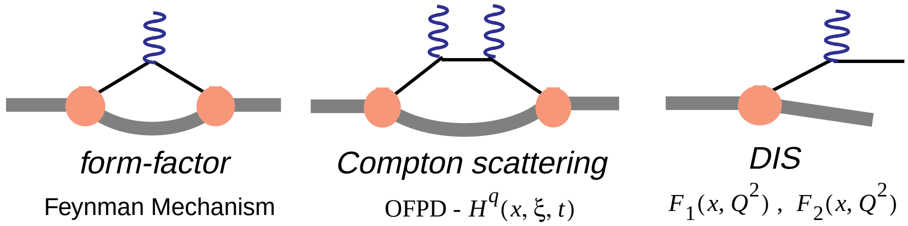

Figure 1: Examples of exclusive reactions and their connection to each other and DIS in terms the NFPD's.

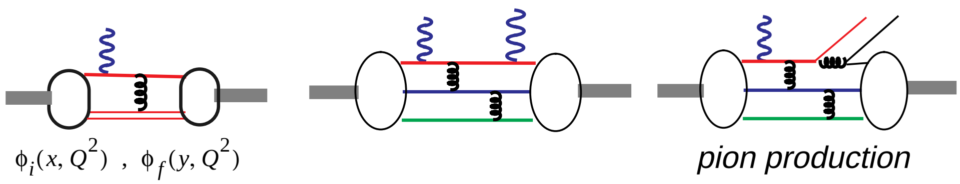

Figure 2: A pQCD interpretation of the same reactions ahown in Figure 1.

conserving form factors. For elastic scattering one expects definite relationships in the Q^2 dependence of helicity conserving and helicity non conserving form factors G_M and G_E (or F_1 and F_2). The models also make predictions of the absolute magnitudes of these form factors as well. Thus it is very important to have as good quality measurements as possible of G_M and G_E for both the neutron and proton. The status of the world's data on these quantities is shown in Figure 3.

Clearly the electric form factors are poorly known in the multi-GeV range, especially for the neutron, which is more difficult to measure than for the proton. Figure 3e. shows the ratio Q^2F_2/F_1. The data including the ratio Q^2F_2/F_1 are suggestive, and clearly point out the need for these measurements. The measurement of G_E^P appears to be feasible to 10 GeV^2/c^2 [6], and it will be interesting to see the prognosis from the experience with the current JLAB experiment 93027 [7]. A high priority is for someone to figure out how to measure G_E^N in the 5 to 10 GeV^2/c^2 range where it can make an impact on this physics. The low Q^2 measurements, on the other hand are less interesting for this physics. In the previous workshop [8] there were several presentations on possible higher Q^2 measurements, and they are still valid. Table 1 summarizes the status of the elastic form factors, and their proposed extentions as presented in [8].

The transition form factors also offer a rich, relatively unexplored area for studying non-perturbative QCD. There are many states with a large variety of

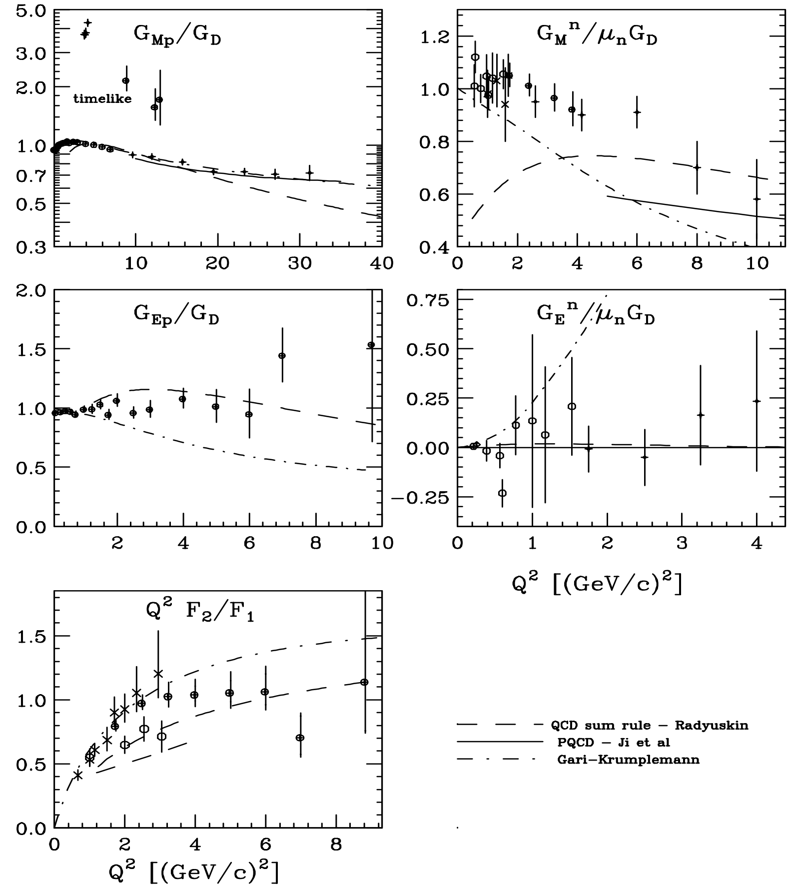

Figure 3: Status of elastic form factors, after [5] and references within.

Table 1:

Form Factor	Reference	Current Q^2 max and ~dQ^2	Proposed Q^2 max and ~dQ^2	Emax	Detector	Reaction
$G_M(N)$	W. Brooks	4 (6%)	9.5 (7%)	8 GeV	CLAS	D(e,n)/ D(e,p)
$G_E(N)$		4 (100%)	-	-	-	-
$G_M(P)$	G. Petratos	22 [1] (~10%)	20 (2.5%)	12 GeV	HRS (A) HMS (B)	p(e,e), L/T[2]
$G_E(P)$	E. Voutier et al	8 (20%)	10 (20%)	8 GeV	HRS (A)	p(e,ep), Pr

properties. Of interest are the *electromagnetic helicity amplitudes* $A_{1/2}, A_{3/2}, C_{1/2}$ for isospin 1/2 and 3/2 states. Resonance cross sections relative to the non-resonant continuum remains constant at all observed Q^2 (Bloom-Gilman Duality [9]), and all three experimental halls have unique capabilities to measure their exclusive decay channels for the first time to high Q^2. Each hall brings to bear unprecidented capabilities which will make these studies possible. A partial list of the more strongly excited resonances which can be accessed is shown bwlow.

Examples of resonance with high Q^2 interest.	
$\Delta(1232)$	$S_{11}(1535)$
$P_{11}(1440)$ - Roper	$S_{11}(1700)$
$F_{15}(1680)$	

Halls A and C have properties which will enable the measurement of single neutral meson production through the reactions $p(e, e'p)\pi^0, \eta$, utilizing missing mass reconstruction of the undetected mesons. This has been discussed in some detail in another contribution to this workshop [10]. Reactions which can be accessed at JLAB include:

Reactions in Hall A or C	Reactions in Hall B
$\Delta(1232)$ via $p(e, e'p)\pi^0$	N^* via $p(e, e'\pi^+)n$
$S_{11}(1535)$ via $p(e, e'p)\eta$	$S_{11}(1535)$ via $p(e, e'p)\eta$
$F_{15}(1680)$ via $p(e, e'p)\pi^0$	$\Delta(1232)$ via $p(e, e'p\gamma)\pi^0$
	Polarization asymmetries

The main potential for hall B lies in the ability to detect charged mesons over a large angular acceptance, as well as over a large Q^2. Neutral mesons can also be tagged by directly observing their decay photons. Hall B is also quite well matched for polarised beam and target experiments. Due to the small cross sections at high Q^2 larger luminosities than present running conditions allow will be needed. As an example, I have estimated the expected number of Δ's produced in a 30 day run period with $\delta Q^2 = 1$ GeV^2/c^2, $\delta W = 0.1$ GeV, and with a luminosity of 1×10^{35} cm^{-1}-s^{-1}, as shown in the table below.

Q^2	$\sigma(\mu b/sr$	# of Δ's
5	2	6×10^5
6	1.5	3×10^5
7	1.1	1×10^5
8	0.9	7×10^4
9	0.7	4×10^4
10	0.6	2×10^4

References

[1] S. J. Brodsky and G. P. Lepage, Phys. Rev. **D23**, 1152 (1981); C. E. Carlson and J. L. Poor, Phys. Rev. **B38**, 2758 (1988); C. E. Carlson and N. C. Mukhopadhyay, Phys. Rev. D, Rapid Communications **D41**, 2343 (1990); Phys. Rev. Lett. **74**, 1288 (1995).

[2] N. Isgur and C. H. Llewellyn-Smith, Phys. Rev. Lett. **52**, 1080 (1984); A. V. Radyushkin, Nucl. Phys. **A527**, 153 (1991).

[3] X. Ji, Phys. Rev. Letters, 78, 610 (1997), and references therein.

[4] A. Radyushkin, Phys. Lett B, **385**, 333 (1996).

[5] G. Sterman and P. Stoler, Ann. Rev. Nucl. Part. Sci. **47**, 193 (1997).

[6] E. Voutier et al, Workshop on CEBAF at Higher Energies, N. Isgur and P. Stoler, eds., CEBAF, p295 (1994).

[7] JLAB experiment 93027, C.F. Perdrisat and V. Punjabi, spokespersons.

[8] Workshop on CEBAF at Higher Energies, op. cit., W. Brooks, p197; G. Petratos, p263; E. Voutier et al, P295;

[9] E.D. Bloom and F.J. Gilman, Phys. Rev. Lett. **25**,1140 (1970; C. E. Carlson and N.C. Mukhopadhyay, Phys. Rev. Lett. **67** ,3745 (1991.

[10] P. Stoler, these proceedings.

[11] P. Stoler, "Baryon Elastic and Transition Form Factors at High Q^2 at JLAB at Higher Energies"; these proceedings.

[12] V. M. Belyaev and A. V. Radyushkin, Phys. Rev. **D53**, 6509 (1996).

[13] P. Stoler, Physics Reports **226**, 103 (1993).

[14] V.V. Frolov, PhD thesis, Rensselaer Polytechnic Institute; C. Armstrong, PhD thesis, College of William & Mary; to be published.