BARYON RESONANCE PRODUCTION
AT HALL C AT HIGH Q^2

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1 Issues for Exclusive Reactions.

One of the primary goals of nuclear physics is to map the nucleon wave functions in terms of their fundamental quark and gluon fields. The measurement of form factors and exclusive reactions at high momentum transfers give unique access to this structure, and Hall C is unique in the world for measuring these reactions. At very large Q^2 (very small distances), it has been widely assumed that the treatment of the reactions in terms of pQCD is uniquely selective of valence quark distribution functions. However, where in momentum transfer *valence pQCD* becomes valid is still not resolved. To look for the onset of the influence of *valence pQCD* effects in baryon form factor type reactions is one of the goals of this proposed experimental study.

In the past few years there have been important theoretical developments in treating exclusive reactions in terms of quark-parton degrees of freedom expressed in terms of *generalized parton distributions* (GPD) [1, 2, 3].

Baryon elastic and inelastic resonant transition form factors are the first moments of the GPDs:

$$F_1(t) = \int_0^1 \sum_q \mathcal{F}_\zeta^q(x,t)dx \qquad F_2(t) = \int_0^1 \sum_q \mathcal{K}_\zeta^q(x,t)dx \tag{1}$$

In a handbag basis, the GPD's are constructed from from two-body nucleon or resonance wave functions:

$$\mathcal{F}(x,t) = \int \Psi^*(x, k_\perp + \bar{x}r_\perp)\Psi(x,k_\perp)\frac{d^2k_\perp}{16\pi^3} \tag{2}$$

Ref. [4] has shown that the form factors are quite sensitive to the $k_\perp$ dependence of $Psi(x,k_\perp)$, and ref. [5] has shown that at high $Q^2$the form factors are specifically selective to map the high $k_\perp$ components of $Psi(x,k_\perp)$.

The unique role of resonance form factors is that they isolate different combinations of $\mathcal{F}(\S,\sqcup)$ and $\mathcal{K}(\S,\sqcup)$. Specifically, the $N\to\Delta$ form factors are selective of the *isovector* ($\mathcal{IV}$) parts of the GPD's:

$$G_M^* = \int_0^1 \sum_q \mathcal{F}_M^{q,\mathcal{IV}}(x,t)dx \qquad G_E^* = \int_0^1 \sum_q \mathcal{F}_E^{q,\mathcal{IV}}(x,t)dx \qquad G_C^* = \int_0^1 \sum_q \mathcal{F}_C^{q,\mathcal{IV}}(x,t)dx \tag{3}$$

2 Proposed Experimental Program

We will measure the evolution of the $\Delta(1232)$ and $S_{11}(1535)$ resonance transition amplitudes to a maximum $Q^2 \sim 15$ GeV^2/c^2. This Q^2 range will allow us to oberve the onset of *hard*-correlated processes, and their interplay with the *soft* mechanisms. We will look for specific signatures of the onset of pQCD, and to measure the $k_\perp$ dependence of the isovector/isoscalar GPD's. This is a component of the high momentum exclusive reaction program proposed for Hall C.

2.1 Signatures of valence-pQCD.

The most important consequence of valence-pQCD is helicity conservation. Consider for example the $N \to \Delta(1232)$ transition. In the CQM the transition corresponds primarily to a single quark spin-flip. This is nearly completely due to an $M1$ electromagnetic multipole, which has a large helicity non-conserving componant ($M1 = -\frac{1}{2}(A_{1/2} - \sqrt{3}A_{3/2})$, where $A_{1/2}$ and $A_{3/2}$ are helicity conserving and non-conserving amplitudes, respectively. This is well borne out by experiments at low Q^2. However, at asymptotically high Q^2 valance pQCD predicts $1/Q^4$ scaling for the leading helicity conserving form factors, and $1/Q^5$ dependence for longitudinal, and $1/Q^6$ dependence for transverse next-to-leading order helicity *non*-conserving form factors. In term of multipoles, the vanishing of $A_{3/2}$ relative to $A_{1/2}$ implies $E2 = +M1$ since $A_{3/2} = (M1 - E2)$. Of course at intermediate Q^2, say in the several GeV^2/c^2 range, we should expect a smoothly increasing $E2/M1$ ($\equiv R_{EM}$ ratio, schematically shown in 1, as *hard* processes begin to play a role.

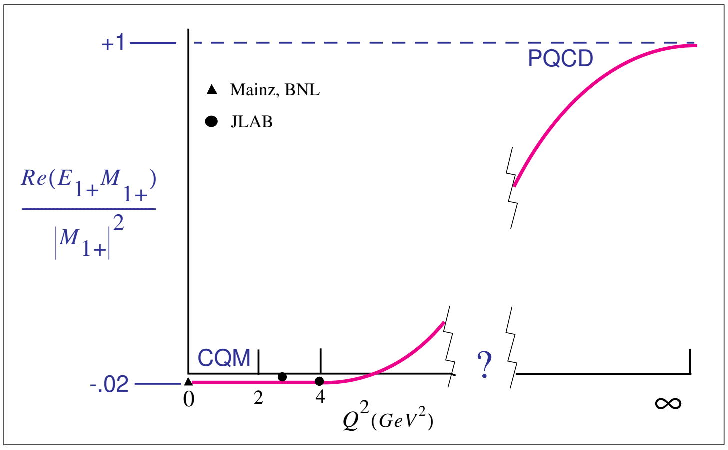


Figure 1: $Re(E^*_{1+}M_{1+})/|M_{1+}|^2$ as a function of Q^2. The datum at Q^2=0, is the result of experiments at Mainz [7] and BNL [6]. The data points at Q^2=2.8 and 4 GeV^2/c^2 are the JLAB [8] results. The unmodified SU(6) value is 0, while the PQCD prediction is +1. The curve is a suggestion of what may be expected. The break in the abscissa and the curve indicates our lack of knowledge about where in Q^2 the transition to *hard* processes occurs.

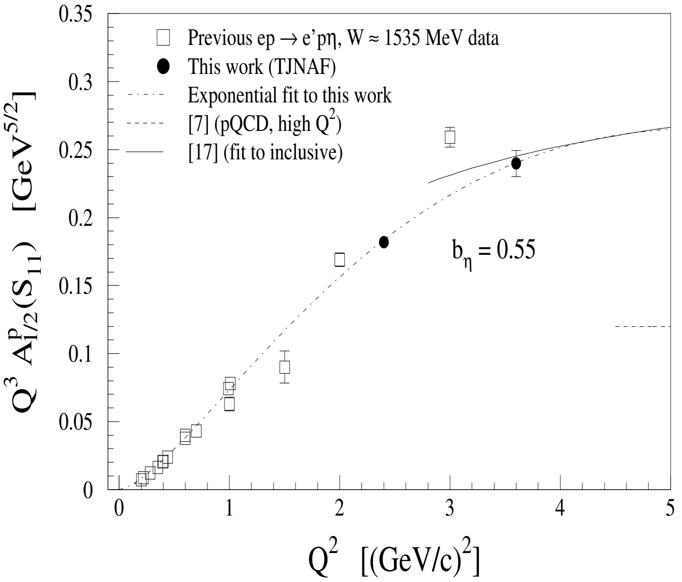
At the proposed Q^2 the characteristic wavelength of the probe is $\sim$ 0.1 fm, which should be small enough to begin to probe the short range correlations inherent in the nucleon's structure. Thus, it is fairly safe to assume that R_{EM} will begin to show the deviation from the low Q^2 values signaling relative onset of *hard* processes.

We also plan to measure the transition to the $S_{11}(1535)$ excited nucleon state. Even though this state is at a W in which there is an overlap with other resonances and significant multi-pion nonresonant production, it is easily isolated since it is the strongest excitation of any resonance at high Q^2, and it is the only major state which de-excites by emission of an η meson. Identification of a single η meson in the final state virtually isolates the $S_{11}(1535)$. Since the $S_{11}(1535)$ has $J^\pi = 1/2^-$ it is only excited by the helicity conserving $A_{1/2}$ amplitude. Therefore this experiment is a very important test case for the onset of hard processes. As with the nucleon and $\Delta(1232)$ it is the lowest lying state with it's quantum numbers, so that it's amplitude can be calculated using PQCD sum-rule, and/or SPD techniques to observe the interplay between soft and hard processes. Fig. 2 shows the current status of the world data. It can be seen that even at $Q^2 = 3.6$ GeV^2/c^2 the $1/Q^4$ scaling is not yet evident, but there may be a suggestion of its onset.

2.2 Study of isovector GPD's.

As pointed out above, the transition form factors are sensitive to different combinations of isoscaler and isovector nucleon GPD's. For the $n \to \Delta$ transition the dominant magnetic form factor G^*_M selects the isosvector componant of the nucleon GPD's $\mathcal{F}_M^{q,\mathcal{IV}}(x,t)$ Thus we will measure G^*_M out to a Q^2 near 15 GeV^2/c^2.

Figure 2: The quantity $Q^3 A^p_{1/2}(Q^2)$ for the $S_{11}(1535)$. The dot-dashed line is an exponential fit to the TJNAF [9] cross section given by the two points at 2.4 and 3.6 GeV^2/c^2, ($\sigma_{res} = 16.5 \exp[-0.565\,Q^2]$ μb, where Q^2 is in [(GeV/c)^2]), and the solid line is a fit to inclusive data.



The experimental status of the $N \to \Delta$ transition magnetic form factor is shown in figure 3. The decrease in G^*_M relative to G_D ($\equiv 3/(1 + Q^2/.71)^2$) indicates that the transition form factor is softer than that for elastic scattering. It is expected in the large n_c limit, the Δ wave function is similar to the proton wave function. In that case, this result would indicate that the $\mathcal{IV}$ part of the nucleon form factor is quite a bit softer than the total would indicate that the total GPD, $\mathcal{IV} + \mathcal{IS}$, accessed in elastic scattering. If we were to extend the measured data to much higher Q^2, as pointed out in ref. [5], together with the elastic form factors, we would uniquely access the high $k_\perp$ componants in the $N \to \Delta$ transition.

3 Experimental Procedures.

The high luminosity coupled with high momentum and high resolution of the HMS and proposed SHMS spectrometers will allow us to measure the very small cross sections encountered at the very highest Q^2. We will measure neutral meson electroproduction at high Q^2. As in experiment 94-014, we will measure the resonant amplitudes of the $\Delta(1232)$ and $S_{11}(1535)$ via $e + p \to \Delta(1232) \to p + \pi^0$ and $e + p \to S_{11}(1535) \to p + \eta$, respectively.

For the single meson decay channel measuring only one of the decay hadrons completely determines the kinematics of the entire reaction, including the other undetected hadron. In particular, the neutral single meson is identified by the missing mass of the detected proton and electron, and it's c.m. kinematics by missing momentum. An important property of high Q^2 reactions which hall C can take advantage of is that the hadronic reaction products are boosted into a narrow cone relative to the momentum transfer, so that large c.m. angular acceptances in θ and ϕ can be obtained with relatively modest angular acceptance spectrometers. This is especially true for the recoil protons in single neutral meson production, ie. in the reactions $p(e, e'p)\pi^0$, and $p(e, e'p)\eta$. The protons emerge in a narrow cone around the momentum transfer $\vec{q}$. For example, if we consider π^0 production at the delta peak, $W = 1232$ MeV, at $Q^2 = 10$ GeV^2/c^2 the cone angle in the lab corresponding to 4π in the c.m. is 2.7° (47 mr). For $\eta's$ at the peak of the $S_{11}(1535)$ resonance the angle is 2.5° (43 mr). With modest solid angle acceptance spectrometers one can obtain almost all of the decay proton cone, and then select the π^0 and η channels by reconstructing their missing mass.

Both spectrometers must have high maximum momentum capabilities. In addition *both* must have excellent resolution, and as large solid angle acceptance possible.

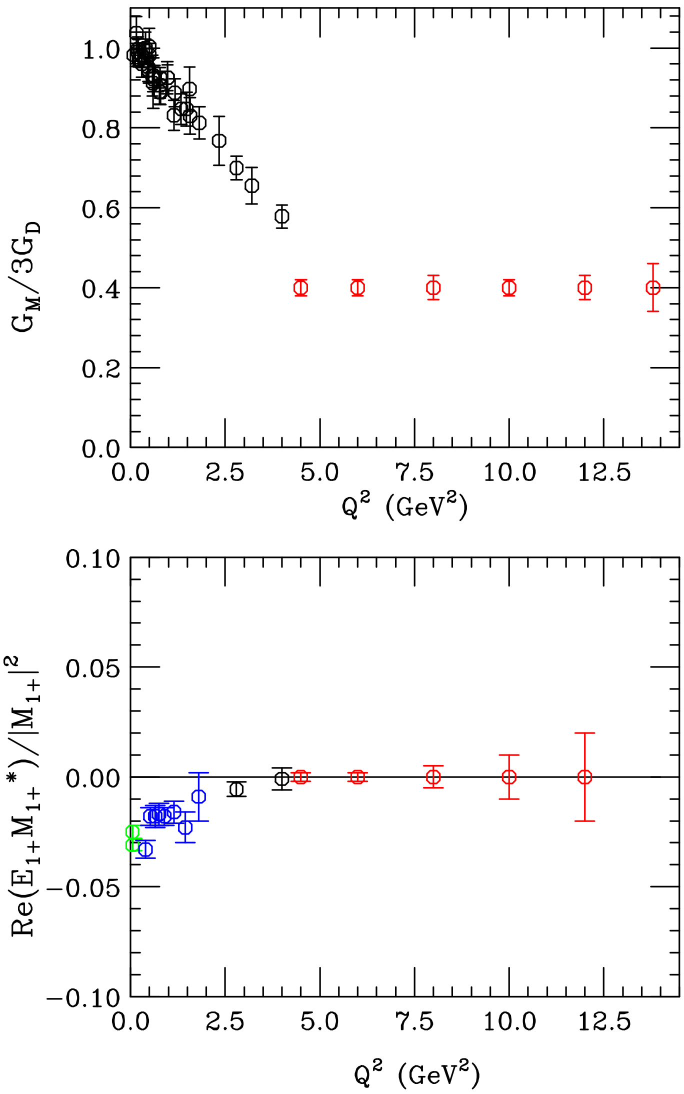


Figure 3: Upper: the $N \to \Delta$ magnetic form factor $G_M^*(Q^2)$ relative to the dipole $G_D = 3/(1+Q^2/.71)^2$. The data points for Q^2 below 2.8 GeV^2/c^2 are from a compilation of ref. [10]. Those at $Q^2 = 2.8$ and 4.0 GeV^2/c^2 are recent JLab data [8]. The points indicated in red are the projection of Hall C upgrade conditions, assuming $G_M^*(Q^2)$ has a dipole shape. Lower: $Re(E_{1+}^* M_{1+})/|M_{1+}|^2$ as a function of Q^2. The data at Q^2=0 (green), are the result of experiments at Mainz [7] and BNL [6]. The data points at Q^2=2.8 and 4 GeV^2/c^2 (black) are the JLab [8] results. The data between Q^2=0.4 and 1.8 GeV^2/c^2 (blue) are the recent JLab Hall B results [11]. The points indicated in red show the projected error of Hall C upgrade conditions, assuming $G_M^*(Q^2)$ has a dipole shape. The projected errors reflect statistics only.

The resolutions in momentum and angle must be excellent because very large Jacobians are involved in transforming the narrow kinematic cone of the detected particles into 4π c.m. The missing mass resolution is limited by the spectrometer resolution, and becomes progressively worse at higher Q^2. At Q^2 = 10 GeV^2/c^2 the missing mass resolution would be poorer such that there will be a larger contamination from elastic radiative processes. Thus high resolution becomes extremely important. Figure 4 shows the Monte Carlo generated missing mass resolution which would be expected at Q^2 = 10 GeV^2/c^2 using two spectrometers with the properties of HMS and SHMS. These do not include radiative tails.

Large solid angle acceptance is important because exclusive cross sections are decreasing rapidly with momentum transfer.

With spectrometers HMS and SHMS the Monte Carlo generated angular acceptance in the c.m. is essentially 4π at the highest Q^2. The η's and π^0's are measured simultaneously in each run.

Table 1 gives the expected conditions, including some of the particulars, including spectrometer resolution and acceptances needed to carry out the experiment.

For the calculation of the projected rates I assumed

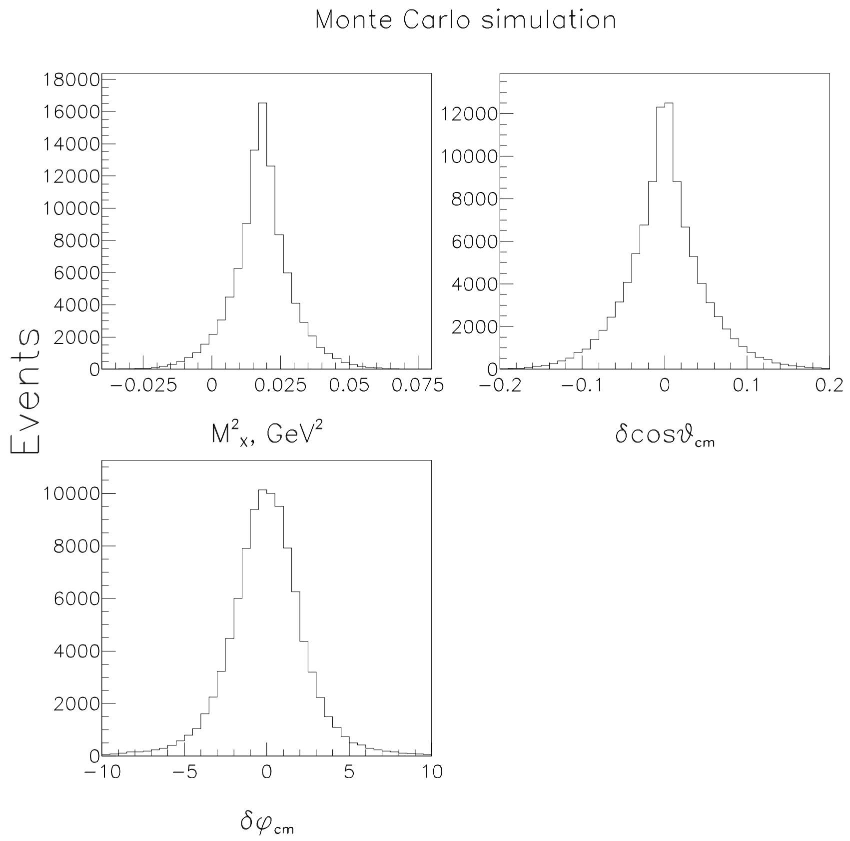


Figure 4: Missing mass for the reaction $p(e,e'p)X$. The result of Monte-Carlo simulation for $p(e,e'p)\pi^0$ at $W = 1.235$ GeV, at $Q^2 = 10$ GeV^2/c^2 using spectrometers HMS and a new spectrometer SHMS. (Note radiative taila are not included.

$$\frac{d\sigma^5}{d\vec{P}_e d\Omega_p} = \Gamma_V \frac{d\sigma^{cm}}{d\Omega_p^{cm}}$$

with

$$\frac{d\sigma^{cm}}{d\Omega_p^{cm}} = \sigma(Q_0^2)\frac{G_D(Q^2)}{G_D(Q_0^2)})^2 f(Q^2)$$

where $\sigma(Q_0^2)$ is the already measured cross section at $Q^2\bar{4}$ GeV^2/c^2, and $G_D(Q^2) = (1 + Q^2/.71)^{-2}$.

Table 2 shows the number of observed $\Delta(1232)$'s events which would be obtained with the beam on target for the number of days shown for each each Q^2, assuming a dipole dependence of G_M^* as a function of Q^2.

One can see that it is possible to perform a high quality experiment to accurately obtain the dominant multipoles of the $e + p \to \Delta(1232) \to p + \pi^0$ and $e + p \to \S_{11}(1535) \to p + \eta$ at a mean Q^2 up to ~ 15. The thing that makes it all possible is the unique Hall C capability including high luminosity coupled with high quality high momentum spectrometers.

References

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Table 1: Experimental conditions assumed for the proposed experiment.

Luminosity ($\mathrm{cm}^{-2}\mathrm{s}^{-1}$)	1×10^{39}
Electron (HMS) acceptance $\Delta P_e/P_e \times \Delta\Omega_e$ (msr)	$20\% \times 7$
Proton (SHMS) acceptance $\Delta P_p/P_p \times \Delta\Omega_p$ (msr)	$20\% \times 4$
Momentum resolution (HMS and SHMS) $\delta p/p$	1×10^{-3}
Angular resolution (HMS and SHMS) (rad) $\delta\theta = \delta\phi$	1×10^{-3}

Table 2: Statistics for $e + p \to \Delta(1232) \to p + \pi^0$ using HMS and SHMS in Hall C.

Q^2	Events	Days
4	7×10^5	1
6	9×10^4	1
8	3×10^4	1
10	5×10^4	10
12	1.6×10^4	10
14	5×10^3	10

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