Proposal for CLAS Approved Analysis

Study of fracture functions in polarized and unpolarized semi-inclusive electron scattering off the proton.

M. Osipenko[a,b] †, G. Ricco[a,c], L. Trentadue[d], F. Ceccopieri[d,e], H. Avakian[f]
M. Anghinolfi[a], M. Battaglieri[a], R. De Vita[a],
E. Golovach[b], G. Nefedov[b],
M. Ripani[a], S. Simula[g], M. Taiuti[c]

[a] *INFN, Sezione di Genova, 16146 Genova, Italy*
[b] *Moscow State University, 119992 Moscow, Russia*
[c] *Dipartimento di Fisica, Università di Genova,*
[d] *Dipartimento di Fisica, Università di Parma,*
[e] *INFN, Sezione di Parma, Parma, Italy*
[f] *Thomas Jefferson National Accelerator Facility, Newport News, Virginia 23606*
[g] *INFN, Sezione di Roma III, Rome, Italy*

February 21, 2005

Abstract

We propose the extraction of the semi-inclusive proton and neutron electroproduction cross sections off the proton ($ep \to e'pX$, $ep \to e'nX$, $\vec{e}\vec{p} \to e'pX$ and $\vec{e}\vec{p} \to e'nX$) using the CLAS detector, including beam and target polarization asymmetries. Below the $p\bar{p}$ electroproduction threshold these processes are completely defined by nucleon fracture functions $M(x,z,Q^2)$. The Q^2 evolution of the fracture functions is known in QCD to NLO. In Regge limit these functions describe internal structure of the object exchanged between high momentum jet and target fragments (Pomeron). In the low momentum limit these functions give insight on the pion structure. Combining the data from intermediate energies of JLab ($1 < Q^2 < 6$ GeV^2) with Regge limit data obtained at HERA will allow a careful study of duality and the Q^2 evolution of the fracture functions. Moreover only JLab can provide a clear separation between target and current fragmentation processes. The large acceptance of the CLAS detector allows an extraction of the semi-inclusive 5-dimensional cross section, providing a tool to test QCD and investigate the hadronization process. This analysis will be based on the data recorded at 6 GeV during the E1-6, E1f and EG1b run periods, providing kinematic coverage for $x = 0.2 - 0.6$ and $Q^2 = 1 - 6$ GeV^2.

†osipenko@ge.infn.it

1 Motivation

Inclusive lepton scattering off the proton provides an important information about internal nucleon structure. In this reaction one studies various proton structure functions e.g. structure function F_2. Thanks to the asymptotic freedom this structure function has a simple interpretation as a sum of parton momentum distributions. Increasing power of particle detectors physicists went beyond the inclusive lepton scattering by measuring few particles in the final state. Semi-inclusive reactions allow to study not only the initial distribution of partons inside the proton, but also shade light on the parton hadronization process. Deep understanding of this process is mandatory for any theory of strong interactions. A part of the semi-inclusive reaction was successfully described and thoroughly studied in so called "current fragmentation" region, which is related to the fragmentation of a highly energetic parton into hardons. However, another part of the semi-inclusive cross section related to dissociation of the target fragments into hadrons was normaly ignored. 10 years ago it was shown that this second part of the measured cross section, called "target fragmentation" part, obeys the normal QCD evolution equations and a number of sum rules. Furthermore, recent HERA measurements emphasized the importance of the target fragmentation process in the observation of the diffraction phenomenon.

Measurement of the semi-inclusive electroproduction cross section with beam energy E_0 implies detection in coincidence of the scattered electron with momentum $k' = (E', E', \theta_e, \phi_e)$ and a hadron with momentum $p_h = (E_h, p_h, \theta_h, \phi_h)$. In the one photon exchange approximation the reaction can be described by five independent kinematic variables: the virtual photon energy $\nu = E_0 - E'$, photon four-momentum squared $Q^2 = 4E_0E' \sin^2 \frac{\theta_e}{2}$, hadron energy E_h in the Laboratory reference frame, hadron transverse momentum with respect to the virtual photon direction p_T and azimuthal angle between hadronic and leptonic planes ϕ.

Unpolarized semi-inclusive electron scattering off the proton can be described in terms of four structure functions H_i

$$\begin{aligned}\frac{d^5\sigma}{dxdydzdp_T^2d\phi} = \; & \frac{4\pi\alpha^2 ME}{Q^4}\frac{E_h}{\sqrt{p_h^2 - p_T^2}}\Bigg[xy^2 H_1(x,z,Q^2,p_T) + \\ & \left(1 - y - \frac{Mxy}{2E}\right) H_2(x,z,Q^2,p_T) + \\ & \frac{p_T}{\sqrt{Q^2}}(2-y)\sqrt{\frac{1 - y - \frac{Mxy}{2E}}{1 + \frac{2Mx}{yE}}} \cos\phi H_3(x,z,Q^2,p_T) + \\ & \frac{p_T^2}{Q^2}\frac{1 - y - \frac{Mxy}{2E}}{1 + \frac{2Mx}{yE}} \cos 2\phi H_4(x,z,Q^2,p_T) \Bigg]\end{aligned} \tag{1}$$

which are functions of Q^2, the fraction of proton energy carried by struck quark $x = Q^2/2Pq = Q^2/2M\nu$ (Bjorken limit), the fraction of the quark energy taken away by the hadron $z = Pp_h/Pq = E_h/\nu$ (Bjorken limit and $p_T << p_h$) and p_T.

The beam asymmetry of longitudinally polarized electrons scattering off an unpolarized target is described by the H'_{LT} structure function as

$$\frac{d^5\Delta\sigma_{LU}}{dxdydzdp_T^2d\phi} = \lambda_e \frac{4\pi\alpha^2 s}{Q^4} xy\sqrt{1-y}\sin\phi H'_{LT}. \tag{2}$$

The structure functions H_i describe two possible physical processes shown in Fig. 1 through which this reaction can occur. In the current fragmentation process (see left panel

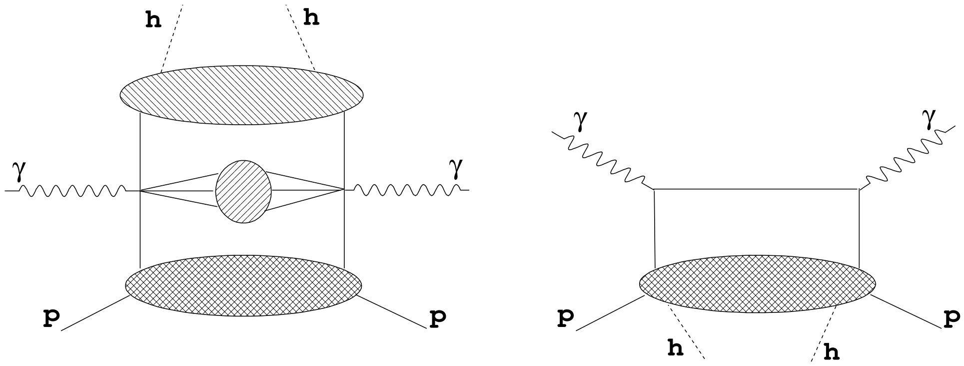

Figure 1: Diagrams of the semi-inclusive hadron electroproduction corresponding to the current fragmentation (left) and target fragmentation (right) processes.

of Fig. 1) the virtual photon γ is absorbed by a quark inside the nucleon, which in turn fragment into hadrons. One of those hadrons emitted by struck quark h is measured in the detector. Meanwhile, the target fragmentation process leads to the observed hadron h emitted not by the struck quark, but rather by the nucleon spectator fragments. These two processes have completely different physics interpretation. In the current fragmentation process at Leading Order (LO) Leading Twist (LT) the cross section can be described as a product of the quark momentum distribution in the nucleon (measured in DIS) on the quark fragmentation function (measured in $e^+e^- \to hX$). The target fragmentation process is more complex. The soft part of handbag (lower blob in the right panel of Fig. 1) here describes a probability to find a quark q of momentum xP in the nucleon, which emits the hadron h. This probability is called "fracture function" $M_q^h(x,z,t,Q^2)$ from a mixture of fragmentation and structure functions. It was shown in Ref. [22] that the fracture functions obey well known QCD Q^2-evolution and have a number of useful properties. One of those is a natural momentum sum rule:

$$\sum_h \int_0^{t_{max}(Q^2)} dt \int_0^1 dzzM_q^h(x,z,t,Q^2) = (1-x)F_q(x,Q^2) \tag{3}$$

i.e. integration on the hadron final state yields the usual proton structure functions. Q^2-evolution is described by pQCD DGLAP integro-differential equation:

$$Q^2\frac{\partial}{\partial Q^2}M_q^h(x,z,t,Q^2)=\sum_i\frac{\alpha_S(Q^2)}{2\pi}\int_{\frac{x}{1-z}}^{1}\frac{du}{u}P_q^i(u)M_i^h(\frac{x}{u},z,t,Q^2) \tag{4}$$

with the same anomalous dimensions as for ordinary structure functions well known in pQCD.

In the Regge limit ($s\to\infty$) and $z\to 1$ fracture functions are directly related to the structure of the object exchanged between the target and the current jet

$$M_q^h(x,z,t,Q^2)\approx\sum_R F(t)(1-z)^{1-2\alpha_R}F_R(x,Q^2) \tag{5}$$

where $F_R(x,Q^2)$ is the structure function of R-th Reggeon and the sum runs over all allowed Regge poles of the intercept α_R.

The fracture functions are related to the measured cross section through the usual convolution equation:

$$\frac{d\sigma}{dxdydzdt}=\sum_q\int_0^1 dx' M_q^h(x',z,t,Q^2)\sigma_q^{hard}(\frac{x}{x'},Q^2) \tag{6}$$

where $\sigma_q^{hard}(x,Q^2)$ is the hard scattering cross section of the virtual photon on the quark q, calculable in pQCD. At Leading Order (LO) this simply yields:

$$\frac{d\sigma}{dxdydzdt}=\frac{1+(1-y)^2}{2y^2}\frac{4\pi\alpha^2}{sx}(1-\epsilon)\sum_q e_q^2M_q^h(x,z,t,Q^2) \tag{7}$$

and similar for polarized semi-inclusive asymmetry

$$\frac{d\Delta\sigma}{dxdydzdt}=\frac{(2-y)}{y}\frac{2\pi\alpha^2}{sx}\sum_q e_q^2\Delta M_q^h(x,z,t,Q^2)\ . \tag{8}$$

As the normal structure and fragmentation functions, the fracture functions *do not depend on particular hard process* under study. Once $M_q^h(x,z,t,Q^2)$ is measured in an electroproduction experiment one can immediately obtain the target fragmentation contribution in the *hadron-hadron collisions*[1] $N_1+N_2\to hX$ (see Fig. 2):

$$\begin{aligned}\sigma_{target}^h = \quad & \sum_{ij}\int_0^{1-z}\frac{dx_i}{x_i}\int_0^{1-z}\frac{dx_j}{x_j}\Big[M_i^{h(N_1)}(x_i,z,t,Q^2)F_j^{N_2}(x_j,Q^2)+ \\ & M_i^{h(N_2)}(x_i,z,t,Q^2)F_j^{N_1}(x_j,Q^2)\Big]\sigma_{hard}^{ij}(i+j\to h)\end{aligned} \tag{9}$$

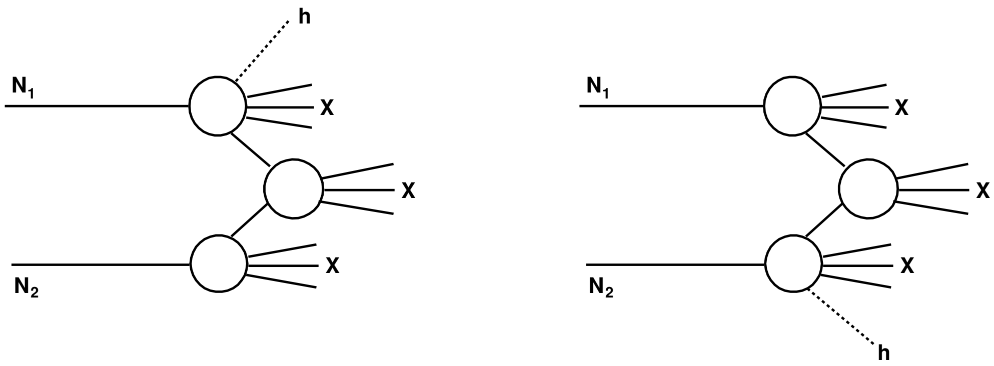

Figure 2: Diagrams of the target fragmentation mechanisms in the hadron-hadron collisions.

where $F_j^{N_i}$ are ordinary structure functions of incoming hadron N_i for the quark flavour j and $M_j^{h(N_i)}$ is its fracture function for measured hadron h.

In the semi-inclusive electroproduction experiment therefore one typically probes both current and target fragmentation processes. The separation of these two mechanisms is not trivial. At present, the only available method is based on kinematic cuts. It is useful to define rapidity of the measured hadron η defined in CM frame as (Ref. [21])

$$\eta = \frac{1}{2}\frac{\log\left(E_h + p_h^{||}\right)}{\log\left(E_h - p_h^{||}\right)} \tag{10}$$

The rapidity for the current and target fragmentation processes is given by Mulders [20]:

$$\eta_c = \log z + \log\frac{W}{\sqrt{m_h^2 + p_T^2}}, \qquad \eta_t = \log\left(\frac{1}{z}\frac{m_h^2}{Q^2}\frac{x}{1-x}\right) + \log\frac{W}{\sqrt{m_h^2 + p_T^2}} \tag{11}$$

therefore, the rapidity gap between the current and target fragments can be written as following:

$$\Delta\eta^{CM} = \log z - \log\left(\frac{1}{z}\frac{m_h^2}{Q^2}\frac{x}{1-x}\right) \tag{12}$$

For the kinematics of CLAS the rapidities and the rapidity gap are shown in Figs. 3 and 4, respectively.

Hence, in the CLAS kinematics the minimal separation interval in the rapidity $\Delta\eta > 2$ (so caller Berger's criterion [21]) between the current and target fragments is achievable in the region of $z > 0.2$ at $2 < Q^2 < 5$ GeV^2 and minimal x values. This can be seen better on example of the semi-inclusive π^+ electroproduction reaction measured in CLAS (see Ref. [27]).

[1] The QCD factorization, on which relies Eq. 9, has not been proved in the hadron-hadron collisions. Moreover, there are indications on possible non-factorization in these processes.

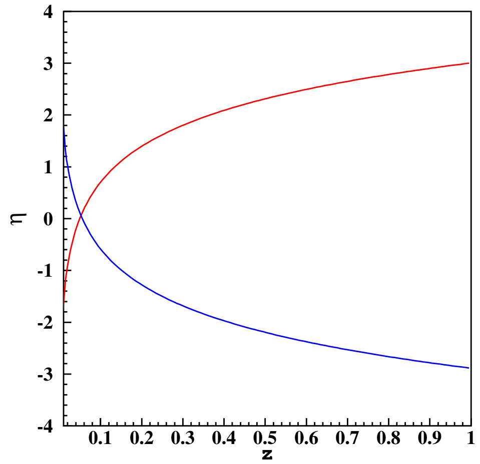

Figure 3: Rapidities of the current (red) and the target (blue) fragments as a function of z at $Q^2 = 3$ GeV^2, $x = 0.3$ and $p_T = 0$ GeV.

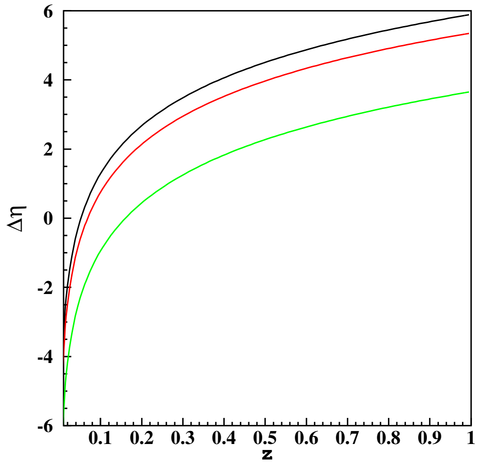

Figure 4: Rapidity gap between the current and target fragments as a function of z for few CLAS kinematics: black - $Q^2 = 3$ GeV^2, $x = 0.3$; red - $Q^2 = 5$ GeV^2, $x = 0.55$; green - $Q^2 = 3$ GeV^2, $x = 0.8$.

In practice, measuring current fragmentation pions one always deals with a mixture of these two processes and the separation is ambiguous. It is in particular true for JLab energies, where large rapidity gap cannot be achieved. Thus, study of concurrent to cur-

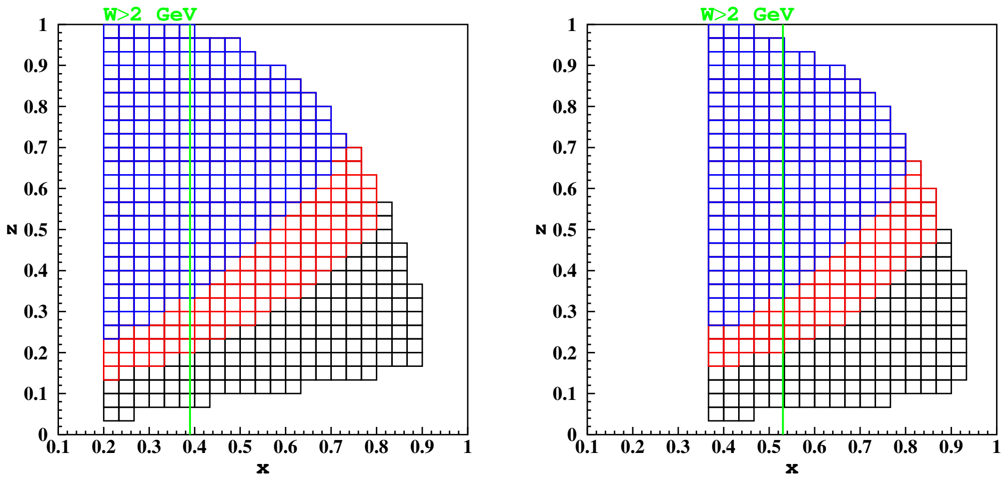

Figure 5: Kinematic coverage of CLAS data on the semi-inclusive π^+ electroproduction at $Q^2 = 2$ GeV^2 (left) and $Q^2 = 3.5$ GeV^2 (right): the red area corresponds to $\Delta\eta > 2$ (Berger's criterion), the blue area $\Delta\eta > 3$, the green line separate DIS ($W > 2$ GeV) region at its l.h.s.

rent fragmentation mechanism is essentially important for deep understanding of obtained results on semi-inclusive cross section, single and double spin asymmetries.

JLab is unique place where the proton target fragmentation in electroproduction can be studied directly, avoiding an ambiguous separation with the current fragmentation. The total energy of the initial state $W^2 = M^2 + 2M\nu - Q^2 <$ is not enough to produce $p\bar{p}$-pair ($W^2 > 9M^2 + P_{min}^2$) [2] and the only baryon in the final state comes from the target proton. In Fig. 5 one can see that data points disappear almost exactly on the $p\bar{p}$ threshold equal to $x = 0.21$ for $Q^2 = 2$ GeV^2 and $x = 0.33$ for $Q^2 = 3.5$ GeV^2. This guaranties absence of the current fragmentation processes in E1-6 and EG1b data. Therefore, an extraction of the semi-inclusive proton electroproduction cross section, single and double spin asymmetries allows direct measurement of all proton fracture functions.

2 Experimental Status of the Proton Semi-Inclusive Electroproduction

Proton semi-inclusive electroproduction was previously studied at SLAC [1], Cornell [2,3], DESY [5], HERA [6–8] and CERN [9–11]. Some data were extracted from charge current interaction of neutrino with the proton at CERN [12,13]. However, all of these experiments

[2] P_{min} is the minimum proton momentum which can be detected by CLAS; $P_{min} \approx 0.4$ GeV.

were undertaken with beam energies well above $p\bar{p}$ threshold (apart of Refs. [2,3]). Therefore the data contain a mixture of the current and target fragmentation events. Moreover, only experiments from Refs. [2,3,10,11] identified measured hadron (see Fig. 6), all others published just charged hadron multiplicities, without any particle identification. Kinematics of experiments from Refs. [2, 3, 5] is most similar to CLAS, but lack of azimuthal ϕ-distributions (data were averaged over ϕ) and a few measured points in x and Q^2 cannot exhibit all properties of undergoing physics processes.

Most interesting results were obtained after publication of the fracture function approach. In Refs. [6,7] mechanism of target fragmentation was used to access in the Regge limit the structure of Pomeron.

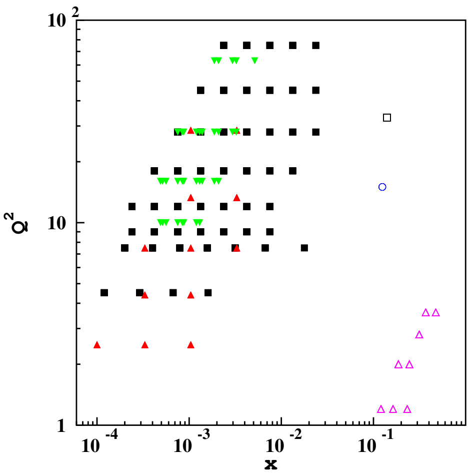

Figure 6: Kinematics covered in previous semi-inclusive proton electroproduction experiments from Refs. [2,3,6,7,10,11].

Lack of the data on the single and double spin asymmetries allows to CLAS Collaboration to provide these data for the first time.

3 Expected Results

We propose to extract five differential absolute cross sections and polarization asymmetries for semi-inclusive proton and neutron electroproduction off the proton from already taken and cooked E1-6, E1f and EG1b data. This will allow a complete study of the proton fracture function in JLab kinematic domain (see Fig. 7). Up to date none of CLAS approved experiments or CLAS approved analyses has proposed to extract these data. This study includes:

- separation of different fracture functions (M_L, M_T, M_LT, $M_{LT'}$ etc.) by means of the Rosenbluth plot and azimuthal asymmetries (for example see Fig. 8): $\cos\phi$, $\sin\phi$, $\cos 2\phi$ and $\sin 2\phi$. Up to date the only fracture function analyzed and discussed in the literature is the transverse ($M_T = M$) component of the total hadronic tensor. Information on the other components is still missing and CLAS Collaboration can provide these data for the first time;

- test of factorization of the fracture functions. In DIS limit the fracture function is expected to factorize in a product of two functions: Reggeon structure function $F_R(x, Q^2)$ and some kinematic term as shown in Eq. 5. Furthermore, the Reggeon $F_R(x, Q^2)$ is only function of x and Q^2, while z-dependence is factorized in the kinematic term $(1-z)^{1-2\alpha_R}$. This separation mimic somehow the factorization effect in the current fragmentation limit and could explain surprising observations of the factorization at low Q^2 and low z values;

- extraction of the fracture function moments and comparison of their Q^2-evolution to pQCD one could represent an important test of QCD in hadronization processes;

- test of the duality between Regge limit and the resonance region can be performed in a more "classical" manner. The duality discovered by G. Veneziano [28] implies an equivalence of the sum over all Regge trajectories in the Regge limit $s \to \infty$ and the sum of s-channel amplitudes at $t \to \infty$. One possible solution for the amplitude satisfying both asymptotic conditions has the following form:

$$A(s,t) = g\frac{\Gamma(1-\alpha(s))\Gamma(1-\alpha(t))}{\Gamma(2-\alpha(s)-\alpha(t))} \tag{13}$$

where $\alpha(s)$ and $\alpha(t)$ are intercepts of t and s-channel trajectories, respectively. The asymptotic limits of this amplitude are given by

$$\begin{aligned} A(s,t) &\longrightarrow s^{\alpha(t)} \quad , \quad s \to \infty \quad (t \text{ fixed}) \\ A(s,t) &\longrightarrow t^{\alpha(s)} \quad , \quad t \to \infty \quad (s \text{ fixed}) \end{aligned} \tag{14}$$

The Regge limit was explored by HERA experiments which measured intercept and structure for various trajectories. Another limit $t \to \infty$ remains still unexplored in electroproduction experiments. The CLAS data can reach $-t = 2M\sqrt{M^2 + P_{p'}^2} - 2M^2 \approx 4 - 5$ GeV^2 at which in the photoproduction data vanishing of t-channel amplitude is clearly observed [29]. Therefore at largest accessible t values we can directly extract $\alpha(s)$ intercept. Moreover, keeping HERA t values ($0.07 < -t < 0.45$ GeV^2) we can test an "two component" assumption: i.e. duality of the Pomeron to the background and non-exotic Regge trajectories to nucleon resonances proposed in [30]. Hence a comparison of the diffractive data from HERA collider to the CLAS data will allow for the first time an interesting verification of the duality phenomenon in the semi-inclusive reactions. This test cannot be done in totally inclusive reactions because there the information about t-momentum transfer is missing;

- extract structure functions of various t and s-channel Regge trajectories. If the factorization from Eq. 5 is observed in the data we can attempt to extract structure functions of Regge trajectories with different quantum numbers using combined the proton and neutron electroproduction data. The neutron detection efficiency can be extracted from the exclusive π^+ electroproduction reaction by a comparison of the expected neutron yield to the measured one in the missing neutron peak shown in Fig. 9. Examples of CLAS neutron detection efficiency taken from Ref. [31] can be found in Fig. 10;

- estimate x and Q^2 behaviour of the target fragmentation contribution into the absolute cross section and spin asymmetries at JLab energies for electroproduction of pions. This can be done by means of the momentum sum rule from Eq. 3 assuming dominance of the pion and proton electroproduction reactions. Then for example the difference between proton structure function and the integrated proton fracture function will give the integrated over t and z contribution of the target fragmentation in the electroproduction of pions

$$\begin{aligned}&(1-x)F_2(x,Q^2) - \int_0^{t_{max}(Q^2)} dt \int_0^1 dzzM_2^p(x,z,t,Q^2) \approx \\ &\sum_{\pi^+\pi^-\pi^0} \int_0^{t_{max}(Q^2)} dt \int_0^1 dzzM_2^\pi(x,z,t,Q^2)\end{aligned} \tag{15}$$

  while z-dependence can be deduced lated from a comparison of theoretical expectations for the current fragmentation cross section to the data.

Summarizing, there is possibility for a broad study program on semi-inclusive reactions at CLAS. Measurement of the semi-inclusive proton and neutron electroproduction could become an important part of this program complementary to other measurements. The extraction of these data would enrich CLAS physics program by a new poorly explored but promising direction.

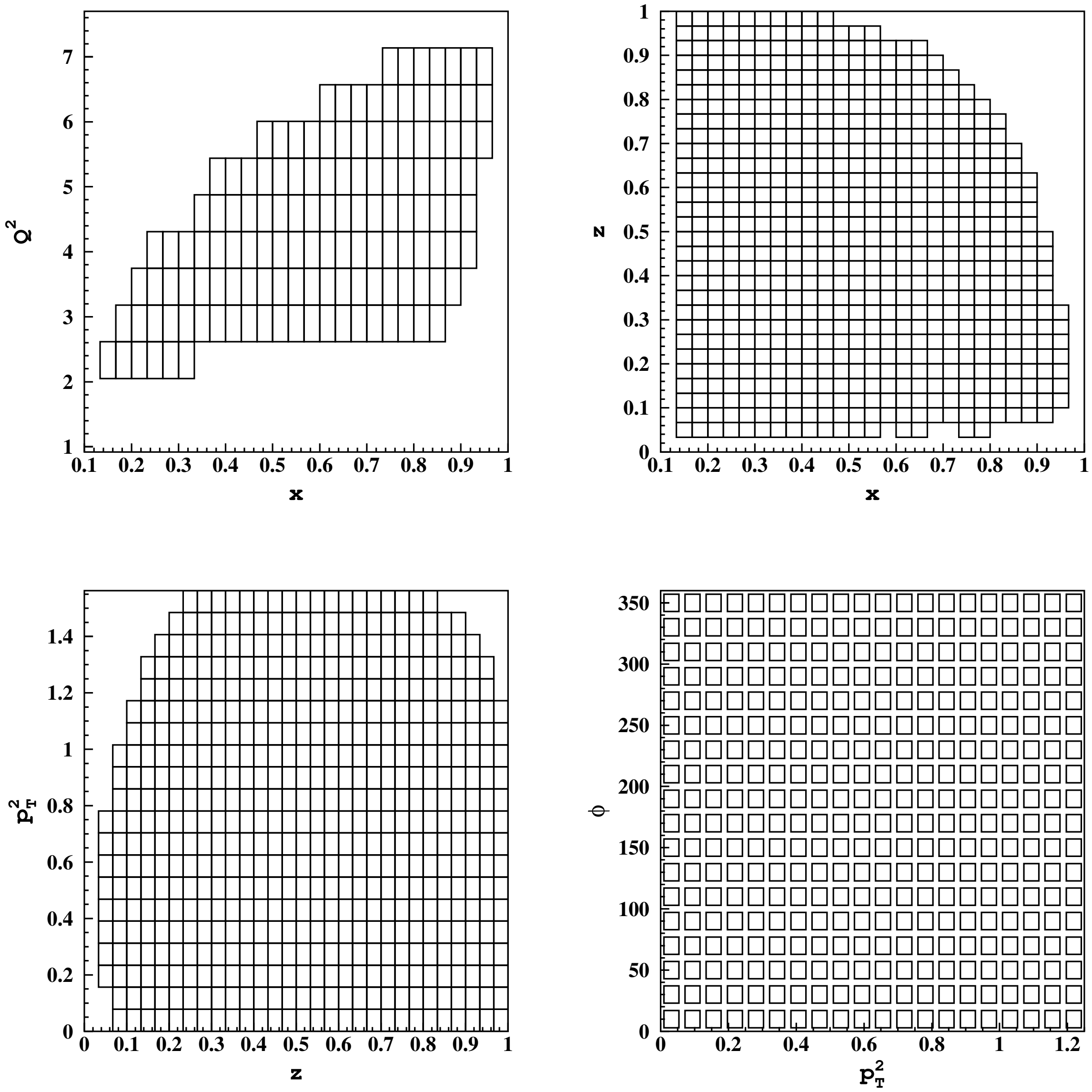

Figure 7: Kinematics accessible in CLAS with E1-6 and EG1b runs.

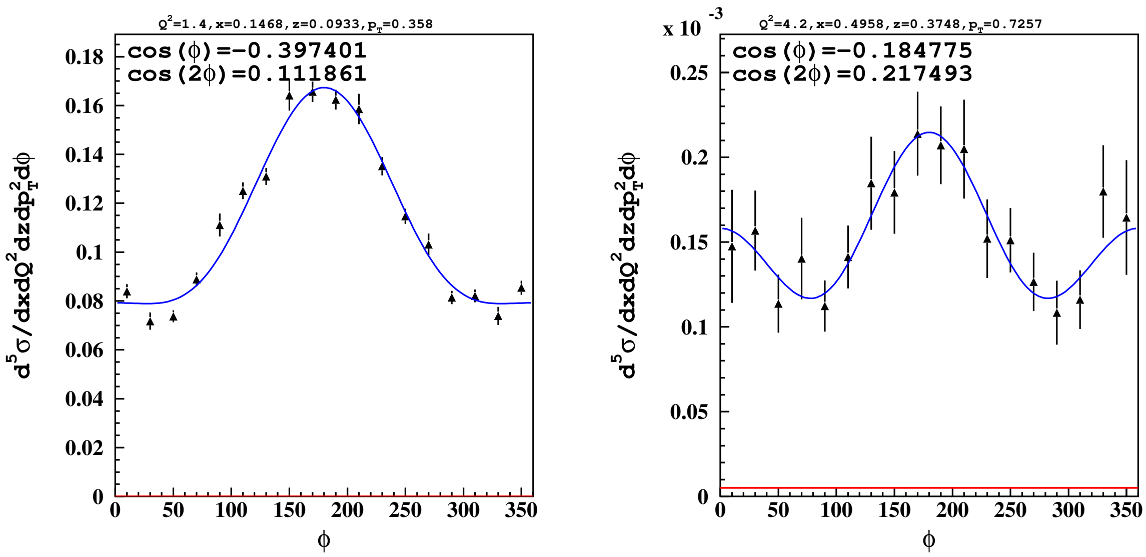

Figure 8: ϕ-asymmetries of the unpolarized semi-inclusive electroproduction of positively charged pions extracted from CLAS E1-6 data.

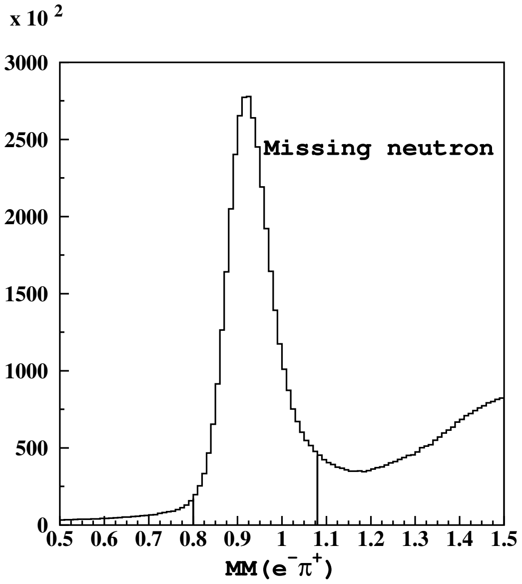

Figure 9: Selection of the missing neutron peak in π^+ electroproduction in CLAS E1-6 data.

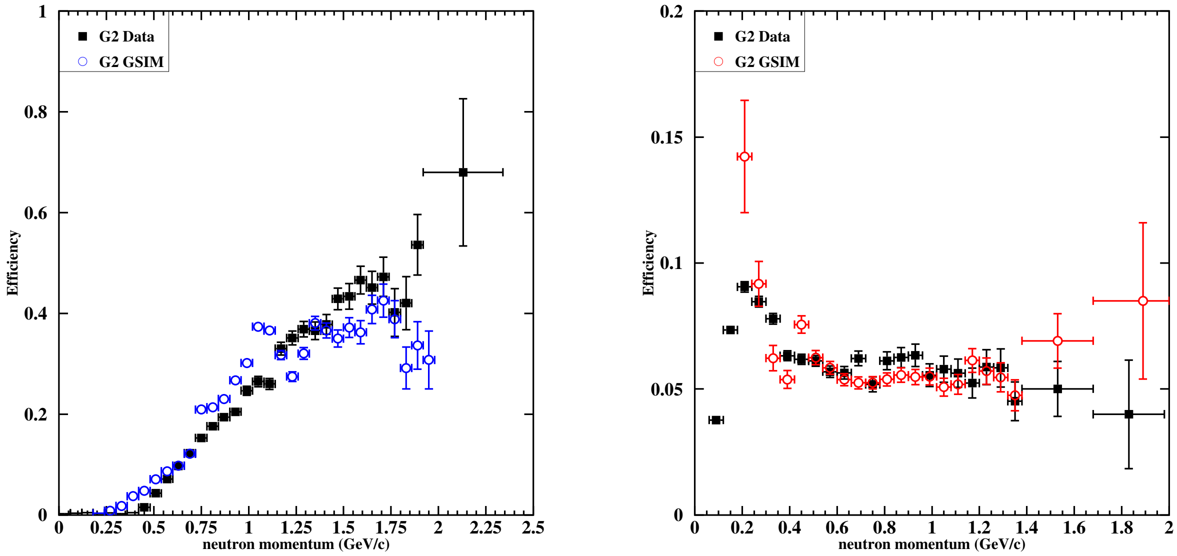

Figure 10: Neutron detection efficiency for EC (left) and SC (right) at CLAS in G2 run period taken from Ref. [31].

References

[1] J.T. Dakin *et al.*, *Phys.Rev.Lett.* **29**, 746 (1972).

[2] C.J. Bebek *et al.*, *Phys.Rev.Lett.* **34**, 1115 (1975).

[3] A. Browman *et al.*, *Phys.Rev.Lett.* **37**, 974 (1976); C.J. Bebek *et al.*, *Phys.Rev.* **D15**, 3077 (1977).

[4] J.M. Scarr *et al.*, *Nucl.Phys.* **B135**, 224 (1978).

[5] H. Ackermann *et al.*, *Nucl.Phys.* **B120**, 365 (1977).

[6] M. Derrick *et al.*, *Z.Phys.* **C70**, 391 (1996); M. Derrick *et al.*, *Z.Phys.* **C67**, 93 (1995); M. Derrick *et al.*, *Z.Phys.* **C67**, 227 (1995); J. Breitweg *et al.*, *Eur.Phys.J.* **C2**, 77 (1998); J. Breitweg *et al.*, *Phys.Lett.* **B414**, 428 (1997).

[7] S. Aid *et al.*, *Nucl.Phys.* **B445**, 3 (1995); I. Abt *et al.*, *Phys.Lett.* **B328**, 176 (1994); I. Abt *et al.*, *Z.Phys.* **C63**, 377 (1994); C. Adloff *et al.*, *Eur.Phys.J.* **C10**, 363 (1999); C. Adloff *et al.*, *Phys.Lett.* **B428**, 206 (1998); C. Adloff *et al.*, *Nucl.Phys.* **B485**, 3 (1997); C. Adloff *et al.*, *Nucl.Phys.* **B504**, 3 (1997).

[8] K. Ackerstaff *et al.*, *Phys.Lett.* **B464**, 123 (1999).

[9] J. Ashman *et al.*, *Z.Phys.* **C52**, 361 (1991);

[10] J.J. Aubert *et al.*, *Phys.Lett.* **B135**, 225 (1984); J.J. Aubert *et al.*, *Phys.Lett.* **B103**, 388 (1981).

[11] M. Arneodo *et al.*, *Z.Phys.* **C35**, 433 (1987); M. Arneodo *et al.*, *Phys.Lett.* **B150**, 458 (1985).

[12] G.T. Jones *et al.*, *Z.Phys.* **C46**, 25 (1990); P. Allen *et al.*, *Phys.Lett.* **B112**, 88 (1982); P. Allen *et al.*, *Nucl.Phys.* **B188**, 1 (1981); P. Allen *et al.*, *Nucl.Phys.* **B181**, 385 (1981); J. Blietschau *et al.*, *Phys.Lett.* **B87**, 281 (1979).

[13] H. Deden *et al.*, *Nucl.Phys.* **B198**, 365 (1982).

[14] M. D. Mestayer *et al.*, *Nucl. Instr. and Meth.* **A449**, 81 (2000).

[15] E. S. Smith *et al.*, *Nucl. Instr. and Meth.* **A432**, 265 (1999).

[16] G. Adams *et al.*, *Nucl. Instr. and Meth.* **A465**, 414 (2001).

[17] M. Amarian *et al.*, *Nucl. Instr. and Meth.* **A460**, 460 (2001).

[18] http://improv.unh.edu/Maurik/gsim_info.shtml.

[19] M. Osipenko *et al.*, *Phys. Rev.* **D67** 092001 (2003).

[20] P.J. Mulders, hep-ph/0010199 (2000).

[21] T. Sloan, G. Smadja and R. Voss, *Phys. Rep.* **162**, 45 (1988).

[22] L. Trentadue and G. Veneziano, *Phys.Lett.* **B323**, 201 (1994).

[23] L. Trentadue, *Nucl.Phys.Proc.Suppl.* **54A**, 176 (1997); L. Trentadue, *Nucl.Phys.Proc.Suppl.* **39BC**, 50 (1995); L. Trentadue, *Nucl.Phys.Proc.Suppl.* **64**, 152 (1998).

[24] C.A. Garcia Canal and R. Sassot, *Int.J.Mod.Phys.* **A15**, 3587 (2000).

[25] G. Camici, M. Grazzini ans L. Trentadue *Phys.Lett.* **B439**, 382 (1998); M. Grazzini, G.M. Shore and B.E. White *Nucl.Phys.* **B555**, 259 (1999); M. Grazzini, L. Trentadue and G. Veneziano, *Nucl.Phys.* **B519**, 394 (1998).

[26] D. de Florian and R. Sassot, *Phys.Rev.* **D58**, 054003 (1998); R. Sassot *Phys.Rev.* **D60**, 114002 (1999); D. de Florian and R. Sassot, *Phys.Rev.* **D56**, 426 (1997).

[27] M. Osipenko *et al.*, in preparation.

[28] G. Veneziano *Phys.Lett.* **B34**, 59 (1971); *Nuovo Cim.* **A57**, 190 (1968); *Phys. Rep.* **9**, 199 (1974).

[29] M. Battaglieri*et al.*, *Phys.Rev.Lett.* **90**, 022002 (2003).

[30] H. Harari, *Phys.Rev.Lett.* **20** 1395 (1968); P.G.O. Freund, *Phys.Rev.Lett.* **20** 235 (1968).

[31] E. Dumonteil, G. Niculescu and I. Niculescu, CLAS-Note-01-006 (2001).