Deeply Virtual Electroproduction of Photons and Mesons.

M. Guidal[a], **M. Vanderhaeghen**[b]
[a] *IPN Orsay, F-91406 Orsay, France*
[b] *University Mainz, D-55099 Mainz, Germany*

Much of the internal structure of the nucleon has been revealed during the last two decades through the inclusive scattering of high energy leptons on the nucleon in the Bjorken -or "Deep Inelastic Scattering" (DIS)- regime ($Q^2, \nu \gg$ and $x_B = \frac{Q^2}{2M\nu}$ finite). Simple theoretical interpretations of the experimental results and quantitative conclusions can be reached in the framework of QCD, when one sums over all the possible hadronic final states. For instance, *unpolarized* DIS brought us evidence of the quark and gluon substructure of the nucleon, quarks carrying about 45% of the nucleon momentum. Furthermore, *polarized* DIS revealed that about 25% of the spin of the nucleon is carried by the quarks' intrinsic spin.
Now, with the advent of the new generation of high-energy, high-luminosity lepton accelerators combined with large acceptance spectrometers, a wide variety of exclusive processes in the Bjorken regime can be envisaged to become accessible experimentally. Until recently, no sound theoretical formalism could really allow to interpret in a unified way such processes. It now appears that such a coherent description is under way through the formalism of new generalized parton distributions, the so-called 'Off-Forward Parton Distributions' (OFPD's). It has been shown that these distributions, which parametrize the structure of the nucleon, allow to describe, in leading order perturbative QCD (PQCD), various exclusive processes such as, in particular, Virtual Compton Scattering ([1][2]) and (longitudinal) vector and pseudo-scalar meson electroproduction [3]. Maybe most importantly, Ji [1] showed that the second moment of these OFPD's gives access to the sum of the quark spin and the quark orbital angular momentum to the nucleon spin, which may shed light on the "spin-puzzle".
In this paper, after a brief summary of the properties of the OFPD's, we give some examples of what could be the experimental opportunities to access the OFPD's at the current high-energy lepton facilities : JLab ($E_e \geq 6$ GeV), HERMES (E_e=27 GeV) and COMPASS (E_μ=200 GeV).

Recently, Ji [1] and Radyushkin [2] have shown that the leading order PQCD DVCS amplitude in the forward direction can be factorized in a hard scattering part (exactly calculable in PQCD) and a nonperturbative nucleon structure part as is illustrated in Fig.(1-a). In these so-called "handbag" diagrams of Fig.(1), the lower blob which represents the structure of the nucleon can be parametrized, at leading order PQCD, in terms of 4 generalized structure functions, the OFPD's. These are defined as $H, \tilde{H}, E, \tilde{E}$, and depend upon three kinematical invariants : x, ξ, t. H and E are spin independent and $\tilde{H}$ and $\tilde{E}$

are spin dependent.

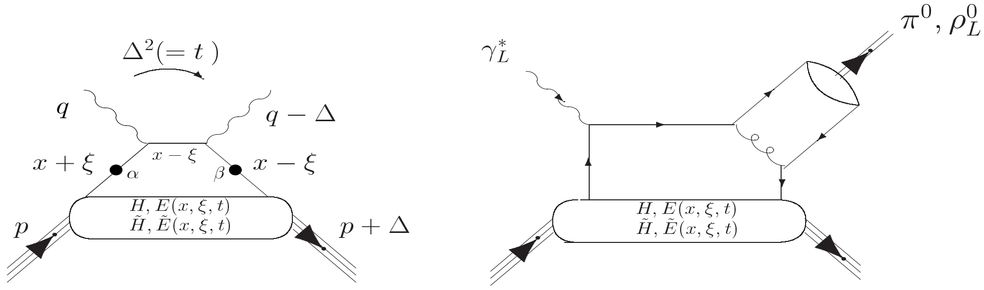

Figure 1: "Handbag" diagrams : a) for DVCS (left) and b) for meson production (right).

The OFPD's H and $\tilde{H}$ are actually a generalization of the parton distributions measured in deep inelastic scattering. Indeed, in the forward direction, H reduces to the quark distribution and $\tilde{H}$ to the quark helicity distribution measured in deep inelastic scattering. Furthermore, at finite momentum transfer, there are model independent sum rules which relate the first moments of these OFPD's to the elastic form factors. The OFPD's reflect the structure of the nucleon independently of the reaction which probes the nucleon. They can also be accessed through the hard exclusive electroproduction of mesons -π^0, ρ^0, ω, ϕ,...- (see Fig.(1-b)) for which a QCD factorization proof was given recently [3]. According to Ref.[3], the factorization applies when the virtual photon is longitudinally polarized because in this case, the end-point contributions in the meson wave function are power suppressed. It was also shown in Ref.[3] that the cross section for a transversely polarized photon is suppressed by $1/Q^2$ compared to a longitudinally polarized photon. Because the transition at the upper vertices of Fig.(1-b) will be dominantly helicity conserving at high energy and in the forward direction, this means that the vector meson will also be predominantly longitudinally polarized (notation $\rho_L^0, \omega_L, \phi_L$) for a longitudinal photon. By identifying then the polarization of the vector meson through its decay angular distribution, one can obtain the longitudinal part of the electroproduction cross sections.
It was also shown in [3] that leading order PQCD predicts that the vector meson channels (ρ_L^0, ω_L, ϕ_L) are sensitive only to the unpolarized OFPD's (H and E) whereas the pseudo-scalar channels ($\pi^0, \eta, ...$) are sensitive only to the polarized OFPD's ($\tilde{H}$ and $\tilde{E}$). In comparison to meson electroproduction, we recall that DVCS depends at the same time on *both* the polarized and unpolarized OFPD's. For a first exploratory approach, we will now show that the meson channels hold the best promises due to the relatively high cross-sections. First estimates for the π^0, ρ_L^0 cross sections were given in Refs.[4] [5] besides the γ-channel using an educated guess for the OFPD's, which consists of a product of elastic form

factors by quark distributions measured in DIS. This ansatz satisfies the first sum rules and the corresponding distributions obviously reduce to the quark distributions from DIS in the forward direction.

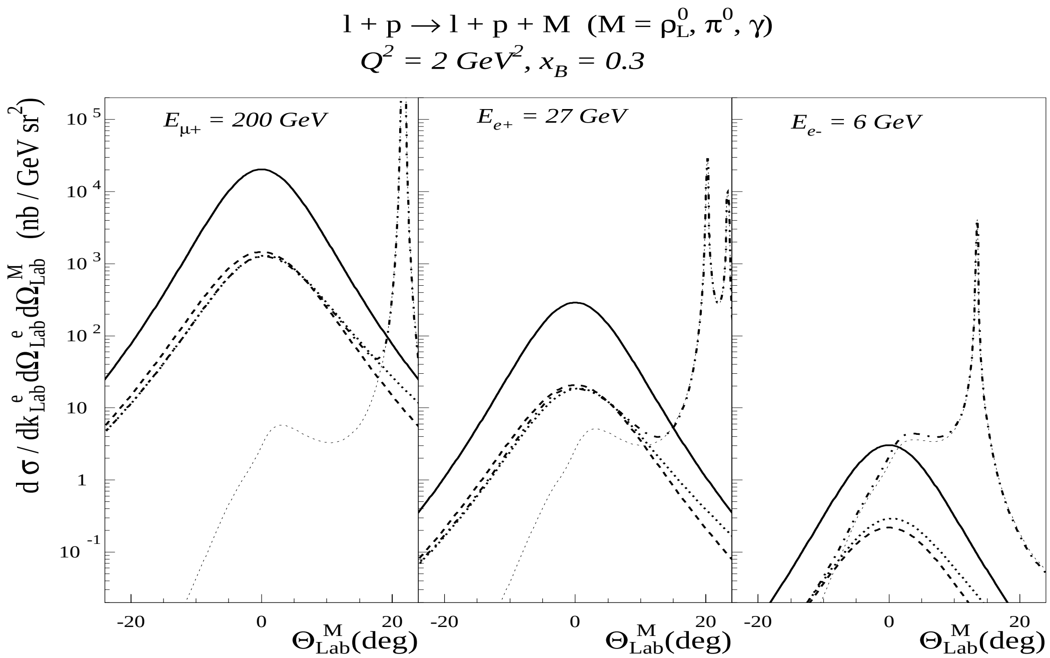

Figure 2: Comparison between ρ_L^0 (full lines), π^0 (dashed lines), DVCS (dotted lines), BH (thin dotted lines) and total γ (dashed-dotted lines) leptoproduction in-plane cross sections at $Q^2 = 2$ GeV^2, $x_B = 0.3$ and for different beam energies : $E_{\mu^+} = 200$ GeV (COMPASS), $E_{e^+} = 27$ GeV (HERMES), $E_{e^-} = 6$ GeV (CEBAF).

We compare in Fig.(2), the ρ_L^0, π^0 and γ cross sections as function of the beam energy at a fixed $Q^2 = 2$ GeV^2 and $x_B = 0.3$. It is clear on this picture that the ρ channel is very favorable. Its cross section is the highest because it depends on the unpolarized OFPD's (H and E). The ω_L channel has a cross section that is substantially higher than the ratio $\sigma_\omega/\sigma_\rho = \frac{1}{9}$ predicted by the diffractive mechanism and this is essentially due to the quark exchange mechanism (QEM). The ω_L and ρ_L^0 channels probe different combination of the u and d OFPD's and a measurement of both therefore allows to separate these u and d-quark unpolarized OFPD's. The π^0 channel depends on the polarized OFPD's ($\tilde{H}$ and $\tilde{E}$) and therefore the PQCD QEM mechanism gives a lower cross section. The DVCS is proportional to *both* the polarized and the unpolarized OFPD's as was already mentioned but it has an extra α_{em} coupling (due to the final state photon) which reduces the cross section. (By comparison, the meson final states go through the exchange of a gluon and therefore has a α_S coupling). Furthermore, at JLab energies, the DVCS suffers from the competing process which leads to the same final state, the Bethe-Heitler process. This extra "parasite" mechanism is dominant at 6 GeV and renders the extraction from the cross section of the DVCS process very difficult. This "parasite" process is absent in the case of meson electroproduction. Going up in energy, the increasing virtual photon flux factor boosts the ρ^0_L, π^0 leptoproduction cross sections and the DVCS part of the γ leptoproduction cross section. For the γ electroproduction cross section the BH process is hardly influenced by the beam energy and therefore overwhelms the DVCS cross section at low beam energies. For a study of the OFPD's such a figure seems to favor high-energy experimental facilities such as COMPASS. However, it should be clearly kept in mind that the actual count rates will be weighted by the luminosity. So, in spite of the relatively "low" energy of the JLab incident beam, the higher luminosity and the better resolution that one can reach with the JLab large acceptance CLAS detector will allow equivalent count rates to the other two facilities in the roughly same equivalent range (but in a shorter period).

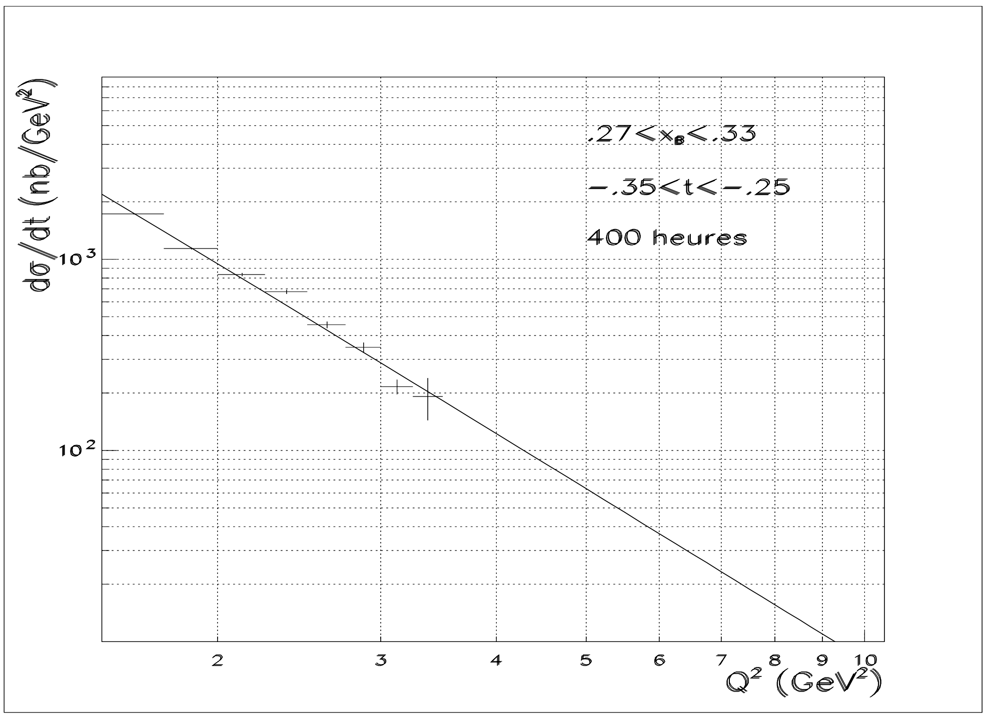

Figure 3: Error estimate (statistical only) on the scaling behavior for the ρ^0_L channel for $t = -.3$ GeV^2 and $x_B = .3$.

Before considering the extraction of the OFPD's from the data, it is mandatory to first demonstrate that the scaling regime has been reached. In leading order PQCD, the DVCS transverse cross section $\frac{d\sigma_T}{dt}$ is predicted to behave as $\frac{1}{Q^4}$ whereas the mesons' longitudinal cross sections will obey a $\frac{1}{Q^6}$ scaling (due to the "extra" gluon exchange for the mesons, see Fig. 1). Recently, an experiment [6] has been approved at JLab where it is proposed to investigate this scaling behavior. Figure 3 shows the estimated lever arm reachable at JLab with 400 hours of beam time in the CLAS detector for the ρ^0 channel. With a maximum Q^2 of $\approx$ 3.5 GeV^2 (for x_B around .3), the cross section can be measured over about a decade. This should provide a sufficient lever arm to test the scaling prediction and test at what value of Q^2 this $\frac{1}{Q^6}$ scaling behavior sets in. With a JLab 8 GeV incident energy, the lever arm extends to 4.5 GeV^2.

In conclusion, we believe that a broad new physics program, i.e. the study of exclusive reactions at large Q^2 in the valence region (where the quark exchange mechanism dominates), opens up. By "constraining" the final state of the DIS reaction, instead of summing over all final states, one accesses some more fundamental structure functions of the nucleon, i.e. the OFPD's. These functions provide a unifying link between a whole class of various reactions (elastic and inelastic) and fundamental quantities as diverse as form factors, parton distributions, etc...

References

[1] X. Ji, Phys.Rev.Lett. **78** (1997) 610; Phys.Rev.D **55** (1997) 7114.

[2] A.V. Radyushkin, Phys.Lett.B **380** (1996) 417; Phys.Rev.D **56** (1997) 5524.

[3] J.C. Collins, L. Frankfurt and M. Strikman, Phys.Rev.D **56** (1997) 2982.

[4] M. Vanderhaeghen, P.A.M. Guichon, M. Guidal, Phys.Rev.Lett. **80** (1998) 5064.

[5] P.A.M. Guichon and M. Vanderhaeghen, Prog.Part.Nucl.Phys., Vol.41 (1998), 125.

[6] Cebaf experiment E98-107, spokespersons M. Guidal, C. Marchand and E. Smith.