Saturation Model for Exclusive Diffractive Processes, DVCS and F_2 at HERA

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In this talk we present a simultaneous analysis, within an impact parameter dependent saturated dipole model, of exclusive diffractive vector meson (J/ψ, ϕ and ρ) production, deeply virtual Compton scattering and the total $\gamma^* p$ cross section data measured at HERA. Various cross sections measured as a function of the kinematic variables Q^2, W and t are well described, with little sensitivity to the details of the vector meson wave functions. We discuss the determination of the properties of the gluon density in both longitudinal and transverse dimensions, including the impact parameter dependent saturation scale. The overall success of the description indicates universality of the emerging gluon distribution and proton shape. The talk is based on the recent paper written together with Leszek Motyka and Graeme Watt.

Exclusive diffractive processes at HERA, such as exclusive vector meson production or deeply virtual Compton scattering (DVCS), are excellent probes of the proton shape in the perturbative regime. Several investigations have already shown that these processes can be well described within a QCD dipole approach with the vector meson wave functions determined by educated guesses and the photon wave function computed within QED. For an overview and the complete set of references see [2].

The vector meson and DVCS processes are measured at HERA in the small-x regime where the behaviour of the inclusive deep-inelastic scattering (DIS) cross section, or the structure function F_2, is driven by the gluon density. The dipole model allows these processes to be calculated, through the optical theorem, from the gluon density determined by a fit to the total inclusive DIS cross sections. Usually, it is assumed that the evolution of the gluon density is independent of the proton shape in the transverse plane. The investigations of Kowalski and Teaney [3] and Kowalski, Motyka and Watt [2] has shown that the Gaussian form of the proton shape, implied by the data, has implications on the emerging pattern of QCD evolution and saturation effects. The interplay of saturation and evolution effects was first investigated by Bartels, Golec-Biernat and Kowalski [4], where it was found that the total inclusive DIS cross sections, or F_2, can be described either by strong saturation and weak evolution or by strong evolution and weak saturation effects. The investigation of Ref. [3, 2], which took into account also the proton shape in the transverse plane, concluded that saturation effects are substantial in the proton centre, but that the Gaussian form implies that a large contribution to the cross section has to come from the outskirts of the proton, where the gluon density is diluted. Hence the evolution effects have to be strong and play an important role.

The t-distributions determine the area size of the interaction region, B_D. The parameter B_D is obtained by making a fit to the t-distributions of the form $\mathrm{d}\sigma/\mathrm{d}t \propto \exp(-B_D|t|)$. For scattering of very small dipoles B_D is connected to the proton radius R_p via $B_D = R_p^2/3$. However, for larger dipoles the size of the interaction area depends not only on the proton radius but also on the size of the produced vector meson or real photon, which we take into account following the work of Bartels, Golec-Biernat and Peters (BGBP) [5]. This allows

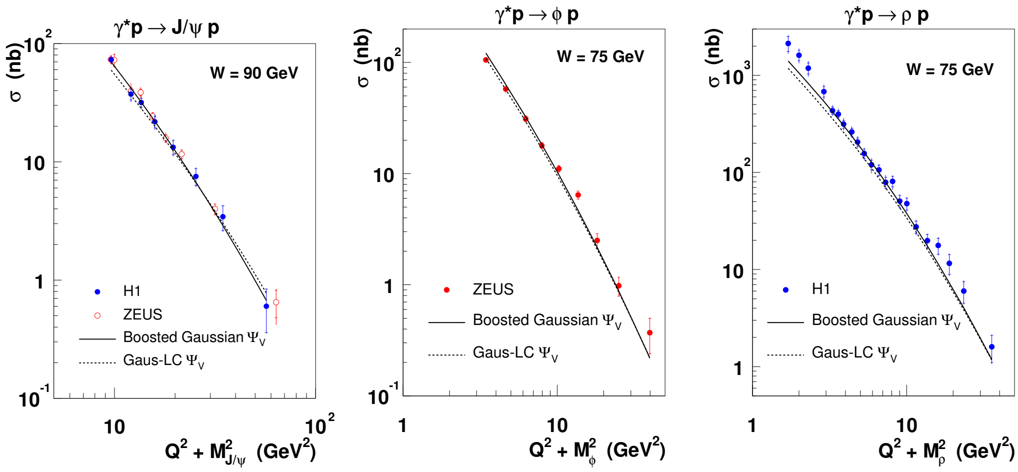

Figure 1: Total vector meson cross section σ vs. $(Q^2 + M_V^2)$ compared to predictions from the model using two different vector meson wave functions.

the data for all vector mesons and DVCS to be described using a unique Gaussian proton shape, independent of the produced final state.

An important finding of this investigation is that, although the vector meson wave functions are not fully known, one obtains a good description of the measured data. The model parameters, which were fixed by the fit to the total inclusive DIS cross section and the vector meson t-distributions, describe the measured Q^2 and W dependence of vector meson production and DVCS very well, together with the absolute normalisation, see Figures 1 and 2. The measured DVCS t-distribution agrees with the model expectation within the measurement error.

The b-Sat model, which gives the best description of data, uses the Glauber–Mueller dipole cross section with DGLAP evolution of the gluon density. Although the overall description of exclusive processes is very good, this approach has some limitations, seen most clearly in the lack of W dependence of B_D in J/ψ photoproduction, see Ref. [2] for more details. Although this is a delicate effect, the measurement precision is sufficient to show that there is a coupling between the transverse and longitudinal evolution variables, that is, $\alpha'_{\mathbb{P}} \neq 0$. We therefore introduced impact parameter dependence into the CGC model, the "b-CGC" model, which leads to a considerably poorer fit to F_2 than the b-Sat model and a worse overall description of exclusive processes, but a better description of the $\alpha'_{\mathbb{P}}$ parameter. The saturation scale Q_S^2 evaluated in this investigation does not depend sizably on the adopted evolution scheme and is consistent with the results of Ref. [3].

An important finding of this investigation is that the t-dependences of all three vector mesons and the DVCS process can be simultaneously described with one universal shape of the proton, see Figure 3. The parameter characterising the size of the proton, $B_G = 4$ GeV^{-2}, determined in this investigation, corresponds to the proton radius of $R_p = \sqrt{3B_G} =$ 0.67 fm. This is rather smaller than the proton charge radius of 0.870 ± 0.008 fm [6]. This leads to a rather surprising result that gluons are more concentrated in the centre of the proton than quarks.

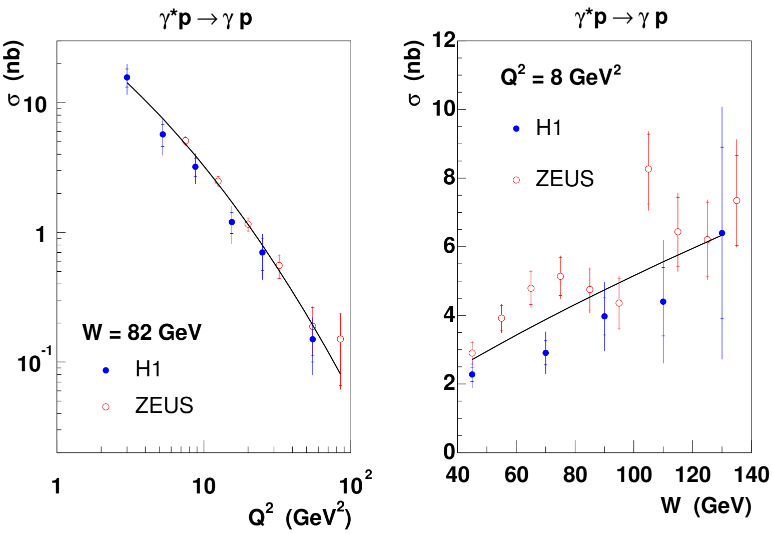

Figure 2: Total DVCS cross sections σ vs. Q^2 (left) and σ vs. W (right) compared to predictions from the b-Sat model.

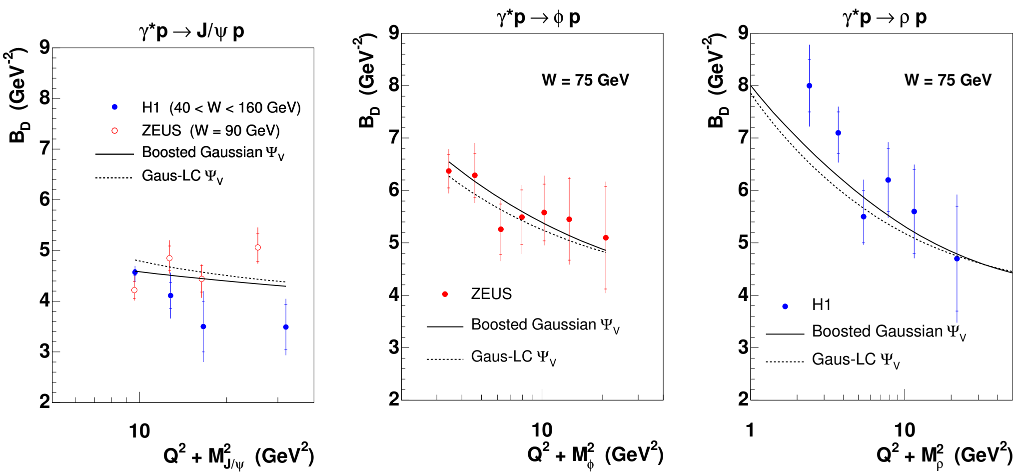

Figure 3: The t-slope parameter B_D vs. $(Q^2 + M_V^2)$, where B_D is defined by fitting $\mathrm{d}\sigma/\mathrm{d}t \propto \exp(-B_D|t|)$, compared to predictions from the b-Sat model using two different vector meson wave functions.

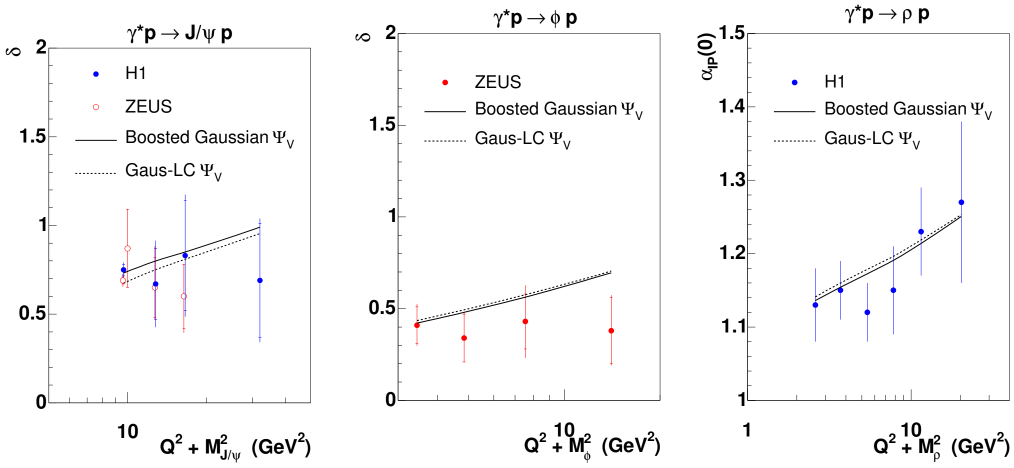

Figure 4: The power δ vs. $(Q^2 + M_V^2)$, where δ is defined by fitting $\sigma \propto W^\delta$, compared to predictions from the b-Sat model using two different vector meson wave functions.

The investigation presented here demonstrates that a wide class of high-energy scattering processes measured at HERA may be understood within a simple and unified framework. The key ingredient is the gluon density which is probed in the longitudinal and transverse directions. The success of the description indicates the universality of the emerging gluon distribution.

Let us finish with a general remark that vector meson and DVCS processes may be used to probe the properties of nuclear matter in a new way. In measurements with polarised beams it is possible to achieve precision which would allow a tomographic picture of protons and nuclei to be obtained. Such a measurement could be performed at the recently proposed *ep* and *eI* collider, EIC, with roughly a half of the HERA centre-of-mass energy and a luminosity of factor 100 to 1000 higher than HERA. The high luminosity should allow to improve substantially the measurement precision for low-x and diffractive processes. This would allow to reduce the errors on the measurement of the rate of rise of the exclusive diffractive process, shown in Fig. 4, and in turn determine precisely the gluon density evolution and saturation effects in the non-forward region, $t \neq 0$.

References

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