DIFFRACTIVE VECTOR MESON PRODUCTION IN $\boldsymbol{k}_{\rm t}$-FACTORIZATION APPROACH*

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We describe the current status of the diffractive vector meson production calculations within the $k_{\rm t}$ factorization approach. Since the amplitude of the vector meson production off a proton is expressed via the differential gluon structure function (DGSF), we take a closer look at the latter and present results of our new improved determination of the DGSF from the structure function F_{2p}. Having determined the differential glue, we proceed to the $k_{\rm t}$-factorization results for the production of various vector mesons. We argue that the properties of the vector meson production can reveal the internal spin-angular and radial structure of the vector meson.

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1. Introduction

Diffractive DIS appears to be a unique probe of the internal structure of hadrons in the Regge regime, *i.e.* at Q^2 fixed, $x \to 0$. It has been always appreciated that diffractive processes can give valuable information of the gluon content inside a rapidly moving proton. Another aspect might not be that obvious, namely, that diffraction can tell us much about the structure of the produced system as well.

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The case of the vector meson production

$$\gamma^{(*)}p \to Vp$$

is especially promising. A general expression for transition $\gamma^{(*)}(\lambda_\gamma) \to V(\lambda_V)$ is given by:

$$\mathcal{A}(x,Q^2,\vec{\Delta}) = is\frac{c_V\sqrt{4\pi\alpha_{em}}}{4\pi^2}\int\limits_0^1 \frac{dz}{z(1-z)}\int d^2\vec{k}\psi(z,\vec{k}) \times \int \frac{d^2\vec{\kappa}}{\vec{\kappa}^4}\alpha_{\rm S}(q^2)\left(1+i\frac{\pi}{2}\frac{\partial}{\partial\log x}\right)\mathcal{F}(x,\xi,\vec{\kappa},\vec{\Delta})I(\gamma^*\to V)\,.$$

Here we have two quantities that are not calculable within pQCD, namely, the radial wave function of the vector meson $\psi(z,\vec{k})$ and the off-forward unintegrated gluon density $\mathcal{F}(x,\xi,\vec{\kappa},\vec{\Delta})$.

By studying the properties of the production of vector mesons with helicity $\lambda_{\rm V}$ from photons with helicity λ_γ, one can peep into the spin-angular structure of the quarks inside the vector meson. Indeed, even the mere fact that helicity-flip $\gamma \to V$ transitions take place implies a certain motion of the constituents inside the meson.

It turns out that the distribution of the absolute values of the relative momenta between the quark and the antiquark inside the vector meson, the quantity that we just called the wave function of the vector meson, does leave signatures in the properties of the diffractive production as well. In our work we do not aim at the most accurate possible way of describing the vector meson wave function. What we do is we take two radically different Ansätze — the Coulomb and the oscillator type — for the wave function and check how different the predictions based on the form of the wave function are. This will give us a reliable estimate of the sensitivity of the whole approach to the details of the wave function.

2. Unintegrated gluon density

Although the unintegrated gluon structure function is not calculable from first principles, it can be extracted from experimental data on F_{2p}. This analysis was performed in [1] and yielded compact and ready-to-use parametrizations of $\mathcal{F}(x,\vec{\kappa}^2)$. Since this analysis was based on simple eye-ball fits and because new data appeared during last two years, we re-extracted the unintegrated gluon density from F_{2p}, this time by means of χ^2-minimization. We used 191 data points in low to moderate Q^2 ($Q^2 < 10$ GeV^2), $x < 0.01$ region and obtained three fits with $\chi^2/n_{\rm d.o.f.} \approx 1.25 \div 1.40$. We hope that later on, when calculating vector meson production cross sections, using these three fits will give us a reliable estimate of the level of uncertainty introduced by unintegrated glue.

This minimization procedure resulted in somewhat unexpected two-peak shape of the unintegrated glue, which means that the soft and hard components of the pomeron are strongly separated. Further analysis is needed in order to establish whether the data indeed favor the non-monotonous $\vec{\kappa}^2$-behavior of $\mathcal{F}(x,\vec{\kappa}^2)$ or this is an artefact.

3. Production of ground state mesons

The $k_{\rm t}$-factorization calculations of the vector meson production cross section are known to possess a *scaling phenomenon*: all ground state vector mesons, when corrected to flavor factor, follow the same $Q^2 + m_{\rm V}^2$ dependence. Moreover, we predict that a similar phenomenon should take place also for the energy rise exponent and for the diffractive slope.

When calculating the production of ρ-meson and comparing them with the data, we observed a good overall agreement except for two Q^2 regions. Fig. 1 display the quantity $\sigma(\gamma^* p \to \rho p)\,(Q^2 + m_\rho^2)^{2.3}$. At low Q^2 we observe the experimental data points drop sharply, while our predictions do not exhibit this behavior. It must be emphasized that this discrepancy is located at $Q^2 \sim 1$ GeV^2, *not at very small* Q^2. In fact, with oscillator wave function, we managed to reproduce the $Q^2 \to 0$ behavior of the total cross section nearly perfectly.

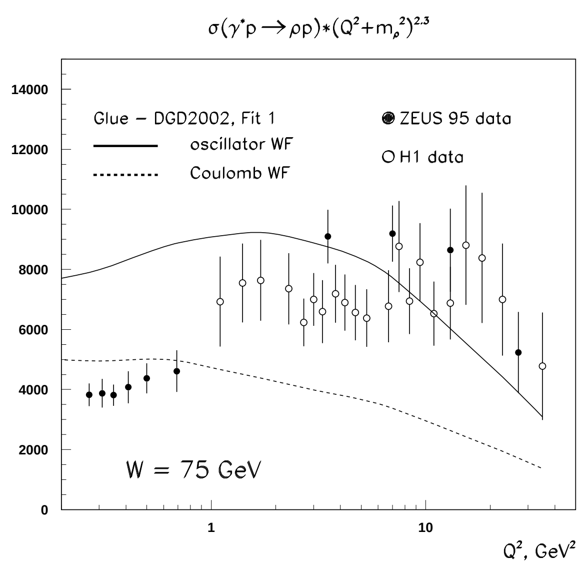

Fig. 1. The ρ meson production cross section multiplied by $(Q^2 + m_\rho^2)^{2.3}$. Discrepancies at $Q^2 \sim 1$ GeV^2 and at $Q^2 > 10$ GeV^2 can be clearly seen.

At large enough Q^2 we observe another deviation between $k_{\rm t}$-factorization prediction and the data. As seen in Fig. 1, at high Q^2 both our predictions for $\sigma(\gamma^* p \to \rho p)\,(Q^2 + m_\rho^2)^{2.3}$ and the data decrease, but our curves start decreasing *earlier*. This problem was dubbed by us the $\sigma_{\rm T}$ puzzle, since it becomes even more glaring when $\sigma_{\rm T}$ and $\sigma_{\rm L}$ are analyzed separately. During the last two years, a number of ideas was investigated — namely, the effect of hard Coulomb tail of the wave function and strong S-wave/D-wave mixing, see [2] — which could in principle cure this problem. However, no satisfactory solution was found.

If we ask not for the absolute values of cross section, but for relative strength of various helicity amplitudes, the agreement between $k_{\rm t}$-factorization prediction and the data is much better. For example, our calculation of the ρ-meson spin density matrix and of the ratios spin-flip/non-spin-flip yielded numbers rather close to data points. This make us believe that we grasped the essential part of the spin physics of the diffractive $\gamma \to \rho$ transition.

In the case of other ground state vector mesons $(\omega, \phi, J/\psi)$, the $k_{\rm t}$-factorization predictions were in a good overall agreement with the data. Here we wish to show one particularly interesting quantity, namely, the ratio of ϕ-meson to ρ-meson cross sections, taken at equal Q^2, Fig. 2. Aside from the observation that our predictions are in a nice agreement with the data, we notice that predictions based on Coulomb and oscillator wave functions virtually coincide. This is highly non-trivial, since these two Ansätze lead

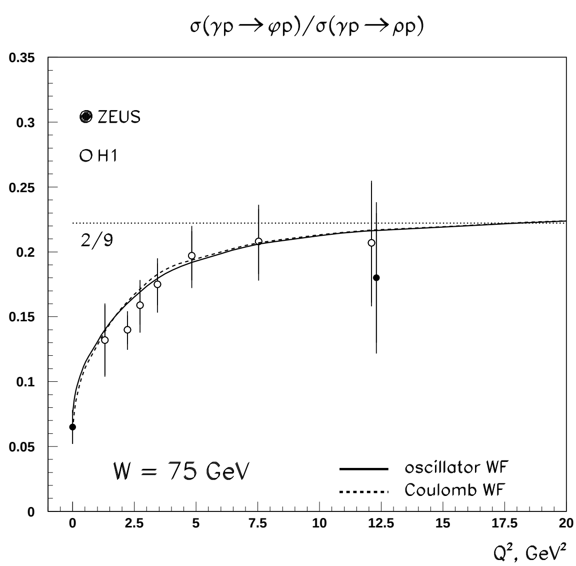

Fig. 2. The ratio $\sigma(\phi)/\sigma(\rho)$ as function of Q^2.

to *very different* absolute values of the cross section. This observation suggests that quantity $\sigma(\phi)/\sigma(\rho)$ is practically insensitive to the details of the internal structure of the vector mesons (provided it is the same for ρ and ϕ). Therefore, in some sense, this quantity appears to be a *parameter-free* prediction of the theory, and the fact that it agrees with the data supports our approach. An interesting issue remains to be settled, namely, what is this quantity mostly sensitive to.

4. Production of excited vector mesons

Since we explicitly take into account the spin-angular coupling inside the vector meson, we can calculate production of pure S-wave or pure D-wave vector mesons, as well as any given S/D-wave mixture. During such calculations, we observed a number of remarkable phenomena. In the case of $2S$ states (radial excitations) we observed the famous *node effect* and studied its influence on production cross sections. We observed characteristic Q^2 and t shape of the (differential) cross sections. Whenever possible, we compared predictions with the data and found good agreement. In the case of D-wave state we found strong overall suppression that comes from orthogonality between the pure D-wave in vector meson and the dominant S-wave in the initial photon.

We also calculated the spin density matrices and $\sigma_{\rm L}/\sigma_{\rm T}$ ratios for all these states. The most spectacular quantity here is $\sigma_{\rm L}/\sigma_{\rm T}$. For $2S$ state in ρ system, we observed a strongly oscillating Q^2 shape of this ratio in the small Q^2 region, which is again manifestation of the node effect. For D-wave state we found an overall suppression of this ration in comparison with $1S$ state by more than an order of magnitude.

We think that study of excited states, especially in the ρ system, will shed light on the nature and internal structure of various ρ' resonances. In this aspect, HERA will yield information hadron structure, complementary to studied at e^+e^- colliders.

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