Phenomenology of helicity amplitudes of high energy exclusive leptoproduction of the ρ meson

I.V. Anikin, A. Besse, D.Yu. Ivanov, B. Pire, L. Szymanowski, S. Wallon, [ArXiv:1105.1761v1], Phys. Rev. D 2011 (in press)

Laboratoire de Physique Théorique (Orsay), Soltan Institute for Nuclear Studies (Warsaw)

Introduction

- Exclusive leptoproduction of vector mesons has been the subject of significant progress in the last 20 years. We work in the hard regime where a highly virtual photon exchange allows to separate a short distance dominated amplitude of hard subprocess from suitably defined hadronic objects.
- The object of our study is the hard exclusive electroproduction of the ρ vector meson in the process $\gamma^*(\lambda_\gamma)\,p \to \rho(\lambda_\rho)\,p$ (λ_γ, λ_ρ : polarisations of the virtual photon and the vector meson). The H1 and ZEUS collaborations have recently provided a complete analysis on ratios of helicity amplitudes $T_{\lambda_\rho\lambda_\gamma}$.
- In this study, we give a prediction for the ratios T_{11}/T_{00} and T_{01}/T_{00}, using the impact factor representation of helicity amplitudes (k_T-factorization), in the kinematical range:

  W (energy on the center of mass) $\gg$ Q (virtuality of the photon) $\gg \Lambda_{QCD}$

  We use expressions for impact factors:
  - $\gamma_T \to \rho_T$ (twist 3) recently computed within the Light Cone Collinear approach (LCCF) at $|t| = |t|_{min} \approx 0$ (Anikin et al. '10)
  - $\gamma_L \to \rho_L$ (twist 2), $\gamma_T \to \rho_L$ (twist3, vanishes at $|t| = |t|_{min} \approx 0$) (Ginzburg, Panfil, Serbo '87)
  - a dipole inspired phenomenological model for the proton coupling (Gunion, Soper '77)

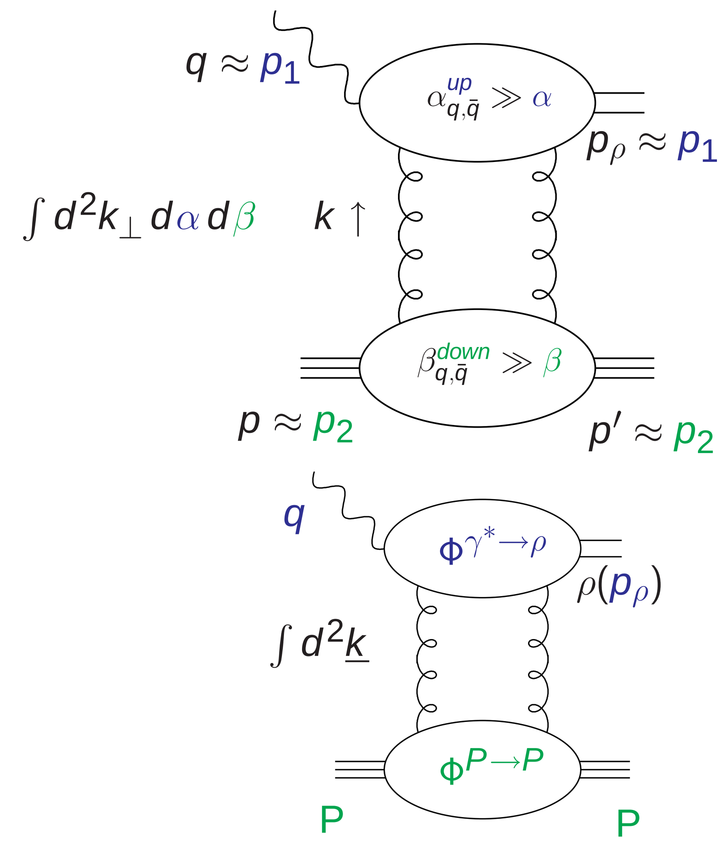
Impact Factor Representation

- At high energy in the center of mass ($s = W^2 \gg Q^2$, $|t| = |t|_{min}$, Masses), amplitudes behave as $s^{\sum \sigma_i - N+1}$ (σ_i (spin) and N (number) of the particles exchanged in t-channel) $\Rightarrow$ the amplitude at large s is dominated by gluons exchange in t-channel.
- Masses and Q^2 are negligible with respect to s $\Rightarrow$ define 2 light-cone vectors p_1, p_2 such as the upper (lower) particles fly almost along p_1 (p_2) and such as $2p_1 \cdot p_2 = s$, to extract the dominant part of the amplitude.
- Sudakov decomposition of gluon momenta : $k = \alpha p_1 + \beta p_2 + k_\perp \Rightarrow$ eikonal approximation $\begin{cases} \alpha^{up}_{q,\bar q} \gg \alpha \\ \beta^{down}_{q,\bar q} \gg \beta \end{cases} \Rightarrow$ gluons longitudinally polarised : $\begin{cases} \varepsilon^{up}_{NS} = \sqrt{\frac{2}{s}}\,p_2 \\ \varepsilon^{down}_{NS} = \sqrt{\frac{2}{s}}\,p_1 \end{cases}$
- Impact factors: $\int d^4k = \frac{s}{2}\int dk_\perp d\alpha d\beta$
  - $\Rightarrow \int d\beta$ acts only on the upper part of the amplitude to give the so called Impact factor $\Phi^{\gamma^* \to \rho}(\underline{k}^2)$.
  - $\Rightarrow \int d\alpha$ acts only on the lower part of the amplitude to give the proton Impact factor $\Phi^{P \to P}(\underline{k}^2)$.

  $\gamma^* \to \rho$ impact factor :

  $$\Phi^{\gamma^* \to \rho}(\underline{k}^2) = e^{\gamma^*\mu}\frac{1}{2s}\int \frac{d\beta}{2\pi} S^{\gamma^* g \to \rho g}_\mu(\beta, \underline{k}^2) \quad \text{with } \underline{k}^2 = -k_\perp{}^2$$

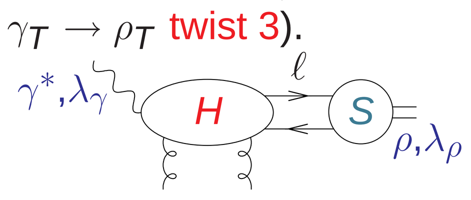
- Helicity amplitudes in the impact factor representation: $T_{\lambda_\rho\lambda_\gamma} = is \int \frac{d^2\underline{k}}{(2\pi)^2}\frac{1}{(\underline{k}^2)^2}\Phi^{\gamma^*(\lambda_\gamma)\to\rho(\lambda_\rho)}(\underline{k})\;\Phi^{P\to P}(-\underline{k})$



Light-Cone Collinear Factorisation (LCCF) of the $\gamma^*_{\lambda_\gamma} \to \rho_{\lambda_\rho}$ impact factors

As $-q^2 = Q^2 \gg \Lambda^2_{QCD}$, impact factors $\Phi^{\gamma^*_{\lambda_\gamma}\to\rho_{\lambda_\rho}}$ can be expanded in $1/Q$. The dominant contributions in $1/Q$ depend on the choice of λ_γ, λ_ρ ($\gamma_L \to \rho_L$ twist 2, $\gamma_T \to \rho_T$ twist 3).

$$\Phi^{\gamma^*_{\lambda_\gamma}\to\rho_{\lambda_\rho}} = \int d^4\ell \cdots \mathrm{tr}[\underbrace{H(\ell\cdots)}_{\text{hard part}}\;\underbrace{S(\ell\cdots)}_{\text{soft part}}] \quad\Rightarrow$$



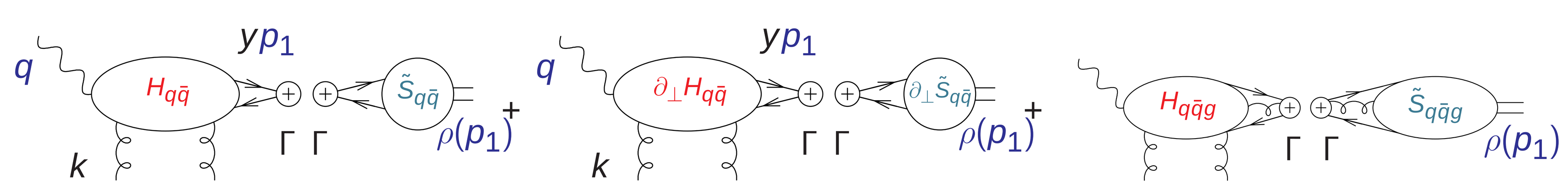
Up to twist 2 ($1/Q$): consider 2 partons ($q\bar q$) exchange between the hard and the soft part with light-cone collinear momenta ($\ell = yp_1$)

Up to twist 3 ($1/Q^2$): consider
- 2 partons exchange with almost collinear momenta $\ell_q = yp_1 + \ell_\perp \Rightarrow$ Taylor expansion of the hard part along $\ell_q = yp_1$

  $$H(\ell) = H(yp_1) + \left.\frac{\partial H(\ell)}{\partial \ell_\alpha}\right|_{\ell = yp_1} \ell^\perp_\alpha + \ldots$$

- 3 partons exchange ($q\bar q g$) with light-cone collinear momenta

Spinor and color indices factorisation (Application of Fierz identities):



Parametrisation of the Soft Parts

Soft part are Fourier transforms of non-local correlators (Coord. space $\lambda n \to$ Momentum space yp_1):

$$(S^\Gamma_{q\bar q}(y),\; \partial_\perp S^\Gamma_{q\bar q}(y)) = \int \frac{d\lambda}{2\pi} e^{-i\lambda y}\langle \rho(p_1)|\bar\psi(\lambda n)\Gamma(1, i\overleftrightarrow{\partial_\perp})\psi(0)|0\rangle \quad \text{with } n = \frac{2}{s}p_2$$

Choose axial gauge $n \cdot A = 0 \Rightarrow$ no Wilson line contributions.

Lorentz and Parity analysis $\Rightarrow$ parameterise these non-local correlators by a set of Distribution Amplitudes (DA),

e.g. $\Gamma_\mu = \gamma_\mu$:

$$S^\gamma_{q\bar q}(y) = m_\rho f_\rho(\varphi_1(y)(e^*_\rho \cdot n)p_{1\mu} + \varphi_3(y)(p_1 \cdot n)e^*_{\rho T\mu})$$

For the $\gamma^*_T \to \rho_T$ transition, a set of 7 DAs appears
- $\Rightarrow$ 5 2-body DAs $\{\varphi_1, \varphi_A, \varphi_3, \varphi_{1T}, \varphi_{AT}\}$
- $\Rightarrow$ 2 3-body DAs $\{B(y_1,y_2), D(y_1,y_2)\}$

Equations of motion + n-independence equations $\Rightarrow$ 3 independent DAs, e.g. $\{\varphi_1, B(y_1,y_2), D(y_1,y_2)\}$.
$\{\varphi_A, \varphi_3, \varphi_{1T}, \varphi_{AT}\}$ are expressed in terms of $\{\varphi_1, B(y_1,y_2), D(y_1,y_2)\}$:
- Solutions in the Wandzura Wilczek (WW) approximation: $\varphi_1 \Rightarrow \{\varphi_3^{WW}(y), \varphi_A^{WW}(y), \varphi_{1T}^{WW}(y), \varphi_{AT}^{WW}(y)\}$
- Genuine twist 3 (gen) solutions $\{B(y_1,y_2), D(y_1,y_2)\} \Rightarrow \{\varphi_3^{gen}(y), \varphi_A^{gen}(y), \varphi_{1T}^{gen}(y), \varphi_{AT}^{gen}(y)\}$

$\{\varphi_1, B(y_1,y_2), D(y_1,y_2)\}$ are solutions of ERBL equations of evolution (taken here at leading order from (Ball, Braun, Koike, Tanaka '98)), they depend on the collinear factorisation scale μ^2.

Helicity Amplitudes, model for the impact factor $\Phi^{P\to P}$

Phenomenological $\Phi^{P\to P}$

$$\Phi^{P\to P}(\underline{k}; M^2) \propto \left[\frac{1}{M^2} - \frac{1}{M^2 + \underline{k}^2}\right] \quad \text{J.F Gunion, D.E Soper '68}$$

- vanishes in the limit $\underline{k} \to 0$ as expected from QCD gauge invariance (Universal feature of impact factors)
- M is a non perturbative mass scale for the proton impact factor (free parameter of this model), it does not depend on polarisation effects.

Master formulae for helicity amplitudes:

- $T_{\lambda_\rho\lambda_\gamma} = is\int \frac{d^2\underline{k}}{(2\pi)^2}\frac{1}{(\underline{k}^2)^2}\Phi^{P\to P}(\underline{k}; M^2)\Phi^{\gamma^*(\lambda_\gamma)\to\rho(\lambda_\rho)}(\underline{k}; Q^2)$
- $\gamma^*_L \to \rho_L$ helicity amplitude:

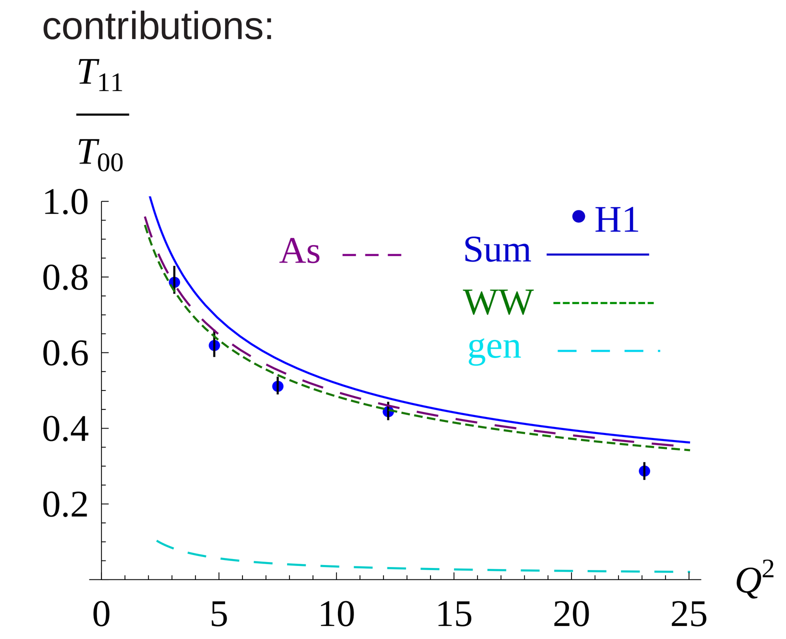
  $$T_{00} \propto \frac{is}{(2\pi)Q}\int_{\lambda^2}^{\infty} d\underline{k}^2 \frac{1}{(\underline{k}^2)^2}\left[\frac{1}{M^2} - \frac{1}{\underline{k}^2 + M^2}\right]\int_0^1 dy\, f_\rho\varphi_1(y,\mu^2)\frac{\underline{k}^2}{\underline{k}^2 + y\bar y Q^2}$$

- Wandzura-Wilczek contribution to $\gamma^*_T \to \rho_T$ helicity amplitude (using explict WW solutions for DAs):

  $$T^{WW}_{11} \propto \frac{is(e_\gamma.e^*_\rho)}{2\pi Q^2}\int_{\lambda^2}^{\infty} d(\underline{k}^2)\frac{1}{(\underline{k}^2)^2}\left[\frac{1}{M^2} - \frac{1}{\underline{k}^2 + M^2}\right]\left(\int_0^1 du \frac{m_\rho f_\rho \varphi_1(u;\mu^2)}{u}\int_0^u dy \frac{\underline{k}^2(\underline{k}^2 + 2y\bar y Q^2)}{(\underline{k}^2 + y\bar y Q^2)^2}\right)$$

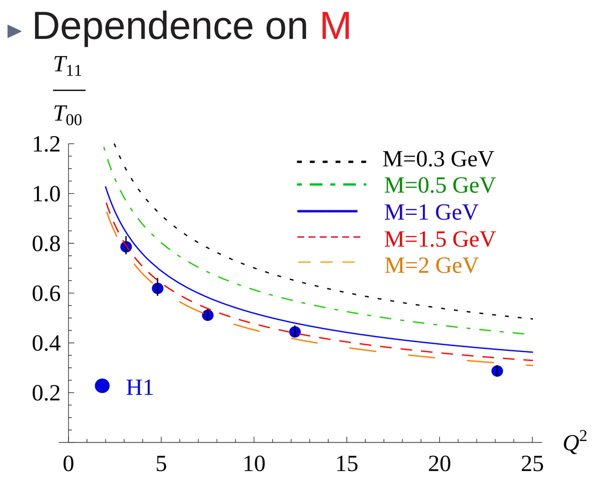
Results and Conclusions

- Genuine and Wandzura-Wilczek contributions:



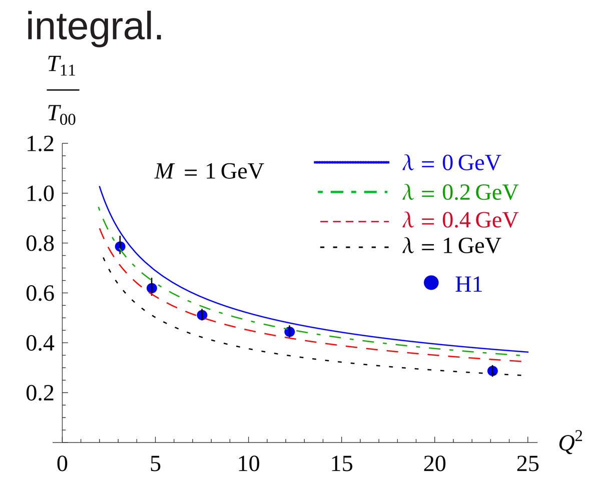
- Result for the ratio T_{11}/T_{00} at $M = 1$ GeV and $\mu^2 = Q^2$
- WW contribution dominates the genuine one
- In purple, result in the limit $\mu^2 \to \infty$ (Asymptotic DAs), genuine contribution vanishes in this limit.
- predictions are close to H1 and ZEUS data for $M = 1$ GeV (reasonable value close to the proton mass).
- Weak sensitivity to the factorisation scale μ^2 (result with $\mu^2 \to \infty$ close to result with $\mu^2 = Q^2$).

- Dependence on M



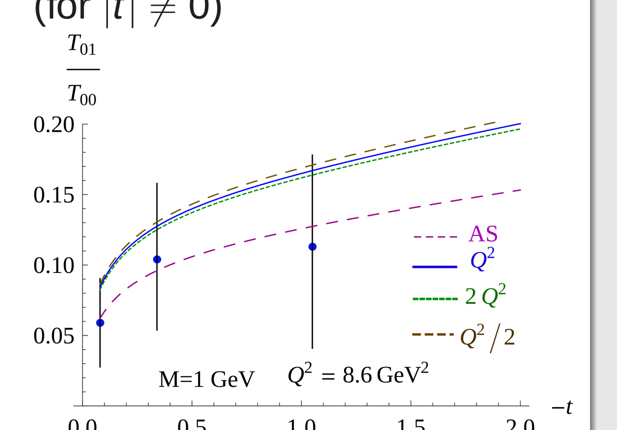
- Result stable for M $\approx$ mass of the proton.
- Good agreement with experimental data.

- Contribution of soft gluons λ is an Infra-red cut-off on the $\underline{k}$ integral.



- Weak contribution of soft gluons (with $|\underline{k}| \leq \Lambda_{QCD}$).

- Prediction for the ratio T_{01}/T_{00} (for $|t| \neq 0$)



- Data are once again in good agreement with predictions