Electroproduction of rho meson

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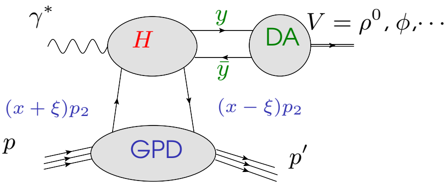
Why hard exclusive processes such as DVCS and meson production are important ?

Crucial to get information or constraints on:

- Nucleon partonic content :
  - Generalized Parton Distributions (GPDs): longitudinal momentum, transverse localization, orbital momentum of quarks and gluons
  - $\mathcal{F}(x, \underline{k})$ unintegrated gluon density, at small x within k_T-factorization
  - $\hat{\sigma}(x, \underline{r})$ color dipole cross-section : at small x within dipole models
- Vector meson partonic content :
  - Wave functions within dipole models and Modified Perturbative Approach (MPA)
  - Distribution Amplitudes (DAs) if using twist expansion of the wave functions
- pQCD evolution equations of these universal non-perturbative quantities (ERBL, DGLAP, BFKL, BK, ...)

Some theoretical issues with the collinear factorization scheme



- Collinear factorization proven for the leading twist transition $\gamma^*_L\, N \to V_L\, N$ (Collins, Frankfurt, Strikman, '97, Radyushkin, '97) in Bjorken limit
- breaks for higher twist contributions such as $\gamma^*_T\, N \to \rho_T\, N$ due to end-point singularities...

  ..but should be described in terms of pQCD (Martin, Ryskin, Teubner, '97)

Outline

Alternative strategies :

- at very low x (*eg.* HERA kinematics), use another factorization scheme adapted to diffractive processes called k_T−factorization
- ..or keep transverse momentum of the parton in the game (MPA (Sterman et al. 92)), allows to describe a large range in x (HERA, HERMES, CLAS, COMPASS)

In this talk:

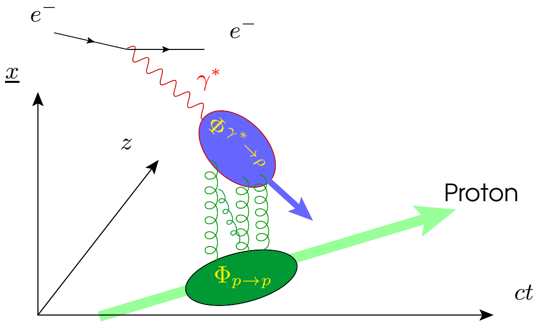
- Model (A.B., Szymanowski, Wallon, '13) for the diffractive rho meson production at small x (HERA kinematics)
  - within k_T−factorization scheme
  - including saturation effects
- DVMP : A testing ground for GPD models
  Preliminary work on Kroll and Goloskokov approach (Kroll, Goloskokov, '03 and later) for the leptoproduction of vector meson
  - within MPA
  - using GPD models

Helicity amplitudes of diffractive ρ meson production

- Helicity amplitudes

$$T_{\lambda_\rho \lambda_\gamma} \;:\; \gamma^*(\lambda_\gamma)\, N \to \rho(\lambda_\rho)\, N$$

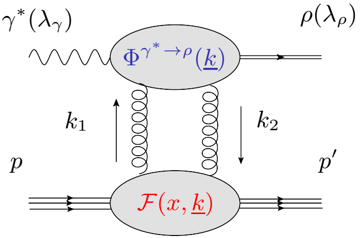
- in the limit $s \gg Q^2 \gg \Lambda^2_{QCD}$
- At $t \sim 0 \Rightarrow$ Only T_{00} and T_{11}
- Amplitudes dominated by $t-$channel gluon exchange



k_T-factorization (at very low x)

- Exchange of a color singlet of 2 gluons at Born level:

$$T_{\lambda_\rho \lambda_\gamma} \propto \int d^2\underline{k}$$



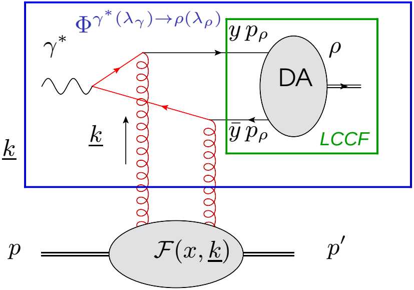
$$T_{\lambda_\rho \lambda_\gamma}(s,t) = is \int \frac{d^2\underline{k}}{(\underline{k}^2)^2} \, \Phi^{\gamma^* \to \rho}(\underline{k}) \, \mathcal{F}(x, \underline{k})$$

- $\underline{k}$: transverse momentum of $t-$channel gluons
- $\mathcal{F}(x, \underline{k})$: unintegrated gluon density
- $\Phi^{\gamma^* \to \rho}$: Impact factor
  Large photon virtuality $Q \Rightarrow$ perturbative treatment of $\Phi^{\gamma^* \to \rho}$

Factorization of helicity amplitudes $T_{\lambda_\rho \lambda_\gamma}$

- k_T-factorization then Light-cone collinear factorization (LCCF)

$T_{\lambda_\rho \lambda_\gamma} = \int d^2\underline{k}$



- Twist 2:
  - $\gamma_L^* \to \rho_L \; (\equiv T_{00})$
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  Ginzburg, Panfil, Serbo, '85

- Twist 3, in the limit $t \sim 0$:
  - $\gamma_T^* \to \rho_T \; (\equiv T_{11})$

  Anikin, Ivanov, Pire, Szymanowski, Wallon, '10

- Twist expansion in LCCF :

  Taylor exp. $H(yp_\rho + \ell_\perp + (\ell \cdot p_\rho)n) = H(yp_\rho) + \ell_\perp \cdot \frac{\partial}{\partial \ell} H(yp_\rho) + \cdots$

  leads to Fourier transform of non-local correlators parameterized by twist 2 and twist 3 DAs:

$$\langle \rho | \, \bar{\psi}(\lambda n) \Gamma \psi(0) \, | 0 \rangle \to \{\varphi_1 \text{ (leading twist)} \, , \, \varphi_A, \varphi_3\}$$

$$\langle \rho | \, \bar{\psi}(\lambda n) \Gamma \, i \, \overset{\leftrightarrow \perp}{\partial_\alpha} \, \psi(0) \, | 0 \rangle \to \{\varphi_1^T, \varphi_A^T\}$$

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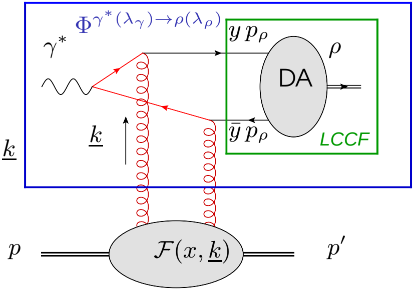

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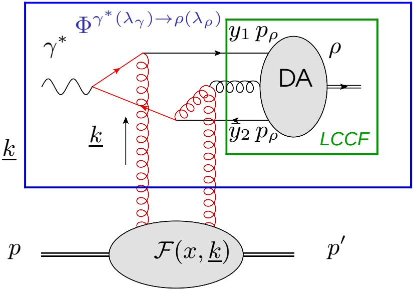

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  Taylor exp. $H_{q\bar{q}g}(y_1 p_\rho + \cdots, y_2 p_\rho + \cdots) = H(y_1 p_\rho, y_2 p_\rho) + \cdots$

  leads to Fourier transform of non-local correlators parameterized by twist 3 DAs:

$$\langle \rho |\, \bar{\psi}(\lambda n) \Gamma\, ig A^{\perp}(\lambda_g n) \psi(0)\, |0\rangle \to \{B(y_1, y_2),\; D(y_1, y_2)\}$$

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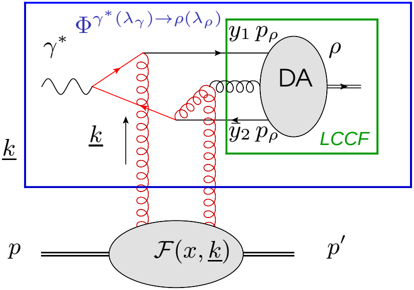

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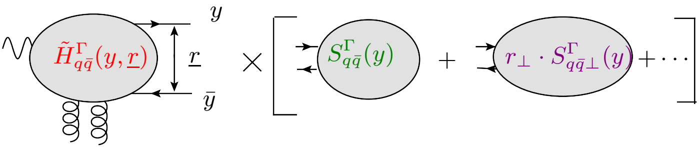
Light-cone collinear factorization beyond leading twist

- In impact parameter space (i.e. transverse coord. space)
  (AB, Szymanowksi, Wallon, Nucl. Phys. B **867** (2013) 19-60)

$$H^{\Gamma}_{q\bar{q}}(\ell) = \int d^2\underline{r}\,\tilde{H}^{\Gamma}_{q\bar{q}}(y,\underline{r})\,e^{-ir_\perp\cdot\ell_\perp} = \int d^2\underline{r}\,\tilde{H}^{\Gamma}_{q\bar{q}}(y,\underline{r})\times\underbrace{(1 + -i\ell_\perp\cdot r_\perp + \ldots)}_{\text{give moments of soft part}} + \ldots$$

- Impact factor $\Phi^{\gamma^*\to\rho}_{q\bar{q}}$

$$\Phi^{\gamma^*\to\rho}_{q\bar{q}} = \int dy \int d^2\underline{r}$$

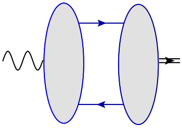


- Goes the same way for the impact factor $\Phi^{\gamma^*\to\rho}_{q\bar{q}g}$

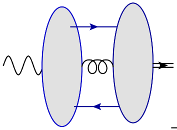
Factorization of the color dipole interaction with the target

- Up to twist 3 : $\Phi^{\gamma_T^*\to\rho_T} = \Phi_{q\bar{q}}^{\gamma_T^*\to\rho_T} + \Phi_{q\bar{q}g}^{\gamma_T^*\to\rho_T}$ and $\Phi^{\gamma_L^*\to\rho_L} = \Phi_{q\bar{q}}^{\gamma_L^*\to\rho_L}$
- The full twist 3 result for $\gamma_T^* \to \rho_T$ transition

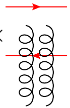
$$\Phi^{\gamma_T^*\to\rho_T} = \int d^2\underline{r} \left[\int dy \right.$$



$$+ \int dy_1 dy_2$$



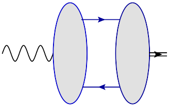
$$\left. \right] \times$$



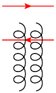
$\psi_{q\bar{q}}^{\gamma_T^*\to\rho_T}(y,\underline{r})$ $\psi_{q\bar{q}g}^{\gamma_T^*\to\rho_T}(y_1,y_2,\underline{r})$ $\mathcal{N}(\underline{k},\underline{r})$

- The twist 2 contribution to the $\gamma_L^* \to \rho_L$ contribution :

$$\Phi^{\gamma_L^*\to\rho_L} = \int dy \int d^2\underline{r}$$



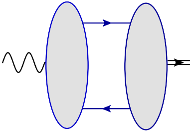
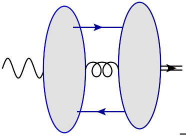
$$\times$$



$\psi_{q\bar{q}}^{\gamma_L^*\to\rho_L}$ $\mathcal{N}(\underline{k},\underline{r})$

Helicity amplitudes

- Helicity amplitude T_{11} corresponding to $\gamma_T^* \, N \to \rho_T \, N$

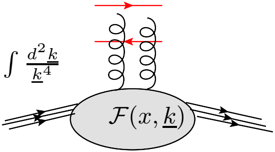
$T_{11} = \int d^2\underline{r} \left[\int dy \right.$  $+ \int dy_1 dy_2$  $\left. \right]$ $\hat{\sigma}(x,\underline{r})$

$\psi_{q\bar{q}}^{\gamma^* \to \rho}(y,\underline{r})$ $\qquad$ $\psi_{q\bar{q}g}^{\gamma^* \to \rho}(y_1,y_2,\underline{r})$

with

$\mathcal{N}(\underline{k},\underline{r})$

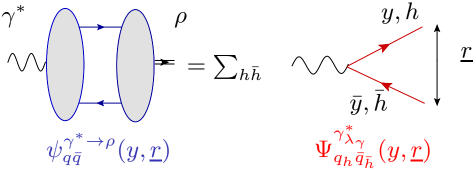
$\hat{\sigma}(x,\underline{r}) \propto \int \frac{d^2\underline{k}}{\underline{k}^4}$



- $\hat{\sigma}(x,\underline{r})$ contains saturation effects + energy dependence
- $\hat{\sigma}(x,\underline{r})$ models completely determined from fits on DIS data

Meaning of the $\psi^{\gamma^* \to \rho}_{q\bar{q}(g)}$ functions

- "Overlap of wave functions"



$$\times \phi^{\rho,\lambda_\rho}_{h,\bar{h}}(y, \underline{r}; \mu^2)$$

- with

$$\phi^{\rho,0}_{h,\bar{h}}(y, \underline{r}) = \delta_{h,-\bar{h}} \sqrt{\frac{\pi}{4N_c}} \, (n \cdot e_L^*) \underbrace{\varphi_1(y; \mu^2)}_{\text{Leading twist DA}}$$

$$\phi^{\rho,\lambda_\rho}_{h,\bar{h}}(y, \underline{r}) = \delta_{h,-\bar{h}} \sqrt{\frac{\pi}{4N_c}} \left(-i\underline{r} \cdot \underline{e}^*_{\lambda_\rho}\right) \times \left(\underbrace{\varphi_A^T(y; \mu^2) + (\delta_{h,\lambda_\rho} - \delta_{h,-\lambda_\rho}) \varphi_1^T(y; \mu^2)}_{\text{Twist 3 DAs}} \right)$$

From forward helicity amplitudes to polarized cross-sections

- Helicity amplitudes (reminder) in the limit $t \sim 0$

$$T_{00} = s \int dy \int d\underline{r}\, \psi^{\gamma^*_L \to \rho_L}_{(q\bar{q})}(y, \underline{r}; Q, \mu_F) \hat{\sigma}(x, \underline{r})$$

$$T_{11} = s \int dy \int d\underline{r}\, \psi^{\gamma^*_T \to \rho_T}_{(q\bar{q})}(y, \underline{r}; Q, \mu_F) \hat{\sigma}(x, \underline{r})$$

$$+ s \int dy_2 \int dy_1 \int d\underline{r}\, \psi^{\gamma^*_T \to \rho_T}_{(q\bar{q}g)}(y_1, y_2, \underline{r}; Q, \mu_F) \hat{\sigma}(x, \underline{r}),$$

- Polarized Cross-sections

$$\frac{d\sigma_{L,T}}{dt}(t) = \underbrace{e^{-b(Q^2)t}}_{T_{01}\text{,etc.. encodded}} \frac{d\sigma_{L,T}}{dt}(t=0)$$

$$\sigma_L = \frac{1}{b(Q^2)} \frac{T_{00}(s, t=0)^2}{16\pi s^2}$$

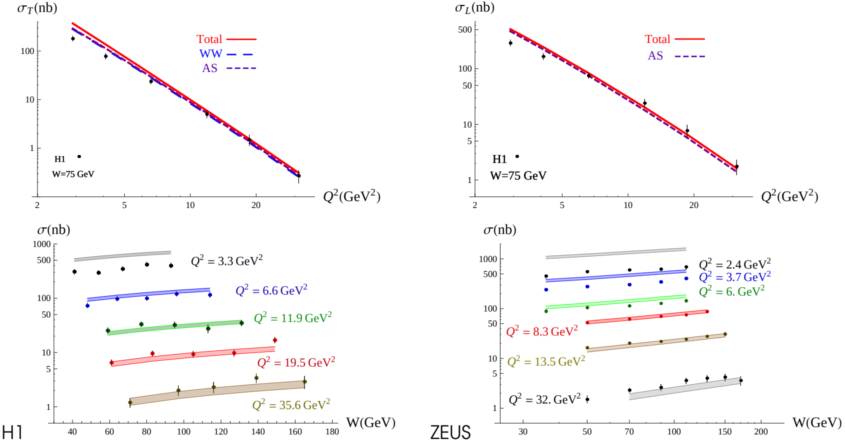
$$\sigma_T = \frac{1}{b(Q^2)} \frac{T_{11}(s, t=0)^2}{16\pi s^2}.$$

Dipole cross-section $\hat{\sigma}(x, r)$

- Models of dipole cross-section:
  - GBW saturation model
    (Golec-Biernat, Wüsthoff, '98)
  - rc-BK numerical solution
    (Albacete, Armesto, Milhano, Quiroga Arias, Salgado, '11)
  - Results weakly dependent on $\hat{\sigma}(x, \underline{r})$ model

- Model for twist 2 and twist 3 DAs
  (Ball, Braun, Koike, Tanaka, '98)
  - based on conformal expansion of DAs
  - take into account renormalization scale μ_F dependence

Comparison with HERA data



Predictions from A.B, Szymanowski, Wallon, (ArXiv:1302.1766 to appear in JHEP)

Data from H1 F.D Aaron et al. '10 and ZEUS S. Chekanov et al. '07

First part summary

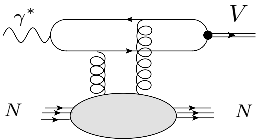
- A model for diffractive hard $\rho-$meson polarized cross-sections in good agreement with data
- Perspectives : Higher twist calculations, implementation of ρ meson wave function models
- Perspective under study : inclusion of the Sudakov form factor in this treatment could allow a better description for small Q^2 values

From small x region to valence region

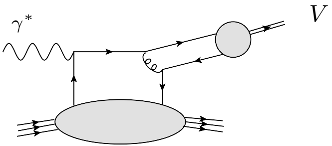
- ANR PARTONS project (collaborations between CPhT, IPN, Irfu, LPT):
  - Software to extract of GPDs from observables with uncertainties on parameters
  - with systematic comparison between theoretical GPD related predictions and data
  - experimental results and theoretical predictions databases
- Preliminary work on DVMP in coll. with H. Moutarde:

  Use Modified perturbative approach in DVMP (Kroll, Goloskokov, '03 and later) in order to confront several GPD models and their evolution with observables.

GPD approach using MPA for the leptoproduction of vector meson



Dominate at low x



important at mid x and in the valence region

- Nucleon interaction described by universal gluon and quark GPDs

$$\{H,\, E,\, \tilde{H},\, \tilde{E}\}_{q,\bar{q},g}(x,\xi,t,\mu_F)$$

modeled from double distribution ansatz

(Mueller et al. '94, Radyushkin '98)

$$F_i(x,\xi,t) = \int_{-1}^{1} d\rho \int_{-1+|\rho|}^{1-|\rho|} d\eta\, \delta(\rho+\xi\eta-x) f_i(\rho,\eta,t) + D_i(x,t)\theta(\xi^2-x^2)$$

$$f_i(\rho,\eta,t) = \omega_i(\rho,\eta) F_i(\rho,\xi=0,t)$$

GPD approach using MPA for the leptoproduction of vector meson

$$\mathcal{M} = e\sum_a e_a \mathcal{C}_a \int dx\, H^a(x,\xi,t,\mu_F)\int dy \int d^2\underline{r}\,\hat{\Psi}_\rho(y,r)\,\alpha_s(\mu_R)\hat{\mathcal{F}}(y,r,x,\xi,Q^2)\,e^{-S(y,r,Q^2)}$$

In order to supress end point singularities:

- keep transverse momenta $\underline{k}$ dependence of the partons forming the meson in the hard part
- assume gaussian dependence of the vector meson wave function in $\underline{k}$
- in Fourier coordinate space $\underline{k} \to \underline{r}$, include Sudakov form factor which resums the emissions of soft gluons from a quark antiquark pair. Suppress the large size $\underline{r}$ contribution.

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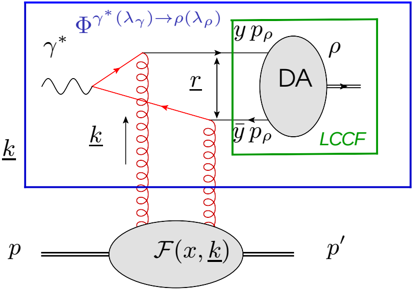
Coming next..

- Work in progress to implement any GPD models within DVMP computational framework within MPA
- Validation by comparison with KG results
- $\Rightarrow$ get contraints on their parameters and check the universality by computing DVCS and DVMP observables

Resummation of soft gluons ?

$$T_{\lambda_\rho \lambda_\gamma} = \int d^2\underline{k}$$



- Separation of color charge $\Rightarrow$ gluon radiation
- Leads to a Sudakov form factor which suppress of large $\underline{r}$ contribution