ρ-mesons leptoproduction as testfield for the unintegrated gluon distribution in the proton

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Outline

Motivation

- **Parton densities** are relevant to the search for **new Physics**

  $\Longrightarrow$ nonperturbative objects

  $\Longrightarrow$ they enter in the expression for cross sections

  $\Longrightarrow$ information about inner proton structure

- Several types of distributions:

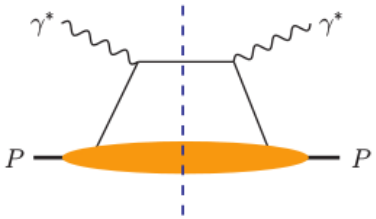
  - parton distribution functions (**PDFs**)
  - generalized parton distributions (**GPDs**)
  - transverse momentum dependent (**TMDs**)
  - unintegrated gluon distributions (**UGDs**)

  $\Longrightarrow$ different factorization schemes...

...A brief overview

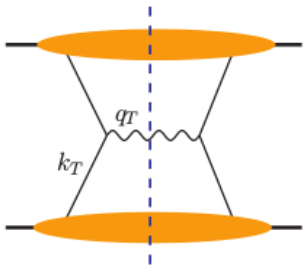
Integrated parton densities:

- **PDF (or collinear) factorization**
  - inclusive processes
  - $\kappa_T \sim$ hardest scale



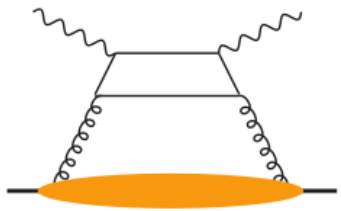
Unintegrated parton densities:

- **TMD factorization**
  - inclusive processes
  - $\kappa_T \ll$ hardest scale



- **GPD factorization**
  - exclusive processes
  - skewness effects

- **κ_T-factorization** (or small-x factorization)
  - inclusive or exclusive processes
  - **Unintegrated gluon distribution**

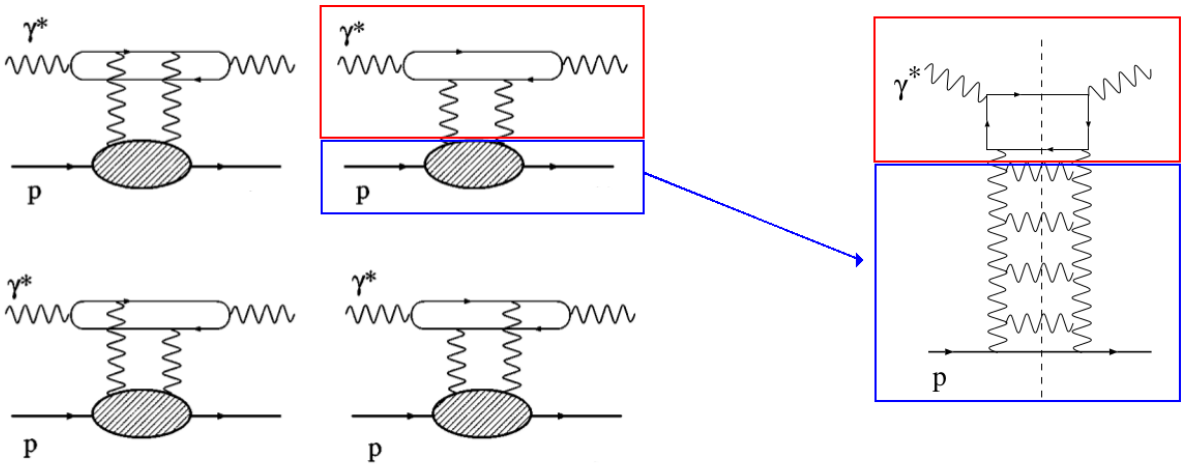


Unintegrated Gluon Distribution (UGD)

- ◇ DIS: conventionally described in terms of PDFs
- ◇ less inclusive processes: need to use distributions unintegrated over the parton κ_T
- example: **virtual photoabsorption** in κ_T**-factorization**

$$\sigma_{tot}(\gamma^* p \to X) = \mathrm{Im}_s\{\mathcal{A}(\gamma^* p \to \gamma^* p)\} \equiv \Phi_{\gamma^* \to \gamma^*} \circledast \mathcal{F}(x, \kappa^2)$$

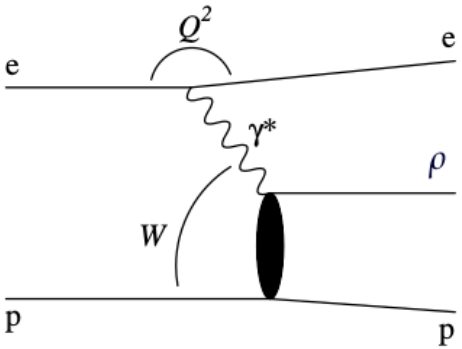
- ◇ $\mathcal{F}(x, \kappa^2)$ is the **unintegrated gluon distribution** (**UGD**) in the proton
- ▶ small-x limit: UGD = [BFKL gluon ladder] $\circledast$ [proton impact factor]



Leptoproduction of ρ mesons at HERA

$e - p$ collisions provide

$$\gamma^* + \text{proton} \longrightarrow \rho + \text{proton} \qquad \textit{...exclusive process!}$$



- High-energy regime:
  $s \equiv W^2 \gg Q^2 \gg \Lambda^2_{\text{QCD}} \Longrightarrow$ small $x = \frac{Q^2}{W^2}$
- photon virtuality Q is the **hard scale** of the process

- **Process solved in helicity** $\Longrightarrow$ so far **unexplored testfield** for UGD

  $\Longrightarrow$ constrain κ_{T}-dependence of UGD in the HERA energy range

  $$2.5 \text{ GeV}^2 < Q^2 < 60 \text{ GeV}^2$$
  $$35 \text{ GeV} < W < 180 \text{ GeV}$$

- Hierarchy of helicity amplitudes: $T_{00} \gg T_{11} \gg T_{10} \gg T_{01} \gg T_{1-1}$

  [H1 collaboration: F.D. Aaron et al., *JHEP* **05** 032 (2010)]

- ρ-meson via **distribution amplitudes (DAs)**: $\varphi(y) = \varphi^{\text{WW}}(y) + \varphi^{\text{gen}}(y)$

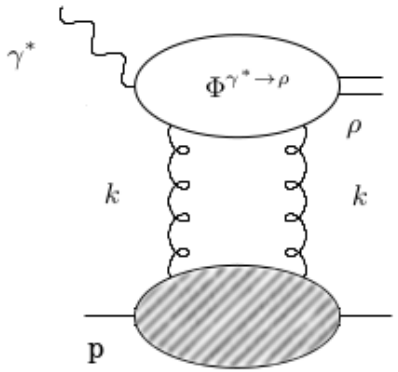
Helicity Amplitudes in κ_T-factorization

- Leading **helicity amplitudes** are known

  Assumption:

  - $\mathrm{Im}_s \{\mathcal{A}(\gamma^* p \to \rho\, p)\}$
  - same W- and t-dependence for T_{11} and $T_{00} \Longrightarrow \kappa_T$-factorization

$$T_{\lambda_\rho \lambda_\gamma}(s; Q^2) = is \int \frac{d^2\kappa}{(\kappa^2)^2} \Phi^{\gamma^*(\lambda_\gamma)\to\rho(\lambda_\rho)}(\kappa^2, Q^2)\, \mathcal{F}(x, \kappa^2)\,, \quad x = \frac{Q^2}{s}$$



Interesting transitions:

- $\gamma_L^* \to \rho_L \xrightarrow{\text{encoded by}} \Phi^{\gamma_L^*\to\rho_L}$
- $\gamma_T^* \to \rho_T \xrightarrow{\text{encoded by}} \Phi^{\gamma_T^*\to\rho_T}$

$\Longrightarrow$ **DAs** enter in $\Phi^{\gamma^*\to\rho}$

- HERA data available for $\mathbf{T_{11}/T_{00}}$ [H1 collaboration: F.D. Aaron et al., *JHEP* **05** 032 (2010)]

T_{11} and T_{00}

Assumption:

- **Wandzura-Wilczek (WW) approximation** $\longrightarrow$ genuine terms neglected

$$T_{11} = -is\,(\epsilon_\gamma \cdot \epsilon_\rho^*)\,2\,B\,C\,\frac{m_\rho}{Q^2}\int \frac{d^2\kappa}{(\kappa^2)^2}\mathcal{F}(x,\kappa^2)\int_0^1 dy\;\varphi_+^{\mathrm{WW}}(y,\mu^2)\,\frac{\alpha\,(\alpha+2y\bar{y})}{y\bar{y}\,(\alpha+y\bar{y})^2}$$

$$T_{00} = is\frac{4\,B\,C}{Q}\int \frac{d^2\kappa}{(\kappa^2)^2}\mathcal{F}(x,\kappa^2)\int_0^1 dy\;\varphi_1^{\mathrm{as}}(y,\mu^2)\left(\frac{\alpha}{\alpha+y\bar{y}}\right)$$

where $\alpha = \frac{\kappa^2}{Q^2}$, $B = 2\pi\alpha_s\frac{e}{\sqrt{2}f_\rho}$, $C = \frac{\delta_{ab}}{2N_c}$

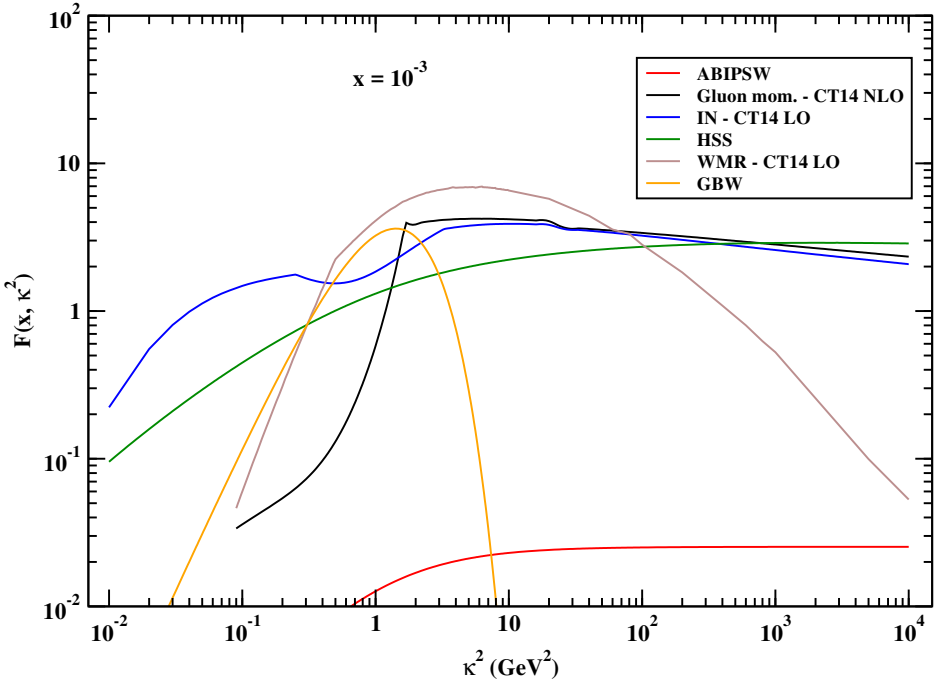
$\Longrightarrow$ ρ-**meson DAs** employed:

- **asymptotic** $\varphi_1^{\mathrm{as}}(y) \xrightarrow{fixing} a_2(\mu^2) = 0$ Gegenbauer coefficient
- $\varphi_+^{\mathrm{WW}}(y,\mu^2) = (2y-1)\varphi_{1T}^{\mathrm{WW}}(y,\mu^2) + \varphi_{AT}^{\mathrm{WW}}(y,\mu^2)$

$\Longrightarrow$ $\mathcal{F}(x,\kappa^2)$ has to be modeled!

UGD models

- Existence of several UGD models $\Longrightarrow$ **different behavior** in κ^2-shape



- **ABIPSW**: x-independent model

[I. V. Anikin et al., *Phys. Rev. D***84** (2011)]

- **Gluon mom. derivative**:

$$\mathcal{F}(x,\kappa^2) = \frac{d\, xg(x,\kappa^2)}{d\ln\kappa^2}$$

- **IN**: soft and hard components $\xrightarrow{\textit{to probe}}$ different regions of κ

[I. P. Ivanov and N. N. Nikolaev, *Phys. Rev. D* **65** (2002)]

- **HSS**: $\mathcal{G}_{\rm BFKL} \otimes$ [proton IF]

[I. Bautista, A. Fernandez Tellez, M. Hentschinski, *Phys. Rev. D* **94** (2016) no.5, 054002]

[G. Chachamis, M. Deák, M. Hentschinski, G. Rodrigo and A. Sabio Vera, *JHEP* **1509** (2015) 123]

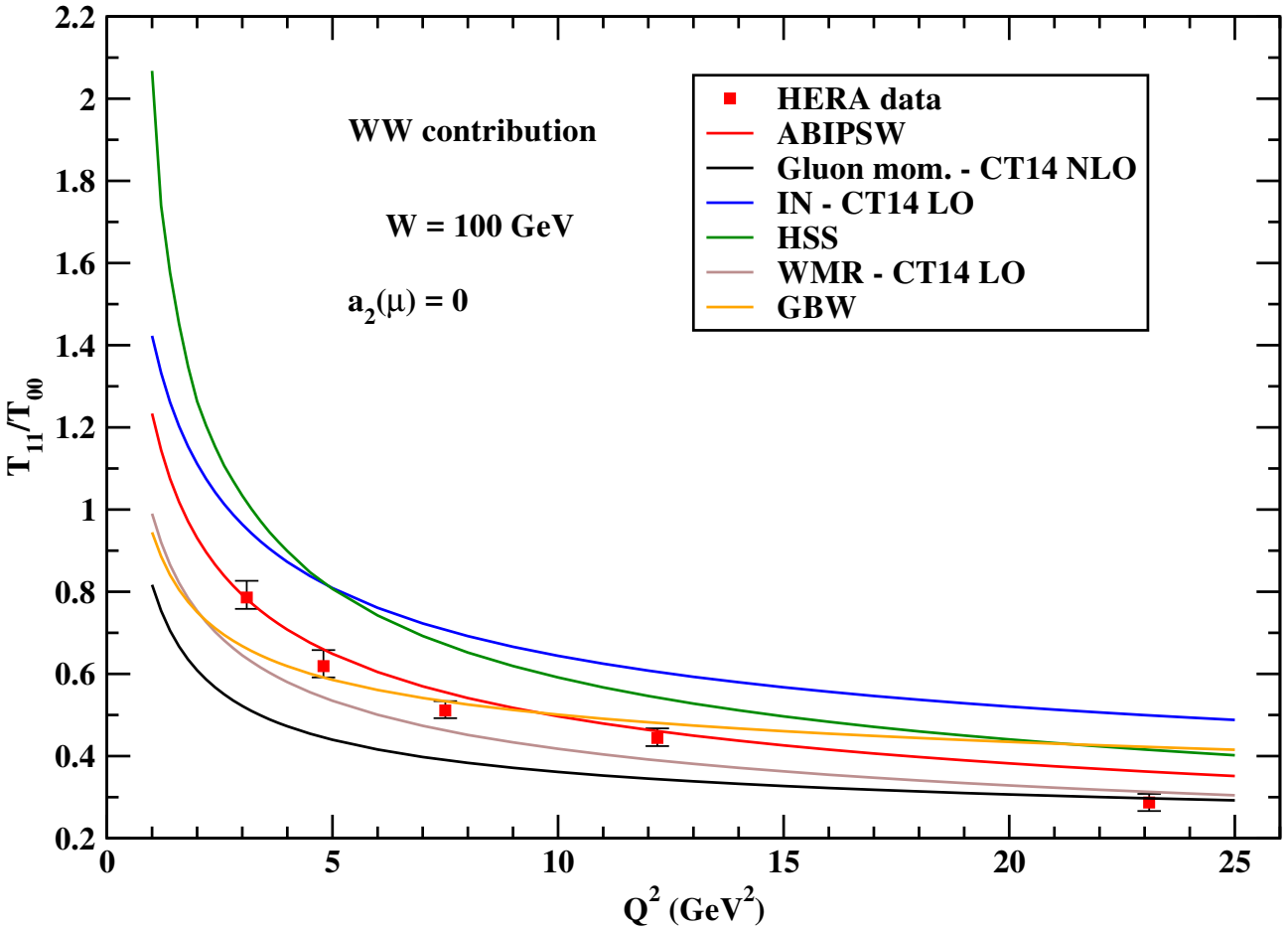
- **WMR**: angular ordering of gluon emissions

[G. Watt, A.D. Martin, M.G. Ryskin, *Eur. Phys. J. C* **31** (2003) 73]

- **GBW**: FT of dipole cross section

[K.J. Golec-Biernat, M. Wusthoff, *Phys. Rev. D* **59** (1998) 014017]

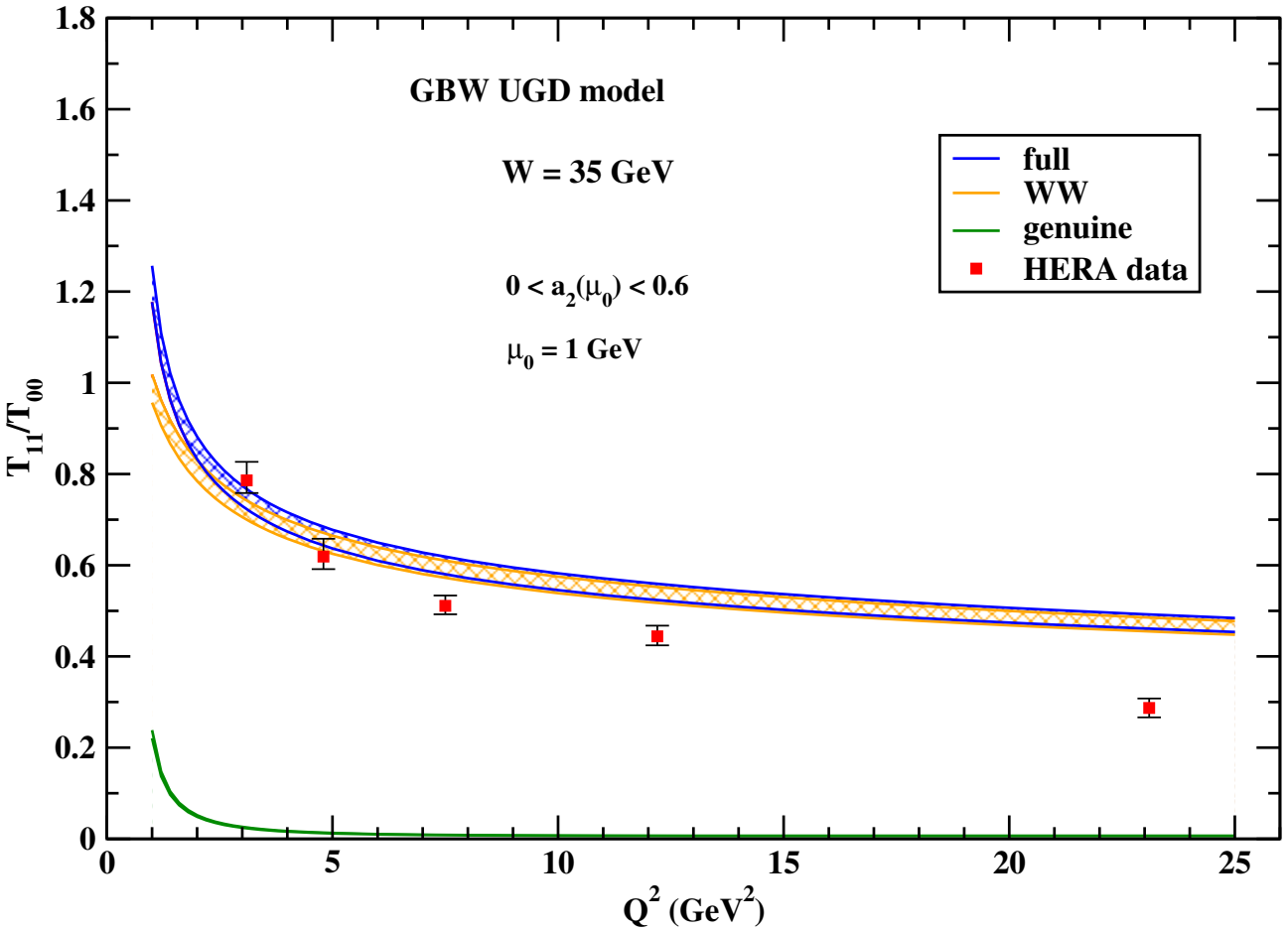
T_{11}/T_{00} for different UGD models - W = 100 GeV



- None of the models is able to reproduce data over the entire Q^2-range
- x-independent ABIPSW and GBW $\longrightarrow$ more suitable models

T_{11}/T_{00} for GBW model - W = 35 GeV

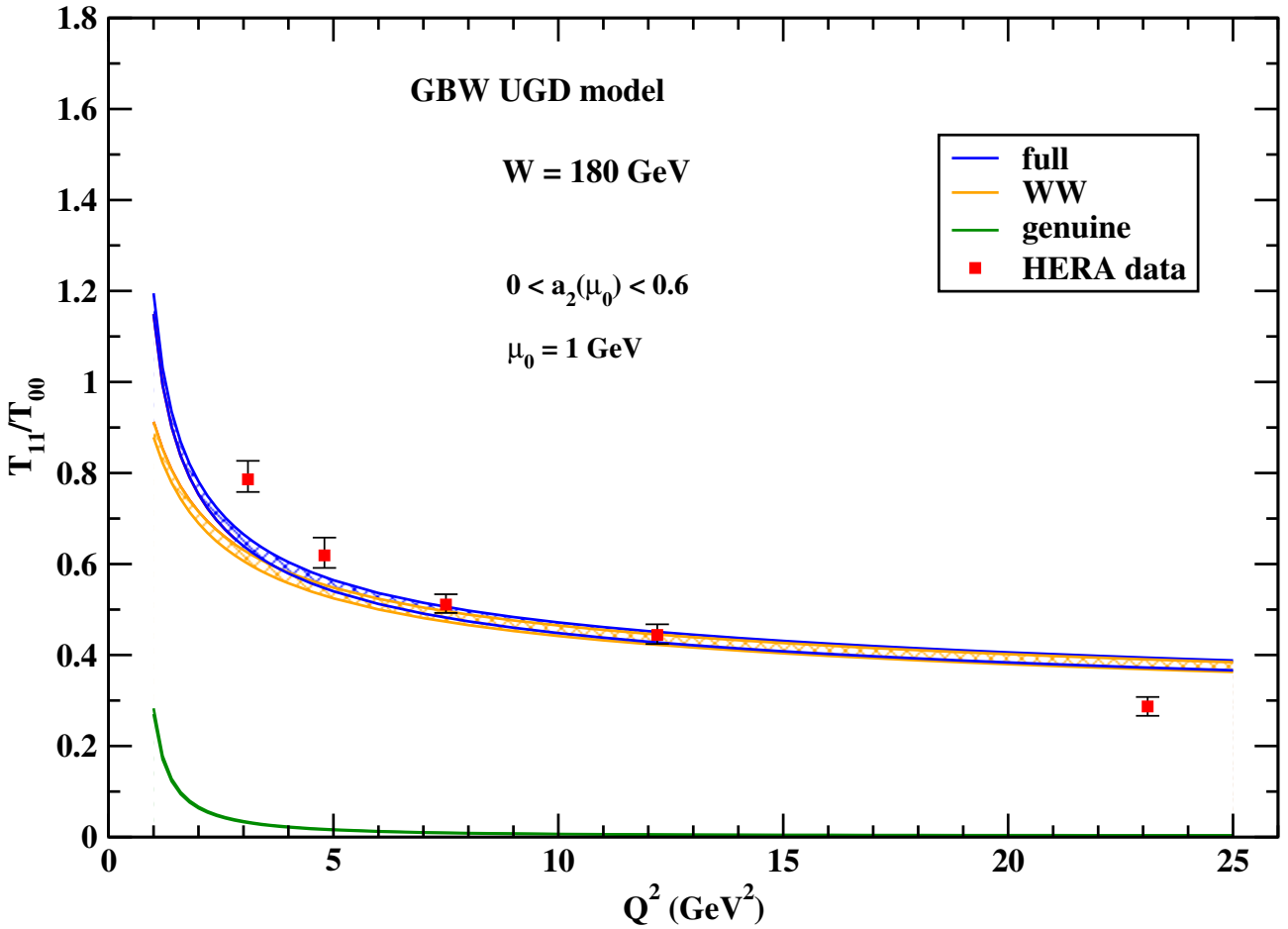
- Genuine twist-3 effect included



- Uncertainty band $\longrightarrow$ variation of $a_2(\mu_0 = 1\ \text{GeV})$

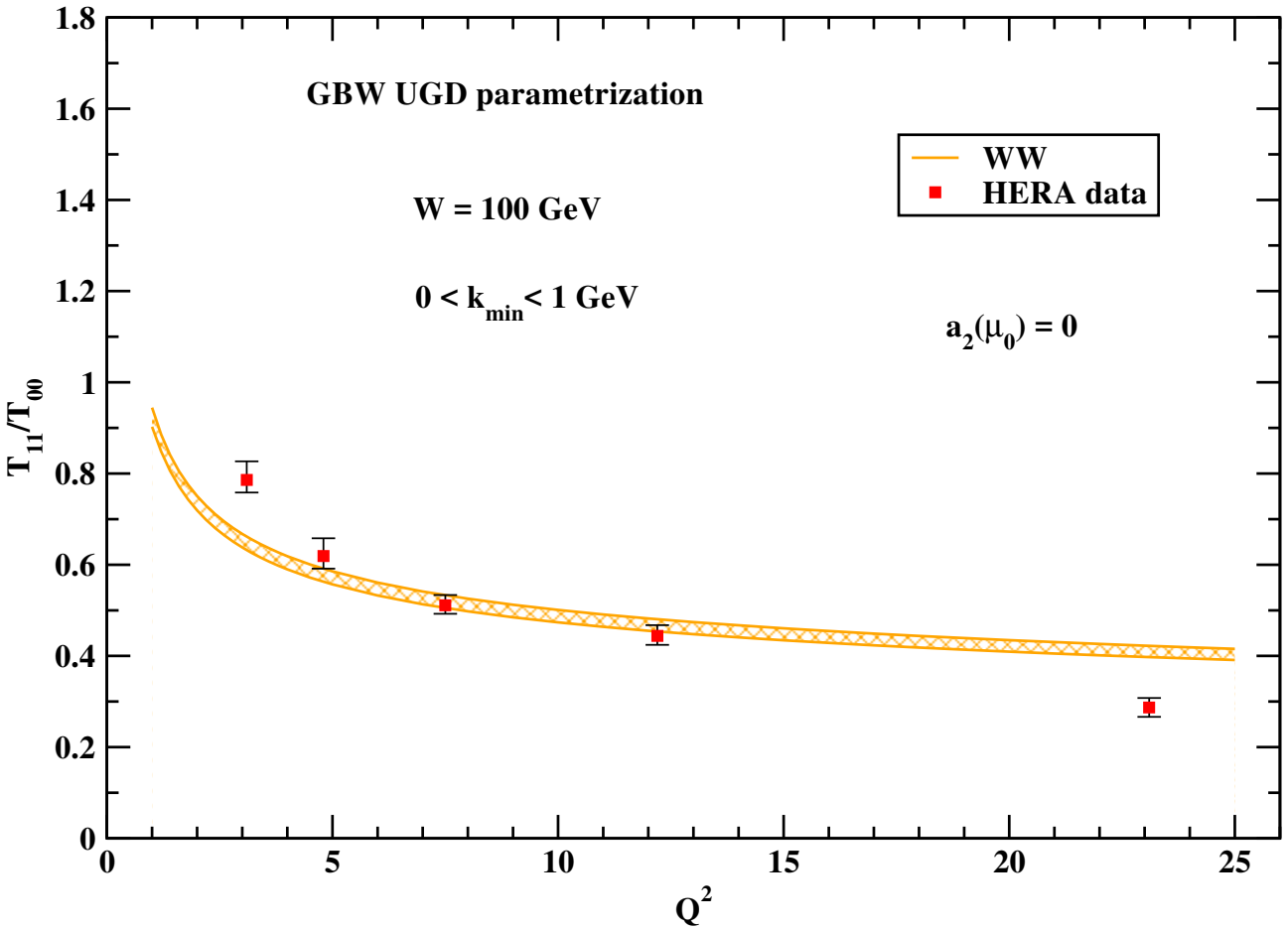
T_{11}/T_{00} for GBW model - W = 180 GeV

- Genuine twist-3 effect included



- Uncertainty band $\longrightarrow$ variation of $a_2(\mu_0 = 1\ \text{GeV})$

Stability of T_{11}/T_{00} on k_{min} cutoff



- Uncertainty band $\longrightarrow$ variation of k_{min} between 0 and 1 GeV
- Small shift of $T_{11}/T_{00} \Longrightarrow T_{11}$ and T_{00} dominated by **large** κ values

Conclusions...

Exclusive electroproduction of polarized ρ-meson as testing ground for UGD:

- Process **never** investigated before in the UGD context!
- **Exclusive** final state + **small-x** limit $\Longrightarrow$ **κ_T-factorization** allowed
- **Process solved in helicity** $\Longrightarrow$ T_{11}/T_{00} to constrain the **κ-dependence** of the UGD in the HERA energy range

$$\Longrightarrow T_{11} \text{ and } T_{00} \text{ sensitive to large } \underline{\kappa \text{ values}}$$

...Outlook

- Study and test of further UGDs
- Proposal of new UGD models
- Consider other processes as testfield for UGD:
  - ◇ heavy-quarks production
  - ◇ Drell–Yan process

Thanks for your attention!