

The longitudinal cross section of vector meson electroproduction

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Outline:

- Handbag factorization
- Modeling the GPDs
- Results for L-L transitions
- Summary and Outlook

talk based on work with S. Goloskokov, hep-ph/0501242, hep-ph/0611290

Handbag factorization

Radyushkin (96); Collins et al (97):

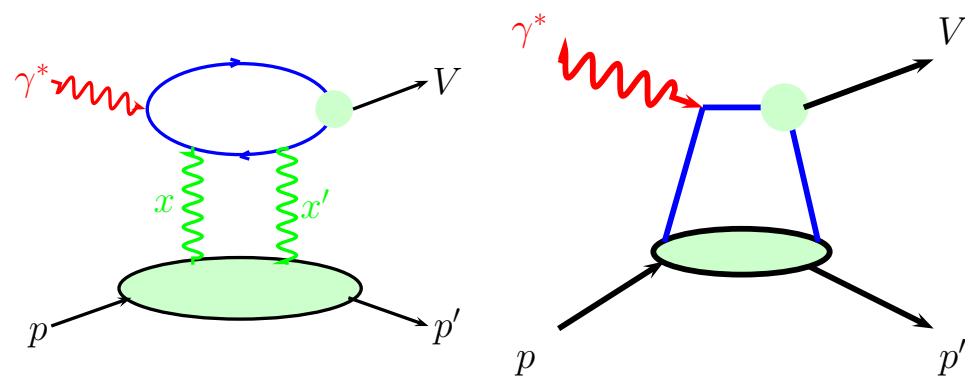
rigorous proof of factorization

for $Q^2 \rightarrow \infty$ into

hard subprocesses

$\gamma^* g \rightarrow Vg$ and $\gamma^* q \rightarrow Vq$

and GPDs ($x \neq x'$)



dominant transition $\gamma_L^* \rightarrow V_L$ (others power suppressed)

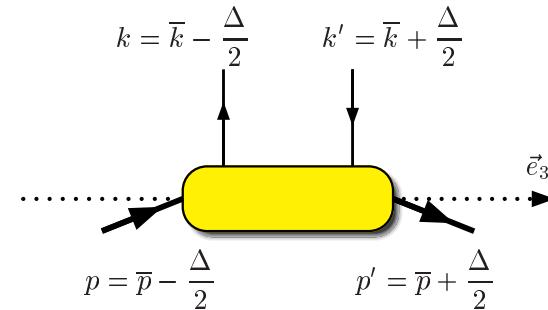
lead. $\ln(1/x_{\text{Bj}})$ appr.: (Brodsky et al): $x \simeq x' \simeq x_{\text{Bj}}$; GPD \rightarrow PDF

Generalized Parton Distributions

D. Müller et al (94), Ji(97), Radyushkin (97)

$$\xi = \frac{(p - p')^+}{(p + p')^+} \quad \bar{x} = \frac{\bar{k}^+}{\bar{p}^+}$$

$$x = \frac{\bar{x} + \xi}{1 + \xi} \quad x' = \frac{\bar{x} - \xi}{1 - \xi}$$



$$\int \frac{dz^-}{\pi} e^{i \bar{x} \bar{p}^+ z^-} \langle p' | G^{+\mu}(-\bar{z}/2) G_\mu^+ (\bar{z}/2) | p \rangle = \\ \bar{u}(p') \gamma^+ u(p) H^g(\bar{x}, \xi; t) + \bar{u}(p') i \sigma^{+\alpha} \frac{\Delta_\alpha}{2m} u(p) E^g(\bar{x}, \xi; t)$$

(gauge $A^+ = 0$; $\bar{z} = [0, z^-, \mathbf{0}_\perp]$) $\tilde{G}_\mu^+ \longrightarrow \tilde{H}^g, \tilde{E}^g$ (quarks analogously)

reduction formulas:

$$H^g(\bar{x}, 0; 0) = \bar{x} g(\bar{x}) \quad \tilde{H}^g(\bar{x}, 0; 0) = \bar{x} \Delta g(\bar{x})$$

sum rules, universality, polynomiality, evolution, positivity constraints

$$\gamma^* p \rightarrow V p$$

gluon subprocess dominant at large Q^2 , W and small $x_{\text{Bj}} (\lesssim 0.2)$, t ;
kinematics fixes skewness: $\xi \simeq \frac{x_{\text{Bj}}}{2-x_{\text{Bj}}} [1 + m_V^2/Q^2] \simeq x_{\text{Bj}}/2 + \text{m.m.c.}$

$$M_{0+,0+}^{V(g)} = \frac{e}{2} \mathcal{C}_V \int_0^1 \frac{d\bar{x}}{(\bar{x} + \xi)(\bar{x} - \xi + i\epsilon)} \times \\ \left\{ \sum_{\lambda} \mathcal{H}_{0\lambda,0\lambda}^{V(g)} [H^g - \frac{\xi^2}{1-\xi^2} \textcolor{red}{E^g}] + \sum_{\lambda} \lambda \mathcal{H}_{0\lambda,0\lambda}^{V(g)} [\tilde{H}^g - \frac{\xi^2}{1-\xi^2} \tilde{E}^g] \right\}$$

$$M_{0-,0+}^{V(g)} = \dots \frac{\sqrt{-t}}{2m} \dots E^g + \dots \xi \tilde{E}^g$$

(\mathcal{C}_V flavor factor, quarks analogously)

Parity conservation: $\sum \lambda \mathcal{H}_{0\lambda,0\lambda}^{V(g)} = 0$

Unpolarized protons: no flip-nonflip interference (expectation $|E| \lesssim |H|$)

$$|M_{0-,0+}|^2 \propto t/m^2 \quad \text{neglected}$$

Electroprod. with unpolarized protons at small x_{Bj} probes H^g and H^q
(pseudoscalar mesons: $\sum \mathcal{H}_{0\lambda,0\lambda}^{P(q)} = 0$ only \tilde{H}^q, \tilde{E}^q contribute)

Double distributions

integral representation ($i = \text{valence, sea quarks, gluons}$)

$$H_i(\bar{x}, \xi, t') = \int_{-1}^1 d\beta \int_{-1+|\beta|}^{1-|\beta|} d\alpha \delta(\beta + \xi\alpha - \bar{x}) f_i(\beta, \alpha, t') + D_i \Theta(\xi^2 - \bar{x}^2)$$

f_i double distributions Mueller *et al* (94), Radyushkin (99)

advantage - polynomiality automatically satisfied

$D_i(\bar{x}, t)$ ($i = \text{gluon, sea}$) additional free function, support $-\xi < \bar{x} < \xi$

useful ansatz with relation to PDFs

$$f_i(\beta, \alpha, t') = h_i(\beta, t) \frac{\Gamma(2n_i + 2)}{2^{2n_i + 1} \Gamma^2(n_i + 1)} \frac{[(1 - |\beta|)^2 - \alpha^2]^{n_i}}{(1 - |\beta|)^{2n_i + 1}}$$

$$h_g(t = 0) = |\beta| g(|\beta|), \quad n_g = 2$$

$$h_{\text{sea}}^q(t = 0) = q(|\beta|) \text{sign}(\beta), \quad n_{\text{sea}} = 2$$

$$h_{\text{val}}^q(t = 0) = q_{\text{val}}(\beta) \Theta(\beta), \quad n_{\text{val}} = 1$$

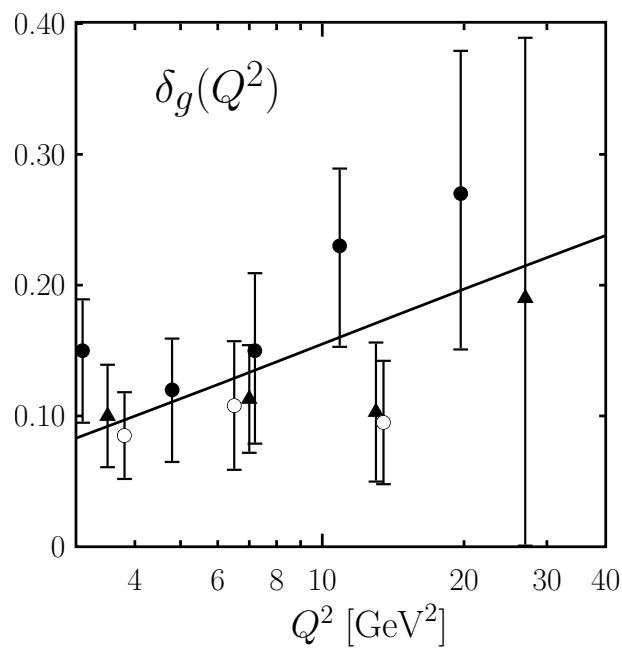
sea quarks mix with gluons under evolution

The t dependence

parameterization of PDFs:
 δ_i Regge intercepts

$$h_i(\beta) = \beta^{-\delta_i} (1 - \beta)^{2n_i + 1} \sum_j c_{ij} \beta^{j/2}$$

Landshoff *et al* (71), Feynman (72)



$$\alpha_i(t) = \alpha_i(0) + \alpha'_i t$$

valence quarks: $\delta_{\text{val}} = \alpha_{\text{val}}(0) \simeq 0.48$,
 $\alpha'_{\text{val}} \simeq 0.9 \text{ GeV}^{-2}$

gluon and sea trajectory
(Pomeron - diffraction)

$\sigma_L \propto W^{4\delta_g(Q^2)}$ - fit to HERA data:

$$\delta_g = \alpha_g(0) - 1 \simeq 0.10 + 0.06 \ln \frac{Q^2}{4 \text{ GeV}^2}$$

$$\delta_{\text{sea}} = \alpha_g(0)$$

$$\alpha'_g \simeq 0.1 - 0.2 \text{ (photoprod. of } J/\Psi)$$

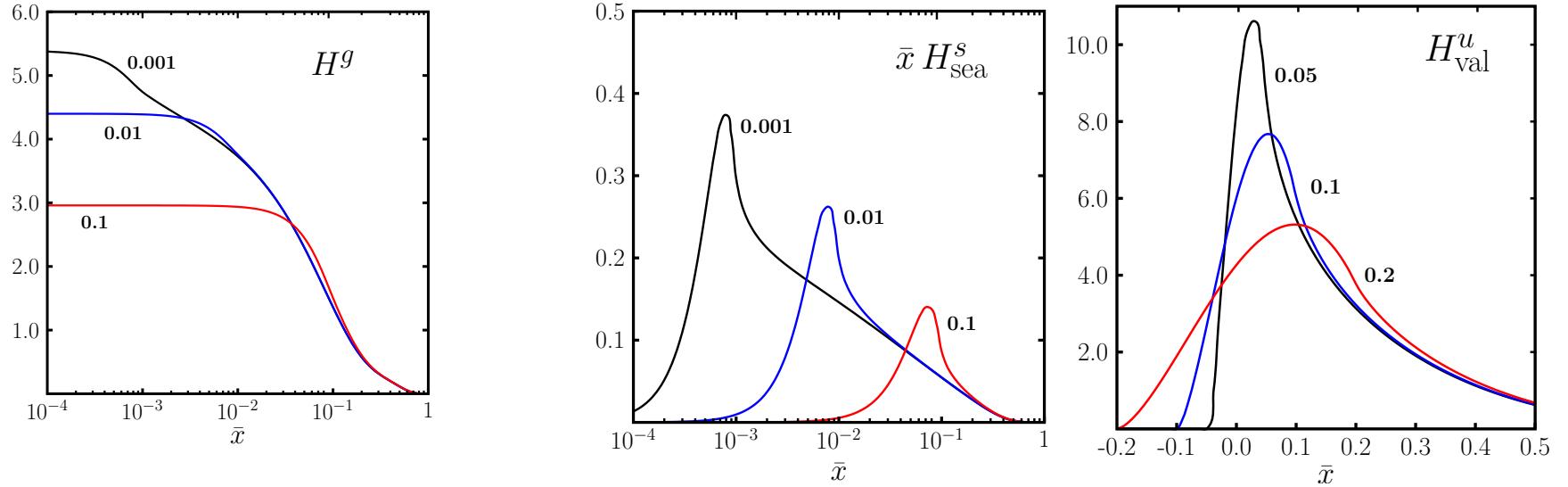
Reggeized GPDs (small $-t$): $h_i(\beta, t) = \exp[b_i t] \beta^{-\alpha'_i t} h_i(\beta, t = 0)$

b_i : t dependence of **Regge residue** (taken from exp.)

$$b_{\text{val}} = 0, b_g = b_{\text{sea}} = [2.58 + 0.25 \ln \frac{m^2}{Q^2 + m^2}] \text{ GeV}^{-2}$$

GPD integral can be executed analytically

The GPDs at $t = 0$

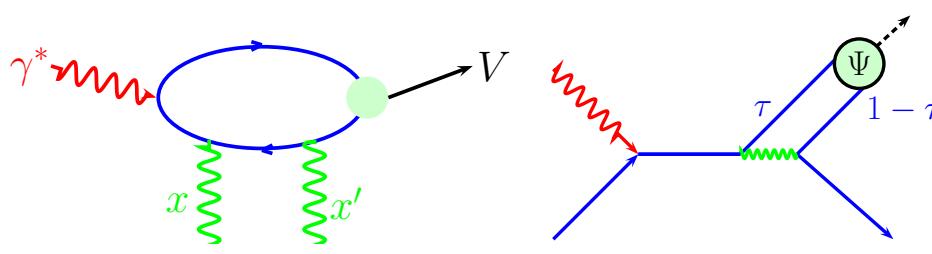


various values of ξ , $\xi \ll \bar{x}$: GPD \rightarrow PDF up to corrections of $\mathcal{O}(\xi^2)$
INPUT: NLO CTEQ6M (with δ_g fixed) at scale 4 GeV^2

$$H_{\text{val}}^d \simeq H_{\text{val}}^u / 2 \quad H_{\text{sea}}^u \simeq H_{\text{sea}}^d \simeq \kappa_s H_{\text{sea}}^s \quad (\kappa_s \simeq 2 \text{ at } 4 \text{ GeV}^2; \rightarrow 1 \text{ for } Q^2 \rightarrow \infty)$$

polynomiality and reduction formulas respected by construction
positivity bounds and sum rule for F_1 respected as checked numerically

$\gamma^* p \rightarrow Vp$ to leading-twist order



$$I_g = 2 \int_0^1 d\bar{x} \frac{\xi H^g(\bar{x}, \xi, t)}{(\bar{x} + \xi)(\bar{x} - \xi + i\epsilon)}$$

$$I_{\text{sea}} = 2 \int_0^1 d\bar{x} \frac{\bar{x} H_{\text{sea}}^s(\bar{x}, \xi, t)}{(\bar{x} + \xi)(\bar{x} - \xi + i\epsilon)}$$

$$I_{\text{val}}^a = 2 \int_{-\xi}^1 d\bar{x} \frac{\bar{x} H_{\text{val}}^a(\bar{x}, \xi, t)}{(\bar{x} + \xi)(\bar{x} - \xi + i\epsilon)},$$

pole terms: $\text{Im} I_i = -\pi H_i(\xi, \xi, t)$

Regge phases for $\xi \rightarrow 0$

$$\mathcal{M}_\phi = e \frac{8\pi\alpha_s}{N_c Q} f_\phi \langle 1/\tau \rangle_\phi \frac{-1}{3} \left\{ \frac{1}{2\xi} I_g + C_F I_{\text{sea}} \right\}$$

$$\mathcal{M}_\rho = e \frac{8\pi\alpha_s}{N_c Q} f_\rho \langle 1/\tau \rangle_\rho \frac{1}{\sqrt{2}} \left\{ \frac{1}{2\xi} I_g + \kappa_s C_F I_{\text{sea}} + \frac{1}{3} C_F I_{\text{val}}^u + \frac{1}{6} C_F I_{\text{val}}^d \right\}$$

t dependence only in GPD considered

(scaled by soft parameter, actually slope of diffraction peak)

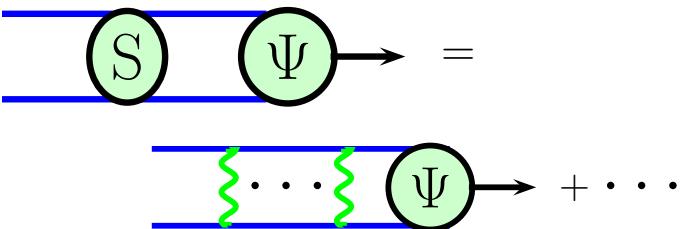
\mathcal{H} provides power corrections of order t/Q^2 , neglected

- leading-twist results too large
- by order of magnitude at $Q^2 \simeq 4 \text{ GeV}^2$
less at larger values of Q^2
- transverse resolution power of γ^* cannot be neglected
as compared with trans. size of meson
- suppression through quark transverse momentum
required

The modified perturbative approach

Sterman et al (92): quark transverse momenta and gluonic radiative corrections (Sudakov) are taken into account **in subprocess**

suppresses end-point regions ($\tau \rightarrow 0, 1$) where q, \bar{q} separated by large transv. distances
 (bears similarities to treatment in lead. $\ln(1/x_{Bj})$ appr. e.g. Frankfurt et al (95))
in axial gauge: modification of wf.



$$S = \frac{8}{3\beta_0} \ln \frac{\tau Q}{\sqrt{2}\Lambda_{\text{QCD}}} \ln \left(\frac{\ln(\tau Q/\sqrt{2}\Lambda_{\text{QCD}})}{-\ln(b\Lambda_{\text{QCD}})} \right) + \text{NLL-terms}$$

resummation $\implies \exp[-S]$

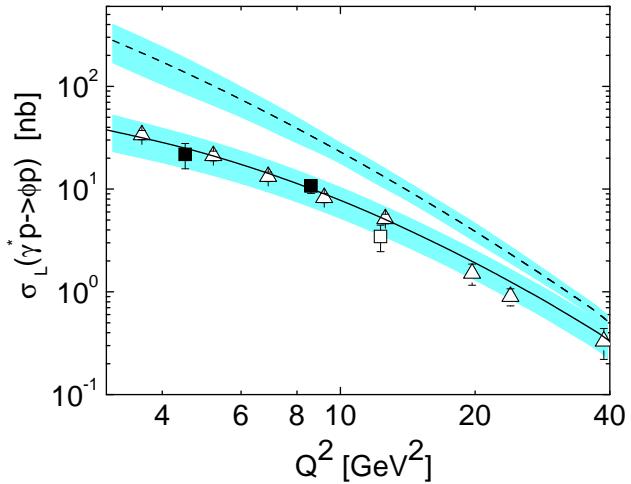
FT $\vec{k}_\perp \rightarrow \vec{b}$:

$$\mathcal{H}_L^V = \int d\tau d^2 b \hat{\Psi}_{VL}(\tau, b) \hat{T}_{LL} \exp[-S(\tau, b, Q^2)]$$

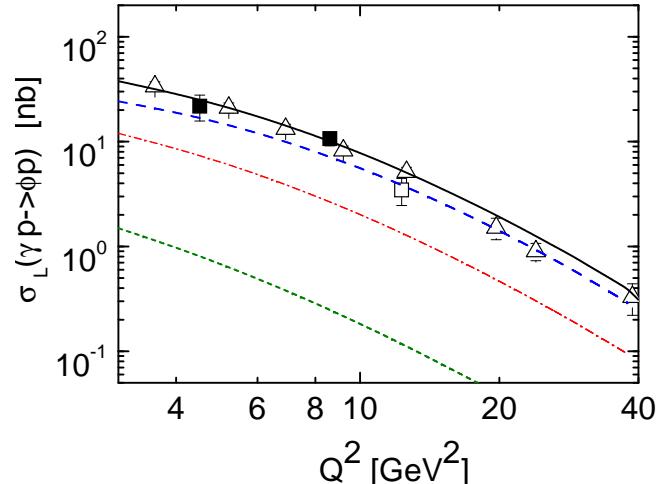
Gaussian wavefunction: $\Psi_{VL} \sim f_{VL} \exp[-a_{VL}^2 k_\perp^2 / (\tau(1-\tau))]$

parameters: $f_{\rho L} = 0.216 \text{ GeV}$ ($V \rightarrow e^+ e^-$) $a_{\rho L} = 0.75 \text{ GeV}^{-1}$ (fit)
 $f_{\phi L} = 0.237 \text{ GeV}$ $a_{\phi L} = 0.70 \text{ GeV}^{-1}$

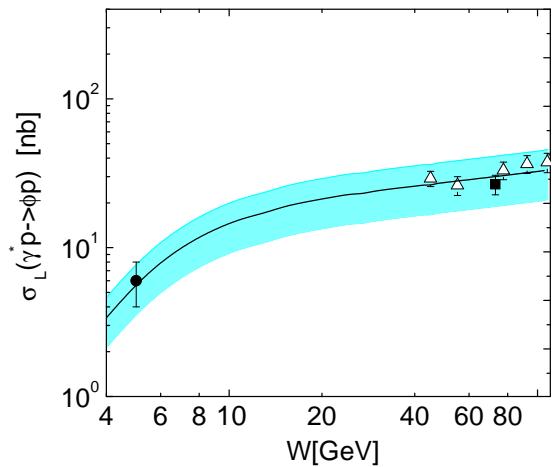
$\sigma_L(\gamma^* p \rightarrow \phi p)$



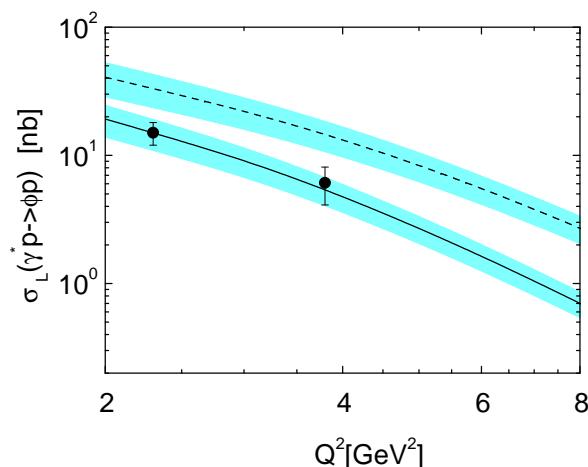
$W = 75$ GeV, dashed line: lead. twist



gluon, gluon-sea interf., sea

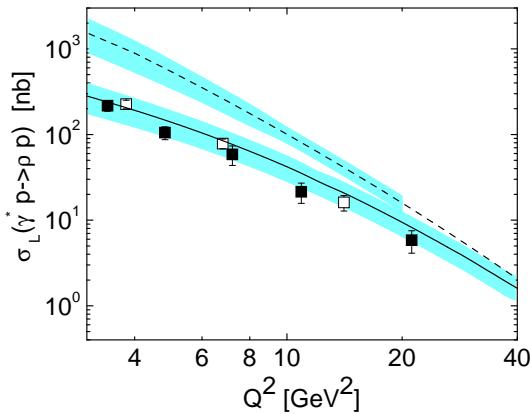


data: HERMES, H1, ZEUS, $Q^2 = 4$ GeV 2 ,

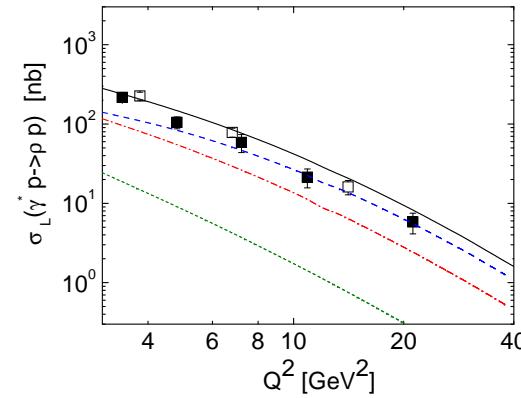


$W = 5(10)$ GeV solid (dashed)

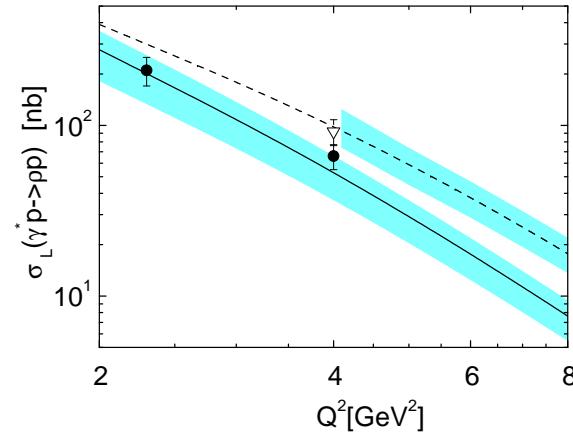
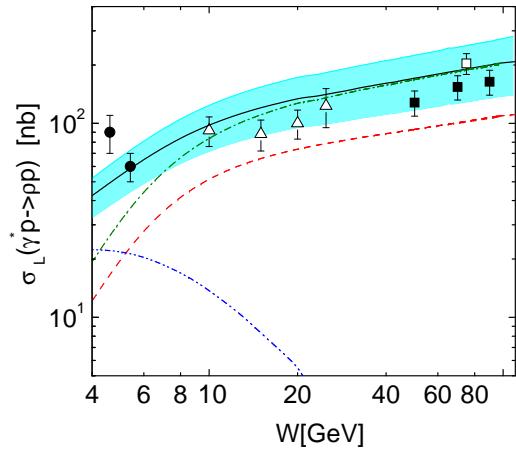
$$\sigma_L(\gamma^* p \rightarrow \rho p)$$



$W = 75$ GeV dashed line: lead. twist

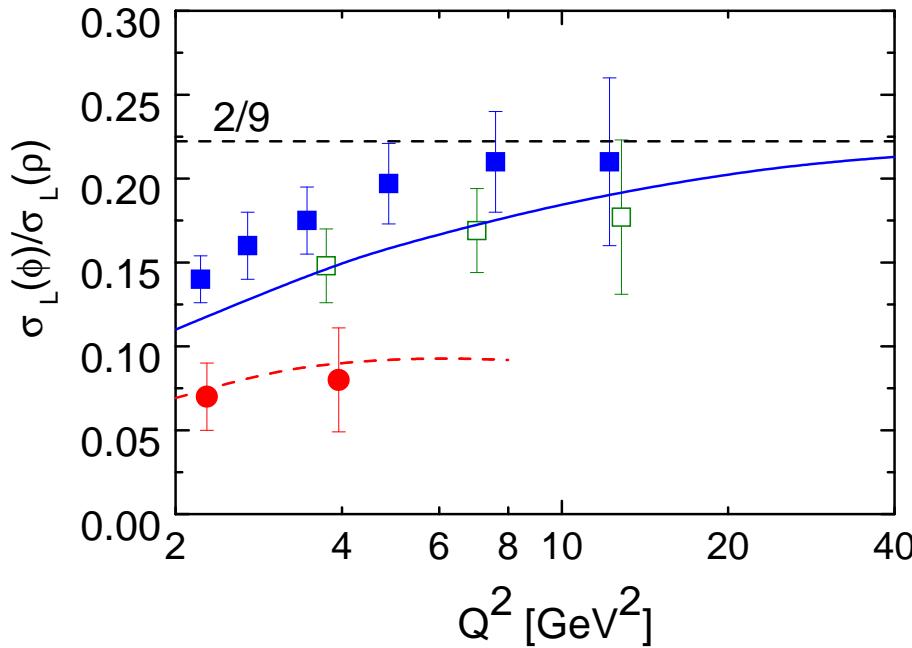


valence quarks negligible



$Q^2 = 3.8$ GeV 2 , glue+sea, glue, valence + interf. $W = 5(10)$ GeV solid (dashed)
data: H1, ZEUS, E665, HERMES

The ϕ - ρ ratio



HERA ($W = 75 \text{ GeV}$): close to $2/9$ at large Q^2

(suppression of ratio due to κ_s and $a_{\rho(\phi)}$)

HERMES ($W = 5 \text{ GeV}$): clear deviation
(see also Diehl-Vinnikov (04))

need for valence quarks

Summary and Outlook

- phenomenology of DVME (DVES) within the handbag approach is complicated, still a lot of work is to be done
- GPDs are modeled through reggeized double distr. ($\alpha_g, \alpha_{\text{val}}$)
 t dependence of valence quark GPDs not well probed as yet
accurate t dependent data ($d\sigma_L/dt$, SDME) required
subprocess calculated within modified pert.approach
- fair agreement with exp. (HERA, E665, HERMES) found for LL transitions
predictions for COMPASS energies made
the gluonic GPD H^g dominates
valence quarks only important for HERMES kinematics
- extension to TT transitions possible and done only for gluons as yet
also fair agreement with data on R and SDME for HERA energies found
- **in progress:** calculation of TT transitions for sea and valence quarks
estimate of effects from GPDs \tilde{H} and E (pol. beams and/or targets)