Spin effects and amplitude structure in vector meson photoproduction at small x

S.V. Goloskokov

Bogoliubov Laboratory of Theoretical Physics, Joint Institute for Nuclear Research,

Dubna 141980, Moscow region, Russia

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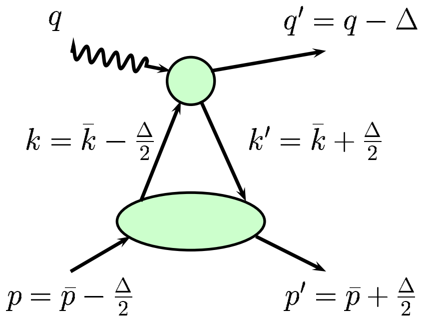
Plan

- Vector meson leptoproduction at $x << 1$ in GPD approach .
- Modified PA
  - transverse degrees of freedom in wave function & hard subprocess
  - Sudakov suppression
- Structure of amplitudes in VM production
- Physical observables -cross sections, SDME A_{LL} asymmetry in light VM production

Leptoproduction of Vector Mesons in GPD approach

The process of VM production



The $L \to L, T \to T$ and $T \to L$ amplitudes are important in analyses of cross section and spin observales. The k- dependent wave function

$$\hat{\Psi}_V = [(\not{V} + M_V)\not{\epsilon}_V + \frac{2}{M_V}\not{V}\not{\epsilon}_V\not{K} - \frac{2}{M_V}(\not{V} - M_V)(\epsilon_V \cdot K)]\phi_V(k,\tau). \quad (1)$$

J. Bolz, J. Körner and P. Kroll, 1994

- V is a vector meson momentum and M_V is its mass
- ϵ_V is a meson polarization vector and K is a quark transverse momentum

The gluon contribution to the amplitudes $\gamma^*_\mu \to V'_\mu$:

$$\mathcal{M}_{\mu'+,\mu+} = \frac{e}{2}\mathcal{C}_V \int_0^1 \frac{d\overline{x}}{(\overline{x}+\xi)(\overline{x}-\xi+i\varepsilon)} \times \Big\{ \big[\mathcal{H}^V_{\mu'+,\mu+} + \mathcal{H}^V_{\mu'-,\mu-}\big]\, H^g(\overline{x},\xi,t) + \big[\mathcal{H}^V_{\mu'+,\mu+} - \mathcal{H}^V_{\mu'-,\mu-}\big]\, \widetilde{H}^g(\overline{x},\xi,t)\Big\} \tag{2}$$

The flavor factors are $\mathcal{C}_\rho = 1/\sqrt{2},\ \mathcal{C}_\phi = -1/3$.

The hard scattering amplitudes

$$\mathcal{H}^V_{\mu'+,\mu+} \pm \mathcal{H}^V_{\mu'-,\mu-} = \frac{8\pi\alpha_s(\mu_R)}{\sqrt{2N_c}} \int_0^1 d\tau \int \frac{d^2\mathbf{k}_\perp}{16\pi^3} \phi_{V\mu'}(\tau,k_\perp^2)\,(\overline{x}^2-\xi^2)\, f^\pm_{\mu'\mu}/D\,. \tag{3}$$

$$\phi_V(\mathbf{k}_\perp,\tau) = 8\pi^2\sqrt{2N_c}\, f_V a_V^2\, \exp\left[-a_V^2\, \frac{\mathbf{k}_\perp^2}{\tau\bar{\tau}}\right]. \tag{4}$$

Generally f_V, a_V may be different for TT and LL amplitudes.

The product of propagator denominators

$$D \;=\; \left(\mathbf{k}_\perp^2 + \bar\tau\, Q^2\right)\,\left(\mathbf{k}_\perp^2 + \tau\, Q^2\right)\,\left(\mathbf{k}_\perp^2 + \bar y\,\bar\tau\, Q^2 - i\hat\varepsilon\right)$$
$$\times\left(\mathbf{k}_\perp^2 + y\,\bar\tau\, Q^2 - i\hat\varepsilon\right)\,\left(\mathbf{k}_\perp^2 + \tau\, y\, Q^2 - i\hat\varepsilon\right)\,\left(\mathbf{k}_\perp^2 + \tau\,\bar y\, Q^2 - i\hat\varepsilon\right)\;.$$

$$y = (x+\xi)/(2\xi)\,, \qquad \bar y = 1 - y\,. \tag{5}$$

The model leads to the following form of helicity amplitudes

$$\begin{aligned}
\mathrm{L} \to \mathrm{L}: &\qquad \mathcal{M}^{V(g)}_{0\,\nu,0\,\nu} \propto 1\\
\mathrm{T} \to \mathrm{L}: &\qquad \mathcal{M}^{V(g)}_{0\,\nu,+\nu} \propto \frac{\sqrt{-t}}{Q},\\
\mathrm{T} \to \mathrm{T}: &\qquad \mathcal{M}^{V(g)}_{+\nu,+\nu} \propto \frac{\mathbf{k}_\perp^2}{QM_V},\\
\mathrm{L} \to \mathrm{T}: &\qquad \mathcal{M}^{V(g)}_{+\nu,0\,\nu} \propto \frac{\sqrt{-t}}{Q}\,\frac{\mathbf{k}_\perp^2}{QM_V}\,,\\
\mathrm{T} \to -\mathrm{T}: &\qquad \mathcal{M}^{V(g)}_{-\nu,+\nu} \propto \frac{-t}{Q^2}\,\frac{\mathbf{k}_\perp^2}{QM_V}\,.
\end{aligned} \tag{6}$$

Thus, the $L \to T$ and $T \to -T$ transitions should be small and we neglect these amplitudes

The impact parameter space

- We consider Sudakov suppression of large quark-antiquark separations. These effects suppress contributions from the end-point regions , in which one of the partons in the meson wave function becomes soft and where factorization breaks down .
- Since the Sudakov factor is exponentiate in the impact parameter space- we have to work in this space.

$$\begin{aligned} \mathcal{M}^{H}_{\mu'+,\mu+} &= \frac{e}{\sqrt{2N_c}} \mathcal{C}_V \int d\overline{x} d\tau \; f^{+}_{\mu'\mu} H^{g}(\overline{x}, \xi, t) \\ &\times \int d^2\mathbf{b}\, \hat{\Phi}_{V\mu'}(\tau, b^2)\, \hat{D}^{-1}(\tau, Q, b)\, \alpha_s(\mu_R)\, \exp\left[-S(\tau, b, Q)\right] \end{aligned} \tag{7}$$

The renormalization scale μ_R is taken to be the largest mass scale appearing in the hard scattering amplitude, i.e. $\mu_R = \max\,(\tau Q, \bar{\tau} Q, 1/b)$.

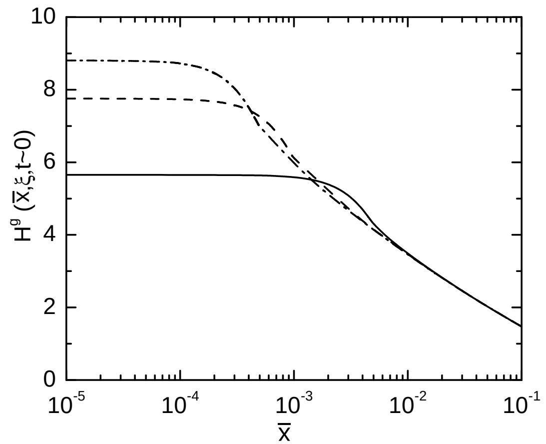
Modelling the GPDs

The double distributions for GPDs Radyushkin ’99

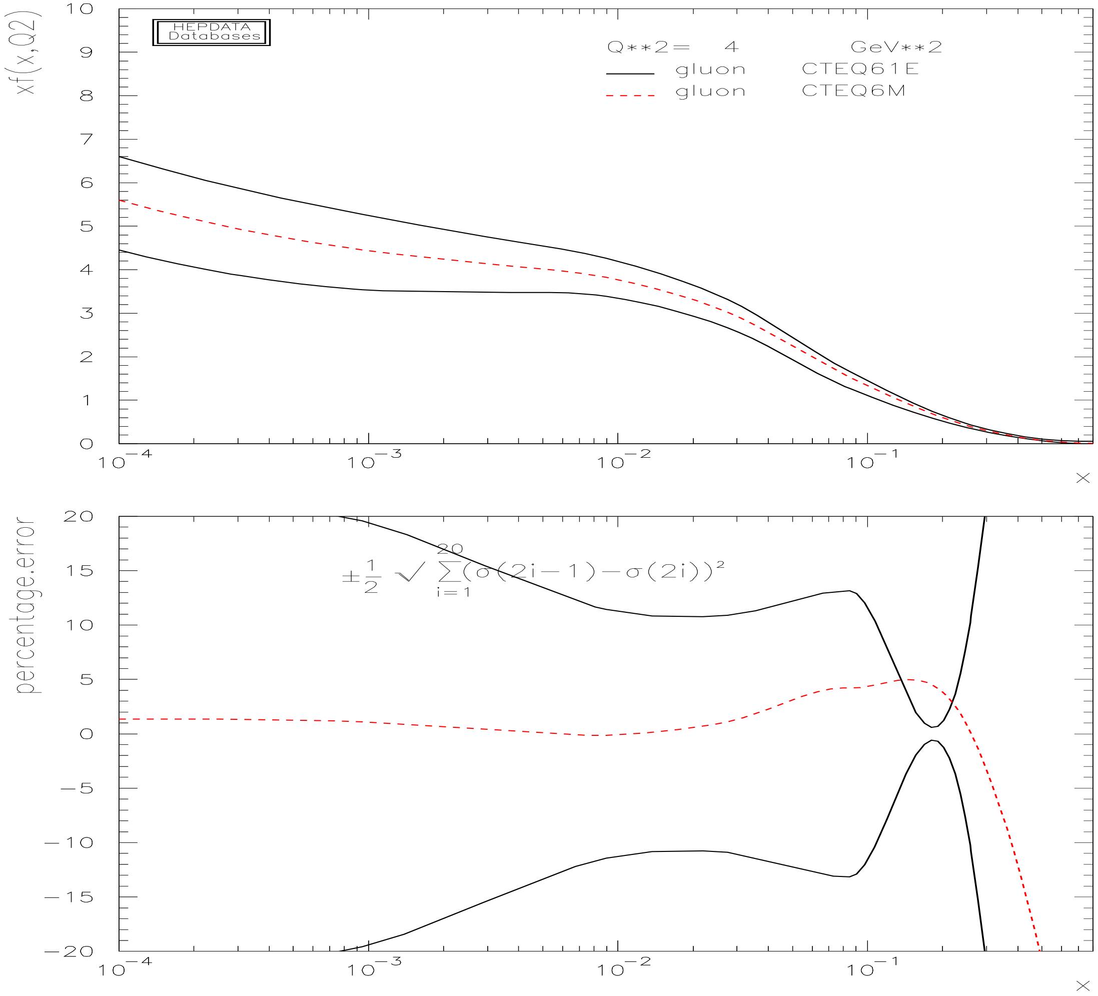
$$H^g(\overline{x},\xi,t) \;=\; \left[\Theta(0\le\overline{x}\le\xi)\int_{\frac{\overline{x}-\xi}{1+\xi}}^{\frac{\overline{x}+\xi}{1+\xi}} d\beta + \Theta(\xi\le\overline{x}\le 1)\int_{\frac{\overline{x}-\xi}{1-\xi}}^{\frac{\overline{x}+\xi}{1+\xi}} d\beta\right]\frac{\beta}{\xi}\, f(\beta,\alpha=\frac{\overline{x}-\beta}{\xi})$$

– simple factorising ansatz for the double distributions $f(\beta,\alpha,t)$

$$f(\beta,\alpha,t\simeq 0) = g(\beta)\,\frac{3}{4}\,\frac{[(1-|\beta|)^2-\alpha^2]}{(1-|\beta|)^3}. \tag{8}$$



Model results for the GPD H^g in the small $\overline{x}$ range. The solid (dashed, dash-dotted) line represents the GPD at $\xi = 5\;(1\,,\;0.5)\;\cdot 10^{-3}$ .The gluon distribution - from the NLO CTEQ5M results.



Errors in gluon distribution estimated by CTEQ collaboration at $Q^2 = 4\,\mathrm{GeV}^2$

t- dependencies and diffraction peak slopes

$$M_{ii}(t) = M_{ii}(0)\; e^{t\,B_{ii}/2}; \quad (ii) = LL,\; TT,\; LT \tag{9}$$

Experimentally slope of $\gamma^* p \to V p$ is measured.

Slopes of individual $LL,\; TT,\; LT$ amplitudes are not well known.

- The combined H1 and ZEUS data on the slopes in the range $4\ \mathrm{GeV}^2 \lesssim Q^2 \lesssim 40\,\mathrm{GeV}^2$ are consistent with

$$B^V_{LL} = 7.5\ \mathrm{GeV}^{-2} + 1.2\ \mathrm{GeV}^{-2} \ln \frac{3.0\ \mathrm{GeV}^2}{Q^2 + m_V^2}.$$

The following combination is tested in integrated cross sections $|M_{TT}|^2 \propto (\frac{f_T^V}{M_V})^2 \frac{1}{B^V_{TT}}$

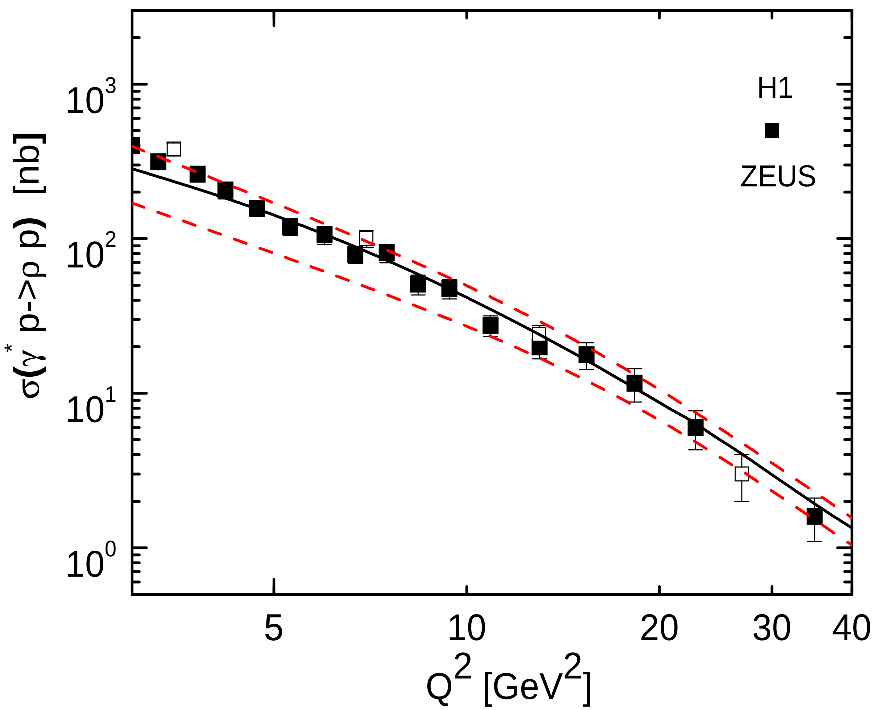
We suppose $B^V_{LL} \sim B^V_{LT}; \quad B^V_{LL} \neq B^V_{TT}.$

We test:

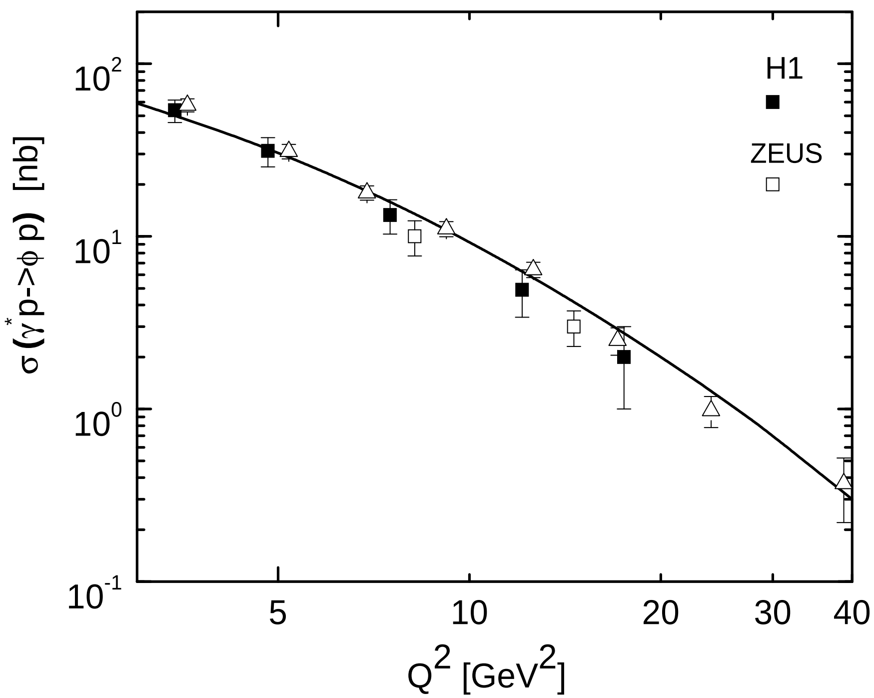
- $B^V_{TT} \sim B^V_{LL}/2; \quad M_V = m_V; \quad f_{\rho T} = .250\,\mathrm{GeV}$.
- $B^V_{TT} \sim B^V_{LL}; \quad M_V = m_V/2; \quad f_{\rho T} = .170\,\mathrm{GeV}$.

Results are the same for the cross sections. Differences are in observables where different amplitudes combinations can be tested (spin dencity matrix elements e.g.).

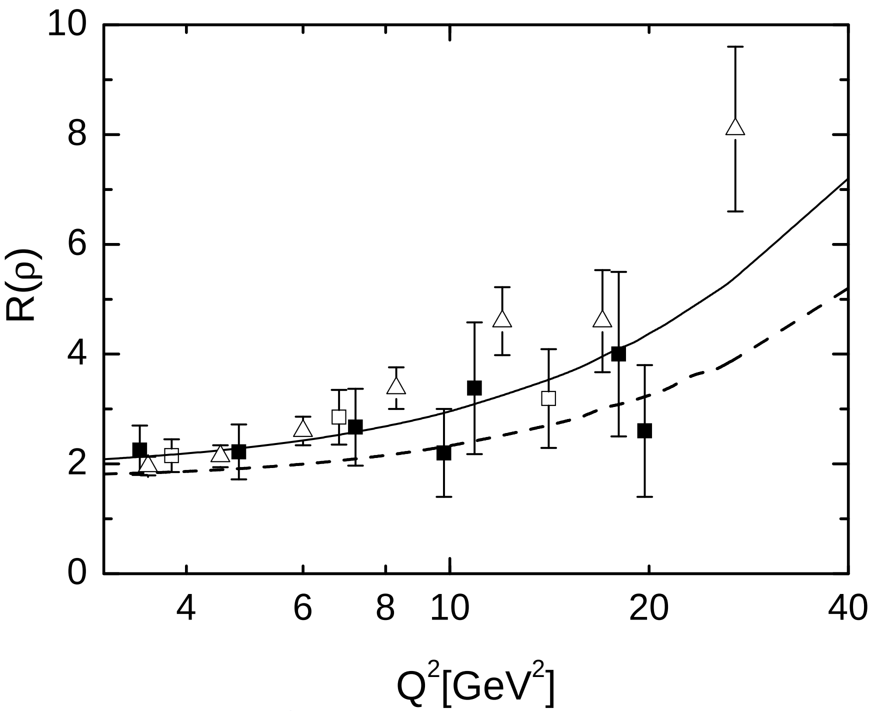
$B^V_{TT} \sim B^V_{LL}/2$ in what follows.



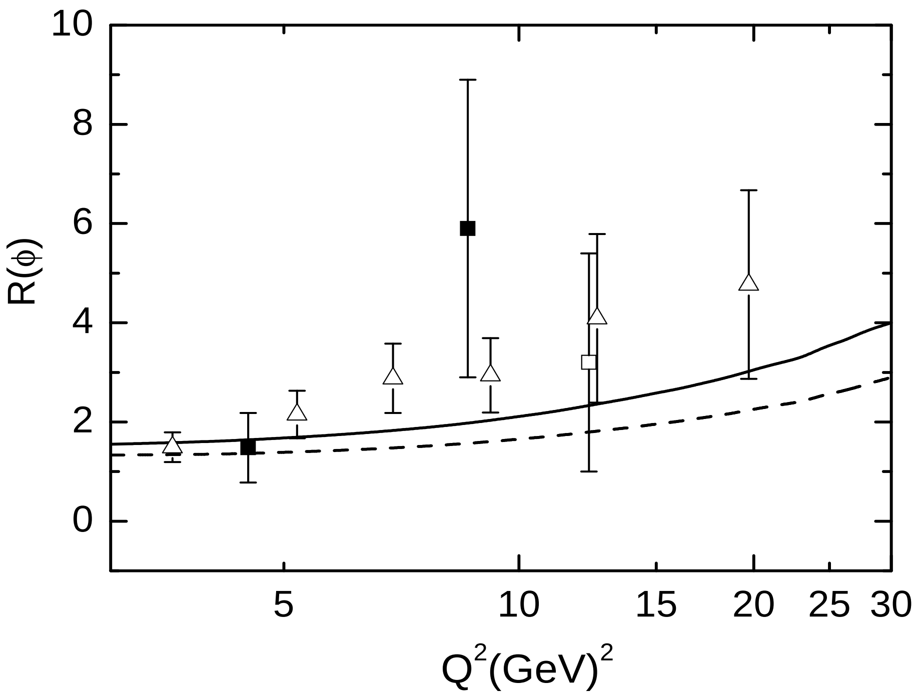
The cross section for $\gamma^* p \to \rho^0 p$ vs. Q^2 for fixed values of $< W >= 75\,\mathrm{GeV}$. Data are taken from H1& ZEUS.



The cross section for $\gamma^* p \to \phi\, p$ vs. Q^2 for fixed values of $< W >= 75\,\mathrm{GeV}$. Data are taken from H1& ZEUS.



The ratio of longitudinal and transverse cross sections for ρ production versus Q^2 at $W \simeq 75\ \mathrm{GeV}$. Data are taken from H1& ZEUS. The solid (dashed) lines are our results for the ratio of differential (integrated) cross sections, $\tilde{R}\,(R)$. The ratio $\tilde{R}$ is evaluated at $t = -0.15\ \mathrm{GeV}^2$.



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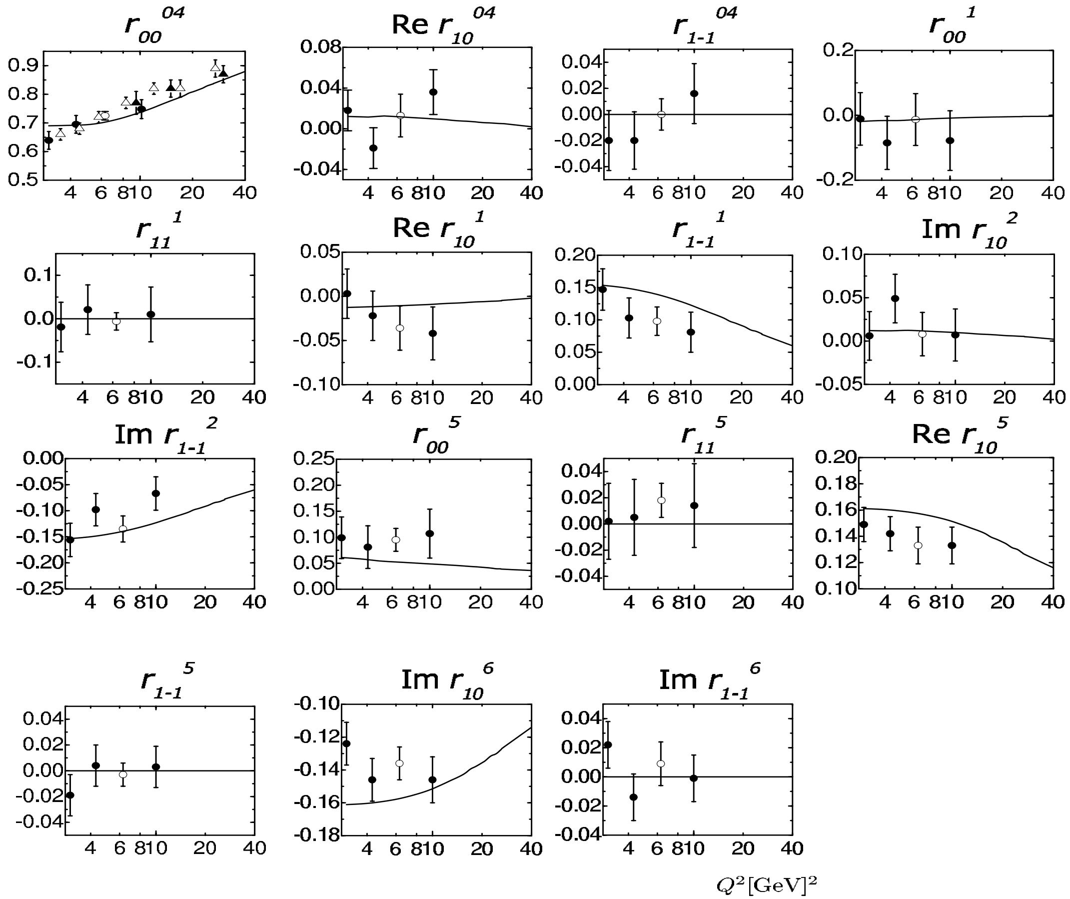
Spin density matrix elements

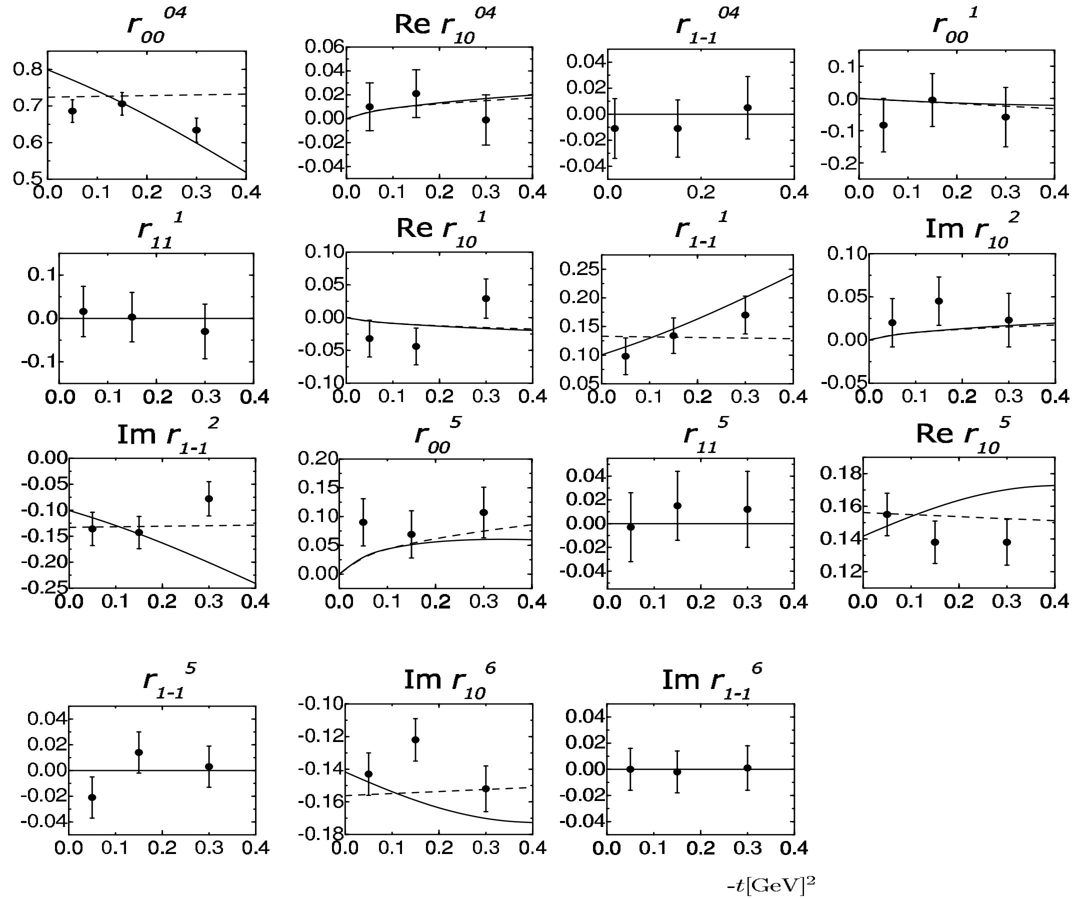
Our simplifications for the spin spin density matrix elements

$$
\begin{aligned}
N_L &= 2|\mathcal{M}^{V(g)}_{0\,+,0\,+}|^2\,, \\
N_T &= \sum_\nu \left[|\mathcal{M}^{V(g)}_{+\nu,+\nu}|^2 + |\mathcal{M}^{V(g)}_{0\,\nu,+\nu}|^2\right]\,, \\
r^{04}_{00} &= \frac{1}{N_T+\varepsilon N_L}\sum_\nu (|\mathcal{M}^{V(g)}_{0\nu,,+\nu}|^2 + \varepsilon\,|\mathcal{M}^{V(g)}_{0\nu\,,0\nu}|^2) \\
\mathrm{Re}\, r^{04}_{10} &= \frac{1}{1+\epsilon\tilde{R}}\,\frac{1}{N_T}\,\mathrm{Re}\left[\mathcal{M}^{H}_{++,++}\,\mathcal{M}^{H*}_{0\,+,++}\right] \\
r^{1}_{00} &= \frac{-1}{1+\epsilon\tilde{R}}\,\frac{2}{N_T}|\mathcal{M}^{H}_{0\,+,++}|^2, \\
r^{1}_{1-1} &= -\mathrm{Im}\, r^{2}_{1-1} = \frac{1}{1+\epsilon\tilde{R}}\,\frac{1}{N_T}\,|\mathcal{M}^{H}_{++,++}|^2, \\
&\quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots
\end{aligned} \tag{10}
$$

Good description of SDME for ρ and ϕ production .



Q^2 dependence SDME of ρ production at $< t >= -.15\,\mathrm{GeV}^2$ and $< W >= 75\,\mathrm{GeV}$.



t- dependence of SDME of ρ production at $Q^2 = 5\,\mathrm{GeV}^2$ and $< W >= 75\,\mathrm{GeV}$.

A_{LL} asymmetry.

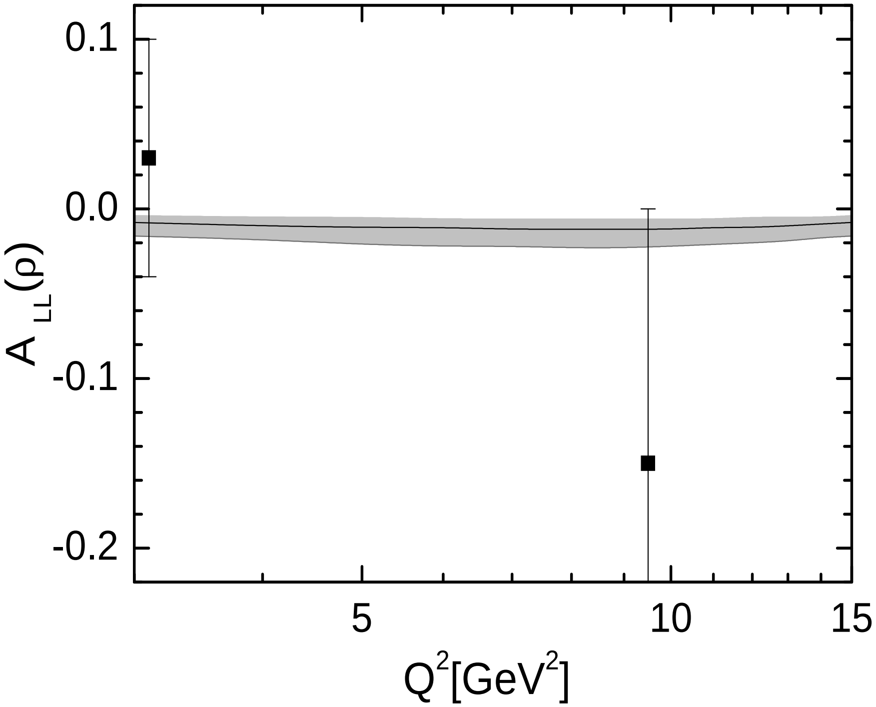
A_{LL} asymmetry – longitudinally polarized beam and target. Integration over the azimuthal angle

– The leading term in A_{LL} is an interference between the H^g and the $\widetilde{H}^g$ terms.

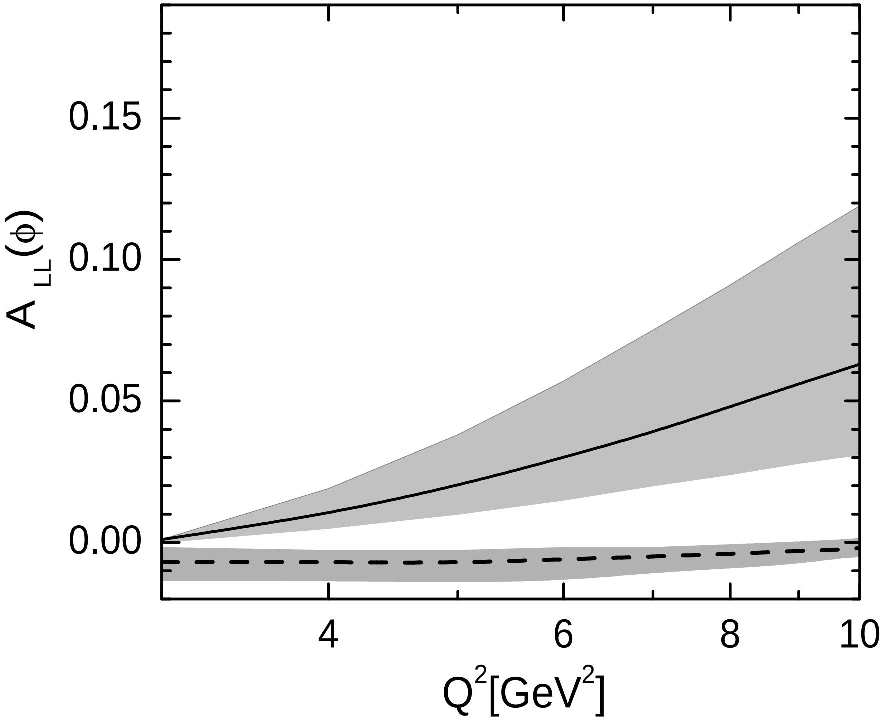
$$A_{LL}[ep \to epV] = 2\sqrt{1-\varepsilon^2}\,\frac{\mathrm{Re}\left[\mathcal{M}^{H}_{++,++}\,\mathcal{M}^{\widetilde{H}*}_{++,++}\right]}{\varepsilon|\mathcal{M}^{H}_{0+,0+}|^2 + |\mathcal{M}^{H}_{++,++}|^2}\,. \tag{11}$$

The ratio is of order $\langle k_\perp^2\rangle/Q^2$ $\langle\widetilde{H}^g\rangle/\langle H^g\rangle$ and small values for A_{LL} are to be expected –$\langle\widetilde{H}^g\rangle/\langle H^g\rangle$ is small at small x.

- $A_{LL} = 0$ if the $\widetilde{H}^g$ terms are neglected.
- At SMC energies $W = 15$GeV A_{LL}- small
- At COMPASS energies $W = 5$GeV A_{LL} – not small.
  The major contribution comes from the region $0.1 \lesssim \overline{x} \lesssim 0.2$ where $\Delta g/g$ is not small.



The A_{LL} asymmetry for ρ electroproduction versus Q^2 at $W = 15$ GeV, $t \simeq 0$ and $y \simeq 0.6$. Data taken from SMC



A_{LL} for ϕ production at $W = 5$ GeV (solid line) and $W = 10$ GeV (dashed line); $y \simeq 0.6$. The shaded bands reflect the uncertainties in our predictions due to the error in the polarized gluon distribution

Conclusion

- Modified PA which consider - transverse degrees of freedom and Sudakov suppressions in the subprocess give reasonable description of cross section and spin observables for light VM production in GPD approach.
- Different slopes in LL and TT amplitudes was proposed. Further theoretical study of t -dependencies of amplitudes are needed .
- Experimental efforts to reduce errors in SDME are important.
  Important problem -study of t dependence of SDME -different slopes of amplitudes.
  If slopes are different problem can appear in existent experimental analyses of SDME.
- Experiments: COMPASS , HERMES .