Probing transversity GPD's in photo and electroproduction of two vector mesons

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Based on work in collaboration with

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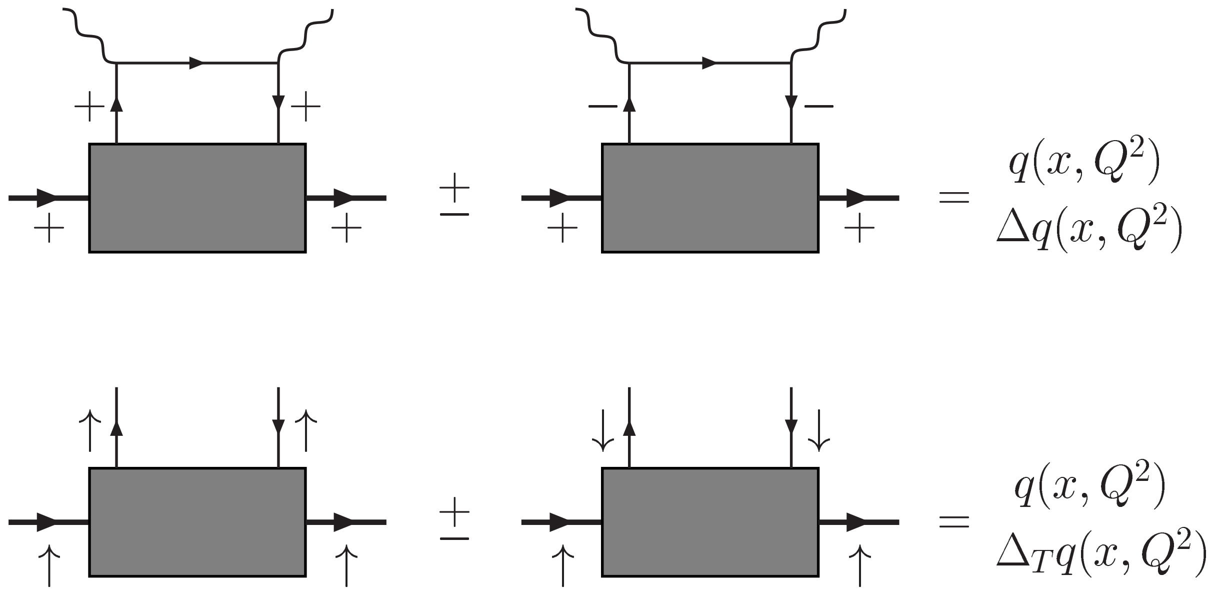
Motivation

- LONGITUDINAL spin versus TRANSVERSE spin:

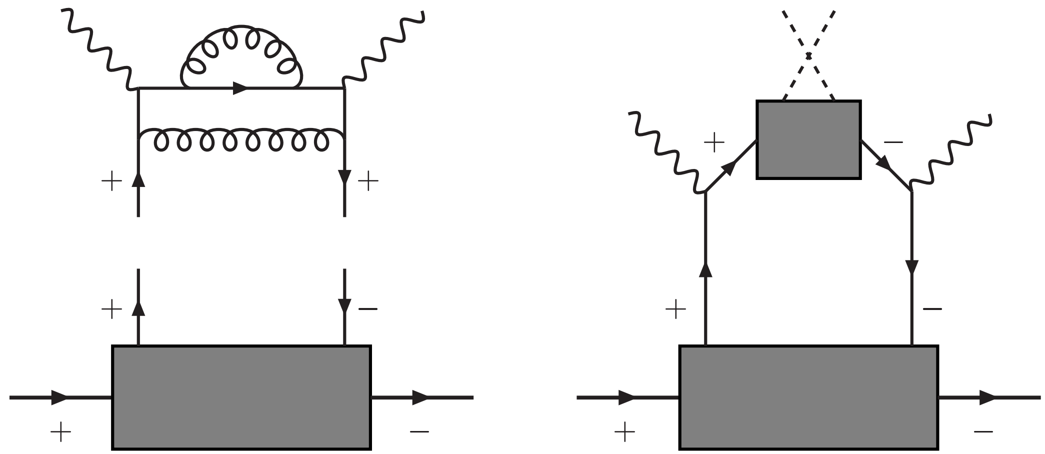


- both are equally important: $\Delta q = g_1$ and $\Delta_T q = h_1$ are $\neq 0$ at twist=2 level

J. P. Ralston and D. E. Soper, Nucl. Phys. B **152** (1979) 109

X. Artru and M. Mekhfi, Z. Phys. C **45** (1990) 669

- transversity is CHIRAL ODD



(a) DIS

(b) Semi-inclusive

$\longrightarrow$ it decouples from DIS

$\longrightarrow$ it can be accessed in semi-inclusive or in Drell-Yan

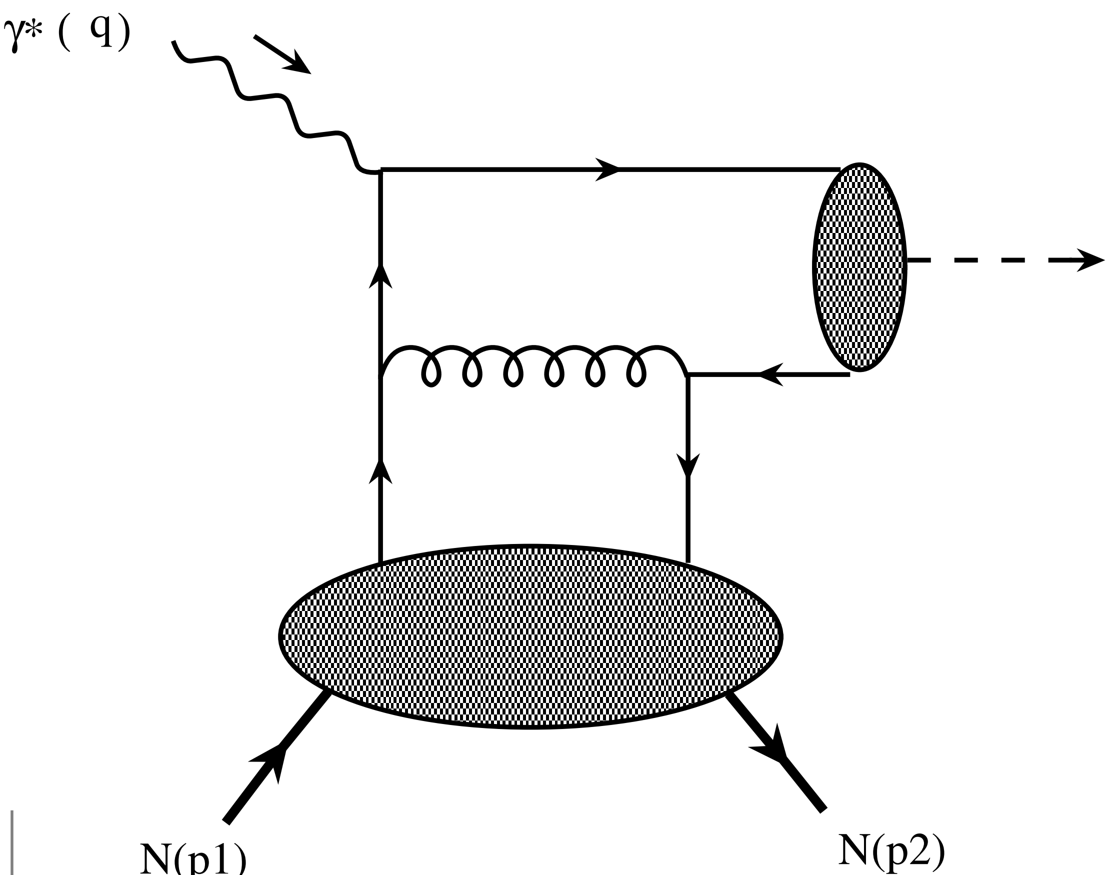
but HARD to measure (appears in pairs)

Transversity GPD

transversity GPD $\equiv$ NON-FORWARD generalization of h_1

- transversity GPD decouples from diffractive meson prod.

J. C. Collins and M. Diehl, Phys. Rev. D **61** (2000) 114015



ρ_T $\quad \langle 0|\bar{q}\sigma^{\alpha\,\beta} q|\rho_T\rangle$

($\sigma^{\alpha\,\beta} = i/2[\gamma^\alpha\,,\,\gamma^\beta]$)

$$\gamma^\mu\,\sigma^{\alpha\,\beta}\gamma_\mu = 0$$

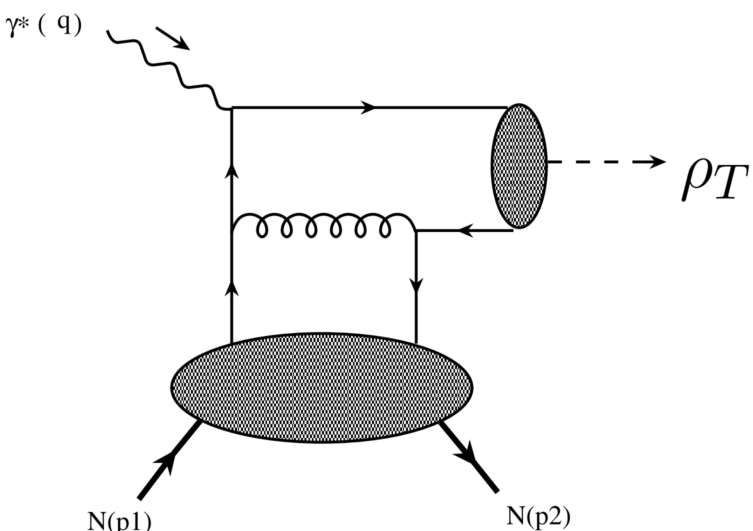
$$\langle N(p2)|\bar{q}\sigma^{\mu\,\nu} q|N(p1)\rangle$$

Our idea:

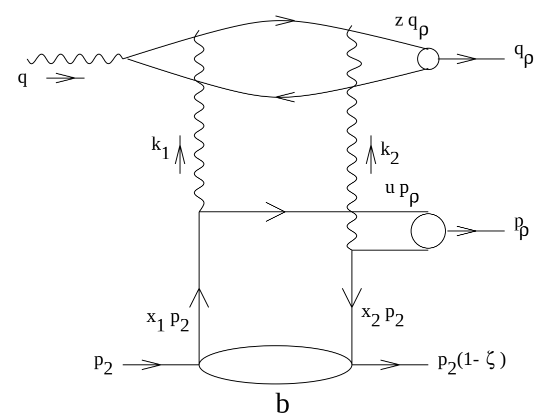
probing the transversity GPD in production of TWO mesons

D. Y. Ivanov, B. Pire, L. Sz. and O. V. Teryaev, Phys. Lett. B **550** (2002) 65

R. Enberg, B. Pire and L. Sz., Eur. Phys. J. C **47** (2006) 87



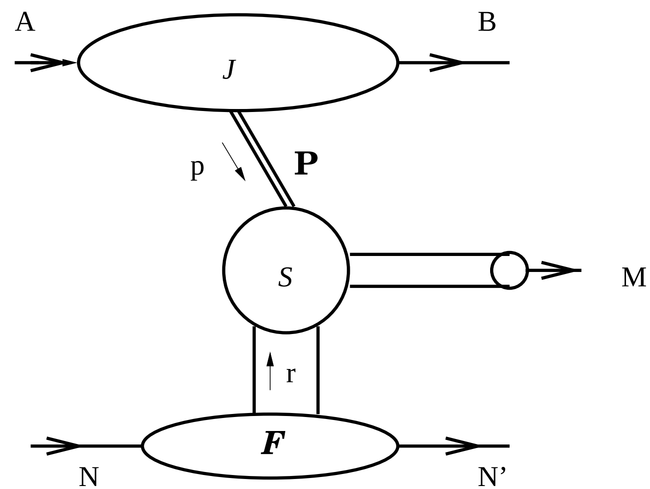
$\Longrightarrow$



$\gamma^*(q)$ $\Longrightarrow$ 2 gluons = “Pomeron”

the $\gamma^\mu\,\sigma^{\alpha\,\beta}\gamma_\mu = 0$ problem is avoided

We studied



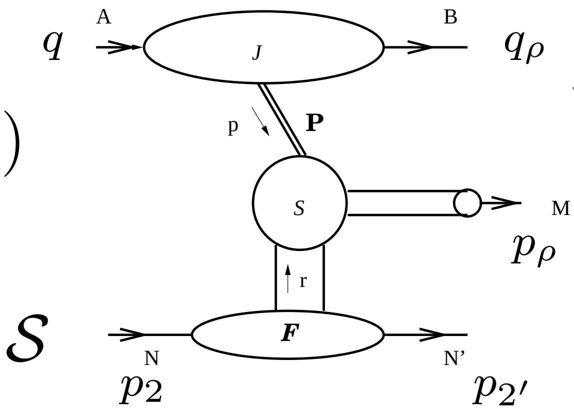
the process WITH the transversity GPD

$$\gamma^{(*)}(q)\; p(p_2) \rightarrow \rho_L^0(q_\rho)\; \rho_T^+(p_\rho)\; n(p_2')$$

and the reference process, WITHOUT the transversity GPD

$$\gamma^{(*)}(q)\; p(p_2) \rightarrow \rho_L^0(q_\rho)\; \rho_L^+(p_\rho)\; n(p_2')$$

Kinematics



Sudakov vectors: p_1 and $P = 1/2(p_2 + p_{2'})$
with $\mathcal{S} = 2p_1.P$

$\gamma^* p$-system $s = (q + p_2)^2$: $s + Q^2 = (1 + \xi)\mathcal{S}$

$$q^\mu = p_1^\mu - \frac{Q^2}{\mathcal{S}} P^\mu \qquad q_\rho^\mu = \alpha p_1^\mu + \frac{\vec{p}^{\,2}}{\alpha \mathcal{S}} P^\mu + p_T^\mu\,, \qquad p_T^2 = -\vec{p}^{\,2}$$

$$p_\rho^\mu = \bar{\alpha} p_1^\mu + \frac{\vec{p}^{\,2}}{\bar{\alpha} \mathcal{S}} P^\mu - p_T^\mu\,, \qquad \bar{\alpha} \equiv 1 - \alpha$$

$$p_2^\mu = (1+\xi) P^\mu\,, \qquad p_{2'}^\mu = (1-\xi) P^\mu$$

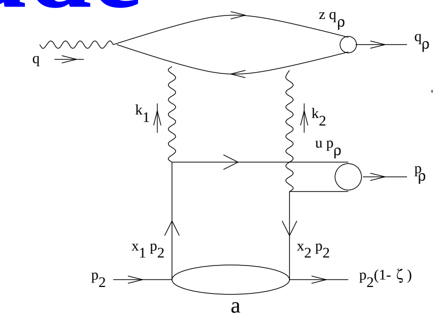
$$\xi = \frac{s_1 + Q^2}{2\mathcal{S}}, \quad s_1 = (q_\rho + p_\rho)^2 = \frac{\vec{p}^{\,2}}{\alpha \bar{\alpha}} \qquad s_2 = (p_\rho + p_{2'})^2 = \mathcal{S}\,\bar{\alpha}\,(1-\xi)$$

Rapidity gap: virtuality of "Pomeron"= the hard scale

$$\mathcal{S} \approx s \qquad s_1 = 2\mathcal{S}\,\xi\,, \quad s_1 \gg \vec{p}^{\,2} \qquad s_2 \to \frac{\vec{p}^{\,2}}{2\xi}\,(1-\xi)$$

$$\alpha \to 1\,, \qquad \bar{\alpha} s_1 \to \vec{p}^{\,2}\,, \qquad \xi \sim 1$$

The scattering amplitude



- the QCD factorization method

$$\mathcal{M} \sim \sum_{q=u,d} \int_0^1 dz \int_0^1 du \int_{-1}^1 dx\, T_H^q(x,u,z)\, H^q(x,\xi,0)\phi_{\rho^+}(u)\phi_{\rho^0}(z)$$

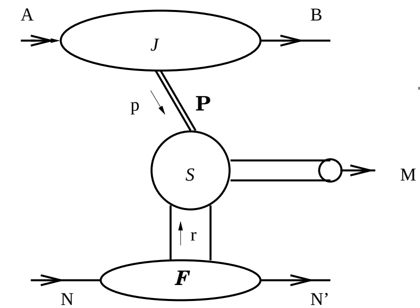
- $\phi_{\rho^+}(u)$ and $\phi_{\rho^0}(z)$: the (non-perturbative) meson DAs

- $H^q(x,\xi,0)$: the (non-perturbative) GPDs of the target

- $T_H^q(x,u,z)$: the hard (perturbative) part

  the hard scale: “Pomeron” virtuality $p^2 = p_T^2 = -\vec{p}^{\,2}$

Meson DAs



- longitudinal $\rho_L^0(q_\rho)$ or $\rho_L^+(p_\rho)$

$$\langle 0|\bar{q}(-x)\gamma^\mu q(x)|\rho_L^0(q_\rho)\rangle = q_\rho^\mu f_\rho^0 \int_0^1 du\; e^{i(1-2u)(q_\rho x)}\phi_{||}(u)$$

$$\phi_{||}(u) = 6u\bar{u} \qquad f_{\rho_L^0} = 216 \pm 5\,MeV$$

$$f_{\rho_L^+} = 198 \pm 7\,MeV$$

- transverse $\rho_T^0(p_\rho)$

$$\langle \rho_T(p_\rho, T) \mid \bar{q}(x)\sigma^{\mu\nu}q(-x) \mid 0\rangle$$

$$= i f_\rho^T \left(p_\rho^\mu \epsilon_T^{*\nu} - p_\rho^\nu \epsilon_T^{*\mu}\right) \int_0^1 du e^{-i(2u-1)(p_\rho x)}\; \phi_\perp(u)$$

$$\phi_\perp(u) = 6u\bar{u} \qquad f_{\rho_T^+} = 160 \pm 10\,MeV$$

Transversity GPDs

$$\int \frac{dz^-}{4\pi} e^{ixP^+z^-} \langle N(p_{2'},n)|\bar{q}(-\tfrac{z}{2})\, i\sigma^{+\,i}\, q(\tfrac{z}{2})|N(p_2,n)\rangle$$

$$= \frac{1}{2P^+}\bar{u}(p_{2'},n) i\sigma^{+\,i} u(p_2,n) H_T^q(x,\xi,t) + \ldots$$

M. Diehl, Eur. Phys. J. C **19** (2001) 485

$\Longrightarrow$ need a model for non-pert. $H_T^q(x,\xi,t)$, see later

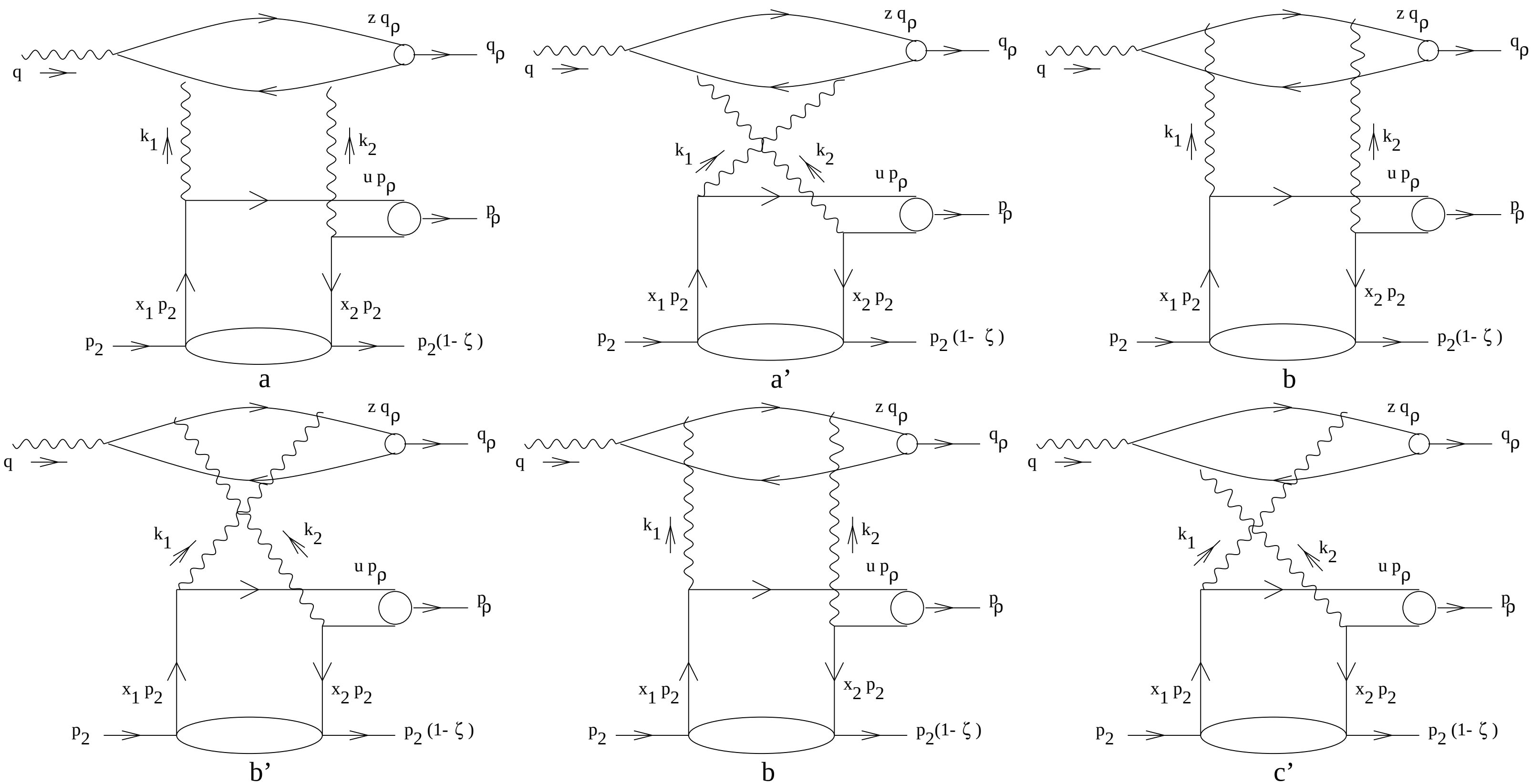
Remark:
for "the reference process” with $\rho_L^+ \Longrightarrow$ “a usual” non-pol. GPD

$$\int \frac{dz^-}{4\pi} e^{ixP^+z^-} \langle N(p_{2'},n)|\bar{q}(-\tfrac{z}{2})\, \gamma^+\, q(\tfrac{z}{2})|N(p_2,n)\rangle$$

$$= \frac{1}{2P^+}\bar{u}(p',\lambda')\gamma^+ u(p,\lambda) H^q(x,\xi,t) + \ldots$$

$\Longrightarrow$ need a model for non-pert. $H^q(x,\xi,t)$ ...

- the hard part $T_H^q(x_1, u, z)$



it involves the impact factors $J^{\gamma^{(*)}_{L/T} \to \rho^0_L}(u\vec{p}, \bar{u}\vec{p})$

$$J^{\gamma_L^{(*)}\to\rho_L^0}(\vec{k}_1,\vec{k}_2) = -f_\rho \frac{e\alpha_s 2\pi Q}{N_c\sqrt{2}} \int_0^1 dz\ z\bar{z}\phi_{||}(z) P(\vec{k}_1,\vec{k}_2)$$

$$P(\vec{k}_1,\vec{k}_2=\vec{p}-\vec{k}_1) = \frac{1}{z^2\vec{p}^{\,2}+m_q^2+Q^2 z\bar{z}} + \frac{1}{\bar{z}^2\vec{p}^{\,2}+m_q^2+Q^2 z\bar{z}} - \frac{1}{(\vec{k}_1-z\vec{p})^2+m_q^2+Q^2 z\bar{z}} - \frac{1}{(\vec{k}_1-\bar{z}\vec{p})^2+m_q^2+Q^2 z\bar{z}}$$

$$J^{\gamma_T^{(*)}\to\rho_L^0}(\vec{k}_1,\vec{k}_2=\vec{p}-\vec{k}_1) = -\frac{e\,\alpha_s\,\pi\,f_\rho^0}{\sqrt{2}\,N} \int_0^1 dz\,(2z-1)\,\phi_{||}(z)\,\left(\vec{\varepsilon}\vec{Q}_P\right)$$

$$\vec{Q}_P(\vec{k}_1,\vec{k}_2=\vec{p}-\vec{k}_1) = \frac{z\,\vec{p}}{z^2\,\vec{p}^2+Q^2\,z\,\bar{z}+m_q^2} - \frac{\bar{z}\,\vec{p}}{\bar{z}^2\,\vec{p}^2+Q^2\,z\,\bar{z}+m_q^2} + \frac{\vec{k}_1-z\,\vec{p}}{(\vec{k}_1-z\,\vec{p})^2+Q^2\,z\,\bar{z}+m_q^2} - \frac{\vec{k}_1-\bar{z}\,\vec{p}}{(\vec{k}_1-\bar{z}\,\vec{p})^2+Q^2\,z\,\bar{z}+m_q^2}$$

Important: $J^{\gamma_{L/T}^{(*)}\to\rho_L^0}(\vec{k}_1,\vec{k}_2)\to 0$ when $\vec{k}_i\to 0$

the gauge invariance

Results for the scattering amplitudes:

- for "the reference process”

$\gamma^{(*)}(q)\, p(p_2) \to \rho^0_L(q_\rho)\, \rho^+_L(p_\rho)\, n(p_2')$ with non-polar. GPD

$$\mathcal{M}^{\gamma^{(*)}_{L/T}\, p \to \rho^0_L\, \rho^+_L\, n} =$$

$$i16\pi^2 s\alpha_s f^+_\rho \xi \sqrt{\frac{1-\xi}{1+\xi}} \frac{C_F}{N\,(\vec{p}^{\,2})^2} \int\limits_0^1 \frac{du\, \phi_\parallel(u)}{u^2\bar{u}^2} J^{\gamma^{(*)}_{L/T} \to \rho^0_L}(u\vec{p}, \bar{u}\vec{p})$$

$$\left[H^u(\xi(2u-1),\xi,0) - H^d(\xi(2u-1),\xi,0)\right]$$

for $\gamma^{(*)}(q)\, p(p_2) \to \rho^0_L(q_\rho)\, \rho^+_T(p_\rho)\, n(p_2')$ with the transversity GPD

$$\mathcal{M}^{\gamma^{(*)}_{L/T}\, p \to \rho^0_L\, \rho^+_T\, n} =$$

$$-\,\sin\theta\; 16\pi^2 s\alpha_s f^T_\rho \xi \sqrt{\frac{1-\xi}{1+\xi}} \frac{C_F}{N\,(\vec{p}^{\,2})^2} \int\limits_0^1 \frac{du\, \phi_\perp(u)}{u^2\bar{u}^2} J^{\gamma^{(*)}_{L/T} \to \rho^0_L}(u\vec{p}, \bar{u}\vec{p})$$

$$\left[H^u_T(\xi(2u-1),\xi,0) - H^d_T(\xi(2u-1),\xi,0)\right]$$

Remark: only ERBL region ($-\xi < \xi(2u-1) < \xi$) contributes

Modeling non-polarized GPD

- based on the double distribution

A. V. Radyushkin, Phys. Rev. D **59** (1999) 014030

$$H(x,\xi,t) =$$

$$\frac{\theta(\xi+x)}{1+\xi}\int_0^{\min\left[\frac{\xi+x}{2\xi},\frac{1-x}{1-\xi}\right]} dy\, F^q\left(\frac{\xi+x-2\xi y}{1+\xi}, y, t\right)$$

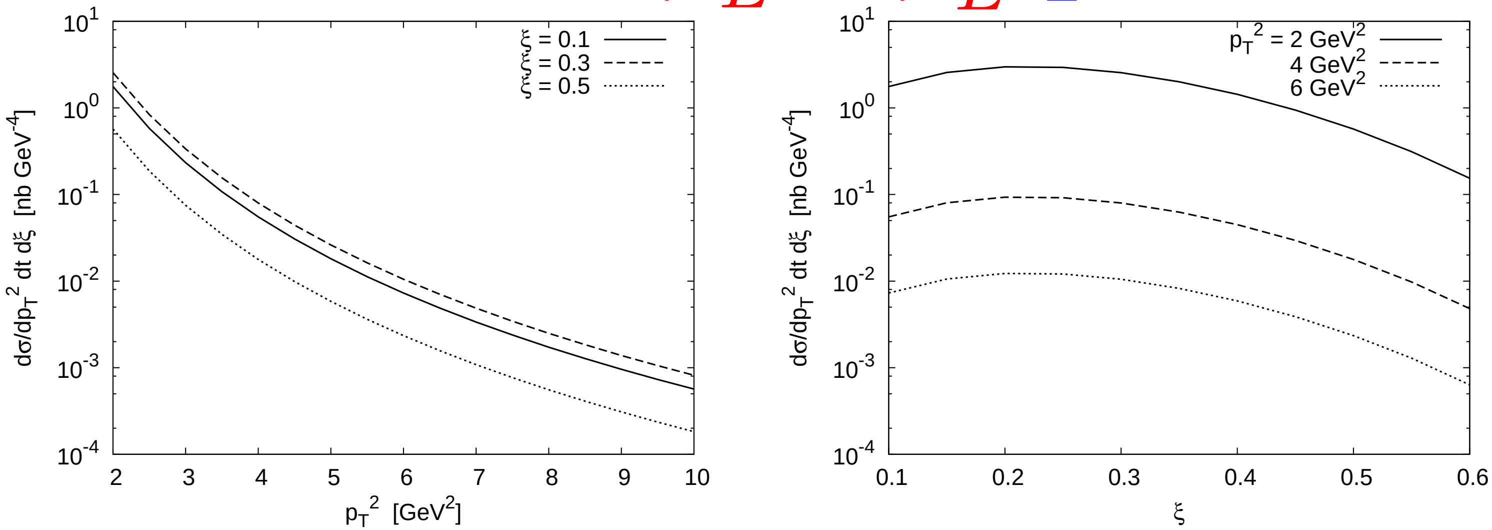
$$-\frac{\theta(\xi-x)}{1+\xi}\int_0^{\min\left[\frac{\xi-x}{2\xi},\frac{1+x}{1-\xi}\right]} dy\, F^q\left(\frac{\xi-x-2\xi y}{1+\xi}, y, t\right)$$

and a factorized ansatz for the dd

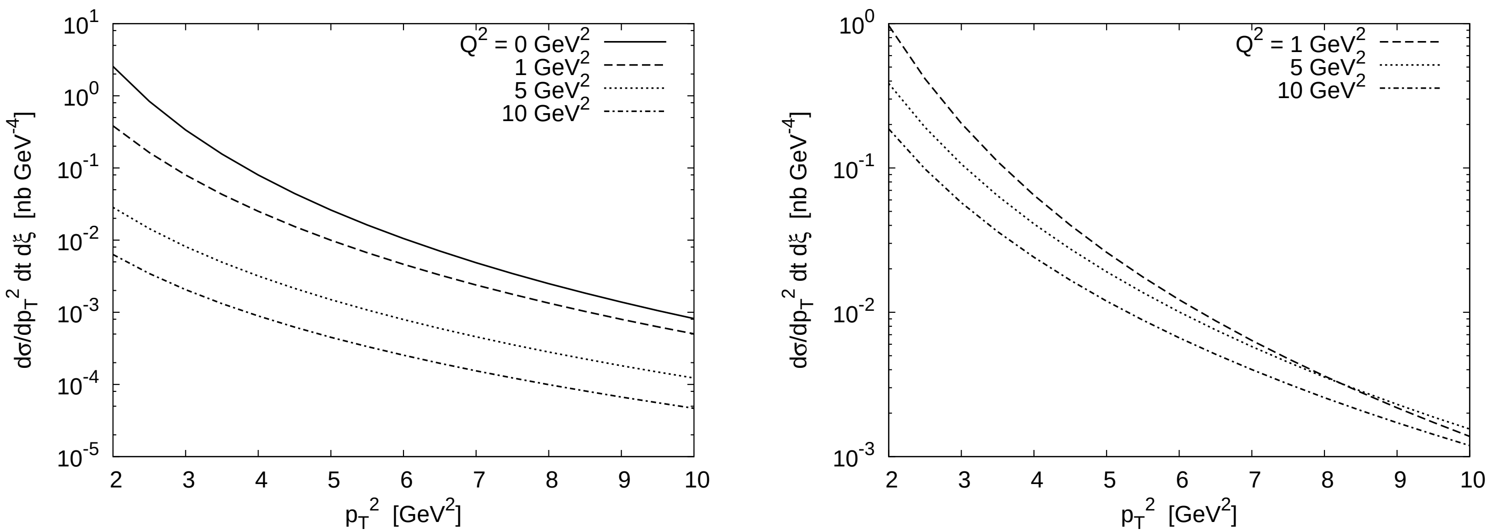
$$F^q(X,Y,t) = \frac{F_1^q(t)}{F_1^q(0)} q(X) 6 \frac{Y(1-X-Y)}{(1-X)^3}$$

$F_1^q(t)$ - e-m. form factor of the nucleon but $t = t_{min}$

Results for the $\rho_L^0 + \rho_L^+$ production



The photoproduction



The cross-s. for γ_T^* and γ_L^*

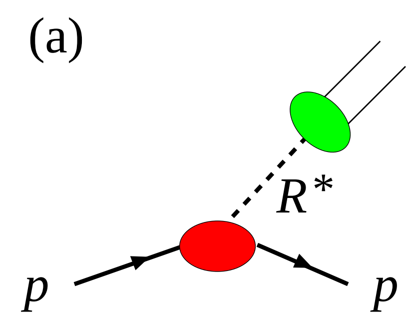
for $\xi = 0.3$, $Q^2 = 0,\ 1,\ 5,\ 10$ GeV^2

Modeling the transversity GPD: 2 models

- Non-forward generalization of the meson pole model for the forward h_1

L. P. Gamberg and G. R. Goldstein, Phys. Rev. Lett. **87** (2001) 242001

$$\mathcal{L}_{\mathcal{ANN}} = \frac{g_{A\,NN}}{2M} \bar{N} \sigma_{\mu\nu} \gamma_5 \partial^\nu A^\mu N$$



$R^* \to A = b_1(1235)$ axial meson 1^{+-}

the DA of A

$$\langle 0 | \bar{q}(-z) \sigma^{\alpha\beta} \gamma_5 \frac{\lambda^a}{2} q(z) | A(k,\lambda) \rangle =$$

$$i\, f_A^{a\,T} \left[\epsilon^\alpha(\lambda) k^\beta - \epsilon^\beta(\lambda) k^\alpha \right] \int_0^1 du\, e^{i(1-2u)k\cdot z}\, \phi_\perp^A(u)$$

the transversity GPD: $H_T^v(x,\xi,t) = \frac{g_{b_1 NN} f_{b_1}^T \langle k_\perp^2 \rangle}{2\sqrt{2} M_N\, m_{b_1}^2} \frac{\phi_\perp^{b_1}\left(\frac{x+\xi}{2\xi}\right)}{2\xi}$

$$\phi_\perp^{b_1}(u) = 6u\bar{u}$$

Remarks:

- the isospin symmetry implies

$$\langle n|\bar{d}Ou|p\rangle = \langle p|\bar{u}Ou|p\rangle - \langle p|\bar{d}Od|p\rangle$$

from which: $H_T^v = H_T^u - H_T^d$

- $\langle k_\perp^2\rangle = (0.58 \div 1.0)$GeV^2

- Parameters:

$$f_{b_1}^T = \frac{\sqrt{2}}{m_{b_1}} f_{a_1}\ , \qquad f_{a_1} = (0.19 \pm 0.03)\text{GeV}^2$$

$$g_{b_1 NN} = \frac{5}{3\sqrt{2}} g_{a_1 NN}\ , \qquad g_{a_1 NN} = 7.49 \pm 1.0$$

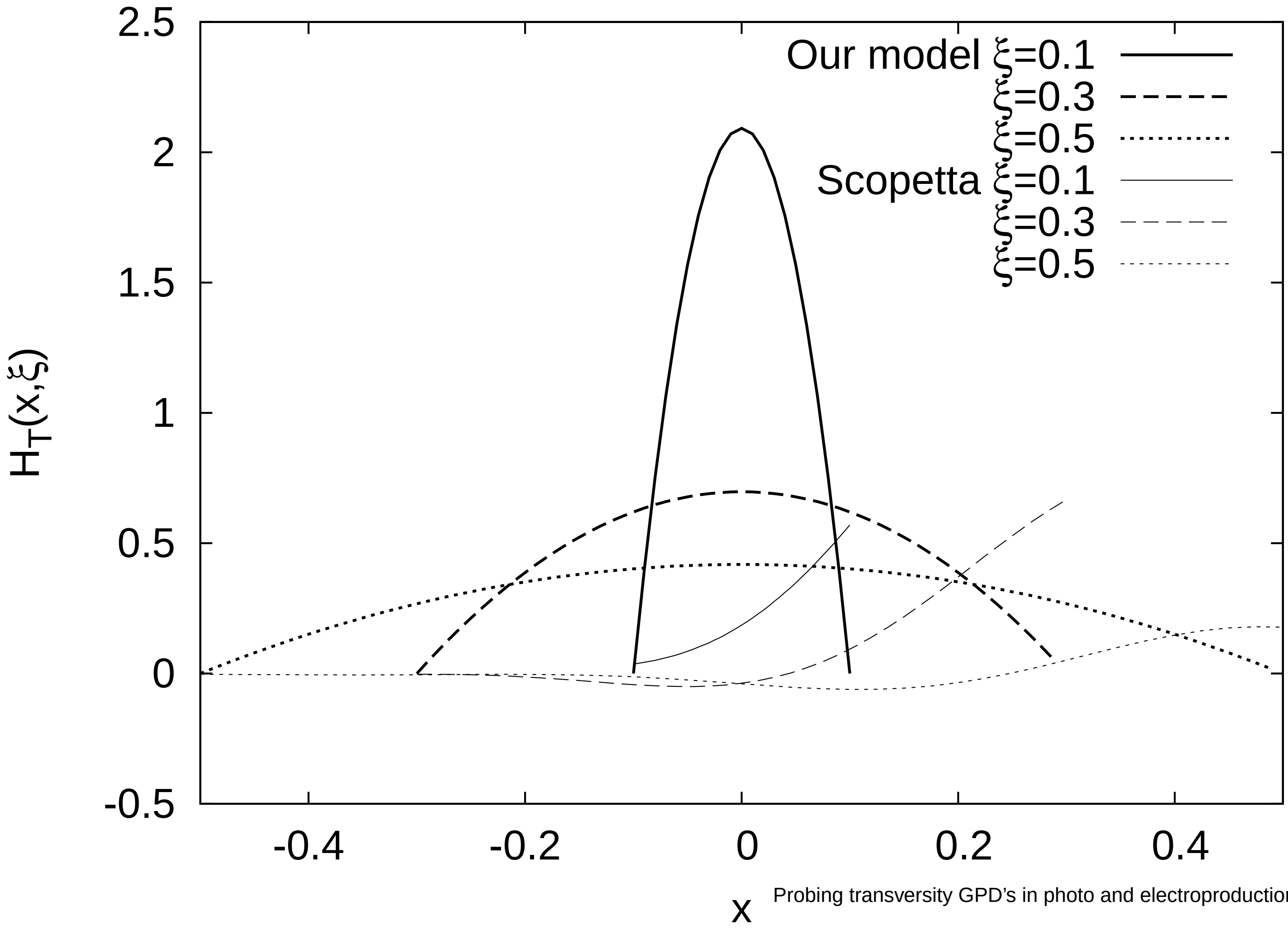
- the scattering amplitude

$$\mathcal{M}^{\gamma\, p \to \rho_L^0\, \rho_T^+\, n}\,|_{Q^2=0} = \sin\theta\, \frac{216\,\pi^3\, s\,\alpha_s^2\, e\, C_F}{N_c^2}\, \frac{g_{b_1 NN} f_\rho^T f_\rho^0 f_{b_1}^T \langle k_\perp^2\rangle}{M_p m_{b_1}^2} \sqrt{\frac{1-\xi}{1+\xi}}\, \frac{1}{|\vec{p}|^5}$$

- 2nd model: the bag model

S. Scopetta, Phys. Rev. D **72** (2005) 117502

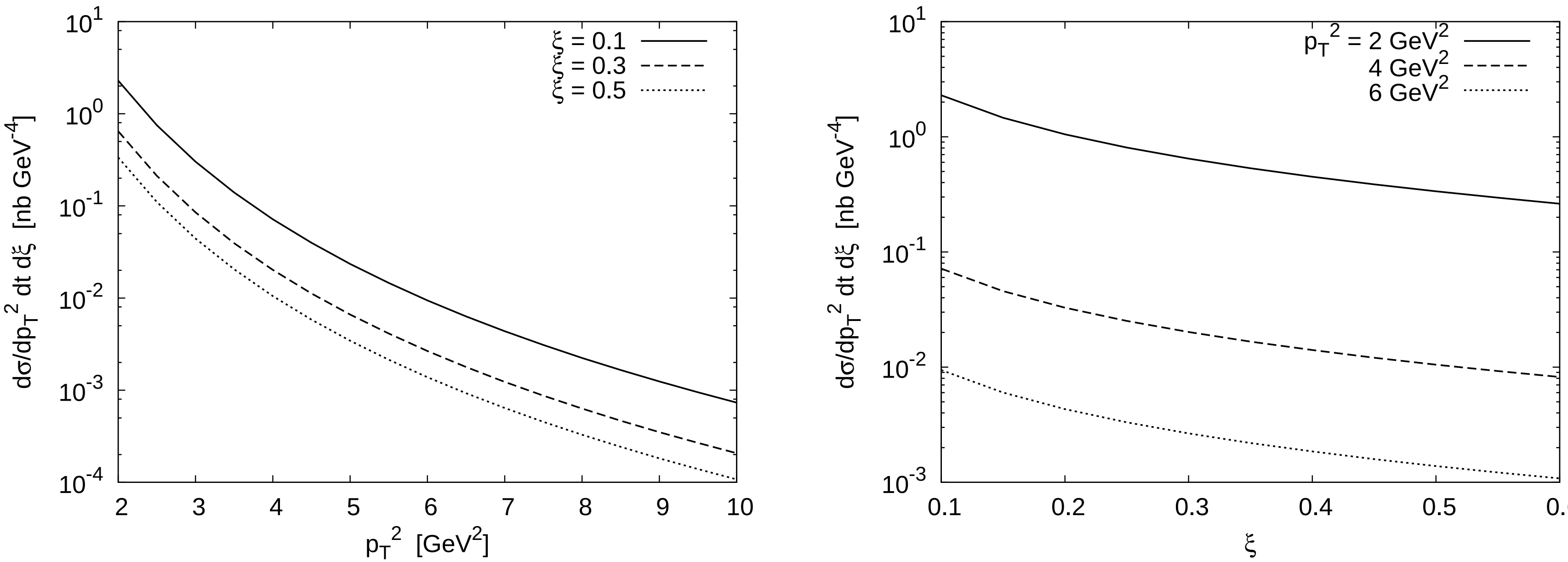
The comparison of two (very different) models



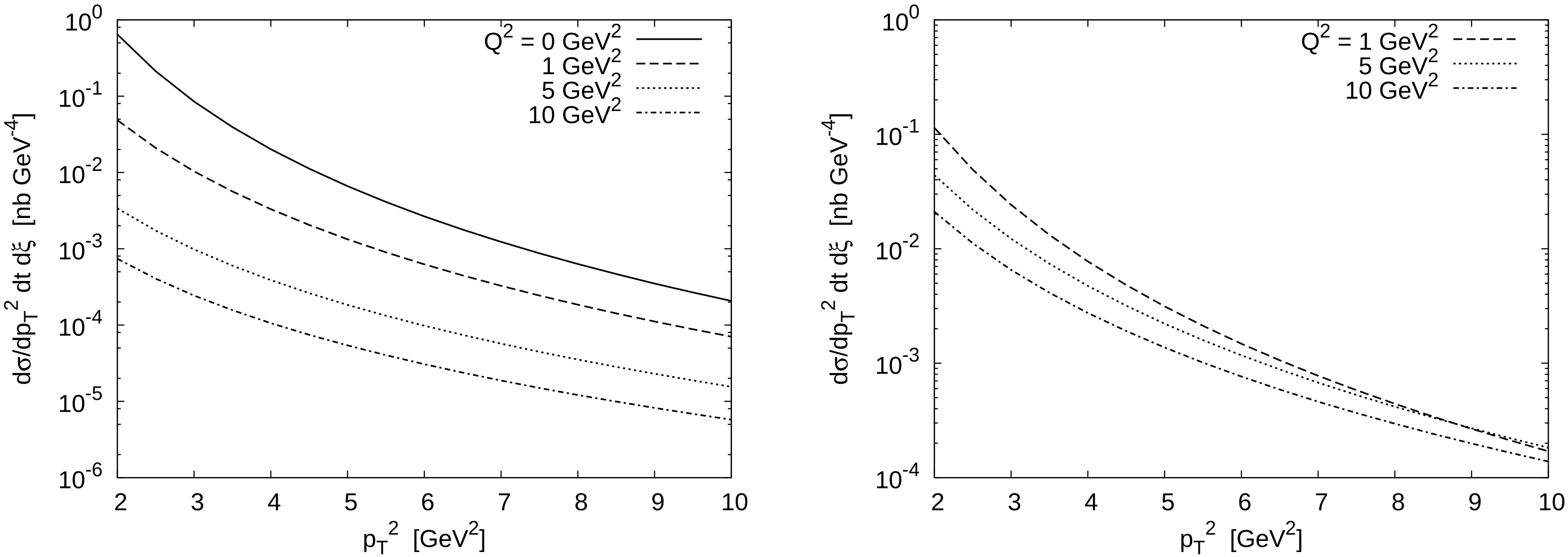
The cross-section with transverse GPDs

- our model:

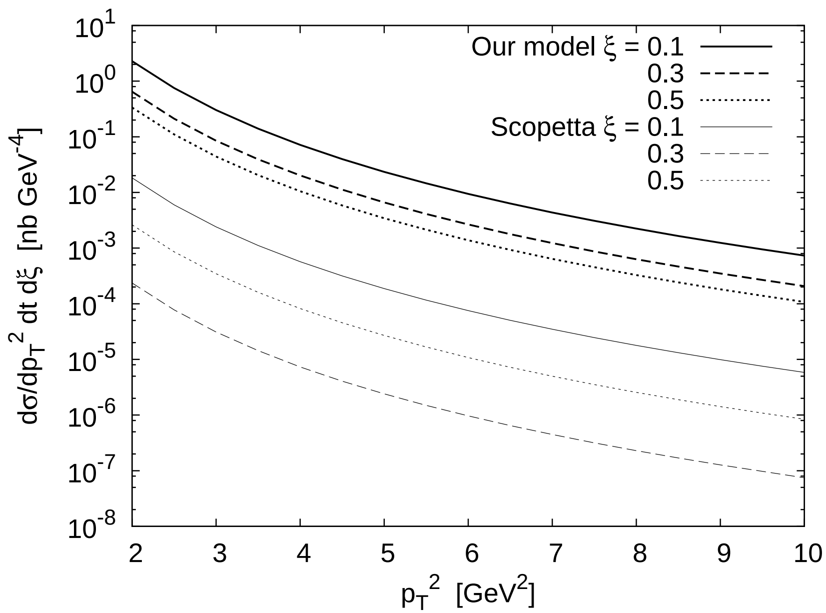
$$\frac{d\sigma}{dp_T^2\,dt\,d\xi} = \frac{729\,\pi^4\,\alpha_s^4\,\alpha_{em}\,C_F^2}{N_c^4}\,\frac{\left[g_{b_1NN}f_\rho^T f_\rho^0 f_{b_1}^T\langle k_\perp^2\rangle\right]^2}{M_p^2 m_{b_1}^4}\,\frac{\sin^2\theta}{\xi(1+\xi)|\vec{p}|^{10}}$$



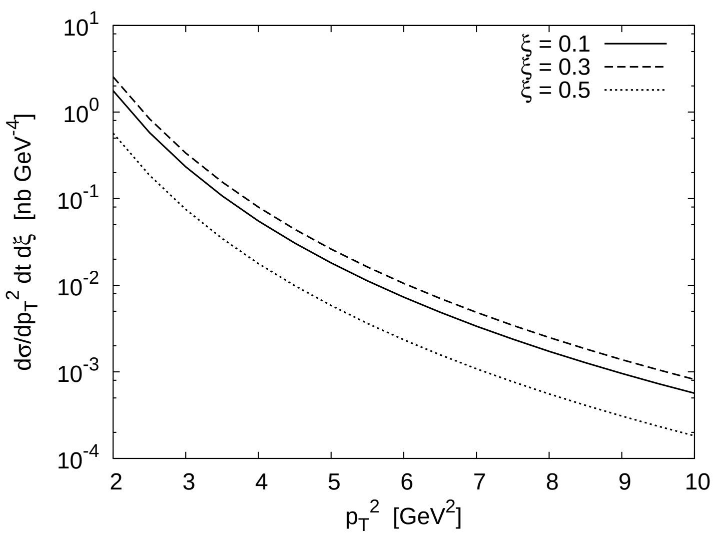
The photoproduction of ρ_L^0 and ρ_T^+

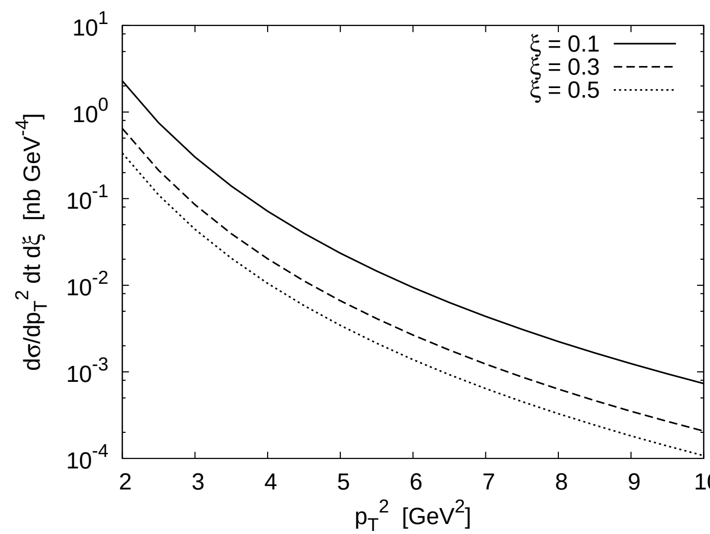


The electroproduction from γ_T^* and γ_L^*



The comparison of cross-sec. from 2 models





The comparison of photoprod. cross-s. for $\rho_L^0\,\rho_L^+$ and $\rho_L^0\,\rho_T^+$

Conclusions

• we proposed a family of processes which probe the transversity GPDs

• using two, very different models of the transversity GPDs we estimated the cross section for $\gamma^{(*)}\,p \to \rho^0_L\,\rho^+_T\,n$

• for a comparison we calculated the cross section for "the reference process" $\gamma^{(*)}\,p \to \rho^0_L\,\rho^+_L\,n$

$\Longrightarrow$ the magnitudes of both cross-s. are similar

$\Longrightarrow$ if one could see $\rho^0_L\,\rho^+_L$ one should also see $\rho^0_L\,\rho^+_T$ with the transversity GPD

COMPASS ????

$\Longrightarrow$ Prospects: extension to lower energies as at JLab
$\Longrightarrow$ the favoured (experimentally) process

$$\gamma^{(*)}\,p \to \pi^+\,\rho^0_T\,p'$$

the quark exchanges contribute, work in progress

Post scriptum

- if in our process $\gamma^{(*)}\, p \to \pi^+\, \rho_T^0\, p'$ the meson ρ_T^0 is replaced by a REAL photon, i.e. $\gamma^{(*)}\, p \to \pi^+\, \gamma(p_\gamma)\, p'$

$\Longrightarrow$ access to the transversity GPDs

AND to the magnetic susceptibility of QCD vacuum

V. M. Braun, S. Gottwald, D. Y. Ivanov, A. Schafer and L. Sz., Phys. Rev. Lett. **89** (2002)
P. Ball, V. M. Braun and N. Kivel, Nucl. Phys. B **649** (2003) 263

$$\langle 0|\bar{q}(0)\sigma^{\alpha\beta}\, q(x)|\gamma^{(\lambda)}(p)\rangle =$$
$$= i e_q\, \chi\, \langle \bar{q} q\rangle \left(\epsilon_\alpha^{(\lambda)} p_\beta - \epsilon_\beta^{(\lambda)} p_\alpha\right) \int_0^1 du\, \exp^{-iu(px)}\, \phi_\gamma(u,\mu)$$

$\phi_\gamma(u,\mu) \to \phi_\gamma^{as}(u,\mu) = 6u(1-u)$ for $\mu \geq 1$ GeV

$\chi\, \langle \bar{q} q\rangle \approx 40 - 70$MeV at $\mu = 1$ GeV