Study of exclusive processes within GPD approach.

S.V. Goloskokov

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

Dubna 141980, Moscow region, Russia

- Introduction : Generalized Parton Distributions (GPDs).
- Model for GPDs. Exclusive meson leptoproduction- GPD model.
- Vector meson production -analyses of GPDs H effects from cross section .
- Vector meson production with polarized beams. A_{UT} asymmetries- GPDs E effects.
- Possibility to study exclusive meson production at NICA .
- Light vector meson production- effects of GPDs H, $\tilde{H}$, E.
- J/Ψ production. Gluon GPDs.
- Exclusine Drell-Yan with double GPDs contribution. First estimations .

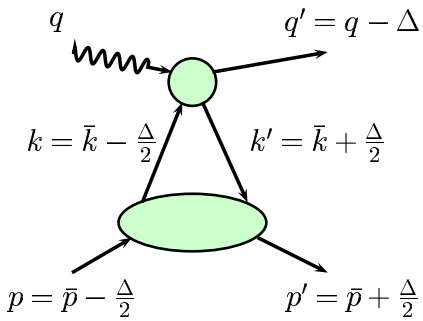
XXIVth International Baldin Seminar on High Energy Physics Problems "Relativistic Nuclear Physics and Quantum Chromodynamics"

September 17 – 22, 2018, Dubna, Russia.

Handbag factorization of Mesons production amplitude

- Large Q^2- factorization into a hard meson photoproduction off partons, and GPDs. (LL)

Radyushkin, Collins,Frankfurt Strikman



$$k = ((\overline{x} + \xi)p_+, ...)$$

$$k' = ((\overline{x} - \xi)p_+, ...)$$

$$k \neq k'; \;\; \xi \sim \frac{x_B}{2 - x_B}$$

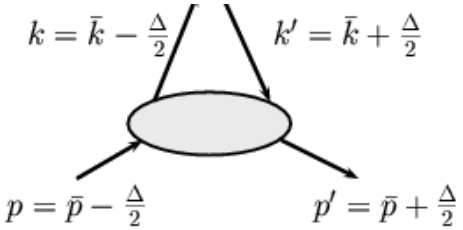
The handbag model typically is valid at the range of large $Q^2 > 3\text{GeV}^2$ and low $x_B \leq 0.1$.
$L \to L$ transition - predominant. Other amplitudes are suppressed as powers $1/Q$

GPDs in different process of meson production

- ρ, ω production (gluon&sea&valence quarks)
- J/Ψ production (gluon)
- ϕ production (gluon&strange sea)
- Pseudoscalar mesons- polarized distributions

Generalized Parton Distributions

D.Mueller, 1994; Ji, 1997; Radyushkin, 1997



$$\xi = \frac{(p-p')^+}{(p+p')^+} \sim \frac{x_b}{2}, \quad \overline{x} = \bar{k}^+/\bar{p}^+, \quad t$$

$$\langle p'\nu'|\bar{\Psi}^\alpha(0)\,\Psi^\beta(\bar{z})|p\nu\rangle \propto$$

$$\times \left\{(\gamma_-)^{\alpha\beta}\left[\frac{\bar{u}(p'\nu')\,\bar{n}\!\!\!/\,u(p\nu)}{2\bar{p}\cdot n}\,H^q(\overline{x},\xi,t) + \frac{\bar{u}(p'\nu')\,i\,\sigma^{\alpha\beta}\,n_\alpha\Delta_\beta\,u(p\nu)}{4m\,\bar{p}\cdot n}\,E^q(\overline{x},\xi,t)\right]\right.$$

$$\left. + \;(\gamma_5\,\gamma_-)^{\alpha\beta}\left[\frac{\bar{u}(p'\nu')\,\bar{n}\!\!\!/\gamma_5\,u(p\nu)}{2\bar{p}\cdot n}\,\widetilde{H}^q(\overline{x},\xi,t) + \frac{\bar{u}(p'\nu')\,n\cdot\Delta\,\gamma_5\,u(p\nu)}{4m\,\bar{p}\cdot n}\,\widetilde{E}^q(\overline{x},\xi,t)\right]\right\}.$$

$$H^q(\overline{x},0,0) = \overline{x}\,q(\overline{x}); \qquad \widetilde{H}^q(\overline{x},0,0) = \overline{x}\,\Delta q(\overline{x}) \tag{1}$$

Distributions E, $(\tilde{E})$ determine mainly proton spin-flip.

Information about GPDs and hadron structure.

⋆ GPDs – extensive information about hadron structure.

- Ordinary parton distribution connected with GPDs

$$H(x,0,0) = xg(x)$$

- Hadron Form factors –are the GPDs moment

$$\int dx H^q(x,\xi,t) = F_1^q(t); \quad \int dx E^q(x,\xi,t) = F_2^q(t); \quad F_1, F_2\text{-flavor } q \text{ components of Dirac and Pauli FF}$$

$$\int dx \tilde{H}^q(x,\xi,t) = G_A^q(t); \quad \int dx \tilde{E}^q(x,\xi,t) = G_P^q(t); \quad G_A^q, G_P^q\text{-flavor } q \text{ components of Axial and Pseudoscalar FF}$$

- Information on the parton angular momenta from Ji sum rules

$$\int x dx (H^q(x,\xi,0) + E^q(x,\xi,0)) = 2J^q$$

- GPDs H^q and E^q can be tested from VM production cross section and asymmetries.
- GPDs $\tilde{H}^q$ and $\tilde{E}^q$ can be tested from pseudoscalar mesons production & UP effects in VM.

Modelling the GPDs

The double distributions for GPDs Radyushkin '99 connect GPDs with PDFs .

$$H_i(\overline{x},\xi,t) = \int_{-1}^{1} d\beta \int_{-1+|\beta|}^{1-|\beta|} d\alpha\, \delta(\beta+\xi\,\alpha-\bar{x})\, f_i(\beta,\alpha,t)$$

simple form for the double distributions function

$$f_i(\beta,\alpha,t) = h_i(\beta,t)\,\frac{\Gamma(2n_i+2)}{2^{2n_i+1}\,\Gamma^2(n_i+1)}\,\frac{[(1-|\beta|)^2-\alpha^2]^{n_i}}{(1-|\beta|)^{2n_i+1}}\,,$$

$\star$ Gluon contribution (n=2). $h_g(\beta,0) = |\beta| g(|\beta|)$

$\star$ $h^q_{sea}(\beta,0) = q_{sea}(|\beta|)\,\mathrm{sign}(\beta)$ - sea quark contribution (n=2).

$\star$ $h^q_{val}(\beta,0) = q_{val}(|\beta|)\,\Theta(\beta)$ –valence contribution (n=1).

PDF parameters from CTEQ6 parameterization.

Regge form with $\alpha_i = \alpha_i(0) + \alpha' t$ for PDF t-dependence.

$$h(\beta,t) = N\, e^{b_0 t}\beta^{-\alpha(t)}\,(1-\beta)^n$$

⋆ Amplitudes in terms of GPDs.

The proton non-flip amplitude is expressed in terms of H GPDs

$$\mathcal{M}_{\mu'+,\mu+} \propto \int_{-1}^{1} d\overline{x}\, H^a(\overline{x},\xi,t)\, F^a_{\mu',\mu}(\overline{x},\xi).$$

The proton spin-flip amplitude is connected with E GPDs

$$\mathcal{M}_{\mu'-,\mu+} \propto \frac{\sqrt{-t}}{2m} \int_{-1}^{1} d\overline{x}\, E^a(\overline{x},\xi,t)\, F'^a_{\mu',\mu}(\overline{x},\xi).$$

The hard scattering parts F, F' are calculated performatively.
They contain as ingredient the nonperturbative meson wave function.

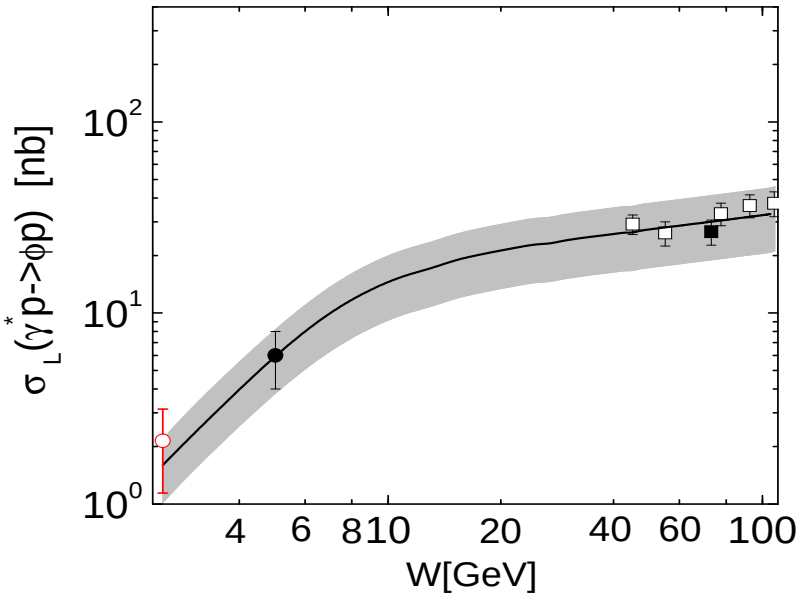
In hard scattering amplitudes F, F' we consider quark transverse momenta in quark propagators which determined by $k_\perp^2/Q^2$ corrections $\frac{1}{(x-\xi)+k_\perp^2/Q^2+i\epsilon}$
-effective consideration of the non-leading contribution.

Similar equations for $\tilde{H}$- determine in VM production Unnatural Parity amplitudes.

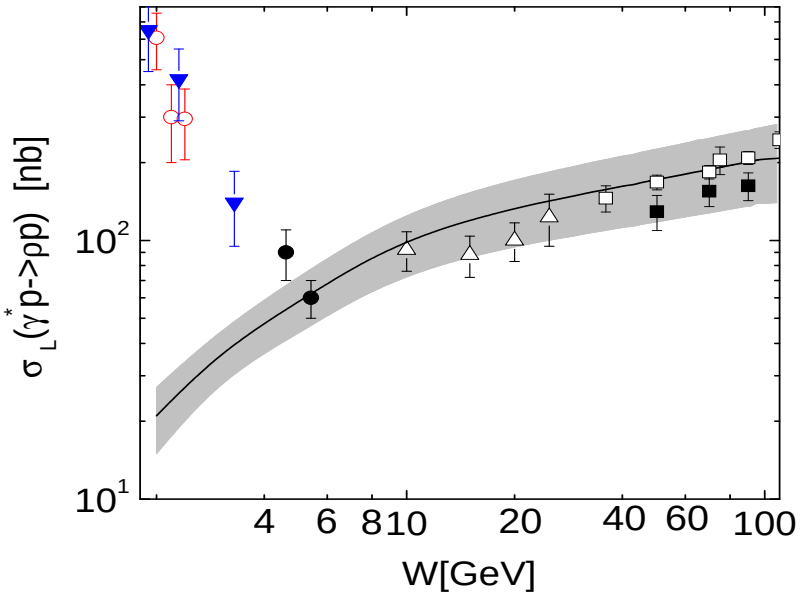
GPDs can be tested by analyses of cross sections and spin observables.

Cross section of ρ and ϕ production -test of GPDs H

SG & P.Kroll



The longitudinal cross section for ϕ at $Q^2 = 3.8\,\mathrm{GeV}^2$. Data: HERMES (solid circle), ZEUS (open square), H1 (solid square), open circle- CLAS data point



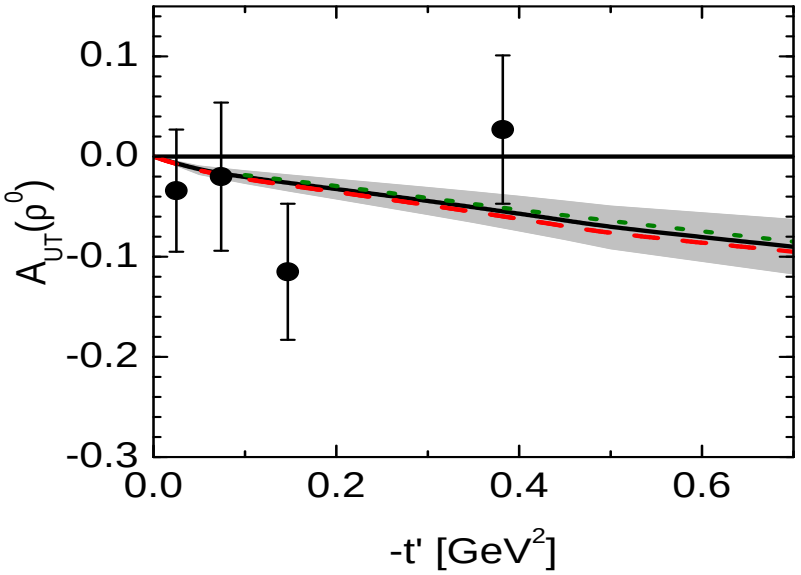
The longitudinal cross section for ρ at $Q^2 = 4.0\,\mathrm{GeV}^2$. Data: HERMES (solid circle), ZEUS (open square), H1 (solid square), E665 (open triangle), open circles- CLAS, CORNEL -solid triangle

Conclusion: Our knowledge about gluon, sea, quarks GPDs is OK. Problem appears at low $W < 5\mathrm{GeV}^2$ in all the cases when valence quark distributions are essential : ρ^0, ρ^+, ω production.- Break in DD, handbag, other effects ???

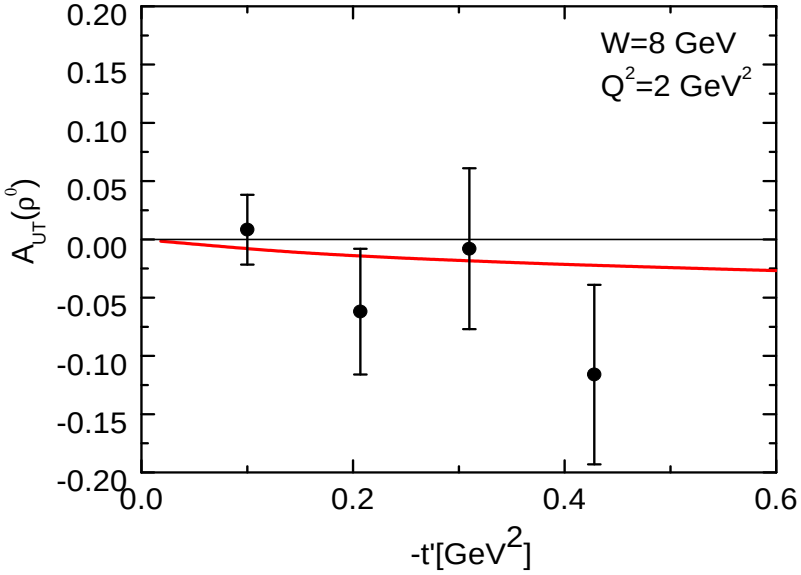
A_{UT} asymmetry for ρ production-test of GPDs E effects.

SG & P.Kroll

$$A_{UT} \propto \frac{\mathrm{Im} < E >^* < H >}{| < H > |^2}$$



Model results for HERMES energy $W = 5$GeV, $Q^2 = 3$GeV^2. HERMES data are shown.



Model results for COMPASS energy $W = 8$GeV. COMPASS data are shown.

Effects of $\tilde{H}$ in σ_U & A_{LL} asymmetry -ρ production.

$\tilde{H}$ determines unnatural parity amplitudes and cross section

$$\sigma_U \propto |\mathcal{M}^{\tilde{H}}|^2$$

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

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

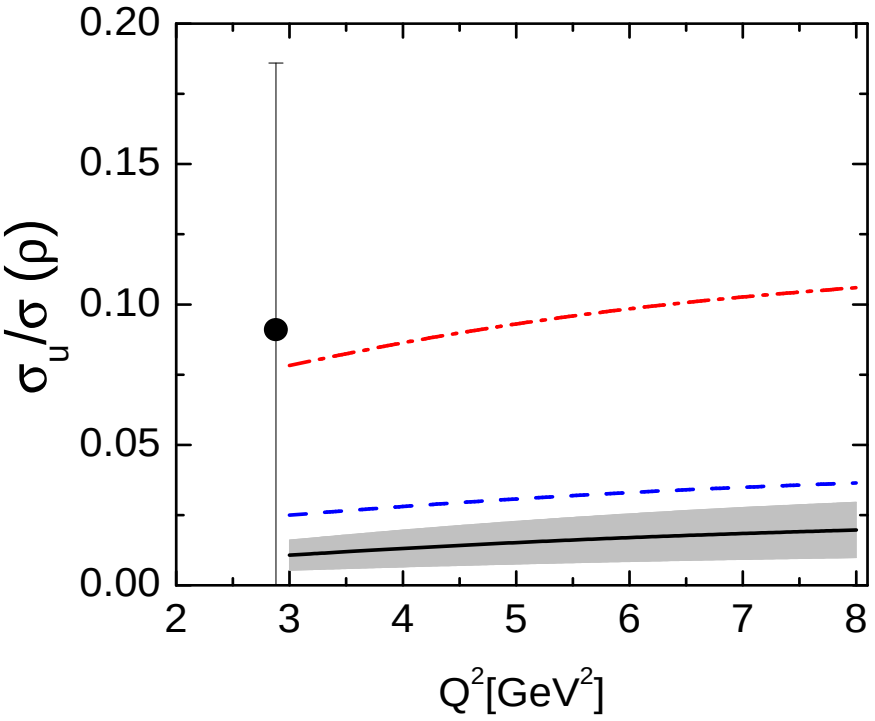
The dominant contribution comes from quark polarized distributions

A_{LL} asymmetry is of order $\langle\widetilde{H}^q\rangle/\langle H^q\rangle$.

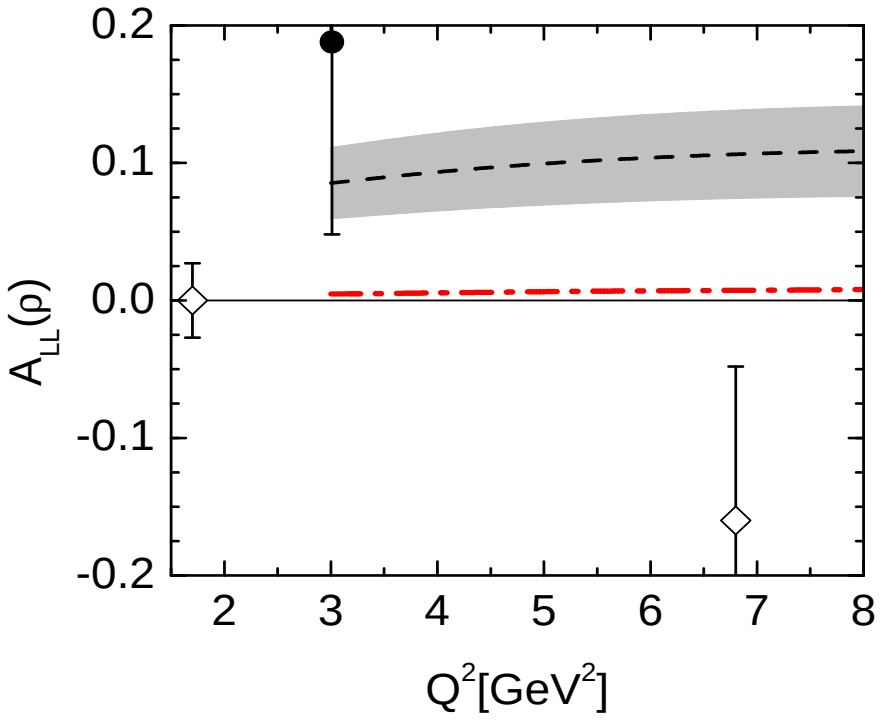
With the help Δu and Δd PDFs we construct GPDs $\widetilde{H}$ using double distribution.

A_{LL} asymmetry can be measured with longitudinally polarized beam and target.

SG & P.Kroll



The ratio of σ_U and σ for ρ production versus Q^2 at $W = 5$ GeV. Data taken from HERMES . Larger result is expected for this ratio for ω cross section ratio.



The A_{LL} asymmetry for ρ production at $W = 5$ GeV dashed and $W = 10$ GeV (dash-dotted) line. Data are taken from COMPASS and HERMES

$M_{0\pm,++}$ – twist-3 amplitudes.

$M_{0\pm,++}$ -is determined by twist 3 contribution .

Transversity GPDs $(H_T, E_T, ...)$ contribute

$$\mathcal{M}^{twist-3}_{0-,\mu+} \propto \int_{-1}^{1} d\overline{x} \mathcal{H}_{0-,\mu+}(\overline{x}, ...)[H_T + ...O(\xi^2 E_T)].$$

$$\mathcal{M}^{twist-3}_{0+,\mu+} \propto \frac{\sqrt{-t'}}{4m} \int_{-1}^{1} d\overline{x} \mathcal{H}_{0-,\mu+}(\overline{x}, ...) \bar{E}_T.$$

$M^{twist-3}_{0-,++} \propto const$ at small t' but handbag amplitude $\propto t'$

Twist-3 amplitude $\mathcal{H}_{/-,\mu+}$ contains twist-3 meson wave function.

Double distribution model

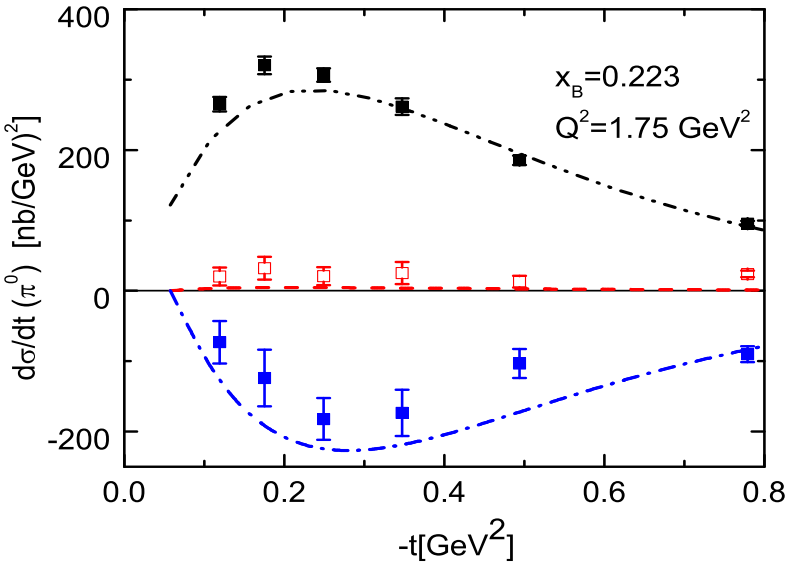
$$H^a_T(x,0,0) = \delta^a(x), \quad \text{transversity } \delta \text{ –Anselmino model}$$

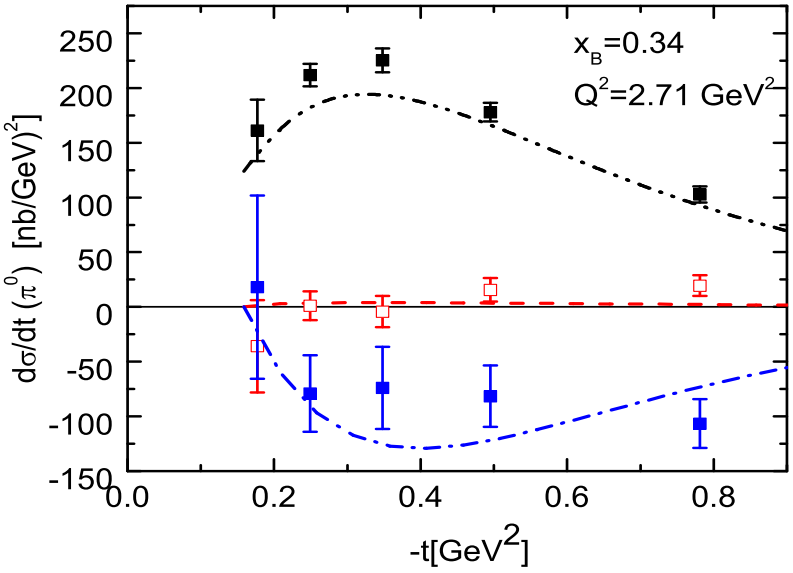
$$\bar{E}^a_T(x,0,0) = e_T, \quad e_T(\beta,t) = N\, e^{b_0 t} \beta^{-\alpha(t)} (1-\beta)^n \tag{3}$$

Parameters of E_T are taken from the lattice results for the moments.

π^0 production at CLAS- test of twist-3 H_T and E_T GPDs

SG & P.Kroll





π^0 production at CLAS energy range together with CLAS data.

π^0 production at CLAS energy range together with CLAS data.

Black line- $\sigma_T + \epsilon\sigma_L$, red line-$\sigma_{LT}$, blue dashed-dotted- σ_{TT}

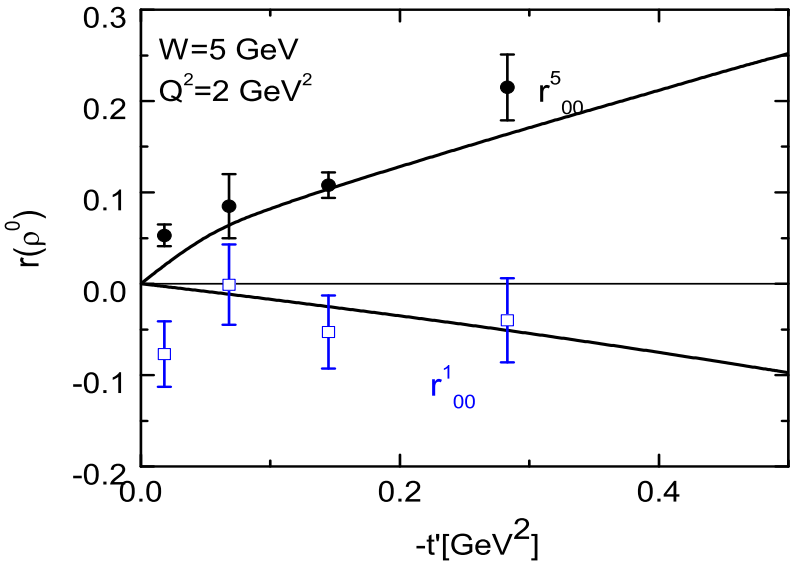
E_T contribution is large and we have at CLAS large $\sigma_T \sim \sigma$. $\sigma_L \sim \sigma_{LT} \sim$ few nb is rather small.

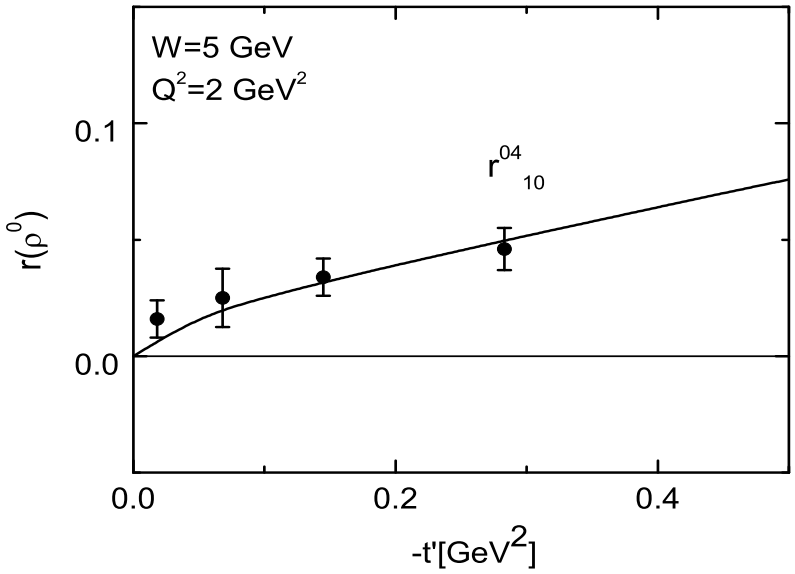
σ_T predominated in π^0 production.

Hall A FNAL experiment confirmation that $\sigma_T >> \sigma_L$. At experiment $\sigma_T\, \sigma_L$ separations done.

Twist-3 E_T effects in SDME of ρ production.

SG & P.Kroll



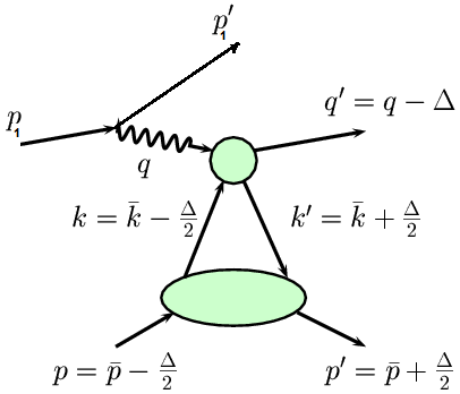


$r^5_{00} \sim \mathrm{Re}[M^*_{0+,0+}M_{0+,++}]; \quad r^1_{00} \sim |M_{0+,++}|^2; \quad r^{04}_{10} \sim \mathrm{Re}[M^*_{++,++}M_{0+,++}]; \quad M_{0+,++} =< E_T >$

Without E_T effects this SDME should be zero in handbag model. Large E_T effects found in π^0 channel are compatible with SDME of ρ production at HERMES energies.

Meson production at NICA. Photon channel.

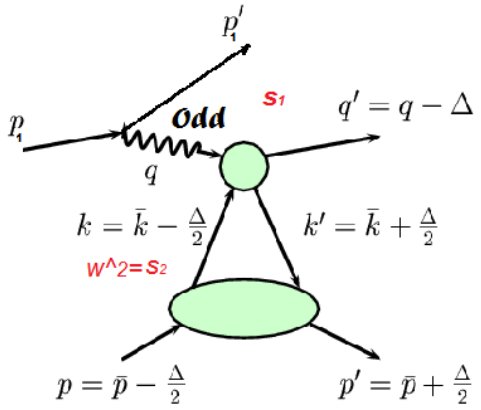
The proposed process is similar to the corresponding process in lepton-proton reaction.



In the final state one detect two protons p_1, p and meson state.

- the proton p_1 radiate a hard photon with virtuality Q^2 which interact with the other proton and produce the meson.
- The photon virtuality Q^2 and momenta q can be determined from the final proton angle and momenta.
- At NICA we shall have the hard photon-proton interaction with energy $W \sim 5 - 15$GeV in the γp system. These energies are closed to HERMES and COMPASS energy range.

Meson production at NICA. Strong interaction contribution.



In addition to photon the strong interaction contribution is possible in hadron-hadron reaction. In VM production this is Odderon.

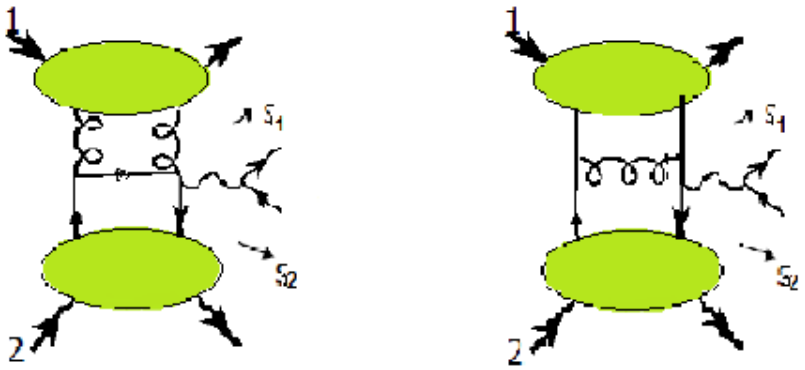
- The energy $s_1 = (p_1' + q_1')^2$ is sufficiently large at NICA.
- The gluon exchange should predominate.
- In VM production 3 gluons can contribute (minimum number)- associated with Odderon
- Odderon effectively can be considered as object similar to photon.
- Such contribution will expressed in terms of GPDs similar to photoproduction channel.

Vector meson production at NICA.

- Light vector meson (ρ, ω) production at NICA can be studied at $Q^2 \sim 3 - 4\text{GeV}^2$
- For such Q^2 and $W \sim 10\text{GeV}$ the photon channel cross section is about $\sigma_\rho \sim 200\text{nb}$ and $\sigma_\omega \sim 20\text{nb}$
- Cross section is rather large and one can obtain information on GPDs H for gluon, sea and valence quark distributions. Transversely polarized proton beam: information on GPD E from A_{UT} asymmetry
- J/Ψ production can be studied at $W \sim 7\text{GeV}$ and $Q^2 \sim 1\text{GeV}^2$. Cross section in the photon channel is about $\sigma_{J/\Psi} \sim 5\text{nb}$. This process is dominated by the gluon GPDs H^g.
- The $\tilde{H}^g$ effects determined by Δg can be tested in the A_{LL} asymmetry of J/Ψ production.
- Generally, the photon channel can dominate in all the cases because the odderon contribution can be rather small in most reactions.

Exclusive Drell-Yan process with two GPDs

SG, in collab. with P.Kroll and O.Teryaev in progress.



We consider quark-gluon and quark-quark effects

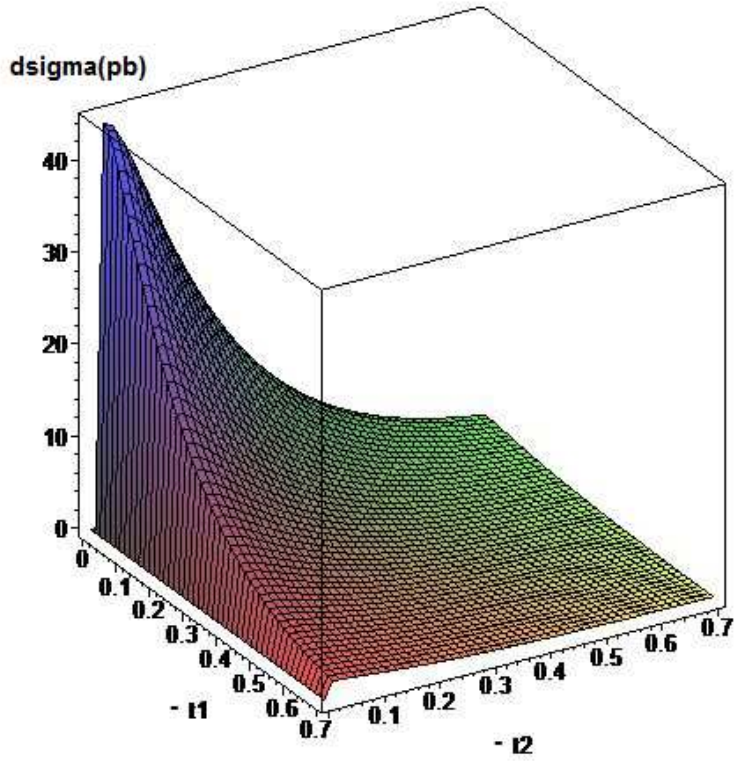
Problem- some divergencies like double pole appear in the amplitudes

$$\frac{1}{(x_1-\xi_1)(x_2-\xi_2)+i\epsilon} \to \frac{1}{(x_1-\xi_1)(x_2-\xi_2)+m_q^2/Q^2+i\epsilon}$$

Regularization like effective quark mass, $m_q^2 \sim 0.1\text{GeV}^2$ is used.

Cross section is integrated over s_1 and s_2 was calculated at NICA energies

First preliminary result for cross section of $p\,p \to p\,p\,l^+\,l^-$ process at NICA energies



Preliminary results for cross section of exclusive Drell-Yan process over t_1 and t_2 at NICA energies. $\frac{d\sigma}{dQ^2 dt_1 dt_2}$ -in pb/GeV^6. Estimations show that such contribution might be visible. Both final protons should be detected

Integrated over t_1 and t_2 cross section $d\sigma/dQ^2 \sim 3$ pb/GeV^2 at $Q^2 = 5$GeV^2 (NICA energies)

Conclusion

- We analyse GPDs model for exclusive meson production.
  – Discuss GPDs properties, amplitudes structure in terms of GPDs.
- Model results for vector meson production (leptoproduction): cross section and asymmetries. Test GPDs
- The study of exclusive processes at NICA to get information on GPDs is possible.
- ρ production-test H, $\tilde{H}$, E GPDs contributions.
- J/Ψ production-gluon GPDs effects.
- Exclusive Drell-Yan with double GPDs contribution - important test of GPD model.
  Cross section is rather small. But hopefully might analysed.
- In all cases both final proton should be detected to indicate exclusivity.
- Important information on GPDs structure can be obtained at NICA with polarized beams.

Thank You