Study of exclusive processes at NICA.

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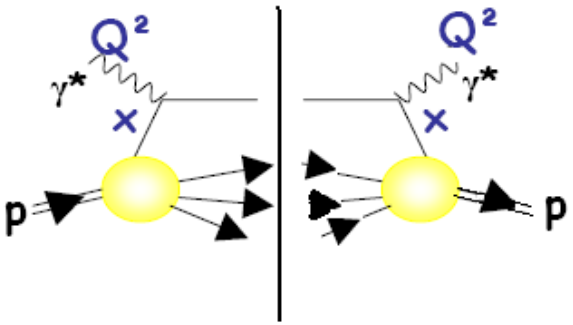
- Introduction : Generalized Parton Distributions (GPDs).
- Model for GPDs. Exclusive meson production- GPD model.
- Vector meson production -analyses of GPDs H effects from cross section .
- Vector meson production with polarized beams. A_{UT} asymmetries- GPDs E effects.
- Possibility to study exclusive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

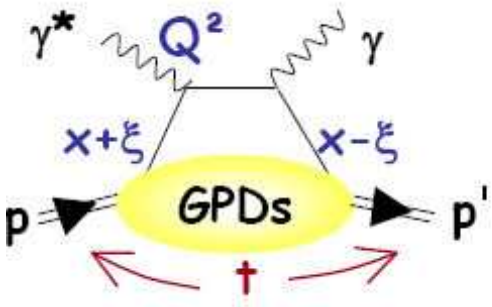
DIS and DVCD

- Deep Inelastic scattering



Cross section - expressed in terms of ordinary parton distributions $q(x)$

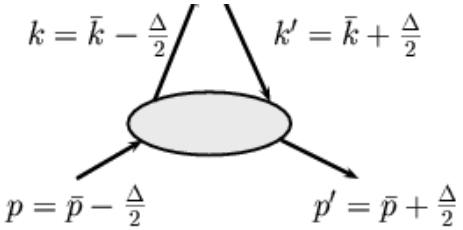
- Deeply Virtual Compton Scattering



Amplitude - proportional to Generalized Parton Distributions GPDs $H(x, \xi, t)$

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

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

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

- 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.

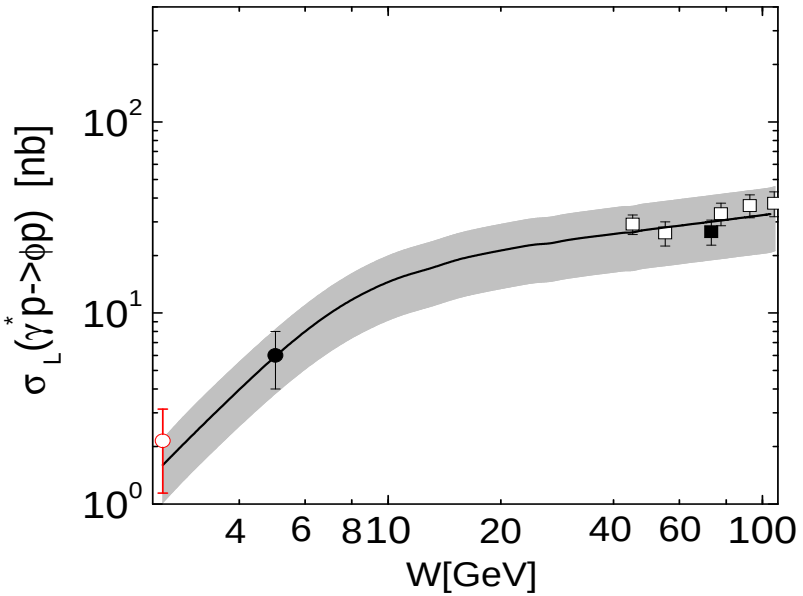
In hard scattering amplitudes F, F' we consider quark transverse momenta in quark propagators which determined by $k_\perp^2/Q^2$ corrections $\frac{1}{(x-\xi)+k_\perp^2/Q^2+i\epsilon}$
-effective consideration of the non-leading contribution.

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

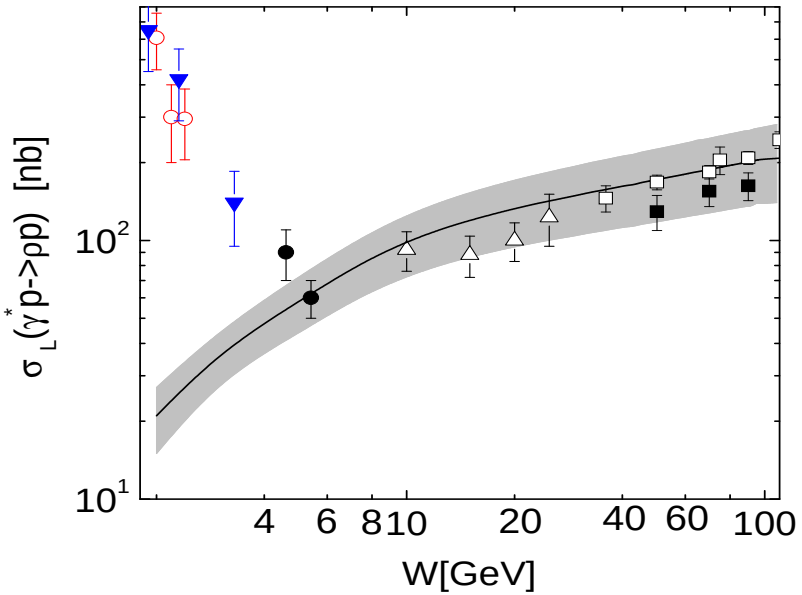
GPDs can be tested by analyses of cross sections and spin observables.

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



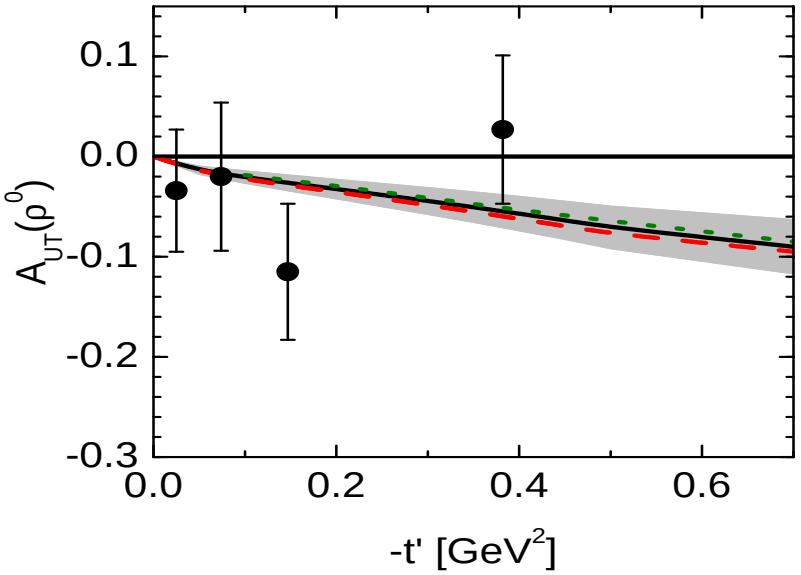
The longitudinal cross section for ρ at $Q^2 = 4.0\,\mathrm{GeV}^2$. Data: HERMES (solid circle), ZEUS (open square), H1 (solid square), E665 (open triangle), open circles- CLAS, CORNEL -solid triangle

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 ???

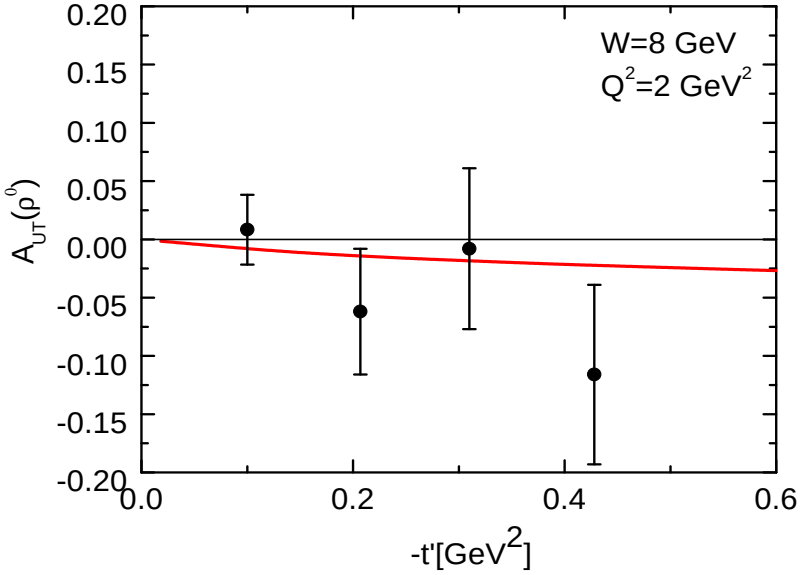
A_{UT} asymmetry for ρ production-test of GPDs E effects.

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.

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

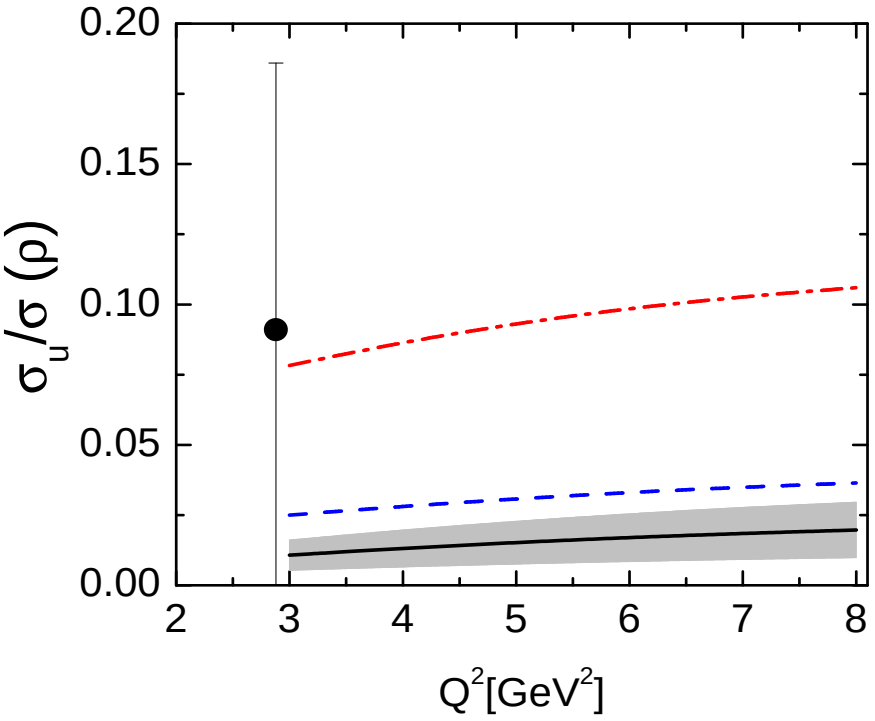
The dominant contribution comes from quark polarized distributions

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

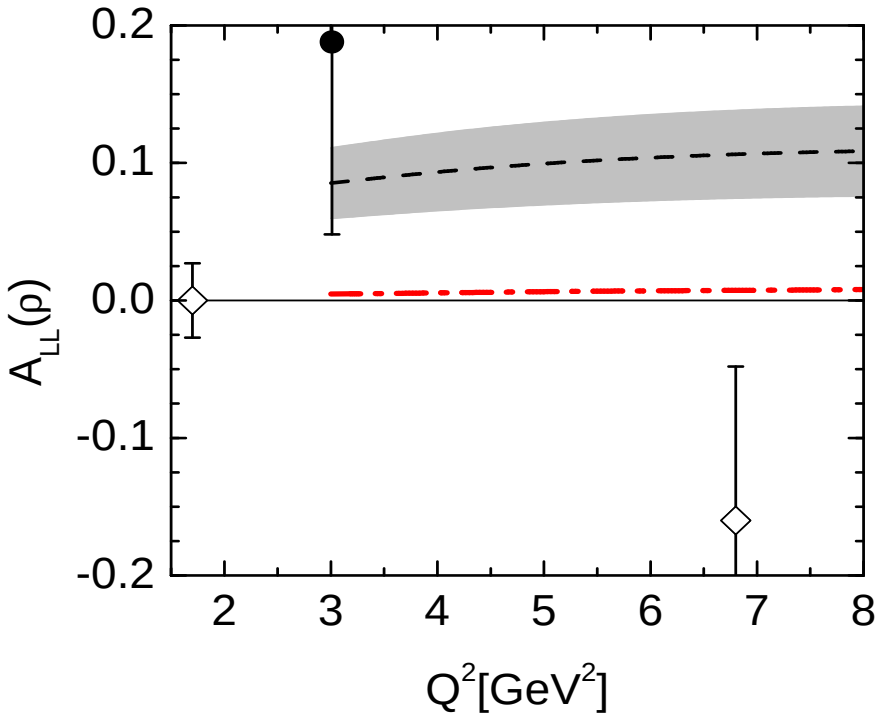
With the help Δu and Δd PDFs we construct GPDs $\widetilde{H}$ using double distribution.

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 $W = 5\,(10)$ GeV dashed (dash-dotted) line. Data 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 $\mathcal{H}_{\prime-,\mu+}$ contains twist-3 meson wave function.

Double distribution model

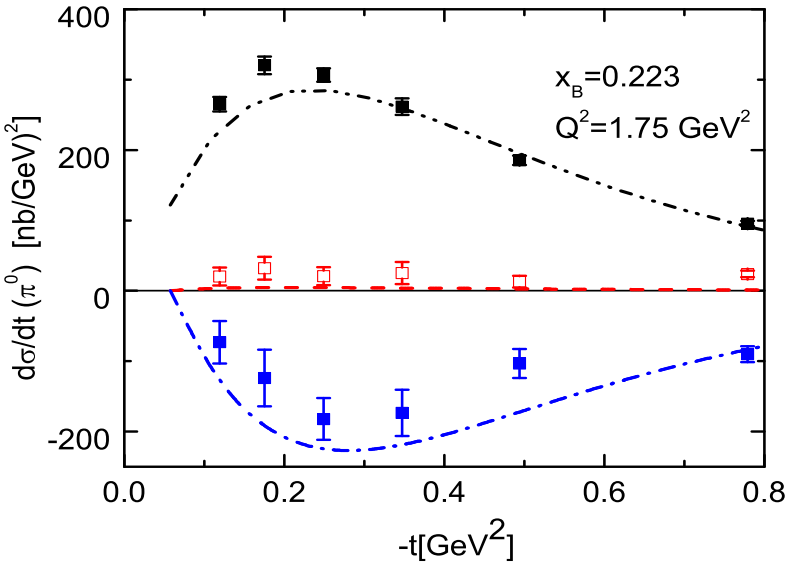
$$H^a_T(x,0,0) = \delta^a(x), \quad \text{transversity } \delta \text{ –Anselmino model}$$

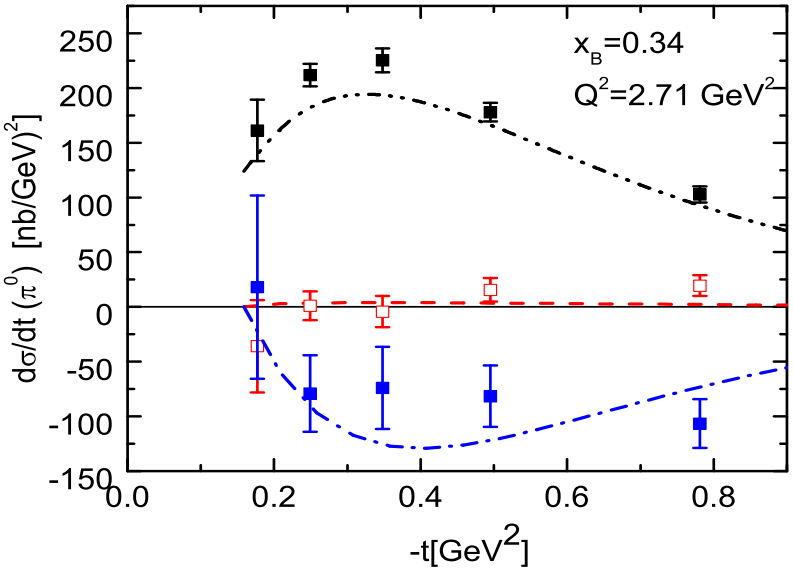
$$\bar{E}^a_T(x,0,0) = e_T, \quad e_T(\beta,t) = N\, e^{b_0 t}\beta^{-\alpha(t)}\,(1-\beta)^n \tag{3}$$

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}

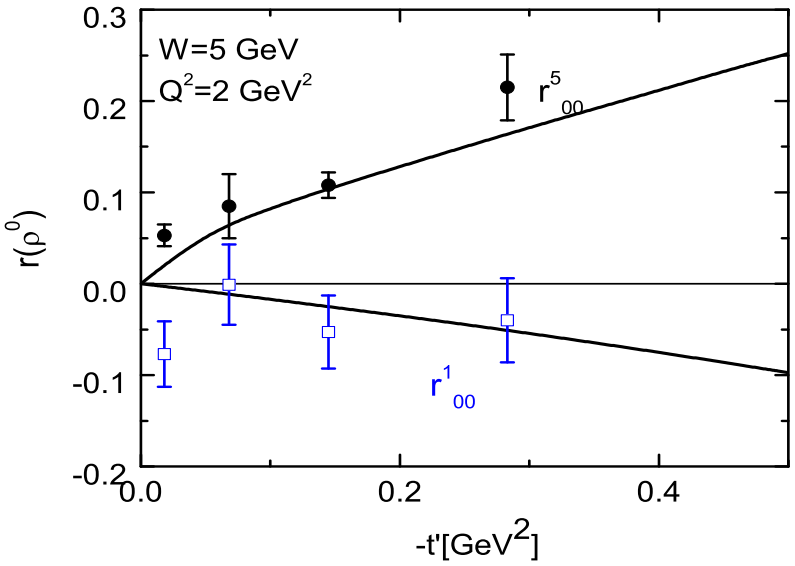
E_T contribution is large and we have at CLAS large $\sigma_T \sim \sigma$. $\sigma_L \sim \sigma_{LT} \sim$ few nb is rather small.

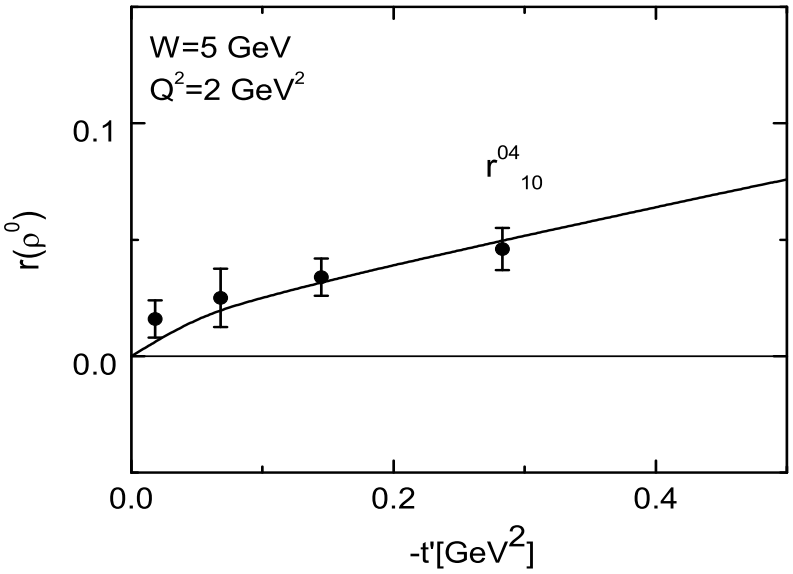
σ_T predominated in π^0 production.

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



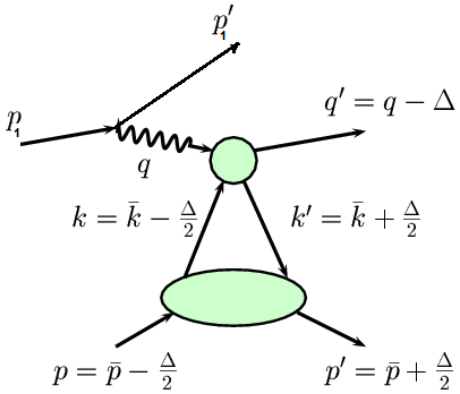


$r^5_{00} \sim \mathrm{Re}[M^*_{0+,0+}M_{0+,++}]; \quad r^1_{00} \sim |M_{0+,++}|^2; \quad r^{04}_{10} \sim \mathrm{Re}[M^*_{++,++}M_{0+,++}]; \quad M_{0+,++} =< E_T >$

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

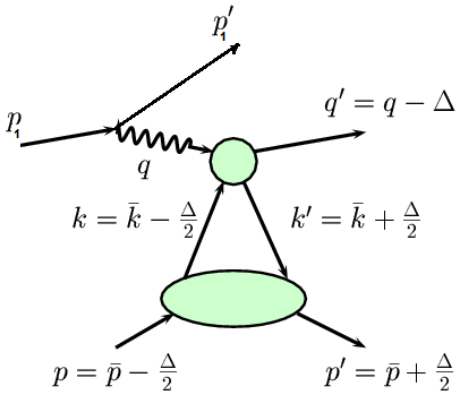
The proposed process is similar to the corresponding process in lepton-proton reaction.



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 $W \sim 5 - 12$GeV in the γp system. These energies are closed to HERMES and COMPASS energy range.

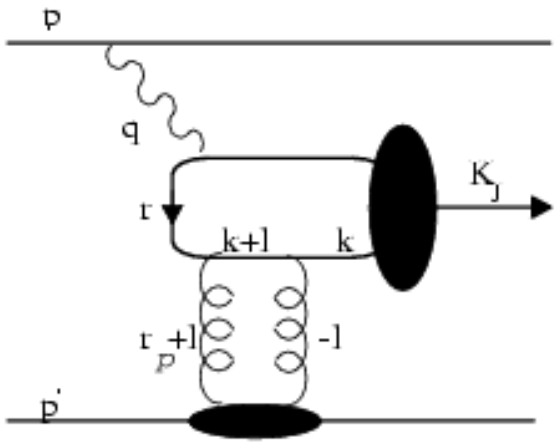
Meson production at NICA

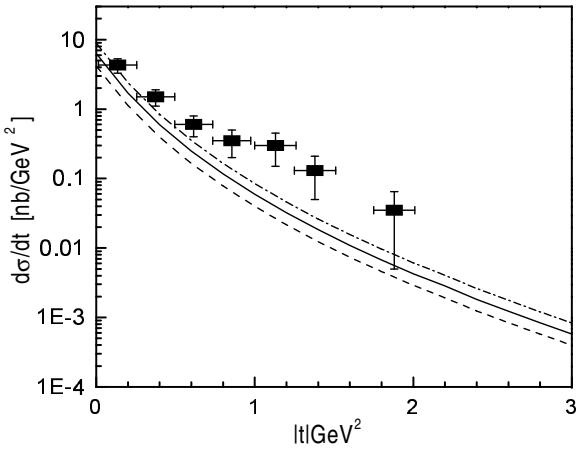


ρ production is interesting. Study H GPDs from cross section.

- There is a possibility to test ρ production cross section from low $W \sim 2$GeV till $W \sim 10$GeV - test effect of cross section growing at $W < 5$GeV in one experiment. H GPDs from ρ production.
- In polarized NICA there is a possibility to test E and $\tilde{H}$ GPDs from asymmetries.
- Background ? It seems, at high Q^2 process of ρ photoproduction should predominate.
- Do not discuss π meson reactions at NICA. Sources of pseudoscalar can be different.
- Exclusive J/Ψ - via photoproduction mechanism seems to be quite clean process at NICA

J/Ψ production at NICA

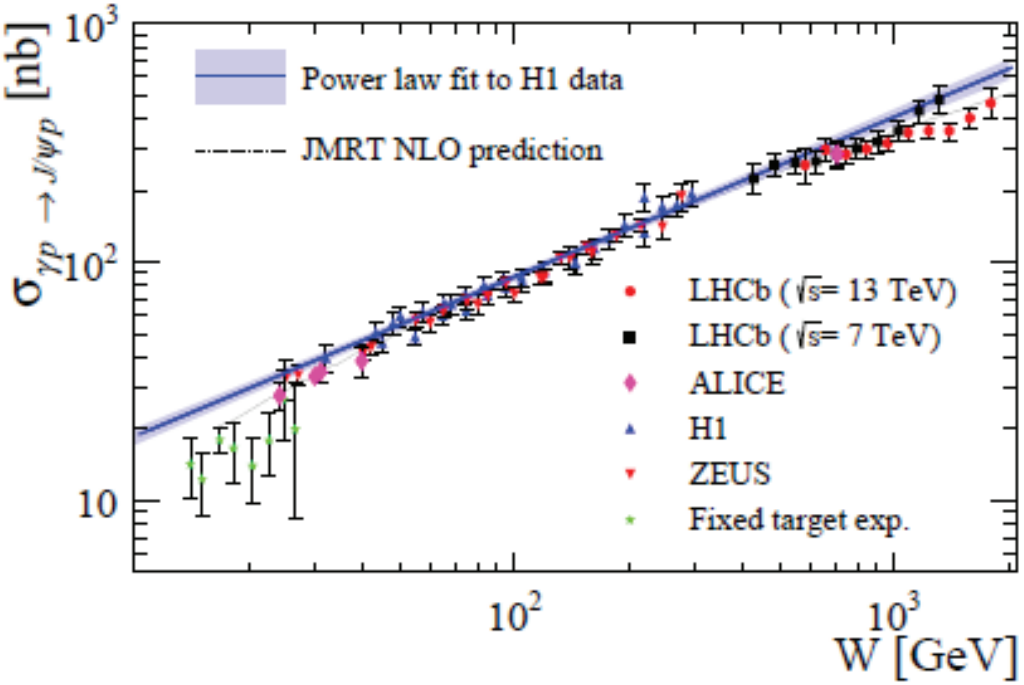




HERA

- Photoproduction mechanism of exclusive J/Ψ production were tested in lepton-proton and proton-proton experiments.
- Gluon H^g GPDs predominate.
- Cross section- test of H^g GPDs
- If analyses of A_{LL} asymmetry is possible at NICA -test $\tilde{H}^g$

J/Ψ production at NICA



Photoproduction cross section of of exclusive J/Ψ in lepton-proton and proton-proton experiments from low to high W.

Cross section of J/Ψ production is not small $\sim$ 20nb at NICA energies

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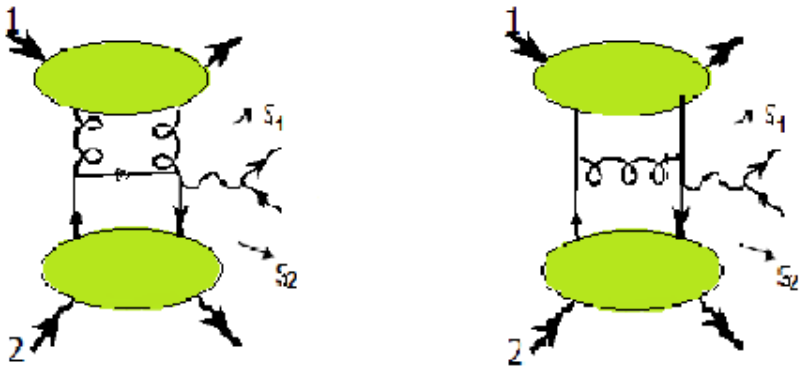
Analyses of this process might be possible.

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

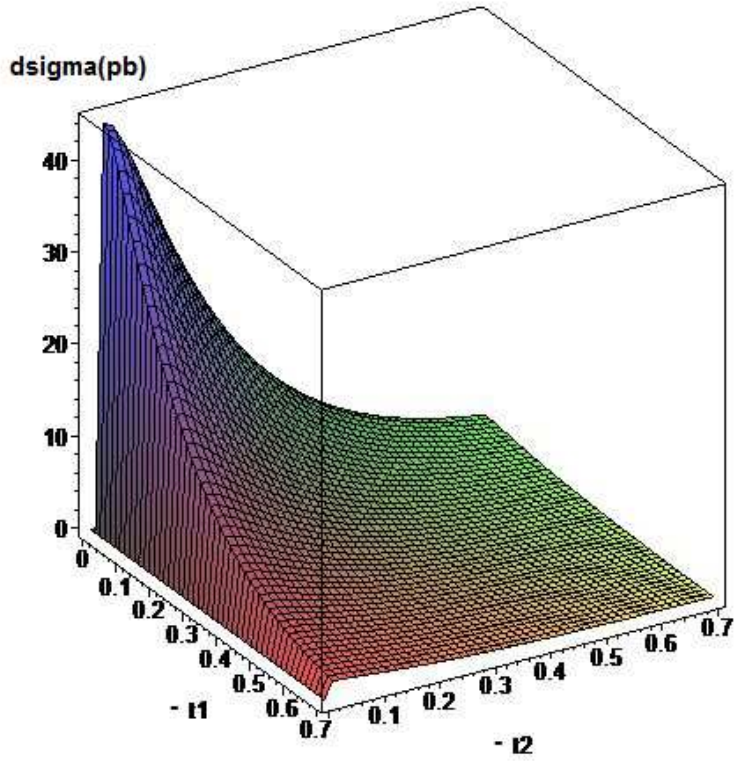
Problem- some divergencies like double pole appear in the amplitudes

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

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: cross section and asymmetries. Test GPDs
- Discussion of possibility to study exclusive processes at NICA to get information on GPDs.
- 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