GPDs in exclusive meson production.

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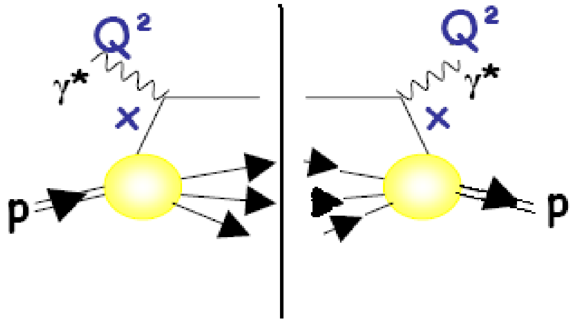
- GPDs properties and their modeling
- Amplitudes of Vector Meson production in terms of GPDs .
- Cross section and spin asymmetry of VM production- effects of GPDs H, E.
- Twist 3 transversity effects in Pseudoscalar Meson production
- Essential transversity effects in PM production at low energies .

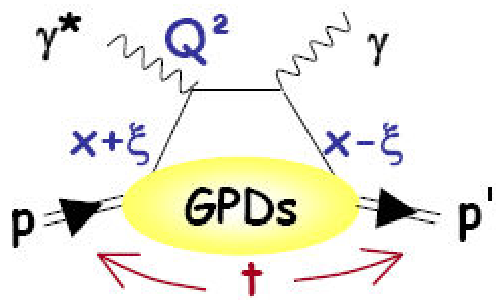
DIS and DVCD

- Deep Inelastic scattering



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

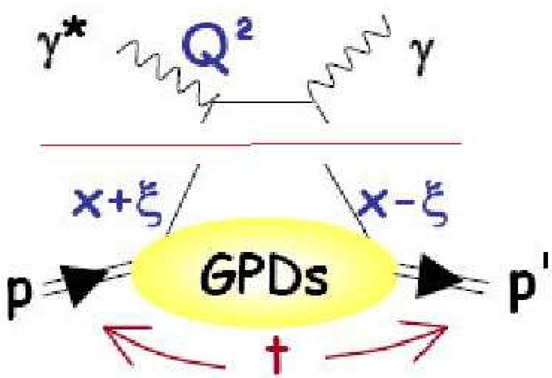
- Deeply Virtual Compton Scattering



Amplitude - proportional to Generalized Parton Distributions GPDs $H(x, \xi, t)$, dependent on 3 variables. GPDs was proposed by Radyushkin and Ji

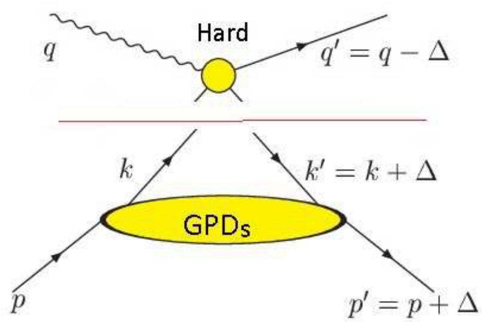
DVCS and DVMP factorization

- DVCS



DVCS factorized into hard part and GPDs .
Radyushkin and Ji, 96, 97

- DVMP



Amplitude of DVMP factorized into Hard part and GPDs
Radyushkin and Ji, 96, 97

GPDs are universal functions that independent on processes . Hard parts are calculated perturbatively .

GPDs: Information about hadron structure.

Radyushkin and Ji, 96, 97

⋆ GPDs – extensive information about hadron structure.

- Ordinary parton distribution connected with GPDs

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

- 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

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

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

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

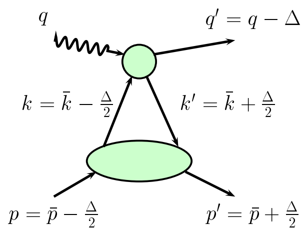
⋆ $h^q_{val}(\beta, 0) = q_{val}(|\beta|) \, \Theta(\beta)$ –valence contribution (n=1).

PDF parameters from CTEQ6 parameterization.

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

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

$\star$ $\gamma p \to V p$ **amplitudes in terms of GPDs.**



The proton non-flip amplitude is a convolution of H GPDs and hard scattering part.

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

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.

The hard scattering amplitudes F, F' is calculated perturbatively by taking into account the quark transverse momenta in quark propagators

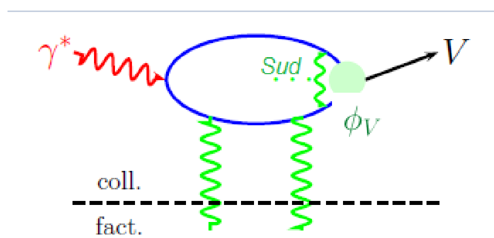
GPDs are modeling using double distribution (Radyushkin) +CTEQ PDFs.

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

Structure hard subprocess amplitude

The hard scattering amplitudes-transverse quark motion

$$F^{a(g)}_{\mu',\mu}(\overline{x},\xi) \propto \alpha_s(\mu_R) \int_0^1 d\tau \int \frac{d^2\mathbf{k}_\perp}{16\pi^3}\phi_{V\mu'}(\tau,k_\perp^2)\ \exp(-S) f^{a(g)}_{\mu',\mu}(\mathbf{k}_\perp,\overline{x},\xi,\tau) D\,.$$



$$\phi_V(\mathbf{k}_\perp,\tau) \propto f_V a_V^2\ \exp\left[-a_V^2\frac{\mathbf{k}_\perp^2}{\tau\bar{\tau}}\right].$$

S- Sudakov factor contains gluonic radiative corrections.

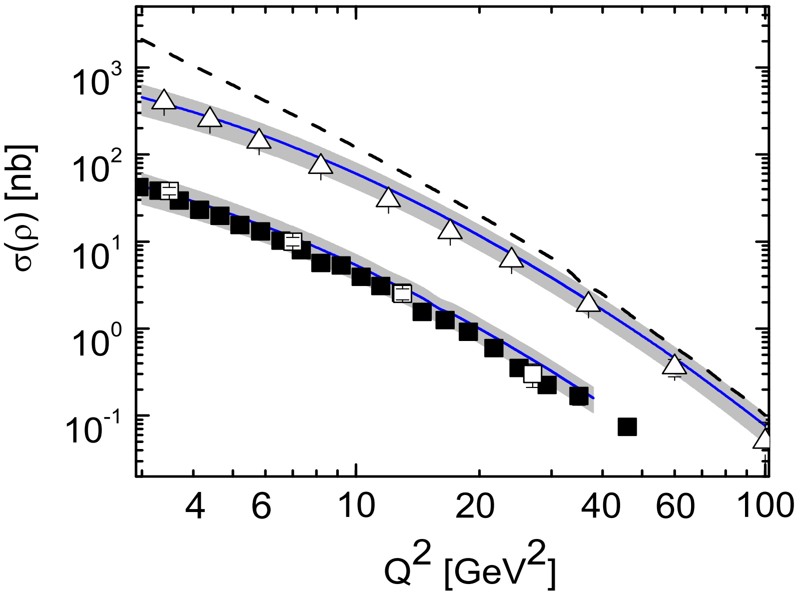
In hard scattering amplitudes f which calculated perturbatively we consider quark transverse momenta in quark propagators which lead to $k_\perp^2/Q^2$ corrections

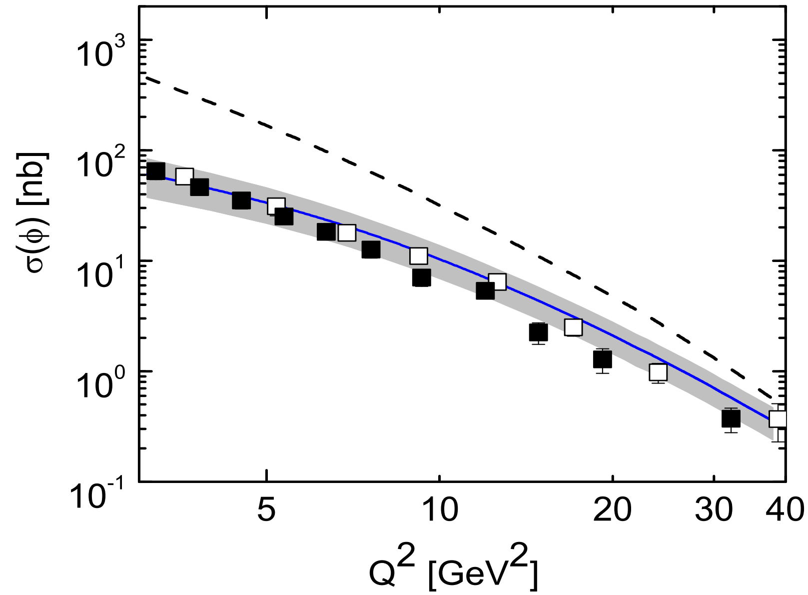
$$D \sim \frac{1}{(k_\perp^2+\tau(\overline{x}-\xi)Q^2)}\cdots$$

-effective consideration of the non-leading contribution.

Cross sections of VM production-Q^2 dependence

Q^2 dependence of cross sections of ρ andϕ production -test GPDs H. H1 and ZEUS data.





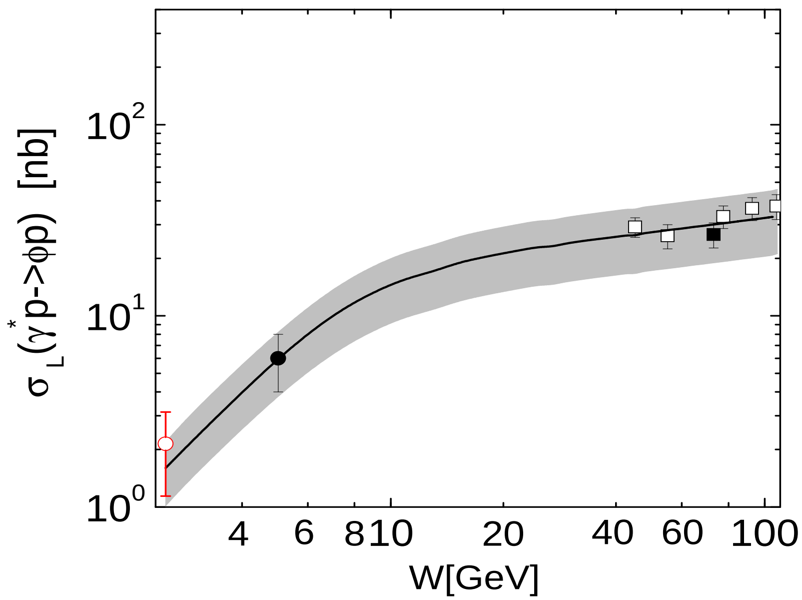
Cross sections of ρ production with errors from uncertainty in parton distributions at $W = 75$GeV/10 and $W = 90$GeV. Dashed line leading twist results.

Cross sections of ϕ production with errors from uncertainty in parton distributions at $W = 75$GeV. Dashed line leading twist results.

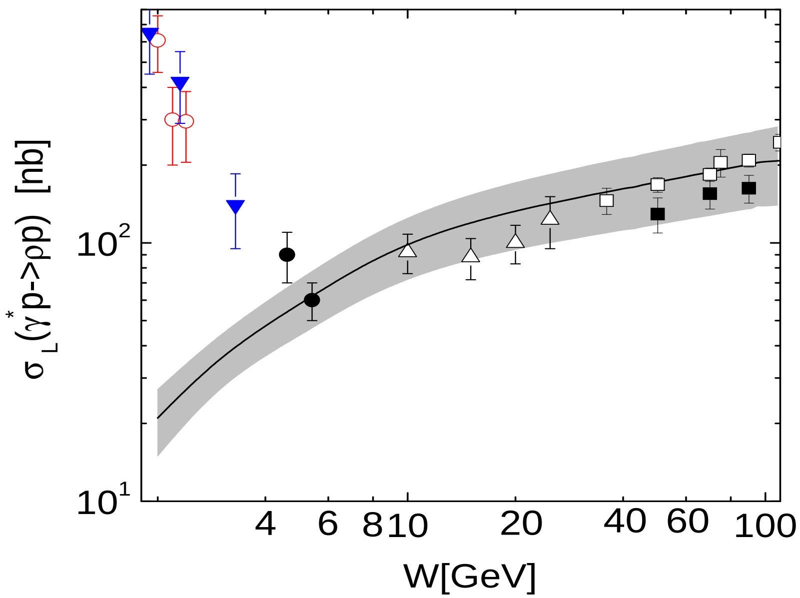
- ⋆ Power corrections $\sim k_\perp^2/Q^2$ in propagators are important at low Q^2–1/10 suppression at $Q^2 \sim 3\text{GeV}^2$

Cross section of ρ and ϕ production - GPDs H effects

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



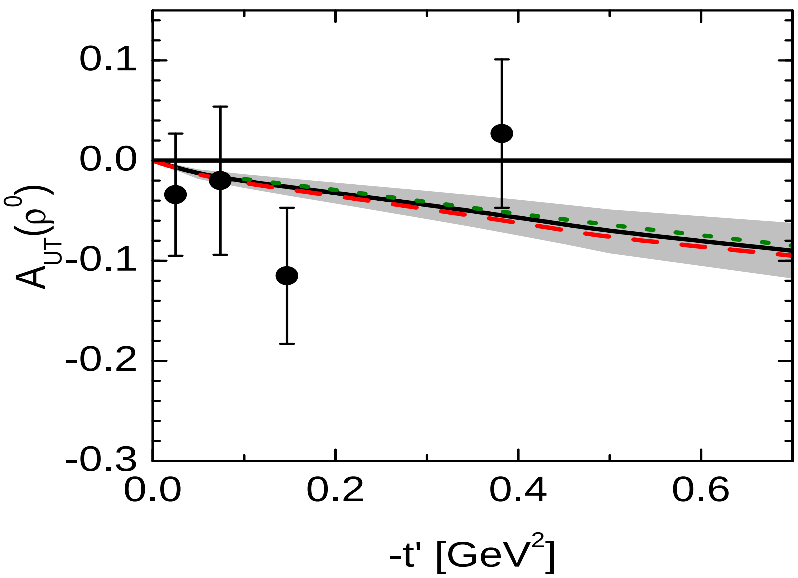
The longitudinal cross section for ρ at $Q^2 = 4.0\,\mathrm{GeV}^2$. Data: HERMES (solid circle), ZEUS (open square), H1 (solid square), E665 (open triangle), open circles- CLAS, CORNEL -solid triangle

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

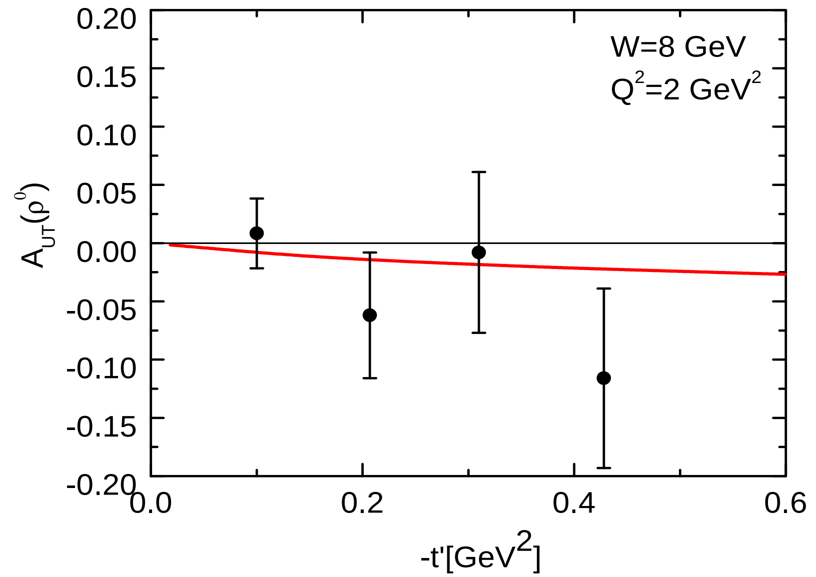
A_{UT} asymmetry for ρ production-test of GPDs E effects.

SG & P.Kroll

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



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

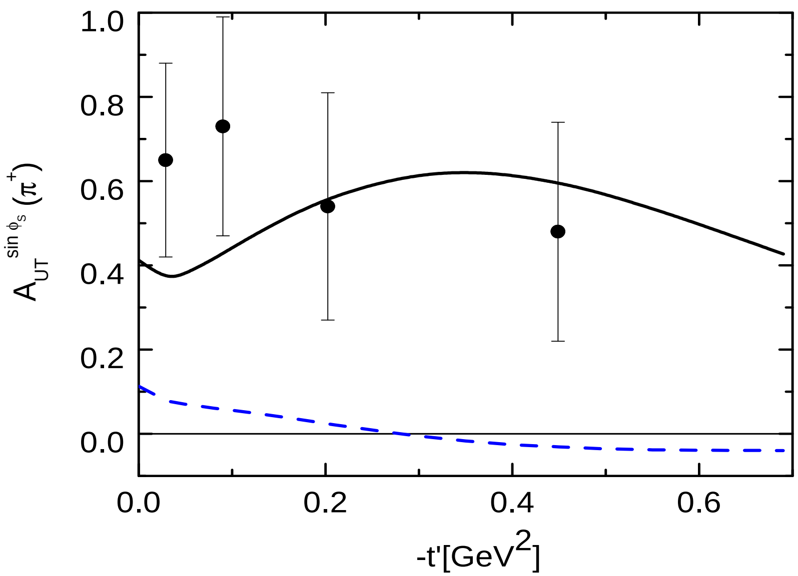


Model results for COMPASS energy $W = 8$GeV. COMPASS data are shown.

Why leading twist effects is not enough at low Q^2 ?

At low Q^2 we have problems with understanding of some observables.

Example: $A_{UT}^{\sin(\phi_s)}$ asymmetry.



$$A_{UT}^{\sin(\phi_s)} \propto \mathrm{Im}[M^*_{0-,++} M_{0+,0+}]$$

The handbag amplitude $M_{0-,++} \propto t'$. Small pole effect in $M_{0-,++}$ can not explain asymmetry. New not small contribution to $M_{0-,++}$ amplitude is needed.

$M_{0\pm,++}$ – twist-3 amplitudes. Transversity GPDs.

$M_{0-,++} \propto \sqrt{-t'}^{\,0} \propto const$ but handbag amplitude $\propto t'$

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

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

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

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

We calculate twist-3 amplitude and use twist-3 meson wave function.

Double distribution model

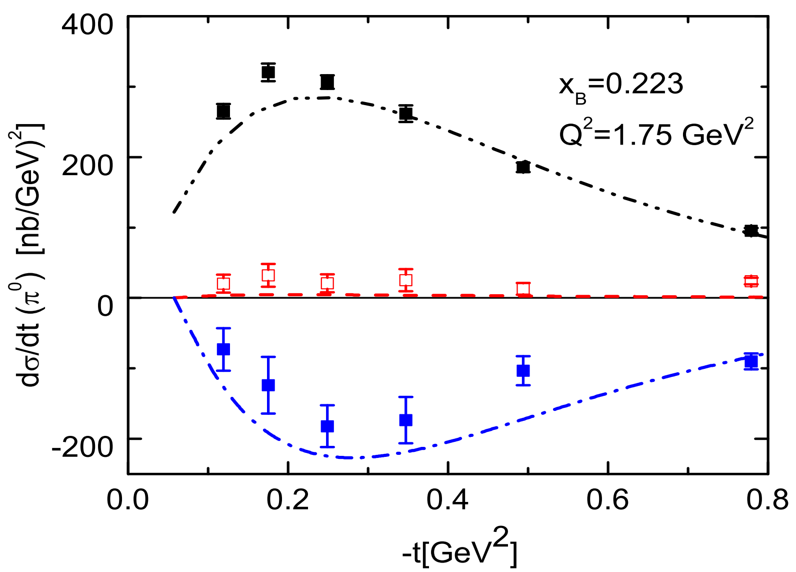
$H^a_T(x,0,0) = \delta^a(x),$ transversity δ –Anselmino model

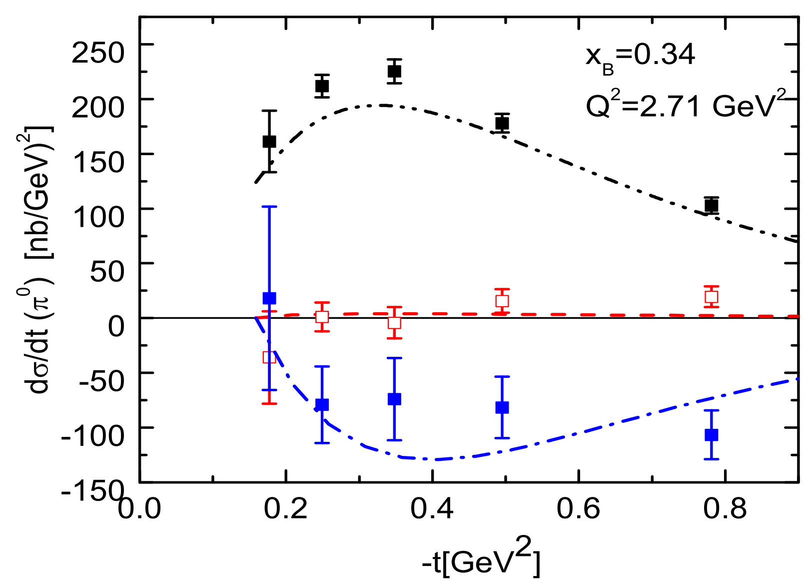
$$\bar{E}^a_T(x,0,0) = e_T, \quad e_T(\beta,t) = N\, e^{b_0 t} \beta^{-\alpha(t)}\, (1-\beta)^n \qquad (1)$$

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

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.

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. $\sigma_L \sim \sigma_{LT} \sim$ few nb is rather small.

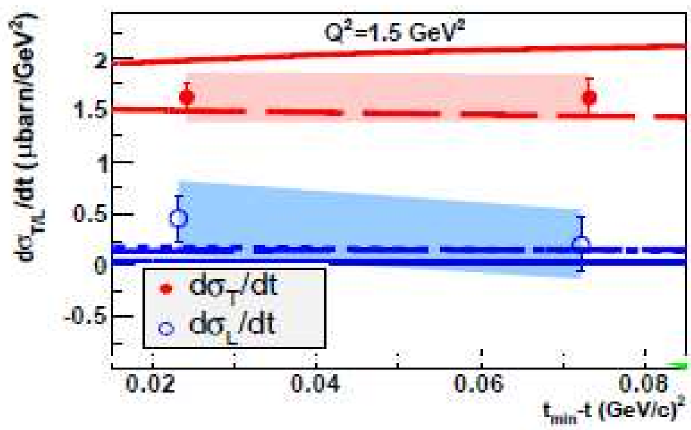
$$\frac{d\sigma_T}{dt} \sim \frac{1}{\kappa}[| < H_T > |^2/2 + | < E_T > |^2]; \quad \frac{d\sigma_{TT}}{dt} \sim -\frac{1}{\kappa}[| < E_T > |^2]; \quad \sigma \sim \sigma_T \sim -\sigma_{TT}$$

σ_T predominated in cross section of π^0 production.

Hall A FNAL experiment confirmation that $\sigma_T >> \sigma_L$.

At experiment σ_T, σ_L separations done.

Rosenbluth separation of the π^0 electroproduction cross section Hall A, JLab



The full lines are predictions from the Goloskokov-Kroll model

the long-dashed lines from the Luth-Goldstein model

The fact that $\frac{d\sigma_T}{dt} \gg \frac{d\sigma_L}{dt}$ shows that this kinematic regime is far from the asymptotic prediction of perturbative QCD

Conclusion

- We show that GPDs with DD form (Radyushrin 96-99) was used successfully for exclusive meson production.

  The leading twist contribution with some non-leading terms in propagators was used to analyse VM production.

- We describe properly ϕ, ρ production in a wide energy range-test H, E GPDs contributions.

- We found that the leading twist contribution is not enough in low energy π^0 production

- Essential contribution of transversity GPSs $\bar{E}_T$ and H_T leads to large σ_T. Leading twist σ_L is rather small.

  Confirmed by FNAL Hall-A experiments.

- Important information on GPDs structure can be obtained at future polarized experiments at COMPASS, CLAS12, NICA.

Thank You