Light Meson Elektroproduction and Generalized Parton Distributions.

S.V. Goloskokov

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

Dubna 141980, Moscow region, Russia

In collaboration with P. Kroll, Wuppertal

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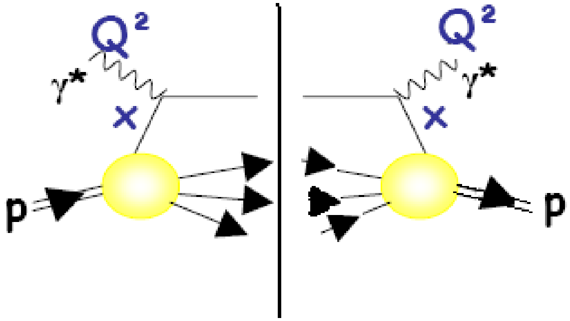
- Introduction : Generalized Parton Distributions (GPDs).
- GPDs & meson leptoproduction .
- Model for GPDs.
- Cross section for vector meson production in a wide energy range.
- Results for A_{UT} asymmetry at HERMES and COMPASS
- Transversity effects in pseudoscalar meson production.

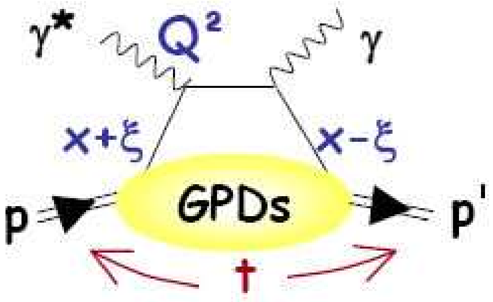
DIS and DVCD

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

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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

$$\int dx H(x,\xi,t) = F(t)$$

....

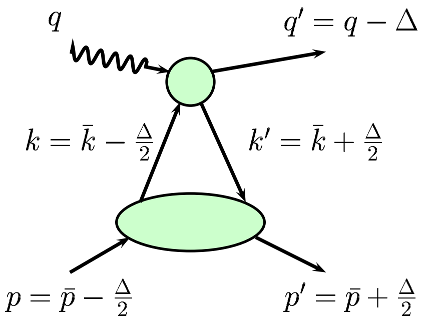
- Information on the parton angular momenta from Ji sum rules

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

Handbag factorization of Mesons production amplitude

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

Radyushkin, Collins,Frankfurt Strikman



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

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

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

$L \to L$ transition - predominant. Other amplitudes are suppressed as powers $1/Q$

The process of VM production

- ϕ production (gluon&strange sea)
- ρ, ω production (gluon&sea&valence quarks)
- Charge mesons- transition GPDs

Combinations of quark contribution to different reactions

Uncharged VM production - Standard $p \to p$ GPDs for ρ, ω: Transition $p \to \Sigma^+$ GPDs for K^{*0}:

$$\rho: \quad \sim \; e^u H^u - e^d H^d = \frac{2}{3}H^u + \frac{1}{3}H^d$$

$$\omega: \quad \sim \; \frac{2}{3}H^u - \frac{1}{3}H^d$$

$$K^{*0}: \quad \sim \; H^d - H^s$$

Charged VM production - Transition $p \to n$ GPDs :

$$\rho^+: \quad \sim H^{(3)} \; = \; H^u - H^d;$$

Pseudoscalar mesons production contribution of polarized distributions:

$$\pi^+: \quad \sim \tilde{H}^{(3)} \; = \; \tilde{H}^u - \tilde{H}^d;$$

$$\pi^0: \quad \sim \quad \frac{2}{3}\tilde{H}^u + \frac{1}{3}\tilde{H}^d$$

These combinations can be tested in mentioned reactions. GPDs in amplitudes are in integrated form. Direct GPDs extraction is impossible .

Our way: parameterization of GPDs and comparison with experiment.

Modelling the GPDs

The double distributions for GPDs Radyushkin '99 .

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

simple for the double distributions. Regge form: $\alpha_i = \alpha_i(0) + \alpha' t$

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

⋆ 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 t-dependence —Regge paramererization

$$h(\beta,t) = N\, e^{b_0 t} \beta^{-\alpha(t)}\, (1-\beta)^n \tag{3}$$

⋆ Amplitudes in terms of GPDs.

The proton non-flip amplitude is associated with F GPDs.

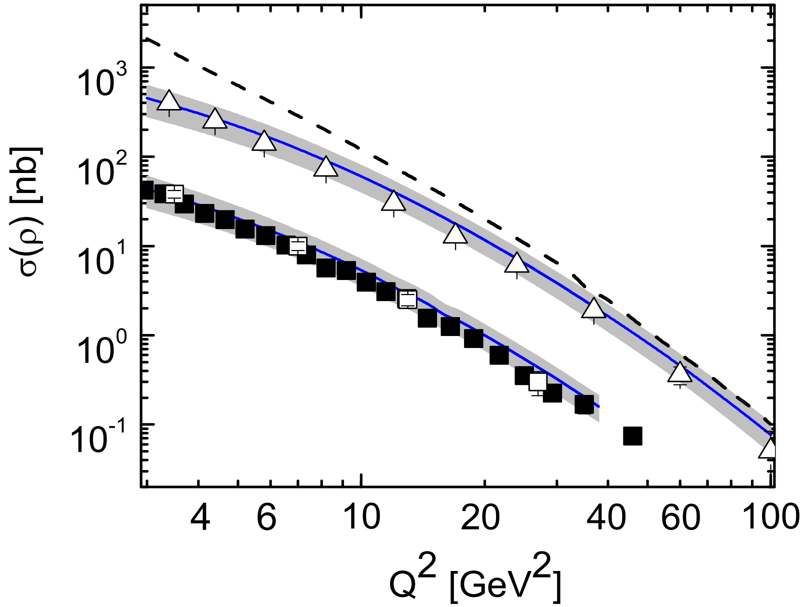
$$\mathcal{M}_{\mu'+,\mu+} \propto \int_{-1}^{1} d\overline{x}\, H^a(\overline{x},\xi,t)\, F^a_{\mu',\mu}(\overline{x},\xi)$$

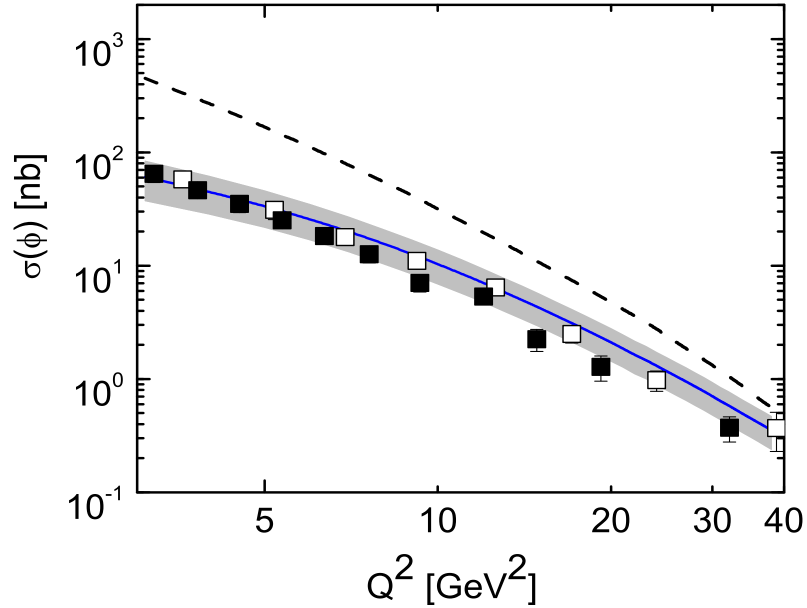
$$H^a(x,0,0) = h^a(x), \qquad H^g(x,0,0) = xg(x)$$

In hard scattering part we consider transverse quark momenta which determine $k_\perp^2/Q^2$ corrections.
Quark (valence, sea), gluon PDFs are determined from CTEQ6 parameterization

Cross sections of VM production

Q^2 dependence of cross sections of ρ andϕ production at $W = 75$GeV. H1 and ZEUS data.



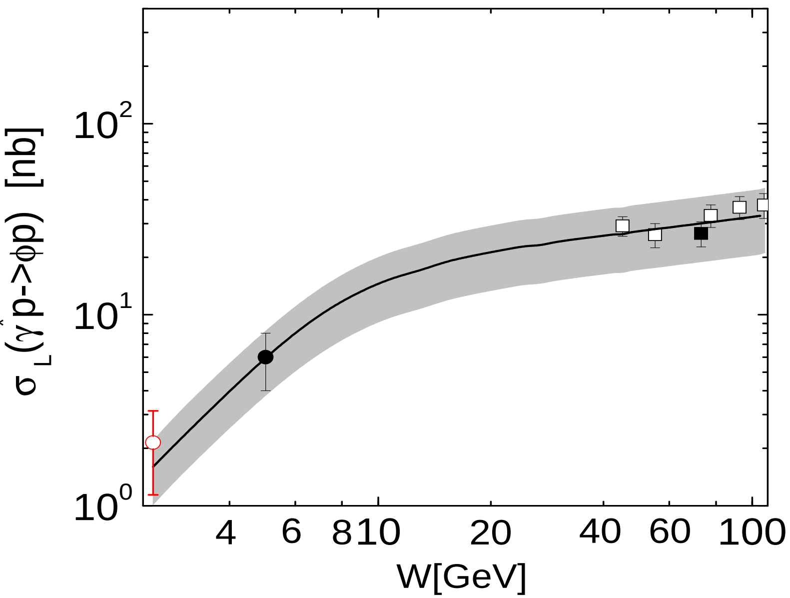


Cross sections of ρ production with errors from uncertainty in parton distributions at $W = 75$GeV/10 and $W = 90$GeV. Dashed line leading twist results.

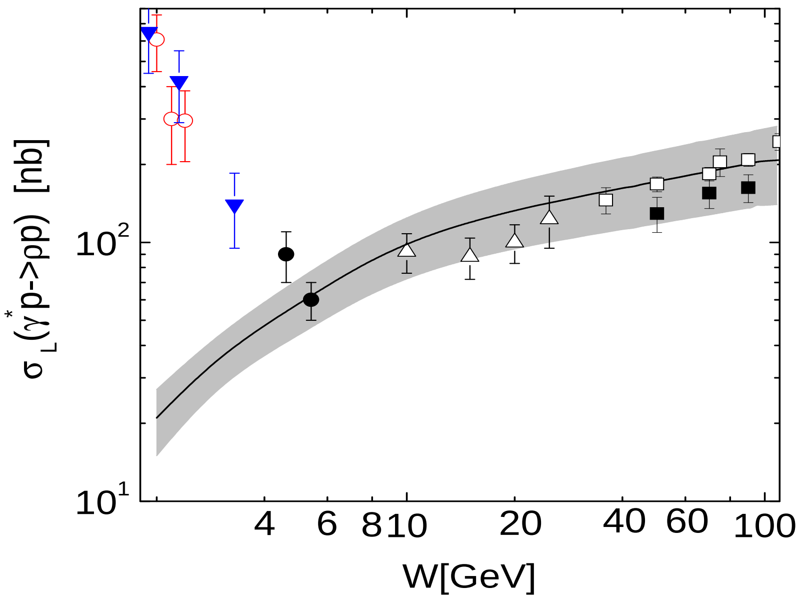
Cross sections of ϕ production with errors from uncertainty in parton distributions at $W = 75$GeV. Dashed line leading twist results.

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

Cross section of ρ and ϕ production cross



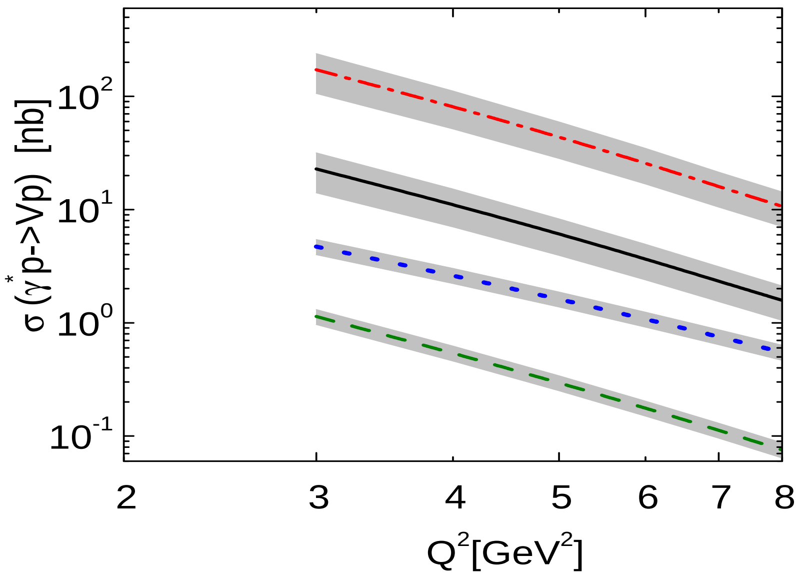
The longitudinal cross section for ϕ at $Q^2 = 3.8\,\mathrm{GeV}^2$. Data: HERMES (solid circle), ZEUS (open square), H1 (solid square), open circle-CLAS data point



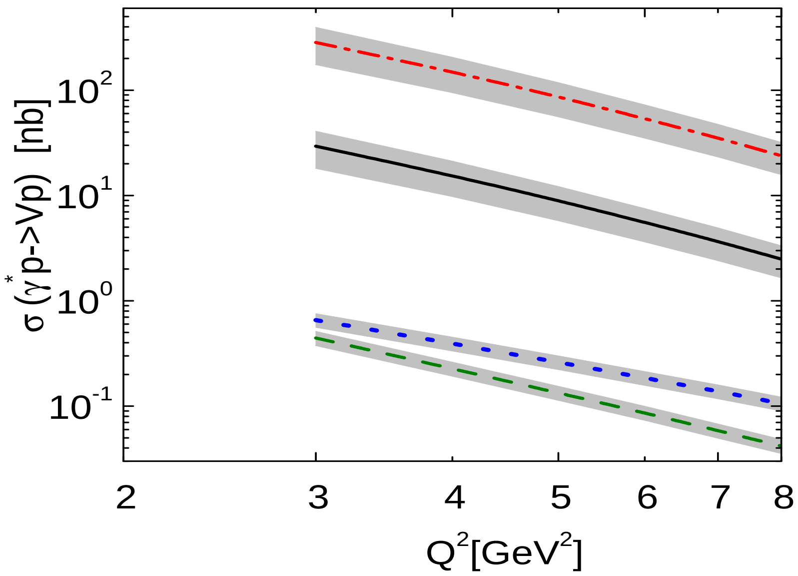
The longitudinal cross section for ρ at $Q^2 = 4.0\,\mathrm{GeV}^2$. Data: HERMES (solid circle), ZEUS (open square), H1 (solid square), E665 (open triangle), open circles- CLAS, CORNEL -solid triangle

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 D-term e.g.???

Hierarchy of cross sections for various meson production.



Our predictions for HERMES energy $W = 5$GeV.



Our predictions for COMPASS energy $W = 10$GeV

- Red- dot-dashed line ρ^0 ; Black-full line ω. –gluon contribution here - growing with energy .
- Blue- dotted line ρ^+ ; Green-dashed line K^{*0}. K^{*0} - sea contribution .

⋆ Spin-flip contribution. Effects of E GPDs.

The proton spin-flip amplitude is associated with E GPDs.

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

Double distribution model is used to construct E GPDs. E parameters- from Pauli form factor.

M. Diehl, ...,P.Kroll '04

Standard connection with ordinary distribution :

$$E^a(x,0,0) = e^a(x)$$

And

$$\int_0^1 dx e^a_{val}(x) = \kappa^a, \quad \kappa^u \sim 1.67, \quad \kappa^d \sim -2.03$$

κ^a -anomalous magnetic moments of valence quarks.

This means that $E^a \propto \kappa^a$ and E^u and E^d have different signs.

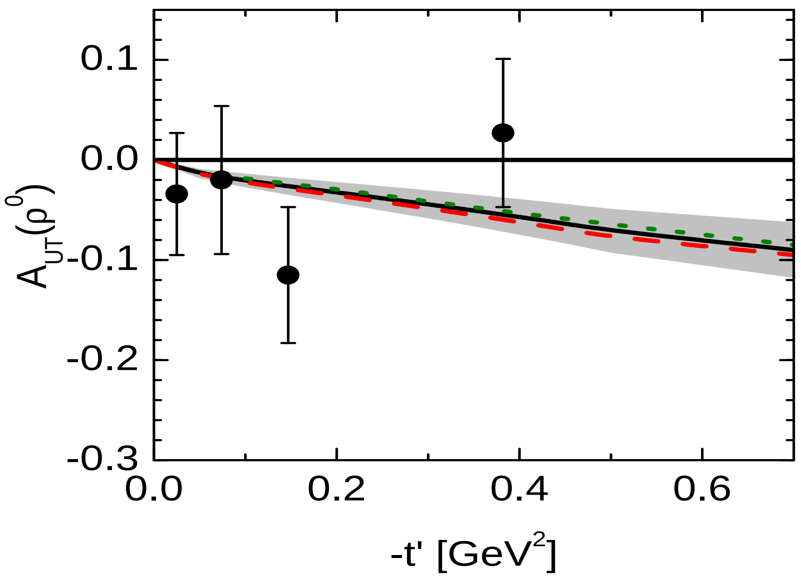
⋆ ρ production- $M^\rho \propto e_u E^u_{val} - e_d E^d_{val} = \frac{2}{3} E^u_{val} + \frac{1}{3} E^d_{val}$ different signs- compensation .

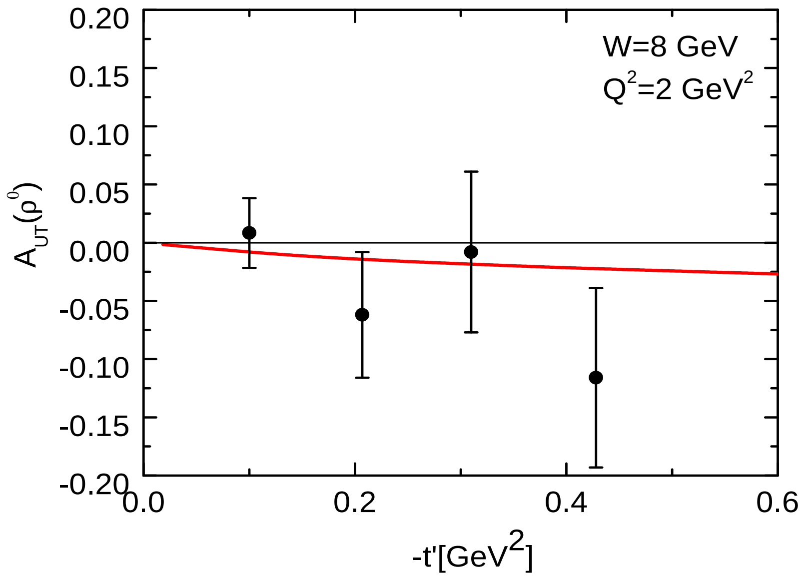
⋆ ω production- $M^\omega \propto e_u E^u_{val} + e_d E^d_{val} = \frac{2}{3} E^u_{val} - \frac{1}{3} E^d_{val}$ same signs- enhancement.

A_{UT} asymmetry for ρ production.

$$A_{UT} = -2\frac{\text{Im}[M^*_{+-,++}M_{++,++} + \varepsilon M^*_{0-,0+}M_{0+,0+}]}{\sum'_\nu [|M_{+\nu',++}|^2 + \varepsilon|M_{0\nu',0+}|^2]} \propto \frac{\text{Im} < E >^* < H >}{| < H > |^2}$$

E distributions needed to calculate $M_{+-,++}$ – from Pauli FF of nucleon. +DD form for GPD.

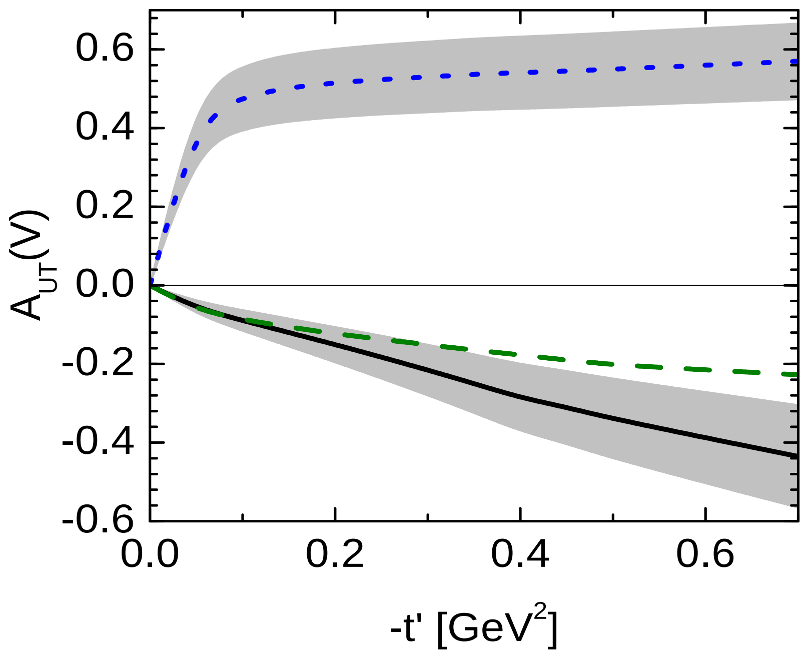


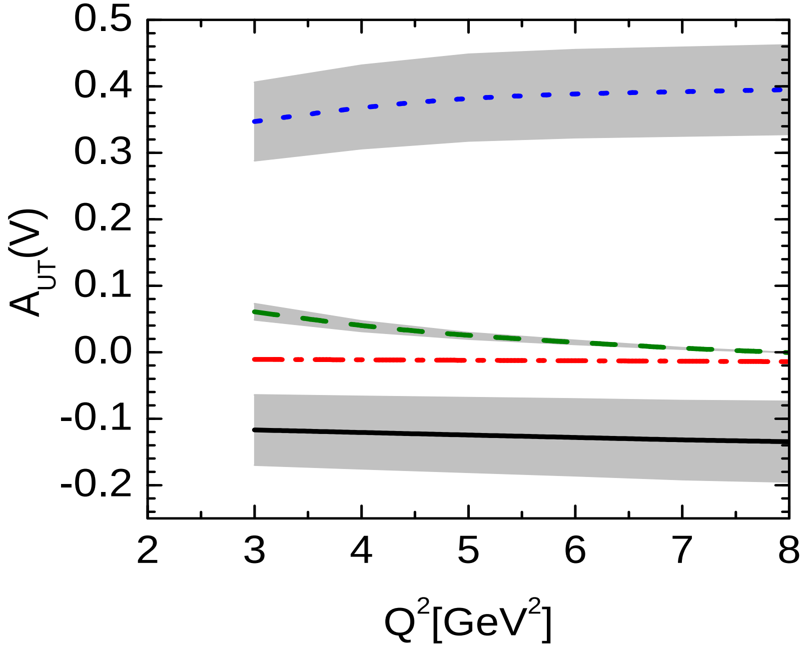


Predictions for HERMES energy $W = 5$GeV, $Q^2 = 3$GeV^2. HERMES data are shown.

Predictions for COMPASS energy $W = 8$GeV. COMPASS data at $W = 8$GeV re shown. Sandacz, Photon 09, Bradamante, TPSH 09

Hierarchy of A_{UT} asymmetry for various meson production.



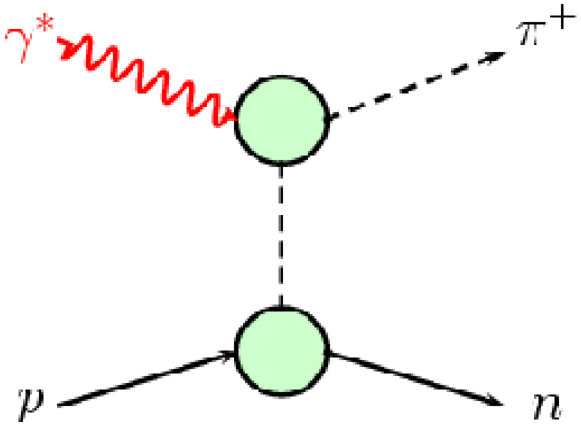


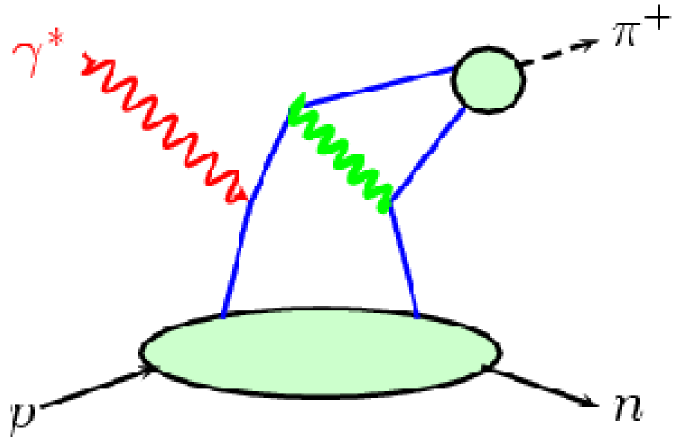
Predictions for HERMES energy $W = 5\text{GeV}$, $Q^2 = 3\text{GeV}^3$.

Predictions for COMPASS energy $W = 10\text{GeV}$. ρ^0 , ω. ρ^+ , K^{*0}

At small $-t$ $A_{UT} \propto \sqrt{-t}$. For ρ^+ flatness caused by large spin-flip contribution E to cross section $\propto t$. (No compensation between u and d quarks here) .

π^+ production.





Pion pole and handbag

contributions to π^+ production.

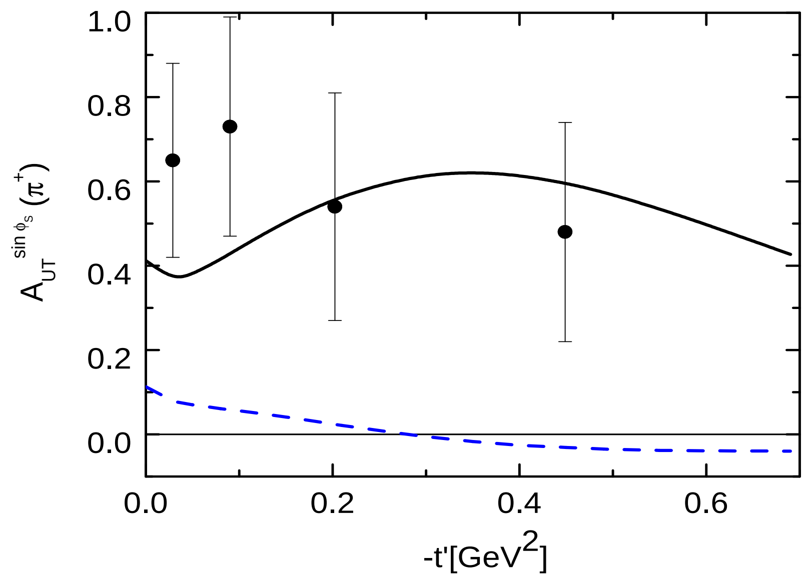
$$\mathcal{M}^{\pi^+}_{0+,0+} \propto \sqrt{1-\xi^2}\,[\langle \tilde{H}^{(3)}\rangle - \frac{2\xi m Q^2}{1-\xi^2}\frac{\rho_\pi}{t-m_\pi^2}];\ \mathcal{M}^{\pi^+}_{0-,0+} \propto \frac{\sqrt{-t'}}{2m}\left[\xi\langle \widetilde{E}^{(3)}\rangle + 2mQ^2\frac{\rho_\pi}{t-m_\pi^2}\right].$$

$$< \tilde{F} >= \sum_\lambda \int_{-1}^{1} d\overline{x}\mathcal{H}_{0\lambda,0\lambda}(\overline{x},\ldots)\tilde{F}(\overline{x},\xi,t),\ \tilde{F}^{(3)} = \tilde{F}^u - \tilde{F}^d.$$

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.

Calculation of $M_{0-,++}$ – special case.

$$M_{\mu'\nu',\mu\nu} \propto \sqrt{-t'}^{|\mu-\nu-\mu'+\nu'|}$$ from angular momentum conservation.

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

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

helicity flip GPDS $(H_T, E_T, ...)$ contributes

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

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

Double distribution model

$$H_T^a(x,0,0) = \delta^a(x)$$

transversity PDFs   Anselmino model

$$\delta^a(x) = C\, N_T^a\, x^{1/2}\,(1-x)\,[q_a(x) + \Delta q_a(x)], \quad N_T^u = 1.1,\;\; N_T^d = -0.3$$

Estimation of $M_{0+,++}$ – twist 3.

Amplitude is important in some asymmetries and cross section σ_T, σ_{TT} e.g.

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

Similar calculation of twist-3 amplitude as for H_T

$$e_T(\beta, t) = N\, e^{b_0 t} \beta^{-\alpha(t)}\, (1-\beta)^n \tag{4}$$

Double distribution model for E_T

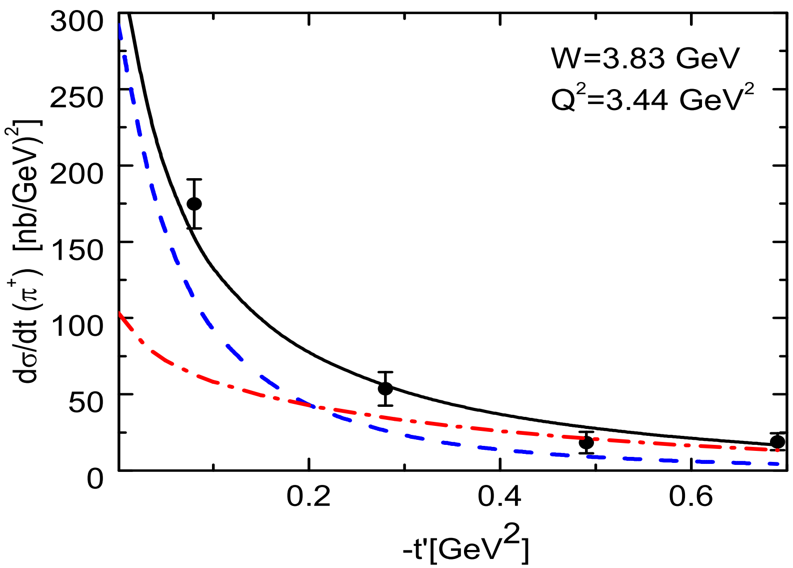
Parameters are taken from the lattice results for the moments of E_T

Moments for u and d are large and have the same sign and not very different each other

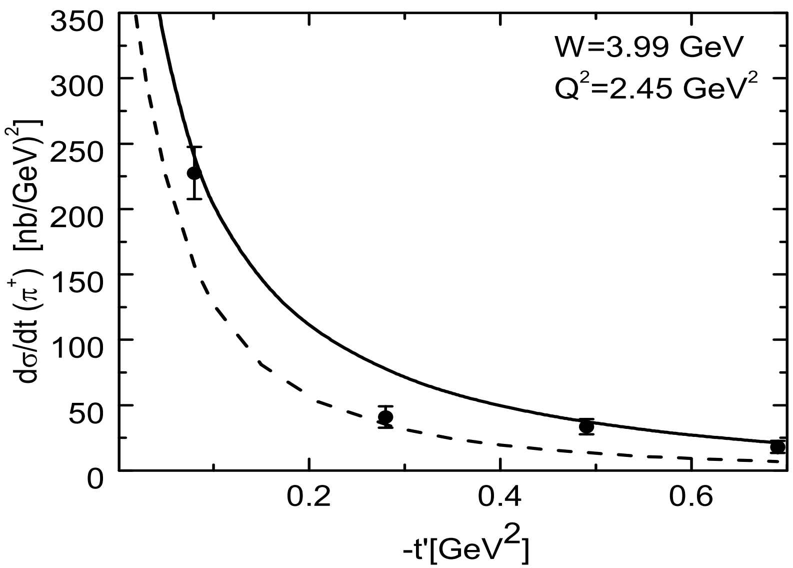
⋆ Essential compensation for π^+: $E_T^{(3)} = E_T^u - E_T^d$

⋆ Enhancement for π^0: $E_T^0 = 2/3\, E_T^u + 1/3\, E_T^d$

Cross section of π^+ production at HERMES.

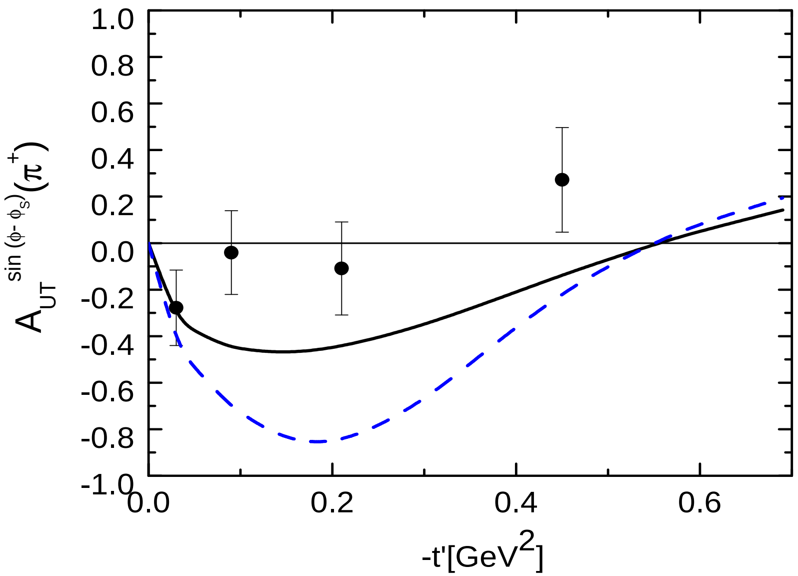


Cross section of π^+ production at HERMES with HERMES data. Full line-full cross section. dashed-dotted- $d\sigma_L/dt$, dotted line- $d\sigma_T/dt$.

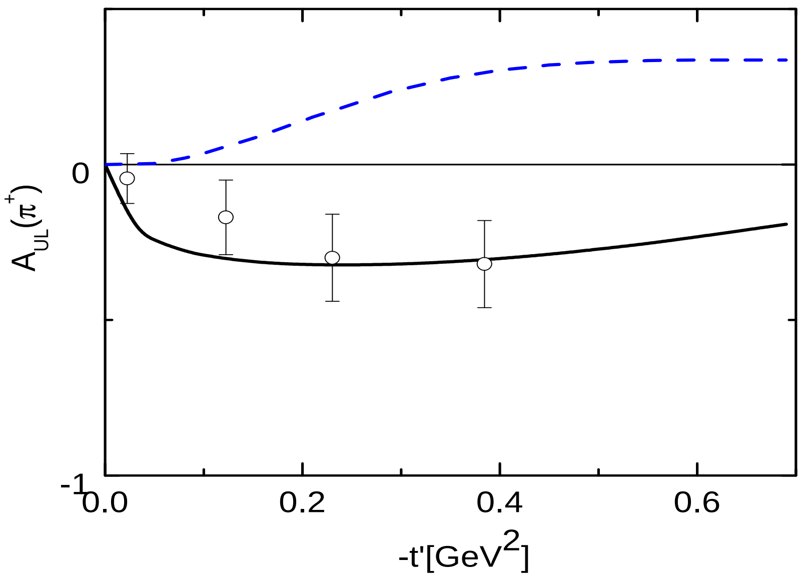


Cross section of π^+ production at HERMES with HERMES data. Full line-full cross section. Dashed line $H_T = 0$.

Asymmetry in π^+ production at HERMES H_T effects.



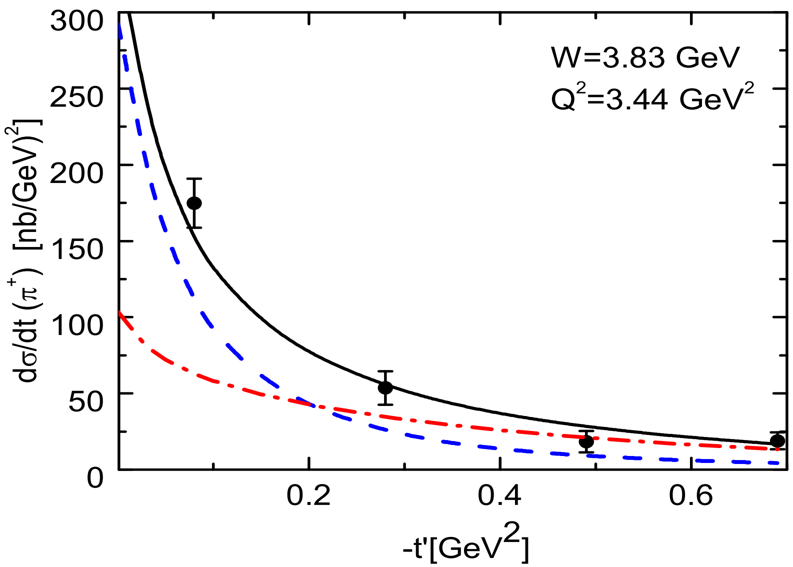
A_{UT} asymmetry of π^+ production at HERMES with HERMES data.



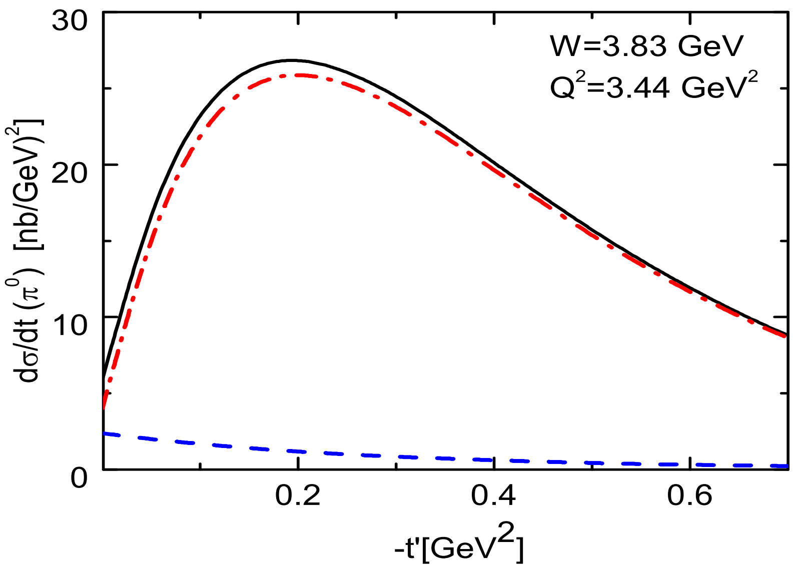
A_{UL} asymmetry of π^+ production at HERMES with HERMES data.

Dashed line- H_T is omitted.

π^+ and π^0 production at HERMES.



Cross section of π^+ production at HERMES.



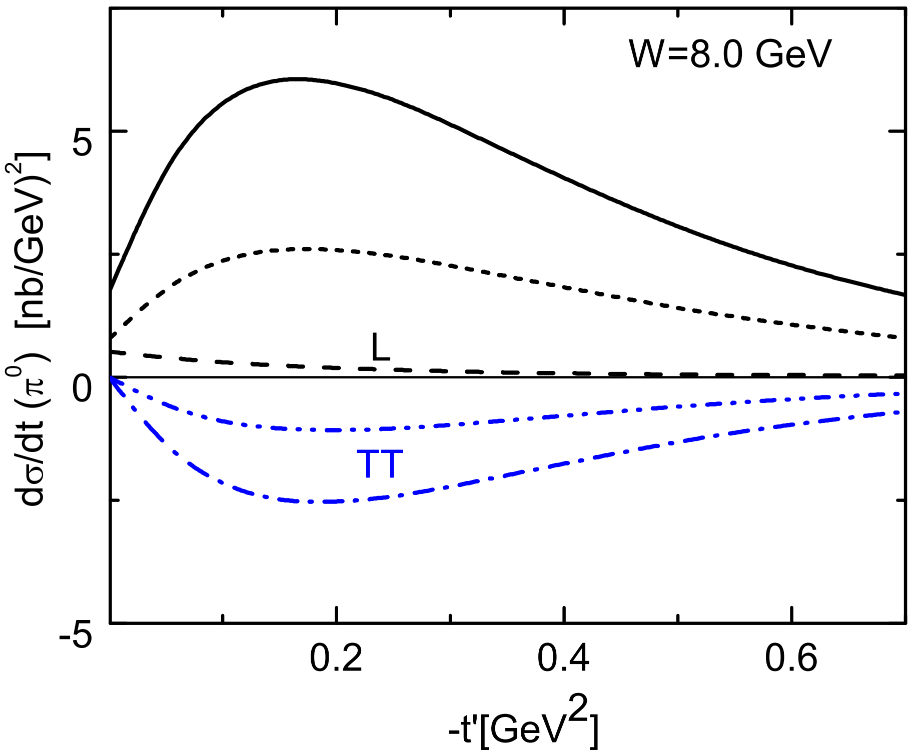
Cross section of π^0 production at HERMES.

Full line-full cross section. dashed-dotted- $d\sigma_L/dt$, dotted line- $d\sigma_T/dt$. .

π^+ production- σ_L is larger σ_T Standard situation.

π^0 production- σ_T is larger σ_L– interesting result . Large E_T effects in the cross section.

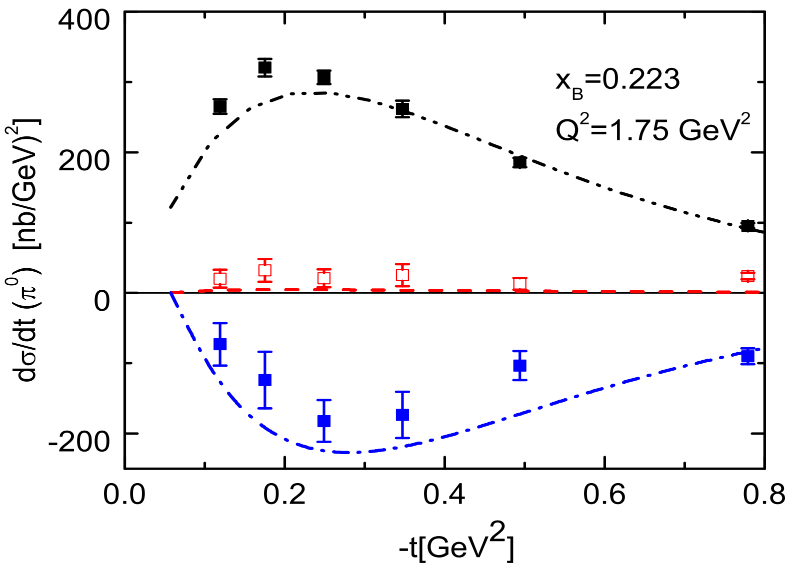
π^0 production at COMPASS.



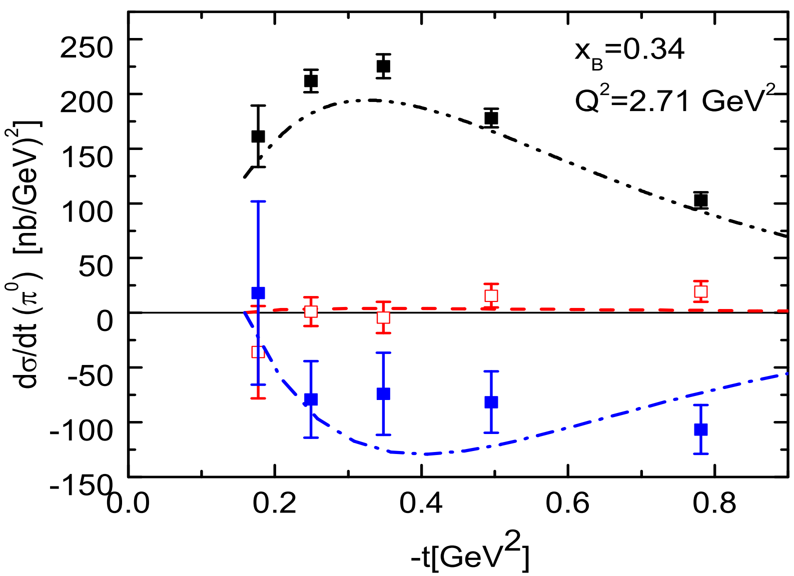
Black: full line- unseparated at $Q^2 = 3\text{GeV}^2$ -and short dashed at $Q^2 = 5\text{GeV}^2$; blue dashed dotted- σ_{TT} at $Q^2 = 3\text{GeV}^2$, dashed dotted- dotted at $Q^2 = 5\text{GeV}^2$.

Predicted effect of large σ_T can be tested. – Direct information on transversity E_T effects can be obtained.

CLAS results for π^0 production.



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

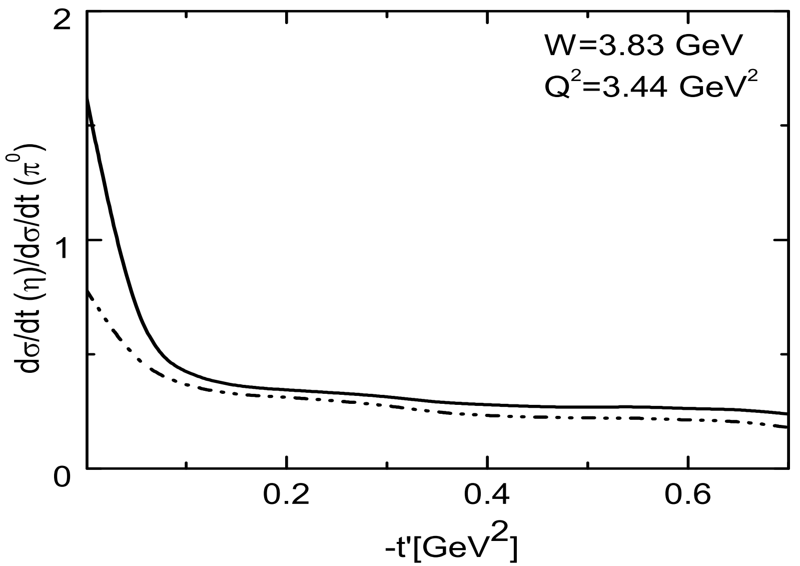


π^0 production at CLAS energy range together with CLAS data. Full line- $\sigma_T + \epsilon\sigma_L$, red dashed line-$\sigma_{LT}$, blue dashed-dotted- σ_{TT}

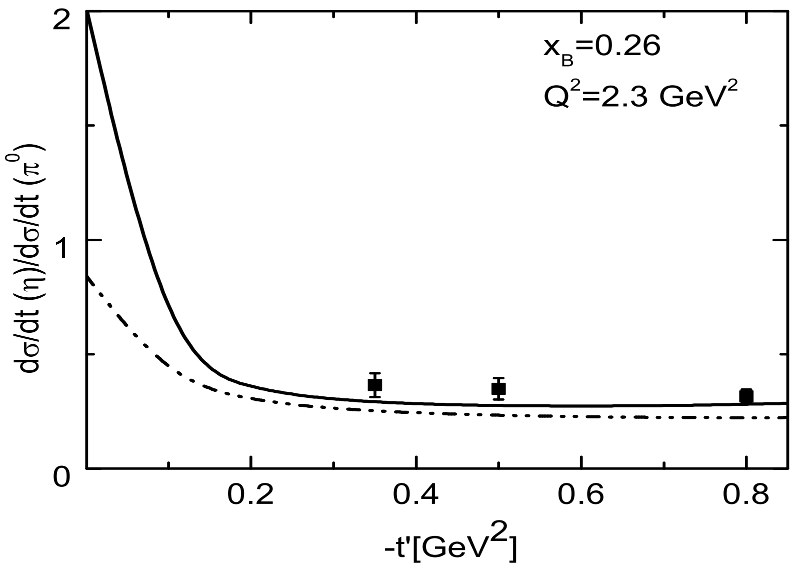
E_T contribution is large and we have at CLAS quite large transverse cross section . To check this it is necessary to have results on σ_L and σ_T separately . May be this will be possible in future experiment .

CLAS results for η/π^0 production ratio.

- At CLAS low energy range we have quite low $1.5\mathrm{GeV}^2 < Q^2 < 3.5\mathrm{GeV}^2$ and large $x_B \geq 0.2$. The handbag model typically is valid at the range of large $Q^2 > 3\mathrm{GeV}^2$ and low $x_B \leq 0.1$.
- At $-t' < 0.1\mathrm{GeV}^2$ the H_T contribution is essential. For $-t' > 0.2\mathrm{GeV}^2$ GPD $\bar{E}_T$ works and from flavor factors we get $\sim 1/3$ for cross section ratio .

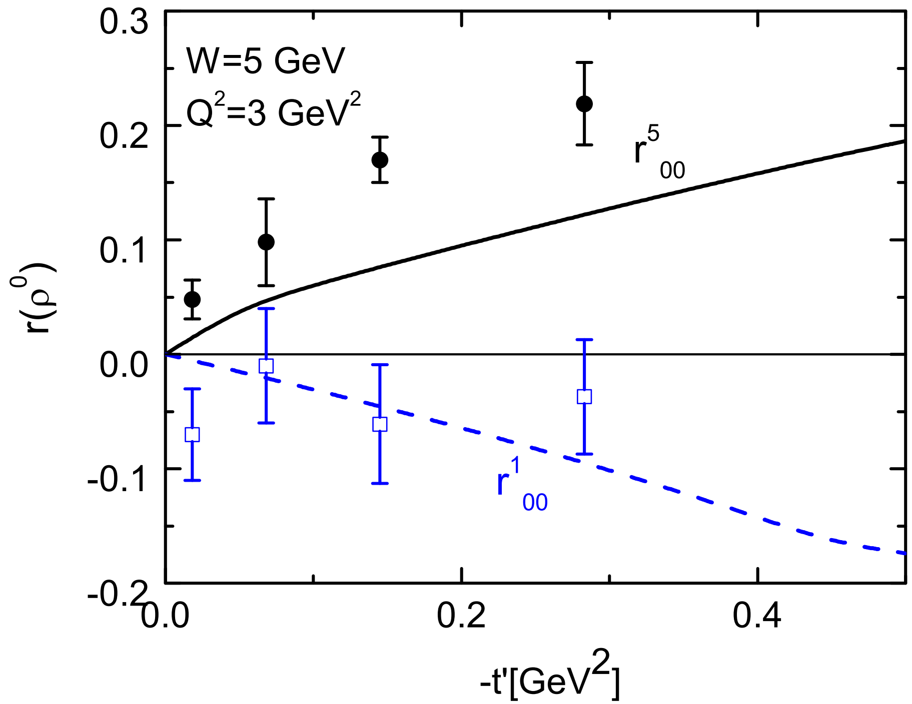


Energy dependence of η/π^0 production ratio at fixed Q^2.



η/π^0 production ratio CLAS energy range together with preliminary data.

E_T effects in SDME of ρ production at HERMES .



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

Conclusion

- We analyse meson electroproduction within handbag approach.
- GPDs are calculated using PDF on the bases of DD representation.
- GPDs from vector meson VM: –gluon, sea, valence PDFs -from CTEQ6 parameterization. Can be tested using VM production cross section -
  –polarized $\tilde{H}$ –from A_{LL} in VM production -
  – E -from Pauli nucleon FF analyses – from A_{UT} in VM production -
- GPDs from pseudoscalar meson production:
  –polarized $\tilde{H}$ GPDs.-information from π^+ production cross section -
  –$\tilde{E}$ GPDs from A_{UT} asymmetries of π^+ production
  –H_T transversity GPDs extracted from azimuthal asymmetry in semi-inclusive DIS
  Can be tested in cross section and A_{UT} asymmetries in π^+ production
  –E_T transversity GPDs– information from lattice estimations only. Essential contribution in cross section of π^0. Confirmed by CLAS. Visible in spin observables of VM production
- Direct GPDs extraction from exclusive meson production is impossible .
  Our way: parameterization of GPDs , amplitudes calculation in handbag approach ; comparison with experiment.

- Light meson electroproduction-can be an excellent object to study GPDs.
  In different energy ranges, information about quark and gluon GPDs can be extracted from the cross section and spin observables of the vector meson electroproduction.

  Future data from Electron-Ion Collider in China will give an important information on GPDs.

Thank You!