Pion Pole and Transversity Effects in Hard Exclusive Meson Leptoproduction.

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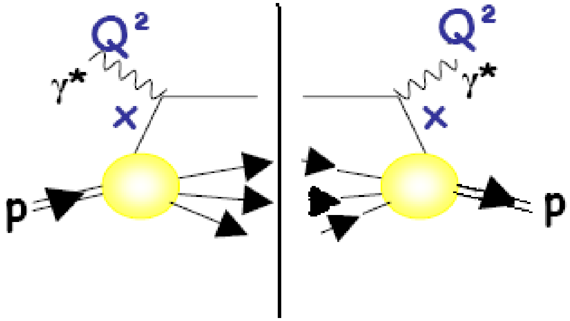
- Introduction : Handbag factorization .
- GPDs and amplitudes structure.
- Transversity effects and twist3 amplitudes
- Transversity effects in PS meson production at HERMES, COMPASS and CLAS.
- Transversity in VM production at HERMES and COMPASS.
- Pion pole effects in pseudoscalar and VM production.

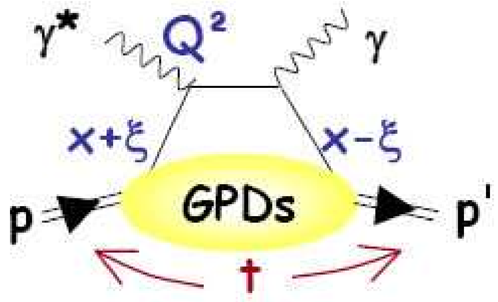
DIS and DVCD (DVMP)

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

$\star$ 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

$\star$ Spin-flip contribution. Effects of E GPDs.

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

E parameters- from Pauli form factor. M. Diehl, ...,P.Kroll

Standard connection with ordinary distribution :

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

Double distribution model is used to construct all GPDs.

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.

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

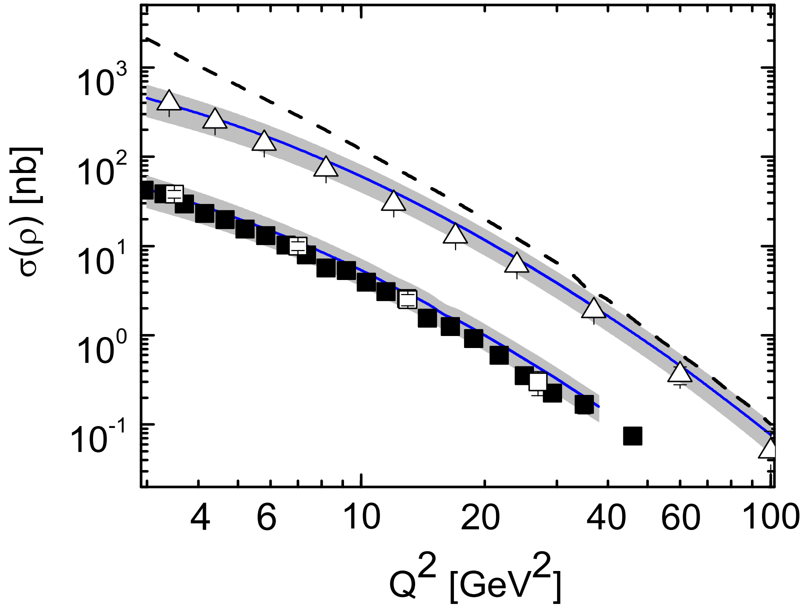
⋆ $h^q_{val}(\beta, 0) \; = q_{val}(|\beta|) \, \Theta(\beta)$ –valence contribution (n=1).

PDF t-dependence —Regge paramererization. Regge form: $\alpha_i(t) = \alpha_i(0) + \alpha' t$

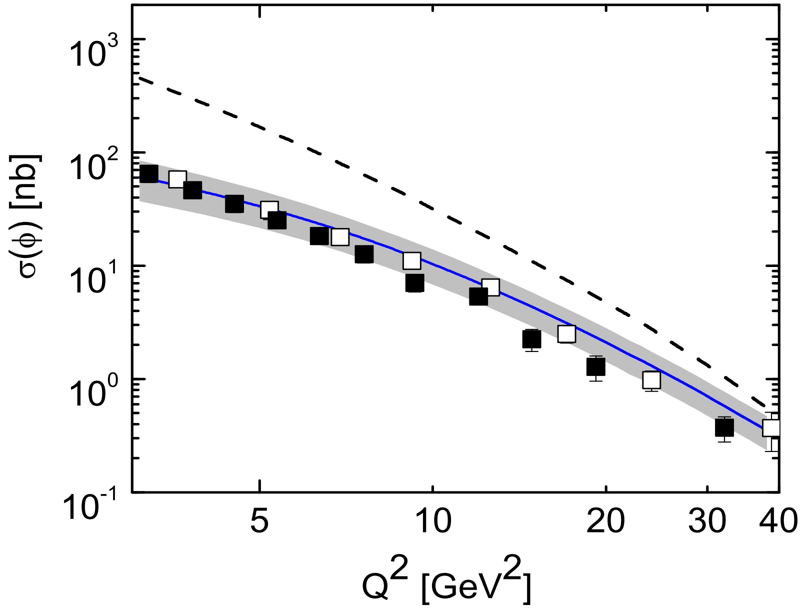
$$h(\beta, t) = N \, e^{b_0 t} \beta^{-\alpha(t)} \, (1 - \beta)^n \tag{3}$$

Cross sections of VM production

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



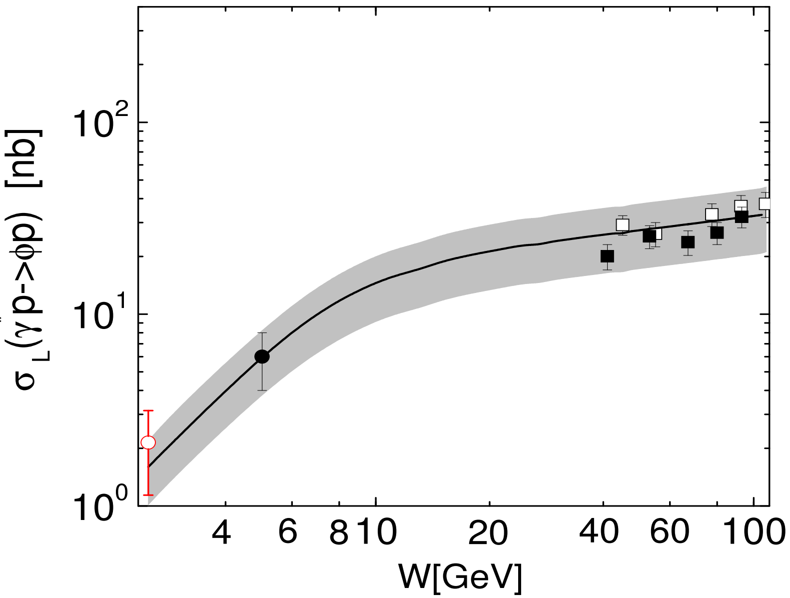
Cross sections of ρ production with errors from uncertainty in parton distributions at $W = 75$GeV/10 and $W = 90$GeV. Dashed line leading twist results.



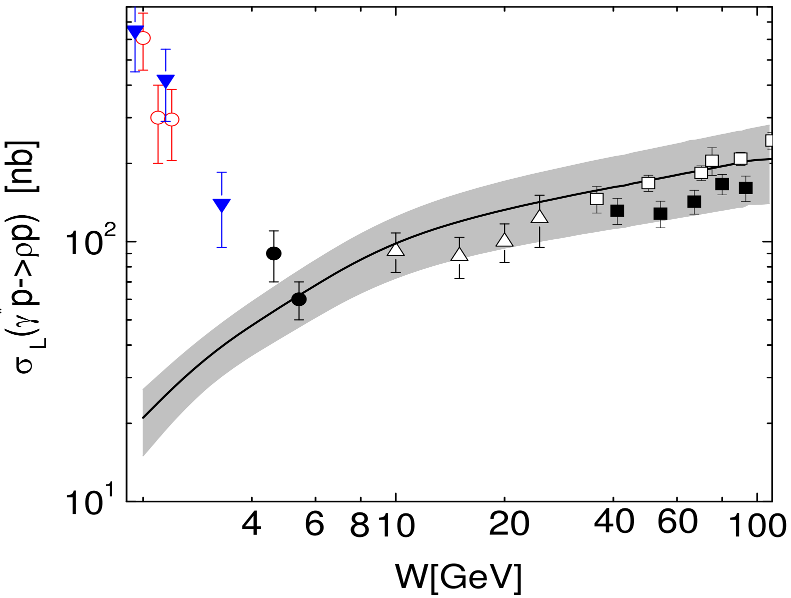
Cross sections of ϕ production with errors from uncertainty in parton distributions at $W = 75$GeV. Dashed line leading twist results.

$\star$ 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



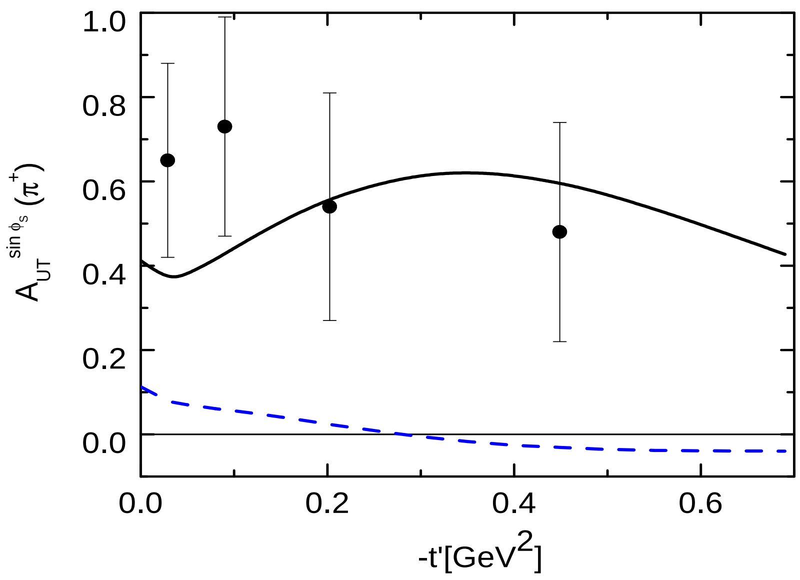
The longitudinal cross section for ρ at $Q^2 = 4.0\,\mathrm{GeV}^2$. Data: HERMES (solid circle), ZEUS (open square), H1 (solid square), E665 (open triangle), open circles- CLAS, CORNEL -solid triangle

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 ???

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 $\to const$.

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

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

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 –from azimuthal asymmetry in semi-inclusive DIS (Anselmino model)

$$\delta^a(x) = C\, N_T^a\, x^{1/2}\,(1-x)\,[q_a(x) + \Delta q_a(x)],$$

$\star$ $N_T^u = 1.1,\ N_T^d = -.3$.

Estimation of $M_{0+,++}$ – twist 3.

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

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

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 $\bar{E}_T$

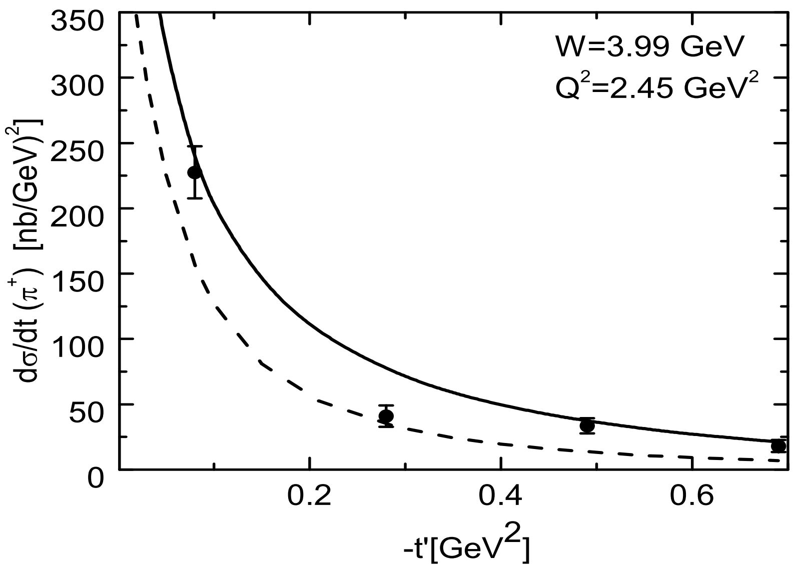
Parameters are taken from the lattice results for the moments of E_T

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

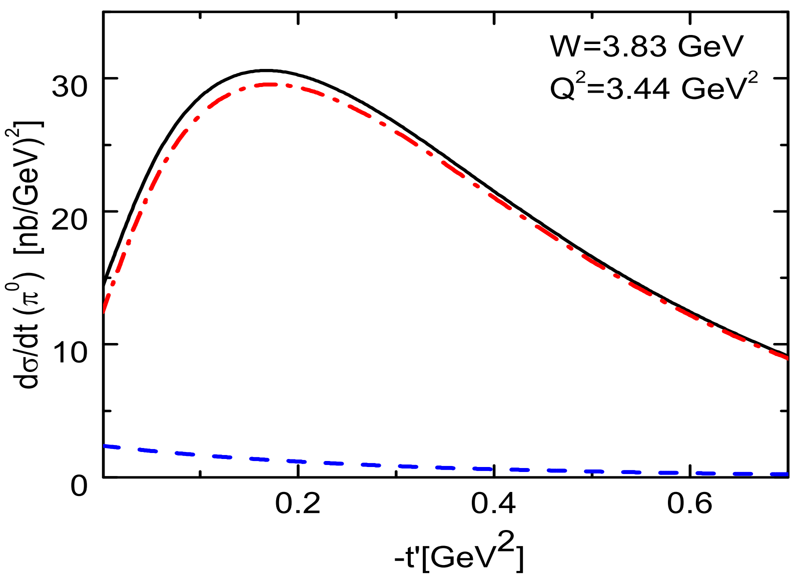
$\star$ Essential compensation for π^+: $\bar{E}_T^{(3)} = \bar{E}_T^u - \bar{E}_T^d$

$\star$ Enhancement for π^0: $\bar{E}_T^0 = 2/3\, \bar{E}_T^u + 1/3\, \bar{E}_T^d$

π^+ and π^0 production at HERMES.



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

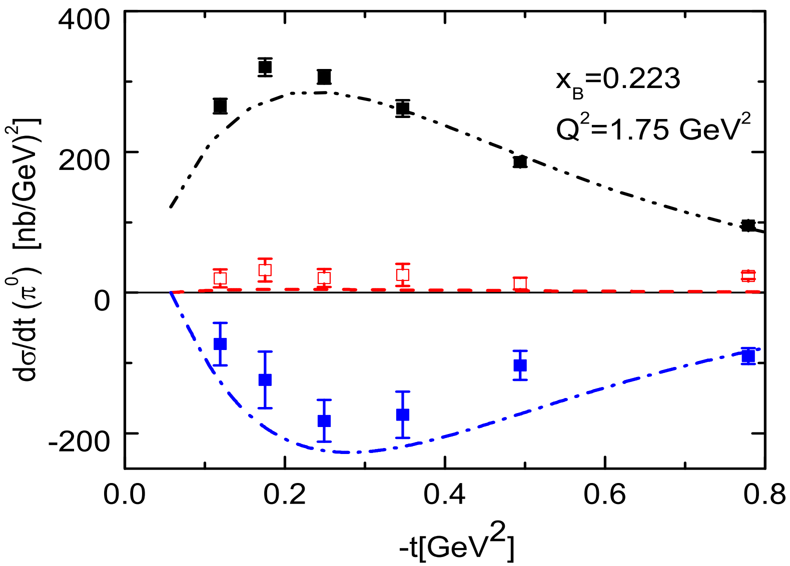


Cross section of π^0 production at HERMES. Full line-full cross section. dashed- $d\sigma_L/dt$, dashed-dotted line- $d\sigma_T/dt$.

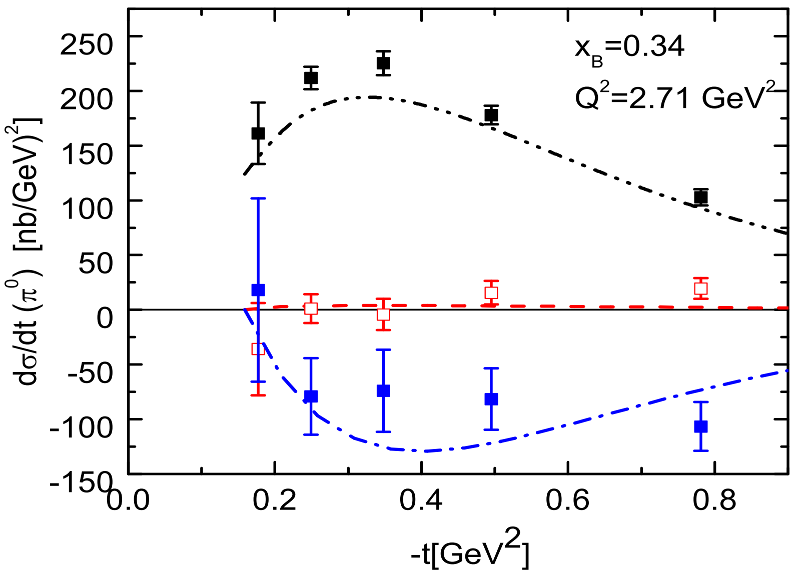
π^+ production- σ_L is larger σ_T Standard situation.

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

Some results at CLAS π^0 production.



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

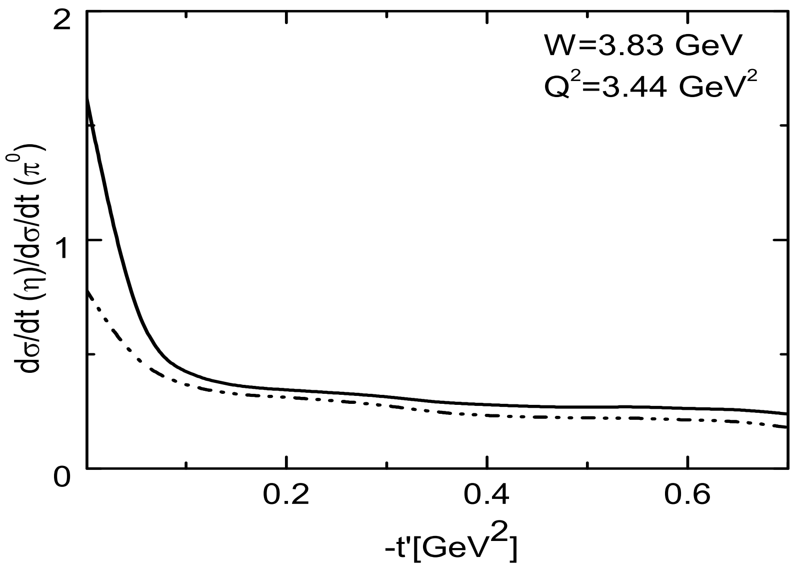


π^0 production at CLAS energy range together with CLAS data. Full line- $\sigma_T + \epsilon\sigma_L$, red dashed line-$\sigma_{LT}$, blue dashed-dotted- σ_{TT}

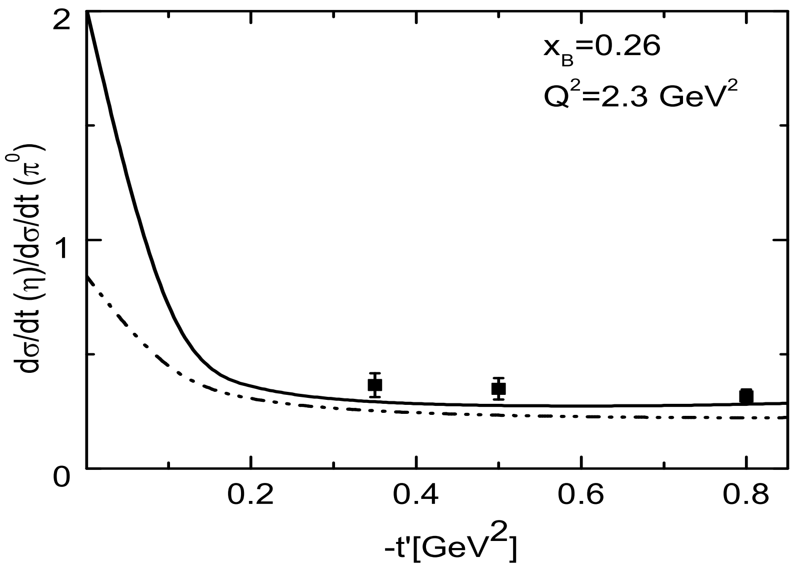
E_T contribution is large and we have at CLAS quite large transverse cross section . To check this it is necessary to have results on σ_L and σ_T separately . May be this will be possible in future JLAB12 .

CLAS results for η/π^0 production ratio.

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



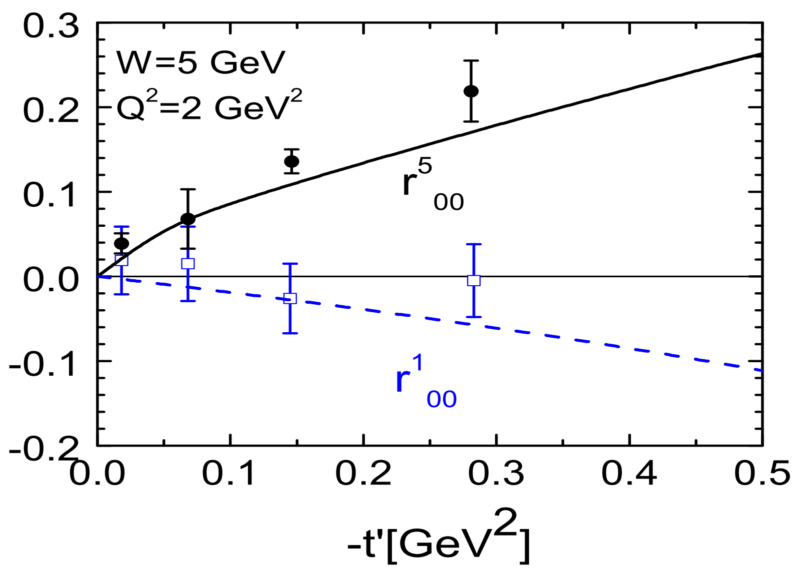
Energy dependence of η/π^0 production ratio at fixed Q^2.



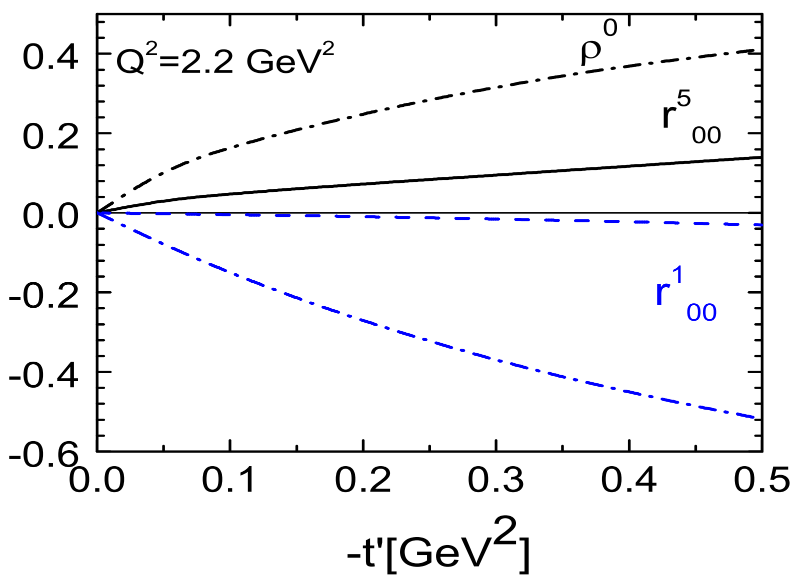
η/π^0 production ratio CLAS energy range together with preliminary data.

Transversity effects in VM production-similar to PS (SDME of ρ)

HERMES data



JLAB and COMPASS

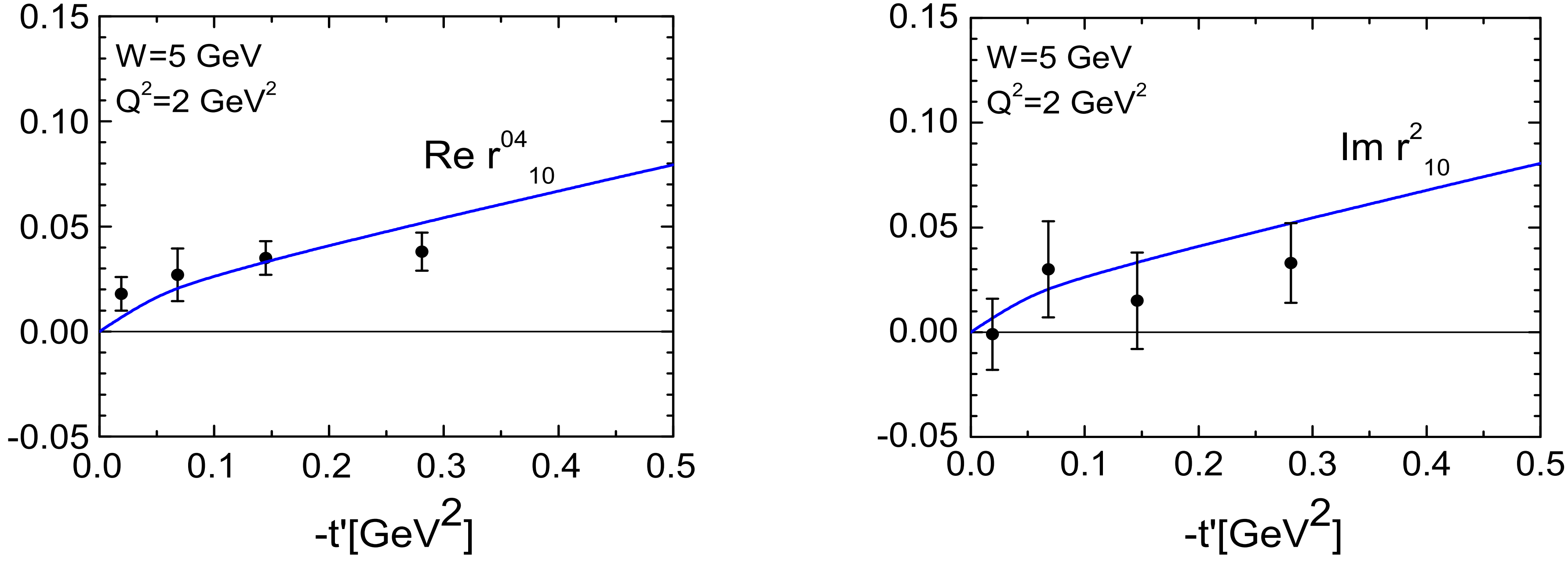


$$r^5_{00} \sim \mathrm{Re}[M^*_{0+,0+} M_{0+,++}]; \quad r^1_{00} \sim |M_{0+,++}|^2; \quad M_{0+,++} =< E_T >$$

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.

Transversity effects in SDME of ρ production

HERMES data



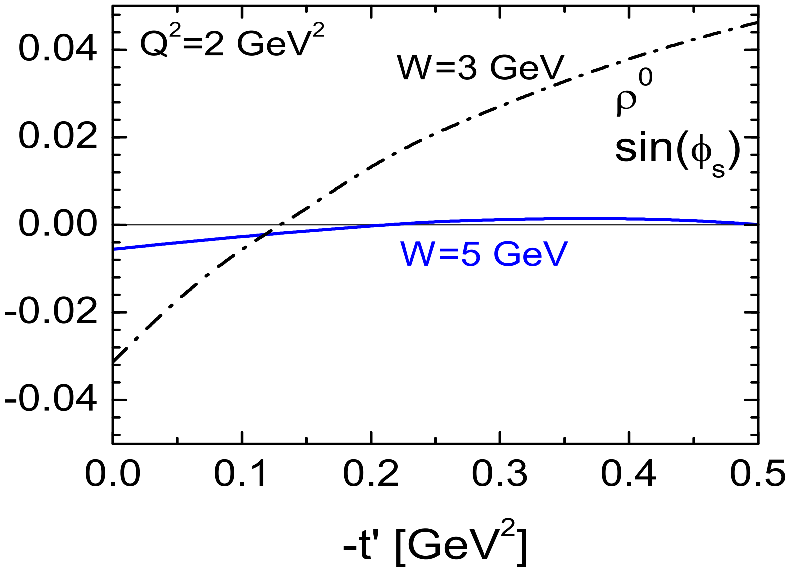
$$r_{10}^{04} \sim \text{Im} r_{10}^{2} \sim \text{Re}[M^{*}_{++,++} M_{0+,++}]; \quad M_{0+,++} =< E_T >$$

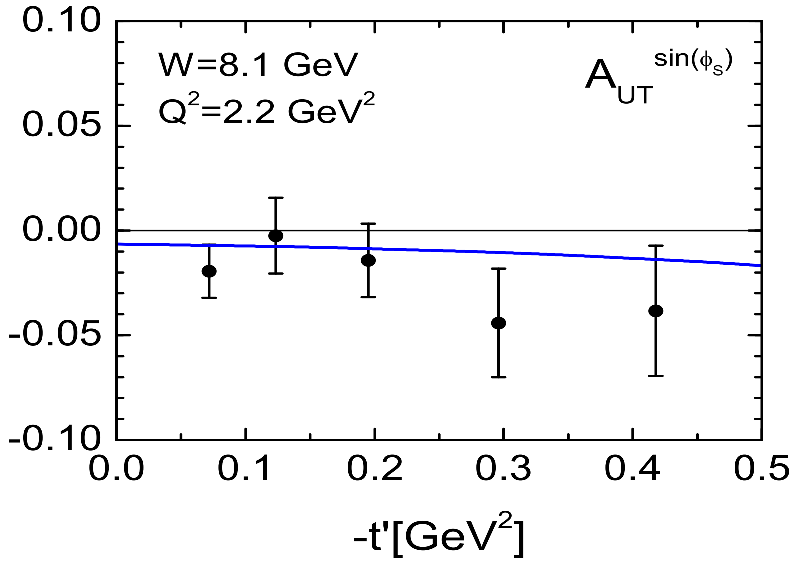
These SDMEs from theoretical point of view should be close each other .

Both SDMEs described well.

Transversity effects in A_{UT} asymmetries of ρ production.

COMPASS, data .

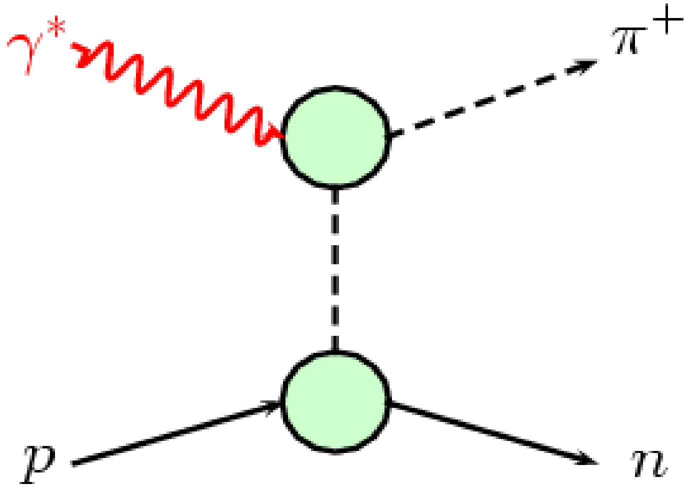


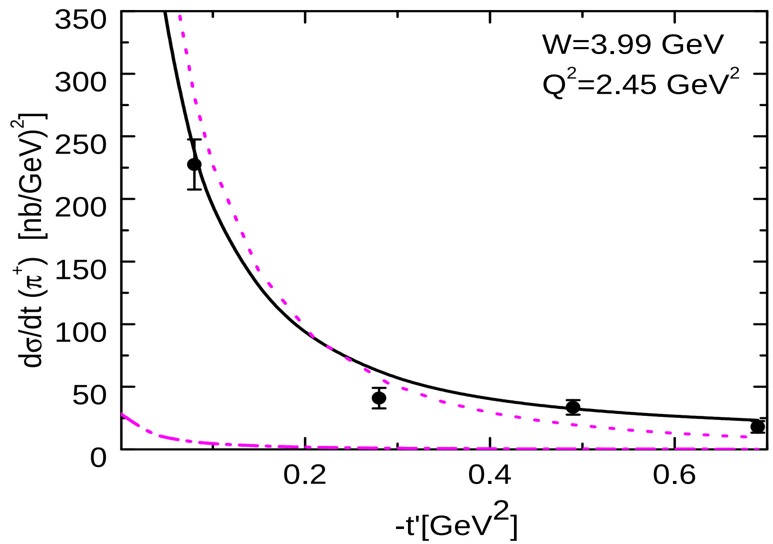


$$A_{UT}^{\sin(\phi_s)} \sim \mathrm{Im}[M^*_{0-,++} M_{0+,0+}]; \quad M_{0-,++} =< H_T >$$

Large H_T effects are compatible with results on A_{UT} asymmetries of ρ production at COMPASS energies.

Pion pole effects in π^+ production.





Dashed line-pion pole contribution to unseparated cross section.

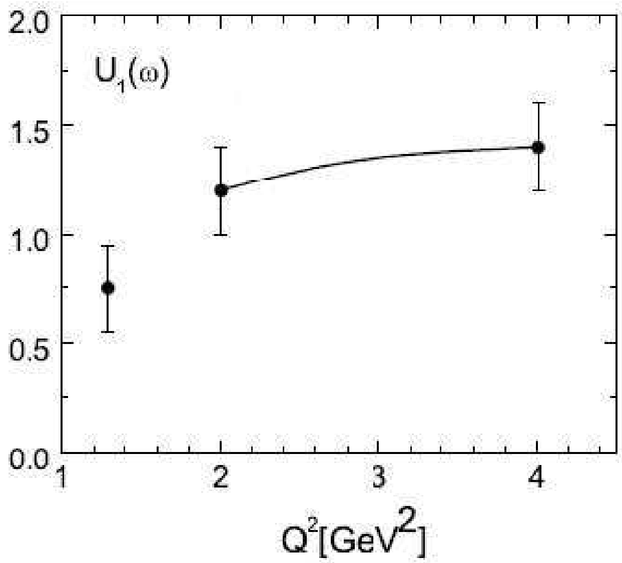
Large pion pole effects in π^+ production.

Large unnatural parity in ω production.

$$\mathcal{M}^{N}_{\mu'\nu',\mu\nu} = \frac{1}{2}\left[\mathcal{M}_{\mu'\nu',\mu\nu} + (-1)^{\mu-\mu'}\mathcal{M}_{-\mu'\nu',-\mu\nu}\right] \quad \text{The natural-parity amplitudes}$$

$$\mathcal{M}^{U}_{\mu'\nu',\mu\nu} = \frac{1}{2}\left[\mathcal{M}_{\mu'\nu',\mu\nu} - (-1)^{\mu-\mu'}\mathcal{M}_{-\mu'\nu',-\mu\nu}\right] \quad \text{unnatural-parity amplitudes}$$

$$U_1 = 2\,\frac{d\sigma^U(\gamma^*_T \to V_T) + \varepsilon d\sigma^U(\gamma^*_L \to V_T)}{d\sigma}\,.$$

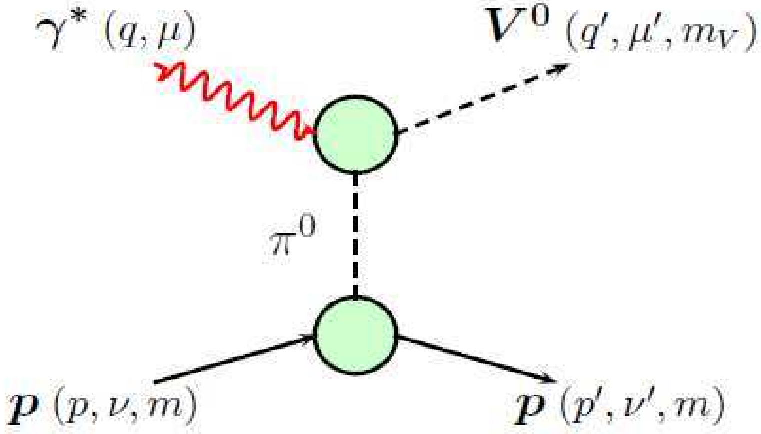


Hermes data 2014.

UP contributions which are usually small becomes even large than NP amplitudes for ω.

$\star$ Can be caused by large pion pole effect in ω production at HERMES.

Pion pole effects in VM production.



$$\mathcal{M}^{\rm pole}_{++,++} \sim \frac{\varrho_{\pi V}}{t - m_\pi^2} \frac{m\xi Q^2}{\sqrt{1-\xi^2}}$$

$$\mathcal{M}^{\rm pole}_{+-,++} \sim -\frac{\varrho_{\pi V}}{t - m_\pi^2} \frac{\sqrt{-t'}Q^2}{2}$$

$$\rho_{\pi V} \propto g_{\pi V}(Q^2)\, g_{\pi NN} F_{\pi NN}(t)$$

Transition form factor $g_{\pi V}(0)$ is determined from VM radiative decay .

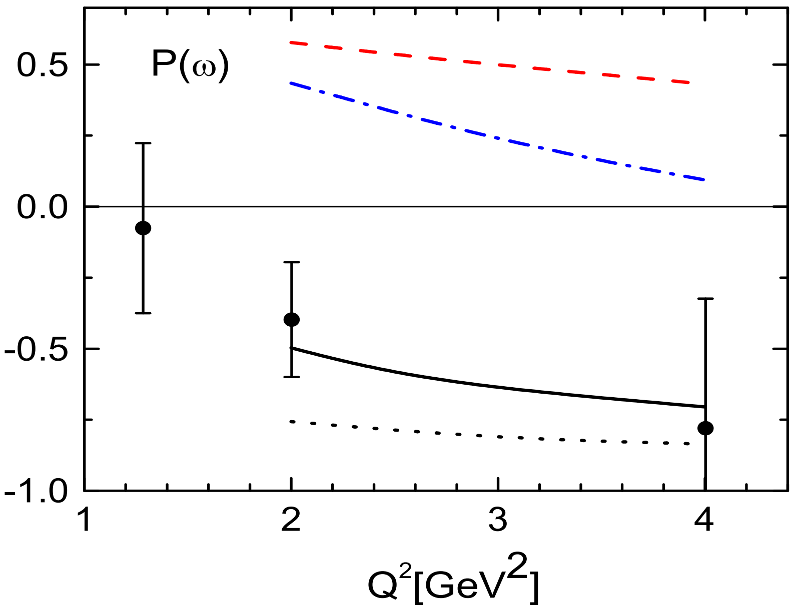
$$\Gamma(V \to \pi\gamma) \;\sim\; \frac{\alpha_{elm}}{24} |g_{\pi V}(0)|^2 M_V^3 \qquad (5)$$

$$|g_{\pi\omega}(0)| = 2.3 \mathrm{GeV}^{-1} \quad , \quad |g_{\pi\rho}(0)| = .85 \mathrm{GeV}^{-1}$$

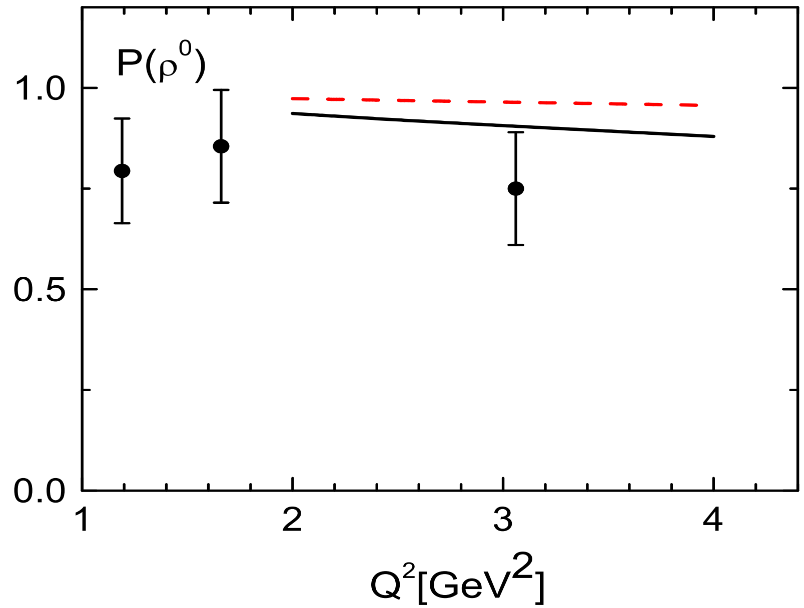
Q^2-dependence $g_{\pi V}(Q^2)$ from U_1. $|g_{\pi\omega}|$ about 3 times larger $|g_{\pi\rho}|$ -large UP effects in ω production

Natural and unnatural parity asymmetry P

$$P = \frac{d\sigma^N(\gamma_T^* \to V_T) - d\sigma^U(\gamma_T^* \to V_T)}{d\sigma^N(\gamma_T^* \to V_T) + d\sigma^U(\gamma_T^* \to V_T)}$$



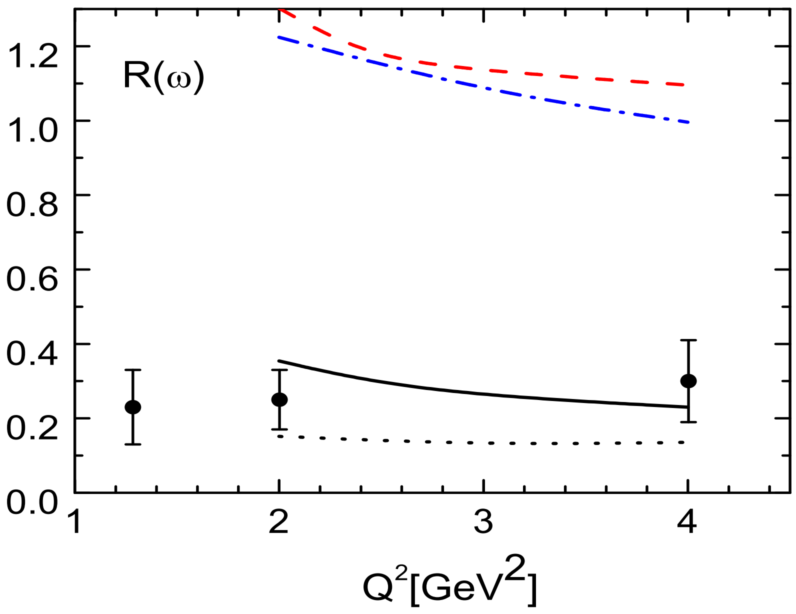
$P(\omega)$ at HERMES. Black solid with pion pole(PP), Red-dashed -without PP. Black dotted-for $W = 3.5$GeV (CLAS), Blue dashed-dotted for $W = 8$GeV (COMPASS)



$P(\rho^0)$ at HERMES. Black solid with pion pole(PP), Red-dashed -without PP.

Ratio of longitudinal and transverse cross section.

$$R \simeq \frac{d\sigma(\gamma^*_L \to V_L)}{d\sigma(\gamma^*_T \to V_T)}$$

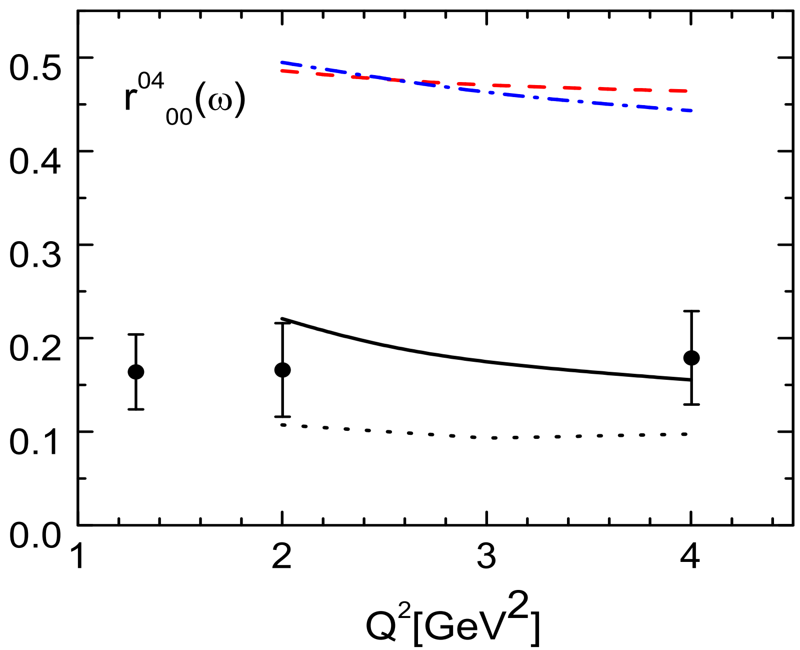


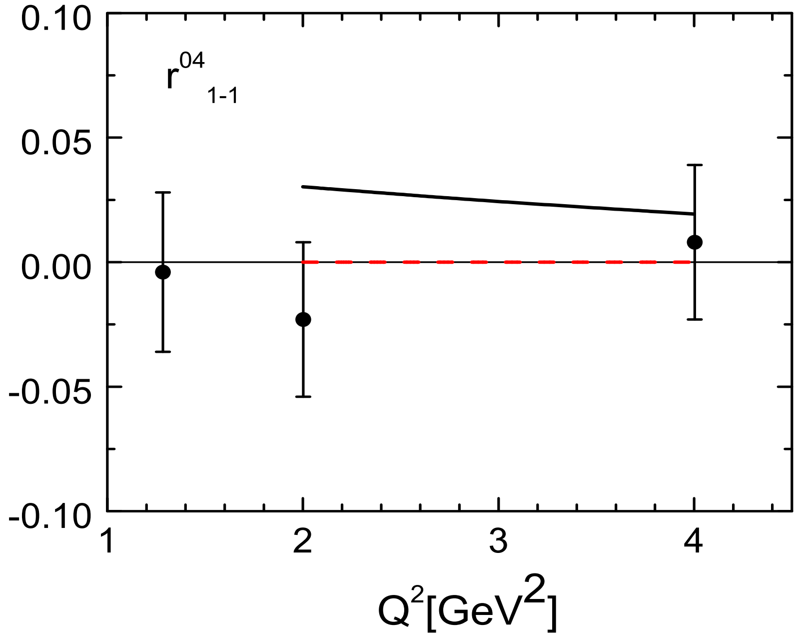
R ratio can be described only with pion pole – large contribution to transverse amplitude.

For ρ -$R \sim$ nonpole case.

Pion pole effects in SDMEs- ω production

HERMES data





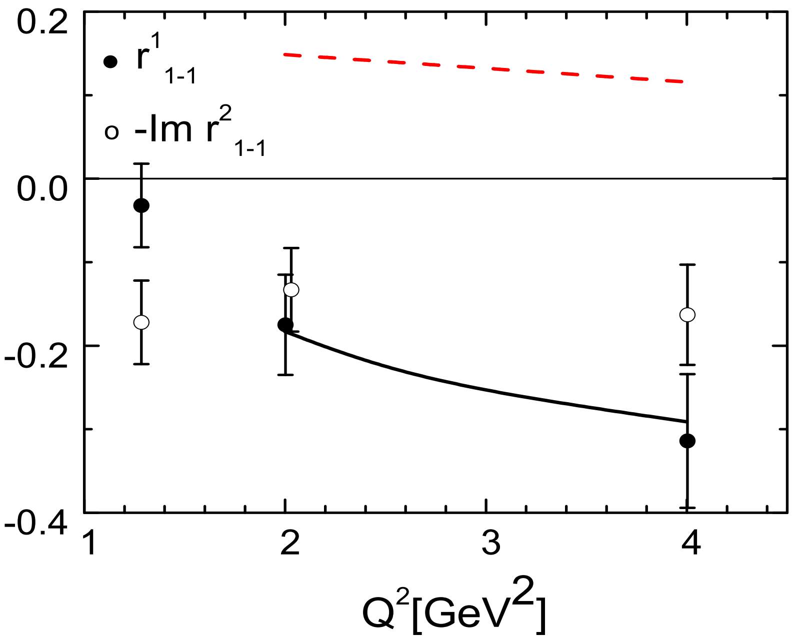
$$r^{04}_{00} = \frac{d\sigma(\gamma^*_T \to V_L) + \epsilon d\sigma(\gamma^*_L \to V_L)}{d\sigma}$$

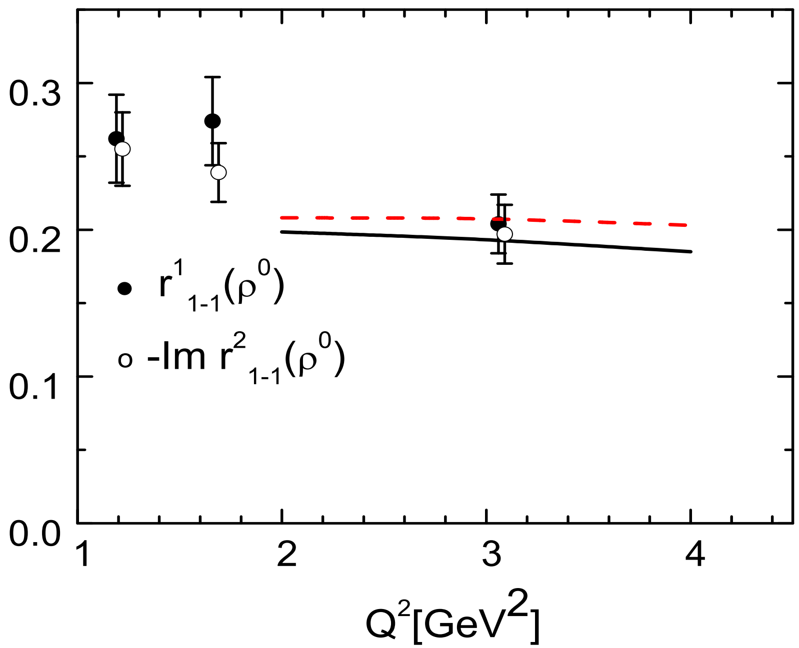
$$r^{04}_{1-1} = \frac{\epsilon d\sigma^U(\gamma^*_L \to V_T)}{2d\sigma}$$

r^{04}_{00} is connected with R -ratio. r^{04}_{1-1} show directly UP and NP cross section ratio.

Pion pole effects in SDMEs- ω and ρ production

ω HERMES data ρ



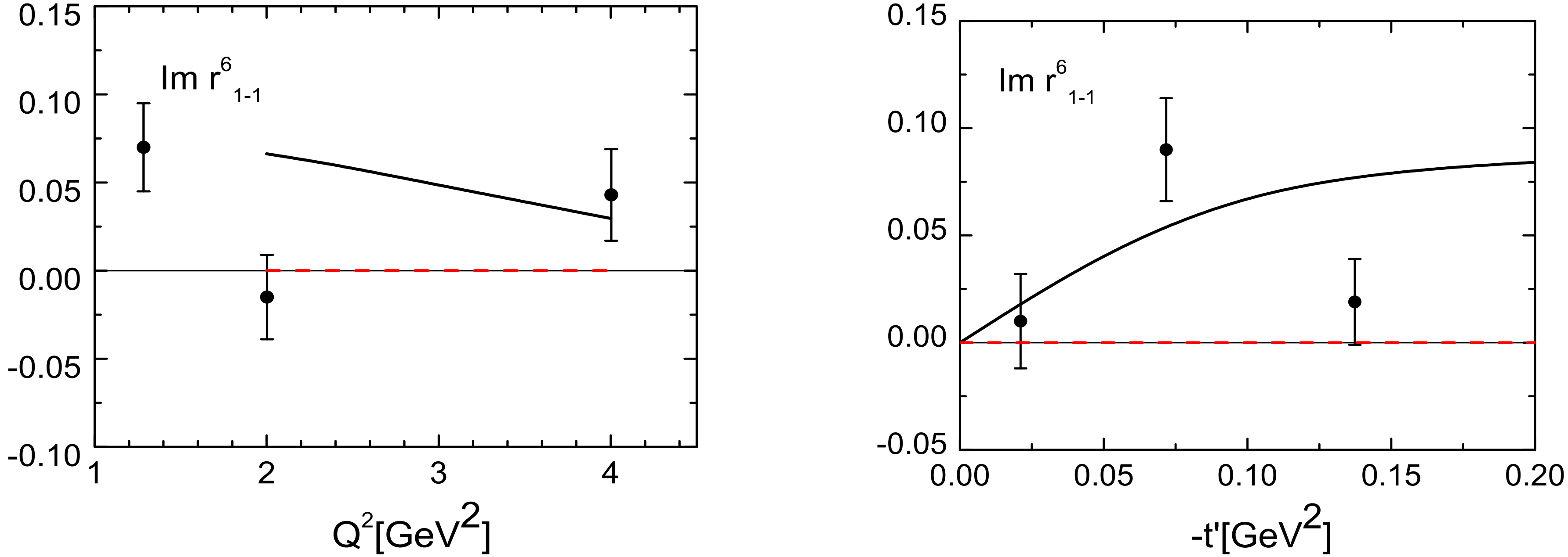


$$r^1_{1-1} = -\text{Im} r^2_{1-1} = \frac{d\sigma^N(\gamma^*_T \to V_T) - \sigma^U(\gamma^*_T \to V_T)}{2d\sigma}$$

Show difference of NP and UP contributions . Large for ω and small for ρ

Pion pole effects in SDMEs -Q^2 and t dependencies

HERMES data



$$\mathrm{Im}r^6_{1-1} \sim \mathrm{Re}M^U(+-++)M^U(+-0+)$$

-Interference of two UP amplitudes. For zero pion pole $\mathrm{Im}r^6_{1-1}$ is zero

Conclusion

- Modified PA is used to calculate hard subprocess amplitude.
- GPDs are calculated using PDFs on the bases of the DD representation.
- Leading twist effects are not sufficient. Transversity twist-3 effects are needed.
- Essential role of transversity in pseudoscalar meson production is shown. (Cross section)
- Transversity effects should be visible in VM production at HERMES and COMPASS.
- Pion pole contribution play an important role in ω production

$\star$ Light meson electroproduction-can be an excellent object to study GPDs.

Thank You!