Unnatural Parity Effects in Hard Exclusive ω Leptoproduction.

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- Introduction : Handbag factorization .
- GPDs and amplitudes structure.
- Transversity effects in PS and VM meson production at HERMES, COMPASS and CLAS.
- Pion pole= unnatural parity (UP) effects in PS and VM production..
- UP effects in ω SDMEs at HERMES and COMPASS
- UP effects in ω spin asymmetries at HERMES and COMPASS

⋆ 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

⋆ 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.

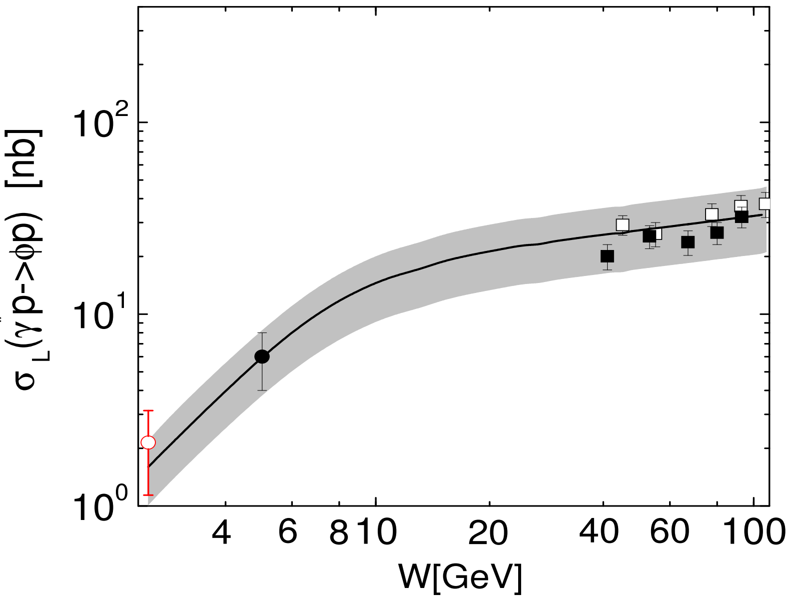
$$f_i(\beta,\alpha,t) = h_i(\beta,t)\,\frac{\Gamma(2n_i+2)}{2^{2n_i+1}\,\Gamma^2(n_i+1)}\,\frac{[(1-|\beta|)^2-\alpha^2]^{n_i}}{(1-|\beta|)^{2n_i+1}}\,, \tag{2}$$

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

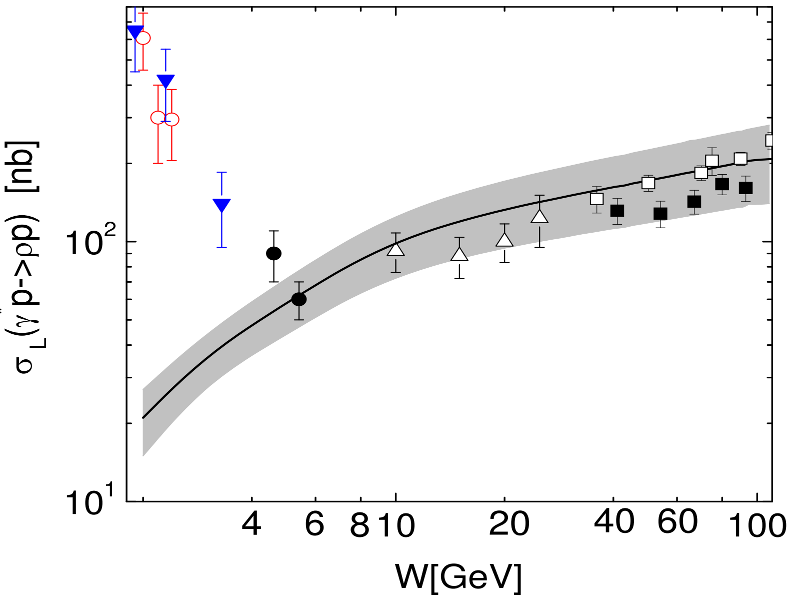
PDF t-dependence —Regge paramererization. Regge form: $\alpha_i(t)=\alpha_i(0)+\alpha' t$

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

Cross 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



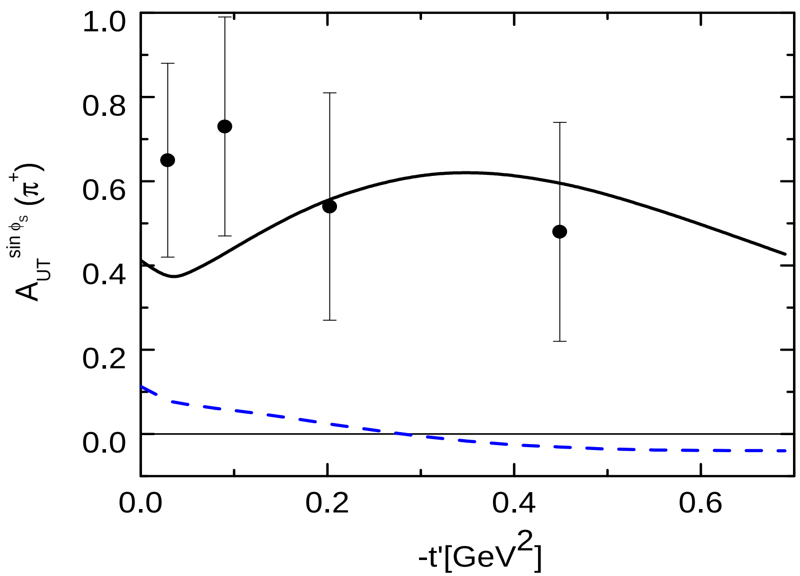
The longitudinal cross section for ρ at $Q^2 = 4.0\,\mathrm{GeV}^2$. Data: HERMES (solid circle), ZEUS (open square), H1 (solid square), E665 (open triangle), open circles- CLAS, CORNEL -solid triangle

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)

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

⋆ $N_T^u = 1.1,\ N_T^d = -.3$.

Estimation of $M_{0+,++}$ – twist 3.

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

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

Similar calculation of twist-3 amplitude as for H_T

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

Double distribution model for $\bar{E}_T$

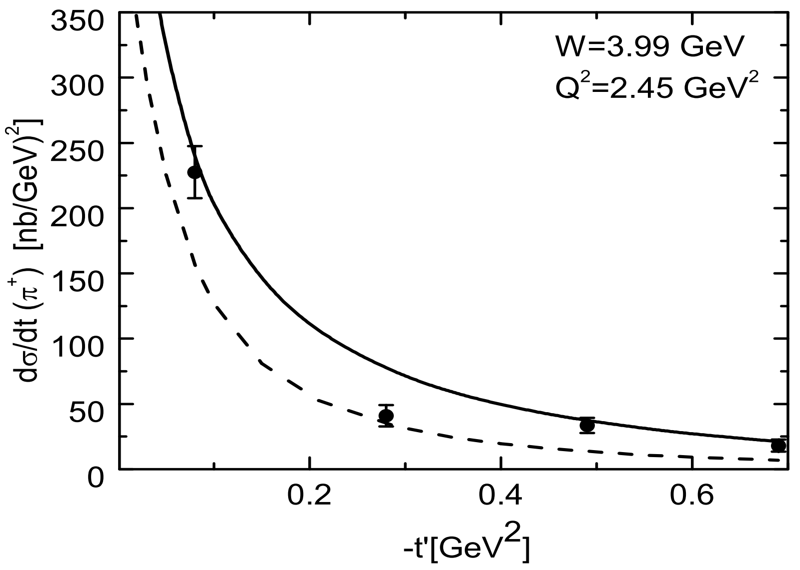
Parameters are taken from the lattice results for the moments of E_T

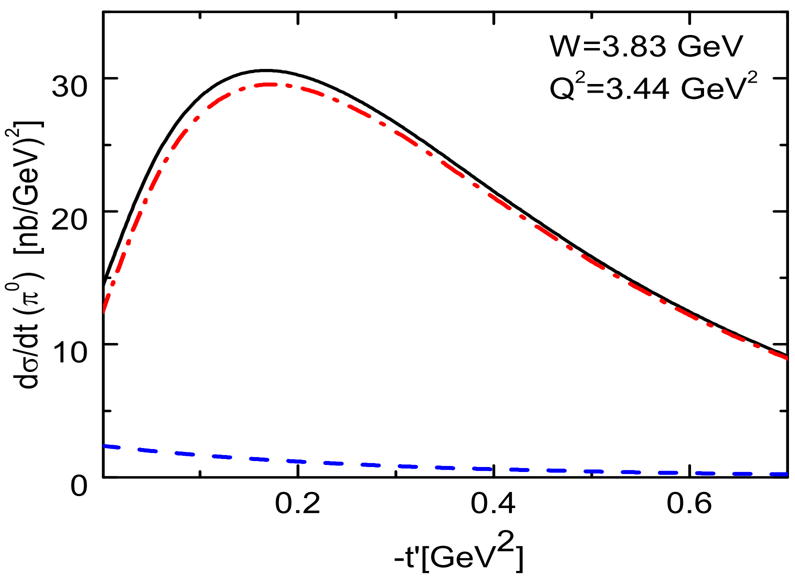
Moments for u and d are large and have the same sign and not very different each other

⋆ Essential compensation for π^+: $\bar{E}^{(3)}_T = \bar{E}^u_T - \bar{E}^d_T$

⋆ Enhancement for π^0: $\bar{E}^0_T = 2/3\, \bar{E}^u_T + 1/3\, \bar{E}^d_T$

π^+ and π^0 production at HERMES.





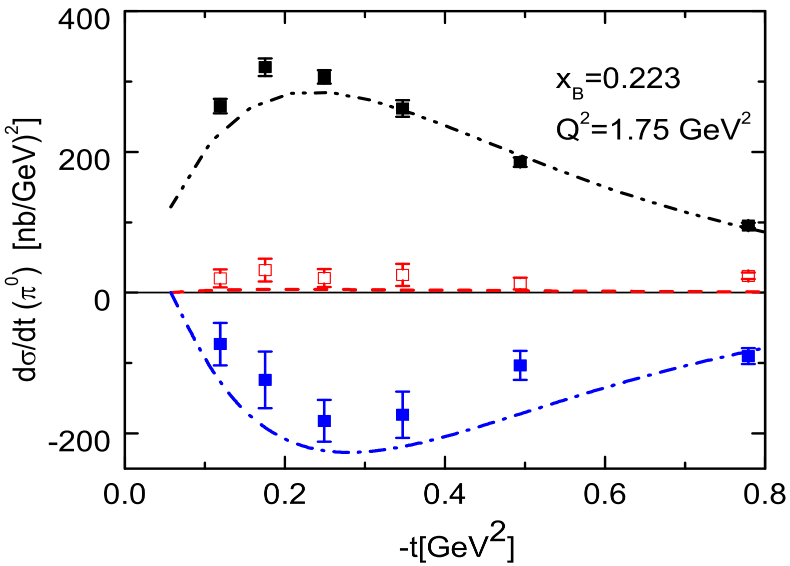
Cross section of π^+ production at HERMES with HERMES data. Full line-full cross section. Dashed line $H_T = 0$.

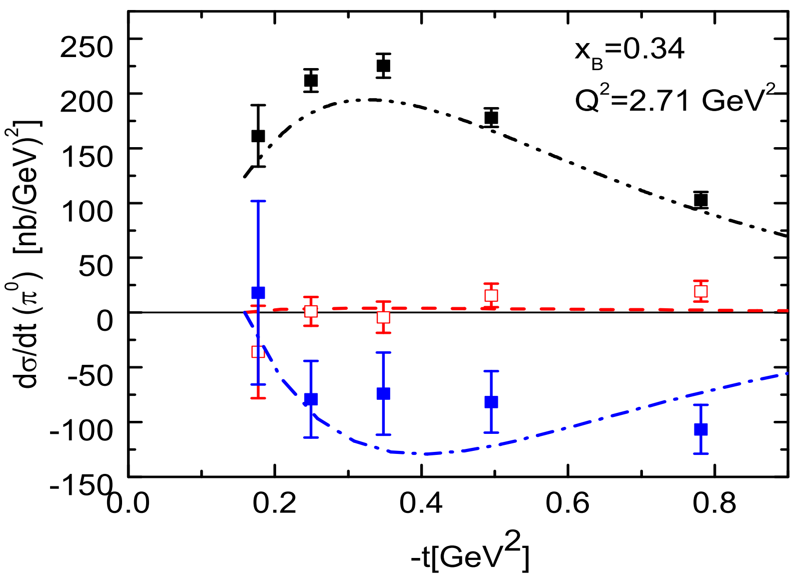
Cross section of π^0 production at HERMES. Full line-full cross section. dashed- $d\sigma_L/dt$, dashed-dotted line- $d\sigma_T/dt$.

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.





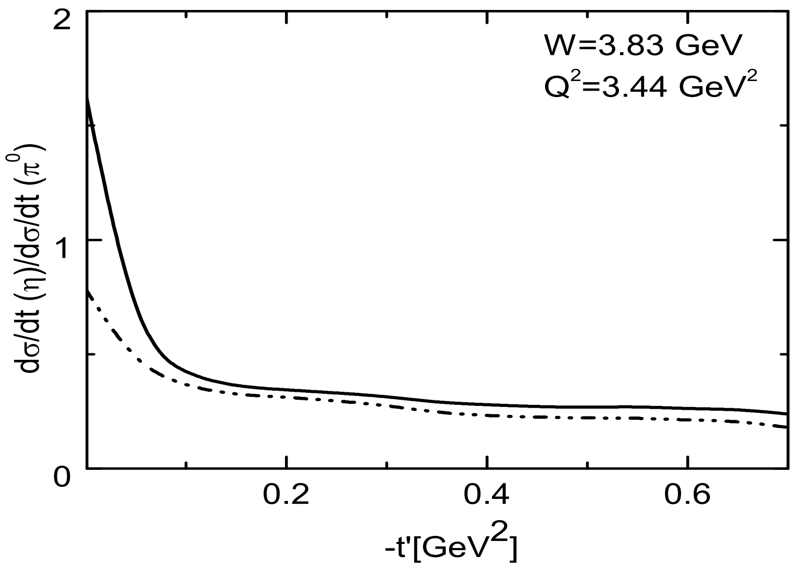
π^+ production at CLAS energy range together with CLAS data.

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}

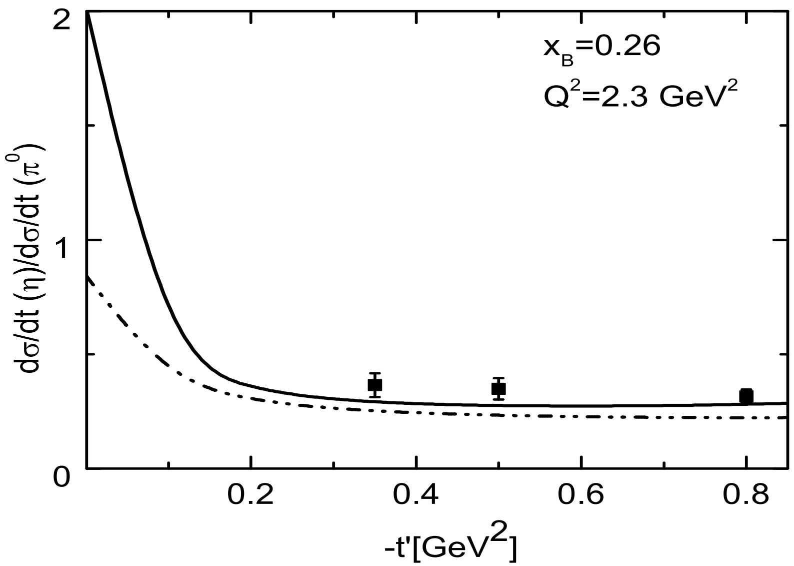
E_T contribution is large and we have at CLAS quite large transverse cross section . To check this it is necessary to have results on σ_L and σ_T separately . May be this will be possible in future JLAB12 .

CLAS results for η/π^0 production ratio.

- At CLAS low energy range we have quite low $1.5\mathrm{GeV}^2 < Q^2 < 3.5\mathrm{GeV}^2$ 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 .



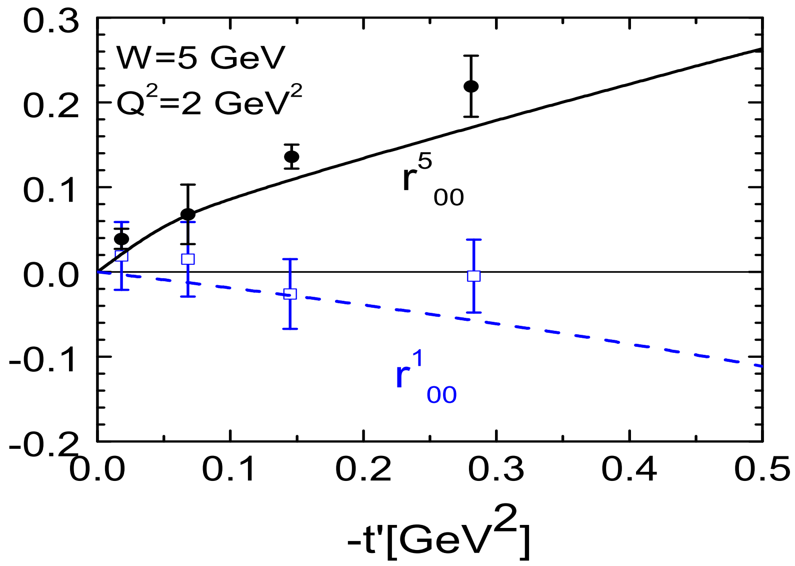
Energy dependence of η/π^0 production ratio at fixed Q^2.



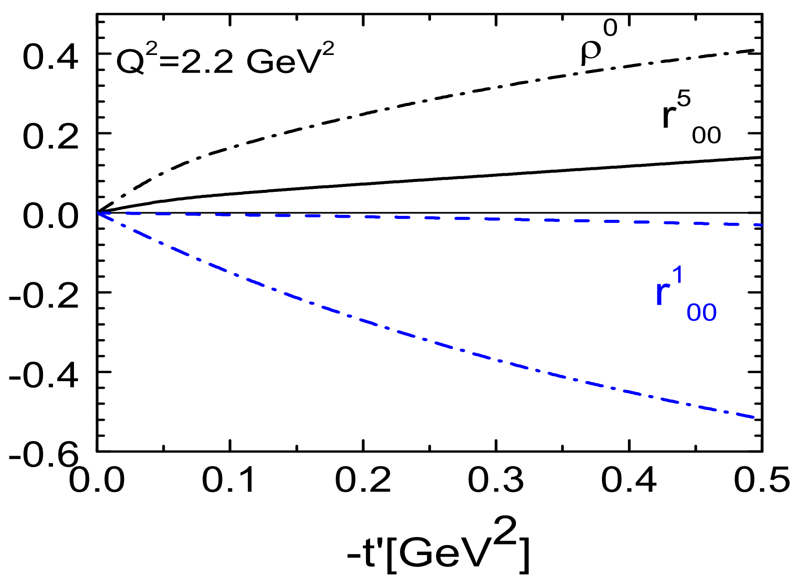
η/π^0 production ratio CLAS energy range together with preliminary data.

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

HERMES data



JLAB and COMPASS

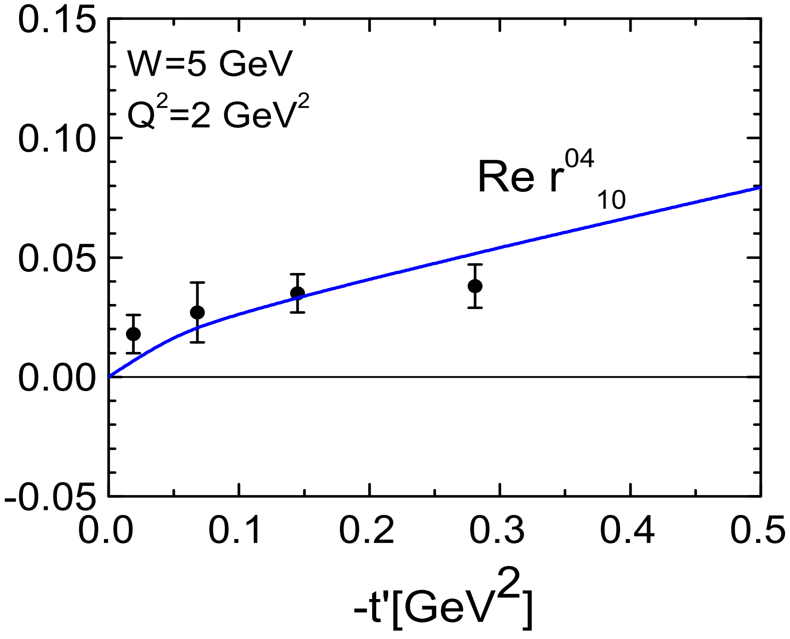


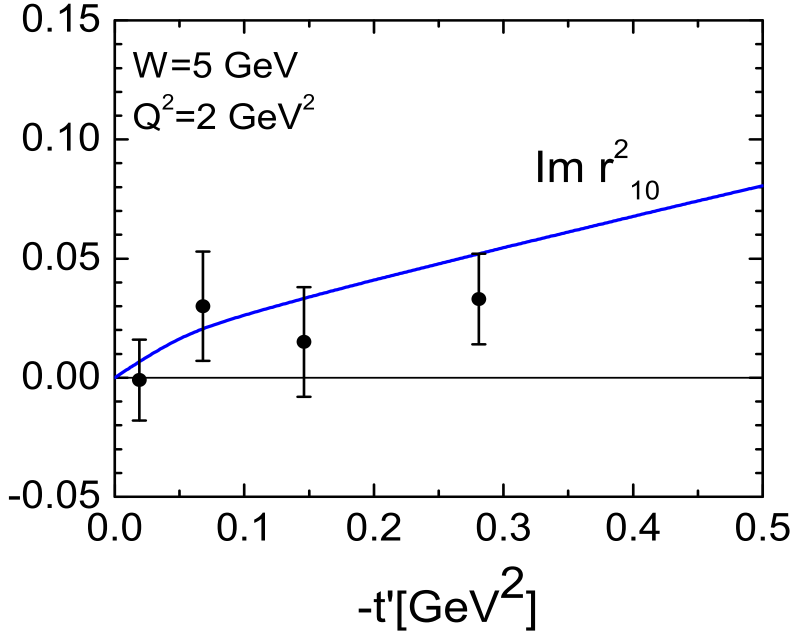
$$r^5_{00} \sim \mathrm{Re}[M^*_{0+,0+} M_{0+,++}]; \quad r^1_{00} \sim |M_{0+,++}|^2; \quad M_{0+,++} =< E_T >$$

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





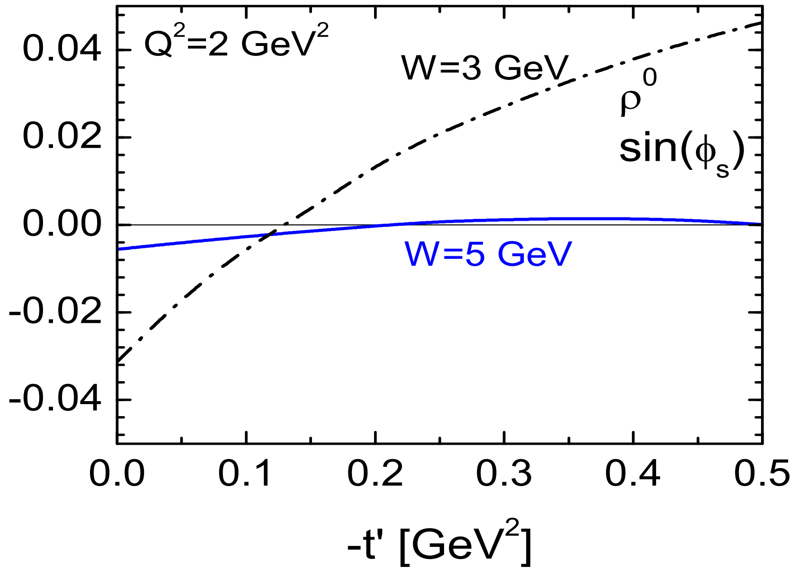
$$r^{04}_{10} \sim \text{Im} r^2_{10} \sim \text{Re}[M^*_{++,++} M_{0+,++}]; \quad M_{0+,++} =< E_T >$$

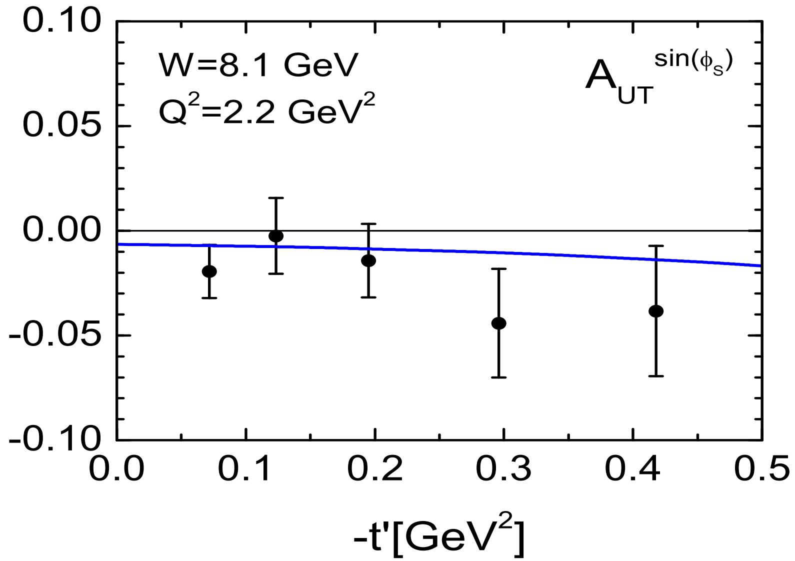
These SDMEs from theoretical point of view should be close each other .

Both SDMEs described well.

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

COMPASS, data .

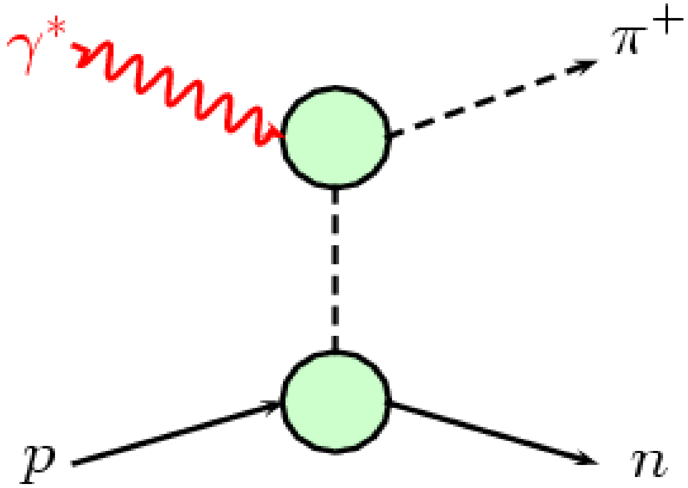


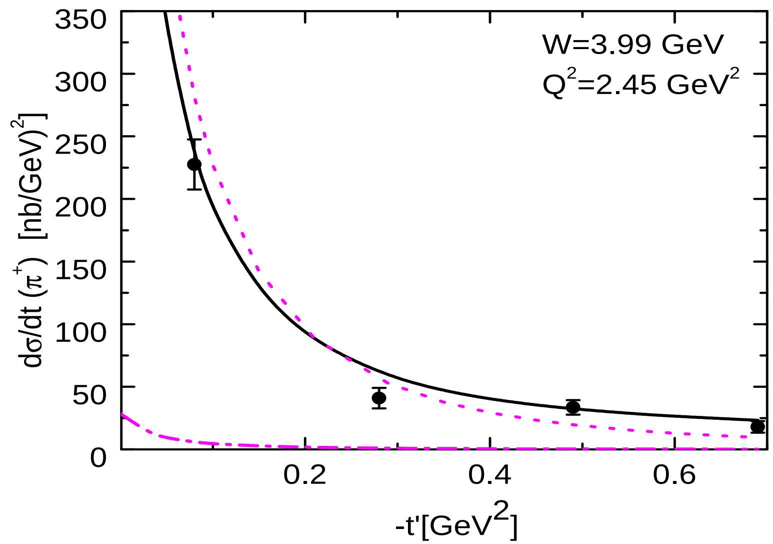


$$A_{UT}^{\sin(\phi_s)} \sim \mathrm{Im}[M^*_{0-,++} M_{0+,0+}]; \quad M_{0-,++} =< H_T >$$

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.

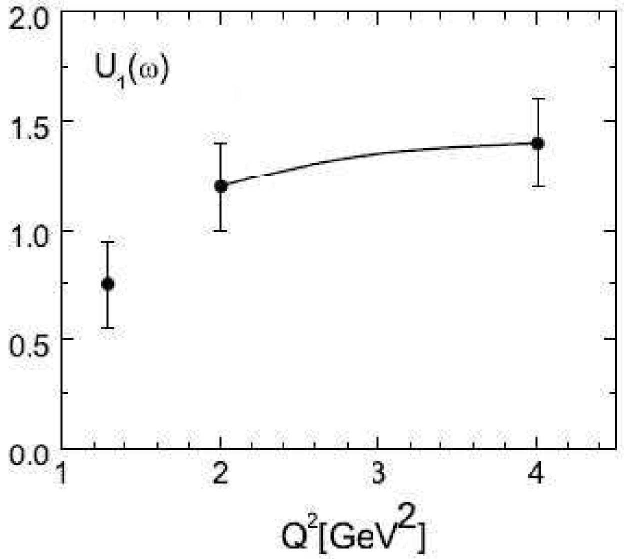
Large pion pole effects in π^+ production.

Large unnatural parity (UP) in ω production.

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

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

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

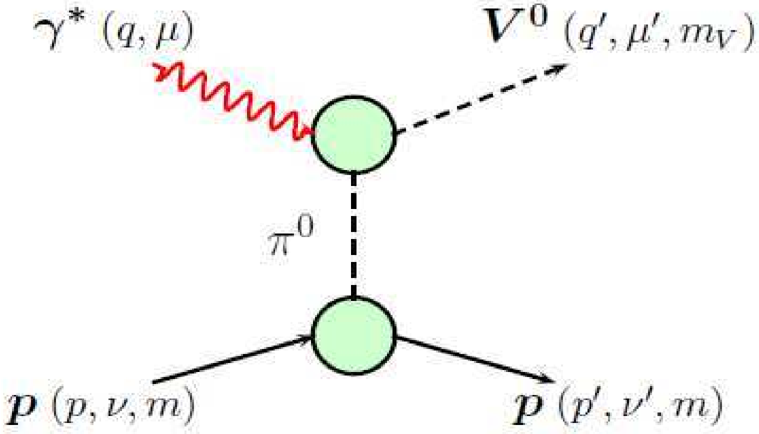


Hermes data 2014.

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.

UP effects in VM production.



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

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

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

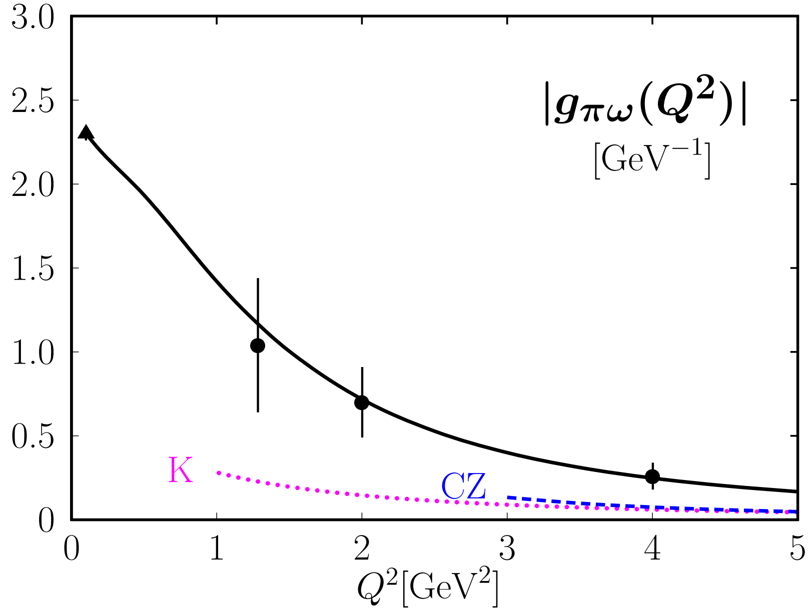
Transition form factor $g_{\pi V}(0)$ is determined from VM radiative decay .

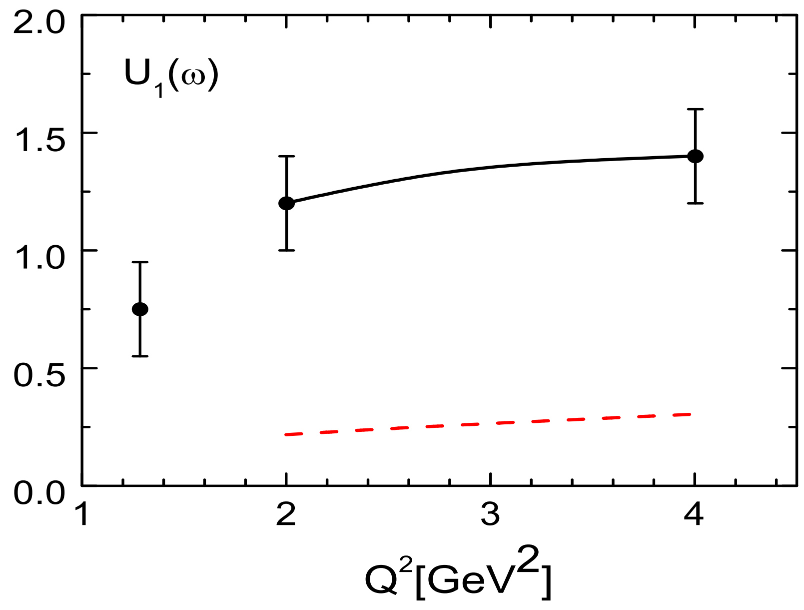
$$\Gamma(V \to \pi\gamma) \;\sim\; \frac{\alpha_{elm}}{24} |g_{\pi V}(0)|^2 M_V^3 \tag{5}$$

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

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

$\pi\omega$ transition form factor from HERMES data.



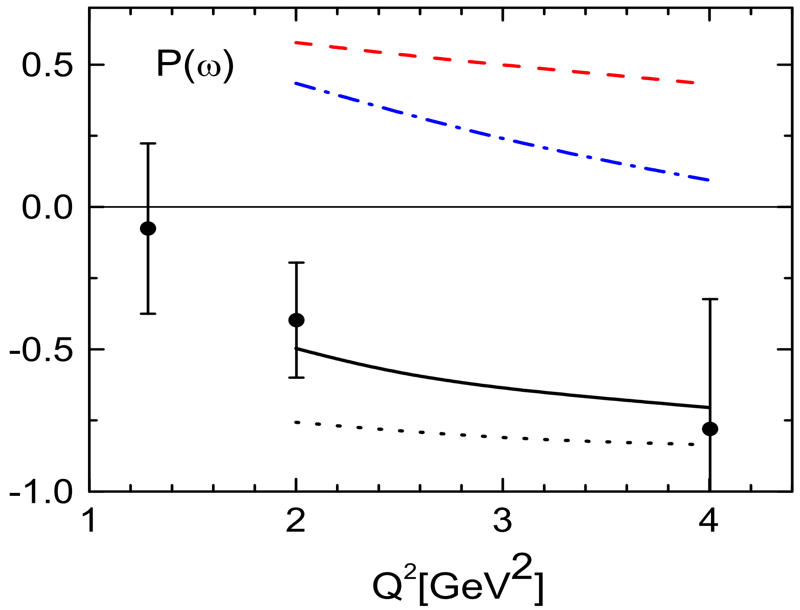


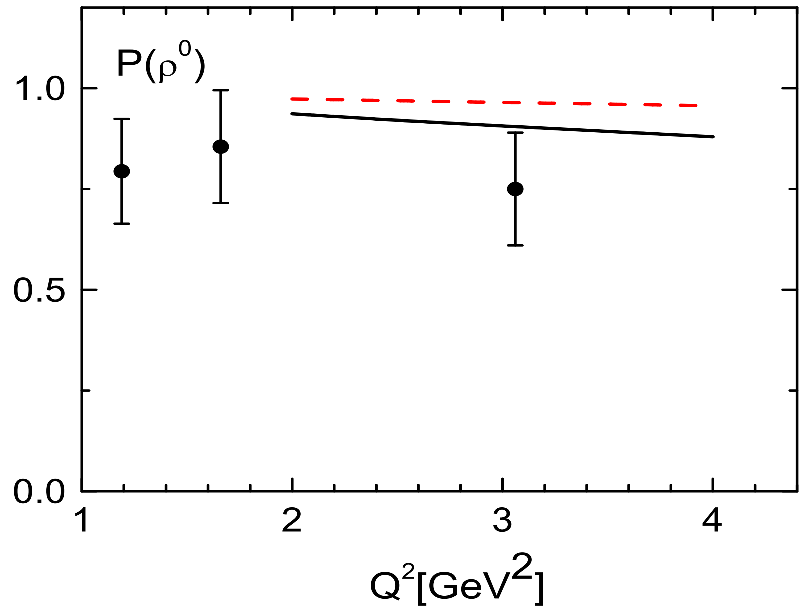
$\pi\omega$ transition form factor extracted from HERMES data on U_1. Dashed line- PQCD result for rho mult by 3.

$$|g_{\pi\omega}(0)| = \frac{2.3\text{GeV}^{-1}}{1 + (Q/2.7\text{GeV})^2 + (Q/1.2\text{GeV})^4}$$

Natural and unnatural parity asymmetry P

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



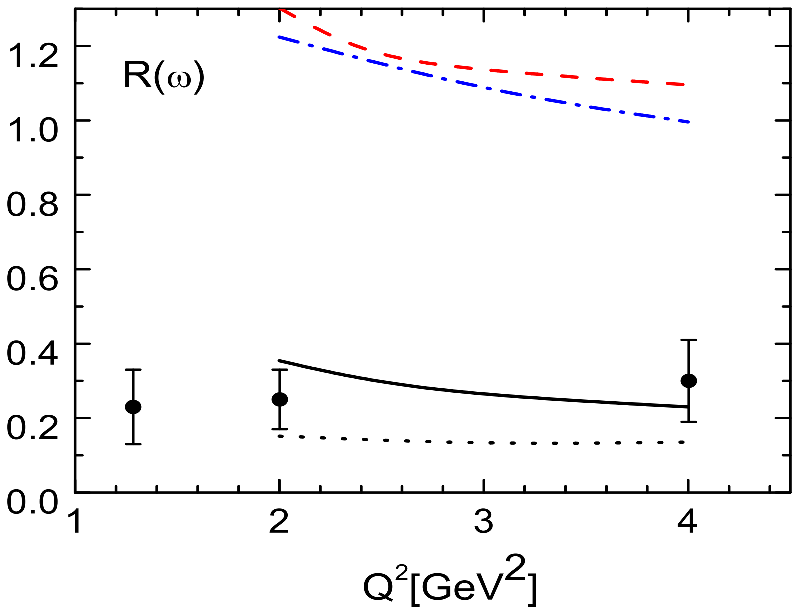


$P(\omega)$ at HERMES. Black solid with pion pole(PP), Red-dashed -without PP. Black dotted-for $W = 3.5$GeV (CLAS), Blue dashed-dotted for $W = 8$GeV (COMPASS)

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

Ratio of longitudinal and transverse cross section.

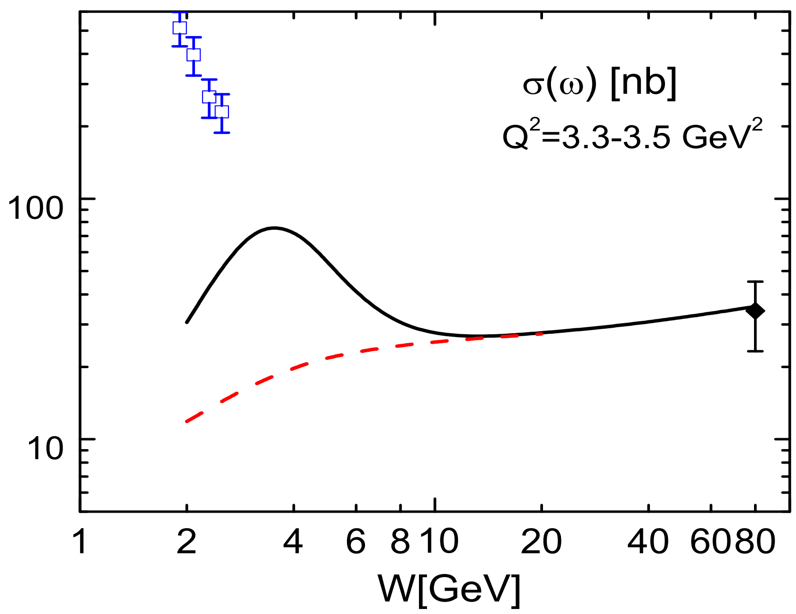
$$R \simeq \frac{d\sigma(\gamma^*_L \to V_L)}{d\sigma(\gamma^*_T \to V_T)}$$



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

For ρ -$R \sim$ nonpole case.

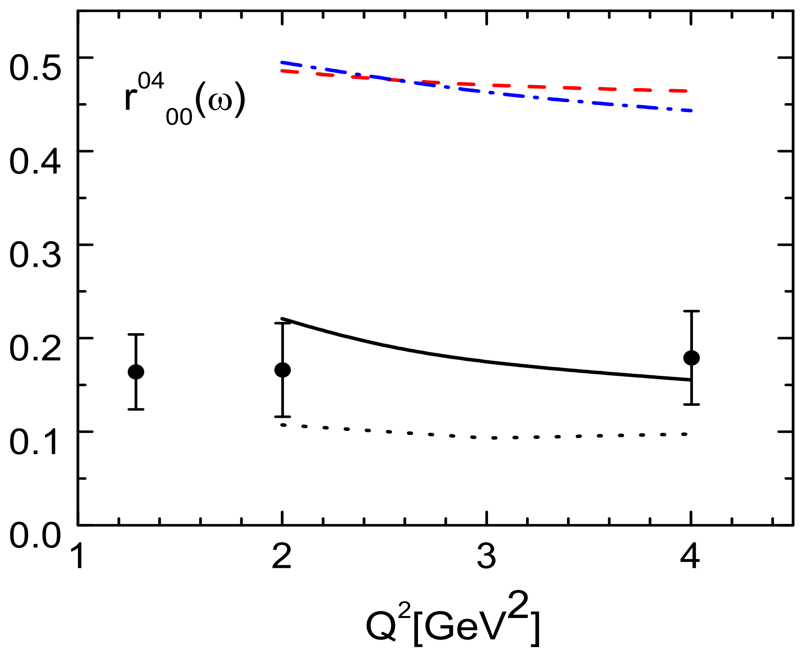
Pion pole effects in cross section of ω production

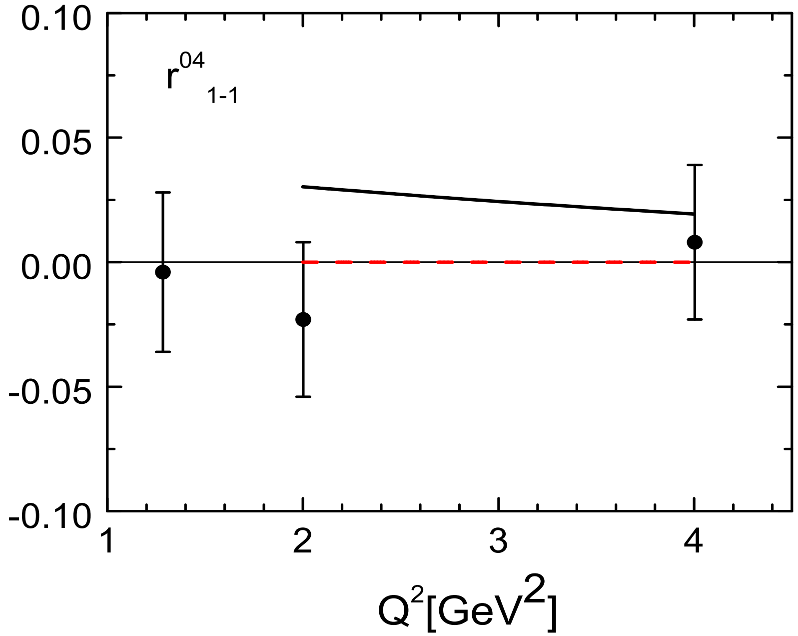


Integrated ω cross section at $Q^2 \sim 3.4$. Solid(dashes) line– with(without) PP.
Data from CLAS and ZEUS.
Pion pole is not enough to describe the cross section grows al low W

UP effects in SDMEs- ω production

HERMES data



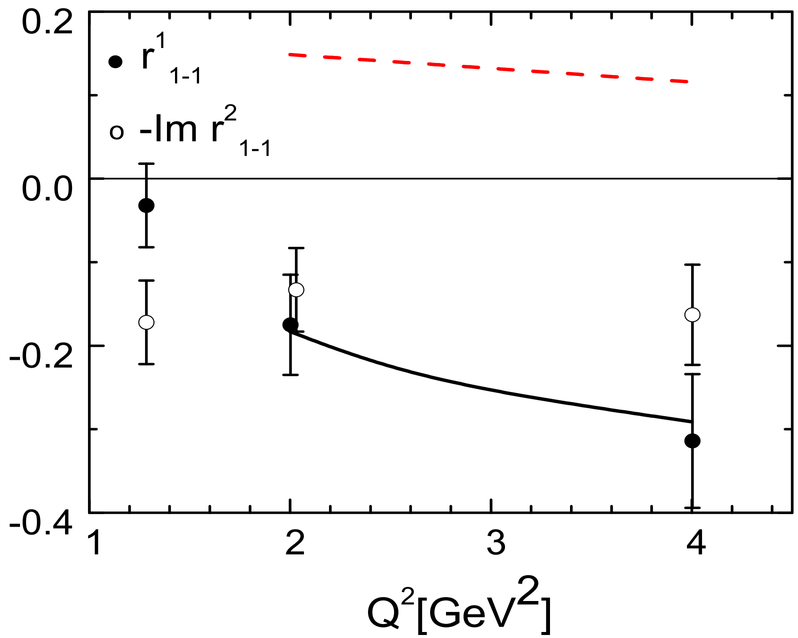


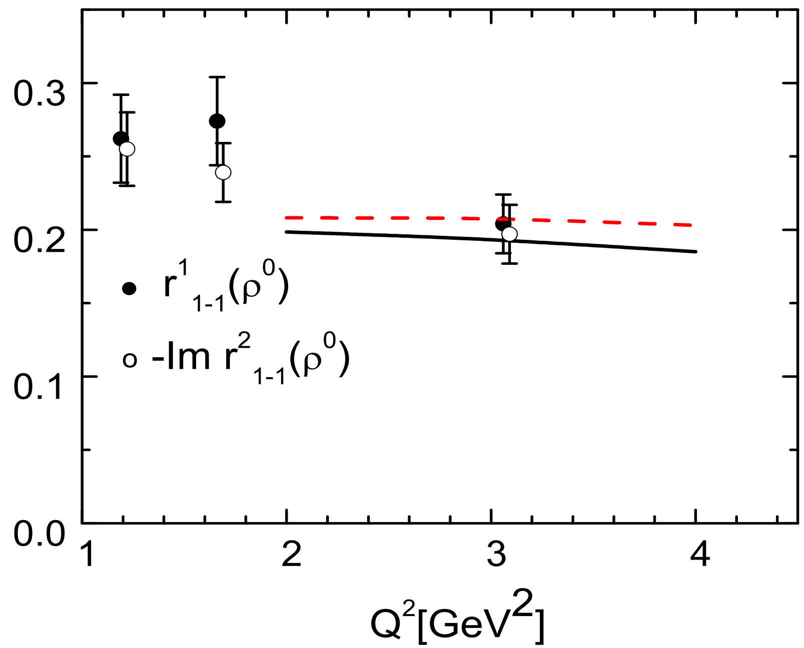
$$r^{04}_{00} = \frac{d\sigma(\gamma^*_T \to V_L) + \epsilon d\sigma(\gamma^*_L \to V_L)}{d\sigma} \qquad r^{04}_{1-1} = \frac{\epsilon d\sigma^U(\gamma^*_L \to V_T)}{2d\sigma}$$

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

UP effects in SDMEs- ω and ρ production

ω HERMES data ρ



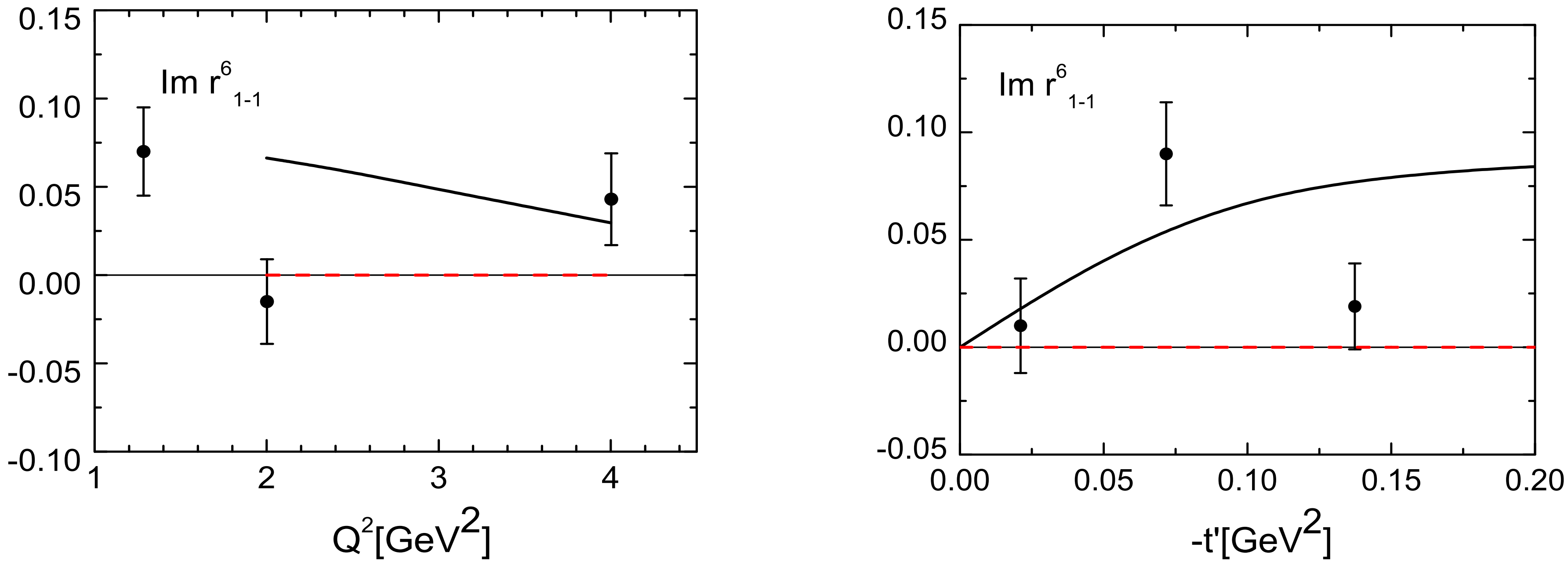


$$r^1_{1-1} = -\mathrm{Im} r^2_{1-1} = \frac{d\sigma^N(\gamma^*_T \to V_T) - \sigma^U(\gamma^*_T \to V_T)}{2d\sigma}$$

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

UP 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

UP effects in spin asymmetries of ω production.

All shown effects are not sensitive to the sign of the transition form factor.

This information can be obtained from spin asymmetries which can contain interference terms of pion pole and other amplitudes:

$$\sim \mathrm{Im} M^N(++++) M^U(+-++)$$

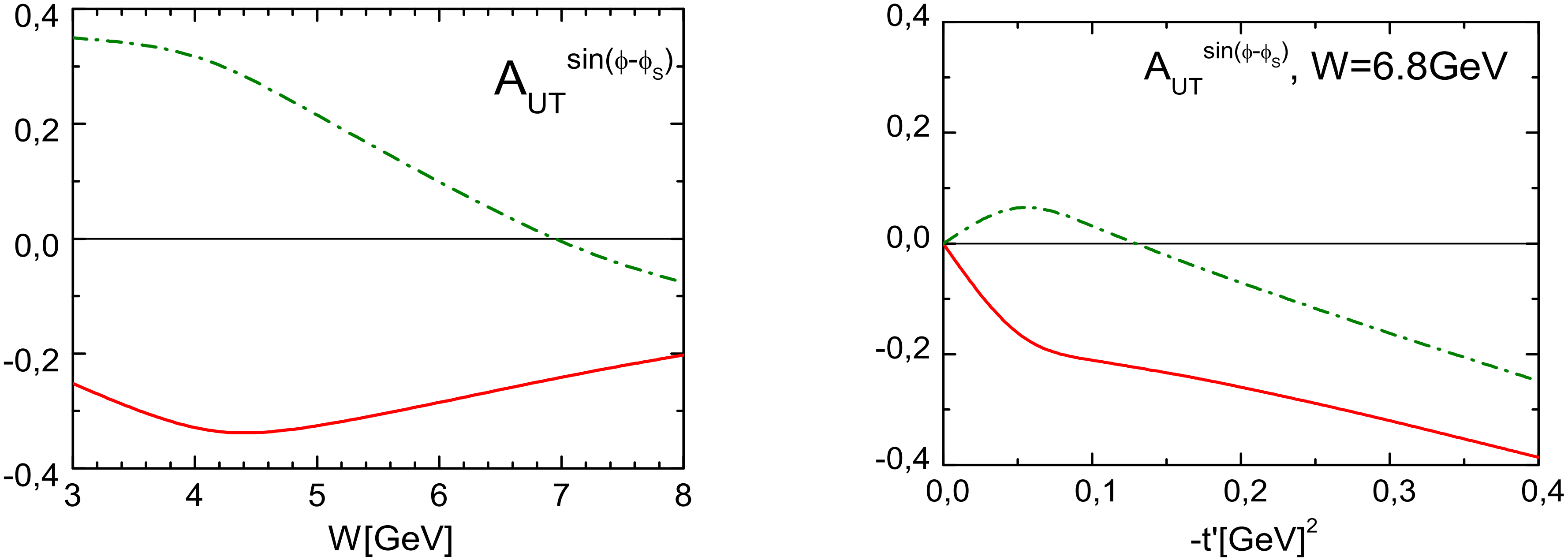
and

$$\sim \mathrm{Im} M^U(++++) M^U(+-++)$$

Here we have large contributions with interference of pion pole with transverse amplitude and amplitude determined by $\tilde{H}$

These contributions change sign with transition form-factor which can be seen in A_{UT} and A_{UL} asymmetries e.g.

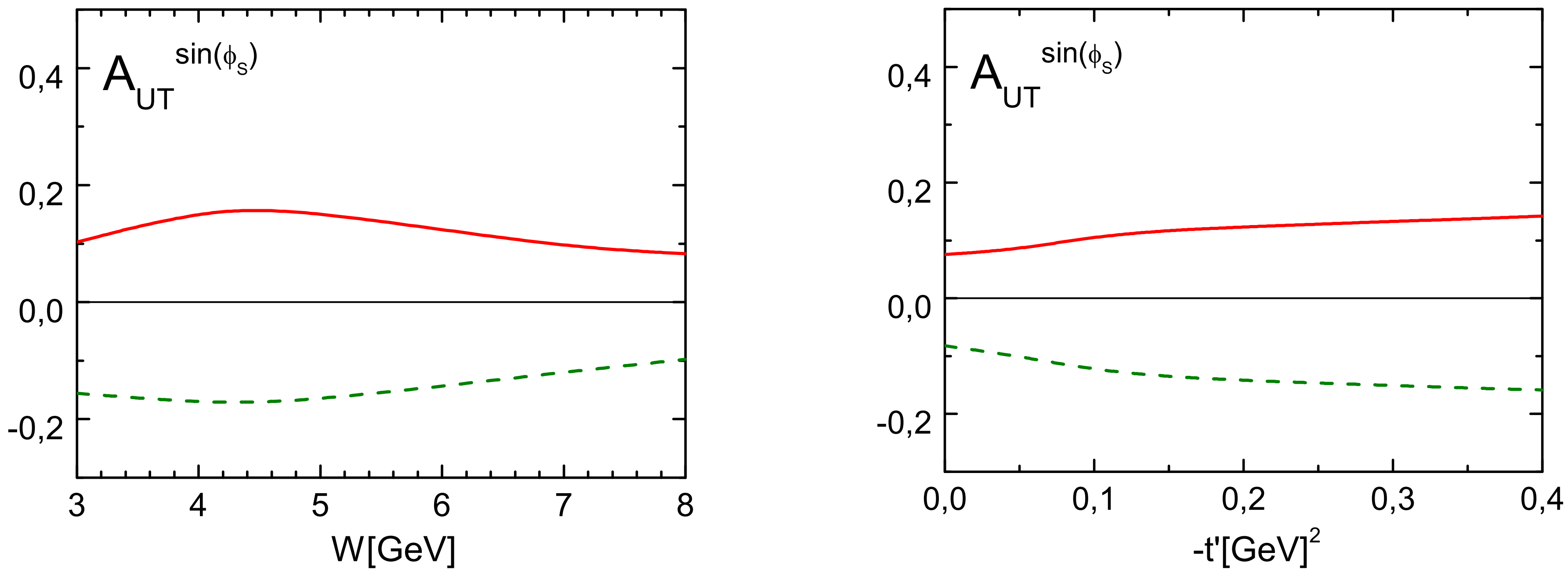
UP effects in A_{UT} -W and t dependencies



essential $\sim \mathrm{Im} M^U(++++) M^U(+-++)$ $\tilde{H}$ – pion pole interference

Red-Positive transition FF Green-Negative transition FF

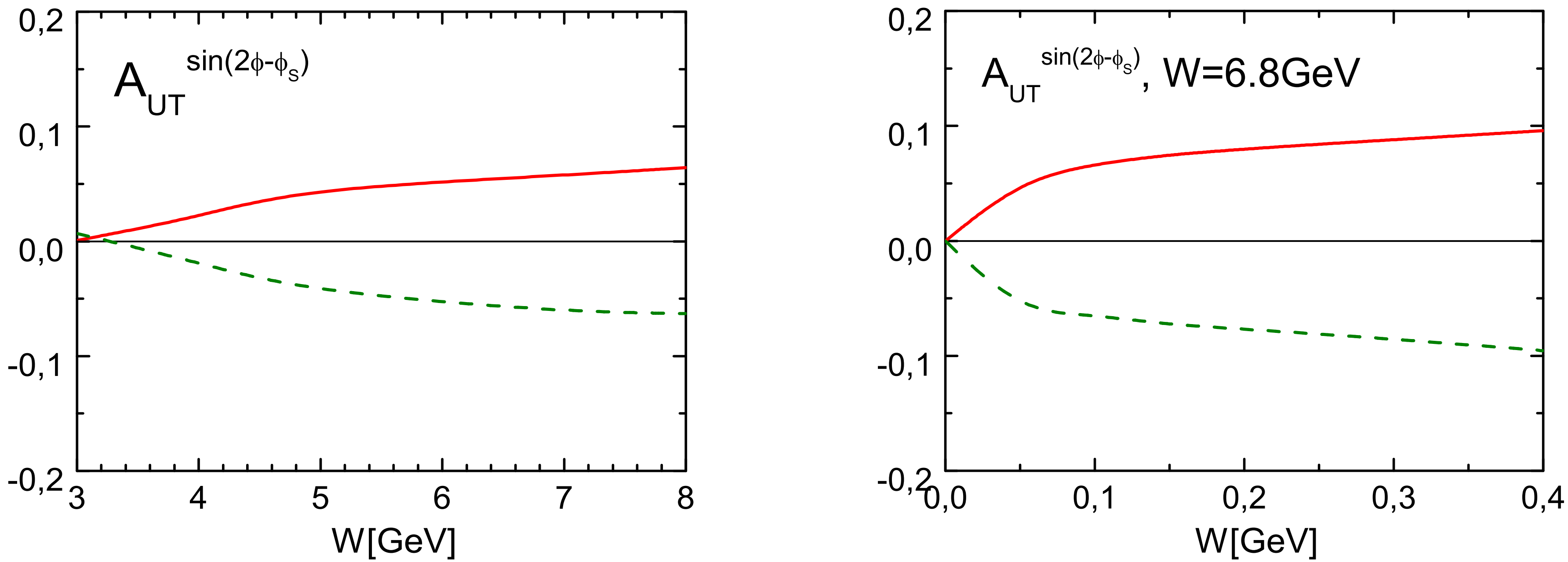
UP effects in A_{UT} -W and t dependencies



essential $\sim \mathrm{Im} M^N(++++) M^U(+-++)$ transverse amplitude $-$ pion pole interference

Red-Positive transition FF Green-Negative transition FF

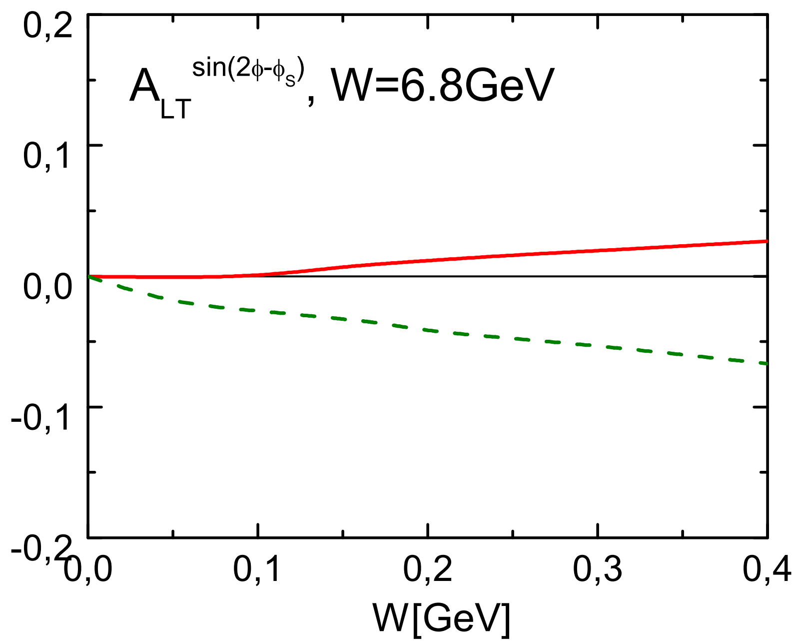
UP effects in A_{UT} -W and t dependencies



essential $\sim \mathrm{Im} M^N(++++) M^U(+-++)$ transverse amplitude $-$ pion pole interference

Red-Positive transition FF Green-Negative transition FF

UP effects in A_{LT} - t dependencies



essential $\sim \mathrm{Re} M^N(++++) M^U(+-++)$ transverse amplitude $-$ pion pole interference

Red-Positive transition FF Green-Negative transition FF

Conclusion

- Modified PA is used to calculate hard subprocess amplitude.
- GPDs are calculated using PDFs on the bases of the DD representation.
- Essential role of transversity in PS and VM production is shown at HERMES and COMPASS.
- UP effects= pion pole contribution play an important role in ω production
- ω SDME show an essential role of UP
- ω spin asymmetries can be used by COMPASS and HERMES to test sign of UP effects

Thank You!