Phenomenology of exclusive meson production and GPDs

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- Amplitudes structure and GPDs. VM production.
- Transversity effects and twist3 amplitudes.
- Transversity and pion pole effects in PS meson production.
- Transversity and pion pole effects in VM production (SDMEs and asymmetries) .
- Pion-induced Drell-Yan process.

4th Workshop on the QCD Structure of the Nucleon (QCD-N'16), July 11-15, 2016, Getxo, Spain

⋆ Amplitudes in terms of GPDs.

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

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

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

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

Double distribution model is used to construct all GPDs.

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

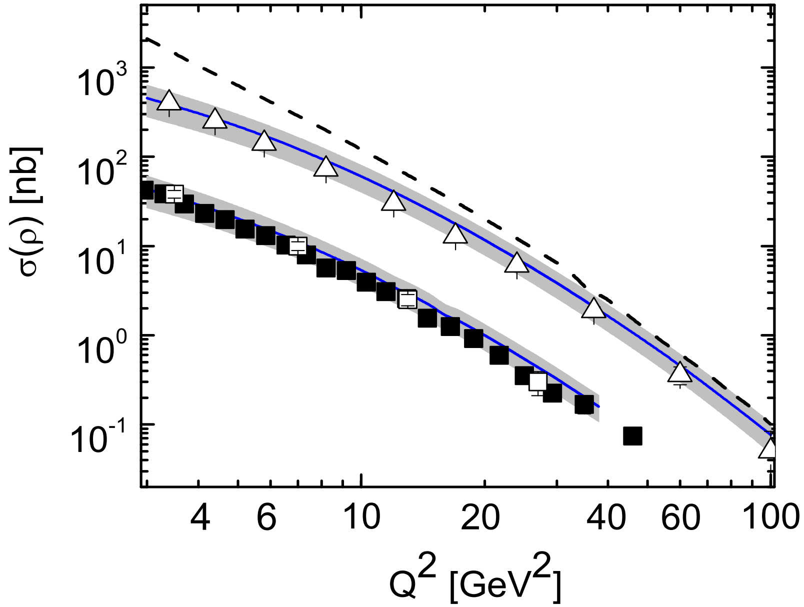
Standard connection with ordinary distribution :

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

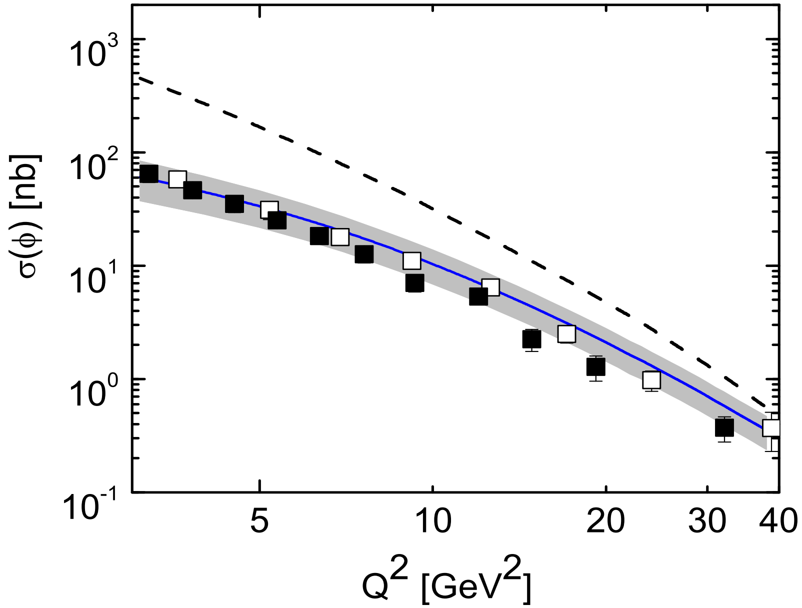
In hard scattering part F we consider transverse quark momenta corrections $k_\perp^2/Q^2$.

Cross sections of VM production

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



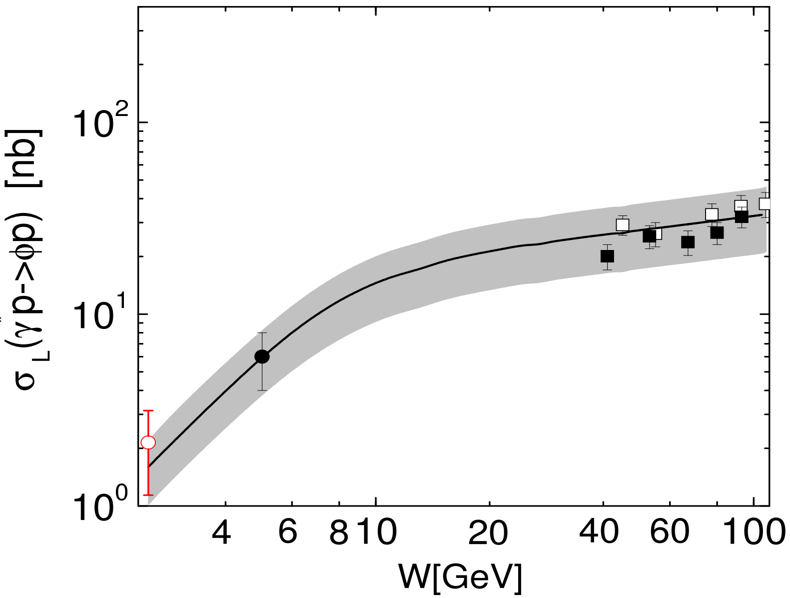
Cross sections of ρ production with errors from uncertainty in parton distributions at $W = 75$GeV/10 and $W = 90$GeV. Dashed line leading twist results.



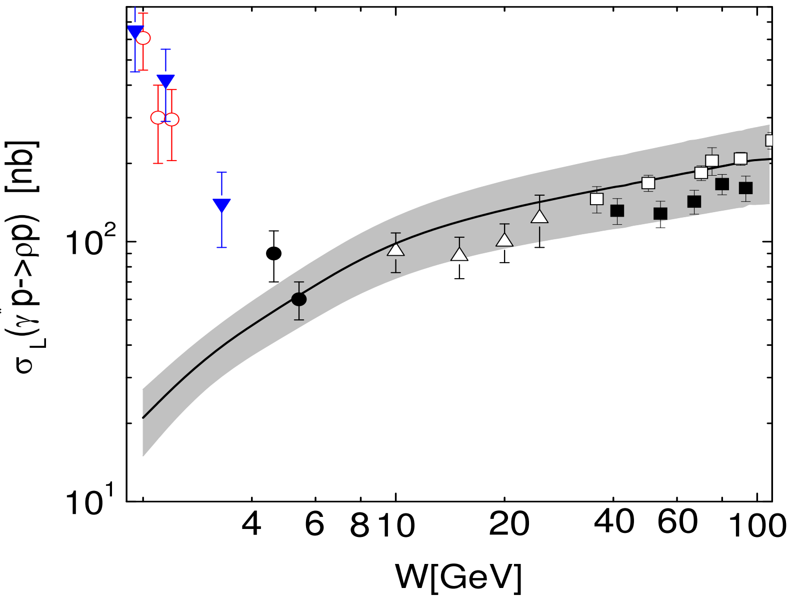
Cross sections of ϕ production with errors from uncertainty in parton distributions at $W = 75$GeV. Dashed line leading twist results.

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

Cross section of ρ and ϕ production



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



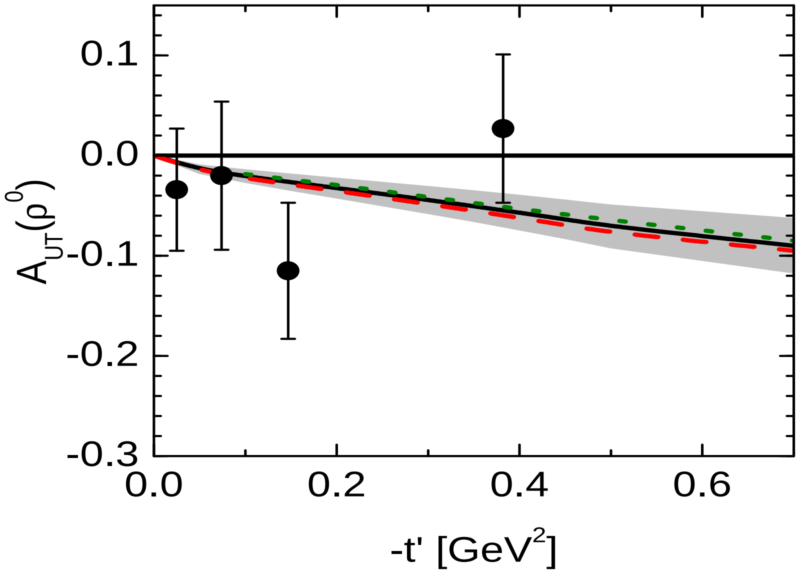
The longitudinal cross section for ρ at $Q^2 = 4.0\,\mathrm{GeV}^2$. Data: HERMES (solid circle), ZEUS (open square), H1 (solid square), E665 (open triangle), open circles- CLAS, CORNEL -solid triangle

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.???

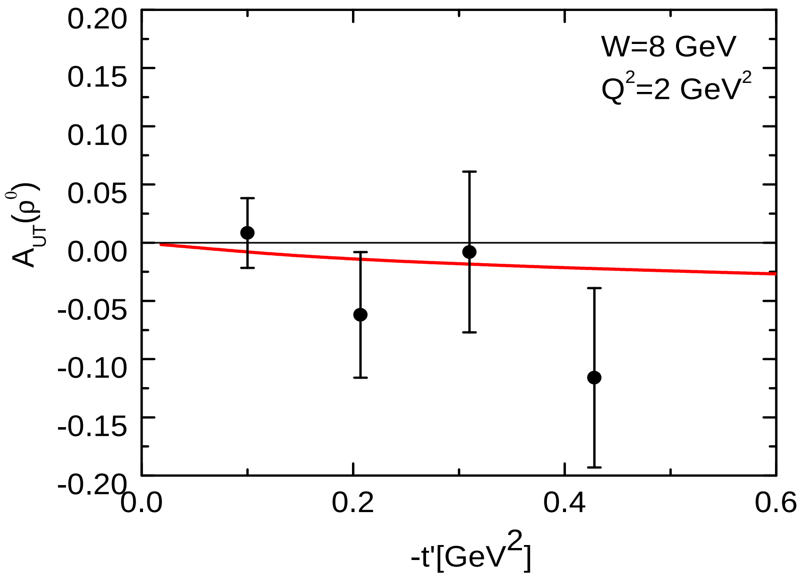
Effects of E GPDs. A_{UT} asymmetry for ρ production.

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

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.

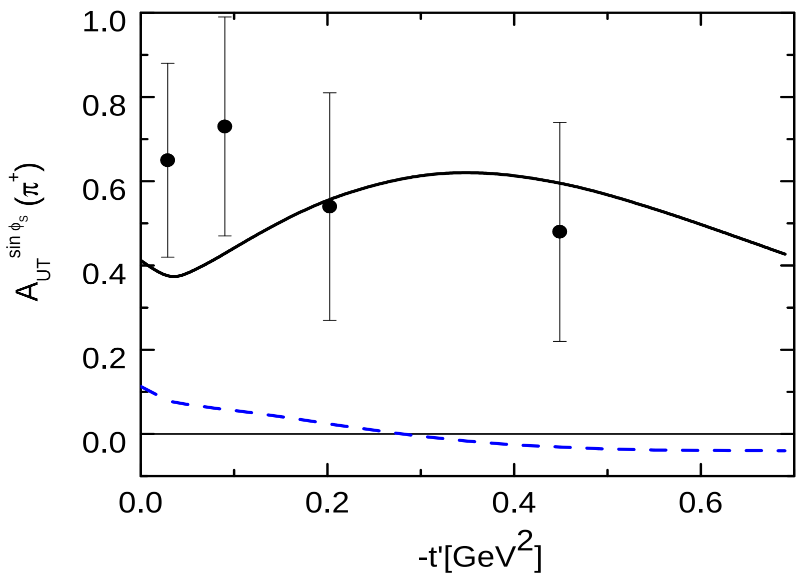


Predictions for COMPASS energy $W = 8$GeV. COMPASS data at $W = 8$GeV are shown.

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.

$M_{0\pm,++}$ – special case.

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

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

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

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

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

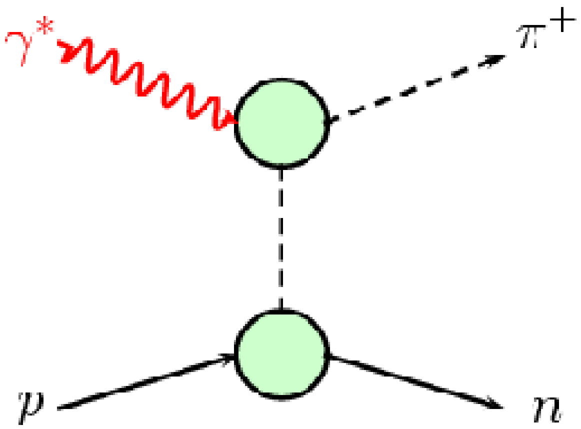
We calculate twist-3 amplitude and use twist-3 meson wave function.

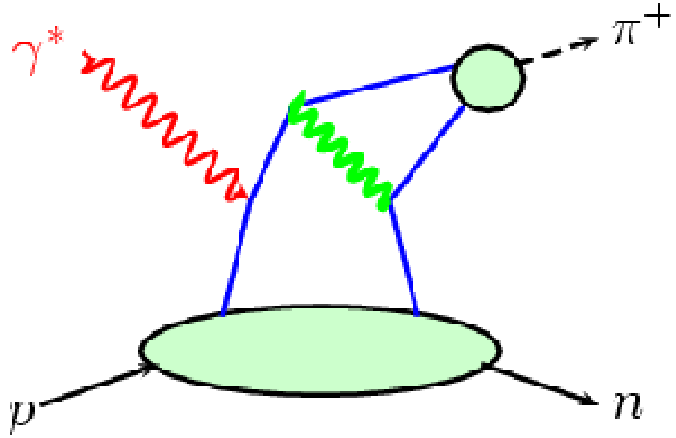
Double distribution model

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

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

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





π^+ production.

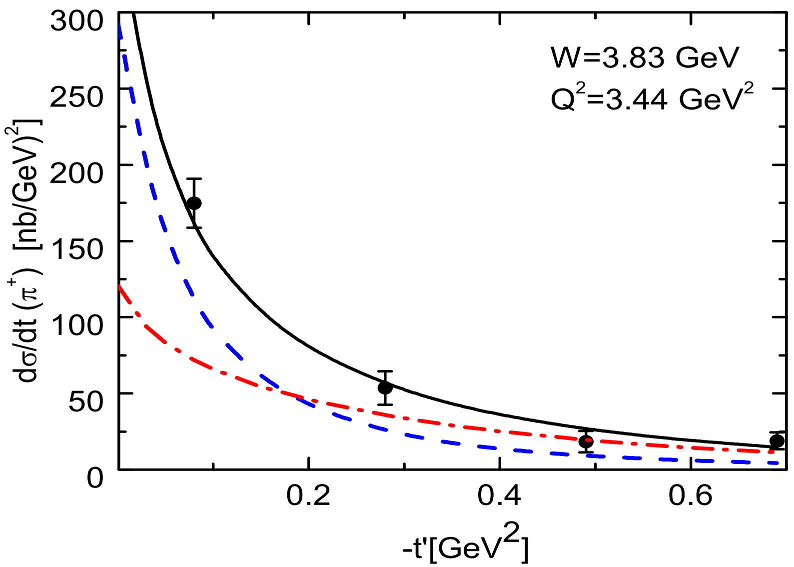
Pion pole and handbag

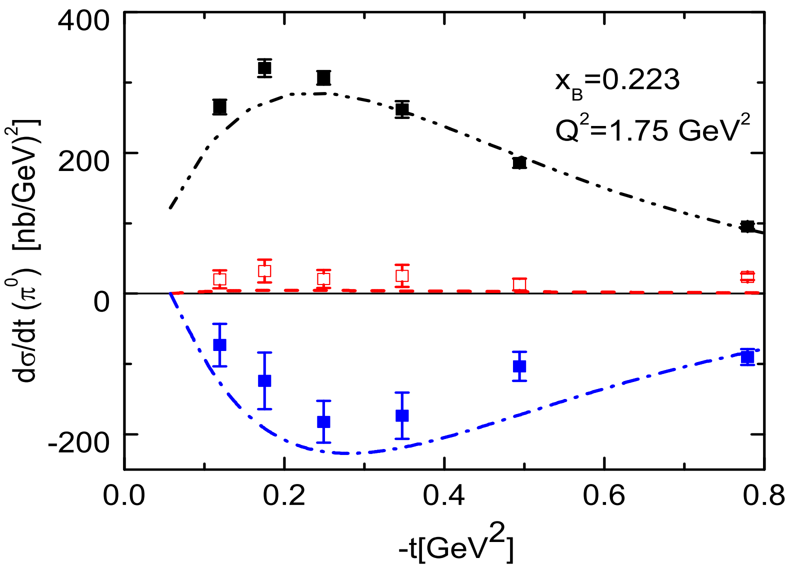
contributions to π^+ production.

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

$$<\tilde{F}> = \sum_\lambda \int_{-1}^{1} d\overline{x}\mathcal{H}_{0\lambda,0\lambda}(\overline{x},\ldots)\tilde{F}(\overline{x},\xi,t),\ F^{(3)} = F^u - F^d,\ \ \rho_\pi = \sqrt{2}\,g_{\pi NN}\,F_{\pi NN}\,F_\pi(Q^2).$$

π^+ and π^0 production.





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

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

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

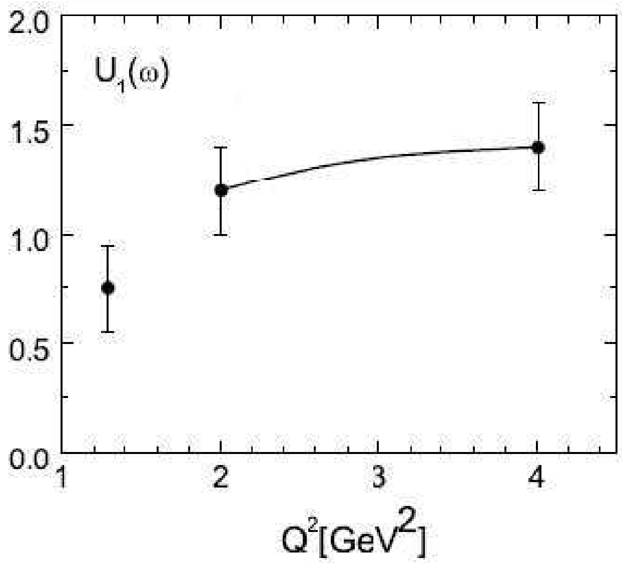
π^0 production- σ_T is larger σ_L– interesting result . Large E_T effects in the cross section.

Large unnatural parity in ω production.

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

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

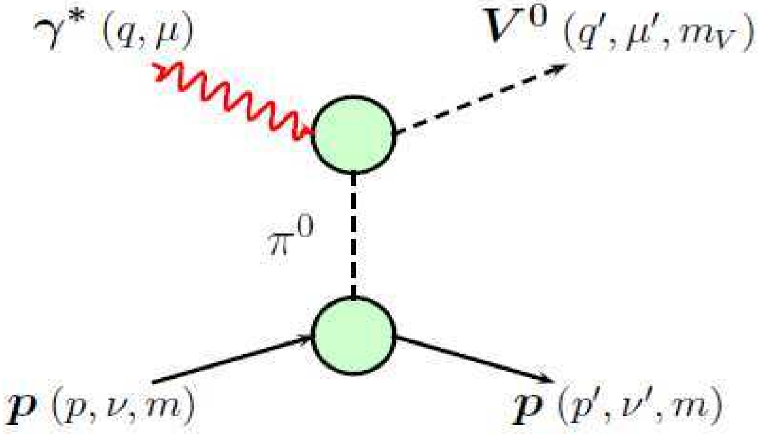


Hermes data 2014.

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.

Pion pole effects in VM production.



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

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

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

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

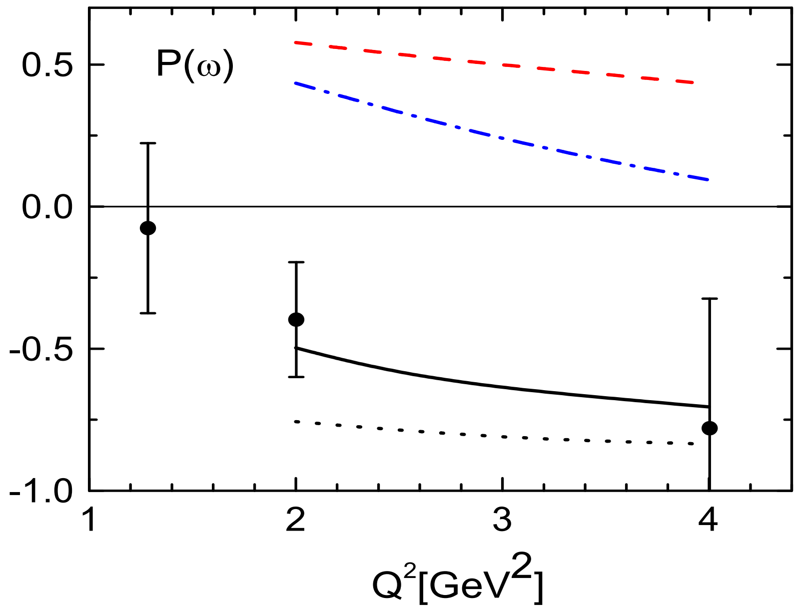
$$\Gamma(V \to \pi\gamma) \;\sim\; \frac{\alpha_{elm}}{24}\,|g_{\pi V}(0)|^2 M_V^3 \qquad (2)$$

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

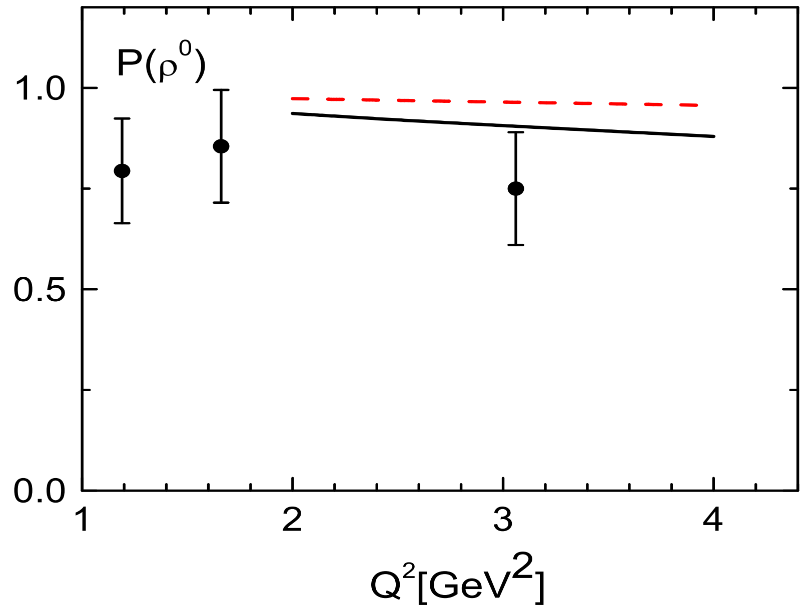
Q^2-dependence $g_{\pi V}(Q^2)$ from U_1. $|g_{\pi\omega}|$ about 3 times larger $|g_{\pi\rho}|$ -large UP effects in ω production

Natural and unnatural parity asymmetry P

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



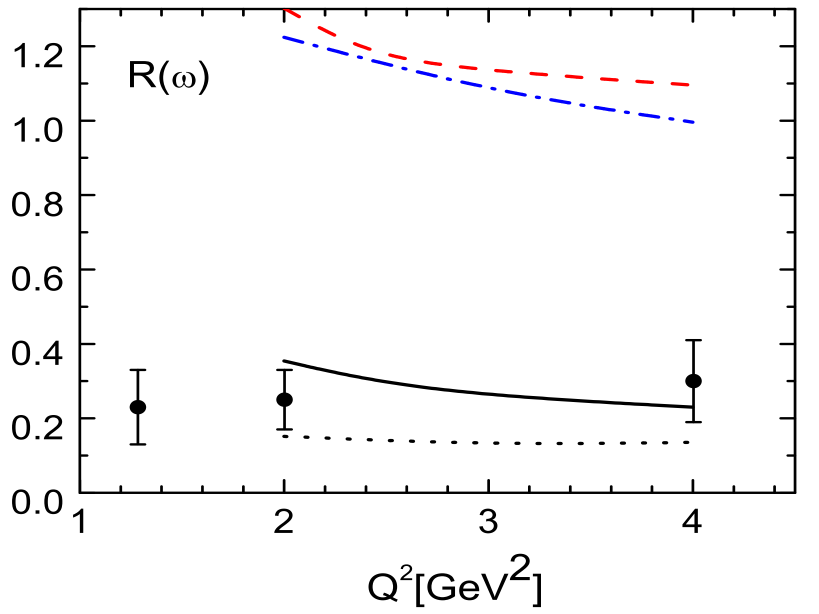
$P(\omega)$ at HERMES. Black solid with pion pole(PP), Red-dashed -without PP. Black dotted-for $W = 3.5$GeV (CLAS), Blue dashed-dotted for $W = 8$GeV (COMPASS)



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

Ratio of longitudinal and transverse cross section.

$$R \simeq \frac{d\sigma(\gamma_L^* \to V_L)}{d\sigma(\gamma_T^* \to V_T)}$$

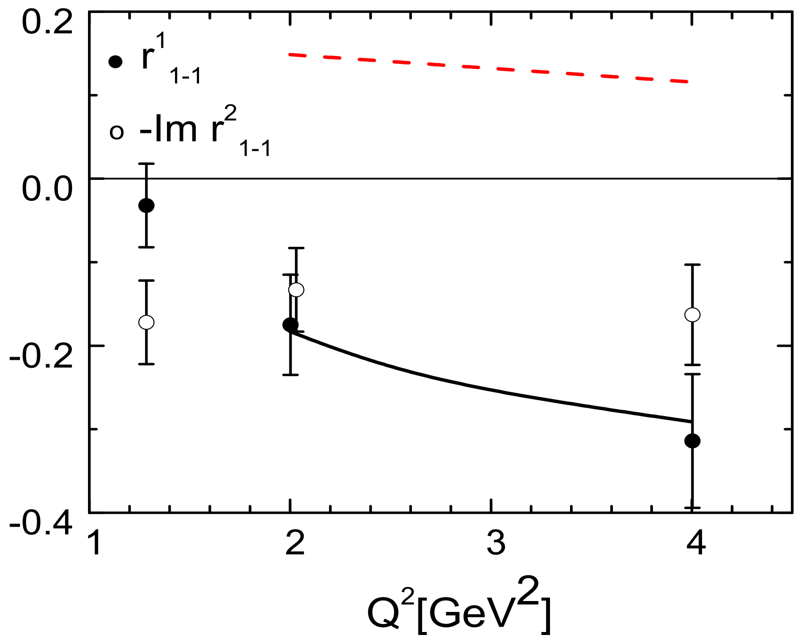


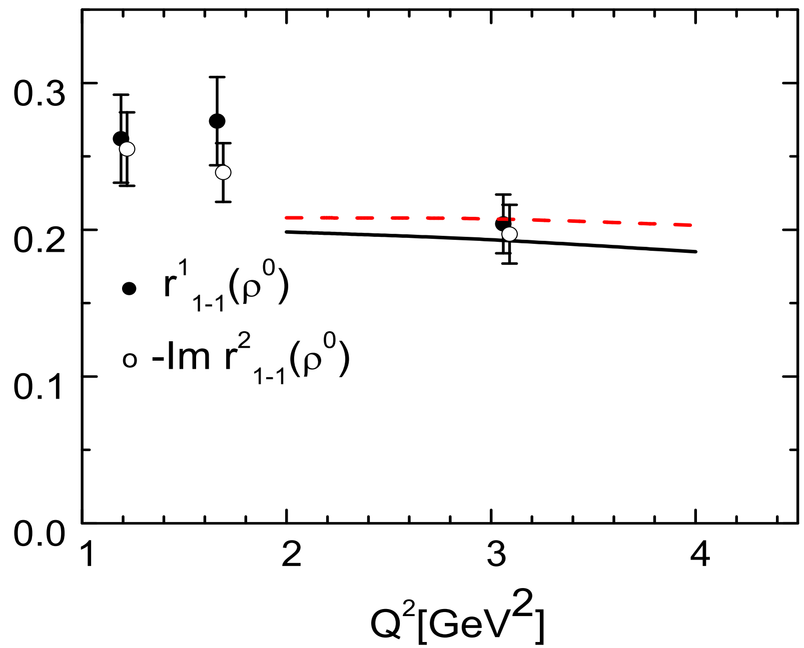
R ratio can be described only with pion pole – large contribution to transverse amplitude.

For ρ -$R \sim$ nonpole case.

Pion pole effects in SDMEs- ω 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 spin asymmetries in 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:

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

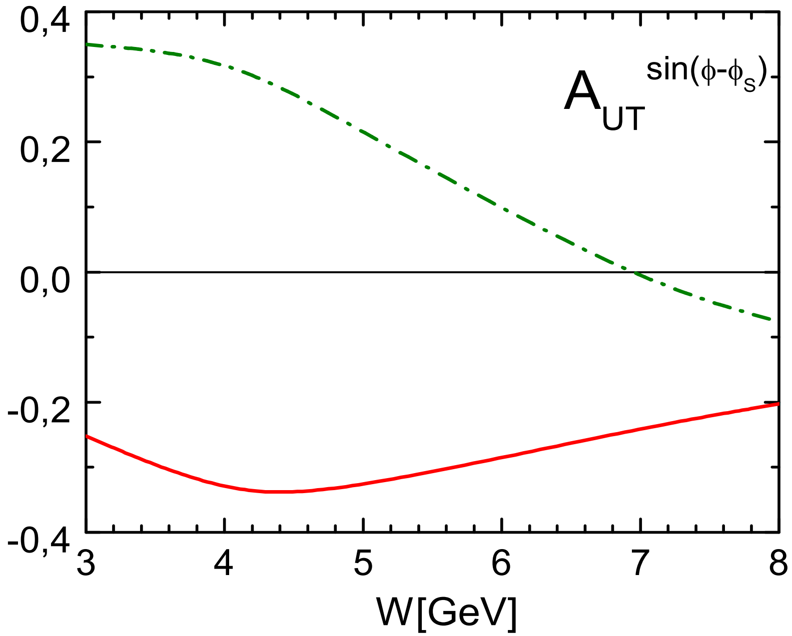
and

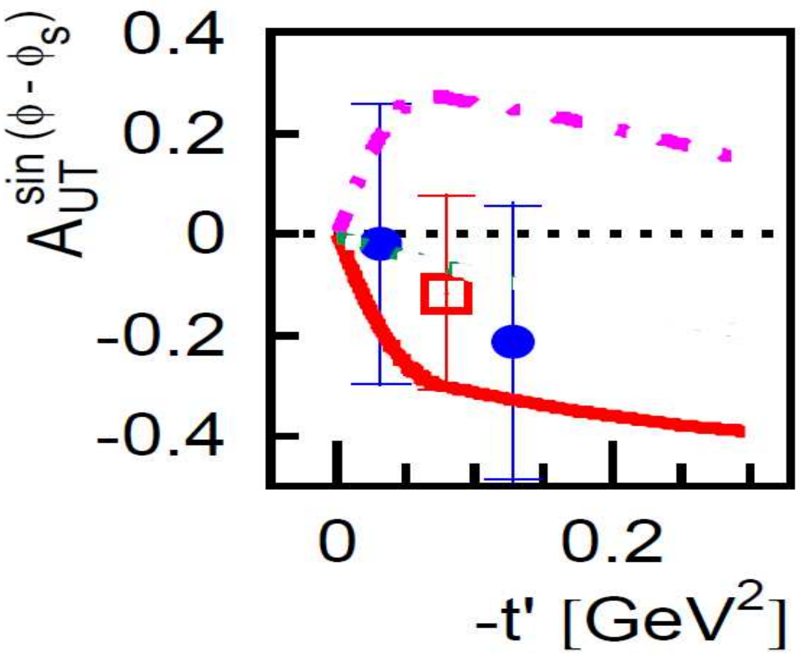
$$\sim \mathrm{Im} M^U(++++) M^U(+-++)$$

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. ω production.





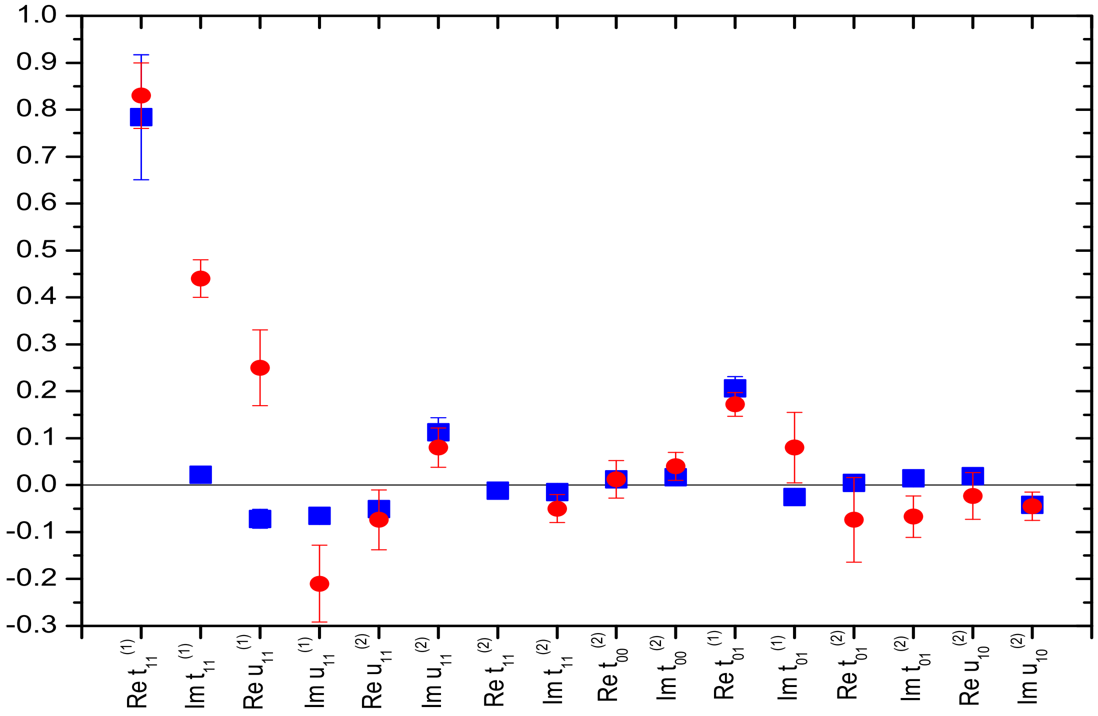
essential $\sim \mathrm{Im} M^U(+++\,+) M^U(+-++)$ $\tilde{H}$ – pion pole interference

Red-Positive transition FF Green-Negative transition FF

HERMES 2015 data). Data mainly consistent with Positive transition FF

Amplitudes ratios at HERMES -ρ^0 production

We calculate the ratio of different helicity amplitudes to the leading twist longitudinal amplitude



Blue- theory positive FF ,Red-HERMES data, S.Manaenkov, DIS 2016 . Consistent with Positive transition FF.

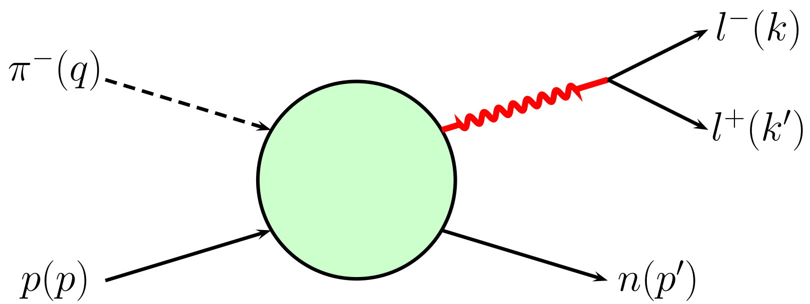
$t^{(i)}_{\lambda\mu} = N^{(i)}_{\lambda\mu}/T_{00}, \quad u^{(i)}_{\lambda\mu} = U^{(i)}_{\lambda\mu}/T_{00}, \quad \lambda, \mu$ – VM and photon helic. N-natural, U-unnatural amlitudes

i=1- proton non-flip, i=2- proton spin-flip

Pion induces Drell-Yan process

SG, P.Kroll. Phys.Lett . **B 748**, 323 (2015)

Time-like analog of π^+ leptoproduction.



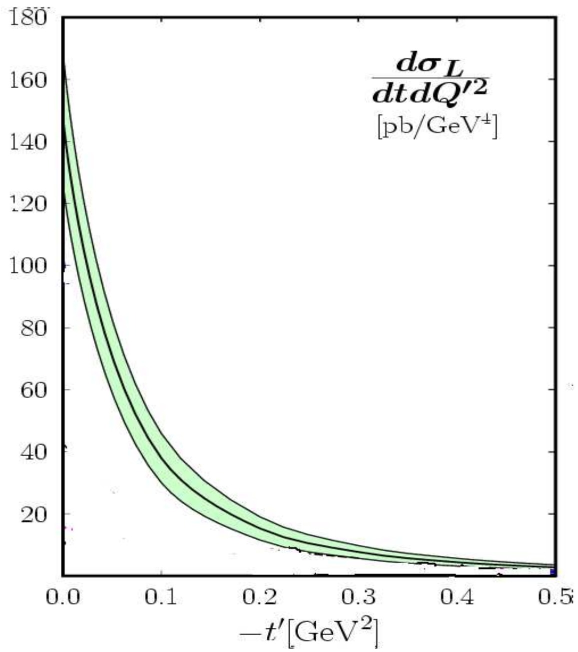
Large

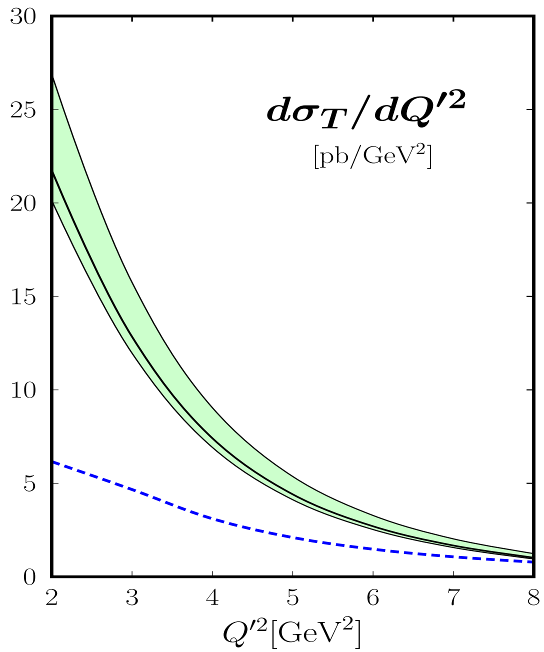
$$s = (p+q)^2; \qquad \text{and photon virtuality} \qquad Q'^2 = q'^2$$

Small τ– time-like analogue of Bjorken x and ξ

$$\tau = \frac{Q'^2}{s-m^2}; \qquad \text{and skewness} \qquad \xi \simeq \frac{\tau}{2-\tau}$$

Pion-induced DY cross section at $s = 20\text{GeV}^2$- close to J-PARC.





$\sigma_L(Q^2 = 5\text{GeV}^2)$. Large pion pole contribution. Other effects are rather small

σ_T. Pion pole contribution is much smaller. Dotted line -H_T effects.

At CERN pion beam with $s = 360\text{GeV}^2$ predicted $\sigma_L \sim 30\text{fb/GeV}^2$ -too small to measure

Detailed discussion of exclusive limit of D-Y processes- Teryaev talk after me.

Informations about GPDs

- Vector meson production: –gluon, sea, valence GPDs can be tested using VM production cross section -
  –polarized $\tilde{H}$ GPDs –from A_{LL} in VM production -
  – E GPDs – from A_{UT} in VM production -

- 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 can be tested in cross section and A_{UT} asymmetries in π^+ production
  –E_T transversity GPDs– Essential contribution in cross section of π^0. Confirmed by CLAS. Visible in spin observables of VM production

- Light meson electroproduction- is 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 JLAB2, COMPASS2, EIC in China $\rightarrow$ an important information on GPDs.

Conclusion

- We analyse meson electroproduction within handbag approach.
- 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 and PP in π^+ meson production is shown. (Cross section)
- PP explain large UP effects which are observes in ω production.
  These effects are visible in ω SDMEs and A_{UT} asymmetries
- PP contribution is essential in pion-induced Drell-Yan process.

Thank You!