GPD analyses of kaons leptoproduction

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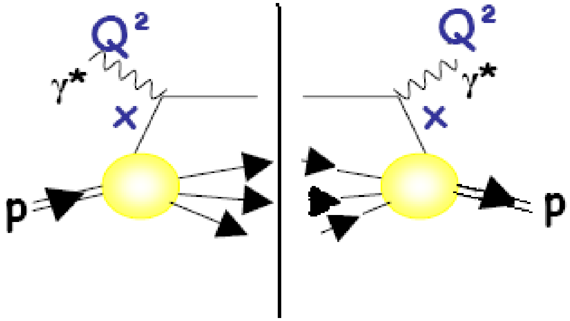
- Handbag factorization .
- GPDs and amplitudes structure.
- Kaons leptoproduction .
- Polarized GPDs and transversity effects.
- Results on kaons production.
- Conclusion.

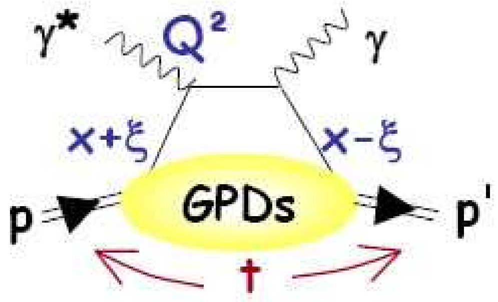
DIS and DVCD

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

GPDs – extensive information about hadron structure.

- Ordinary parton distribution connected with GPDs

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

....

- Hadron Form factors –are the GPDs moment

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

....

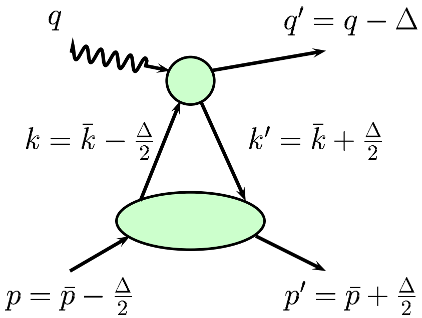
- Information on the parton angular momenta from Ji sum rules

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

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 meson production

- ϕ production (gluon&strange sea)
- ρ, ω production (gluon&sea&valence quarks)
- Pseudoscalar mesons- polarized distributions

The handbag model typically is valid at the range of large $Q^2 > 3\text{GeV}^2$ and low $x_B \leq 0.1$.

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.

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

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

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

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

⋆ Amplitudes in terms of GPDs.

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

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

$k_\perp/Q^2$ and Sudakov corrections are taken into account.

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

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

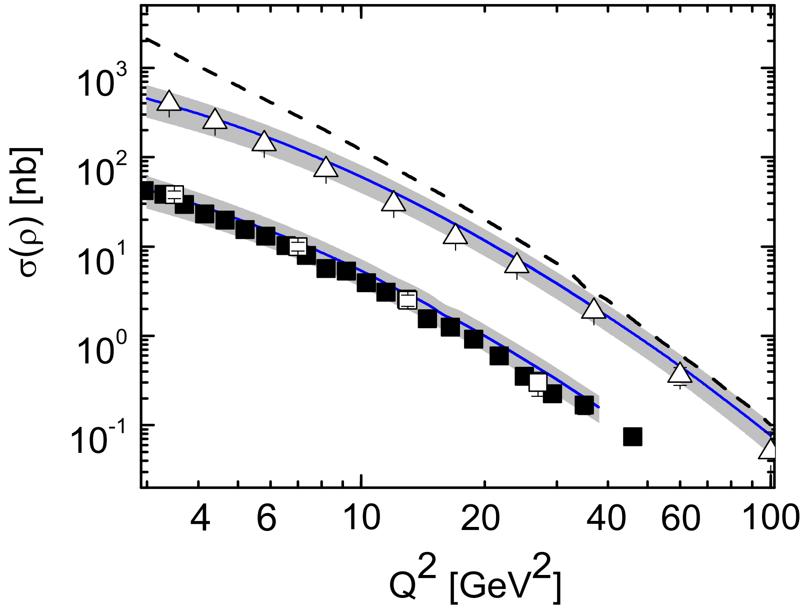
Standard connection with ordinary distribution :

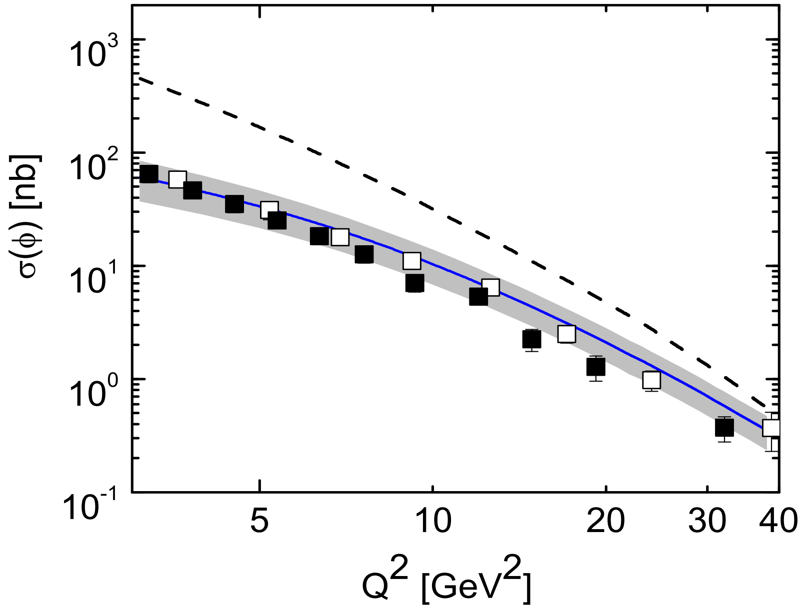
$$E^a(x,0,0) = e^a(x)$$

Double distribution model is used to construct all GPDs.

Cross sections of VM production

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





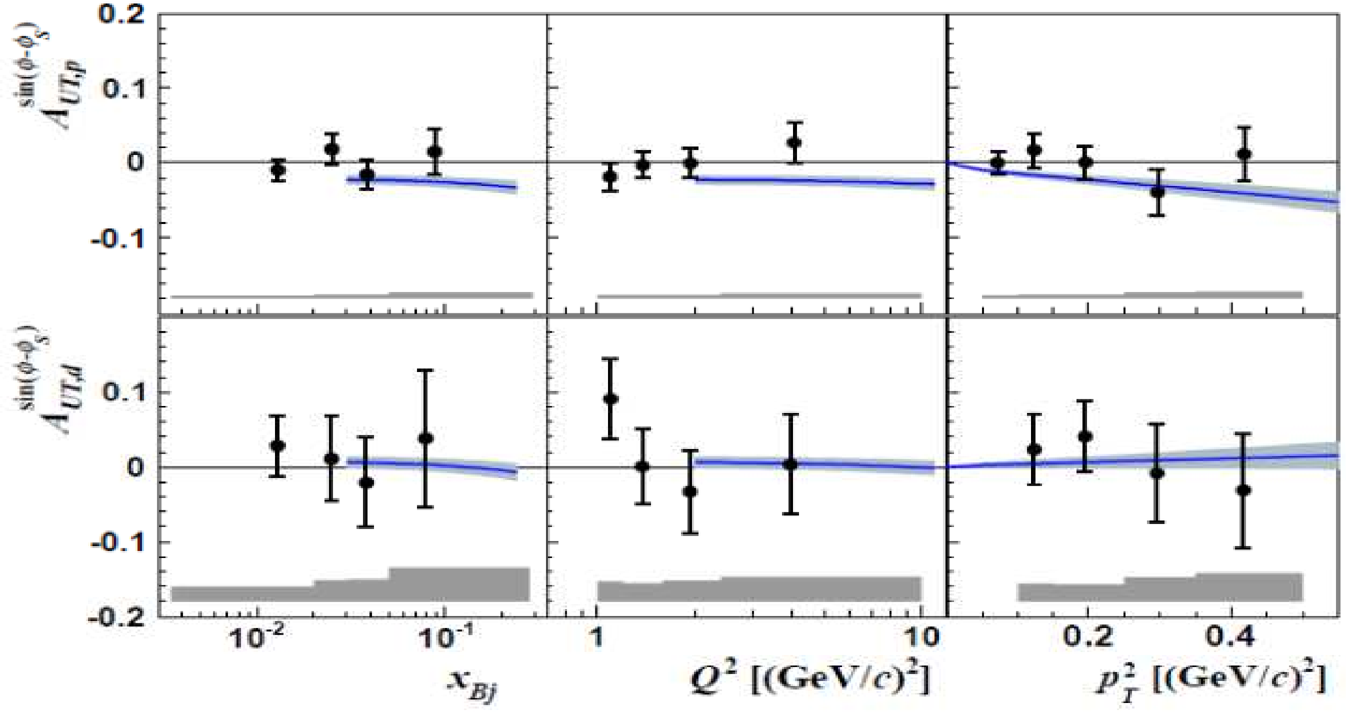
Cross sections of ρ production with errors from uncertainty in parton distributions at $W = 75$GeV/10 and $W = 90$GeV. Dashed line leading twist results.

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

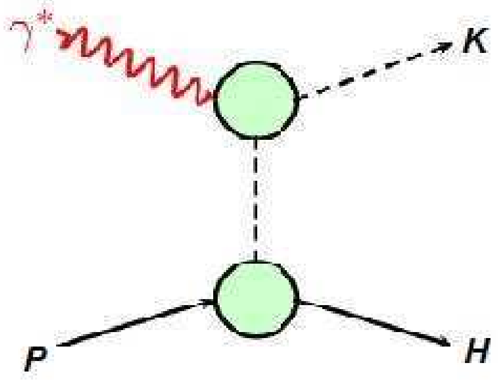
A_{UT} asymmetries in VM production.

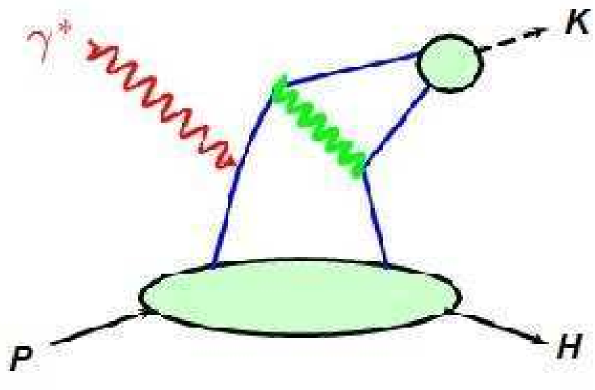
$$A_{UT} =\propto \frac{\mathrm{Im} < E >^* < H >}{| < H > |^2}$$



Our results on $A_{UT}^{\sin(\phi-\phi_s)}$ asymmetry for ρ production on the proton and deuteron togeter with COMPASS data.

Pseudoscalar K meson production.





Pole and handbag

contributions to Kaons production.

⋆ Meson pole (charge mesons) is essential mainly in $\mathcal{M}_{0+,0+}$ amplitude.

⋆ Contribute to $\mathcal{M}_{0-,0+}$, $\mathcal{M}_{0+,++}$, $\mathcal{M}_{0-,++}$ amplitudes too.

General case of Pseudoscalar meson production

$$\mathcal{M}^{M}_{0+,0+} \propto \sqrt{1-\xi^2}\,[\langle \tilde{H}^M \rangle - \frac{\xi^2}{1-\xi^2}\langle \widetilde{E}^M_{n.p.}\rangle - \frac{\xi(m_{N^i}+M_{N^f})Q^2}{1-\xi^2}\frac{\rho_M}{t-m^2_M}]; \quad (4)$$

$$\mathcal{M}^{M}_{0-,0+} \propto \frac{\sqrt{-t'}}{(m_{N^i}+M_{N^f})}\left[\xi\langle \widetilde{E}^M_{n.p.}\rangle + (m_{N^i}+M_{N^f})Q^2\frac{\rho_M}{t-m^2_M}\right].$$

Masses: M- produced pseudoscalar meson ,N^i-initial nucleon (proton) ,M_{N^f}-final nucleon (Λ, Σ)

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

The hard scattering amplitudes-transverse quark motion

$$H^a_{0\lambda,0\lambda}(\overline{x},\xi) \;=\; \frac{8\pi\alpha_s(\mu_R)}{\sqrt{2N_c}}\int_0^1 d\tau \int \frac{d^2\mathbf{k}_\perp}{16\pi^3}\phi_{V\mu'}(\tau,k^2_\perp)\; f^a_{0\lambda,0\lambda}(\mathbf{k}_\perp,\overline{x},\xi,\tau)D\,. \quad (5)$$

$$\phi_V(\mathbf{k}_\perp,\tau) \;=\; 8\pi^2\sqrt{2N_c}\,f_V a^2_V\;\exp\left[-a^2_V\,\frac{\mathbf{k}^2_\perp}{\tau\bar{\tau}}\right]. \quad (6)$$

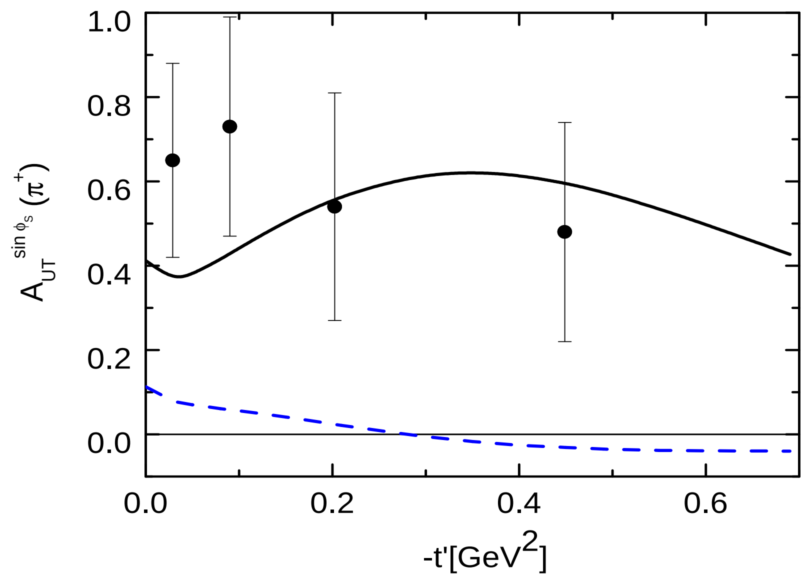
Meson pole contribution (charge meson production)

$$\rho_M = g_{MN^iN^f}\,F_{MN^iN^f}(t)\,F_M(Q^2) \quad (7)$$

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 in π^+ production.



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

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 $M_{0-,++}$ – transversity effects.

$M_{\mu'\nu',\mu\nu} \propto \sqrt{-t'}^{|\mu-\nu-\mu'+\nu'|}$ 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

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

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

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

Estimation of $M_{0+,++}$ – transversity effects.

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

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

Similar calculation of twist-3 amplitude as for H_T

$$\bar{E}_T(\beta,0,0) = e_T(\beta); \quad e_T(\beta,t) = N\, e^{b_0 t} \beta^{-\alpha(t)}\,(1-\beta)^n \tag{8}$$

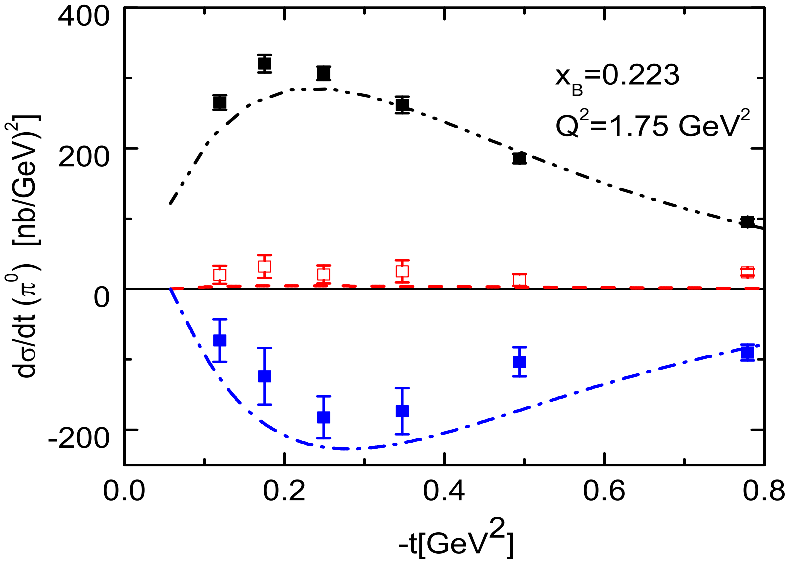
Double distribution model for $\bar{E}_T$

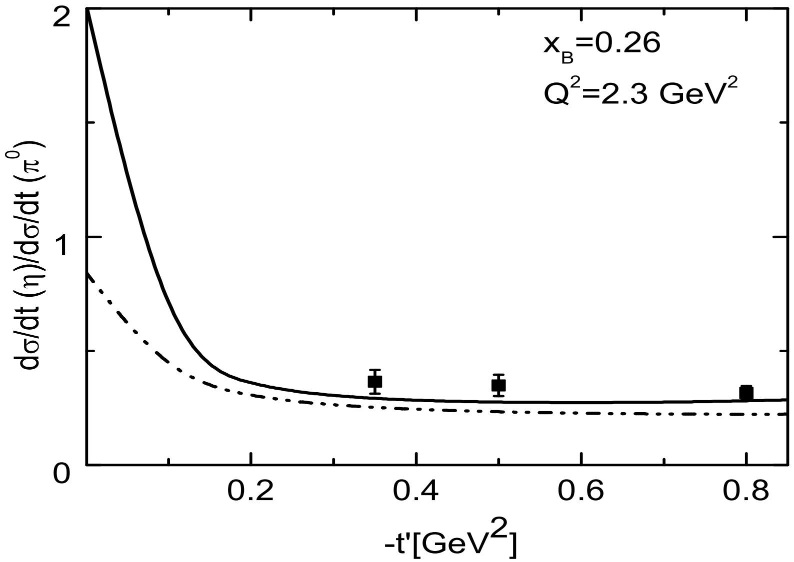
Parameters are taken from the lattice results for the moments of E_T

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

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

Transversity effects at CLAS.





Predictions for 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}

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

Transversity contributions are essential in the cross section of pseudoscalar meson production.
Model predictions for π^0 cross sections and η/π^0 ratio were confirmed later by CLAS experiment.

Kaon production. Coupling constants and GPDs

- Wave function -non symmetric over $\tau \to \bar{\tau}$. Reason-quarks have different masses.
- Coupling constants-SU(3) predictions

$$g_{K^+p\Lambda} \sim -13.3; \qquad g_{K^+p\Sigma^0} \sim -3.5;$$

  Pole contribution is larger for $K^+p\Lambda$ channel .

- Form Factors: $F_{K^+}(Q^2) \sim 0.9\, F_{\pi^+}(Q^2)$ in agreement with CLEO data

GPDs in kaon production.
Proton- hyperon transition GPDs contracted with the help of SU(3) flavor symmetry.

$$\star\ \gamma p \to K^+\Lambda : \qquad \tilde{F}_{p\to\Lambda} \sim -\frac{1}{\sqrt{6}}[2\tilde{F}^u - \tilde{F}^d - \tilde{F}^s]$$

$$\star\ \gamma p \to K^+\Sigma^0 : \qquad \tilde{F}_{p\to\Sigma^0} \sim -\frac{1}{\sqrt{2}}[\tilde{F}^d - \tilde{F}^s]$$

$$\star\ \gamma p \to K^0\Sigma^+ : \qquad \tilde{F}_{p\to\Sigma^+} \sim -[\tilde{F}^d - \tilde{F}^s]$$

Polarized distributions contribute.

Transversity effects at kaons production.

$\star$ Parameterization the same as for π^0 production .

Large H_T contributions for Kaons especially in $K^+\Lambda$ channel.

$$H_T(p \to \Lambda) \sim -\frac{1}{\sqrt{6}}[2H_T^u - H_T^d]$$

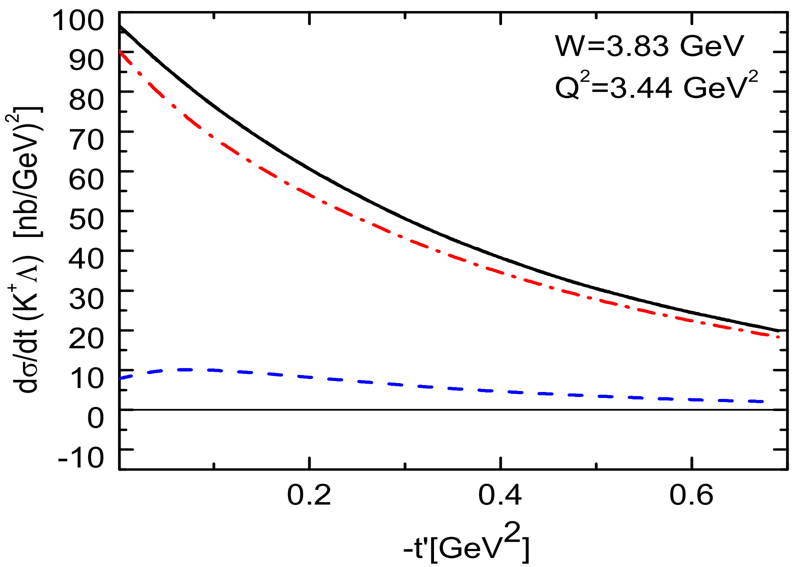
$$H_T(p \to \Sigma^0) \sim -\frac{1}{\sqrt{2}}[H_T^d]$$

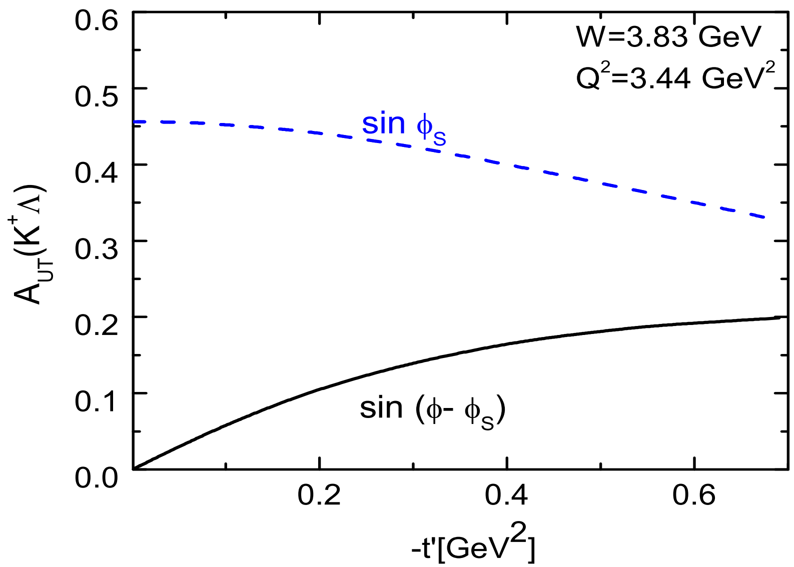
$$H_T(p \to \Sigma^+) \sim -[H_T^d]$$

$\bar{E}_T$ effects. $H_T \to \bar{E}_T$

In all processes of Kaons production we have and large $\bar{E}_T$ contribution.

$\gamma p \to K^+\Lambda$ reaction.



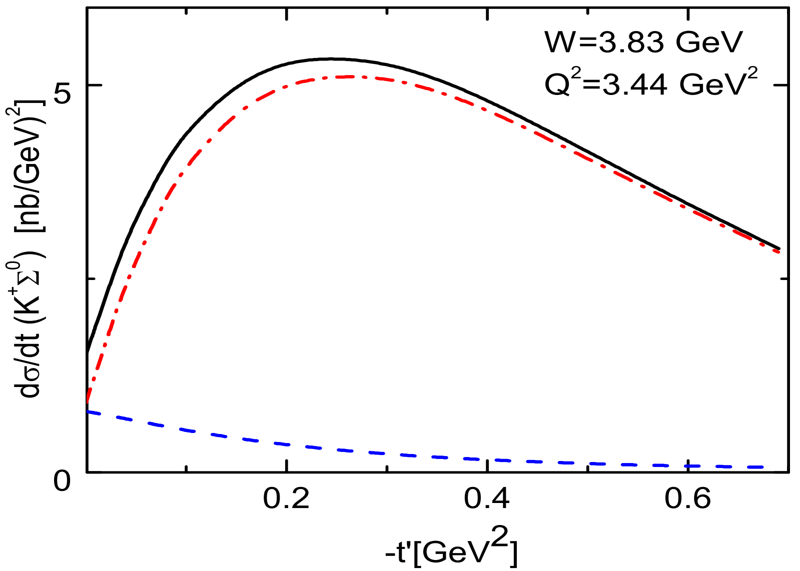


Cross section of $K^+\Lambda$ production. Dashed line- σ_L, dashed-dotted - σ_T

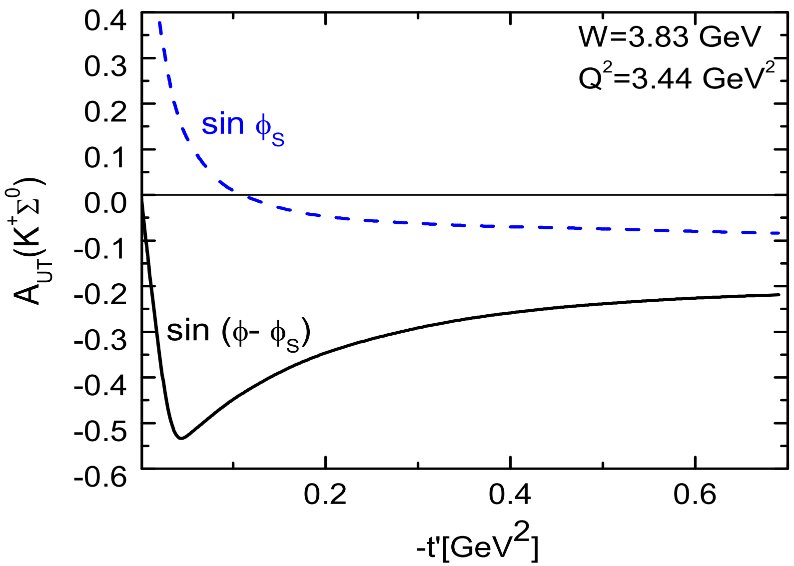
$\sin(\phi - \phi_s)$ and $\sin(\phi_s)$ moments of transverse target asymmetry of $K^+\Lambda$ production.

Pole contribution is essential here- H_T is large no dip in σ_T . σ_T- is large with respect to the leading twist σ_L. Twist-3 transversity effects predominate at low Q^2.

$\gamma p \to K^+\Sigma^0$ reaction.



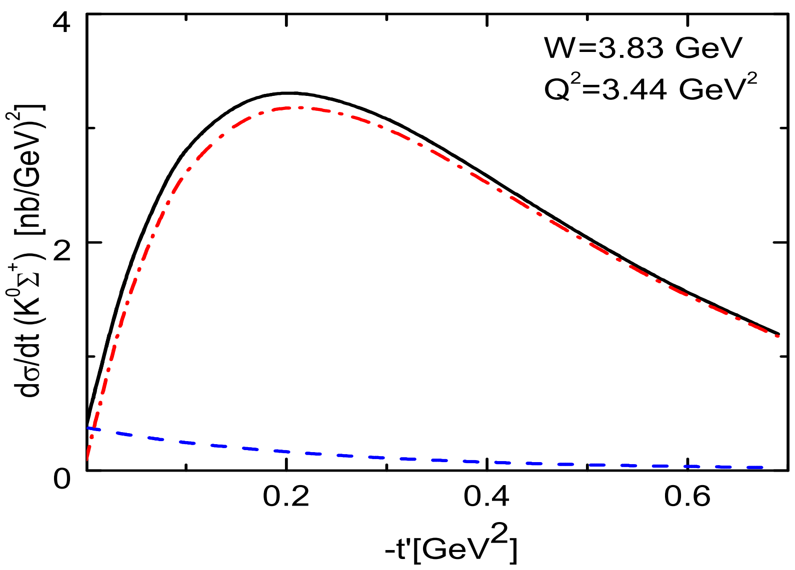
Cross section of $K^+\Sigma^0$ production.

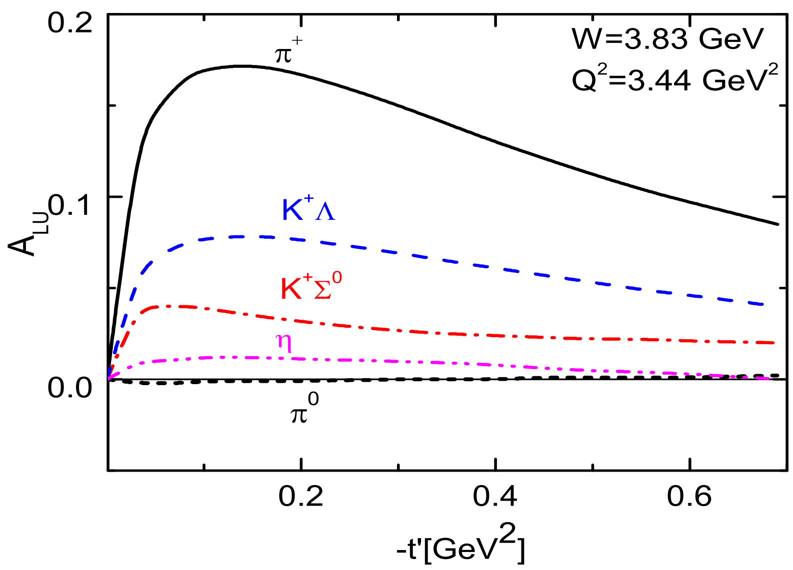


$\sin(\phi - \phi_s)$ and $\sin(\phi_s)$ moments of transverse target asymmetry of $K^+\Sigma^0$ production.

Pole contribution is much smaller here (small $K^+p\Sigma^0$ coupling constant) - dip in σ_T . σ_T is large with respect to σ_L- E_T effects. We predict large transversity effects in $K^0\Sigma^+$ channel.

$\gamma p \to K^0\Sigma^+$ reaction and A_{LU} asymmetry for meson channels.





Cross section of $K^0\Sigma^+$ production.
No pole contribution -sizeable dip in σ_T observed . σ_T is large- E_T effects with respect to σ_L. Large transversity effects in this reaction too.

The beam spin asymmetry for various pseudoscalar-meson channels

Conclusion

- Polarized GPDs are essential pseudoscalar K mesons production.
- GPDs are calculated using PDF on the bases of DD representation.
- At low Q^2 H_T effects are mostly essential in $K^+\Lambda$ channel.
- E_T effects are predominated in $K^+\Sigma^0$ and $K^0\Sigma^+$ channels . Dip in cross section at small momentum transfer is predicted.
- Moments of A_{UT} asymmetry are expected to be not small.
- Transversity H_T and E_T contributions are twist-3 effects. They decrease with Q^2 growing. At high Q^2 the leading twist σ_L will predominate.
- Future JLAB12 and COMPASS results will should throw the light on importance of transversity effects in pseudoscalar mesons production at low Q^2.

Thank You!