Hard Electroproduction of Strangeness

P. Kroll

Fachbereich Physik, Univ. Wuppertal

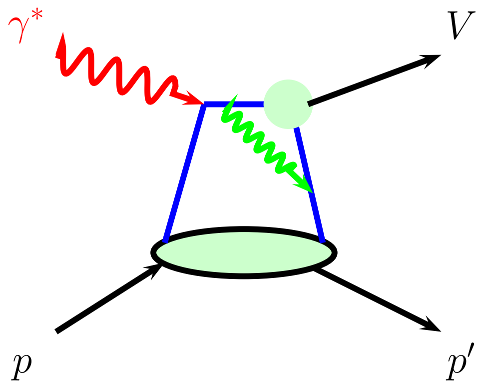
Frascati, October 2010

Outline:

- **Exclusive Electroproduction of mesons**
- **What do we know about the GPDs?**
- **Results on vector meson production**
- **The GPD E**
- **Results on pseudoscalar mesons**
- **Summary**

The $\gamma^* p \to VB$ amplitudes

consider handbag factorization for large Q^2, W and small t;
kinematics fixes skewness: $\xi \simeq \frac{x_{\rm Bj}}{2-x_{\rm Bj}}[1+m_V^2/Q^2] \simeq x_{\rm Bj}/2 + $ m.m.c.



$$\mathcal{M}_{\mu+,\mu+}(V) = \frac{e_0}{2}\left\{\sum_a e_a \mathcal{C}_V^{aa}\langle H_{\rm eff}^g\rangle_{V\mu} + \sum_{ab}\mathcal{C}_V^{ab}\langle H_{\rm eff}^{ab}\rangle_{V\mu}\right\}$$

$$\mathcal{M}_{\mu-,\mu+}(V) = -\frac{e_0}{2}\frac{\sqrt{-t'}}{M+m}\left\{\sum_a e_a \mathcal{C}_V^{aa}\langle E^g\rangle_{V\mu} + \sum_{ab}\mathcal{C}_V^{ab}\langle E^{ab}\rangle_{V\mu}\right\}$$

$\mathcal{C}_V^{ab}$ flavor factors, $M(m)$ mass of $B(p)$, $H_{\rm eff} = H - \xi^2/(1-\xi^2)E$
contributions from $\widetilde{H}$ to T-T amplitude not shown

electroproduction with unpolarized protons at small ξ:
E not much larger than H (see below) $\Longrightarrow H_{\rm eff} \to H$
$|M_{\mu-,\mu+}|^2 \propto t'/m^2$ neglected $\Longrightarrow$ probes H (exception ρ^+)

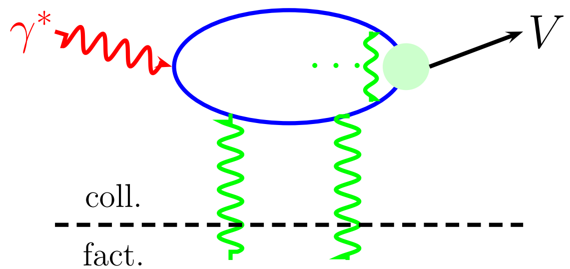
trans. polarized target: probes $Im[\langle E\rangle^*\langle H\rangle]$ interference
polarized beam and target: probes $Re[\langle H\rangle^*\langle\widetilde{H}\rangle]$ interference

Subprocess amplitudes

$F = H, E \qquad \lambda$ parton helicities

$$\langle F\rangle^{ab(g)}_{V\mu} = \sum_\lambda \int d\bar{x}\mathcal{H}^{Vab(g)}_{\mu\lambda,\mu\lambda}(\bar{x},\xi,Q^2,t=0)\, F^{ab(g)}(\bar{x},\xi,t)$$

$F^{aa}_{p\to p} = F^a\,, \quad F^{ab}_{p\to B} = F^a - F^b \quad (a\neq b)$ (flavor symmetry f. ground state baryons)



$$\mathcal{H}^{Vab}_{\mu\lambda,\mu\lambda} = \int d\tau d^2b\, \hat{\Psi}_{V\mu} \exp[-S]\hat{\mathcal{F}}^{ab}_{\mu\lambda,\mu\lambda}$$

Sudakov factor (Sterman et al)

$$S \propto \ln\frac{\ln(\tau Q/\sqrt{2}\Lambda_{\rm QCD})}{-\ln(b\Lambda_{\rm QCD})} + \text{NLL}$$

LO pQCD

$+$ quark trans. mom.

$+$ Sudakov supp.

$\Rightarrow$ coll. appr. for $Q^2\to\infty$

LCWF: $\hat{\Psi}_{V\mu} \sim \Phi_V(\tau)\exp[-\tau(1-\tau)b^2/4a^2_{V\mu}]$

$\hat{\mathcal{F}}$ FT of hard scattering kernel

e.g. FT of $\propto e_a/[k_\perp^2 + \tau(\bar{x}+\xi)Q^2/(2\xi)]$

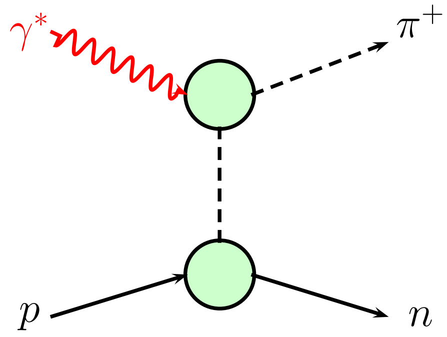
in collinear appr:

regularizes also TT amplitude

$$\text{TT}: \int_0^1 d\tau \frac{\Phi_V(\tau)}{\tau^2}$$

IR singular for large Q^2

The $\gamma^* p \to P p$ amplitudes



$\sim \frac{g_{PNN} F_P(Q^2) F_{PNN}(t)}{t - m_P^2}$

$$\mathcal{M}_{0+,0+}(P) = \frac{e_0}{2} \sum_{ab} \mathcal{C}_P^{ab} \langle \widetilde{H}_{\text{eff}}^{ab} \rangle_P \; + \text{(pole)}$$

$$\mathcal{M}_{0-,0+}(P) = \frac{e_0}{2} \frac{\sqrt{-t'}}{M + m} \sum_{ab} \mathcal{C}_P^{ab} \xi \langle \widetilde{E}_{\text{n.p.}}^{ab} \rangle_P \; + \text{(pole)}$$

$$\widetilde{H}_{\text{eff}} = \widetilde{H} - \xi^2/(1-\xi^2)\widetilde{E}$$

π^+:	$\widetilde{F}_{p\to n} = \widetilde{F}^u - \widetilde{F}^d$	pion exchange
π^0:	$e_u \widetilde{F}^u - e_d \widetilde{F}^d$	
$K^+\Lambda$:	$\widetilde{F}_{p\to\Lambda} = -\frac{1}{\sqrt{6}}(2\widetilde{F}^u - \widetilde{F}^d - \widetilde{F}^s)$	Kaon exchange
$K^+\Sigma^0$:	$\widetilde{F}_{p\to\Sigma^0} = -\frac{1}{\sqrt{2}}(\widetilde{F}^d - \widetilde{F}^s)$	Kaon exchange
$K^0\Sigma^+$:	$\widetilde{F}_{p\to\Sigma^+} = -(\widetilde{F}^d - \widetilde{F}^s)$	
η, η':	$\widetilde{F}^1 \sim e_u \widetilde{F}^u + e_d \widetilde{F}^d + e_s \widetilde{F}^s$	$\widetilde{F}^8 \sim e_u \widetilde{F}^u + e_d \widetilde{F}^d - 2e_s \widetilde{F}^s$

gg Fock state negligible since $\mathcal{H}^{Pg} \sim -t'/Q^2$ K.-Passek(02)

flavor symmetry among ground state baryons - can be probed

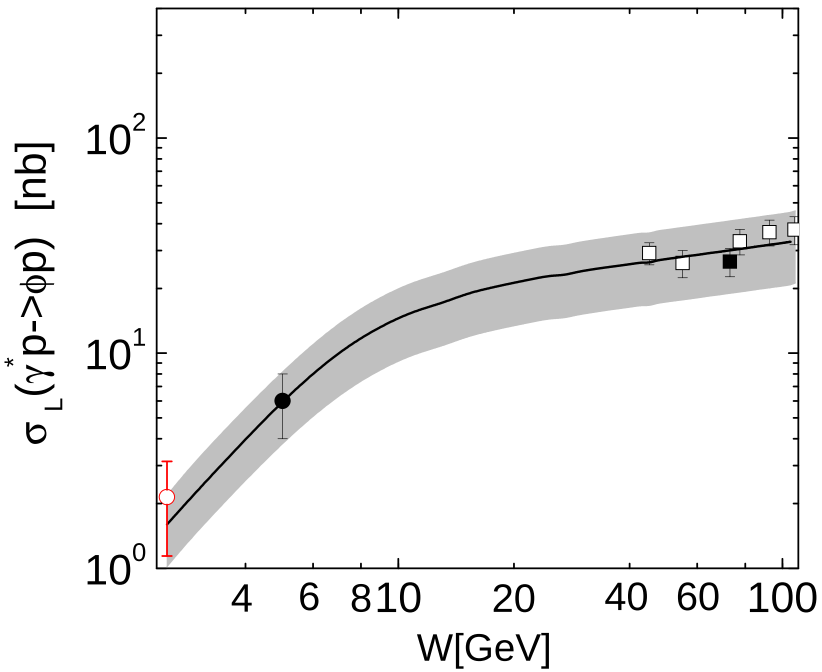
(flavor symmetric sea assumed)

What do we know about GPDs?

GPD	probed by	constraints	status
H	ρ^0, ϕ cross sections	PDFs	known
$\widetilde{H}$	$A_{LL}(\rho^0)$	polarized PDFs	probably small
E	$A_{UT}(\rho^0, \phi)$	sum rule for 2^{nd} moments	probably small
others	-	-	unknown
H	ρ^0, ϕ cross sections	PDFs, Dirac ff	known
$\widetilde{H}$	π^+ data	pol. PDFs, axial ff	known
E	$A_{UT}(\rho^0, \phi)$	Pauli ff	known
$\widetilde{E}^{n.p.}$	π^+ data	-	uncertain
H_T	π^+ data	transversity PDFs [1]	known
others	-	-	unknown

Status of small-skewness GPDs as extracted from meson electroproduction data. The upper part is for gluons and sea quarks, the lower part for valence quarks. Except of H for gluons and sea quarks all GPDs are probed for scales of about $4\,\mathrm{GeV}^2$ ([1] Anselmino (09))

The ϕ cross section



at $Q^2 = 3.8\,\mathrm{GeV}^2$

HERMES, ZEUS, H1, CLAS

Goloskokov-K (08) calculation with E neglected

H constructed from double distr., forward limit CTEQ6 PDFs

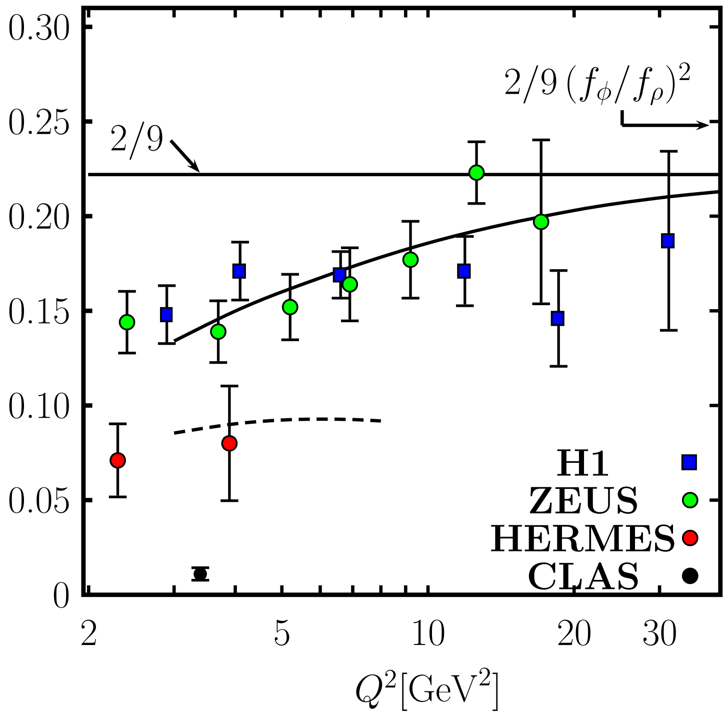
extrapolation to small W hints at small E^g

also shape of diff. cross section shows no hint at large E^g:

$d\sigma/dt \sim |\langle H_{eff}\rangle|^2 - t'/(4m^2)|\langle E\rangle|^2$

JLAB12: measure ϕ cross section at $W = 3, 4\,\mathrm{GeV}$

The ϕ/ρ^0 ratio



$$\sigma_L(\phi)/\sigma_L(\rho^0)$$

HERA: $W \simeq 80\,\text{GeV}$

HERMES: $W = 5\,\text{GeV}$

CLAS: $W \simeq 2.2\,\text{GeV} \quad Q^2 = 3.4\,\text{GeV}^2$

$\sigma(\phi)/\sigma(\rho) \simeq 0.011 \pm 0.004$

suppression due to different a_V

SU(3) breaking in sea $\kappa_s = \frac{(u(x)+d(x))/2}{s(x)}$ CTEQ6

$\kappa_s \simeq 2$ at low Q^2 and $\rightarrow 1$ for $Q^2 \rightarrow \infty$

and valence quarks for HERMES, CLAS

COMPASS data on ρ^0 and ϕ may verify dominance of gluons ($+$ sea)

JLAB12: checks sea

What do we know about E?

analysis of Pauli FF for proton and neutron at $\xi = 0$ Diehl et al (04):

$$F_2^{p(n)} = e_{u(d)} \int_0^1 dx E_v^u(x, \xi = 0, t) + e_{d(u)} \int_0^1 dx E_v^d(x, \xi = 0, t)$$

ansatz for small $-t$: $E_v^a = e_v^a(x) \exp\left\{ t\left(\alpha'_v \ln(1/x) + b_a^e\right)\right\}$

forward limit: $e_v^a = N_a x^{-0.48}(1-x)^{\beta_v^a}$ (analogously to PDFs)

N_a fixed from $\kappa_a = \int_0^1 dx E_v^a(x, \xi = 0, t = 0)$ (κ^a anom. magn. moment)

fitting FF data: $\beta_v^u = 4$, $\beta_v^d = 5.6$

sum rule (Ji's s.r. and momentum s.r. of DIS) at $t = \xi = 0$

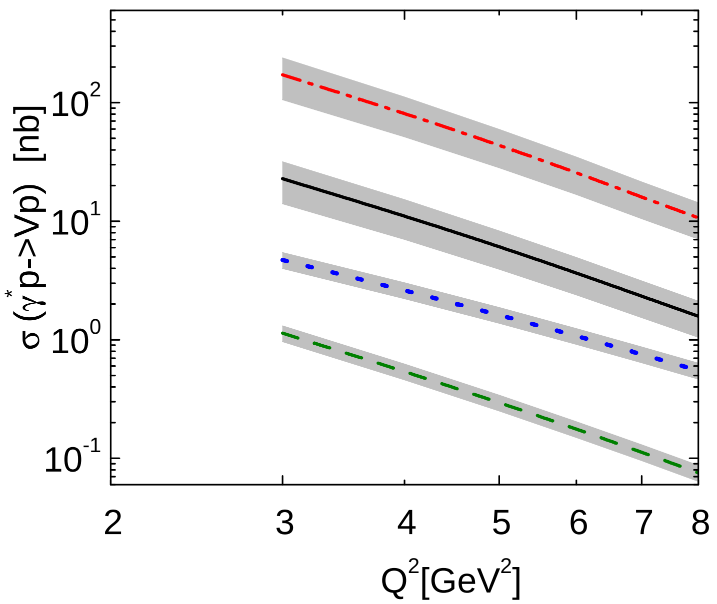
$\int_0^1 dx x e_g(x) = e_{20}^g = -\sum e_{20}^{a_v} - 2\sum e_{20}^{\bar{a}}$

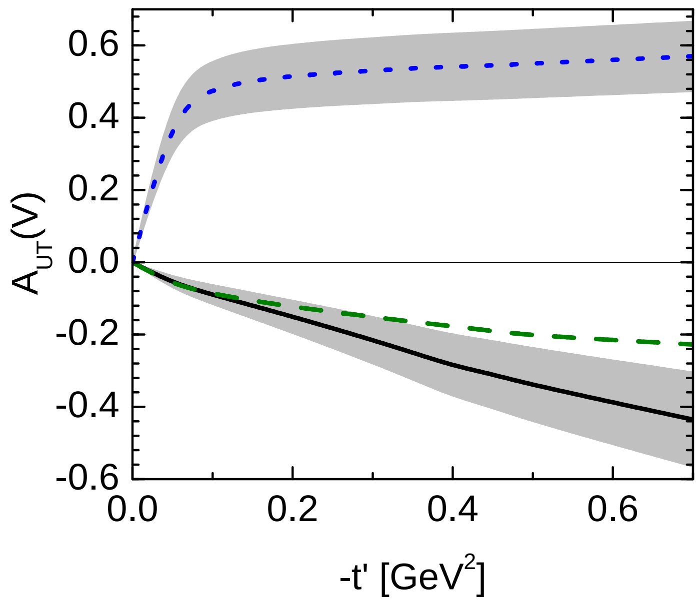
valence term very small $\Rightarrow$ gluon and sea quark moments cancel each other

parameterization as above, N_s fixed from positivity bound, N_g from sum rule

input to double distribution ansatz

Cross sections and A_{UT} for vector mesons





ρ^0, ω, ρ^+, K^{*0} at $W = 5\,\mathrm{GeV}$ Goloskokov-K(08)

t dependence of $A_{UT} \sim \mathrm{Im}[\langle E\rangle^* \langle H\rangle]$ controlled by trivial factor $\sqrt{-t'}$

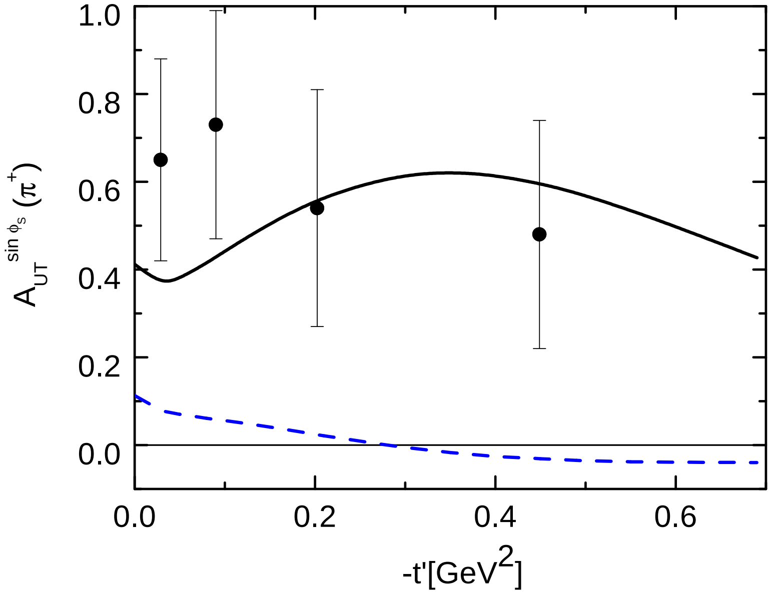
except for ρ^+: since $H_v^u - H_v^d$ small and $E_v^u - E_v^d$ large

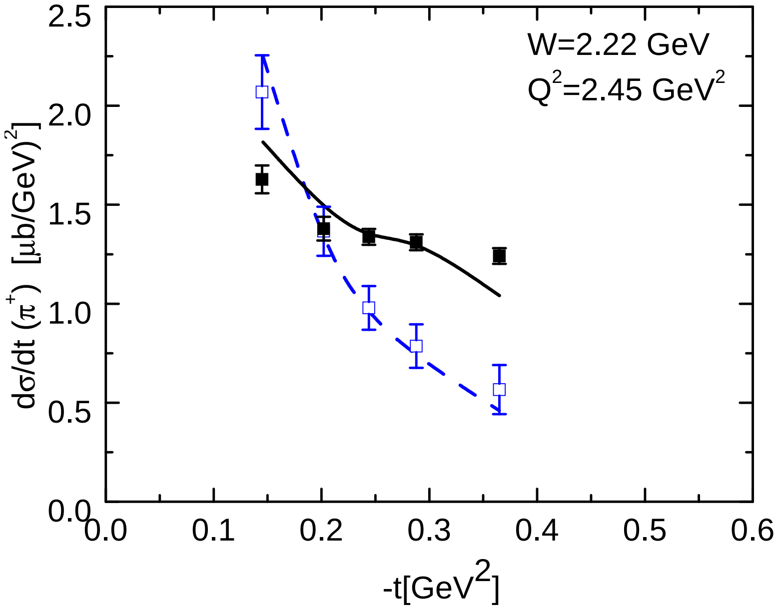
E non-negligible in cross section, contribution from helicity flip ampl. $\propto t'$

data on $\rho^0, \omega, \phi, K^{*0}$ from HERMES and COMPASS will come JLAB12?

for K^{*0}: transition GPD $F^{ds}_{p\to\Sigma^+} = F^s - F^d$

π^+: Transverse photon polarization matters





HERMES $Q^2 \simeq 2.5\,\mathrm{GeV}^2$, $W = 3.99\,\mathrm{GeV}$

various moments of π^+ cross section

measured with trans. pol. target

$\sin\phi_s$ moment very large

does not seem to vanish for $t' \to 0$

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

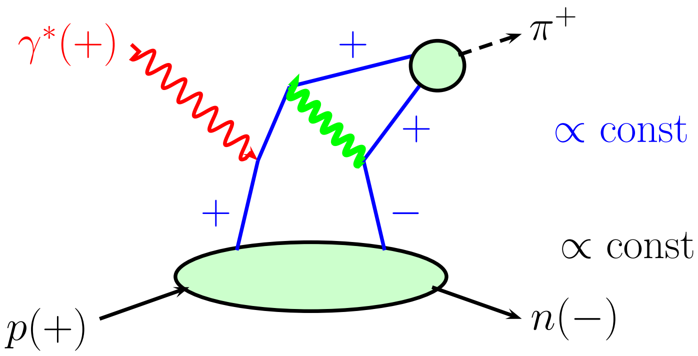
n-f. ampl. $\mathcal{M}_{0-,++}$ required

JLab $F_\pi - 2$ black: σ_T blue: σ_L

σ_T large at large $-t$

$\gamma^*_T \to \pi^+$ transitions substantial

Twist-3



$\mathcal{M}_{0-,++} \propto$ const

twist-3 pion w.f.

helicity-flip GPDs $(H_T, E_T, \widetilde{H}_T, \widetilde{E}_T)$

required

Hoodbhoy-Ji (98), Diehl (01)

at small ξ and small $-t'$: H_T dominant

$$\mathcal{M}^{\rm twist-3}_{0-,\mu+} = e_0\sqrt{1-\xi^2}\int_{-\xi}^{1} d\bar{x}\,\mathcal{H}^{\rm twist-3}_{0-,\mu+}\left[H_T^u - H_T^d\right]$$

$\mathcal{H}_{0-,\mu+}$: with pseudoscalar w.f.

$\langle\pi^+(q') \mid \bar{d}(x)\gamma_5 u(-x) \mid 0\rangle = f_\pi\mu_\pi \int d\tau \mathrm{e}^{q'^+ x\tau}\Phi_P(\tau)$

local limit $x \longrightarrow 0$ related to divergency of axial vector current

$\Longrightarrow \mu_\pi = m_\pi^2/(m_u + m_d) \simeq 2\,\mathrm{GeV}$ at scale $2\,\mathrm{GeV}$

$\mathcal{M}^{\rm twist-3}_{0-,\mu+}$ formally suppressed by μ_π/Q but large at $Q^2 = 2-5\,\mathrm{GeV}^2$

Results and generalizations

detailed analysis of HERMES data on π^+ production
(cross sections and transverse as well as longitudinal target asymmetries)
see $\sin(\phi_s)$ moment Goloskokov-K(09), Bechler-Müller(09)
(π^0: Goldstein-Liuti(08))

straightforward extension to JLAB6 kinematics (large ξ) fails in detail
COMPASS? (also time-like process $\pi^- p \to l^+ l^- n$)
π^0 data from HERMES, COMPASS and JLAB12?

Generalization to K production straightforward (but not done)
Kaon exchange and twist-3 effect similar
(latter perhaps smaller $\mu_K = m_K^2/(m_u + m_s) \simeq 1.5\,\mathrm{GeV}$)

K data from JLAB12 would probe $\widetilde{H}$ and $\widetilde{E}$ for strange quarks

Summary

- electroproduction of strangeness will provide information about strange quarks GPDs, not much known as yet

- GPDs are process independent fcts, may be used to predict other processes
  - Fourier transform $\Delta_\perp \Longrightarrow b$ ($\Delta_\perp^2 = -t$) gives access to localization of partons in transverse configuration space
  - total angular momentum of strange quarks through Ji's sum rule

- Jlab 12 may allow measurements at sufficiently small ξ
  - for $\xi \gtrsim 0.2$ one may likely run into problems with normalization $\Longrightarrow$ study ratios of oberservables (Strikman-Weiss(08))
  - warning: at low Q^2 large NLO correction (Diehl-Kugler(07))