Hard exclusive meson production at HERMES, COMPASS and JLAB

Probing Strangeness in Hard Processes

Frascati, Italy

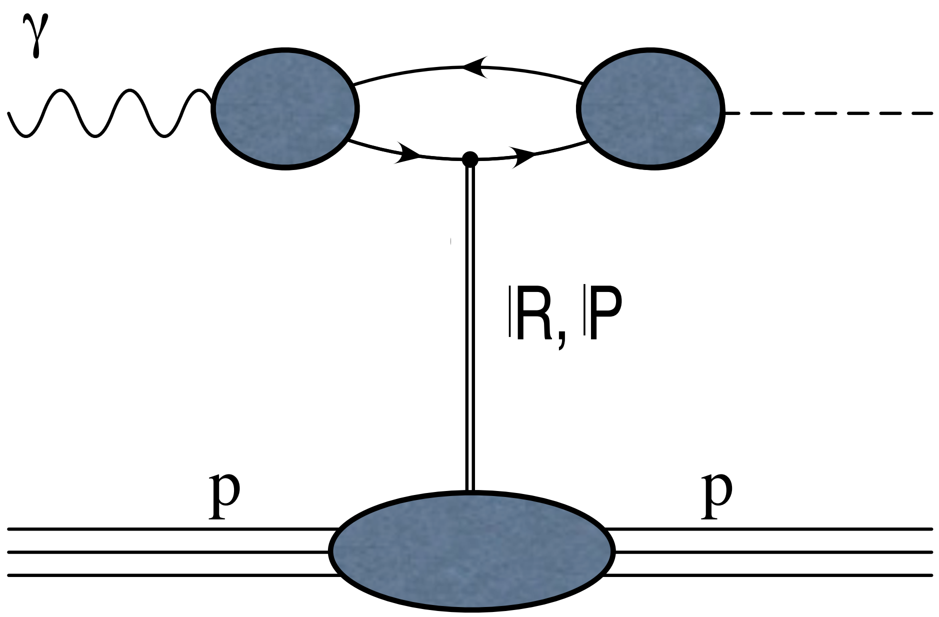
18-21 October, 2010

Ami Rostomyan

exclusive meson production

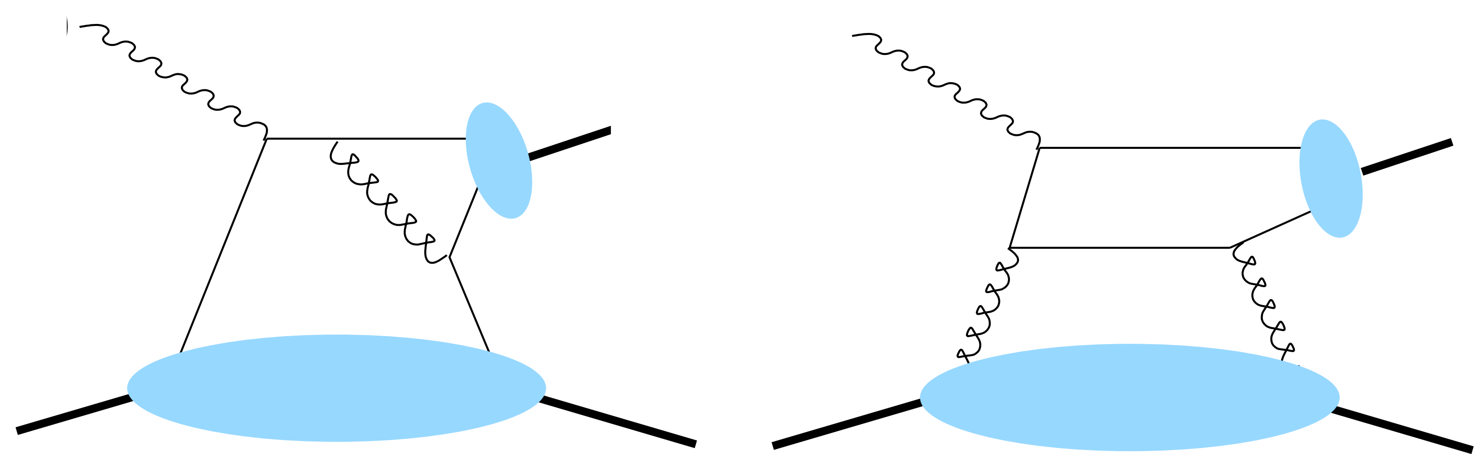
VMD

$$0 < Q^2 < \text{few GeV}^2$$

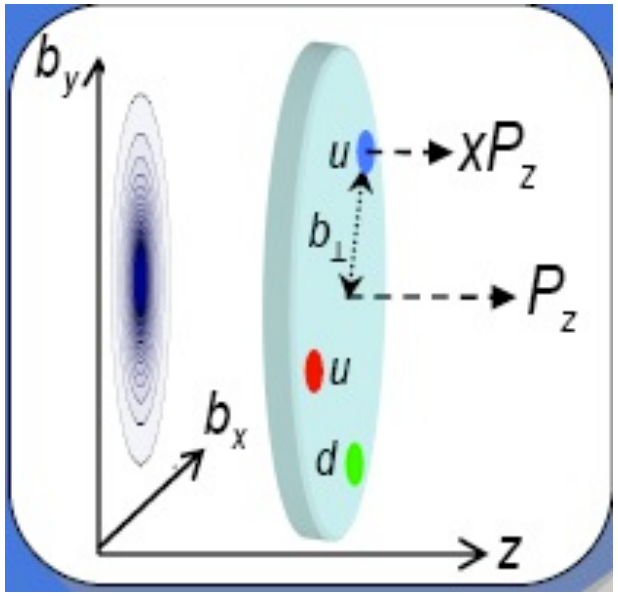


GPD

$$Q^2 \gg 1\text{GeV}^2$$



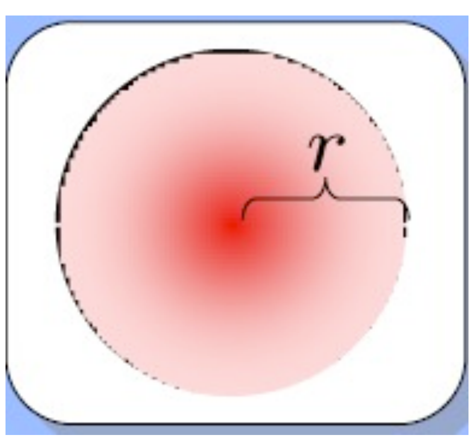
generalized parton distributions



Nucleon Tomography

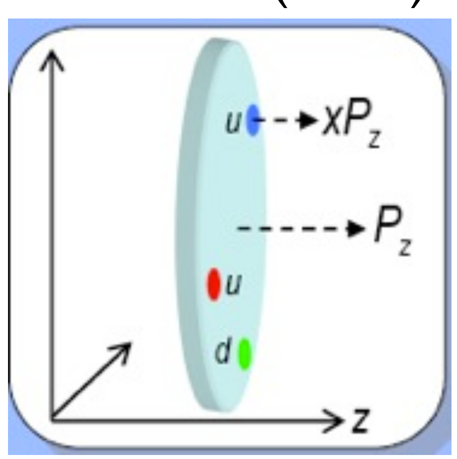
correlation between longitudinal momentum and transverse position

Elastic Form Factors



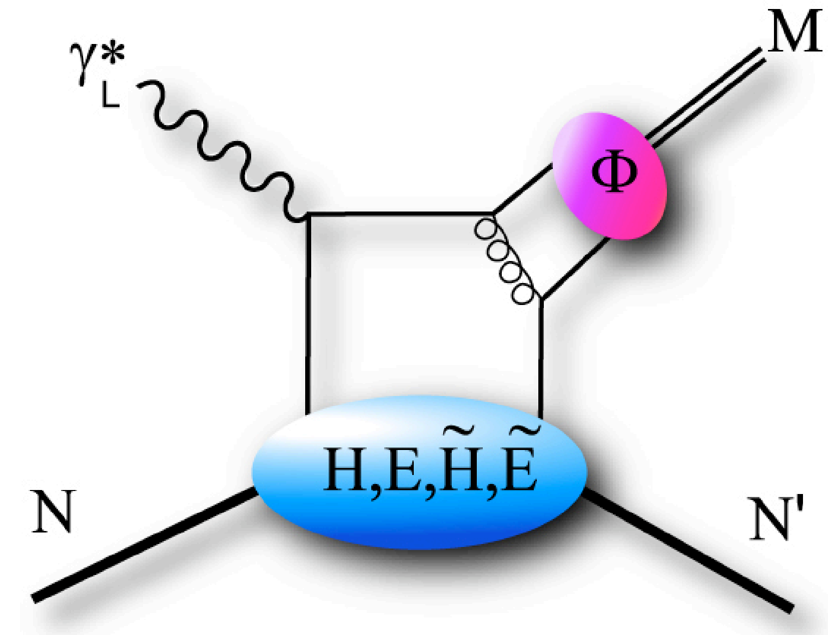
transverse position of partons

Parton Distribution Functions (PDFs)



longitudinal momentum of partons

at leading twist: $H \; E \; \widetilde{H} \; \widetilde{E}$



$$J_q = \frac{1}{2} \lim_{t \to 0} \int_{-1}^{1} dx \, x \, [H_q(x,\xi,t) + E_q(x,\xi,t)]$$

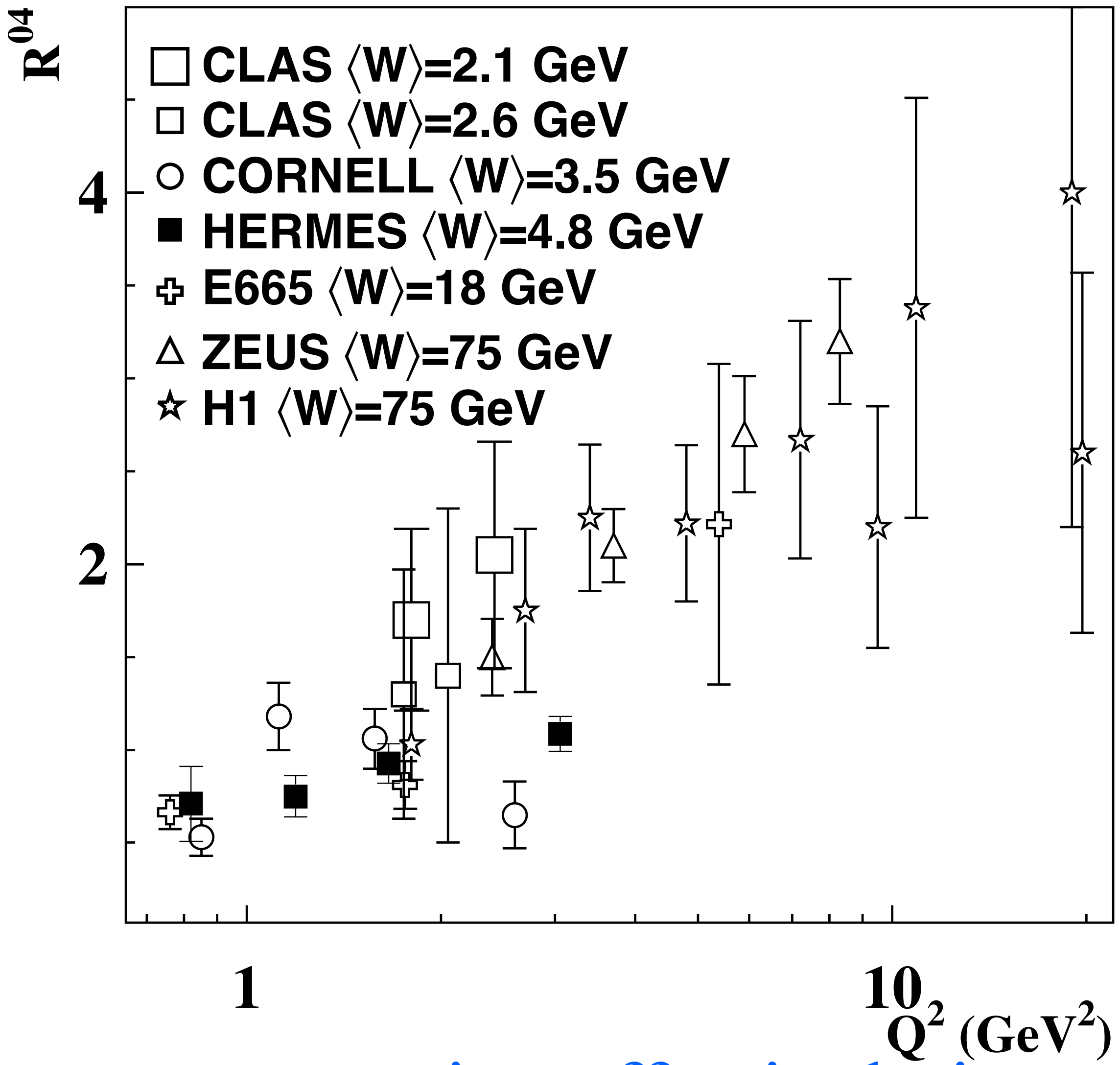
$$J_g = \frac{1}{2} \lim_{t \to 0} \int_{0}^{1} dx \, [H_g(x,\xi,t) + E_g(x,\xi,t)]$$

factorization for σ_L (and ρ_L, ω_L, ϕ_L) only

- $\sigma_L - \sigma_T$ suppressed by $1/Q$
- σ_T suppressed by $1/Q^2$

generalized parton distributions

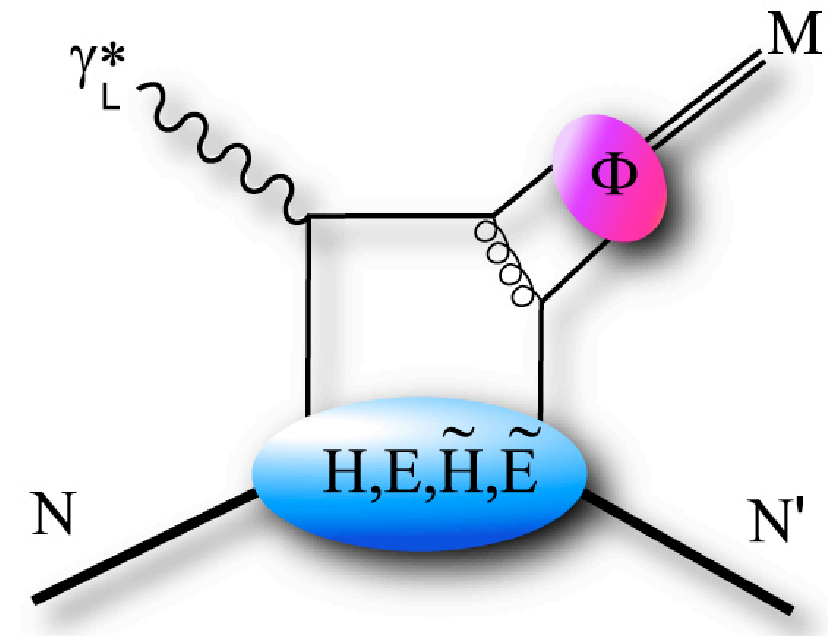
$$R = \frac{\sigma_L}{\sigma_T}$$



✦ suppression effectively is not working for $Q^2 \sim$ few GeV

✦ valuable information on GPDs from higher twist terms

at leading twist: $H \;\; E \;\; \widetilde{H} \;\; \widetilde{E}$



$$J_q = \frac{1}{2} \lim_{t\to 0} \int_{-1}^{1} dx\, x \left[H_q(x,\xi,t) + E_q(x,\xi,t)\right]$$

$$J_g = \frac{1}{2} \lim_{t\to 0} \int_{0}^{1} dx \left[H_g(x,\xi,t) + E_g(x,\xi,t)\right]$$

factorization for σ_L (and ρ_L, ω_L, ϕ_L) only

- $\sigma_L - \sigma_T$ suppressed by $1/Q$
- σ_T suppressed by $1/Q^2$

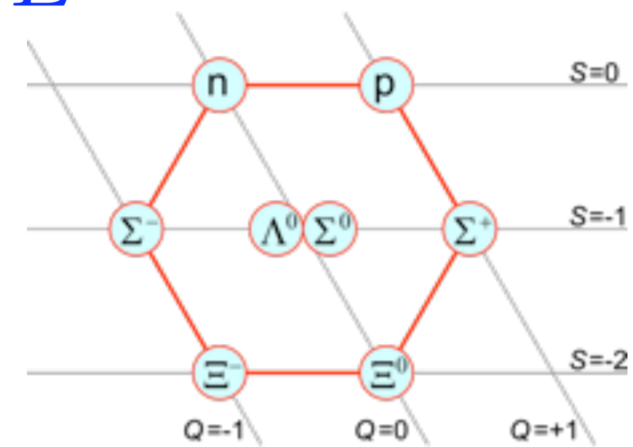
given channel probes specific GPD flavor

vector mesons

at leading twist: $H \quad E$

higher twist: $\widetilde{H} \quad \widetilde{E}$

$\rho^0 p$	$\frac{1}{\sqrt{2}}[2u+d]+\frac{1}{\sqrt{2}}[2\bar{u}+\bar{d}]+\frac{9}{4}\,g$
ωp	$\frac{1}{\sqrt{2}}[2u-d]+\frac{1}{\sqrt{2}}[2\bar{u}-\bar{d}]+\frac{3}{4}\,g$
ϕp	$-[s+\bar{s}]+\frac{3}{4}\,g$
$\rho^+ n$	$2[u-d]-[\bar{u}-\bar{d}]$
$K^{*+}\Lambda$	$-\frac{2}{\sqrt{6}}[2u-d-s]$
	$+\frac{1}{\sqrt{6}}[2\bar{u}-\bar{d}-\bar{s}]$
$K^{*+}\Sigma^0$	$-\frac{2}{\sqrt{2}}[d-s]+\frac{1}{\sqrt{2}}[\bar{d}-\bar{s}]$
$K^{*0}\Sigma^+$	$[d-s]+[\bar{d}-\bar{s}]$



SU(3):

- relate nucleon to octet hyperon
- relate $p \rightarrow N$ transition GPDs to $p \rightarrow p'$

pseudoscalar mesons

at leading twist: $\widetilde{H} \quad \widetilde{E}$

higher twist: H_T

$\pi^+ n$	$2[\Delta u-\Delta d]+[\Delta\bar{u}-\Delta\bar{d}]$
$\pi^0 p$	$\frac{1}{\sqrt{2}}[2\Delta u+\Delta d]-\frac{1}{\sqrt{2}}[2\Delta\bar{u}+\Delta\bar{d}]$
$K^+\Lambda$	$-\frac{2}{\sqrt{6}}[2\Delta u-\Delta d-\Delta s]$
	$-\frac{1}{\sqrt{6}}[2\Delta\bar{u}-\Delta\bar{d}-\Delta\bar{s}]$
$K^+\Sigma^0$	$-\frac{2}{\sqrt{2}}[\Delta d-\Delta s]-\frac{1}{\sqrt{2}}[\Delta\bar{d}-\Delta\bar{s}]$
$K^0\Sigma^+$	$[\Delta d-\Delta s]-[\Delta\bar{d}-\Delta\bar{s}]$

modeling GPDs

- constraints on the t-behavior of valence quark and gluon GPDs

$H^q(x,\xi,t) \;=\; H^q(x,\xi)\, F_1^p(t)$ $\qquad$ $H^g(x,\xi,t) \;=\; H^g(x,\xi)\, F_1^p(t)$

- t-behavior of sea quarks is unknown
- same t-dependence for quarks and gluons

quarks $\qquad$ quarks and gluons

➡ measure the t-dependence of cross section (e.g. ρ^+ and ρ^0)

$$\int_0^1 dx\, E_g + \sum_q \int_{-1}^{1} dx x E_q = 0$$

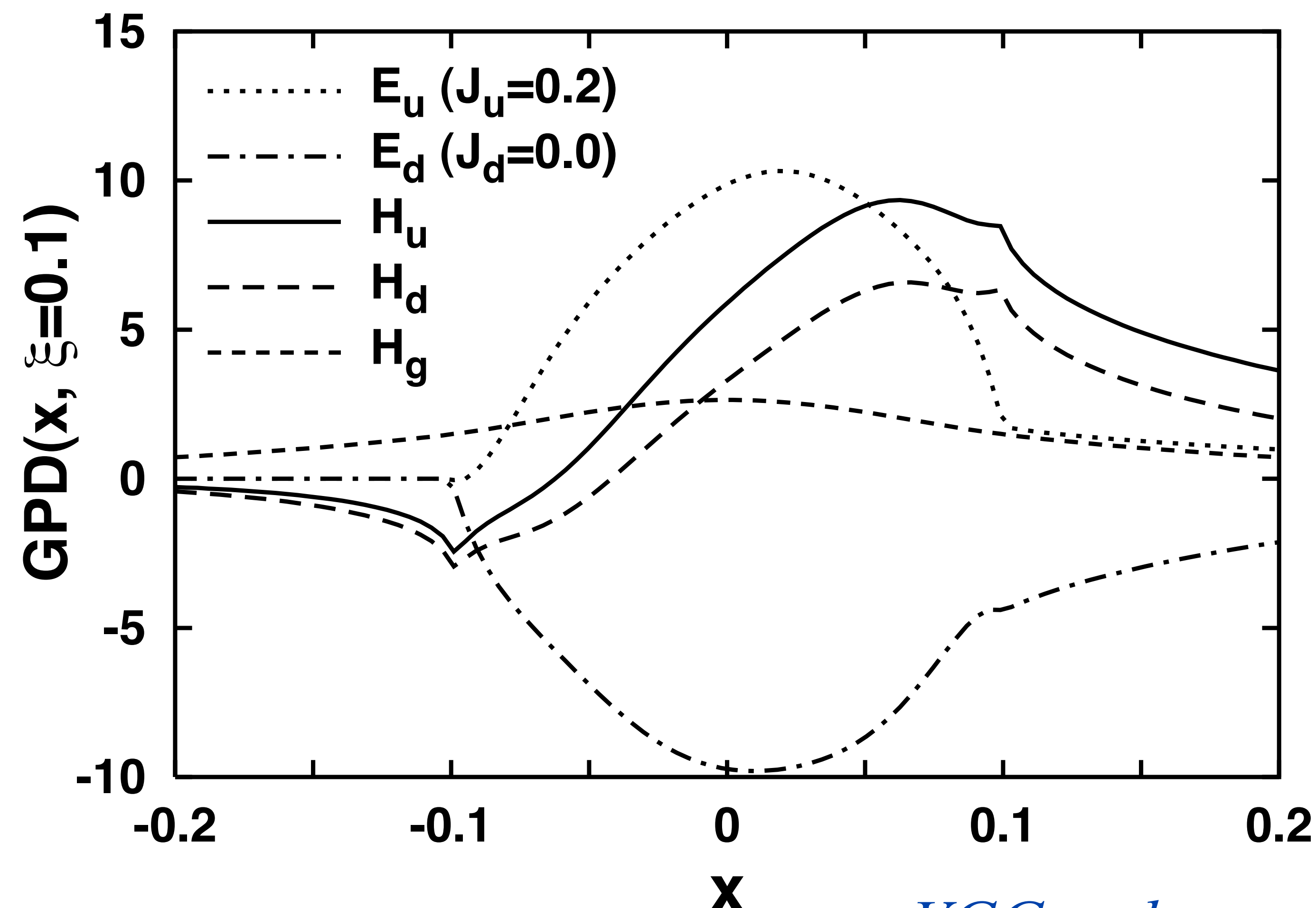
- Diehl (2003) -

- $E_u \approx -E_d$
- expectation:

$$\int_0^1 dx\, E_g = -2 \sum_q \int_0^1 dx\, x\, E_{\bar{q}}$$

- $E_{\bar{q}}$: small see quark contribution at $x \sim 0.1$
- small E_g

- Ellinghaus, Nowak, Vinnikov, Ye (2005) -



- VGG code -

vector mesons

t-dependence

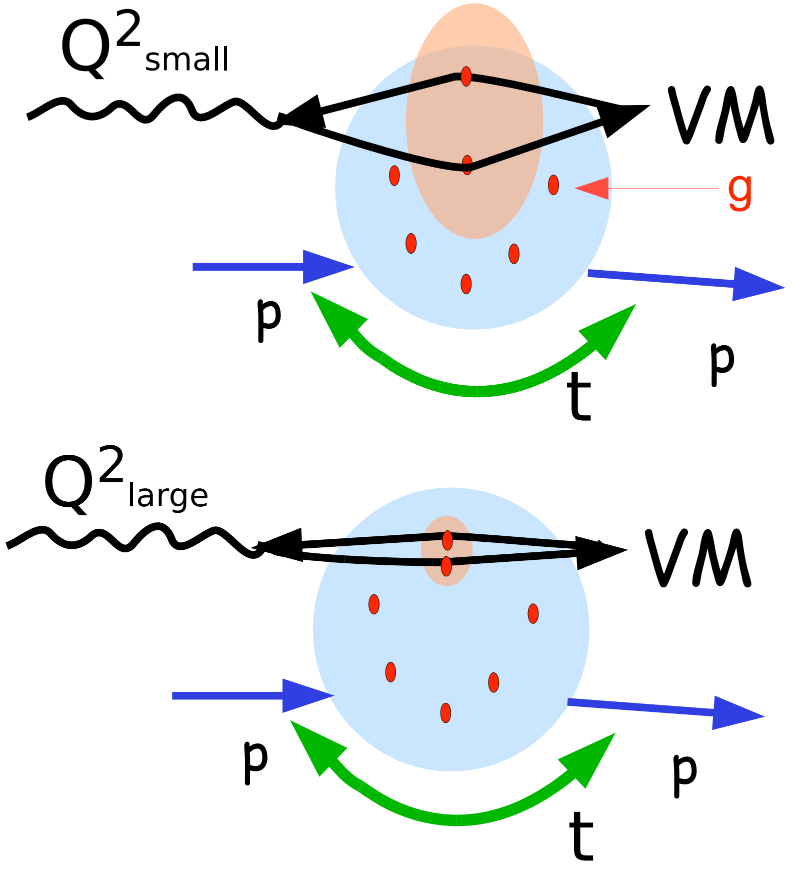
$$\frac{d\sigma}{dt} \sim e^{-bt}$$

$$b \sim R_p^2 + R_{q\bar{q}}^2$$

t-dependence

$$\frac{d\sigma}{dt} \sim e^{-bt}$$

$$b \sim R_p^2 + R_{q\bar{q}}^2$$



t-dependence

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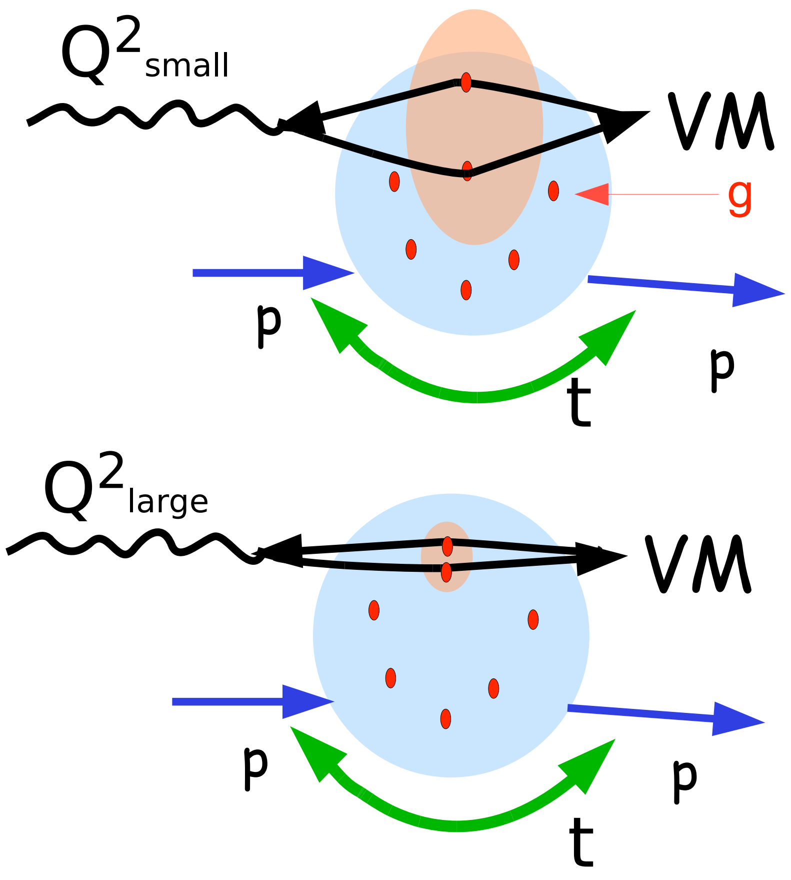

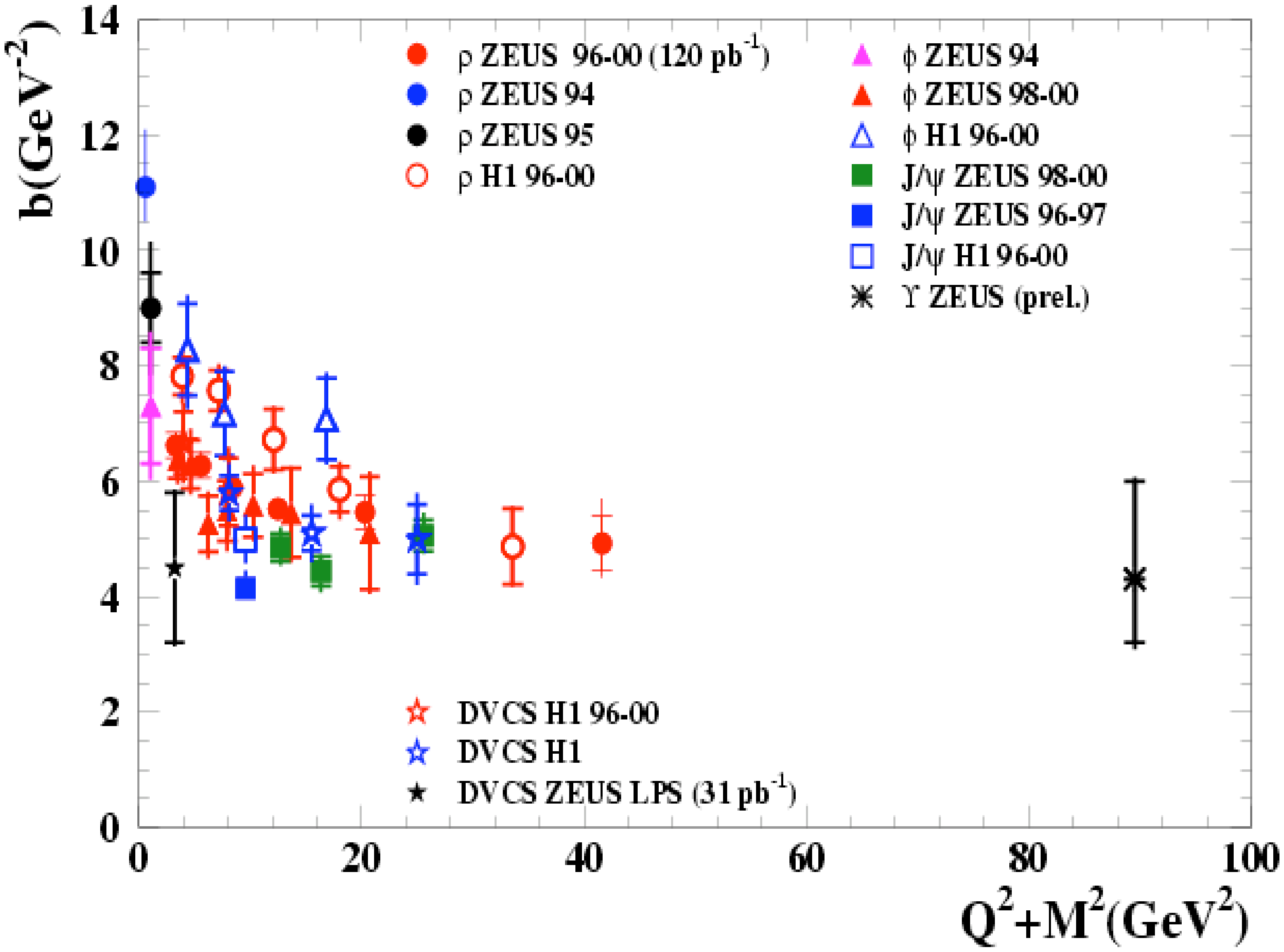

t-dependence

$$\frac{d\sigma}{dt} \sim e^{-bt}$$

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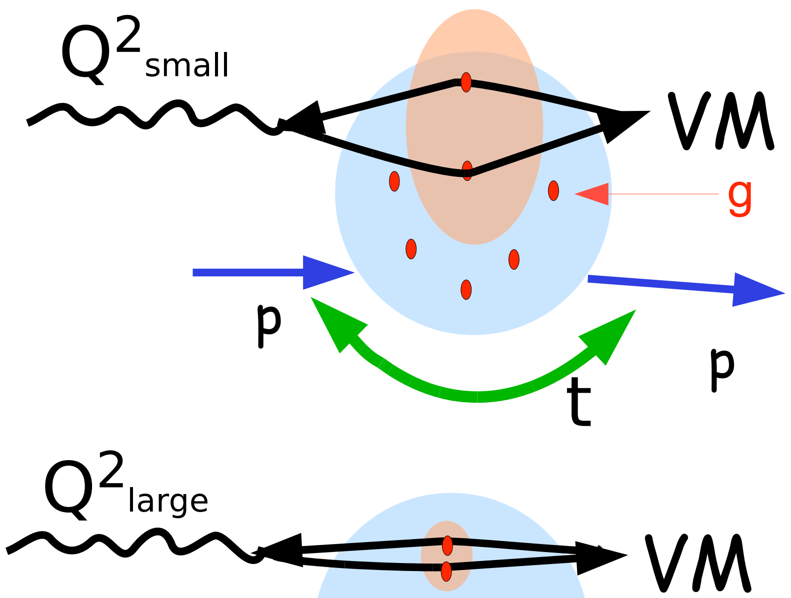

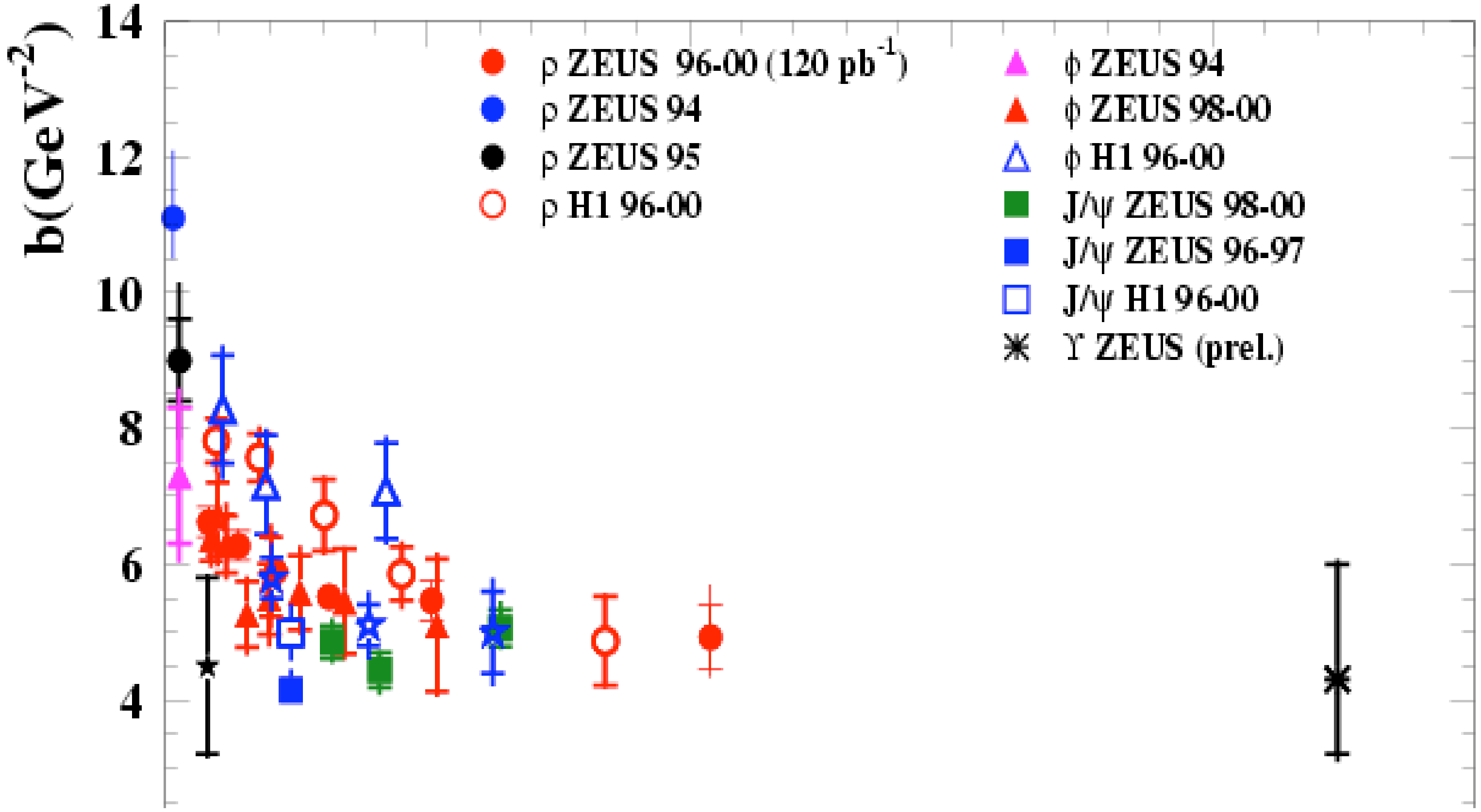

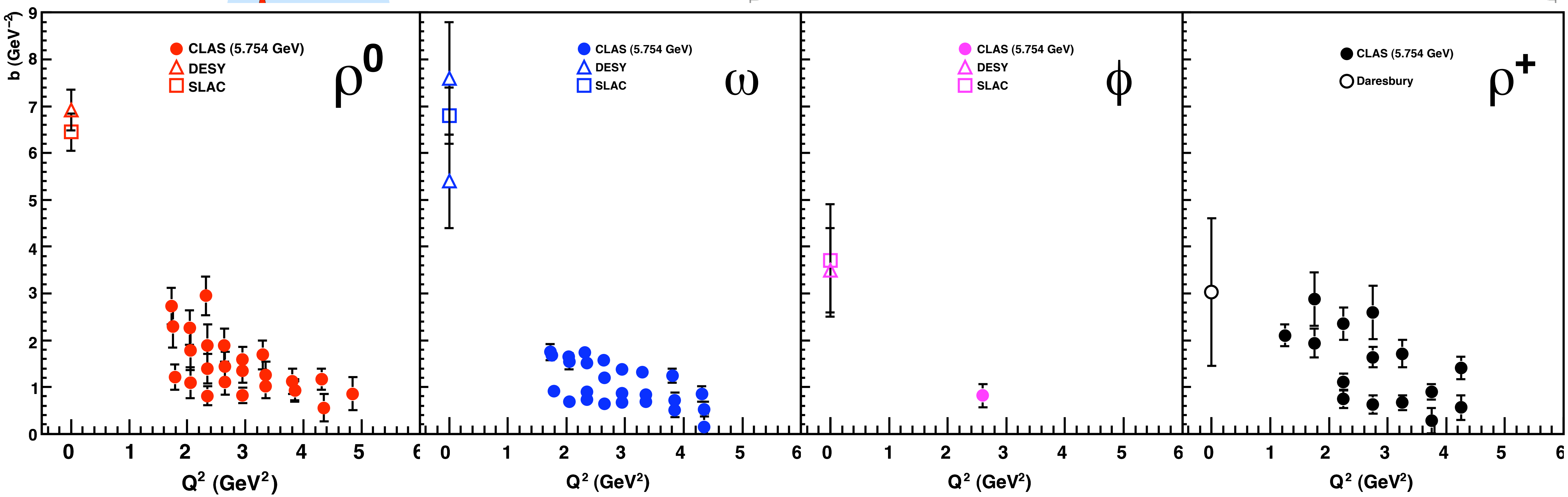

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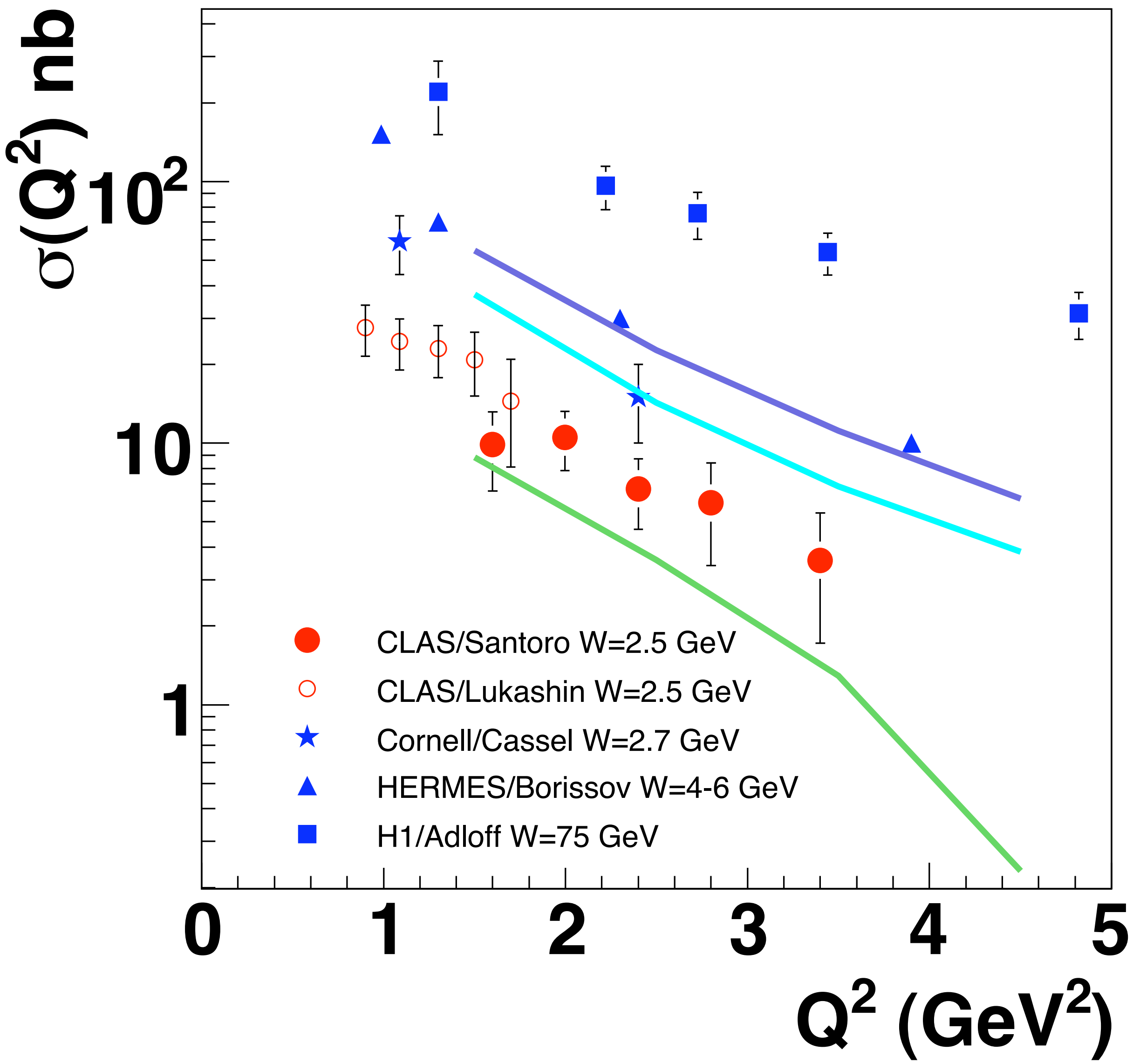
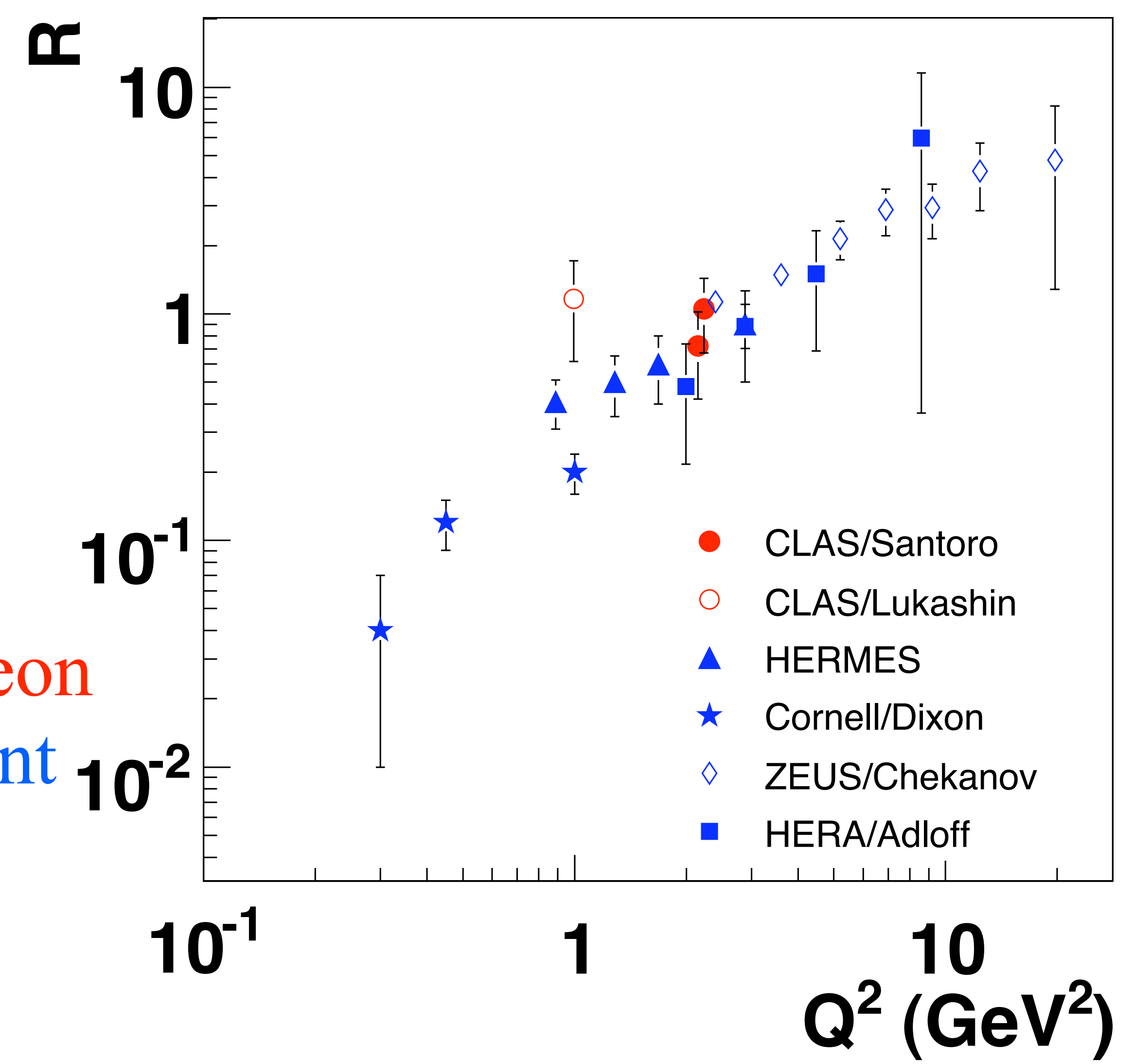
$\gamma^* p \rightarrow \phi p$ cross section



- similar trend as a function of Q^2
- monotonically increase with W
- Regge model calculation
  W = 2.1, 2.45, 2.9 GeV
  - Laget (2003) -
  ➡ overestimate the CLAS data

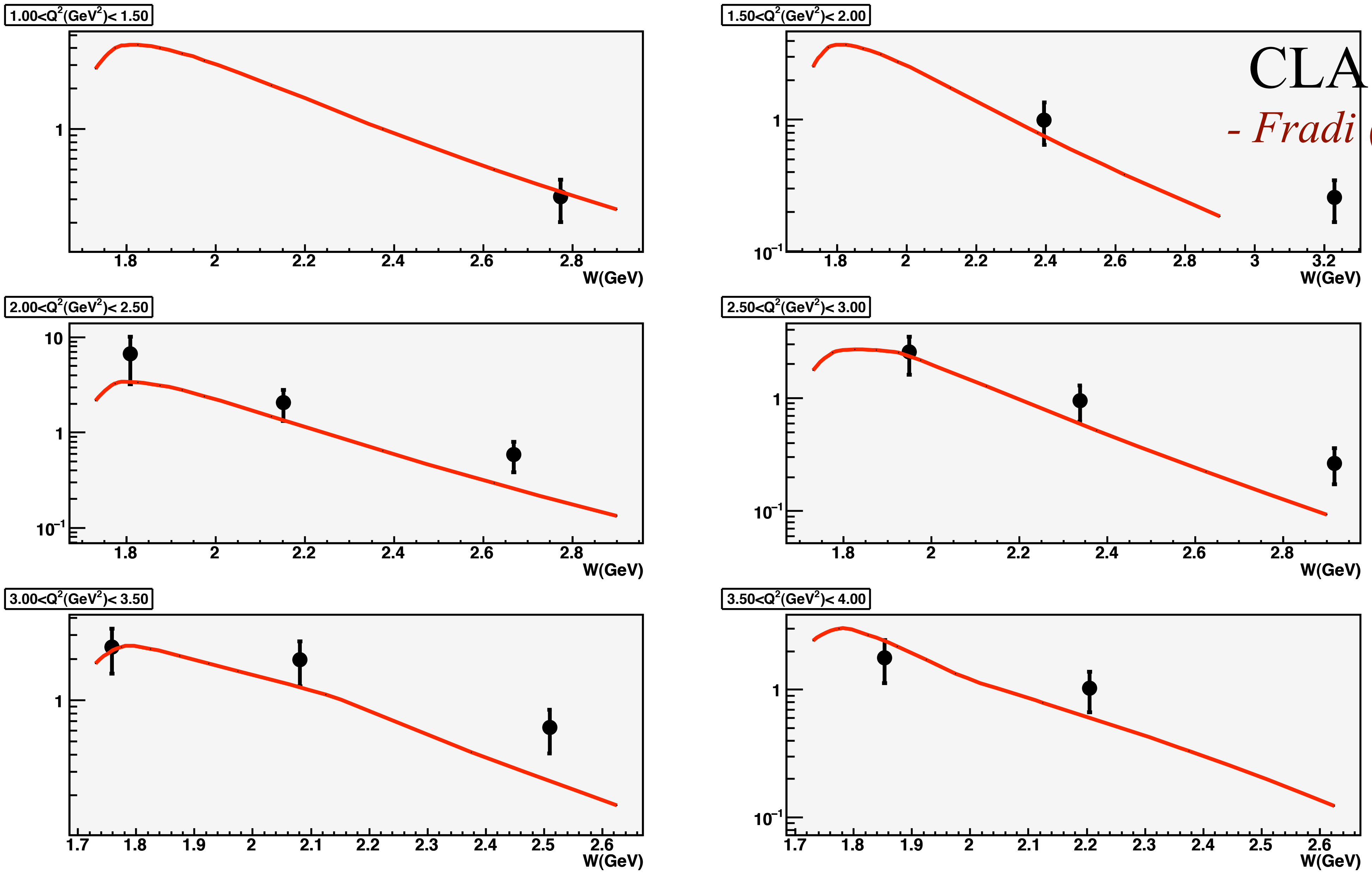


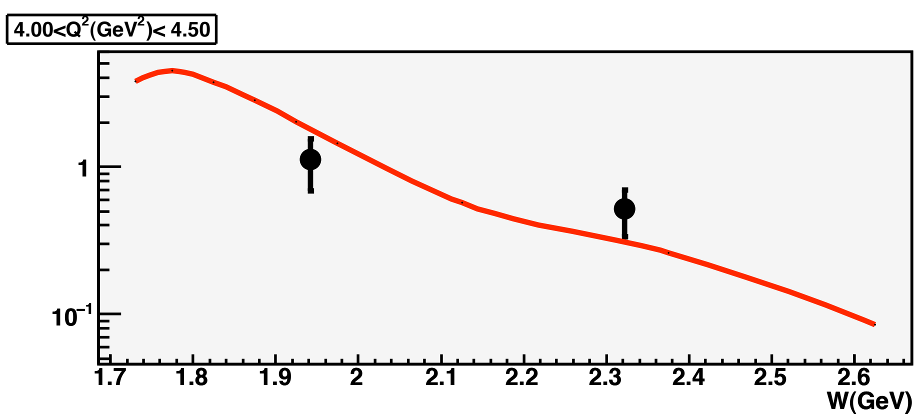
- applicability of GPD formalism at low W data? probe of gluon field in the nucleon
- longitudinal cross section is not dominant in low-W kinematics
- modified perturbative approach might be successful *- Goloskokov Kroll (2007) -*

$\gamma^* p \to \rho^+ n$ cross section

CLAS preliminary data

- Fradi (2010) hep-ex/10101198 -





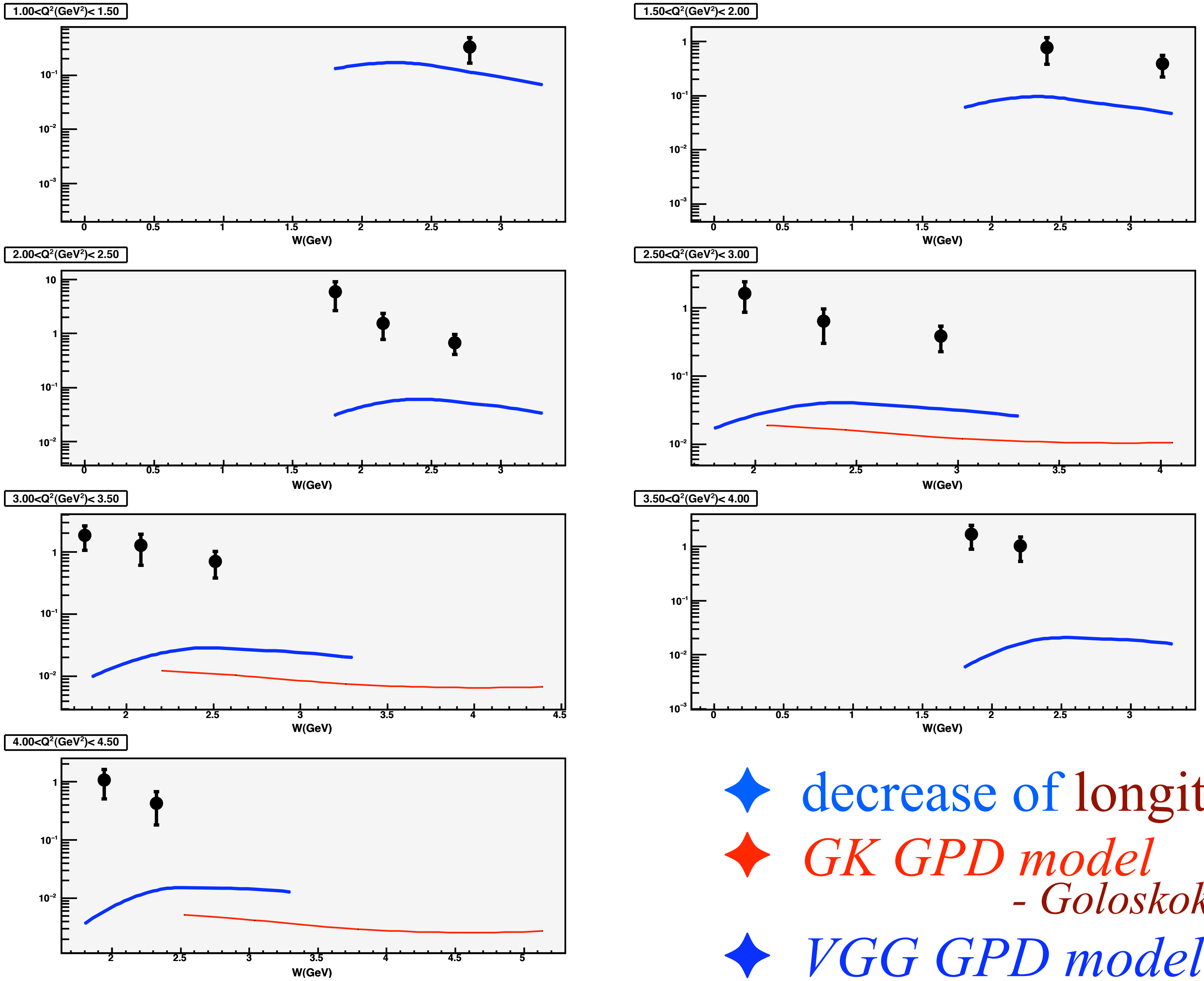
- decrease of total cross section with W

Regge model

- Laget (2003) -

- exchange of ρ^+ and π^+
- good description in all ranges

$\gamma^* p \rightarrow \rho^+ n$ cross section



CLAS preliminary data

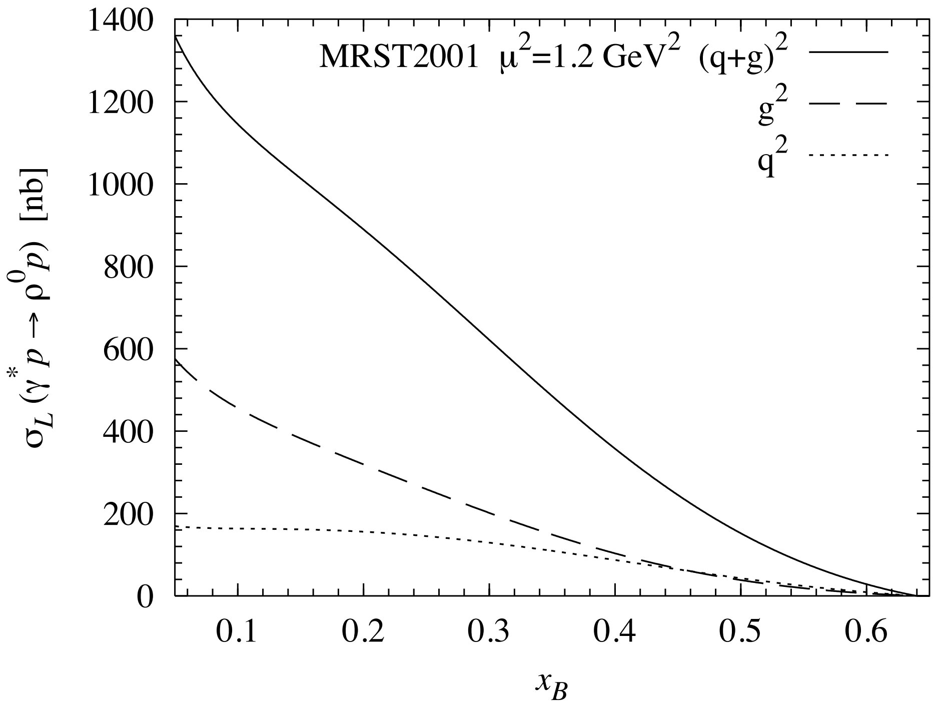
- Fradi (2010) hep-ex/10101198 -

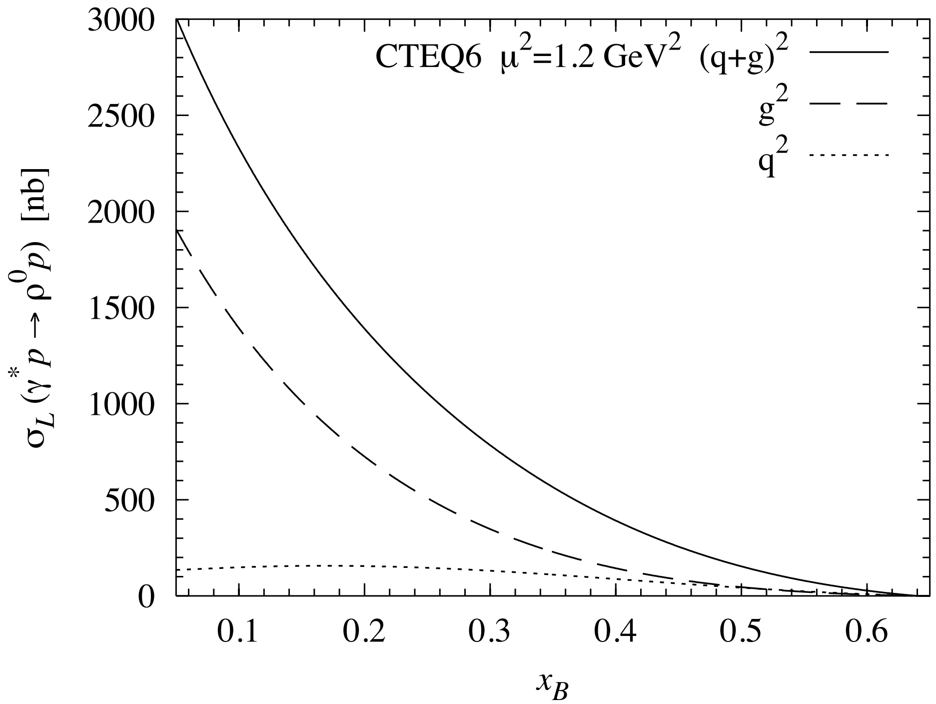
- decrease of longitudinal cross section with W
- *GK GPD model*
  - Goloskokov Kroll (2005) -
- *VGG GPD model*
  - Vanderhaeghen, Guichon, Guidal (1999)
- models do not describe the data
  - GPD formalism is not applicable
  - missing contribution is GPD parameterizations

cross section ratios

- cross sections change significantly when varying the nonperturbative input: MRST % CTEQ
  - unpolarized gluon densities at low scales

- Diehl, Kugler, Schaefer, Weiss (2005) -





- next-to leading order corrections
- substantial power corrections
  - ➡ cross section ratios for similar channels
  - ➡ cancelation of theoretical uncertainties

$$\frac{\sigma_L(\gamma^* p \to \phi p)}{\sigma_L(\gamma^* p \to \rho^0 p)} = \text{const.}$$

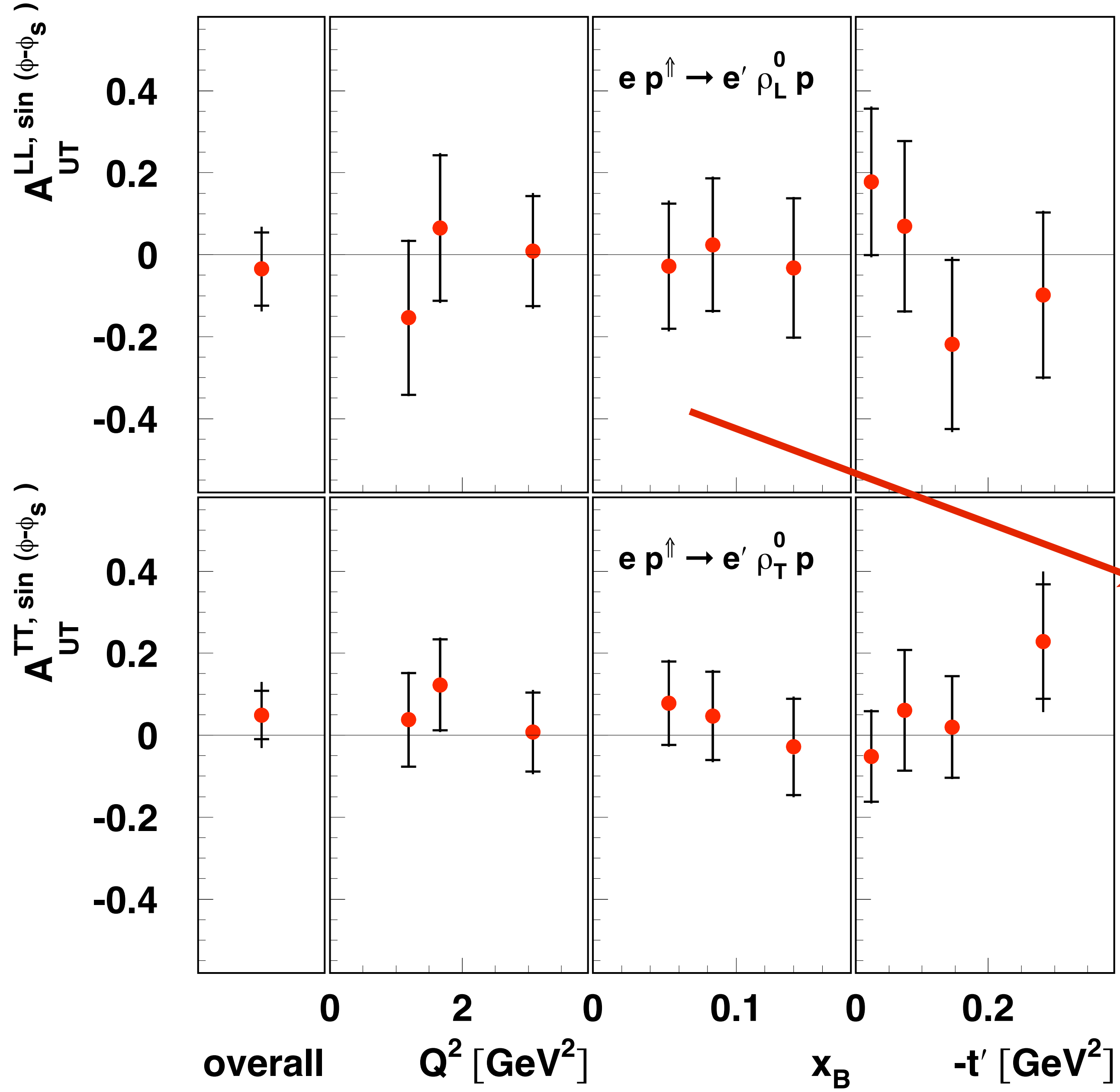
$$\frac{\sigma_L(\gamma^* p \to K^{*+}\Lambda)}{\sigma_L(\gamma^* p \to \rho^+ n)} \approx \frac{3}{2}$$

ρ^0 transverse target spin asymmetry

- cross section asymmetry with respect to transverse target polarization

$$A^{\gamma^* p \to \rho^0_L p}_{\text{target pol.}} = \frac{|\boldsymbol{\Delta}_\perp| \, \mathrm{Im}(\mathcal{E}^* \mathcal{H})}{(1-\xi^2)|\mathcal{H}|^2 - (\xi^2 + t/4M^2)|\mathcal{E}|^2 - 2\xi^2 \mathrm{Re}(\mathcal{E}^* \mathcal{H})}$$

- depends linearly on the helicity-flip GPD E
- no kinematic suppression of GPD E with respect to GPD H



- HERMES Collaboration (2009) -

average kinematics:
$\langle -t' \rangle = 0.13$ GeV^2
$\langle x_B \rangle = 0.09$
$\langle Q^2 \rangle = 2.0$ GeV^2

- L/T separation using the angular distribution
- leading twist contribution: compatible with 0 overall value

$$A^{\gamma^* p \to \rho^0_L p}_{\text{target pol.}} = -0.033 \pm 0.058$$

- implies that the E^g is small

$$A^{\gamma^* p \to \rho^0_L p}_{\text{target pol.}} \propto \frac{E}{H} \propto \frac{E^q + E^g}{H^q + H^g}$$

ρ^0 transverse target spin asymmetry

✦ cross section asymmetry with respect to transverse target polarization

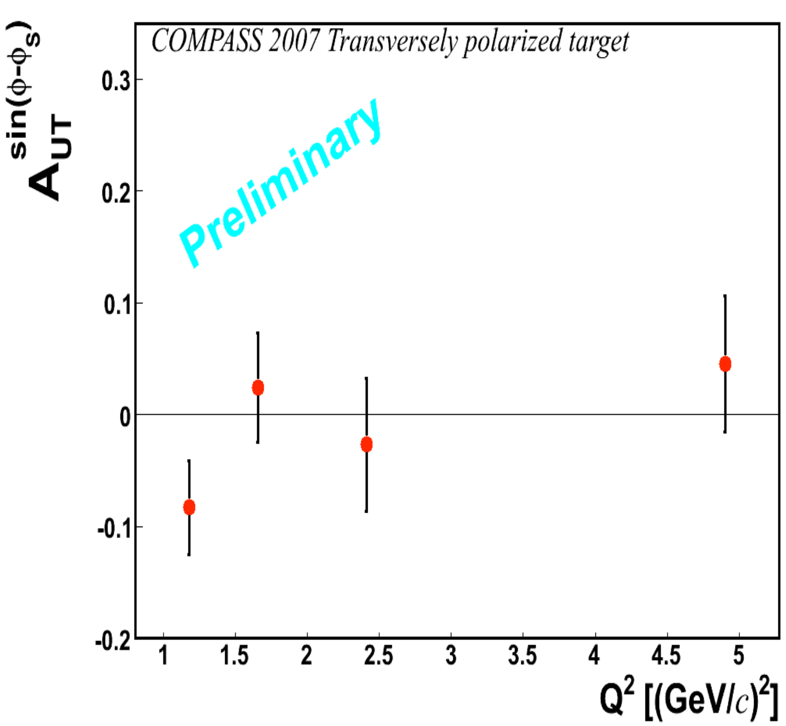
$$A_{\text{target pol.}}^{\gamma^* p \to \rho_L^0 p} = \frac{|\mathbf{\Delta}_\perp|\,\mathrm{Im}(\mathcal{E}^*\mathcal{H})}{(1-\xi^2)|\mathcal{H}|^2 - (\xi^2 + t/4M^2)|\mathcal{E}|^2 - 2\xi^2\mathrm{Re}(\mathcal{E}^*\mathcal{H})}$$

✦ depends linearly on the helicity-flip GPD E

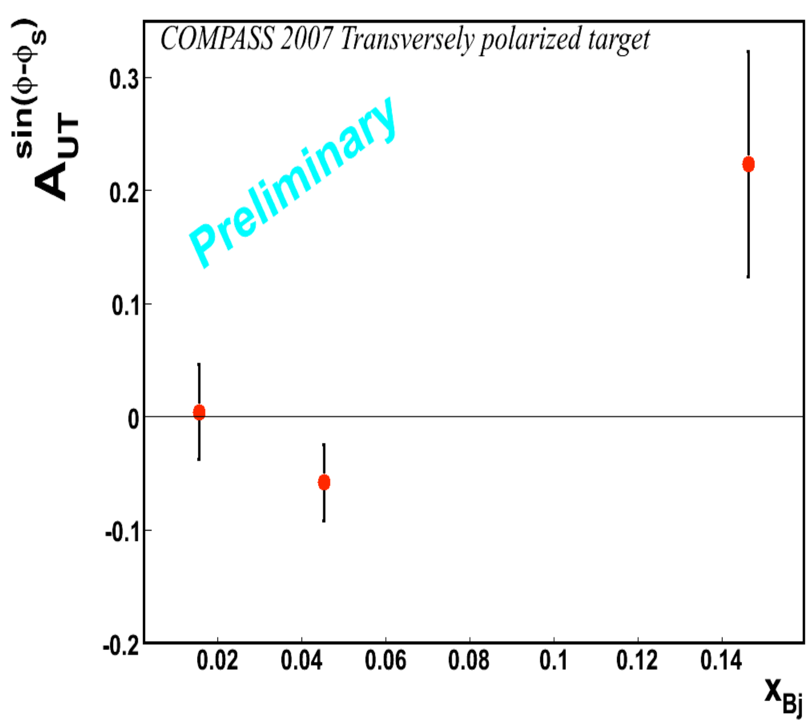
✦ no kinematic suppression of GPD E with respect to GPD H

- COMPASS Collaboration -

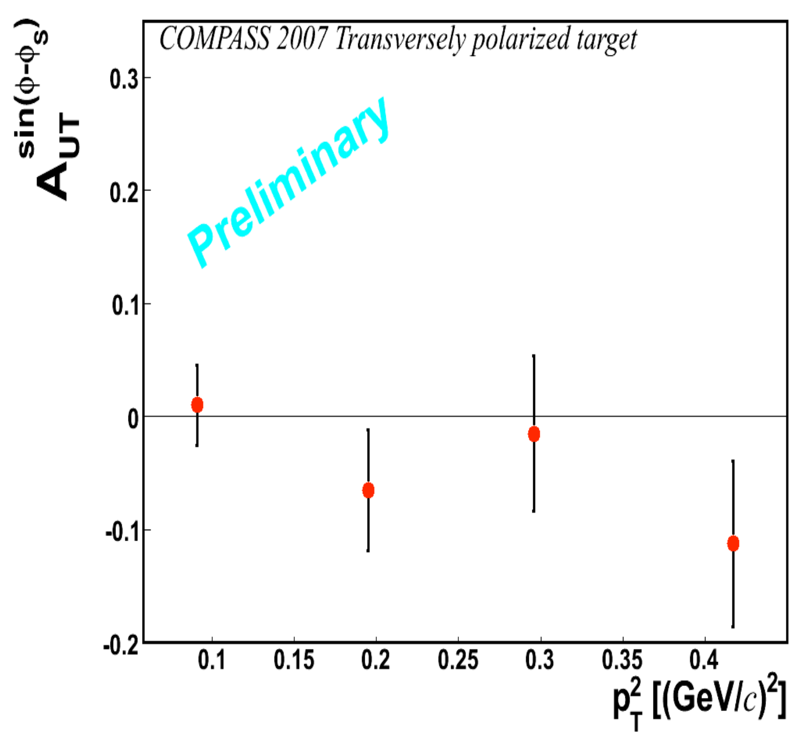
$< Q^2 > \approx 2.2\ (\mathrm{GeV}/c)^2$



$< x_{Bj} > \approx 0.04$



$< p_t^2 > \approx 0.18\ (\mathrm{GeV}/c)^2$



✦ no L/T separation yet

✦ compatible with 0 overall value

ρ^0 transverse target spin asymmetry

- cross section asymmetry with respect to transverse target polarization

$$A^{\gamma^* p \to \rho^0_L p}_{\text{target pol.}} = \frac{|\boldsymbol{\Delta}_\perp| \,\mathrm{Im}(\mathcal{E}^* \mathcal{H})}{(1-\xi^2)|\mathcal{H}|^2 - (\xi^2 + t/4M^2)|\mathcal{E}|^2 - 2\xi^2 \mathrm{Re}(\mathcal{E}^* \mathcal{H})}$$

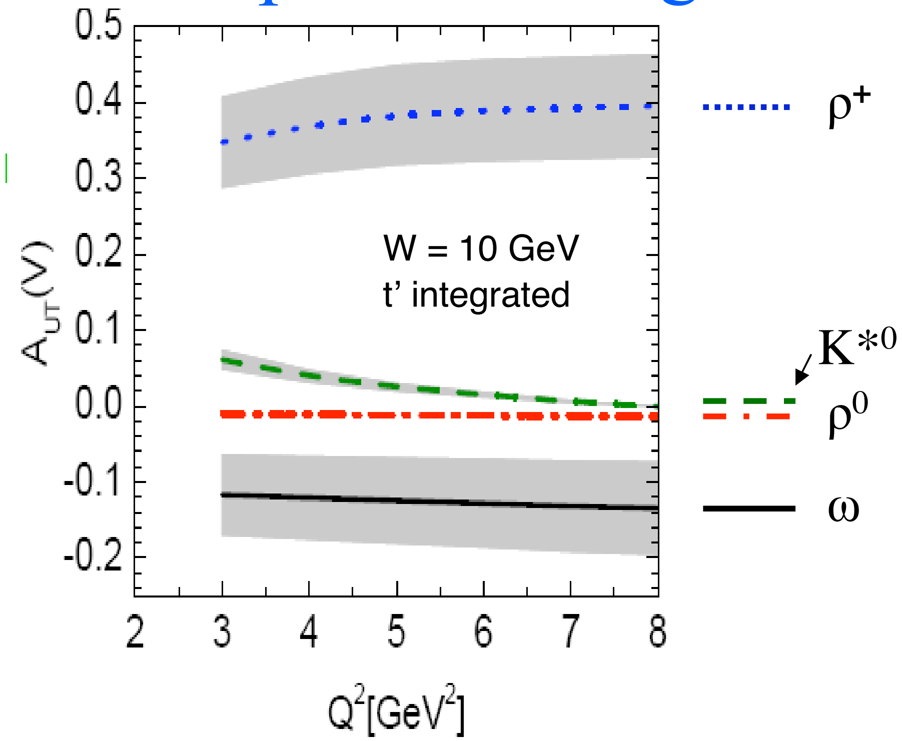
- depends linearly on the helicity-flip GPD E
- no kinematic suppression of GPD E with respect to GPD H

recoil polarization asymmetry

- cross section asymmetry with respect to recoil polarization

$$A^{\gamma^* p \to K^{*+} \Lambda}_{\text{recoil pol.}} = \frac{|\boldsymbol{\Delta}_\perp| \,\mathrm{Im}(\mathcal{E}^* \mathcal{H})}{(1-\xi^2)|\mathcal{H}|^2 - (\xi^2 + t/4M^2)|\mathcal{E}|^2 - 2\xi^2 \mathrm{Re}(\mathcal{E}^* \mathcal{H})}$$

- access to GPD E from unpolarized target



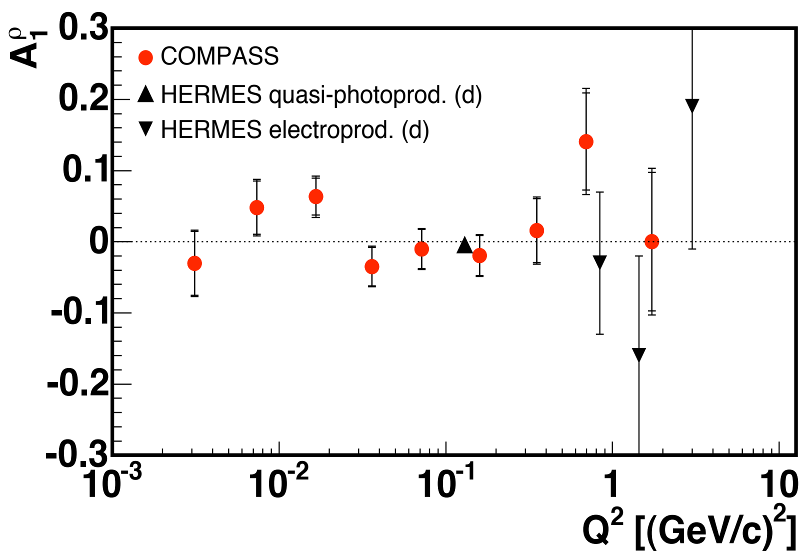
- Goloskokov, Kroll (2008) -

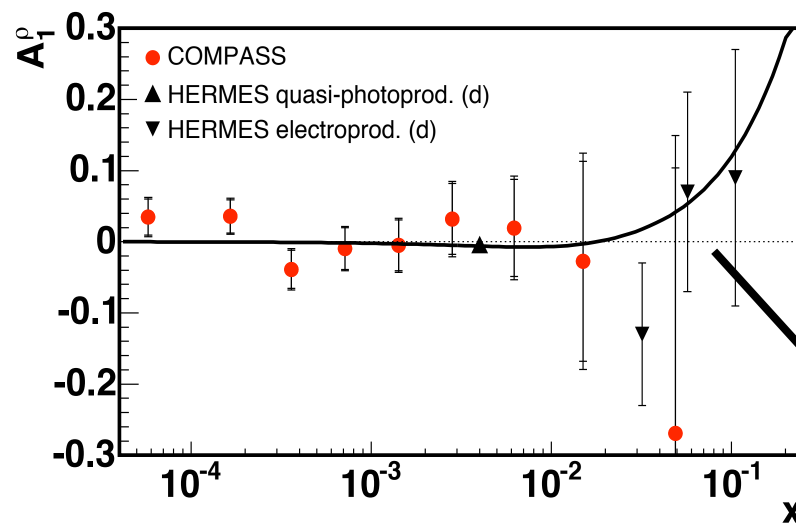
double spin asymmetry

✦ asymmetry arise due to interference between natural and unnatural parity exchange amplitudes

✦non-leading twist: interference between the GPD $H^{s,g}$ and $\widetilde{H}^{s,g}$

D





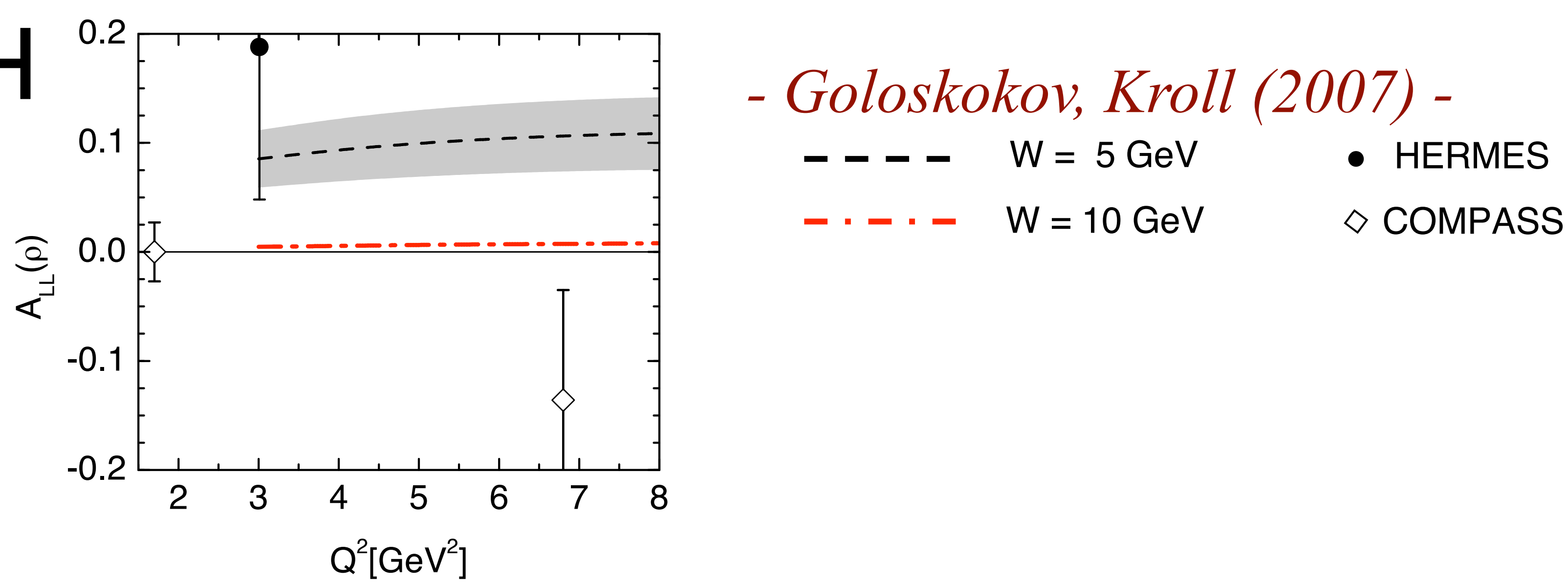
✦ asymmetry is compatible with 0

➡ UPE contribution is negligible

✦ measurements at different W ranges

➡ no W-dependence

H



✦ prediction: relate the A_1^ρ to inclusive asymmetry

$$A_1^\rho = \frac{2A_1}{1 + (A_1)^2}$$

- Fraas -

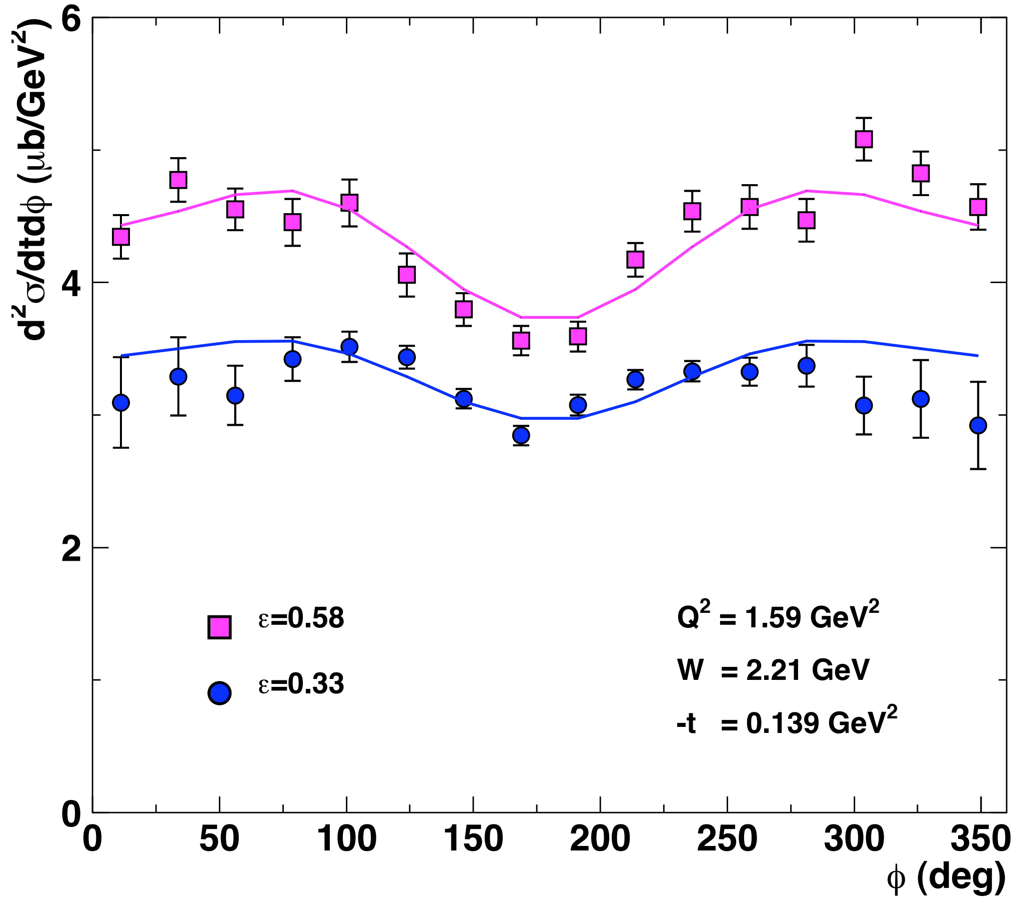
➡ prediction is consistent with data

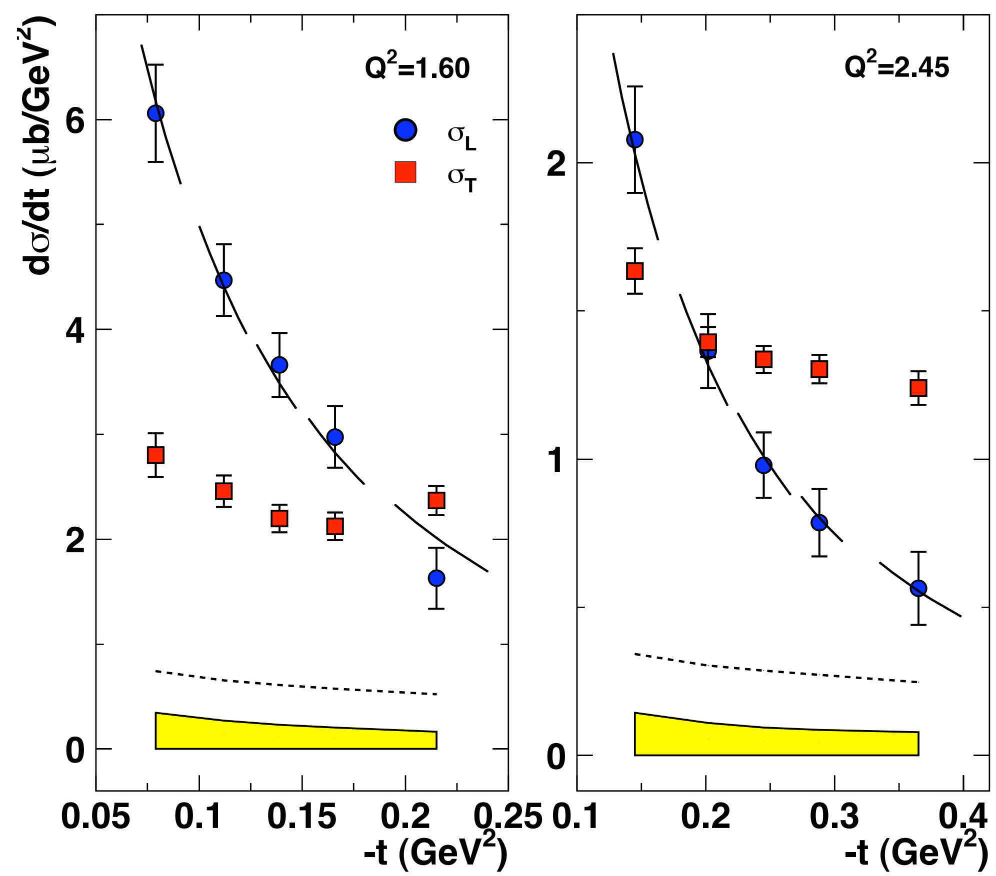
pseudoscalar mesons

π^+ cross section from Hall C

$$2\pi\frac{d^2\sigma}{dtd\phi} = \frac{d\sigma_T}{dt} + \epsilon\frac{d\sigma_L}{dt} + \sqrt{2\epsilon(1+\epsilon)}\frac{d\sigma_{LT}}{dt}cos\phi + \epsilon\frac{d\sigma_{TT}}{dt}cos2\phi.$$

- The Jefferson Lab F_{pi}-2 Collaboration (2006) -





✦ two beam energies
➡ Rosenbluth separation
✦ simultaneous fit to the angular distribution

✦ L/T separated cross sections
✦ longitudinal cross section is well reproduced by the model prediction: pion and rho Regge trajectory exchange
- Vanderhaeghen, Guidal, Laget (1997) -
✦ transverse component undershoot

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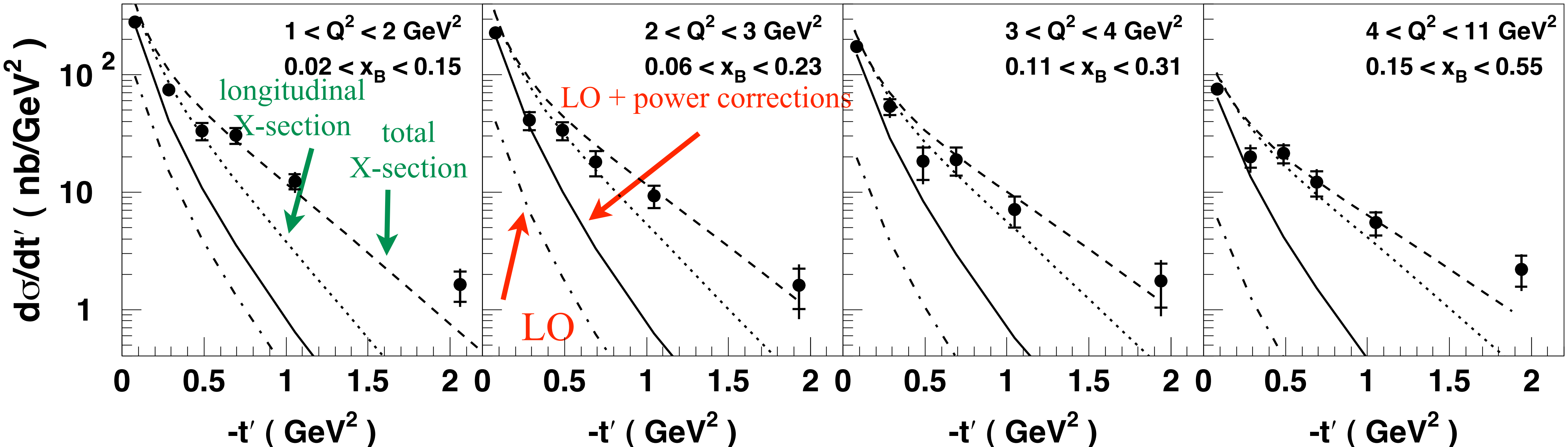
π^+ cross section from HERMES



- HERMES Collaboration (2007) -

- no L/T separation
- longitudinal component is expected to dominate (large t)

GPD model calculations

- GPD $\widetilde{E}$ is considered to be dominated by the t-channel pion pole
- $\widetilde{H}$ is neglected
- leading order calculations underestimate the data
- power corrections agree with data

Regge model calculations

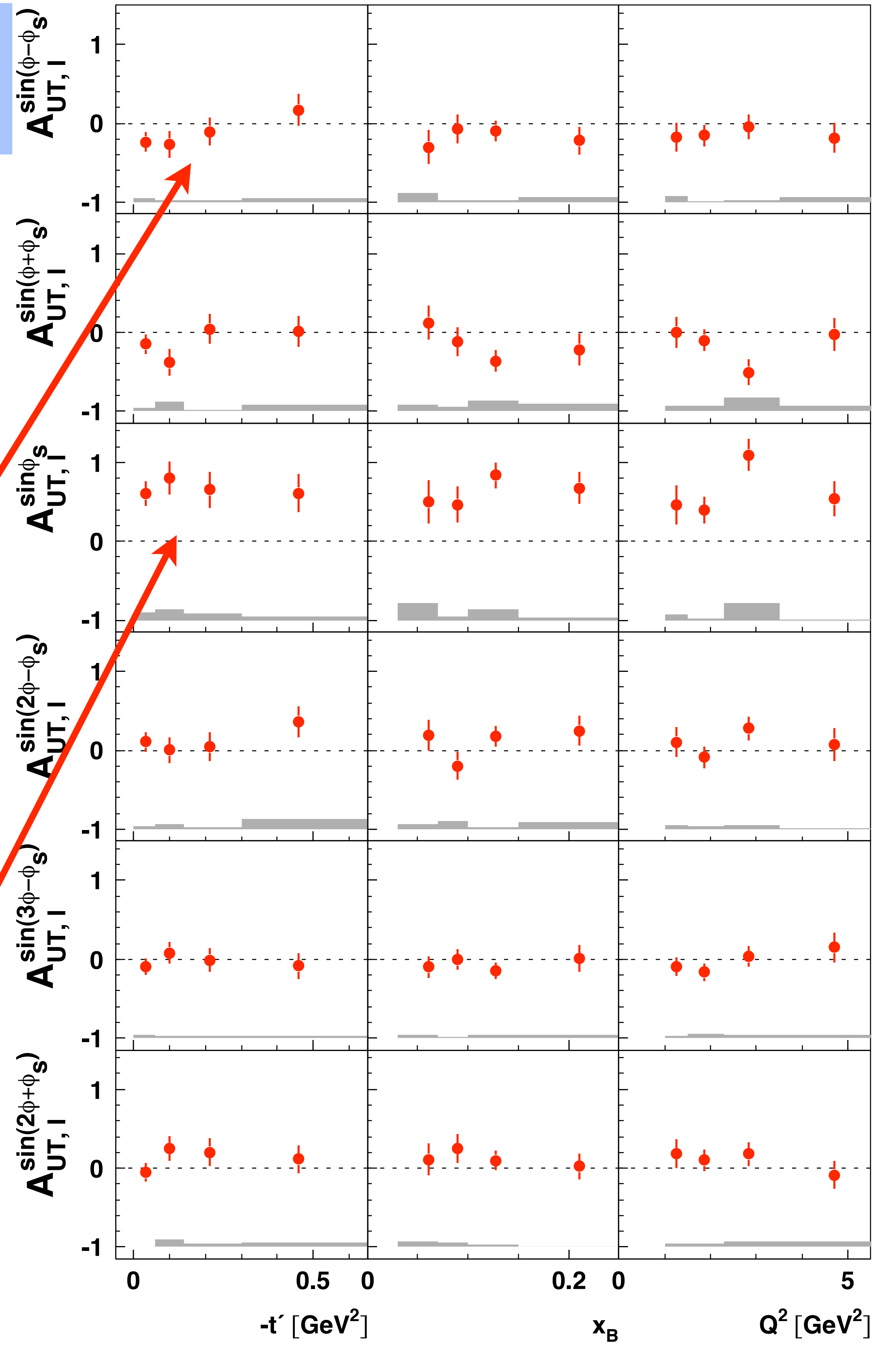
- transverse component of the cross section 6-8% at -t'<0.07 GeV^2
- the same model underestimate the JLAB data (holds also for HERMES higher W kinematics?)

π^+ transverse target asymmetry

$$A_{\mathrm{UT},\ell}^{\sin(\phi-\phi_S)} = -\frac{\sqrt{-t'}}{M_p} \times \frac{\xi\sqrt{1-\xi^2}\,\mathrm{Im}(\widetilde{\mathcal{E}}^*\widetilde{\mathcal{H}})}{(1-\xi^2)\widetilde{\mathcal{H}}^2 - \frac{t\xi^2}{4M_p^2}\,\widetilde{\mathcal{E}}^2 - 2\xi^2\,\mathrm{Re}(\widetilde{\mathcal{E}}^*\widetilde{\mathcal{H}})}$$

- HERMES Collaboration (2007) -

average kinematics:
$\langle -t' \rangle = 0.18$ GeV^2
$\langle x_B \rangle = 0.13$
$\langle Q^2 \rangle = 2.38$ GeV^2

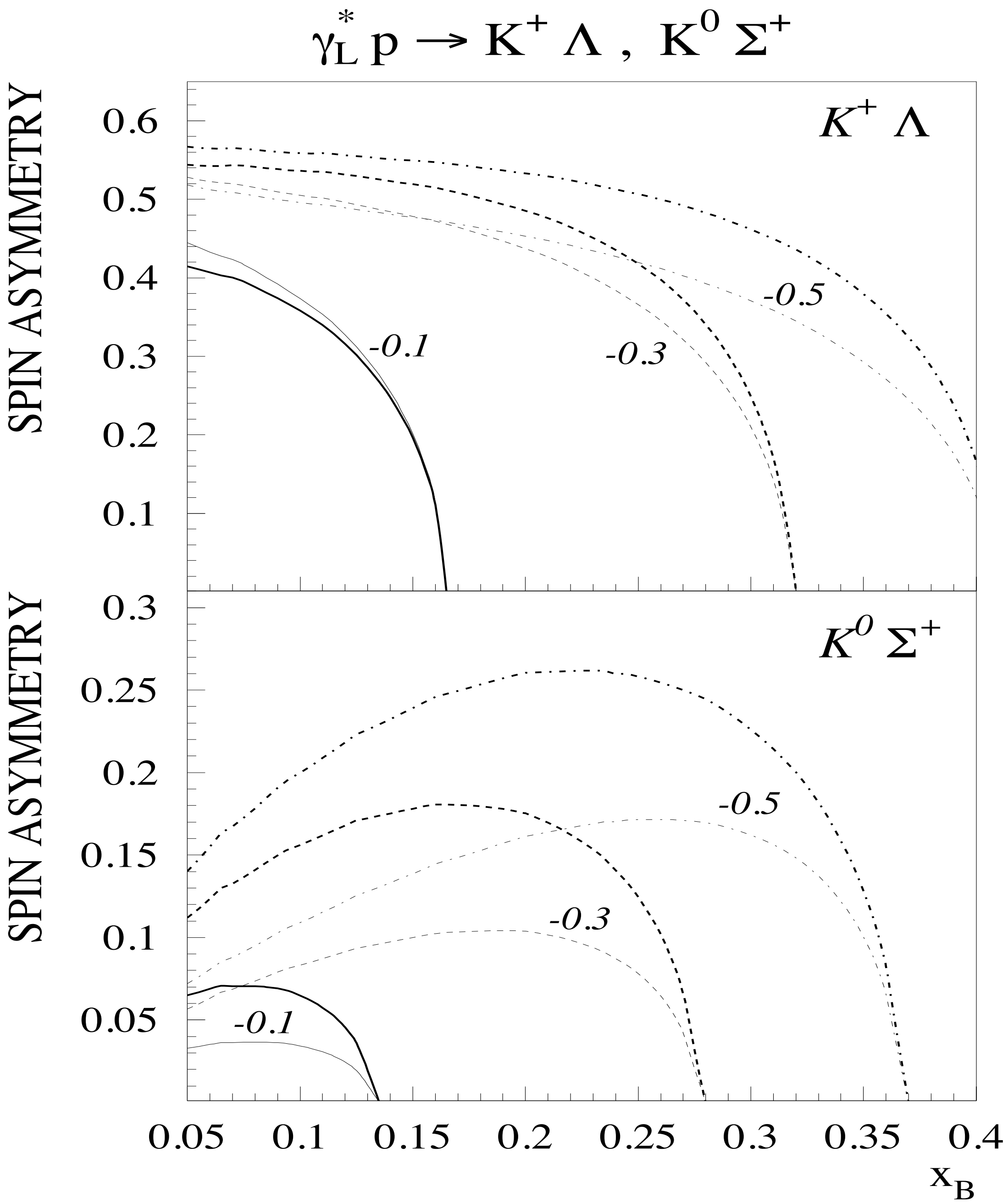


- ✦ 6 azimuthal moments extracted according to *- Diehl, Sapeta (2005) -*
- ✦ no L/T separation
- ✦ small overall value for leading asymmetry
- ✦ unexpected large overall value for $A_{UT}^{\sin\phi_s}$
- ➡ evidence of contribution from transversely polarized photons

more on K and π mesons

$$A_{\mathrm{UT},\ell}^{\sin(\phi-\phi_S)} = -\frac{\sqrt{-t'}}{M_p} \times \frac{\xi\sqrt{1-\xi^2}\,\mathrm{Im}(\widetilde{\mathcal{E}}^*\widetilde{\mathcal{H}})}{(1-\xi^2)\widetilde{\mathcal{H}}^2 - \frac{t\xi^2}{4M_p^2}\widetilde{\mathcal{E}}^2 - 2\xi^2\,\mathrm{Re}(\widetilde{\mathcal{E}}^*\widetilde{\mathcal{H}})}$$

✦ the same GPDs accessible from



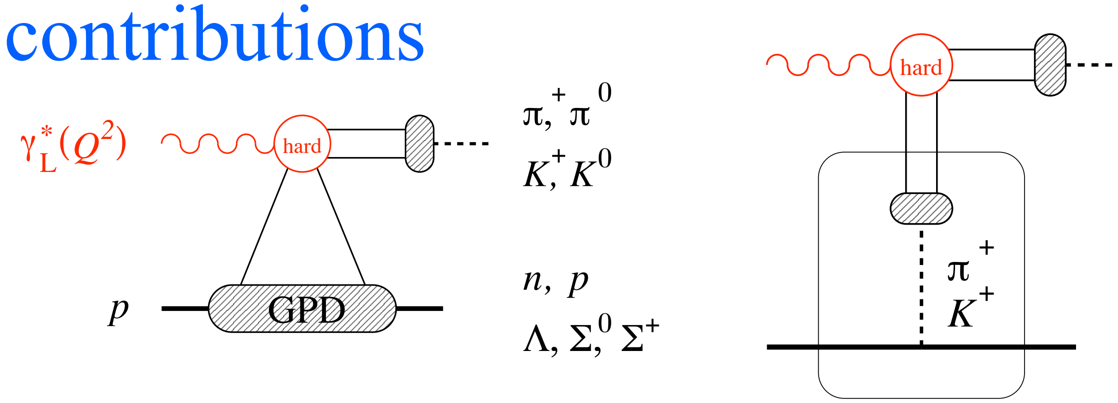
- Goeke, Polyakov, Vanderhaeghen (1999) -

✦ results from CLAS on Beam-recoil polarization transfer in the nucleon resonance region in exclusive reactions

$\gamma^* p \to K^+\Lambda,\ K^0\Sigma^+$

✦ beyond the resonance region measurements of cross sections and asymmetries might be helpful

✦ separate the pion/kaon pole term contributions



$$\frac{\gamma^* p \to \pi^+ n}{\gamma^* p \to \pi^0 p} \qquad \frac{\gamma^* p \to K^+\Sigma^0}{\gamma^* p \to K^0\Sigma^+}$$

- Strikman, Weiss (2008) -

- Diehl, Kugler, Schaefer, Weiss (2005) -

summary