# Exclusive meson production

recent experimental results

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Electromagnetic Interactions with Nucleons and Nuclei

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- Motivation
- Exclusive vector meson production at small $x$

  H1 and ZEUS
- Unpolarised cross sections for $\rho^0$ at large $x$

  CLAS
- Single transverse target spin asymmetries for $\rho^0$

  HERMES and COMPASS
- More results on spin dependence in VM production

  COMPASS and HERMES
- Exclusive $\pi^+$ and $\pi^0$ production

  HERMES, CLAS and JLAB Hall A
- Conclusions

# Why hard exclusive meson production ?

- Nucleon structure ⟺ Hard exclusive processes (DVCS + DVMP)
  - ❖ constrain GPDs

    'Holy Grails' of GPDs:
    - distribution of partons in transverse plane vs. $x$ 'nucleon tomography'
    - orbital angular momentum of quarks
  - ❖ VM production at small $x$ sensitive to gluons
- Meson structure ⟺ Deep virtual meson production

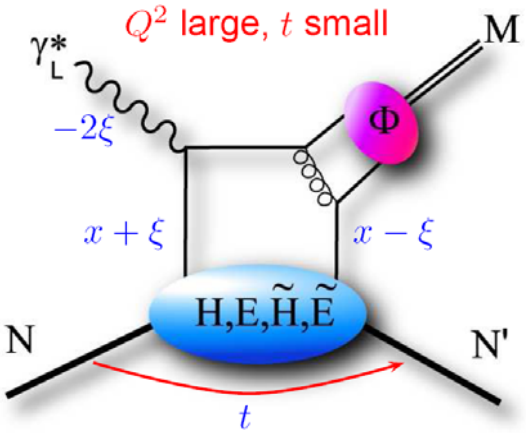
  wave function / DA
- Mechanism of high energy diffraction (exclusive VM production)

  BFKL vs. DGLAP, $k_t$-factorisation, …
- Space-time evolution of hadronic fluctuations of $\gamma^*$

  Color Transparency (also Color Opacity) – important predictions of pQCD

  → cf. talk by K. Hafidi

# Hard exclusive meson production




- 4 Generalised Parton Distributions (GPDs)
  for each quark flavour and for gluons

  GPDs depend on 3 variables: $x,\ \xi,\ t$

- factorisation proven only for $\sigma_L$
  $\sigma_T$ suppressed of by $1/Q^2$

  necessary to extract longitudinal contribution to observables ($\sigma_L$ , …)

- allows separation $(H,E) \leftrightarrow (\tilde{H},\tilde{E})$ and wrt quark flavours

$H, \tilde{H}$ conserve nucleon helicity — $E, \tilde{E}$ flip nucleon helicity

Vector mesons ($\rho$, $\omega$, $\varphi$)

Pseudoscalar mesons ($\pi$, $\eta$)

- quarks and gluons enter at the same order of $\alpha_s$

- wave function of meson (DA Φ)
  additional information/complication

Flavour sensitivity of DVMP on the proton

| | |
|---|---|
| $\rho^0$ | 2u+d, 9g/4 |
| $\omega$ | 2u-d, 3g/4 |
| $\varphi$ | s, g |
| $\rho^+$ | u-d |
| J/ψ | g |

# LT-LO observables in hard exclusive meson production relevant for GPDs

## for vector mesons: $\rho^0$, $\rho^+$, $f_2$, …

unpolarised cross section ($\sigma_{00}^{++} \equiv \sigma_L$)

$$\frac{1}{\Gamma'}\frac{d\sigma_{00}^{++}}{dt} = (1-\xi^2)\,|\mathcal{H}_M|^2 - \left(\xi^2 + \frac{t}{4M_p^2}\right)|\mathcal{E}_M|^2 - 2\xi^2\,\mathrm{Re}\,(\mathcal{E}_M^*\mathcal{H}_M),$$

transverse target spin asymmetry

$$\frac{1}{\Gamma'}\,\mathrm{Im}\,\frac{d\sigma_{00}^{+-}}{dt} = -\sqrt{1-\xi^2}\,\frac{\sqrt{t_0-t}}{M_p}\,\mathrm{Im}\,(\mathcal{E}_M^*\mathcal{H}_M)$$

**access to GPD E related to orbital momentum**

## for pseudoscalar mesons: $\pi^0$, $\pi^+$, $\eta$ , …

unpolarised cross section

$$\frac{1}{\Gamma'}\frac{d\sigma_{00}^{++}}{dt} = (1-\xi^2)\,|\tilde{\mathcal{H}}_M|^2 - \xi^2\frac{t}{4M_p^2}\,|\tilde{\mathcal{E}}_M|^2 - 2\xi^2\,\mathrm{Re}\,(\tilde{\mathcal{E}}_M^*\tilde{\mathcal{H}}_M),$$

transverse target spin asymmetry

$$\frac{1}{\Gamma'}\,\mathrm{Im}\,\frac{d\sigma_{00}^{+-}}{dt} = \sqrt{1-\xi^2}\,\frac{\sqrt{t_0-t}}{M_p}\,\xi\,\mathrm{Im}\,(\tilde{\mathcal{E}}_M^*\tilde{\mathcal{H}}_M)$$

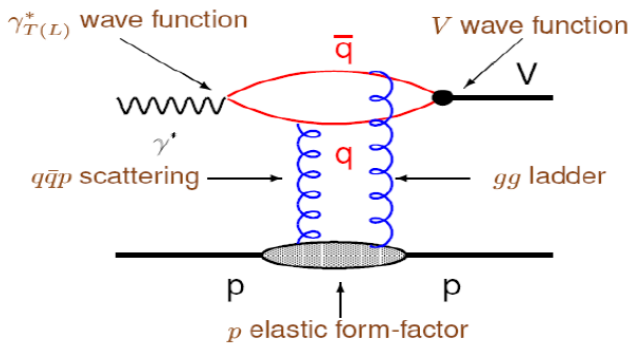
$$\Gamma' = \frac{\alpha_{\mathrm{em}}}{Q^6}\,\frac{x_B^2}{1-x_B} \qquad \xi = \frac{x_B}{2-x_B}, \qquad -t_0 = \frac{4\xi^2 M_p^2}{1-\xi^2}$$

(large $Q^2$ approximation)

$\mathcal{H}_{\mathcal{M}}, \tilde{\mathcal{H}}_{\mathcal{M}}, \mathcal{E}_{\mathcal{M}}, \tilde{\mathcal{E}}_{\mathcal{M}}$ are integrals of GPDs $H, \tilde{H}, E, \tilde{E}$ appropriate for production of meson $\mathcal{M}$

# Models for exclusive VM production at small $x$

- at small x sensitivity mostly to gluons
- at very small x huge NLO corrections, large ln(1/x) terms (BFKL type logs)
- pQCD models to describe colour dipole-nucleon cross sections and meson WF




| dipole transv. size | W-dep. | t-dep. |
|---|---|---|
| large | weak | steep |
| small | strong | shallow |

- Frankfurt-Koepf-Strikman (FKS)
Phys.Rev. D57 (1998) 512
- Martin-Ryskin-Teubner (MRT)
Phys.Rev. D62 (2000) 014022

→ sensitivity to different gluon density distibutions

- Farshaw-Sandapen-Shaw (FSS)
Phys.Rev. D69 (2004) 094013
- Kowalski-Motyka-Watt (KMW)
Phys.Rev. D74 (2006) 074016
- Dosch-Fereira (DF)
hep-ph/0610311 (2006)

sensitivity to $\rho^0$ wave function

# Recent ZEUS results on exclusive $\rho^0$ production

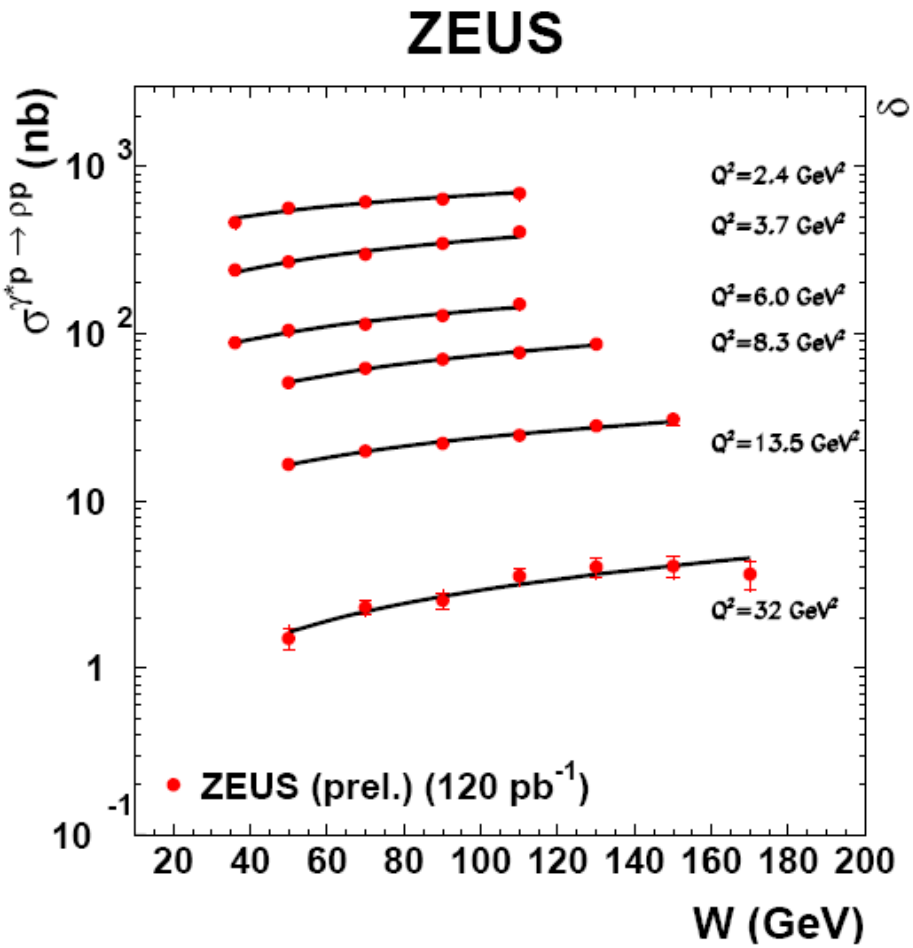
96-00 data: 120 pb$^{-1}$

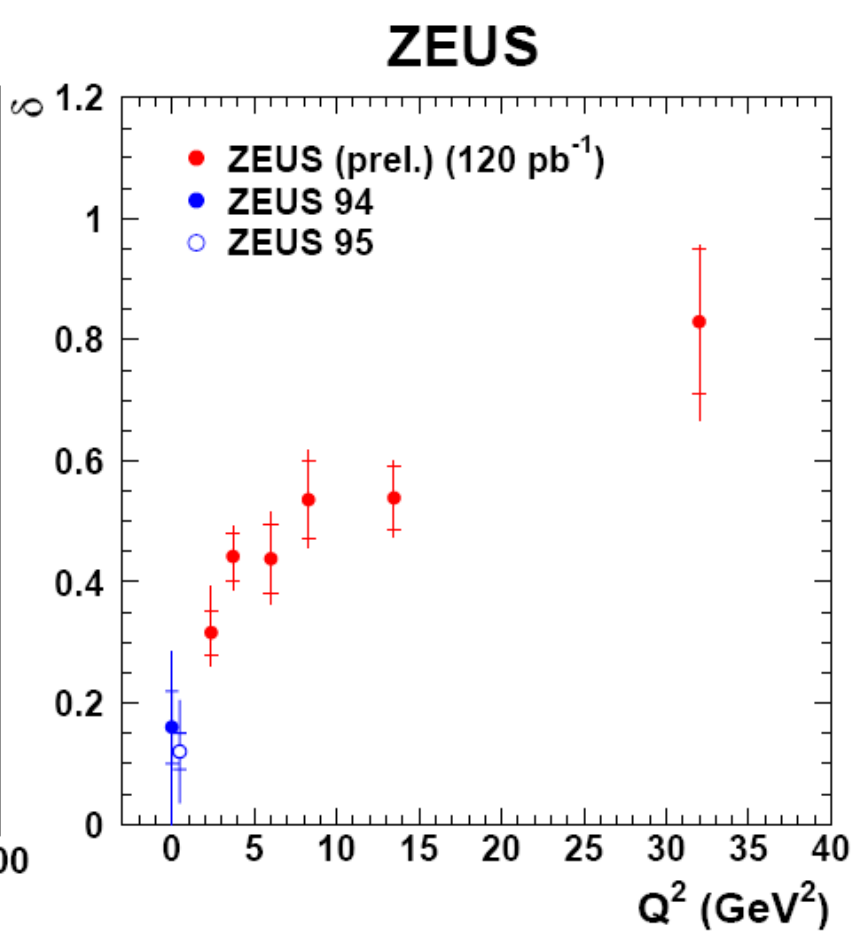
arXiv:0708.1478[hep-ex]

significant increase of precision
+ extended $Q^2$ range

$2 < Q^2 < 160$ GeV$^2$
$32 < W < 180$ GeV
$2 \cdot 10^{-4} < x_{Bj} < 10^{-2}$
$|t| < 1$ GeV$^2$

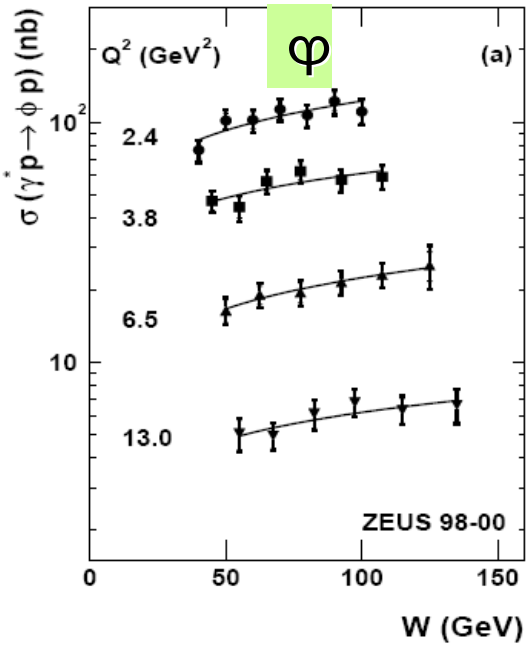
W-dependence $\quad \sigma \propto W^{\delta}$

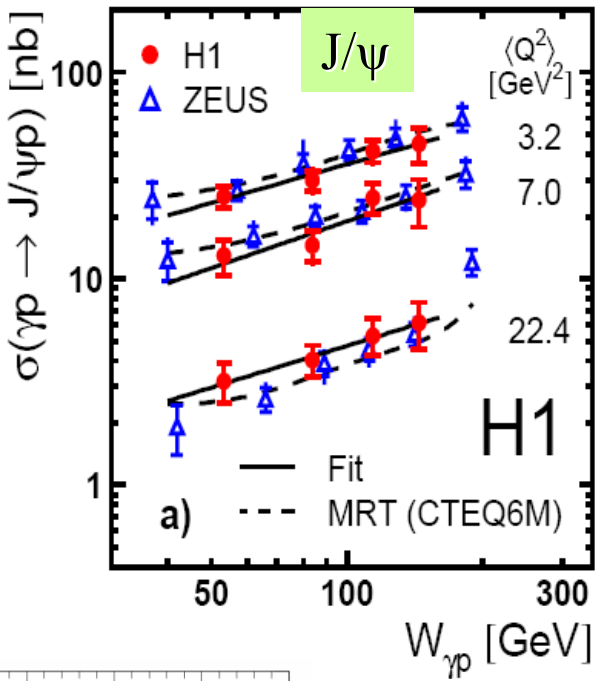


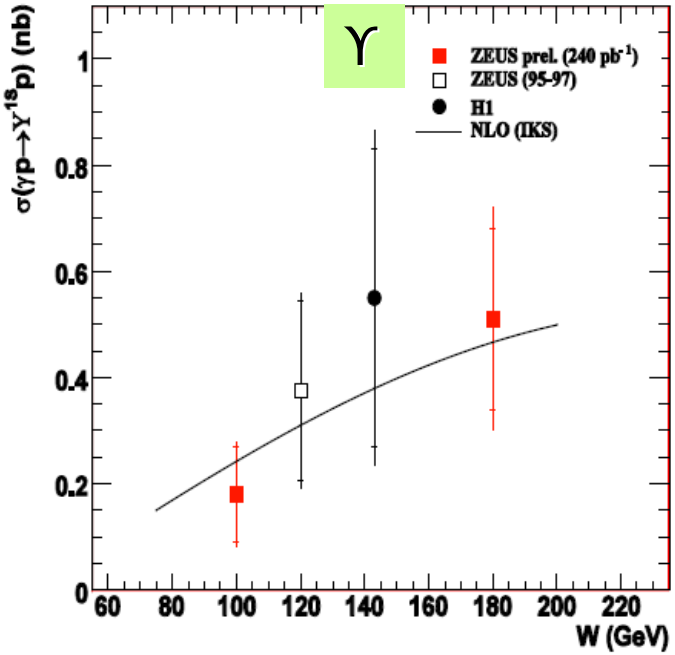



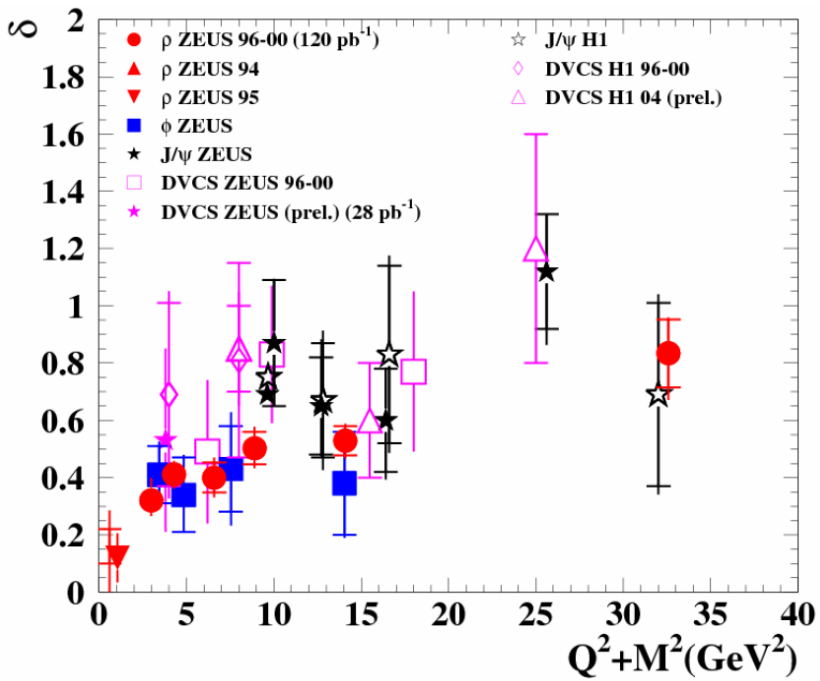

➢ steeper energy dependence with increasing $Q^2$

# W-dependence for hard exclusive processes at small x



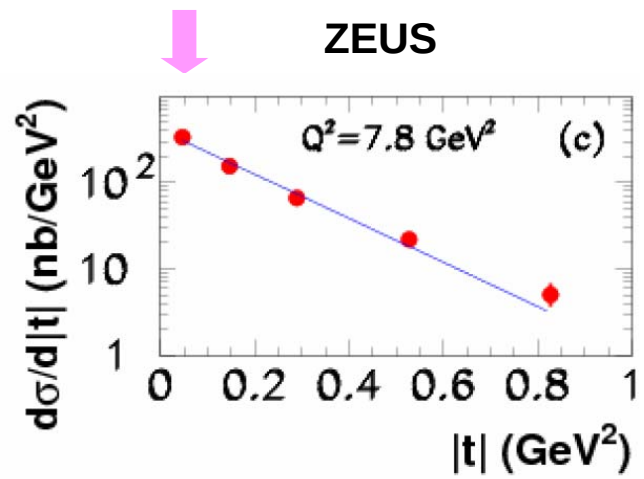




- steep energy dependence for all vector mesons in presence of hard scale $Q^2$ and/or $M^2$
- 'universality' of energy dependence at small x?

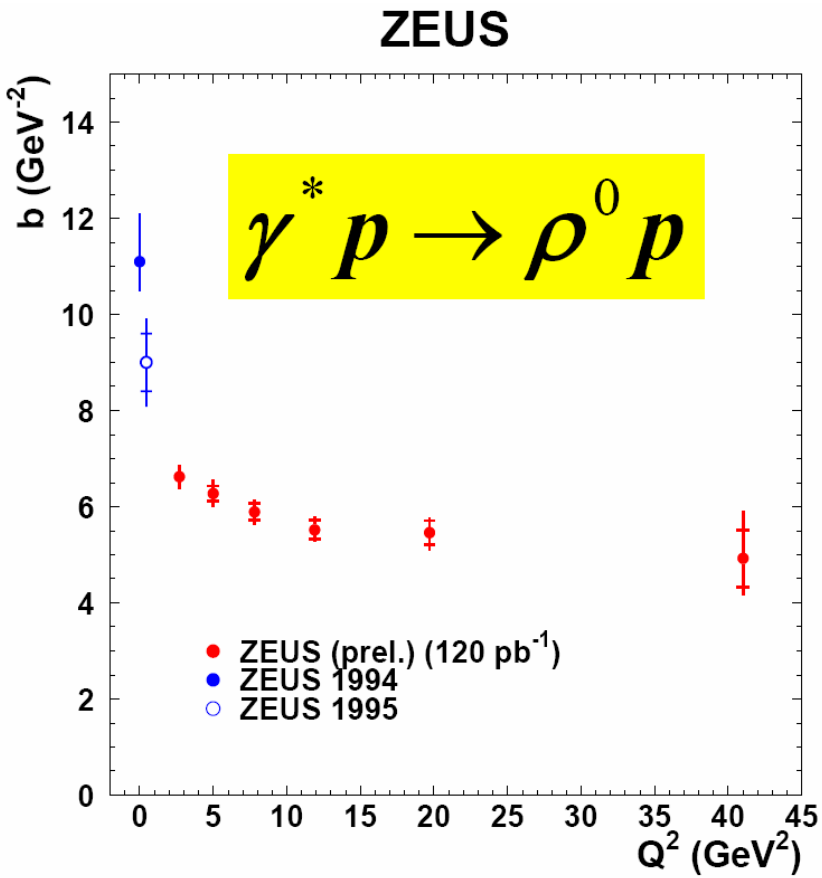
at $Q^2+M^2 \approx 10$ GeV$^2$ still significant difference between ρ and J/ψ

# $d\sigma / dt \;\; - \;\; \rho^0$

example (1 out of 6)

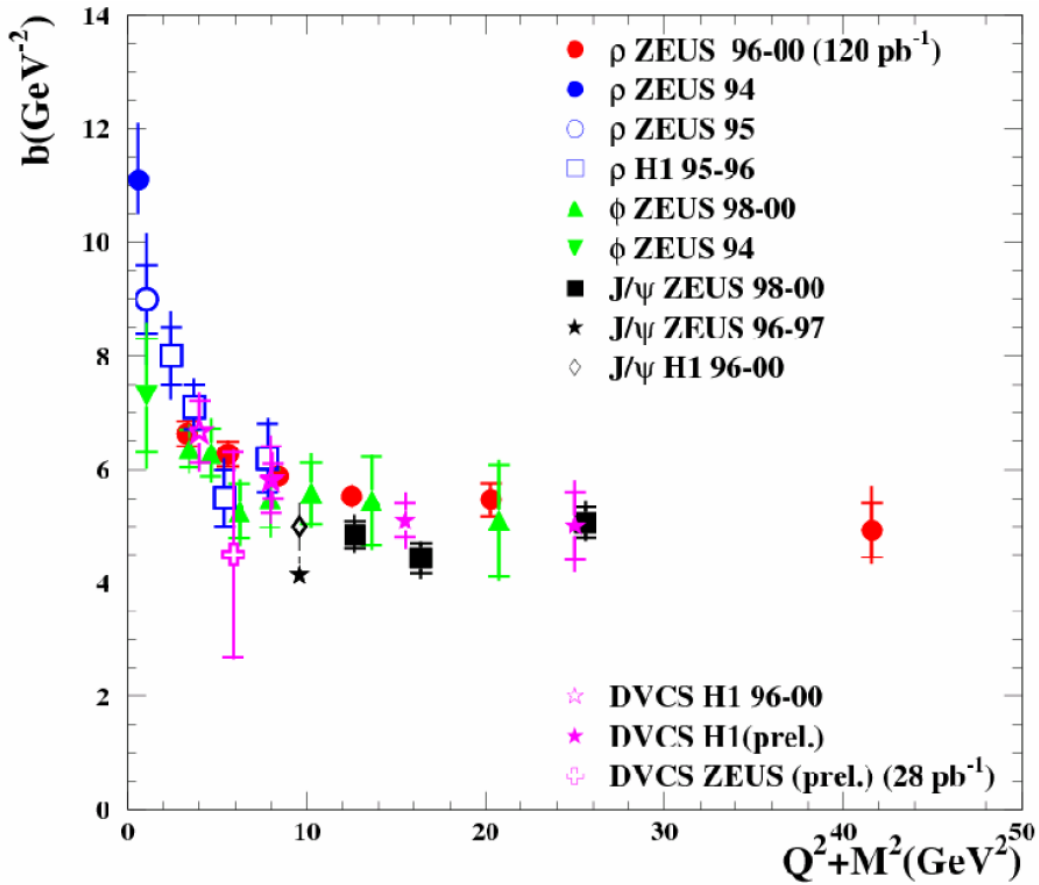



Fit $\dfrac{d\sigma}{dt} \propto e^{-b|t|}$




- shallower t-dependence with increasing $Q^2$

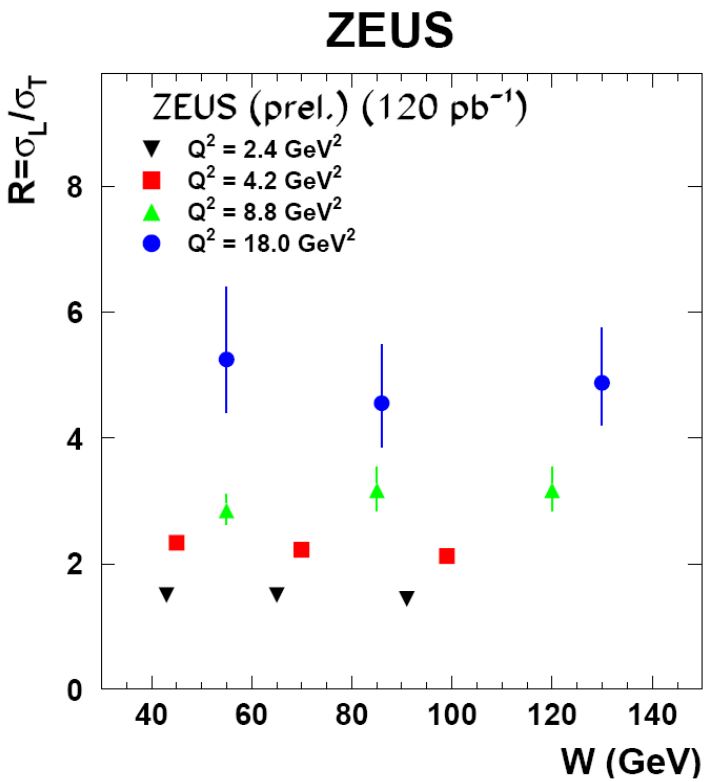
# t-dependence for hard exclusive processes at small x

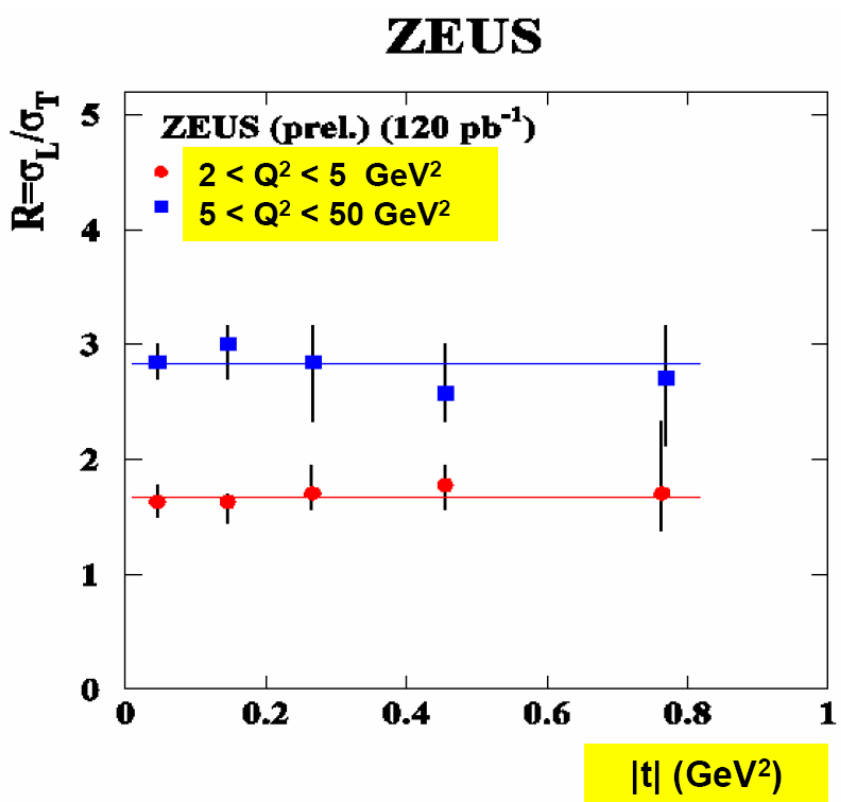



- b-slopes decrease with increasing scale $Q^2$ and/or $M^2$
  approaching a limit ≈ 5 GeV$^{-2}$ at large scales
- approximate 'universality' of slopes as a function of $(Q^2 + M^2)$

recent data suggestive of possible ≈ 15% difference between ρ and J/ψ

# Selected results on $R = \sigma_L/\sigma_T$ for $\rho^0$ production




the same W- and t-dependence for $\sigma_L$ and $\sigma_T$

$\delta_L \approx \delta_T$ ⇓ $b_L \approx b_T$

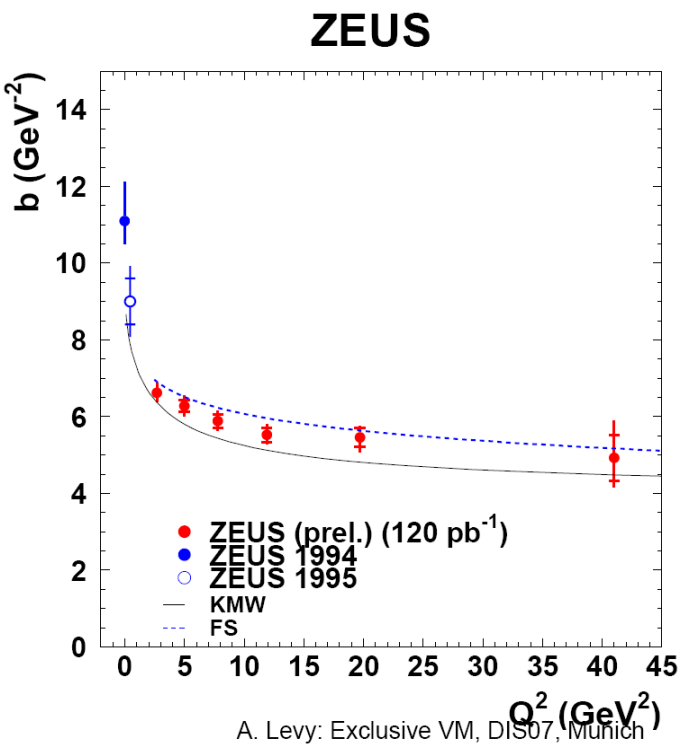
the same size of the longitudinal and transverse $\gamma^*$ involved in hard $\rho^0$ production

i.e. contribution of large qqbar fluctuations of transverse $\gamma^*$ suppressed

# Comparison to theory

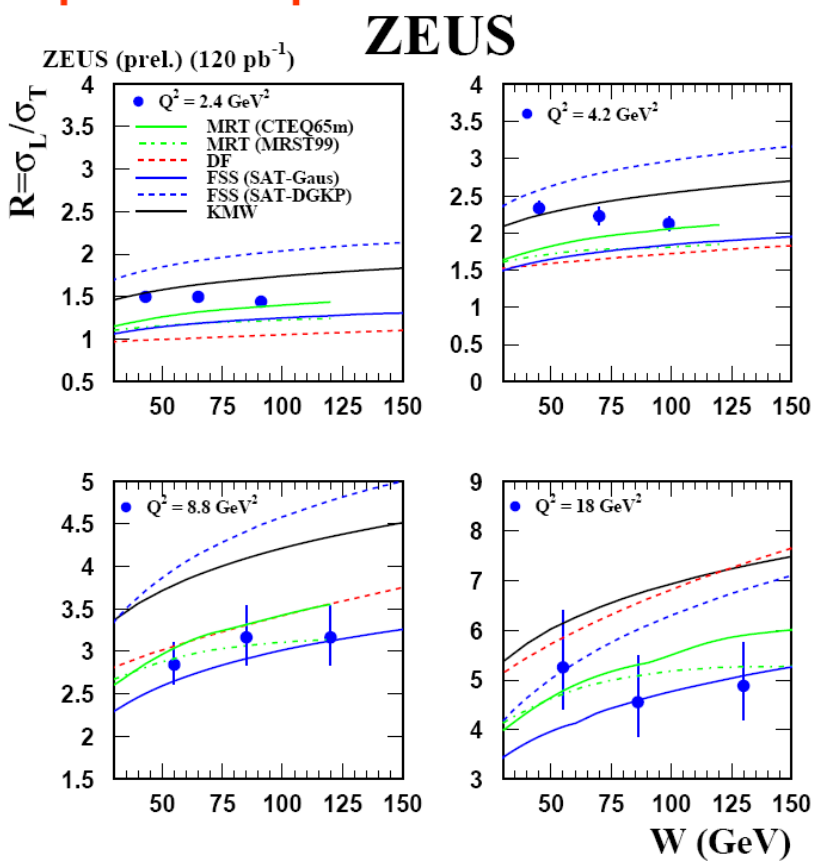
extensive comparison of the models to recent ZEUS $\rho^0$ data in arXiv:0708.1478[hep-ex]

below just selected examples




A. Levy: Exclusive VM, DIS07, Munich

## $\rho^0$ electroproduction



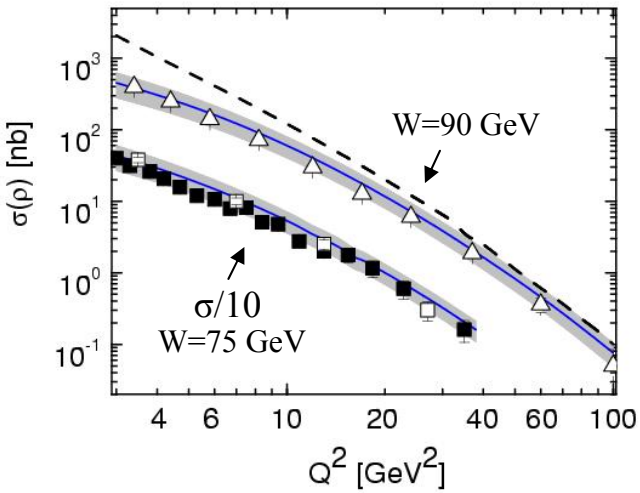

- considered models describe qualitatively all features of the data reasonably well
- recent ZEUS data are a challenge; none of the models gives at the moment satisfactory quantitative description of all features of the data

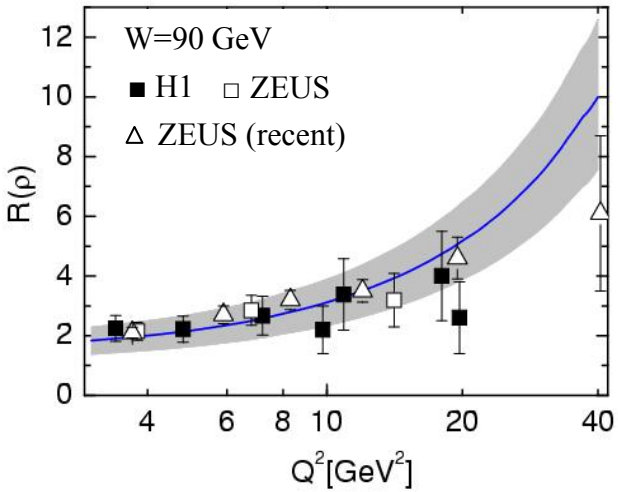
# More comparison to theory

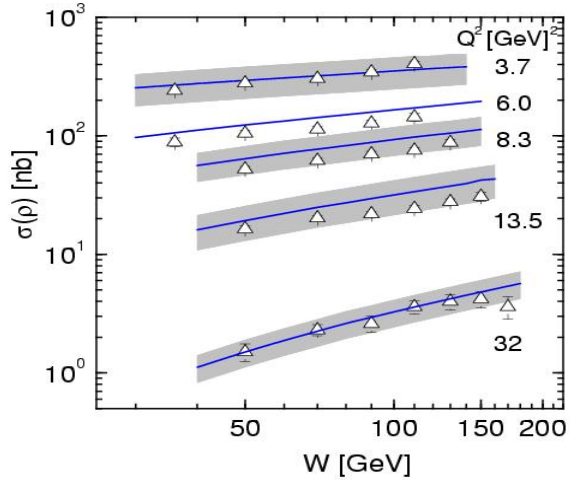
- Goloskokov-Kroll
  arXiv:0708,3569[hep-ph]

'Hand-bag model'; GPDs from DD using CTEQ6
power corrections due to $k_t$ of quarks included

→ both contributions of $\gamma^*_L$ and $\gamma^*_T$ calculated




complete calculation

leading twist only (in collinear approx.)

- leading twist prediction above full calculation, even at $Q^2$ = 100 GeV² ≈ 20%
- contribution of $\sigma_T$ decreases with Q², but do not vanish even at $Q^2$ = 100 GeV² ≈ 10%
- sea quark contribution, including interference with gluons, non-negligible 25% at $Q^2$ = 4 GeV²

# Exclusive $\rho^0$ production at 5.75 GeV from CLAS

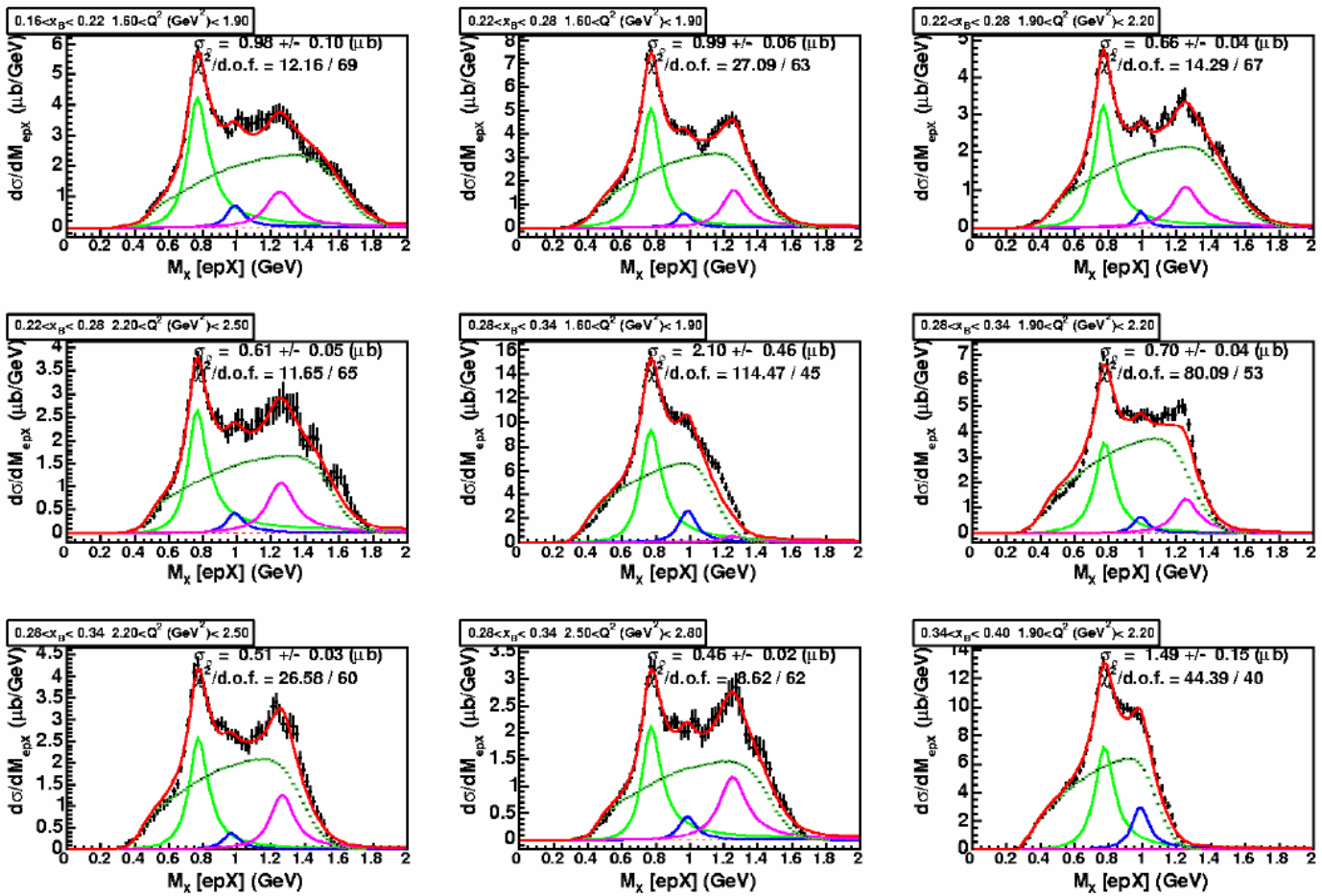
$$e\,p \rightarrow e\,p\,\pi^+\,(\pi^-)$$

strong interference with $\Delta^{++}\pi^-$ production + $f_0(980)$ + $f_2(1270)$

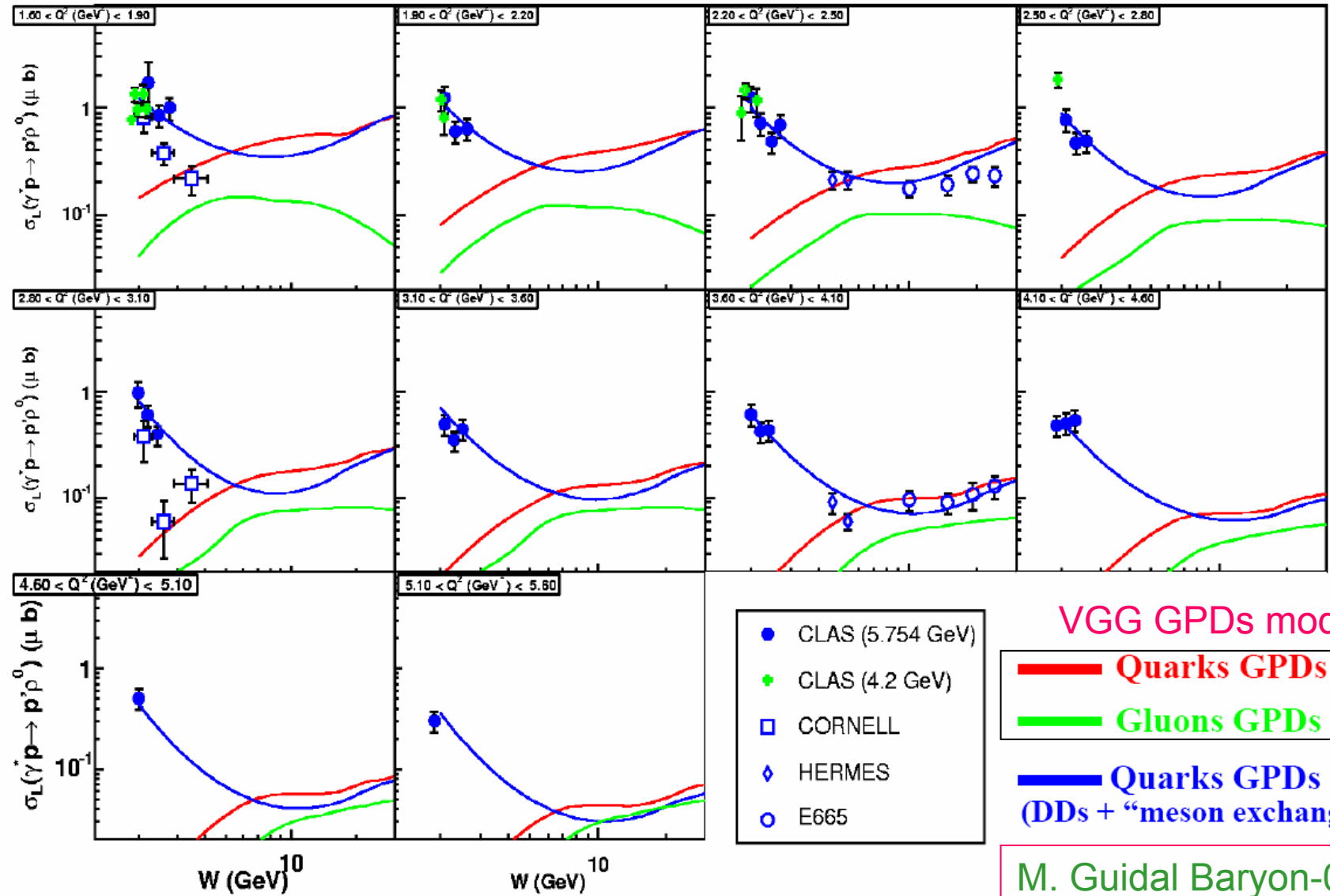
strong correlation between $Q^2$ and x

$t_{min}$ increases with $Q^2$ and x (> 1.0 GeV² at x > 0.5)

$1.6 < Q^2 < 5.6$ GeV²
$1.8 < W < 2.5$ GeV
$0.16 < x_{Bj} < 0.7$
$|\,t_{min}\,| < |\,t\,| < 3$ GeV²



# Longitudinal cross section $\sigma_L(\gamma^* p \rightarrow \rho^0_L\, p)$ and various GPD contributions




similar agreement for Regge approach of Laget
for the bins where data dominated by small t

# Transverse target spin asymmetry for exclusive $\rho^0$ production

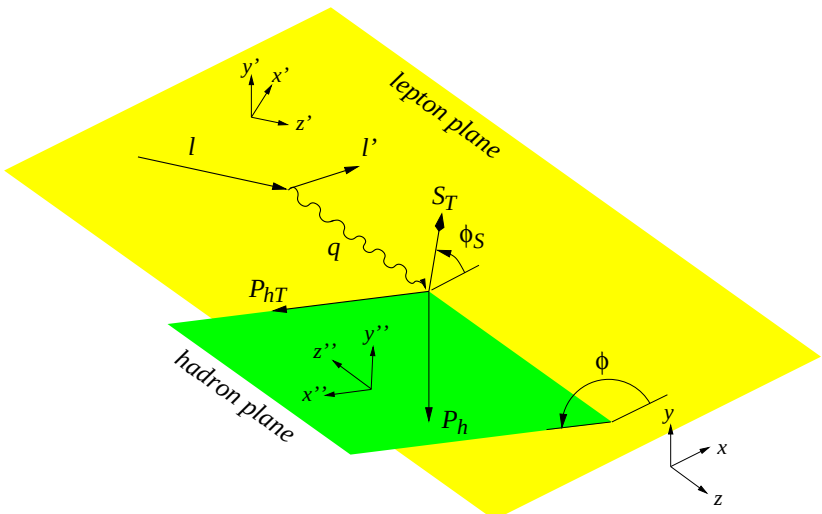
Give access to GPD $E$ related to the orbital angular momentum of quarks

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

Ji's sum rule

So far GPD $E$ poorly constrained by data (mostly by Pauli form factors)

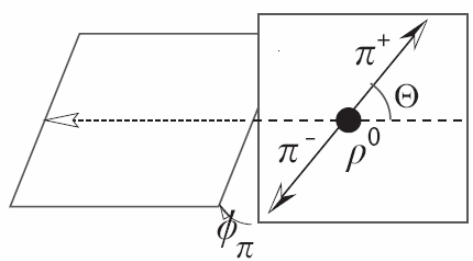
The asymmetry defined as $A_{UT}(\varphi,\varphi_s) = \frac{1}{S_T}\frac{d\sigma(\varphi,\varphi_s) - d\sigma(\varphi,\varphi_s+\pi)}{d\sigma(\varphi,\varphi_s) + d\sigma(\varphi,\varphi_s+\pi)}$




to disentangle contributions from $\gamma_L$ and $\gamma_T$ the distribution of $\rho^0$ decay polar angle needed in addition

Diehl and Sapeta

Eur. Phys. J.C 41, 515 (2005)




$\rho^0$ Rest Frame

# Method for L/T separation used by HERMES

A. Rostomyan and J. Dreschler arXiv:0707.2486

## Angular distribution $W(\cos\theta, \varphi, \varphi_s)$ and Unbinned Maximum Likelihood fit

Assuming SCHC

$$W(\cos\theta,\varphi,\varphi_S) \propto \; [\; \cos^2\theta\, r_{00}^{04}\,\{1 + A_{UU,\rho L}(\varphi) + S_T\, A_{UT,\rho L}(\varphi,\varphi_S)\} + \frac{1}{2}\sin^2\theta\,(1-r_{00}^{04})\,\{1 + A_{UU,\rho T}(\varphi) + S_T\, A_{UT,\rho T}(\varphi,\varphi_S)\}\,]$$

where $A_{UU,\rho L(\rho T)}(\varphi) = A_{UU,\rho L(\rho T)}^{\cos(\varphi)}\cos(\varphi) + A_{UU,\rho L(\rho T)}^{\cos(2\varphi)}\cos(2\varphi)$

$A_{UT,\rho L(\rho T)}(\varphi) = A_{UT,\rho L(\rho T)}^{\sin(\varphi-\varphi_S)}\sin(\varphi-\varphi_S) + \ldots$ (5 additional terms $A_{UT,\rho L(\rho T)}^{\sin(m\varphi\pm\varphi_S)}\sin(m\varphi\pm\varphi_S)$)

- $A_{UU,\rho L(\rho T)}^{\cos(\varphi)}$ and $A_{UU,\rho L(\rho T)}^{\cos(2\varphi)}$ obtained from SDMEs $r_{00}^5, r_{11}^5, r_{00}^1, r_{11}^1$
- 2 x 6 = 12 parameters $A_{UT,\rho L(\rho T)}^{\sin(m\varphi\pm\varphi_S)}$ from the fit

$$A_{UT,\rho L}^{\sin(\varphi-\varphi_S)} = -\frac{\mathrm{Im}\,\sigma_{00}^{+-}}{\sigma_L} \sim \mathrm{Im}\,(\mathcal{E}^*_{\mathcal{M}}\mathcal{H}_{\mathcal{M}}) \,/\, |\mathcal{H}_{\mathcal{M}}|^2$$

a prerequisite for the method: determination of acceptance correction

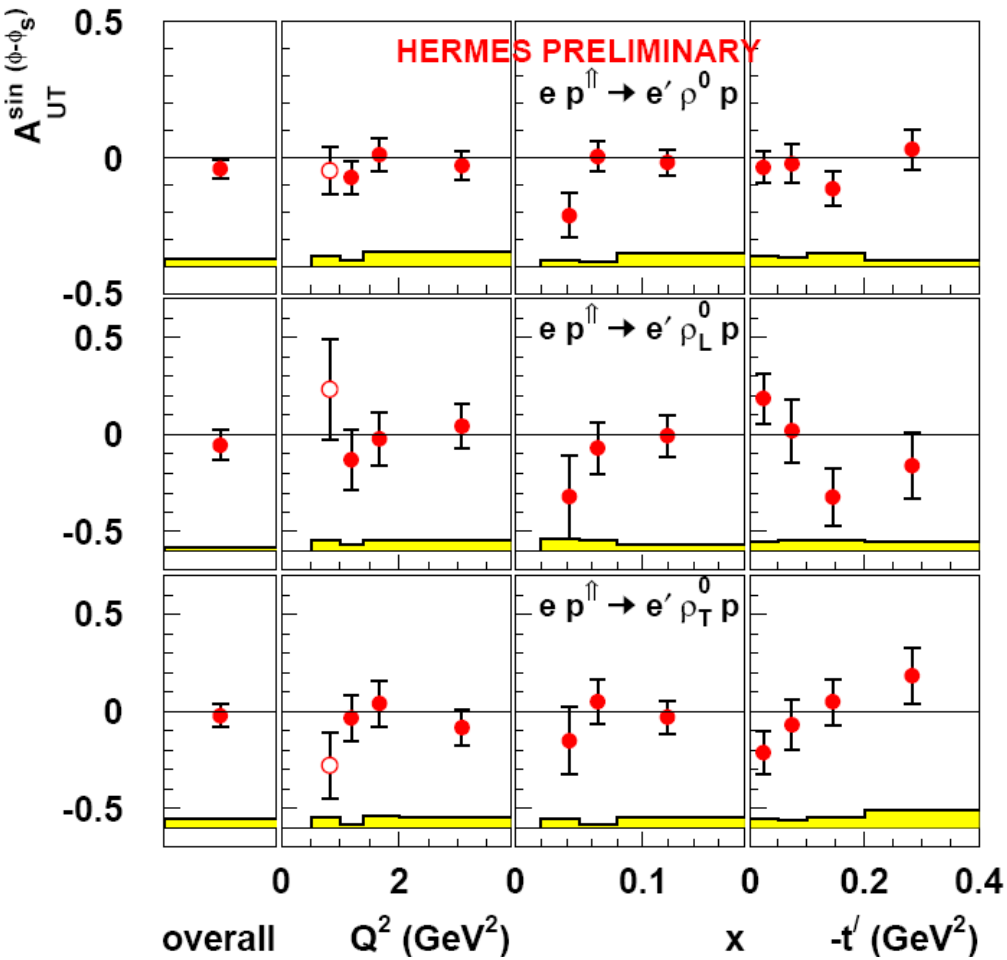
as a function of $\cos\theta$, $\varphi$ and $\varphi_s$

# $\rho^0$ transverse target spin asymmetry from HERMES

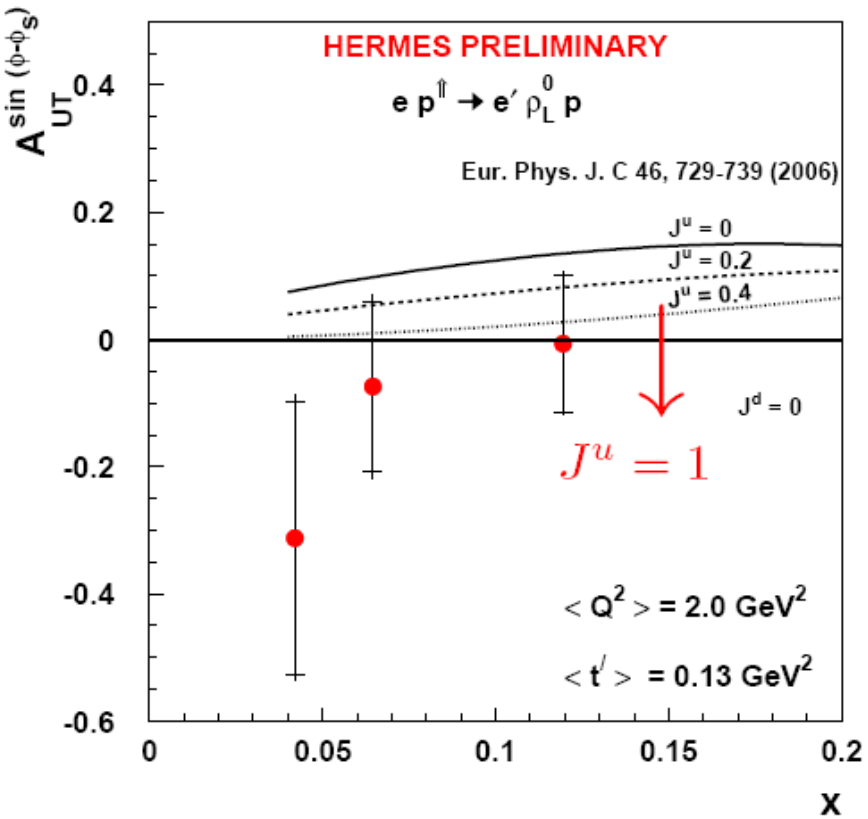
Transversely polarised proton target, $P_T \approx 75\%$
2002-2005 data, 171.6 $pb^{-1}$

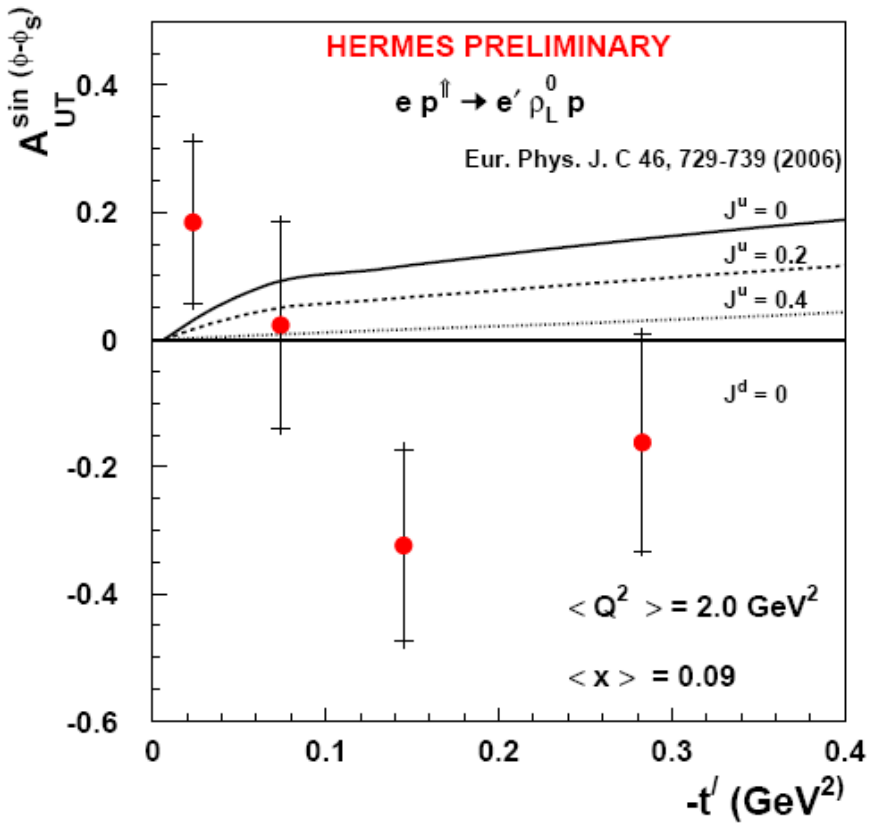
$1 < Q^2 < 7\ GeV^2$
$W^2 > 4\ GeV^2$
$0.023 < x_{Bj} < 0.4$
$|t'| < 0.4\ GeV^2$

- for the first time $\rho^0$ TTSA extracted separately for $\gamma^*_L$ and $\gamma^*_T$



# $\rho^0$ transverse target spin asymmetry from HERMES




- in a model dependent analysis data favours positive $J_u$

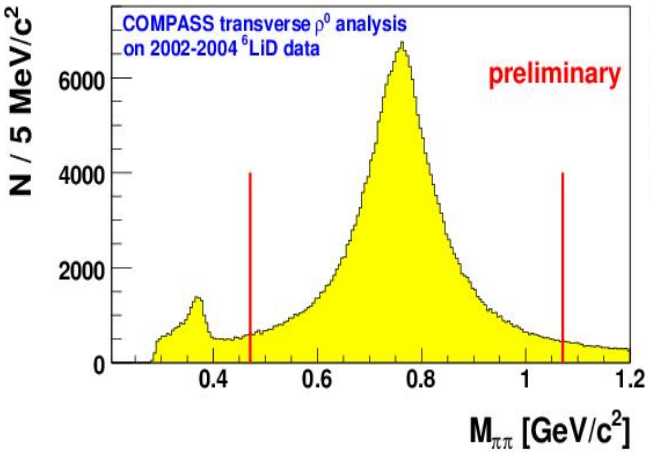
in agreement with DVCS results from HERMES

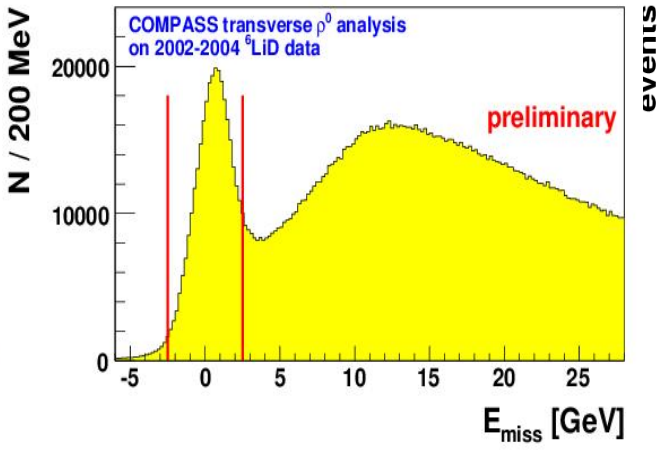
cf. talk by W.-D. Nowak

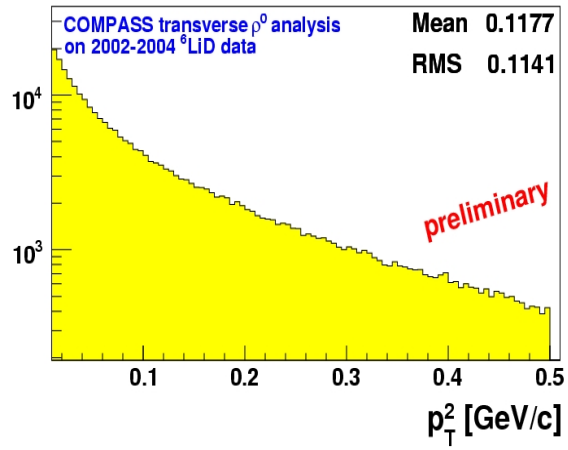
# $\rho^0$ transverse target spin asymmetry from COMPASS

$Q^2 > 1$ GeV²
$W > 5$ GeV
$0.005 < x_{Bj} < 0.1$
$0.01 < p_t^2 < 0.5$ GeV²

Transversely polarised deuteron target ($^6$LiD), $P_T \approx 50\%$
2002-2004 data




$A_{UT}^{\sin(\varphi-\varphi_S)}$ obtained using Double Ratio Method

in bins of $\vartheta = \varphi - \varphi_S$:

$$DR(\eta) = \frac{N_u^{\uparrow}(\eta)\cdot N_d^{\uparrow}(\eta)}{N_u^{\downarrow}(\eta)\cdot N_d^{\downarrow}(\eta)} = \frac{a_u^{\uparrow}(\eta)\cdot a_d^{\uparrow}(\eta)}{a_u^{\downarrow}(\eta)\cdot a_d^{\downarrow}(\eta)} \frac{[1+\varepsilon\sin(\eta)]^2}{[1-\varepsilon\sin(\eta)]^2}$$
$$\cong C\cdot[1+4\varepsilon\sin(\eta)]$$

*u* (*d*) are for upstream (downstream) cell of polarised target
arrows indicate transverse polarisation of corresponding cells

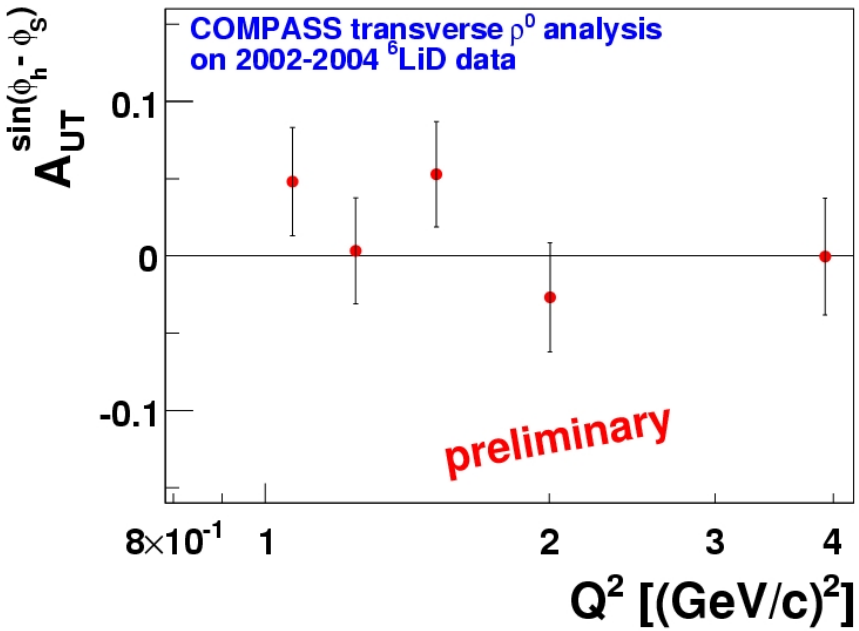
raw asymmetry $\varepsilon$
from the fit to $DR(\eta)$

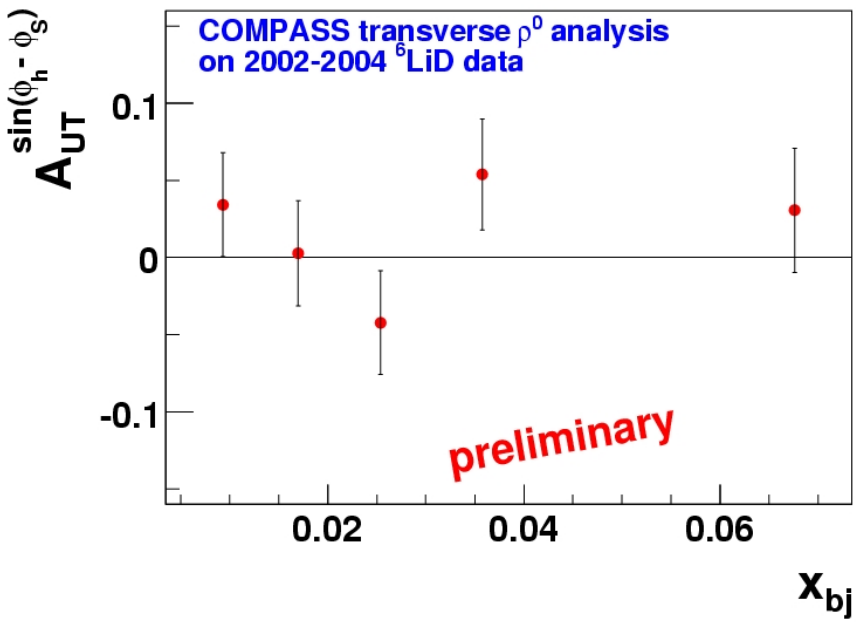
$$A_{UT}^{\sin(\varphi-\varphi_S)} = \frac{\varepsilon}{f\cdot\langle P_T\rangle}$$

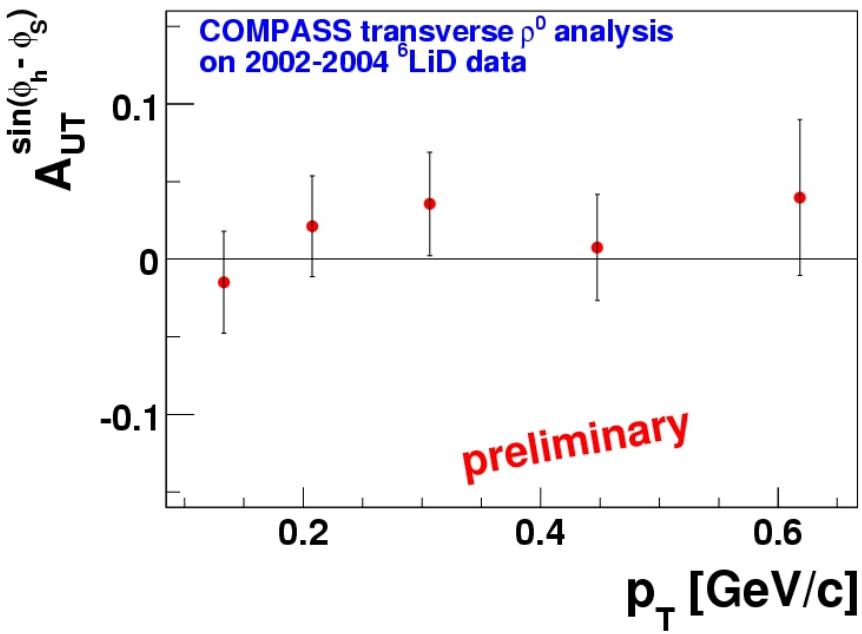
dilution factor $f \approx 0.38$

# $\rho^0$ transverse target spin asymmetry from COMPASS

new




- asymmetry for deuteron target consistent with zero

ongoing work on:

- longitudinal/transverse separation
- separation of incoherent/coherent

in 2007 data taken with transversely polarised proton target ($NH_3$)

# Longitudinal double-spin asymmetry for exclusive $\rho^0$ production (COMPASS)

arXiv:0704.1863[hep-ex]

longitudinally polarised deuteron target ($^6$LiD), $P_T \approx 50\%$

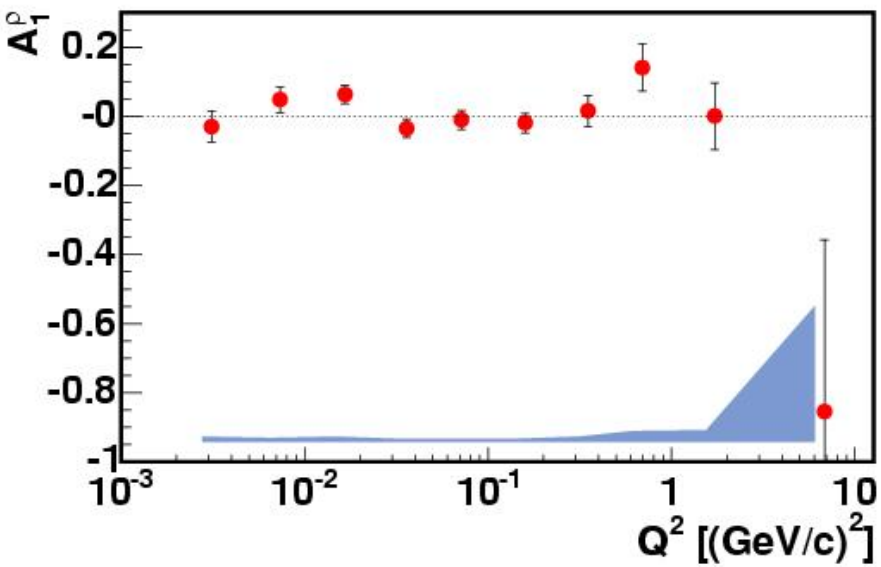
wide range of $Q^2$ and x , $W > 7.5$ GeV , $0.15 < p_t^2 < 0.5$ GeV²

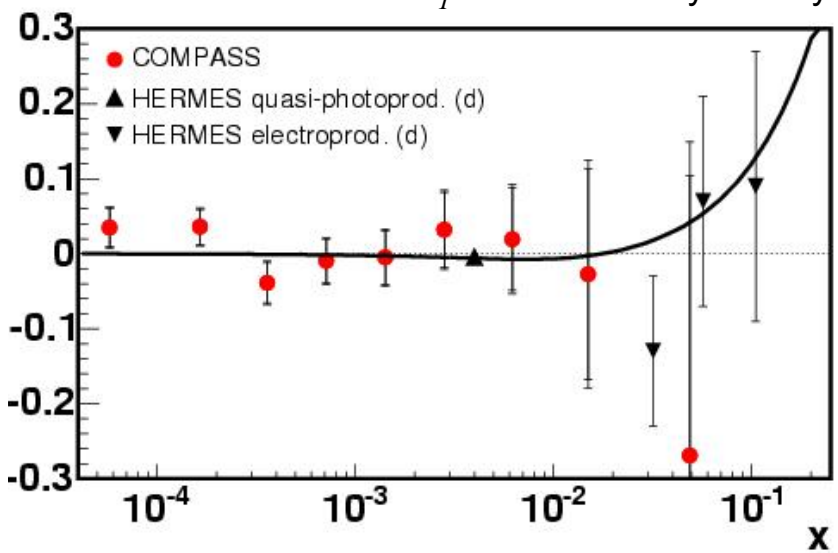
$$A_{LL}(\mu N \to \mu N \rho^0) = \frac{\sigma(\mu N)_{\uparrow\downarrow} - \sigma(\mu N)_{\uparrow\uparrow}}{\sigma(\mu N)_{\uparrow\downarrow} + \sigma(\mu N)_{\uparrow\uparrow}} = \frac{1}{f} \cdot \frac{1}{P_b} \cdot \frac{1}{P_t} \cdot A_{LL}^{raw}$$

$$A_1^\rho(\gamma^* N \to \rho^0 N) \approx \frac{1}{D} A_{LL}(\mu N \to \mu N \rho^0)$$

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

where $A_1$ – inclusive asymmetry (d)




- $A_1^\rho$ on polarised deuterons consistent with 0
- at small $Q^2$ and $x$ precise constraint on contribution of exchanges with unnatural parity
- at large $Q^2$ $A_1^\rho$ related to GPDs (higher-twist) $\propto k_T^2 \tilde{H}_g / (Q^2 H_g)$

Goloskokov, Kroll (2006)

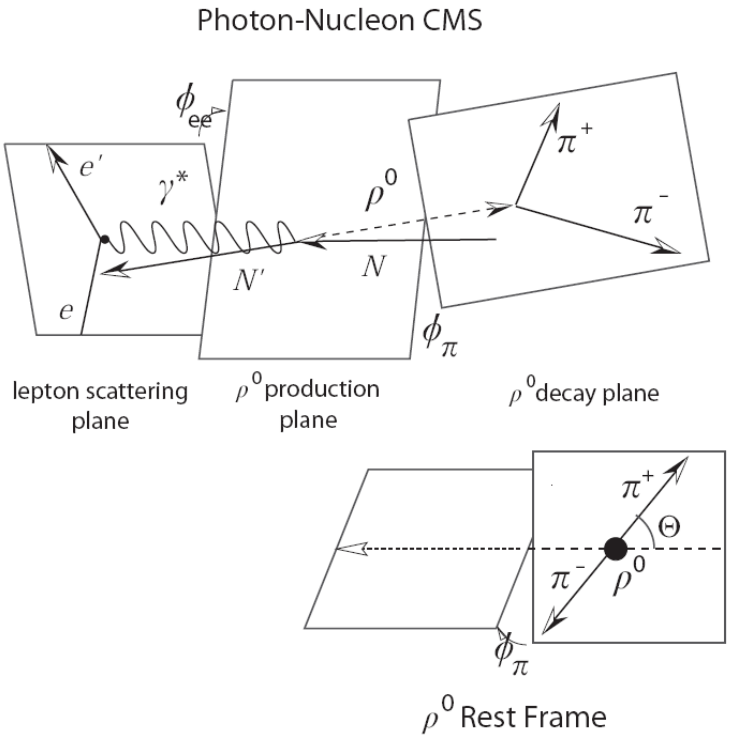
# Spin Density Matrix Elements

VM angular distributions W(cosθ, φ, Φ) depend on the spin density matrix elements (SDME) ⇨ 23 (15) observables with polarized (unpolarized) beam

SDMEs are bilinear combinations of the helicity amplitudes $T_{\lambda m\ \lambda\gamma}(\gamma^{*}N \rightarrow mN)$

$\lambda_\gamma = \pm 1, 0 \quad \lambda_m = \pm 1, 0$

(averaged over nucleon spins)

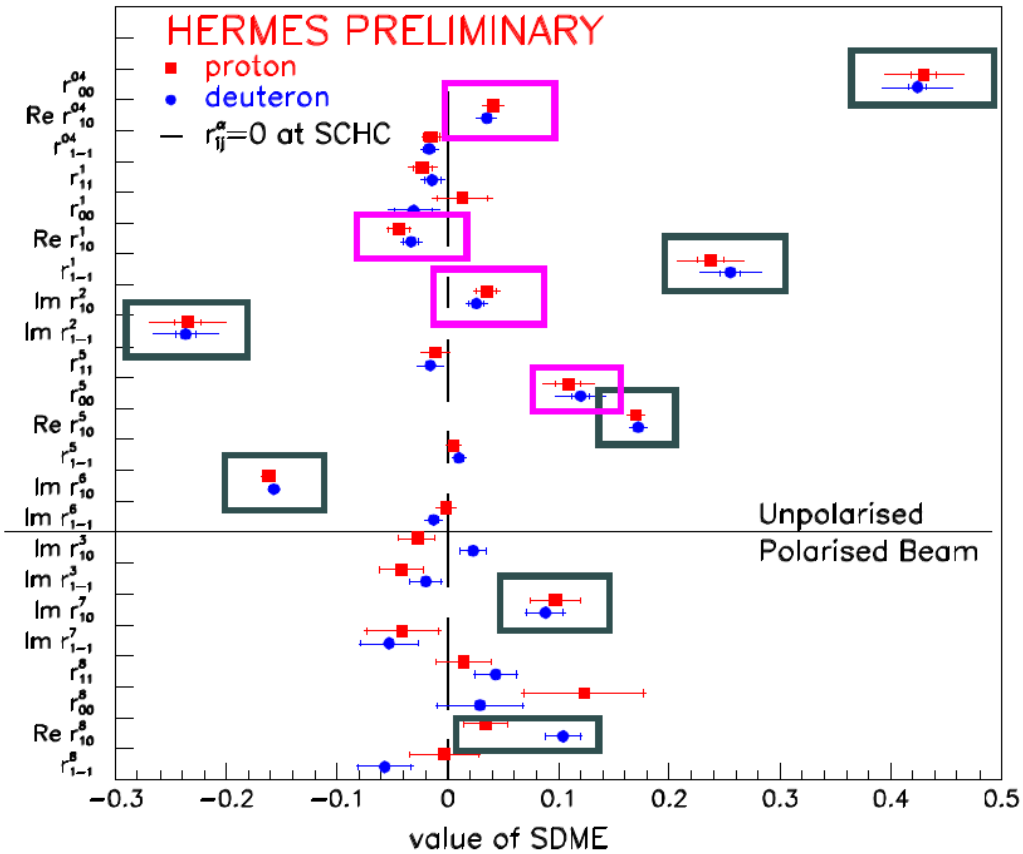



- describe helicity transfer from $\gamma^*$ to VM
  s-channel helicity conservation (SCHC)
- describe parity of t-channel exchange
  (NPE vs. UPE)
- impact on GPD studies – determination of $\sigma_L$

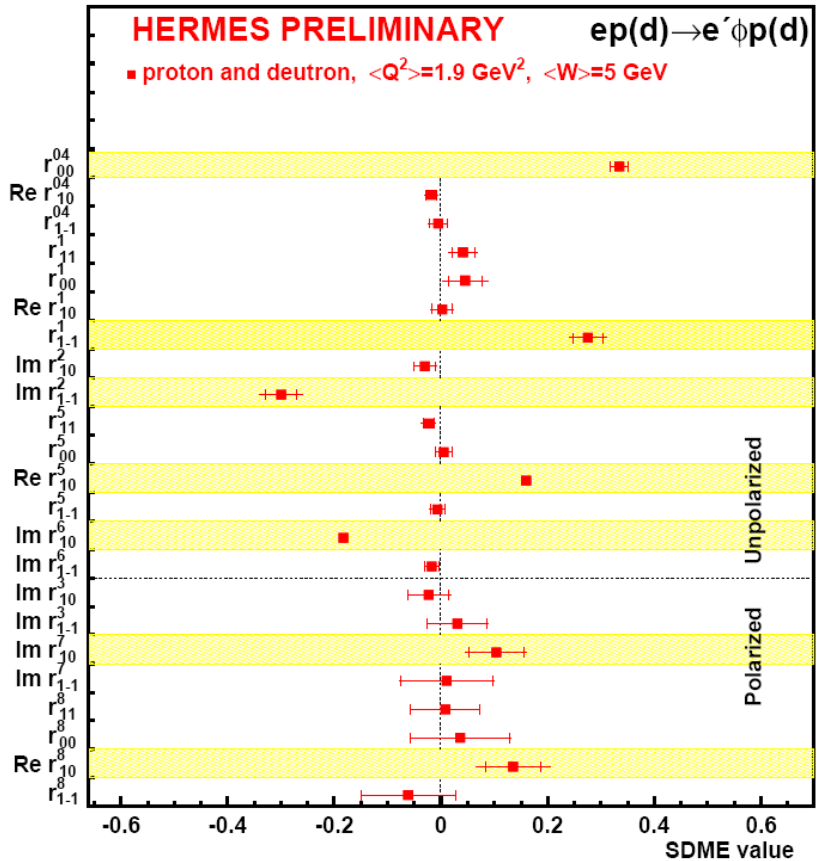
SDME $r_{00}^{04} \xrightarrow{SCHC} R = \dfrac{\sigma_L}{\sigma_T}$

# Spin Density Matrix Elements from HERMES

$\rho^0$




$\varphi$




- for $\rho^0$ s-channel helicity violation in $\mathrm{Re}\, r^{04}_{10}$, $\mathrm{Re}\, r^{1}_{10}$, $\mathrm{Im}\, r^{2}_{10}$ (mild) and $r^{5}_{00}$ (~ 10%)
- for $\rho^0$ a (small) contribution of unnatural-parity exchanges seen
- for $\varphi$ no s-channel helicity violation
- for proton and deuteron targets SDMEs (mostly) the same

more in talk of S. Manayenkov

# Exclusive $\pi^+$ production from HERMES

accepted for Phys Lett B

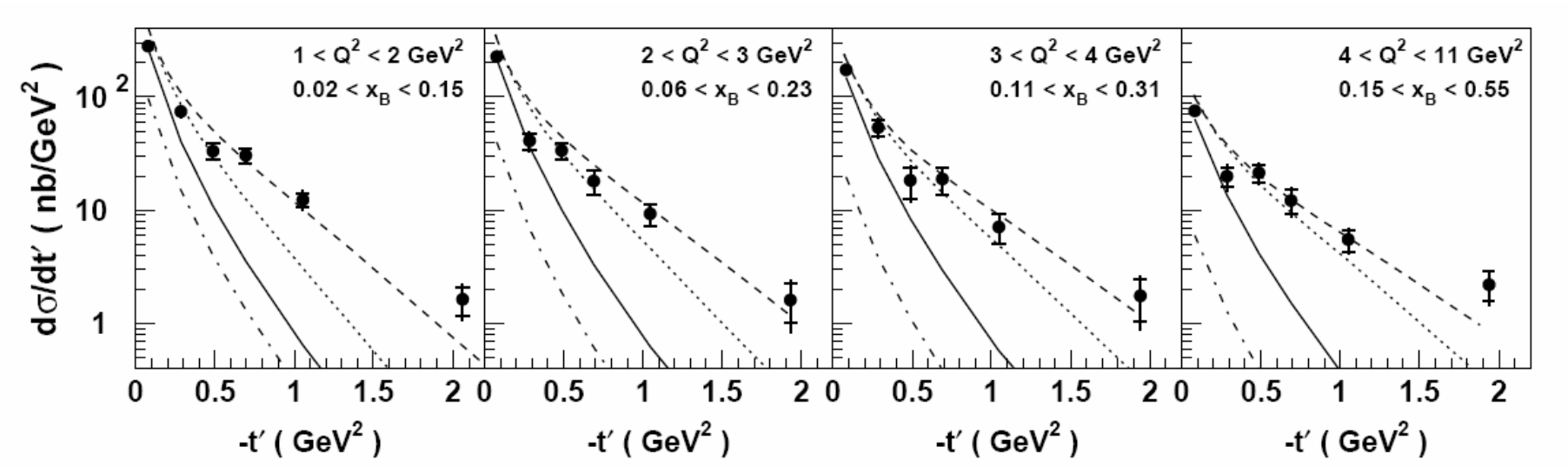
$$e\,p \rightarrow e\,n\,\pi^+$$

1996-2005 data with proton target (unpolarised and polarised)

$1 < Q^2 < 11$ GeV²
$W^2 > 11$ GeV²
$0.02 < x_{Bj} < 0.55$
$|t'| < 2$ GeV²

- L/T separation at HERMES not possible
- $\sigma_T$ expected to be supressed as $1/Q^2$

  dominance of $\sigma_L$ at large $Q^2$ supported by Regge model (Laget 2005)
- at leading twist $\sigma_L$ sensitive to GPDs $\tilde{H}$ and $\tilde{E}$
- at small $|t'|$ $\tilde{E}$ dominates as it contains $t$-channel pion-pole



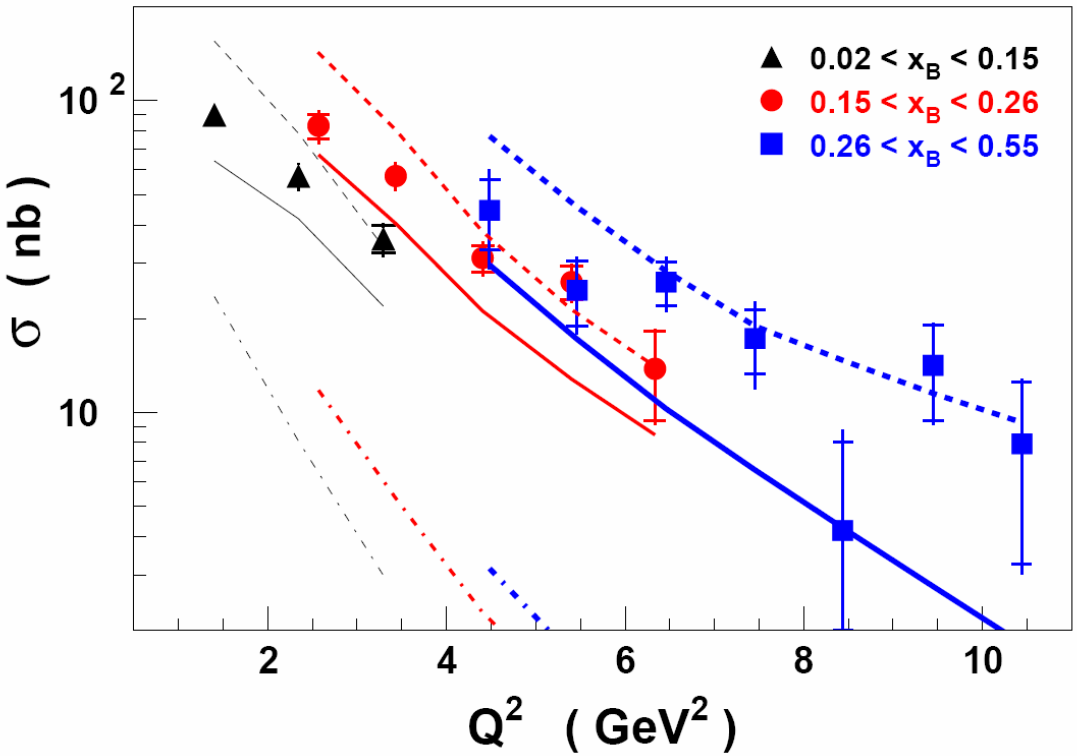

$\sigma_L$ VGG LO

$\sigma_L$ VGG LO+power corrections

$\sigma_L$ Regge model (Laget)

$\sigma_T + \varepsilon\,\sigma_L$ Regge model (Laget)

# Exclusive $\pi^+$ production from HERMES




$\sigma_L$ VGG LO

$\sigma_L$ VGG LO+power corrections

$\sigma_T + \varepsilon\, \sigma_L$ Regge model (Laget)

- LO calculations underestimate the data
- data support magnitude of the power corrections ($k_t$ and soft overlap)
- Regge calculations provides good description of the magnitude of $\sigma_{tot}$ and of $t'$ and $Q^2$ dependences

# Beam spin asymmetry in exclusive $\pi^0$ production from CLAS

$e\,p \rightarrow e\,p\,\pi^0$

$1 < Q^2 < 4.5$ GeV²
$W > 2$ GeV
$0.1 < x_{Bj} < 0.55$
$0.09 < |t| < 1.8$ GeV²

2005 data, $E_e$ = 5.77 GeV, all final state particles measured
Extended acceptance for $\gamma$'s due to installation of Inner Calorimeter

- essentially no experimental data for neutral pseudoscalar mesons in this range
- at leading twist $\sigma_L$ sensitive to GPDs $\tilde{H}$
- no $t$-channel pion-pole (in contrast to exclusive $\pi^+$ production)
- magnitude of $\sigma_T$ contribution unknown

$$\frac{d^2\sigma_{\gamma^* p\to p\pi^0}}{dt\,d\varphi} = \frac{1}{2\pi}\left(\frac{d\sigma_T}{dt} + \varepsilon\frac{d\sigma_L}{dt} + \varepsilon\cos 2\varphi\frac{d\sigma_{TT}}{dt} + \sqrt{2\varepsilon(1+\varepsilon)}\cos\varphi\frac{d\sigma_{TL}}{dt} + h\sqrt{2\varepsilon(1-\varepsilon)}\sin\varphi\frac{d\sigma_{TL'}}{dt}\right)$$

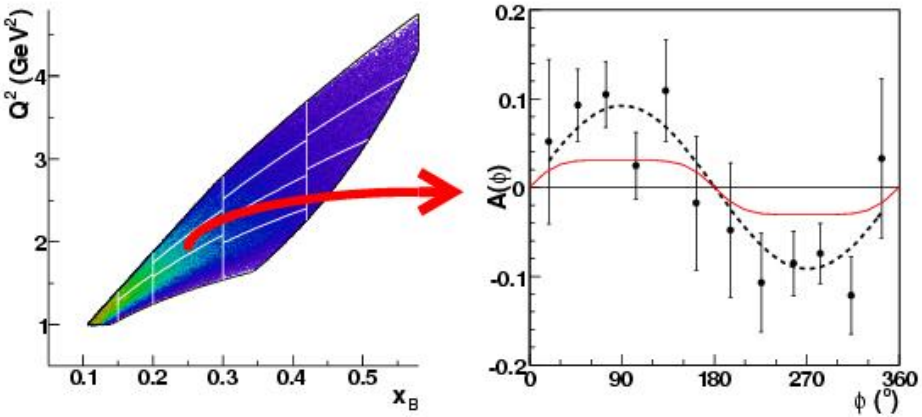
$h = \pm 1$ is the beam helicity

Beam Spin Asymmetry has the following $\varphi$ dependence

$$A_{LU} = \frac{d^4\vec{\sigma} - d^4\overleftarrow{\sigma}}{d^4\vec{\sigma} + d^4\overleftarrow{\sigma}} = \frac{\alpha\sin\varphi}{1 + \beta\cos\varphi + \gamma\cos 2\varphi}$$

- any non-zero BSA would indicate $L$-$T$ interference
  i.e. contribution not described in terms of GPD's

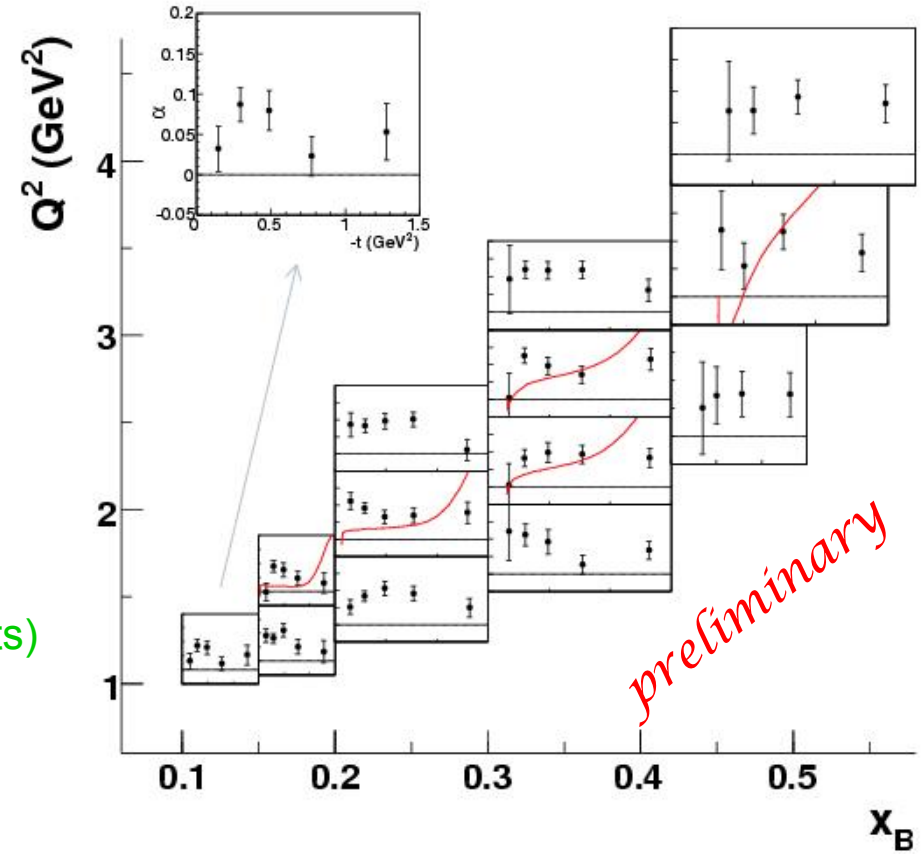
# Beam spin asymmetry in exclusive $\pi^0$ production from CLAS




- - - - a fit $\alpha \sin\varphi$

——— Regge model (Laget)

pole terms ($\omega$, $\rho$, $b_1$) + box diagrams (cuts)




- first measurement of BSA for exclusive $\pi^0$ production above resonance region
- sizeable BSA (0.04 – 0.11) indicate that both transverse and longitudinal amplitudes participate
- necessity for L/T separation and measurements at higher $Q^2$

# Cross sections for exclusive $\pi^0$ production from JLAB HALL A DVCS Collab.

E00-110

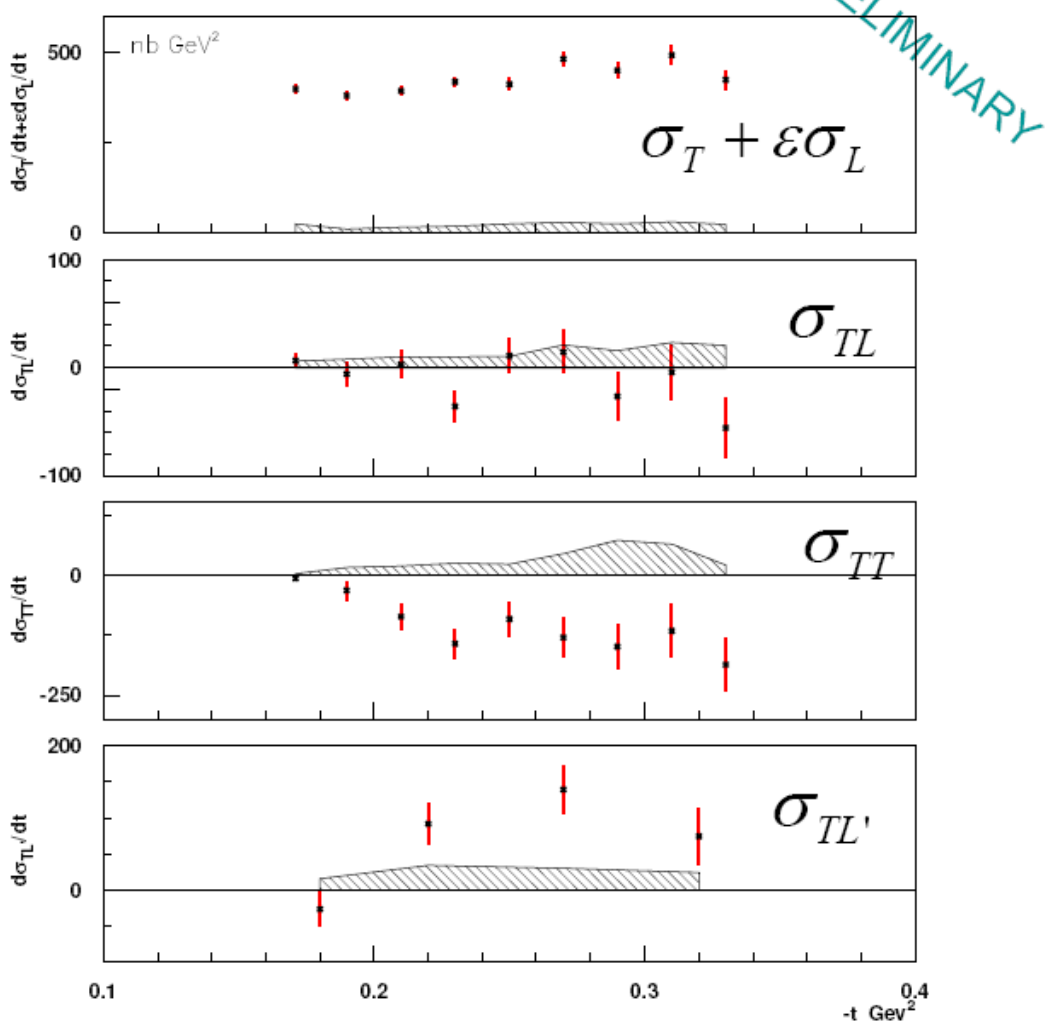
t-slope close to 0, maybe even small negative

$Q^2$=2.3 GeV$^2$

$x_{Bj}$=0.36

$\varepsilon$=0.64

$\chi^2$=1.11




from P. Bertin, Baryon-07

more in talk of A. Camsonne

Corrected for real+virtual RC
Corrected for efficiency
Corrected for acceptance
Corrected for resolution effects

Regge model (Laget) underestimates cross sections ≈ 5x

# Prospects for more results on exclusive meson production

## ➢ Other ongoing analyses of the data already taken

- ZEUS + H1 data from HERA II : $\rho^0$, $\varphi$, $J/\psi$, $\Upsilon$ cross sections + SDMEs
- HERMES : $\rho^0$, $\varphi$ SDMEs + unpolarised cross sections for full set of data including 2006-2007, expected factor of 2 gain in accuracy, hopefully with RD
  $\pi^+$ transverse target spin asymmetry (protons)
- COMPASS : $\rho^0$ TSA for polarised deuterons with $\gamma^*_L$-$\gamma^*_T$ separation
- CLAS : $\rho^+$, $\varphi$, $\pi^+$, $\pi^0$ and $\eta$ cross sections

## ➢ Data being taken or expected soon

- COMPASS : $\rho^0$ from transversely polarised proton target (2007)
  mesons from longitudinally polarised proton target (2007 (?))
- Hall A DVCS Coll.: $\pi^0$ Rosenbluth separation (2009)
- CLAS : $\pi^0$ and $\eta$ cross sections and BSA (2008), LTA (2009)

## ➢ Future projects with impact on GPDs

- COMPASS : DVCS and DVMP with Recoil Detector, large LH (LD) target and extended EM calorimetry , $\rho$ up to 20 GeV², $\gamma$, $\omega$, $\varphi$, $\pi$ and $\eta$ up to 7 GeV² (2010)
- JLAB 12 GeV Upgrade (2014) cf. talk by B. Wojtsekhowski
- PANDA at FAIR (2014) cf. next-to-last talk on Saturday
- EIC (> 2014) cf. talk by H. Kowalski

# Conclusions

- New precise data on cross sections and SDME's result in significantly more stringent constraints on the models for DVMP

- To describe present data on DVMP, both at large and small $x$, including power corrections (or higher order pQCD terms) is essential

- First experimental efforts in DVMP to constrain GPD $E$ and quark orbital momentum

- A rich program of future experiments and projects with impact on studies of DVMP and GPDs