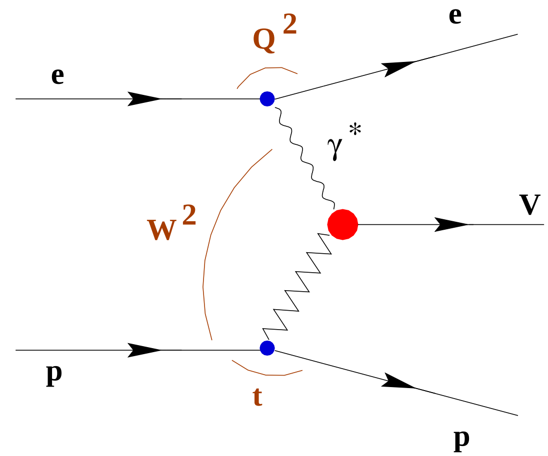
DIFFRACTION 2006, Adamantas, Milos Island, Greece, September 7th, 2006

Exclusive Diffractive Electroproduction of Vector Mesons at

hermes

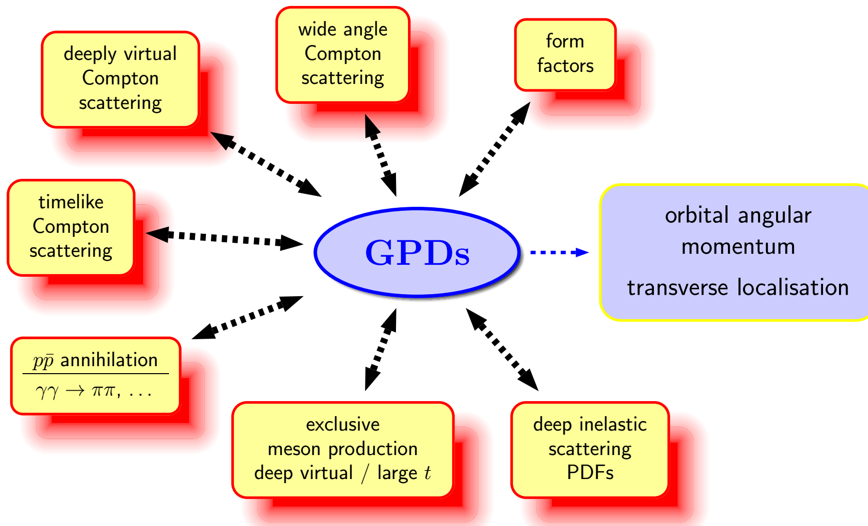


- Objectives: Generalized Parton Distributions
- Kinematics of Exclusive Vector Mesons
- Selected Results:
  - Color Transparency as a Prerequisite for Factorization
  - Total and Longitudinal Cross Sections and its Ratios
  - ρ^0 Transversely Polarized Target Spin Asymmetry
  - Spin Density Matrix Elements
- Projections until June 2007
- Summary

Alexander Borissov, DESY Zeuthen, on behalf of HERMES Collaboration

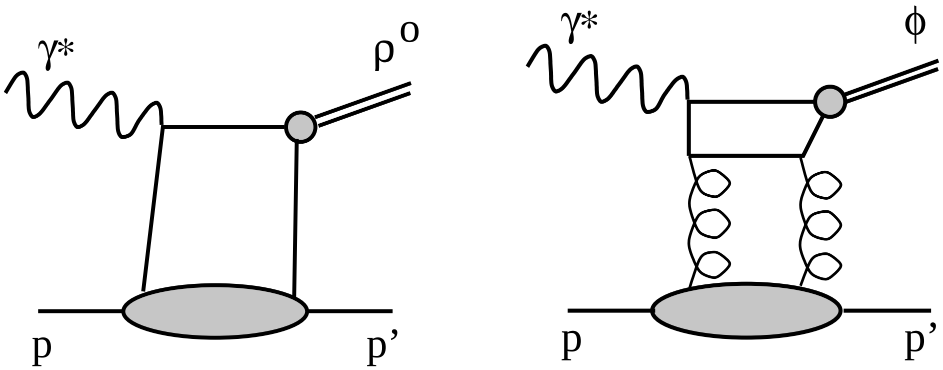
Generalized Parton Distributions (GPDs)

a bridge between fundamental QCD, phemomenology and experimental observables:



Unified description of hard exclusive processes via $H^{q(g)}(x, \xi, t)$, $\tilde{H}$, E, $\tilde{E}$

ρ^0, ω and ϕ vector mesons as a helicity and flavour filter $\longrightarrow$ access to unpolarised E, H via

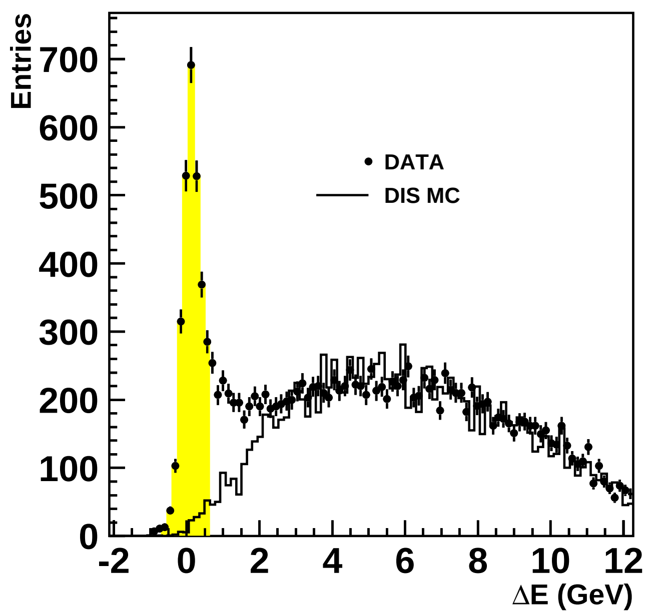


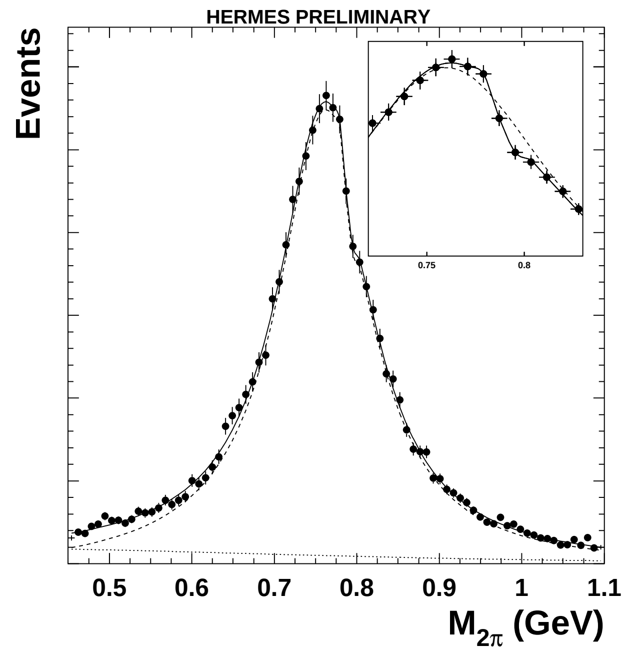
quark exchange and/or two-gluon exchange, tested via: Cross Sections
Transversely Pol. Target Spin Asymmetry
Spin Density Matrix Elements

Kinematics of exclusive ρ^o, ω and ϕ

- $\nu = 5 \div 24$ GeV, $<\nu>= 13.3$ GeV, $Q^2 = 1.0 \div 5.0$ GeV^2,$<Q^2>= 2.3$ GeV^2
- $W = 3.0 \div 6.5$ GeV, $<W>= 4.9$ GeV, $x_{Bj} = 0.01 \div 0.35$,$<x_{Bj}>= 0.07$
- $t' = 0.0 \div 0.4$ GeV^2, $<t'>= 0.13$ GeV^2

ρ^0 Exclusivity and Invariant Mass

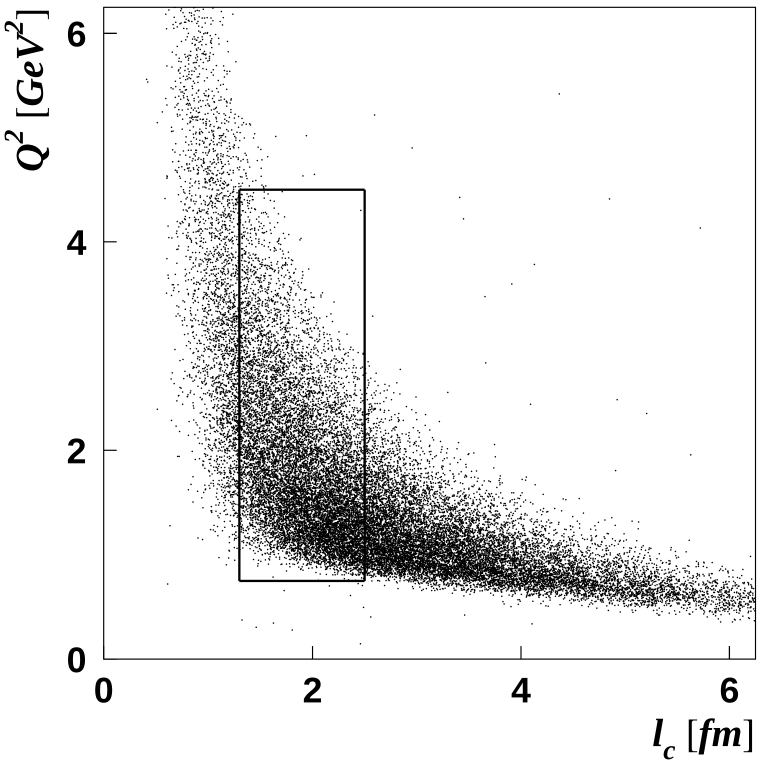




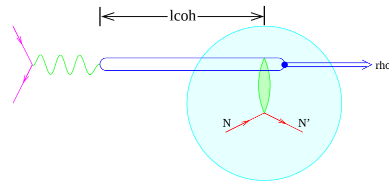
$$\Delta E = \frac{M_X^2 - M_p^2}{2M_p} \text{ with } M_X^2 = (p + q - v)^2$$

Background is subtracted with the aid of MC (PYTHIA)

Kinematics of exclusive ρ^o matches dimension of Nuclei



- radius of the nucleus: $r_{14_N} \simeq 2.5$ fm
- coherence length: distance traversed by qq



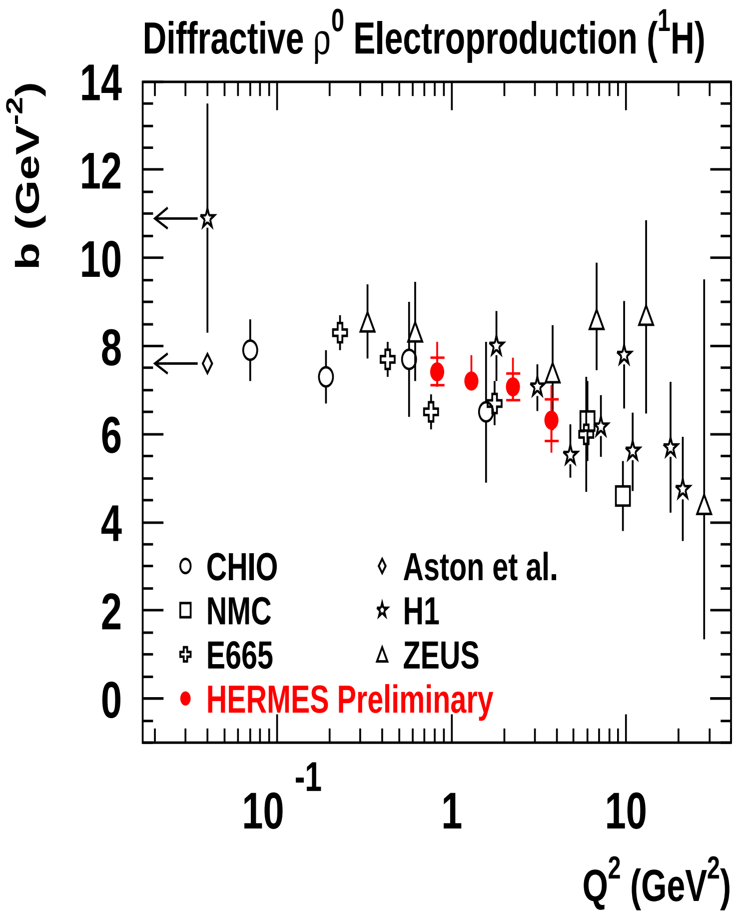
$l_c = \frac{2 \cdot \nu}{Q^2 + m_V^2} = 0.6 \div 8$ fm,
$< l_c >= 2.7$ fm, $l_c \gtrsim r_{14_N}$

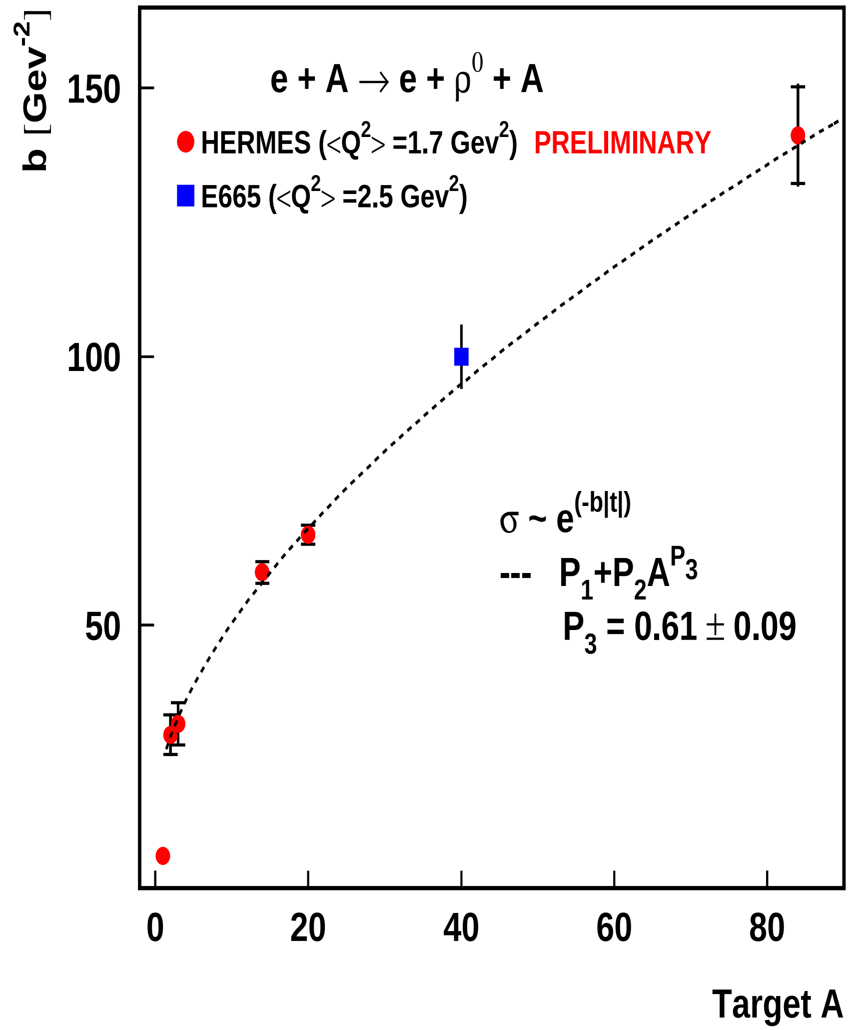
- transverse size of the qq wave packet
  $r_{q\bar{q}} \sim 1/ < Q^2 > \simeq 0.4$ fm $< r_p = 1$ fm
- formation length: distance needed for qq to develop into hadron:
  $l_{form} = \frac{2 \cdot \nu}{m_{V'}^2 - m_V^2} = 1.3 \div 6.3$ fm
  $< l_{form} >= 3.47$ fm

Transparency $T(l_c, Q^2) = \sigma^A / \sigma^H$
i/ l_c-dependent due to Glauber attenuation: coherence length effect HERMES coll., Phys.Rev.Lett. 82 (1999) 3025,
ii/ Q^2-dependent: color transparency effect

$\Longrightarrow$ 2-dimensional analysis of $T(l_c, Q^2)$ was developed

Prerequisites for Color Transparency: 'Photon Shrinkage' and A-dependence of Coherent Slope





→ Size of γ^* controlled via Q^2

→ No strong W−dependence

→ $b_{(coh)} \approx r_A^2/3$ is in agreement with world data of nuclear size measurements

(H.Alvensleben et al,Phys.Rev.Let. **24**,792 (1970)).

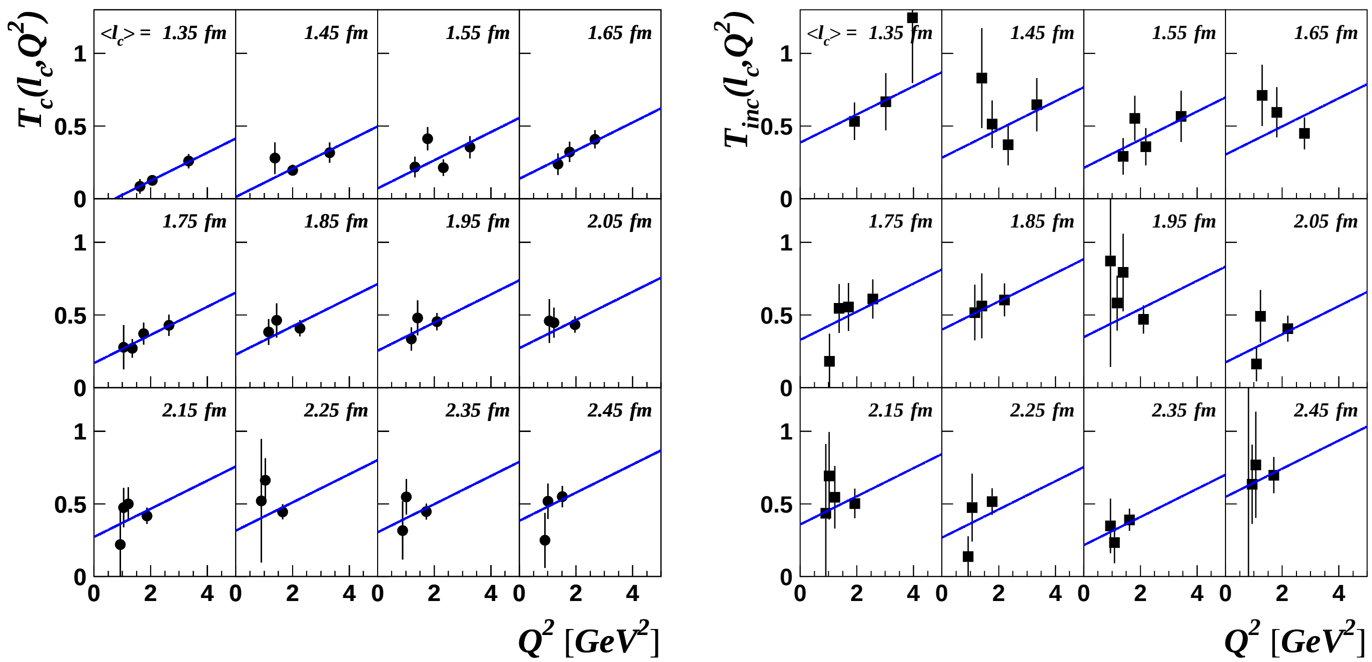
Color Transparency: Prerequisite for Factorization

J.Collins,L.L.Frankfurt,M.Strikman Phys.Rev.D**56**,2982 (1997); M.Strikman, Nucl.Phys.A663&664,**64**,2000

The QCD factorization theorem rigorously not possible without the onset of the color transparency:

$\rightarrow r(qq)$ decreases with the increase of Q^2 $\Longrightarrow$ $T_{c(inc)}(l_c, Q^2) = \sigma^A_{c(inc)}/\sigma^H$ grows with Q^2

At fixed $l_{c(inc)}$ (HERMES collab., Phys.Rev.Let.,**90**,5,052501,2003) :

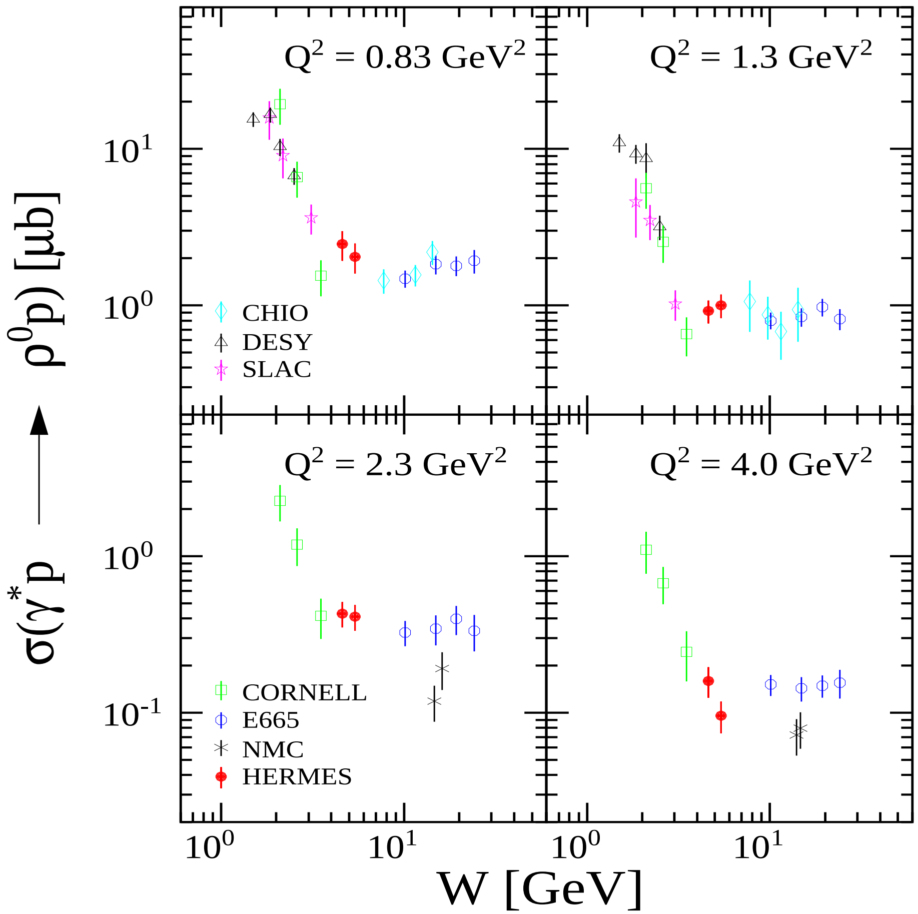


data	Slope of Q^2-dependence, GeV^{-2}	Prediction, GeV^{-2}
N incoh.	$0.089 \pm 0.046_{st} \pm 0.020_{syst}$	0.060
N coh.	$0.070 \pm 0.027_{st} \pm 0.017_{syst}$	0.048
N combined	0.074 ± 0.023	0.058

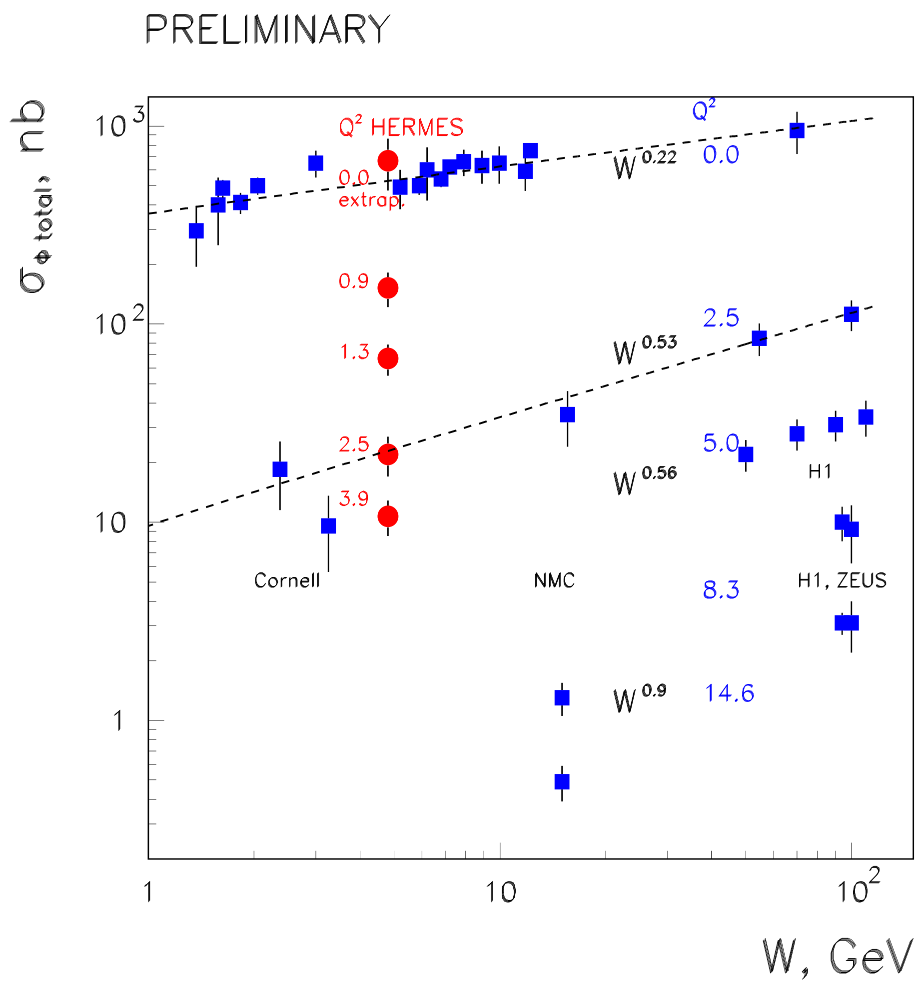
Agreement with theoretical calculations where positive slope of Q^2-dependence was derived from the onset of the color transparency effect (B.Z. Kopeliovich et al, Phys.Rev. C, **65**, 035201, 2002) .

Color Transparency Analysis was started on DIFFRACTION 2000:

ρ^0 and ϕ Total Cross Section



(HERMES collab. EPJ C 17 (2000) 3, 389-398).



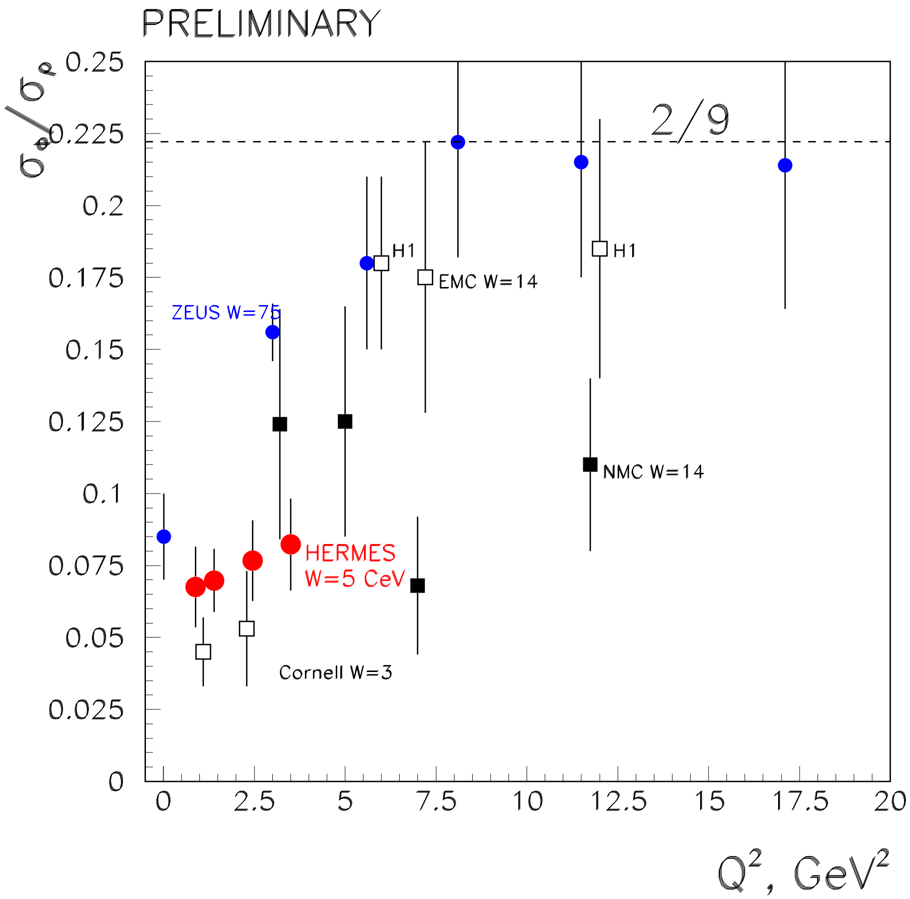
→ ρ^0 (and ω) are in the transition region, which production mechanisms are involved?

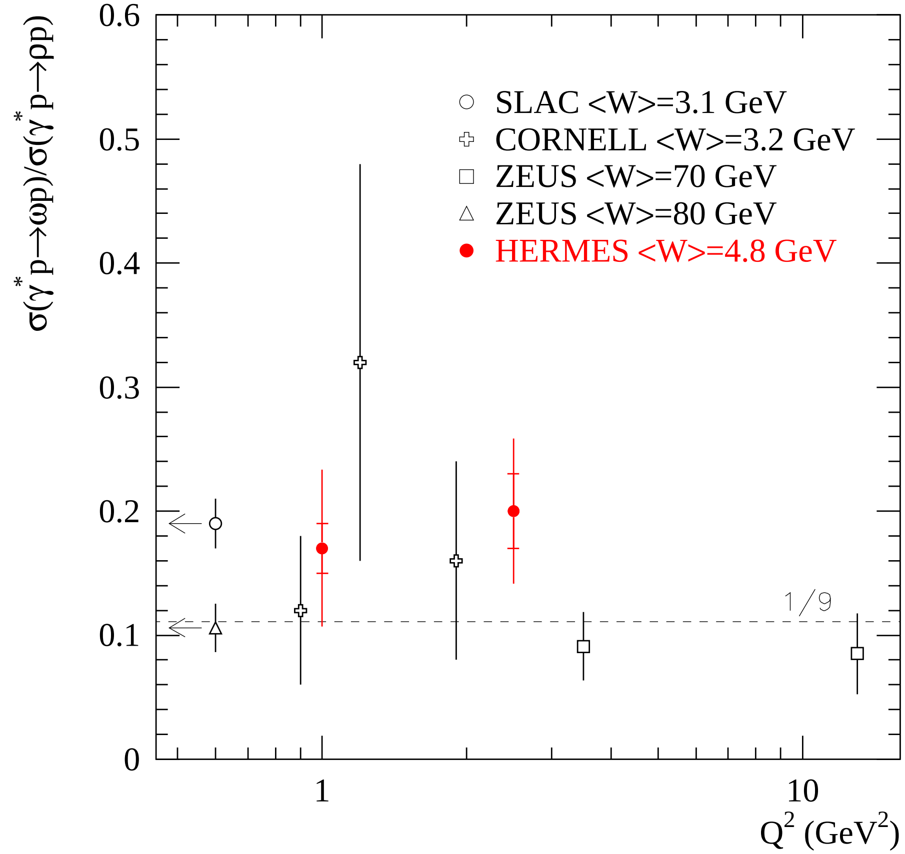
→ ϕ: $W^{\delta_\phi(Q^2)}$ describes all data, $\delta_\phi = 0.22$ at $Q^2 = 0$, $\delta_\phi = 0.53$ at $Q^2 = 2.5$ GeV^2

→ ϕ: Two-gluon (or Pomeron) exchange could be sufficient

Cross Section Ratios: $\sigma_\phi/\sigma_{\rho^o}$, $\sigma_\omega/\sigma_{\rho^o}$

Asymptotic SU(4) pQCD predicts: $\rho^o : \omega : \phi : J/\Psi = 9 : 1 : 2 : 8$





$\longrightarrow$ $W-$dependence at $Q^2 = 2.5 \sim 4$ GeV^2

$\longrightarrow$ Substantial two-gluon contribution for ρ^0: $0.38 \leq |g_\rho/q_\rho| \leq 1.5$

(M.Diehl and A.V.Vinnikov Phys.Lett. **B609** (2005) 286)

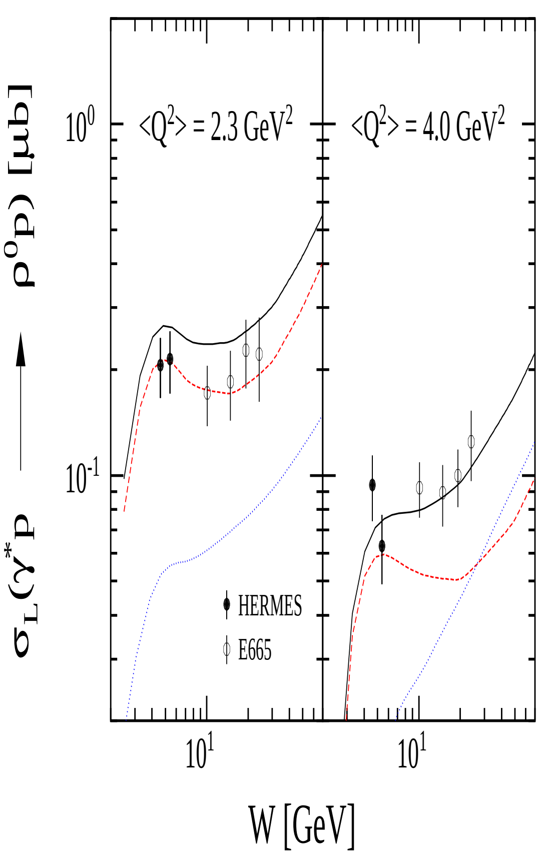
$\longrightarrow$ trend to $W-$dependence of $\sigma_\omega/\sigma_{\rho^o}$

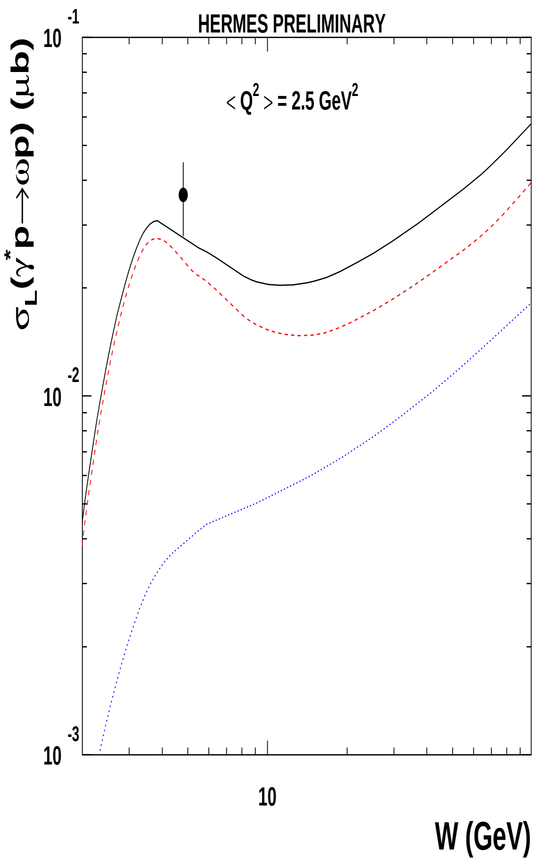
$\longrightarrow$ VGG model: $\sigma_L^\omega/\sigma_L^{\rho^o} \sim 0.2$

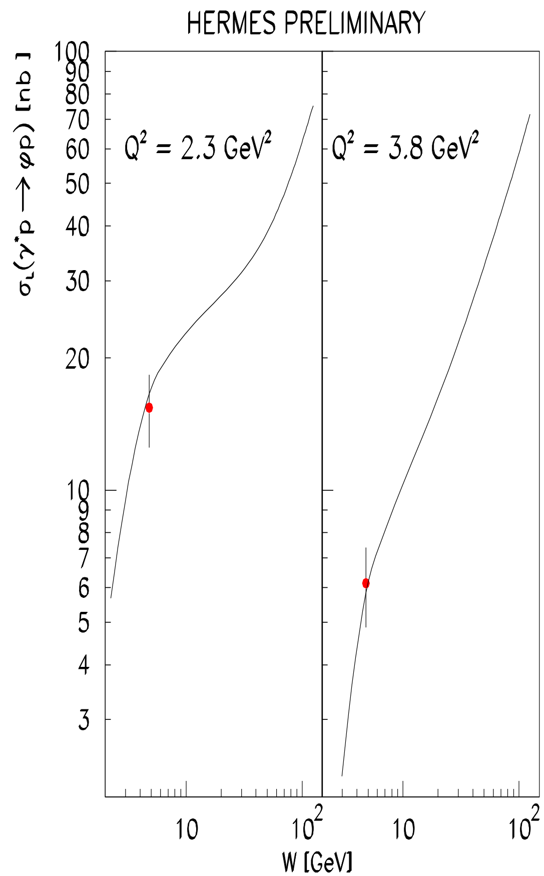
(M.Vanderhaeghren,P.A.M.Guichon,M.Guidal,Phys.Rev.Let.**80**5064,1998)

ρ^o, ω and ϕ Longitudinal Cross Sections

GPD calculations of VGG model (M.Vanderhaeghren, P.A.M. Guichon, M. Guidal, Phys.Rev.Let.**80** 5064, 1998). Higher twist effects accounted (M.Vanderhaeghren, P.A.M. Guichon, M. Guidal, Phys.Rev.D **60** 094017, 1998)







2-gluon exchange, quark exchange, sum of both $(R_\omega = R_\rho)$ 2-gluon exchange only

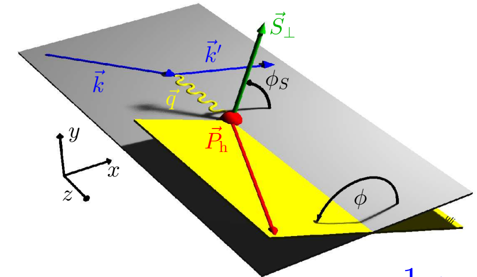
→ Dominance of quark exchange for ρ^o and ω from VGG model.
→ Dominance of 2-gluon exchange for ϕ meson

...and good agreement for σ_L^ϕ with S.Goloskokov&P.Kroll (GK) calculations based on gluon-exchange and gluon-strange quark interference (NEXT TALK, Eur.Phys.J. C **42** (2005) 02298, http://gpd.gla.ac.uk/gpd2006/programme.phptuesession3)

ρ_L^o Transversely Polarized Target Spin Asymmetry $A_{UT}^{\sin(\phi-\phi_s)}$

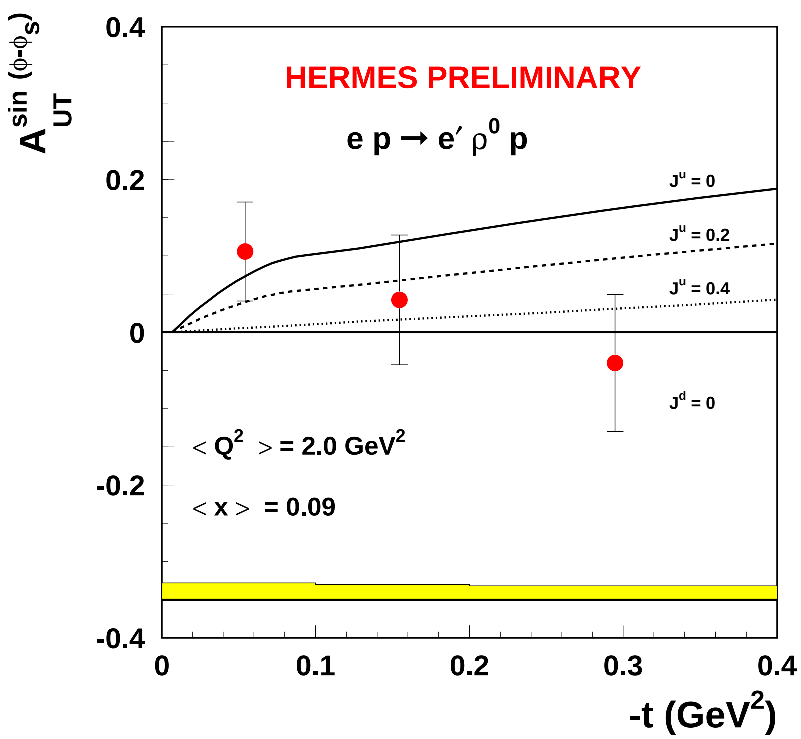
$$A_{UT}^{\sin(\phi-\phi_s)} \sim \frac{E(\rho_L)}{H(\rho_L)} \sim \frac{E_q+E_g}{H_q+H_g} \sim -\mathcal{A} = \frac{1}{|S_\perp|}\frac{\int_0^\pi d\beta\sigma(\beta)-\int_\pi^{2\pi} d\beta\sigma(\beta)}{\int_0^{2\pi} d\beta\sigma(\beta)}$$

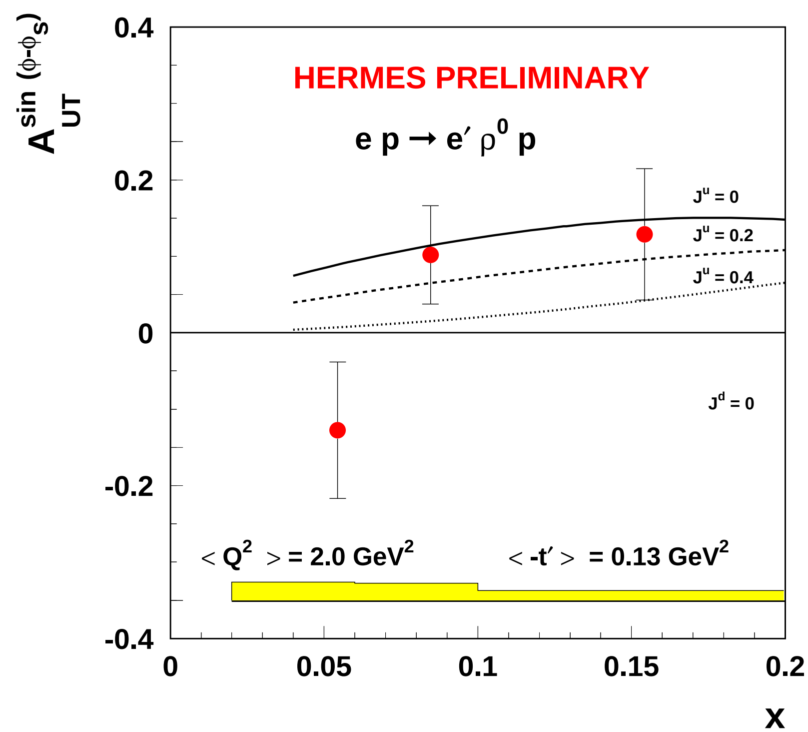
$$\beta = \phi - \phi_s$$



Open a way to the total spin of the quarks J_q and therefore to their orbital angular momentum L_q: $J_q = \frac{1}{2}\Delta\Sigma + L_q$

(K.Goeke,M.Polyakov,M.Vanderhaeghen, Prog.Part.Nucl. Phys.,**47**,410,(2001))





→ general agreement with GPD calculations (F.Ellinghaus et el, hep-ph/0506264), but not enough to estimate J^u

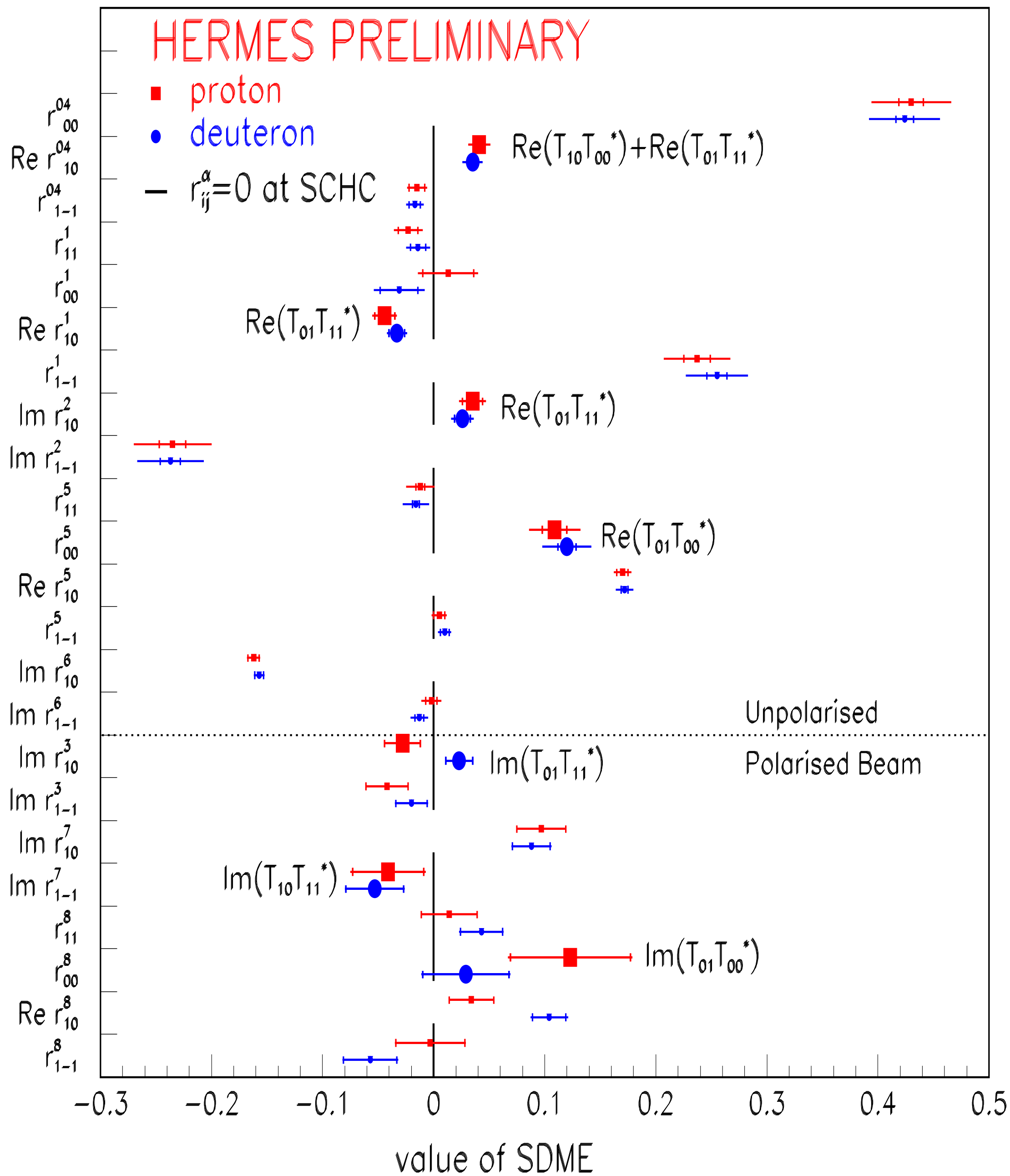
→ FULL data (2002-2005) are under analysis, factor of two in statistics

→ L/T separation has not been done yet, will reduce accuracy on some factor

⟹ ...hard to conclude on the sensitivity to J^u

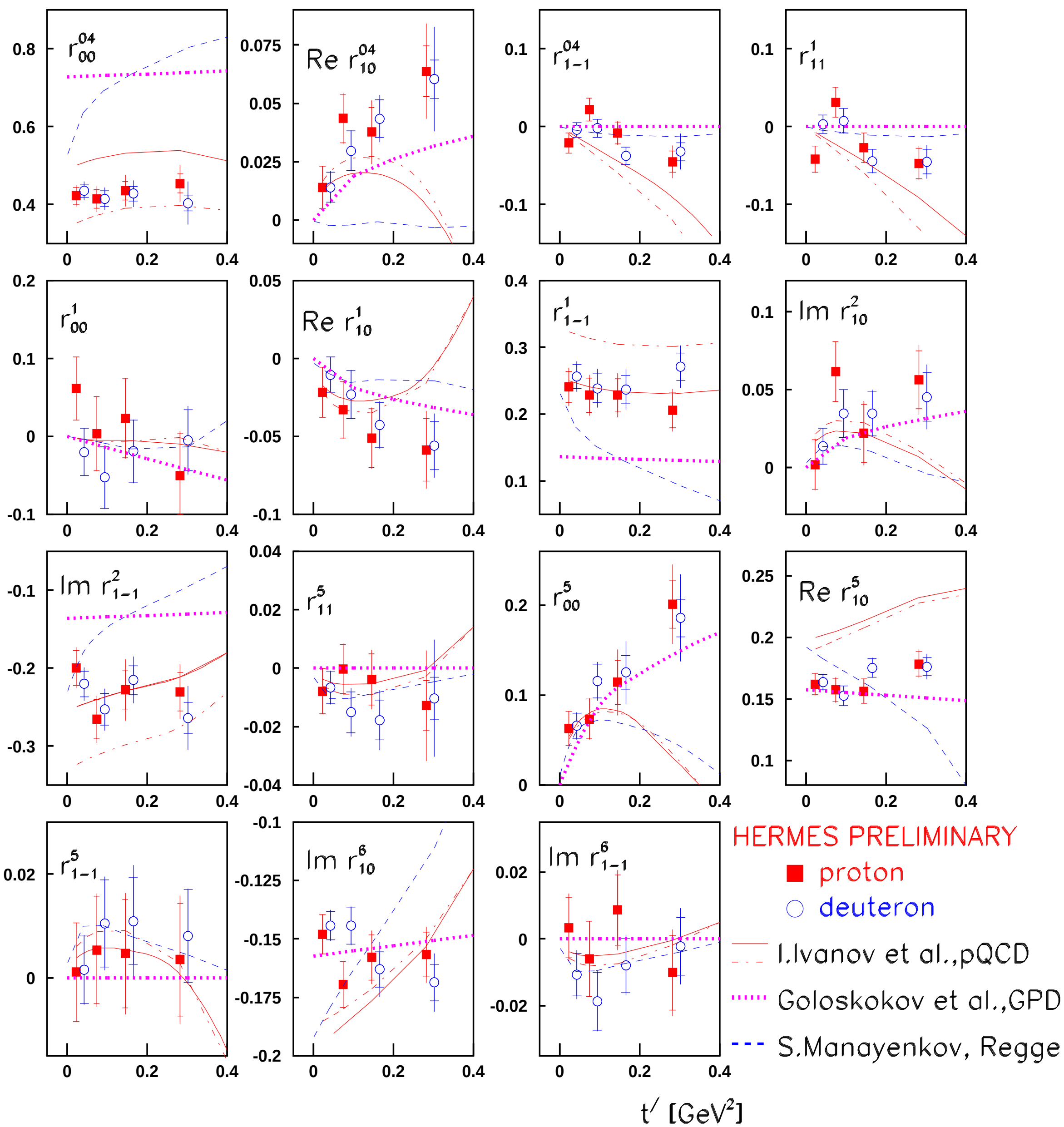
23 Spin Density Matrix Elements $r^{\alpha}_{\lambda_\rho \lambda'_\rho}$ from $\gamma^* + N \rightarrow \rho^0 + N'$

at $0 < t' < 0.4$ GeV^2 and $1 < Q^2 < 5$ GeV^2



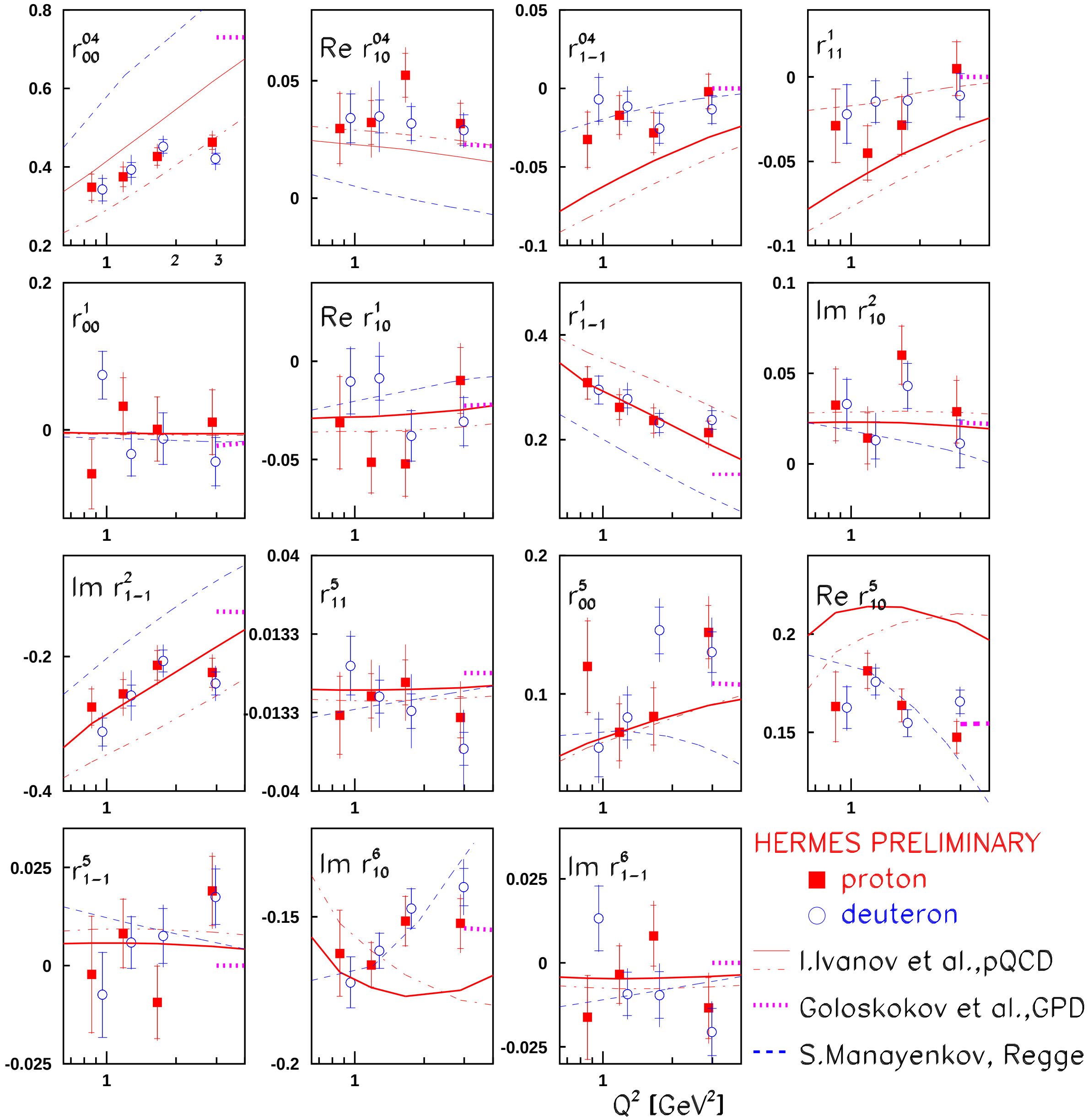
- $r^{\alpha}_{\lambda_\rho \lambda'_\rho} \sim \rho(V) = \frac{1}{2} T \rho(\gamma) T^+$
  Spin-density matrix of the vector meson $\rho(V)$ in terms of the photon matrix $\rho(\gamma)$ and helicity amplitude $T_{\lambda_V \lambda_\gamma}$
- Access to the spin structure of ρ^0 production mechanism and ρ^0 wave function: spin state of γ^* is known, decay $\rho^0 \rightarrow \pi^+ + \pi^-$ is self-analysing $\Longrightarrow$ tested by comparing kinematic dependences of SDMEs with calculations
- $q\bar{q}$-exchange with isospin 1 can be observed in case of difference between proton and deuteron data $\Longrightarrow$ No significant difference between proton and deuteron.
- Spin flip amplitudes or s-channel helicity violation $\Longrightarrow$ enlarged SDMEs violating SCHC $(2 \div 5\ \sigma)$, indicating non-zero spin-flip amplitudes: T_{01}, T_{10}, T_{1-1}
- Estimate of hierarchy of amplitudes $\Longrightarrow$ $T_{00} \sim T_{11} \gg T_{01} > T_{10} \sim T_{1-1}$

t'-Dependence of SDMEs Compared with Calculations for HERMES kinematics



- I.Ivanov: pQCD, two-gluon exchar
  oscillator and Coulomb ρ^0 wave functi
  $T_{00}, T_{11}, T_{01}, T_{10}, T_{1-1}$ $\Longrightarrow$ Disagreem
  for $\mathrm{Re}\{r^5_{10}\}$, $\mathrm{Im}\{r^6_{10}\}$
- S.Goloskokov: GPD at $Q^2 > 3.0$ GeV^2
  parameterization of gluonic double distributi
  Gaussian ρ-meson wave function (S-wa
  accounted secondary reggeon exchange
  amplitudes T_{00}, T_{11}, T_{01} $\Longrightarrow$ Disagreement
  r^{04}_{00}, r^{1}_{1-1}, $\mathrm{Im}\{r^2_{1-1}\}$ connected with σ_L/σ
- S.I.Manayenkov: Regge phenomenol
  with Pomeron,ρ,ω,f,A_2 exchanges, part
  hadron duality, $T_{00}, T_{11}, T_{01}, T_{10}, T_{1-1}$ $=$
  Disagreement for r^{04}_{00}, r^{1}_{1-1}, $\mathrm{Im}\{r^2_1$
  connected with σ_L/σ_T ratio
- Still reasonable agreement for the majority
  SDMEs (12 elements) at low t'
- But no model describes well all unpolar
  SDMEs $\Longrightarrow$ Waiting for the inclusion
  quark-exchange into GPD-based model,
  which lowest Q^2-limit is possible???

Q^2-Dependence of SDMEs Compared with Calculations



Same comments as for t'-dependeces

References on models:

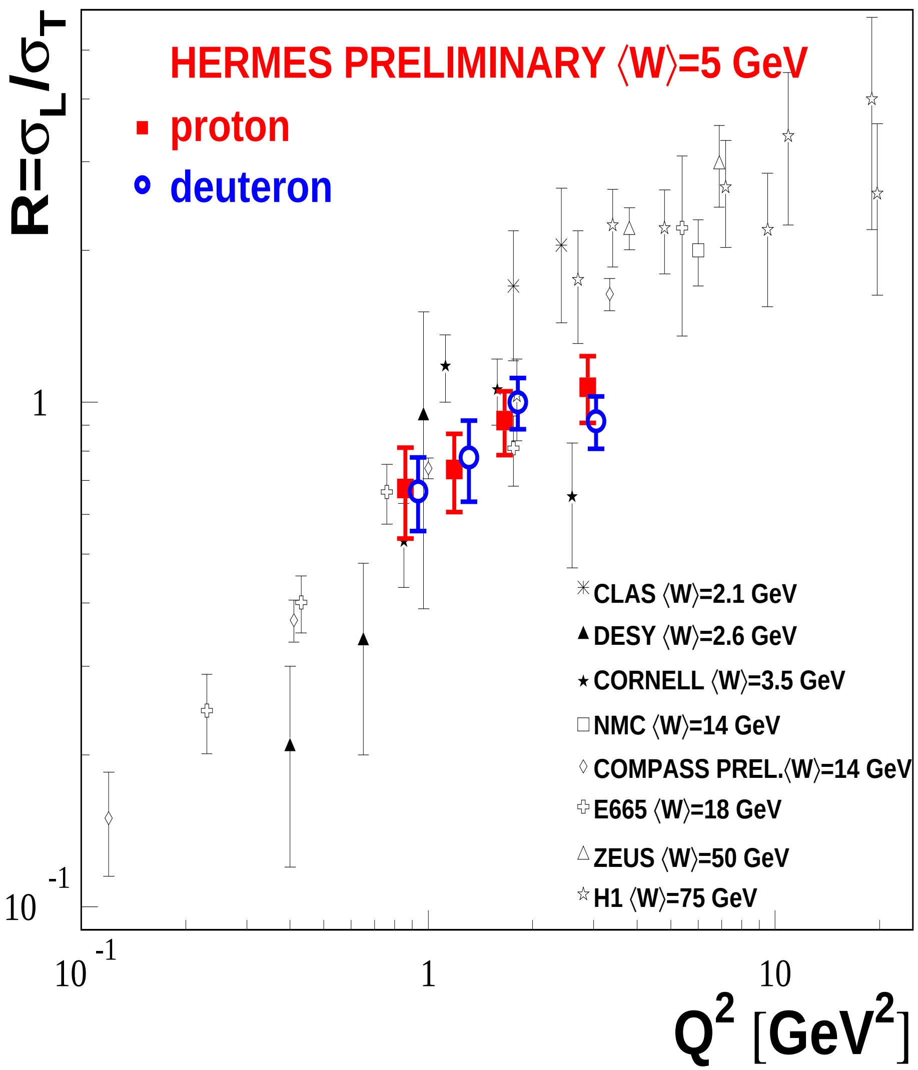
- I.P.Ivanov, N.N.Nikolaev,JETP Lett, **69** (19 294; I.P.Ivanov Ph.D. Bonn Uni,2003,I ph0303053
- S.V.Goloskokov and P.Kroll, Eur.Phys.J. C (2005) 281;hep-ph/0501242:
- S.I.Manayenkov Eur.Phys.J. C**33** (2004)397

Longitudinal-to-Transverse Cross-section Ratio $R = \sigma_L/\sigma_T$

In general: $\sigma_L = \frac{1}{2}\sum_{\lambda_N \lambda'_N}[|T_{00}|^2 + |T_{10}|^2 + |T_{-10}|^2]$, $\sigma_T = \frac{1}{2}\sum_{\lambda_N \lambda'_N}[|T_{11}|^2 + |T_{01}|^2 + |T_{-11}|^2]$

at SCHC: $R^{SCHC} = |T_{00}|^2/|T_{11}|^2 \approx \frac{r^{04}_{00}}{\epsilon(1-r^{04}_{00})}$

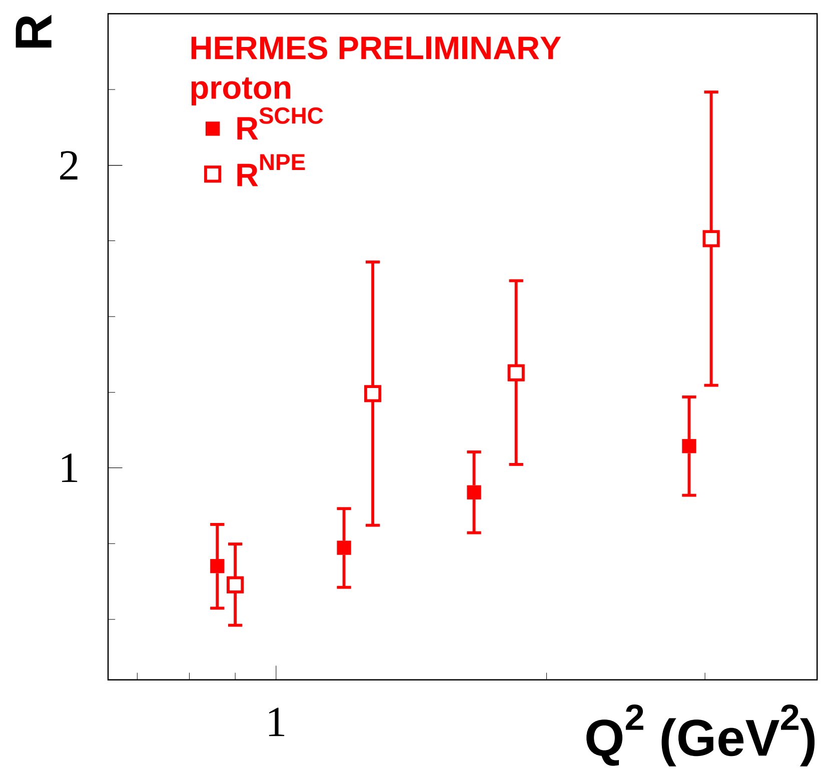
at NPE: $R^{NPE} = \frac{1}{\epsilon}\left\{\frac{1}{2r^1_{1-1} - r^1_{00}} - 1\right\}$



NPE - Natural Parity Exchange with particle quantu numbers $J^P = 0^+, 1^-, 2^+, \ldots$

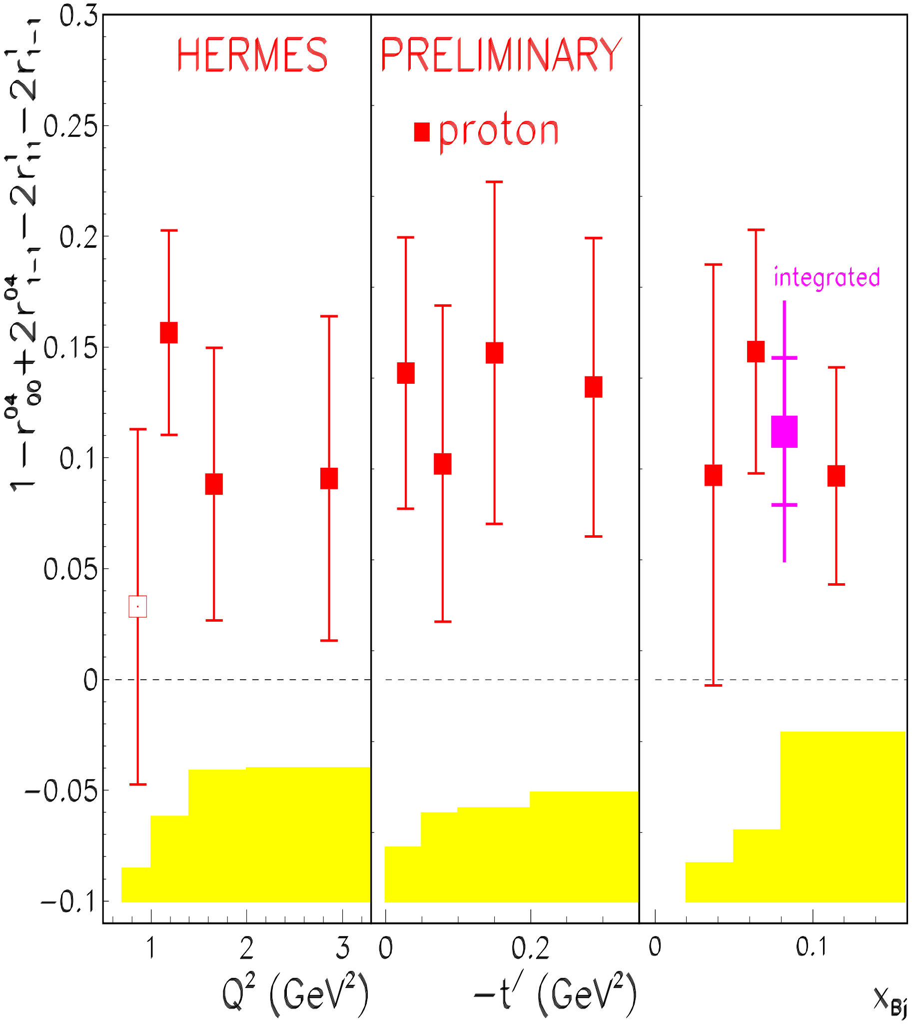
(but accuracy of R^{NPE} is lower then R^{SCHC})

R^{NPE} is the upper limit for R ($R \le R^{NPE}$)



Experimental data for UnPE contribution from SDMEs

U_1 Data:



p: $U_1 = 0.112 \pm 0.033_{st} \pm 0.049_{syst}$

d: $U_1 = 0.059 \pm 0.026_{st} \pm 0.047_{syst}$

for coherent ρ^0 production only NPE is expected

$$U_1 = 1 - r^{04}_{00} + 2r^{04}_{1-1} - 2r^{1}_{11} - 2r^{1}_{1-1}$$

$$= \sum_{\lambda_N,\lambda'_N} \frac{2\epsilon|T^U_{1\lambda'_N,0\lambda_N}|^2 + |T^U_{1\lambda'_N,1\lambda_N} + T^U_{-1\lambda'_N,1\lambda_N}|^2}{\sigma_T + \epsilon\sigma_L}$$

$$U_2 = r^5_{11} + r^5_{1-1}$$

p: $U_2 = -0.0066 \pm 0.0063_{st} \pm 0.0098_{syst}$

d: $U_2 = -0.0064 \pm 0.0048_{st} \pm 0.0095_{syst}$

$$U_3 = r^8_{11} + r^8_{1-1}$$

p: $U_3 = +0.0112 \pm 0.040_{st} \pm 0.0092_{syst}$

d: $U_3 = -0.0142 \pm 0.031_{st} \pm 0.0061_{syst}$

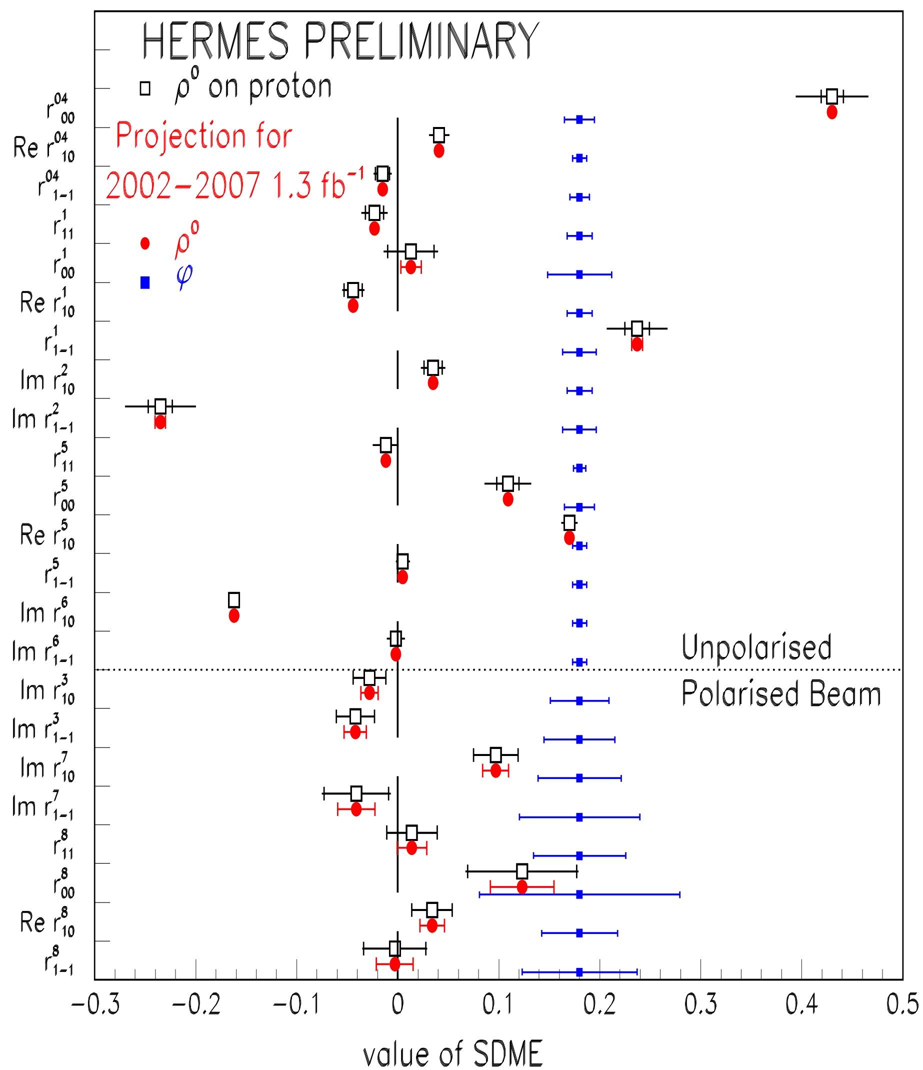
$$U_2 + iU_3 = \frac{1}{\sqrt{2}} \sum_{\lambda_N,\lambda'_N} \frac{T^U_{1\lambda'_N,0\lambda_N}[T^U_{1\lambda'_N,1\lambda_N} + T^U_{-1\lambda'_N,1\lambda_N}]^*}{\sigma_T + \epsilon\sigma_L}$$

$\longrightarrow$ indication on hierarchy of UnP amplitudes, as $|T^U_{10} \cdot T^U_{11*}|$ is consistent with zero,

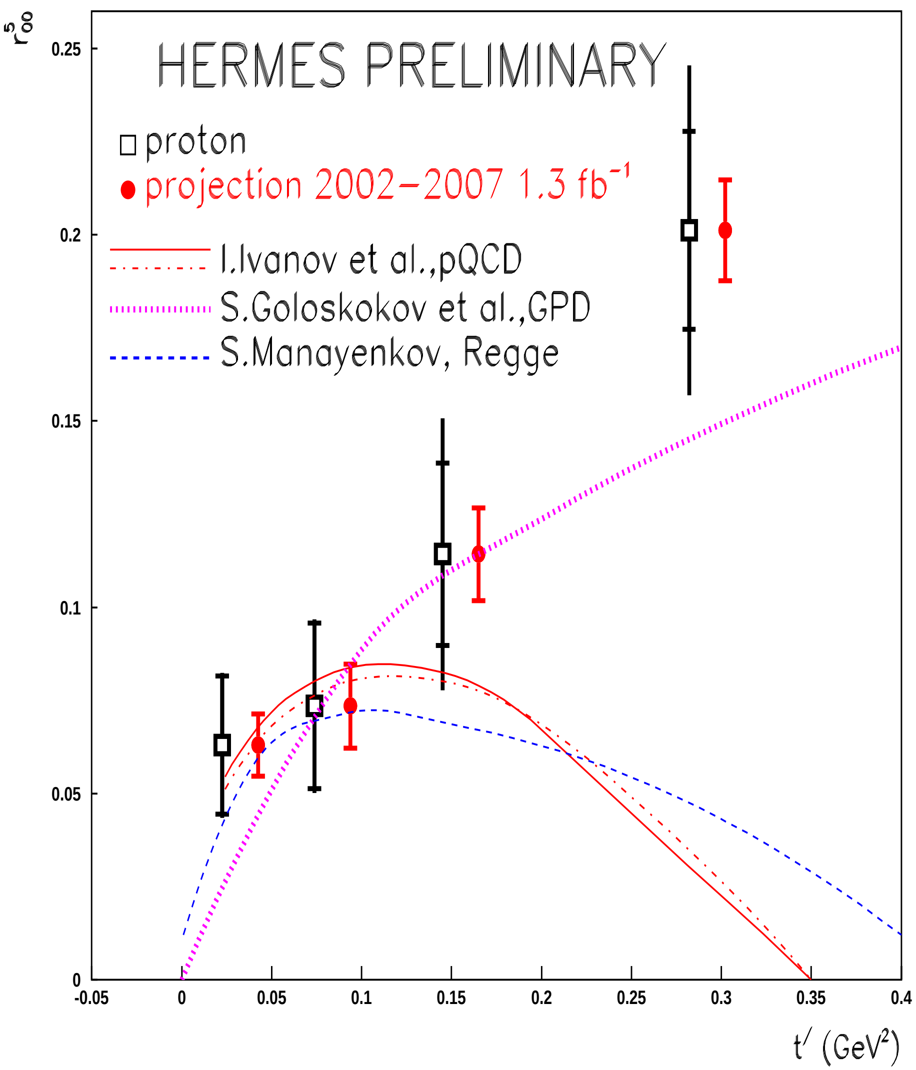
$\longrightarrow$ only one out of two is non-zero

More Data are expected until June 2007 at Planned Luminosity 1.3 fb^{-1}

at $0 < t' < 0.4$ GeV^2 and $1 < Q^2 < 5$ GeV^2



in 4 t'-bins at $1 < Q^2 < 5$ GeV^2



$\longrightarrow$ More than factor of two in accuracy for ρ^0 and ϕ SDMEs

...and detailed comparison with GPD-based calculations anticipated

Summary

- Color transparensy of exclusive ρ^o production supports factorization
- Quark exchange is essential for ρ^o and ω production
- ϕ production can be explained by two-gluon exchange mechanism
- Longitudinal cross sections of ρ^o and ω are in agreement with VGG calculations.
- Longitudinal cross sections of ϕ are in agreement with VGG and GK calculations.
- First measurement of A_{UT} for exclusive ρ^0 done, more data available
- Recent ρ^0 SDMEs analysis:
  - 23 SDMEs, including 8 polarized, measured in the first time
  - No significant difference between proton and deuteron data
  - Violation of SCHC from non-zero values of several elements
  - Q^2 and t'-dependences compared with calculations for Pomeron/two-gluon exchange

    $\Longrightarrow$ Quark-exchange GPD-based calculations are necessary!
  - σ_L/σ_T ratio measured under SCHC and NPE assumptions
  - An indication on unnatural parity exchange amplitude on proton

$\rightarrow$ Vector meson data are available for the tests of GPD models

$\rightarrow$ Significant increase of HERMES statistics is expected