Diffraction 2000
Cosenza, Italy
September 4th, 2000

Diffraction and deeply virtual exclusive scattering at intermediate W and Q^2 of

hermes

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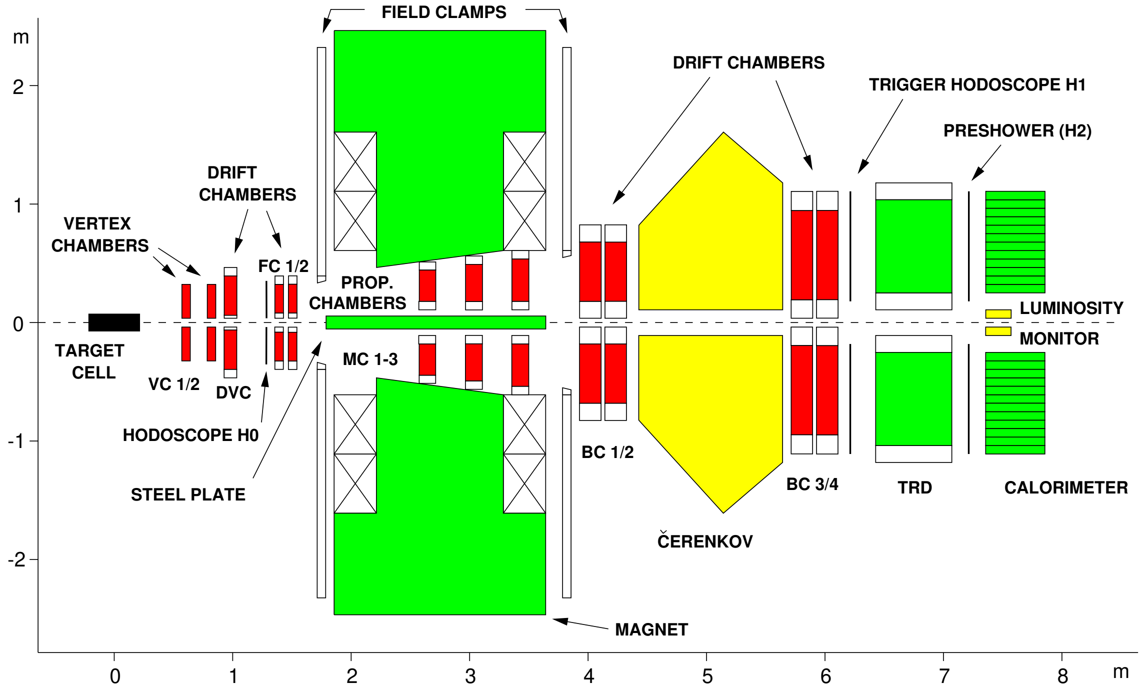
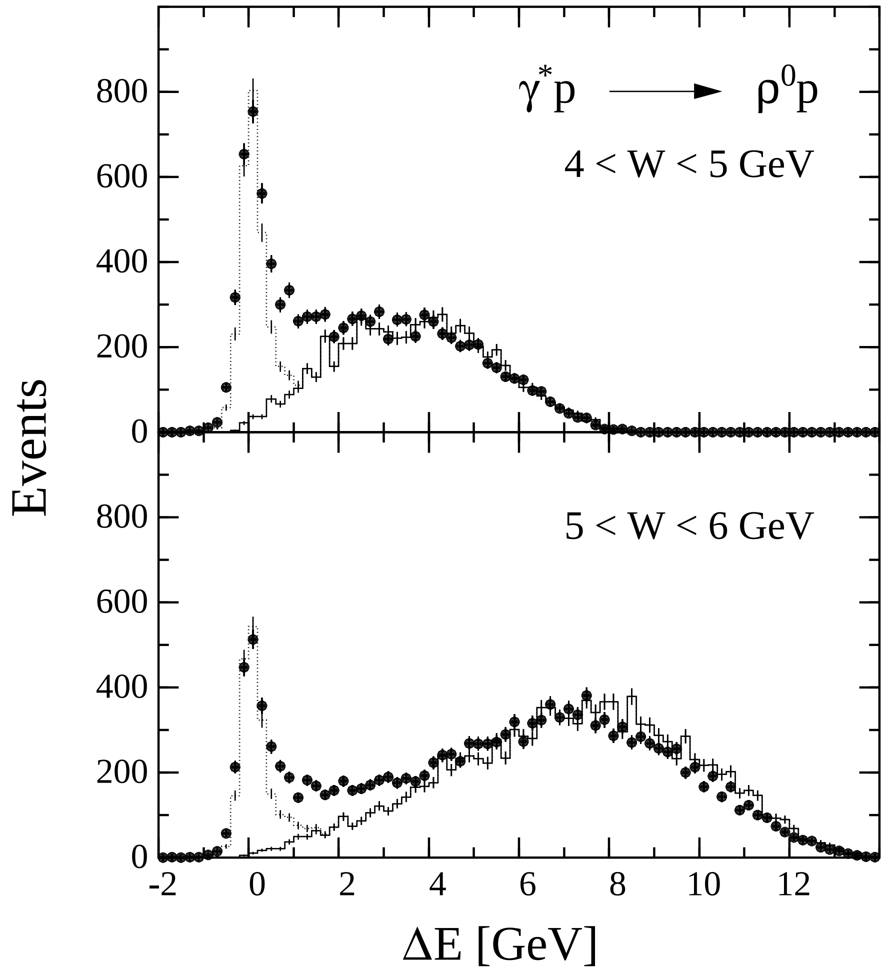
- The Experiment
- Diffractive ρ^o and ϕ production:
  - selection of diffractive events
  - Q^2-dependence of ρ^o skewing
  - cross section, $W-$dependence
  - cross section, Q^2-dependence
  - cross section ratio $\sigma_\phi/\sigma_{\rho^o}$
  - SDME's, $R(Q^2) = \sigma_L/\sigma_T$
  - double spin asymmetry
- Deeply virtual exclusive scattering:
  - exclusive π^+ production
  - observation of DVCS
- Summary and Overlook

The Experiment in 1995-1997



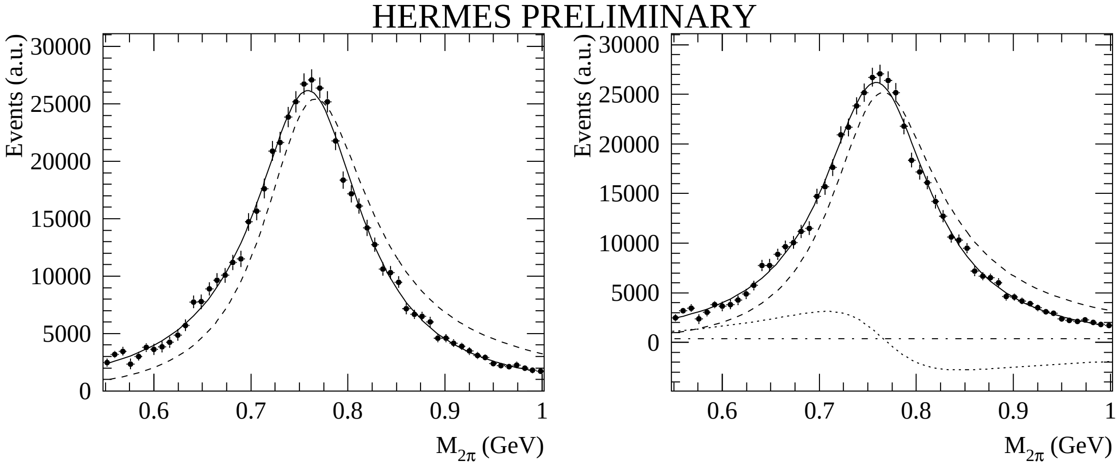
- Two identical halves of forward spectrometer having acceptance $40 < \Theta < 220mrad$ with momentum resolution $\leq 1\%$.
- Identification of electron with efficiency $> \ 97\%$ at hadron contamination $< 1\%$.
- Cherenkov detector momentum thresholds for pions 4 GeV/c and kaons 13 GeV/c in $'96,' 97$.
- Longitudinally polarised $e^{\pm}$ beam in HERA storage ring ($P = 27.5$ GeV/c, current 40 mA, $P_{beam} = 40 \ldots 60\%$)
- Internal storage cell gas target with high density:
  - polarised: $\sim 10^{14}$ nucl./cm^2, polarization 90% for H/D.
  - unpolarised: $\sim 10^{15}$ nucl./cm^2

Diffractive ρ^o and ϕ



- Main cuts:
  - ρ^o,ϕ select exclusive: -0.4 GeV$< \Delta E < 0.4$ GeV
  - ρ^o,ϕ select diffractive: -$t' < 0.4 GeV^2$
  - ρ^o select mass: 0.6 GeV$< M_{2\pi} <$1 GeV
  - ρ^o eliminate ϕ background: 1.04 GeV $< M_{2K}$
  - ϕ select mass: 0.99 GeV $< M_{2K} <$1.05 GeV
  - ϕ eliminate background: $\mid p_1 - p_2 \mid \leq 0.3 * (p_1 + p_2)$
  - ϕ kaon PID: $P_{K+} > 4$ and $P_{K-} > 4$ GeV/c
- Kinematics
  - $\nu = 5 \div 23$ GeV, $< \nu >= 15$ GeV
  - $Q^2 = 0.7 \div 5$ GeV^2, $< Q^2 >= 1.7$ GeV^2
  - $W = 4. \div 6.$ GeV, $< W >= 5$ GeV
  - $x_{Bj} = 0.02 \div 0.22, < x_{Bj} >= 0.1$

Mass Peak of ρ^o



Relativistic $p-$wave Breit-Wigner and Ross-Stodolsky

$$\frac{dN}{dM_{2\pi}} = BW(M_{2\pi})(\frac{M_\rho}{M_{2\pi}})^{n_{skew}}$$

$M_\rho = 770.9 \pm 1.2$ MeV, $\Gamma\rho = 138.9 \pm 2.0$ MeV, $n_{skew} = 2.68 \pm 0.13$

Söding shape

$$\frac{dN}{dM_{2\pi}} = A_{reso}BW(M_{2\pi}) + A_I I(M_{2\pi}) + A_{nr}$$

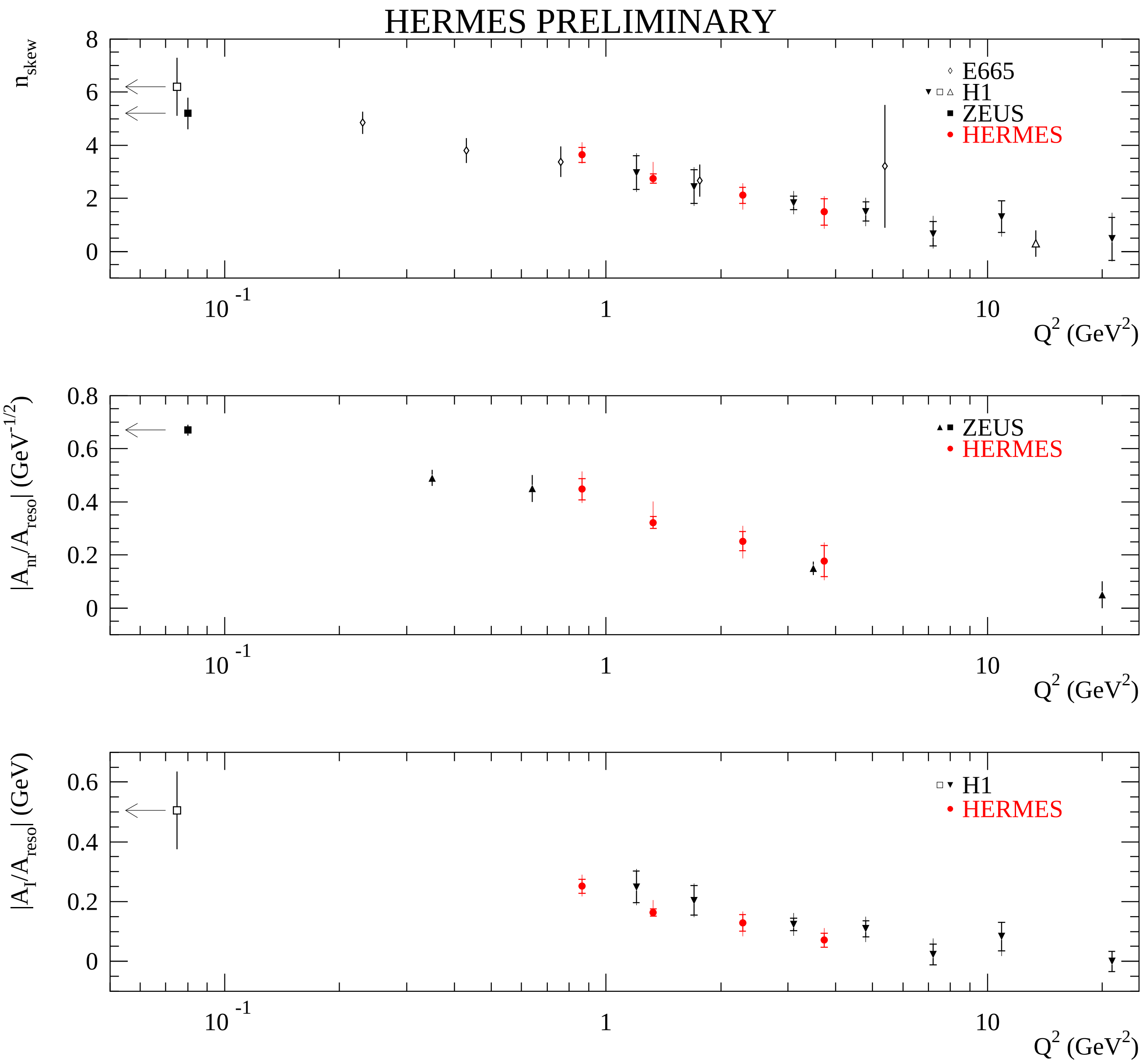
where $I(M_{2\pi}) = \frac{M_\rho^2 - M_{2\pi}^2}{(M_\rho^2 - M_{2\pi}^2)^2 + M_\rho^2 \Gamma^2(M_{2\pi})}$

$M_\rho = 768.9 \pm 1.3$ MeV, $\Gamma_\rho = 129.5 \pm 1.9$ MeV, $|A_I/A_{reso}| = 159. \pm 10$ MeV.

At constant and real A_{nr}: $|A_{nr}/A_{reso}| = 316 \pm 16$ MeV$^{-1/2}$,
$M_\rho = 770.2 \pm 1.2$ MeV, $\Gamma_\rho = 138.2 \pm 2.0$ MeV.

No target mass dependence $(H, D, ^3He, ^{14}N)$ was found.

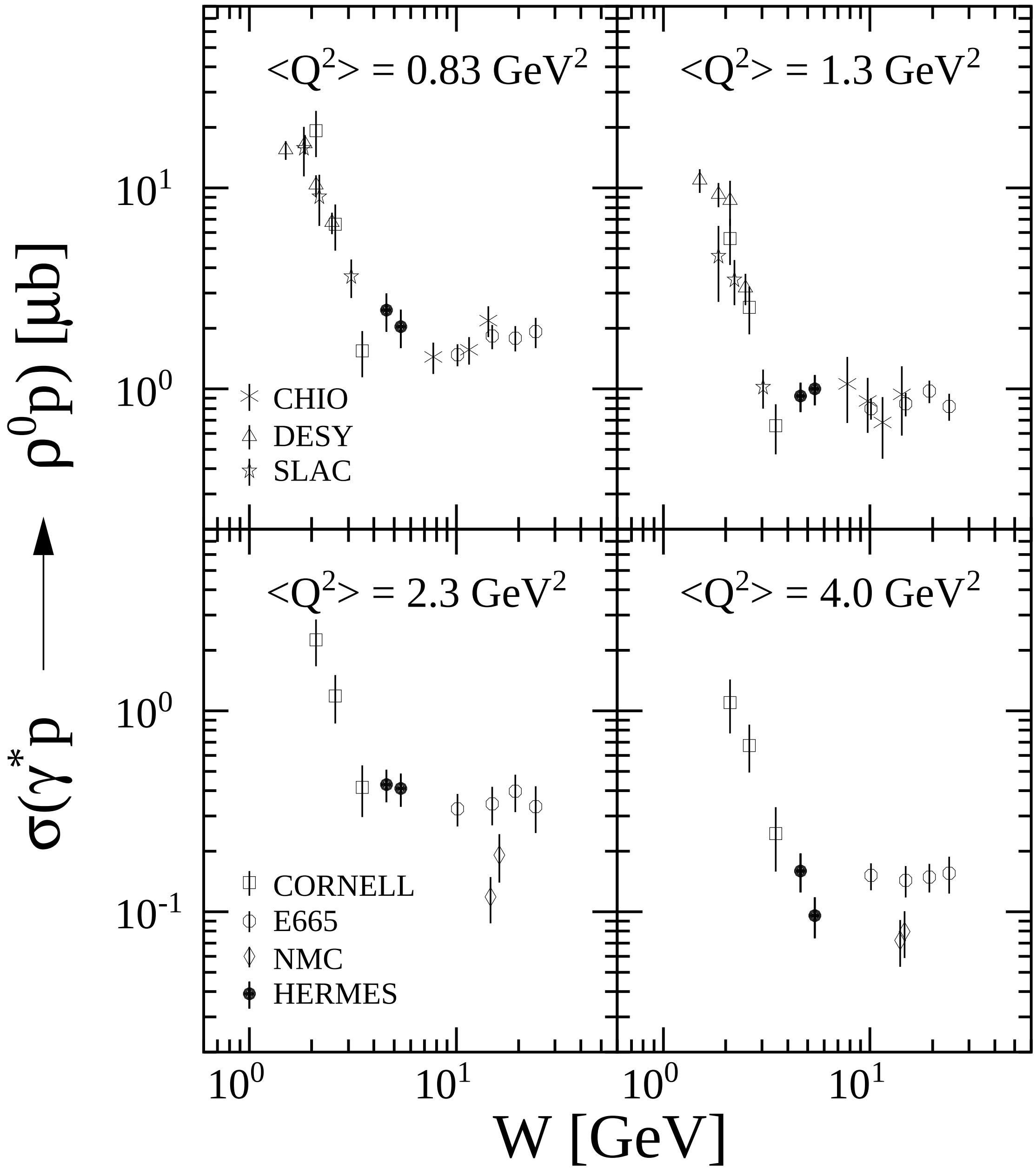
Kinematical Dependence ρ^o Skewing



$\rightarrow$ Skewing seems independent of energy.

$\rightarrow$ Skewing of ρ^o disappears at high Q^2.
$\rightarrow$ No significant $t-$dependence of n_{skew} seen.

ρ^o Cross Section (Q^2, W)



The error bars represent both the statistical and systematic uncertainties added in quadrature.

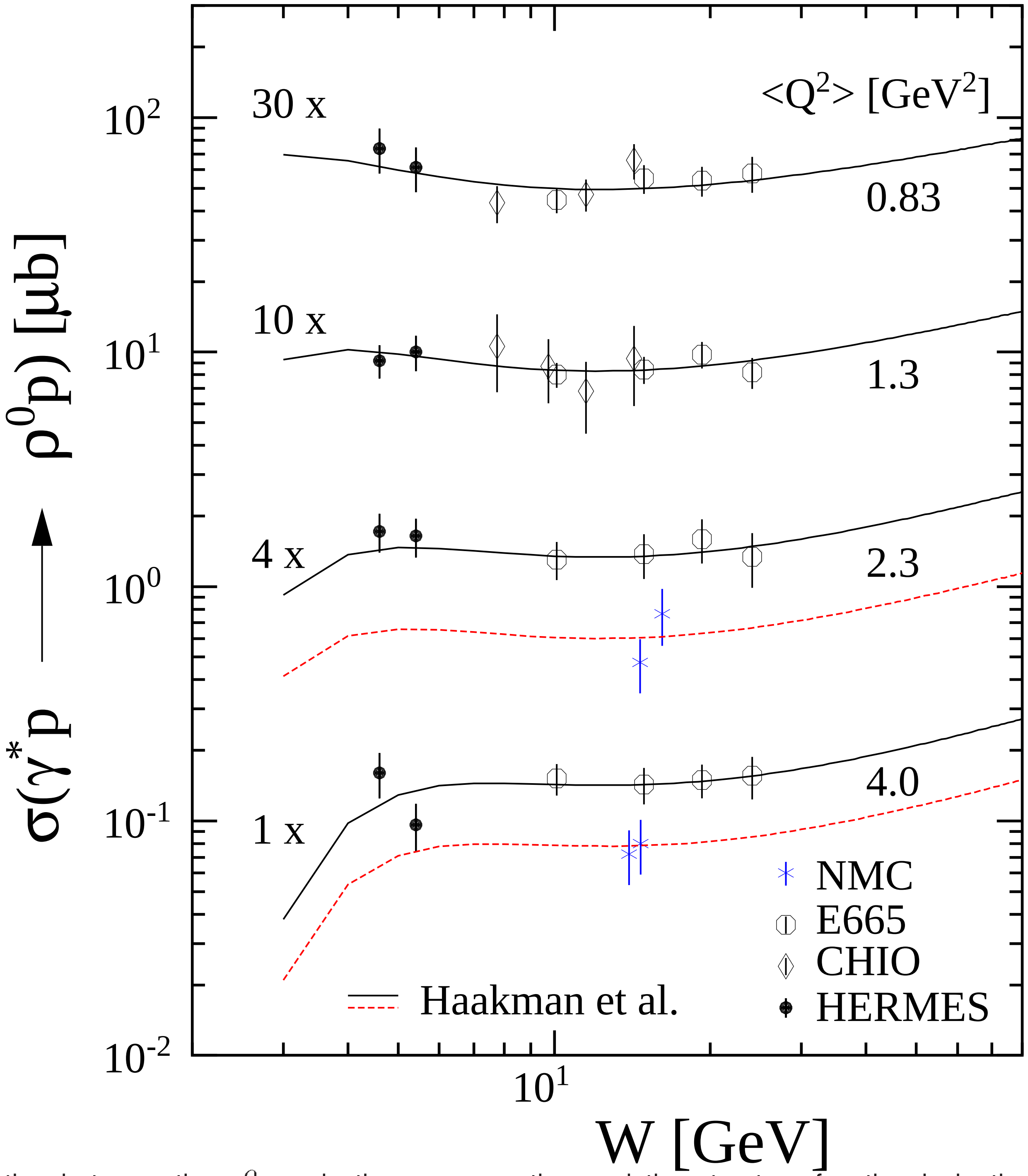
$\rightarrow$ HERMES data are in the transition region where different production mechanisms involved.

HERMES collab. DESY 00-058, hep-ex 0004023, accepted in EPJ

ρ^o Cross Section (Q^2, W)

Comparison with '**Reggeon**' based calculations

of L.P.A.Haakman, A.Kaidalov, J.H.Koch, Phys.Lett.B **365** (1996) 411.



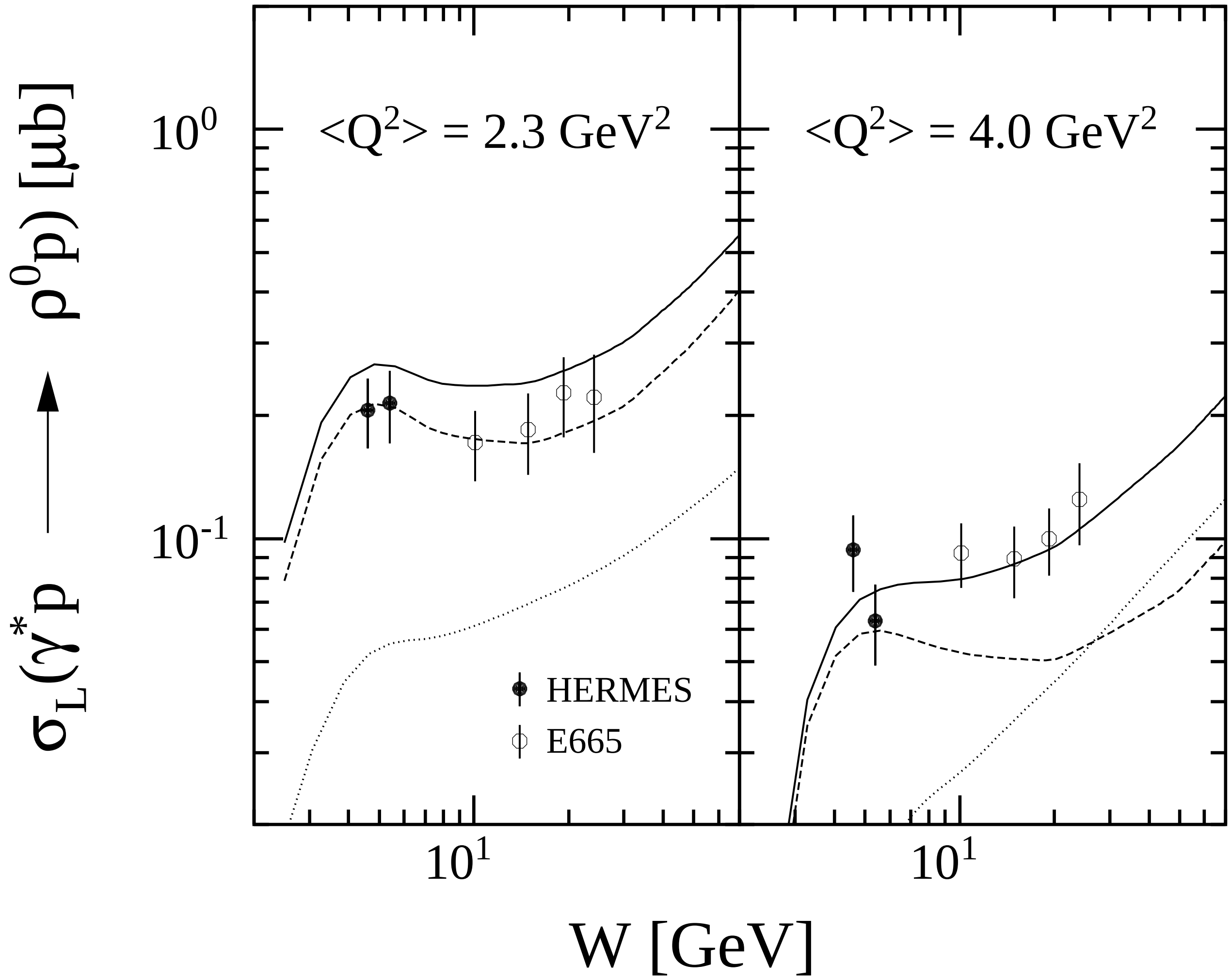
The relation between the ρ^o production cross section and the structure function is in the expression for the t-dependence of the cross section

$$\frac{d\sigma}{dt} = f_\rho(Q^2) F_2^{\mathrm{p}}(x, Q^2)^2 \exp[\Lambda(W)t].$$

$f_\rho(Q^2)$ has been obtained from a fit to the experimental data.

ρ^o Longitudinal Cross Section

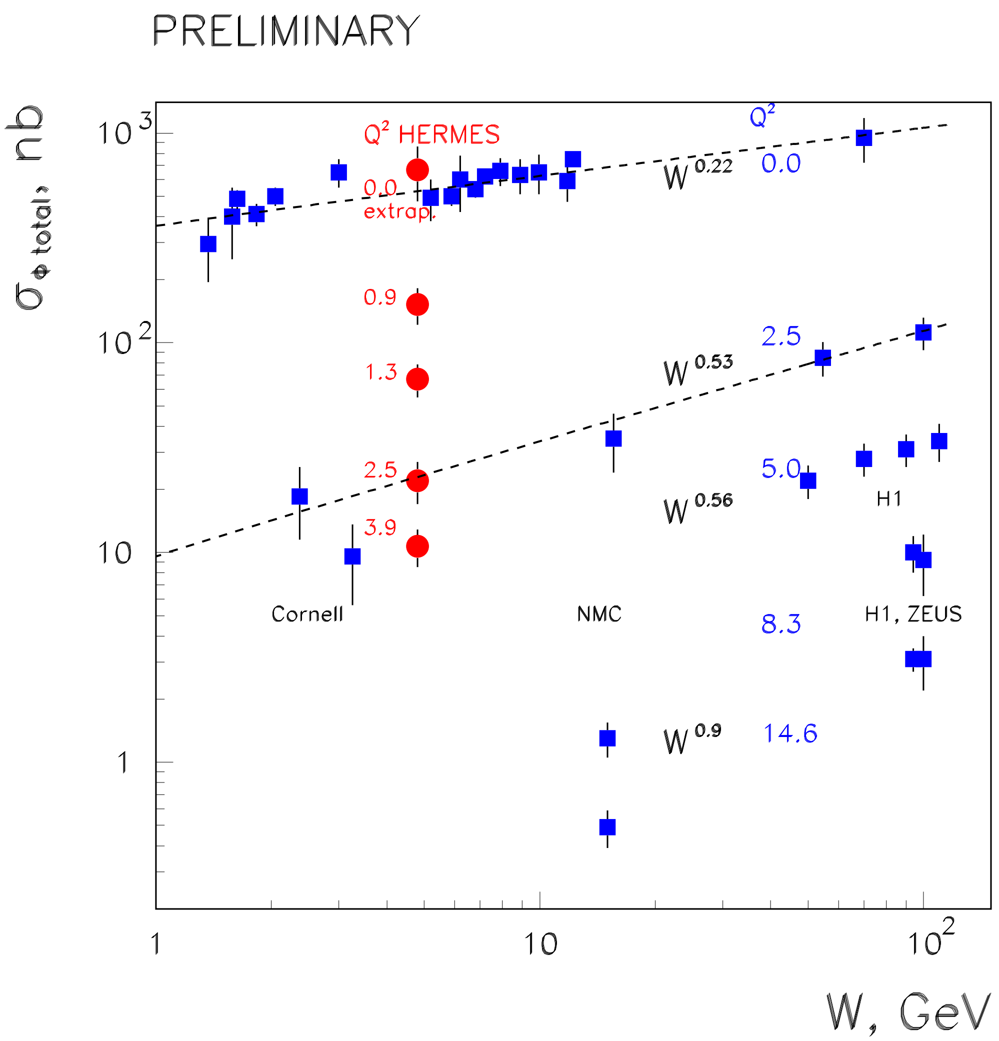
Comparison with recent OFPD calculations
M.Vanderhaeghen, P.A.M. Guichon, M. Guidal, Phys.Rev.Lett. **80** (1998) 5064.



Dotted curve - 2-gluon exchange, dashed - quark exchange, solid - sum.

$\rightarrow$ Domination of quark exchange at $W \sim 5$ GeV.

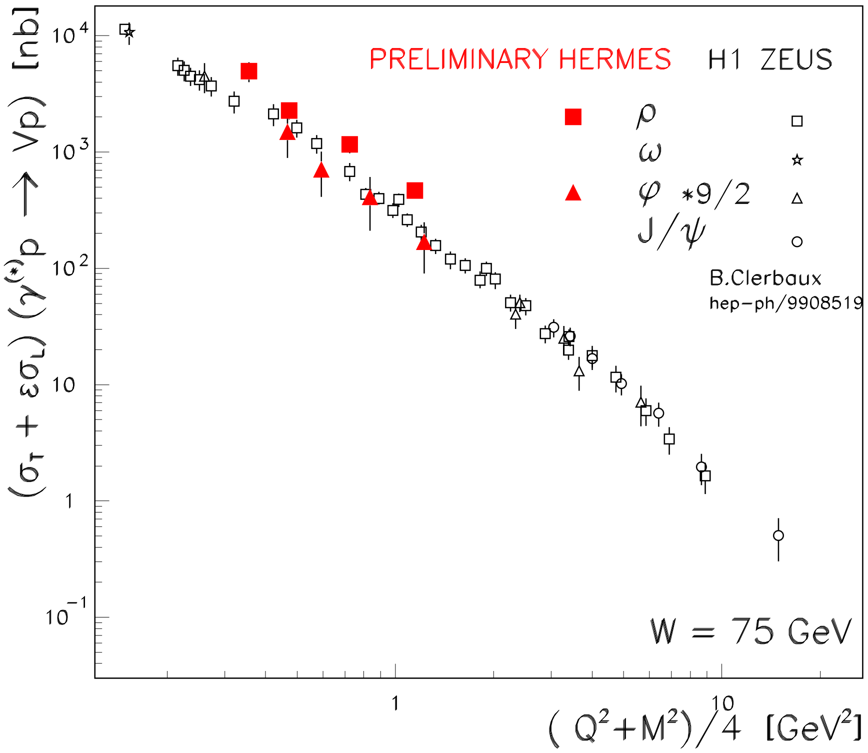
ϕ Cross Section (Q^2, W)



$\rightarrow$ Q^2–dependence of $W^{\delta_\phi(Q^2)}$ exponent:

Q^2, GeV^2	$\delta_\phi(Q^2)$
0.0	0.22
2.5	0.53 ± 0.09
5.0	0.56 ± 0.25
$>$8.0	0.90 ± 0.18

$\sigma_{\rho^o,\phi}$ scaled up to $W = 75$ GeV



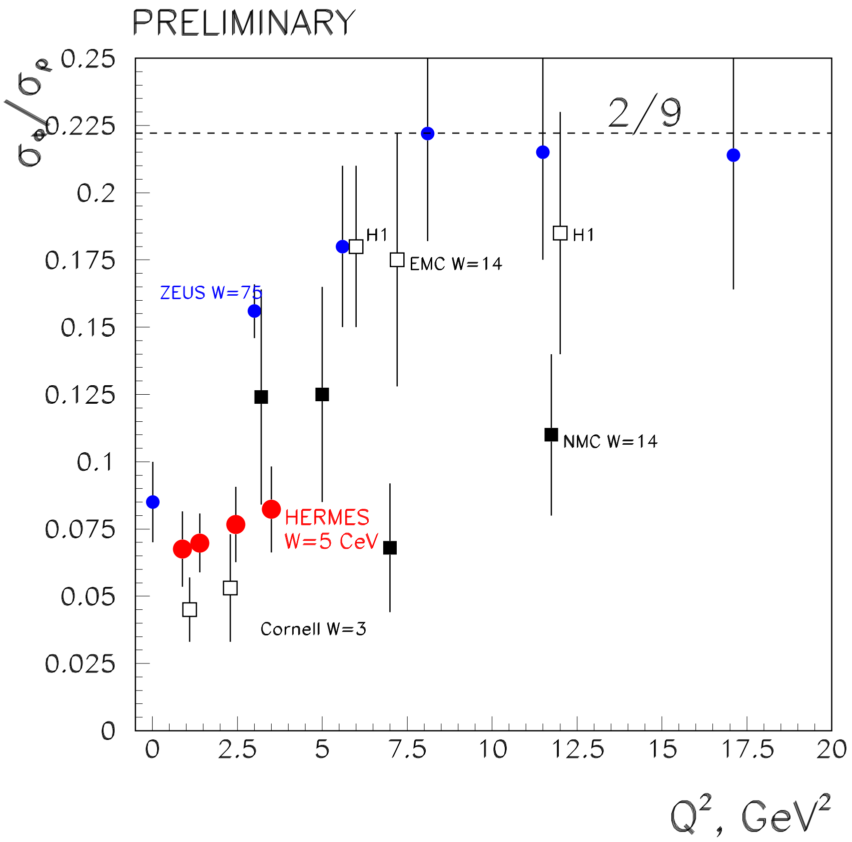
Use $W^{\delta_{\rho^o}(Q^2)}$ dependence from H1 and ZEUS data for HERMES $(\sigma_L + \sigma_T)$ of ρ^o and ϕ cross sections by means of the linear fit of the points at $\delta(0) = 0.22$ and $\delta(3.5) = 0.4$

H.Abramowicz,A.Caldwell DESY 98-192, H.Abramowicz DESY 00-025,hep-ph/0001054

$\rightarrow$ ρ^o at HERMES - additional to 'IPomeron exchage' mechanism involved

$\rightarrow$ ϕ at HERMES - consistent with 'IPomeron exchage', but can not distinguish $\delta_{\rho^o}(Q^2)$ and $\delta_{\phi}(Q^2)$ dependences at present statistics.

Ratio of $\sigma_\phi/\sigma_{\rho^o}$



$\rightarrow$ $W-$dependence of $\sigma_\phi/\sigma_{\rho^o}$ at $Q^2 = 2.5 \sim 4$ GeV^2.

Cornell[1] at $W \sim 3$ GeV

HERMES at $< W >= 5$ GeV

NMC[2] at $W \sim 14$ GeV

ZEUS[3] data at $< W >\sim 75$ GeV

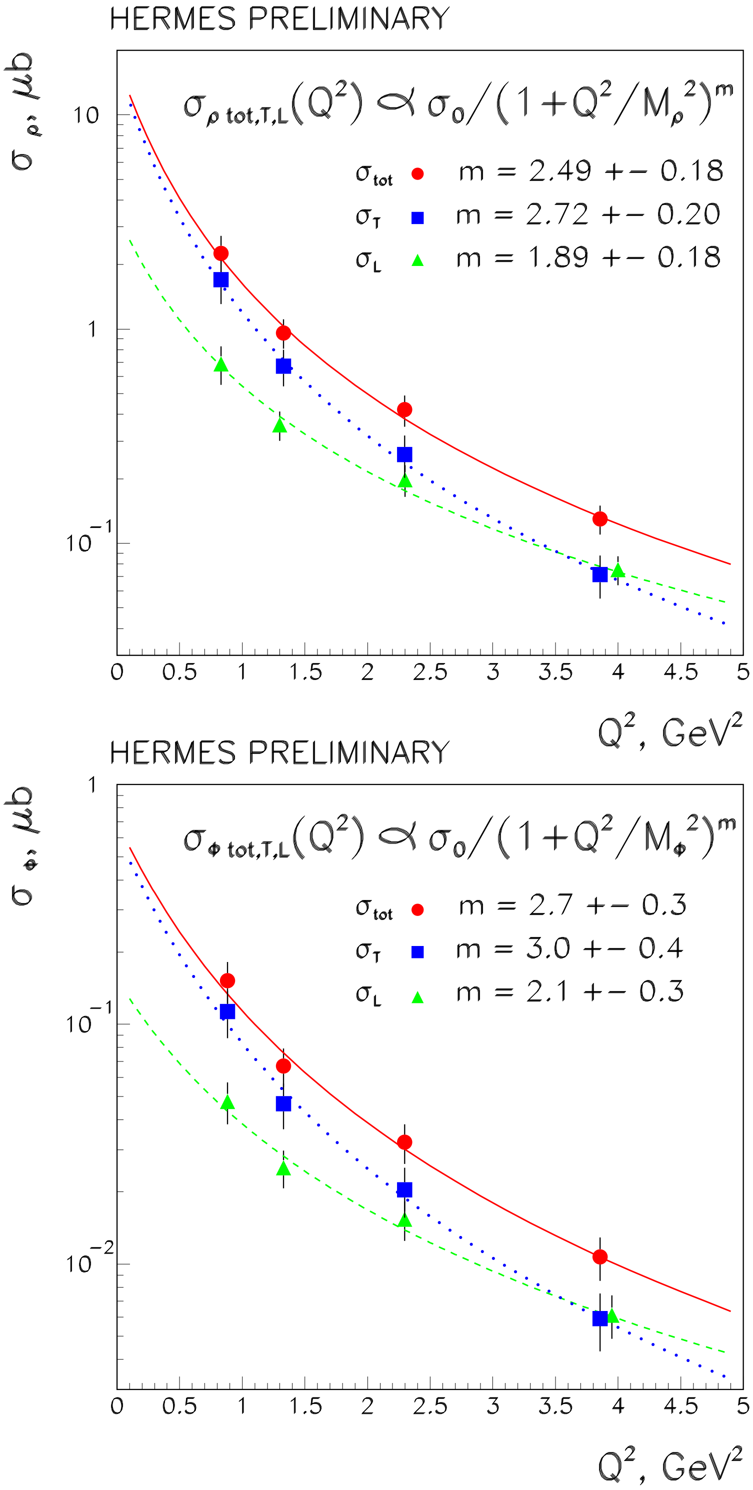
Systematic errors partially cansel out for the ratio at the same data sample.

[1] D.G. Cassel et al, Phys.Rev.D, V.24,11,1981,2787-282

[2] NMC Collab., M.Arneodo et al, Nucl.Phys. B429 (1994) 503-529

[3] ZEUS Collab. M. Derrick et al, Preprints DESY 96-002, 96-067, 1996

ρ^o, ϕ fit of $\sigma_{total,T,L}(Q^2)$

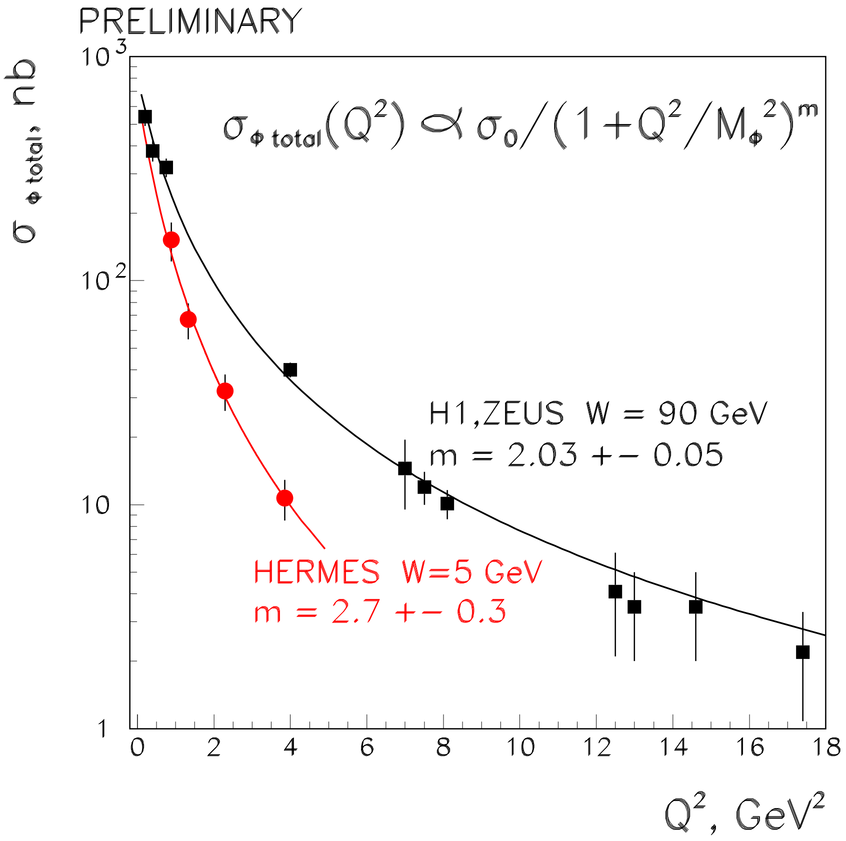


$\rightarrow m_\phi$ is a little bit larger then m_{ρ^o}

$\rightarrow m_T$ is larger then m_L on 1 for ρ^o and ϕ, agreement with predictions for H1 and ZEUS kinematics

A.D.Martin, M.G.Ryskin, T.Teubner hep-ph/9912551

ρ^o ϕ fit of $\sigma_{total,T,L}(Q^2)$

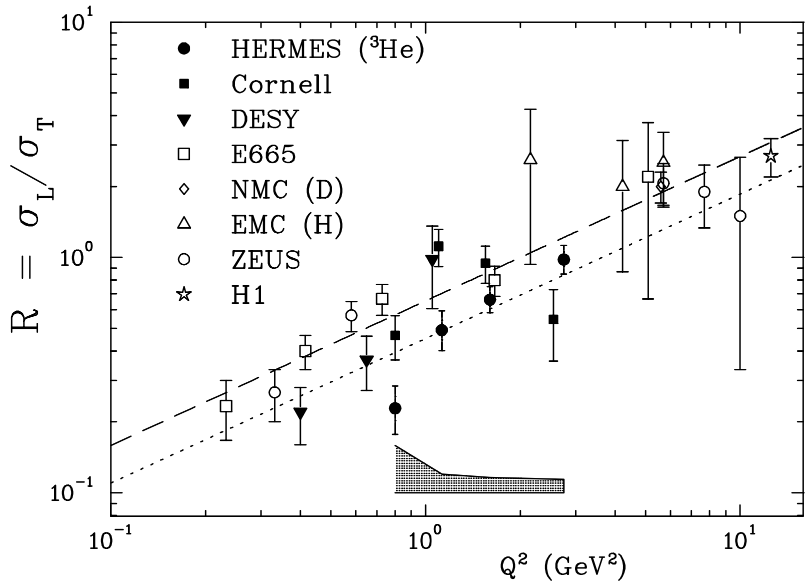


which σ	m at HERMES	m at H1, ZEUS
$\sigma_{total\phi}$	2.70 $\pm$ 0.28	2.03 $\pm$0.05 [1]
$\sigma_{L\phi}$	2.067 $\pm$ 0.275	
$\sigma_{T\phi}$	3.018 $\pm$ 0.344	2.8 $\pm$0.1 [2]
$\sigma_{total\rho}$	2.49 $\pm$ 0.18	2.37$\pm$0.10 [2]
$\sigma_{L\rho}$	1.89 $\pm$ 0.18	
$\sigma_{T\rho}$	2.72 $\pm$ 0.23	2.47$\pm$0.03 [2]

[1] S.Kananov, DIS '98 Proceedings, 308, 1998.
[2] B.Clerbaux, hep-ph/9908519.

$\rightarrow$ m_ϕ at W ~ 5 GeV is larger then at W ~ 75 GeV

Data of $R_{\rho^o} \equiv \sigma_L/\sigma_T$



Measured from the matrix elements consistent with natural parity exchange and SCHC

$R \equiv \sigma_L/\sigma_T = \frac{1}{\epsilon}\frac{r^{04}_{00}}{1-r^{04}_{00}}$

Fit of Q^2-dependence:

$$R(Q^2) = c_0(W) \cdot \left[\frac{Q^2}{M_\rho^2}\right]^{c_1} \quad (1)$$

VDM predicts $c_0 = const(W)$ and $c1 = 1$.
Two values of c_0:
$2 < W < 7$ GeV (DESY and HERMES) dashed line
$7 < W < 140$ GeV (EMC, NMC, E665, Zeus, and H1) dotted line:

$$c_0 = \begin{cases} 0.33 \pm 0.03 & (4 < \langle W \rangle > 7 \text{ GeV}) \\ 0.48 \pm 0.03 & (\langle W \rangle > 7 \text{ GeV}) \end{cases}$$

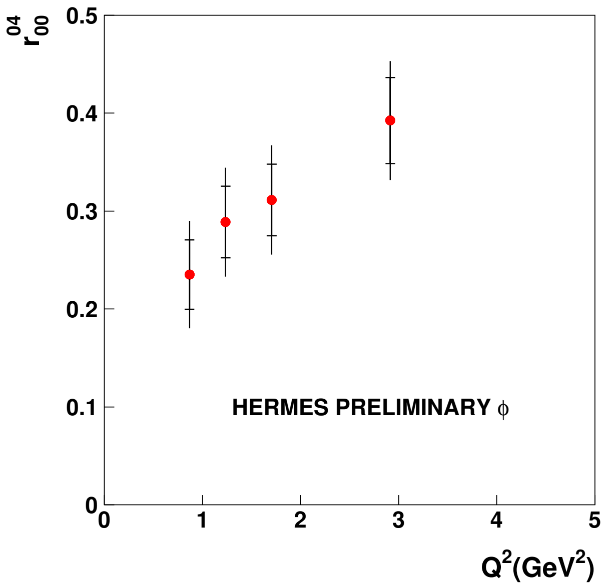
$$c_1 = 0.61 \pm 0.04.$$

Q^2-dependence of R is in disagreement with the VDM prediction, consistent with previous experiments, and suggest **enhanced transverse strength** at lower energy for fixed Q^2.

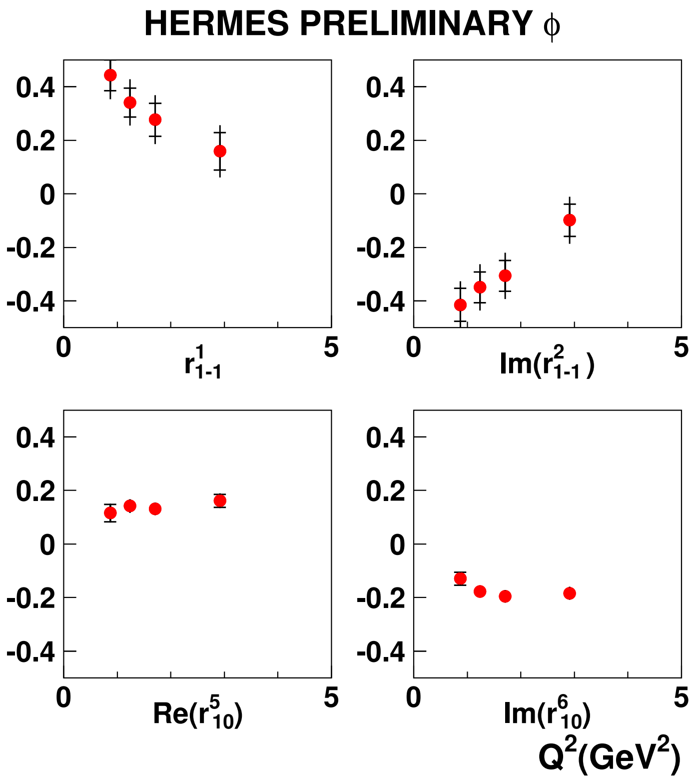
HERMES collab, DESY 99-199, hep-ex/0002016

SDME's of ϕ

All spin density matrix elements for ϕ presented:
15 for unpolarized beam and 8 for polarized.

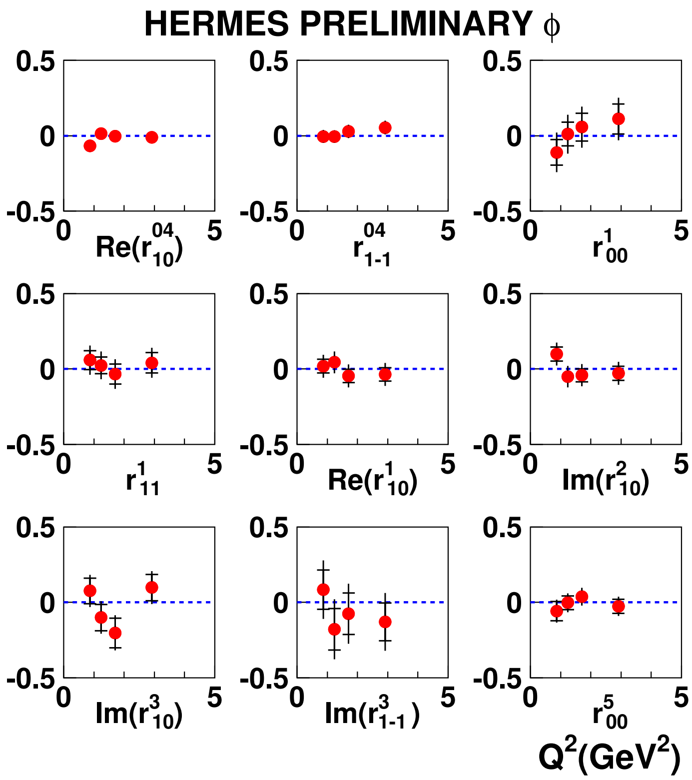


The longitudinal polarization of ϕ meson at HERMES

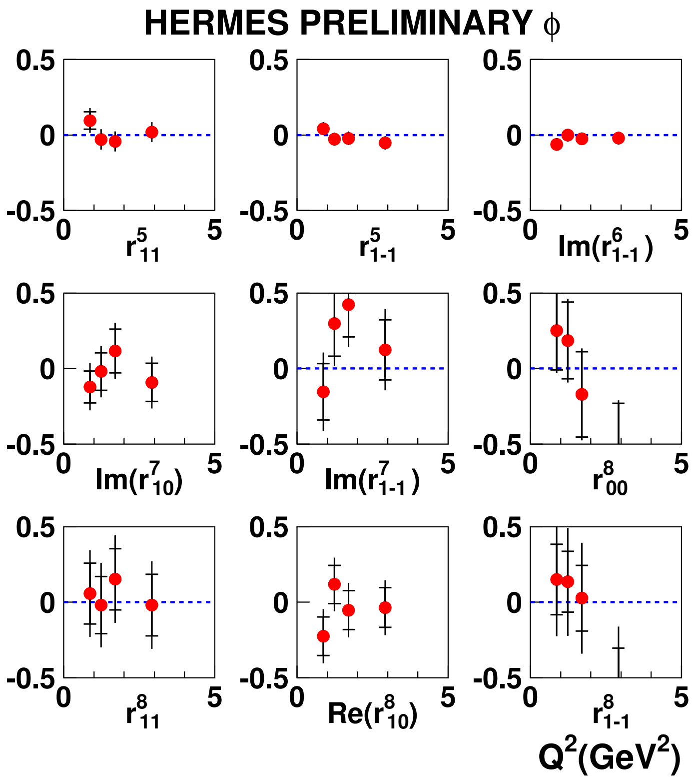


Non-zero SDME's of ϕ mesons

SDME's of ϕ

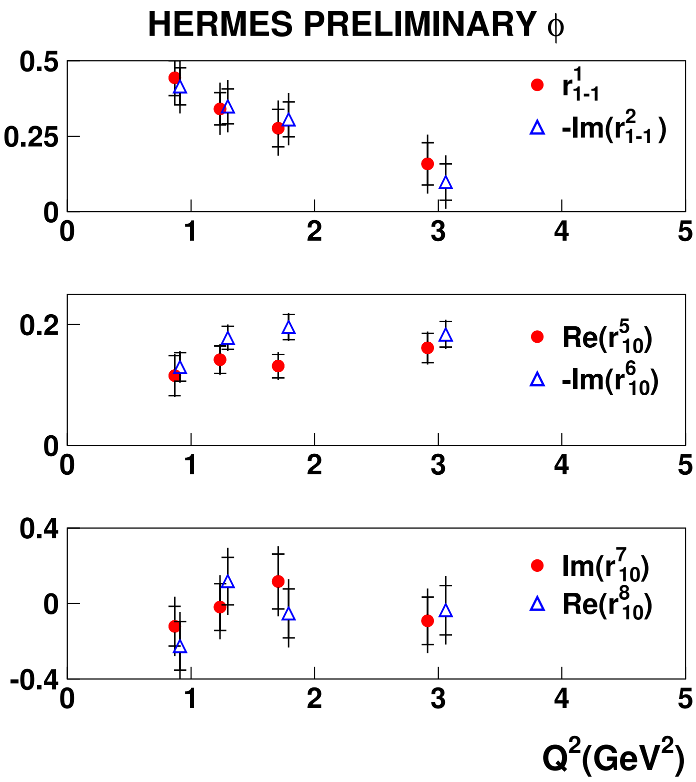


Over all Q^2 $r^5_{00} = 0.024 \pm 0.022 \pm 0.043$

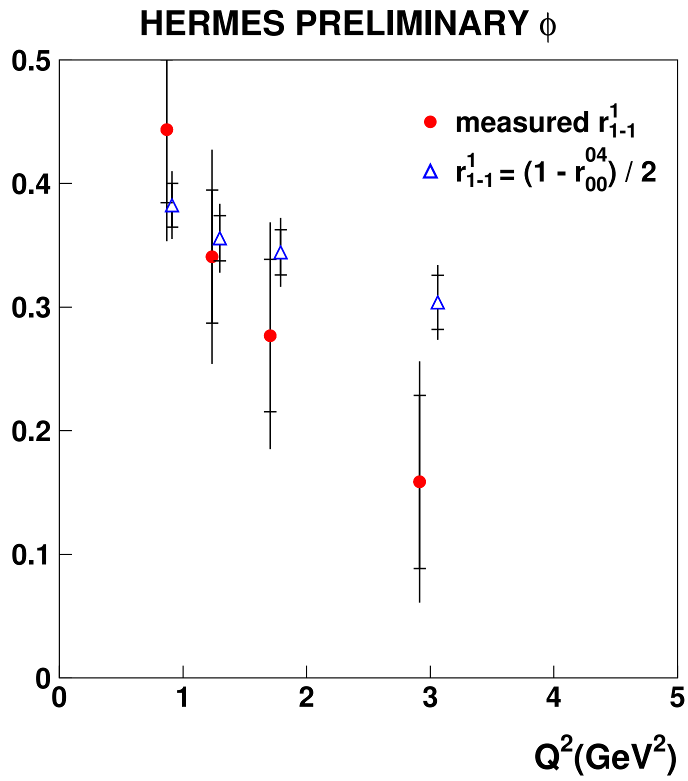


The dashed lines indicate the values expected in the case of SCHC

SDME's of ϕ

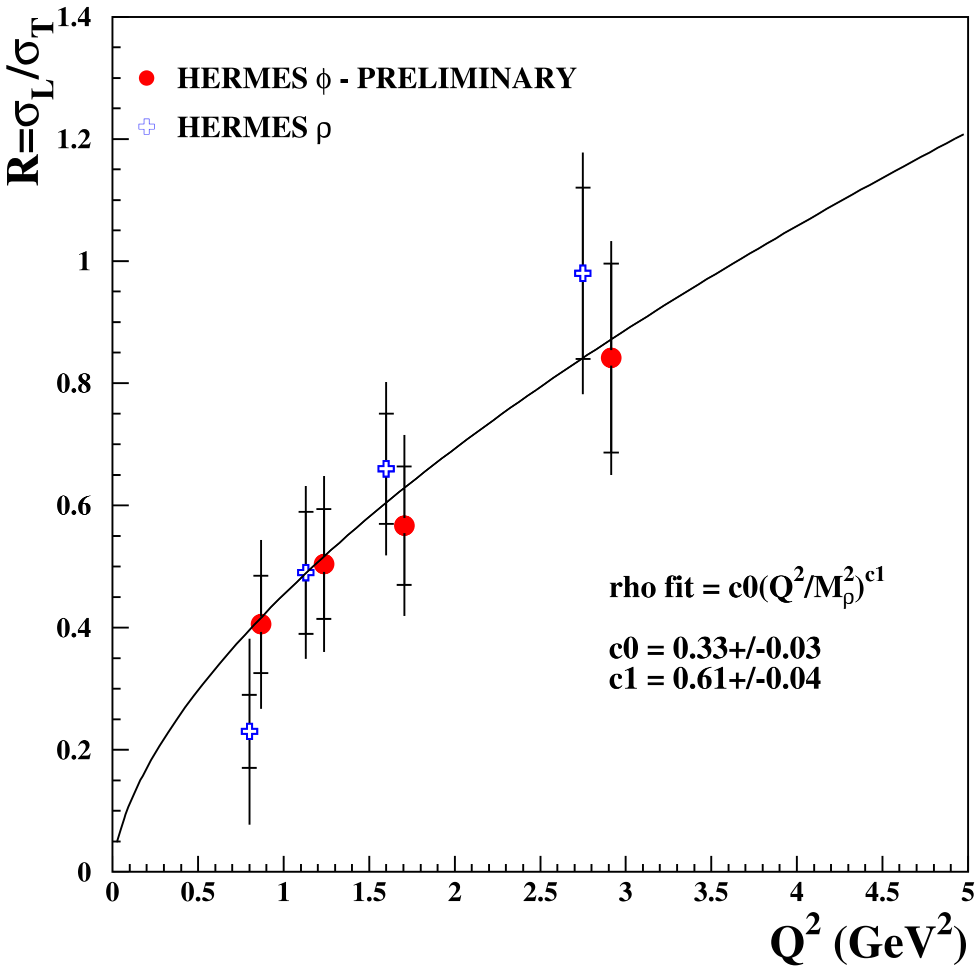


Relations predicted to be true between particular SDME's in the case of SCHC



The relation which is predicted to be true in the case of SCHC and NPE

$R_\phi(Q^2)$ vs $R_{\rho^o}(Q^2)$

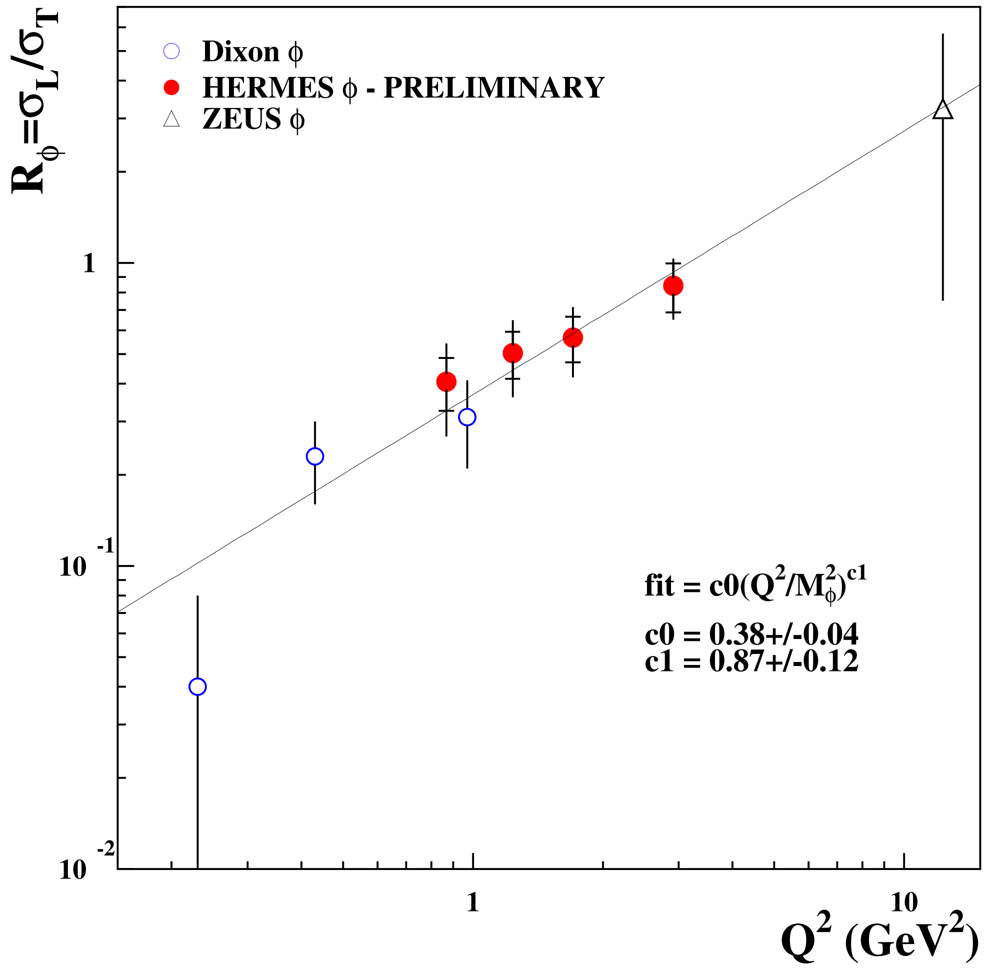


$\rightarrow$ $R_\phi(Q^2) = R_{\rho^o}(Q^2)$ at $W \sim 5$ GeV

$\rightarrow$ No enhanced transverse strength for ϕ.

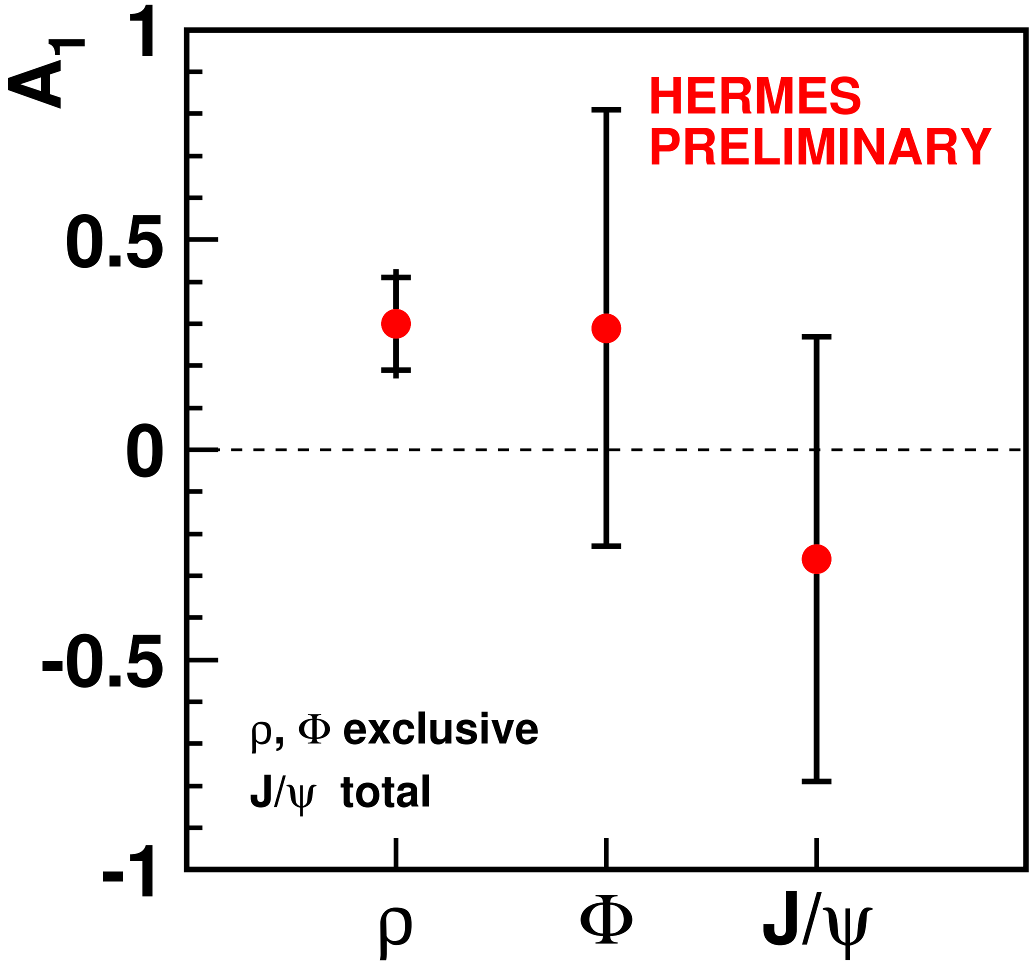
Fit of $R_\phi \equiv \sigma_L/\sigma_T$

Comparison with existing data



$\rightarrow$ $c1_\phi$ is consistent with VDM.

Double spin asymmetry of VM



(The same $A_1 = A_{||}/D$ for all vector mesons is in this plot)

Measured $A_{||} = D \cdot (A_1 + \eta A_2)$

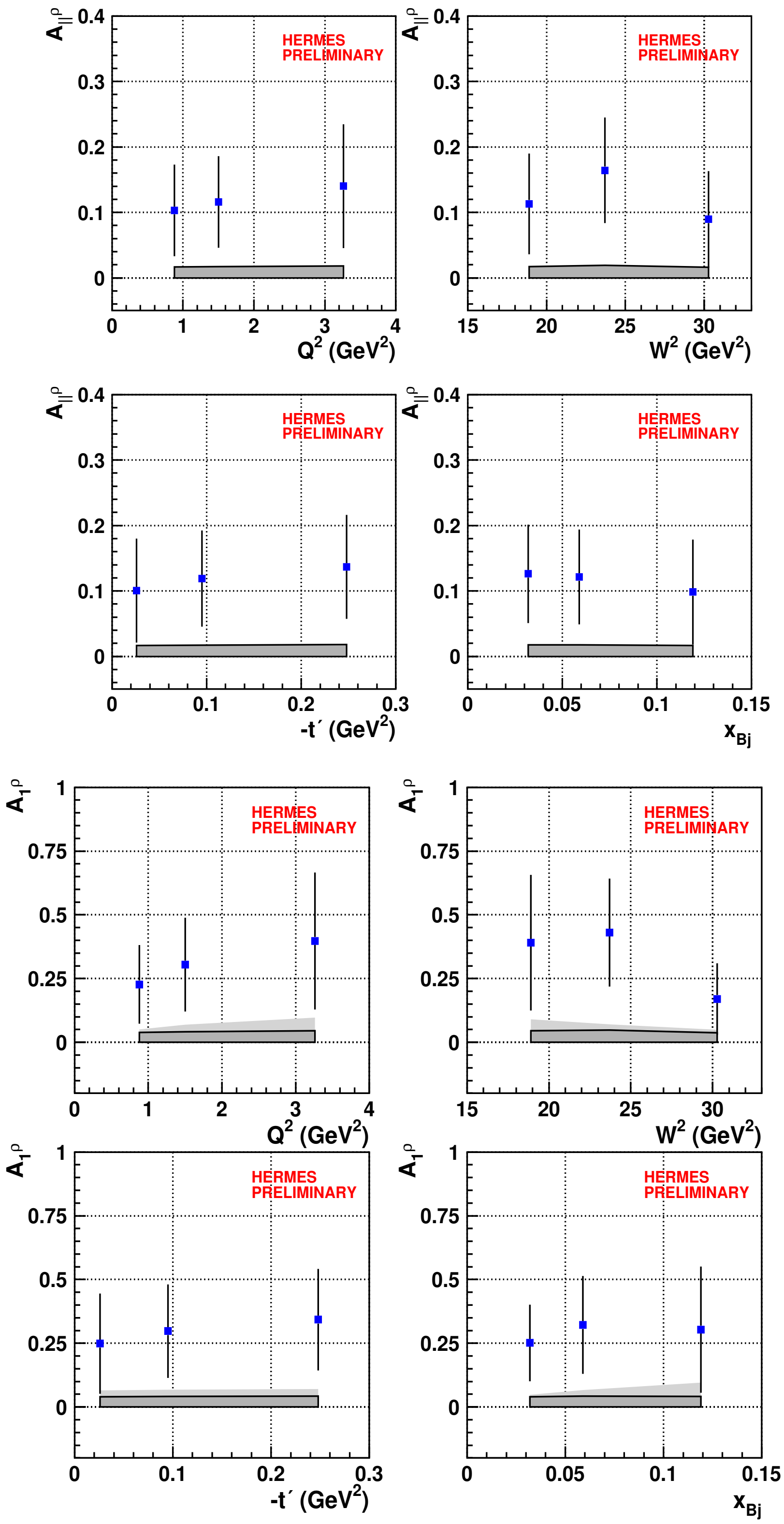
$$< A_{||}^{\rho^o} >= 0.119 \pm 0.045_{stat} \pm 0.008_{syst}$$

$$A_1 = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}}, \qquad A_2 = \frac{\sigma_{LT}}{\sigma_{1/2} + \sigma_{3/2}} \sim \sqrt{R(Q2))}$$

$$< A_1^{\rho^o} >= 0.244 \pm 0.111_{stat} \pm 0.021_{syst}$$

$A_1^{\rho^o} \neq 0$ at significant contribution of exchange process which can be mediated by di-quark objects, H.Fraas, Nucl.Phys. **B113**, 532, 1976 (!).

Double spin asymmetry of ρ^o



$\rightarrow$ No strong kinematical dependence of A_{ρ^o} observed.

$\rightarrow$ $A_1^{\rho^o} \sim 0$ at SMC where $W \sim 15$ GeV and the difftractive process is dominated by IPomeron or gluon exchange.

A.Tripet, Nucl.Phys. **B(Proc.Suppl. of DIS'99) 79**, 529, (1999).

Deeply virtual exclusive scattering

$$\gamma^* p \rightarrow Mp \text{ \& } \gamma^* p \rightarrow \gamma p$$

to get access into the OFPD's (SPD's) which may provide a new inside into nucleon spin structure

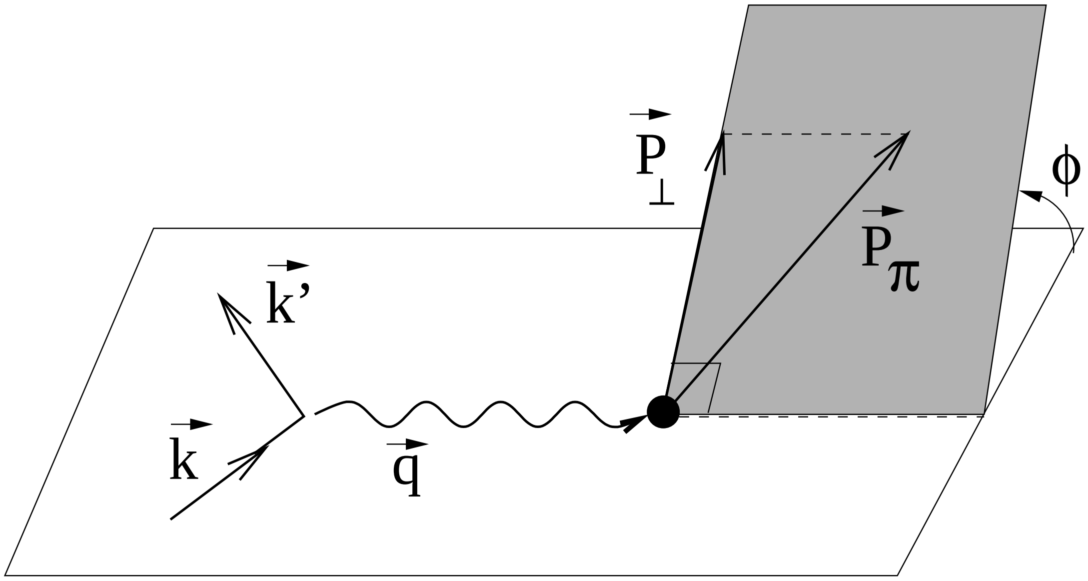
$$S_z = \delta\Sigma/2 + \delta G + L_z^q + L_z^g = 1/2$$

(X.Ji Phys.Rev.Lett. 78 (1997),610; ...)

For meson production the $sin(\phi)$ moment of single spin asymmetry with unpolarized beam and longitudinal target polarization:

$$A_{UL}^{sin\phi} = \frac{1}{P_T} \frac{\int_0^{2\pi} d\phi\, sin(\phi)\, dN_+ - \int_0^{2\pi} d\phi\, sin\phi\, dN_-}{0.5(\int_0^{2\pi} d\phi\, dN_+ + \int_0^{2\pi} d\phi\, dN_-)}$$

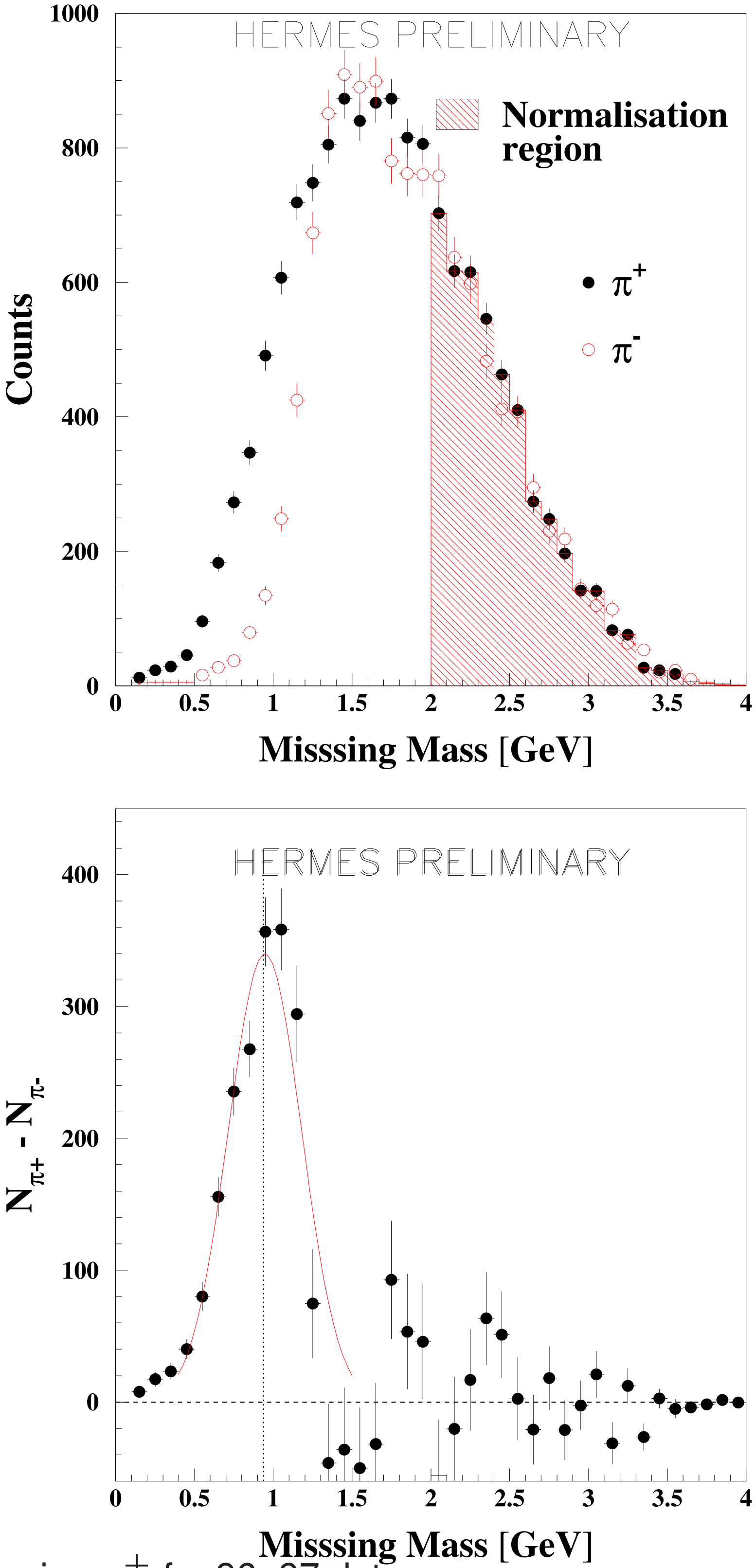
$P_{T(B)}$ is the longitudinal polarization of the target (beam) with $\pm$ state,
ϕ is the angle between scattering plane and meson production plane:



For DVCS the $sin(\phi)$ moment of the single spin azimuthal asymmetry with longitudinal beam polarization and unpolarized target:

$$A_{LU}^{sin\phi} = \frac{2\int_0^{2\pi} d\phi\, sin(\phi)\, (d\sigma_+ - d\sigma_-)}{<|P_B|> \int_0^{2\pi} d\phi\, (d\sigma_+ + d\sigma_-)}$$

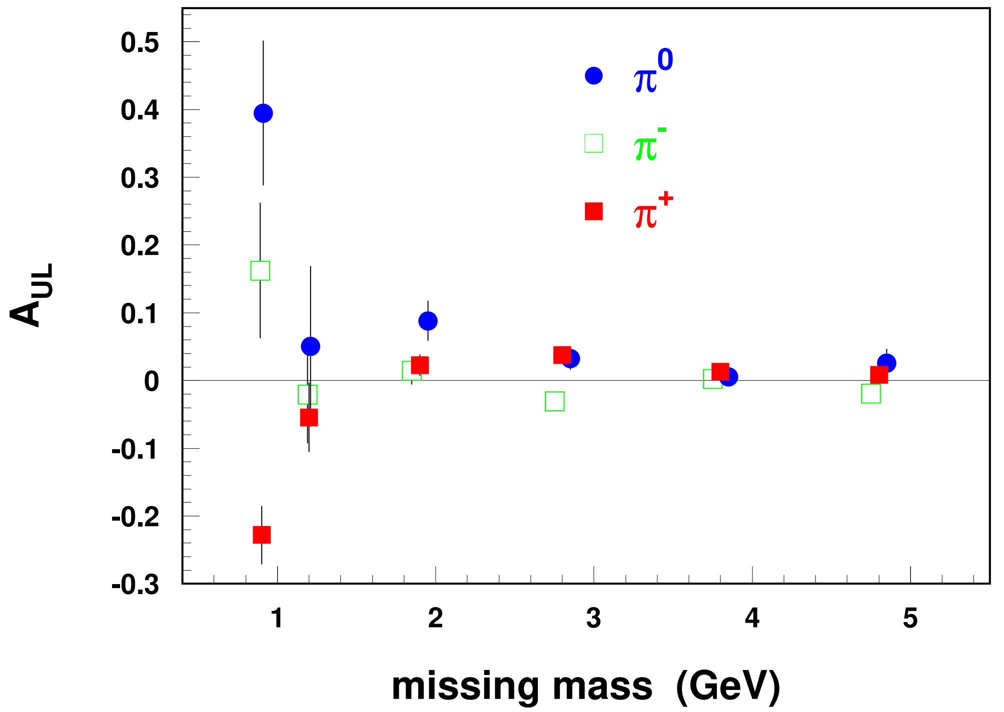
Exclusive π^+

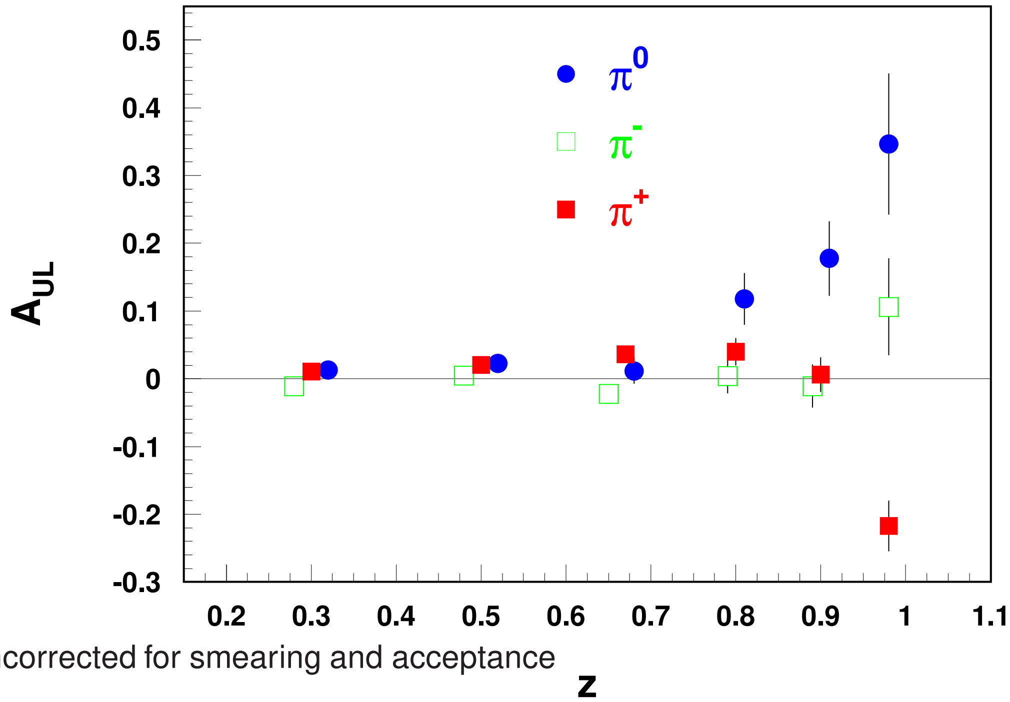


$\rightarrow \sim 1.7k$ exclusive π^+ for 96+97 data

$\rightarrow$ missing mass resolution ~ 0.25 GeV.

Single spin asymmetry of π's



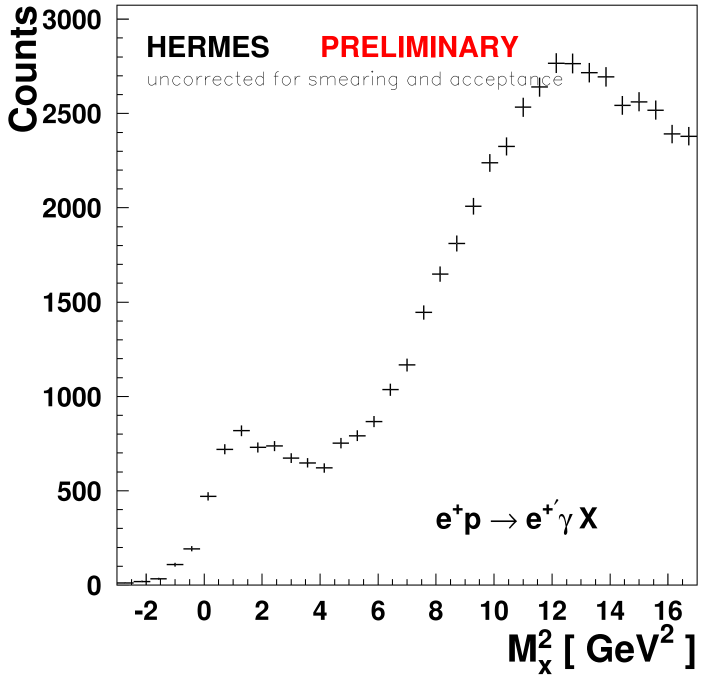


Preliminary, uncorrected for smearing and acceptance

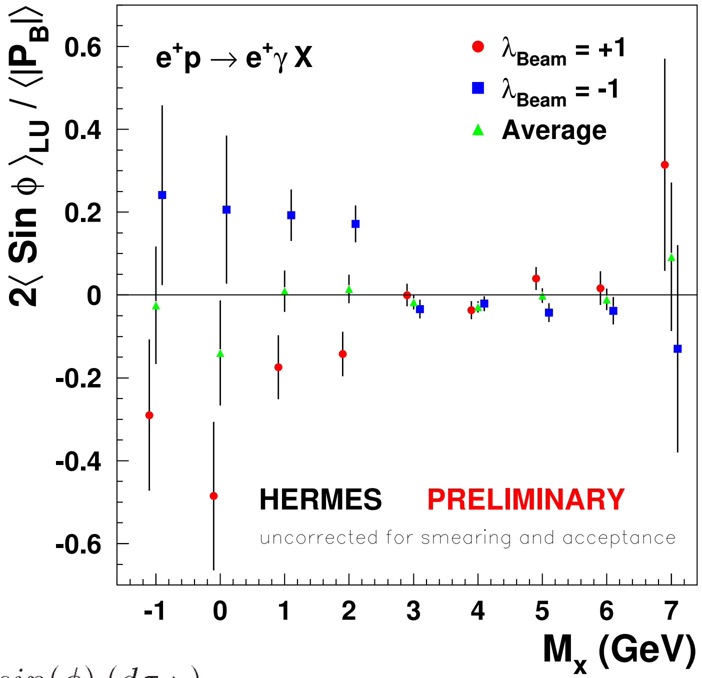
$$A_{UL}^{sin\phi} = \frac{1}{P_T}\frac{\int_0^{2\pi} d\phi\, sin(\phi)\, dN_+ - \int_0^{2\pi} d\phi\, sin\phi\, dN_-}{0.5(\int_0^{2\pi} d\phi\, dN_+ + \int_0^{2\pi} d\phi\, dN_-)}$$

$\rightarrow$ Large SSA in the exclusive region. The sign is opposite to the predictions for transverse target (L.L. Frankfurt, M.V. Polyakov, M. Strikman, M. Vangerhaeghen Phys.Rev.Lett. 84, 2000, 2589.)

DVCS



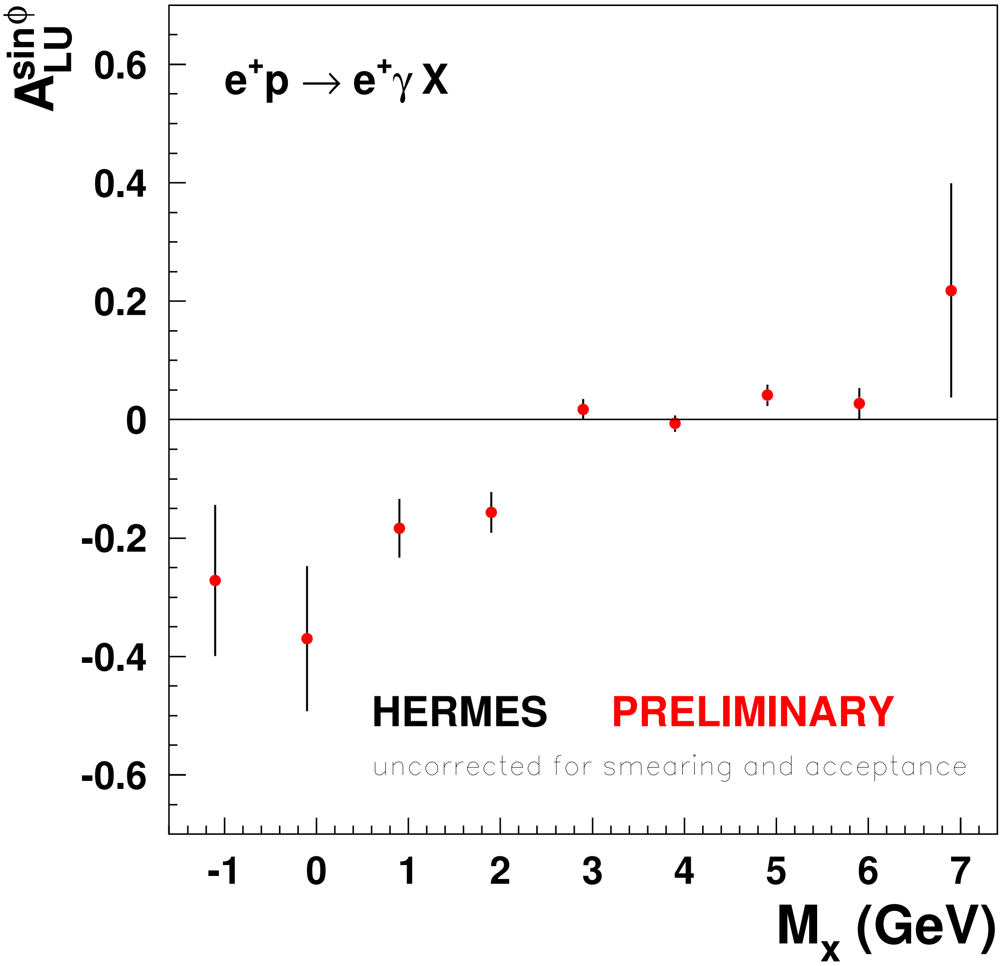
Negative M_{X^2} is due to the worse resolution determined by the calorimeter.
$\rightarrow$ Need $electron$ beam for the relative alalysis.



$$A_{LU}^{sin\phi} = \frac{2\int_0^{2\pi} d\phi\, sin(\phi)\,(d\sigma_\pm)}{<|P_B|>\int_0^{2\pi} d\phi\,(d\sigma_\pm)}$$

The $sin(\phi)$ moment of the single spin azimuthal asymmetries for the positive helicity state, the negative state and the helicity average.
$\rightarrow$ Effect comes from the beam polarization only.

DVCS

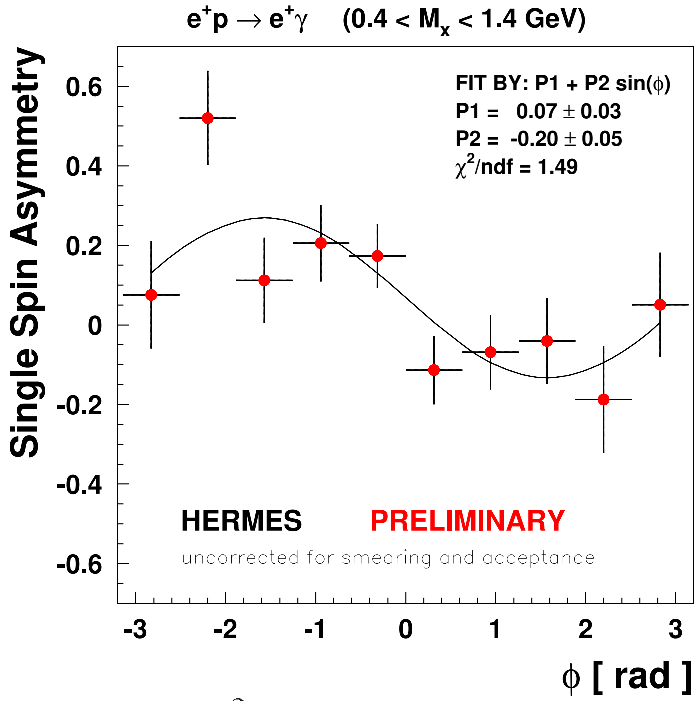


$$A_{LU}^{sin\phi} = \frac{2\int_0^{2\pi}\ d\phi\, sin(\phi)\ (d\sigma_+ - d\sigma_-)}{<|P_B|>\int_0^{2\pi}\ d\phi\ (d\sigma_+ + d\sigma_-)}$$

The $sin(\phi)$ moment of the single spin azimuthal asymmetry.

$\rightarrow$ Significant asymmetry at $M_X \sim 1GeV$.

DVCS



$$A_s = \frac{2\int_0^{\pi} \, d\phi\,(d\sigma_+ - d\sigma_-) - \int_{\pi}^{2\pi} \, d\phi\,(d\sigma_+ - d\sigma_-}{<|P_B|> \int_0^{2\pi} \, d\phi\,(d\sigma_+ + d\sigma_-)}$$

The fit to the single spin azimuthal asymmetry versus the azimuthal angle (ϕ).

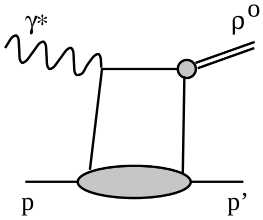
M.Vanderhaeghen, Talk at DESY, 15.02.2000.

→ Agreement with the data.

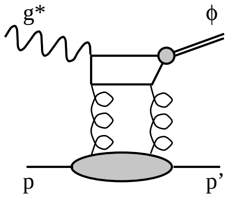
SUMMARY

Diffraction

- no $W-$dependence of ρ^o skewing, the same Q^2- dependence
- ρ^o cross section - domination of 'quark exchange' mechanism at $W \sim 5$ GeV



- ϕ cross section - agreement with 'IPomeron exchange' predictions



- ϕ over ρ^o cross section ratio presents clear $W-$dependence
- SDME's of ρ^o and ϕ mesons are in agreement with SCHC and NPE.
- $R_\phi(Q^2) = R_{\rho^o}(Q^2)$ at HERMES and the same $R_\phi(Q^2)$ over all world data. Enhanced transverse strength of ρ^0 cross section.
- $\sigma_T(Q^2)$ dependence is steeper then $\sigma_L(Q^2)$ on one for ρ^o and ϕ
- $A_1^{\rho^o} = 0.244 \pm 112$ is consistent with early predictions based on guark exchange processes.

Deeply virtual exclusive scattering

- clear π^+ exclusive peak observed
- significant negative SSA of π^+ and positive one of π^o observed at longitudinal polarised target
- significant azimuthal SSA relative the longitudinal polarization of the beam has been observed for the DVCS sample in the agreement with the theoretical prediction.

OVERLOOK

- ρ^o cross section determined by 'quark exchange' mechanism. $\sigma_L(Q^2)$ agreeds with absolute OFPD calculations based on OFPD framework which makes it possible to calculate various observables in one unified approach.

- ϕ cross section determined by 'soft IPomeron exchange' mechanism does not seem to change character at intermediate $W \sim 5$ GeV and $Q^2 \sim 2$ GeV^2. That is in the non-pQCD domain where no theoretical predictions known so far.

- Single spin asymmetries of DVCS and exclusive mesons have been presented in the first time relative the longitudianl polarization of the the beam and of the target. Enlargement of the data samples is foreseen as well as improvements of the exclusive event identification.

Much larger data sample (1995 - 2000)
will be soon available at HERMES.
More interesting data are expected.