SPIN-01

IX WORKSHOP ON HIGH ENERGY SPIN PHYSICS

Spin Physics of Vector Meson Production at Intermediate W and Q^2 of

hermes

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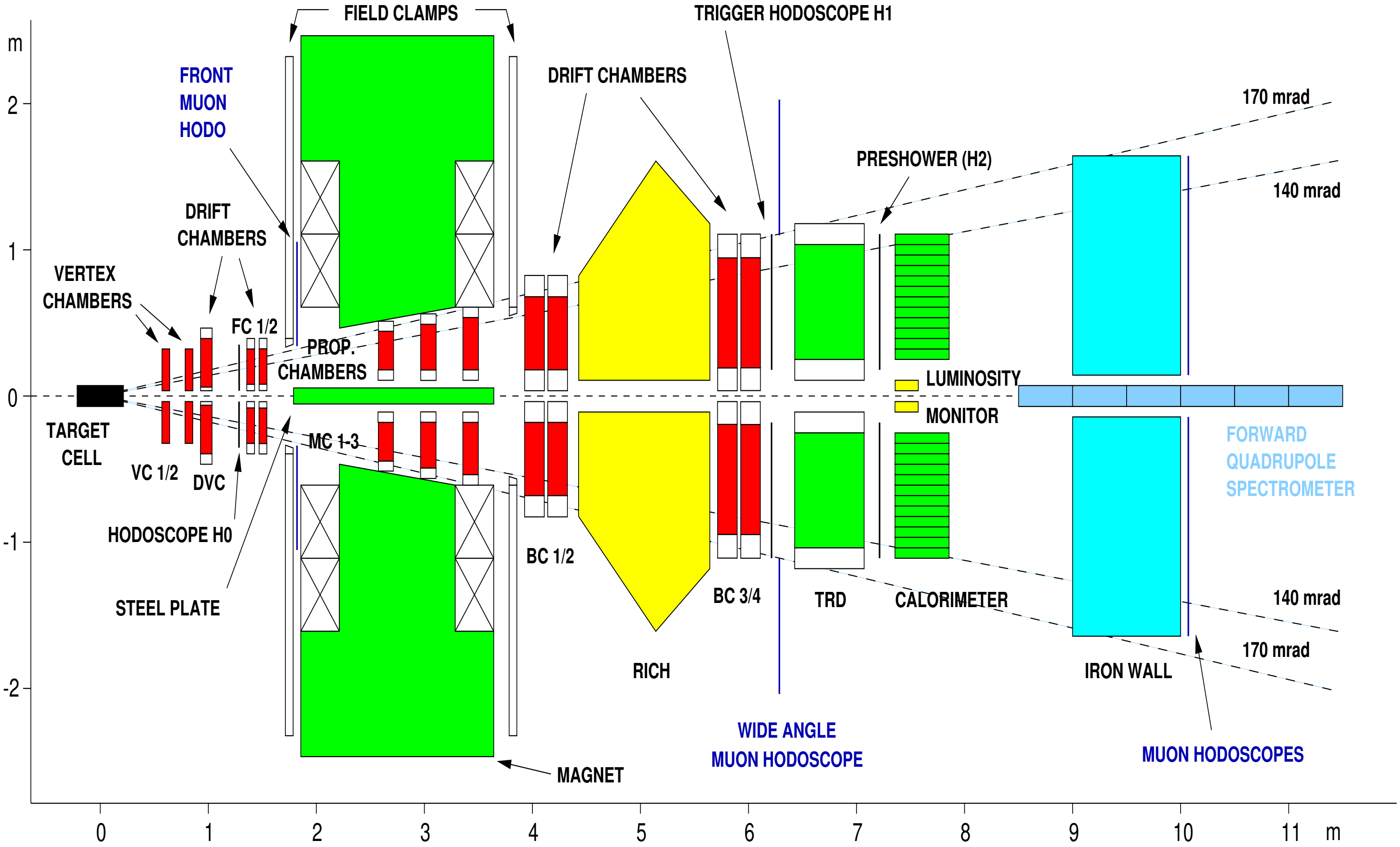
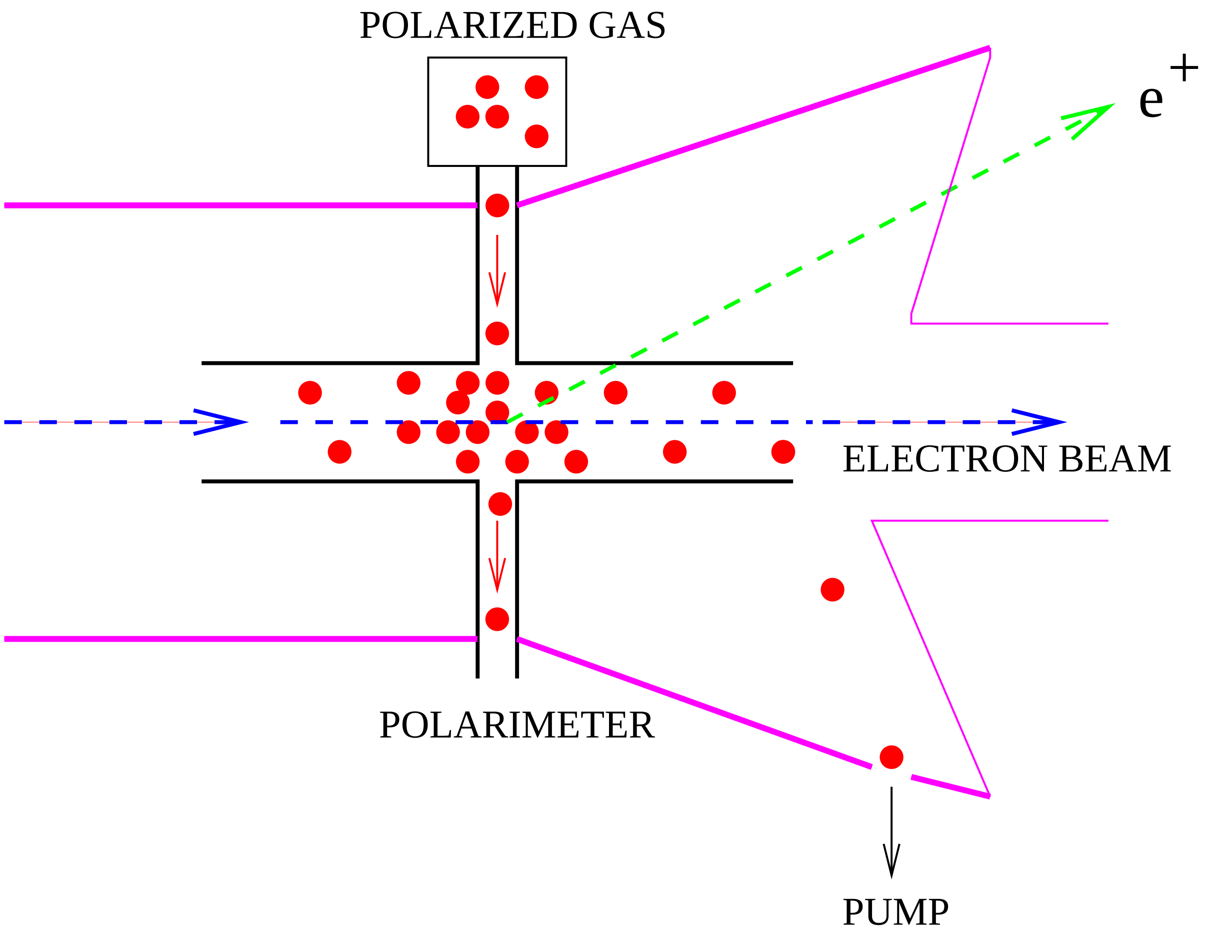
- The Experiment
- Diffractive ρ^o, ω and ϕ production:
  - selection of diffractive events
  - cross sections
  - double spin asymmetry
  - polarization of ρ^o and ϕ
- Summary

The Detector



- Two identical halves of forward spectrometer having acceptance $40 < \Theta < 220 mrad$ with momentum resolution $\leq 1\%$.
- Identification of electron with efficiency $> \ 97\%$ at hadron contamination $< 1\%$.
- Calorimeter resolution $\Delta E/E[\%] = (1.5 \pm 0.5) + (5.1 \pm 1.1)/\sqrt{E[GeV]}$
- Cherenkov detector momentum thresholds for pions 4 GeV/c and kaons 13 GeV/c in $'96,' 97$.
- RICH from 1998 with π^{+-} vs K^{+-} and p separation over all kinematical region.

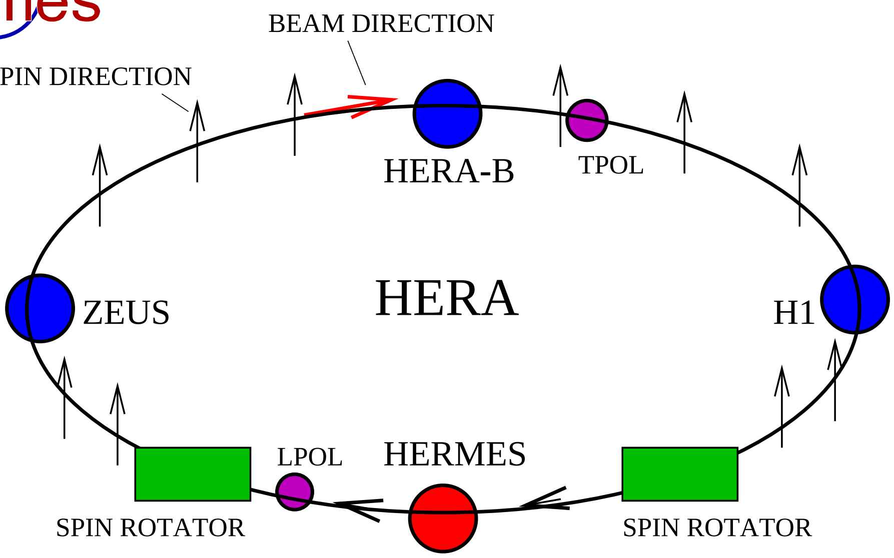
The Target

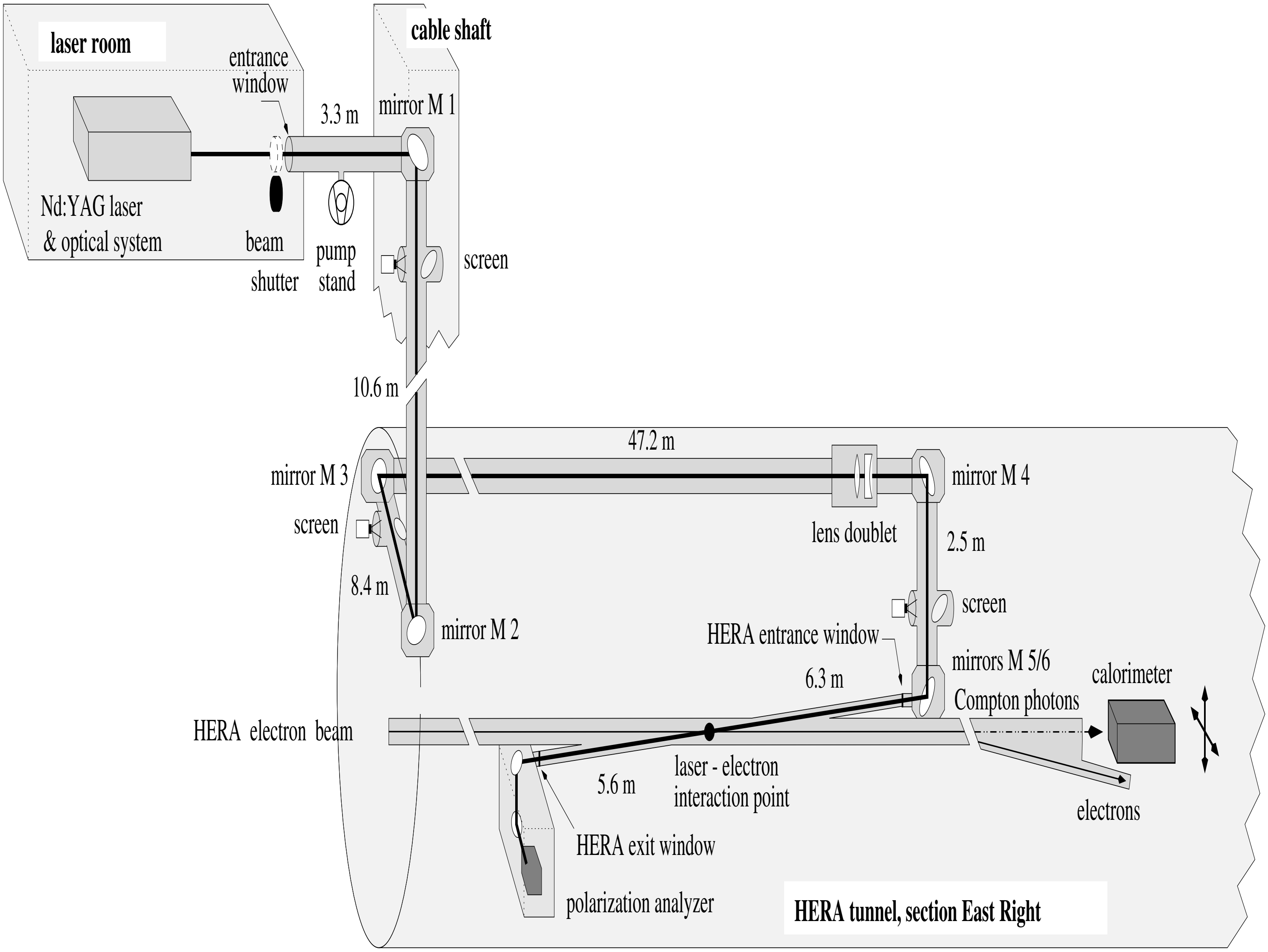


Internal storage cell gas target with high density:

- polarised: $\sim 10^{14}$ nucl./cm^2, polarization $\sim 88\%$ for H/D.
- unpolarised: $\sim 10^{15}$ nucl./cm^2
- high density runs at the end of the fill in 2000 with $^1H,^2D,^4He$ and ^{20}Ne gases at $\sim 5 \cdot 10^{15}$ nucl./cm^2.

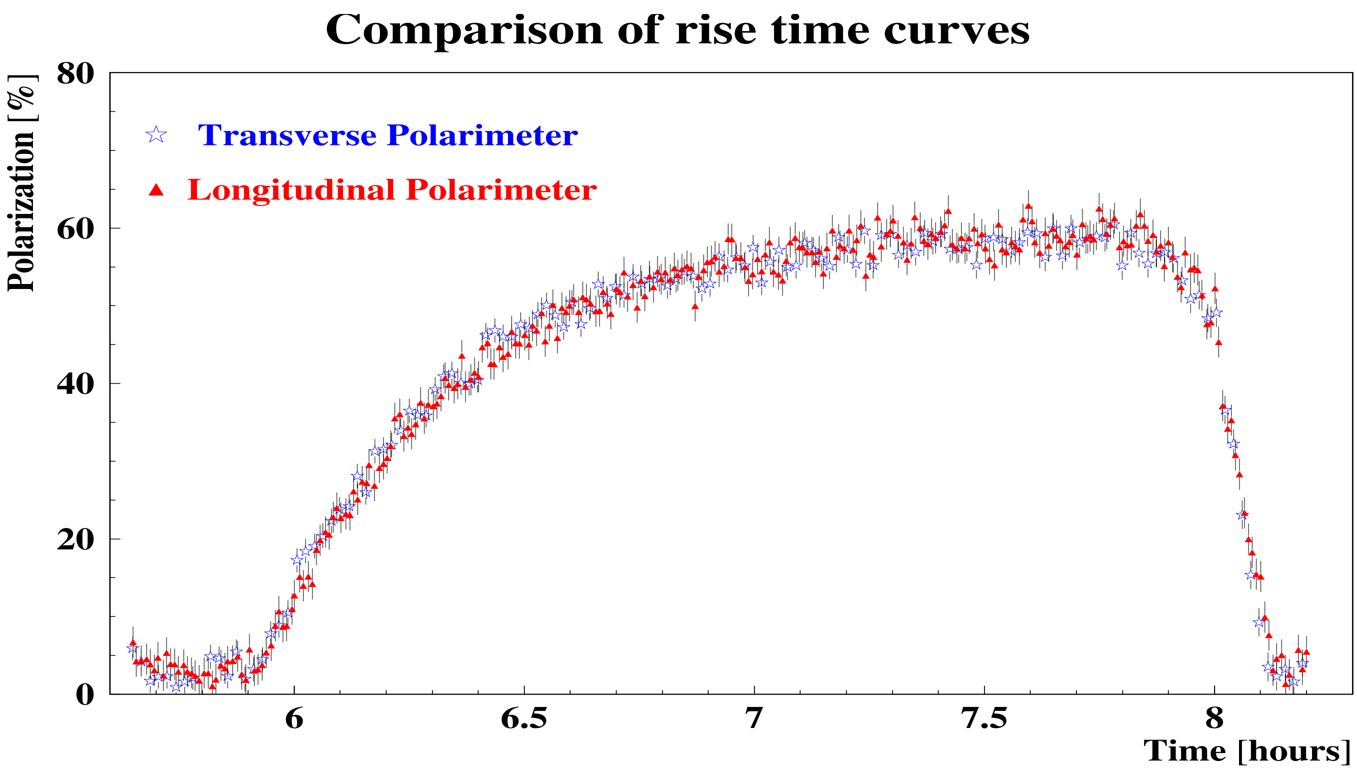
The Beam

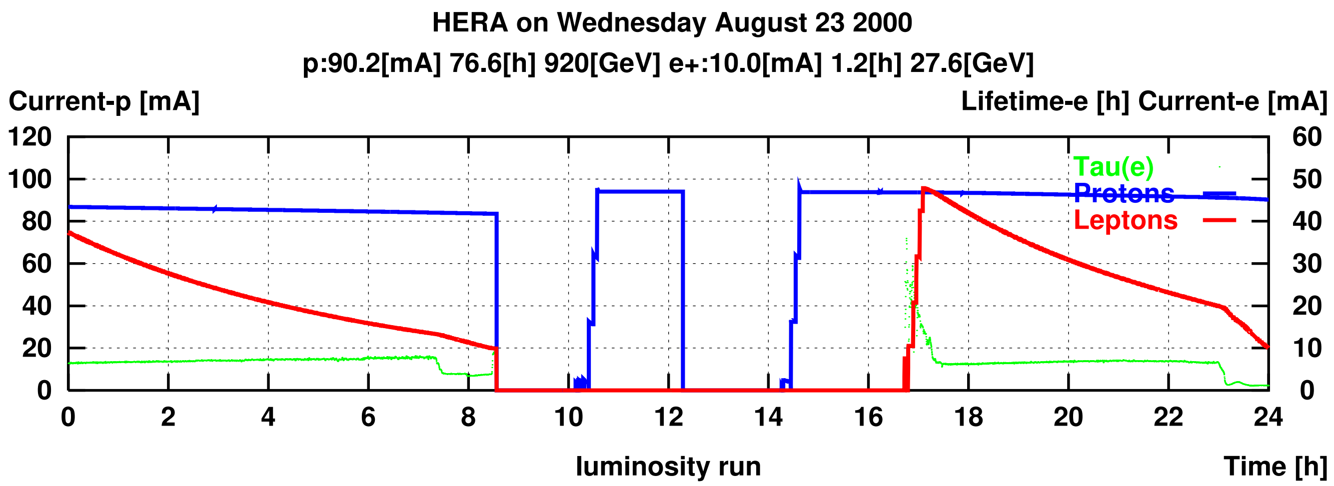




Relative systematic error of the beam polarization measurement at longitudinal polarimeter is 1.6% (NIM A of this summer, hep-ex/0009047 , DESY-00106).

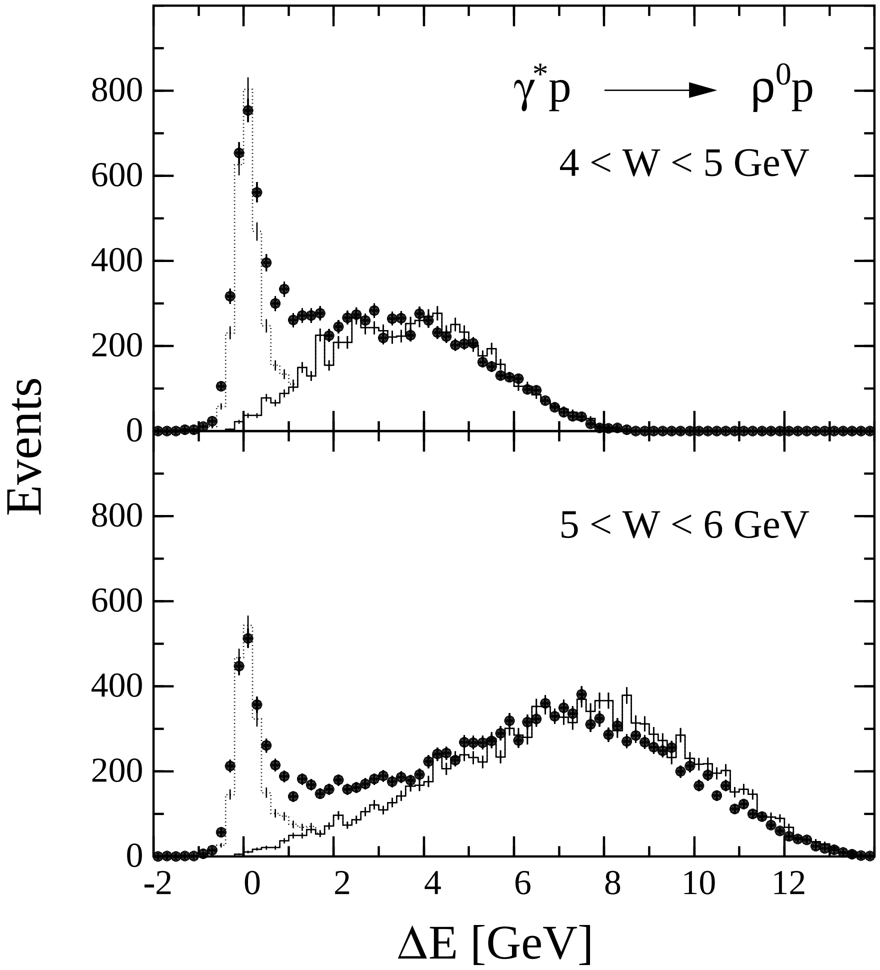
The Beam Performance





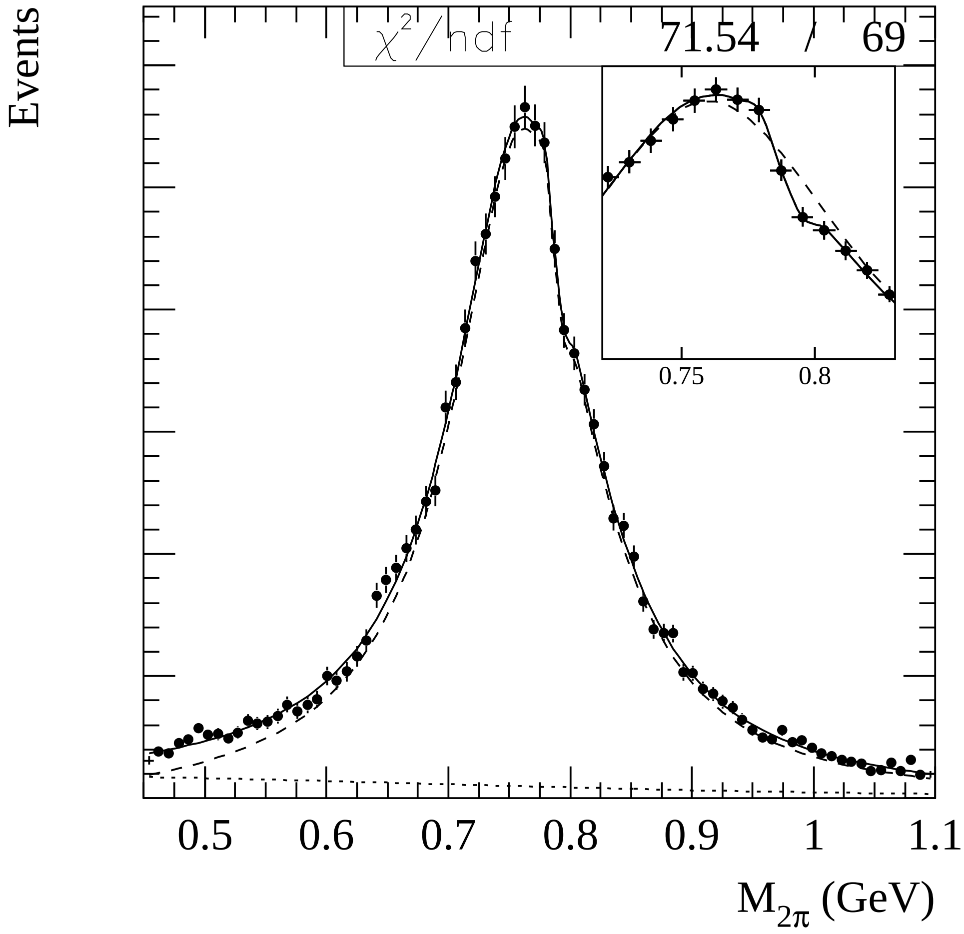
Longitudinally polarised $e^{\pm}$ beam at HERMES:
$P = 27.56$ GeV/c, current 50...10 mA, $P_{beam} = 40 \ldots 60\%$,
in 2000 high density unpolarized runs at the end of the fill at current $< 15mA$.

Diffractive ρ^o, ω 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 $< M_{2K}$
  - ω exclusive: $\Delta E < 1.$ GeV, diffractive -$t' < 0.5 GeV^2$
  - ω mass: 0.72 GeV$< M_{3\pi}, M_{\pi,\gamma} <$0.88 GeV
  - 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



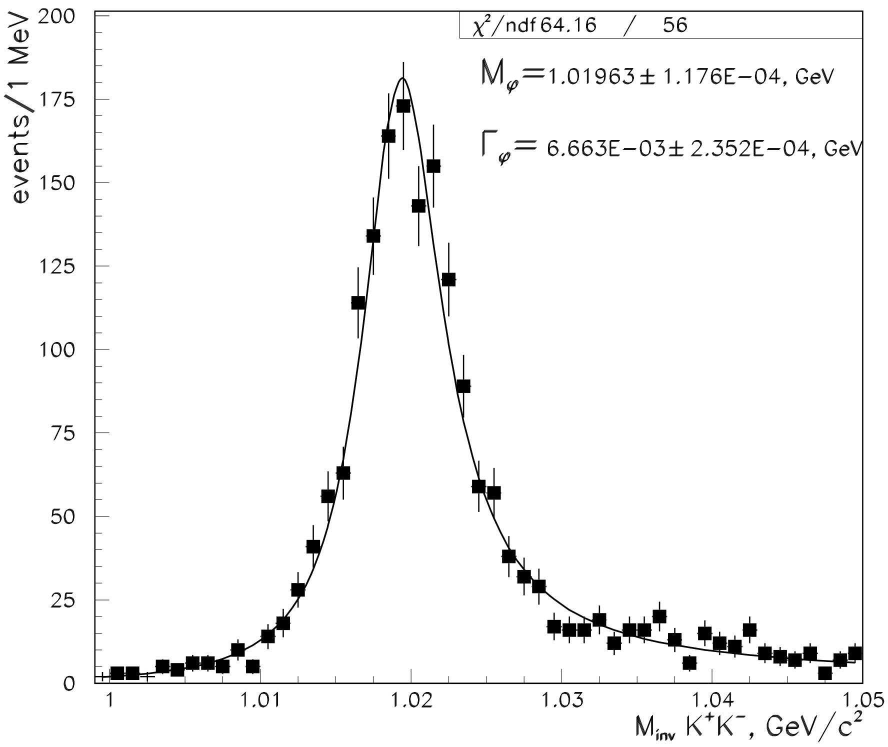
Relativistic $p-$wave Breit-Wigner and Ross-Stodolsky

$\frac{dN}{dM_{2\pi}} = BW(M_{2\pi})(\frac{M_\rho}{M_{2\pi}})^{n_{skew}}$
$M_\rho = 770.9 \pm 1.2$ MeV, $\Gamma\rho = 138.9 \pm 2.0$ MeV, $n_{skew} = 2.68 \pm 0.13$

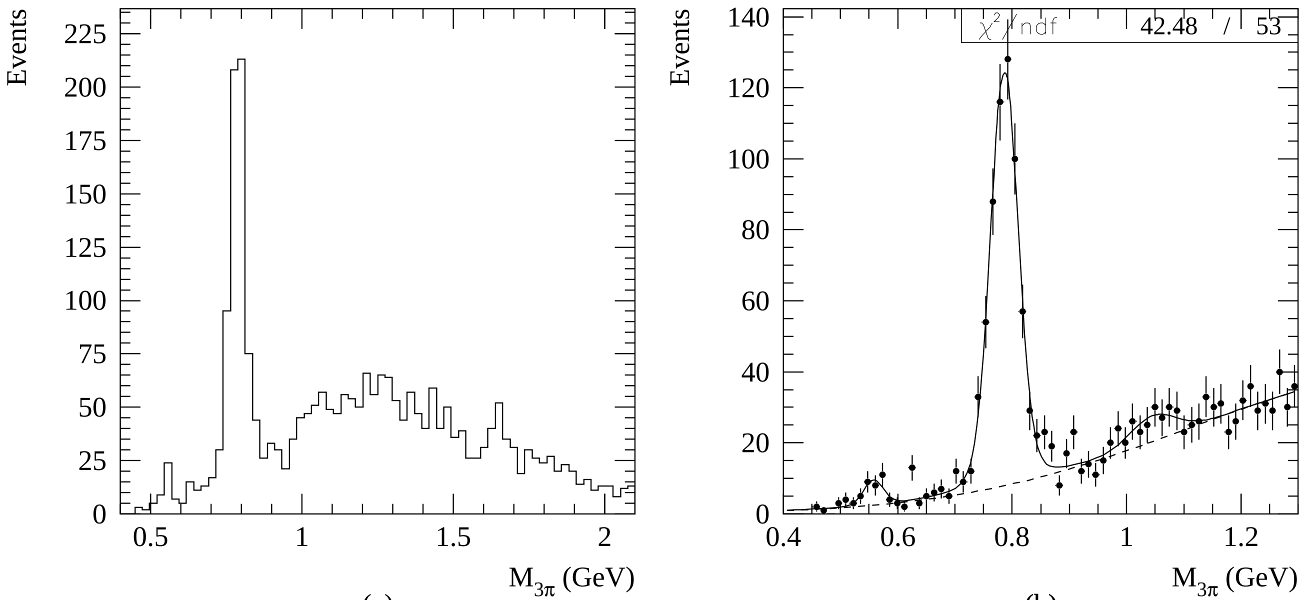
Corrections to include $\rho^o - \omega$ interference applied added.

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

Mass Peaks of ϕ and ω



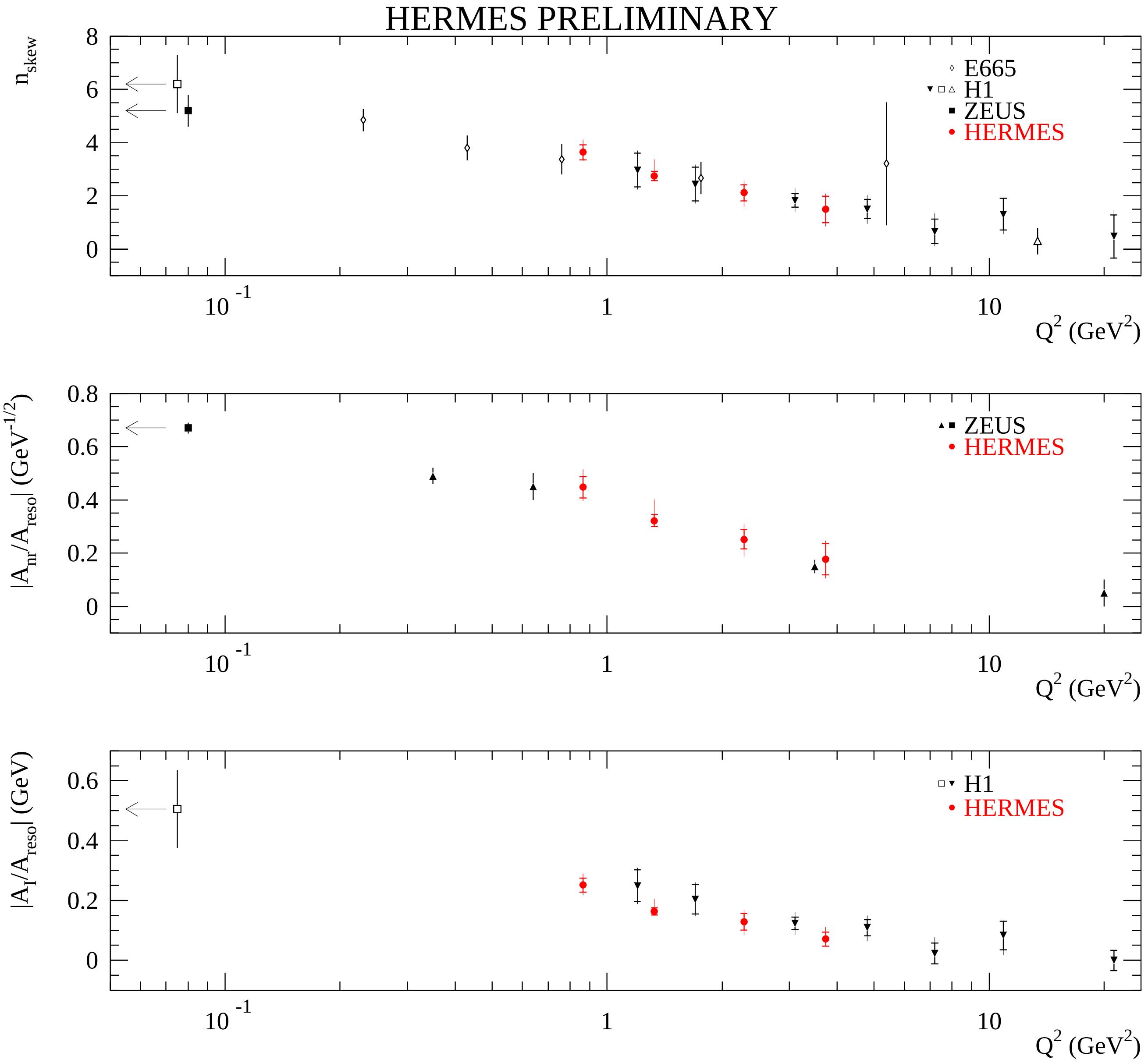
The K^+K^- invariant mass distribution.



(a) (b)

The $\pi^+\pi^-\pi^0$ invariant mass distribution. Peak fitted by convolution of non-relativistic Breit-Wigner with Gaussian function. The two Gaussian shapes on tge left and right side of ω resonance represent production of η and ϕ mesons. The dotted line represents the combinatorial background described by 4th order polinom.

Kinematical Dependence ρ^o Skewing

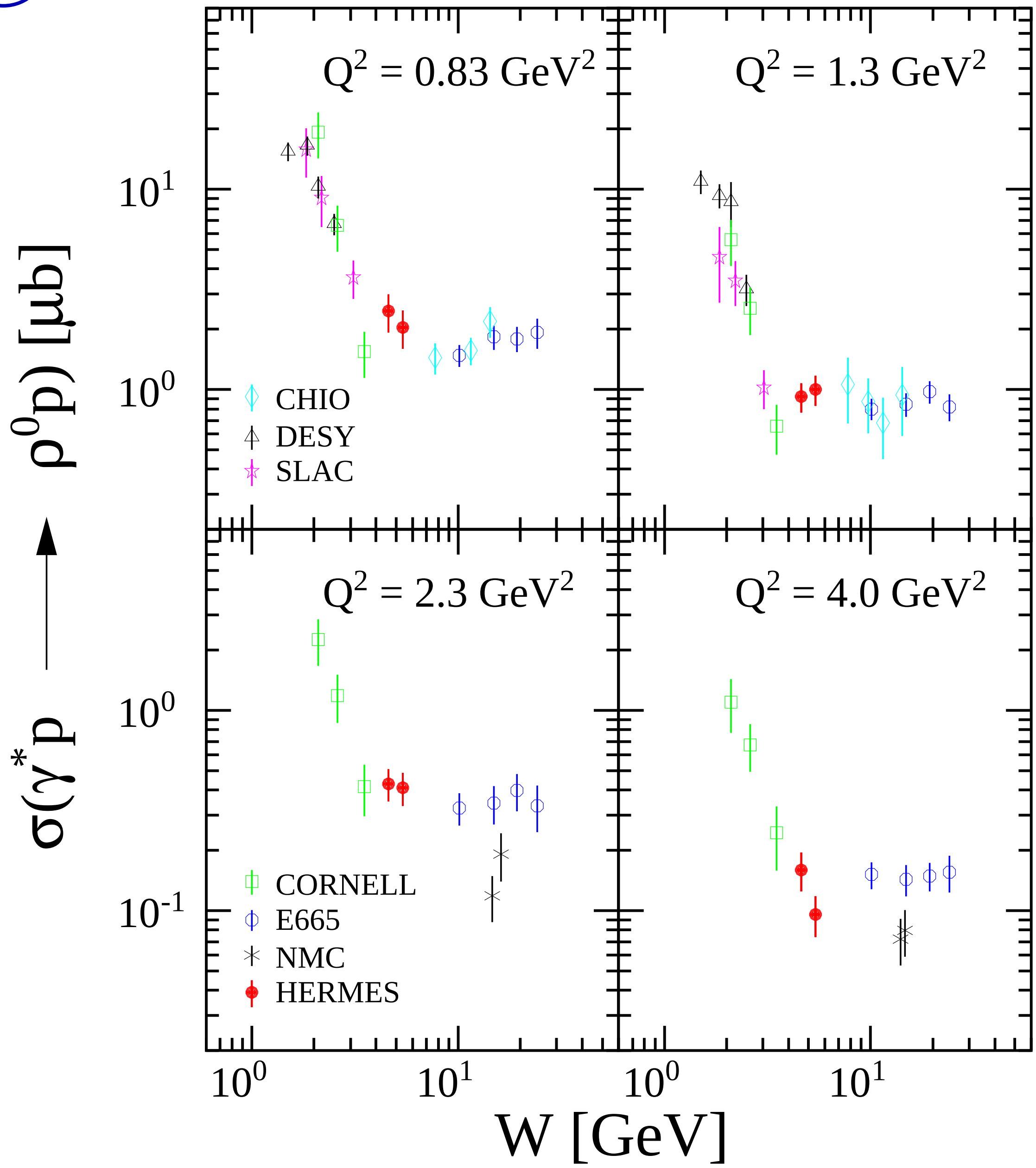


$\longrightarrow$ Skewing seems independent of energy.

$\longrightarrow$ Skewing of ρ^o disappears at high Q^2.

$\longrightarrow$ 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.

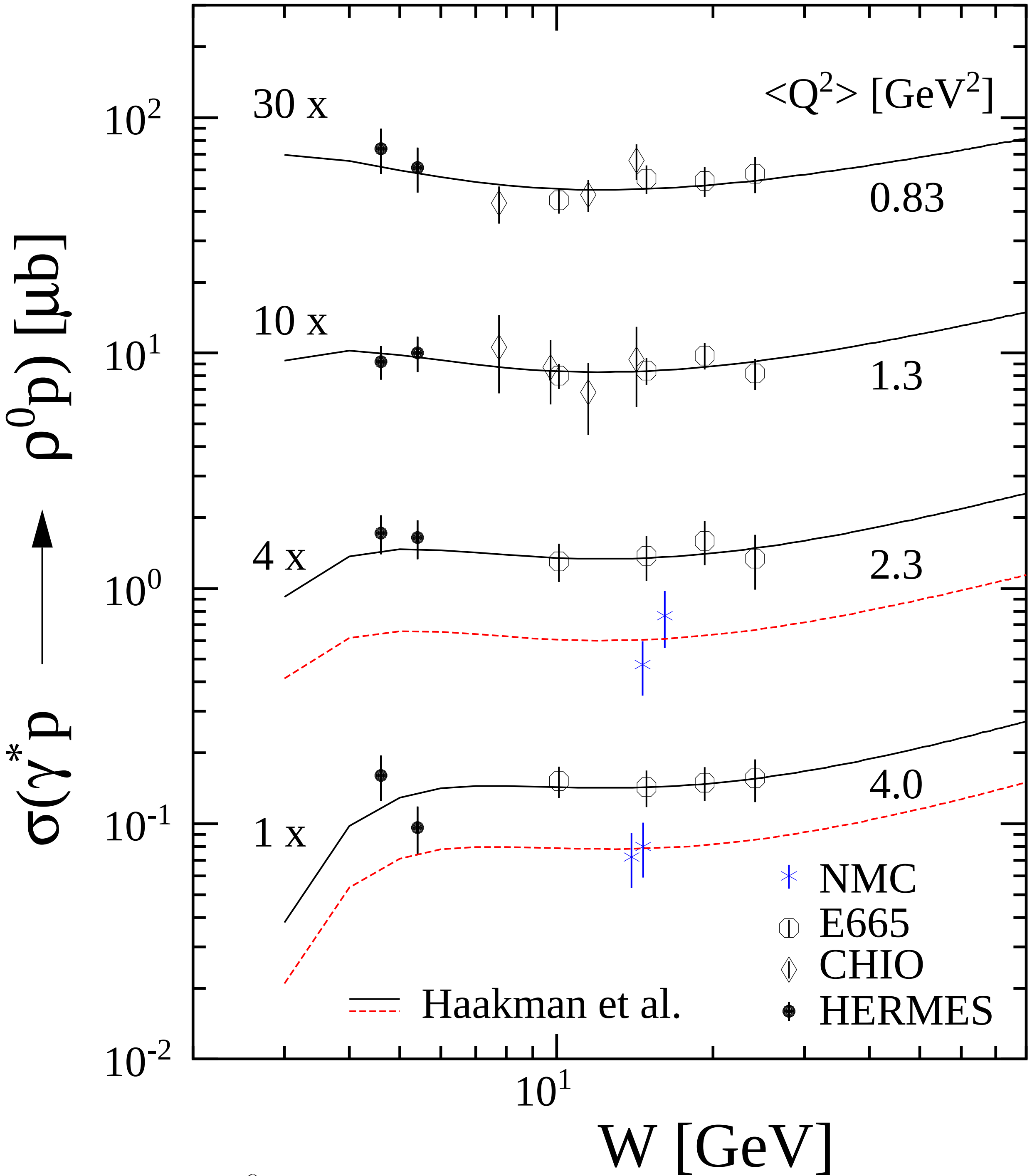
$\rightarrow$ HERMES data are in the transition region where different production mechanisms involved.

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

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

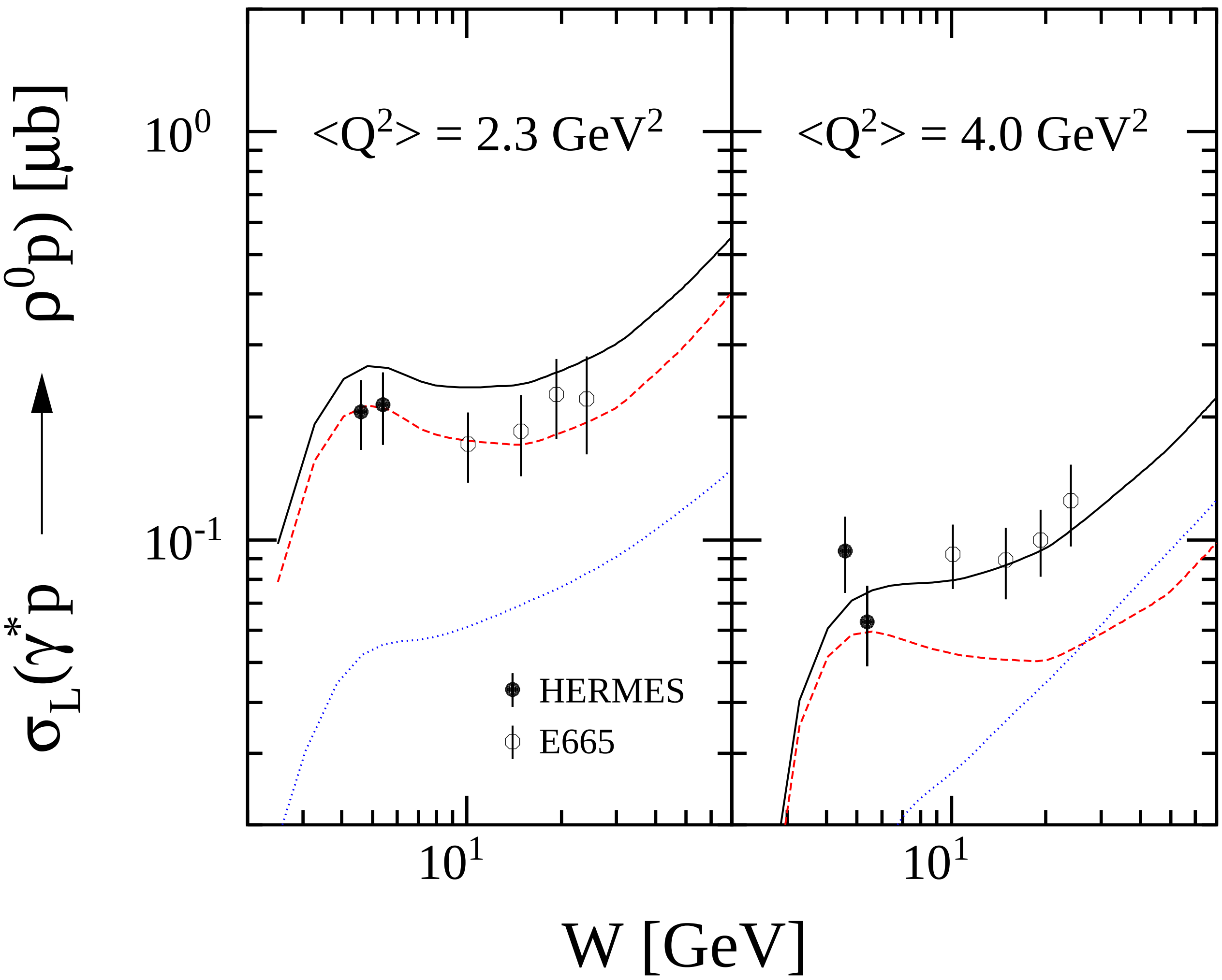
$\frac{d\sigma}{dt} = f_\rho(Q^2) F_2^{\mathrm{p}}(x, Q^2)^2 \exp[\Lambda(W)t]$.

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

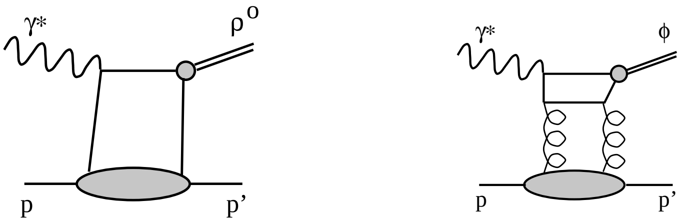
ρ^o Longitudinal Cross Section

Comparison with recent OFPD calculations

M.Vanderhaeghen, P.A.M. Guichon, M. Guidal, Phys.Rev.Lett. **80** (1998) 5064.

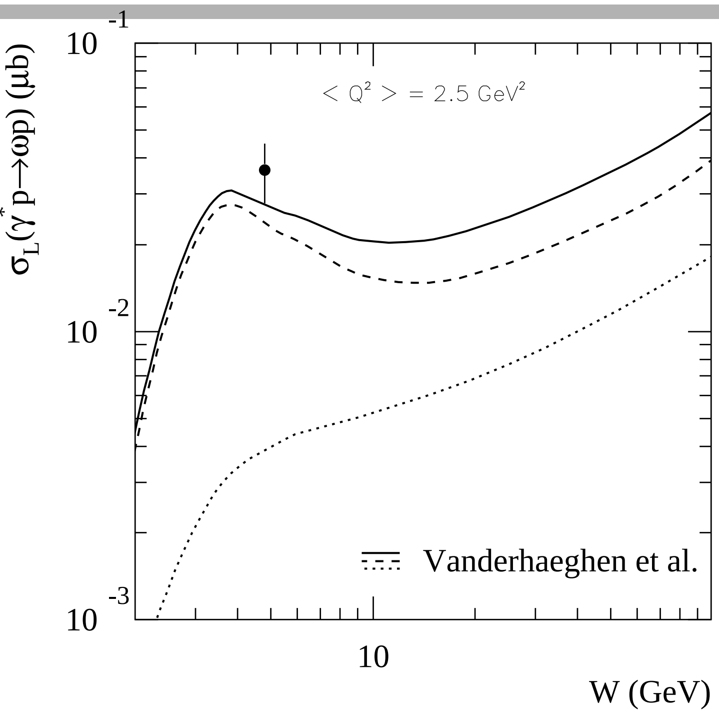


Dotted curve - 2-gluon exchange, dashed - quark exchange, solid - sum.



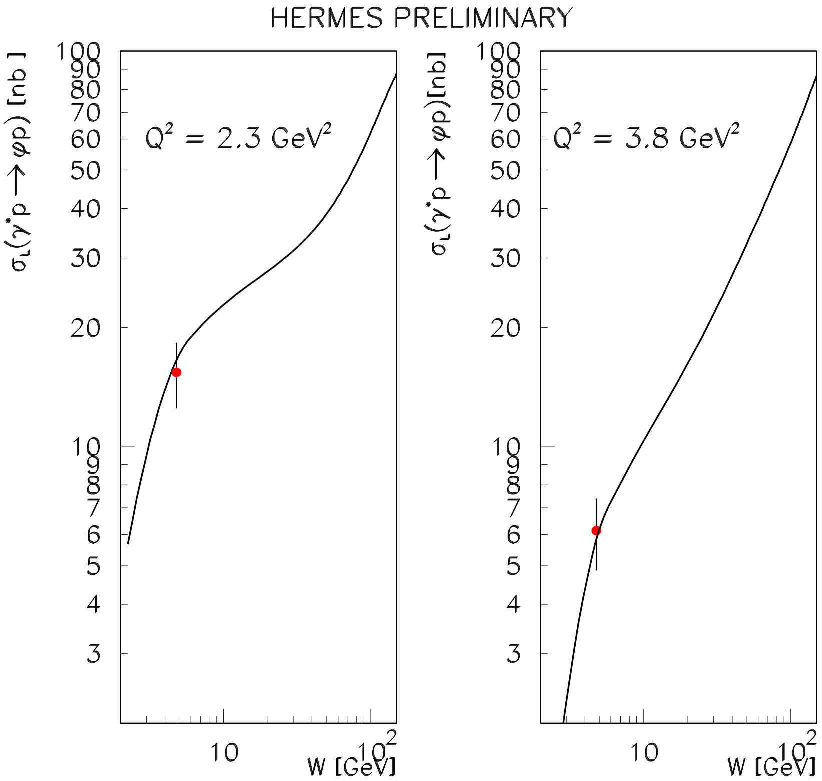
$\rightarrow$ Domination of quark exchange at $W \sim 5$ GeV.

ω and ϕ Long. Cross Sections



solid line sum, dashed - quark exchange, dotted - 2-gluon exchange

$\longrightarrow$ Domination of quark exchange for ω.

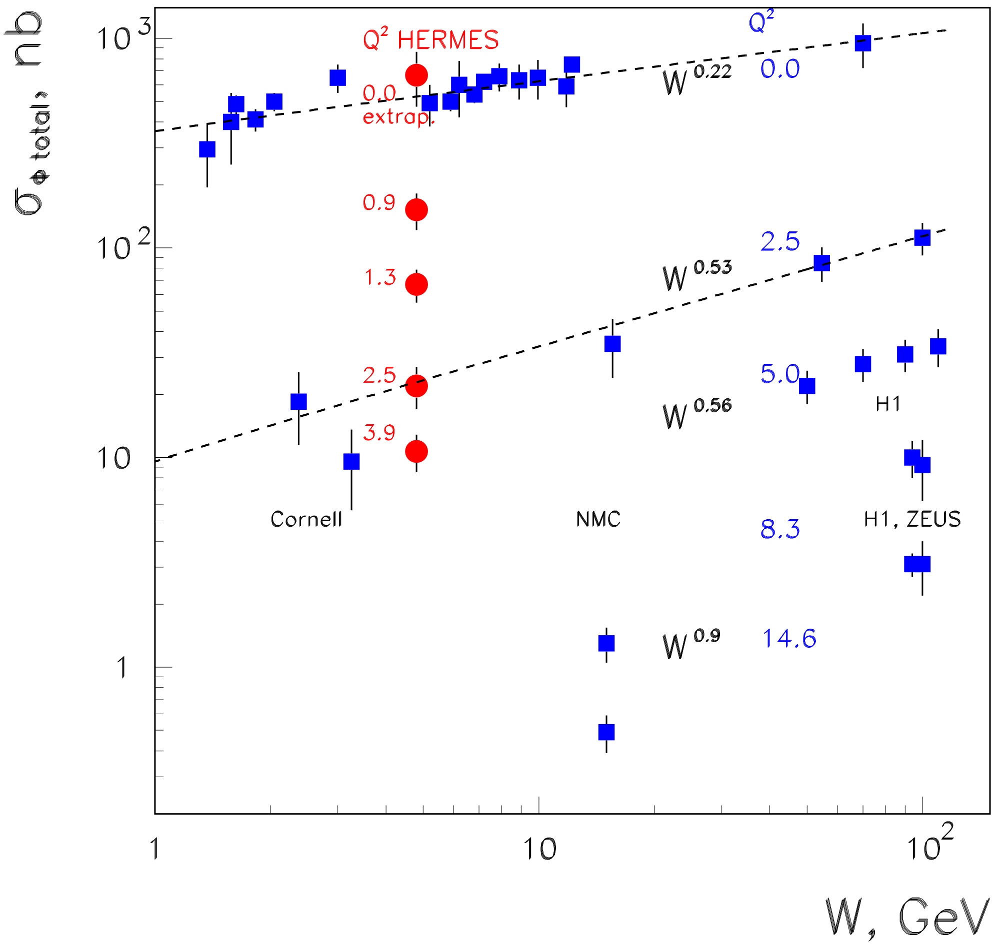


solid line - 2-gluon exchange

$\longrightarrow$ Domination of gluon exchange for ϕ

ϕ Cross Section (Q^2, W)

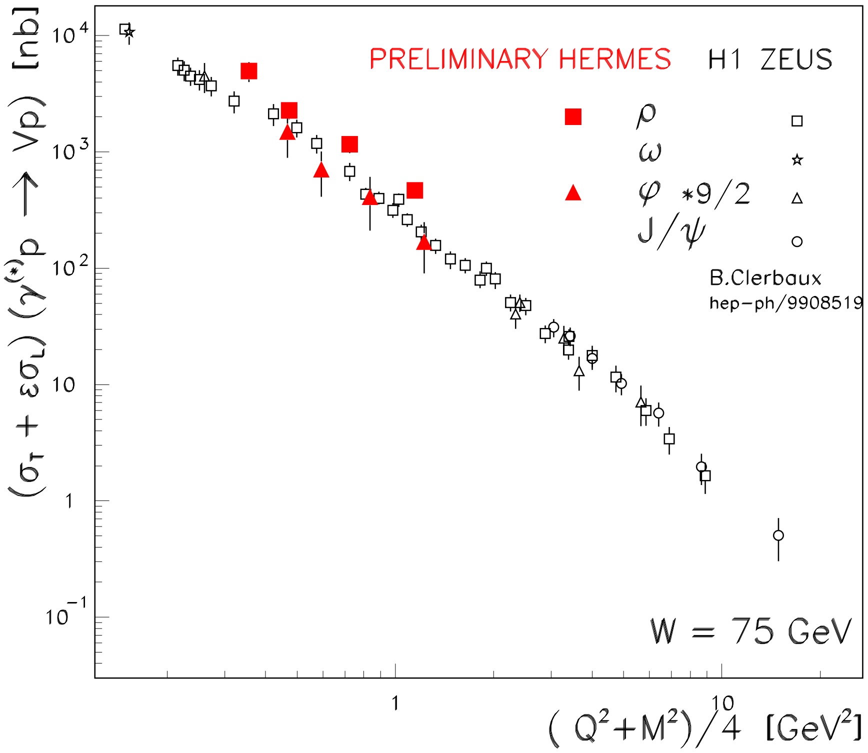
PRELIMINARY



$\rightarrow Q^2-$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 $\delta(3.5) = 0.4$

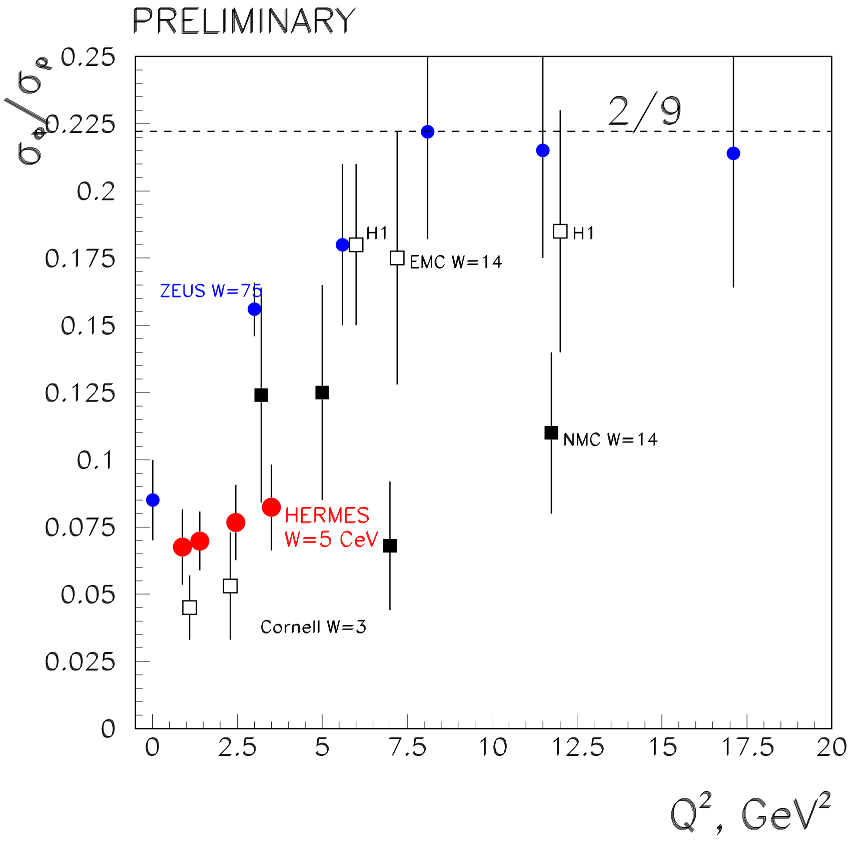
H.Abramowicz,A.Caldwell DESY 98-192, H.Abramowicz DESY 00-025,hep-ph/0001054

$\rightarrow$ 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 $\sigma_\phi/\sigma_{\rho^o}$

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



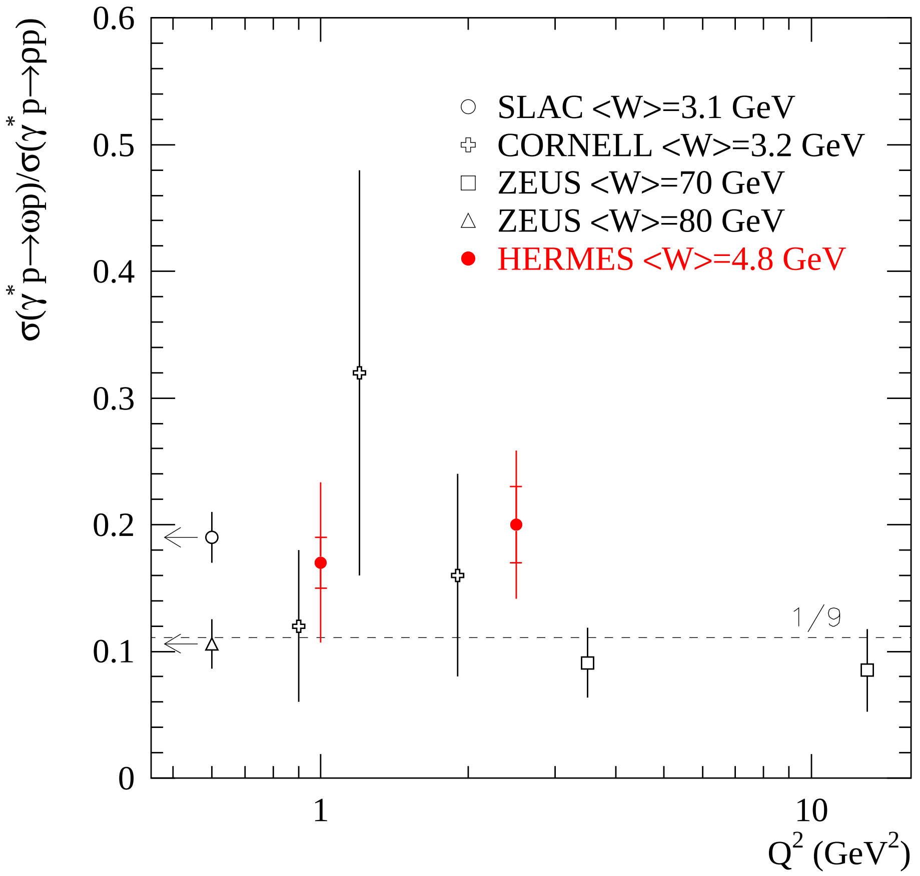
$\rightarrow$ $W-$dependence of $\sigma_\phi/\sigma_{\rho^o}$ at $Q^2 = 2.5 \sim 4$ GeV^2.

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

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

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

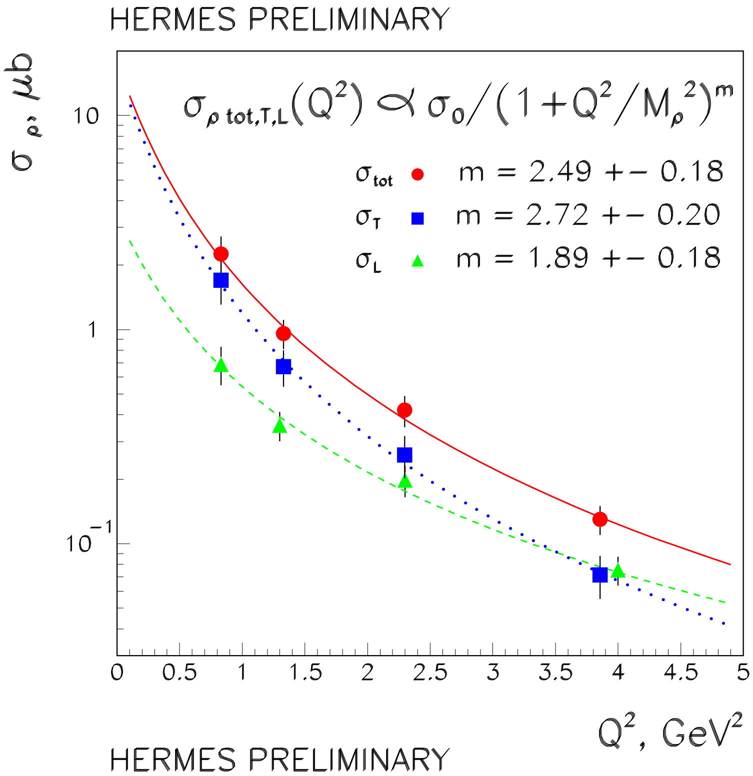


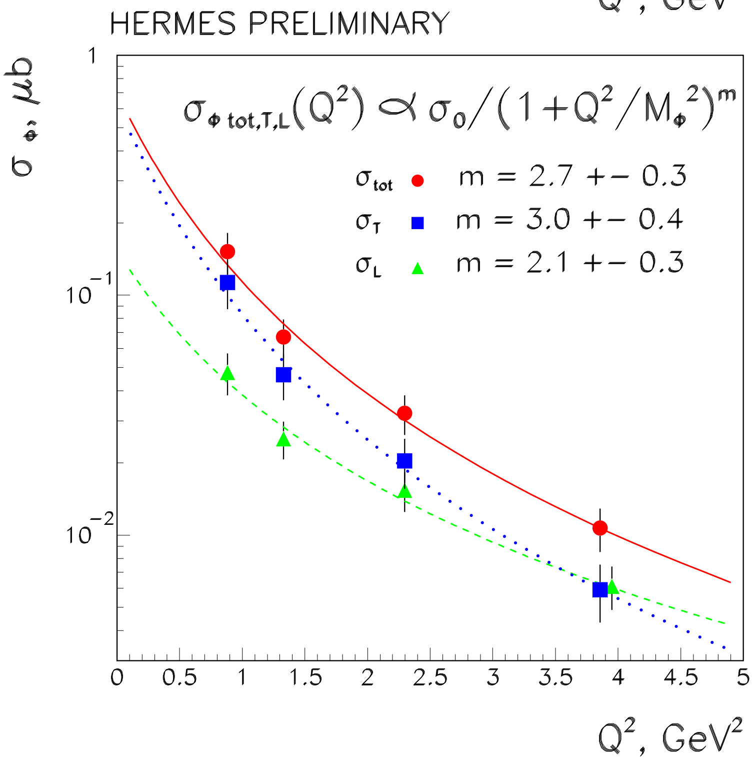
$\rightarrow$ No indication of Q^2-dependence.

$W - dependence?$

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

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



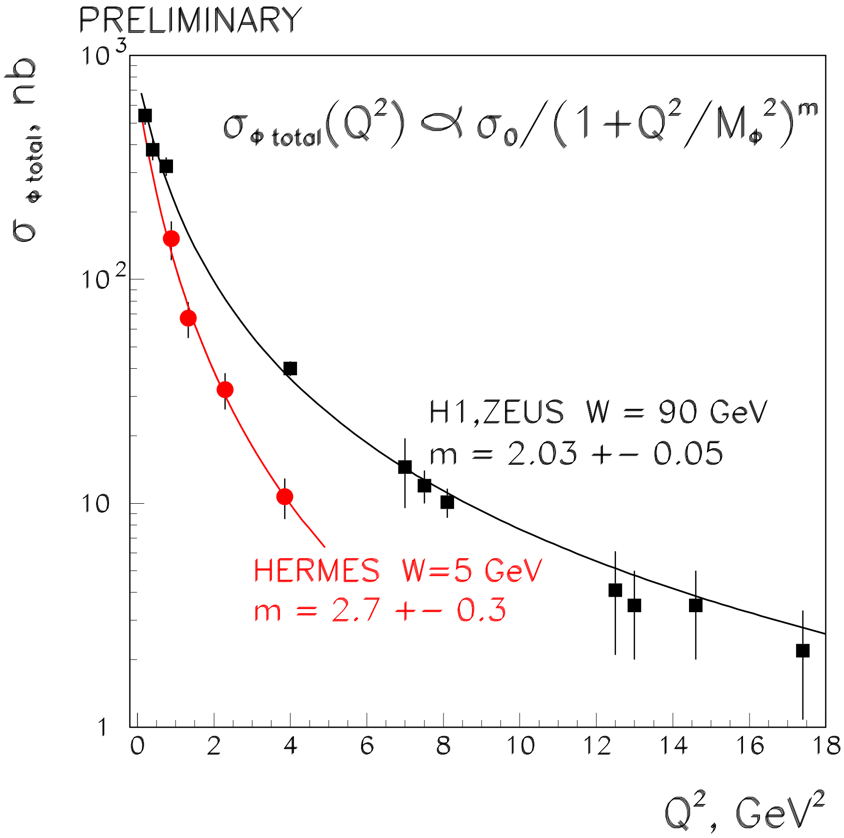


$\rightarrow$ m_ϕ is a little bit larger then m_{ρ^o}

$\rightarrow$ 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 $\sigma_{total,T,L}(Q^2)$



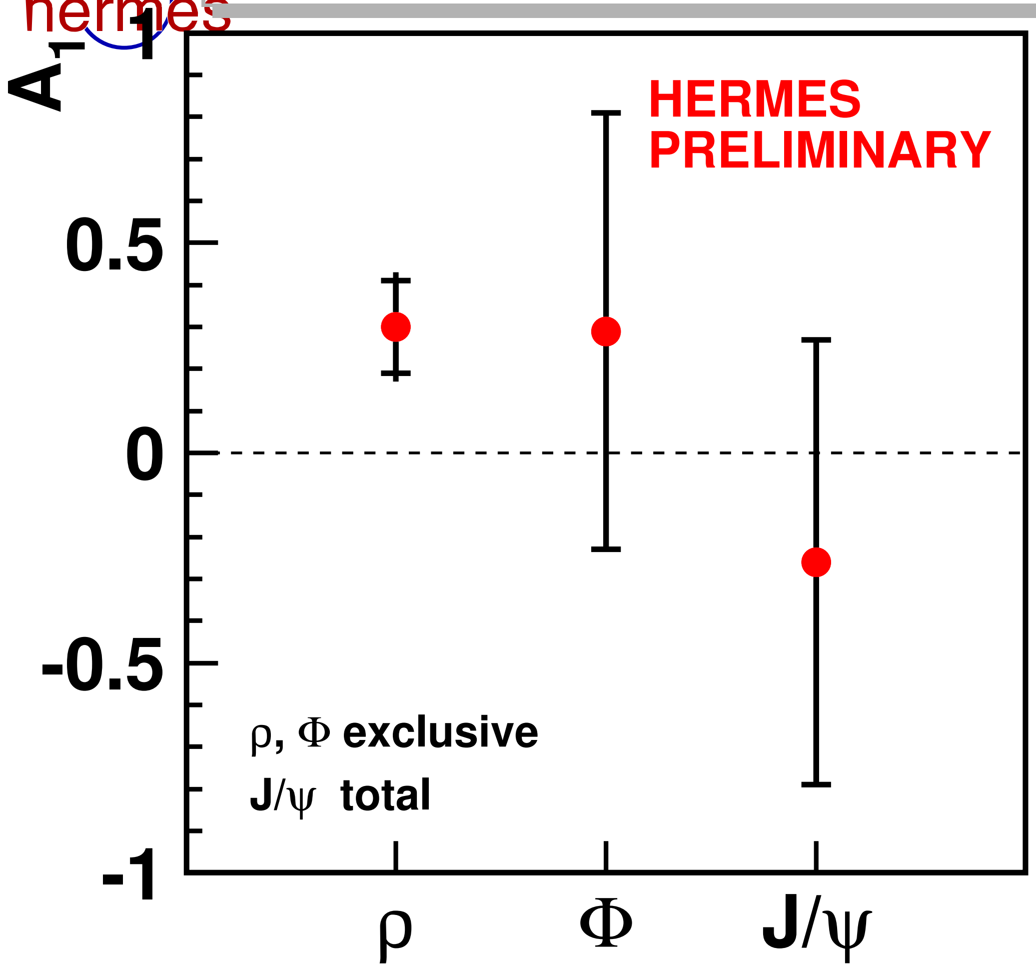
which σ	m at HERMES	m at H1, ZEUS
$\sigma_{total\phi}$	2.70 ± 0.28	2.03 ± 0.05 [1]
$\sigma_{L\phi}$	2.067 ± 0.275	
$\sigma_{T\phi}$	3.018 ± 0.344	2.8 ± 0.1 [2]
$\sigma_{total\rho}$	2.49 ± 0.18	2.37 ± 0.10 [2]
$\sigma_{L\rho}$	1.89 ± 0.18	
$\sigma_{T\rho}$	2.72 ± 0.23	2.47 ± 0.03 [2]

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

$\rightarrow m_\phi$ at $W \sim 5$ GeV is larger then at $W \sim 75$ GeV. In agreement with 2-gluon exchange of pQCD predictions.

$\rightarrow m_{\rho^o}$ at $W \sim 5$ GeV is similar as at $W \sim 75$. ...Due to the domination of quark exchange mechanism?

Double spin asymmetry of VM



on proton target

$$A_1 = \frac{\sigma^{1/2} - \sigma^{3/2}}{\sigma^{1/2} - \sigma^{3/2}} = A_{||}/D - \eta A_2$$

$A_2 = \frac{\sigma_{LT}}{\sigma_{1/2}+\sigma_{3/2}} \sim< \sqrt{R_\rho}$ in VM prodiction, $A_2 \approx 0$ in DIS

$D \approx 0.40$ photon depolarization factor

$\eta \approx 0.06$ kinematical factor.

$$A_{||} = \frac{\sigma^{\uparrow\downarrow} - \sigma^{\uparrow\uparrow}}{\sigma^{\uparrow\downarrow} + \sigma^{\uparrow\uparrow}} = \frac{N^{\uparrow\downarrow} L^{\uparrow\uparrow} - N^{\uparrow\uparrow} L^{\uparrow\downarrow}}{N^{\uparrow\downarrow} L_p^{\uparrow\uparrow} + N^{\uparrow\uparrow} L_p^{\uparrow\downarrow}}$$

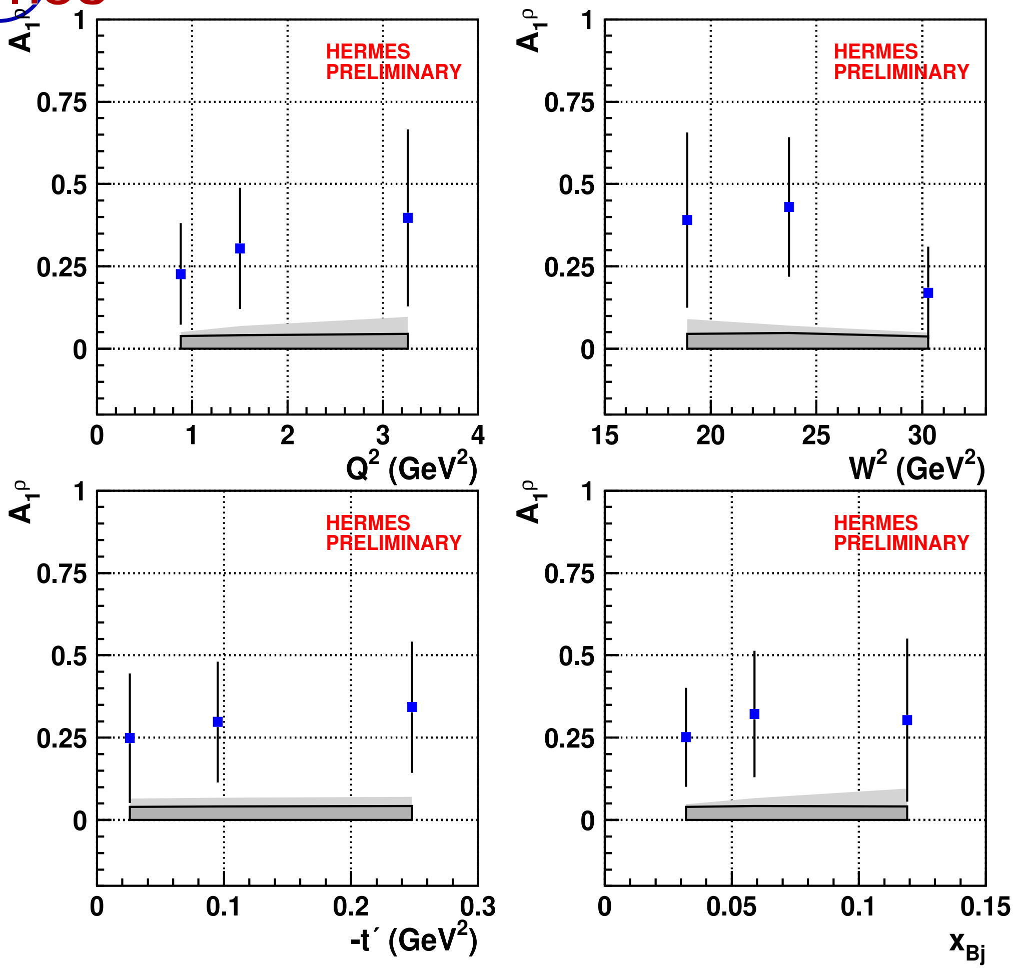
with $L_p =< L|P_{beam} P_{target}| >$

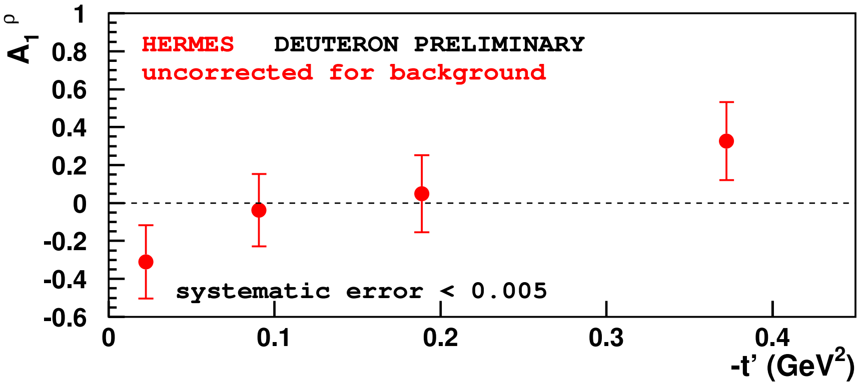
$$< A_{||}^{\rho^o} >= 0.119 \pm 0.045_{stat} \pm 0.008_{syst}$$

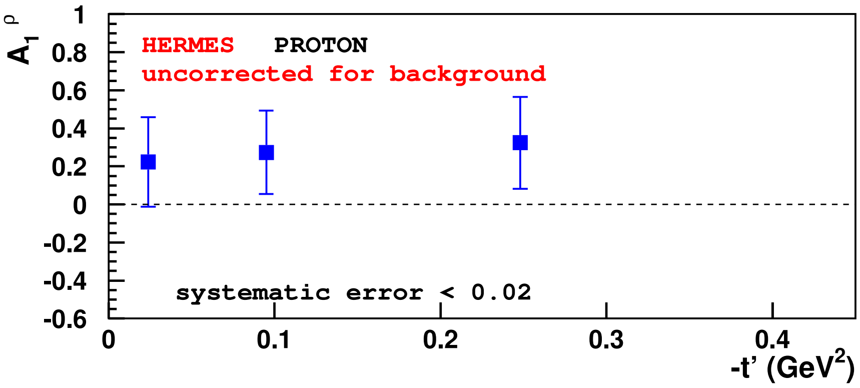
$$< A_1^{\rho^o} >= 0.244 \pm 0.111_{stat} \pm 0.021_{syst}$$

[Phys.Rev. B 513 (2001) 301, hep-ex/0102037, DESY00-189]

Double spin asymmetry of ρ^o



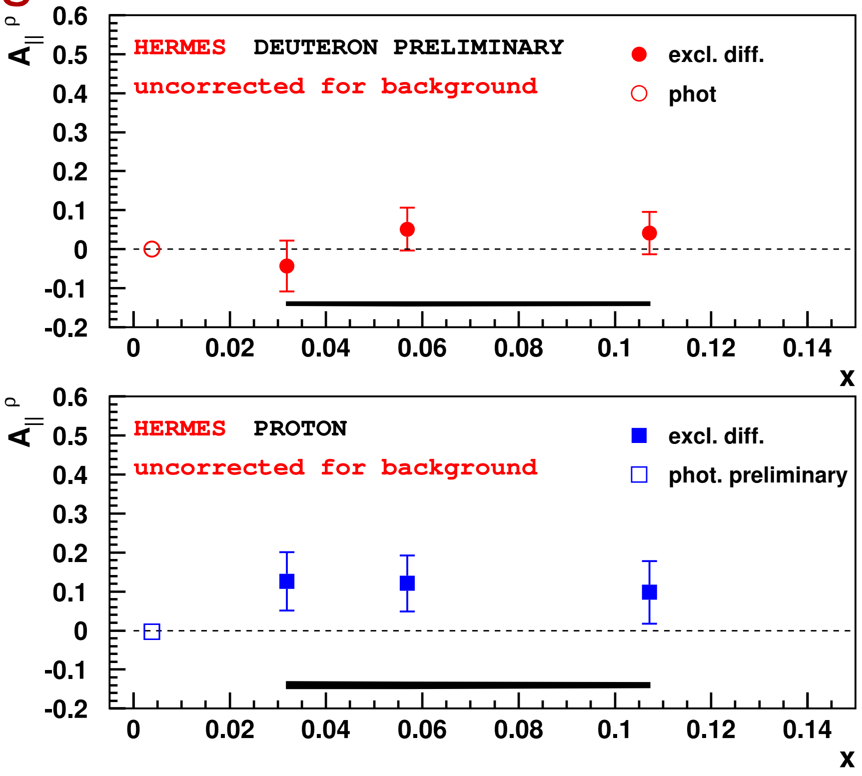


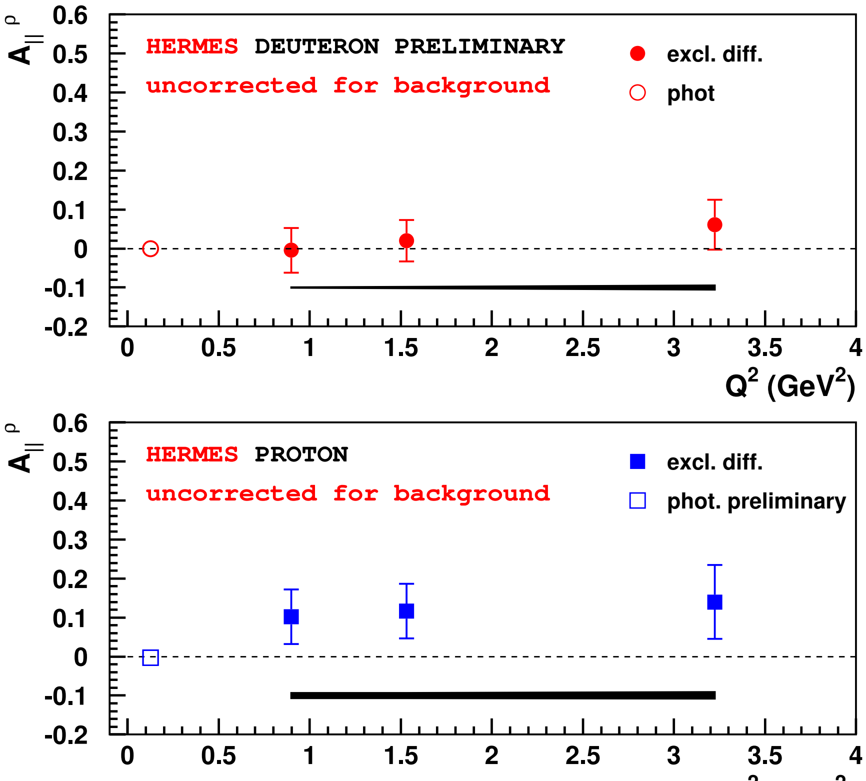


$\rightarrow$ No strong kinematical dependence of A_1^ρ observed on proton target

$\rightarrow$ Possible t' $-$dependence on deuteron target

Double spin asymmetry of ρ^o

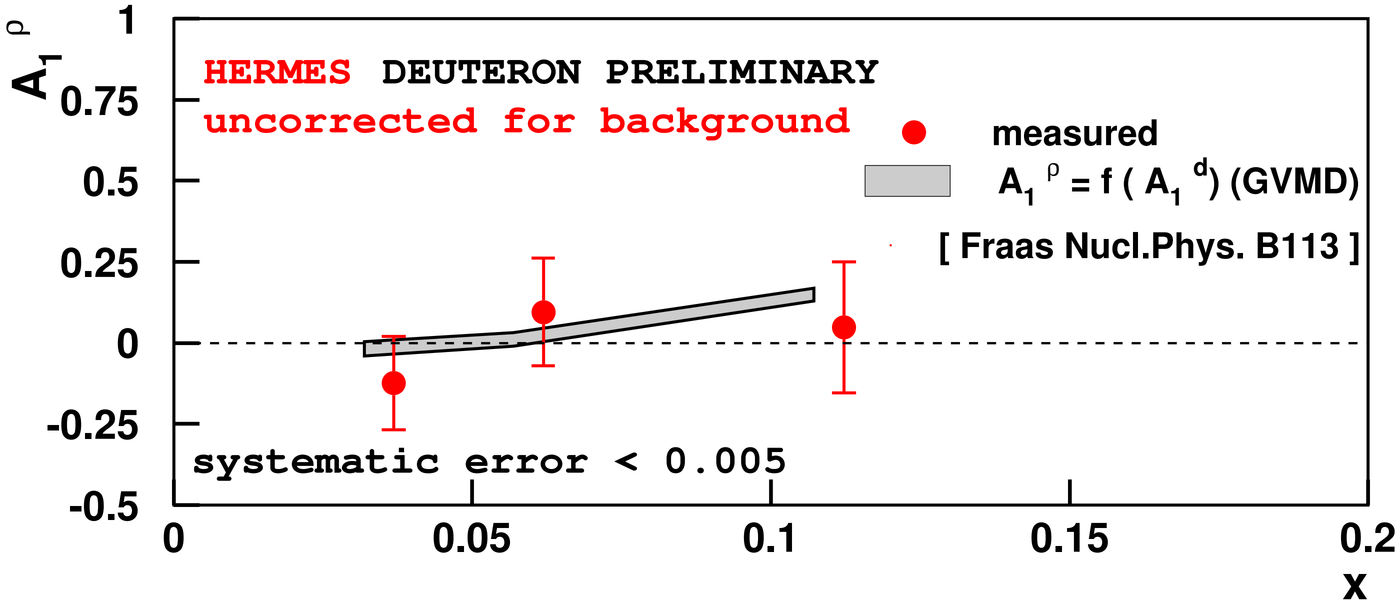


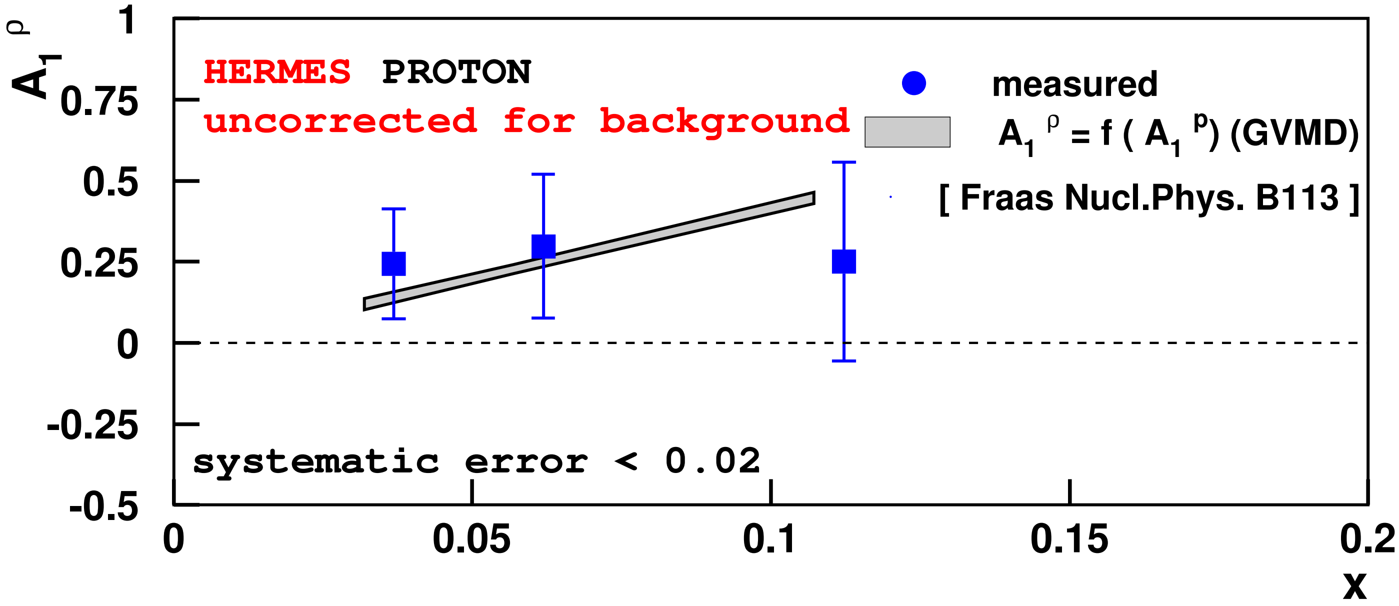


$\rightarrow A_{||}^{\rho} \sim 0$ in DIS region on deuteron target

$\rightarrow A_{||}^{\rho} \sim 0$ of photoproduction on proton and deuteron targets

Double spin asymmetry of ρ^o



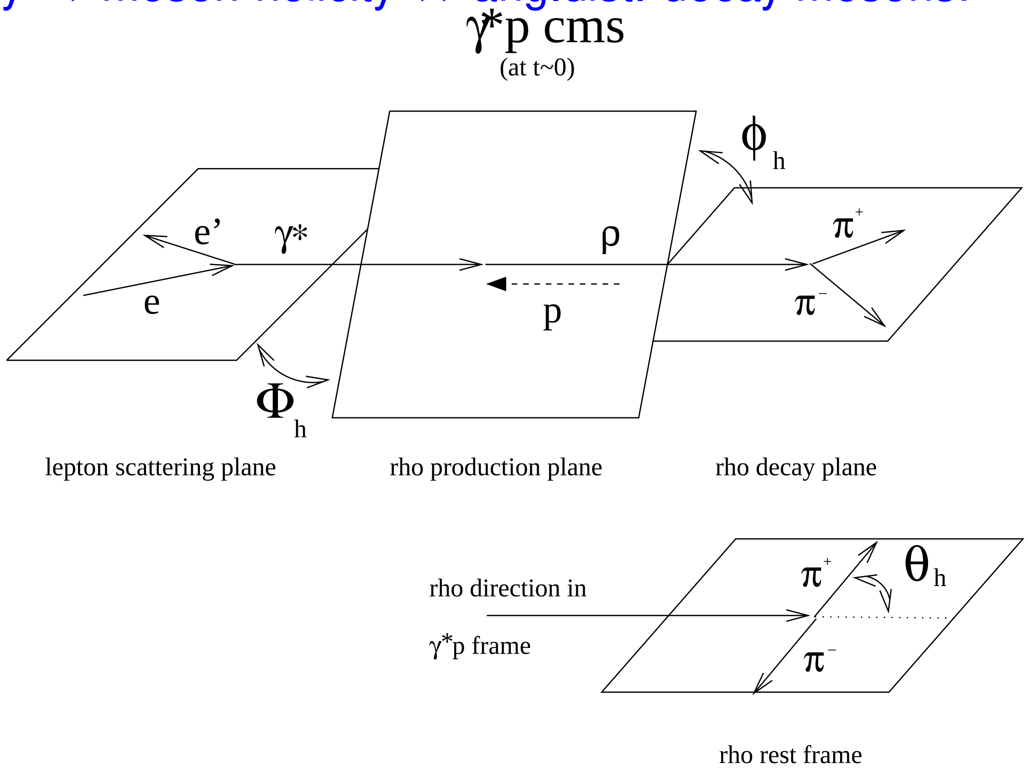


$A_1^{\rho^o} \approx 2A_1^{\gamma^* p} \approx g1/F1$
Significant contribution of exchange process which can be mediated by di-quark objects, [H.Fraas, Nucl.Phys. **B113**, 532, 1976 (!)]

$A_1^{\rho^o} \sim 0$ at SMC where $W \sim 15$ GeV, [A.Tripet, Nucl.Phys. **B(Proc.Suppl. of DIS'99) 79**, 529, (1999)]

Polarization of vector mesons

γ^* −helicity → meson-helicity ↔ ang.dist. decay mesons:



- Measurement of 23 independent Spin-Density Matrix Elements (r^{α}_{ij}) at the longitudinal beam polarization of HERMES (15 unpolarized + 8 polarized) and helicity amplitudes $T_{\lambda_V \lambda_{N'} \lambda_\gamma \lambda_N}$ (λ's denote the helicities).

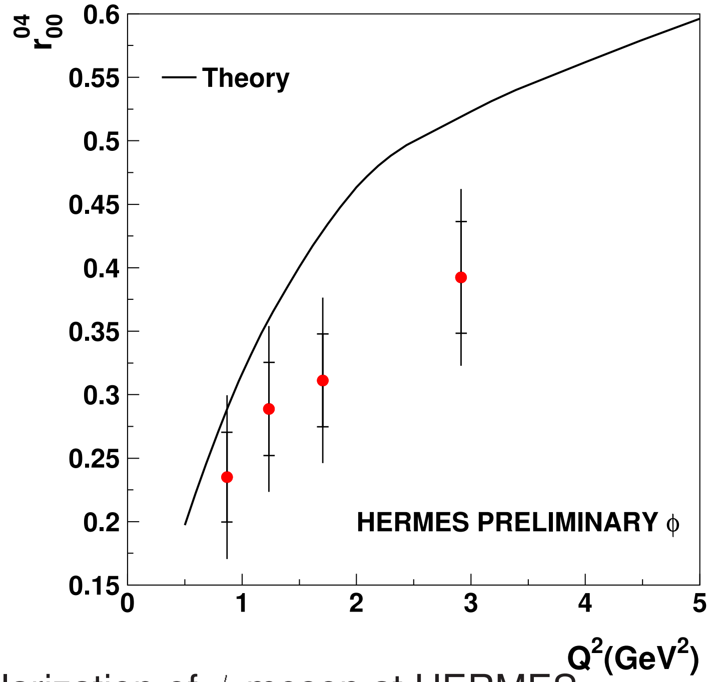
- Natural parity exchange in the t-channel:
  $T_{-\lambda_V \lambda_{N'}, -\lambda_\gamma \lambda_N} = (-1)^{(\lambda_V - \lambda_\gamma)} T_{\lambda_V \lambda_{N'}, \lambda_\gamma \lambda_N}$
  $\rightarrow 1 - r^{04}_{00} + 2r^{04}_{1-1} - 2r^{1}_{11} - 2r^{1}_{1-1} = 0$
  ($= 0.148 \pm 0.063_{stat} \pm 0.132_{syst}$ at HERMES)

- S-Channel Helicity Conservation (SCHC, helicity of γ^* retained by VM):
  → helicity change amplitudes
  $T_{01} = T_{10} = T_{0-1} = T_{-10} = T_{-11} = T_{1-1} = 0$
  → all SDMEs vanush exept
  r^{04}_{00},r^{1}_{1-1}, Im r^{2}_{1-1}, Re r^{5}_{10}, Im r^{6}_{10},Im r^{7}_{10}, Re r^{8}_{10}
  $\rightarrow R = \sigma_L/\sigma_T = |T_{00}|^2/|T_{11}|^2$

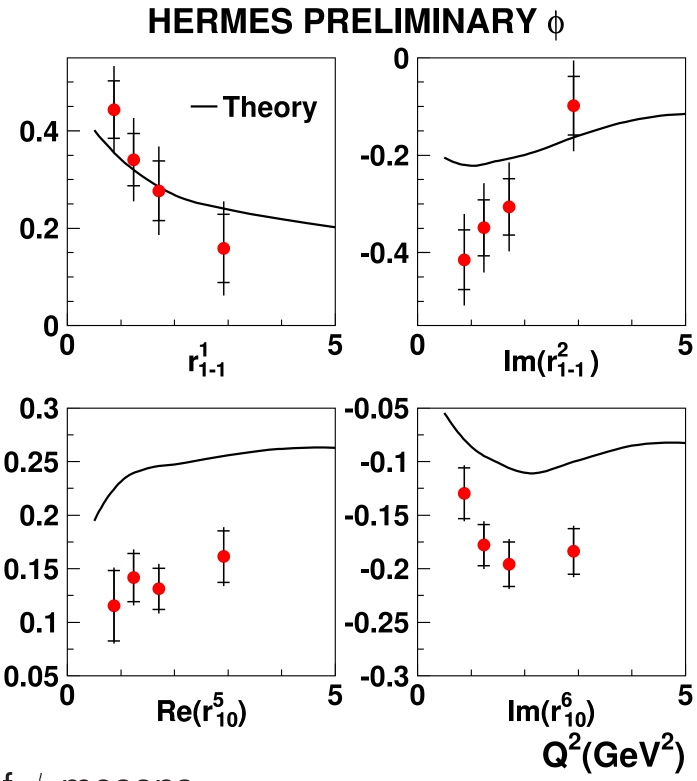
- at SCHC and NPE: $1 - r^{04}_{00} + 2r^{1}_{1-1} = 0$

SDME's of ϕ

Theory curve produced by I.Ivanov calculations for HERMES kinematics of the model of: I.Ivanov, N.Nikolaev, JETP Lett.,69, (1999) 294. The model is expected to be valid at high Q^2 providing a scale for PQCD and high energy: $W^2 >> Q^2$ and is in good agreement with H1 and ZEUS data.

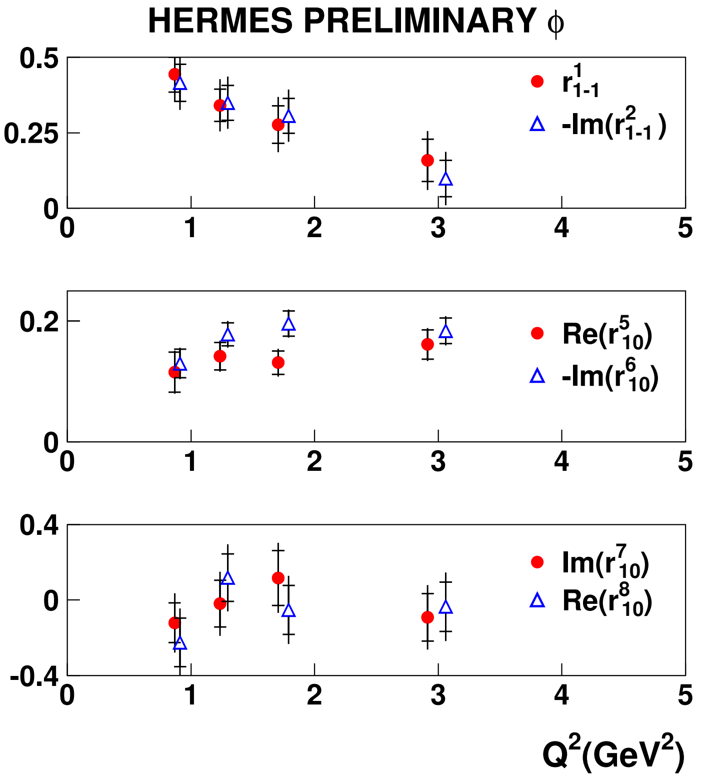


The longitudinal polarization of ϕ meson at HERMES

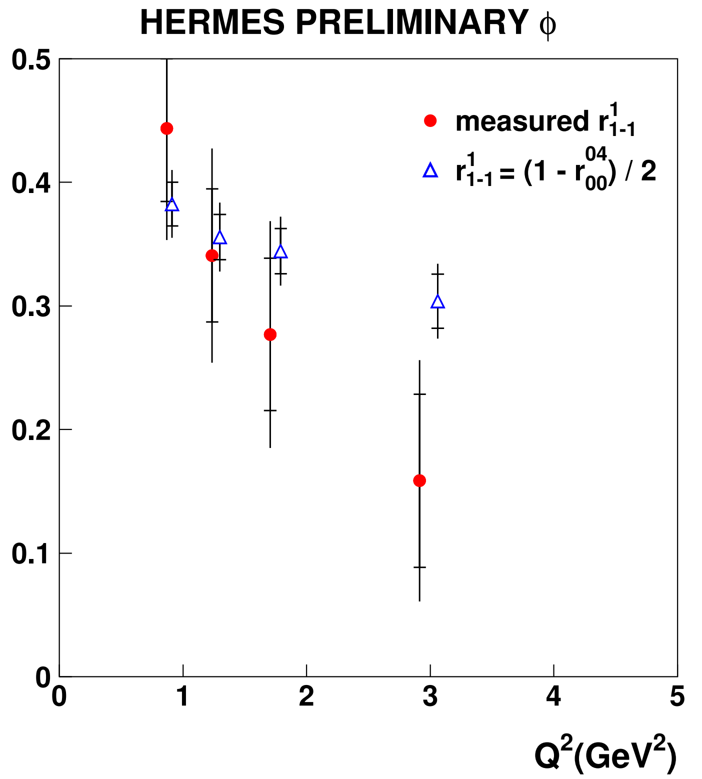


Non-zero SDME's of ϕ mesons

SDME's of ϕ

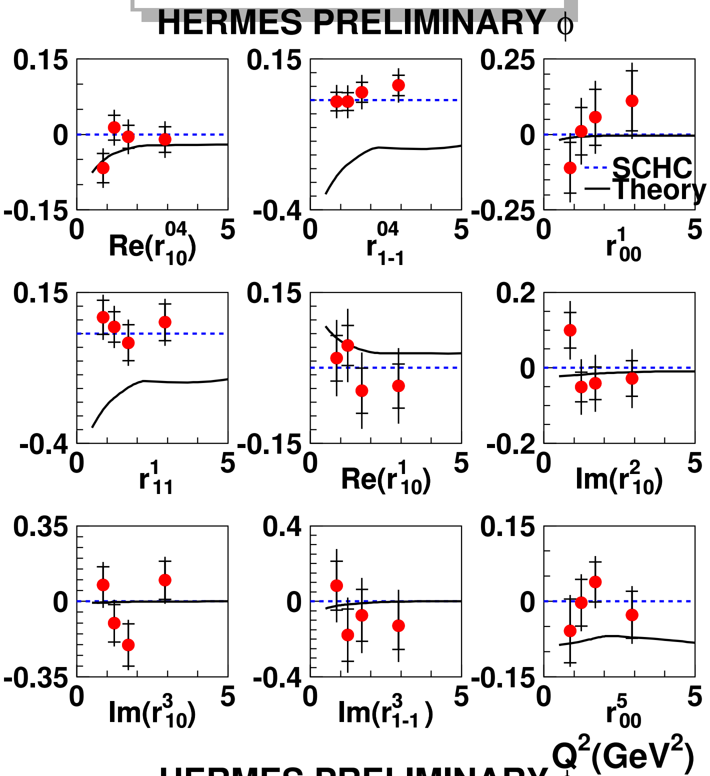


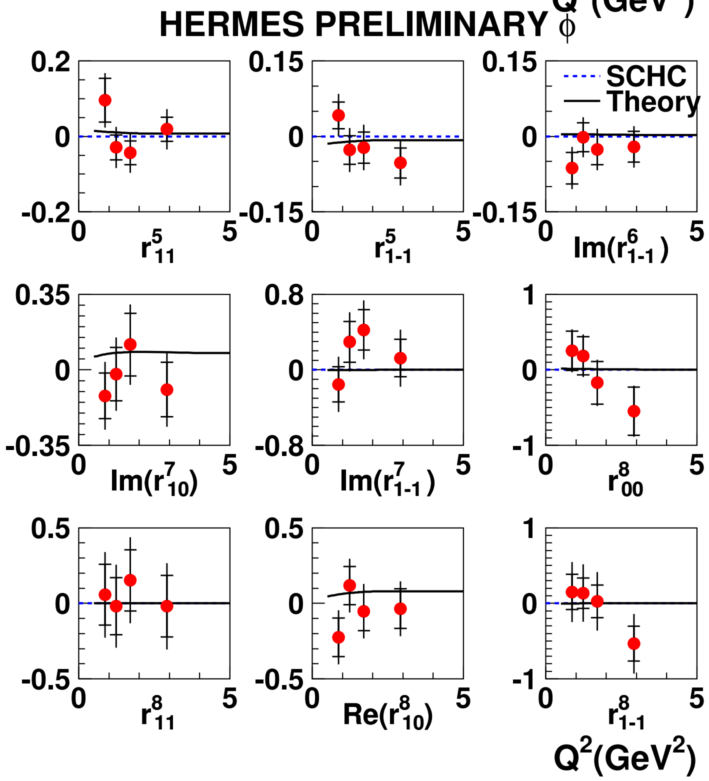
Relations predicted to be true between particular SDME's in the case of SCHC



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

SDME's of ϕ





Over all Q^2 $r^5_{00} = 0.024 \pm 0.022 \pm 0.033$, $r^5_{11} = -0.017 \pm 0.017 \pm 0.043$,

$$2r^5_{11} + r^5_{00} \approx -0.10 \pm 0.095$$

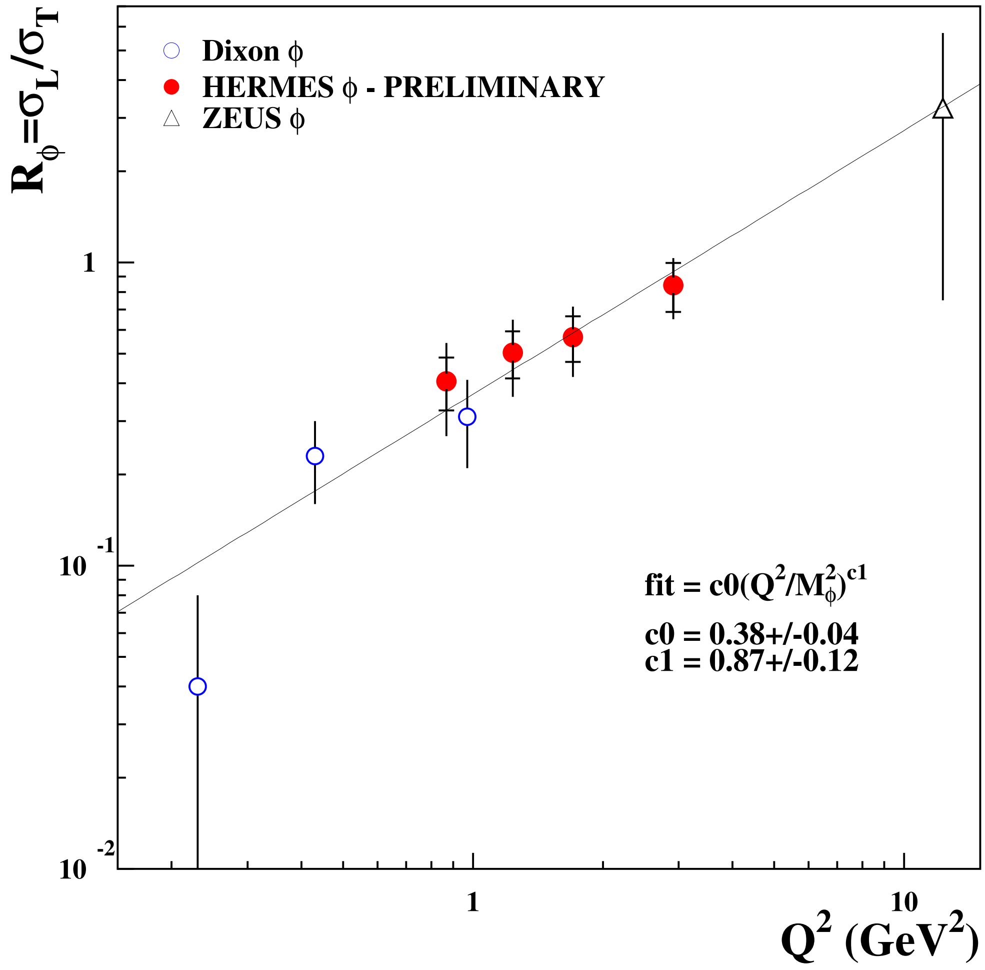
H1 [DESY 00-070] over all Q^2: $2r^5_{11} + r^5_{00} \approx 0.17 \pm 0.05$

$\rightarrow$ No disagreement.

$\rightarrow$ ϕ is consistent with SCHC and NPE at HERMES

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

Comparison with existing data

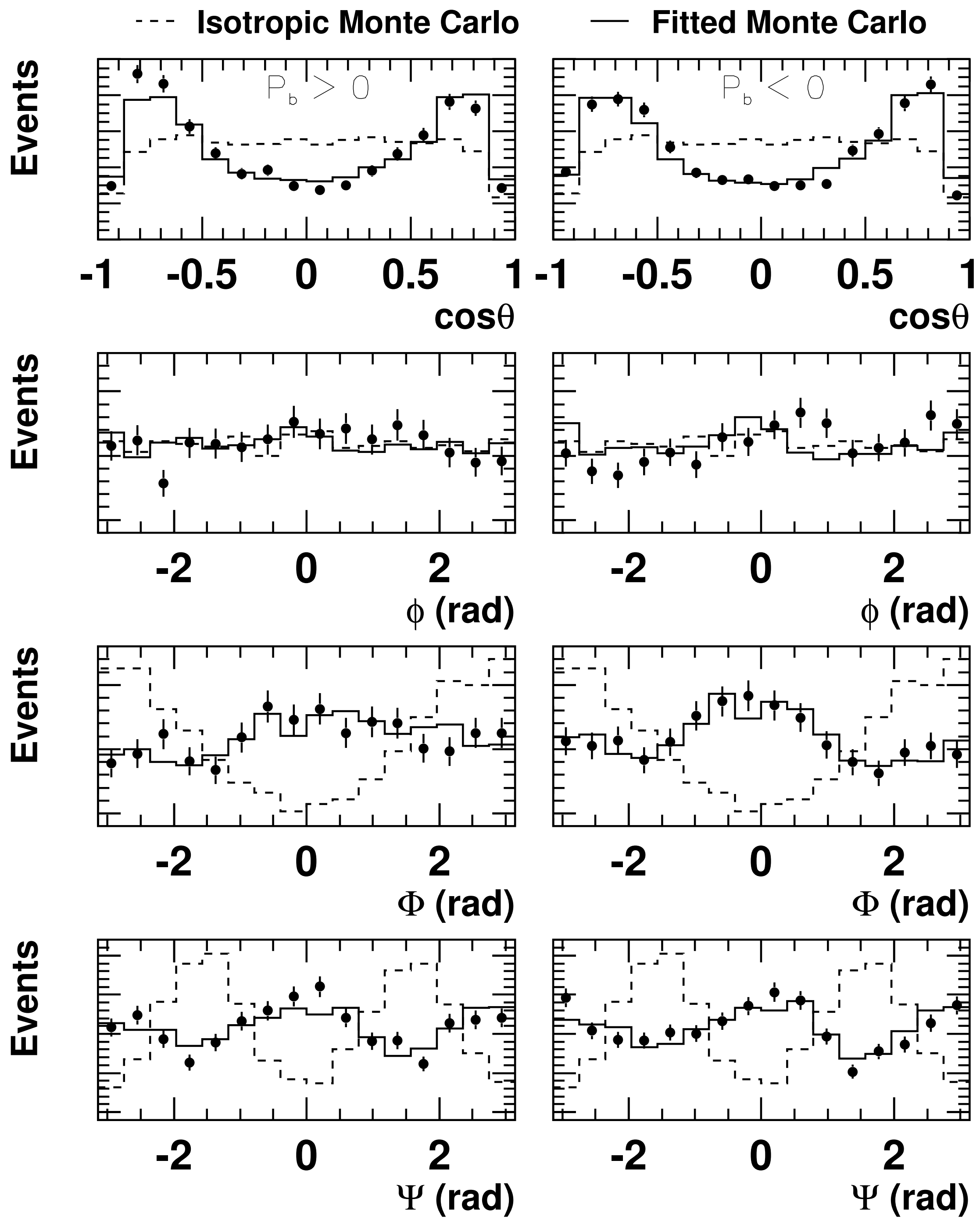


$\rightarrow$ $c1_\phi$ is consistent with VDM.

SDME's of ρ^0

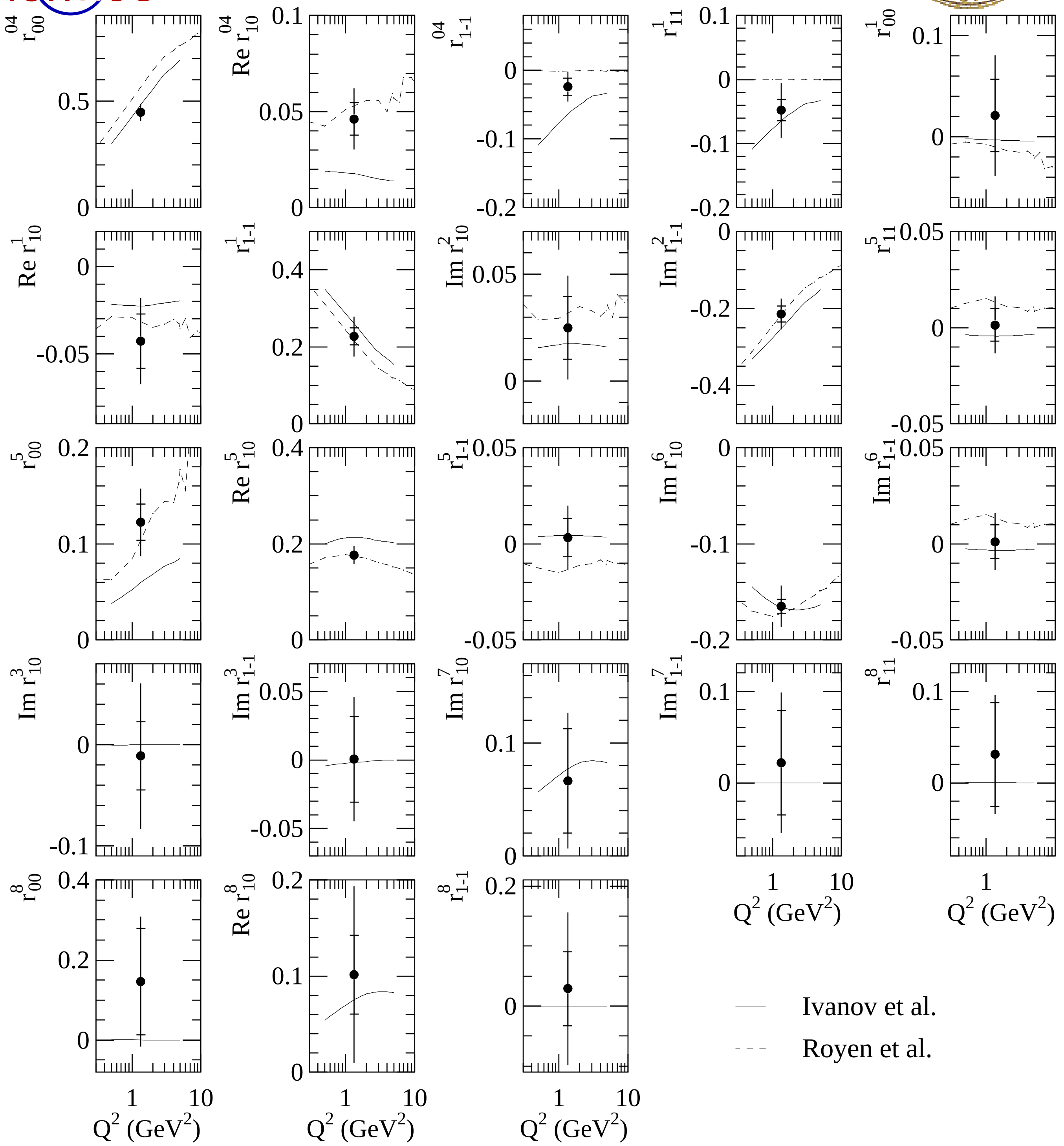
HERMES PRELIMINARY

Diffractive ρ^0 Electroproduction (^1H)



The observed distributions for $cos\Theta$, angles ϕ, Φ and Ψ for positive (a) and negative (b) beam helicity. The dotted lines show the Monte Carlo distributions obtained from isotropically generated ρ^o events, the full lines correspond to the MC distributions fitted to data with the maximum likelihood method.

SDME's of ρ^o

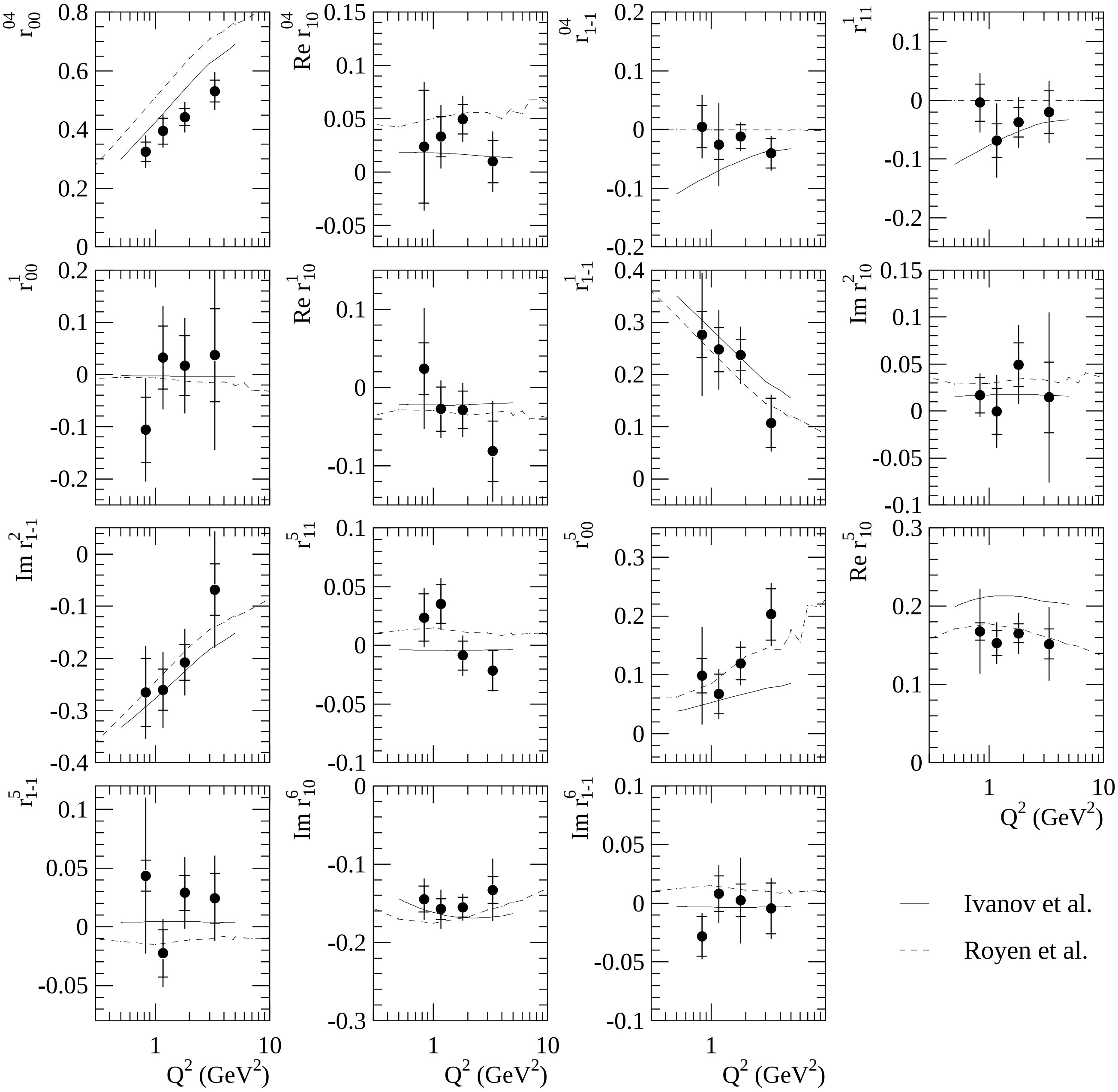


$\mid t \mid = 0.14$ GeV^2.

I.P.Ivanov, N.N.Nicolaev JETP Lett 69, (1999) 294, solid line: pQCD calculations of 2-gluon exchange, strong dependence of $\mid t \mid$, good agreement, exept underextimated r^5_{00} and Rer^{04}_{10}.

I.Royen, hep-ph/0006044, dashed line: quark off-shell model for unpolarized SDMEs, good agreement with data.

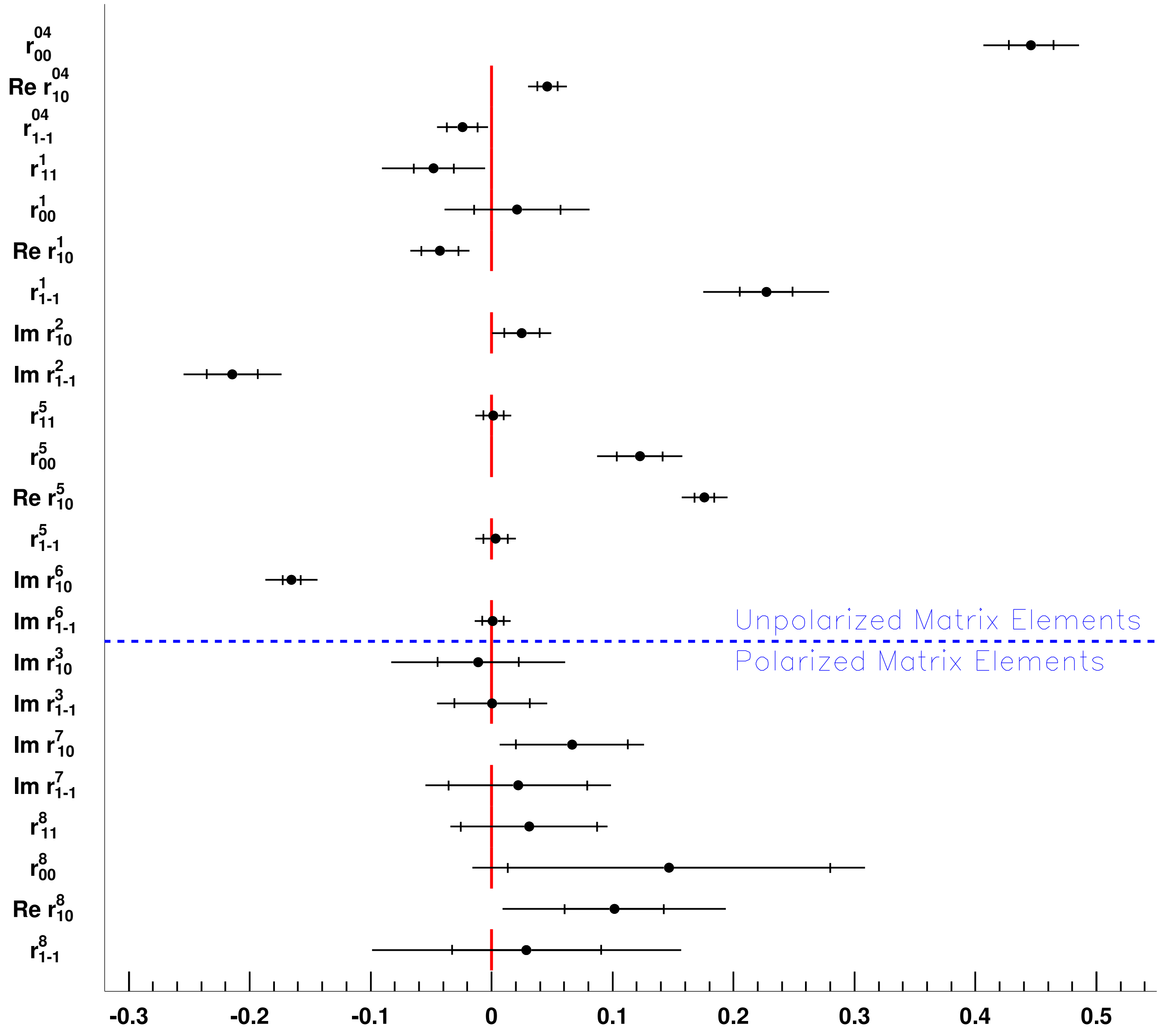
SDME's of ρ^o



SDME's of ρ^o

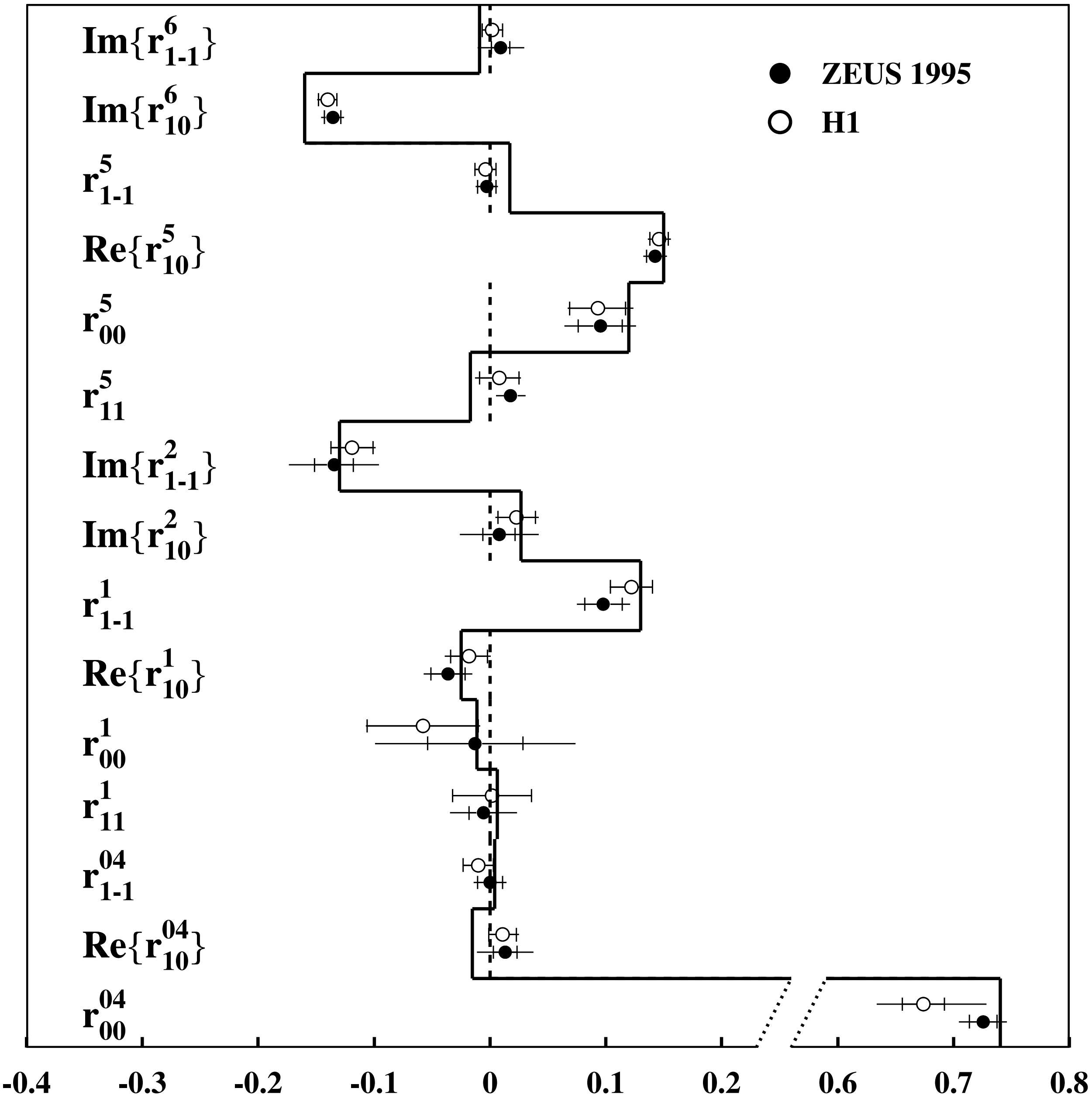
HERMES PRELIMINARY

Diffractive ρ^0 Electroproduction (^{1}H)



$\rightarrow$ r^5_{00} significantly different from 0
$\rightarrow$ small SCHC violation

SDME's of ρ^o of H1 and ZEUS

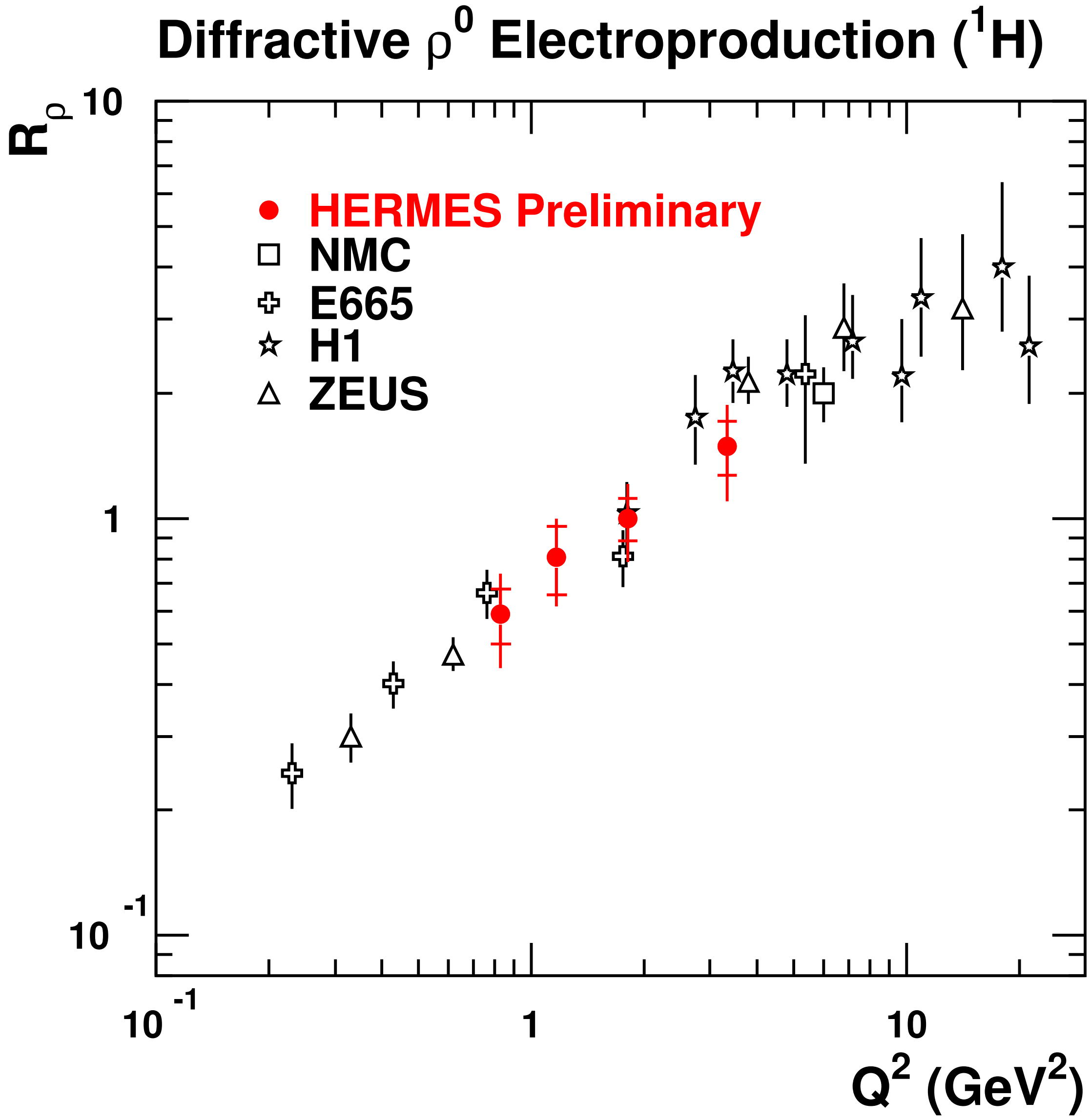


$R \equiv \sigma_L/\sigma_R$ of ρ^0

At SCHC follows ($\epsilon \equiv \Gamma_L/\Gamma_T$): $R = \frac{1}{\epsilon}\frac{r^{04}_{00}}{1-r^{04}_{00}}$

at SCHnC follows: $R = \frac{1}{\epsilon}\frac{r^{04}_{00}-\Delta^2}{1-(r^{04}_{00}-\Delta^2)}$, with $\Delta \approx r^5_{00}\sqrt{\epsilon/2r^{04}_{00}}$

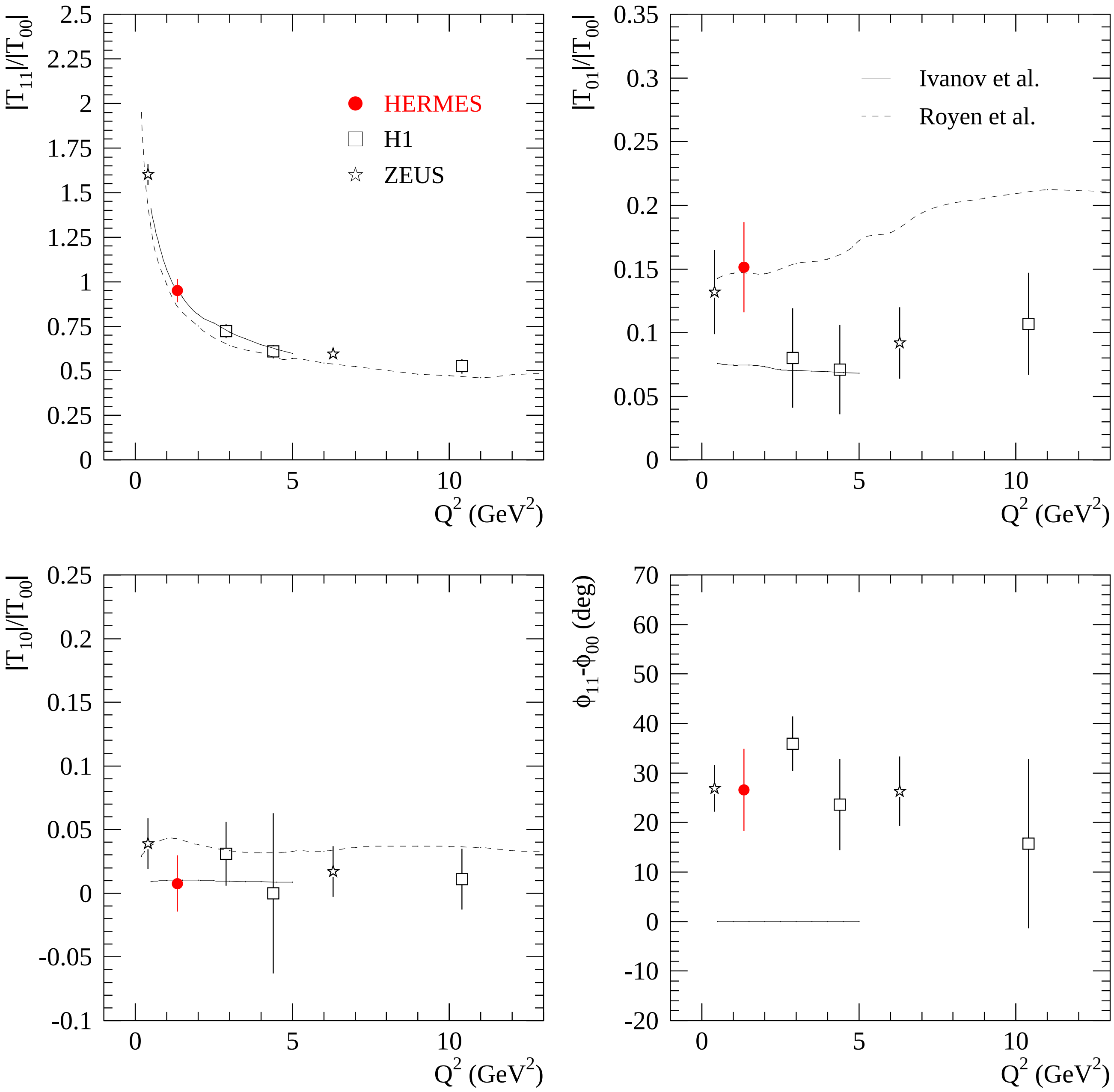
$\rightarrow$ SCHnC effects less than 10%



$\rightarrow$ No strong W-dependence

Helicity Amplitudes

Assuming natural parity exchange in t-channel next independent complex amplitudes measured

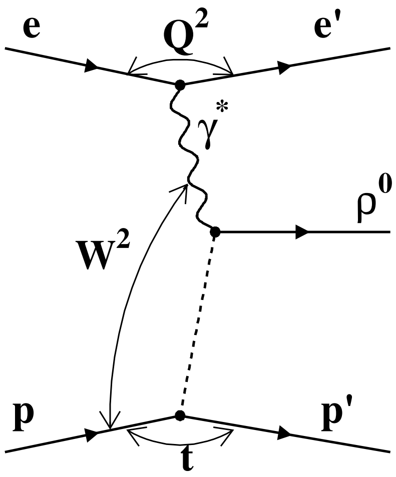


$\rightarrow$ non-zero helicity single flip amplitude T_{01}
(transverse $\rightarrow$ longitudinal)

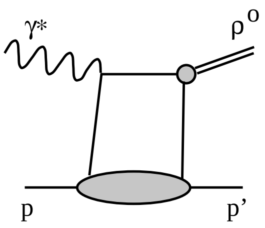
$\rightarrow$ No strong $W-$dependence

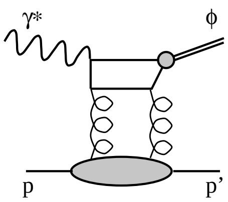
SUMMARY

Complementary $\&$ independent spin physics with longitudinaly polarized target and beam seen on top and bottom part of vector meson production diagramm: (?)



- Top:
  Agreement with high energy data on the observed SDMEs, some violation of SCHC and $R(Q^2)$-dependence.
- Bottom:
  Domination of quark exchange production mechanism of ρ^o and ω from the cross section analysis:





Agreement of measured nonzero double spin asymmetry of ρ^o virtual photoproduction with predictions based on diquark exchage. Disagreement with data at higher W.

New data from the next running perion of HERMES will be with transversely polarized targets.