DIS 99
Zeuthen
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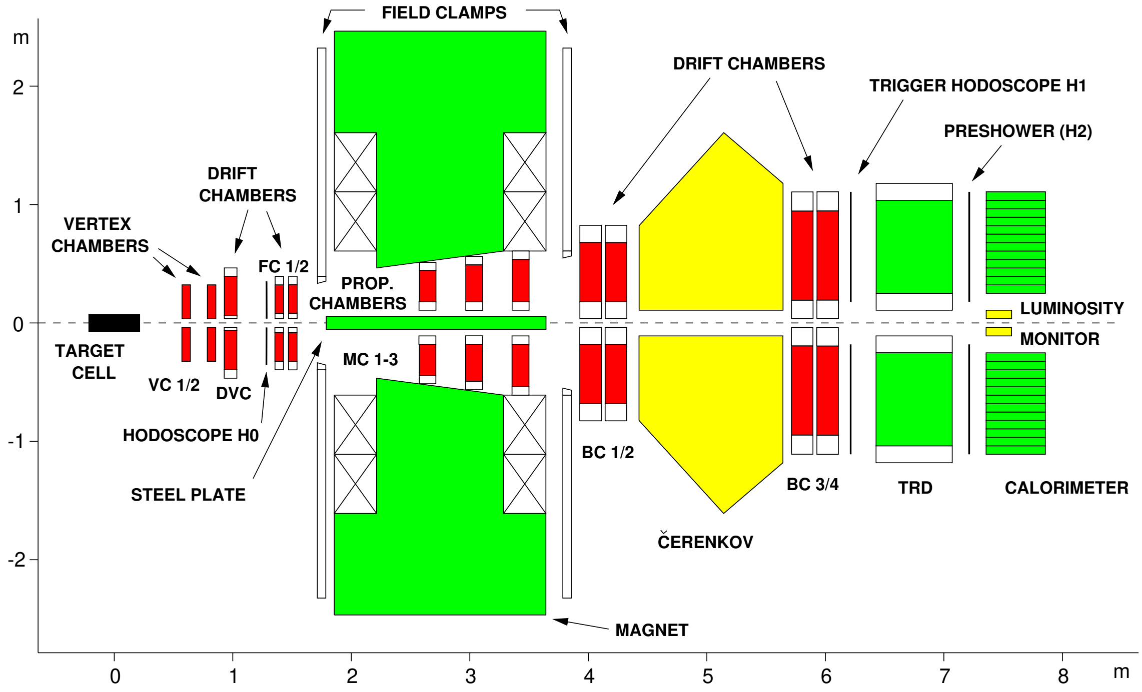
Diffractive Physics at hermes

(via Vector Meson production)

Alexander Borissov
Michigan State University
e-mail: borissov@hermes.desy.de

- The Experiment
- Overview of VM production
- ρ-Production: – coherence length effect
  – decay angular distributins
  – cross section
- 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 (5.6) GeV/c and kaons 16 (19.8) GeV/c in $'96,' 97('95)$.
- 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: $10^{14 \ldots 15}$ nucl./cm^2, polarization 90% for H/D, 50% for He^3.
  - unpolarised: $10^{15 \ldots 17}$ nucl./cm^2

Overview VM-Production

$$\begin{array}{lcll} \rho & \to & \pi^+\pi^- & (100\%) \\ \omega & \to & \pi^+\pi^-\pi^0; \quad \pi^0 \to \gamma\gamma & (88\%) \\ \phi & \to & K^+K^- & (49\%) \\ J/\psi & \to & e^+e^- & (6\%) \\ & \to & \mu^+\mu^- & (6\%) \end{array}$$

HERMES Targets:

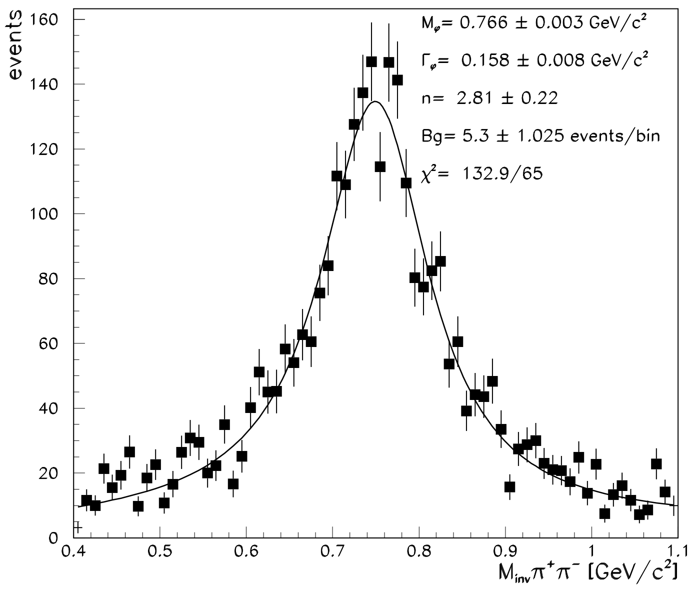
year	polarised	DIS, 10^6	unpolarised	time (weeks!)	DIS, 10^6
1995	^{3}He	$\sim$ 2.5	H, D	$\sim$ 1/2	0.5
1996	H	$\sim$ 0.9	H, D, ^{3}He	$\sim$ 2	3.6
1997	H	$\sim$ 1.9	H, D, ^{14}N	$\sim$ 3	6
1998	D		...		
...	...		...		

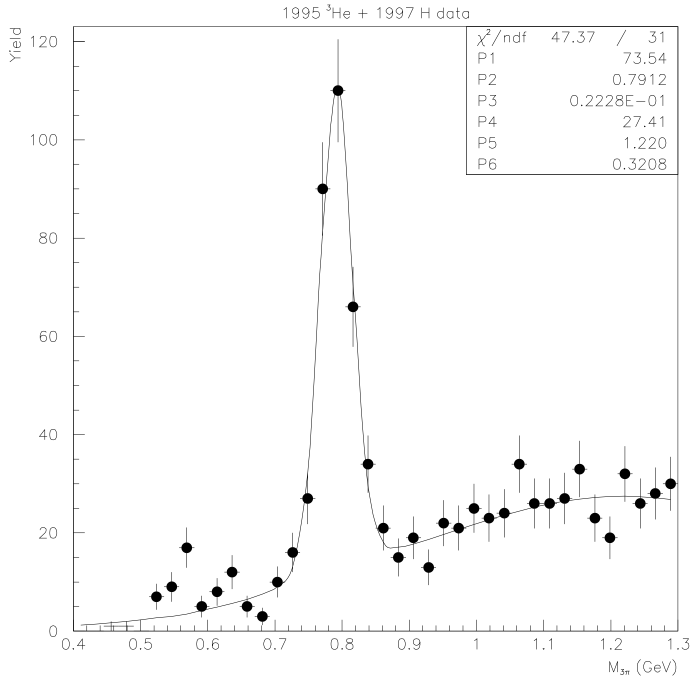
$$Luminosity \approx 22pb^{-1} * DIS/10^6$$

Approximate Elastic Event Numbers (95-97):

ρ	$\sim$ 11000
ω	$\sim$ 500
ϕ	$\sim$ 1200
J/ψ	$\sim$ 120

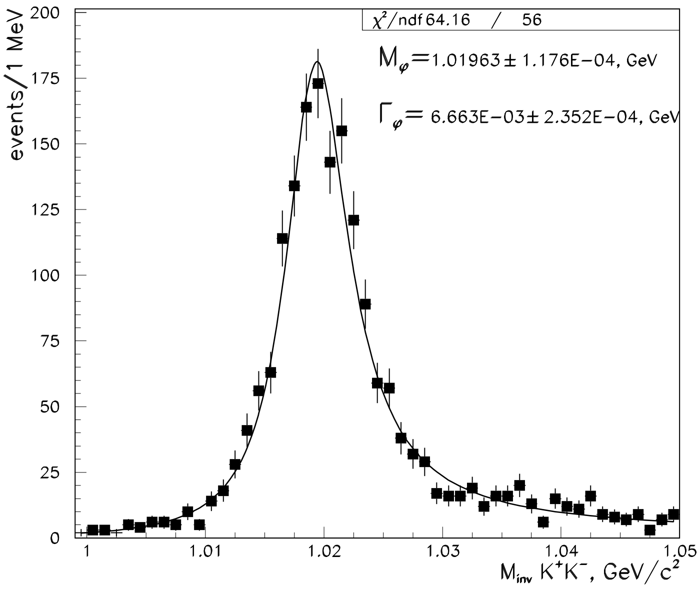
Mass Peaks

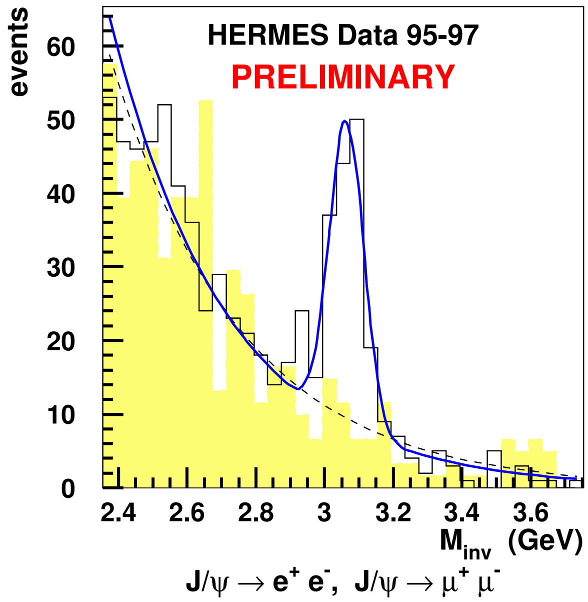




$\rho \to \pi^+\pi^-$

$\omega \to \pi^+\pi^-\pi^0; \quad \pi^0 \to \gamma\gamma$



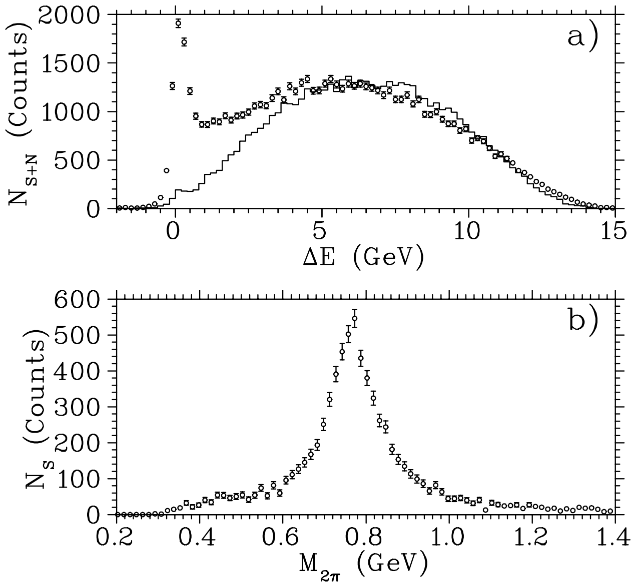


$\phi \to K^+K^-$

$J/\psi \to e^+e^-, \to \mu^+\mu^-$

J/ψ are triggered by decay products, small part of the events is detected with scattered positron.

Diffractive ρ Production



Kinematics:

$\nu = 5 \div 23$ GeV $\equiv E_e - E_{e'}$ Energy of photon in nucleon rest frame

$Q^2 = 0.5 \div 6$ GeV^2 $\equiv -q^2 = -(p_e - p_{e'})^2$ Virtuality of photon

$W = 3.5 \div 6.5$ GeV $\equiv M_p^2 + 2M\nu - Q^2$ Maximum allowed invariant mass

$x_{Bj} = 0.02 \div 0.22$

$M_{2\pi}^2 = v^2 = (p_{\pi^-} + p_{\pi^+})^2$ Reconstructed mass of ρ^0
$t = (q - v)^2$ Squared momentum transfer to target
$t_0 \equiv t(\theta_{q\rho} = 0)$ Minimum t
$t' = t - t_0 \sim p_t^2$
$\Delta E = \nu - E_{2\pi} + t/2M_T = 0$ Missing energy for exclusive production

Main cuts:

select ρ mass:	0.6 GeV $<$	$M_{2\pi}$	< 1 GeV
eliminate ϕ background:	1.04 GeV $<$	M_{2K}	
select exclusive ρ's:	-2 GeV $<$	ΔE	$< 0.6(0.4)$ GeV
select diffractive process:		$-t'$	< 0.4 GeV^2

Note similar cuts for diffractive ϕ and ω selection.

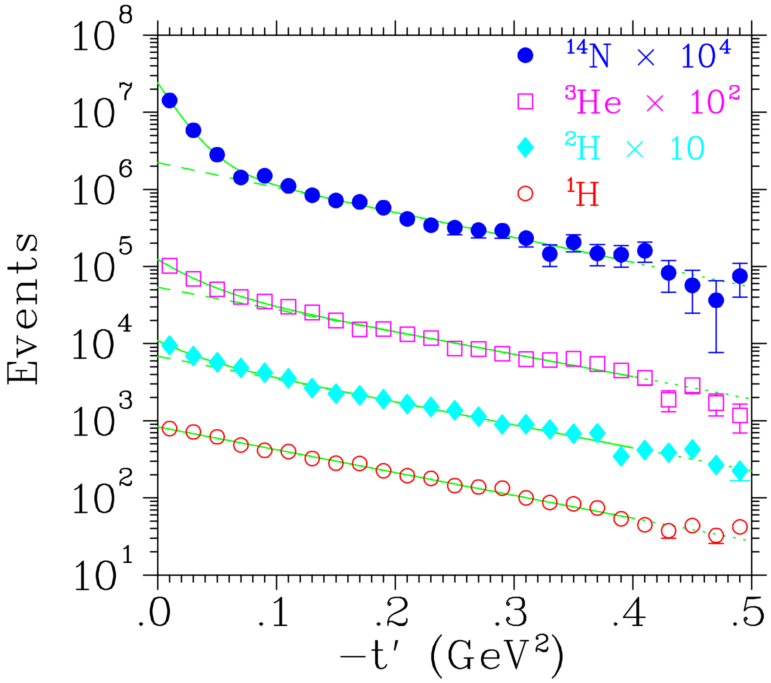
Coherence Length Effect

(K. Ackerstaff et al.(HERMES), Phys. Rev. Lett. 82 (1999) 3025.)

was measured as Nuclear Transparency $T_A(l_c)$. T_A is the reduction of incoherent exclusive cross section in nuclear medium due to initial and final state interactions:

$$T_A = \frac{\sigma_A}{A\sigma_H} = \frac{N_A L_H}{A N_H L_A} < 1$$

- L_A is the luminosity determined from the DIS rate
- N_A is the number of exclusive events at $t'_l < -t' < 0.4\ GeV^2$
  - chosen $t'_l = 0.02 - 0.09\ GeV^2$ for each $A > 1$ so that coherent contribution $\leq 5\%$
  - non-exclusive background is subtacted by $-2 < \Delta E < 0.6\ GeV$ cut



Distribution of momentum transfer t' for exclusive events from ^{1}H, ^{2}H, ^{3}He, and ^{14}N targets. The solid curves are fits to $a_N(b_N e^{b_N t'} + f_A b_A e^{b_A t'})$, the dotted lines are extrapolations beyond the fit interval $-t' < 0.4$ GeV^2, and the dashed lines are the inferred incoherent contributions $a_N b_N e^{b_N t'}$.

$T_{2_H} = 0.970 \pm 0.024_{stat} \pm 0.040_{syst}$

$T_{3_{He}} = 0.862 \pm 0.042_{stat} \pm 0.061_{syst}$

Coherence Length Effect

- Fluctuation of $\gamma \rightarrow q\bar{q}$ state of $M_{q\bar{q}}$ and its propagation distance or coherence length $l_c = 2\nu/(Q^2 + M_{q\bar{q}}^2)$
- HERMES kinematics matches nuclear dimensions:
  at $0.4 < Q^2 < 6\ GeV^2$, $9 < \nu < 20$ GeV

$$0.6 < l_c < 8 \text{ fm.}$$

$$R_A = 2.1, 1.9, 2.5 \text{ fm for } {}^2H, {}^3He, {}^{14}N$$

(consistent with measured coherent slope $b_A \approx R_A^2/3$)

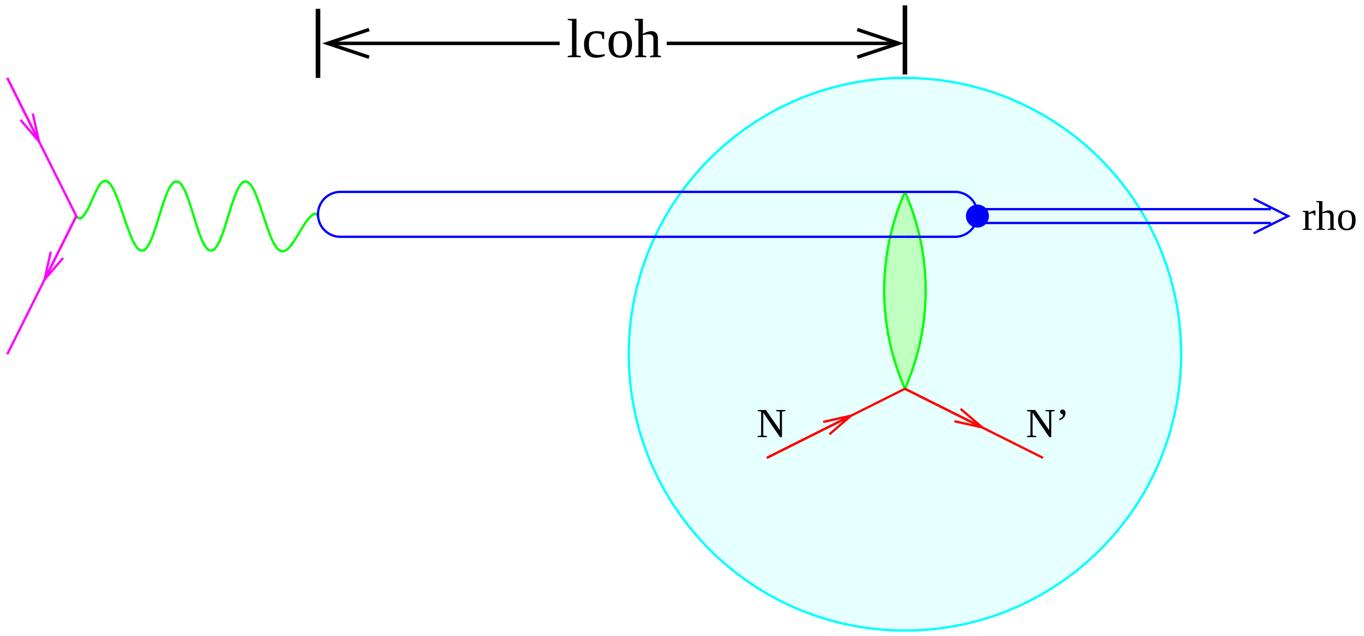
$\rightarrow$ Variations of ν, Q^2 and A allow to probe nuclear effects:

- Strong hadronic initial state interactions (ISI) of $q\bar{q}$ states with the nuclear medium on distance l_c are small at $l_c \ll R_A$ and saturated at $l_c \gg R_A$.`
- Final state interactions (FSI) only reduce T_A from unity at $l_c \ll R_A$

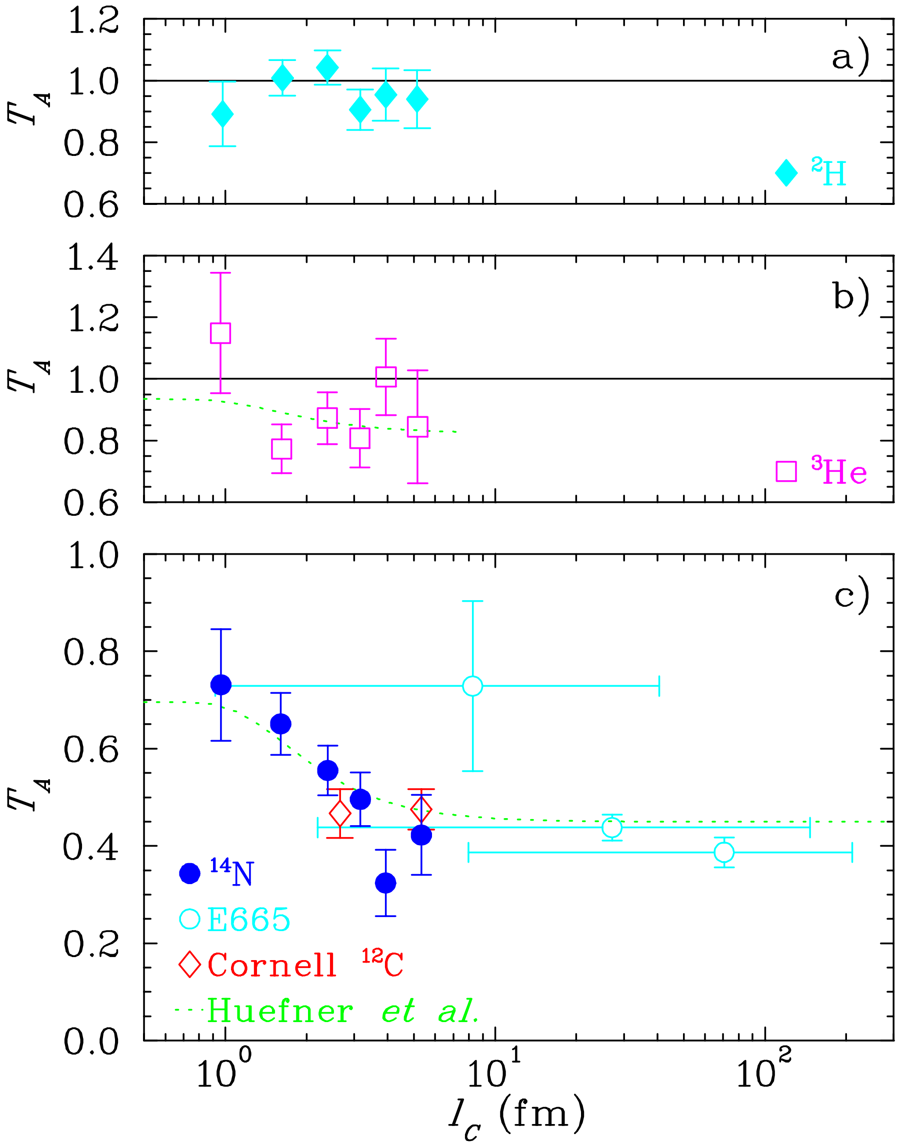
$$T_{FSI} \approx T_{1_{4N}}(l_c < 1.8 fm) = 0.681 \pm 0.060$$

- So when $l_c \gg R_A$

$$T_{ISI}T_{FSI} \approx T_{1_{4N}}(l_c > 3.6 fm) = 0.401 \pm 0.054$$



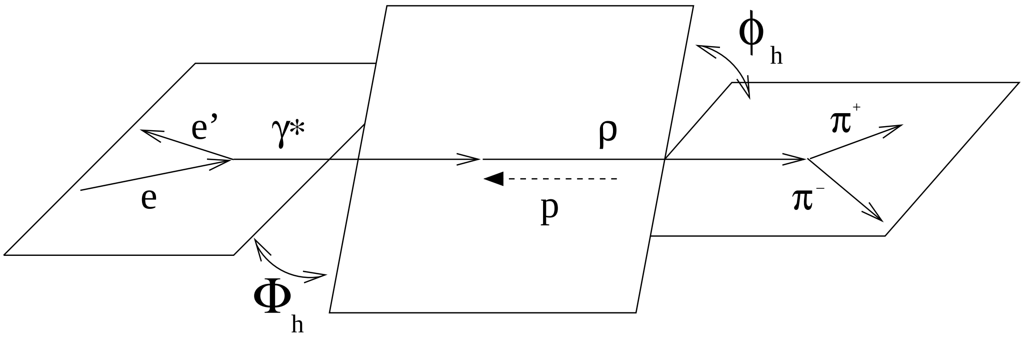
Coherence Length Effect Data

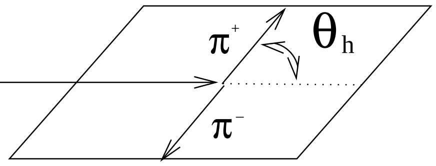


The error bars include statistical and systematical uncertainties added in quadrature. The curve is the Glauber calculation of Hüfner *et al.* that uses the standart treatment of initial and final state interactions. Panel (c) includes comparisons with previous photoproduction (open diamonds) CornellC^{12} and muoproduction (open circle) E665 experiments. Due to the acceptance for $20 < \nu < 370, GeV$, the three Q^2 bins measured by E665 correspond to broad ranges in l_c (horizontal error bars).

Direct evidence that in the lab frame the exclusive ρ is formed as a direct fluctuation on the virtual photon: the strength of the initial state interactions increases with increasing coherent length l_c of the fluctuation untiul it approximately equals the strength of the ρ^0 final state interactions.

Angular Distributions





Motivation:

- S-Channel Helicity Conservation (SCHC):
  $\rightarrow$ 2 relevant angles: θ and $\Psi \equiv \phi - \Phi$ with:

$$W(\cos\theta) = \frac{3}{4}\left[1 - r^{04}_{00} + (3r^{04}_{00} - 1)\cos^2\theta\right]$$

$$W(\Psi) = \frac{1}{2\pi}\left[1 + 2\epsilon r^{1}_{1-1}\cos 2\Psi\right]$$

$\rightarrow$ r^{04}_{00} $\sim$ longitudinal polarisation of ρ-meson
$\rightarrow$ r^{1}_{1-1} $\sim$ linear polarisation of ρ-meson.

- From natural parity exchange in the t-channel follows:

$$r^{1}_{1-1} = \frac{1}{2}(1 - r^{04}_{00})$$

- With $\epsilon \equiv \Gamma_L/\Gamma_T$ follows:

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

Angular Distributions Data

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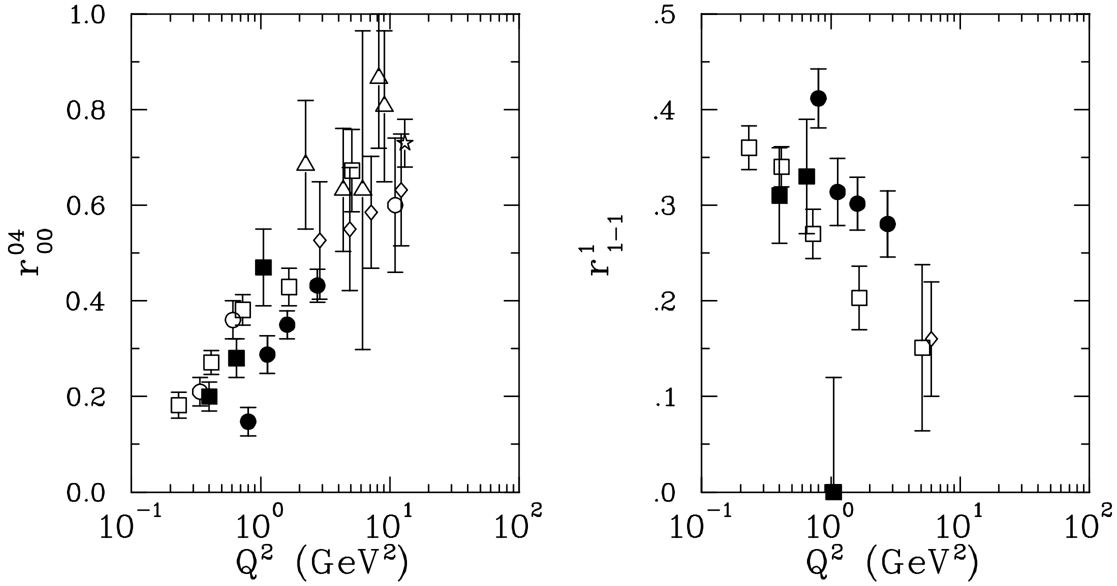
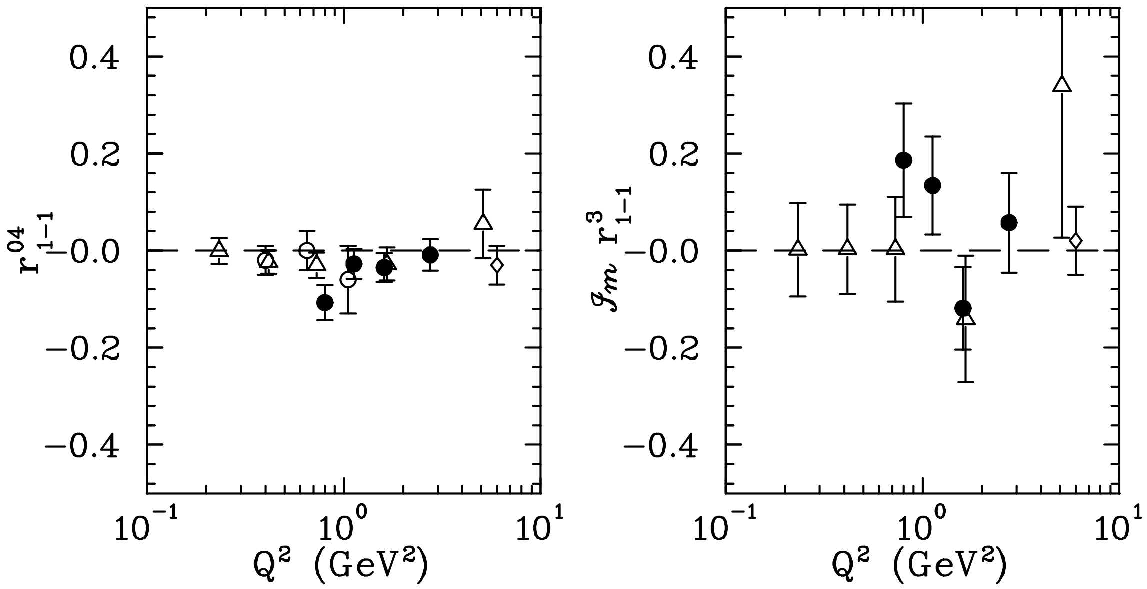


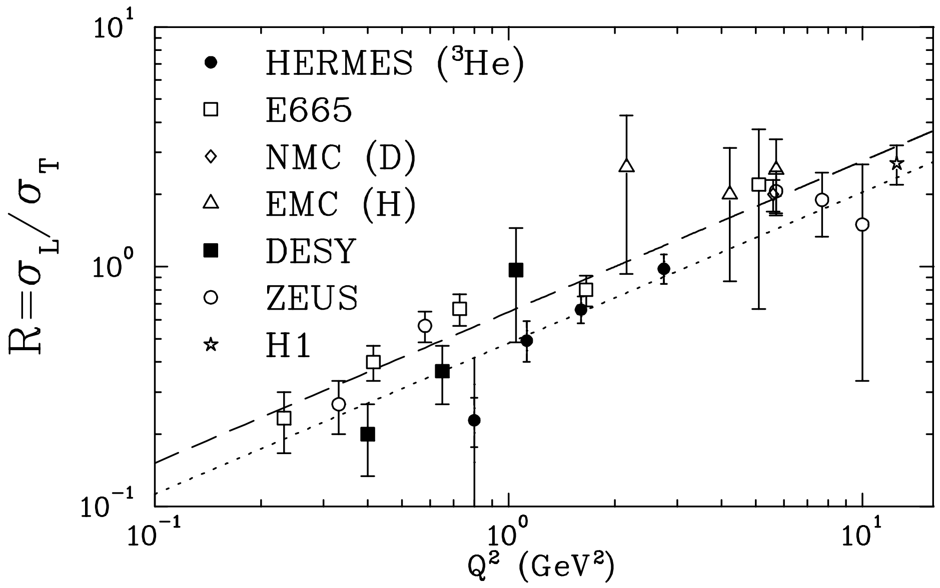
Measured r^{04}_{00} and r^{1}_{1-1} are full circles with statistical errors only. Previous measurements (with statistical errors only) from DESY, NMC, EMC, ZEUS and H1 are shown for comparison.



Measured r^{04}_{1-1} and $\mathrm{Im}(r^{3}_{1-1})$ are full circles with statistical errors only. Previous measurements (with statistical errors only) from DESY, NMC and ZEUS are shown for comparison.

Consistent with SCHC and
natural parity exchange in the $t-$channel.

Data of $R \equiv \sigma_L/\sigma_T$



$R = \sigma_L/\sigma_T$ determined from the measurement of r^{04}_{00}. The lowest Q^2 point includes a point-to-point systematic uncertainty, all other errors bars are statistical only. The inner error bar represents the statistical error. The outer error includes the systematic error added linearly. Previous measurements are shown for comparison. The dashed (dotted) line represents a simultaneous fit according to fit of the world data to data with average W above (below) 10 GeV:

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

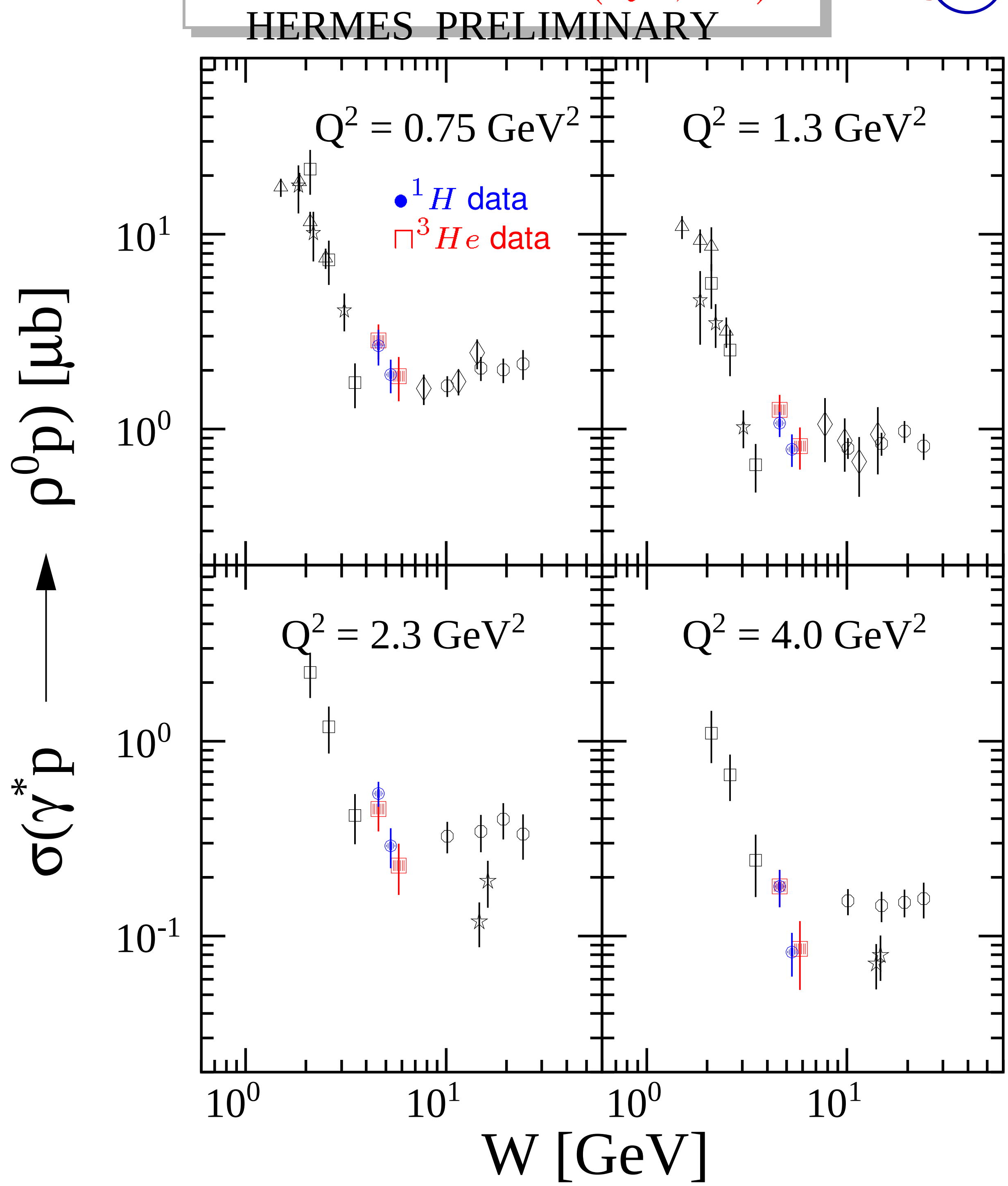
Two values of c_0: one for the data from high energy muon beams and collider experiments spanning $6 < W < 140$ GeV (EMC, NMC, E665, Zeus, and H1), and another for data with lower beam energy covering $2 < W < 6.5$ GeV (DESY and HERMES), yielding:

$$c_0 = \begin{cases} 0.47 \pm 0.03 & (\langle W \rangle > 10 \text{ GeV}) \\ 0.35 \pm 0.03 & (\langle W \rangle < 10 \text{ GeV}) \end{cases}$$

$$c_1 = 0.62 \pm 0.04.$$

As observed in previous experiments, the Q^2 dependence of R is in marked disagreement with the VDM prediction $c_1 \equiv 1$, consistent with previous experiments, and suggest enhanced transverse strength at lower energy for fixed Q^2.

Cross Section (Q^2, W)

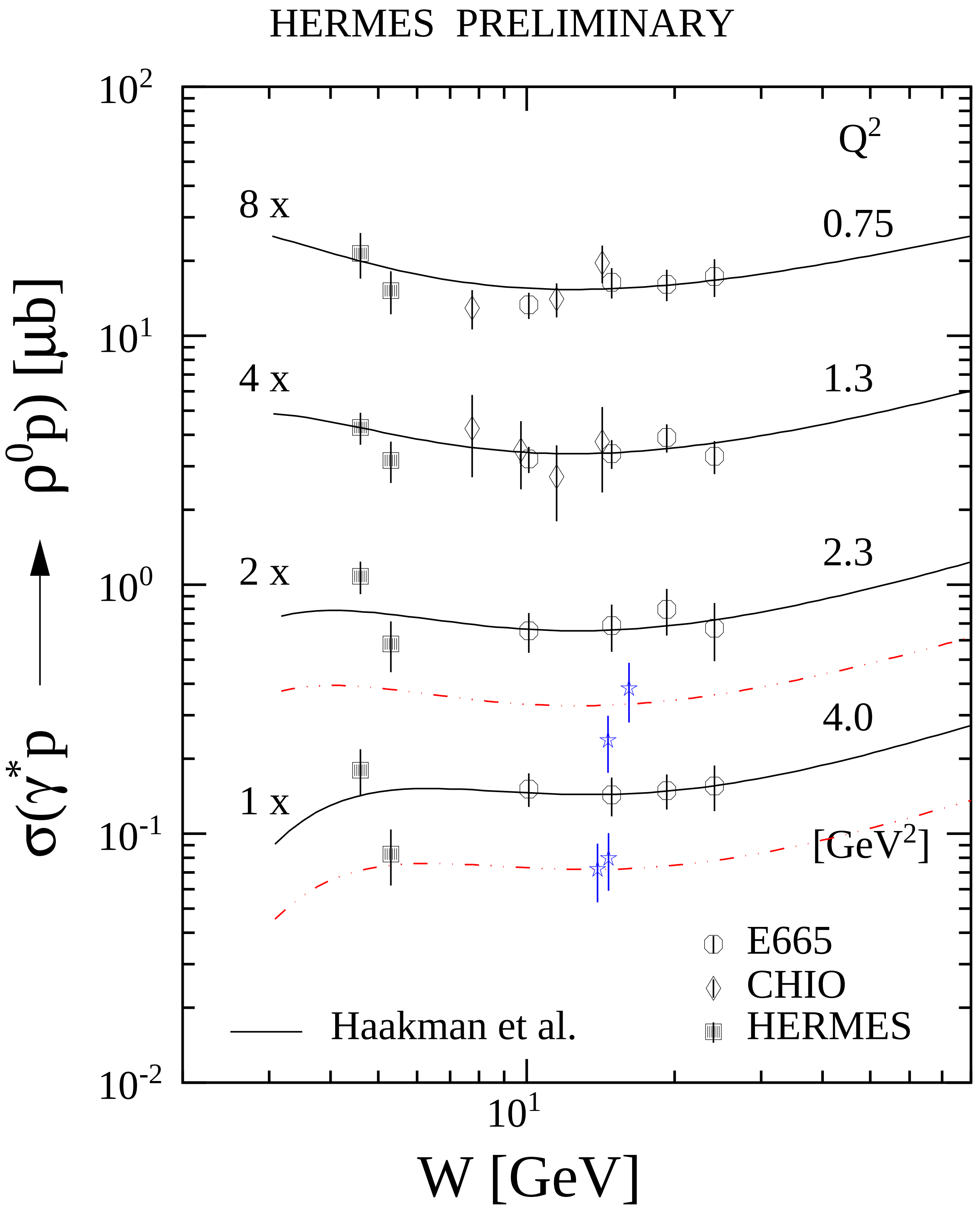


The error bars represent both the statistical and systematic uncertainties added in quadrature.

The open squares are from D.G.Cassel et al.,Phys.Rev.D **24** (1981)2787,
open triangles from P.Joos et al., Nucl.Phys. B **113** (1976) 53,
open stars C. from del Papa et al., Phys.Rev. D **19** (1979) 1303,
open diamonds from W.D. Shambroom et al.,Phys. Rev. D **26** (1982),
open circles from M.R.Adams et al. (E665),Z.Phys.C **74** (1997) 237,
closed stars from M. Areneodo et al.(NMC),Nucl.Phys.B **429** (1994) 503.

Cross Section (Q^2, W)

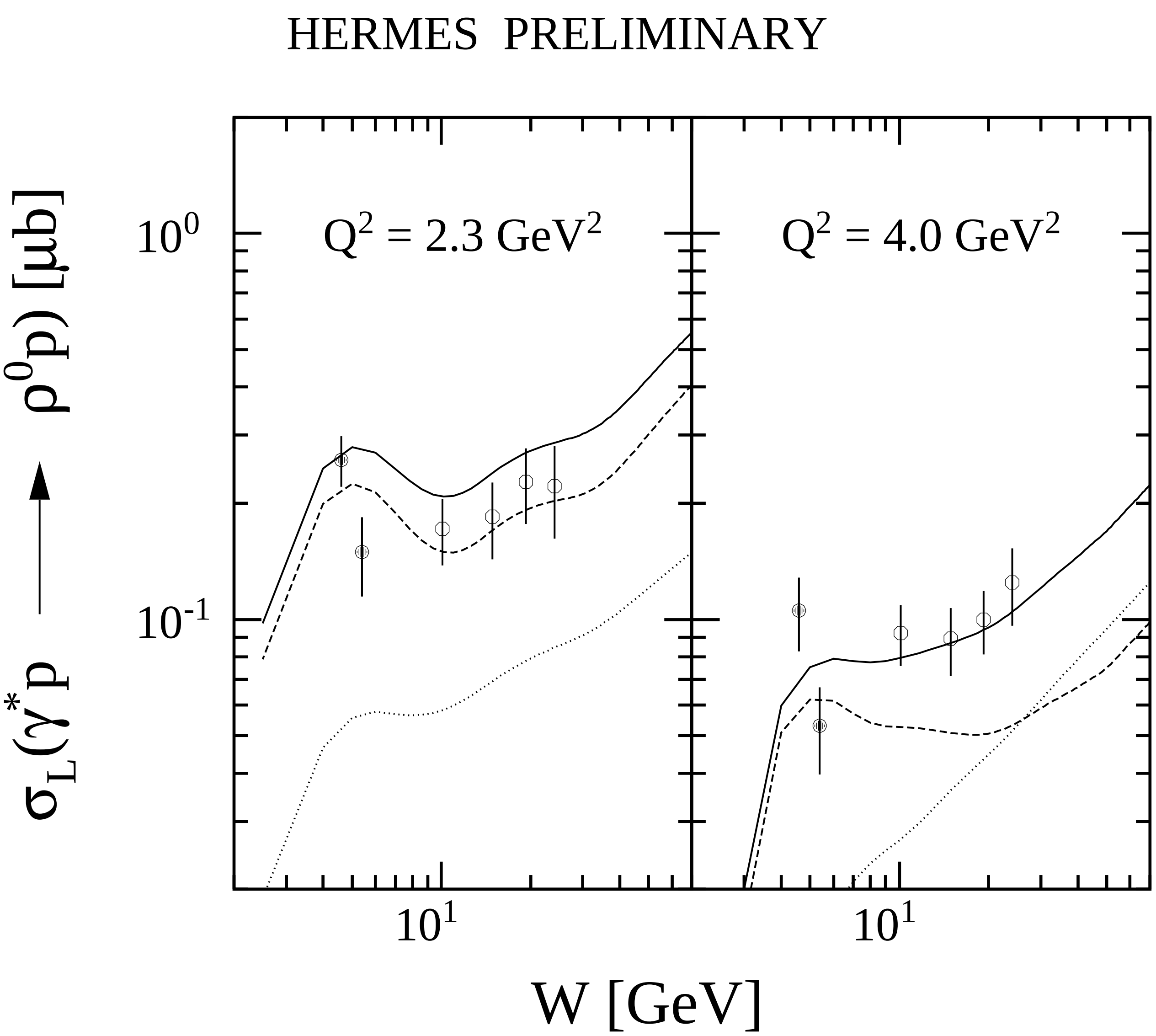
Comparison with Reggeon based calculations



Lines from L.P.A.Haakman, A.Kaidalov, J.H.Koch, Phys.Lett.B **365** (1996) 411.
Open stars from Areneodo et al.(NMC),Nucl.Phys.B **429** (1994) 503.

Longitudinal Cross Section

Comparison with recent pQCD calculations

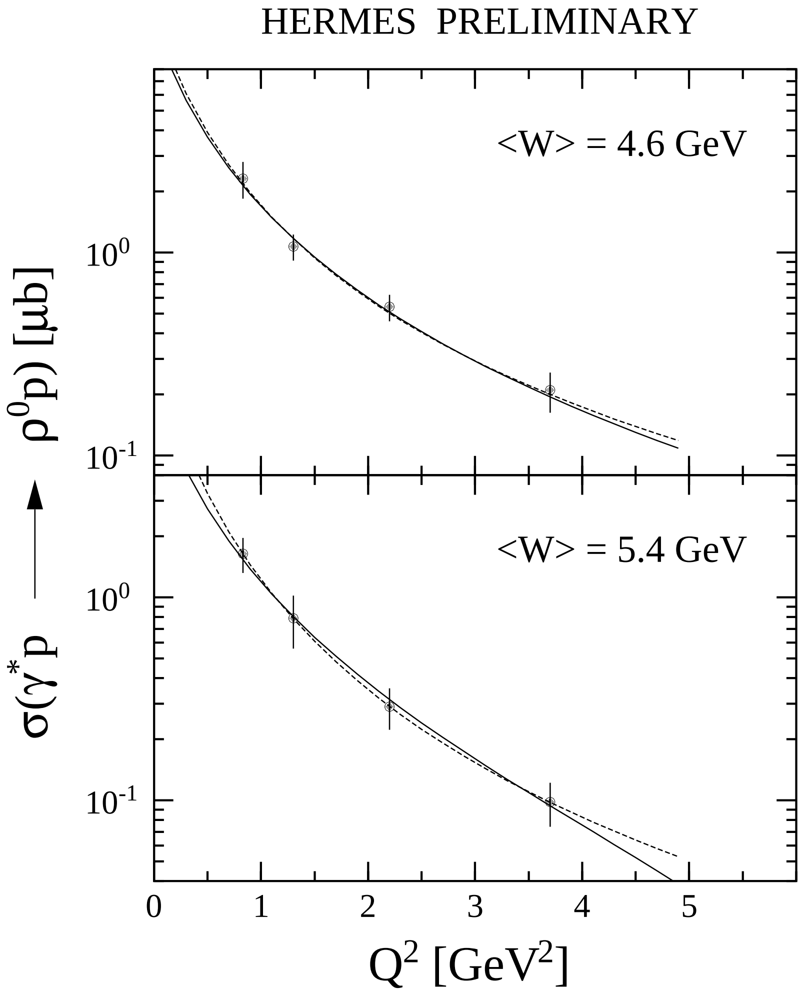


Black circles are from HERMES, open from M.R.Adams et al. (E665),Z.Phys.C **74** (1997) 237,

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

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

Fits of Q^2 dependence

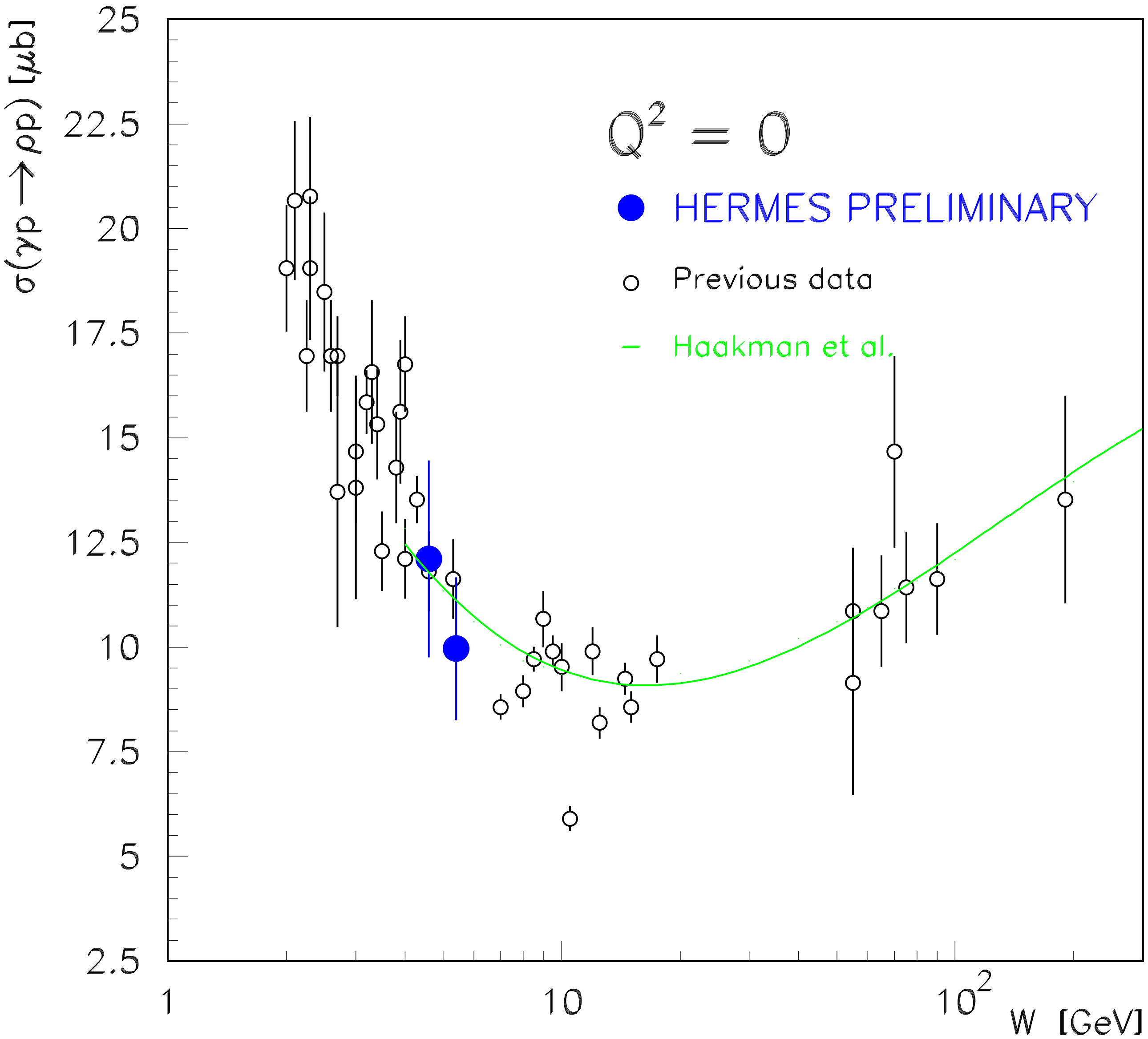


Solid line fit $$\sigma(Q^2) = \sigma(Q^2=0) \cdot \left(\frac{m_\rho^2}{Q^2+m_\rho^2}\right)^2 \cdot (1+\epsilon \cdot \xi^2 Q^2/m_\rho^2)$$

Dashed line fit $$\sigma(Q^2) = \sigma(Q^2=0) \cdot \left(\frac{m_\rho^2}{Q^2+m_\rho^2}\right)^m \cdot (1+\epsilon R_{data}(Q^2))$$

$< W >, GeV$	$\sigma(Q^2=0)$ (μb)	ξ^2
4.6	12.11 $\pm$ 2.35	-0.02 $\pm$ 0.06
5.4	9.96 $\pm$ 1.71	-0.12 $\pm$ 0.040
$< W >, GeV$	$\sigma_(Q^2=0)$ (μb)	m
4.6	12.38 $\pm$ 3.79	2.39 $\pm$ 0.22
5.4	14.96 $\pm$ 4.86	2.83 $\pm$ 0.24

Photoproduction Cross Section



Previous data: The European Physical Journal C2 (1998) 247.

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

SUMMARY

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- Coherence length effect shows clear evidence of the interaction of $q\bar{q}$ pairs within the nuclear medium.

- Angular distributions of ρ^0

  - consistent with SCHC and natural parity exchange
  - ratio $R(Q^2) = \sigma_L/\sigma_R$ is different from VDM predictions

– R argees and adds data sample at $W < 10$ GeV.

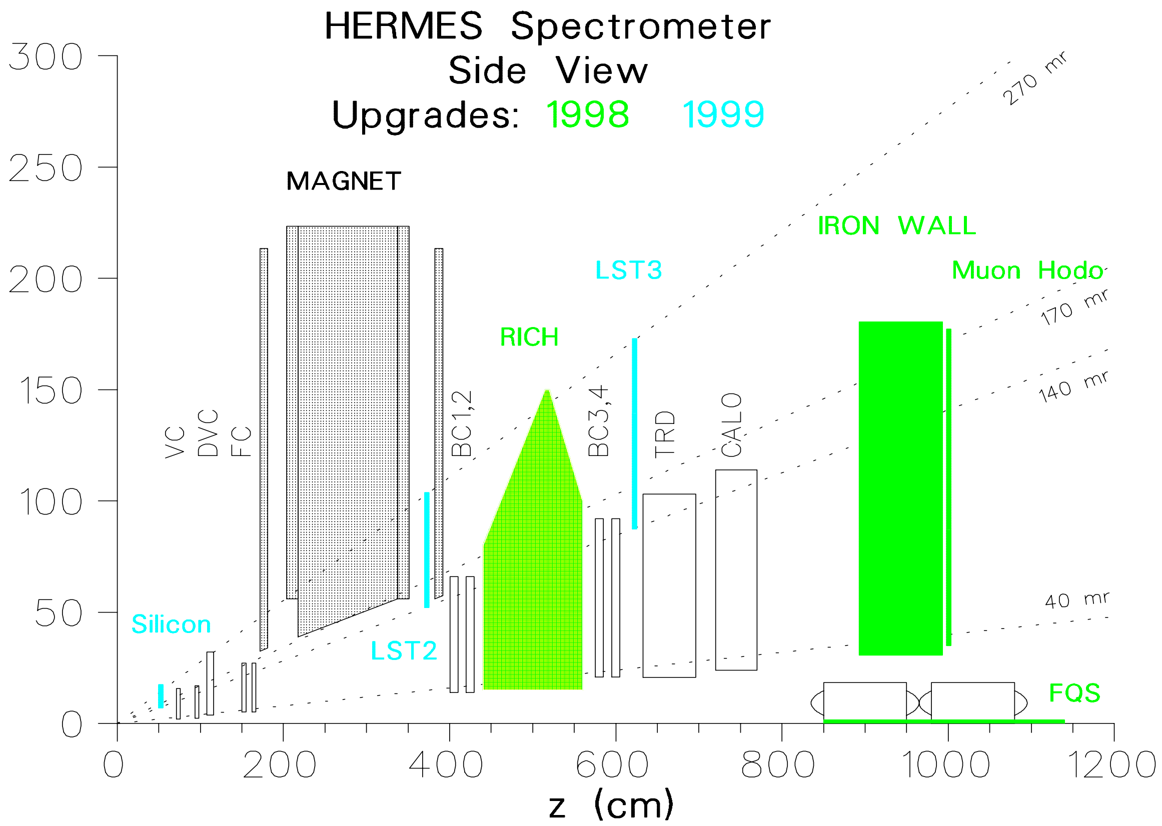
- Cross section

  - decrease with W and
  - general agreement with world data at intermediate W values observed
  - agrees with Reggeon based calculations of L.Haakman et al.
  - comparison of σ_L with OFPD calculations shows reasonable agreement
  - fits of Q^2 dependence disagree with VDM predictions
  - $\sigma_{\gamma p \to \rho^o p}(Q^2 = 0)$ agrees with world data and theoretical calculations.

OVERLOOK

- Vector-Dominace Model is not applicable at HERMES kinematics
- From W dependence of cross section it follows that Pomeron exchange mechanism strongly suppressed

$\rightarrow$ HERMES data are in the transition region where quark exchange mechanism comes to be dominating, at least for longitudinal component of cross section.



→ new interesting data are expected