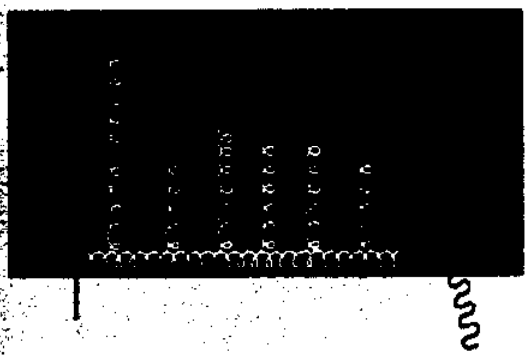


DIS97

Chicago, Illinois, USA
April 14-18, 1997

EXCLUSIVE VECTOR MESON PRODUCTION AT HERA

Frank Gaede
MPI für Physik München

for the H1 Collaboration

- introduction
- experimental results in photoproduction and at high Q^2
- conclusion

introduction

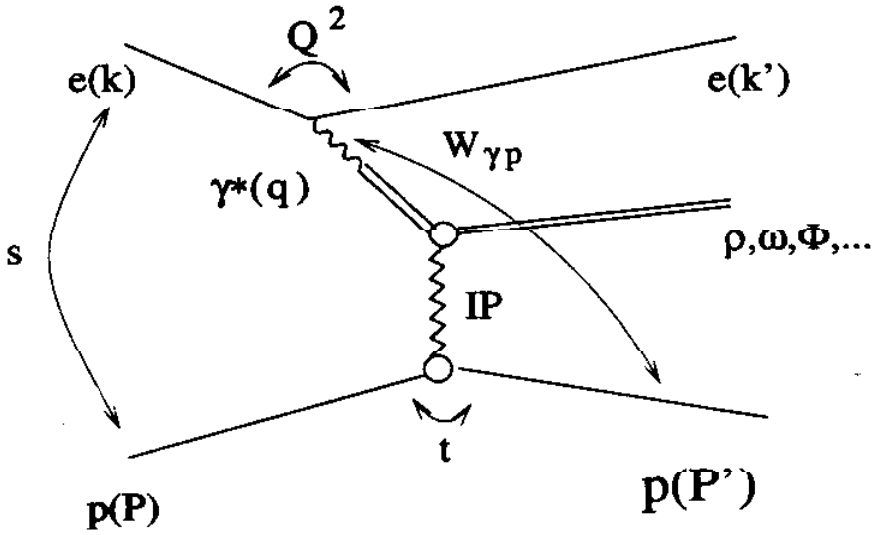
- different theoretical predictions for the dependence on kinematic varibales of the differential cross sections
  - phenomenological model:
    Regge theory – pomeron exchange
  - perturbative QCD calculations
- which is the appropriate description at HERA energies ($W_{\gamma p} \approx 100\ GeV$) ?
- analysed decay modes

$$\begin{aligned} \rho^0 &\rightarrow \pi^+\pi^- \\ (\omega &\rightarrow \pi^+\pi^-\pi^0) \\ \phi &\rightarrow K^+K^- \\ J/\Psi &\rightarrow l^+l^- \ (l = e, \mu) \\ \Psi' &\rightarrow J/\Psi\ \pi^+\pi^- \\ \rho' &\rightarrow \pi^+\pi^-\pi^+\pi^- \end{aligned}$$

- study transition region from soft to hard physics on two scales:
  mass of the vector meson
  virtuality of the photon Q^2

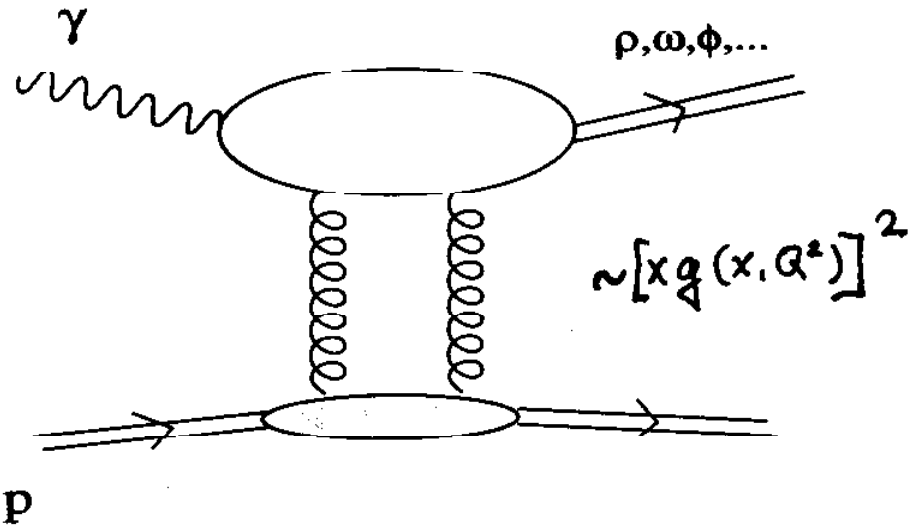
kinematics and production mechanisms

- Regge model - pomeron exchange (VDM)



(Donnachie - Landshoff)

- pQCD models



(Brodsky et.al.,Ryskin,...)

dependence on kinematic variables

- $W_{\gamma p}$

$$\frac{d\sigma}{dt}|_{t=0} \propto W_{\gamma p}^{4*0.0808} \quad \text{(REGGE)}$$

$$\frac{d\sigma}{dt}|_{t=0} \propto \frac{[x\ g(x,Q^2)]^2}{Q^6} \quad \text{(pQCD)}$$

$$W_{\gamma p}^2 = \frac{1-x}{x}Q^2 \rightarrow \propto W_{\gamma p}^{\approx 4*0.2}$$

- Q^2

$$\frac{d\sigma}{dQ^2} \propto (m_{VM}^2 + Q^2)^{-n} \quad (n \approx 2-3)$$

- t

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

$$b = b_0 + 4\,\alpha\prime\, ln\frac{W_{\gamma p}}{W_0} \quad \text{(REGGE)}$$

$\rightarrow$ shrinkage

(pQCD) little prediction, if then small shrinkage

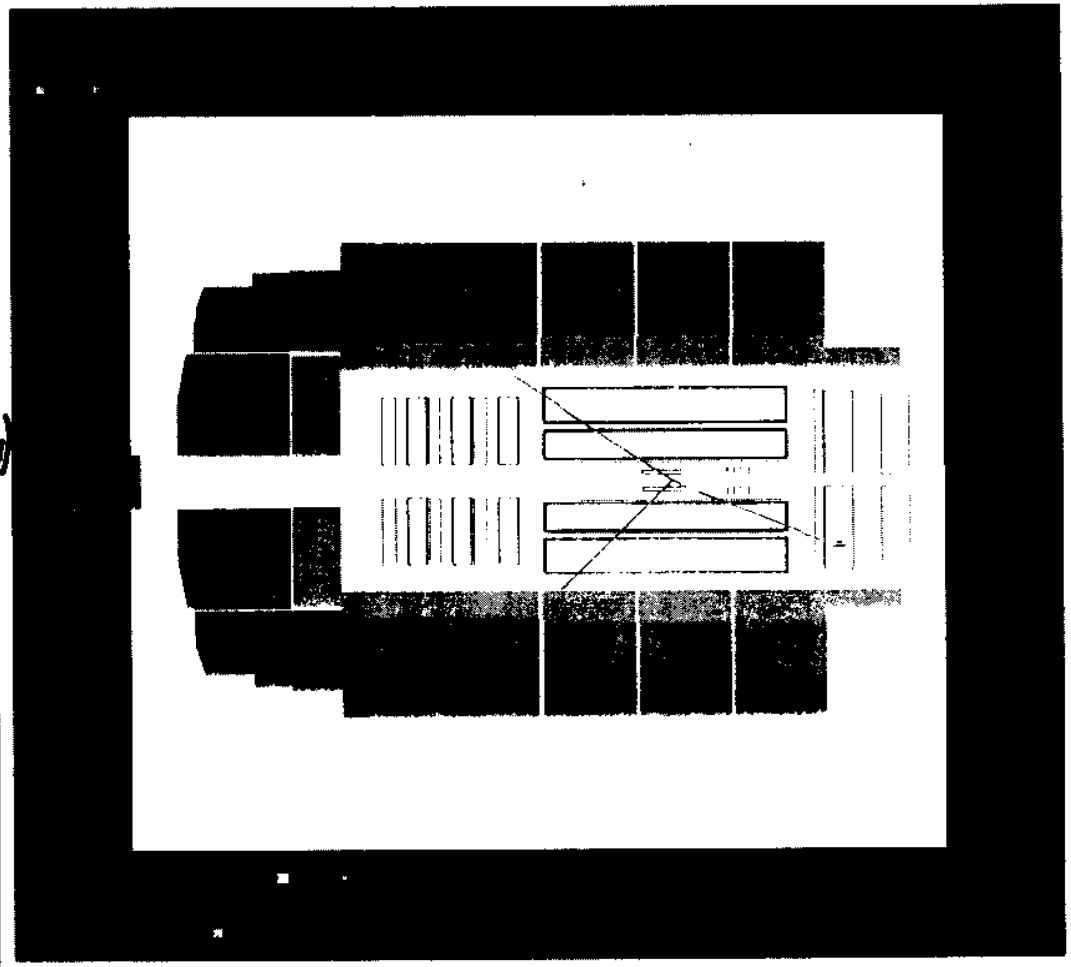
- decay angular distribution

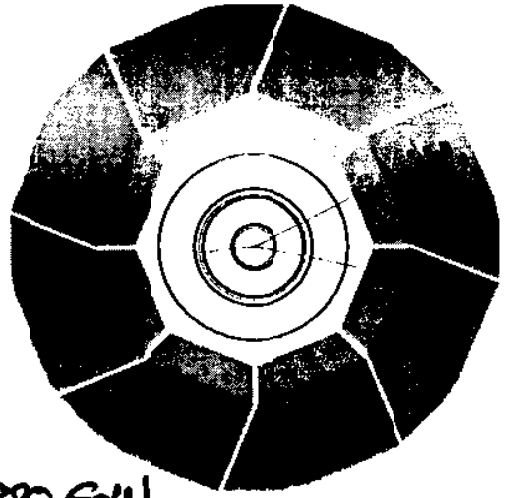
$$\frac{d\sigma}{d\ cos(\Theta^*)} \propto (3\ r_{00}^{04} - 1)\ cos^2(\Theta^*) + (1 - r_{00}^{04})$$

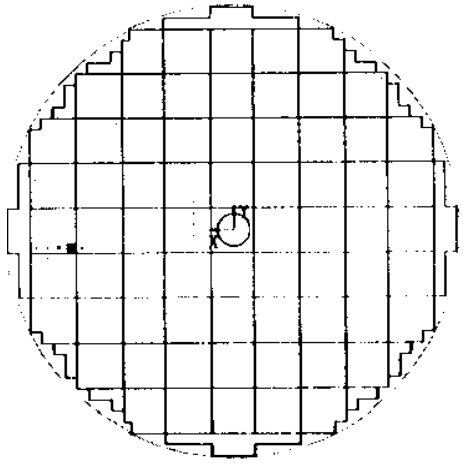
$(SCHC)$

Run 120704 Event 3250 Class: 3 11 15 20 22 24 Date 16/05/1996

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







R

Z

H1

common analysis cuts

- exact two charged tracks in central tracker with unlike signs, fitted to the primary vertex (+ 1 track for the scattered electron)
- no additional energy deposition in calorimeters
- forward cuts against proton dissociation
  no signal (above noise) in forward detectors:

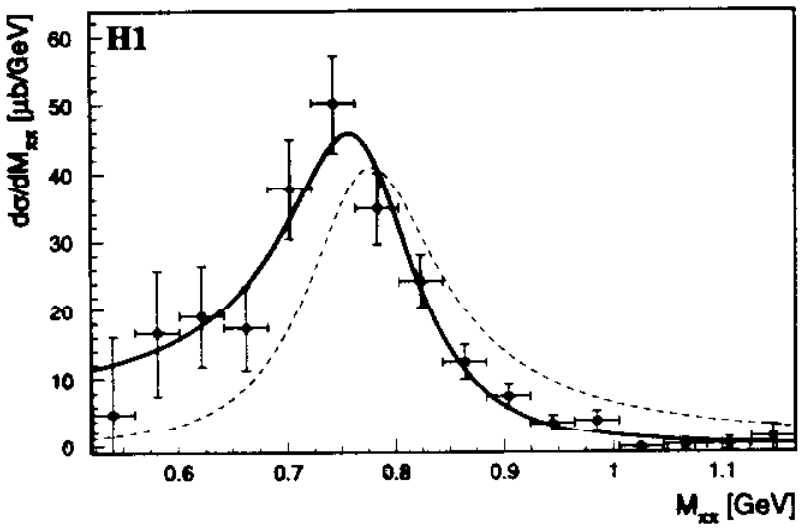
  – proton tagger (+24 m)
  – forward muon system
  – forward part of LAr

  $\Rightarrow M_Y \lesssim 1.6\,GeV$

- **t cut:**
  $|t| < 0.5 - 0.6\ GeV^2$
- for high Q^2 events:
  - good electromagnetic shower in backward calorimeter
  - associated hit in backward track chamber
  - cut against radiation:
    $\sum_i E_i - p_{zi} > 45 - 48\ GeV$

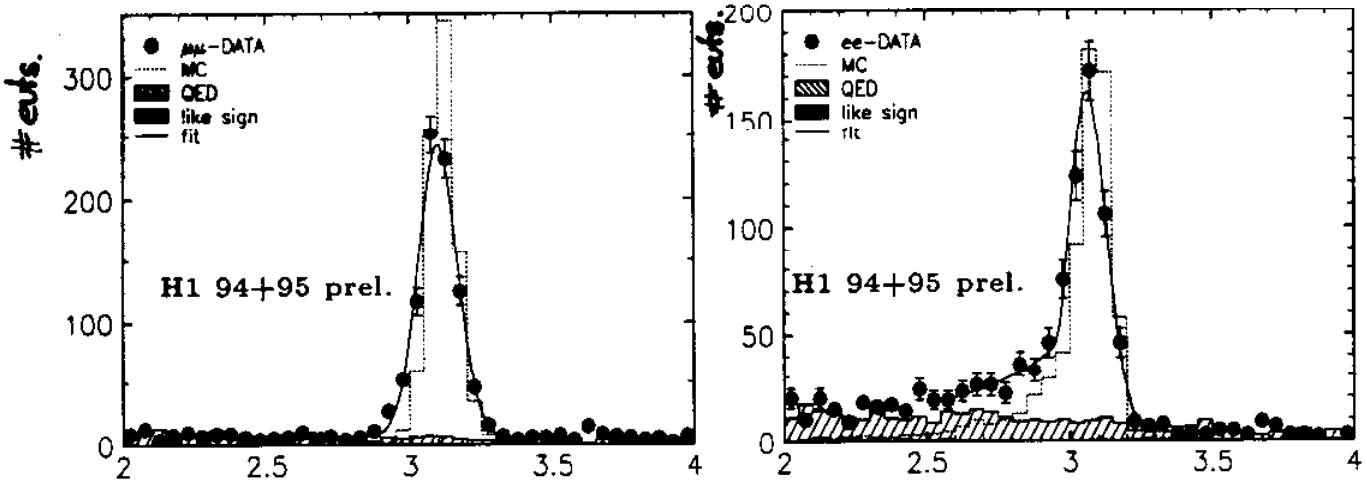
mass signals in photoproduction

- $\rho^0 \rightarrow \pi^+\pi^-$



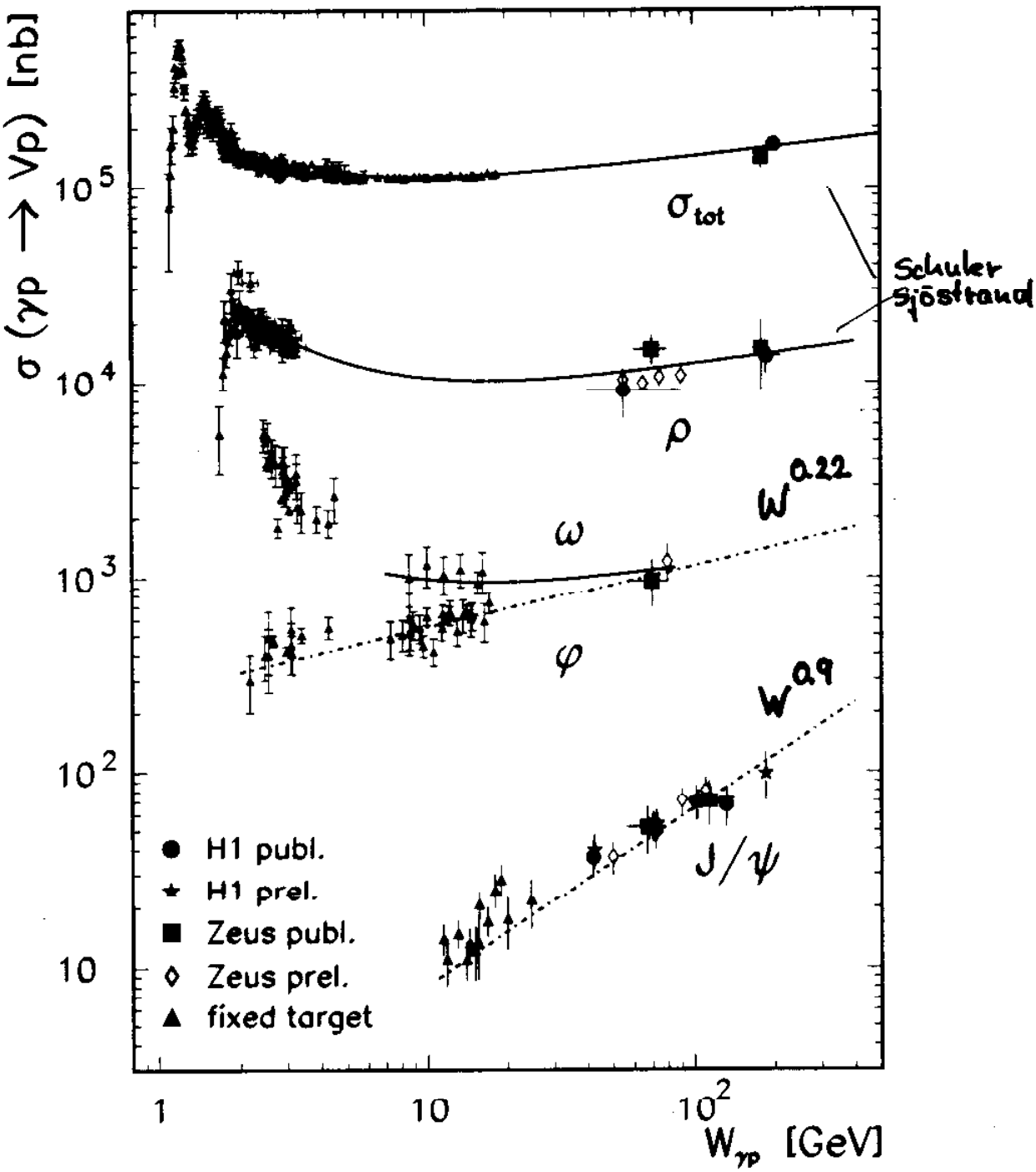
skewed mass (Ross-Stodolsky)

- $J/\Psi \rightarrow l^+l^-$



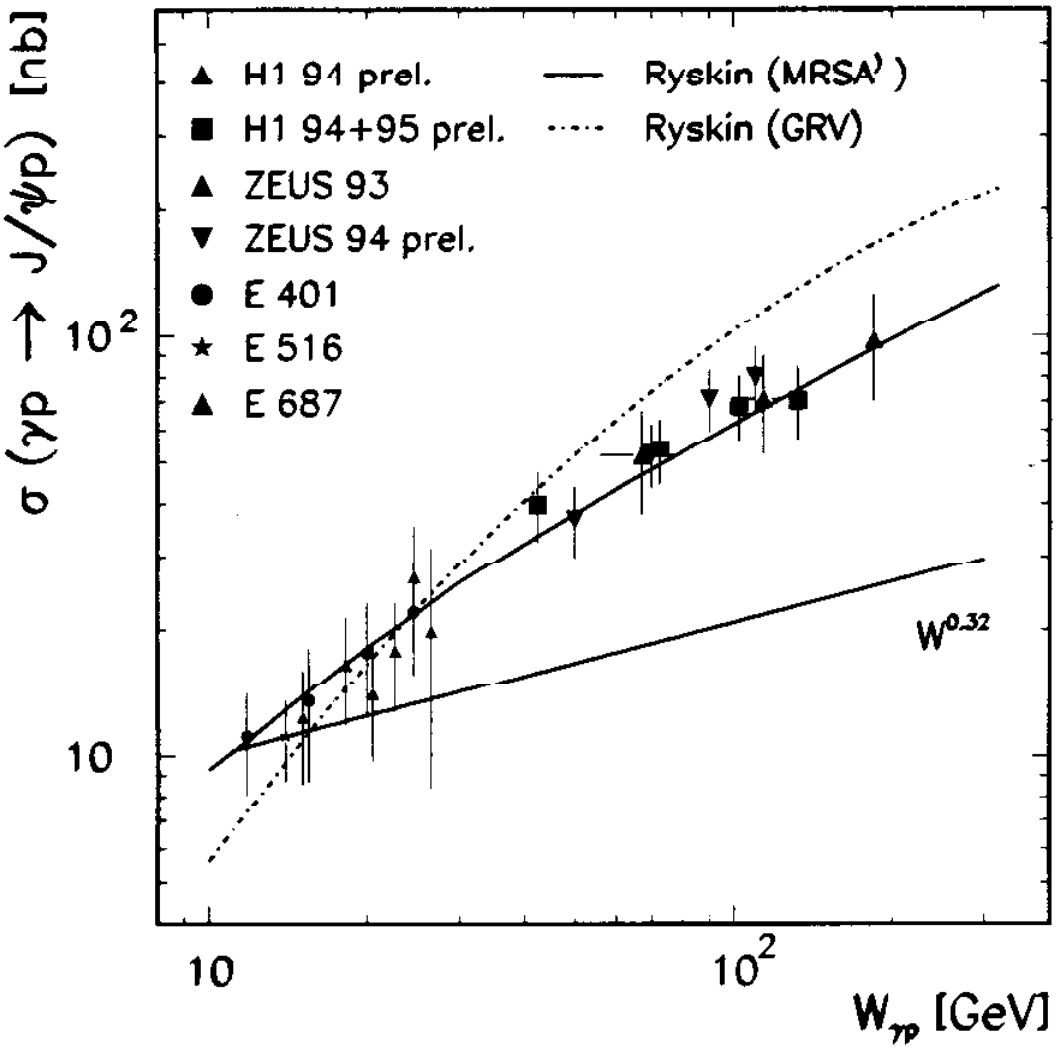
$M_{\mu^+\mu^-}$ $M_{e^+e^-}$

photoproduction cross sections



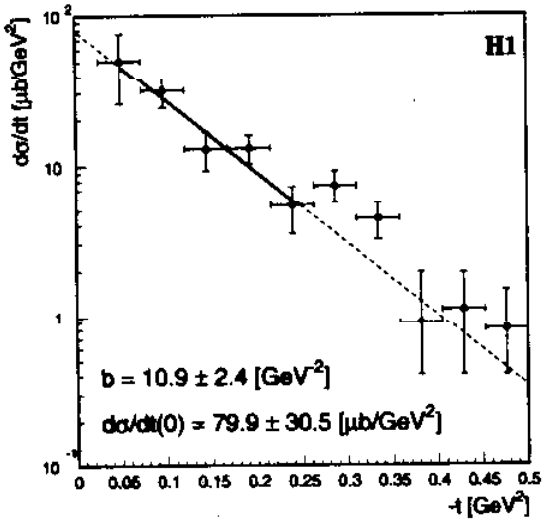
- light vector mesons described by soft pomeron
- J/Ψ steeper rise $\rightarrow$ 'hard' pomeron

pQCD description of J/Ψ photoproduction

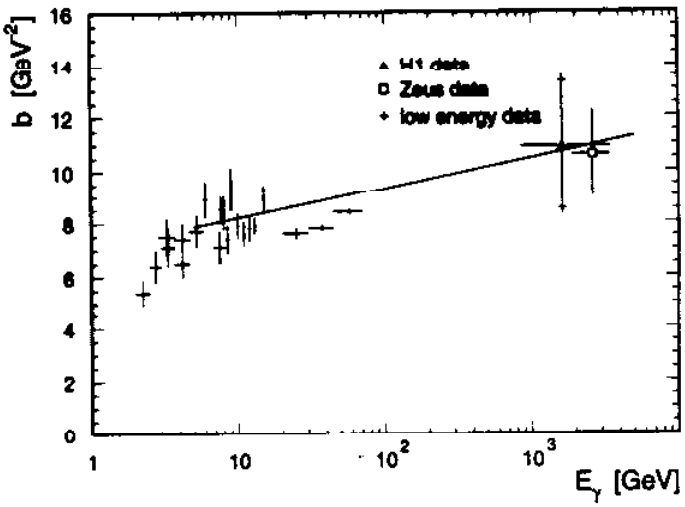


- Ryskin model with MRS(A') parametrisation of the gluon density agrees well with the data (normalisation uncertain $\rightarrow$ compare shape only)
- hard scale due to large charm quark mass

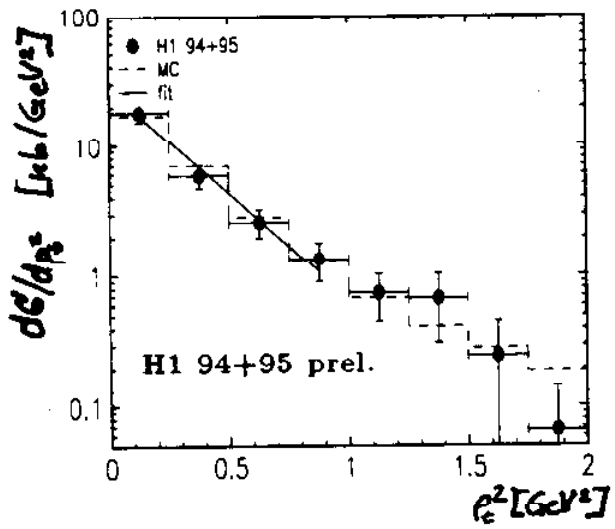
t distribution in photoproduction



ρ^0 : diffractive peak

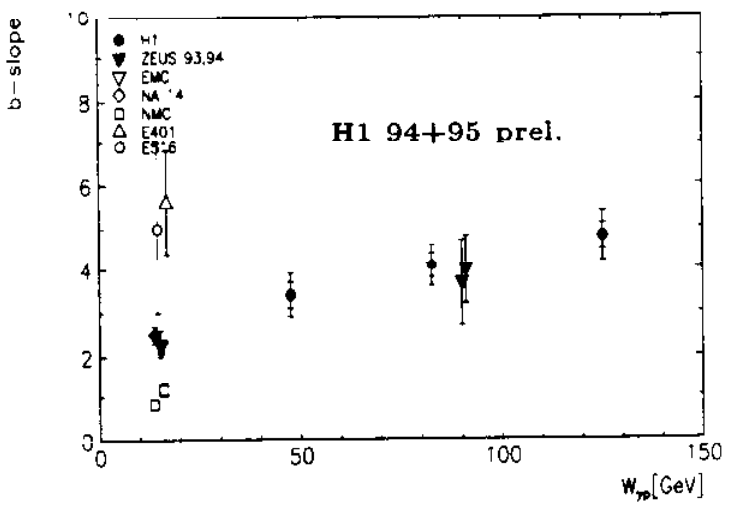


shrinkage



J/Ψ :

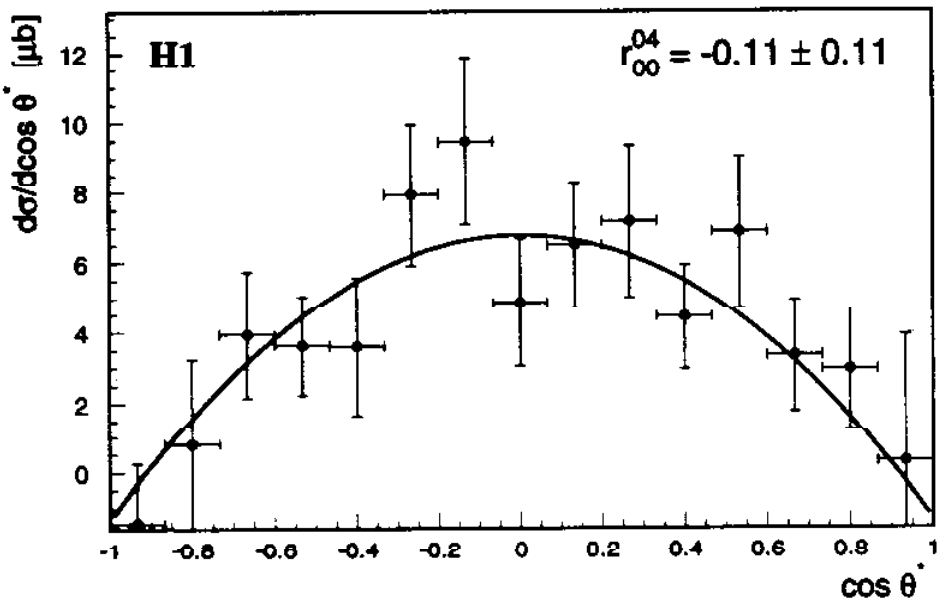
$b = 4.1 \pm 0.2 \pm 0.45\ GeV^{-2}$



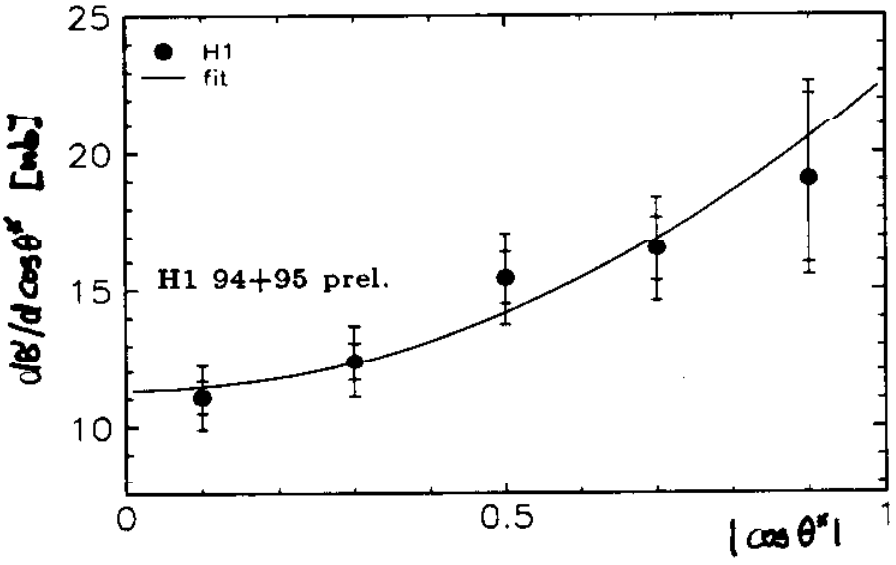
indication for shrinkage ?

H1: $\alpha' = 0.36 \pm 0.21\ GeV^{-2}$

decay angular distribution



$$\rho^0 : r_{00}^{04} = -0.11 \pm 0.11$$



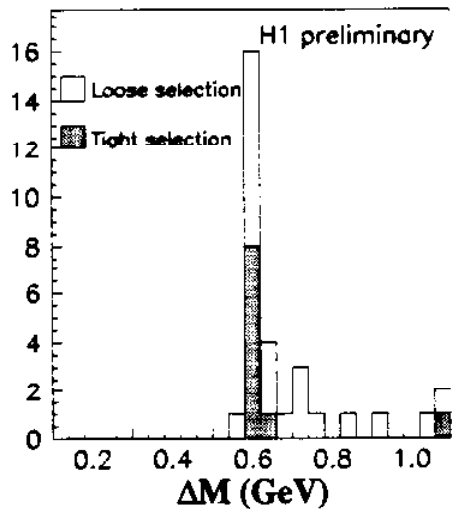
$$J/\Psi : r_{00}^{04} = -0.02 \pm 0.07$$

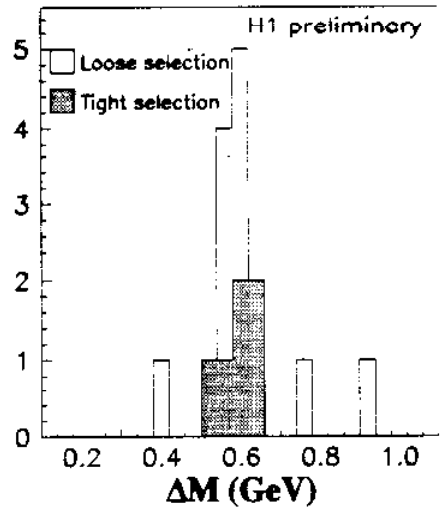
consistent with SCHC !

photoproduction of $\Psi(2S)$ mesons

$$\Psi(2S) \longrightarrow J/\Psi\ \pi^+\pi^-$$
$$\longrightarrow l^+l^-\pi^+\pi^- \quad (l = \mu, e)$$

$$(\text{br} = 1.9 \pm 0.2\ \%)$$





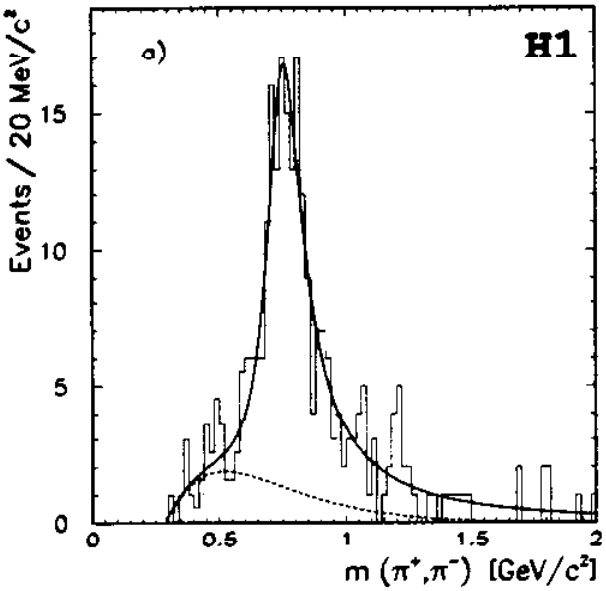
$\mu : \sigma_{\gamma p} = 19 \pm 6 \pm 4\ nb$ $\qquad$ $e : \sigma_{\gamma p} = 18 \pm 7 \pm 4\ nb$

$$\Rightarrow \sigma_{\gamma p} = 19 \pm 5 \pm 4\ nb$$

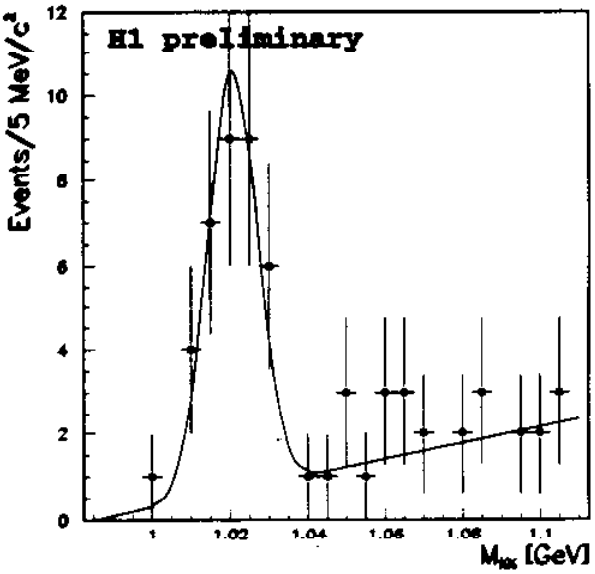
$$\Rightarrow \frac{\sigma_{\gamma p}(\Psi(2S))}{\sigma_{\gamma p}(J/\Psi)} = 0.16 \pm 0.06$$

similar result in low energy experiments
$\Rightarrow$ no strong energy dependence of the ratio

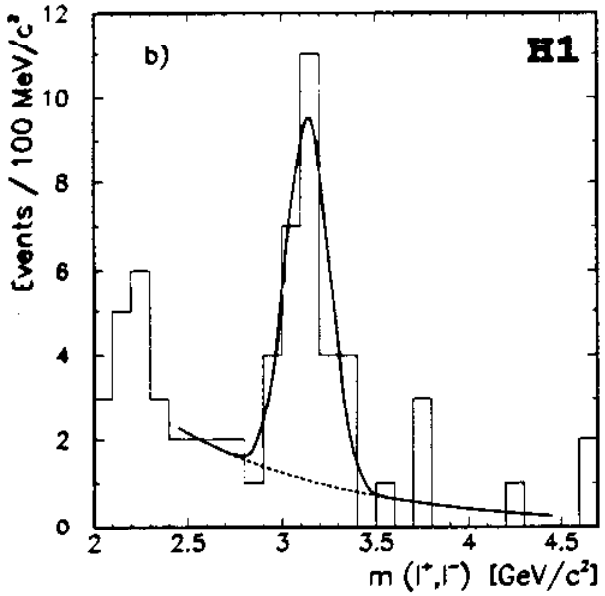
mass signals at high Q^2



$\rho^0 \rightarrow \pi^+\pi^-$



$\Phi \rightarrow K^+K^-$



$J/\Psi \rightarrow l^+l^-$

ρ^0 :
rel. BW (m.d.w.) + BG
(no skewing)

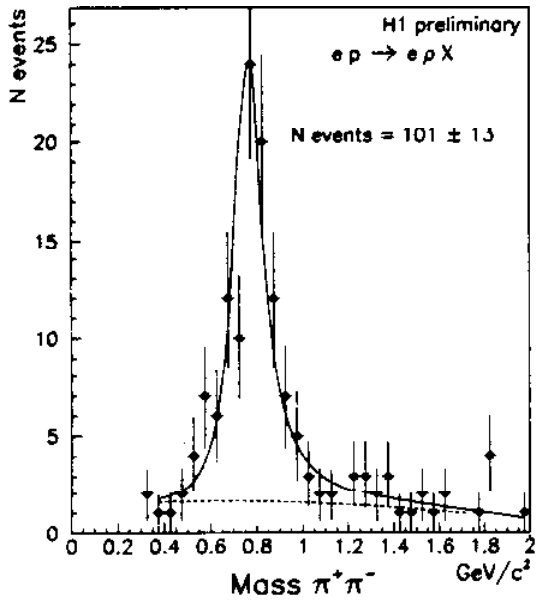
Φ :
rel. BW $\otimes$ Gauss + BG

J/Ψ :
Gauss + BG

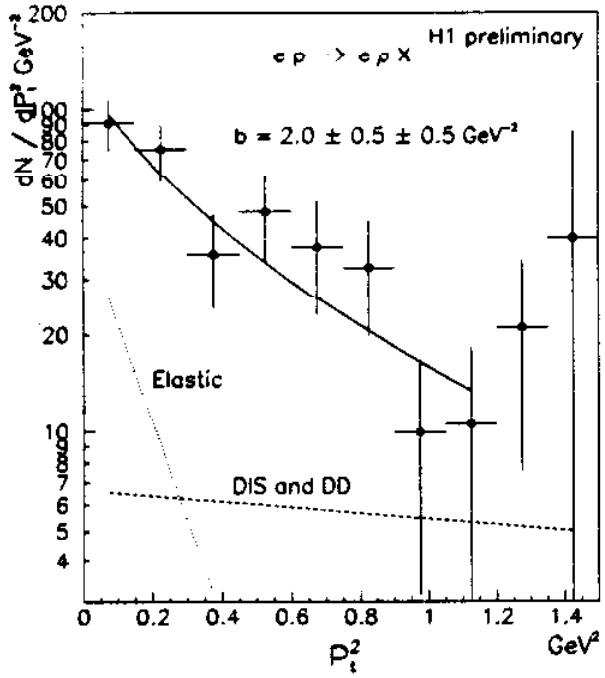
$Q^2 > 8\ GeV^2$ ($> 6\ GeV^2$ for Φ)

ρ^0 electroproduction with proton dissociation

proton dissociation with forward detectors $\rightarrow M_Y > 1.6 GeV$



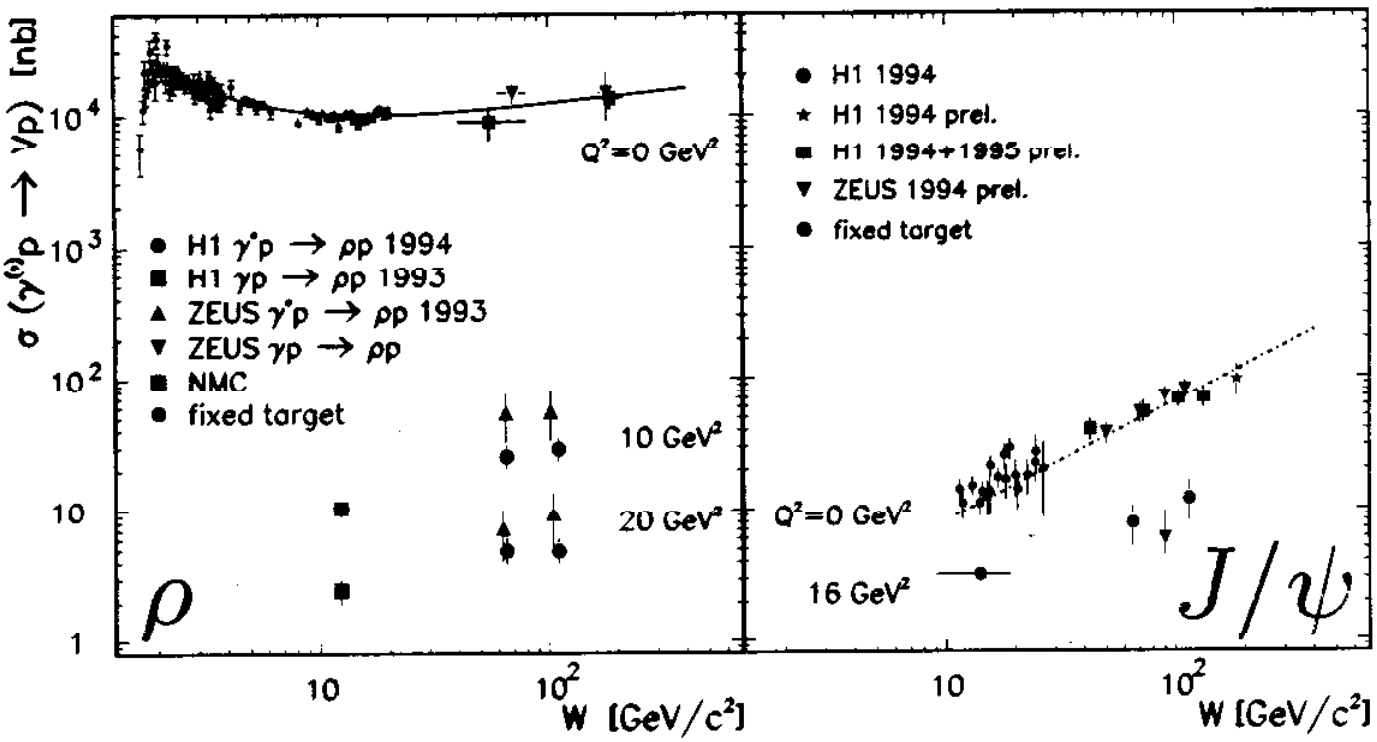
- $7 < Q^2 < 36\ GeV^2$
- $60 < W_{\gamma p} < 180\ GeV$
- $\sigma_{\gamma^* p \rightarrow \rho Y} / \sigma_{\gamma^* p \rightarrow \rho p} = 0.65 \pm 0.16 \pm 0.12$
- no dependence on $W_{\gamma p}$ and Q^2 observed



- $b_{elastic}\ /\ b_{pdis} \simeq 3.5$
- similar result as in J/Ψ photoproduction

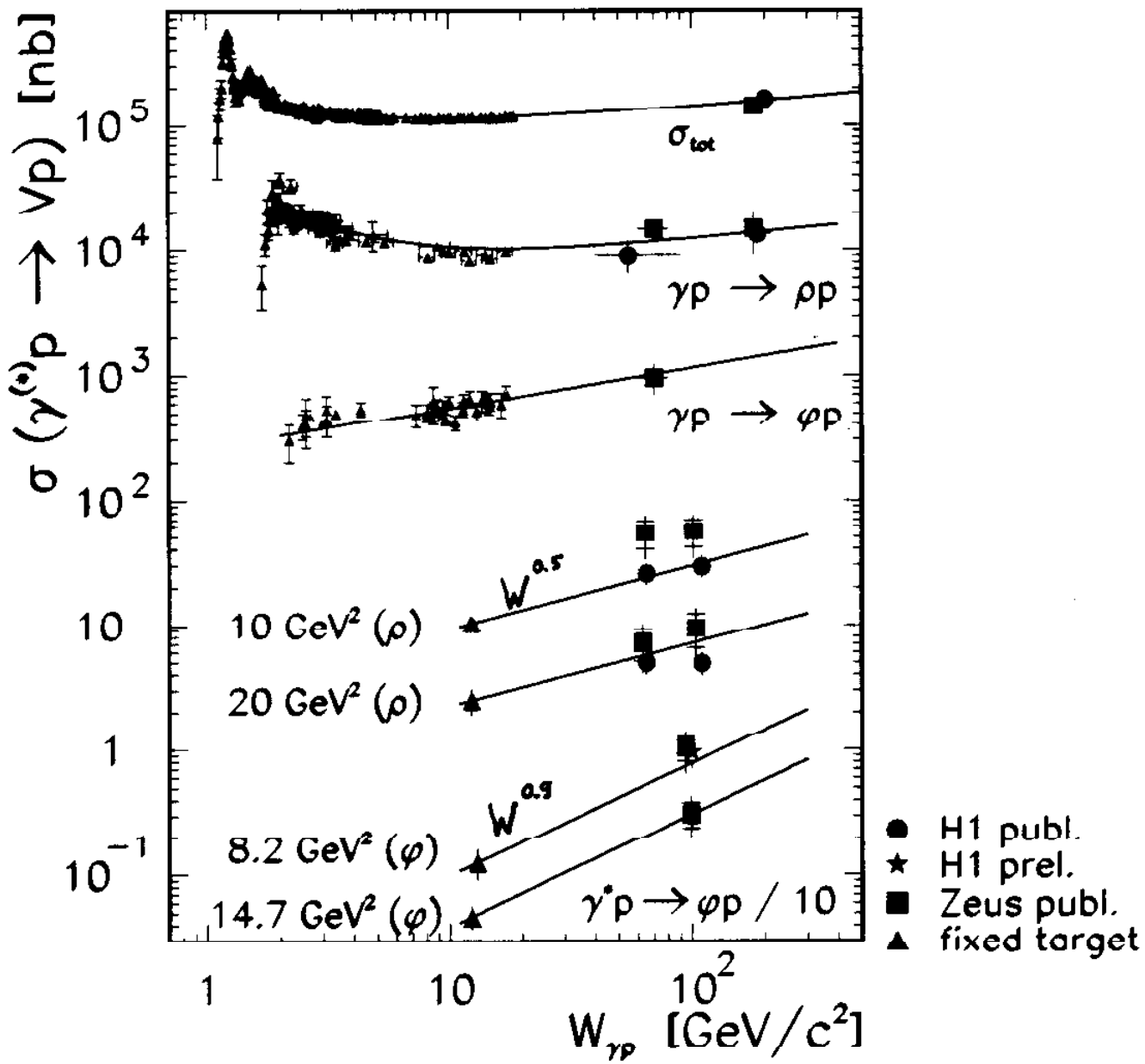
not shown: Q^2 and $\cos(\theta^*)$ dependence compatible within errors to elastic production

$W_{\gamma p}$ dependence ρ^0 vs. J/Ψ at high Q^2



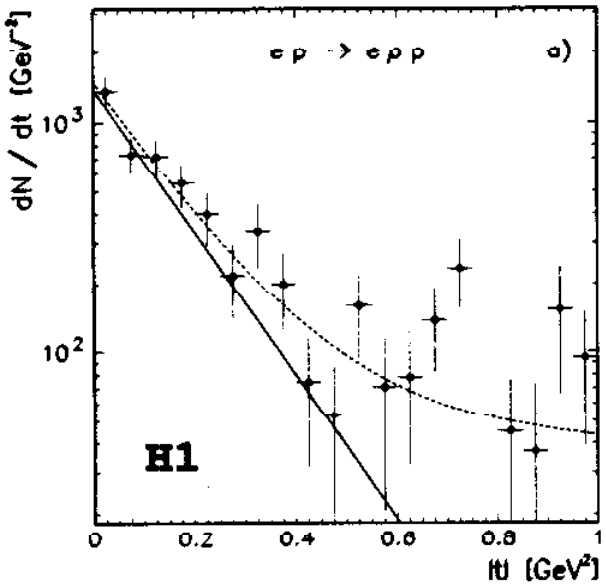
- ρ^0 : situation unclear
  - discrepancy between H1 an ZEUS
  - new E665 result (at $Q^2 \approx 6\ GeV^2$) indicates consistency with soft pomeron
- soft pomeron not ruled out
- J/Ψ : same as in photoproduction

$W_{\gamma p}$ dependence ρ^0 vs. Φ

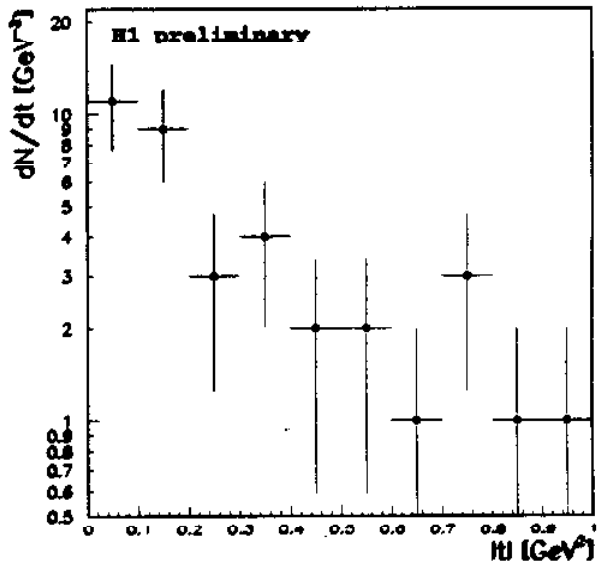


- Φ : steeper rise with $W_{\gamma p}$ than in photoproduction
- increase larger for Φ than for ρ^0

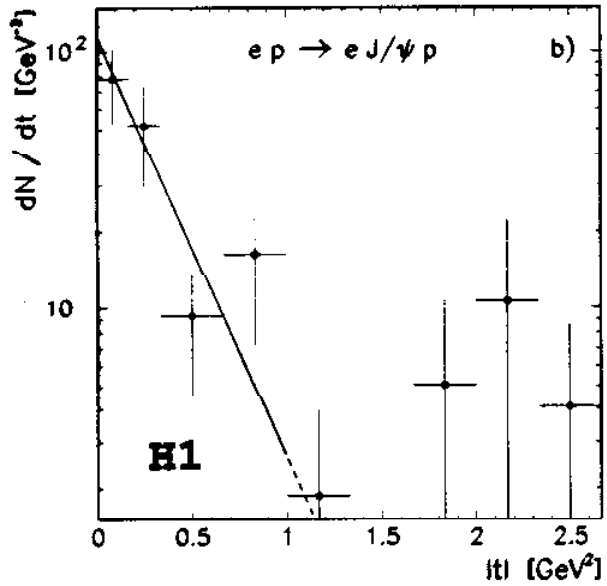
t dependence at high Q^2



$\rho^0 \rightarrow \pi^+\pi^-$



$\Phi \rightarrow K^+K^-$



$J/\Psi \rightarrow l^+l^-$

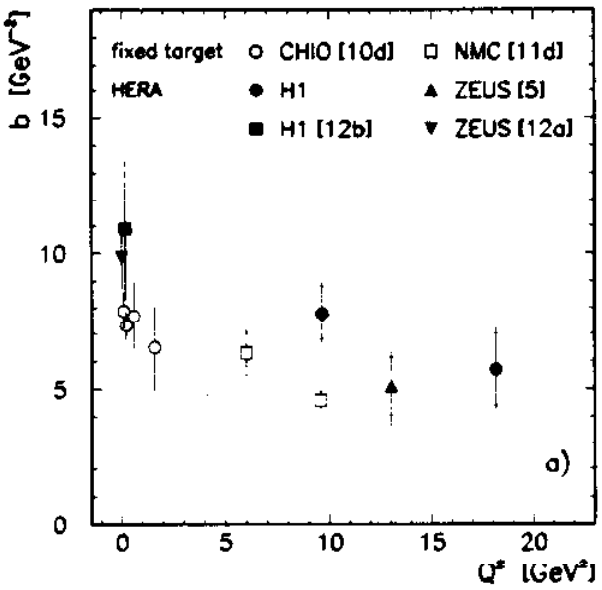
$\rho^0 : b = 7.0 \pm 0.8 \pm 0.4 \pm 0.5\ GeV^{-2}$

$\Phi : b = 5.2 \pm 1.6 \pm 1.0\ GeV^{-2}$

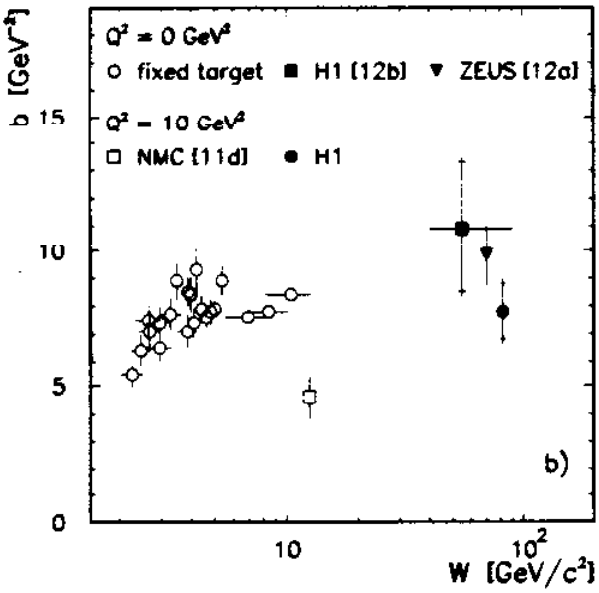
$J/\Psi : b = 3.8 \pm 1.2^{+2.0}_{-1.6}\ GeV^{-2}$

evolution of the t slope at high Q^2

- for ρ^0

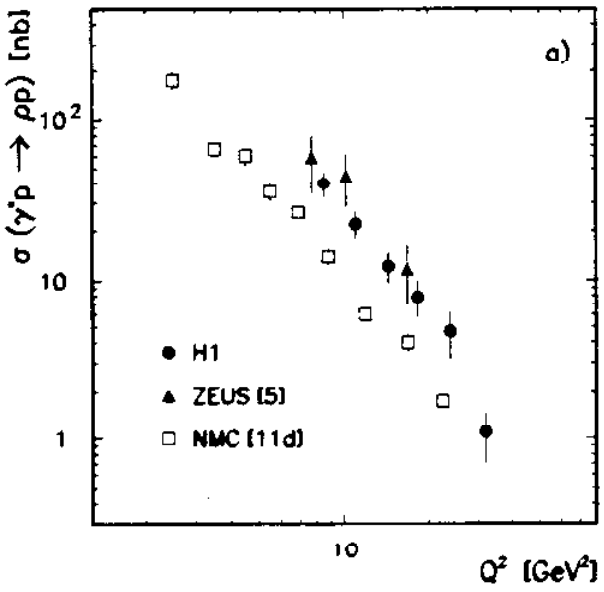


decrease with Q^2
as seen for low energy

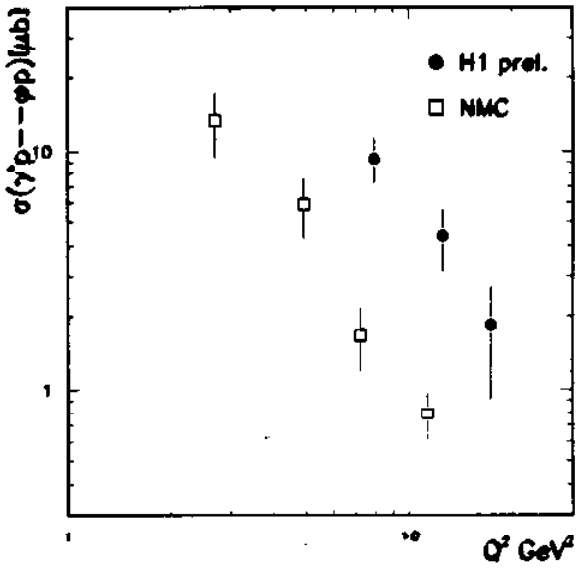


shrinkage with $W_{\gamma p}$?
relies on fixed targed point

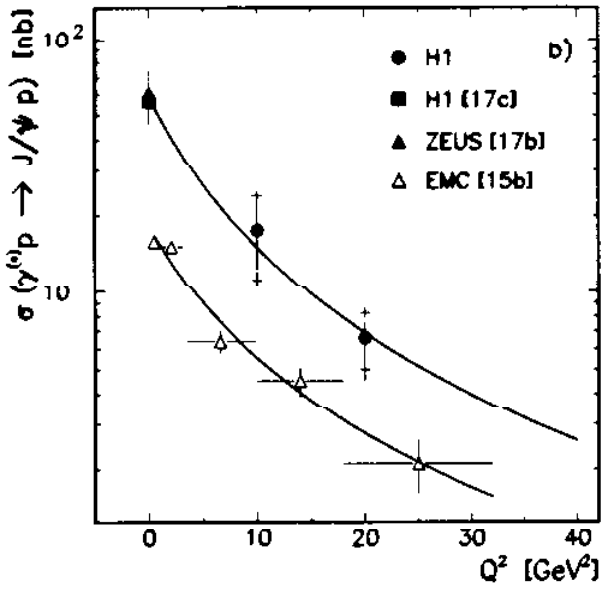
Q^2 dependence at high Q^2



$\rho^0 : \propto Q^{-2n}$



$\Phi : \propto Q^{-2n}$



$J/\Psi : \propto 1/(Q^2 + m_\Psi^2)^n$

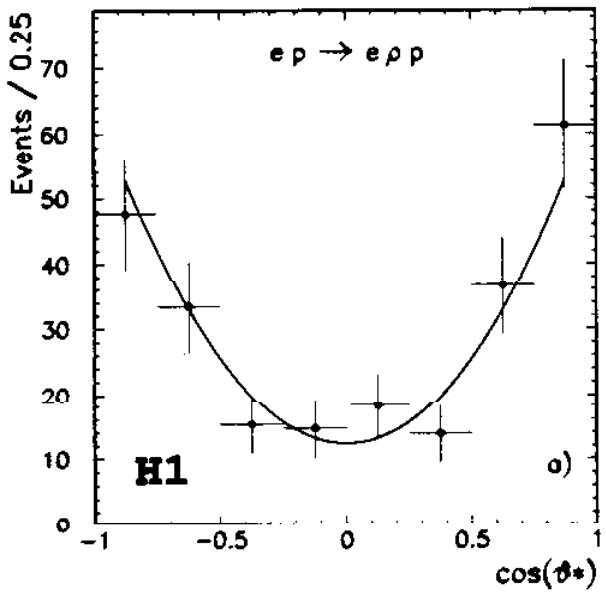
$\rho^0 : n = 2.5 \pm 0.5 \pm 0.2$

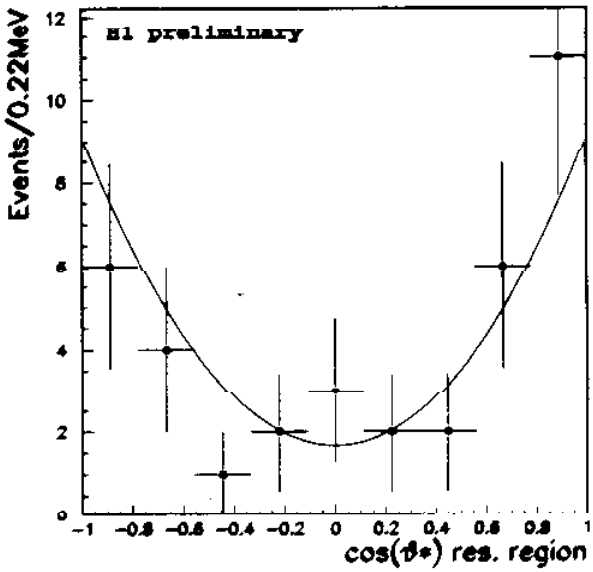
$\Phi : n = 2.0 \pm 0.6 \pm 0.2$

$J/\Psi : n = 1.9 \pm 0.3$

good agreement with low energy data

decay angular distribution at high Q^2





$\rho^0 : r_{00}^{04} = 0.73 \pm 0.05 \pm 0.02$ $\Phi : r_{00}^{04} = 0.77 \pm 0.11 \pm 0.0$

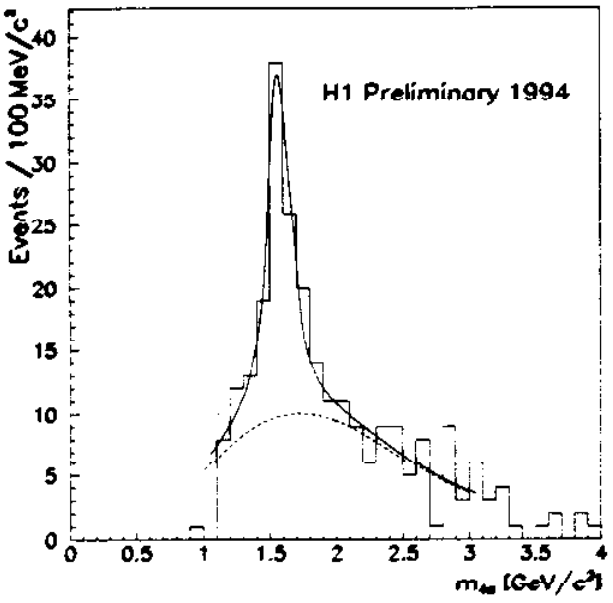
assuming SCHC $\Rightarrow$

$R = \sigma_L/\sigma_T = 2.7^{+0.7\ +0.3}_{-0.5\ -0.2}$ $R = 3.3^{+4.0}_{-1.4}$

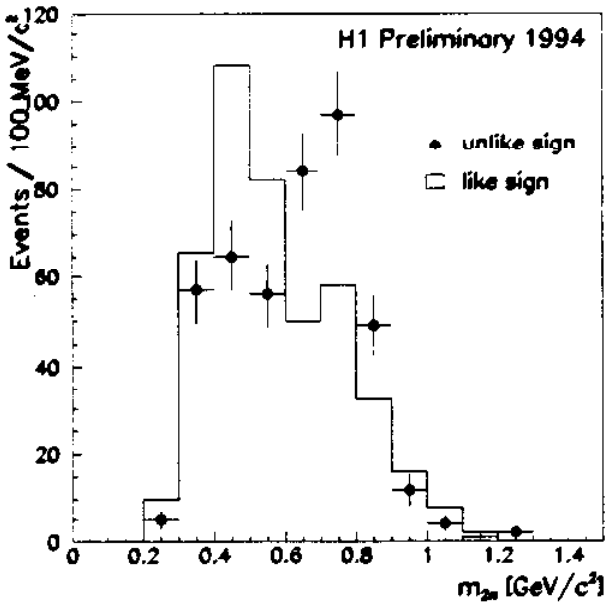
at high Q^2 VM are predominantly
longitudinaly polarized

ρ' signal at high Q^2

$$\rho' \rightarrow (\rho \pi^+\pi^-) \rightarrow \pi^+\pi^- \pi^+\pi^-$$



- clear enhancement in $m_{4\pi}$
- rel. BW + BG ($O(m^5)$)
- $\rightarrow$ $m_{\rho'} = 1.57 \pm 0.02 \pm 0.01\ GeV$
- $\rightarrow$ $\Gamma_{\rho'} = 0.18 \pm 0.06 \pm 0.07\ GeV$

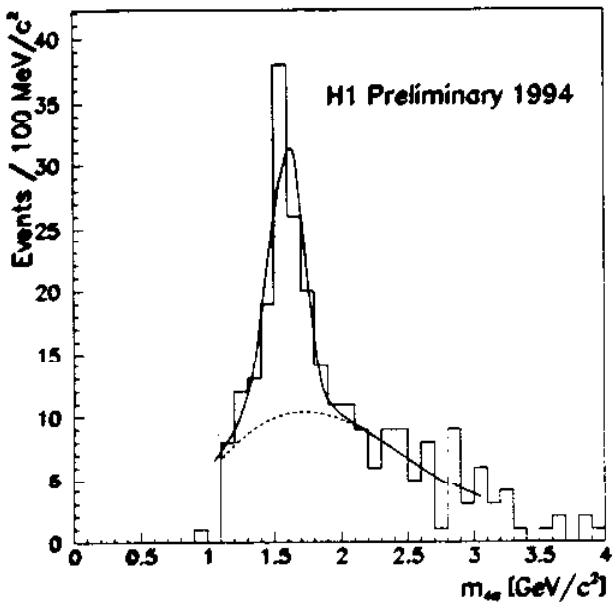


- ρ signal in unlike sign distribution
- consistent with one ρ per event

$$4 < Q^2 < 50\ GeV^2 \quad 40 > W_{\gamma p} < 140\ GeV$$

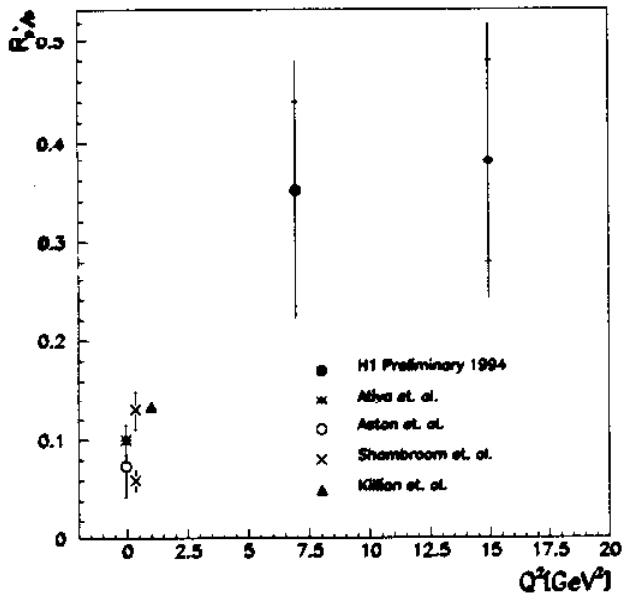
$\rho(1450)$ and/or $\rho(1700)$?

Ansatz: $| BW\ (\rho(1450)) + \alpha\, e^{i\beta}\, BW\ (\rho(1700)) |^2$



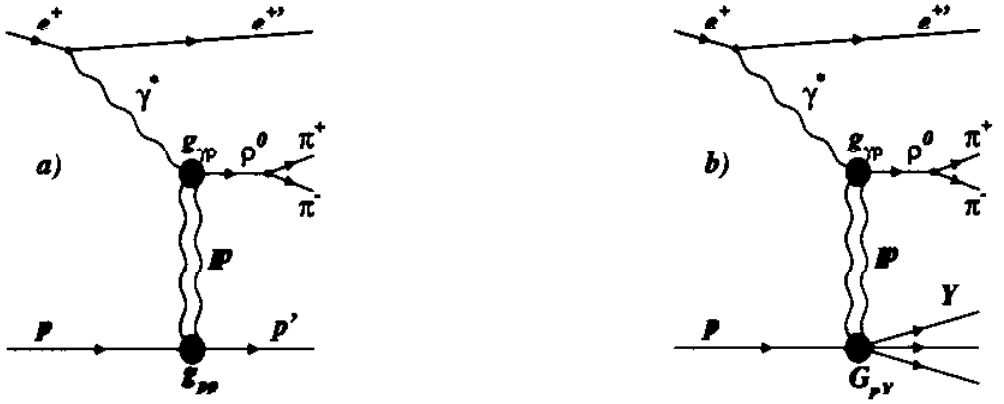
- $\rightarrow \alpha = 1.0 \pm 0.3$
- $\rightarrow \beta = 3.1 \pm 0.9$
- comparable χ^2 as for single resonance
- $\rightarrow$ no conclusion possible

ratio of ρ' to ρ production



- assuming single resonance
- $R_{\rho'/\rho} = 0.36 \pm 0.07 \pm 0.11$
- larger than at $Q^2 = 0$ (as expected by theory)

test of a factorisation hypothesis



$$\frac{d^2\sigma_{pdis}/dtdM_Y^2}{d\sigma_{el}/dt} = \left(\frac{G_{pY}(t,M_Y)}{g_{pp}(t)}\right)^2 = f(t,M_Y)$$

$$\frac{\sigma_{pdis}b_{pdis}}{\sigma_{el}b_{el}} = f_1(W) \qquad b_{el} - b_{pdis} = f_2(W)$$

f_1 and f_2 should be independent of the process

experiment	ISR,pp	H1 (ρ)	H1 (J/Ψ)
E_{cms} / GeV	53	60-180	30-150
f_1	0.24 ± 0.04	0.19 ± 0.08	0.40 ± 0.11
f_2 / GeV^{-2}	6.6 ± 1.0	5.0 ± 1.2	2.4 ± 0.4

$\Rightarrow$ factorisation seems to hold for ρ
perturbative effects for J/Ψ !?
further confirmation needed !

conclusion

- photoproduction
  - slow rise of $\sigma_{\gamma p}$ with $W_{\gamma p}$ for the ρ^0 well described by soft pomeron
  - steeper rise for the J/Ψ, now seen from HERA data alone
    $\rightarrow$ best evidence yet for 'hard' pomeron
  - ρ^0 and J/Ψ consistent with SCHC
  - shrinkage observed for ρ^0 (indication for J/Ψ ?)
- high Q^2
  - Φ and J/Ψ show steep rise with $W_{\gamma p}$ at high Q^2
    but still depending on low energy data
    situation unclear for the ρ^0
    $\rightarrow$ need $W_{\gamma p}$ dependence from HERA data alone
  - same for shrinkage
  - ρ^0 and Φ are predominantly longitudinaly polarized
  - clear signal of ρ' at high Q^2
    unclear whether it consists of one or two resonances
  - ρ^0 electroproduction with proton dissociation shows much flatter t dependence
- what can we learn from ρ' and Ψ' production ?

reconstruction of kinematic variables

$$
\begin{aligned}
Q^2 &= 4E_0^2 \, \frac{\sin\theta_V \, (1+\cos\theta_e)}{\sin\theta_V + \sin\theta_e - \sin(\theta_V+\theta_e)} \\
y &= \frac{\sin\theta_e \, (1-\cos\theta_V)}{\sin\theta_V + \sin\theta_e - \sin(\theta_V+\theta_e)} \\
E'_e &= [2E_0 - (E_V - |P_V| \cdot \cos\theta_V)]/(1-\cos\theta_e) \\
x &= \frac{Q^2}{sy} \qquad W^2 = Q^2\left(\frac{1}{x}-1\right) \\
t &\simeq (\vec{p}_{tp})^2 = (\vec{p}_{te} + \vec{p}_{tV})^2 \\
E - p_z &= (E_e + E_V) - (p_{ze} + p_{zV})
\end{aligned}
$$

$Q^2 \to 0$

$y = \frac{2(E - E_e)}{2E_e}$

cross section definitions

$$
\begin{aligned}
\frac{\mathrm{d}^2\sigma_{tot}(ep \to eVp)}{dy\, dQ^2} &= \Gamma_{\mathrm{T}} \, \sigma_{tot}(\gamma^* p \to Vp) \\
&= \Gamma_{\mathrm{T}} \, \sigma_T(\gamma^* p \to Vp) \, (1+\varepsilon \, R)
\end{aligned}
$$

$$
\Gamma_{\mathrm{T}} = \frac{\alpha_{em} \, (1 - y + y^2/2)}{\pi \, y \, Q^2}
$$

$$
\varepsilon = \frac{1-y}{1-y+y^2/2}. \quad ; \quad R = \sigma_L/\sigma_T
$$