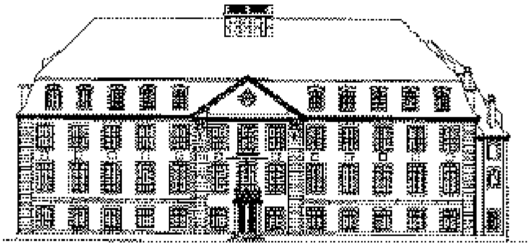
Teilchenphysikalisches Seminar 23 April 1998

P.I. Bonn



Scale Issues in High-Energy Diffractive Vector-Meson Production

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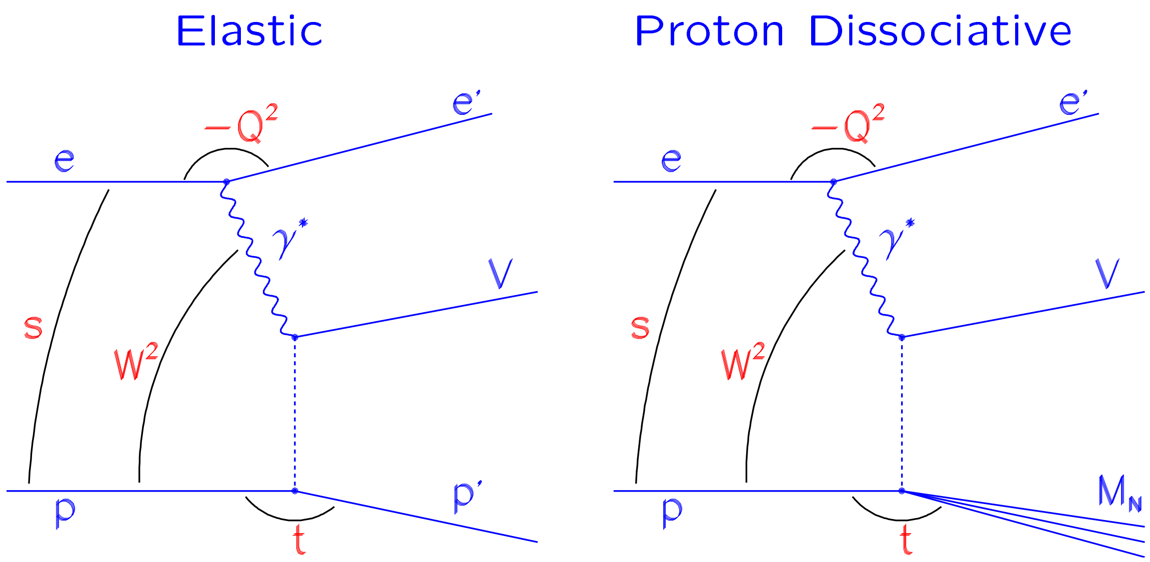
Diffractive Electroproduction of Vector Mesons



$\sqrt{s}$: Center–of–mass energy of e–p system (300 GeV)

W: Center–of–mass energy of γ^*–p system (20 – 240 GeV)

Q^2: Photon Virtuality (10^{-10} – 20 GeV^2)

t: Square of Momentum Transfer at the Proton Vertex ($|t| < 13$ GeV^2)

Can the hard scale necessary for perturbative QCD calculations be set by <u>either</u> Q^2, M_V^2, <u>or</u> $|t|$??

What experimental signatures for the region of pQCD validity ?

Signatures for pQCD

☞ Energy Dependence of Elastic Cross Sections

$\Longrightarrow$ Exchange of the phenomenological Pomeron

$$\frac{d\sigma}{d|t|} \propto e^{-b_0|t|}\left(\frac{s}{s_0}\right)^{2(\alpha_{I\!P}(t)-1)} \qquad \alpha_{I\!P}(t) = 1.08 + 0.25\,t$$

$$\left.\frac{d\sigma}{d|t|}\right|_{t=0} \propto \left(\frac{s}{s_0}\right)^{2(\alpha_{I\!P}(0)-1)} \propto W^{4\epsilon} = W^{0.32}$$

$\Longrightarrow$ Exchange of a gluon ladder

$$\left.\frac{\mathrm{d}\sigma_{\gamma^* \mathrm{p}\to \mathrm{Vp}}}{\mathrm{d}|t|}\right|_{t=0} = A_{\mathrm{V}}\frac{\alpha_s^2(\bar{Q}^2)}{\alpha\bar{Q}^6}\left|\left[1+\frac{i\pi}{2}\frac{\mathrm{d}}{\mathrm{d}(\ln x)}\right]xG(x,\bar{Q}^2)\right|^2$$

Energy dependence determined by $G(x,Q^2)$, $\quad x \approx Q^2/W^2$

☞ Pointlike couplings; small-size $q\bar{q}$ configurations

$$\frac{d\sigma}{d|t|} \propto e^{-b|t|} \quad b = b_0 + 2\,\alpha'_{I\!P}\ln\frac{s}{s_0}$$

$$|t|_{min} = m_p^2\,\frac{(M_V^2+Q^2)^2}{W^4}$$

$\Longrightarrow$ $b \propto R_{\mathrm{p}}^2 + R_{\mathrm{VM}}^2$ (Elastic)

$\Longrightarrow$ Only longitudinally polarized configurations pointlike !!

☞ Absence of ρ^0 mass spectrum skewing

Skewing is interesting ($\sigma_{\pi p}^{tot}$?), but not pQCD

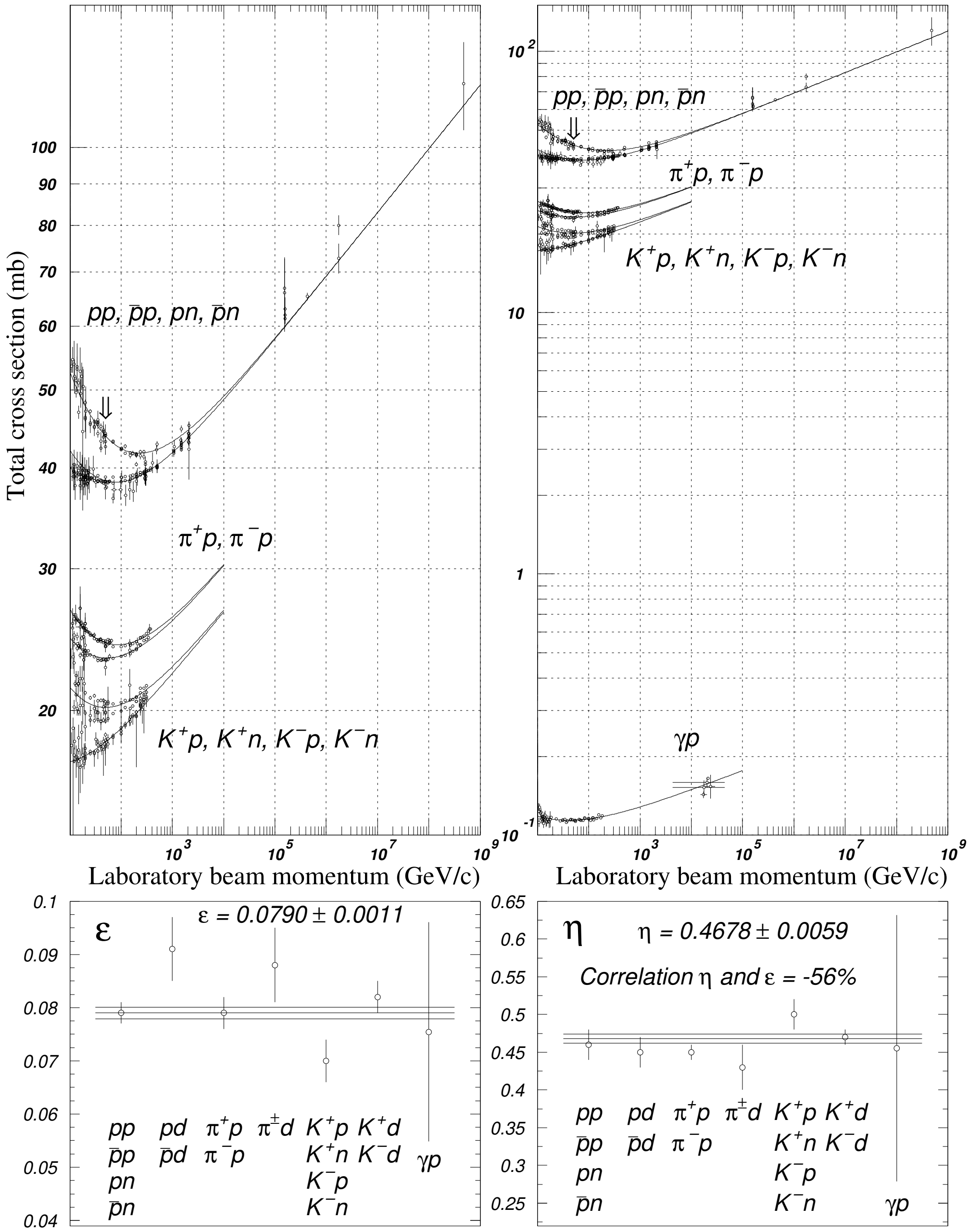
☞ Absence of shrinkage

$\alpha'_{I\!P} > 0$? (Gribov, JETP Lett. 41 (1961) 667)

Total Cross Sections

Donnachie + Landshoff, PL B296 (1992) 227

$$\sigma^{tot} = X\, s^{\epsilon} + Y\, s^{-\eta}$$

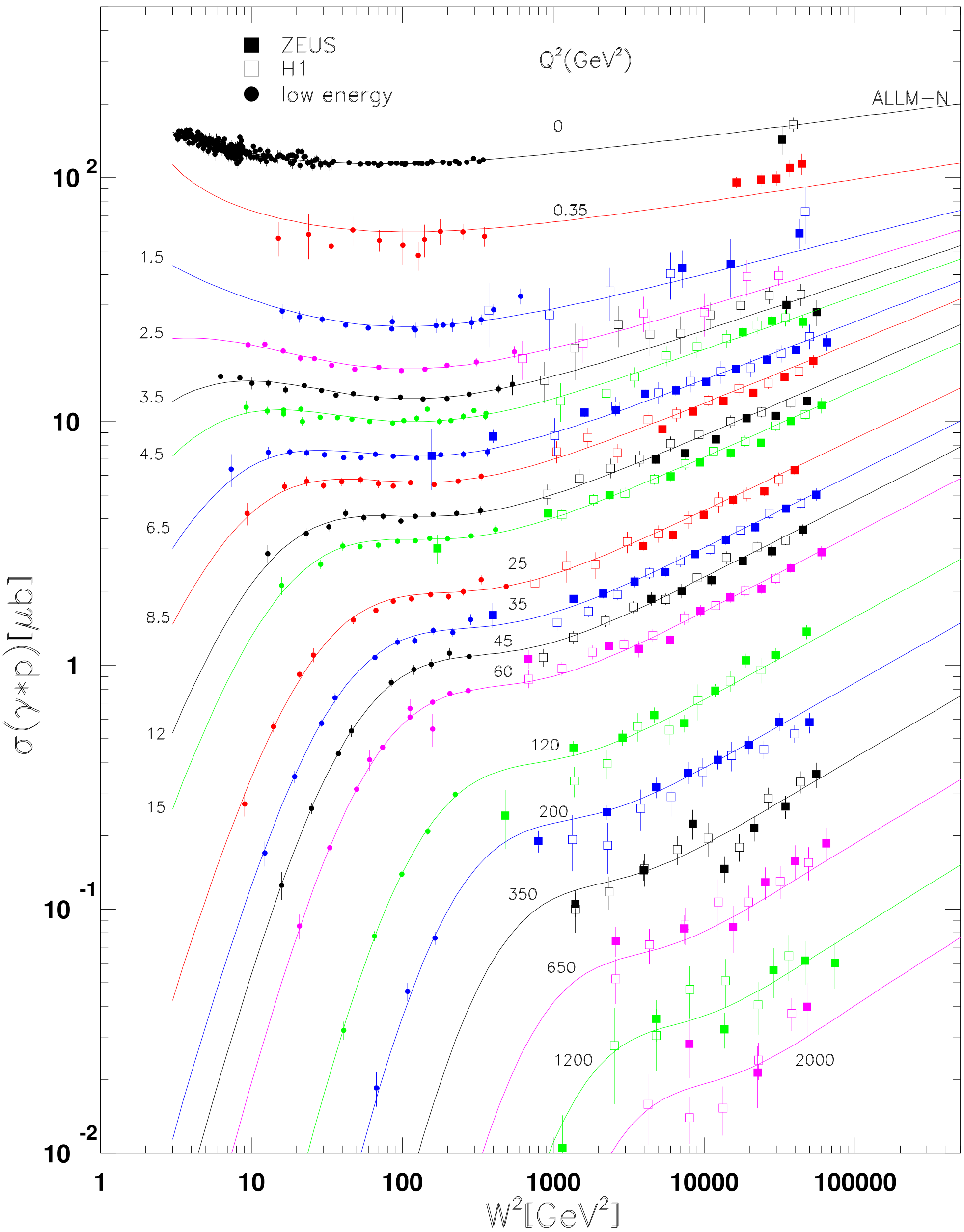


PDG
1996

ϵ = 0.0790 ± 0.0011 η = 0.4678 ± 0.0059

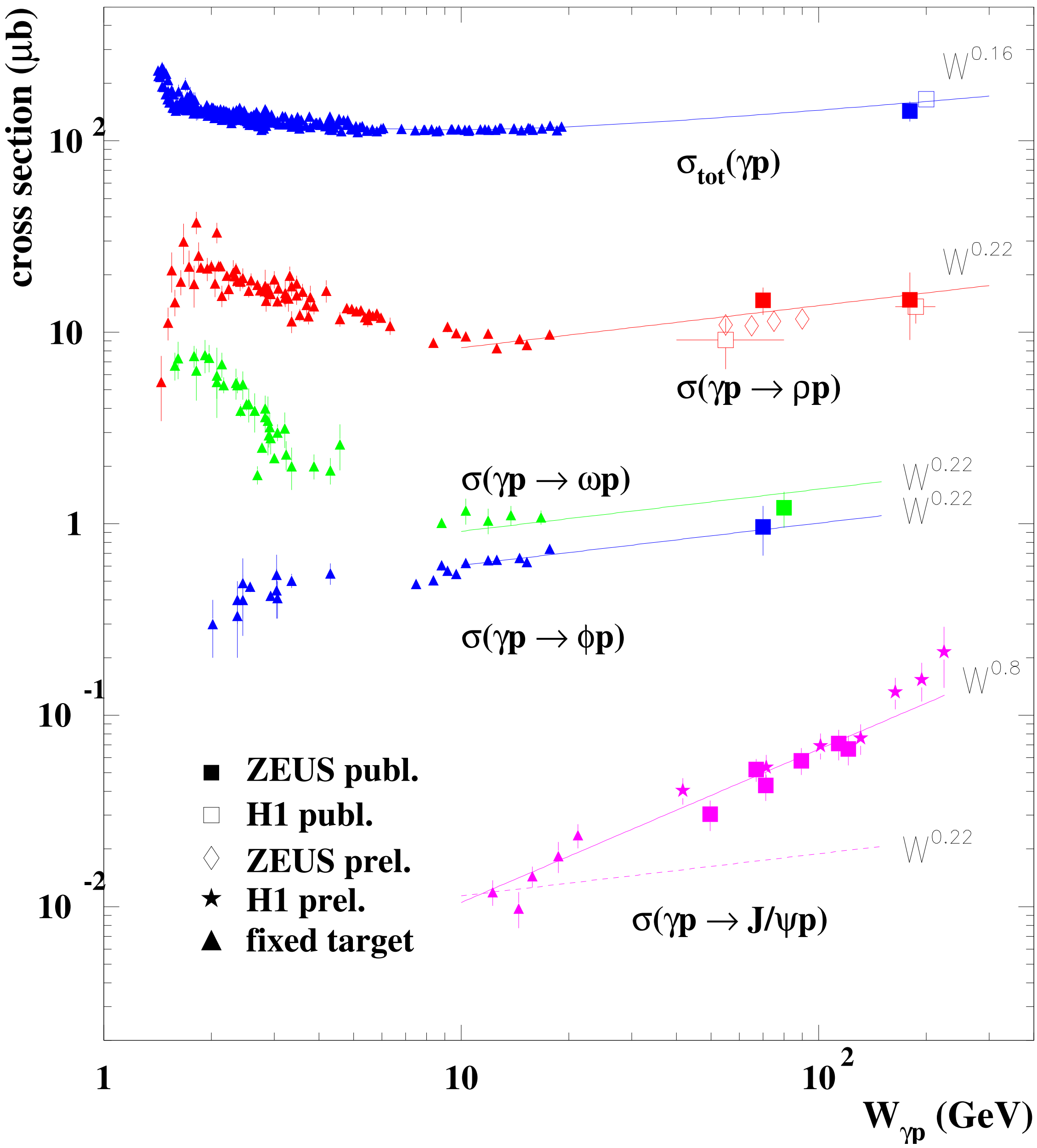
Total Photon-Proton Cross Sections

$$\sigma^{tot}_{\gamma^* p} \approx \frac{4\pi^2\alpha}{Q^2(1-x)} F_2(x,Q^2)$$



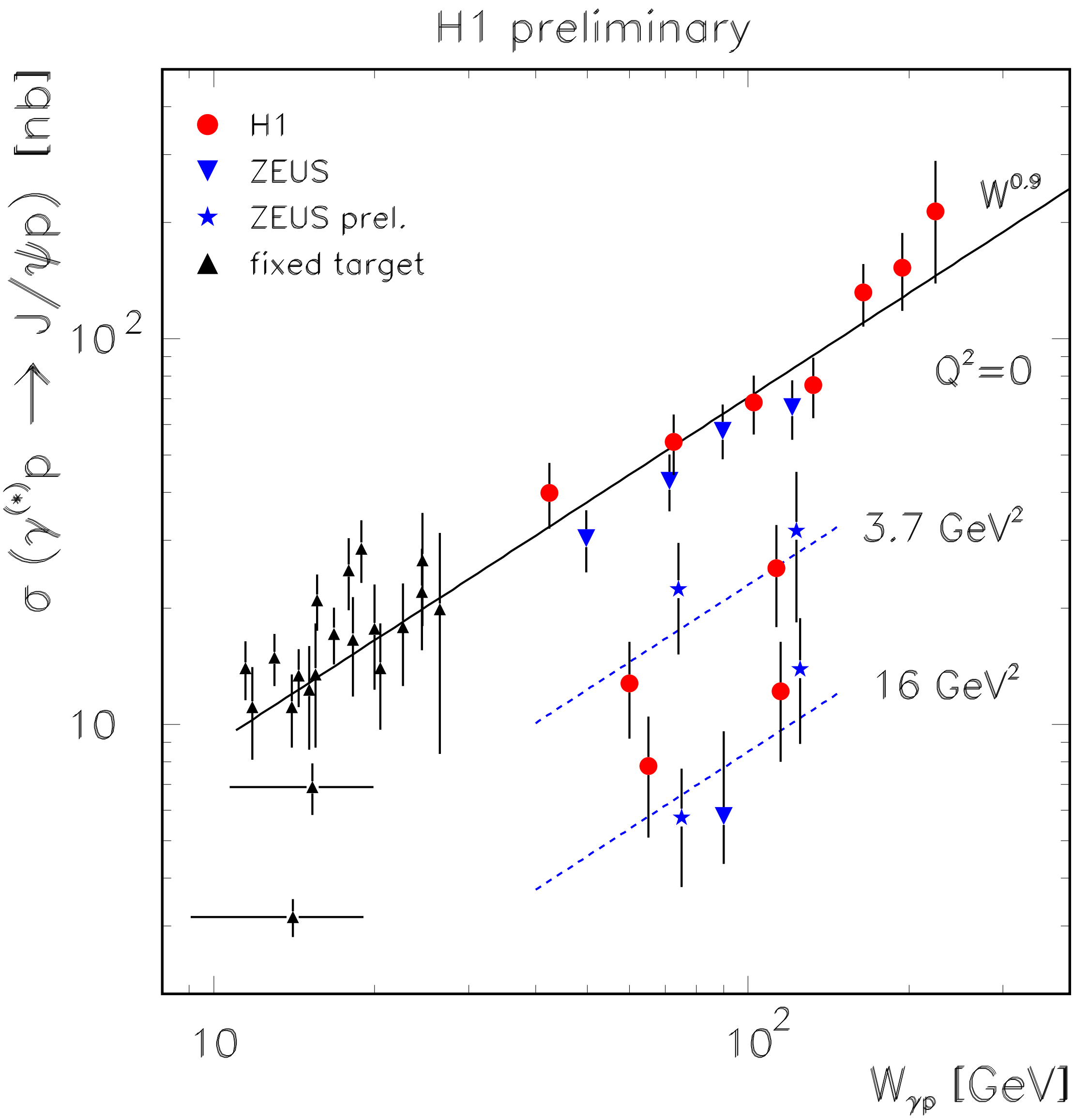
$\Rightarrow$ See Adi Bornheim's talk

Elastic Vector-Meson Photoproduction Cross Sections



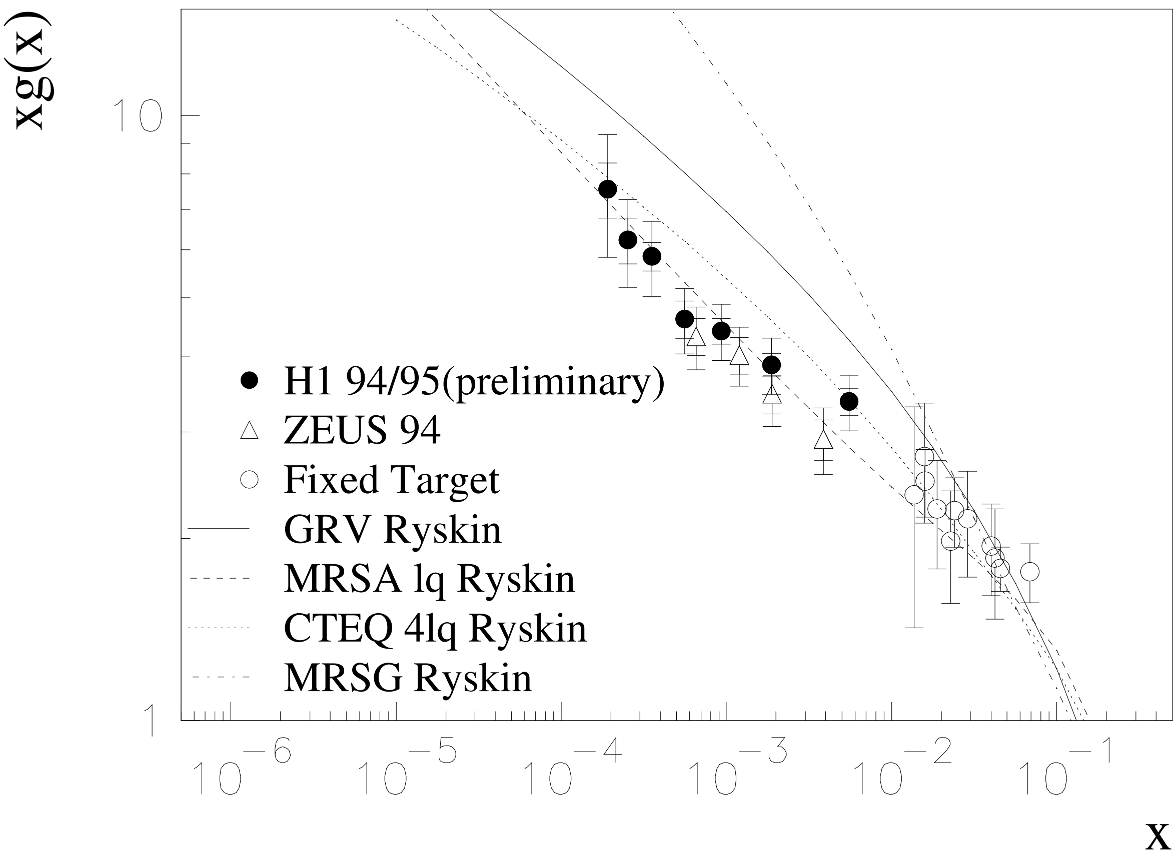
$\Rightarrow$ Energy dependence for the J/ψ much steeper !

Elastic J/ψ Cross Sections



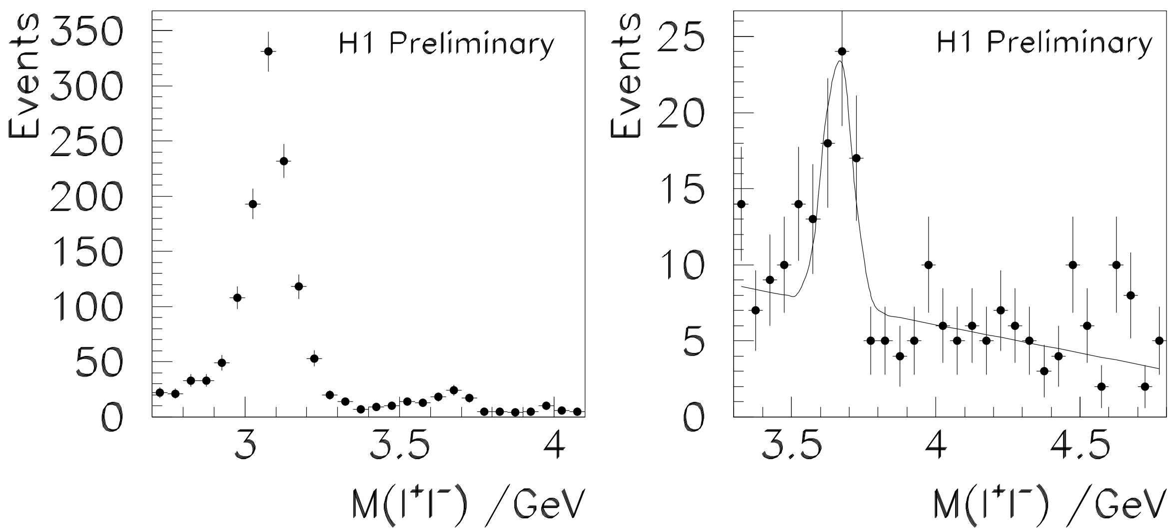
Elastic J/ψ Cross Sections

Ryskin et al, Z. Phys. C76 (1997) 231



$\Longrightarrow$ Can derive shape of gluon distribution !!

$\psi(2S)$ Signal from H1



$$\frac{\sigma(\psi(2S))}{\sigma(J/\psi)} = 0.150 \pm 0.027 \pm 0.022$$

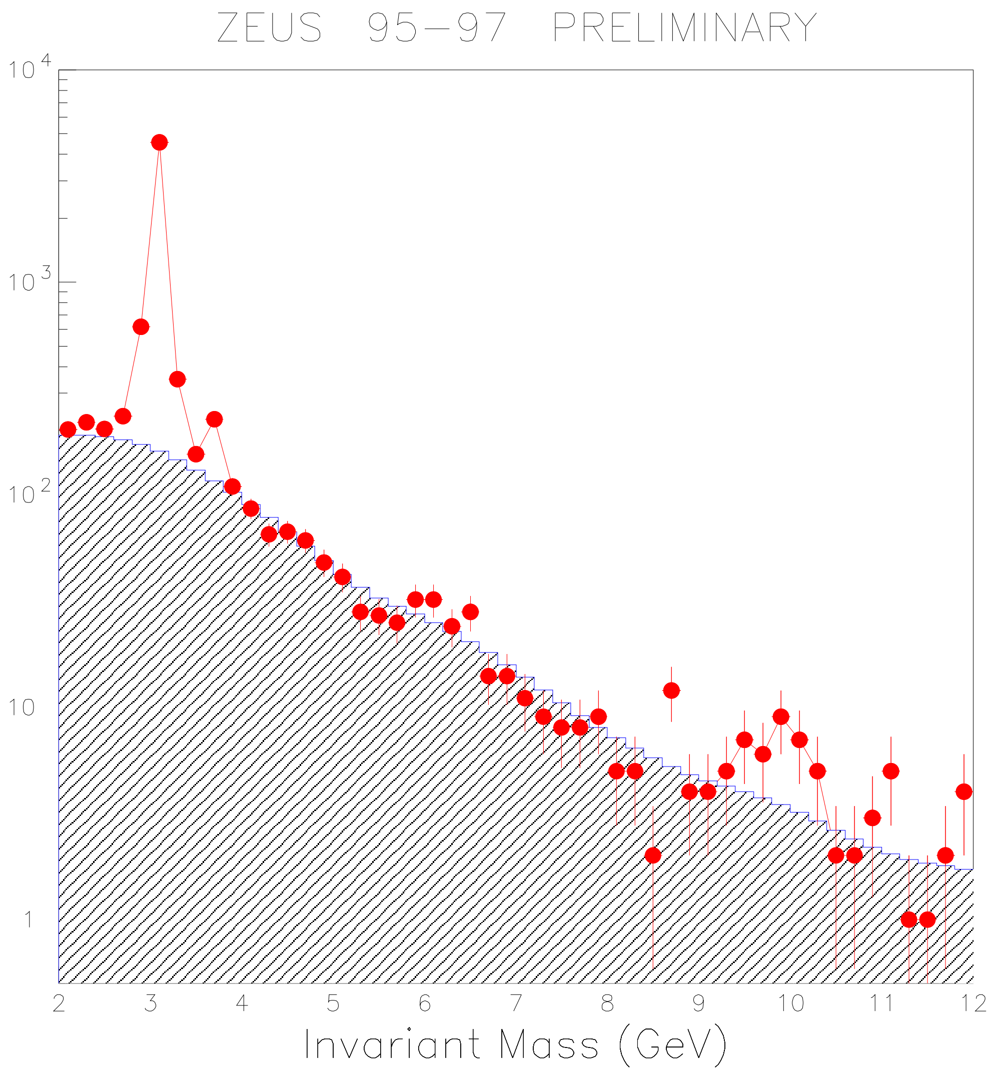
Consistent with color dipole model prediction

Nemchik et al, PL B341 (1994) 228, hep-ph/9712469

Preliminary Υ Signal from ZEUS

$$\gamma p \rightarrow \mu^+ \mu^- \; p$$

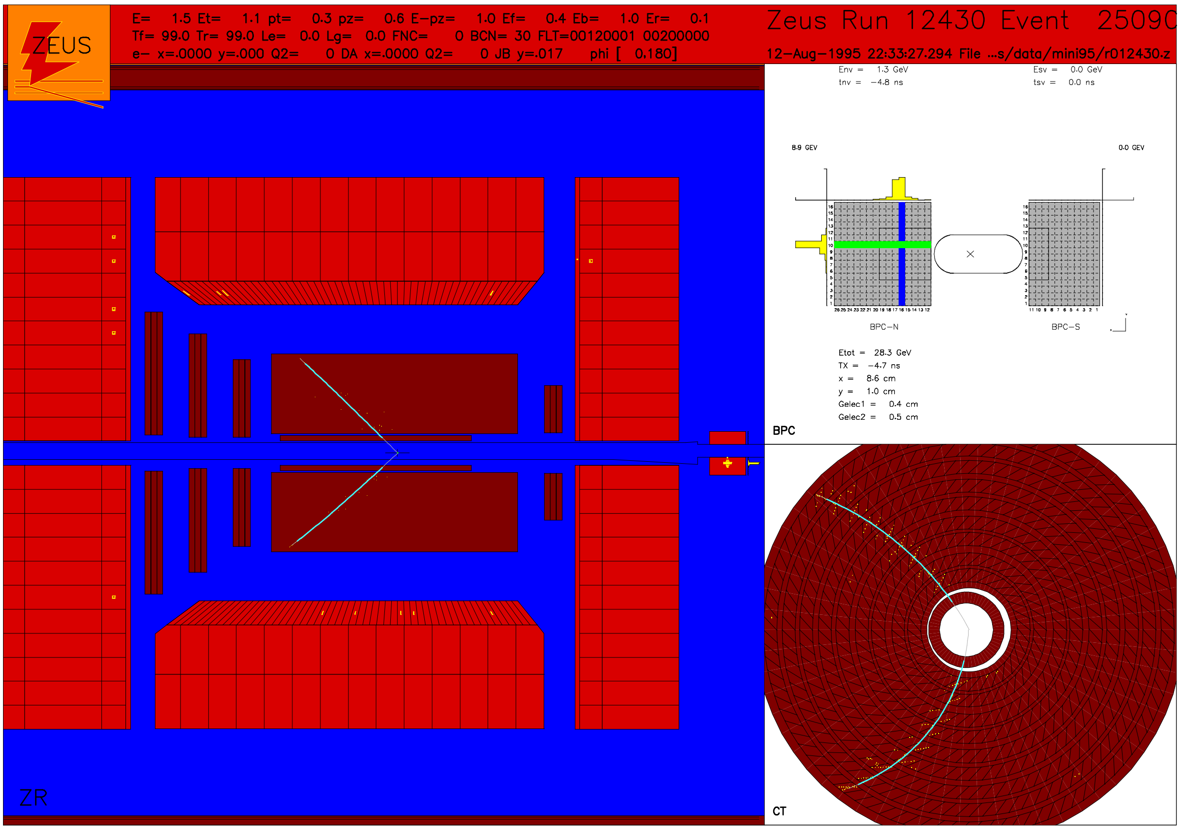
$80 < W < 280$ GeV, $Q^2 < 1$ GeV^2



$\sigma = 0.9 \pm 0.3 \pm 0.3$ nb

The Υ resonances are not resolved !

Diffractive Production of ρ^0 Mesons



e^+ in BPC

1995: 3.8 pb^{-1}

$0.25 < Q^2 < 0.85$ GeV^2

$20 < W_{\gamma^* p} < 90$ GeV

$\approx$ 6000 events

e^+ in UCAL

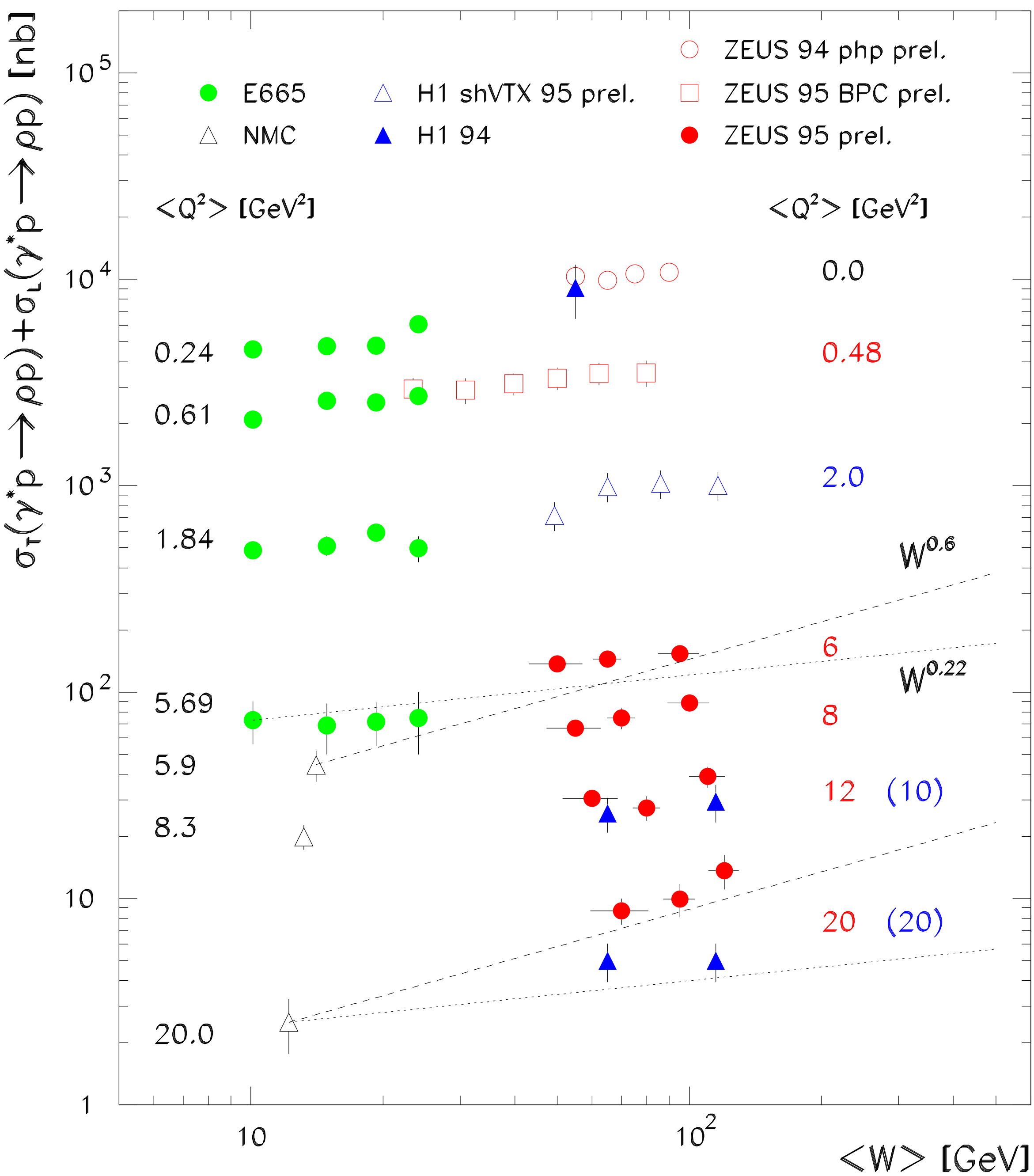
1995: 6 pb^{-1}

$5 < Q^2 < 30$ GeV^2

$34 < W_{\gamma^* p} < 144$ GeV

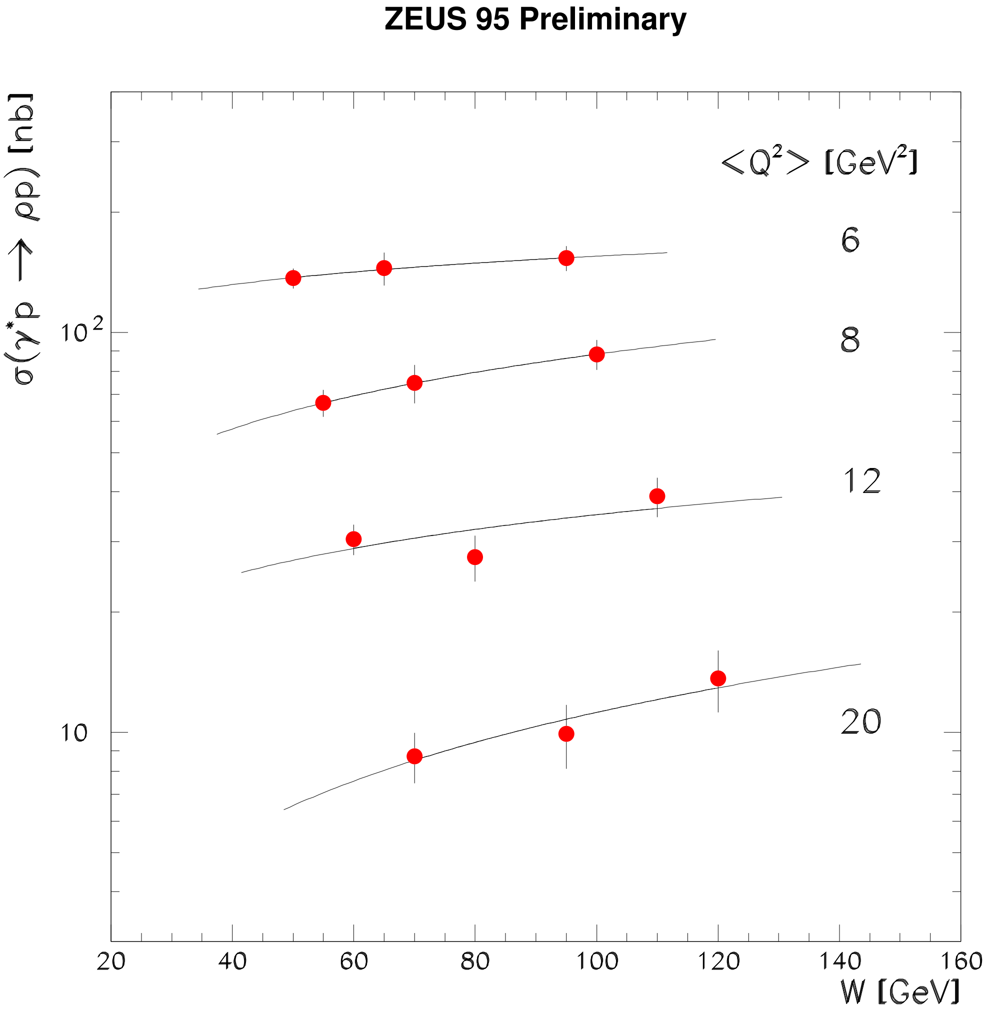
$\approx$ 2000 events

Elastic ρ^0 Cross Sections



$\Rightarrow$ Experimental discrepancies require further study

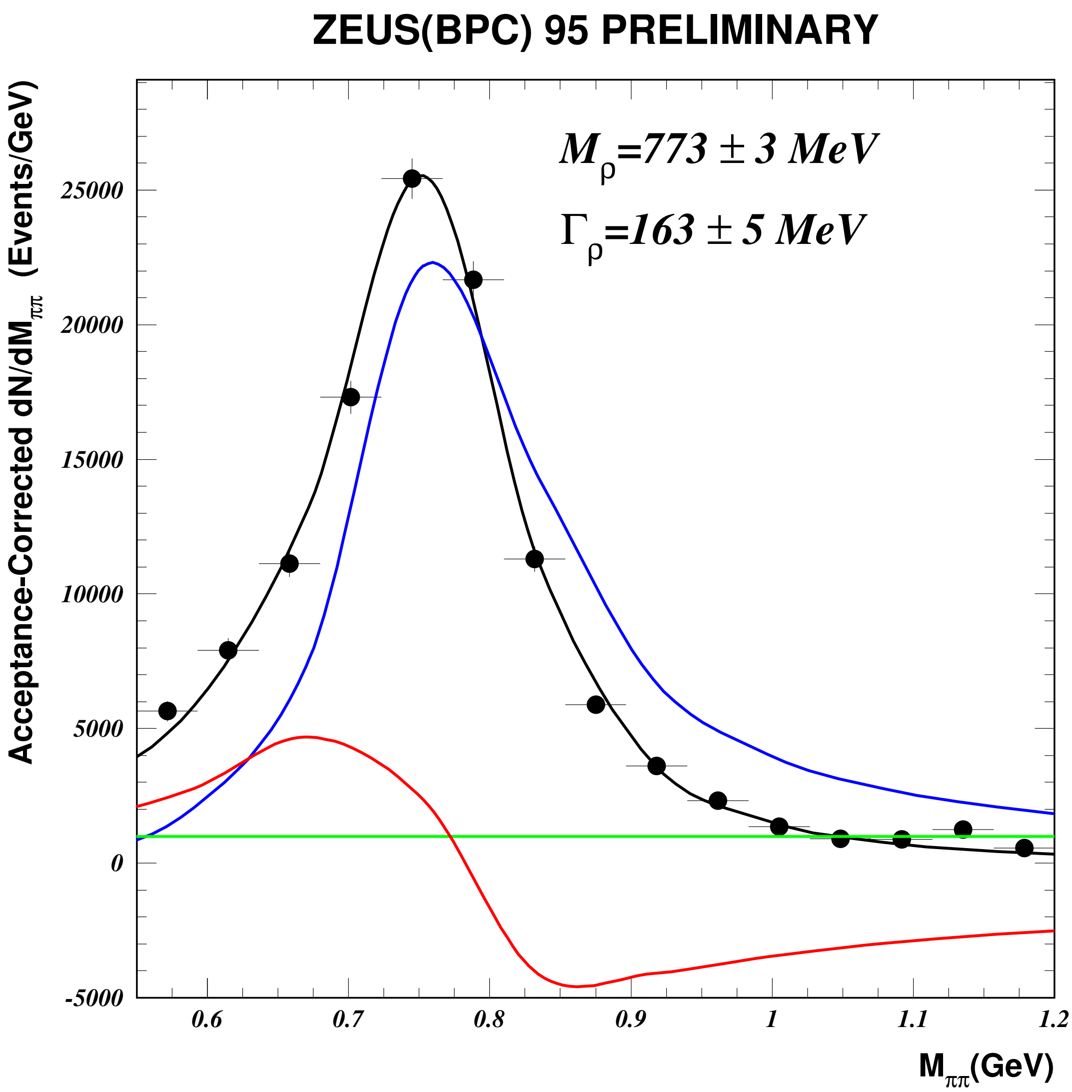
Elastic ρ^0 Cross Sections at High Q^2



$\Longrightarrow$ Steepening with Q^2 expected in pQCD

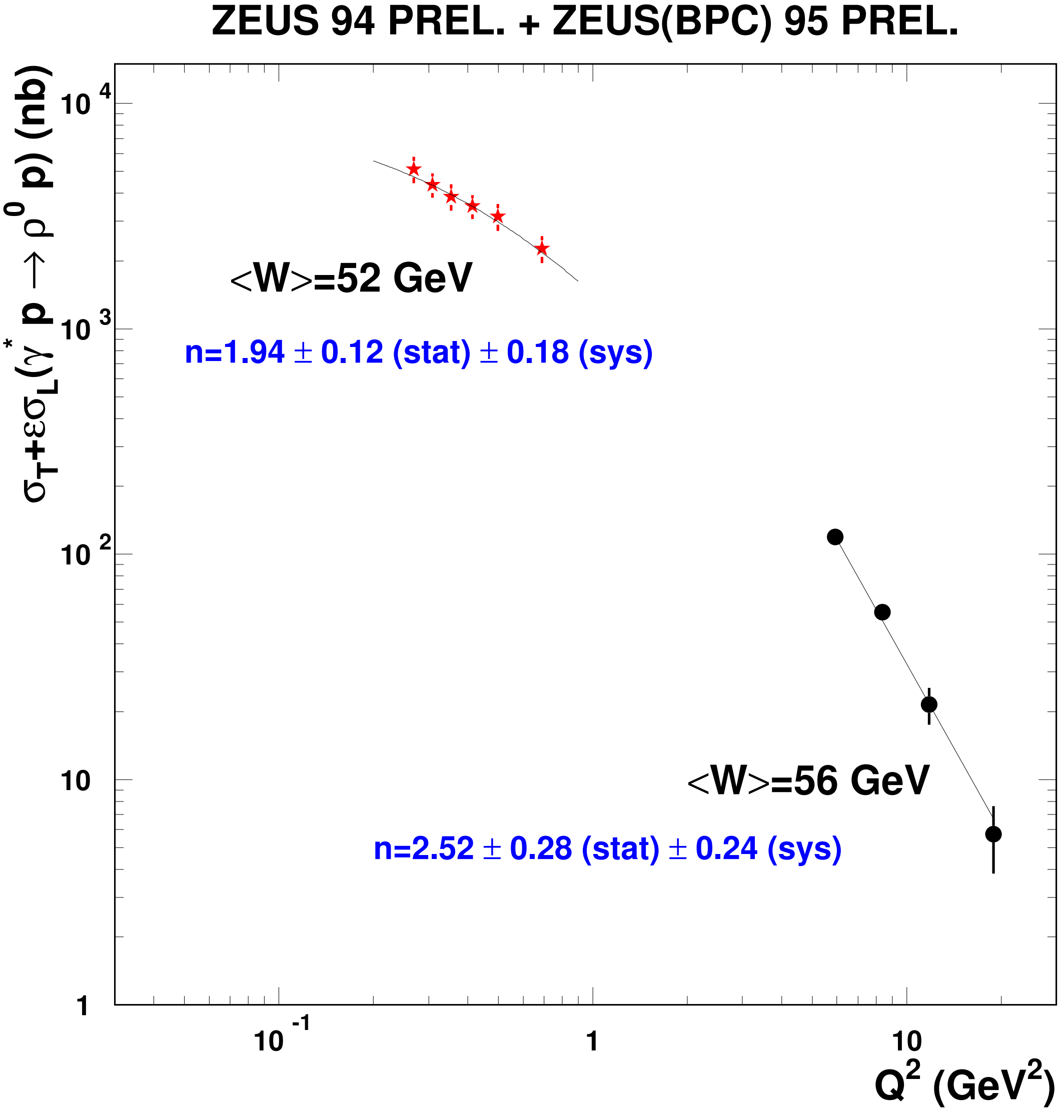
$\Longrightarrow$ Need more data

$\pi^+\pi^-$ Invariant Mass Spectrum



$$\frac{dN}{dM_{\pi\pi}} = \left| A \frac{\sqrt{M_{\pi\pi} M_\rho \Gamma_\rho}}{M_{\pi\pi}^2 - M_\rho^2 + i M_\rho \Gamma_\rho} + B \right|^2$$

$\sigma_T + \epsilon\,\sigma_L(\gamma^* p \to \rho^0 p)$

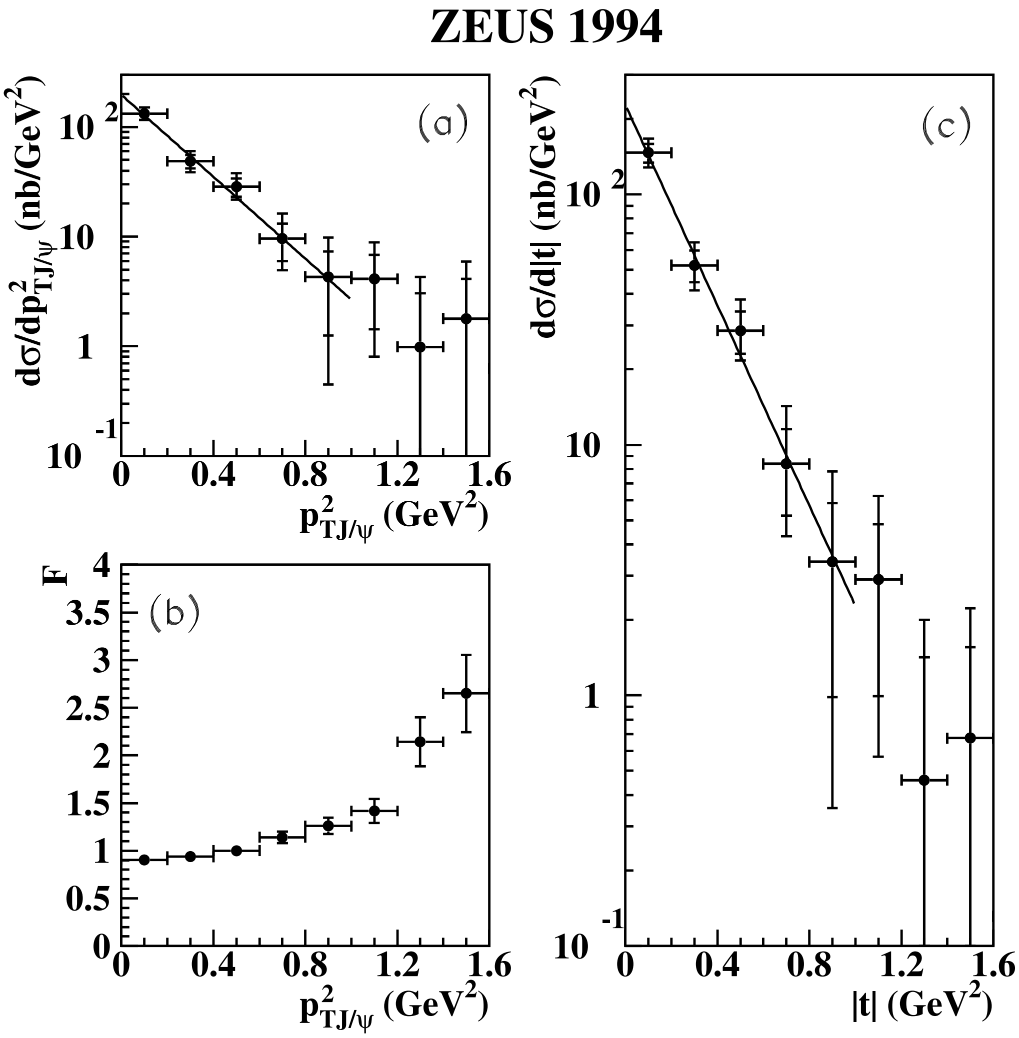


Fit to the shape $(Q^2 + M_\rho^2)^{-n}$

but notice the mixture of σ_L and σ_T ($\epsilon \approx 1$) ...

Photoproduction of J/ψ Mesons

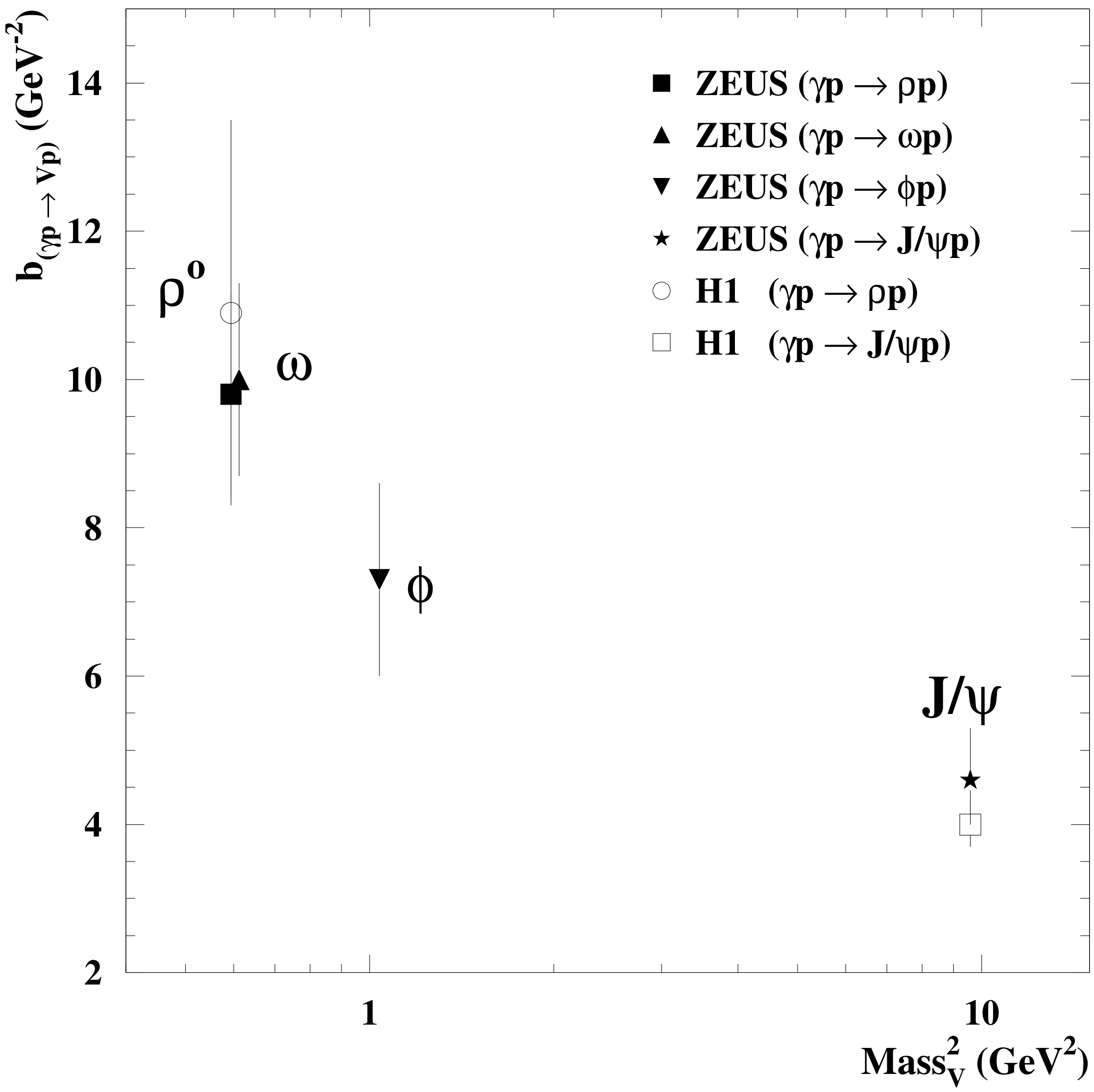
The Exponential Slope in $|t|$



$$b_{J/\psi} = 4.6 \pm 0.4\,(stat)^{+0.4}_{-0.6}\,(sys)\ \text{GeV}^{-2}$$

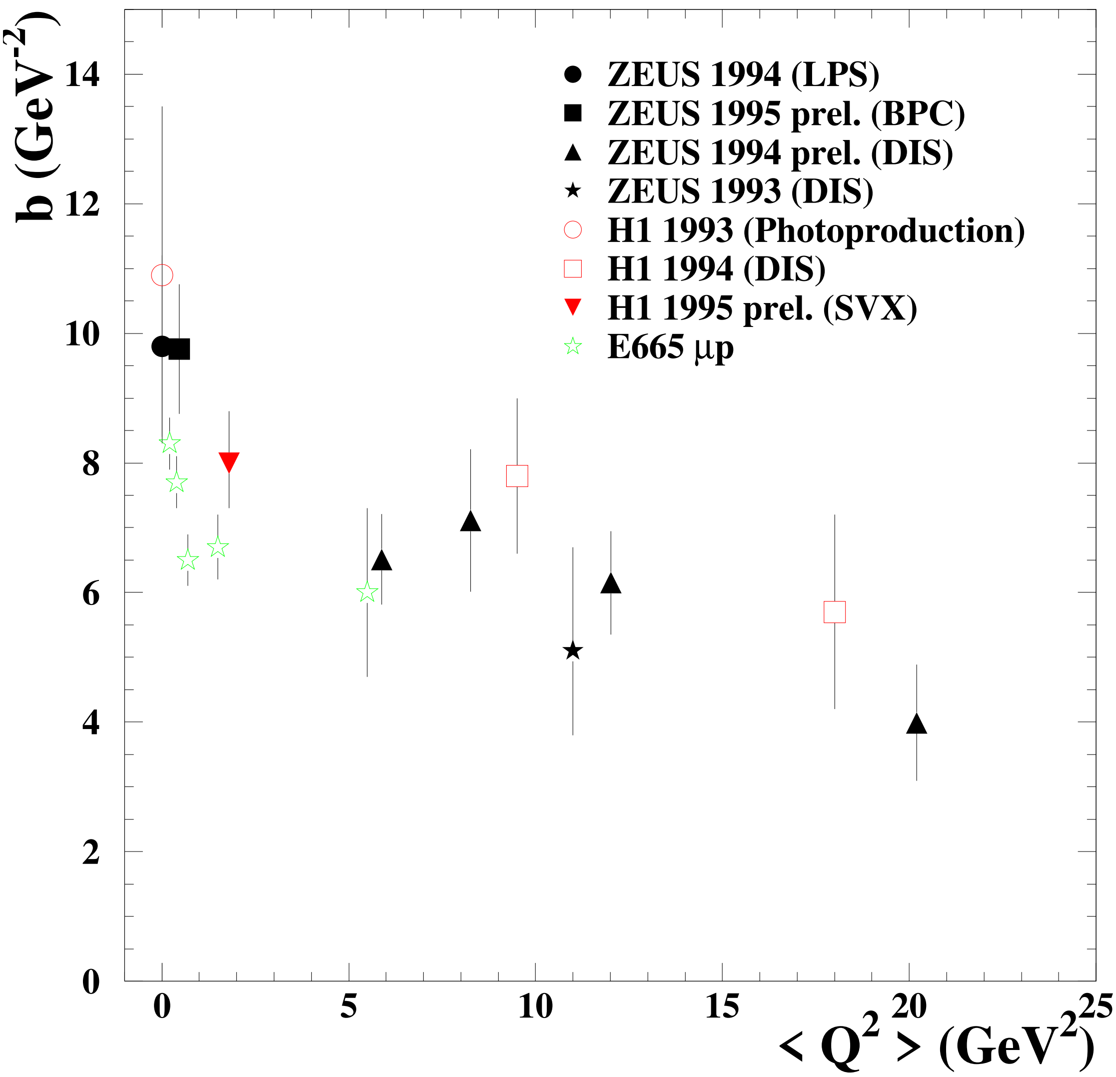
(Reminder : $b_{\rho^0} = 9.8 \pm 0.8\,(stat) \pm 1.1\,(sys)$ GeV^{-2})

t-Slope vs M^2_{VM}



$$b = b_p + b_{J/\psi} : \quad b_{J/\psi} < 1\,\text{GeV}^2$$

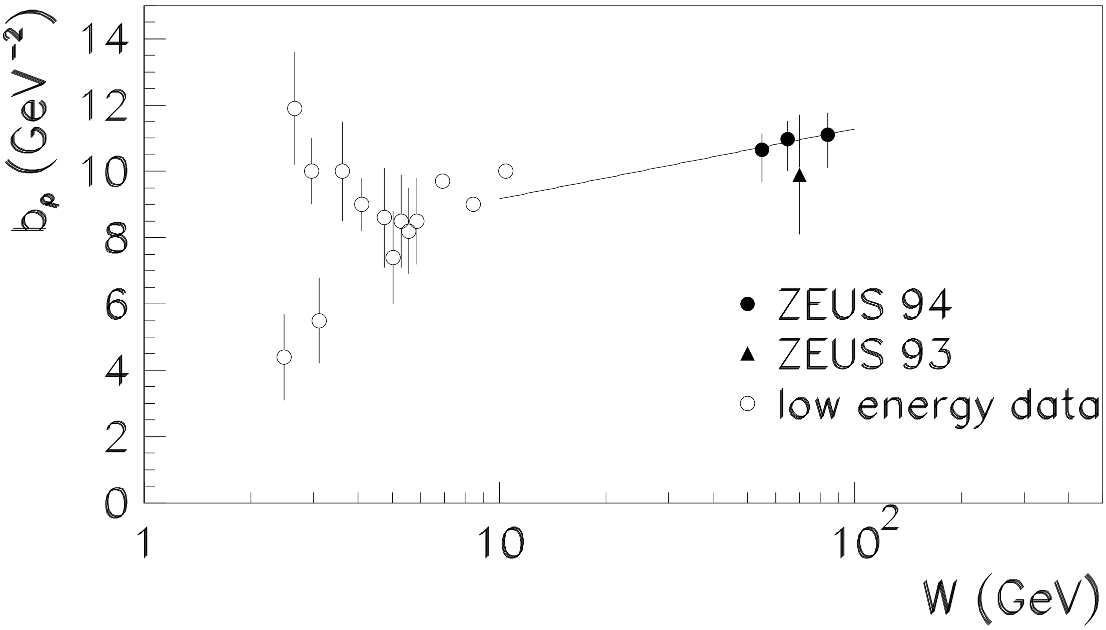
t-Slope for ρ^0 Mesons vs Q^2



$\Rightarrow$ The shrinking photon !!

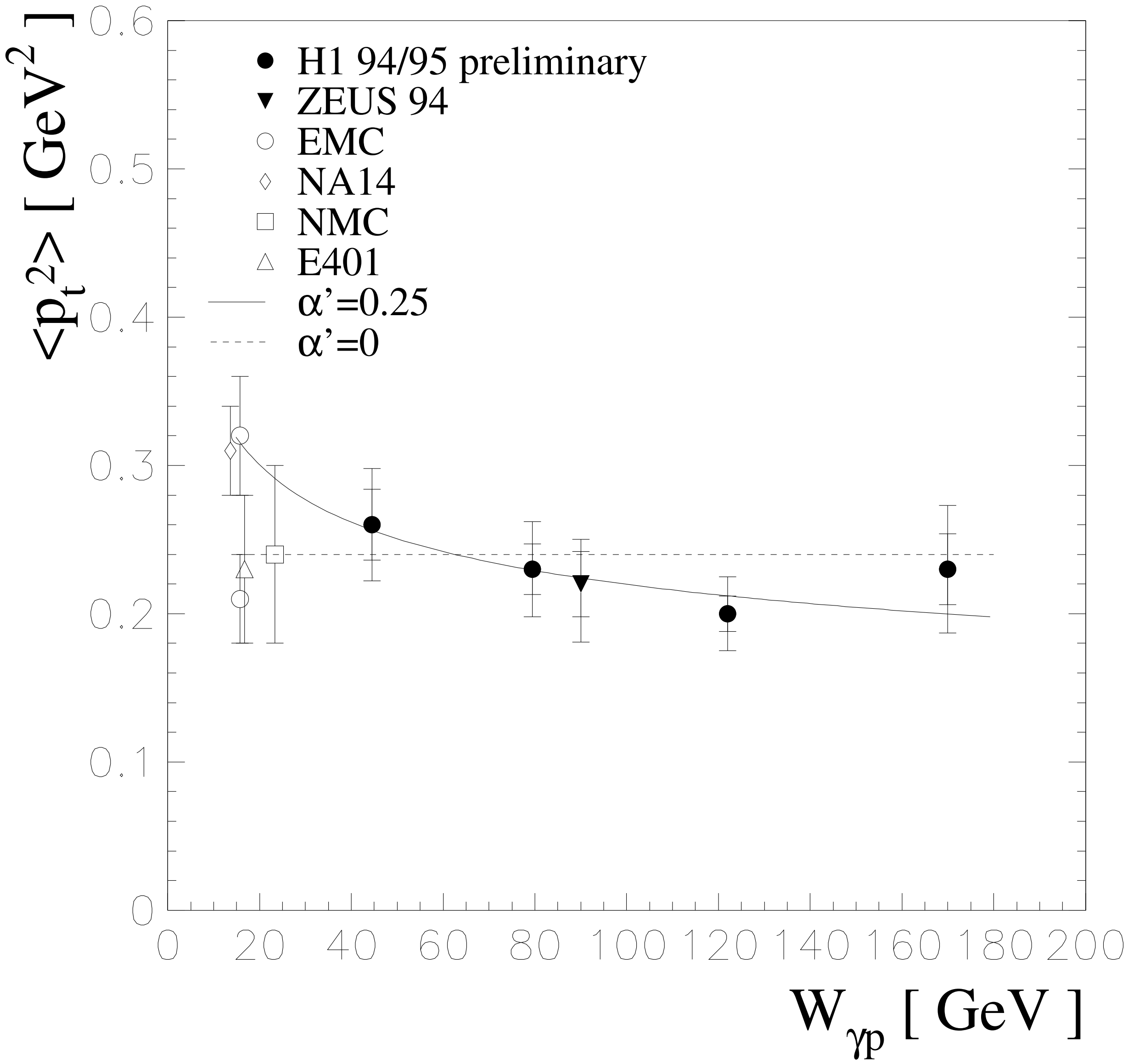
t-Slope for ρ^0 Mesons vs W

Does the t-slope depend on energy?



$\Rightarrow$ Test for shrinkage inconclusive

Elastic J/ψ Cross Sections



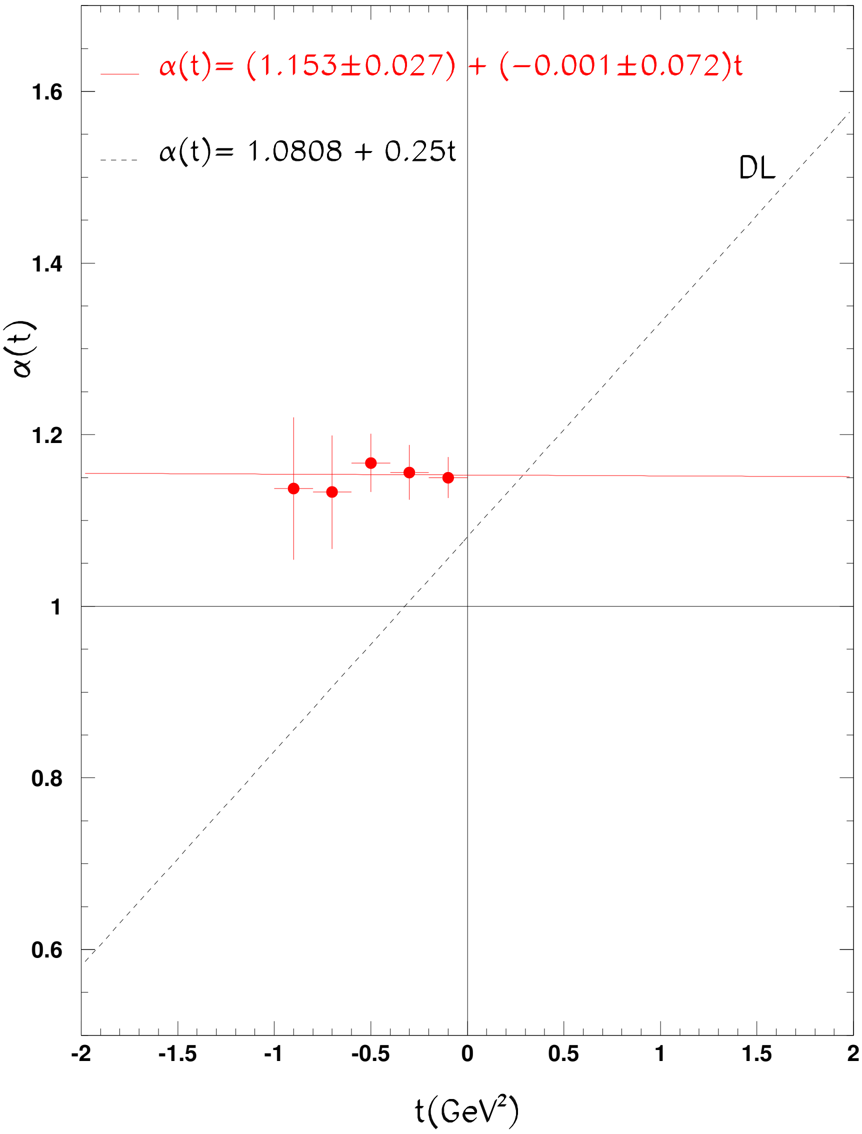
$\Longrightarrow$ Again inconclusive on shrinkage

The Case Against Shrinkage

A. Levy, hep-ph/9712519

Compares EMC, E401 (W=16 GeV) with H1, ZEUS (W=85 GeV)

$\gamma\, p \rightarrow J/\psi\, p$



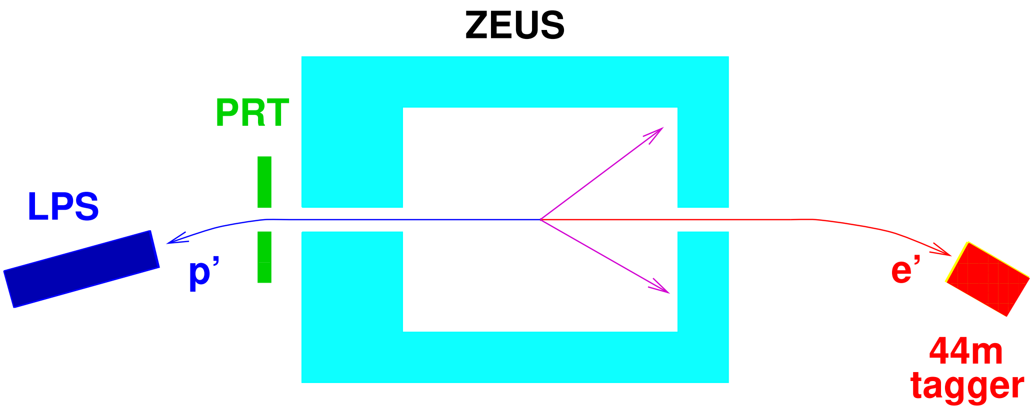
$\Rightarrow$ Inconsistent with $\alpha'_{I\!P} = 0.25\ \mathrm{GeV}^{-2}$

$\Rightarrow$ Concludes pQCD applicable

Collins et al, PL B307 (1993) 161 $\rightarrow$ "perturbative Pomeron"

High-$|t|$ Photoproduction

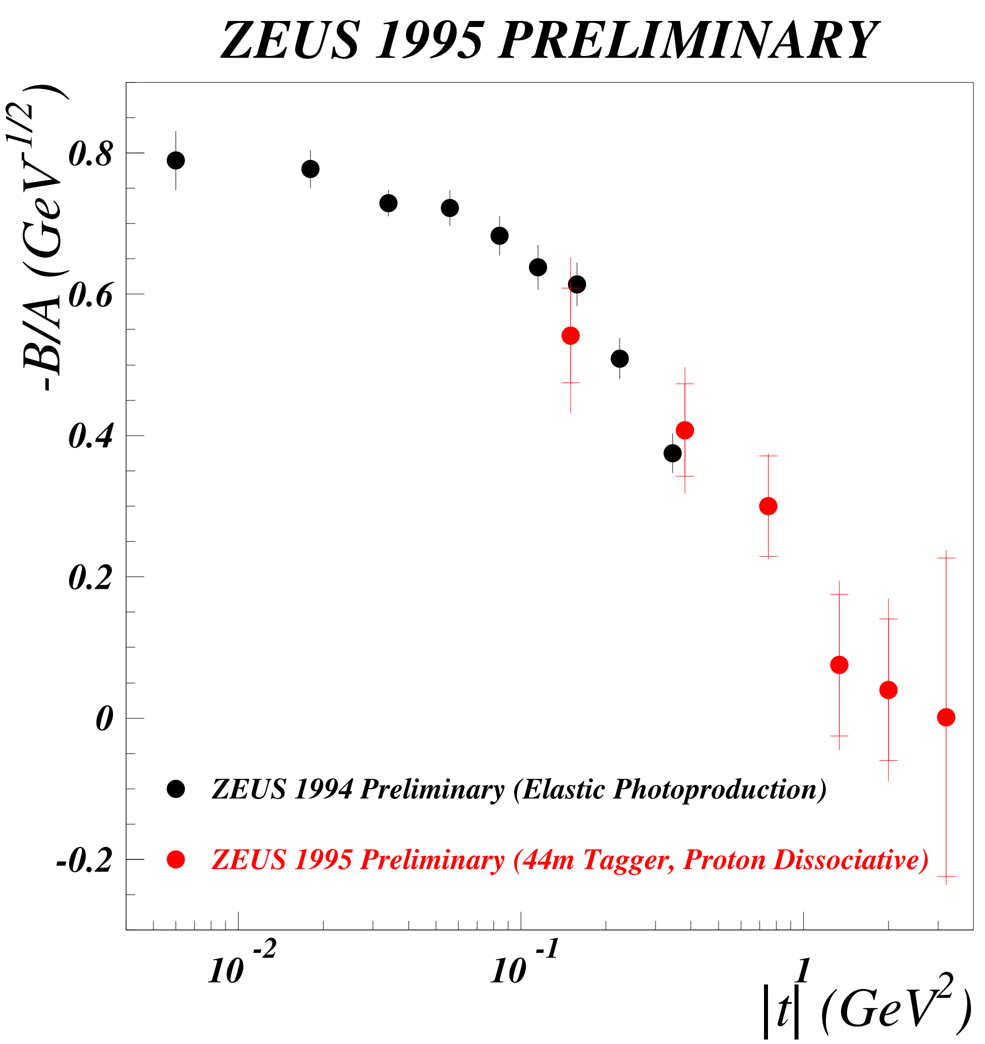
$$\left|\,|t| - p_T^2(\rho^0)\,\right| < Q^2$$



e$^+$ in 44m Tagger	Untagged Sample
1995: 2.1 pb^{-1}	1994: 2.2 pb^{-1}
$10^{-5} < Q^2 < .01$ GeV^2	$10^{-10} < Q^2 < 4$ GeV^2
$85 < W_{\gamma^* p} < 105$ GeV	$50 < W_{\gamma^* p} < 100$ GeV
$\|t\| < 4$ GeV^2	$\|t\| < 0.5$ GeV^2
$\approx 3k$ events	$\approx 80k$ events
(primarily proton dissociative)	(primarily elastic)

ρ^0 Mass Spectrum Skewing vs $|t|$

$$\frac{dN}{dM_{\pi\pi}} = \left| A\frac{\sqrt{M_{\pi\pi}M_\rho\Gamma_\rho}}{M_{\pi\pi}^2 - M_\rho^2 + iM_\rho\Gamma_\rho} + B \right|^2$$

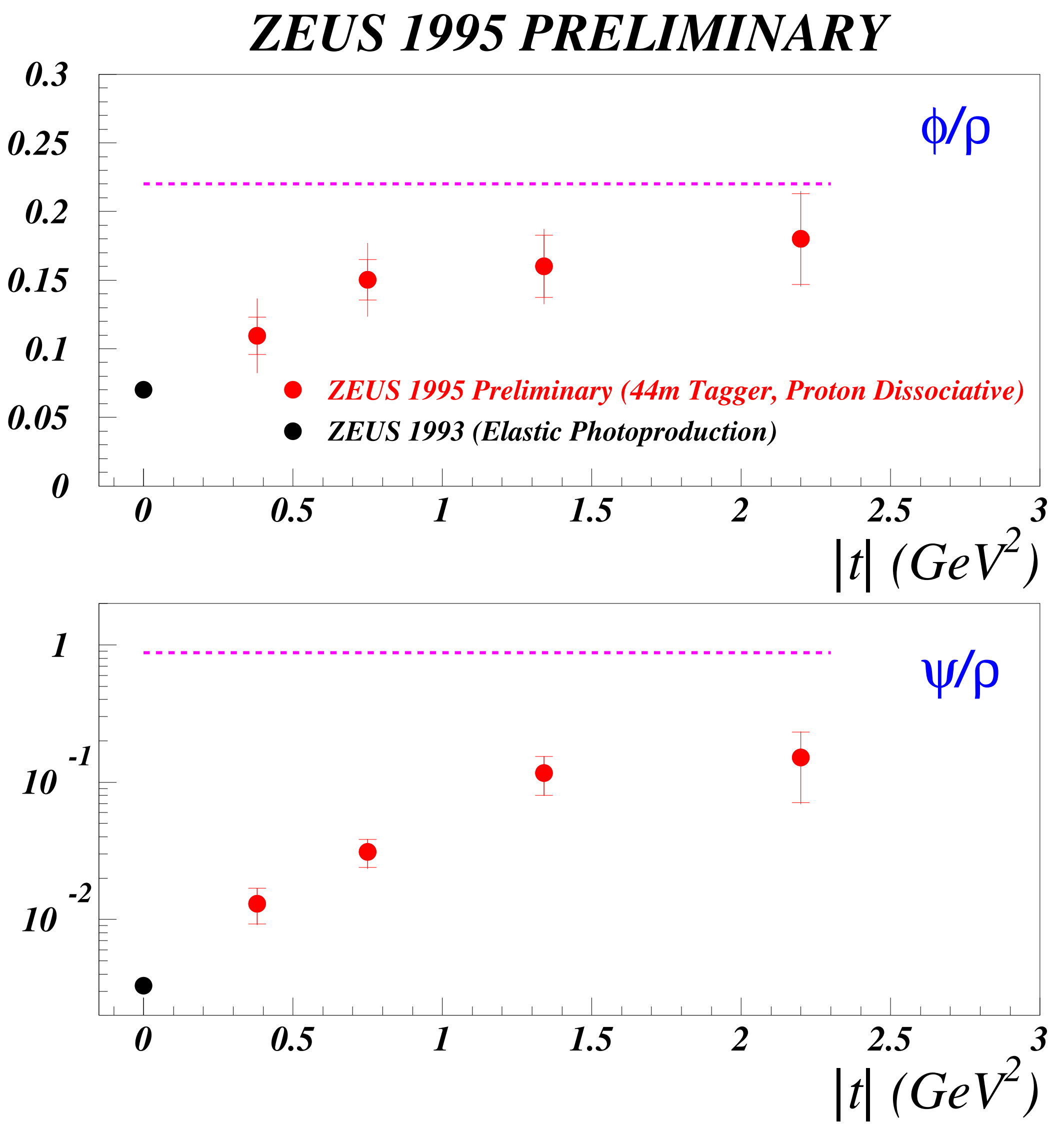


Vector Meson Production Ratios

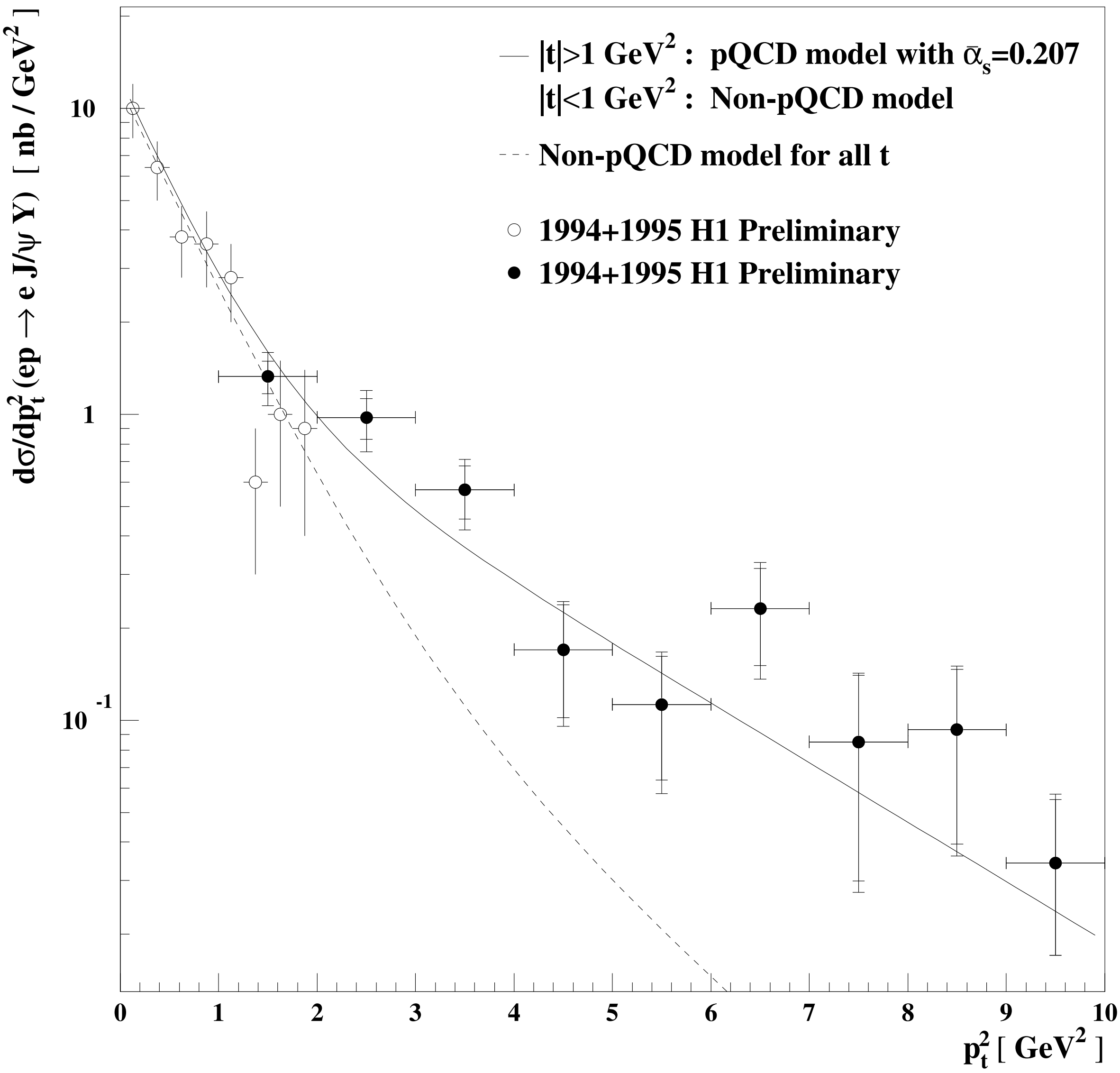
If direct e–m coupling to quarks without form factors

$$\rho^0 : \omega : \phi : J/\psi : \Upsilon$$

$$9 : 1 : 2 : 8 : 2$$



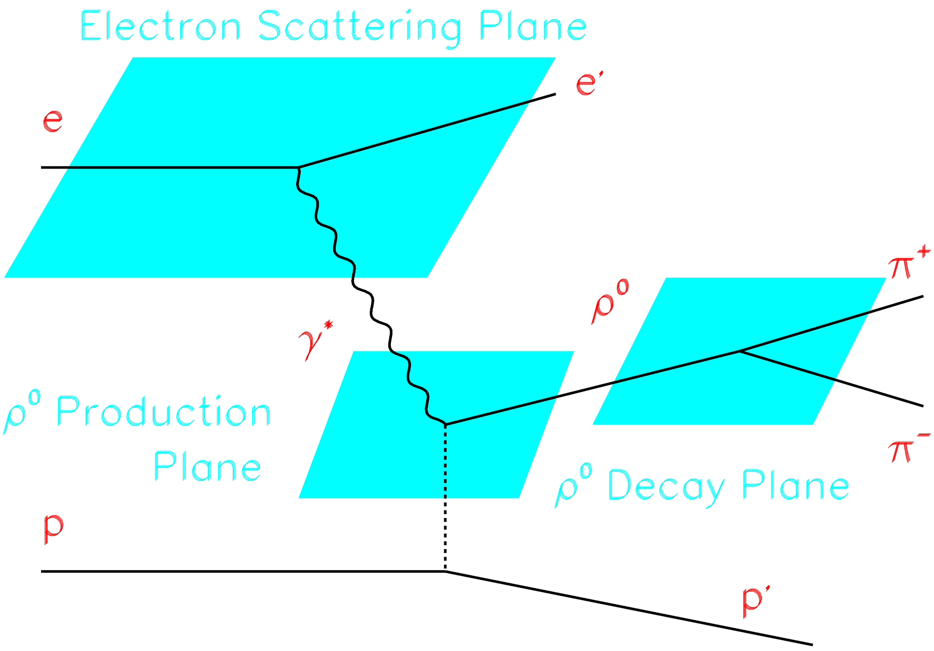
J/ψ Photoproduction at High $|t|$



$\Rightarrow$ pQCD works at high $|t|$!!

Bartels et al, PL B375 (1996) 301

Helicity Analyses



Φ_h	Angle between the electron scattering plane and the ρ^0 production plane
θ_h	Polar angle of π^+ in the ρ^0 rest frame
ϕ_h	Azimuthal angle of π^+

If helicity is conserved in the γ/ρ^0 transition, then the decay angular distributions depend only on the difference $\psi_h = \phi_h - \Phi_h$.

Decomposing the Spin Density Matrix

How to couple real photons ($\lambda = \pm 1$)
to vector mesons ($\lambda = 0, \pm 1$) ??

Helicity conserved in strong interactions
(but in what frame??)

Schilling, Seyboth, and Wolf, Nucl.Phys. B15, 397 (1970)
Formalism developed generally for arbitrary
real photon polarization (2x2 matrices!)

- Circular polarization: $\vec{\epsilon_\gamma} = \pm P^c_\gamma \, (0, 0, 1)$
- Linear polarization: $\vec{\epsilon_\gamma} = P^l_\gamma \, (-\cos\Phi, \sin\Phi, 0)$

Decompose ρ^0 decay angle distribution W(θ,ϕ)
into four parts W^i(θ,ϕ) (i=0,3) such that:

1. Unpolarized: W(θ,ϕ) = W^0(θ,ϕ)
2. Circularly polarized:
   W(θ,ϕ) = W^0(θ,ϕ) $\pm$ P$^c_\gamma$ W^3(θ,ϕ)
   Need long. pol. initial-state lepton$\rightarrow$E665(μ),HERMES(e)
3. Linearly polarized:
   W(θ,ϕ,Φ) = W^0(θ,ϕ) - P^l_γ $\cos 2\Phi$ W^1(θ,ϕ)
   - P$^l_\gamma$ $\sin 2\Phi$ W^2(θ,ϕ)

Generalizing to $R = \frac{\sigma_L}{\sigma_T} > 0$

Schilling and Wolf, Nucl.Phys. B61, 381 (1973)

Define linear combinations of the matrix elements:

(Helicity states $i, k = -1, 0, +1$)

$$r_{ik}^{04} = \frac{\rho_{ik}^{0} + \epsilon R \rho_{ik}^{4}}{1 + \epsilon R}$$

The angular distributions do not distinguish unpolarized transverse photons from longitudinally polarized photons!

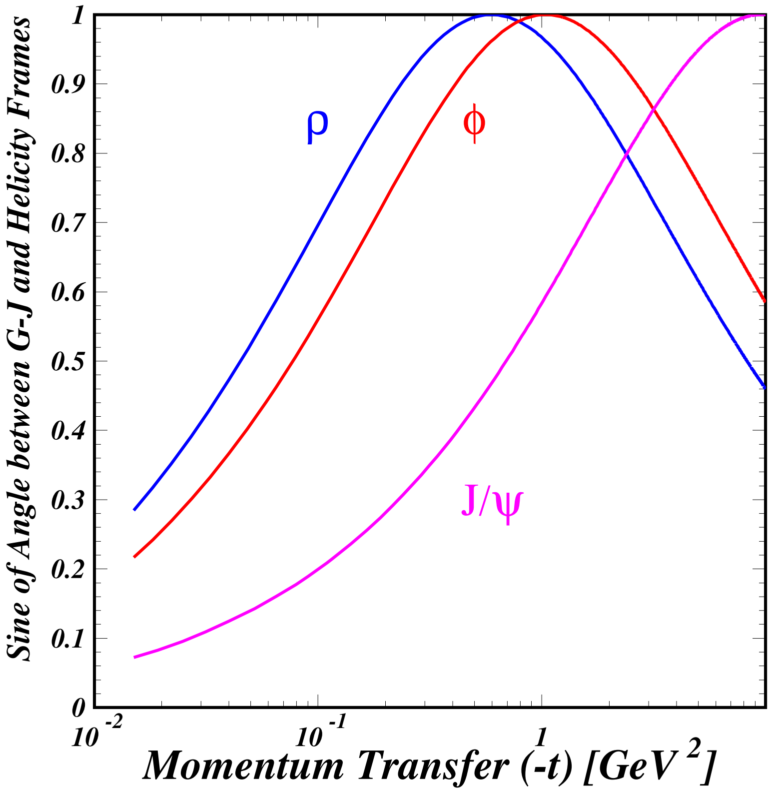
$$r_{ik}^{\alpha} = \begin{cases} \dfrac{\rho_{ik}^{\alpha}}{1+\epsilon R} & \alpha = 1-3 \text{ (Trans.)} \\ \dfrac{\sqrt{R}\,\rho_{ik}^{\alpha}}{1+\epsilon R} & \alpha = 5-8 \text{ (L/T int.)} \end{cases}$$

Constraints from hermiticity, parity conservation

The Choice of Frame

- Gottfried-Jackson frame
  Spin quantized along photon direction (t-channel)
- Helicity frame
  Spin quantized along meson direction (s-channel)

The angle χ between the two frames: $\cos\chi = \left(\frac{m_\rho^2 + t}{m_\rho^2 - t}\right)$

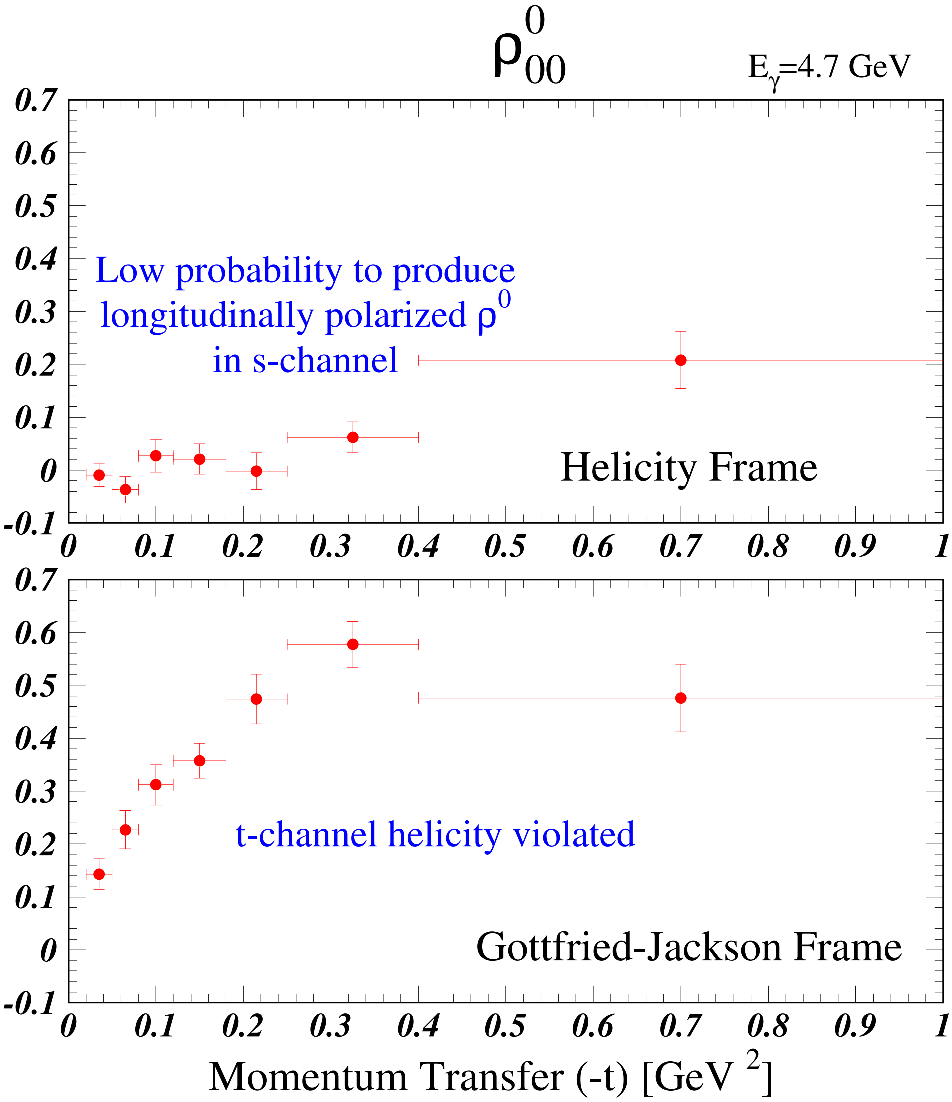


$\Rightarrow$ ρ^0 most sensitive to a violation of helicity conservation in the s-channel amplitudes (SCHC)

SCHC in ρ^0 Photoproduction

Ballam et al., Phys. Rev. D5, 545 (1972)

- Backscattered laser beam at SLAC
- Linear polarization measured to be greater than 90%
- 2.8 and 4.7 GeV photons
- 3k $\rho^0 \to \pi^+\pi^-$ reconstructed in bubble chamber



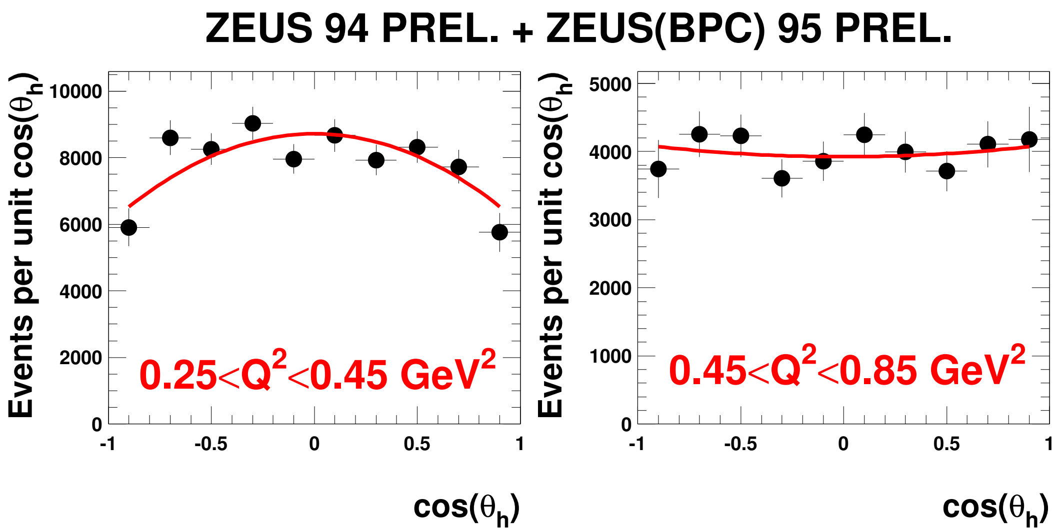
Inconsistent with t-channel exchange of spin 0 object

Gilman et al PL B31 (1970) 387

$\Longrightarrow$ Conclude SCHC holds for $|t| < 0.4\ \text{GeV}^2$

ρ^0 Electroproduction at HERA

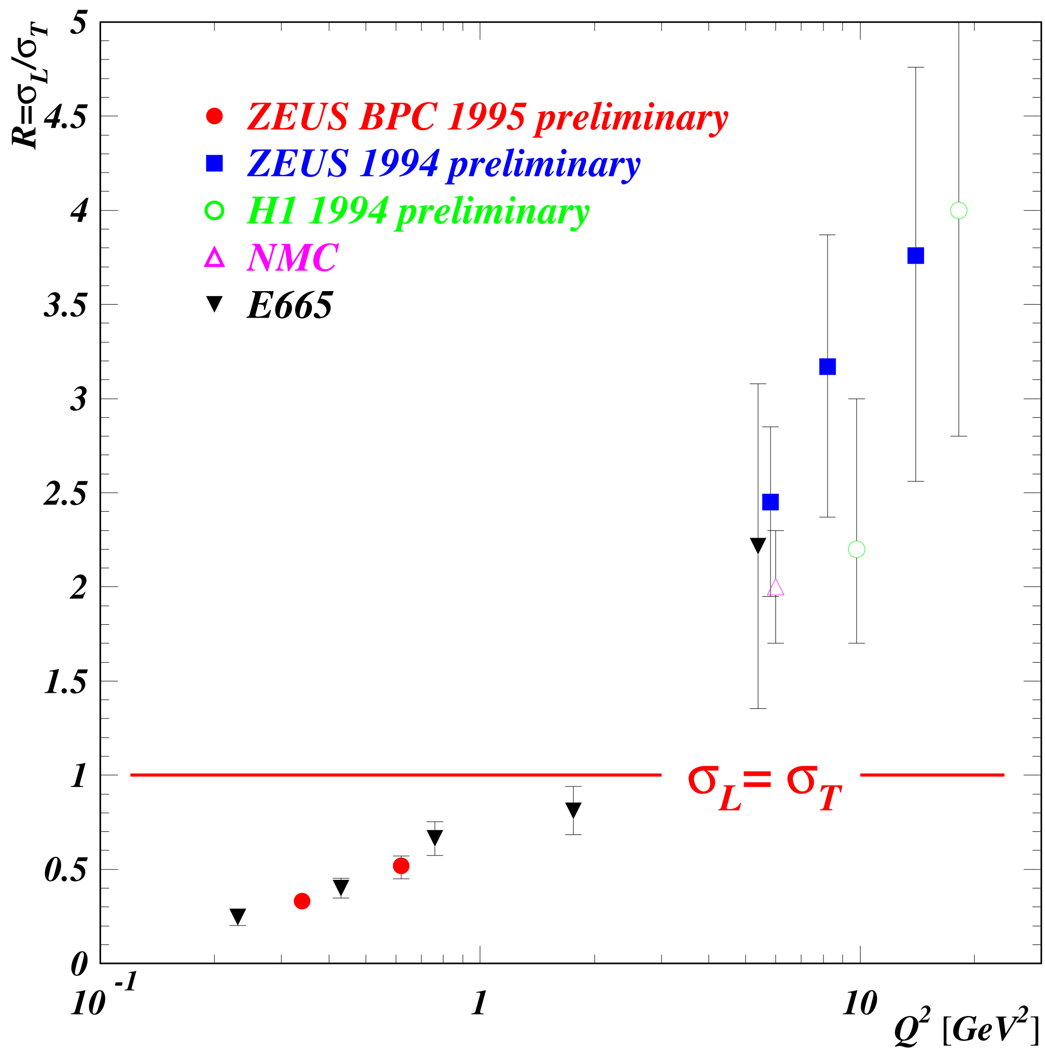
$$\frac{dN}{d\cos\theta_h} \propto 1 - r^{04}_{00} + (3r^{04}_{00} - 1)\cos^2\theta_h$$



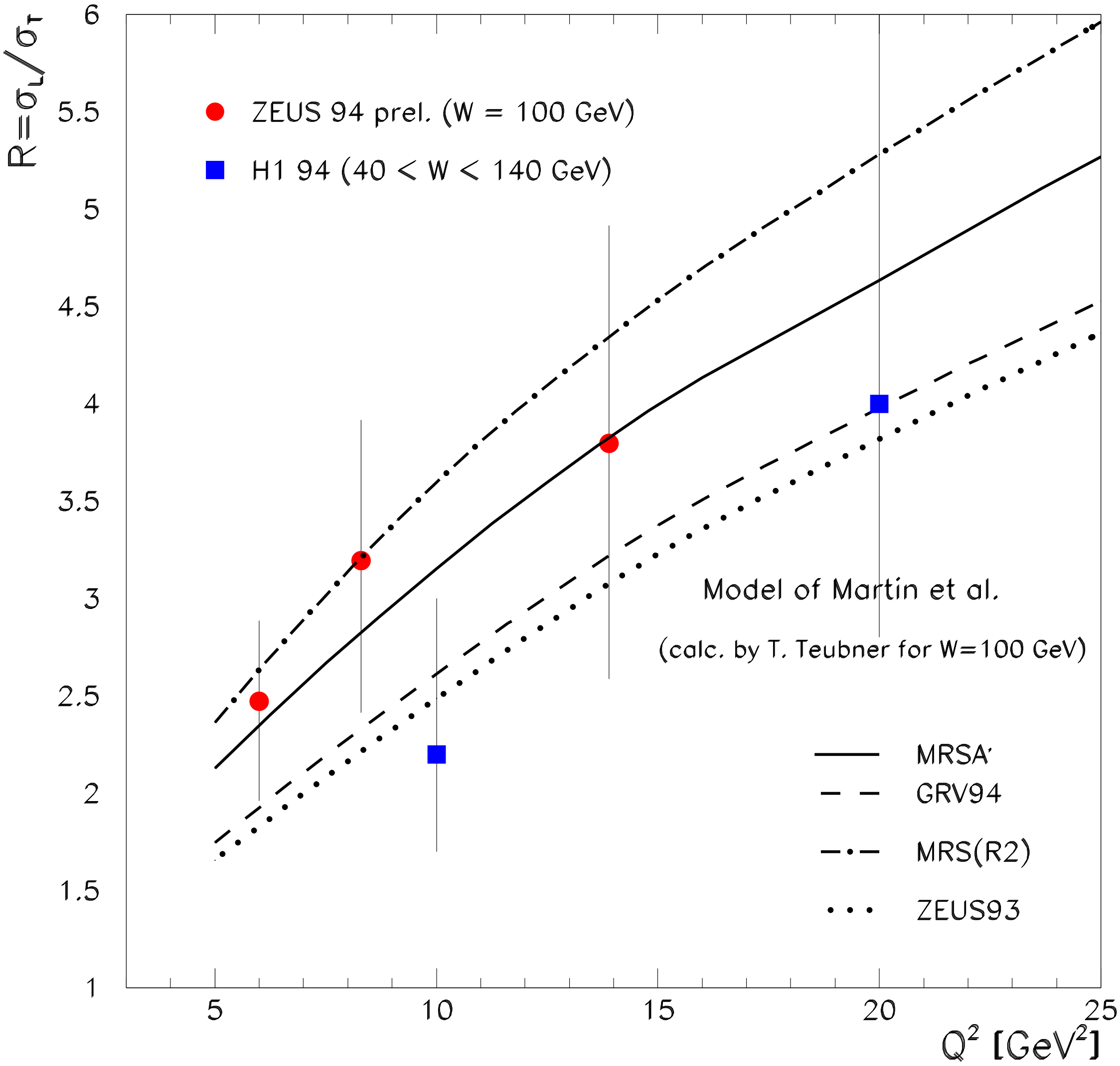
Q^2 (GeV^2)	r^{04}_{00}
0.34	0.24 ±0.02(stat)
0.62	0.34 ±0.03(stat)
5.8	$0.71^{+0.03}_{-0.04}$(stat)$^{+0.01}_{-0.01}$(sys)
8.2	$0.76^{+0.04}_{-0.04}$(stat)$^{+0.00}_{-0.02}$(sys)
14	$0.79^{+0.04}_{-0.05}$(stat)$^{+0.02}_{-0.01}$(sys)

$$R = \frac{\sigma_L}{\sigma_T} \text{ vs } Q^2$$

Assuming SCHC: $R = \frac{1}{\epsilon} \frac{r_{00}^{04}}{1 - r_{00}^{04}}$



pQCD Calculation of R



⇒ Need more data !

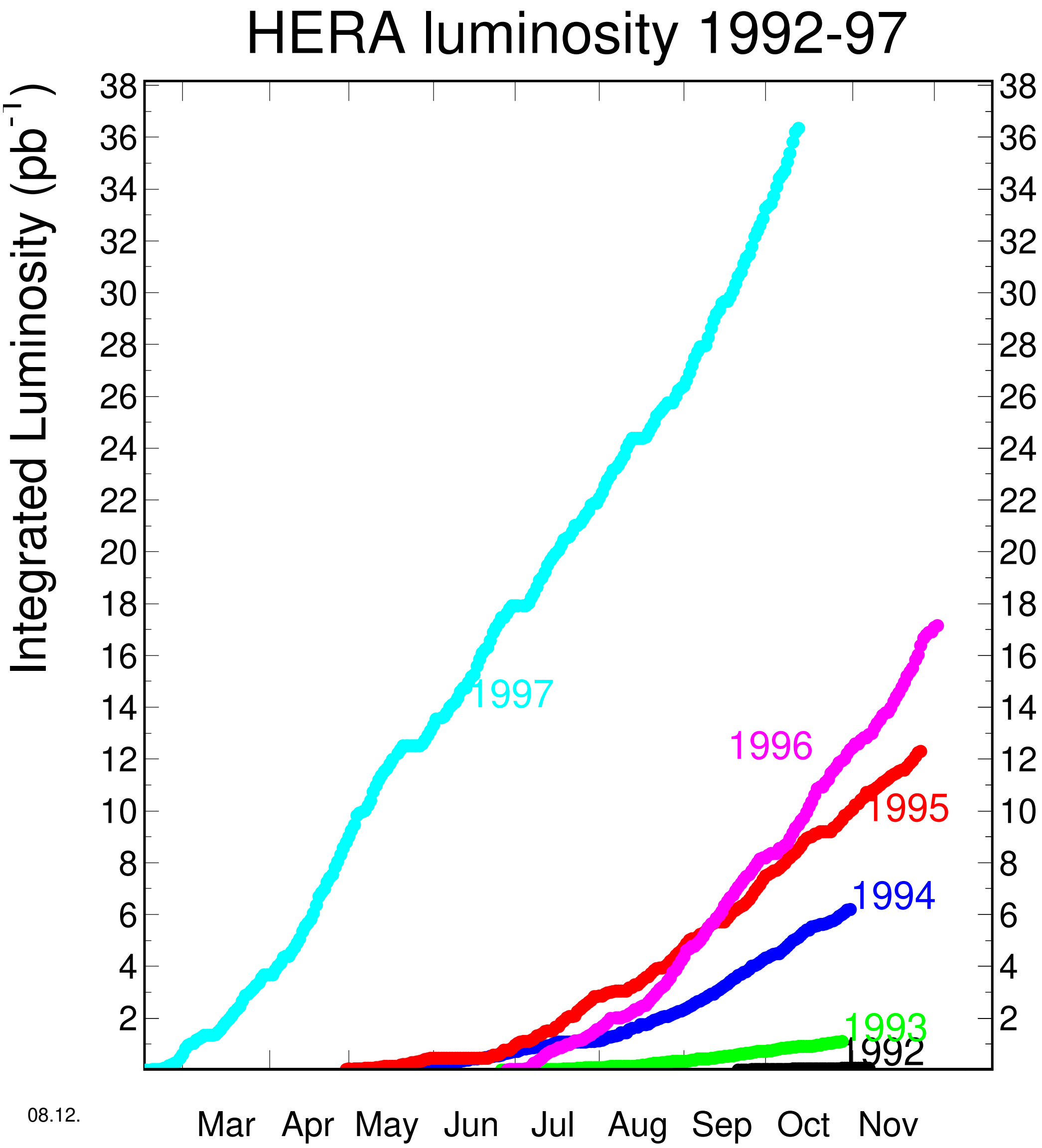
Conclusions

These results show preliminary evidence for the hard scale to be given by either Q^2, M_V^2, or $|t|$

The H1 and ZEUS experiments are sensitive to the transition region in *EACH* of these variables

These studies are statistics-limited
1996/97 data still to be analyzed

HERA Integrated Luminosity



Only the ZEUS high-$|t|$ and Υ analyses include data recorded after 1995