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ON BEHALF OF
THE ZEUS COLLABORATION

Proton-Dissociative Diffractive Photoproduction of Vector Mesons at Large $\mid t \mid$ at HERA

1. Physics Motivations
2. Kinematics
3. Monte Carlo Simulation
4. Results
   - Differential Cross Sections $\mathrm{d}\sigma/\mathrm{d}t$
   - Decay Angle Analysis
5. Summary
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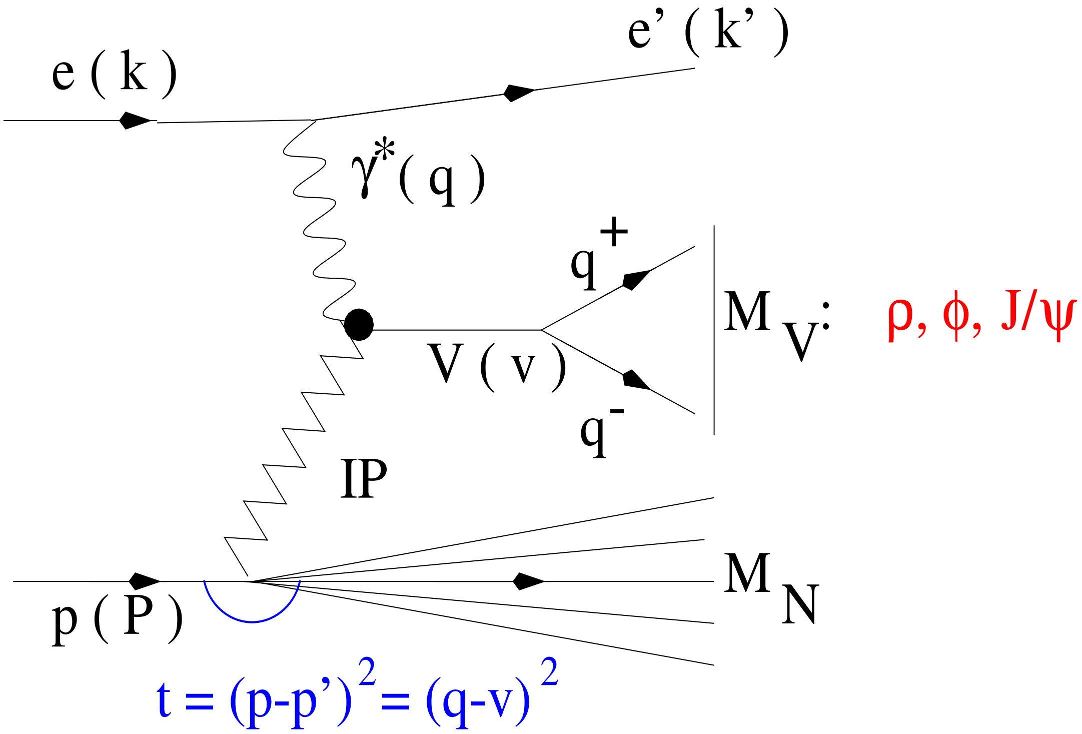
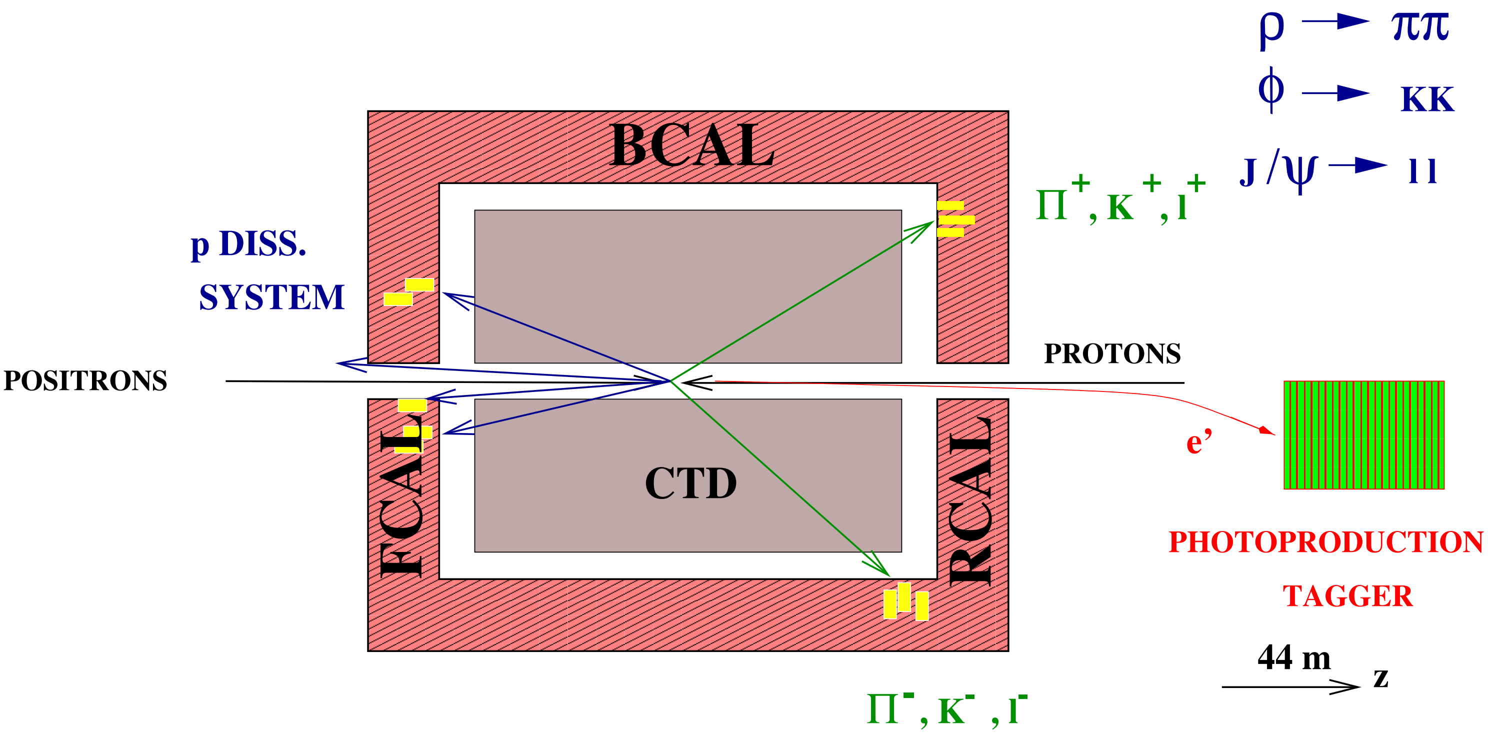
PHOTON2000
28.08.2000

PHYSICS MOTIVATION



- Is $|\,t\,|$ providing a hard scale ?
- Is $|\,t\,|$ scale on same footing as Q^2, M_V^2 ?
- At which $|\,t\,|$ pQCD description is valid ?
- Do the spin density matrix elements agree with pQCD calculations?

RECONSTRUCTION OF KINEMATIC VARIABLES



- All kinematic variables are reconstructed from three-momenta of the meson decay products measured by the **C**entral **T**racking **D**etector

$$E_{VM} = E_{\pi^+\pi^-(K^+K^-)(l^+l^-)}$$

$$Q^2 \simeq 0$$

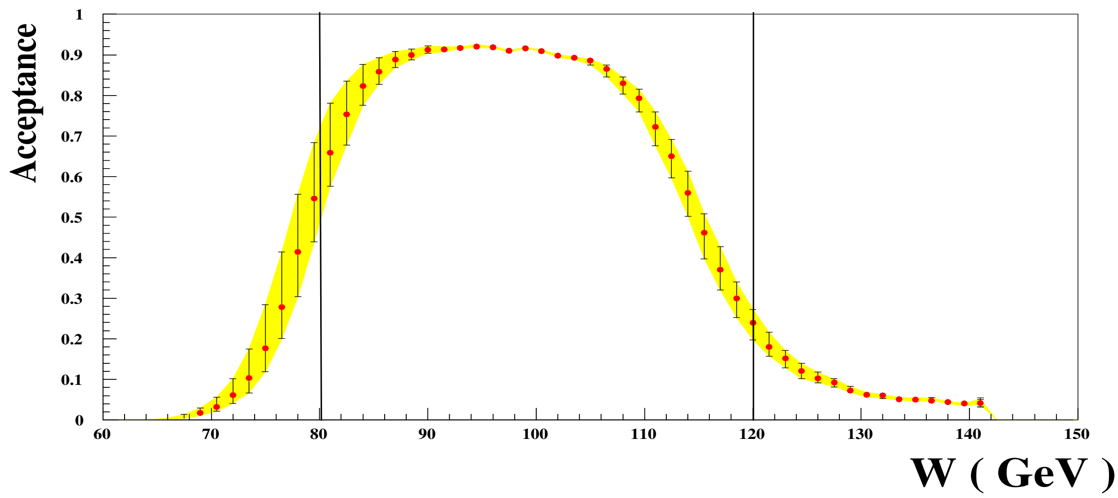
$$W^2 \simeq 2 \cdot E_p(E_{VM} - p_{z_{VM}})$$

$$t \simeq -p^2_{T_{VM}}$$

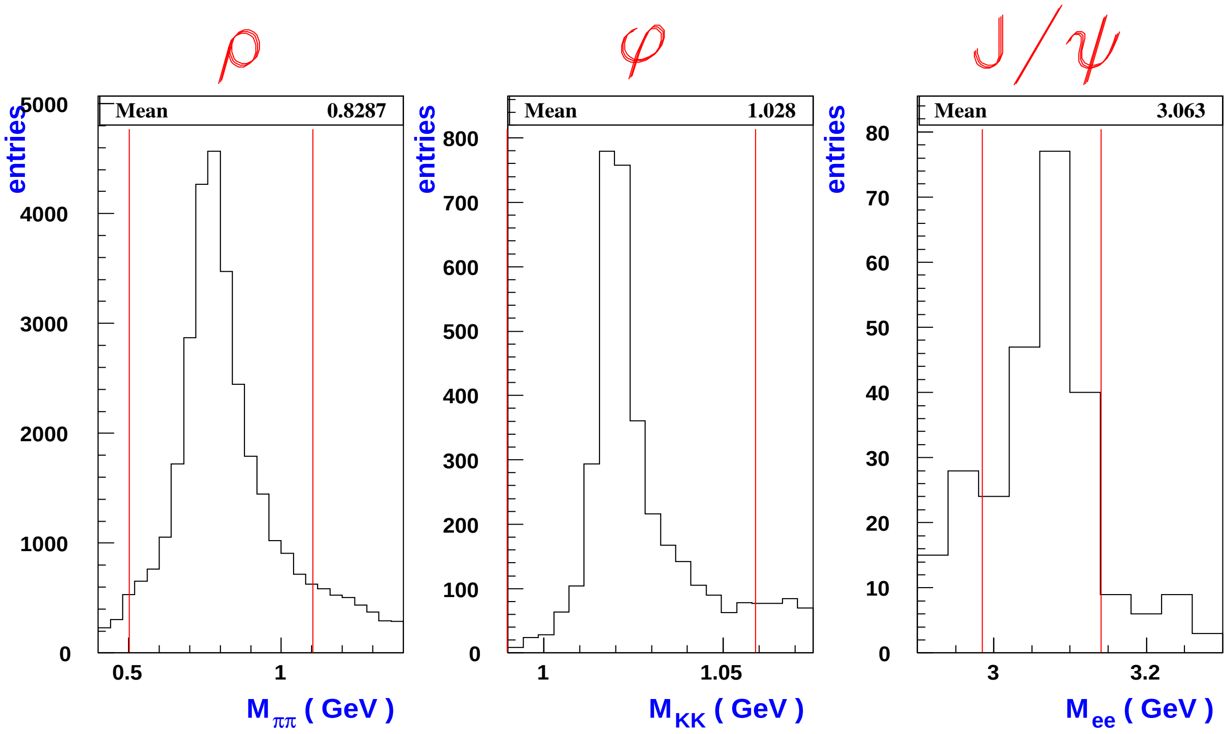
KINEMATIC RANGE

'96 and '97 DATA $\Rightarrow \mathcal{L} = 24\text{pb}^{-1}$

- *photoproduction:* $Q^2 < 0.02$ GeV^2
- $|\, t \,|$ *range:* 1.2 - 12.2 GeV^2
- W *range:* $80 < W < 120$ GeV
  (44m Tagger Acceptance)
- *average* W*:* $\simeq$ 100 GeV



EVENT SELECTION



- *the invariant mass range for 3 vector mesons*:

$$\begin{array}{llll} 0.50 & < M_{\pi\pi} < 1.1 GeV & \text{for} & \rho \\ 0.99 & < M_{KK} < 1.06 GeV & \text{for} & \phi \\ 2.98 & < M_{ee} < 3.13 GeV & \text{for} & J/\psi \end{array}$$

- fits to ρ, ϕ and J/ψ masses and widths agree with PDG values

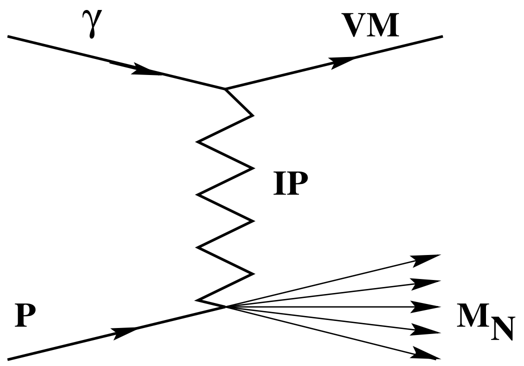
Final sample contains:

24400	ρ
3300	ϕ
180	J/ψ

MONTE CARLO SIMULATION

EPSOFT Proton Dissociative Monte Carlo

- simulates diffractive **E**lectron-**P**roton **SOFT** collisions at HERA
- diffractive pomeron-proton and pomeron-photon scattering $\Rightarrow$ soft hadron-hadron collisions
- tuned to ZEUS photoproduction data
- proton-dissociative process

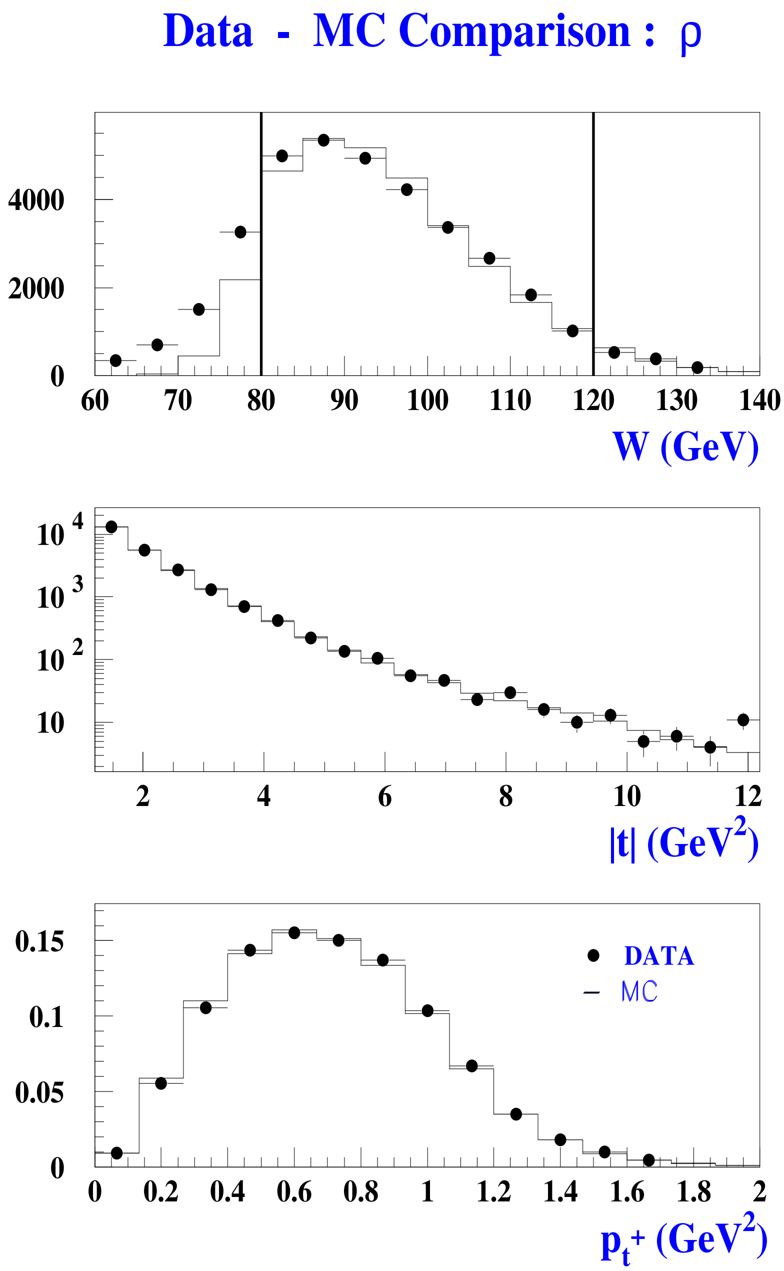


- reweighted according to:

$$\frac{d^2\sigma(\gamma p \to VN)}{dtdM_N^2} \propto f(t) \cdot (\frac{W^2}{M_N^2})^{\beta(t)}$$

  - $f(t)$ fitted to match t-distribution in data
  - $\beta(t)$ fitted to data to match energy distributions of system N in the calorimeter

MONTE CARLO SIMULATION



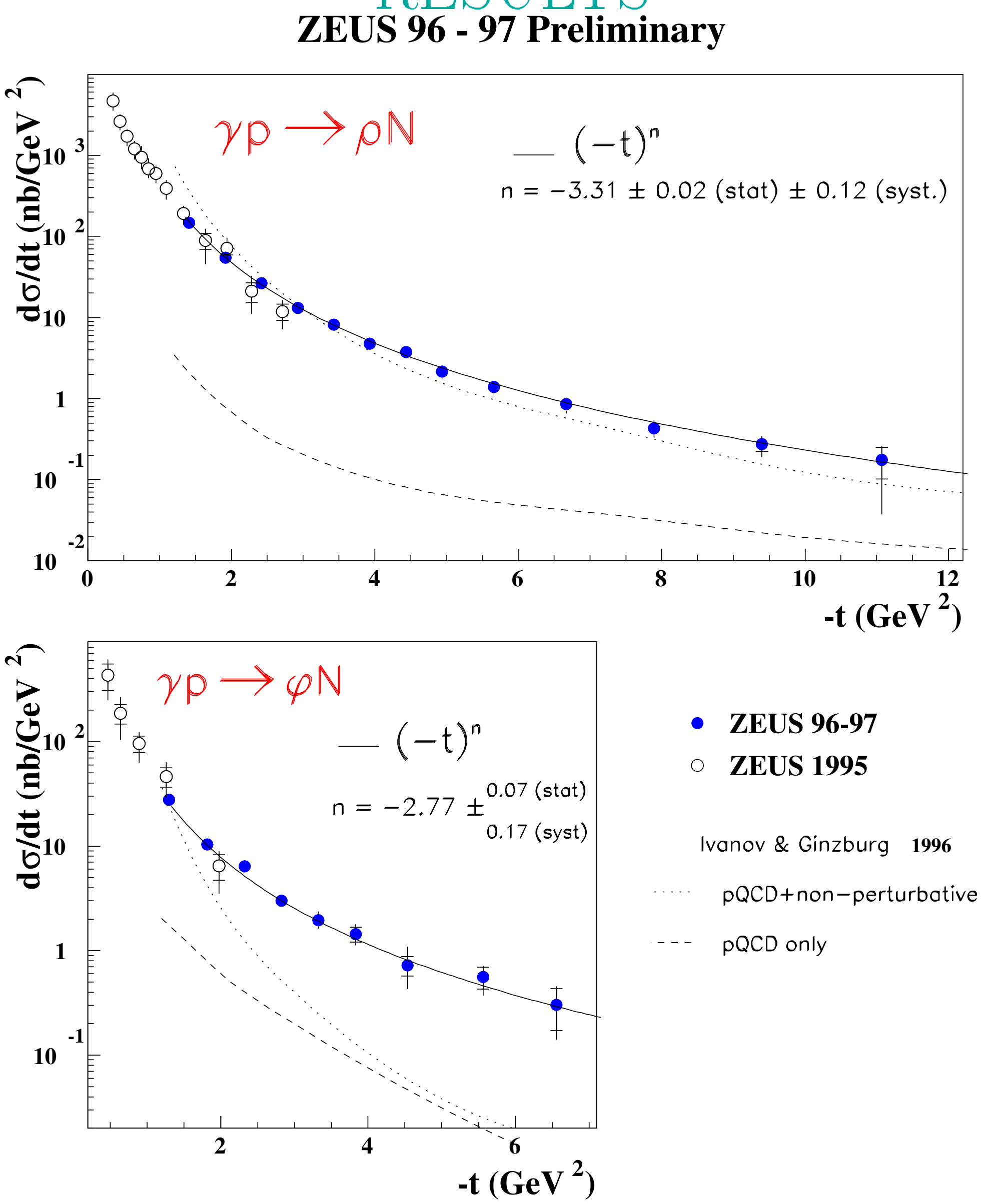
- data and MC for ρ^0 in satisfactory agreement
- similar for ϕ and J/ψ

Ivanov & Ginzburg (1996)
pQCD predictions in lowest order in α_S

D. Yu. Ivanov, Phys. Rev. D 53 (1996) 3564.

- *Valid for:*
  - photoproduction $Q^2 = 0$
  - large momentum transfer: $|t| \gg \Lambda^2_{QCD}$
  - large centre-of-mass energy: $s \gg |t|$
- *Features:*
  - normalization of the non-perturbative contribution is a parameter
  - the dominant helicity-conserving production mechanism is mainly non-perturbative
  - prediction for the perturbative contribution is absolute
  - light mesons have zero helicity, independently of the initial photon polarization at asymptotic large $|t|$

RESULTS



- pQCD predicts power-like behavior of cross sections with $|t|$:

$$\frac{d\sigma}{dt} \propto |t|^n$$

L. Frankfurt and M. Strikman, Phys. Rev. Lett. 63 (1989) 1914.

A.H. Mueller and W-K. Tang, Phys. Lett. B 284 (1992) 123.

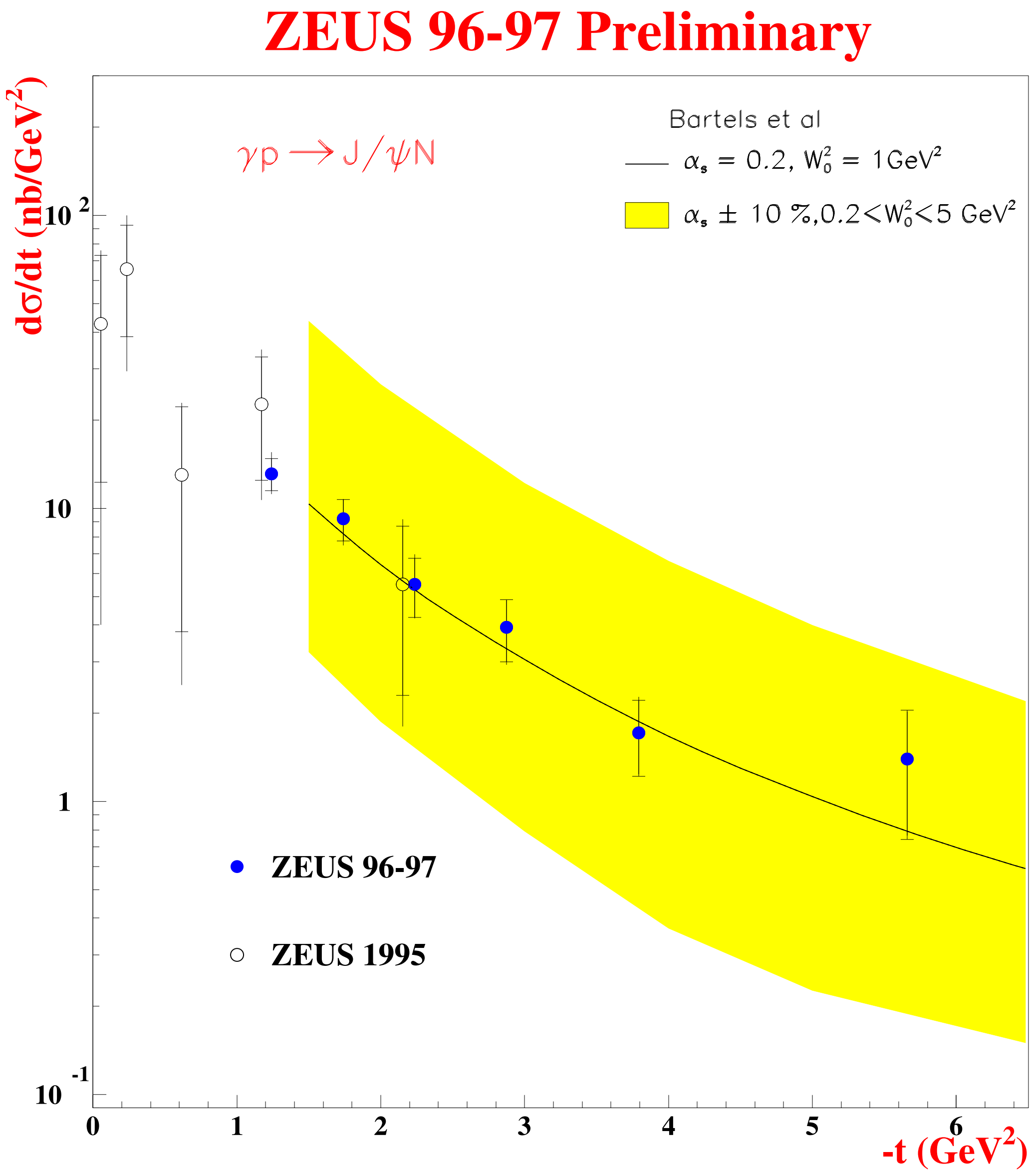
- fitted exponents:

$$n = -3.31 \text{ for } \rho, \ |t| > 1.2$$

$$n = -2.77 \text{ for } \phi, \ |t| > 1.2$$

- pQCD alone does NOT describe ρ^0 and ϕ cross sections
- pQCD with soft contribution still below ρ and ϕ data

RESULTS



- BFKL calculations describe J/ψ cross section

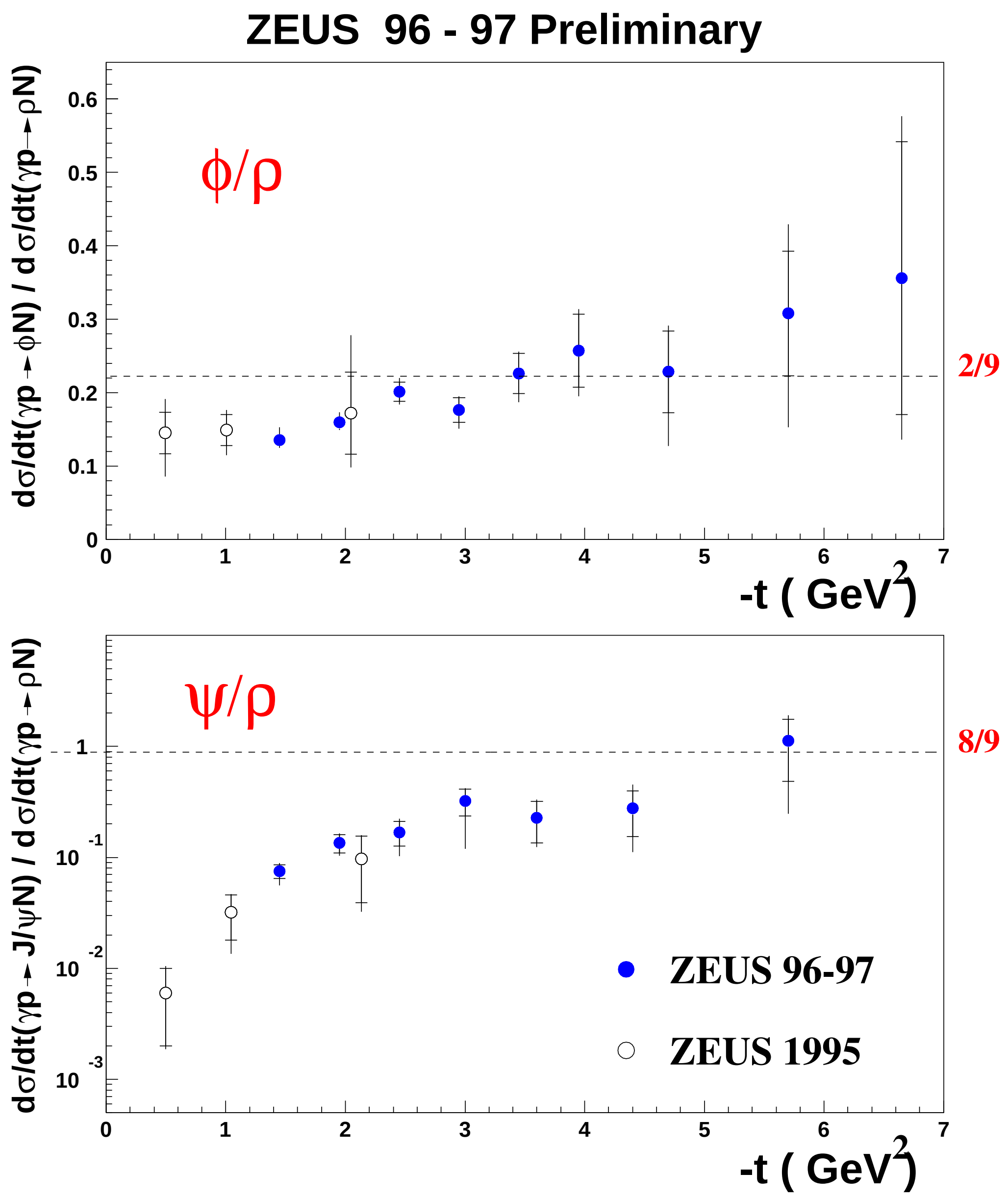
  J. Bartels et al., Phys. Lett. B 375 (1996) 301.

- very large uncertainties due to the model parameters

- power like behavior $\frac{d\sigma}{dt}(J/\psi) \propto | t |^n$,

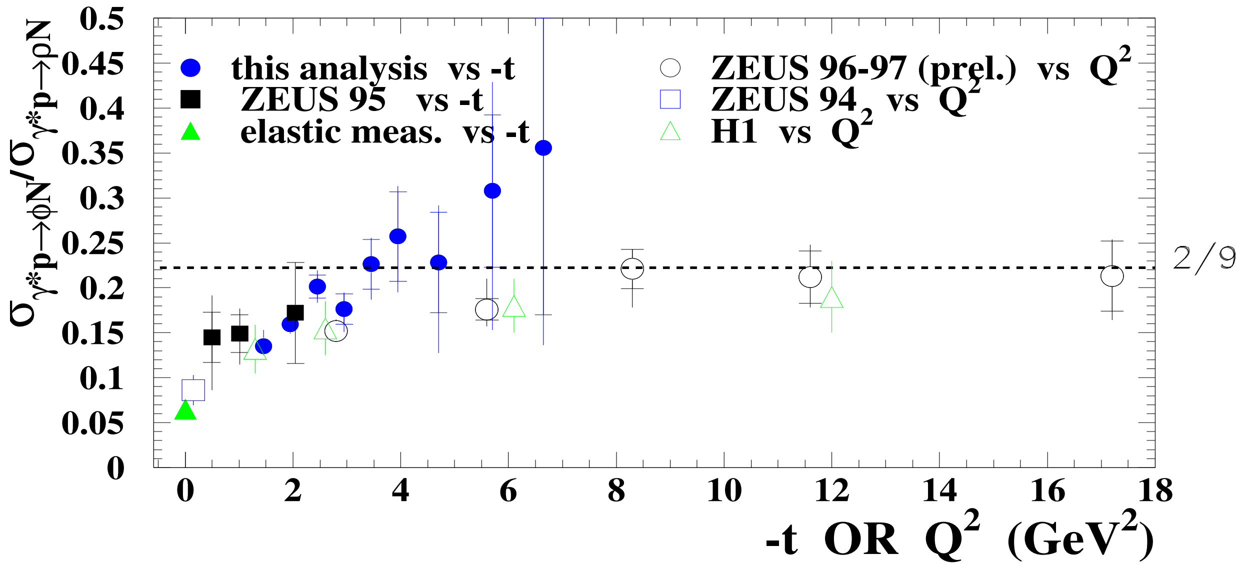
$$n = -1.7 \pm 0.2(stat.) \pm 0.2(syst.)$$

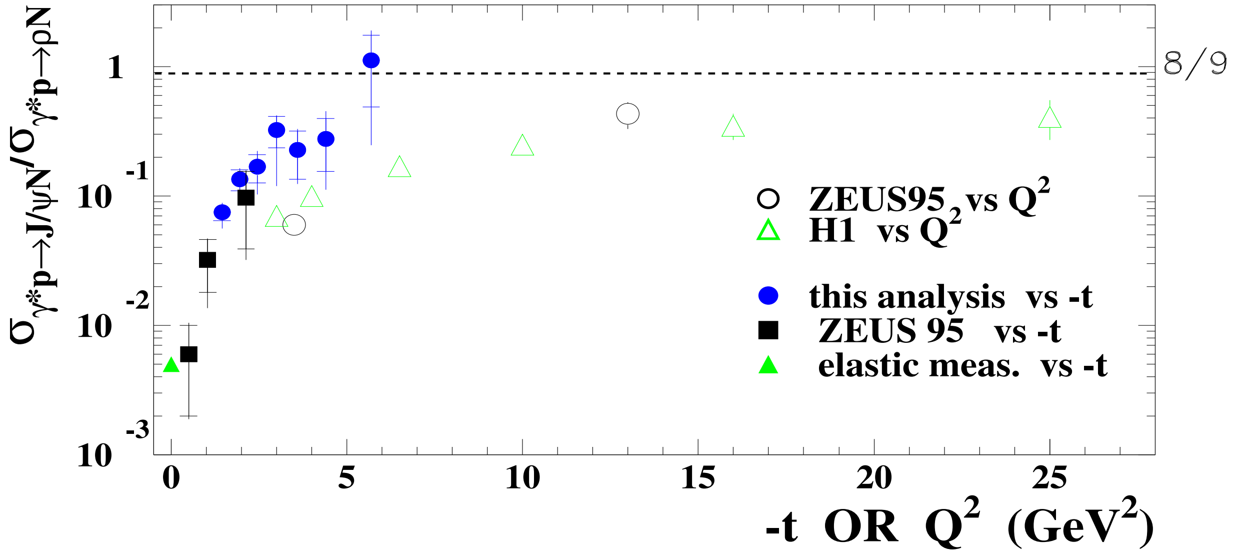
RESULTS



- ratio ϕ/ρ increases with | t | and approaches SU(4) value at $|t| \simeq 3.5$ GeV^2
- ratio ψ/ρ also increases with | t | but is much below the SU(4) prediction up to | t | values of 4 GeV^2

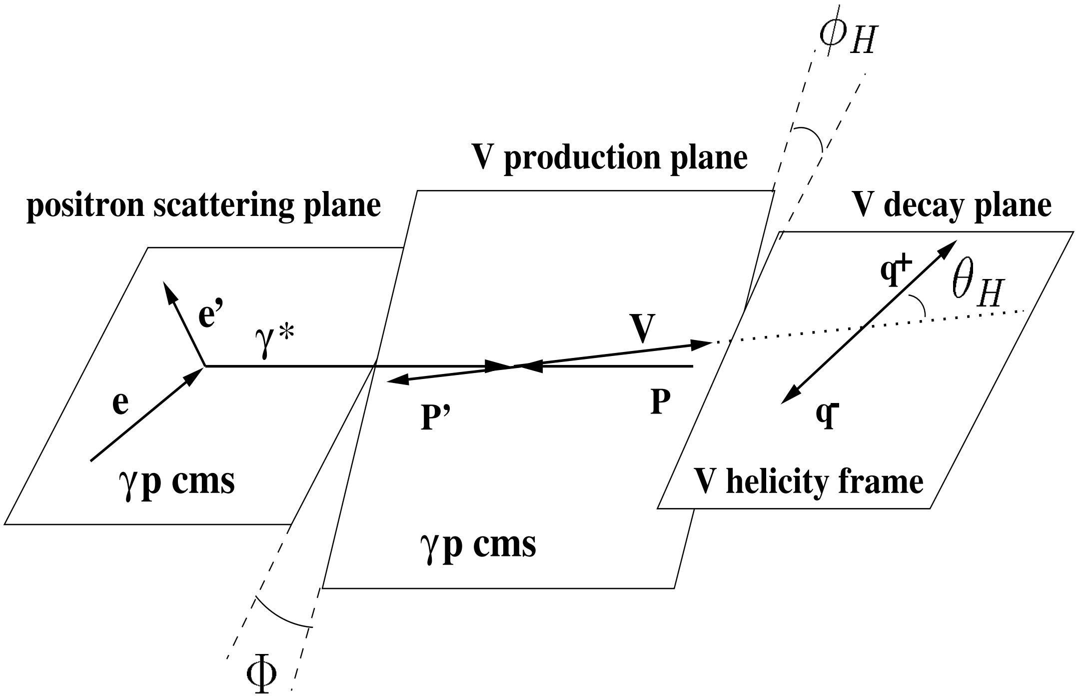
RESULTS





- in DIS the ϕ/ρ ratio reaches the SU(4) value for $Q^2 > 6$ GeV^2
- in photoproduction the ϕ/ρ ratio approaches the SU(4) values for $| t | > 3.5$ GeV^2
- for $| t | \approx 3.5$ GeV^2 the ψ/ρ ratio in photoproduction is a factor of five above the ratio for DIS
- cross section ratios raise faster with $| t |$ than with Q^2
- indication that t and Q^2 are NOT equivalent scales

Decay Angles



- Two-dimensional angular distribution:

$$W\left(cos\theta_H, \phi_H\right) = \frac{3}{4\pi}\left[\frac{1}{2}\left(1 - r^{04}_{00}\right) + \frac{1}{2}\left(3r^{04}_{00} - 1\right) cos^2\theta_H \right.$$
$$-\sqrt{2}Re\left(r^{04}_{10}\right) sin2\theta_H cos\phi_H$$
$$\left. -r^{04}_{1-1} sin^2\theta_H cos2\phi_H\right]$$

- Integrated over one variable $\Rightarrow$ one-dimensional distributions:

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

$$W\left(\phi_H\right) = \frac{1}{2\pi}\left(1 - r^{04}_{1-1} cos2\phi_H\right)$$

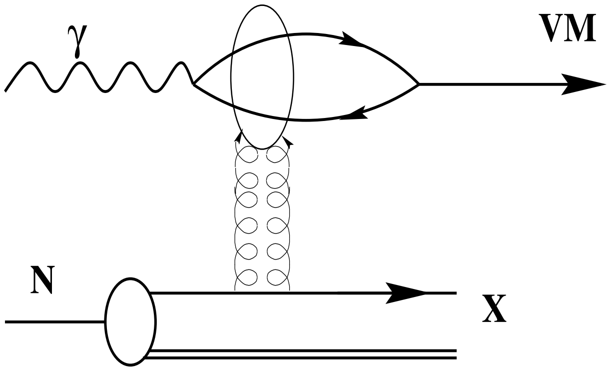
- Extracting spin-density matrix elements:

r^{04}_{00} – probability of helicity single – flip
r^{04}_{1-1} – amplitude of helicity double – flip
$Re\left(r^{04}_{10}\right)$ – interference between helicity non – flip and single – flip amplitudes

Ivanov et al. (2000)
NEW pQCD predictions

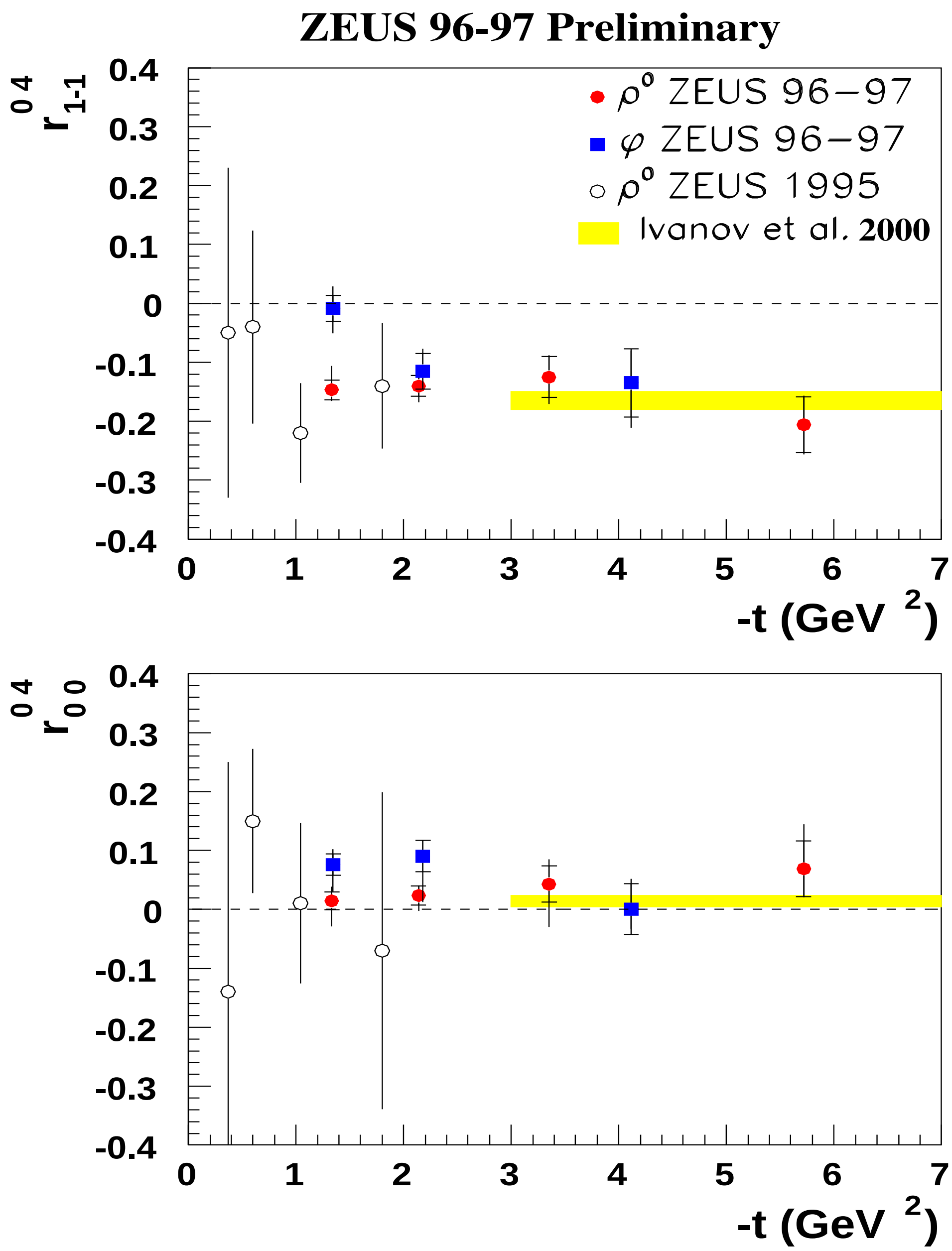
D. Yu. Ivanov et al., Phys. Lett. B 478 (2000) 101.

- *Subject of studies:*
  - photoproduction of light vector mesons at large t
  - all independent helicity amplitudes
- *New hard production mechanism*
  - real photon can fluctuate into a massless $q\bar{q}$ pair in a chiral-odd spin configuration (helicities of quark and antiquark parallel)



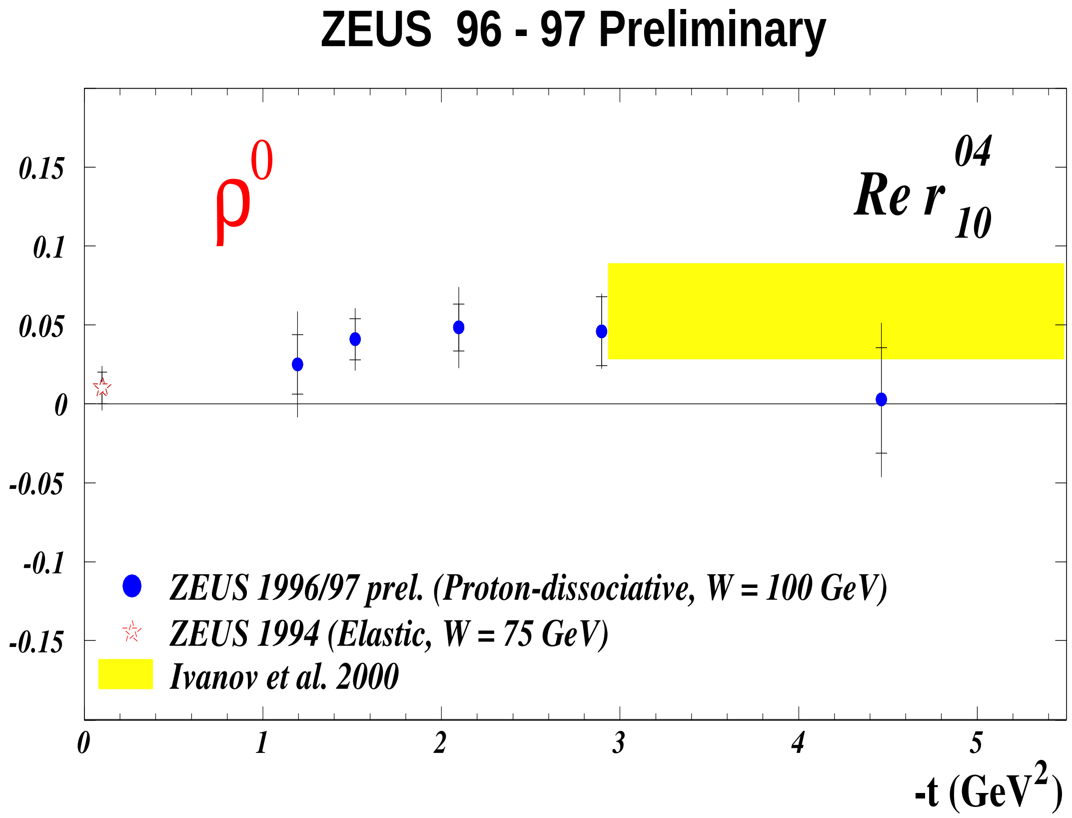
  - chiral-odd spin configuration (non-perturbative component of the γ wave function) gives a very important contribution
  - the interaction of this chiral-odd contribution can be described in pQCD
- *Expected to significantly increase the pQCD cross sections*

RESULTS



- one-dimensional fits
- values of r^{04}_{1-1} show a clear indication of the helicity double-flip contribution for large | t | - deviation from SCHC
- r^{04}_{00} measurements show that the helicity single-flip contribution is small over the entire | t | range - consistent with SCHC
- very good agreement with pQCD calculations

RESULTS



- data subsample & two-dimensional fit
- NON-zero interference between helicity non-flip and single-flip amplitudes - clear deviation from SCHC
- result in agreement with pQCD predictions

- Vector meson photoproduction at large | t |: weak SCHC breaking (predicted by pQCD)
- DIS for large Q^2: consistent with pQCD small deviation from SCHC

ZEUS Collaboration; J. Breitweg et al., Eur. Phys. J. C 12 (2000)3, 393

SUMMARY

- diffractive photoproduction of ρ^0, ϕ and J/ψ with proton dissociation has been measured at $W \simeq 100$ GeV for $|t|$ values up to 12 GeV^2

- $\frac{d\sigma}{dt} \propto |t|^n$ (expected from pQCD)

$$n = -3.31 \;\; \text{for} \;\; \rho, \;\; |t| > 1.2$$

$$n = -2.77 \;\; \text{for} \;\; \phi, \;\; |t| > 1.2$$

$$n = -1.70 \;\; \text{for} \;\; \psi, \;\; |t| > 1.2$$

- ρ and ϕ cross sections: NOT described by pQCD
  J/ψ: agrees with BFKL

- ratio ϕ/ρ increases with $|t|$: SU(4) at $|t| \simeq 3.5$ GeV^2
  ψ/ρ below the SU(4) value up to $|t| \simeq 4$ GeV^2

- ϕ/ρ and ψ/ρ, increase with $|t|$ is faster than with Q^2

- from decay-angles for ρ^0 and ϕ: deviation from SCHC (consistent with pQCD)

to conclude ...

CONCLUSION: MIXED MESSAGES

- *Picture is not clear*
  - indication that large t can provide a suitable hard scale for pQCD
  - but available pQCD calculations do not describe results quantitatively
  - t and Q^2 are not equivalent scales