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ON BEHALF OF
THE ZEUS COLLABORATION

For DIS2002 in Kraków

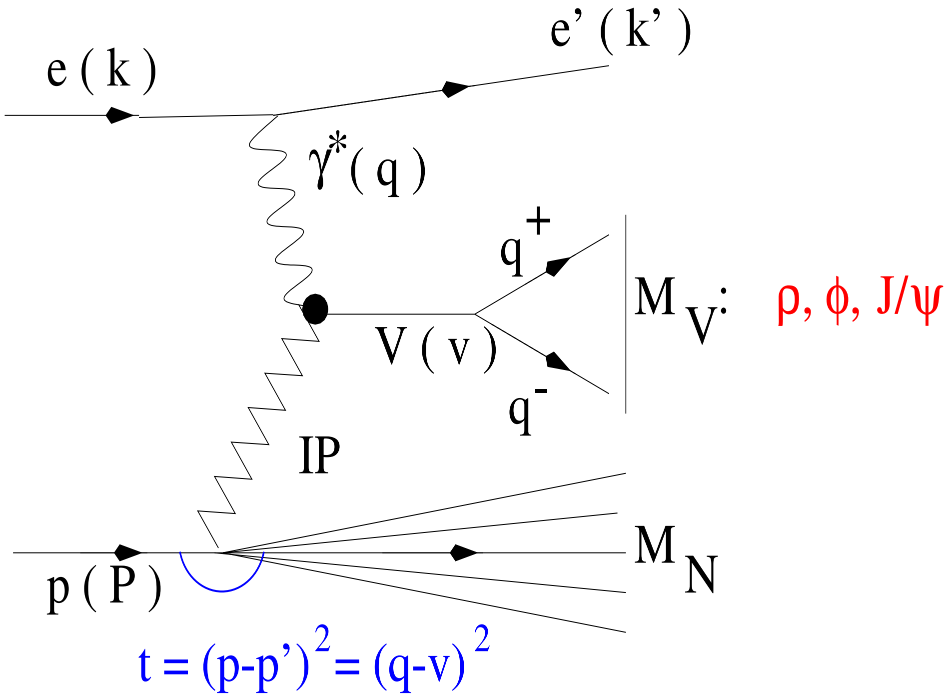
Proton-Dissociative Diffractive Photoproduction of Vector Mesons at Large $-t$ at HERA

1. Physics Motivations
2. Kinematics
3. Results
   - Differential Cross Sections $d\sigma/dt$
   - Slope of Pomeron Trajectory α'
   - Decay Angle Analysis
4. Summary & Conclusions

PHYSICS MOTIVATION

determination of the characteristic features of the VM production at large $-t$

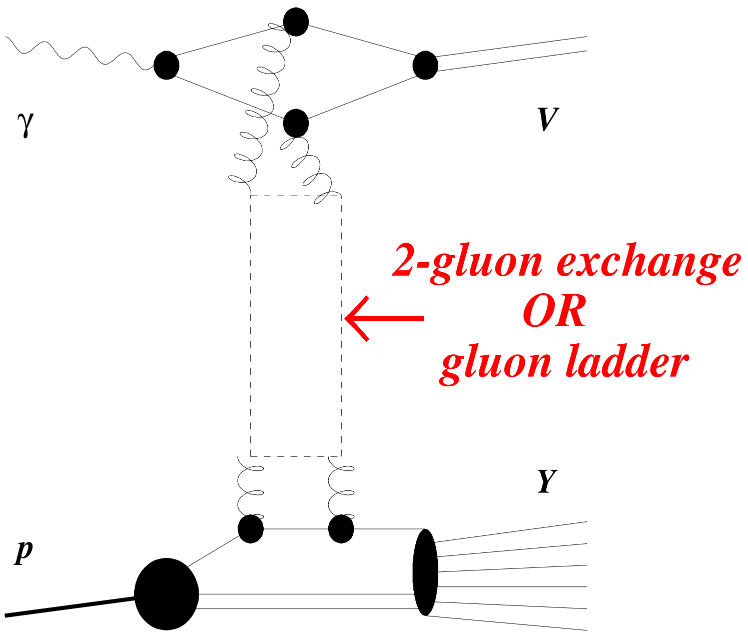
in pQCD: large Q^2 and M_V provide hard scale



- Is $-t$ providing a hard scale ?
- Is $-t$ scale on same footing as Q^2, M_V^2 ?
- At which $-t$ is pQCD description valid ?
- Do the mesons retain photon helicity?

pQCD Approach

In a presence of a hard scale

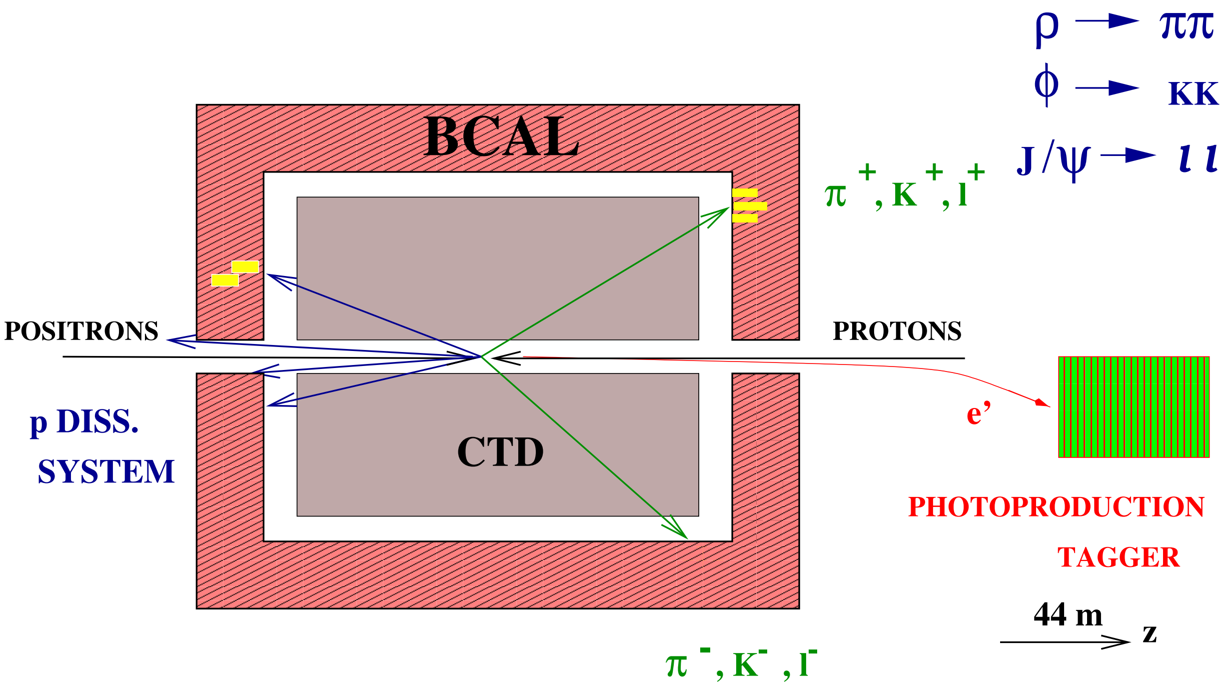


Expectations of pQCD models:

- ♣ $d\sigma/dt$ follows power-like behavior
- ♣ $\alpha' = 0$ GeV^{-2} (2-gluon exchange) or $\alpha' \lesssim 0.1$ GeV^{-2} (gluon ladder)
- ♣ SCHC breaking for light VM (6-12% of transversely polarized mesons produced)

measured cross section $d\sigma/dt$, Pomeron slope α' and spin-density matrix elements r^{04}_{00}, $Re[r^{04}_{10}]$, r^{04}_{1-1} confronted with pQCD calculations

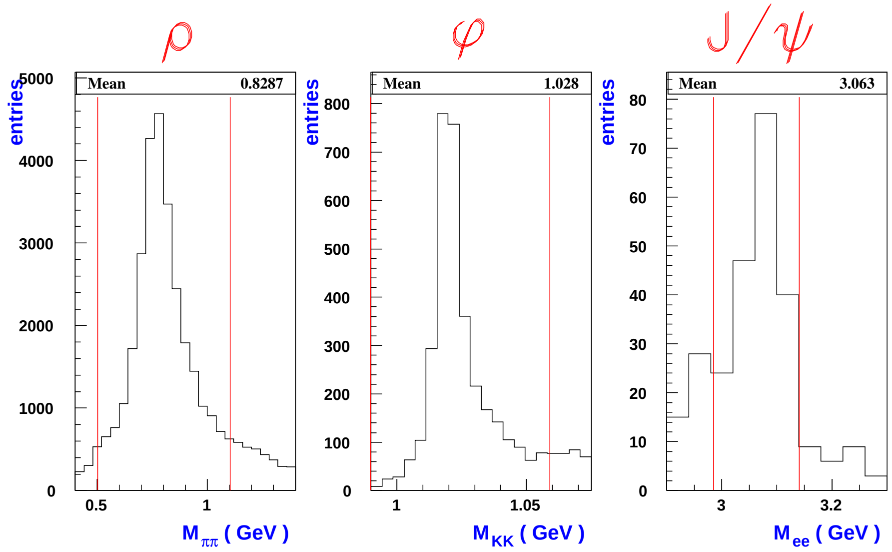
RECONSTRUCTION OF KINEMATIC VARIABLES



All kinematic variables reconstructed from four-momenta of decay products

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

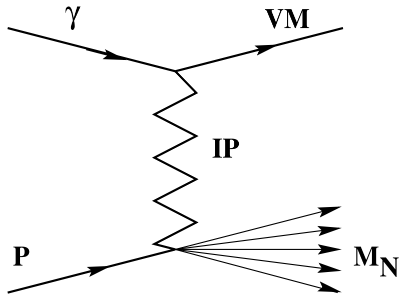
- *photoproduction:* $Q^2 < 0.02$ GeV^2
- $-t$ *range:* 1.2 - 12.2 GeV^2
- W *range:* $80 < W < 120$ GeV (Photoproduction Tagger Acceptance)



MONTE CARLO SIMULATION

EPSOFT Proton Dissociative Monte Carlo

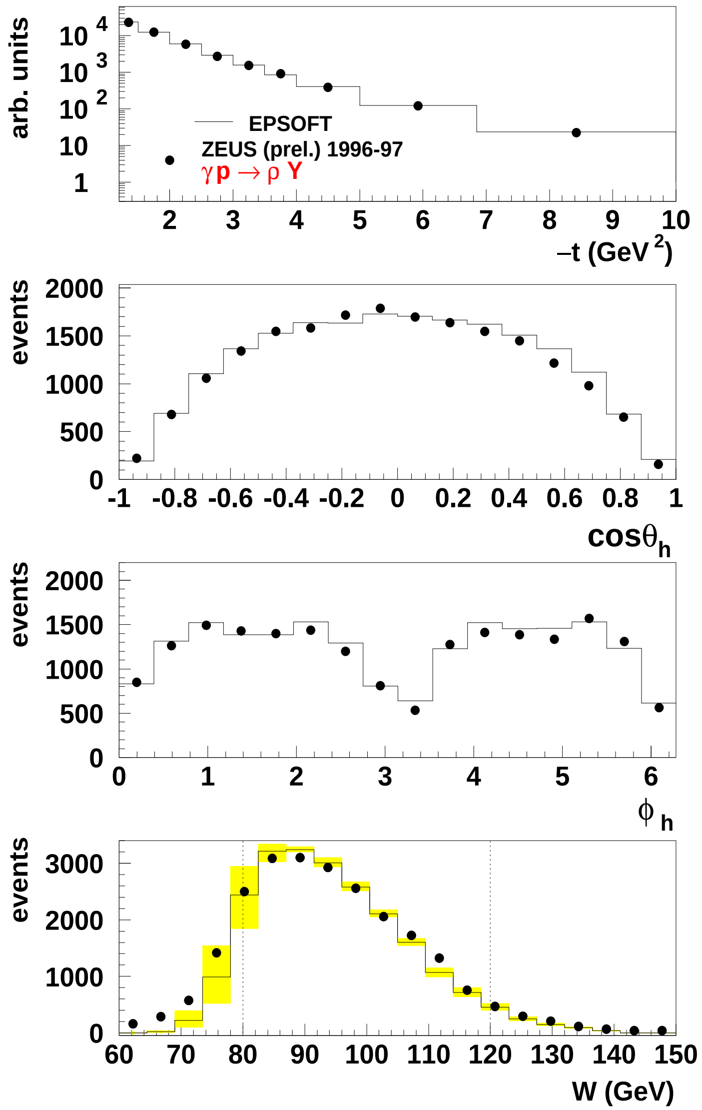
- simulates diffractive **E**lectron-**P**roton **SOFT** collisions at HERA
- diffractive pomeron-proton and pomeron-photon scattering ⇒ soft hadron-hadron collisions
- tuned to ZEUS photoproduction data
- proton-dissociative process



- reweighted according to:

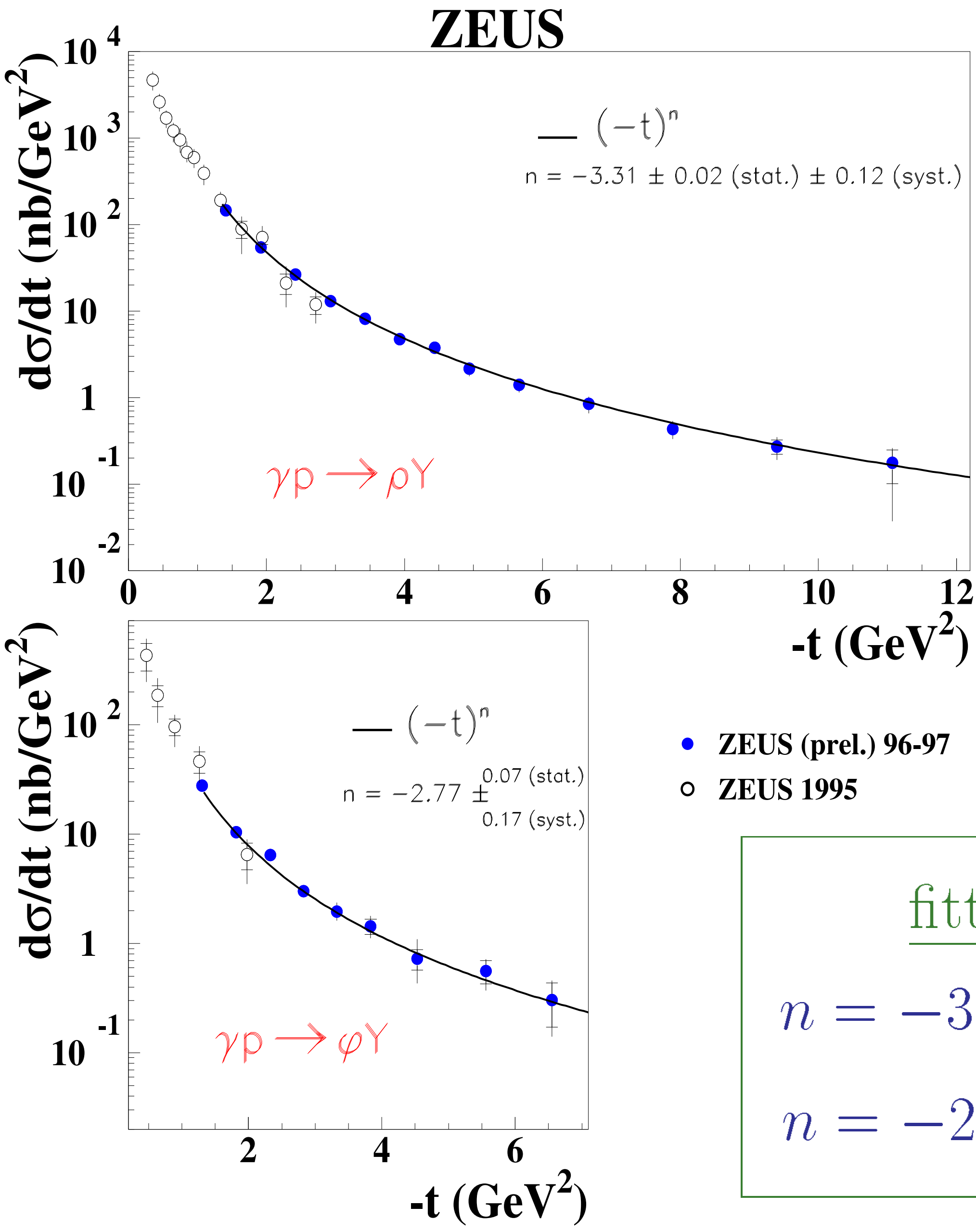
$$\frac{d^2\sigma(\gamma p \to VN)}{dt dM_N^2} \propto f(t) \cdot (\frac{W^2}{M_N^2})^{\beta(t)}$$

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



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

Differential Cross Section $d\sigma/dt$ for ρ^0 and ϕ



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

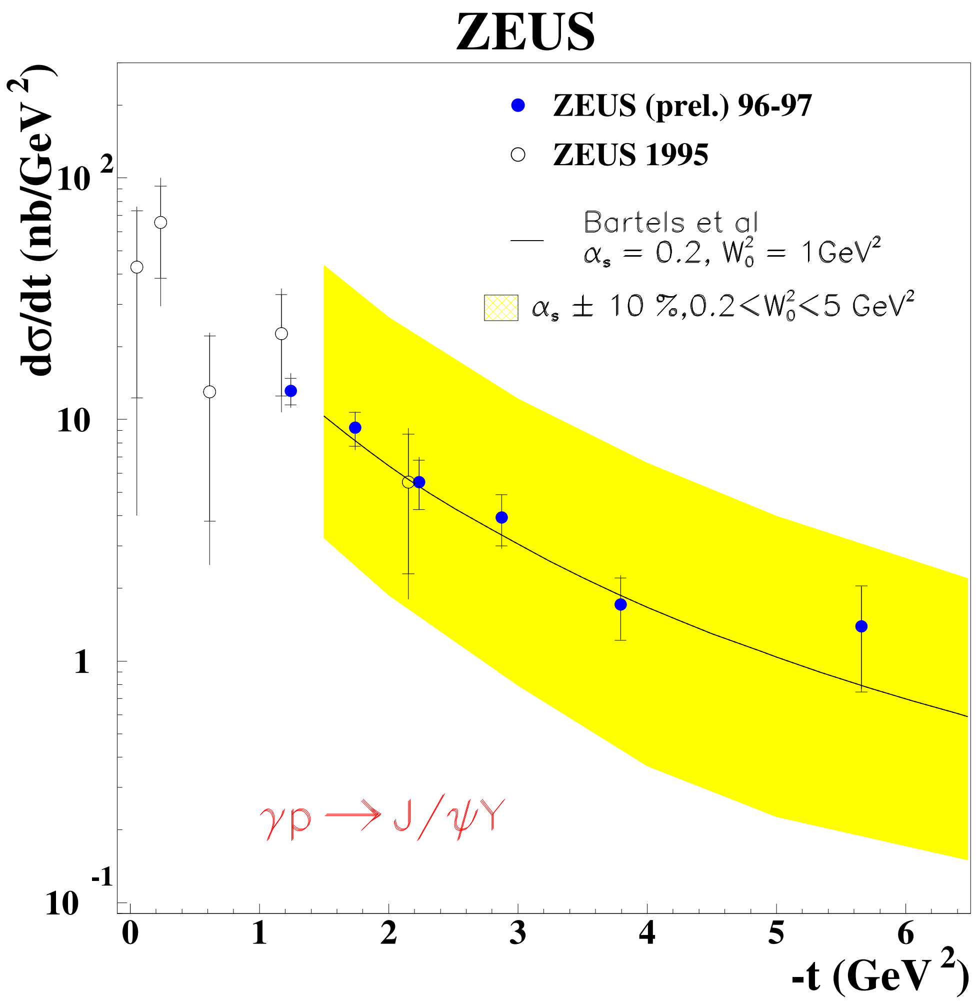
$$\frac{d\sigma}{dt} \propto -t^n$$

fitted powers for $-t > 1.2$ GeV^2:

$n = -3.31 \pm 0.02(\text{stat.}) \pm 0.12(\text{syst.})$ for ρ

$n = -2.77 \pm 0.07(\text{stat.}) \, {}^{+0.07}_{-0.17}(\text{syst.})$ for ϕ

Differential Cross Section $d\sigma/dt$ for J/ψ



- BFKL calculations describe J/ψ cross section

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

- large uncertainties due to the model parameters

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

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

Forshaw & Poludniowski pQCD model

(hep-ph/0107068)

- ⋆ BFKL Pomeron
- ⋆ $\mathbb{P}$ couples to single parton
- ⋆ assumed SCHC
- ⋆ non-relativistic VM wave function
- ⋆ α_S constant

cross section in terms of $\ln(xW^2/W_0^2)$
$W_0^2 = \beta M_V^2 - \gamma t$

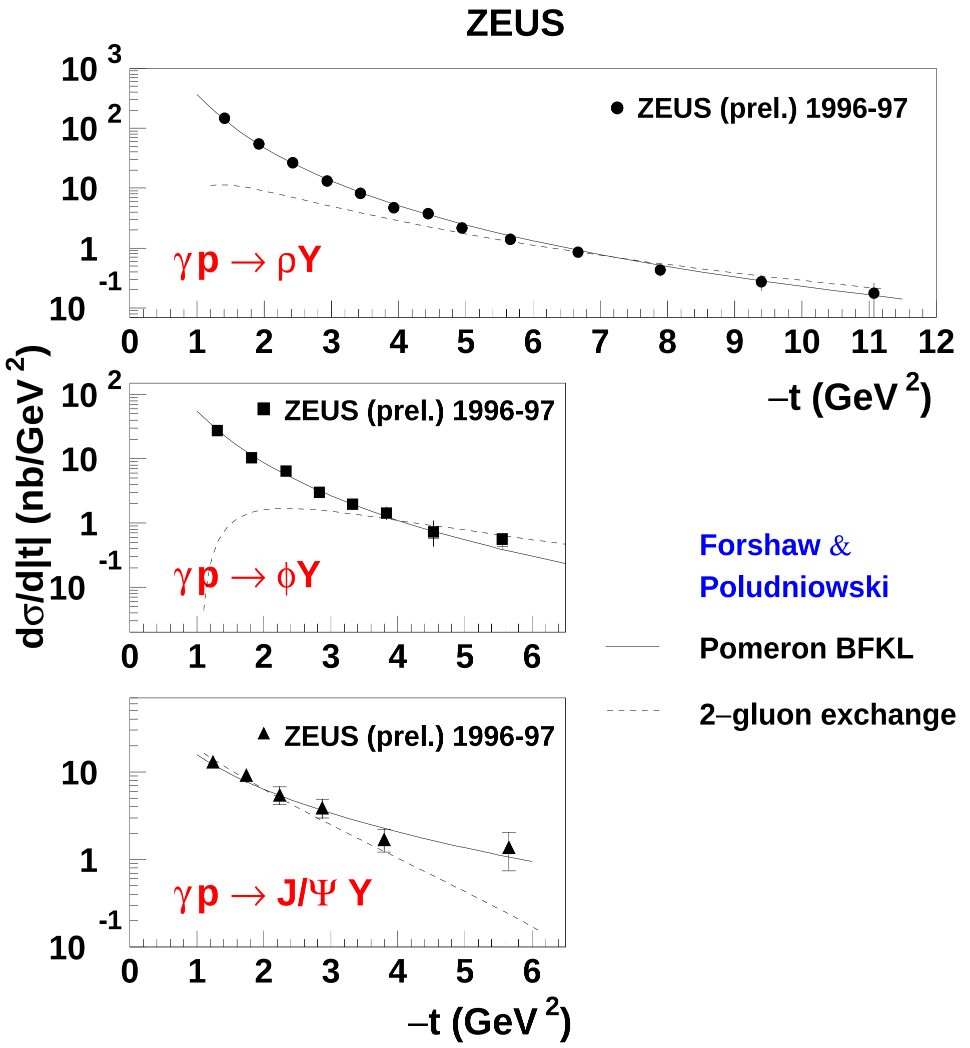
α_S, β and γ $\longrightarrow$
parameters fitted to ZEUS data

...shortcomings:

- *FIT* not *PREDICTION*
- VM wave function *NOT PROPER* for light VM

to be continued...

Comparison with pQCD Model



Forshaw & Poludniowski pQCD model

(hep-ph/0107068)

!! 3 free parameters fitted to ZEUS data

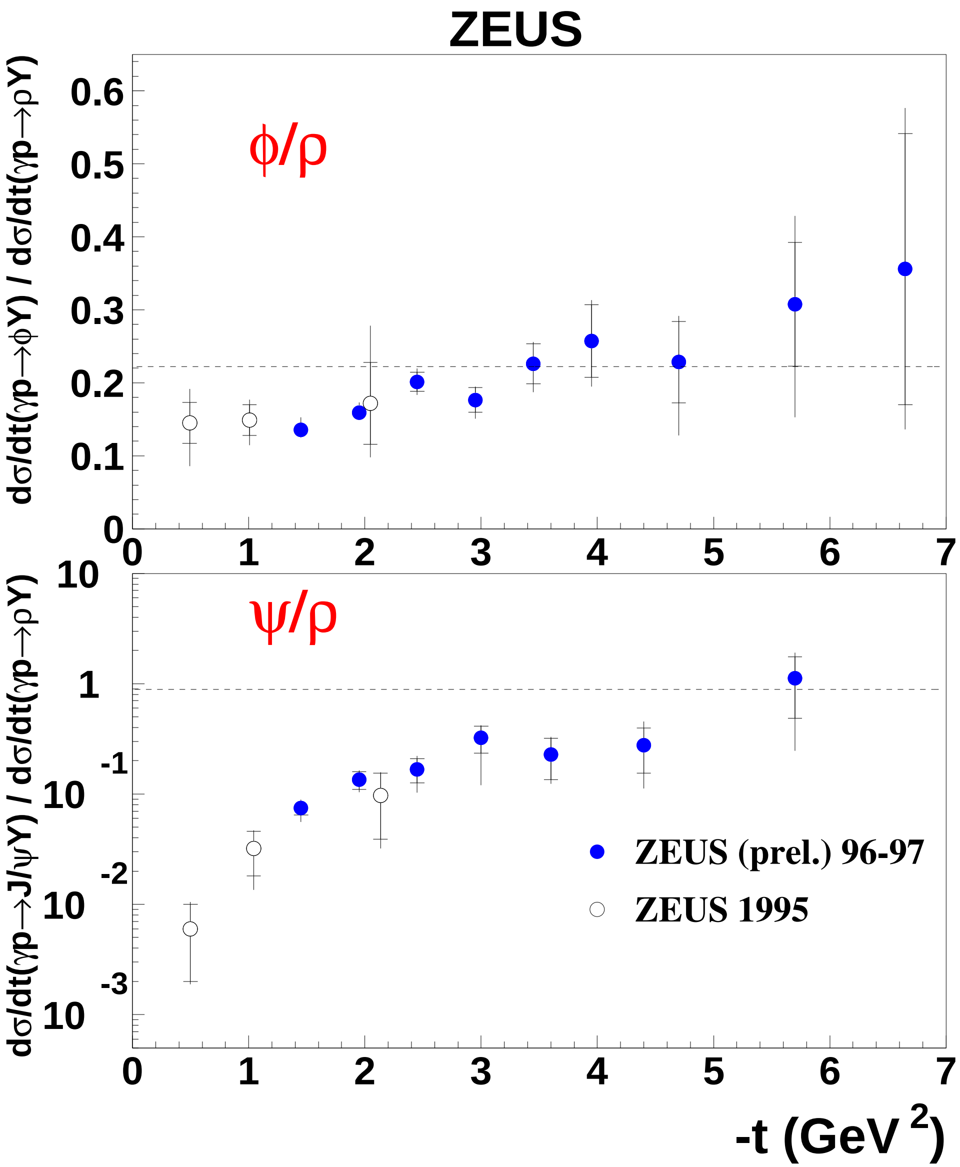
BFKL calculations describe data

simple 2-gluon exchange does NOT describe data

$\Longrightarrow$ " smoking gun for BFKL?...

indication that high $-t$ can provide a hard scale

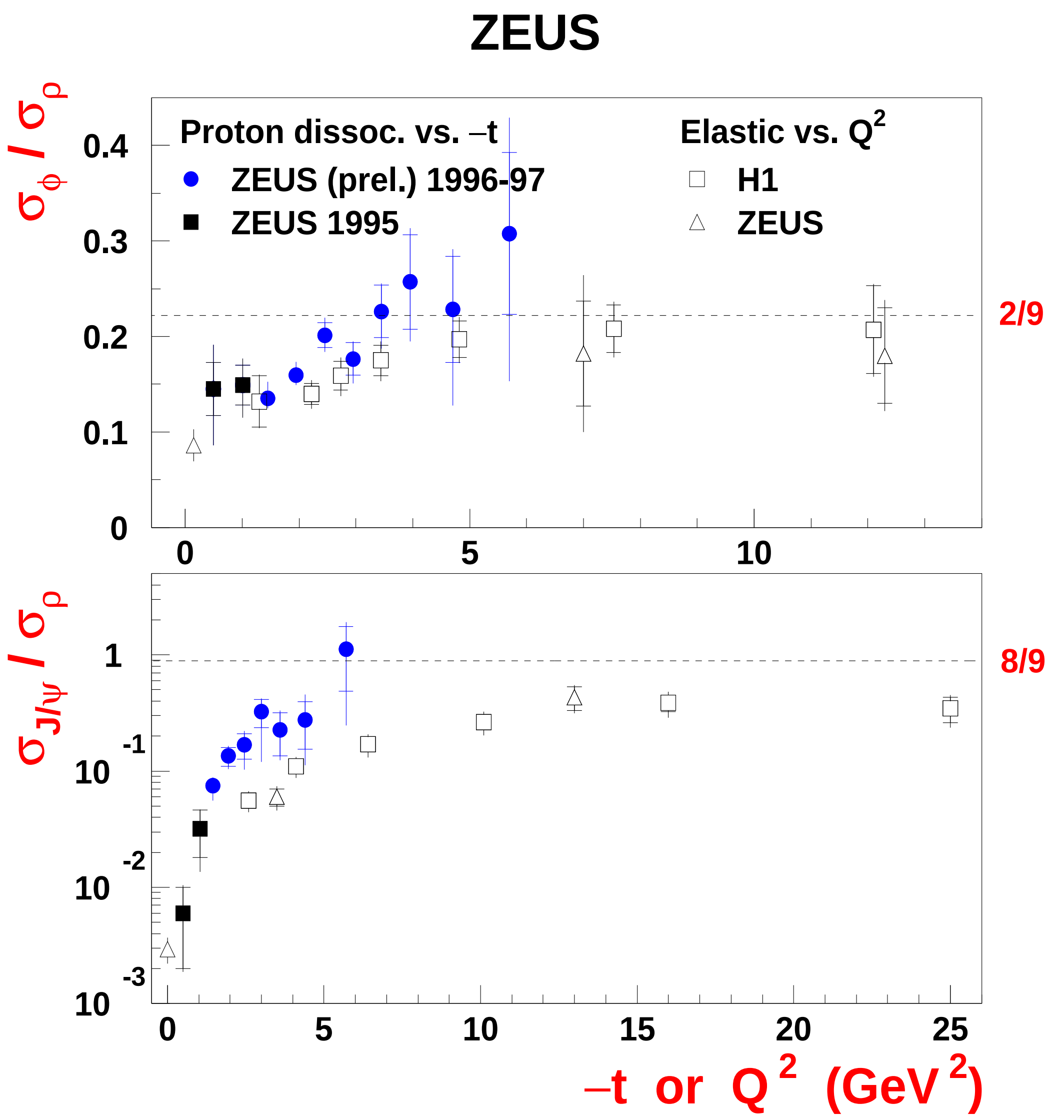
Cross Section Ratios



2/9 ◇ ratio ϕ/ρ increases with $-t$ and approaches SU(4) value at $-t \simeq 3.5$ GeV^2

8/9 ◇ ratio ψ/ρ also increases with $-t$ but is below the SU(4) prediction up to $-t$ values of 4 GeV^2

Cross Section Ratios



- 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 rise faster with $-t$ than with Q^2

Determination of Effective Slope of Pomeron Trajectory α'

Regge theory: W-dependence of the cross section:

$$\frac{d\sigma}{dt} \propto W^{4\alpha(t)-4} = W^{4\alpha(0)+4\alpha' t-4}$$

In order to avoid large correlated systematic errors:
possible determination of Pomeron slope α' only

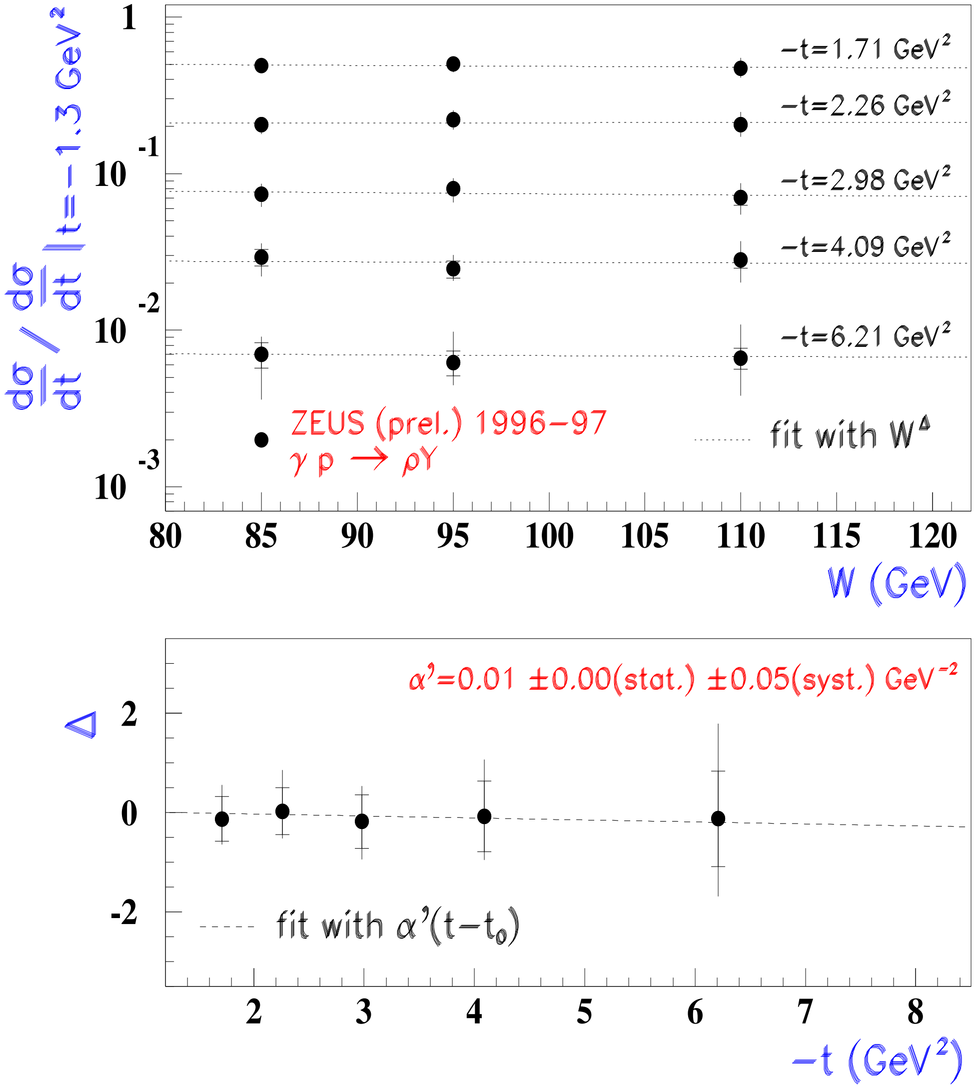
$$R_{t_0}(t,W) \equiv \frac{\frac{d\sigma}{dt}}{\frac{d\sigma}{dt}\big|_{t=t_0}} \propto W^{4(\alpha(t)-\alpha(t_0))} = W^{4\alpha'(t-t_0)} \equiv W^{\Delta(t)}$$

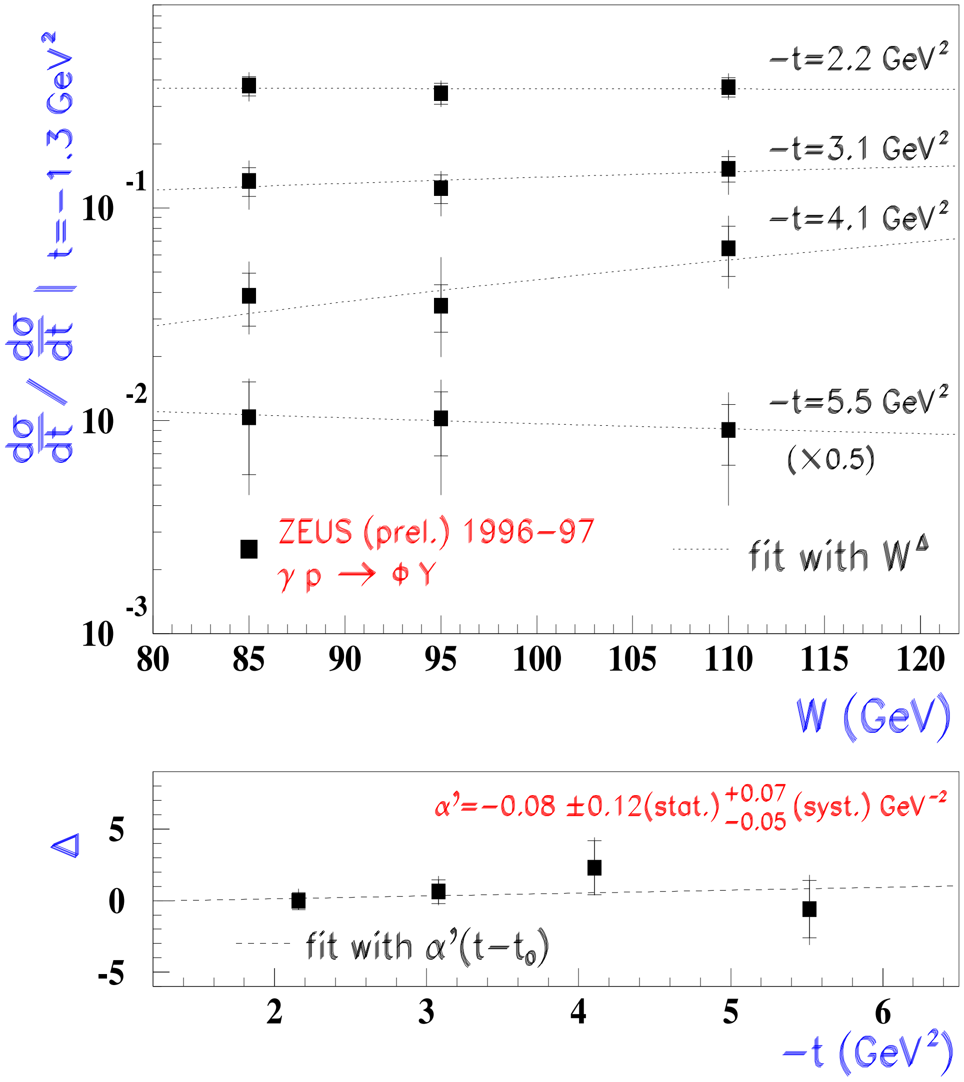
1. $R_{t_0}(W)$ measured in t bins
2. in each t bin R_{t_0} dependence on W fitted with $W^{\Delta(t)}$

3. extracting α' from $\Delta(t)$

$$\Longrightarrow \Delta(t) = 4\alpha'(t-t_0)$$

Measurement of Effective Pomeron Slope α'





Pomeron Slope α'

$\alpha' \approx 0$ consistent with pQCD

◇ soft hadronic processes (DL Pomeron)

$$\alpha' = 0.25\ \mathrm{GeV}^{-2}$$

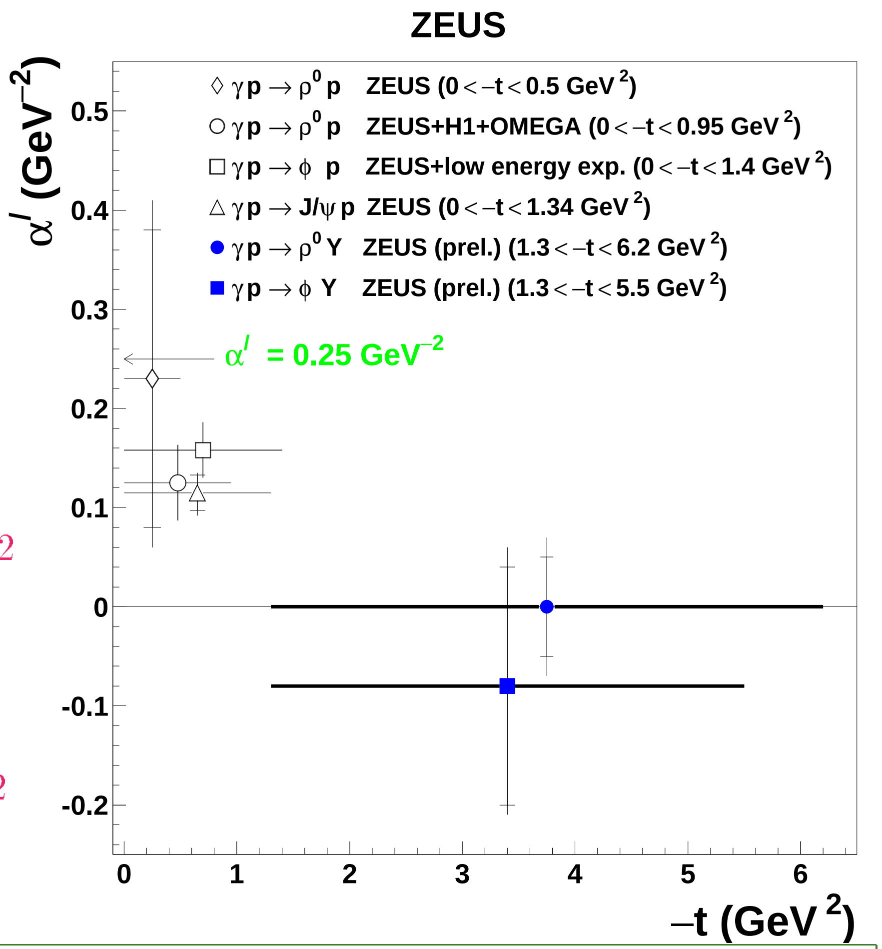
◇ VM photoproduction at $-t > 1.3\ \mathrm{GeV}^2$

ρ^0 :

$$\alpha' = 0.00 \pm 0.05(stat.) \pm 0.05(syst.)\mathrm{GeV}^{-2}$$

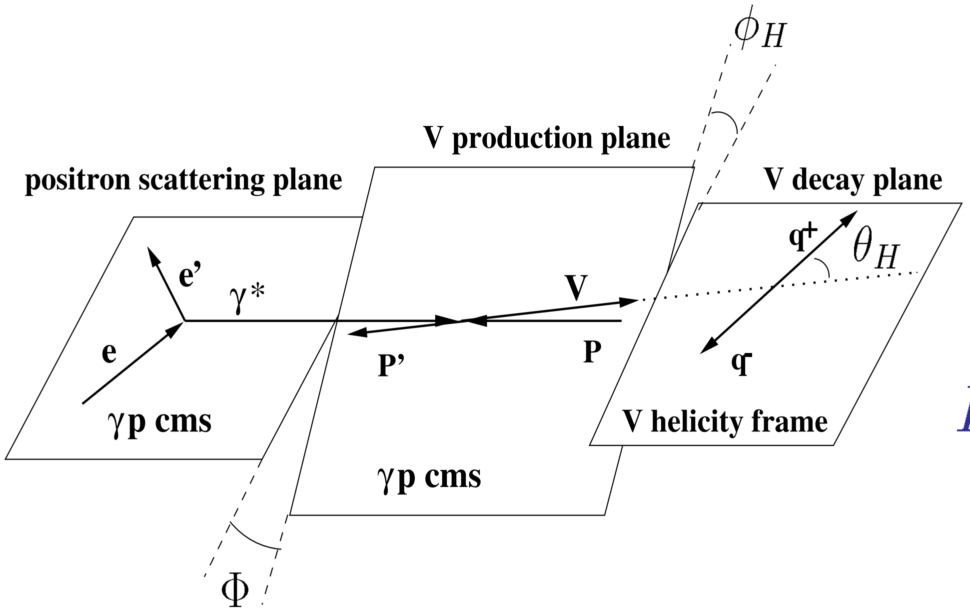
ϕ :

$$\alpha' = -0.08 \pm 0.12(stat.)^{+0.07}_{-0.05}(syst.)\mathrm{GeV}^{-2}$$



for both ρ and ϕ: α' for $-t > 1.3\ \mathrm{GeV}^2$ smaller than DL $\alpha' = 0.25\ \mathrm{GeV}^{-2}$ and than α' from elastic VM photoproduction at HERA at lower $-t$

Decay Angles



Extracting spin-density matrix elements:

r^{04}_{00} : probability of helicity single − flip

r^{04}_{1-1} : interference between helicity non − flip and double − flip ampl.

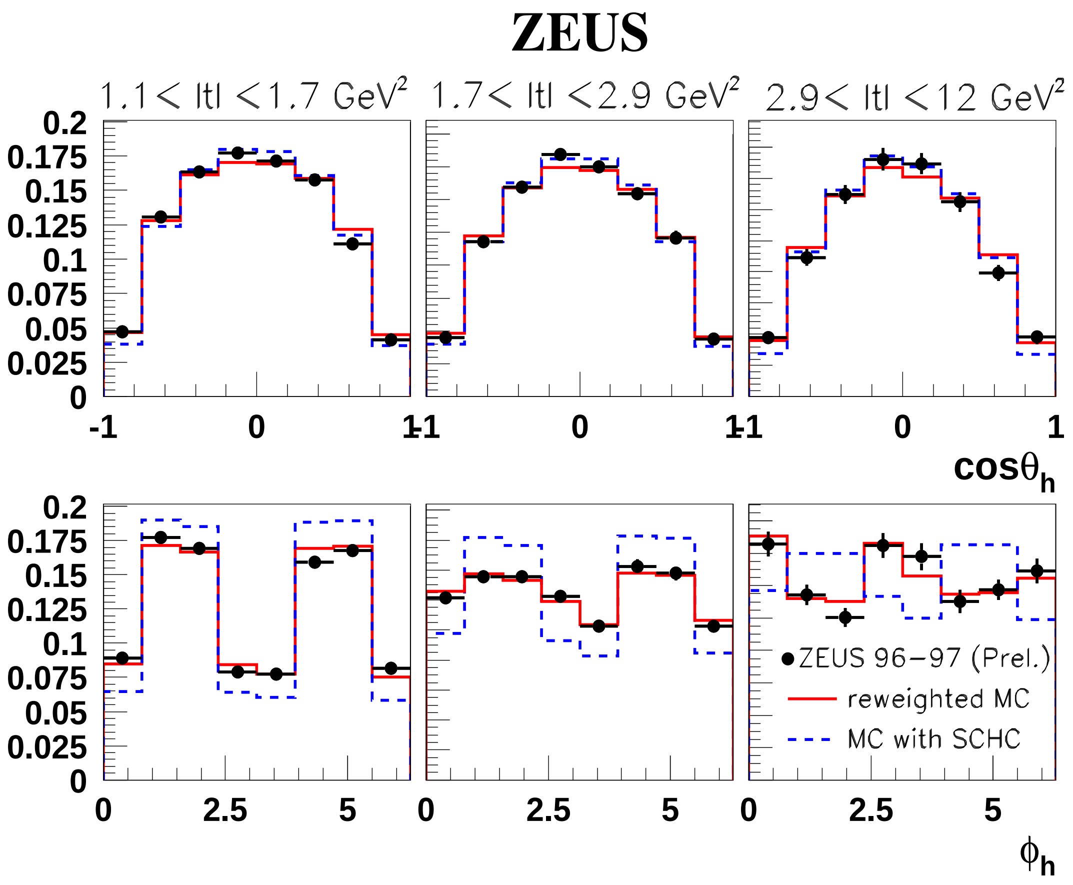
$Re\left(r^{04}_{10}\right)$: interference between helicity non − flip and single − flip ampl.

Two- and one-dimensional angular distributions in $\cos\theta_H$ and ϕ_H

If SCHC holds:

$$r^{04}_{00} = r^{04}_{1-1} = Re[r^{04}_{10}] = 0$$

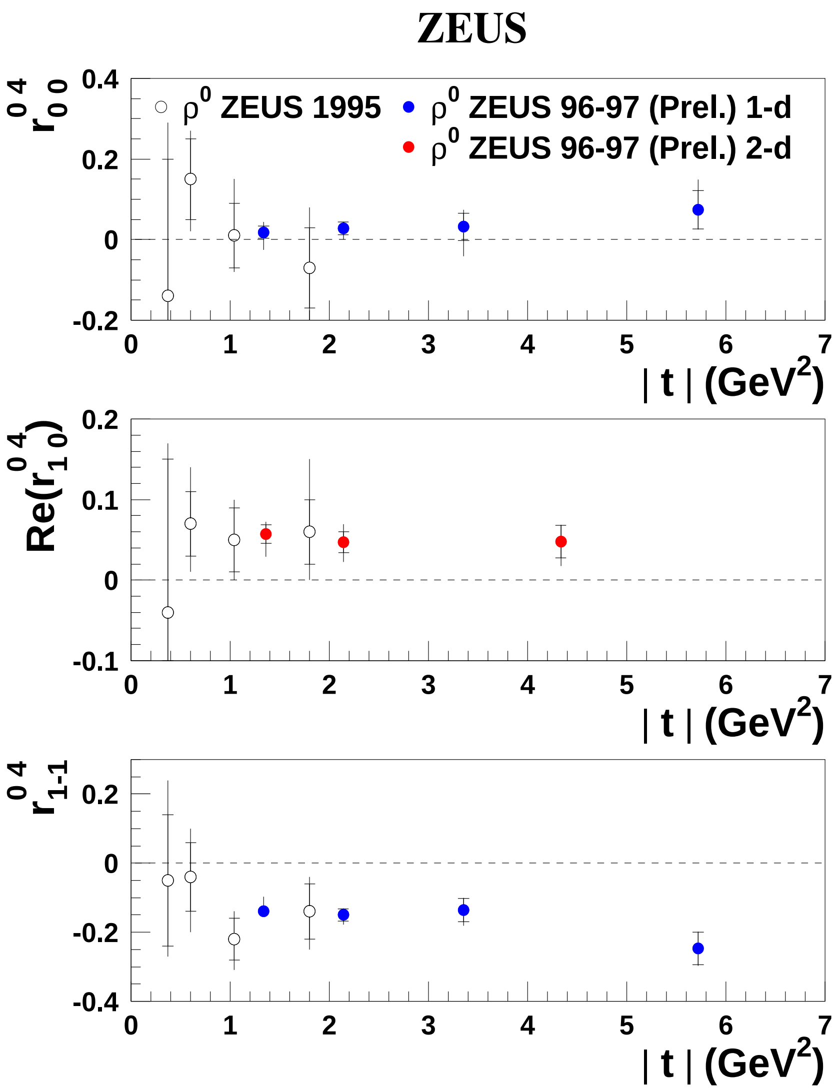
Angular distributions for ρ^0



- MC with SCHC does not describe data

- MC reweighted according to this analysis results in good agreement with data

Spin-density Matrix Elements for ρ^0



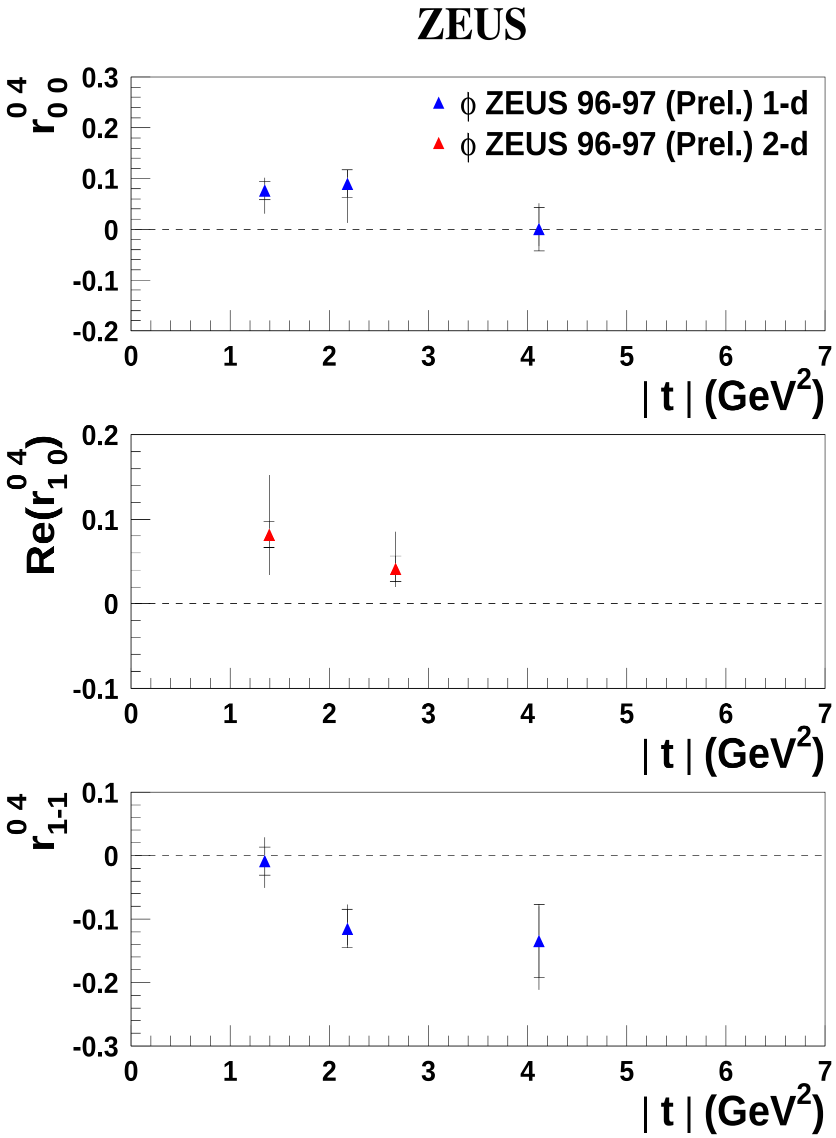
◇ production of transversely polarized ρ's dominates (small probability of helicity single-flip)

◇ $\mathrm{Re}[r^{04}_{10}]$ significantly differs from zero $\Longrightarrow$ longitudinal ρ's produced from transverse photons

◇ non-zero helicity double-flip amplitude

ρ^0 : deviation from SCHC, qualitatively in agreement with pQCD prediction

Spin-density Matrix Elements for ϕ



◇ production of transversely polarized ϕ's dominates

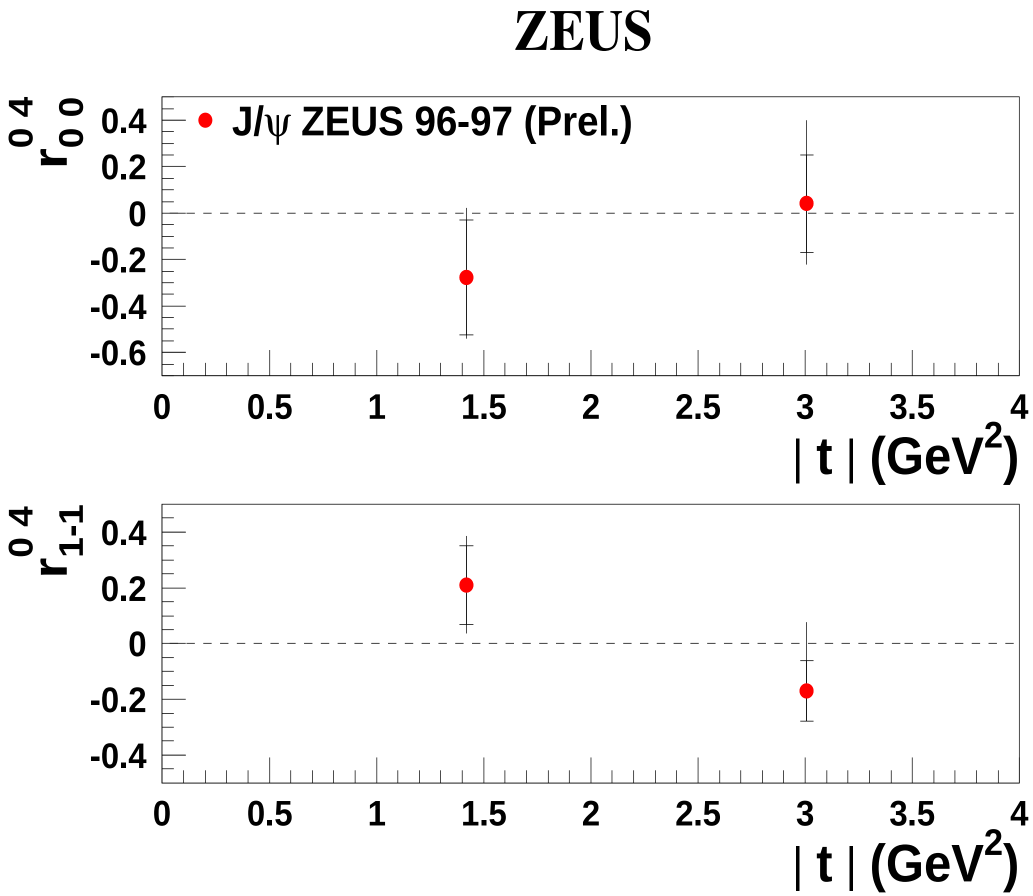
◇ $\mathrm{Re}[r^{04}_{10}]$ differs from zero $\Longrightarrow$ longitudinal ϕ's produced from transverse photons

◇ non-zero helicity double-flip amplitude

ϕ : deviation from SCHC, comparable with pQCD
Results for ρ^0 and ϕ mesons the same

deviation from SCHC at large $-t$ of the order of magnitude predicted by pQCD calculations $\Longrightarrow$ indication that $-t$ provides a hard scale

Spin-density Matrix Elements for J/ψ



- $\star$ only 1-dimensional analysis
- $\star$ not enough statistics for 2-dim analysis

J/ψ consistent with SCHC expectations

Summary

♠ power-like behavior of cross section on t (expected from pQCD), NOT exponential!

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

♠ all 3 mesons described by BFKL model fitted to the data

♠ 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

♠ measured Pomeron slope α' consistent with zero

♠ from decay-angles for ρ^0 and ϕ: deviation from SCHC
from decay-angles for J/ψ: consistent with SCHC

to conclude ...

high $-t$ provides hard scale!