XVIIth Rencontre de Blois

XIth International Conference on Elastic and Diffractive Scattering:

Towards High Energy Frontiers

Vector Meson Production at HERA

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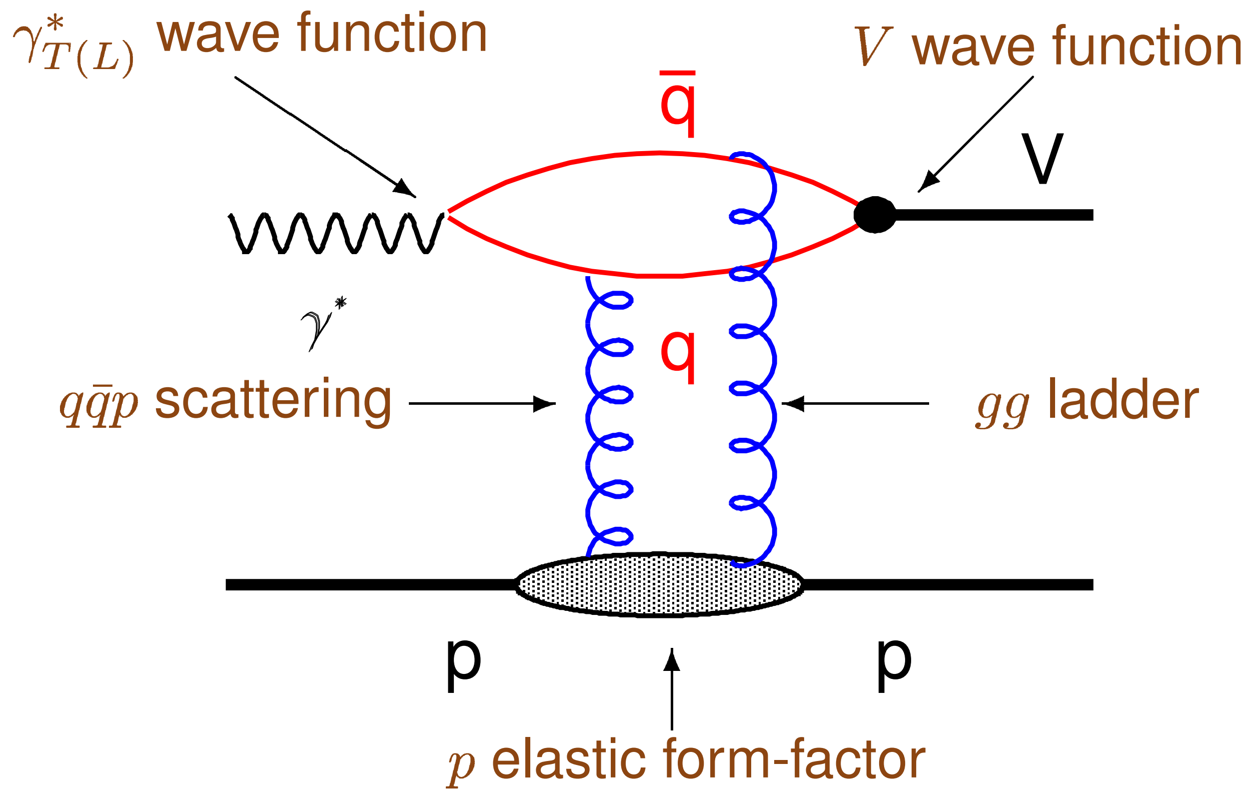
Aim is understand dynamics of high energy scattering in QCD

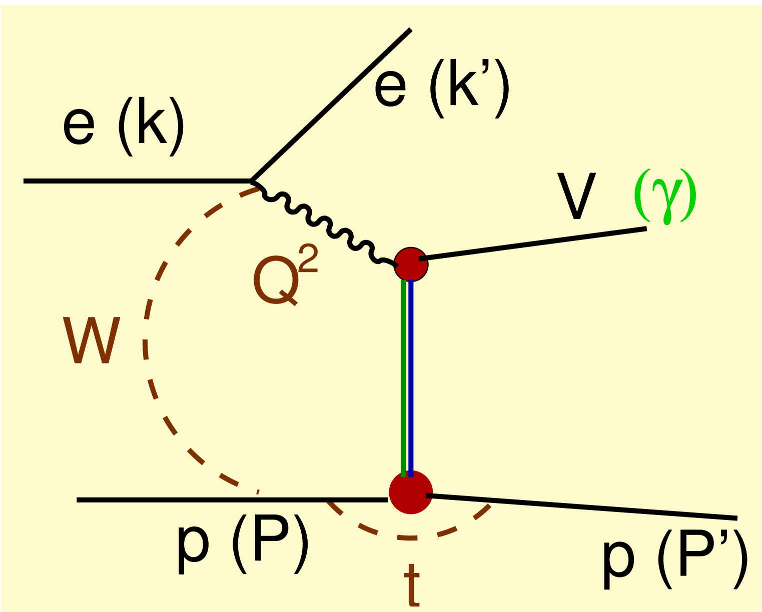


- test pQCD in transition regime soft-hard
- measure non-perturbative quantities (generalised) pdfs

Vector meson production in $\gamma^* p$

HERA regime: collisions of 27.5 GeV e with 920 GeV p

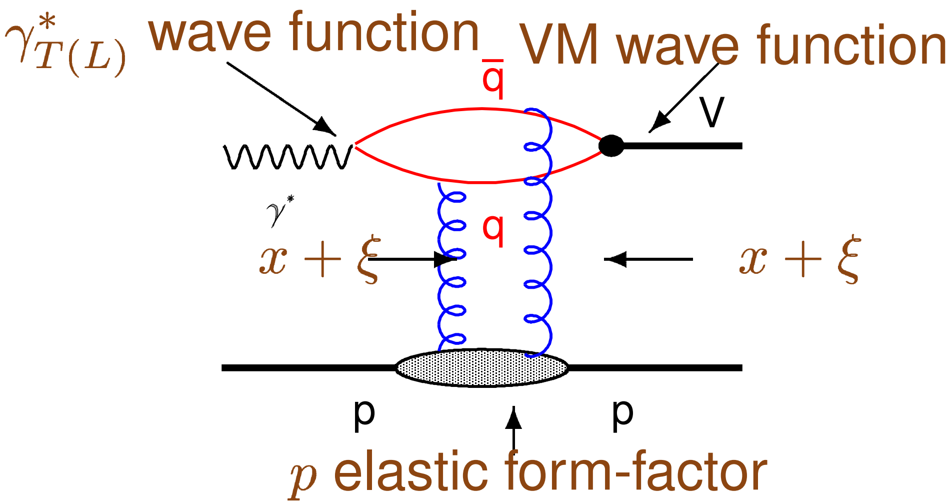
$0 < Q^2 < 100\ \mathrm{GeV}^2$ and $30 < W < 220\,\mathrm{GeV}$



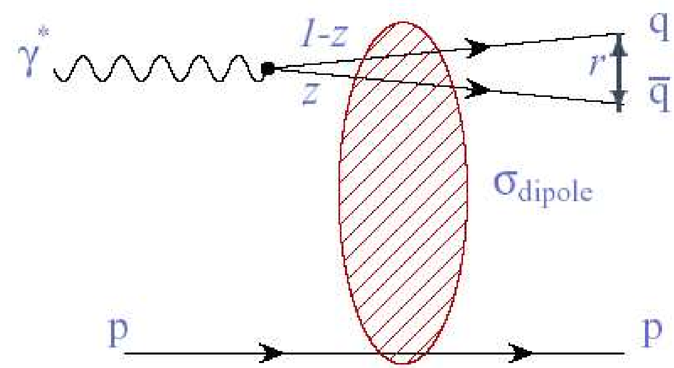
- Q^2 - virtuality of exchanged γ^*
  $Q^2 = -q^2 = -(k - k')^2$
- W - $\gamma^* p$ centre of mass energy
  $W = (q + p)^2$
- 4-momentum transfer squared at the p vertex $t = (P - P')^2$
- x - Bjorken variable $x = \frac{Q^2}{P \cdot q} = \frac{Q^2}{Q^2 + W^2}$

QCD factorization - two approaches

QCD - Breit frame



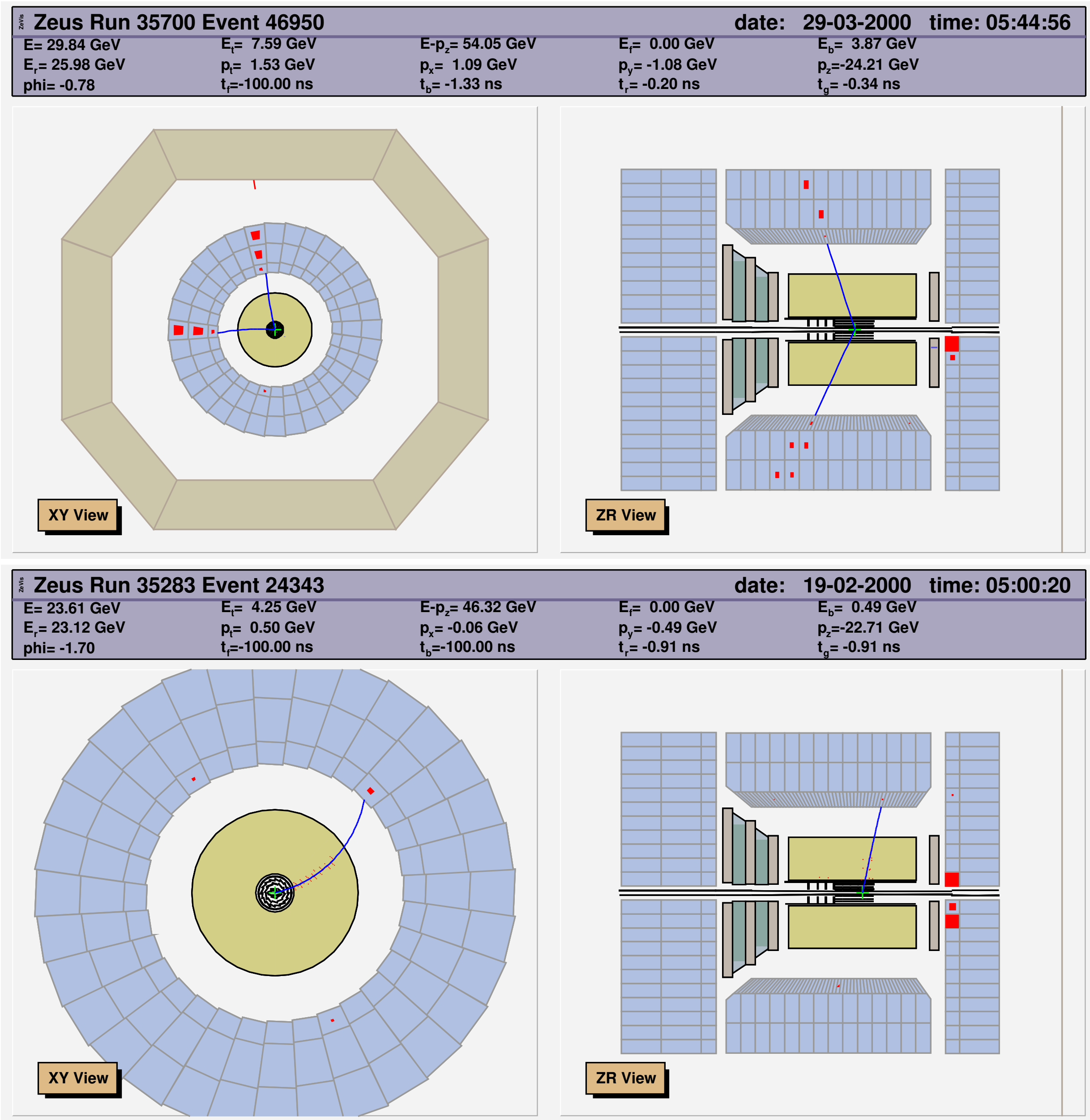
Colour dipole - target frame



NLO calculation available for
J/ψ (γp, DIS) and ρ (DIS)
$\sigma_L \simeq \frac{\alpha_S^2}{Q^6}|xG(x,Q^2)|^2 \Rightarrow$
$\sigma_L \propto \frac{\alpha_S^2}{Q^6}|H(x_1,x_2,t,Q^2)|^2$
Generalised PDFs build from PDFs
with skewing effect and t-dependence

- γ^* fluctuates in $q\bar{q}$ + $q\bar{q}g$ + ..
- Lifetime of dipole very long because of large γ boost
- Transverse size $\propto 1/(Q^2+M^2_{q\bar{q}})$

  $\sigma_{\gamma^* p}(x,Q^2) = \int dr^2 dz \psi^{in}(r,z,Q^2)\sigma^2_{dipole}(x,$
- σ_{dipole} from model (2-gluons, ..)

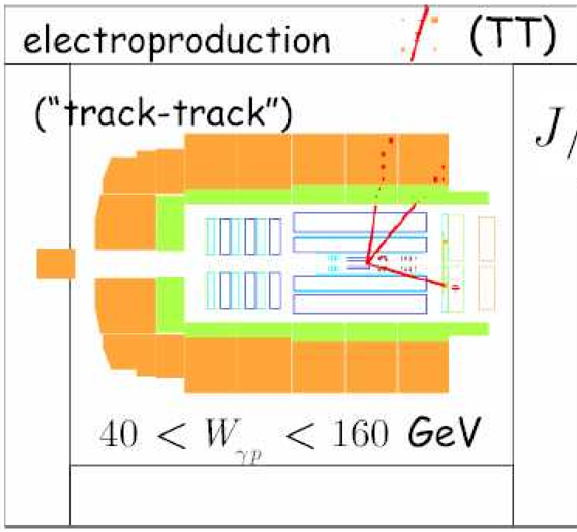


Clean experimental signature

- scattered e reconstructed in CAL or beam pipe calorimeter (DIS) or undetected (γp)
- scattered p undetected
- i.e. $\rho \to \pi^+\pi^-$,
  $J/\psi \to l^+l^-$ (BR 6%)
  2 tracks reconstructed in central chamber associated to pions, electrons or muons in CAL
  electrons can be reconstructed in CAL, outside tracking acceptance
- nothing else in the detector

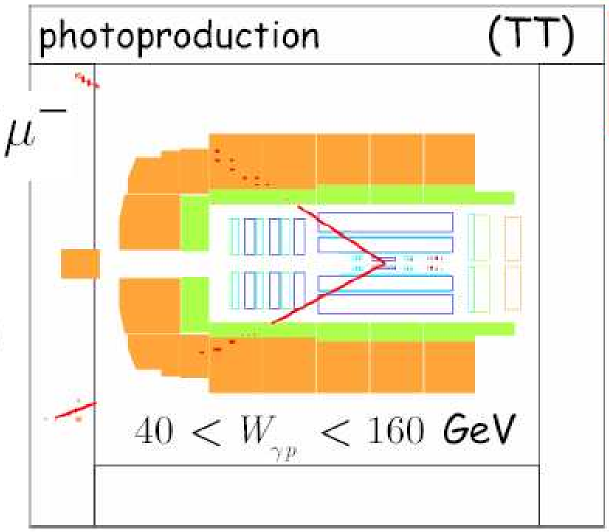
Clean experimental signature - J/ψ

data from 1999/2000 (HERA I): 55 pb^{-1} central, 30 pb^{-1} backward



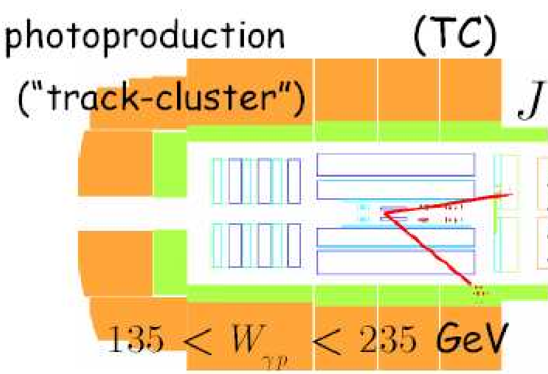
$J/\psi \to \mu^+\mu^-$

2 tracks
$\geq$ 1 muon
+ scatt. electron



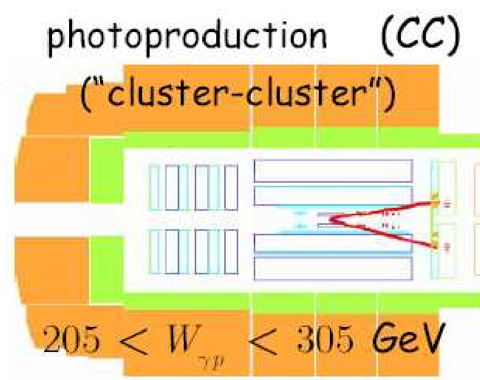
Muon analysis

2 tracks
$\geq$ 1 muon



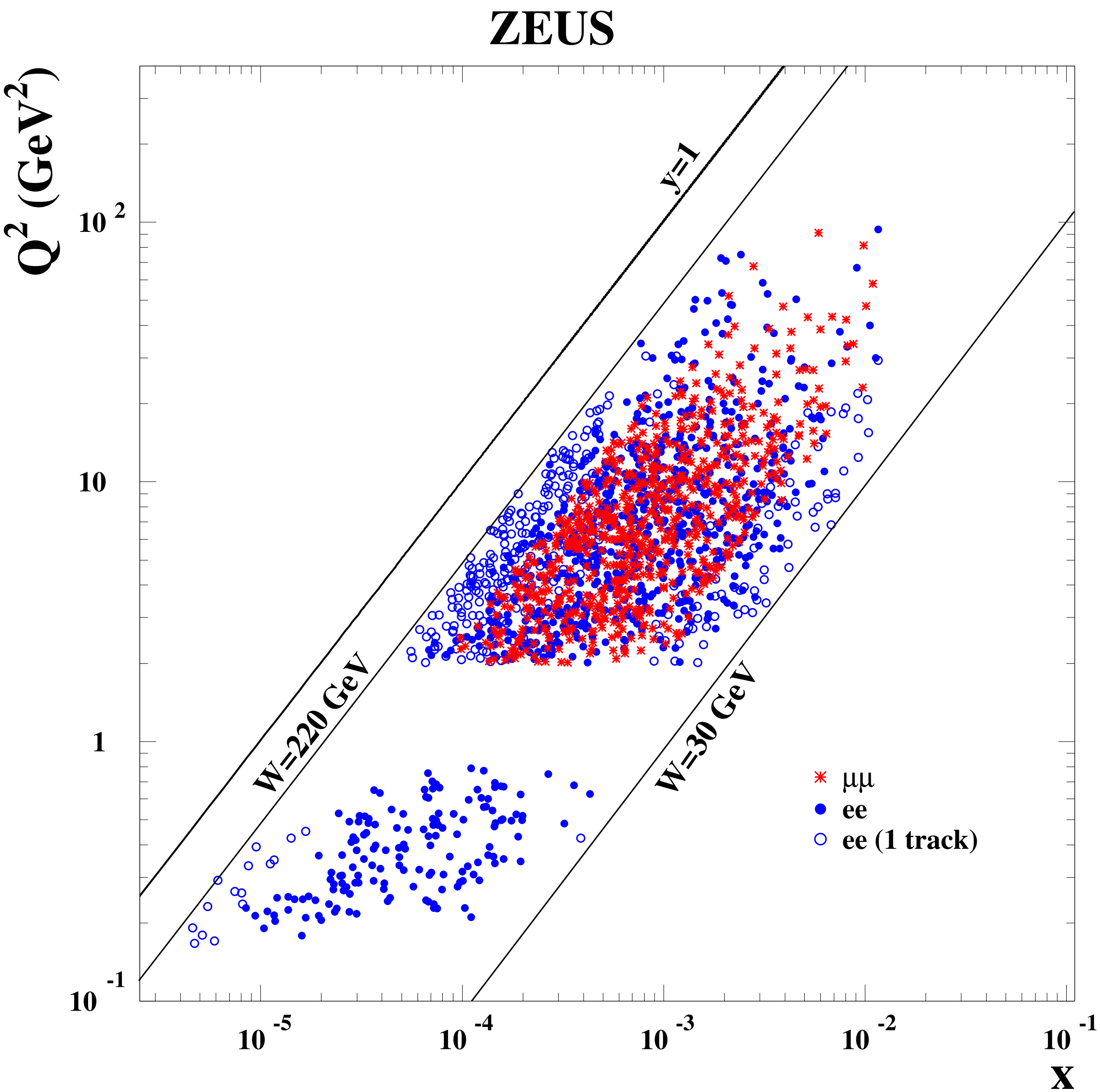
$J/\psi \to e^+e^-$

1 cluster
1 track



Electron analysis

2 clusters



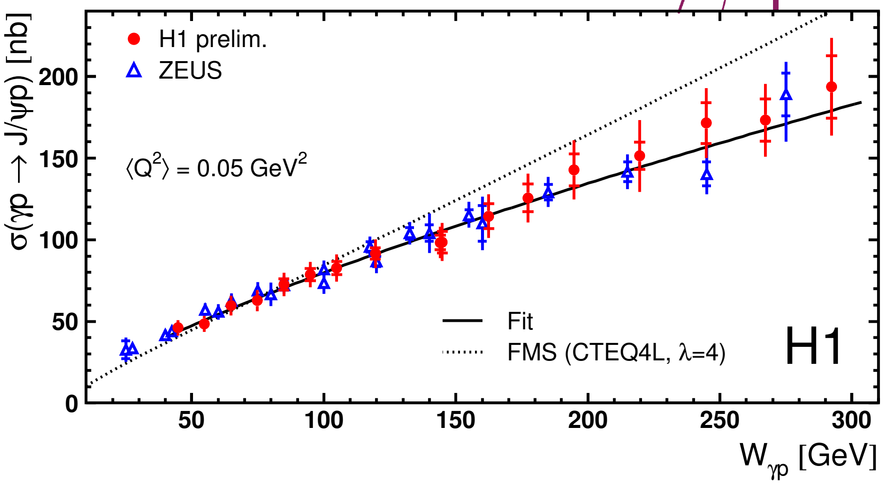
Exclusive J/ψ production

Kinematic range

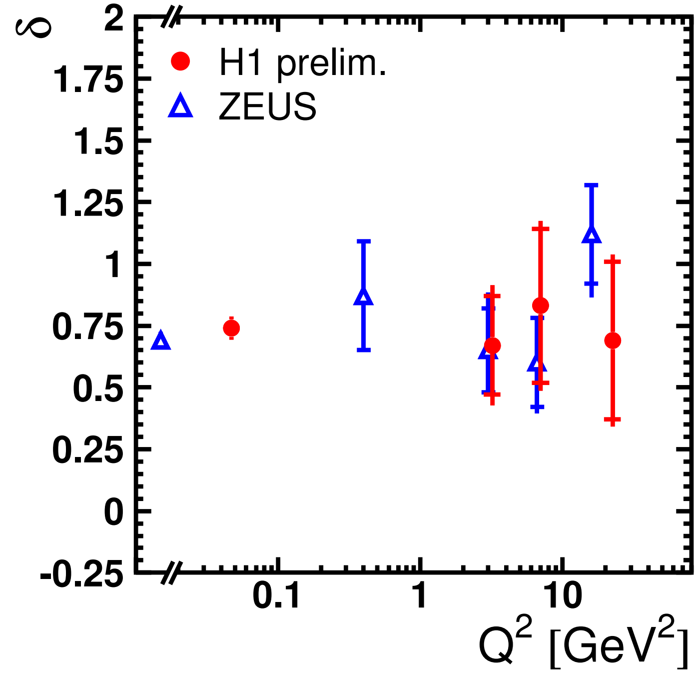
- ZEUS
  $Q^2 \simeq 10^{-5}$
  $35 < W < 280$ GeV
  $-t < 1.5$ GeV^2

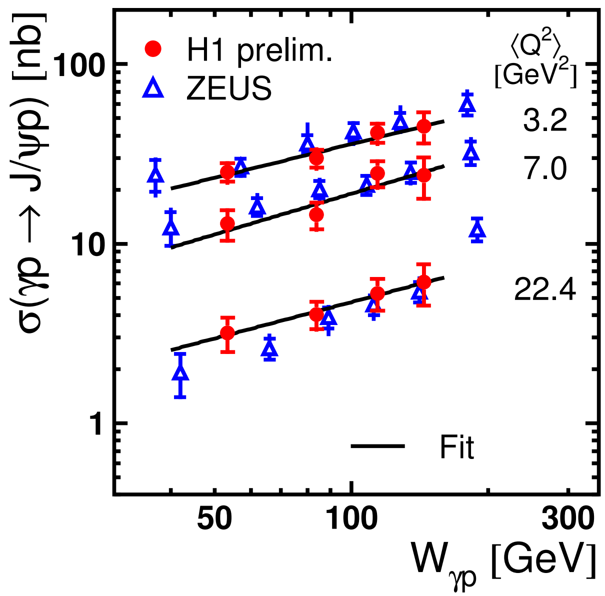
  $0.15 < Q^2 < 0.8$ GeV^2(69 pb^{-1})
  $2 < Q^2 < 100$ GeV^2 (83 pb^{-1})
  $30 < W < 220$ GeV
  $-t < 1$ GeV^2
- H1
  $Q^2 \simeq 0.05$, $2 < Q^2 < 80$ GeV^2
  $40 < W < 300$ GeV
  $-t < 1.2$ GeV^2

Exclusive J/ψ production - W dependence



σ vs W in bins of Q^2

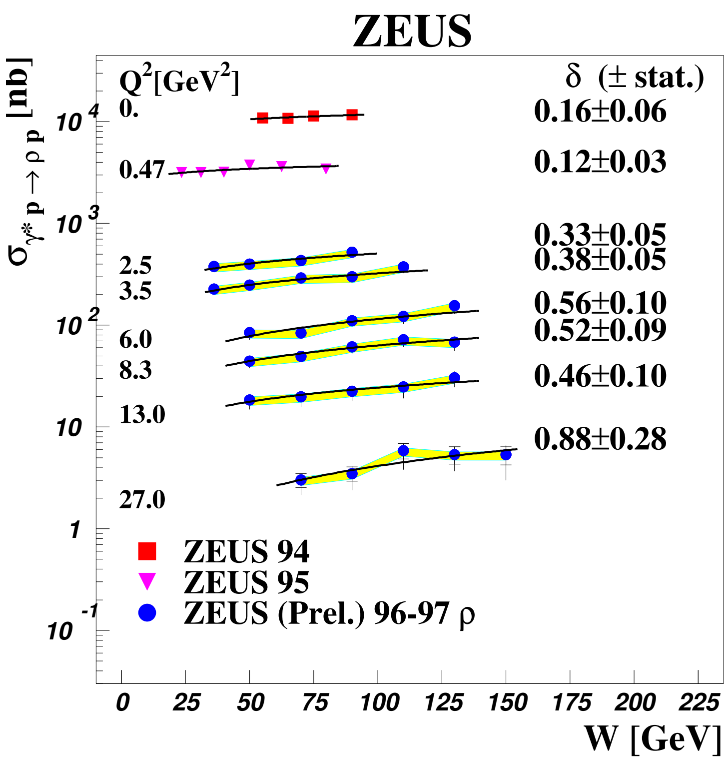




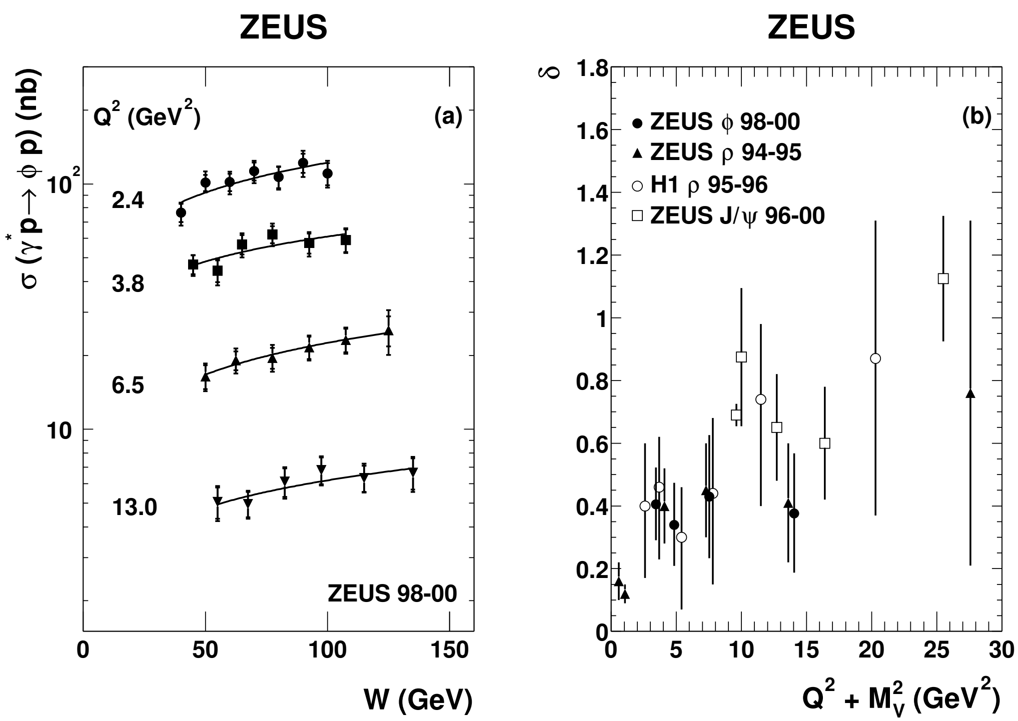
- $\sigma \propto W^{\delta}$, with $\delta = 0.7$
- no dependence of δ from Q^2

σ vs W in bins of Q^2

ρ

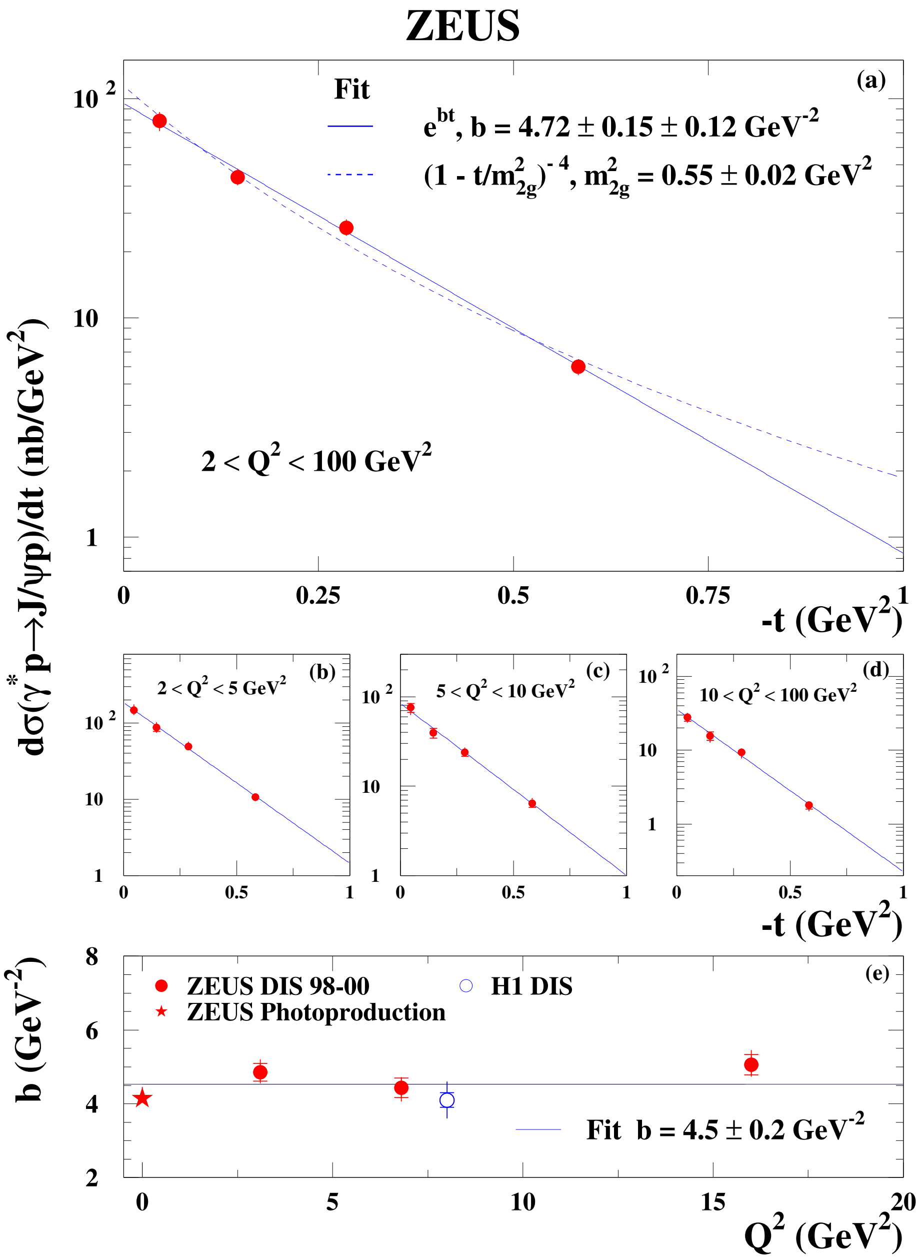


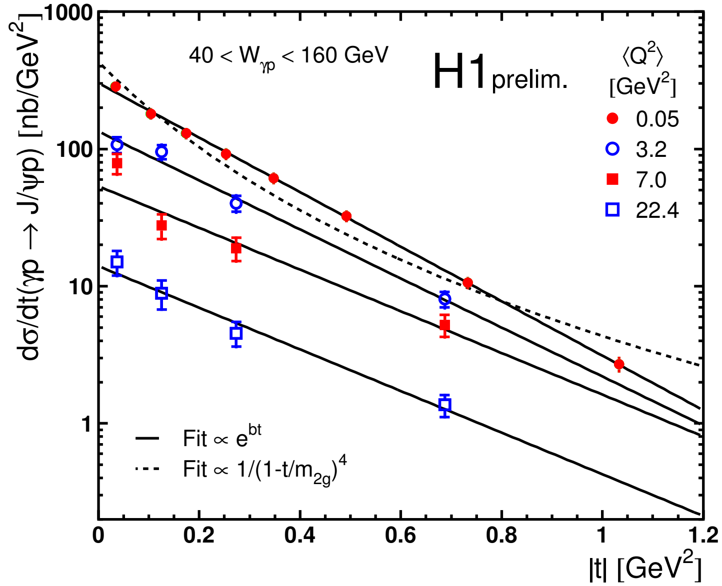
ϕ



- General transition to hard behaviour at high values of $Q^2 + M^2$

t-dependence in bins of Q^2

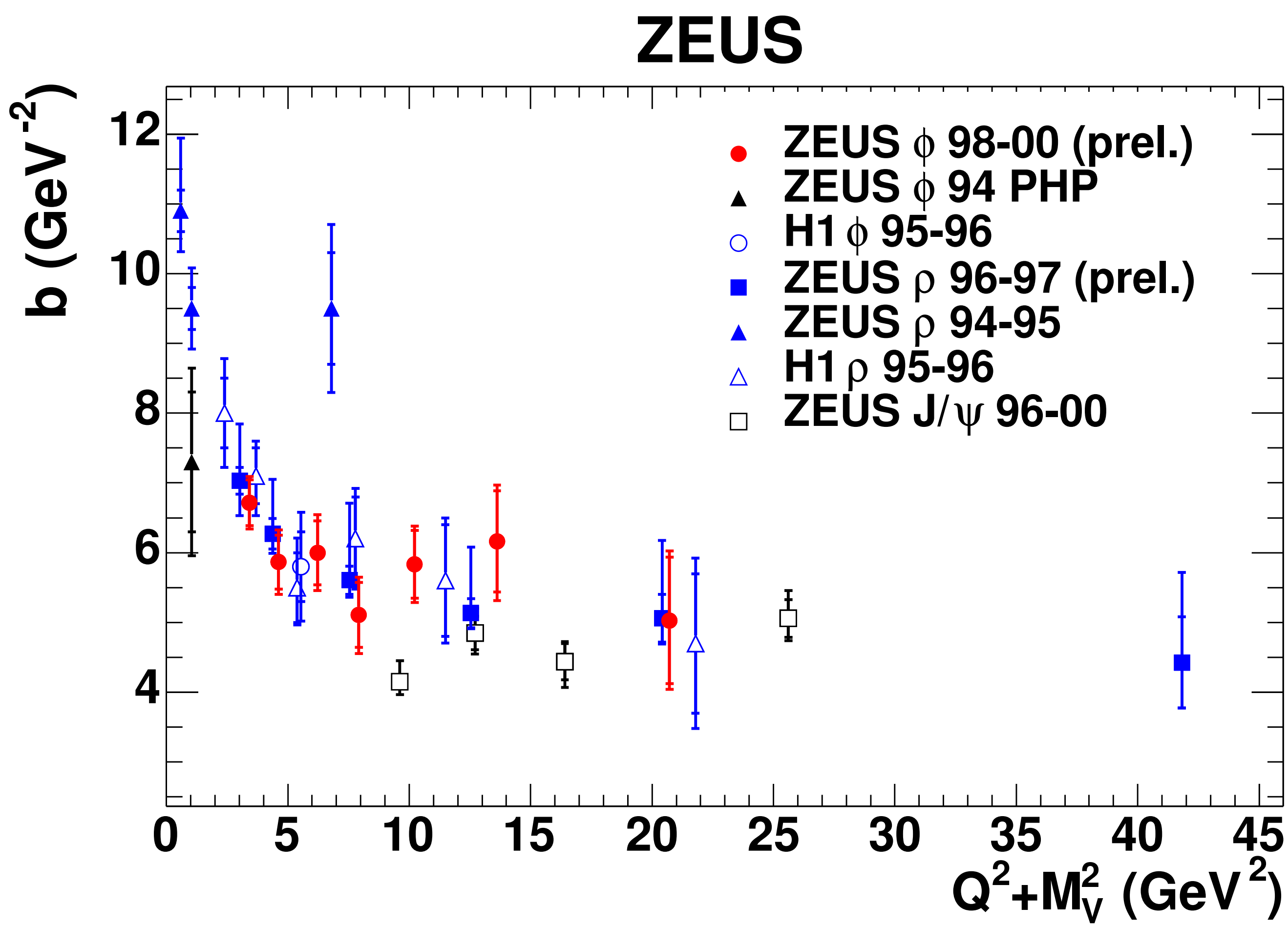




- $d\sigma/dt \propto e^{bt}$, for $|t| < 1$ GeV^2
- $d\sigma/dt \propto e^{bt}$
- b related to transverse size of the interaction $c\bar{c}$-p
- no dependence of b from Q^2, interaction dominated by size of p

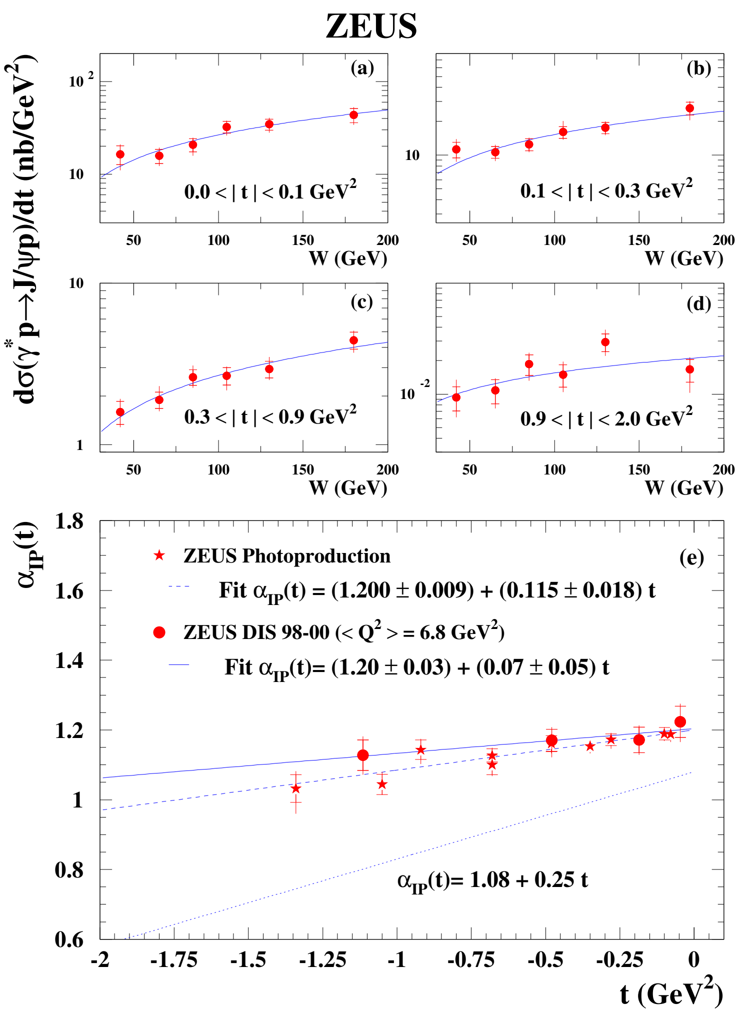
t dependence

$d\sigma/dt \propto e^{bt}$

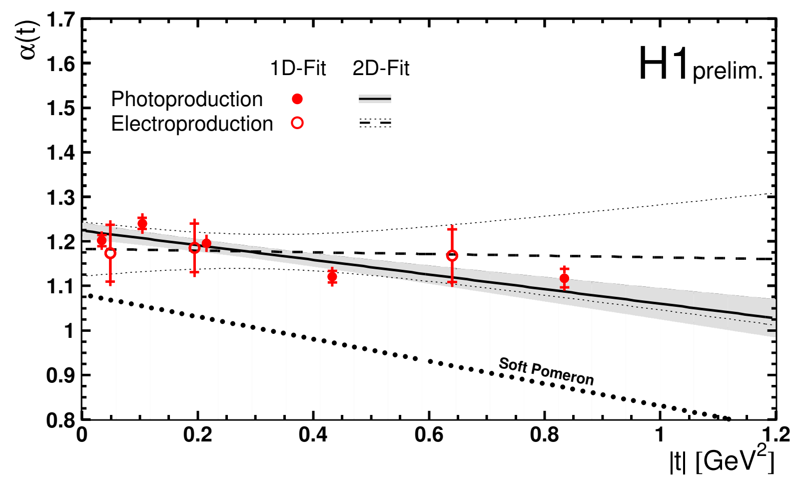


- General transition to small configuration at high values of $Q^2 + M^2$

Exclusive VM production - effective Pomeron trajectory



$$d\sigma/dt \propto \exp^{b_0 t} W^{4(\alpha_{I\!P}(t)-2)}$$



Photoproduction:

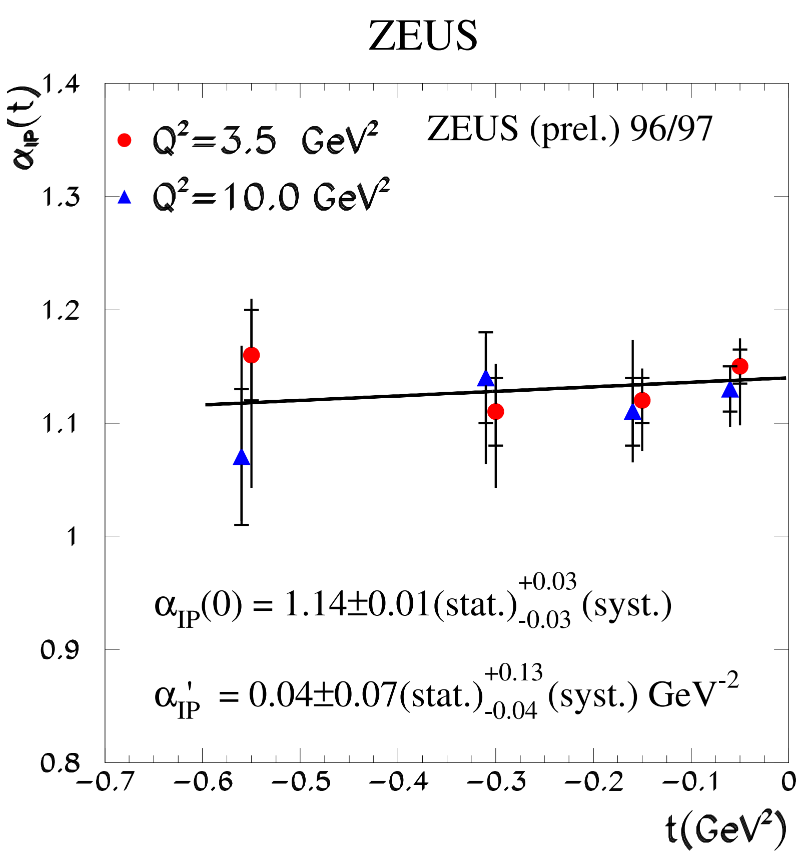
$\alpha_{I\!P}(t) = (1.224 \pm 0.010 \pm 0.012) + (0.164 \pm 0.028 \pm 0.030) GeV^{-2} t$

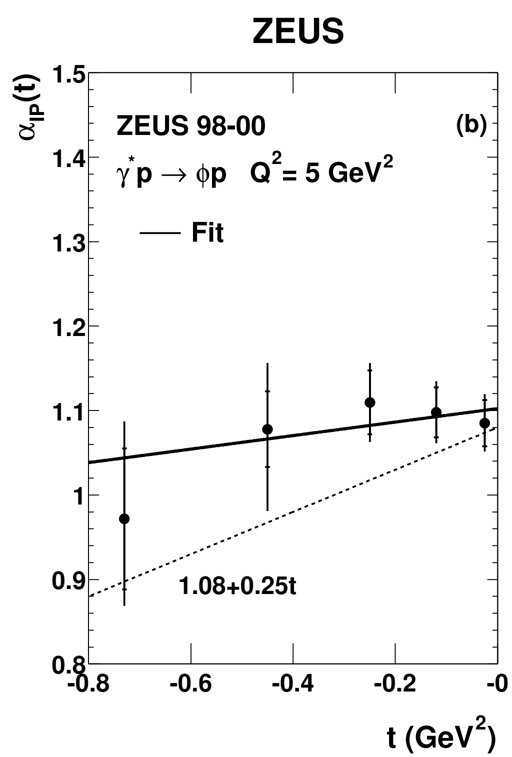
DIS:

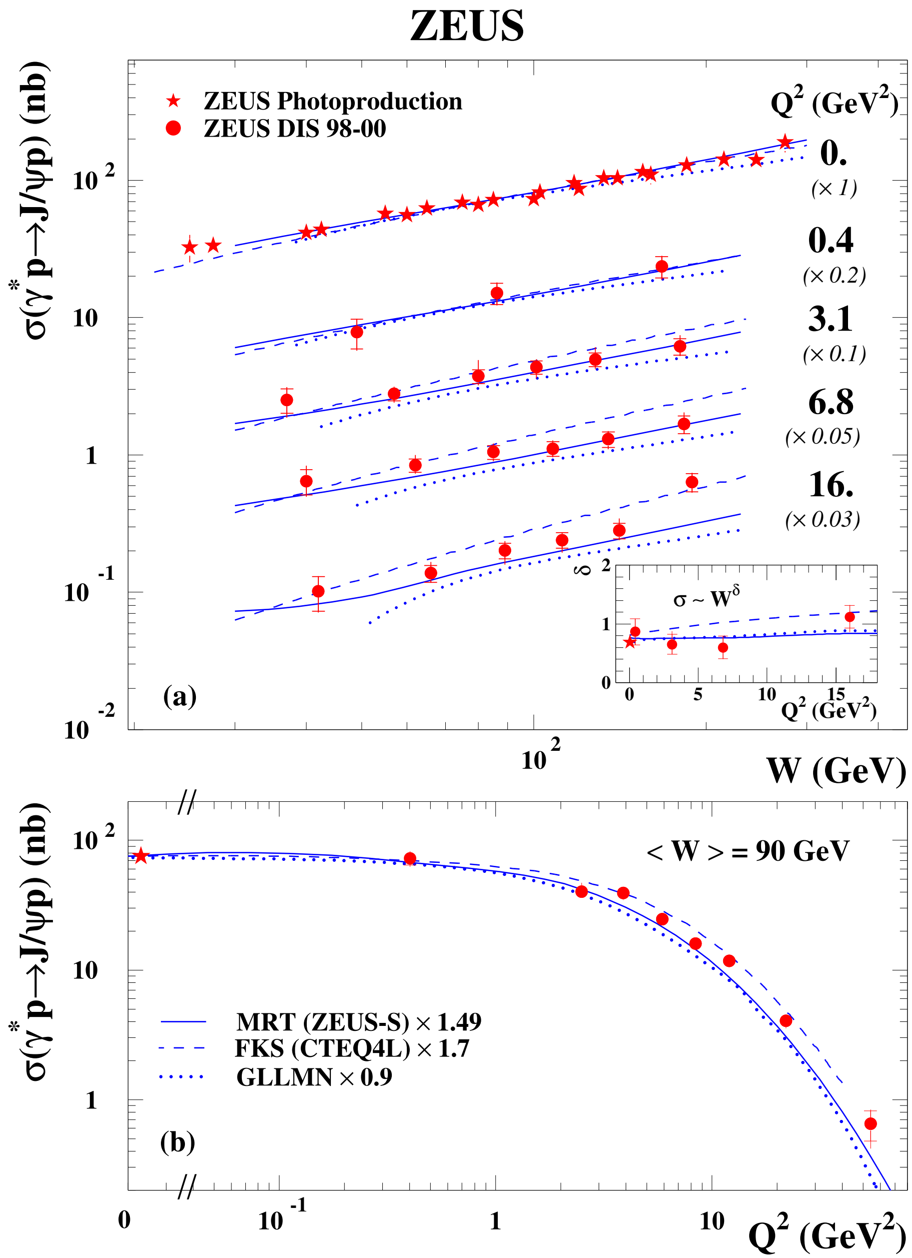
$\alpha_{I\!P}(t) = (1.18 \pm 0.05 \pm 0.03) + (0.02 \pm 0.14 \pm 0.07) GeV^{-2} t$

Exclusive VM production - effective Pomeron trajectory

$$d\sigma/dt \propto \exp^{b_0 t}\, W^{4(\alpha_{I\!P}(t)-1)} \text{ with } \alpha_{I\!P}(t) = \alpha_{I\!P}(0) + \alpha'_{I\!P} t$$







Exclusive J/ψ production

comparison with QCD models

Martin, Ryskin Teubner

Frankfurt, Koepf, Strikman

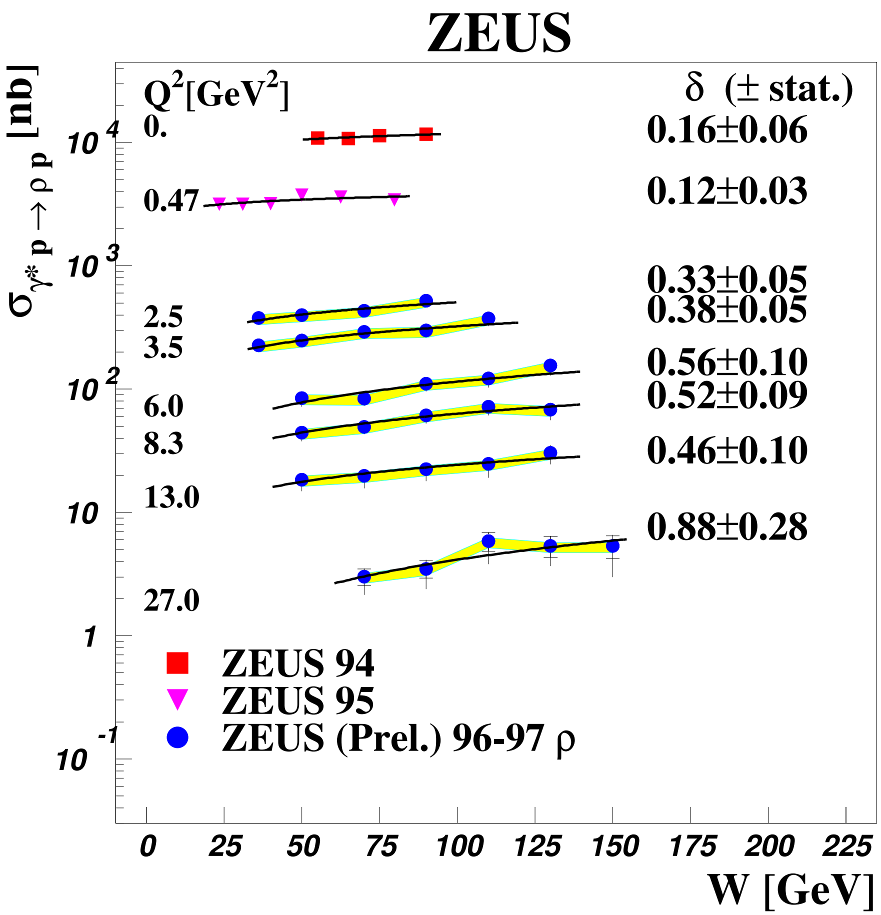
Gotsman, Levin, Lublisky, Maor, Naftali

models differ for

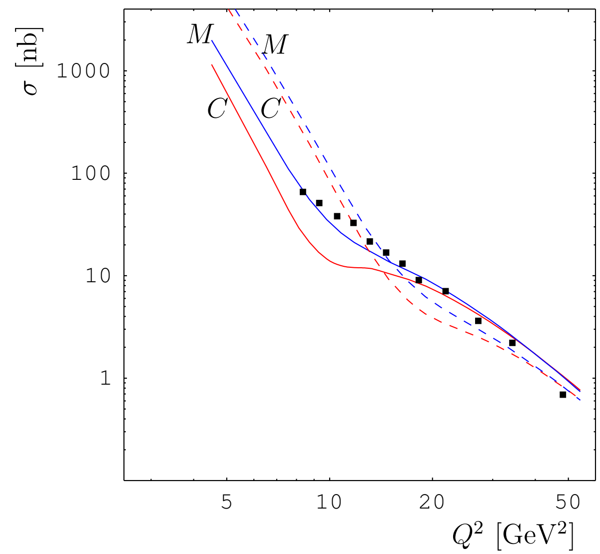
- assumptions on $c\bar{c}$ wave function
- corrections applied to LO calculations
- assumptions on GPDFs

- large uncertainty in normalisation
- models describe qualitatively data
- rise of σ with W related to increase in gluon density at low x

Exclusive ρ - comparison with models



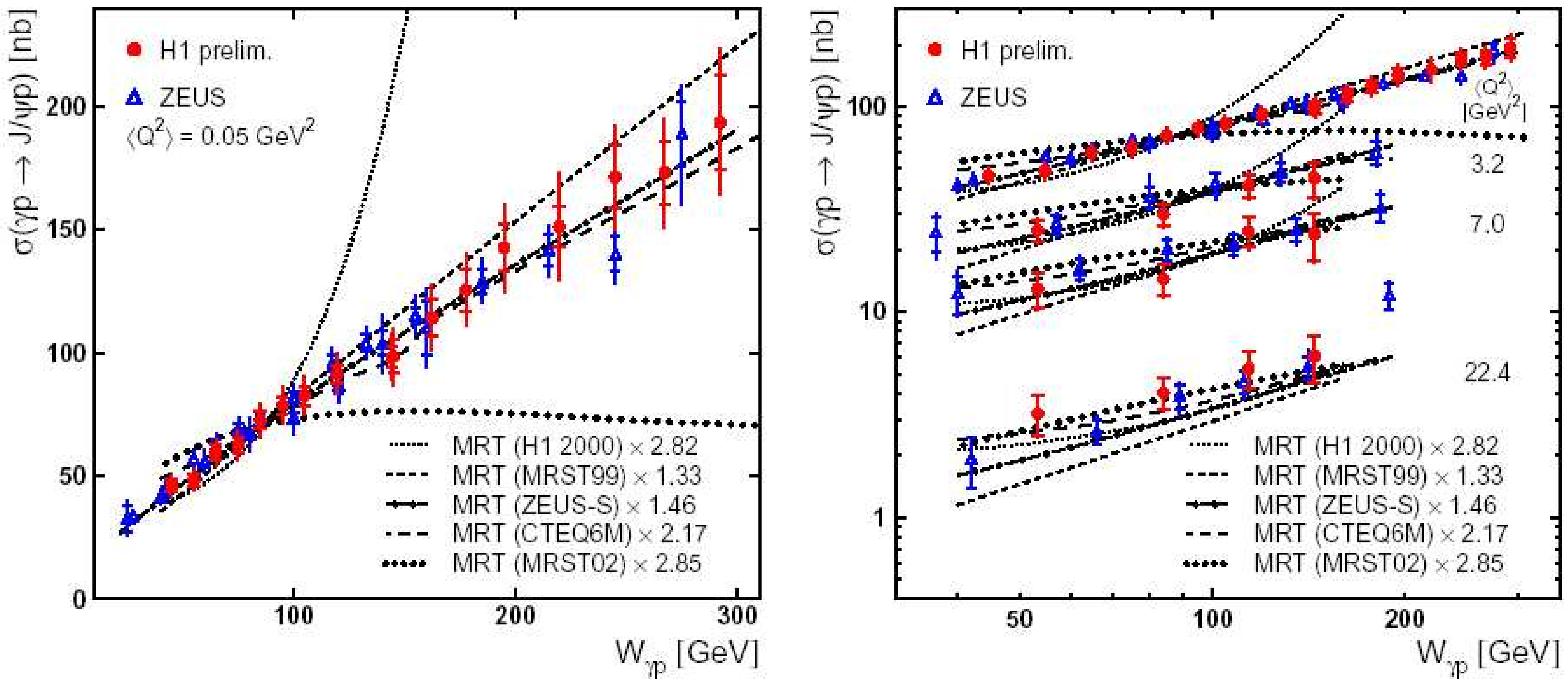
- First NLO: Ivanov, Krasnikov and Szymanowski



M=MRST2001, C=CTEQ6M

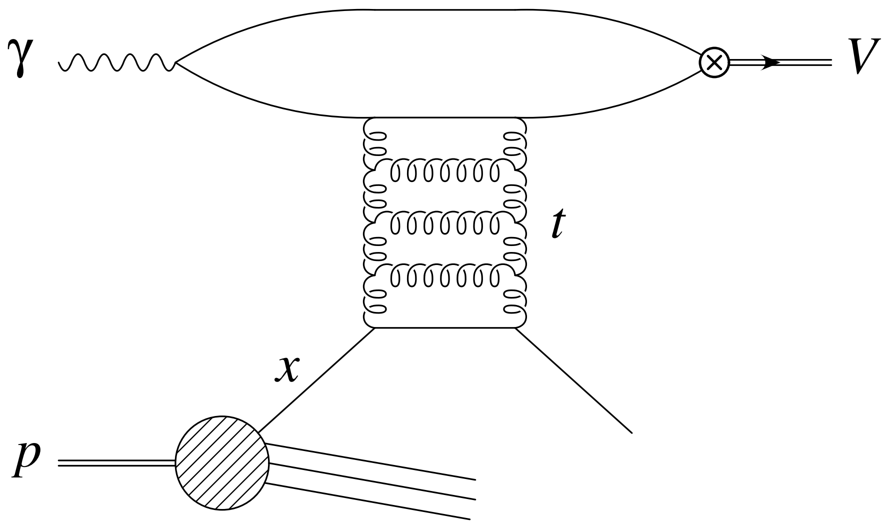
solid line $\mu_R = \mu_F$, dashed line $\mu_R = Q$

Exclusive J/ψ production - comparison to different PDFs



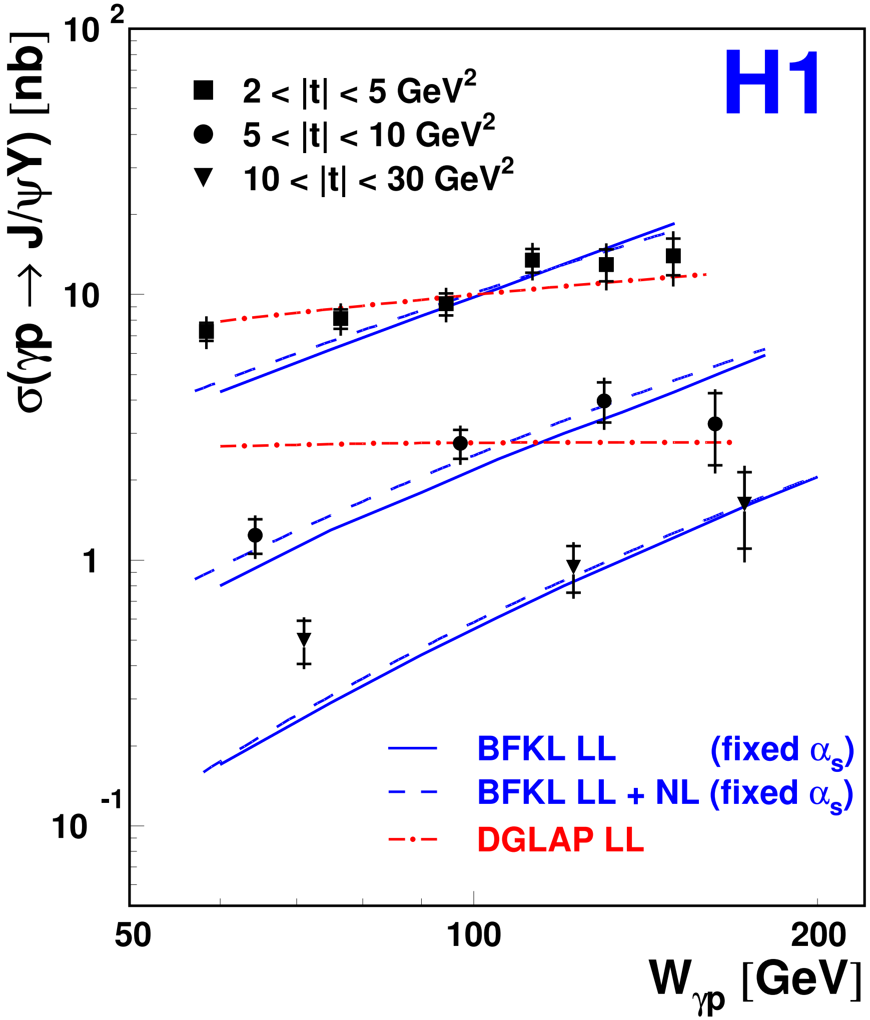
- strong sensitivity to generalised gluon distribution
- could the data be used to constrain gluon density?

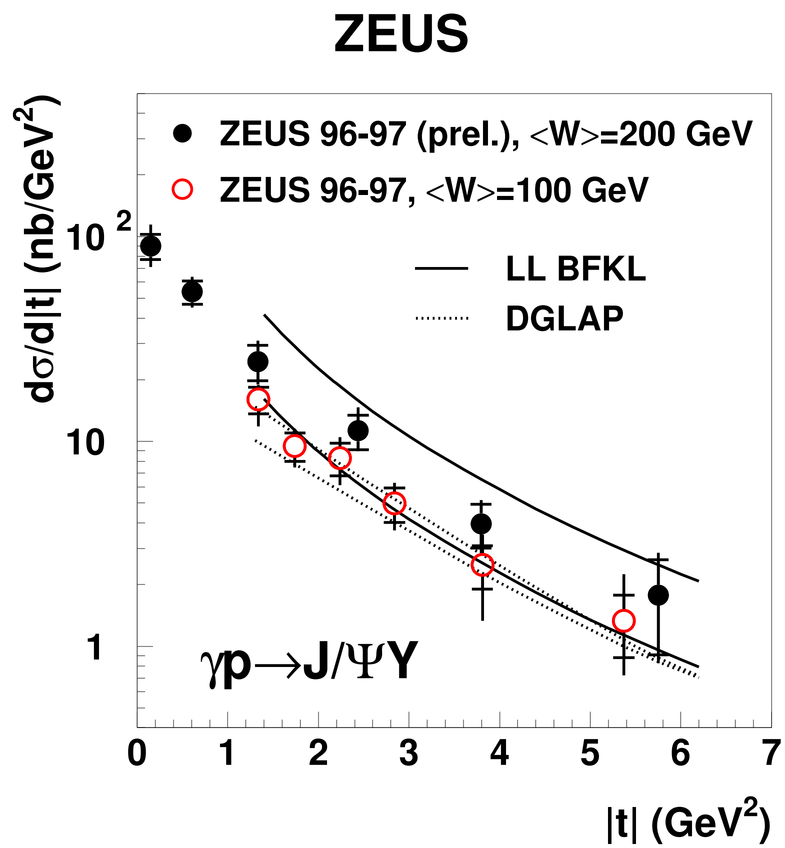
VM at large t: BFKL dynamics



- BFKL evolution driven by terms $\alpha_S^n \ln^n(W^2/|t|)$
- At high t, proton mostly dissociates
- BFKL-based models reproduce the trend of data (but NLO missing)

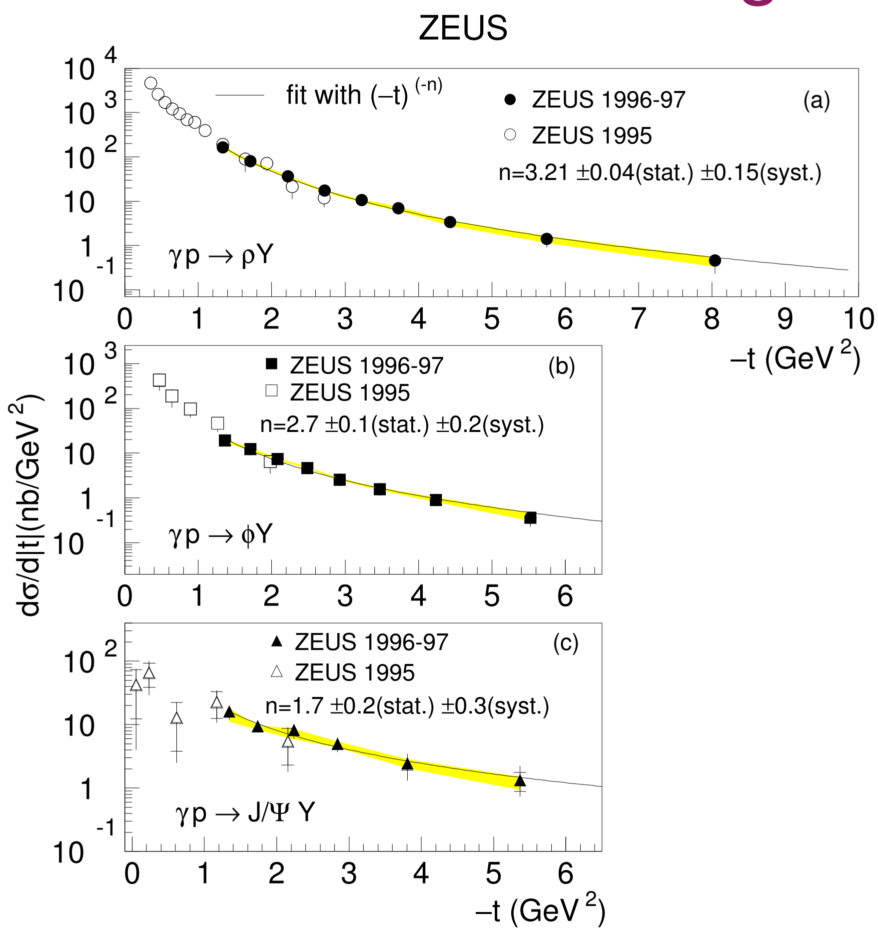
BFKL dynamics

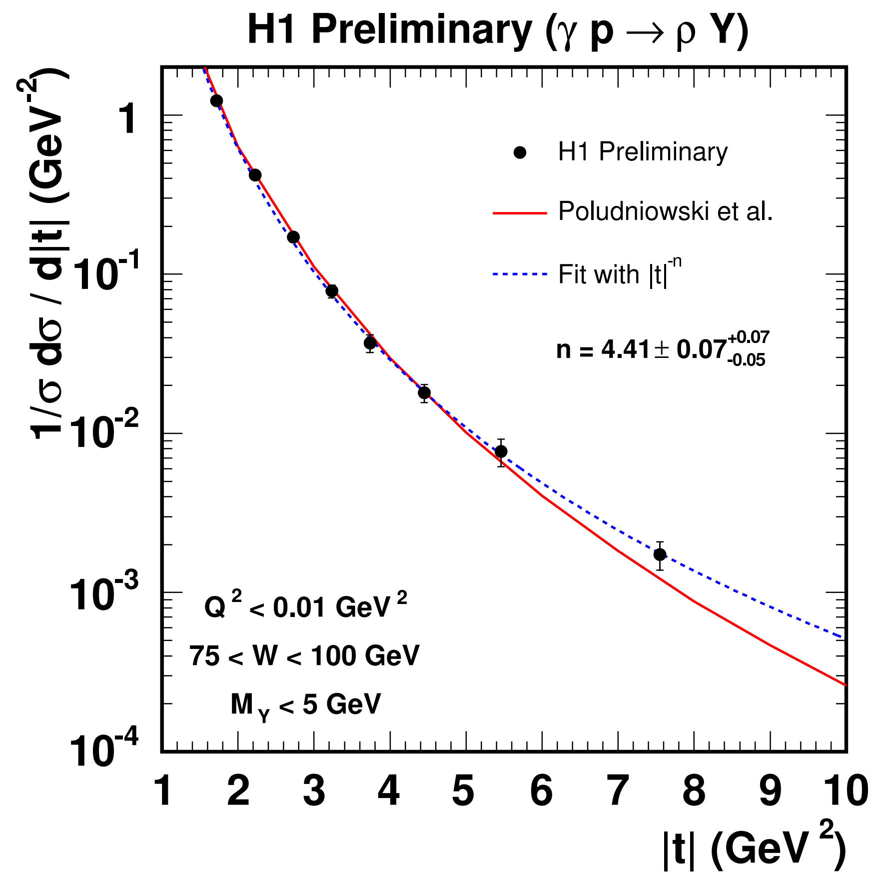




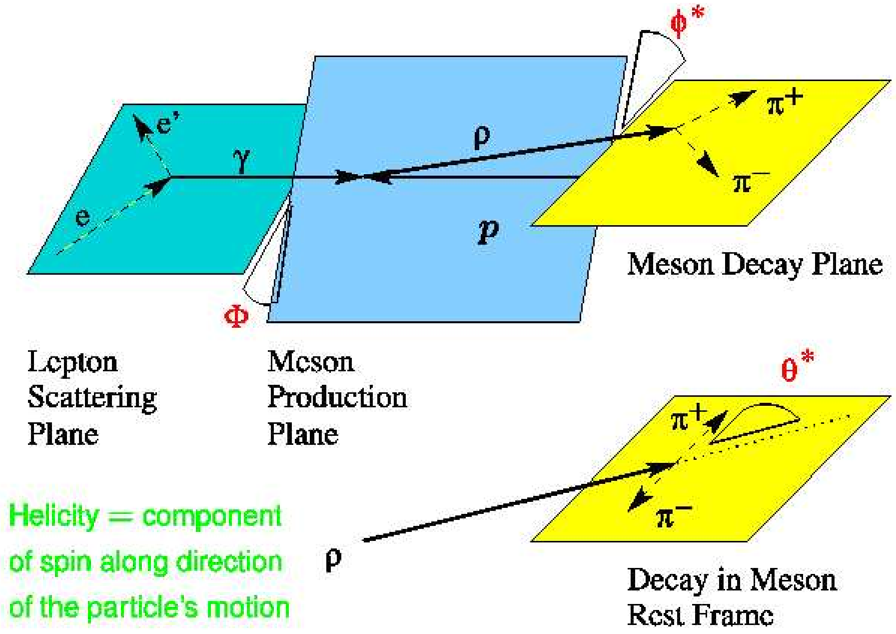
- DGLAP fails to descrive evolution at large t

VM at large t: BFKL dynamics





Decay angular distributions



Helicity angles

θ_h, ϕ_h - angles of decay particle in the meson rest frame

Φ - angle between scattering and production plane

Angular distributions are related to the spin of γ^* and meson

Angular distr. $\rightarrow$ spin density matrix elements r_{ij}^{kl} $\rightarrow$ helicity amplitudes $T_{\lambda_{VM}\lambda_\gamma}$

Decay Angular Distributions

Spin Matrix Elements

s-channel helicity conservation (SCHC):

- the VM retains the γ^* helicity. $R = \sigma_L/\sigma_T$ is related to the spin density matrix elements r_{00}^{04} (good approximation).

pQCD:

- during the interaction, the orbital angular momentum of the $q\bar{q}$ can be modified through the transfer of transverse momentum carried by gluons;
- the helicity of the outgoing vector meson can be different from that of the incoming photon, helicity flip between photon and meson is possible.

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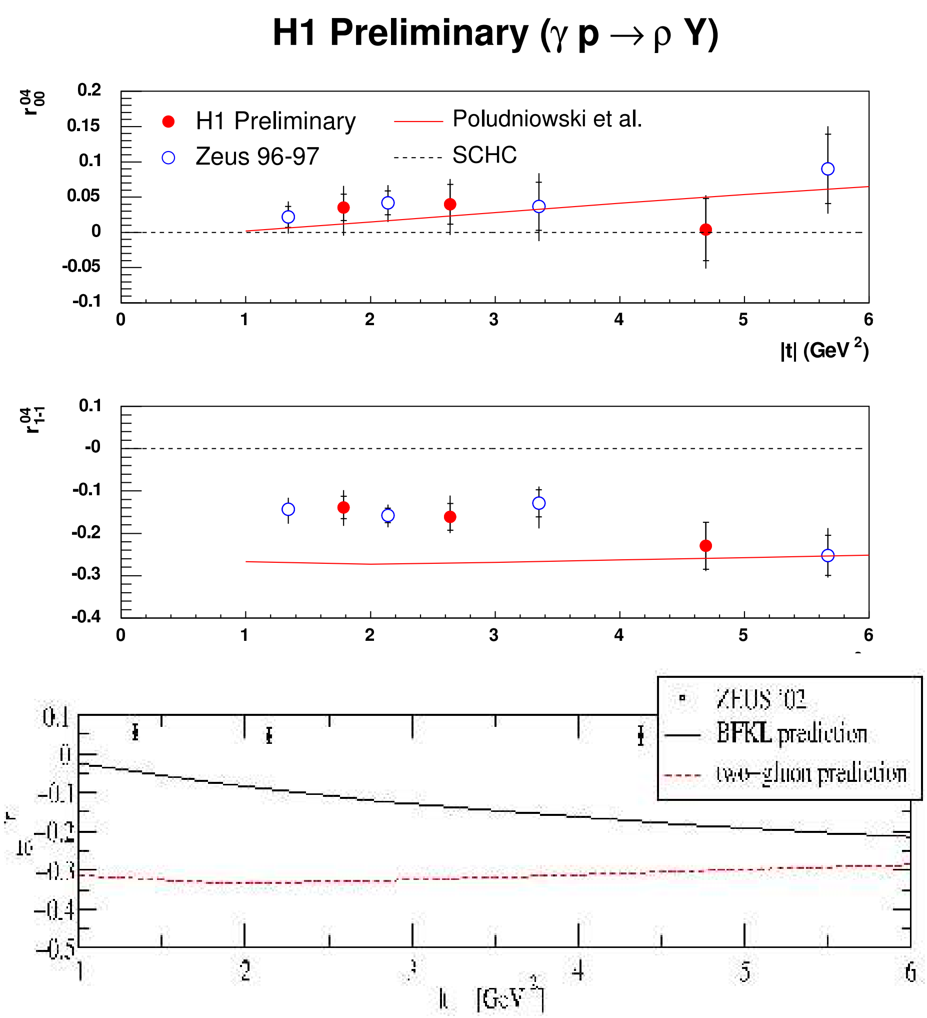
VM at large t: BFKL dynamics



- t dependence well described by BFKL models
- but BFKL models unable to describe r^{04}_{10}
- progress expected

Summary

- Experimentally much progress has been achieved,
  - high precision in wide kinematic region
  - increased statistics at high Q^2 will help (700 pb^{-1} expected at HERA II)
- Theoretically chance to investigate the QCD dynamics in the semi-hard regime,
  - the overall picture looks correct
  - large uncertainties
  - full NLO calculations are missing