Diffraction at HERA

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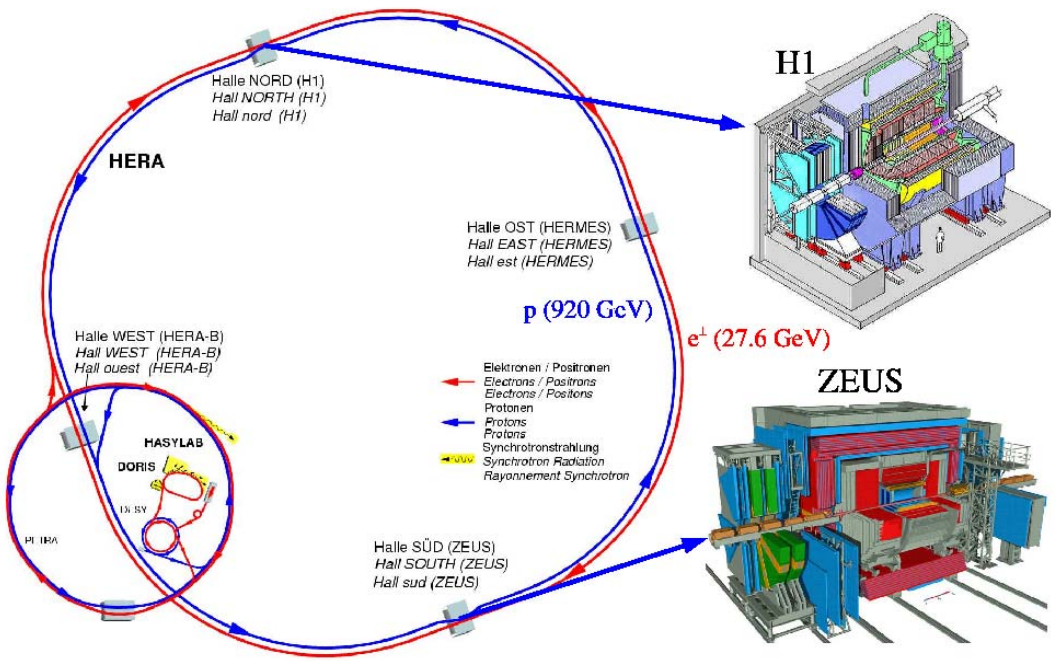
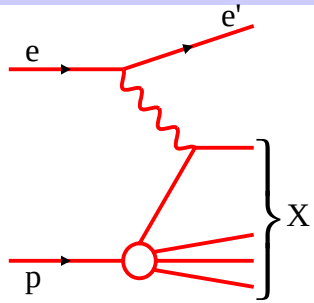
on behalf of H1 and ZEUS collaborations

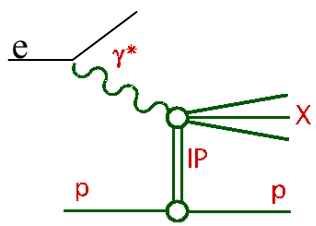
HERA collider experiments

- 27.5 GeV electrons/positrons on 920 GeV protons →√s=318 GeV
- two experiments: H1 and ZEUS
- HERA I: 16 pb^{-1} e-p, 120 pb^{-1} e+p
- HERA II: ~ 550 pb^{-1}, ~ 40% polarisation of e+,e-





DIS: Probe structure of proton → F_2



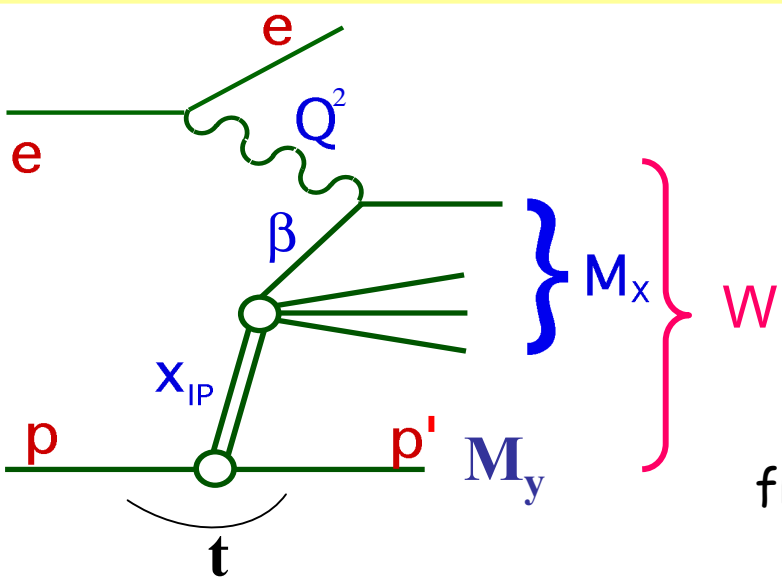
Diffractive DIS: Probe structure of color singlet exchange → F_2^D

Diffraction and diffraction kinematics

HERA: ~10% of low-x DIS events are diffractive

Why to study diffraction?

- **fundamental aim**: to understand high energy limit of QCD (gluodynamics)
- **novelty**: for the first time probe partonic structure of diffractive exchange
- **practical motivations**: to study factorisation properties of diffraction – try to transport to **hh** scattering (e.g.predict diffractive Higgs production at LHC)



$$x_{IP} = \frac{q\cdot(p-p')}{q\cdot p} \approx \frac{Q^2 + M_X^{\,2}}{Q^2 + W^2}$$

momentum fraction of color single exchange

$$\beta = \frac{x}{x_{IP}} \approx \frac{Q^2}{Q^2 + M_X^{\,2}}$$

fraction of exchange momentum, coupling to γ*

$$t = (p - p')^2$$ → 4-momentum transfer squared

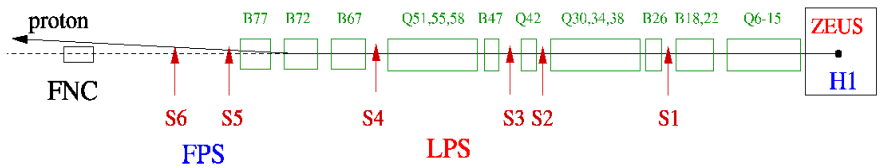
Diffractive Event Selection

1) Proton Spectrometers:

- ZEUS: LPS (1993-2000)
- H1: FPS (1995-), VFPS (2004-)

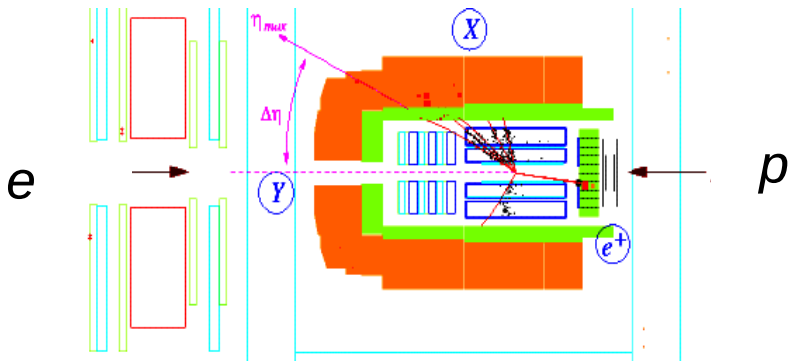
→ t measurement

- access to high x_{IP} range
- free of p-dissociation background at low x_{IP}
- small acceptance → low statistics ☠



2) Large Rapidity Gap, H1, ZEUS:

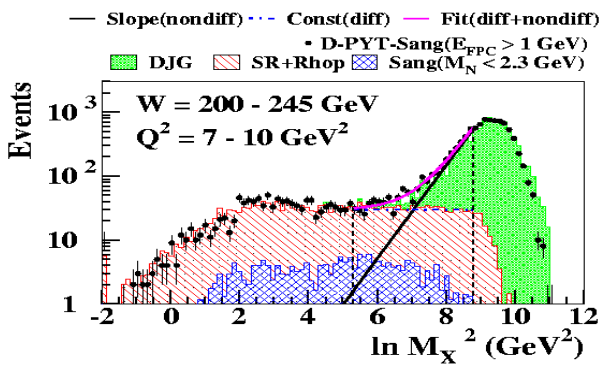
- Require no activity beyond η_{max}
- t not measured, some p-diss background ☠



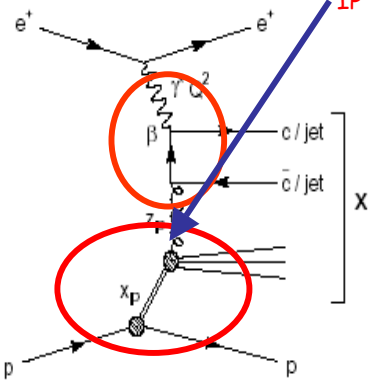
3) M_x method, ZEUS:

- Diffractive vs non-diffractive: exponential fall off vs constant distribution in ln M_x^2
- Some p-diss contribution ☠

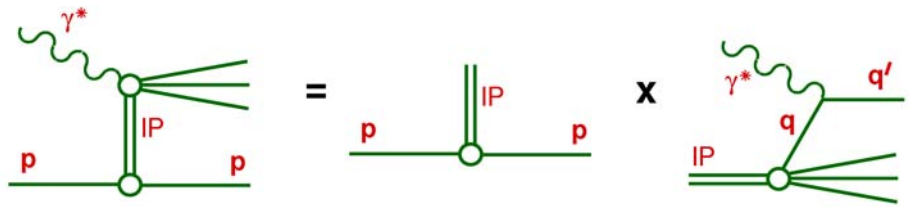
$$\frac{dN}{d\ln M_x^2} \propto \underbrace{D}_{\text{diff.}} + \underbrace{Ce^{B\ln M_x^2}}_{\text{non-diff}}$$



Factorisation properties in diffraction



z_{IP}: longitudinal momentum fraction of gluon rel to colorless exchchange



QCD factorisation & Regge factorisation

rigorously proven for DDIS by Collins at al

conjecture, e.g. Resolved Pomeron Model by Ingelman, Schlein

$$\sigma^D(\gamma^* p \to Xp) \propto \sum_{parton\_i} f_i^{\,D}(x, Q^2, x_{IP}, t) \cdot \sigma^{\gamma^* i}(x, Q^2)$$

Regge motivated pomeron flux

$$f_{IP/p}(x_{IP}, t) = \frac{e^{Bt}}{x_{IP}^{2\alpha(t)-1}}$$

$$f_i^{\,D}(x, Q^2, x_{IP}, t) = f_{IP/p}(x_{IP}, t) \cdot f_i^{\,IP}(\beta = x / x_{IP}, Q^2)$$

$\sigma^{\gamma^* i}$ universal hard scattering cross section (same as in inclusive DIS)

$f_i^{\,D}$ diffractive parton distribution functions → obey DGLAP, universal for diffractive *ep* DIS (inclusive, di-jets, charm)

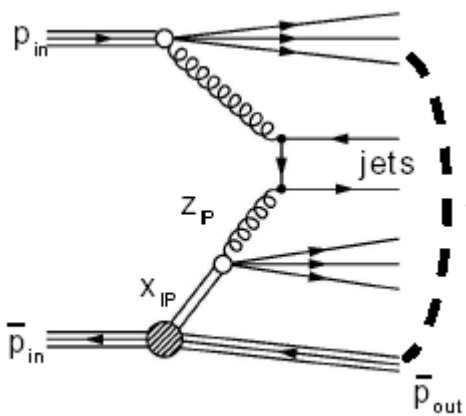
Exctracted from inclusive diffraction!

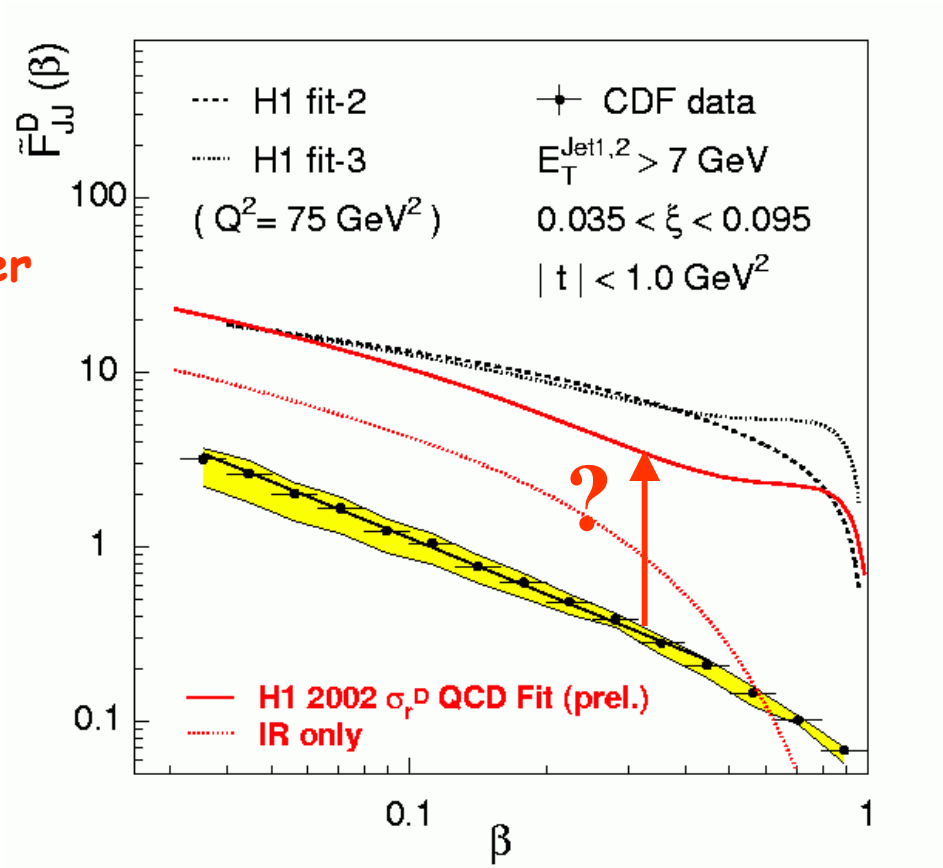
Exporting PDFs from HERA to the Tevatron.....

CDF Tevatron data:

At Tevatron HERA PDF's do not work....????

Dijet cross section factor **5-10 lower** than the QCD calculation using HERA PDFs





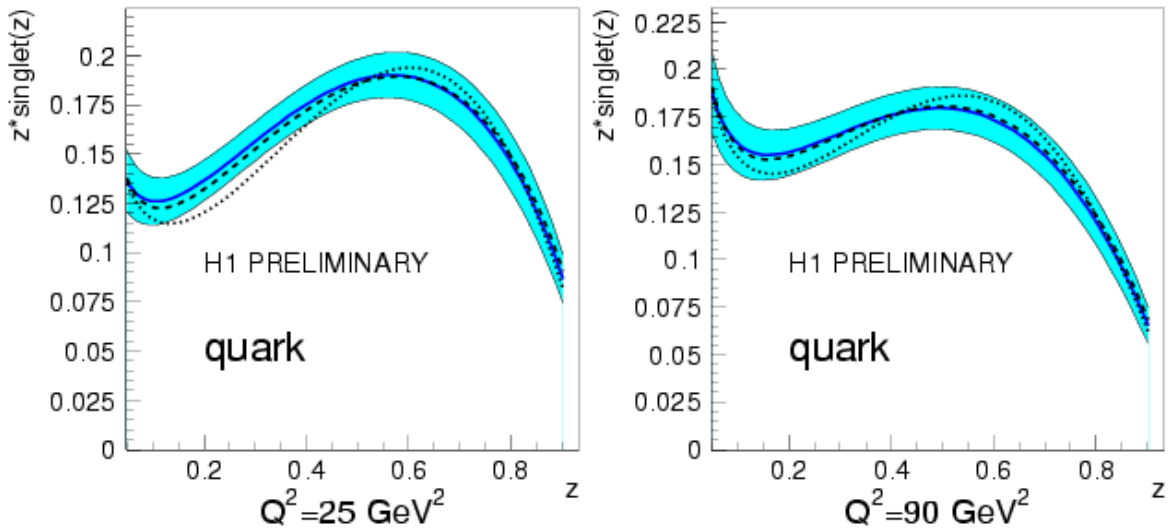
QCD factorisation in diff. DIS

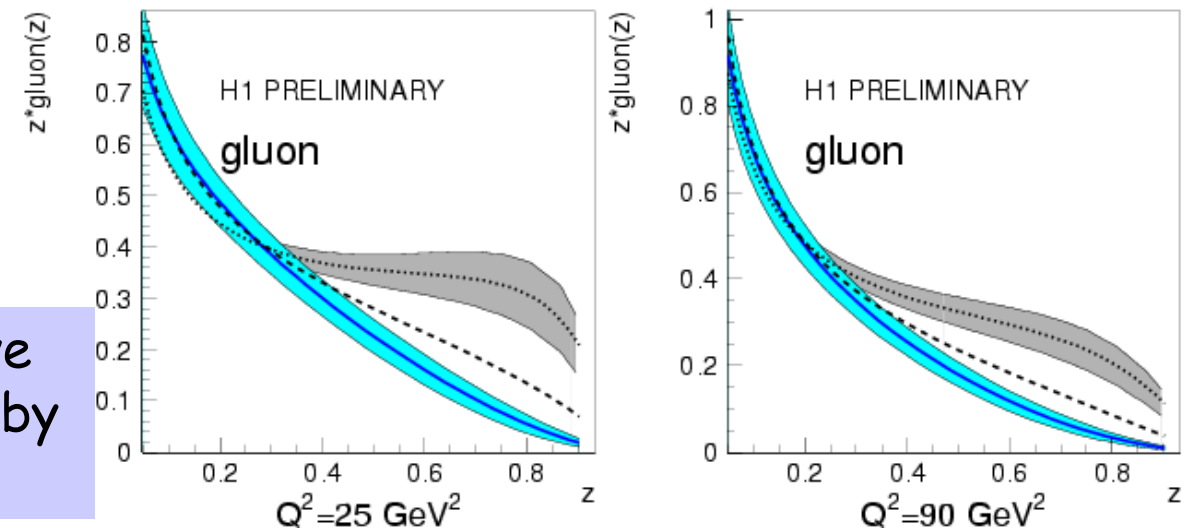
Factorisation in DIS difraction dijets proven by both H1 and ZEUS

Low sensitivity of fits to inclusive cross section to gluon PDF especially at large z_{IP} → use jets to combined fits!

H1 dijet DIS measurement:

- new NLO QCD fit





combined fit (exp. err.)

H1 2006 DPDF Fit

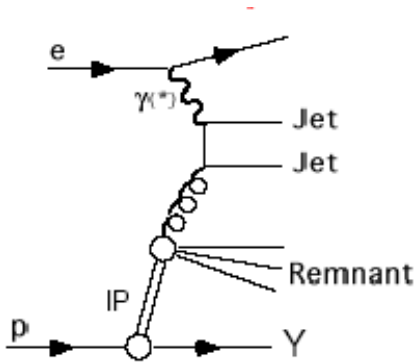
H1 2006 DPDF Fit B

Factorisation in diffractive DIS D*production proven by both H1 and ZEUS

Direct and resolved photoproduction at HERA

x_γ - fraction of photon's momentum in hard subprocess

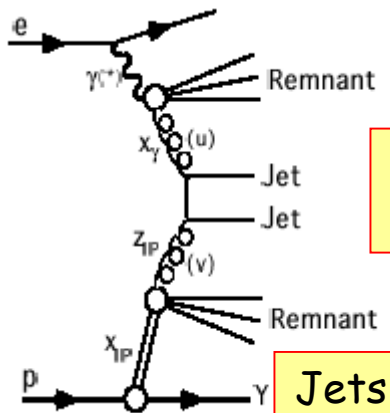
$$x_\gamma = x_\gamma^{OBS} = \frac{\sum (E - p_z)_{jets}}{(E - p_z)_{hadrons}}$$



DIS (Q^2>5GeV^2) and direct photoproduction ($Q^2\simeq0$):

- photon directly involved in hard scattering
- $x_\gamma = 1$

unsuppressed! ?



Resolved photoproduction ($Q^2\simeq0$):

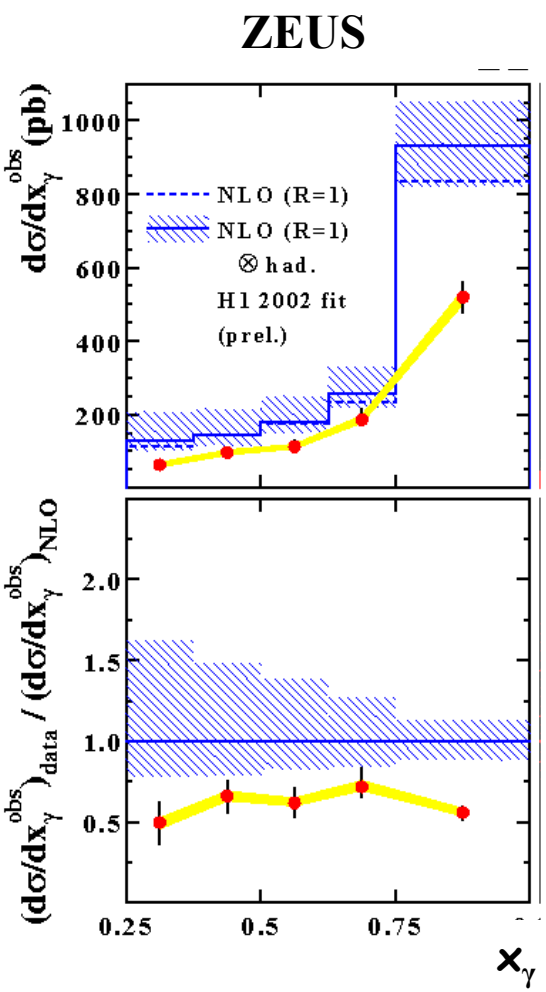
- photon fluctuates into hadronic system, which
  ronic scattering
  0
- $x_\gamma < 1$

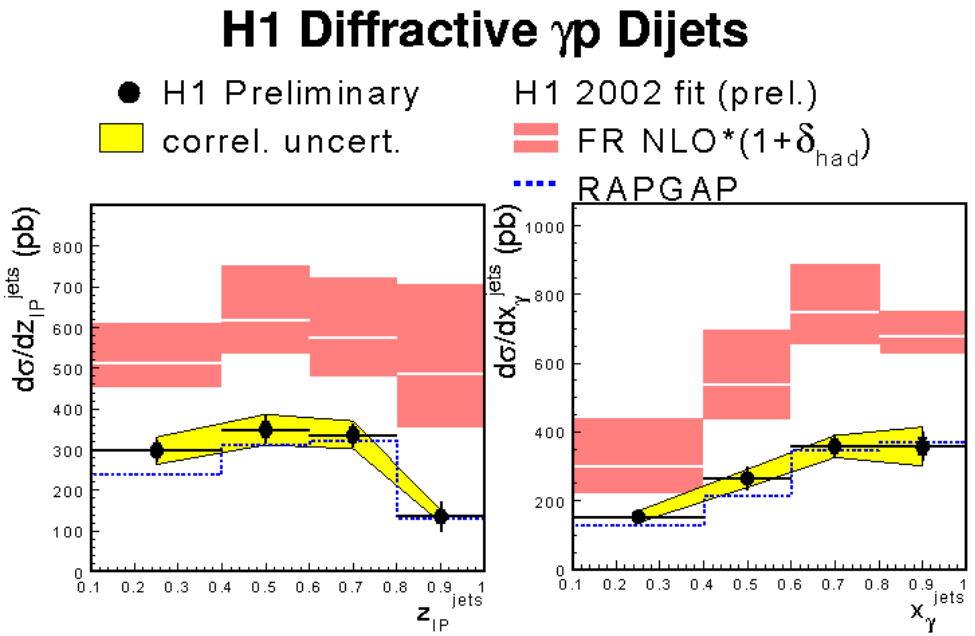
Secondary interactions between spectators??

suppressed! ?

Jets in photoproduction thought to be ideal testing ground for rescattering

Diffraction in Photoproduction-dijets



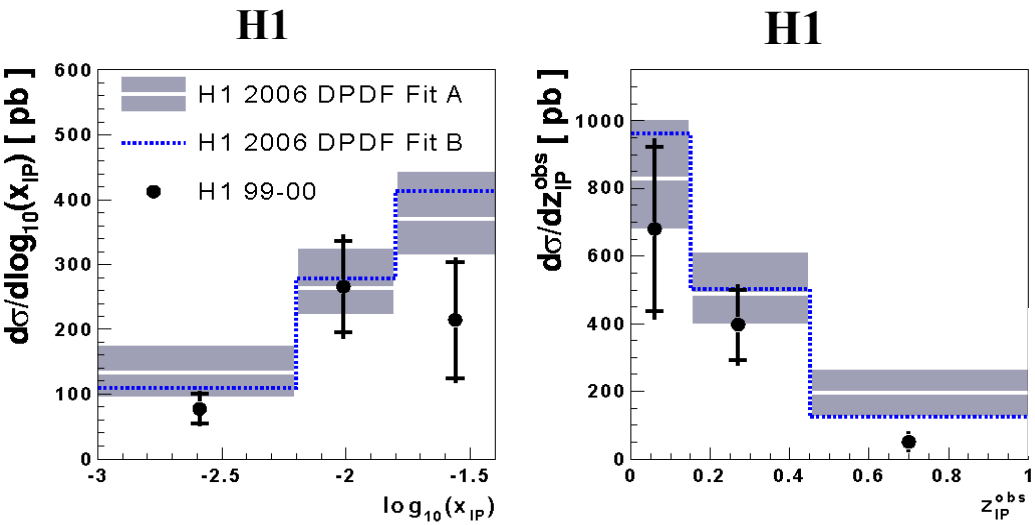


H1 and ZEUS:

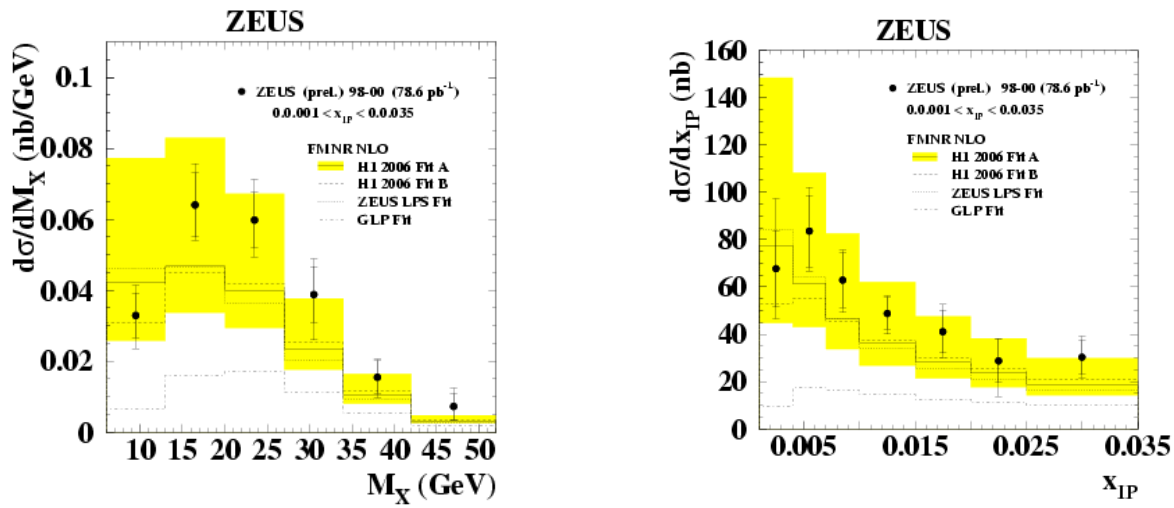
- NLO overestimates data by factor ~1.6
- Scaling only resolved part doesn't describe data either
- PDF uncertainty? Unlikely, as DIS is described…

Within errors suppression observed for both dir and res!

Factorisation in photoproduction-D*



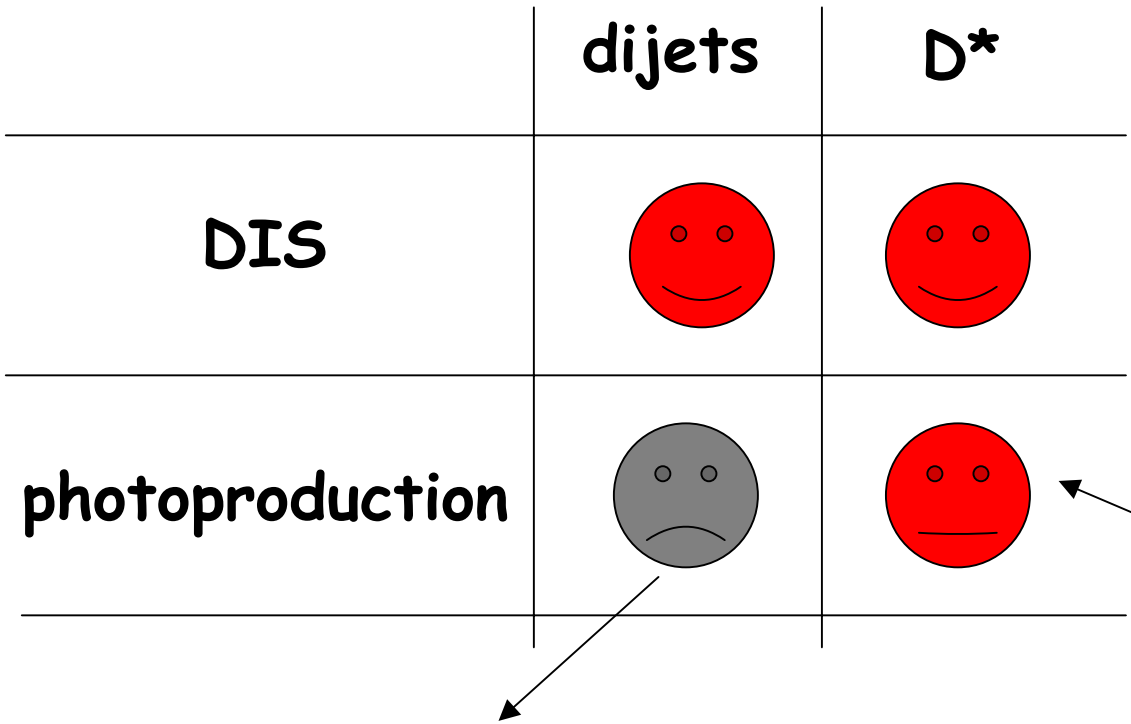
- data consistent with NLO QCD prediction within scale uncertainties
- no evidence for suppression of charm direct photoproduction



- however – large NLO uncertainties

Within errors no suppression observed !

Summary – status of factorisation

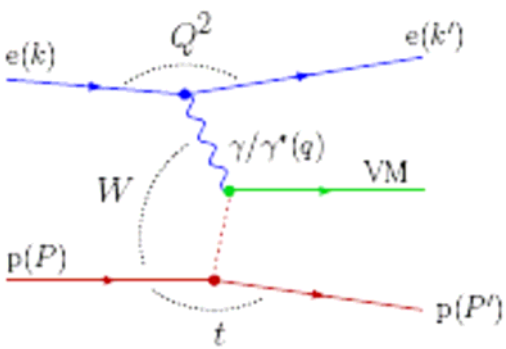


Vector meson production

Vector mesons have $J^{PC} = 1^{--}$ as photon

- no quantum number exchange necessary

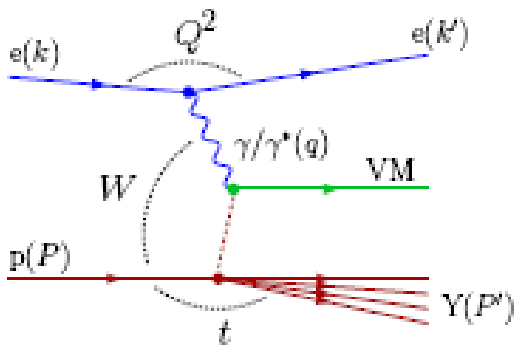
Large diffractive cross sections in wide kinematic range
→ HERA is an excellent place for VM studies



Elastic – exclusive,
dominates at low |t|

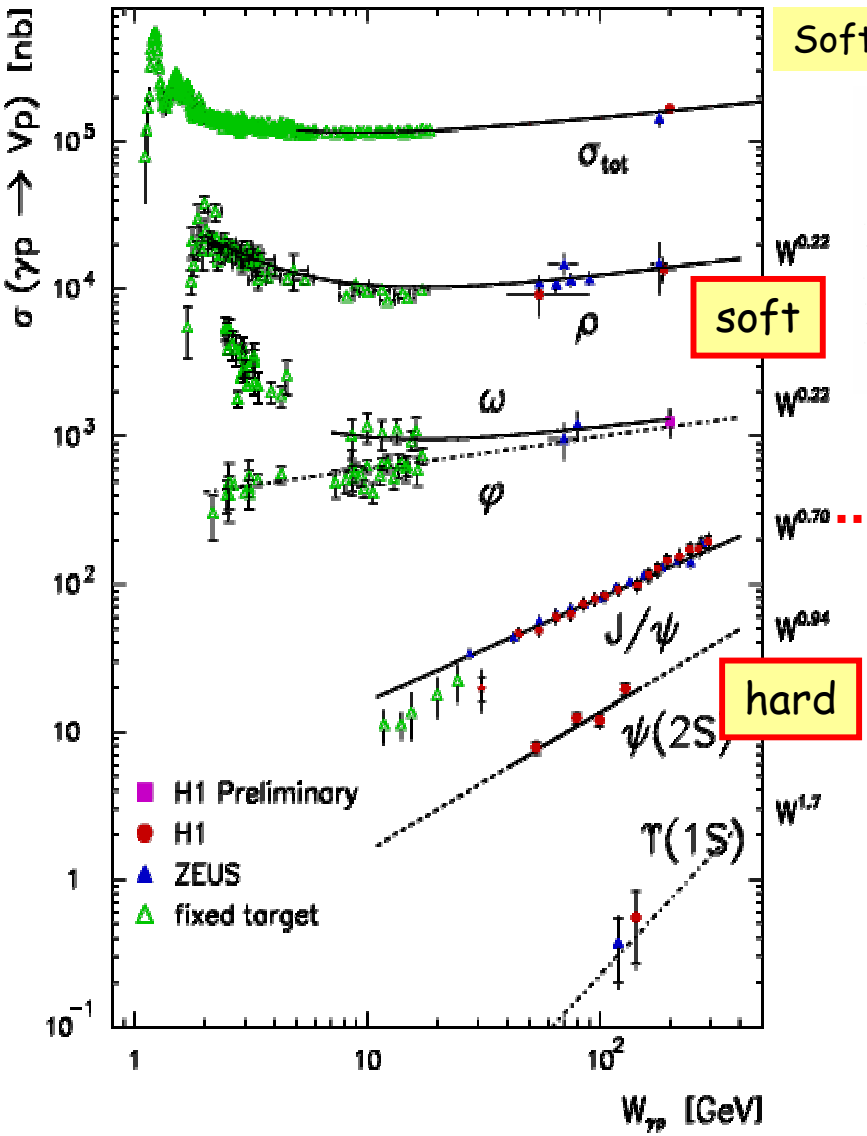
$e + p \rightarrow e + VM + p$ (or Y)

VM = $\rho,\omega,\Phi,J/\psi,\psi',\Upsilon\ldots..$



Proton dissociative
mainly at high |t|

Two regimes of VM production

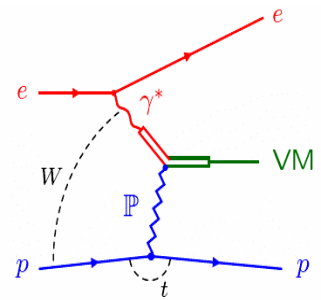


soft

hard

Regge phenomenology, soft pomeron

Soft pomeron exchange



$$\frac{d\sigma}{dt} = e^{bt}\left(\frac{W}{W_0}\right)^{4(\alpha_0-1)}$$

$a_P(t)=a_0+a't$

$a_0=1.08$, $a'=0.25$ GeV^2

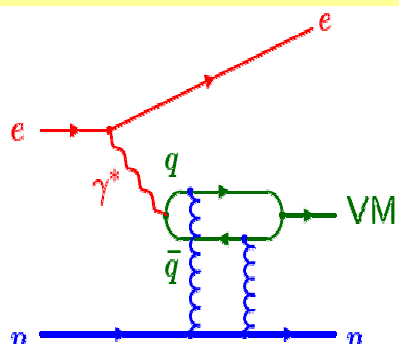
Slow rise: $\sigma \propto W^{0.22....0.32}$

Shrinkage: b=b(W)

Light VMs at $Q^2\approx 0$, $t\approx 0$

Calculable in pQCD

Exchange of 2 gluons or ladder



$$\sigma \propto (xg(x,Q^2))^2$$

Steep rise of σ

~~Shrinkage~~

Presence of hard scale:

Q^2, t, M_{VM}

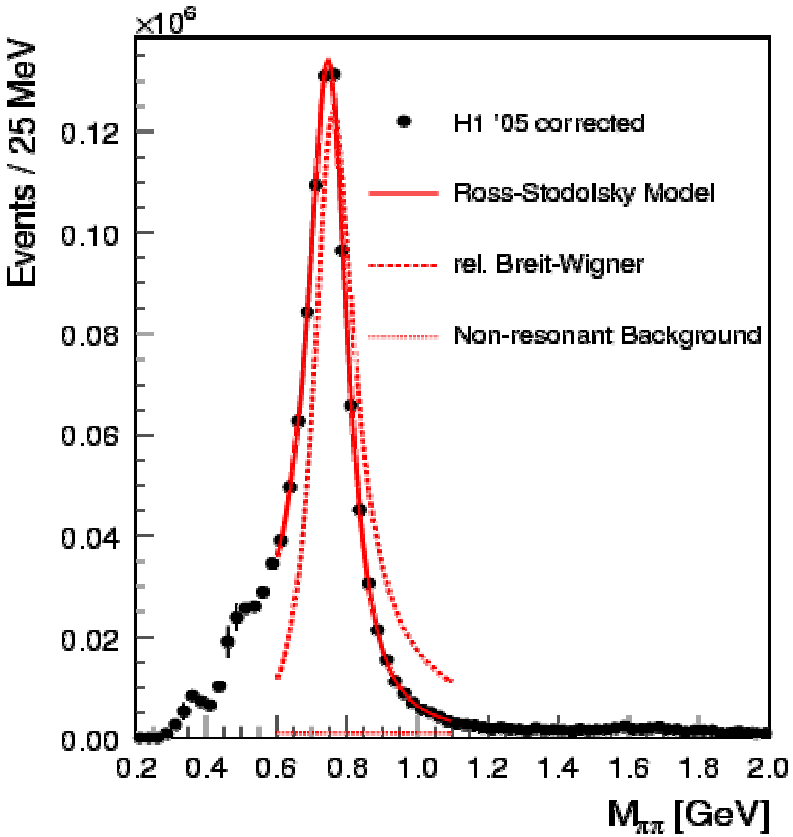
ρ^0 in photoproduction

H1: new measurement

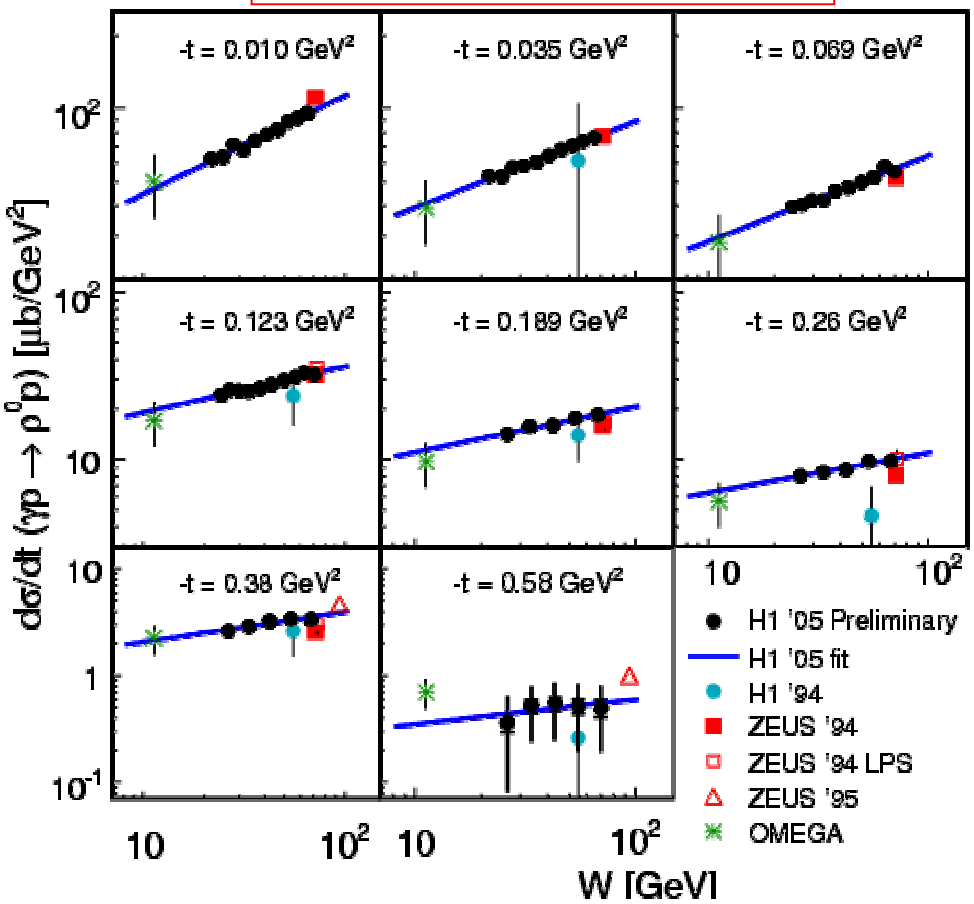
HERA II data (2005)

$Q^2 < 4$ GeV^2 ; $20 < W < 90$ GeV

~ 240000 ρ^0 candidates



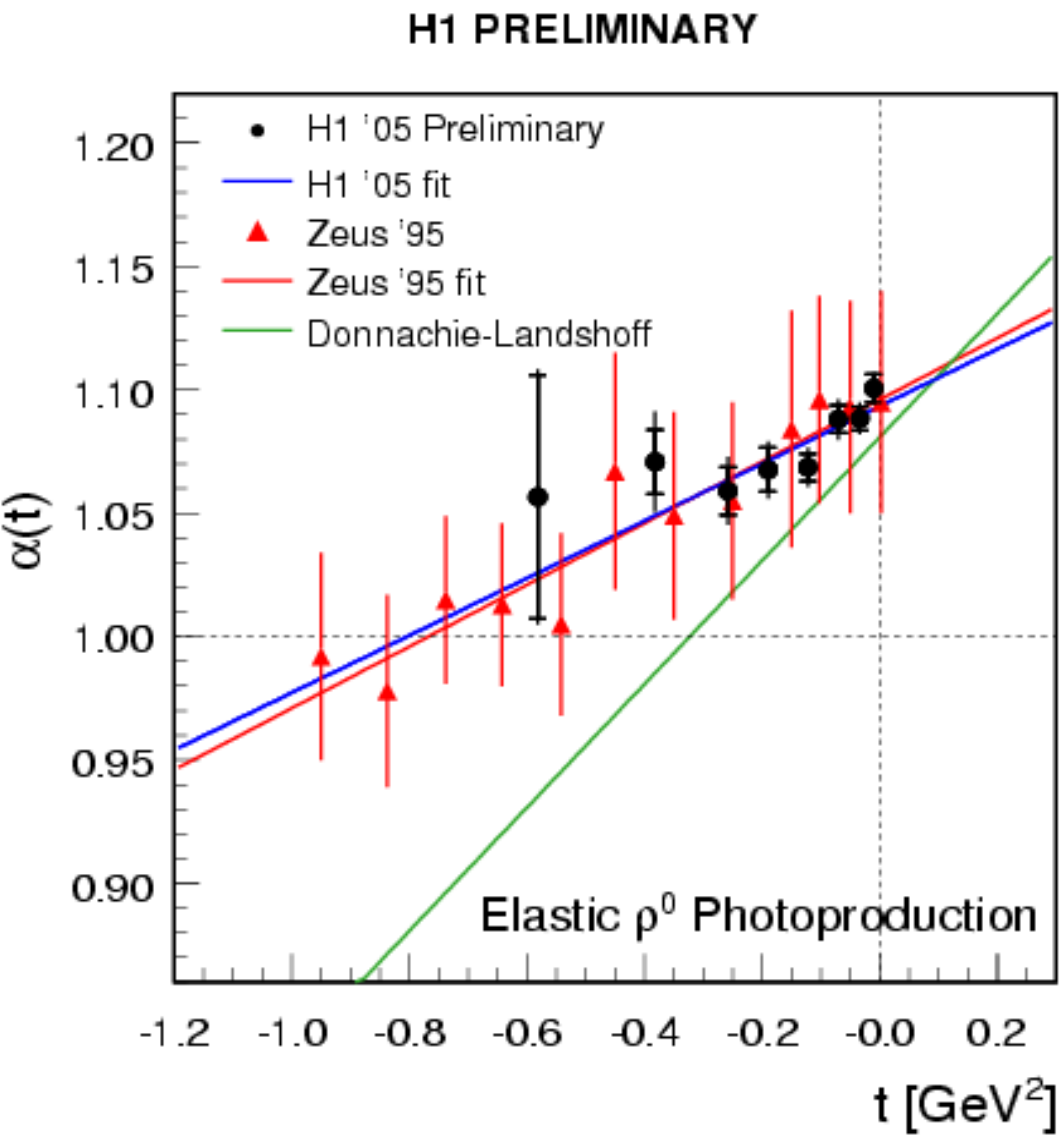
$$fit \quad \frac{d\sigma(W)}{dt} = \frac{d\sigma(W_0)}{dt}\left(\frac{W}{W_0}\right)^{4(\alpha-1)}$$



Fits from data from a single experiment

Very good agreement with previous results from H1, ZEUS and OMEGA

ρ^0 Pomeron Trajectory



Fit to the H1 data assuming a linear Pomeron trajectory

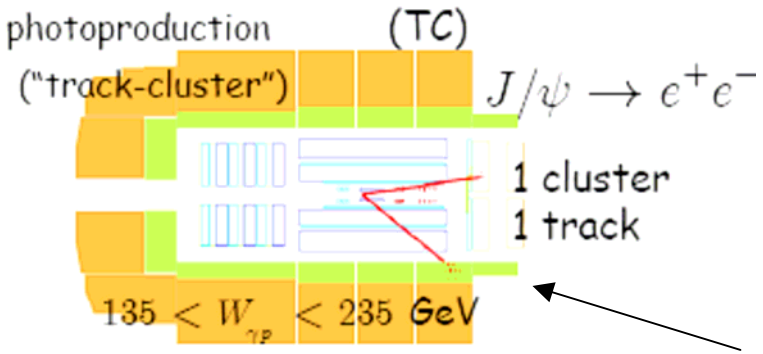
$$\alpha(t) = \alpha_0 + \alpha' \cdot t$$

$$\alpha_{IP}(t) = (1.093 \pm 0.003\,^{+0.008}_{-0.007}) + (0.116 \pm 0.027\,^{+0.036}_{-0.046})\,\mathrm{GeV}^{-2} \cdot t$$

Supports previous measurement of ZEUS →

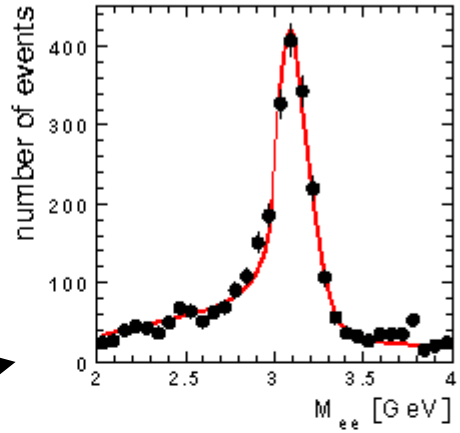
α' significantly smaller than 0.25 GeV^{-2}

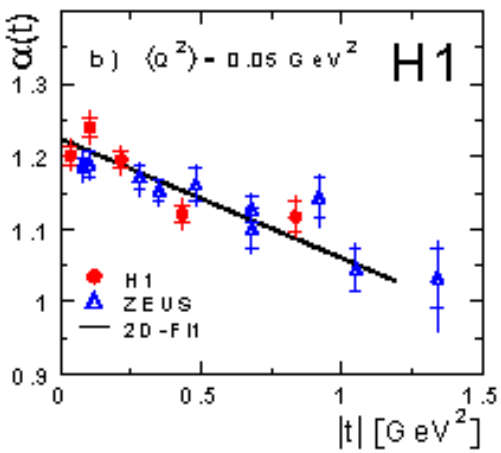
Elastic J/ψ production

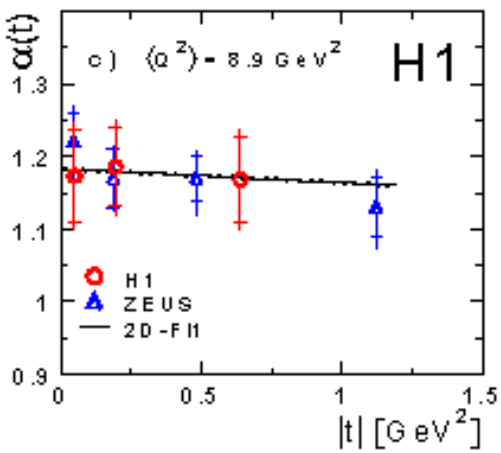


$Q^2 < 1$ GeV^2,
$40 < W < 305$ GeV,
$|t| < 1.2$ GeV^2

$40 < W < 160$ GeV
J/ψ→μ+μ-
$135 < W < 305$ GeV
J/ψ→e+e-







photoproduction

electroproduction

Electroproduction also studied in the region $2 < Q^2 < 80$ GeV^2

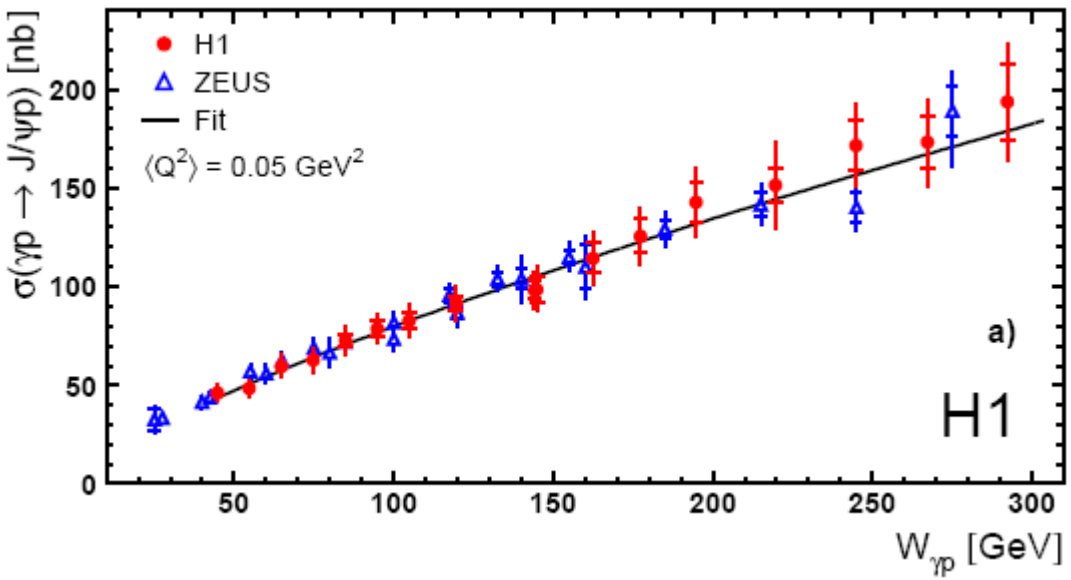
Pomeron trajectory

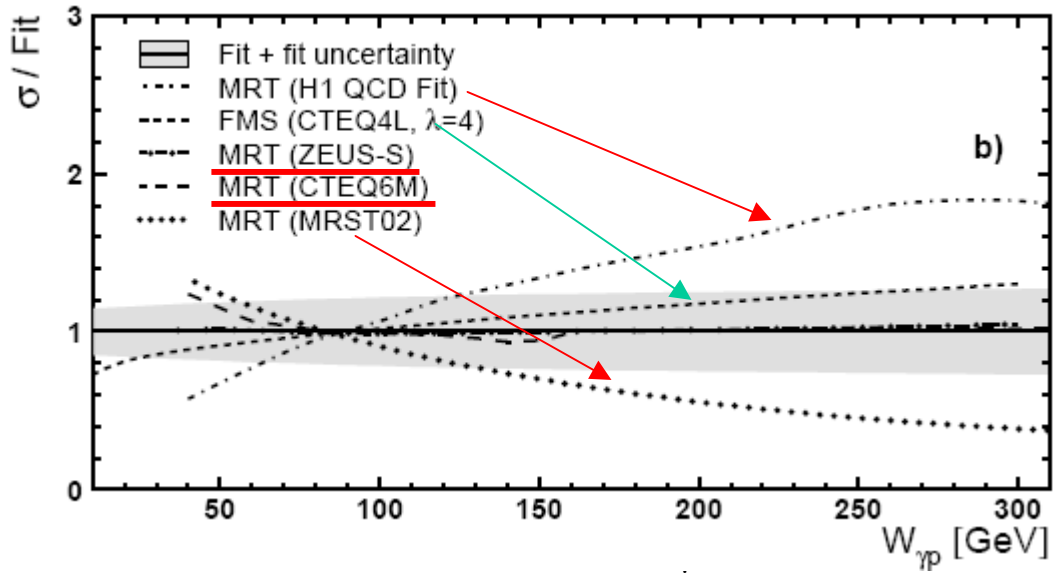
very far from "soft" value 0.25 GeV^{-2}

PhP: $\alpha(t) = (1.224 \pm 0.010 \pm 0.012) + (0.164 \pm 0.028 \pm 0.030)$ GeV^{-2} t

DIS: $\alpha(t) = (1.183 \pm 0.054 \pm 0.030) + (0.019 \pm 0.139 \pm 0.076)$ GeV^{-2} t

Elastic J/ψ photoproduction





$J/\Psi \rightarrow \mu^+\mu^-$; $J/\Psi \rightarrow e^+e^-$

$Q^2 < 1\ GeV^2$, $|t| < 1\ GeV^2$

$40 < W < 305\ GeV^2$

Good agreement with measurement by ZEUS

Fit W^{δ}

$\delta = 0.75 \pm 0.03 \pm 0.03$

(soft pomeron $\delta \sim 0.22$-0.32)

MRT – pQCD model by Martin, Ryskin and Teubner

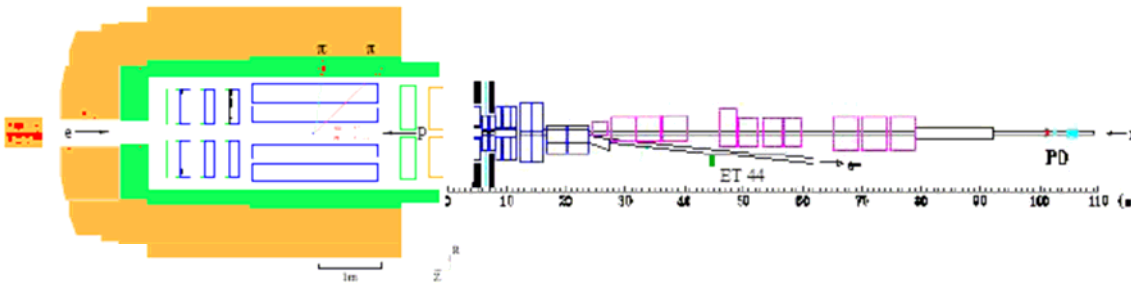
FMS – dipole model by Frankfurt,McDermott,Strikman

W dependence is sensitive to the shape of the generalised gluon distribution!

Vector mesons at large |t|

- vector meson photoproduction at large |t| proposed as test of BFKL
- challenge is to describe both the t dependence and the helicity structure

H1 – ρ^0 photoproduction

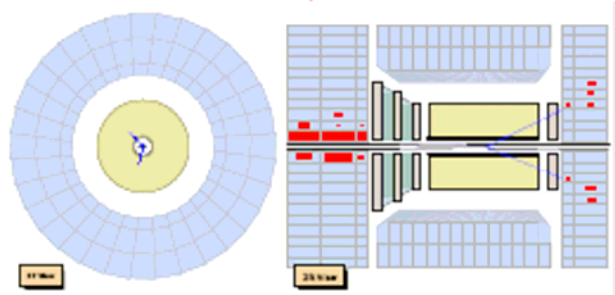


Data 2000
$Q^2 < 0.01$ GeV^2
$75 < W < 95$ GeV
$1.5 < |t| < 10$ GeV^2
$M_Y < 5$ GeV

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

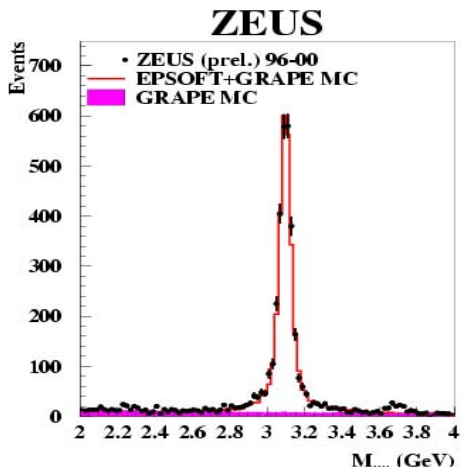
ZEUS – J/ψ photoproduction

$$e\ p \to e\ J/\psi\ Y$$
$$J/\psi \to l^+l^-$$

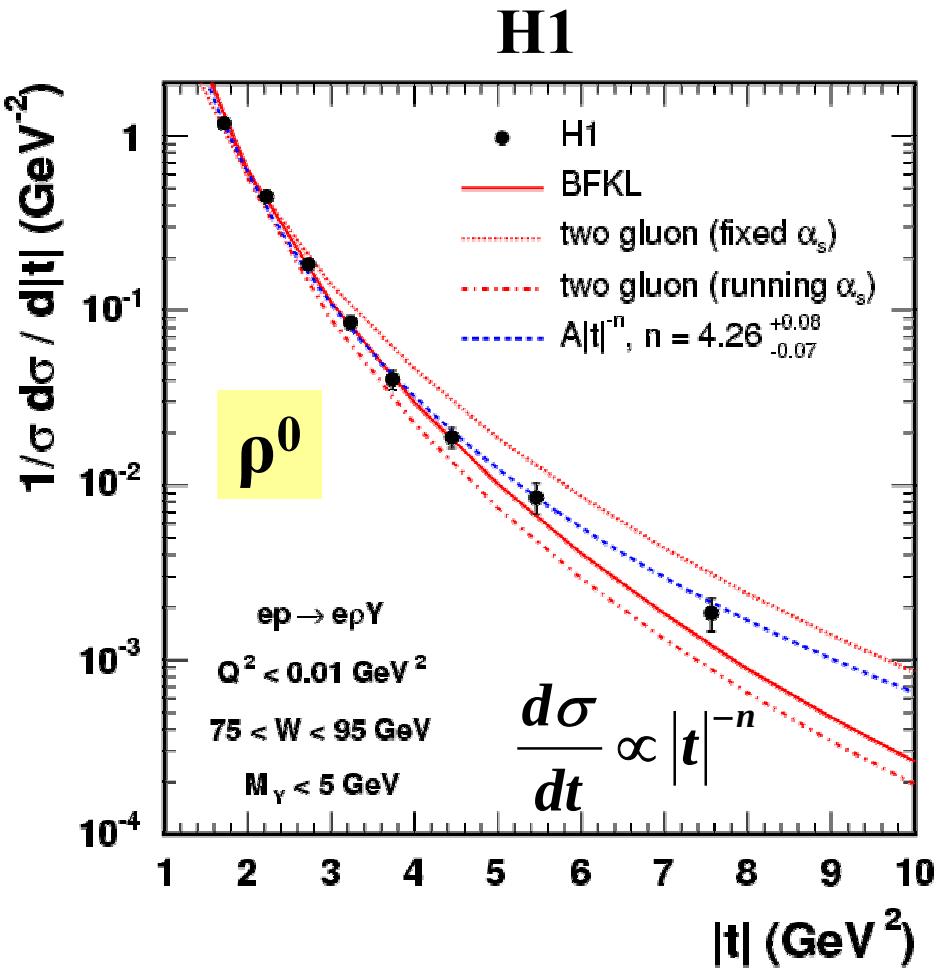


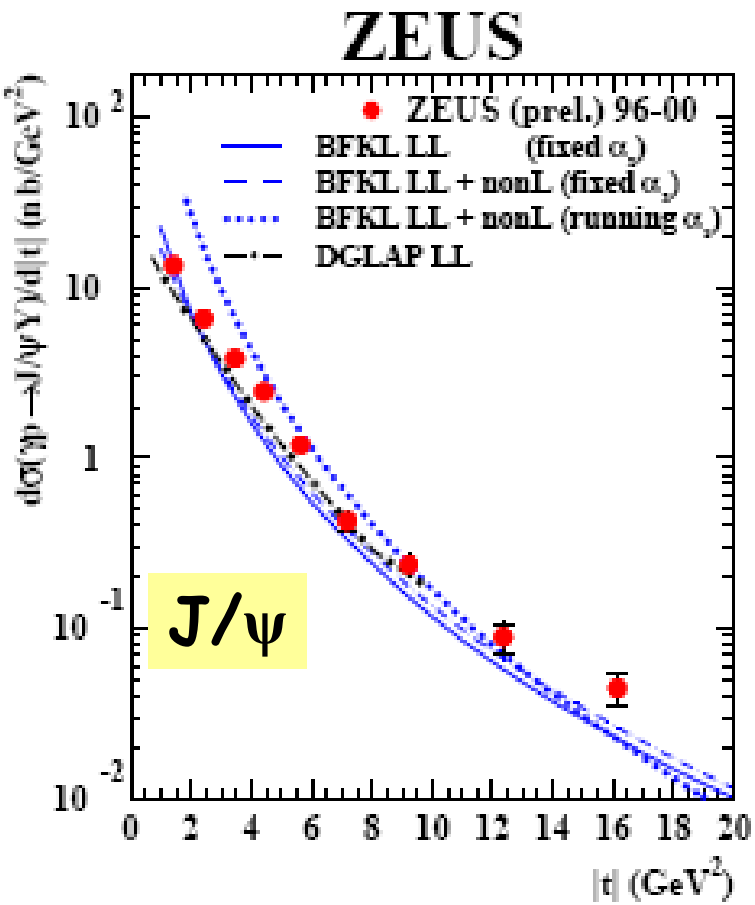
Data 1996-2000
$Q^2 < 1$ GeV^2,
$50 < W < 150$ GeV,
$1 < |t| < 20$ GeV^2
$M_Y < 30$ GeV

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



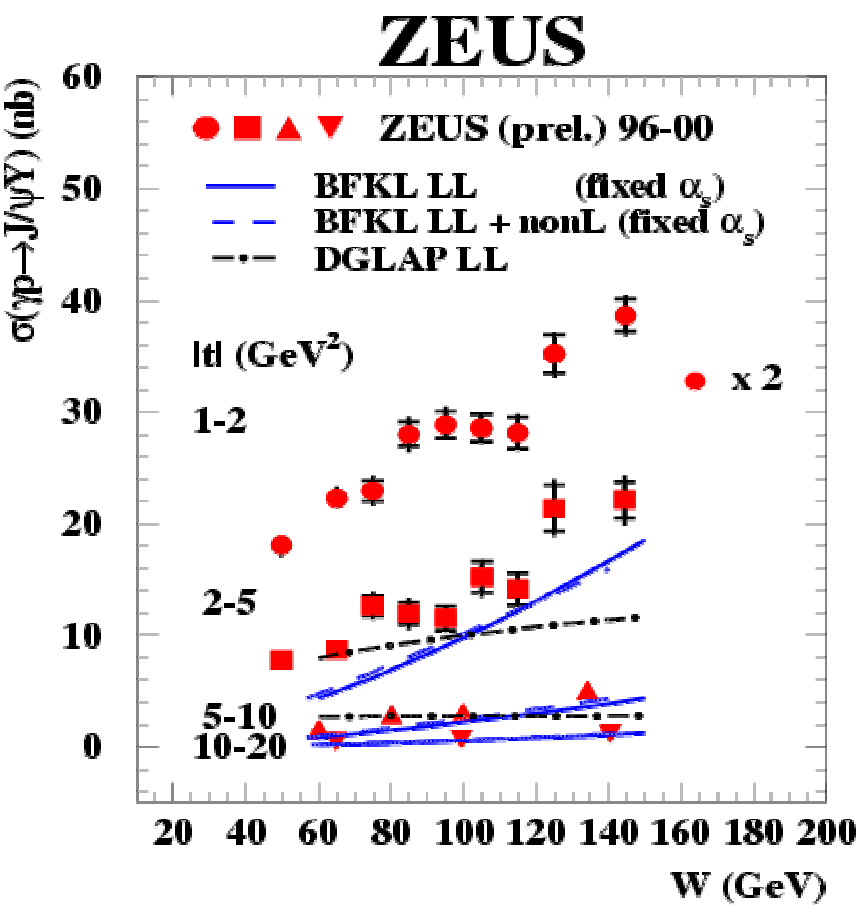
Vector mesons at large |t|





- Power-like behaviour supported by data
- BFKL model gives reasonable description, "two gluon" model doesn't describe data

VM at large |t| -W dependence



J/ψ

Fit $\sigma \propto W^{\delta}$, δ rises with |t|

Effective pomeron trajectory:

$\alpha(0) = 1.153 \pm 0.048 \pm 0.039$

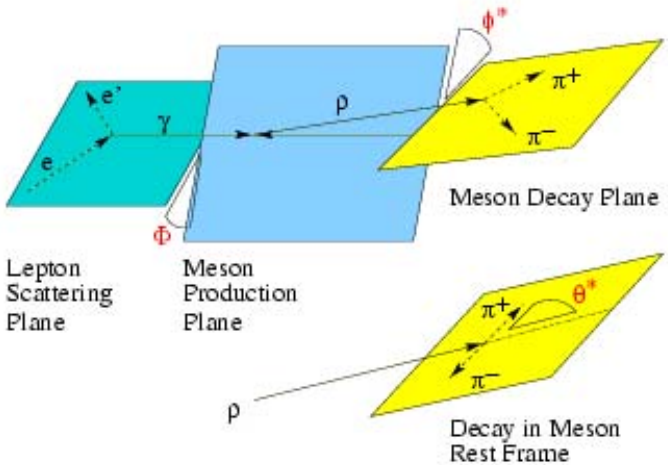
$\alpha' = -0.020 \pm 0.014 \pm 0.010$ GeV^{-2}

(in agreement with older H1 result)

- BFKL reproduces general behaviour of data
- DGLAP is not able to describe rise of cross section with W

Testing the Meson Wavefunction

Helicity = component of spin along direction of the particle's motion



SDMEs are bilinear combinations on the helicity amplitudes

$$r^{ij}_{kl} \propto M_{\lambda_{VM}\lambda_\gamma} M_{\lambda'_{VM}\lambda'_\gamma}$$

- in photoproduction can only measure Θ* & Φ*
  ⇒ allows measurement of 3 of the 15 spin density matrix elements (SDME)

- s-channel helicity conservation (SCHC)
  ⇒ vector meson retains helicity of photon
  ⇒ all 3 SDMEs are predicted to be zero

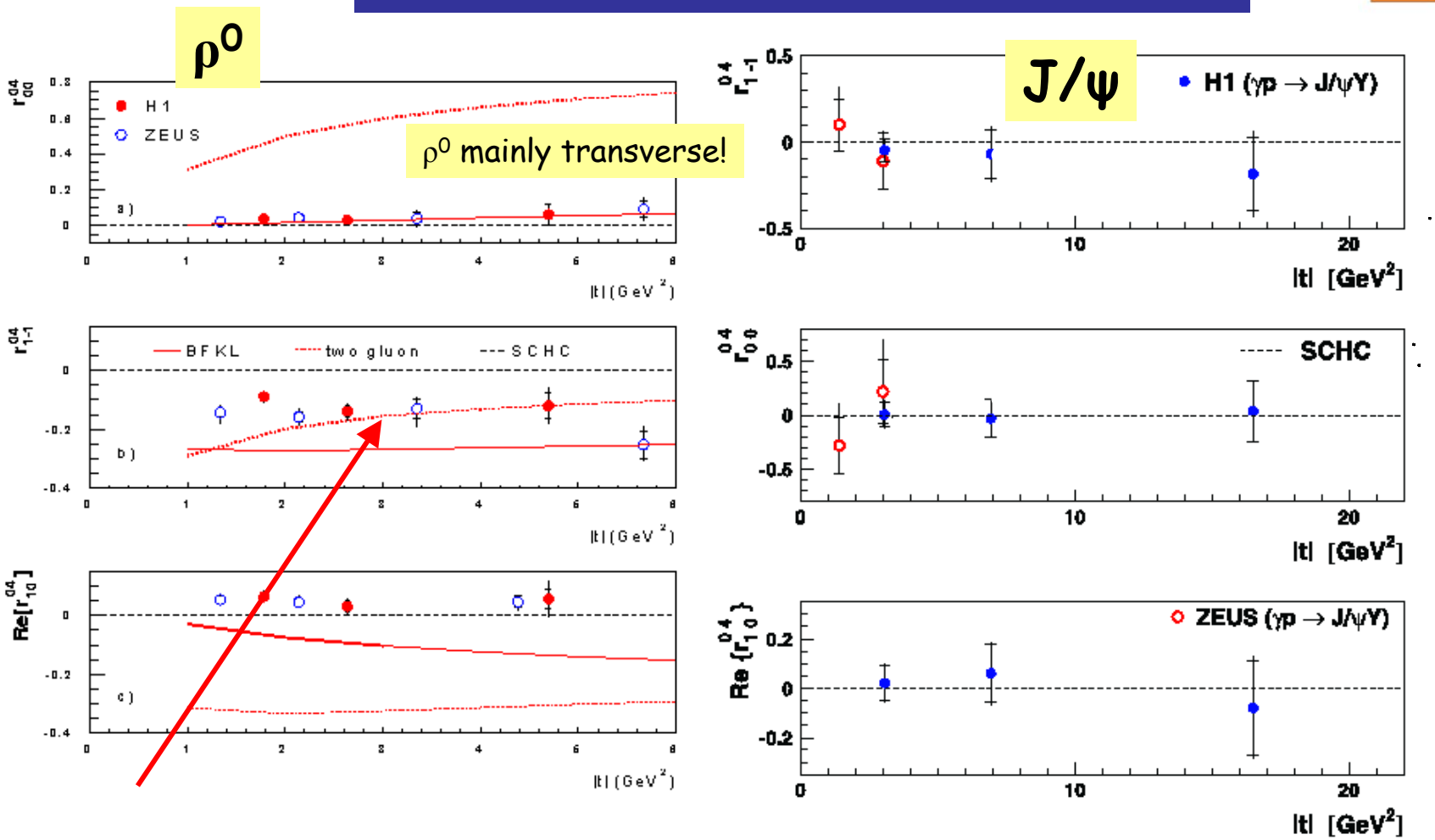
pQCD:

- During the interaction, the orbital momentum of $\bar{q}q$ can be modified through the 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

$$\frac{1}{\sigma}\frac{d^2\sigma}{d\cos\theta^* d\phi^*} = \frac{3}{4\pi}\left(\begin{array}{l}\frac{1}{2}\left(1+r^{04}_{00}\right) - \frac{1}{2}\left(3r^{04}_{00}-1\right)\cos^2\theta^* + \\ \sqrt{2}\,\mathrm{Re}\left\{r^{04}_{10}\right\}\sin 2\theta^*\cos\phi^* + r^{04}_{1-1}\sin^2\theta^*\cos 2\phi^*\end{array}\right)$$

Helicity conservation?



s-channel helicity violation observed

H1 collab. Phys Lett B568 (2003),205

Two-gluon and BFKL models clearly inconsistent with data!

Summary

Factorisation tested with diffractive DIS and photoproduction dijets and charm:

- indication of QCD factorisation breaking in diffractive dijet photoproduction (but still large errors)

Elastic ρ^0 and J/ψ in photoproduction:

- pomeron trajectory determined using data within one experiment
- α' significantly less than 0.25 GeV^{-2}
- transition from soft to hard diffraction regime observed,(large $|t|$, M_{VM})
- heavy Vector Meson measurements sensitive to gluon densities

ρ^0 and J/ψ photoproduction at large $|t|$:

- W and t dependencies described by pQCD BFKL model
- BFKL model fails to describe the helicity structure