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Elastic J/ψ, $\psi(2S)$ and Υ Photoproduction at HERA

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Outline

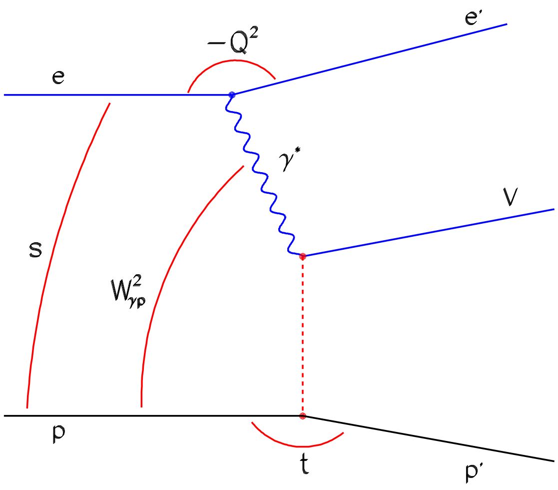
- Cross Section
- Differential Cross Section
- t-Slope Measurement
- Determination of the Pomeron Trajectory
- Summary

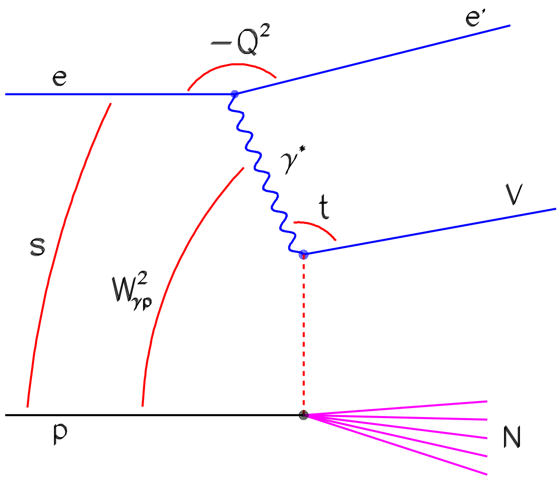
Diffractive Vector Meson Production at HERA

HERA CMS energy $\sqrt{(s)} \simeq 300$ GeV

Exclusive (or Elastic) $\gamma p \to V p$

Proton Dissociative $\gamma p \to V N$





Kinematic range:

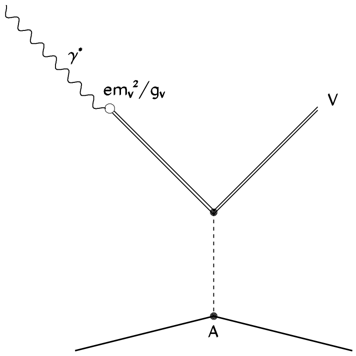
Q^2	photon virtuality, $\sim 10^{-6}$ GeV^2
$W_{\gamma p}$	centre of mass energy of γ^*–p system $\simeq 2E_p(E - p_z)_V$, 20 – 290 GeV
$\lvert t \rvert$	square of 4–momentum transfer at the proton vertex $\simeq p_T^2$, 0 – 2 GeV^2

▶ The HERA energy range is almost completely covered in J/ψ photoproduction

Theoretical Status - Non Pert. Model

Non-perturbative description based on

Regge theory and Vector Dominance Model



$\Rightarrow$ exchange of a $soft$ $\mathbb{P}$ trajectory:

$$\alpha_{\mathbb{P}}(t) = \alpha_{\mathbb{P}}(0) + \alpha'_{\mathbb{P}} \cdot t = 1.08 + 0.25\, t$$

- slow rise of cross section with energy

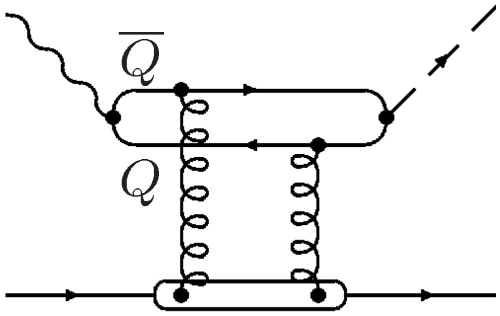
$$\sigma(W) \propto \frac{W^{4(\alpha_{\mathbb{P}}(0)-1)}}{b} \sim W_{\gamma p}^{0.22}$$

- shrinkage of the forward peak $\frac{d\sigma}{dt} \propto e^{-b\ |t|}$

$\Rightarrow$ b increasing with energy $b = b_0 + \alpha'_{\mathbb{P}} \cdot \ln(W_{\gamma p})$

Theoretical status - QCD

When a hard scale is provided, by Q^2, M_V or $|t|$, perturbative QCD can be applied



Colourless exchange described in terms of gluon ladders

- fast increase of the cross-section with $W_{\gamma p}$ related to the evolution of the gluon density in the proton

$$\sigma(W) \propto \left[\alpha_s(\bar{q}^2)\bar{x}g(\bar{x},\bar{q}^2)\right]^2 \quad \bar{x} \propto \frac{Q^2+M_V^2}{W_{\gamma p}^2}$$

- universal shape of the t distribution, flavour and energy independent (almost no shrinkage)

Event Selection

Common to all analyses:

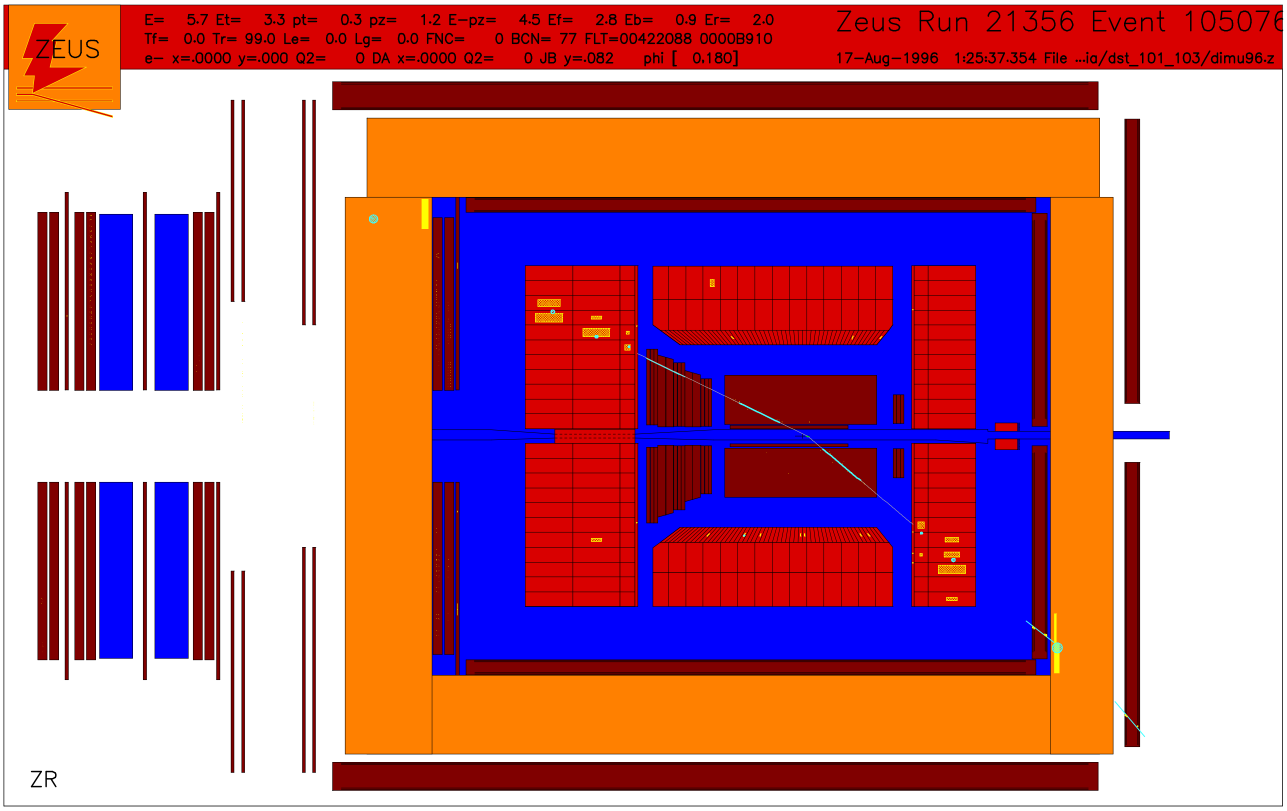
- Use leptonic decay modes $J/\psi \to \mu^+\mu^-$, $J/\psi \to e^+e^-$, $\Upsilon \to \mu^+\mu^-$, $\psi(2S) \to \mu^+\mu^-$, $\psi(2S) \to J/\psi\ \pi^+\pi^-$

- elastic selection: no energy deposits in the main detector other than decay particles

- forward detectors allow to tag proton dissociative events

- e' not observed $\Rightarrow$ median $Q^2 \sim 10^{-6}$ GeV^2

Υ candidate event



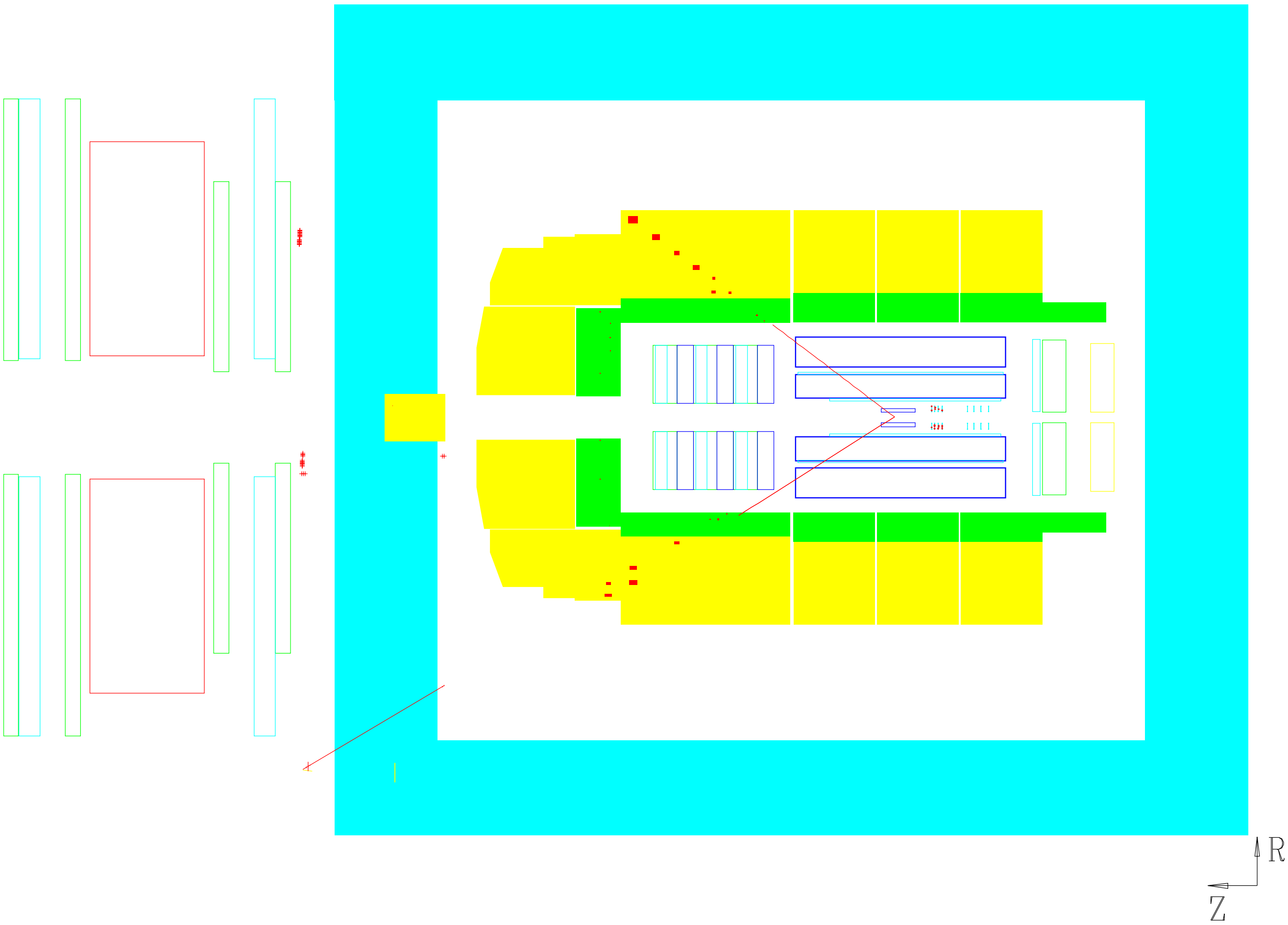
ZEUS reconstructs 2 μs in the central tracking detector
$\Rightarrow 30 < W_{\gamma p} < 170$ GeV

Event Selection

H1 uses

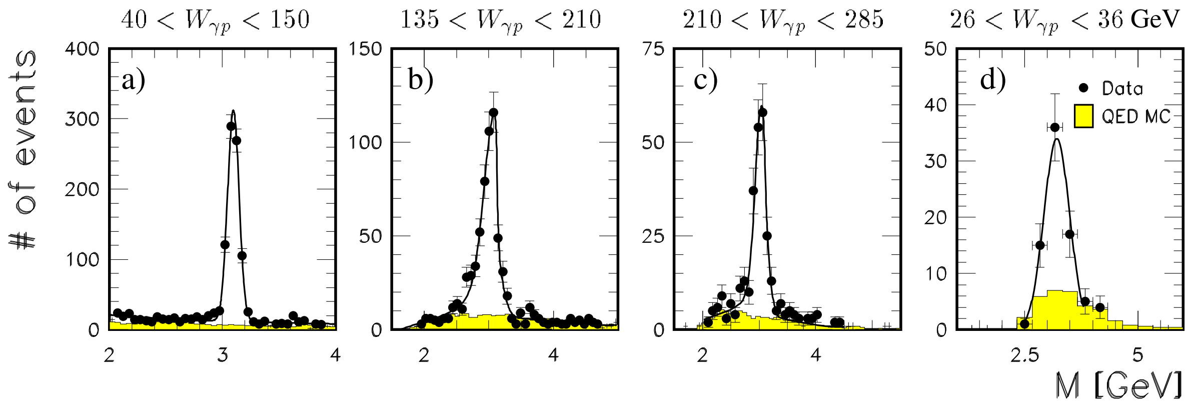
- decay μs reconstructed one in the forward tracking and one in the central tracking at low W, $26 < W_{\gamma p} < 36$ GeV
- decay μs both reconstructed in the central tracking at medium W, $40 < W_{\gamma p} < 150$ GeV for J/ψ, $70 < W_{\gamma p} < 250$ GeV for Υ
- decay es one measured in the central tracking and one in the calorimeter for $135 < W_{\gamma p} < 210$ GeV or both reconstructed in the calorimeter for $210 < W_{\gamma p} < 285$ GeV

J/ψ candidate event

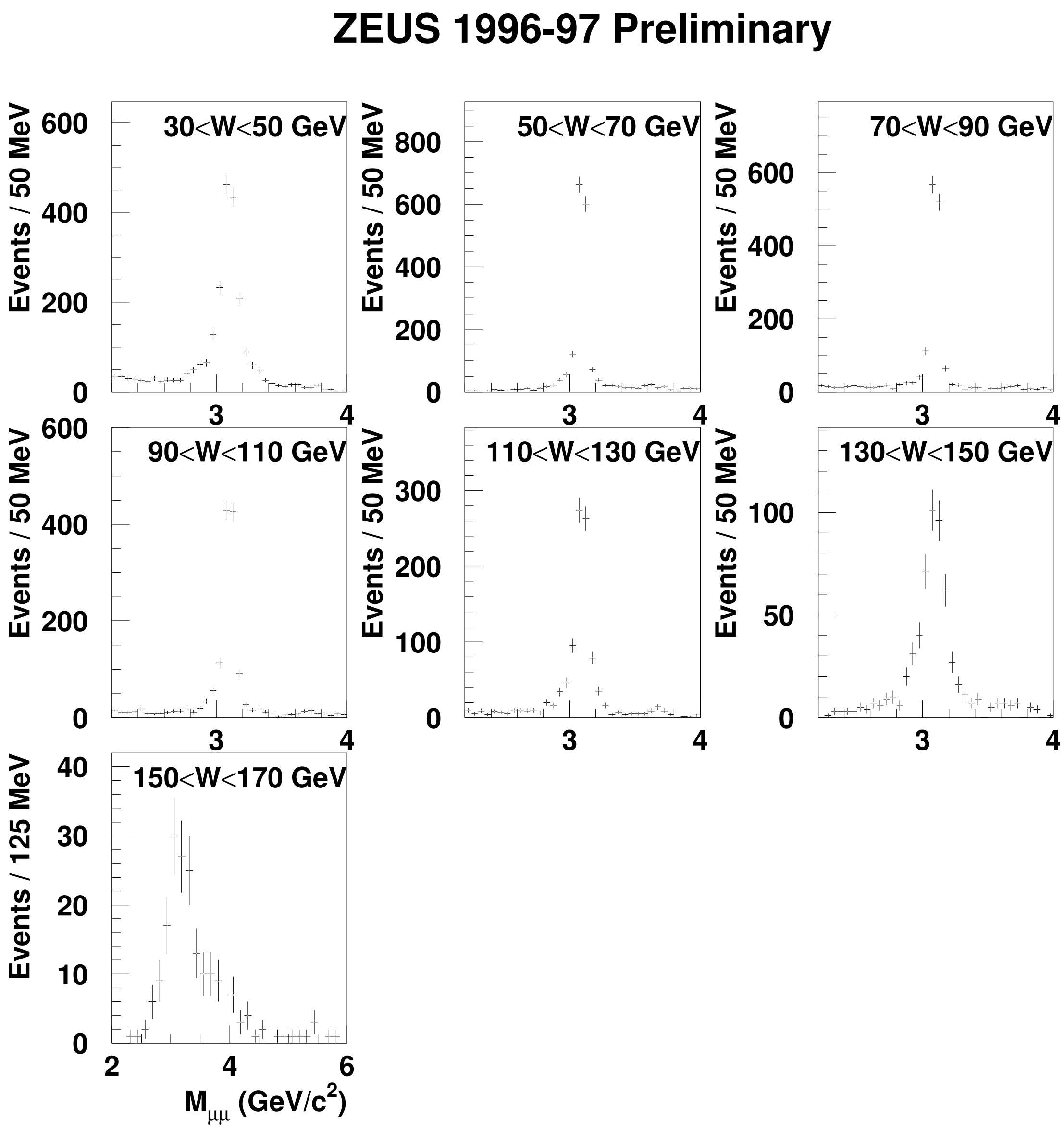


Invariant Mass in $W_{\gamma p}$ Bins

H1 1996-97, $\int \mathcal{L} \simeq 21\ pb^{-1}$

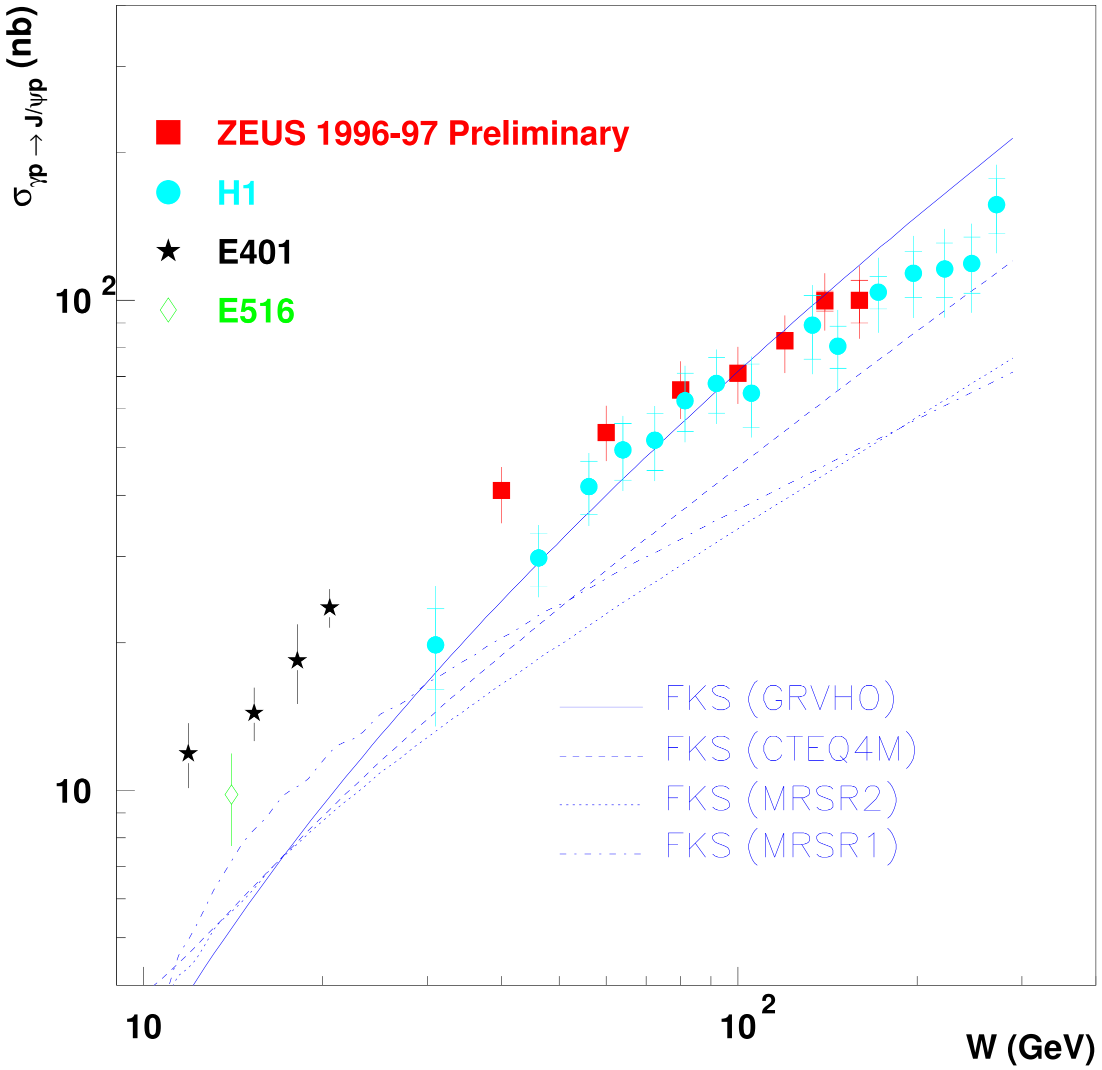


ZEUS $\int \mathcal{L} \simeq 38\ pb^{-1}$



Elastic J/ψ Photoproduction

- cross section vs energy



- High sensitivity to parameterizations of $xg(x)$

Need to understand the normalization of the models

Elastic J/ψ Photoproduction

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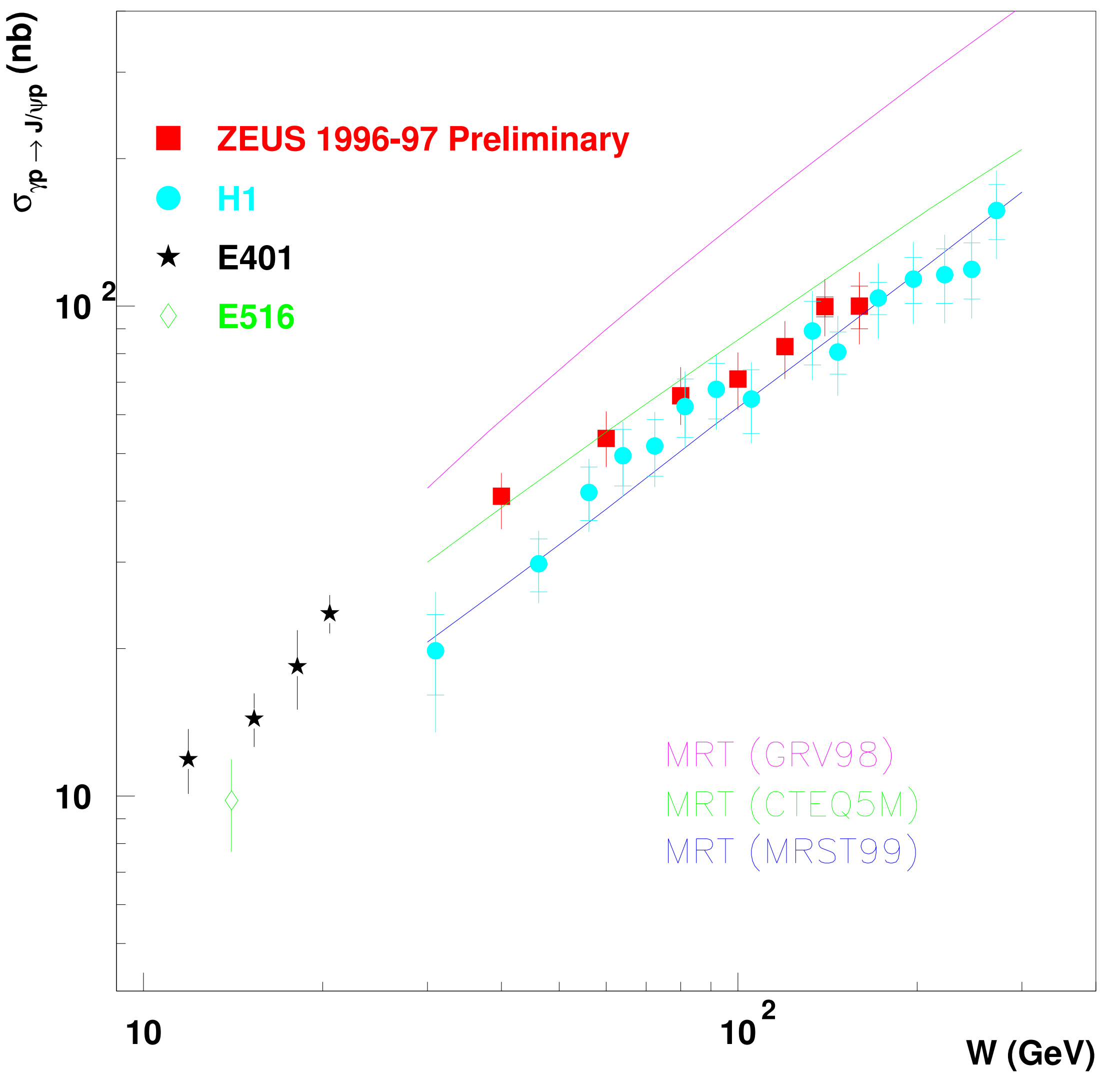


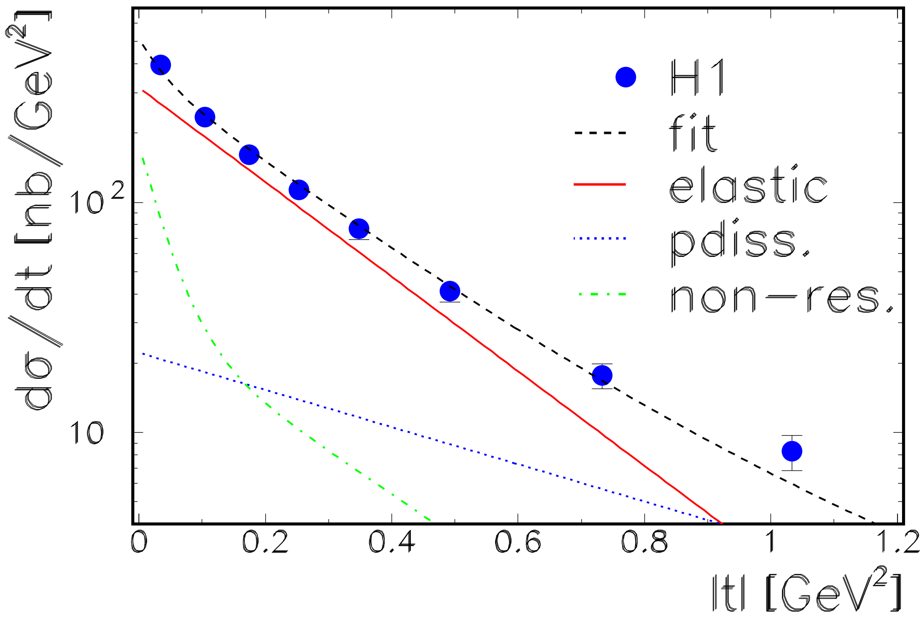
- High sensitivity to parameterizations of $xg(x)$

Need to understand the normalization of the models

Differential Cross Section and t-Slope

Exponential fall characteristic of diffractive processes

$$\frac{d\sigma}{dt} \sim e^{-b|t|}$$



The fit of the elastic part yields:

- $b = 4.73 \pm 0.25^{+0.30}_{-0.39}$ GeV^{-2}

(averaged over $W_{\gamma p}$, $40 < W_{\gamma p} < 150$ GeV)

b is related to the size of the scattered particles

$b \sim \frac{(R_p^2 + R_{c\bar{c}}^2}{4})$ $R_p^2/4 \sim 4$ GeV^{-2}

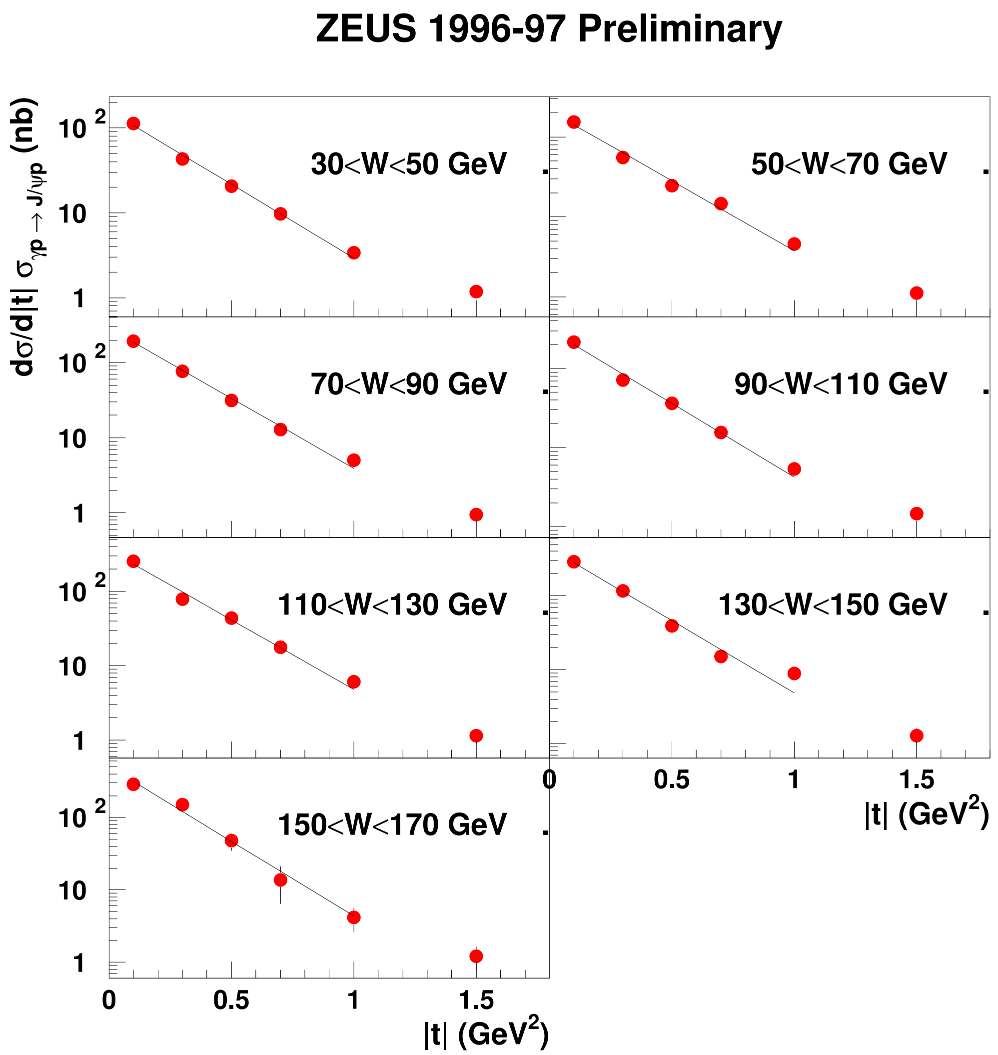
$\rightarrow c\bar{c}$ is small

Energy Dependence of the t-Slope

- Regge phenomenology: $\frac{d\sigma}{dt} \sim f(t) \cdot W^{2\cdot(2\alpha(t)-2)}$

Assuming $f(t) \sim e^{-b|t|}$ and $\alpha(t) = \alpha_0 + \alpha' \cdot t$

$$\frac{d\sigma}{dt} \sim e^{-b|t|}, \qquad b = b_0 + 2\alpha' \cdot \log(\frac{W}{W_0})^2$$



- fit: $\frac{d\sigma}{dt} \sim e^{-b|t|}$

Energy Dependence of the t-Slope

- Regge phenomenology: $\frac{d\sigma}{dt} \sim f(t) \cdot W^{2\cdot(2\alpha(t)-2)}$

Assuming $f(t) \sim e^{-b|t|}$ and $\alpha(t) = \alpha_0 + \alpha\prime \cdot t$

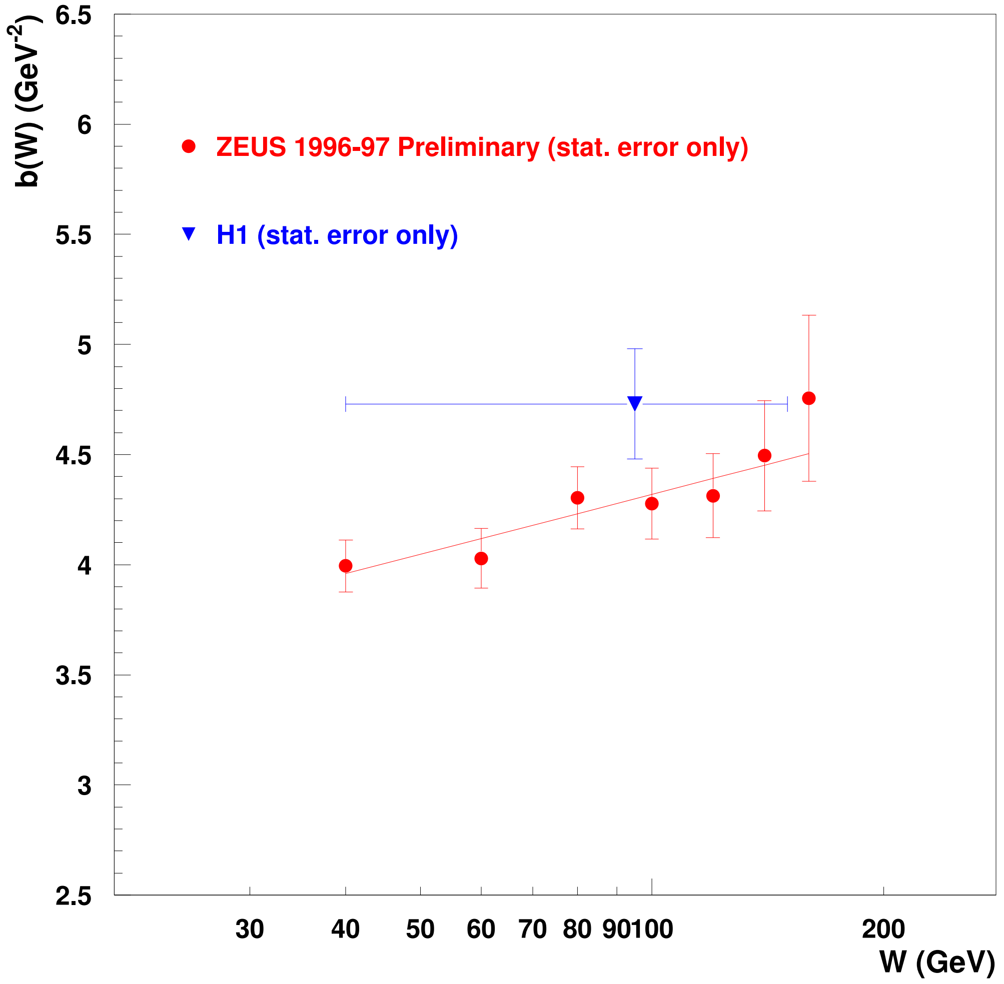
$$\frac{d\sigma}{dt} \sim e^{-b|t|}, \qquad b = b_0 + 2\alpha\prime \cdot \log(\frac{W}{W_0})^2$$

$\alpha(t) = 1.08 + 0.25 \cdot t$ (DL) $\Rightarrow$ shrinkage

- QCD: the t distribution is energy independent

$\Rightarrow$ almost no shrinkage of the forward diffractive peak

Extraction of α'



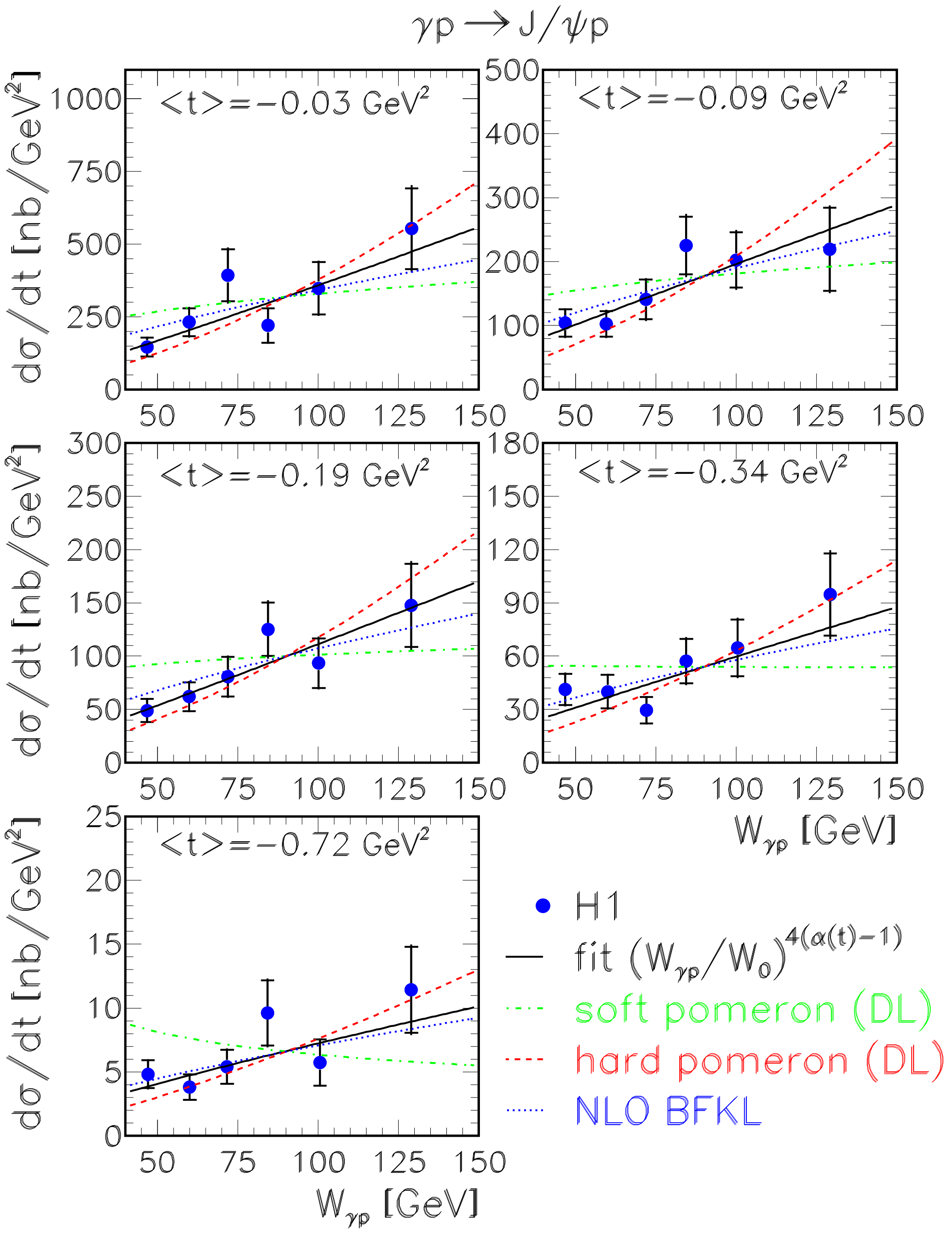
- ZEUS: $\alpha'_{\mathbb{P}} = 0.098 \pm 0.035(stat) \pm 0.050(syst)$

Pomeron Trajectory

More precise method is to study the $W_{\gamma p}$ dependence of $d\sigma/dt$ at fixed t

$$\frac{d\sigma}{dt} = f(t)(W^2)^{[2\alpha_{\mathbb{P}}(t)-2]}$$

fit a linear trajectory $\alpha_{\mathbb{P}}(t) = \alpha_{\mathbb{P}}(0) + \alpha'_{\mathbb{P}} \cdot t$



- fit: $\frac{d\sigma}{dt} \sim (W^2)^{[2\alpha_{\mathbb{P}}-2]}$

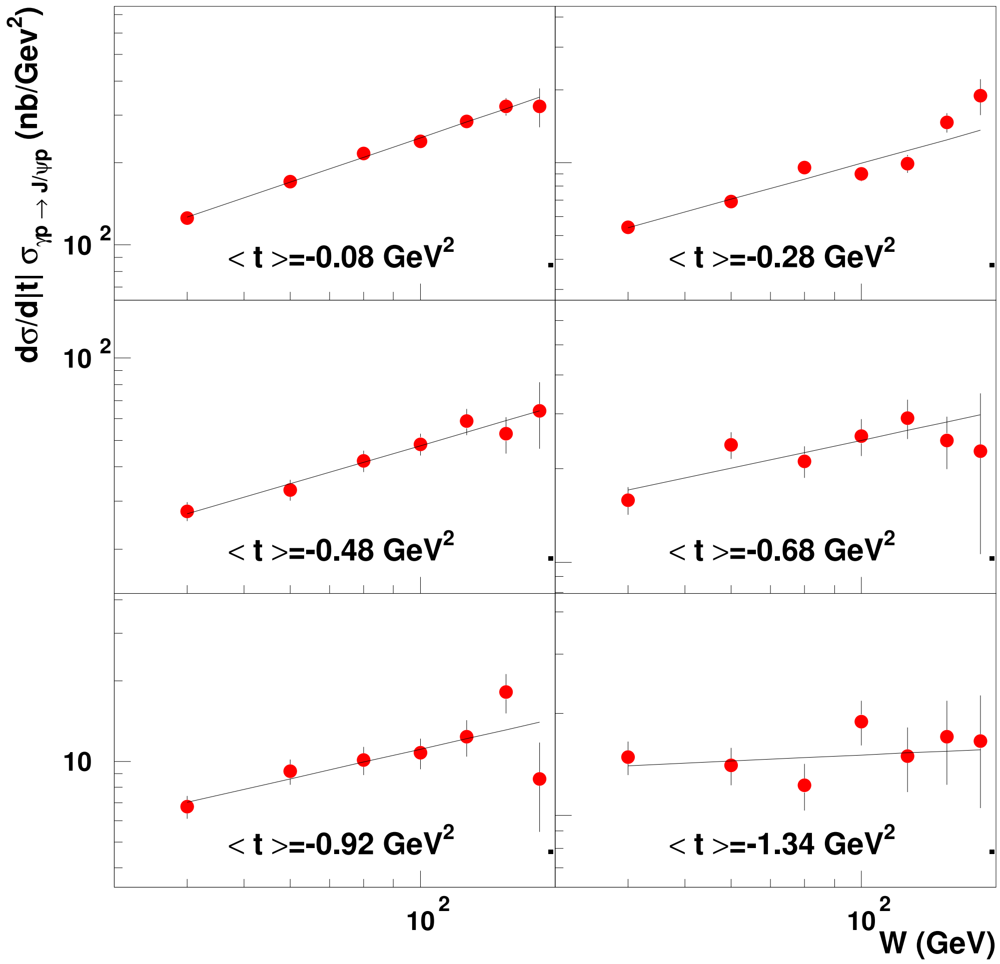
Pomeron Trajectory

Study the $W_{\gamma p}$ dependence of $d\sigma/dt$ at fixed t

$$\frac{d\sigma}{dt} = f(t)(W^2)^{[2\alpha_{\mathbb{P}}(t)-2]}$$

fit a linear trajectory $\alpha_{\mathbb{P}}(t) = \alpha_{\mathbb{P}}(0) + \alpha'_{\mathbb{P}} \cdot t$

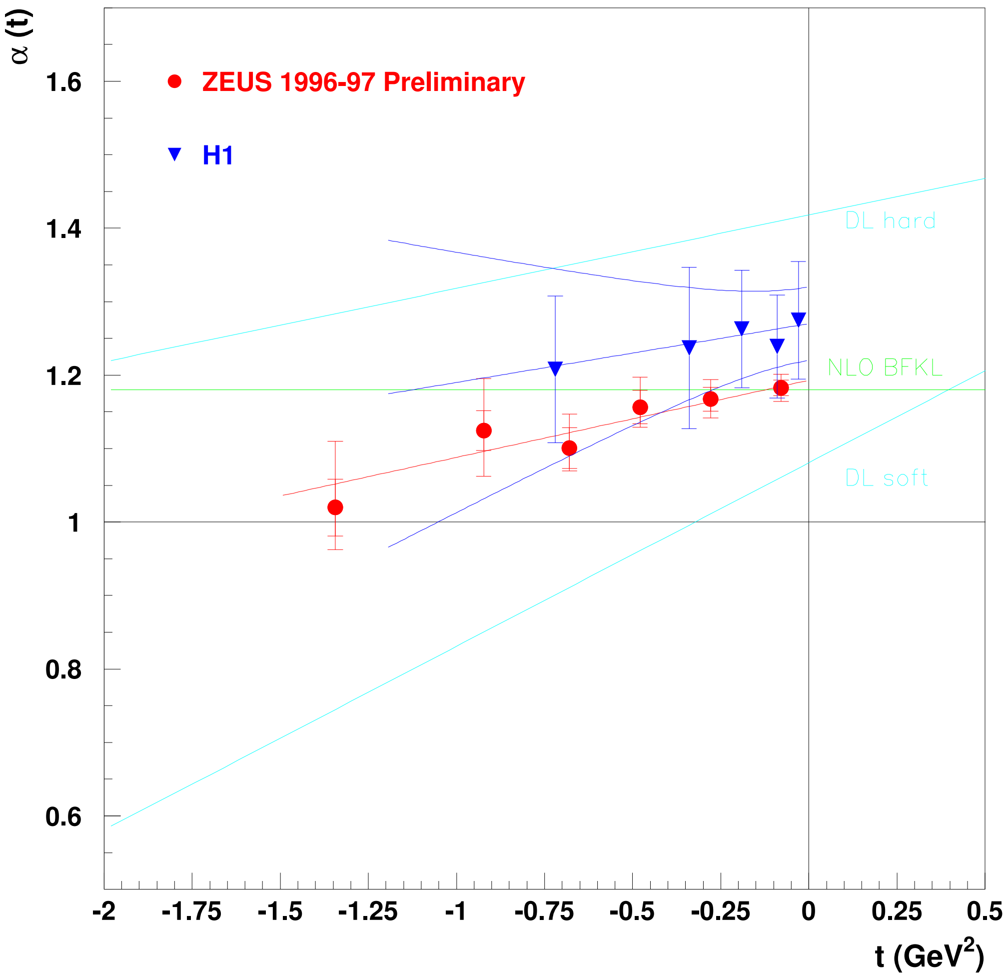
ZEUS 1996-97 Preliminary



- fit: $\frac{d\sigma}{dt} \sim (W^2)^{[2\alpha_{\mathbb{P}}-2]}$

Pomeron Trajectory

- $\text{fit:}\alpha(t) = \alpha(0) + \alpha' \cdot t$



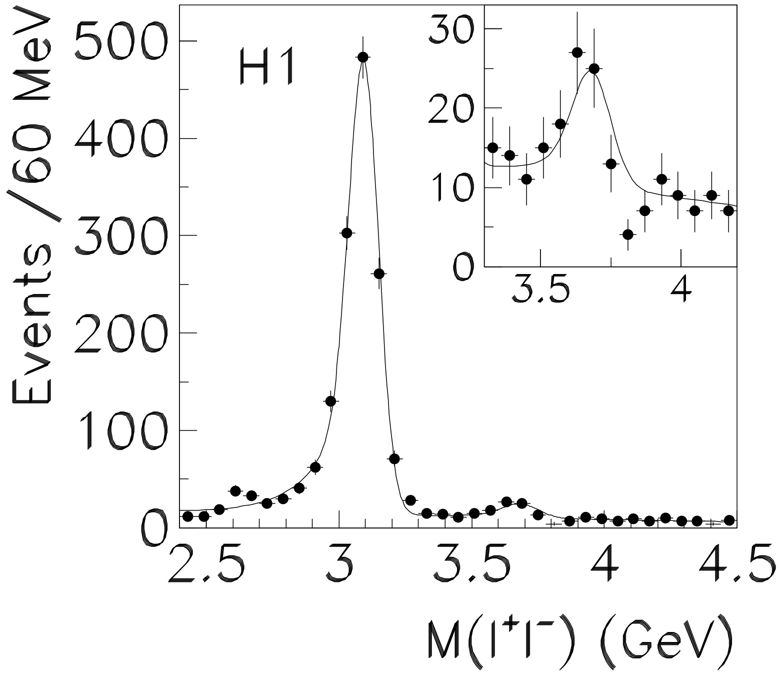
H1: $\alpha(0) = 1.27 \pm 0.05$
$\alpha' = 0.08 \pm 0.17 \ \mathrm{t/GeV^2}$

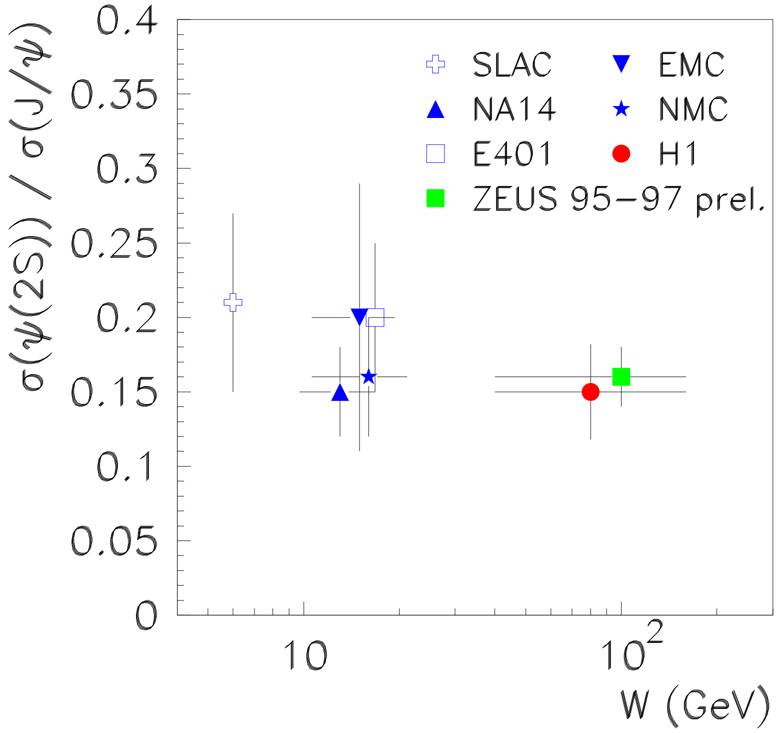
ZEUS: $\alpha(0) = 1.193 \pm 0.011^{+0.015}_{-0.010}$
$\alpha' = 0.105 \pm 0.024^{+0.022}_{-0.020} \ \mathrm{t/GeV^2}$

Elastic $\psi(2S)$ Photoproduction

The ratio $R = \frac{\sigma_{\gamma p}(\psi(2S))}{\sigma_{\gamma p}(J/\psi)}$ is sensitive to the radial wave function of the charmonium

QCD prediction: $R = 0.17$

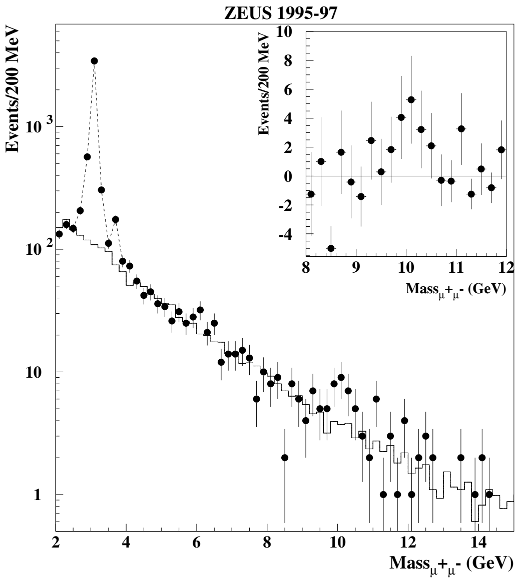


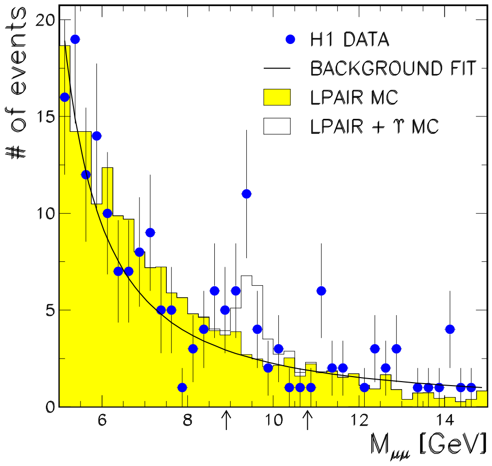


- No significant dependence on $W_{\gamma p}$

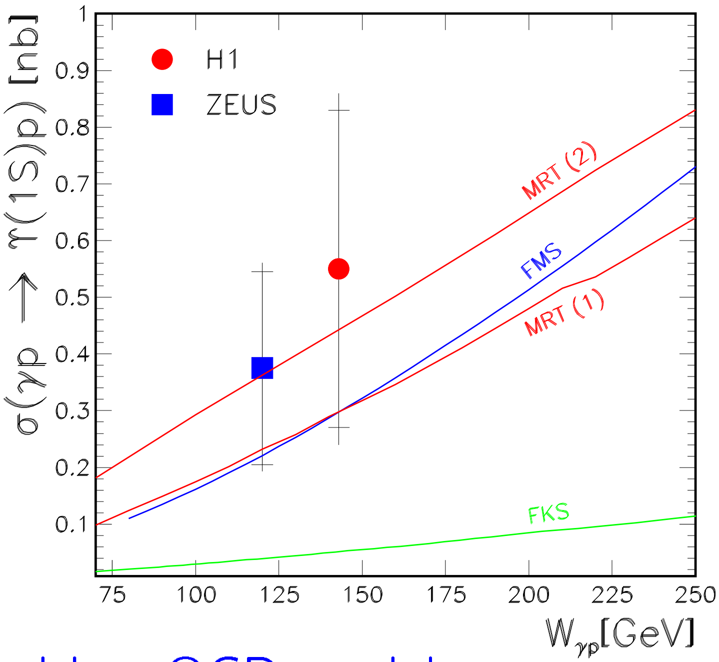
Elastic Υ Photoproduction

ZEUS $\int \mathcal{L} \simeq 43\ pb^{-1}$ H1 $\int \mathcal{L} \simeq 27\ pb^{-1}$





- $\Upsilon(1S), \Upsilon(2S), \Upsilon(3S)$ cannot be resolved
- Observed mass spectrum consistent with $\simeq 70\%$ contribution from $\Upsilon(1S)$ as observed elsewhere
- ZEUS: 17.1 ± 7.5 events, H1: 12.2 ± 6.3 events



▶ Described by pQCD models

Summary

Improved results over an extended kinematic range are presented

- The HERA γp energy range is almost completely covered
- Improvement in the statistical precision of the data
- Strong sensitivity to the gluon content in the proton
- The cross section strongly rises with the γp energy
- Data demand a better theoretical understanding
- Pomeron trajectory of the J/ψ is measured by H1 and ZEUS
- Strong shrinkage is ruled out
- Data in agreement with pQCD pomeron
- Cross Section of Υ and $\psi(2S)$ described by the theory

Exclusive production of heavy mesons is a testing ground of pQCD