Exclusive photoproduction at HERA

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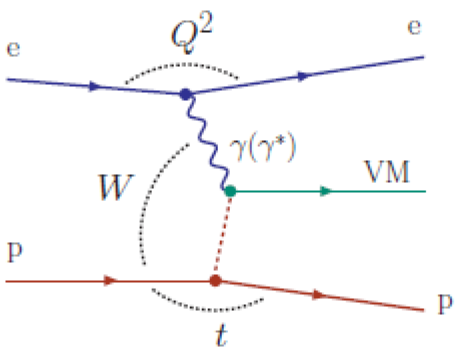
on behalf of

Lake Louise Winter Institute 2010

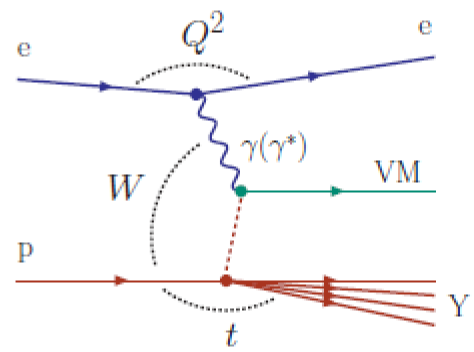
exclusive diffraction

elastic (exclusive)



$|t| < 1\ \mathrm{GeV}^2$

proton dissociative



dominates at high |t|

experimentally: very clean process in wide kinematic range

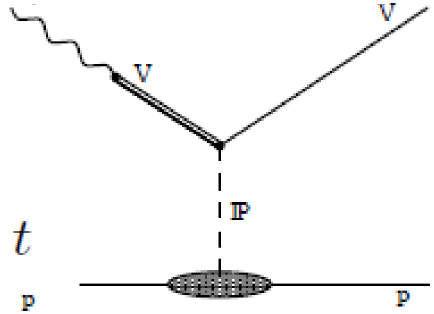
VM	Vector Meson or γ	$\rho, \omega, \phi, J/\psi, \psi', \Upsilon$
Q^2	photon virtuality	$Q^2 = -q^2 = -(k-k')^2$
W	c.m. energy of γp system	$W = (q+p)^2$
t	(4-mom. transfer)^2 at p-vertex	$t = (P-P')^2$

$\longrightarrow$ **VM at HERA: transition between soft and hard regime**

diffractive vector meson production

- **VDM + Regge theory:** $\gamma^* p \rightarrow Vp = (\gamma^* \rightarrow V) \times (Vp \rightarrow Vp)$

$Vp \rightarrow Vp$: **soft** interaction => Pomeron exchange



$$\sigma \propto \left(\frac{W}{W_0}\right)^{4(\alpha_{I\!P}(t)-1)}$$, where

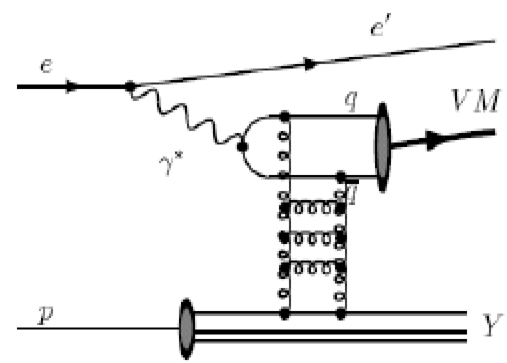
$$\alpha_{I\!P}(t) = \alpha(0) + \alpha'_{I\!P} \cdot t = 1.08 + 0.25 \cdot t$$

Light vector mesons at low Q^2 and low |t|

- **pQCD models:**

V $= q\bar{q}$ dipol, exchange of $\geq$ 2 gluons (color singlet – QCD Pomeron)

Hard scale Q^2, t, or m_q required



Exclusive production :

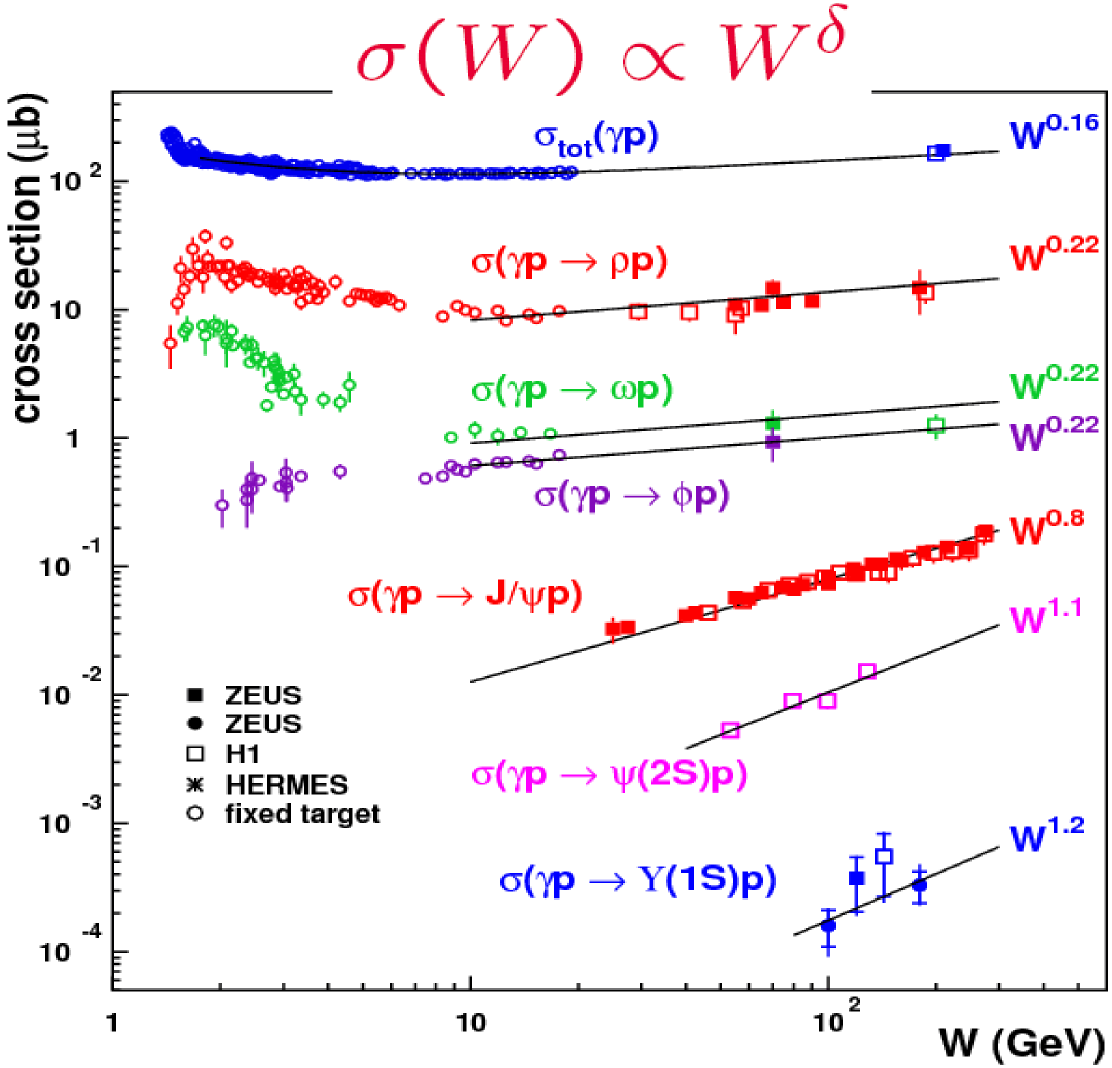
$$\sigma \propto (xG(x,Q^2))^2$$

$xG(x,Q^2)$ => steep rise with energy

Proton dissociative production:

- 2-gluon exchange – no energy dependence
- gluon ladder exchange – energy dependence: weak (DGLAP) or strong (BFKL)

vector mesons in photoproduction ($Q^2 \approx 0$ GeV^2)



Low mass (ρ, ϕ, ω)

- $M^2_{VM} \approx 1$ GeV^2
- no perturbative scale
- weak W dependence (soft regime)

High mass (J/ψ, ψ(2S), Υ)

- perturbative scale
- strong W dependence (hard regime)

- **The larger M_{VM} the harder process (steeper W dependence)**
- **Vector meson mass sets hard scale**

Υ production – energy dependence

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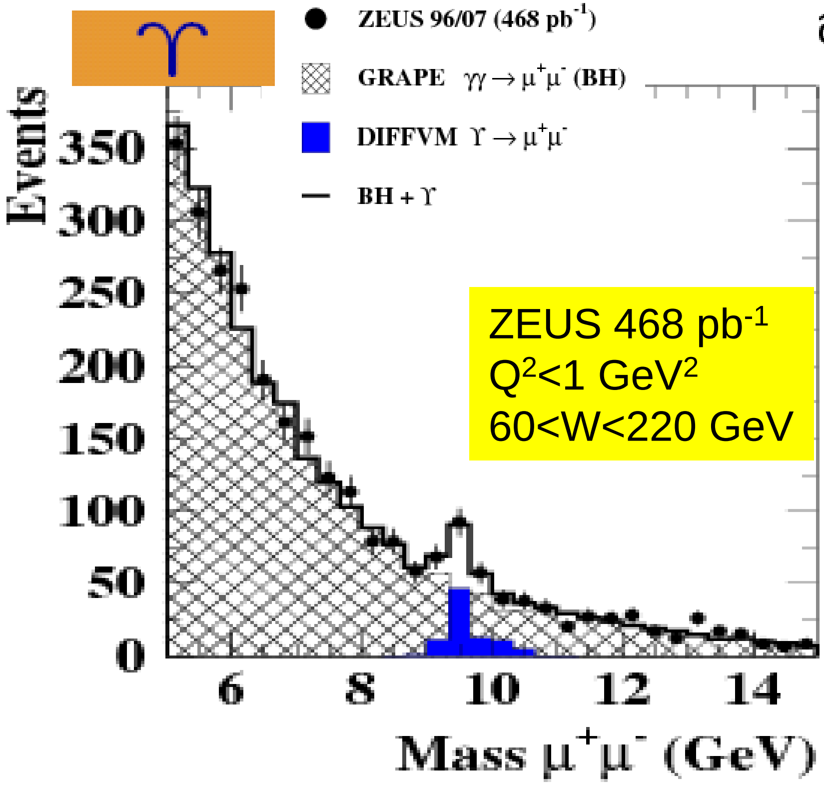
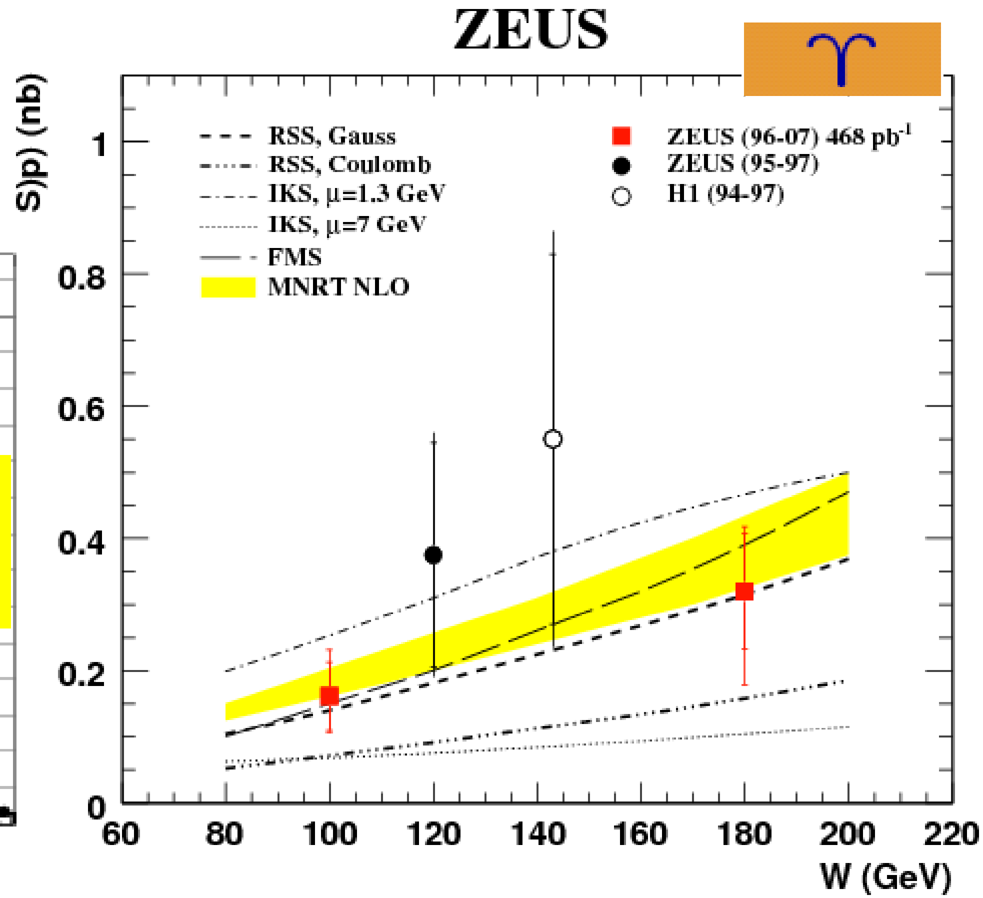




Sensitivity to :

- vector meson wave function
- hard scale value

pQCD models – W-slope prediction:

FMS LO: $\delta \approx 1.7$

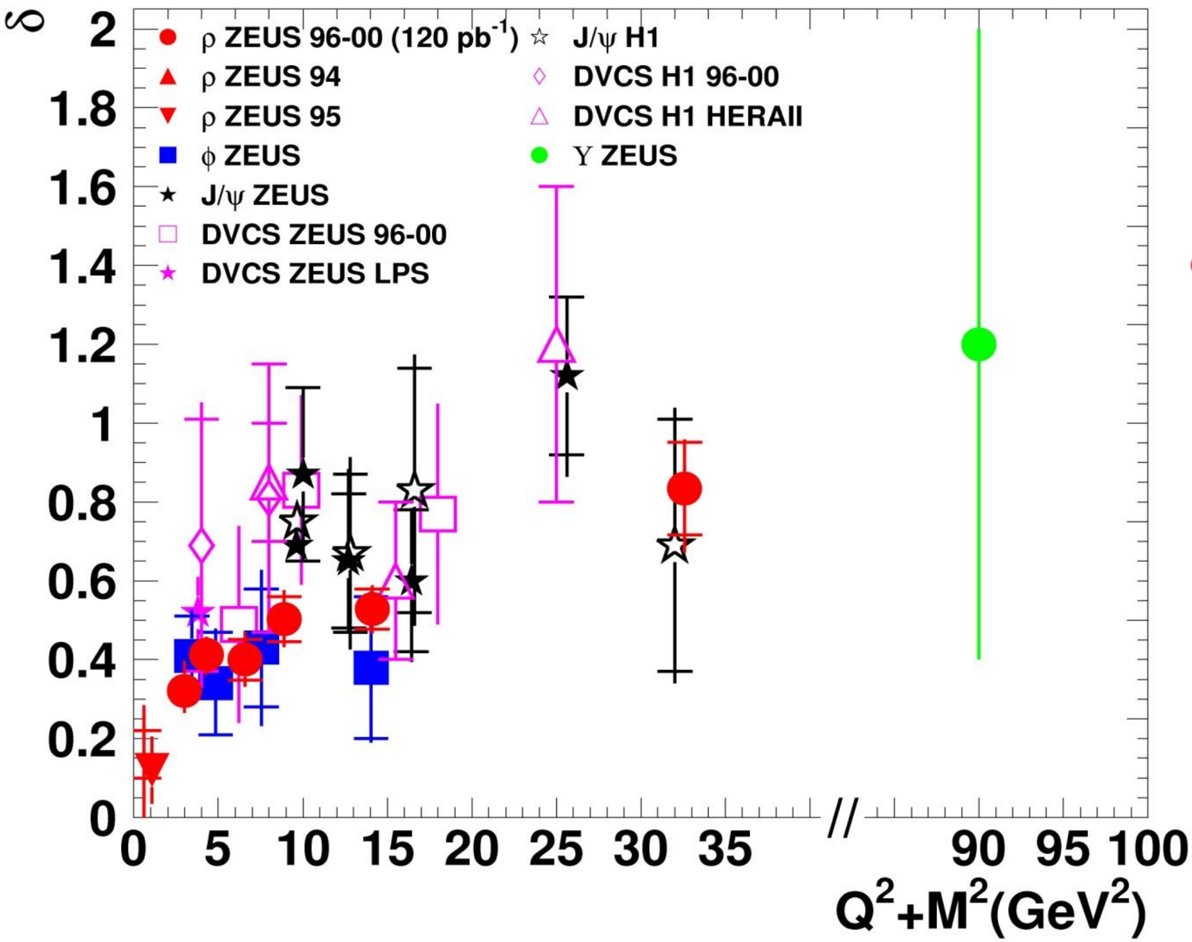
MNRT NLO: $\delta \approx 1.2$

data: $\delta = 1.2 \pm 0.8$

FMS – Frankfurt, McDermott, Strikman (CTEQ4L)
MNRT NLO – Martin, Nockles, Ryskin, Teubner
IKS – Ivanov, Krasnikov, Szymanowski
RSS –Rybarska, Schaefer, Szczurek

W dependence

Transition from soft to hard regime with increasing hard scale



$\sigma(W) \propto W^{\delta}$

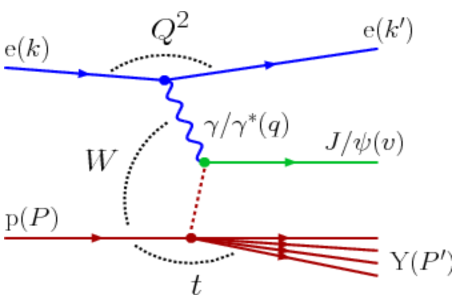
δ rises with $Q^2+M^2_{VM}$

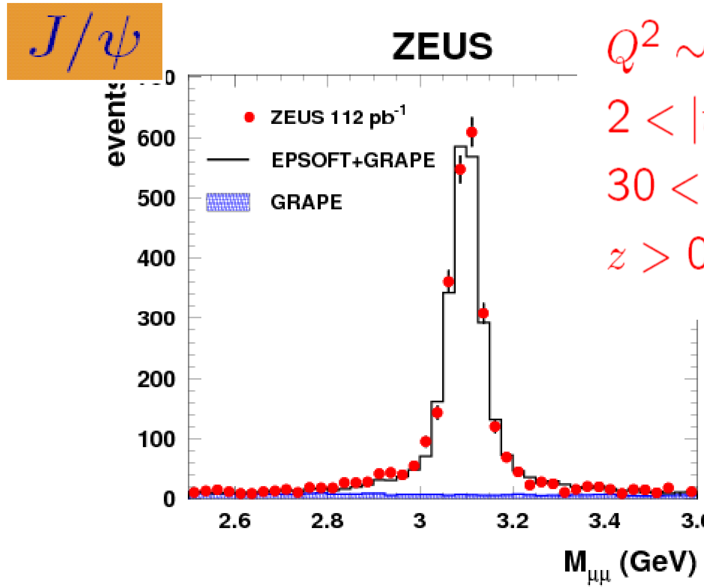
Large Q^2 and M_{VM} sets hard scale

large |t| domain

Diffractive photoprod. of J/ψ mesons with large momentum transfer at HERA (to be published in JHEP)

$$\gamma p \to J/\psi Y$$





$Q^2 \sim 0$

$2 < |t| < 20$ GeV^2

$30 < W < 160$ GeV

$z > 0.95$

$$z = \frac{P \cdot v}{P \cdot q}$$

$$y_{I\!P} = \frac{P \cdot (P - P')}{q \cdot P}$$

$$z = 1 - y_{I\!P}$$

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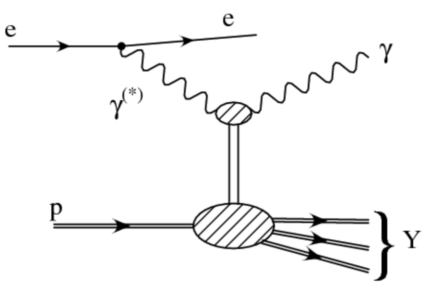
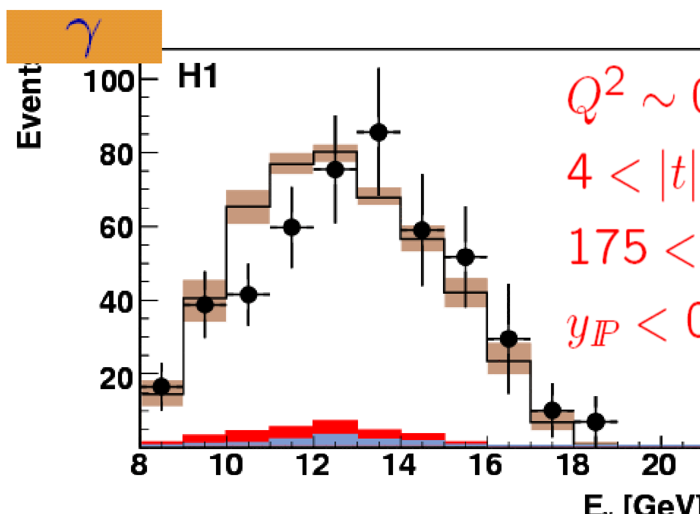
$$\gamma p \to \gamma Y$$





$Q^2 \sim 0$

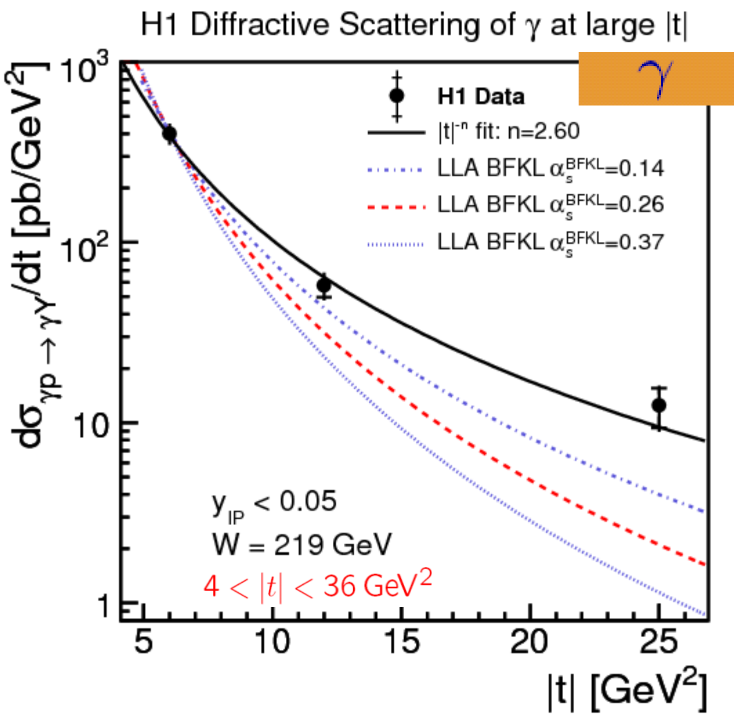
$4 < |t| < 36$ GeV^2

$175 < W < 247$ GeV

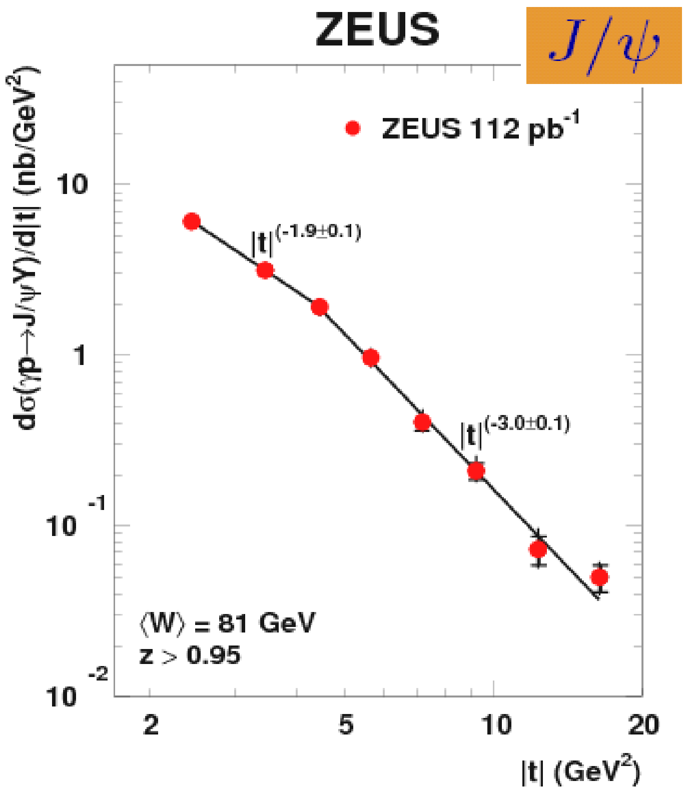
$y_{I\!P} < 0.05$

large |t|: |t|-dependence

- dσ/d|t| falls steeply with |t|
- pQCD expectation: $\frac{d\sigma}{d|t|} \sim |t|^{-n}$



fit $|t|^{-n}$ gives $n = 2.60 \pm 0.19^{+0.03}_{-0.08}$



not possible to describe the whole |t| region nor by exp(-b|t|) neither t^{-n}

fit $|t|^{-n}$ gives

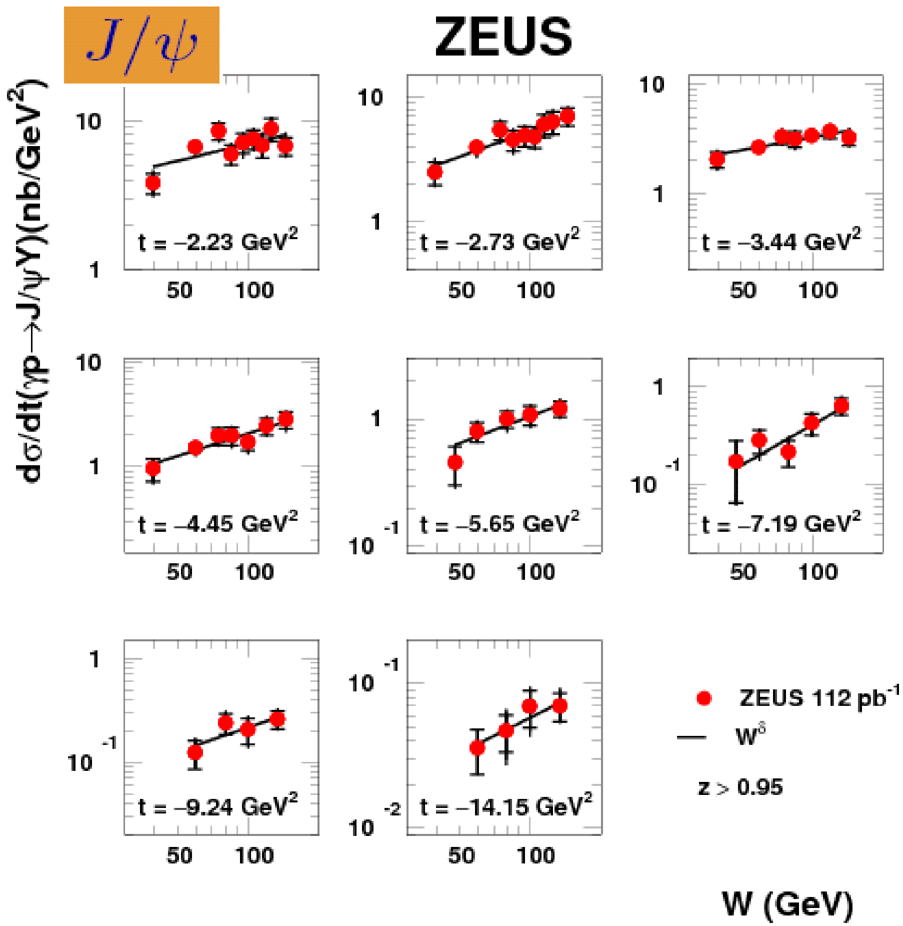
n=1.9±0.1 for 2<|t|<5 GeV^2

n=3.0±0.1 for 5<|t|<20 GeV^2

Good fit for 2<|t|<20 GeV^2 could be obtained using also exp(-b|t|+c|t|^2)

energy dependence and Pomeron trajectory

large |t|

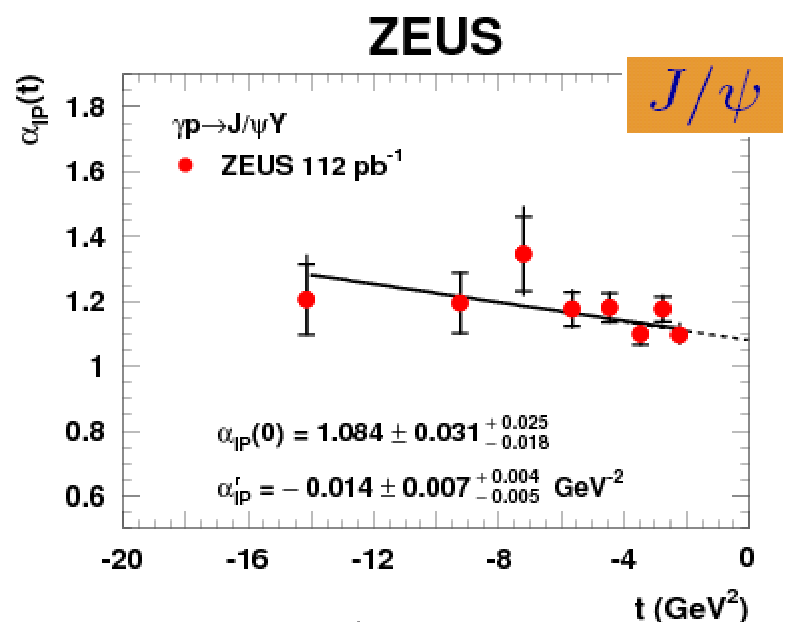


$$\frac{d\sigma}{d|t|} \propto \left(\frac{W}{W_0}\right)^{4(\alpha_{I\!P}(t)-1)}$$

$$\frac{d\sigma}{d|t|} \propto \left(\frac{W}{W_0}\right)^{\delta}$$

Regge theory inspired

$$\alpha_{I\!P}(t) = \alpha(0) + \alpha'_{I\!P} \cdot t$$



soft pomeron (DL):

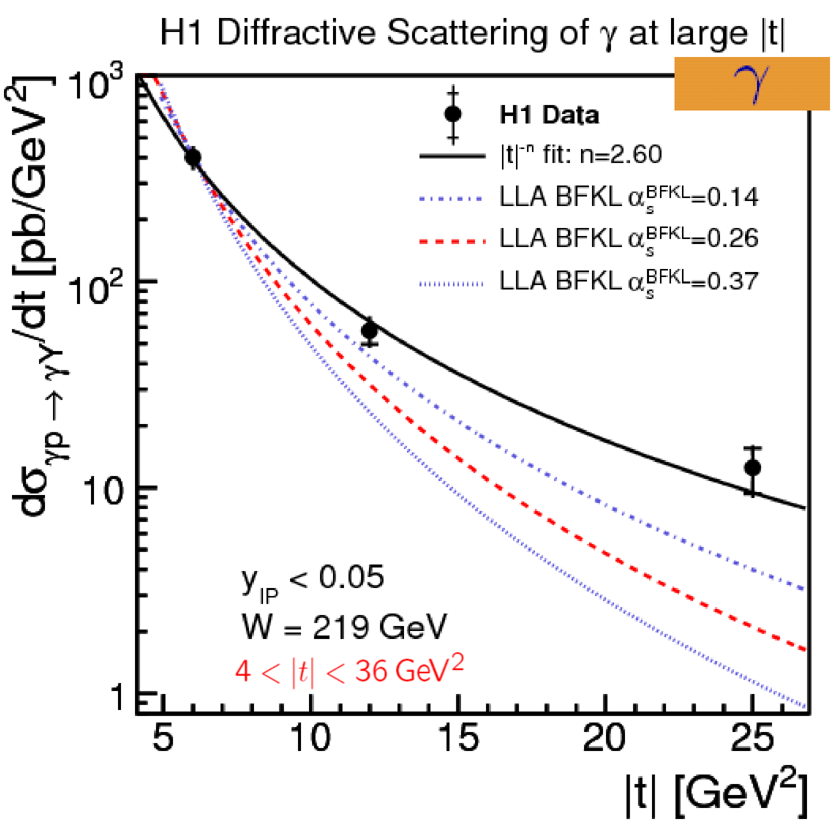
$$\alpha_{I\!P}(t) = 1.08 + 0.25t$$

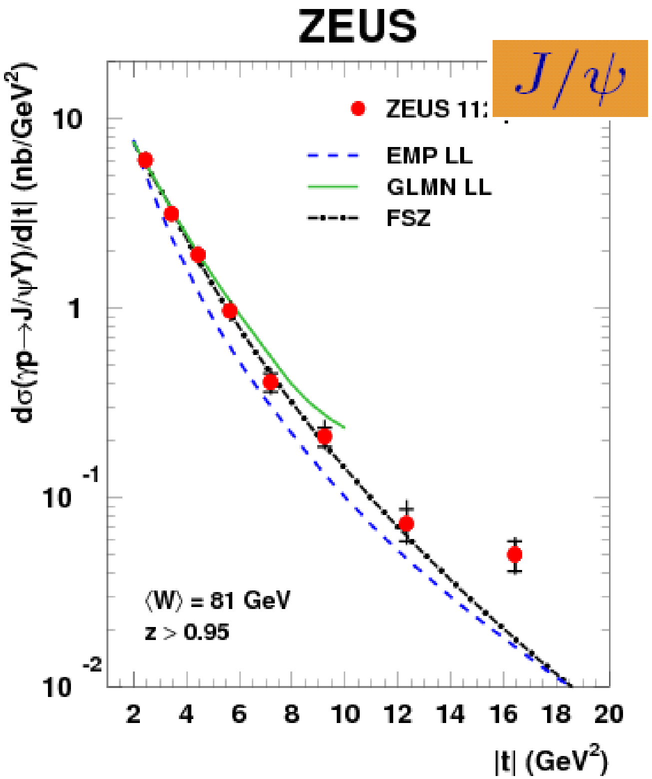
$$\alpha_{I\!P}(0) = 1.084 \pm 0.031^{+0.025}_{-0.018}$$

$$\alpha'_{I\!P} = -0.014 \pm 0.007^{+0.004}_{-0.005}\ \text{GeV}^{-2}$$

large |t|: dσ/d|t| vs theory

- BFKL LL calculations steeper than data
- DGLAP work up to $|t|=5\ GeV^2$ but later falls slower than data
- FSZ gives good description up $|t|=12\ GeV^2$





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E.Gotsman, E.Levin, U. Maor, E. Naftali Phys. Lett. B532 (2002) 37

BFKL LL – EMP LL:
R.Enberg, L. Motyka, G. Poludniowski, Eur. Phys. J. C26, (2003) 219

FSZ:
L. Frankfurt, M.Strikman, M. Zhalov, Phys. Lett. B670, (2008) 32
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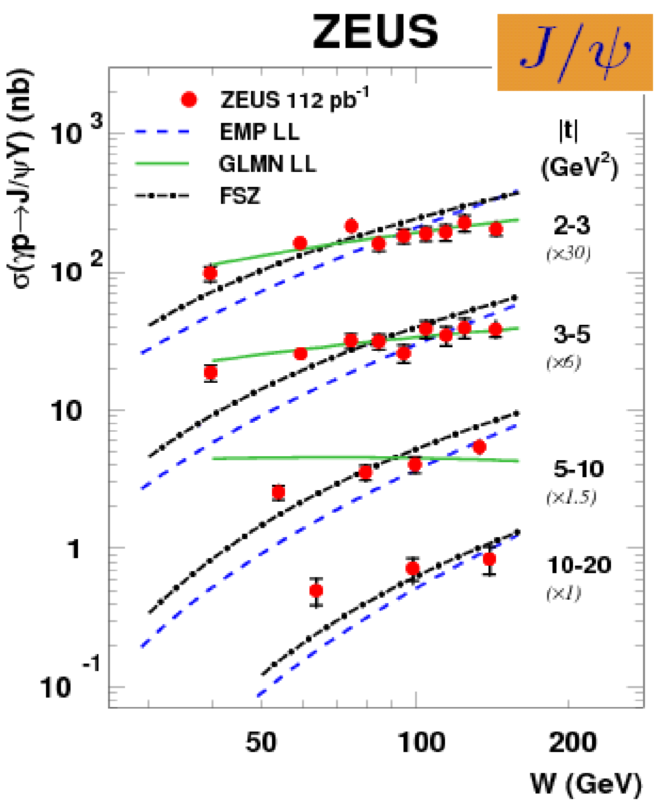
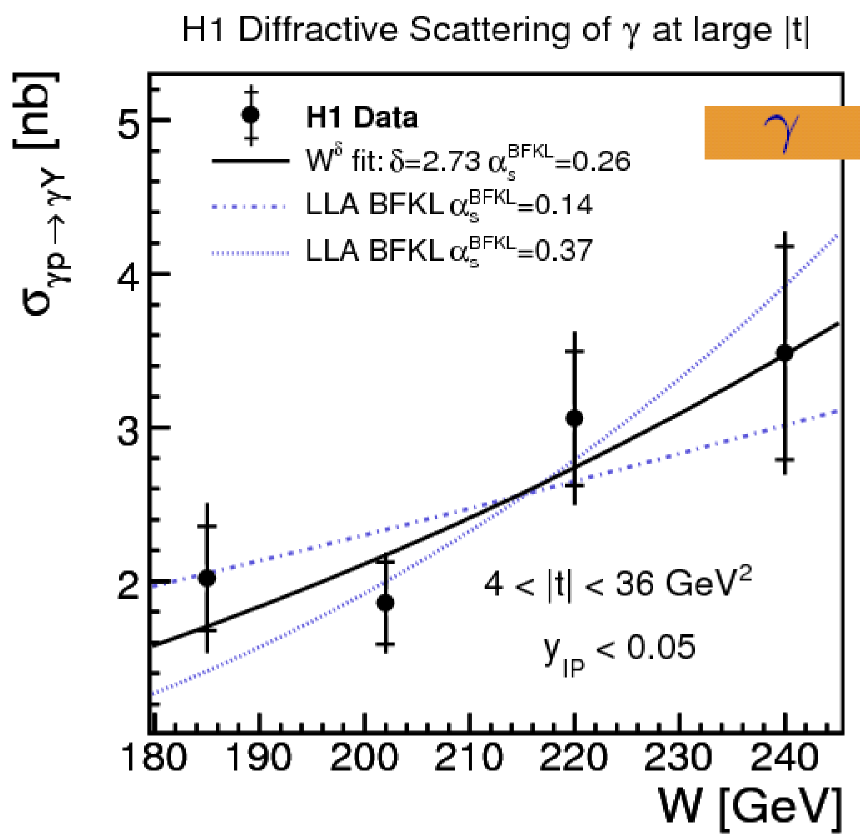
large |t|: σ vs theory

- DGLAP (GLMN LL) describes data very well up to $|t|=5\ \mathrm{GeV}^2$
- BFKL (EMP LL, $\alpha_s=0.16$) and FSZ are too steep



- BFKL describes W dependence



strong W dependence

$$\delta = 2.73 \pm 1.02^{+0.56}_{-0.78}$$

summary

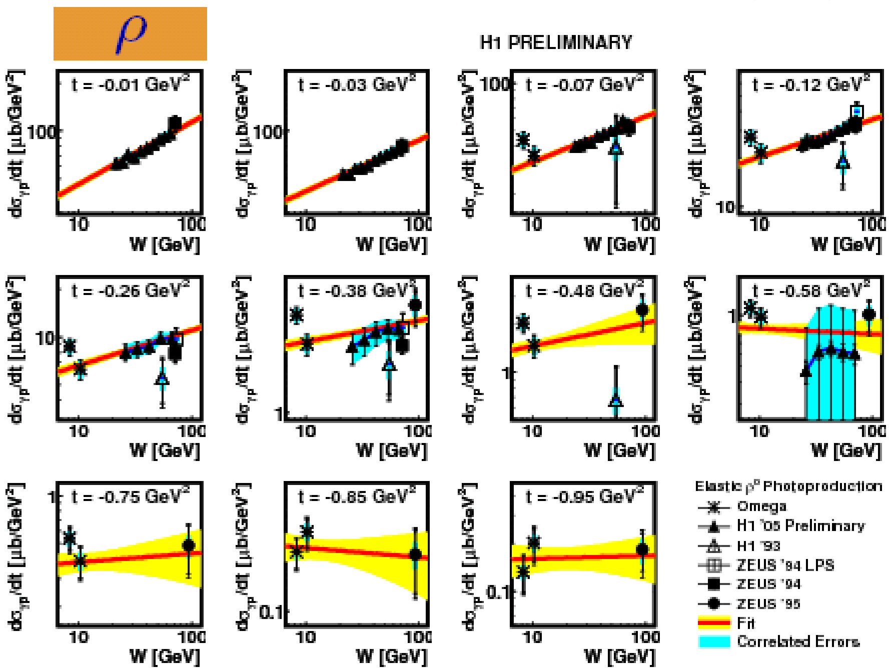
- New measurements of vector mesons and high-p_t photons
- The Υ cross section rises as W^{δ}. Data are sensitive to wave function modelling in pQCD predictions.
- Fit $d\sigma/dt \backsim t^{-n}$ for large |t| does not describe data in the full kinematic range (J/ψ)
- None of the models in large |t| domain can reproduce the data in the full kinematic range (J/ψ / γ)
- Effective Pomeron trajectory for large |t| (J/ψ) has smaller slope than that extracted from soft hadron-hadron scattering

Backup

energy dependence and Pomeron trajectory

elastic PHP ρ

A Measurement of the Pomeron Trajectory based on Elastic Rho Photoproduction (H1 preliminary)



$$\frac{d\sigma}{d|t|} \propto \left(\frac{W}{W_0}\right)^{4(\alpha_{I\!P}(t)-1)}$$

$$\frac{d\sigma}{d|t|} \propto \left(\frac{W}{W_0}\right)^{\delta}$$

Regge theory inspired

$$\alpha_{I\!P}(t) = \alpha(0) + \alpha'_{I\!P} \cdot t$$

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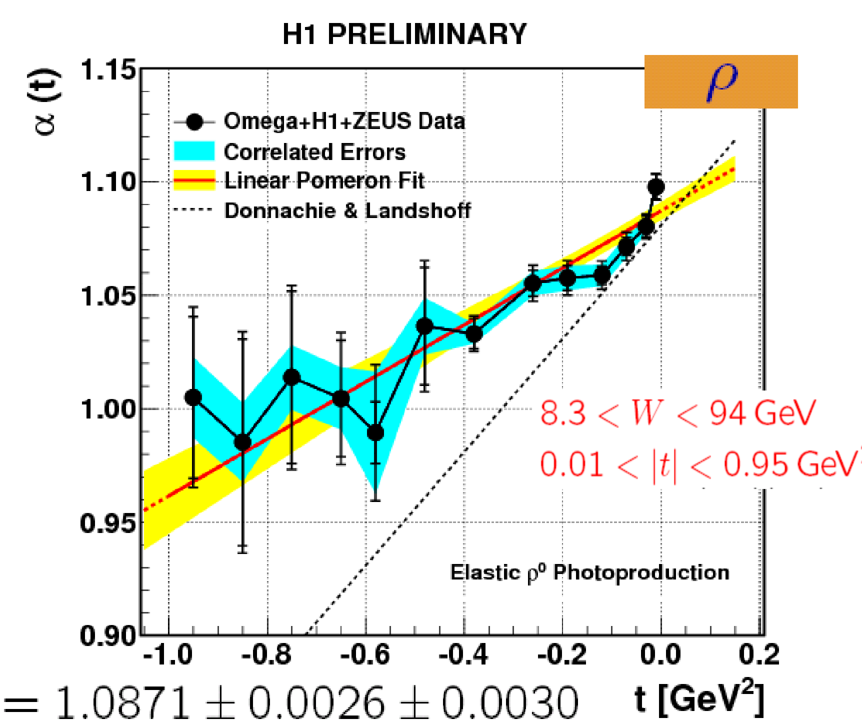

Soft pomeron (DL):

$$\alpha_{I\!P}(t) = 1.08 + 0.25t$$

$$\alpha_{I\!P}(0) = 1.0871 \pm 0.0026 \pm 0.0030$$

$$\alpha'_{I\!P} = 0.126 \pm 0.013 \pm 0.012 \,\mathrm{GeV}^{-2}$$