

# Exclusive photoproduction at HERA

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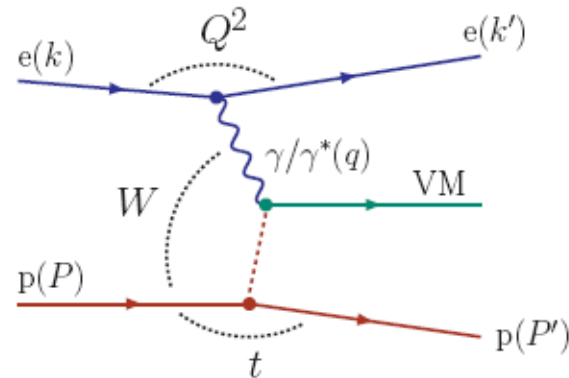
DESY, Hamburg

on behalf of



EPS2009, Kraków, Poland

# exclusive diffraction



experimentally: very clean process in wide kinematic range

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

→ VM at HERA: transition between soft and hard regime

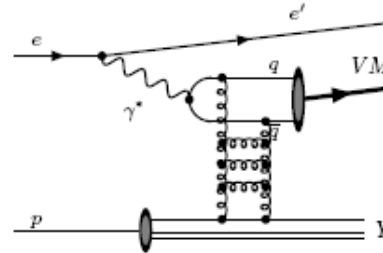
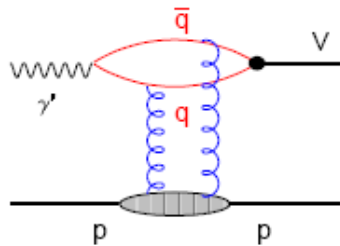
→ simultaneous study of **different scales**:  $Q^2, |t|, M_{VM}^2$

# diffractive vector meson production

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

large  $Q^2, M_{VM}^2$  or  $|t| \Rightarrow$  small  $q\bar{q}$  and interaction size

**hard** interaction  $\Rightarrow$  **perturbative QCD** applicable, factorization holds



'Exclusive' VM electroproduction:

- steep rise of  $\sigma(W)$ ,  $\sigma \sim \frac{\alpha_s(Q^2)}{Q^6} [xg(x, Q^2)]^2$ ,  $x \approx Q^2/W^2$
- universal  $t$  dependence:  $\sim \exp^{-b_{2g}|t|}$ ,  $b_{2g} \sim 4 - 5 \text{ GeV}^{-2}$  and  $\alpha'_{\text{IP}} \approx 0$
- possible SCHC violation

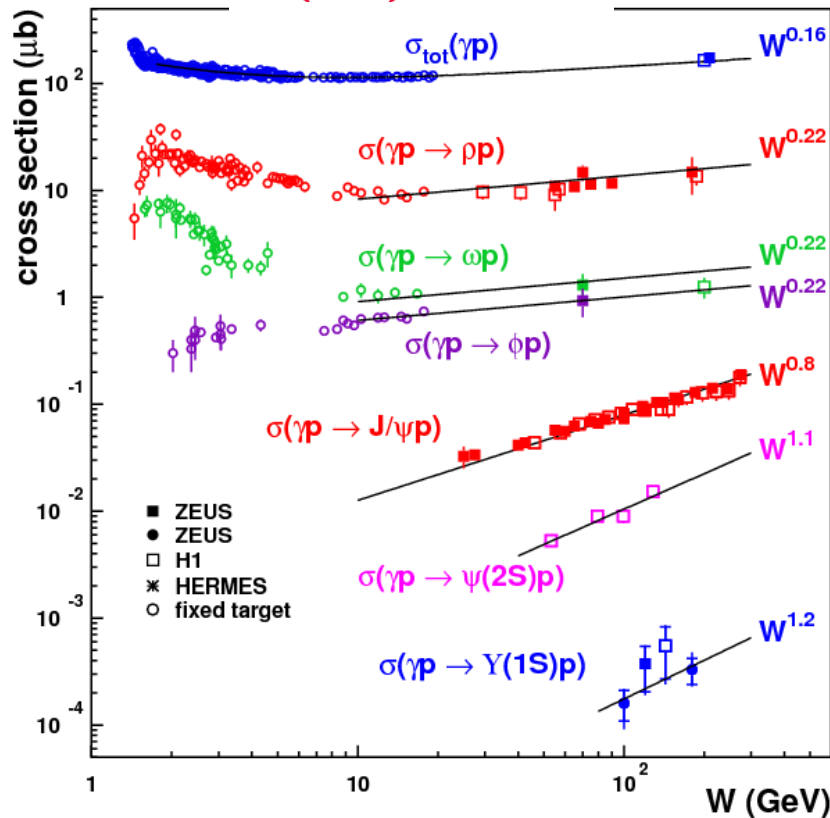
'Proton dissociative' VM photoproduction;

- $d\sigma/d|t| \sim |t|^{-n}$
  - 2-gluon exchange - no energy dependence
- gluon ladder exchange – energy dependence:
- weak (DGLAP)
  - strong (BFKL)

# vector mesons in photoproduction ( $Q^2 = 0 \text{ GeV}^2$ )

$$\gamma p \rightarrow VM + p \quad (VM = \rho, \phi, \omega, J/\psi, \psi, \Upsilon)$$

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



Low mass ( $\rho, \phi, \omega$ )

- $M_{VM}^2 \approx 1 \text{ GeV}^2$
- no hard scale
- weak  $W$  dependence

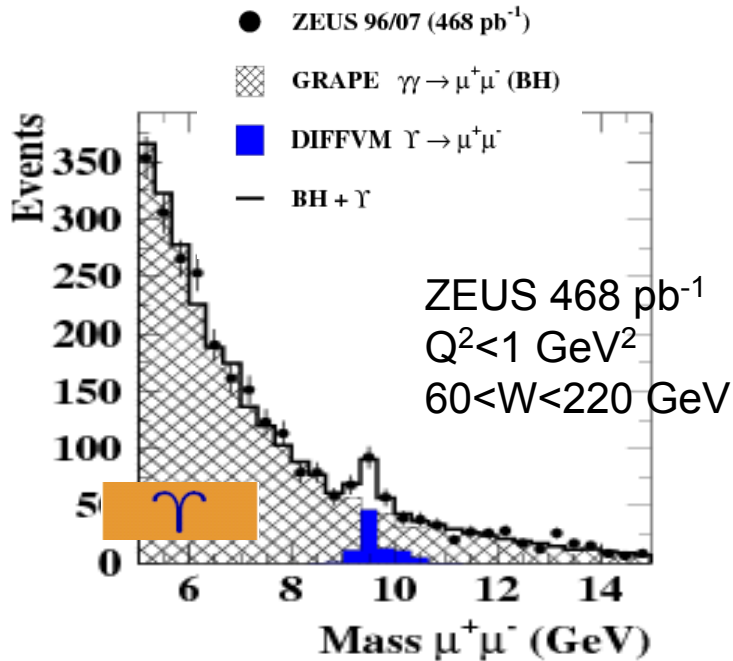
High mass ( $J/\psi, \psi, \Upsilon$ )

- hard scale
- strong  $W$  dependence

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

# $\Upsilon$ production – energy dependence

accepted by Phys. Lett. B (Ref. No. PLB-D-09-00488)

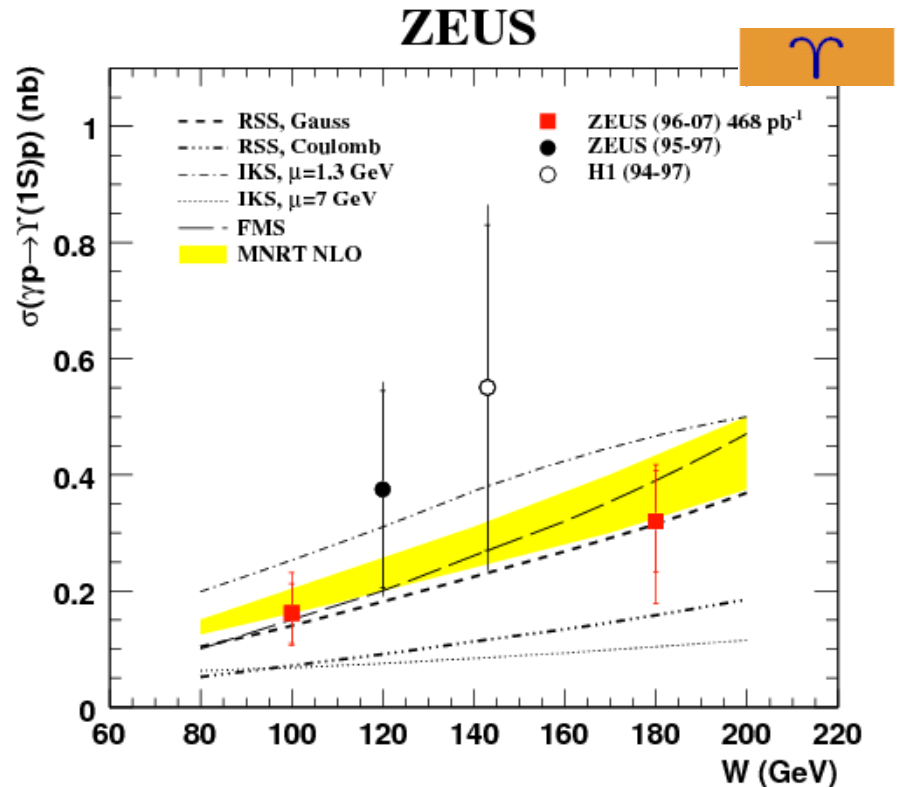


pQCD models – W-slope prediction:

FMS LO:  $\delta \approx 1.7$

data:  $\delta = 1.2 \pm 0.8$

MNRT NLO:  $\delta \approx 1.2$



Sensitivity to:

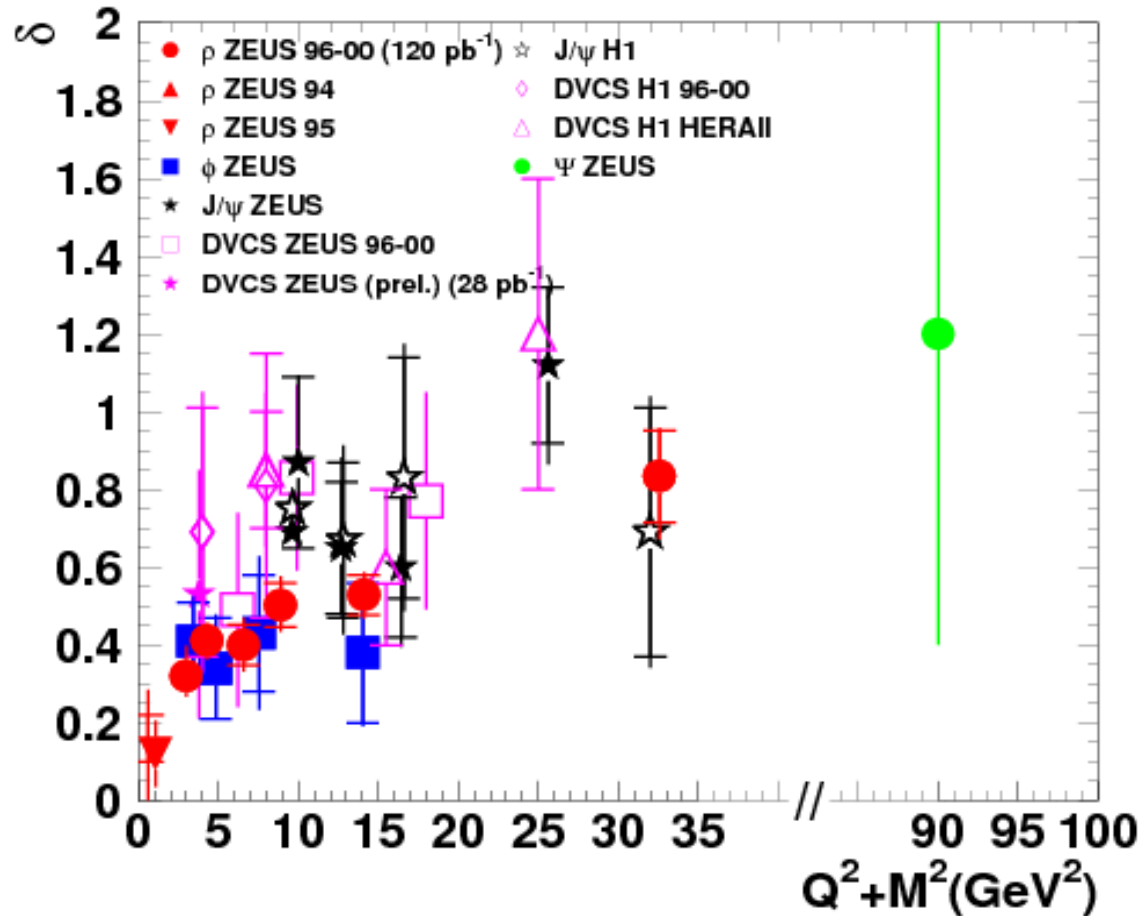
- (RSS model) vector meson wave function: data seem to prefer Gauss to Coulomb
- hard scale value: in IKS model scale is between  $1.3 < \mu < 7$  GeV

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

# $\delta(Q^2+M_{VM}^2)$

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

Steep slope observed for all VM in the presence of hard scale



$\sigma \sim W^\delta$   
 $\delta$  rises with  $Q^2+M_{VM}^2$

Transition from soft to hard regime with increasing of hard scale

# large $|t|$ domain

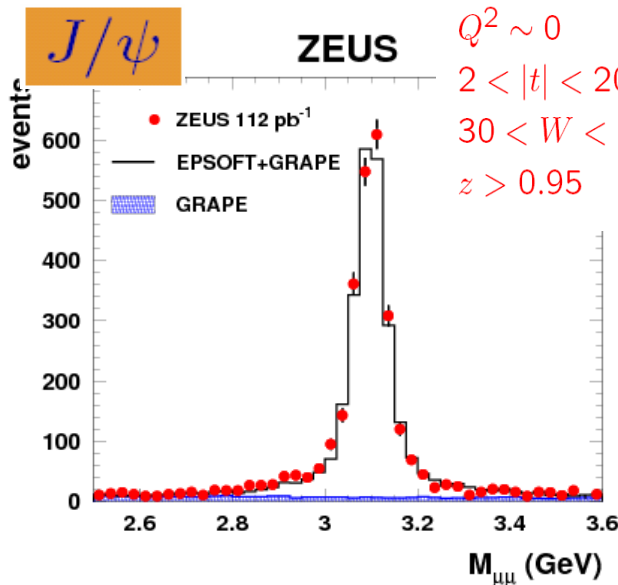
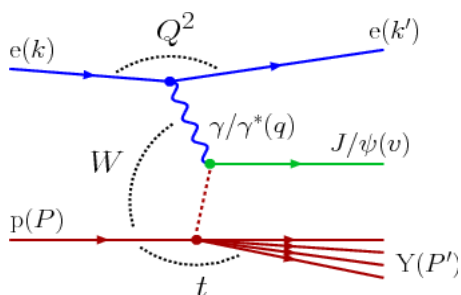
Diffractive photoproduction of  $J/\psi$  mesons with large momentum transfer at HERA (ready for publication)

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

$$y_P = \frac{P \cdot (P - P')}{q \cdot P}$$

$$z = 1 - y_P$$

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



$Q^2 \sim 0$   
 $2 < |t| < 20 \text{ GeV}^2$   
 $30 < W < 160 \text{ GeV}$   
 $z > 0.95$

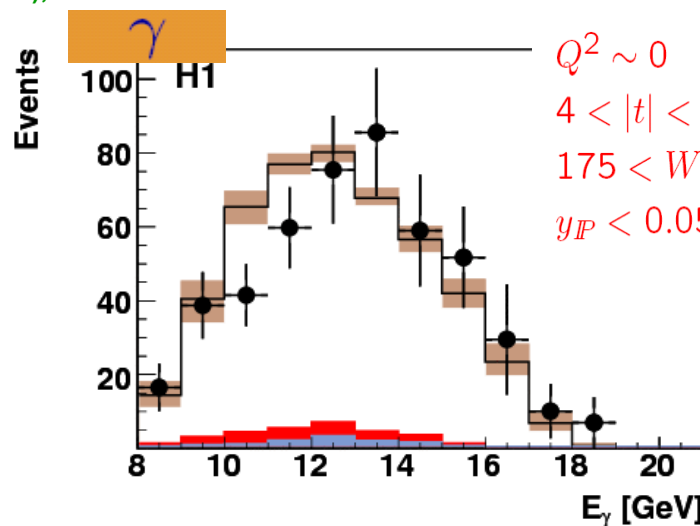
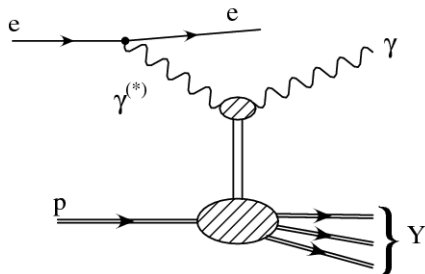
pQCD models:

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

$$\sigma \sim W^\delta$$

Phys.Lett., B672 (2009), 219-226

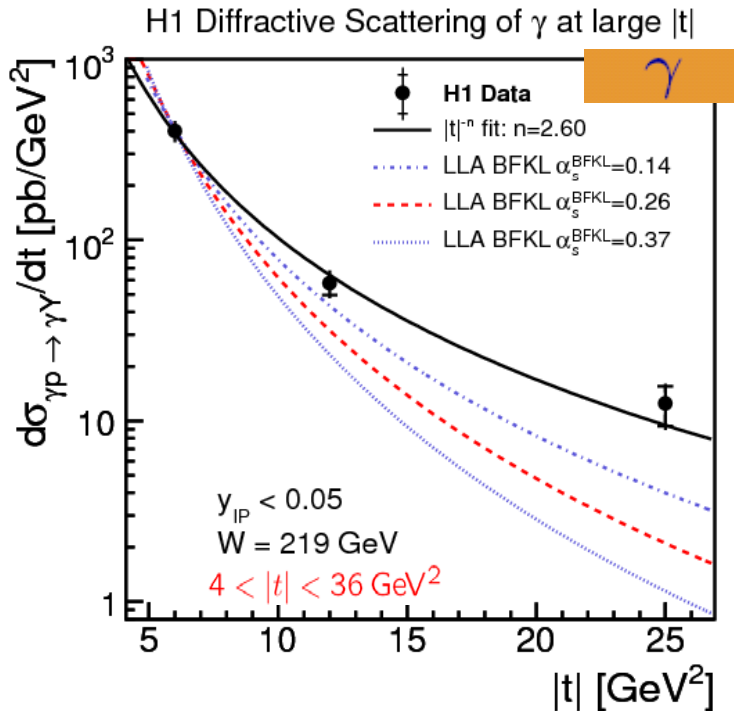
$$\gamma p \rightarrow \gamma Y$$



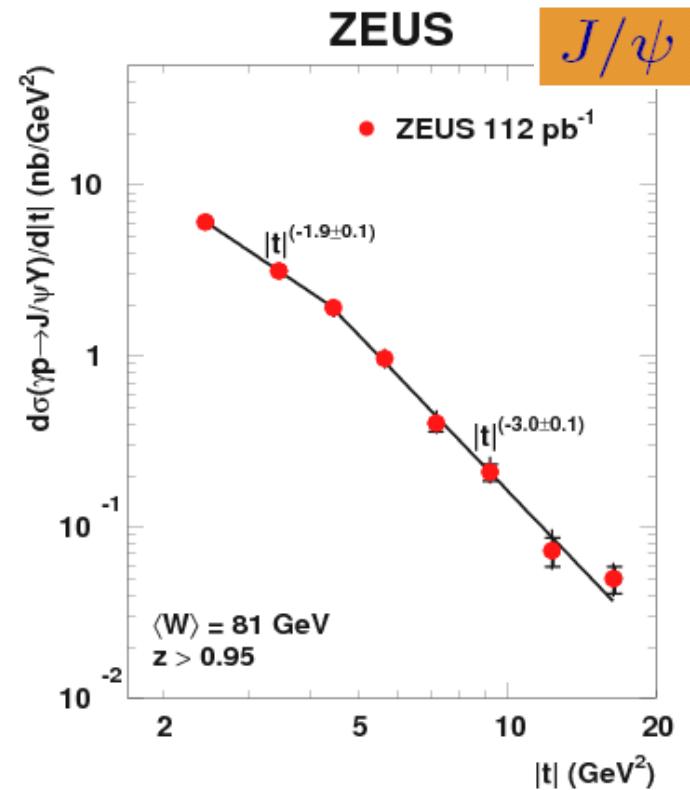
$Q^2 \sim 0$   
 $4 < |t| < 36 \text{ GeV}^2$   
 $175 < W < 247 \text{ GeV}$   
 $y_P < 0.05$

# large $|t|$ : $|t|$ -dependence

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



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



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

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

$n=1.9 \pm 0.1$  for  $2 < |t| < 5 \text{ GeV}^2$

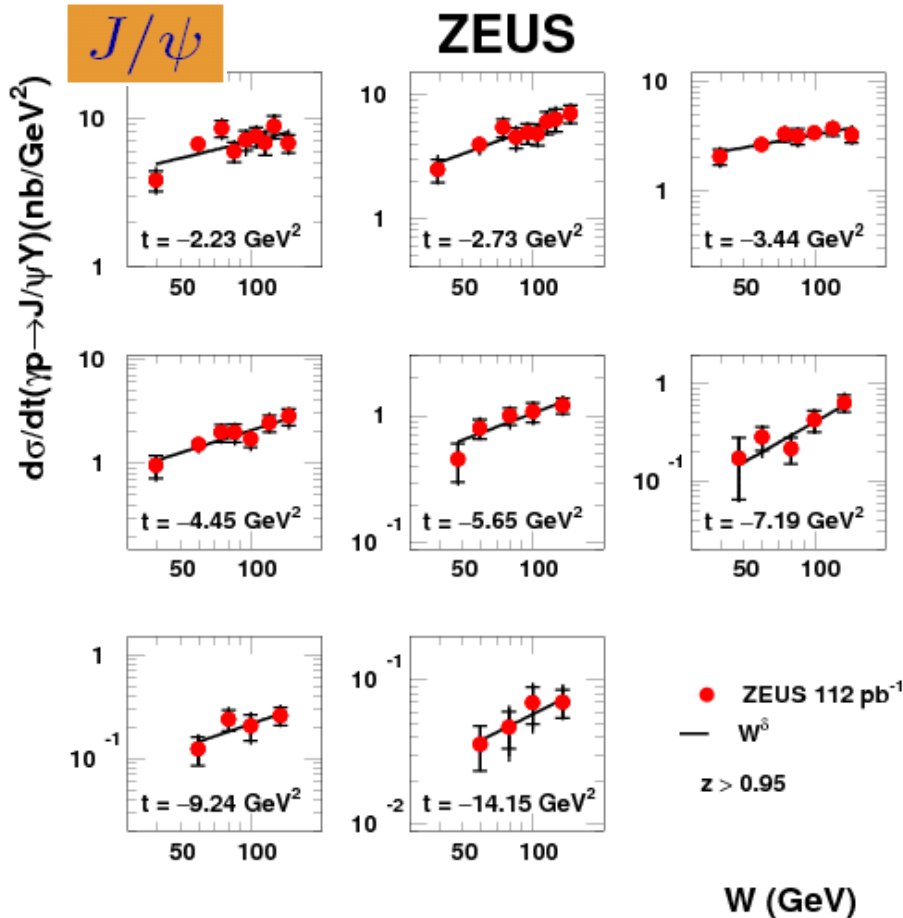
$n=3.0 \pm 0.1$  for  $5 < |t| < 20 \text{ GeV}^2$

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



# energy dependence and Pomeron trajectory

large  $|t|$

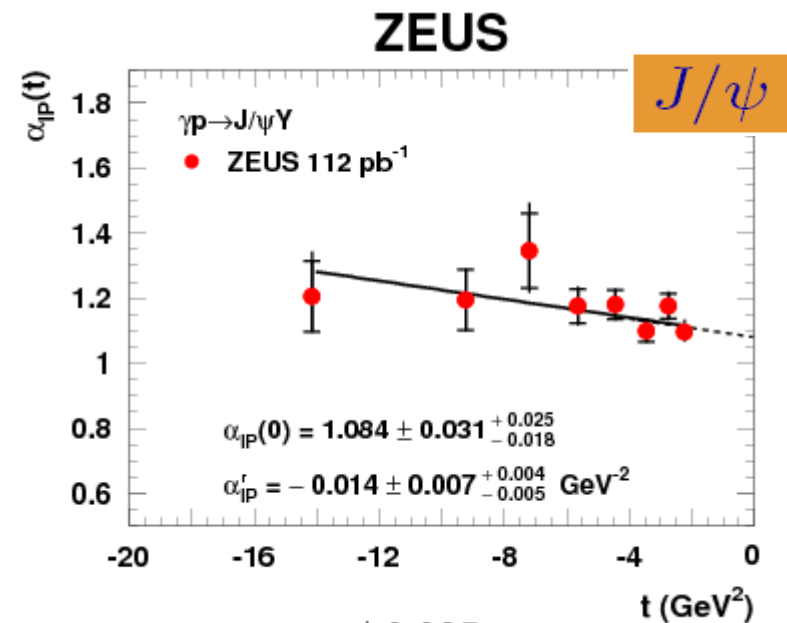


$$\frac{d\sigma}{d|t|} \propto \left(\frac{W}{W_0}\right)^{4(\alpha_{\mathbb{P}}(t)-1)}$$

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

Regge theory inspired

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



soft pomeron (DL):

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

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

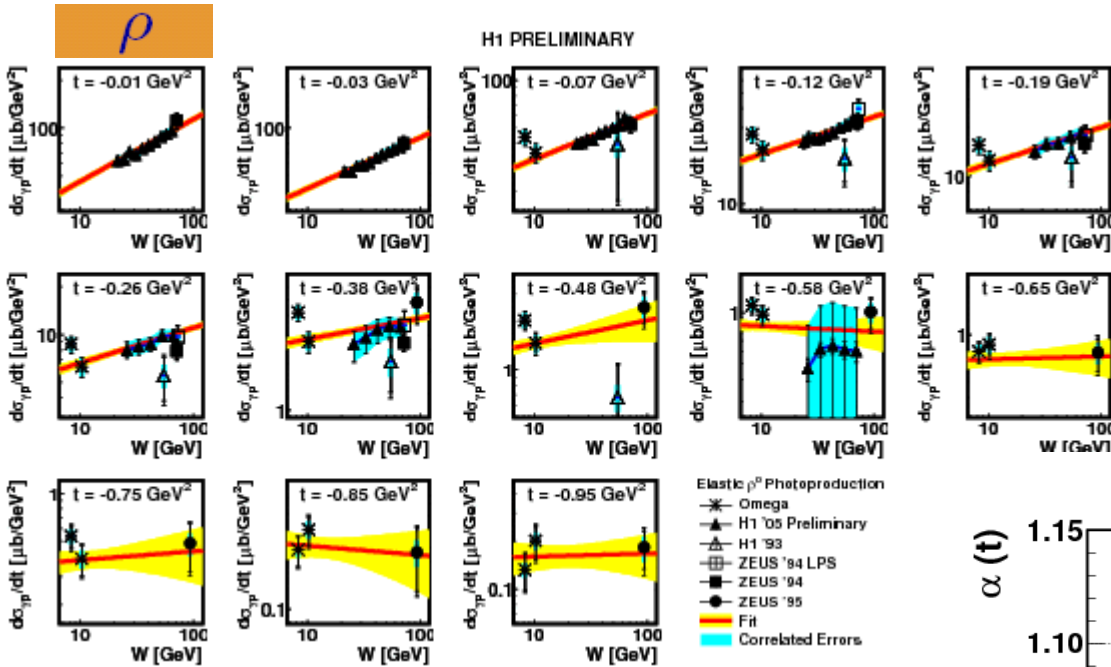
$$\alpha'_{\mathbb{P}} = -0.014 \pm 0.007^{+0.004}_{-0.005} \text{ GeV}^{-2}$$

# energy dependence and Pomeron trajectory

elastic PHP

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

$\rho$



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

$$\frac{d\sigma}{d|t|} \propto \left(\frac{W}{W_0}\right)^\delta \quad \text{Regge theory inspired}$$

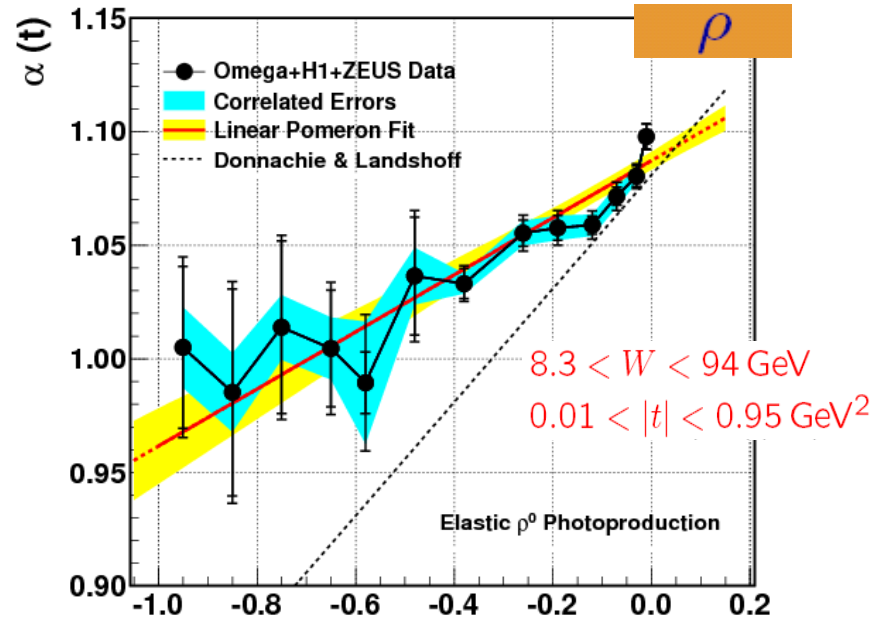
$$\alpha_P(t) = \alpha(0) + \alpha'_P \cdot t$$

Omega – Nucl. Phys. B209 (1982) 56  
 ZEUS 94 LPS – Z. Phys. C 73 (1997) 253  
 ZEUS 94 – Eur. Phys. J. C 2 (1998) 247  
 ZEUS 95 – Eur. Phys. J. C 14 (2000) 213  
 H1 93 – Nucl. Phys. B 463 (1996) 3  
 H1 05 - preliminary

Soft pomeron (DL):

$$\alpha_P(t) = 1.08 + 0.25t$$

H1 PRELIMINARY

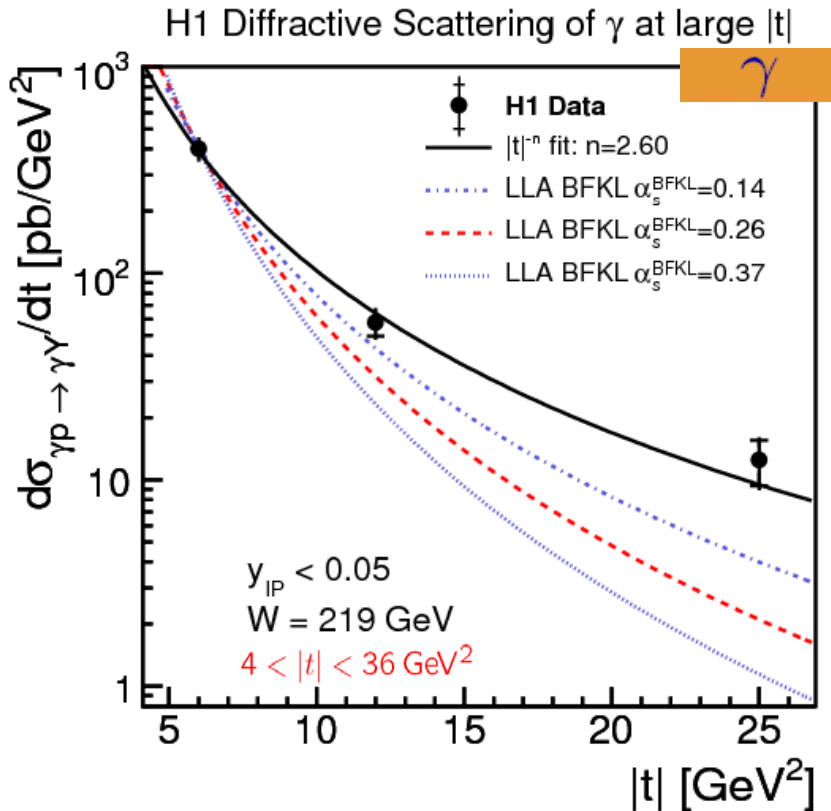


$$\alpha_P(0) = 1.0871 \pm 0.0026 \pm 0.0030 \quad t \text{ [GeV}^2\text{]}$$

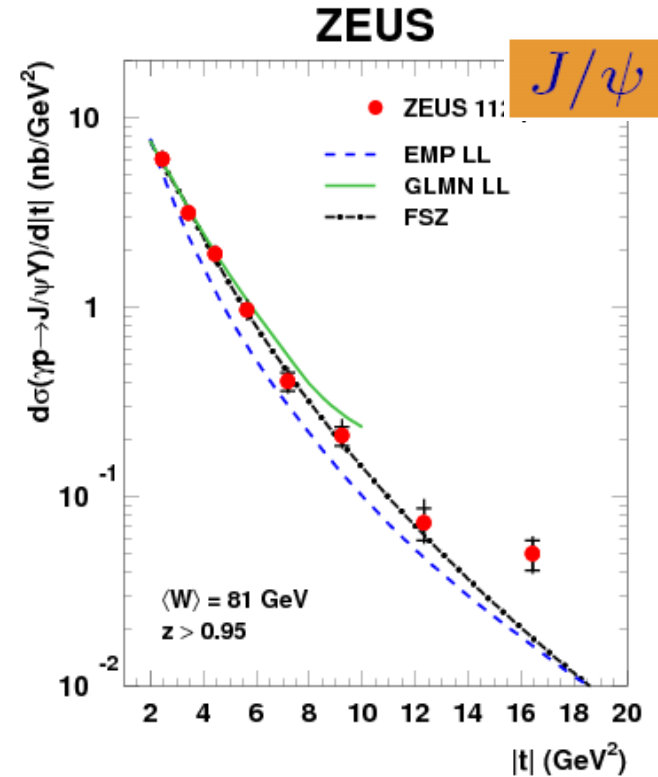
$$\alpha'_P = 0.126 \pm 0.013 \pm 0.012 \text{ GeV}^{-2}$$

# large $|t|$ : $d\sigma/d|t|$ vs theory

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



D.Y. Ivanov, M.Wusthoff, Eur. Phys. J. C8 (1999) 107  
 N.G. Evanson, J.R. Forshaw, Phys. Rev. D60 (1999) 034016  
 B.E. Cox, J.R. Forshaw, J. Phys. G26 (2000) 702



DGLAP–GLMN LL:

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

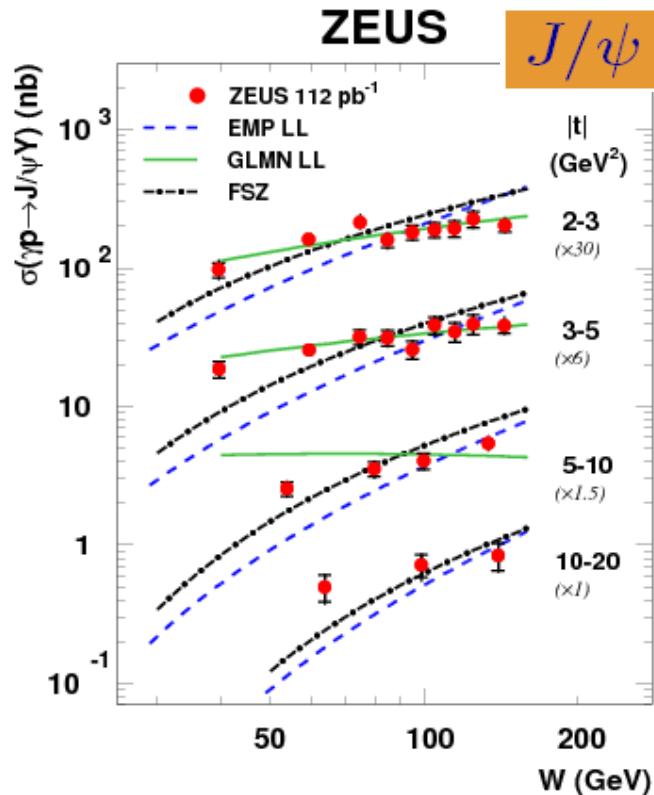
FSZ:

L. Frankfurt, M.Strikman, M. Zhalov, Phys. Lett. B670, (2008) 32

L. Frankfurt, M.Strikman, Phys. Rev. Lett. 63 (1989) 1914

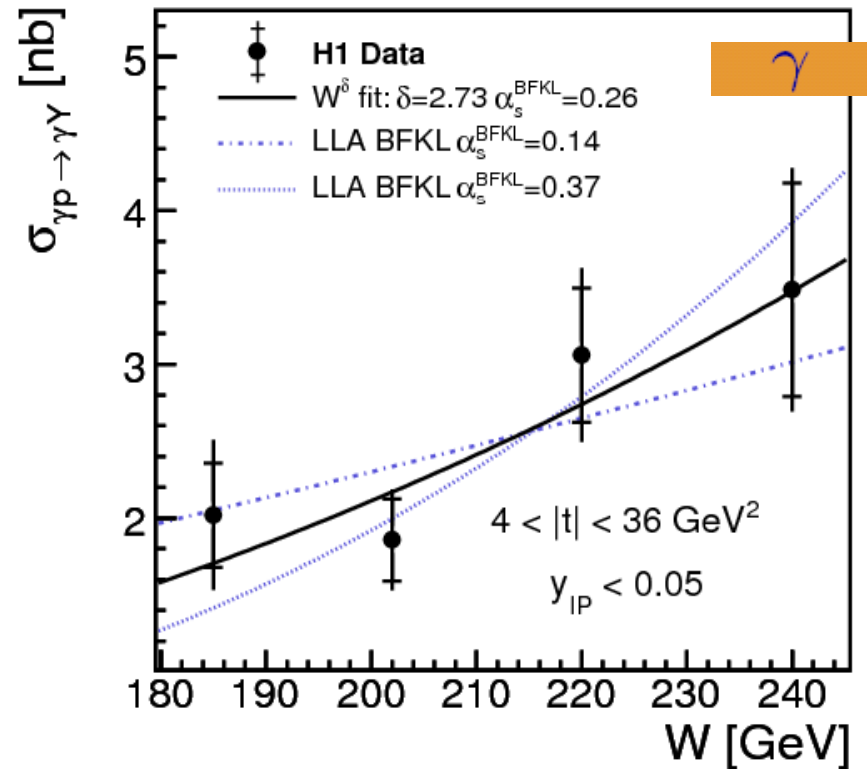
# large $|t|$ : $\sigma$ vs theory

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



- BFKL describes  $W$  dependence

H1 Diffractive Scattering of  $\gamma$  at large  $|t|$



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  $\Upsilon$  cross section rises as  $W^\delta$  and  $\delta$  grows with the universal hard scale  $Q^2+M_{VM}^2$
- pQCD motivated fit  $d\sigma/dt \sim t^{-n}$  for large  $|t|$  does not describe data in the full kinematic range (J/ $\psi$ )
- Effective Pomeron trajectory has smaller slope than that extracted from soft hadron-hadron scattering for large  $|t|$  (J/ $\psi$ ) as well as for elastic  $\rho$  production
- None of the models in large  $|t|$  domain can reproduce the data in the full kinematic range (J/ $\psi$  /  $\gamma$ )