# Exclusive photoproduction at HERA

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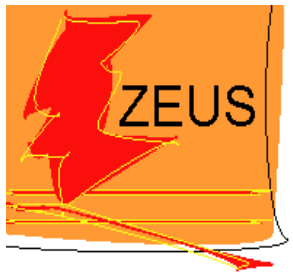
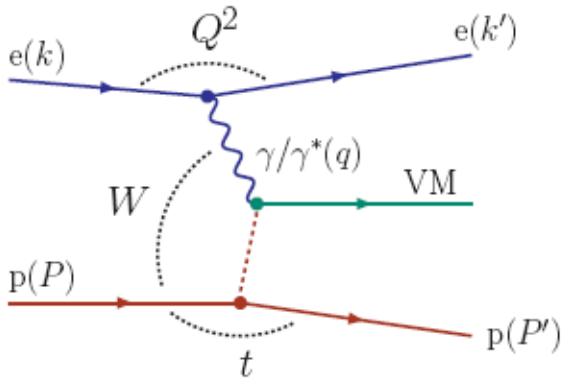
on behalf of





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)$^2$ at p-vertex | $t = (P-P')^2$ |

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

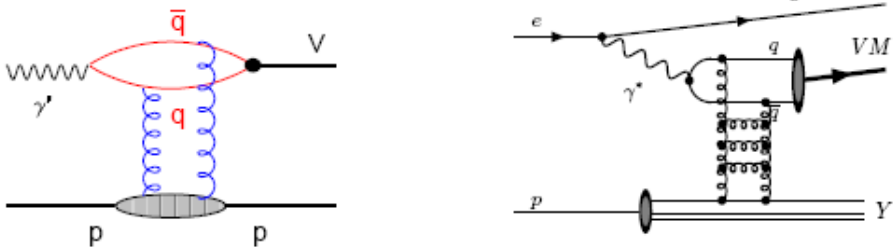
$\longrightarrow$ **simultaneous study of different scales: $Q^2$, $|t|$, $M^2_{VM}$**

# diffractive vector meson production

VM $= q\bar{q}$ dipol, 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: $\sim \exp^{-b_{2g}|t|}$, $b_{2g} \sim 4-5\,\mathrm{GeV}^{-2}$ and $\alpha'_{\mathrm{IP}} \approx 0$
- 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:

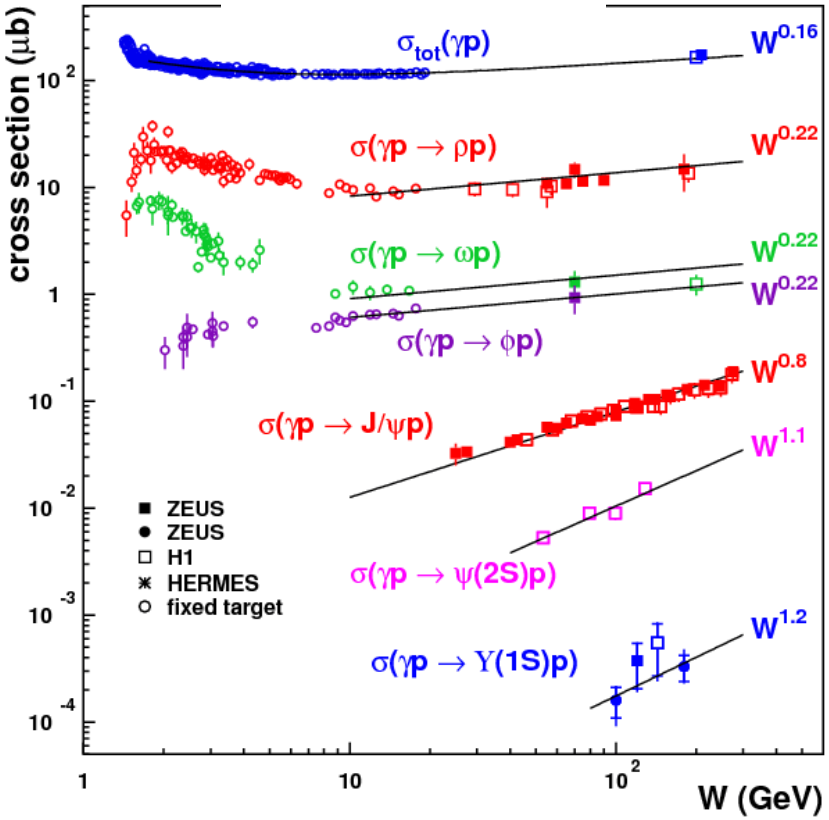
– weak (DGLAP)

– strong (BFKL)

# vector mesons in photoproduction ($Q^2$ = 0 $GeV^2$)

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

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




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

- $M^2_{VM} \approx 1$ $GeV^2$
- 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

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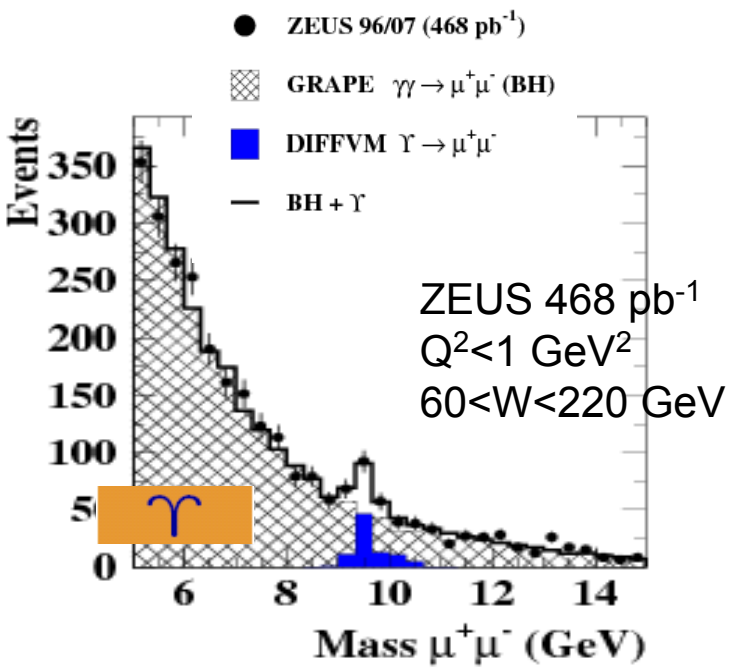


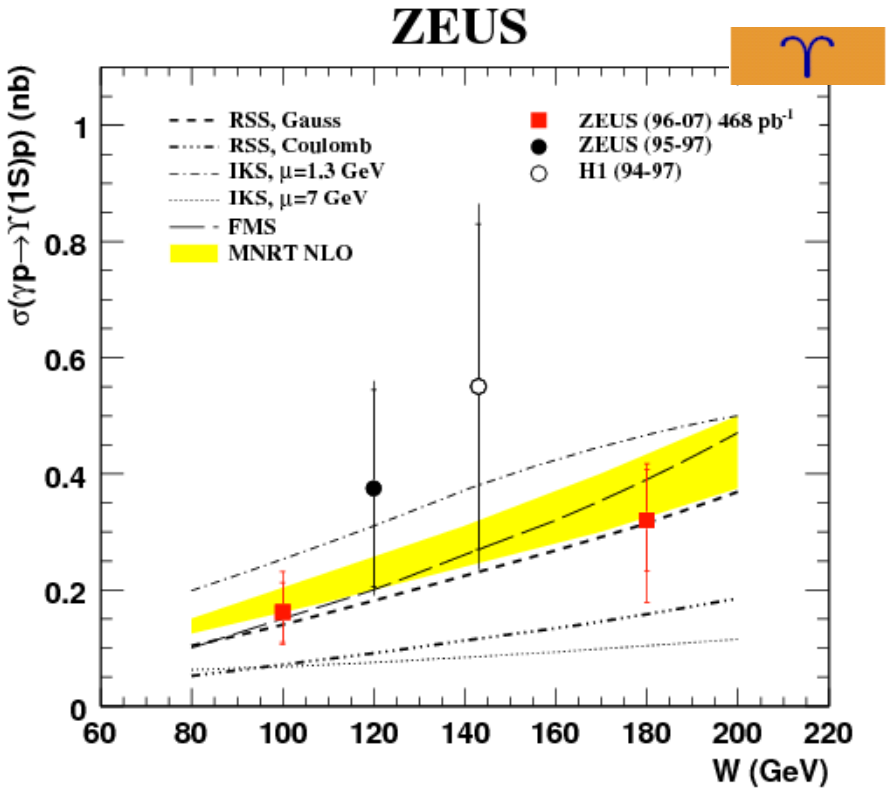

ZEUS 468 pb$^{-1}$
$Q^2$<1 GeV$^2$
60<W<220 GeV

pQCD models – W-slope prediction:

FMS LO: $\delta \approx 1.7$

MNRT NLO: $\delta \approx 1.2$

data: $\delta = 1.2 \pm 0.8$




Sensitivity to:

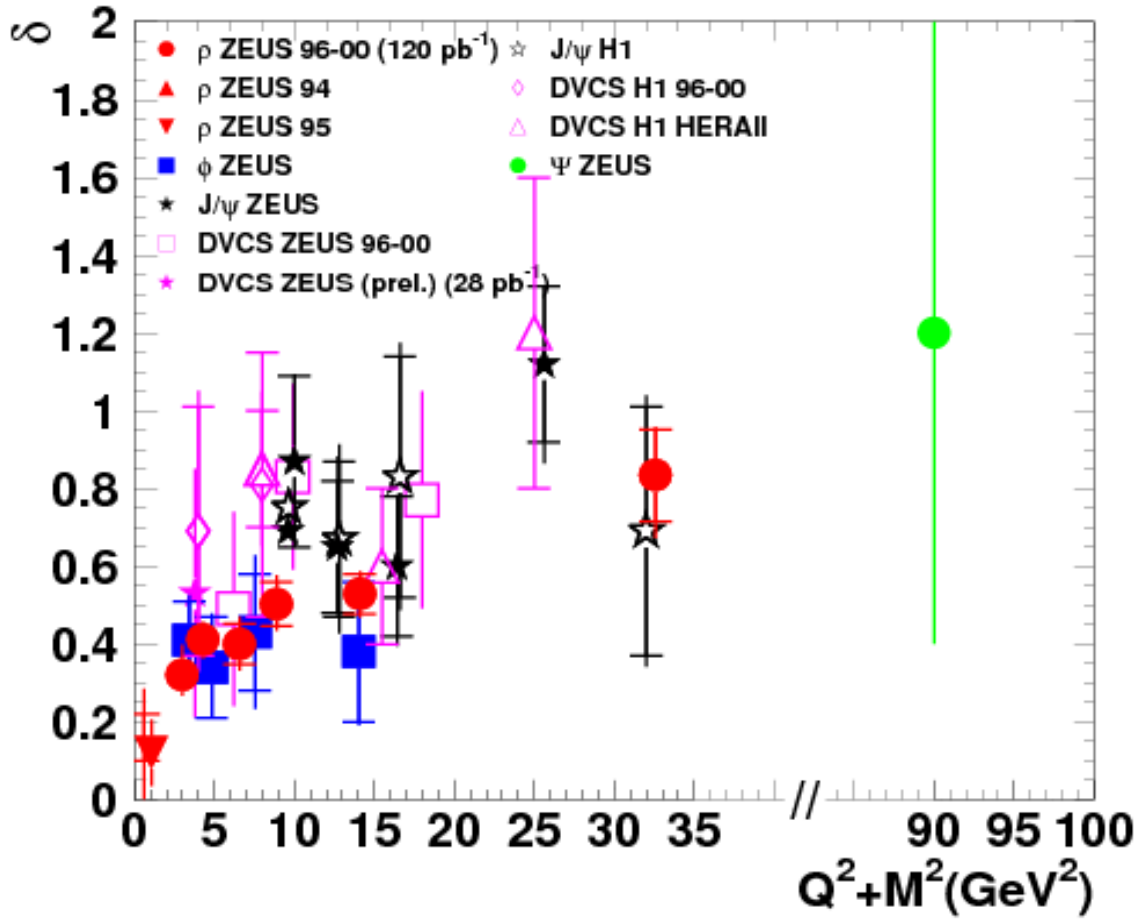
- (RSS model) vector meson wave function: data seem to prefer Gauss to Coulomb
- hard scale value: in IKS model scale is between 1.3<μ<7 GeV

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

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

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 $Q^2+M^2_{VM}$

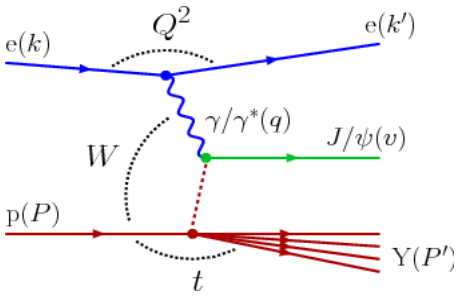
Transition from soft to hard regime with increasing of hard scale

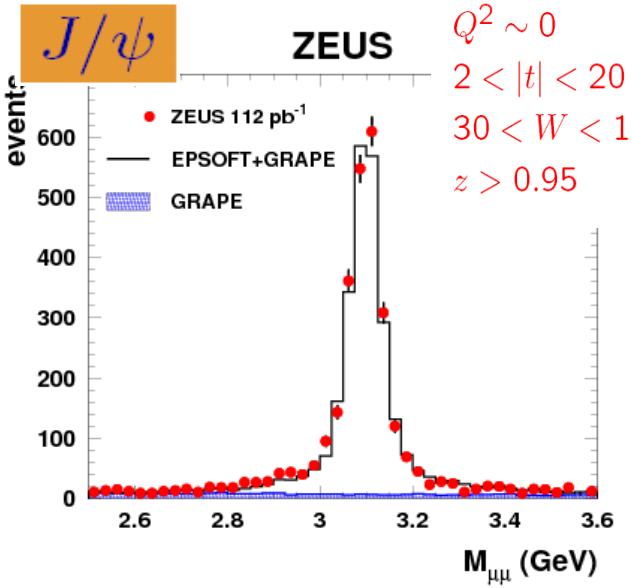
# large |t| domain

$$z = \frac{P\cdot v}{P\cdot q}$$
$$y_{I\!P} = \frac{P\cdot(P-P')}{q\cdot P}$$
$$z = 1 - y_{I\!P}$$

**Diffractive photoproduction of J/ψ mesons with large momentum transfer at HERA (ready for publication)**

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




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

pQCD models:

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

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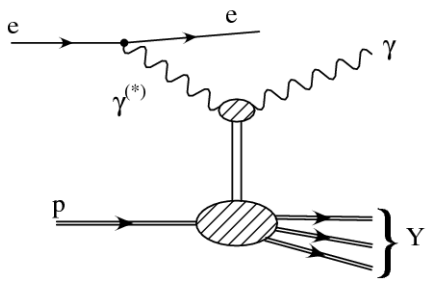
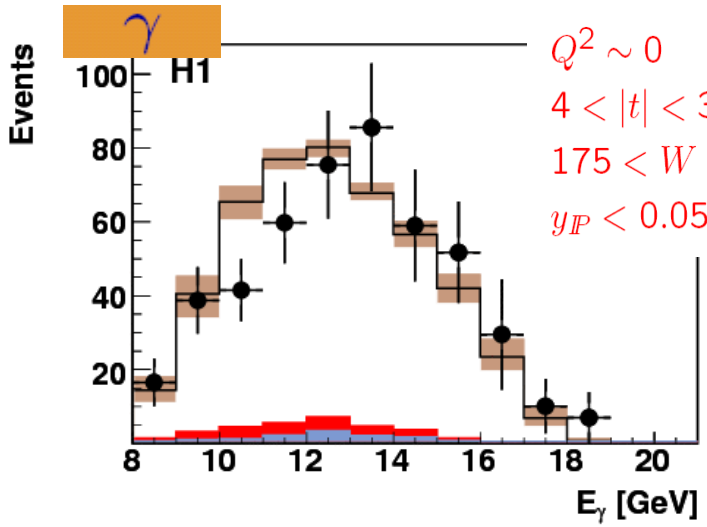
$$\gamma p \to \gamma Y$$

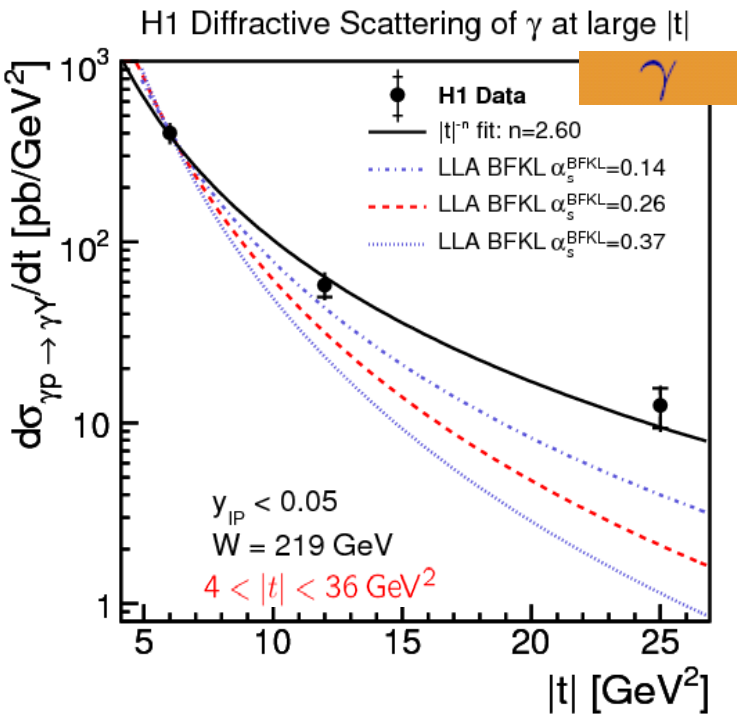


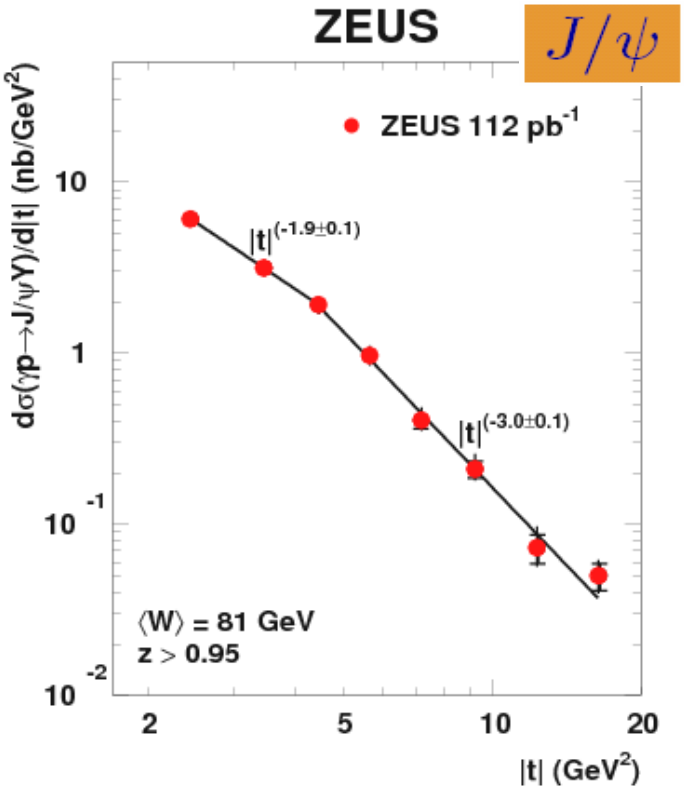

$Q^2 \sim 0$
$4 < |t| < 36$ GeV$^2$
$175 < W < 247$ GeV
$y_{I\!P} < 0.05$

# 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

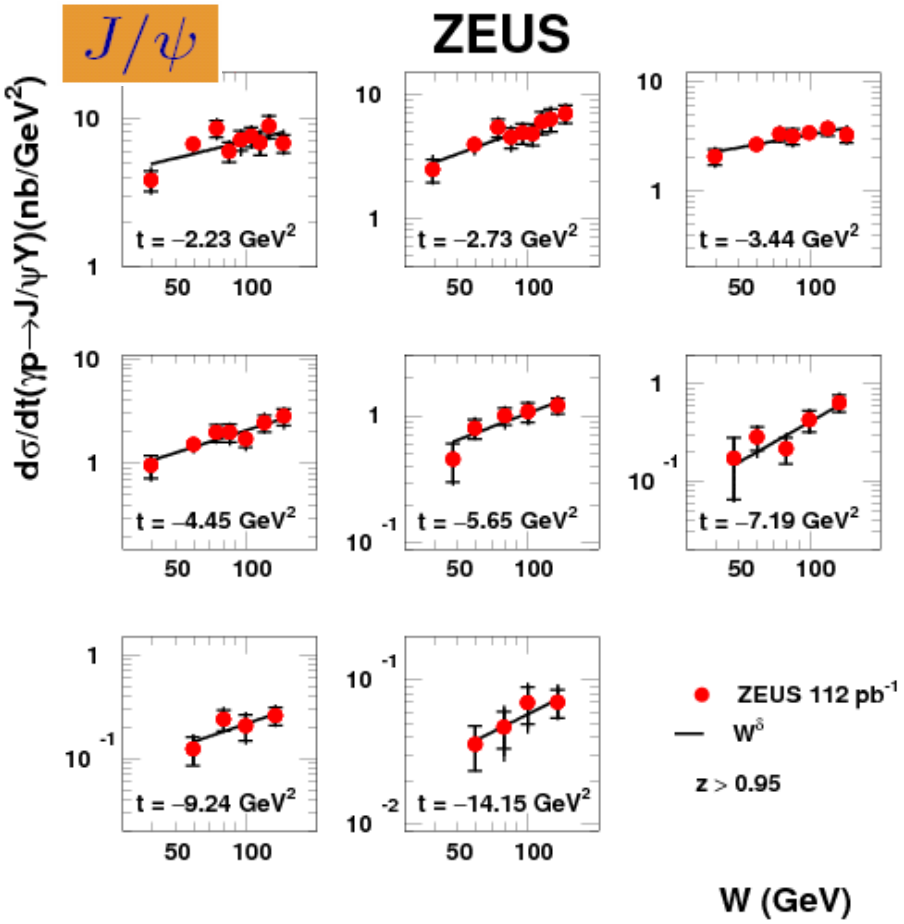
n=1.9±0.1 for 2<|t|<5 GeV²

n=3.0±0.1 for 5<|t|<20 GeV²

Good fit for 2<|t|<20 GeV² could be obtained using also exp(-b|t|+c|t|²)

# energy dependence and Pomeron trajectory

large |t|

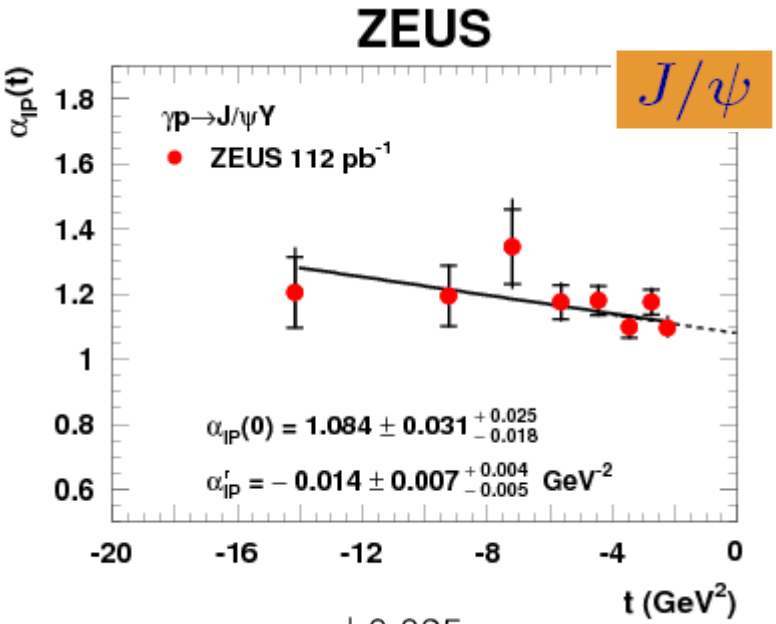



$$\frac{d\sigma}{d|t|} \propto \left(\frac{W}{W_0}\right)^{4(\alpha_{I\!P}(t)-1)}$$

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

Regge theory inspired

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




soft pomeron (DL):

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

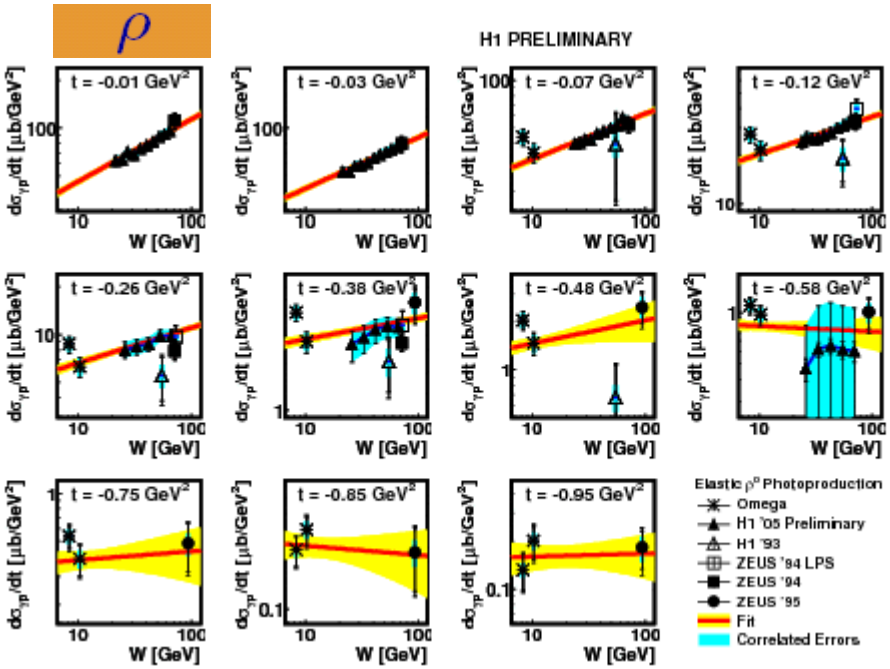
$$\alpha_{I\!P}(0) = 1.084 \pm 0.031^{+0.025}_{-0.018}$$

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

# energy dependence and Pomeron trajectory

elastic PHP ρ

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

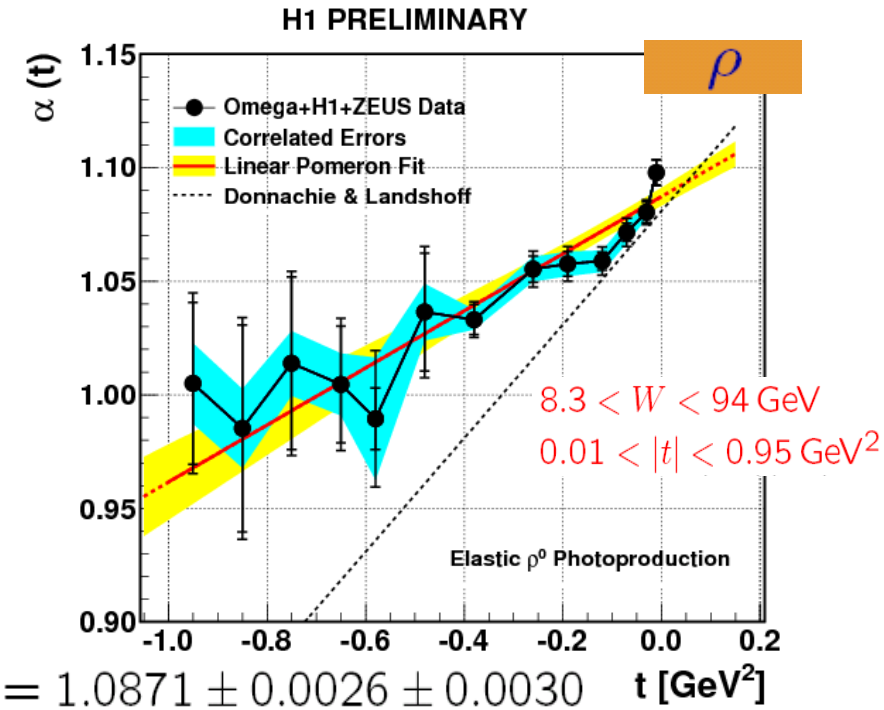



$$\frac{d\sigma}{d|t|} \propto \left(\frac{W}{W_0}\right)^{4(\alpha_{I\!P}(t)-1)}$$

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

Regge theory inspired

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

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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):

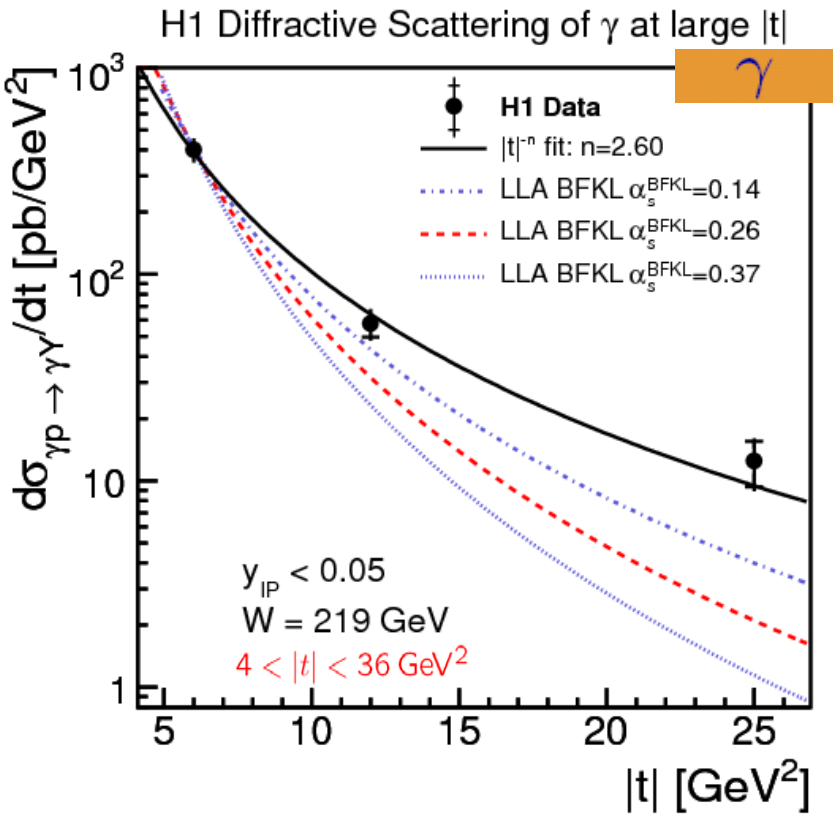
$$\alpha_{I\!P}(t) = 1.08 + 0.25t$$

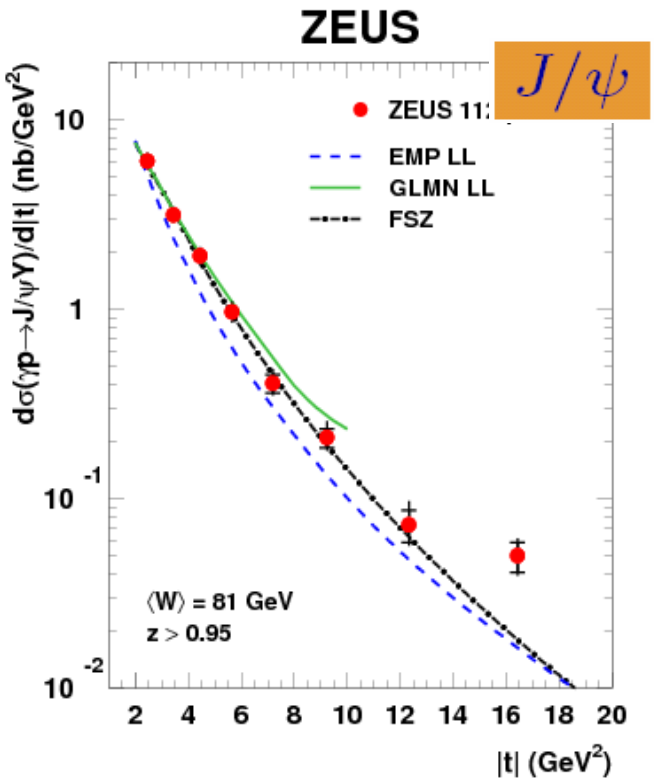
$$\alpha_{I\!P}(0) = 1.0871 \pm 0.0026 \pm 0.0030$$

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

# 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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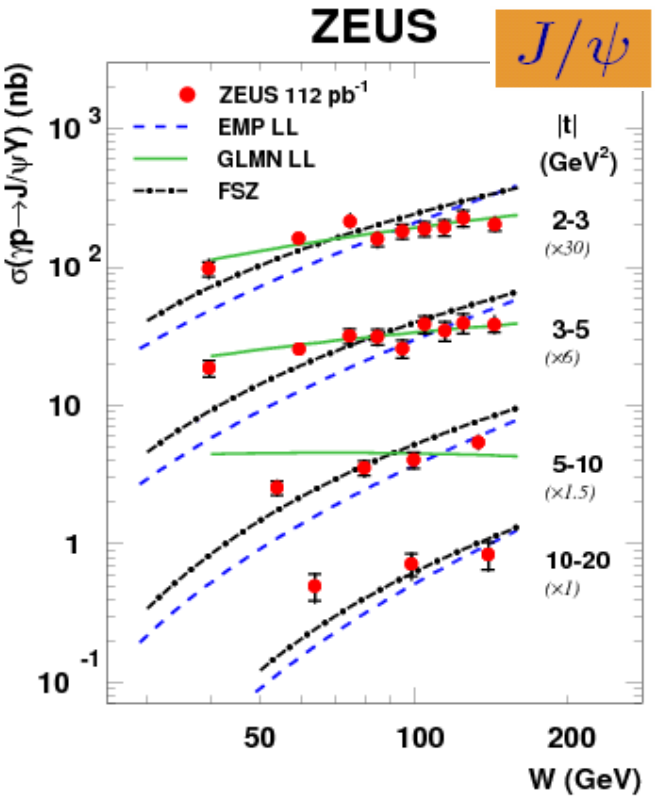
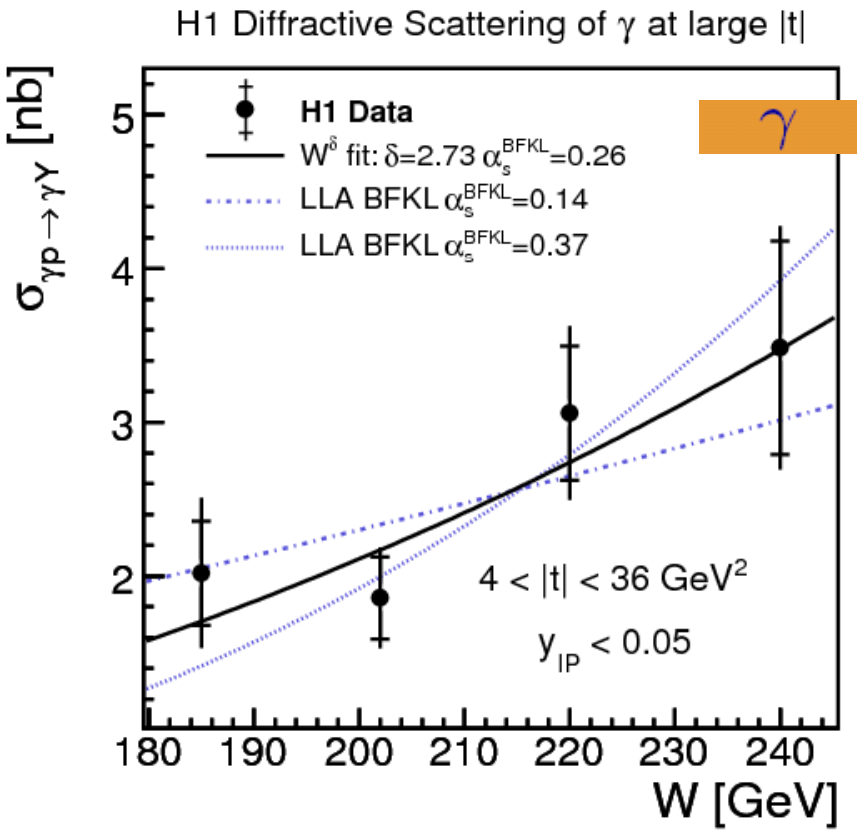
# large |t|: σ vs theory

- DGLAP (GLMN LL) describes data very well up to |t|=5 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 $\Upsilon$ cross section rises as $W^{\delta}$ and $\delta$ grows with the universal hard scale $Q^2+M^2_{VM}$
- pQCD motivated fit $d\sigma/dt \backsim t^{-n}$ 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 ($J/\psi$ / $\gamma$)