# QCD fits & Factorisation tests in diffraction at HERA

## *A next-to-leading-order QCD analysis of diffractive processes measured by the ZEUS experiment*

DIS 2009

Diffraction and Vector Mesons parallel session

April 2009, Madrid

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*On behalf of the ZEUS collaboration*

# *Fitting & testing procedure*

- **A systematic investigation**
  - NLO QCD fit to the inclusive DIS data
  - comparison and fit to dijets in DIS
  - comparison to dijets in PHP

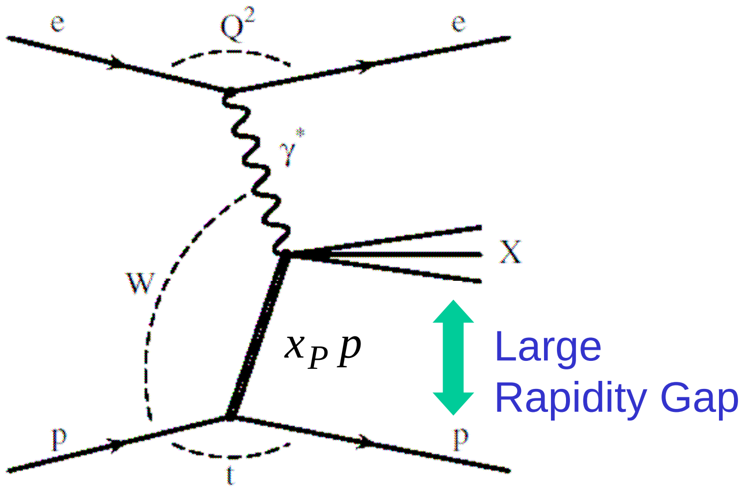
- **Massive quarks treatment**
  - VFNS vs. FFNS
  - arguments for GM-VFNS

- **Fixing gluons**

# *Inclusive diffractive DIS*

Kinematics of diffractive deep inelastic scattering

$$\beta = \frac{Q^2}{2(p-p')q} \approx \text{parton in IP fract. momentum}$$




$$p' = (1 - x_{IP})p$$

***t*-integrated cross section**

$$\frac{d\sigma}{d\beta\, dQ^2\, dx_{I\!P}} = \frac{2\pi\alpha^2}{\beta Q^4} \left(1 + (1-y)^2\right) \sigma_{\mathrm{r}}^{D(3)}(\beta, Q^2, x_{I\!P})$$

**expressed in terms of diffractive structure functions**

$$\sigma_{\mathrm{r}}^{D(3)}(\beta, Q^2, x_{I\!P}) = \underline{F_2^{D(3)}(\beta, Q^2, x_{I\!P})} - \frac{y^2}{1+(1-y)^2} \underline{F_{\mathrm{L}}^{D(3)}(\beta, Q^2, x_{I\!P})}$$

# *A model for diffractive $F_{2/L}$*

## Regge factorisation assumption

$$F_{2/\mathrm{L}}^{D(4)}(\beta, Q^2, x_{I\!P}, t) = f_{I\!P}(x_{I\!P}, t)\, F_{2/\mathrm{L}}^{I\!P}(\beta, Q^2) + f_{I\!R}(x_{I\!P}, t)\, F_{2/\mathrm{L}}^{I\!R}(\beta, Q^2)$$

*This assumption works for the inclusive DIS with*

- Regge-type flux $f(x_{I\!P}, t) = \frac{A\, e^{Bt}}{x_{I\!P}^{2\alpha(t)-1}}$ with $\alpha(t) = \alpha(0) + \alpha' t$
- free $F_{2/\mathrm{L}}^{I\!P}(\beta, Q^2)$
- $F_{2/\mathrm{L}}^{I\!R}(\beta, Q^2) \propto F_{2/\mathrm{L}}^{\pi}(\beta, Q^2)$ (GRV)

see Marta Ruspa talk

**Can QCD + DGLAP describe $F_{2/\mathrm{L}}^{I\!P}(\beta, Q^2)$ ?**

# *Factorisation & heavy quarks*

- **$F_{2/L}$ or any other cross section $\sigma$ for *N* massless flavours**
  - collinear divergencies caused by massless quarks factorised and absorbed into non-perturbative PDFs

$$\sigma\left(Q^2,\ldots\right)=\sum_k f_k^{(N)}\left(Q^2\right)\otimes\hat{\sigma}_k(\ldots)$$

  - nb. in diffraction $f_k^{(N)}\left(Q^2\right)\to f_k^{D(N)}\left(Q^2,x_{IP},t\right)$

Diffractive PDFs

- **+ 1 heavy flavour (massive quark) in FFNS**

$$\sigma\left(Q^2,\ldots\right)=\sum_k f_k^{(N)}\left(Q^2\right)\otimes\hat{\sigma}_k^{\mathrm{FF}}\left(m^2/Q^2,\ldots\right)$$

  - still *N* partons, heavy flavour in final state only
  - no extra collinear divergencies
  - new types of terms
    - $m^2/Q^2$ — important at low $Q^2$
    - $\log(m^2/Q^2)$ — large at high $Q^2$

Fixed Flavour Number Scheme

# *Heavy quarks treatment in VFNS*

- $m^2 / Q^2 \to 0$ **massless or infinite $Q^2$ limit**
  - large logs must be resummed
  - ➔ N+1 massless flavours

$$\sigma\left(Q^2,\ldots\right) = \sum_k f_k^{(N+1)}\left(Q^2\right) \otimes \hat{\sigma}_k(\ldots)$$

- **ZM(zero mass)-VFNS**
  - use (N+1) massless formula at $Q^2 > m^2$
- **GM(general mass)-VFNS**
  - log($m^2/Q^2$) resummed ➔ heavy quark PDF
  - proper behaviour at $Q^2 \sim m^2$

$$\sigma\left(Q^2,\ldots\right) = \sum_k f_k^{(N+1)}\left(Q^2\right) \otimes \hat{\sigma}_k^{\mathrm{VF}}\left(m^2 / Q^2,\ldots\right)$$

  - non-unique — Thorne-Roberts scheme used (as in ZEUS QCD fits)

***recover massless limit at N+1***

***Variable Flavour Number Scheme***

# *FN scheme choice*

- **GM-VFNS is most general → best choice**
- **Inclusive DIS**
  - FFNS and VFNS formulae available
  - both schemes give good description of the data
- **Dijets production**
  - available formulae (computer codes) use massless quarks
  - “closer” to VFNS than FFNS
  - VFNS provides heavy quark PDFs
    - OK at high $\mu$
    - still threshold effects missing at $\mu$ close to $m_h$

# *Diffractive PDFs parametrization*

## Regge factorisation assumption

$$f_k^{D(3)}(z,Q^2,x_{\mathbb{P}}) = f_{\mathbb{P}}(x_{\mathbb{P}})\, f_k^{\mathbb{P}}(z,Q^2) + f_{\mathbb{R}}(x_{\mathbb{P}})\, f_k^{\mathbb{R}}(z,Q^2)$$

Reggeon PDFs
taken from pion (GRV)

**Flux parametrization**

$$f(x_{\mathbb{P}},t) = \frac{A\,e^{Bt}}{x_{\mathbb{P}}^{2\alpha(t)-1}}$$

with $\alpha(t) = \alpha(0) + \alpha' t$

$$f_{\mathbb{P}/\mathbb{R}}(x_{\mathbb{P}}) = \int_{t_{\min}}^{t_{\max}} dt\, f_{\mathbb{P}/\mathbb{R}}(x_{\mathbb{P}},t)$$

4 parameters per flux:

$$A,\, b,\, \alpha(0),\, \alpha'$$

Half of the parameters ($b$ and $\alpha'$)
fixed by Regge fits
to e-p (ZEUS)
and p-p (Donnachie–Landshoff)

# *Pomeron PDFs parametrization*

Pomeron PDFs parametrized at some initial $Q_0^2$

for all flavours $q = \bar{q}$

$\Rightarrow$ quark singlet (total sea) $f_S^{IP} = \sum_q f_{q+}^{IP} = 2\sum_q f_q^{IP}$

symmetric light quarks assumed: *d* = *u* = *s*

$zf_k^{IP}\left(z, Q_0^2\right) = A_k\, z^{B_k}\,(1-z)^{C_k}$ $\quad k$ = g,S $\quad$ 6 parameters

× regularizing factor $\exp\left(-\frac{0.001}{1-z}\right)$ to allow for any $C_k$

*Free flux parameters:* $\alpha_P(0), \alpha_R(0), A_R$ $\quad$ 3 parameters

**9 parameters in total**

# Models for gluons

Gluons expected to be poorly constrained by the inclusive data.

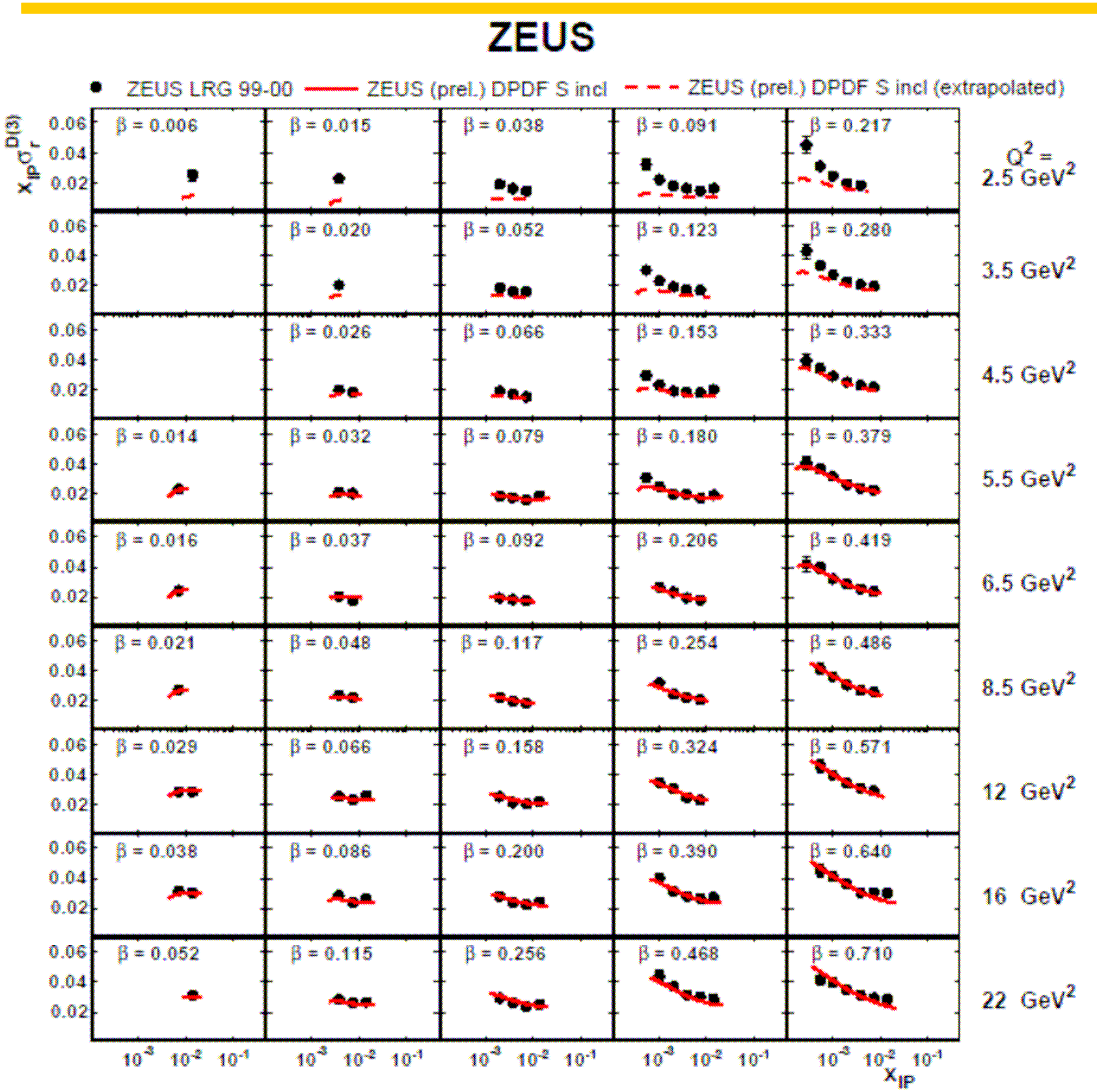
Consider two cases of the gluon parametrization

$$zf_g^{IP}\left(z,Q_0^2\right)=A_g\, z^{B_g}\left(1-z\right)^{C_g}$$

"Standard": Fit S with $B_g$, $C_g$ fitted
"Constant": Fit C with $B_g = C_g = 0$ (as in H1-2006B)

Both models provide equally good data description
but
very different gluons

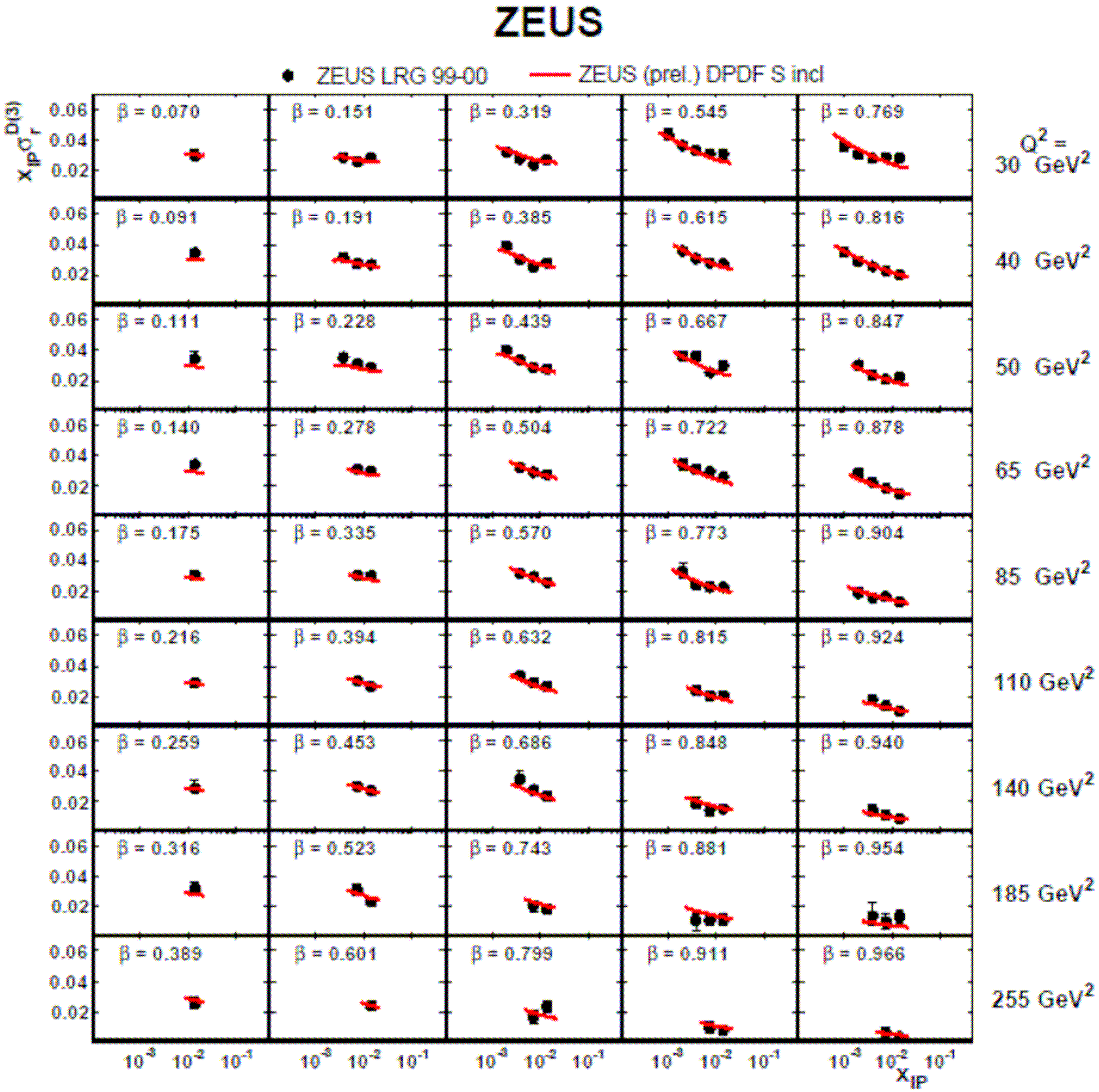
# *LRG data well described – low $Q^2$*




not used in the fits

$$x_{IP}\,\sigma_r^{D(3)}\left(\beta, Q^2, x_{IP}\right)$$

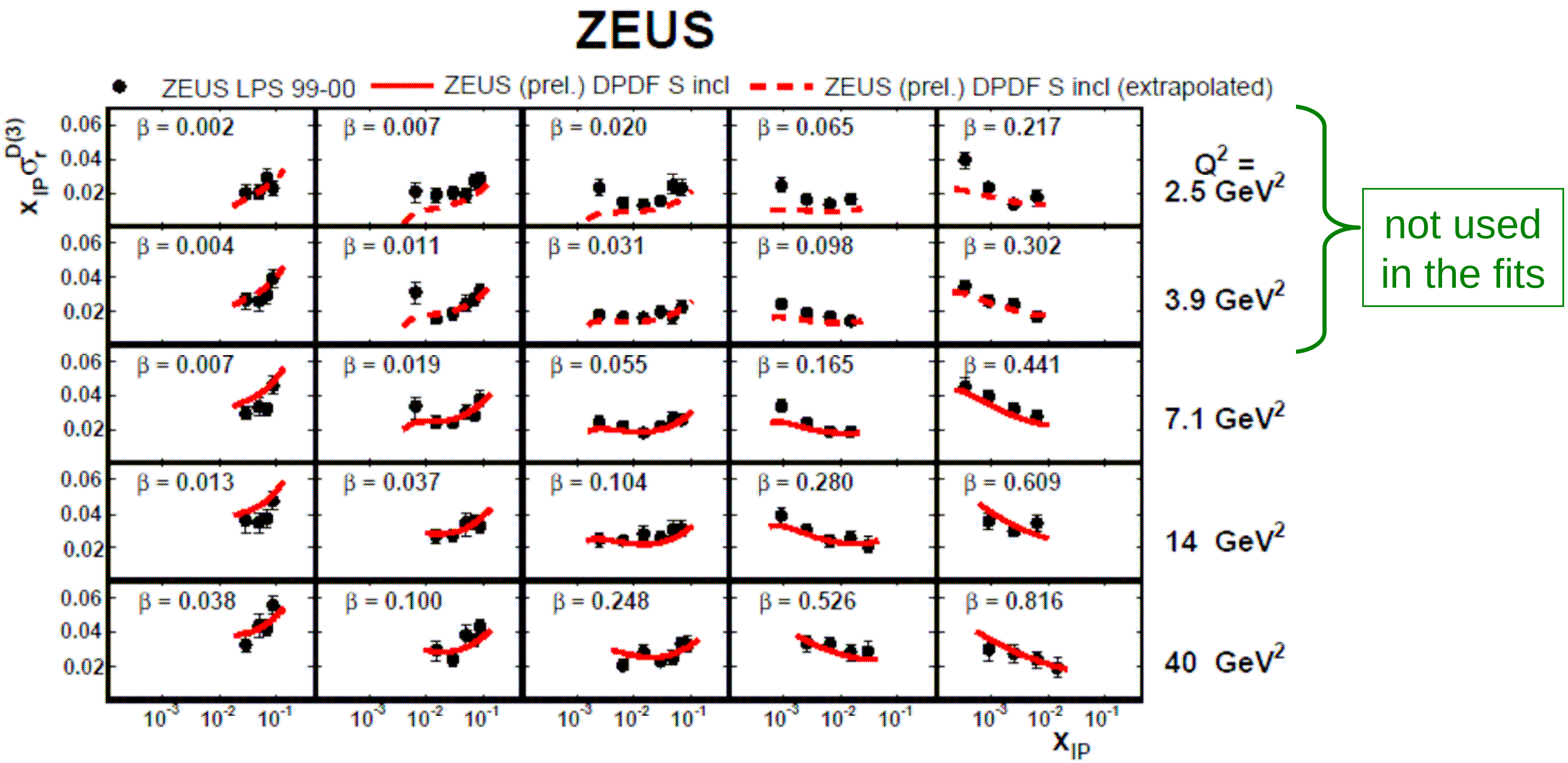
# LRG data well described – high $Q^2$



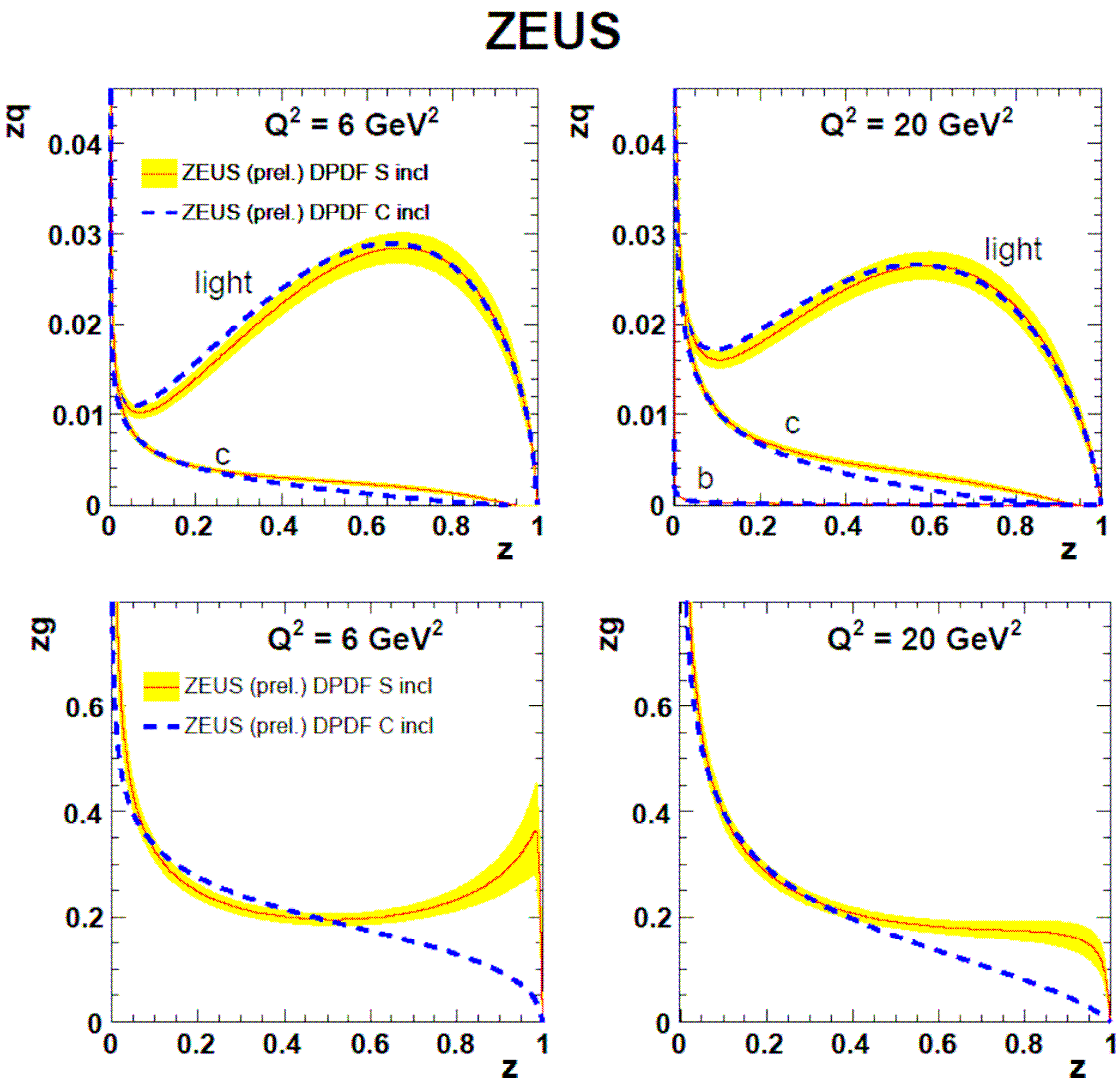

$$x_{IP}\,\sigma_r^{D(3)}\left(\beta,Q^2,x_{IP}\right)$$

# *LPS data well described*

$$x_{IP}\,\sigma_r^{D(3)}\left(\beta, Q^2, x_{IP}\right)$$



# *DPDFs from the inclusive fits*




yellow band shows fit experimental uncertainty

*flexible gluons*

*stiff gluons*

**Huge gluons uncertainty**

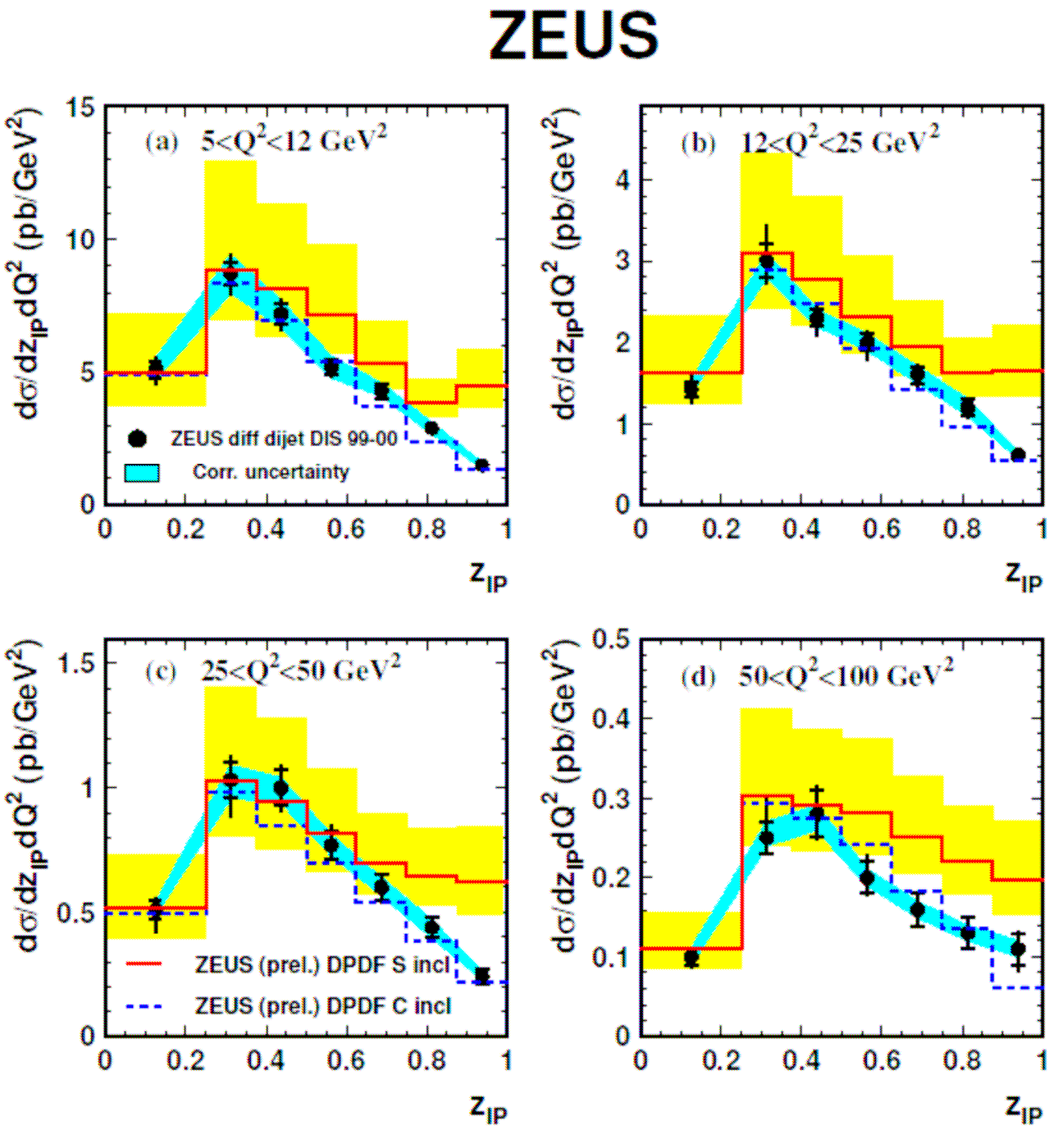
# *Dijets in diffractive DIS & PHP*

- **Dijet production is directly sensitive to gluons**
  - photon-gluon fusion at LO
- **DiJets in DIS (large $Q^2$)** *(J.C. Collins 1998)*
  **factorisation holds in pQCD**
  - compare to predictions based on inclusive DIS fits
  - use in incl+dijets fit
- **DiJets in PHP ($Q^2 \rightarrow 0$)**
  **factorisation assumed *for the resolved photon contribution***

$$\sigma\left(E_\perp^2,\ldots\right)=\sum_{j,k} f_j^{IP}\left(E_\perp^2\right)\otimes\hat{\sigma}_{jk}(\ldots)\otimes \boxed{f_k^{\gamma}\left(E_\perp^2\right)}$$

  - strong suppression observed in pp collisions (CDF/Tevatron)
  - compare to predictions based on incl+dijets fit

# *Dijets in DIS sensitive to gluons*



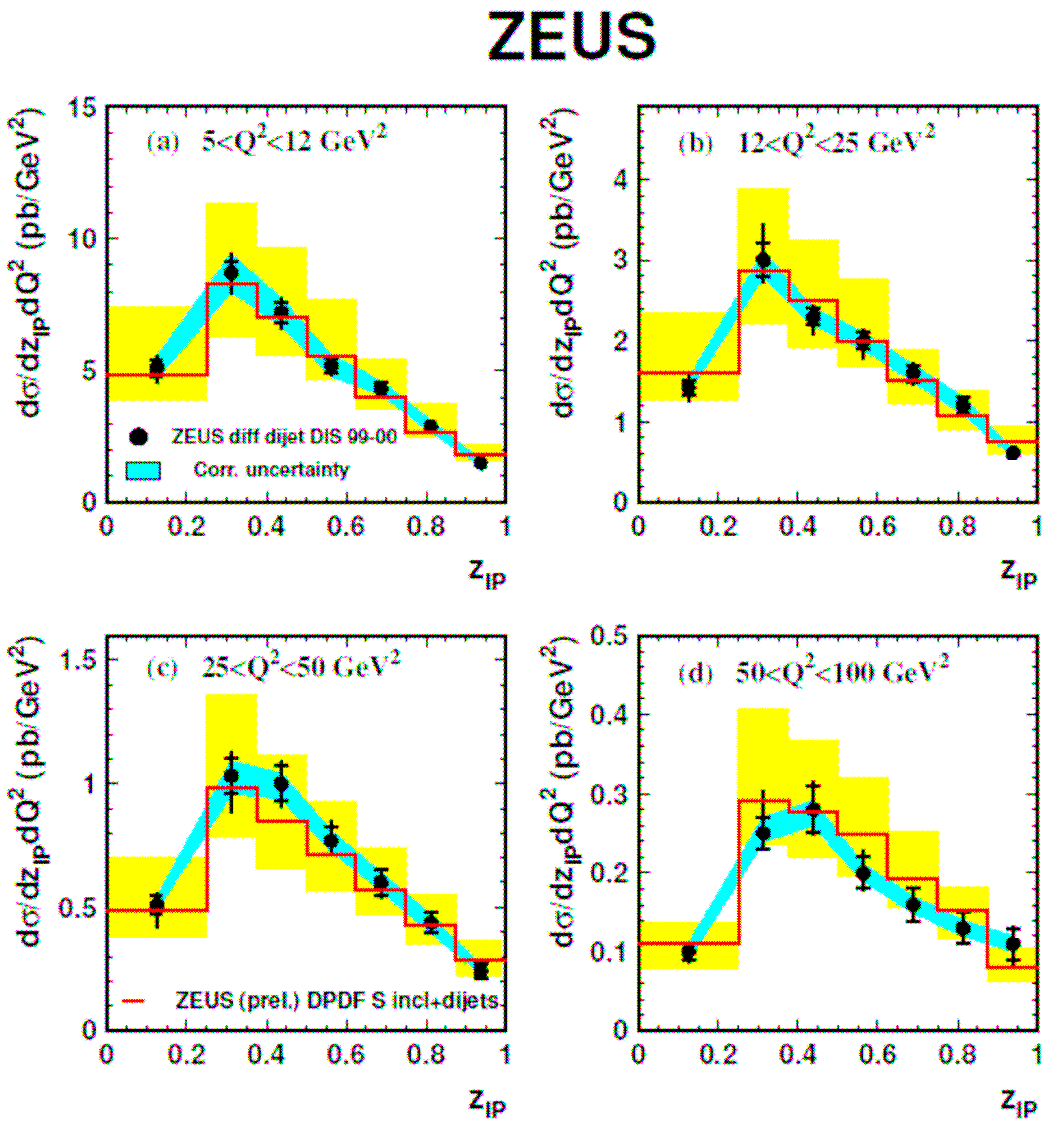

Fit S fails at $z > 0.4$

Fit C works surprisingly well

NLO QCD predictions from DISENT *(Catani, Seymour)* vs. ZEUS data
EPJ C52 (2007) 813

*NLOJET++ (Nagy) results agree within 5%*

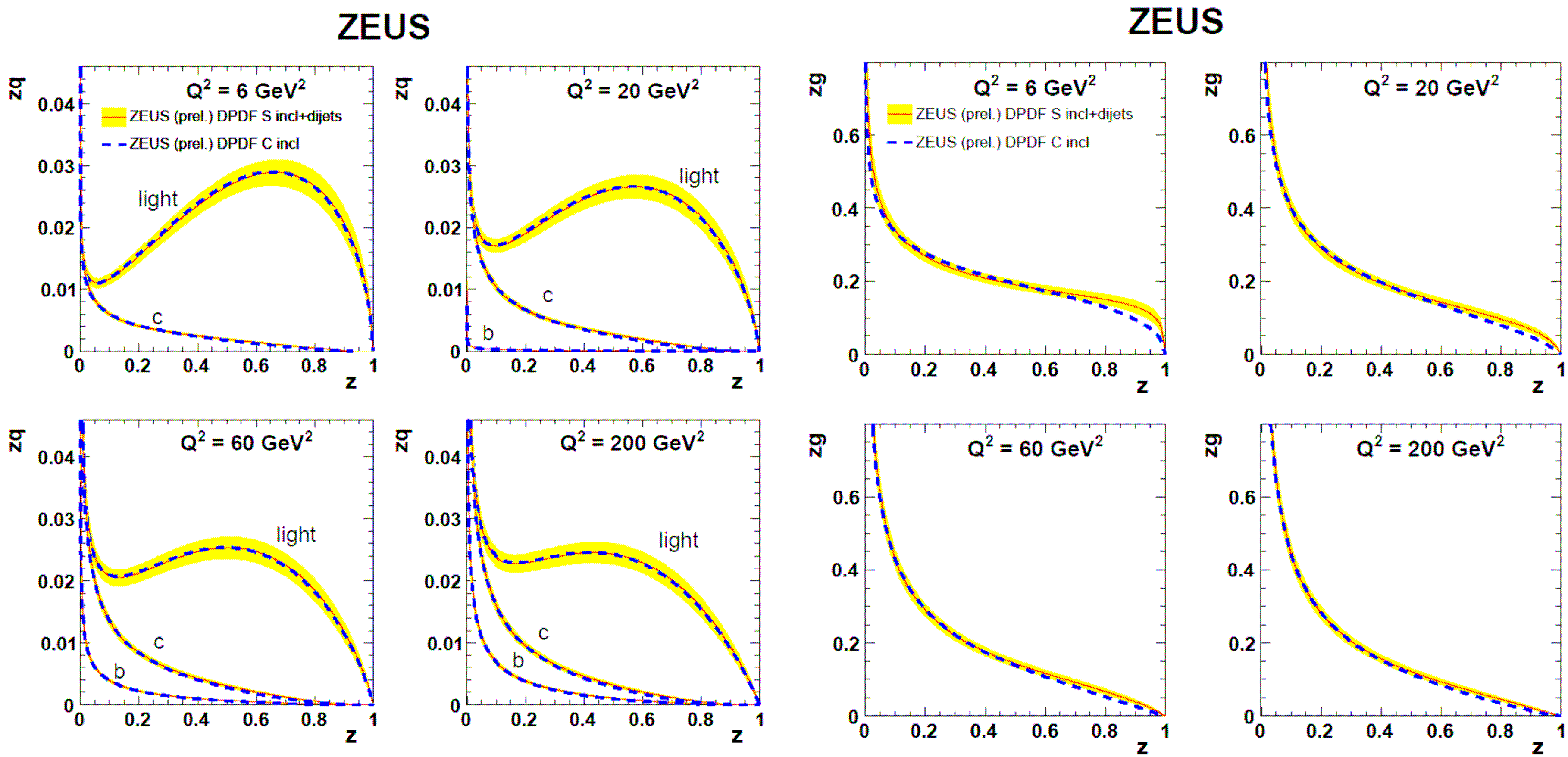
# *Inclusive + DIS dijets fit*




Fit S incl+dijets

good data description

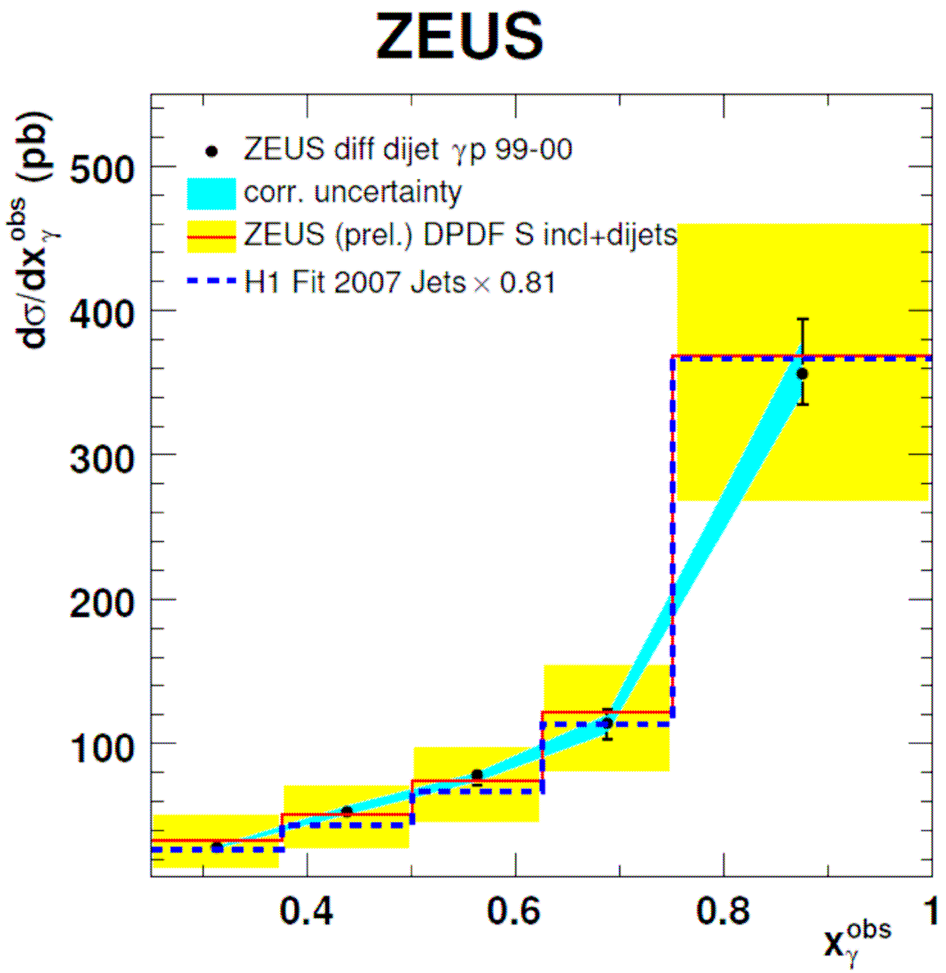
# *DPDFs from the inclusive+dijets fit*



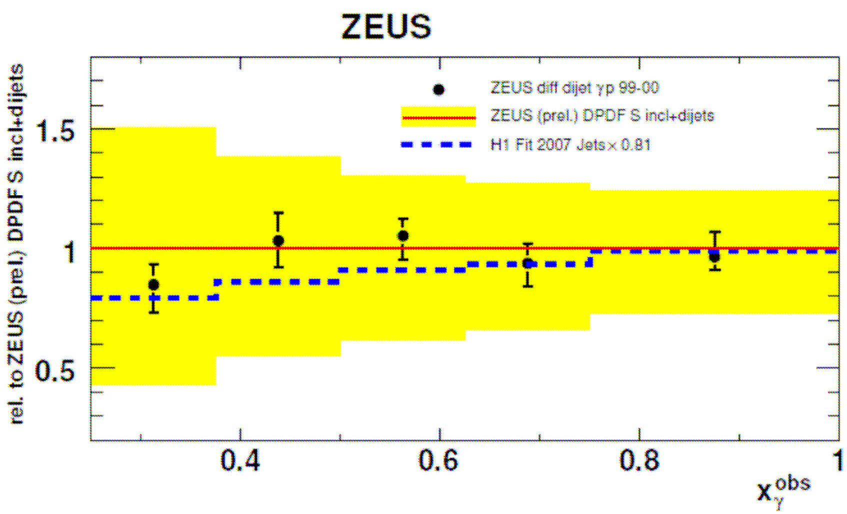

ZEUS (prel.) DPDF S incl+dijets — **gluons fixed by dijet data**

ZEUS (prel.) DPDF C incl — **gluons guessed**

# *Predictions for photoproduction of dijets vs. $x_\gamma$*



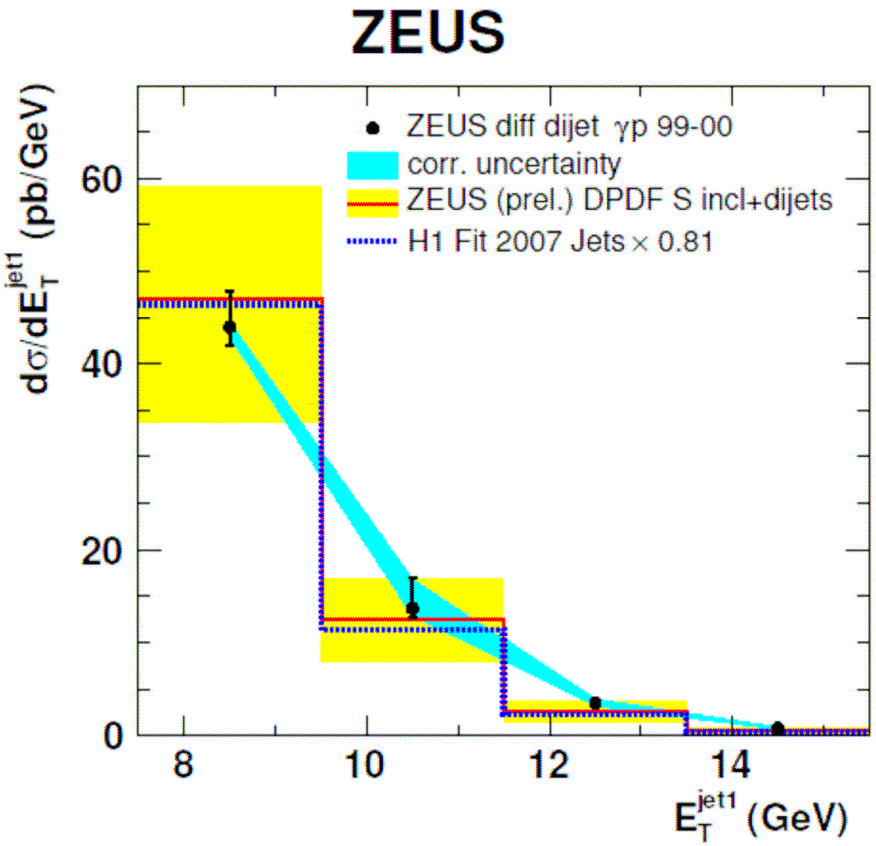

ZEUS data EPJ C55 (2008) 177

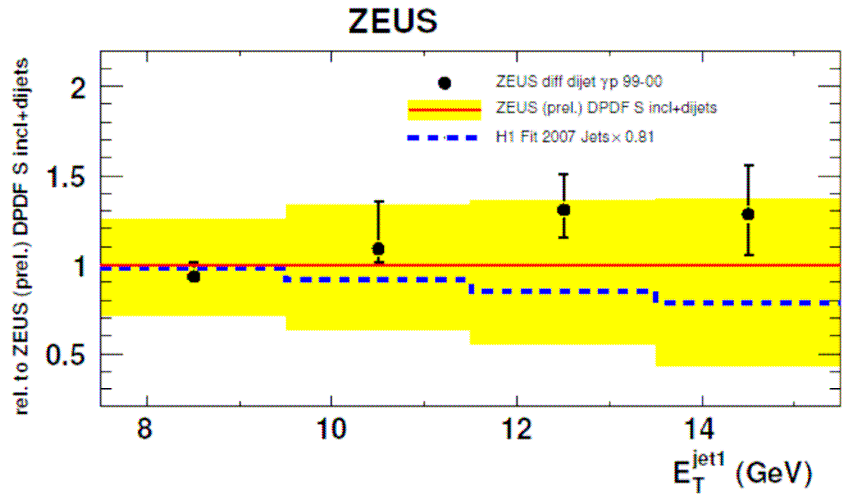



Very good data description
No evidence for suppression

NLO QCD predictions obtained *assuming factorisation*
Computer code by Frixione & Ridolfi, **γ PDFs: GRV-HO**

# Predictions for photoproduction of dijets vs. $E_T$




Good data description
No evidence for suppression

NLO QCD predictions obtained *assuming factorisation*
Computer code by Frixione & Ridolfi

# *Summary*

- **A systematic NLO analysis of the ZEUS diffractive data performed**
- **Successful GM-VFNS (Thorne-Roberts) fits to**
  - inclusive DIS only
  - inclusive DIS + DIS-dijets
- **NLO predictions for dijet production, using new DPDFs agree very well with the data**
- **No evidence for suppression in photoproduction**