# NLO DGLAP QCD Fit to H1 Inclusive Diffractive DIS Data

**10th Workshop on Deep Inelastic Scattering (DIS)**

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**H1 Collaboration**

- **NLO DGLAP QCD fit**
- **Parton distributions including error erstimate**
- **Gluon fraction and $F_L^D$**
- **Comparisons with diffractive final state data (HERA and TEVATRON)**

# Foundation

**Theoretical:**

**Proof of semi-inclusive QCD hard scattering factorization for diffractive DIS (J. Collins):**

**At leading twist:**

$$\frac{d^2\sigma(x,Q^2,x_{I\!P},t)^{\gamma^* p\rightarrow p' X}}{dx_{I\!P}\ dt} = \sum_i \int_x^{x_{I\!P}} d\xi \hat{\sigma}^{\gamma^* i}(x,Q^2,\xi)\ p_i^D(\xi,Q^2,x_{I\!P},t)$$

- Clear theoretical framework to define diffractive parton distributions $p_i^D$ (at fixed $x_{I\!P}$, $t$)
- Equivalent to standard DIS:
  - Determine $p_i^D$ in a DGLAP QCD fit to inclusive diffr. cross section $\sigma_r^D$
  - Test factorization by comparisons with diffractive final state data (e.g. Dijets)
- Apply same NLO QCD DGLAP apparatus to $Q^2$ and $\beta$ or $x$ dep. as in inclusive DIS

**Experimental:**

- Precise H1 measurement of $Q^2$,$\beta$ dep. of diffractive reduced cross section

$$\sigma_r^{D(3)} = F_2^{D(3)} - \frac{y^2}{1+(1-y)^2} F_L^{D(3)} \qquad (\sigma_r^D = F_2^D \text{ if } F_L^D = 0)$$

(see previous talk)

# Fitting Technique

## Modelling of $\sigma_r^{D(3)}$:

- Ideally determine diffractive pdf's at at fixed $x_{I\!P}$ , but ...
- Shape of $Q^2$,$\beta$ dep. of $\sigma_r^D$ observed to be largely independent of $x_{I\!P}$:

$$\sigma_r^{D(4)}(x_{I\!P}, t, \beta, Q^2) = f_{I\!P}(x_{I\!P}, t) * \sigma_r^{D(2)}(\beta, Q^2)$$

- $x_{I\!P}$ dependence conveniently parameterized as

$$f_{I\!P}(x_{I\!P}) = \int dt\ x_{I\!P}^{1-2\alpha_{I\!P}(t)} e^{B} t$$

  using $\alpha_{I\!P}(0) = 1.173 \pm 0.018$ (determined from data)
- Small contribution from sub-leading exchange at large $x_{I\!P} > 0.01$ required

## PDF parameterization:

- At starting scale $Q_0^2 = 3\ \mathrm{GeV}^2$:
  - Singlet distribution $\Sigma(z, Q_0^2)$ $(\Sigma = 6u,\ u = d = s = \bar{u} = \bar{d} = \bar{s})$
  - Gluon distribution $g(z, Q_0^2)$
- Parameterization using unbiased, flexible functional form: Chebychev polynomials

$$zp_i(z, Q_0^2) = \left[\sum_{j=1}^{n} C_j^i P_j(2z-1)\right]^2 e^{\frac{a}{z-1}}$$

- Charm treatment in massive approach (BGF)

## Minimization and Error Propagation

**DGLAP QCD fit performed using same framework as for inclusive QCD analysis of $F_2(x, Q^2)$ by H1** **(C. Pascaud, F. Zomer, LAL)**

### (1) Experimental Uncertainties:

**Full propagation of correlated experimental systematic uncertainties yield uncertainty information for extracted pdfs**

$$\chi^2 = \sum_i \frac{\left[\sigma_i^{exp} - \sigma_i^{th}(1 - \sum_j c_j \Delta_{sys,ij})\right]^2}{\Delta_{stat,i}^2 + \Delta_{unc,i}^2} + \sum_j c_j^2$$

$\Delta_{sys,ij}$: Effect of correlated systematic error source $j$ on data point $i$
$c_j$: Systematic parameters
$\longrightarrow$ systematic errors fitted by shifting data central values

### (2) Model uncertainties estimated from variations of:

- Strong coupling $\Lambda_{QCD} = 200 \pm 30$ MeV $\longleftarrow$ small
- Charm mass $m_c = 1.5 \pm 0.1$ GeV $\longleftarrow$ small
- Parameterization of $x_{I\!P}$ dependence ($\alpha_{I\!P}(0)$,$\alpha'_{I\!P}$,$B_{I\!P}$) $\longleftarrow$ dominant
- Parameterization of sub-leading high $x_{I\!P}$ contribution $\longleftarrow$ negligible

# NLO QCD Fit to $\sigma_r^D$

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

## Datasets:

- H1 1997 preliminary data $6.5 \le Q^2 \le 120\ \mathrm{GeV}^2$ (284 points)
- H1 94-97 preliminary data $200 \le Q^2 \le 800\ \mathrm{GeV}^2$ (29 points)

## Phase space and Cuts:

- $x_{I\!P} < 0.05 \qquad 0.01 \le \beta \le 0.9$
- $M_X > 2\ \mathrm{GeV} \longrightarrow$ leading twist analysis, avoid high $\beta$ at low $Q^2$ ($\sigma_L^{H.T.}$ region)
- NLO fit: full $y$ range of measurement ($y < 0.75$); LO fit: $y < 0.45$ ($F_L^D$)

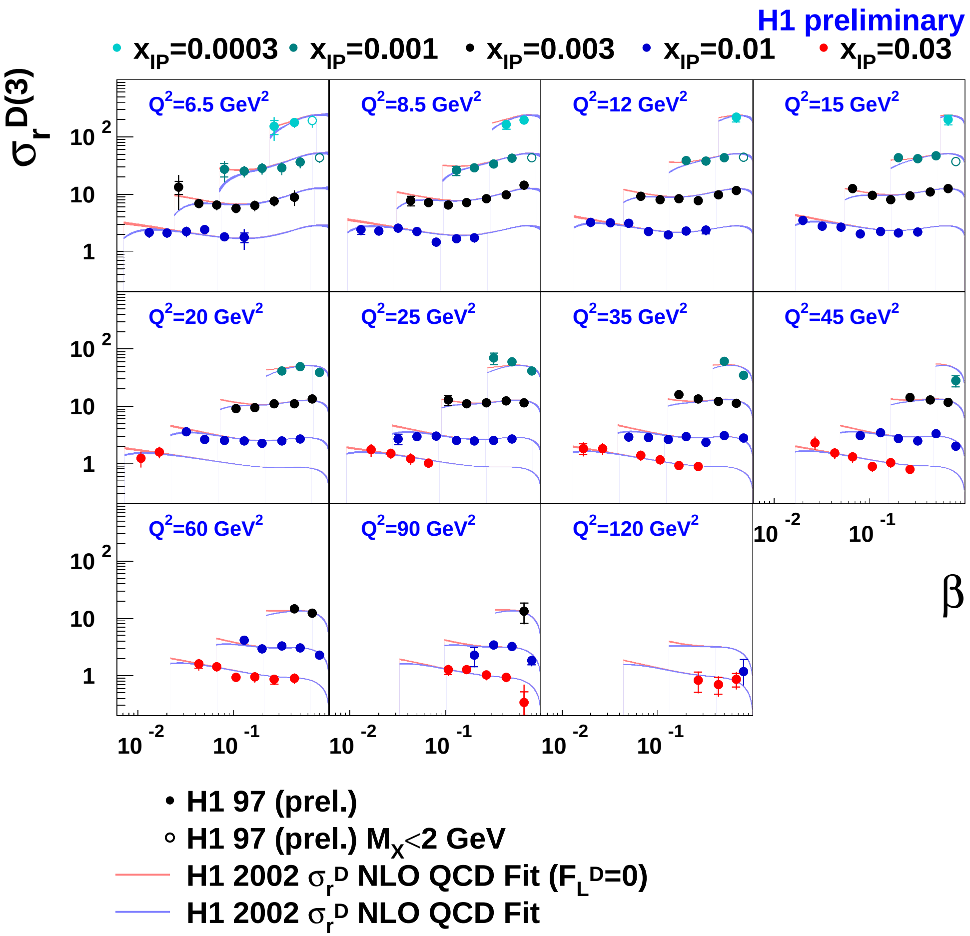
## Free fit parameters and $\chi^2$:

- 3+3 parameters for singlet $\Sigma(z)$ and gluon $g(z)$ parameterization (from systematic study)
- 1 normalization of sub-leading exchange contribution at high $x_{I\!P} > 0.01$

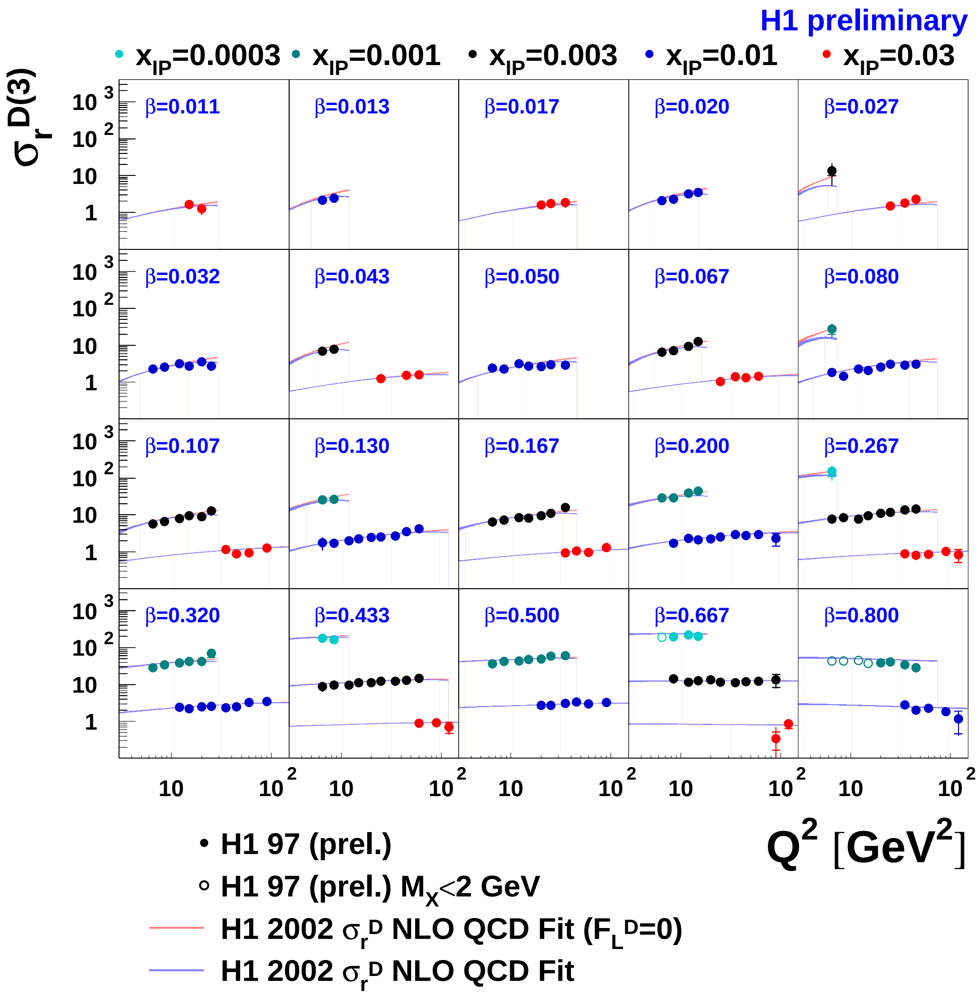
- $\chi^2/ndf = 308.7/306$

# Comparison of NLO QCD fit with Data

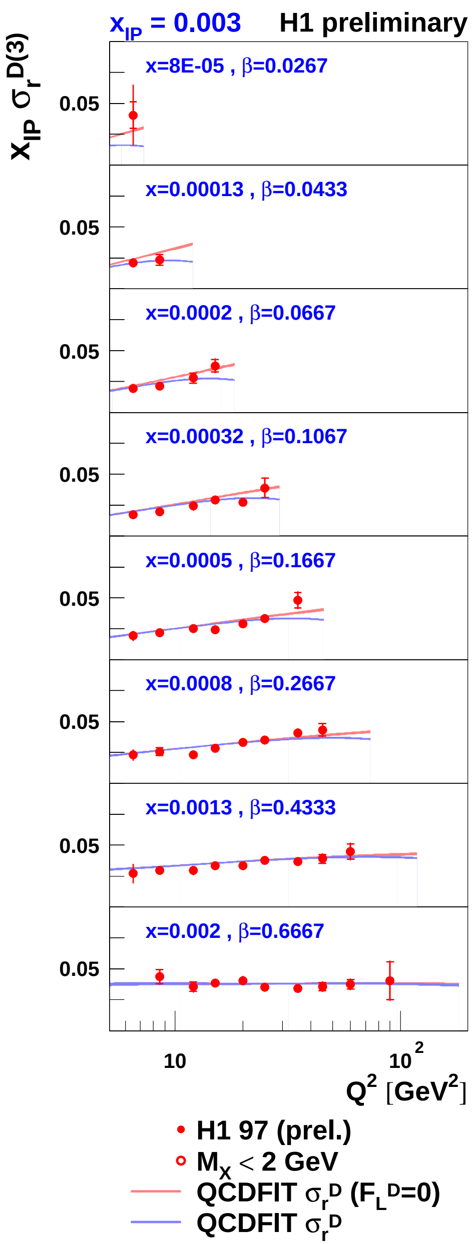
## $\beta$ dependence at fixed $Q^2$:

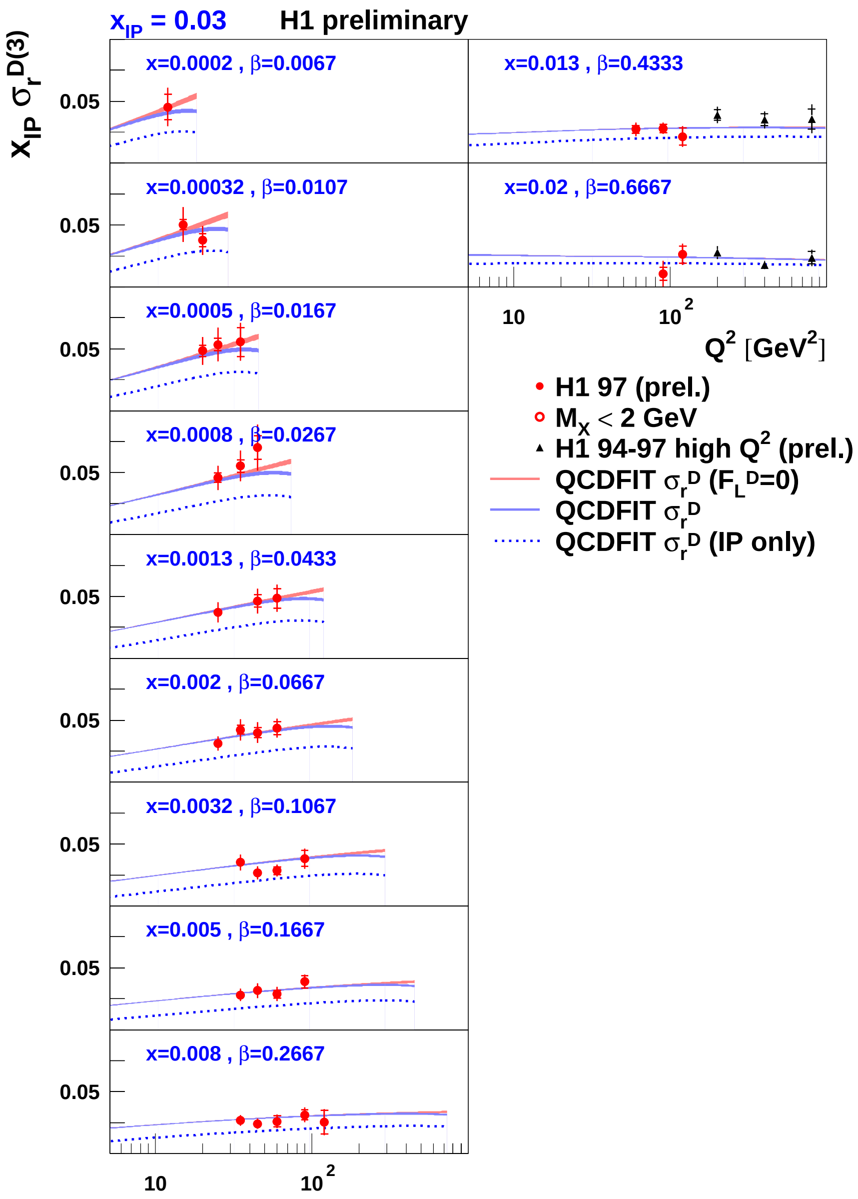



## $Q^2$ dependence at fixed $\beta$:



# Comparison of NLO QCD fit with Data: $Q^2$ dep.




**Two example $x_{\mathbb{P}}$ bins**

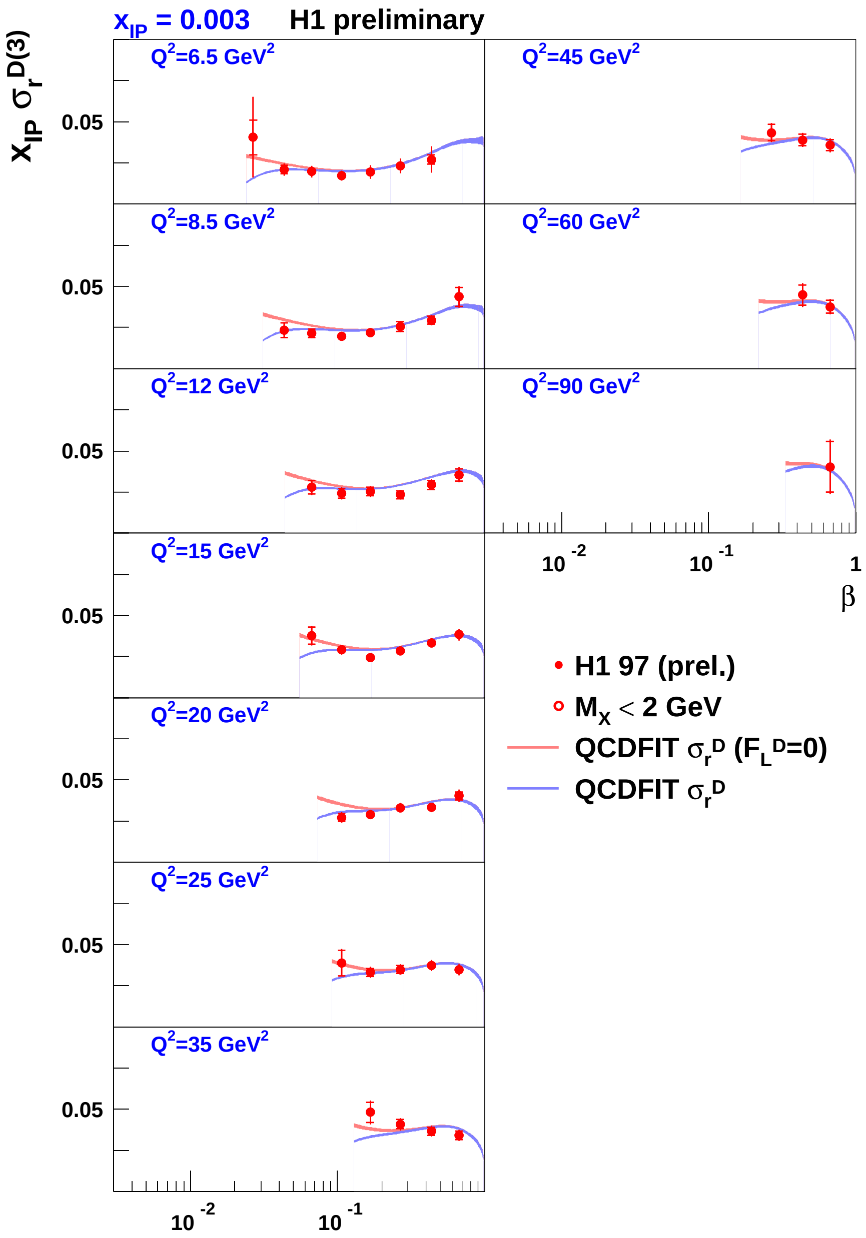
**$Q^2$ scaling violations well constrained by data**

**Rising except at highest $\beta$**

**Well reproduced by QCD fit up to $Q^2 = 800\ \mathrm{GeV}^2$**

**Sub-leading contribution at $x_{\mathbb{P}} = 0.03$, smaller than for previous data**

# Comparison of NLO QCD fit with Data: $\beta$,$x$ dep.




**Example $x_{I\!P}$ bin at 0.003:**

**Rising behaviour at $\beta \longrightarrow 1$, low $Q^2$ reflected by $\Sigma(z,Q^2)$**

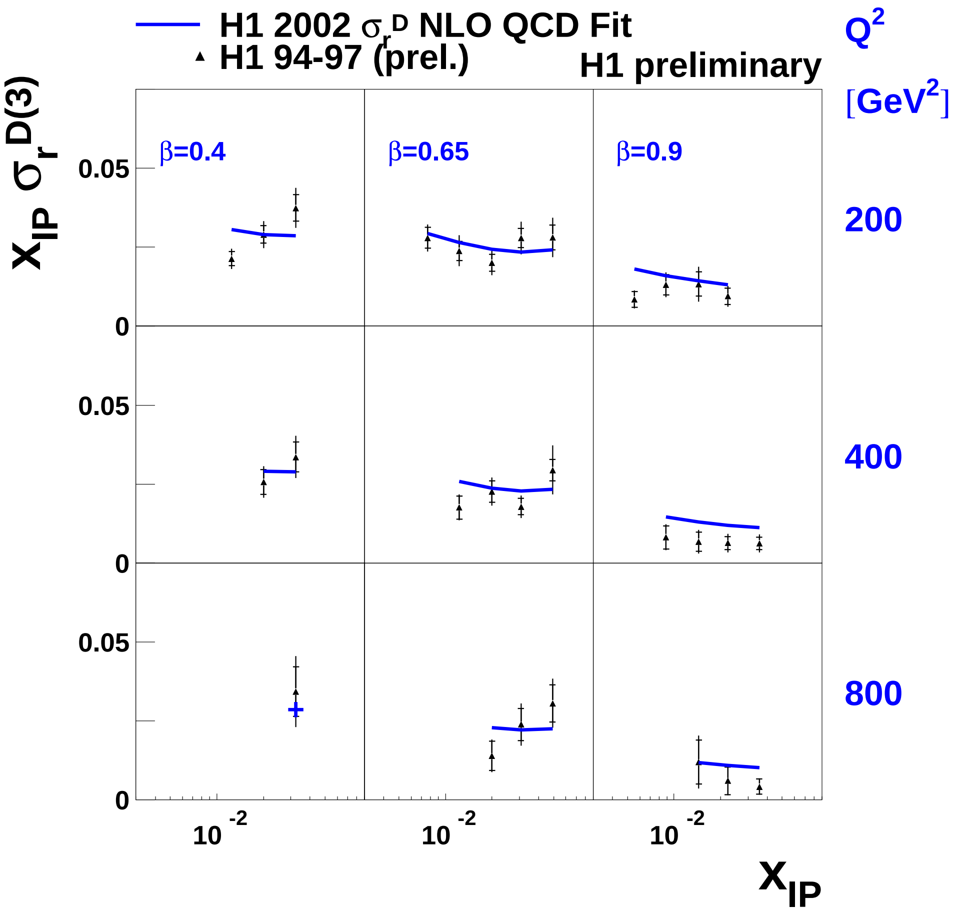
**$\beta$ dependence independent of $x_{I\!P}$**

**high $y \leftrightarrow$ low $x$ or $\beta$ at fixed $x_{I\!P}$: Effect of $F_L^D$**

**presently no direct handle on $F_L^D$ from data**

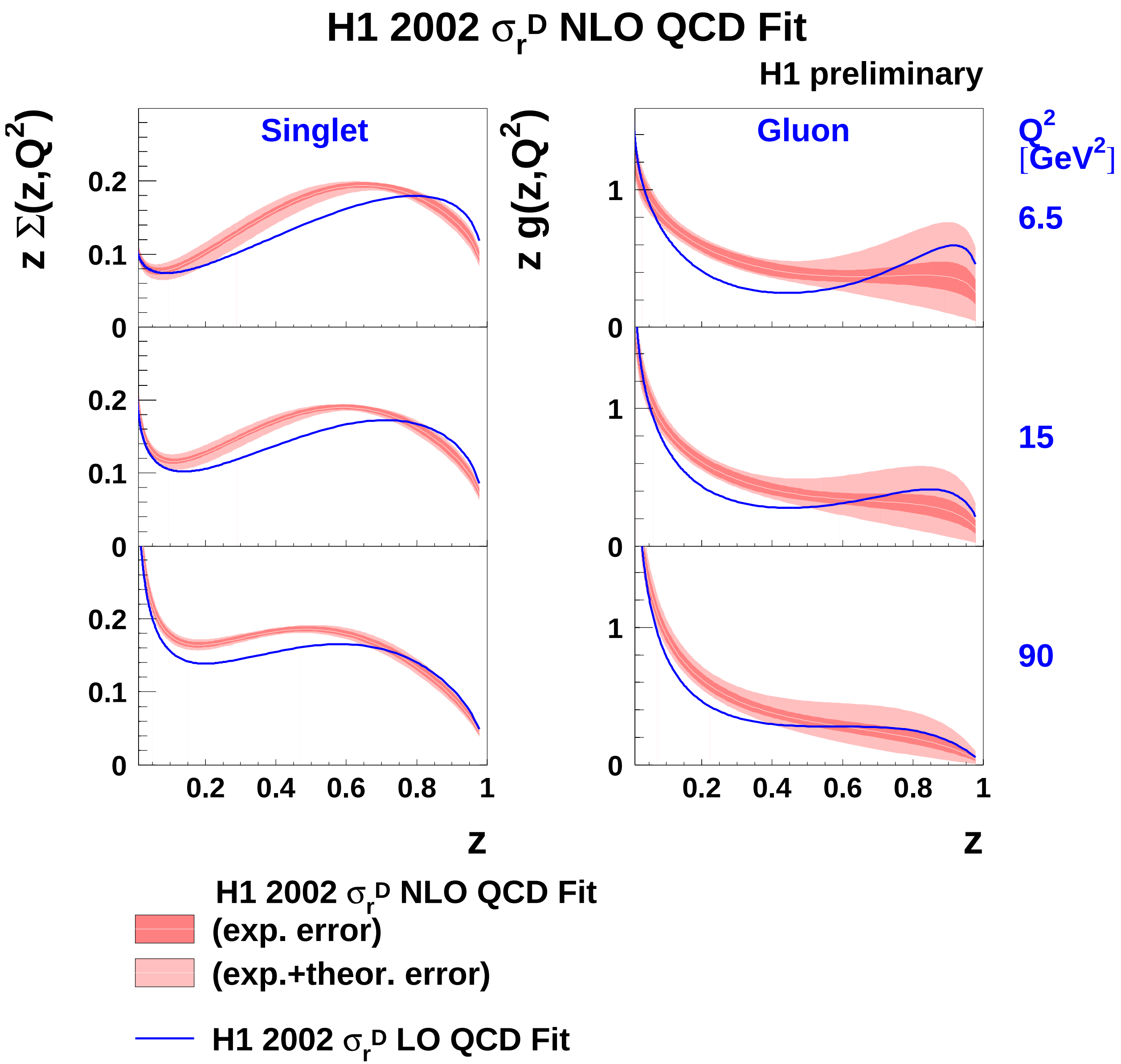
# Comparison of QCD fit with high $Q^2$ data

## Fair agreement within experimental errors



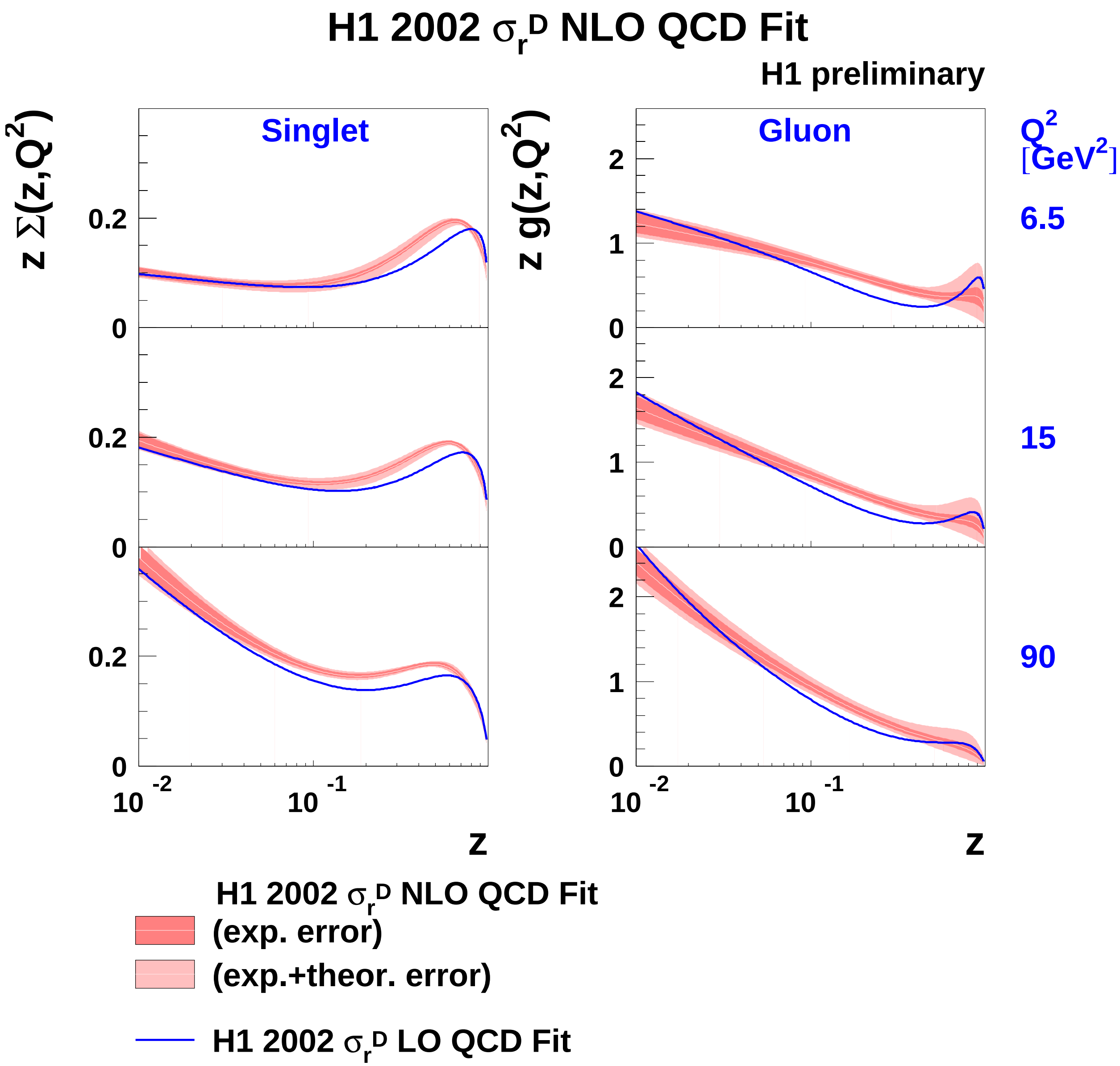

→ **Precision at high $Q^2$ to be improved**

# Result of NLO fit




- pdfs extending to large fractional momenta $z$
- precise measurement of singlet distribution $\Sigma(z, Q^2)$
- hard gluon distribution, flat or rising towards $z \longrightarrow 1$ (LO fit more peaked than central NLO fit)
- large uncertainty for $g(z, Q^2)$ at $z > 0.6$ (mainly related to model)

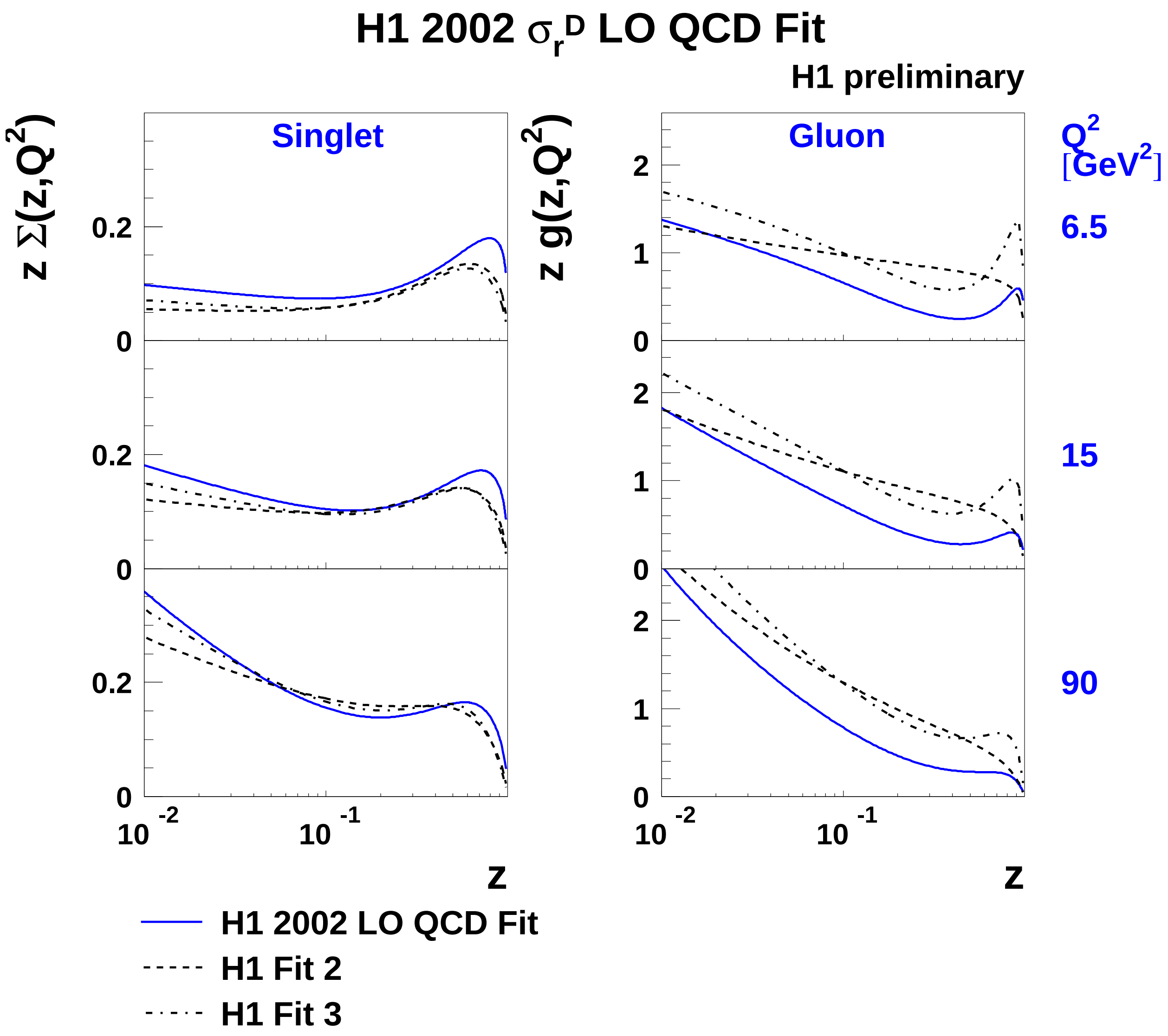
# Result of NLO fit




**Same pdf's shown on a log z axis:**

- **low-$z$ behaviour driven by QCD evolution**
- **gluon distribution dominating**

# Leading order Fit and Comparison with previous H1 fits

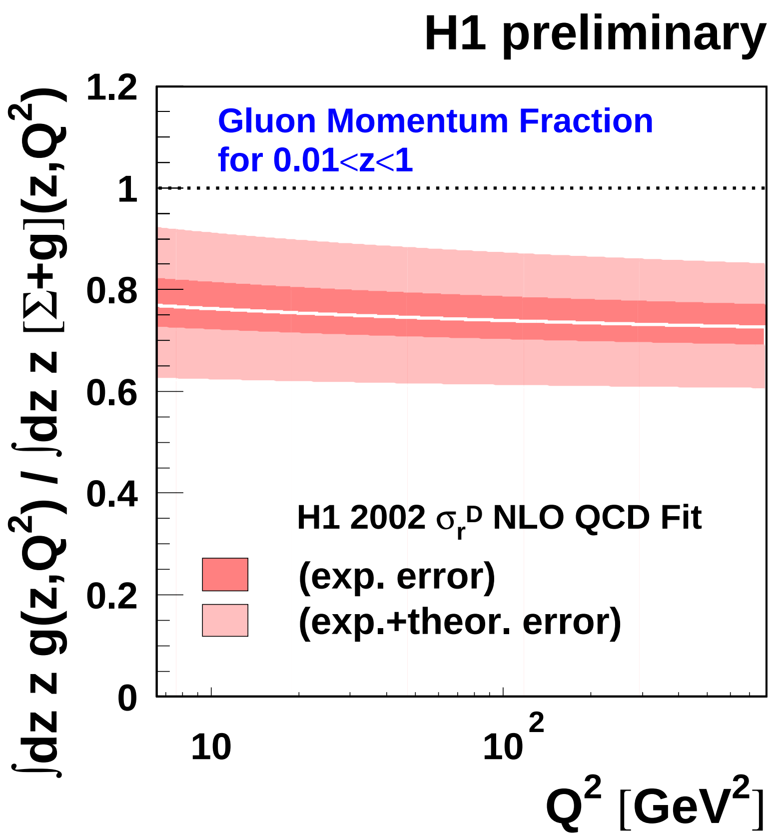



- **Comparisons with previous LO fits to 1994 data:**
  - H1 Fit 2 ("flat gluon")
  - H1 Fit 3 ("peaked gluon")
- **Reasonable agreement of $\Sigma(z, Q^2)$ for $z < 0.65$ (common fit range)**
- **Gluon normalization smaller by $20 - 30\%$ at low $z$, $50\%$ at high $z$**

**Agreement reasonable , taking errors of old and new fits into account**

# Gluon Momentum Fraction

## From NLO Fit:

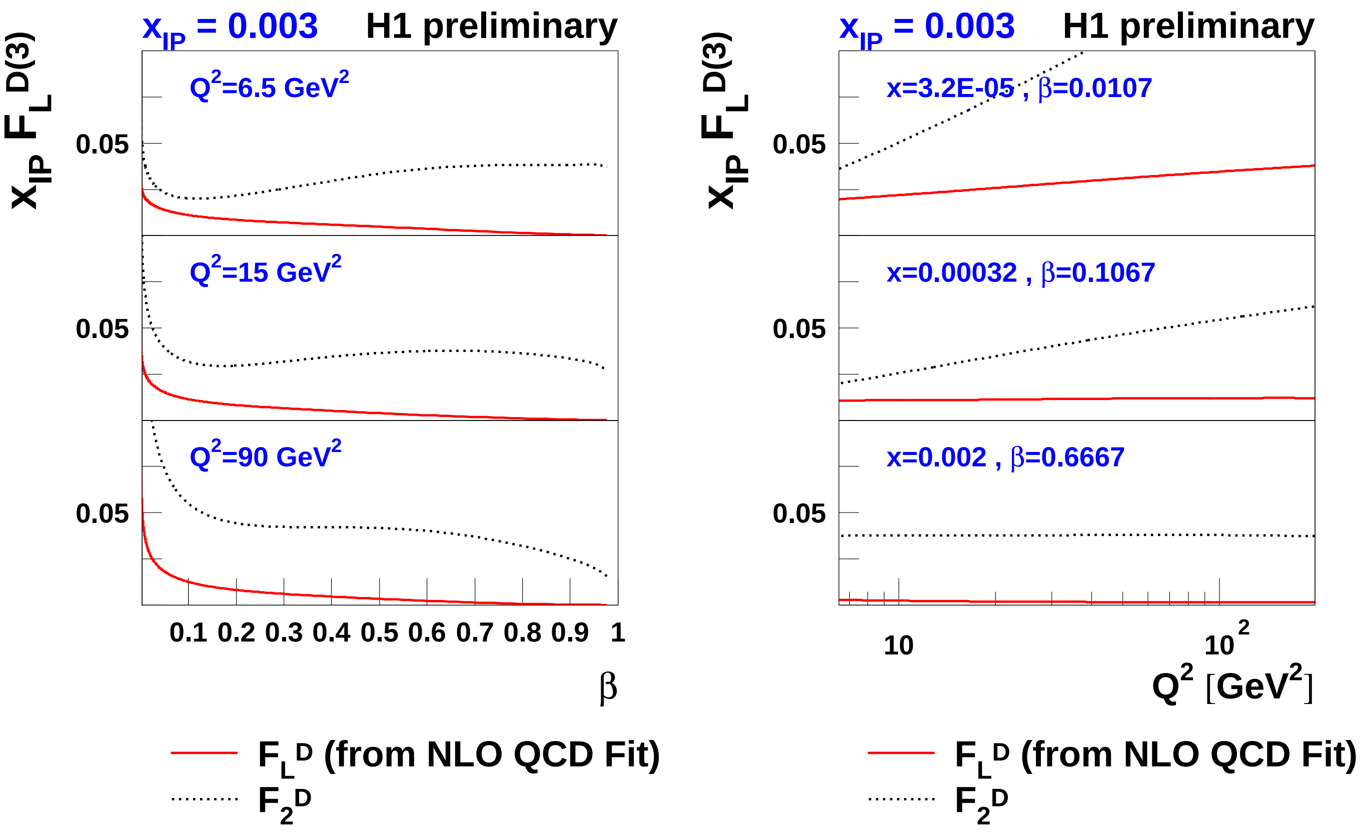



- **Integration of pdf's in measured range $0.01 < z < 1$**
- **Momentum fraction of colour singlet exchange carried by gluons $75\%$ for $6.5 < Q^2 < 800\ \mathrm{GeV}^2$**
- **Fully consistent with results from previous H1 data**

# Longitudinal Structure Fraction $F_L^D$

**At NLO QCD, the leading twist longitudinal structure function $F_L^D$ is predicted:**

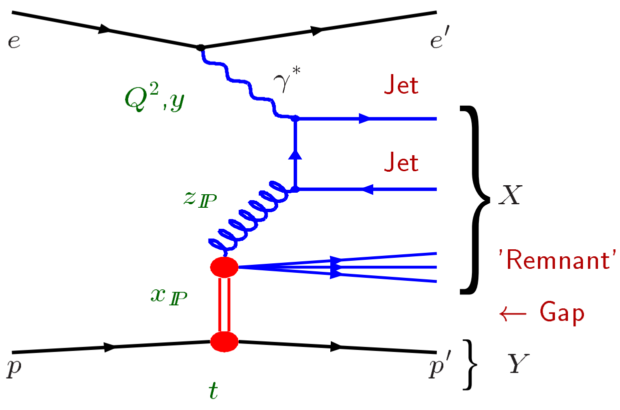
$$F_L^D \sim \frac{\alpha_s}{2\pi}\left[C_q^L \otimes F_2^D + C_g^L \otimes \sum_i e_i^2 \; z g^D(z,Q^2)\right]$$




**$\longrightarrow$ pert. $F_L^D$ rel. large, in particular at low $Q^2$, low $\beta$ (due to large $g(z,Q^2)$)**

# Comparison with H1 diffractive DIS final states

**Use pdf's from LO fit to predict dijets / $D^*$ cross sections in diffractive DIS as measured by H1:**

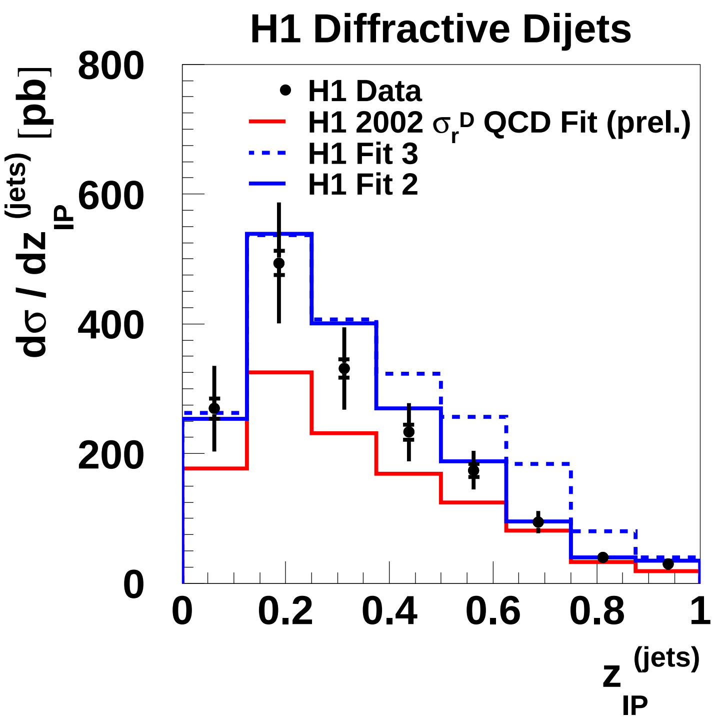


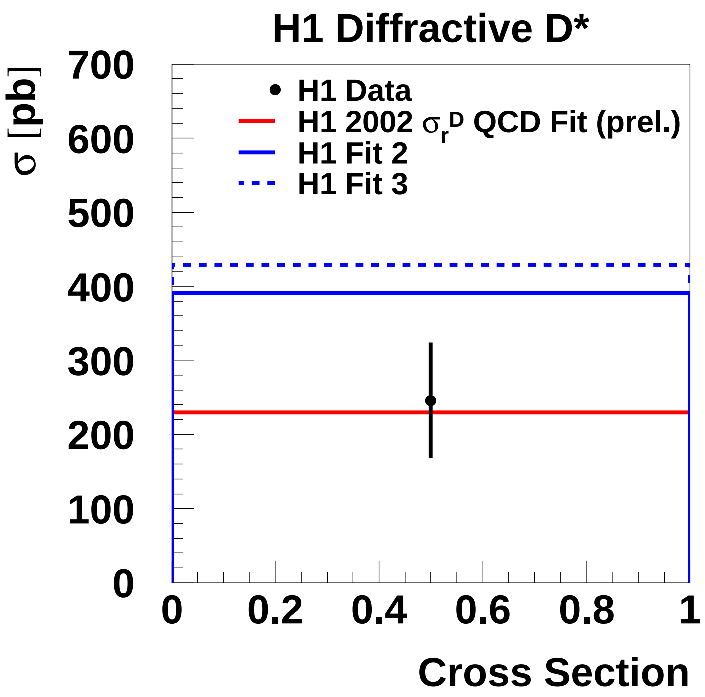

**Comparison based on MC model (RAPGAP)**

$$\mu^2 = Q^2 + p_T^2 + m^2$$

**Diffferential distributions remain well described**

**Normalization: pdf/NLO/scale uncertainty**



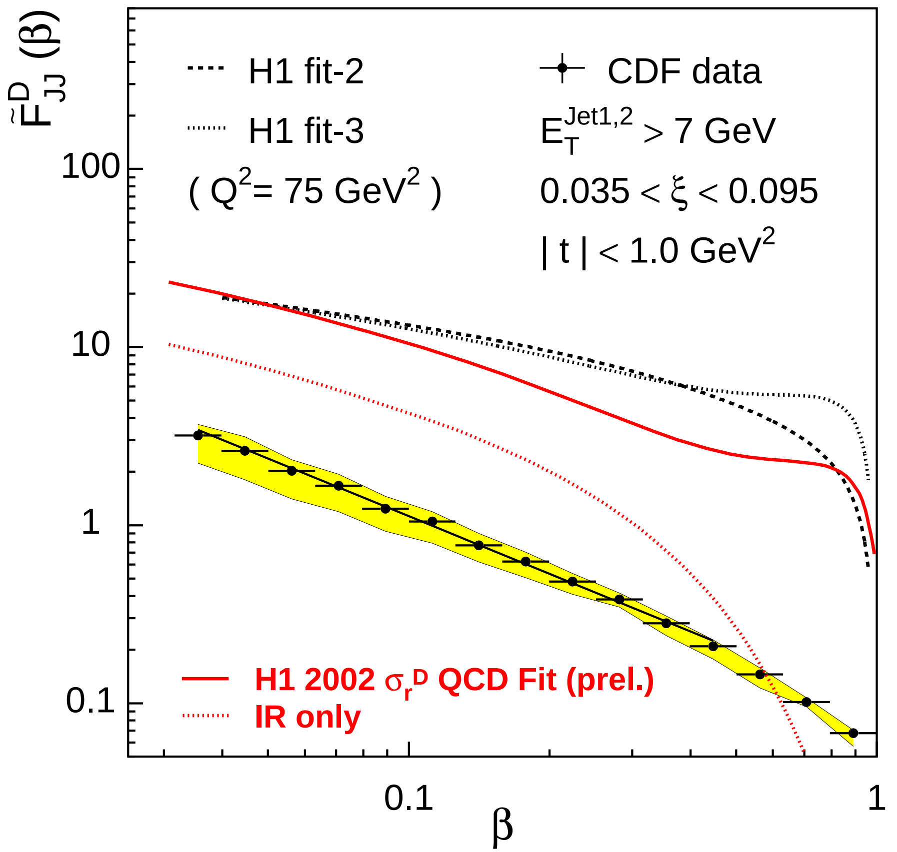



# Comparison with CDF diffractive Dijet cross sections

## Dijet production with tagged leading anti-proton at TEVATRON:

**Effective diffractive structure function $\tilde{F}^D_{jj}$:**

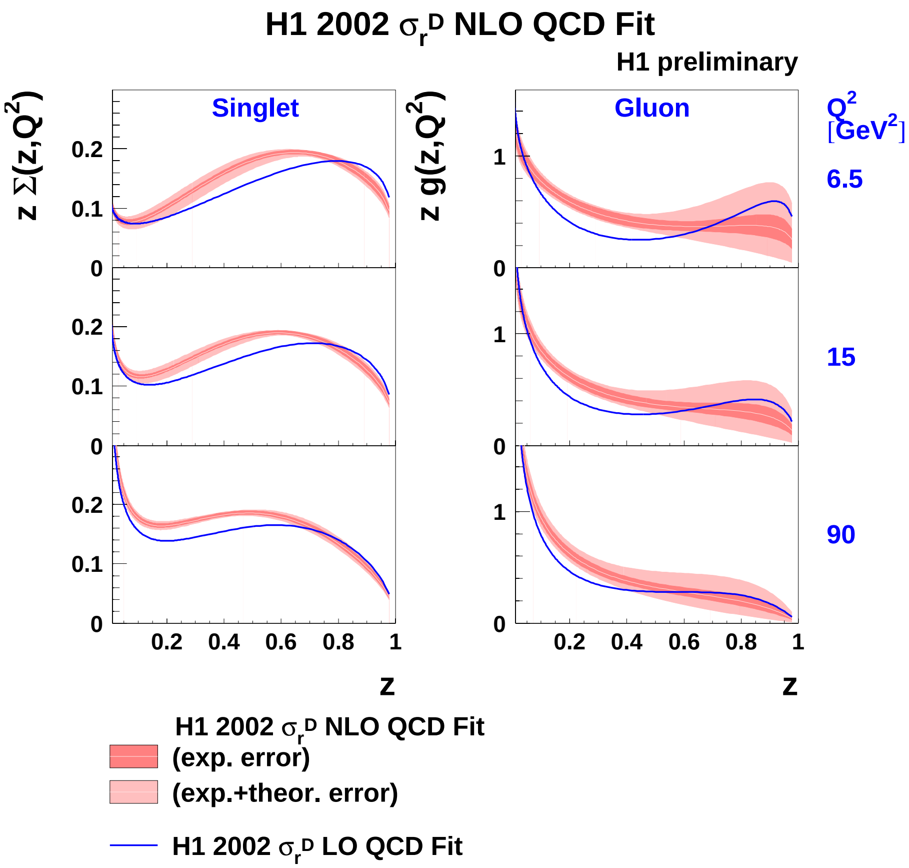
$$\tilde{F}^D_{jj}(\beta) = \int dx_{\mathbb{P}} dt f(x_{\mathbb{P}}, t)\ \beta \left[g(\beta, Q^2) + \frac{4}{9}\Sigma(\beta, Q^2)\right] \qquad (Q^2 = 75\ GeV^2)$$




- **New fit confirms serious breakdown of factorization**
- **$\beta$ dependence similar (except highest $\beta$)**
- **NOTE $x_{\mathbb{P}}$ domain: 50% contribution from sub-leading exchange in this kinematic regime**

# Conclusions

- Precise measurement of $Q^2$ and $x$ dependence of latest H1 diffractive DIS data
- Data consistent with factorizing $x_{\mathbb{P}}$ dependence (except highest $x_{\mathbb{P}}$)
- Diffractive parton distributions derived from NLO DGLAP QCD fit
- Experimental and model uncertainties of diffractive pdfs evaluated for the first time
- pdfs extending to high $z$ and dominated by hard gluon distribution ($75\%$ of exchange momentum)




- Factorization tests with diffractive final state data from HERA and TEVATRON:
  - Consistent with QCD factorization in $ep$
  - Failure in $pp$ confirmed (more details in talk by P. Thompson tomorrow)