NLO DGLAP QCD Fit to H1 Inclusive Diffractive DIS Data

10th Workshop on Deep Inelastic Scattering (DIS)

May 2002, Krakow

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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:

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

- 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 σ_r^D
  - Test factorization by comparisons with diffractive final state data (e.g. Dijets)
- Apply same NLO QCD DGLAP apparatus to Q^2 and β or x dep. as in inclusive DIS

Experimental:

- Precise H1 measurement of Q^2,β 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,β dep. of σ_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

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

$\Delta_{sys,ij}$: 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 σ_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 $6.5 \leq Q^2 \leq 120\ \mathrm{GeV}^2$ (284 points)
- H1 94-97 preliminary data $200 \leq Q^2 \leq 800\ \mathrm{GeV}^2$ (29 points)

Phase space and Cuts:

- $x_{I\!P} < 0.05 \qquad 0.01 \leq \beta \leq 0.9$
- $M_X > 2\ \mathrm{GeV} \longrightarrow$ leading twist analysis, avoid high β 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)

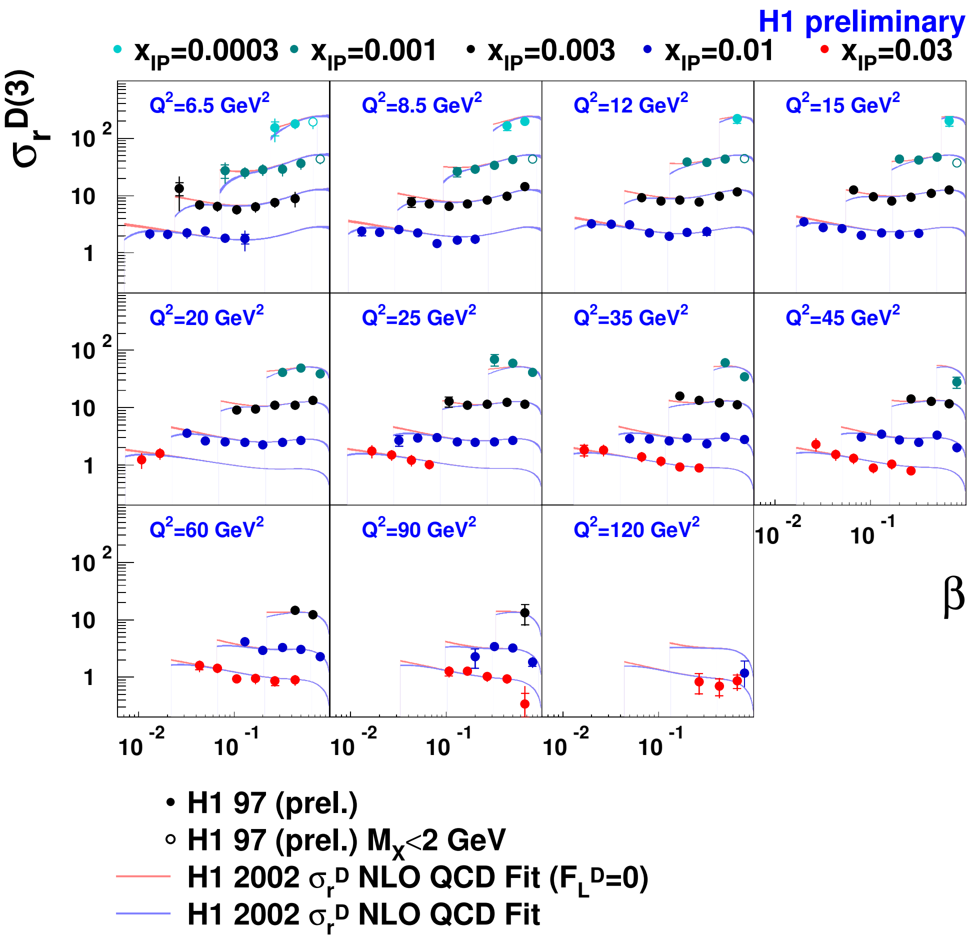
Free fit parameters and χ^2:

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

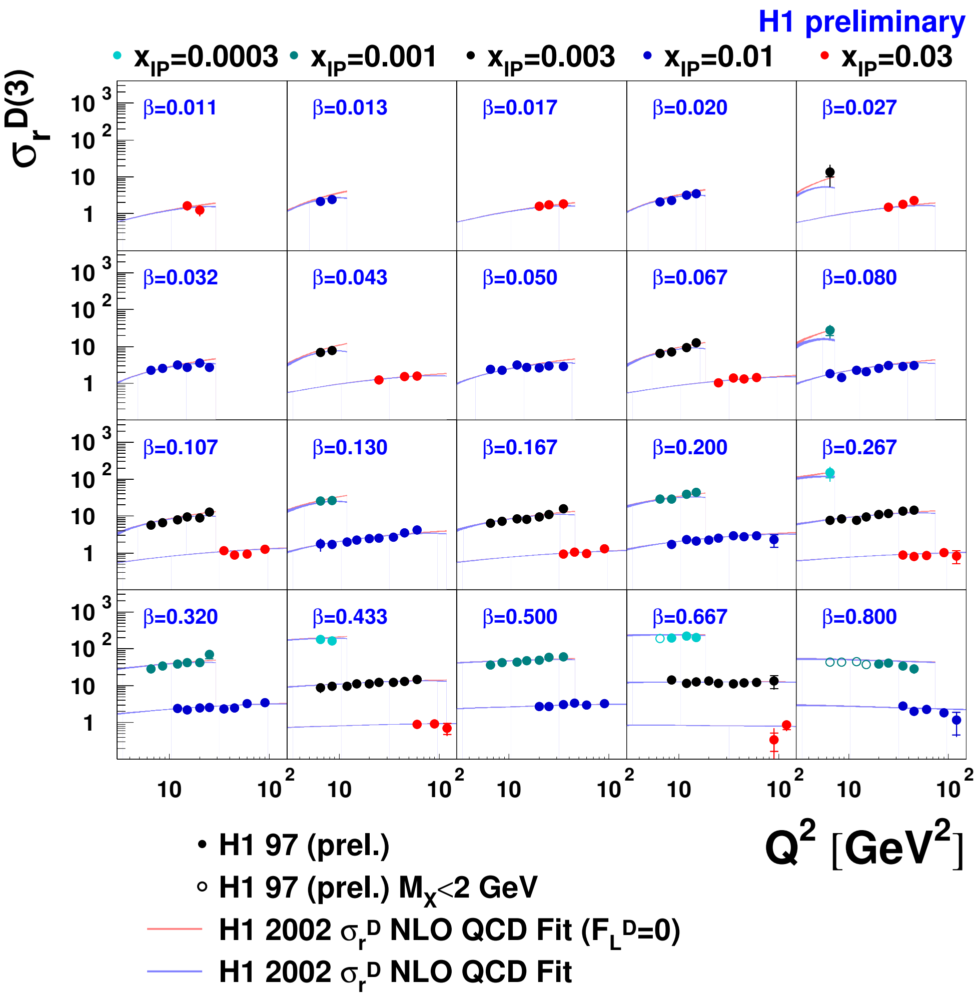
- $\chi^2/ndf = 308.7/306$

Comparison of NLO QCD fit with Data

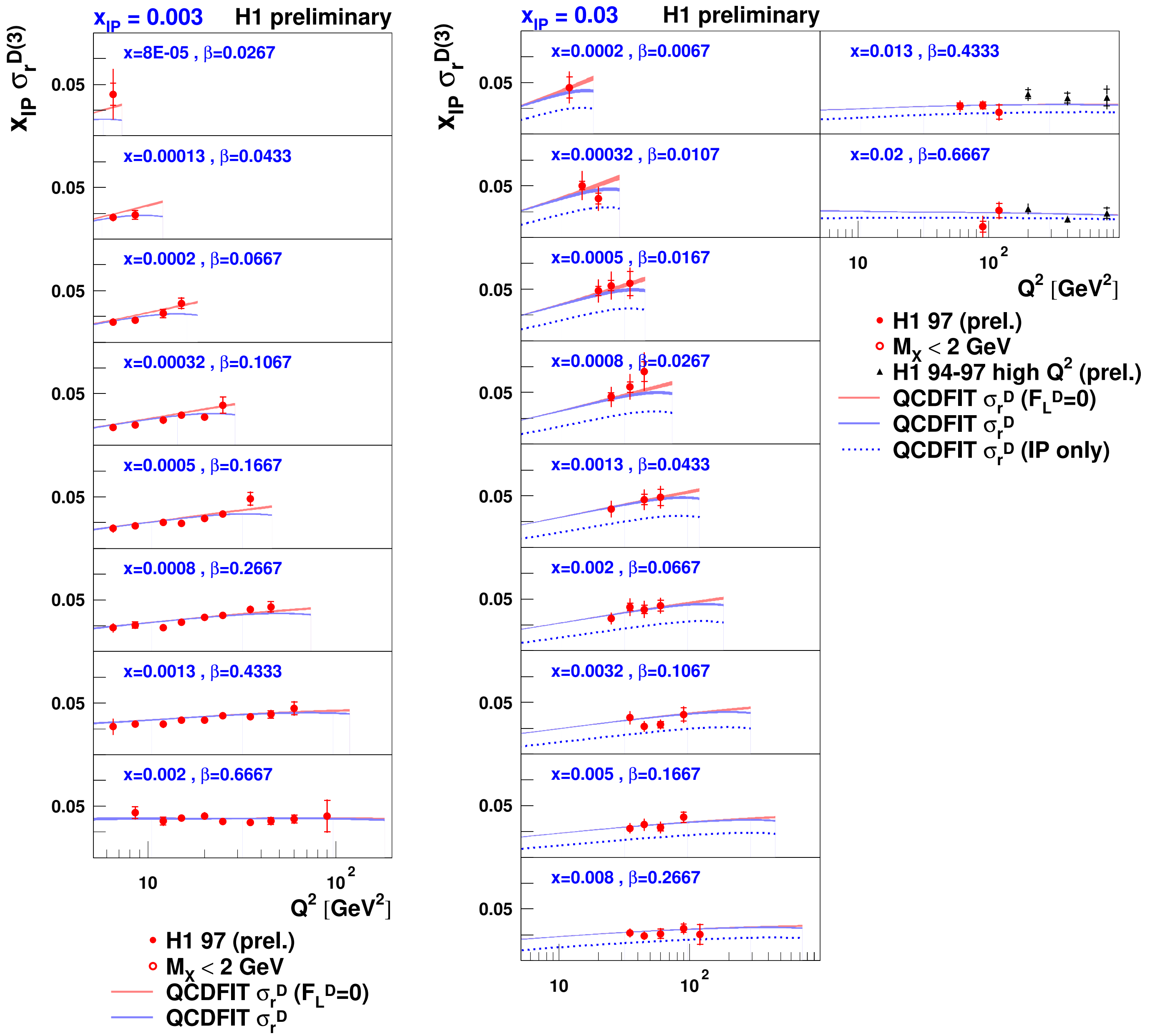
β dependence at fixed Q^2:



Q^2 dependence at fixed β:



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



Two example $x_{I\!P}$ bins

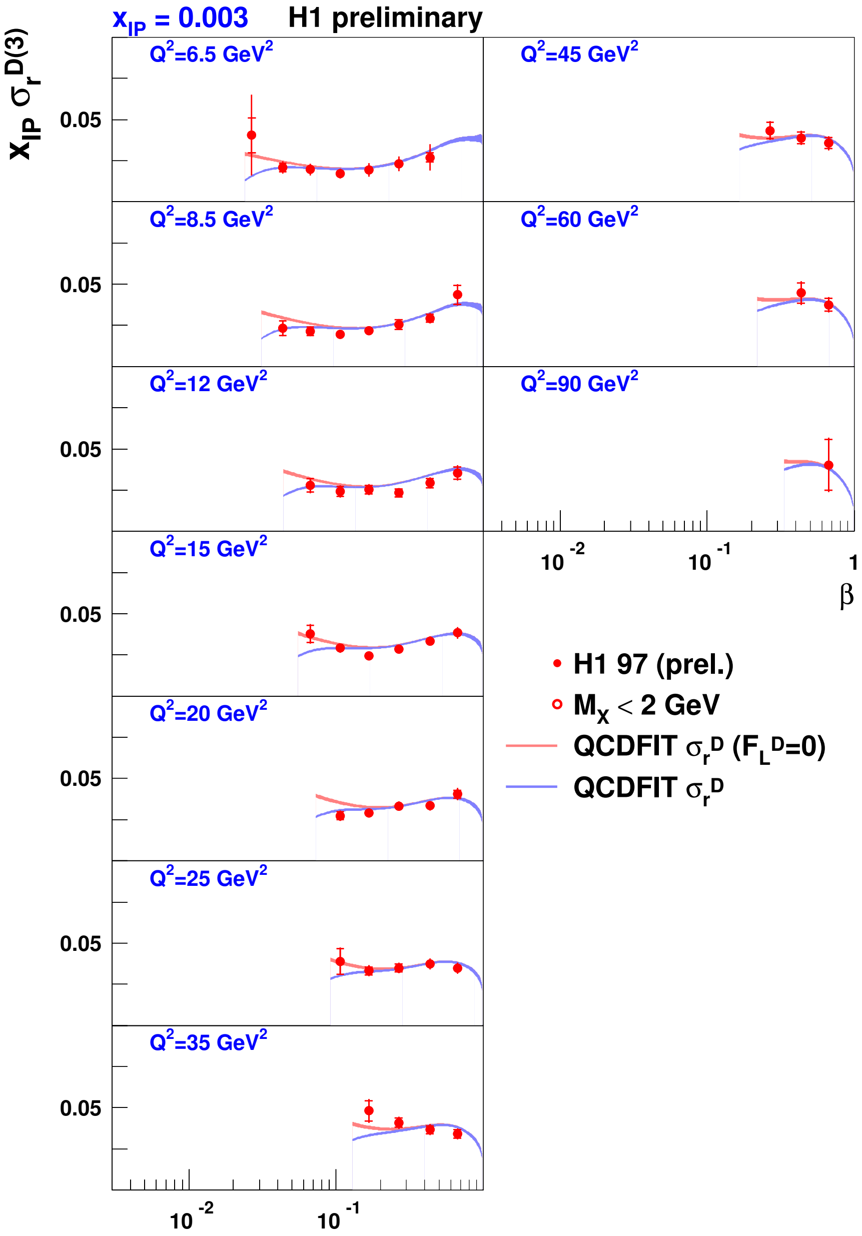
Q^2 scaling violations well constrained by data

Rising except at highest β

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

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

Comparison of NLO QCD fit with Data: β,x dep.



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

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

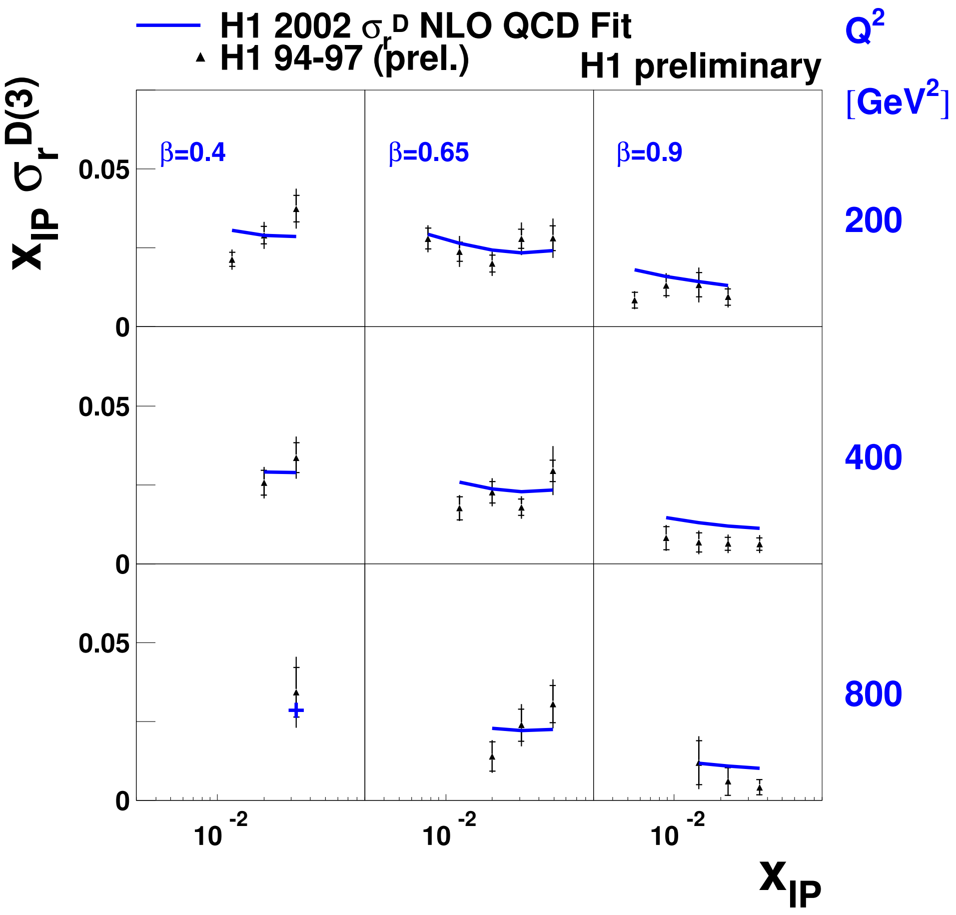
β dependence independent of $x_{I\!P}$

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

presently no direct handle on F_L^D from data

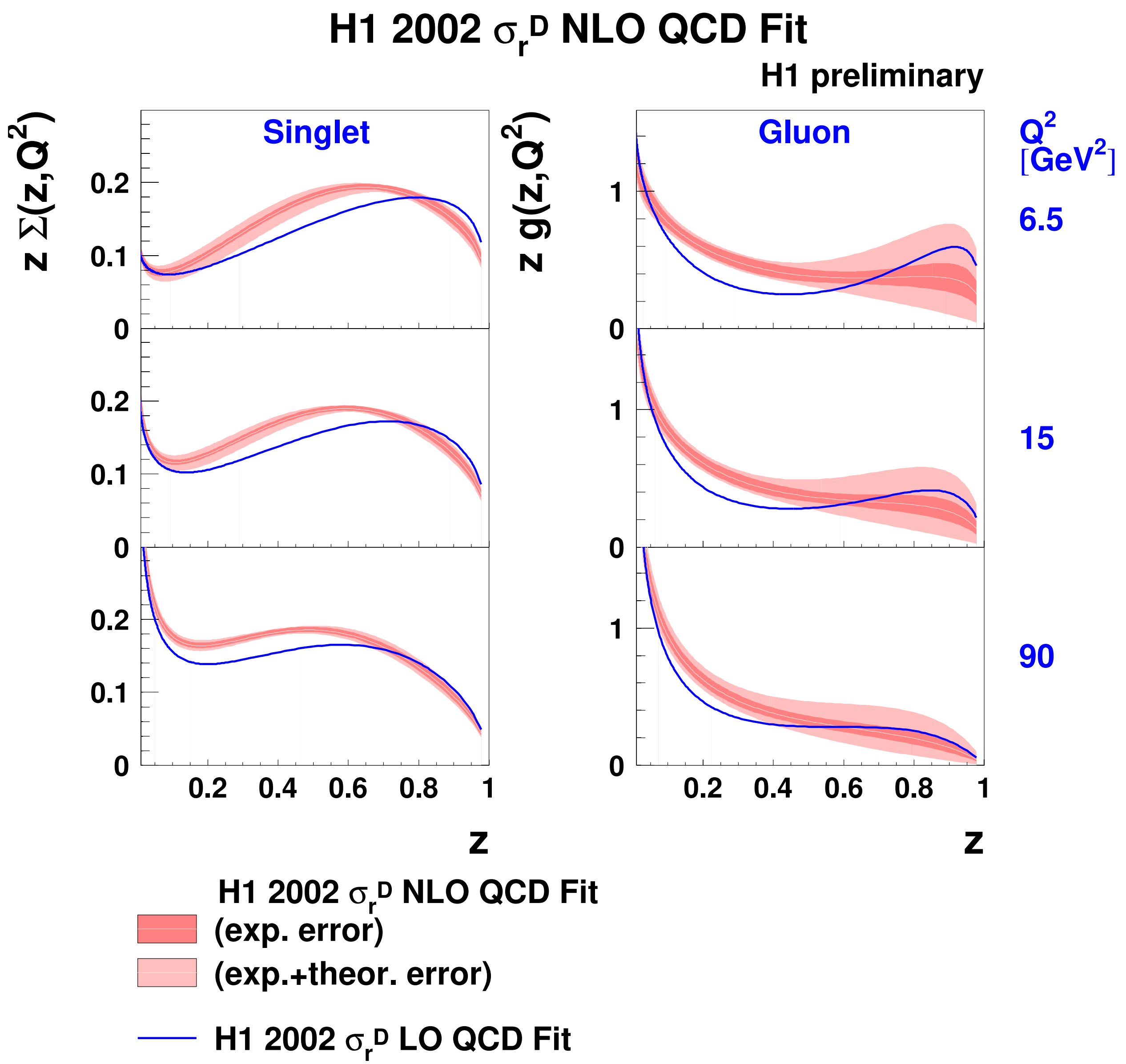
Comparison of QCD fit with high Q^2 data

Fair agreement within experimental errors



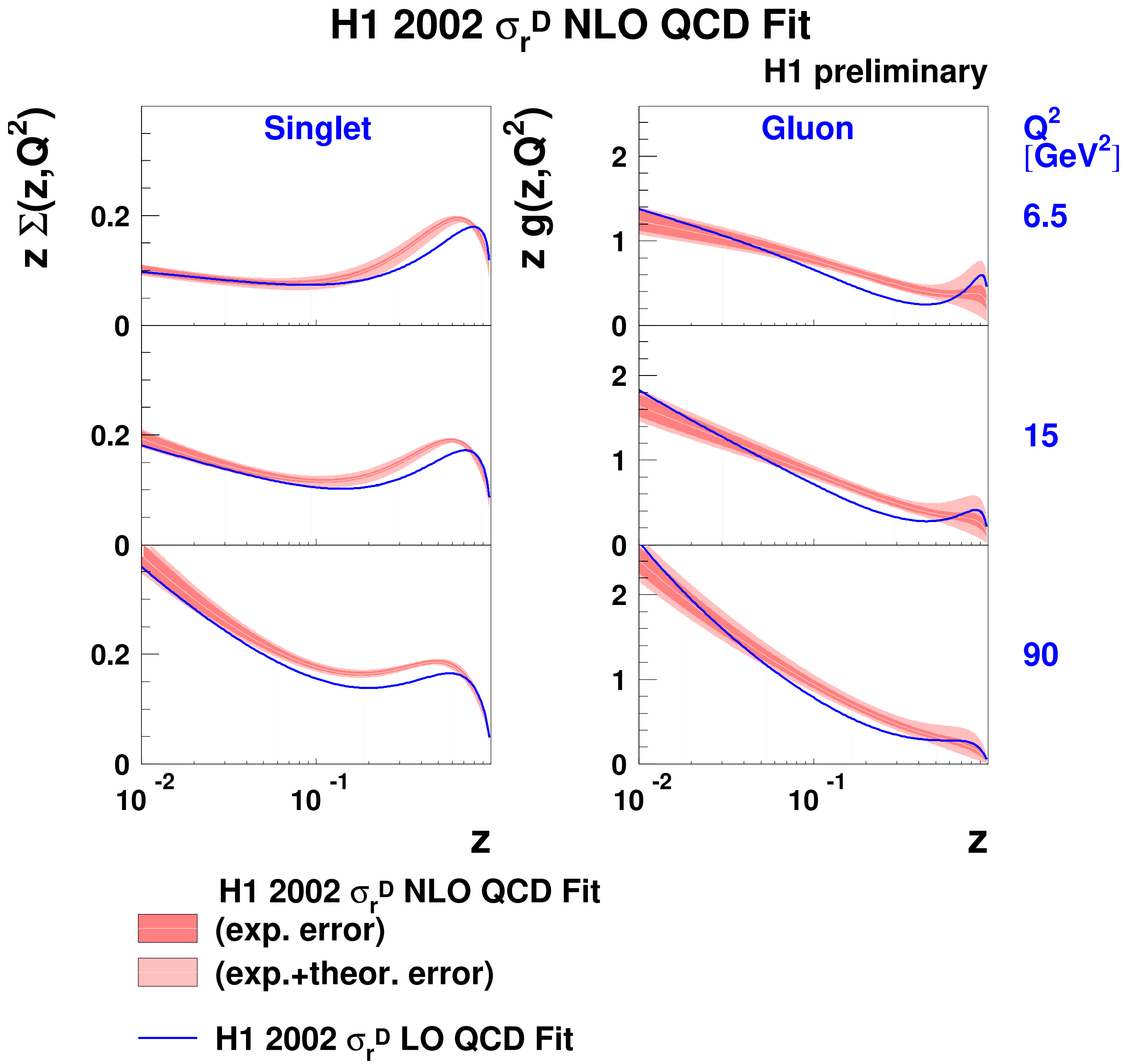
→ **Precision at high Q^2 to be improved**

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)

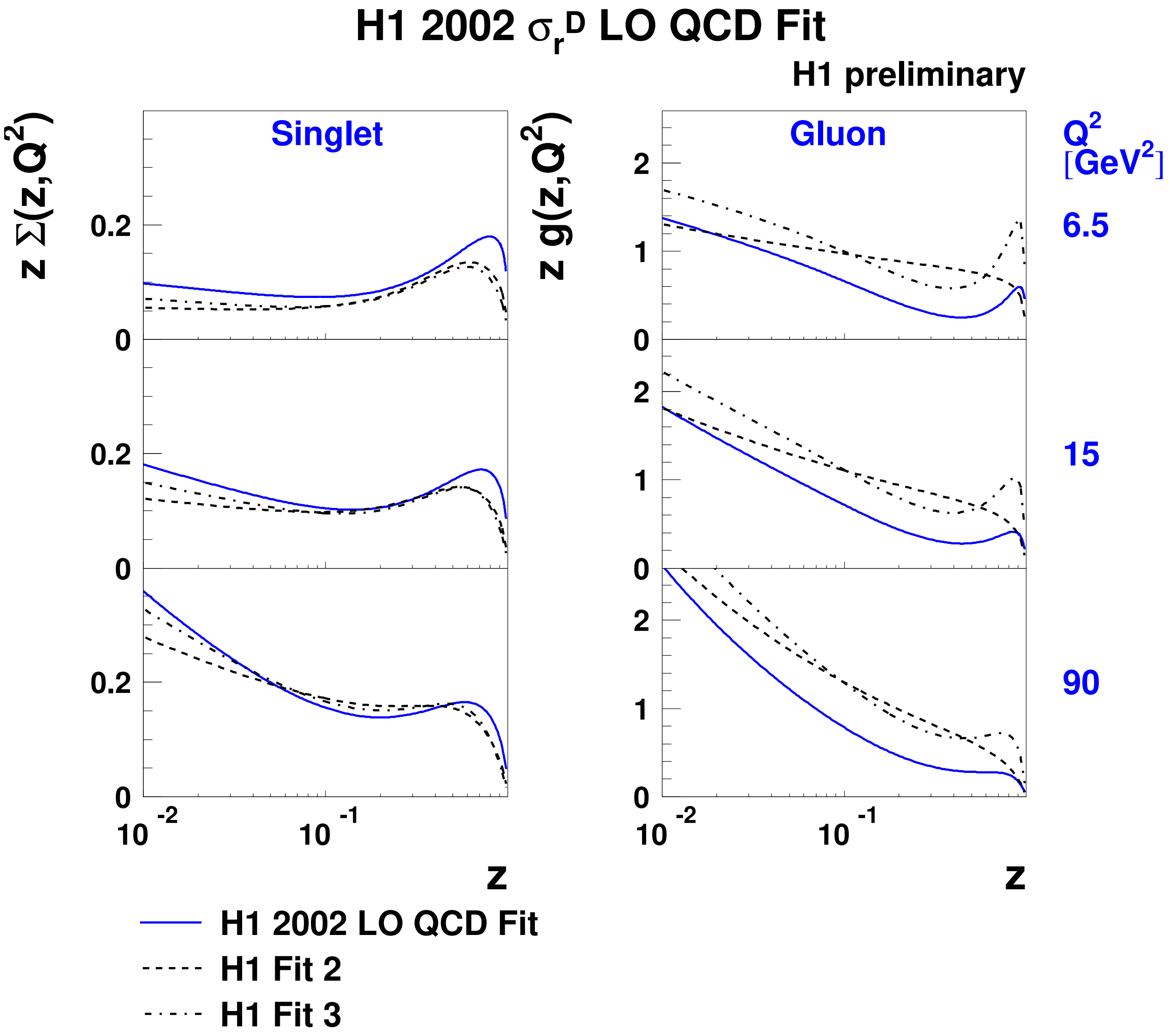
Result of NLO fit



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

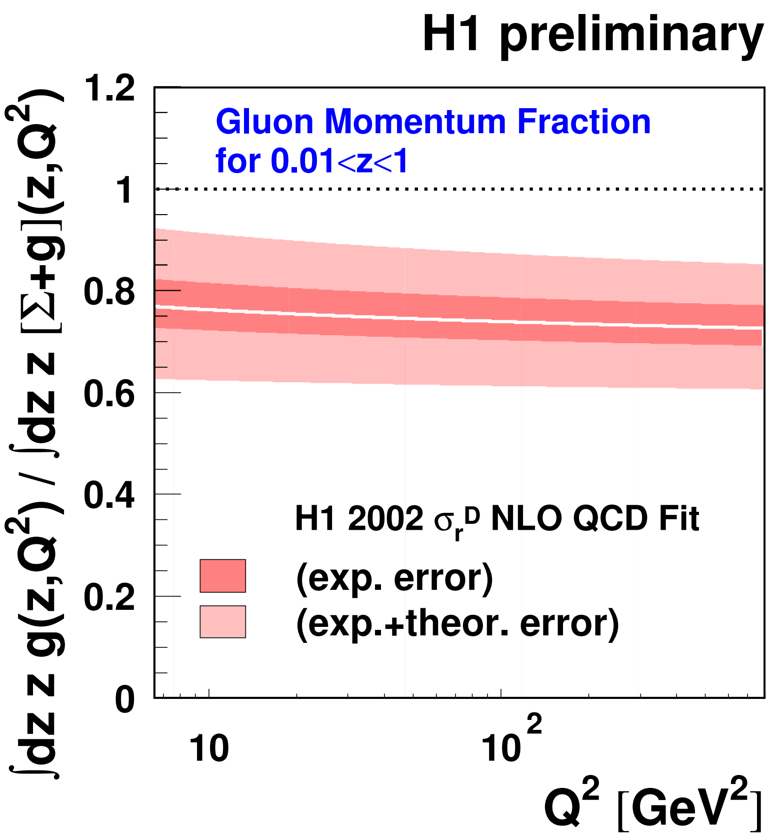


- Comparisons with previous LO fits to 1994 data:
  - H1 Fit 2 ("flat gluon")
  - H1 Fit 3 ("peaked gluon")
- Reasonable agreement of $\Sigma(z, Q^2)$ for $z < 0.65$ (common fit range)
- Gluon normalization smaller by $20 - 30\%$ at low z, 50% at high z

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

Gluon Momentum Fraction

From NLO Fit:

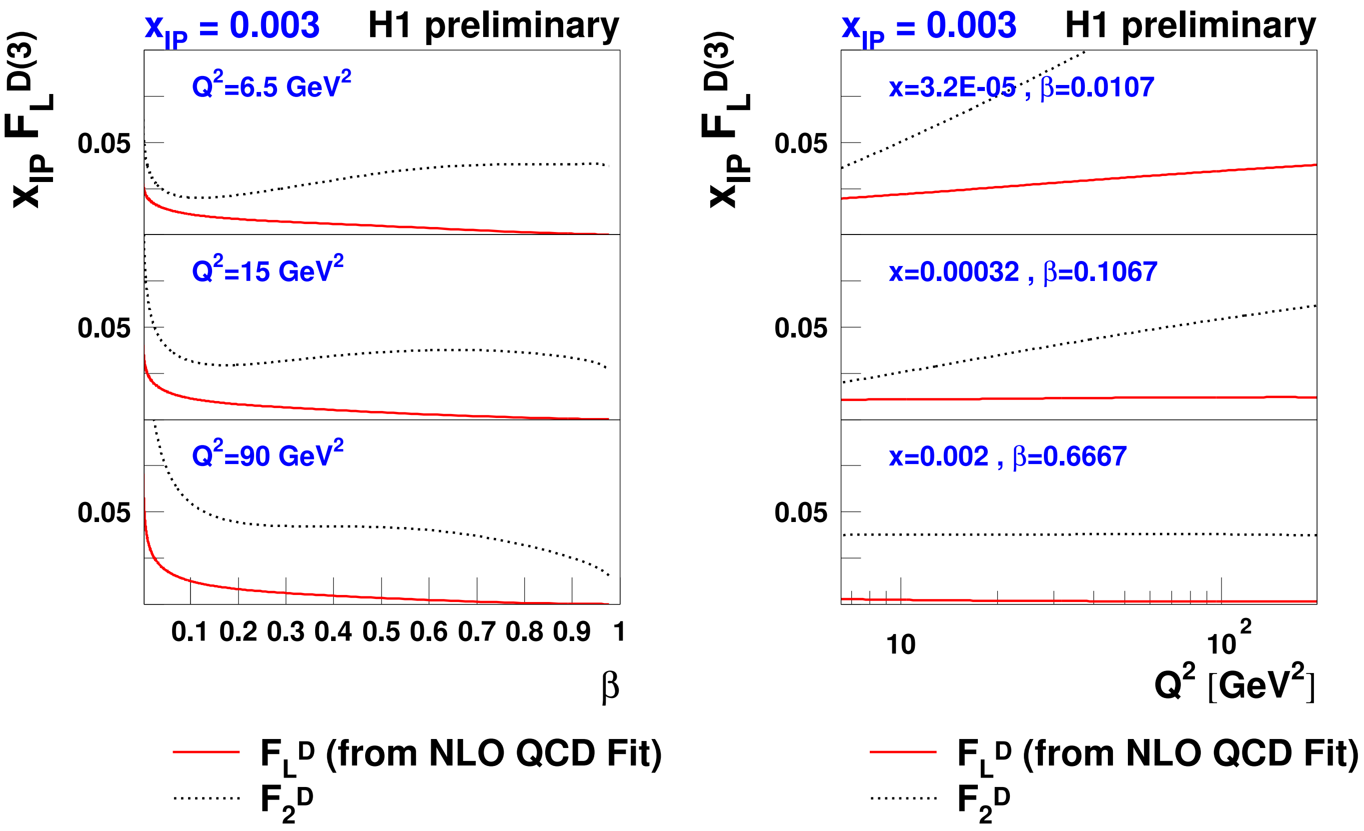


- **Integration of pdf's in measured range** $0.01 < z < 1$
- **Momentum fraction of colour singlet exchange carried by gluons 75% for** $6.5 < Q^2 < 800\ \mathrm{GeV}^2$
- **Fully consistent with results from previous H1 data**

Longitudinal Structure Fraction F_L^D

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

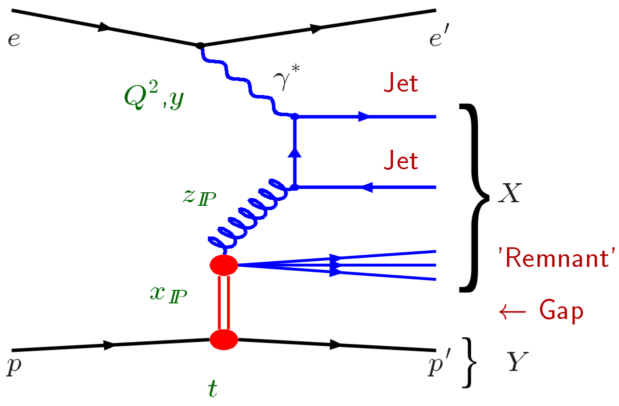
$$F_L^D \sim \frac{\alpha_s}{2\pi}\left[C_q^L \otimes F_2^D + C_g^L \otimes \sum_i e_i^2\, zg^D(z,Q^2)\right]$$



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

Comparison with H1 diffractive DIS final states

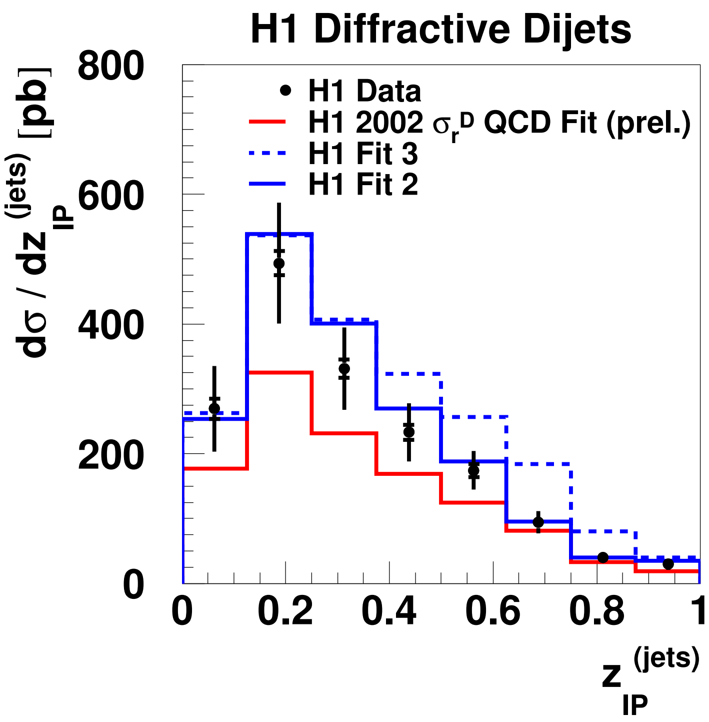
Use pdf's from LO fit to predict dijets / D^* cross sections in diffractive DIS as measured by H1:

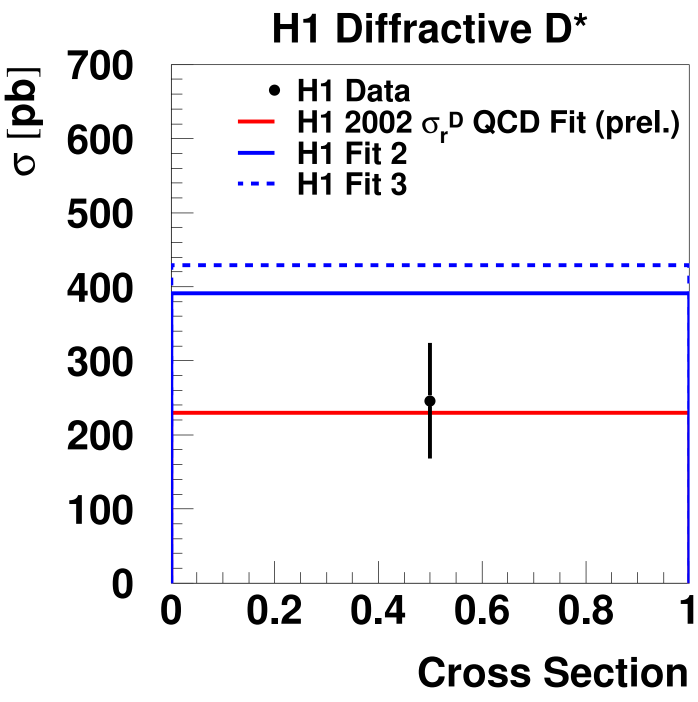


Comparison based on MC model (RAPGAP)

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

Diffferential distributions remain well described
Normalization: pdf/NLO/scale uncertainty



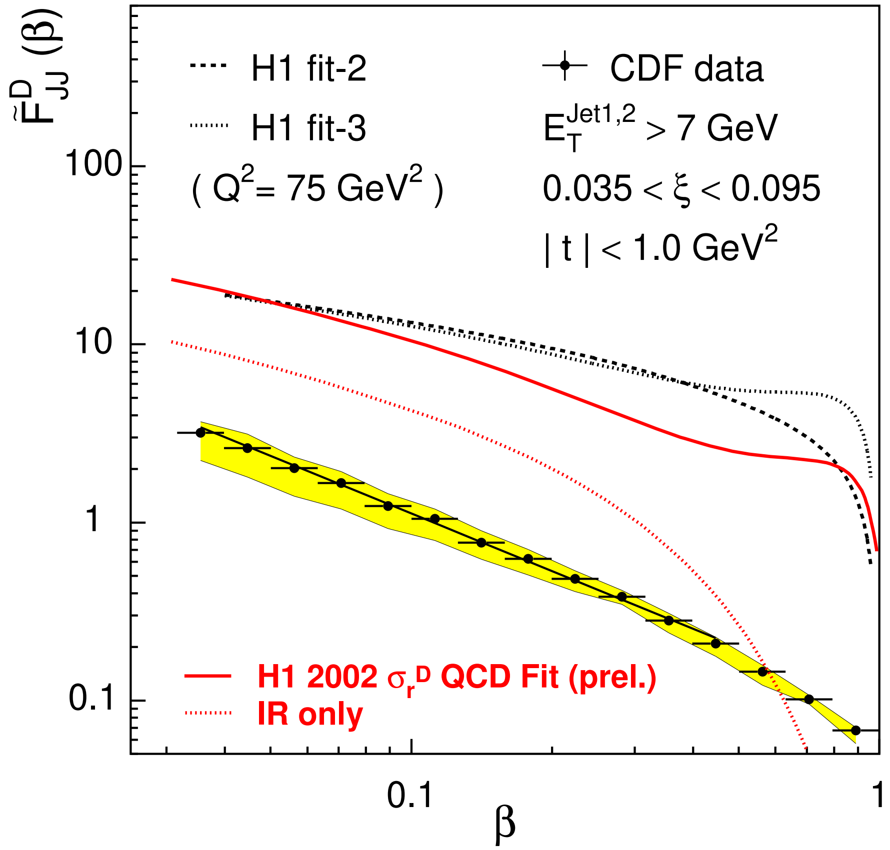


Comparison with CDF diffractive Dijet cross sections

Dijet production with tagged leading anti-proton at TEVATRON:

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

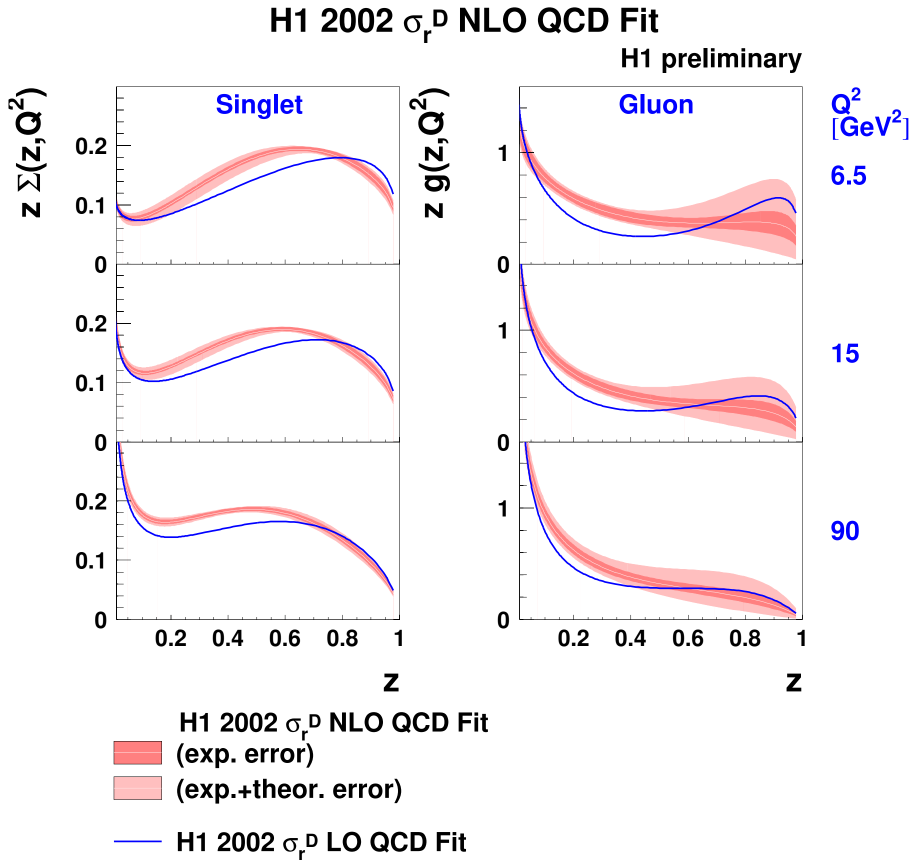
$$\tilde{F}^D_{jj}(\beta) = \int dx_{I\!P}\,dt\,f(x_{I\!P},t)\;\beta\left[g(\beta,Q^2)+\tfrac{4}{9}\Sigma(\beta,Q^2)\right] \qquad (Q^2 = 75\ GeV^2)$$



- **New fit confirms serious breakdown of factorization**
- **β dependence similar (except highest β)**
- **NOTE $x_{I\!P}$ 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 $x_{I\!P}$ dependence (except highest $x_{I\!P}$)
- 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)