Diffractive partons from perturbative QCD

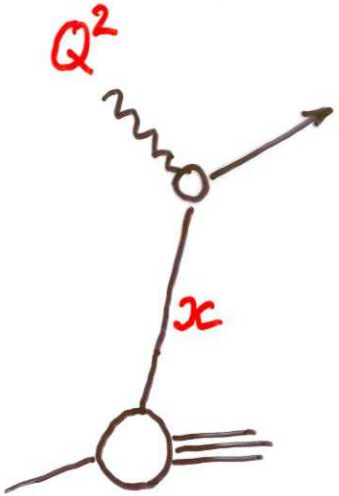
Alan Martin, Misha Ryskin and Graeme Watt

Conventionally DDIS analyses use two levels of factorisation - collinear factorization and Regge factorization

- ☆ We replace Regge factorization by pQCD
- ☆ Collinear factorization, which holds asymptotically, needs modification in the HERA regime:
  - -- inhomogeneous term in DGLAP evolution
  - -- direct charm contribution
  - -- twist-4 F_L^D component
- ☆ We present universal diffractive partons

Alan Martin, DIS05
Madison, April 2005

DIS

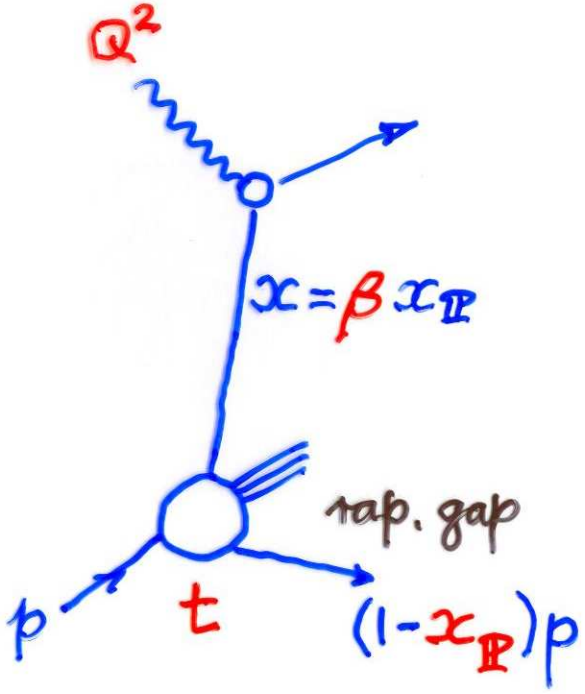


↓

parton densities q

Diffractive DIS

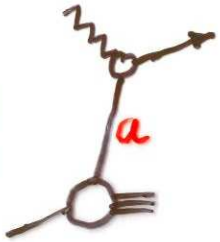
(10-20%)



↓

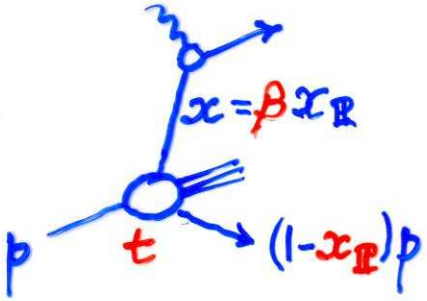
diffractive parton densities q^D

DIS



$$F_2(x,Q^2) = \sum_a C_{2,a} \otimes a$$

DDIS



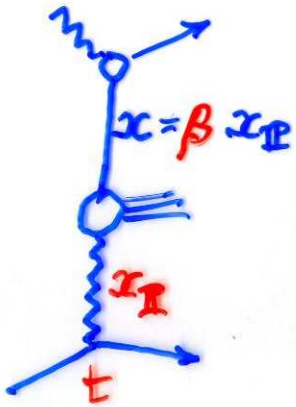
$$F_2(x_{I\!P},\beta,Q^2) = \sum_a C_{2,a} \otimes a^D$$

factorization proved for DDIS (Collins), but important modifications in the HERA regime

conventional to also assume Regge fact.^{n}

Ingelman-Schlein

$I\!P$ ~ particle

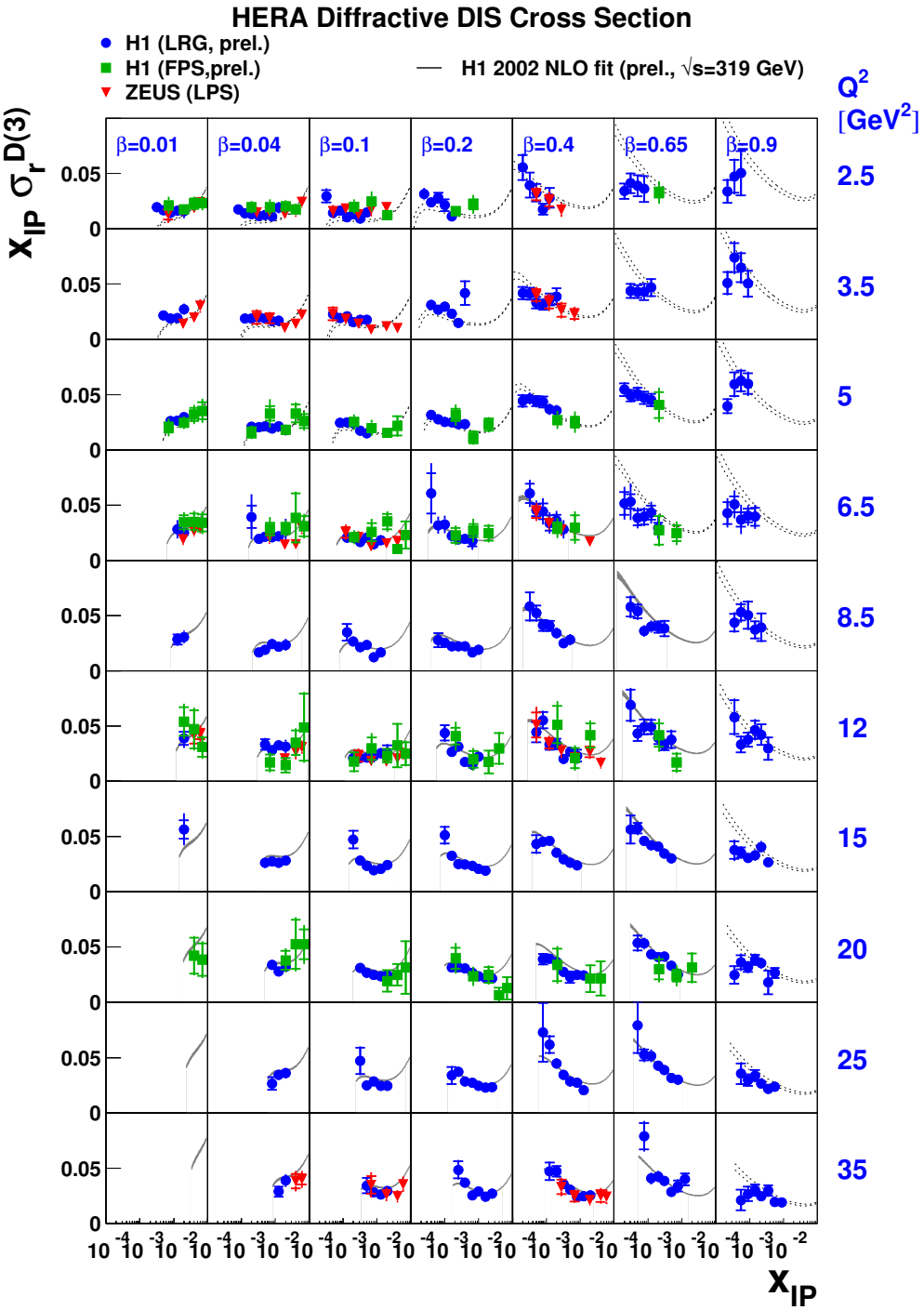


$$a^D(x_{I\!P},\beta,Q^2) = f_{I\!P}(x_{I\!P})\, a^{I\!P}(\beta,Q^2)$$

$$I\!P \text{ flux } \quad f_{I\!P} = \int dt \, \frac{e^{Bt}}{x_{I\!P}^{2\alpha_{I\!P}(t)-1}}$$

B, $\alpha'_{I\!P}$ from soft data, but

$\alpha_{I\!P}(0)$ = parameter

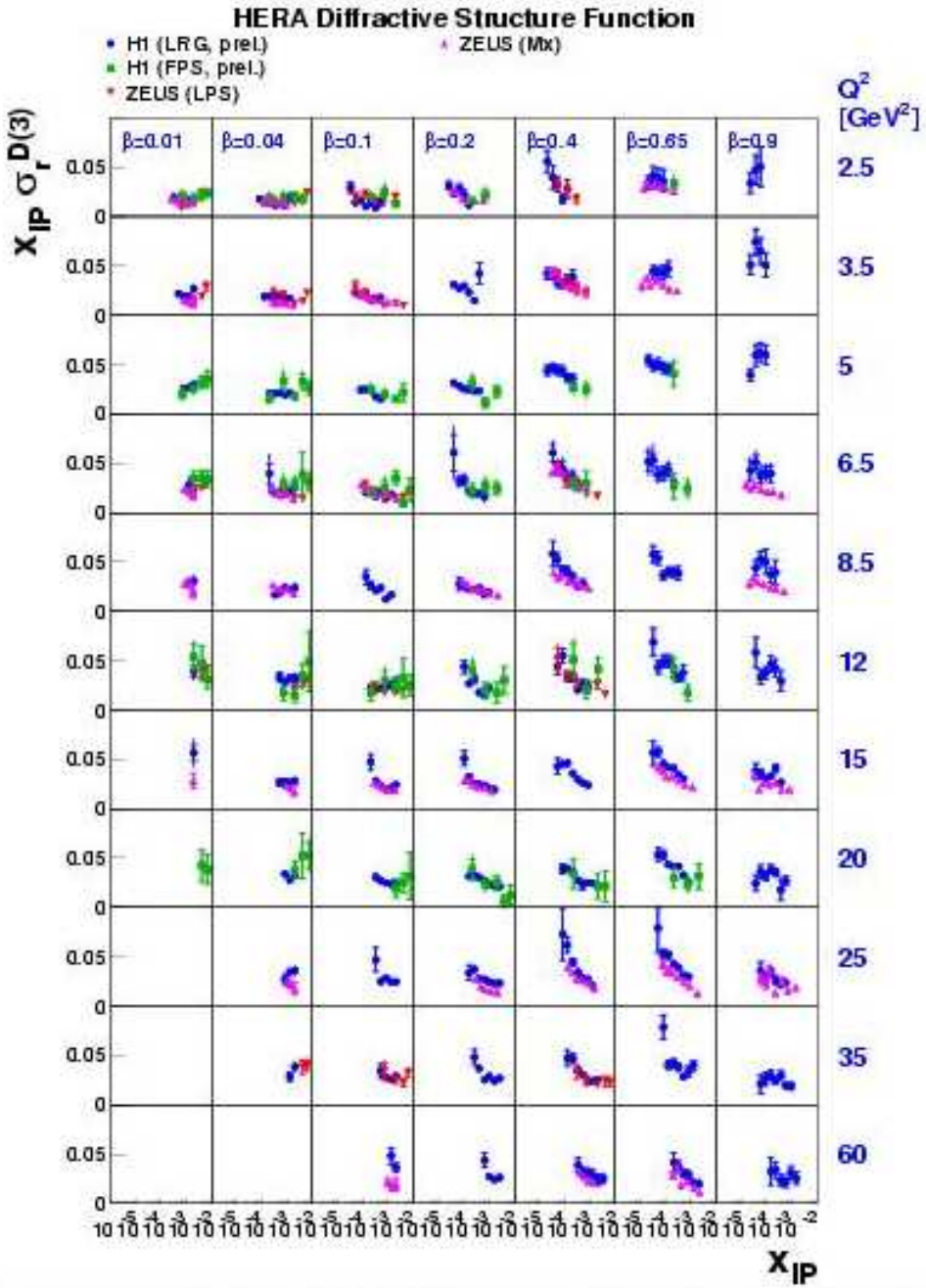


H1 Large rapidity gap selection:
M_Y<1.6 GeV and |t|<1 GeV^2

H1 LPS proton selection: $M_Y = m_p$ extrapolated to |t|<1 GeV^2

➔Good agreement between two methods and two experiments

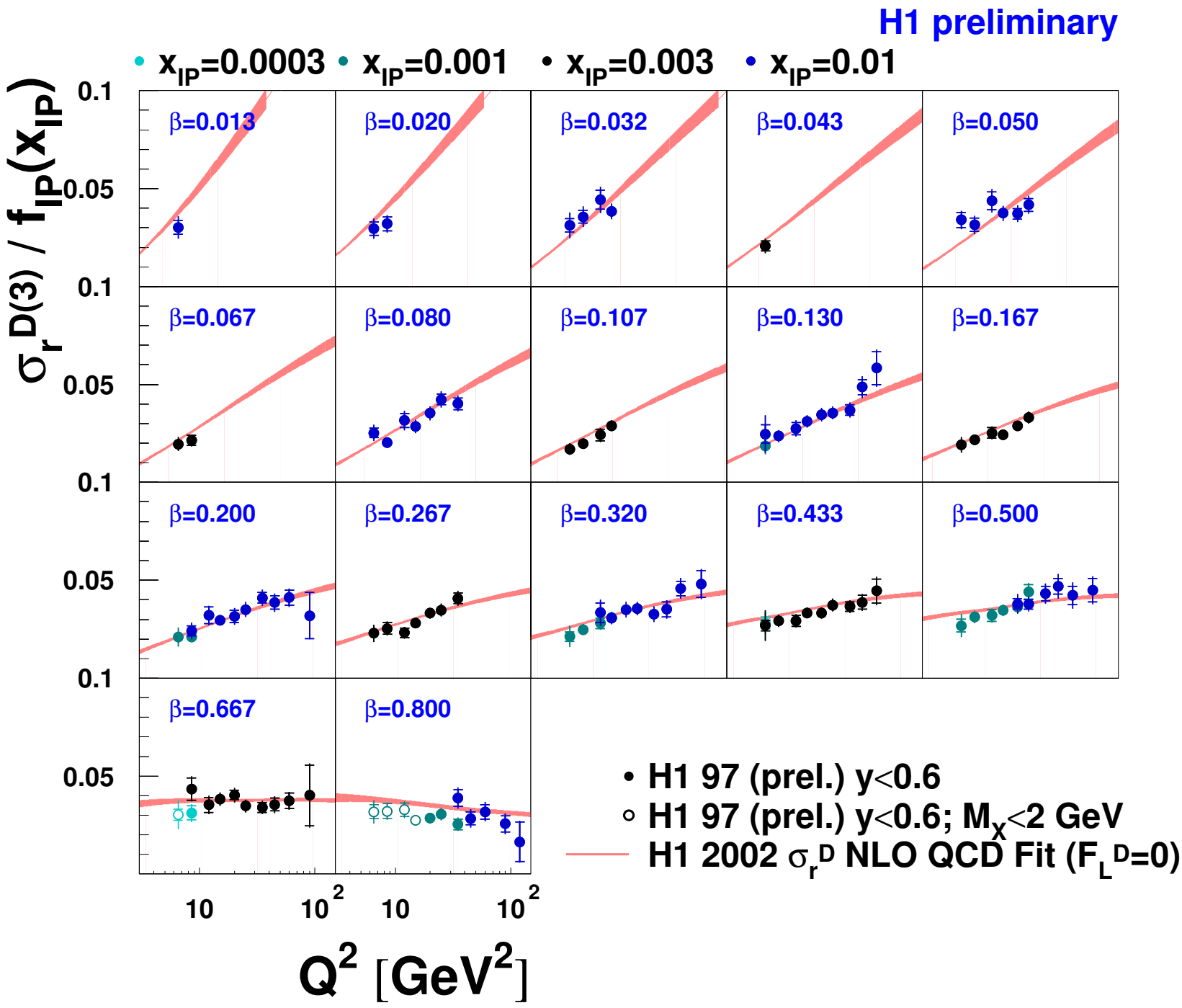
➔Data well described by H1 QCD fit to LRG data



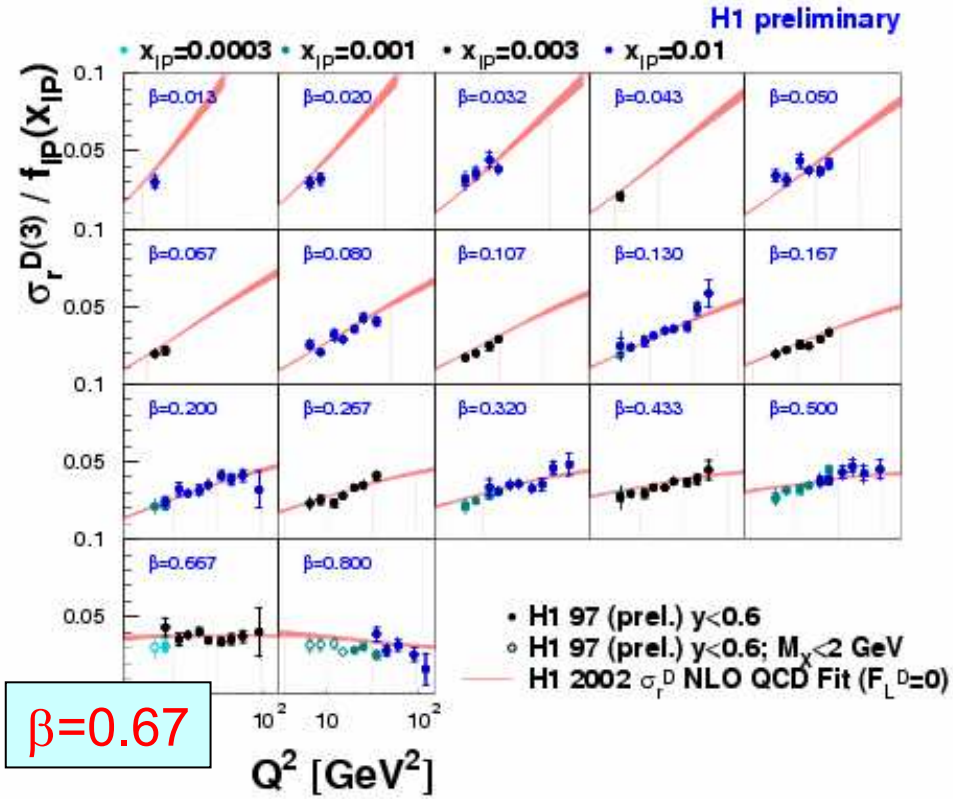
Comparison of all data ($M_Y < 1.6$)

(only Q^2 bins with at least two datasets shown

see Laycock

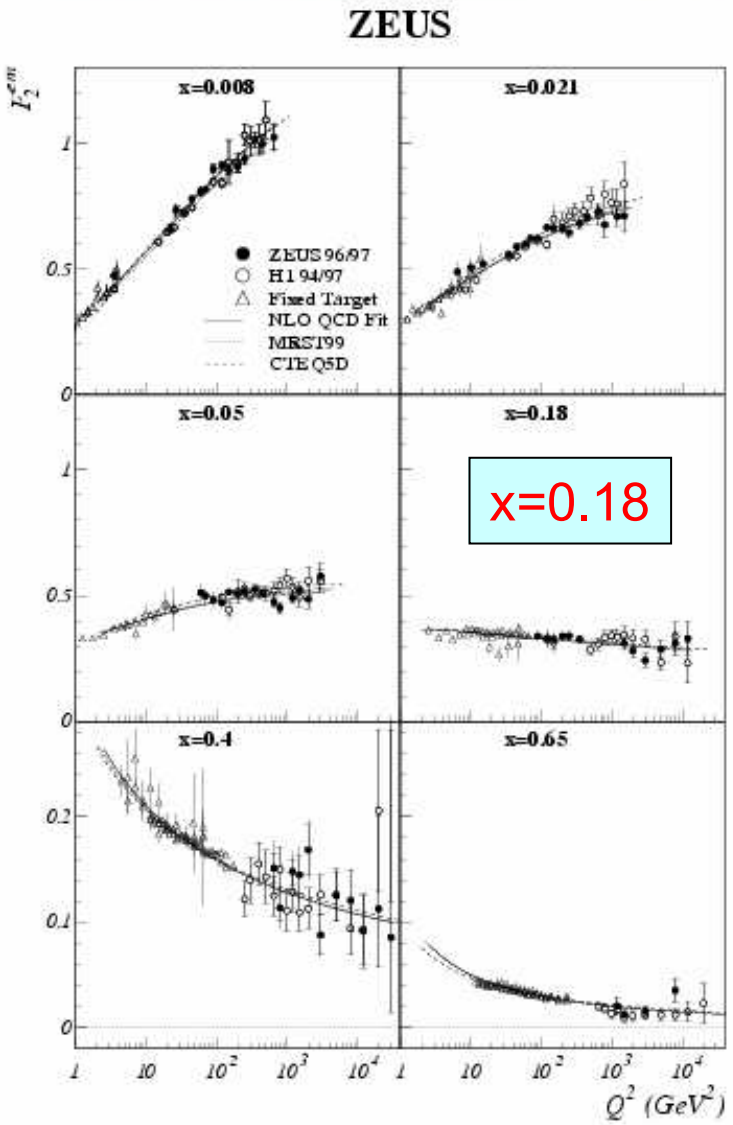

H1 preliminary
• x_{IP}=0.0003 • x_{IP}=0.001 • x_{IP}=0.003 • x_{IP}=0.01
$\sigma_r^{D(3)} / f_{IP}(x_{IP})$
β=0.013
β=0.020
β=0.032
β=0.043
β=0.050
β=0.067
β=0.080
β=0.107
β=0.130
β=0.167
β=0.200
β=0.267
β=0.320
β=0.433
β=0.500
β=0.667
β=0.800
0.1
0.05
10
10^2
Q^2 [GeV^2]
• H1 97 (prel.) y<0.6
◦ H1 97 (prel.) y<0.6; M_X<2 GeV
H1 2002 σ_r^D NLO QCD Fit (F_L^D=0)

Diffractive DIS



β=0.67

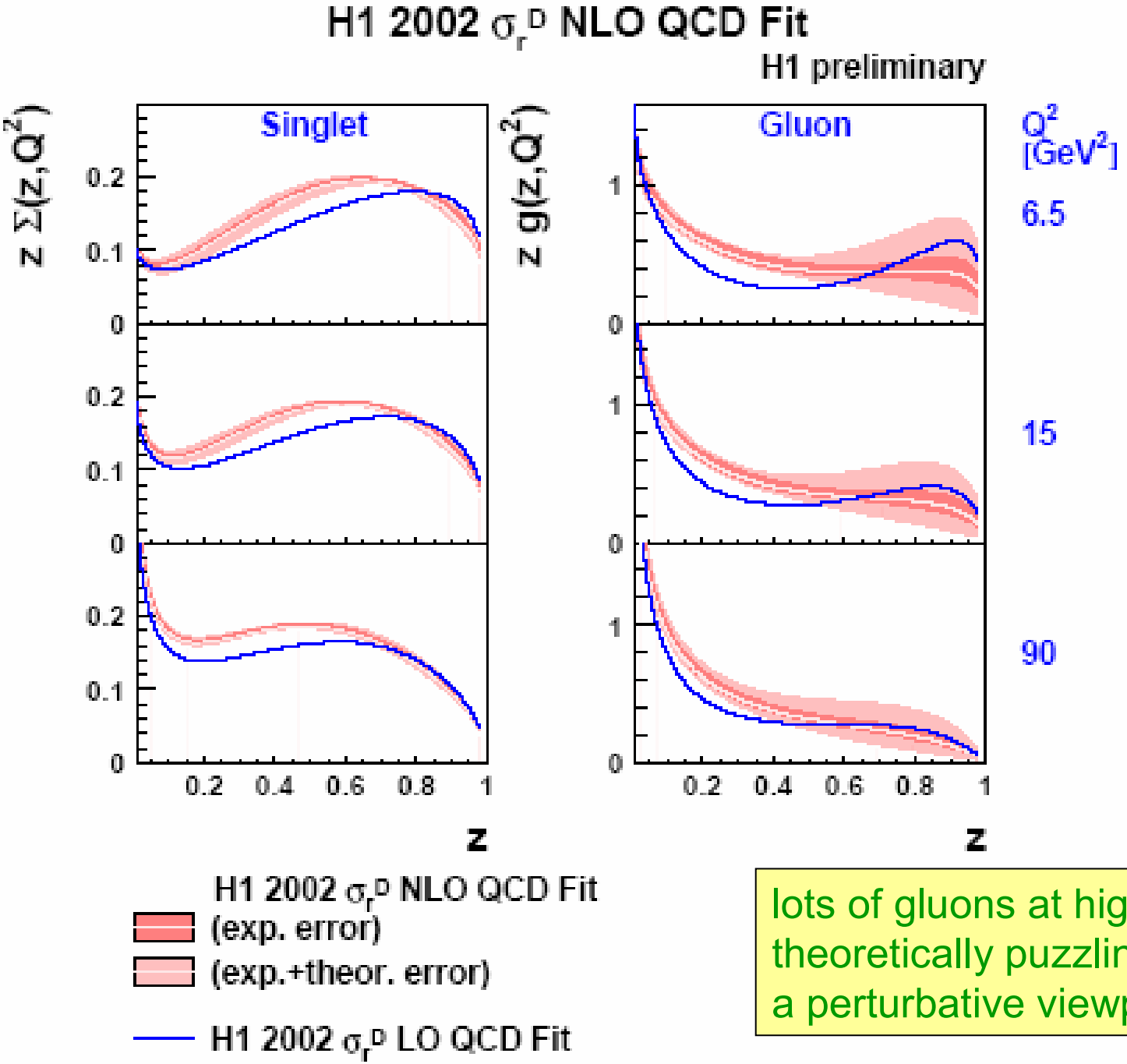
DIS



x=0.18

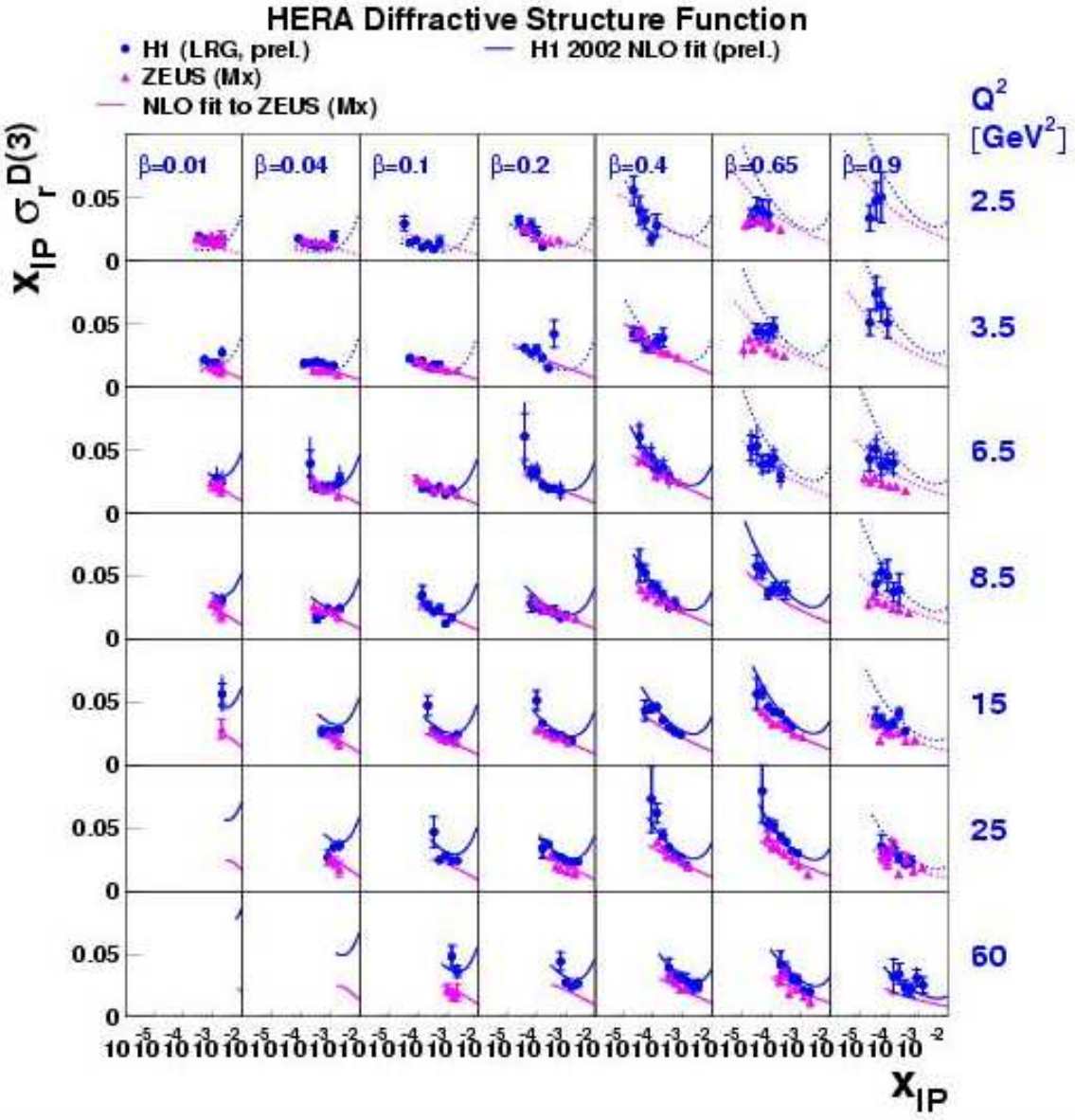
- Positive scaling violations to highest β

→ lot of gluons



lots of gluons at high β, theoretically puzzling from a perturbative viewpoint

H1 and ZEUS data and fits

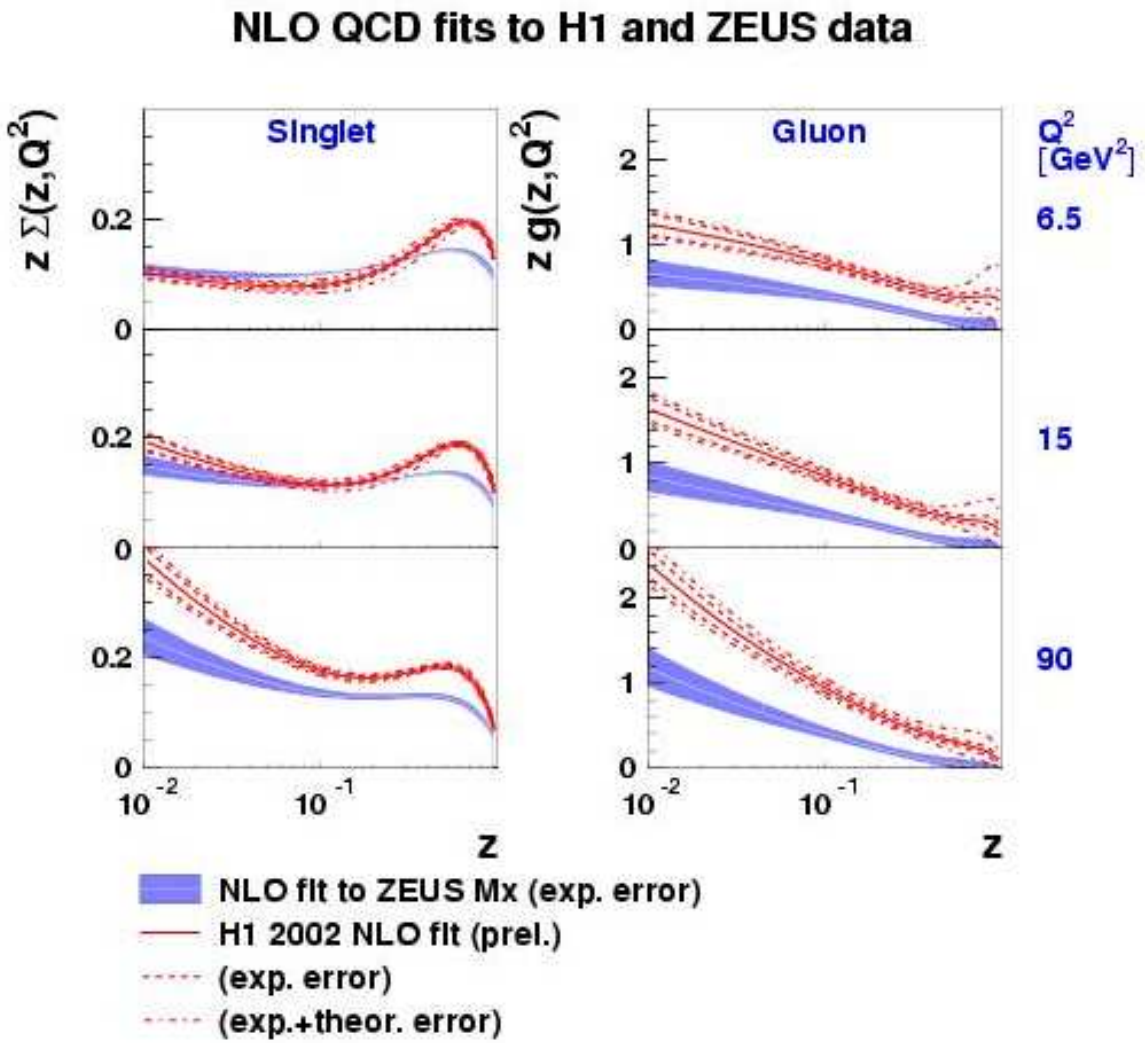


- Differences in data in high β region not included in fits
- Smaller positive scaling violations in ZEUS data, leading to smaller gluon

H1 NLO fits to
(i) H1 LRG data
(ii) ZEUS M_X data

see Laycock

NLO fit to ZEUS Mx data



H1 NLO fits to
(i) H1 LRG data
(ii) ZEUS M_X data

- Singlet similar at low Q^2, evolving differenly to higher Q^2 due to coupling to gluon
- Gluon factor ~ 2 smaller than H1 gluon

see Laycock

Hint of problem with Regge factorisation assumption

assumes Pomeron ~ hadron of size R
Regge fact^{n} occurs in non-pert region $\mu<\mu_0$, where μ~1/R

but $\alpha_P(0)$~1.2 from DDIS > $\alpha_P(0)$~1.08 from soft data

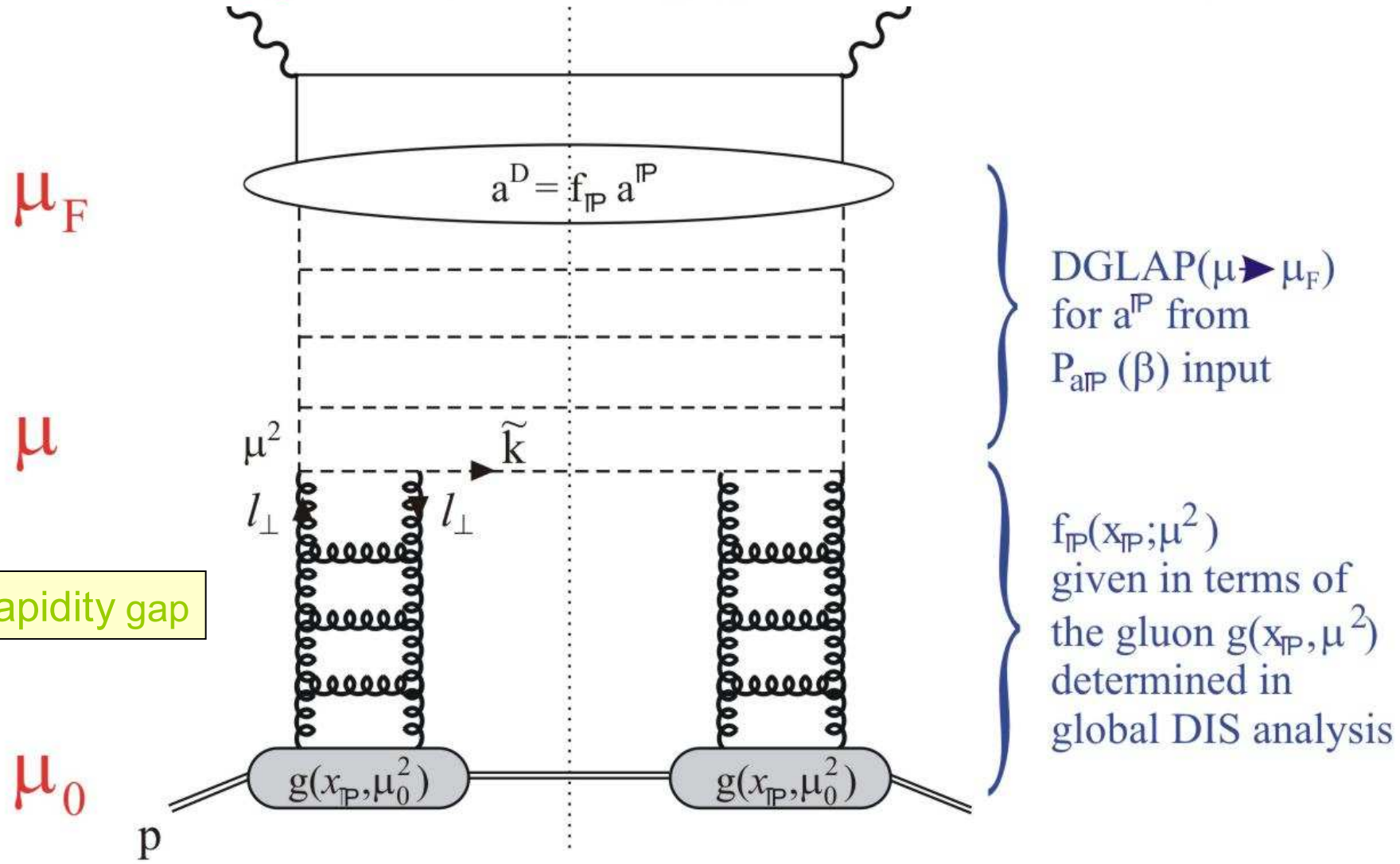
→ small-size component from pQCD domain with larger $\alpha_P(0)$

MRW study impact of applying pQCD to DDIS

find DDIS factorization OK asymptotically, but

important modifications in HERA (subasymptotic) regime

$$a^D = \int_{\mu_0^2}^{\mu_F^2} \frac{d\mu^2}{\mu^2} f_{I\!P}\, a^{I\!P}(\beta, \mu_F^2, \mu^2) \quad \text{with} \quad f_{I\!P} \sim [g(x_{I\!P}, \mu^2)]^2$$



$$a^D = \int_{Q_0^2}^{Q^2} \frac{d\mu^2}{\mu^2} f_{I\!P}(x_{I\!P}, \mu^2)\, a^{I\!P}(\beta, Q^2, \mu^2)$$

given by pQCD

$a^{I\!P}(\beta, \mu_I^2, \mu^2)$

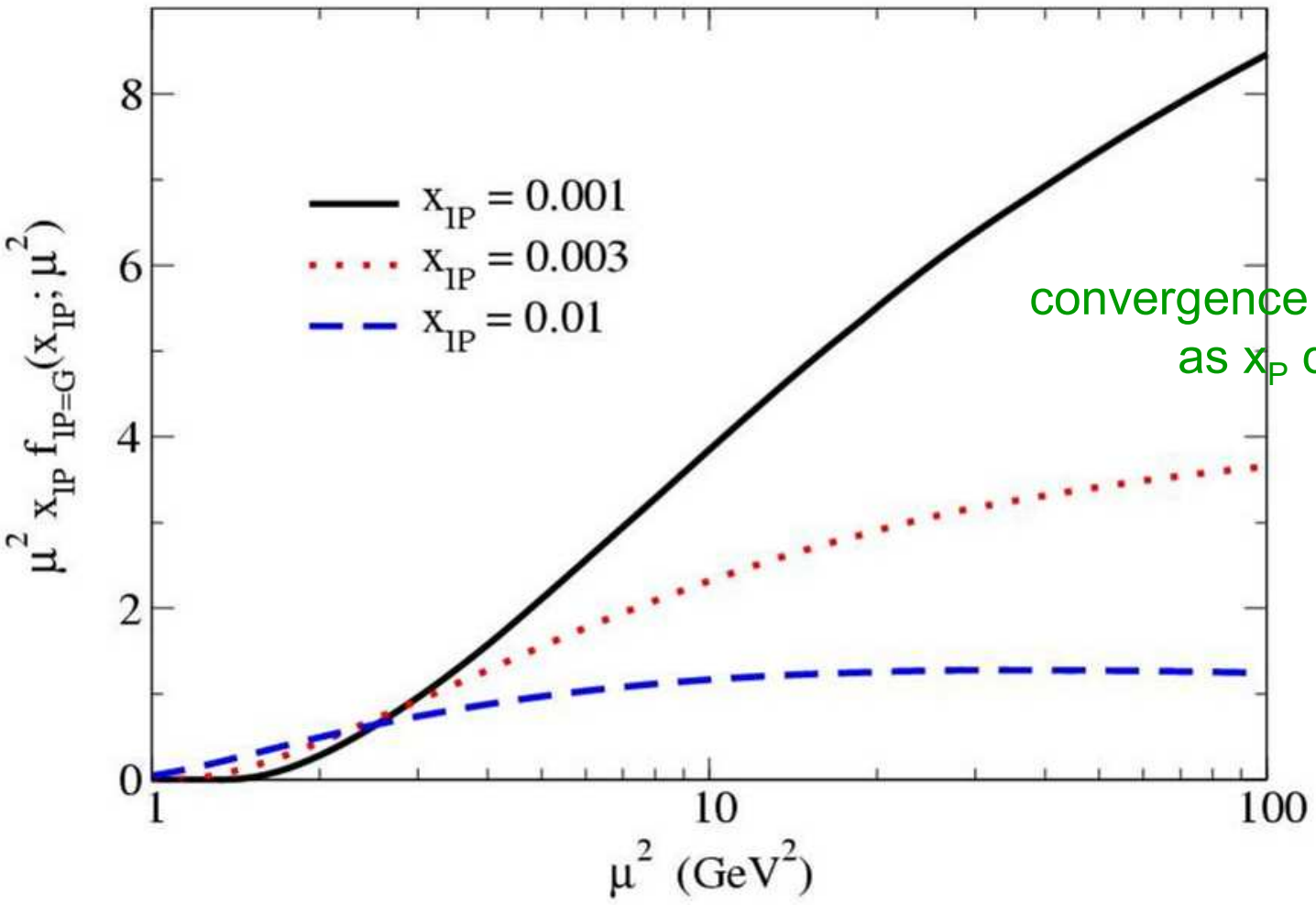
$$\underbrace{\frac{\partial a^D}{\partial \ln Q^2} = \sum_a P_{aa'} \otimes a'^D}_{\text{DGLAP}} + \underbrace{f_{I\!P}(x_{I\!P}, Q^2)\, P_{a I\!P}(\beta)}_{\text{with inhomogeneous term}}$$

cf DGLAP for γ

Recall flux $f_{I\!P}(x_{I\!P}, Q^2) = \frac{1}{x_{I\!P}} \left[\frac{\alpha_s}{Q} x_{I\!P}\, g(x_{I\!P}, Q^2)\right]^2$

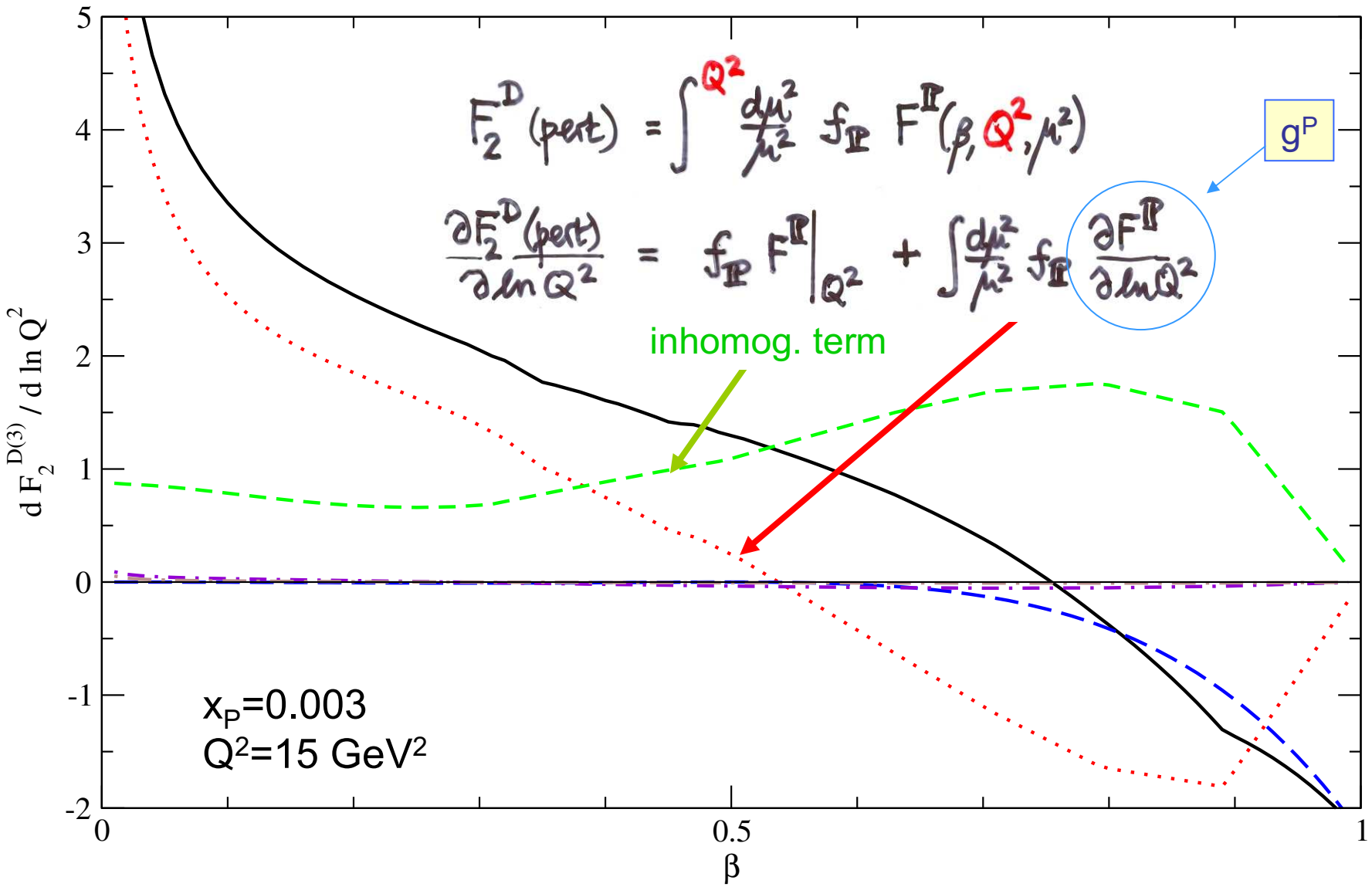
- if $f_{I\!P} \sim \frac{1}{Q^2}$ then inhomogeneous term ~ power correction
  collinear DDIS factn & DGLAP OK
- but at small $x_{I\!P}$, $g(x_{I\!P}, Q^2)$ grows rapidly with Q^2
  so inhomogeneous term must be included

$\mu^2 f_P$ → flux does not behave as $1/\mu^2$



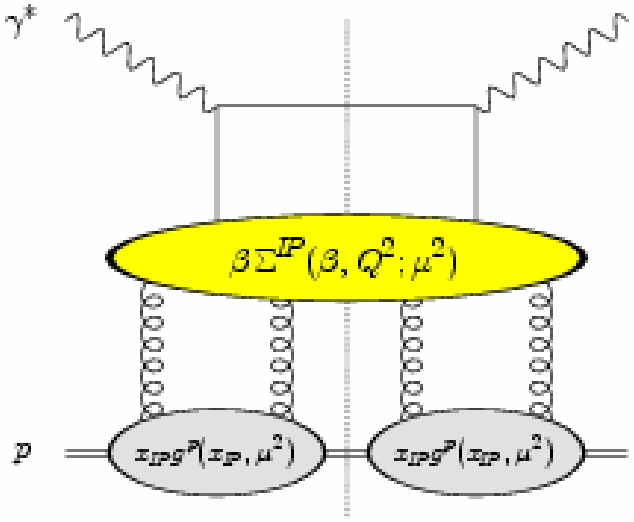
convergence decreases as x_P decreases

inclusion of the inhomogeneous term makes g^P smaller



In practice, more convenient to solve standard DGLAP for each μ starting from its own scale μ (provided $\mu > Q_0$). Then to integrate over μ.

$$F_2^{D(3)}(x_{I\!P}, \beta, Q^2) = \int_{Q_0^2}^{Q^2} \frac{\mathrm{d}\mu^2}{\mu^2} \; f_{I\!P}(x_{I\!P}; \mu^2) \; F_2^{I\!P}(\beta, Q^2; \mu^2)$$



$F_2^{I\!P}(\beta, Q^2; \mu^2)$ → DGLAP $\mu^2 \to Q^2$
$g^{I\!P}(\beta)$, $\Sigma^{I\!P}(\beta)$ input
obtained from LO pQCD
each with K parameter

$f_{I\!P}(x_{I\!P})$ → given by $x_{I\!P} g^p(x_{I\!P}) \sim x_{I\!P}^{-\lambda}$
where data $\to \lambda \simeq 0.17$

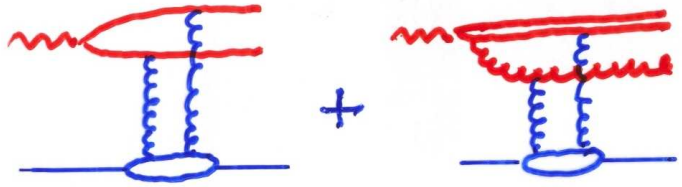
$$F_2^D = \underbrace{(F_2^D)_{\text{pert.}}}_{\mu > Q_0} + \underbrace{(F_2^D)_{\text{non-pert.}}}_{\mu < Q_0} + F_L^D + \text{sec. Reggeon}$$

The perturbative contribution $(\mu > Q_0)$

$$F_2^{D(3)}(x_{I\!P}, \beta, Q^2) = \int_{Q_0^2}^{Q^2} \frac{d\mu^2}{\mu^2} f_{I\!P}(x_{I\!P}, \mu^2) \; F_2^{I\!P}(\beta, Q^2; \mu^2)$$

input forms:

$\beta \Sigma^q \sim \beta^3(1-\beta)$ $\quad$ $\beta g^G \sim (1+2\beta)^2(1-\beta)^2$



flux factor given by

$$[x g^{I\!P}(x, \mu^2)]^2$$

NLO DGLAP evol.^{n} using QCD starting values of $I\!P$ distributions

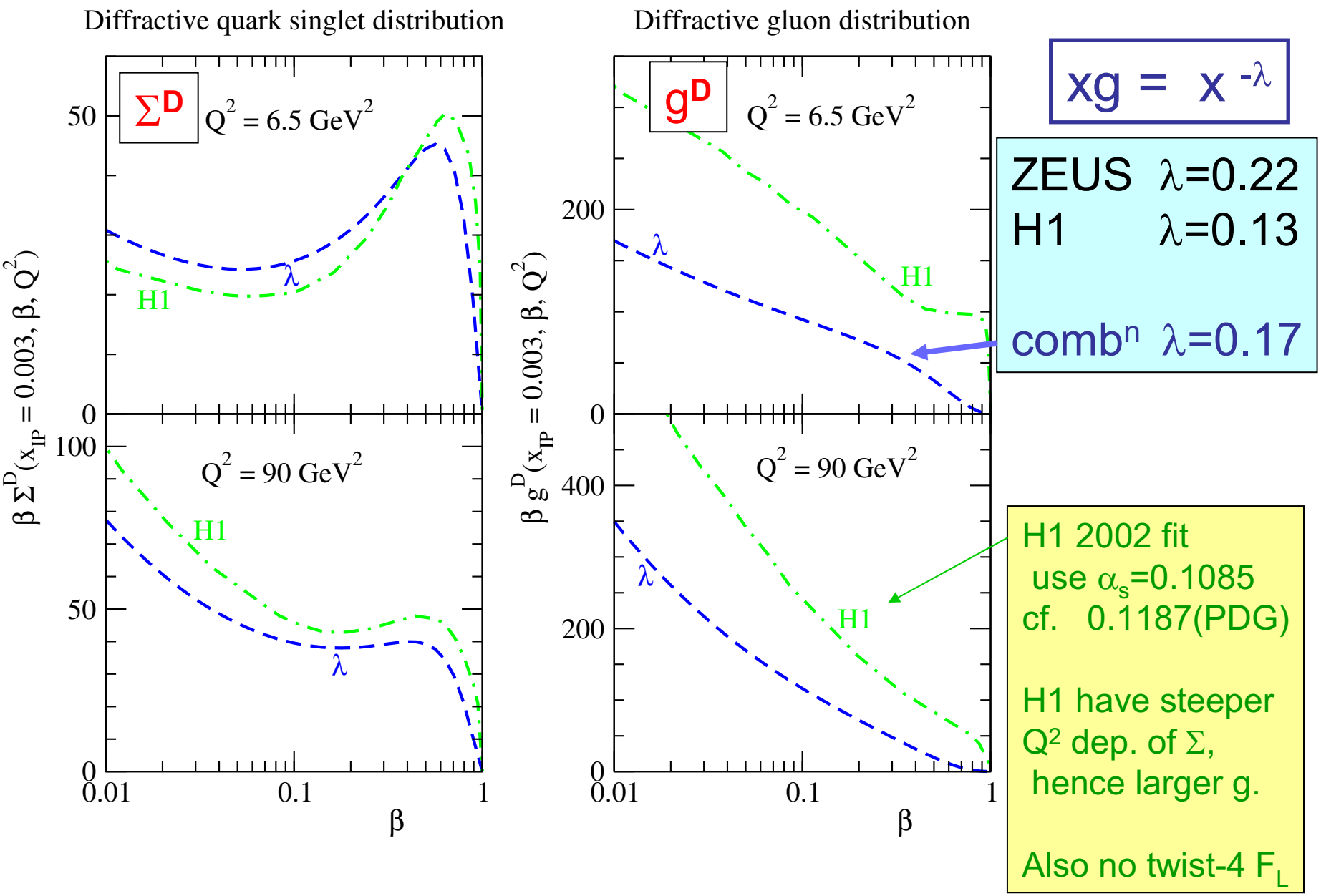
first try: assume $xg \sim x^{-\lambda}$

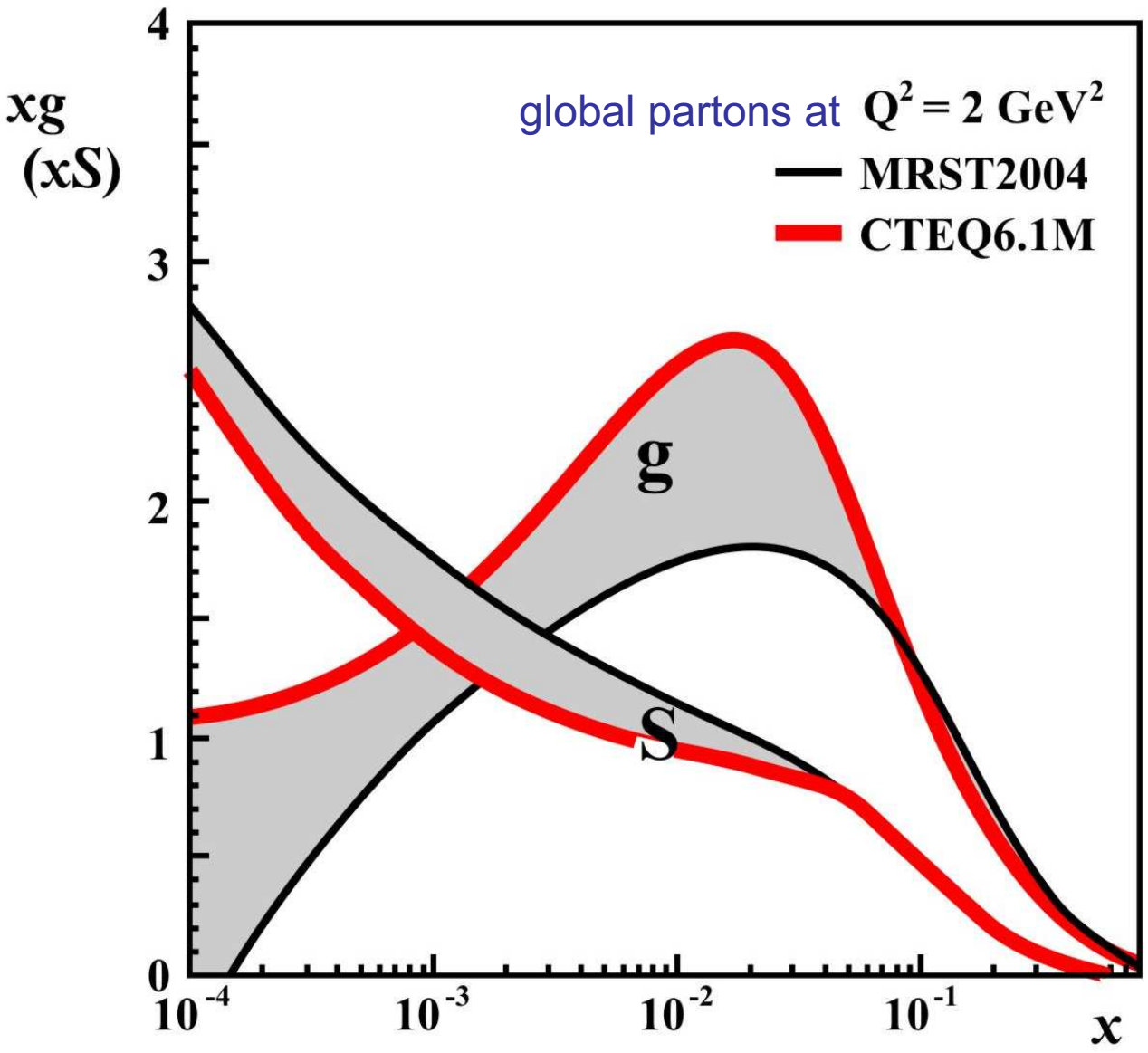
following Wusthoff, BEKW loosely based parametrizations on such forms

Fit to ZEUS and H1 diffractive DIS (prelim.) data

Data sets fitted Number of points	ZEUS LPS 69	ZEUS M_X 121	H1 214	ZEUS + H1 404
χ^2/d.o.f.	0.67	0.78	1.08	1.08
$c_{q/G}$ (GeV^2)	0.71 ± 0.39	0.48 ± 0.12	2.2 ± 0.4	1.13 ± 0.15
$c_{g/G}$ (GeV^2)	0.11 ± 0.05	0.10 ± 0.02	0.26 ± 0.05	0.17 ± 0.02
$c_{L/G}$ (GeV^2)	0	0.20 ± 0.08	0.54 ± 0.17	0.36 ± 0.08
c_{q/N_F} (GeV^{-2})	0.87 ± 0.13	1.22 ± 0.04	0.91 ± 0.05	1.09 ± 0.05
c_{IH} (GeV^{-2})	6.7 ± 0.8	—	7.5 ± 2.0	6.2 ± 0.6
λ	0.23 ± 0.04	0.21 ± 0.02	0.13 ± 0.01	0.17 ± 0.01
N_Z	—	1.56 (fixed)	—	1.56 ± 0.06
N_H	—	—	1.26 (fixed)	1.26 ± 0.05
$R(6.5\,\text{GeV}^2), R(90\,\text{GeV}^2)$	0.60, 0.60	0.56, 0.57	0.54, 0.55	0.55, 0.56

$xg = x^{-\lambda}$


Diffractive quark singlet distribution
Diffractive gluon distribution
Σ^D
g^D
$Q^2 = 6.5$ GeV^2
$Q^2 = 90$ GeV^2
$\beta\,\Sigma^D(x_{IP} = 0.003, \beta, Q^2)$
$\beta\,g^D(x_{IP} = 0.003, \beta, Q^2)$
λ
H1
β
0.01
0.1
1
xg = x$^{-\lambda}$
ZEUS λ=0.22
H1 λ=0.13
combⁿ λ=0.17
H1 2002 fit
use α_s=0.1085
cf. 0.1187(PDG)
H1 have steeper
Q^2 dep. of Σ,
hence larger g.
Also no twist-4 F_L



but one of the HERA surprises….

g: valence-like
S: Pomeron-like

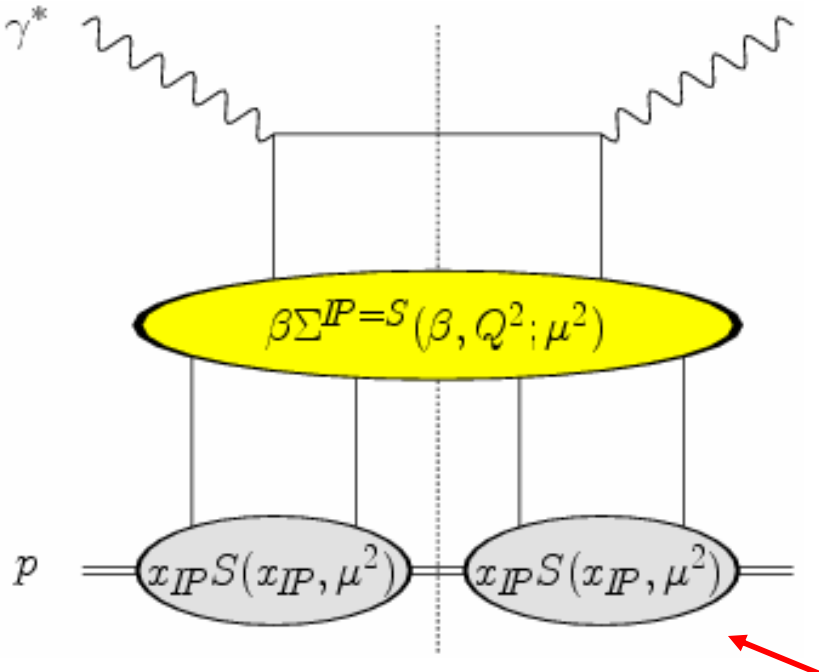
whereas expect
$\lambda_g \sim \lambda_S \sim 0.1$

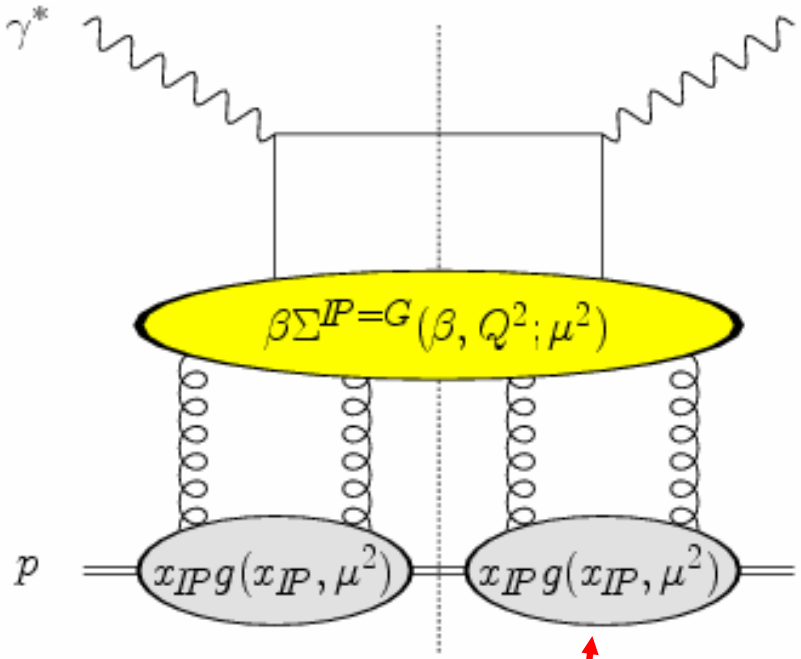
($xg \sim x^{-\lambda g}$
$xS \sim x^{-\lambda S}$)

need to introduce Pomeron made of col. singlet $q\bar{q}$ pair

as well as

Pomeron made of two gluons





Now Pomeron flux factors depend on S^p as well as g^p

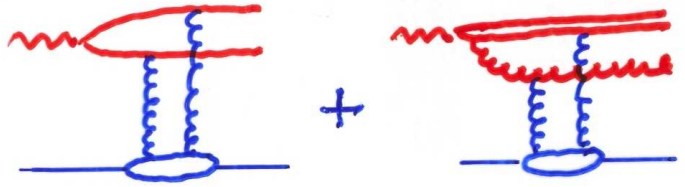
The perturbative contribution $(\mu > Q_0)$

$$F_2^{D(3)}(x_{I\!P}, \beta, Q^2) = \int_{Q_0^2}^{Q^2} \frac{d\mu^2}{\mu^2} f_{I\!P}(x_{I\!P}, \mu^2) \; F_2^{I\!P}(\beta, Q^2; \mu^2)$$

flux factor given by

input forms:

$\beta\Sigma^G \sim \beta^3(1-\beta)$ $\quad$ $\beta g^G \sim (1+2\beta)^2(1-\beta)^2$



$\beta\Sigma^S \sim \beta(1-\beta)$ $\quad$ $\beta g^S \sim (1-\beta)^2$

$[x g^{I\!P}(x, \mu^2)]^2$

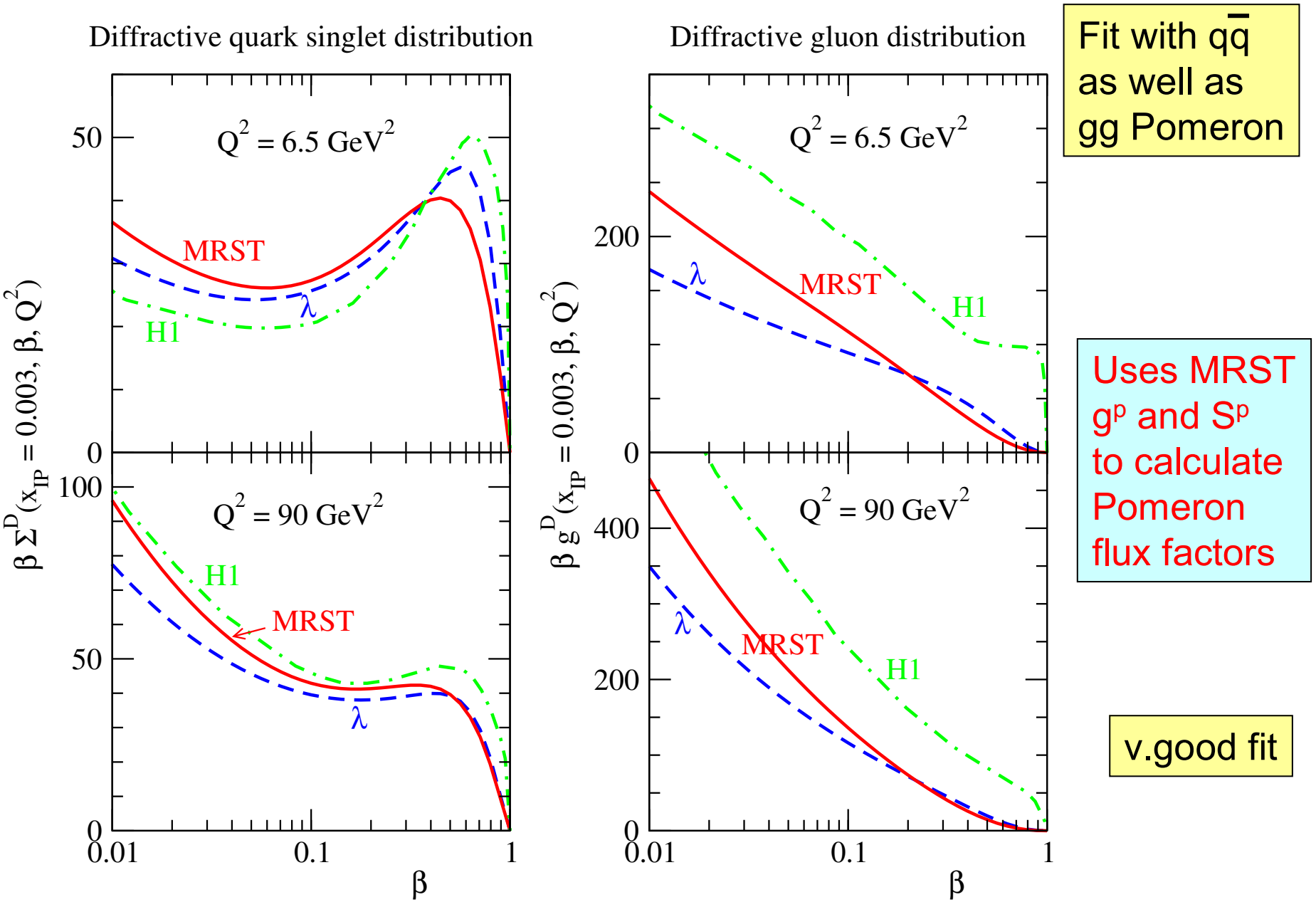
$[x S^{I\!P}(x, \mu^2)]^2$

NLO DGLAP evol.^{n} using QCD starting values of $I\!P$ distributions

$\Sigma^{I\!P=G,S}$

$g^{I\!P=G,S}$

use MRST/CTEQ partons



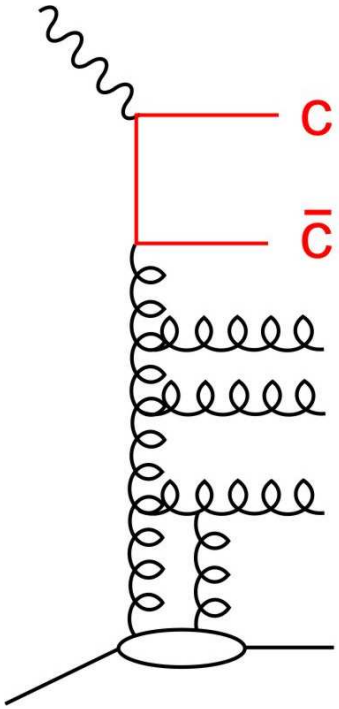
Fit with $q\bar{q}$ as well as gg Pomeron

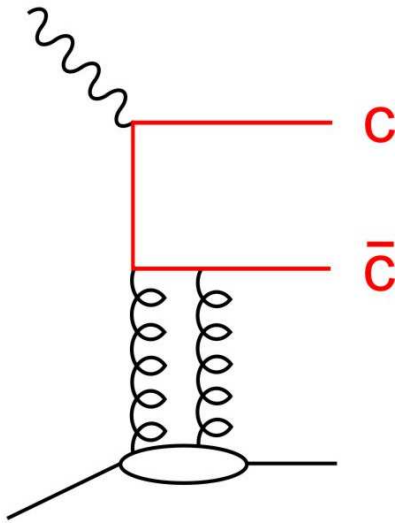
Uses MRST g^p and S^p to calculate Pomeron flux factors

v.good fit

diffractive charm production

constrains gluon



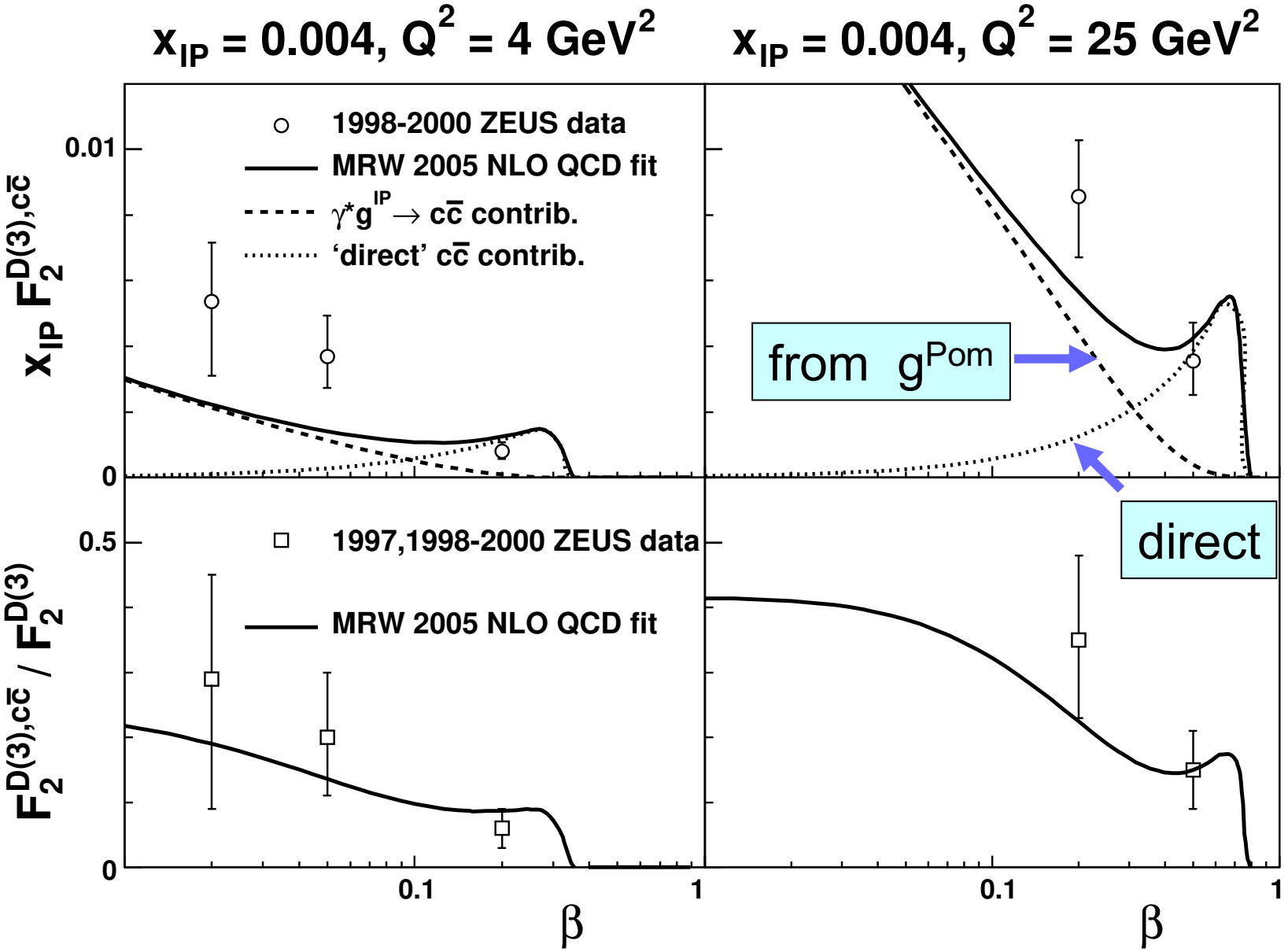


direct contribution

from g^{Pom}

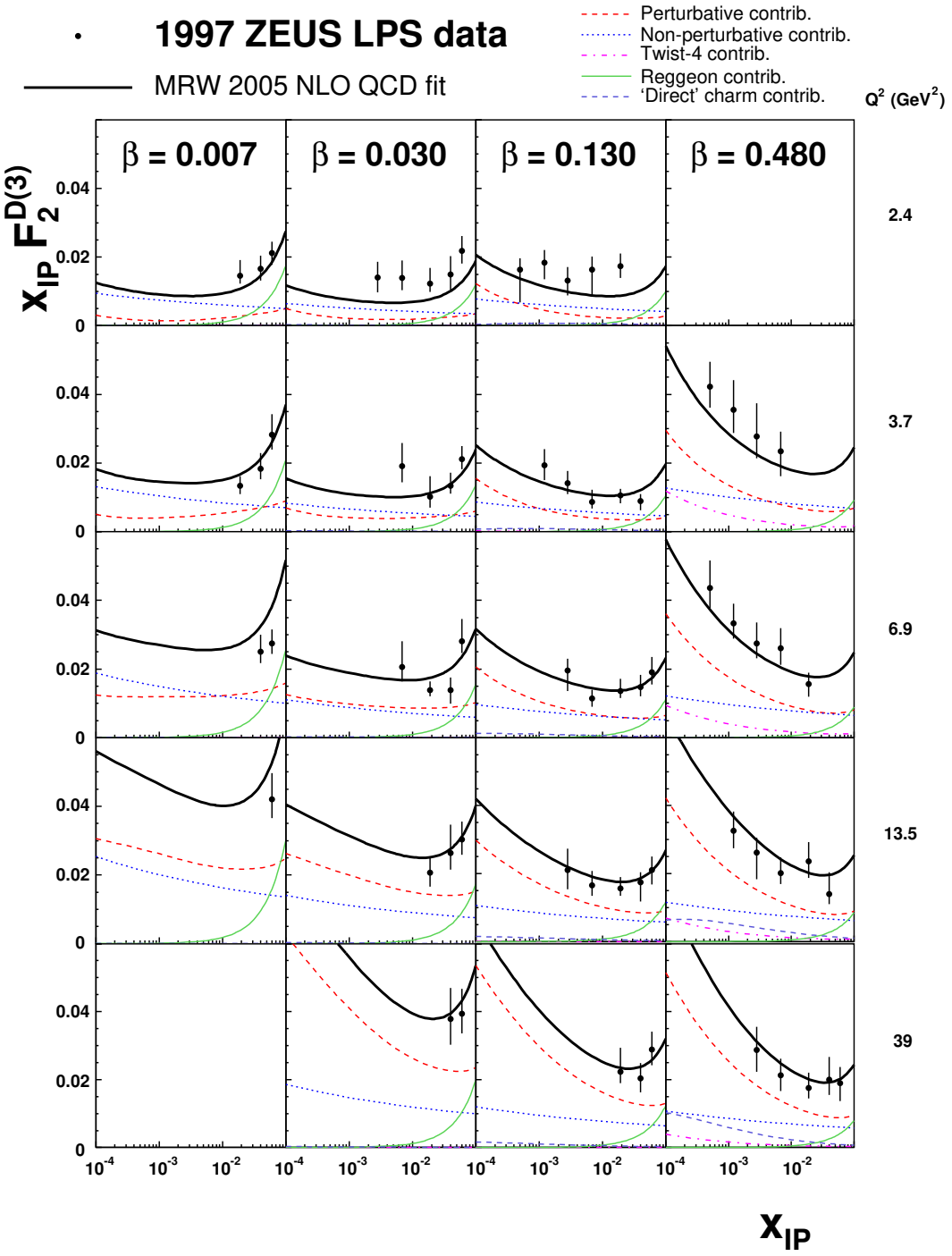
add separately.
No evolution and
no DDIS factorization

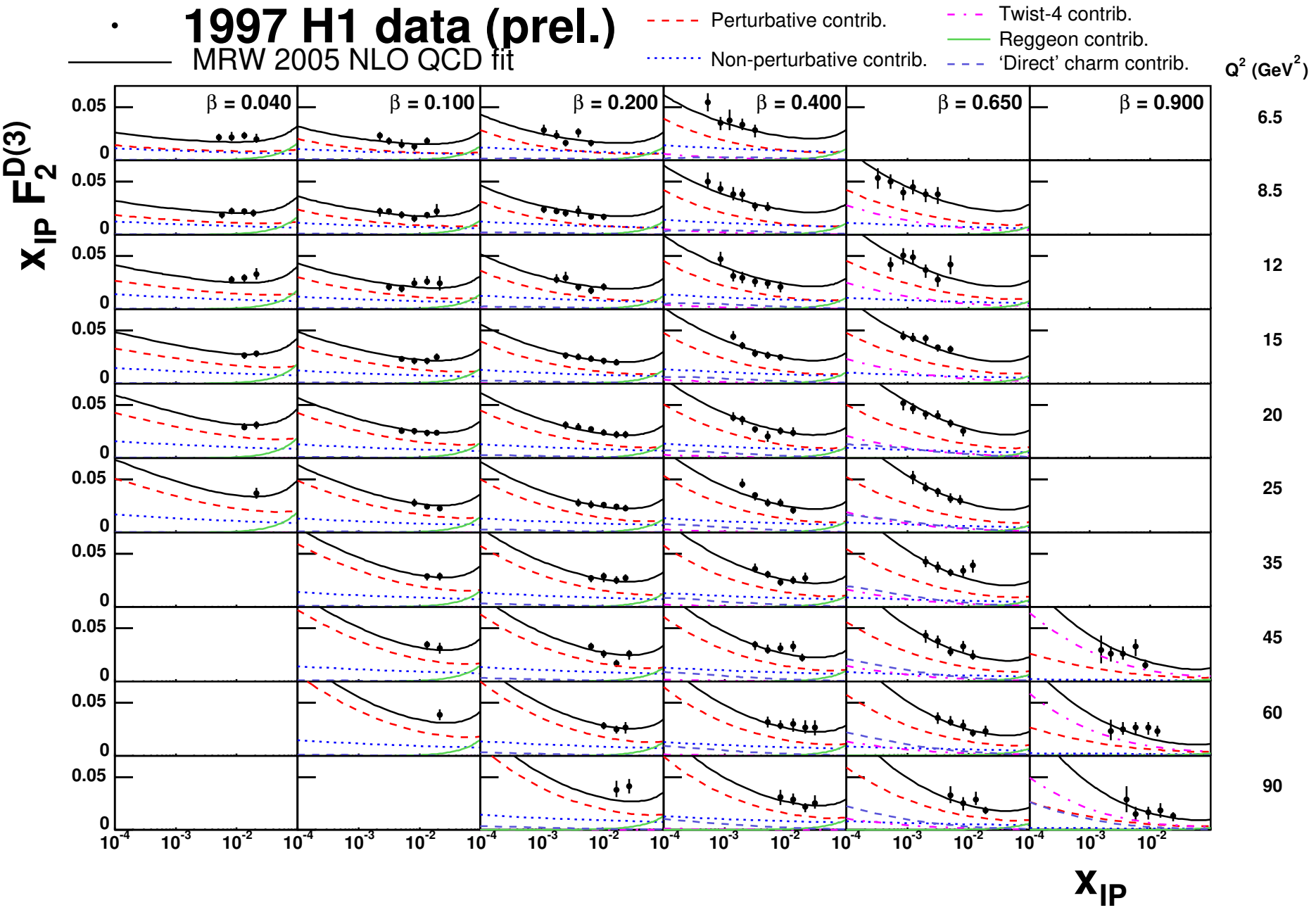
the description of ZEUS diffractive charm production

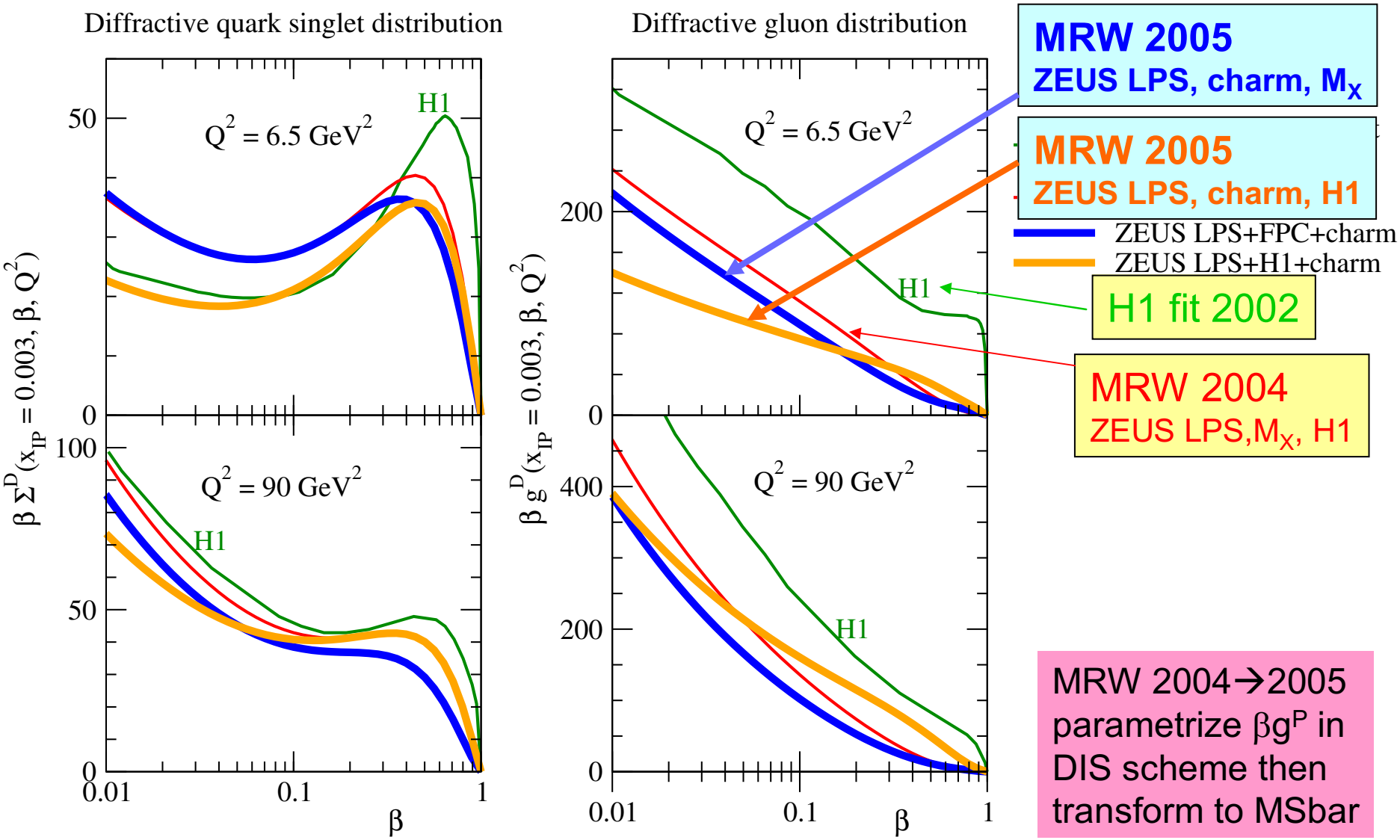


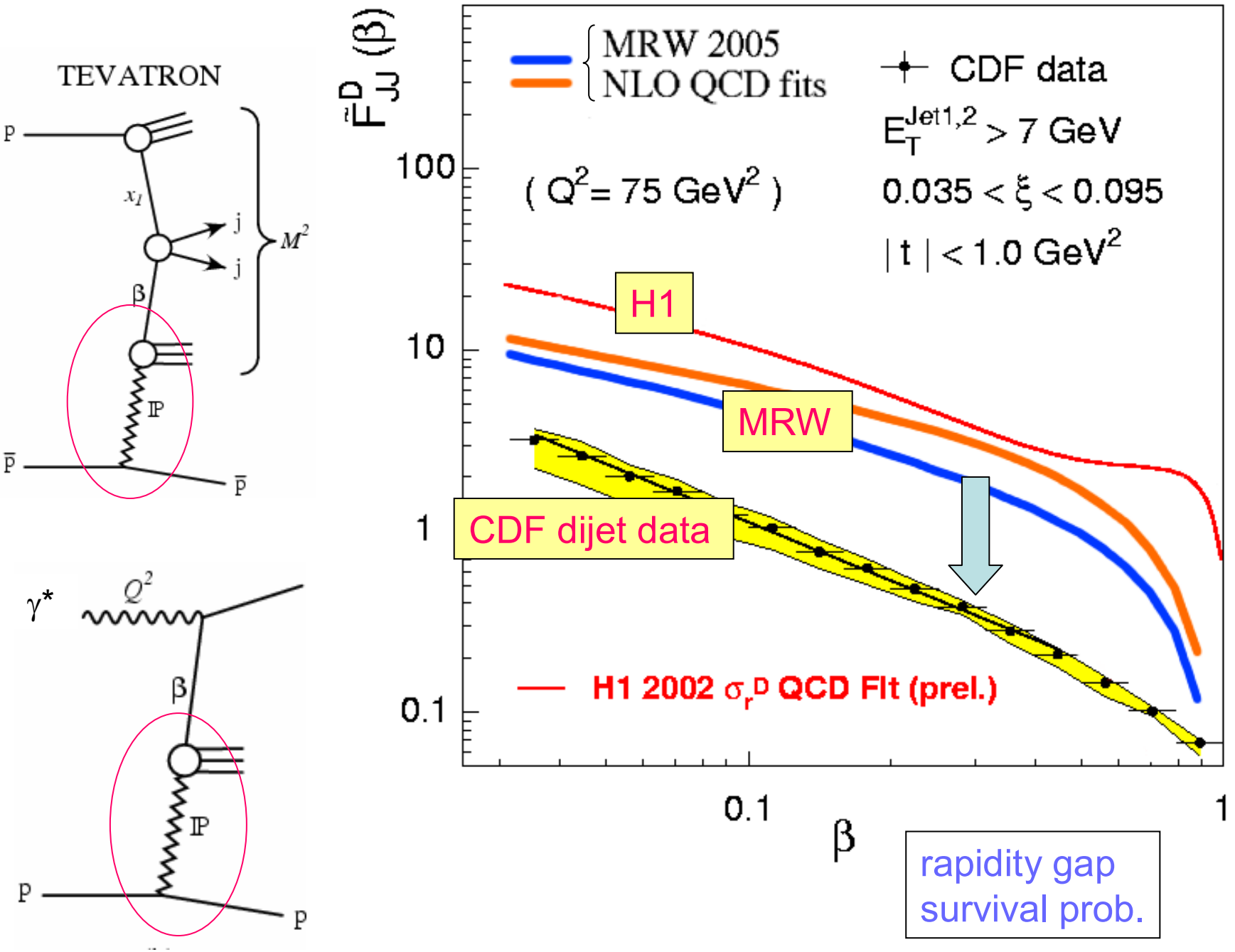
The corresponding MRW fit to the ZEUS LPS data →

and H1 (prelim.) data




1997 H1 data (prel.)
MRW 2005 NLO QCD fit
Perturbative contrib.
Non-perturbative contrib.
Twist-4 contrib.
Reggeon contrib.
'Direct' charm contrib.
$x_{IP} F_2^{D(3)}$
x_{IP}
Q^2 (GeV^2)
β = 0.040
β = 0.100
β = 0.200
β = 0.400
β = 0.650
β = 0.900
6.5
8.5
12
15
20
25
35
45
60
90
0.05
0
10^{-4}
10^{-3}
10^{-2}


Diffractive quark singlet distribution
Diffractive gluon distribution
$\beta \Sigma^D(x_{IP} = 0.003, \beta, Q^2)$
$\beta g^D(x_{IP} = 0.003, \beta, Q^2)$
$Q^2 = 6.5$ GeV^2
$Q^2 = 90$ GeV^2
H1
β
0.01
0.1
1
MRW 2005
ZEUS LPS, charm, M_X
MRW 2005
ZEUS LPS, charm, H1
ZEUS LPS+FPC+charm
ZEUS LPS+H1+charm
H1 fit 2002
MRW 2004
ZEUS LPS,M_X, H1
MRW 2004→2005 parametrize βg^P in DIS scheme then transform to MSbar


TEVATRON
p
x_I
j
j
M^2
β
IP
$\bar{p}$
$\bar{p}$
γ^*
Q^2
β
IP
p
p
$F_{JJ}^{D}(\beta)$
MRW 2005
NLO QCD fits
CDF data
$E_T^{Jet1,2} > 7$ GeV
$0.035 < \xi < 0.095$
$|t| < 1.0$ GeV^2
($Q^2 = 75$ GeV^2)
H1
MRW
CDF dijet data
H1 2002 σ_r^D QCD Fit (prel.)
100
10
1
0.1
0.1
1
β
rapidity gap
survival prob.

Conclusions

☆ Analysis of DDIS, which goes beyond collinear + Regge fact^{n}

☆ Regge factorization replaced by pQCD

--need quark-antiquark Pomeron, in addition to two-gluon Pomeron

--the input forms of the Pomeron PDFs given by QCD diagrams

☆ Collinear DDIS factorization modified in HERA regime:

--inhomogeneous DGLAP evolution → smaller g^{Pom}

☆ Good description of H1, ZEUS DDIS data

☆ We obtain universal diffractive partons

--diffractive gluon considerably smaller than that of H1 fit

--for hadron-hadron diffraction, must include rap. gap survival probability

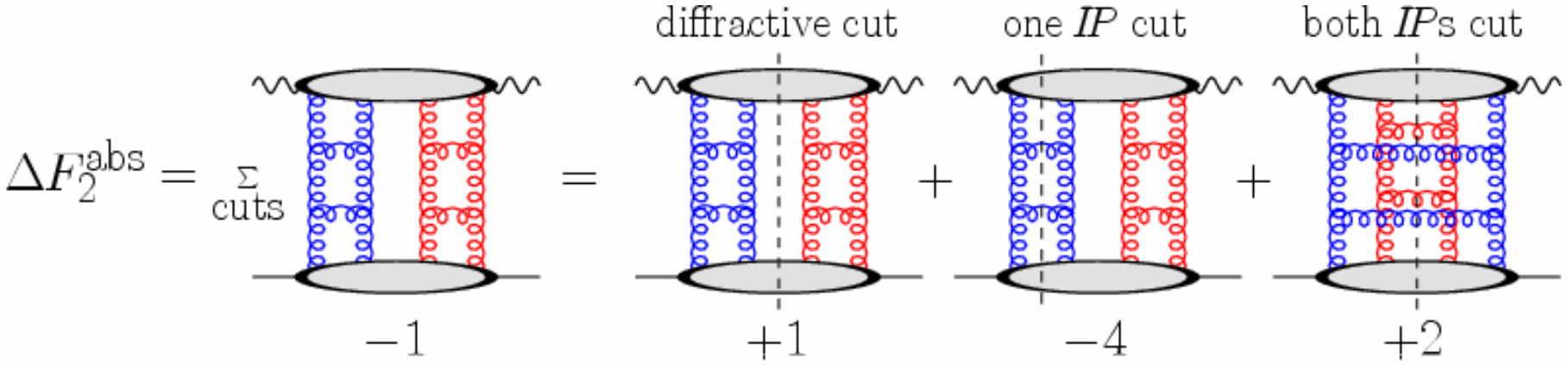
☆ Moreover---the diffractive fit allows an estimate of the absorptive corrections in global DIS fit

Contribution of diffractive F_2 to inclusive F_2

Apply the AGK cutting rules to $\mathbb{P} \otimes \mathbb{P}$ contrib.

AGK in QCD: Bartels & Ryskin

Im $T_{el} \sim \sigma_{tot}$



$\Delta F_2^{abs} \sim - F_2^D$

negative (~Glauber shadowing)