Diffractive partons from perturbative QCD

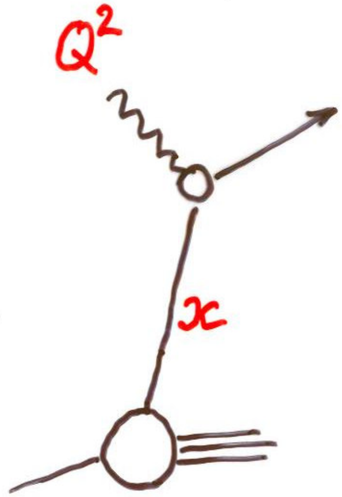
Alan Martin, Misha Ryskin and Graeme Watt

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

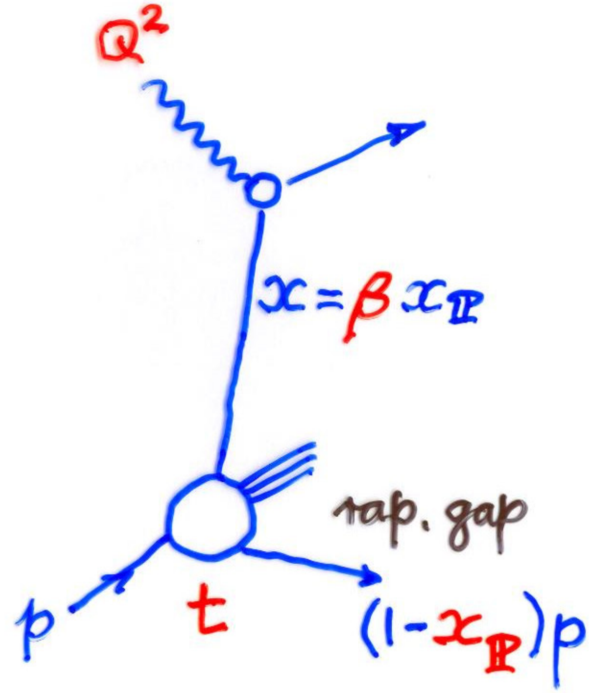


↓

parton densities a

Diffractive DIS

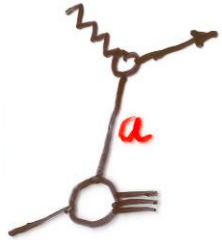
(10-20%)



↓

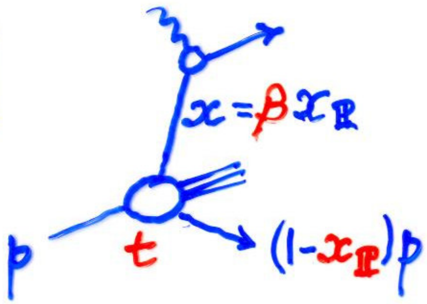
diffractive parton densites a^D

DIS



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

DDIS



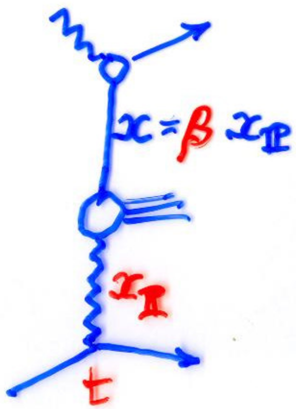
$$F_2(x_{\mathbb{P}}, \beta, Q^2) = \sum_a C_{2,a} \otimes a^D$$

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

conventional to also assume Regge fact.^{n}

Ingelman-Schlein

$\mathbb{P}$ ~ particle

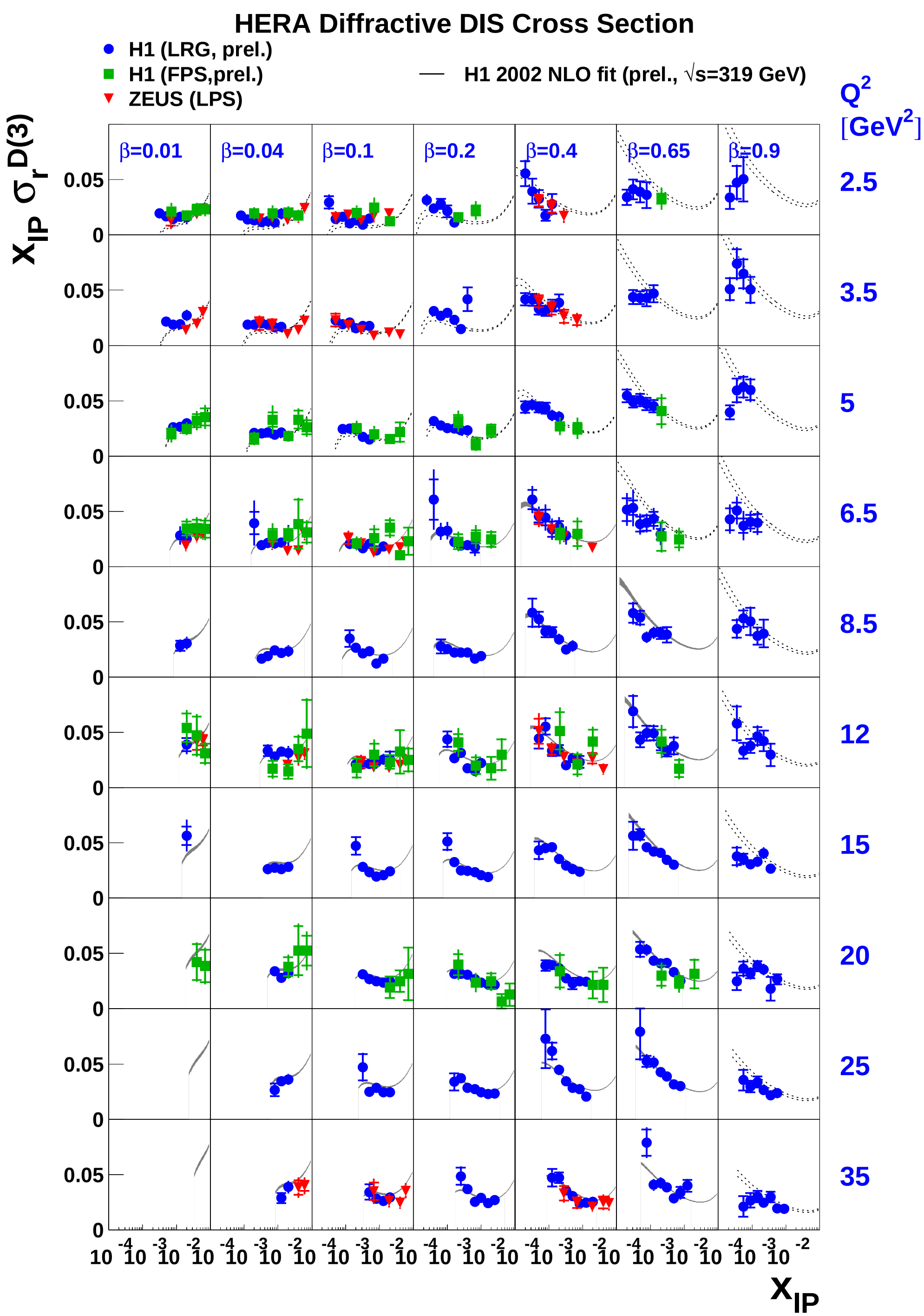


$$a^D(x_{\mathbb{P}}, \beta, Q^2) = f_{\mathbb{P}}(x_{\mathbb{P}})\, a^{\mathbb{P}}(\beta, Q^2)$$

$\mathbb{P}$ flux $\quad f_{\mathbb{P}} = \int dt \, \dfrac{e^{Bt}}{x_{\mathbb{P}}^{\,2\alpha_{\mathbb{P}}(t)-1}}$

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

$\alpha_{\mathbb{P}}(0)$ = parameter



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

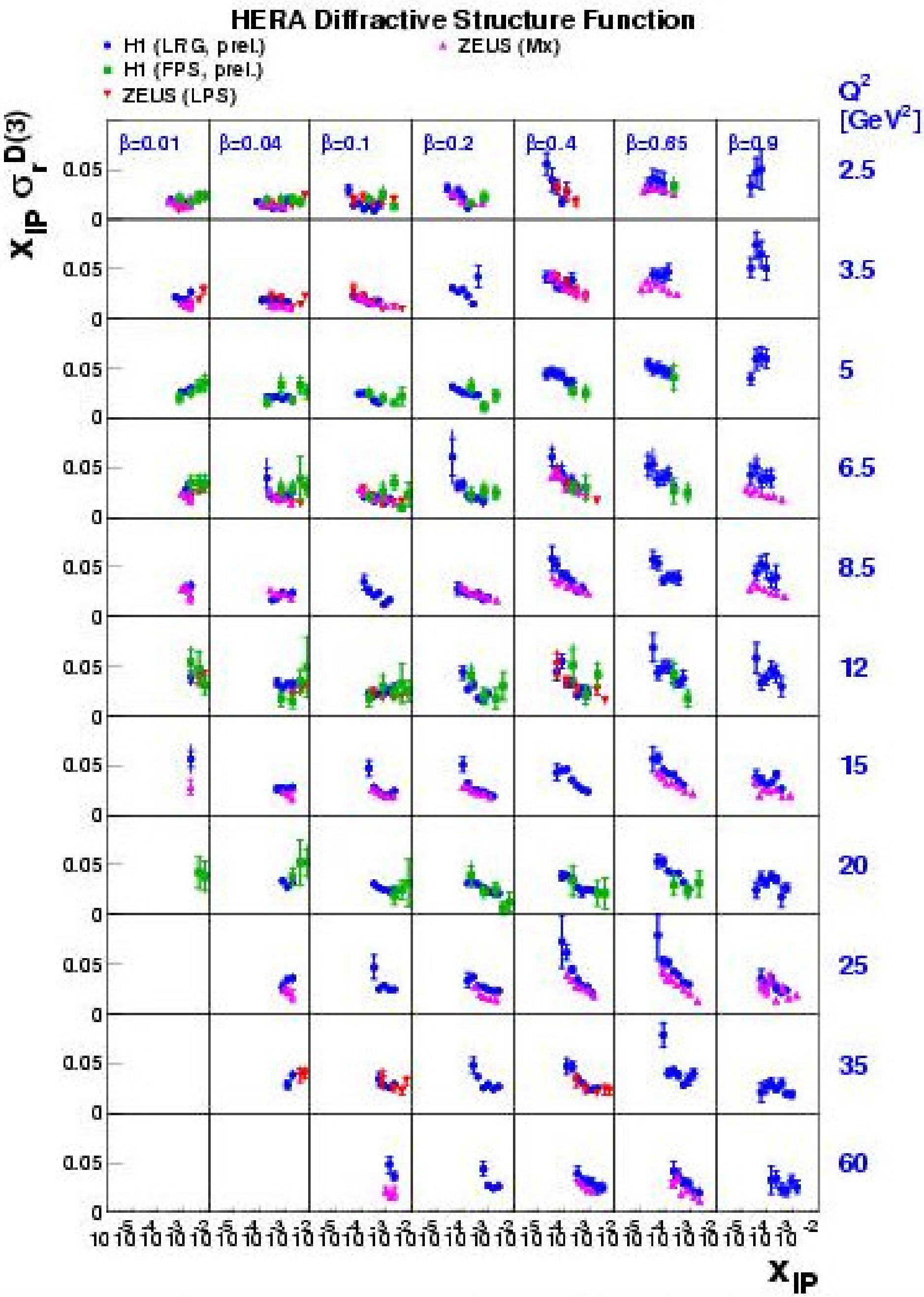
H1 LPS proton selection: $M_Y = m_p$
extrapolated to |t|<1 GeV^2

➔ Good agreement between two methods and two experiments

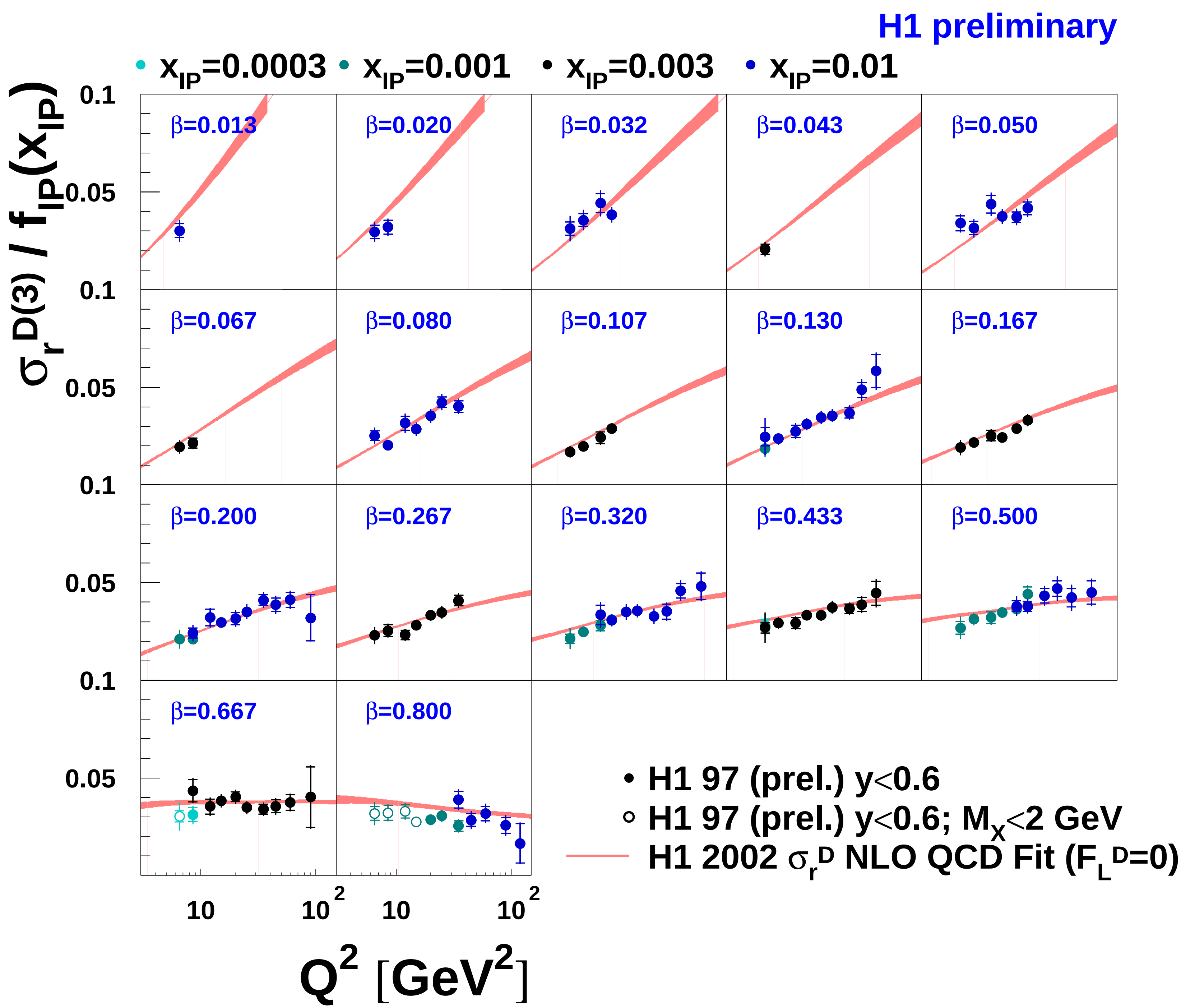
➔ Data well described by H1 QCD fit to LRG data

Comparison of all data ($M_Y < 1.6$)

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

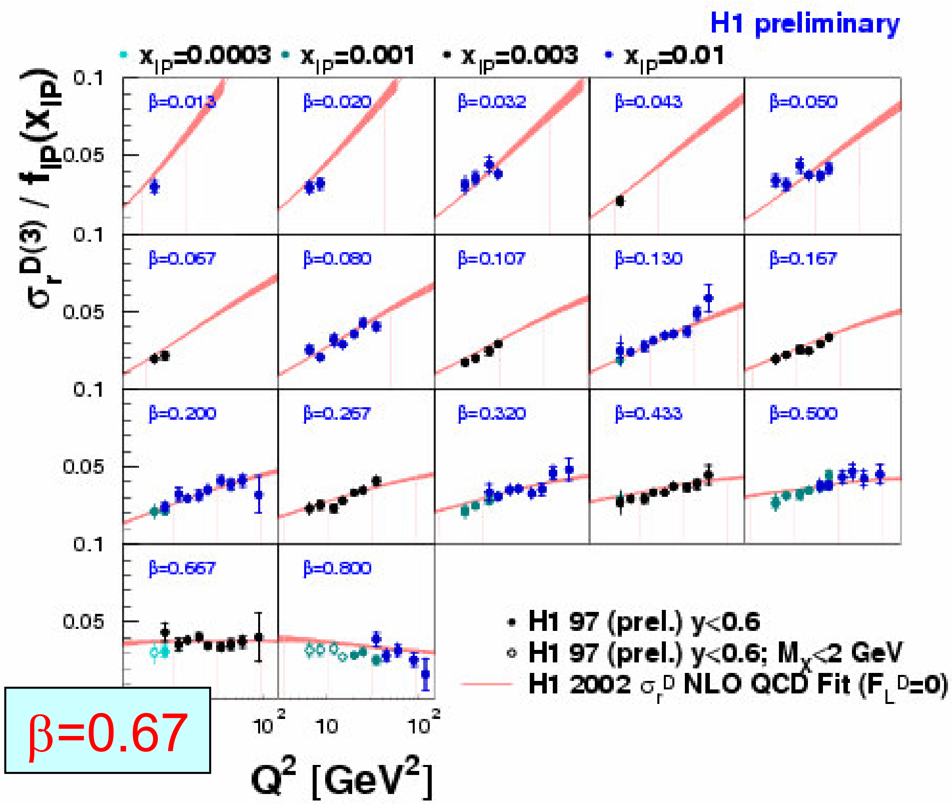


see Laycock

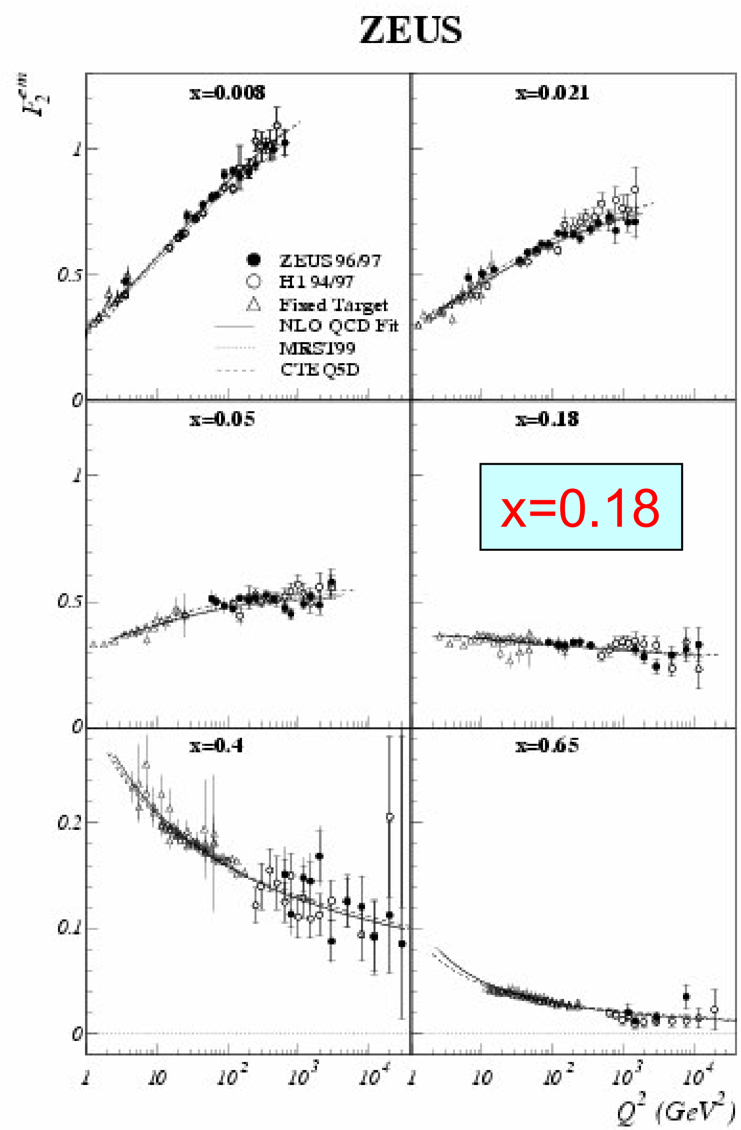


H1 preliminary
x_{IP}=0.0003
x_{IP}=0.001
x_{IP}=0.003
x_{IP}=0.01
$\sigma_r^{D(3)} / f_{IP}(x_{IP})$
β=0.013
β=0.020
β=0.032
β=0.043
β=0.050
β=0.067
β=0.080
β=0.107
β=0.130
β=0.167
β=0.200
β=0.267
β=0.320
β=0.433
β=0.500
β=0.667
β=0.800
0.1
0.05
10
10^2
Q^2 [GeV^2]
H1 97 (prel.) y<0.6
H1 97 (prel.)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

Diffractive DIS

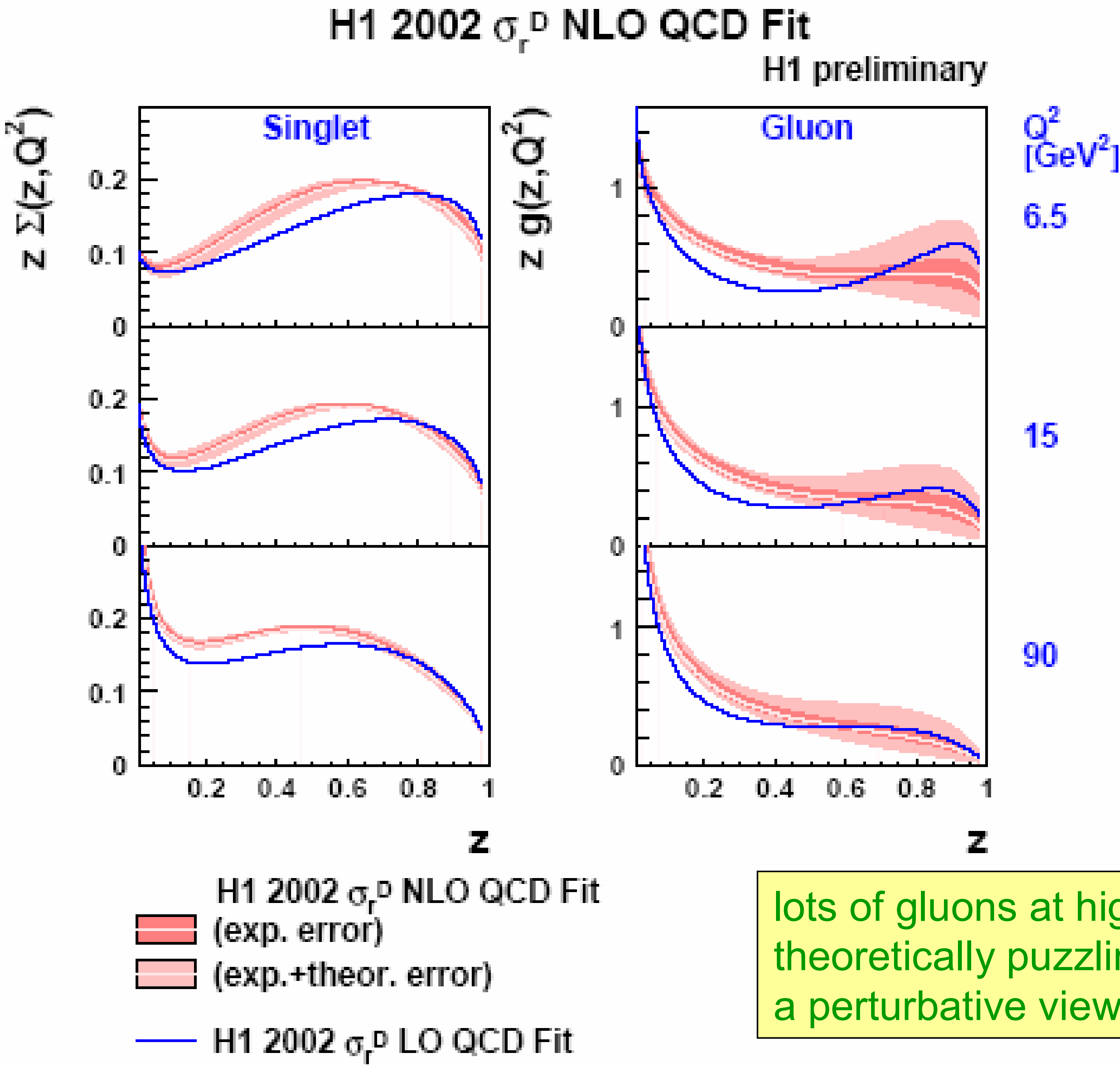


DIS



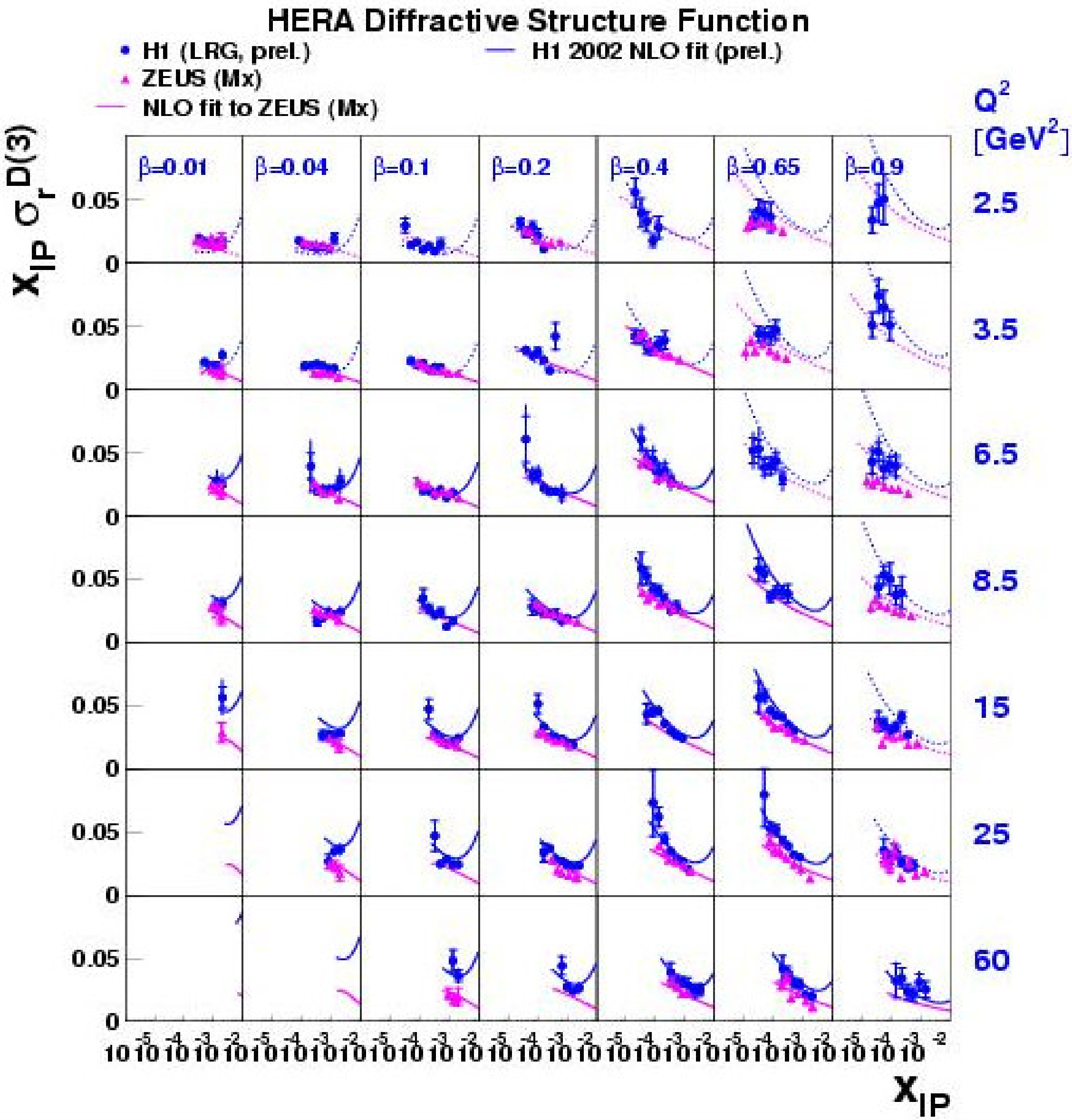
- Positive scaling violations to highest β

→ lot of gluons



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

H1 and ZEUS data and fits

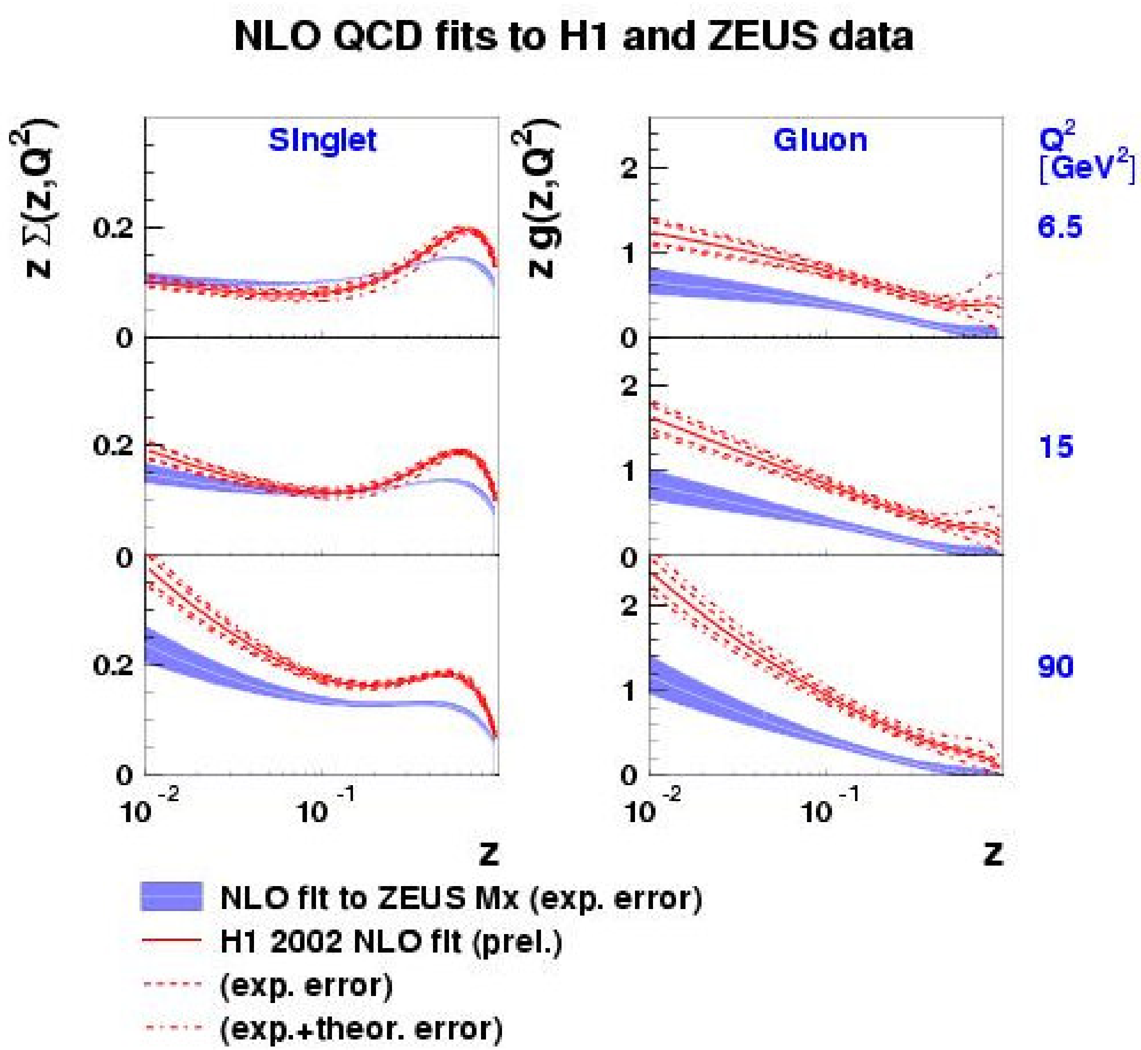


- Differences in data in high β region not included in fits
- Smaller positive scaling violations in ZEUS data, leading to smaller gluon

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 diferenly to higher Q^2 due to coupling to gluon
- Gluon factor $\sim$ 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 $\mu \sim 1/R$

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

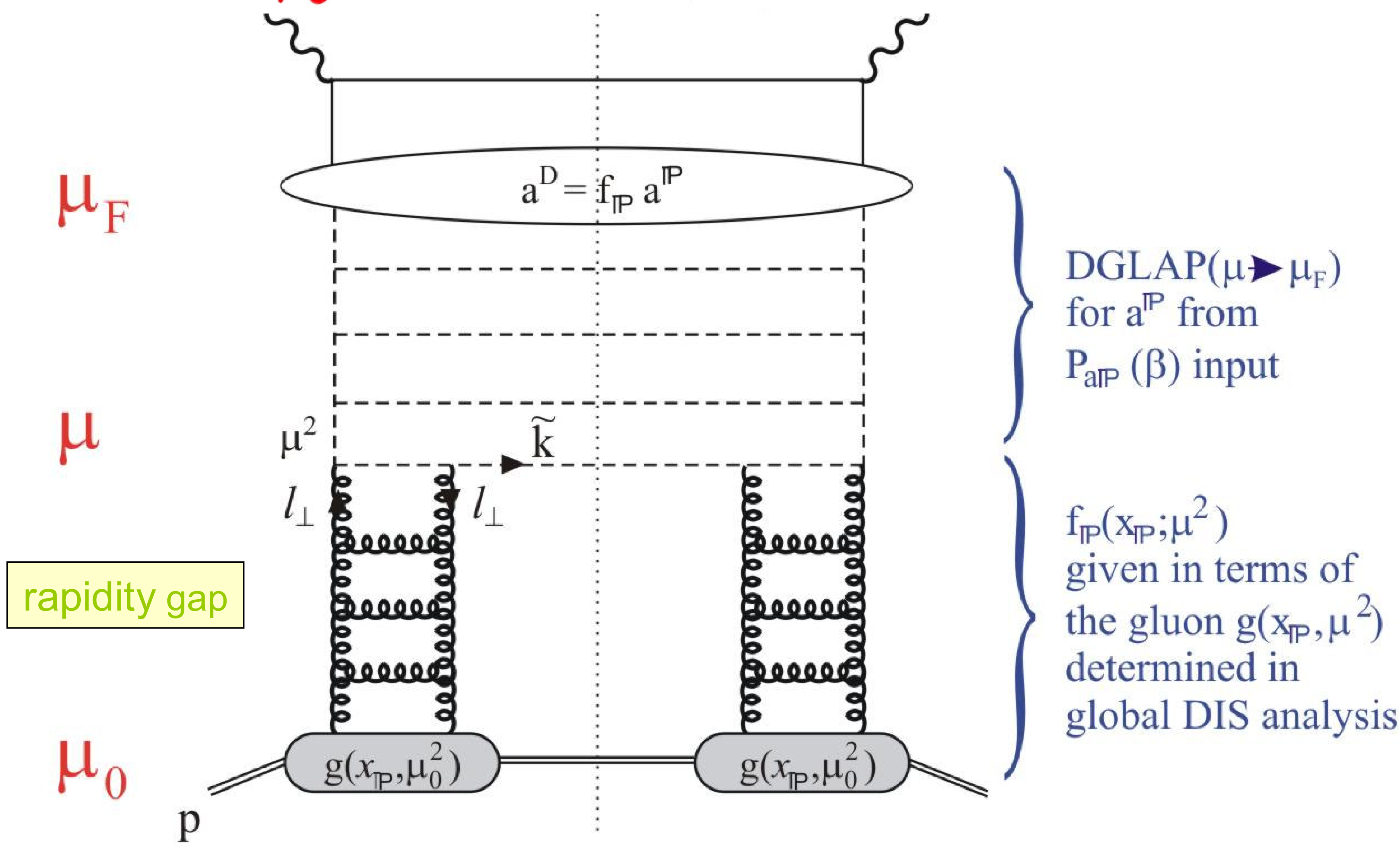
→ small-size component from pQCD domain with larger $\alpha_P(0)$

MRW study impact of applying pQCD to DDIS

find DDIS factorization OK asymptotically, but

important modifications in HERA (subasymptotic) regime

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



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

given by pQCD

$$a^{\mathbb{P}}(\beta, \mu^2, \mu^2)$$

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

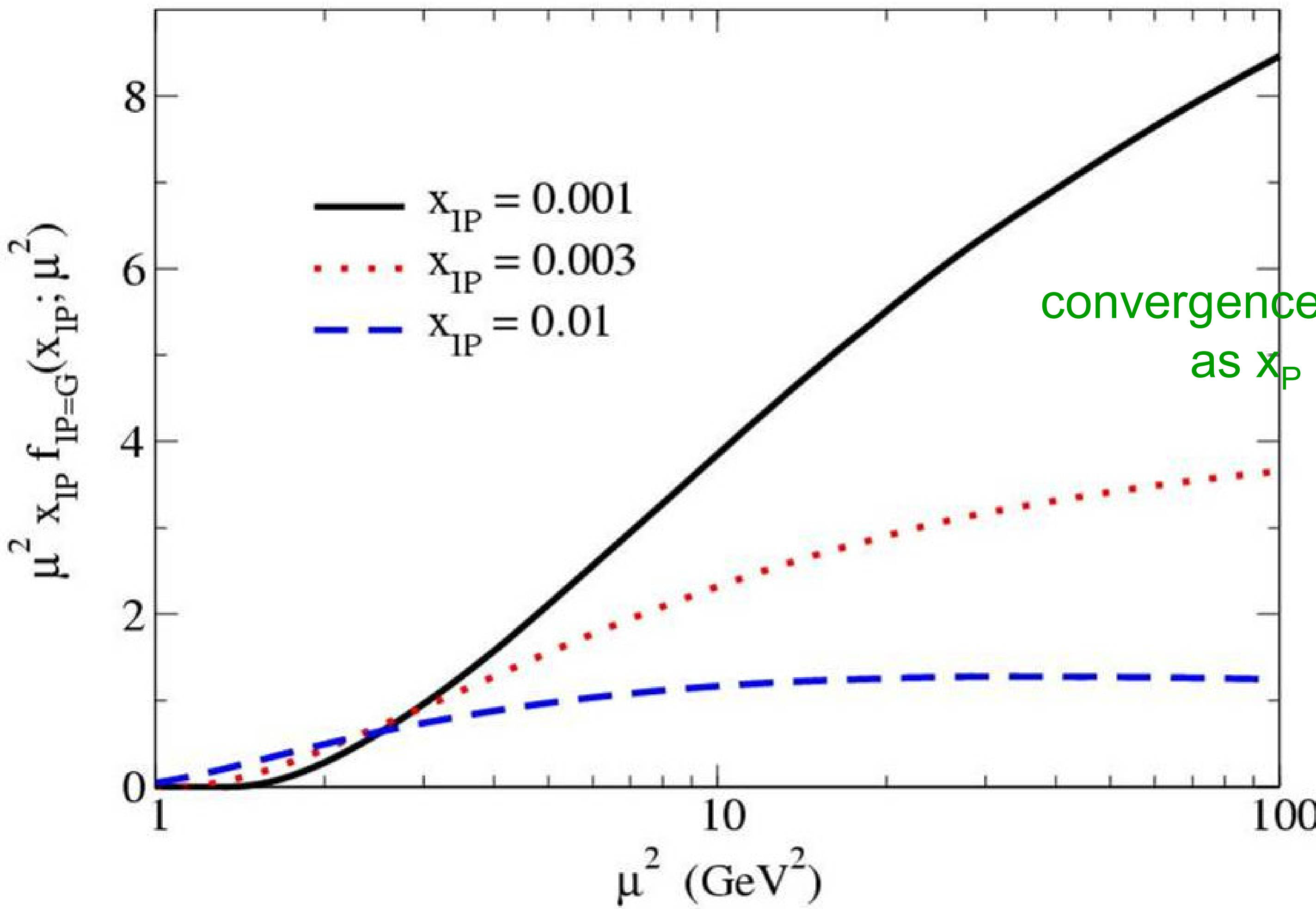
DGLAP with inhomogeneous term

cf DGLAP for γ

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

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

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

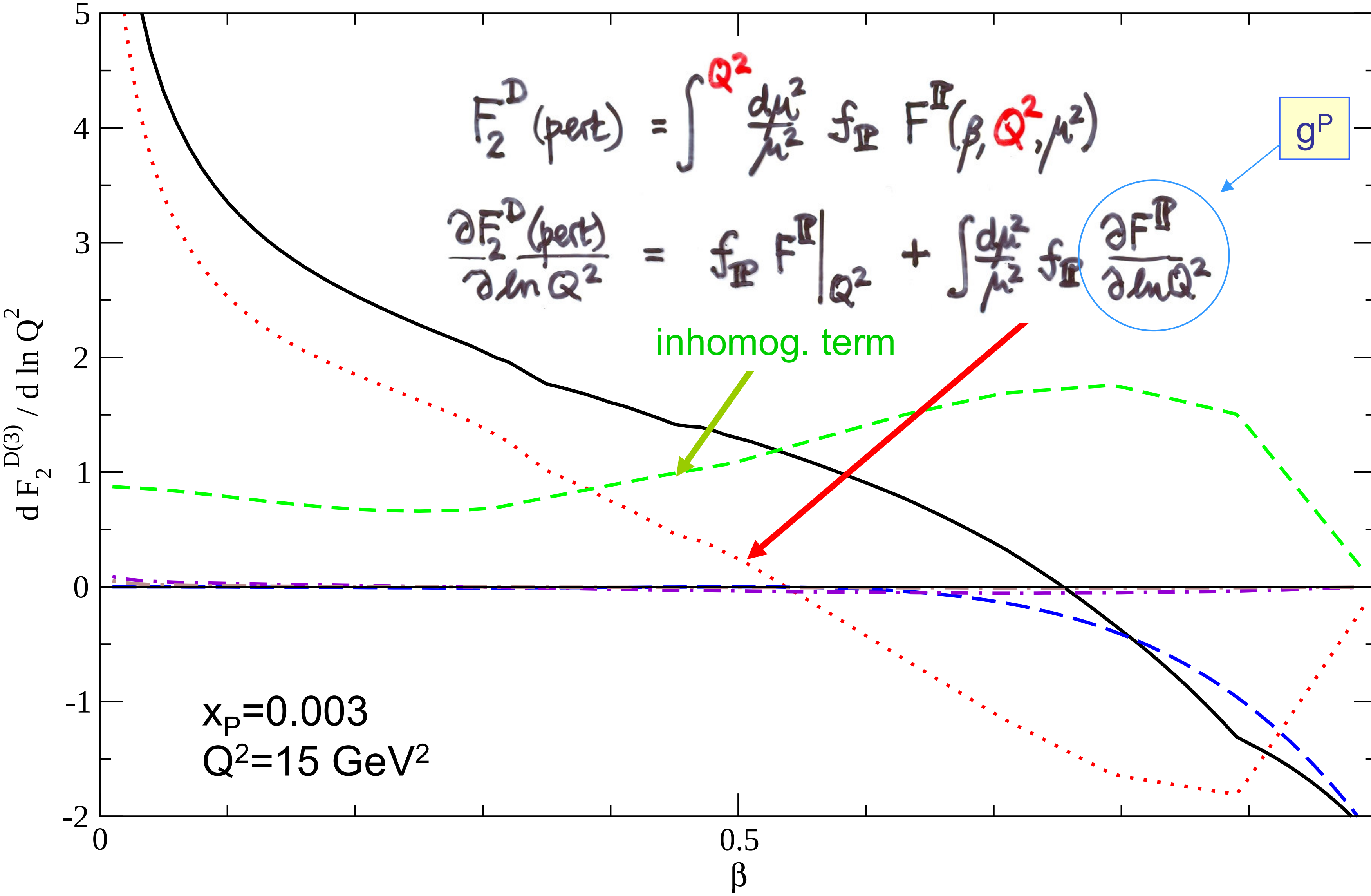


convergence decreases as x_P decreases

inclusion of the inhomogeneous term makes g^P smaller

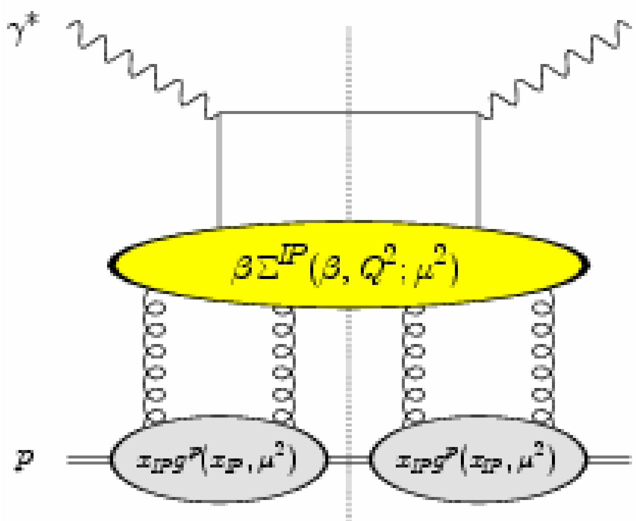
$$F_2^D(\text{pert}) = \int^{Q^2} \frac{d\mu^2}{\mu^2} f_{I\!P}\, F^{I\!P}(\beta, Q^2, \mu^2)$$

$$\frac{\partial F_2^D(\text{pert})}{\partial \ln Q^2} = f_{I\!P}\, F^{I\!P}\Big|_{Q^2} + \int \frac{d\mu^2}{\mu^2} f_{I\!P} \frac{\partial F^{I\!P}}{\partial \ln Q^2}$$



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.

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



$F_2^{I\!P}(\beta, Q^2; \mu^2)$

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 ($\mu > Q_0$)

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

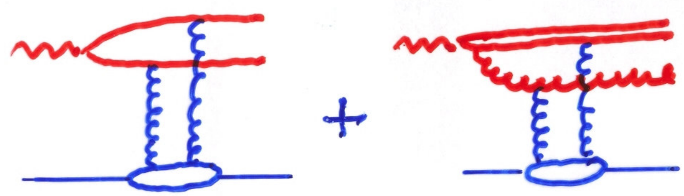
flux factor given by $\left[x g^p(x, \mu^2)\right]^2$

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

input forms:

$\beta \Sigma^q \sim \beta^3 (1-\beta)$

$\beta g^q \sim (1+2\beta)^2 (1-\beta)^2$



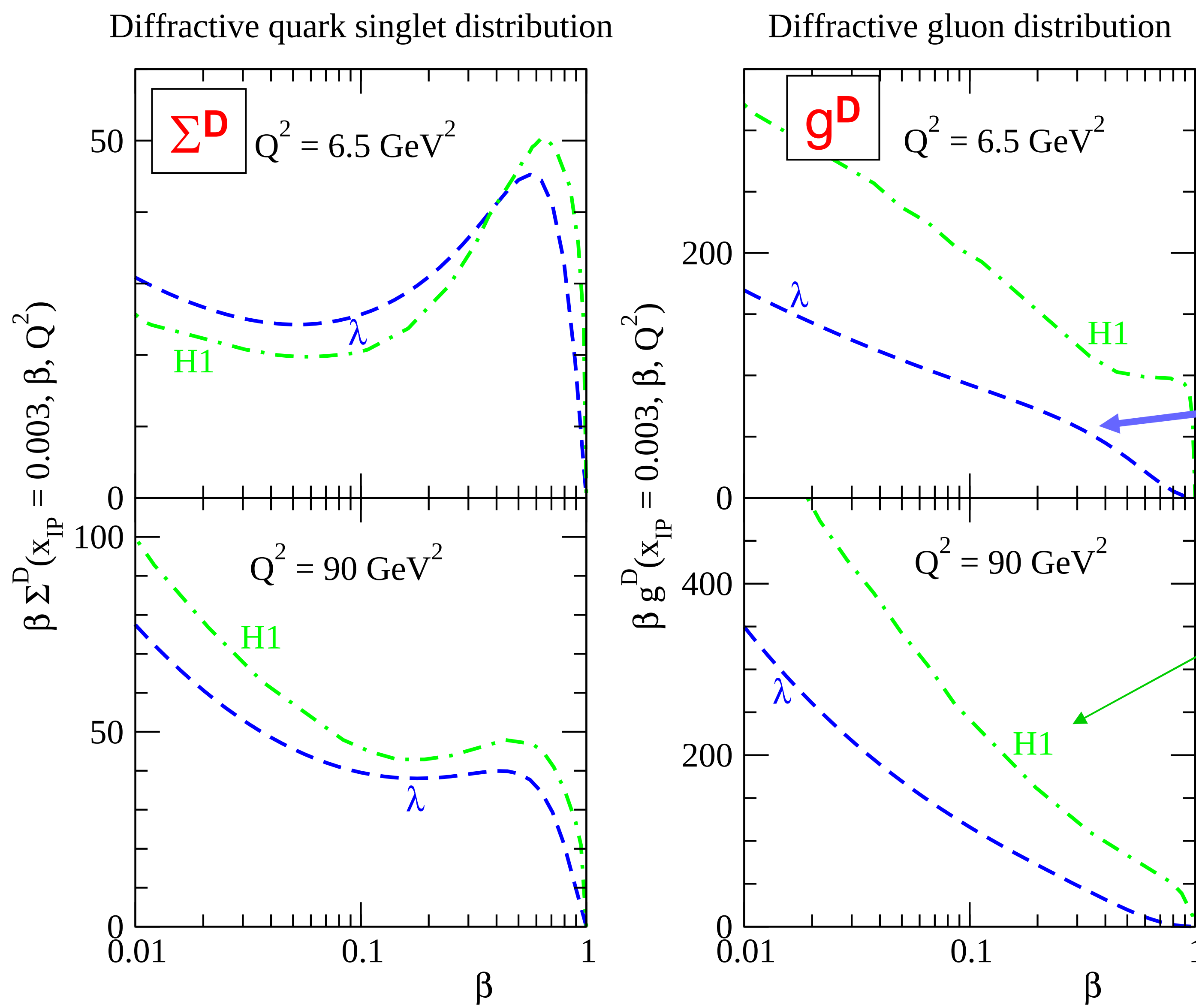
first try: assume $xg \sim x^{-\lambda}$

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
$c_{q/NP}$ (GeV^{-2})	0.87 ± 0.13	1.22 ± 0.04	0.91 ± 0.05	1.09 ± 0.05
c_{LH} (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
$R(6.5\,\mathrm{GeV}^2), R(90\,\mathrm{GeV}^2)$	0.60, 0.60	0.56, 0.57	0.54, 0.55	0.55, 0.56

$xg = x^{-\lambda}$



$xg = x^{-\lambda}$

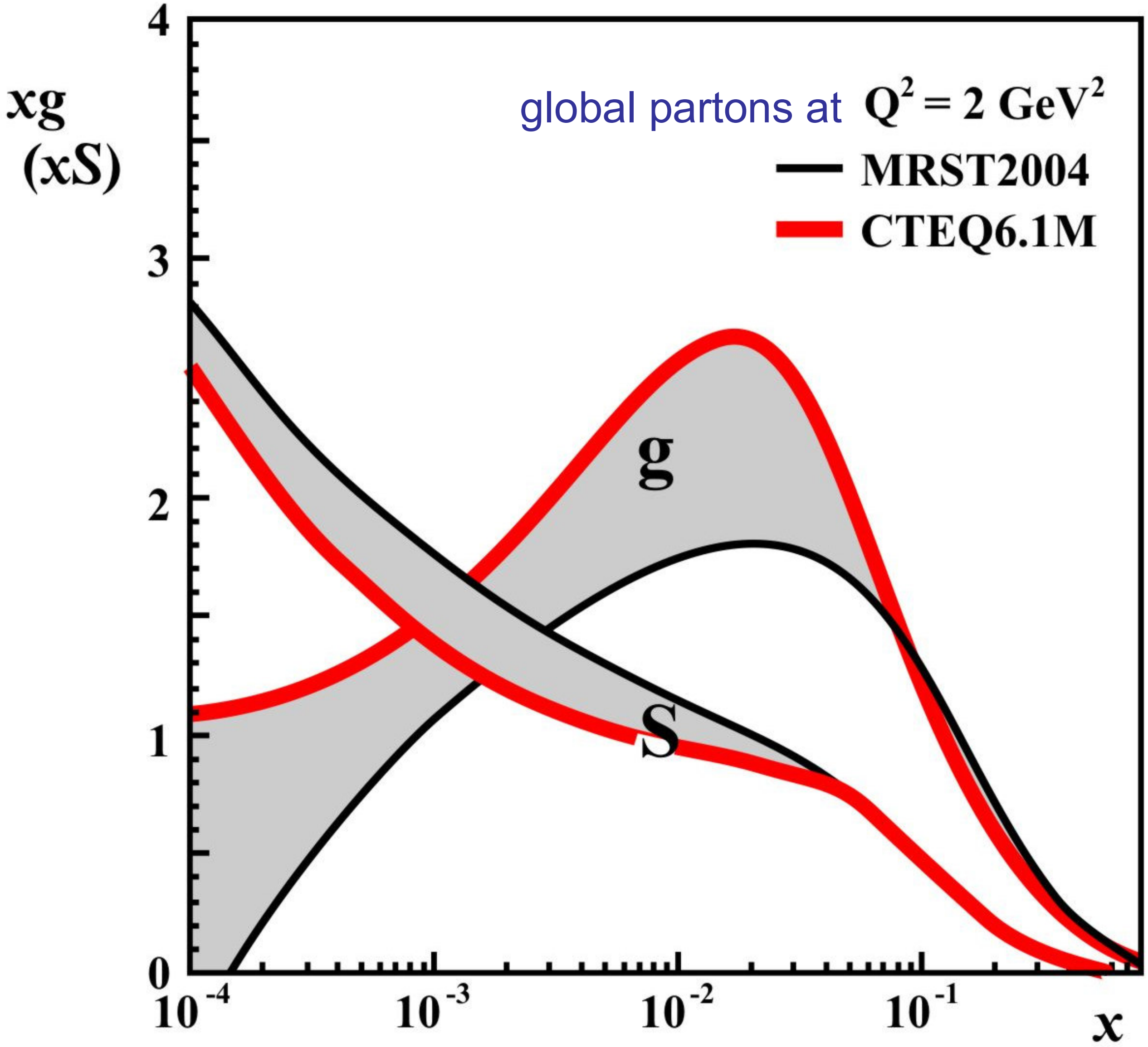
ZEUS λ=0.22
H1 λ=0.13

comb^n 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

$\lambda_g \sim \lambda_S \sim 0.1$

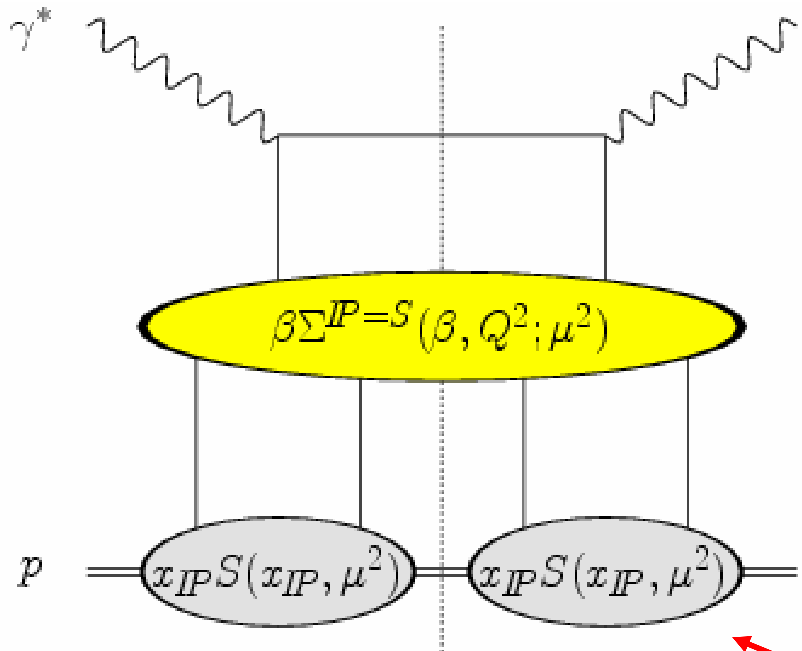
($xg \sim x^{-\lambda g}$

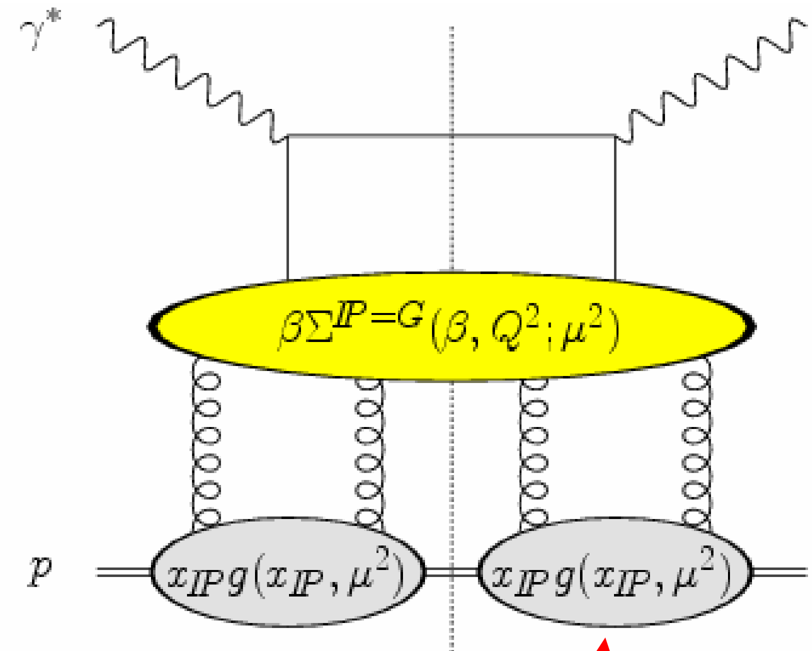
$xS \sim x^{-\lambda S}$)

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 $(\mu > Q_0)$

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

$f_{\mathbb{P}}$: flux factor given by

$$[x g^p(x,\mu^2)]^2$$

$$[x S^p(x,\mu^2)]^2$$

use MRST/CTEQ partons

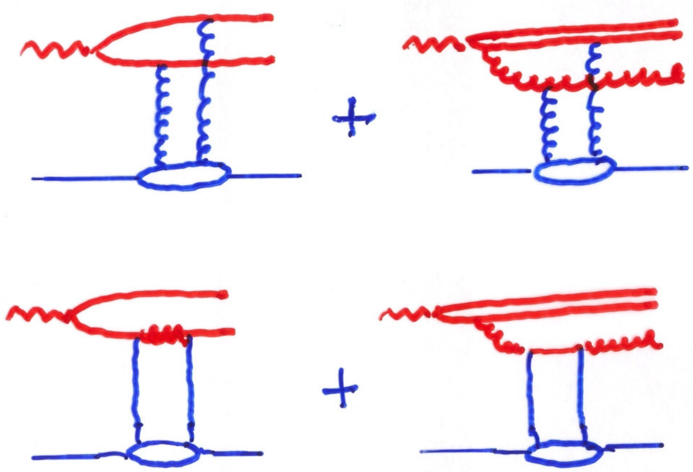
$F_2^{\mathbb{P}}$: NLO DGLAP evol$^{\underline{n}}$ using QCD starting values of $\mathbb{P}$ distributions

$$\Sigma^{\mathbb{P}=G,S}$$

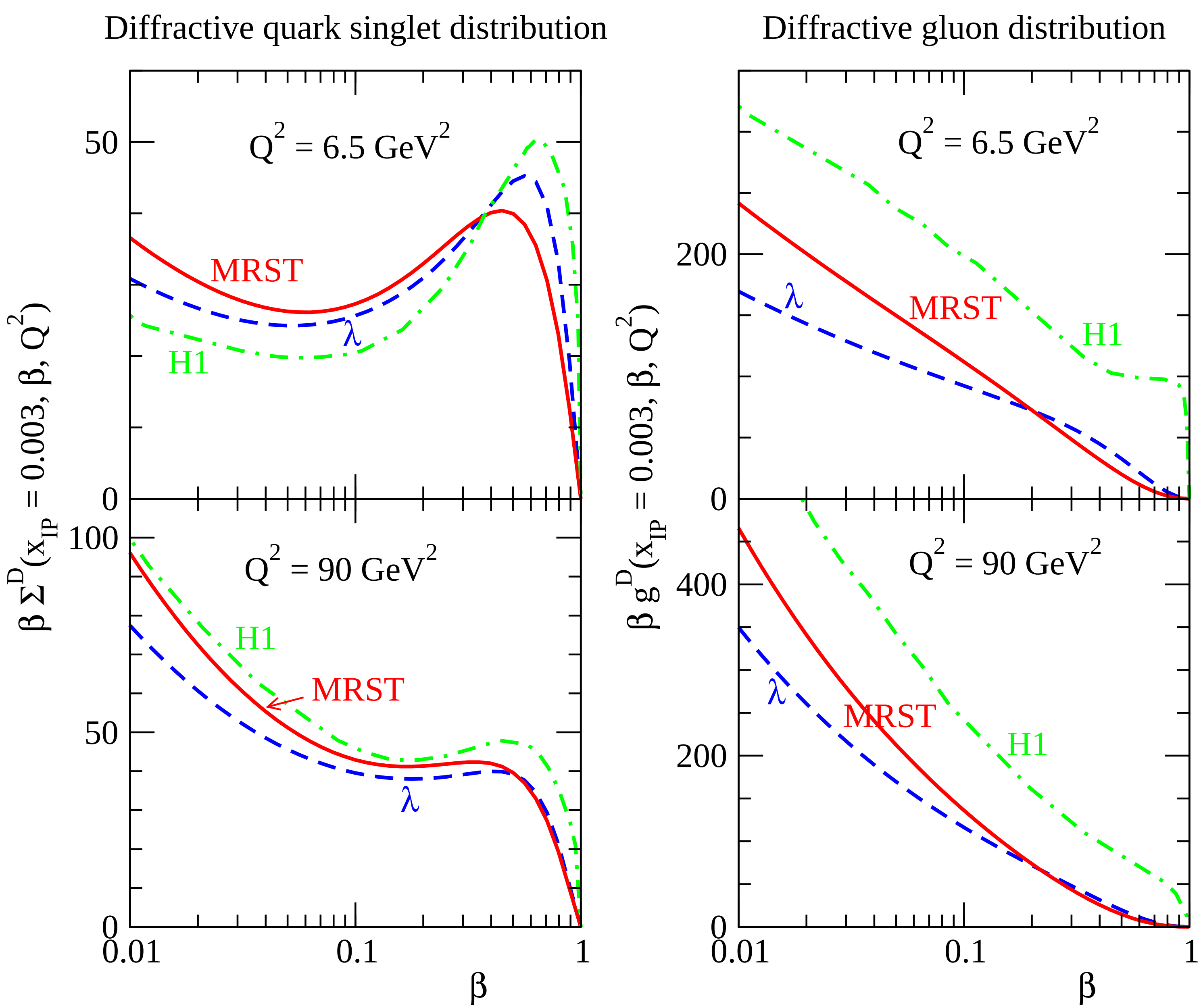
$$g^{\mathbb{P}=G,S}$$

input forms:

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



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



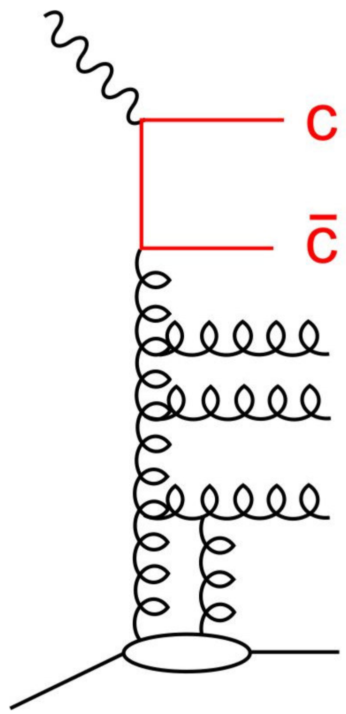
Fit with $q\bar{q}$ as well as gg Pomeron

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

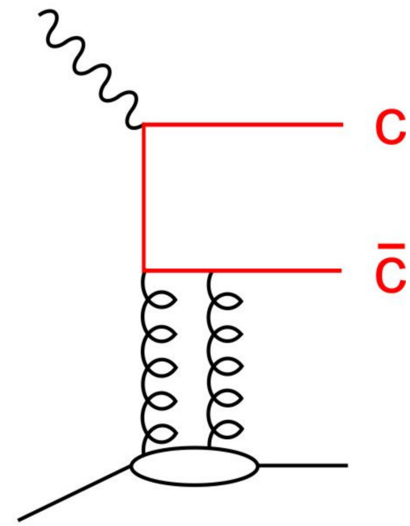
v.good fit

diffractive charm production

constrains gluon



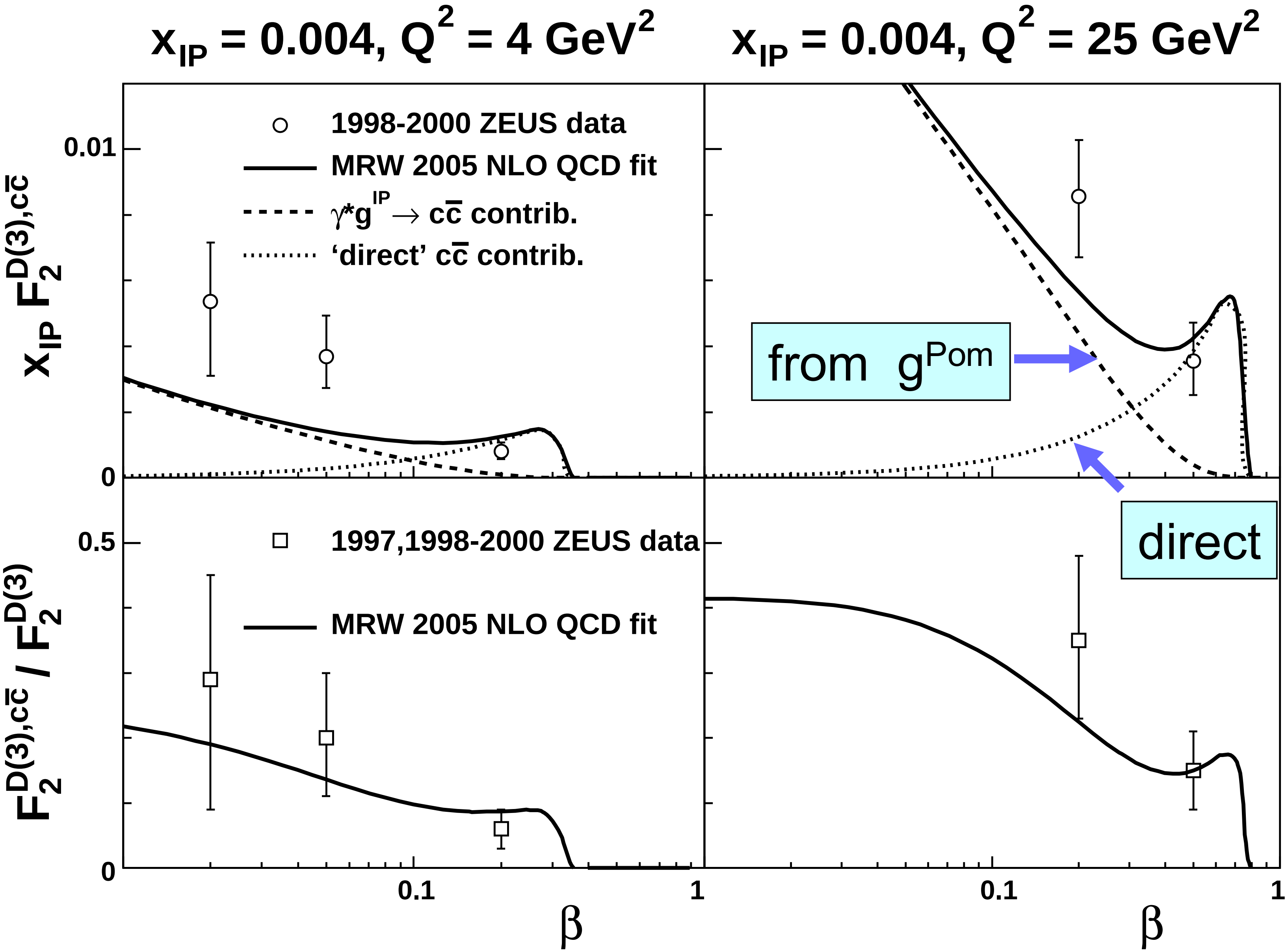
from g^{Pom}



direct contribution

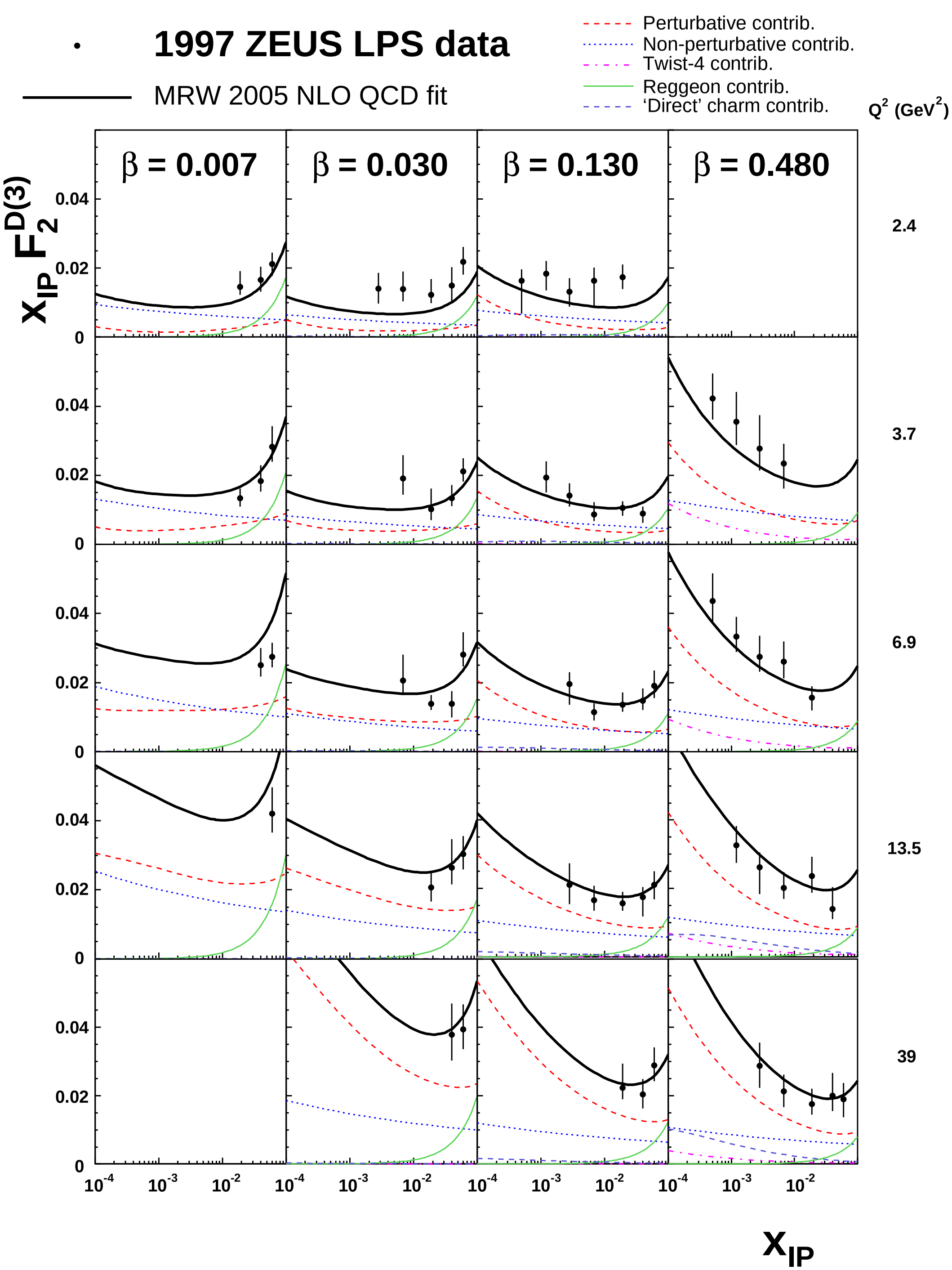
add separately.
No evolution and
no DDIS factorization

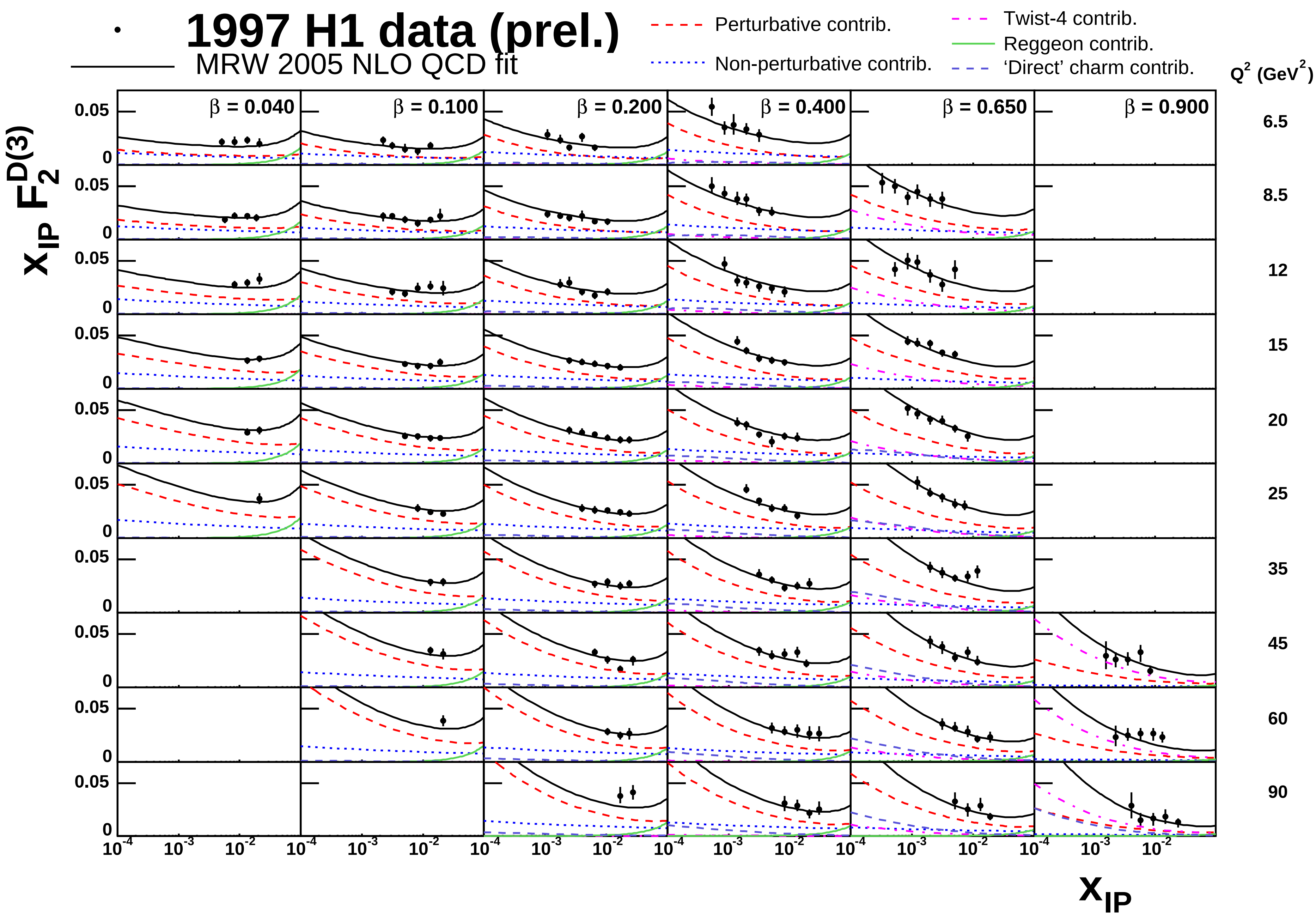
the description of ZEUS diffractive charm production



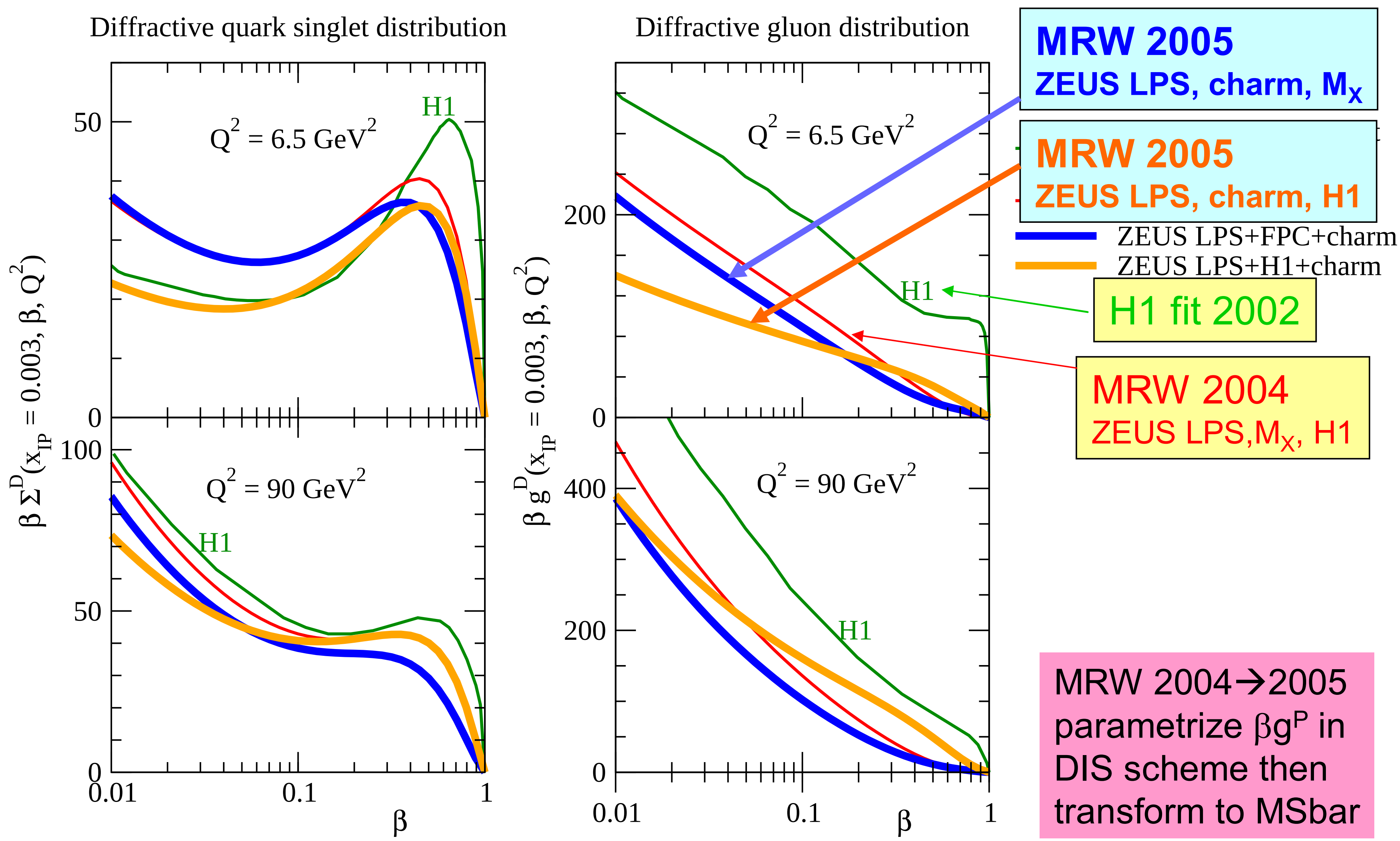
The corresponding MRW fit to the ZEUS LPS data →

and H1 (prelim.) data

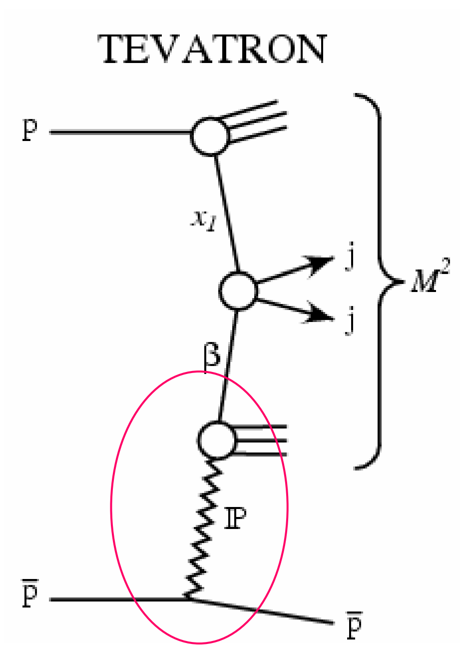


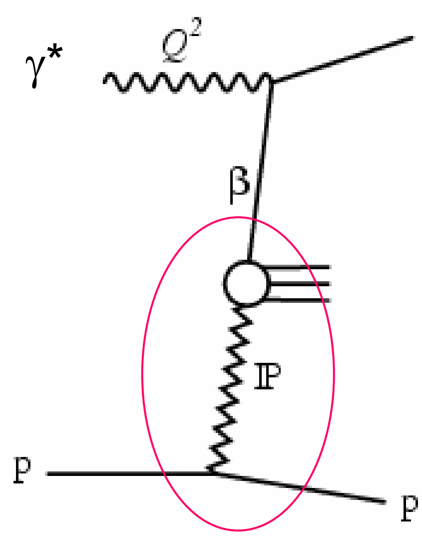


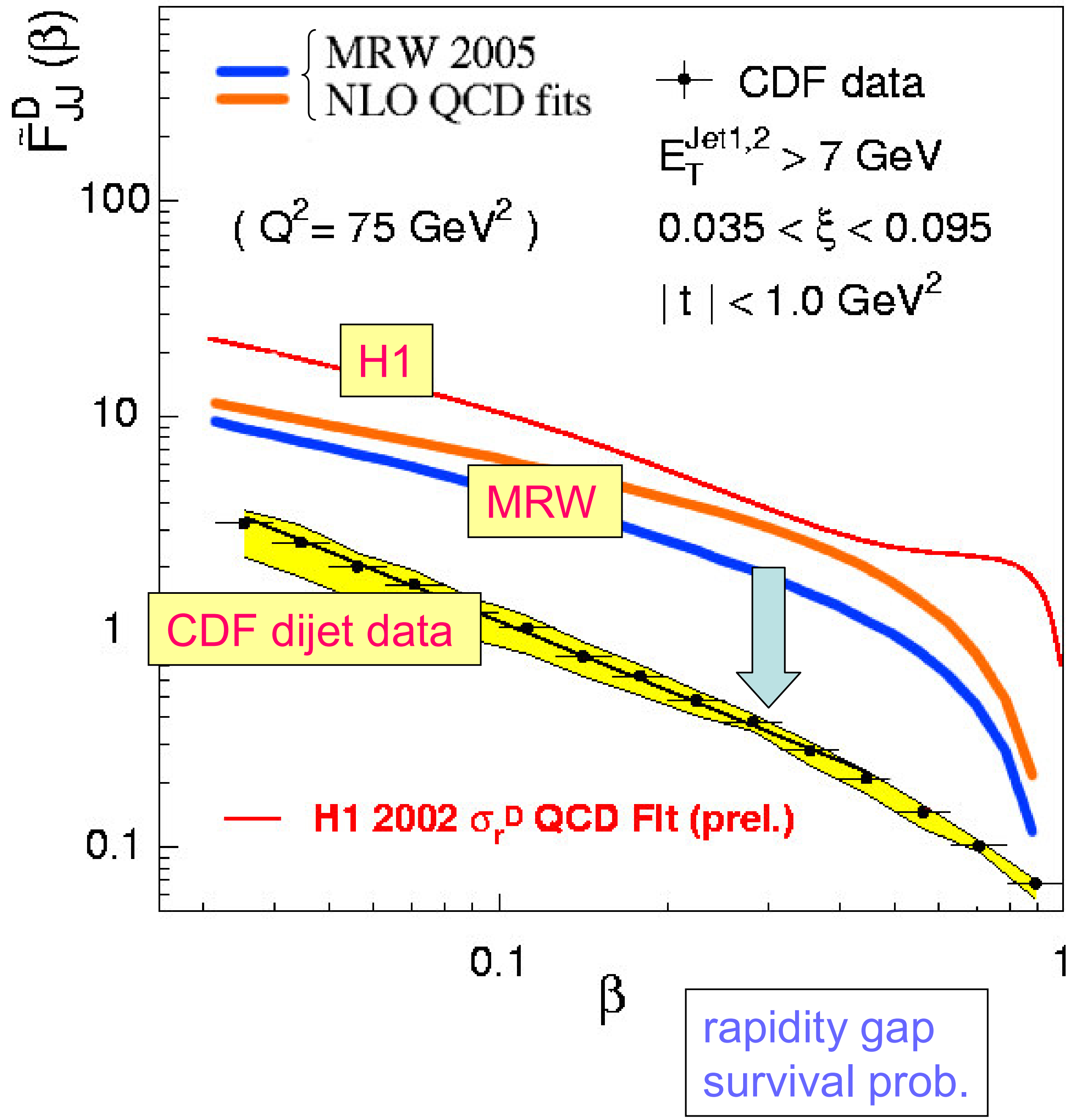
1997 H1 data (prel.)
MRW 2005 NLO QCD fit
Perturbative contrib.
Non-perturbative contrib.
Twist-4 contrib.
Reggeon contrib.
'Direct' charm contrib.
Q^2 (GeV^2)
β = 0.040
β = 0.100
β = 0.200
β = 0.400
β = 0.650
β = 0.900
6.5
8.5
12
15
20
25
35
45
60
90
$x_{IP} F_2^{D(3)}$
x_{IP}



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
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
x1
j
j
M2
β
IP
p̄
p̄


γ*
Q2
β
IP
p
p


F̃D JJ (β)
MRW 2005
NLO QCD fits
CDF data
E_T^{Jet1,2} > 7 GeV
(Q2 = 75 GeV2)
0.035 < ξ < 0.095
|t| < 1.0 GeV2
H1
MRW
CDF dijet data
H1 2002 σr D QCD FIt (prel.)
100
10
1
0.1
0.1
1
β
rapidity gap
survival prob.

Conclusions

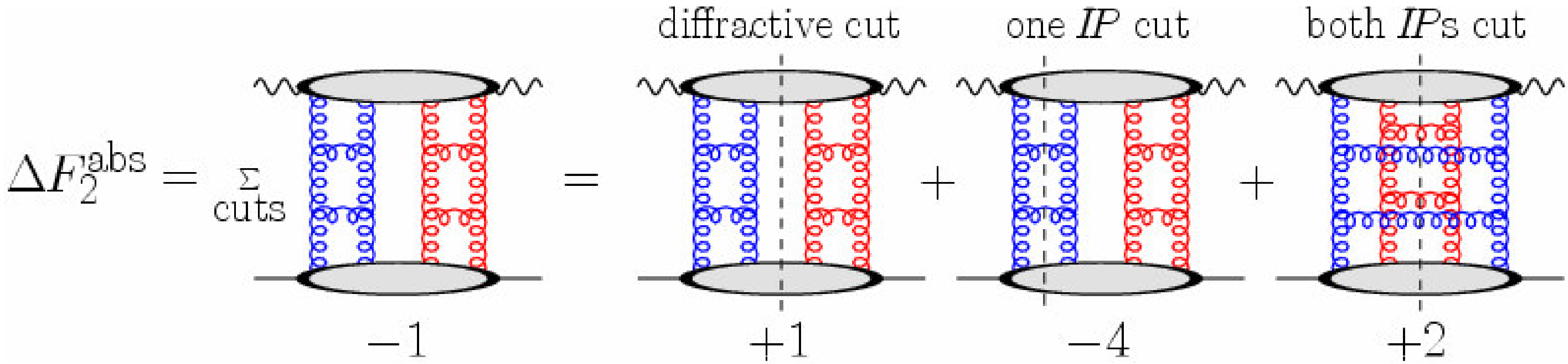
- ☆ Analysis of DDIS, which goes beyond collinear + Regge fact^n
- ☆ Regge factorization replaced by pQCD
  - --need quark-antiquark Pomeron, in addition to two-gluon Pomeron
  - --the input forms of the Pomeron PDFs given by QCD diagrams
- ☆ Collinear DDIS factorization modified in HERA regime:
  - --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

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



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

negative (~Glauber shadowing)