Diffraction

Working group summary (Part 1)

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Workshop on HERA and the LHC
CERN, 13 October 2004

Ongoing projects

- Diffractive structure functions
- AGK cutting rules
- Electroweak processes with rapidity gaps
  e.g. charged current diffraction at HERA,
  Higgs production in WW fusion at LHC
- Theory of central exclusive processes in pp and $p\bar{p}$
  gap survival
  diffractive Higgs $pp \to p + H + p$
- Forward protons at the LHC

Ongoing projects

- Diffractive structure functions $\longrightarrow$ this talk
- AGK cutting rules $\longrightarrow$ this talk
- Electroweak processes with rapidity gaps
  e.g. charged current diffraction at HERA,
  Higgs production in WW fusion at LHC
- Theory of central exclusive processes in pp and $p\bar{p}$
  gap survival
  diffractive Higgs $pp \longrightarrow p + H + p$
  $\longrightarrow$ Valery Khoze's talk, see also J. Forshaw (June meeting)
- Forward protons at the LHC
  $\longrightarrow$ Henri Kowalski's talk

More theory contributions

Will not cover for lack of time, with apologies

- Small-x theory S. Munier (March meeting)
  - Saturation:D. Kharzeev, C. Marquet (March meeting)
  - BFKL at nonzero momentum transfer

    A. Sabio Vera (this meeting)
- Physics with real (bremsstrahlung) photons at LHC

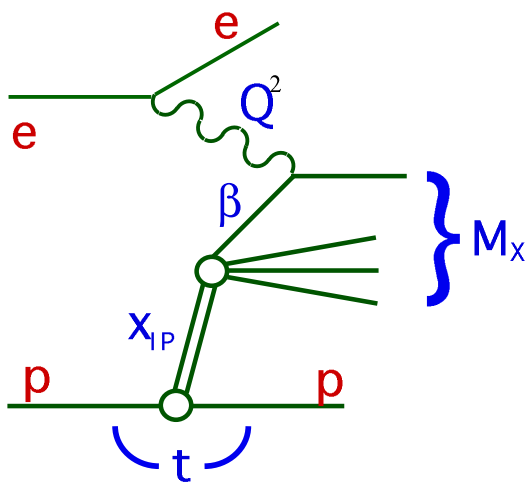
  e.g. $\gamma p \to \Upsilon p$ J. Nystrand (March meeting)

Diffractive parton densities

- Have factorization theorem for inclusive diffraction in $\gamma^* p$, processes like
  - $\gamma^* p \to X + p$ diffractive structure function F_2^D (and F_2^L)
  - $\gamma^* p \to \text{jets} + X + p$
  - $\gamma^* p \to c\bar{c} + X + p$
- description as for usual inclusive processes
  (same hard-scattering kernels and evolution equations),
  but with usual PDFs replaced by diffractive PDFs
  new H1 and ZEUS data: support universality

Diffractive Cross section and Structure Functions

In a frame where the proton is moving fast:



$x_{I\!P} = \xi = \frac{Q^2+M_X^2}{Q^2+W^2} = x_{I\!P/p}$
(momentum fraction of colour singlet exchange)

$\beta = \frac{Q^2}{Q^2+M_X^2} = x_{q/I\!P}$
(fraction of exchange momentum of q coupling to γ^*, $x = x_{I\!P}\beta$)

$t = (p - p')^2$
(4-momentum transfer squared)

Diffractive reduced cross section σ_r^D:

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

Structure functions F_2^D and F_L^D:

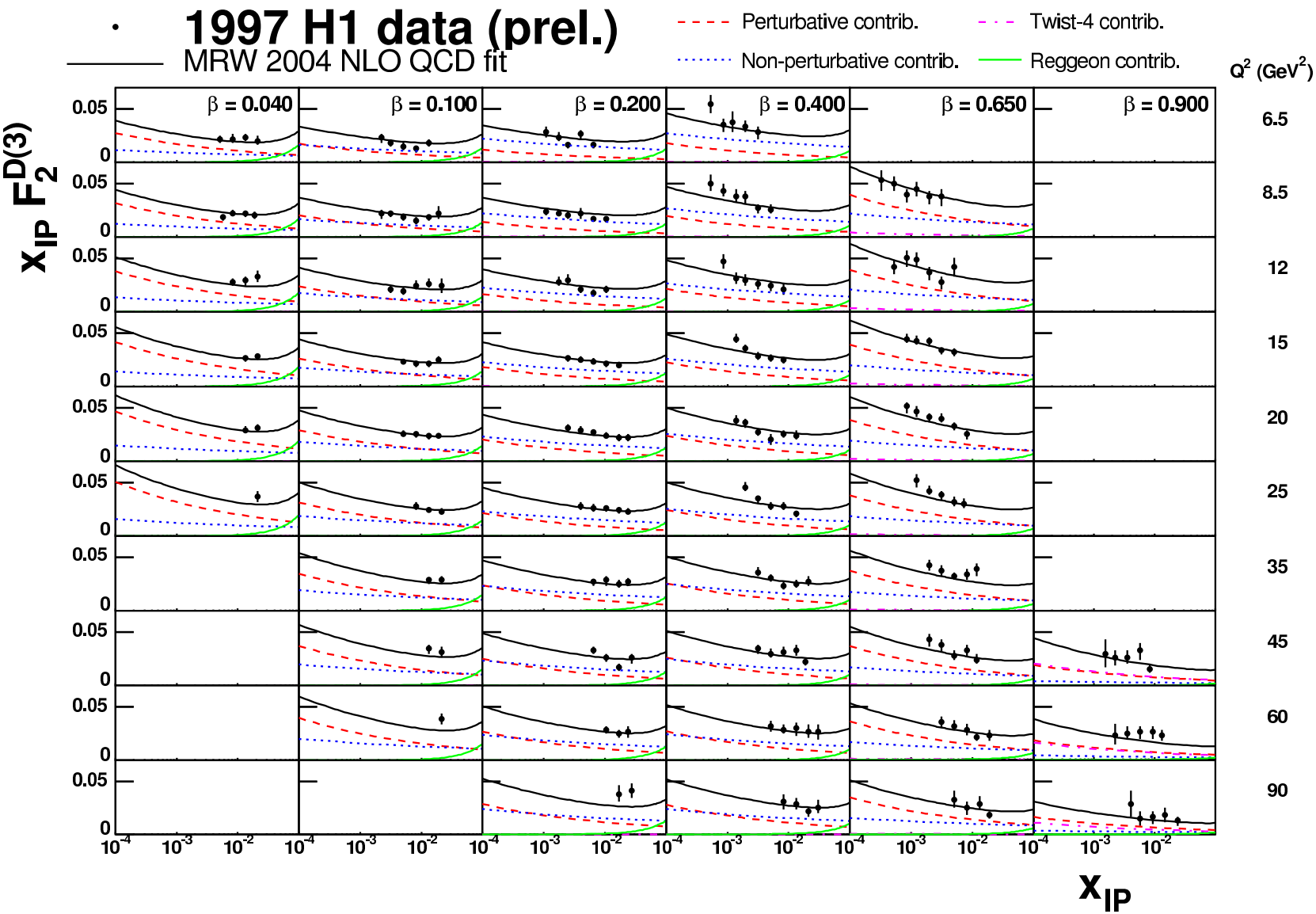
$$\sigma_r^{D(4)} = F_2^{D(4)} - \frac{y^2}{2(1-y+y^2/2)}\, F_L^{D(4)}$$

Integrated over t: $F_2^{D(3)} = \int dt\, F_2^{D(4)}$

– Longitudinal F_L^D: affects σ_r^D at high y

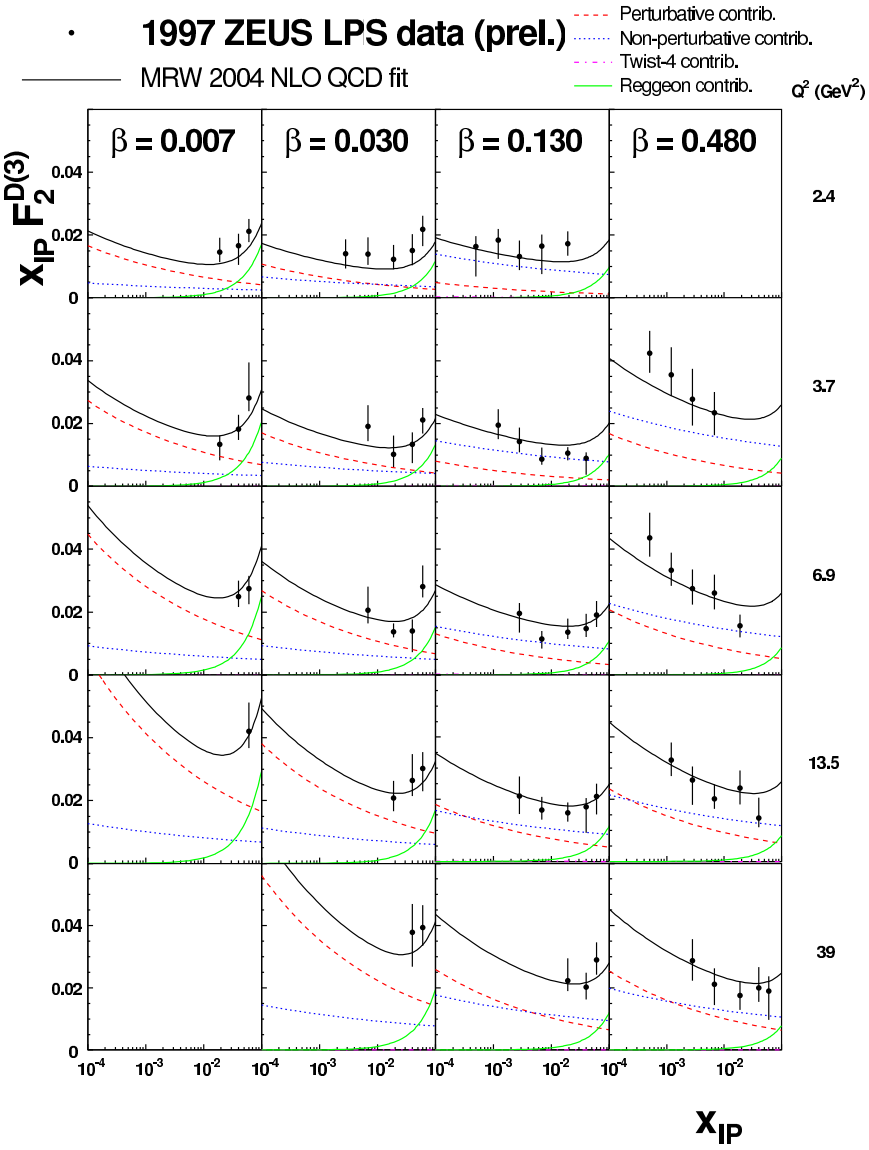
[γ inelasticity $y = Q^2/sx$]

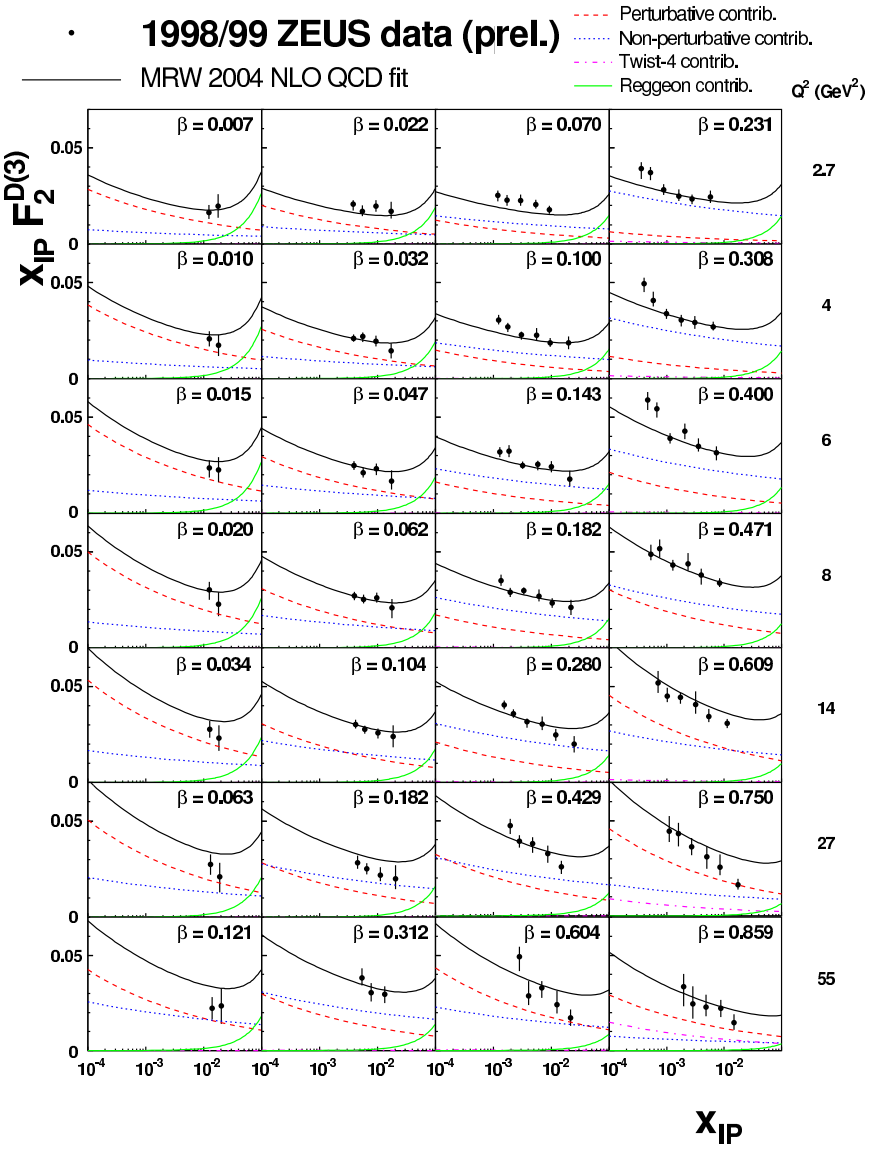
– If $F_L^D = 0$: $\sigma_r^D = F_2^D$



G. Watt (June meeting)

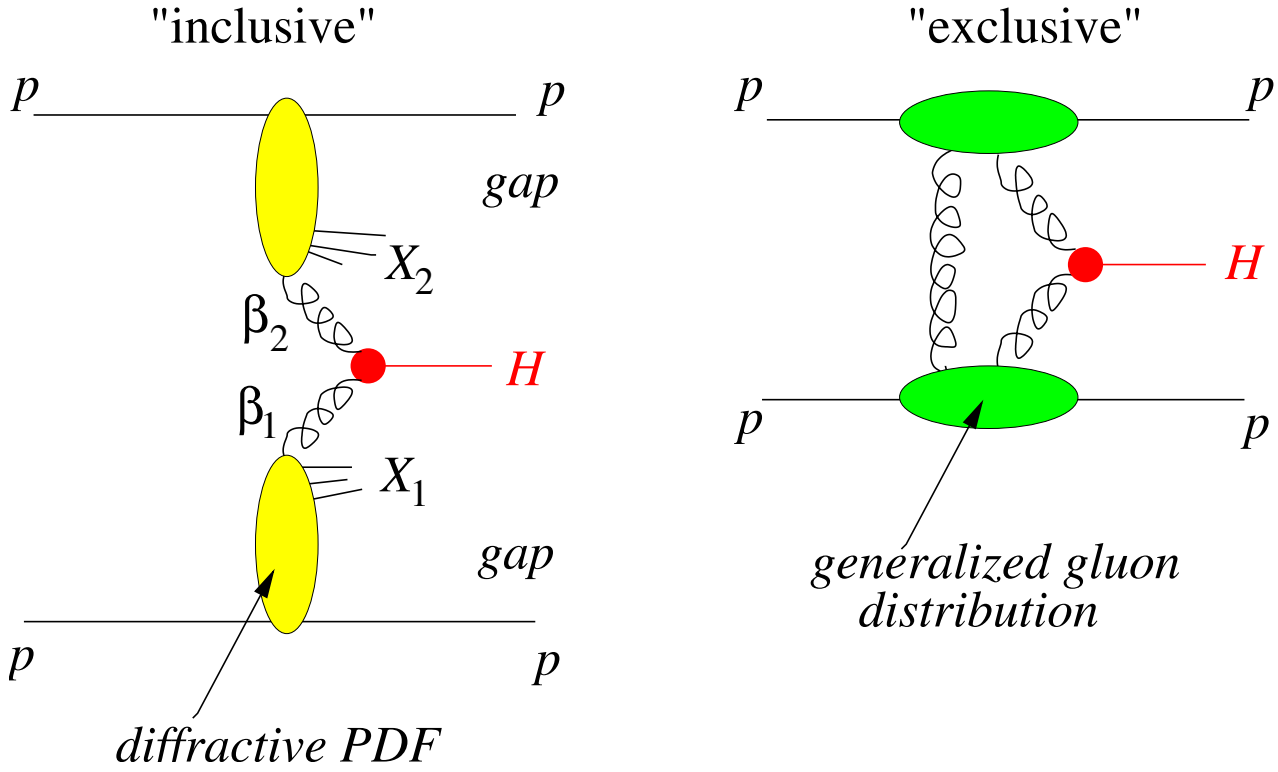
NB: large β much less suppressed than large x_B in inclusive F_2


1997 ZEUS LPS data (prel.)
MRW 2004 NLO QCD fit
Perturbative contrib.
Non-perturbative contrib.
Twist-4 contrib.
Reggeon contrib.
Q^2 (GeV^2)
$x_{IP} F_2^{D(3)}$
β = 0.007
β = 0.030
β = 0.130
β = 0.480
2.4
3.7
6.9
13.5
39
x_{IP}

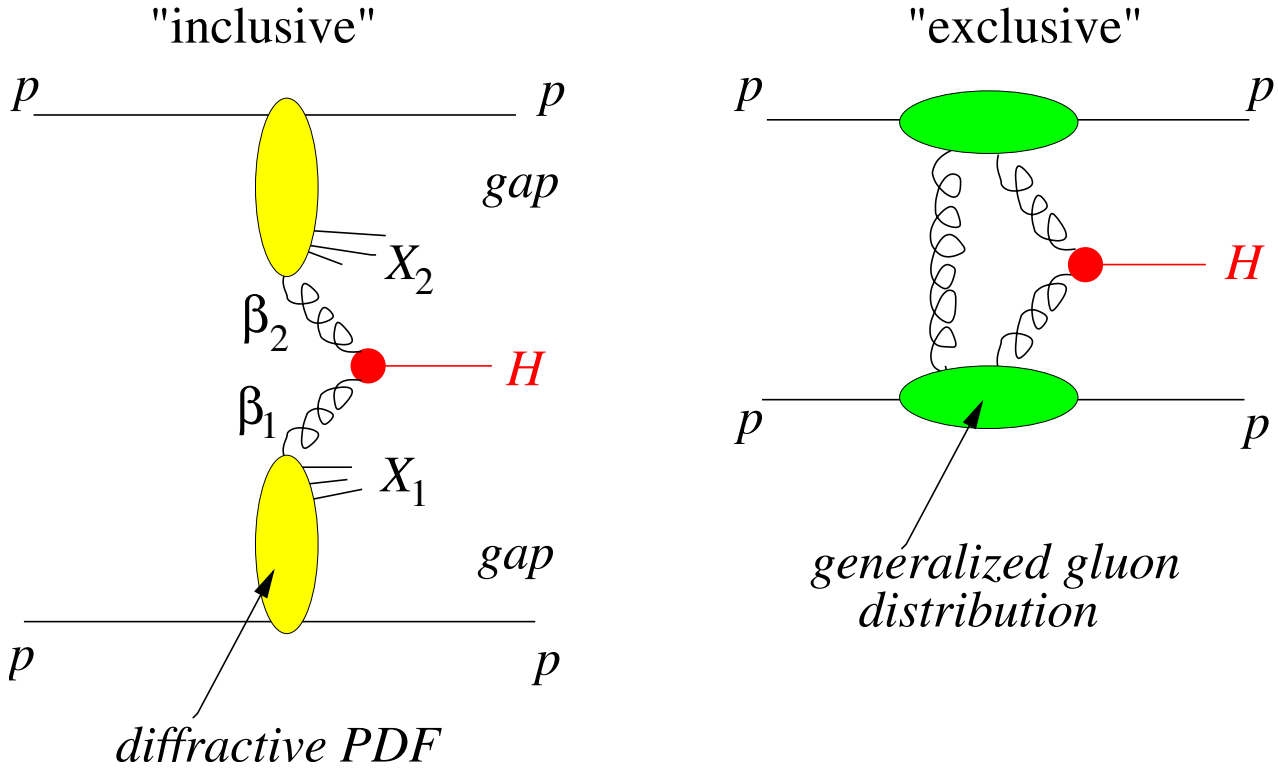

1998/99 ZEUS data (prel.)
MRW 2004 NLO QCD fit
Perturbative contrib.
Non-perturbative contrib.
Twist-4 contrib.
Reggeon contrib.
Q^2 (GeV^2)
$x_{IP} F_2^{D(3)}$
β = 0.007
β = 0.022
β = 0.070
β = 0.231
β = 0.010
β = 0.032
β = 0.100
β = 0.308
β = 0.015
β = 0.047
β = 0.143
β = 0.400
β = 0.020
β = 0.062
β = 0.182
β = 0.471
β = 0.034
β = 0.104
β = 0.280
β = 0.609
β = 0.063
β = 0.182
β = 0.429
β = 0.750
β = 0.121
β = 0.312
β = 0.604
β = 0.859
2.7
4
6
8
14
27
55
x_{IP}

Diffractive non-factorization

- no factorization for
  - γp processes $\rightarrow$ summary WG2
  - $p\bar{p} \rightarrow p + \text{jets} + X$ (single diffractive)
  - $p\bar{p} \rightarrow p + \text{jets} + X + \bar{p}$ (double diffractive)
  - $pp \rightarrow p + H + X + p$
  - $pp \rightarrow p + (b\bar{b}) + X + p$
- factorization broken by interactions between spectators (gap survival probability < 1)
  $\rightarrow$ soft physics, have to model
  need to validate models in data (HERA, Tevatron, LHC)
- to investigate gap survival, need reliable diffractive PDFs to start with

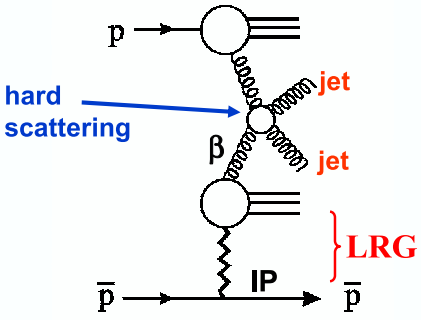


- "inclusive" diffractive events become background to "exclusive" ones when remnant systems $X_{1,2}$ become soft
- for "exclusive" mechanism $b\bar{b}$ is suppressed compared with H, but not for "inclusive" one
  $\longrightarrow$ potentially dangerous background, need to estimate

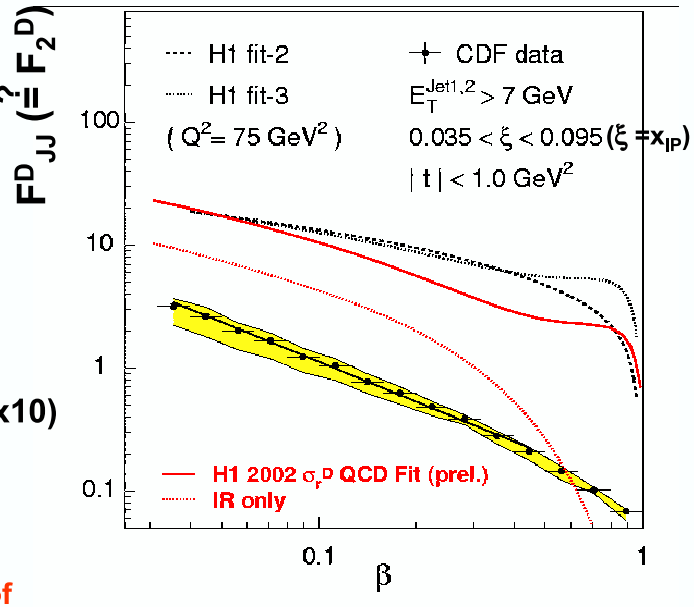


- "inclusive" diffractive events become background to "exclusive" ones when remnant systems $X_{1,2}$ become soft
- relevant region for diffractive PDFs:
  $\beta_{1,2} \to 1$ and $Q^2_{1,2} \sim M^2_H$
  access to large Q^2 at HERA: diffractive charged current events

The CDF vs H1 comparison



Normalisation discrepancy (x10)

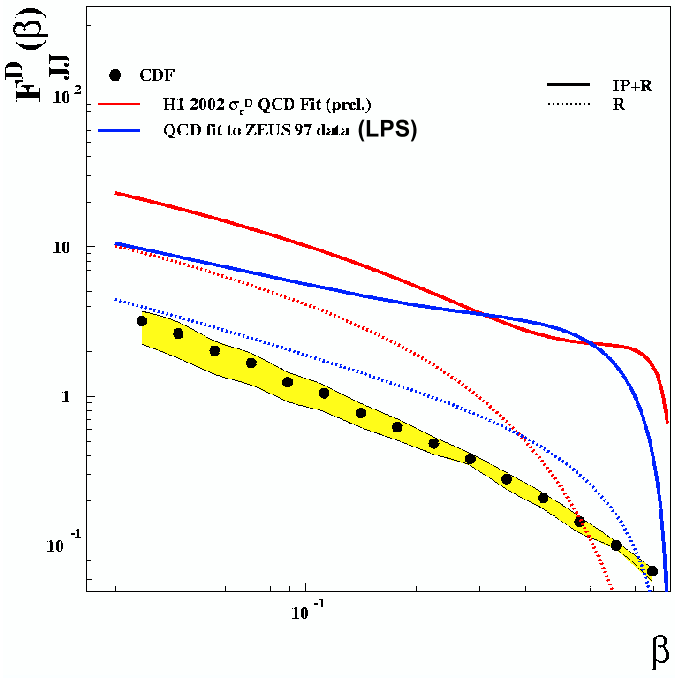


Possible reason: rescattering of spectator partons in p,$\bar{p}$ (Khoze et al)

Phys Rev Lett 84 (2000) 5043

M. Arneodo (this meeting) with A. Proskuryakov, Y. Yamazaki:
diffractive PDFs fitted to new ZEUS LPS data on F_2^D
extended coverage to larger $x_{I\!P}$,
$\longrightarrow$ closer to values of CDF single diffractive dijet measurement

Comparison with CDF



- No estimate of uncertainties yet:
  large at high β (no coverage !)
  result stable at low β
- Smaller discrepancy with respect to CDF than suggested by H1 estimate
- CDF data close to Reggeon contribution –
  does this mean something ?
- Difference with respect to H1:
  - a small contribution (10% ?) possibly due to proton-dissociative background in H1 data.
  - Where does the rest come from ?? (in particular for the Reggeon part)
  - Different x_{IP}coverage (LPS up to x_{IP}=0.07) ?

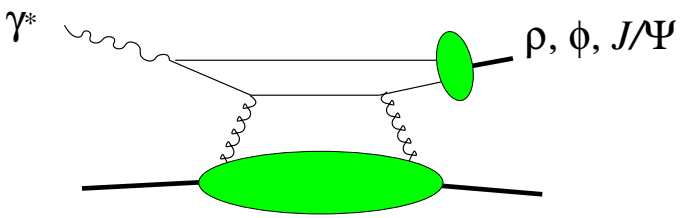
discrepancies in diffractive PDFs to be clarified

Ongoing work

- both H1 and ZEUS will publish new F_2^D data soon
- aim: clarify possible inconsistencies between F_2^D data from H1 and ZEUS, to achieve common diffractive PDF fits
- project of a library D-LHAPDF F.-P. Schilling (this meeting) in order to have systematic access of community to diffractive PDFs

What can we learn from the t dependence of diffractive events?

- $t \leftrightarrow (p - p')_T$ transverse momentum transfer to proton
- Fourier transform of scattering amplitude from $(p - p')_T$ to b (keep momenta in longitudinal direction):
  $b =$ impact parameter
  $=$ transverse distance between collision partners
- more specific information in hard exclusive processes when twist-two description is valid $\rightarrow$

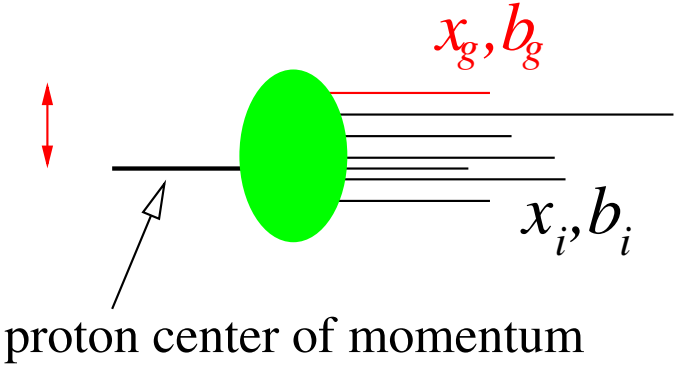


$b =$ transverse distance
between $q\bar{q}$ and proton
$=$ transverse location
of g within proton

generalizes to non-diffractive exclusive processes

Impact parameter distribution of partons

- more precisely, b is distance of gluon from center of momentum of proton



$$b = b_g - b_p$$

$$\text{center of momentum } b_p = \frac{\sum_i x_i b_i}{x_i}$$

consequence of Lorentz invariance

- from diffractive and non-diffractive data $\longrightarrow$
  $\langle b^2 \rangle$ of partons decreases with x
- production of high-mass systems in pp collisions requires large enough momentum fractions x
  $\longrightarrow$ collisions more central than generic inelastic pp collisions
  various consequences/applications M. Strikman (this meeting)
- diffraction in pp:
  survival probability naturally described in b space
  b is conserved in rescattering, transverse momentum is not
  amount of rescattering depends on b
  $\longrightarrow$ need to know t-dependence of diffractive PDFs/generalized gluon distribution

AGK cutting rules

status report: J. Bartels (this meeting)

relate different cuts of the same diagram
$\longrightarrow$ can lead to subtle connections or cancellations

- in $\gamma^* p$ connects absorptive corrections to F_2 with F_2^D
  new analysis of Durham group G. Watt (June meeting)
  - new parametrization of F_2^D
    NB: contains contribution $\sim 1/Q^2$, beyond leading twist
  - subtract "hard part" of F_2^D from F_2,
    fit remaining part of F_2 with standard DGLAP formalism
    resulting $g(x)$ less negative at small x and small Q^2
- evaluation in dipole model finds large absorptive effects
  $\longrightarrow$ H. Kowalski (June meeting)

A. Completely inclusive:

Abramowsky, Gribov, Kancheli

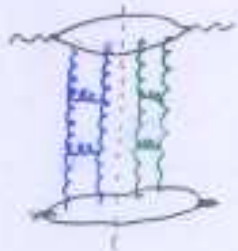
$\gamma^* p$:

Single chain:

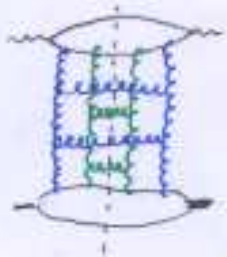
ficeon

single multiplicity,
~ homogeneous rapidity density

double chain:

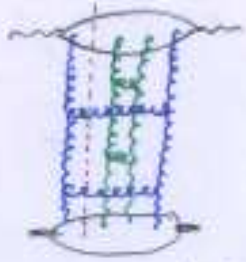


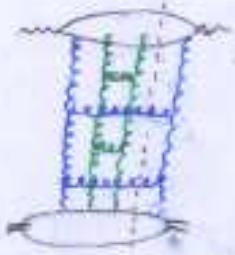
rap. gap
+1



double multiplicity
+2

+1+2
−4 = −1





absorptive corrections, single multiplicity
−4

J. BARTELS
(THIS MEETING)

AGK cutting rules

status report: J. Bartels (this meeting)

relate different cuts of the same diagram
$\longrightarrow$ can lead to subtle connections or cancellations

- cut gluon ladders $\longrightarrow$ look into final state
  $\rightsquigarrow$ multiple interactions
  - absorptive corrections in inclusive processes
    $\leftrightarrow$ special final states
  - can study in $\gamma^* p$ and in pp

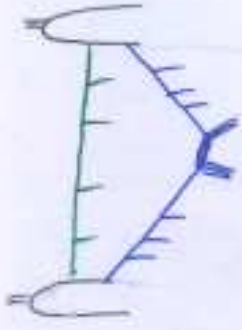
B. One pair of jets: "one pair exclusive cross section"

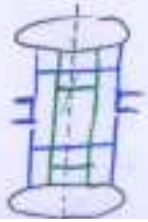
pp- collisions:

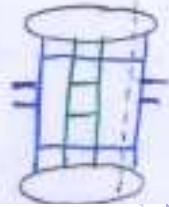
one chain:

factorization theorem for leading-twist:
cancellation of final state, initial state rescattering

double chain:







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(THIS MEETING)

D. Most promising signal:

two-jet correlation function

$$g(k_1,k_2) = \frac{d^2\sigma}{d^2k_1\, d^2k_2} - \frac{1}{N}\frac{d\sigma}{d^2k_1}\frac{d\sigma}{d^2k_2}$$

AGK

vs rapidity difference

J. BARTELS
(THIS MEETING)

AGK cutting rules

status report: J. Bartels (this meeting)

relate different cuts of the same diagram
$\longrightarrow$ can lead to subtle connections or cancellations

- cut gluon ladders $\longrightarrow$ look into final state
  $\rightsquigarrow$ multiple interactions
  - absorptive corrections in inclusive processes
    $\leftrightarrow$ special final states
  - can study in $\gamma^* p$ and in pp
- Tasks:
  - rederive AGK cutting rules in QCD (color degree of freedom $\longrightarrow$ structures not present in original formulation)
  - provide Monte Carlo program for "cut ladder" final states incoroporating dynamical information from AGK rules

Conclusisons

- strategy to describe hard diffraction (esp. Higgs production) at LHC: hard factorized process $\otimes$ survival probability
  HERA provides input quantities
  test gap survival models at Tevatron and HERA
- t dependence in exclusive processes
  $\longrightarrow$ impact parameter profile of partons in nucleon
  of relevance also in pp collisions
- sharpen theoretical tools to connect
  absorptive corrections ($\rightsquigarrow$ saturation) with final states,
  can study at both HERA and LHC

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Special thanks

- to my co-convenors
- to the contributors to our working group
- to J. Bartels and V. Khoze for helpful discussions