Diffrazione da HERA a LHC
(una rassegna per non iniziati)

M. Arneodo
Universita' del Piemonte Orientale, Novara,
INFN Torino

Congressino INFN-Torino
16 dicembre 2004

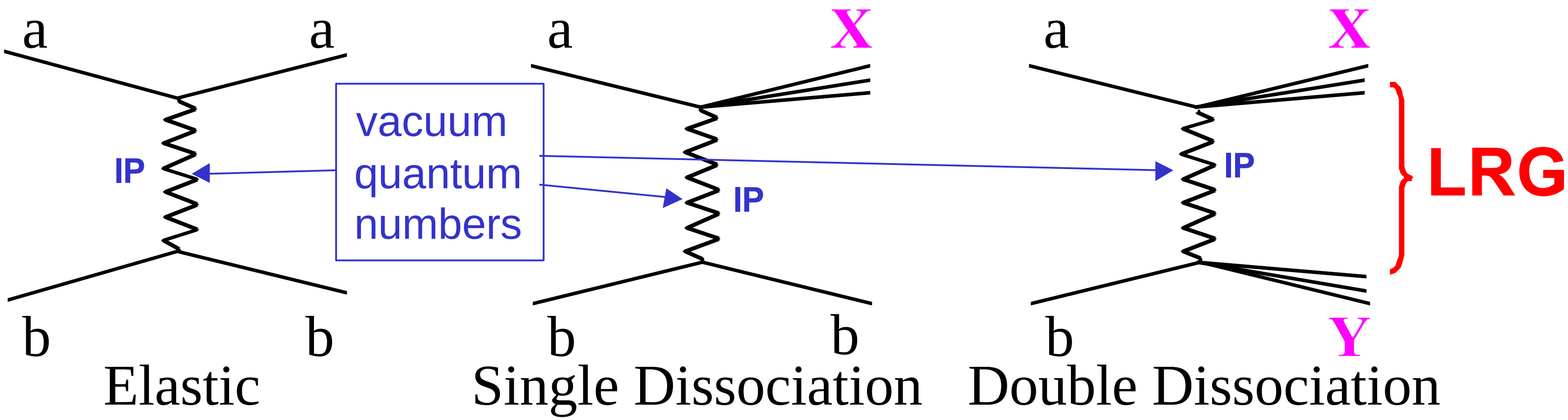
1. Diffrazione in collisioni elettrone-protone a HERA

2. Diffrazione in termini di quark, gluoni e QCD

3. Uno sguardo al futuro: produzione diffrattiva di Higgs – canale privilegiato per scoprire un Higgs leggero a LHC ?

Diffraction in hadron scattering

Diffraction is a feature of hadron-hadron interactions (30% of σ_{tot}):



o) Beam particles emerge intact or dissociated into low-mass states. Energy » beam energy (within a few %)

o) Final-state particles separated by large polar angle (or pseudorapidity, In tan(q/2)): Large Rapidity Gap (LRG)

o) Interaction mediated by t-channel exchange of object with vacuum quantum numbers (no colour): the Pomeron (IP)

Pomeron ?!

Pomeron goes back to the '60s: Regge trajectory, ie a moving pole in complex angular momentum plane.

Would like to understand diffraction in terms of quarks, gluons and QCD

A worthwhile task:

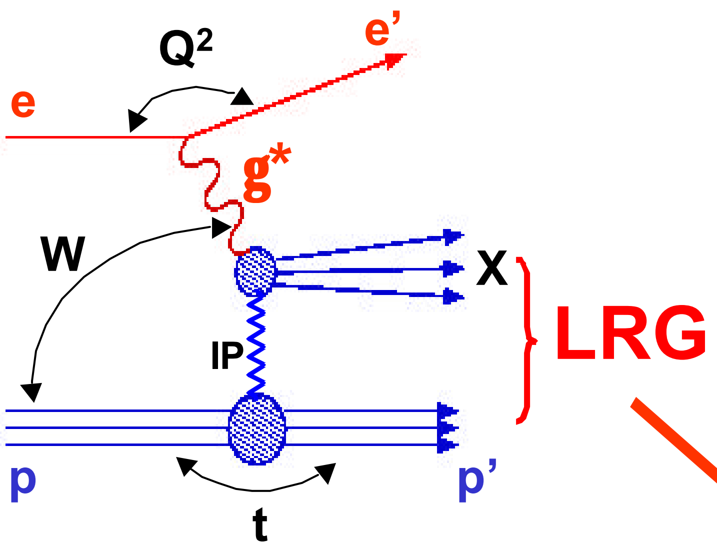
- **Diffraction is a significant part of s_{tot}**
- **Elastic cross section drives s_{tot} via optical theorem: $ds_{el}/dt|_{t=0}$ µ $(s_{tot})^2$**
- **Understanding diffraction in terms of QCD offers new insight into the proton and QCD itself**

In the last 5-10 years, we learned a lot about diffraction by scattering pointlike probes (electrons) on Pomerons
® *Diffractive Deep Inelastic Scattering*

No longer a field for initiated...

NB in following will often refer to Pomeron as if it were real particle (it isn't)

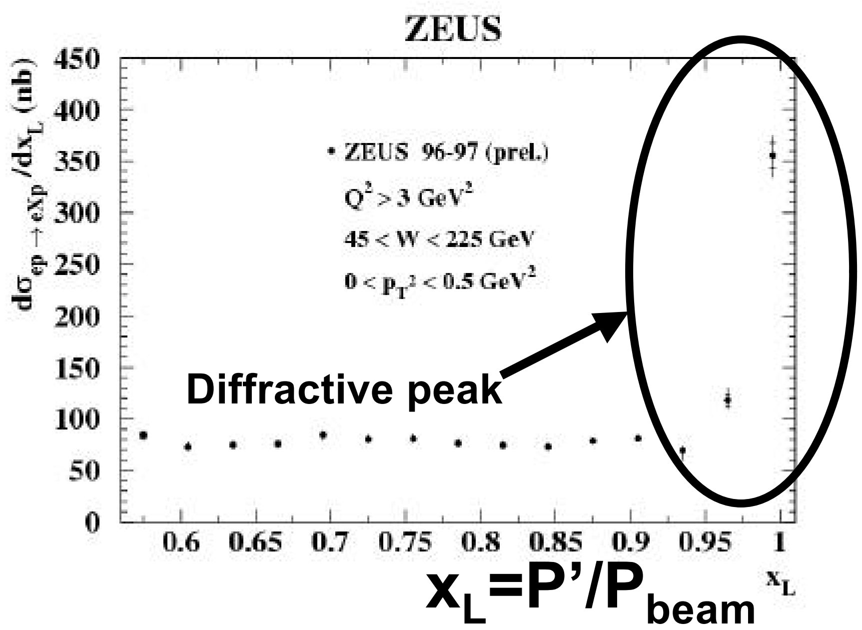
Diffractive Deep Inelastic Scattering

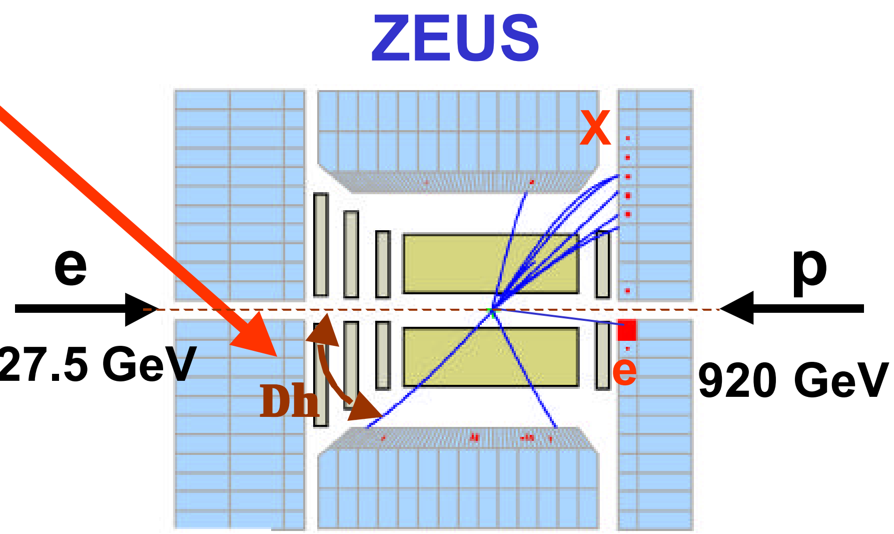


Q^2 = virtuality of photon =
= (4-momentum exchanged at e vertex)^2

t = (4-momentum exchanged at p vertex)^2
typically: $|t|<1$ GeV^2

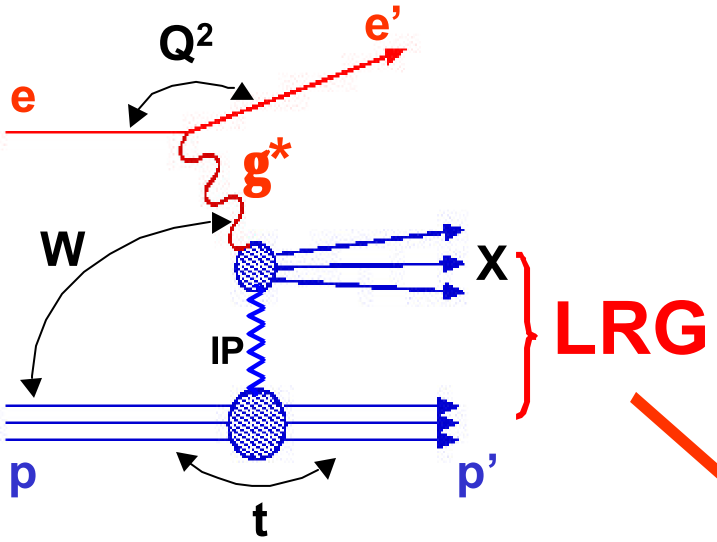
W = invariant mass of photon-proton system





Ös » 320 GeV

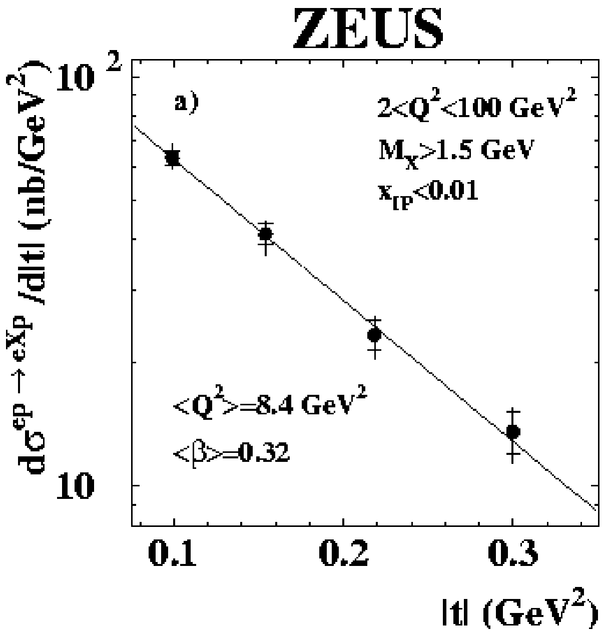
Diffractive Deep Inelastic Scattering

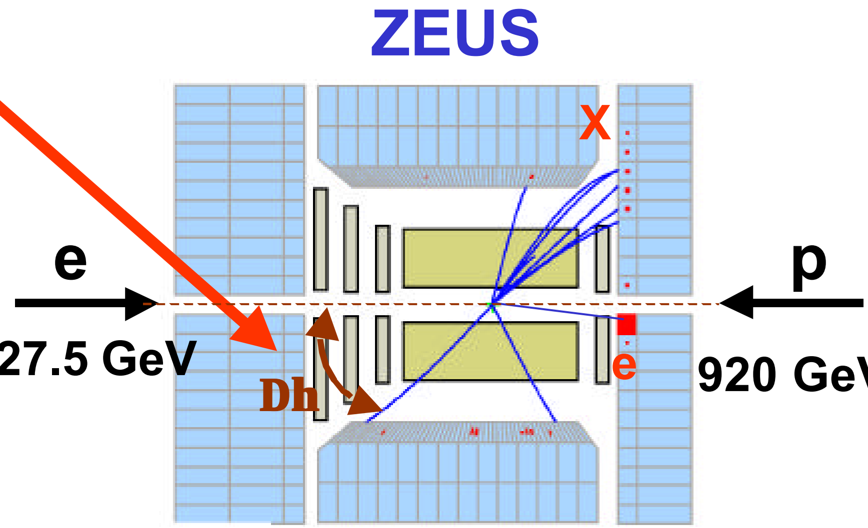


Q^2 = virtuality of photon =
= (4-momentum exchanged at e vertex)^2

t = (4-momentum exchanged at p vertex)^2
typically: $|t|<1$ GeV^2

W = invariant mass of photon-proton system

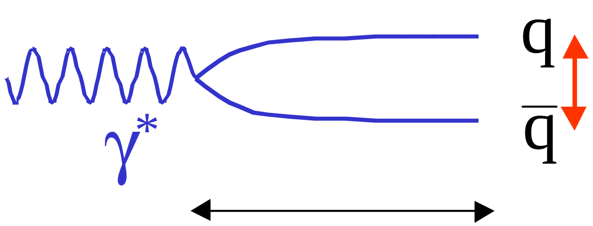




Ös » 320 GeV

Diffraction in ep collisions ?!

1) Go to proton rest-frame
2) Virtual photon fluctuates to $q\bar{q}$ (colour dipole)



$$\propto \frac{1}{\sqrt{Q^2 + M_{q\bar{q}}^2}}$$

$$\propto E_\gamma \sim W^2 \sim 1/x$$

- Lifetime of dipoles very long because of large γ boost ($E_\gamma \approx$ 50TeV!)
  $\rightarrow$ it is the dipole that interacts with the proton
- This is why can do diffraction in ep collisions !
- Transverse size proportional to $1/\sqrt{(Q^2 + M_{q\bar{q}}^2)}$
  (for *longitudinally* polarised photons)

Transverse size of incoming hadron beam can be reduced at will. Can be so small that strong interaction with proton becomes perturbative (colour transparency) !

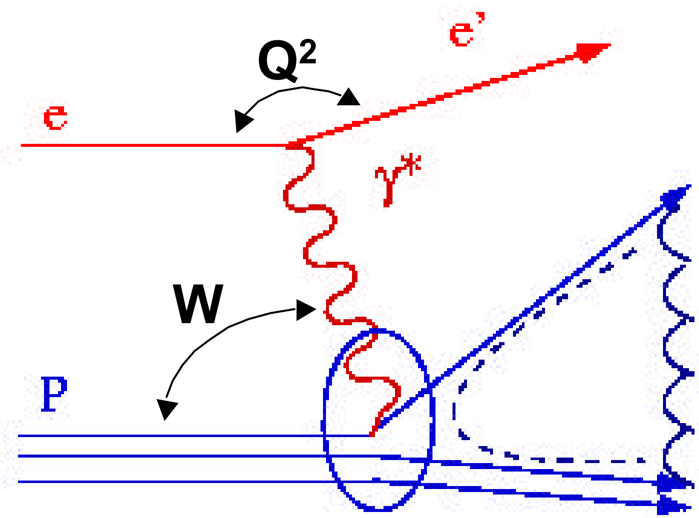
Part I:
hard scattering on a Pomeron

- **The partonic structure of the Pomeron as probed by a pointlike virtual photon**

- **Rather than Pomeron: diffractive PDFs**

Standard Deep Inelastic Scattering

For $Q^2 << M_Z^2$:



In a frame in which the proton is very fast (Breit frame):

x = Bjorken's variable=
= fraction of proton's momentum carried by struck quark
» Q^2/W^2

W = photon-proton centre of mass energy

y = W^2/s

$$\frac{d^2 s}{dx dQ^2} = \frac{4pa^2}{xQ^4}\left\{1 - y + \frac{y^2}{2[1+\underline{R(x,Q^2)}]}\right\}\underline{F_2(x,Q^2)}$$

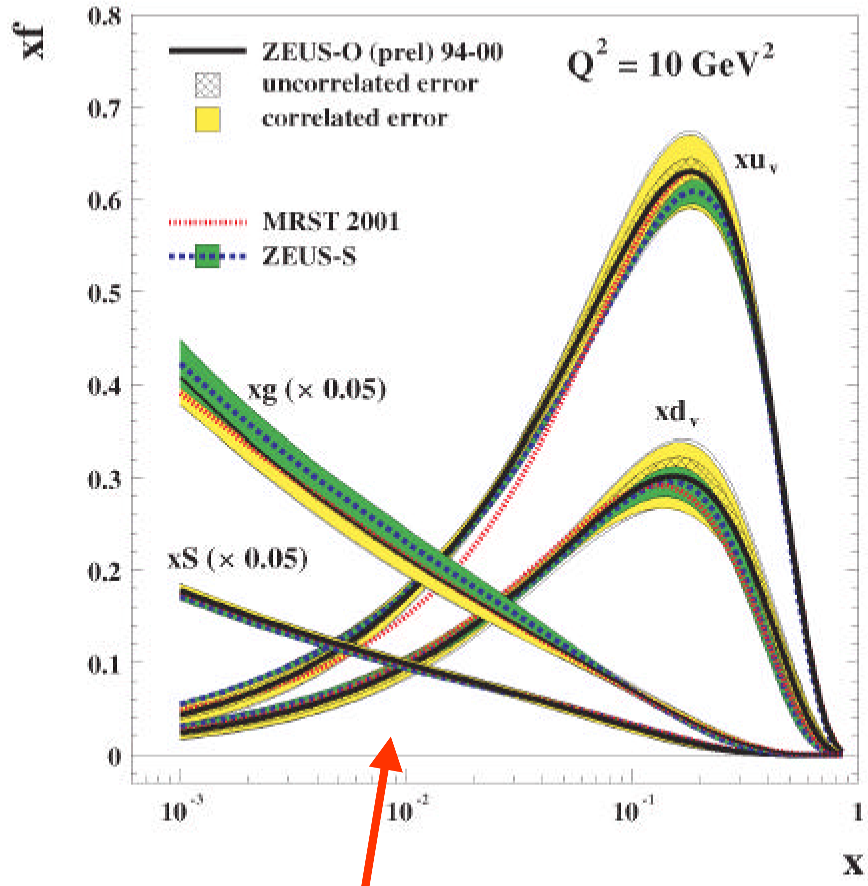
$F_2 = S_i[e_i^2 \; x \; f_i(x,Q^2)]$

$R = s_L/s_T$

proton PDF

DIS probes the partonic structure of the proton

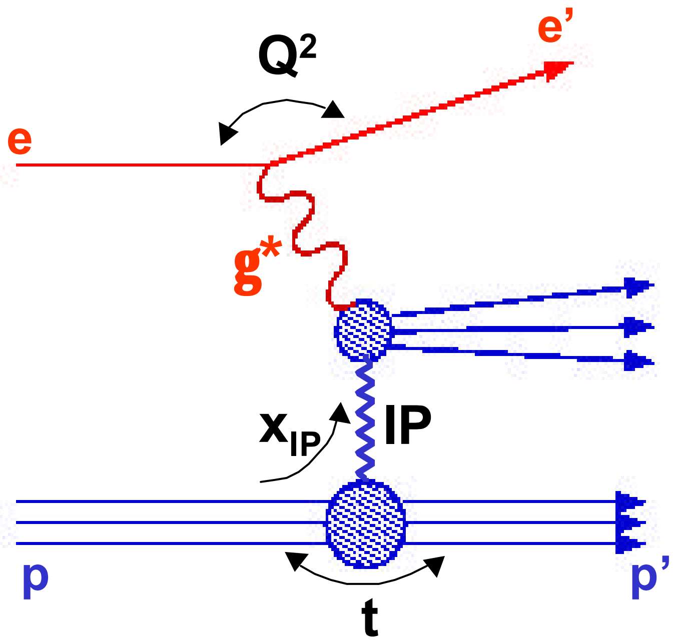
Standard Deep Inelastic Scattering



$$F_2=\Sigma_i[e_i^2\ x\ f_i(x,Q^2)]$$

proton PDF

Diffractive Deep Inelastic Scattering



x_{IP} = fraction of proton's momentum taken by Pomeron

= **x** in Fermilab jargon

b = Bjorken's variable for the Pomeron
= fraction of Pomeron's momentum carried by struck quark
= x/x_{IP}

$$\frac{d^4 s}{db\,dQ^2\,dx_{IP}\,dt} = \frac{4pa^2}{bQ^4}\left\{1 - y + \frac{y^2}{2(1+R^{D(4)})}\right\} F_2^{D(4)}(b, Q^2, x_{IP}, t)$$

Naively, if IP were particle: $F_2^{D(4)}$ » $f_{IP}(x_{IP},t)\, F_2^{IP}(b,Q^2)$

Flux of Pomerons

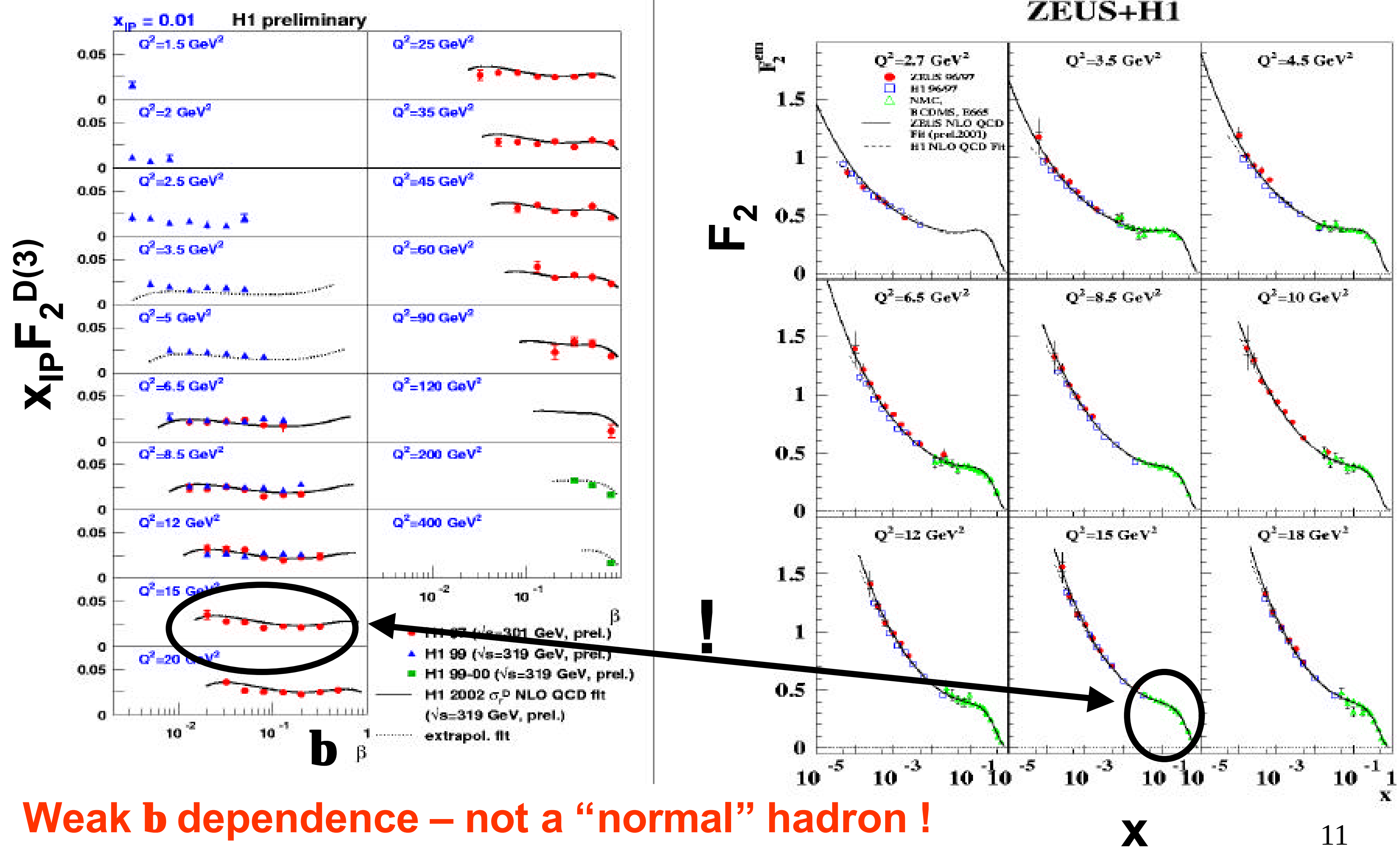
"Pomeron structure function"

[Ingelman, Schlein]

Diffractive Structure Function vs b

Pomeron:

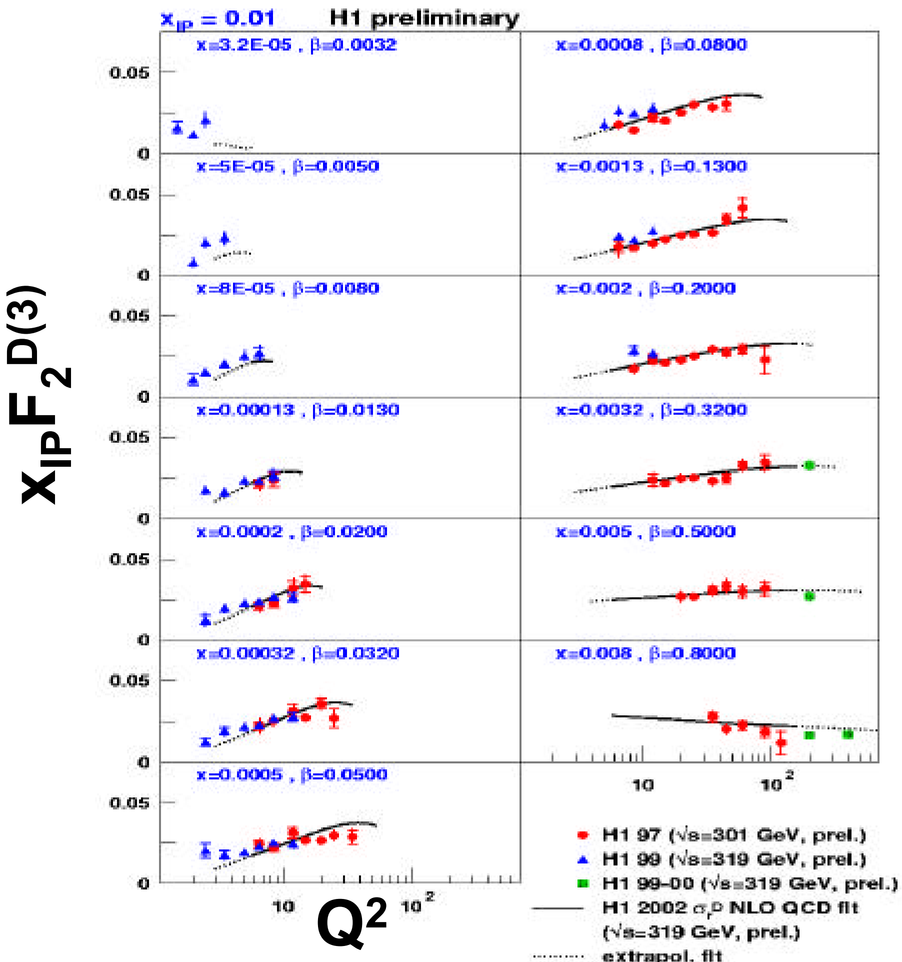
Proton:



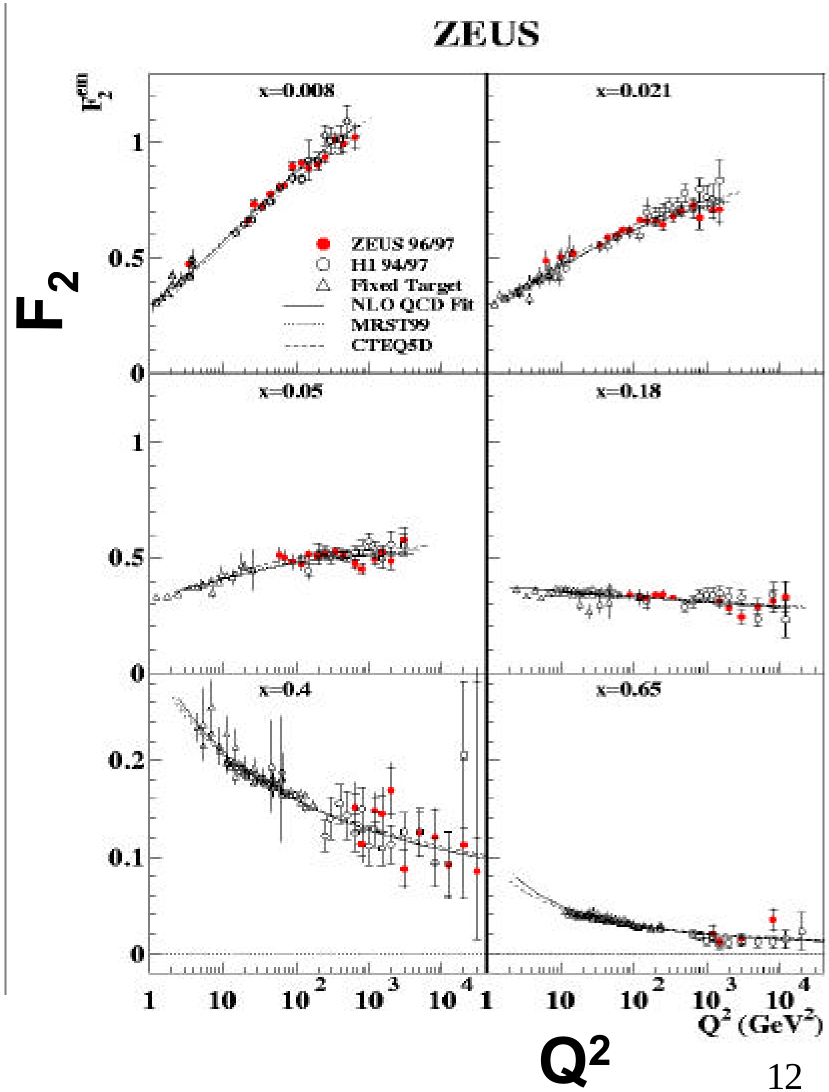
Weak b dependence – not a "normal" hadron !

Diffractive Structure Function vs Q^2

Pomeron:



Proton:

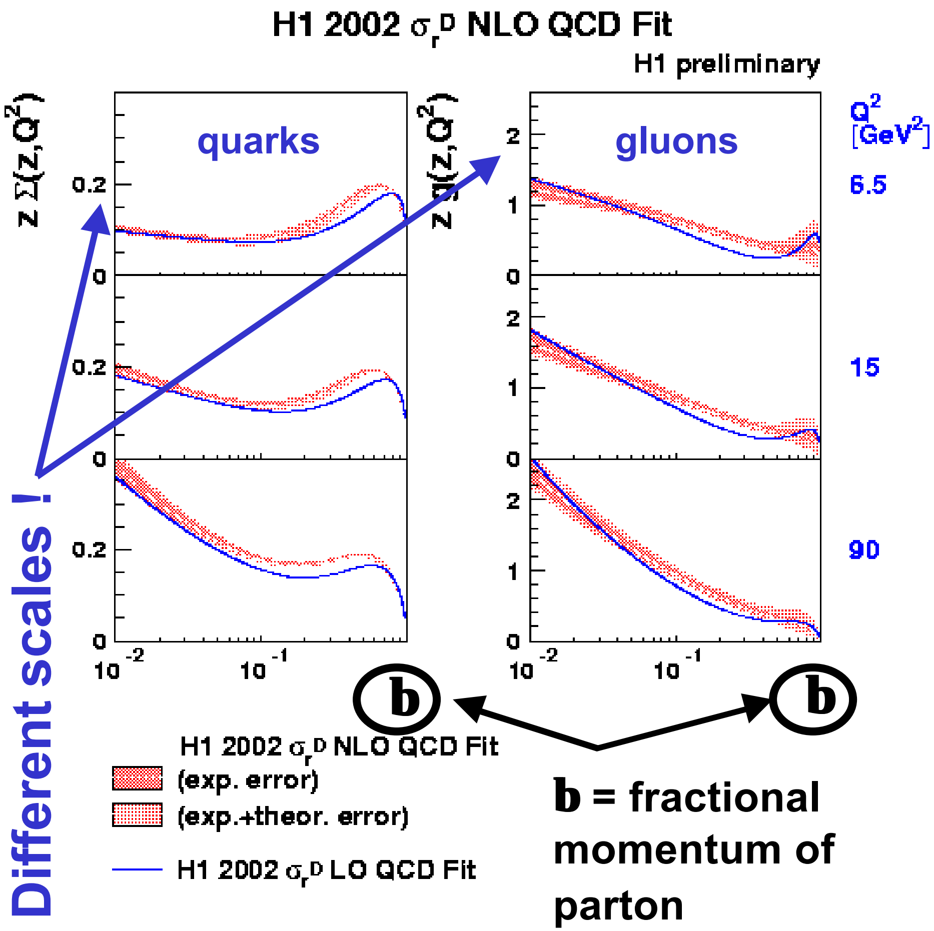


Positive scaling violations:
lots of gluons !

Diffractive PDFs

Fit with Altarelli-Parisi evolution equations:

- **Parametrise Flavour Singlet (quarks+antiquarks) and Gluons at $Q^2 = 3$ GeV^2**
- **Evolve with NLO Altarelli-Parisi equations and fit**



Gluon dominated: integrated fraction of exchanged momentum carried by gluons is (75 ± 15)%

Diffractive PDFs:

$f_{i/p}^D(b, Q^2, x_{IP}, t)$: probability to find, with probe of resolution Q^2, in a proton, parton *i* with momentum fraction *b*, under the condition that proton remains intact, and emerges with small energy loss, x_{IP}, and momentum transfer *t*

Diffractive PDFs are a feature of the proton

Diffractive PDFs

A new type of PDFs, with same dignity as standard PDFs.
Applies when vacuum quantum numbers are exchanged

Rather than IP exchange: probe diffractive PDFs of proton

Diffractive PDFs:
$f_{i/p}^{D}(\beta,Q^2,x_{IP},t)$: probability to find, with probe of resolution Q^2, in a proton, parton i with momentum fraction β, under the condition that proton remains intact, and emerges with small energy loss, x_{IP}, and momentum transfer t

Diffractive PDFs are a feature of the proton

(Diffractive) hard scattering factorisation

Diffractive DIS, like inclusive DIS, is factorisable

[Collins (1998); Trentadue, Veneziano (1994); Berera, Soper (1996)…]:

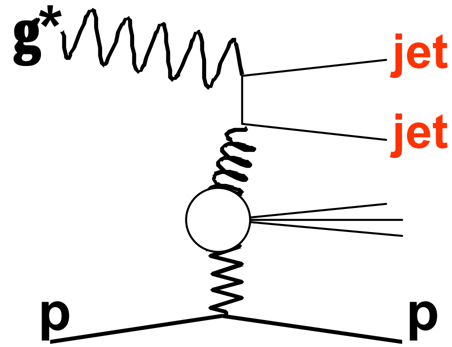
$$F_2^D \sim f_{i/p}^D \otimes \widehat{\sigma}_i$$

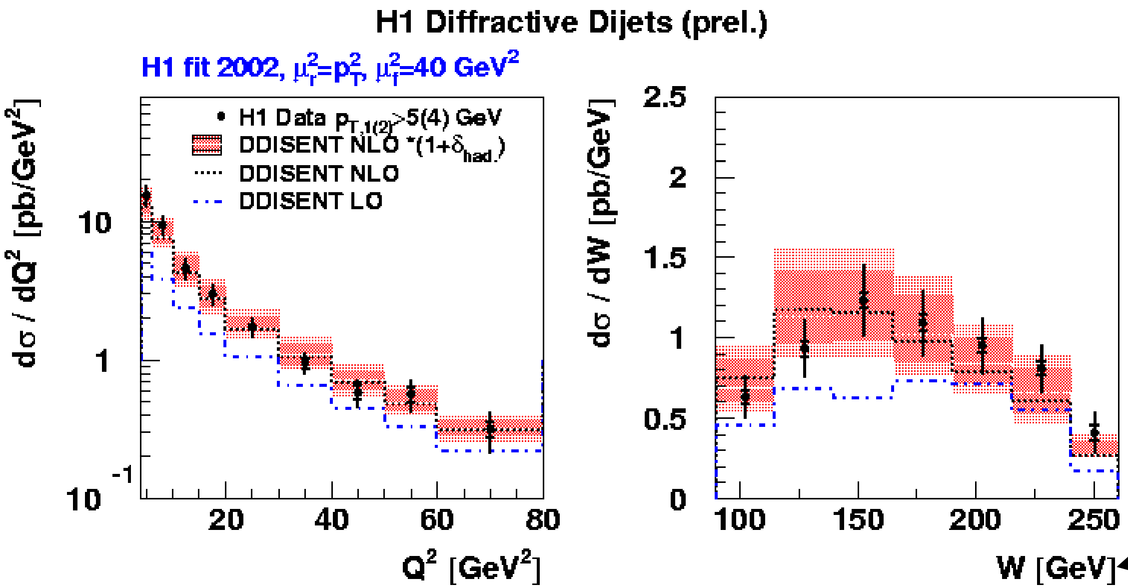
universal partonic cross section

diffractive parton distribution functions: evolve according to Altarelli-Parisi

Test factorisation in ep events

Use diffractive PDFs from previous slides to predict diffractive dijet production cross section:





$4<Q^2<80$ GeV^2
CDF cone algorithm
$P_t^{jet\ 1(2)} > 5(4)$ GeV
$x_{IP}<0.05$

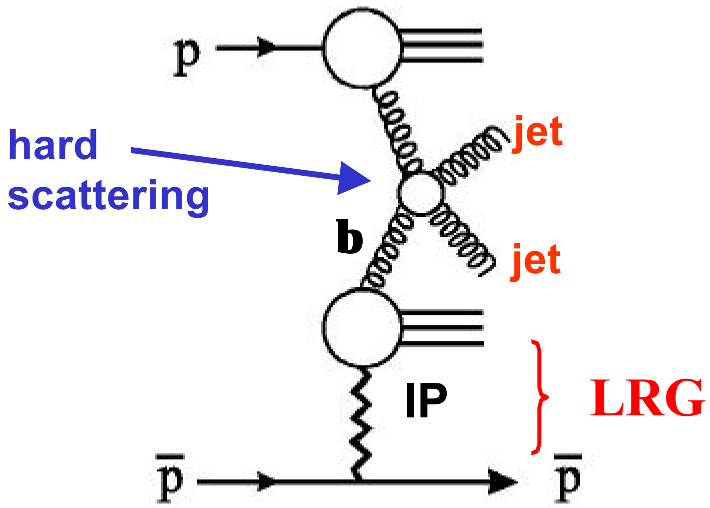
gp centre-of-mass energy

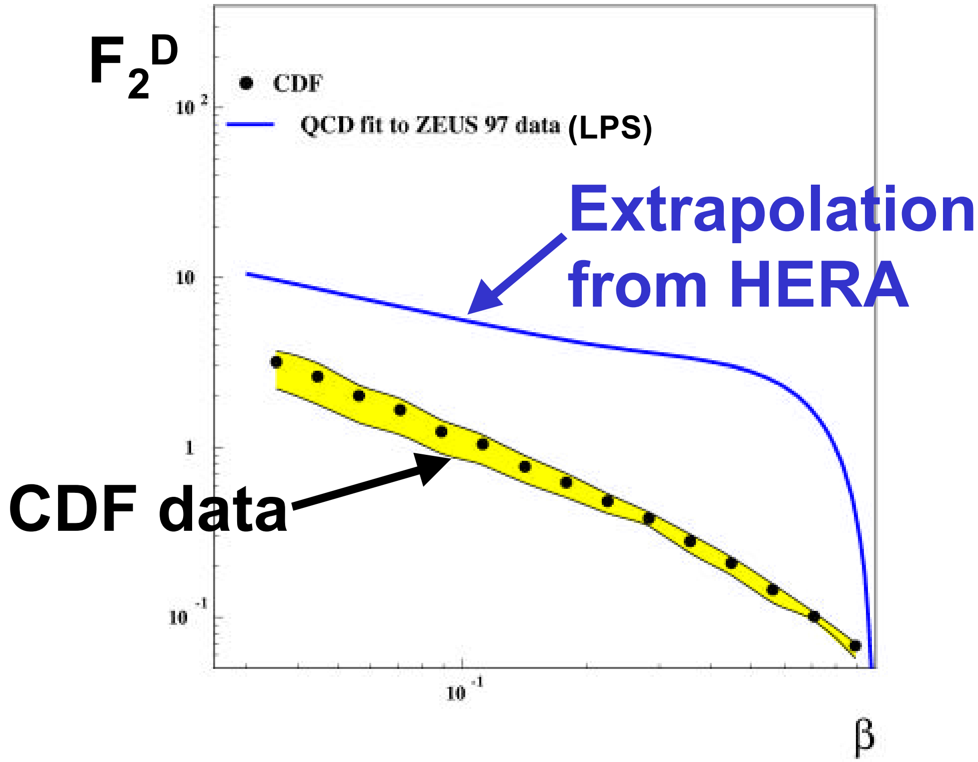
- **Data well described !**
- **Same conclusion for charm production**

➡ **Hard scattering factorisation works in diffractive DIS**

Test factorisation in $p\bar{p}$ events

Measure diffraction at Fermilab: find a factor 10 less than expected from HERA



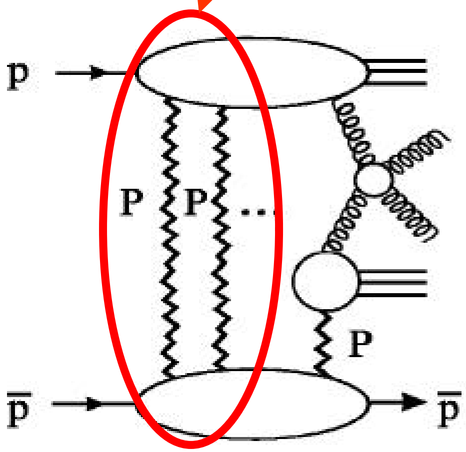


Diffractive PDFs from HERA do not work at Fermilab ?!

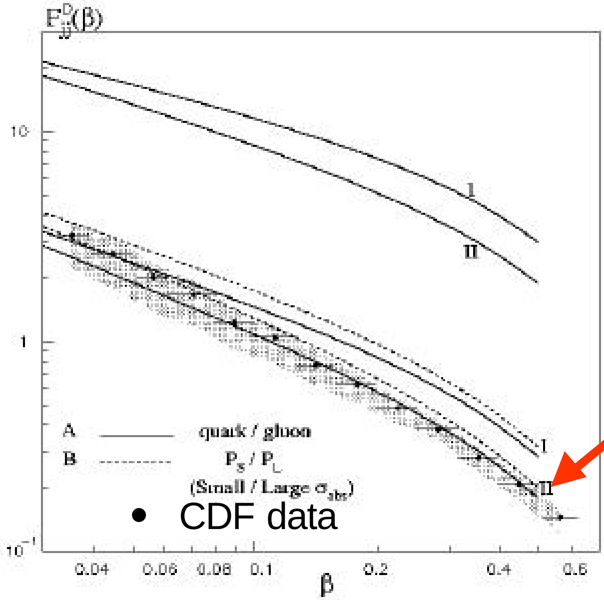
Why is diffr factorisation violated in $p\bar{p}$?

- Proton and anti-proton are both large objects, unlike the pointlike virtual photon.

- In addition to the hard diffractive scattering, there may be soft <u>interactions among spectator partons</u>. They fill the rapidity gap and slow down the outgoing $p, \bar{p}$



F_2^D



Predictions based on rescattering assuming HERA diffractive PDFs

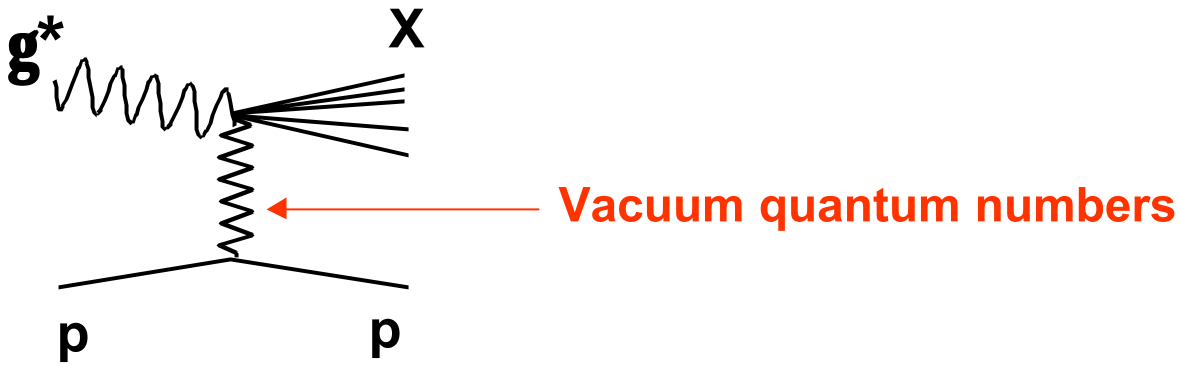
Kaidalov, Khoze, Martin, Ryskin (2000)

b

Summary I

- We have measured the partonic content of the exchange responsible for elastic and diffractive interactions – mainly gluons [ie we think we know what a Pomeron is]
- Rather than viewing diffraction as due to the exchange of IP ® exchange of partons belonging to the proton
- This has led to a new kind of PDFs relevant when the vacuum quantum numbers are exchanged: diffractive PDFs
- Hard scattering factorisation of diffractive PDFs works in DIS. We are on the way to understanding the *large* breaking of factorisation observed in ep vs $p\bar{p}$

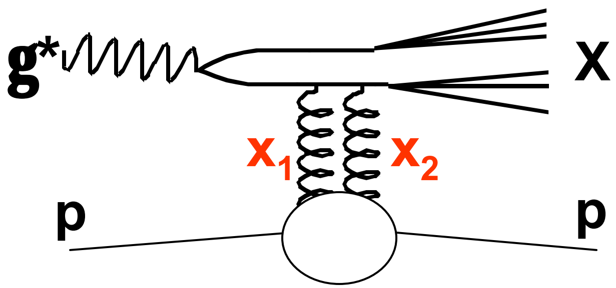
Digression: diffraction as a window on parton-parton correlations in the proton



- Vacuum quantum numbers are exchanged

- Since exchange consists of partons from the proton, need to exchange more than one parton to get the vacuum quantum numbers

- Simplest possibility: two gluons

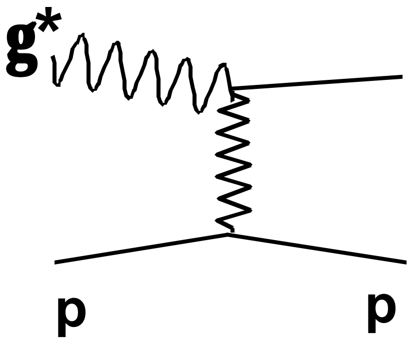


Sensitivity to parton-parton correlations in proton – quantified by *Generalised PDFs (GPDs)*

$$s \propto [\mathrm{H}(x_1, x_2, Q^2)]^2$$

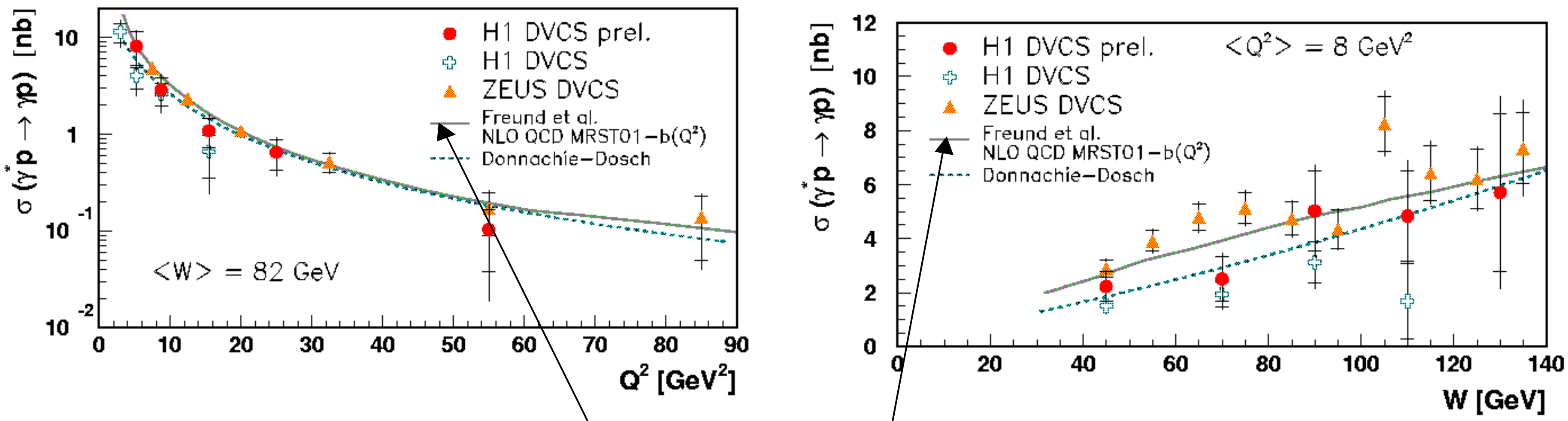
Sensitivity to GPDs

- **Sensitivity to GPDs largest for exclusive final states**



X= vector meson or
single photon (Deeply Virtual Compton Scattering, DVCS)

- **Effect is large – factor 3 in Υ production**



GPD-based calculations, NLO (!)

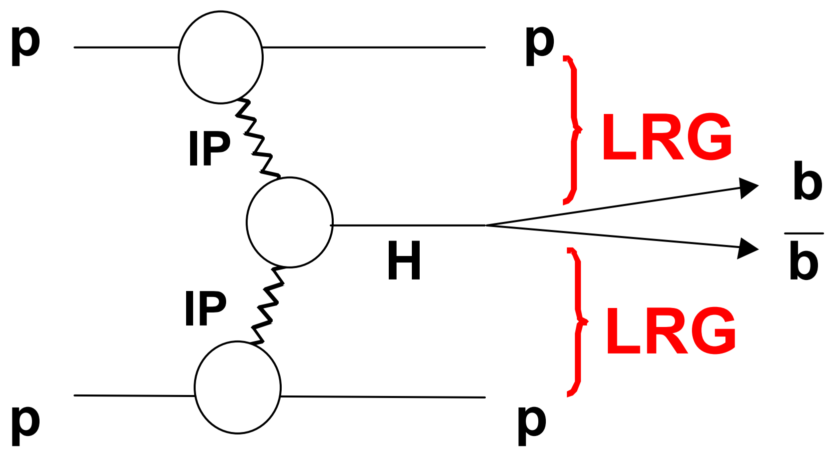
Part II

The future:

Diffractive Higgs production – the way to discover a light Higgs ?!

Diffractive Higgs at LHC

- **For light Higgs (» 120 GeV), gg ®H, H ® $b\bar{b}$ mode has highest branching ratio, but signal swamped by gg ®$b\bar{b}$**
- **Signal-to-background ratio improves dramatically for diffractive production: S/B~3; for 30 fb^{-1}, observe 11 events** [Khoze, Martin, Ryskin,2000]

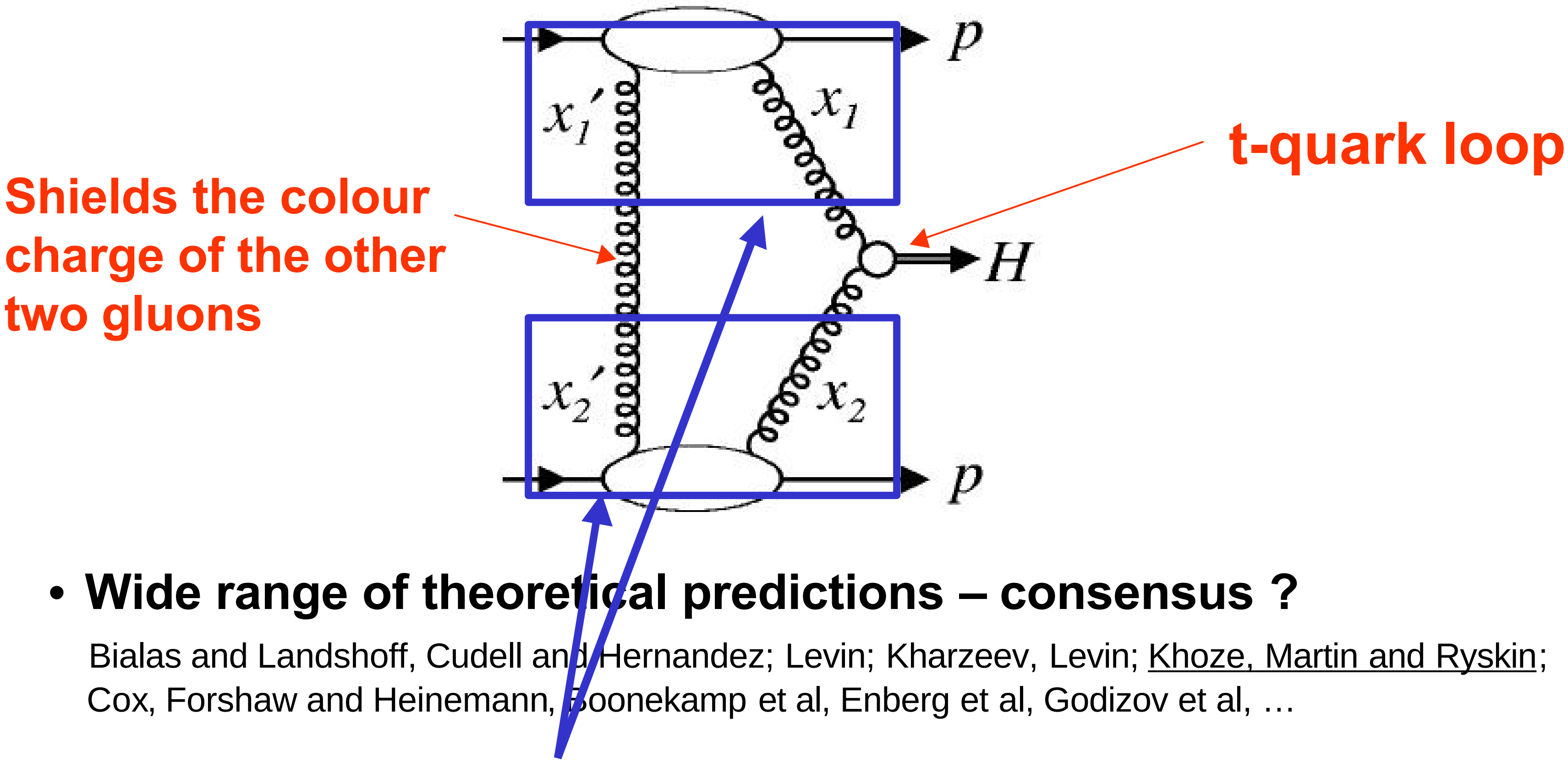


- **Reconstruct M_H from $b\bar{b}$ (central detector)**
- **and/or from scattered protons (proton spectrometer in tunnel) with missing mass method 1-2 GeV resolution**
- **H ®$t\bar{t}$, WW also OK**

Major, but not insurmountable, experimental difficulties:
event pile-up at high lumi (»23 interactions/bunch crossing) 'spoils' rapidity gaps; Roman Pot signals too late for L1 trigger

Diffractive Higgs at LHC

- **More in detail:**



- **Wide range of theoretical predictions – consensus ?**

  Bialas and Landshoff, Cudell and Hernandez; Levin; Kharzeev, Levin; Khoze, Martin and Ryskin; Cox, Forshaw and Heinemann, Boonekamp et al, Enberg et al, Godizov et al, …

- **Diffractive PDFs, GPDs essential for prediction**

- **Understanding of factorisation breaking ep vs pp essential**

- **LOI expected from CMS/Totem in Spring 2005**

Grand summary

- Diffrazione capita, quantitativamente, in termini di QCD (non piu' indispensabile parlare di traiettorie e pomeroni), almeno in presenza di una scala dura

- Diffrazione dovuta allo scambio di partoni *del protone* che trasportano i numeri quantici del vuoto
  ® si sondano le PDF diffrattive del protone (per lo piu' gluoni)

- Fattorizzazione di QCD funziona per gli eventi diffrattivi
  (ma con importanti correzioni di rescattering per andare da ep a $p\bar{p}$, pp)

- Sensibile alle correlazioni nel protone (GPD)

- Canale privilegiato per la scoperta di un Higgs leggero ?