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Low x and Diffraction at HERA

Lake Louise Winter Institute

Richard Hall-Wilton

York University, Canada

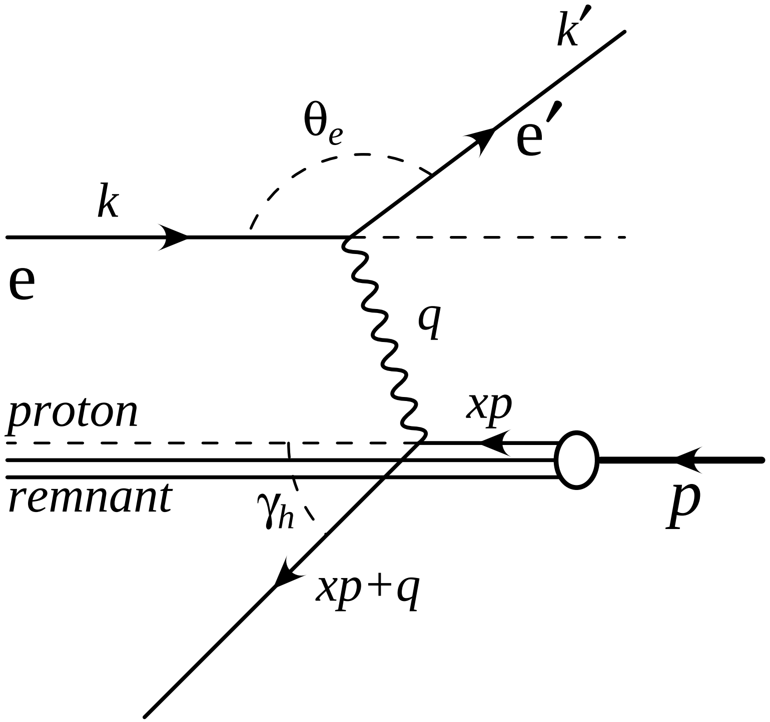
On behalf of ZEUS and H1

Introduction

▷ **HERA collides 27.5 GeV e$^{\pm}$ with 920 (820) GeV protons**

$$\rightarrow \sqrt{s} = 320\ (300)\ \mathrm{GeV}$$

Neutral Current Exchange:



$$ep \rightarrow e' X$$

Q^2 photon virtuality

$$Q^2 \equiv -q^2 = -(k - k')^2$$

x **fraction of proton's momentum carried by struck parton**

$$x \equiv \frac{Q^2}{2p.q}$$

Factorises:

$$\sigma_{DIS} \sim f_p(Q^2, x) \otimes \hat{\sigma}$$

$f_p(Q^2, x)$ **Universal parton densities**

Structure Functions

Express cross section in terms of a proton structure function:

$$\frac{d^2\sigma^{e^\pm p}}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}(Y_+F_2 - y^2F_L \pm Y_-xF_3) \qquad \text{where } Y_\pm = 1 \pm (1-y)^2$$

F_2 proton structure function

F_L longitudinal structure function

xF_3 γ-Z interference term (see A. Tapper's talk)

$$F_2(x,Q^2) = \Sigma_i e_i^2(xq_i(x,Q^2) + x\overline{q}_i(x,Q^2)) \qquad \text{(LO Picture)}$$

Structure functions not calculable

▷ Measure them

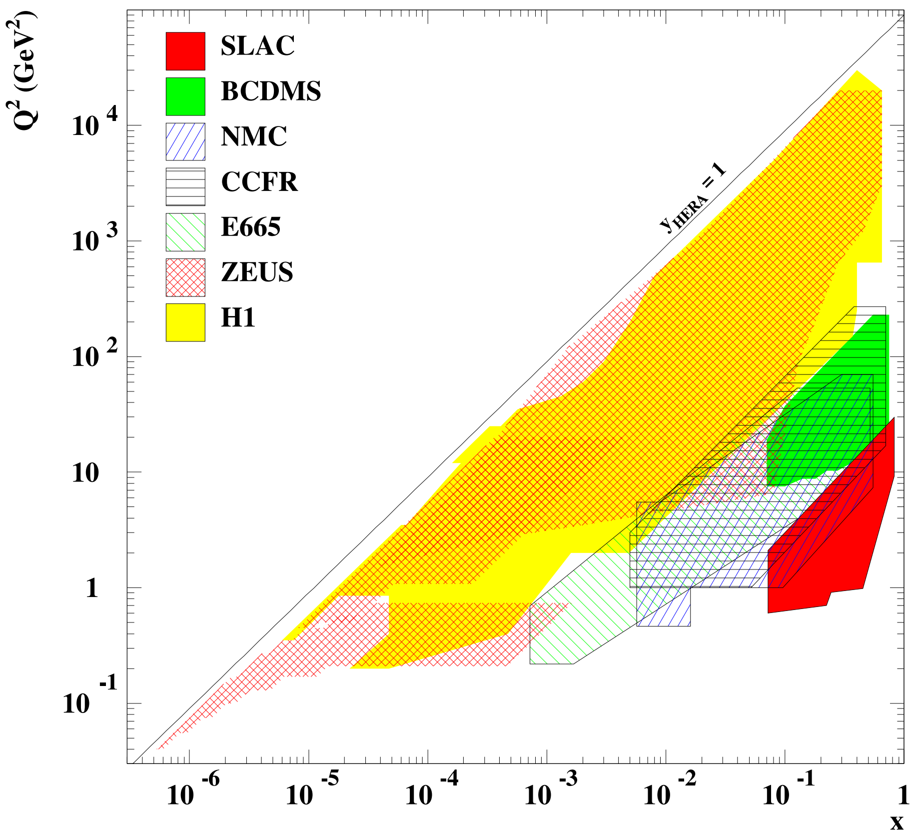
▷ Use pQCD to predict how they vary with Q^2

DGLAP ▷ uses Alterelli-Parisi to describe parton splitting (P):

$$\frac{\delta f(x,Q^2)}{\delta \ln(Q^2)} = f(x,Q^2) \otimes P$$

Motivation

Kinematic plane at HERA:



▷ **Spans 6 orders of magnitude in x and Q^2**

DGLAP - $\ln(Q^2)$ expansion

▷ **Low Q^2 $\Rightarrow$ when does it fail?**

▷ **Low x $\Rightarrow$ $ln\frac{1}{x}$ terms large**

▷ **Can we see evidence of non-DGLAP evolution in the data?**

Diffraction - often considered a *"soft"* process

▷ **Can DGLAP evolution be applied to diffraction with a *"hard"* scale (Q^2) present?**

Overview

- **Introduction**
- **Inclusive Measurements at Low x**
- **Charm Production**
- **Very Low x and Q^2**
- **Inclusive Diffraction**
- **Diffractive final states**
- **Summary**

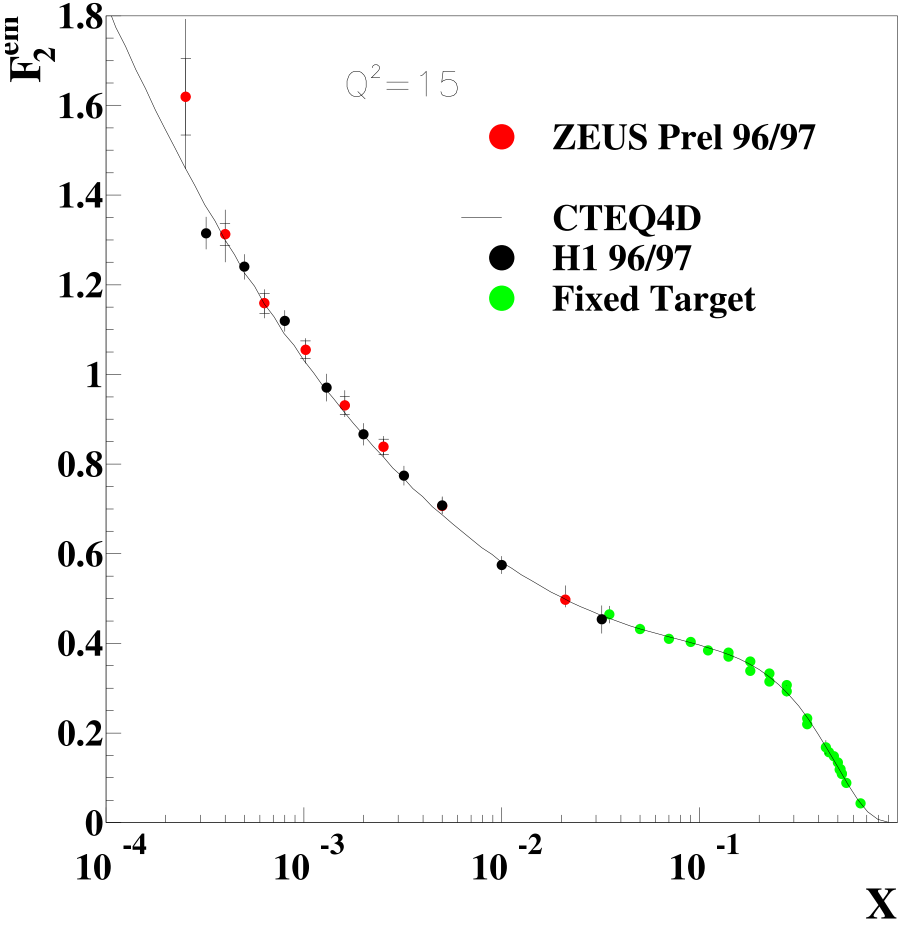
The Proton Structure Function

Fit - pQCD DGLAP approach at NLO

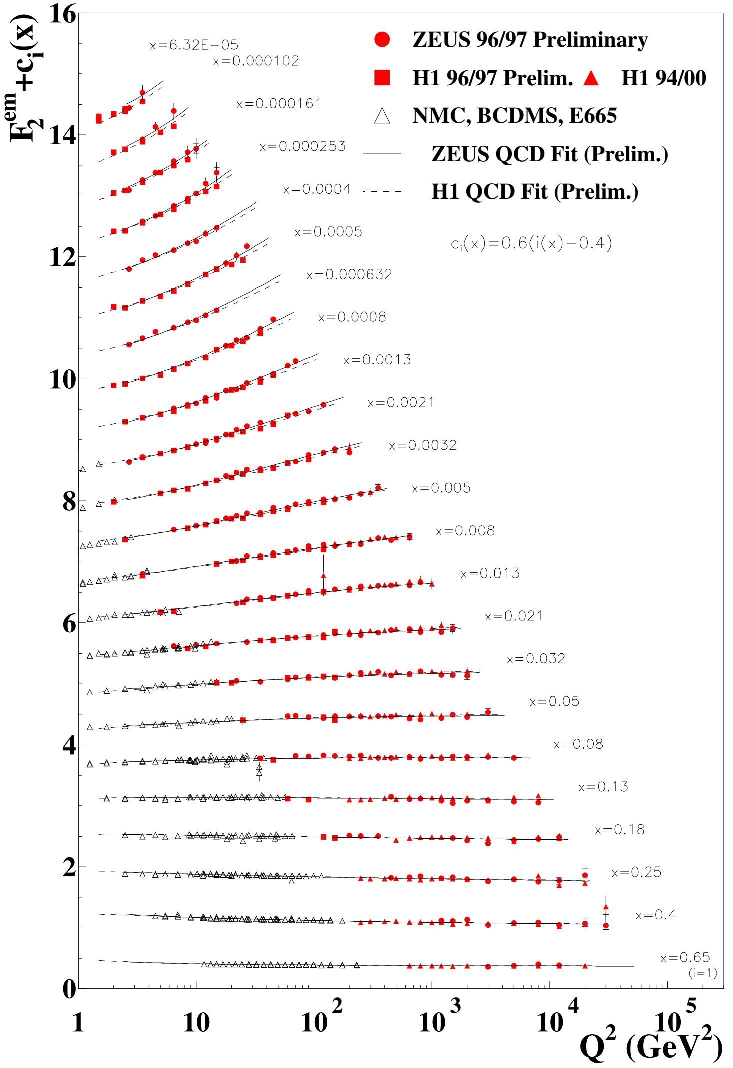
F_2 rises strongly at low x

▷ Rising parton densities at small x

Fits agree with data down to $Q^2 \sim$ few GeV^2



Scaling Violations



F_2 vs Q^2:

Scaling – F_2 independent of Q^2 for $x \sim 0.1$

Violations observed at smaller x

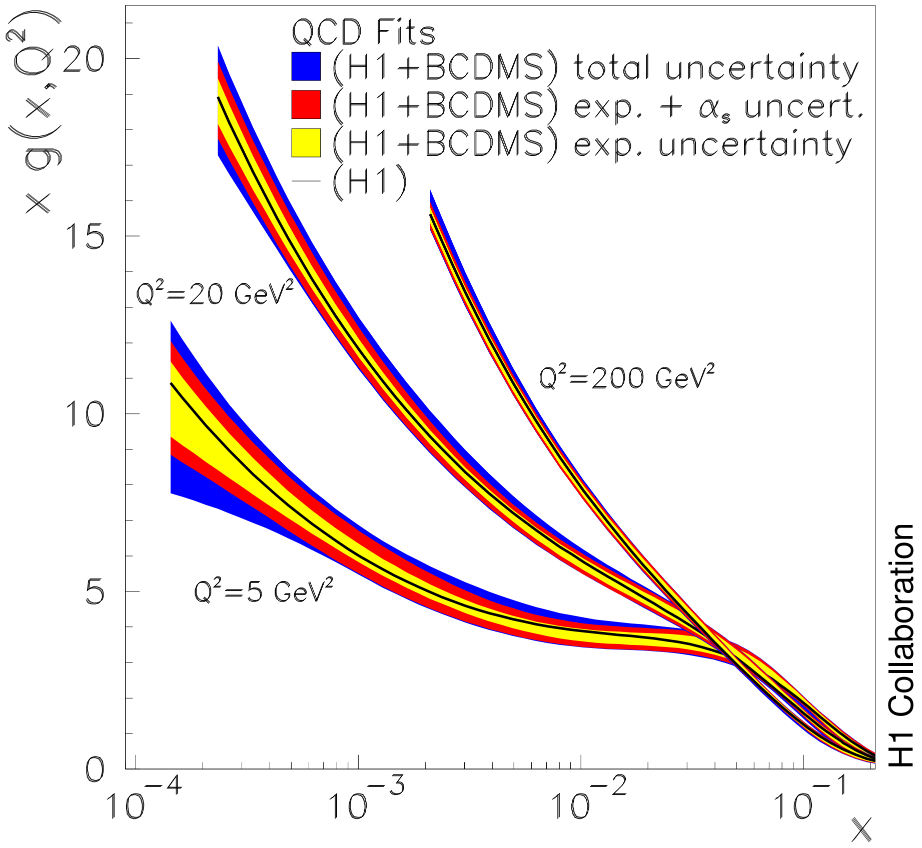
$\Rightarrow$ effect of gluons

Leading Order picture:

$$\frac{\delta f(x, Q^2)}{\delta \ln(Q^2)} \sim xg(x, Q^2)$$

▷ NLO picture more complicated, but can fit and extract gluon density

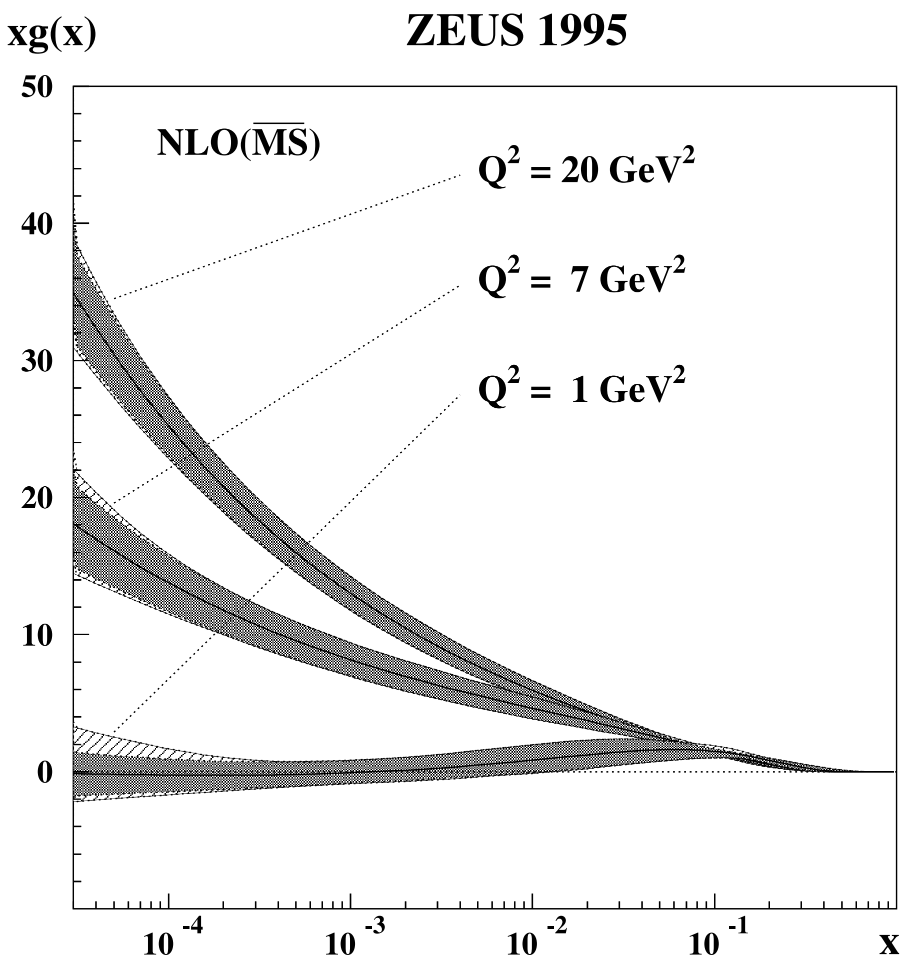
Gluon Distribution – $xg(Q^2, x)$



$Q^2 \sim 1$ GeV^2 gluon is $\sim$ 0

▷ **What do we mean by gluon density?**

▷ **Gluon rises strongly at low x**

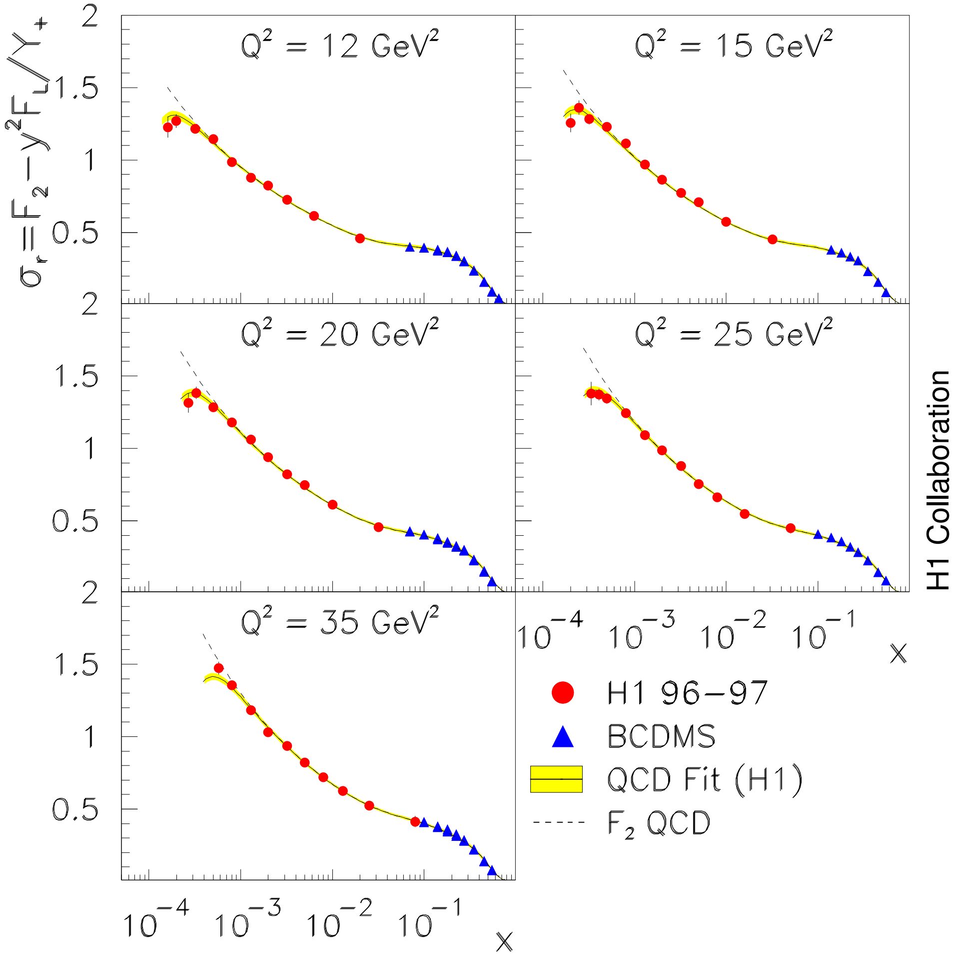


The Longitudinal Structure Function – F_L

H1 have extracted F$_L$ from cross section data

▷ **Compare data with DGLAP fit (with F$_L$ set to 0)**

▷ **Difference gives F$_L$**



The Longitudinal Structure Function – F_L

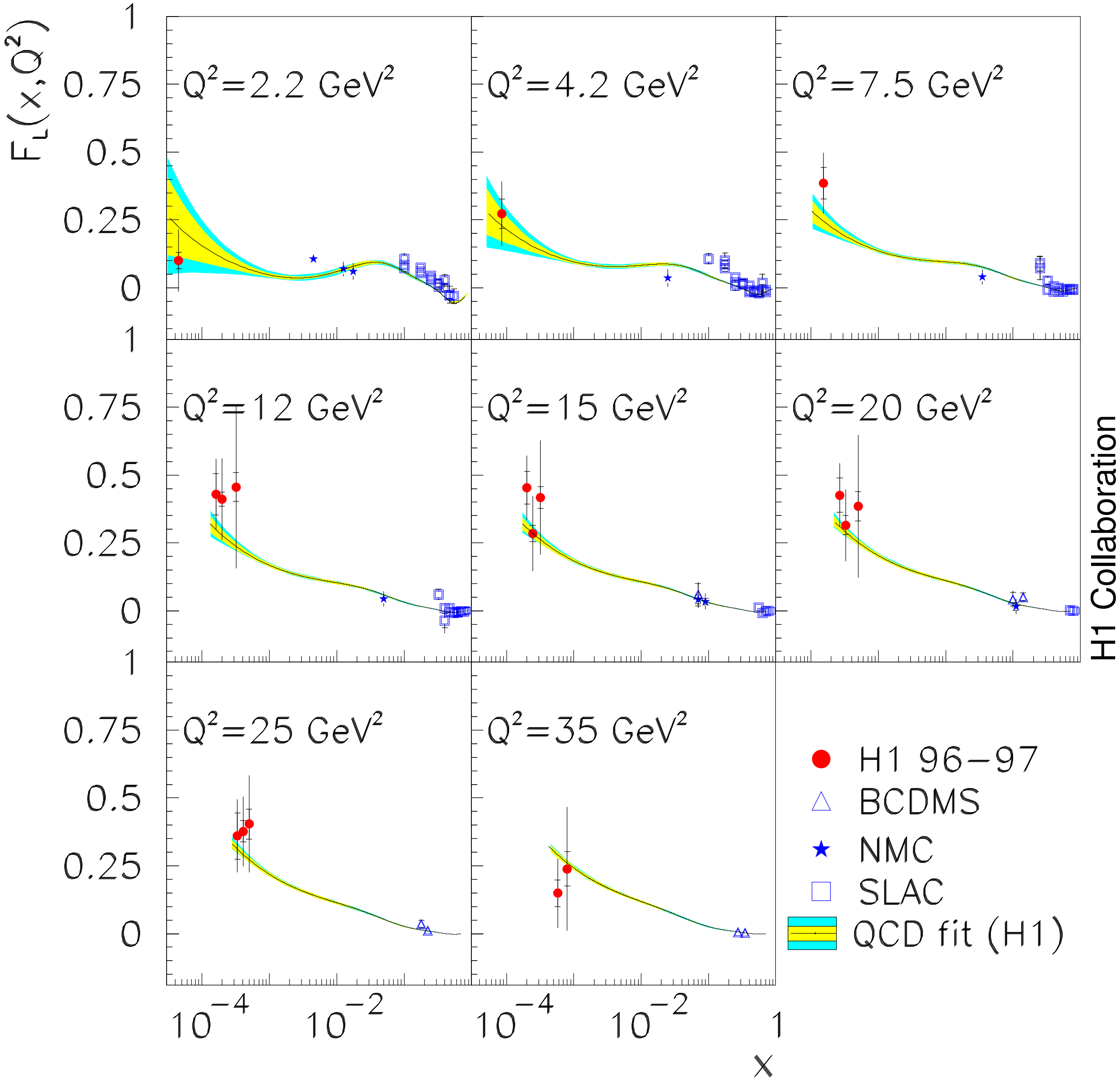
Knowledge of behaviour vastly increased from fixed target data

F_L increases towards lower x

▷ **Rise in gluon density at low x**

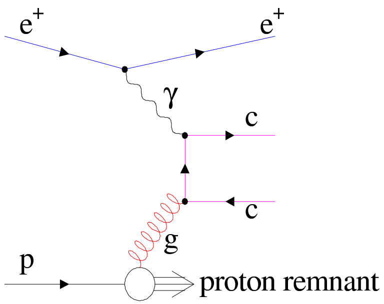
F_L is consistent with predictions of NLO DGLAP fit

▷ **Now look at specific final states sensitive to the gluon**



Charm Production

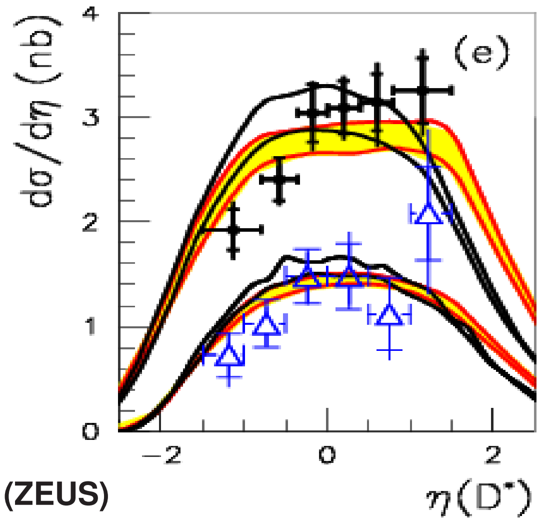
Look at charm final state:



$$ep \to e' D^\star X$$

Dominant contribution to cross-section gluon-induced

▷ **Gluon density is especially important for charm**



(ZEUS)

HVQDIS - DGLAP

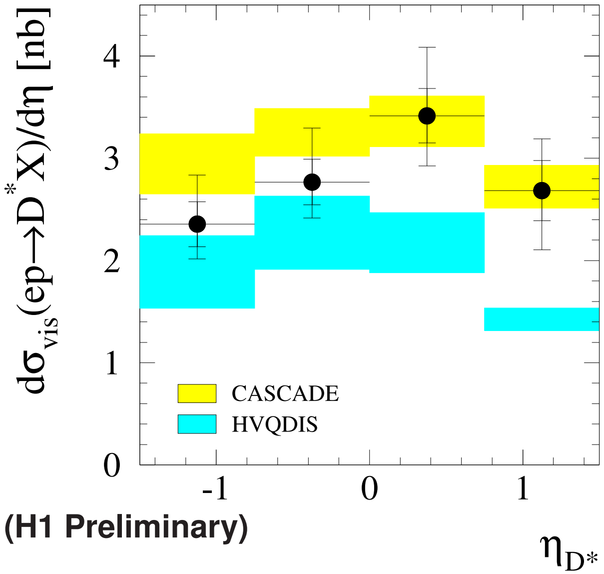
CASCADE - non-DGLAP (includes $\ln\frac{1}{x}$ terms)

ZEUS: added fragmentation model to DGLAP

H1: DGLAP below data in the forward region

▷ **Are we seeing non-DGLAP behaviour?**

▷ **Results on forward jet production also showed indications of non-DGLAP evolution**



(H1 Preliminary)

Really Small x

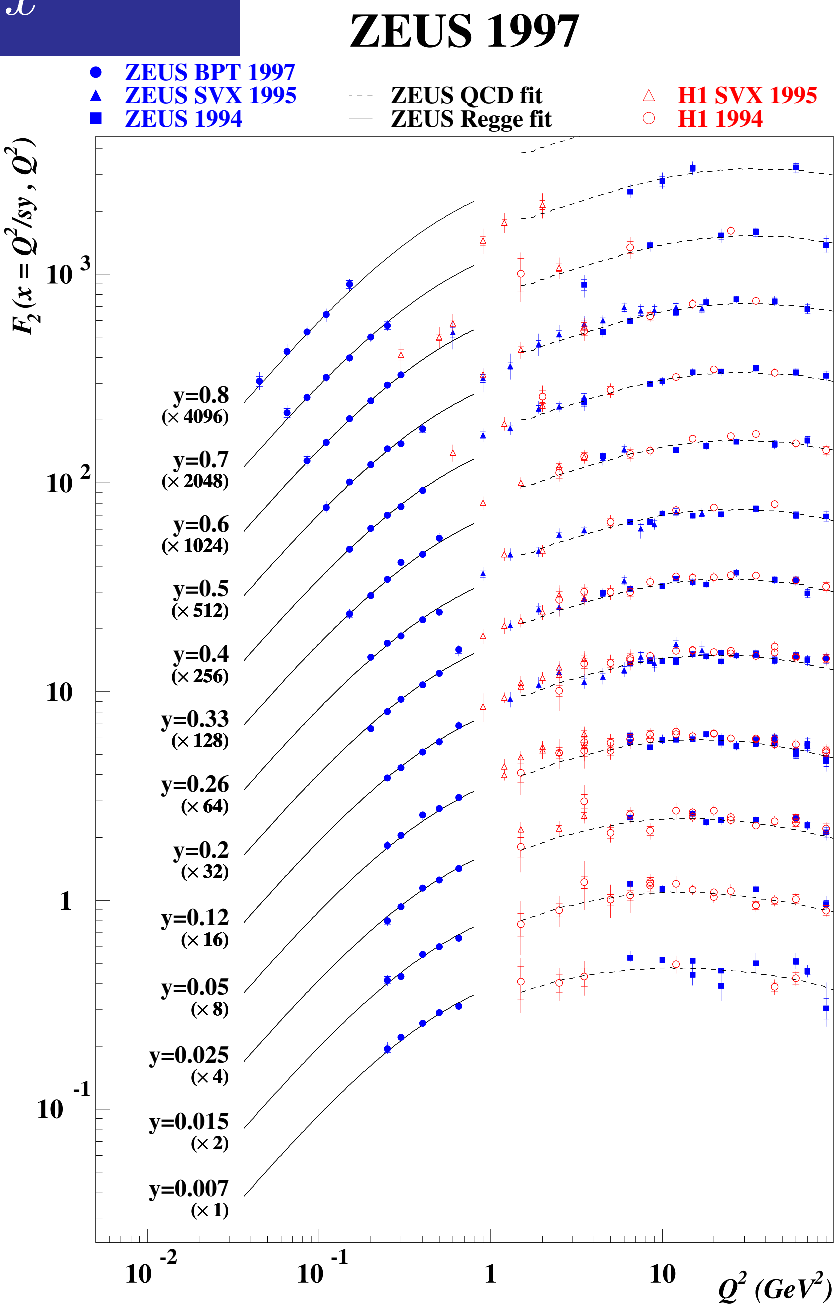
Small $x \Rightarrow$ Small Q^2 (kinematics)

- ▷ **No *"hard"* scale for pQCD calculation**
- ▷ **Expect transition to *"soft"* physics**
- ▷ **Expect DGLAP evolution to fail here**

Below Q^2 $\sim$ 1 GeV^2 Regge-type phenomenological fit gives good description of the data

- ▷ **At lowest Q^2, F$_2$ $\rightarrow$ k Q^2**

At Q^2 $\sim$ 1 GeV^2 DGLAP fit gives good description of data



Diffraction at HERA

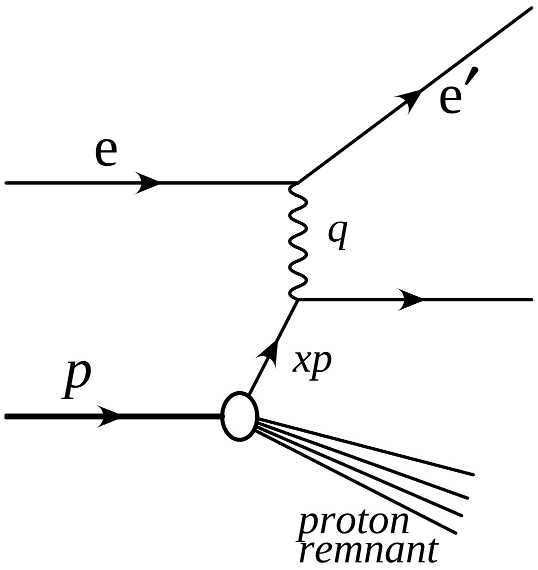
About 10% of events at HERA have little or no activity in the forward direction

▷ **Termed Diffractive events**

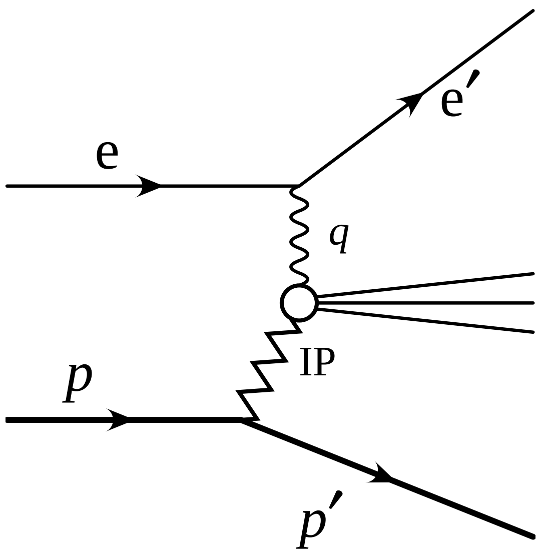
▷ **Should be suppressed due to parton radiation into the colour field between struck quark and proton remnant**

▷ **Describe in terms of the exchange of a colourless object - the pomeron ($I\!P$)**

"Standard" **DIS**



"Diffractive" **DIS**



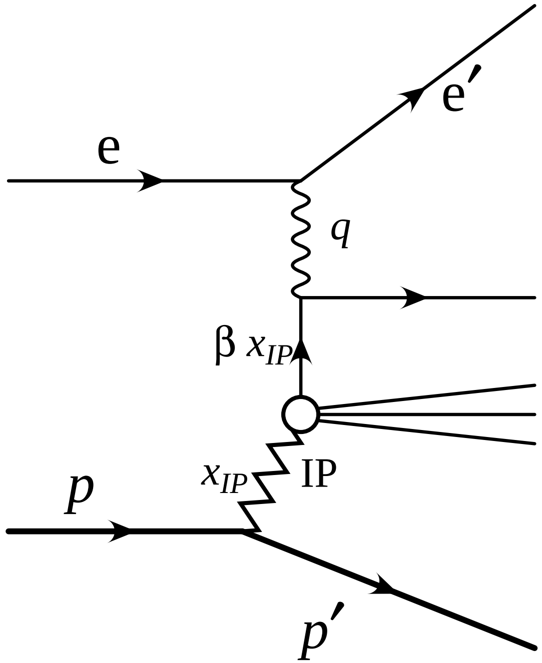
Models of Diffraction - Resolved $I\!P$

Resolved $I\!P$ approach (Ingelman + Schlein) $\longrightarrow$ partonic $I\!P$

Need 2 more variables:

$x_{I\!P}$ **is fraction of the proton's momenta carried by pomeron**

β **- fraction of pomeron momenta that struck parton carries**



$$\frac{d^3\sigma^D}{d\beta dQ^2 dx_{I\!P}} = \frac{4\pi\alpha^2}{\beta Q^2}(1 - y + \frac{y^2}{2})F_2^{D(3)}(\beta, Q^2, x_{I\!P})$$

The cross section factorises (Collins, 1997):

$$F_2^D \sim f^D \otimes \hat{\sigma}$$

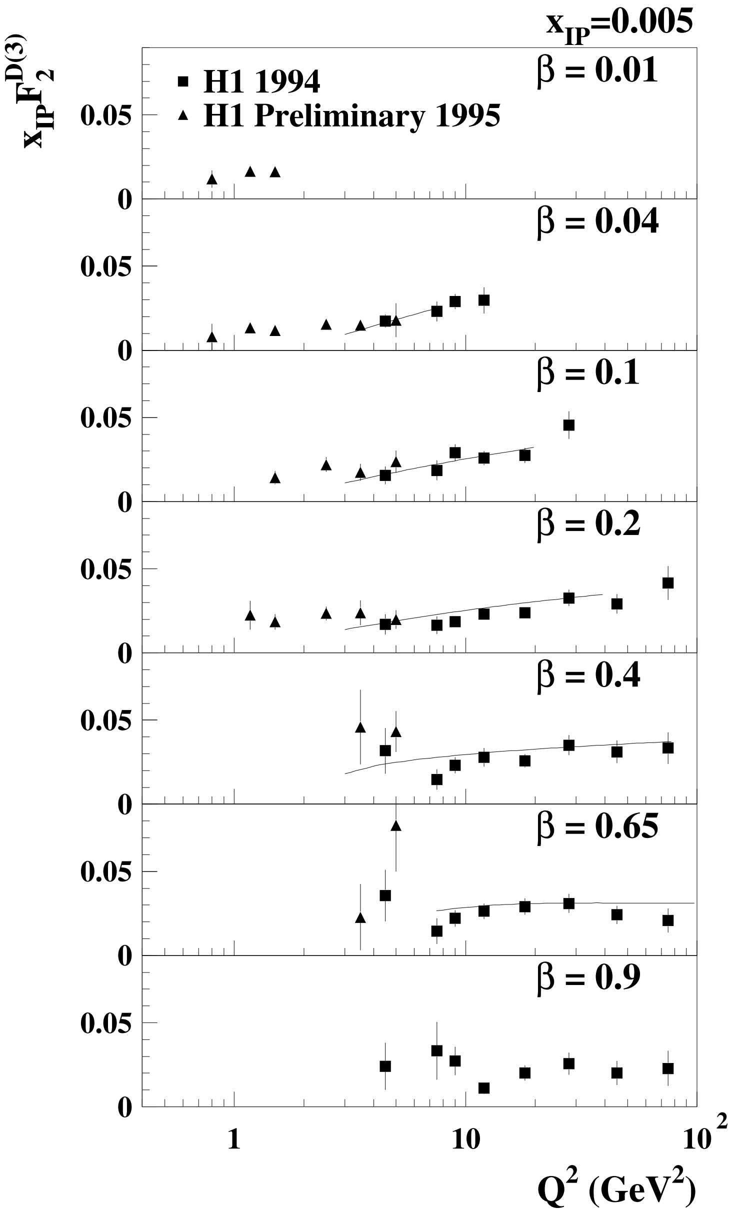
Assuming Regge factorisation:

$$F_2^D \sim f(x_{I\!P}, t).F_2^{I\!P}(\beta, Q^2)$$

The pomeron flux factor, $f(x_{I\!P}, t) \sim \frac{1}{x_{I\!P}}$

$\triangleright$ **Do DGLAP analysis of F$_2^{I\!P}$ in an analogous way to F$_2$**

Diffractive Structure Functions - Scaling Violations



Observe scaling violations in diffraction

- ▷ **High gluonic content of the pomeron**
- ▷ **Gluons are important in diffraction**

Diffractive Structure Functions - really low Q^2

Analogous behaviour to F_2

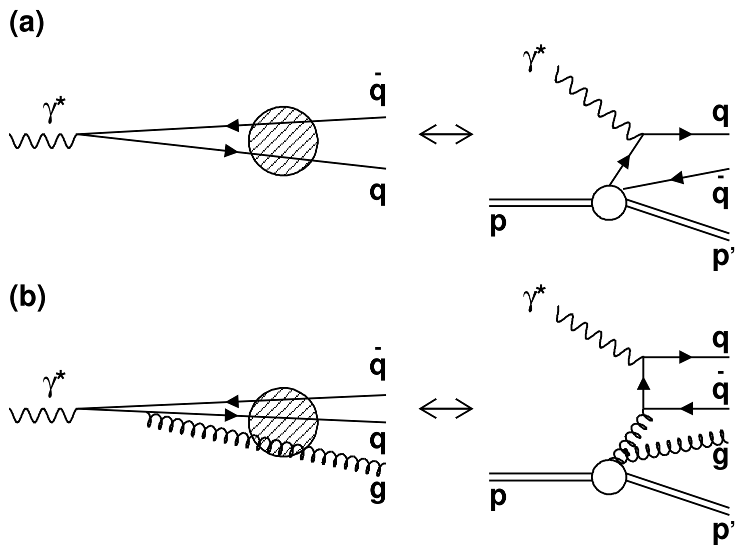
▷ **Clear transition in behaviour at low Q^2**

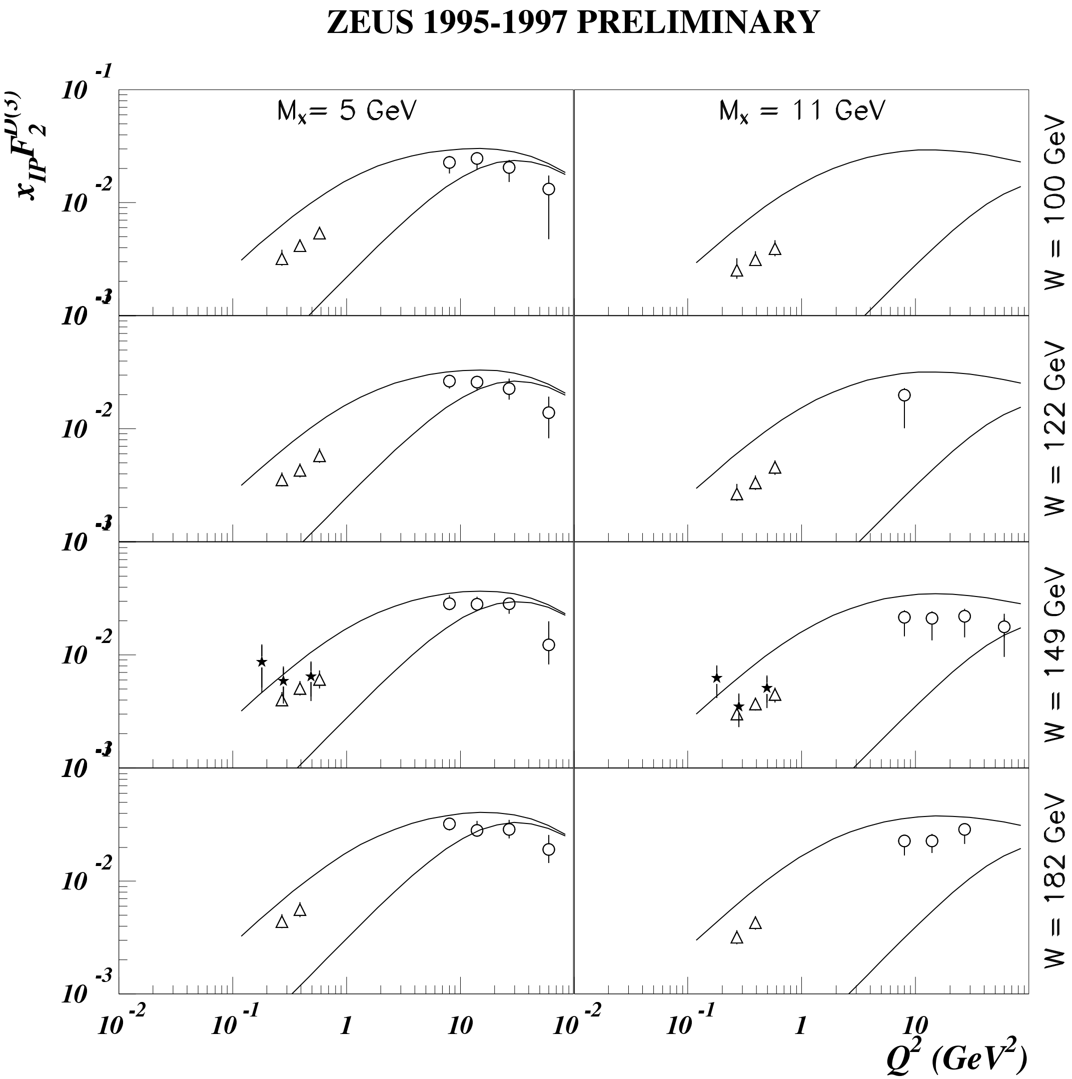
Fit shows a 2 gluon exchange model

Components - $q\overline{q}$ and $q\overline{q}g$ final states

Boost to infinite momentum frame

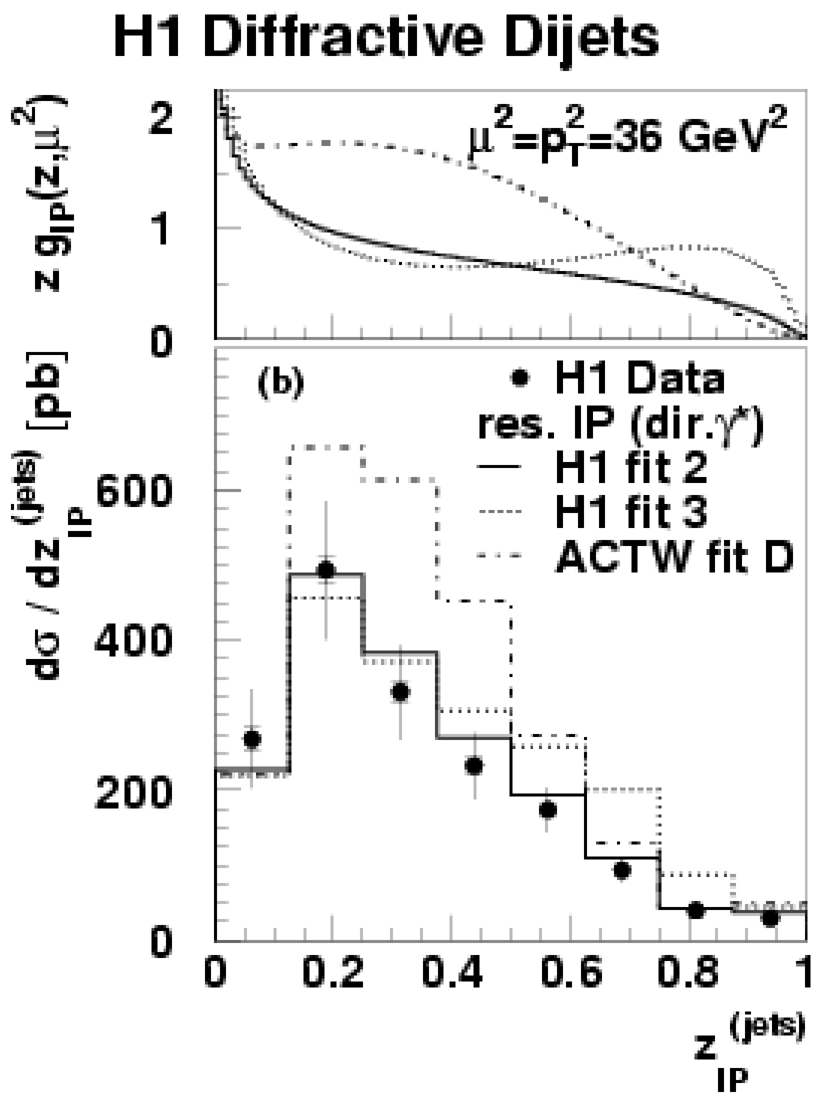
$\sim$ resolved pomeron picture:





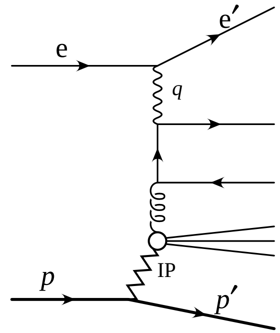
▷ **Look at 2 and 3 jet events**

Jets in Diffraction



▷ Use diffractive parton densities and make predictions for diffractive final states

Diffractive dijet production:



$$ep \to e^{'} jjXp^{'}$$

$z_{I\!P}$ $\sim$ fraction of energy of system X contained within dijets

▷ Sensitive to changes in gluon distribution

▷ Large gluon component preferred

▷ Diffractive gluon tightly constrained by dijet data

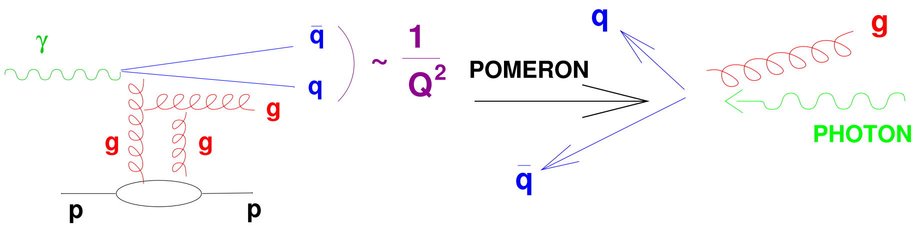
▷ Approach looks consistent with resolved $I\!P$

▷ Results from diffractive charm production - no clear picture yet

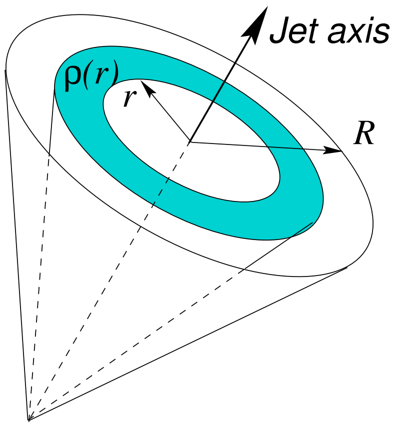
▷ Large model discrimination in diffractive charm

Three Jet production in Diffraction

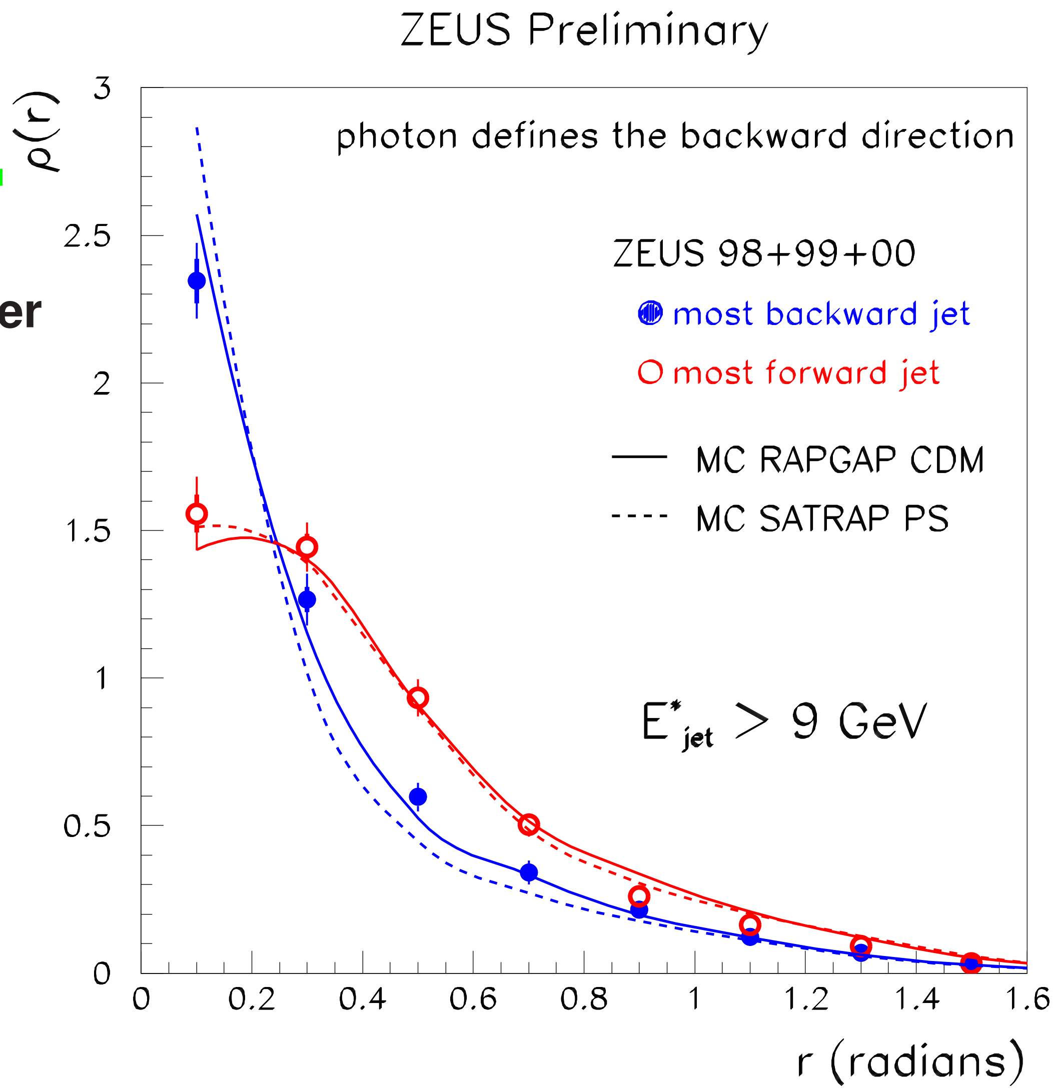
In pQCD picture:



At same jet energy, gluon jets are broader



Plot jet profiles:



▷ **Most backward jet narrower**

▷ **Most forward jet broader**

Agrees with pQCD picture

Summary

Many new results in low x and diffraction at HERA

Low x:

▷ Gluon distribution very important at low x

▷ DGLAP evolution describes data to $Q^2 \sim 1$ GeV^2

▷ Some indication of non-DGLAP parton dynamics in charm production and forward jets

▷ Regge-type phenomenological approach fits data, $Q^2 < 1$ GeV^2

Diffraction:

▷ Can fit data to give diffractive parton densities

▷ Transition to low Q^2 regime similar to non-diffractive data

▷ Dijet data consistent with resolved $I\!P$ model $\rightarrow$ gluon dominated $I\!P$

▷ HERA - ideal place to study evolution schemes and the transition between *"soft"* and *"hard"* physics