Diffractive Physics at HERA

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on behalf of
the H1 and ZEUS collaborations

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- Regge theory and photoproduction
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  - Inclusive diffraction at low Q^2
  - Diffractive di-jet production
  - DIS diffractive D^* production
  - Deeply Virtual Compton Scattering (DVCS)
- Summary

Regge theory and diffraction

- The behaviour of high energy hadron-hadron total cross sections are well described by Regge theory.

- In Regge theory, the cross section of the elastic process, $A + B \to A + B$, is described as

$$d\sigma/dt \propto s^{2(\alpha(t)-1)}.$$

The $\alpha(t) = \alpha(0) + \alpha' \cdot t$ represents the trajectory which is formed from the particles exchanged between A and B.

- From the optical theorem, the total cross section can be obtained as

$$\sigma \propto s^{\alpha(0)-1}.$$

- The measured total cross sections are almost constant at high energy.

$\to \alpha(0) \sim 1$: Pomeron trajectory

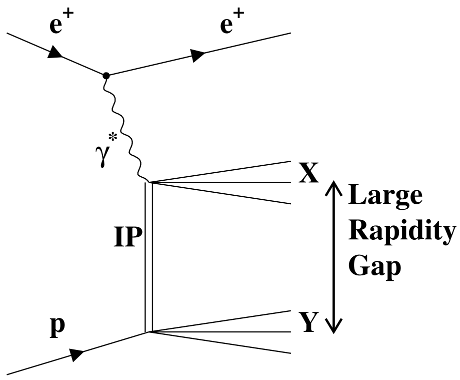
- Donnachie and Landshoff (DL) parameterization:

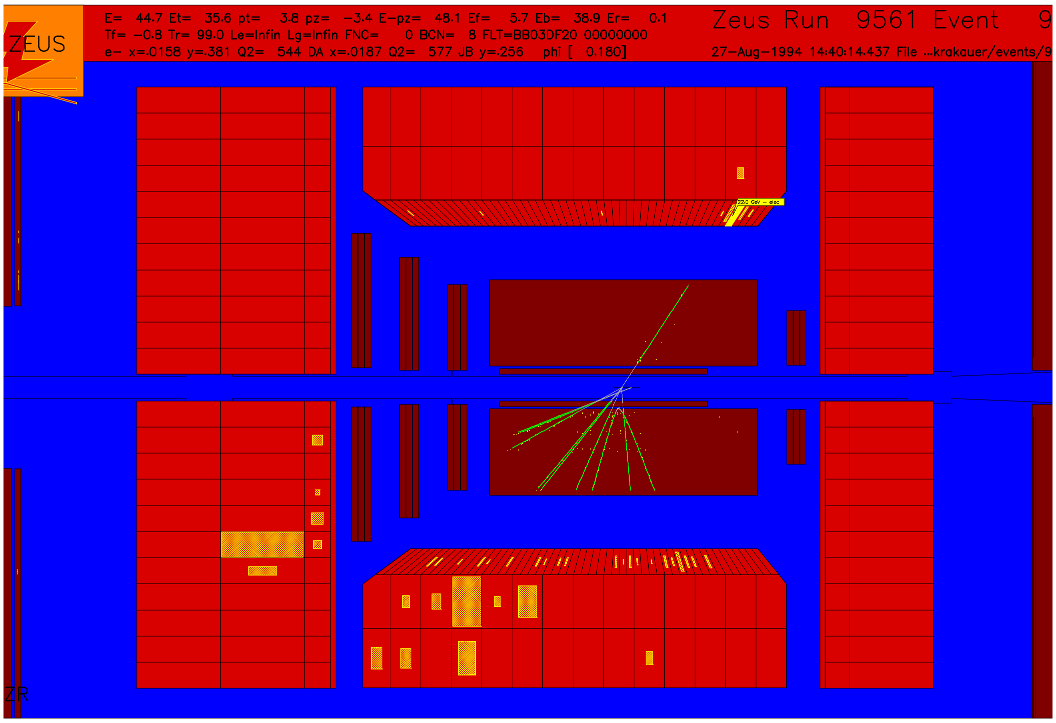
$$\sigma_{tot} = X s^{\epsilon} + Y s^{-\eta}$$

$\to \alpha_{\mathbb{P}}(0) = 1 + \epsilon = 1.0808$: Soft Pomeron

- The diffractive process is mediated by the exchange of Pomeron.

Diffraction at HERA



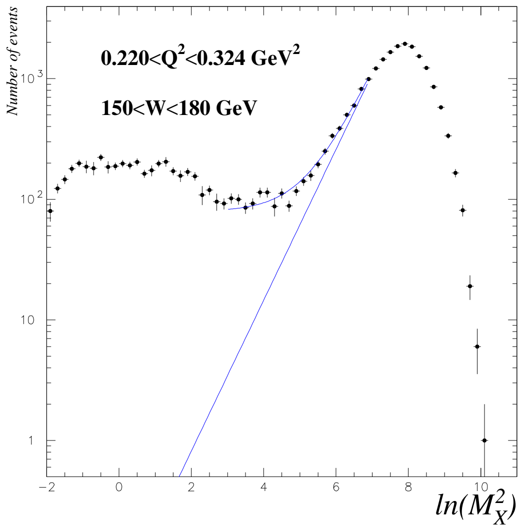


Identification of diffractive events:

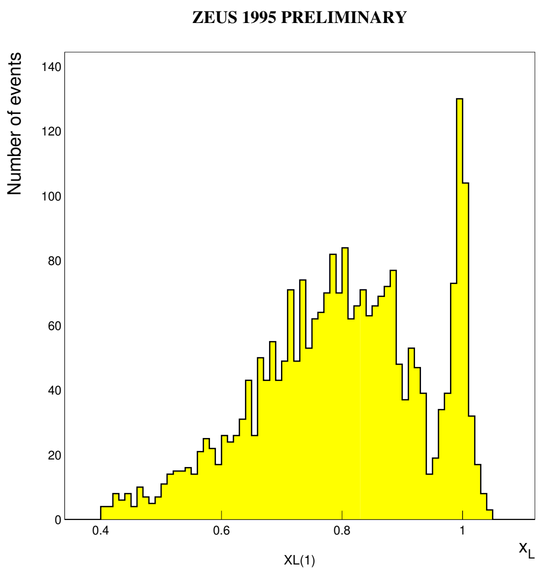
- Large rapidity gap
- ...

Diffraction at HERA

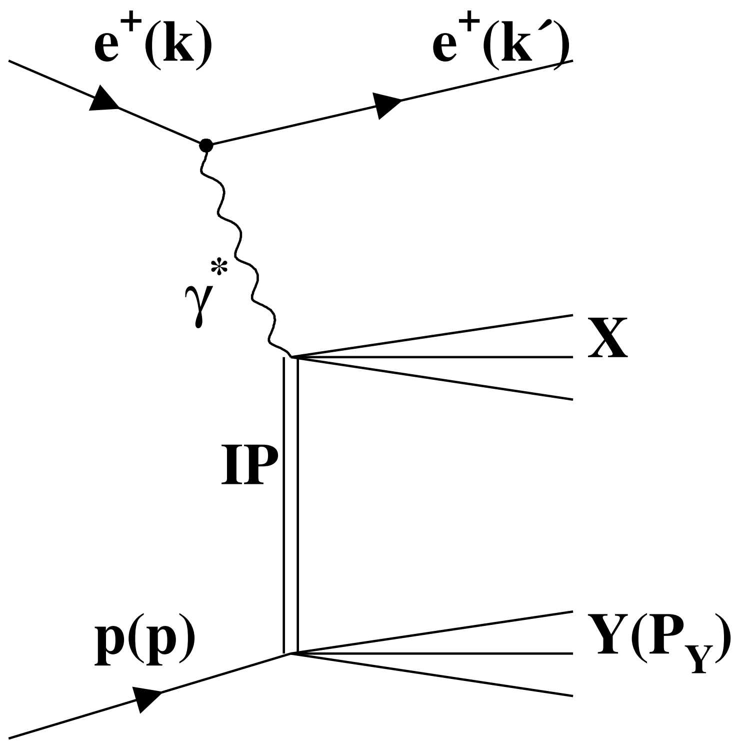
- Invariant mass distribution



- Tagging scattered proton(ZEUS:LPS, H1:FPS)



Kinematic variables



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

$$x \equiv \frac{-q^2}{2q \cdot p} \qquad y \equiv \frac{q \cdot p}{k \cdot p}$$

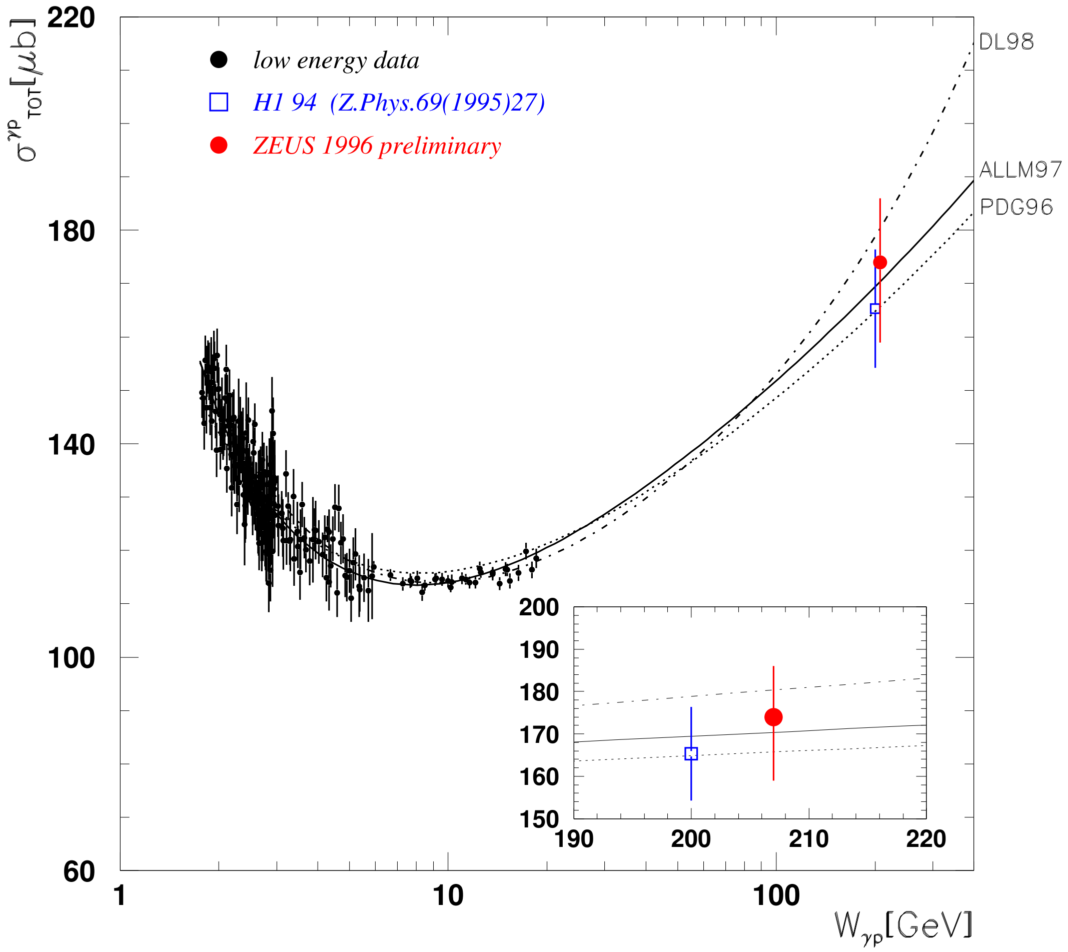
$$W^2 = (q+p)^2$$

$$t = (p - p_Y)^2$$

$$x_{I\!P} = \frac{M_X^2 + Q^2}{W^2 + Q^2} \qquad \beta = \frac{Q^2}{Q^2 + M_X^2}.$$

Regge theory and photoproduction

- The γp total photoproduction cross section at HERA:

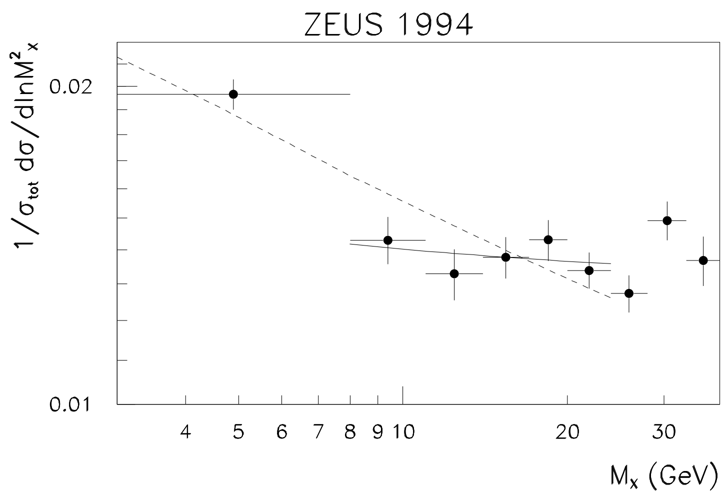


$\rightarrow$ Consistent with the parametrisations motivated by Regge theory

Regge theory and photoproduction

- Inclusive diffraction in photoproduction:

  The $\alpha_{I\!P}(0)$ was obtained from the shapes of M_X distributuions.



ZEUS:

$$\alpha_{I\!P}(0) = 1.12 \pm 0.04(stat) \pm 0.08(syst)$$

H1:

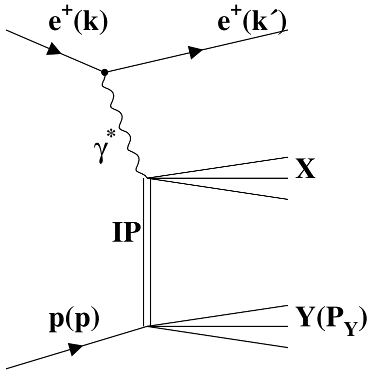
$$\alpha_{I\!P}(0) = 1.068 \pm 0.016(stat)$$
$$\pm 0.022(syst) \pm 0.041(model)$$

Consistent with soft Pomeron, $\alpha_{I\!P}(0) = 1.08$

Resolved Pomeron model and DIS diffraction

- The diffractive cross section in terms of the diffractive structure function:

$$\frac{d^4\sigma_{ep}^{diff}}{dx_{I\!P}\,dt\,dx\,dQ^2} = \frac{2\pi\alpha^2}{xQ^4}[1+(1-y)^2]F_2^{D(4)}(x,Q^2,x_{I\!P},t)$$



- Assumption of factorisation (Ingelman and Schlein):

$$F_2^{D(4)} = f_{I\!P/p}(x_{I\!P},t)\cdot F_2^{D(2)}(\beta,Q^2)$$

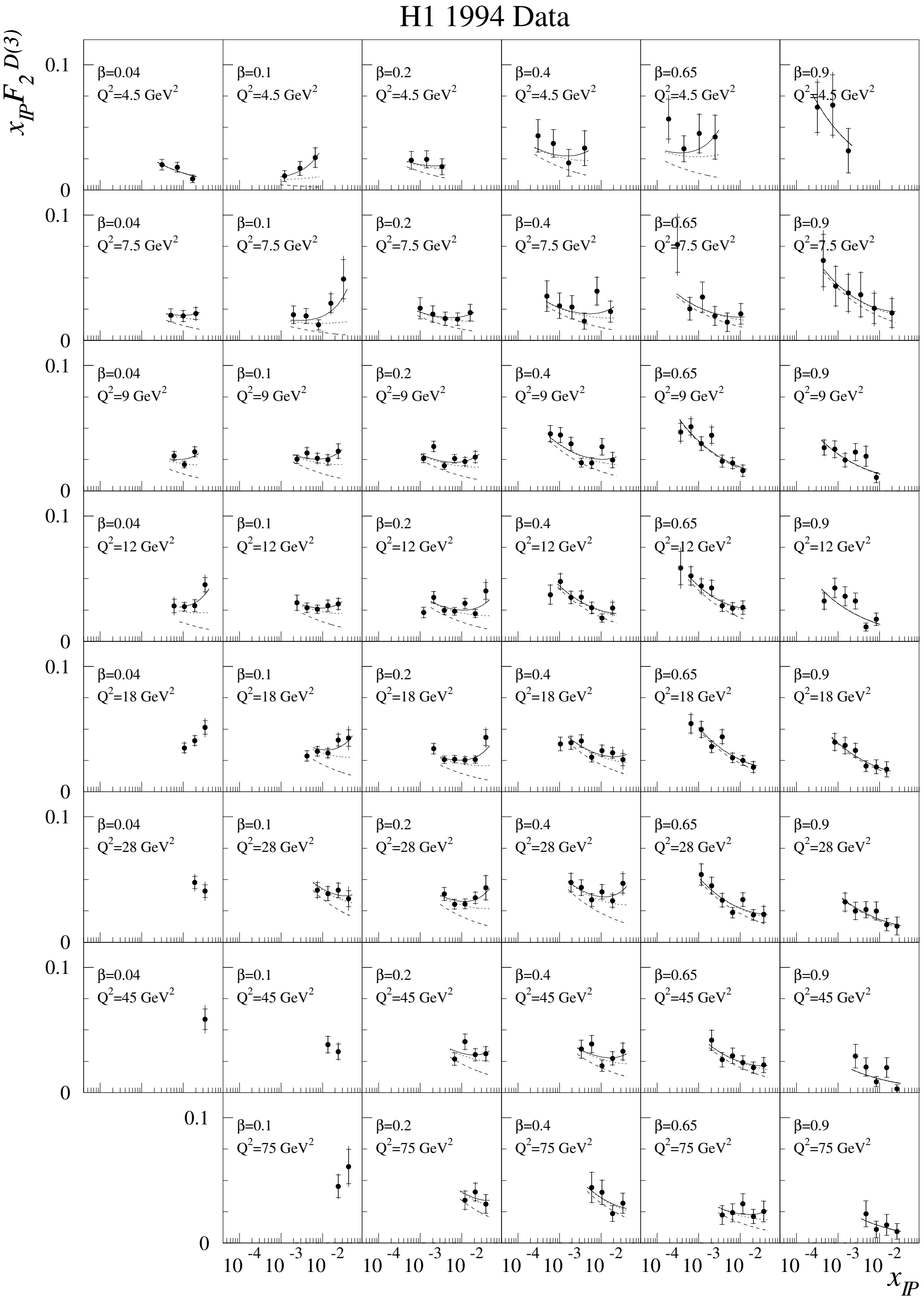
Decomposed into the Pomeron structure function, $F_2^{D(2)}(\beta,Q^2)$, and the Pomeron flux factor:

$$f_{I\!P/p}(x_{I\!P},t) \sim \left(\frac{1}{x_{I\!P}}\right)^{2\alpha_{I\!P}(0)-1} \exp(b_0^D - 2\alpha'_{I\!P}\ln x_{I\!P})t$$

- Extract $\alpha_{I\!P}(0)$ from the measurement of DIS inclusive diffraction $\rightarrow$

Inclusive diffraction in DIS (H1)

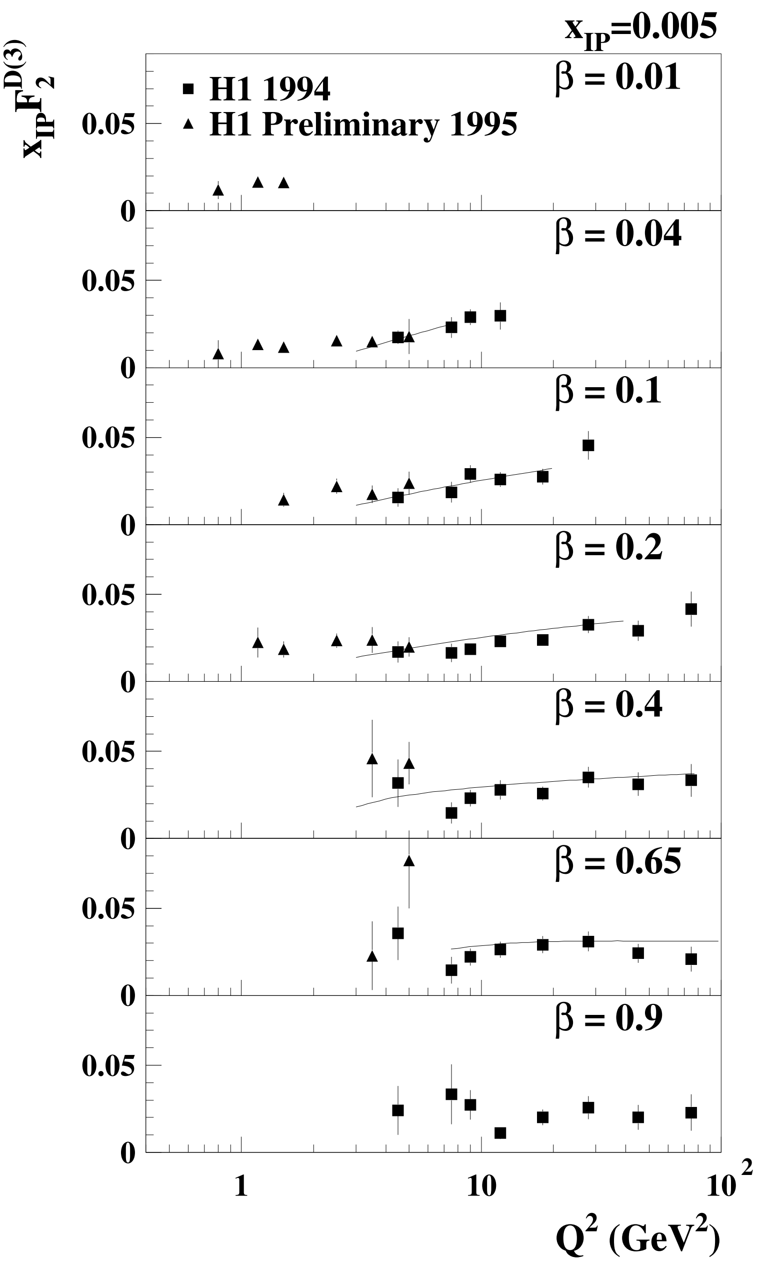
H1 data fitted by taking into account a sub-leading Reggeon trajectory as well as a Pomeron trajectory.



$$\alpha_{I\!P}(0) = 1.203 \pm 0.020(stat) \pm 0.013(syst)^{+0.030}_{-0.035}$$

It is higher than soft Pomeron, $\alpha_{I\!P}(0) = 1.08$.

Scaling violation

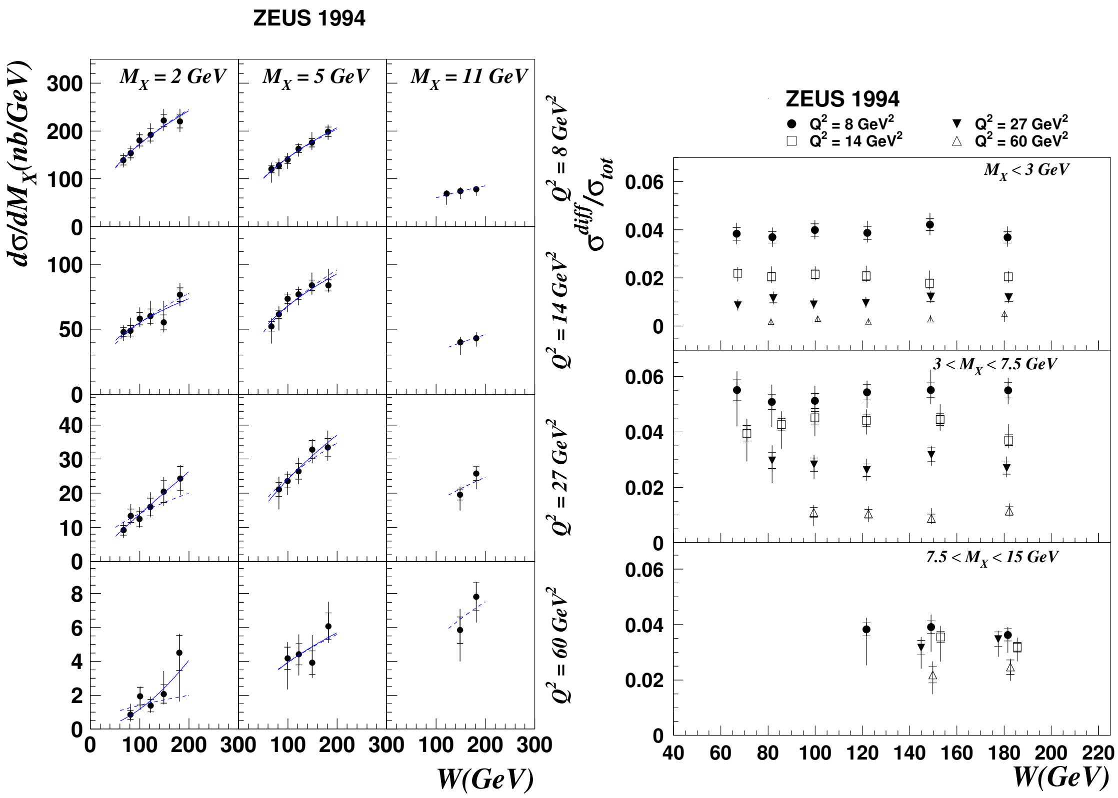


- Scaling violations are observed in Q^2 dependence of $x_{I\!P}F_2^{D(3)}$.

  $\rightarrow$ Large gluon component.

Inclusive diffraction in DIS (ZEUS)

- The $\alpha_{I\!P}$ from ZEUS DIS inclusive diffractive cross section:



$$\alpha_{I\!P}(0) = 1.16 \pm 0.01(stat)^{+0.04}_{-0.01}(syst)$$

Higher than soft Pomeron, $\alpha_{I\!P}(0) = 1.08$.

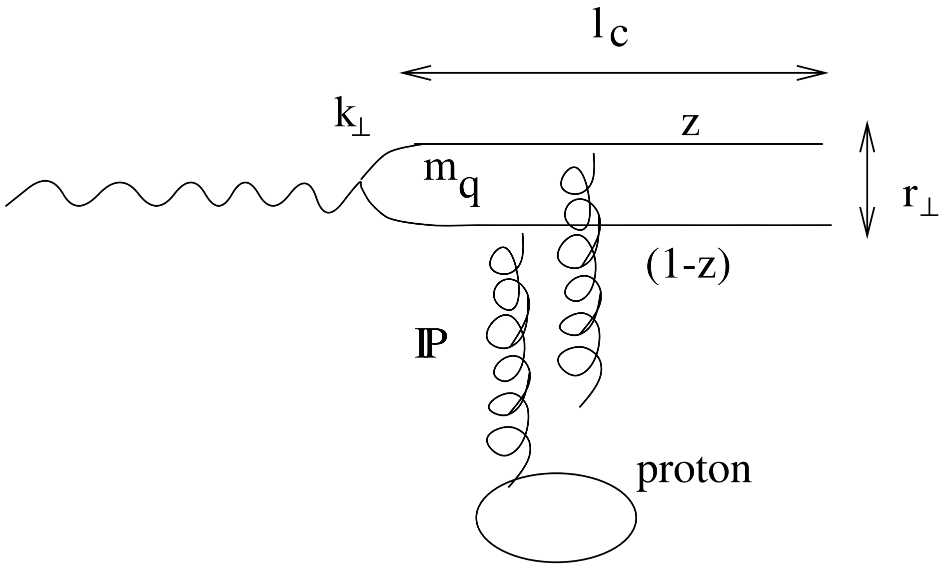
- The ratio of diffractive to total cross section shows flat W dependence.

  (Inconsistent with the expectation from Regge phenomenology.)

  $\rightarrow$ pQCD to describe DIS diffraction!

Models of DIS diffraction

- 2-gluon exchange:

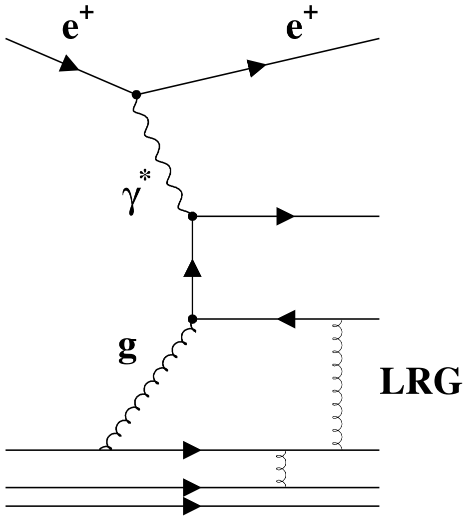


- Saturation model (K.Golec-Biernat and Wüsthoff):
  - γ^* fluctuates into $q\bar{q}$ and $q\bar{q}g$ colour dipole states
  - dipole cross section as a function of the transverse size of the dipole

Models of DIS diffraction

- Soft colour interaction

  (Edin, Ingelman, Rathsman):



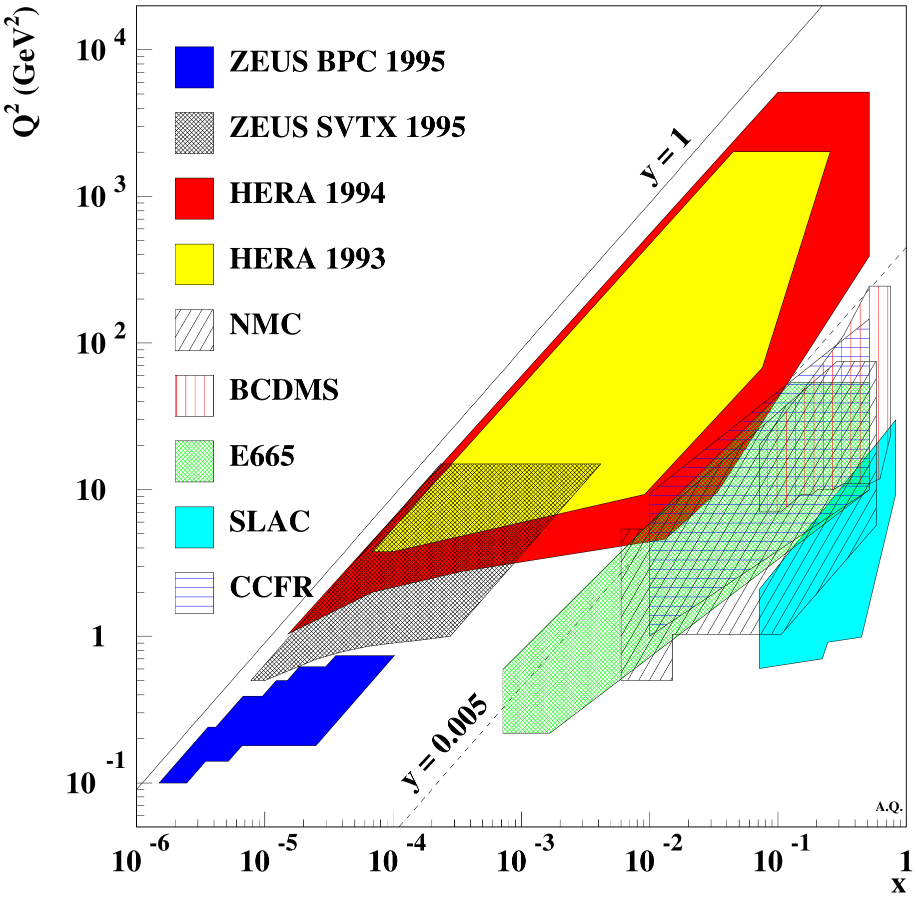
- Semiclassical model

  (Buchmüller, Gehrmann, Hebecker):

  - γ^* fluctuates into $q\bar{q}$ and $q\bar{q}g$
  - interacts with soft colour field of proton

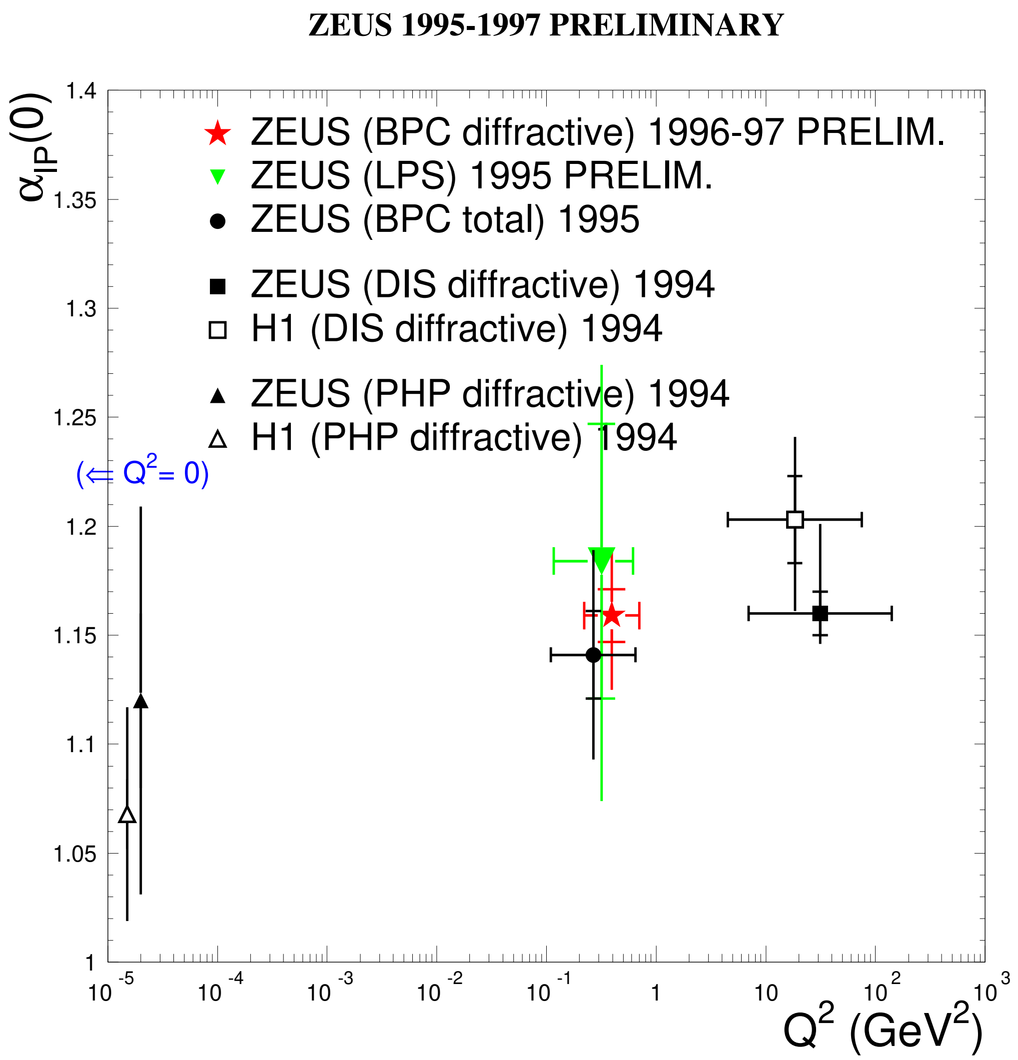
Inclusive diffraction at low Q^2

- The photoproduction ($Q^2 \sim 0$) is described by Regge phenomenology. The pQCD is applied in high Q^2 region ($Q^2 \gg 1\mathrm{GeV}^2$).
- The intermediate Q^2 region has been explored using ZEUS Beam Pipe Calorimeter (BPC).



- Inclusive diffractive cross sections are obtained from $\ln M_X^2$ method and LPS method.

Inclusive diffraction at low Q^2

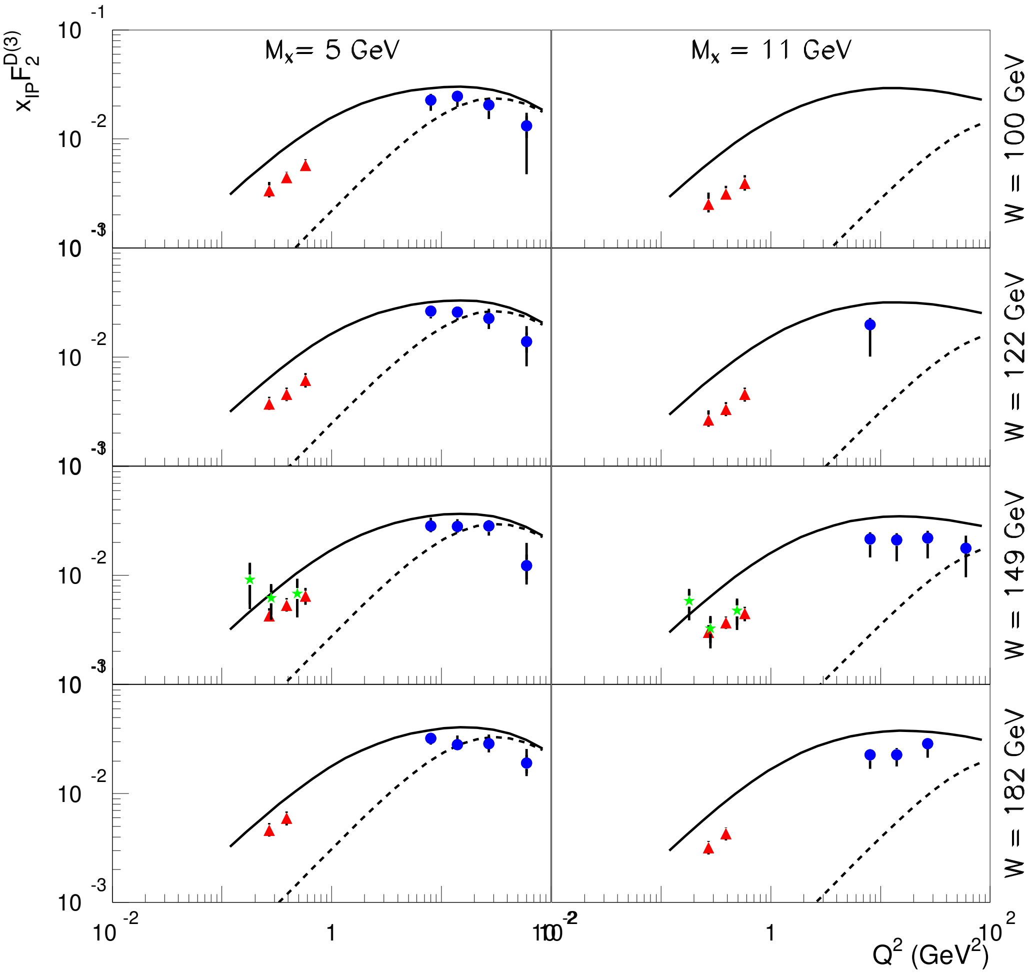


- The $\alpha_{I\!P}(0)$ was obtained from W dependence of inclusive diffractive cross sections.

Inclusive diffraction at low Q^2

- Q^2 dependence of $F_2^{D(3)}$:

ZEUS 1995-1997 PRELIMINARY



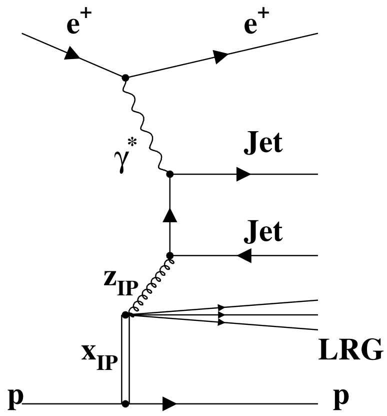
The first comparison with theoretical model:

Curves by K. Golec-Biernat (private communication)

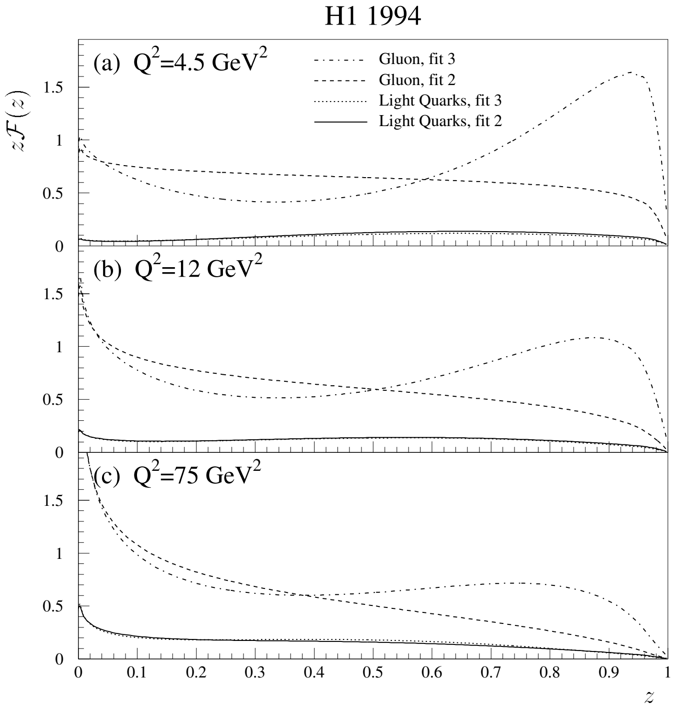
→ Important contribution of $q\bar{q}g$ at low Q^2?

Diffractive di-jet production

- The partonic structure of Pomeron can be explored by studying diffractive di-jet events:



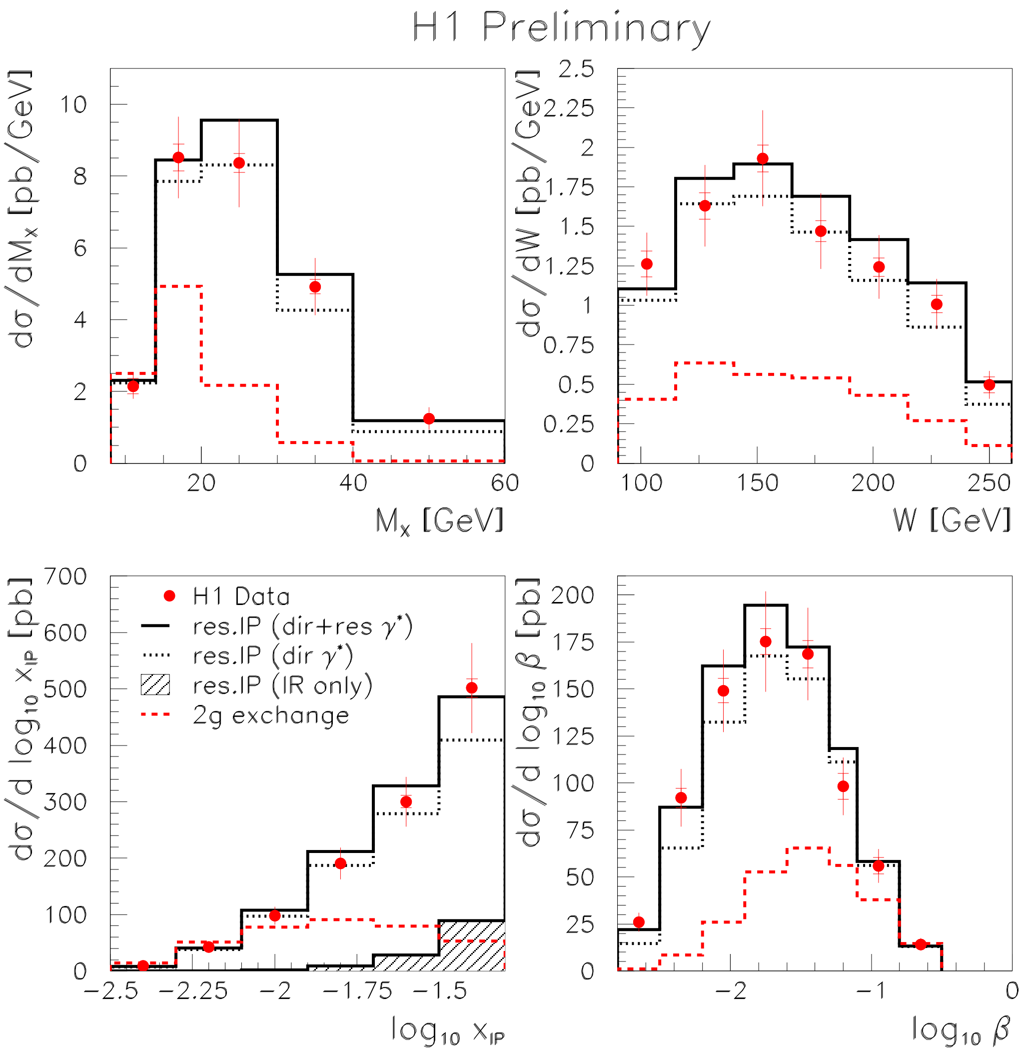
- PDF obtained from H1 QCD fits to $F_2^{D(3)}$:



$\rightarrow$ Applying to di-jet analyses

Diffractive di-jet production

- Comparison with Resolved Pomeron and 2-gluon exchange:

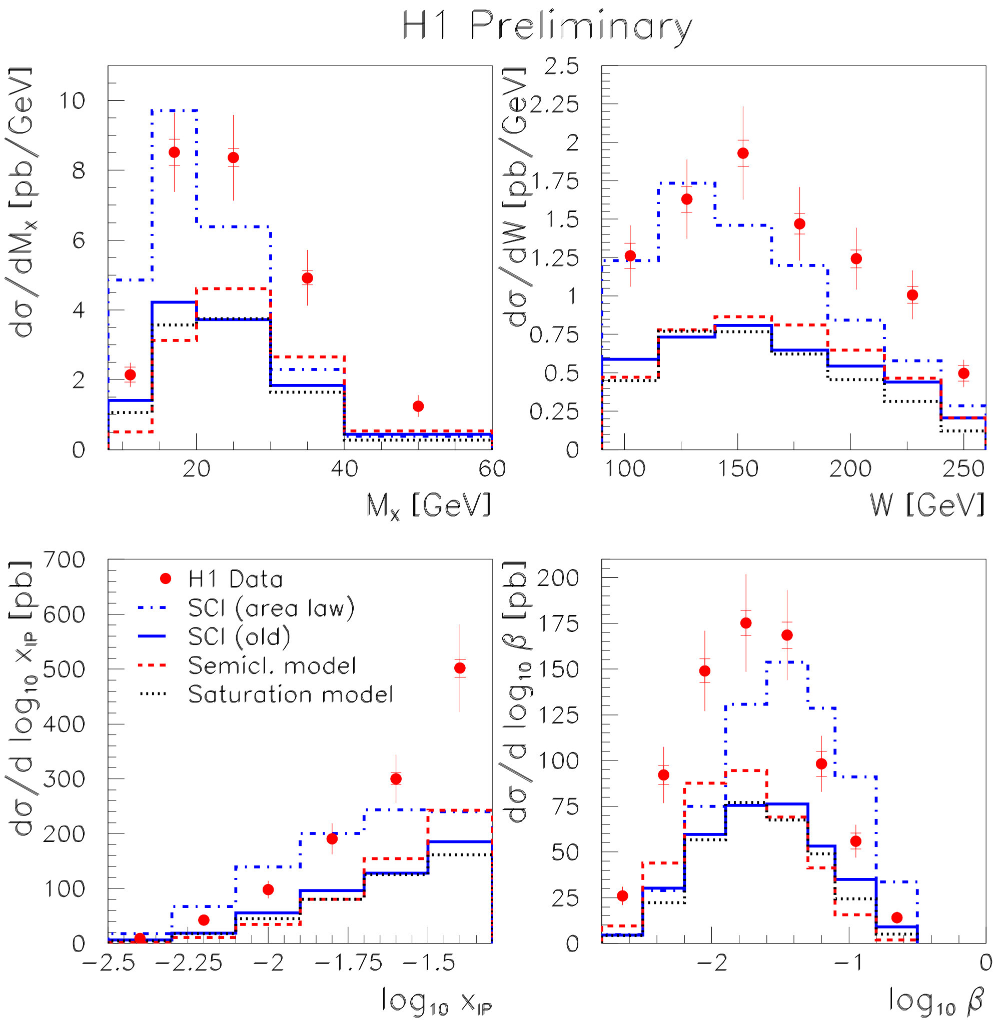


- The data are described well by H1 QCD fits to $F_2^{D(3)}$, though the used β range is different.

- The rate from 2-gluon exchange model is too low, but the data is well described in low $x_{I\!P}$ region.

Diffractive di-jet production

- Comparison with soft colour interaction and semi-classical model:



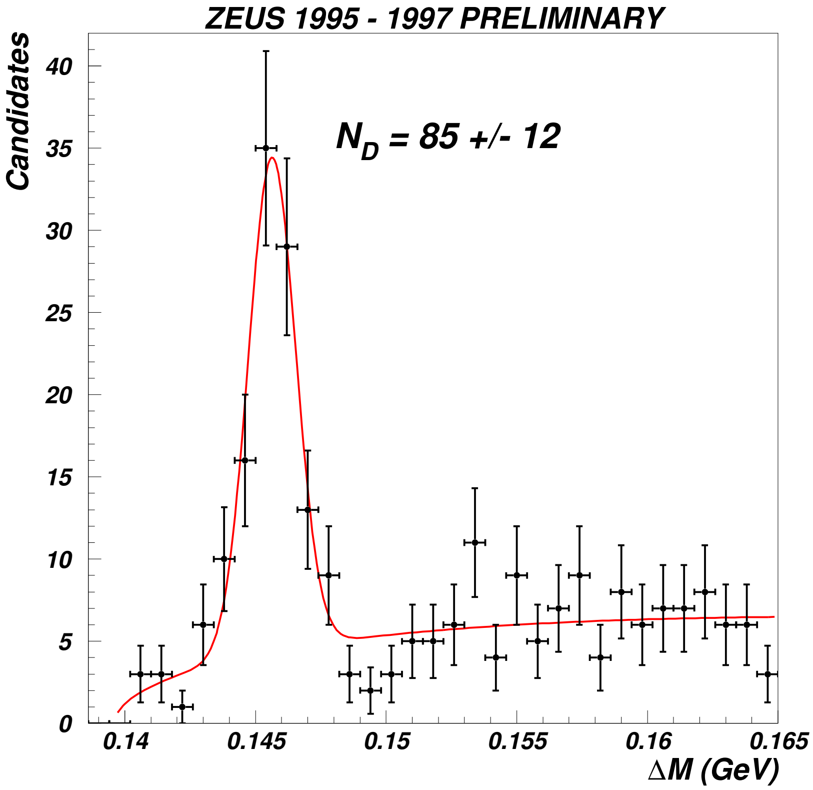
- The rates from the old version of SCI and the semi-classical model are too low.

- The new version of SCI does not reproduce the shapes.

- Saturation model reproduces the shapes, but the rate is about half of data.

Diffractive $D^{*\pm}(2010)$ production in DIS

- Measurement of open charm in diffraction
  - Charm is sensitive to role of gluons in diffractive exchange
  - Test of underlying dynamics of diffraction



ZEUS:

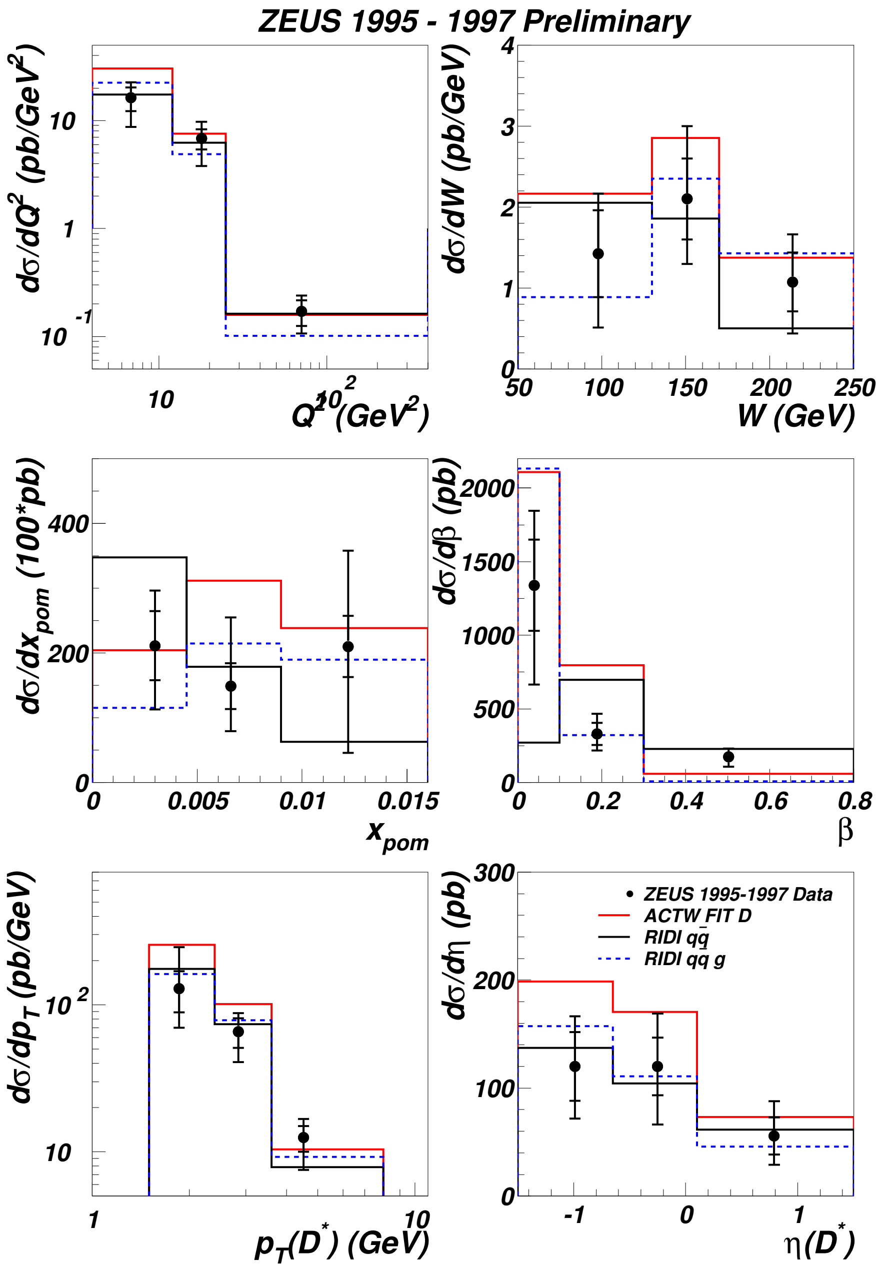
$$\sigma(ep \to eD^{*\pm}Xp) = 281 \pm 41(stat)^{+79}_{-73}(syst)pb$$

H1:

$$\sigma(ep \to eD^{*\pm}Xp) = 154 \pm 40(stat) \pm 35(syst)pb$$

Diffractive $D^{*\pm}(2010)$ production in DIS

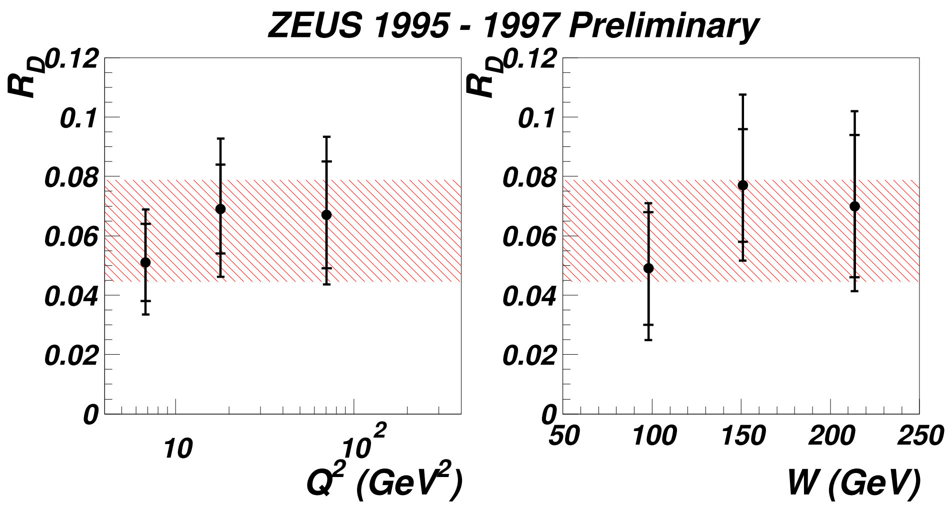
- Differential cross sections:



- Reasonable description except β distribution

Diffractive $D^{*\pm}(2010)$ production in DIS

- Ratio of diffractive $D^{*\pm}$ production to all $D^{*\pm}$ production:

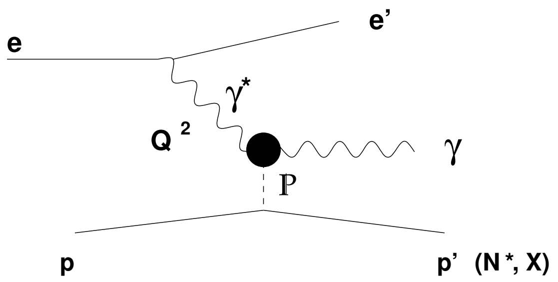


- $R_D = 6.1 \pm 0.9(stat)^{+1.6}_{-1.4}(syst)\%$
- Independent of Q^2 and W $\rightarrow$

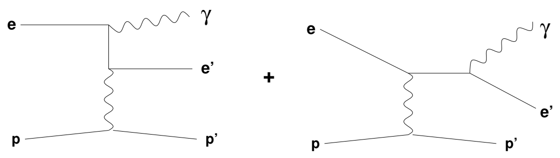
  Charm production is not suppressed in diffractive DIS.

DVCS

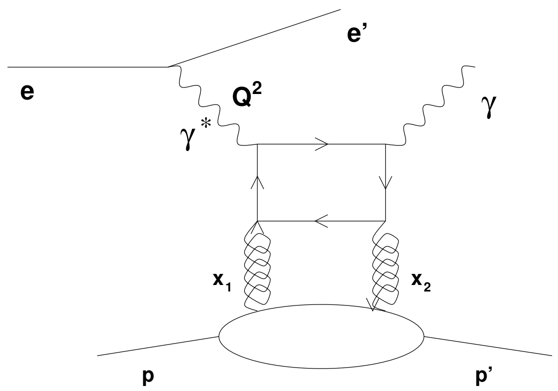
Deeply Virtual Compton Scattering (DVCS):



The final state is identical with QED Compton process:



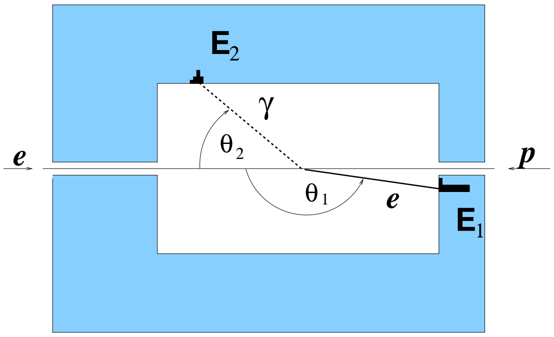
QCD interpretation of DVCS
(L.Frankfurt, A.Freund and M.Strikman (FFS)):

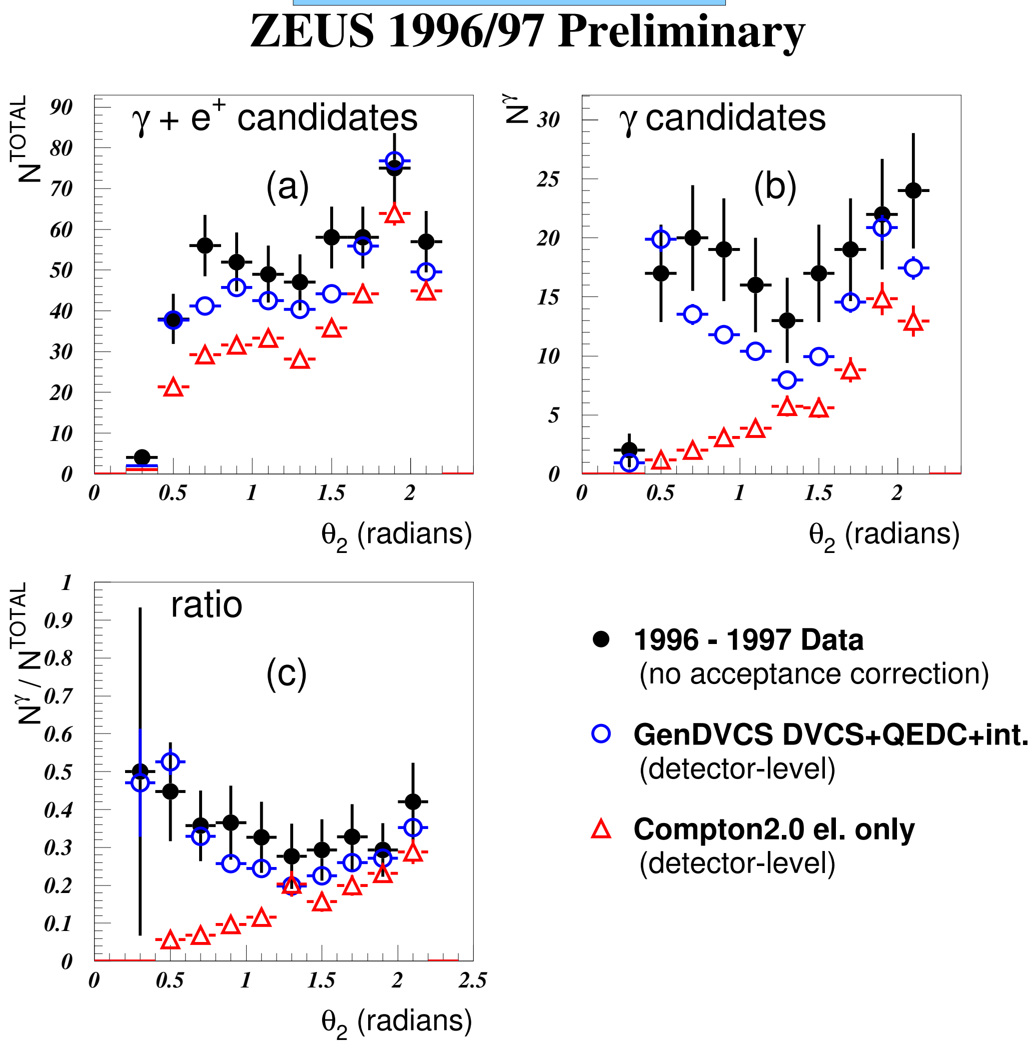


$\rightarrow$ Indirect measurement of skewed parton distributions.

DVCS

- 2 EM clusters in ZEUS detector:

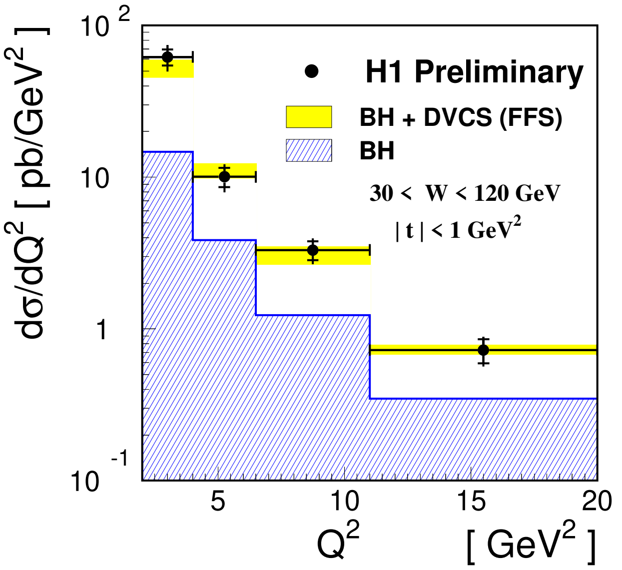


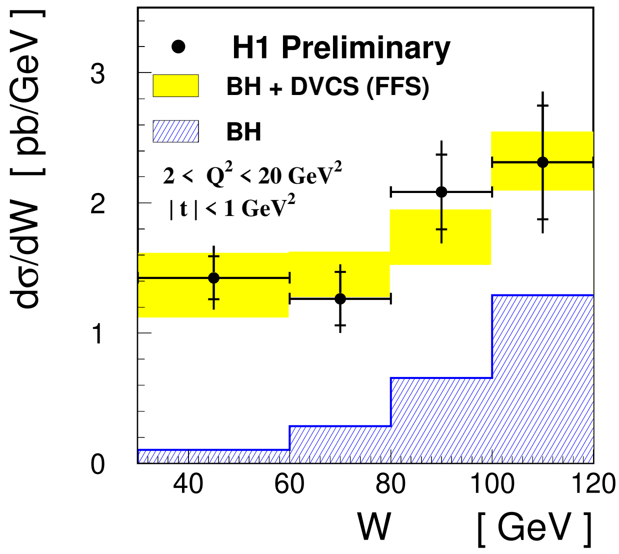


→ First observation of DVCS at HERA!

DVCS

- H1 cross section measurements of DVCS:





→ Agreement with the prediction of FFS model.

Summary

- HERA is a good facility to study diffraction.
- The diffraction and the γp total cross section in photoproduction ($Q^2 \sim 0$) are well described by Regge phenomenology.
- To understand the underlying mechanism and dynamics of diffraction ($Q^2 \gg 1\text{GeV}^2$), the theoretical models based on pQCD are necessary.
- Recent results of diffractive physics at HERA:
  - Measurement of $x_{I\!P} F_2^{D(3)}$ at low Q^2 and the comparison with Saturation model.
  - Diffractive di-jet cross sections are well described by Resolved Pomeron model.
  - 2-gluon exchange model reproduces the diffractive $D^{*\pm}$ production reasonably.
  - DVCS is described by pQCD calculation with the skewed parton distributions in proton.
- The analyses with HERA data are going on ...