# Inclusive Diffraction at HERA

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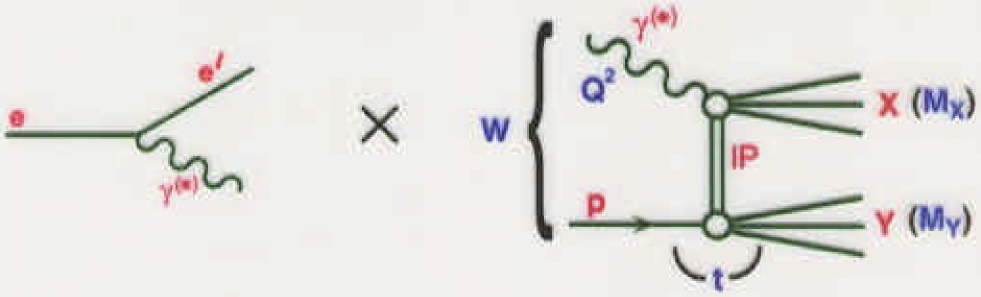
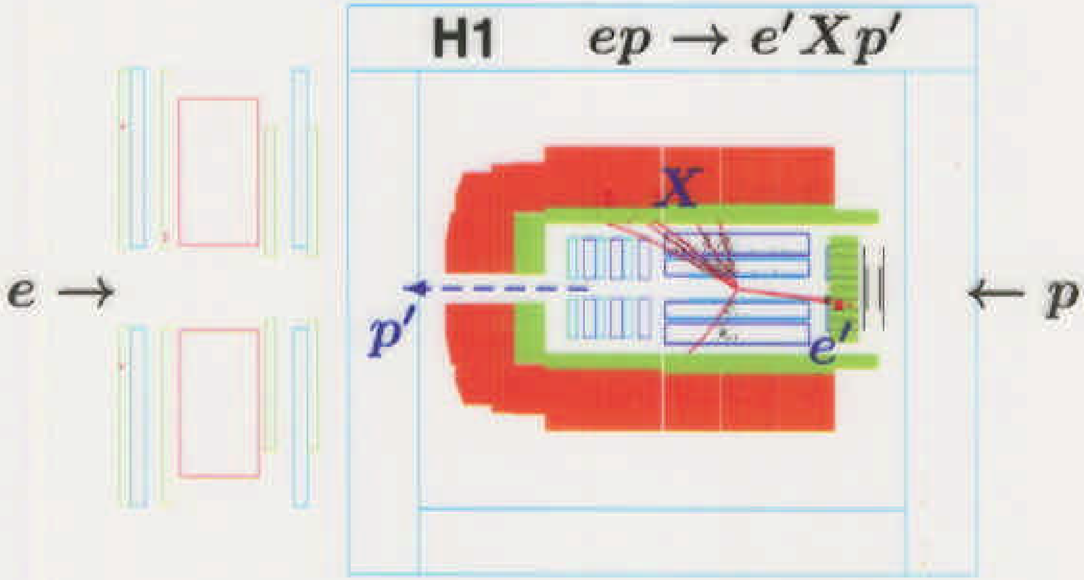
representing the H1 and ZEUS Collaborations.

- Diffraction at HERA.
- The Diffractive Structure Function $F_2^{D(3)}$ at Low $Q^2$.
- Rapidity Gaps Between High $p_T$ Jets in Photoproduction.

# Diffraction at HERA

At HERA, diffractive $\gamma^{(*)}p$ interactions can be studied ...



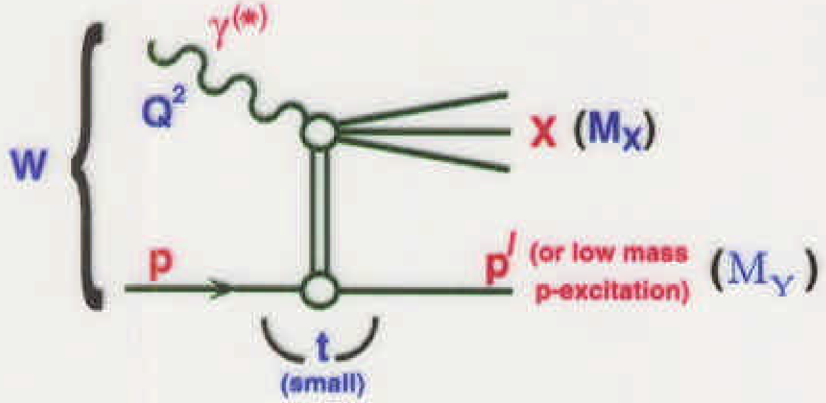




All five kinematic variables can be measured:

- $Q^2 \sim 0$, $|t| \sim 0$. → similar to soft hadronic diffraction.
- Large $Q^2$. → pQCD at $\gamma^* \mathbb{P}$ vertex. $\gamma^*$ 'probes' $\mathbb{P}$?
- Large $|t|$. → $\mathbb{P}$ itself calculable in pQCD?

... All regions interesting - transitions particularly revealing?

# Diffraction of Virtual Photons, $\gamma^\star p \rightarrow Xp$



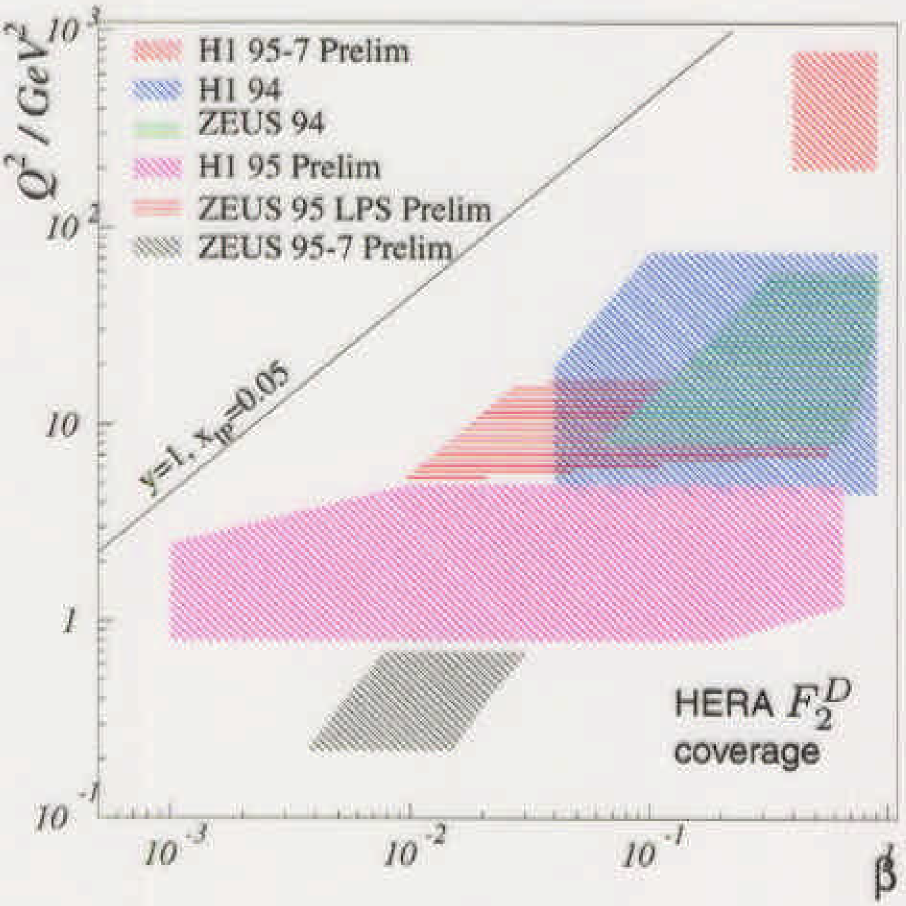

$$x_{I\!P} = \frac{q.(p-p')}{q.p} = x_{I\!P/p}$$

$$\beta = \frac{Q^2}{q.(p-p')} = x_{q/I\!P}$$

$$(x = x_{I\!P}\beta)$$

Data presented as a Diffractive Structure Function ...

$$F_2^{D(3)}(\beta, Q^2, x_{I\!P})$$




New ZEUS BPC data ($0.2 < Q^2 < 0.7$ GeV$^2$) start to fill transition to photoproduction.

Method 1: Decompose observed $M_X$ distribution.

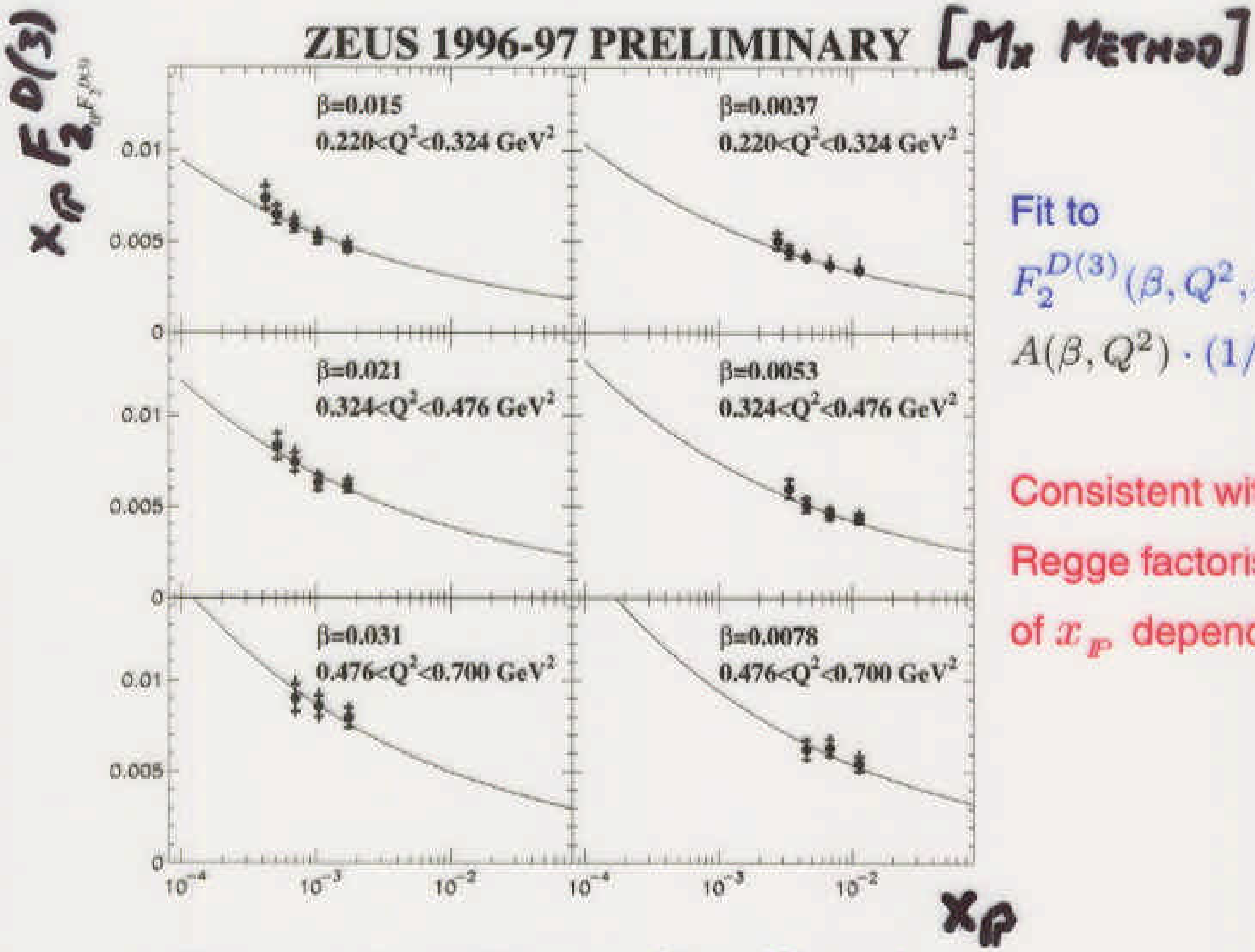
Method 2: Measure leading proton in LPS.

# $x_{I\!P}$ Dependence of $F_2^{D(3)}$ at low $Q^2$

Diff. structure function $F_2^{D(3)}(\beta, Q^2, x_{I\!P})$ for $M_Y \lesssim 6\,\text{GeV}$

By comparing $M_X$ decomposition and LPS methods …

P-dissociation contribution $= 29 \pm 15\,(\text{stat.})\,\%$




Fit to $F_2^{D(3)}(\beta, Q^2, x_{I\!P}) = A(\beta, Q^2) \cdot (1/x_{I\!P})^a$

Consistent with Regge factorisation of $x_{I\!P}$ dependence

In Regge pole models, $a = \langle 2\alpha_{I\!P}(t) - 1 \rangle \ldots$

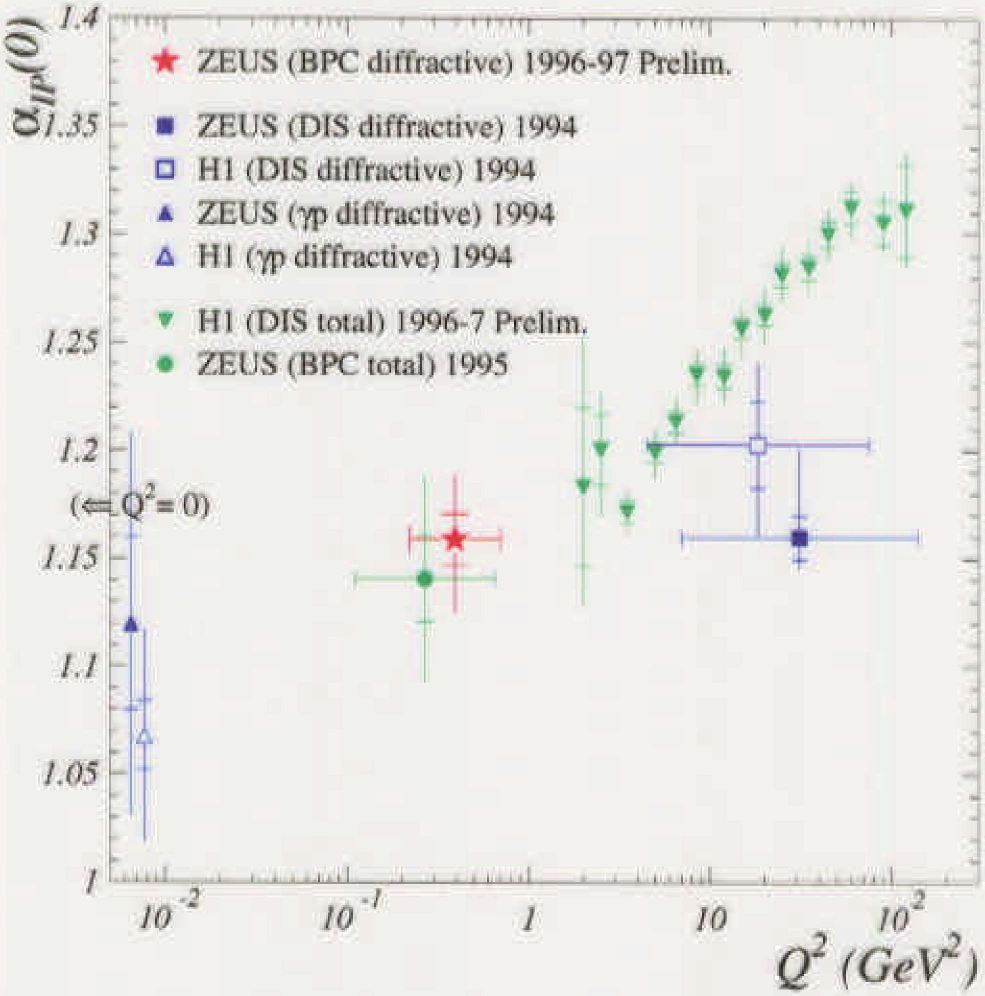
$$\langle \alpha_{I\!P}(t) \rangle = 1.126 \pm 0.012\,(\text{stat.})\,^{+0.027}_{-0.032}\,(\text{syst.})$$

# Variation of Energy Dependence with $Q^2$

Expressed through Regge parameterisations ...

$x_{I\!P} F_2^D \sim A(\beta, Q^2)\ x^{2-2\langle\alpha_{I\!P}(t)\rangle}$ $\qquad F_2 \sim B(Q^2)\ x^{1-\alpha_{I\!P}(0)}$

Effective pomeron intercept $\alpha_{I\!P}(0)$, corrected for finite $t$ ...



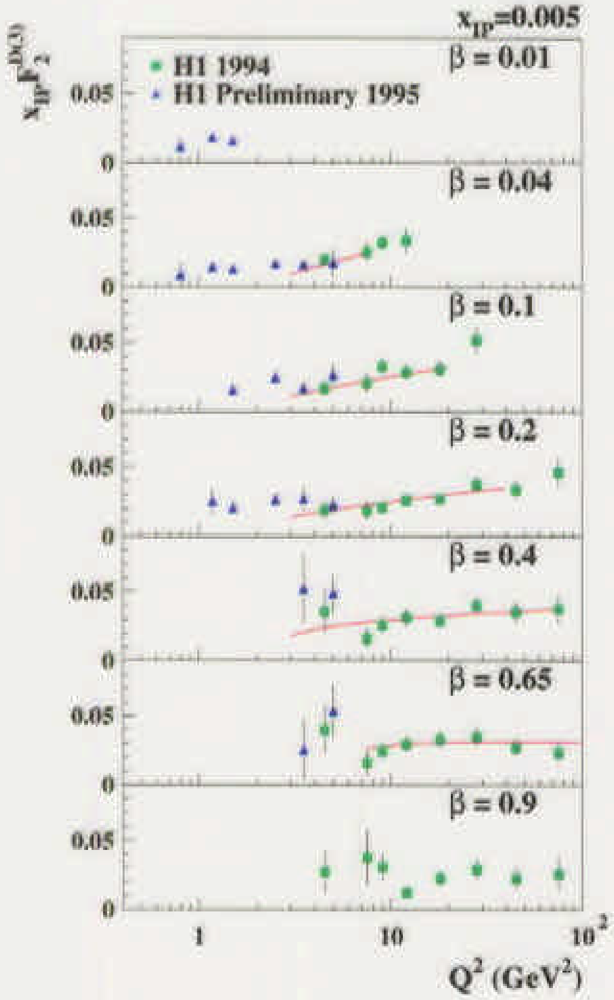

Also From LPS, $\alpha_{I\!P}(0) = 1.18 \pm 0.06\ (\text{stat.})\ ^{+0.06}_{-0.09}\ (\text{syst.})$

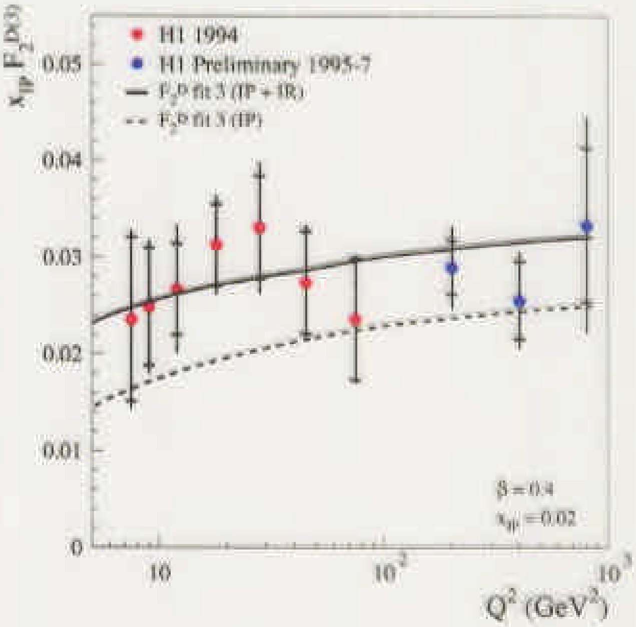
At low $Q^2$, diffractive and inclusive $\alpha_{I\!P}(0)$ compatible.

At higher $Q^2$, diffractive and inclusive $\alpha_{I\!P}(0)$ incompatible.

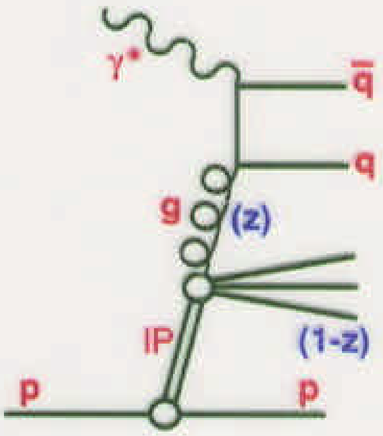
(Energy dependences of diff & incl become more similar at high $Q^2$.)

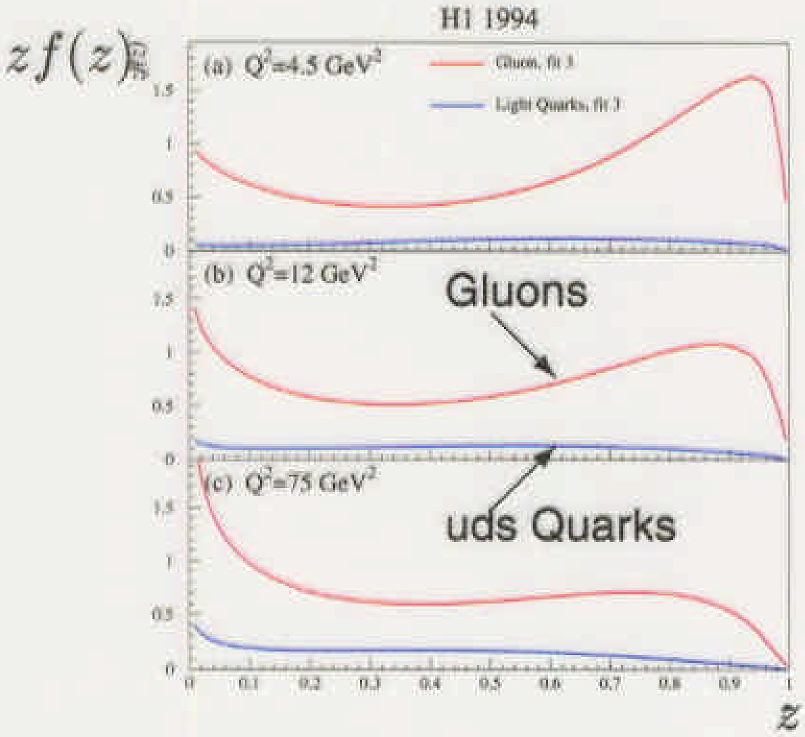
# $\beta/Q^2$ dependence of $F_2^{D(3)}$



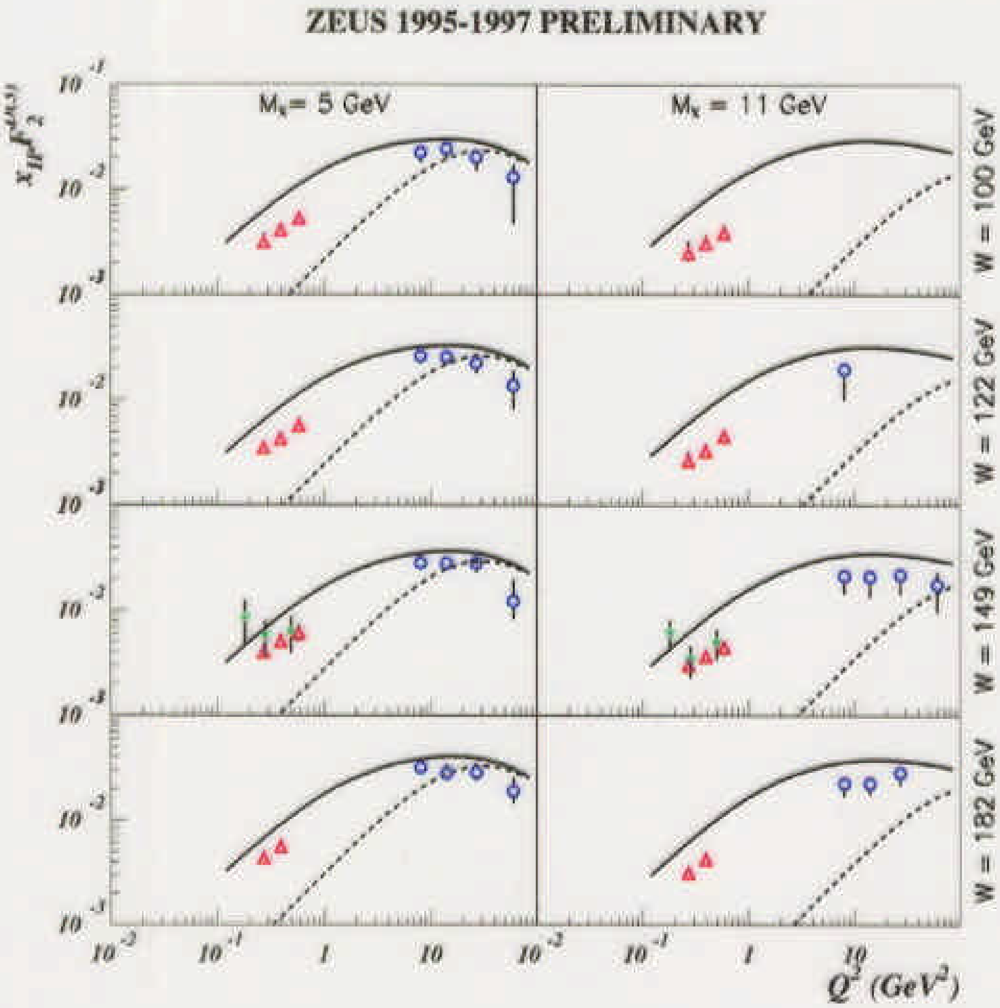

Rising scaling violations over large range of $Q^2$ up to large fractional momenta ($\beta$)




DGLAP analysis yields IP parton distributions dominated by "hard" gluons.

# $Q^2$ Dependence of $F_2^D$




$\triangle$ $M_X$ Prelim

$\star$ LPS Prelim

$\bigcirc$ 94

—— Sat'n ($q\bar{q} + q\bar{q}g$)

- - - Sat'n ($q\bar{q}$)

(94 and $M_X$ data scaled to remove p-diss)

Clear transition at low $Q^2$. Similar to that in total $F_2$.

**'Saturation' Model** (Golec-Biernat & Wüsthoff)

Describes $Q^2 \to 0$ transition in $F_2$ and $Q^2$ dependence of diff, incl $\alpha_{\mathbb{P}}(0)$.

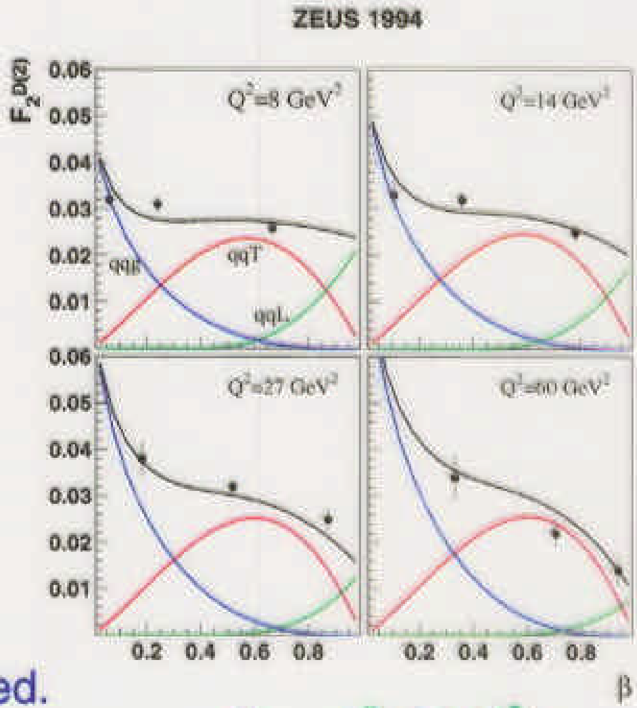
No new free parameters for diffraction!

Good agreement with high $Q^2$ diff data.

Diff'n of $\gamma^* \to q\bar{q}g$ dominates at low $\beta$.

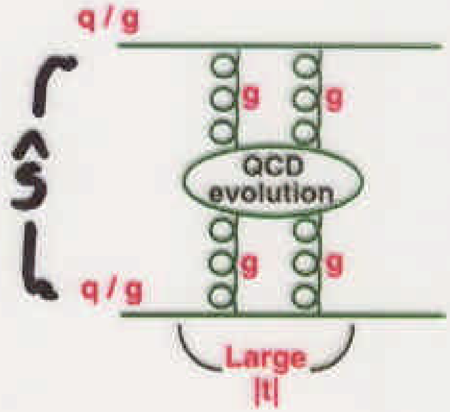
Applicability of present $q\bar{q}g$ model questionable at low $Q^2$.

Qualitative features of transition described.




$x_{\mathbb{P}} = 0.0042$

# Rapidity Gaps between Jets at $Q^2 = 0$




Parton level

Elastic parton-parton scattering in Regge limit ($\hat{s} \gg \hat{t}$), yet pQCD calculable ($\hat{t}$ large)? ... BFKL?

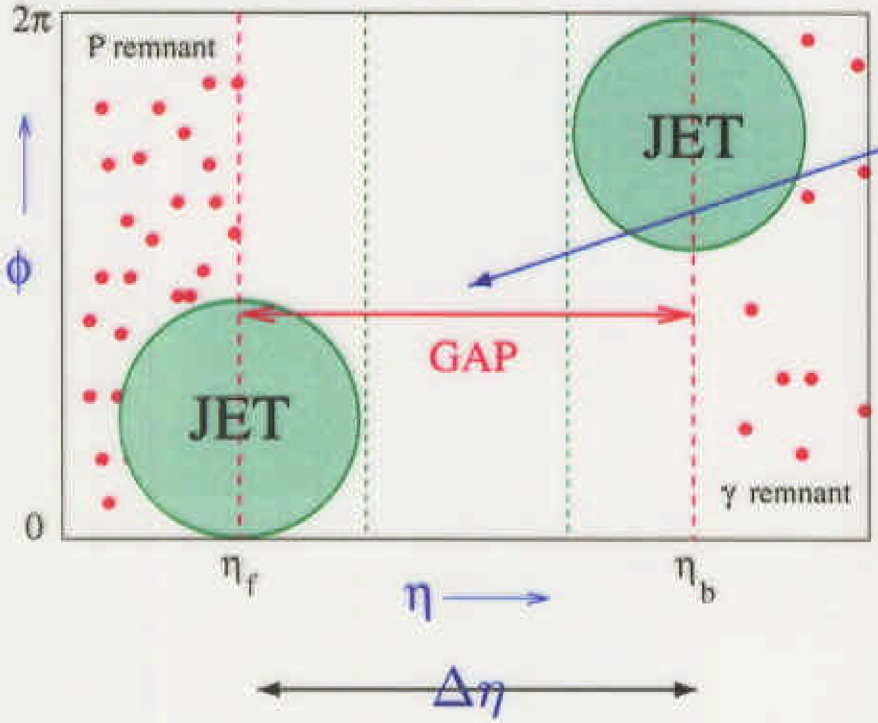
Hadron level Classic experimental signature is rapidity gap between high $p_T$ jets. $|\hat{t}| \sim p_{t,jet}^2$

Complication: Remnant-remnant interactions produce hadronic activity between jets?

New Measurement Method:

Require two central jets (inclusive $k_t$ clustering algorithm):

$E_t^1 > 6\,\mathrm{GeV}$ $\quad E_t^2 > 5\,\mathrm{GeV}$ $\quad \Delta\eta > 2.5$ [redacted]



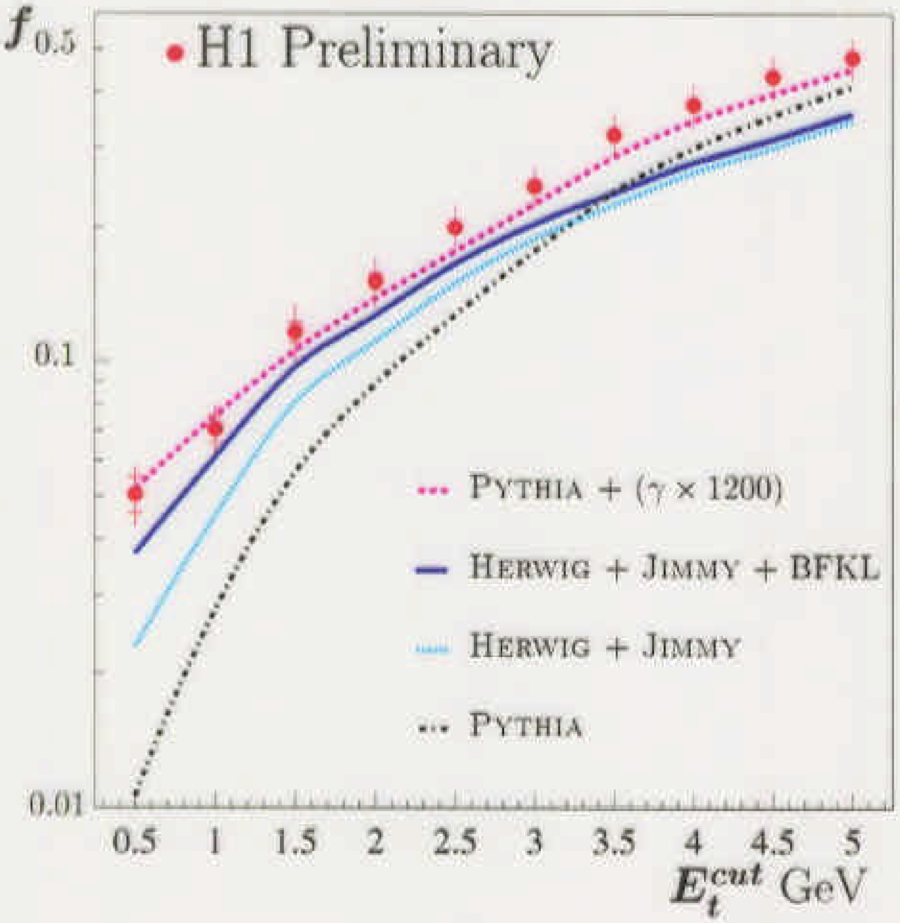

$\not{E}_t^{jets} = \sum E_t$ for $\eta_f > \eta > \eta_b$. outside two leading jets

Rapidity gap event if $\not{E}_t^{jets} < E_t^{cut}$

Vary $E_t^{cut}$ to study effect of spectator interactions.

# Dependence of Gap Fraction on $E_t^{cut}$

$f$ = Fraction of events with $\not{E}_t^{jets} < E_t^{cut}$ $(\Delta\eta > 2.5)$




pQCD treatment of spectator interactions possible at large $E_t^{cut}$?

Models with standard $\gamma p$ matrix elements and multiple interactions (HERWIG + JIMMY, PYTHIA) underestimate $f$

Models with high $|t|$ colour singlet exchange more successful

HERWIG + JIMMY + BFKL: LO BFKL calculation of $qq \to qq$

($q, g$ couplings. - $\alpha_s = 0.17$).

PYTHIA + $(\gamma \times 1200)$: $qq \to qq$ through $\gamma$ exchange.

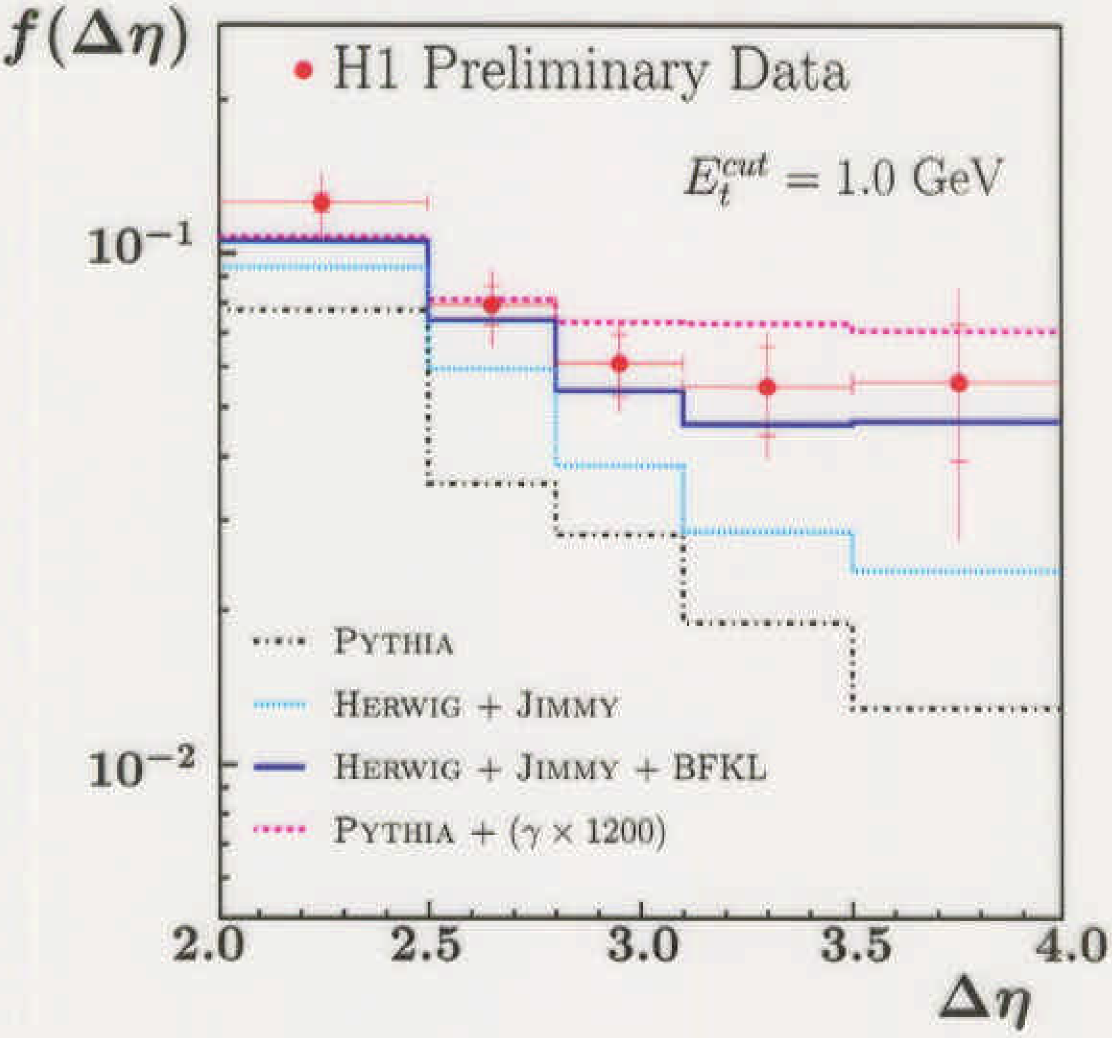
($q$ coupling only - tuned to data).

Tuning of multiple interactions still required!

## Dependence of Gap Fraction on $\Delta\eta$

Dependence on jet separation $\Delta\eta$ particularly sensitive to dynamics.

Measured for various $E_t^{cut}$, $1\ \mathrm{GeV}$ chosen here.




Clear signal above standard $\gamma p$ models, increases with $\Delta\eta$

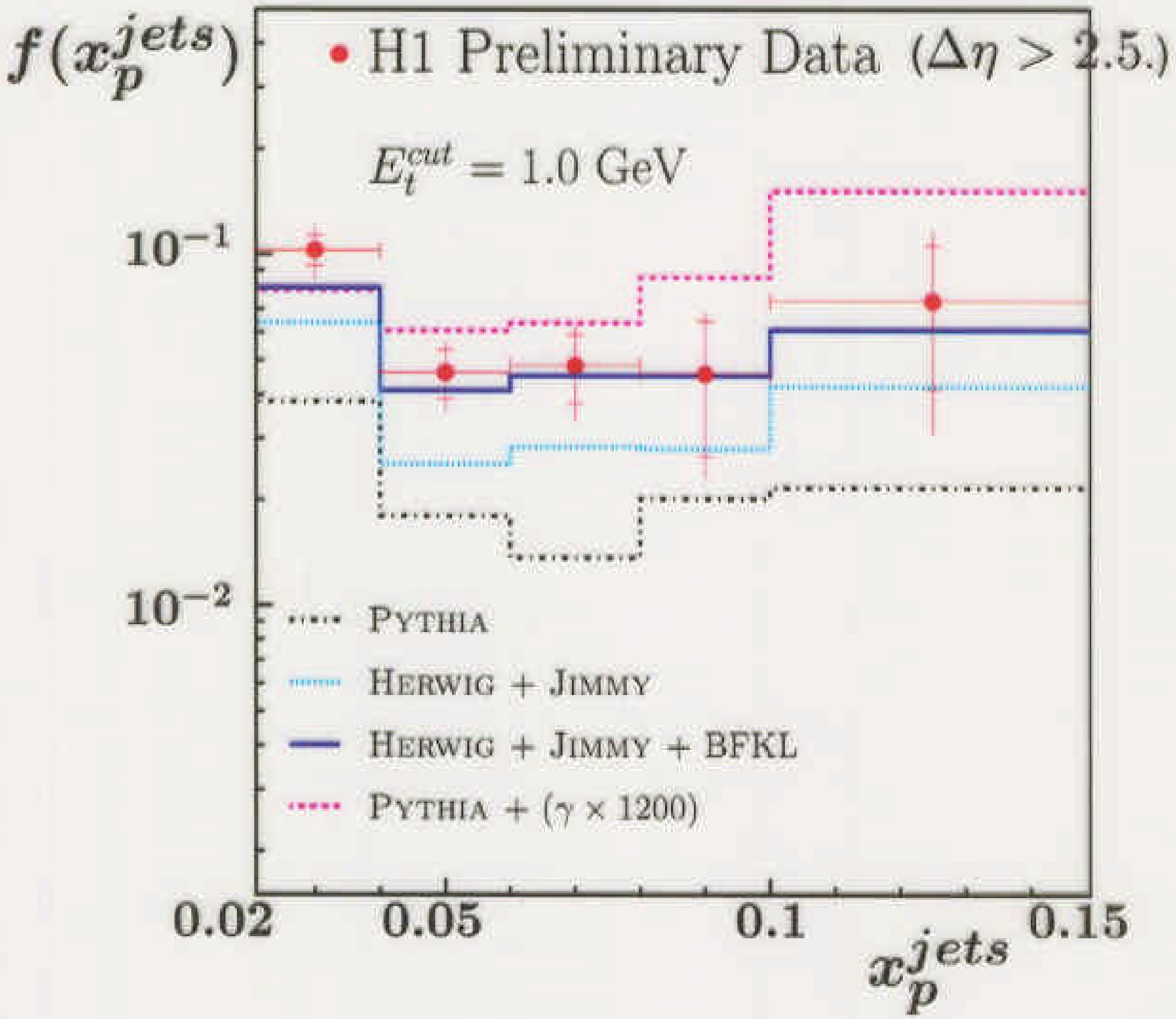
Gap fraction at large $\Delta\eta$ significantly larger than Tevatron $p\bar{p}$.

Both models simulating colour singlet exchange describe data.

# Dependence of Gap Fraction on $x_p^{jets}$

$q, g$ composition of proton changes with $x$

$x_p^{jets}$ dependence of $f$ sensitive to $q, g$ couplings of exchange.




Clear signal above standard $\gamma p$ models at all $x_p^{jets}$.

PYHTIA + $\gamma$ differs in shape from HERWIG + BFKL.

Data favour some $g$ coupling to exchange? - Improved statistics needed!

# Summary

- New data in two previously unexplored regions ...

- $F_2^D$ data for $0.2 < Q^2 < 0.7\,\mathrm{GeV}^2$:
  - Effective $\mathbb{P}$ intercept significantly larger than soft $\mathbb{P}$ @ high $Q^2$.
  - Energy dependence of $\sigma^{\mathrm{diff}}/\sigma^{\mathrm{incl}}$ consistent with simple Regge prediction. @ low $Q^2$.
  - Transition $Q^2 \to 0$ qualitatively similar to inclusive $F_2$

- Rapidity Gaps between Jets in Photoproduction:
  - Clear signal for colour singlet exchange at high $|t|$.
  - Good treatment of spectator interactions is crucial.
  - Sensitivity to $q, g$ couplings of colour singlet exchange.