Rapidity Gaps between Jets at HERA

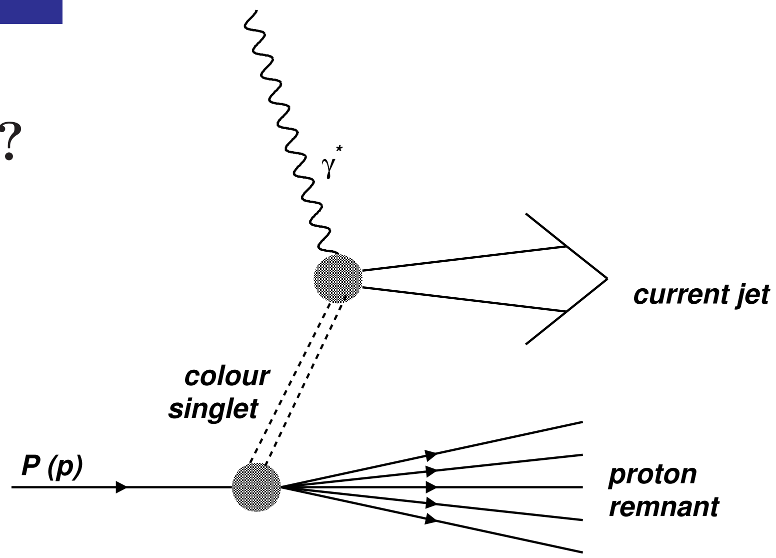
Jo Cole
University of Bristol
On behalf of the ZEUS and H1 Collaborations

- ▷ Why look at rapidity gaps between jets ?
- ▷ Experimental methods & theoretical predictions
- ▷ ZEUS analysis of 1994 data
- ▷ H1 & ZEUS analyses of more recent data
- ▷ Conclusions

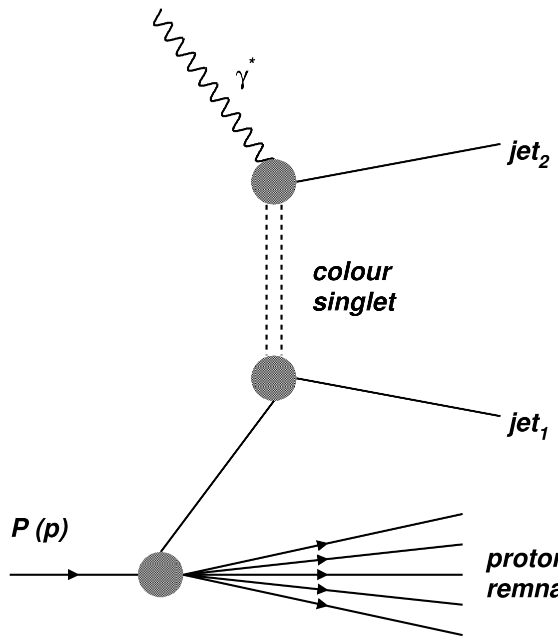
Introduction

▷ **Why look for rapidity gaps between jets ?**

- **Consider Diffractive DIS:**
  - hard scale from γ^*
  - but not from proton vertex
  - have to mix pQCD & Regge theory



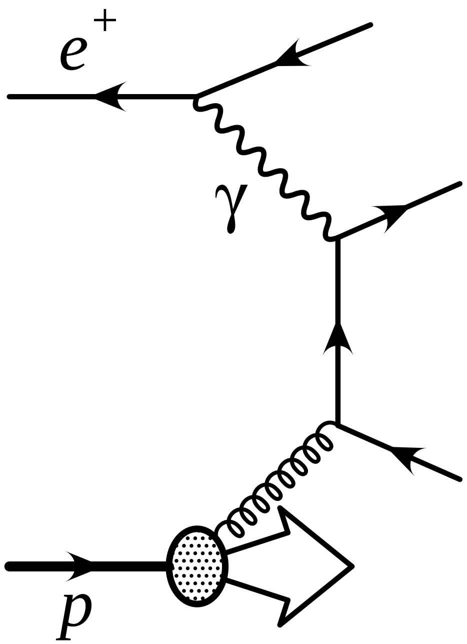
- **Consider event with jets + gap:**
  - high E_T jets ⇒ hard scale at both ends
  - perturbative Pomeron



▷ ideal environment to study "Pomeron" in a regime where pQCD is expected to be valid

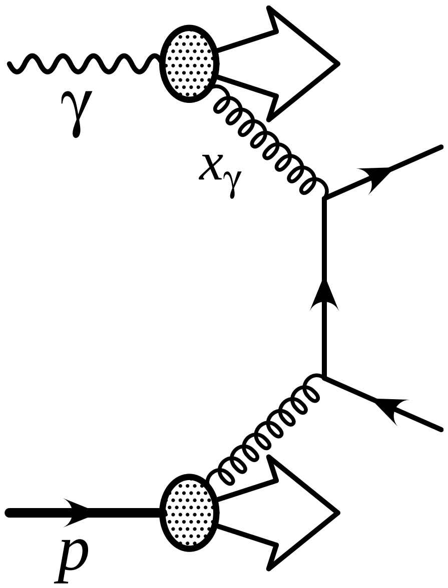
Dijet photoproduction at HERA

▷ **At lowest order, two processes contribute**



▷ **"direct" processes**

- **high x_γ^{obs}**



▷ **"resolved" processes**

- **low x_γ^{obs}**

$$\boxed{\mathbf{x_\gamma^{obs} = \frac{E_{T_1} e^{-\eta_1} + E_{T_2} e^{-\eta_2}}{2 y E_e}}}$$

▷ **defined to all orders**

Rapidity Gaps between Jets at HERA

▷ **Standard dijet mechanism: Exchange of q or g propagator**

- **Jets are colour-connected**
- **gaps created by multiplicity fluctuations**

$\Rightarrow$ **exponential fall-off in $\Delta\eta$**

▷ **Colour-singlet exchange:**

- **At LO, only occurs in resolved processes**
- **Jets are unconnected $\Rightarrow$ rapidity gap produced**
- **Flat distribution in $\Delta\eta$**

▷ **Candidates for colour-singlet**

- **γ, Z^0, $W^\pm$ $\rightarrow$ very small cross section**
- **$\mathbb{P}$-like object**

Theoretical Predictions & Considerations

▷ **QCD predictions: Standard PYTHIA and HERWIG**

- **Exponential fall-off with increasing gap size ($\Delta\eta$)**

▷ **Include underlying event models**

- **possible reduction of gap events . . .**
- **present in both PYTHIA and HERWIG predictions (use MPI)**

▷ **Colour singlet exchange**

- **Leading log approximation (LLA) BFKL (Mueller & Tang)**
- **$\mathbb{P}$-intercept $= 1 + \omega_0$, where $\omega_0 = \alpha_s C_A (4 \ln 2/\pi)$**
- **Normalisation controlled by α_s (ZEUS: $\alpha_s = 0.17$, H1: $\alpha_s = 0.18$)**
- **add to sum of direct and resolved HERWIG**

▷ **EW exchange (high-t γ exchange)**

- **scaled contribution added to PYTHIA (H1 only)**
- **Test for underlying dynamics**

How to identify gaps between jets ?

▷ **Method I:**

- identify jets

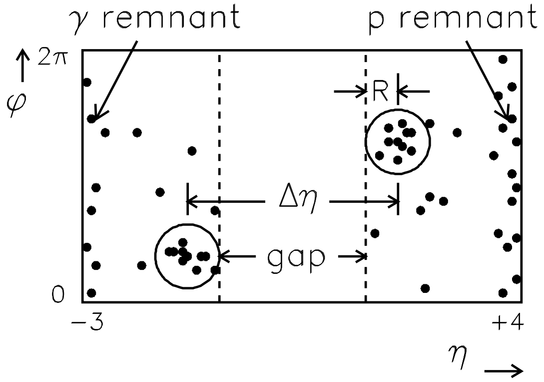
  $\Rightarrow$ cone algorithm

- determine particle multiplicity

  $\Rightarrow$ look for particles with $E_T > 300$ MeV

- Gap definition:

  $\Rightarrow$ No particles between two highest E_T jets



▷ **Method II:**

- identify jets

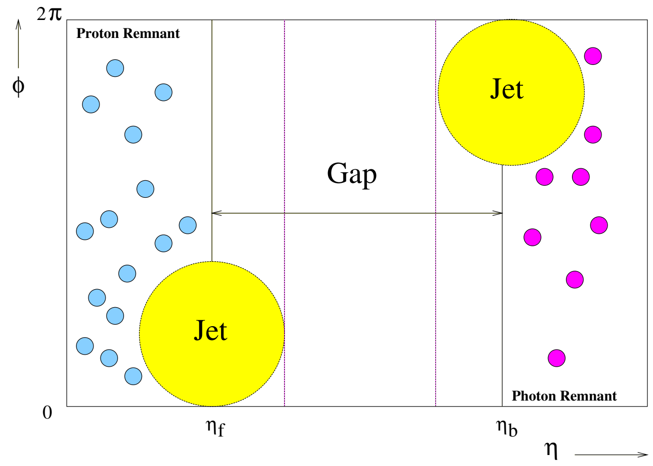
  $\Rightarrow$ inclusive k_T algorithm

- Calculate energy flow between two highest E_T jets

  $\Rightarrow E_T^{gap} = \sum_{i>2} E_T^{jet_i}$

- Gap definition:

  $\Rightarrow E_T^{gap} < E_T^{cut}$

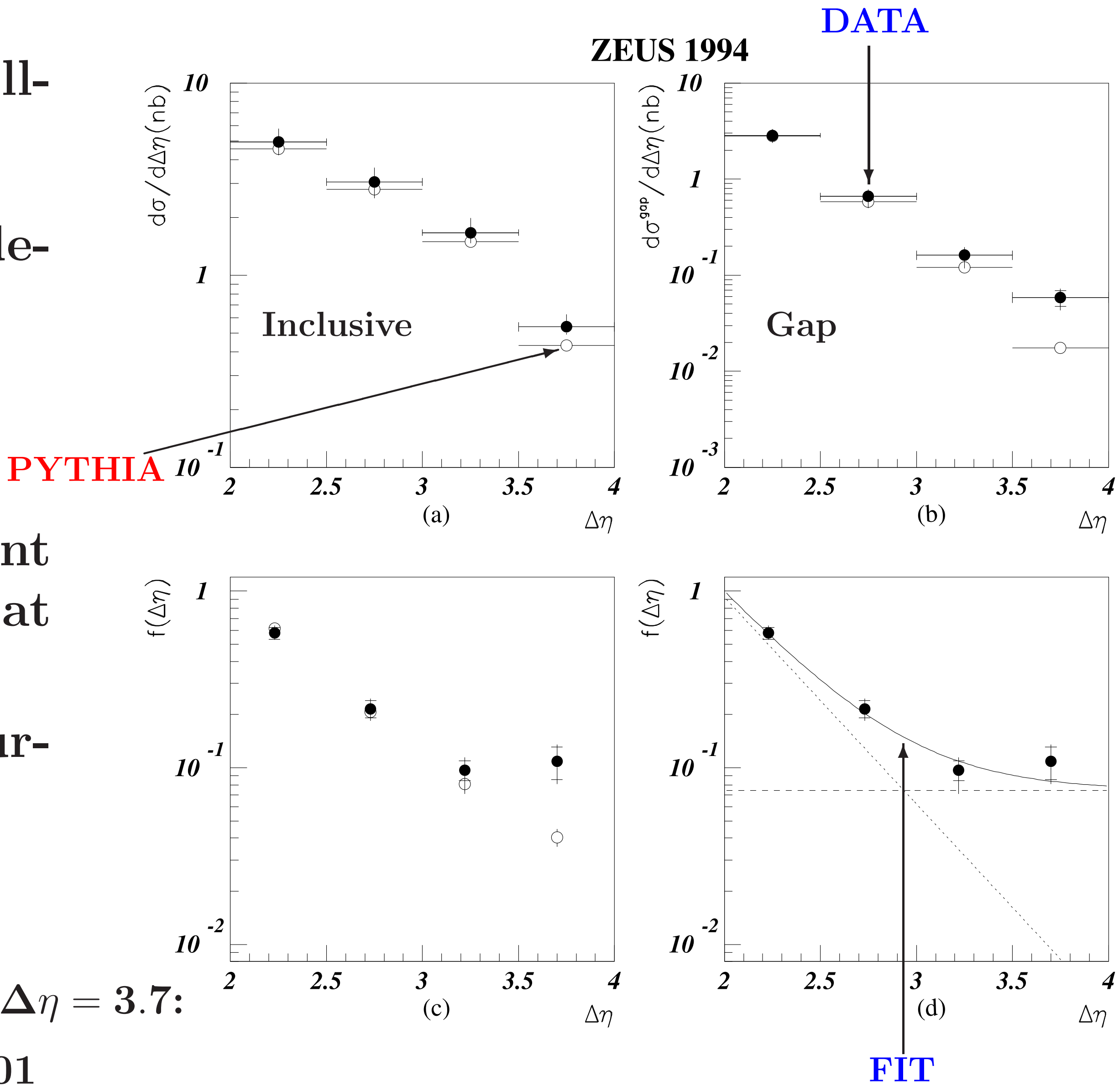


First observation of gaps between jets at HERA

- **1994 ZEUS data (2.6 pb^{-1})**
- **Use method I**
- **Kinematic region:**
  - $\mathbf{Q^2 < 4\ GeV^2}$
  - $\mathbf{0.2 < y < 0.85}$
  - $\mathbf{E_T^{jet_1}, E_T^{jet_2} > 6\ GeV}$
  - $\eta^{1,2} < 2.5$
  - $2 < \Delta\eta < 4$
  - $|\eta_1 + \eta_2|/2 = |\bar{\eta}| < 0.75$
- **Measure differential cross sections**
- **Also Measure gap fraction f$(\Delta\eta)$:**
  - $\dfrac{\text{dijet+gap events}}{\text{all dijet events}}$

Results of Analysis of 1994 ZEUS Data

- ▷ Inclusive cross section well-described
- ▷ Gap cross section poorly described
  - Particularly at high $\Delta\eta$
- ▷ Fits shows data consistent with sum of exponential + flat contribution
  - Exchange of QCD colour-singlet ?
- ▷ Estimate of gap fraction
  - $0.11 \pm 0.02(\text{stat.})^{+0.01}_{-0.02}(\text{syst.})$ at $\Delta\eta = 3.7$:
  - gap fraction at Tevatron ~ 0.01



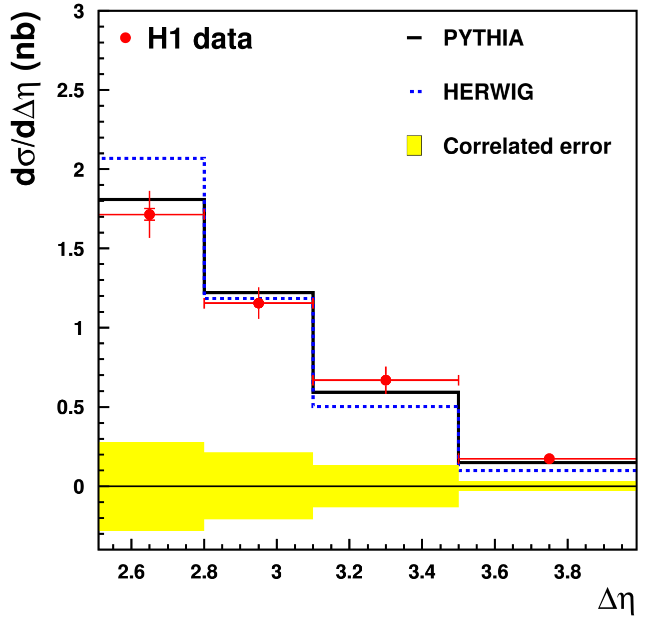
And more recently . . .

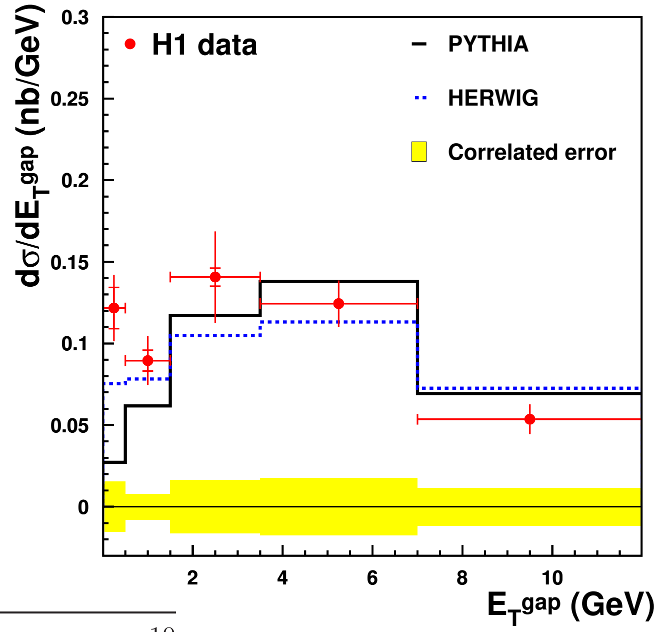
- ▷ **1996-7 ZEUS data (38.6 pb^{-1})**
- ▷ **Use method II**
- ▷ **Kinematic Region:**
  - $Q^2 < 1$ GeV^2
  - $0.2 < y < 0.85$
  - $E_T^{jet_1} > 6$ GeV, $E_T^{jet_2} > 5$ GeV
  - $|\eta^{1,2}| < 2.4$
  - $2 < \Delta\eta < 4$
  - $|\eta_1 + \eta_2|/2 = |\bar{\eta}| < 0.75$

- ▷ **1996 H1 data (6.6 pb^{-1})**
- ▷ **Use Method II**
- ▷ **Kinematic Region:**
  - $Q^2 < 0.01$ GeV^2
  - $0.3 < y < 0.6$
  - $E_T^{jet_1} > 6$ GeV, $E_T^{jet_2} > 5$ GeV
  - $\eta^{1,2} < 2.65$
  - $2.5 < \Delta\eta < 4.0$

Differential cross sections (H1)

- Cross section versus $\Delta\eta$
  - Reasonable description by MC
- Cross section versus E_T^{gap}
  - Excess in data at low E_T^{gap}





Gap Fraction versus $\Delta\eta$ (ZEUS)

▷ Measured for different E_T^{cut}

▷ Comparison to:

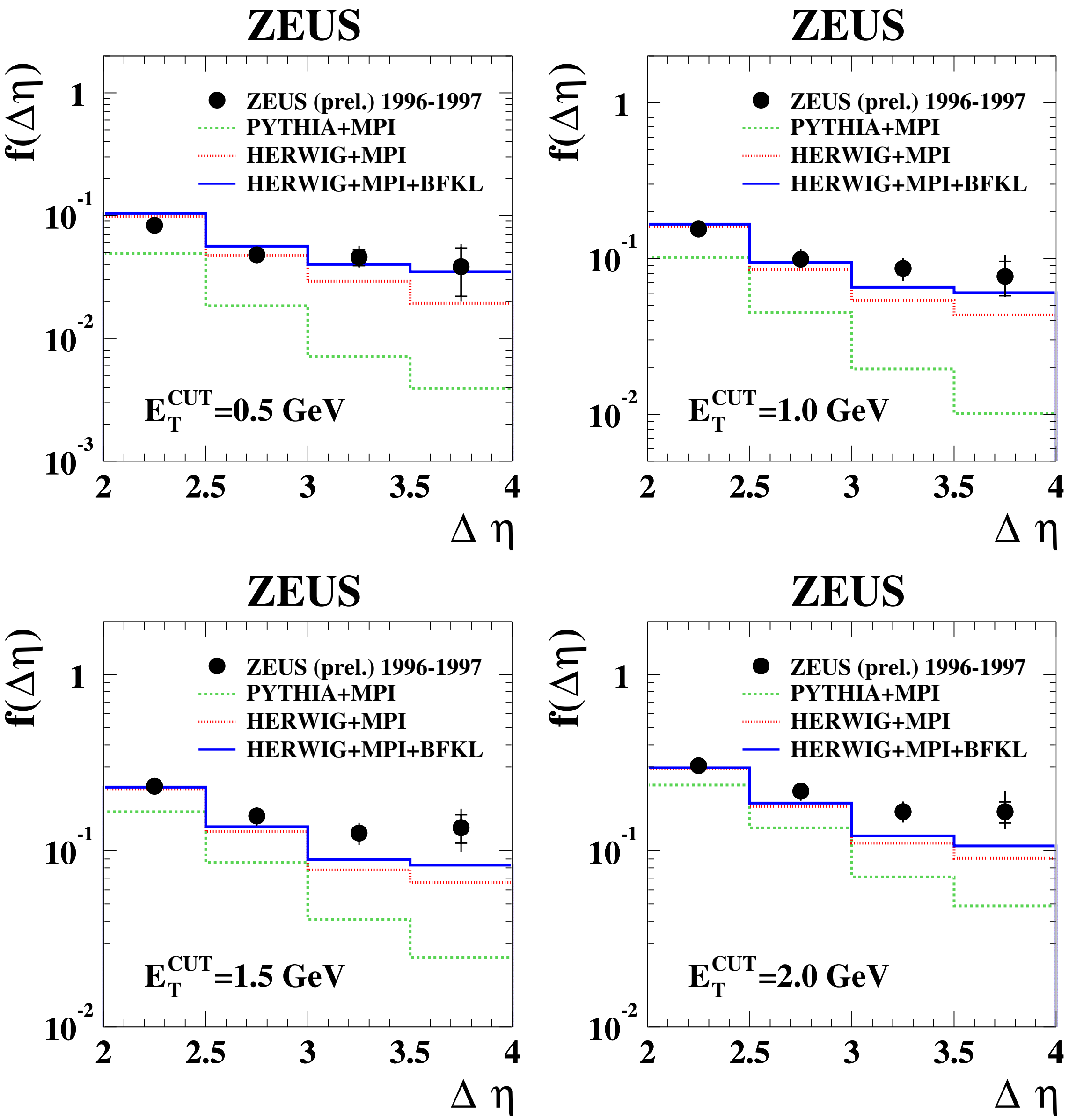
▷ HERWIG & PYTHIA non-singlet (NS)

- below data at high $\Delta\eta$

▷ known effect of hadronisation models

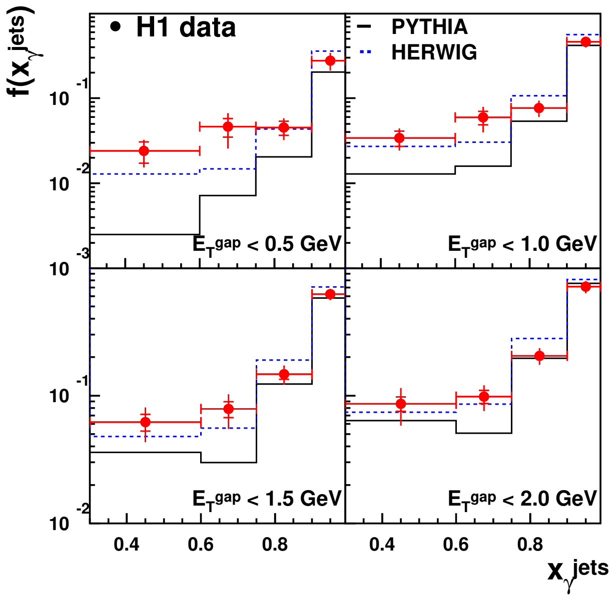
▷ HERWIG + BFKL

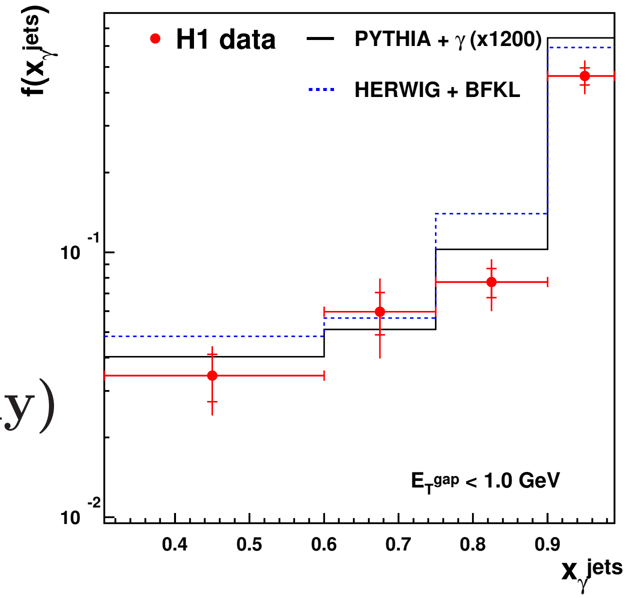
- closer to data than non-singlet prediction



Gap Fraction versus x_γ^{obs} (H1)

- ▷ Measured for different E_T^{cut}
- ▷ $f(x_\gamma^{obs})$ rises with x_γ^{obs}
  - Direct ⇒ q propagator
  - Resolved ⇒ g propagator
- ▷ HERWIG & PYTHIA (NS)
  - clear deficiency at low x_γ^{obs}
- ▷ HERWIG + BFKL
  - improvement at low x_γ^{obs}
  - over-estimate at high x_γ^{obs}
- ▷ PYTHIA + scaled γ exchange
  - test underlying dynamics ($\gamma \rightarrow$ q only)
    - data are not sensitive



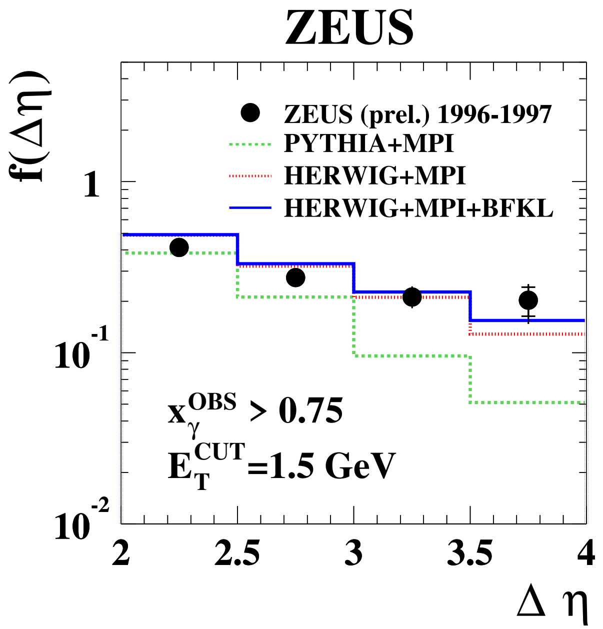


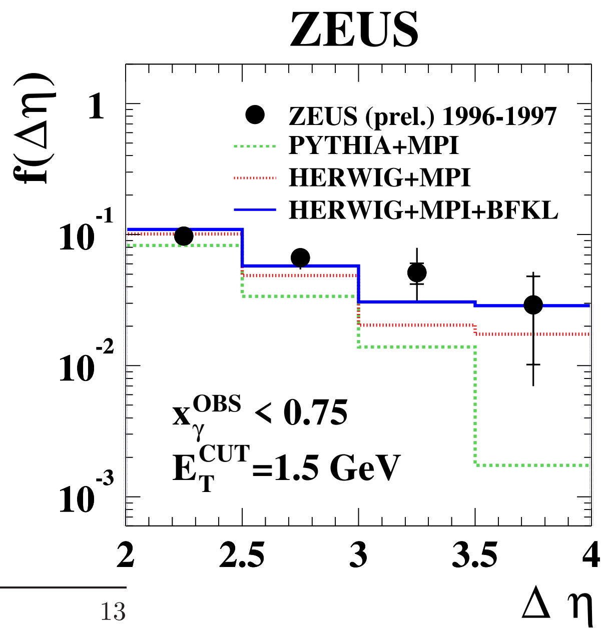
Gap Fraction for Direct & Resolved Events (ZEUS)

▷ Choose $E_T^{cut} = 1.5$ GeV

▷ High x_γ^{obs}:
- Comparison to HERWIG
  - reasonable agreement
- Comparison to PYTHIA
  - lower than the data

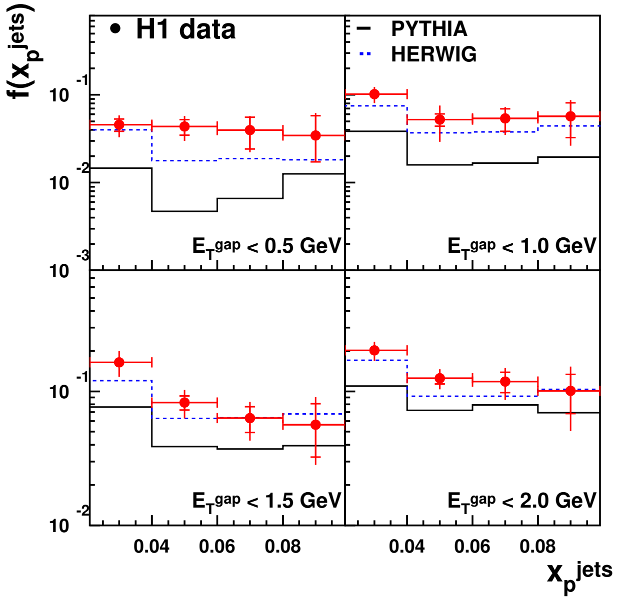
▷ Low x_γ^{obs}:
- HERWIG + BFKL closest to data
- PYTHIA & HERWIG (NS)
  - lower than data

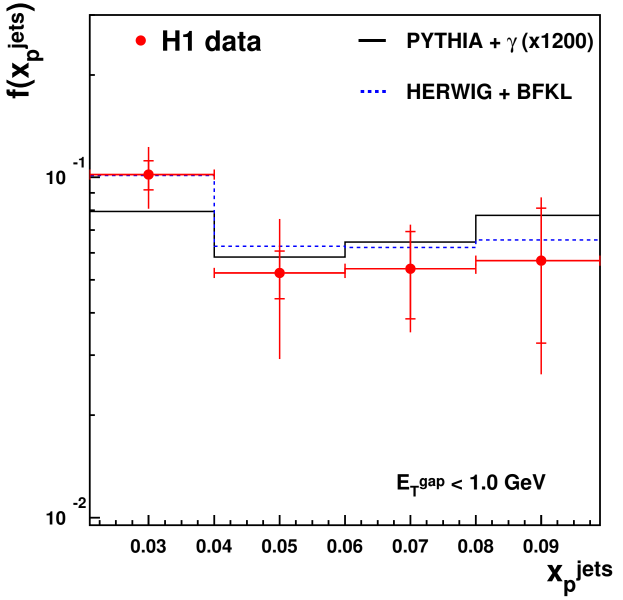




Gap Fraction versus x_p^{jets} (H1)

- ▷ $x_p^{jets} = \frac{(E+p_z)_{jet1}+(E+p_z)_{jet2}}{2E_p}$
- ▷ fraction rises at low x_p^{jets}
  - correlation: x_p^{jets} and x_γ^{obs}
- ▷ Comparison with NS models:
  - Both models below data
- ▷ Comparison with singlet models:
  - reasonable description





Conclusions

- **Rapidity gaps between jets $\Rightarrow$ studied with two different methods**
- **Both Collaborations see $\sim 10\%$ gap fraction at $\Delta\eta = 3.7$**
  - **Compare to Tevatron $\sim 1\%$ gap fraction**
- **Data higher than MC when no colour-singlet exchange present**
  - **See effect of cluster fragmentation model in HERWIG**
  - **At parton level, HERWIG & PYTHIA the same !**
- **HERWIG + BFKL gives reasonable description of the data**
- **gap fraction rises with x_γ^{obs}**
  - **direct processes prefer q propagator**
- **Test underlying dynamics using scaled γ exchange component**
  - **data are not sensitive**

Conclusions (II)

▷ **Excess in data can be described by BFKL colour singlet exchange**

▷ **However . . .**

- **Significant uncertainties in LLA BFKL**
  - **higher order corrections**
  - **choice of parameters**
  - **rapidity gap survival**

- **Difference in hadronisation models in PYTHIA & HERWIG**

- **Different models of underlying event**

▷ **For a definitive answer, need to understand all these things !**

HERA Kinematics

$\mathbf{Q^2 = -q^2 = -(k - k')^2}$ Square of momentum transfer

$\mathbf{x = \frac{Q^2}{p \cdot k}}$ mom fraction carried by struck parton

$\mathbf{y = \frac{p \cdot q}{p \cdot k}}$ relative energy transfer

$\mathbf{W^2 = (q + p)^2}$ $\gamma^* \mathbf{p}$ CoM energy^2

$$\mathbf{Q^2 = xys}$$

- **HERA collider . . .**

  $\mathbf{e^\pm \longrightarrow \longleftarrow p}$

  27.5 GeV 820-920 GeV

- $\sqrt{\mathbf{s}} \sim$ **300 GeV**