Diffractive Photoproduction at Large Momentum Transfer

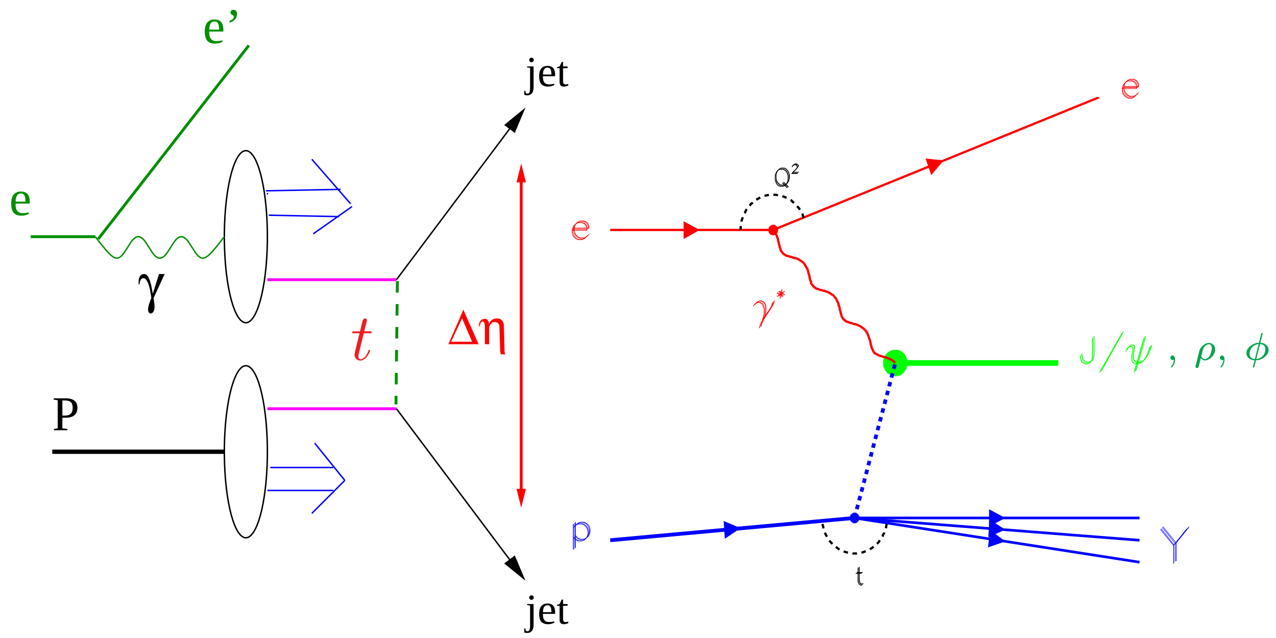
Angela Wyatt

- Introduction
- High $|t|$ Vector Meson Production
- Rapidity Gaps between Jets
- Summary

High $|t|$ Diffractive Processes at HERA

At HERA can study diffractive processes such as

Gaps Between Jets & **Vector Meson Prod.**:



where the momentum transfer is large

→ hard scale at both ends of the exchange

→ pQCD

What is Responsible for the gap ?

- The 'soft' pomeron ?

  Pomeron trajectory : $\alpha(t) = \alpha(0) + \alpha' t$

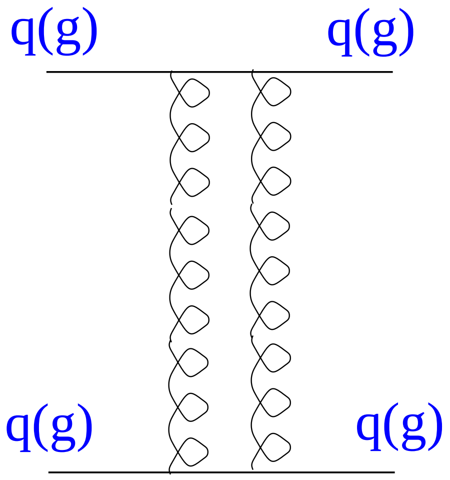
  $\rightarrow \frac{\mathrm{d}\sigma}{\mathrm{d}t} \simeq s^{2(\alpha(0)+\alpha' t)}$

  Any reasonably large α' (~ 0.25) leads to vanishing cross section at high $|t|$

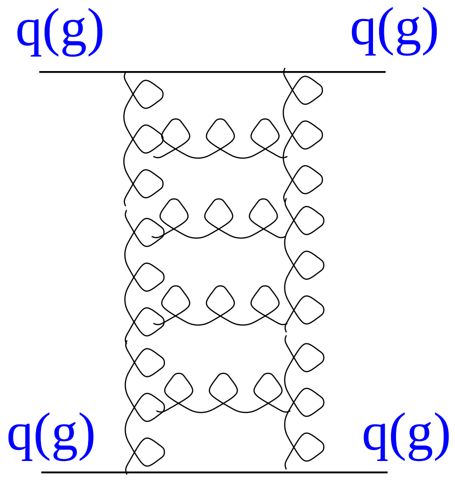
- QCD ?

  No fundamental colour singlet object $\rightarrow$

  BUT Large t $\rightarrow$ can construct one using pQCD e.g. BFKL calculation

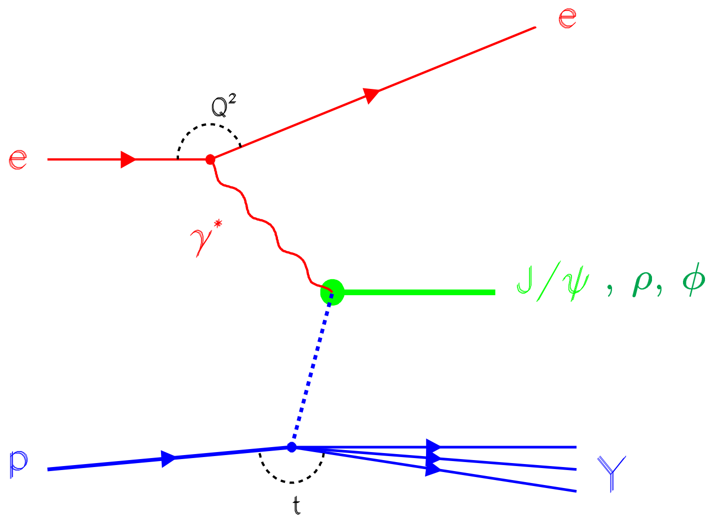


Two gluon



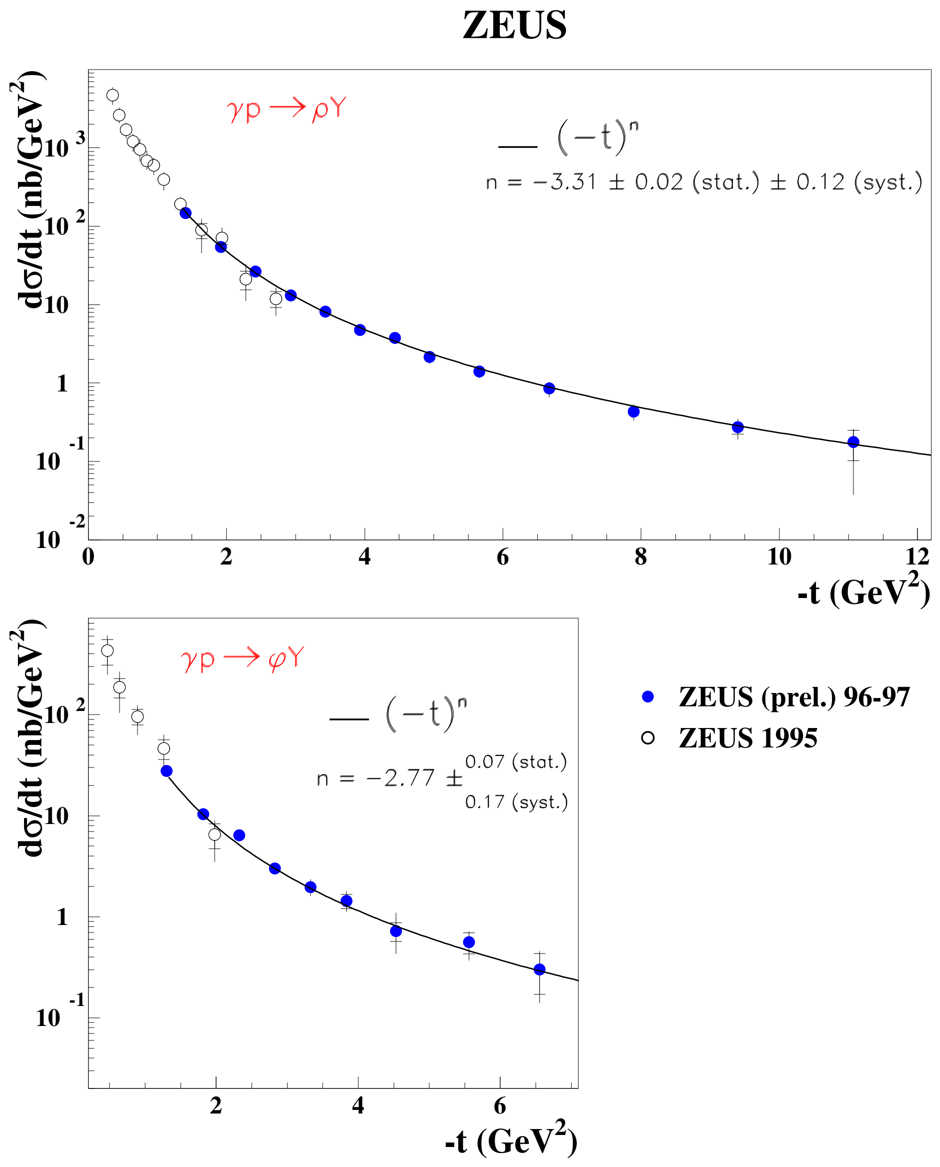
BFKL

VM Production at high $|t|$



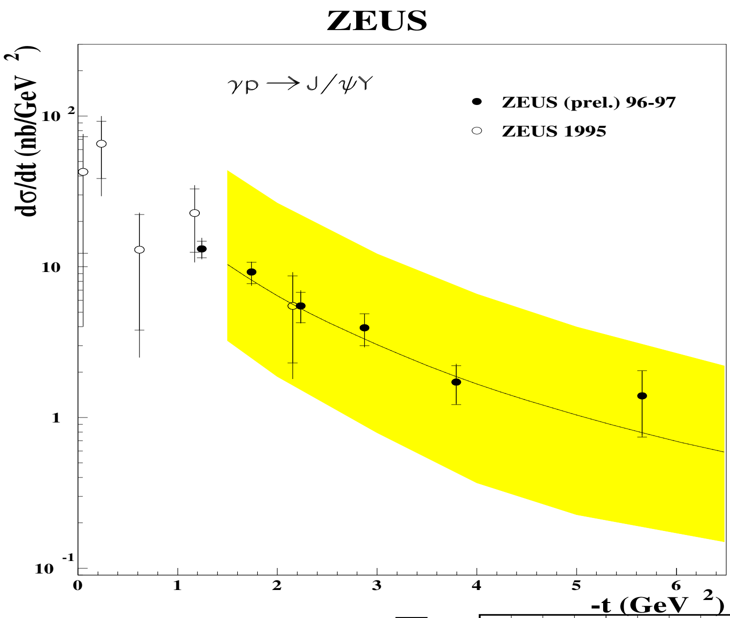
- High $|t|$: proton dissociates.
- Select photoproduction $Q^2 \sim 0$ GeV^2
  - ZEUS: $Q^2 < 0.02$ GeV^2 H1: $Q^2 < 1$ GeV^2
- Select high $|t|$ events. Range:
  - ZEUS : $1.1 < |t| < 12$ GeV^2 H1: $1 < |t| < 21$ GeV^2
- Centre of mass energy:
  - ZEUS: $80 < W < 120$ GeV H1: $50 < W < 160$ GeV

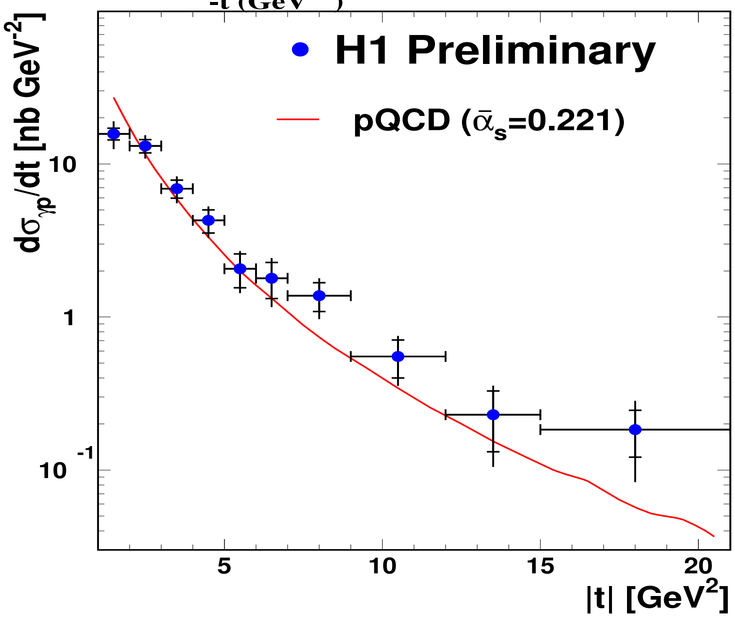
ρ and ϕ Production at high $|t|$



- pQCD predicts power-like behaviour of cross sections with $|t|$
- Data fitted with exponents ~ -3

J/ψ Production at high $|t|$





- LO BFKL model is able to describe the data.

  J. Bartels et al., Phys Lett. B375 (1996) 301.

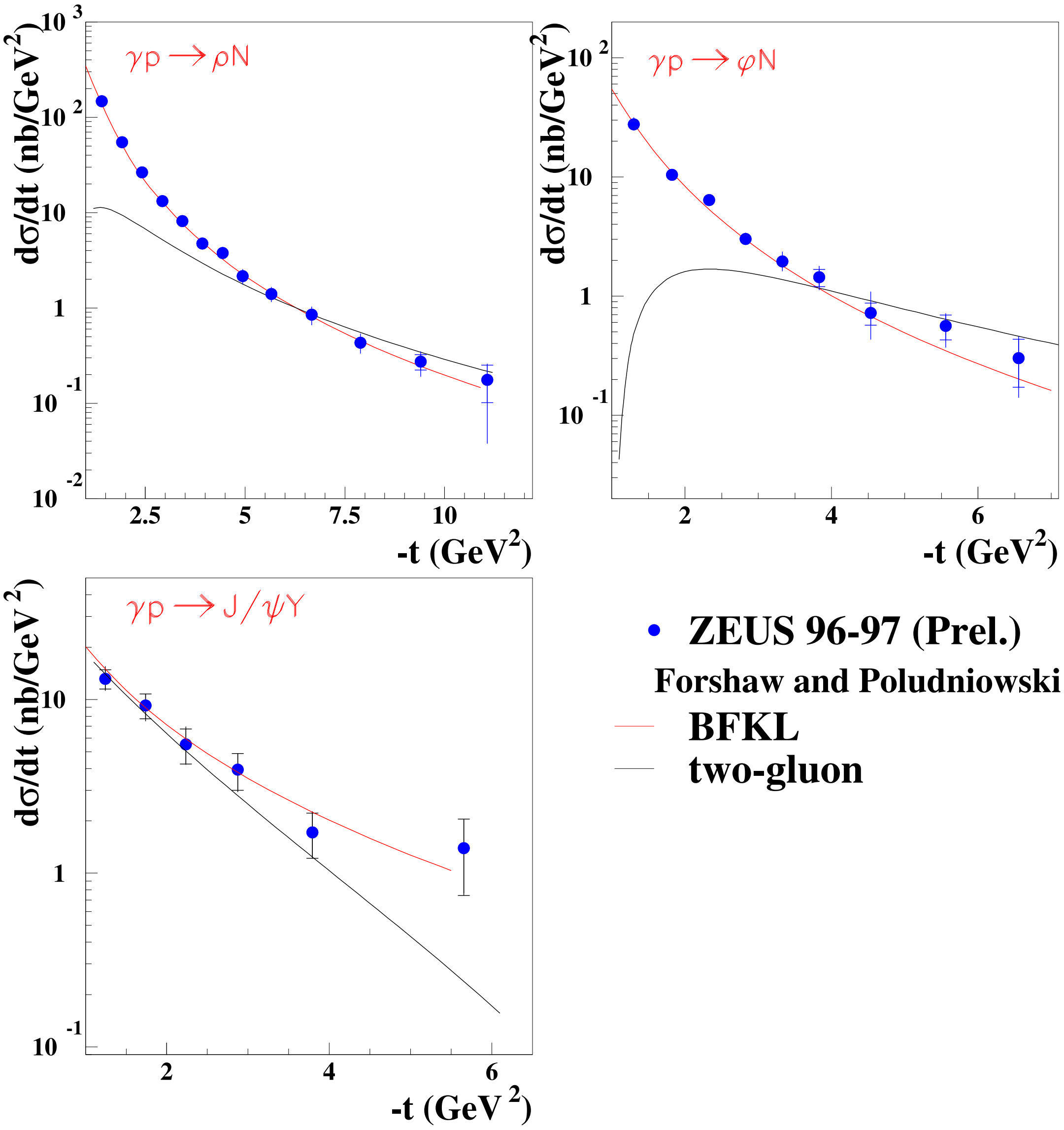
- Large normalisation uncertainty from choice of $\bar{\alpha}_s$

- Power-like behaviour: $\frac{d\sigma}{dt} \propto -t^n$, $n \sim -1.7$

Comparison to BFKL Calculation

J. R. Forshaw, G. Poludniowski, hep-ph/0107068

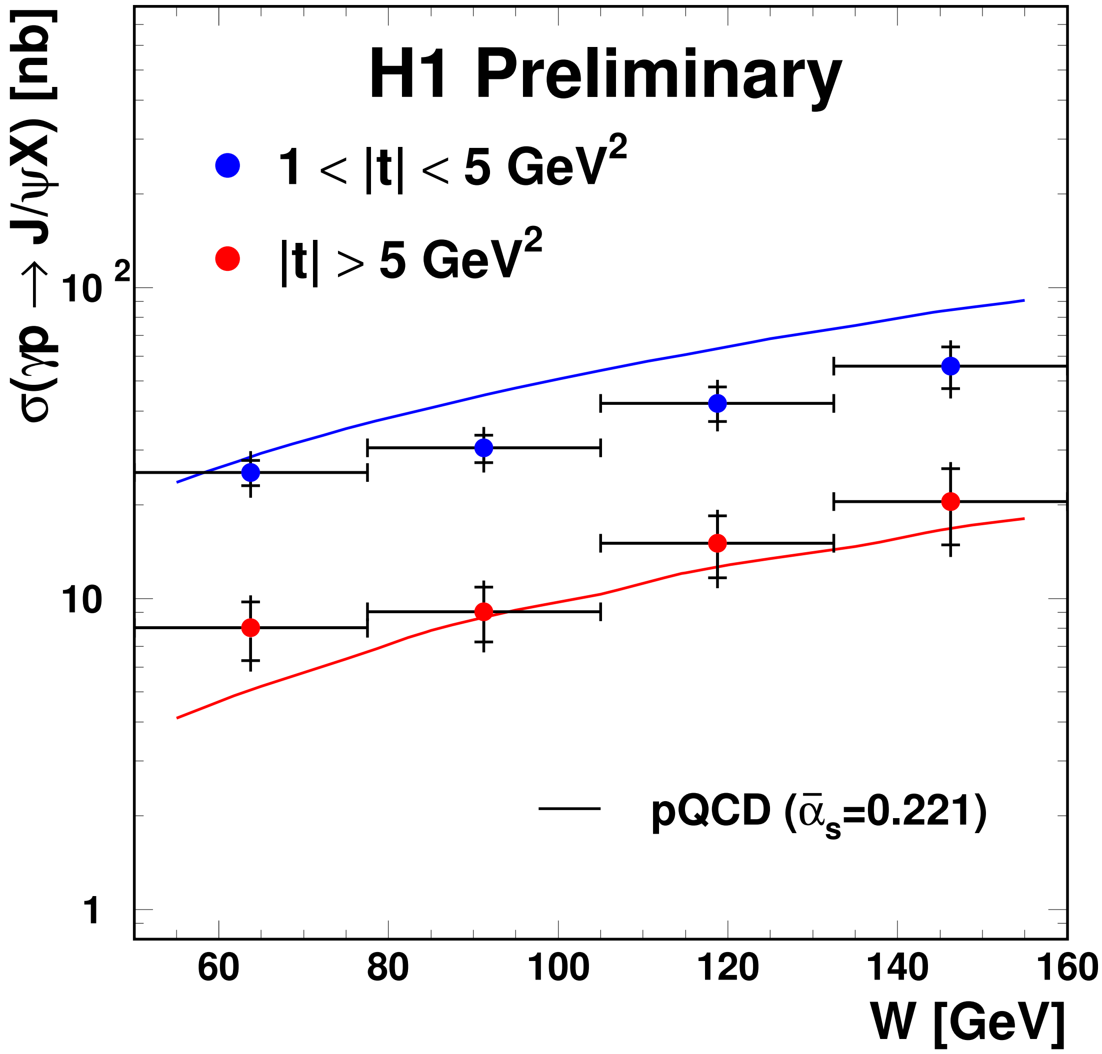
Recent calculations show BFKL approach consistent with all VM data. Fit with fixed $\alpha_s = 0.2$:



Data consistent with LLA BFKL $0.17 < \alpha_s < 0.29$

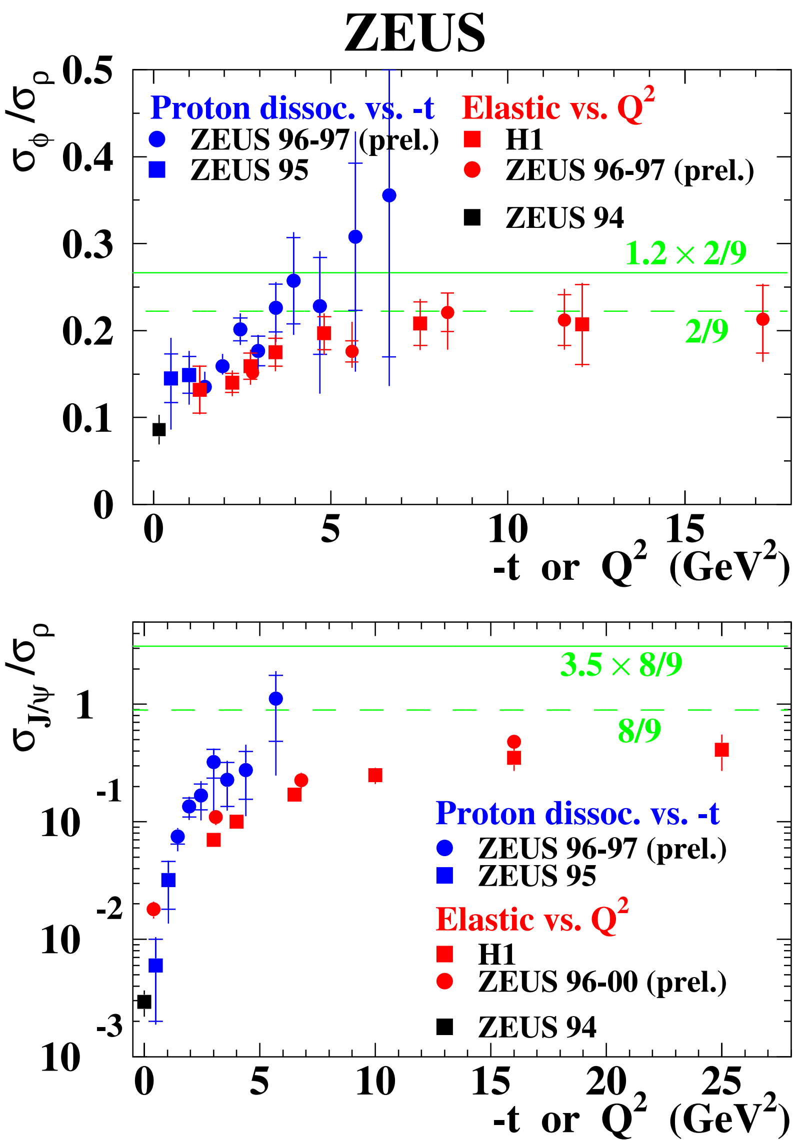
Two gluon exchange gives a poorer description.

Energy Dependence at high $|t|$



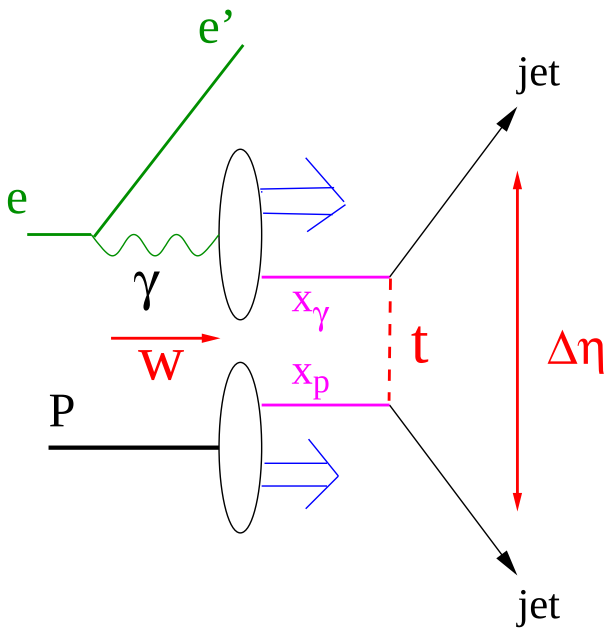
- W-dependence similar to elastic J/ψ at low $|t|$.
- LO BFKL model with $\bar{\alpha_s} \sim 0.22$ gives fair description of W-dependence as well as $|t|$.

VM Production Cross Section Ratios



- γ coupling directly to quarks + flavour independence $\rightarrow$ cross sections in ratio $\rho : \phi : J/\psi = 9 : 2 : 8$. Including masses: 9: 2x1.2: 8x3.5
- ratio rising with $|t| \rightarrow$ indication that $|t|$ is a scale.
- rise in $|t|$ faster than in $Q^2 \rightarrow Q^2$, $|t|$ not equivalent

Rapidity Gaps Between Jets



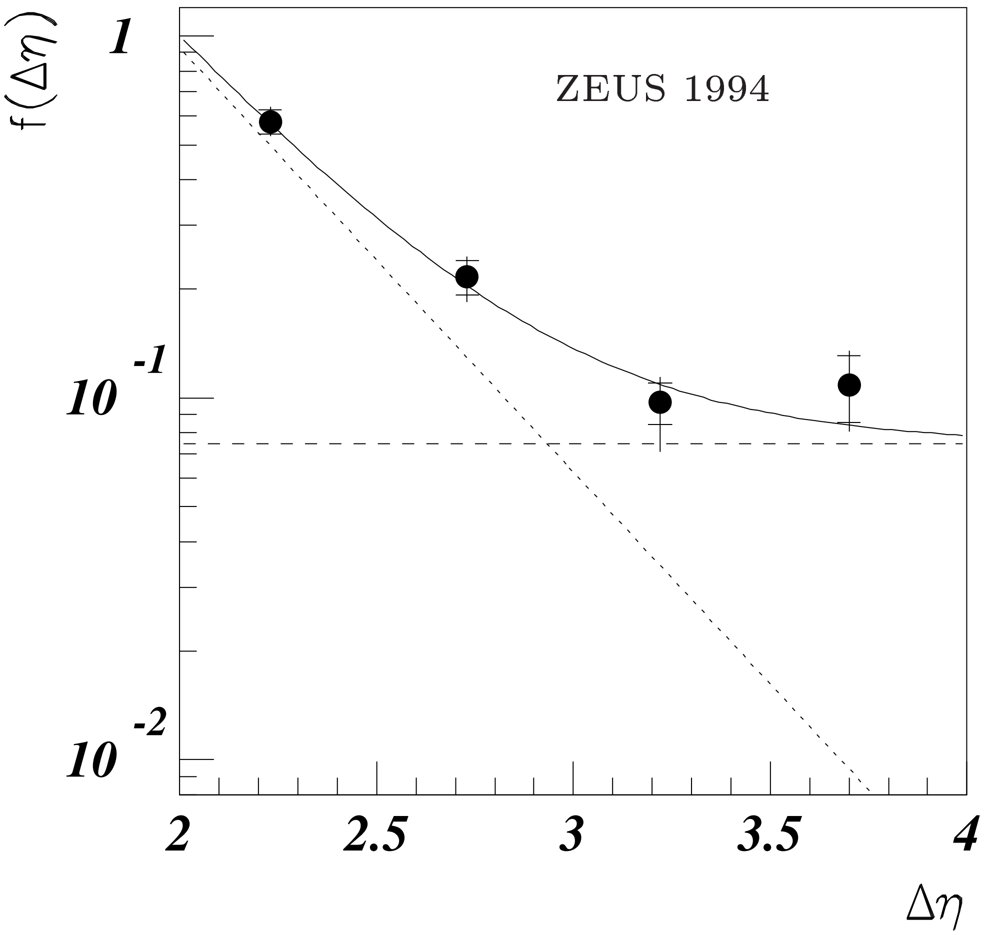
- Select large rapidity gap $\rightarrow$ colour singlet exchange
- High P_T jets ($\sim 6\,\mathrm{GeV}$) $\rightarrow$ hard scale at both ends of the exchange $\rightarrow$ pQCD
- Measure the Gap Fraction:
  $\mathrm{f} = \frac{N_{gap}}{N_{inc}}$
- Other useful variables:

$$x_p^{jets} = \frac{\sum_{jets1,2}(E^{jet}+p_z^{jet})}{2E_p}$$

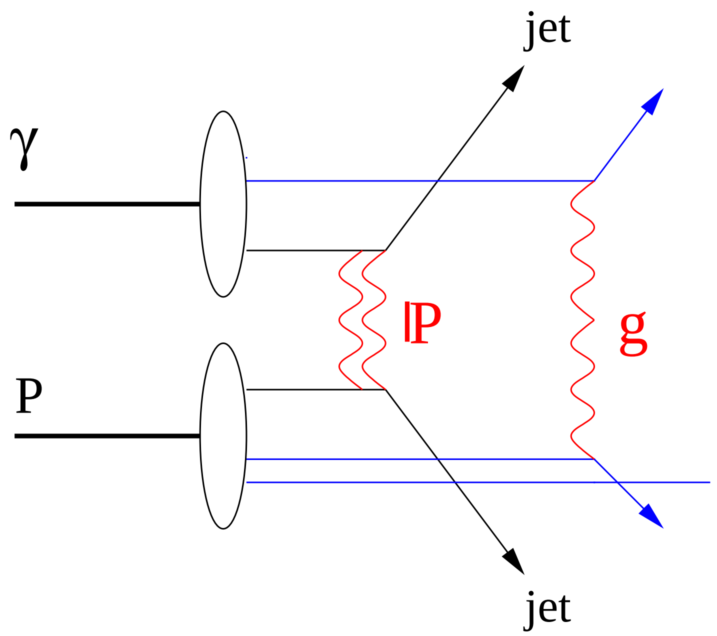
$$x_\gamma^{jets} = \frac{\sum_{jets1,2}(E^{jet}-p_z^{jet})}{\sum_{objects}(E^{obj}-p_z^{obj})}$$

ZEUS Gaps Between Jets

- $Q^2 < 0.4$ GeV^2, $135 < W < 280$ GeV
- Jet Finding - cone algorithm, radius 1.0
  $P_t^{jet1,2} > 6.0$ GeV, $\quad \eta^{jet1,2} < 2.5$
  $|\bar{\eta}| < 0.75, \quad \Delta\eta > 2.0$
- Gap Finding- no final state particle
  $E > 300\mathrm{MeV}$ between the jet edges



Complications



- Multiplicity definitions are not infra-red safe.
- Multiple parton-parton interactions.

  – Gap survival probability → potentially large non-perturbative corrections

  – Interesting place to study interplay between long and short distance physics. Gap formation:
  – Non-perturbative → soft color models
  – Perturbative exchange (e.g BFKL) + gap survival probability
  – Purely perturbative (up to pdfs) if E_t^{cut} large
  (Oderda + Sterman Phys Rev Lett 81,3591 (1998))

Energy Flow Between Jets

Oderda + Sterman Phys Rev Lett 81,3591 (1998)

Identify rapidity gaps by the energy flow in the inter-jet region, Q_C, rather than a multiplicity.

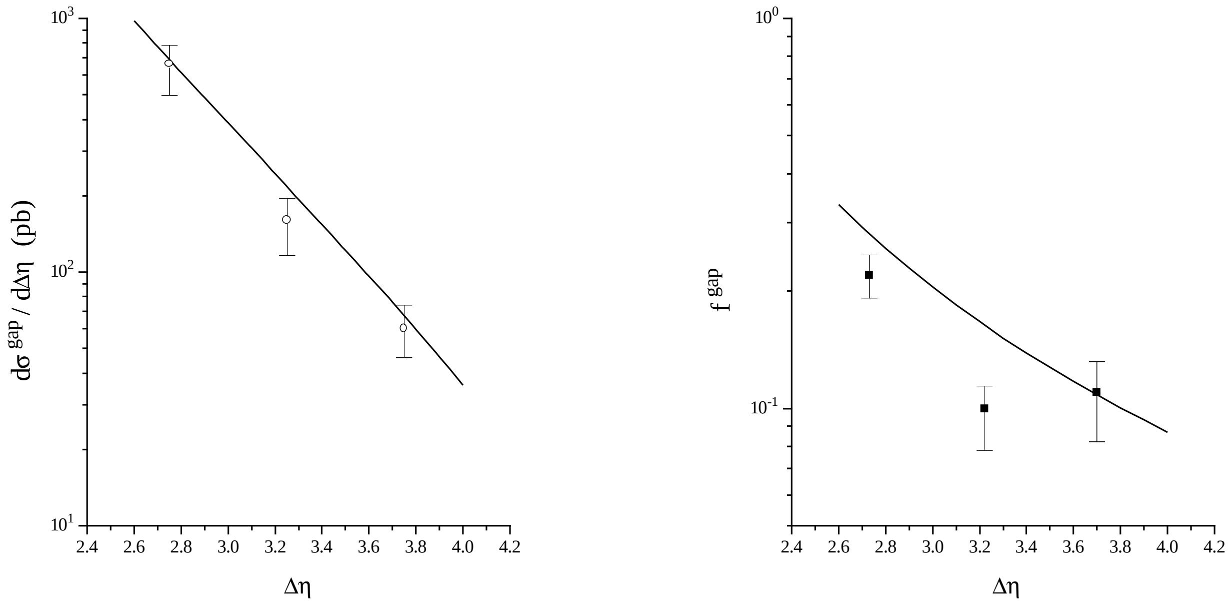
- If $Q_c \gg \Lambda_{QCD} \rightarrow$ perturbatively calculable cross-section.

  Results:

  - Perturbative part of the gap survival probability is calculable
  - the low Q_c cross-section is dominated by colour-singlet exchange

Comparison with the ZEUS data

The Gap Cross-section (a) and fraction (b) for the gap identified by the energy threshold $Q_0 = 350$ MeV

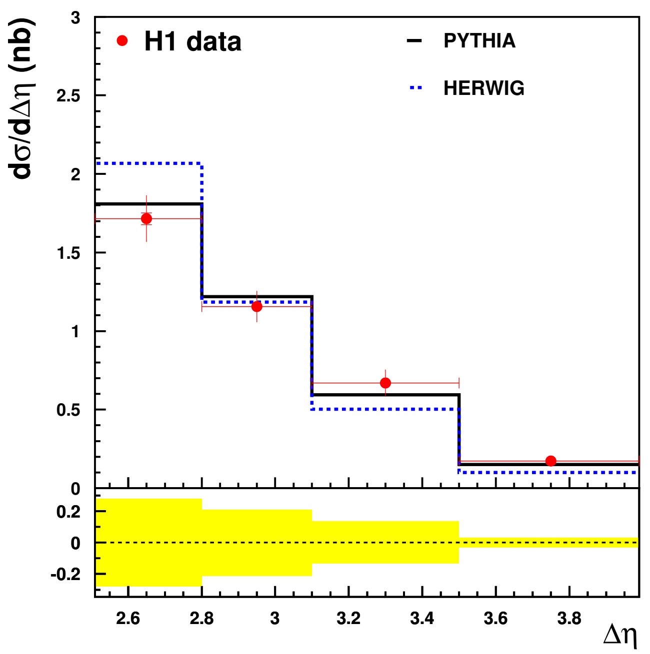


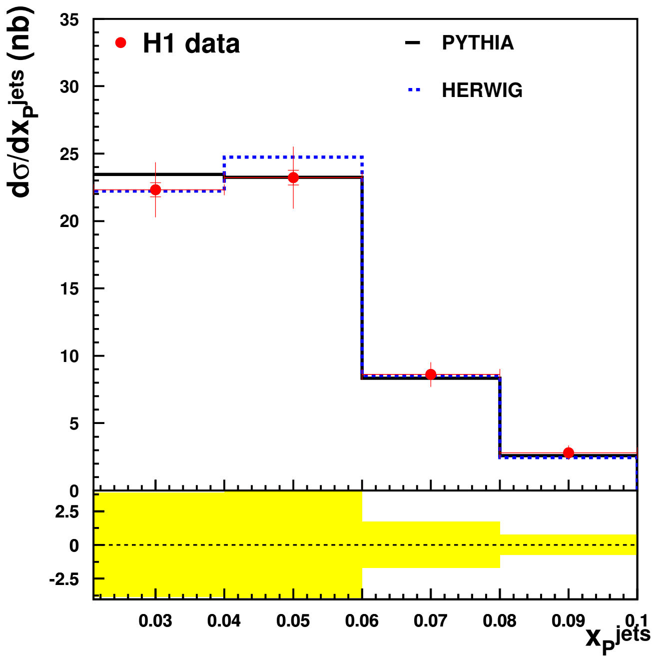
(a) (b)

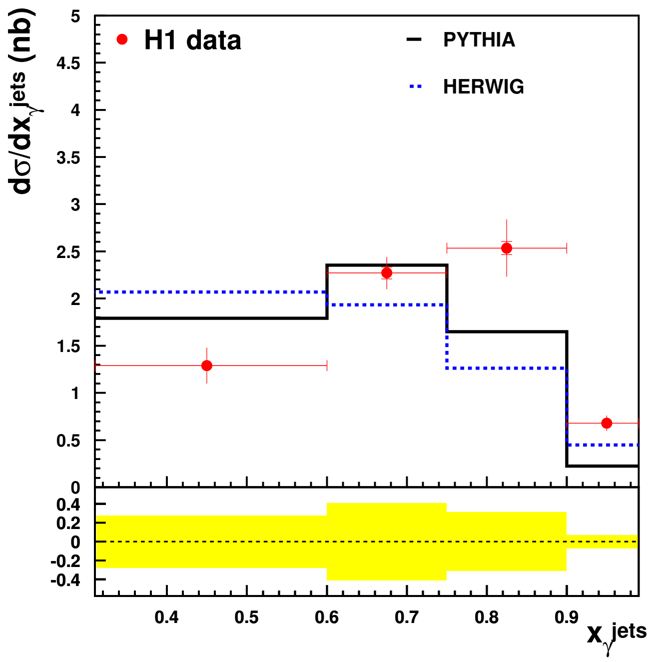
Oderda, Phys Rev D61,014004 (2000)

- Behaviour of the ZEUS data is approx. reproduced.
- Clear meaning of the colour content of the hard scatter

Differential Dijet Cross Sections







inclusive k_t algorithm

$E_t^{jet1} > 6.0$ GeV

$E_t^{jet2} > 5.0$ GeV

$\eta^{jet1,2} < 2.65$

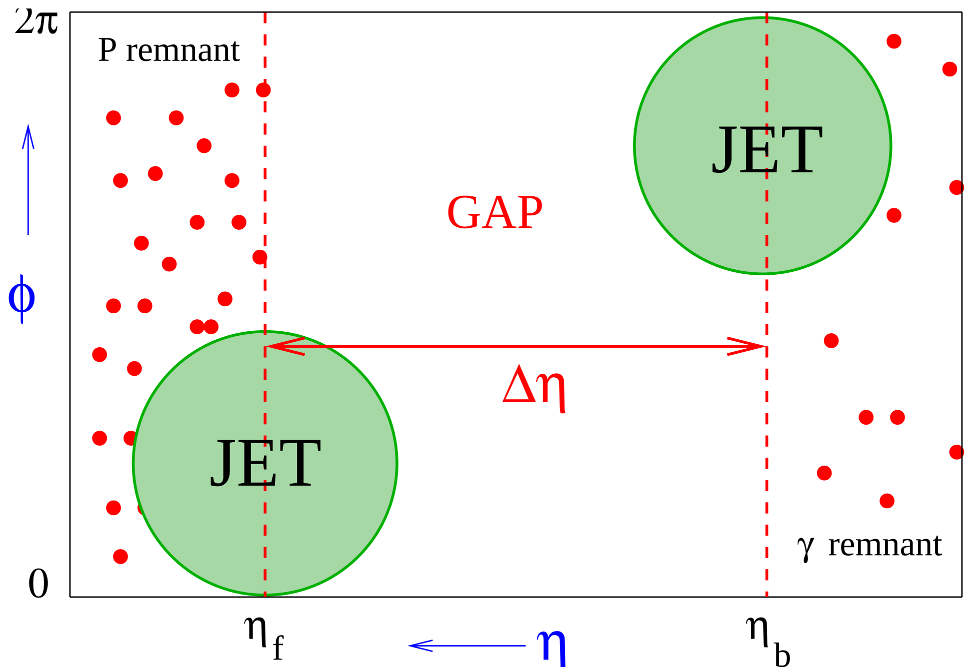
$2.5 < \Delta\eta < 4.0$

$Q^2 < 0.01\,\mathrm{GeV}^2$

$165 < W < 243$ GeV

Pythia 5.7 and Herwig 6.1 + Jimmy multiple interaction models tuned to fit data

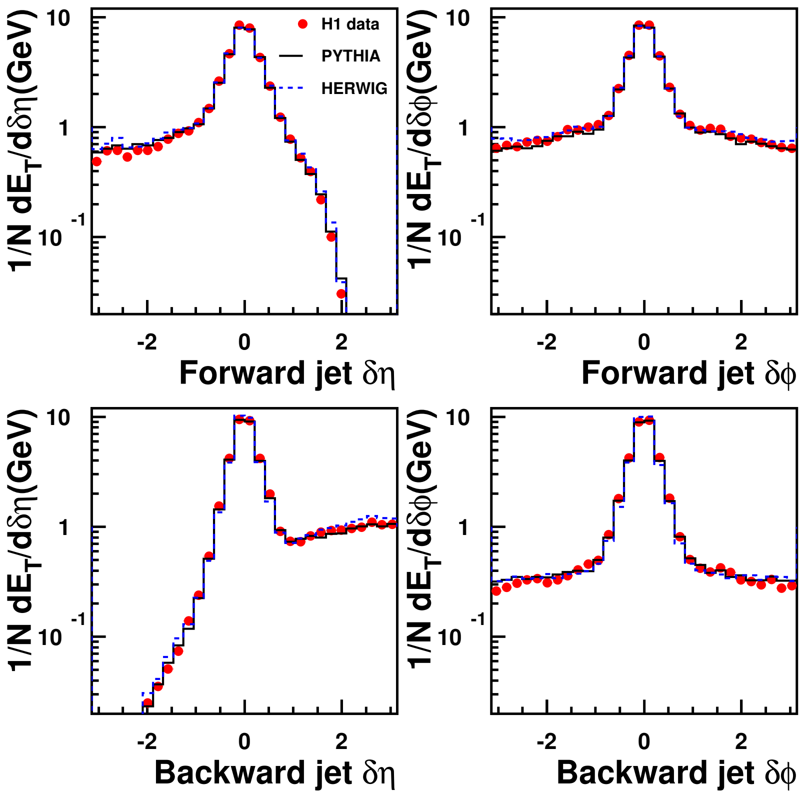
Definition of Rapidity Gap Events



- Inclusive k_t algorithm $\rightarrow$ every object associated with a jet
  $E_t^{gap} = \sum E_t^{jet}, \ \eta_f^{jet} > \eta_{jet} > \eta_b^{jet}$
- $\boxed{\text{Gap event : } E_t^{gap} < E_t^{cut}}$
- Perturbative calculation possible for $E_t^{cut} \gg \Lambda_{QCD}$
- Completely infra-red safe definition of gap
- Large η region used to define E_t^{gap}
- Activity at edge of gap 'removed' from gap

Monte Carlo Models

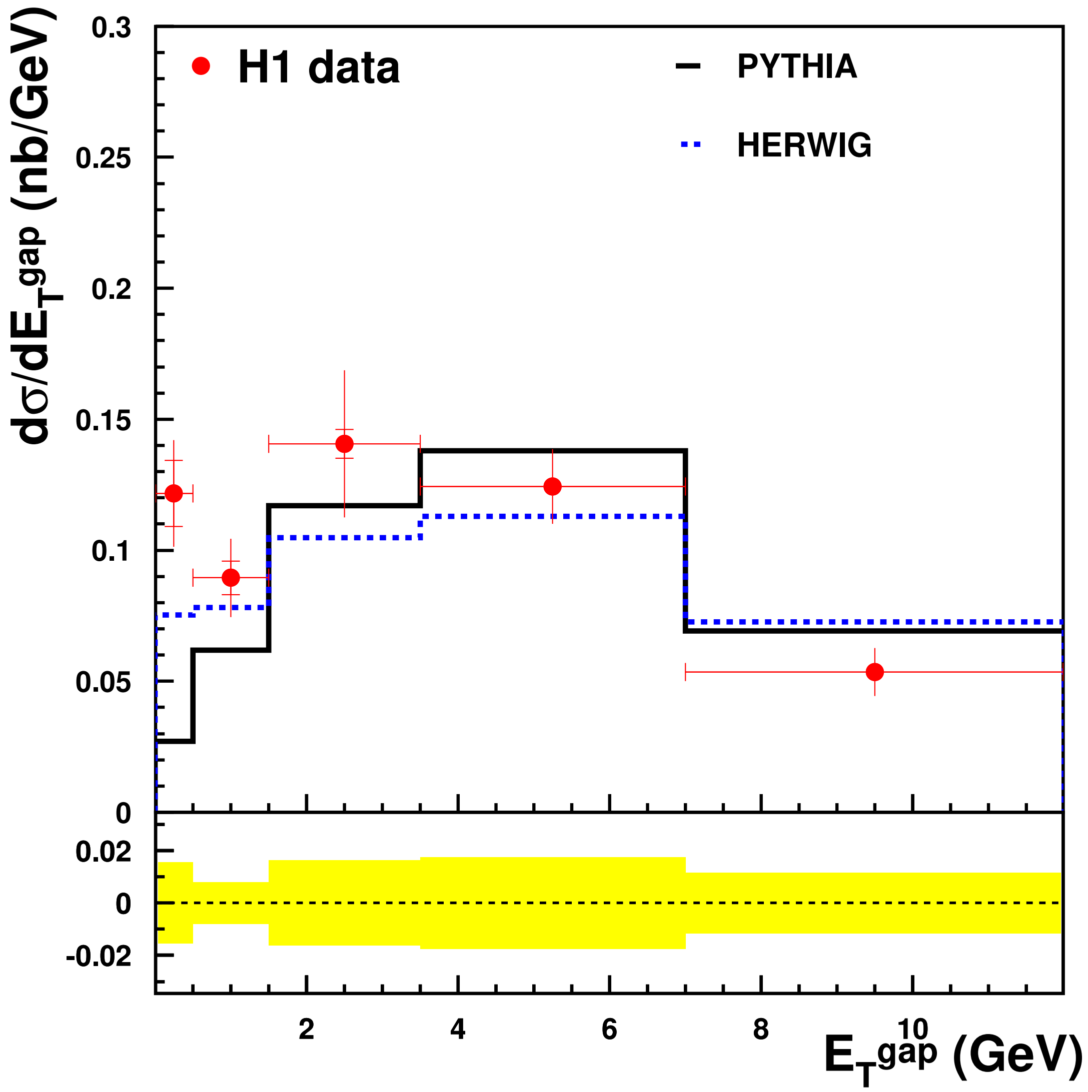
- Pythia 5.7
- Herwig 6.1 + JIMMY
- Multiple interactions tuned to data:



Colour Singlet Models

- Pythia 5.7 high-t γ exchange ($\times$1200)
- Herwig 6.1 + JIMMY BFKL $\mathbb{P}$ $\alpha_s = 0.18$

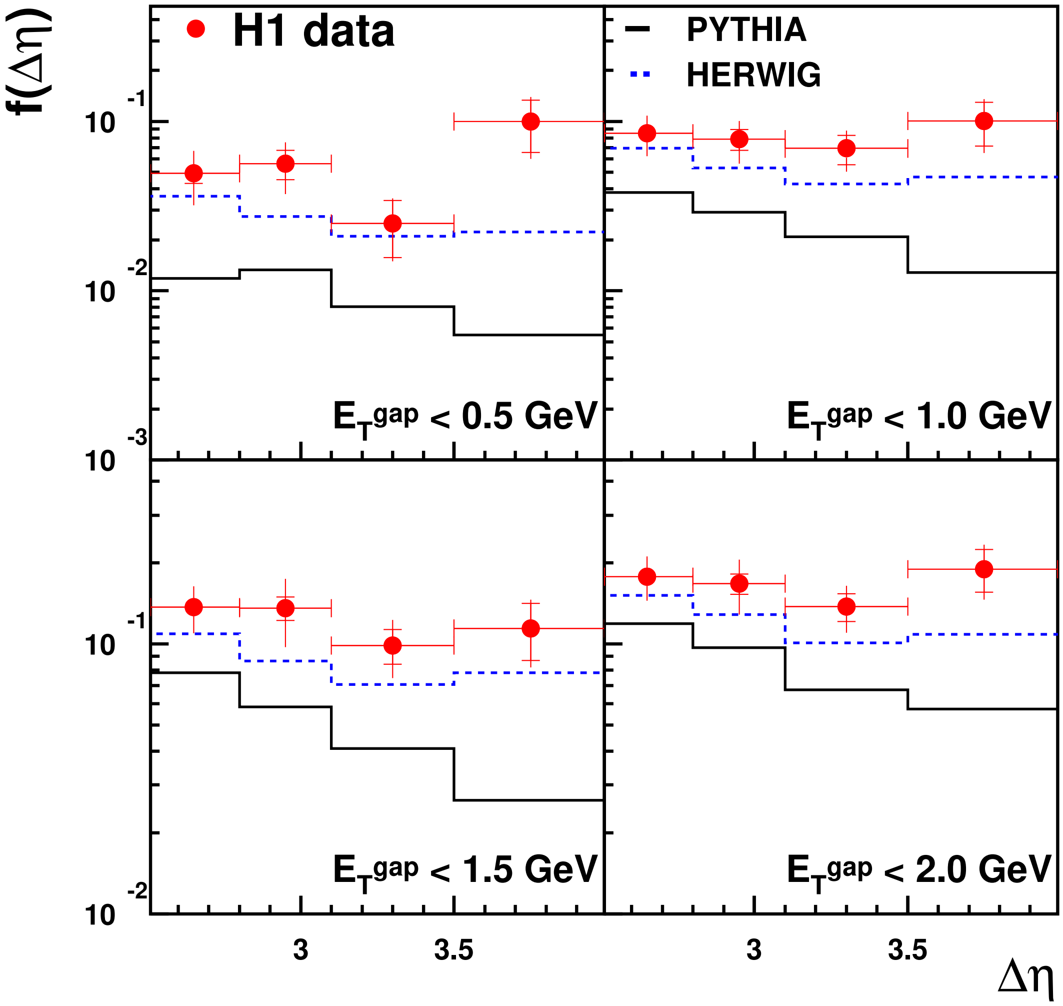
The Cross-section Differential in E_t^{gap}



$E_t^{jet1} > 6.0$ GeV , $E_t^{jet2} > 5.0$ GeV , $2.5 < \Delta\eta < 4.0$

- Clear excess at $E_t^{gap} < 0.5$ GeV over both Herwig and Pythia
- There are significant differences between the two predictions.

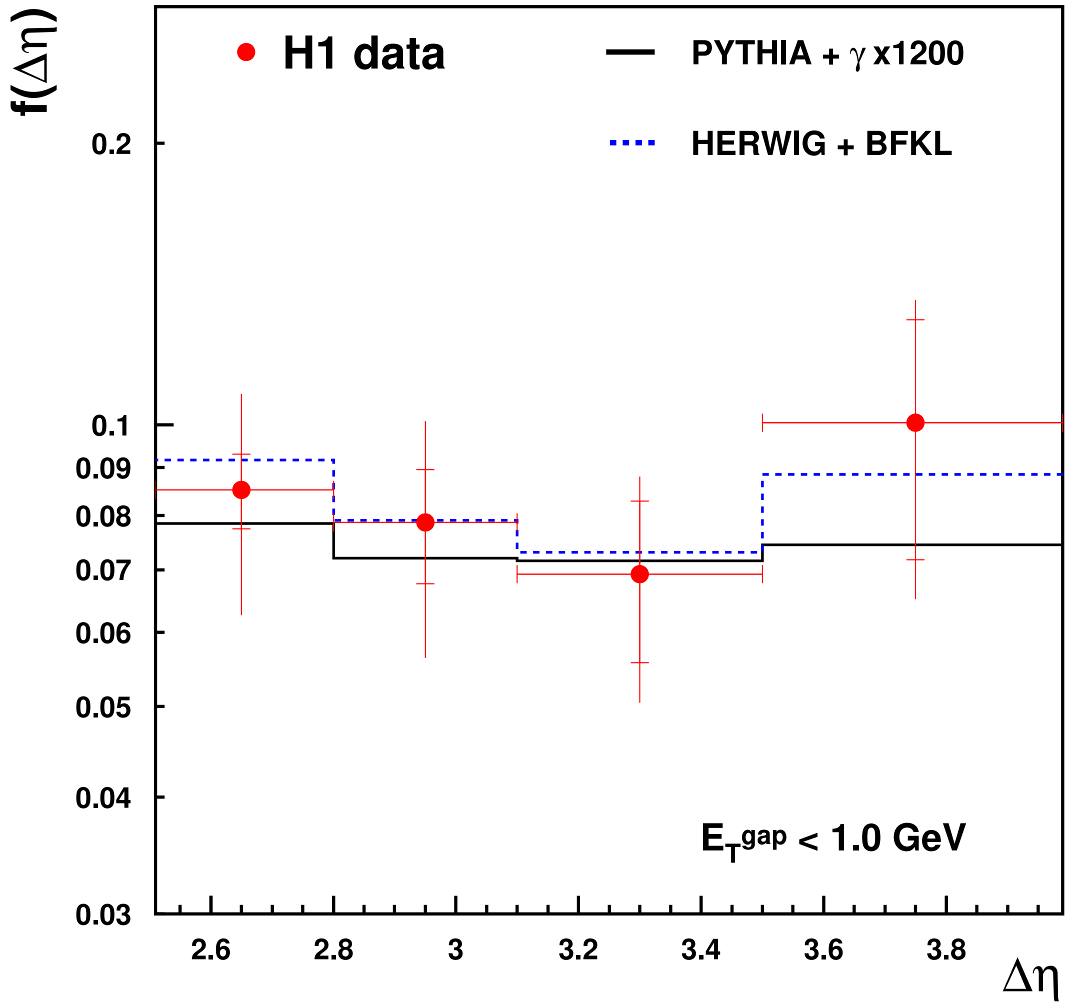
The Gap Fraction Differential in $\Delta\eta$



$E_t^{jet1} > 6.0$ GeV , $E_t^{jet2} > 5.0$ GeV , $2.5 < \Delta\eta < 4.0$

- Can plot the gap fraction for different gap definitions.
- PYTHIA prediction falls exponentially with $\Delta\eta$, data are flat or rising: diffractive

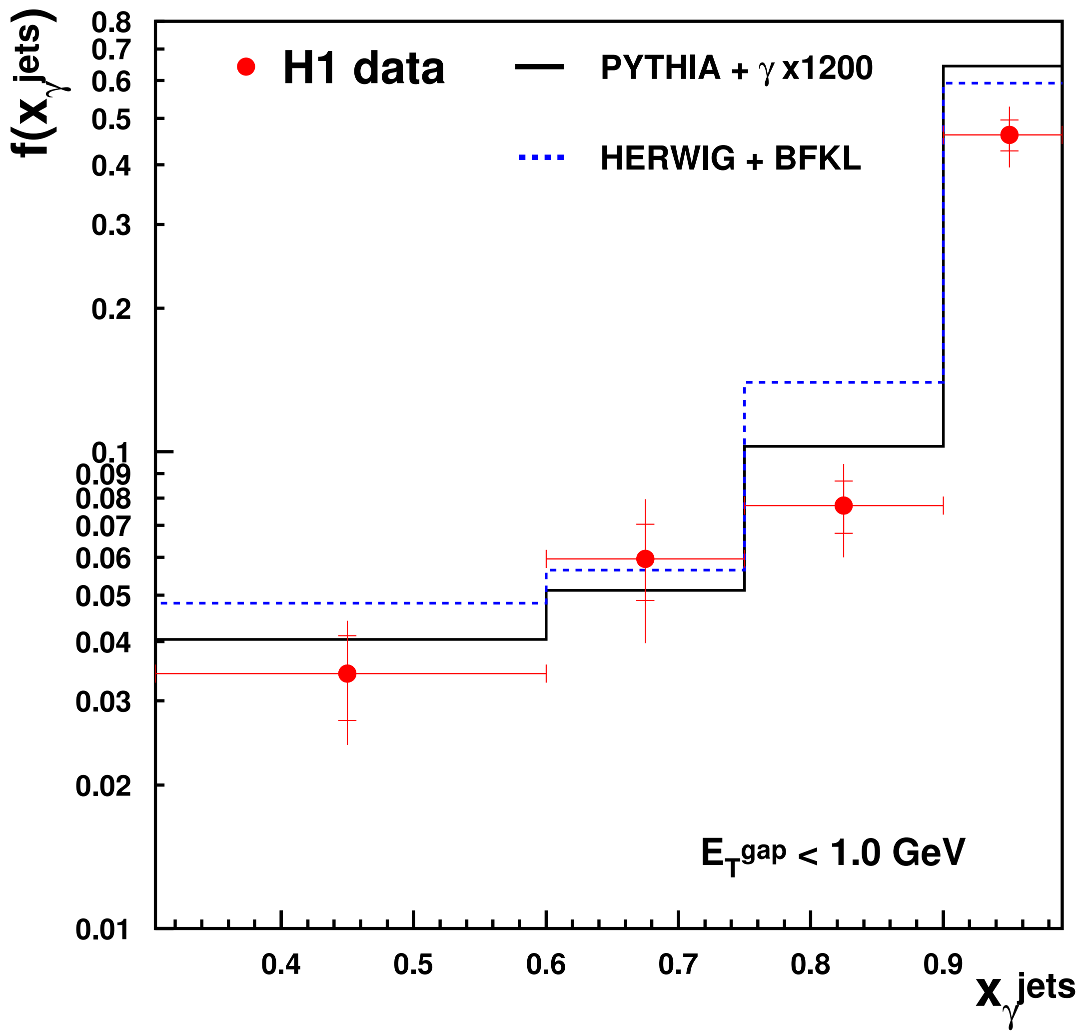
The Gap Fraction Differential in $\Delta\eta$



$E_t^{jet1} > 6.0$ GeV , $E_t^{jet2} > 5.0$ GeV , $2.5 < \Delta\eta < 4.0$

- Large $\Delta\eta$ similar to ZEUS: 11% at $\Delta\eta = 3.7$.
- LO BFKL describes data normalisation and shape $\alpha_s = 0.18$ ($\omega_0 = 0.48$, $\equiv \alpha(0) = 1.48$).

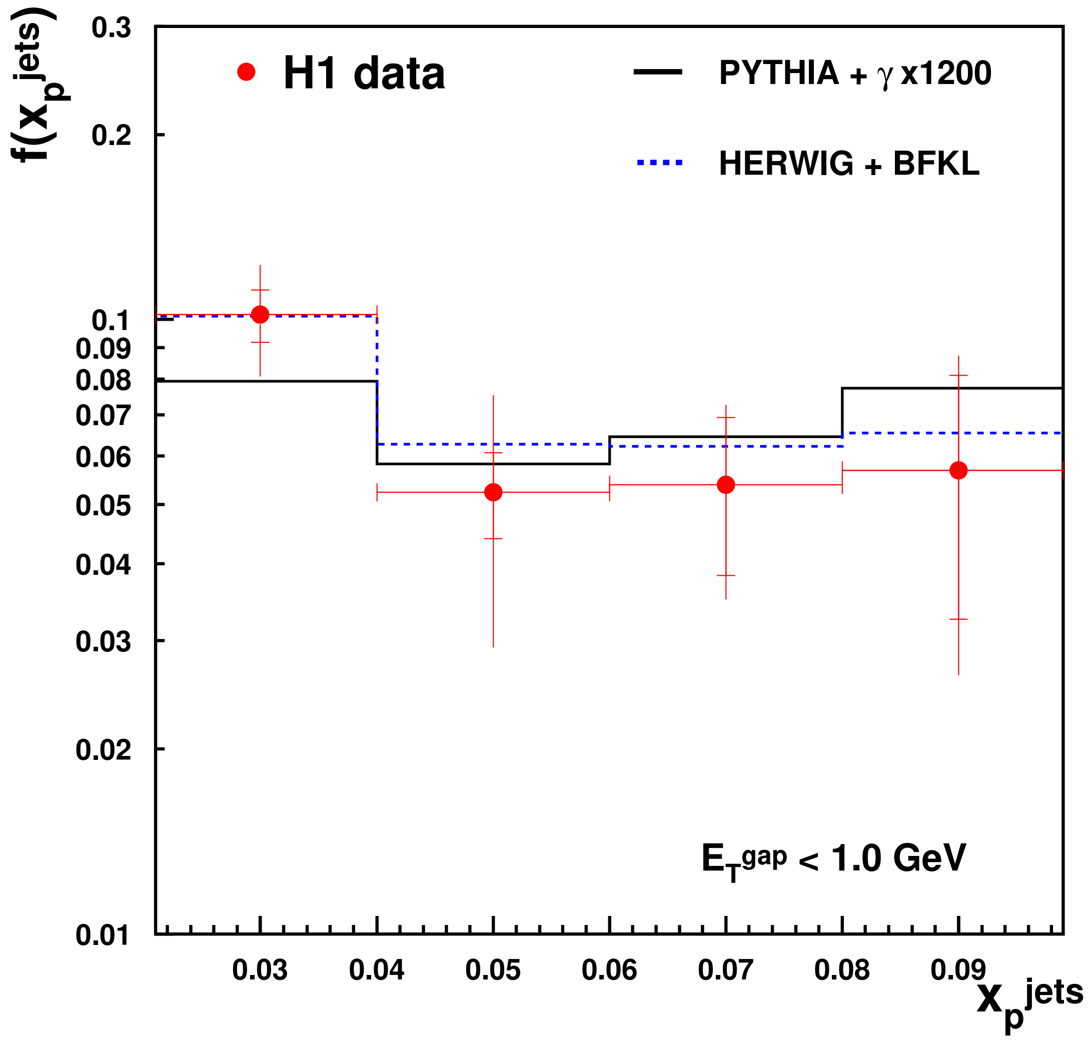
The Gap Fraction Differential in x_γ



$E_t^{jet1} > 6.0$ GeV , $E_t^{jet2} > 5.0$ GeV , $2.5 < \Delta\eta < 4.0$

- Standard photoproduction largely at high x_γ
  - Direct events more likely to produce gaps

The Gap Fraction Differential in x_p

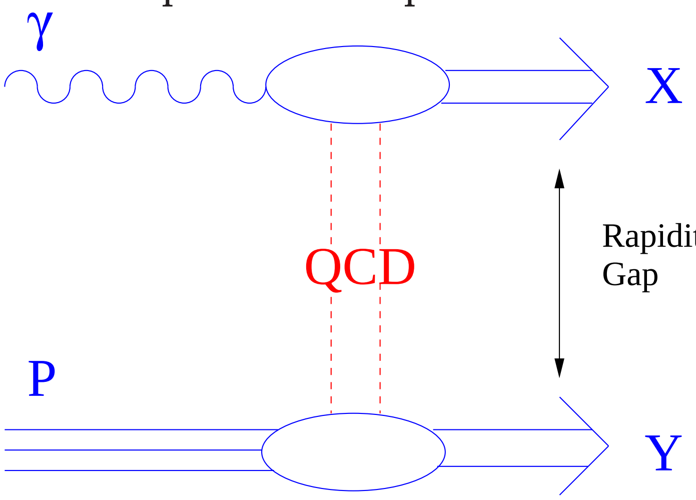


$E_t^{jet1} > 6.0$ GeV , $E_t^{jet2} > 5.0$ GeV , $2.5 < \Delta\eta < 4.0$

- In principle, could distinguish between models coupling preferably to quarks/gluons.
- Currently, insufficient statistics.

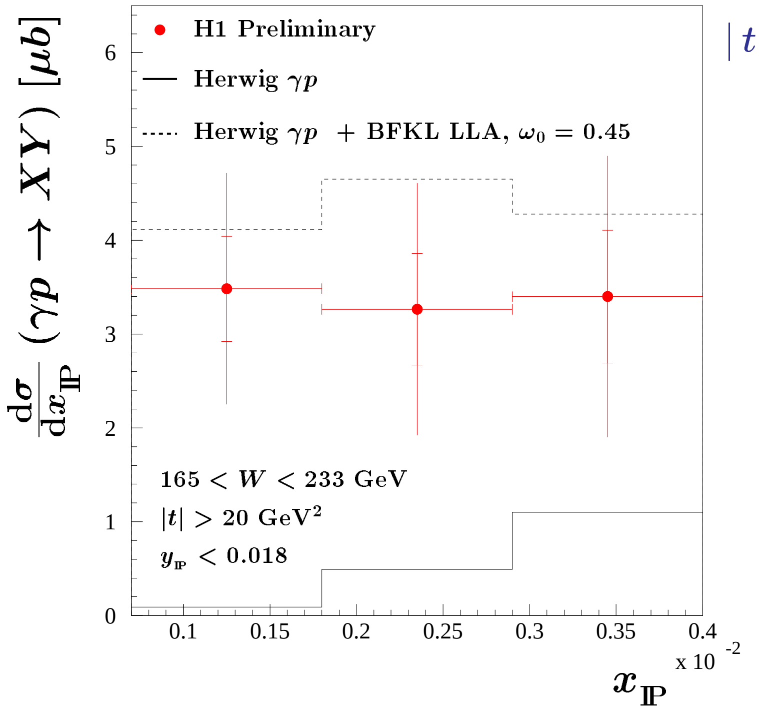
Double Diffraction Dissociation

At high $|t|$ both the proton and photon can dissociate:



X and Y are separated by the largest gap in the event.

Larger $\Delta\eta$ can be reached.



$|t| > 20\,\mathrm{GeV}^2$

Agreement with LLA BFKL with $\alpha_s = 0.17$

($\omega_0 = 0.45$,$\equiv \alpha(0) = 1.45$).

Conclusions

- Vector Mesons
  - New vector meson results allow higher precison over a larger kinematic region ($|t| < 21$ GeV^2).
  - Power-law behaviour of $\frac{d\sigma}{dt}$ suggests t can be used as a hard scale.
  - All cross sections can be described with LO BFKL $0.17 < \alpha_s < 0.29$.

    !! Although many theoretical uncertainties exist!!
- Gaps Between Jets
  - New definition is more infra-red safe, allows perturbative calculations
  - Evidence of an excess of events with a rapidity gap between jets
  - LO BFKL gives good description in both normalisation and shape for choice of $\alpha_s = 0.18$.
  - LO BFKL with $\alpha_s = 0.17$ also describes Double Dissociation well.

    !! Although MC and underlying event models also play a significant role !!