Rapidity gaps in strong and electroweak interactions

D. Rainwater and D. Zeppenfeld

Department of Physics, University of Wisconsin, Madison, WI 53706

An important characteristic of scattering events at the LHC is the color flow in the underlying partonic process. In forward scattering, where the t-channel exchange of light quanta dominates, color octet exchange of gluons vs. color singlet exchange of electroweak bosons or Pomerons are expected to lead to very different hadronization patterns. In t-channel color singlet exchange color coherence between initial and final state gluon radiation leads to soft gluon emission preferentially into the region between the beam and the forward scattered parton. This leaves the central region (between the two jets in a dijet event) free of gluons and their hadronization products. In t-channel color octet exchange, on the other hand, gluon radiation in the central region is preferred. t-channel color singlet exchange thus leads to a rapidity gap, *i.e.* a rapidity region of exceptionally low hadronic activity, for the fraction of pp collisions which produce no underlying event, *i.e.* for which there is no double parton scattering.

An excess of dijet events with rapidity gaps has already been observed at the Tevatron [1]. About 1% of all dijet events with rapidity separations $|\eta_{j_1} - \eta_{j_2}| \gtrsim 4$ exhibit anomalously low hadronic activity in the rapidity region between the jet cones. At the LHC, FELIX, with its unique angular coverage, can continue and extend these studies of rapidity gaps in dijet events.

Fig. 1 shows the dijet cross section as a function of the separation of jet definition cones, $\Delta\eta_c = |\eta_{j_1} - \eta_{j_2}| - 1.4$, and as a function of the maximal jet rapidity η_{max}, for E_T thresholds defining a jet of $E_T > 10$, 20, 30, and 50 GeV. For an integrated luminosity of 100 pb^{-1} and a 1% fraction of rapidity gap events, the dijet cross section in pb corresponds to the total number of rapidity gap events. From Fig. 1 it is then clear that FELIX can record meaningful samples of gap events with gaps which are 8 or even 10 units of rapidity wide. What is perhaps more important, FELIX can study the continuous transition from soft diffraction, mediated by Pomeron exchange

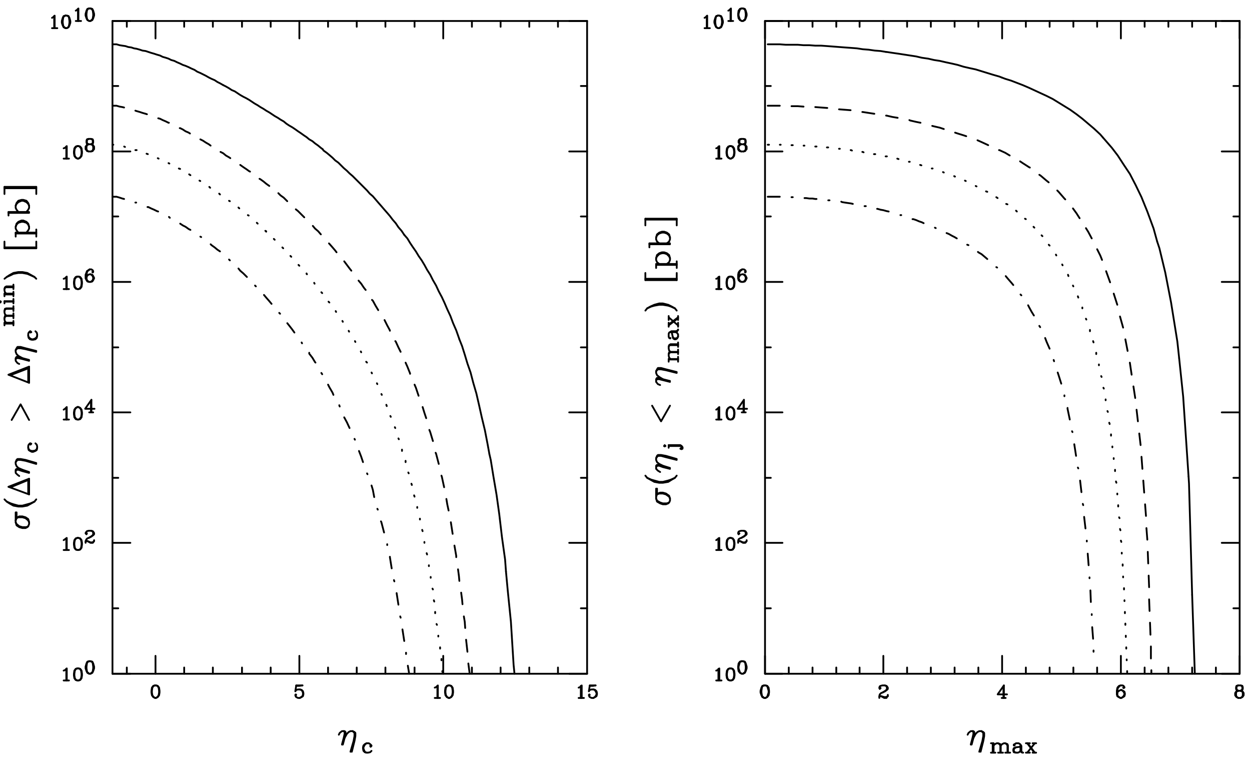

FIG. 1. Dependence of the dijet cross section on (a) the rapidity distance $\Delta\eta_c$ between the jet cones and (b) the rapidity range covered by the detector. Curves are for minimal jet E_T's of 10 (solid), 20 (dashed), 30 (dotted), and 50 GeV (dash-dotted lines).

with Q^2 in the 1 GeV^2 range or below to the hard gap events considered here, with a momentum transfer in excess of $Q^2 \approx p_{Tj}^2 \gtrsim 100$ GeV^2.

In a dijet event, with two jets at rapidities y_1 and y_2 and average transverse energy E_T, the momentum fractions of the initial partons can be reconstructed as

$$x_1 = \frac{E_T}{\sqrt{s}} \left(e^{y_1} + e^{y_2}\right) \ , \tag{1}$$

$$x_2 = \frac{E_T}{\sqrt{s}} \left(e^{-y_1} + e^{-y_2}\right) \ . \tag{2}$$

Symmetric events with $x_1 \approx x_2$ will be dominated by scattering of valence quarks for $x_1 \gtrsim 0.3$ and by glue-glue scattering for $x_1, x_2 \ll 0.01$. Asymmetric events with large x_1 but small x_2 on the other hand will be dominated by quark-gluon scattering. The large acceptance in rapidity of the FELIX detector will be crucial in separating these samples. Such a study will allow measurement of the fraction of rapidity gap events separately for quark-quark, quark-gluon and gluon-gluon scattering, an issue which is crucial for distinguishing different models of hard rapidity gap events. Bjorken's model [2] views rapidity gaps as being due to two-gluon color singlet exchange in the t channel and predicts, due to the stronger coupling of the gluons to the color octet charge of the scattered gluons, an enhanced rapidity gap fraction in glue-glue scattering. A color evaporation model, on the other hand, makes it more difficult for the color octet charge of scattered gluons to be bleached and implies that the rapidity gap fraction is largest for quark-quark scattering [3]. FELIX will be able to discriminate between these possibilities.

In dijet production the objective is to study rapidity gaps in strong interaction events. The very small fraction of genuine color singlet exchange events, via t-channel γ, Z, or W exchange, will be masked by gluon exchange events which exhibit the same angular distributions at large $\Delta\eta_c$ and hence cannot be reduced by kinematic cuts. The situation is more promising for single W or Z production events, mediated by t-channel electroweak boson exchange as shown in Fig. 2.

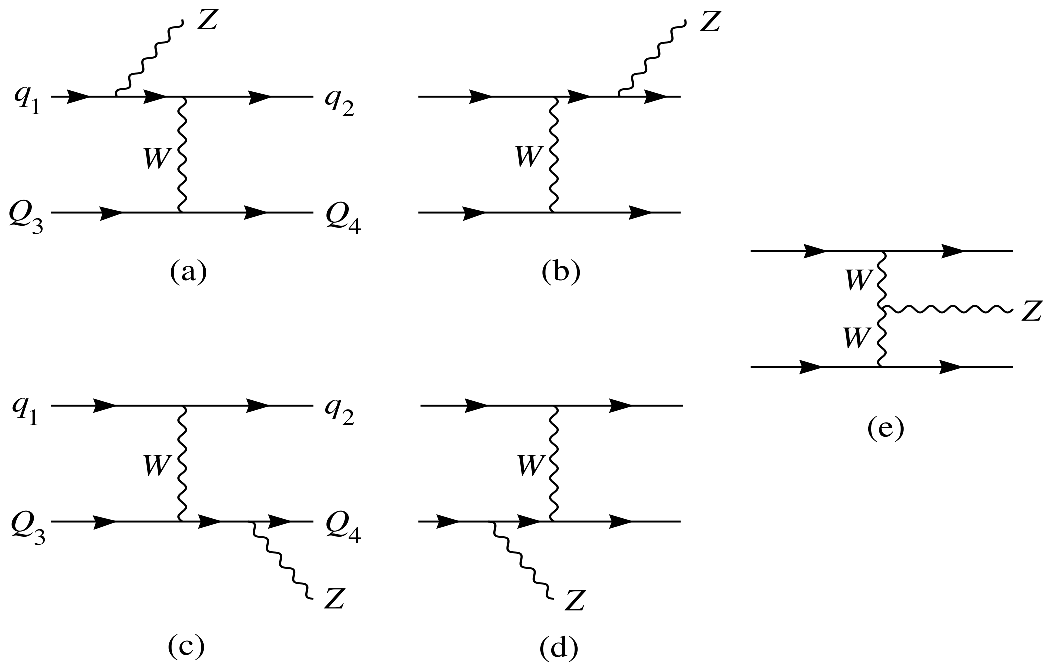

FIG. 2. Feynman graphs for Zjj production via charged-current exchange. The WW-fusion graph (e) simulates weak-boson scattering processes.

The signature for these events are two forward tagging jets and the charged decay leptons from the Z or W. The gauge boson fusion graph of Fig. 2(e) has no analogue in the main

TABLE I. Signal and background cross sections $B\sigma$ for Zjj and Wjj events. Leptonic decays of the W or Z into electrons and muons are considered. Results are given in units of pb after increasingly stringent cuts.

	Zjj signal	Zjj bkgd	Wjj signal	Wjj bkgd
forward jet tagging, [Eq. (4)]	0.153	6.4	2.2	63
+ $m_{jj} > 2500$ GeV, $\Delta\eta_{\ell j} > 1.6$	0.019	0.056	0.29	0.68

background processes, Wjj or Zjj production via QCD corrections to the Drell-Yan process, and hence acceptance cuts can be imposed which suppress these backgrounds below the signal rate [4]. Unfortunately one is left with relatively small signal rates.

As an example, we require leptons to be well isolated from jets, $R_{\ell j} = \sqrt{(\eta_\ell - \eta_j)^2 + (\phi_\ell - \phi_j)^2} > 0.7$ and to have minimal transverse momentum $p_{T\ell} > 20$ GeV. In addition, the dilepton invariant mass must be consistent with Z decay,

$$m_Z - 10 \text{ GeV} \; < \; m_{\ell\ell} \; < \; m_Z + 10 \, \text{GeV} \, . \tag{3}$$

For jets we require $p_{Tj} > 20\,\text{GeV}$ and $R_{jj} > 0.7$. Within these generic cuts the signal is still completely swamped by the QCD background processes. The boson fusion process of Fig. 2(e) can be enhanced by imposing a wide separation between the two tagging jets, and requiring them to reside in two opposite detector hemispheres and to be less central than the decay leptons:

$$|\eta_j^{\text{tag1}} - \eta_j^{\text{tag2}}| > 4.4 \, , \qquad \eta_j^{\text{tag1}} \cdot \eta_j^{\text{tag2}} < 0 \, , \tag{4a}$$

$$\eta_j^{\text{tag1}} + 0.7 < \eta_\ell < \eta_j^{\text{tag2}} - 0.7 \qquad \text{or} \qquad \eta_j^{\text{tag2}} + 0.7 < \eta_\ell < \eta_j^{\text{tag1}} - 0.7 \, . \tag{4b}$$

With these cuts one finds the cross sections in the first row of Table I. A signal to background ratio around 1:30 is achieved, which still is not sufficient to study the signal processes.

The source of the problem is shown in Fig. 3. Here the minimal transverse momentum of the two tagging jets is shown, for the cuts listed above. For both Wjj and Zjj production the QCD backgrounds exhibit a much steeper p_T^{min} dependence than the electroweak signal, and much higher transverse momenta than 20 GeV must be required for the tagging jets to achieve

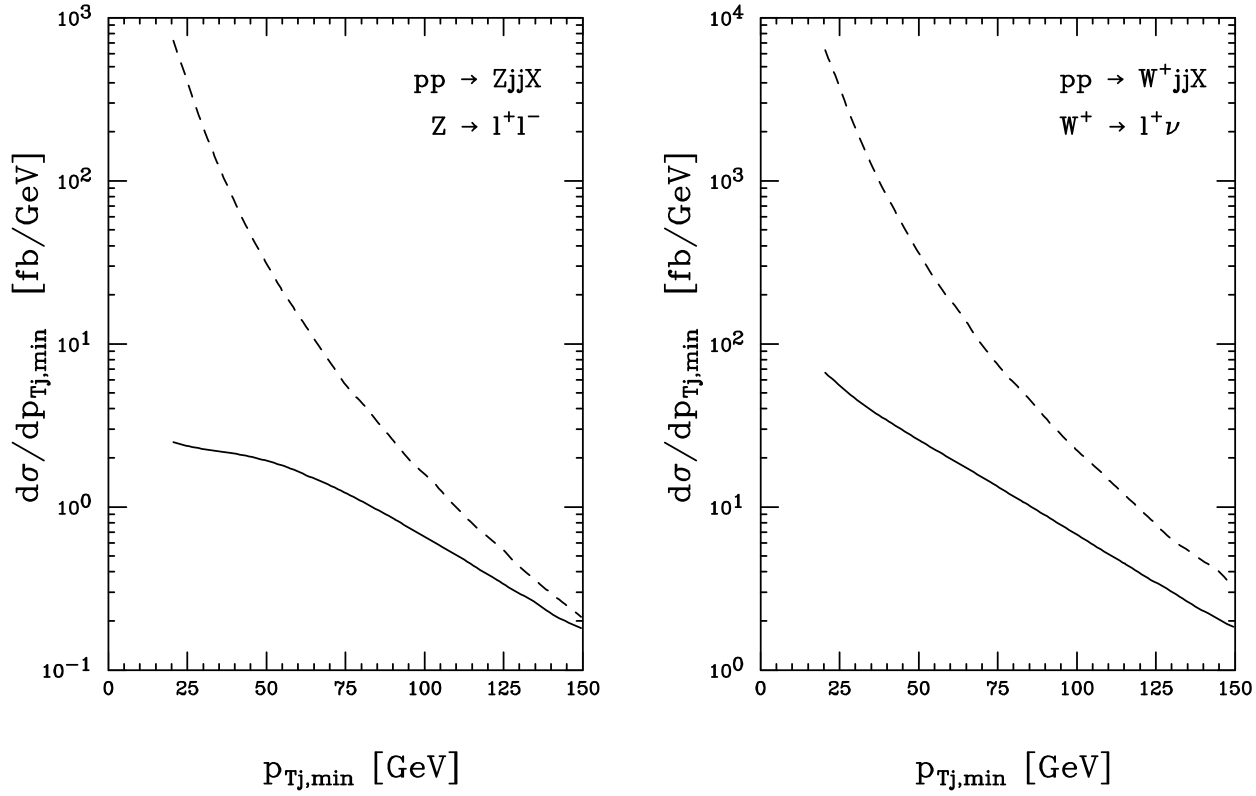

FIG. 3. Dependence of (a) the Zjj cross section and (b) the Wjj cross section on the minimal transverse momentum required for the two tagging jets. Results are shown for the electroweak signal (solid line) and for the QCD Vjj background (dashed line), after the tagging cuts of Eq. 4.

acceptable signal to background ratios. Higher p_T^{tag} thresholds, however, reduce the event rates, and they force the entire event into the central part of the detector. This means that the large angular coverage of the FELIX detector is not really exploited for the study of these events. Another possibility is to require a very large invariant mass of the two tagging jets and a larger separation of tagging jets and leptons in pseudorapidity:

$$m_{jj} > 2500 \text{ GeV} , \qquad \Delta\eta_{\ell j} = \min_{\ell,j} \{|\eta_\ell - \eta_j^{tag}|\} > 1.6 , \tag{5}$$

Results after these cuts are shown in the second row of Table I. The small signal rates for Wjj or Zjj events imply that FELIX must run at the highest possible luminosity. Even then only about 5-10% of the signal events are expected to exhibit rapidity gaps and one is thus left with marginal event samples to study further details of rapidity gap generation in electroweak color singlet exchange events.

REFERENCES

[1] D0 Collaboration, S. Abachi et al., Phys. Rev. Lett. **72** (1994) 2332; CDF Collaboration, F. Abe et al., Phys. Rev. Lett. **74** (1995) 855; D0 Collaboration, S. Abachi et al., Phys. Rev. Lett. **76** (1996) 734.

[2] J. D. Bjorken, Int. J. Mod. Phys. **A7**, 4189 (1992); Phys. Rev. **D47**, 101 (1993); D. Zeppenfeld, UW-Madison preprint MADPH-96-933 (1996) [hep-ph/9603315].

[3] O. J P. Eboli, E. M. Gregores, and F. Halzen, UW-Madison preprint MADPH-96-965 (1996) [hep-ph/9611258].

[4] D. Rainwater, R. Szalapski, and D. Zeppenfeld, Phys. Rev. **D54**, 6680 (1996), [hep-ph/9605444].