Radiation of gluons gives rise to extra jets in top quark events that can lead to complications in event reconstruction and mass measurement. I review recent results for gluon radiation in top quark production and decay, and discuss their implications for top quark physics.

1 Tevatron

The presence of extra jets in $t\bar{t}$ events can complicate attempts to reconstruct the mass of the top quark from the momenta of its decay products. Depending on whether the associated gluon was emitted during top production or decay, it may or may not be appropriate to include its momentum in top reconstruction. Unfortunately, it is not easy to tell the difference. Therefore we must consider top production and decay together in our treatment of gluon radiation.

We have computed the complete order $\alpha_s^3$ tree-level cross section for $t\bar{t}$ production and decay with an extra jet at the Tevatron and the LHC; for more details see the references. At the Tevatron we find that the contribution (after kinematic cuts) from gluons radiated in the top production process is comparable to that from decay. As we might expect, the decay-stage gluons appear mostly in the central rapidity region. Production-stage radiation occupies a wider rapidity range, but it, too, contributes substantially in the central region. The distribution in the angle between the extra jet and the $b$ quark is dominated at small angles by the decay-stage contribution, but the production-stage piece is non-negligible in that region as well. The bottom line is that there is no clear way experimentally to distinguish the two contributions, and they must be taken into account together in our analyses.

2 LHC

The higher energy of the LHC compared to the Tevatron leads to a large increase in radiation in $t\bar{t}$ events, most of it associated with production. The increase

---

*a*Presented by L.H. Orr at the 1996 Meeting of the Division of Particles and Fields, Minneapolis, MN, August 10–15, 1996
Figure 1: $\sigma(t\bar{t}j)/\sigma(t\bar{t})$ for $E_T > E_T$ at the Tevatron (solid line) and LHC (dashed line).

Figure 2: Distributions in (a) the minimum $\Delta R$ and (b) the minimum $y$ for additional jets produced in $e^+e^-$ collisions at 360 GeV c.m. energy.

is due to the larger color charge of the $gg$ initial state which dominates at the LHC, the behavior of the parton distributions, and the phase space available for radiating a gluon. The amounts of production-stage radiation at the Tevatron and LHC can be seen in Fig. 1 where we show $\sigma(t\bar{t}j, E_T > E_T)/\sigma(t\bar{t})$ as a function of $E_T$. For all values of the $E_T$ cut, the ratio of (tree-level) NLO to LO cross sections is much larger at the LHC.

The rapidity distribution of extra jets in top production and decay at the LHC is relatively flat. It is dominated by the production-stage contribution; the exact proportions depend on cuts on the jet $E_T$ and $\Delta R$ between the jet and $b$ quarks. The distribution in $\Delta R$ is dominated by the production contribution for all values above 0.4. This abundance of radiation at the LHC can lead to difficulties in momentum reconstruction when, for example, production stage radiation gets included in top decay products’ jet cones.

3 Comparison with HERWIG

It is useful to compare the results from the fixed-order QCD calculation described above to those obtained from commonly used Monte Carlo programs which gener-
ate extra jets via parton showers. In previous work, a comparison of our results with those from HERWIG version 5.8 revealed discrepancies in regions where the two calculations should agree. HERWIG 5.8 was later shown to contain a bug which caused decay-stage radiation to be suppressed.

In the most recent version of HERWIG (5.9), the restoration of decay-stage radiation leads to better agreement. Some questions still remain, however: there now appears to be too much decay-stage radiation in HERWIG compared to the matrix-element result. This is most easily seen for $e^+e^-$ colliders, where there are no complications due to initial-state gluon radiation. We consider gluon radiation in top production and decay at center-of-mass energy 360 GeV, just above top pair threshold, so that most of the gluons originate in the decays. In Fig. 2 we show the distributions in the minimum $\Delta R$ and $y_{\text{Durham}}$ for jet pairs in top events. We see that HERWIG 5.8, with the bug, vastly underestimates the exact matrix-element distribution, while HERWIG 5.9 overestimates it. More subtle is an additional discrepancy in the production-stage radiation which appears on the jet rapidity distribution at hadron colliders. The HERWIG distribution shows a slight dip in the central region; the matrix element distribution does not. It appears that HERWIG still needs a hard correction for gluon radiation from quarks as heavy as top.

As statistics improve, systematic uncertainties associated with gluon radiation will dominate top physics, $m_t$ measurements especially. It is important that the relevant physics is incorporated correctly in experimental analyses.

Acknowledgments

This work was supported in part by U.S. D.O.E. grant DE-FG02-91ER40685.

References

1. L.H. Orr, T. Stelzer and W.J. Stirling, Phys. Rev. D 52, 124 (1995).
2. L.H. Orr, T. Stelzer and W.J. Stirling, preprint UR-1473, August 1996.
3. L.H. Orr, T. Stelzer and W.J. Stirling, Phys. Lett. B 354, 442 (1995).
4. G. Marchesini et al., hep-ph/9607393, and references therein.