SLAC – PUB – 3429
August 1984
(T/E)

COHERENT QCD RADIATION FROM ACTIVE AND SPECTATOR JETS AT THE SSC*

STANLEY J. BRODSKY
Stanford Linear Accelerator Center
Stanford University, Stanford California 94305

Abstract

A gauge theory model is given which accounts for spectator jet radiation, interference effects between spectator and active jets, and coherence corrections when final state quark and gluon jets overlap. A simple Abelian complex color charge model can be used to mimic the QCD coherence effects.

Recently there has been important progress[1–3] in understanding particle production mechanisms and coherent effects in QCD involving the "active" quark and gluons which participate in high momentum transfer reactions. However, the soft gluon radiation and hadronization of the "spectator" constituents produced at low momentum transfer has not been discussed in detail. Since the hard scattering subprocesses generally leave the spectators with non-zero color, radiation along the forward direction will occur. An understanding of the interference effects between active and spectator systems is necessary for a meaningful separation of high and low p_T jets in the low z overlap region as well as for an interpretation of the high p_T jet "pedestals". In the case of collisions at the SSC, the properties of spectator jets [qq, $(qqq)_8$, etc.] could in principle be used to distinguish the various hard scattering reactions.

The simplest gauge theory example which includes the effects of spectator radiation is positronium-positronium hard-scattering collisions in QED. [See Fig. 1(a).] Consider an event where an electron and positron are scattered to large angles with $p_T^2 \gg m_e^2$. In association with the high momentum transfer pair, the final state consists of:

(a) High-momentum-transfer photons and leptons emitted in higher order subprocesses. If the kinematics of the particles produced in the final state all satisfy $p_i \cdot p_j > \beta p_T^2$ ($\beta \neq 0$), then these reactions occur at relative order $\frac{1}{\pi}\ \alpha(p_T^2) \log \frac{1}{\beta}$ or higher. [See Fig. 1(b).]

(b) Collinear photons and lepton pairs radiated from the constituents active in the hard scattering reaction, with invariants in the range $\epsilon < p_i \cdot p_j < \beta p_T^2$. [See Fig. 1(c).] The lower limit $\epsilon \cong \langle k_\perp^2 \rangle \geq O(\alpha^2 m^2)$ is the off-mass-shell scale set wavefunctions. The collinear radiation is responsible for structure and fragmentation function evolution up to the scale βp_T^2. It can be computed to leading order in α/π using angle (or rapidity) ordering.[1–3]

(c) Soft photon radiation[4] emitted from the *outgoing* leptons with invariant momenta satisfying $k \cdot p_i < \epsilon$. The QED radiation pattern[5] is computed from a coherent sum over all of the active and spectator charged lines which appear in the final state:

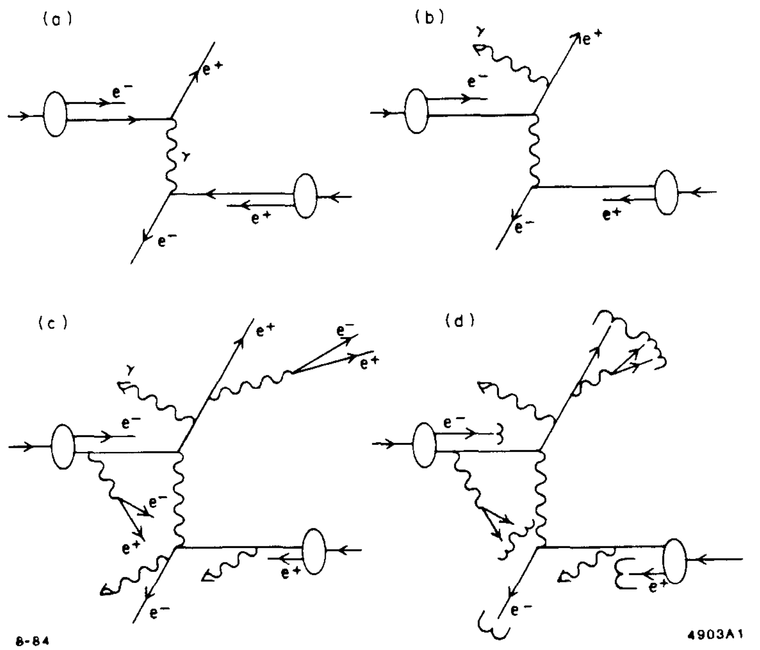

Fig. 1. Radiation associated with hard scattering in positronium-positronium scattering. Figure (d) indicates the classical radiation pattern from the outgoing charged lines computed from Eq. (1).

* Work supported by the Department of Energy, contract DE–AC03–76SF00515

Contributed to the 1984 Summer Study on the Design and Utilization of the Superconducting Super Collider, Snowmass, Colorado, June 23 - July 13, 1984.

$$2(2\pi)^3 \frac{dN}{d^3k/E_k} = \left| \sum_{i=out} e_i \frac{p_i \cdot \epsilon}{p_i \cdot k} \right|^2 , \qquad (1)$$

as indicated schematically in Fig. 1(d). This soft photon result automatically contains all coherent effects between overlapping radiators: e.g. two collinear positions emit *four* times the radiation of one positron. The radiation from spectator systems is insensitive to the high p_T scale: at large transverse momenta, the photons emitted from spectators fall-off as $k_\perp^{-4}$, compared to $k_\perp^{-2}$ for radiation from active lines (for $k_T^2 \ll p_T^2$).

The situation for radiation in QCD is of course much more complex than the above Abelian example due to confinement and non-perturbative effects. However, using perturbation theory as a guide, we can make a model for soft radiation effects and the energy flow in hadronic collisions by mimicking the above steps (a)-(c), in each case keeping track of the color labeling for each subprocess. The charge for outgoing quarks in Eq. (1) is replaced[3] by the color matrix gT_a, $a = 1, \ldots, 8$. [path ordering is necessary for computing higher orders in perturbation theory]. This model accounts for spectator jet radiation, interference effects between spectator and active jets, and coherence corrections when the final state quark and/or gluon jets overlap.

There is even a simpler way to mimic the color coherence effects of final state radiation. We assign a Z_3 "complex color charge" to the three quarks

$$e_R, e_Y, e_B = 1, e^{i2\pi/3}, e^{i4\pi/3} , \qquad (2)$$

so that the charge of any color-singlet hadron is zero. The gluon charge is obtained additively

$$e_{R\bar{Y}} \equiv e_R + e_{\bar{Y}} = e_R - e_Y . \qquad (3)$$

The radiation pattern for an Abelian "photon" coupled to this charge can then be computed in leading order directly from Eq. (1), producing a simple model for the distribution of hadronic energy radiation.

Coherence effects between overlapping colored systems including the spectator particles are automatically included. For example, a gluon exchange subprocess leads to constructive interference between the quark jet scattered to large p_T and a spectator antiquark.[6] The average squared gluon charge $|\overline{e^2}|_g$ is 9/4 that of the quark, in agreement with the leading order result for the relative energy density of gluon versus quark jets as in QCD.[1,4] All of the predicted coherence effects are of relative order $1/N^2$ for color $SU(N)$. It would be interesting to compare this computationally simple model[7] with energy densities measured for different jet configurations in $e^+e^- \to q\bar{q}g$, and $\Psi \to ggg$ decays as well as in high p_T hadron collisions.

Acknowledgements

I would like to thank J. Collins, S. Ellis, T. Gottschalk, J. Gunion, A. Mueller, M. Peskin, and G. Veneziano, for helpful conversations.

References

1. J. B. Gaffney and A. H. Mueller, Columbia preprint CU-TP-285 (1984).
2. G. Marchesini and B. R. Webber, Nucl. Phys. B238, 1 (1984), G. Marchesini, Parma preprint UPRF-113 (1984).
3. S. Catani and M. Ciafaloni, Firenze preprint DFF-61/84 (1984).
4. S. J. Brodsky and J. F. Gunion, Phys. Rev. Lett. 37, 402 (1976). D. Amati, and G. Veneziano, Phys. Lett. 83B, 87 (1979).
5. D. R. Yennie, S. C. Frautschi and H. Suura, Ann. Phys. 13, 379 (1961).
6. S. Ellis, private communication.
7. Although the charge is complex, the results are hermitian to leading order.