STAR Note 242
Version 1.00
March 14, 1996

Jet Quenching using Gamma-Jet Events

Thomas J. LeCompte and David G. Underwood
Argonne National Laboratory

1 Introduction

One goal of the heavy ion program at STAR is the study of jet quenching. The energy loss of propagating quarks and gluons is expected to be sensitive to the medium of propagation. A jet passing through nuclear matter is expected to lose energy to this medium and thus appear attenuated and broader. On the other hand, a Quark-Gluon Plasma is expected to be more transparent and therefore increase the yield of jets.

It has been suggested that the way to go after this physics is via event-by-event photon-jet balancing. If you have a hard scattering resulting in a direct photon recoiling off a jet, leading order QCD predicts that $E_T(\gamma) = E_T(\text{jet})$. By comparing the measured jet (transverse) energy to the measured photon (transverse) energy, one measures how much energy the jet has lost to the medium. Typical energy losses are expected to be a few GeV.

Although this technique appears to be promising, upon closer examination there are serious difficulties which suggests that alternative analyses may be far more fruitful. In this note, we attempt to outline some of these difficulties.

2 k_T kick

While at leading order, QCD predicts $E_T(\gamma) = E_T(\text{jet})$, this is not true at next-to-leading order.

The assumption that the photon E_T is an accurate probe of the parton p_T that gives rise to the jet can be tested. The traditional test is to look at diphoton events, and to see how well the E_T of one photon balances the E_T of the other: the difference is the k_T "kick" given to the diphoton system. Results from several experiments [1] indicate that at 200 GeV per nucleon we can expect an average k_T of 2 GeV, with substantial tails.

Because the partons involved in the hard scatter have typically a GeV or a few GeV of p_T with respect to the beam axis, the event-by-event balancing already has a fundamental uncertainty comparable in size to the effect one wants to measure. This is completely independent of the detector design or choice of technology: it is simply a consequence of the physics of hadron-hadron collisions.

3 Underlying Event Fluctuations

3.1 Photon Effects

In a detector with $\Delta\eta \times \Delta\phi$ towers of 0.1×0.1, we find that there is 640 ± 520 MeV of underlying event energy per tower. The 520 MeV fluctuation can be treated as a constant term in the resolution: $\Delta E = .16\sqrt{E} \oplus .52$. For photons above about 10 GeV, the $16\%/\sqrt{E}$ term dominates anyway.

3.2 Jet Effects

Jets present a more significant problem than photons. The smallest cone size one can reasonably use is $R(\equiv \sqrt{\Delta\eta^2 + \Delta\phi^2}) < 0.4$. Typically 25% of the energy inside a cone of $R < 1.0$ is *not* in a cone of $R < 0.4$. We looked at generic central Au-Au HIJING events, and measured the energy in a random cone of $R < 0.4$. (Actually, five random cones per event in 25 events.)

In these events, we find that at the generator level (i.e. no detector effects), the average transverse energy in a cone of 0.4 is 45.7 GeV, and the 1σ fluctuation was 6.8 GeV. Here the energy was obtained by summing up the p_T's of the tracks and the E_T's of the photons, and then correcting for the 7.5% of the energy in neutrons, antineutrons, and K_L^0's.

Because only 75% of the jet energy is in this core, the 6.8 GeV mean fluctuation in the cone energy corresponds to 9.05 GeV in the jet energy. That is, the 1σ uncertainty on a jet energy due just to the underlying event is ± 9 GeV.

There are many ways to define what is the minimum reconstructible jet. If one makes the particular choice that the requirement on the jet is that the probability of a fluctuation of any cone of 0.4 anywhere in the detector be as small or smaller than the probability of a 3σ upward fluctuation in a Gaussian distribution, one obtains 36 GeV as the minimum reconstructible jet. Looser requirements will reduce this threshold somewhat, and tighter requirements will increase it.

Again, this is completely independent of the detector design or choice of technology: it is simply a consequence of the physics of hadron-hadron collisions.

4 Yields

The EMC CDR[2] says that the yield of photon+jet events with $E_T(\gamma)$ between 10 and 20 GeV (essentially, that is most of the yield above 10 GeV) is 6400 events per month in *pp* collisions at 200 GeV.

In AuAu, the luminosity is $2 \times 10^{26}\mathrm{cm}^{-2}/\mathrm{s}$ rather than the $8 \times 10^{31}\mathrm{cm}^{-2}/\mathrm{s}$ for *pp*. However, the direct photon cross section is larger in AuAu. How much larger is unmeasured (that's why we are running the experiment, after all), but a reasonable guess is that since there are 200 times as many nucleons participating in the collision, the cross section is $A^{4/3}$ or 1170 times larger. This results in a yield of roughly 19 events per month or 225 events per year.

A photon of 10 GeV will recoil off a jet of approximately 10 GeV, so even these 40 events have large uncertainties in the jet energies: as shown above, a 10 GeV jet has an uncertainty in its energy of 100%! Moving the photon energy up to 15 GeV (to try and get higher energy and thus better measured jets) reduces the yield to 15 events. A 20 GeV requirement has an expected yield of between 1 and 2 events. Since only a small fraction of collisions are expected to form a plasma, this is further reduced by a large factor. To summarize, the rate of $\gamma+$jet events in AuAu is too small to make the measurement in this way, by a large factor.

Again, this is independent of the choice of calorimeter technologies: the inputs are just the size of the detector in $\eta - \phi$ space, the luminosity of RHIC, and the photon-jet cross section.

5 Alternatives

We are certainly not arguing that it is impossible to measure jet quenching. We are, however, arguing that γ-jet balancing is not the way to do it. To increase the yield over the γ-jet technique, it makes sense to investigate mechanisms that require only jets or a single jet, such as $d\sigma/dE_T$. To avoid the difficulty with cone algorithms, one might look at global variables that are correlated with the "jettiness" of an event - sphericity, aplanarity, thrust, higher moments in energy flow, these are all possible choices. (For example, the sphericity of an event is lower if the event contains jets than if it does not.) The degree of jet quenching will affect the distribution of these global variables. Observations in AuAu can be compared to theoretical predictions directly, or with pp or lighter ion data.

Another possibility is to study the single particle p_T distributions, which are driven by jet activity at high p_T. The EMC allows one to do this with π^0's, either stand-alone, or in combination with the TPC's equivalent measurement using $\pi^{\pm}$'s.

6 Conclusions

Measuring jet quenching using photon-jet balancing in AuAu collisions at RHIC appears impossible. First, the very premise that $E_T(\gamma) = E_T(\text{jet})$ is only good to about 2 GeV, which is the size of the effect we are trying to measure. Second, the statistical fluctuations in the underlying event introduce a 9 GeV uncertainty in measuring jet energies using even small cone sizes, and make the determination of whether an energy cluster was due to a jet or a fluctuation difficult below about 36 GeV. Finally, even if neither of these problems existed and we could accurately measure 10 GeV jets and photons, we only expect to record a few hundred events or so per year, far too few to make a precise measurement, especially when one considers that only small fraction of events form a QGP.

None of these conclusions are specific to the choice of EMCal technology. They rely only on the underlying AuAu event physics and the acceptance of STAR.

References

[1] F. Abe *et al.*, Phys. Rev. Lett. **70**, 2232 (1993) More recent CDF results are in agreement with this publication.

[2] M.E. Beddo *et al.* "The Electromagnetic Calorimeter for the Solenoidal Tracker at RHIC: A Conceptual Design Report" PUB-5380