TEST OF COHERENT VERSUS INCOHERENT SHOWER DEVELOPMENT

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ABSTRACT

We compare the results of conventional incoherent shower development in a Monte Carlo program to the results of shower development with angular ordering to represent soft gluon interference. The comparison uses the energy-energy correlation function as a measure of the width of 3 TeV jets. We find that angular ordering gives better agreement with the analytic QCD result.

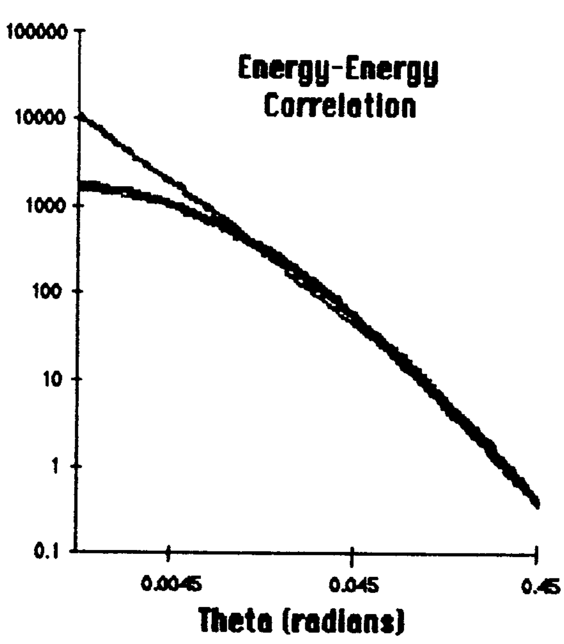
In this note, we compare two different methods of generating final state parton showers in Monte Carlo event generating programs that simulate Quantum Chromodynamics. In these programs, parton decays are generated with a probability proportional to the lowest order matrix element for an off shell parton to decay into two nearly on shell partons. In the conventional method, based on [1], there is no restriction on the angle between the daughter partons. The coherent method, based on [2], is more sophisticated. In order to account for cancellations [3] between real and virtual graphs involving soft gluons, the angle between the daughter partons at any stage in a parton shower development is restricted to be less than the corresponding angle at the previous generation.

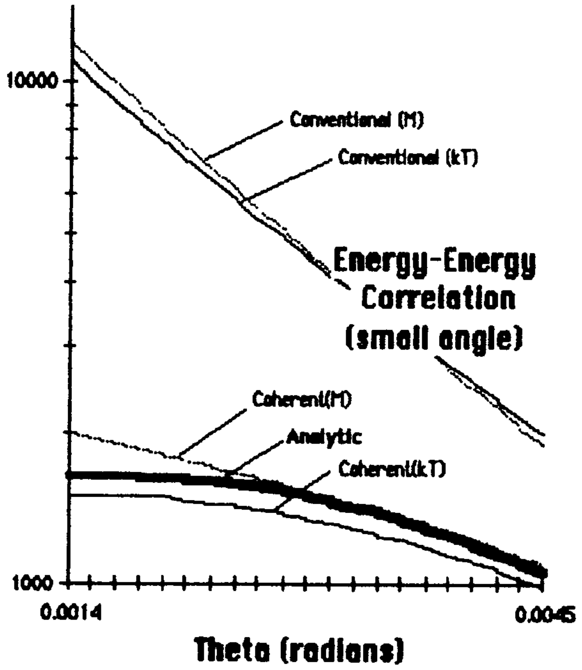
We have used the Lund Monte Carlo described in [4] to simulate the development of final state jets that would be produced in electron-postiron annihilation at 6 TeV center of mass energy. Such jets are similar to 3 TeV quark jets that would be produced in hard collisions at the SSC.

A useful measure of the distribution of particles in the jet as a function of angle relative to the jet axis is the energy-energy correlation function [5]. This function is proportional to the probability for the momentum of one particle in one jet to making an angle θ with respect to the negative of the momentum of a second particle observed in the opposite jet. The probabilities are weighted by the energies of the two particles. If all particles moved exactly parallel to one of the two back-to-back jet axes, the energy-energy correlation function would be a delta function at the back-to-back direction $\theta = 0$ (plus another delta function at $\theta = \pi$). In reality, the observed particles will have small momentum components transverse to the jet axis. The shape of this distribution of particle directions relative to the jet axes is reflected in the shape of the energy-energy correlation function.

We should emphasize that, in hadron collisions as contrasted with electron-positron collisions, the scattered partons do not emerge nearly back-to-back, since the parton-parton center of momentum frame does not coincide with the hadron-hadron c.m. frame. Thus the energy-energy correlation function is not such a useful quantity to measure in hadron collisions. Nevertheless the same physical questions of jet angular structure could be studied there in terms of other, more complicated, quantities.

The e^+e^- energy-energy correlation function is a difficult quantity for a Monte Carlo program to predict correctly because in perturbation theory it involves two powers of $\ln(\Theta)$ for each power of α_s. The second logarithm results from soft gluon effects. More inclusive quantities such as structure functions are not sensitive to such subtle effects and contain only one logarithm per power of α_s.





The upper lines in the figures above show the result of the Monte Carlo program using the conventional method. (We used $\Lambda_{QCD} = 250$ MeV and did not include any hadronization of the partons; hadronization is not very important in this region of angle at such a high jet energy). We tried two versions of the conventional method. In one, $\alpha_s(\mu^2)$ at the parton decay vertices was evaluated with $\mu = \frac{1}{2}M$, where M is the virtuality of the parent parton. In the other version, we took $\mu = |\mathbf{k}_T|$, where $\mathbf{k}_T$ is the transverse momentum of one of the daughter partons relative to the direction of the parent parton. (For on shell daughter partons $(\frac{1}{2}M)^2 = \mathbf{k}_T^2/4x(1-x) > \mathbf{k}_T^2$.) The two versions gave the same result to within the accuracy of the left hand graph. The differences can be seen in the expanded view of the small angle region shown on the right.

The lower narrow lines in the figures show the results from the coherent method. Here there is a larger difference between the $\mu = \frac{1}{2}M$ version, which produces the upper curve, and the $\mu = |\mathbf{q}_T|$ method, which produces the lower curve. (A larger value of μ produces a smaller value of $\alpha_s(\mu^2)$, which produces narrower jets and thus a higher peak in the energy-energy correlation function at $\Theta = 0$.) The difference produced by taking the two choices for μ is not, however, great.

The result is similar to that found earlier by Ingelman and one of the present authors [6]. In the earlier paper, however $\mu = \frac{1}{2}M$ was used with the conventional method while $\mu = |\mathbf{q}_T|$ was used with the coherent method. Thus it was uncertain whether the difference in result was due to the angular ordering or the choice of μ. What is new here is that the choice of μ has been independently varied and is found not to be important. Thus it seems likely that it is the angular ordering that makes the difference. (There are also a number of technical differences in the way the two Monte Carlo programs are oonstructed. Unfortunately, it would be difficult to eliminate these differences so that one could simply switch angular ordering on or off.)

The remaining, heavy curve in the figures is the result of the QCD analytical formula for the energy-energy correlation function [7,8,9]. We see that the angular ordering Monte Carlo method, reflecting soft gluon interference, produces much better agreement with the analytical formula than does the conventional method.

In the analytical formula, $\Lambda_{\overline{MS}} = 250$ MeV is used. The analytical formula contains some non-perturbative parameters that are fit to low energy experiments, as explained in ref. [9]; the parameters used here are midway between the $\Lambda_{\overline{MS}} = 150$ MeV parameters (fit A) and the $\Lambda = 450$ MeV parameters (fit G) of ref. [9]. The results at 3 TeV jet energy are not very sensitive to the non-perturbative parameters. The results at 3 TeV *are* sensitive to $\Lambda_{\overline{MS}}$: doubling $\Lambda_{\overline{MS}}$ will roughly halve $d\Sigma/d\cos\Theta$ at $\Theta = 0$. This sensitivity to Λ is important because it is not quite clear how Λ_{QCD} in the Monte Carlo program should be related to $\Lambda_{\overline{MS}}$. Nevertheless, reasonable variations in $\Lambda_{\overline{MS}}$ would not change the qualitative result evident in the figure.

We conclude that, at SSC energies, ordering of emmission angles in jet evolution Monte Carlo programs produces significantly fatter jets, which agree well with the analytical QCD formula. This conclusion is based on comparison of Monte Carlo program results. We have not investigated whether the improved agreement was to have been expected on theoretical grounds. Such an investigation would be of considerable interest.

An equally important conclusion that may be drawn from the figure is that the Monte Carlo program agrees remarkably well with the analytical formula, considering that they are based on quite different approaches to

QCD theory and that both are extrapolated two orders of magnitude in jet energy beyond the region of present experimental experience.

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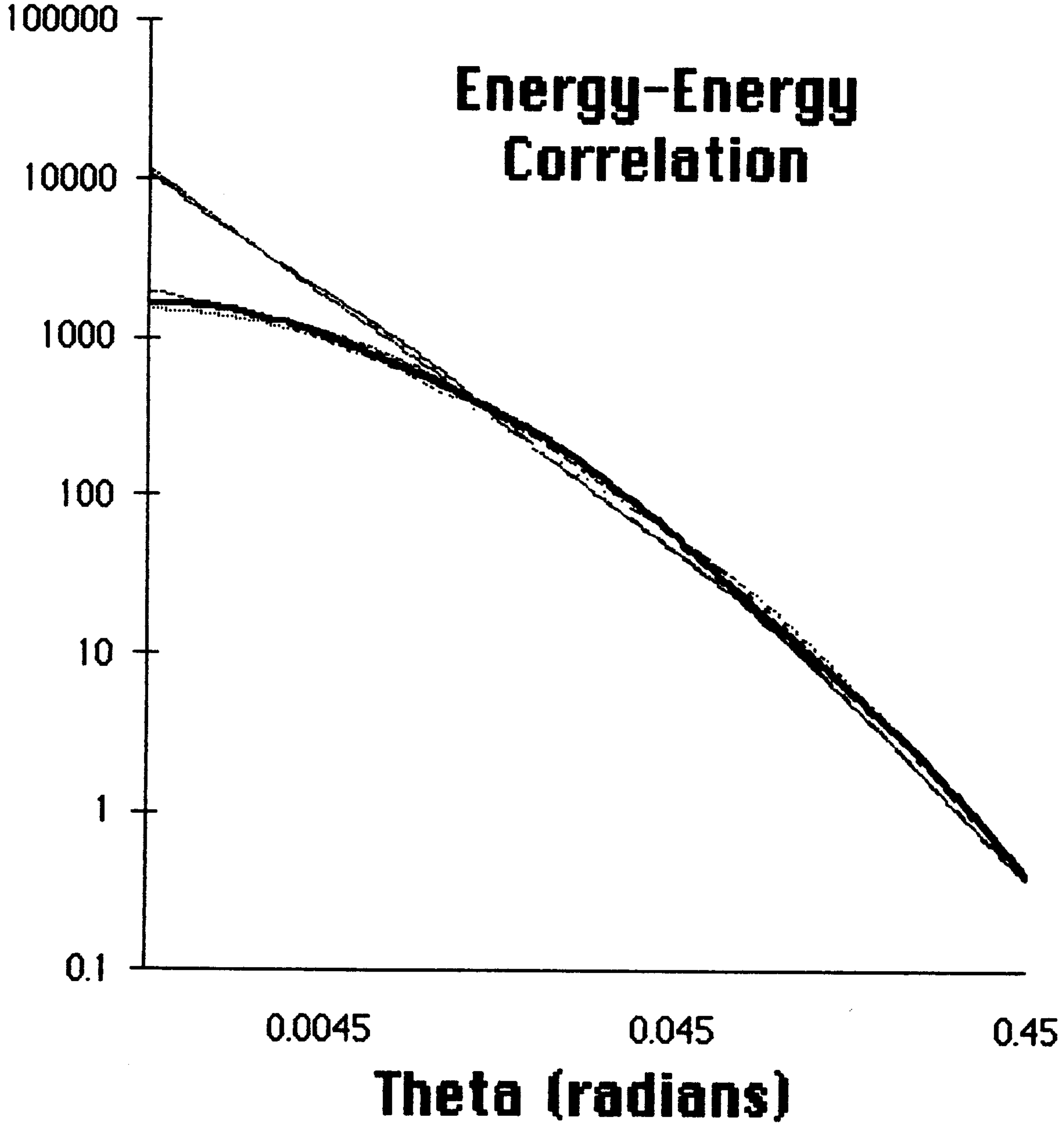
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1000
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1
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0.0045
0.045
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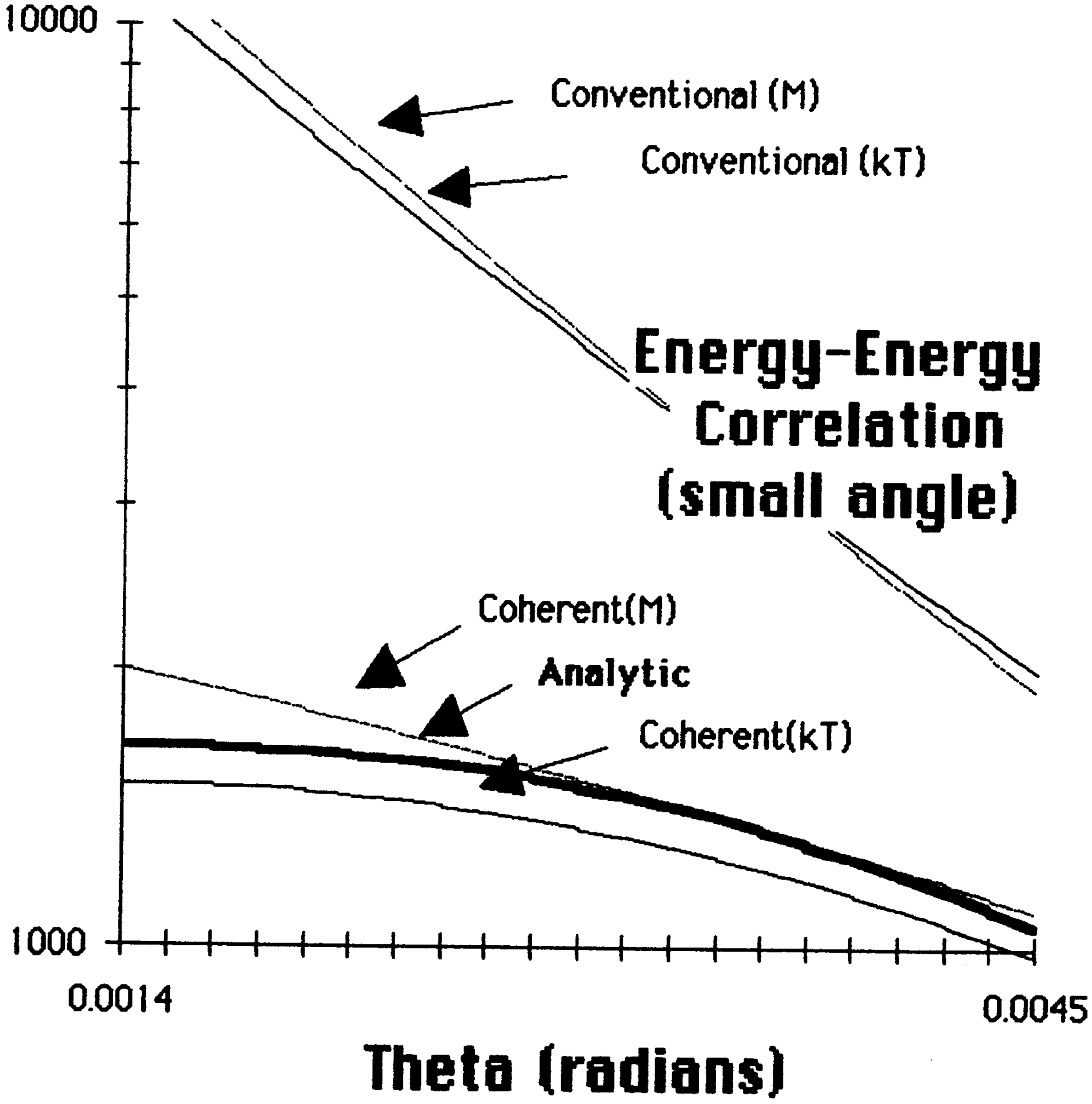
Theta (radians)


10000
1000
0.0014
0.0045
Theta (radians)
Conventional (M)
Conventional (kT)
Energy-Energy Correlation (small angle)
Coherent(M)
Analytic
Coherent(kT)