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Toward a Standardization of Jet Definitions *

John E. Huth and Naor Wainer
Fermi National Accelerator Laboratory
P.O. Box 500
Batavia, Illinois 60510

Karlheinz Meier
Deutsches Elektronen Synchrotron (DESY)
Hamburg 52, Germany

Nicholas Hadley
University of Maryland
College Park, Maryland 20742

F. Aversa and Mario Greco
Instituto Nazionale di Fiscia Nucleare (INFN)
Frascati, Italy

P. Chiappetta and J. Ph. Guillet
CTP-CRNS, Luminy
Marseille, France

Stephen Ellis
University of Washington
Seattle, Washington 98195

Zoltan Kunszt
Eidg. Technische Hochschule
Zurich, Switzerland

Davison Soper
University of Oregon
Eugene, Oregon 97403

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John E. Huth, Naor Wainer
Fermi National Accelerator Laboratory, Box 500, Batavia, IL 60510 USA

Karlheinz Meier
DESY, Notkestraße 85, D-2000 Hamburg 52, Germany

Nicholas Hadley
Phys. Dept., University of Maryland, College Park MD 20742 USA

F. Aversa, Mario Greco
INFN, Frascati Italy

P. Chiappetta, J.Ph. Guillet
CTP-CRNS, Luminy, Marseille France

Stephen Ellis
Dept. of Physics, University of Washington, Seattle WA 98195 USA

Zoltan Kunszt
Eidg. Technische Hochschule, Zurich, Switzerland

Davison Soper

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Institute of Theoretical Science, University of Oregon,
Eugene, OR 97403 USA

ABSTRACT

In order to reduce uncertainties in the comparison of jet cross section measurements, we are proposing a standard jet definition to be adopted for QCD measurements involving light quarks and gluons. This definition involves the use of a cone in the $\eta - \phi$ metric with a radius of 0.7 units.

1 PROPOSED STANDARD

Until now, direct comparisons of jet cross sections in hadron collisions have been hindered by differences in jet definition adopted by various experiments. As an example, the plenary discussion by S. Ellis in these proceedings [1] of jet cross section measurements at the $S\bar{p}pS$ collider indicates the problems that can arise when different experiments use different definitions. Because of this, and with the advent of new calculations of the jet cross sections to higher orders in hadron collisions [3,2,4], it is desirable to agree on a standardization of jet reconstruction algorithms and definitions in order that both theory and experiment can be directly compared. As members of hadron collider experiments and theorists directly involved in calculating jet cross sections, we are proposing a standardized definition of jets to facilitate comparisons.

This standard definition is intended for use in measurements where light quarks and gluons are involved, and the cross sections are sensitive to the definition used. It should be emphasized that there are many cases where experimentalists will use different algorithms to enhance the mass resolution for various processes, for example, $W \rightarrow \text{Jet}_1 + \text{Jet}_2$. We recognize the importance of ongoing work on such algorithms and encourage such efforts. The standardization proposed here is intended as for use as a minimal definition to be applied in a variety of measurements, such as the inclusive jet cross section, jet angular distributions, etc, where light quarks and gluons are involved, and a uniform treatment will facilitate comparisons.

The most widely accepted clustering definition for hadron collider experiments involves a clustering of calorimeter cells in a metric of pseudorapidity

($\eta \equiv -ln(tan\,\theta/2)$)) and azimuth ($\phi$) (CDF, UA1, D0, UA2). θ is the polar angle with respect to the beamline. The (η, ϕ) metric has the virtue of taking into account the Lorentz boosts of jet systems, and is an integral part of most new calorimeter designs [5] [6].

Several important properties that should be met by a jet definition are [3]:

1. Simple to implement in an experimental analysis;
2. Simple to implement in the theoretical calculation;
3. Defined at any order of perturbation theory;
4. Yields finite cross section at any order of perturbation theory;
5. Yields a cross section that is relatively insensitive to hadronization.

We have studied various jet cluster definitions and have reached an agreement on a standard definition. As a starting point for experimental data, it is assumed that a cluster of energy has been identified in a segmented calorimeter. The theoretical starting point is that partons have been identified with some separation in the $\eta - \phi$ metric.

We propose to use a standard jet definition using cones in $\eta - \phi$ space. This has the advantage that it is related to the prescription for handling radiation in QCD introduced by Sterman and Weinberg [7]. The cone algorithms in $p\overline{p}$ collisions were first explored by the UA1 collaboration [8]. This technique is to be contrasted to nearest neighbor algorithms where clusters are formed from contiguous towers above some energy threshold. Clusters are defined as separate if some local minimum can be found between peaks of energy [9].

A cone of a radius R_o is used to define the energy associated with the jet. Calorimeter cells or partons have a distance from the jet center defined by the radius $R \equiv \sqrt{(\phi_i - \phi_o)^2 + (\eta_i - \eta_o)^2}$, where ϕ_o and η_o represent the center of the cone and ϕ_i and η_i are the coordinates of the parton or the center of the calorimeter tower. Either partons or the energy found in calorimeter towers are associated with the jet if they lie inside the cone, that is, $R \leq R_o$.

There is no precise guidance for the choice of the value of R_o, but studies involving the simulation of jet fragmentation at transverse energies in excess of 20 GeV indicate that values between 0.4 and 1.0 yield results where the effects of hadronization and the influence of the underlying event are minimized [10] [11]. These studies indicate that an optimum value of R_o lies near 0.7. To be definite, a cone of radius 0.7 will be adopted as a standard. Note that some interesting measurements, like the variation of the jet cross section with R_o makes it desirable to use different values of R_o [3,12].

It should be noted that the procedure for finding an initiating cluster, before a cone is introduced, may be experiment dependent. As such, this represents a potential drawback for standardization. The adoption of an iterative approach in forming the cluster centroid after a cone is determined may alleviate this problem. In this case the centroid would be recalculated using the towers inside the cone, and a new cone would be drawn. Once the list of towers in the cone is stable, the iteration stops.

Many quantities can be derived from the energies in the calorimeter towers or the partonic energy. Of particular interest are the quantities transverse energy E_t, pseudorapidity, η, and azimuth ϕ of the jet. There are many possible ways of deriving these quantities; two common uses are of interest. One is to define the transverse energy as the sum of the transverse energies of partons or calorimeter cells inside R_o:

$$E_t \equiv \sum_{i\in R\leq R_o} E_{ti} \tag{1}$$

where i is an index for the i^{th} cell or parton, and R is defined above. The jet axis can likewise be identified with E_t weighted sums as:

$$\eta_j = \frac{1}{E_t} \sum_{i\in R\leq R_o} E_{t\ i}\ \eta_i \tag{2}$$

and

$$\phi_j = \frac{1}{E_t} \sum_{i\in R\leq R_o} E_{t\ i}\ \phi_i \tag{3}$$

Transverse momentum can be defined from the components of momentum in the transverse plane, assuming the towers represent energies from massless particles:

$$P_x \equiv \sum_i P_{x,i} \tag{4}$$

$$P_y \equiv \sum_i P_{y,i} \tag{5}$$

then

$$P_t \equiv \sqrt{P_x^2 + P_y^2} \tag{6}$$

These definitions are enumerated in reference [3], and have the advantage that the Lorentz boost properties are explicit.

A second definition, in use by CDF, is to treat each calorimeter cell as a massless particle, and forming an overall p_μ vector from the sum of these, and projecting onto the transverse plane. For work where mass reconstruction may be important, this would lead to a natural definition of invariant mass of jet pairs from $p^\mu p_\mu$. As a practical matter, the differences in the two definitions of E_t yield differences which are numerically quite small. The values of E_t for typical jets found both in generators [15,16] and in CDF data [17,18] at a clustering radius of 0.7 using the two definitions above differ by only about 1 %. This is for jets with values of E_t in excess of 35 GeV in the central region of pseudorapidity (0.0 ± 1.0 units) The invariant mass values that arise from the two definitions differ by similar amounts.

In order to achieve a uniform definition which can be used by both theorists and experimentalists for QCD measurements involving gluons and light quarks, we recommend that the cone clustering algorithm with a radius of 0.7 and a use of the definition of E_t and centroids in equations 1,2 and 3 be adopted as a standard.

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