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Review

Simulation of jets at colliders

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ABSTRACT

We review the development of the physics behind event generators during the last decade. After a more general description of parton showers, we focus mostly on the perturbative side of the simulations. Two newer developments of parton showers, as implemented in HERWIG++, are described in greater detail. Matching and merging of parton showers with fixed order computations are discussed. We describe some developments of multiple partonic interactions which are relevant for the simulation of jets from the underlying event, where the implementation in HERWIG++ is again taken as a generic example. Finally, we compare some event generator results to collider data from LEP and the LHC.

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1. Introduction

Jets are an integral part of collider final states today. At lepton colliders, such as the large electron positron collider (LEP), the production of jet pairs from quark–antiquark final states has been studied in great detail. Now, with the Tevatron at Fermilab, and the Large Hadron Collider (LHC) at CERN plenty of hadron–hadron collision data are being analysed. At hadron colliders, jets are ubiquitous, as in the primary subprocess colour charge is extracted from the incoming hadrons. This results in a strong colour field as a source for the radiation of multiple jets.

These primary coloured particles (partons) emerging from a hadronic collision will radiate additional partons, the so called parton showers before there is a transition to observable hadrons. Typically, the hadrons that stem from a single primary parton form a particle jet. A jet is a collection of hadrons that moves more or less into the same direction in the detector. Clustering back the momenta of all hadrons to a single pseudo particle, one arrives at a good approximation of a primary parton which by itself is never directly visible. The jets themselves are the visible footprint of Quantum Chromodynamics (QCD) activity in all collider experiments and hence are a very important subject of study. Not only to understand the jets by themselves but also to gain a precise understanding of the background of new physics beyond the standard model it is important to give precise predictions for jet activity at colliders. As the initial state is coloured it is clear that all collider signatures contain jets. But whenever the new particles which are directly produced in a hard process are coloured by themselves they will be a copious source of additional jet activity as they are typically also very heavy.

The production of these particles will, reversely, be analysed on the hadron level. Here, one uses jet algorithms to give a unique mapping from any hadronic final state to a jet final state. Such an algorithm is parametrized in terms of a small number of resolution parameters. A resolution parameter characterizes the size of a jet. Obviously, a number of hadrons observed with a fine-grained jet algorithm will tend to result in a larger number of jets than the same set of hadrons, analysed with a rather coarse resolution parameter. Taken together, one is able to define observables like the number of jets at a given resolution, or their transverse momenta. A particular property a jet algorithm should have, is the so-called infrared safety. The output of an infrared-safe jet algorithm will not depend on the fact whether or not a very soft emission from a particle has been taken into account or not. Similarly an almost collinear splitting of a single particle into two particles, e.g. by radiating off one particle, will not change the result of the algorithm. As a result, the output of infrared safe jet algorithms will allow us to compare measurements at the hadron level with predictions on the parton level, at least up to a certain degree of accuracy. In particular, there will be a one-to-one correspondence between primary partons and jets in the final state.

In this article we describe important theoretical developments during the last decade that helped to improve the theoretical description and modelling of jets, particularly at hadron colliders. A previous review article [1] covered all aspects of event generation on very general grounds. Here, in contrast, we put more emphasis on the perturbative aspects of the simulation and enter a more specific discussion for the event generator HERWIG++, particularly for parton showers and the modelling of the underlying event with multiple partonic interactions.

In an introductory Section 2 we describe jet algorithms and their use for analyses at the LHC and give a general overview over the event simulation with Monte Carlo event generators. We round off the section with the most important results and recent developments for the generation of hard partonic final states in fixed order perturbation theory. In Section 3 we give a more detailed overview of the theory behind parton showers and describe more recent developments in this field for the examples of the details of the HERWIG++ parton shower and a newly developed shower, based on Catani–Seymour subtraction terms. We finish the section with a brief overview of hadronization models. In Section 4 we describe the systematic improvement of the accuracy of jet modelling with the help of tree-level matrix elements for additional jets. Matching with next-to-leading order calculations in parton showers is described in some detail in Section 5. In Section 6