PARTON SHOWERS AND MULTIJET EVENTS *

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A Monte-Carlo event–generator has been developed which is dedicated to simulate electron–positron annihilations. Especially a new approach for the combination of matrix elements and parton showers ensures the independence of the hadronization parameters from the CMS energy. This enables for the first time the description of multijet–topologies, e.g. four jet angles, over a wide range of energy, without changing any parameter of the model. Covering all processes of the standard model our simulator is capable to describe experiments at present and future accelerators, i.e. the LEP collider and a possible Next Linear Collider (NLC).

1 Introduction

Multijet events play a crucial role in present and future high energy particle physics. Already in past experiments multijet observables have lead to proofs of the theory of strong interaction, e.g. the underlying symmetry group has been established. With rising energies the production of multijet events via the electroweak interaction becomes more important, e.g. the creation of \(ZH\) and \(W\)-pairs involves at least four jets and dominates the QCD background. In addition, the majority of signals for new physics, e.g. supersymmetry is related to multijet topologies.

Our Monte-Carlo generator APACIC++ (A Partron Cascade In C++) in combination with our matrix element generator AMEGIC++ (A Matrix Element Generator in C++) was developed with the aim to describe these multijet events in a correct manner over a wide range of energy. This was achieved with a new approach for combining the advantages of matrix elements and parton showers, which leads to a good description of experiments at present accelerators, i.e. the LEP collider. Including extensions of the standard model, primarily supersymmetry, APACIC++/AMEGIC++ will be dedicated for the search of new physics at a possible Linear collider.

The paper is outlined as follows. Tracking the physics features related to event generation in the subsequent sections we describe briefly the treatment of initial state radiation, matrix element generation and evaluation, the

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combination with the parton shower and the parton shower itself.

2 Initial state radiation

At the beginning of every event generation the initial state has to be defined. At present our package supports $e^+e^-$ as colliding particles, but due to initial state radiation of photons the energy as well as the momentum are not fixed yet. Different approaches describing the subsequent radiation of photons are the structure function ansatz, the electromagnetic shower, and the Yennie-Frautschi-Suura (YFS) scheme. Within AMEGIC++ the first and the last version are implemented. The structure function ansatz considers the effect of diminishing the electron energies by initial state photons without generating them explicitly. However, the YFS-approach allows a direct generation of photons in a theoretical well defined way up to an arbitrary order of $\alpha_{\text{QED}}$. In the present state we have implemented this scheme in the soft photon limit, i.e. an exponentiation of all effects to leading logarithmic order. In Fig. one can see, that AMEGIC++ agrees with KoralZ to the considered order. Furthermore we display the effect of higher order corrections, which lead to significant changes. Hence, we will extend our treatment of initial state radiation accordingly.

3 Matrix elements

Now, the initial state is set and the event generation proceeds with the determination of the jet structure. Jets are defined within different schemes, e.g. the DURHAM and the JADE cluster algorithm. Utilizing these schemes the matrix elements are regularized, i.e. the soft and collinear divergencies are avoided. Within APACIC++ different matrix element generators are supplied, namely Excalibur, Debrecen, and AMEGIC++. They all differ in their field of application. Our preferred choice is AMEGIC++, which is applicable for all standard model tree level processes up to 6 massive outgoing particles. Its fully automatic procedure for the determination and integration of the amplitudes can be divided into three major steps:

1. The Feynman diagrams are achieved through the mapping of the eligible vertices onto tree topologies.

2. The diagrams are translated into helicity amplitudes and stored into word-strings for easy evaluation.

3. Integrating the amplitudes with Rambo, Sarge or a multi-channel
Figure 1. AMEGIC++ and KoralZ are compared in the $s'$-distribution at 189 GeV CMS-energy on the upper panel. On the lower panel the corresponding energy distribution of the ISR-photon is displayed.
Figure 2. The 4 jet rate for four massless and massive quarks at 91 GeV and 200 GeV CMS-energy are displayed.

approach (which can include the former ones) the total cross section is derived.

For further details we refer the reader to a more concise description of our program. A comparison between massless and massive four jet cross sections as evaluated with AMEGIC++ is depicted in Fig. 2.

4 Combining matrix elements and parton shower

Once the jet structure is established by the matrix elements a parton shower should evolve these different jets. Since particles calculated via a hard matrix element are naturally on their mass-shell and a parton shower can handle off-shell particles only, it is obvious that a scheme for combining these two steps is indispensable. Moreover such a procedure should take advantage of the virtues of matrix elements, i.e. the description of jet correlations, and parton shower, i.e. the evolution of jets. This can be achieved following four steps:

1. The number and the flavour of the outgoing jets are determined utilizing the different matrix elements.
2. The kinematical configuration is chosen according to the matrix element. An extra weight appears, when higher order corrections are taken into account, i.e. a combination of rescaled coupling constants $\alpha_S(y_{\text{cut}})$ and Sudakov form factors care for an exact treatment of leading logarithms. This guarantees a smooth transition of the kinematics from the matrix element to the parton shower regime.

3. One of the contributing Feynman diagrams is chosen in order to gain the colour configuration of the event. The probability for the selections can be obtained for instance in a parton shower like manner.

4. A history of the parton branchings is deduced from the chosen Feynman diagram. Now the partons can be provided with virtual mass utilizing the Sudakov form factor originating from the parton shower.

The success of this combination scheme is especially reflected in four jet events, see Fig. 3. Needless to say, that this total agreement between the different phases of event generation could not be achieved using a parton shower starting from two partons only. A detailed comparison of the four jet angles between the different event generators is presented in [17].

Figure 3. The $\alpha_{34}$ (the angle between the lowest energy jets) angle for QCD four jet events at $\sqrt{s} = 206$ GeV.
5 Parton shower and fragmentation

After all partons gained a virtual mass the evolution of jets can proceed. Different schemes according to different approximations are implemented in APACIC++, i.e. the ordering by virtualities (LLA) and angles (MLLA). Further details can be found in many textbooks, see for instance\textsuperscript{18}. In addition, azimuthal correlations between the different planes of parton branchings are taken into account.

Subsequently the outgoing partons have to be hadronized. This is performed with the help of the Lund-string model provided by Pythia\textsuperscript{4}.

6 Results

We performed a comparison between Ariadne\textsuperscript{19}, Herwig\textsuperscript{20}, Pythia, our event generator APACIC++/AMEGIC++ and the data of the DELPHI collaboration at different CMS-energies. In Fig. 4 the thrust distribution (an event shape variable) at 91 GeV is displayed and shows a good overall agreement with the data. The transversal momentum $p_{\text{out}}^\perp$ could not be described correctly in...
the high momentum region. This is seemingly a common feature of all event generators, see Fig. 5. Even though our program includes the full information of matrix elements an energy extrapolation has been achieved, see Fig. 6. This is an important feature of APACIC++/AMEGIC++, since a pure matrix element generator does not have this property.

We conclude, that we reached the aim of providing an event generator, which is able to describe multijet topologies with a proper energy scaling.

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Figure 6. The energy extrapolation from the differential three jet rate from 91 GeV (upper panel) to 189 GeV (lower panel).
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