THE PYTHIA AND JETSET PROGRAMS

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ABSTRACT

The Pythia and Jetset event generators together allow the simulation of a large number of processes in e^+e^-, ep and pp collisions. This includes processes within the four main areas of QCD, electroweak, Higgs and exotic physics. Complete events may be generated, including initial and final state QCD radiation, fragmentation and decays, and underlying events. A detailed physics description and manual is available.

1. Introduction

The Pythia [1] and Jetset [2] programs are frequently used for event generation in high-energy physics. The emphasis is on multiparticle production in collisions between elementary particles. This in particular means hard interactions in e^+e^-, ep and pp colliders, although also other applications exist.

The objective is to generate complete events, that can be compared with experimentally observable ones. This includes, for each event, a list of the particles produced, together with momenta, secondary vertices, etc. The full event history is available, including the underlying partonic configuration and intermediate unstable particles. With Monte Carlo techniques one hopes to model not only the average behaviour but also fluctuations around that average. As a by-product of the event generation, the programs also do the integration of cross-sections.

The generation of an event may be subdivided into several stages. In the first stage, the hard scattering matrix element is folded with the structure functions of the two incoming hadrons, to define the basic hard scattering. Next, initial and final state radiation is included in a parton shower picture. Thereafter beam remnants are added. Finally, fragmentation and subsequent decays are considered. By this subdivision of the complete process in a number of smaller subtasks, it is possible to build up a very complex picture from reasonably simple pieces.

Of course, the scenario above is somewhat simplified, and does not cover all possible cases. Furthermore, one should remember that each of the components involve some level of approximation; several independent event generators exist which differ in the underlying assumptions, and which therefore provide a healthy amount of cross-checks.

2. Some Main Features

The capabilities of an event generator are related to what processes are implemented in it. In Pythia the QCD processes include standard $2 \to 2$ parton scattering, heavy flavour production, high-$p_\perp$ J/Ψ production, and 'minimum bias' processes such as elastic and diffractive scattering and low-$p_\perp$ events. The electroweak processes include prompt photon production, photoproduction, $\gamma\gamma$ interactions, deep inelastic scattering, single W/Z production, and W/Z/γ pair production. The Higgs sector includes the standard model Higgs, alternatively the $h^0/H^0/A^0/H^\pm$ of a two-Higgs-doublet scenario. In the limit of a heavy Higgs, the standard prodution graphs are complemented by those for longitudinal gauge boson scattering. The exotics section includes a mixed bag of fourth generation, new W′/Z′ gauge bosons, leptoquarks, compositeness (contact interactions), excited fermions and technicolour.

The processes above are normally only included in lowest order, i.e. typically as $2 \to 2$ processes. Higher order corrections are included by parton showers. These give the universal approximate behaviour. The radiation is, for simplicity, subdivided into initial state and final state showers. Both of these have a common structure, in that they are built up from a sequence of branchings of the types q→qg, g→gg, g→q$\bar{\mathrm{q}}$, and q→qγ. The naive leading log picture is complemented by a number of additional effects, such as angular ordering.

The underlying event may well contain several semihard additional parton-parton interactions, so-called multiple interactions. In the Pythia scenario, the cutoff scale for these processes is expected to occur at $p_{\perp min} \approx 1.5$ GeV. This means that a typical high-$p_\perp$ event at current energies may contain one or two additional interactions at a $p_\perp$ of around 2 GeV. These do not give rise to visible jets, but increases the activity of the underlying event.

The partonic state is turned into hadrons using the string fragmentation model. This model is based on an linear confinement picture of QCD. It requires that the full colour flow of an event is specified.

Many of the particles produced are unstable and decay further. In some cases this is trivial, in others extensive modelling is required. Also decays of various resonances (such as Z^0 or H^0) need be considered; these often decay to quark pairs, which subsequently undergo parton showers and fragmentation.

3. Recent Additions

The Pythia and Jetset programs are being continuously developed. In this section we summarize a few recent additions.

The major changes are related to recent work in the area of photoproduction [3], especially intended for HERA applications. It is now possible to simulate separately three different event classes for the interactions of an incoming beam of real photons on a p target:
(i) direct events, wherein the photon interacts as a pointlike particle,
(ii) VDM resolved events, wherein the photon behaves like a vector meson $\rho^0/\omega/\phi$, and
(iii) anomalous resolved events, wherein the photon is resolved by a perturbative branching $\gamma \to$q$\bar{\mathrm{q}}$.

Classes (ii) and (iii) involve the same parton-parton hard scatterings, only the structure functions involved are different. Often the two classes are lumped together, and a single photon structure function is defined. This possibility is also left open.

As a by-product of the photoproduction work, new parametrizations have been introduced for the total, elastic and single and double diffractive cross-sections in γp and pp interactions. The description of diffractive events has been improved.

With the shift of our interest towards a heavier top than assumed a few years ago, the modelling of top need be modified. If the top is lighter than about 100 GeV, top hadrons have time to form and these hadrons subsequently decay. For top masses above 130 GeV the top quarks decay before hadronization is finished, and the b quarks produced in the decay subsequently fragment. A switch is now available so that either of these behaviours may be selected. Further, in a t→bW decay, the b quark is allowed to radiate gluons, as in an ordinary parton shower.

In deep inelastic scattering, the scheme for conservation of x and Q^2 has been improved.

4. Support

The master copies of files are stored on my disk `TORSJO 192` on the CERNVM machine. The programs are stored in `PYTHIA56 FORTRAN` and `JETSET73 FORTRAN`, the combined Pythia/Jetset manual in `PYTHIA56 TEX` and update notes to the manual in `UPDATE MANUAL`.

The complete manual is almost 300 pages long, and is therefore not so easily printed. Copies are distributed by the CERN program library, and also by the program libraries at several other high energy physics laboratories, such as DESY, FNAL and SSCL.

Any questions concerning program distribution, especially in PATCHY or CMZ, should be sent to the CERN program library, CERNLIB@CERNVM. Physics questions and comments can be addressed to the author, phone +41 - 22 - 767 2820 or Bitnet TORSJO@CERNVM. However, bear in mind that this is a one-person effort, so have reasonable expectations.

The intention is that the programs will continue to evolve and be supported in the future. Since they have come to be more and more tightly connected, they will probably be merged into one single Pythia program. This may take place as the same time as the programs are rewritten to make use of Fortran 90 features.

5. References

1. H.-U. Bengtsson and T. Sjöstrand, *Computer Physics Commun.* **46** (1987) 43.
2. T. Sjöstrand, *Computer Physics Commun.* **39** (1986) 347;
   T. Sjöstrand and M. Bengtsson, *Computer Physics Commun.* **43** (1987) 367.
3. G. Schuler and T. Sjöstrand, CERN-TH.6718/92, to appear in *Phys. Lett.* **B**.
4. T. Sjöstrand, CERN-TH.6488/92.