YaJEM v1.1
user's guide

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1 Overview

YaJEM is a Monte-Carlo (MC) generator for the in-medium evolution of QCD parton showers. It is based on the PYSHOW algorithm [1] of PYTHIA 6 to which it defaults in the absence of any specified medium effects.

Like in PYSHOW, the QCD shower is treated as a virtuality-ordered, iterated series of $1 \to 2$ branchings corresponding to the processes $q \to qg$, $g \to gg$ and $g \to q\overline{q}$. This evolution terminates as soon as partons reach a lower, non-perturbative virtuality scale, at which point a hadronization model (by default the Lund string model of PYTHIA) is used to convert the parton shower into hadrons.

The physics ideas underlying YaJEM are published in [2] and [3]. YaJEM can be run in several different basic scenarios. The default scenario, YaJEM, is based on an explicit modification of the virtuality of intermediate shower partons by their interaction with the medium. This interaction increases the available transverse radiation phase space, thus leading to copious production of soft gluons, and it is parametrized by a transport coefficient $\hat{q}$. A different scenario, YaJEM-E, is based on an elastic drag force which reduces the energy of intermediate partons, assuming that this energy gets dissipated directly into the medium. This is parametrized by a transport coefficient $\hat{e}$. A third scenario, YaJEM+BW is based on the Borghini-Wiedemann prescription [4] to modify the singular parts of the QCD splitting kernels. This is parametrized by a number f_{med}. Unlike the previous scenarios, this is a purely probabilistic picture in which no energy and momentum are exchanged between parton shower and medium, which leads to an enhanced emission of low z gluons. In practice, any combination of these three basic mechanisms can be simulated. A comparison between the three basic scenarios is published in [3].

YaJEM outputs event records in OSCAR format which can then be analyzed using other tools, for instance the FastJet package [5].

2 Installation and compilation

Unpacking the distribution of YaJEM should result in this manual, two files of Fortran code (`yajem.f`and `pythia_yajem.f`) and a data file (`profile.dat`).

YaJEM can be compiled using the g77 Fortran compiler with

```
g77 -o yajem yajem.f pythia_yajem.f
```

or has been reported to compile using gfortran with

```
gfortran -fno-range-check -ffixed-line-length-180
-o yajem yajem.f pythia_yajem.f
```

Compilation with other Fortran compilers may be possible but is not tested and may require to set special flags. The compilation typically throws some harmless warnings abour large memory consumption during compile, which should not be an issue on modern computers.

The file `yajem.f` contains the control structures for the code and is intended to be modified by the user. Here, various flags can be set and the basic parton kinematics of the shower initiators is specified. The recommended and tested mode of usage of YaJEM is exemplified by this file. First, a back-to-back parton pair is inserted into the simulation, then PYSHOW is called to compute the in-medium shower evolution, followed by a PYEXEC call to handle hadronization and decay.

The file `pythia_yajem.f` contains the code of PYTHIA 6 with the PYSHOW routine modified to simulate in-medium shower evolution. Thus, a PYTHIA-like simulation of complete p-p events embedded in a medium may be possible but is untested and not the recommended usage of YaJEM. This file should normally not be modified by the user.

The file `profile.dat` contains the time-evolution of the medium density the parton shower encounters along its path through the medium. After installation, this contains a default profile, but the user is responsible to set this according to the physics that should be simulated, e.g. to a density sampled from a fluid dynamical simulation of a heavy-ion collision.

3 Usage

Most settings a user may want to adjust are specified in `yajem.f`. Here, parton kinematics and number of events as well as special flags which determine how the shower is simulated, both from PYSHOW and specific for YaJEM, are set.

3.1 Basic shower settings

The type and kinematics of shower initiating partons is set in the code block

```
ip=-1
kf1=1
kf2=-1
pecm=40.0D0
```

As it stands, this sets a $d\bar{d}$ back to back pair at $\sqrt{s} = 40$ GeV, i.e. each of the two jets has 20 GeV. YaJEM uses normal PYTHIA flavour codes, i.e. the u quark corresponds to a code 2 and the gluon to a code 21. These settings are inserted into the event record and passed on to the shower routine further down in

```
call py2ent(ip,kf1,kf2,pecm)
call pyshow(1,2, pecm/2.0D0)
```

Note that PYSHOW accepts as third argument the maximum virtuality range the initial partons may have, and this can (if so desired), be changed from the default value `pecm/2`.

Note also that the Lund model requires simulation of a back-to-back parton to properly draw color connections, i.e. hadronization will result in errors if only a single parton is allowed to shower.

3.2 Setting the medium density

The time evolution of the medium density as encountered by the parton is specified in the user-supplied file `profile.dat`. The normalization of the integral over this evolution is set to unity when the file is read, and the true normalization should be passed by the value of `YAPARS(2)`. The deeper reason for this somewhat odd choice is that due to a scaling law identified in [2], for many physically relevant profiles the detailed functional shape of the density profile is not important, only the integral is. Thus, in many situations different in-medium path to a good approximation do not require to recompute with a different profile, but just to recompute with a different value of `YAAPARS(2)`.

For the transport coefficients $\hat{q}$ and $\hat{e}$ which modify the shower, the relations

$$\hat{q}(t) = \texttt{profile.dat}(t) \cdot \texttt{YAPARS(2)} \cdot \texttt{YAPARS(3)} \tag{1}$$

and

$$\hat{e}(t) = \texttt{profile.dat}(t) \cdot \texttt{YAPARS(2)} \cdot \texttt{YAPARS(4)} \tag{2}$$

hold, using two additional parameters `YAPARS(3)`and `YAPARS(4)`to control the relative magnitude of $\hat{q}$ and $\hat{e}$ for a given density profile.

The mode YaJEM+BW does not use the specified matter profile, in accordance to the BW prescription, all branchings are modified using the same number $f_{med} > 0$ which can be set using `YAPARS(1)`.

Note that the physics of YaJEM is based on the assumption that the medium-induced virtuality is a correction to the parton virtuality cascading down from the initial hard scattering process, $Q^2 > \Delta Q^2$. The validity of this condition limits the matter profiles that can be used, in particular YaJEM does not result in useful output for infinitely long media or media with an increase of the density over time. For physically reasonable density profiles as can be extracted from fluid dynamics, no severe issues exist.

3.3 Useful flags

Several flags of PYSHOW are tested to work in a meaningful way together with YaJEM and can be used to influence details of how the shower is computed.

`MSTJ(1)`: switches between Lund model (1) and independent fragmentation (2) as hadronization model

`MSTJ(41)`: type of branchings in shower, switches between (1) QCD branchings only (2) QCD and QED branchings and (3) QCD and QED branchings with QED branchings enhanced by `PARJ(84)` — useful for computation of fragmentation photons.

`MSTJ(42)`: sets whether explicit angular ordering is enforced (2) or not (1)

`MSTJ(42)`: sets whether α_s runs (2) or is kept fixed (0) to the value in `PARU(111)` during shower evolution

Note that `MSTJ(43)=3` **must** be set to 3 for YaJEM to work properly!

YaJEM itself has a few more flags:

`YAFLAGS(1)`: print out internal debug info on time ordering of parton evolutions if set

YAFLAGS(2): use randomized parton formation time rather than average time if set (recommended)

YAFLAGS(3): switch jet-photon conversion routines on (experimental)

3.4 Momentum conservation

Running YaJEM may produce multiple errors from the PYTHIA core about energy-momentum nonconservation. The reason is that energy and momentum are genuinely not conserved inside a YaJEM shower alone as interactions with the medium allow a flow of energy and momentum between parton and medium, and the PYTHIA core needs to be tricked into accepting the event nevertheless, which sometimes fails. Energy and momentum would only be conserved when considering the sum of parton shower and medium.

As the medium is currently not explicitly co-simulated with YaJEM, this is in theory a problem for operations like jet-background separation. In practice, experience has shown that for any jet cone radius used in a heavy-ion environment (i.e. up to $R = 0.6$) this is not an issue and YaJEM jets can be mixed into background events and clustered without creating noticable fake energy due to the lack of proper treatment of a coupled jet-medium evolution.

3.5 Output

YaJEM writes the output in OSCAR format into a file `YaJEM_OSC.dat`. Specifically, after a general header, each event starts with the event number and the number of particles in the event. The line for a particle begins with the particle number, followed by the PID code. The next three entries are the momentum components (p_x, p_y, p_z), followed by the energy E and the particle mass M. The following spatial components (x, y, z, t) of the OSCAR format are not set to physically meaningful values by YaJEM.

Note that as the code of `yajem.f` is organized, the shower initiating quarks go along the z-axis.

4 Special situations

4.1 Limited in-medium virtuality

Following a proposal by A. Majumder, the in-medium formation time for a medium of length L should limit the lowest virtuality a parton with energy E can evolve to inside the medium to $Q_0 = \sqrt{E/L}$. This has been implemented in YaJEM as the scenario YaJEM-D [6] and turns out to be crucial to correctly describe pathlegth-dependent observables.

Technically it is realized by computing Q_0 according to the actual length L for the given in-medium path and then setting `PARJ(82)`to this value. Note that this involves an approximation, i.e. that the evolution of the shower after L is not substantial and can be treated by the Lund model (see discussion in [6]. This approximation should not be made by default but needs to be investigated case by case!

The scenario which tests best against the whole available body of data is YaJEM-DE which sets `YAPARS(3) = 0.8`, `YAPARS(4) = 0.1` in addition to

PARJ(82) to Q_0, and this is the recommended default mode in which to run YaJEM.

4.2 Heavy quarks

YaJEM is in principle capable of simulating heavy quark showers, however only during the evolution time of the corresponding vacuum shower. As dicussed in [7], this leads to reasonable results for c-quarks but prevents the applicability of the code to b-quark showers unless at energies significantly above 100 GeV.

If D-mesons should appear as explicit states in the event record rather than decayed automatically, the use of the following PYTHIA flags is recommended:

MSTJ(22): set to 2 to decay particles only if their averge lifetime is shorter than PARJ(71)

PARJ(71): set to 0.1

In general, the application of YaJEM to heavy quark showers requires stringent checks that the validity of the assumptions which underly the code are not violated.

4.3 Conversion photons

YaJEM contains experimental code to compute photon emission from conversion reactions with medium constituents, e.g. via $qg \to q\gamma$ or $q\overline{q} \to g\gamma$ with a scattering partner from the medium. This code is described in [8].

Unlike the basic YaJEM scenarios which do not require knowledge of the detailed nature of the medium in terms of its degrees of freedom, but rather just the action of the medium in terms of transport coefficients, conversion reactions need a model for the medium DOF. The experimental code computes these in terms of an ideal thermal gas of quarks and gluons. The code then requires as additional input to the modelling of the medium the initial temperature of the medium, which is then decreased using a Bjorken scaling assumption. This procedure is manifestly at odds with the success of a hydrodynamical description of the bulk medium, and at this point it is not clear how good the approximation made here is. The conversion code is therefore experimental and should be used with sufficient caution.

The settings controlling the conversion code are:

YAFLAGS(3): switches conversion code on if set

YAPARS(10): initial medium temperature used to model the medium constituents for the conversion reaction

5 Caveats

A summary of known caveats and limitations:

- YaJEM is based on a perturbation of a vacuum shower evolution and hence can not accomodate the physics of on-shell parton propagation through the medium. This limits the applicability to 'thin' media which can at most have an extent of the shower formation time.

- No medium-modification is computed for the Lund hadronization of the shower. This means that subleading hadron production, especially at high mass, can not be expected to be treated correctly by the code.

- YaJEM inherits properties of the PYSHOW routine, in particular gluon fragmentation in general (both in vacuum and in the medium) appears too soft when comparing with fragmentation function fits like KKP.

- YaJEM has no explicit energy-momentum conservation inside the shower alone. This limits comparison with observables to jets with a radius of $R < 0.6$.

- YaJEM allows to specify only one medium description file, yet evolves a back-to-back dijet. This is in general unrealistic, as the real medium would not be symmetric. However, the dijet requirement is imposed by the Lund model. A viable solution for the moment is to simply cut the event in the analysis and only consider the +z going branch of the medium-modified dijet. Future plans to allow to specify separate medium descriptions for the +z and the -z jets exist.

6 Final comments

If you're using YaJEM, please cite the appropriate papers:

[1] and [2, 3] should be cited for the basic functionality of the code. [9] introduces the scenario YaJEM-DE which currently yields the best description of the combined experimental data and is hence considered the default mode. Users of YaJEM applied to heavy quark showers are requested to cite [7] and users of photon emission from YaJEM [8].

In case of any problems or unexpected results, please consider contacting the author under

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References

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