

# The parton and hadron cascade model PACIAE 4

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**PACIAE 4 (Parton And-hadron China Institute of Atomic Energy)** is a multipurpose Monte Carlo event generator developed to describe a wide range of collisions, including lepton-lepton, lepton-hadron, lepton-nucleus, hadron-hadron, hadron-nucleus, and nucleus-nucleus collisions. It is built based on **PYTHIA 6.4** & **PYTHIA 8.3**, and incorporates parton and hadron rescattering stages to address the nuclear medium effects. PACIAE 4 is the new generation of **PACIAE** model surpassing the version **PACIAE 3**. In PACIAE 4, the old fixed-format FORTRAN 77 code has been refactored and rewritten by the free-format modern Fortran mixed with C++ languages. The C++-based **PYTHIA 8** is interfaced in. More physics and features are available.

## Installation

Just download the file and decompress it. Then you can get the PACIAE 4 source code directly.

## Prerequisites

1. **make** tool, **gfortran** and **g++** compilers are required.
2. **PYTHIA 8** library is indispensable. PYTHIA official website: <https://pythia.org/> . Download then build PYTHIA 8 using the following command:

```
./configure  
make -j
```

**-j** flag will compile PYTHIA 8 more quickly using multiple cores. After the compilation and build completed, copy the **Makefile.inc** file the PYTHIA 8 generated and paste it into the PACIAE 4 directory. If you have the installed PYTHIA 8 already, just copy the **Makefile.inc** from your own installed PYTHIA 8 directory and paste it into the PACIAE 4 directory. **Makefile.inc** file is very important for the running of PACIAE 4. It specifies the PYTHIA 8 distribution path.

**NB:** The current Makefile is designed for linux system. The support for other OS will be updated in the next version.

## Usage

We encourage users to run the program on LINUX.

Two ways to run the program are provided.

1. Manual running. Use the **make** tool to compile the source code, link and build the PACIAE program. Then execute it by hand. **GFortran** and **g++** compilers have been pre-specified inside **Makefile**:
  - Compile code, link and build the programs by the command:

```
make
```

One can choose `make -j` to compile in parallel. The executable program **xPaciae.x** and the input files **usu.dat**, **pythia6\_extra.cfg** and **pythia8\_extra.cfg** will be generated in the folder **sim** (simulation). Enter **sim**.

- Modify the input files according to your wish. The basic PACIAE-related and few PYTHIA-related parameters and switches are included in the **usu.dat** file. Moreover, user can add extra settings for PYTHIA 6/8 in **pythia6\_extra.cfg** and **pythia8\_extra.cfg** files, which requires the knowledge of PYTHIA parameters. See [PYTHIA 6.4 Physics and Manual, JHEP 05 \(2006\) 026](#) and [PYTHIA 8 online manual](#) for more details. Thanks to these two files, PACIAE 4 can use almost all PYTHIA 6/8 features.
- Run the program by the command:

```
./xPaciae.x
```

One can use the following command to run the program in the background and record the time and log information.

```
nohup time ./xPaciae.x > paciae.log &
```

2. Use the [PACIAE.sh](#) shell-script to compile, link and build the program, generate input files and run the program automatically.

- Modify the [PACIAE.sh](#) file as needed. **usu.dat**, **pythia6\_extra.cfg** and **pythia8\_extra.cfg** have been integrated within [PACIAE.sh](#) file. User can modify them in [PACIAE.sh](#) directly. See [USU\\_DAT\\_BLOCKTEXT](#), [PY6\\_CFG\\_BLOCKTEXT](#) and [PY8\\_CFG\\_BLOCKTEXT](#) parts inside it.
- If executable permissions are missing, grant executable permissions to [PACIAE.sh](#) by command (only once):

```
chmod +x PACIAE.sh
```

- Run the [PACIAE.sh](#) script by the command:

```
./PACIAE.sh
```

- **rms\_analysis.f90** is a stand-alone program used in conjunction with the [PACIAE.sh](#) script to average the internal analysis files **rms.out** generated by each PACIAE simulation.

It is also worth mentioning that tasks can be submitted to computer clusters and supercomputers using the [PACIAE.sh](#) script (It is currently available for SLURM, LSF and PBS scheduling systems only.). More detailed information and usage can be found in the [SCHEDULE\\_SYSTEM\\_BLOCKTEXT](#) part of the [PACIAE.sh](#) file.

## Oscar format output

- The ASCII (text) human-readable output file **oscar.out** of the final particles following the OSCAR1997A standard can be generated via the switch **nosc=1**. A file snippet is as follows:

```

1 | OSC1997A
2 | final_id_p_x
3 | PACIAE program_version projectile+target frame energy 1
4 | Event_1 number_of_events number_of_particles b_parameter b_angle event_weight
5 | Particle_No_1 id1 px1 py1 pz1 E1 m1 x1 y1 z1 t1 (GeV & fm)
6 | Particle_No_2 id2 px2 py2 pz2 E2 m2 x2 y2 z2 t2
7 | ...
8 | Event_2 number_of_events number_of_particles b_parameter b_angle event_weight
9 | Particle_No_1 id1 px1 py1 pz1 E1 m1 x1 y1 z1 t1
10 | ...

```

- The full event history following the OSCAR199A standard including (**STAGE\_0**) the initial state, (**STAGE\_1**) the initial partonic state, (**STAGE\_2**) the final partonic state, (**STAGE\_3**) the initial hadronic state from the hadronization, and (**STAGE\_4**) the final hadronic state, can be generated via **nosc=2**. A file snippet is as follows:

```

1 | # OSC1999A
2 | # full_event_history
3 | # PACIAE program_version
4 | # projectile+target frame energy 1
5 | Event_1 N_events N_particles b_parameter b_angle STAGE_0 event_weight
6 | Particle_No_1 id1 px1 py1 pz1 E1 m1 x1 y1 z1 t1 (GeV & fm)
7 | Particle_No_2 id2 px2 py2 pz2 E2 m2 x2 y2 z2 t2
8 | ...
9 | Event_1 N_events N_particles b_parameter b_angle STAGE_1 event_weight
10 | Particle_No_1 id1 px1 py1 pz1 E1 m1 x1 y1 z1 t1
11 | ...
12 | Event_1 N_events N_particles b_parameter b_angle STAGE_2 event_weight
13 | Particle_No_1 id1 px1 py1 pz1 E1 m1 x1 y1 z1 t1
14 | ...
15 | Event_1 N_events N_particles b_parameter b_angle STAGE_3 event_weight
16 | Particle_No_1 id1 px1 py1 pz1 E1 m1 x1 y1 z1 t1
17 | ...
18 | Event_1 N_events N_particles b_parameter b_angle STAGE_4 event_weight
19 | Particle_No_1 id1 px1 py1 pz1 E1 m1 x1 y1 z1 t1
20 | ...
21 | Event_2 N_events N_particles b_parameter b_angle STAGE_9 event_weight
22 | Particle_No_1 id1 px1 py1 pz1 E1 m1 x1 y1 z1 t1
23 | ...

```

## Maintainers

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## Contributing

Feel free to dive in! Any bug reports, comments and suggestions are welcome. Please do not hesitate to contact us.

## Contributors

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## License

[GPL v2.0](#) and any later version.

## Released programs

PACIAE 4.0 code are hosted on <https://github.com/ArcsaberHep/PACIAE4> and <https://gitee.com/arcsaberhep/PACIAE4>.

The released code are available on <https://github.com/ArcsaberHep/PACIAE4/releases> and <https://gitee.com/arcsaberhep/PACIAE4/releases>.

## Released papers

- **Recent version:**
  - PACIAE 4.0: A brief introduction to PACIAE 4.0, [Comput.Phys.Commun. 310 \(2025\) 109520](#) or [2411.14255 \[hep-ph\]](#).
  - PACIAE 3.0: An introduction to the parton and hadron cascade model PACIAE 3.0, [Phys. Rev. C 108 \(2023\) 6, 064909](#) or [2309.05110 \[hep-ph\]](#).
- **Past version:**
  - PACIAE 2.2.2: Revisiting the centrality definition and observable centrality dependence of relativistic heavy-ion collisions in PACIAE model, [Comput. Phys. Commun. 284 \(2023\) 108615](#) or [arXiv:2212.04087 \[nucl-th\]](#).
  - PACIAE 2.2.1: An updated issue of the parton and hadron cascade model PACIAE 2.2, [Comput. Phys. Commun. 274 \(2022\) 108289](#).
  - PACIAE 2.2.0: Announcement for the replacement of the PACIAE 2.1 and PACIAE 2.2 series, [Comput. Phys. Commun. 224 \(2018\) 417-418](#).
  - PACIAE 2.2.0: An upgraded issue of the parton and hadron cascade model, PACIAE 2.2, [Comput. Phys. Commun. 193 \(2015\) 89-94](#) or [arXiv:1412.7579 \[nucl-th\]](#).
  - PACIAE 2.1: An updated issue of the parton and hadron cascade model PACIAE 2.0, [Comput. Phys. Commun. 184 \(2013\) 1476-1479](#) or [arXiv:1206.4795 \[nucl-th\]](#).

- PACIAE 2.0: An updated parton and hadron cascade model (program) for the relativistic nuclear collisions, [Comput. Phys. Commun. 183 \(2012\) 333-346](#) or [arXiv:1104.1238 \[nucl-th\]](#).
- PACIAE 1.0: Charge particle universal rapidity scaling in e+e-, pbar + p and Au + Au collisions at relativistic energies and its partonic origin, [J. Phys. G 32 \(2006\) 243-250](#); Influence of the partonic Pauli blocking on the hadronic final state in relativistic nucleus-nucleus collisions, [Phys. Rev. C 70 \(2004\) 034904](#).
- **Ancient version:**
  - JPCIAE: J/psi dynamical suppression in a hadron and string cascade model (or Formation time effect on J/psi dynamical nuclear suppression), [Phys. Rev. C 59 \(1999\) 2728-2733](#) or [arXiv:nucl-th/9803033](#); J/psi normal and anomalous suppressions in a hadron and string cascade model, [J.Phys.G 25 \(1999\) 1123-1133](#) or [arXiv:nucl-th/9809020](#); Inclusive and direct photons in S + Au collisions at 200A GeV/c, [Phys. Rev. C 61 \(2000\) 064905](#) or [arXiv:nucl-th/9904035](#).
- **Original version:**
  - LUCIAE 3.0: A New version of a computer program for firecracker model and rescattering in relativistic heavy ion collisions, [Comput. Phys. Commun. 116 \(1999\) 353](#) or [arXiv:nucl-th/9804001](#)
  - LUCIAE 2.0: An Event generator for the firecracker model and the rescattering in high-energy pA and AA collisions: LUCIAE version 2.0, [Comput. Phys. Commun. 90 \(1995\) 121-140](#); Final state interactions in the (nuclear) FRITIOF string interaction scenario, [Z. Phys. C 70 \(1996\) 499](#).
- **Special version:**
  - HYDRO-PACIAE, a hydrodynamic and transport hybrid model for ultra-relativistic heavy ion collisions, [J.Phys.G 40 \(2013\) 025102](#) or [arXiv:1110.6704 \[nucl-th\]](#).

## Relevant papers

- A comprehensive guide to the physics and usage of PYTHIA 8.3, [SciPost Phys.Codeb. 8 \(2022\)](#) or [arXiv:2203.11601 \[hep-ph\]](#).
- PYTHIA 6.4 Physics and Manual, [JHEP 05 \(2006\) 026](#) or [arXiv:hep-ph/0603175 \[hep-ph\]](#) (and its update notes: <https://pythia.org/download/pythia6/pythia6428.update>).

## External links

- [PYTHIA 8 \(& 6\)](#)
- [EPS & EPPS PDFs](#), [LHAPDF](#), [CTEQ PDFs](#)
- [ROOT](#), [CERNLIB](#)
- [HEPForge](#)
- [MCnet](#)

## Update notes:

## 12/2024 ~ 07/2025: In version PACIAE 4.0.03

- In "analy\_40.f90" and "Rms\_analysis.f90", fixed analysis code of mean  $p_T < p_T >$ . Analysis code of anisotropic flows were added.
- In "Pythia8CppInterface.cpp", fixed two bugs of "B\_PY8" and "C\_PY8" frameworks.
  - When performing lepton-nucleus collisions, nPDF statements might be applied to the lepton.
  - A "Beams:idB" was wrongly written as "Beams:idA", which caused serious problems for lepton-nucleus collisions when instantiating and initializing subcollisions ( $lp$ ,  $ln$ ,  $nl$  and  $pl$ ).

Thanks to Simón Fonseca for reporting the bug.

## 11/2024 PACIAE 4.0 is now released!

- The released version is 4.0.02.
- The code have been refactored and rewrite by the free-format modern Fortran + C++ from the fixed-format FORTRAN77.
- PYTHIA 8 can be interfaced in now.
- The gluon splitting and quark deexcitation mechanisms, along with the coalescence hadronization model have been improved.
- The partonic and hadronic cascades have been improved.
- Some other aspects.

## 01/2024 PACIAE 4 project launched!

## 12/2023 PACIAE 3.0 is now released!