The parton and hadron cascade model PACIAE 4

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 **pythia6_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. (Recommended) 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 **pythia6_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.

Advanced usage for PACIAE.sh

- More PACIAE-related settings.

  The forward parameters in the PACIAE.sh file provide some basic settings for simulations (They are actually aliases for those in the `usu.dat` part.). More PACIAE-related settings can be found and

modified in the embedded `usu.dat` part of PACIAE.sh. The meanings of those parameters can be found in the `Annotation of usu.dat` part.

For example, one can choose to turn off the nPDF of nuclei by setting the parameter ***adj1(5) = 0*** (Default = 9):

```
...
####################              usu.dat              ####################
...
${k_parcas}, 0.47, 0.4, 1000, 0, ${a_lund}, ... ! adj1(1)-adj1(10)
...
```

For comparison, the original line is

```
${k_parcas}, 0.47, 0.4, 1000, 9, ${a_lund}, ... ! adj1(1)-adj1(10)
```

Note that the default nPDF is a preset *208Pb EPS09 LO nPDF*. If one wants to simulate Au+Au collisions with the accurate *197Au EPS09 LO nPDF*, an ***adj(5) = 1*** and a corresponding grid file (place it into *your-PYTHIA8-directory/share/Pythia8/pdfdata/* directory manually) are required.

- More PYTHIA-related settings.

  In the embedded `pythia6/8_extra.cfg` part of PACIAE.sh, one can find statements of direct inputs of PYTHIA 6/8. They are "cardfiles" of PYTHIA 6/8. This part of the statement will prioritize overwriting the previous PYTHIA-related settings and will be passed into PYTHIA 6/8 directly. It 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. With this way, we can use almost all the features of PYTHIA 6/8.

  For example, one can use a lower reference scale (***pT0Ref***) of the minimum pT cutoff (related to the regularization of the divergence of the QCD cross section for pT -> 0) to enhance the underlying-events (multiparton interactions), leading to a larger multiplicity of final-state hadrons:

```
...
################              pythia6/8_extra.cfg              #############
...
# pythia8_extra.cfg
...
MultipartonInteractions:pT0Ref = 1.0  // Default = 2.28, pT0Ref scale
...
```

- Freely specified subprocesses.

  PACIAE provides several pre-defined subprocesses, e.g. inelastic (INEL), non-single diffractive (NSD), etc., controlled by the input parameter ***nchan*** in the input file `usu.dat` (or the alias ***i_channel*** in PACIAE.sh). But in fact, one can specify any subprocesses freely (as long as PYTHIA, and physics, allow) as follows: Choose a ***nchan*** (***i_channel***) > 10 (If not, the subprocesses you choose and those the

PACIAE pre-defines will be mixed together.), then specify subprocesses in the `pythia6/8_extra.cfg` part. See PYTHIA 6.4 Physics and Manual, JHEP 05 (2006) 026 and PYTHIA 8 online manual for more details about subprocesses.

For example, one can simulate the Higgs boson production process ***fermion + anti-fermion -> H0*** by setting

```
...
i_channel=999
...
################              pythia6/8_extra.cfg              #############
...
# pythia8_extra.cfg
...
HiggsSM:ffbar2H = on   // Specify fermion + anti-fermion -> H0 process
...
```

- Scheduling system task submission.

  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
```

```
# PACIAE  program_version
# projectile+target   frame   energy   1
Event_1  N_events  N_particles  b_parameter  b_angle  STAGE_0  event_weight
  Particle_No_1  id1  px1  py1  pz1  E1  m1  x1  y1  z1  t1  (GeV & fm)
  Particle_No_2  id2  px2  py2  pz2  E2  m2  x2  y2  z2  t2
  ...
Event_1  N_events  N_particles  b_parameter  b_angle  STAGE_1  event_weight
  Particle_No_1  id1  px1  py1  pz1  E1  m1  x1  y1  z1  t1
  ...
Event_1  N_events  N_particles  b_parameter  b_angle  STAGE_2  event_weight
  Particle_No_1  id1  px1  py1  pz1  E1  m1  x1  y1  z1  t1
  ...
Event_1  N_events  N_particles  b_parameter  b_angle  STAGE_3  event_weight
  Particle_No_1  id1  px1  py1  pz1  E1  m1  x1  y1  z1  t1
  ...
Event_1  N_events  N_particles  b_parameter  b_angle  STAGE_4  event_weight
  Particle_No_1  id1  px1  py1  pz1  E1  m1  x1  y1  z1  t1
  ...
Event_2  N_events  N_particles  b_parameter  b_angle  STAGE_0  event_weight
  Particle_No_1  id1  px1  py1  pz1  E1  m1  x1  y1  z1  t1
  ...
```

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:

01/2026 : In version PACIAE 4.0.03

- In "main_40.f90", "Pythia8CppInterface.hpp" and "Pythia8CppInterface.cpp", the random 2*pi angle of the impact parameter was introduced for the Angantyr modes.
- In "main_40.f90" and "Pythia8CppInterface.cpp", the subprocesses for lepton-induced collisions were adjusted.
- In "Pythia8_fort_interface.f90" and "Pythia8CppInterface.cpp" a series of helper functions were added.
- In "Pythia8CppInterface.cpp" and "Pythia8CppInterface.hpp", the PYTHIA 8 interface version compatibility was improved.
- In "analy_40.f90" and "Rms_analysis.f90", fixed analysis code of mean pT, < pT >. Analysis code of anisotropic flows were added.
- **Bug fix**
    - 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.
    - In "Parcas_40.f90", fixed a bug of the upper integral limit of the momentum transfer in the inelastic process q1 + q1bar -> g + g, which was 0 leading to a ''nan'' cross section

Thanks to Guan-Yu Wang for reporting the bug.

- In "Makefile", fixed a PYTHIA8 dynamic shared library missing bug when PACIAE4 and PYTHIA8 folders were placed in the same directory.

  Thanks to Qiang Wang for reporting the bug.

- In "Pythia8CppInterface.cpp", an accidental bug of the pA/Ap nPDF was fixed, which assigned a proton nPDF.

  Thanks to Qiang Wang 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!