PYTHIA8— status and plans

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On behalf of the PYTHIA8 collaboration

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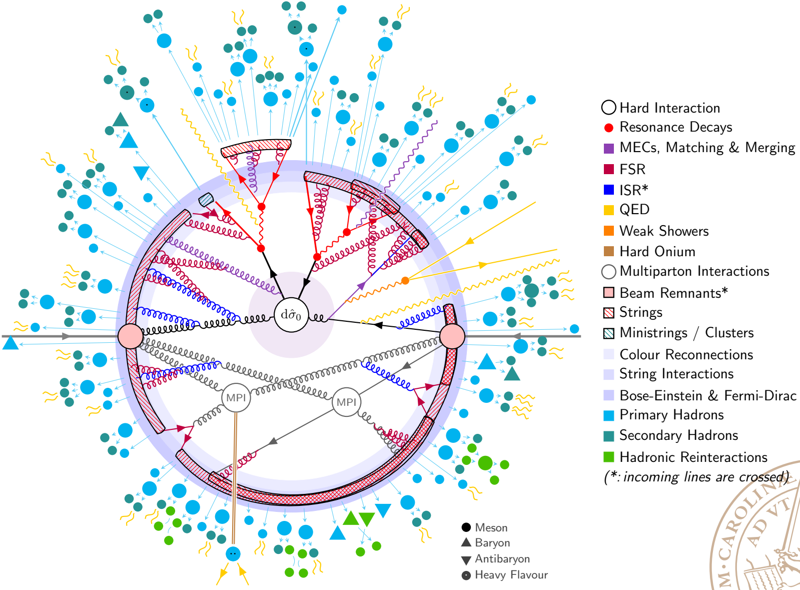
DESY, 2024-05-14

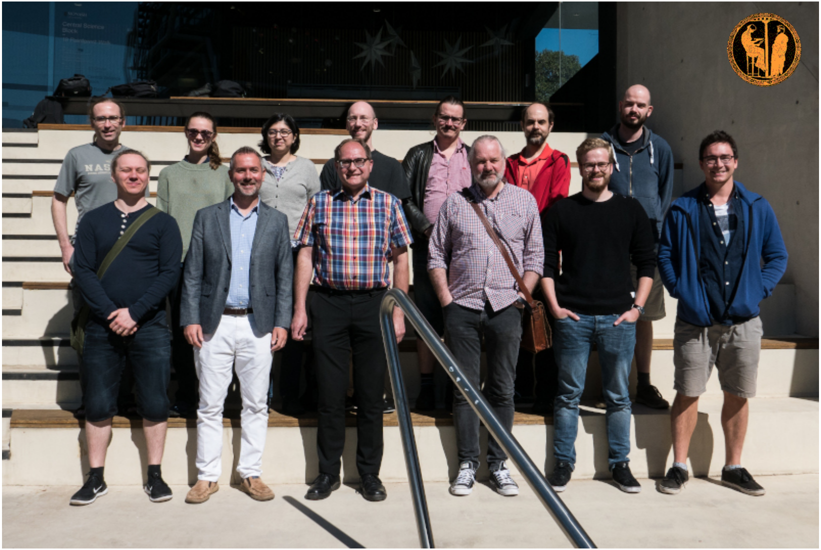
Outline

- Introduction
- Recent developments
  - **`ParallelPythia`**, Shower variations, biasing
  - Hadronisation weights, Onium showers
  - Variable energies and beams (air showers, GEANT)
- Future
  - New *Contrib* area for plugins
  - Move to **`gitlab.cern.ch`**
  - Tuning
  - Funding
  - Career paths

[arXiv:2203.11601, A comprehensive guide to the physics and usage of PYTHIA8]


dσ̂0
MPI
MPI
Hard Interaction
Resonance Decays
MECs, Matching & Merging
FSR
ISR*
QED
Weak Showers
Hard Onium
Multiparton Interactions
Beam Remnants*
Strings
Ministrings / Clusters
Colour Reconnections
String Interactions
Bose-Einstein & Fermi-Dirac
Primary Hadrons
Secondary Hadrons
Hadronic Reinteractions
(*: incoming lines are crossed)
Meson
Baryon
Antibaryon
Heavy Flavour

The PYTHIA8 collaboration



The PYTHIA8 collaboration

Javira Altman (Monash), Christian Bierlich (Lund), Naomi Cooke (Glasgow), Nishita Desai (Mumbai), Leif Gellersen (Lund), Ilkka Helenius (Jyväskylä), Philip Ilten (Birmingham), Leif Lönnblad (Lund), Stephen Mrenna (Fermilab), Christian Preuss (Zürich), Torbjörn Sjöstrand (Lund), Peter Skands (Monash), Marius Utheim (Jyväskylä), Rob Verheyen (UCL)

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Current release is 8.311 (8.312 imminent)

Paralellisation

Every event is independent, so PYTHIA8 itself can be parallelised

- Each `Pythia` object is perfectly thread safe
- OpenMP and HDF5 LHEF supported
- New wrapper class using `std::thread`

ParallelPythia

```
# from examples/main161.cc

#include "Pythia8/Pythia.h"
#include "Pythia8/PythiaParallel.h"
using namespace Pythia8;
int main() {
  // Use the PythiaParallel class for parallel generation.
  PythiaParallel pythia;
  pythia.readString("Beams:eCM = 8000.");
  pythia.readString("HardQCD:all = on");
  pythia.readString("PhaseSpace:pTHatMin = 20.");
  pythia.init();
  Hist mult("charged multiplicity", 100, -0.5, 799.5);
  // Use PythiaParallel::run to generate the specified number of events.
  pythia.run(10000, [&](Pythia* pythiaPtr) {
    // Find number of all final charged particles and fill histogram.
    int nCharged = 0;
    for (int i = 0; i < pythiaPtr->event.size(); ++i)
      if (pythiaPtr->event[i].isFinal() && pythiaPtr->event[i].isCharged())
        ++nCharged;
    mult.fill( nCharged );
    // End of event loop. Statistics. Histogram. Done.
  });
  pythia.stat();
  cout << mult;
  return 0;
}
```

Shower variations

With multiple weights per event we can save a lot of CPU time for scale variations etc.

Scale variations is easy for MEs. Showers are more tricky.

- We have splitting functions and no emission functions

$$P(p_\perp^2) \times \exp\left(- \int_{p_\perp^2}^{p_{\perp,\text{prev}}^2} dk_\perp^2 P(k_\perp^2) \right)$$

- Using the veto algorithm we oversample with a simple overestimate function and throw to get the correct distribution.

[arXiv:1605.08352]

Every time we accept/reject we can get weights for different variations,

$$P(p_\perp^2, \alpha_s(\mu_R)) \to P(p_\perp^2, \alpha_s(C\mu_R)) \quad \Rightarrow \quad p_{\mathrm{acc}} \to p'_{\mathrm{acc}}, p_{\mathrm{rej}} \to p'_{\mathrm{rej}},$$

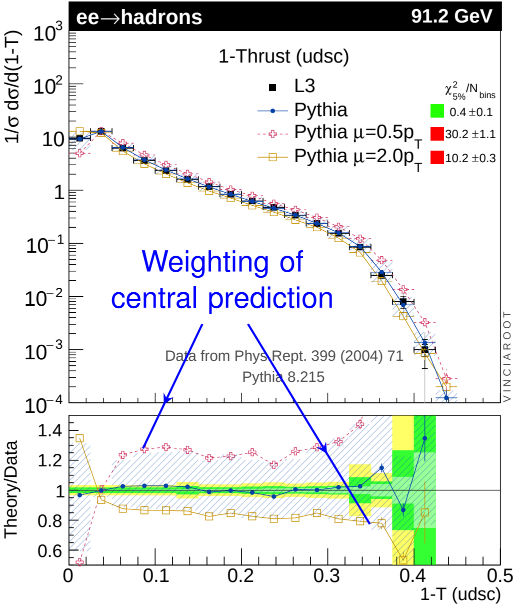
accept/reject according p_{acc} and p_{rej}, and get an event weight

$$w_{ev} = \prod_i \frac{p'_i}{p_i}$$

Note that large reweighting factors may result in fluctuating weights, so the statistical uncertainty will increase:

$$N_{\mathrm{ev,\ eff}} = \frac{\left(\sum w\right)^2}{\sum w^2}$$

- μ_R scale for QCD emissions in FSR
- μ_R scale for QCD emissions in ISR
- inclusion of non-singular terms in QCD emissions in FSR
- inclusion of non-singular terms in QCD emissions in ISR
- PDF members of a PDF family in LHAPDF6
- individual PDF members of a PDF family in LHAPDF6


ee→hadrons
91.2 GeV
1-Thrust (udsc)
L3
Pythia
Pythia μ=0.5p_T
Pythia μ=2.0p_T
χ²_5%/N_bins
0.4 ±0.1
30.2 ±1.1
10.2 ±0.3
Weighting of
central prediction
Data from Phys.Rept. 399 (2004) 71
Pythia 8.215
1/σ dσ/d(1-T)
Theory/Data
1-T (udsc)
VINCIA ROOT

Biasing

The same procedure may be used to bias your events, e.g. to get more $g \to b\bar{b}$

$$P'_{b\bar{b}}(p_\perp^2) = C P_{b\bar{b}}(p_\perp^2)$$

but now the rôle of variation and standard setting are reversed, so we accept/reject according to p'_{acc} and p'_{rej}, and get an event weight

$$w_{ev} = \prod_i \frac{p_i}{p'_i}$$

Biasing works well for low probability processes, but for more common processes we are hit by large weight fluctuations.

The statistical uncertainty of an observable scales like a power of the inverse no-emission probability, Δ^{-h}

For an *n*-emission observable we get an uncertainty

$$\delta\mathcal{O}_n \propto \frac{\Delta^{-h}}{\sqrt{C^n}}, \quad \text{with} \quad h \approx C$$

You cannot bias MPI.

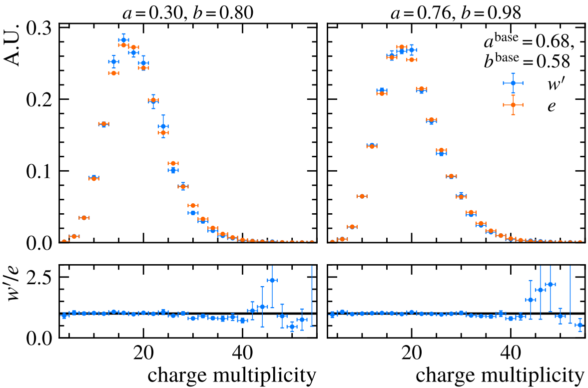
Hadronisation weights

In addition, weight variations are soon also available for hadronisation parameters.

Works on the same principle as shower variations (with the same caveats), but this time modifying hit-and-miss algorithms for e.g. the Lund symmetric fragmentation function.

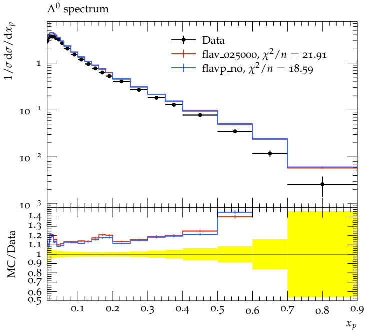
$$p(z) \propto \frac{(1-z)^a}{z} e^{-bm_\perp^2/z}$$

[arXiv:2308.13459]

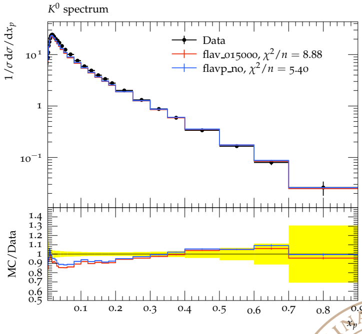

$a = 0.30$, $b = 0.80$
$a = 0.76$, $b = 0.98$
$a^{\text{base}} = 0.68$,
$b^{\text{base}} = 0.58$
w'
e
A.U.
0.3
0.2
0.1
0.0
w'/e
2.5
0.0
20
40
charge multiplicity

Flavour variations

$\rho =$ `StringFlav:probStoUD`

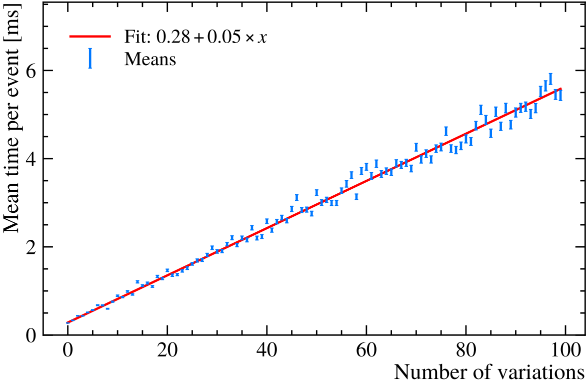


$\rho = 0.217 \rightarrow \rho = 0.25$



$\rho = 0.217 \rightarrow \rho = 0.15$

Timing


Fit: $0.28 + 0.05 \times x$
Means
Mean time per event [ms]
0
2
4
6
0
20
40
60
80
100
Number of variations

This is mainly useful for tuning

But again, if you can do weight variations you can do biasing (caveats still applies)

Onia showers

PYTHIA8 now includes shower splittings into charmonium and bottomonium splittings, e.g. $c \rightarrow J/\psi + c$ and $g \rightarrow O(^3P_J) + g$

(it's unfortunately a bit slow)

Biasing with a constant factor available.

[available since version 8.310]

Even-by-event beams types and energies

```
pythia.readString("Beams:allowVariableEnergy = on");
pythia.readString("Beams:allowIDAswitch = on");

// ...

pythia.init();

// ...

pythia.setBeamId(idProj, idTarg);
pythia.setKinematics(pBeam, pTarg);
pythia.next();
```

Mainly useful for Cosmic ray air showers, but is fairly general.

Could (will?) also be used in GEANT4

Pythia8/Contrib

PYTHIA8 is very configurable and it is possible to plug in you own model for a part of the generation.

- **LHAup** add your own MEs.
- **DecayHandler** add your favourite decays.
- **RndmEngine** use your favourite random number generator.
- **ShowerModel** build your own parton shower.
- ...

There is also a general **UserHooks** class for manipulating the generation in PYTHIA8 at predefined places.

Now there is a new **Plugin** system where such modifications can be loaded at run time using the existing **Settings** system.

This will now be further facilitated by a **`contrib`** area where developers of such models can make their code available (as is done in e.g. **`fastjet`**).

Developer:

```
% git clone git@gitlab.com:pythia8-contrib/develop.git pythia8-contrib-devel
% cd pythia8-contrib-devel
% ./generate MyCoolHook UserHooks/MyCoolHook
% ls MyCoolHook
configure  include  Makefile  README.md  share  src
# Hack away
```

Create a ticket on **`gitlab.com/pythia8-contrib`** to get a repo for your project.

User:

```
% git glone git@gitlab.com:pythia8-contrib/contrib.git pythia8-contrib
% cd  pythia8-contrib
% ./enable MyCoolHook
% ./configure
% make install
```

Use **`Init:plugins`** settings to include contributed modules at run-time.

gitlab.where?

Yes, we use `gitlab.com`

- CI/CD with runners in Lund (a bit unstable)
- Special release repo with service desk to which non git users can e-mail issues.
- Web-page builder for web server in Lund
- Repository of tutorials

Our main *customers* are affiliated with CERN and we feel that PYTHIA8 belongs on `gitlab.cern.ch`. But not all users. And not all developers. Lightweight CERN accounts do not give you access to gitlab.

Tuning

The standard *Monash* tune for PYTHIA8 is ten years old. It needs to be updated.

We are embarking on a new tuning effort using the Professor/Apprentice framework.

This will hopefully produce new, better, easily reproducible tunes of PYTHIA8 this year.

What is MCnet?

- 2007–2010 MCnet RTN (FP6, MCA)
- 2012–2016 MCnet ITN (FP7, MSCA)
- 2017–2021 MCnet ITN3 (H2020, MSCA)

Manchester, Durham, Göttingen, Glasgow, Karlsruhe, Louvain, Lund, UCL, Vienna, Graz, CERN, Heidelberg, Monash, Dresden, Edinburgh, Fermilab, Kennesaw State.

Contur, HEJ, Herwig, MadGraph, Professor, Pythia, Rivet, Sherpa, . . .

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- 2024– ?

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MCnet

Funding and MCnet

There is a large demand for PYTHIA8 and other event generators and tools. But who pays for them?

Since 2007 MCnet has received three major grants from MSCA, but is currently not funded at all.

Through LPCC we have been promised some basic funding for meetings and short projects at CERN.

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MSCA

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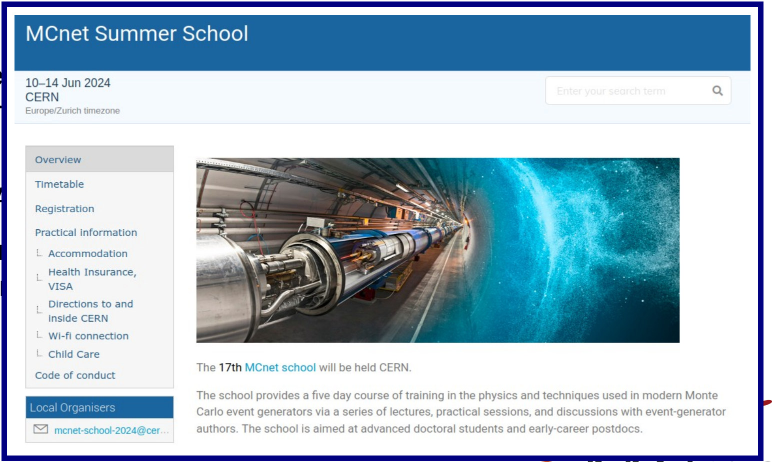

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Career paths

MCnet has trained $\sim$ 100 PhD students. Where are they now

Event generator authors are mainly

- Theorists
- close to experiments, but not experimenters
- developing software but not computer scientists

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Who wants to hire us

- as Postdocs?
- as Junior faculty?
- as Permanent faculty?

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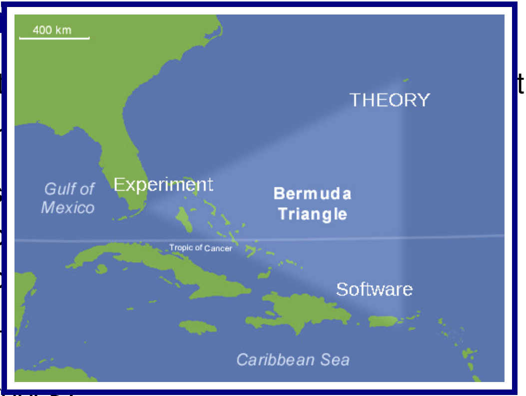
- close to
- develop



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HL-LHC Computing Review arXiv:2109.14938

Conclusions

- Where are all the event generator authors?
- Who wants to hire event generator authors? CERN?
- LPCC will soon start a MC working group – what will be the relationship to HSF Generators group.
- Who will take responsibility for the continued development of event generators? CERN?
- Who will train the new generation of authors.

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Thank you for your attention!

- Who will train the new generation of authors.

Who will pay the bills?