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HERA and the LHC Workshop  
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CERN, Geneva

# PYTHIA 8 Status Report

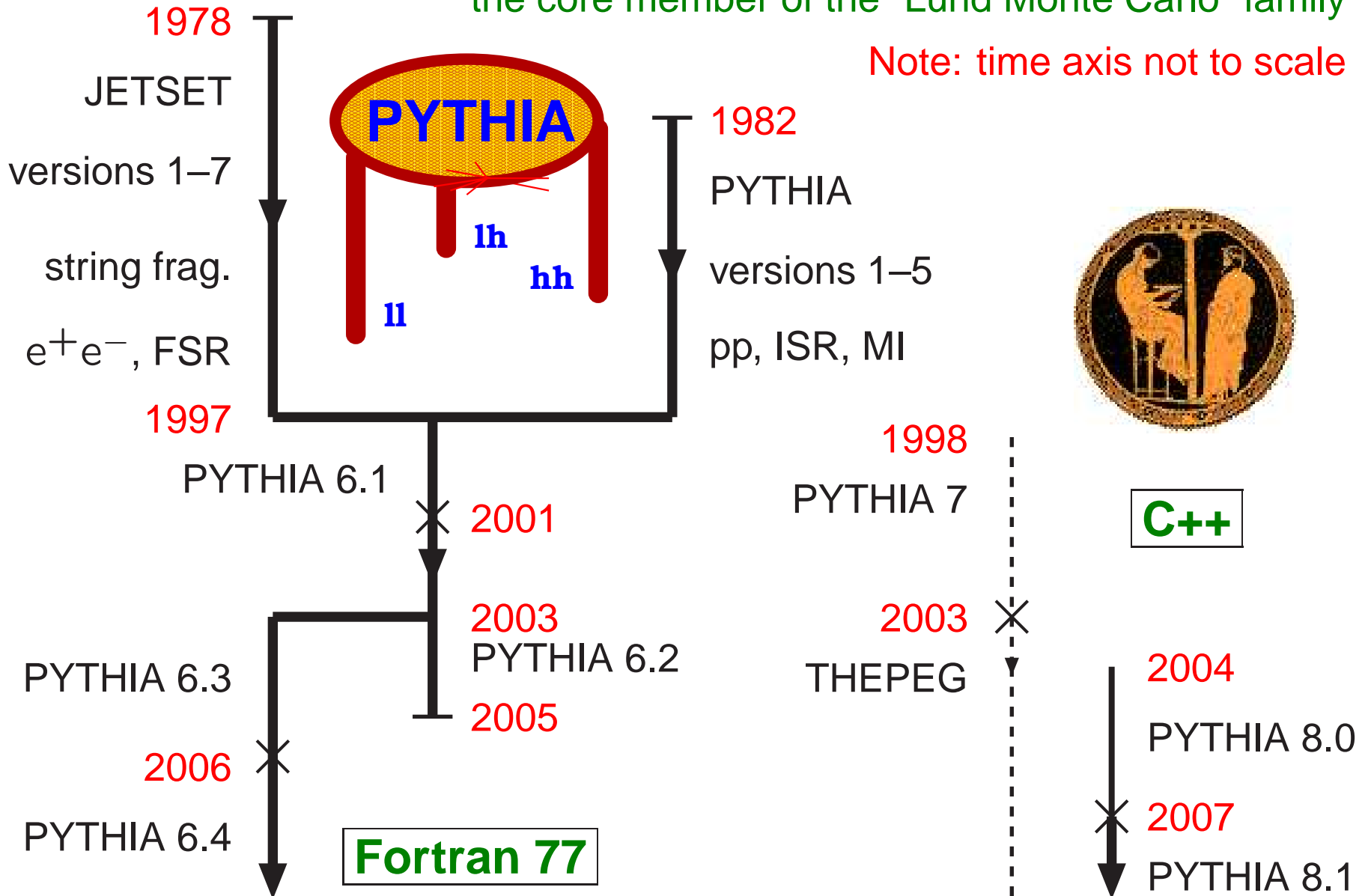
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# PYTHIA history

the core member of the “Lund Monte Carlo” family

Note: time axis not to scale



# PYTHIA Physics (part I)

## Hard processes:

- Built-in library of many leading-order processes.  
Standard Model: almost all  $2 \rightarrow 1$  and  $2 \rightarrow 2$ , a few  $2 \rightarrow 3$ .  
Beyond the SM: a bit of each (PYTHIA 8 not yet SUSY and TC).
- External input via Les Houches Accord and Les Houches Event Files from MadGraph, CompHep, AlpGen, ...
- Resonance decays, often but not always with angular correlations .

## Showers:

- Transverse-momentum-ordered ISR & FSR, but PYTHIA 6 still older virtuality-ordered as default.
- Includes  $q \rightarrow qg$ ,  $g \rightarrow gg$ ,  $g \rightarrow q\bar{q}$ ,  $f \rightarrow f\gamma$ ,  $\gamma \rightarrow f\bar{f}$  ( $f = \text{fermion}$ ).
- ISR by backwards evolution.
- Dipole-style approach to recoils.
- Matching to ME's for first (=hardest) emission in many processes, especially gluon emission in resonance decays.

# PYTHIA Physics (part II)

## Underlying events and minimum-bias events:

- Multiple parton–parton interactions, with dampening of cross-section in  $p_{\perp} \rightarrow 0$  limit, impact-parameter dependence, and tailormade PDF's.
- Combined evolution MI + ISR + FSR downwards in  $p_{\perp}$ .
- Beam remnants colour-connected to interacting systems, and detailed modelling of flavour and momentum structure.

## Hadronization:

- String fragmentation (“the Lund Model”).
- Particle decays, usually isotropic.
- Link to external decay packages, say for  $\tau$  (TAUOLA) or B (EVTGEN).
- Optional Bose-Einstein effects.

## Utilities:

- Four-vectors, random numbers, parton densities, ...
- Event study routines: sphericity, thrust, jet finding.
- Simple built-in histogramming package (line-printer mode).

# Multiple Interactions: A New Evolution Equation

	time	evolution	probability
FSR	forwards	$p_{\perp} \searrow 0$	normal & local
ISR	backwards	$p_{\perp} \searrow 0$	conditional
MI	simultaneous	$p_{\perp} \searrow 0$	conditional

ISR + MI: PDF competition  $\Rightarrow$  interleaving (PYTHIA 6.3)

FSR: previously at end, now also interleaved (PYTHIA 8.1):

$$\frac{d\mathcal{P}}{dp_{\perp}} = \left( \frac{d\mathcal{P}_{\text{MI}}}{dp_{\perp}} + \sum \frac{d\mathcal{P}_{\text{ISR}}}{dp_{\perp}} + \sum \frac{d\mathcal{P}_{\text{FSR}}}{dp_{\perp}} \right) \times \exp \left( - \int_{p_{\perp}}^{p_{\perp i-1}} \left( \frac{d\mathcal{P}_{\text{MI}}}{dp'_{\perp}} + \sum \frac{d\mathcal{P}_{\text{ISR}}}{dp'_{\perp}} + \sum \frac{d\mathcal{P}_{\text{FSR}}}{dp'_{\perp}} \right) dp'_{\perp} \right)$$

“resolution evolution”

Monte Carlo: winner takes all

+ many other assumptions/models

# Key differences between PYTHIA 6.4 and 8.1

Old features definitely removed include, among others:

- independent fragmentation
- mass-ordered showers

Features omitted so far include, among others:

- ep,  $\gamma p$  and  $\gamma\gamma$  beam configurations
- several processes, especially SUSY & Technicolor

New features, not found in 6.4:

- interleaved  $p_{\perp}$ -ordered MI + ISR + FSR evolution
- richer mix of underlying-event processes ( $\gamma$ ,  $J/\psi$ , DY, ...)
- possibility for two selected hard interactions in same event
- possibility to use one PDF set for hard process and another for rest
- elastic scattering with Coulomb term (optional)
- updated decay data

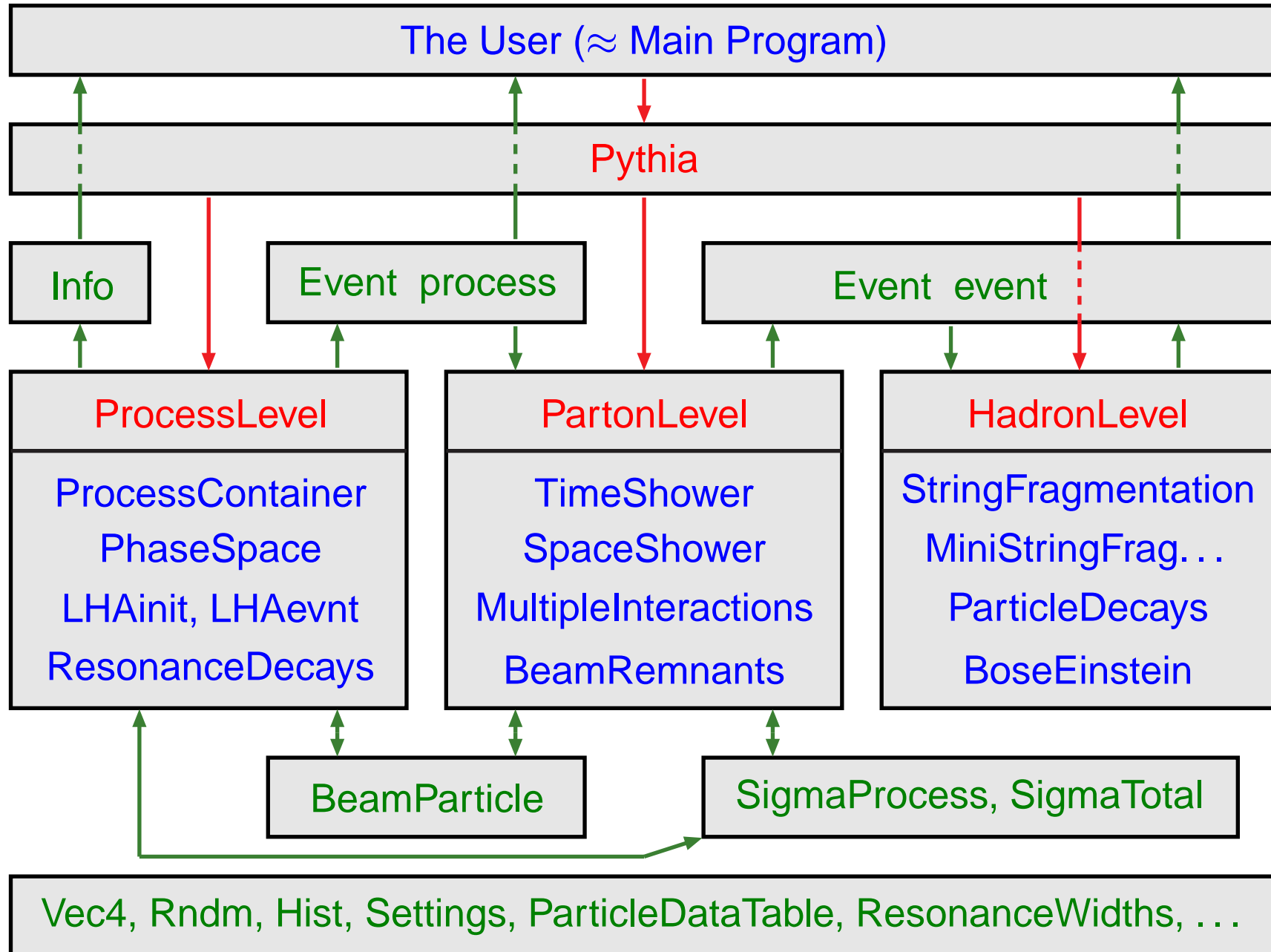
Plans for the future:

- rescattering in multiple interactions (with Florian Bechtel & Richard Corke)
- more ME/PS matching (with Richard Corke)

# News since PYTHIA 8.100

- Acolliner beams and beam momentum spread.
- Beam vertex spread.
- Reduced use of `static`:  
possibility to have several almost separate `Pythia` instances,  
e.g. signal + background events in pileup.
- Combine event records with `new =` and `+=` methods.
- Updated `SusyLesHouches` interface handles SLHA version 2.
- Neutralino pair production now operational.
- Updated routine for HepMC conversion; support for version 1 dropped;  
bug fix for `onium`  $\rightarrow$  `ggg` or  $\gamma$ `gg`.
- Improved capability for standalone hadronization.
- Improved handling of Higgs width.
- Safety checks on  $\alpha_s$  at small scales.
- Changed for compilation with gcc 4.3.0 and with `-Wshadow` option.
- Some further minor improvements and bug fixes.

# PYTHIA 8 structure





# Initialization and generation commands

Standard in beginning:

- `#include "Pythia.h"`
- `using namespace Pythia8;`
- `Pythia pythia;`

Initialization by one of different forms:

- `pythia.init( idA, idB, eA, eB)` along  $\pm z$  axis
- `pythia.init( idA, idB, eCM)` in c.m. frame
- `pythia.init( "filename")` for Les Houches Event Files
- `pythia.init()` takes above kinds of input from “cards”
- `pythia.init( LHAinit*, LHAevnt*)` for Les Houches Accord  
returns **false if failed** (normally user setup mistake!)

Generation of next event by:

- `pythia.next()`

with no arguments, but value **false if failed** (rare!)

At the end of the generation loop:

- `pythia.statistics()`

provides some summary information

# Settings and Particle Data

Can read in settings and particle data changes by

- `pythia.readString("command")`
- `pythia.readFile("filename")` with one `command` per line in file

**Settings** come in four kinds

- **Flags**: on/off switches, bool  
(on = yes = ok = true = 1, off = no = false = 0)
- **Modes**: enumerated options, int
- **Parms**: (short for parameters) continuum of values, double
- **Words**: characters (no blanks), string

and `command` is of form `task:property = value`, e.g.

`PartonLevel:ISR = off` no initial-state radiation

`SigmaProcess:alphaSOrder = 0` freeze  $\alpha_s$

`TimeShower:pTmin = 1.0` cut off final-state radiation at 1 GeV

To access **particle data**, instead `command` should be of form

`id:property = value` or `id:channel:property = value`, e.g.

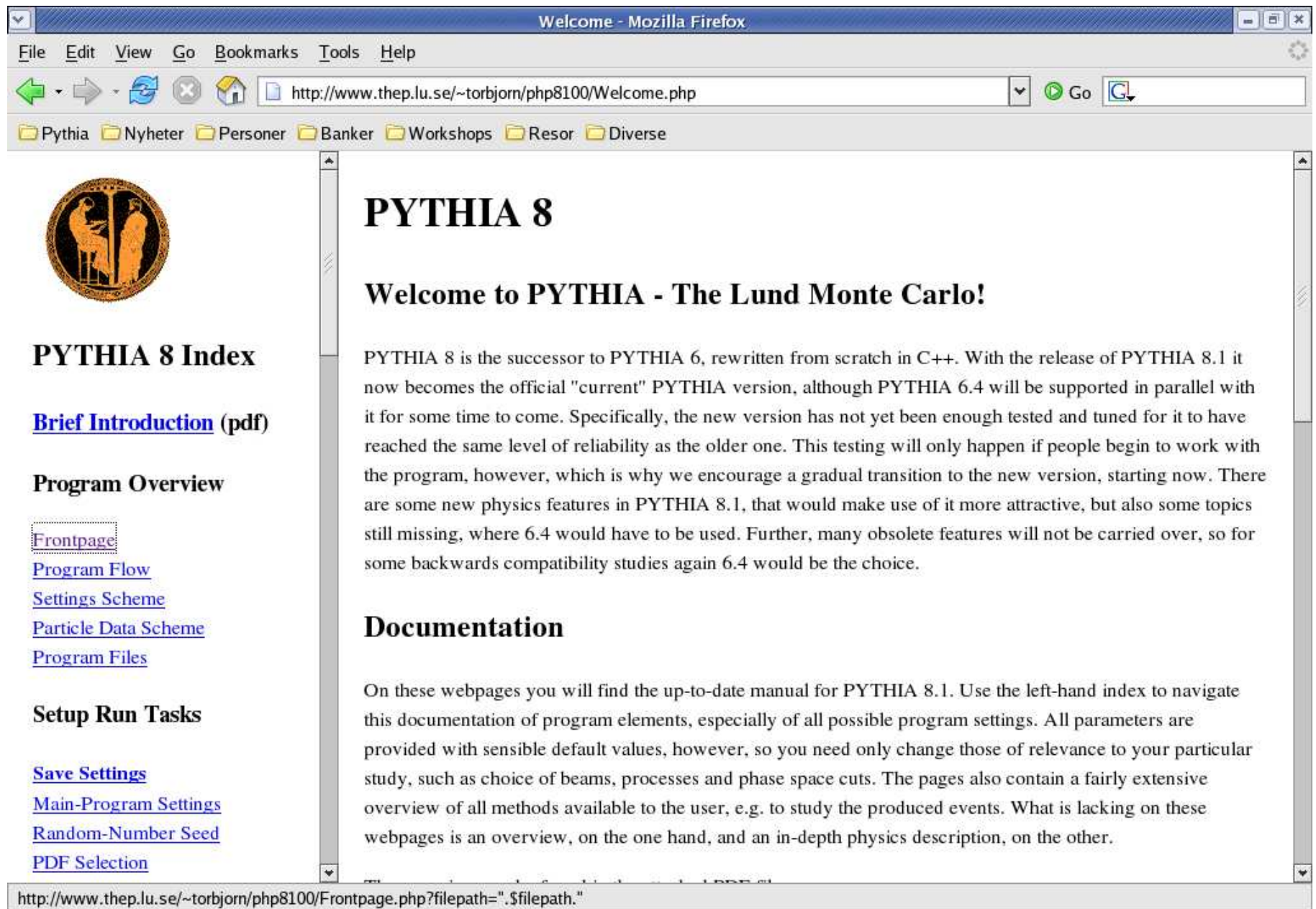
`3122:mayDecay = no` do not allow  $\Lambda^0$  to decay

`215:3:products = 211 111 111` to let  $a_2^+ \rightarrow \pi^+ \pi^0 \pi^0$

**Note: case-insensitive search/matching in databases!**

ProcessGroup	ProcessName
SoftQCD	minBias,elastic, singleDiffractive, doubleDiffractive
HardQCD	gg2gg, gg2qqbar, qg2qg, qq2qq, qqbar2gg, qqbar2qqbarNew, gg2ccbar, qqbar2ccbar, gg2bbbar, qqbar2bbbar
PromptPhoton	qg2qgamma, qqbar2ggamma, gg2ggamma, ffbar2gammagamma, gg2gammagamma
WeakBosonExchange	ff2ff(t:gmZ), ff2ff(t:W)
WeakSingleBoson	ffbar2gmZ, ffbar2W, ffbar2ffbar(s:gm)
WeakDoubleBoson	ffbar2gmZgmZ, ffbar2ZW, ffbar2WW
WeakBosonAndParton	qqbar2gmZg, qg2gmZq, ffbar2gmZgm, fgm2gmZf qqbar2Wg, qg2Wq, ffbar2Wgm, fgm2Wf
Charmonium	gg2QQbar[3S1(1)]g, qg2QQbar[3PJ(8)]q, ...
Bottomonium	gg2QQbar[3S1(1)]g, gg2QQbar[3P2(1)]g, ...
Top	gg2ttbar, qqbar2ttbar, qq2tq(t:W), ffbar2ttbar(s:gmZ), ffbar2tqbar(s:W)
FourthBottom	gg2bPrimebPrimebar, qq2bPrimeq(t:W) , ...
FourthTop	qqbar2tPrimetPrimebar, fbar2tPrimeqbar(s:W), ...
FourthPair	ffbar2tPrimebPrimebar(s:W), fbar2tauPrimenuPrimebar(s:W)
HiggsSM	ffbar2H, gg2H, ffbar2HZ, ff2Hff(t:WW), ...
HiggsBSM	h, H and A as above, charged Higgs, pairs
SUSY	qqbar2chi0chi0 (SUSY barely begun)
NewGaugeBoson	ffbar2gmZZprime, ffbar2Wprime, ffbar2R0
LeftRightSymmetry	ffbar2ZR, ffbar2WR, ffbar2HLHL, ...
LeptoQuark	ql2LQ, qg2LQl, gg2LQLQbar, qqbar2LQLQbar
ExcitedFermion	dg2dStar, qq2uStarq, qqbar2muStarmu, ...
ExtraDimensionsG*	gg2G*, qqbar2G*, ...

# Online manual $\implies$ Graphical User Interface




Welcome - Mozilla Firefox

File Edit View Go Bookmarks Tools Help

http://www.thep.lu.se/~torbjorn/php8100/Welcome.php

Pythia Nyheter Personer Banker Workshops Resor Diverse



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## PYTHIA 8

### Welcome to PYTHIA - The Lund Monte Carlo!

PYTHIA 8 is the successor to PYTHIA 6, rewritten from scratch in C++. With the release of PYTHIA 8.1 it now becomes the official "current" PYTHIA version, although PYTHIA 6.4 will be supported in parallel with it for some time to come. Specifically, the new version has not yet been enough tested and tuned for it to have reached the same level of reliability as the older one. This testing will only happen if people begin to work with the program, however, which is why we encourage a gradual transition to the new version, starting now. There are some new physics features in PYTHIA 8.1, that would make use of it more attractive, but also some topics still missing, where 6.4 would have to be used. Further, many obsolete features will not be carried over, so for some backwards compatibility studies again 6.4 would be the choice.

### Documentation

On these webpages you will find the up-to-date manual for PYTHIA 8.1. Use the left-hand index to navigate this documentation of program elements, especially of all possible program settings. All parameters are provided with sensible default values, however, so you need only change those of relevance to your particular study, such as choice of beams, processes and phase space cuts. The pages also contain a fairly extensive overview of all methods available to the user, e.g. to study the produced events. What is lacking on these webpages is an overview, on the one hand, and an in-depth physics description, on the other.

http://www.thep.lu.se/~torbjorn/php8100/Frontpage.php?filepath=". \$filepath."

# Example: timelike parton showers

Welcome - Mozilla Firefox

File Edit View Go Bookmarks Tools Help

http://www.thep.lu.se/~torbjorn/php8100/Welcome.php

Pythia Nyheter Personer Banker Workshops Resor Diverse

- [Electroweak](#)
- [Onia](#)
- [Top](#)
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the choice is not as unique. Here the factorization scale has been chosen as the maximum evolution scale. This would be the  $pT$  for a  $2 \rightarrow 2$  process, supplemented by mass terms for massive outgoing particles. Some small amount of freedom is offered by

**TimeShower:pTmaxFudge**  (default = 1.0; minimum = 0.5; maximum = 2.0)

While the above rules would imply that  $pT_{max} = pT_{factorization}$ , pTmaxFudge introduced a multiplicative factor  $f$  such that instead  $pT_{max} = f * pT_{factorization}$ . Only applies to the hardest interaction in an event. It is strongly suggested that  $f = 1$ , but variations around this default can be useful to test this assumption.

The amount of QCD radiation in the shower is determined by

**TimeShower:alphaSvalue**  (default = 0.137; minimum = 0.06; maximum = 0.25)

The  $\alpha_{strong}$  value at scale  $M_Z^2$ . The default value corresponds to a crude tuning to LEP data, to be improved.

The actual value is then regulated by the running to the scale  $pT^2$ , at which the shower evaluates  $\alpha_{strong}$

**TimeShower:alphaSorder** (default = 1; minimum = 0; maximum = 2)

Order at which  $\alpha_{strong}$  runs,

- 0 : zeroth order, i.e.  $\alpha_{strong}$  is kept fixed.
- 1 : first order, which is the normal value.
- 2 : second order. Since other parts of the code do not go to second order there is no strong reason to use this option, but there is also nothing wrong with it.

http://www.thep.lu.se/~torbjorn/php8100/TimelikeShowers.php?filepath=files/

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Event Information

Event Statistics  
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Event Analysis  
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## Link to Other Programs

Les Houches Accord  
Access PYTHIA 6 Processes  
Semi-Internal Processes  
Semi-Internal Resonances  
Hadron-Level Standalone  
SUSY Les Houches Accord  
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User Hooks  
Random Numbers  
Implement New Showers

## Reference Material

PYTHIA 6 Translation Table  
Update History  
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Version

# Link to other program

PYTHIA is standalone, but several ways to link to it.

## Possibilities similar to PYTHIA 6.4:

- Input from Les Houches Accord & Les Houches Event Files
- Output to HepMC event format (more robust than PYTHIA 6!?)
- SUSY Les Houches Accord (input file with masses, couplings, ...)
- Link to external decays, e.g. for  $\tau$  and B.
- Link to LHAPDF version 5.3.0 or later, or to your own PDF.

New possibilities, based on derived classes and pointers to them:

- Semi-internal process: write derived matrix-element class,

```
SigmaProcess* mySigma = new MySigma();
```

```
pythia.setSigmaPtr( mySigma);
```

and let PYTHIA do phase space integration, process mixing, ...

- Semi-internal resonance in same style: calculate partial widths
- Link to external random-number generator.
- Link to external shower, e.g. [VINCIA](#) for FSR.
- User hooks: veto events early on or reweight cross section.

# Trying It Out

- Download `pythia8108.tgz` from  
`http://www.thep.lu.se/~torbjorn/Pythia.html`
- `tar xvzf pythia8108.tgz` to unzip and expand
- `cd pythia8108` to move to new directory
- `./configure ...` needed for external libraries + debug/shared  
(see `README`, libraries: HepMC, LHAPDF, PYTHIA 6)
- `make` will compile in  $\sim 3$  minutes  
(for archive library, same amount extra for shared)
- The `htmldoc/pythia8100.pdf` file contains A Brief Introduction
- Open `htmldoc/Welcome.html` in a web browser for the full manual
- Install the `phpdoc/` directory on a webserver and open  
`phpdoc/Welcome.html` in a web browser for an interactive manual
- The `examples` subdirectory contains  $> 30$  sample main programs:  
standalone, link to libraries, semi-internal processes, ...  
(`make mainNN` and then `./mainNN.exe > outfile`)
- A `Worksheet` contains step-by-step instructions  
and exercises how to write and run a main program



# PYTHIA 8 status

## task

administrative structure  
hard processes, internal  
resonance decays  
hard processes, external  
SUSY(+more) parameters  
initial-state showers  
final-state showers  
matching ME's to showers  
multiple interactions  
beam remnants & colour flow  
parton densities  
string fragmentation  
decays & particle data  
Bose-Einstein  
analysis  
graphical user interface  
tuning  
testing  
ep,  $\gamma p$ ,  $\gamma\gamma$

## status

operational; extensions planned  
much of PYTHIA 6; SUSY & TC & more to do  
much of PYTHIA 6; SUSY & TC & more to do  
interfaces to LHA F77, LHEF, PYTHIA 6  
SLHA2; more needed  
operational  
operational  
some exists; much more needed  
operational; extensions planned  
operational; alternatives to come  
only 2 internal, but interface to LHAPDF  
operational; improvements planned  
operational; may need updates  
operational; off by default (tuning)  
some simple tools; may be enough  
operational; could be extended  
major task for MCnet postdocs!  
major task for experimentalists!  
not in the foreseeable future

# Summary

## Legacy PYTHIA 6.416:

- 75,000 lines of code (including comments/blanks).
- 580 page PYTHIA 6.4 Physics and Manual, T. Sjöstrand, S. Mrenna and P. Skands, JHEP**05** (2006) 026 [hep-ph/0603175].
- + update notes, sample main programs, etc.

## Current PYTHIA 8.108:

- 53,000 lines of code (including comments/blanks),
- 27 page A Brief Introduction to PYTHIA 8.1, T. Sjöstrand, S. Mrenna and P. Skands, Comput. Phys. Comm. **178** (2008) 852 [arXiv:0710.3820].
- + online manual, sample main programs, worksheets, etc.

- + Thanks to the GENSER group, and especially Mikhail Kirsanov, for help with Makefiles, configure scripts and HepMC interface.
- Adoption of PYTHIA 8 by experimental collaborations has been slow.