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PYTHIA 8 Status Report

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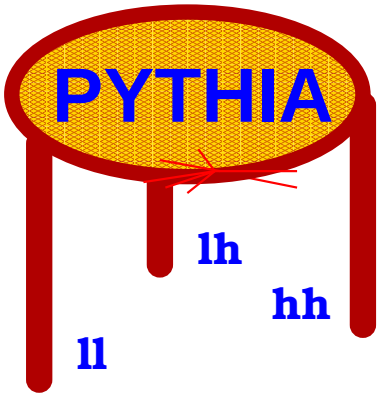
PYTHIA history

the core member of the “Lund Monte Carlo” family

Note: time axis not to scale



1978

JETSET

versions 1–7

string frag.

e^+e^-, FSR

1982

PYTHIA

versions 1–5

pp, ISR, MI

1997

PYTHIA 6.1

2001

2003

PYTHIA 6.2

2005

PYTHIA 6.3

2006

PYTHIA 6.4

Fortran 77

1998

PYTHIA 7

2003

THEPEG

C++

2004

PYTHIA 8.0

2007

PYTHIA 8.1

PYTHIA Physics (part I)

Hard processes:

- Built-in library of many leading-order processes.
  Standard Model: almost all $2 \to 1$ and $2 \to 2$, a few $2 \to 3$.
  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 $q \to qg$, $g \to gg$, $g \to q\overline{q}$, $f \to f\gamma$, $\gamma \to f\overline{f}$ (f = 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 $p_\perp \to 0$ 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 τ (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):

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

“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, γp 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 (γ, J/ψ, 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

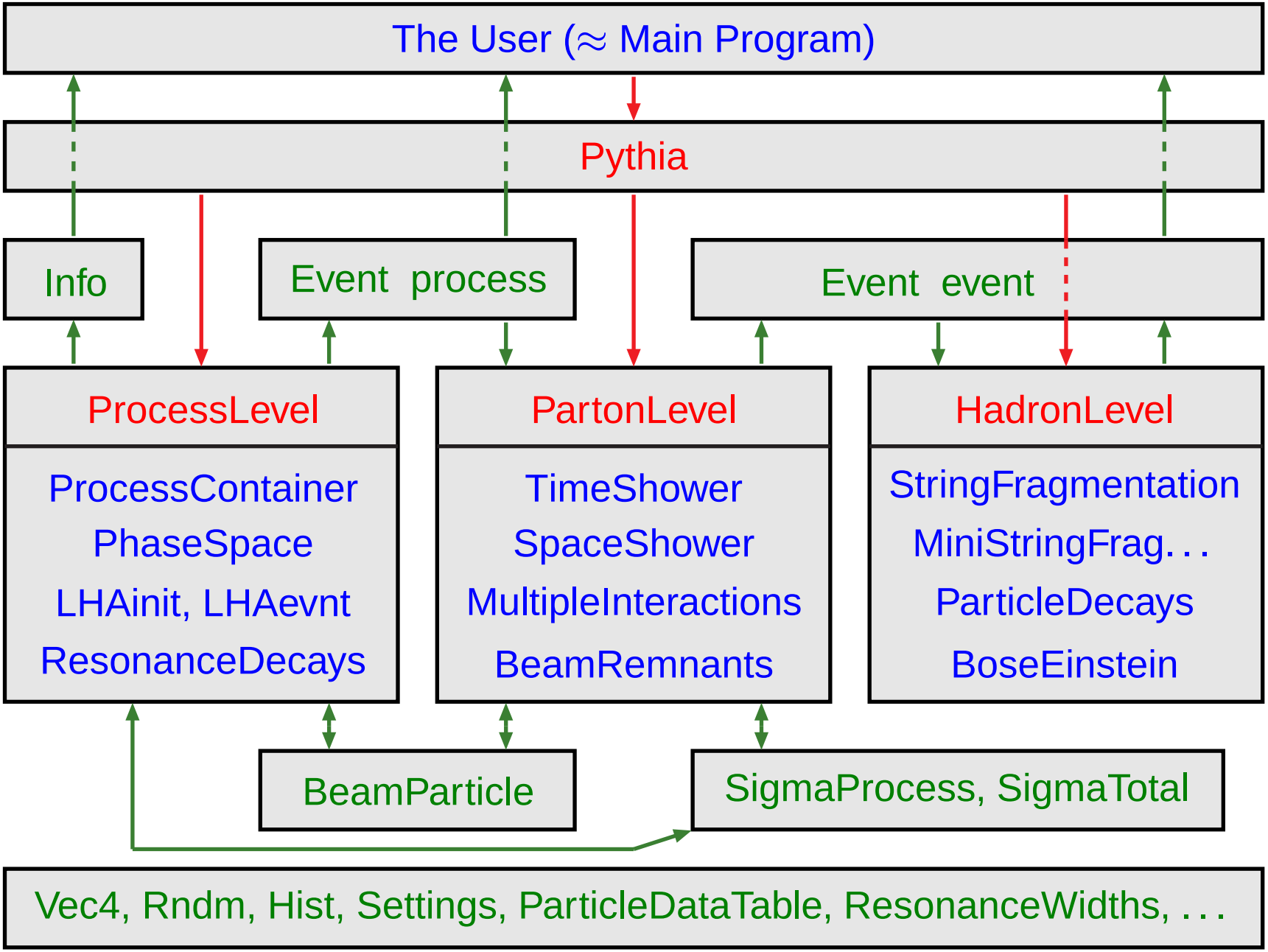
Plans for the future:

- 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 $\to$ ggg or γgg.
- Improved capability for standalone hadronization.
- Improved handling of Higgs width.
- Safety checks on $\alpha_{\rm S}$ 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 α_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.

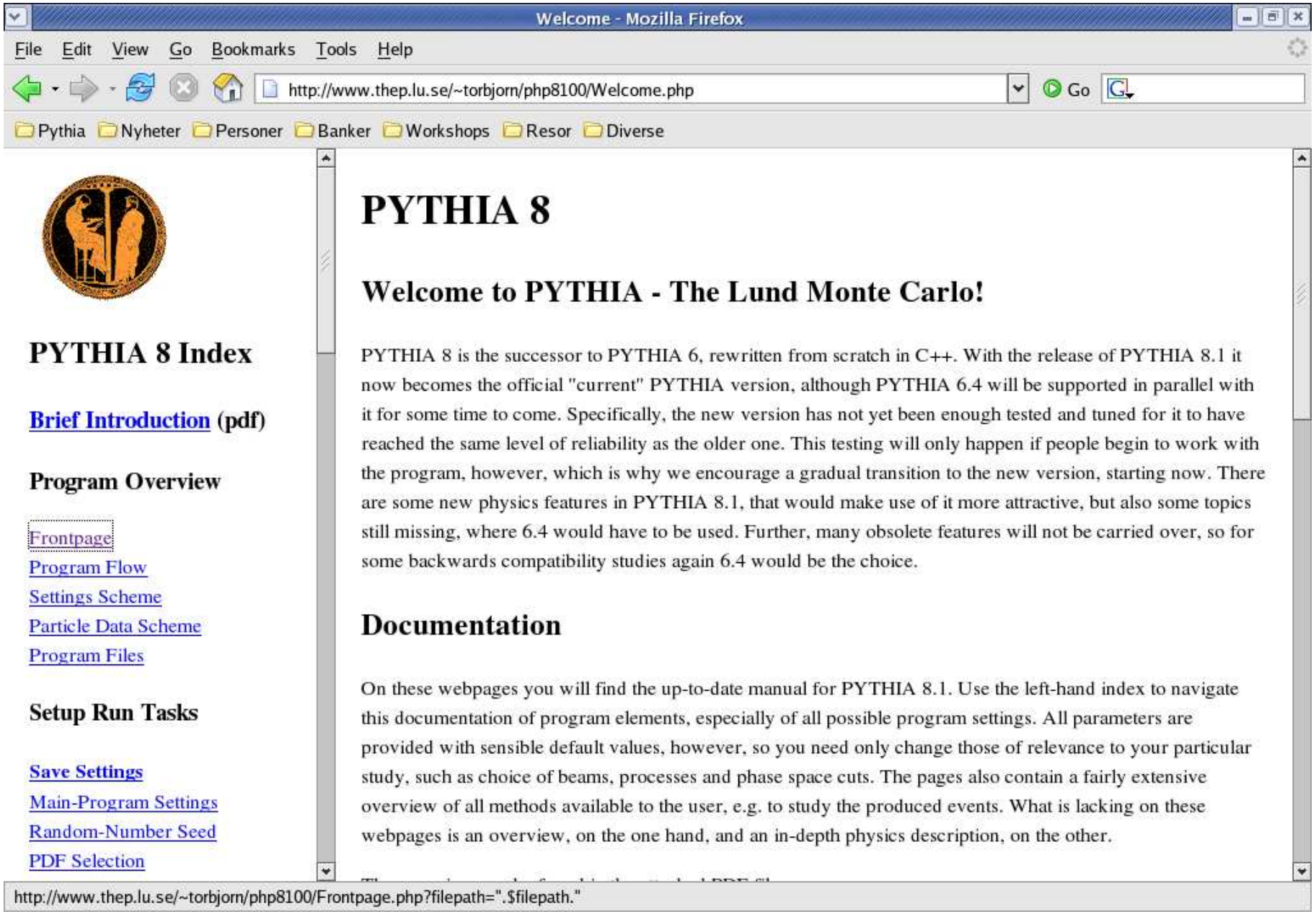
`3122:mayDecay = no` do not allow Λ^0 to decay

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

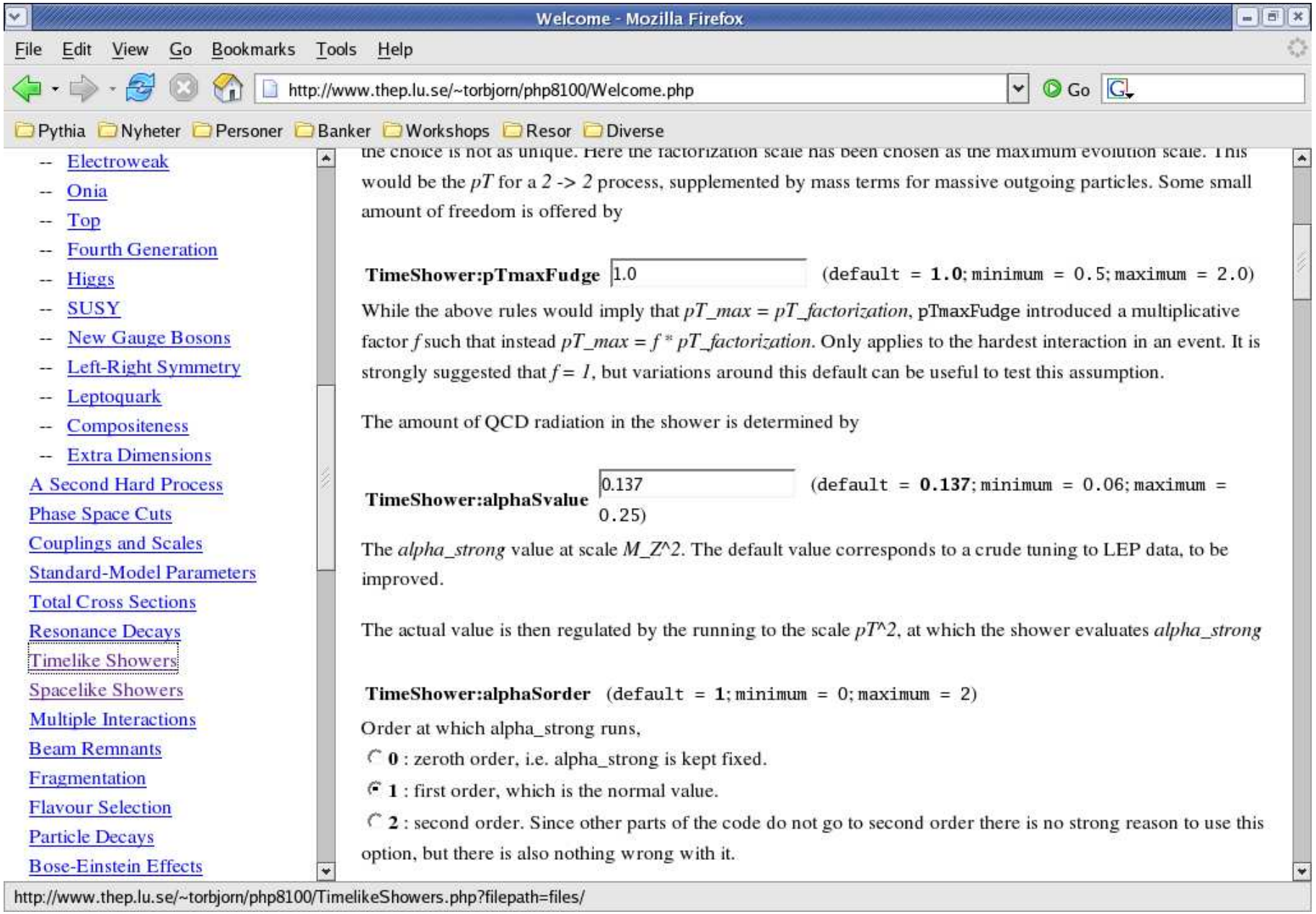
Note: case-insensitive search/matching in databases!

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
LeftRightSymmmetry	ffbar2ZR, ffbar2WR, ffbar2HLHL, ...
LeptoQuark	ql2LQ, qg2LQl, gg2LQLQbar, qqbar2LQLQbar
ExcitedFermion	dg2dStar, qq2uStarq, qqbar2muStarmu, ...
ExtraDimensionsG*	gg2G*, qqbar2G*, ...

Online manual $\Longrightarrow$ Graphical User Interface



Example: timelike parton showers



Manual Sections

Program Overview

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Particle Data Scheme
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Sample Main Programs

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Main-Program Settings
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Random-Number Seed
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– Electroweak
– Onia
– Top
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– Higgs
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– Leptoquark
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A Second Hard Process
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Les Houches Accord
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Semi-Internal Processes
Semi-Internal Resonances
Hadron-Level Standalone
SUSY Les Houches Accord
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External Decays
User Hooks
Random Numbers
Implement New Showers

Reference Materiel

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 τ 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 xvfz 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	status
administative structure	operational; extensions planned
hard processes, internal	much of PYTHIA 6; SUSY & TC & more to do
resonance decays	much of PYTHIA 6; SUSY & TC & more to do
hard processes, external	interfaces to LHA F77, LHEF, PYTHIA 6
SUSY(+more) parameters	SLHA2; more needed
initial-state showers	operational
final-state showers	operational
matching ME's to showers	some exists; much more needed
multiple interactions	operational; extensions planned
beam remnants & colour flow	operational; alternatives to come
parton densities	only 2 internal, but interface to LHAPDF
string fragmentation	operational; improvements planned
decays & particle data	operational; may need updates
Bose-Einstein	operational; off by default (tuning)
analysis	some simple tools; may be enough
graphical user interface	operational; could be extended
tuning	major task for MCnet postdocs!
testing	major task for experimentalists!
ep, γp, $\gamma\gamma$	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.