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PYTHIA 8
and its tuning parameters

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Development overview

Ambition (relative to PYTHIA 6)

- Meet experimental request for C++ code.
- Housecleaning ⇒ more homogeneous.
- More user-friendly (e.g. settings names).
- Better match to software frameworks (e.g. card files).
- More space for growth.
- Better interfaces to external standards.

Reality

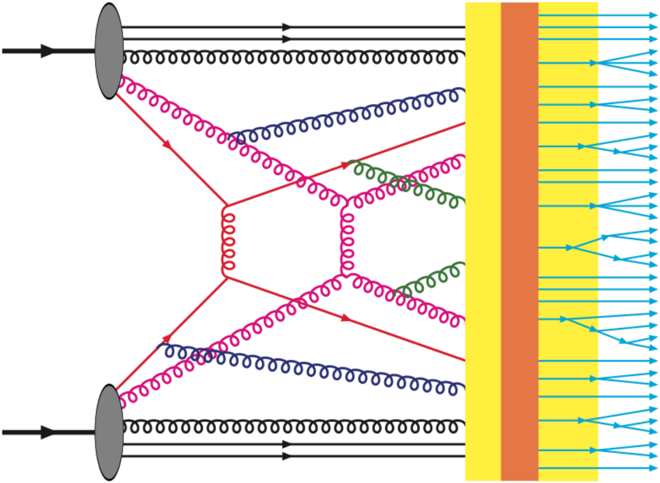
- Work begun autumn 2004.
- 3 years at CERN ⇒ good progress.
- First release autumn 2007.
- Since then: slower progress, but gradually things get done.
- Usage is taking off, at long last.

Team members
Stephen Mrenna
Stefan Prestel
Peter Skands

Former members
Stefan Ask
Richard Corke

Contributors
Robert Ciesielski
Nishita Desai
Philip Ilten
Tomas Kasemets
Mikhail Kirsanov
...

Physics overview



All of this is needed, + more ⇒ can only get more complicated

(Semi)recent progress

- More SUSY processes & other exotica & improved SLHA
- Long-lived R-hadrons
- Hidden Valley showers and hadronization
- Rescattering in MPI (but effects small)
- An x-dependent proton size in MPI (see tuning)
- MPI in diffractive system, central diffraction, MBR model
- Masses updated to RPP 2012, BR's of light hadrons coming
  LHCb help with charm and bottom BR's would be great!
- Several PDF's available internally, mainly LO ones
- τ decays with full spin correlations (Philip Ilten)
- `SlowJet` lightweight substitute for FastJet
- `UserHooks/MergingHooks` expanded with many options
- Progress on weak parton showers, i.e. $\mathrm{W}^{\pm}/Z^0$ emission
- VINCIA plug-in will offer more sophisticated showers

Interfaces

- Les Houches Event Files or runtime LHA interface
- LHAPDF or other external PDF libraries
- SUSY LHA input
- External random number generator
- External beam momentum and vertex spread
- Semi-internal matrix elements or resonance widths (MadGraph 5 can generate code for inclusion in PYTHIA)
- External parton showers (e.g. VINCIA)
- External decay of selected particles (EvtGen?)
- User hooks: step into generation process, e.g. to veto
- Particle/resonance gun (e.g. decay Higgs in isolation)
- HepMC output
- Combine with RIVET analyses

Matching/merging at LO or NLO

- Built-in NLO+PS for many resonance decays ($\gamma^*/\mathrm{Z}^0, \mathrm{W}^\pm, \mathrm{t}, \mathrm{H}^0$, SUSY, ...)
- Some built-in +1 matching ($\gamma^*/\mathrm{Z}^0/\mathrm{W}^\pm + 1$ jet)
- Default max scale gives fairly good QCD jet rates, also for gauge boson pairs, top pairs (with damping), SUSY
- Accepts just about any valid Les Houches Event input (but matching at an ill–defined "scale")
- POWHEG interface extends on "scale" matching to showers
- no MC@NLO interface, but Frixione et al working on it
- MLM matching code for ALPGEN input recently introduced, coming for MadGraph5
- CKKW-L LO matching (tested for MadGraph5 input)
- CKKW-L NLO matching coming (for POWHEG input)
- Special tunes for CKKW-L schemes planned

Strengths and weaknesses

(subjectively, absolute or compared with Herwig++ and Sherpa)

+ fair selection og built-in processes ready to go
− no built-in ME generator (need e.g. MadGraph)
− matching/merging/NLO usually not automatic
± parton showers of comparable quality
+ most sophisticated & robust MPI framework
+ models for diffractive events
+ most sophisticated & robust hadronization framework
− no QED in hadronic decays (need e.g. Photos)
+ interfaces & many options ⇒ flexible
+ user-friendly, well documented, many examples
+ generally comparing well with LHC data . . .
− . . . but known discrepancies, e.g. flavour composition

Tuning parameters: hard process

- `SoftQCD:all` for "total cross section"
- `HardQCD:all` hard QCD $2 \to 2$ processes
  $+$ `PromptPhoton:all` hard $2 \to 2$ with 1 or 2 photons
  $+$ `Charmonium:all`, `Bottomonium:all, +`
- `PhaseSpace:pTHatMin` preferably > 20 GeV
  (no $p_{\perp} \to 0$ damping, unlike SoftQCD)
- `PhaseSpace:mHatMin, :mHatMax` preferably for hard $2 \to 1$
- `PDF:pSet, +` choice of proton PDF (LO!), also LHAPDF
- `PDF:useHard, :pHardSet` separate PDF for hard process
- `SigmaProcess:alphaSvalue` $\alpha_{\mathrm{s}}(M_{\mathrm{Z}})$
- `SigmaProcess:alphaSorder` running to 0th, 1st, 2nd order
- `SigmaProcess:Kfactor` multiplicative (scale-independent)
- `SigmaProcess:renormScale2, +` renormalization scale
- `SigmaProcess:factorScale2, +` factorization scale
- `StandardModel:alphaEMmZ, +` $\alpha_{\mathrm{em}}(M_{\mathrm{Z}})$
- `StandardModel:sin2thetaW, +` weak parameters, CKM

Tuning parameters: parton showers

Final-state timelike shower mainly constrained by LEP data.

- TimeShower:alphaSvalue, + $\alpha_{\mathrm{s}}(M_{\mathrm{Z}})$
- TimeShower:pTmaxFudge, + matching to hard process
- TimeShower:pTmin lower QCD cut-off
- TimeShower:pTminChgQ lower QED cut-off for q (not ℓ)
- TimeShower:dampenBeamRecoil fixes doublecounting
- SpaceShower:alphaSvalue, + $\alpha_{\mathrm{s}}(M_{\mathrm{Z}})$
- SpaceShower:pTmaxFudge, + matching to hard process
- SpaceShower:pT0Ref, :ecmRef, :ecmPow, :pTmin smooth turn-off and sharp cut-off for QCD emissions
- SpaceShower:pTminChgQ lower QED cut-off for q (not ℓ)
- SpaceShower:rapidityOrder order emissions both in $p_{\perp}$ and rapidity (too restrictive?)

Tuning parameters: underlying event

- `MultipartonInteractions:alphaSvalue, +` $\alpha_{\mathrm{s}}(M_{\mathrm{Z}})$
- `MultipartonInteractions:processLevel` MPI processes
- `MultipartonInteractions:pTmaxMatch` matching to hard
- `MultipartonInteractions:pT0Ref, :ecmRef, :ecmPow`

$$\frac{\mathrm{d}\hat{\sigma}}{\mathrm{d}p_\perp^2} \propto \frac{\alpha_s^2(p_\perp^2)}{p_\perp^4} \to \frac{\alpha_s^2(p_{\perp 0}^2 + p_\perp^2)}{(p_{\perp 0}^2 + p_\perp^2)^2} \text{ with } p_{\perp 0}(E_{\mathrm{CM}}) = p_{\perp 0}^{\mathrm{ref}} \times \left(\frac{E_{\mathrm{CM}}}{E_{\mathrm{CM}}^{\mathrm{ref}}}\right)^{\epsilon}$$

Note: cutoff value crucial for MPI, unlike ISR/FSR

- `MultipartonInteractions:bProfile, :coreRadius, :coreFraction, :expPow, :a1` impact-parameter profile, single Gaussian, double Gaussian, overlap $\exp(-b^p)$, Gaussian with radius $a(x) = a_0(1 + a_1 \ln(1/x))$
- `BeamRemnants:primordialKThard` $\sigma(k_\perp)$ for hard processes
- `BeamRemnants:reconnectRange` colour reconnection

Tuning parameters: Total and diffractive cross sections

- `SigmaTotal:setOwn`, `:sigmaTot`, `:sigmaEl`, `:sigmaXB`, `:sigmaAX`, `:sigmaXX`, `:sigmaAXB` force set cross sections
- `SigmaDiffractive:dampen`, `:maxXB`, `:maxAX`, `:maxXX`, `:maxAXB` limit rise of diffractive cross sections
- `SigmaTotal:zeroAXB`, `:sigmaAXB2TeV` central diffraction
- `Diffraction:PomFlux` diffractive model
- `Diffraction:probMaxPert` mix pert./nonpert.
- `Diffraction:sigmaRefPomP` σ_{Pp} in MPI (inverse to activity)
- `Diffraction:bProfile`, `:coreRadius`, `:coreFraction`, `:expPow` impact-parameter profile (no x-dependent option)

Tuning parameters: hadronization

Supposedly fixed at LEP by universality, but . . .

- `StringZ:aLund, :bLund, :aExtraDiquark, :rFactC, :rFactB` longitudinal momentum sharing
- `StringPT:sigma` transverse width
- `StringFlav:probStoUD, :probQQtoQ, :probSQtoQQ, :probQQ1toQQ0` s/ud, qq/q, sq/qq, $\mathrm{qq}_1/\mathrm{qq}_0$ composition
- `StringFlav:mesonUDvector, :mesonSvector, :mesonCvector, :mesonBvector` V/PS meson ratio
- `StringFlav:etaSup, :etaPrimeSup` η, η' suppression
- `StringFlav:popcornRate, :popcornSpair, :popcornSmeson` baryon-meson-antibaryon topologies
- `ParticleDecays:limitTau0, :tau0Max, +` handover to detector simulation
- `ParticleDecays:mixB, :xBdMix, :xBdMix` $x_{\mathrm{d}}, x_{\mathrm{s}}$

Some in-house tunes

Parameter	2C	2M	4C	4Cx
SigmaProcess:alphaSvalue	0.135	0.1265	0.135	0.135
SpaceShower:rapidityOrder	on	on	on	on
SpaceShower:alphaSvalue	0.137	0.130	0.137	0.137
SpaceShower:pT0Ref	2.0	2.0	2.0	2.0
MultipartonInteractions:alphaSvalue	0.135	0.127	0.135	0.135
MultipartonInteractions:pT0Ref	2.320	2.455	2.085	2.15
MultipartonInteractions:ecmPow	0.21	0.26	0.19	0.19
MultipartonInteractions:bProfile	3	3	3	4
MultipartonInteractions:expPow	1.60	1.15	2.00	N/A
MultipartonInteractions:a1	N/A	N/A	N/A	0.15
BeamRemnants:reconnectRange	3.0	3.0	1.5	1.5
SigmaDiffractive:dampen	off	off	on	on
SigmaDiffractive:maxXB	N/A	N/A	65	65
SigmaDiffractive:maxAX	N/A	N/A	65	65
SigmaDiffractive:maxXX	N/A	N/A	65	65

R. Corke & TS, JHEP 03 (2011) 032, JHEP 05 (2011) 009

Some ATLAS tunes

Start from Tune 4Cx + `SpaceShower:rapidityOrder = off`.

t1 = `MultipartonInteractions:pT0Ref`

t2 = `MultipartonInteractions:ecmPow`

t3 = `MultipartonInteractions:a1`

t4 = `BeamRemnants:reconnectRange`

name-PDF	t1	t2	t3	t4
MB tune A2-CTEQ6L1	2.18	0.22	0.06	1.55
MB tune A2-MSTW2008LO	1.90	0.30	0.03	2.28
UE tune AU2-CTEQ6L1	2.13	0.21	0.00	2.21
UE tune AU2-MSTW2008LO	1.87	0.28	0.01	5.32
UE tune AU2-CT10	1.70	0.16	0.10	4.67
UE tune AU2-MRST2007LO*	2.39	0.24	0.01	1.76
UE tune AU2-MRST2007LO**	2.57	0.23	0.01	1.47

Tunes with NLO PDFs omittted: dangerous at low $p_{\perp}$!

See ATLAS note ATL-PHYS-PUB-2012-003 (August 2012).

(Previous generation in ATL-PHYS-PUB-2011-009 (July 2011).)

Prepackaged tunes

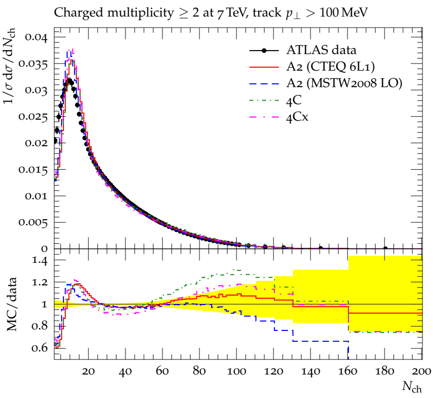
`Tune:pp` selects prepackaged set of parameter changes.

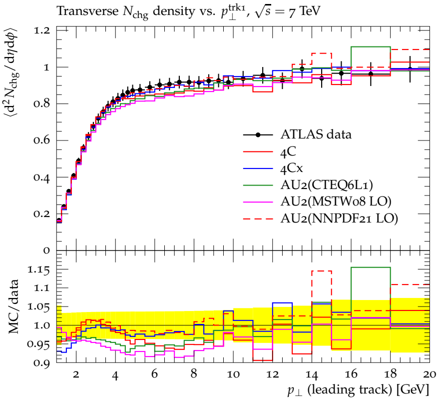
1	original values before any tunes
2	Tune 1
3	Tune 2C (CTEQ 6L1)
4	Tune 2M (MRST LO**)
5	Tune 4C
6	Tune 4Cx
7	ATLAS MB tune A2-CTEQ6L1
8	ATLAS MB tune A2-MSTW2008LO
9	ATLAS UE tune AU2-CTEQ6L1
10	ATLAS UE tune AU2-MSTW2008LO
11	ATLAS UE tune AU2-CT10
12	ATLAS UE tune AU2-MRST2007LO*
13	ATLAS UE tune AU2-MRST2007LO**

Changes to some parameters can be done *after* `Tune:pp` line.

`Tune:ee` similar but less extensive for FSR and hadronization.

Example ATLAS results

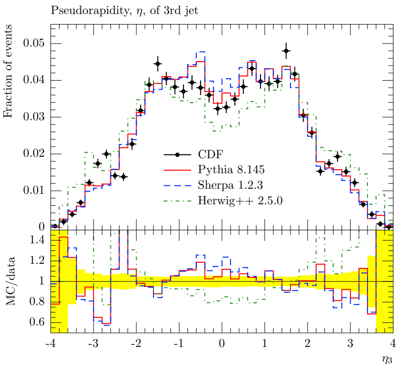


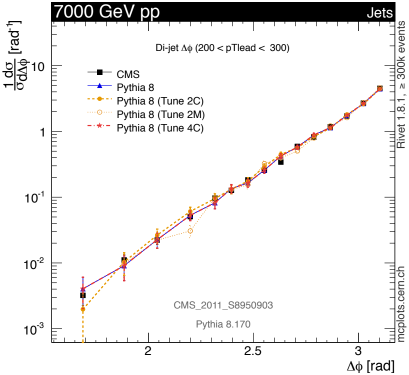


Not so easy to do appreciably better than in-house 4C and 4Cx, for better or worse!

MCnet & MCPLOTS

"General-purpose event generators for LHC physics",
A. Buckley et al. (MCnet), Phys. Rep. 504 (2011) 145,
compares PYTHIA 8.145 tune 4C, Herwig++, SHERPA.
Note: new EU funding to MCnet ⇒ new activity)





Many comparisons on MCPLOTS: http://mcplots.cern.ch/

Summary and outlook

- PYTHIA 6 is winding down
  - currently supported but not developed
  - *not* supported after long shutdown 2013–14
- PYTHIA 8 is the natural successor
  - is (sadly!) not yet quite up to speed in *all* respects
  - but for most physics clearly better than PYTHIA 6
- Advise/plea to experimentalists
  - gradually step up PYTHIA 8 usage to gain experience
  - if you want new features then be prepared to use PYTHIA 8
  - provide feedback, both what works and what does not
  - help with charm and bottom decay tables if you can
  - make relevant data available in RIVET
  - do your own tunes to data and tell outcome

News list:

`http://www.hepforge.org/lists/listinfo/pythia8-announce`

The work is never done!

Appendix: check on kinematical cuts setup

Smearing from parton showers, underlying event, hadronization
$\Rightarrow$ need "fiducial cuts": generate in overestimated region.
Question: How to check that choice makes sense?
Answer: plot (generated and) accepted events
as a function of $\widehat{p}_{\perp}$ = `pythia.info.pTHat()`