Status of PYTHIA 8

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PYTHIA 8 history

- 1978: JETSET work begins; now part of PYTHIA 8
- 1982: PYTHIA work begins
- 2004: PYTHIA 8 work begins; Fortran $\rightarrow$ C++
- 2007: PYTHIA 8.100
- 2014: PYTHIA 8.200
- 2016–01–04: PYTHIA 8.215
- 2016–01–11: previous MCGW presentation, by Steve Mrenna
- 2016–05–10: PYTHIA 8.219
- 2017–01–05: PYTHIA 8.223
- **2017–04–26: PYTHIA 8.226**

Foresee 2–3 new releases/year.

The PYTHIA collaboration

Current members:

- Nishita Desai (Montpellier)
- Nadine Fischer (Monash, Melbourne)
- Ilkka Helenius (Tübingen)
- Philip Ilten (MIT)
- Leif Lönnblad (Lund)
- Stephen Mrenna (FNAL)
- Stefan Prestel (FNAL)
- Christine Rasmussen (Lund)
- Torbjörn Sjöstrand (Lund)
- Peter Skands (Monash, Melbourne)

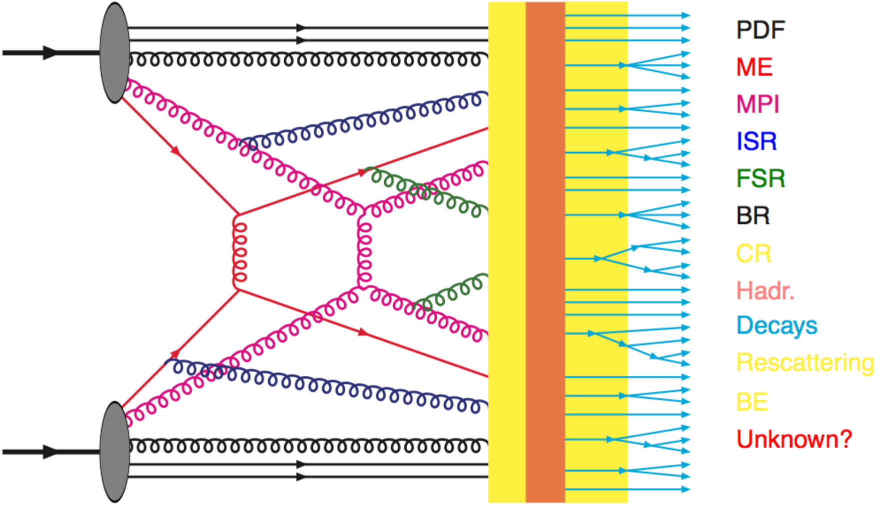
. . . but many have other projects as their main research interest.

Significant code pieces contributed by $\sim$ 30 more persons.

Comments and bug reports from $>$ 100 persons.

The structure of an event

An event consists of many different physics steps to be modelled:



Hard processes

Many simple processes implemented internally,
but **no internal ME generator**, so often needs external input,
e.g. MadGraph5_aMC@NLO, PowHeg Box, AlpGen,
typically using Les Houches Event Files.

News:

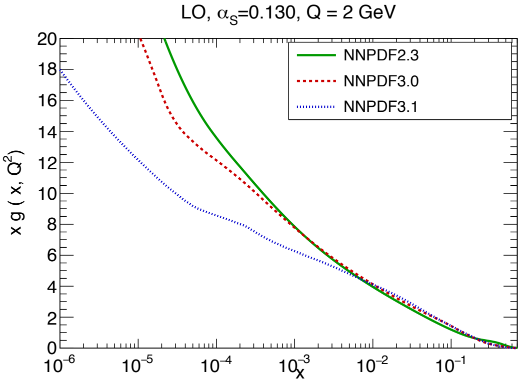
- Can run MadGraph5_aMC@NLO and PowHeg Box from inside Pythia, wrapped as Les Houches-input plugins.
- Runtime interface to the HelacOnia onium production.
- Double production of charmonium and bottomonium ${}^3S_1$ states, but with only the colour-singlet processes included.
- Running coupling in Hidden Valley scenarios.
- Various minor bug fixes in BSM cross sections.

Only planned extension is for Dark Matter production, to offer simple pedagogical tool, but open to other minor additions.

Parton Distribution Functions

Can access PDFs several ways:

- 16 internal sets;
- LHAPDF 5 and LHAPDF 6 interfaces;
- lhagrid1 .dat file name (= standard LHAPDF member files);
- 4 NNPDF 3.1 central members (LO 2 α_{s}, NLO, NNLO).



Beware changed x shape $\Rightarrow$ need to retune MB/UE, including energy dependence.

Picture courtesy J. Rojo

Parton showers

Currently three (main) parton shower options;

- Internal default `SpaceShower + TimeShower`;
- VINCIA plugin;
- DIRE plugin.

Same basic structure, e.g. MPI + ISR + FSR interleaved evolution:

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

Support the same facilities, like

- matching and merging machinery,
- automated **uncertainty band** from factorization and renormalization scale choices, and finite splitting-kernel terms.

SpaceShower + TimeShower

FSR two main options:

- Dipole evolution (= single recoil parton): default.
- Global recoil (= all FSR partons): option for match & merge.

ISR one → two main options:

- Global recoil (= all FSR partons): default.
- Dipole evolution (= sometimes single recoil parton): coming; will also allow DIS *ep*.

Other updates:

- Weak showers: allow $q \to qZ^0$ and $q \to q'W^{\pm}$ branchings, and merge ME + PS contribution to W/Z production.
- Optionally allow charged resonances, like $W^{\pm}$, to radiate γ's.
- Improved handling of "dead cone" suppression effects for $g \to gg$ with a massive recoiler.
- Separate rapidity ordering of ISR by hardest vs. rest of MPIs.

VINCIA: an Interleaved Antennae shower

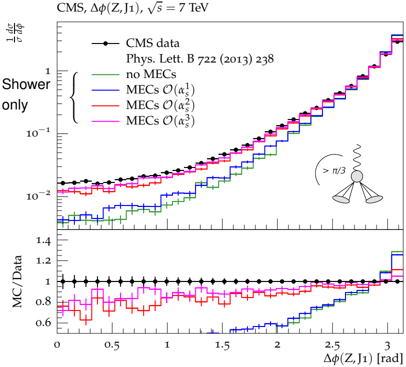
Markovian process: no memory of path to reach current state.

Based on antenna factorization of amplitudes and phase space.

Smooth ordering fills whole phase space.

Step-by-step reweighting to new matrix elements: $Z \to Zj \to Zjj \to Zjjj$ (also Sudakov), e.g.

$$W = \frac{|\mathcal{M}_{\mathrm{Zj}}|^2}{\sum_i a_i |\mathcal{M}_{\mathrm{Z}}|_i^2}$$



New release with ISR + FSR.

First NLL shower study, only with incomplete FSR so far.

Future development path: towards complete NLL shower.

see further: Stefan Prestel, Thursday morning

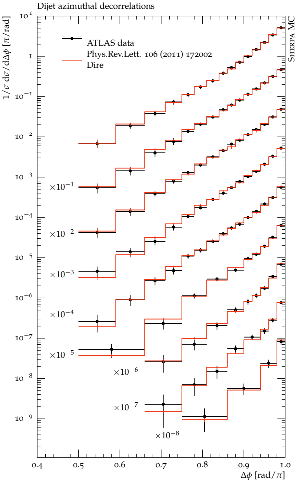
DIRE: a Dipole Resummation shower

Joint Sherpa/PYTHIA development, but separate implementations, means technically well tested.

"Midpoint between dipole and parton shower",
not quite CS dipoles:
unified initial–initial, initial–final, final–initial, final–final.

Soft term of kernels in all dipole types is less singular

$$\frac{1}{1-z} \rightarrow \frac{1-z}{(1-z)^2 + p_\perp^2/M^2}$$



Future development path: towards complete NLL shower.

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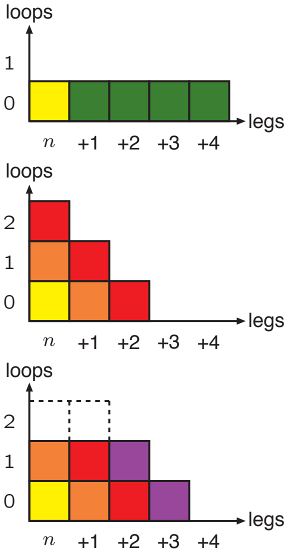
Match and merge strategies

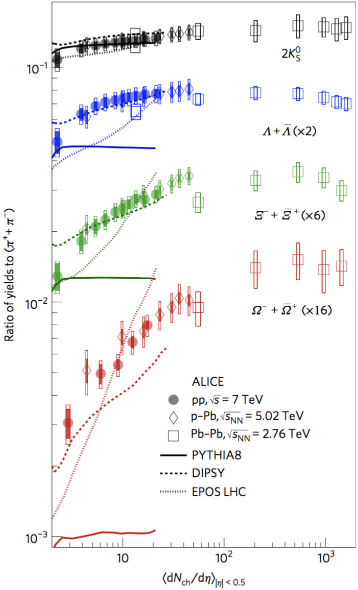


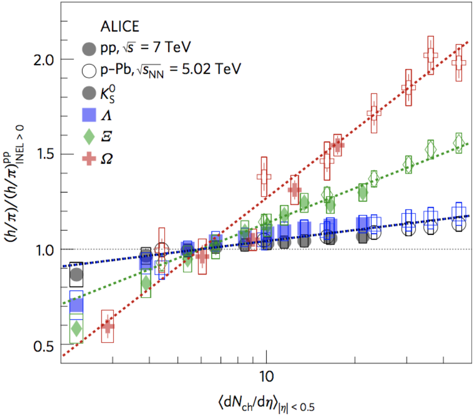
Methods implemented in PYTHIA:

- internal merging for resonance decays (POWHEG-style; NLO)
- POWHEG or aMC@NLO event input for NLO
- CKKW-L multileg matching
- MLM multileg matching (AlpGen and MadGraph versions)
- UMEPS: unitarized ME + PS
- NL^3, UNLOPS: unitarized NLO
- FxFx and shower-$k_\perp$ matching

New: write your own matching and merging plugin, making use of existing history facilities.

The ALICE revelation: goodbye jet universality!

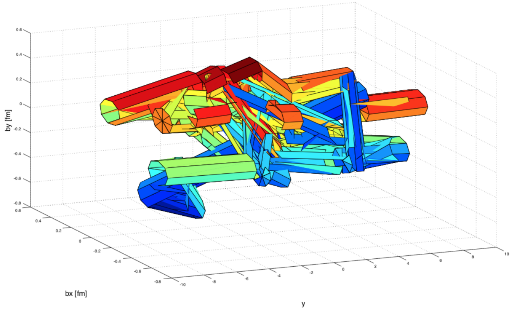




Signs of QGP in high-multiplicity *pp* collisions? If not, what else? A whole new game!

DIPSY, ropes and FritiofP8

DIPSY: initial-state dipole evolution in transverse coordinates and longitudinal momenta.



Ropes: combination of several overlapping strings into higher colour multiplets $\Rightarrow$ higher string tension favour strangeness, notably multistrange baryons.
Shove: overlap pushes strings apart $\Rightarrow$ ridge effects etc.

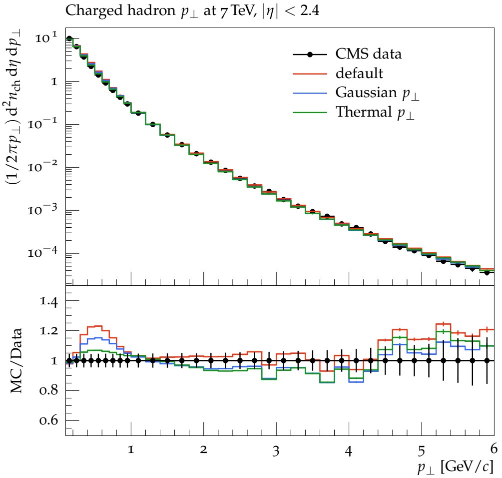
Future: DIPSY slow, only minbias $\Rightarrow$ FritiofP8 for pA, maybe AA.

see further: Christian Bierlich, Thursday lunchtime

Thermodynamical string model

String model:
Gaussian $p_\perp$ spectrum $\exp(-p_\perp^2/2\sigma^2)$ for quarks and hadrons $\Rightarrow$ wrong shape at low $p_\perp$ in pp.

Thermodynamical string fragmentation: $\exp(-m_{\perp\mathrm{had}}/T)$ with $m_{\perp\mathrm{had}} = \sqrt{m_{\mathrm{had}}^2 + p_\perp^2}$, but preserve string local $p_\perp$ and flavour conservation.

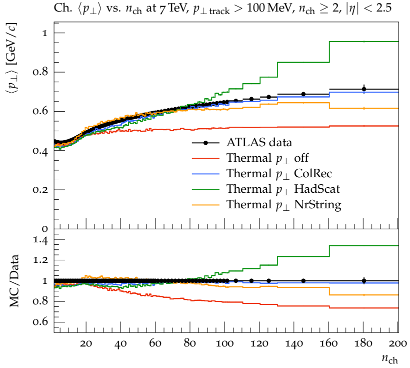


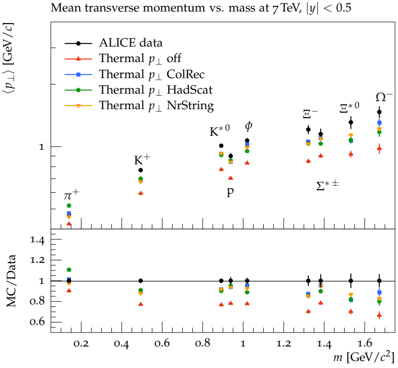
Effects strongly diluted by resonance decays.
Situation improved but not “solved” for individual hadron species.

String close-packing; Hadron rescattering

Many MPIs ⇒ strings close-packed ⇒ higher σ or T
⇒ more strangeness, higher $\langle p_\perp \rangle$ (∼ like ropes, but continuous).

High hadron multiplicity ⇒ hadrons close-packed
⇒ hadron rescattering.





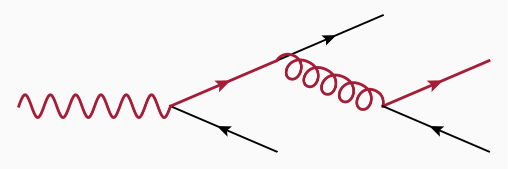
Still primitive, especially rescattering ⇒ more detailed studies.

$\gamma\gamma$ and γp physics

Dual nature of photon: direct (pointlike) and resolved (hadronlike).
DGLAP evolution has additional term from $\gamma \to q\bar{q}$:

$$\frac{\mathrm{d}f_i^{\gamma}(x, Q^2)}{\mathrm{d}\ln Q^2} = \frac{\alpha_{\mathrm{em}}(Q^2)}{2\pi}\, e_i^2\, P_{i/\gamma}(x) + \frac{\alpha_{\mathrm{s}}(Q^2)}{2\pi} \sum_j \int_x^1 \frac{\mathrm{d}z}{z}\, f_j\left(\frac{x}{z}\right)\, P_{i/j}(z)$$

so backwards evolution can find photon beam.



Have implemented combined direct + resolved for γp and $\gamma\gamma$, for hard and soft processes, but not yet elastic or diffractive.

Also ep and e^+e^- in quasi-real Equivalent Photon Approximation.

To come: Photon flux from hadrons (p and A), nuclear PDFs.

Further physics-related news

- Changes to the cross section handling of user vetoes/weights:
  1. The counter for selected event is updated immediately after the hard-process generation.
  2. More fine-grained input settings to enforce that PYTHIA generates/reads exactly a fixed number of hard-process events.
  3. The internal cross section and event weights directly include the effect of event vetoes and reweighting, e.g from M&M.
- New method `Pythia::addUserHooksPtr(...)` allows the simultaneous use of several User Hooks. The net effect of several hooks is multiplicative, in weights or in veto survival.
- New User Hooks added to set the space–time vertices for the ISR, FSR and MPI evolution process.
- Allow sequential decays in external decays interface.
- Recalculate LHEF kinematics for massless outgoing leptons, c and b quarks.

Input/output news

- Settings can be forced outside allowed range by new format parameter `FORCE = value` in `readString()` or `readFile()`. Alternatively new optional `force` argument in specialized routines.
- Extended `Settings` input, with { } used to delimit strings with embedded blanks, vectors, splits across lines.
- New methods `Settings::getReadHistory` and `ParticleData::getReadHistory` return a vector with all strings that have been read in by `readString()` or `readFile()` calls.
- Rename ...`print()` methods to ...`list()` for consistency.
- Added functionality to write PYTHIA events to an LHEF3-style string, e.g. for use in an external PYTHIA caller.
- Unhadronized q's/g's throw exception in the HepMC interface.

Programming news

- An interface to the Python programming language has been introduced, making all PYTHIA classes and methods available.
- Minor `configure` and `Makefile` improvements.
- `Pythia` constructor can take references to `Settings` and `ParticleData` objects, to reduce file reading.
- `Pythia` constructor also accepts input streams, so that the contents of a file can be read once and then broadcast to multiple `Pythia` instances.
- Replace optional arguments `ostream& os = cout` by hardcoded `cout`.
- FJcore updated to v. 3.2.1 and brought inside `Pythia8` namespace.
- New `#define PYTHIA_VERSION_INTEGER 82xx` in `Pythia.h`.

Major bug fixes

- Fix error in the automatic calculation of the combined cross section for the machinery with two hard processes. (Statistics on impact-profile enhancement factor added once correctly, but also once with weight unity.)
- Fix that the unitary checks of SLHA mixing matrices previously ignored imaginary components, leading to failures when reading in spectra with explicit CP violation.
- Fix that some Hidden Valley particles were left massless.
- Tunes were not updated when the ISR rapidity ordering switch was split into one for hardest and one for further MPIs.
- Corrected typos where some bottomonium long-distance matrix elements had been set larger than normally assumed.
- Handling of decay `meMode` ranges 52–60 and 62–70 were incorrect for check against duplication of existing channels.
- . . . and sadly many more

Summary and outlook

- NLL showers eventually to come from VINCIA and DIRE.
- New "QGP" results for high-multiplicity *pp* collisions
  $\rightarrow$ development of various soft-physics models.
- FRITIOFP8 to bring *pA* capability, maybe even *AA*.
- $\gamma\gamma$ and $\gamma\mathrm{p}$ coming along, also with *e* beams.
- Diffraction studies on hold, but will resume.
- $\Rightarrow$ Slow but steady physics evolution on many fronts.

2017 MCnet summer school:

2 – 7 July in Lund, Sweden.

Excellent chance to learn more about generators.

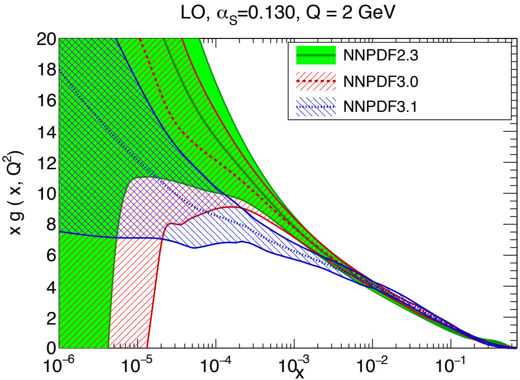
Intended for PhD students and beginning postdocs.

No fee, most local costs paid!

Deadline yesterday,
but a few slots left, so
encourange students to apply immediately.

Backup: PDF uncertainty bands

Even if systematic shift of NNPDF PDFs, error bands still overlap:



Changes affect all distributions, e.g.

$$F(x, Q) = \frac{9}{4} xg(x, Q) + \sum_q \left(xq(x, Q) + x\overline{q}(x, Q) \right)$$

$$\frac{F_{3.1}(0.1, 2)}{F_{2.3}(0.1, 2)} \approx 1.15 \qquad \frac{F_{3.1}(10^{-6}, 2)}{F_{2.3}(10^{-6}, 2)} \approx 0.25$$