LUND UNIVERSITY

Status and Future of PYTHIA

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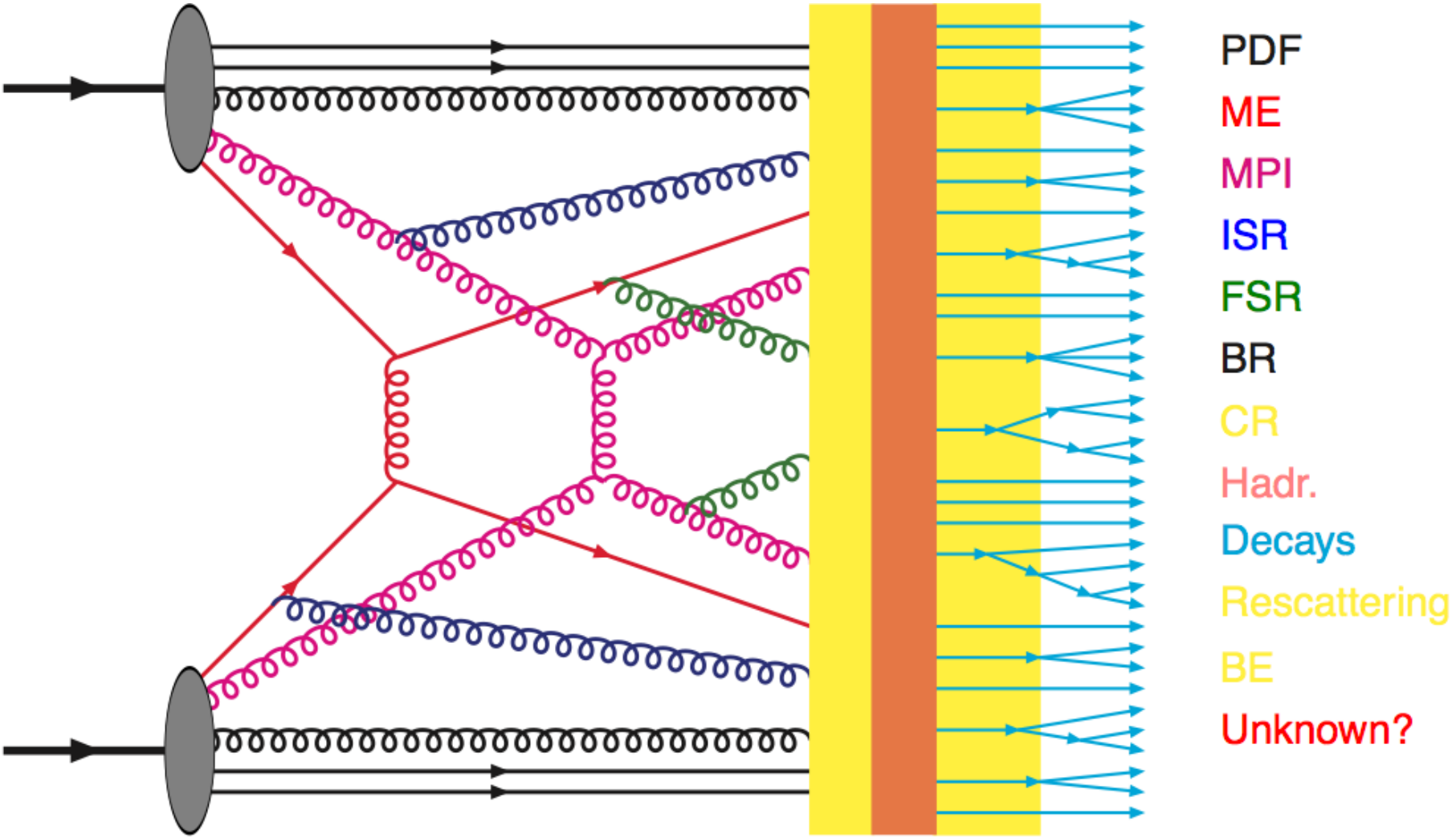
The structure of an event

An event consists of many different physics steps:



PYTHIA mission

Vision/dream:
describe high-energy $\mathrm{e^+e^-/pp/p\bar{p}}$ interactions in every detail,
so that it can predict and be compared with any observable.

Means:

- use Standard Model (and BSM) formulae where available
- develop own models where not, notably in QCD sector
- use data for guidance and tunes

Traditional Lund frontline physics areas:

- Initial- and final-state parton showers
- Matching/merging of matrix elements and showers
- Multiparton interactions
- Colour reconnection
- Hadronization
- (Heavy-ion collisions, small-x, ep, . . .)

Pythia 8 objectives

Pythia 4/5/6 used for LHC/SSC studies since 1984.
Since a year frozen legacy code, with limited support.
Experimentalists are asked to switch to Pythia 8.

- Meet experimental request for C++ code.
- Credibility in industry for ex-students.
- Housecleaning $\Rightarrow$ more homogeneous.
- More user-friendly (e.g. settings names).
- Better match to software frameworks (e.g. card files).
- Better interfaces to external standards;
  program flow designed for input of parton-level events.
- More space for growth.

2004: Pythia 8 work begins
2007: first full release 8.100
2014: at 8.185, soon time for 8.2

The PYTHIA group

Current members, by seniority:

- Torbjörn Sjöstrand: baseline version, coordination
- Stephen Mrenna (FNAL): CMS support, BSM, matching
- Peter Skands (CERN): colour reconnection, tuning, SUSY
- Stefan Prestel (DESY): matching/merging
- Philip Ilten (CERN/MIT) τ decays, LHCb support
- Jesper Roy Christiansen: weak showers, colour reconnection
- Nisita Desai (Heidelberg): SUSY
- (Christine Rasmussen: diffraction)

Code pieces contributed by $\sim$ 30 more persons, e.g.

- Mikhail Kirsanov: configure/makefile
- Gavin Salam et al: FJcore jet finders
- Juan Rojo et al: NNPDF 2.3 QCD+QED sets
- Robert Ciesielski: MBR diffractive model

Comments and bug reports from $\sim$ 100 persons.

Interfaces

PYTHIA intended to describe the complete structure of an event, but nobody can do everything – need to be open to the World.

- 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 B decays)
- User hooks: step into generation process, e.g. to veto
- Particle/resonance gun (e.g. decay Higgs in isolation)
- HepMC output
- FASTJET jet analysis
- RIVET analyses

Matching/merging

Calculational progress in $\sim$ last ten years:

- automated multiparton generation to LO, and
- automated NLO calculations.

Partly replaces showers, but requires strategies that consistently match/merge different orders with each others and with showers.

Inclusive $\Rightarrow$ exclusive: Sudakov form factors provided by showers.

Many matching/merging schemes provided in PYTHIA, e.g.

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

Selected news 1

- ⋆ Several new processes, within and beyond the SM, from onium production to extra dimensions and hidden valleys
- ⋆ Possibility to select two hard processes in same event
- ⋆ Improved dipole-style ISR and FSR showers
- ⋆ W and Z emission in showers
- ⋆ Improved scale setting in MEs and showers
- ⋆ New options to explore $\mathrm{g} \to \mathrm{Q}\overline{\mathrm{Q}}$ mass ambiguities
- ⋆ Fully interleaved $p_\perp$-ordered MPI + ISR + FSR evolution

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

Selected news 2

⋆ built-in selection among 16 p PDF sets, several recent
⋆ allow rescattering and x-dependent proton size in MPI framework
⋆ richer mix of underlying-event processes (γ, J/ψ, DY, . . .)
⋆ hadron–hadron collision machinery for diffractive systems
⋆ R-hadron modelling improved and built-in
⋆ τ lepton polarization in production and decay
⋆ updated particle and decay data
⋆ built-in jet finders like $k_\perp$, C/A, anti-$k_\perp$
⋆ possibility to have several simultaneous `Pythia` instances
⋆ distribution contains $\sim$ 40 main programs exemplifying use
⋆ manual as html or php, continuously updated
⋆ worksheet for summer schools or self-study, to get going
⋆ · · ·

Objectives for the future

No central planning, no time plan, but to exemplify:

- React to new discoveries, new accelerator plans, new theories, or badly described data
- New colour reconnection models (ongoing)
- Hard (non-QCD) processes in diffractive events
- $\gamma\gamma$, γp and ep beam configurations
- QED radiation in hadronic decays (replace PHOTOS)
- New tunes (Monash 2013 recently published)
- Space–time evolution of hadronization process
  $\Rightarrow$ hadronic rescattering and Bose-Einstein
- Radiation pattern for large-width resonances
- Built-in ME merging for photon emission in resonance decays
- Improve junction fragmentation
- Innumerable minor updates and bug fixes ...

Appendix 1: The Lund group

Seven senior members of group

- Johan Bijnens, hadronic physics (low energies, rare decays)
- Gösta Gustafson (emeritus), dipole models for AA collisions
- Leif Lönnblad, dipole models, matching/merging, ...
- Roman Pasechnik, standard and new physics, astroparticle
- Johan Rathsman, new physics (Higgs sector)
- Malin Sjödahl, showers beyond leading colour, ...
- Torbjörn Sjöstrand, models for high-energy collisions

+ 3 post-docs

+ 6 graduate students (3 from Copenhagen!)

Appendix 2: Particle Physics Phenomenology

Course on phase space, MEs, ISR, FSR, matching/merging, PDFs, MPIs, hadronization, jets, jet algorithms, applications (also BSM), generators, . . . , mainly in the context of the LHC.

Target audience:
graduate students in experimental or theoretical particle physics.

Taught $\sim$ every three years, with Copenhagen participation.

Last time: October 2011, in Copenhagen, concentrated version;
1 week full-time + hand-in exercises.

Next time: Lund, February - April 2015, 1 day/week, 10–12 times, 10.15 - 12.00 and 13.15 - 15.00, lectures + exercises ($\sim 3 + 1$), should give 7.5 ECTS after final hand-in + oral exam.

Overlapping with summer schools like MCnet, but more in-depth.