LUND UNIVERSITY

LCG Generator Services
monthly meeting
23 September 2009
CERN, Geneva

PYTHIA 8.130

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Objective: cover news since 8.108, presented at CERN May 2008.
Warning: slower pace than before release, many small details.

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.
- 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.
- 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 $p_\perp \longrightarrow 0$ 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).

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 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
- optionally allow rescattering in MI framework
- hard scattering in diffractive systems
- elastic scattering with Coulomb term (optional)
- possibility to use one PDF set for hard process and another for rest
- up-to-date decay data

News since PYTHIA 8.108

- Author list expanded by Richard Corke and Stefan Ask $\Rightarrow$ 5 people
- Professor tune by H. Hoeth to LEP1 data now default for hadronization and timelike showers
- A simple tune by P. Skands default for the rest; Professor tune under way.
- Improved/extended documentation, e.g. alphabetical index of methods, enlarged worksheet, ROOT interface.
- Makefile + examples now work with FastJet, while PYTHIA6 removed; HEPMC and LHAPDF stay with some fixes and improvements.
- Added support for π^+, π^-, π^0, **P** beams.
- Allow processes with incoming photon inside proton.
- `Rndm::dumpState(file)` and `Rndm::readState(file)`.
- Many further bug fixes, corrections, improvements, minor new features.

- Some new processes.
- Expanded second hard process.
- Rescattering.
- Diffraction machinery.

New processes

SUSY expanded to main processes, but still not all complete and tested.

- Compelete, with non-minimal flavour violation and/or CP violation:
  $\tilde{q}\tilde{q}^*$, $\tilde{q}\tilde{q}$, $\tilde{q}\chi^{0,\pm}$, $\chi^{0,\pm}\chi^{0,\mp}$
- In flavour-diagonal, CP-conserving limit: $\tilde{g}\tilde{g}$, $\tilde{g}\tilde{q}$
- Still missing: $\tilde{g}\chi^{0,\pm}$, $\tilde{\ell}^+\tilde{\ell}^-$, $\tilde{\ell}^\pm\tilde{\nu}$, $\tilde{\nu}\tilde{\nu}$

Process control: all, 12(+) subgroups, specific pair of outgoing flavours.

Randall-Sundrum extra dimensions, massive decaying G^*, since before.

Now also Large Extra Dimensions, invisible variable-mass G:

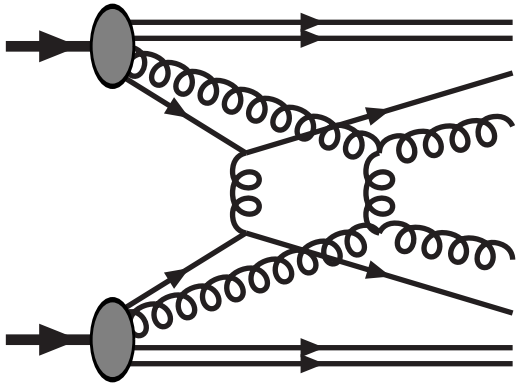
- monojets: Gg, Gq, $G\gamma$, GZ^0
- virtual G exchange: $\gamma\gamma$, $\ell^+\ell^-$

Same processes reused for Unparticle production,
only with different process names and parameter space.

Underway: generic colour-triplet particle production.

A second hard process

Multiple interactions key aspect
of PYTHIA since > 20 years.
Central to obtain agreement with data:
Tune A, Professor, Perugia, ...



Before 8.1 no chance to select character of second interaction.
Now free choice of first process (including LHA/LHEF)
and second process combined from list:

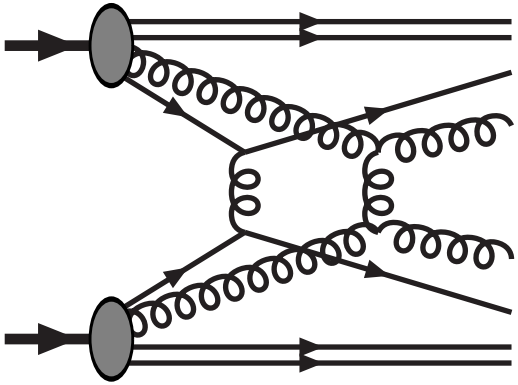
- TwoJets (with TwoBJets as subsample)
- PhotonAndJet, TwoPhotons
- Charmonium, Bottomonium (colour octet framework)
- SingleGmZ, SingleW, GmZAndJet, WAndJet
- TopPair, SingleTop

Can be expanded among existing processes as need arises.

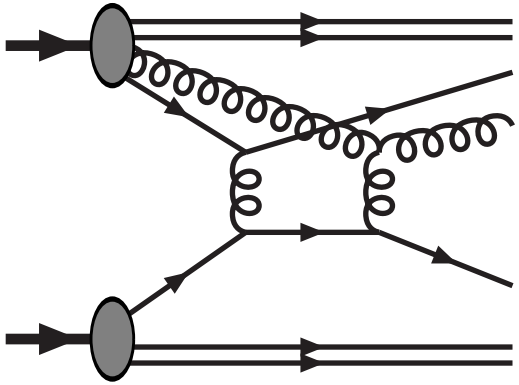
By default same phase space cuts as for "first" hard process
$\Longrightarrow$ second can be harder than first.
However, possible to set $\hat{m}$ and $\hat{p_\perp}$ range separately.

Rescattering

Often assume that MI =



. . . but should also include



Same order in α_S, $\sim$ same propagators, but

- one PDF weight less $\Rightarrow$ smaller σ
- one jet less $\Rightarrow$ QCD radiation background $2 \to 3$ larger than $2 \to 4$

$\Rightarrow$ will be tough to find direct evidence.

Rescattering grows with number of "previous" scatterings:

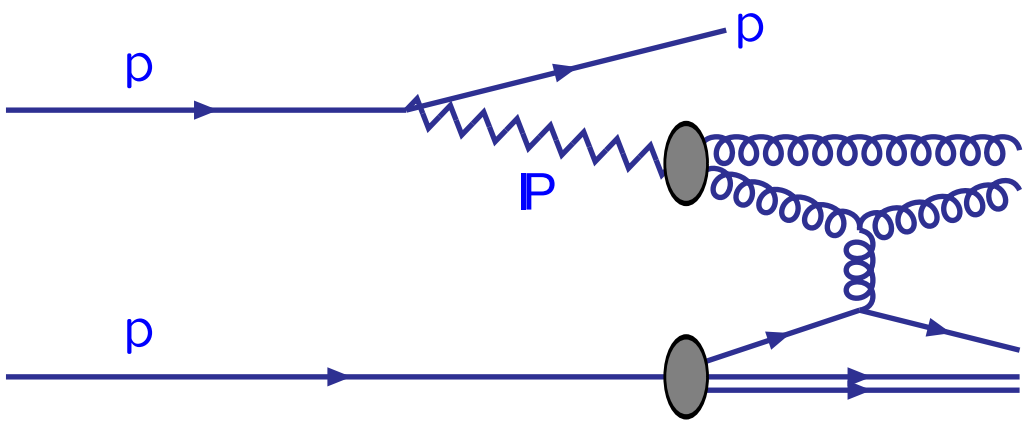
	Tevatron		LHC	
	Min Bias	QCD Jets	Min Bias	QCD Jets
Normal scattering	2.81	5.11	5.21	12.20
Single rescatterings	0.37	1.20	0.93	3.64
Double rescatterings	0.01	0.03	0.02	0.11

Article with Richard Corke almost complete.

Diffraction I

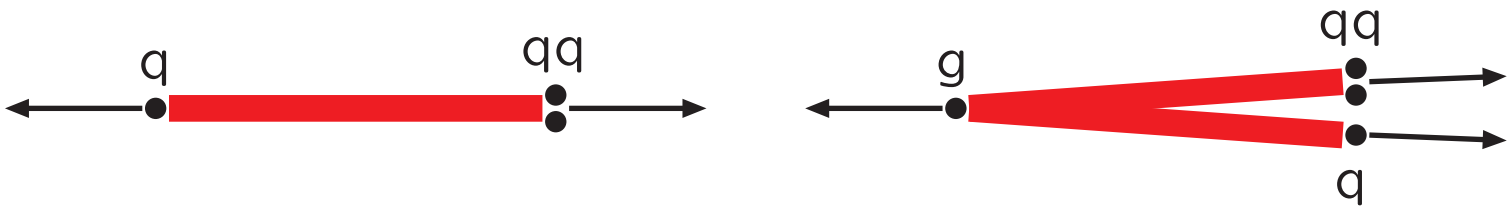
Different main approaches to diffraction:

- Optical analogies: cross sections, not properties.
- Pomeron/Reggeon picture: ditto, a bit more concretely.
- Ingelman-Schlein: Pomeron as hadron with partonic content
  used e.g. in POMPYT, POMWIG, PHOJET.
  Diffractive event = (Pomeron flux) $\times$ (**I**Pp collision)

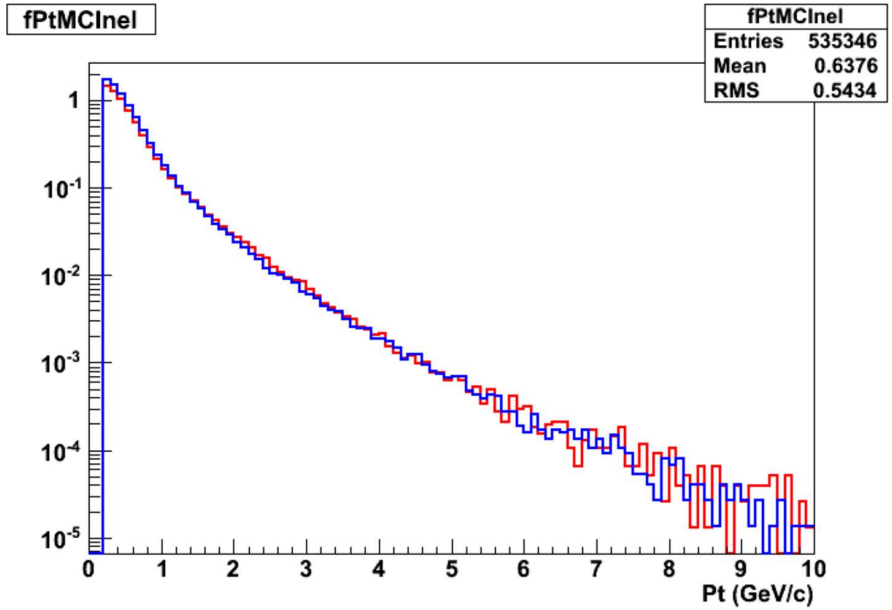


- Colour reconnection.

PYTHIA up till now: simple longitudinal string(s) with kicked-out q or g

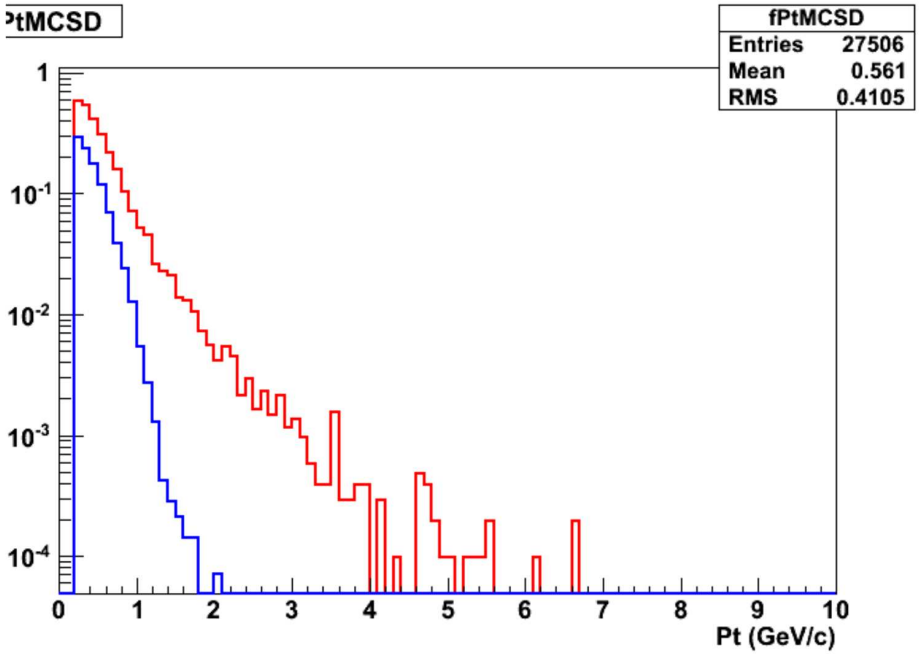


Charged transverse momentum spectrum – old



Inelastic = SD + DD + ND

SD



Pythia

Phojet

(produced by Sparsh Navin)

Diffraction II

New POMPYT-inspired framework puts together several components:

1) σ_{SD} and σ_{DD} taken from existing parametrization or set by user; involves Pomeron formulae + screening.

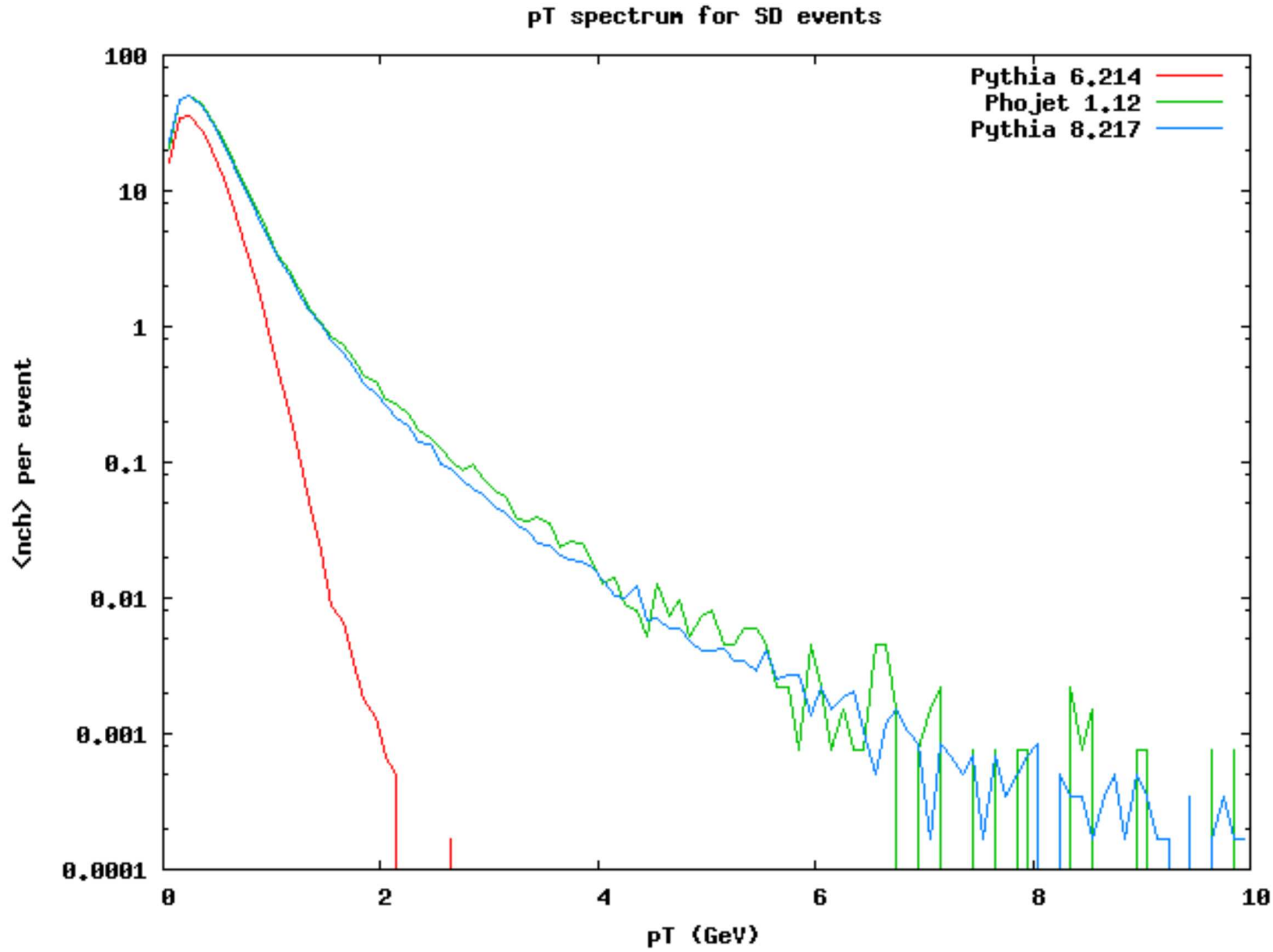
2) Shape of Pomeron distribution inside a proton, $f_{\mathbb{P}/\mathrm{p}}(x_{\mathbb{P}}, t)$ gives diffractive mass spectrum, $M^2 = x_{\mathbb{P}} s$, and scattering $p_\perp$ of proton, $p_\perp^2 \approx (1 - x_{\mathbb{P}})(-t)$. Option of four different shapes, some with tunable parameters, but only old PYTHIA thought-through also for double diffraction.

3) At low masses retain old framework, with longitudinal string(s). Above 10 GeV begin smooth transition to $\mathbb{P}$p handled with full pp machinery: multiple interactions, parton showers, beam remnants, ...

4) Choice between 5 Pomeron PDF's: Q^2-independent, π^0, H1 Fits A and B (2006) and H1 Jets (2007). Warning: H1 not normalized, momentum sum $\approx 0.5 \Rightarrow$ free to rescale. Free parameter $\sigma_{\mathbb{P}\mathrm{p}}$ needed to fix $\langle n_{\mathrm{interactions}} \rangle = \sigma_{\mathrm{jet}}/\sigma_{\mathbb{P}\mathrm{p}}$.

5) Framework needs testing and tuning, e.g. of $\sigma_{\mathbb{P}\mathrm{p}}$.

Charged transverse momentum spectrum – new



(produced by Sparsh Navin)

Summary

Legacy PYTHIA 6.421:

- 79,000 lines of code (including comments/blanks),
  growth +2,500 since 6.416 (UED, tunes, bug fixes, . . .).
- 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 8.130:

- 65,000 lines of code (including comments/blanks),
  growth +11,000 since 8.108 (processes, rescattering, bug fixes, . . .).
- 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 begun.