Event Generators at $\sqrt{s} = 115$ GeV

Which one to use for which purpose?

Triggering the discussion …
Outline

- Event generators physics
- Why to use them?
- Questions raised by AFTER
- Non-exhaustive Overview of event generators on the market
- Which one to do what?
- Conclusions
Event generators physics

Goal (dream?):

- to reproduce entirely an event: particles in final states with all properties
- with all steps and physics features (soft, hard, interplay between the two, hydro?, all observables, …)
- Should give access to exclusive observables
- Different from a calculation/computation usually inclusive and for one observable (for example pT spectrum in \( pp \rightarrow J/\Psi +X \))

Strategy:

Initial state
Elementary interactions: soft, hard, both?
Radiation
Remnants
Multiple interactions
Underlying events
Particle production (string picture?)
Why to use them?

- Simulate events for detector/analyse purpose
  - Simulate event for corrections
  - Test an analysis process on MC data prior to real data
  - Test your comprehension of your detector (MC =? Event generation+Geant simulation of detector)

- Model-Comparison
  - If you look at pure inclusive observable, maybe there is a model on the market that will be more adapt
  - If you start looking at exclusive staff: particle correlations, soft vs. hard, ... Event generators trying to reproduce all aspect of the event could be of interest

For this, do you need a sophisticated baseline model of your event generator?
Questions raised by AFTER

- **Fixed target** ➔ Various possible target with two beams (p or Pb)
  ➔ Various systems: pp, pA, AA
  ➔ \(-4.8 < \gamma_{\text{cms}} < 1\)

Do you want one single event generator for all systems?

- **Energy**: \(\sqrt{s} = 72-115\) GeV ➔ Between SPS and RHIC
  You need an event generators that give consistent simulation at SPS and RHIC.

Do you need all new features developed for Tevatron and LHC?

- **Observables**: photons, jets, Quarkonia and open heavy flavor, identified soft particles
  ➔ Various observables either soft and hard

Do you want one single event generator for all observables?
Non-exhaustive Overview of event generators on the market

- **pp event generators**
  - PYTHIA: Based on pQCD approach: the hard interaction is the basis of the framework
  - Herwig: Specialization, complement
    - ALPGEN: include detailed multiple hard processes
    - Jimmy
    - Cascade: hard process with parton evolution
  - EPOS: Based on Gribov-Regge approach, multiple interactions are the basis of the framework
  - Sherpa

- **pp, pA, AA**
  - Hijing: Based on PYTHIA, with emphasize on minijet, includes nuclear shadowing
  - AMPT: Hijing for initial condition, add final state scattering to generate elliptic flow
  - EPOS: Picture of Elementary parton-parton interactions viewed as color flux tube extended to all system, with shadowing and hydro evolution
  - Hydjet++: Hydro evolution (only AA?)

https://karman.physics.purdue.edu/OSCAR-old/models/list.html
A completely biased selection

In the following:

- PYTHIA
- EPOS
- A bit of Hijing and AMPT
1) The first hard interaction is the first step of event machinery:
Computed in pQCD framework with factorisation, when select hard probes: charm, bottom, jets, photon -> tune this step

2) MPI: other processes (soft or hard) can happen in parallel:
PYTHIA model: the first hard interaction is particular, other are reconstructed afterward, ordered in hardness, in PYTHIA 6, only g,u,d,s available in other interaction, in PYTHIA 8: second hard can include charm and bottom
PYTHIA Physics : ref 6.4 Manual

All produced partons (in hard process, ISR/FSR, MPI, remnants, ...) are connecting via strings: the LUND procedure, Resonance let out of the machinery.

Formed strings decays into hadrons (fragmentation via \( \bar{q}q \) pairs, pop-corn to produce baryons).

\( \bar{q}q \): u,d,s,c (c is suppressed but available), heavier not implemented.
PYTHIA 8

In C++

The actual developed code (PYTHIA 6 maintained, but not developed)

MPI scenario: possibility of charm and bottom in the hard process of second hard interaction: user can play with this!!!

Tagging of particles: cluster $J/\Psi$ not visible anymore: !to take with care, to be checked

PYTHIA +

A bit of everything, even if the physics model is not perfect
Extensively used, tuned, debugged, interfaced to other codes

PYTHIA -

Only pp

A bit of everything, even if the physics model is not perfect (eg. quarkonia)
Not PYTHIA, but PYTHIAS: many many tunes, really one single framework?
How to produce heavy state in PYTHIA?

- In the 2->2 hard sub-process: Hard production
  1) Open heavy flavor
     ![Diagram of open heavy flavor]
  2) Resonance production
     ![Diagram of resonance production]

- Gluon splitting (g->QQbar, gluon originated from ISR/FSR)
  ![Diagram of gluon splitting]

To be checked: can a pre-resonant state decay into D meson?

Pre-resonant state (NRQCD): decay into J/Psi or Upsilon

Color reconnection make this contribution available with only one g->Qqbar: artificial enhancement of this contribution in PYTHIA6.4

p p
\(c/b\) \(\bar{c}/\bar{b}\)
Partons, connected to strings

p p
\(c/b\) \(\bar{c}/\bar{b}\)
Any hard 2->2 sub-process (gg->gg for example)
Partons, connected to strings

p p
\(c/b\) \(\bar{c}/\bar{b}\)
cc cluster decay into J/Ψ
Any hard 2->2 sub-process (gg->gg for example)
Other c/b connected to strings
(N.B: Cluster: small piece of string: decay directly into hadrons)
How to produce heavy state in PYTHIA?

- String fragmentation

\[ \text{A MB event can still produces J/Psi and D mesons via gluon splitting and string fragmentation} \]

\[ \text{cc pair production suppressed as compare to u, d, s, but available: limit at high energy?} \]

\[ \text{Higher state not available} \]

How to tag the origin of heavy state?

- easy for resonance: direct information
  Via the mother!

- Due to final string procedure: difficult for open charm and open beauty: they all finally comes from strings

- For open charm and open beauty is there really a physical sense for differentiation?
J/\Psi \text{ vs. mult in pp } @ 7 \text{ TeV}

At LHC: looking at more exclusive observables in pp@ 7 TeV

ArXiv:1202.2816

Will you look with AFTER at such observables, or quarkonia+correlations?
EPOS for pp

Parton-based Gribov-Regge Theory

Mixed approach between parton model and Gribov-Regge

Energy shared between all elementary interactions

Same formalism for cross section computation and particle production

Elementary interaction = \[ \sum_{\text{soft}} + \text{Semi-hard} \]

soft: parameterized

hard: parton model

semi-hard: soft pre-evolution before the hard part

EPOS theoretical framework

Energy conserving quantum mechanical multiple scattering approach based on:

- Partons, parton ladders, strings
- Off-shell remnants
- Splitting of parton ladder

Elementary scattering - flux tube

- Parton evolutions from the projectile and the target side towards the center (small $x$)

- Evolution is governed by an evolution equation, in the simplest case according to DGLAP.

- Parton ladder may be considered as a quasi-longitudinal color field, a so-called flux tube, conveniently treated as a relativistic string.

- Intermediate gluons are treated as kink singularities in the language of relativistic strings, providing a transversely moving portion of the object.

- Flux tubes decay via the production of quark-antiquark pairs, creating in this way fragments - which are identified with hadrons.
EPOS for heavy ion

Same framework extended

pp $\rightarrow$ AB
EPOS for heavy ion

In heavy ion collision / or very high energy pp scattering:

- The usual procedure has to be modified, since the density of strings will be so high that they cannot possibly decay independently.

- Some string pieces will constitute bulk matter, which expands as a fluid, others show up as jets.

Event by event hydro-evolution

Initial condition given by flux tube picture


"Jets, Bulk Matter, and their Interaction in Heavy Ion Collisions at Several TeV." arXiv: 1203.5704
EPOS for heavy ion

Pions at RHIC: AuAu, $\sqrt{s}=200$ GeV

EPOS for heavy ion

Kaons at RHIC: AuAu, $\sqrt{s}=200$ GeV

EPOS for heavy ion

Protons and lambda at RHIC: AuAu, \( \sqrt{s} = 200 \) GeV

EPOS for heavy ion

Xi and Omega at RHIC: AuAu, $\sqrt{s}=200$ GeV


Many other variables and energies available in literature
Main features of HIJING:

- Multiple mini-jet production according an eikonal formalism for each nucleon-nucleon collision at given impact parameter $b$. Kinematic of each pair of jets + their ISR/FSR done by PYTHIA model

- Events without jet production (with $p_T > p_0$) + underlying soft parton interaction in event with jet production modeled by exitation of quark-diquark strings with gluon links (FRITIOF and DPM model) + multiple low-$p_T$ exchange

- Nuclear modification of the PDF inside the nuclei with a set of impact-parameter dependent parton distribution functions, $V_2$ with more modern parameterized PDF

- Simple model for jet-quenching (jet-medium interaction in AA)
Hadron production in p+p, p+Pb, and Pb+Pb collisions with the HIJING 2.0 model at energies available at the CERN Large Hadron Collider.

Hadron production in p+p, p+Pb, and Pb+Pb collisions with the HIJING 2.0 model at energies available at the CERN Large Hadron Collider

AMPT

An hybrid model, 2 versions

Structure of the default AMPT model

A+B

HIJING energy in nucleon

excited strings and minijet partons spectators

ZPC (Zhang’s Parton Cascade) till parton freezeout

recombine with parent strings

Lund string fragmentation

ART (A Relativistic Transport model for hadrons)

Structure of AMPT model with string melting

A+B

HIJING energy in nucleon

excited strings and minijet partons spectators

fragment into partons

ZPC (Zhang’s Parton Cascade) till parton freezeout

Quark Coalescence

ART (A Relativistic Transport model for hadrons)

« Pb-Pb collisions at $\sqrt{s_{\text{NN}}}=2.76$ TeV in a multiphase transport model » arXiv 1101.2231

« A Multi-phase transport model for relativistic heavy ion collisions. »
« Pb-Pb collisions at $\sqrt{s_{\text{NN}}}=2.76$ TeV in a multiphase transport model » arXiv 1101.2231
<table>
<thead>
<tr>
<th>Model</th>
<th>EPOS</th>
<th>PYTHIA</th>
<th>Hijing</th>
<th>AMPT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>Multiple Interaction</td>
<td>Hard process</td>
<td>PYTHIA 5,3? + minijet + nuclear structure</td>
<td>HIJING + transport model (ZPC parton cascade)</td>
</tr>
<tr>
<td>MPI</td>
<td>Parton-based Gribov-Regge Theory</td>
<td>Reconstructed after the hard process. Interaction ordered in hardness. In the new model: color reconnection</td>
<td>modeled by exitation of quark-diquark strings with gluon links + multiple low-pT exchange</td>
<td></td>
</tr>
<tr>
<td>Hard process</td>
<td>Hard and semi-hard ladder with soft pre-evolution u, d, s, g, gamma, c in progress</td>
<td>Based on inclusive cross section Almost everything, if not in the code, can couple with extra code</td>
<td></td>
<td></td>
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<tr>
<td>Quarkonia</td>
<td>No</td>
<td>Yes: model to be taken with caution. Cluster J/Psi in 6.4</td>
<td>?</td>
<td>?</td>
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<tr>
<td>Initial and Final state radiation</td>
<td>Iterative procedure from partons in hadrons to 2-&gt;2 process</td>
<td>A posteriori reconstruction Available for MPI in the new model (6.4)</td>
<td>PYTHIA 5,3</td>
<td>transport model</td>
</tr>
<tr>
<td>Collectivity</td>
<td>Yes, available with string density, eg. for all systems if energy density high enough: event by event hydro</td>
<td>No</td>
<td>No?</td>
<td></td>
</tr>
<tr>
<td>Hadronization</td>
<td>String model with aera law, diquark for baryon production</td>
<td>String model with fragmentation function, popcorn for baryon production</td>
<td>PYTHIA 5,3</td>
<td></td>
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<tr>
<td>Remnant</td>
<td>Yes</td>
<td>Yes</td>
<td>PYTHIA 5,3</td>
<td></td>
</tr>
<tr>
<td>Connection between hard processes and MPI</td>
<td>Total by construction: several ladders soft or hard, energy conservation and color connection</td>
<td>In MPI color reconnection (6,4), final state effect</td>
<td>modeled by exitation of quark-diquark strings with gluon links + multiple low-pT exchange</td>
<td>?</td>
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Conclusions

The first question you should ask yourself: what do I want to do with my event generator?

- In pp at $\sqrt{s}=115$ GeV, do you need all theory development needed for tevatron and LHC?

- If your goal is to study pA and AA: do you gain to have one single event generator (one physical framework and computing framework) for all systems and energies?

- Do you gain to have to have one single event generator for all observables?

- For quarkonia: at present moment there isn’t a full event generator for pp, pA, AA with quarkonia implemented in a single framework (see Smbat and Cynthia’s work)

- The field is evolving quickly, maybe there will be more advanced MC when AFTER will be in operation, stay tuned

There isn’t one easy answer, it depends on your preferences!