Event Generators : an overview

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Experiment vs. simulation

Experiment

Collision of particles / nuclei : generation of new particles/tracks

↓

Particles / tracks passing through detectors: deposition of energy: creation of space points (Detectors+DAQ)

Simulation

Event generator: hypothetical collision: generation of particles/tracks

↓

Response of detectors: energy deposition: calibration: creation of space points (GEANT)

Coordinates of the points joined using suitable algorithm: reconstruction / tracking

↓

Physics analysis

- (blue) Information about the generated particles extracted from the reconstructed ones
- (green) All information about the generated particles are available

Why do we need simulation?

- Test and refine the performance of

1. Detector
2. Tracking/reconstruction software

Will not be discussed

GEANT

- Check what one expects from known physics input and compare with the final results from experiment

Event Generators

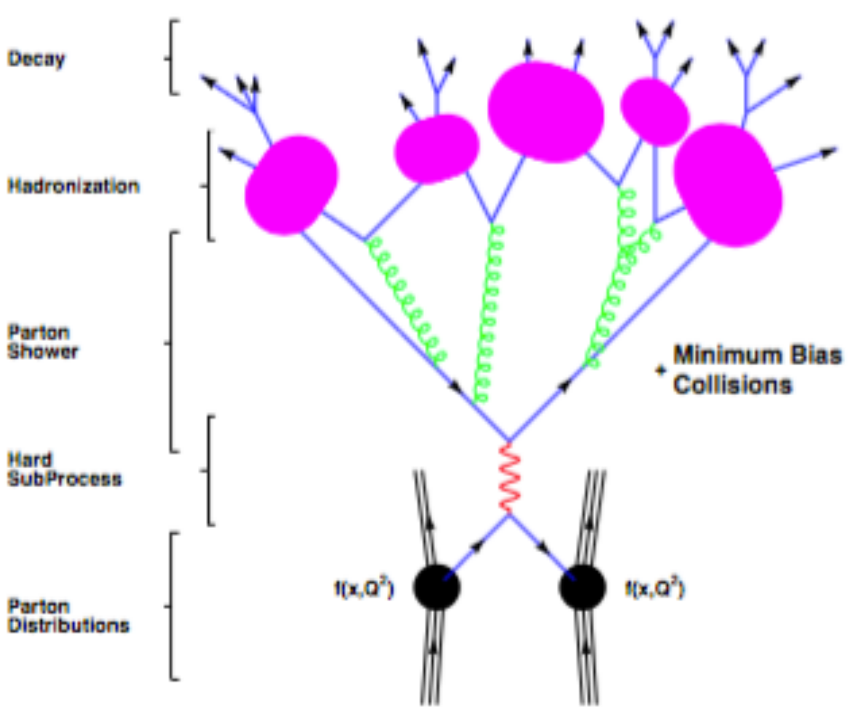
Events: how different are they?

Research in **Experimental High Energy Physics** could broadly be divided into two areas :

- Elementary particle physics : involves elementary collisions (p+p, e+p *etc.*)
- Heavy-ion Physics : involves collisions of heavy nuclei (and hadron+nucleus)

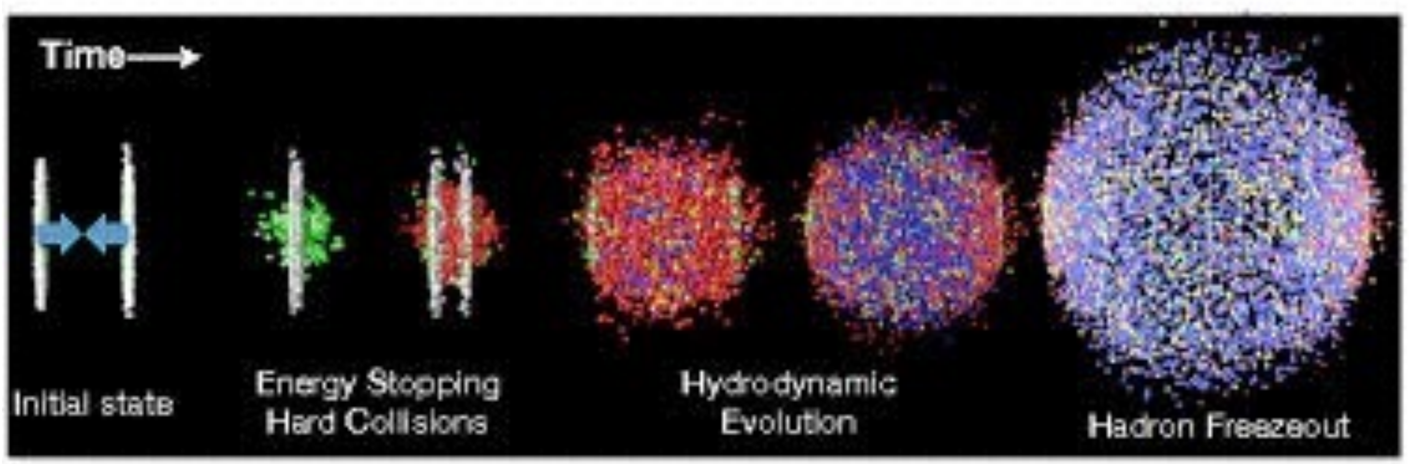
Elementary collisions

1. Hard scattering
2. Parton shower
3. Hadronization
4. Underlying event
5. Decay of unstable particles



Collisions of heavy nuclei

1. Large number of elementary collisions
2. Time evolution of the collision
3. Final state interactions of produced particles



Generators of elementary collisions

Les Houches Guidebook : hep-ph/0403045

Let’s start with the hard scattering …..

$$d\sigma(u\bar{u} \to Z^0 \to d\bar{d}) = \frac{1}{2\hat{s}} |\mathcal{M}(u\bar{u} \to Z^0 \to d\bar{d})|^2 \frac{d\cos\theta d\phi}{8(2\pi)^2}$$

1. Candidate event: chose θ, ϕ from uniformly distributed random number generator
2. Differential cross-section (or *event weight* or *probability of the occurrence of the event*) of the candidate event,dσ, comes from the equation
3. Average of event weight, <dσ>, is an approximation to the measured cross-section

However, the candidate events are distributed flat in phase space - contrary to physical world.

Two ways to approach the physical world from here:

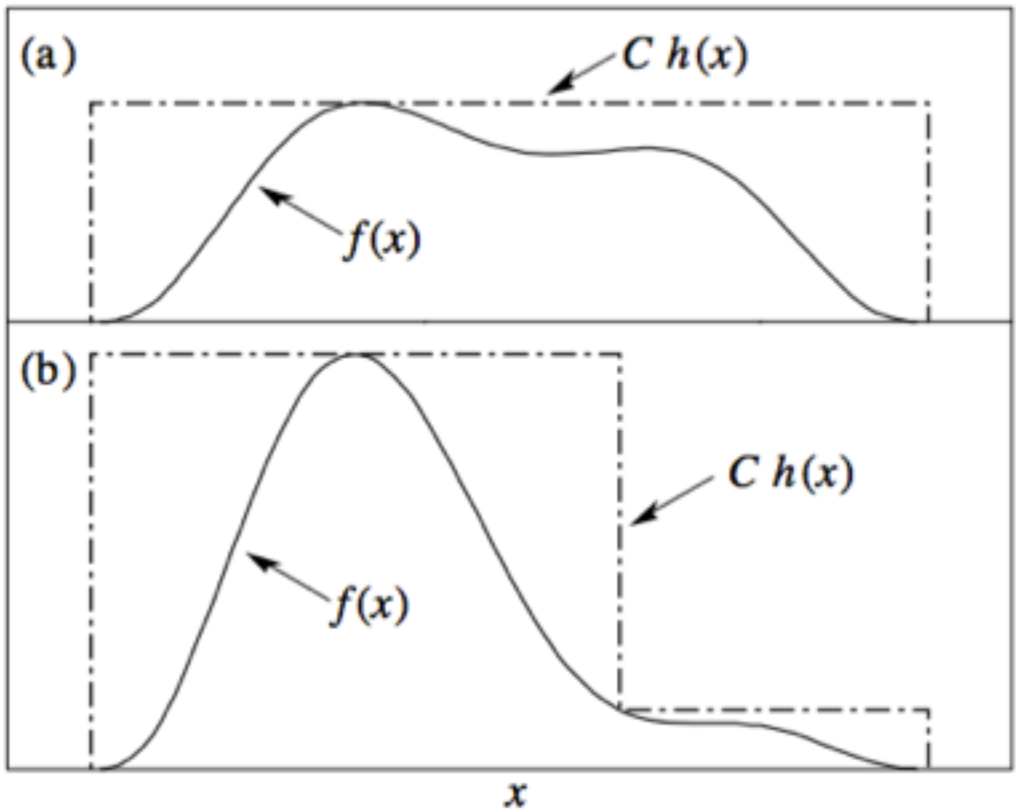
1. Use the event weights to create distribution of physical quantities
2. Candidate events are created not from uniform distribution but following physical distributions

Cross-section integrator

Event generator

Generators of elementary collisions (contd.)

Monte Carlo simulation : acceptance-rejection technique by *John von Neumann*



1. *h(x)* is a uniform or normalised sum of uniform distribution; both *f(x)* and *h(x)* must be normalised to unit area
2. Generate a candidate *x* following *h(x)*
3. Compute *f(x)* and *Ch(x)*
4. *G*enerate a random number *u* and test if *uCh(x) <= f(x)*
5. If 'yes', accept *x* else reject *x* and start again

Efficiency is the ratio of the areas under *Ch(x)* and the one under *f(x).*

- For us, the maximum event weight $d\sigma_{max}$ must be known :

  when the two quarks are collinear, *i.e.* $\cos\theta = +/- 1$

- For each candidate event compute $d\sigma/d\sigma_{max}$
- If $d\sigma/d\sigma_{max} > g$ (a uniformly generated random number), accept the event, else reject it
- The accepted events have frequency and distribution same as the equation we started with.

Generators of elementary collisions (contd.)

But life is not bed of roses …..

1. The kinetics of the process is trivial: the transverse momentum of Z_0 is zero
2. Neither beams of quarks can be delivered, nor quarks can be detected

- Radiation in addition to hard subprocess : higher order corrections using perturbation theory
- Dressing of bare quarks : hadronization

Higher order correction

- Exact computation of small number of emissions
  - *tree level matrix element generators,* ***NLO computations***
- Estimation of dominant effects at all orders in perturbation theory
  - *resummation,* ***parton shower technique***

Hadronization

- QCD improved version of Feynman's parton model (factorization)
- Phenomenological models to describe parton <-> hadron transition at mass scale where perturbation techniques are not applicable
  - none of the above can be computed from first principles (only hope is
  - lattice results) and must be extracted from data

Generators of elementary collisions (contd.)

Most commonly known generators for elementary collisions:

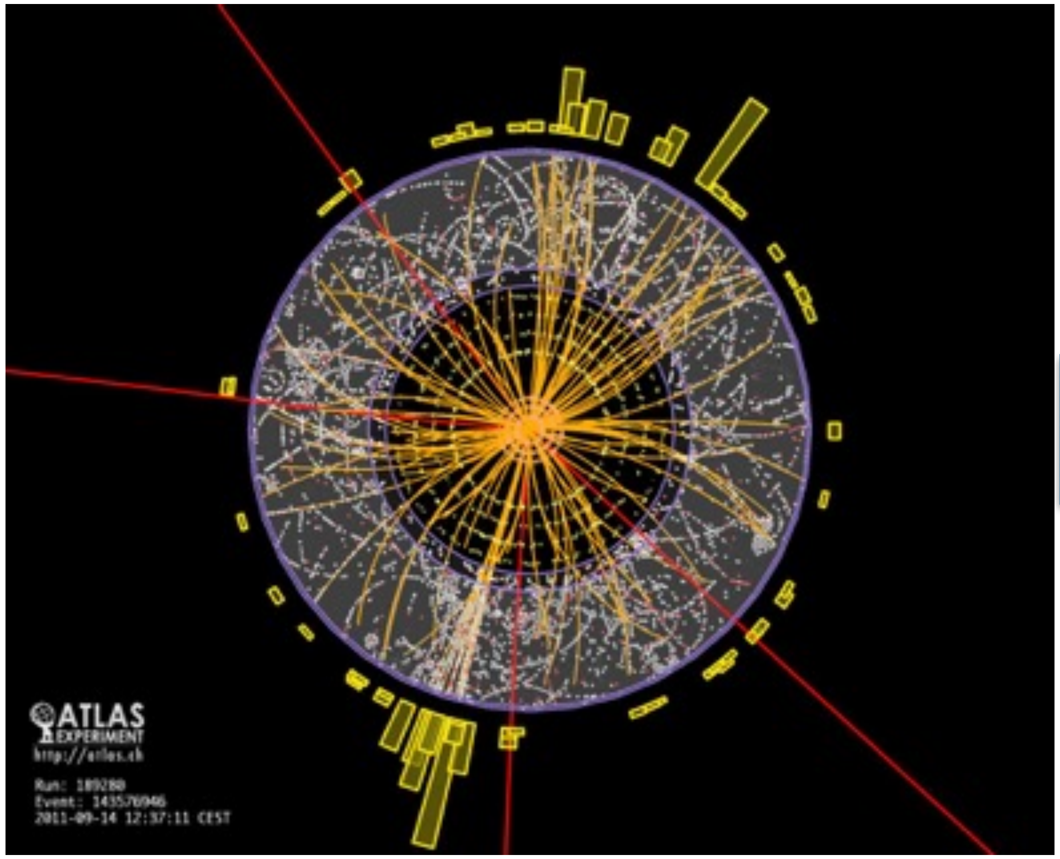
- **PYTHIA** : http://home.thep.lu.se/~torbjorn/pythia.html; arXiv:0710.3820 [hep-ph]
  - Works for either *hadron-hadron (p/pbar/n/nbar/π) or lepton-lepton* collisions
  - Working range CM energy 10 GeV - 100 TeV (may work at lower energies for e^-/e^+)
  - A large number of hard processes: QCD processes, Electroweak processes, Top production, Higgs processes
  - Soft processes include all components of total cross-section *i.e.* elastic, single diffractive, double diffractive ones
  - Multipartonic interactions (MPI) dominate the soft sector
  - Hadronization is achieved via string fragmentation and decay of unstable hadrons

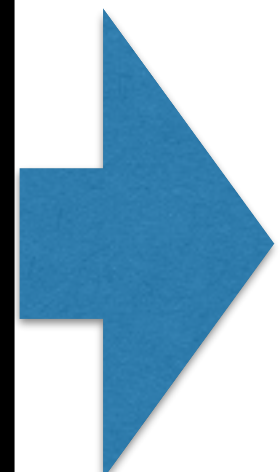
- **PHOJET** : hep-ph/9803437;hep-ph/9509373
  - Monte Carlo implementation of two component Dual Parton Model
  - Useful for hadron-hadron, photon-hadron and photon-photon collisions

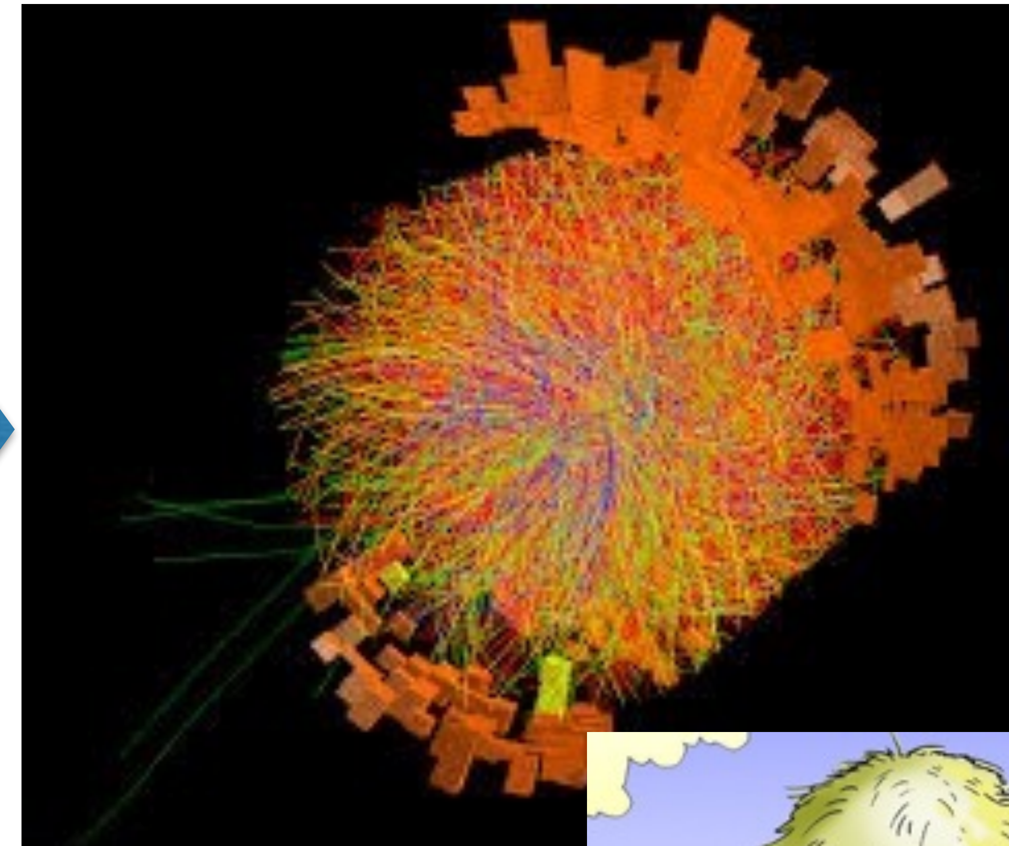
- **HERWIG** : https://herwig.hepforge.org
  - General purpose Monte Carlo event generator for lepton-lepton, lepton-hadron and hadron-hadron collisions
  - Particularly different in its sophisticated treatment of decays
  - Uses cluster model for hadronization as opposed to string fragmentation in PYTHIA

This list is not exhaustive.

Heavy-ion event generator: the task







Well, that's not the only problem …

Detectors detect particles/tracks a long time after the collision.
Event generators need to take care of what happens during that time

Heavy-ion event generator : types

Hadronic models

- Nucleus-nucleus collisions are described as simple superposition of hadron-hadron collisions
- Number of such collisions at a given impact parameter is determined by the geometry using the Glauber-Gribov theory
- LUCIFER, LEXUS

Parton cascade models

- Relativistic Boltzmann equation is solved for partons.
- Cross-section and splitting are computed in pQCD

String models

- Exchange of colour or momentum between partons of the projectile and target.
- Partons are joined by colourless objects called strings/ropes/flux tubes
- Include both soft and hard components: crucial for HI collisions at RHIC and LHC
- HIJING, DPMJET, NEXUS

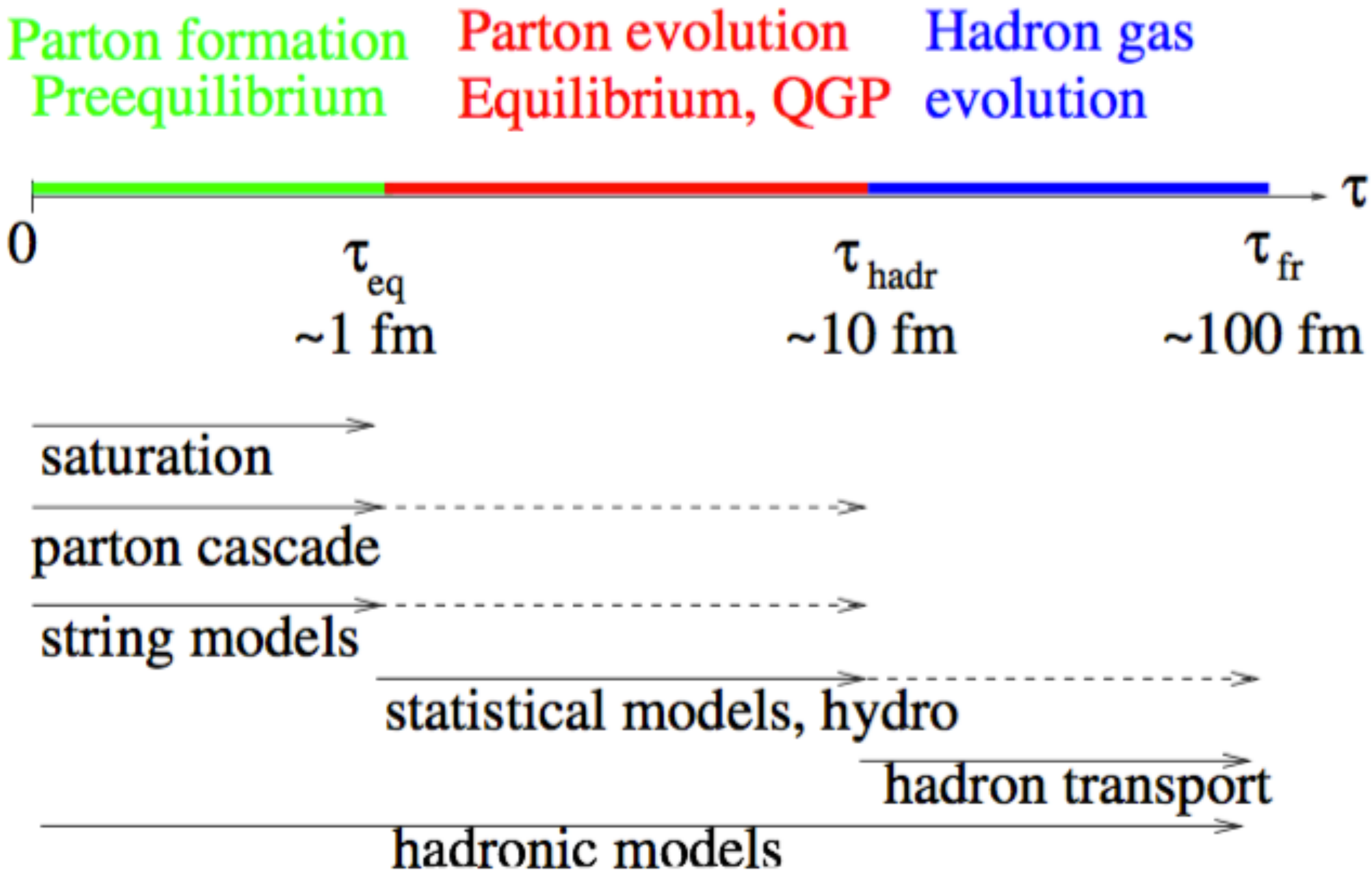
Hydrodynamical/statistical models

- Assumes local thermodynamical equilibrium at partonic level.

Hadron transport models

- Relativistic Boltzmann equation is solved for hadrons after hadronization.
- AMPT, RQMD, UrQMD, HSD

Heavy-ion event generators : timescale



Caveat: The borders between two stages are indeed artificial.

Heavy-ion event generators : popular candidates

Heavy Ion Jet INteraction Generator (HIJING)

- Based on minijets formed in collisions (not resolvable as distinct jets, but lead to wide variety of correlations)
- QCD inspired model for jet production, Lund string model for jet fragmentation
- Uses PYTHIA for each hard scattering and JETSET for fragmentation

Ultra relativistic Quantum Molecular Dynamics (UrQMD)

- Relativistic Boltzmann equation + hydrodynamics
- Very useful to study the evolution of system

EPOS

- Hard scatterings are modelled as parton ladders
- Initially developed for high energy cosmic ray interactions, now used for HI collisions

A Multi Phase Transport model (AMPT)

- Initial hard scatterings simulated using HIJING
- Zhang's Parton Cascade (ZPC) used for later stages

Thank you