Workshop on Monte Carlo Tools for the LHC

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Tools for Heavy Ion Physics

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Contents:

1. General considerations

• Heavy Ion Physics: very complex field, many physical mechanisms at work.

• Available Monte Carlo tools: not comparably standardized and developed to hadron-hadron, but our knowledge is far more limited $\Longrightarrow$ many models.

• Goal: production and characterization of the QGP, to gain information about basic properties of QCD like confinement or chiral symmetry breaking.

• But even without any phase transition, our understanding of heavy ion collisions is far from being complete.

• Main differences with hadron-hadron collisions: high density of produced particles and the possibility of phase transition(s).

• The standard procedure for hadron-hadron collisions: hard collisions (+ radiation) + hadronization + soft event has to be reconsidered.

• Monte Carlo simulators are intended (supposed) to give full information about the event, so they must deal both with hard probes (jets, heavy flavors,...), under theoretical control in pQCD, and the underlying soft event, model-dependent and, at most, inspired in QCD. Thus they try to describe observables like total multiplicities, out of strict theoretical control.

• Key point: sometimes the underlying event is not only the background (for jet quenching, charmonium suppression,...) but the signal itself (strangeness, correlations, HBT, flow,...).

• Simplest approach: superposition of nucleon-nucleon collision; it fails (e.g. to describe multiplicities), so interference (collectivity) has to be introduced. These simplest models are used as basis to study QGP formation.

• Question: fully thermalized QGP (initial conditions?) or non-thermalized system (applicability of models?)?

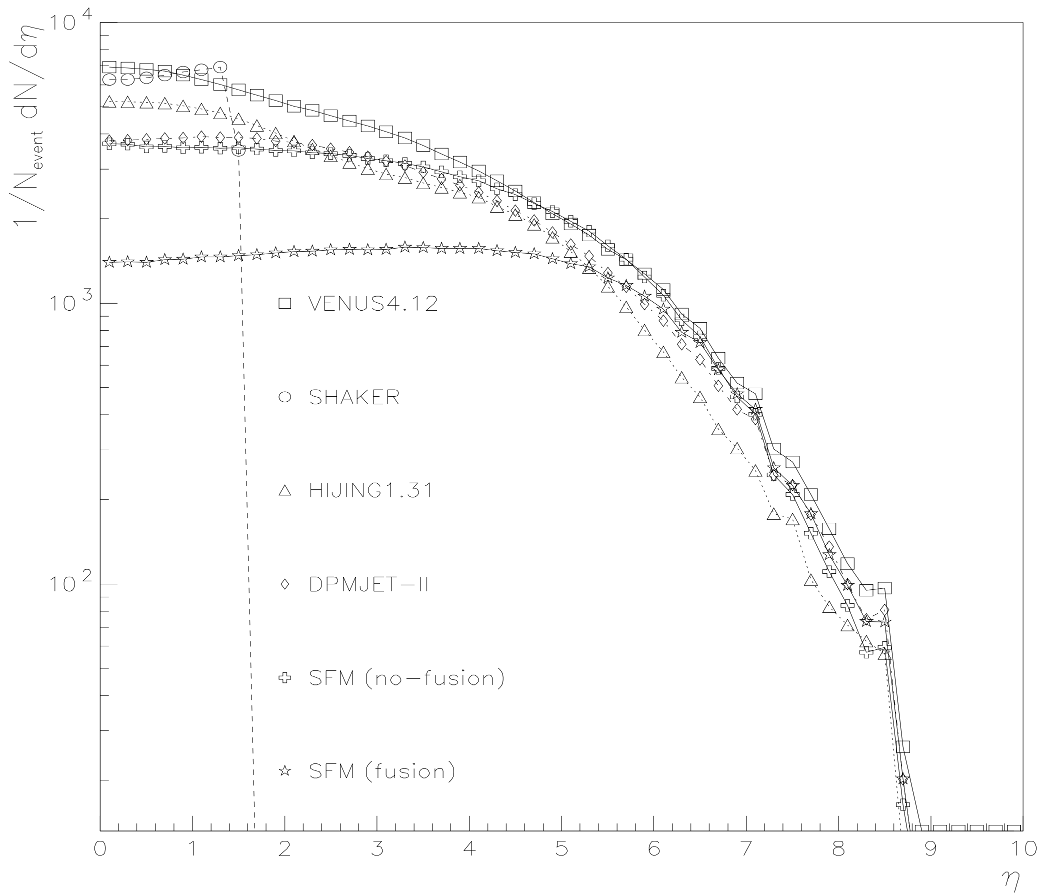
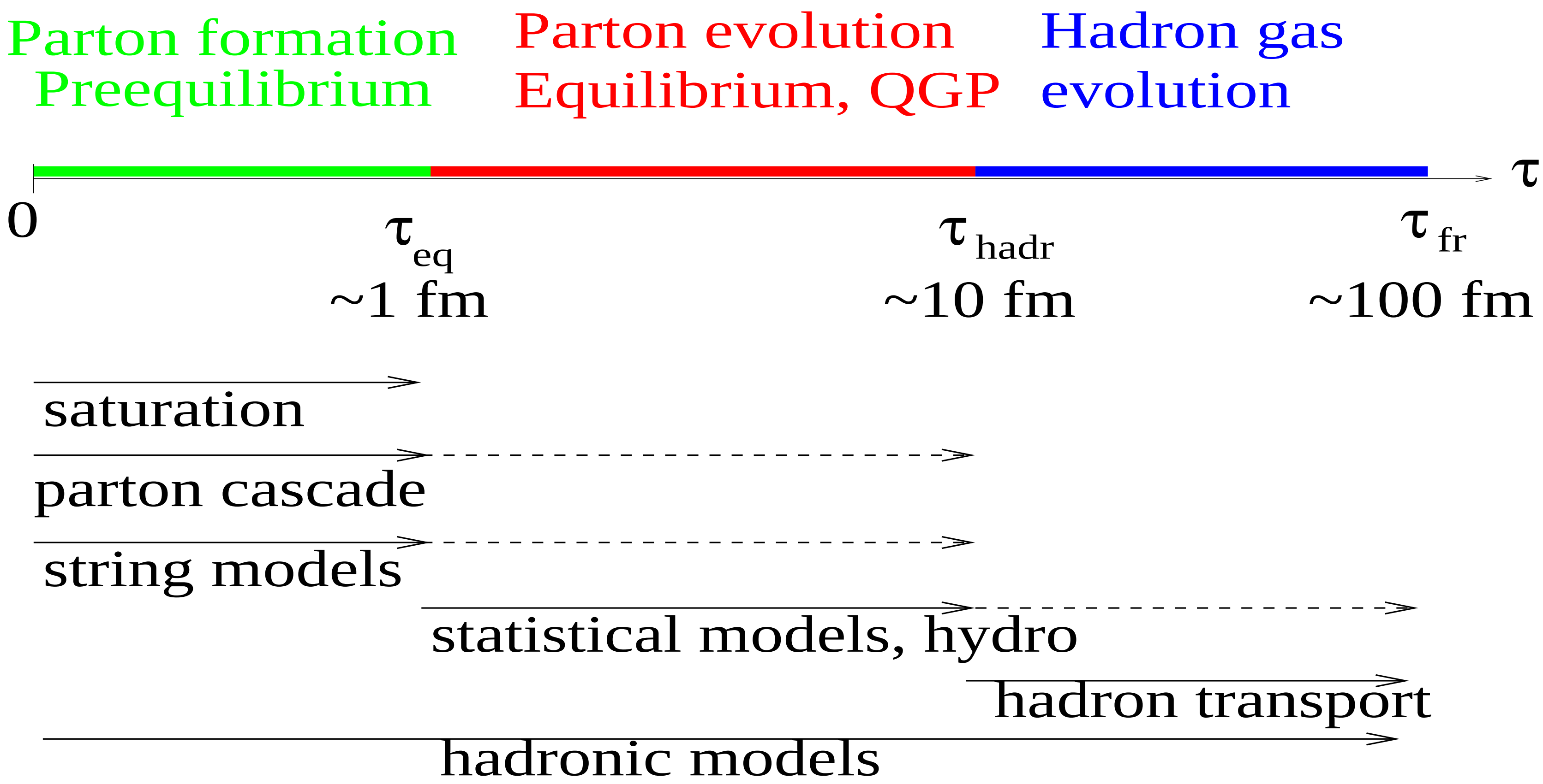


Figure 1: Predictions from different models for the charged pseudorapidity density in central ($b \leq 3$ fm) Pb-Pb collisions at $\sqrt{s} = 6$ TeV per nucleon, from the ALICE Technical Proposal (December 1995).

2. Classification of models: stages in a heavy ion collision



Hadronic models:

• Consecutive hadron-hadron collisions (LUCIFER: D.E.Kahana et al.,PRC58(98)3574).

Parton cascade:

• A relativistic Boltzmann equation is solved for partons, starting from some initial conditions given either by a nuclear wave function (PCM: J.R.Shin et al.,JPG28(02)2643; VNI: K.Geiger,PRD47(93)133) or by partons produced in initial collisions (by HIJING) (AMPT: B.Zhang et al.,PRC61(00)067901).

• Initial and final state radiation, coherence of the initial state and the possibility of hadronization via coalescence is (will be) considered in PCM.

String models:

• Initial stage given by soft and hard partons joined in colorless objects: strings, ropes, flux tubes. Models coming from hadron-hadron, generalized to nucleus-nucleus through Glauber-Gribov.

• Hard collisions considered through pQCD (HIJING: X.N.Wang et al.,PRD44(91)3501; PSM: NA et al.,EPJC22(01)149; DPMJET: J.Ranft,PRD51(95)64; NEXUS: H.J.Drescher et al.,NPA661(99)604; LUCIAE: B.Andersson et al.,ZPC71(96)155).

• VENUS and Fritiof obsolete; strings as initial stage in transport models (RQMD, UrQMD or HSD), and as fragmentation method in most models.

• Collectivity introduced through pomeron interactions in DPMJET and NEXUS, through high color fields in PSM, HIJING, RQMD, LUCIAE and DPMJET; increased stopping through baryon junction migration in HIJING and DPMJET.

Hydro:

- Hydrodynamical evolution of a QGP with a phase transition to hadronic matter (S.A.Bass et al., PRC60(99)021902), linked to hadronic transport by UrQMD; also T.Hirano et al.,nucl-th/0307015.

- Jet quenching introduced in HIJING.

Hadron transport:

- Transport equation for hadrons, with a (huge) variety of hadron species and cross sections (RQMD: H.Sorge et al.,AP192(89)266, UrQMD: S.A.Bass et al.,PPNP41(98)225, HSD: W.Cassing et al.,NPA623(97)570, AMPT).

- Simple models to estimate the effects of rescattering in LUCIAE, DPMJET and PSM.

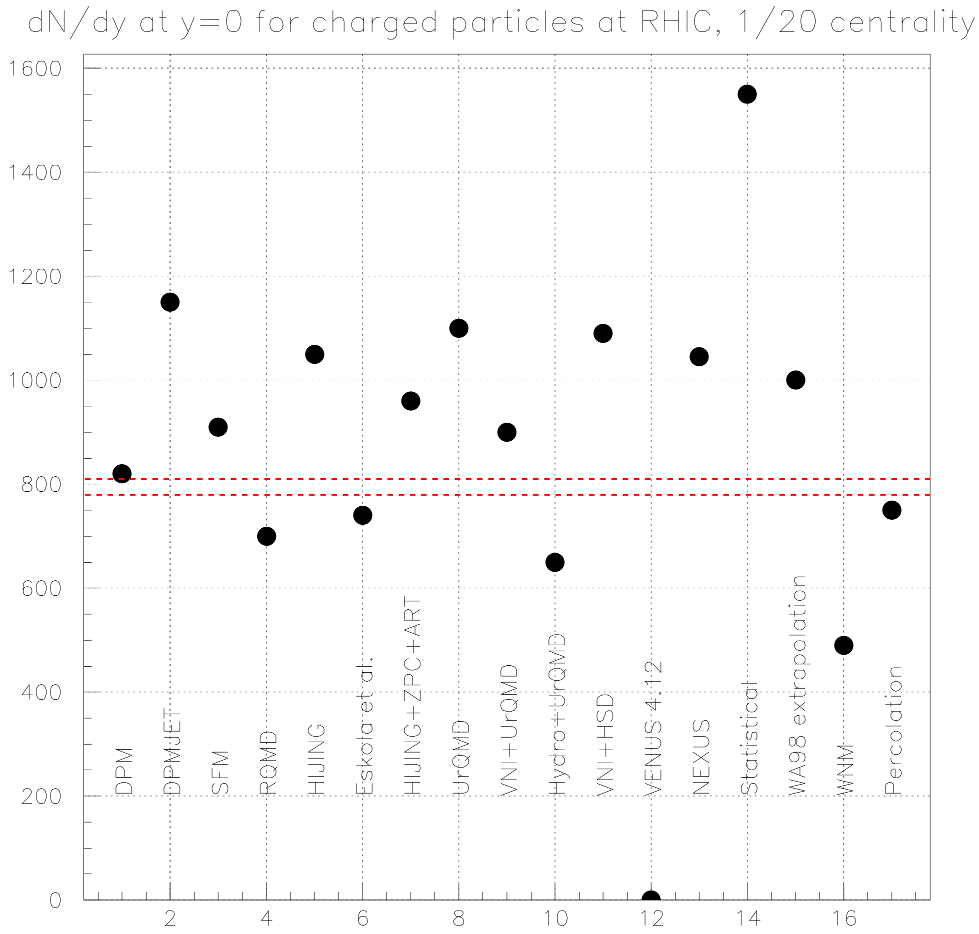
General comments:

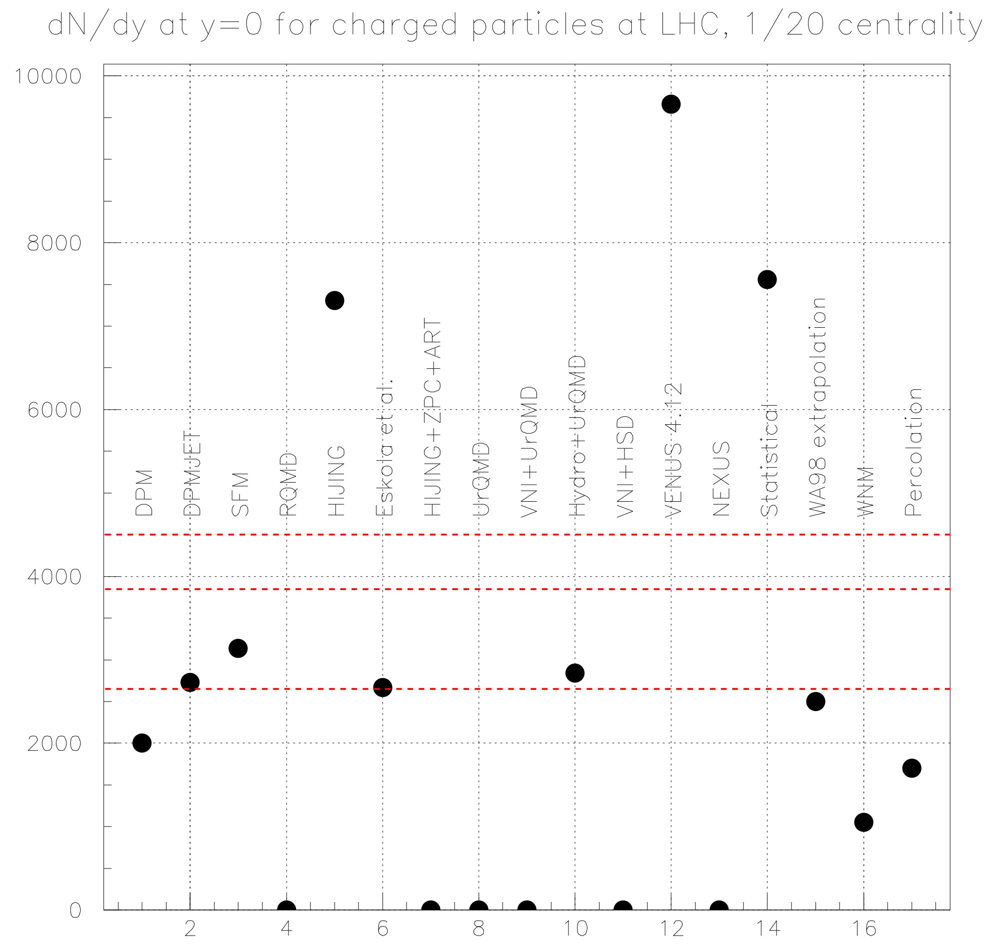
• No clear border between one stage and the previous one; factorization, causality assumed but not at all guaranteed.

• Models (see S.A.Bass et al.,NPA661(99)205 or NA et al.,IJPMA15(00)2019 for pre-RHIC reviews) try to describe the full event, not just one of the stages $\Longrightarrow$ mixed models; not all of them available as Monte Carlo simulators, among them just a few working for LHC conditions (DPMJET, HIJING, PSM); charm, bottom included through PYTHIA.

• Codes in Fortran, no C++; little standardization (OSCAR protocols followed by few codes); pieces of PYTHIA+ARIADNE+JETSET used in many codes.

• Predictions for LHC should be constrained by RHIC results but still uncertain: small x nPDF, degree of collectivity, QGP?


dN/dy at y=0 for charged particles at RHIC, 1/20 centrality
1600
1400
1200
1000
800
600
400
200
0
2
4
6
8
10
12
14
16
DPM
DPMJET
SFM
RQMD
HIJING
Eskola et al.
HIJING+ZPC+ART
UrQMD
VNI+UrQMD
Hydro+UrQMD
VNI+HSD
VENUS 4.12
NEXUS
Statistical
WA98 extrapolation
WNM
Percolation


dN/dy at y=0 for charged particles at LHC, 1/20 centrality
10000
8000
6000
4000
2000
0
2
4
6
8
10
12
14
16
DPM
DPMJET
SFM
RQMD
HIJING
Eskola et al.
HIJING+ZPC+ART
UrQMD
VNI+UrQMD
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Statistical
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3. Some personal comments and outlook

- Several Monte Carlo tools already available for heavy ion collisions at the LHC; with constraints coming from RHIC, low multiplicities seem to be favored.

- Models contain different decoupled stages: theoretical justification pending.

- Collectivity is well established, although phenomenological realizations differ.

- A description of the initial stage in terms of partons, not hadrons, looks unavoidable.

- Codes not standardized; the lack of a reliable, generally accepted theoretical baseline makes it difficult to establish long term programs.

- Some models will be ruled out by RHIC data, others will simply extinguish.

- Constraints from RHIC will reduce basic uncertainties for LHC, but some of them will remain, e.g. multiplicity reduction or transverse momentum spectra (RHIC is preasymptotic compared with theory and LHC).

Future: my wish-list

- Increasing modularity (e.g. OSCAR, http://nt3.phys.columbia.edu/OSCAR/): different initial stages coupled with different possibilities for thermalization or intermediate transport and hadronic cascades.

- Interplay with the Cosmic Ray Physics community possible and desirable.

- Hard probes like jet quenching, for which we have reliable theoretical understanding, included in a simulation of the whole event. Even with a rough knowledge of the underlying event, this would be a great help.

- Coherence in the initial stage, and QGP or some phase transition, in full simulation.

- Parton cascade with detailed balance and Lorentz invariance; this problem also appears in hadron-hadron.

Status of the field is still at the beginning, there are many open fundamental questions which are theoretically accessible but not yet solved completely;

NOTE

that not all interesting questions demand such precision as is intended in hadron-hadron (even simple implementations of the underlying event may provide valuable conclusions) and, plasma or no plasma, there is a lot to learn which is equally valuable for hadron-hadron.

Code list is not exhaustive (sorry); please see the talks by A.Morsch (ALICE), P.Nevski (ATLAS) and I.P.Lokhtin (CMS), and on DPMJET III (J.Ranft) and PSM (NA) for more information on the physical content and practical implementation of the models.