Event Generators at sqrt(s)=115 GeV

Which one to use for which purpose?

Triggering the discussion …

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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

<u>Goal (dream ?) :</u>

- 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-> J/Ψ +X)

<u>Strategy :</u>

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)

For this, do you need a sophisticated baseline model of your event generator ?

- 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

Questions raised by AFTER

- Fixed target → Various possible target with two beams (p or Pb)
  → Various systems : pp, pA, AA
  → -4,8 < Y_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
- Herwig

Based on pQCD approach : the hard interaction is the basis of the framework

- EPOS
- Sherpa

Based on Gribov-Regge approach, multiple interactions are the basis of the framework

Specialization, complement

- ALPGEN : include detailed multiple hard processes
- Jimmy
- Cascade : hard process with parton evolution

❑ 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

http://en.wikipedia.org/wiki/Event_generator

A completely biased selection

In the following :

PYTHIA

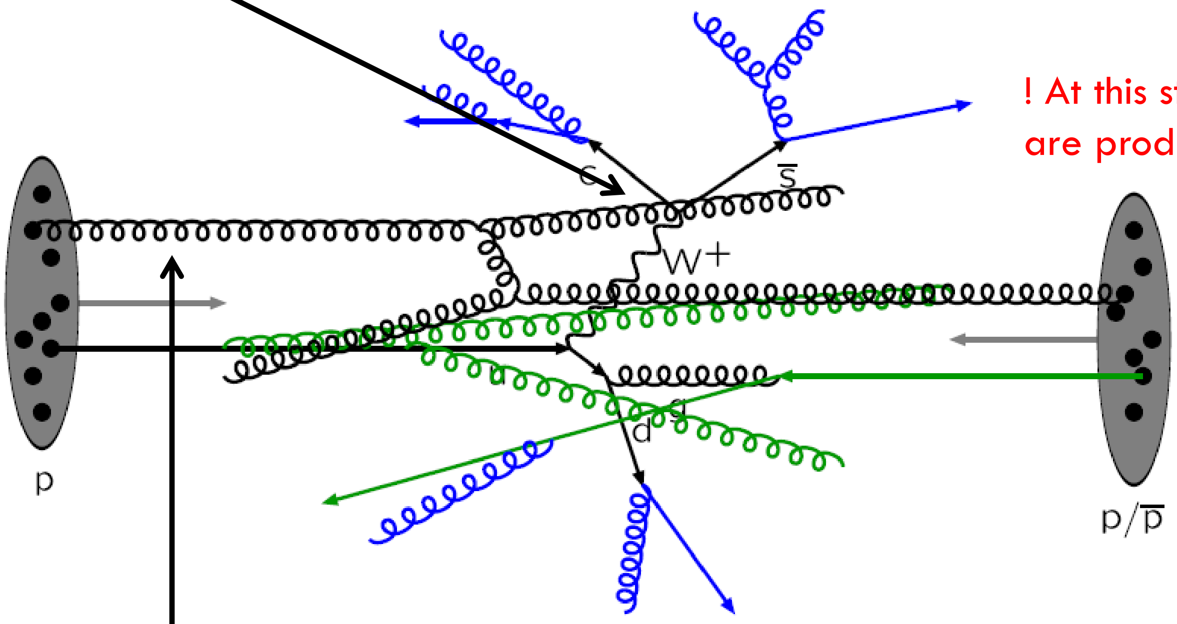
EPOS

A bit of Hijing and AMPT

PYTHIA Physics : ref 6.4 Manual

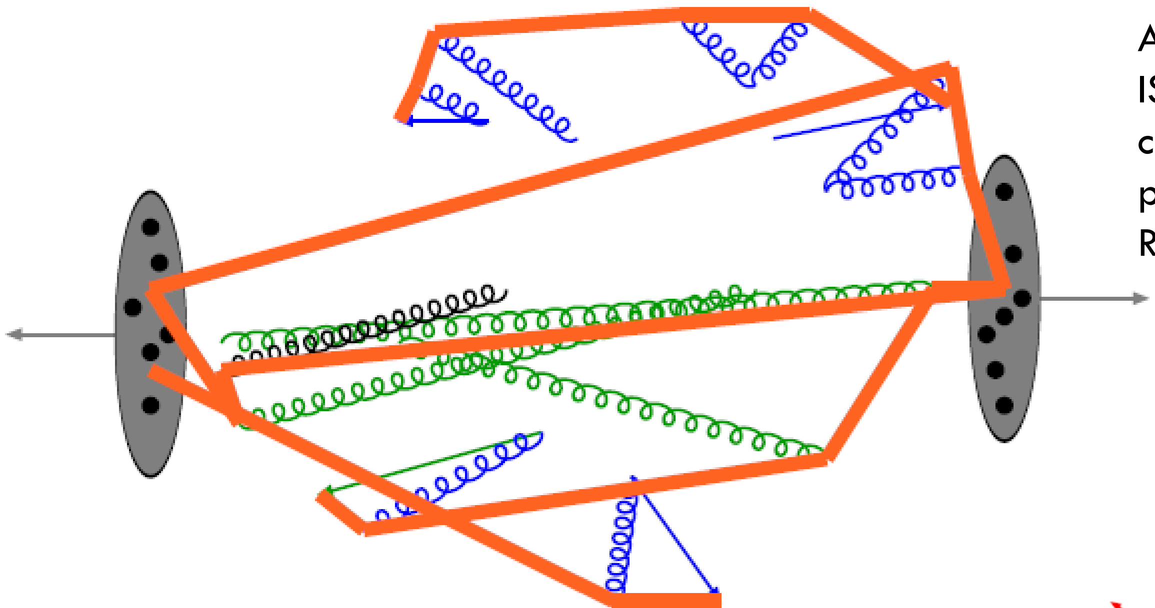
1) The first hard interaction is the first step of event machinery :
Computed in pQDC framework with factorisation, when select hard probes : charm, bottom, jets, photon -> tune this step

! At this step only partons are produced

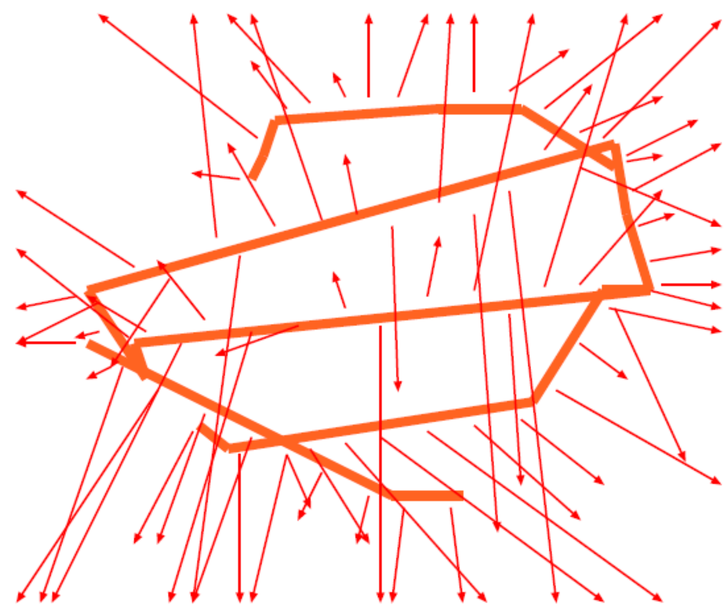


2) MPI : other processes (soft or hard) can happen in parallel:
PYTHIA model : the first hard interaction is particular, other are reconstructed afterward, ordered in hardness, in PYTHIA 6, only g,u,d,s available in other interaction,
In PYTHIA 8 : second hard can include charm and bottom

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 qqbar pairs, pop-corn to produce baryons)
qqbar : u,d,s,c (c is suppressed but available), heavier not implemented

PYTHIA 8

http://arxiv.org/pdf/0710.3820.pdf
http://home.thep.lu.se/~torbjorn/pythia8/worksheet8160.pdf

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/Ψ 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

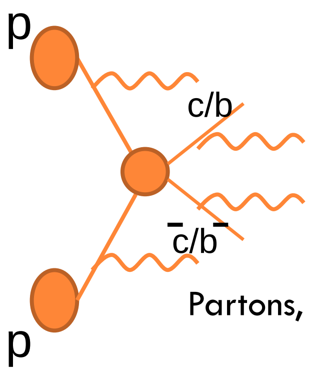
A bit of everything, even if the physics model is not perfect (eg. quarkonia)

Not PYTHIA, but PYTHIAS : many many tunes, really one single framework?

How to produce heavy state in PYTHIA?

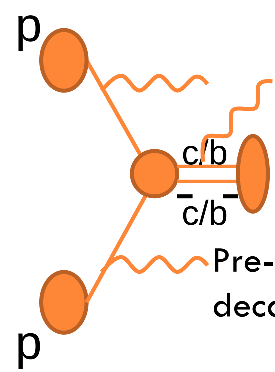
- In the 2->2 hard sub-process : Hard production

1) Open heavy flavor



Partons, connected to strings

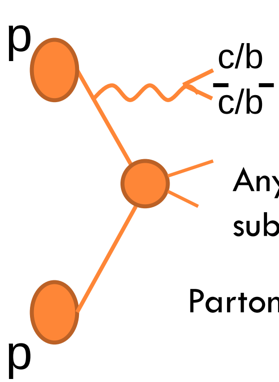
2) Resonnance production



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

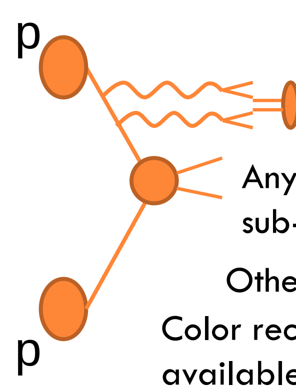
Pre-resonant state (NRQCD): decay into J/Psi or Upsilon

- Gluon splitting (g->QQbar, gluon originated from ISR/FSR)



Any hard 2->2 sub-process (gg->gg for example)

Partons, connected to strings



$c\bar{c}$ cluster decay into J/Ψ

Any hard 2->2 sub-process (gg->gg for example)

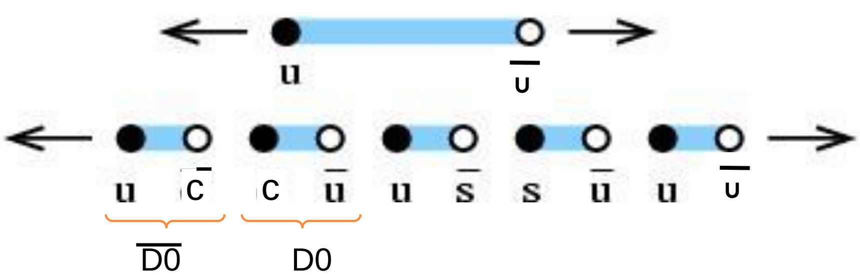
Other c/b connected to strings

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

(N.B : Cluster : small peace of string : decay directly into hadrons)

How to produce heavy state in PYTHIA?

❖ String fragmentation



A MB event can still produces J/Psi and D mesons via gluon splitting and string fragmentation

cc pair production suppressed as compare to u, d ,s, but available : limit at high energy?

Higher state not available

How to tag the origin of heavy state?

Via the mother!

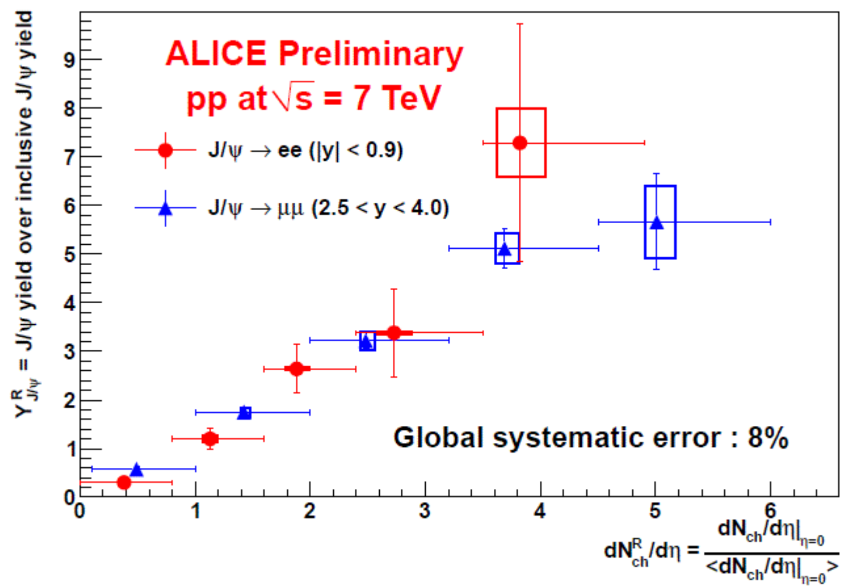
- ➢ easy for resonance : direct information

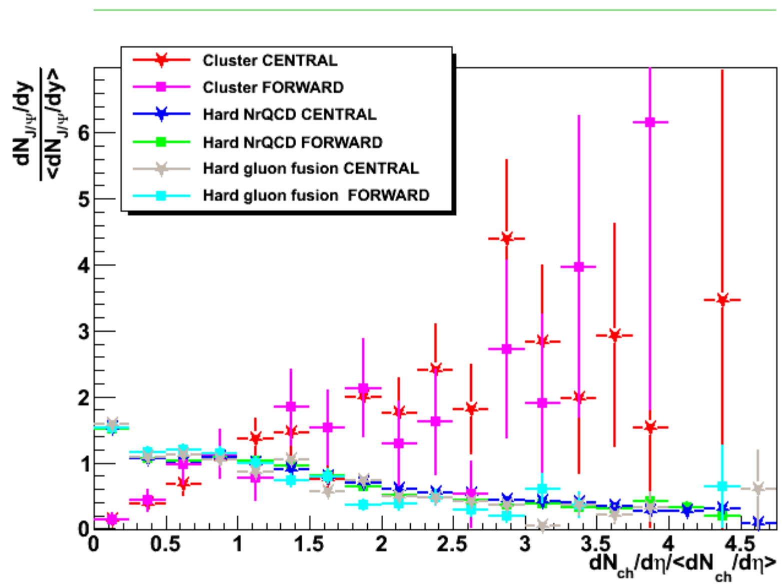
- ➢ Due to final string procedure : difficult for open charm and open beauty : they all finally comes from strings

- ➢ For open charm and open beauty is there really a physical sense for differentiation?

J/Psi vs. mult in pp @ 7 TeV

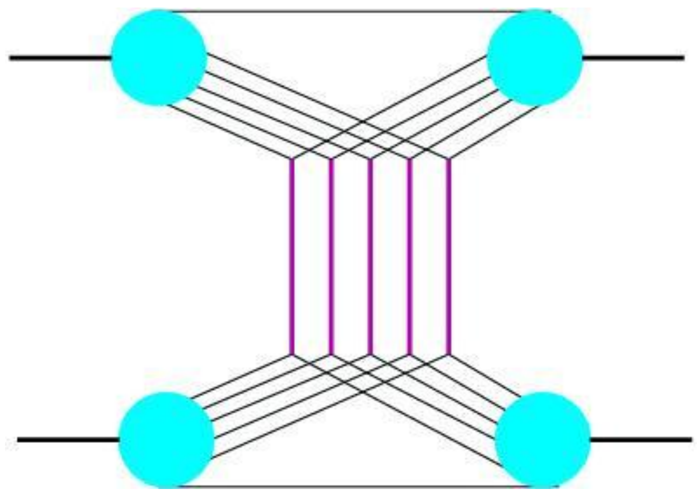
At LHC : looking at more exclusive observables in pp@ 7 Tev
ArXiv:1202.2816





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 = $\sum$ soft + Semi-hard

soft: parameterized

hard: parton model

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

EPOS
theoretical framework

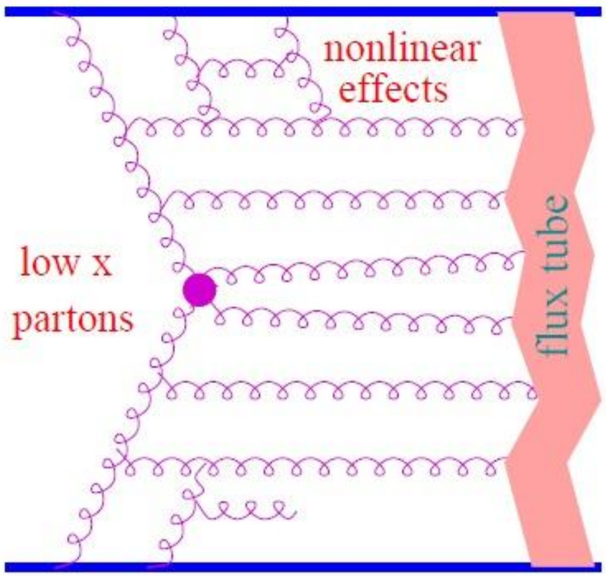
Energy conserving quantum mechanical multiple scattering approach based on :

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

S. Ostapchenko, T. Pierog, K. Werner, H.J. Drescher, M. Haldik Phys. Rep. 350 (2001)

EPOS for pp

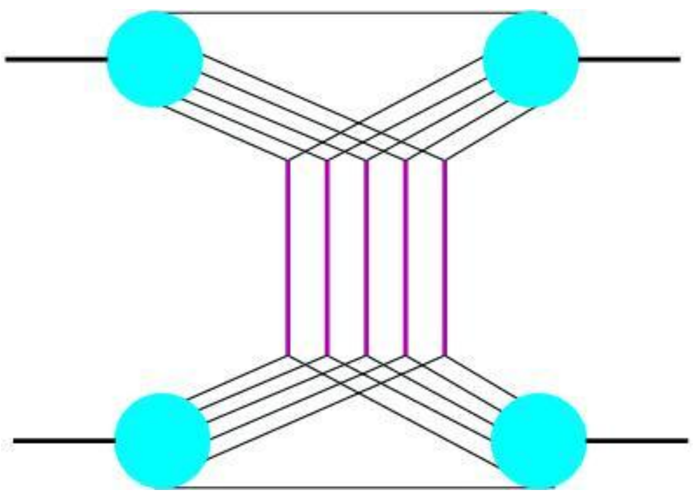
Elementary scattering - flux tube

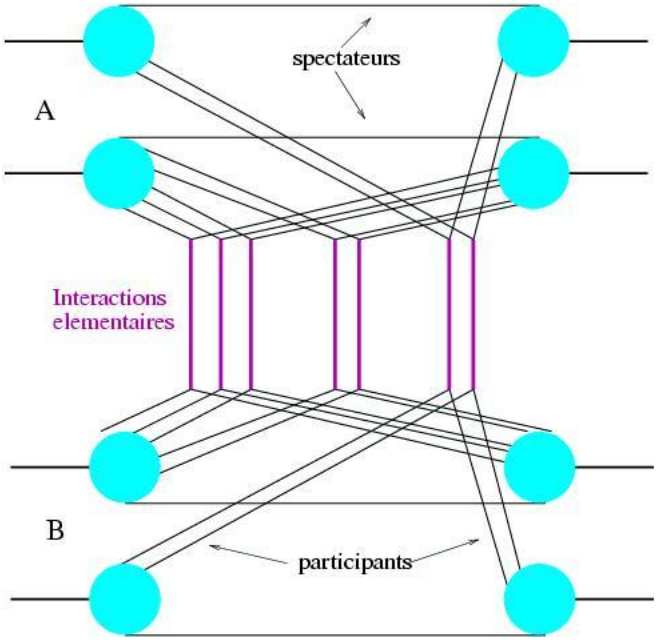


- Parton evolutions from the projectile and the target side towards the center (small x)
- Evolution is governed by an evolution equation, in the simplest case according to DGLAP.
- **Parton ladder may be considered as a quasi-longitudinal color field, a so-called flux tube, conveniently treated as a 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 → 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

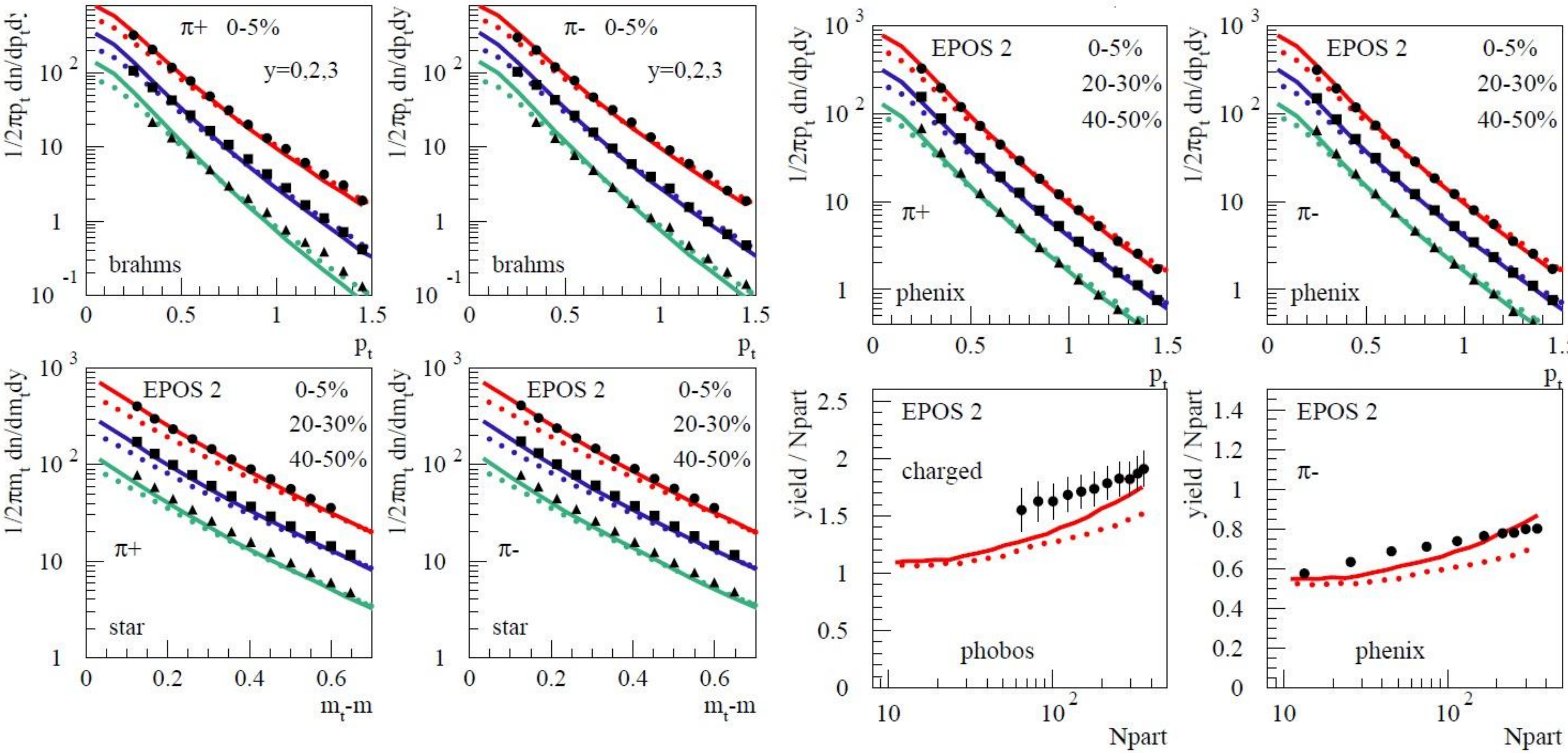
Initial condition given by flux tube picture

"Event-by-Event Simulation of the Three-Dimensional Hydrodynamic Evolution from Flux Tube Initial Conditions in Ultrarelativistic Heavy Ion Collisions" arXiv: 1004.0805

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

EPOS for heavy ion

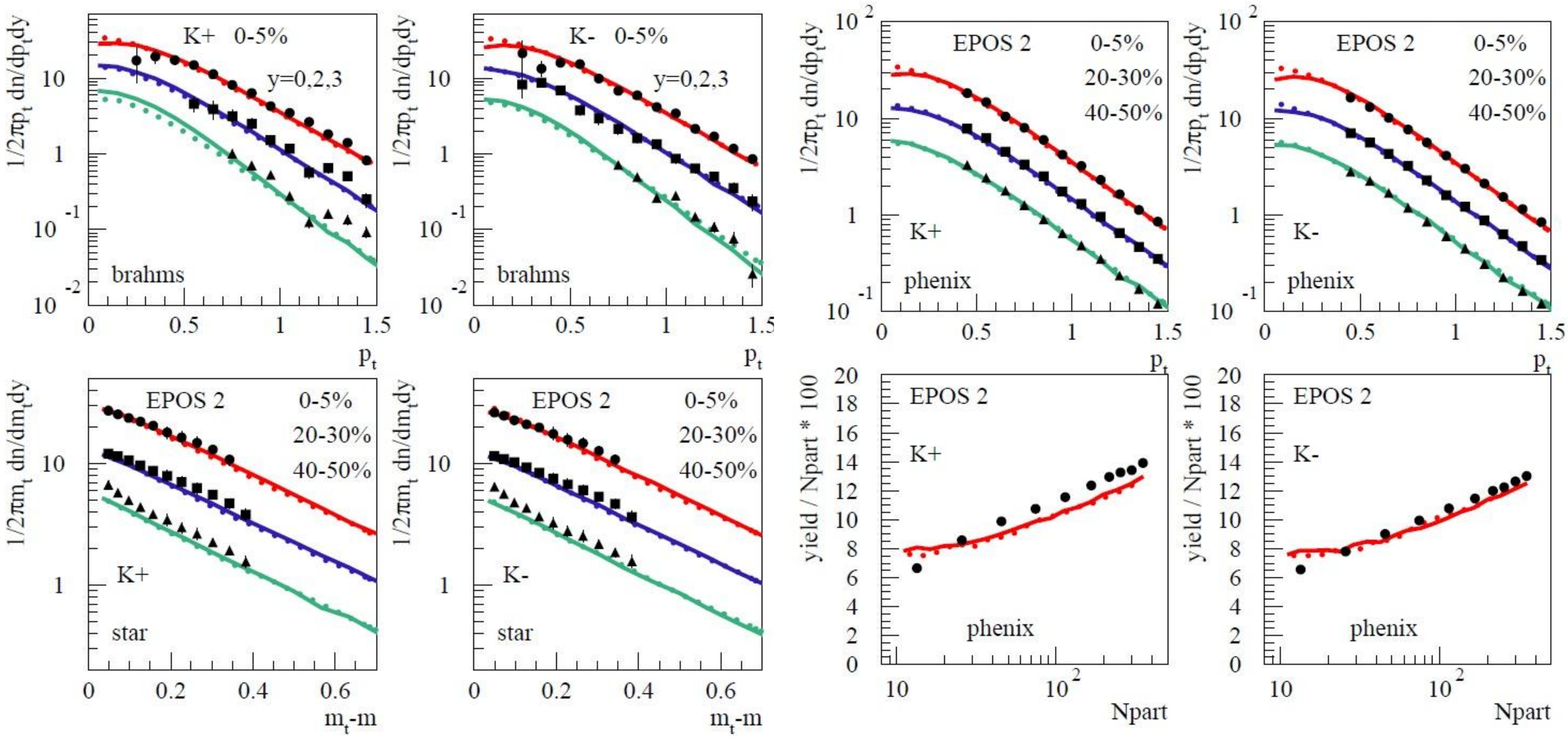
Pions at RHIC : AuAu, sqrt(s)=200 GeV



"Event-by-Event Simulation of the Three-Dimensional Hydrodynamic Evolution from Flux Tube Initial Conditions in Ultrarelativistic Heavy Ion Collisions" arXiv: 1004.0805

EPOS for heavy ion

Kaons at RHIC : AuAu, sqrt(s)=200 GeV



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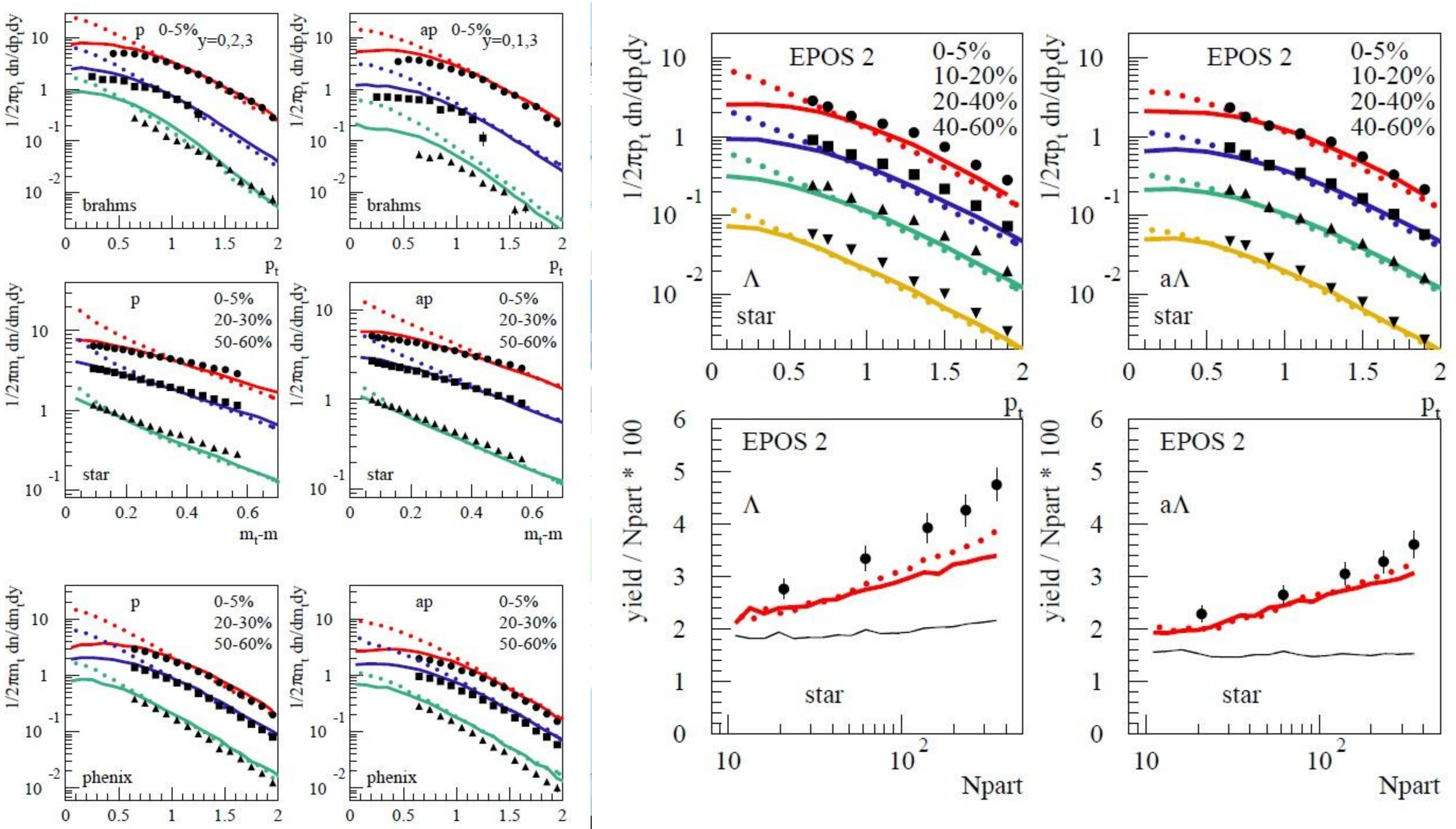
EPOS for heavy ion

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



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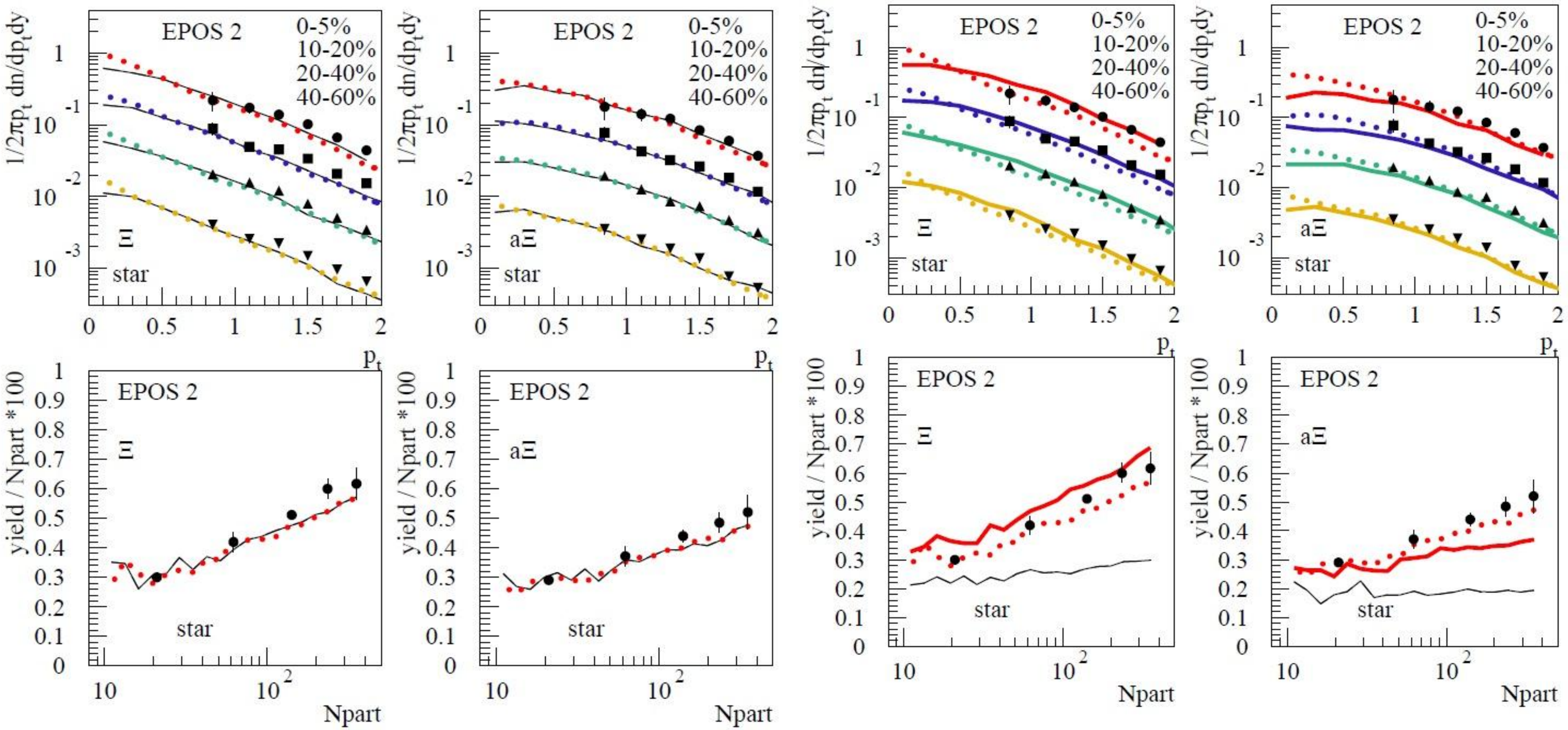
EPOS for heavy ion

Xi and Omega at RHIC : AuAu, sqrt(s)=200 GeV



“Event-by-Event Simulation of the Three-Dimensional Hydrodynamic Evolution from Flux Tube Initial Conditions in Ultrarelativistic Heavy Ion Collisions” arXiv: 1004.0805

Many other variables and energies available in literature

HIJING

« HIJING 1.0: A Monte Carlo program for parton and particle production in high-energy hadronic and nuclear collisions. »
nucl-th/9502021,LBL-34246. Comput.Phys.Commun. 83 (1994) 307 e-Print: nucl-th/9502021

« 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 »
Published in Phys.Rev. C83 (2011) 014915 e-Print: arXiv:1008.1841 [hep-ph]

Main features of HIJING :

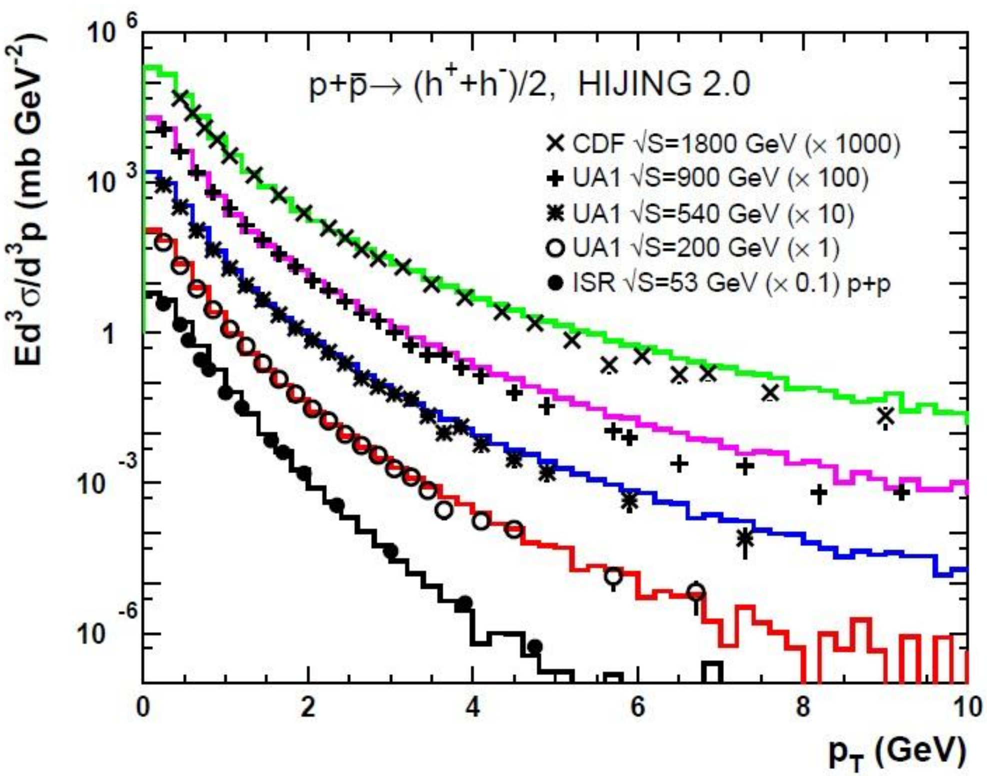
- Multiple mini-jet production according an eikonal formalism for each nucleon-nucleon collision at given impact parameter b.
  Kinematic of each pair of jets + their ISR/FSR done by PYTHIA model

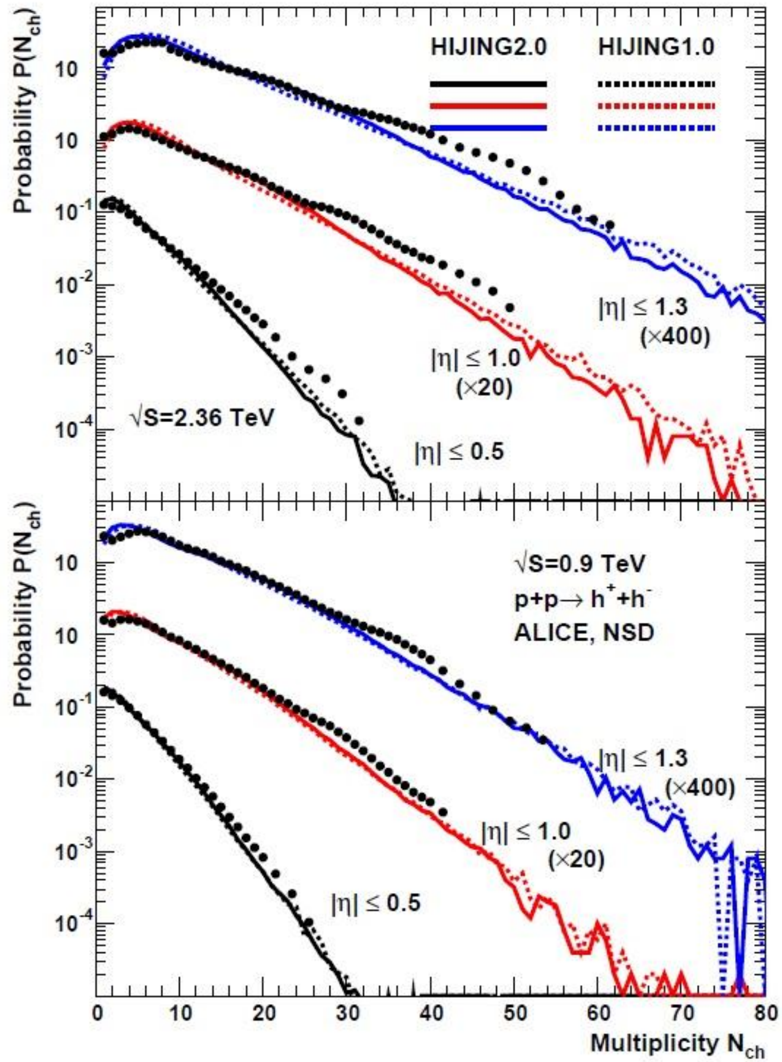
- Events without jet production (with pT>p0) + underlying soft parton interaction in event with jet production
  modeled by exitation of quark-diquark strings with gluon links (FRITIOF and DPM model)
  + multiple low-pT exchange

- Nuclear modification of the PDF inside the nuclei with a set of impact-parameter dependent parton distribution functions, V2 with more modern parameterized PDF

- Simple model for jet-quenching (jet-medium interaction in AA)

HIJING





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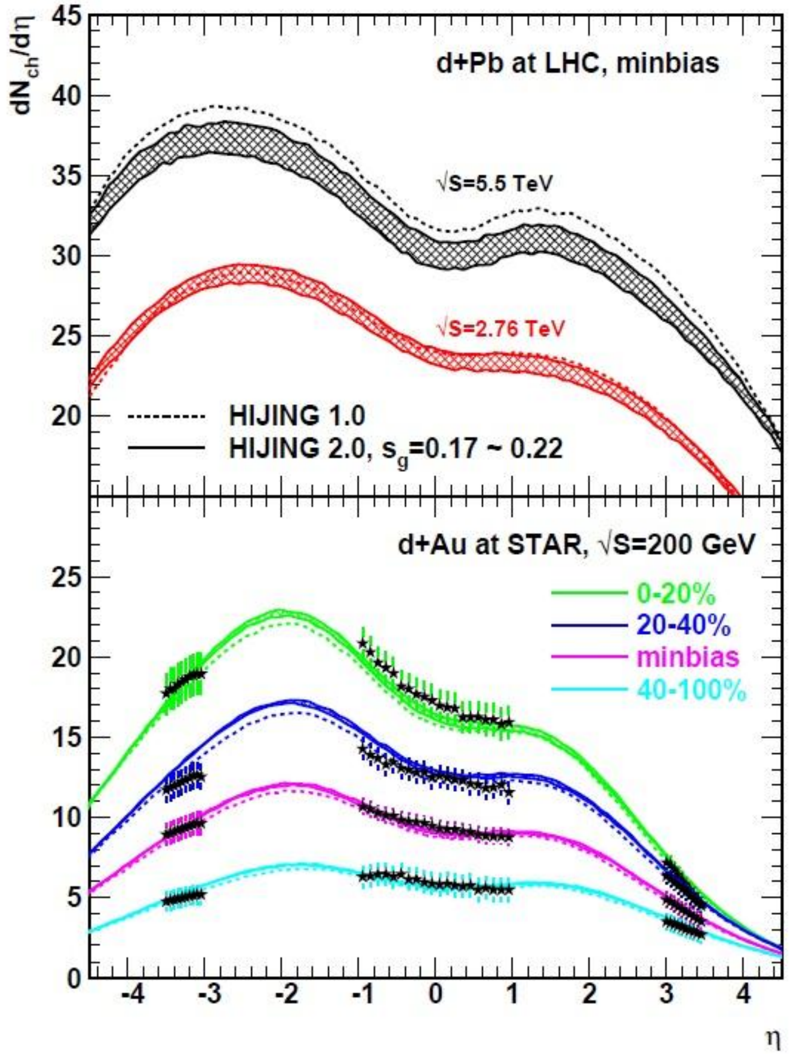

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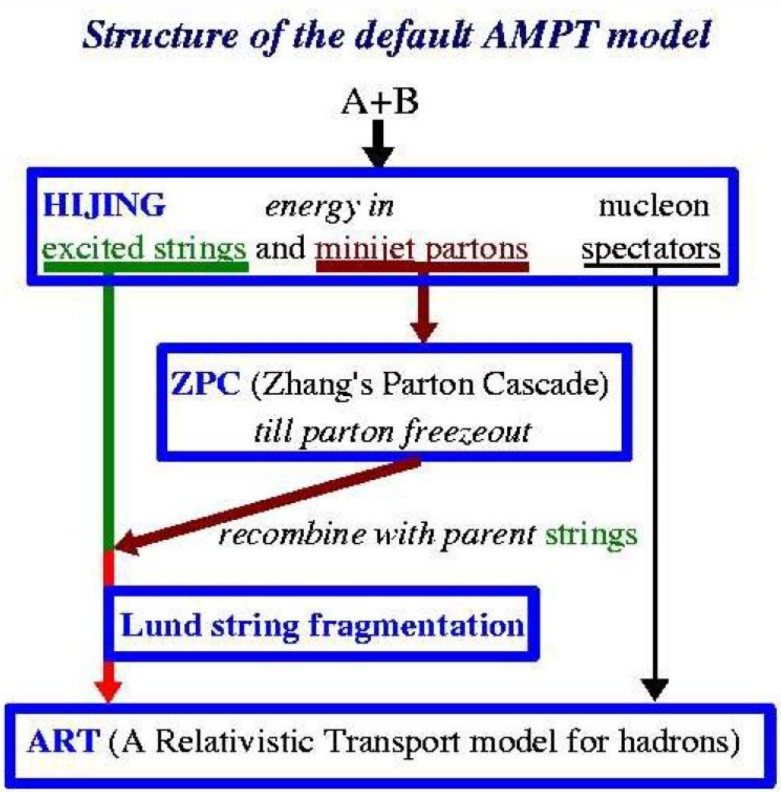
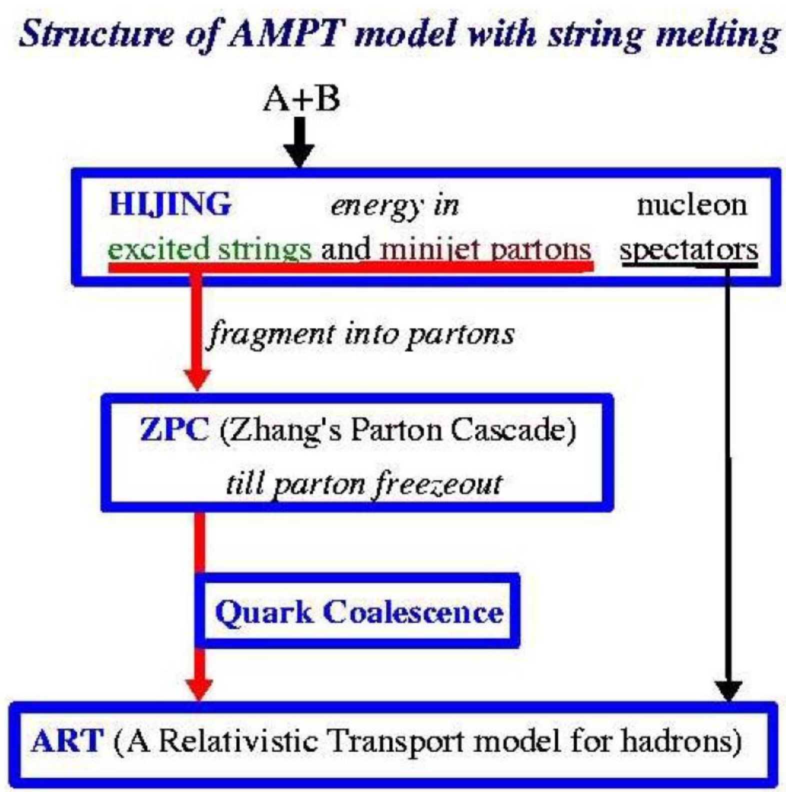
AMPT

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

« A Multi-phase transport model for relativistic heavy ion collisions. » Published in Phys.Rev. C72 (2005) 064901 e-Print: nucl-th/0411110

An hybrid model, 2 versions





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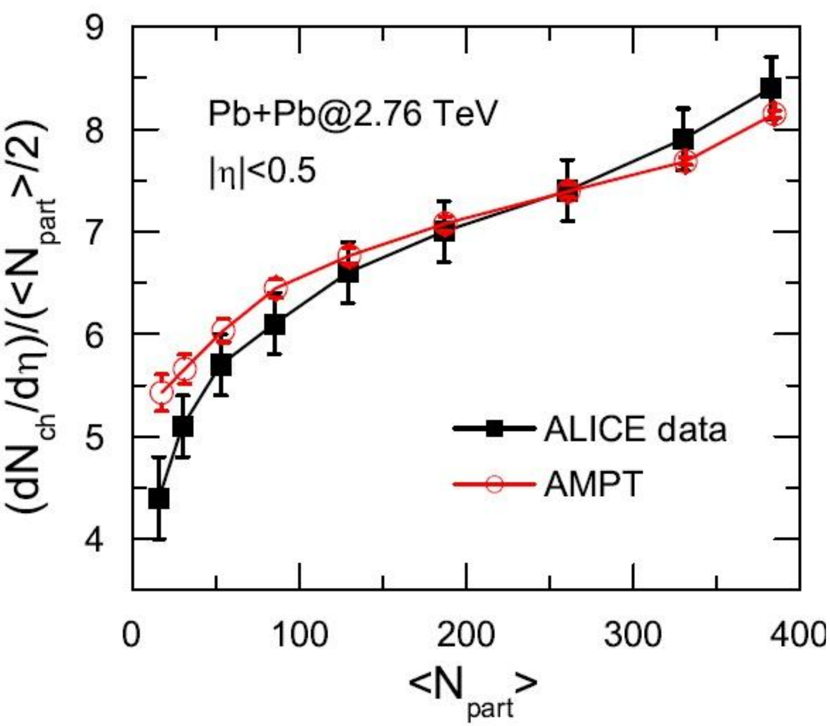

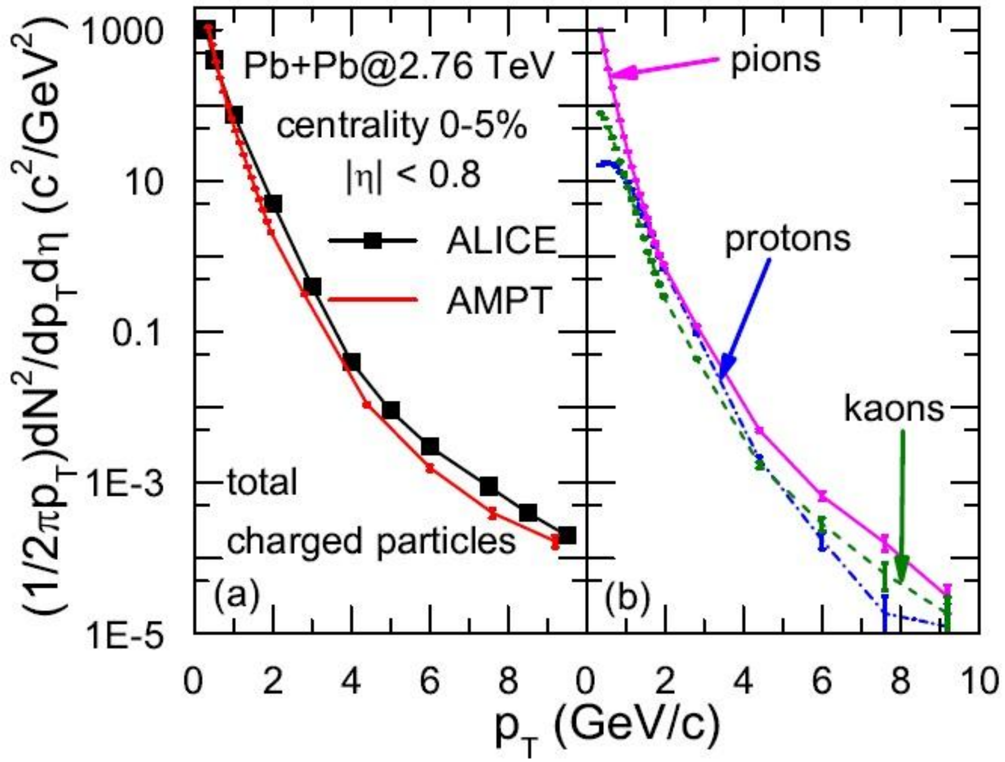

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Which one to do what?

model	EPOS	PYTHIA	Hijing	AMPT
systems	pp, pA, AA	pp	pp, pA, AA	pp?, pA, AA
Baseline	Multiple Interaction	Hard process	PYTHIA 5,3? + minijet + nuclear structure	HIJING + transport model (ZPC parton cascade)
MPI	Parton-based Gribov-Regge Theory	Reconstructed after the hard process. Interaction ordered in hardness. In the new model : color reconnection	modeled by exitation of quark-diquark strings with gluon links + multiple low-pT exchange	
Hard process	Hard and semi-hard ladder with soft pre-evolution u, d, s, g, gamma, c in progress	Based on inclusive cross section Almost everything, if not in the code, can couple with extra code		
Quarkonia	No	Yes : model to be taken with caution. Cluster J/Psi in 6.4	?	?

Which one to do what?

model	EPOS	PYTHIA	Hijing	AMPT
Initial and Final state radiation	Iterative procedure from partons in hadrons to 2->2 process	A posteriori reconstruction Available for MPI in the new model (6.4)	PYTHIA 5,3	
Collectivity	Yes, available with string density, eg. for all systems if energy density high enough : event by event hydro	No	No?	transport model
Hadronization	String model with aera law, diquark for baryon production	String model with fragmentation function, popcorn for baryon production	PYTHIA 5,3	
Remnant	Yes Off-shell treatment	Yes	PYTHIA 5,3	
Connection between hard processes and MPI	Total by construction : several ladders soft or hard, energy conservation and color connection	In MPI color reconnection (6,4), final state effect	modeled by exitation of quark-diquark strings with gluon links + multiple low-pT exchange	?

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!