HYDJET++ – the new model for study heavy ion collisions

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Outline

- **HYDJET++ hydro + part related to the partonic states**

  Soft part: FASTMC
  Physical framework
  Examples of calculations for RHIC
  Predictions for LHC

- **Hard, multi-parton part: PYTHIA+PYQUEN**
  Physical framework
  Examples of calculation for RHIC
  Predictions for LHC

  Conclusions

HYDJET++: hydro + part related to the partonic states

The soft part of HYDJET++ event represents the "thermal" hadronic state FASTMC: Part I: N.S. Amelin, R. Lednisky, T.A. Pocheptsov, I.P. Lokhtin, L.V. Malinina, A.M. Snigirev, Yu.A. Karpenko, Yu.M. Sinyukov, Phys. Rev. C 74 (2006) 064901; Part II: N.S. Amelin, R. Lednisky, I.P. Lokhtin, L.V. Malinina, A.M. Snigirev, Yu.A. Karpenko, Yu.M. Sinyukov, I.C. Arsene, L. Bravina, Phys. Rev. C 77 (2008) 014903 http://uhkm.jinr.ru

The hard, multi-partonic part of HYDJET++ event is identical to the hard part of Fortran-written HYDJET (PYTHIA6.4xx + PYQUEN1.5) : I.P.Lokhtin and A.M.Snigirev, Eur. Phys. J. C 45, 211 (2006), http://cern.ch/lokhtin/pyquen, http://cern.ch/lokhtin/hydro/hydjet.html

First "official" version of HYDJET++ code and web-page with the documentation has been just completed (16 September, 2008): http://cern.ch/lokhtin/hydjet++

The complete manual: I.Lokhtin, L.Malinina, S.Petrushanko, A.Snigirev, I.Arsene, K.Tywoniuk, e-print arXiv:0809.2708, submitted to Computer Physics Communications

FASTMC- fast Monte Carlo procedure of hadron generation:

We consider the hadronic matter created in heavy-ion collisions as a hydrodynamically expanding fireball.

- Matter is thermally equilibrated. Particle multiplicities are determined by the temperature and chemical potentials. Statistical model. Chemical freeze-out.

- Particles can be generated on the chemical ($T_{th}=T_{ch}$) or thermal freeze-out hypersurface represented by a parameterization (or a numerical solution of the relativistic hydrodynamics). Concept of chemically frozen evolution, assumption of the conservation of the particle number ratios from the chemical to thermal freeze-out. No evolution in FASTMC!

- Decays of hadronic resonances (from u,d and s quarks) .

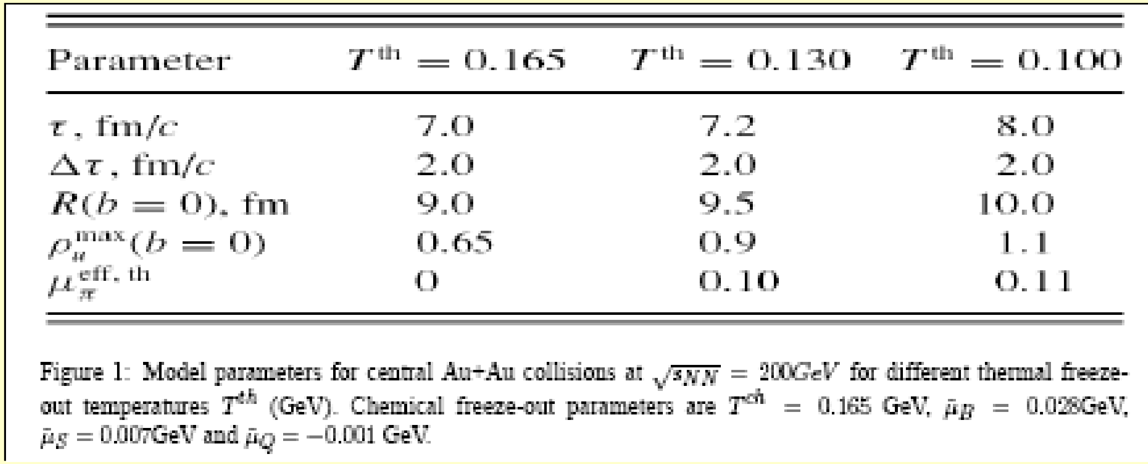
- Various parameterizations of the hadron freeze-out hypersurface and flow velocity. Bjorken model with hypersurface

$$\tau = (t^2 - z^2)^{1/2} = const$$

Particle number ratios near mid-rapidity in central Au Au collisions

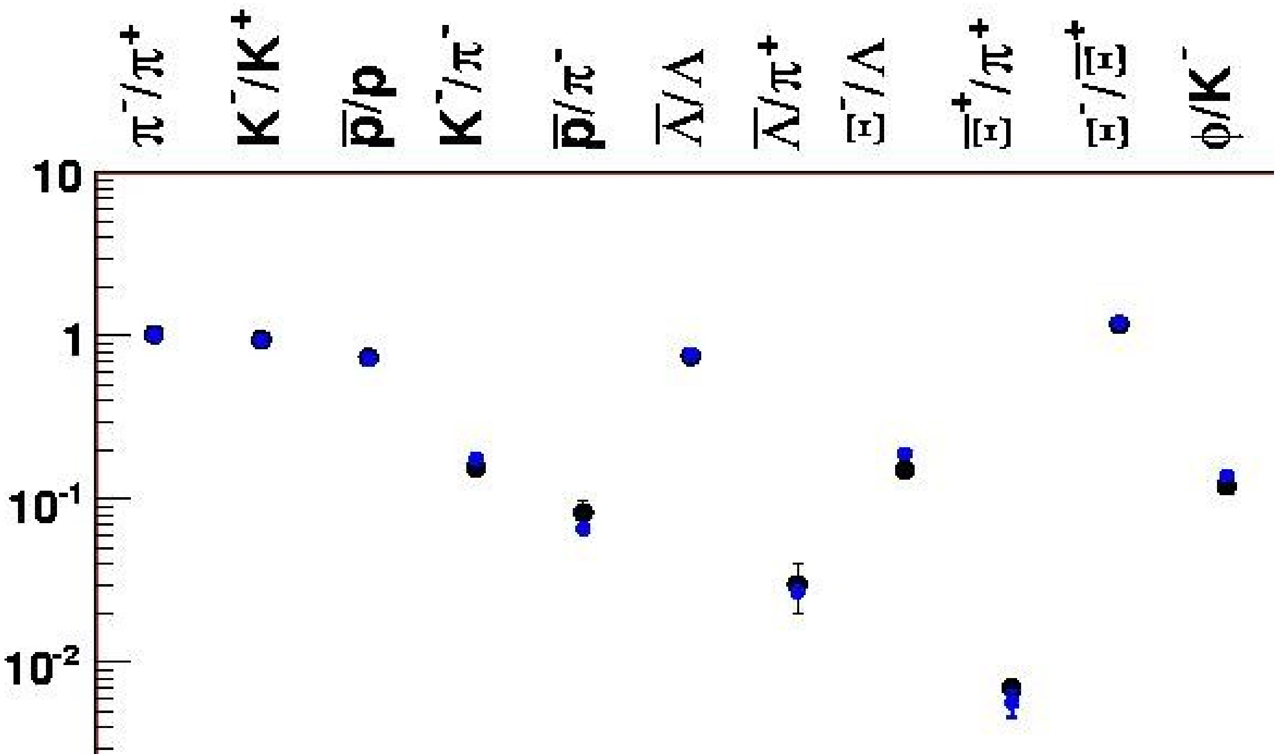
Thermodynamic parameters at chemical freeze-out: Tch=0.165 GeV μB=0.028, μS=0.007, μQ=-0.001GeV

Tth=0.100, 0.130 GeV, have been choosen

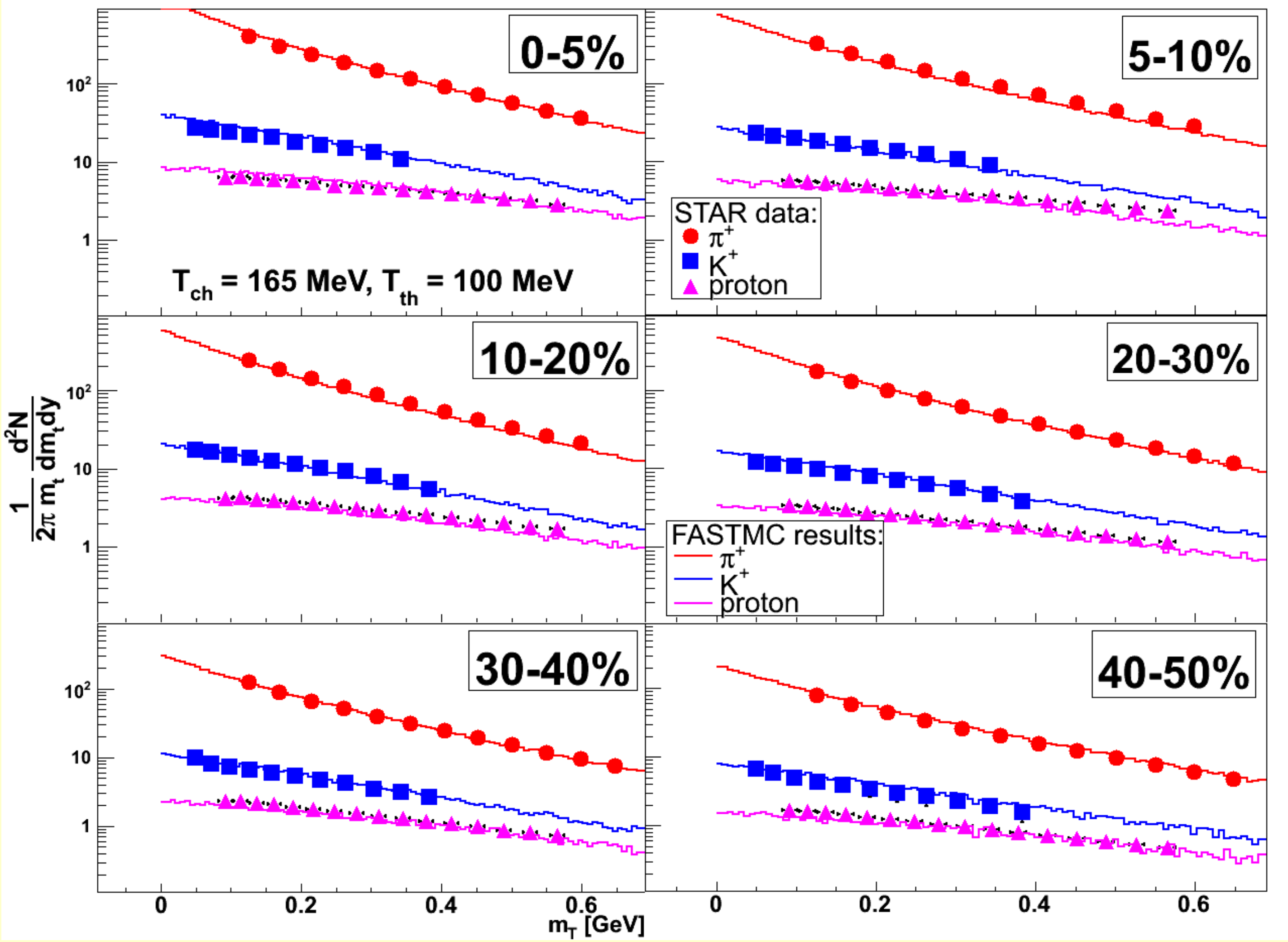


Parameter	$T^{th} = 0.165$	$T^{th} = 0.130$	$T^{th} = 0.100$
τ, fm/c	7.0	7.2	8.0
$\Delta\tau$, fm/c	2.0	2.0	2.0
$R(b=0)$, fm	9.0	9.5	10.0
$\rho_u^{max}(b=0)$	0.65	0.9	1.1
$\mu_\pi^{eff,\,th}$	0	0.10	0.11

Figure 1: Model parameters for central Au+Au collisions at $\sqrt{s_{NN}} = 200GeV$ for different thermal freeze-out temperatures T^{th} (GeV). Chemical freeze-out parameters are $T^{ch} = 0.165$ GeV, $\tilde{\mu}_B = 0.028$GeV, $\tilde{\mu}_S = 0.007$GeV and $\tilde{\mu}_Q = -0.001$ GeV.



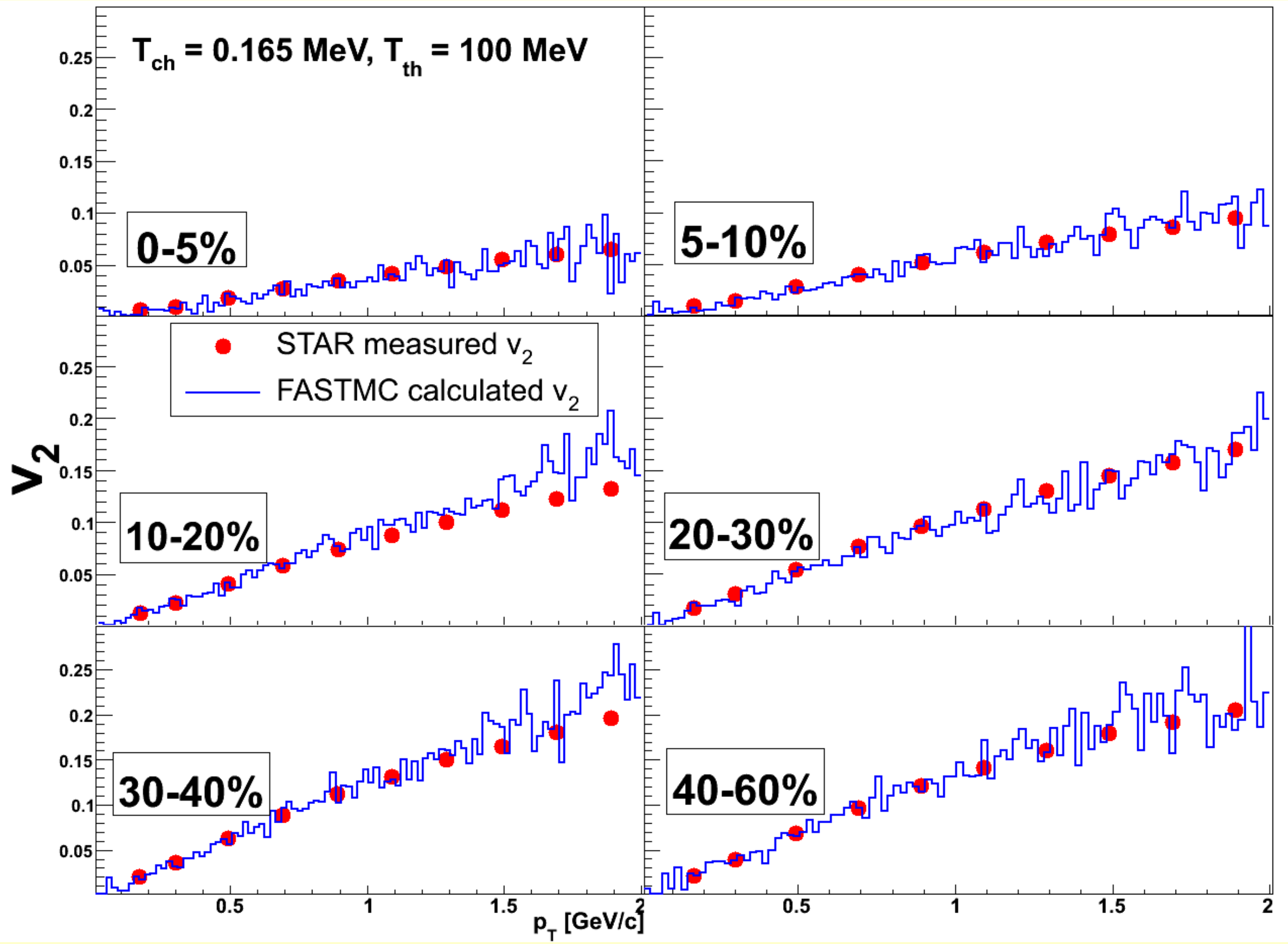
Mt- spectra of π,K,p (STAR)—FASTMC (thermal f.o +weak decays)



Fixing the temperatures of the chemical and thermal freeze-out at 0.165 GeV and 0.100 GeV respectively, and using the same set of model parameters as for the central collisions, we have described the single particle spectra at different centralities with an accuracy of ~ 13 %.

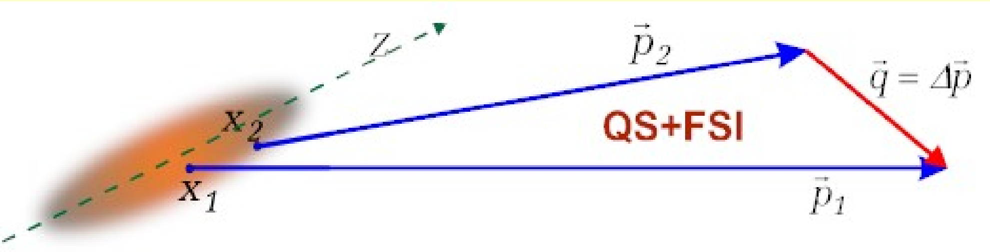
Elliptic flow- versus pt (STAR)—FASTMC (thermal f.o T=100 MeV)

$$\frac{dN}{d^2 p_t dy} = \frac{dN}{2\pi p_t dp_t dy}(1 + v_2 \cos 2\varphi + 2v_4 \cos 4\varphi + \ldots)$$



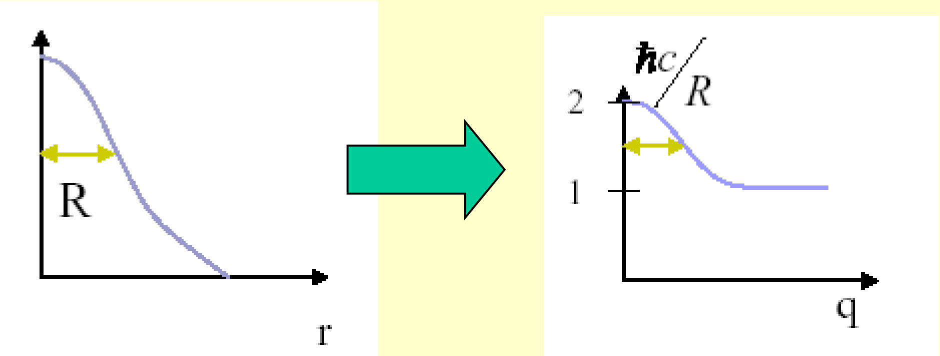
The comparison of the RHIC v_2 measurements with our MC generation results shows that the scenario with two separated freeze-outs describes better the p_t-dependence of the elliptic flow

Momentum correlations

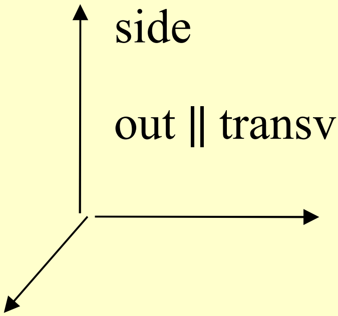


Due to the effects of QS and FSI, the momentum correlations of two or more particles at small relative momenta in their center-of-mass system are sensitive to the space-time characteristics of the production process so serving as a correlation femtoscopy tool.

$q = p1 - p2$, $\Delta x = x1 - x2$ $w = 1 + \langle \cos q\Delta x \rangle$



$$CF = N \frac{S(Q_{inv})}{B(Q_{inv})}$$



side

out || transverse

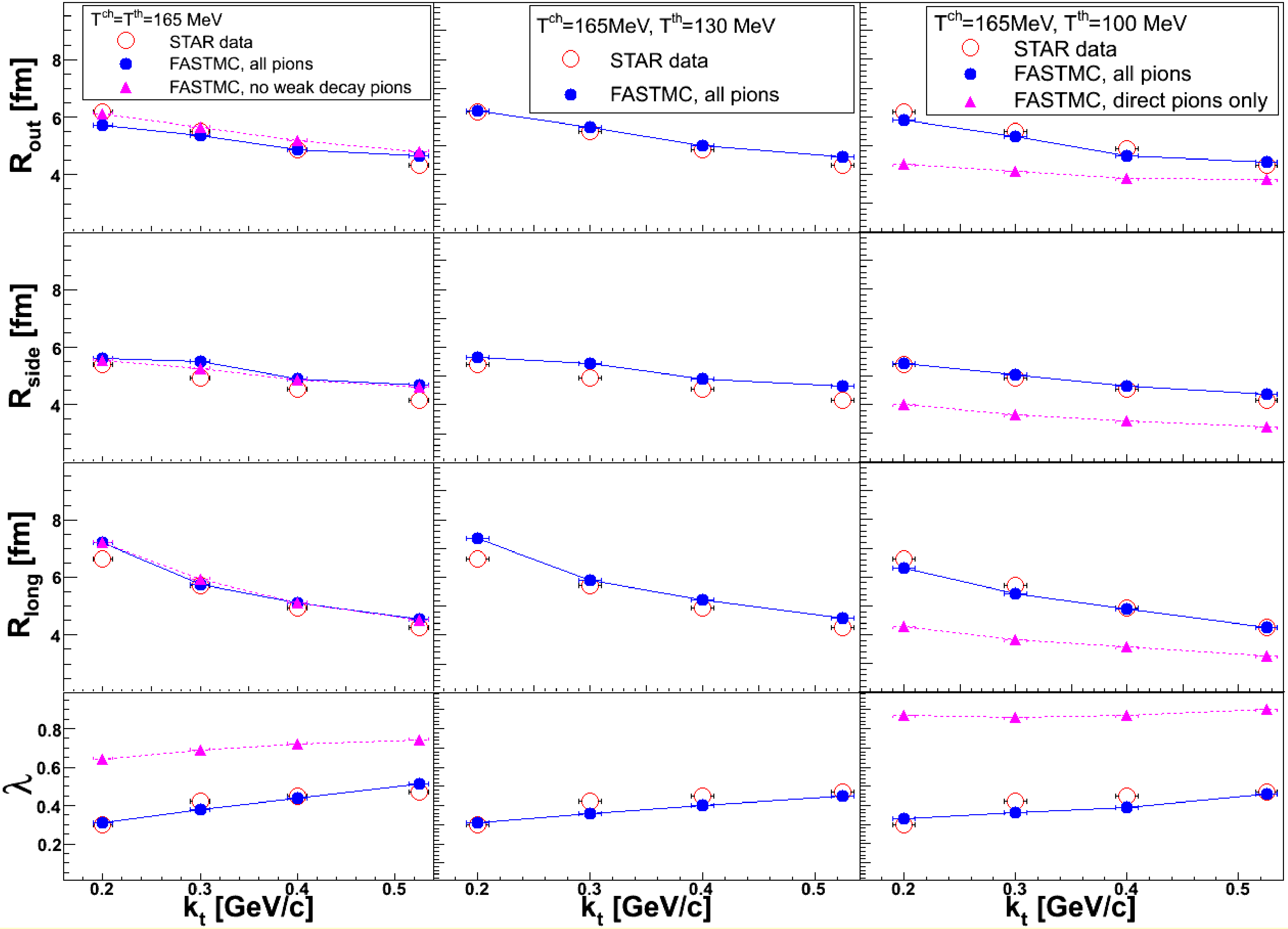
pair velocity vt

long || beam

The corresponding correlation widths are usually parameterized in terms of the Gaussian correlation radii R_i:

$$CF(p_1, p_2) = 1 + \lambda \exp(-R_{out}^2 q_{out}^2 - R_{side}^2 q_{side}^2 - R_{long}^2 q_{long}^2 - 2R_{out,long}^2 q_{out} q_{long})$$

We choose as the reference frame the longitudinal co-moving system (LCMS)



The description of the k_t-dependence of the radii has been achieved within ~ 10%

Momentum correlations: some other approaches

The concept of a later thermal freeze-out occurring at $T_{th}<T_{ch}$ and with no multiplicity constraint on the thermal effective volume was successfully used in e.g. F. Retiere and M. Lisa, Phys.Rev. C70 (2004) 044907

A more complex form of the freeze-out hypersurface taking into account particle emission from the surface of expanding system: M.S.Borysova, Yu.M.Sinyukov, S.V.Akkelin, B.Erazmus and Iu.A.Karpenko, Phys. Rev. C 73, 024903 (2006).

The negative correlation coefficient between the freeze-out proper time $\boldsymbol{\tau}$ and the radial variable **r**: A.Kisiel, T.Taluc, W.Broniowski, and W.Florkowski, Comput. Phys. Commun. 174, 669 (2006); W.Florkowski, W.Broniowski, A.Kisiel, and J.Pluta, Acta Phys. Polon. B37, 3381 (2006), **Therminator**

Study the problem of particle **rescattering** and resonance excitation after the chemical and/or thermal freeze-out: T. Humanic, Int.J.Mod.Phys.**E15**197(2006)

Only minor effect of elastic rescatterings on particle spectra and correlations is expected N.S.Amelin, R.Lednicky, L.V.Malinina, T.A.Pocheptsov and Y.M.Sinyukov, Phys. Rev. C 73, 044909 (2006)
For the latter, our earlier developed C++ kinetic code can be coupled to FASTMC.

For Heavy Ion Collisions at the LHC – Last Call for the Predictions heo-ph/0711.0974

I.P. Lokhtin, A.M. Snigirev , L.V. Malinina: Moscow State University, Institute of Nuclear Physics,Russia
R. Lednicky: Joint Institute for Nuclear Research, Dubna, Russia
Iu.A. Karpenko, Yu.M. Sinyukov ,: Bogolyubov Institute for Theoretical Physics, Kiev, Ukraine

We considered the naive ``scaling" of the existing physical picture of heavy ion interactions over two order of magnitude in $\sqrt{s_{NN}}$ to the maximal LHC energy $\sqrt{s_{NN}} = 5500$ GeV

We performed:
- FASTMC fitting of the existing experimental data on mt-spectra, particle ratios, rapidity density dN/dy, kt-dependence of the correlation radii from SPS ($\sqrt{s_{NN}}$ = 8.7 - 17.3 GeV) to RHIC ($\sqrt{s_{NN}}$ = 200 GeV)

-The linear extrapolation of the model parameters in $\ln\left(\sqrt{s_{NN}}\right)$ to LHC $\sqrt{s_{NN}} = 5500$ GeV

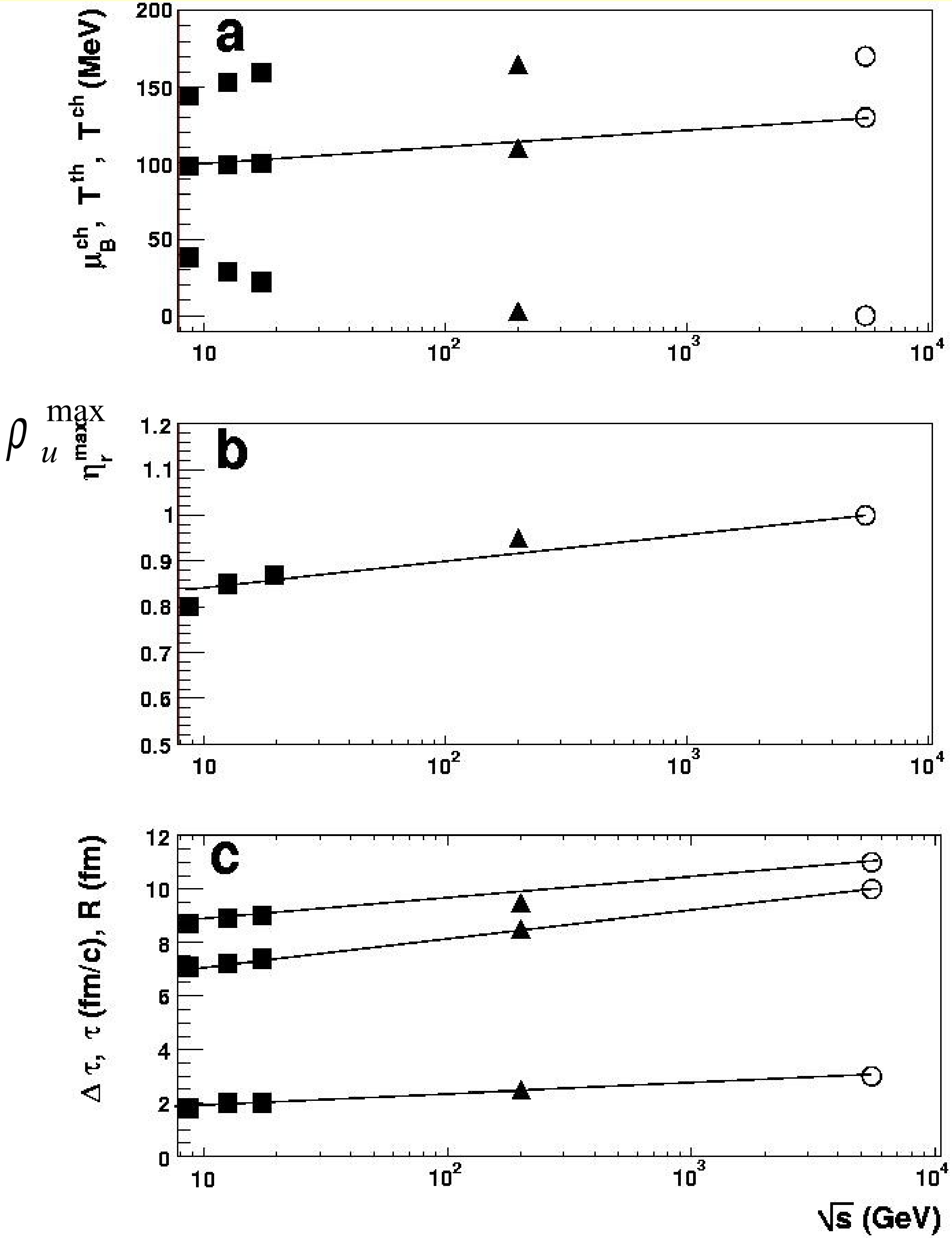
For LHC energies we have fixed the thermodynamic parameters at chemical freeze-out as the asymptotic ones:**Tch**=170 MeV, μ_B=0, μ_S=0, μ_Q=0 MeV.

Predictions for LHC

■ SPS ($\sqrt{s_{NN}}$ = 8.7 - 17.3 GeV)

▲ RHIC ($\sqrt{s_{NN}}$ = 200 GeV)

○ LHC ($\sqrt{s_{NN}}$ = 5500 GeV)



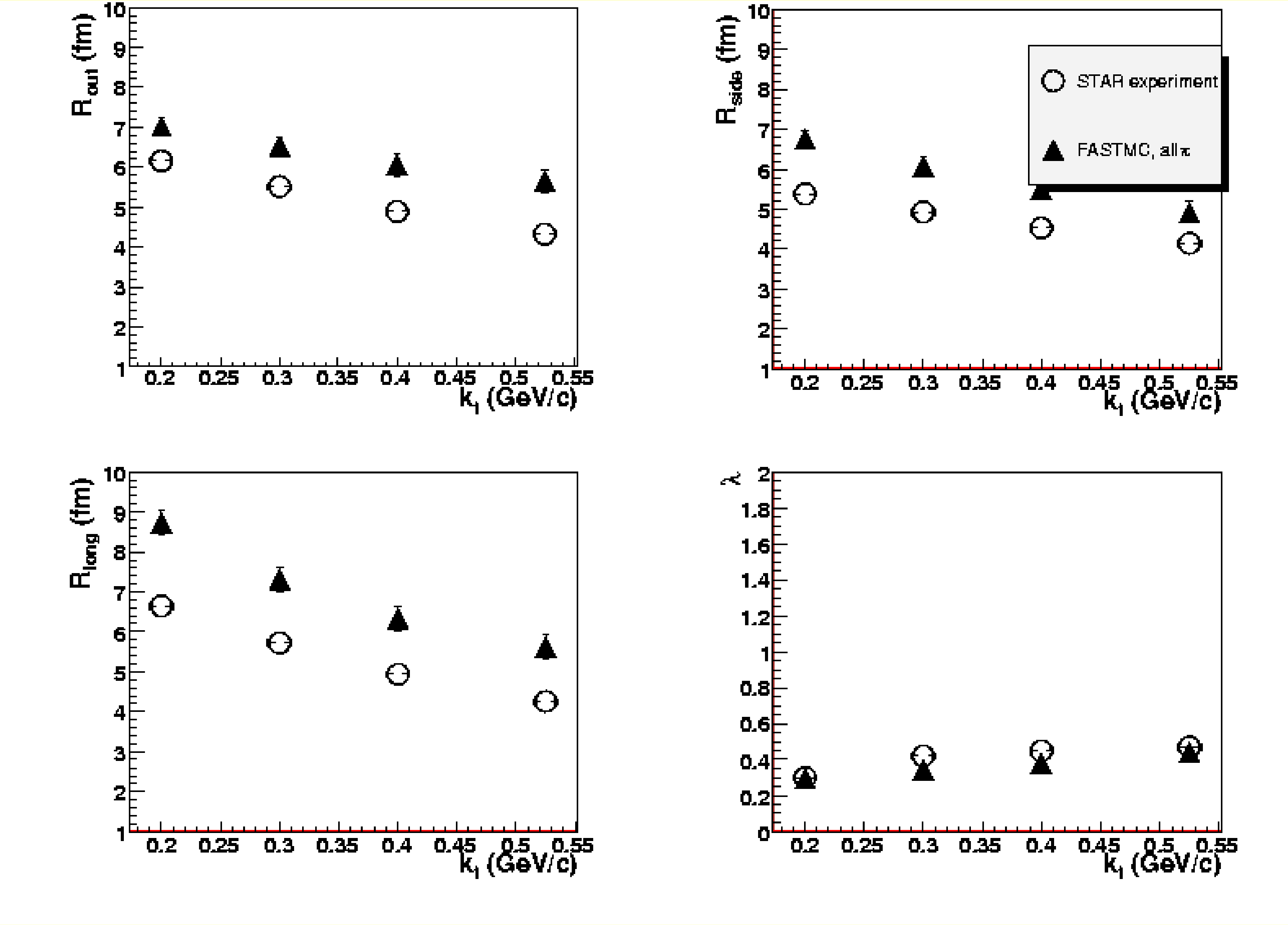
The extrapolated values :

R ~ 11 fm,
τ ~ 10 fm/c,
Δτ~ 3.0 fm/c,

ρ_u^{max} ~ 1.0,
T_{th} ~ 130 MeV.

T_{ch}=170 MeV,
μ_B=0, μ_S=0, μ_Q=0 MeV

Predictions for LHC:



HYDJET++ : hard, multi-parton part of event simulation

PYQUEN, event generator for simulation of rescattering, radiative and collisional energy loss of hard partons in expanding quark-gluon plasma created in ultrarelativistic heavy ion AA collisions modifying PYTHIA6.4 jet event

HYDJET++ includes nuclear shadowing correction for parton distributions (important at LHC!) Impact-parameter dependent parameterization of NS (K.Tywoniuk, I.Arsene, L.Bravina, A.Kaidalov and E.Zabrodin, Phys. Lett. B 657 (2007) 170) is provided by Konrad Tywoniuk from Oslo University. It based on Glauber-Gribov theory for NS (Pomeron diagram sum). **Estimated reducing in "hard" multiplicty due to NS for central PbPb at 5.5 TeV is strong, up to ~50% !** (for comparison: increasing in "hard" multiplicity due to JQ is only ~10%)

Goals of this work

-We are studying influence of the mini-jets/jets production on v2 and correlation radii at RHIC/LHC energies.

-FASTMC produces background for the jet production, direct gammas…

HYDJET++ : hard part of event simulation

generates njet (b, ptmin) NN subcollisions and formation of jet-induced state by calling (PYTHIA+PYQUEN) njet times

PYQUEN (PYthia QUENched)

Initial parton configuration

PYTHIA6.4 w/o hadronization: mstp(111)=0

↓

Parton rescattering & energy loss (collisional, radiative) + emitted g

PYQUEN rearranges parton to update ns strings: ns call PYJOIN

↓

Parton hadronization and final particle formation

PYTHIA6.4 with hadronization: call PYEXEC

FASTMCj - Model parameters.

1. Thermodynamic parameters at chemical freeze-out: **T_{ch}** , {**μ_B, μ_S, μ_Q**}

2. If thermal freeze-out is considered: **T_{th}** , **μ_π**-normalisation constant

3. Volume parameters: **τ, $\Delta\tau$**, **R**

4. ρ_u^{max} -maximal transverse flow rapidity for Bjorken-like parametrization

5. **η_{max}** -maximal space-time longitudinal rapidity which determines the rapidity interval **[- η_{max}, η_{max}]** in the collision center-of-mass system.

6. Impact parameter range: minimal **b_{min}** and maximal **b_{max}** impact parameters

7. Flow anisotropy parameters **δ**(b), **ε**(b)

PYTHYA+PYQUEN obligatory parameters

9. Beam and target nuclear atomic weight **A**

10. $\sqrt{s_{NN}}$ –c.m.s. energy per nucleon pair (PYTHIA initialization at given energy)

11. **ptmin** – minimal pt of parton-parton scattering in PYTHIA event (ckin(3) in /pysubs/)

12. **nhsel** flag to include jet production in hydro-type event:

0 - jet production off (pure FASTMC event),
1 - jet production on, jet quenching off (FASTMC+njet*PYTHIA events),
2 - jet production & jet quenching on (FASTMC+njet*PYQUEN events),
3 - jet production on, jet quenching off, FASTMC off (njet*PYTHIA events),
4 - jet production & jet quenching on, FASTMC off (njet*PYQUEN events);

13. **ishad** flag to switch on/off nuclear shadowing

Parameters of energy loss model in PYQUEN

(default, but can be changed from the default values by the user)

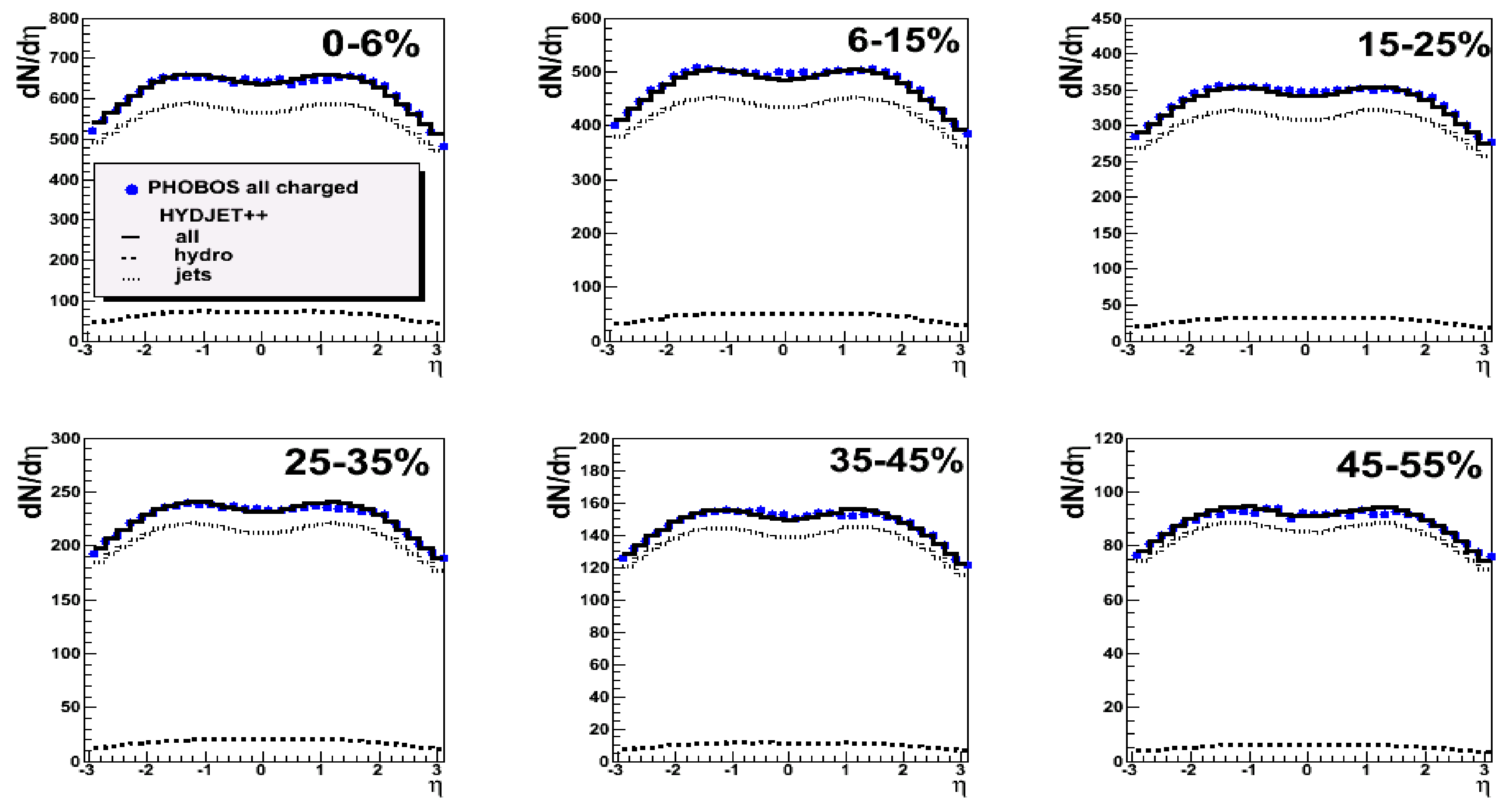
1. T0 - initial temparature of quark-gluon plasma for central Pb+Pb collisions at mid-rapidity (initial temperature for other centralities and atomic numbers will be calculated automatically) at LHC: T0=1 GeV, at RHIC(200 AGeV) T0=0.300 GeV

2. tau0 - proper time of quark-gluon plasma formation at LHC: tau0=0.1 fm/c, at RHIC(200 AGeV) tau0=0.4 fm/c

3. nf - number of active quark flavours in quark-gluon plasma (nf=0, 1, 2 or 3) at LHC: nf=0, at RHIC(200 AGeV) nf=2

4. ienglu - flag to fix type of medium-induced partonic energy loss
   (ienglu=0 - radiative and collisional loss, ienglu=1 - radiative loss only,
   ienglu=2 - collisional loss only, default value is ienglu=0);
   ianglu - flag to fix type of angular distribution of emitted gluons
   (ianglu=0 - small-angular, ianglu=1 - wide-angular,
   ianglu=2 - collinear, default value is ianglu-0).
   ienglu=0

Pseudorapidity spectra vs. event centrality at RHIC

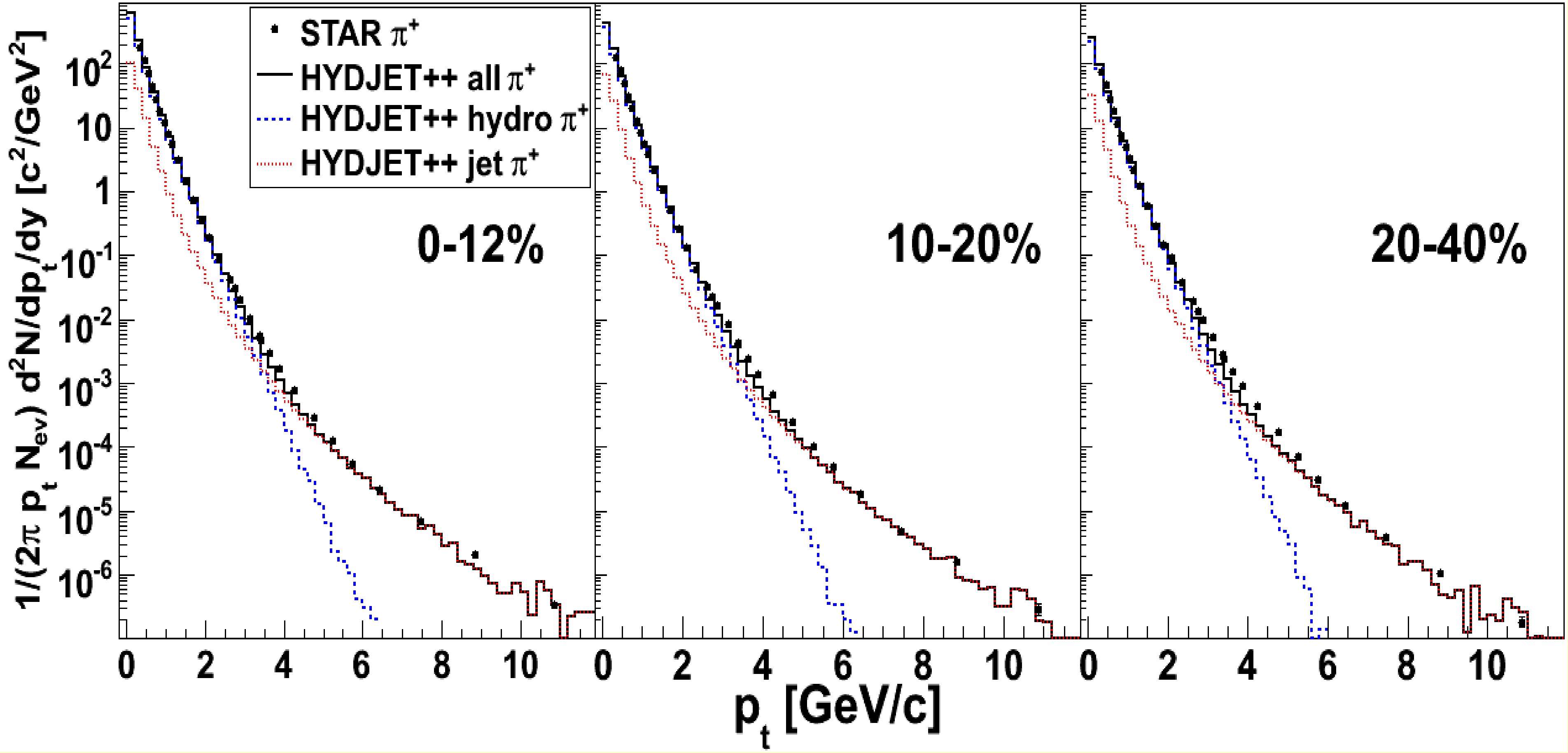


$$\frac{dN}{dyd^2b} = \frac{dN^{thermal}}{dyd^2b}(\sim npart) + \frac{dN^{jets}}{dyd^2b}(\sim nbin)$$

Width of the spectra allows one to fix η^{max}=3.3,

Centrality dependence of multiplicity allows one to fix ptmin=3.4 GeV/c and μ_π=0.053

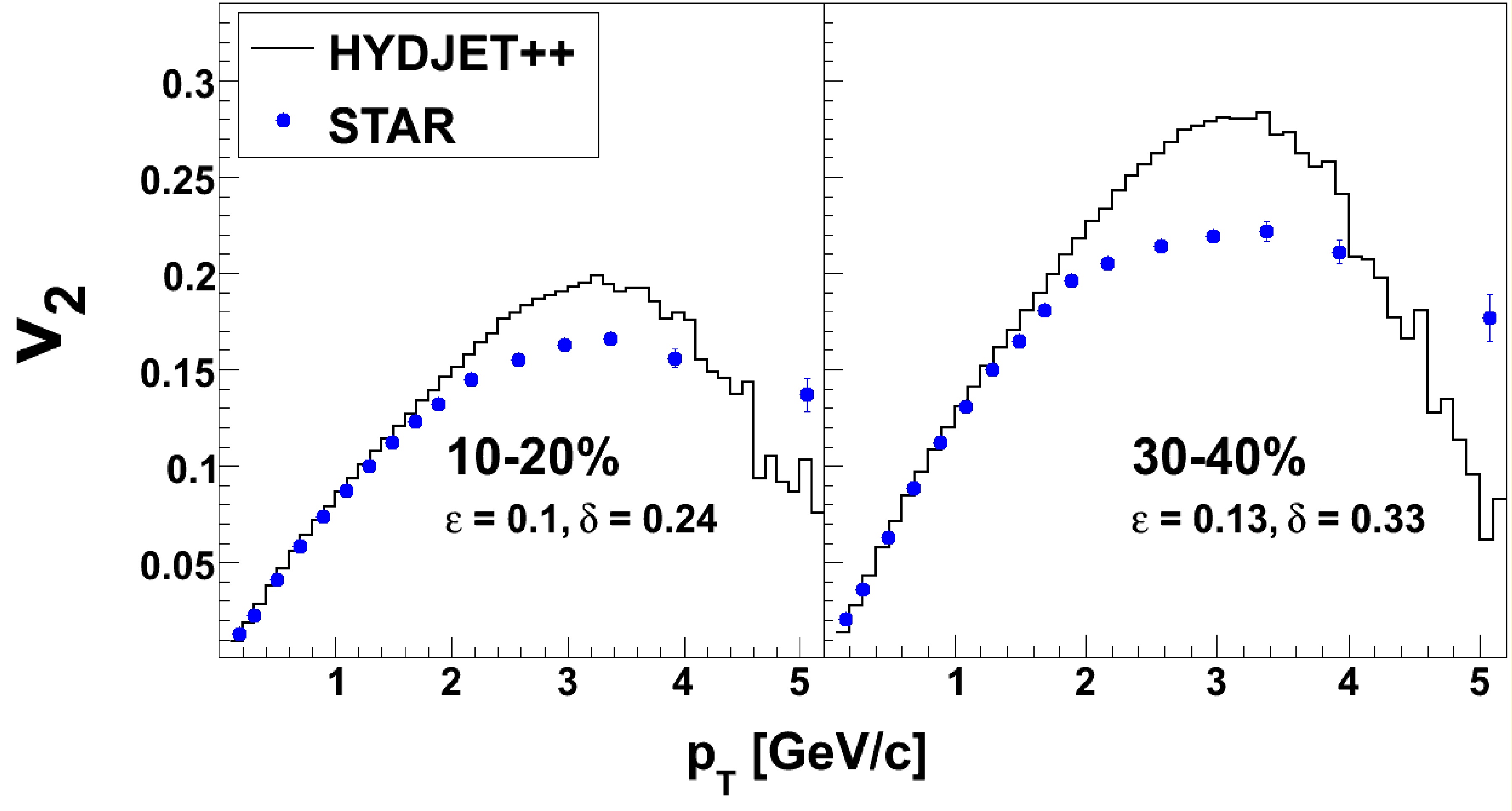
High transverse momentum spectra at different centralities at RHIC



Using the same set of model parameters as for the central collisions, we have described the pt-spectra at different centralities.

PYQUEN energy loss model parameters: T_0(QGP)=300 MeV, τ_0(QGP)=0.4 fm/c

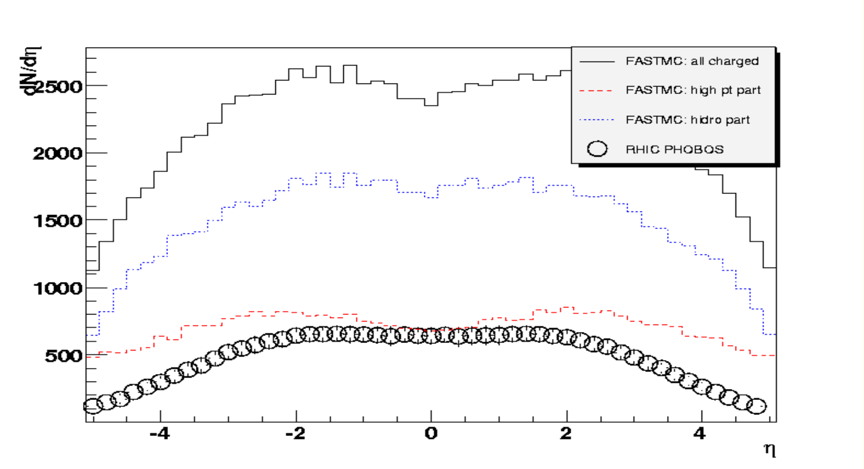
Elliptic flow v2(pt) at RHIC



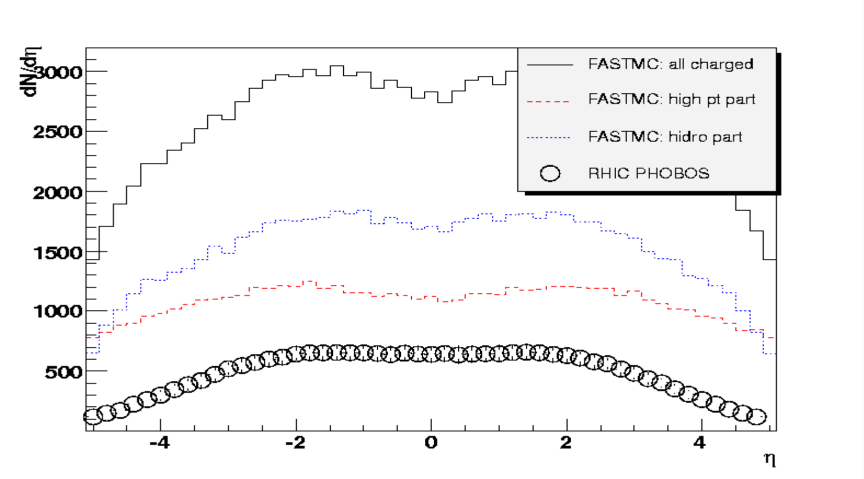
Soft part dominates at pt < 2 GeV/c, v2(pt) increases with pt; pt>2 GeV/c, contribution of soft part in pt-spectra decreases and «jets» part increases. The jet-quenching effect introduces asimuthal assymetry in pt-spectra because the free path of the parton in the medium depends on φ, so the parton energy losses depends on φ also.

Predictions for LHC: η and pt spectra

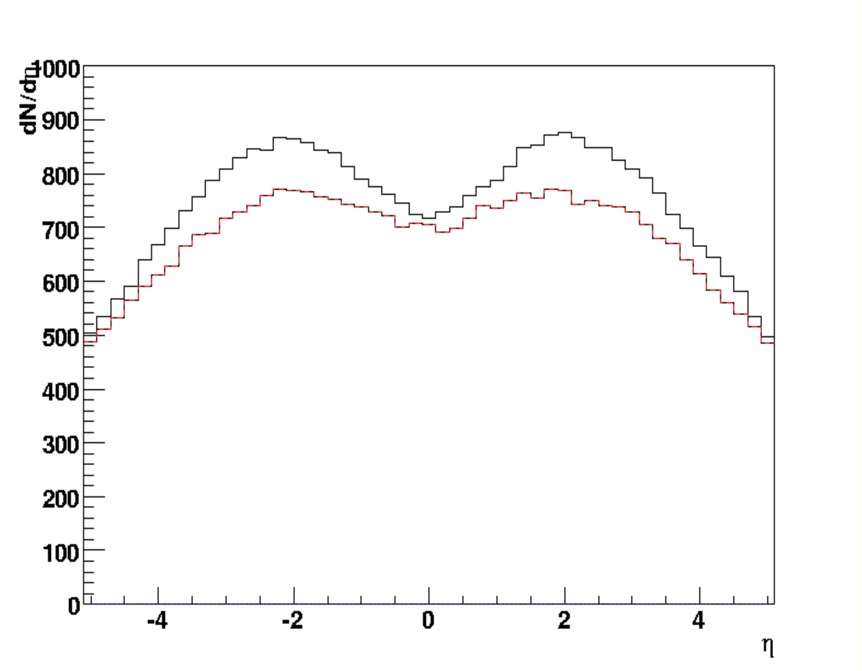
Jet quenching , Shadowing



Jet quenching , no shadowing



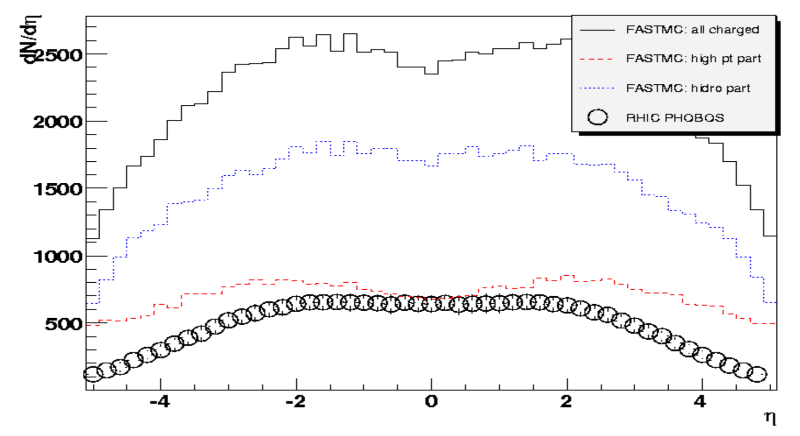
Jet quenching/no quenching
Shadowing , high-pt part only



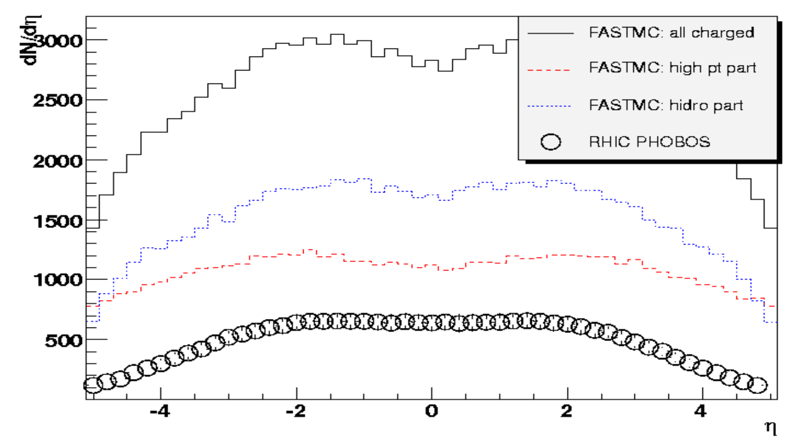
reducing in “hard” multiplicty due to NS for central PbPb at 5.5 TeV is strong, up to ~50% ! increasing in “hard” multiplicity due to JQ is only ~10%

Predictions for LHC: η and pt spectra

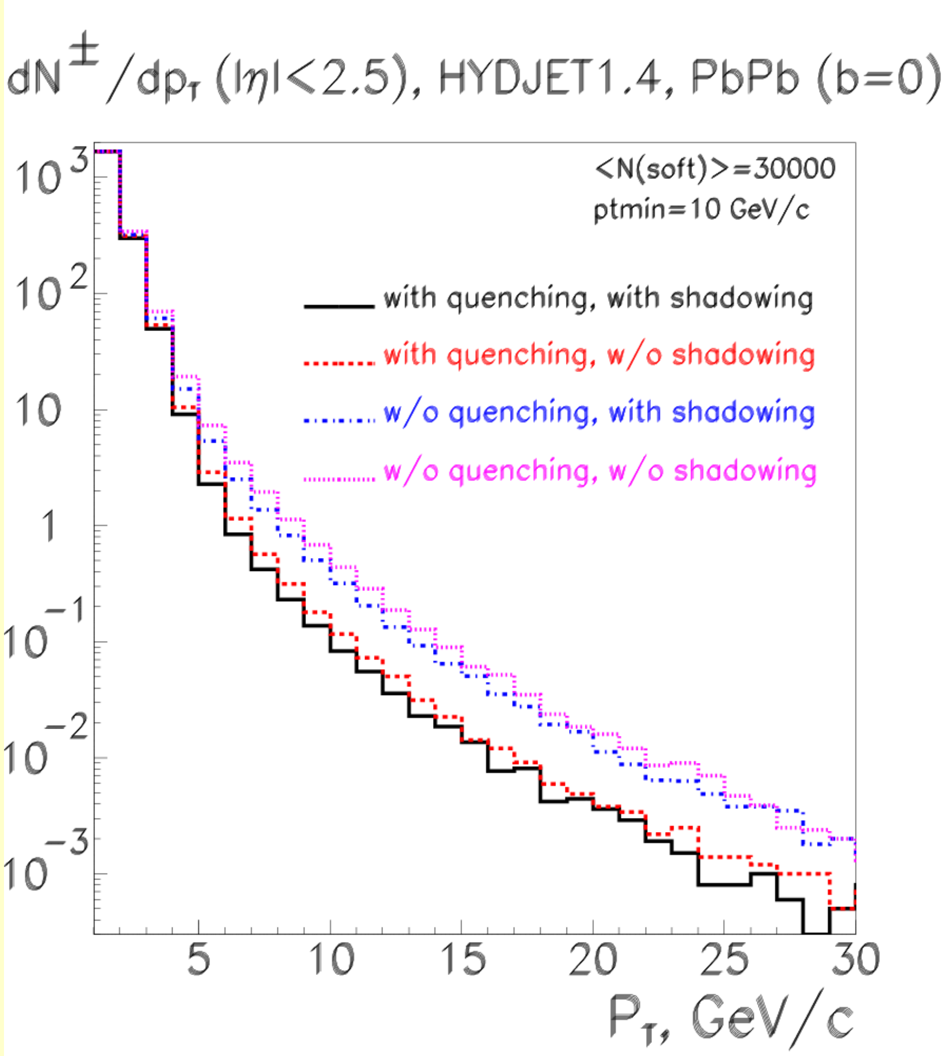
Jet quenching , Shadowing



Jet quenching , no shadowing



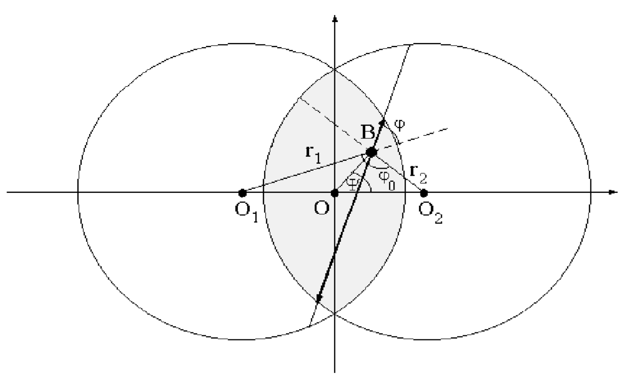
Jet quenching/no quenching Shadowing , high-pt part only



reducing in “hard” multiplicty due to NS for central PbPb at 5.5 TeV is strong, up to ~50% ! increasing in “hard” multiplicity due to JQ is only ~10%

Influence of “jets” part on correlation functions

- Quenching leads to essential softening of the spectra of the hadrons coming from the centre of the nuclear overlap region r<<Ra, for the hadrons coming from peripheral regions r~Ra the spectra doesn't change. At RHIC energies we observed such effect of “surface emission” for π with pt>5 GeV/c.



- Shadowing factor S depends on the jet production vertex r. Hadron production in the nuclear centre is more suppressed then in periphery, but the dependence S(r) is quite weak compared with the r-dependence of quenching. Shadowing modifies the hadron pt-spectra, making them more hard, because it is maximal for low pt and it is absent for high pt. It influence on Nsoft/Nhard (pt).
- These effects are negligible for RHIC but may be very important for LHC

Conclusions & plans

-Among other HI event generators (HIJING, FRITIOF, UrQMD, QGSM, AMPT, THERMINATOR,...), HYDJET++ is concentrated on detailed simulation of jet quenching, and also reproducing main features of nuclear collective dynamics (longitudinal, radial and eliptic flows) by fast (but realistic) way. The final hadron state in HYDJET++ represents the superposition of two independent parts: hard multi-parton and soft hydro-type.

-HYDJET++ is capable of reproducing the bulk properties of multi-particle system created in heavy ion collisions at RHIC (hadron spectra and ratios, radial and elliptic flow, momentum correlations), as well as the main high-p_T observables.

-First version of HYDJET++ code, web-page http://cern.ch/lokhtin/hydjet++ with the documentation and the complete manual arXiv:0809.2708(submitted to Comp.Phys.Com.) have been just completed (September 2008):

Additional slides

Physical framework of the model: Hadron multiplicities

2. “concept of effective volume” T=const and μ=const the total yield of particle species is:

$$N_i = \rho_i(T,\mu_i)V_{eff}$$

total co-moving volume, ρ-particle number density

V_{eff}

2. Chemical freeze-out: all macroscopic characteristics of particle system are determined via a set of equilibrium distribution functions in the fluid element rest frame:

$$f_i^{eq}(p^{0*};T,\mu_i) = \frac{1}{(2\pi)^3}\frac{g_i}{\exp([p^{0*}-\mu_i]/T)\pm 1}$$

$$\rho_i^{eq}(T,\mu_i) = \int_0^\infty d^3\vec{p}^{\,*} f_i^{eq}(p^{0*};T(x^*),\mu(x^*)_i) = 4\pi\int_0^\infty dp^* p^{*2} f_i^{eq}(p^{0*};T,\mu_i)$$

$$\rho_i^{eq}(T,\mu_i) = \frac{g_i}{2\pi^2} m_i^2 T \sum_{k=1}^{\infty}\frac{(\mp)^{k+1}}{k}\exp\left(\frac{k\mu_i}{T}\right)K_2\left(\frac{km_i}{T}\right)$$

Physical framework of the model: Thermal freeze-out

1. The particle densities at the chemical freeze-out stage are too high to consider particles as free streaming and to associate this stage with the thermal freeze-out

2. Within the concept of chemically frozen evolution, assumption of the conservation of the particle number ratios from the chemical to thermal freeze-out :

$$\frac{\rho_i^{eq}(T^{ch},\mu_i^{ch})}{\rho_\pi^{eq}(T^{ch},\mu_\pi^{ch})} = \frac{\rho_i^{eq}(T^{th},\mu_i^{th})}{\rho_\pi^{eq}(T^{th},\mu_\pi^{th})}$$

1. The absolute values $\rho_i^{eq}(T^{th},\mu_i^{th})$ are determined by the choice of the free parameter of the model: effective pion chemical potential $\mu_\pi^{eff,th}$ at T^{th} Assuming for the other particles (heavier then pions) the Botzmann approximation :

$$\mu_i^{th} = T^{th}\ln\left(\frac{\rho_i^{eq}(T^{ch},\mu_i^{ch})}{\rho_i^{eq}(T^{th},\mu_i = 0)}\,\frac{\rho_\pi^{eq}(T^{th},\mu_\pi^{eff,th})}{\rho_\pi^{eq}(T^{ch},\mu_i^{ch})}\right)$$

Particles (stable, resonances) are generated on the thermal freeze-out hypersurface, the hadronic composition at this stage is defined by the parameters of the system at chemical freeze-out

Physical framework of the model: Hadron momentum distribution

We suppose that a hydrodynamic expansion of the fireball ends by a sudden system breakup at given T and chemical potentials. Momentum distribution of produced hadrons keeps the thermal character of the equilibrium distribution.

We avoid straightforward 6-dimentional integration by the special simulation procedure

FASTMC-1 PRC 74 064901 (2006)

$$p^0 \frac{d^3 N_i}{d^3 p} = \int_{\sigma(x)} d^3\sigma_\mu(x) p^\mu f_i^{eq}(p^\nu u_\nu(x); T, \mu_i)$$ **Cooper-Frye formula**:

Freeze-out surface parameterizations

1. The **Bjorken model** with hypersurface $\tau = (t^2 - z^2)^{1/2} = const$

2. **Linear transverse flow rapidity profile**: $\rho_u = \frac{r}{R}\rho_u^{\max}$

3. The total effective volume for particle production at

$$V_{eff} = \int_{\sigma(x)} d^3\sigma_\mu(x) u^\mu(x) = \tau \int_0^R \gamma_r r dr \int_0^{2\pi} d\phi \int_{\eta_{\min}}^{\eta_{\max}} d\eta = 2\pi \tau \Delta\eta \left(\frac{R}{\rho_u^{\max}}\right)^2 (\rho_u^{\max} \sinh\rho_u^{\max} - \cosh\rho_u^{\max} + 1)$$

FASTMC-Model parameters for central collisions:

1. Thermodynamic parameters at chemical freeze-out: T_{ch} , $\{\mu_B, \mu_S, \mu_Q\}$

2. If thermal freeze-out is considered: T_{th} , μ_π-normalisation constant

3. As an option, strangeness suppression $\gamma_s < 1$

4. Volume parameters:

τ -the freeze-out proper time and its standard deviation $\Delta\tau$ (emission duration)

R- firebal transverse radius

5. $\rho_u^{\max}$ -maximal transverse flow rapidity for Bjorken-like parametrization

- η_{max} -maximal space-time longitudinal rapidity which determines the rapidity interval $[-\eta_{max}, \eta_{max}]$ in the collision center-of-mass system.

- To account for the violation of the boost invariance, an option corresponding to the substitution of the uniform distribution of the space-time longitudinal rapidity by a Gaussian distribution in η.

8. Option to calculate **T**, μ_B using phenomenological parametrizations

$$\mu_B(\sqrt{s}), T(\mu_B)$$

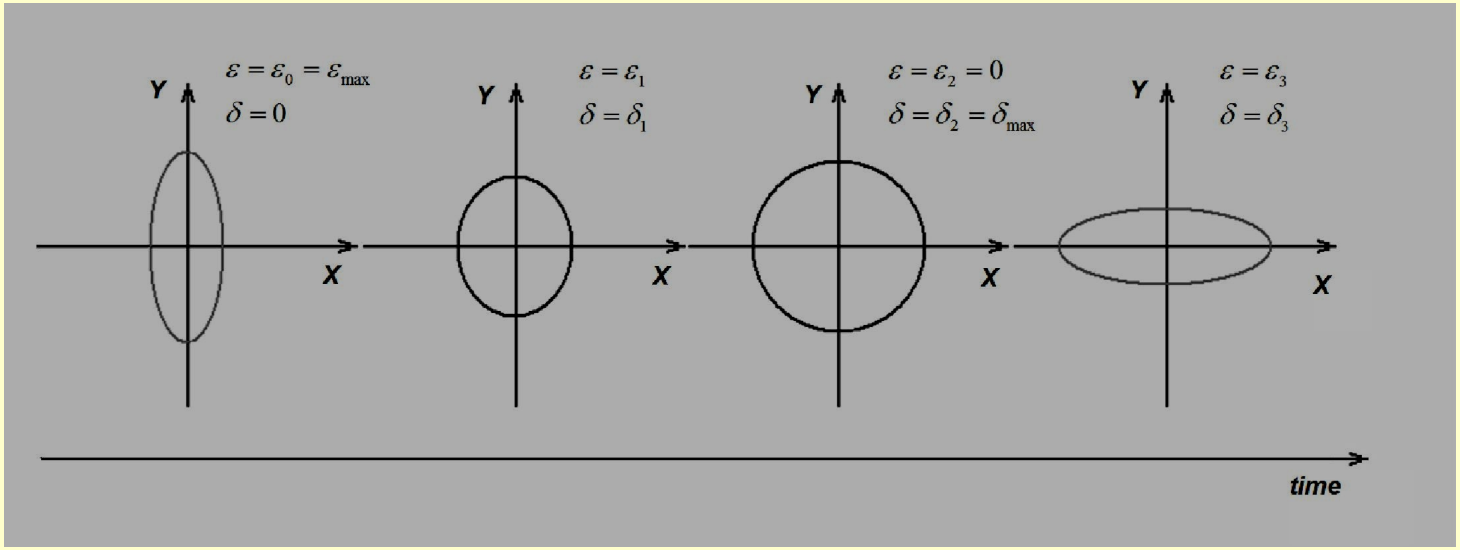
FASTMC-Model parameters for non-central collisions:

The SAME parameters which were used to simulate central collisions were used for noncentral collisions at different centralities. The additional parameters needed only for noncentral collisions are:

For the impact parameter range: (**b**min , **b**max)

9. Flow anisotropy parameter: **δ**(b)

10. Coordinate anisotropy parameter: **ε**(b)



Hard part, related with partonic states:

I.P.Lokhtin and A.M.Snigirev, Eur. Phys. J. C 45, 211 (2006).

The mean number of jets produced in AA events at a given **b** is proportional to the number of binary nucleon-nucleon sub-collisions :

$$N_{AA}^{jet}(b,\sqrt{s}) = T_{AA}(b) \int_{p_T^{\min}} dp_T^2 \int dy \frac{d\sigma_{pp}^{hard}(p_T,\sqrt{s})}{dp_T^2 dy}$$

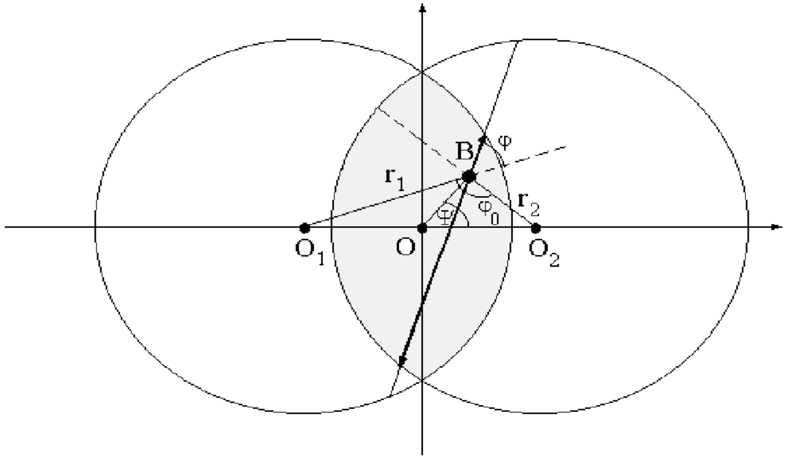
$d\sigma_{pp}^{hard}(p_T,\sqrt{s}) / dp_T^2 dy$ Cross section of the corresponding hard process in pp collisions (at the same CMS energy of colliding beams) with the minimum transverse momentum transfer

$p_T^{\min}$ -parameter of the model-minimal pt of parton-parton scattering in PYTHIA event in GeV (ckin(3) in /pysubs/)

Partons produced with $p_T < p_T^{\min}$ are considered as being “thermalized”, so their hadronization products are included in the soft part of event automatically.

High-pt part: Event simulation

I.P.Lokhtin and A.M.Snigirev, Eur. Phys. J. C 45, 211 (2006).



- Generation of the initial parton spectra with PYTHIA (fragmentation off)

- Generation of the jet production vertex:

$$\frac{dN^{jet}}{d\psi\, dr}(b) = \frac{T_A(r_1)T_A(r_2)}{T_{AA}(b)},$$

$$T_A(r) = A\int \rho_A(r,z)dz$$

nuclear thickness function with the nuclear density distribution $\rho_A(r,z)$

$$T_{AA}(b) = \int_0^{2\pi} d\psi \int_0^{r_{\max}} r dr T_A(r_1)T_A(r_2)$$

nuclear overlap function

- Calculation of the scattering cross section: $\sigma = \int dt d\sigma/dt,$

$$d\sigma/dt = C\frac{2\pi\alpha_s^2(t)}{t^2}\frac{E^2}{E^2 - m_p^2}$$

α_s- QCD-running coupling constant, depending on Nf active quark flavors, Tc-critical temperature

High-pt part: Event simulation

- Generation of the displacement between ith and (i+1)th scatterings and calculation of the corresponding transverse distance between parton scatterings
- Reducing of the parton energy by collisional and radiative loss per each ith scattering:

$$\Delta E_{tot,i} = \Delta E_{col,i} + \Delta E_{rad,i}$$

- Transverse momentum kick due to elastic scattering i:
- Formation of additional (in-medium emitted) gluon
- Halting the rescattering if: parton escape the dense zone,or QGP cools down Tc=200 Mev, or parton loss so much energy that pt<2T
- adding new (in medium emitted) gluons to the PYTHIA parton list and rearrangement of partons to update string formation
- Formation of the final state particles by PYTHIA (fragmentation on)

Simulation of high-pt part related to the partonic states

Initialization

- PYTHIA initialization at given c.m.s. energy per nucleon pair

- calculation of total inelastic NN cross section at given energy

-calculation of hard scattering cross section at given **ptmin** and energy

-calculation of the Pjet(**probability of the hard parton-parton scattering) =**
hard scattering NN cross section (ptmin, energy) / total inelastic NN cross section(energy)

- tabulation of nuclear thickness function and nuclear overlap function

-calculation of number of participants & binary collisions at Pb+Pb (b=0)

Event generation

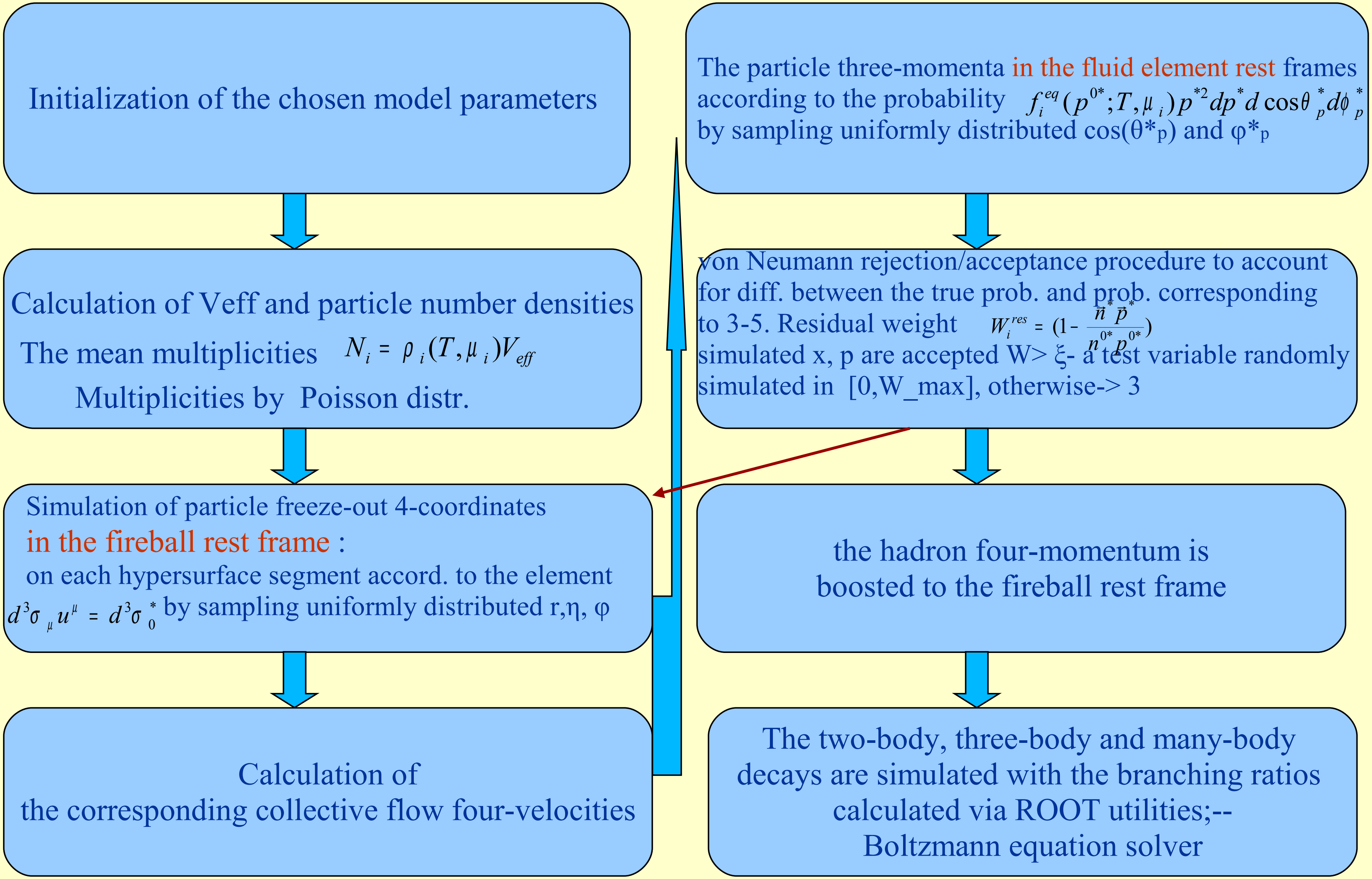
-generation of impact parameter (b) of A-A collision

-calculation of number of nucelons-participants and binary NN sub-collisions (**b**)

-generation of number of “jets” **njet(b)** (binominal distribution according with **Pjet)**.

-generation of hard parton-parton scatterings (Q>ptmin) '**njet**' times-
call **PYTHIA(pyexec)+PYQUEN**

Hadron generation procedure



Initialization of the chosen model parameters

Calculation of Veff and particle number densities

The mean multiplicities $N_i = \rho_i(T,\mu_i)V_{eff}$

Multiplicities by Poisson distr.

Simulation of particle freeze-out 4-coordinates

in the fireball rest frame :

on each hypersurface segment accord. to the element

$d^3\sigma_\mu u^\mu = d^3\sigma_0^*$ by sampling uniformly distributed r,η, φ

Calculation of
the corresponding collective flow four-velocities

The particle three-momenta in the fluid element rest frames according to the probability $f_i^{eq}(p^{0*};T,\mu_i)p^{*2}dp^*d\cos\theta_p^*d\phi_p^*$ by sampling uniformly distributed cos(θ*$_p$) and φ*$_p$

von Neumann rejection/acceptance procedure to account for diff. between the true prob. and prob. corresponding to 3-5. Residual weight $W_i^{res} = (1 - \frac{\vec{n}^*\vec{p}^*}{n^{0*}p^{0*}})$
simulated x, p are accepted W> ξ- a test variable randomly simulated in [0,W_max], otherwise-> 3

the hadron four-momentum is
boosted to the fireball rest frame

The two-body, three-body and many-body
decays are simulated with the branching ratios
calculated via ROOT utilities;--
Boltzmann equation solver