New RHIC Data and the Multichain Monte Carlo DPMJET-III

Fritz W. Bopp, Johannes Ranft, R. Engel and S. Roesler

Department of Physics, University, 57068 Siegen
Inst. for Nuclear Physics , FZ, 76021 Karlsruhe
CERN, Geneva

Basic Concept of String Models

Hadronic collisions at high energies involve the soft production of usually many particles with low transverse momenta. The theoretical tools available at present are not sufficient to understand this feature from QCD alone and *phenomenological models* are typically applied in addition to perturbative QCD.

Successful soft models often postulate an *independent* production and decay of *several hadronic strings*. The rather compact hadronic final state involving only a few such string objects regulates the infrared gluon production quite strongly and limits the possibly large entropy during this phase.

One such string model is the *Dual Parton Model*. Its fundamental ideas are presently the basis of numerous "microscopic" Monte Carlo implementations.

We will point out that RHIC data indicate that the *independent production* has to be *amended* for special case of extremely dense systems produced in central heavy ion collisions.

Monte-Carlo Generator PHOJET of Hadron–Hadron Collisions

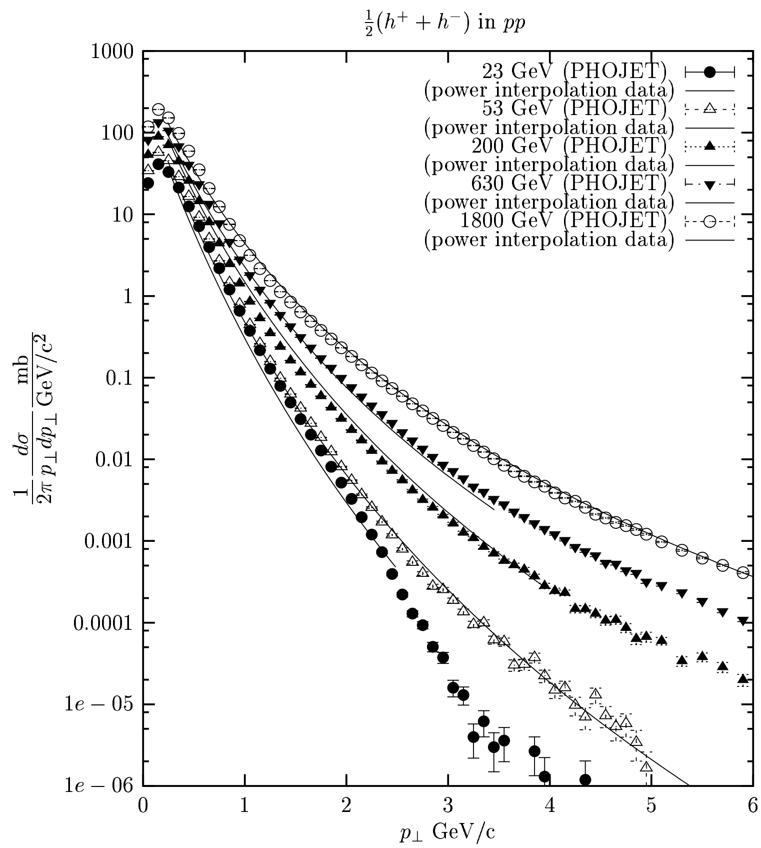
PHOJET is a modern event generator, based on the dual parton model and perturbative QCD describing hadron resp. hadronic photon interactions with energies greater than 5 GeV.

Each collision includes multiple hard pomeron exchanges (i.e. perturbative processes) as well as multiple soft pomeron exchanges. Also for hard processes there can be initial and final state radiation. The iteration of such elementary processes relies on *Gribov's reggeon field theory*. It incorporates many details; it contains a model for *high-mass diffraction dissociation* allowing for multiple jet production and treatment of recursive insertions of *enhanced pomeron graphs* (triple-, loop- and double- Pomeron graphs).

The *basic building* blocks formed are *color neutral strings*. They are hadronized in a *universal* way using Lund model program Pythia.

How good is PHOJET?

PHOJET has been extensively tested. Here we look at the transverse momentum distributions in $p-p$ and $\bar{p}-p$ collisions from colliders. The points are from the PHOJET, the data are represented by lines fitted to available data collected from many experiments.



The model nicely fits the data.

Of course the figure has a tiny scale and in a closer look deviations exists.

DPMJET-III Generator of Nuclear Collisions

DPMJET-III simulates arbitrary combinations of *photon, hadron, and nucleus interactions from a few GeV up to cosmic ray energies.*

It implements Gribov–Glauber theory for nuclei collisions. Realistic light nuclear profiles & Woods-Saxon profiles are used. Cross sections a taken from PHOJET.

After sampling, *individual hadron–nucleon interactions* are then *described by* PHOJET.

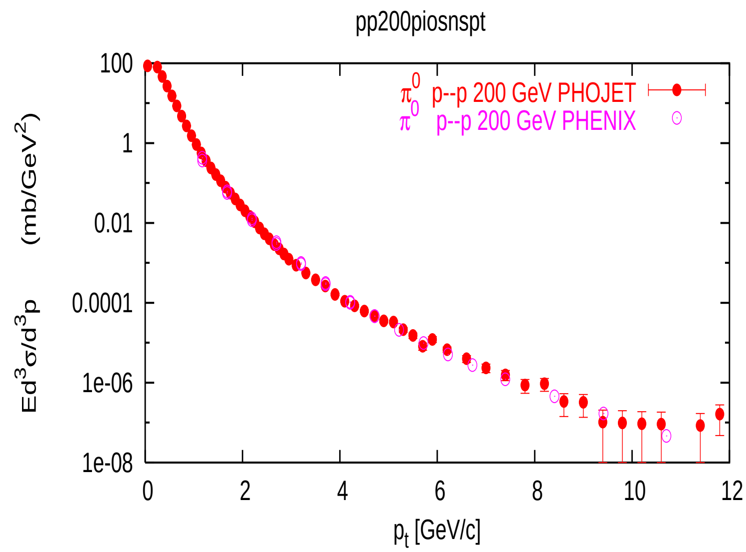
Features of DPMJET-III are:

- enhanced graph cuts in non-diffractive interactions,
- formation zone intranuclear cascade,,
- implementation of certain baryon stopping diagrams.

The code is used in the CORSIKA simulation of cosmic ray showers.

RHIC p-p collisions at 200 GeV

For preliminary π^0 transverse momentum distribution in $p-p$ collisions at $\sqrt{s} = 200$ GeV from PHENIX we found an excellent agreement with PHOJET up to transverse momenta of about $p_{perp} = 10$ GeV/c :



Spectra for different particle types are available.

A relatively large amount of net protons (i.e. $\bar{p} - p$) at central rapidity is consistent with unpublished HERA data.

Au–Au collisions at 130 GeV are requiring percolation

The multiplicities measured at RHIC are significantly lower *than predicted* by independent multi–string models.

	N_{ch}	$dN_{ch}/d\eta\|_{\eta=0}$
original Dpmjet- III	6031	968
BRAHMS	3860 $\pm$300	553 $\pm$36
PHOBOS		613 $\pm$24
PHENIX		622 $\pm$41

In situations with a very high density like in central nucleus–nucleus collisions *some mechanism* must prevent the usual independent developements of strings.

A percolation process, which leads with increasing density to more and more *fusion of strings*, seems natural. It was first proposed by groups at Lisboa and Santiago de Compostela.

Fusion of strings in the DPMJET (fusion)

The fragmentation with the Jetset (Pythia) code admitts only simple configurations of complete strings. This presently restricts the percolation only to certain configuration with acceptable quantum numbers.

Examples are:

1st	2nd	3rd	fused
$q_1 - \bar{q}_2$	$q_3 - \bar{q}_4$		$q_1 q_3 - \bar{q}_2 \bar{q}_4$
$q_1 - q_2 q_3$	$q_4 - \bar{q}_2$		$q_1 q_4 - q_3$
$q_3 - q_1 q_2$	$q_4 - \bar{q}_1$	$\bar{q}_3 - q_5$	$q_4 - \bar{q}_3$
$q_4 - \bar{q}_1$	$q_5 - \bar{q}_3$	$\bar{q}_5 - q_1$	$q_4 - \bar{q}_3$

The *percolation condition*

$R_{1st-2nd} \leq R_{fusion}$ where $R_{fusion} = 0.75$ fm

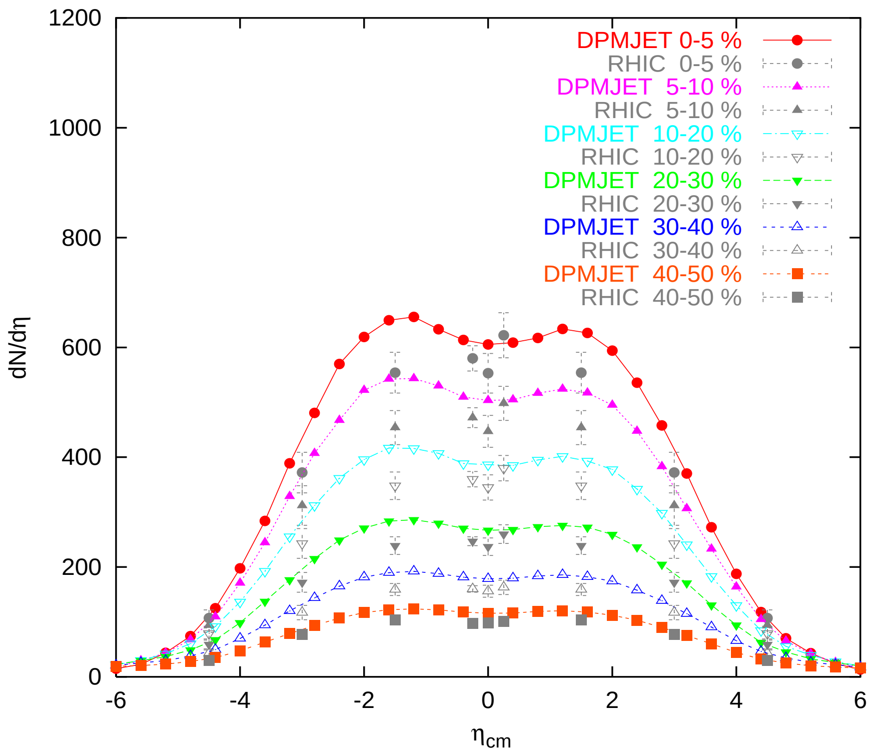
requires *fusion of strings* which overlapp transverse space

A p_{perp} dependent $R_{fusion}(p_{perp})$ can be expected. Presently it is taken to be constant but only chain-ends with $p_{per}^{fusion} < 2$ GeV/c are considered.

Results of DPMJET (fusion)

- New diquark and anti–diquark ended chains yield extra baryon–antibaryon production.
- Chain fusion decreases the multiplicity $N_{hadrons}$.

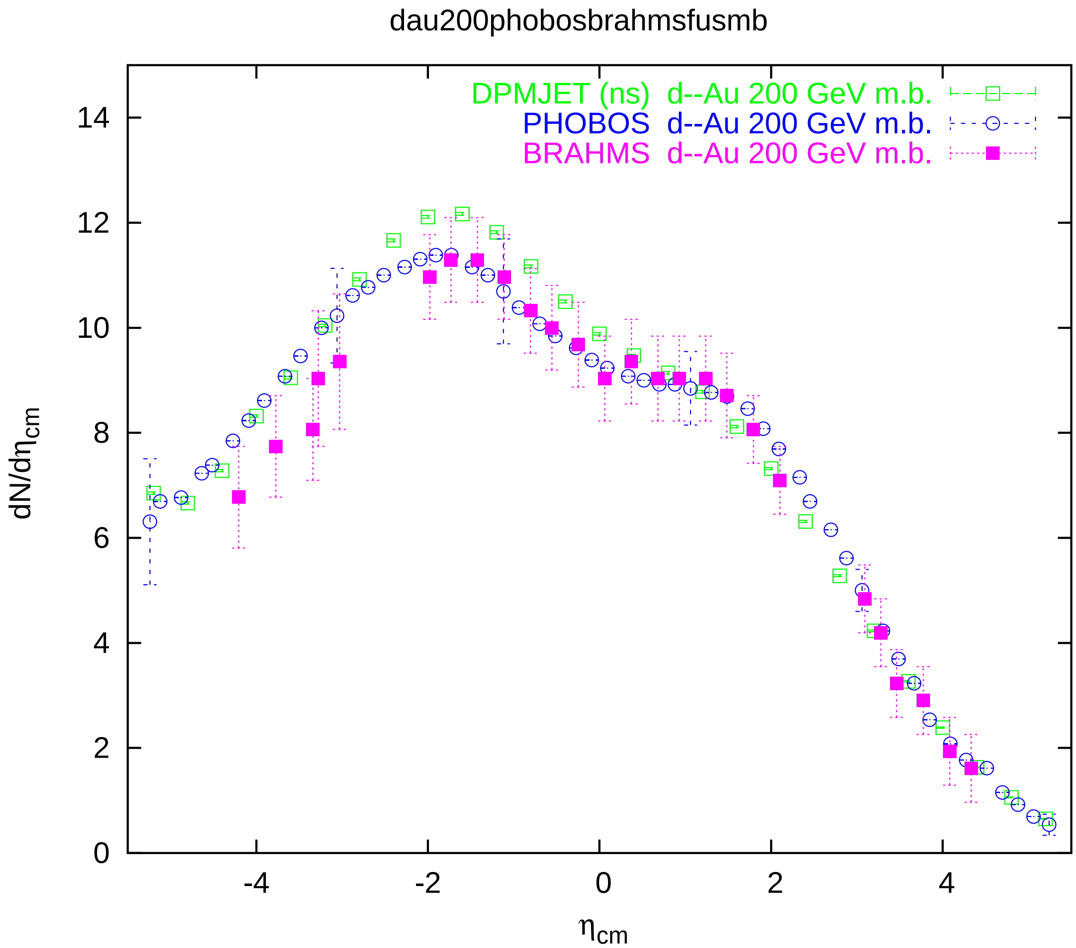
Pseudorapidities of charged hadrons in Au–Au collisions at $\sqrt{s}_{NN}$= 130 GeV for centralities 0–5 % up to 40-50 % are compared with the (mainly) BRAHMS data below.



The η=0.0 points displayed at η=0.25 resp. -0.25 are from PHENIX resp. PHOBOS.

d-Au collisions DPMJET(fusion)

Chain fusion is already required for d-Au . The figure compares PHOBOS charged pseudorapidities of minimum bias $\sqrt{s} = 200$ GeV d–Au collisions to DPMJET-III calculations. With fusion the DPMJET distribution is within the systematic errors.



Collision Scaling

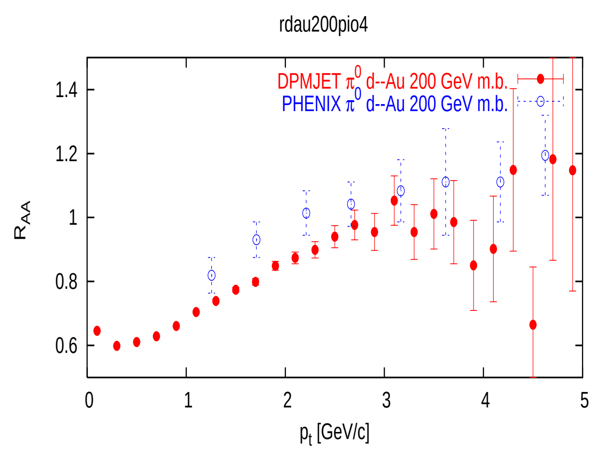
Several RHIC experiments find an approximate collision scaling in d-Au collisions at large $p_\perp$ for π^0 production. Collision scaling means:

$$R_{AA} = \frac{\frac{d^2}{dp_\perp d\eta} N^{A-A}}{N^{A-A}_{binary} \cdot \frac{d^2}{dp_\perp d\eta} N^{N-N}} \approx 1.0$$

Here N^{A-A}_{binary} is the number of binary Glauber collisions in the nucleus–nucleus collision A–A.

DPMJET–III in its original form gave for π^0 production in d+Au collisions $R_{AA} \approx 0.5$ at large $p_\perp$!

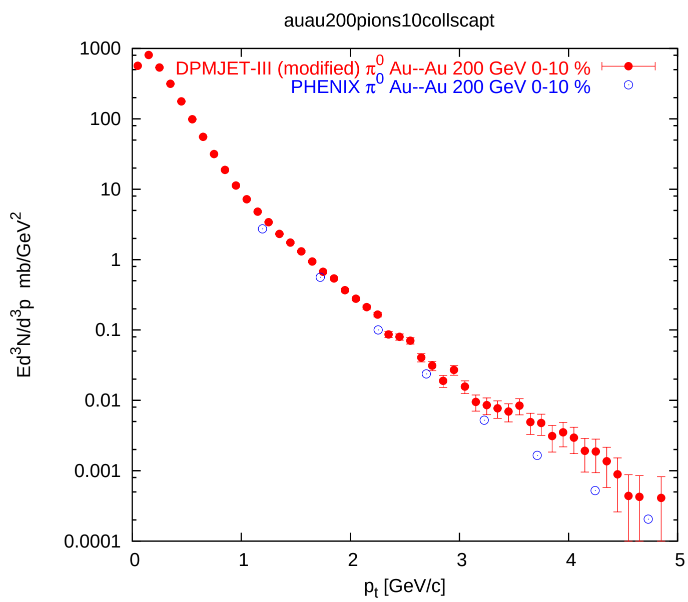
The effect strongly depends on the iteration procedure which rejects singletts too small to hadronize which redistributes their energies-momenta. Using a reordered iteration procedure it was possible to obtain a comparable collision scaling:



Collisions-Scaling in Au-Au Collisions

The changed iteration procedure also influences heavy ion processes in a way, that the deviations from collision scaling are reduced. Hence we have to *recalculate* all hadron production at large $p_\perp$ in Au–Au collisions. These modifications have not been done.

Available is a recalculation of the $p_\perp$ dependence of the π^0 production for DPMJET–III with full percolation and chain fusion and with the change in the iteration procedure.

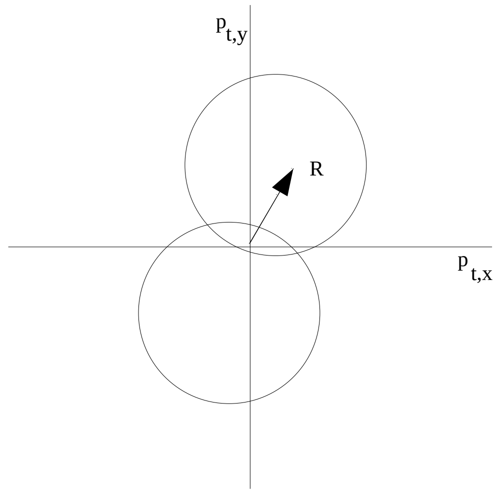


As expected, at large p_{perp} DPMJET–III produces a p_{perp} distribution above the data. There is no jet quenching in DPMJET III.

Elliptic flow in DPMJET-III

Non central heavy ion scattering posseses an direction:

$\Phi :_R$



The elliptic flow v_2 is defined as a *Fourier coefficient of the single particle distribution around this direction*

$$v_2 =< \cos 2(\phi - \Phi_R) >$$

As the direction has also be determined from the distribution the measurements of v_2 relies on azimuthal correlation.

- Two-particle cumulants can be used.
- There are a number of known sources of azimuthal (lower order) correlations. To concentrate on bulk properties a number of different v_2 extraction methods have been proposed. Here considered is a method using Lee–Yang zeroes.

For Au–Au collisions at $\sqrt{s_{NN}} = 130$ GeV data for the integrated flow from the STAR collaboration are compared in the table with the model.

The model uses the two–particle cumulant method (I) and the Lee–Yang - zeroes method (I) with a systematic error estimated (III).

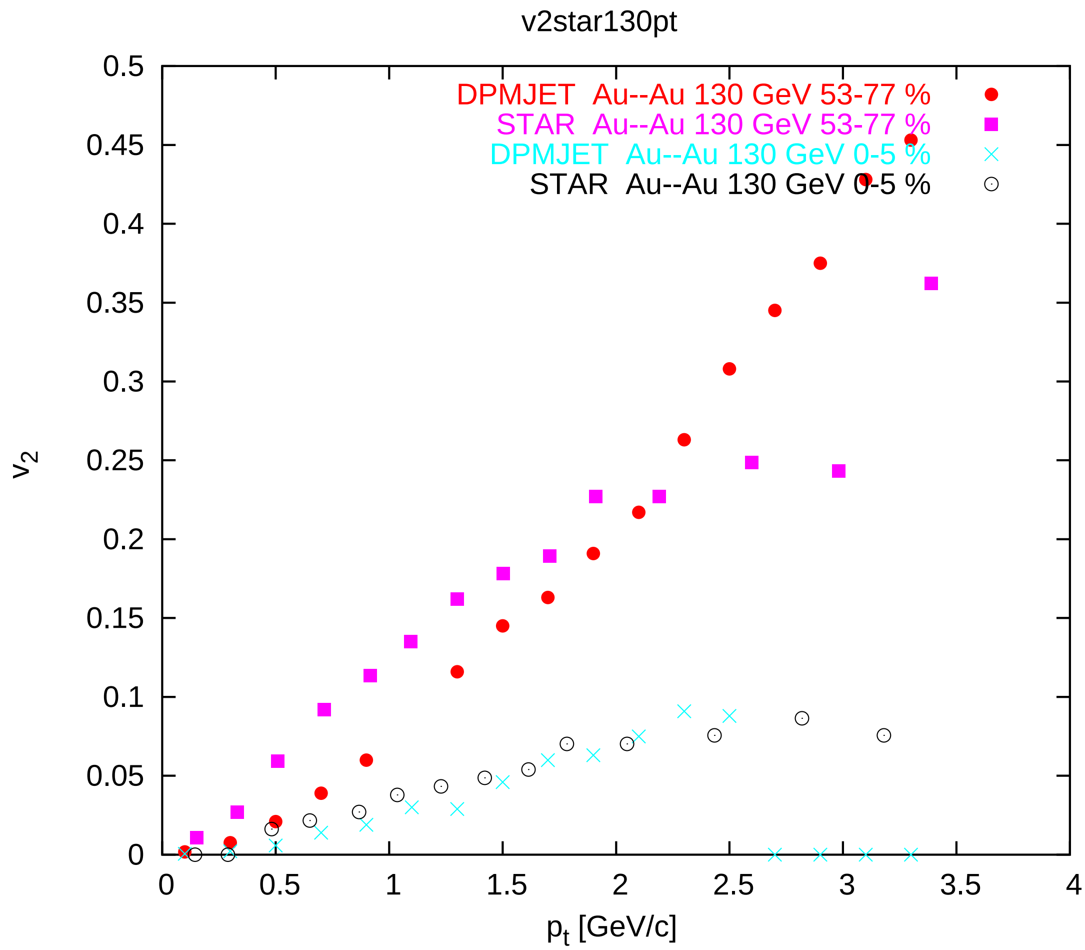
centrality	particles	I	II	III	STAR
53 – 77%	charged	0.0107	0.0140	0.047	0.07
		0.0182	0.0135	0.051	
		0.060	0.037	0.164	
0 – 5%	charged	0.00685	0.00644	0.0129	0.02
		0.00595	0.00693	0.0139	
		0.0188	0.0215	0.0419	

We note:

(i) The flow values calculated with methods I and II agree reasonably well, however III shows II to be unreliable.

(ii) The flow calculated from DPMJET-III is significantly smaller than the experimental one. The centrality dependence is stronger in the data than in the model.

The $p_\perp$- dependence of the flow (two–particle cumulant method) is plottet in the figure for both centralities again with STAR data:



i) Responsible for the deficit is the region below $p_\perp < 2$ GeV .

iii) At large $p_\perp$ values DPMJET shows larger flow than the data. There is no jet quenching in DPMJET.

What does it mean for v_2

In a multichain model with non-interacting hadronic strings we expect of course *no true elliptic flow*.

It shown that a *sizable fraction* of v_2 in central events and a substantial part of v_2 in non central events arises *from general azimuthal correlations*.

An interaction of hadronic strings can *not* be *restricted to fusion*. Also expected are other interaction which introduce some genuine elliptic flow in the direction of the density gradient.

1. It could be a *dynamical force between strings*.

2. It could be that the non-fused strings are selected “not to touch” i.e. to be *spacially sqeezed*. This could result in an unisotropic increase in transverse momenta of the needed form.

Conclusion

The data obtained at RHIC are extremely useful to improve hadron production models like Dpmjet-III. So far two important correction were found:

(i) Percolation and fusion of chains, the data from RHIC allow to determine the amount of percolation to be implemented into Dpmjet–III.

(ii) Collision scaling of large $p_\perp$ hadron production in d–Au collisions: The data indicate that we have to change the iteration procedure (of the selection of all soft and hard chains in nuclear collisions) in such a way, that collision scaling is obtained.

The RHIC data have a "RICH" structure and from our side the work is not yet finished