VERY HIGH MULTIPLICITY PHYSICS

Proceedings
of the Fourth International
Workshop

On the Status of VHM Physics

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Phenomenology indications of statistics: brief review of statistical models (1999 - 2003)

•Theoretical background:
Schwinger & Keldysh (1964); Niemi & Semenoff (1984); Carruthers & Zachariazen (1986), ...

- The statistical thermal model is in good agreement with experimental data of heavy ion collisions:

  F.Becattini, et al, hep-ph/0002267;hep-ph/00110221; hep-ph/0206203; P.Braun-Munzinger, et al., nucl-th/9903010; U.Heinz & P.F.Kolb, hep-ph/0204061; ...

- The "improved" statistical model shows that the chemical equilibrium is reached in heavy ion collisions:

  U.Henz, Nucl.Phys., A661 (1999) 140c; P.Braun-Munzinger, et al., hep-ph/0105229; H.Oeschler, nucl-ex/0011007; Zhong-Dao Lu, hep-ph/0207029; R.Baier et al., hep-ph/0204211;...

- Statistical methods in multiple production:

  J.B.Elliot et al., Phys. Rev. Lett., 85 (2000) 1194; C.Tsallis, Lect. Notes in Phys. LNP 560 (2000), G.A.Kozlov, New J. Phys., 4 (2002) 23; D.Kharzeev, hep-ph/0204015; E.Shuryak, hep-ph/0205031; I.M.Dremin & V.A.Nechitailo, hep-ph/0207068; L.Gutay et al., E-735 Coll. (FNAL), ISMD-02; A.Sissakian, Nucl.Phys. (in press, 2003), J.Manjavidze, VHMp Proc. (2003), N.Shubutidze, Proc. XI Lomonosov Conf. (2003) ...

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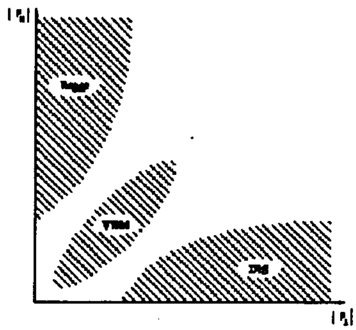
It should be mentioned first of all the rising interest to the statistical approach in the inelastic hadron and heavy ion collisions. In a series of later papers the phenomenological basis of this approach is justified.

The structure of phase space

- "Regge" - soft hadron dynamics:
  (V.Gribov, K.Ter-Martirosyan, A.Kaidalov, P.Landshof, BFKL, ...)
- "DIS" - hard hadron dynamics:
  (DGLAP,...)
- "VHM" - hard low-x hadron dynamics
  (L.Gribov et al., L.Lipatov, J.Manjavidze & A.Sissakian,...)



•Symmetry constraints are not important outside "Regge" domain
• LLA ideology cannot be used outside "DIS" domain
• Strong coupling tQCD was built to describe the "VHM" domain
(J.Manjavidze & A.Sissakian, Theor. Math. Phys. 130 (2002) 153)

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First of all, it is useful to have a transparent picture of the multiple production kinematics to classify various mechanisms of particle production.

One may extract two domains, well described by the dynamical models:

--- The multiperipheral-type models belong to "Regge" domain. This kinematics characterized by small and independent from initial energy and multiplicity the mean value of transverse momentum.

--- The QCD applicability region belong to "Deep Inelastic Scattering" domain. In this case the transverse momentum of produced hadrons is larger than the longitudinal one.

Thermodynamics assumes the uniform distribution of the energy over all degrees of freedom. Then, one can assume that the place of thermodynamics lies between "Regge" and "DIS" domains, where the longitudinal and transverse momenta are approximately equal to each other.

It must be noted that the BFKL approach in Regge domain and DGLAP in the DIS domain assumes the LLA accuracy. In the VHM domain this accuracy did not work because of the approximate equality of produced particles momenta. At the same time the next-to- and so on calculations are too complicate. Just this is a main theoretical problem in the VHM domain.

--- For this reason a new type of perturbation theory for ordinary Yang-Mills field was constructed. It describes the conserving fields of topology excitations and was calling as the topological QCD.

Necessary and sufficient condition of thermalization

•***One can prove**: if the inequality:*

$$|K_l(E,n)|^{2/l} << K_2(E,n), l = 3,4,...$$

is hold, then the thermalization occurs.

J.Manjavidze & A.Sissakian, Phys. Rep., 346 (2001) 1

The central energy correlation functions:

$$K_l(E,n) =< \prod_{k+1}^{l} (\varepsilon_k - < \varepsilon >) >, \varepsilon_k = (q_k^2 + m^2)^{1/2}, < 1 >= 1$$

Averaging is performed over the semi-exclusive cross sections

$$\frac{d^{3l}\sigma_n}{d^3q_1 d^3q_2 \cdots d^3q_l} \propto \int \prod_{l+1}^{n} \frac{d^3q_{k1}}{(2\pi)^3 2\varepsilon_k} | A_n(q_1, q_2, ..., q_l, q_{l+1}, ..., q_n) |^2 , l < n$$

A_n **is the n-particle amplitude**

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The second step toward statistical description consists in observation that latter, means necessity to have the **well defined thermodynamical parameters**.

One can prove that if the inequality is satisfied then the statistical description actually occurs. Therefore, to have a rights to introduce, for example, the temperature and to use the statistical models, one must check the experimental data from this point of view.

It should be stressed that the given inequality is necessary and sufficient for thermalization. We understand this phenomenon as the transition to the uniform distribution of the perturbation over all degrees of freedom. It practically independent on the type of Lagrangian, on symmetries and other details.

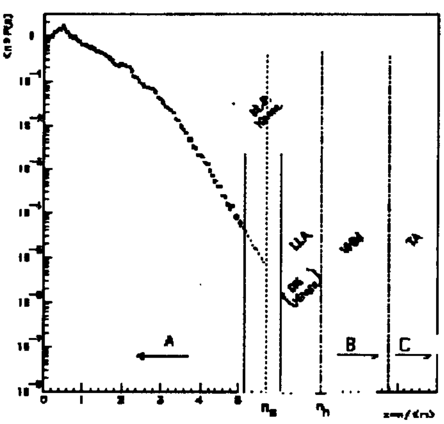
One can observe here the analogy with the principle of "vanishing of correlations", offered by N.N. Bogolyubov for statistical physics.

--- I'd like to add that this conclusion is general, it weakly depends on details of dynamics.

The scenario of transition to thermalized state

- $n < n_s \sim (\bar{n})^2$ - mutiperipheral kinematics region
- $n > n_s$ - hard (multi)-jet kinematics
- $n_h > n_s$ - LLA kinematics threshold
- VHM -- region of thermalization
- C - limiting thermalization region: produced particle momentum,

$$|p_i| < m_h \approx .2GeV, i = 1,2,...,n$$



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We have definite scenario for hadron-hadron collisions as the thermalized state achieved with rising multiplicity. The Fig. illustrates it in terms of multiplicity distribution.

Let us consider now what may happened if the multiplicity growth.

--- Multiperipheral models are "work" up to mean multiplicity square.

--- The "hard" processes take place at larger values of multiplicity.

--- The LLA ideology is applicable up to the multiplicity *“**n hard**”*.

--- The VHM region belongs to the domain “ B”, where thermalization occur. On the to-day level of theory we cannot prove that the VHM region is not empty in the **high energy** experiments. Existing experimental data will be shown.

Just the question of thermalization will be investigated by the new experiment at U70 in Protvino. More details about this experiment was given on our previous Symposium in the talk of **Vladimir Nikitin,** the head of this experiment**.** He cannot come here to present the to-day status of the experiment

--- “C” is the domain of the "ideal gas approximation". This domain is not interesting from dynamical point of view, but it is interesting for investigation of the Bose-Einstein correlations.

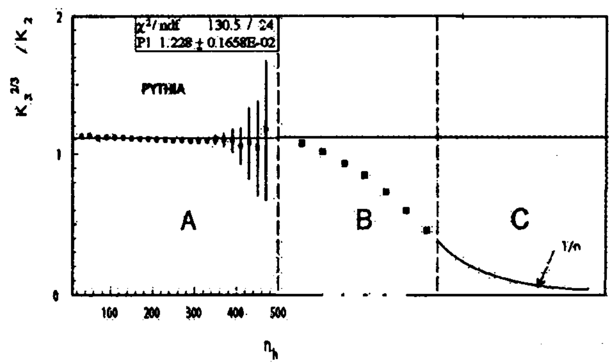
Prediction of generators: PYTHIA

A. One may conclude that the dynamical models built into the PYTHIA cannot predict thermalization.

B. The transition region to thermalized state. VHM may belong to it.

C. The limiting thermalization region:

$$\frac{|K_3|^{2/3}}{K_2} \sim \frac{1}{n}$$



Yu.Kulchitski et al.

We are starting now the consideration of predictions of the most popular generators of events.

---By the definition, the generators are absorb all existing experimental and theoretical information concerning multiple production events. For this reason this information must be important.

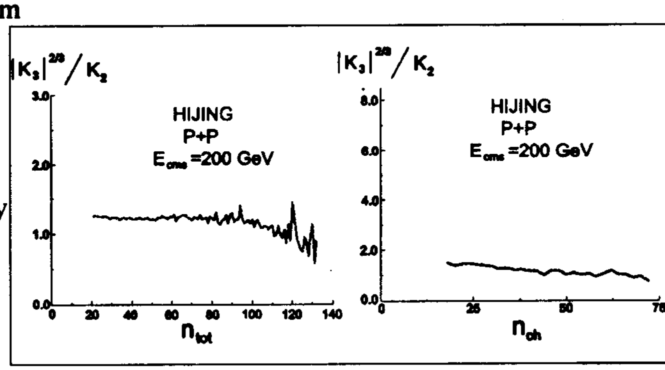
--- Fig. presents the PYTHYA prediction for LHC energy.

(To have sufficiently large multiplicity, it was assumed that the produced particle transverse momentum is larger than 0.3 GeV.)

--- As follows from this figure, see the “A” domain, one may conclude that the dynamical models underlying the PYTHIA cannot predict thermalization.

Prediction of generators: HIJING

- The “tendency” to equilibrium is interpreted as a result of rescattering.
- The heavy ion collisions may be a preferable to observe thermalization phenomenon.



V. Uzhinsky et al.

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--- "HIJING" is the generator which gives already a tendency to equilibrium since it takes rescattering into account. This means that, presumably, the effect of thermalization may be seen in the heavy ion collisions at smaller multiplicity.

--- The experimental SPS data on ion inelastic collisions will be shown.

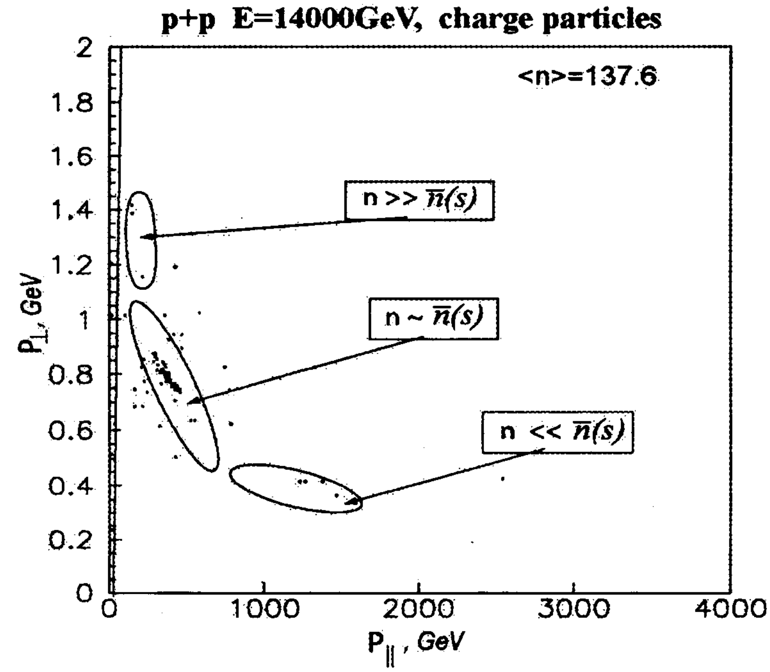
PYTHIA

- The ratio:

$$r = \frac{< p_{\parallel} >}{< p_{\perp} >}$$

•Red line:

$$r = 4/\pi$$



•M.Gostkin et al.

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The ratio of mean values of longitudinal to the transverse momenta is one of the indicators of thermalization.

Indeed, in the thermalized state the mean values of the momenta components must be of the same order. This means that the value of the produced particle momenta must be the same. Just this condition gives the ratio **r** equal to 4/pi.

Toward the experiment

To observe thermalization it is necessary to investigate inequality:

$$|K_3(E,n)|^{2/3} << K_2(E,n) \quad (**)$$

•If the inequality (**) is hold then

$$\mu(E,n) = -<\varepsilon;E,n> \ln\frac{\sigma_n(E)}{\sigma_{tot}(E)}$$

is the **chemical potential,**

$$<\varepsilon;E,n>$$

is the **temperature**.

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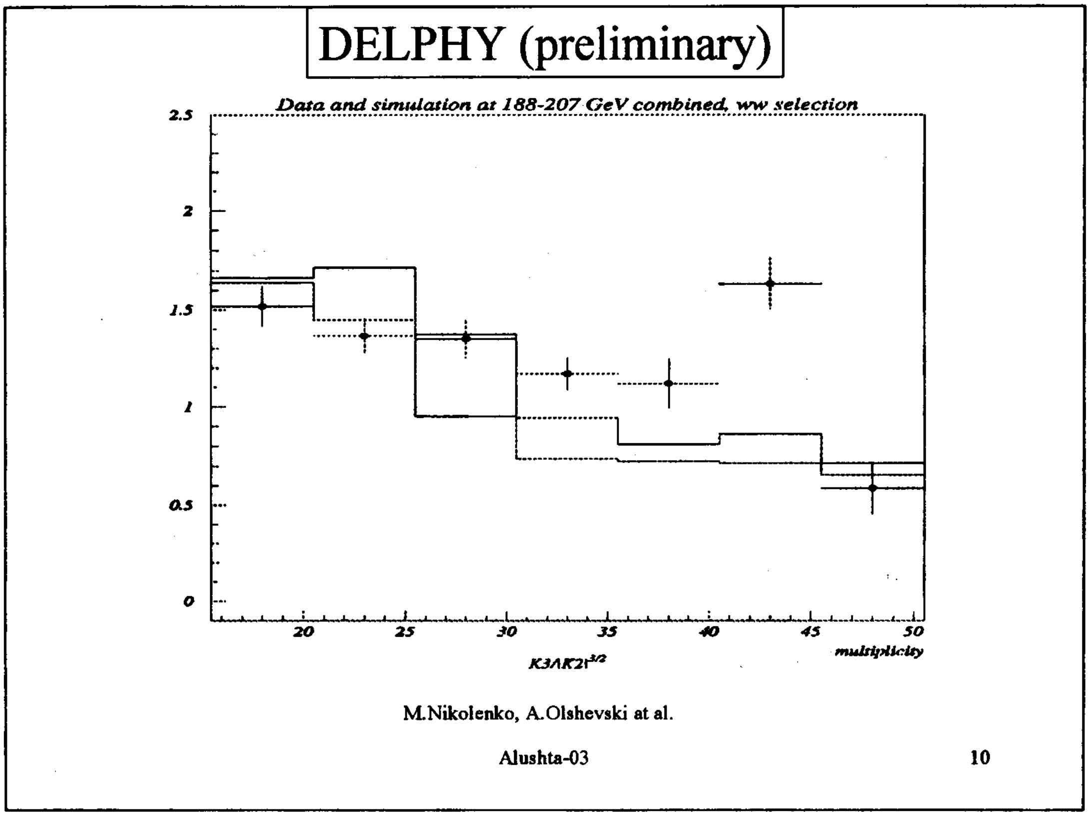
--- From our point of view, the primordial is following question to experiment what is the value of "the ratio K3/ K2".

--- This ratio defines correctness of statistical point of view on the multiple processes at given multiplicity and energy. I'd like to note once more here that this ratio is the necessary and sufficient condition.

--- Information concerning this ratio is **basic** for our future investigations. Satisfying this inequality we hope investigate such effects as the phase transitions in the colored state, existence of the topological defects in this state, the problem of finding of the quark plasma, etc. This ratio will allow also to define quantitatively the range of validity of the LLA of perturbative QCD.

--- So, one may define the "chemical potential" "mu" through the topological cross section if the ratio "K3/ K2" less than one. Having the well defined chemical potential "mu" we can investigate the first order phase transitions.

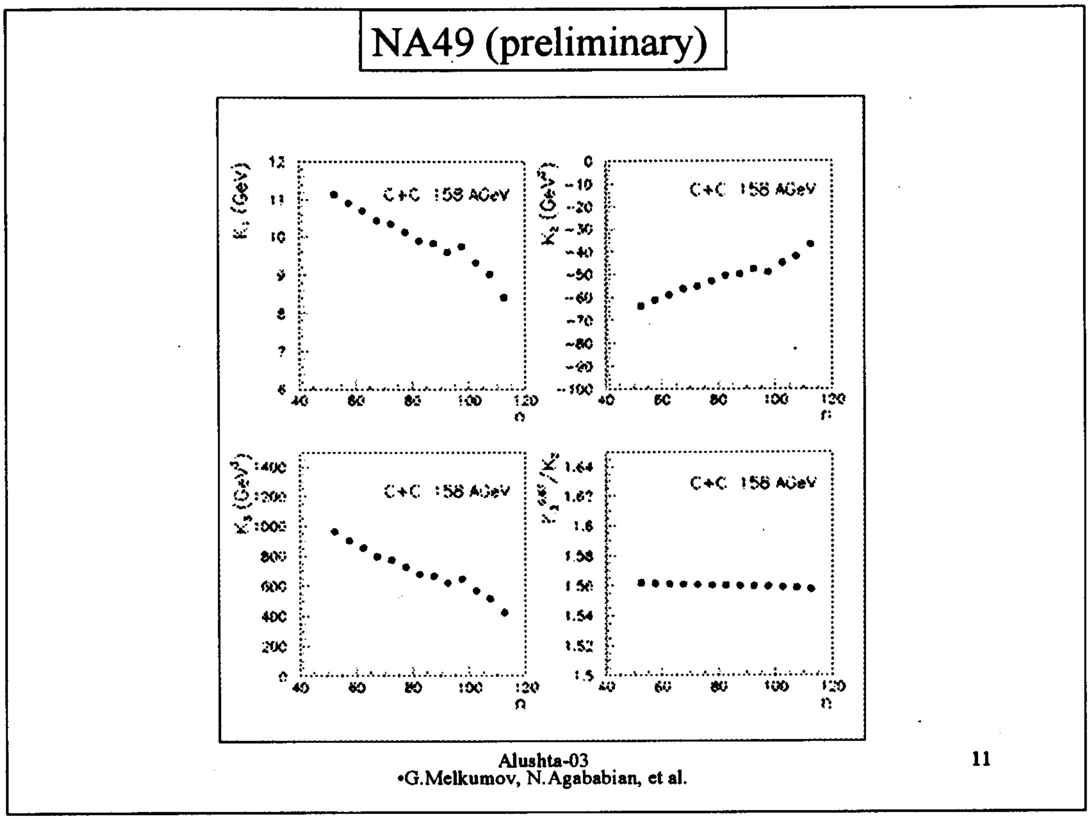


I’d like to show now the experimental data. We will start from the LEP data.

--- Points show the DELPHY data for the ratio “K3/K2”.

--- One may see some tendency to thermalization. This lies in the frame of our prediction that the VHM final state must be result of hard interactions.

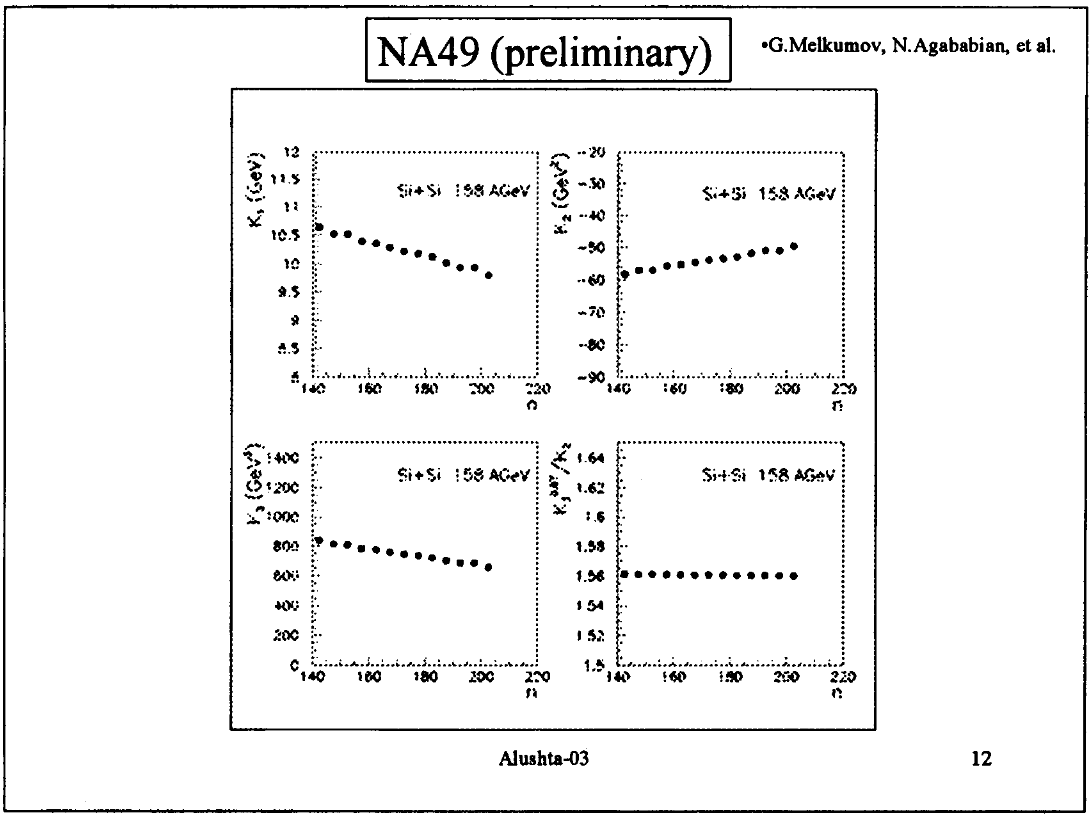
--- So, it is important to continue study of “K3/K2” in the hard processes.



This picture shows the result of ion inelastic collisions This data from the NA49 experiment (SPS, CERN).

--- The correlations were considered for multiplicities larger than the corresponding mean multiplicity.

--- The ratio of correlators “K3/ K2” is approximately constant and is equal to 1.56.

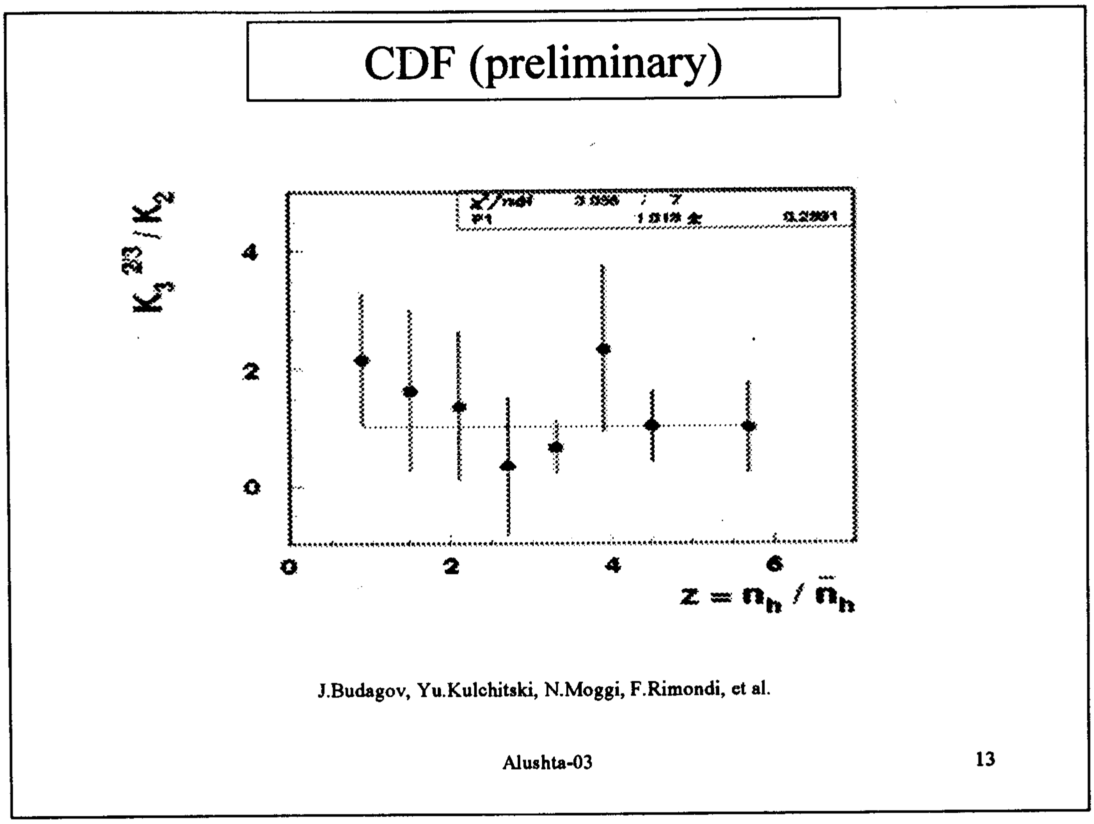


The same we have for ions of silicium.

--- The value of the ratio is again equal to 1.56.

--- Therefore the ratio is larger than one and is approximately constant for given values of multiplicity.

--- We intensively work also with STAR Collaboration, on the upgraded RHIC II, to have the experimental information about **heavy** ion inelastic collisions at **higher energies**.



The slide presents the run I of the Tevatron data given by CDF Collaboration.

The experimental data overlaps a narrow range, approximately equal to two, of central domain of the rapidities.

The used statistics is low, approximately 2000 events, and therefore it is difficult to give definite conclusion.

Conclusions

•Ordinary ("Regge", pQCD in LLA,...) theoretical models cannot predict even the tendency to equilibrium

•Our S-matrix interpretation of thermodynamics shows that the thermalization must occur, at least, in a deep asymptotics over multiplicity.

•Impact of the approach: is it possible to use the thermodynamics in hadron collisions?

•The fact that we have a multiparticle system is not enough to justify the use of the thermodynamics

•The method that makes it possible to find the necessary and sufficient conditions for a thermodynamic description to be valid.

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Presented above **experimental data are in good, at least qualitative, agreement with predictions of theory**.

Experiment shows that **there is not any possibility to use thermodynamical description for the data of existing multiplicities**.

Nevertheless, some **very weak tendency to thermalization in the hard collisions is observed.**

Now **we investigate heavy ions inelastic collisions at STAR and NA49 experiments.** We are planning also to continue this investigations on CDF and future ATLAS data.

I'd like to conclude that we are far from the interesting from physical point of view VHM region. The **special experiment with larger multiplicity seems extremely important.**