Statistical Models and Thermalization

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Introduction

Why statistical approach is attractive

The hadron multiple production is the *process* of (energy) dissipation:

E.Fermi (1950), L.Landau (1950), E.Feinberg (1958) , R.Hagedorn (1965), I.Dremin & I.Andreev (1977)...

General statement:
If the system can be described by thermodynamical "rough" parameter *completely*, then the system is equilibrium over it
(the *inverse statement* is well known from canonical thermodynamics)
J.Manjavidze & A.Sissakian , Phys. Rep., 346 (2001) 1

The governing hadron dynamics symmetry prevents thermalization:
J.Manjavidze & A.Sissakian, Theor. Math. Phys., 130 (2002) 153

Agenda

- **Fermi-Landau model:**

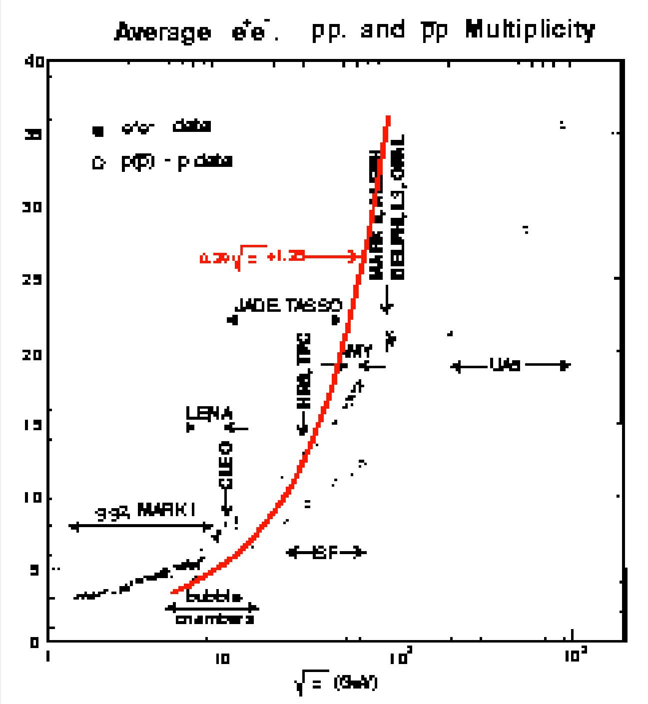
$$\overline{n}(s) \sim \sqrt{s}$$

- **Threshold multiplicity:**

$$n_{\max} \sim \sqrt{s}$$

$$\Downarrow$$

Complete dissipation of incident energy



- **Existence of phenomenological indications of statistics**
- **The necessary and sufficient condition to predict thermalization theoretically**
- **What will happen if** $n \to n_{\max}\,(*)$ **?**
- **Our statement: the preventing thermalization constrains must switched out if** $n \to n_{\max}\,(*)$ **(J.Manjavidze & A.Sissakian, Phys.Rev., 346 (2001) 1)**

Phenomenology indications of statistics: breaf review of statistical models (1999 - 2002)

- **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:**

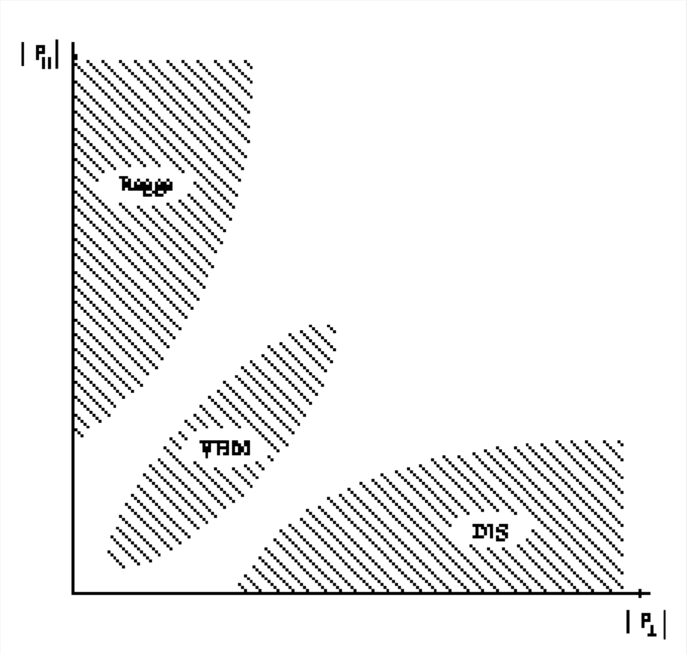
  F.Becattini, et al, hep-ph/0002267;hep-ph/00110221; hep-ph/0206203; P.Braun-Munzinger, et al., nucl-th/9903010, U.Heinz & P.F.Kolb, hep-ph/0204061;...

- **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. LNP560 (2000), G.A.Kozlov, New J. Phys., 4 (2002) 23; D.Kharzeev, hep-ph/0204015; E.Shuryak, hep-ph/0205031; ...

The “dynamical” structure of phase space

- **“Regge” - soft hadron dynamics:**
  (V.Gribov, K.Ter-Martirosyan, A.Kaidalov, P.Landshof, BFKL, 1976 -- 78,...)
- **“DIS” - hard hadron dynamics:**
  (DGLAP, 1972 -- 1977,...)
- **“VHM” - hard low-*x* hadron dynamics**
  (L.Gribov et al., L.Lipatov, J.Manjavidze & A.Sissakian, 1983 -- 2002)



•Symmetry constrains are not important outside “Regge” domain

• LLA ideology can not 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)

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 valid, then the thermalization occurs.

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

Here:

$$K_2(E,n) = <\varepsilon^2; E,n> - <\varepsilon; E,n>^2,$$

$$K_3(E,n) = <\varepsilon^3; E,n> - 3<\varepsilon^2; E,n><\varepsilon; E,n> + 2<\varepsilon; E,n>^3, ...$$

$$<\varepsilon^l; E,n> = \frac{\int \prod_{k=1}^{l} \{\varepsilon(q_k) d^3 q_k\} \frac{d^{3l}\sigma_n}{d^3q_1 d^3q_2 \cdots d^3q_l}}{\int \prod_{k=1}^{l} \{d^3 q_k\} \frac{d^{3l}\sigma_n}{d^3q_1 d^3q_2 \cdots d^3q_l}}$$

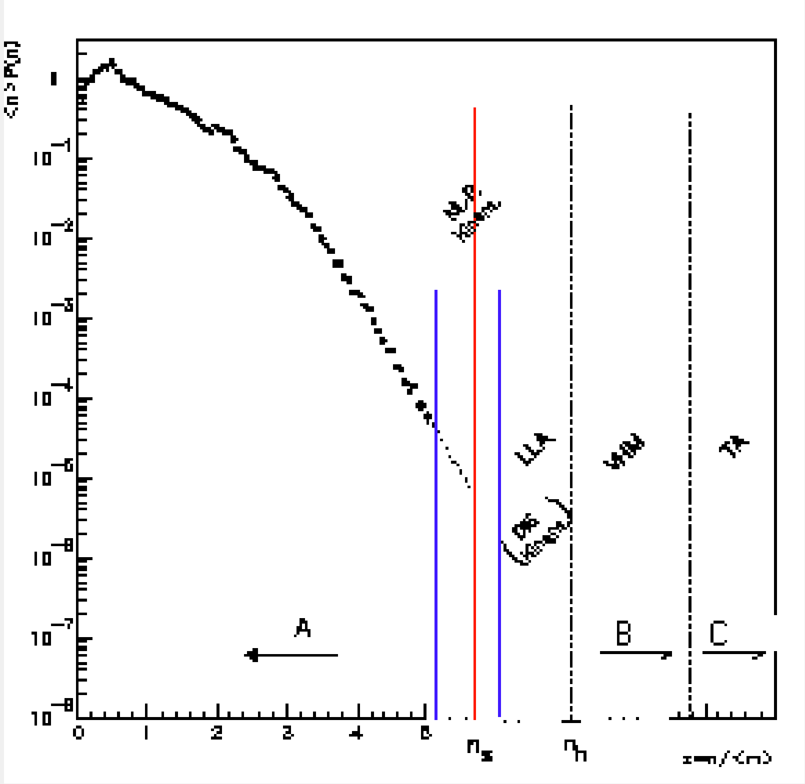
(**) **is the necessary and sufficient condition** $\Longrightarrow$

N.N.Bogolyubov (1960) " The principle of vanishing of correlations"

The scenario of transition to thermalized state

- $n < n_s \sim (\overline{n})^2$ - **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,**

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



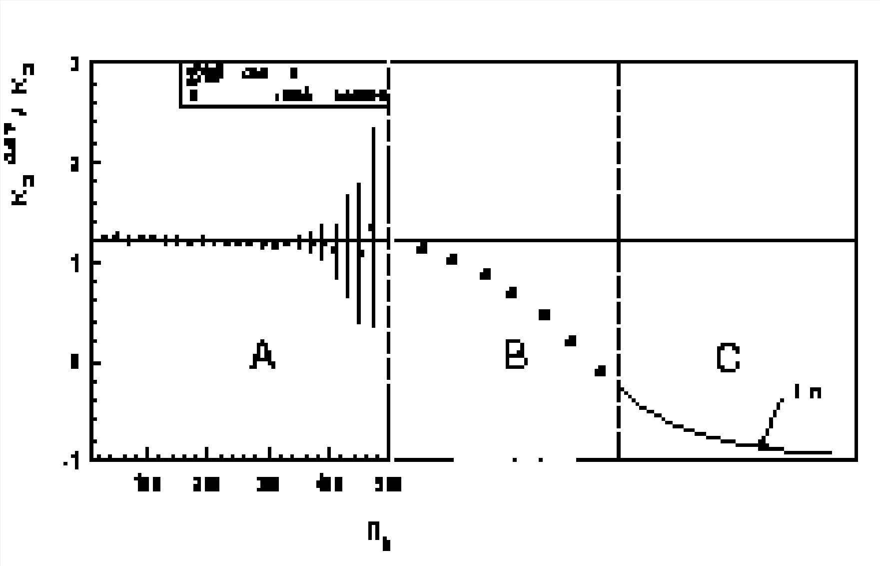
Prediction of generators: PITHYA

A. One may conclude that the dynamical models built into the PITHYA can not predict thermalization.

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

C. The limiting thermalization region:

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

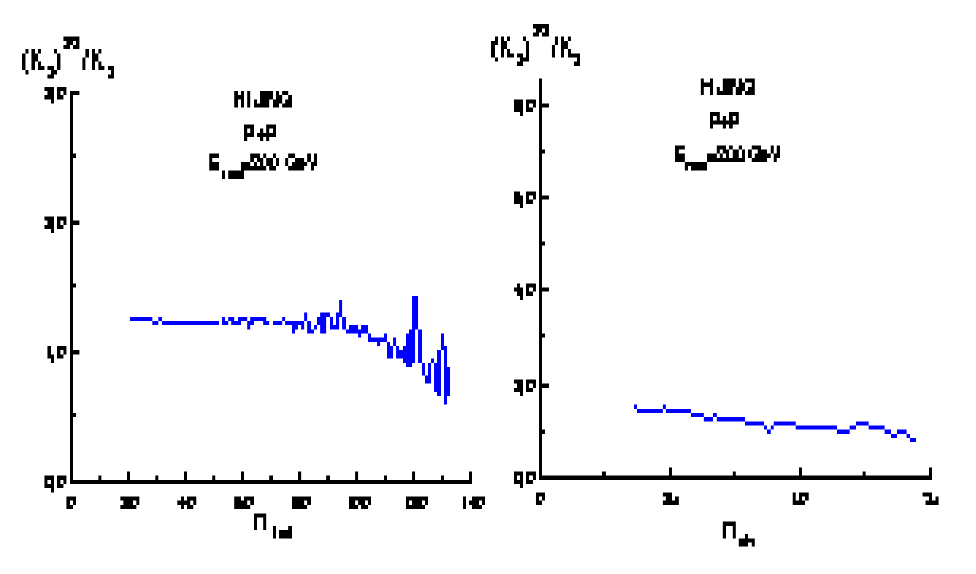


•Yu. Kulchitsky et al.

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..

Toward the experiment

To observe thermalization it is necessary to investigate the following relations:

- **The inequality**: $|K_3(E,n)|^{2/3} << K_2(E,n)$ **(**)**

- **The ratio of produced particle momenta: defines tendency to equilibrium** $\frac{< p_l >}{< p_{tr} >} \rightarrow \frac{\pi}{4}$

- **If the inequality (**) is held then**

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

is the chemical potential and $< \varepsilon; E,n >$ **is the temperature**.

Conclusions

- **Definite indications of thermalization phenomena exist in the heavy ion collisions**
- **Besides, some recent publication have appeared based on pp collisions which point to experimental evidence for thermalization phenomena (A.Erwin, L.Gutay et al, "Evidence for hadronic deconfinement in anti-proton proton collisions at 1.8 TeV", Phys. Lett. B 528, 43, 2002)**
- **The VHM kinematical region is outside of LLA abilities**
- **Ordinary ("Regge", pQCD in LLA,…) theoretical models can not predict even the tendency to equilibrium**
- **Our S-matrix interpretation of thermodynamics permits to show that the thermalization must occur, at least, in a deep asymptotics over multiplicity**
- **The test of pQCD frames in VHM region is a necessary task**

tQCD is on the "baby" stage: we can not give the "fast" predictions

Future steps:

- **Fast generator of events based on tQCD**
- **Formulation of effective trigger for VHM events with suppression ratio** $< 10^{-7}$