Thermalization Effect in High Energy Hadron Collisions

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1. Introduction

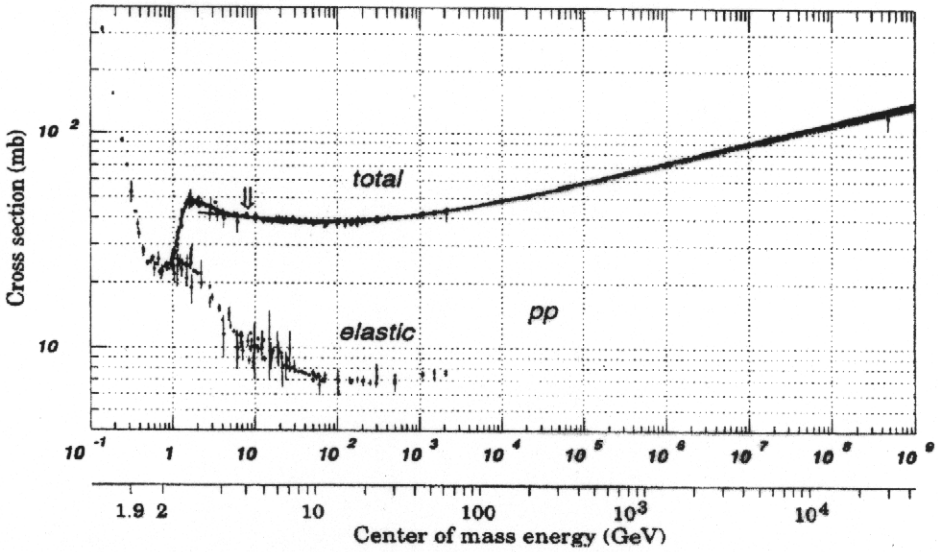

Figure 1: Total cross section. It is remarkable that σ_{tot} is approximately constant in the interval of 10 - 100 GeV. The Froissart constrain: $\sigma_{tot} \lesssim \ln^2 s$.

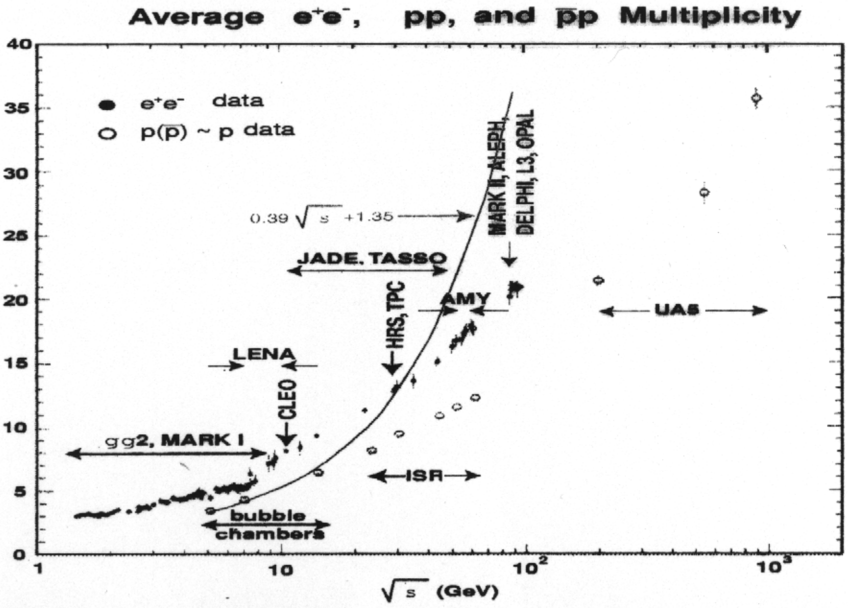

Figure 2: Mean multiplicity. The mean multiplicity in QCD jet $\bar{n}(s)_j$ and in the e^+e^- annihilation processes is relatively high: $\ln \bar{n}(s)_j \sim \sqrt{\ln s}$.

Main problem:
Why is the process of incident energy dissipation stopped at such an early stage that $\bar{n}(s) << \sqrt{s}/m_\pi$?

2. Basic idea

- **Input idea: the symmetry constrain may prevent thermalization.**

- **We will consider:**

— The necessary and sufficient condition, when thermalization is achieved.

— The way how this effect may be observed experimentally.

- **The thermalization effect is important** since

— The long-range "confinement" forces should be switched out.

— The coloured plasma is produced.

— The "rough" thermodynamical description is applicable.

— The "collective phenomena" can be observed.

3. List of Main References

The VHM physics phenomenology:
J.Manjavidze & A.Sissakian, **JINR Pap. Comm.**, P2-88-724, 1988; 5/31 (1988) 5; 2/281 (1988) 13

Introduction into the multiple production thermodynamics:
J.Manjavidze & A.Sissakian, **Phys. Rep.**, 346 (2001) 1

Generating functionals for QCD on the topological manifolds:
J.Manjavidze & A.Sissakian, **J. Math. Phys.**, 41 (2000) 5710, 42 (2001) 641, 42 (2001) 4158

Symmetry-constrained dissipation processes:
J.Manjavidze & A.Sissakian, **Th. Math. Phys.**, 123 (2000) 776, 130 (2002) 153

Formulation of a new general principle for the theory of symmetry-constrained dynamics:
J.Manjavidze & A.Sissakian, **hep-ph/0201182**, Title: Symmetries, Variational Principles and Quantum Dynamics .

G.Chelkov, M.Gostkin, J.Manjavidze, A.Sissakian and S.Tapprogge, JINR Rap. Comm., 4[96] (1999) 45; [3] G.Chelkov, J.Manjavidze and A.Sissakian, JINR Rap. Comm., 4[96] (1999) 35; J.Budagov, G.Chelkov, Y. Kulchitsky, J.Manjavidze, A.Olchevsky, N.Russakovich, A.Sissakian, Talk at the ATLAS Week, Lund, 2001

4. Definition of the VHM region

- General definition:

$$n >> \bar{n}(s)$$

- The inelasticity coefficient:

$$k = \frac{E - \epsilon_{\max}}{E}$$

- Kinematical definition:

$$0 < \frac{\epsilon_{\max}}{E} = 1 - k << 1$$

$\epsilon_{\max}$ - energy of the fastest particle in the given frame.

- Restriction from above:

$$n << n_{\max} = \frac{E}{m}, \quad m \approx 0.2 \text{ GeV}.$$

- VHM are rear processes:

$$\sigma_n \lesssim 10^{-7} \sigma_{tot}$$

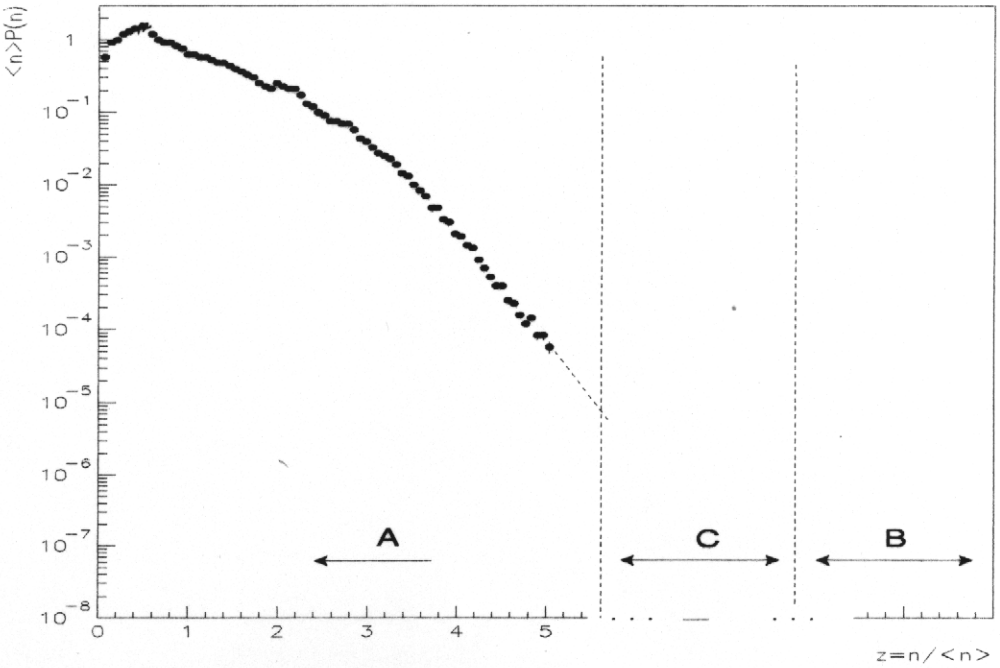

Figure 3: Multiplicity distribution: E-735 (Tevatron) data.

— **A**: multiperipheral kinematics domain;

— **B**: $|p| << m$ – thermodynamical limit of multiplicity;

— **C**: VHM domain.

5. VHM phenomenology

- Only three classes of asymptotics can be realized:

$$\mathbf{I}: \quad \sigma_n < O(e^{-n}) : \ \textbf{multiperipheral interactions}$$

$$\mathbf{II}: \quad \sigma_n = O(e^{-n}) : \ \textbf{hard processes}$$

$$\mathbf{III}: \quad \sigma_n > O(e^{-n}) : \ \textbf{vacuum instability}$$

- We offer to measure cross sections only with logarithmic accuracy considering

$$\mu = + < \varepsilon > \frac{1}{n} \ln \frac{\sigma_{tot}}{\sigma_n},$$

$< \varepsilon >$ is the mean energy of secondaries.

In the high multiplicity region:

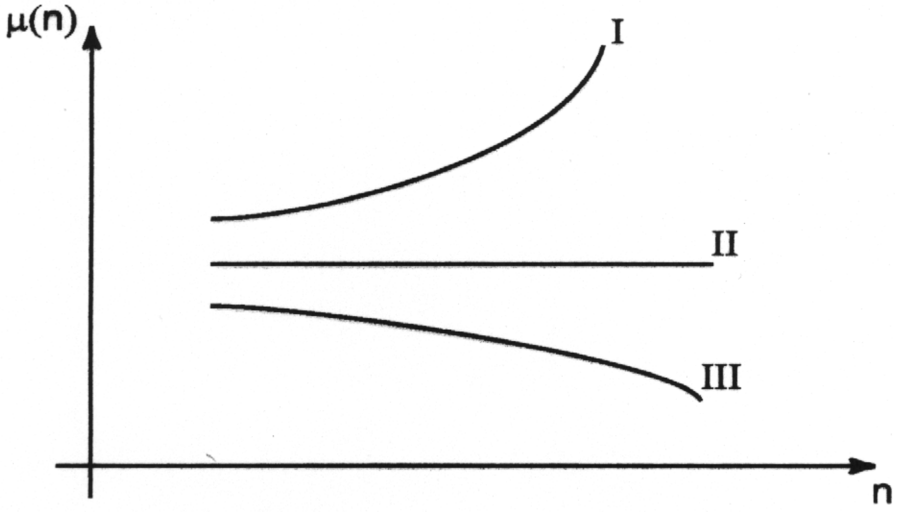

Figure 4: "Chemical potential" $\mu = - < \varepsilon > \frac{1}{n} \ln \frac{\sigma_n}{\sigma_{tot}}$ vs. multiplicity. Case **I** corresponds to the multiperipheral model; case **II** is predicted by the QCD jet; **III** – is a case when the vacuum is unstable against particle production. The latter case may include a situation with final-state interactions. To distinguish this possibility, one should investigate the analytical properties of μ over n.

6. Thermodynamics

- The straight line gives a Poisson distribution.
  There is the following decomposition:

$$\mu(z) = \sum_k (z-1)^k C_k,$$

C_k – **the binomial moment,** $C_1(s) = \bar{n}(s)$.

- The deviation means that the multiplicity distribution is wider than the Poisson's.

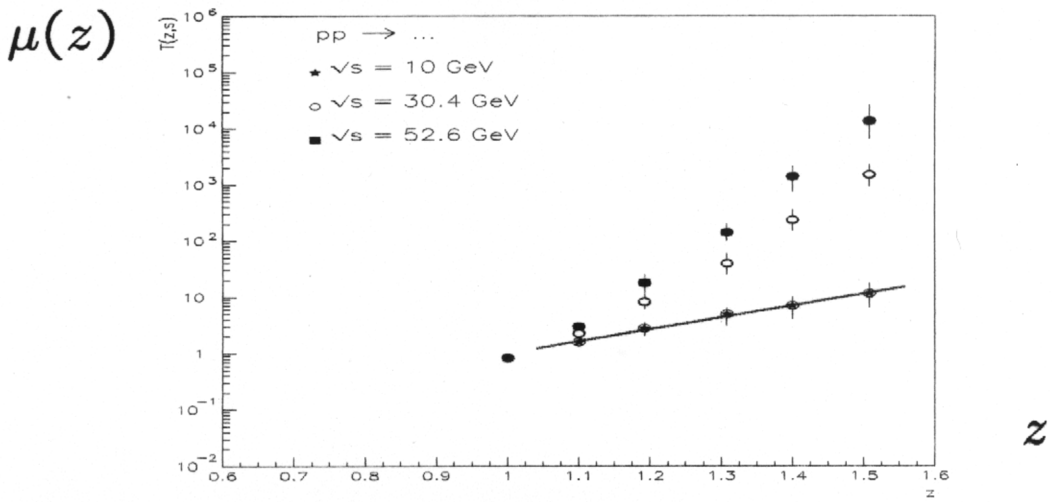

Figure 5: Chemical potential vs. activity z.

- If

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

then the thermalization occurs.
The correlation functions are usually defined as follows:

$$K_2(n,E) = <\varepsilon^2; n, E> - <\varepsilon^1; n, E>,$$

$$K_3(n,E) = <\varepsilon^3; n, E> -3 <\varepsilon^2; n, E><\varepsilon^1; n, E> +2 <\varepsilon^1; n, E>^3,$$

etc.

$$<\varepsilon^l; n, E> = \frac{\int \varepsilon(q_1)d^3q_1\varepsilon(q_2)d^3q_2\cdots\varepsilon(q_l)d^3q_l\left\{d^{3l}\sigma_n(E)/d^3q_1d^3q_2\cdots d^3q_l\right\}}{\int d^3q_1d^3q_2\cdots d^3q_l\left\{d^{3l}\sigma_n(E)/d^3q_1d^3q_2\cdots d^3q_l\right\}}$$

- Our conclusion ($\star$) is general, it weakly depends on details of dynamics.
- It is easy to prove that the system is equilibrium in the domain **B**.

7. Theory

- Multiperipheral (Regge) kinematics:

— **Longitudinal momenta**:

$$m << |p_i| << |p_{i+1}|, \;\; i = 1, 2, ..., n-1.$$

— **Transverse momenta**:

$$|k_i| = const, \;\; i = 1, 2, ..., n-1.$$

- DIS kinematics:

— **Longitudinal momenta**:

$$|p_i| = const, \;\; i = 1, 2, ..., n-1.$$

— **Transverse momenta**:

$$m << |k_i| << |k_{i+1}|, \;\; i = 1, 2, ..., n-1.$$

- VHM kinematics:

— $|k_i| \sim |p_i| << E, \;\; i = 1, 2, ..., n.$

Figure 6: Produced hadrons phase space.

8. Multiperipheral models

- The amplitude of one Pomeron approximation:

$$A^{\mathbb{P}}_{ab}(s,t) = i g_a g_b (s/s_0)^{\alpha(t)-1},$$

$$\alpha(t) = \alpha(0) + \alpha'(0)t,\ 0 < \alpha(0) - 1 << 1,$$

$$\alpha'(0) = 1\ GeV^{-2},\ s_0 = 1\ GeV^2$$

- Multiplicity distribution:

$$\sigma^{\mathbb{P}}_n = \sigma_{tot}\, e^{-\bar{n}(s)} (\bar{n}(s))^n / n! \quad (Poisson)$$

- Range of the multiperipheral models validity:

— Mean impact parameter of ν Pomeron exchange:

$$\bar{\mathrm{b}^2} \simeq 4\alpha' \ln(s/s_0)/\nu,$$

— $\bar{\mathrm{b}^2} \sim \alpha' \frac{\bar{n}(s)^2}{n}$ if $n \sim \nu \bar{n}(s)$

— Therefore, for the Regge multiperipheral model

$$n \lesssim \bar{n}(s)^2 \quad \text{if} \quad \alpha' \bar{\mathrm{b}^2} \gtrsim 1$$

- The cross section must sharply fall down for

$$n > \bar{n}(s)^2.$$

9. Perturbative QCD

- The probability to find parton b in parton a is $D_{ab}(x, q^2; n)$, where

$$D_{ab}(x, q^2) = \sum_n D_{ab}(x, q^2; n), \quad \alpha_s(\lambda) << 1.$$

- Leading logarithm approximation:

— $\ln(1/x) >> \ln \ln |q^2|$

— $\ln(1/x) << \ln |q^2/\lambda^2|$.

— $\lambda^2 << k_i^2 << -q^2$, where $k_i^2 > 0$ is the "mass" of a produced gluon.

- Leading Logarithm Approximation in HM region:

— $\omega(\tau, z) << \ln(1/x) << \tau = \ln(-q^2/\lambda)$,

— $\omega(\tau, z) = \sum_n z^n \int_{\tau_0}^{\tau} \frac{d\tau'}{\tau'} w_n^g(\tau')$,

w_n^g – the multiplicity distribution in the gluon jet.

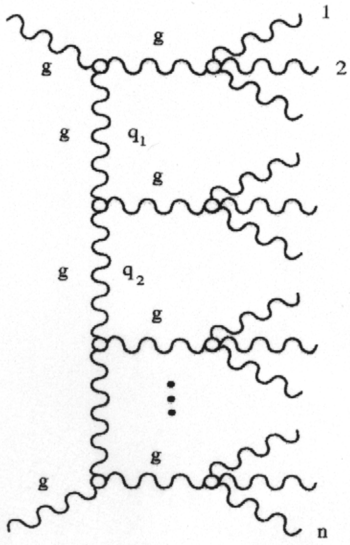

Figure 7: Feynman ladder diagram: $-q_1^1 >> -q_2^2 >> ....$

10. VHM process scenario

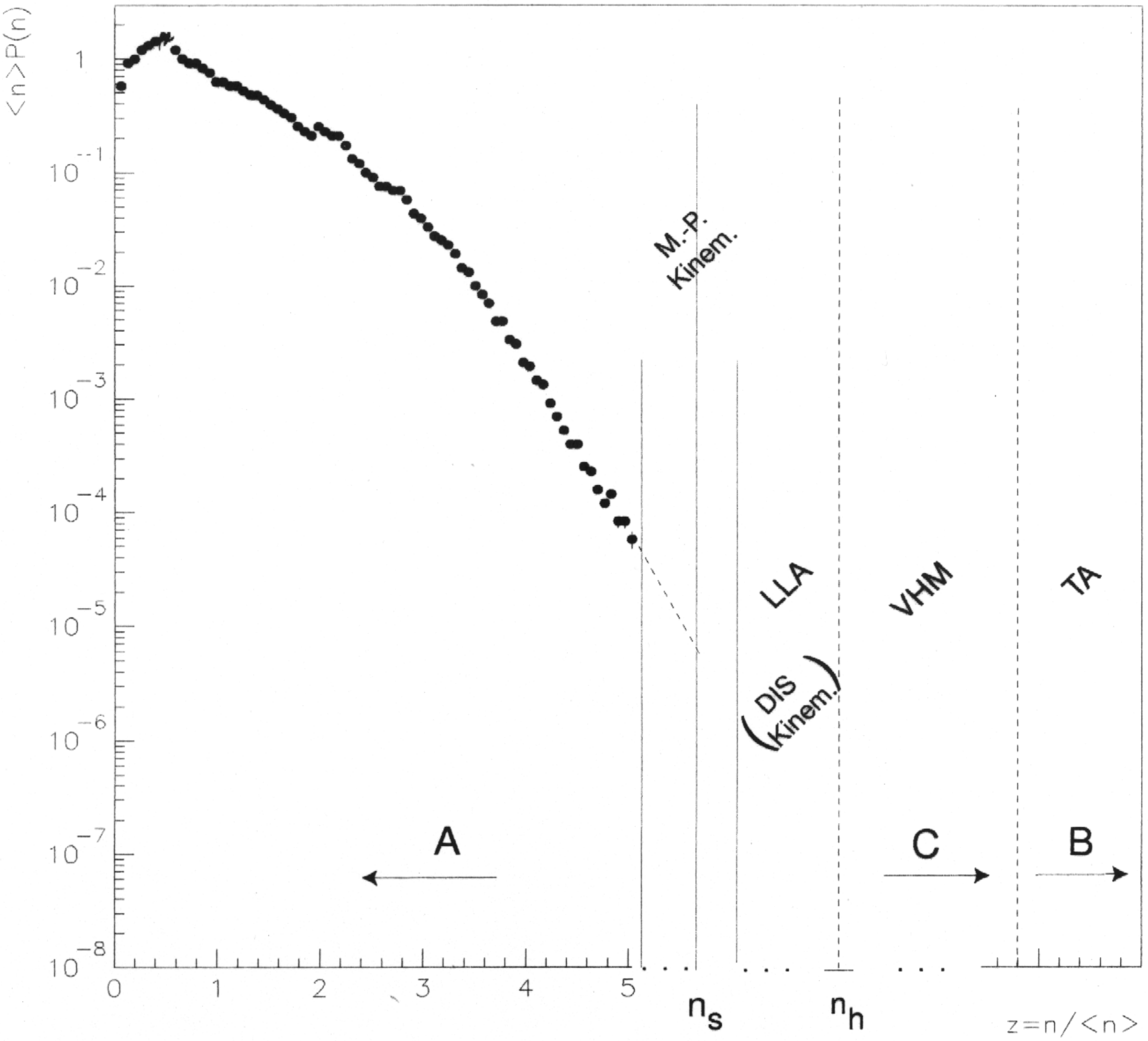

Figure 8:

$n_s \sim \langle n \rangle^2$

— $n_s \simeq \bar{n}^2(s)$ – the multiperipheral kinematics threshold

— $n_h > n_s$ – the LLA kinematics threshold

— VHM region – the region of thermalization

11. Prediction of generators

- PITHYA:

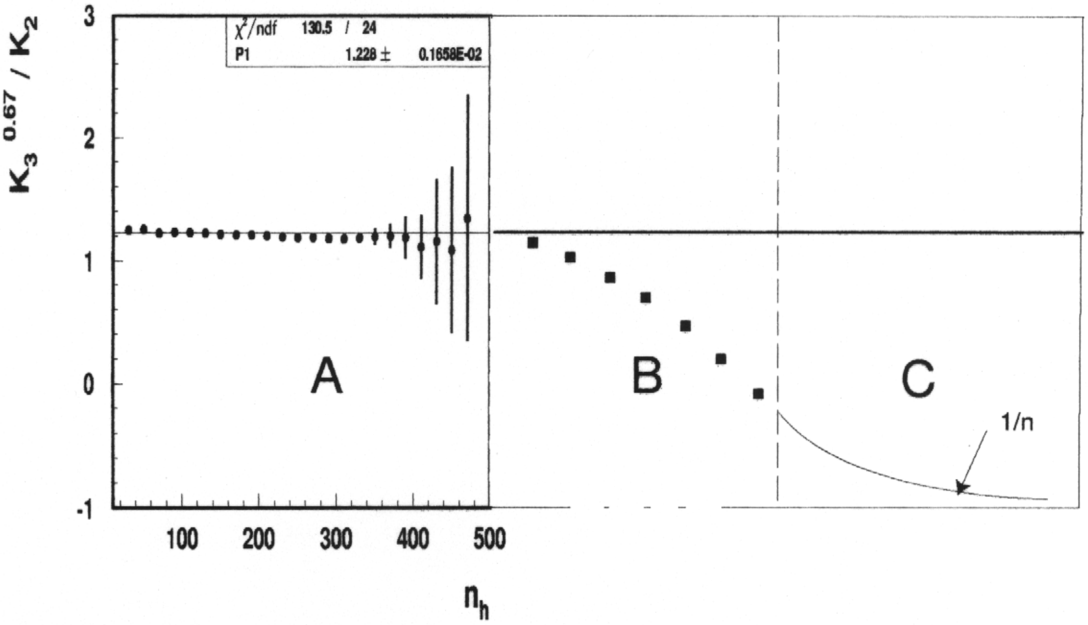

Figure 9: PYTHIA: K_3/K_2.

- HIJING:

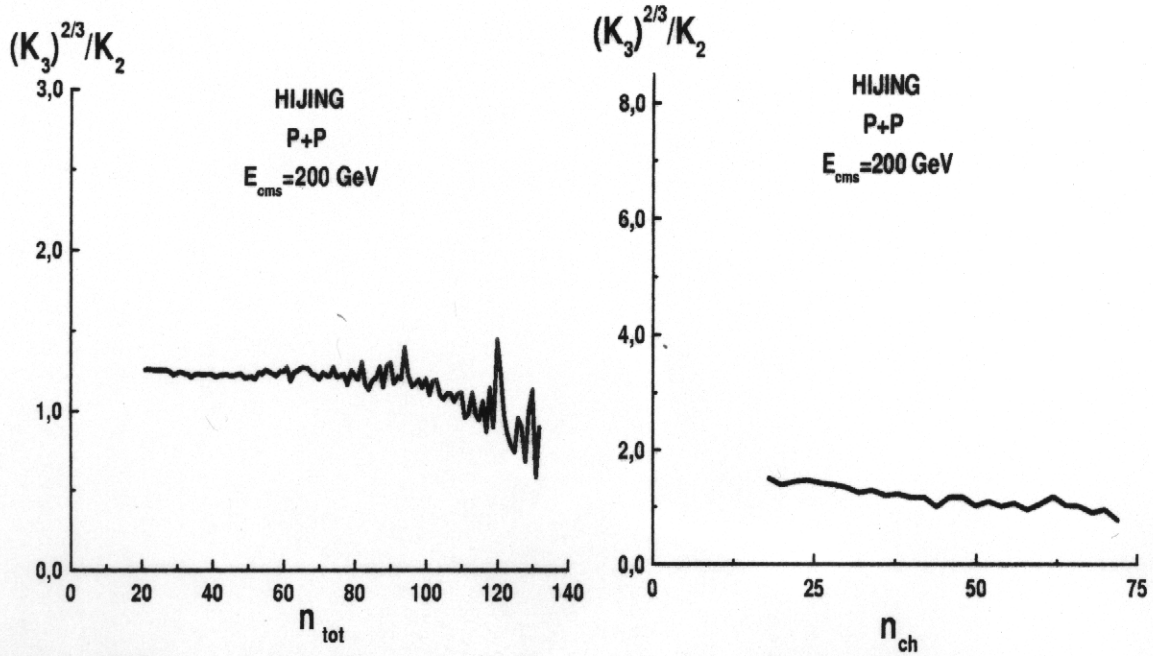

Figure 10: HIJING: K_3/K_2. The soft tendency to thermalization is seen from this picture. From this point of view the ion collisions, probably, are interesting.

12. Topological QCD

— There is no tendency to equilibrium in existing theoretical models.

— The VHM processes are hard.

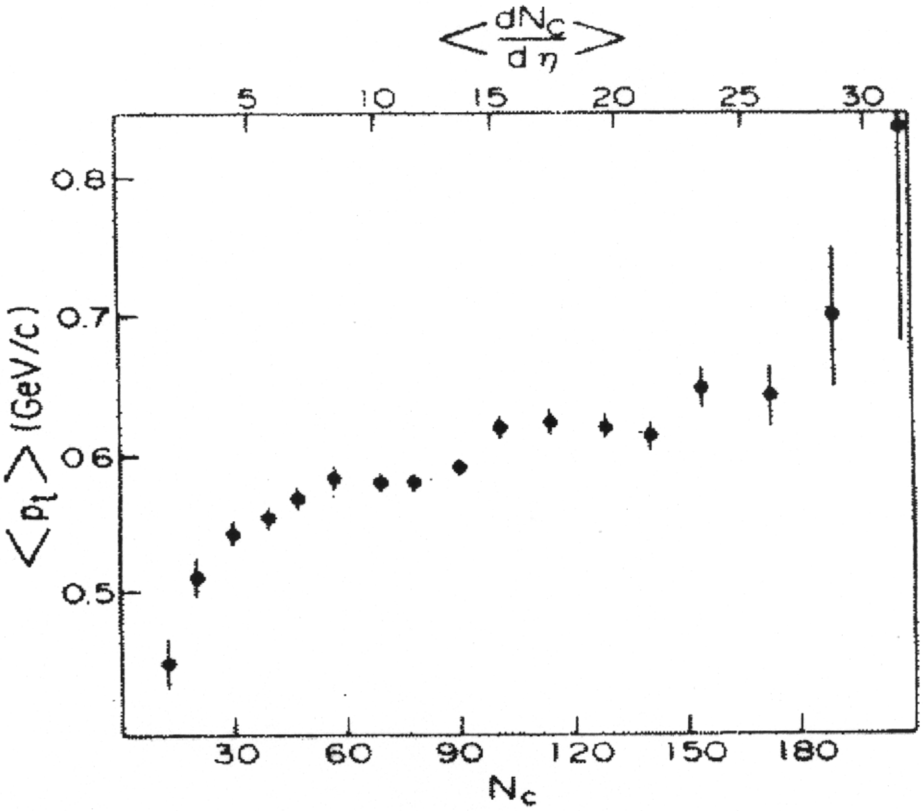

Figure 11: Transverse momentum vs. multiplicity. The Tevatron data (E-735 Group). This result is in strong contradiction with the multiperipheral model.

Properties of topological QCD (a new theory of VHM)

— The LLA is not applicable.

— tQCD includes the perturbative QCD.

— The theory is free from divergences.

— Expansion is performed over $1/g$.

— Thermalization effect.

13. Experiment

- Main problems:

— The thermalization problem.

— Quantitative definition of the range of validity of the LLA in the high multiplicity domain.

— Phase transition in the coloured state.

— The "pre-confinement" VHM state presents the **equilibrium** coloured plasma.

— The process of VHM production is "fast": **the isotop spin orientation may be frozen randomly** and large fluctuations of the charge must be valid.

- The following parameters as a function of energy E and multiplicity n should be measured in the VHM domain:

⋆ the ratio of the correlators

$$(|K_3(E,N)|^{2/3}/K_2(E,N)) << 1$$

– to observe thermalization;

⋆ the ratio of the mean values of the produced particles momentum

$$(\bar{p}_{\|}(E,n)/\bar{p}_{\perp}(E,n)) \to \pi/2$$

– to see the tendency to thermalization;

⋆ the "chemical potential"

$$\mu(E,n) = - < \epsilon > \frac{1}{n} \ln \sigma_n/\sigma_{tot}$$

– to observe the phase transition – (coloured plasma)→(hadrons);

⋆ the ratio of the number of charged to neutral particles

$$n_c(E,n)/n_0(E,n)$$

to see the vacuum topological defect.

14. Conclusion

The next steps
to observe the thermalization effect are:

- **from the theoretical point of view:**

— to construct the generator of VHM events based on tQCD;

- **from the experimental point of view:**

— to solve problems of trigger,

— to obtain the experience in the analysis of the VHM events.