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CERN EXPERIMENT EMU-15 ON ULTRARELATIVISTIC VERY HEAVY ION CENTRAL COLLISION.

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Abstract:

The group of experimentalists and theoreticians from three Former Soviet Union (FSU) institutions lanches a new experiment at CERN SPS. Main object of this experiment is investigation of properties of extremely dense/hot matter created in central collisions of ultrarelativistic (160 GeV/n) very heavy ions (Pb) with the identical target partners, using Emulsion Magnetic Chamber. Exposition is to be done at CERN, main data treatment and analysis is supposed to be performed in Lebedev Physical Institute, Moscow. Specific aim of the experiment is to provide exclusive data on super high multiplicity individual events (charge sign and full three-momenta of secondary particles) with corresponding analysis at the event-by-event level. Besides, specific goal of our group is also theoretical investigations of related problems basing, in particular, on works of participating theoreticians, both done earlier and those in progress. We suppose that our experiment will allow to enlarge statistics of events with possible indications to Quark-Gluon Plasma production and contribute to deeper understanding of matter under extreme conditions.

INTRODUCTION.

During last decades D-r K.A.Kotelnikov's experimental group investigated high energy nuclear interactions in cosmic rays using balloon born stratospheric emulsion chambers [1,2]. There were some one week duration flights from Kamchatka to Volga river (with 11 successful flights total exposition time being 1500 hours). Forty events have been collected and thoroughly studied, among them seven with super high multiplicity of secondary particles.

Excellent spatial resolution of tracks allowed to find some rare phenomena, e.g.: 1) for the first time there was observed so called a *ring-like* event (where recorded particles were uniformly distributed along a ring in the target plane [3]); 2) there were found events with large number of narrow spikes in pseudo-rapidity distribution of secondaries, and 3) events with extremely high transverse momenta of the majority of secondary particles (similar to those found by JACEE collaboration [4]). All these phenomena later were found also in accelerator experiments (e.g.[5-7]); they can not be explained within usual cascading-type models (e.g., FRITTIOF and so on), at least some of them might have direct relation to possible Quark-Gluon Plasma (QGP) production signals.

These experiments proved high reliability of used technique. However further development of stratospheric experiments does not seem to be promising because of very low intensity of cosmic ray heavy nuclei with high energy and hence low statistics of events. Naturally there arised the idea of transferring emulsion technique to accelerator experiment. The later possesses definite advantages:

i) the atomic number and initial energy of colliding nuclei are known precisely;

ii) there is a possibility to place emulsion chamber into strong magnetic field and thus measure full three components of secondary particle momenta.

The Lebedev Physical Institute group consisting of experimentalists and theoreticians has worked out the proposal P270. It has been suggested to use the Emulsion Magnetic Chamber (EMC) for investigations of peculiarities of hadroproduction process in collisions of high energy (160 GeV per nucleon) very heavy ions (Pb) with identical target partners at the CERN accelerator SPS. This proposal has been adopted by SPSL Committee in July,1993 as an experiment EMU15. First exposition is planned for 1994, now the experiment has the status "preparation".

The experimental data treatment needs hard labor, so we succeeded in involving into collaboration other groups. Now the group EMU15 includes also people from Institute of High Energy Physics of the Kazakh National Academy of Sciences as well as from St.-Peterburg Physico-Technical Institute of the Russian Academy of Sciences. Thus our collaboration includes FSU scientists only.

Taking into account our decades' long experience of experimentation with multi-layer emulsion systems we can hope to carry out treatment and interpretation analysis of at least 10 central events per year. Due to large amount of particles expected in events of such a type it would provide good statistical material for theoretical speculations and interpretations.

Physical objectives and specific goals of the EMU15 experiment are discussed in Section II. The descriptions of experimental set-up and planned methods of data analysis are presented in Sections III and IV respectively. Summary will be given in Section V. Some special questions connected with possible peculiarities of the QGP phase transition are discussed in Appendix A.

II. PHYSICAL OBJECTIVES.

The fundamental objective of the ultrarelativistic heavy ion collision experiments is to study high density state of hadronic matter, especially to clarify the problem of its deconfined state (i.e. QGP). Collisions of high energy very heavy ions (e.g.,Pb-Pb) where collective effects and, thus formation of thermolized super hot matter are highly probable seem to be most promising ([8-16]). The identification of QGP signals is a complicated task requiring efforts of various experimental groups (see, e.g., [16] and refs. therein) as well as further theory development.

Emulsion technique as a vertex defector with extremely high track resolution is most efficient for exclusive analysis of central collision high multiplicity events. Here rather significant results (e.g.[4]) may be obtained: it should be stressed that QGP might not manifest itself in the averaged central collisions but possibly could be recognized in some rare events, at the exclusive level analysis.

Our specific goal is to provide exclusive information on super high multiplicity events (as they seem to be the best candidates for possible QGP manifestation). Ve suppose: i)to study in details individual events; ii) to extract the event class where QGP signals might appear and analyze this class separately.

Use of the magnetic field enables to measure charge sign and three components of momenta of central rapidity secondary particles with sufficiently high precision. Until now such kind emulsion experiment data are scarce (at present there is a single group EMU05, the one working in CERN, which uses similar technique [17], and none in FSU).

Exclusive information on the secondary momentum components is especially important for extracting events with QGP manifestation since possible deconfined state signals (e.g., [9-10]) turn out to be essentially influenced by the entire dynamics of evolution and phase transition of the QGP blob: the first order phase transition, that seems to be the most probable case for QGP (see, e.g., [15,19]), leads to possibility of realization of various nonequilibrium hadronization scenarios with corresponding specific event patterns (e.g. [12-14,20-23], this point will be discussed in appendix A). Let us stress that in each particular event this pattern can follow some one particular chosen from a set of possible scenarios. Thus any attempt to interpret an event pattern has to be based on the reconstruction of the full history of this event, i.e. on the detailed dynamic picture of evolution (expansion and cooling) of the initially hot matter. This purpose requires for careful interferometry analysis; for analysis of fractal properties of the hadroproduction process; for identification of the event transverse momentum pattern. These goals call for detailed information on all three components of secondary particle momenta which is exactly what we can obtain with our technique.

Besides the analysis of traditional characteristics we are planning, in particular, to study in detail:

1) Two-particle correlations with possible collective flow effects taken into account. It would help in clarifying true character of collective flow in hadronic matter [24], to estimate the size and lifetime of particle source [25,26], etc.

2) Fluctuation patterns of individual events for fractal property analysis. The origin of short scale fluctuations in particle rapidity density is now widely discussed (e.g., [27,28]) due to its possible connection with the QGP production signals.

It deserves stressing that traditional characteristics of the collision process are reliable only with large statistics of events meanwhile the last two items mentioned above are meaningful even for individual events in question due to large number of particles providing high statistics within an event.

3) Transverse momentum spectrum at the event-by-event level (it is very sensitive to the choice of phase transition scenario [20-23]).

The data obtained are to be compared to predictions of known model scenarios of QGP evolution (e.g., [9-14, 20-23]).

This program refers to event-by-event level analysis. Besides, it is very important to select carefully the *ensemble of events* where QGP production is *in principle possible*. This very class is to be analyzed separately *instead of* averaging over all available central collision events as it is usually done (see,e.g., [16,17]): within averaged analysis specific information connected with QGP manifestations might be lost. Threshold effects may be recognized within *comparative* analysis of such chosen ensembles, statistically similar but satisfying or not satisfying to the chosen separation criterion. The choice of this criterion will be discussed below.

We keep also in mind further theoretical study of QGP blob evolution, especially of the phase transition process.

We hope that the program suggested would contribute to deeper understanding of super hot/dense matter and, in particular, would probably enable to extract possible QGP manifestations.

III. EXPERIMENTAL SET-UP.

The experimental set-up in main features consists of multi layer emulsion chamber placed into the usual CERN magnet and supplied with thin Pb target. It is to be exposed to 160 GeV/n Pb beam of the SPS accelerator. Data treatment is secured by semi-automatic track measuring complex constructed in the Lebedev Institute (with its spatial resolution being of 0.5μm).

The emulsion chambers contain typically 30-50 emulsion layers 50 μm thick each coated on organic (mylar) base which we succeeded to make as thin as 25μm thick. Such thin base helps to diminish background of tracks produced by secondary interactions. The first layer is supposed to be double-side, with the back side being covered by special type emulsion (so called K-emulsion) which is not sensitive to single-charged particles. Such emulsion layer is able to register only charged nuclear fragments and thus helps to extract central collision events (which hardly can produce nuclear fragments) at the first stage of treatment. Up to our knowledge such simple method of searching for central events has not been used so far.

Emulsion chambers are to be installed with layers perpendicular to the beam as it is shown in Fig.1. A thin target plate made of metallic 300 μm thick lead is to be installed just in front of the first emulsion layer. Common diameter of the target and the chamber is equal to 70 mm. For measuring charged particle momenta such chambers are placed in the transverse magnetic field equal to 1.5-2 Tesla induced by the usual CERN magnet.

The chamber in total is up to 300 mm long; inter-layer gaps of 3-9 mm are set up with high precision secured by special construction of layer holders. Total number of layers and their mutual distances are to be chosen with the help of an error optimization conditions. One of reasonable versions of the chamber construction is presented in Fig.1: here several first layers are close to each other in order to detect better the vertex position and secondary tracks at the beginning. Next layers where secondary tracks are more spreaded are separated by larger gaps (6 mm in the chamber central part and 9mm at the farther edge). Such construction would enable to measure secondary particle momenta with the precision of several percents.

In the process of exposition to the Pb beam with total number of some 10 000 beam particles uniformly distributed over the target area, some tens interactions with target nuclei are expected to be registered, among them several events have to be central collisions. The total statistics of central events can be increased by simultaneous use of several chambers.

Many hundreds of secondary charged particles are expected to be produced in each central collision (see, e.g., [16]). Tracing of these particle tracks through many layers of nuclear emulsion and measuring their coordinates are the main part of the procedure of experimental material treatment. This hard and scrupulous work is to be fulfilled mainly in Moscow Lebedev Physical Institute, in collaboration with other participating institutions. We suppose to be able to analyze about 5-10 central collision events per year.

The procedure of particle tracing through the emulsion layers includes a set of difficult points. The first problem is connected with the background (e.g., charged particles resulting due to some different nucleus interactions of the same beam, electron-positron pairs, etc). Taking into account that the total thickness of the emulsion chamber is equal to some 0.07 cascade units or .01 proton mean free path one can estimate the track background: for the first and the middle chamber layers it turns out to be 0.3 and 2 tracks within the area seen in microscope (100 x 100 μm) respectively. According to our previous experience on cosmic ray event analysis [2] such a value of background would allow to trace the track of each single secondary particle through all chamber layers and to measure coordinates of these tracks with the accuracy of 2 μm. For checking such tracing procedure the Monte-Carlo simulations have been fulfilled. Calculated track pattern in the first emulsion layer is shown in Fig.2 (assumed charged particle multiplicity N_{ch}=600). Treatment and analysis of this calculated target diagram revealed good reliability of the track tracing and the measuring procedures.

Another problem is connected with the particle Coulomb multi-scattering within the chamber emulsion layers. For checking this point we have done the Monte-Carlo simulation for particle momenta measurement taking into account the coordinate measurement error (equal to 2 μm) as well as errors due to particle multiple scattering. Averaged deviation angle within one layer has been estimated as $2*10^{-4}$ for central rapidity particles (with the momentum of some 3-5 GeV/c). The results of model calculations are presented in Fig.3. Available averaged accuracy of particle momentum measurements turned out to be equal to few percents (~6-8) for central rapidity particles and not worse than 15% for forward spectators.

Thus the use of Emulsion Magnetic Chambers (EMC) as a vertex detector with very high spatial resolution enables to measure not only charge sign and the emission angles (connected with the pseudo rapidity) but also all three components of the secondary particles momenta with a rather high precision. Such an experiment can not provide large statistics of events since the treatment of a single central collision event calls for long time. However it is just reasonable to use such device for exclusive analysis of individual high multiplicity events.

The group EMU05 exploits the device [17] very similar to our EMC. They succeeded in obtaining very interesting results, e.g., analyzing some 40 central events in S-Pb collisions at 200 GeV/n energy [17,18]. We hope to enlarge the statistics of highest multiplicity events working in parallel (perhaps in contact) with them.

IV. DATA ANALYSIS and INTERPRETATION.

Our approach to data analysis and interpretation is based to considerable extent on theoretical investigations of our group members [20-23,27,29] concerning multiple production and the phase transition, as well as on modern works on interferometry [24-26] and fluctuation [28,30] analysis.

It has been shown that possible QGP manifestations do depend essentially on the scenario of QGP blob evolution and further phase transition. In the case of first order phase transition (and this very case is recently generally accepted for QGP ([e.g.,15,19]) various nonequilibrium scenarios are possible, with different versions being possibly realized in different individual events. Some examples of such scenarios together with possible original signals of nonequilibrium transition will be discussed in Appendix A. In order to recognize these scenarios it is necessary to reconstruct carefully the entire dynamic picture of each particular event. For this goal detailed information on the secondary particle momenta is necessary.

Besides the analysis of traditional characteristics (such as particle pseudo rapidity and momentum distribution, averaged transverse momentum, etc) we are planning to do the following:

1) Detailed two-particles correlation analysis taking into account complicated dependence of the correlation function $C_2(\vec{p}_1,\vec{p}_2)$ not only on particle momentum (or rapidity) difference, but on full three momentum of each particle.

The form of the correlation function fit is most important for proper interpretation of experimental data. Usually the data are fitted by the simplified correlation form (see,e.g., [26,31]):

$$C_2(\vec{Q}) = 1 + \lambda * \exp(-\vec{Q}^2 * \vec{R}^2/2)$$

where $\vec{Q}=\vec{p}_1-\vec{p}_2$ is momentum difference between two particles, λ is so called incoherency parameter, with $\vec{R} = (R_{\parallel},R_{\perp})$ being interpreted as the source size. This form is based on the assumption that particle emitting source is an infinitely long living blob of hot thermally equilibrated matter at rest.$^{1)}$ If it is not the case one should study full Bose-Einstein correlation function containing 10 independent parameters referring to proper space-time evolution of

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$^{1)}$Moreover, it has been shown that such fit leads to underestimate of source sizes even in the simplest (but more realistic) case of the source at rest with *finite* correlation length (see [25]).

the source: correlation 4-length (L_0, L), transverse and longitudinal sizes of the system $(R_\perp, R_\parallel)$ and lifetimes τ for both chaotic and coherent parts of source, as well as coherence measure λ. Such fit is much more complicated but enables to perform so called interferometry analysis and to get an idea on the character of evolution dynamics. These results are to be compared to various QGP scenarios [e.g.10- 14,20-23] as well as to simulations within cascading-type models.

2) Analysis of the character of fluctuations in particle pseudo rapidity distribution, using the standard fractal moment method (see e.g., [27]) as well as the one suggested recently [30].

Analysis of fractal moment dependence on rapidity bin size allows to distinguish chaotic origin of fluctuations (or so called *intermittency*) from some regular but special type dynamics of the evolution. This method is based on the analysis of a *fractal moment* functions:

$$F_q = \left< \sum_{j=1}^{M} \frac{n_j*(n_j-1)*\cdots*(n_j-q+1)}{\langle n_j\rangle^q} \right>$$

where q is the momentum number, n_j is number of particles in the j-th rapidity bin, <n> is corresponding averaged value, M is total bin number. Data from all bins are summarized and averaged "vertically" (for inclusive analysis) or "horizontally", when the averaging is carried out within one event (if this event provides enough particles for statistical analysis). The size of each bin is: $\delta y=\Delta Y/M$, with ΔY being total rapidity size of the event.

Normally n_j has to decrease with δy so that F_q does not increase (for one special case of Poisson distribution all F_q are equal to unity, in other cases they should usually decrease). But in a set of special cases (e.g., δ-clusters [27],α-model [28],etc.) this dependence is more complicated. In some particular but interesting *intermittency* case (which is now widely discussed, e.g.[28]) there exist a linear dependence in double-log scale:

$$\ln F_q = \phi_q * \ln \delta y$$

where the moment slopes ϕ_q remain constant for any bin size. This case corresponds to some fractal cascading process and is hardly connected with deconfined state signals²⁾. Within several models

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2) however this problem is not yet fully clarified

dealing with phase transition [21,22] predictions for F_q vs δv dependence differ from intermittent pattern. Thus the experimental data here is of much interest.

Another method is based on the analysis of the fractal to cumulant moment ratio: the cumulant moments are connected with inclusive q-particle densities $\rho_q(p_1,...,p_q)$ by a set of linear relations [27] in such a way that they turn out to be zero when their arguments are statistically independent. This ratio may also serve as a sensitive parameter for distinguishing between cascading and collective nature of the process: recent predictions based on the modernized cascading approximation have been successfully approved on a set of experiments[31]. It would be very interesting to check it for heavy ion central collisions.

We wish to stress once again that the last two items are meaningful even for individual events in question due to high statistics within an event. During last years the most interesting information on this subject was provided by the exclusive data.

(3) Analysis of the transverse momentum spectrum at the event-by-event level. This is very important because the majority of phase transition scenarios described in literature (e.g. [20,11-13, 21-23]) influence essentially the transverse momentum pattern of the event (here again in different individual events this pattern may follow different scenarios). Thus transverse momentum pattern of the event is to be analyzed together with the space-time characteristics of this very event which can be clarified by the interferometry analysis.

Besides, specific information may be obtained by simultaneous analysis of spikes in particle (pseudo-)rapidity distribution and averaged transverse momenta for correspondingly chosen groups of particles: in some cases such narrow spikes may be treated as a sign of definite non-stationary phase transition process [22, 23]. In particular some specific scenario suggested is connected with creation of small long-living plasma drops with total transverse momentum within each drop equal to zero. Observation of such an exotic structures within one event would be indication to the phase transition from deeply supercooled QGP.

4) The comparative ensemble analysis. All the above mentioned characteristics refer to the *individual event* analysis. Next step is to separate from each other two *ensembles of events*

- the one including events where QGP participation is in principle possible, and another one, statistically similar but including events which do not satisfy the conditions, necessary for QGP production, - and to compare specific features of these two ensembles. The main point here is to choose sensitive enough parameter of separation: it has to be connected with initial temperature of the matter since in the central rapidity region QGP may arise only if the initial temperature exceeds the phase transition one T_c. We shall use the Bjorken criterion [8] based on the assumption that definite critical value of secondary particle rapidity density in central rapidity region corresponds to initial critical temperature $T_{in}=T_c$. Comparison of two ensembles including events with central rapidity region particle density larger and smaller than this critical one would enable to look for some threshold effects [22] if averaged values of some characteristics within each of these ensembles would turn out different. This would serve as some indication in favor of QGP participation in the events above critical threshold. At least, it would be a material for speculations.

Up to now such comparative analysis of two separated in such a way ensembles was not carried out: usually the criterion for event selection is connected with centrality (e.g., [6]) or high multiplicity (e.g. [18]) to provide sufficiently high statistics. This method seems hardly enable to extract any threshold effects.

It should be mentioned however that Bjorken criterion itself seems to need a modernization. As it has been reminded recently [32], the time necessary for primary thermalization is determined mainly by gluonic interactions while quarks interact much less intensively: they either penetrate through the *gluonic cloud* with forming then the fragmentation regions, or are included into the hot blob on a later stage. This scenario results in the estimate for initial time $\tau_{in} \approx 0.3$ fm instead of previous Bjorken assumption ≈ 1 fm. However this problem calls for further researches on fundamental problems of QGP creation and primary evolution to be ultimately clarified.

(5) Further theoretical investigations. The main point of difficulty for the search of the QGP manifestations is connected with the fact that each particular "suspective" effect observed earlier (and this probably is to remain like that in future) turned

out to be interpretable within some modernized models without turning to deconfinment phenomena. Therefore permanent efforts of theoreticians are required to develop detailed modeling and computer simulations of various possible versions of the deconfined state evolution.

We are planning to perform in particular:

- computer calculations of hydrodynamic equations for QGP blob evolution with nonequilibrium phase transition taken into account;
- modernization of the hydrodynamic model with complicated state equations;
- theoretical analysis of possible Bose Einstein correlation patterns within various scenarios of QGP blob evolution;
- analysis of yield of direct photons and lepton pairs within different scenarios of plasma evolution;
- search and study of other possible specific phenomena which may serve as signals of QGP production.

We are planning also to study the fundamental problem of double phase transitions from purely deconfined state to hadronic matter via specific phase of deconfined constituent quarks.

V. Summary

Preliminary investigations have demonstrated high spatial resolution of our EMC; strong magnetic field secures measurements of secondary particles charge signs and momentum components with high precision. This information is necessary to look for possible signals of QGP expected to appear in central collision events. At present only a single group (CERN experiment EMU05) uses similar technique.

Our specific goals are:

(1) to provide exclusive experimental data on super high multiplicity events (including detailed correlation and fluctuation analysis; transverse momentum spectra, etc);

(2) to carry out comparative analysis of two statistically similar ensembles of events separated, e.g., by the Bjorken criterion [8].

(3) to develop theoretical investigations of related problems, to provide, in particular, proper interpretation of the expected experimental material.

We also keep in mind possibility to observe some extraordinary phenomena and to study them if found.

We hope that the combination of three factors, i.e.: 1) the possibility of experimentation with very heavy high energy ions; 2) the possibility of obtaining full (exclusive) information on secondaries momenta accessible within our technique; 3) close collaboration between experimentalists and theoreticians within one group - give a good chance to investigate specific properties of thermolized hadronic matter under extreme conditions.

VI. ACKNOWLEDGEMENT.

We are very indebted to I.M.Dremin and I.V.Andreev for many extremely fruitful discussions.

VII. FIGURE CAPTIONS

Fig.1. Schematic picture of the emulsion magnetic chamber. 1 - 300 μm lead target; 2 - emulsion layers 50 μm thick, coated on the 25 μm thick organic base; 3 - spacers (3-6 mm thick).

Fig.2. Secondary particle track pattern in the first emulsion layer (Monte-Carlo simulations for multiplicity $N_{ch} = 600$). Magnification 813:1.

Fig.3. Results of Monte-Carlo calculations of the momentum measurement errors: with (a) and without (b) multiple scattering within emulsion layers taken into account.

APPENDIX A.

On the possible nonequilibrium scenarios of QGP blob hadronization

The identification of the QGP signals is a rather complicated and nontrivial problem. It has been shown [21] that *signals of the hot deconfined initial state* (such as strangeness enhancement, J/Ψ production, etc: see, e.g., [10]) may be distorted during the subsequent evolution process, especially at the stage of hadronization phase transition if, as it is widely accepted now [15], the latter is of the first order. From the other hand, the detailed consideration of the transition process enables to extract some special phenomena which may serve as specific *signals of phase transition*. Here we shall discuss several possible peculiarities resulting from the very fact of the first order phase transition, stressing the importance of exclusive data with measurement of 3-momenta of all particles created in an individual event.

According to dominating way of thinking first order transition from the hot deconfined state to hadronic matter lasts long in the rest frame of each element of expanding stuff, with the greatest part of time system spends in the *mixed phase* stage beginning just after the temperature of expanding system T_q falls down to the critical value T_c. However, detailed analysis of the transition process at micro level shows that there exist possibilities of various scenarios of phase transition which lead to various event patterns depending on the cooling conditions. Let us clarify this point.

In the process of expansion and cooling of a QGP blob, in the vicinity of the phase transition temperature T_c there should appear local thermodynamic fluctuations resulting in formation of new (hadronic) phase bubbles inside the QGP medium. The probability of such fluctuations can be estimated in a common way within the thermodynamic approach: it is connected with the free energy change ΔF resulting from such a fluctuation:

$$\Delta F = \frac{4}{3}\pi R^3 (p_q - p_h) + 4\pi R^2 \sigma \qquad (A.1)$$

$$V = \exp(-\Delta F/T_q) \qquad (A.2)$$

where R is the bubble radius; p_q, p_h are averaged pressures inside deconfined matter and hadronic phase respectively, σ is surface tension energy density at the two phase boundary (it is usually parameterized as: $\sigma=\delta * T_c^3$, with δ being called the surface tension coefficient).

According to thermodynamic laws such a fluctuation would be favored if corresponding ΔF is negative (note that it is possible only in supercooled metastable state when $T_q < T_c$). But the fluctuations satisfying this condition would increase violently (see, *e.g.* [33]) so that the medium would lose stability and could not be described as the thermodynamic meta-equilibrium state. Consequently the expression (A.2) becomes invalid. From the other hand, energetically unprofitable effect of the phase boundary formation accompanying the new phase bubble appearance results in fast degradation of too small bubbles (those with surface effects overcoming the volume ones).

Thus further fate of the fluctuation bubble can not be described within thermodynamic approach but should be defined by the *kinetics* of its evolution (i.e. should obey the Focker- Planck or Langevin type equations, see, *e.g.* [33,34]; those equations are rather complicated and ask for computer calculations mainly). However there is some region of bubble radius called *critical* one ($R \approx R_c$) where the fluctuation bubble turns out to be in (at least unstable) equilibrium - it corresponds to the maximum value of $\Delta F = \Delta F^*$, called the *phase barrier value*:

$$\Delta F^* = {}^2\!/_3 \pi * |p_q - p_h| * R_c^3 = T_c * \frac{16\pi}{3} * \delta^3 * \left(\frac{p_q - p_h}{T_c^4} \right)^{-2} \qquad (A.3)$$

with the critical radius defined as:

$$R_c = \frac{1}{T_c} * \frac{2\delta}{|p_q - p_h|} * T_c^4 \qquad (A.4)$$

The bubbles with radii close to the critical one are capable to survive and to proceed increasing inside metastable QGP medium and so developing initial local fluctuation into the global hadronization process remaining at the same time (at least at the first stage of growth) in equilibrium with the surrounding medium. Thus being constructing to the thermodynamic approach one can estimate only the *probability of the surviving fluctuation* appearance (while the character of its evolution is a subject for the kinetic description [36]). It is determined just by the phase barrier value (A.3):

$$V \approx \exp\left(- \frac{2\pi R^3}{3} * \frac{|p_q - p_h|}{T_q}\right) \approx \exp\left(- \frac{16\pi}{3} * \frac{\delta^3 * T_c^9}{|p_q - p_h|^2 * T}\right) \qquad (A.5)$$

All the statements made above refer to general theory of phase transitions. As far as concrete transition from the QGP to hadronic phase is considered the last formula can be reduced to the one with single variable dependence $V = V(T)$ using e.g. the common Bag model [35] for state equations:

$$\left.\begin{aligned} p_h &= {}^{1}\!/_{3} * T^4 \\ p_q &= {}^{1}\!/_{3} * (\varkappa\, T^4) - B \end{aligned}\right] \quad \Delta p = p_h - p_q = B - \frac{\varkappa - 1}{3} * T^4 \qquad (A.6)$$

where $\varkappa$ reflects the number of degrees of freedom in the deconfined state; B being Bag constant ($\approx$ 1 GeV/fm^3) reflecting the energy difference between physical and perturbative vacua; it is connected with the transition temperature T_c by the equilibrium condition:

$$p_h(T_c) = p_q(T_c) \quad \rightarrow \quad B = \frac{\varkappa - 1}{3} * T_c^4$$

Taking into account (A.6) the formation probability may be expressed (see, e.g., [22,23]) as:

$$V \approx \exp\left(- \frac{16\pi}{3} * \frac{\delta^3}{x\,(1 - x^4)^2} * \left({}^{T_c^4}\!/_{B}\right)^2 \right) \qquad (A.5)^*$$

where $x = {}^{T}\!/_{T_c} < 1$ is dimensionless temperature of the system; δ is considered here as phenomenological parameter (there were attempts to estimate it within lattice model calculations [e.g.,19] but the results are not ultimate; we shall discuss various possibilities).

Note that this function does depend strongly on temperature x; it tends to zero in the vicinity of critical point (when $x \rightarrow 1$ and critical bubble radius tends to infinity). Thus definite time should pass and some degree of super cooling achieved for a realistic hadronic bubble to appear. Thus the V value defines in turn the characteristic time τ_b necessary for launching the transition. In the rest frame of each element it may be estimated (see, e.g., [20]) accordingly to (A.5)* as:

$$\tau_b \sim \frac{1}{T} * V^{-1} \sim \frac{1}{T_c} * \exp\left(\frac{16\pi}{3} * \frac{\delta^3}{x\,(1 - x^4)^2} * \left({}^{T_c^4}\!/_{B}\right)^2 \right) \qquad (A.7)$$

One should note that this time is not the duration of the whole transition process (it is much smaller), this is only the *time delay* between the moment of cooling down to the critical temperature τ_c and the transition process beginning. This value usually is treated (after Bjorken) as 1 fm/c and thus negligible.

However, as a matter of fact, according to (A.7) it does depend essentially on the parameter δ so that the widely used estimate is correct only if δ is so small that the probability V is close to unity. Then large number of bubbles would arise simultaneously; their evolution and mutual interactions result in temperature increase in the whole system up to T_c value. Further evolution proceeds in equilibrium: T_q remains equal to T_c while energy and entropy densities decrease slowly due to spatial expansion of the whole medium until all the stuff would transfer into hadronic phase. It is exactly this micro-picture which corresponds to the well known *mixed phase* hadronization scenario at the global level.

In another case of not too small δ value the bubbles creation time could be considerably large so that considerable degree of super cooling might be achieved without phase transition. Then further events, being described by the kinetic laws (see e.g. [36]) would depend on the initial conditions (defining the blob cooling rate) and the δ value (defining the characteristic time of bubble appearance τ_b). Without entering technical details we shall describe here several possible scenarios of the local fluctuation developing up to global hadronization process. The following patterns are possible:

i) In the case of small value of δ and fast cooling, see [21], there appears the possibility for *vacuum bubbles* formation in the vicinity of the critical temperature T_C (this probability is defined by the formula A.5* with p_h=0). Since pressure inside the bubble p_h=0 exceeds that of surrounding plasma such bubbles would grow up violently; as a result, the blob would decay into separate small droplets. Further evolution of such droplets (proceeding by the deflagration process mainly, similarly to the Van Hove scenario [11]) would lead to fluctuations in the particle rapidity distribution with the rapidity size being of the order of unity: $\delta y \approx 1$. To identify such pattern experimentally it is necessary to estimate transverse momentum p_t and temperature for each clot of particles (it has to be close to the value characteristic for deflagration: $T \approx T_C$, $p_t \sim .4$ GeV/c). It is desirable also to estimate the size of emitted regions by the interferometry method.

ii)In the case of moderate δ value and moderate cooling rate, see [22], formation of the *hadronic bubbles* in sensibly super cooled medium seems to be the most probable. The process of such a bubble growth has non-equilibrium and non-stationary character. It results in narrow "bursts" of particles in rapidity space as well as in angular space (their rapidity range being of the order of some 10^{-1}). Transverse momentum of the particles inside such bursts is to be comparatively high: $p_t>.5$ GeV/c. Note that at least one event of this type has been found in cosmic rays [36]: significant short-rang ($\delta y \approx 0.2$) fluctuations in secondary particle rapidity distribution were at the same time characterized by the high value of transverse momenta: $\langle p_t \rangle \approx .8$ GeV/c. Thus it seems to be quite important to measure all p_t for narrow groups of particles within each event with considerable short-range fluctuations in secondary rapidity distribution dN/dy.

iii) In the case of large δ value, see [23], any type of bubble formation is possible only in conditions of deep super cooling and leads to rather specific pattern. The longitudinal expansion of the stuff dominating at the first stage of the system evolution (due to the inertial motion) would keep as well at the super cooled phase, while transverse expansion would stop just after the pressure inside the stuff becomes negative. Further super cooling results in the compression in the transverse direction, so that the drop may oscillate and, due to instability, may decay into individual small droplets moving in the *longitudinal direction only* and well separated in rapidity space. Here again the fluctuations in the particle rapidity distribution are expected (their rapidity range being about unity). However, contrary to the first pattern above, total transverse momentum of the droplets has to be equal to zero. Thus, the signal of this scenario would be the observation of few ring-like structures (symmetrical with respect to the collision axis) within one particular event. Again measurements of momenta of particles within each particular clot is necessary; it is needed also to define the spatial size of single droplets.

We would like to stress that orientation and motion along a single axis of several drops of matter seems to be specific feature for QGP stuff and is hardly probable for hadronic matter (alternative interpretation of this signal seems to be difficult). Thus the experimental observation of the last pattern would be encouraging evidence in favor of the QGP presence (with the transition barrier value being large).

iiii) In the limiting case of extremely slow cooling, see [21], (it has to correspond to very hot initial state) all nonequilibrium effects do not play any important role and the hadronization proceeds through the usual mixed phase stage for any realistic δ

value. This process would last long so that longitudinal size of the blob is to be very large. Such pattern also could be identified by careful interferometry analysis.

Thus the identification of any of all the patterns described calls for detailed interferometry analysis as well as for analysis of secondary particle momenta. This aim requires for detailed information on all components of secondary particle momenta.

Moreover, such an analysis would enable to extract a special phenomenon which may be treated as a signal of *the very fact of the first order phase transition.* Any of the above mentioned patterns could be realized in a particular individual event since initial conditions (actually, T_{in}) and, consequently, the cooling duration can differ from one central collision event to another. Thus the ensemble of the events above threshold (those with $T_{in}>T_c$) has to include a large variety of different patterns for, e.g., the p_t distribution. As a result the p_t distribution within an ensemble chosen in such a manner would demonstrate wide spreading around the averaged data when compared to the statistically similar ensemble of the beyond threshold events (i.e. those where deconfined phase participation is definitely excluded: $T_{in}<T_c$). Let us stress that averaged p_t distribution for those two ensembles on the contrary may differ not so considerably (if any), so that the comparison of averaged data only would not show any threshold effects, while the fact of nonequilibrium phase transition in this case would manifest itself only in relatively large data spreading. Thus detailed analysis described above and demanding detailed information on secondary particle momenta seems to be an important tool when looking for manifestations of phase transition from the deconfined state (QGP).

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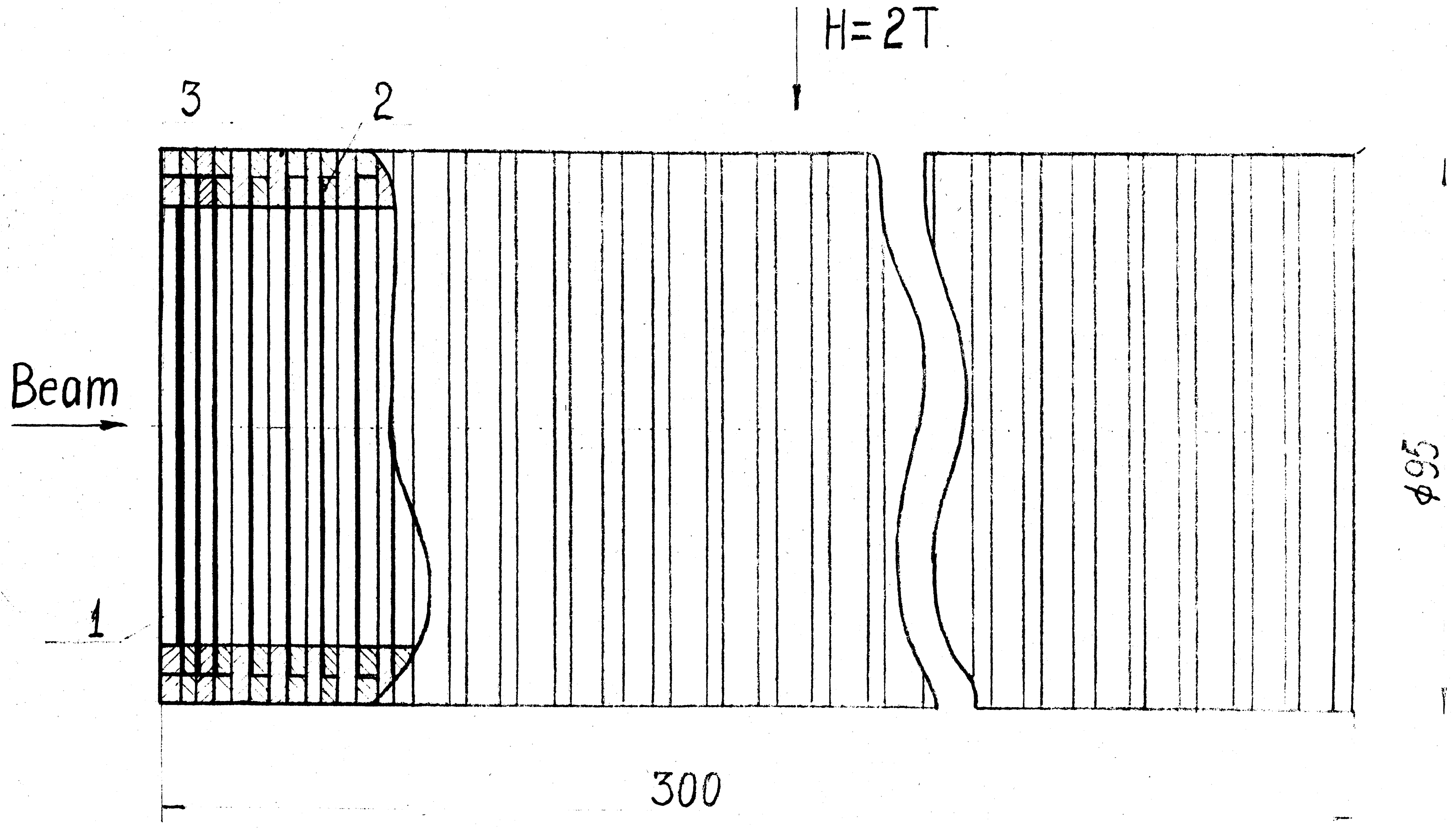

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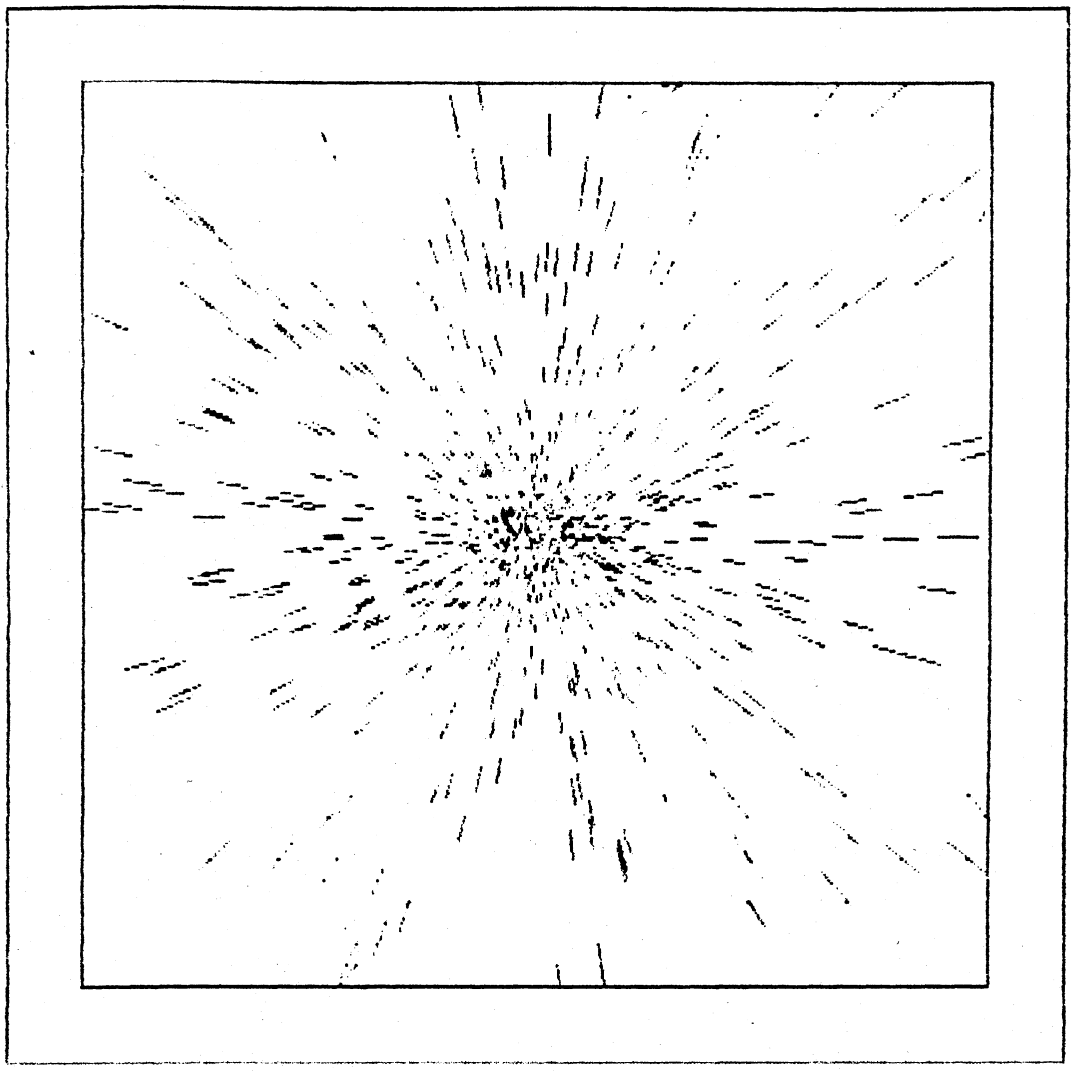

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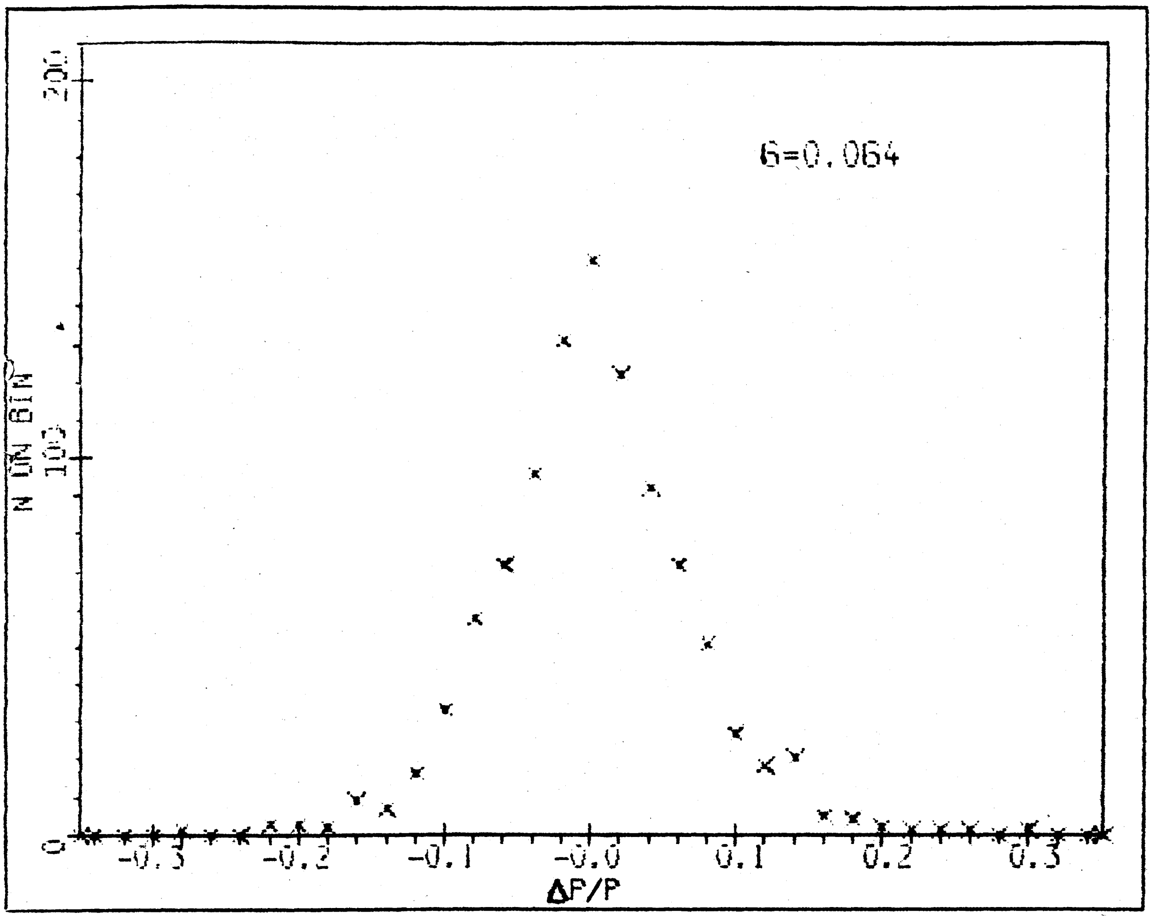
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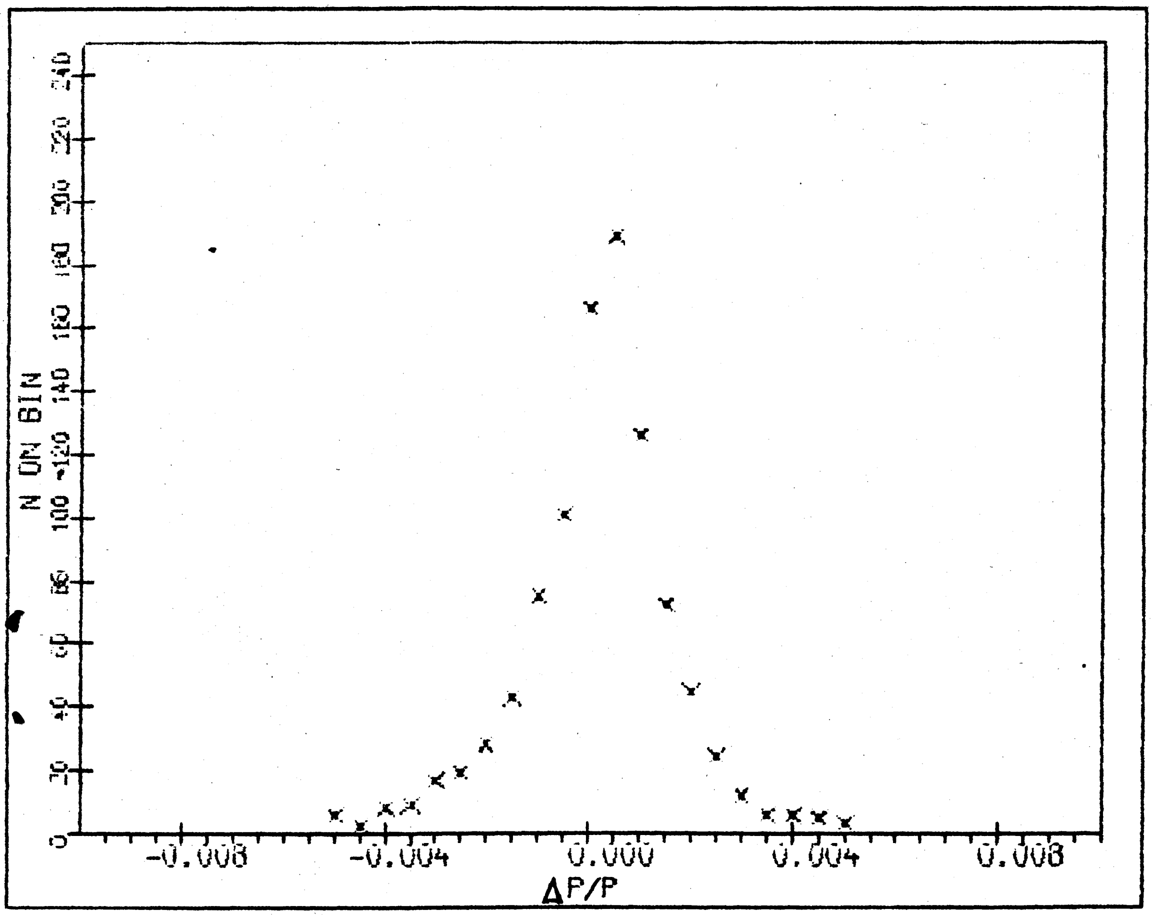
Fig.3(a)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ΔP/P

Fig.3(b)

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