RESEARCH

CERN/SPSLC 91-14
SPSLC P258
1 MARCH 1991

PROPOSAL

PARTICLE PRODUCTION, DENSITY FLUCTUATIONS AND BREAK UP OF DENSE NUCLEAR MATTER IN CENTRAL Pb+Ag AND Pb+Pb INTERACTIONS AT 60-160 A GeV

N. P. Andreeva, Z. V. Anson, V. I. Bubnov, I. Y. Chasnikov, G. Z. Eligbaeva, L. E. Eremenko, A. S. Gaitinov, G. S. Kalyachkina, E. K. Kanygina, V. N. Lepetan and T. I. Shakhova
Alma Ata, High Energy Physics Institute, USSR

G. F. Xu and P.Y. Zheng
Beijing, Academica Sinica, Peoples Republic of China

M. M. Aggarwal, R. Arora, V. S. Bhatia, I. S. Mittra and B. Singh
Chandigarh, Panjab University, India

Z. G. Liu, Z. Q. Weng and Y. L. Xia
Changsha, Hunan Educational Institute, Peoples Republic of China

M. Karabova, S. A. Krasnov, G. S. Shabratova, K. D. Tolstov and S. Vokal
Dubna, JINR Institute, USSR

K. B. Bhalla, S. K. Gupta, V. Kumar, P. Lal, S. Lokanathan, S. Mookerjee, H. S. Palsania, R. Raniwala and S. Raniwala
Jaipur, University of Rajasthan, India

S. K. Badyal, A. Bhasin, S. Kachroo, G. L. Kaul, L. K. Mangotra and N. K. Rao
Jammu, University of Jammu, India

V. G. Bogdanov, V. A. Plyushchev and Z. I. Solovjeva
Leningrad, V G Khlopin Radium Institute, USSR

X. Chan, S. B. Luo, Y. M. Qin and D. H. Zhang
Linfen, Shanxi Normal University, Peoples Republic of China

S. Garpman, B. Jakobsson, I. Otterlund*, K. Söderström and E. Stenlund
Lund, University of Lund, Sweden

E. R. Ganssauge and J. T. Rhee
Marburg, Philipps University, Germany

M. I. Adamovich, Y. A. Alexandrov, M. M. Chernyavski, S. G. Gerassimov, S. P. Kharlamov, V. G. Larionova, N. V. Maslennikova, G. I. Orlova, N. G. Peresadko, V. M. Rappoport, N. A. Salmanova and M. I. Tretyakova
Moscow, Lebedev Institute, USSR

T. H. Burnett, J. Grote, T. Koss, J. Lord, D. Skelding, S. C. Strausz and R. J. Wilkes
Seattle, Washington University, USA

E. Basova, H. Nasrulaeva, S. H. Nasyrov, N. V. Petrov, T. P. Trofimova and U. Tuleeva
Tashkent, Inst. Nucl. Phys., USSR

K. G. Gulamov, F. G. Kadyrov, N. S. Lukicheva, V. S. Navotny, N. Saidkhanov, L. N. Svechnikova and S. I. Zhokhova
Tashkent, Physical-Technical Inst., USSR

X. Cai, H. Huang, L. S. Liu, W. Y. Qian, H. Q. Wang and D. C. Zhou
Wuhan, Hua-Zhong Normal University, Peoples Republic of China

F. A. Avetyan, N. A. Marutyan, L. G. Sarkisova and V. R. Sarkisyan
Yerevan, Yerevan Physics Institute, USSR

*spokesman

PARTICLE PRODUCTION, DENSITY FLUCTUATIONS AND BREAK UP OF DENSE NUCLEAR MATTER IN CENTRAL Pb+Ag AND Pb+Pb INTERACTIONS AT 60-160 A GeV

Alma Ata - Beijing - Chandigarh - Changsha - Dubna - Jaipur - Jammu - Leningrad - Linfen - Lund - Marburg - Moscow - Seattle - Tashkent - Wuhan - Yerevan collaboration

1. INTRODUCTION

This proposal requests exposures with lead beams at 60 - 160 A GeV at the new heavy ion facility at the CERN SPS in 1993/94. Two different energies would be preferable. For collisions of such massive nuclei as Pb+Pb and Pb+Ag in this energy range theoretical estimates[1,2] suggest the possibility of a phase transition from normal hadronic matter to a quark gluon plasma (QGP).

The aim of the experiment is to study multiparticle production globally and locally, fluctuations in particle densities and the break up of dense nuclear matter in central Pb+Pb and Pb+Ag interactions. We will measure multiplicities and pseudo-rapidity distributions of produced particles, multiplicities and angular distributions of projectile and target fragments, production cross sections of projectile fragments and energy distributions of slow target associated fragments. The experiment will employ emulsion chambers with thin Pb and Ag target foils, as well as conventional emulsion pellicle stacks, which, as we shall show, have the necessary spatial resolution even at the highest predicted particle densities. Central interactions can, as in our previous experiments, be selected by the number of charges found in a narrow forward cone, which measures the remnant of the projectile nucleus, and a low charge flow in the forward direction will assure that most of the incident matter is stopped in the central region. This selection criteria is especially useful for comparisons between the outcome from event simulations and the experimental results.

It is of particular interest to see how well multiplicities and pseudo-rapidity distributions can be reproduced by a zero-degree geometrical approximation[3] using the knowledge we have gained from less complex systems, and significant deviations may indicate non-linear phenomena of coherent or collective nature.

The proposed experimental techniques have been extensively developed and tested by the collaboration. Identical apparatus and analysis methods were employed in the CERN experiment EMU01 and the parallell BNL experiment E815, which have been highly sucessful in collecting data from relativistic heavy ion collisions using oxygen, silicon and sulphur beams with energies ranging from 14.6-200 A GeV. Appendix A provides a list of publications containing results from runs at CERN and BNL during the period 1986-1989. The proposed CERN experiment will systematically extend our data to a significantly higher projectile mass range.

Before the exposures at the CERN SPS in 1993/94 we intend to realize two experiments where we will study Gold induced interactions at lower energies. One experiment is a study of Gold-Gold and Gold-Silver interactions at 1 A GeV in emulsions stacks and chambers exposed at GSI/SIS, Darmstadt. In the other experiment, already approved, we intend to investigate Gold-Gold and Gold-Silver interactions at ~ 10 A GeV at the BNL/Linac-Booster-AGS. We expect the Gold-beam in 1992 and results both from the GSI/SIS experiment and the BNL/AGS experiment should be available in due time before the CERN Pb-experiment. The collaboration will thus have access to similar types of heavy ion interactions registered in the same kind of detectors but at different energies. This will be the first time that a heavy ion collaboration has had an oppertunity to apply uniform data selection and analysis procedures to such a broad range of projectile mass-energy combinations.

Intercomparisons with ^{16}O-, ^{28}Si- and ^{32}S-nucleus data down to 2 A GeV and p-A data in the range 67-800 GeV from previous experiments are also possible using pooled databases supplied by the collaboration members.

The total demands upon CERN resources from this experiment will be very modest: pouring and processing facilities at CERN, approximately 16 hours of beam time (excluding tuning), a dose monitoring counter system to ensure proper exposures and the possibility to deflect the beam in order to select the predetermined flux of the exposure. Measurements, data selection and analysis will be performed in a large number of laboratories.

2. THEORETICAL PREDICTIONS RELEVANT TO THIS EXPERIMENT

The most important requirement for a phase transition to QGP in central collisions of two heavy nuclei at high energy is that the nucleons pile up and stop rather than have the nuclei pass through each other. The availability of Pb-ion beams at 160 A GeV represents an important advance in the range of baryon densities accessible to experiments aiming to deconfine quarks and gluons.

When the asymptotic products of the reaction become observable, the primordial state has long since dissapeared. Only the memory of the early evolution of the hot and dense matter, carried by some of the particles, is left and can be used to recognize the event as one in which a quark-gluon plasma was formed. After the plasma hadronizes, diagnostic signals for the QGP could be:

1. Particle densities, fluctuations. → energy density of the compressed system.
2. Interferometry → source sizes and life-times
3. Particle ratios (K/π, ...) → thermodynamics
4. Vector mesons with low mass (ρ, ω, Φ), vector mesons with high mass (J/ψ, ψ′, Υ...), thermal photons, jets, ... → primordial features

The amount of compression in central collisions is expected to grow with increasing energy until it is limited by longitudinal growth and transparency effects. Longitudinal growth refers to a finite amount of time (and therefore distance) required for particle creation. Because of this effect many of the particles produced in interactions between two sufficienly fast nuclei materialize outside the initial nuclei. From studies of high energy pA reactions we know that the nuclei are comparatively transparent and that transverse intranuclear cascading is small. It is then an interesting dynamical question to find out where the transparency sets in for the case of nucleus-nucleus collisions. To determine the amount of transverse and longitudinal cascading in Pb+Pb and Pb+Ag interactions, at which incident energies maximum baryon density is achieved and how much the central rapidity densities fluctuate and grow with energy, are important to investigate.

One of the models for interacting hadronic matter is Fritiof[4]. The first Monte Carlo versions where developed as a joint project between experimentalists and theorists at the University of Lund already in 1985, i.e. before the first heavy ion runs at CERN/SPS. In Fritiof colliding hadrons, in our case nucleons, become longitudinally excited objects referred to as strings. Such strings can then reinteract with other hadrons or strings, thereby transforming kinetic energy to excitational energy. When all binary collisions have taken place each string independently fragments into hadrons as described by the Lund fragmentation scheme. This last stage, due to a long formation time, is supposed to take place well outside the interaction region and interactions between the produced particles and the remaining spectator matter is neglected. Fritiof, which have been used by most of the ultra-relativistic heavy-ion experiments, has proven to be a useful tool for understanding the geometrical effects of nuclear interactions. One limitation of Fritiof is that the intra-nuclear cascade of slow target associated particles is neglected. For this cathegory of particles we will make use of another model named Venus[5] which better handles those particles.

3. THE EXPERIMENT

3.1 Experimental techniques

One important feature of the nuclear emulsion detector is the high spatial (and angular) resolution, combined with 4π coverage. The latter property will be somewhat limited in the backward region, where a part of the emulsion is obscured by the thick lead track. We intend to make accurate angular measurements of all the produced particles in central events, and also to measure the target fragments emitted at large angles. The latter will be done in conventional emulsion stacks. Specially designed emulsion chambers will be used to study particles emitted with angles less than 30 degrees from the beam.

3.2 Emulsion detector arrangements

3.2.1 Emulsion chambers

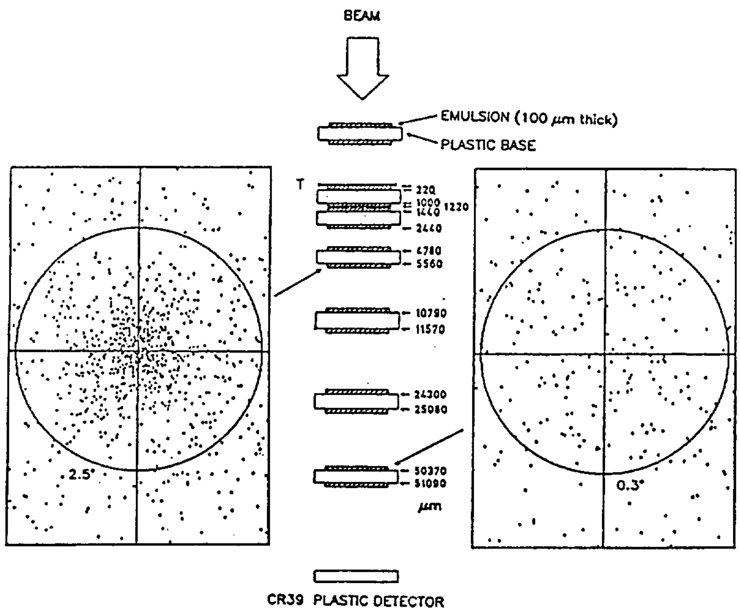


Figure 1: Principal layout of the emulsion chamber. Also shown are two microscopic fields of view showing the distribution of particle tracks from a simulated central Pb+Pb event with 1964 charged particles. The interaction is supposed to have occured in the target foil (T).

The emulsion chamber consists of 7 plastic base plates, each coated on both sides with nuclear emulsion (Fig 1). The target is either the emulsion material itself or a foil (Ag or Pb) sitting just in front of the second plate. Each chamber will be exposed at 4 different spots. The design is essentially the same we had for oxygen and sulphur. We have handled interactions with 600 produced particles, and there is no saturation effect felt so far. From a technical point of view the same basic design can be used for events with 2000 produced charged particles, foreseen in central Pb+Pb interactions at 160 A GeV. We plan to expose chambers with two different target materials, lead and silver. For a fraction of the chambers we also propose to put sheets of CR-39 plastics downstream of the emulsion chamber allowing particles with more than 0.1 milliradian in relative angle to be separated . The purpose of this arrangement is to make accurate measurements of the charges of the fragments produced in peripheral interactions. This is of evident interest for interactions of inverse kinematics, where the target is smaller than the projectile, and a sizable spectator should remain even in the most central events. Will some of these events be free from projectile fragments, i.e. will, in the extreme case, the transverse cascading be large enough to stop a lead nucleus with a silver nucleus? To use inverse kinematics will of course not change the physics involved, but it will change the response of the detector in such a way that new information is obtained.

The Pb beam tracks will be very thick due to the high density of their delta rays. The dense core will be about 20 microns in diameter, and the halo around the core, where measurements of minimum ionizing particles will be difficult, is about 100 microns.

It is simply not desirable to have any background beam track in the region where measurements are done. Consequently the particle density has to be quite low, about 500 cm^{-2} should be reasonable. One source of background which produce particles with angular correlations is conversions of π^0 gammas in the target material. 250 microns of lead is 0.04 radiation lengths. Assuming that the number of π^0's is half of the number of charged particles, we can estimate that the contamination due to this source is 2% on the average.

3.2.2 Conventional emulsion stacks

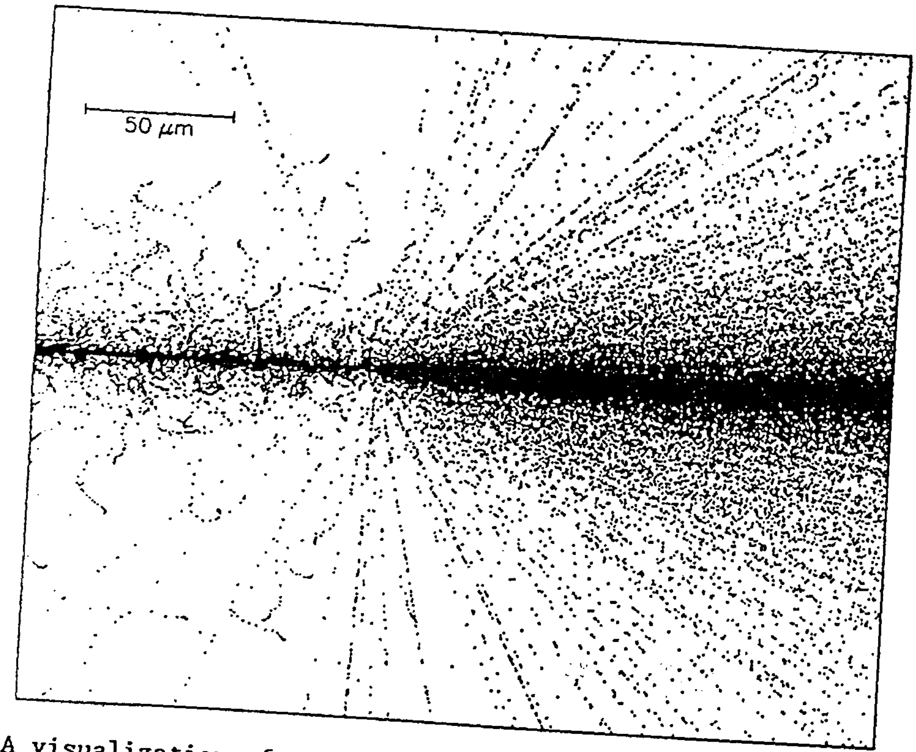


Figure 2: A visualization of a typical high multiplicity Pb+Ag event, as seen in the emulsion. Based on a Fritiof[4] simulation.

It will not be possible to get a true minimum bias sample of interactions in a horizontally exposed emulsion (Fig 2). For peripheral interactions the forward region will be partially obscured by the thick track from the projectile fragment. This will make electromagnetic dissociation, although very common, hard to detect. The horizontally exposed stacks will be very suitable for the study of the target fragmentation region, which make them complementary to the emulsion chambers, which are essentially blind for particles emitted at more than 30 degrees. It will also be considered to expose low sensitivity emulsion for the study of slow particles and projectile fragments. Relativistic singly charged particles are not recorded in such emulsion, and the delta ray halo around the lead track is much suppressed. Measurements in the emulsion stacks will be done with digitized microscope stages connected to computers.

3.2.3 Track measurement techniques

With Pb-induced events in the chambers we will face two new major difficulties:

i) Problem to find a suitable calibration track for defining the beam direction in the vicinity of the interaction.

ii) High multiplicity of charged particles.

The beam particle density has to be quite low and there is usually no beam track in the microscope field under study. With an accurate digitized microscope stage it will be possible to use quite distant beam tracks for the coordinate calibration. Due to the high density of delta rays the Pb tracks will be very thick and the center will not be very well defined. Tests show, however, that the center of such a track can be located visually with a standard deviation of less than 1 micron. Consequently, the lead beam tracks can still be used to calibrate the beam direction, in spite of their fuzziness. It will be possible to locate the position of the extrapolated path of the beam particle to an accuracy of 2 microns. The corresponding angular error for the most forward particles is 0.03 milliradians with existing equipment.

The high multiplicity (up to 2000 charged particles) is no fundamental problem for existing measurement systems, but the work will be time consuming. It is estimated that an event with 2000 particles will take 20 hours to measure. For this reason a new automatic system is under development. It is based on image analysis of microscope images from a CCD-camera. To register all information of an event takes about 1000 pictures, which corresponds to 300 Mbyte of data. This can be reduced to 3 Mbyte by zero-level suppression and by adding information from many individual images, corresponding to images in different planes, into one single image. The depth coordinate information can be stored as the colour of the pixel. A three-dimensional track search will then be done in this image. The measurement procedure is quick, but the large amount of data requires a fast image processor. There are several suitable processors for this purpose on the market today.

3.3 Event rates

With a typical beam particle density of 500 cm^{-2}, an effective beam-spot diameter of 4 cm would give us about 6000 particles per beamspot. Assuming a 250 micron thick lead target and 3.8 cm mean free path, we can expect about

40 inelastic interactions per beamspot. Electromagnetic dissociation is not included in this figure. This kind of interaction will in general not be detectable in the emulsion chambers. 80 chambers with 4 beamspots each will thus contain about 13000 inelastic interactions. The corresponding number for 60 chambers with 250 micron silver target will be about 15000 interactions. The beam particle density requested (500 cm^{-2}) is about at the upper limit which can be accepted. If the effective diameter of the beam will be smaller than 4 cm, the number of events will be reduced accordingly.

3.4 Beam requirements

Both emulsion chambers and stacks require a defocused beam. A diameter of the beam-spot of 4 cm would be ideal. The desired beam particle density is about 500 cm^{-2}. It is essential that the beam can be switched off within a fraction of a spill, when the required number of particles has been counted. With this arrangement we need just one spill for each exposed spot. The exposure equipment designed for the oxygen and sulphur runs allows us to make use of every beam spill. The experiment requires about 600 exposures, which will take less than 16 hours. The beam requirements are quite similar to those we had for the experiments with the oxygen and sulphur beams.

3.5 Pouring and processing facilities at CERN

We plan to produce the chamber plates at CERN with nuclear emulsion gel. It is essential for the experiment that we have access to the pouring and processing facilities at CERN. In order to keep the background low the time lapse between pouring and processing should be minimized. A very low background is essential for the automatic CCD-camera based measuring system mentioned above. The gel pouring operation is estimated to take 2 weeks, and the processing also requires about 2 weeks.

3.6 Measuring facilities in the participating laboratories

Laboratory	Measuring facilities		
Alma Ata, Inst. of High Energy Physics, USSR	H	(V)	
Beijing, Academica Sinica, China	H		
Chandigarh, Panjab University, India	H	V	(CCD)
Dubna, JINR, USSR	H	(V)	
Jaipur, University of Rajasthan, India	H	V	
Jammu, University of Jammu, India	H	V	
Leningrad, V G Khlopin Radium Institute, USSR	H	(V)	
Linfen, Shanxi Normal University, China	H	(V)	
Lund, University of Lund, Sweden	H	V	CCD
Marburg, Philipps University, Germany	H	V	CCD
Moscow, Lebedev Physical Institute, USSR	H	(V)	
Seattle, University of Washington, USA	H	V	CCD
Tashkent, Institute of Nuclear Physics, USSR	H		
Tashkent, Physical-Technical Institute, USSR	H	(V)	
Wuhan, Hua-Zhong Normal University, China	H	V	
Yerevan, Physical Institute, USSR	H		

H : Equipment for measuring horzontally exposed plates
V : Equipment for measuring vetically exposed chambers
CCD : CCD-camera based systems
() : Equipment the lab probably will have in near future

4. THE PHYSICS OBJECTIVES

4.1 Nuclear fragmentation

It was observed in recent heavy ion experiments that the breakup properties of the target nuclei in ^{16}O induced reactions, as measured by black prong particles (energy $\lesssim$ 25 A MeV), are remarkably constant from ~ 0.1 A GeV to 200 A GeV. In fact similar observations, though not systematically studied over such a wide energy interval, has been reported also for the projectile breakup. It is of interest to further investigate the production of slow, target associated particles from interactions between nuclei with higher masses.

All projectile fragments will essentially continue in the beam direction with the velocity of the beam, and will thus be observed in a narrow forward cone.

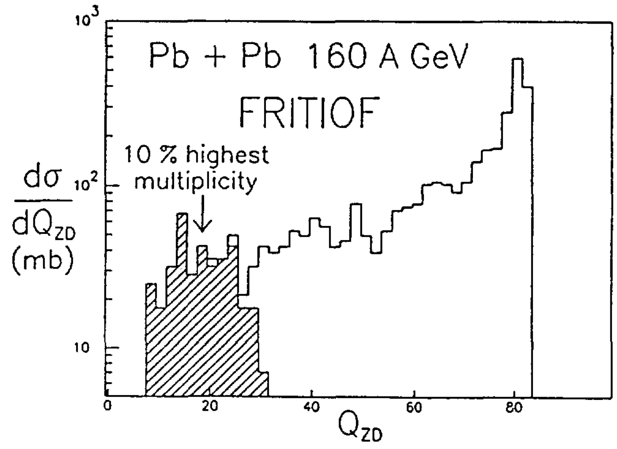


Figure 3: The cross section of events with a given number of charges, Q_{ZD}, inside a forward cone.

Particles, which are produced in the overlapping parts of the nuclei, will normally emerge with larger angles. In our previous experiments we have used the quantity Q_{ZD}, which is the total number of charges observed in a cone with the angle $\theta_{ZD} \simeq 0.6/p_{beam}$, for event selection. From studies of ^{16}O+A and $^{32}S(^{28}Si)$+A interactions at 14.6, 60 and 200 A GeV, we have observed that Q_{ZD} is an energy independent measure of the centrality of the collision. Q_{ZD} distributions in Pb+Pb(Ag) and Au+Au(Ag) interactions will be investigated and used for impact parameter selection. In Fig 3 we show the minimum bias Q_{ZD} distribution for Pb+Pb interactions where the 10% most central events are indicated. From the Fritiof simulations it is evident that the cross section for a totally empty forward cone is vanishing. Will this also be true in reality? If so, it will point to a larger stopping than expected, presumably due to an increased transverse cascading.

With a combination of emulsion chambers and horizontally exposed stacks we will be able to collect data for both projectile and target fragmentation. The experimental difficulties to identify all fragments event-by-event will be large, but the introduction of CCD-based measurement devices will help to carry throuh this challenge. A special effort should also be made to study the dependence of the grey particle multiplicity (produced in pre-equilibrium processes) on the beam energy as well as on the degree of target and projectile breakup. This is important for the understanding of the degree of intranuclear cascading. For this purpose we intend to propose experiments on Au induced collisions also at ~ 10 A GeV (BNL/AGS) and at ~ 1 A GeV (GSI/SIS), as mentioned above.

4.2 Global characteristics

An experiment, as the one proposed here, has, due to its almost uniform 4π coverage, its main merits in the global studies of produced particles and can in many ways complement other experiments focused on limited regions of phase space. The lack of information, like particle identities, charge and momenta, is thus counterbalanced by the gain of having information from both the target and projectile region as well as from the central region. This is even more emphasized in the new generation of experiments where the large scale counter experiments mainly are devoted to a few specific signals, i e strangeness enhancement, thermal photons, J/Ψ suppression, Bose-Einstein correlations and so on. The emulsion technique has been used to collect data from a large variety of interacting systems at several different energies. We will thus have a unique possibility to address a lot of interesting questions involving the dependence of the size of the interacting system and of the incident energy, and to be able to answer them with data collected by essentially the same detector. Using emulsion chambers equipped with thin target foils of different materials we will be able to study multiplicity distributions and rapidity density distributions as a function of target mass, and together with our previous measurements with lighter projectiles, be able to study how the nuclear matter influences the particle production.

In the string picture, there will be a tremendous number of overlapping strings in the mid-rapidity region in central lead on lead collisions. According to recent string calculations it means that one can expect the strings to interfere with each other[6], and when they do one would expect non-linear effects to arise. It is suggested that some of the produced particles can receive a collective longitudinal momentum-kick, which will move particles from the mid-rapidity region closer to the fragmentation regions, thereby broadening the rapidity distribution. It is furthermore suggested that the interference between strings can increase the energies of jets by a factor which is strongly dependent on the number of interfering strings.

4.3 On the importance of understanding multiparticle production and fluctuations in high dense nuclear matter

It is fair to say that our knowledge of the processes responsible for the particle production in heavy-ion collisions, forming the foundation for searches for new phenomena related to dense matter, is obtained through studies of the experimental observables, in which the parameters are varied. It has also been of great help for the formulation of new ideas that the studies of observables have been as complete as possible, so that these ideas can be tested not only for a specific signal, but also how this signal is correlated to other observables. With lead projectiles it must thus be our first priority to gain understanding of multiparticle production and related fluctuations in dense nuclear matter before the next step involving the interpretations of any new phenomena.

This means firstly, to test simple extrapolations from less complex interacting systems using the zero-order geometrical approximation[3] or phenomenological models, and secondly, to try to modify these ideas taking the dense matter into account. In this process we might single out effects which has to be interpreted from a different view point, effects which then can be studied in more detail. In Fig 4 we show charged particle density distributions from Fritiof[4] simulations for Pb+Ag and Pb+Pb collisions at 160 A GeV for the 10% highest multiplicities and the multiplicity distribution for

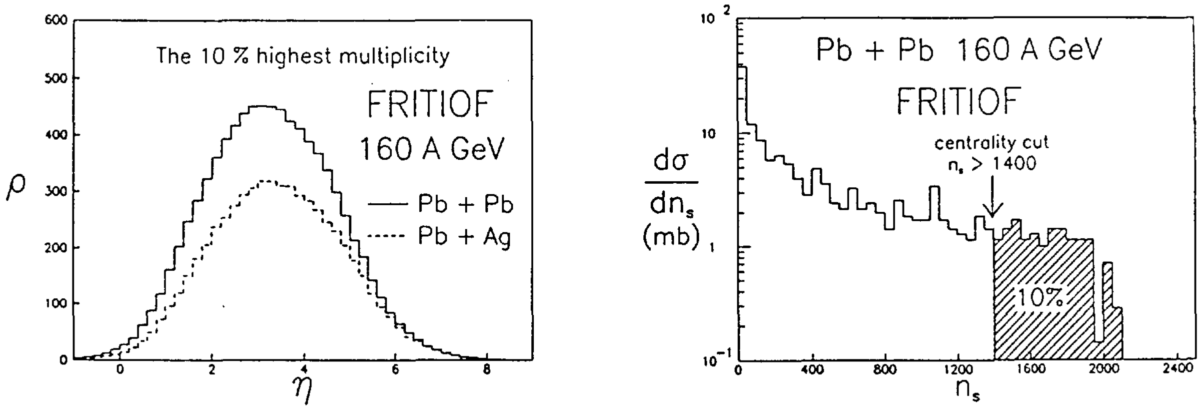


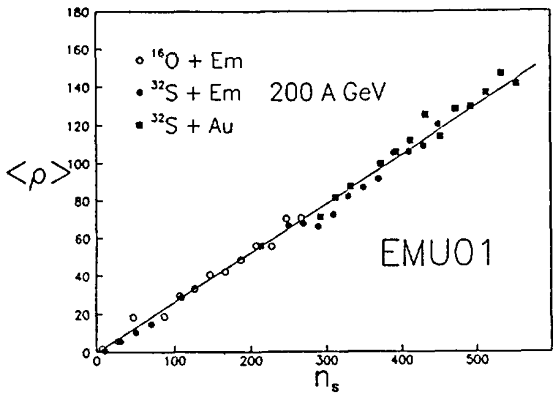
Figure 4: Pseudorapidity distributions for Pb+Pb and Pb+Ag collisions at 160 A GeV incident energies (left) and multiplicity distribution for Pb+Pb collision at 160 A GeV (right) as predicted by Fritiof.

Pb+Pb collisions at 160 A GeV where the tail has been shaded to indicate the 10% centrality cut. These distributions have a direct bearing on the experimental set-up, and we have to be prepared to measure events with more than 2000 particles (see Section 3.2.3).

In experiments dedicated to specific physics questions one might find that the lack of global information can prevent the answer of the question from being given. We thus strongly believe that at least one experiment with the lead beam, like the one proposed here, has to be concerned with the global studies of the produced particles.

4.4 Multiparticle production

To a large degree, the shapes of the multiplicity distributions can be reproduced by treating the A+A collisions as a sequence of individual N+N collisions i.e. by a geometrical approximation. Such a picture of the interaction suffers of course from the neglection of cascading and other collective phenomena. The main task of ultrarelativistic heavy ion physics is to isolate and interpret the effects which go beyond the geometrical approximations, since these non-linear effects may contain new interesting dynamics. As an example consider the correlation between the rapidity density of charged particles ρ_c in a centrally chosen rapidity interval and the total number of shower particles n_s. In a geometrical approximation we expect this relation to be independent on the size of the interacting system and for ^{16}O and ^{32}S interactions this seems to be fulfilled. In Fig 5 a strong linear correlation is evident with a slope seemingly independent of projectile and target mass. Such a relationship is useful when examining eventual new interesting physics which could deviate from the predicted line. From the fitted line the multi-



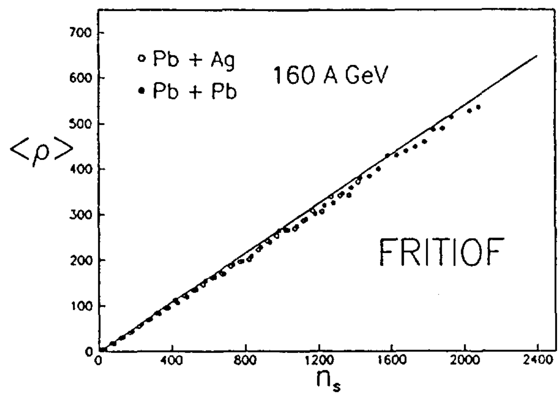


Figure 5: Average charged particle density <ρ> versus the shower particle density n_s for real (left) and simulated data (right).

plicity of shower particles can be related to the energy density ε (GeV/fm^3), one of the key parameters for achieving the QGP.

The question of multiparticle production in a nuclear environment is an essential one to study in its own right, since the degree of multiplication through repeated scattering of the nuclear medium is not a priori known. An ultrarelativistic proton impinging on a lead nucleus with a sharp radius of about 7 fm will in central collisions have about 10 interaction lengths to pass the diameter. In a Pb on Pb collision, with a geometrical cross section of about 8 barn, we will on the average have about 200 binary NN collisions and therefore in central Pb+Pb the chance of achieving high compression and thermalization seems promising. It is interesting to note that the densities obtainable at midrapidity in a sample of central Au+Au collisions (b= 0-1 fm) differs by a factor of 2 among different theoretical models, (Fig 6) the Dual Parton Model Venus[5] gives a rapidity density of about 800 charged particles whereas the Lund Model inspired Attila code[7] gives a density of about 400 charged particles. Thus an emulsion experiment could easily discriminate between existing models.

Attempts have been done to parametrize the multiplicity data by Negative Binomial Distributions both globally and locally in restricted rapidity windows. A novel approach has also been applied[8], (influenced by the analogy of turbulence in chaos theory) where fractal dimensions are used to analyse the multiplicity of charged particle in different rapidity windows. A further motivation for the study of the multiplicity of charged particles, locally as well as globally, is that it is emphatically related to the entropy density[9] a quantity useful in conjunction with QGP searches.

Due to the minimal amount of material present in our emulsion chambers the measurents of central interactions will be very precise and essentially free of bias.

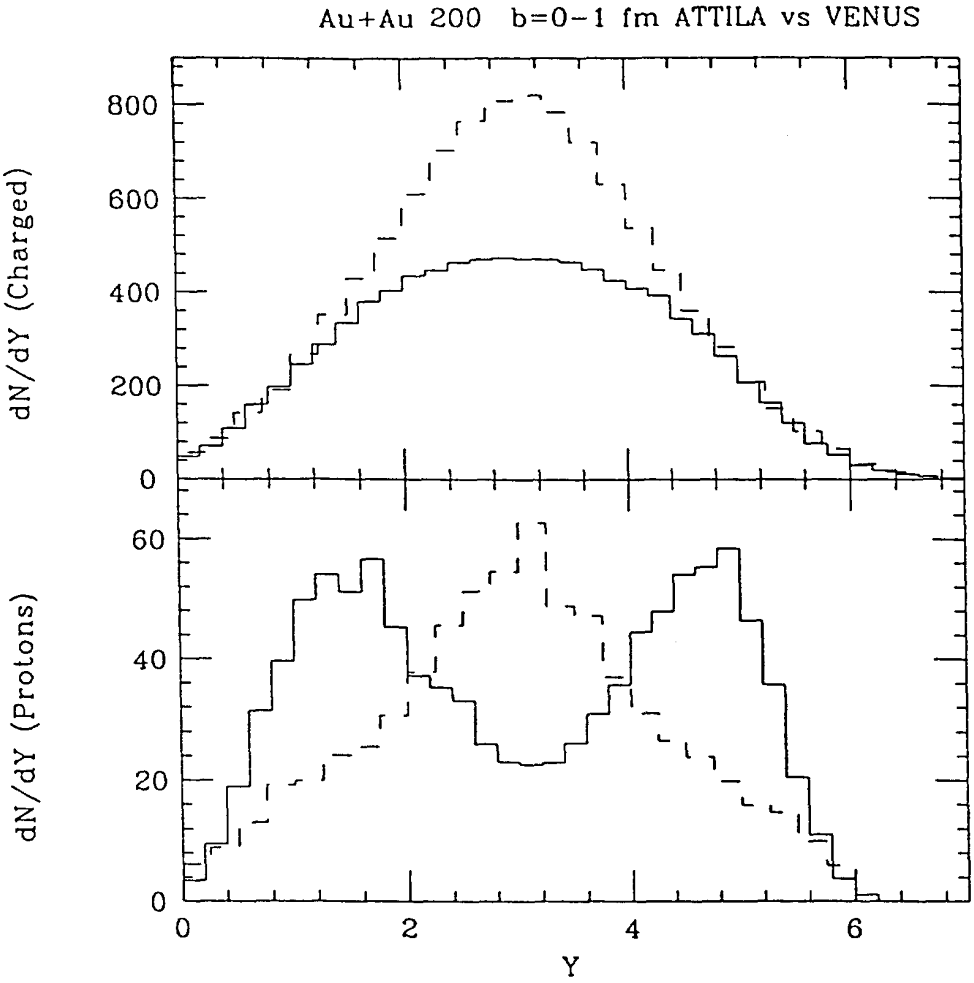


Figure 6: Simulation of Au+Au collisions at 200 A GeV. The solid histogram shows the result from Attila calculations, whereas the dashed histogram shows the outcome from Venus. From [7].

4.5 Inverse kinematics

In the case where the projectile is more massive than the target (i.e. Pb+Ag) we have an inverse reaction geometry where, in a central event, the total target will be enclosed by the heavy projectile nucleus. In case of a high degree of stopping the target region will therefore be emptied. Thus the topology of the event, e.g. the number of black, grey and shower particles, will be of large interest. In Fig 7 we show a comparison of the pseudo-rapidity spectra from a fireball type of calculation (T = 200 MeV, R = 12 fm) compared to a string-model calculation (Fritiof). From the Fritiof calculations there are an additional 10 - 15 particles with $\beta < 0.7$ in the target region ($\eta \approx 0$) not shown in the figure, whereas such particles are absent in the Fireball calculation.

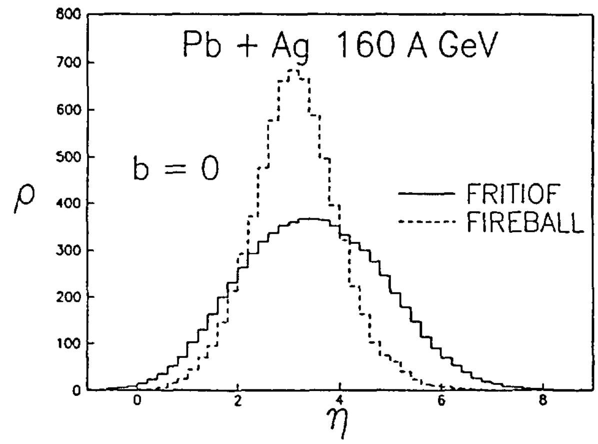


Figure 7: Charged particle pseudorapidity spectra in Pb+Ag collisions for incomplete (Fritiof) and complete stopping (fireball type calculation).

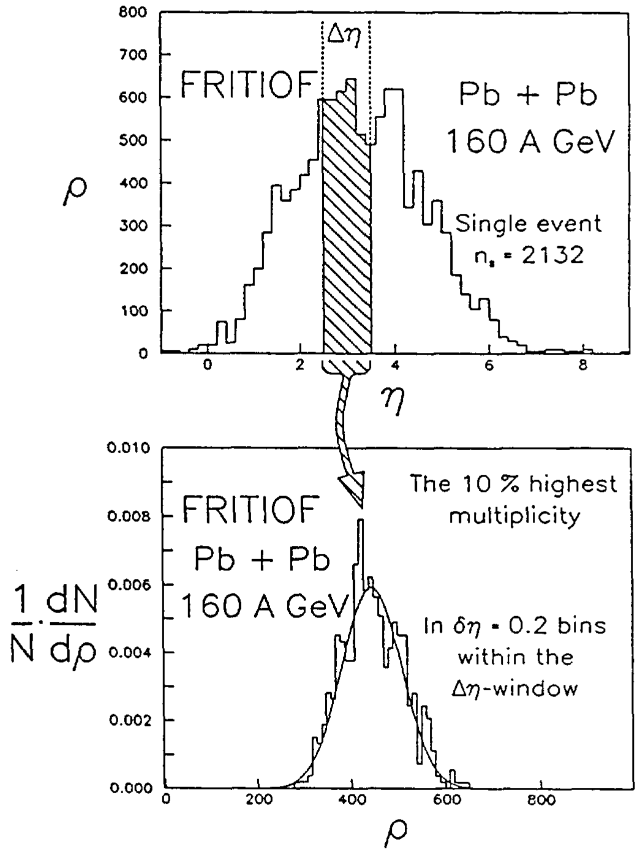


Figure 8: Top figure shows the pseudorapidity distribution $\rho(\eta)$ for a single Pb+Pb collision at 160 A GeV. Below the event distribution of ρ is shown for centrally selected bins of width $\delta\eta$=0.2

4.6 Stochastic emission of particles in the central region

Due to the nature of heavy-ion interactions one would expect the produced particles to come from many different subsources, as, for instance, in a picture where the participant nucleons develop into strings, which later on fragment independently. With many such sources, as will be the case in central lead-lead collisions, the particle production will approach the stochastic limit, and the probability, p, that a given particle produced in the region $\Delta\eta$ will end up in the smaller region $\delta\eta$ will essentially be independent of all other particles (unless some new coherent effects occur) and can be written

$$p = \frac{\delta\eta\cdot\langle\rho(\delta\eta)\rangle}{\Delta\eta\cdot\langle\rho(\Delta\eta)\rangle}$$

where $\langle\rho\rangle$ is the average particle density in a considered region. In fig 8 we show the pseudorapidity distribution for a single event (top figure) and below we show the event distribution of the charged particle density ρ.

We see that the Fritiof model predicts a Gaussian shaped $1/N\cdot dN/d\rho$ distribution, expected from a situation with a large number of sources. Deviations from this behaviour, especially in the high-ρ tail, would indicate strong non-linear fluctuations.

If it is assumed that the average particle density distribution has the same shape independent of the multiplicity (or centrality) of an event one finds[10] that the normalized variance of the multiplicity distribution in a given region, $\Omega(\eta,\delta\eta) = \sigma^2/\langle n\rangle^2$, will have the property

$$\Omega(\eta,\delta\eta) = \frac{1}{\delta\eta\cdot\langle\rho(\eta)\rangle} + \text{constant}$$

independent of the size and location of the region. Similar expressions can be found for higher moments of the multiplicity distributions[11]. In our studies of local multiplicity distributions from interactions with oxygen and sulfur there are no significant deviations from this simple picture of stochastic emission. This shows that the effects studied by the behaviour of the normalized factorial moments (see below) are, globaly speeking, rather small and only found using tools which are extremely sensitive to the "spikeyness" of a small fraction of the observed events. The simple picture also provides a suitable input for calculations of the uncertainties in the results obtained with more sophisticated tools.

4.7 Non-statistical fluctuations in the density of produced particles

Ever since the first occurances of spiky events, first observed in cosmic ray studies and later confirmed in the laboratory, non-statistical fluctuations in the density of produced particles have attracted a lot of attention. The reasons for this are many. Unusually large fluctuations may be a signal for a phase transition[12] and the understanding of the origin of these fluctuations may provide new insights into the underlying mechanisms, responsible for the particle production.

The EMU01 collaboration is in a rather unique position to study a large variety of systems utilizing the same experimental technique and the same chain of analysis, which is of great importance for the systematic studies of the energy and mass dependence of non-statistical fluctuations[13]. It is found that for a given system, independent on energy and centrality cut, the second order intermittency index, ϕ_2, obtained from an analysis of scaled factorial moments, can be parametrized as[14]

$$\phi_2 = \kappa \cdot n^{-1}$$

where n is the multiplicity or, as in the Fig 9 below, the particle density, and κ is a constant. κ is found to be approximately the same for oxygen induced as for hadron induced interactions with emulsion. When sulphurinduced interactions are investigated it is found that κ increases about a factor of two as compared to oxygen-induced interactions. It points to some collective behaviour not present for smaller systems.

It is of great interest to persue these studies with the lead beam. Will κ be the same for Pb+Pb interactions as for ^{32}S+Au or will it increase further? This cannot be answered until the experiment is performed, but will be possible to answer with a small number of central Pb+Pb events. The experimental uncertainty in the determination of ϕ_2, i e $\sigma(\phi_2)$, is found to be dependent on both the number of interactions, N, and the multiplicity of particles in the interactions <n> and can be summarized as

$$\sigma(\phi_2) \propto N^{-1/2} \cdot \langle n \rangle^{-1}$$

This is, however, only an aproximation since it also depends on higher moments of n. We see from the expression that large multiplicities in the events are more important than large statistics. In Pb+Pb interactions we can expect 4 times as many particles as in ^{32}S+Au and we can thus with a sixteenth of the present ^{32}S+Au sample obtain the same uncertainty for Pb+Pb, and thus with a small number of events be able to answer the above question. It might even be possible with rather small uncertainties to do an event-by-event analysis, but

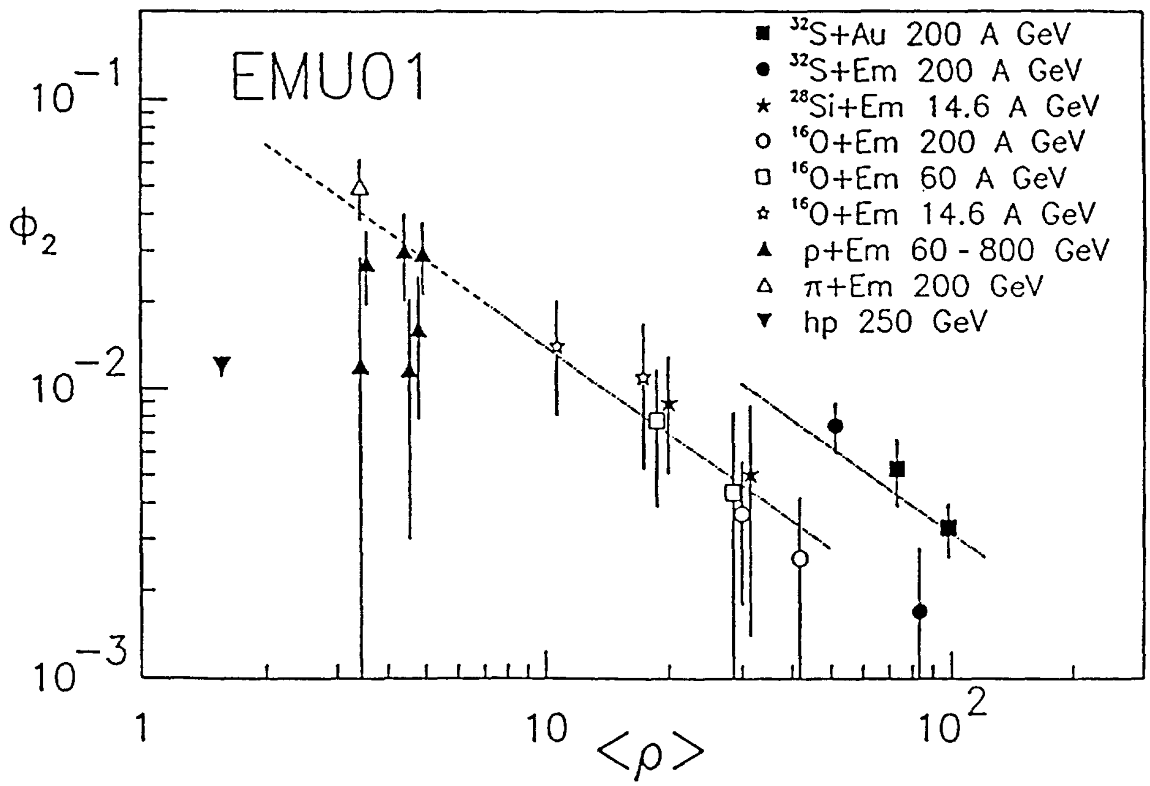


Figure 9: Experimentally determined intermittency-index Φ_2 as a function of $\langle\rho\rangle$ for various projectile and target combinations as well as different incoming energies.

this depends on whether κ increases or not.

When it comes to higher order indices it may, due to the increased multiplicities be possible to see deviations from the scaling rule[15]

$$\phi_q = \binom{q}{2} \cdot \phi_2$$

For the systems studied so far these deviations seem to be of the same order as the experimental uncertainties. For such an investigation, however, a larger sample will be needed. How large? This depends on how large the scaling violation is.

The source of systematic errors due to electron pairs produced either by a direct Dalitz decay or through γ-conversion have been carefully studied in the present samples and are found to be of minor importance. Extrapolations to Pb+Pb show that the relative importance will be the same. If κ is increased in Pb+Pb interactions these errors can be safely neglected. A parametrization of the errors, based on Fritiof[4] simulations, is

$$\phi_{q,pair} \simeq 0.033 \cdot \binom{q}{2} \cdot \frac{p}{\langle\rho\rangle}$$

where p is the percentage of gammas giving rise to electrons, which are considered as hadrons in the experiment and $\langle\rho\rangle$ is the particle density.

5. REQUESTS

The total effective beam time required is about 16 hours. In order to perform our experiment within this time, it is absolutely essential that the beam can be switched off from the experimental site. Without this arrangement the request of beam time would increase with a substantial amount. We intend to put scintillators behind the chambers/stacks and count the beam particles with a preset counter. When the preset number of particles has been counted, the switch off signal is sent out. In our previous runs a kicker magnet, close to the extraction point, was used to switch the beam.

We need a defocused beam with an ideal spot diameter of 4 cm. The beam particle density in the centre of an exposed beam spot should be about 500 cm^{-2}. This means about 6000 particles totally.

We need access to the emulsion pouring facility at CERN for two weeks immediately before the run, and acess to the development facility for another two weeks after the run.

All the above mentioned requests are quite similar to the conditions during our previous runs.

6. SUMMARY

In this proposal we request beams of Pb-nuclei at 60-160 A GeV for irradiation of emulsion stacks and chambers. Particle production, fluctuations and nuclear fragmentation will be studied in Pb+Pb and Pb+Ag interactions. The measurements will be performed with computer based measurement systems in a large number of laboratories which now upgrade their capacities for measurements. All our data collected sofar both from proton-nucleus and nucleus-nucleus interactions as well as data in prospect from this proposal and studies of Au+Au and Au+Ag interactions of ~ 1 A GeV at the GSI/SIS and ~ 10 A GeV of the BNL/AGS will give us the oppertunity to study heavy ion interactions in a very broad range of mass and energy combinations. This is unique and will be of importance in understanding the reaction mechanism and in tracing the quark-gluon plasma.

REFERENCES

[1] L. McLerran, Rev. Mod. Phys. 58 (1986) 1021 and Phys. Rep. 88 (1982) 379.
[2] M. Gyulassy, Nucl. Phys. B237 (1984) 477.
[3] L. van Hove, Proc. ICPA-QGP'88, Ed: B. Sinha and S. Raha, World Scientific, Singapore, 1988;
E. Stenlund, Mod. Phys. Lett. A 5 (1990) 1159.
[4] B. Nilsson-Almqvist and E. Stenlund, Comp. Phys. Comm. 43 (1987) 387.
[5] K Werner, Phys. Lett. B208 (1988) 520; Z. Phys. C42 (1989) 85; K. Werner and P. Koch, Phys. Lett. B242 (1990) 252.
[6] B. Andersson et al, Nucl. Phys. A496 (1989) 781;
B. Anderson, Stony Brook preprint SUNY (July 1990).
[7] M. Gyulassy in Quark Gluon Plasma, ed R. Hwa, Advanced Series in High Energy Physics Vol 6, p. 223 (World Sci. 1990) and LBL/28148
[8] I. M. Dremin, Mod. Phys. Lett. A3 (1988) 1333.
[9] V. Simak. M. Sumbera and I. A. Zborovsky, Phys. Lett. B206 (1988) 159.
[10] M. I. Adamovich et al, Phys. Lett. 242B (1990) 512;
R. Albrecht et al, Z. Phys. C45 (1989) 31.
[11] M. I. Adamovich et al, Lund Univ preprint LUIP-9010 (1990) to appear in Mod. Phys. Lett. A.
[12] J. Wosiek, Acta Phys. Pol. B19 (1988) 863; Nucl. Phys. B9 (1989) 640;
H. Satz, Nucl. Phys. B326 (1989) 613; B. Bambah, J. Fingberg and H. Satz, Nucl. Phys. B332 (1990) 629; N. G. Antoniou, CERN-TH.5625/90; CERN-TH.5688/90.
[13] M. I. Adamovich et al, Lund Univ preprint LUIP-9011 (1990) submitted to Phys. Rev. Lett.
[14] D. Seibert, Minesota preprint Nov, 1989, to appear in Phys. Rev. D.
[15] A. Bialas and R Peschanski, Nucl. Phys. B273 (1986) 703; B308 (1988) 857.

EMU01 PUBLICATIONS AND RESULTS FROM THE CERN HEAVY ION RUNS 1986 - 1989

International Journals

1. Multiplicities and Rapidity Densities in 200 A GeV ^{16}O Interactions with Emulsion Nuclei. M I Adamovich et al, Phys Lett B201(1988)397.
2. A Computer Based Coordinate Measuring Station for Nuclear Emulsion Chambers. S Garpman et al, Nucl Instr Meth A269(1988)134.
3. Production of Helium (Z=2) Projectile Fragments in ^{16}O Interactions at 14.6, 60 and 200 A GeV. M I Adamovich et al, Phys Rev C 40(1989)66.
4. Measurement and Three Dimensional Reconstruction of Particle Tracks in Emulsion Chambers. S Persson, Comp Phys Comm 55(1989)103.
5. A Track Reconstruction Program (TRP) for Evaluation of Nucleus-Nucleus Collisions in Nuclear Track Emulsion Chambers. E Ganssauge et al, Comp Phys Comm 55(1989)233.
6. Limiting fragmentation in Oxygen Induced Emulsion Interactions at 14.6, 60 and 200 A GeV. M I Adamovich et al, Phys Rev Lett 62(1989)2801.
7. Scaling Properties of Charged Particle Multiplicity Distributions in Oxygen Induced Emulsion Interactions at 14.6, 60 and 200 A GeV. M I Adamovich et al, Phys Lett 223B(1989)262.
8. Charged Particle Spectra in Oxygen Induced Reactions at 14.6 and 60 GeV/Nucleon. M I Adamovich et al, High Energy Physics and Nuclear Physics in China 13(1989)865. (English and Chinese).
9. Rapidity Densities and their Fluctuations in Central 200 A GeV ^{32}S Interactions with Au and Ag,Br Nuclei. M I Adamovich et al, Phys Lett 227B(1989)285.
10. A Study of Recoil Protons in Ultra-Relativistic Nucleus-Nucleus Collisions. M I Adamovich et al, Phys Lett 230B(1989)175.
11. A Search for Non-Statistical Particle Density Fluctuations in ^{16}O+Ag(Br) and ^{32}S+Au Interactions at 200 A GeV. E Stenlund et al, Nucl Phys A498(1989)541c.
12. On the Energy and Mass Dependence of the Multiplicity in Relativistic Heavy-Ion Interactions. M I Adamovich et al, Modern Physics Letters A 5(1990)169.
13. Target Nucleus Fragmentation in ^{16}O + (Ag,Br) Interactions at 200 A GeV. M I Adamovich et al, Phys Lett 234B(1990)180.
14. On the Multiplicity Fluctuations in Relativistic Heavy-Ion Collisions. M I Adamovich et al, Phys Lett 242B(1990)512.
15. Scaled Factorial Moment Analysis of 200 A GeV Sulphur + Gold Interactions. M I Adamovich et al, Phys Rev Lett 65(1990)412.
16. Limiting Fragmentation, Scaling and Substructual Dependence of Multi-particle Production in High-Energy Heavy-Ion Interactions. I Otterlund et al, Physica Scripta T32(1990)168.
17. Energy, Target, Projectile and Multiplicity Dependence of Intermittency Behaviour in High-Energy O(Si,S)-Emulsion Interactions. M I Adamovich et al, accepted for publication in Z Phys C.
18. Stochastic Emission of Particles in Ultra-Relativistic Heavy-Ion Collisions. M I Adamovich et al, Lund University Preprint LUIP 9010 (1990), accepted for publication in Modern Physics Letters A.
19. On the Systematic Behaviour of the Intermittency-Indices in Nuclear Interactions. M I Adamovich et al, Lund University Preprint LUIP 9011 (1990), submitted to Phys Rev Lett.
20. Multiplicities in ^{16}O Induced Heavy Ion Collisions from 5 A to $2 \cdot 10^5$ A MeV. M I Adamovich et al, Lund University Preprint LUIP 9102 (1991), to be submitted to Phys Rev Lett.
21. Slow, Target Associated Particles Produced in Ultrarelativistic Heavy-Ion Interactions. M I Adamovich et al, Lund University Preprint LUIP 9103 (1991), to be submitted to Phys Lett B.

Theses

1. F G Kadyrov, PhD-Thesis, Tashkent.
2. V Sh Navotny, Master-Thesis, Tashkent.
3. Heavy-Ion Interactions in the TeV Energy Domain. S Persson, PhD-Thesis, Lund, Dec 1989.
4. Fluktuationen in den Pseudorapiditätsdichte-Verteilungen der bei hoch energetischen Schwerionen-Kollisionen produzierten Schauerteilchen. C Müller, Inaugural-Dissertion, Marburg/Lahn, Dec, 1989.
5. Paarbildungs-Effekte und Cluster-Formation in relativistischen Schwerionen-Kollisionen. B Dressel, Inaugural-Dissertion, Marburg/Lahn, Dec, 1989.
6. Analysis of Interactions of 200 A GeV Oxygen Nuclei with Nuclear Emulsion. F Liu, Master-Thesis, Beijing (1989).
7. Analysis of Interactions of 14.6 A GeV Oxygen Nuclei with Nuclear Emulsion. Y Qin, Master-Thesis, Beijing (1989).
8. Investigation of the Relativistic Nucleus-Nucleus Collisions Using the Nuclear Emulsion. G F Xu, Master-Thesis, Beijing (1990).
9. The Study of the Phenomena and Characteristics of the Projectile and Target Fragmentations in the 60 A GeV ^{16}O+Em and 200 A GeV ^{32}S+Em Interactions. H Gau, Master-Thesis, Beijing (1990).
10. Ett Statistiskt Problem vid Empirisk Verifiering av Kvark-Gluonplasma. R Perfekt, Diploma-Thesis, Lund (1990).