New developments at nuclear emulsion experiment*

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Abstract Three new nuclear emulsion techniques used for measuring emission angles of charged particles in central events at ultra-high evergy heavy-ion collisions are fully described.
Keywords Nuclear emulsion detector, Heavy ion collisions, Multiparticle production

1 Introduction

In 1896 Henri Bequerel discovered the spontaneous decay of uranium by noticing that a photographic emulsion was blackened despite being wrapped in black paper. Moreover, the particles π^+, π^-, K^+, K^- were discovered using emulsion detectors.[1] Even today, nuclear emulsion is still in active service in both high energy particle physics and nuclear physics researches. There are many research topics involved, from studying basic nuclear fragmentation, and multiparticle production to searching for τ neutrinoes in neutrino oscillation experiments. The main difference between today's nuclear emulsion research techniques and those used twenty years ago is that the former can be applied with modern techniques such as computer-controlled measurement systems and systems based on CCD technology.[2,3]

Nuclear emulsion is characterized by high spatial resolution $\sim 1\mu m$, complete 4π angle coverage and almost perfect detector efficiency which make it well suitable for measuring the charged particle multiplicity and pseudorapidity distributions. The drawback of emulsion detector is to take a long time to accumulate data, difficult to identify the particles and has limitations for the measurement of particle momenta, especially, in central Pb-Pb interactions at 158A GeV at CERN/SPS, where the number of charged particles may be as high as about 1500. Therefore, it is impossible to measure such big events with the traditional emulsion technique. In this paper three sets of new nuclear emulsion techniques are described for fast and accurate measurements and the three-dimensional reconstruction of charged particle tracks at ultra-high energy heavy-ion collisions can be performed.

2 Emulsion experiments

2.1 Emulsion stacks

The photographic emulsions used for recording the tracks of charged particles differ from those of ordinary photography in two respects: the ratio of silver halide to gelatine is about eight times greater and the emulsion layer thickness is commonly ten to a hundred times thicker in the nuclear emulsion. The density of standard emulsion is about 3.8g/cm^3. The sensitivity is about 30 grains per 100 microns for minimum ionizing particles.

The nuclear emulsion consists of three basic components: (a) silver halide, chiefly the bromide density of 6.47 g/cm^3; (b) gelatine and a plasticiser, such as glycerine; and (c) water. The elements present in the gelatine and plasticiser are carbon, nitrogen, oxygen, hydrogen and sulphur. A charged particle passing the emulsion will activate silver bromide crystals along its trajectory. During the development of the emulsion the activated silver bromide crystals will be reduced to metallic silver and deposited in the gelatine as black grains.

The emulsion stack serves both as target and detector. The pellicle stacks provide a good estimate of minimum bias cross-sections. Because "along the track" scanning can be used to determine the fate of all the projectile ions observed. In the stacks it is possible to determine the charge of the fragments by grain counting, ray counting or photometric width measurement. In emulsion experiments according to ionization of tracks, particles can be categorized

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into: (a) shower particles, singly charged particles with a velocity $v \geq 0.7c$, most of them are pions; (b) grey particles, velocity $v < 0.7c$ and a residual range greater than 3mm, mainly recoiling target protons which carry information on intranuclear cascading; (c) black particles with a range smaller than 3 mm, these are from the evaporation of the target spectator excited by intranuclear cascading; (d) projectile fragments

2.2 NGC 12×12 system

NGC is a semi-automatical system (see Fig.1) which was designed to measure horizontal exposed stacks[4] and which has very good angular resolution $1\mu m$ and an efficiency close to 100%.

The main components of NGC 12×12 setup are nuclear track precision coordinate equiped with camera head and TV monitor; a pentum 586 microcomputer equiped with Color Image Card; microscope controled by a step motor(the resolution of x, y and z is $1\mu m$). The $x-y-z$ coordinate readout system has been engineered to achieve speedy processing of any coordinate or luminance information provided on the face of a film. Employing a TV camera in the primary means, the unit will perform data transfer of the darkest or brightest point on the screen to the reading host computer. It also permits transfer of luminance data to the CPU, by converting into digital signals projected images on a sampling line. The stage control unit permits shifting the stages of x, y and z coordinate axes to match the CPU-designated coordinates.

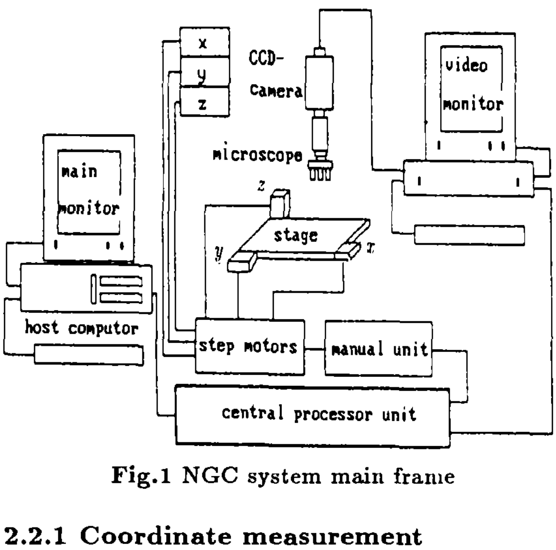

Fig.1 NGC system main frame

2.2.1 Coordinate measurement

The unit is capable of making automatic detection of the position of the point in the image, when the command pressed, picked up by the TV camera and projected onto the screen, and of out-putting the x, y and z coordinates of the point detected.

2.2.2 Inspection of the event

The program allow the operator to check event, to add the tracks lost, to discard the wrong tracks.

2.2.3 Track reconstruction

After the measurement, all the tracks coordinates are obtained. The tracks can be reconstructed. The tracks η and ϕ are calculated after reconstruction.

2.3 Emulsion chambers

The particle production in a central interaction between a projectile nucleus and S, Au or Pb at $200A$ GeV was expected to be very high, i.e. several hundreds or more than one thousand of charged particles. The emission angle of most of these particles should be very small, typically less than $5°$. These two facts made it difficultly make accurate measurements of all the emission angles with the normal emulsion technique, therefore, we also design a special emulsion technique for fast measurements, by using emulsion layers perpendicular to the beam direction during exposure. This technique needs a special designed measuring station combined with new computer programs.

The emulsion chambers contain 7 base plates with two layers of FUJI ET-7B emulsion (emulsion plates), as shown in Fig.2. The geometrical arrangement has been the same in all run experiments. The emulsion thickness of each side is $180\mu m$ on plates 2,3 and $90\mu m$ on other plates. The target foil is of $250\mu m$-thick Ag, Au and Pb, located in front of plate 2. The beam nucleus is perpendicular incident onto the target. The charged particles are visualized as tracks in the emulsion layers. The angles can be measured, but momentum measurement and particle indentification is not possible since the exposures were made without a magnetic field.

The plates in the chambers are separated by honeycomb paper spacers made of very little material, which means that the particles travel mostly through air. This greatly reduces the secondary interactions and γ-conversion. The other advantage of the design of the chambers is that track pattern can be observed at a long distance from the vertex($\sim$ 5cm). Therefore it is easy to separate all the tracks even within the dense core in high multiplicity Pb+Pb interactions. Interactions with multiplicity as large as 1500 charged particles, can easily be measured using a newly developed automatic measurement system based on the CCD technique and image processing.

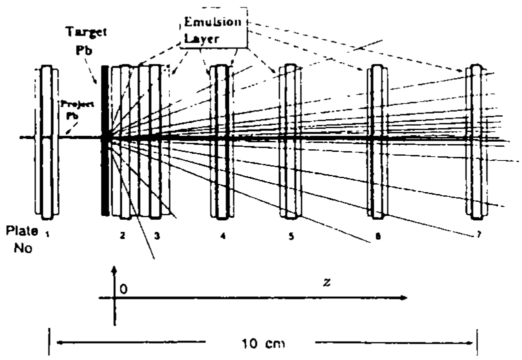

Fig.2 Sketch of the emulsion chamber

One disadvantage of the chambers is that "along-the-track" scanning is not possible, so that the minimum bias cross-sections can not be determined. The events in the chambers are found by "area" scanning, which is inefficient for finding low multiplicity events. The tracks from a very peripheral event are hidden in the dense core of the projectile fragment. The second disadvantage is that it is impossible to measure large angles and backward moving particles. Only particles produced within 30° can be measured with nearly 100% efficiency.

2.4 EMU-PAD system

In order to obtain tracks information an EMU-PAD system was built[5] (see Fig.3). The EMU-PAD is a computer-aided measurement system which was designed and successfully employed for measuring central events of multiplicity roughly up to about 500 or more but with skilled operators, the system has been proven to be able to handle even large multiplicities. The EMU-PAD consists of a microcomputer and a coordinate digitizing pad with a cursor and a microscope equipped with a projection tube with a 70% to 30% beam splitting prism at the end. The system superimposes three different images into the eyepieces of the microscope i.e. the image of the EMU-PAD and the display of the monitor onto the microscope image.

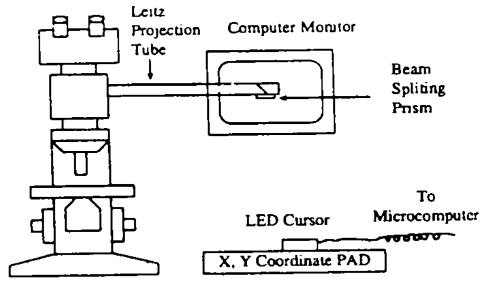

Fig.3 EMU-PAD station for emulsion chamber

The event is measured through the whole chamber, starting with the emulsion layer closest to the vertex point. All coordinates of tracks measured in the different planes are transfered to a common coordinate system using non-interacting beam tracks in the vicinity of the collision as reference. During the measuring and inspection procedures all the coordinates and other relevant information will automatically be stored in the computer. All the measured points will give a small spot on the screen at the same position as where they were measured with the EMU-PAD cursor as seen through the eyepieces of the microscope. The operator can therefore concentrate on comparing the emulsion picture and picture on the screen. When the measurement in one plane is finished, coordinates in the next plane are predicted and projected onto the screen. When all predicted points have been handled the operator can add further tracks in regions previously not measured. All tracks are then reconstructed using a three-dimensional least square fit.

The measuring station needs a complex software package both during the installation of the package and especially during the measuring, the event reconstruction and the data analysis procedures. The EMU-PAD software package consists of 14 programs, of which 9 are used to make a complete measurement of event i.e. choose the interesting events for measurment, reconstrust and check the measurements.

A menu is automatically displayed on the screen when entering the EMU directory. From this menu the operator chooses among the 9 programs. All data files produced are stored on two different sub directories, one with the raw data files and the other with the reconstructed data files. With this measuring station, events with 600 charged particles can be measured in 4 to 5 h.[6]

2.5 CCD automatic system

To be able to study Pb-Pb interactions to search for the quark-gluon plasma which is believed to exist under extreme conditions of high enengy density and high temperatures. We develop a new CCD system for automatically measuring the charged tracks in the Pb-Pb interactions[2] (see Fig.4). The basic idea of such CCD system is to scale the images in different z coordinates to the same z value, then the scaled images are added together. In such way the ratio of signal/background (S/B) will be enhanced. The tracks coordinates can be calculated after pixel background subtraction by using some kind of track cluster algorithm. With such technique, the measurement time are dramatically reduced to about half to an hour for events with charged multiplicity high as about 1500. We fully describe the experiment equipments and software which control the whole measurement and track reconstruction process.

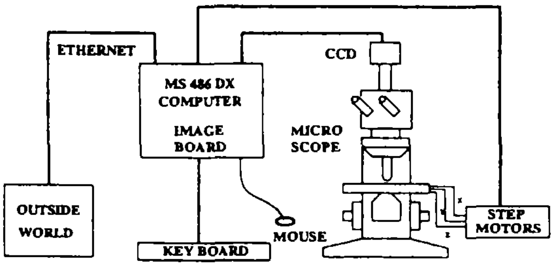

Fig.4 Automatic measurement system based on CCD-technique and image processing

The main experiment setup are an image series board(IM-LC) installed in a host PC computer, a CCD camera, a high resolution colour monitor and a microscope where stage motion and focusing is controled by step motors. The detector is emulsion chamber.

2.5.1 Image-board

The MATROX Image-LC consists of a series of boards(Base board, image real time processor board and digitizer board).

2.5.2 Monitor

The monitor is a high resolution(1024×1024 pixels) colour screen, but in present application it is configured as 640×480 pixels. The window from (123,0) to (639,479) (corresponding to $312\times295\mu m^2$ with a 22× oil immersion objective) is used to display the image from the camera.

2.5.3 The CCD camera

The camera(LDH 0703/30) is equipped with a charged couple device. A C-mount device (OLYMPUS U-CMAD-2 and U-TVO.5X) reduces the image scale on the CCD by a factor of 2.

The camera delivers an analog video signal to the image processor. The signal is then digitized by an 8-bit flash A/D converter which produces interlaced black and white video picture of 625 lines at 50 Hz.

2.5.4 Software

The image of emulsion in the certain field of view of the microscope(Region of Interest(ROI)) is transfered to the image processor and displayed on the window of the monitor. The track coordinates in the field of the microscope are then calculated according to the corresponding position in the window.

2.5.5 Measure the distance between star and ref track

A non-interesting reference track is used to define the coordinate system. This is calibrated in plate 1, upstream of the interaction. When a plate is changed, this reference track is manually moved to the center window. Then the step motors move the stage to a position where the event center is in the center of the window.

2.5.6 Measure the event

In the measurements, each emulsion layer is divided into sequential sublayers at $1\mu m$ distance along the beam direction. The microscope is focused automatically onto each sublayer and the image is grabbed by the image processor. After being digitized, the image is transfered to the grame buffers of the base board and displayed on the monitor. The image is treated by spatial filtering, is geometrically scaled and the images at different sublayers are summed pixel-by-pixel to enhance track S/B ratio. This is done in the image real time processor (Image-RTP). The summed images are stored on the hard disk of the computer. When all the summed images for the event have been recorded, tracks are identified and reconstructed by conventional methods.

2.5.7 Reconstruction of tracks

After track finding in the summed images, the tracks are reconstructed by tracing the tracks through the emulsion plates, starting with the last plate. The "search radius" depends slightly on the track position in the image.

$$\Delta r = r_0(1 + \frac{d}{140.0})$$

Here r_0 is 3.4 μm and 2.1μm in the first layer of emulsion plate 2 and the other layers of the plates, respectively and d is the distance of the track from the window center. For a track to be accepted, it is required that the track appears in at least 75% of total number of summed images, after considering the geometrical acceptance.

2.5.8 Alignment

It is not unusual that the actual distance between two emulsion plates deviate somewhat from the nominal distance. There may also be a translation error in the coordinate system, since the lead track used to define the coordinate system is quite fuzzy. The error in the measurement of the centroid may be several microns. To compensate these effects, a final alignment is done. The two images are displayed on the monitor. By visual recognition of track patterns the operator identifies the tracks of a particle in both images. They are marked, and this is done in different parts of the image, preferentially along the edges. The software then makes the final alignment.

3 Conclusions

As shown, the three sets of new technigues are fully described. With such technique one can make fast and accurate measurement and three-dimensional reconstruction of charged particle tracks.

References

1 Walter H Barkas. Nuclear research emulsions, techniques and theory. In: David A Evans ed. Pure and applied physics. New York: Academic Press, 1963

2 Cai Xu. Nucl Tracks Radiat Meas, 1993, 22:547

3 Wang H Q *et al.* To be submitted to Nucl Instr Meth

4 Cai Xu, Liu Lian-Shou, Qian Wan-Yan *et al.* Nucl Electr Detec Technol (in Chinese), 1990, 3:186

5 Garpman S *et al.* Nucl Inst Meth, 1988, A269:134

6 Adamovich M I, Aggarwal M M, Alexandrov Y A *et al.* Phys Rev Lett, 1990, 65:412