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FAST DETECTOR FOR TRIGGERING ON CHARGED PARTICLE MULTIPLICITY FOR RELATIVISTIC NUCLEUS-NUCLEUS COLLISIONS

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The simple and fast detector of charged particle multiplicity for relativistic nucleus-nucleus collision studies is performed. The multiplicity detector has been designed for the first level trigger of the CERES/NA45 experiment to study Pb-Au collisions at CERN SPS energies. The detector has allowed a realization of the 40 ns trigger for selection of events with definite impact parameters. The construction, operation characteristics, method of calibration, and testing results are described in detail.

The investigation has been performed at the Laboratory of High Energies, JINR.

Быстрый детектор для триггера по множественности заряженных частиц для релятивистских ядро-ядерных столкновений

Г.Агакишиев и др.

Создан простой и быстрый детектор множественности заряженных частиц для изучения релятивистских ядро-ядерных столкновений. Детектор множественности разработан для триггера первого уровня эксперимента CERES/NA45 по изучению Pb-Au столкновений при энергиях SPS ускорителя в ЦЕРН. Детектор позволяет реализовать 40 нс триггер для выделения событий с определенными прицельными параметрами. Подробно описаны конструкция, рабочие характеристики, метод калибровки и результаты тестирования.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

1. Introduction

Ultrarelativistic heavy ion collisions with 160 GeV/n lead beam have been investigated in CERN since November 1994. For study of the events with specific inpact parameter which is not a priori known it is necessary to consider a global feature of an event correlated with centrality. There are two main approaches to get this aim:

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1. to measure transverse energy, $dE_T/d\eta$ or beam energy deficiency at zero degree by calorimeter;

2. to study the multiplicity of secondaries that can quite comfortably be done by hodoscope scintillator arrays or by semiconductor detectors with appropriate segmentation.

Both of them were successfully used for the first level triggering for experiments with ultrarelativistic heavy ions.

In this paper we report the fast low-segmented scintillation Multuplicity Detector (MD) designed specially for the first level trigger of the CERES/NA45 double RICH spectrometer at CERN SPS [1] to study Pb-Au collisions at 160 GeV/nucleon. Previous trigger was based on SIPD (SIlicon Pad Detector) [2] with 64 segments and was used for the first level triggering in the CERES experiments with proton and sulphur beams. It provided an interaction trigger sensitive to low multiplicity events for proton beam and an impact parameter selective collision trigger for sulphur beam. The counter was situated immediately behind a Silicon Drift Chamber (SIDC) [3] in the target area of the experiment. The upgrading of the CERES/NA45 spectrometer, with an aim to start the experiments with ultrarelativistic lead-nuclei beam of the SPS, CERN, was performed in a period 1994-95. A new tracking device consisting of a doublet of the SIDC [4] was installed at about 10 cm distance downstream of the target. Simultaneously the SIPD was taken out from the target area with a goal to minimize a mass of materials in the region between the target and the entrance window of the RICH1 detector. A new conception of the trigger detectors was designed. Trigger is based on information from small-mass gaseous Cherenkov beam counters [5] and the scintillation array of the MD. One of the Cherenkov micro-counters is placed in a gap between the target and the SIDC doublet, and it is used for selection of the events with the absence of lead ions behind the target (the interaction trigger). The impact parameter selection is done by multiplicity triggering with the MD, located 5.35 m downstream from the target and about 2 m behind the RICHs. A role of the MD is to measure charged particle multiplicity at mid rapidity region which is in strong correlation with an impact parameter of collision. Very fast, 40 ns, analysis of the MD response leads to high quality selection of useful events and good time synchronization of the trigger signals and a readout of information from the slower main detectors, of the spectrometer such as RICH detectors [6], SIDCs and PC (Pad Chamber). The MD is one of the most important elements in the trigger detector system, but it can also be considered as an independent elements of the spectrometer giving the charged particle multiplicity data for more complete physical analysis of the events.

2. Multiplicity Detector

The MD has to content the following criterions:

1. Active zone of the MD has to cover essential part of midrapidity range corresponding to the maximum of charged particle multiplicity from fireball decay;

2. Analog signal from the MD has to be proportional to the number of charged particles produced in nucleus-nucleus collision;

3. To cover a broad multiplicity range up to a few thousands;

4. A readout and an analysis of the information for trigger signal processing have to be as fast as possible;

5. There has to be very low level of the background contribution to the MD response;

6. To work under the magnetic field generated by the CERES magnet system;

7. To have small mass, to be simple and stable in exploitation for the long term and cheap.

Most of these requirements could be contented by using a plastic scintillator for the MD active zone. Requirements for stability, simplicity and cheapness are equivalent to the requirement to minimize a granularity of the detector. For this problem to be solved special investigations were done with an aim to find the best way for sectioning of the active zone of the MD which could give a standard analog signal per minimum ionization particle (mip) independently of a particle hitting point position. The active zone of the MD for the CERES experiment is a disk made of plastic scintillator of 1 cm thickness and outer diameter of 120 cm with a central hole of 20 cm in diameter. The measurements have shown that the requirement mentioned above can be reached by using the active zone consisting of 24 equal sectors/counters (with an opening angle 15°, each) and with special way of polishing of the scintillator surface. Worked out this way, the MD allows realization of two branches of the logical and analog signals:

— 24 logical signals from counters are used for generation of the minimum bias pretrigger signal corresponding to the lowest level of the multiplicity;

— processing of 24 analog signals provides a possibility to set a threshold on a number of charged particles produced in nucleus-nucleus collision and by this way to organize the main N_{ch}-trigger (multiplicity trigger).

To study collisions with low multiplicity of charged particles the logical mode can be used as a base for trigger signal. In the case of relativistic heavy nuclei collisions, with high multiplicity of secondary particles, the analog mode is used for the main trigger signal. Minimization of background contribution to the MD response is done by fast analog signal processing including summing of pulses from all counters and then 40 ns integration. The sketch of the MD construction is shown in Fig.1. Basic characteristics of the MD are given in the Table.

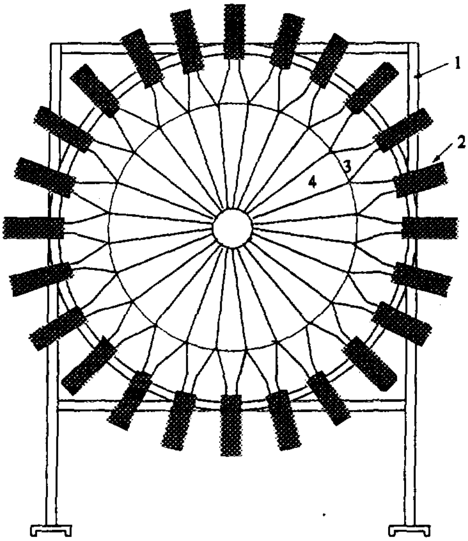


Fig.1. A sketch of the multiplicity detector (1 — mechanical support, 2 — photomultiplier tube within a magnetic shield, 3 — light guide, 4 — plastic scintillator)

Table. Main Characteristics of the Multiplicity Detector

Distance from the target	567 cm
Angular coverage	1.01° — 6.05°
Pseudorapidity region	2.94 — 4.73
Material	plastic scintillator
Thickness	1 cm
Inner diameter	20 cm
Outer diameter	120 cm
No. of sections	24
Photomultiplier	FEU-85

3. Monte Carlo Simulation Results

A research and development stage of the MD design for the CERES expeirment included the analysis of different characteristics of secondary radiation in the MD acceptance. Background conditions and effects were also estimated. For this purpose the VENUS 3.11 [7] and the HIJING [8] event generators were used. An analysis of radiation propagation through the experimental apparatus and the MD response were performed with

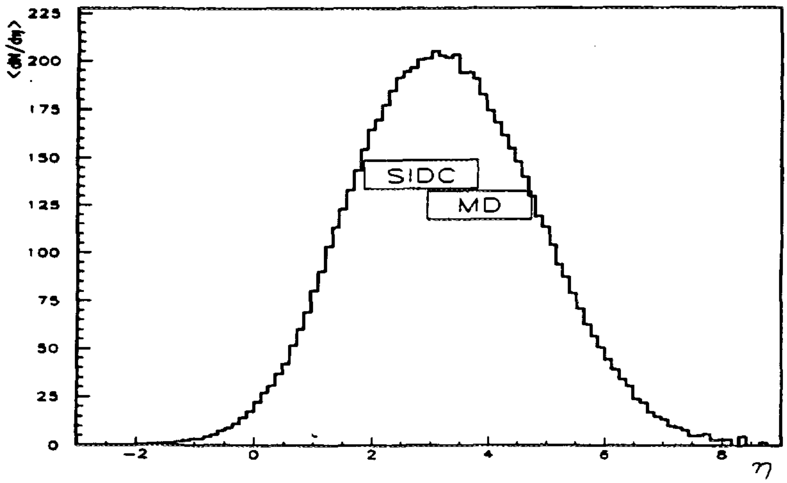


Fig.2. Average charged hadron distribution over pseudorapidity scale for Pb-Au collisions with impact parameters $b < 10$ fm at 160 GeV/n. Pseudorapidity ranges covered by the SIDC and the MD are also shown. The HIJING event generator was used

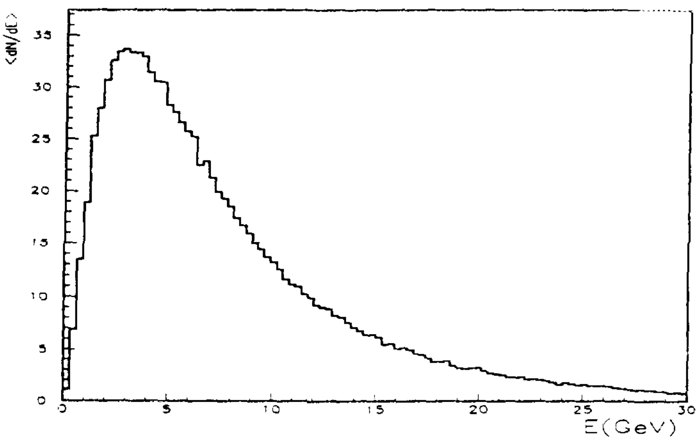


Fig.3. The energy spectrum of charged hadrons produced in Pb-Au collisions with $b < 10$ fm at 160 GeV/n obtained with the HIJING event generator for acceptance of the MD

the GEANT code [9]. A simulation of the projectile nucleus fragmentation characteristics was done according to the experimental distributions [10] where the result of the HIJING calculation was used as input information. The perpendicular momentum of the fragments was generated due to parabolic law [11]. All estimations were done for Pb projectile with energy 160 GeV/n and the gold target. Pseudorapidity distribution for charged secondaries originating from Pb-Au collisions with impact parameters less than 10 fm are shown in Fig.2. In the same figure the pseudorapidity ranges covered by the SIDC and the MD are also shown. Energy distribution of charged particles in the MD acceptance is shown in Fig.3. Practically, all hadrons are relativistic, so energy deposition of each of them inside the MD scintillator corresponds to approximately 1 mip. An analysis of radiation propagation within the CERES area showed that interaction of photons and charged hadrons with matter increases a number of charged particles within the MD acceptance. The result of the

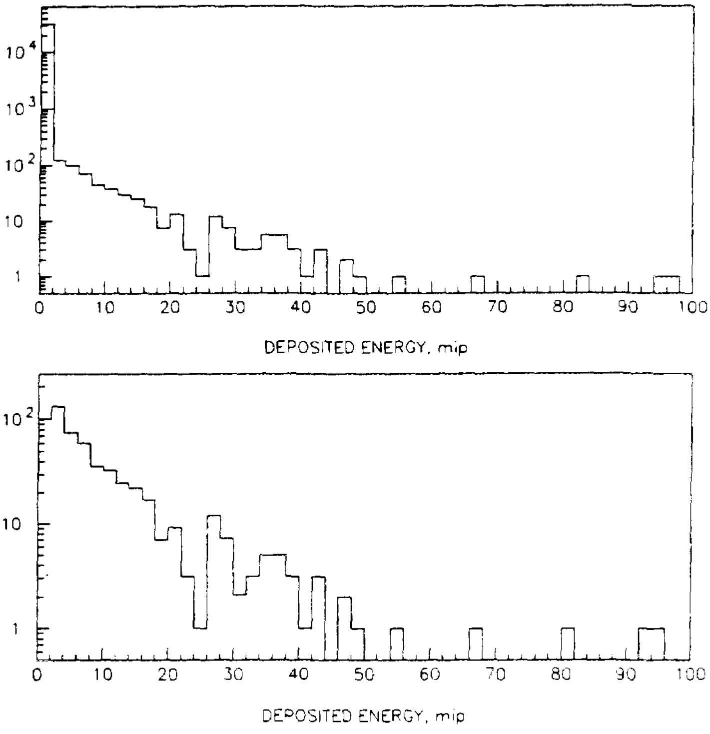


Fig.4. Monte Carlo simulation of the deposited energy distribution for 1-cm plastic scintillator and 10-GeV incident protons, total (top) and for nuclear reactions in the scintillator (bottom)

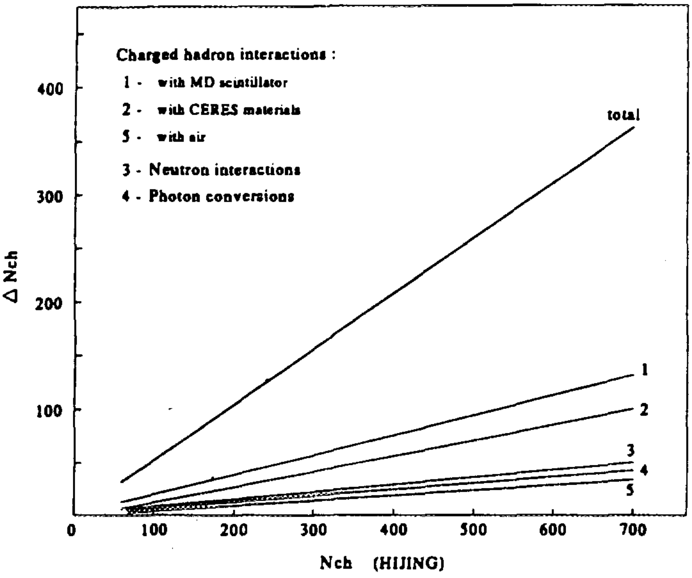


Fig.5. Average contributions from different background processes to the MD response

MC simulation of the energy loss in the MD scintillator for 10 GeV protons is shown in Fig.4. The energy loss per incident proton achieves 100 mips due to the inelastic nuclear

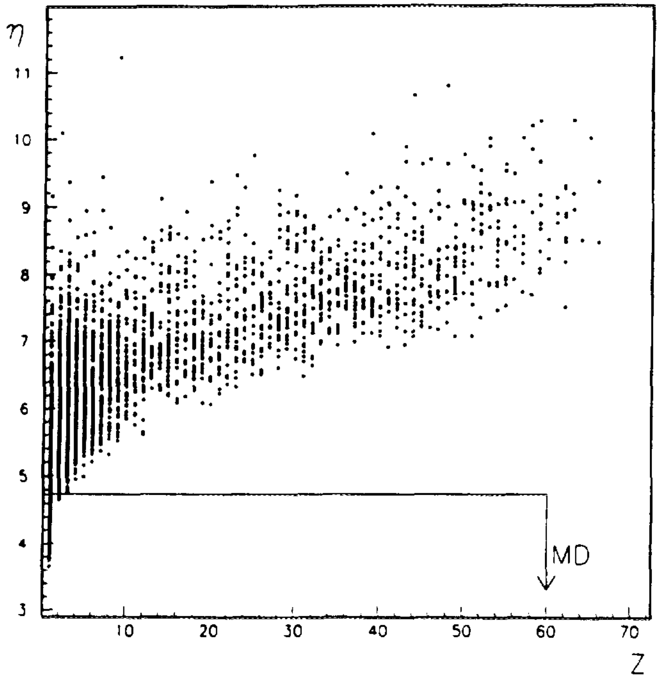


Fig.6. Monte Carlo simulation of the pseudorapidity distribution of lead ion fragments versus the fragment charge for Pb-Au collisions with $b < 10$ fm at 160 GeV/n. The upper edge of the MD region is also shown

interactions inside the scintillator. This is an additional contribution to the MD response, and it is the main source of the counter response fluctuations. The HIJING code predicts in average 657 charged hadrons in the MD acceptance for the central Pb-Au collisions at 160 GeV/n. It was obtained that this magnitude rises by a factor of 1.5 by means of particle multiplication process in the CERES medium. The average contributions from different background processes leading to the increasing of the MD respose are shown in Fig.5. Pseudorapidity destribution of Pb projectile fragments with charge Z for Pb-Au collisions with impact parameters $b \leq 10$ fm is shown in Fig.6. As one can see, there are only single charged fragments in the pseudorapidity region covered with the MD.

4. Counter Design

Each counter of the MD consists of plastic scintillator connected with photocathode of photomultiplier tube FEU-85 by means of the lightguide worked out from polished plexiglass as shown in Fig.7. Each plastic scintillator has 50-cm length and 1-cm thickness with an opening angle of 15°. Polystyrene based scintillators were produced in LHE, JINR. Light collecting homogeneity was achieved with different polishing of main and flanking areas of scintillator. Flanking surfaces with width of 1 cm were polished to the mirror quality level, but the surface of the active zone was done to the diffusion level. Scintillator together with lightguide are wrapped around by an aluminized mylar and black paper. The PMT has 25-mm diameter photocathode and 11 stages of amplification. Important characteristics of FEU-85 are good single electron response and timing properties (rise time and duration of anode pulse are 3 ns and 25 ns, respectively) with pulse height resolution not worse than 9%. Voltage divider of PMT is shown in Fig.8. To provide stable work and to expand dynamical range three last dinodes were supplied from the chain of the diodes BZTO3C150/C180. Voltage supply of the divider is in the range 1500-1600 V, while the value of current through the divider is $\simeq$ 1.2 mA.

An influence of the CERES magnetic field on regime of PMTs was tested at the working conditions in the experimental area of the spectrometer. Two identical samples of counters and different types of magnetic screens were used in test measurements. Results

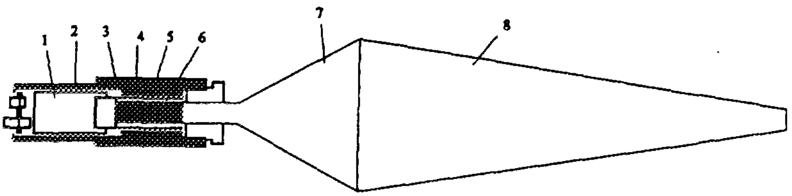


Fig.7. Sketch of a single counter of the MD array (1 — voltage divider, 2 — soft iron tube of the counter, 3 — additional soft iron cylinder, 4 — permaloy-B screen, 5— electrostatic screen, 6 — photomultiplier, 7 — lightguide, 8 — plastic scintillator)

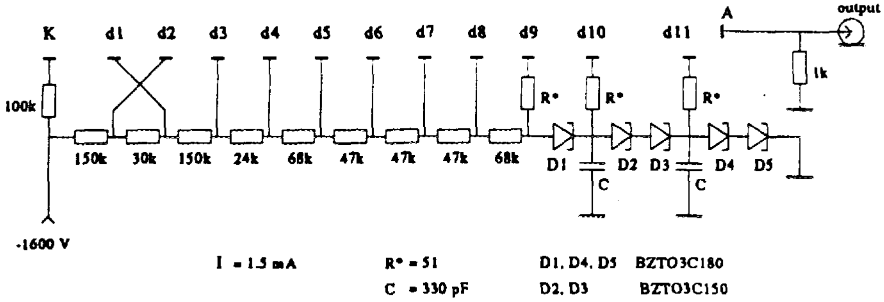


Fig.8. Voltage divider of the photomultiplier FEU-85

are shown in Fig.9 as a function of the distance from magnetic system of the CERES spectrometer. The measurements showed a high influence of the magnetic field on a counter operation at the distance of 1-2 m from the last correction magnet. Testing of different types of magnetic screens led to a choice of final variant of the counter design. The MD was installed at a distance of 2 m from the magnet system (5.35 m downstream of the target position). The PMTs were placed inside the 1.5-mm permaloy-B screen which was put into the counter tubes of soft iron with inner and outer diameters of 36 and 40 mm, respectively. An additional soft iron cylindrical screen, 180 mm long and 3.5 mm thick, was also used. For more stable operation of counter an electrostatic screen was wraped around PMT at photocathode potential. Homogeneity of light output for the MD counter was studied with collimated β-source of ^{144}Ce. Results of measurements are shown in Fig.10 as a map of relative response values for the different hitting points. The pulse height dispersion is less

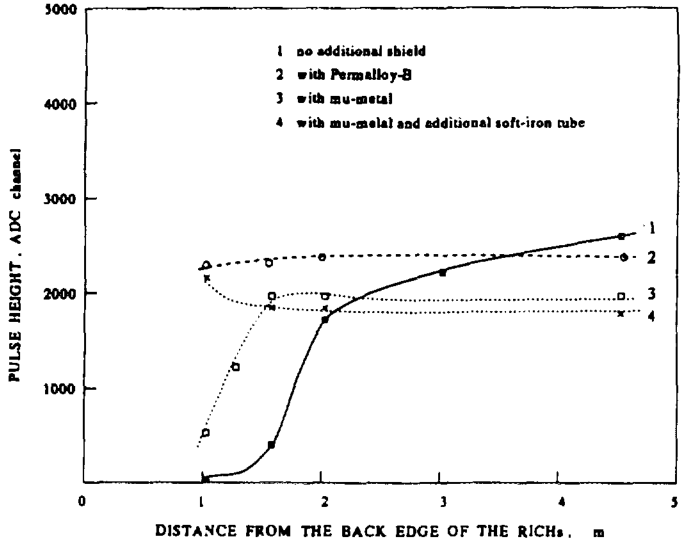


Fig.9. Test results on a dependence of the pulse height response of the MD counter on a distance from the magnetic system of the CERES spectrometer

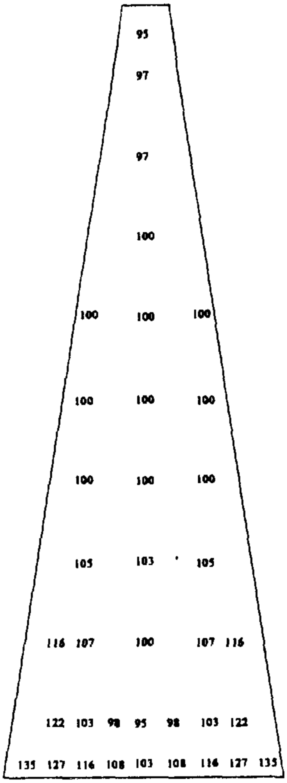


Fig.10. The response map for the MD counter scintillator obtained with a collimated β-source ^{144}Ce

than ~ 5% in the most part of counter active area and only in the angles far from the MD center it rises up to 35%.

The pulse height distribution for mip was also studied with deuteron beam with momentum of 8.9 GeV/c. The results were obtained for 4 cases when deuteron beam passed through the scintillator in three different points 10, 30 and 47 cm from the lightguide along counter axis and through the lightguide itself. For the first three cases the distributions are practically identical, and the beam passage through the lightguide does not produce any additional influence on the counter response.

So a requirement of independency of detector response on a hitting point position is well realized. Similar pulse height distributions for all counters of the MD were measured with muons at CERN and will be discussed below. One can consider this fact as a confirmation of proportionality of pulse height value to a number of hits. In a linear region of the detector, the MD responses for different number of charged mips were obtained with Monte Carlo simulation on a base of 1-mip distribution measured. With increasing of particle number,n, the distribution becomes close to Gaussian shape with a mean value A_n and a dispersion ΔA_n:

$$A_n = n \cdot A_1$$

$$\Delta A_n = 0.45\sqrt{A_n}\,.$$

The MD scintillators were pushed to be close to each other by fixing of the counters on a metallic frame. Dead space between the scintillators was less than 0.5 mm.

5. Signal Processing Electronics

The analog and trigger electronics of the CERES spectrometer is located 20 m from the experimental zone. The HV supply of PMTs is realized by 32-channel system (LeCroy model). Block scheme of electronics providing readout and processing of the MD signals is shown in Fig.11. The timing diagram of the MD signal processing is shown in Fig.12. Signals are taken from anodes of PMTs and brought to the inputs of the discriminators (LHE/JINR model 4F115). These discriminators allow one to set small thresholds ~ 10 mV, i.e., much lower than mean value of mip amplitude. The output NIM signals come to input register and to 24 inputs of majority logic unit (CEAN model, NIM) which generates the signal with a pulse height proportional to a number of pulses from the MD. By VME

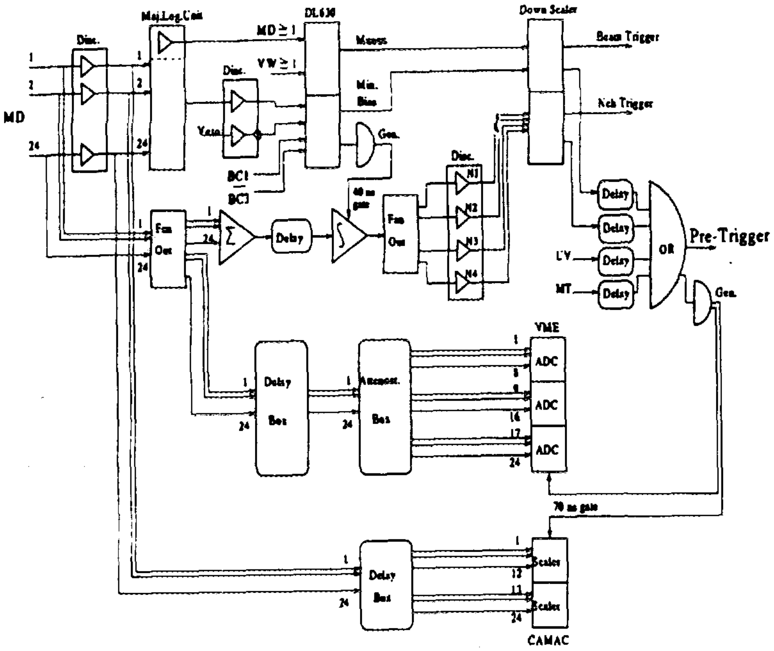


Fig.11. A scheme of the MD signal processing electronics

discriminator (Heidelberg univ. model) one can set a threshold on a number of MD pulses. Fast coincidence of pulse from VME discriminator with pulses induced with BC (BC1, BC3) and veto detectors (VETO) allows one to produce the minimum bias trigger signal by multifunctional logical module (Heidelberg univ. model DL630).

On the one hand, this signal can be used as a trigger with given minimum value of multiplicity threshold. On the other hand, it ptovides time synchronization of the trigger electronics. An experience has shown that a calibration of the MD can be carried out very effectively with the background muons produced by SPS beam in the experimental hall of the North Area. The muons passing through 8-m concrete shield come into the CERES zone. A 20-ns coincidence of signals of two scintillation arrays VW (Veto Wall) and the MD with about the same active areas gives a special trigger signal «muon» for the calibration goal. A distance between the VW and the MD is 9.8 m. The trigger signal appears only in a case if single counters of both arrays have given the pulses at the same time.

Analog signals of the MD are splitted on two branches. One set of the signals passing through a delay box and an attenuator (fine tuning of signal amplitudes) come to inputs of ADCs, VME modules. Another set arives in a sum module (LHE/JINR model 24LS243) which performs an analog summing of the input signals for next step of signal processing by integrator module (LHE/JINR model LV253). A time interval of sum pulse integration is given with 40-ns gate pulse generated by minimum bias trigger signal. As a result the amplitude of integrator signal is proportional to a charge particle multiplicity plus a

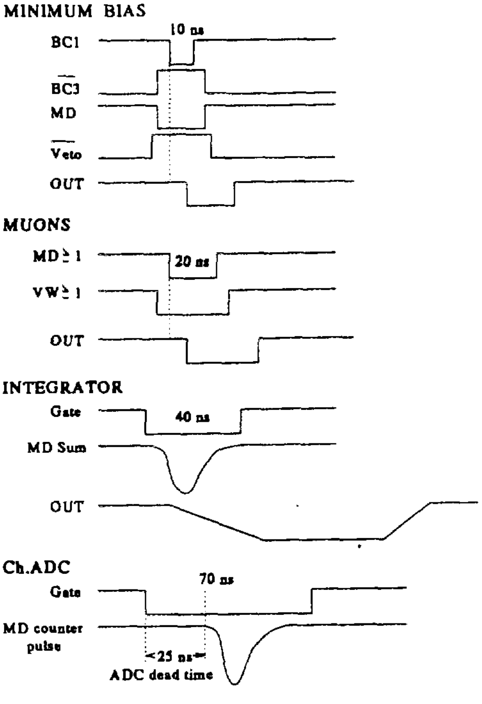


Fig.12. A timing diagram of the MD signal processing

pedestal. This signal after splitting is passed to four inputs of VME discriminator with different thresholds on a multiplicity calibrated. The N_{ch}-trigger signal is provided by the Down Scaler VME module (Heidelberg univ. model) which performs a selection of input signals from the N_{ch}-discriminators in a correspondence with a set of reduction factors. The output signal of this module is sent to the first level trigger electronics to generate the main trigger signal.

6. Adjustment and Calibration

An analysis has shown that the response of the MD for Pb-Au central collisions at 160 GeV/n achieves approximately 950 mips. An adjustment of the MD was performed right before the beginning of experiment when the magnetic system of the CERES spectrometer has been turned on. An investigation of dynamical range of the MD counter operation has shown a good linearity with unchanged pulse shape up to the pulse height value of 2.5 V. So the tuning procedure has a goal to get a correspondance between a maximum deposited energy (~ 60 mips per counter) and above-mentioned dynamical range. At this regim a mean value of pulse height from PMT for 1 mip is $\simeq$ 40 mV. Rough test of working capabilities of the MD counters can be carried out with the light emitted diodes (LED) placed on the lightguides of the counters. Short pulses with pulse height of ~ 70 V are produced for the LED system by a special generator (LHE/JINR model GSD712).

The main stage of adjustment and calibration of the MD was carried out with background muon flux using the special muon trigger. A typical number of the triggers per burst was about 3000-4000.

The fine tuning of 1 mip responses for individual counters was done by playing with the HV supply of PMTs. It was the iterative procedure performed with muon trigger and usually three steps were enough. The typical pulse height distributions measured with muons for some counters are shown in Fig.13.

To study Pb-Au semicentral and central collisions the following set of parameters was settled to realize the minimum bias trigger:

— Thresholds of discriminators for MD counter pulses $\simeq$ 140 mV (> 3 mips);

— Threshold on a number of pulses from the MD array was 15.

Such parameter set corresponded to an effective bias of the trigger of 80-90 mips. The next stage of calibration was an establishment of correspondence between the values of

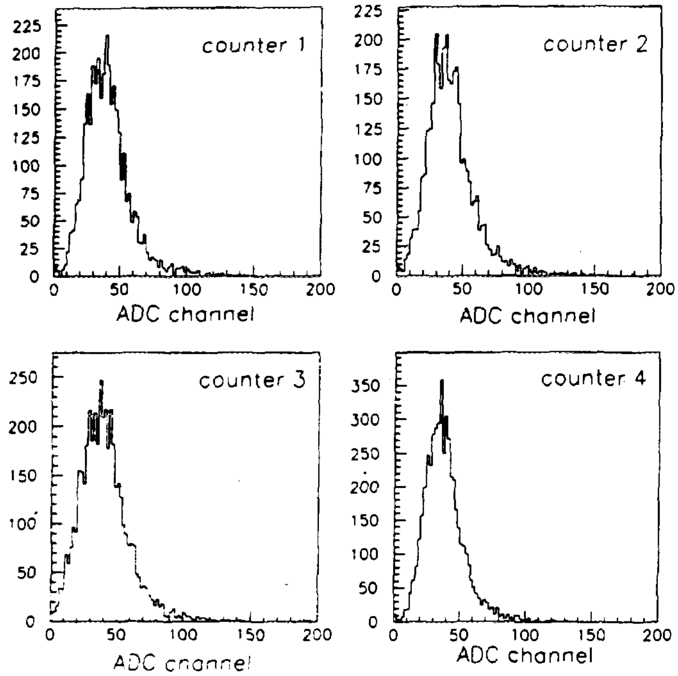


Fig.13. One-mip pulse height responses for some counters of the MD measured with background muon stream generated by the SPS beam in the North Area

discriminator threshold in mV and the multiplicity of particles measured with the MD or, in other words, the calibration of the main first level trigger signal, N_{ch}-trigger. With this aim special measurements for different threshold magnitudes were carried out with the lead-ion beam and the gold target. The distribution of number of charged particles was obtained by summing of 24 distributions measured with the individual counters calibrated before with muons.

7. Test Measurements with Lead Beam

The detector was tested with 160 GeV/n lead beam of the SPS CERN in November 1995. A background response of the MD for the single lead ion passed through the experimental zone without nuclear interactions is shown in Fig.14. Such response can be explained with the δ-electron production upstream of the MD, and it is much less in the case of close nucleus-nucleus collisions without high-charged projectile fragment. So 40 mips in average is the maximum background contribution from the CERES beam line. A correlation between responses of two detectors, the MD and the SIDC, measuring the multiplicity of charged particles for the Pb-Au collisions with the interaction trigger (the lowest bias trigger) is shown in Fig.15. The SIDC1 was located at 9.8 cm behind the target and covered the pseudorapidity region $1.8 < \eta < 3.8$. There is a good correlation and linearity between responses of both detectors in all dynamical range. A correlation of two processes such as the multiple charged particle production within the MD acceptance and the projectile fragmentation measured with the Cherenkov counter BC2 is shown in Fig.16 (interaction trigger). The BC2 was located about 1 m behind the MD and covered pseudorapidity region $\eta > 6.7$. The counter response is proportional to the sum of fragment charges squared and so the big response can occur only in a case if the high-charged fragments are available. One can see that there are no big responses of the BC2 for the high-multiplicity events. Only for the peripheral collisions, $N_{ch} < 150$ ($b > 10$ fm), we can observe the fragmentation process with high-charged fragments. The bump in the multiplicity distribution at low multiplicities is explained with a high cross section of lead nucleus disintegration in the peripheral collisions.

A comparison of the experimental multiplicity distribution measured by the MD for Pb-Au collisions at 160 GeV/n with the HIJING-GEANT prediction for four different impact parameter cuts $b < 4, 6, 8$, and 10 is shown in Fig.17. There is a good agreement between experimental and predicted distributions in the range of semi-central and central Pb-Au collisions. The impact parameter regions $b < 10, 8, 6$ and 4 fm approximately correspond to the MD responses with $N_{ch} > 160, 350, 550$, and 750 respectively. The CERES gold target consisted of 8 microtargets of 600 μm diameter and 25 μm thickness, separated along the beam direction by 3 mm. The main statistics in the run'95 was got with the N_{ch}-trigger at the N_{ch}-bias of 300 ($b \simeq 8.5$ fm). The dependence of MD multiplicity on the interaction point, i.e., z coordinate of the vertex, is shown in Fig.18 for two triggers, interaction trigger and N_{ch}-trigger. Vertex reconstruction was done by double tracking device SIDC1,2. The most of produced particles originated in the target region. It is cleary visible there are two additional background sources, the mylar windows of the vacuum pipe at $z = -5.3$ cm and of the Cherenkov counter BC3 at $z = 0.5$ cm in the interaction trigger case. For N_{ch}-trigger one can see practically only particles produced in the gold microtargets.

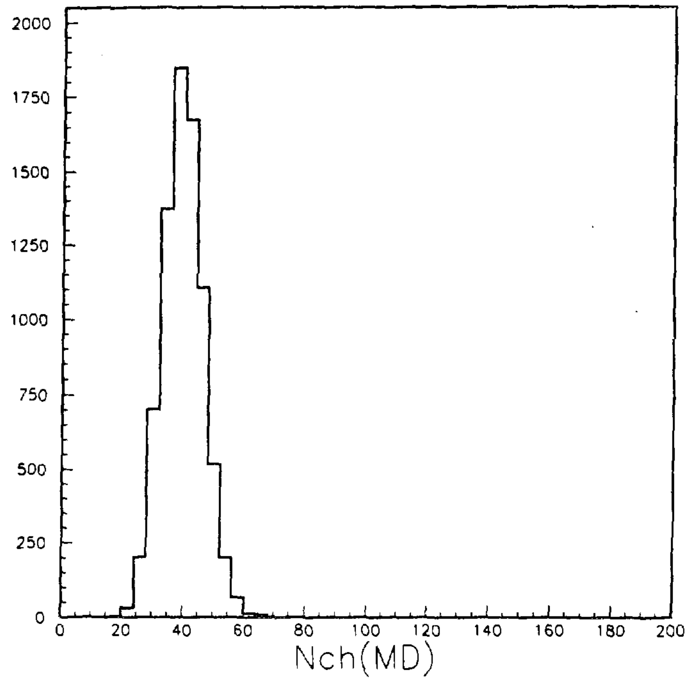


Fig.14. Background response of the MD for the case of single lead ion passage through the experimental zone without nuclear interactions

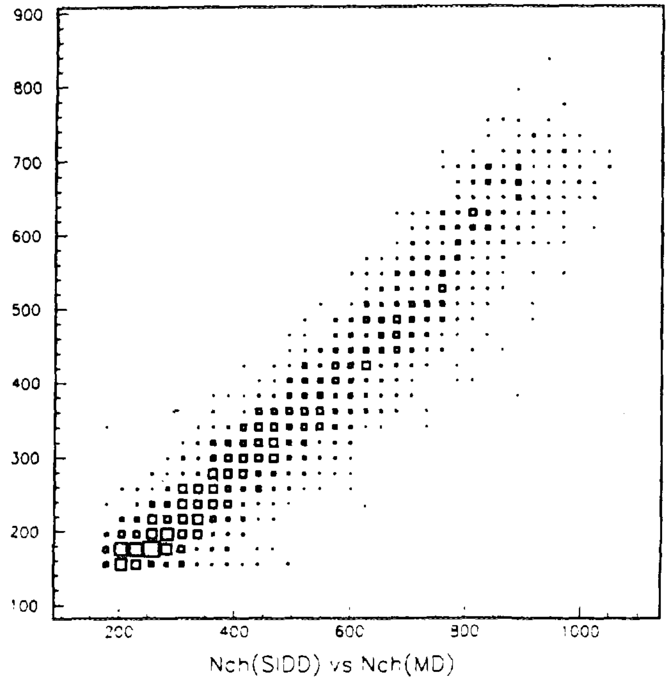


Fig.15. A correlation between the MD and the SIDC responses measured with minimum bias trigger

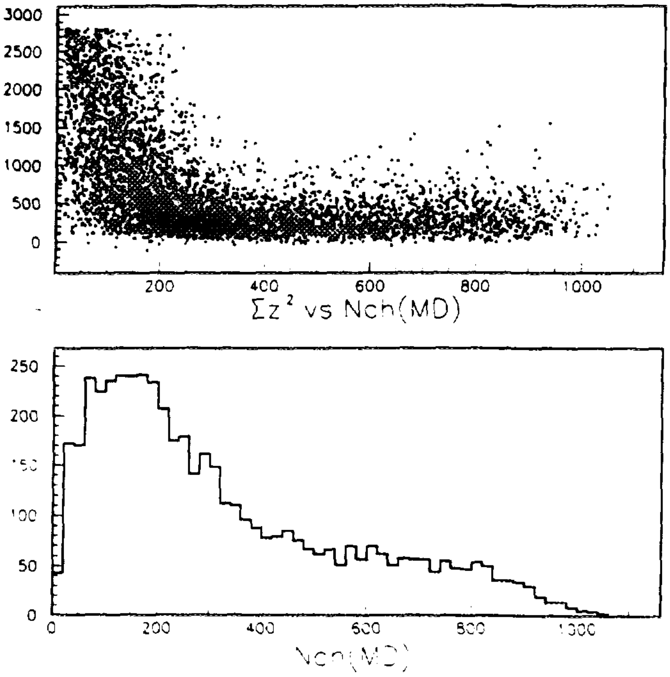
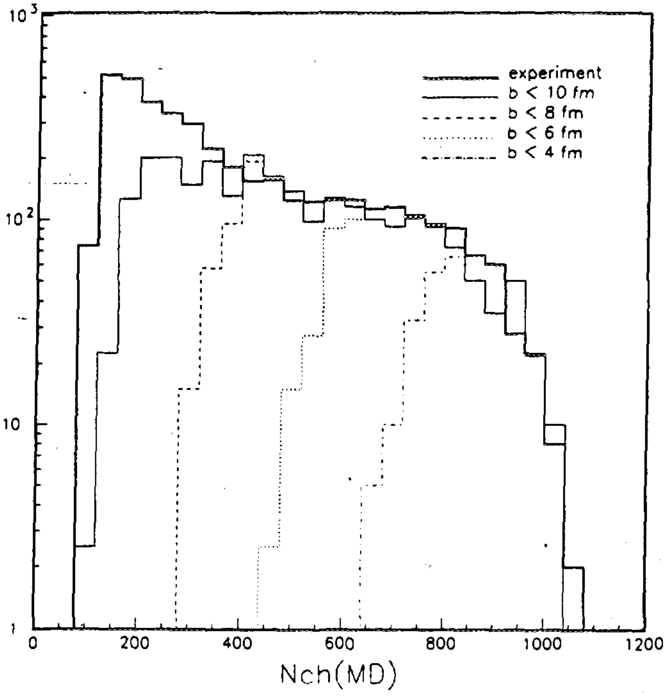


Fig.16. A correlation of multiple charged particle production within the MD acceptance and projectile fragmentation measured with the BC2 (top). A distribution of charged particle multiplicity measured by the MD with the interaction trigger (bottom)

Fig.17. The MD multiplicity distributions measured and predicted with the HIJING-GEANT for the Pb-Au collisions with $b < 10$, 8, 6, 4 fm



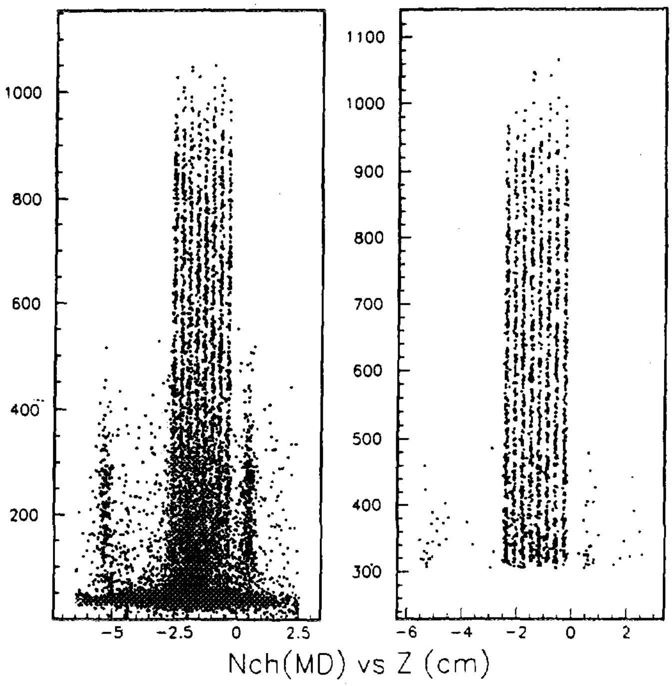


Fig.18. A dependence of the MD multiplicity on Z-coordinate obtained by vertex for the interaction trigger (left) and the N_{ch}-trigger (right)

8. Conclusion

We described the capabilities of the low-segmented scintillation array for the fast multiplicity triggering in a broad dynamical range up to a few thousand mips within the detector acceptance. The active time of the MD is defined by the 40-ns integration of sum pulse and can be even reduced twice. The test measurements with 160 GeV/n lead beam have shown a good correlation and linearity for the multiplicity data obtained with the MD and the SIDC. The maximum background response of the MD is about 40 mips whereas the MD response for central Pb-Au collision corresponds to about 950 mips. The HIJING event generator prediction of multiplicity is in good agreement with the SIDC data and has to be multiplied by a factor of 1.5 with a goal to reproduce the MD results. The GEANT simulation and estimation performed have shown that this effect is produced by particle multiplication process in the CERES medium and nuclear reactions in the MD scintillator. First level triggering with $N_{\rm ch} > 300$ selects only Pb-Au collision events with the impact parameters less than $\simeq$ 8 fm. It has been the major trigger for the CERES experiment in 1995 and 1996. In a future we plan to use the MD as one of the major trigger detectors of the DISC spectrometer for nucleus-nucleus collision study at the Nuclotron energy in Dubna.

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