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# MC SIMULATION OF ZERO DEGREE CALORIMETER FOR INVESTIGATION OF Pb-Pb INTERACTION AT 160 GeV/NUCLEON IN WA-98 EXPERIMENT

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The characteristics of the lead Zero Degree Calorimeter have been investigated in the framework of Geant package. This calorimeter is used like the major trigger device of nucleus-nucleus central collisions. The simulation of nuclear interaction of projectile and it's fragments with calorimeter media has been done. The calorimeter resolution as a function of projectile energy is evaluated. The scintillation light absorption in light drivers and the fluctuation of photocathode electrons have been taken into account. The resolution was equal to:

$$\mathrm{RES} = (49.2 \pm 1)\%\sqrt{E} \oplus (1.89 \pm 0.34)\%.$$

The maximal radiation load for scintillator tile and light drivers has been estimated. It is equal to 2.31 Mrad for single scintillators tile and 164 krad for single driver at intensity of $10^6$ Pb nuclei per spill for 4 runs by 30 days.

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

## Моделирование переднего калориметра эксперимента WA-98 по исследованию взаимодействий ядер свинца со свинцом при энергии 160 ГэВ на нуклон

***Р.Еремеев и др.***

В рамках моделирующего пакета GEANT исследованы характеристики адронного свинцового калориметра, который используется для выделения центральных ядро-ядерных взаимодействий. Предложен метод моделирования ядерных процессов при прохождении ядра и его фрагментов через вещество калориметра. Оценено разрешение калориметра с учетом поглощения света, испущенного в сцинтилляторе, в световодах, а также флуктуация электронов с катода фотоумножителя. Зависимость разрешения от энергии снаряда может быть представлена в виде

$$\mathrm{RES} = (49{,}2 + 1{,}0)\%\sqrt{E} \oplus (1{,}89 + 0{,}34)\%.$$

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Найдено, что максимальная радиационная загрузка сцинтилляторов при интенсивности пучка ядер свинца $10^6$ за сброс в течение 4 сеансов по 30 дней составит 2,31 Мрад, а максимальная загрузка световодов — 164 крад.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

The interest of a scientific community to an investigation of nucleus-nucleus collisions at high energies was manifested in carring out of copious experiments at high energy nuclear beams in last ten years. The selection of collisions with small impact parameters (central collisions) is an important task in such investigations.

The large acceptance experiment of WA-98 was started in 1994 at CERN SPS. The study of Pb-Pb collisions at 40, 80 and 160 GeV with high statistics of hadrons and photons was planned in it. The Zero Degree Hadronic Calorimeter (ZDC) measured a forward energy flux is used like a major triggering device of central collisions. According to this aim main requirements to the calorimeter are:

- high resolution of deposited energy measurements;
- high radiation resistance of the calorimeter.

The MC study of the Zero Degree Calorimeter has been done in the framework of GEANT [1] code. It was carried out in accordance with the above requirements:

- optimization of ZDC geometry;
- estimation of the calorimeter resolution;
- estimation of radiation loads for the calorimeter sensitive elements.

## 1.The Calorimeter Geometry

The main purpose of a calorimeter usage in an experiment is a measurement of incoming particle energy with good resolution. This means that the geometry of calorimeter should provide minimal lateral and longitudinal leakages. There is an additional requirement in the case of a hadron calorimeter. The calorimeter response to hadron and electromagnetic showers should be very close, i.e., compensation should be full. The ZDC geometry has been chosen in accordance with requirements mentioned above. The calorimeter consists of a 35 modules of $15 \times 15$ cm$^2$ with a cross section of $105 \times 75$ cm$^2$ in the plane perpendicular to the beam direction. It has about 9.4 interaction legth along the beam direction with division of each module into 158 layers of 1 cm lead tile and 0.25 cm polystyrene scintillator tile. Four steel plates have been inserted among these layers for mechanical rigidity of the module. The ratio of the thicknesses of lead and scintillator tiles was chosed to be equal to 4 in order to provide full compensation of the calorimeter [2]. Wave length shifters (WLS) were used like drivers of the scintillator light to photo multipliers.

## 2. The Calculation Method

The goals of our MC study were to simulate calorimeter features as close to a reality as possible. The detailed consideration is needed, partially, for the description of relativistic nuclei interaction with the calorimeter media and an evaluation of scintillator gamma losses during it passes through the WLS matter. Before the starting of this consideration we shall discuss some GEANT parameters used in our calculation. First of all, the possible in GEANT frame-work secondary prosses were switch on:

| | |
|---|---|
| photoelectric effect, | compton scattering, |
| pair production, | bremsstrahlung, |
| Raleigh effect, | δ-ray production, |
| positron annihilation, | nuclear fission by photon, |
| decay in flight, | hadron interaction, |
| muon-nucleon interaction, | multiple scattering. |

The hadron interactions were simulated with the help of the FLUKA package. The values of the energy threshold from which the process of given particle is started have been taken equal to 1 MeV for gamma, electron, hadron, muon and 5 MeV for neutrals. The energy conservation of the primary protons was the main criterion in the choice of these CUT values.

*2.1. The Interaction of the Fast Nuclei with the ZDC Matter.* In our case fast Pb nuclei and their fragments pass through the calorimeter media. They create a huge number of hadrons and fragmentate into nuclei with smaller atomic numbers in the same time. In order to simulate this rather complicated process we combined the following:

- the GEANT estimation of nucleus ionization losses during it's passage through media;
- the VENUS [3] calulations of the number and kinematical characteristics of particles, produced in an overlapping area of colliding nuclei;
- the generation of the projectile nucleus fragmentation characteristics according to the EXPERIMENTal distributions.

The main algorithm was the following:

- the interaction point of a projectile with target nucleus was generated according to the nucleus-nucleus cross section

$$\sigma_{BA}^{inel} = 71(\sigma_{pA}^{inel})^{0.29}B^{0.68}(\mathrm{mb}), \qquad (1)$$

with

$$\sigma_{pA}^{inel} = 18(\sigma_{pp}^{inel})^{0.34}A^{0.68}(\mathrm{mb}) \; ; \qquad (2)$$

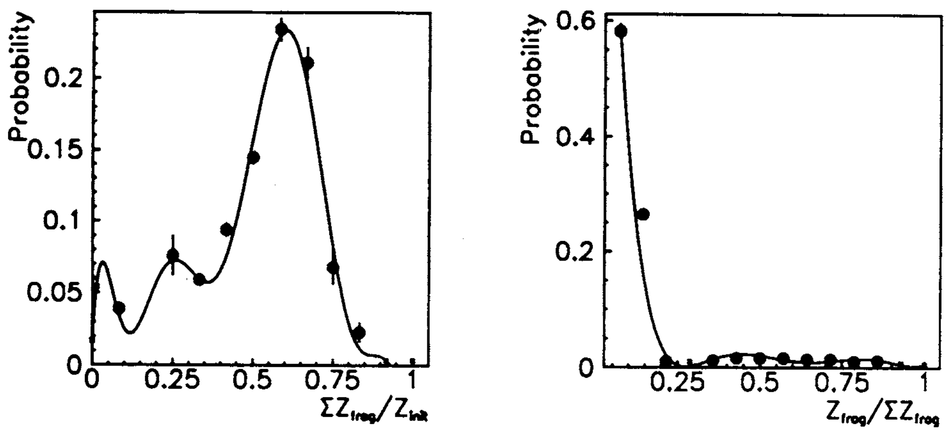
- the degree of projectile fragmentation and it's charge composition were generated according to approximation of experimental distributions for the summary charge of fragments ($Q = \sum Z_{frag}$) and their charge composition [4] (see Fig.1);
- the perpendicular momentum of the fragment was generated due to parabolic law [5]

$$d\sigma/dP_{\perp} \approx \exp(-P_{\perp}^2/2\sigma), \qquad (3)$$

here

$$\sigma = (1/5)^{1/2}(F(A-F)/(A-1))^{1/2}P_F\,, \qquad (4)$$

with the Fermi momentum $P_F = 221$ MeV/c, $A$ — atomic number of projectile and $F$ — fragment atomic number. There are two simplifications in simulation: the hadron interaction of projectiles and their fragments was switched on only for Pb and Fe targets; the fragment




(a) (b)

Fig.1. The distributions of: (a) summary charge of fragments and (b) their charge composition

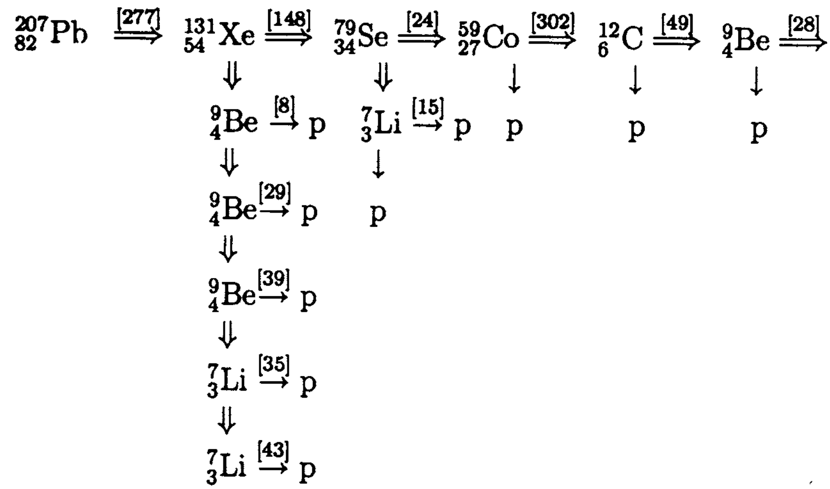



Fig.2. The scheme of the Pb nuclei fragmentation along it's pass through the ZDC. The values in the square brackets are the numbers of produced particles

with $F < 3$ were returned to FLUKA as protons with the momentum of 160 GeV/c times their atomic numbers.

One can find in Fig.2 the example of the fragmentation of the Pb nuclei during their pass through the ZDC matter.

*2.2. The Attenuation of the Scintillator Light.* The losses of the scintillation photons along their light way and the fluctuations of photoelectron have been taken into account.

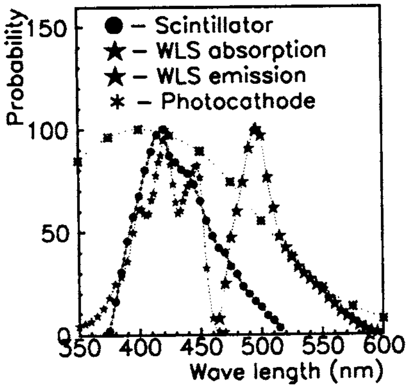



Fig.3. Optical spectra

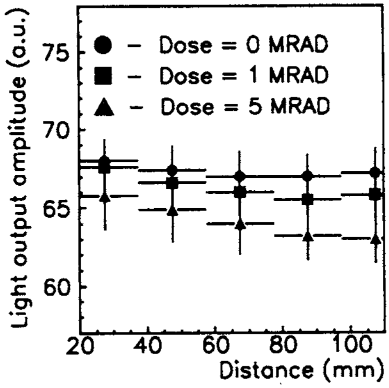



Fig.4. The light output amplitude of scintillator tile as a function of distance from the WLS contact

The number of photons emitted at a given point of a polystyrene tile is equal to:

$$N_\gamma = E_{\text{scin}} / \varepsilon \,, \tag{5}$$

where $E_{\text{scin}}$ is the energy deposited in polystyrene and realised into scintillations, $\varepsilon = h \langle \nu \rangle$ — average frequency of emitted light. The spectrum of light emitted by the polystyrene is shown in Fig.3. The influence of the tile transparency to the light collection ($N'_\gamma$) has been done in accordance to the empirical function shown in Fig.4. The scintillator tile was exposed by the radioisotope source and masking then with the black paper. We have used the empirical function for radiation dose equal to 5 Mrad. After this the $N'_\gamma$ has been corrected to the light absorbtion in the wave length shifter medium:

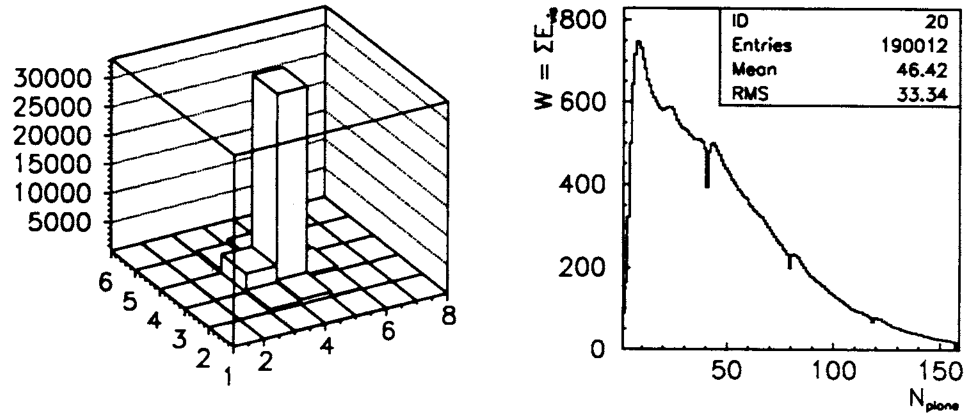
$$N''_\gamma = N'_\gamma \, e^{-z/L_{WLS}} \eta_{\text{trans}} \,, \tag{6}$$

where $z$ is the distance from light creation point to photomultiplier (PM) entrance, $L_{WLS}$ is the light absorbtion length in WLS and $\eta_{\text{trans}}$ is a transition coefficient including an efficiency of light reemission by the WLS (see Fig.3) and the geometrical efficiency of light transition from the creation point to PM entrance.

A convolution of the spectra of photocathode emission and light emission of WLS — (see Fig.3) has been done in order to take into account the photoelectron fluctuation.

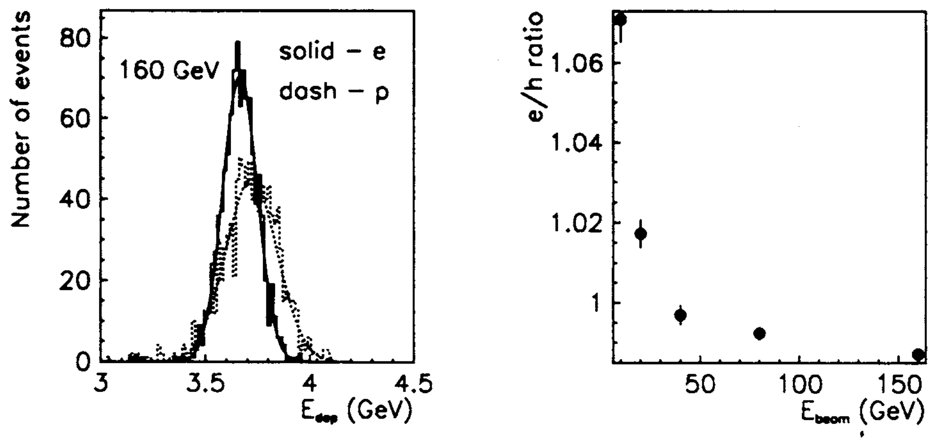
## 3. Results

*3.1. The General Characteristics of the Calorimeter.* The geometrical characteristics of the ZDC as a device with almost full deposit of incoming particle energy can be illustrated by the data shown on Fig.5. We see that the huge part of the initial energy is absorbed in




(a) (b)

Fig.5. The lateral development of showers initiated by Pb nuclei in ZDC at 160*A* GeV (a); the longitudinal development of these showers (b)




(a) (b)

Fig.6. The spectra of the energy deposited in scintillators and WLSs in ZDC at 160 GeV electrons and 160 GeV protons (a); the *e/h* ratio as a function of initial energy (b)

two central modules of our calorimeter (Fig.5a) both for incoming protons (82.505 ± 0.007)% and for Pb nuclei (84.4 ± 0.7)%. In fact there is no lateral leakage, practically, in our case (Fig.5a). The punchthrough is not larger than 0.6% for the initial proton and 0.4% for the nucleus beam (Fig.5b). The *e/h* ratios for ZDC are shown in Fig.6.

*3.2. The Energy Resolution.* The energy resolution of the calorimeter has been estimated for the initial protons. Five beam energies were taken: 10, 20, 40, 80 and 160 GeV. Absorbtion length of the WLS matter varied from 2 up to 10 m. The value of transition coeffisient of $\eta_{trans}$ from (4) has been taken equal to 0.01 in the semi-emperical way. The results of simulation are shown in the table and Fig.7.

The approximation of the mentioned above resolutions in the form

$$RES = a/\sqrt{E} \oplus b \qquad (7)$$

gives the values of coefficients of $a = (49.2 \pm 1.0)\%$ and $b = (1.89 \pm 0.34)\%$ for $L_{WLS} =$ $= 10m$. The variation of the WLS absorbtion length does not change stochastic term of $a$, practically. The constant term of $b$ is varied from $(3.15 \pm 0.20)\%$ at $L_{WLS} = 5m$ to $(1.89 \pm 0.34)\%$ at $L_{WLS} = 10m$.

**Table. Calorimeter resolution at $L_{WLS} = 10m$**

| $E_{init}$ (GeV) | 10 | 20 | 40 | 80 | 160 |
|---|---|---|---|---|---|
| *RES(%)* | 15.64 ± 0.49 | 11.78 ± 0.37 | 7.76 ± 0.20 | 5.75 ± 0.15 | 4.38 ± 0.12 |

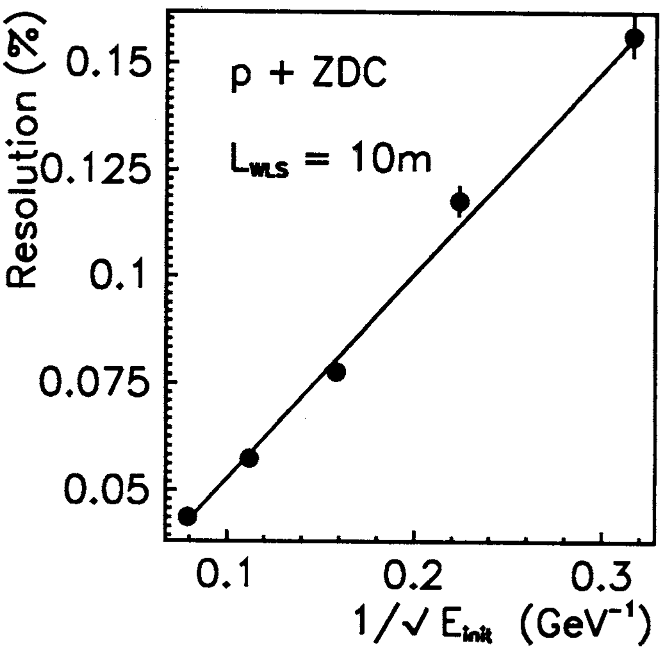



Fig.7.The resolution of ZDC as a function of $\sqrt{E_{init}}$

Let us estimate an expected accuracy of energy measurement for central collision events (CC) and for minimum bias events (MB), using the energy resolution at $L_{WLS}$ = 10$m$. The average values of full energy deposited in scintillation tiles and WLS at 160 GeV/n are:

$E$ = 3.784 ± 0.0002 GeV for $p$ + ZDC (1000 events),

$E$ = 1192.0 ± 7.0 GeV for Pb + ZDC (37 events).

Thus the deposited energies will be:

in CC case — 3.784 GeV × 207 = 783.3 GeV ± 20.2 GeV,

in MB case — 1192 GeV ± 28 GeV.

One can see that the selection of central collision events in ZDC can be done with high degree of reliability.

*3.3. Radiation Load.* The knowledge of the distribution of deposited energy in single scintillator tile and in WLS lets us to estimate radiation load of sensitive parts of our calorimeter in the case of initial Pb nuclei. This value is expected to be rather overestimated as we consider the case when 100% of the beam consist from the Pb nuclei. In the experiment the content of the particles incoming into the ZDC will be spread from Pb nuclei up to single protons. The distributions of the deposited energy for the single tile and single WLS of the central modules as a function of the plane number (longitudinal development of showers) are shown in Fig.8. The areas of maximal energy deposit are hatched. The

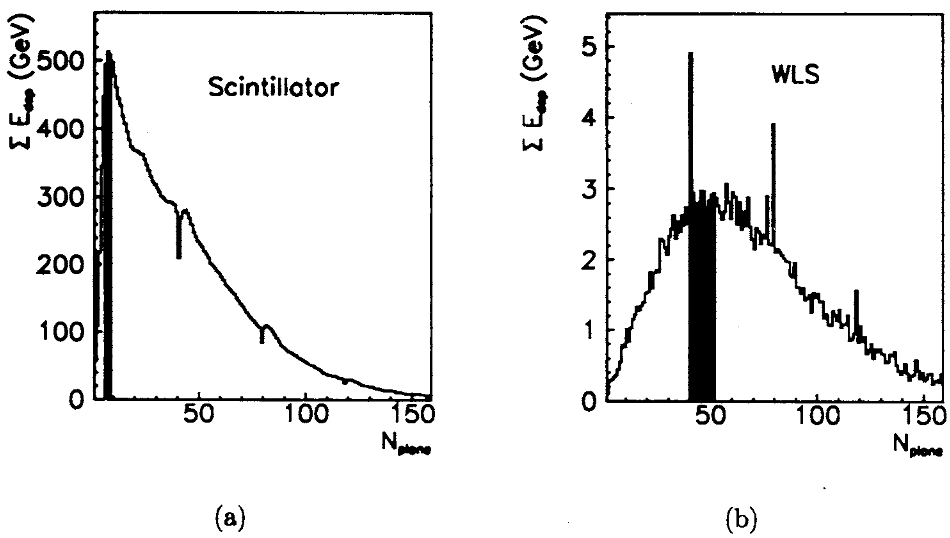



Fig.8. The longitudinal development of energy deposition in scintillator tile (a) and WLS (b) at 160$A$ GeV Pb nuclei

maximal value for scintillator tile per event is equal to 13.67 GeV, for part of WLS with the equivalent volume — 0.971 GeV.

The maximal radiation loads suitable to these values for intensity of $10^6$ Pb per spill for 4 runs by 30 days are equal to:

for single scintillate plate 2.31 Mrad,

for single WLS 164 krad.

As the radiation load of sensitive parts of ZDC is rather large we have given a trial of an emergency variant to use the lead block in front of the ZDC entrance in order to attenuate the beam intensity. The lead block $2 \times 2 \times 18$ cm$^3$ was placed at the entrance of the central ZDC module. The radiation loads were decreased in this case. The scintillator tile, for instance, is loaded up to 1.9 Mrad. The energy resolution is degraded, naturally, and at $L_{WLS} = 10m$ is equal to:

$$RES = (52.73 \pm 0.49\% / \sqrt{E} \oplus (4.24 \pm 0.29)\%. \qquad (8)$$

The average deposited energy, in case of MB events, is equal to (1053 ± 48) GeV and to (782.5 ± 36.3) GeV for CC interactions. One can see that the selection of MB and CC events can be done, in this emergency varuant, with sufficient accuracy, too.

## 4. Conclusion

1. The selection of central collision events can be done with high degree of reliability by means of ZDC measurements.

2. The detector parts of ZDC will have a large radiation load during their exposition in Pb nuclei beam. The degradation of ZDC energy resolution as a result of this load can be compensated by the placing of attenuation block in front of ZDC entrance, or by using any semi-peripheral modules like a central.

## 5. Acknowledgments

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