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CHARACTERISTICS OF THE ELECTROMAGNETIC CALORIMETER PROTOTYPE FOR SEGMENTED LARGE–x BARION SPECTROMETER (FERMILAB EXPERIMENT E–781)

MOSCOW 1992

УДК 536.62 М-16

CHARACTERISTICS OF THE ELECTROMAGNETIC CALORIMETER PROTOTYPE FOR SEGMENTED LARGE - x BARION SPECTROMETER (FERMILAB EXPERIMENT E-781); Preprint ITEP 92-109/

M.Balatz, V.Vishnyakov, G.Dzubenko et al. - M., 1992 - 20p.

Design and construction of the prototype of the lead glass electromagnetic calorimeter was made. The characteristics of the detector were studied. The energy resolution of the detector in the region of electron energies of 2 - 5 GeV was found to be described by expression

$$\sigma / E = (1.2 + 4.7/\sqrt{E}) \%$$

The space resolution was better than 6 mm. The detector responce was found to be linear within accuracy of our measurements up to energy of 23 GeV. After completion of the tests the full scale production of the calorimeter have been started. The basic geometry of the calorimeter sections and schemes of their elements are presented.

Fig. - 9, ref. - 6

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An international collaboration of the Fermilab experiment E781 is constructing a large spectrometer SELEX for study of properties of charmed barions produced in the hyperon beam of the Tevatron [1]. There are decays of these barions involving neutral pions and gamma quanta and semileptonic decays among these physics processes [2,3]. For example these include electroweak decays of ground states of the charmed barions:

$$\Lambda_c^+ \to \Lambda^0 \pi^+ \pi^0 \quad ;$$
$$\Lambda_c^+ \to p K^- \pi^+ \pi^0 \quad ;$$
$$\Lambda_c^+ \to p K^0 \pi^0 \quad ;$$
$$\Lambda_c^+ \to \Sigma^0 \pi^+ \quad ;$$
$$\Sigma_c^+ \to \Lambda^0 K^+ \pi^0 \quad ;$$
$$\Sigma_c^+ \to \Sigma^+ \pi^0 \quad ;$$

radiative and strong transitions:

$$\Sigma_c^+ \to \Lambda_c^+ \pi^0 \quad ;$$

$$\Sigma_c' \to \Sigma \gamma \quad ;$$

and semileptonic decays with electrons:

$$\Lambda_c \to e \nu X \quad ;$$
$$\Xi \to e \nu X \quad ;$$
$$\Omega \to e \nu X \quad ;$$
$$\Lambda_b \to (\Lambda_c)^* e \nu \quad .$$

For measurements of characteristics of photons and electrons produced in these processes it has been proposed to build an electromagnetic calorimeter based on Cherenkov counters of full absobtion with radiators of lead glass. According a layout of the experiment the calorimeter will consist of three sections. The basic geometry of the detectors are presented in the Table 1 and schemes of their elements configurations are presented on the Fig. 1. Simulation of the physical processes of production and decays of the charmed barions (PYTHIA [4]) gives multiplicities and energies of the photons produced in the ranges of angles covered by the photon detectors. Thus the first section, Photon-I should measure photons in the energy interval of 1 - 20 GeV (energy in the maximum of the spectrum is about 2 - 3 GeV) with typical photon multiplicity of 2 - 3 per event. The second section, Photon-II will register gammas with energies between 2 - 50 GeV (maximum of the spectrum about 10 GeV) with multiplicity about 2. The third section, Photon-III will measure photons in very forward direction with enegies up to several hundred GeV (maximum of the spectrum is about 20 Gev) with

typical multiplicity of 2.

To determine properties of the calorimeter under construction and to gain an experience of work at the Tevatron the prototype of the calorimeter was constructed and irradiated at first in the electron beam of the ITEP 10 GeV accelerator and then in the Fermilab hyperon beam during the 1991 test run. A description of the prototype and the results of these measurements are presented in the following sections.

A PROTOTYPE DESIGN

The prototype was constructed as a small electromagnetic calorimeter consisting of 18 modules as shown on the Fig. 2. The modules were made as independent counters of which the array of desired dimensions was assembled. The main parts of the module are: a lead glass block - radiator ; a photomultiplier (PM) with magnetic shielding; a high voltage divider.

The blocks of lead glass of TF-1 type (a radiation length of 25.4 mm) with dimensions of 42.5 x 42.5 x 340 mm (16 pieces) and 85 x 85 x 340 mm (2 pieces) have formed the prototype array. The PM's were optically coupled with the lead glass blocks by means of an optical silicon grease to allow to change the PM's.

The blocks of 42.5 x 42.5 mm were viewed by the PM's of FEU-84 type and the blocks of 85 x 85 mm were viewed by FEU-110 PM's. The PM's were selected using a stable flash of a light emitting diod (LED). Thus a working value of high voltage was

determined and a PM gain stability was checked with light intensity equivalent to a signal of 10^5 pions transversing the block per second. This intensity is an expected maximum flux of particles through one counter during the experiment.

There were steel and mu-metal cylinders for magnetic shielding around the PM's.

The high voltage dividers were checked on a test stand. A total resistance of the divider was 8.41 MOhm for the PM of FEU-84 and 9.02 MOhm for the PM of FEU-110 with a tolerance of 0.5%. An average divider current was about 150 mkA under typical working conditions.

A time stability control of the modules was made by means of a green LED. The LED flash was distributed to every module via glass light guides. The LED was fired by a stabilized generator producing pulses with an amplitude of 4 A and a duration of 20 ns. A value of the LED signal was equivalent to an electron energy deposition of 10 GeV (with a variation from the module to the module of 20 %). The LED source temperature was stabilized within 0.5 °C at 30 °C so its light output was stable within 0.5%.

PROTOTYPE CHARACTERISTICS

The prototype tests and measurements of its characteristics were carried out at the ITEP accelerator and the Fermilab Tevatron.

A beam of pions enriched by electrons with momentum in the range of 2 - 5 GeV was used in ITEP [5]. A hodoscope of

scintillation counters selected the beam particles (a plastic scintillator of a size of 5 by 5 mm was used at the entrance of the test module) and a gas Cherenkov counter was used to select electron and to supress the pion triggers.

At the first step all modules were calibrated using the beam of electrons with momentum of 4 GeV (a momentum spread of about 1 %). The beam was directed on the center of the module under calibration. The PM high voltage value was tuned on to obtain the electron signal amplitude of 170 mV as measured with an oscilloscope with an impedance of 50 Ohms. Then the counter outputs were connected to analog-digital converters (ADC) with sensitivity of 0.5 pC per count. Thus the equivalent ADC sensibility was typically 20 MeV per an ADC count. Final calibration coefficients were obtained during the following off-line analysis.

From the observed distribution of energy deposition in the modules it was found that 88 % of the detected energy of the incident 4 GeV electron is deposited in the lead glass block when the beam is directed onto its center. More than 99 % of the absorbed energy in the calorimeter was deposited in the group of 9 blocks in this case (we did not consider energy leakage through the rear plane of the calorimeter). A typical amplitude spectrum as measured by the array of 9 counters is presented on the Fig. 3. Good uniformity of the responce was found when the electron beam scanned different lead glass blocks (between the points A and B on the Fig. 2): deviations were within of 1 % as it is seen from the Fig. 4 .

Observed energy resolution in the region of electron

energies of 2 - 5 GeV can be approximated by an expression:

$$\sigma/E = (1.2 + 4.7/\sqrt{E})\ \%,$$

where E is the electron energy in GeV. The resolution was found to be independent (within experimental uncertainties) on the position of the entrance of the incident particle into the block as shown on the Fig. 5.

Detector space resolution is determined by transversal dimensions of the electromagnetic shower (a shower profile) as well as a size of the lead glass block. To estimate the shower profile in the blocks a ratio of the amplitudes in two blocks was measured as a function of the coordinate of an entrance point of the electron beam (Fig. 6). An observed slope of this curve is in agreement with a value of the Moliere radius of the TF-1 lead glass. These data were used to estimate the value of a space resolution of the detector as a function of a beam position (Fig.7). A coordinate determination algorithm was used as discribed in [6]. No corrections were made for the beam spread on the block entrace plane (about 2 mm) so presented values should be considered as an upper limit.

Further studies of the prototype properties were carried out in the hyperon beam of the Fermilab accelerator during the test run. The main goals of these measurements were to study detector properties for higher energies up to about 25 GeV and to make a final design of the detector modules taking into account Fermilab safety requirements.

The prototype was mounted in the beam in the Proton Center experimental area of the Tevatron accelerator. A beam of secondary particles with several momenta between 8 and 23 GeV/c was formed by the hyperon magnet and directed on the tested detector. This negative beam consisted of electrons, muons and hadrons where the electron fraction varied from 50 % at 8 GeV/c down to about 5 % at 23 GeV/c. The beam has a momentum spread of about 15 % (a FWHM) which was determined by the aperture of the hyperon magnet. A position and dimensions of the beam were determined by a hodoscope of scintillation counters and a set of proportional gas chambers. Only particles passing through the center the lead glass block under study were accepted.

Typical amplitude spectra of the signals of the module of a size of 8.5 by 8.5 cm are presented for incident particles momenta of 8 and 13 GeV/c in the Fig. 8. A good peak due to incident electrons was observed as well as a peak of a Landay type due to noninteracting pions and muons at a low end of the spectrum. The position of the electron peak as a function of the incident beam momentum is presented in the Fig. 9. The points corresponding energy deposited by noninteracting pions ($\sim$0.5 GeV) and electrons with momenta of 4 GeV/c (ITEP data) are presented on the same figure. Thus it was found that the detector responce is linear for electrons with momenta up to 23 GeV/c.

After completion of the described tests the full scale production of the E781 electromagnetic calorimeter have been started.

Authors are grateful for help and useful discussions to P. Cooper, A. Dolgolenko, T. Dubbs, S. Gerson, J. Lach, L. Landsberg, M. Moinster, A. Nilov, N. Rabin, J. Russ, L. Stutte, S. Timm and technical stuff of ITEP and Fermilab.

TABLE 1

Structure of the E781 Electromagnetic Calorimeter

Section	Size of Block (mm)	Number of Blocks	Outer Size, (mm)	Hole Size, (mm)
Photon I	42.5 x 42.5 x 340	576	1360 x 1105	425 x 170
	85 x 85 x 340	54		
Photon II	42.5 x 42.5 x 340	448	2380 x 1105	510 x 595
	85 x 85 x 340	210		
Photon III (preliminary)	39 x 39 x 450	284	702 x 624	78 x 78

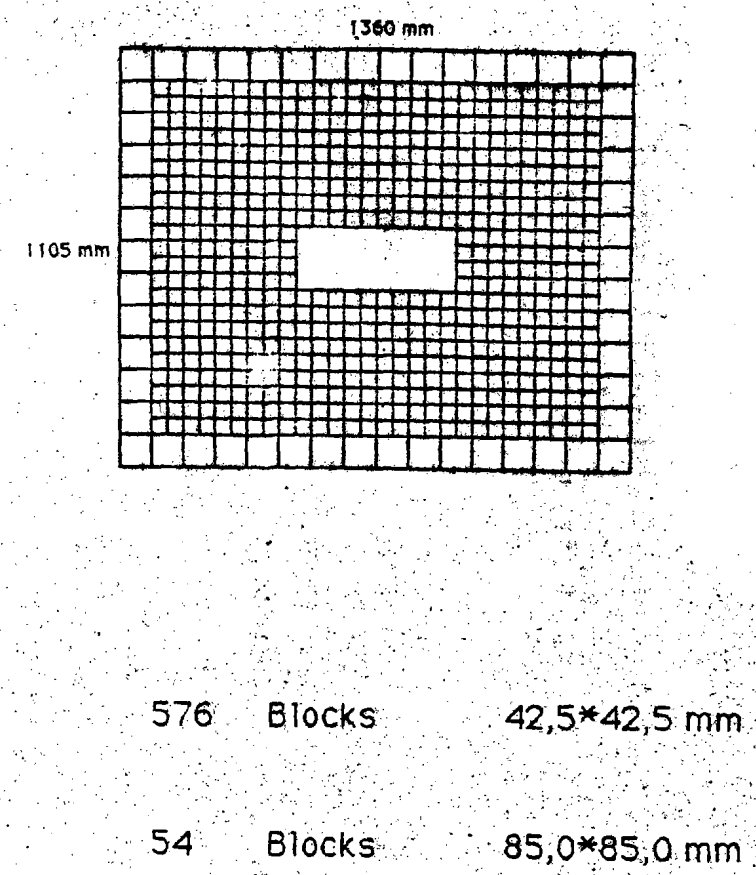
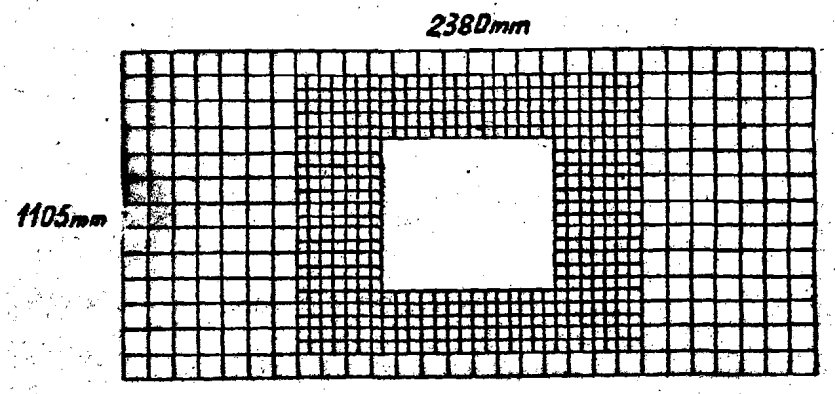


Fig.1a. The schemes of three sections of the calorimeter.

Photon - 2.



448 Blocks 42.5×42.5 mm.

210 Blocks 85.0×85.0 mm.

Fig.1b. The schemes of three sections of the calorimeter.

Prototype.

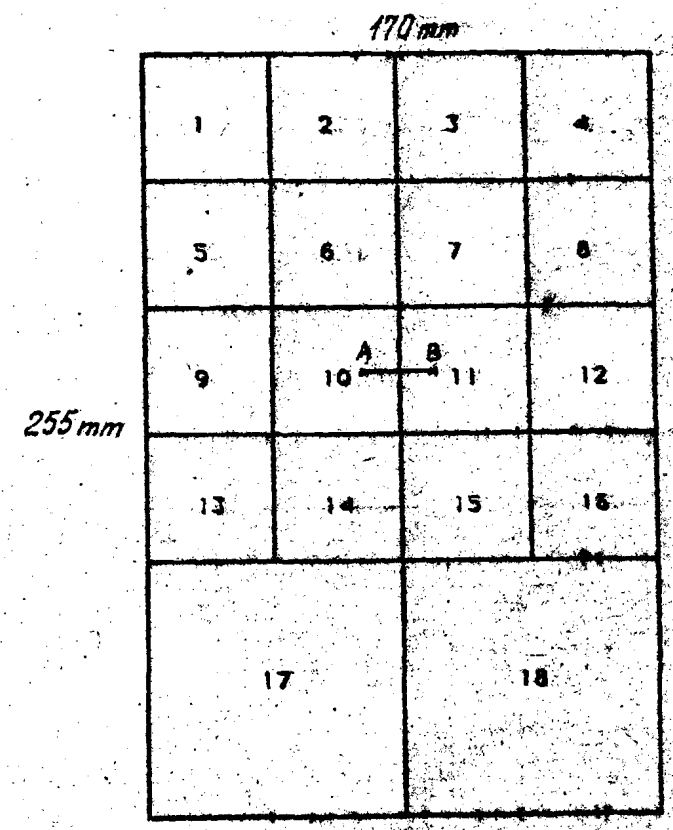


Fig. 2. The scheme of the calorimeter prototype. The modules are scanned from the point A to the point B.

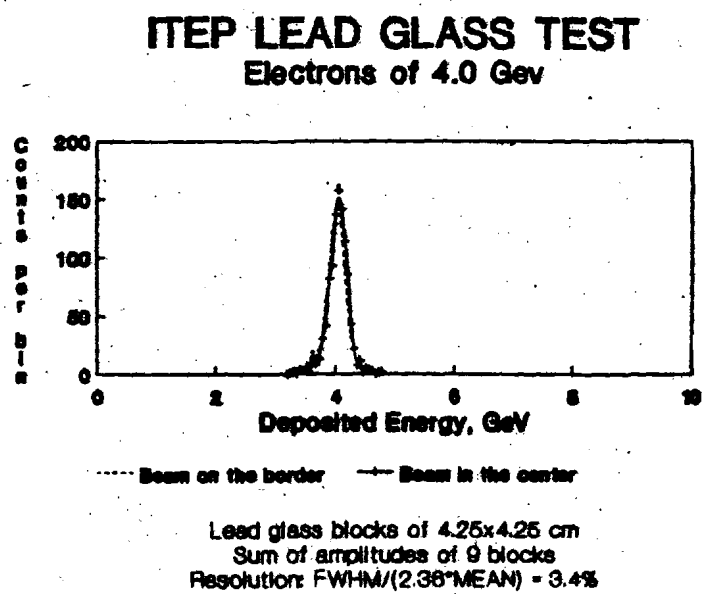


Fig. 3. An amplitude spectrum (a sum of amplitudes in 9 counters) for electrons with energy of 4 GeV.

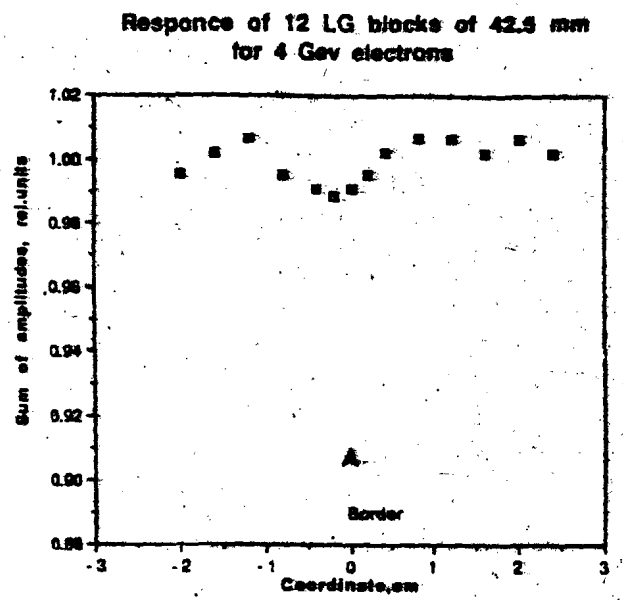


Fig. 4. An average electron amplitude as a function of the beam position on the detector.

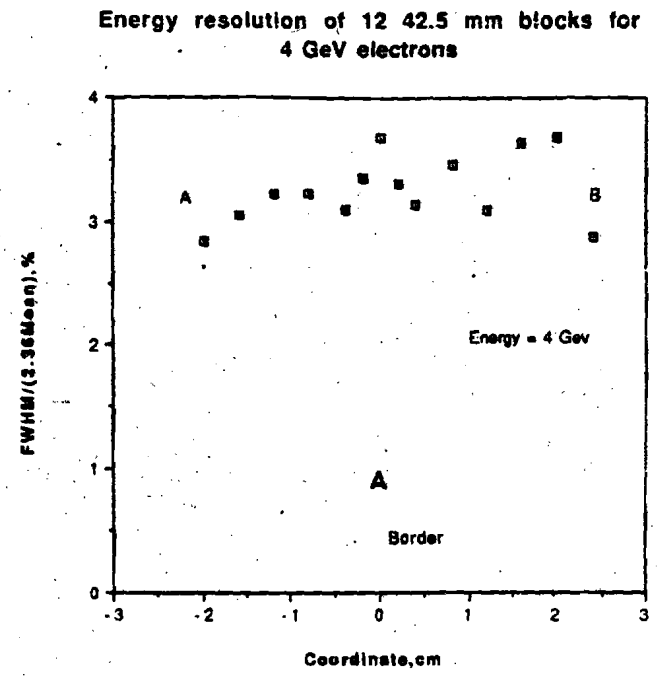


Fig. 5. Electron energy resolution at 4 GeV as a function of the beam position on the detector.

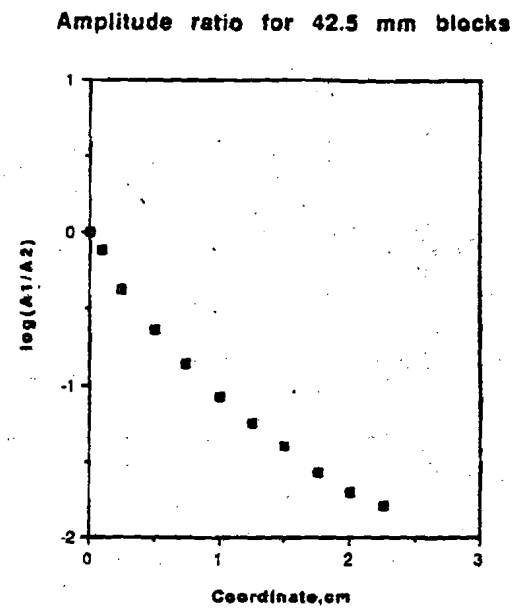


Fig. 6. A ratio of amplitudes in two neighbouring blocks as a function of the beam position on the detector.

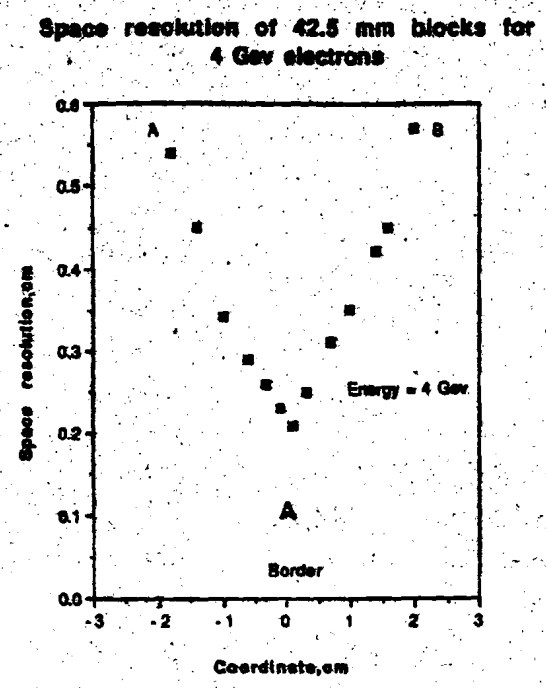


Fig. 7. Estimated position resolution as a function of the beam position on the detector.

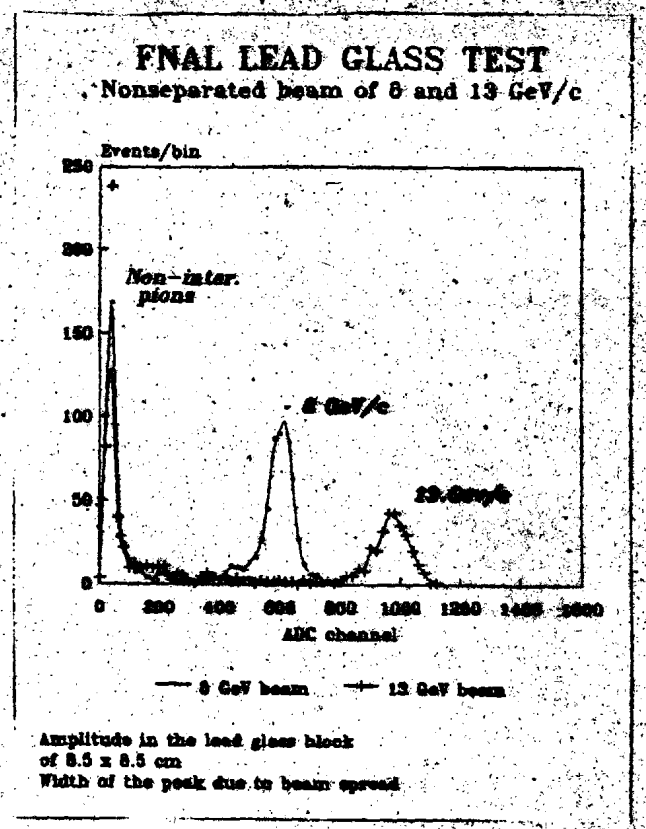


Fig. 8. Amplitude spectra for particles of momenta of 8 and 13 GeV/c in the test beam. Pion and electron peaks are observed.

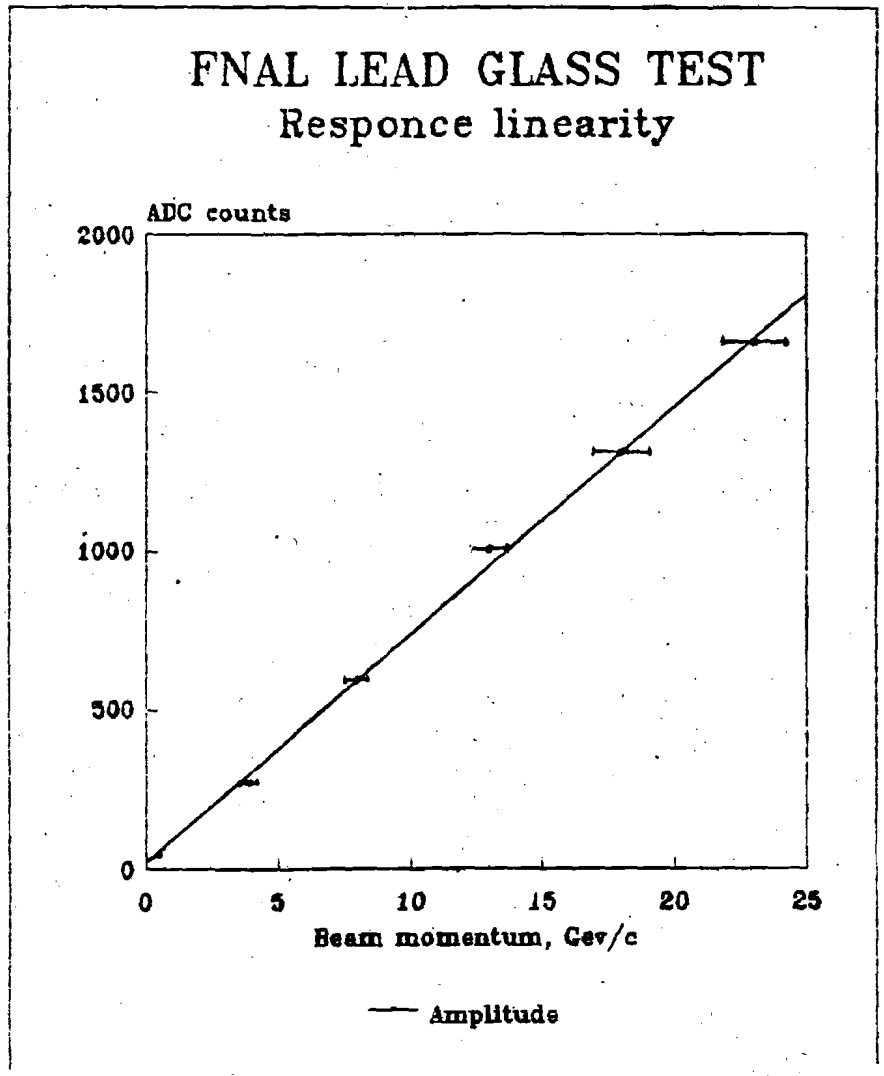


Fig. 9. Observed electon amplitude in the calorimeter as a function of the beam momentum

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Характеристики прототипа электромагнитного калориметра для установки "SELEX"

Подписано к печати 21.12.92 Формат 60x90 1/8 Офсетн.печ.
Усл.-печ.л.1,25. Уч.-изд.л.0,9. Тираж 170 экз. Заказ 109
Индекс 3649

Отпечатано в ИТЭФ, 117259, Москва, Б.Черемушкинская, 25