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THE INVESTIGATION TEST OF A MODEL OF EM-CALORIMETER ON THE $NaBi(WO_4)_2$ CRYSTALS

B. N. Kalinin, Yu. F. Krechetov, A. M. Kolchuzhkin, D. E. Kustov, A. V. Moiseenko, G. A. Naumenko, A. P. Potylitsyn, O. C. Saigushkin, M. N. Strikhanov[1], Ye. N. Shuvalov, I. S. Tropin

[1] MEPhI, Moskow

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Institute for Nuclear Physics,
634050, Tomsk, Russia

ABSTRACT

We have constructed a mock-up model consisting up of 9 elements to evaluate the space and energy resolution of the $NaBi(WO_4)_2$ crystals electromagnetic calorimeter. The characteristics of a mock-up model have been studied at 700 MeV electron beam. It is shown that with cell dimensions of about 2.4 cm one can achieve accuracy of <3 mm in measuring the coordinates. The investigations have shown that the calorimeter has fast operation, satisfactory energy resolution and good space resolution characteristics.

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1 MEPhI, Moskow

The experiments using a new generation of accelerators, including RHIC, are faced with the problem of appropriate choice of materials for detecting elements of the crystal electromagnetic calorimeters (EMC). The crystals have to comply with several requirements, such as high speed of operation, high radiation resistance, small radiation length, small Moliere radius, feasibility of mass production and low cost, etc.

The $NaBi(WO_4)_2$ crystal (ρ =7.58 g/cm^3, X =1.04 cm, R_M =2.4 cm, n_D =2.15) is suggested as a potential candidate for the EMC radiator. In our previous work we examined properties of the crystal, viz. transparence, homogeneity, mechanical and scintillation properties, radiation resistance and feasibility of producing large samples, etc. At room temperature the crystals exhibit virtually no scintillation properties unless scintillating elements are added. Otherwise, the crystals meet most of the requirements imposed and can be regarded as Cherenkov radiators for EMC. It should be stressed that these crystals have high radiation resistance (~ 10 Mrad).

We have constructed a mock-up model consisting of 9 elements to evaluate the space and energy resolution of the $NaBi(WO_4)_2$ crystals electromagnetic calorimeter. Each element was a 2.4 x 2.4 x 18 cm^3 tungstate crystal with polished faces. It was surrounded from all sides,except one end face, by an aluminized lavsan reflector. The crystal could be viewed through the open end by a small PMT-86. The latter was surrounded by a permalloy magnetic shield. In addition, the crystal , PMT and signal preamplifier were placed in a 0.25 mm thick soft-iron case. The PMTs signals after the preamplifiers entered the multiple charge-to-digit converter (CDC). The mock-up model was tested using a secondary 700 MeV electron beam from the Tomsk synchrotron. The electron energy spread was ~1%. A schematic of the experiment is shown in Fig.1. CDC was controlled by two trigger scintillation counters forming an electron beam size of 8 x 6 cm^2 at the mock-up model. Two scintillation hodoscopes were placed before the mock-up model to determine precise position of the point where the electrons were injected into the crystal. The hodoscopes consisting of scintillation fibers, ~ 0.45 mm in diameter, assembled in a 150 x150 x

8 mm^3 stack. The ends of the fiber stack could be viewed from one of the sides by a GFEU-30 hodoscopic PMT /1/. The hodoscopes made it possible to determine the electron coordinates to an accuracy of ~1 mm. The mock-up model was exposed to the e-beam at electron energies of 300, 500 and 700 MeV. Individual channels were energy calibrated according to the following formula:

$$E_{rel} = ai + bi \times Ai \quad , \qquad (1)$$

where i is the number of one of the 9 elements used, Ai is the signal amplitude from that element and E_{rel} is the relative electron energy. The ai and bi were determined at electron energies of 30, 300, 500 and 700 MeV for those electrons only that hit the center of each of the crystal. The absolute calibration was performed for one point when the electrons were incident in the middle of the central crystal, assuming that the electromagnetic shower was within the dimensions of the mock-up model crystals. A fairly good energy resolution was obtained for Ee= 700 MeV with $\Delta E/E < 14\%$ (FWHM). The resulting data on the energy resolution can yield the upper bound of the fluctuating term in the expression for the energy resolution of the mock-up model and we have $\sigma/E = (a/\sqrt{E} + b)$. Assuming that the distribution width is generally due to photoelectron statistics gives $\sigma/E < (7/\sqrt{E})$ %, where E is a few GeV.

The statistics obtained was then used to estimate the space resolution of the mock-up model. Fig.2 presents the measured dependence of the pulse-height ratio A_i/A_{i+1} for two adjacent counters on the electron coordinate X_c. X_c=0 corresponds to the center of the (i+1)th cell, and X_c=12.5 mm is the boundary between the ith and (i+1)th cells. From this ratio we found, using the method of least squares, the radial response distribution function for the shower developing in the tungstates. Two kinds of the approximation function were tested. In the first case the radial distribution of the total charged particle track length was taken as the sources function. The distribution was calculated for tungstate by Monte-Carlo method using "CASCADE" computer code /2/. The resulting distribution was then approximated by a one-dimensional spline F(r) convoluted with a smoothing function of gaussian form where the only unknown variable was dispersion. By fitting the light yield ratio an optimal dispersion of the "smoothing" gaussian was found. In the second case use was made of the sum of two terms

$$f(r) = A1 * e^{-r/r1} + A2 * e^{-r/r2} \qquad (2)$$

This form has been successfully used in Refs /3-5/. The following values for r1=0.33 , r2=1.0 and A1/A2=13.3 were obtained. The results of the fits for the two cases are shown in Fig.2. It is evident that the first version fails to provide adequate agreement with experiment (χ^2/ number of degrees of freedom > 40). It is likely that the distribution of the total charged particle track length for the shower in crystal and the shower response in terms of Cherenkov light entering PMT differ drastically in their form. This is supported by our early experimental measurements of the fraction of shower leaving the tungstate and the TF-5 lead-glass radiators at 300 and 700 MeV, provided that the amount of light at PMT is proportional to the sum of the charged particle track lengths for the shower. The fraction of shower leaving the crystal in our experiment was much higher than the calculated value obtained by CASCADE computer code. Table 1 lists the fractions of shower leaving the central tungstate crystal and TF-5 lead-glass radiator of the same cross sizes for 500, 700 and 1000 MeV. The number in round brackets obtained for Ee=700 MeV with the radial response distribution function in the form (2). The fit is quite good.

Table 1.

Radiator		500 MeV	700 MeV	1000 MeV
TF-5	calculated	0.25	0.28	----
	experiment	0.48	0.52	----
Tungstate	calculated	0.17	(0.30)	0.18
	experiment	0.23	0.31	----

We obtained function C(r) in the form (3) using f(r) and Monte-Carlo radial distribution F(r) ratio.

$$C(r) = 1 - \exp[-p1(r^2+p2)] \qquad (3)$$

Function F(r)*C(r) has also good χ^2 -value for the experimental ratio A_i/A_{i+1}. Function C(r) is defined a least squares method, and show in fig.3 (p1 = 4.0 , p2 = 0.021). This result removes the contradiction in Table 1. The easiest explanation of our results is that the photomultipliers "sees" the "shower-stem" badly because of the Cherenkov radiation takes place at angles ~ 60° relative to the crystal axis. The light is detected very bed at this angles.

Using form (2) of shower distribution we reconstructed the position of the electron incident point into the central detector of the mock-up model in linear approximation by the formula

$$Xo = \sum_i (Xi * Ei) / \sum_i Ei \qquad (4)$$

where i is the number of the detector used, Xi is the coordinate of the center of the detector, Ei is the relative energy released in the detector. The results obtained are shown in Fig.4. Also given for comparison are the reconstruction data obtained by formula (2) using the experimentally measured coordinates. A fairly good agreement was obtained. This coordinate reconstruction procedure results in a systematic deviation from the "actual" coordinate. There are a number of ways of coordinate reconstruction which do not cause any appreciable systematic deviation /8/. The values for the coordinates X,Y were defined also by minimizing the functional

$$\chi^2 = \sum_i [\ E_i - A_i(x,y)\ ]^2 / \sigma_i^2 , \qquad (5)$$

where E_i is energy released in the detector, A_i is the calculated energy released in the ith cell with the radial response function (2), σ_i is parameter of E_i distribution. The dependency between the measured and real coordinates has been obtained to be linear (within the limits of <1 mm, fig.5). The coordinate reconstruction error disregarding the deviation was <4 mm (the estimate averaged over the area of the central detector). Figs.6 and 7 exemplify distribution of coordinates obtained experimentally for two energies in the case where electrons are incident in the middle of the central detector. The space resolution depends but slightly on the electron energy in the 300 - 700 MeV range. This is accounted for by the fact that at low energies of the initiating particle the spatial fluctuations of the shower are more important than the energy resolution of the detectors.

Thus, the investigations have shown that the $NaBi(WO_4)_2$ crystal calorimeter exhibits fast operation, satisfactory energy resolution and good space resolution characteristics.

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Figure Captions

Fig.1 Experimental layout.
S1 and S2 -scintillation counters; H1,H2 - scintillation hodoscopes; C -multiple-element prototype of EMC; F -pulse former; TR -trigger

Fig 2 Average signal pulse height ratio in two adjacent blocks of counters vs electron coordinate Xc. Dots are the measured values,curve is the calculated profile of shower (2).

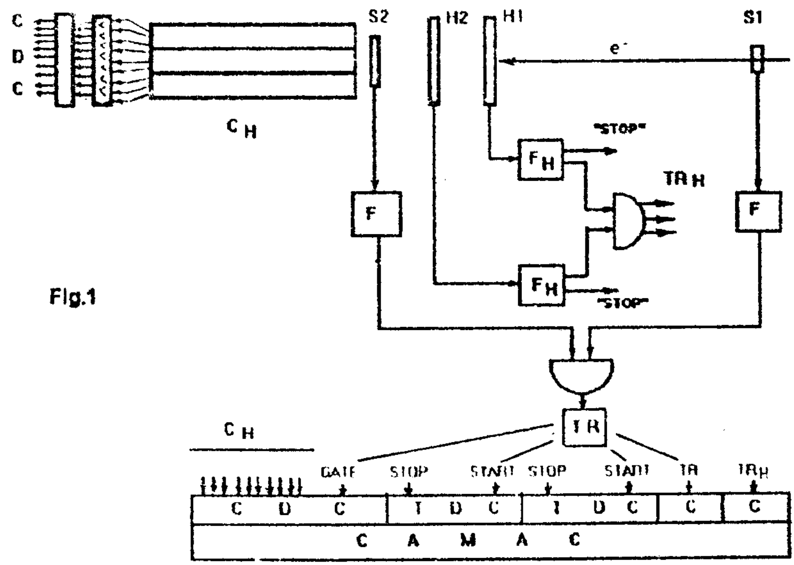
Fig 3 Function C(r).

Fig.4 Shower center-of-gravity coordinate Xo at various electron positions Xc at 700 MeV. Dots are measured values for Xo by formula (4). The curve was calculated by (2). The dotted lines is the boundary between the cells.

Fig.5 Shower center-of-gravity coordinate Xo at various electron positions Xc at 700 MeV. Dots are measured values for Xo by formula (5). The dotted lines is the boundary between the cells.

Fig.6 Space resolution in the center of central crystal at 300 MeV.

Fig.7 Same as in Fig.6 at 700 Mev.



C
D
C
C H
S2
H2
H1
S1
e⁻
F
F H
"STOP"
TR H
F
F H
"STOP"
TR
C H
GATE
STOP
START
STOP
START
TR
TR H
C D C
T D C
T D C
C
C
C A M A C

Fig.1

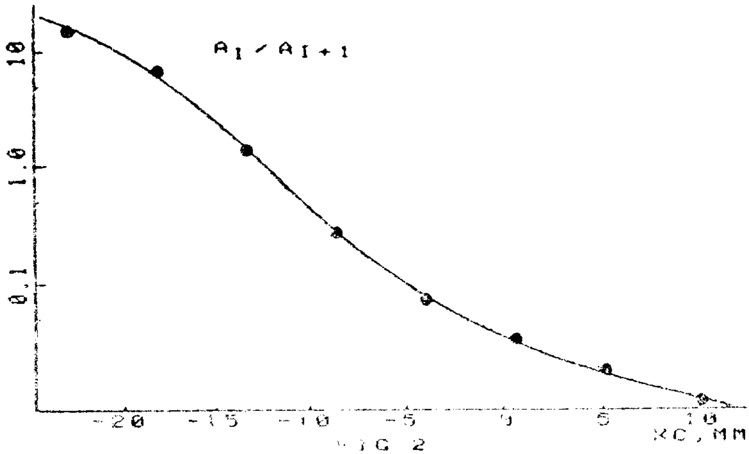


FIG 2

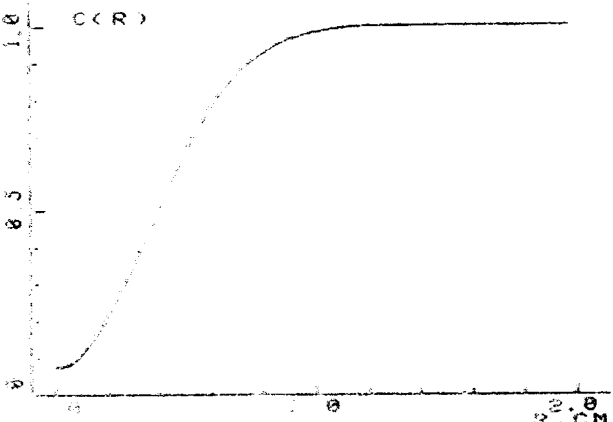


FIG 3

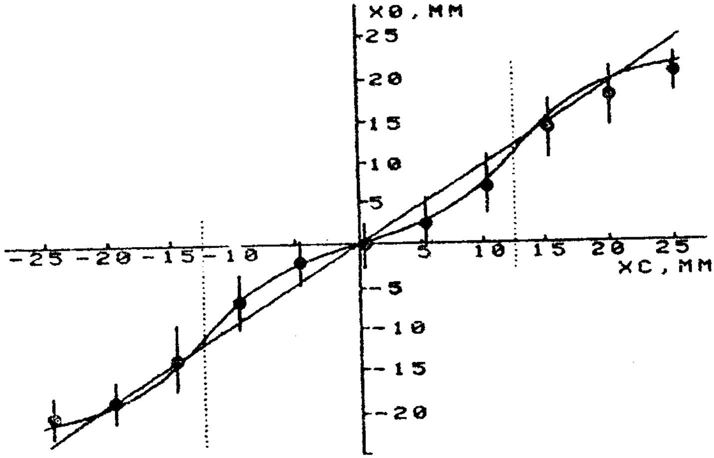

X0, MM
25
20
15
10
5
-5
-10
-15
-20
-25 -20 -15 -10
5 10 15 20 25
XC, MM

FIG. 4

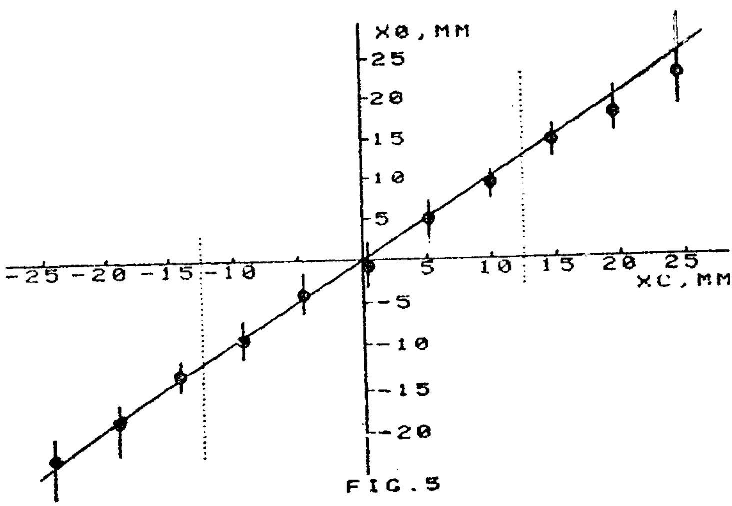

X0, MM
25
20
15
10
5
-5
-10
-15
-20
-25 -20 -15 -10
5 10 15 20 25
XC, MM

FIG. 5

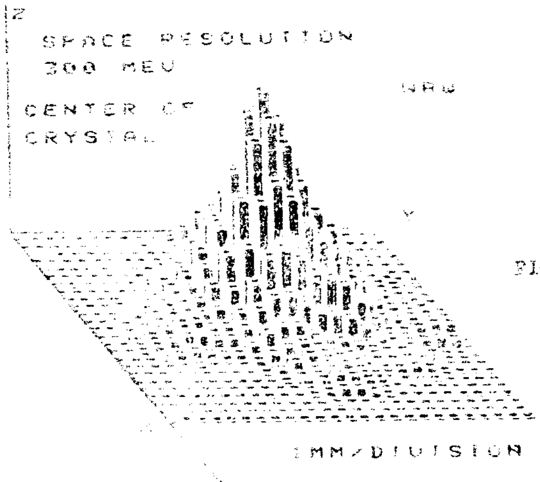

Z
SPACE RESOLUTION
300 MEV
NAW
CENTER OF
CRYSTAL
Y
1MM/DIVISION

FIG.6

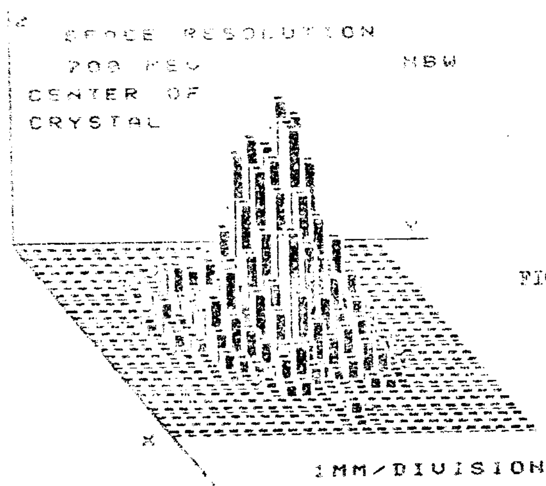

Z
SPACE RESOLUTION
700 MEV
NBW
CENTER OF
CRYSTAL
Y
X
1MM/DIVISION

FIG.7

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