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BEAM TESTS OF THE BAYAN ELECTROMAGNETIC CALORIMETER

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Abstract

A.V. Inyakin et al. Beam test ot the BAYAN electromagnetic calorimeter : IHEP Preprint 93-157. – Protvino, 1993. – p. 9, figs. 10, tables 1, refs.: 11.

A new version of the fine sampling lead-scintillator calorimeter (BAYAN), a promising EM-detector in collider experiments, as well as in fixed-target experiments at high energy/ intensity, is studied. Two prototypes are tested in an electron beam of the IHEP 70 GeV proton accelerator. The light yield for a minimum ionizing particle amounts 30 photons per 1 mm track length in a scintillator. The number of photoelectrons in S20 photocathode PMT, produced by EM-shower in BAYAN, is measured to be 2500/GeV; it may be increased two times. BAYAN response is uniform within 1.2% when an electron beam moves across its surface.

Аннотация

А.В. Инякин и др. Исследование электромагнитного калориметра типа БАЯН на пучке электронов: Препринт ИФВЭ 93-157. – Протвино, 1993. – 9 с., 10 рис., 1 табл., библиогр.: 11.

Исследован новый тип калориметра (БАЯН), который может применяться как на коллайдерах, так и в экспериментах с фиксированной мишенью при высоких энергиях и светимостях. Калориметр построен из тонких пластин сцинтиллятора и свинца, которым придана волнообразная форма. Два прототипа изучены на электронном пучке 70 ГэВ протонного ускорителя ИФВЭ. Световыход от минимально ионизирующей частицы составляет 30 фотонов на 1 мм трека в сцинтилляторе. Измеренное число фотоэлектронов, образуемое ЕМ-ливнем в БАЯНе, равно 2500 ф.э./ГэВ для фотоумножителя с фотокатодом S20 и может быть увеличено еще в два раза. Неоднородность отклика БАЯН калориметра не превышает 1,2% при сканировании электронным пучком его фронтальной поверхности.

1. Introduction

This paper presents the beam test results of a new version of a fine sampling lead-scintillator electromagnetic calorimeter (see also [1]). The calorimeter which we call BAYAN (Russian musical instrument, similar to accordion) follows the idea of [2], but with the converter and scintillator sheets having a wave structure [3] to dump the uniformity and dead zones existing in a parallel-to-beam version.

The calorimeter prototype measurements were performed in a 4 GeV to 16 GeV electron beam using GAMS setup at the IHEP 70 GeV proton accelerator [4]. The aim of these measurements is to obtain the principal information on this novel type of EM-calorimeter and to compare the results with Monte Carlo simulations. This will allow to choose optimal BAYAN parameters which satisfy the requirements of future high-energy projects, such as ALICE [5] and CMS [6] at LHC, RHIC at BNL, UNK at IHEP [7].

2. BAYAN prototypes

Two BAYAN prototypes, 1 and 2, have been built and beam studied. They differ in lead converter thickness (0.5 mm and 1 mm). The schematic view of BAYAN 1 is shown in fig. 1. It is assembled of $120 \times 300 \times 0.5\ mm^3$ lead plates interleaved by 1.2 mm thick scintillators. 63 such layers are stacked together in BAYAN 1 (32 in BAYAN 2) and bent to form a 1 cm amplitude wave with two 14 cm periods along the calorimeter (fig. 1,2).

The polysterene scintillator with 1.5% PTP (para-terphenyl) + 0.01% POPOP (1,4-bis-[2-(5-phenyloxazolyl)]-benzene) dopants is used in BAYAN, the scintillator sheets being produced with the IHEP extrusion technology [8].

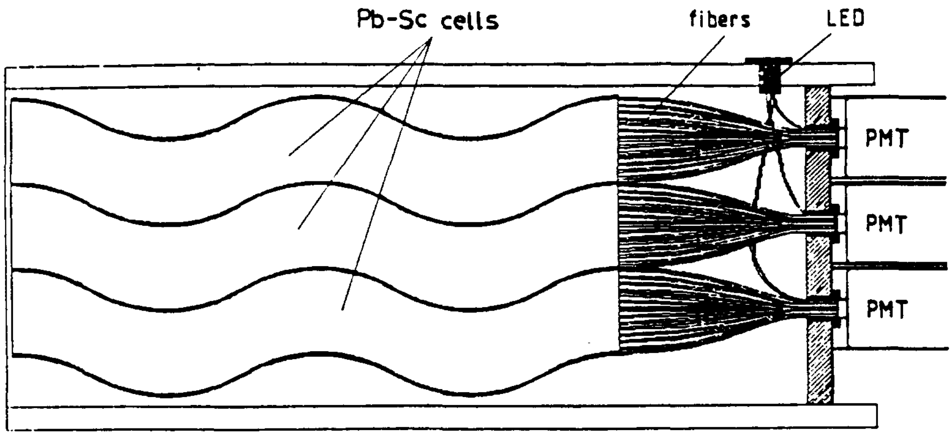

Figure 1. Schematic view of Bayan 1 calorimeter.

The WLS (wavelength shifter) fiber, 1.2 mm in diameter, is positioned between two 19 mm wide scintillator sheets. The scintillators, together with fibers, are wrapped up to 50 micron aluminyzed mylar. The fiber (produced in INR, Troitsk) has polysterene core with the K-27 dopant, its refractive index being n=1.59. A fluorinated PMMA (polymetilmetacrilat) with n=1.43 is used for cladding.

After leaving the scintillators, the fibers are assembled together, put in a plastic matrix (100 micron precision) and epoxy glued. Thereafter the fiber edges are polished and coupled to the photomultiplier (PMT) FEU-84 [9] through an air light guide, each PM thus views one 38×38 mm^2 cell. 9 PMTs are used in BAYAN 1 forming a 3×3 matrix of such cells (2×3 in BAYAN 2).

For better light collection, an aluminium mirror of 70% reflection is evaporated on the front fiber edge. Light attenuation length measured for these scintillator-fiber elements amounts 3 meter (1.6 m without Al mirror). This value guarantees a constant term in BAYAN energy resolution being smaller than 0.5%.

The attenuation length drops by one half after irradiating the fiber to 3.4 MRad [10].

The number of photoelectrons produced by minimum ionizing particle (mip) in a single scintillator-fiber element was measured with ^{106}Ru source. It is found to be 3.1 (4.0 and 3.6 with S11 FEU-85 and XP1911). The quantum efficiency of FEU-84, used in BAYAN, is 9% in green region (500-550 nm). This gives 30 photons delivered by a fiber from a mip traversing 1 mm of scintillator in BAYAN.

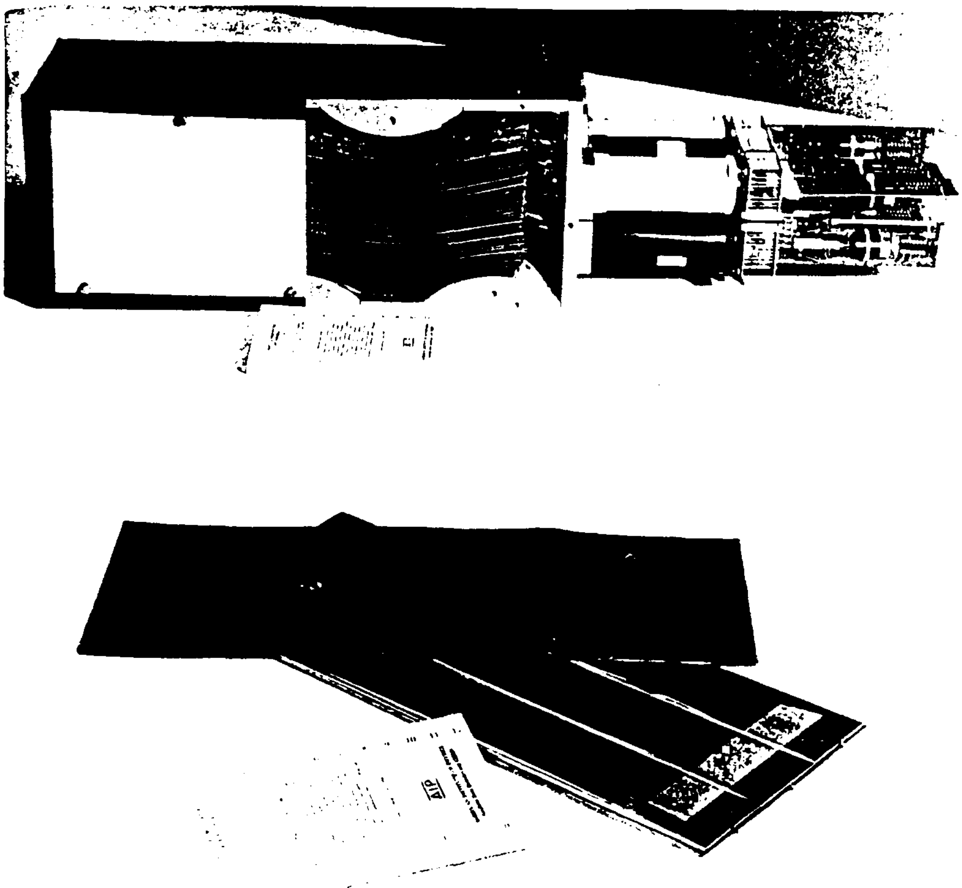

Figure 2. Photo of BAYAN 2 and scintillator-fiber element.

3. Beam test results

During the beam tests each calorimeter cell was irradiated by 4, 9 and 16 GeV electrons. The 9 GeV electron beam has a muon contamination (20%), the muons were used for the cell calibration. Light-emitting diodes (fig.1) were used for monitoring [11]. The impact points of the beam particles were defined within $\pm 1mm$ with the GAMS hodoscopes.

3.1. BAYAN 1

BAYAN 1 prototype was irradiated only in 9 GeV electron beam. Fig. 3a shows the amplitude spectrum produced by muons in a single central cell. The spectrum of total matrix signal obtained with 9 GeV electrons after the muon

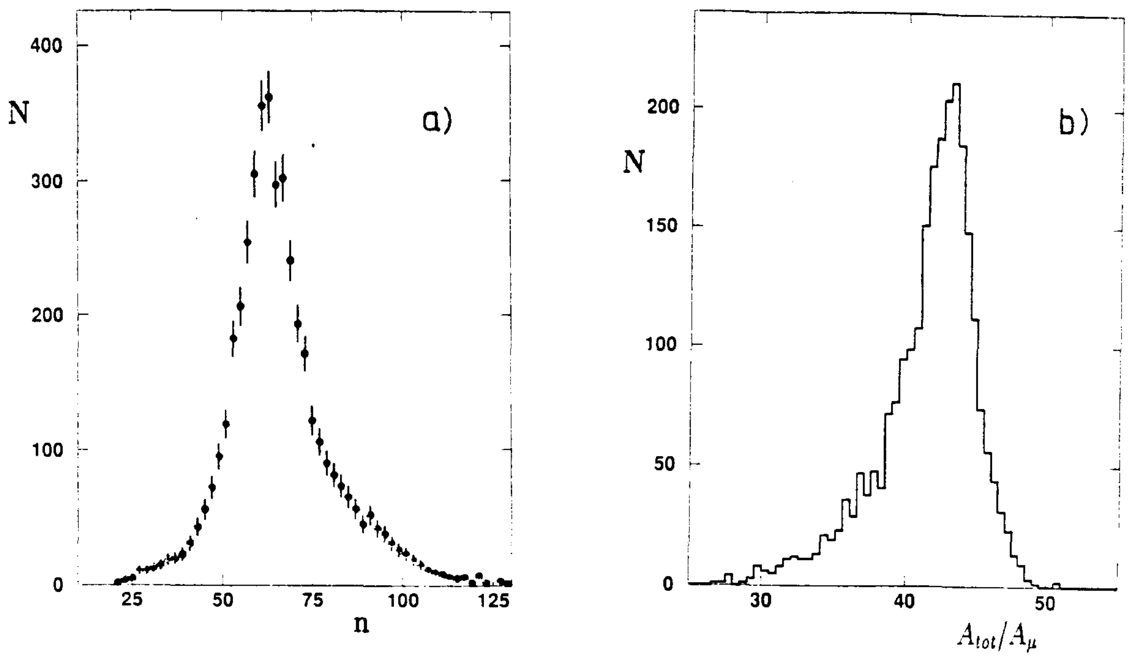

Figure 3. Amplitude spectra in BAYAN 1 measured: a) in the 9 GeV muon beam; b) in the 9 GeV electron beam. Here and further **n** is the ADC channel number.

calibration is presented in fig. 3b. Its maximum corresponds to 23,000 photoelectrons in FEU-84 [1] or

$$N_{phe} = 2500/GeV. \quad (1)$$

With 9% efficiency of FEU-84, this gives a number of photons delivered by fibers to PMT:

$$N_{phot} = 28,000/GeV. \quad (2)$$

BAYAN 1 is not thick enough ($15X_0$ only) to absorb all 9 GeV EM-shower, more than $18X_0$ is required for the total absorption. This results in a low-energy tail in fig. 3b spectrum and in worsening the energy resolution. Such leakage effect is well reproduced by the Monte Carlo GEANT simulation of BAYAN 1 response (fig. 4a), which also shows that the energy resolution for this calorimeter structure equals $\sigma_E/E = 7\%$ at 1 GeV photon energy (fig. 4b), with the shape being Gauss.[2] The e/μ signal ratio comes out to be 44 (fig. 3), mip energy loss in BAYAN 1 is equal to 200 MeV, in the EM-scale.

BAYAN 1 shows a good uniformity, when the electron beam scans its surface (fig. 5), both in signal value (within $\pm 1.2\%$) and in energy resolution ($\pm 5\%$). No drop of response in the fiber region is observed.

[1] The calorimeter signal may be further increased, up to 4500 photoelectrons per GeV, when using a green extended PMT like XP2081B or XP2201B

[2] This differ from 6% given in [1] due to a more detailed treatment of the experimental and MC simulation results.

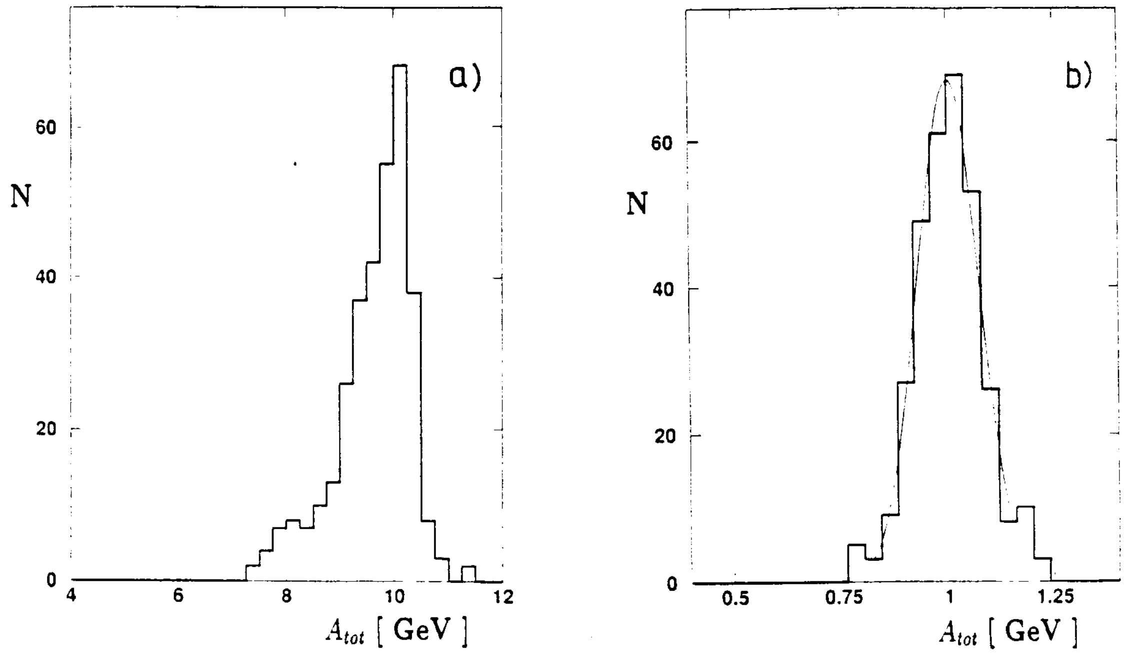

Figure 4. GEANT simulation of the BAYAN 1 response: **a)** to 10 GeV photons, $\sigma_E/E = 3.8\%$; **b)** to 1 GeV photons, $\sigma_E/E = 7.1\%$.

3.2. BAYAN 2

The BAYAN 2 prototype was beam tested in the same manner as BAYAN 1 but in more details. This calorimeter, with its $23X_0$ thickness, provides the total

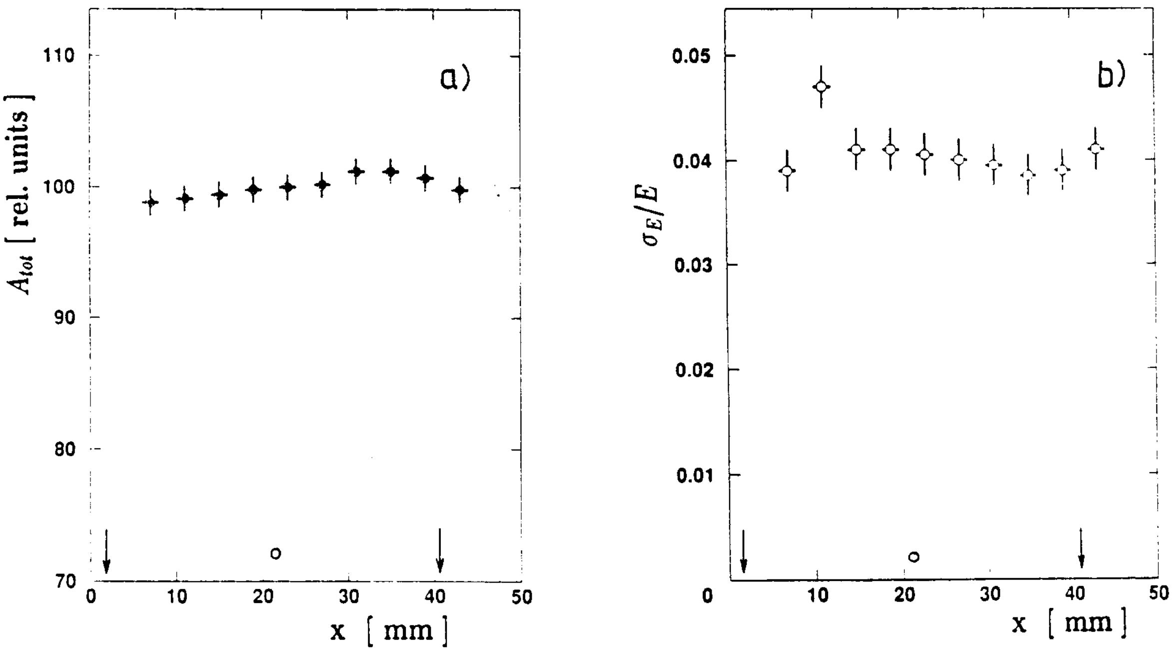

Figure 5. BAYAN 1 total signal (**a**) and energy resolution (**b**) measured in various electron beam impact points. Arrows show the cell boundaries, fiber position is indicated by open circle.

absorption of 16 GeV electron showers. The amplitude spectrum is practically symmetrical (fig. 6a), a small low energy tail may be attributed to some material

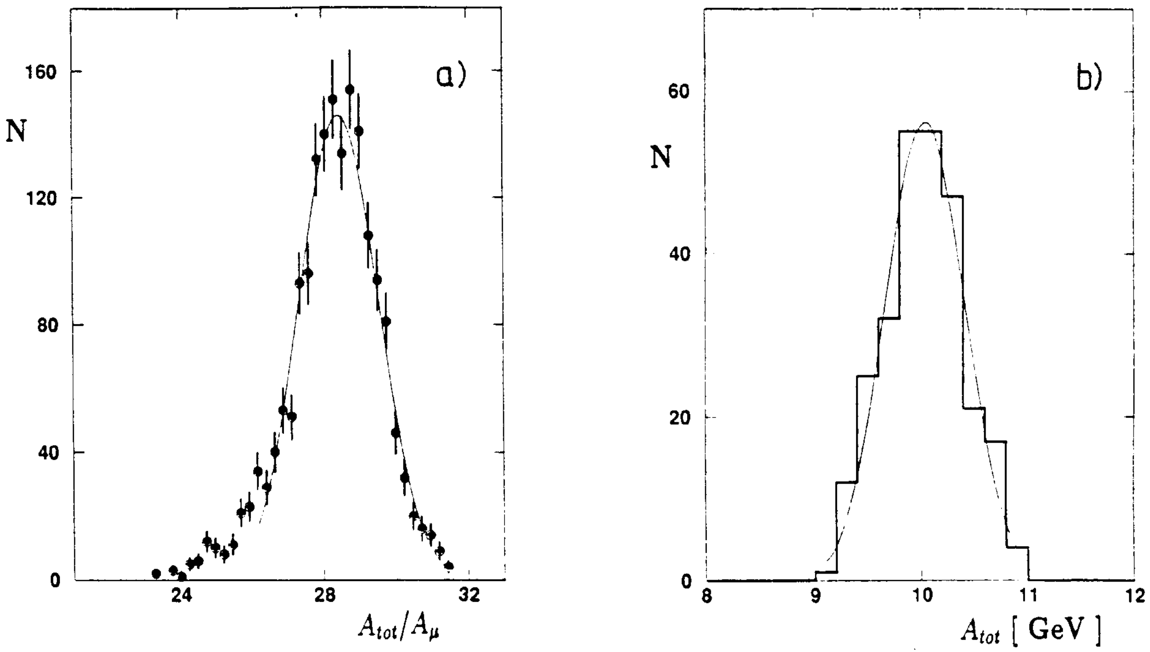

Figure 6. BAYAN 2 amplitude spectra: **a)** measurements in the 9 GeV electron beam; **b)** GEANT simulation in the 10 GeV photons.

present in the beam ($\approx 0.2X_0$). BAYAN 2 energy resolution is governed by sampling fluctuations, the scintillator-to-lead thickness ratio being small in this calorimeter (s/t = 1.2) unlike BAYAN 1. GEANT simulation of BAYAN 2 reproduces fig. 6a spectrum nicely (fig. 6b) and gives $\sigma_E/E = 10.5\%$ for 1 GeV photons. This is in agreement with BAYAN 1 7% value ($\sigma_E \sim \sqrt{t}$).

BAYAN 2 response is uniform, the energy resolution depends neither on the impact point, nor on the incidence angle (fig. 7 for vertical angle; no change with horizontal angle within 200 mrad). The calorimeter signal stays constant within $\pm 1\%$ in the whole area showing only a small, 2% to 3%, drop in the fiber region (fig. 8).

The energy dependence of the BAYAN 2 energy resolution, measured at 4, 9 and 16 GeV (fig. 9), is described by: $\sigma_E/E = 0.105/\sqrt{E} + 0.004$.. The constant term is very small due to a high transparency of our WLS fibers and a high detector uniformity.

The lateral profile of EM-shower in BAYAN 2 is very narrow (fig. 10), more than 90% of shower energy is released in a single $38 \times 38\ mm^2$ cell.

The comparison of muon signal in BAYAN 2 to that of an electron gives $e/\mu = 28$, mip energy loss is equal to 310 MeV, with $N_{phe} = 500$. This results

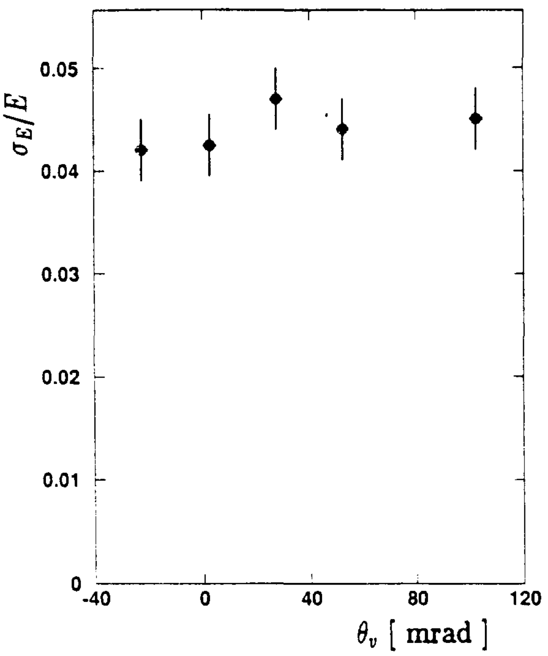

Figure 7. BAYAN 2 energy resolution measured at various vertical angles θ_v of electron beam incidence.

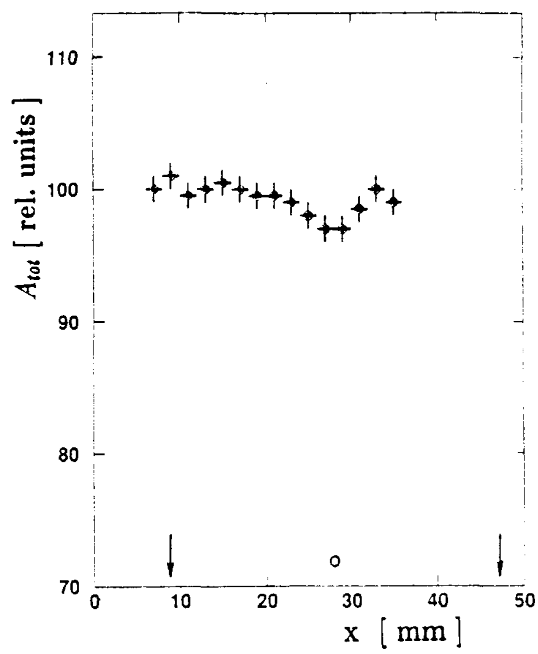

Figure 8. BAYAN 2 total signal measured in various electron beam impact points.

in a yield of 3 photoelectrons per 1mm track length in the BAYAN scintillator in a good agreement with a value measured with ^{106}Ru source (see above).

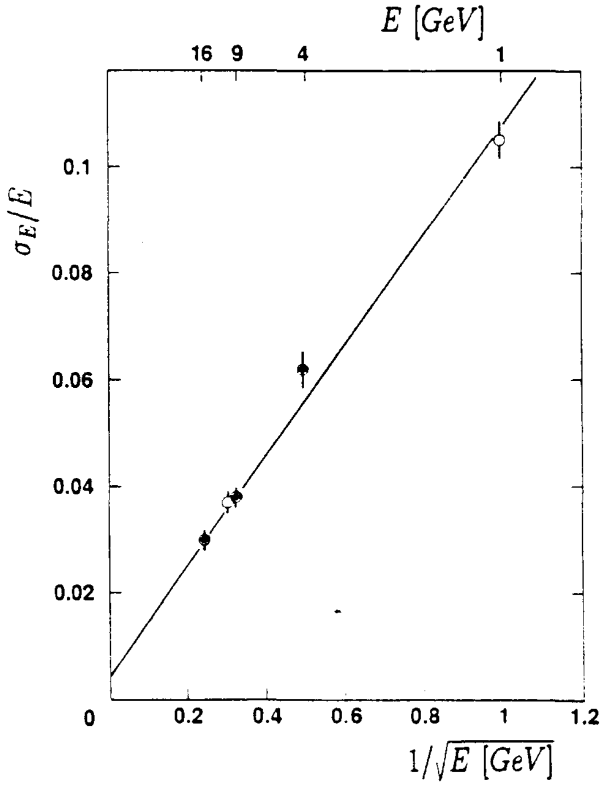

Figure 9. BAYAN 2 energy resolution measured with 4, 9 and 16 GeV electrons (black point). Open circles show the Monte-Carlo calculated values. The straight line is a $\sigma_E/E = 0.105/\sqrt{E} + 0.004$.

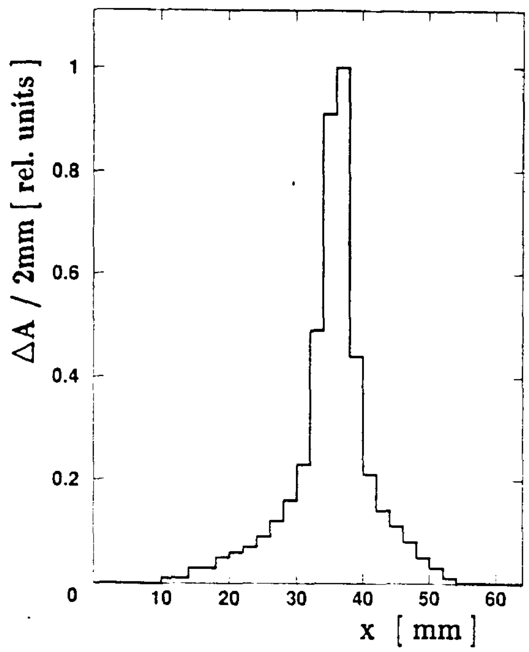

Figure 10. Lateral EM–shower profile in BAYAN 2.

4. Conclusions

Table 1 summarizes the results of our measurements performed with two BAYAN prototypes. They allow to reliably extrapolate BAYAN parameters, satisfying the requirements of various experiments. E.g., in the BARC calorimeter (ALICE project at LHC, CERN) which should be sensitive to low energy photons ($\ll$ 1 GeV), large s/t ratio must be used to get both high light yield and good energy resolution (last column of table 1). For a high energy domain

Table 1. Characteristics of the BAYAN calorimeters. Last column shows the parameters of BARC calorimeter, designed for ALICE experiment at LHC [5].

calorimeter	**BAYAN 1**	**BAYAN 2**	**CMS [6]**	**BARC**
Sc/Pb	2.4	1.2	2.0	4.0
Pb, mm	0.5	1.0	2.0	0.35
X_0, mm	18.5	11.8	16.8	28.0
Moliere radius, mm	25.5	22	24.5	29.0
total thickness	$15X_0$	$23X_0$	$26X_0$	$20X_0$
uniformity, %	1.2	1.8	2.0	≤ 1.0
σ_E/E, %	$7/\sqrt{E}$	$10.5/\sqrt{E}$	$8.4/\sqrt{E}$	$5.2/\sqrt{E}$
photons per GeV	27,000	17,000	10,700	30,000
cell size, mm^2	38×38	38×38	47×47	70×70
fibers per cell	21	16	25	37
fibers per cm^2	1.4	1.1	1.1	0.8

(e.g., CMS project at LHC), BAYAN calorimeter may be built more compact, with s/t ≈ 2, providing 25 photon/MeV light yield and $\sigma_E/E = 7\%/\sqrt{E}$ with exellent energy resolution at high energies[3]

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[3] Our recent beam test of the BAYAN calorimeter prototype at higher energies (CERN, October 1993) confirmed a low constant term in energy resolution: $\sigma_E/E = 0.7\%$ and 1% have been achieved in 100 GeV and 50 GeV electron beams.