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AN ALTERNATIVE PHOTON DETECTOR FOR THE H1 LUMINOSITY SYSTEM

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Abstract

A simple alternative photon detector for the H1 luminosity system is proposed for a first running stage instead of the main Cherenkov hodoscope. The detector represents lead-scintillator calorimeter made from four $7.5 \times 7.5 cm^2$ blocks with a total length of $30X_0$. Full scale prototype of one such block has been made and tested on the electron beam in the energy interval $1 \div 5\ GeV$. The energy resolution was found to be $14\%/\sqrt{E}$.

1 Introduction

The general concept of the luminosity monitoring and the photoproduction events tagging at the H1 calorimeter is based on the use of additional detectors of electrons and photons placed separately in the HERA tunnel far from the interaction region [1]. This detectors will registrate a bremsstrahlung process $ep \rightarrow ep\gamma$ having a good experimental signature for an absolute luminosty measurement as well as single electrons emitting from the interaction point (IP) at very small angles for low Q^2 events. In a latter case the photon detector will be used as a veto counter only. It was suggested to use two hodoscopes of the shower [illegible] will be exploited at a hard radiation conditions (synchrotron radiation, bremsstrahlung, beam halo background) the special sheilding should be foreseen. Moreover, the hodoscopes must be installed on a movable remote controlled support tables to enable displacement down to about 60 cm off the beam plane during injection and acceleration time.

2 The choice of the detector type

In order to save KRS crystals of the main photon detector from the damages by radiation, especially at the beginning of the HERA running, it seems reasonable to use more simple and cheap photon detector. It will allow to measure radiation level close to the beam pipe during acceleration and to protect main detector from the possible destruction by the unexpected high radiation levels. We propose to use a lead-scintillator calorimeter of the sandwich type as an alternative photon detector for the luminosity monitoring system.

Generally, a sandwich calorimeter consists of the passive absorber plates made from a high Z material separated by the gaps filled with an active material. To estimate calorimeter dimensions one has take into account both longitudinal and lateral shower development in a sandwich. As it is known, for longitudinal absorption of $\geq 98\%$ of the electromagnetic shower a total detector length must be at least $3t_m$ for the particles with energies of 1 GeV or higher [3]. The median depth t_m is an absolute depth within which one half of the energy will be deposited (in the X_0 units):

$$t_m = ln\frac{E}{E_0} + 1.22$$

where E is a primary photon energy (for primary electrons second addentum is 0.4 instead of 1.22); E_0 - critical energy (7.2 MeV for lead). Note, that thickness t, expressed in radiation length units, is approximately universal for different materials.
Thus the necessary attenuation length for 30 GeV photons turns out to be $\sim 28X_0$.

According to a lateral shower development which is dominated by a multiple scattering the nearly total absorbtion ($\sim$ 98%) of the shower is achieved in a cylinder of $4X_0$ radius corresponding to $\sim 2.25cm$ for Pb. Taking into account photon space distribution at the detector front plane obtained from the detailed Monte-Carlo study [1], it gives for the active lateral area of the calorimeter $\leq 12cm$ in diameter. Dividing the calorimeter on a four equal cells of $7.5 \times 7.5cm^2$ each we hope to avoid the influence of the boundary effects as well as to reconstruct roughly the position of the photon impact point.

An average number N of charged shower particles after lead plates of a thickness t each (taking into account the minimum detectable energy E_{cut}) can be estimated from the Monte-

Carlo data as [4]:

$$N = \frac{50E(GeV)}{t(X_0)}$$

for

$$E_{cut} = 1MeV.$$

The shower electrons deposit their energy into a calorimeter material via ionization and excitation of atoms. An accuracy of the energy determination is limited by the fluctuations in a total number of shower particles. Assuming Gaussian distribution for the sampled number of particles one can define the fluctuations as:

$$\sigma(\%) = \frac{1}{\sqrt{N}} = 2.1\sqrt{t(g/cm^2)}\frac{\sqrt{E_o(MeV)}}{\sqrt{E(GeV)}}$$

Then the resolution of the calorimeter depends on a material as $\sqrt{E_o}$ (which determines the shower statistics) and on the absorber plate thickness as $\sqrt{t}$.

All results obtained in the different experiments [5] quite well satisfy such energy dependence ($\sim E^{-0.5}$), so that the value

$$k = \sigma(\%)\sqrt{E(GeV)}$$

is constant for any absorber materials. The values of k for the lead and iron absorbers, plotted on Fig.1, demonstrate a $\sqrt{t}$-dependence on the absorber thickness. These experimental data can be parametrized by the above mentioned expression with $k = 2.1$ for the Pb and $k = 1.9$ for the Fe.

By choosing an absorber thickness $1X_0$ of Pb for each calorimeter layer we hope to get an accuracy of the incident particles energy measurements about $\sigma\sqrt{E} = 14$ for the energy range from 2 to 30 GeV.

One module of the proposed construction have been made. The calorimeter represents a lead-scintillator sandwich of 30 layers with a total longitudinal length of $30X_0$ in which lead convertors are alternated by scintillator plates with 5 mm thickness. Each sensitive plate was covered with aluminium foil and whole module was wrapped with a black tape. The light from every scintillator plate was transmitted to the photomultiplier (the FEU-84 having a cathode diameter of 40 mm, the USSR manufacture) by using the wave length shifter bar readout (but only from one side) and the light guide.

3 Result of the test experiment

The test experiment was perfomed at the DESY electron beam-22 in the beginning of 1989 in the energy range between 1 and 5 GeV. The main aim of the measurements with this sandwich was to study the energy resolution and the energy leakage over the calorimeter side planes. The beam was being defined by a pair of scintillation counters and a vetocounter which had a hole in the center and provided the calibration beam of 4 mm diameter..

Fig.2 shows the resolution dependence on the primary particle energy for the electron beam hitting a center of the calorimeter front plane. For each energy only statistical errors are given. The main sources of the e^- test beam energy spread were the following:

a) finite dimensions of the photon beam on the Cu converter of the electron tagging system,

b) multiple scaterring of the electrons in the converter and in the air between the convertor and calorimeter front plane,

c) lateral size of the beam counters were used for monitoring.

Taking into account this uncertainties of the calibration conditions, energy resolution of the lead-scintillator sandwich have been determined for the beam particles hitting the center of the sample front plane (see table).

Table. Results of the energy resolution measurements in the DESY test beam for the Pb-Sc sandwich

(GeV)	$E(test-beam)$							
	1.32	1.85	2.0	2.65	3.0	3.5	4.0	5.0
$E^{-0.5}$	0.87	0.735	0.707	0.614	0.577	0.534	0.5	0.447
$\sigma(E)_{exp}$	16.59	13.64	12.76	10.66	9.93	9.11	8.29	7.30
$\sigma(E)_{beam}$	11.45	8.88	8.29	6.47	5.85	5.21	4.62	3.81
$\sigma(E)_0$	12.01	10.35	9.71	8.48	8.02	7.48	6.89	6.23

Thus, the energy resolutuon of the calorimeter may be parametrized as

$$\sigma(\%) = \frac{13.8 \pm 1.0}{\sqrt{E(GeV)}}.$$

Comparison with the intended data shows quite good agreement.

For a calorimeter of a finite size part of the shower energy is lost due to escaping soft shower electrons and photons. Therefore, the sandwich was surrounded by the lead blocks, in order to get a real albedo of the secondary particles on the radiator boundaries. This is especially important if the module will be used in future as a hodoscope cell.

Fig.3 shows the energy deposition in the counter when the impact point of the test beam scanned over the front surface of the sample. It is seen that only in a small central area (of about 1 cm radius) the detector response does not depend on a transverse displacement of the impact point. In other words, for these cases total absorbtion was realized, at least shower leakage was negligible. However, the energy losses increase when the impact point moves away from the detector center. One can define an electromagnetic shower profile using the dependence of the value R^*, the pulse-height ratio of two adjacent counters in a hodoscope system, on the impact point coordinate. In our extreme case of one cell

$$R^* = \frac{E_{abs}}{E_{beam} - E_{abs}}.$$

In a lead-scintillator sandwich the profile can be described by the expotential function:

$$A(d) = A(0)e^{-\frac{d}{b}}$$

where b represents the chacteristic shower width equivalent to the attenuation length; b=5 mm for Pb [6].

As it is seen from the last picture, at the normal running conditions already one such block will allow fast luminosity monitoring with a sufficient accuracy, because at least 80% of photons hit detector within a circle of 1 cm radius where an energy leakage is negligible. If however, a primary electron beam will sometimes have a tilt more than $10^{-4} rad$ at the IP, a coordinate reconstruction will be necessary first, for a correct energy determination and second, to recognize such a beam behavior. For this purpose photon detector must have a cell structure.

center-of-gravity d_0 of a shower:

$$d_0 = 2D\frac{\Sigma k A_k}{\Sigma A_k},$$

where

2D - the lateral dimension of the sandwich
A_k - a pulse height in the cell k.

However, the unshifted estimation for the impact point coordinate can be obtained only when taking into account real shower profile, for instance, using the signals from the neighbouring counters [7]:

$$d = D - b ln\frac{A_k + A_{k+1}}{2A_{k+1}}$$

The accuracy of the coordinate reconstruction with this method will be about 5 mm for the proposed hodoscope.

References

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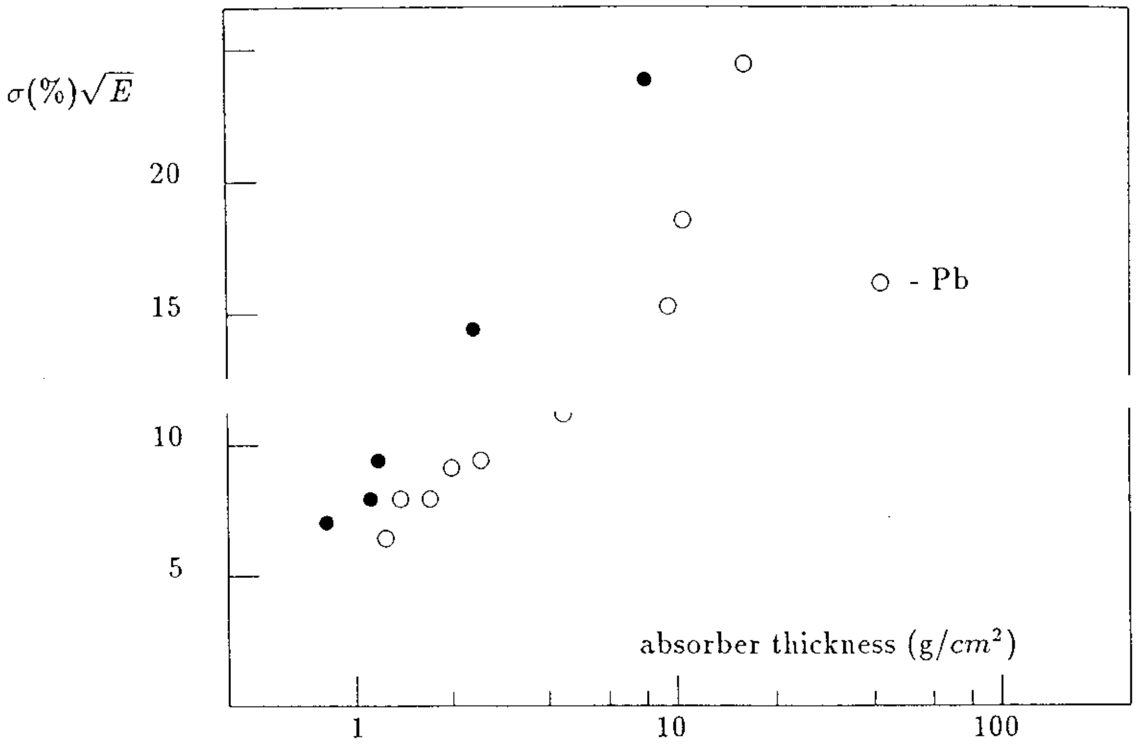

Figure 1: *Dependence of the energy resolution on the absorber thickness for Pb and Fe*

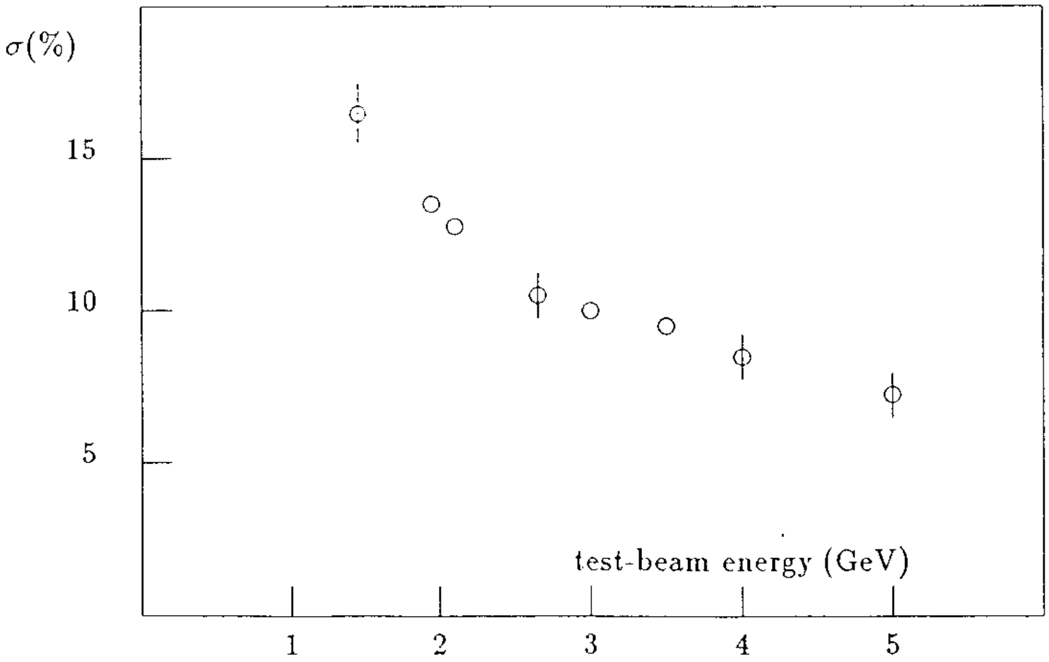

Figure 2: *Experimental energy resolution of the calorimeter as a function of the test beam energy*

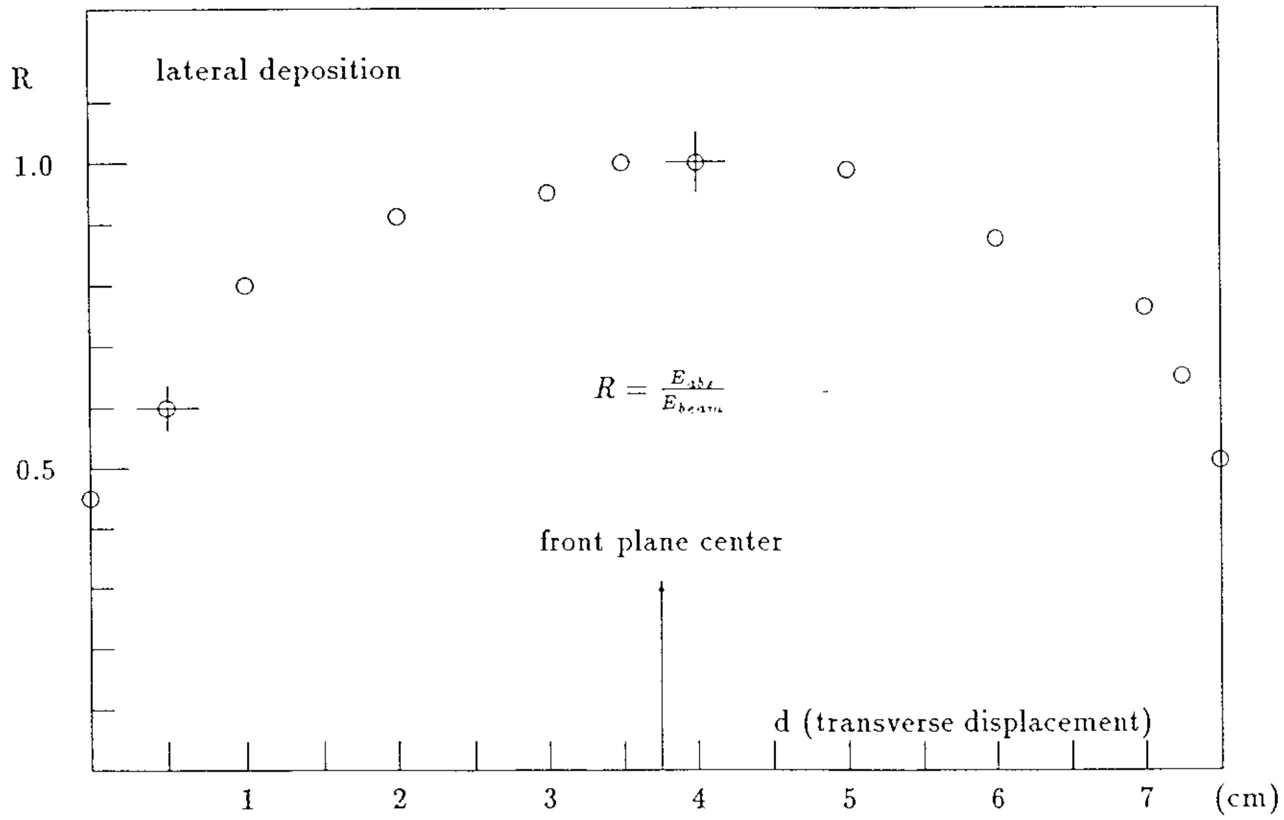

Figure 3: *Dependence of the energy deposition in the sandwich on the transverse coordinate of the impact point*