Title

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Beam Viewing Camera Using Rapid-Development Film[*]

by

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ABSTRACT

To facilitate the adjustment of external beams, a beam profile camera has been made using Polaroid Land rapid-development film. The camera contains a 5 inch diameter, 0.88 inch thick NaI(Tℓ) scintillator, a 45° first-surface aluminized mirror, a Nikkor N-C 50 mm f/1.1 lens, used at 4.1:1 reduction, and a Polaroid roll-film holder. With Type 47 film it is found that the minimum detectable exposure corresponds to about 2×10^5 pions of 180 Mev/c ($\beta = 0.785$) per cm^2 of scintillator, in fair agreement with an estimate using sensitometric data provided by the manufacturer. This sensitivity is sufficient to make the camera useful (exposure times in the range 1-10 minutes) for adjusting typical external meson beams at the 184-inch synchrocyclotron and the bevatron. Design considerations for luminescent beam viewing are presented.

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I. Introduction

Availability of a simple, rapid means for determining the exact location and size and shape of an external particle beam would save a good deal of time in the setting up of accelerator experiments. The intensities currently available in the meson beams from the 184-inch synchro-cyclotron and the Bevatron are on the order of 10^4 to 10^5 particles cm^{-2} min^{-1}. The rapid-development film now available from the Polaroid Corporation permits a considerable saving of (processing) time in comparison with conventional film, and the sensitivity of the Type 47 appears to be comparable with that of x-ray film. It is reasonable to design a camera for exposure times of the same order of magnitude as the development time. Since the latter is about two minutes, it becomes of interest to determine whether a beam-viewing camera using Polaroid film can be made with a sensitivity on the order of 10^5 particles cm^{-2}.

II. The Camera

The camera tested uses a disk of NaI(Tℓ) as the light source. The scintillator consists of four superposed 5" diameter disks, each about 0.22" thick, in an aluminum holder whose bottom presents 1/16" thickness for the particles to traverse. The top is closed by a 1/16" glass plate. The space containing the scintillators is filled up, with "Dow Corning 200" silicone fluid (1000 cs), to protect the NaI(Tℓ) from water vapor. In use the scintillator is, of course, placed normal to the beam.

In order to minimize the bulk placed in the beam, a first-surface aluminized glass mirror is placed at 45° to the beam, to deflect the light to the side. The light is then brought to a focus form on the film by a Nikkor N-C 50 mm f/1.1 lens used at 4.1:1 reduction. A commercially available Polaroid roll-film holder is used, with Type 47 "Speed 3000" film.

III Results

Test exposures were made in a synchrocyclotron meson beam, 210 Mev/c before filtering by 10.5 g cm^{-2} graphite. It then consists mainly of 88 Mev pions (β = 0.785), with an admixture of 107 Mev muons (β = 0.86). Figure 1 shows a pair of the exposures, differing in duration by a factor of 3.3. The sharp straight edge on the left is caused by an error in locating the mirror, a small segment of the scintillator being blocked from view. The somewhat diffuse straight edge on the right is the shadow cast by the edge of the collimator.

Measurements have been made of the reflection density at a fixed central region of the beam picture. Over a wide range of exposures the density varies from 1.7 at background (no distinguishable image) to 0.5 at saturation. There is easily detectable contrast with background at density 1.5

In order to determine the absolute beam intensities, exposures were made at reduced beam level with a counter telescope determining the flux. An exposure of 5.6 x 10^4 pions per square centimeter gave no detectable image (density equal to 1.7). An exposure of 5 x 5.6 x 10^4 pions per square centimeter gave a readily detectable image (density 1.5). The threshold of visibility appears to correspond to some intermediate value; on the basis of the density versus exposure characteristic (H and D curve) of the film$^{(1)}$, a judicious estimate, corresponding to a reflection density of 1.6, appears to be about 2 x 10^5 pions cm^{-2}. This result is subject to the reservation, however, that the linearity of the counting system was not conclusively established, through the recorded counting rate (2.8 x 10^6 min^{-1}) corresponds to an instantaneous rate within the pre-scaler specifications.

From the given H and D curve, density 1.6 corresponds to 1.4×10^{-8} lumen-second per square centimeter (daylight). For this type of film, 500 lumens of daylight correspond to about 1 watt of 4000 Å light$^{(1)}$, so that the blue light exposure should be 6×10^{7} photons cm^{-2}.

IV Discussion

It is of interest to see whether these numbers are consistent. The illumination of the film, I, is

$$I = \frac{By}{n^2} \; \frac{1}{16} \; F \left(\frac{D}{f} \right)^2 \frac{1}{(m+1)^2} \text{ photons cm}^{-2} \text{ sec}^{-1}, \qquad (1)$$

where

B = particle flux, in cm^{-2} sec^{-1};

y = number of photons emitted isotropically in the scintillator, per particle;

n = refractive index of scintillator relative to air;

F = transmission factor of the lens and mirror system;

$\frac{f}{D}$ = f/number of the lens;

m = magnification.

For NaI(Tℓ), assuming an efficiency of 10% for converting energy lost into violet photons, $y = 4.2 \times 10^{5}$ for 0.88" thickness and $\beta = 0.785$. With $n = 1.77$, $F = 0.5$, $f/D = 1.1$, $m = 1/4.1$, the illumination is

$$2.2 \times 10^{3} \; B$$

If $B = 2 \times 10^{5}$ particles cm^{-2}, the illumination is 4.4×10^{8} photons cm^{-2}. This figure is about seven times that inferred from the given H and D curve. As some of the numbers entering in the calculations are uncertain to within a factor of 2, the discrepancy is not serious. Agreement within a factor of ten should be considered gratifying.

V. Design Considerations for Luminescent Beam Viewing

In the choice of a scintillator one seeks maximum light emission per beam particle, subject to the requirement that the image from a single particle not be so large as to blur the beam shape. The size of the image increases with the thickness of the scintillator, for given optical conditions. In view of (1), a figure of merit for comparing different scintillators is the photon output per unit thickness divided by the square of the refractive index. The best material is NaI(Tℓ), with CsI at room temperature worse by a factor of 3, and plastic scintillator worse by a factor of 12.

How thick can one make the scintillator? The scintillation light from a particle spreads in all directions inside the scintillator, but, with optically smooth boundaries, only the light emitted in a narrow forward cone reaches the lens. This effectively limits the breadth of the brightness distribution in the image produced by a single particle, so that the geometrical aperture of the lens determines the usable scintillator thickness. With the f/1.1 lens at m= 1/4.1, the cone determined by the lens aperture and a point at the center of the scintillator intercepts a circle of about 0.045" ($\simeq$ 1.1 mm) diameter at the front and back of the scintillator (the equivalent air thickness of the scintillator is only 0.88/1.77 = 0.50"). One would not wish to make the circle much larger. Something like an inch of NaI(Tℓ) appears to be the greatest thickness one might use. To obtain adequate resolution with a greater thickness would require stopping down the lens, which would defeat the purpose of increasing the scintillator thickness.

One could gain a factor of 5 in illumination of the film by placing the film against the scintillator without use of a lens. The light produced by a particle would, however, be spread in a circular pattern of radius

$$\frac{t}{n^2 - 1} = 0.685\ t$$

for NaI(Tℓ). Half of the light would be contained in a circle of diameter 0.38 t. Limiting this circle to 0.1" would limit the scintillator thickness to 0.26", and nullify the advantage of this method for practical purposes. In addition there is a practical difficulty: Polaroid 3000 film is not at present available in sheet form.

VI. Conclusions

The camera tested appears to respond to fluxes $\geqslant 2 \times 10^5$ particles cm^{-2}, of velocity 0.785 c. Thus external beams of 10^4 to 10^5 particles cm^{-2} min^{-1} require exposures in the range 20 to 2 minutes. The development time of the Polaroid Land film is about 2 minutes.

It appears that any further increase in sensitivity of a photographic beam viewer could be gained only at the expense of resolution.

VII. Acknowledgements

I should like to thank R. Clark Jones of the Polaroid Corporation for his kindness in providing sensitometric data about Polaroid Land film, and Howard L. Smith of the Lawrence Radiation Laboratory technical photography department for procuring and measuring the lens.

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References

(1) R. Clark Jones (private communication, 1960).

Figure Captions

Figure 1. Typical pictures obtained in an external meson beam at the 184-inch synchro-cyclotron. They were taken at the same beam level with exposure times of 0.8 and 2.6 minutes respectively. In the bright central region referred to in the text the reflection densities are 1.2 and 0.7.

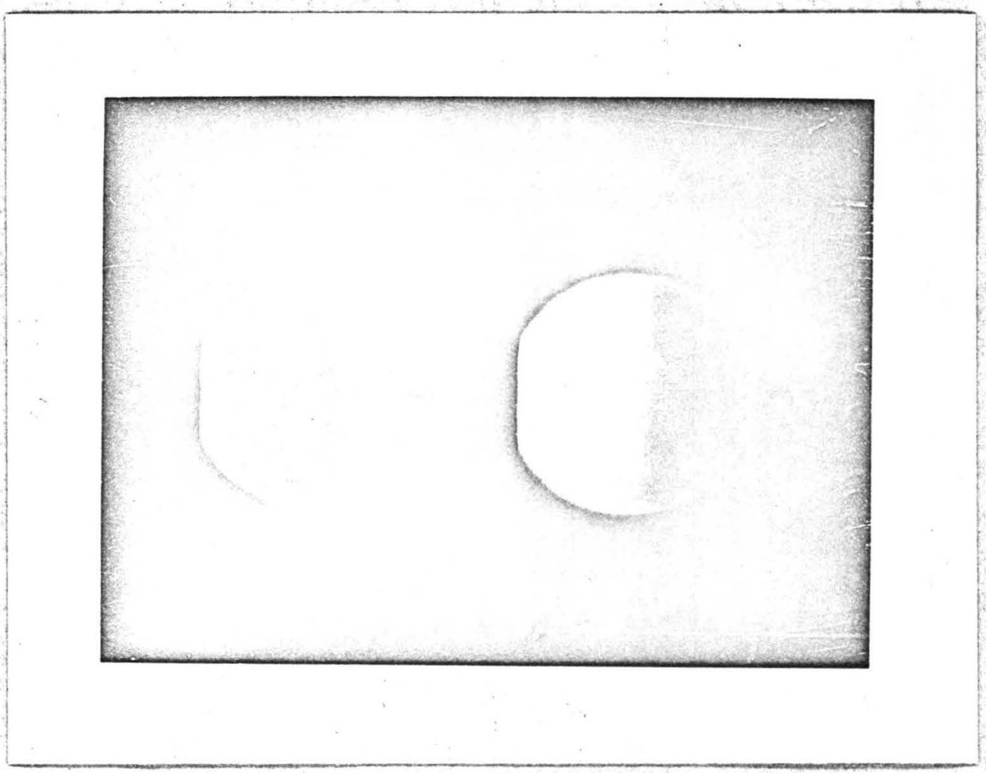

Fig. 1. Two exposures in a full-intensity 88 Mev pion beam, one for 0.8 min, the other for 2.6 min.