# SUGGESTED DEVICE FOR PRECISE MEASUREMENT OF PARTICLE TRAJECTORIES

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## ABSTRACT

A suggested device for particle detection and measurement is described in which the intersection of a high-energy particle's trajectory with a detecting plane may be measured with a potential precision of 0.01 mm or better.

## I. INTRODUCTION

A clear need exists in multi-BeV physics for an electronic particle detector that can be used to define a particle's trajectory with accuracy and with a minimum of disturbance to that trajectory. Several such devices now exist, such as the wire spark chamber and the wide-gap chamber. At the present time the accuracy with which a trajectory can be determined at any one point in space is of the order of a fraction of a millimeter, though many instruments of this type can do no better than one millimeter in measuring position.

It has been pointed out[1] that an increase in accuracy or position-measurement by a factor of 100 may possibly be obtained by the use of conduction processes in condensed materials, such as liquid argon or liquid xenon. The conduction process has many advantages for this purpose, as well as some disadvantages. It is the purpose of this note to indicate how the scintillation phenomenon may permit a realization of high accuracy of measurement of particle trajectories. The factor of improvement may reach one hundred and possibly even a higher figure if great care is exercised in the development of the proposed device.

## II. SUGGESTED DEVICE

Our idea is to use a "detector plane" of some thin inert material, such as stainless steel or aluminum, coated with a thin layer of scintillation material. It will be assumed that the particle trajectory will cross the plane at some angle, say within 45° of the normal. The "scintillation spot" in the detector plane may be viewed in many ways, among which we sketch the following (see Fig. 1):

Model A: The scintillating detector plane lies adjacent to an image intensifier equipped with a fiber optics face plate. The image intensifier output is viewed by a vidicon or a lens system and photographic plate.

Model B: The scintillation detector plane lies adjacent to an image orthicon tube equipped with a fiber optics face plate. In an even more attractive possibility, the scintillator plane is placed inside the vacuum envelope. In either case the output is direct and provides the appropriate electrical signals.

Model C: The scintillating detector plane lies adjacent to the sensitive photoconductive surface of a vidicon tube. In this case the scintillator is placed within the vacuum envelope and can be separated, if necessary, by a very thin inert transparent layer to prevent chemical interaction of the scintillation layer and the photo-conductive layer. The output of the vidicon presents a direct electrical signal indicating the particle's path through the scintillator plane.

Model D: The scintillating detector plane is viewed by a lens or mirror system and then by a photographic plate or by some photoelectric imaging system.

Model E: The scintillating detector plane lies adjacent to some photo-sensitive detector assembly consisting of discrete elements such as photoconductive diodes. In addition to this scheme we may envision the possible direct use of a semiconductive device[2] (not a scintillator! ) such as an assembly of silicon chips. The latter scheme is somewhat different from others discussed above and might really be called Model F.

## Possible Accuracy

In all cases mentioned the accuracy is determined primarily by the ultimate performance of the scintillating detector plane. Let the backing of the scintillating layer be a mirror surface, or in some cases, a white diffusing surface. In either case the intent is to preserve as much of the light for purposes of subsequent measurement.

## III. PHOTON YIELD

Let us calculate a typical number of photons produced in the primary scintillation act. An example will illustrate the quantities involved: If the scintillation layer is 10 microns thick the size of the luminous spot will be of this order, as we shall see later. Such a spot will give us an increase in accuracy of measurement by approximately a factor of 50 over conventional devices. If the scintillator is NaI(Tl) the thickness, expressed in mass units, is 3.67 mg/cm$^2$. If the scintillator is CsI(Na) the thickness is 4.50 mg/cm$^2$. If ZnS(Ag) or ZnS(Cn) is used the thickness is 4.0 mg/cm$^2$.

Now the luminous efficiency in the above three materials is approximately 12%, 10%, and 25%. In the case of NaI(Tl) the average energy loss of a high-energy particle passing normally through the detector plane in a ten micron layer will be approximately 7.3 keV. In the other cases it will be greater. In NaI(Tl) the energy released in the form of photons of wave-length 4300 Å is approximately 0.87 keV. This results in an emission of 300 photons of characteristic blue-violet light.

In NaI(Tl) the emission process is exponential with a decay constant of 250 nanoseconds. This number of photons (300) is quite appreciable and will allow detection by any of the means mentioned in the discussion of Models A-E. Of course, if a spot of 25 microns or greater is acceptable the number of primary photons will be 750 or greater. In the case of CsI(Na) or ZnS the number of released photons will be larger because of the higher density, or higher luminous efficiency, respectively. The calculation of the appropriate numbers of photons in the general case is obvious, and may be applied to anthracene, stilbene, or other scintillators whether organic or inorganic.

The above scintillation yields may now be examined in relation to Models A-E (Figs 1-5).

Model A: A photoelectric efficiency of 20% may be assumed for the image intensifier's photoelectric surface, say, a bi-alkali surface. Allowing even for an unexpected loss of 50% in coupling to the fiber optics face plate, say of thickness 1/16 in., the number of electrons is over 30 and far above the noise level. Thus the luminous spot should be quite clear and will require at most two stages of optical amplification. For example, a Varo Corp. unit with a gain of $10^4$ would be suitable, although this tube has only a 25-micron resolution. This resolution can be improved in more advanced tubes, according to Professor G. T. Reynolds, and a 10-micron resolution should be obtainable. An up-to-date vidicon which can follow the image intensifier has a typical resolution of 100 lines per millimeter and is compatible with the 10-micron accuracy desired in the measurement of the particle trajectory.

The small amount of Cerenkov light emitted by the fiber optics face plate results in about 10% or less of the scintillator yield and only adds to the resultant signal, at least approximately. Any shadow effects, if present, are very small.

Model B: In this case the number of emitted photoelectrons is similar to that described in Model A. The image orthicon tube is, however, more expensive. The simplicity inherent in Model B is very desirable. Of course, the scintillating layer may also be placed within the vacuum envelope of the orthicon.

Model C: This is also a very simple device, as in the orthicon case. The optical sensitivity of the surface is smaller, however, and a rough estimate indicates that the NaI(Tl) thickness should be increased to about 25 microns so that the "spot" signal will exceed vidicon or amplifier noise.

Model D: In the case of a lens system the probable upper limit on the fraction of light collectible by the optical system is about 10%. In this case a 10 micron spot would yield only about 30 photons. This would still be suitable for image orthicon operation but, without image intensification, would not be suitable for registration by a photographic plate. However, only one stage (of gain 100) of image intensification would be adequate for use with a photographic plate.

Model E: This is a generalized and somewhat speculative model in which the nature of the contiguous photosensitive detector may involve improvement over present-day techniques, e.g., a silicon photoconductive matrix. Perhaps the glass semiconductor matrix is a possibility. It also seems possible that a sensitive semiconductor matrix can be developed that can register the passage of a particle without additional image intensification. Note that a sensitive semiconductive array could measure directly the passage of an ionizing particle.[2] This is what we referred to earlier as Model F.

## IV. DIMENSIONS OF DETECTOR PLANE

At the present time, image intensifier tubes, image orthicons, and vidicons generally have face diameters of about 5/8 in. to 2 in. Though these dimensions are suitable for some high-energy applications it would clearly be desirable to have larger area devices. There seems to be no inherent reason why the optical devices relevant to our proposed technique cannot be increased to diameters of twenty inches or so. Certainly five-inch diameters seem possible.

## V. PERTURBATION OF PARTICLE TRAJECTORY

The scintillator layer in the detector plane and the mirror backing have very little effect on a particle trajectory whenever the energy of the particle is even above the (low) value of a few BeV. For example, the combined thickness of backing and scintillator layer is less than $10^{-3}$ of a radiation length, and at 10 BeV this produces a multiple scattering angle of about $6 \times 10^{-5}$ radians. The corresponding energy loss is completely negligible.

On the other hand, the image intensifier, the image orthicon, etc., generally will introduce perhaps 1 gm/cm$^2$ into the path of the particle. A 10-BeV particle will suffer multiple scattering of about $3 \times 10^{-4}$ radian. Although this is not large, it would be desirable to eliminate the thickness responsible for the scattering. This can possibly be done by tilting the photosensitive tube, scanning obliquely, or by bending the tube trajectories with a small magnetic field. This is a technical problem and may not be difficult to surmount.

## VI. TIMING AND GATING

The timing ability of the proposed device will depend primarily on the scintillator. For any model involving, e.g., scanning in the vidicon, or flourescent response time of the screen in an image intensifier, an additional timing element is introduced. It is possible that time intervals of this type can be reduced by suitably increasing voltages in the tubes or by changing the flourescent screen. There would not seem to be much difficulty in obtaining 100-nanosecond timing. In going to 10 nanosecond resolution the organic scintillators might prove suitable, or pure NaI at reduced temperature is a distinct possibility. To resolve two events within the same scan would probably involve new technical problems, but for the NAL duty cycle there is probably no real difficulty in this respect.

Gating can readily be carried out within an image intensifier tube. Incorporation of triggerable grids in this and other photosensitive tubes seems feasible.

## VII. SCINTILLATOR SPOT SIZE

If a fiber optics layer of scintillator of very small thickness, such as 10 microns, can be made, the spot size will be limited, for normal particle incidence, to the diameter of the fibers. Although this is a very desirable mode of operation, we shall assume a more conventional approach below. However, the fiber optics-scintillator technique should be pursued.

With good optical coupling between the scintillator layer and the photosensitive surface no losses that are not included in the 20% efficiency figure need to be taken into account. Thus the figure of 50-60 electrons quoted earlier seems reasonable.

The curve exhibiting light intensity versus radius of the spot on the photosensitive surface can be estimated by considering that a cone of light with solid angle of apex angle $90^\circ$ ($\pm 45^\circ$) will fall on the surface without loss. This cone will include about 45 of the original 300 photons. If we imagine the light to be produced on the average at a distance of 5 microns (for a 10 micron layer) from the photosensitive or fiber optics, surface the appropriate diameter on the screen will be 10 microns. Reflected light from the backside mirror will supply another 45 photons within a 30 micron diameter. The remaining solid angles will add to the spot dimensions and the resulting spot size will have to be calculated with some care.

On the other hand, if the texture of the scintillator surface consists of small crystalline grains of the order of 10 microns, the spot size will also be of this size. Thus it is a matter of experimentation to try to decide whether small crystal grains should be laid down in the surface, and whether a reflector or a diffuser should be used as a backing surface. There is a great deal of experience with oscilloscope cathode ray screens and spot sizes, and we know that very small spots <u>are</u> achievable.

I feel that a 25 micron "spot" should be readily obtainable. A 10 micron spot can probably be achieved with some care.

## VIII. CONCLUSION

The very flexible scheme of a scintillating detector plane followed by a photosensitive device seems to make possible the determination of high-energy particle trajectories without requiring the development of basic new techniques. It is therefore suggested that some preliminary experiments be initiated using commercial image intensifiers, image orthicons, and vidicons. With presently available instruments of this type, 25 micron precision ought be to obtained easily. A precision of 10 microns would not seem to be beyond realization in the near future.

## Acknowledgments

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## Note

During preparation of this report I became aware of the "channel electron multiplier" concept but I have not had an opportunity to pursue the possibility of using this device in association with a scintillator plane.

## REFERENCES

[1] L. W. Alvarez, Memo No. 672, Lawrence Radiation Laboratory Physics Note of November 26, 1968. This author also mentions the possibility of using the scintillation technique for obtaining good resolution but states that, "Perhaps someone else will see his way from this point to a practical high resolution device."

[2] T. M. Buck, A Silicon Diode Array for Image Sensing, in Semiconductor Nuclear-Particle Detectors and Circuits, (edited by W. L. Brown, W. A. Higinbotham, and R. L. Chase), National Academy of Sciences, Washington, D.C. (1969).

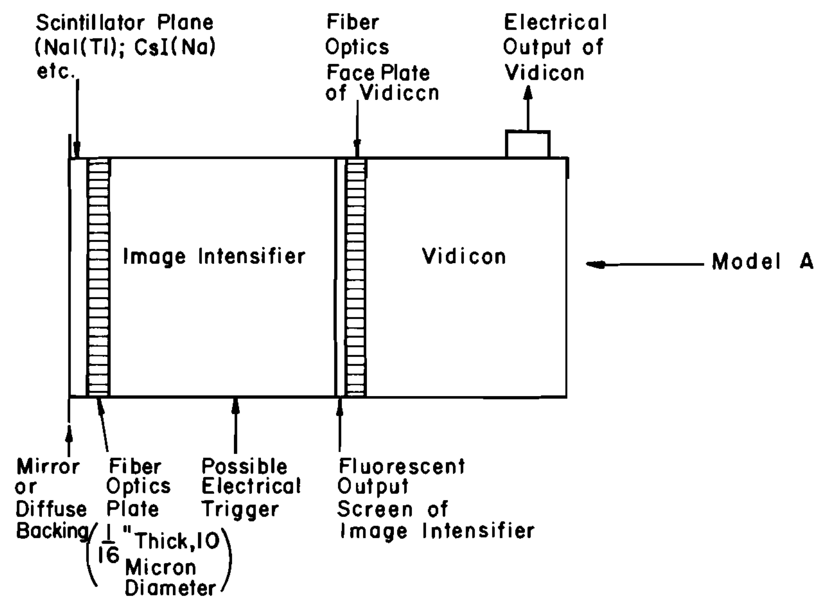


Fig. 1. Model A detector: cascaded scintillator, image intensifier, and vidicon with fiber-optics coupling.

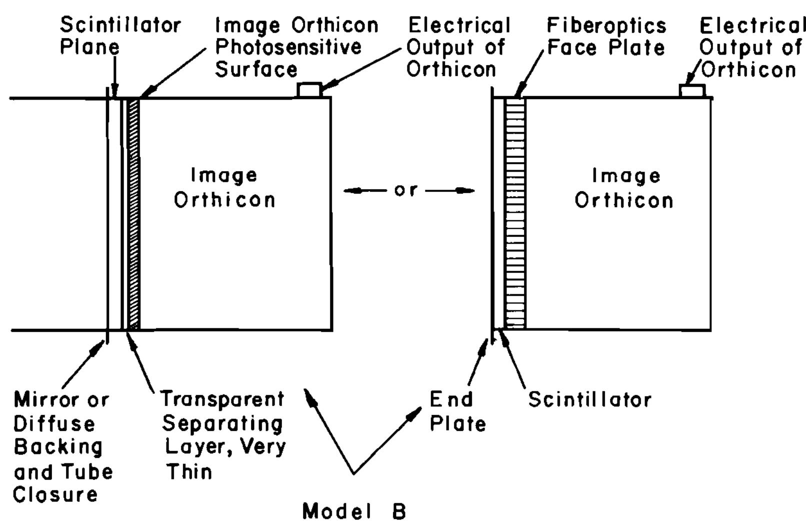


Fig. 2. Model B. Scintillator and image orthicon.

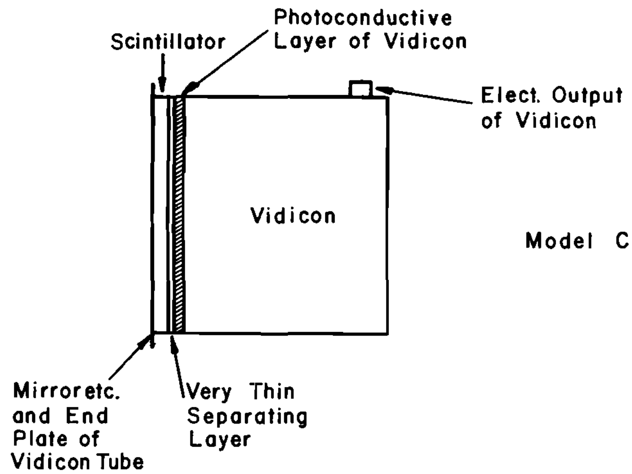


Fig. 3. Model C. Scintillator coupled to vidicon.

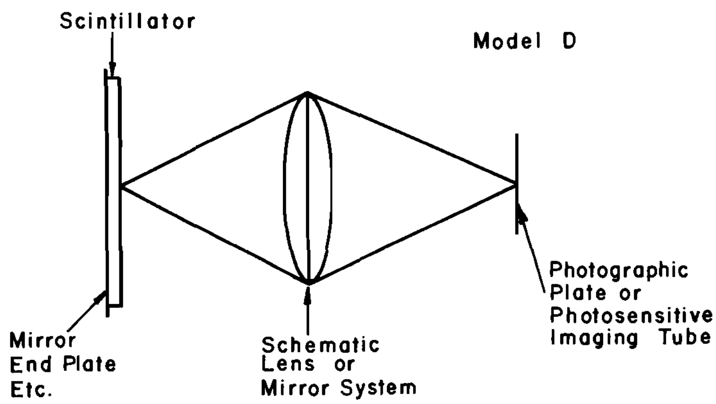


Fig. 4. Model D. Lens coupling between scintillator and imaging device.

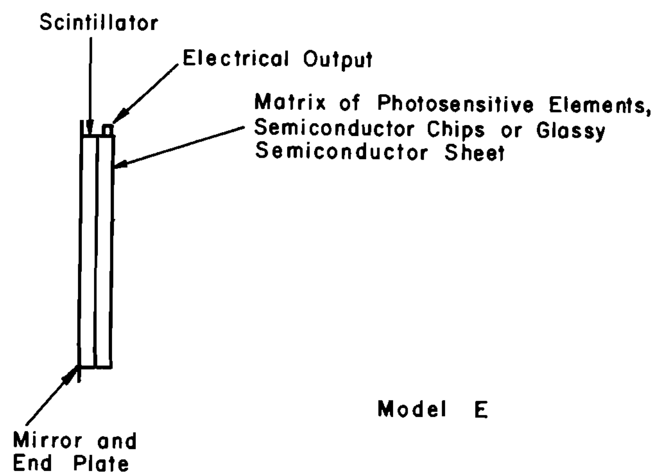


Fig. 5. Model E. Scintillator coupled to mosaic of photosensitive elements with direct electrical output.