JUN 21 1965

BNL 9218

CONF-650510-4

Paper to be presented at Purdue Conference on Instrumentation for High Energy PhysicsMay 12-14, 1965

MASTER

RECENT DEVELOPMENTS IN HIGH ENERGY COUNTERS*

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During the past few years, there have been some remarkable advances in high energy counter techniques. Just a few examples are: scintillation hodoscope systems with on-line computer; sonic spark and wire chambers with digitization of track location into a computer machine; large gap spark chamber; sophisticated versions of Cerenkov counters, and so on. It was through the use of these highly developed detection techniques that many important contributions to high energy physics have been made possible in this period.

I shall give a brief review of some of the most recent aspects of these developments, with the exception of spark chamber techniques, which have already been taken up and treated in detail by other speakers in previous sessions. I shall also attempt to say a few words about some possible new detection techniques which may be of interest to you.

(1) Cerenkov Counter

As is well known, the angle θ of emission of the Cerenkov radiation caused by a traversing charged particle in a medium is given by

$$\cos\theta = \frac{1}{\beta n}$$

where β is the velocity of the particle and n the index of refraction of the medium. For the identification of particles in the very high momentum region, say for $\beta \gtrsim .95$, a differential gas Cerenkov counter is extremely useful, especially since the momentum of the desired particle can be varied easily by varying the index of refraction, n , of the gas (simply by varying the gas pressure). However, there is a practical limitation on how high a pressure one can exert on a certain gas (i.e., how high an index of refraction can be reached) without converting the gas into liquid phase at normal operating temperatures. This limits essentially the usefulness of a gas Cerenkov counter for lower momentum particles, say kaons, to

* Work performed under the auspices of the U. S. Atomic Energy Commission.

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a momentum of not lower than approximately 1.5 BeV/c. This fact, and the necessity of a wide momentum range of the desired particle (i.e. large variation in the index) led one to use a differential Cerenkov counter with liquid solutions as radiators whose refractive indices could be varied by changing the relative proportion of the components in the solution. Such a counter has been designed by Sacharidis, Ozaki and Reed⁽¹⁾ at Brookhaven for the detection of kaons in the momentum range of 0.60 to 2 BeV/c. It has a high efficiency (>80%), and incorporates pion and proton anticoincidence channels so that rejection ratios of better than 10^5 for the pions and protons can easily be achieved. Thus, it proves to be a very simple and extremely useful device in this momentum region. Figure 1 shows the optics of this counter and Figure 2 shows the particle spectrum obtained with it. One can easily see the clean kaon peak well separated from a large sea of pions and protons present in the beam.

With better beam optics and smaller apertures in the counter, rejection ratios better than 10^6 can probably be obtained.

(2) Time of Flight Method

Recently there have been some very interesting applications of the time of flight technique to certain high energy experiments, and offer some specific advantages. One of these is the time of flight measurement making use of the R.F. structure of the beam; another is the combination of time of flight measurement and beam separation technique.

(a) Time of Flight Measurements Using the R.F. Structure of Beam

If, at the end of the accelerating cycle, the internal proton is still strongly coupled to the R.F. voltage, then the circulating protons would strike the target in R.F. bunches. This is true also for the secondary beam from the target. If each R.F. bunch is narrow enough a time of flight measurement can be easily made by using the R.F. as a timing signal from the target. A detailed description of such a method is given by Piroué and Smith⁽²⁾ in their paper submitted to this Conference. They have used this technique in a recent experiment in which kaons produced in p-p collisions were detected over a wide momentum range (350-1300 MeV/c), using only time of flight techniques and momentum analysis. The time of flight measurements were made between two scintillation counters and also between one of these two counters and the target. These two times of flight were then displayed on a two-dimensional pulse-height analyzer. This method has the advantage of eliminating any momentum dependence of the kaon detection efficiency while keeping the background low. Figure 3 shows a two-dimensional distribution for a 1 BeV/c positive beam from the Princeton Penn accelerator. The coincidence requirements

were such that most pions and protons were rejected. Since the background itself is also structured, the background can be enormously reduced in a region of interest by choosing a suitable distance from the target.

(b) Combined Time of Flight Measurements and Beam Separator Method

This method is extremely useful for searching for new particles of unknown mass. This is because of the large mass range that can be explored in one setting of the system, while still affording a precise measurement of the mass. If the abundance of the searched-for particle is of the order of a few parts in a million or less, accidental counts can be avoided by separating out from the beam the very abundant light particles (pions) by using a high energy separated beam. In a recent experiment at the Brookhaven AGS by Franzini et. al.⁽³⁾, in the search for heavy triplets as conjectured by Gursey, Lee and Nauenberg⁽⁴⁾, this method was used very successfully in carrying out such an experiment, and proves to be potentially very useful for future applications of a similar nature.

The arrangement of this scheme is shown in Figure 4. The first separator was so adjusted as not to let negative pions and antiprotons go through the first mass slit. This arrangement alone gave a rejection of pions by $\sim 10^4$. The light particles were further rejected by a gas Cerenkov counter. The remaining particles going through the system were detected by two telescopes, T_1 , T_2 , each composed of two scintillation counters approximately one foot apart, in coincidence. The time lag between the signals from T_1 and T_2 was measured with conventional time to pulse height converter and pulse height analyzer.

Calibration runs with pions, protons, deuterons and tritons gave an absolute time scale and showed that the time measurement resolution was slightly better than 1 nsec.

The beam momentum was set at 7 BeV/c over a path of 190 ft.; the time of flight for a 4 BeV particle is 29 nsec longer than for a pion. The total rejection for pions versus particles of 4 BeV mass was about 10^9 and the percentage error on the mass was given by $\frac{dm}{m} \approx 3\%$.

(3) Scintillation Hodoscope and On-Line Computer Method

This method was first used by our group at Brookhaven in 1961 and it was used successfully to investigate the elastic scattering of various elementary particles by protons. The unqualified success of this method and its many advantages, especially the on-line computer technique, have opened up a new avenue in counter and spark chamber experiments. Some of the experiences in the on-line data analysis we have encountered during the past five years will be given later by Dr. William Love⁽⁵⁾ of our group. I shall only mention here some of the recent improvements in

our hodoscope system. Because of the extremely fast time resolution of scintillators, scintillation hodoscopes offer much greater advantages when large statistics or high counting rates are required. Although the space resolution of sonic spark chambers or wire chambers is extremely good, say ~ 1 mm in most cases, we have recently developed a hodoscope with much smaller elements which can give a space resolution of 3 mm. This is within a factor of 3 of the space resolution of the wire or sonic spark chambers, whereas the angular resolution can be made comparable by extension of path lengths. Figure 5 shows such a hodoscope element, together with a new smaller size photo tube (7767) and a newly-designed thin base board which can be conveniently stacked without taking up much space.

It is evident that a combined system of scintillation hodoscope and wire or sonic spark chamber with on-line data analysis would be an extremely useful and valuable technique. Wherever high flux measurements are required, such as in the incident beam, a high resolution scintillation hodoscope should be used, and where high space resolution is needed but event rate is low, a spark chamber system would be advantageous.

(4) Detectors Using the Relativistic Rise Effect

It is well known that the ionization loss of a very high energy particle traversing a gaseous medium shows an appreciable rise after passing the minimum ionizing region as the energy of the particle is further increased. A number of studies have been made using Xe gas as a possible detector for the identification of particles in the relativistic region⁽⁶⁾, and the results thus far have been encouraging.

Another possibility of making use of the relativistic rise effect is the secondary emission detector which was also reported some time ago⁽⁶⁾. The secondary electron emission from a solid material showing an appreciable relativistic rise effect without the normal density effect present in a solid material was at first puzzling. Later, Aggs⁽⁷⁾ adopted a simple theory to explain this, and his theoretical treatment gave good agreement with experimental results as shown in Figure 6.

One of the difficulties encountered in such detectors is the low efficiency in secondary electron emission. For the detection of single charged particles, hundreds of foils will be needed. Recent studies by Blankenburg et. al.⁽⁸⁾ on the emission efficiencies of twelve different metal foils with 70 MeV electrons showed that the lighter elements have a noticeably larger secondary emission coefficient per target electron (i.e. the measured relative yields divided by the electron density $\delta N_0 Z/A$ in the foils, where N_0 is Avogadro's number, δ is the density of the foil, Z is the atomic number and A is the atomic weight). The emission coefficient of Be was found to be approximately twice that of Al.

Also Garibyan⁽⁹⁾ showed that if a particle passes through a sufficiently thin plate, then its electric field remains the same as it was in vacuum. Therefore, in such a plate the particle ionizes in a manner as if there is no density effect.

Alikhanyan⁽¹⁰⁾ estimated the minimum thickness a of a material through which a charged particle traverses without introducing the density effect. He found that

$$a \ll [2\omega/\sigma] [\ln(\sqrt{\sigma/\bar{\omega}}/1-\beta^2)]$$

where v is the velocity of the ionizing particle, $\bar{\omega}$ is the mean frequency of electron oscillation in the atom of the matter, $\sigma = \frac{4\pi Ne^2}{m}$ the plasma frequency, Ω is the frequency above which the dielectric constant of the medium can be given by the formula $\epsilon(\omega) = 1 - \frac{\sigma}{\omega^2}$. For polystyrene films, the critical thickness a_0 for different values of electron energy are estimated below:

$p/\mu c$	10	40	100	200
$a_0 (10^{-6} \text{ cm})$	31.7	37.5	39.5	45.0

Experimental verification of this theory was carried out by Alikhanyan et. al.⁽¹¹⁾ Electron beams of energies 20.5, 40, 47.5 and 88 MeV were in turn focused on a target consisting of a scintillation film of 10^{-6} cm thick deposited on an aluminum substate of 10μ thick. The experimental setup is shown in Figure 7. In a control experiment, measurements were also made on a thick film (2×10^{-3} cm). Figure 8 shows the results of measurements and the theoretical curves⁽¹²⁾ on density effect calculated by Sternheimer⁽¹²⁾ for films of 10^{-6} cm and 2×10^{-3} cm thick respectively. The experimental data for thin films agree satisfactorily with the curve having no density effect whereas the results for a thick film agrees with that including the density effect.

(5) Transition-Radiation Detectors

We are familiar with the Cerenkov radiation which is emitted by a charged particle traversing a medium of refractive index n , when the particle velocity exceeds the velocity of light in that medium. It is not well known, however, that when a charged particle traverses from one medium into another medium with different electrodynamic properties, a radiation is emitted which is called "transition radiation." This radiation was first predicted theoretically by Ginzburg and Frank⁽¹³⁾ in 1946. They have shown that when a charged particle passes from one medium into another, a readjustment must take place in the field associated with the particle; as a result, part of the field is shaken off forming into transition radiation.

The energy loss, in the case of vacuum-medium or medium-vacuum, is

$$\frac{e^2}{3c} \sqrt{\sigma \gamma}$$

The transition radiation caused by this energy loss is emitted with an almost constant spectrum from optical frequencies to the limit $\omega_{lim} = \sqrt{\sigma\gamma}/2$. The angular distribution of these photons vanishes at small angles with respect to the direction of the traversing particle.

Similar to the case of ionization loss in a thin slab mentioned in the previous section, the electric field of the particle in a thin slab is the same as in vacuum and there is no density effect.

The total energy loss in such a slab is given by

$$F = \frac{2\pi Ne^4}{mc^2} a \left\{ \ln \frac{c^2 k_0^2}{\Omega^2} \gamma^2 + 2a_1 - 1 \right\}$$

where

$$c_1 = \frac{8}{\sigma} \int_0^{\Omega} \frac{\sqrt{\epsilon}(\sqrt{\epsilon}-1)}{(\sqrt{\epsilon}+1)^2} \omega d\omega$$

k_0 = quantity inversely proportional to the distance beyond which the macroscopic approach is applicable.

The expression for F is comparable to the usual energy loss by ionization but without the density effect.

The critical thickness a_0 is given by

$$a_0 = 2 \frac{c \Omega}{\sigma} \left\{ \ln \frac{c k_0 \gamma}{\Omega} \right\}$$

and the total emitted energy is given by

$$f = \frac{1}{3} \frac{g^2 \sqrt{\sigma}}{c \sqrt{1-\beta^2}}$$

which varies linearly with the particle energy. Since σ is proportional to the density, ρ , of the medium, we see that f is proportional to the square root of the density of the medium, but the critical thickness, a_0 , is proportional to $\frac{1}{\rho}$.

The probability for the particle to radiate, by transition effect, a photon between ω_{opt} and $\omega_{lim} = \sqrt{\sigma\gamma}/2$ is about 10^{-1} . In order to have a greater efficiency a large number of thin slabs is needed.

The intensity of the transition radiation is a function of $E/\mu c^2$ of the particle. This effect may be useful for the identification of particles in the super high energy region.

Alikhanyan and his co-workers^(10,13) performed an experiment to detect the transition radiation from high energy muons in cosmic rays. They used 300 layers of paper with a thickness $a = 2 \times 10^{-2}$ cm, spaced 1 cm apart between layers. The main

measurements were periodically interchanged by control measurements, during which a plexiglass absorber with a thickness of 11.5 gr/cm^2 was inserted. One hundred events attributed to transition radiation have been registered during 7526 hours of measurement, and only three events have been registered during 1800 hours of control measurements. The results also show an intensity dependence of $E/\mu c^2$ as predicted by theory.

(6) Solid State Detector with Internal Pulse Amplification

By properly shaping the surface of a p-n junction silicon detector, called "surface contour," it is possible to lower the surface field and build up peak internal fields to the avalanche point in silicon ($200\text{-}300 \text{ kv/cm}$) at reverse bias voltages in the kilovolt range, so that a pulse formed at the junction can be amplified as a result of the high internal field⁽¹⁴⁾.

Amplification of electron pulses is reasonably constant as a function of incident electron energy. Electron peak resolution decreases with amplification, but the rise time of the amplified pulses is not much different from that of the non-amplifying ones. A diagram of the detector geometry is shown in Figure 9. Figure 10 shows the pulse shift as a function of the detector bias with 200 keV electrons incident on the p^+ (gallium diffused) side of the junction. An amplification factor of approximately 50 is indicated for 50 keV electrons, and all pulses display risetimes characteristic of the electronic system ($1.5 \mu\text{sec}$) with none slower.

These contoured detectors also can be used as photon detectors with high sensitivity. The speed of response of these detectors seems to lie in the sub-nanosecond region.

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Figure Captions

Figure 1. Cerenkov counter optics.

2. Cerenkov counter system resolution for 0.670 BeV/c K.
3. Two-dimensional distribution of times of flight for a 1 BeV/c positive beam.
4. Schematic of the time of flight and beam separator system.
5. 1/8" x 1/8" hodoscope element.
6. Comparison of theoretical predictions with Richter's experimental results.
7. Schematic representation of the experimental setup:
1) secondary-emission monitor; 2) target; 3) vacuum windows.
8. Theoretical curves and experimental values of energy losses in polystyrene films of thicknesses 10^{-6} cm (a) and 2×10^{-3} cm (b).
1) theoretical curve without allowance for the density effect;
2) theoretical curve with allowance for the density effect.
The circles denote the results of measurements. The ordinate axis gives the specific luminescence in relative units.
9. Diagram of contour detector geometry.
10. Pulse shift as a function of detector bias - 200 keV incident on p^+ face.

FIG.1 ČERENKOV COUNTER OPTICS

///: MIRROR SURFACE

FIGURE 1

C. COUNTER SYSTEM RESOLUTION
FOR .670 BeV/c K

FIGURE 2

FIGURE 3

FIGURE 4

FIGURE 5

FIGURE 6

FIGURE 7

FIGURE 8

FIGURE 9

FIGURE 10