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Future Trends in Detection Techniques at
Super High Energies *

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Future detection techniques will be determined by the future trends in experiments and accelerators which will certainly be characterized by either higher energy or higher intensity, or both. Basing on current developments in the high energy field and the experimental requirements for the future as can be foreseen now, we can examine the three main categories of detection methods listed below:

- 1) Bubble chamber
- 2) Spark chamber
- 3) Counter systems.

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I) Future of Bubble Chambers.

The bubble chamber is a tool of excellent space resolution. With existing chambers one can count on obtaining tracks of one meter or more. Sagittas of curved tracks can be measured to accuracies ¹ approaching 25 microns. With a magnetic field of 20 kilogauss, these

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measurements are sufficient to determine the momentum of a 100 BeV/c particle track with a 3% accuracy. However, measurements in angle are not so good in bubble chambers. For instance, a precision of 0.03° can be obtained for particle tracks of 500 BeV/c momentum and 1 meter long in a plane perpendicular to the chamber axis and a precision of only 0.2° for tracks with a large dip angle. When transformed to the center of mass system, this corresponds to an indeterminacy of at least several degrees.

As for the future development of bubble chambers, the size of the present chambers is already quite big (80" BNL chamber) and for many experimental purposes, this size is quite adequate but a considerably higher magnetic field is very much desirable. Owing to the recent progress in the super-conducting magnets, magnetic field of the order of 100 kilogauss seems to be feasible in the not too distant future and this would play a very important role in the future bubble chamber applications at super-high-energies.

Even though bubble chambers can be triggered by various counter arrangements, but the basic limitation in the bubble chamber time resolution makes the usefulness of such an application very much restricted.

II) Future of Spark Chambers.

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The many advantages of a spark chamber makes it a very powerful tool for future applications at super high energies. These advantages are (1) its excellent spatial resolution ~ 0.1 mm. (2) Very good time resolution of ~ 0.5 μ sec thus enabling extensive application.

by triggering by counter arrangements for event identification, background reduction, etc. (3) extreme flexibility and (4) its practically unlimited size, or dimension. (30-ton spark chambers for the present neutrino experiment).

The future trend in spark chambers at super-high-energies would certainly be larger size, their use with magnetic field, more sophisticated triggering; use as hodoscopes in extremely precise spectrometers; use in various assemblies of spark chamber and absorber sandwiches to roughly classify particles; and new techniques developed in extricating information. The last item relates to the use of either sonic or wire spark chambers.

The sonic chamber involves measuring the time interval between the pulse of the spark and the arrival of its sound to a transducer. From the velocity of sound, a time interval of 3 microseconds corresponds to a distance of 1 mm. Transducers made either of barium titanate loaded with araldite and tungsten or of electrostatic type have rise times of $\sim 0.5 \mu\text{sec}$. With this one can obtain a spatial resolution of $\sim 0.15 \text{ mm}$ in principle. The wire spark chamber consists of wire meshes instead of solid plates. Each wire of the mesh is connected separately to a magnetic core which detects the spark current in the individual wire and thus the spark location can be read with computer techniques.

III) Future of Counter Systems.

As was mentioned earlier, the future trend in experiments will certainly be characterized by higher momentum or higher intensity or both. Hence in the use of super-high-energy accelerators, it is essential that high momentum particles be identified as well as low momentum particles.

Among the presently known techniques a counter system, consisting of Cerenkov counters, is by far the best method for identifying high momentum particles. On the other hand, because of its extremely fast resolution time, a scintillation counter is by far the best detector for high intensity applications and is capable of high counting rates. It is very likely that high field super conducting magnets will be extensively used and some detectors will be required to operate in extremely high fringing fields.

a) Cerenkov Counters.

A differential gas Cerenkov counter with a built-in anti-coincidence feature has been used very successfully to identify high momentum particles up to ~ 22 Bev/c. A typical resolution, $\frac{\Delta\beta}{\beta}$, of such a detector⁽³⁾ is $\sim 10^{-4}$. Much higher resolution can be obtained by reducing the angle of the Cerenkov radiation and by applying corrections for chromatic aberration. Using axiconic lenses made of fused SiO_2 and NaCl respectively for correcting chromatic aberrations and with a Cerenkov angle of $2\frac{1}{2}^\circ$, improvement in resolution by a factor of 15 to 20 is expected.⁽¹⁾

It is reasonable to believe that, with the above mentioned improvements in the resolution, particles of a few hundred Bev/c momentum can be identified.

In a conventional high resolution Cerenkov counter system, the incident particles would all have to be extremely parallel to the axis of the counter in order to be detected by the counter. Any particle incident at a small angle off the axis of the Cerenkov counter will result in a displacement of the Cerenkov light cone from the position of the slit and consequently, this light will not enter the slit.

In the future, one can possibly replace the conventional slit by a hodoscope system of light pipes and photomultipliers, the signals from which are fed directly to a computer system. Thus, the position and the radius of the

Cerenkov light cone for each particle can be determined. Not only can the off axis particles be detected, but particles possessing different velocities can also be selectively detected and identified.

b) Solid State Detectors.

The solid state detector may play an important role in the future experiments with super-high-energy accelerators. This can be exemplified by the following:

- (i) It gives much high energy resolution than conventional detectors such as scintillation detectors or ionization chambers. It requires only about $1/10$ of the energy to produce an electron-hole pair than is needed for regular ionization processes. It compares even more advantageously when compared with a scintillation detector where about 50 electron volts is needed to produce one photon and approximately 10 photons are needed to produce a photoelectron in the photocathode of a photomultiplier. In the solid state detector, on the other hand, it requires only $\sim 1/200$ of the energy to create an electron-hole pair.
- (ii) It is insensitive to magnet field. This is especially important in the future applications when we will certainly have high field superconducting magnets, and detectors may have to be placed in close proximity to such high fields.
- (iii) Its size is small and no photomultiplier or light pipes are needed. It can be placed conveniently close to a target for detecting particles of short life times or it can be installed in otherwise inaccessible locations.

(iv) Its energy response is linear over a wide energy region (below minimum ionization). In the relativistic region, since the mechanism for producing electron-hole pairs is not known, it is hard to predict how the relativistic-rise behavior is affected by the "density effect" existing in normal ionization processes.

Recent measurements at Brookhaven⁽⁴⁾ using a lithium drift solid state detector 5 mm thick were made at several energies to determine this effect. The results are shown in Figs. 1-3. Previous results⁽⁵⁾ have already established that the pulse height distribution follows very closely the Landau distribution for a thin detector.

Fig. 1 shows the pulse height distribution in a mixed proton and π^+ beam at a momentum of 5 Bev/c. Fig. 2 shows the pulse height distribution for a similar beam but at 1 Bev/c. Here we see that the π^+ and proton spectrum can be separated. Fig. 3 shows the position of the spectrum peaks as a function of particle momenta. From these results we can conclude that up to 5 Bev/c momentum, they are in agreement with the density effect on the relativistic rise.

c) Relativistic Rise Detectors.

One of the most promising methods for identifying extremely high momentum particles in the relativistic region, say, momentum greater than several hundred Bev/c is the well-known relativistic rise effect in ionization loss during the passage of high momentum particles, higher than minimum ionization, through matter. The amount of rise depends on the density of the medium. The rise is high in gases but low in solid or liquid material. This reduction in relativistic rise is called the density effect. Previous studies at Brookhaven using a Xenon

counter⁽¹⁾ showed very promising results. By using a number of such counters in cascade and making use of the steep part of the Landau distribution curve for each counter, one can possibly identify particles of very high momentum. If the density effect is indeed exceedingly small in such a Xenon counter, the separation of the Landau distribution curves for two different particles of the same momentum in the relativistic region is independent of their momentum and is only a function of their mass difference. Thus if one can separate particles of different mass of the same momentum at say 200 Bev/c, then one should be able to separate these same particles at 1000 or 2000 Bev/c.

Another useful phenomenon is the rise in secondary emission at high energies⁽¹⁾. This also holds some promise of future application in super-high-energy experiments.

d) Scintillation Hodoscope Systems with On-line Computer.

The extremely fast time resolution of a scintillation detector ($\sim 10^{-9}$ sec) together with its flexibility in application in various forms of hodoscopes, telescopes, etc. leads one to feel quite certain that it will play a major rôle in future experiments at super-high-energies and at high intensities. The fast time resolution allows one to reduce background effects and to obtain high counting rates in an experiment. The immense flexibility in the choice of counter elements of practically any size and in any desired shape of hodoscope or telescopes arrays makes it extremely valuable in future experiments. This is especially true if the information registered in the hodoscope can be fed directly into a fast computer and the desired computations can be made instantaneously. An example of this is the recent elastic scattering experiment ⁽⁶⁾ ⁽⁷⁾ performed at the Brookhaven AGS, employing a system of scintillation hodoscopes for determining the scattering angle and momentum of each scattered particle with high precision. The counting rate obtained in this experiment is at least two orders of magnitude higher than any other existing detection systems under consideration.

The information on each event is stored in a buffer memory unit. At the end of each AGS pulse, all the stored information was transmitted to a fast computer which is programmed to compute all the essential results derived from the experiment, such as the classification of elastic and inelastic events in each angular region under study, the momentum spectrum of the desired particle, the elastic differential cross-sections corresponding to the various values of t (negative momentum transfer squared), etc. These computed results are then transmitted back to the experimental station and displayed on an oscilloscope before the start of the next beam pulse. I believe that this is the first time that an on-line computer system was successfully designed and operated in an experiment of such complexity. Fig. 4 shows the experimental set up. Fig. 5 shows one of the counter hodoscopes. Fig. 6 shows the buffer memory unit and some of the electronic circuits. Fig. 7 shows a momentum spectrum with an elastic peak on the display oscilloscope.

The tremendous advantage of obtaining instantaneously the analyzed experimental results cannot be over emphasized. It not only serves to monitor the progress of the experiment, but seeing the results helps to make important modifications of the experiment on the spot which are necessary but were not realized before the experiment. Not only this on-line computer system enables us to efficiently use the valuable machine time but most important of all, it results in a much better experiment and in a much shorter time. One must bear in mind that the results of counter experiments are ordinarily not in as visual a form as are they with bubble and spark chamber experiments. The application of the above-mentioned data handling process is a very great improvement in high energy experiments not only for the present but even more so for future experiments. I feel strongly that in future experiments the on-line computer system will play an extremely important rôle, especially in those involving high intensity beams.

Scintillation detectors will certainly be advantageously used as triggering systems in spark chambers and bubble chamber experiments as well.

REFERENCES

1. Experimental Program Requirements for a 300 to 1000 BeV Accelerator and Design Study for a 300-1000 BeV Accelerator, BNL Report 772 (T-290), Aug. 28, 1961, Revised December 1962.
2. Future Program for the CERN and the Brookhaven AGS, Minutes of a Meeting held Sept. 10-14, 1962, BNL.
3. L. C. L. Yuan & C. S. Wu, Methods of Experimental Physics, Nuclear Physics, Vol. 5A, Academic Press, New York, 1962
4. G. L. Miller, L. Tepper and L. C. L. Yuan. To be published.
5. G. L. Miller, S. Wagner, L. C. L. Yuan, Nuclear Instruments and Methods, 20 (1963) 303-305; North Holland Publishing Co.
"Investigations on Lithium-Drift Solid-State Detectors for High-Energy Particle Detection"
6. K. J. Foley, S. J. Lindenbaum, W. A. Love, S. Ozaki, J. J. Russell and L. C. L. Yuan, Phys. Rev. Letters 10, 376 (1963)
7. K. J. Foley, S. J. Lindenbaum, W. A. Love, S. Ozaki, J. J. Russell and L. C. L. Yuan, Phys. Rev. Letters 10, 543 (1963)

Figure Captions

Fig. 1 Pulse height distribution in a lithium drift detector
5 mm. thick in a 5 Bev/c positive beam from the AGS

Fig. 2 Pulse height distribution in a lithium drift detector
5 mm. thick in a 1 Bev/c positive beam from the AGS

Fig. 3 Position of spectrum peaks as a function of incident beam
energy.

Fig. 4 Schematic of experimental set-up of the high energy elastic
scattering experiment at Brookhaven AGS

Fig. 5 One of the scintillation counter hodoscopes

Fig. 6 Actual experimental set-up

Fig. 7 Display of momentum distribution from on-line computer

FIGURE 1

FIGURE 2

FIGURE 3

FIGURE 4

FIGURE 5

FIGURE 6

FIGURE 7