A STREAMER CHAMBER DETECTOR FOR PEP

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ABSTRACT

A streamer chamber in an axial magnetic field is discussed as a possible central track detector around which additional detectors, such as shower counters, Cherenkov counters, time-of-flight counters, etc., can be assembled.

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Introduction:

Streamer chambers(1) appear to offer a number of advantages over other track detectors presently being considered for PEP. Among these are:

(1) excellent spatial resolution, approaching $\sigma = 100\ \mu$(1,2),
(2) excellent multiple-track efficiency,
(3) high information density of about 2 streamers per cm (useful in pattern recognition),
(4) large solid angle ($\sim 0.85 \cdot 4\pi$),
(5) excellent compatibility with other detectors,
(6) good separation of π/K, K/p, π/p by ionization below about 0.7, 1.0, and 1.4 GeV/c, respectively, and some separation via the relativistic rise of ionization in the region $5 < \gamma < 200$.(1,3)

In addition, we should mention that the basic interaction rate is expected to be small so that excessive numbers of events do not have to be analyzed. It is therefore important to extract as much information as possible from each event, a task for which streamer chambers are especially well suited.

Physics:

The advantages listed above suggest that the streamer chamber would be particularly well suited to the following types of experiments:

(1) total cross section,
(2) multiplicity of charged hadrons,
(3) angular distributions of charged hadrons,
(4) strange-particle production,
(5) search for new particles,
(6) general class of experiments involving event types in which one particle is identified.

Geometry:

We consider the streamer chamber as a central track detector around which other detectors, such as shower counters, Cherenkov counters, time-of-flight counters, etc., can be assembled. This argues in favor of an open magnet configuration such as that shown in side view in Fig. 1 and in beam view in Fig. 2. Two streamer chambers are placed back to back, and two coils in a Helmholtz configuration (coil separation equals radius) produce a rather uniform magnetic field of modest value parallel to the beam pipe. The electrodes of the chambers are perpendicular to the beam pipe and yield electric fields parallel to the beam pipe and thus to the magnetic field. The chambers can be driven by Blumleins and Marx generators below the magnet, as shown, or located on any other side of the magnet, if this is more convenient.

The magnet coils subtend narrow bands in polar angle θ, and the iron vanes that return the flux subtend narrow bands in azimuth ϕ. Approximately half of the 4π solid angle about the interaction region is accessible to peripheral equipment with very little mass in between. The iron vanes can be reassembled in various configurations, as may be required by particular experiments. Each chamber is photographed separately by 3 cameras (total of 6) through a circular hole in the respective pole face. It may be feasible to use a total of only 3 cameras, or to use a filmless device, such as a matrix of solid state photodiode arrays.

Parameter Values:

Good performance is possible for a wide range of parameter values. For example, the magnetic field and the magnet power can be relatively modest and still yield excellent momentum resolution. Further, both the momentum-analyzing power and the cost are roughly proportional to BL^2, where B is the magnetic field strength, and L is a typical track length. Thus the performance depends largely upon the available funds and is relatively insensitive to the choice of magnet field and radius, a 2 kG field and 200 cm radius being comparable in performance and cost with an 8 kG field and 100 cm radius.(4) A representative set of parameter values for the PEP energy range might be as follows:

(1) magnetic field B = 4 kG,
(2) sensitive radius about beam R = 150 cm,
(3) sensitive distance along the beam D = 150 cm,
(4) radius of insensitive region around beam r = 25 cm,
(5) typical track length for momentum analysis L = 100 cm,
(6) height above the beam line $h_{max} = + 3.0$ meters,
(7) depth below the beam line $h_{min} = - 3.5$ meters if driven from below the magnet and $h_{min} = - 3.0$ meters if driven from the side,
(8) total width of the experimental area w = 6 meters,
(9) total distance along beam of experimental area d = 12 meters,
(10) magnet power (without compensating coils) w = 1.0 MW,
(11) estimated cost of streamer chamber, magnet, and cameras is $800,000.

We emphasize again that this is a representative set of values, and no attempt has been made to optimize the design with respect to external criteria.

Particle Identification by Ionization:

It is desirable, but by no means essential, that the streamer chamber be operated in the avalanche mode. This mode leads to better isotropy and spatial resolution than the streamer mode and will eliminate flares, i.e., discharges caused by spiraling delta rays and by other steep tracks. (The flare problem has been effectively controlled in the streamer mode by using antihalation film with light absorbing dye immediately under the emulsion.(1)) Image intensifiers or diode arrays can be used to record avalanche tracks, which have low light yields.

In either mode, significant particle identification is possible on the basis of the number of streamers or avalanches per unit track length.(5) The situation is illustrated in Fig. 3, which is a plot of the relative ionization dE/dX versus momentum p in GeV/c. With an accuracy of one standard deviation for a count of the number of avalanches on an individual track (e.g., ± 10% for a 100 cm track length), one is able to distinguish between pions and kaons below 0.7 GeV/c, between kaons and protons below 1.0 GeV/c, and between pions and protons below 1.4 GeV/c. The separation of pions and kaons in the region of the relativistic rise after the ionization minimum is about 16% (1.6 standard deviations), while the separation of kaons and protons in this region is about 8% (slightly less than one standard deviation). The possibility of identifying charged particles over a large solid angle by ionization is particularly attractive in view of the difficulties posed by other techniques (e.g., time-of-flight or Cherenkov counters).

Angular Acceptance:

It is convenient to define the minimum useful polar angle of the streamer chambers shown in Figs. 1 and 2 by requiring that a straight track from the interaction vertex pass through at least one complete chamber gap. We assume two 38-cm gaps per chamber and a very conservative radius of 25 cm for the unobserved volume surrounding the beam pipe. The minimum useful polar angle is then

$$\theta_{\min} = 34^\circ \ .$$

The sensitive angular range is

$$34^\circ < \theta < 146^\circ \ ,$$

yielding a solid angle of

$$d\Omega = 0.86 \cdot 4\pi \ .$$

The solid angle can be increased still further by adding auxilliary small-angle drift chambers upstream and downstream of the open pole faces. The lever arm is much longer in these locations, and the radius of the unobserved region can be reduced to perhaps 10 cm. Note that the streamer chambers can be viewed through drift chambers. The range of polar angle θ available for optically thick detectors extends from 65° to 115° and corresponds to $0.5 \cdot 4\pi$.

Momentum Resolution:

The momentum resolution $\Delta p/p$ of a streamer chamber(1,6) is given by

$$\frac{\Delta p}{p}^2 = \left(\frac{\Delta p}{p}\right)^2_{ms} + \left(\frac{\Delta p}{p}\right)^2_{\Sigma} \ , \qquad (1a)$$

where

$$\left(\frac{\Delta p}{p}\right)^2_{ms} = \frac{0.133\left[\ln 4.8\,p + \ln(145p/Mc^2)\right]}{H^2 L\beta\cos^2\lambda} + \frac{5\cdot 10^{-2}\,L\tan^2\lambda}{p^2\beta^2} \tag{1b}$$

is due to multiple scattering and dominates below about 700 MeV/c, and where

$$\left(\frac{\Delta p}{p}\right)^2_{\Sigma} = \frac{144\,p^2\epsilon^2\cdot 10^{-4}}{H^2L^2\cos^2\lambda} + \frac{1.2\cdot 10^{-5}\epsilon^2\sin^2\lambda}{L^2\cos\lambda} \tag{1c}$$

is the result of measurement setting error and dominates above 700 MeV/c. In these equations, p is the momentum in MeV/c, $\beta \approx 1$ is the particle velocity relative to the speed of light, $H =$ is the magnetic field strength in kG, L is the measured length of track in cm, λ is the dip angle ($90^\circ - \lambda = \Theta$, where Θ is the polar or production angle in the geometry of Figs. 1 and 2), and ϵ is the measurement error in microns.

The results for a streamer chamber having $H = 4$ kG, $L = 100$ cm, and $\epsilon = 100\ \mu$ are plotted as a function of momentum and for various polar angles Θ in Fig. 4 . Evidently, the momentum resolution is excellent or acceptable over the full momentum range of PEP and over the full angular acceptance defined in the previous section.

Angular Precision:

The azimuthal angular precision $\Delta\phi$ of a streamer chamber in the configuration of Figs. 1, 2 is given by(1,6)

$$(\Delta\phi)^2 = \frac{0.13\cdot 10^{-2}\cdot L}{p^2\cos^2\lambda} + \frac{3.8\cdot 10^{-6}\epsilon^2}{L^3\cos^3\lambda}\ , \tag{2}$$

where the symbols have the values given in the previous section. The results for a streamer chamber with $H = 4$ kG, $L = 100$ cm, and $\epsilon = 100\mu$ are plotted as a function of momentum for various angles Θ in Fig. 5 . The uncertainty in the measured polar angle Θ is typically about 3 times larger than the values given in Fig. 5 for $\Delta\phi$.

Background Tracks:

The time between collisions in successive bunches at PEP is about 2.4 μsec. The memory time of the streamer chambers can easily be made shorter than 2.4 μsec, so that only the beam backgrounds associated with one bunch traversal need be considered. Further, since the bunch traversal time is only of the order 0.3 ns, no competing detector can resolve in time two tracks occurring within the same bunch traversal. As far as time resolution is concerned, then, the streamer chamber is no worse off than other detectors in the presence of a given background.

Excellent spatial resolution, on the other hand, combined with the superb track definition, gives the streamer chamber a significant advantage over other detectors both in pattern recognition and in the elimination of backgrounds coming from the interaction region and elsewhere.

We have already noted that charged hadrons from the interaction region must traverse the streamer chambers at an angle $\theta > \theta_{min} = 34^{\circ}$, which is sufficiently large to prevent flares. Backgrounds coming from the ends of the straight sections could, however, travel parallel to the beam pipe and remain in time coincidence with the bunches that generated them. Such backgrounds can be controlled by adding shielding material near the spurious sources. Knock-on electrons can, of course, occur along tracks in the sensitive volume of the streamer chamber, but these are not a problem when antihalation film is used. In general, the streamer chamber appears to have less difficulty with steep tracks than do wire chambers.

Trigger:

In the early operation of PEP, the most promising trigger would seem to be a very general one consisting of a beam crossing signal, a beam-pipe detector, and an additional set of counters around the visible volume of the streamer chambers. The beam-pipe detector could consist of plastic scintillators such as those used at SPEAR. The second set of detectors would have to cover as large a solid angle as possible to maximize the geometric efficiency. Peripheral counters, such as a matrix of lead-glass shower detectors or an array of Cherenkov counters or of time-of-flight counters could also be incorporated into the trigger.

A recent innovation is that of operating the streamer chamber in the storage mode.(7) In this mode, a moderate prepulse is applied to the chamber electrodes on the basis of a very general trigger, the tracks streamers are stored in metastable states from an early stage of avalanche formation for about 1 ms, and a second high voltage pulse is applied in response to a more complex trigger or even some computer analysis. This could reduce the fraction of uninteresting pictures by a significant factor.

Other options:

One of the most important advantages of the streamer chamber is its compatibility with peripheral equipment. Among the possibilities not already discussed are the following:

(1) detect photons by adding non-conducting PbO plates ($X_o \approx 2$ cm) inside the chamber,
(2) identify particles of 800 MeV/c $< p <$ 3 GeV/c by time-of-flight with detectors outside the chamber,
(3) use drift chambers detect small-angle tracks and improve the momentum resolution for certain high-momentum tracks,
(4) add shower detectors in the open sectors ($65^{\circ} < \theta < 115^{\circ}$) of the

magnet yoke to detect and measure the energy of neutral particles,

(5) add gas Cherenkov counters in the open sectors of the magnet yoke to identify charged particles above 3 GeV/c.

Relevant Questions:

Among the problems requiring further study, the following appear to be particularly important:

(1) design a special beam pipe and high-voltage shield to prevent spark breakdown,
(2) design correction coils,
(3) design a suitable trigger,
(4) consider methods for installing all or part of the system during limited periods of access,
(5) study the problem of changing film or find a filmless alternative.

REFERENCES

(1) For a recent discussion of streamer chamber performance, see F. Villa and H. Meyer (presented at the International Conference on Instrumentation for High Energy Physics, Frascati, Italy, May 8-12, 1973).

(2) D. Notz, Thesis, Hamburg, DESY F-73/13, December 1973.

(3) CERN/SPSC/I 73-42

(4) A magnet with 100 cm radius and maximum field strength of 15 kG already exists at SLAC, namely, the 2-meter streamer chamber magnet.

(5) K. Eggert (presented at the International Conference on Instrumentation for High Energy Physics, Frascati, Italy, May 8-12, 1973).

(6) C. M. Fisher "Optimization of Bubble Chamber Design Parameters: Measuring Accuracy for Charged Particles," CERN 67-26 Vol. I, page 25 (1967).

(7) V. Eckardt, Nuovo Cimento Letters, 12 June, 1971.

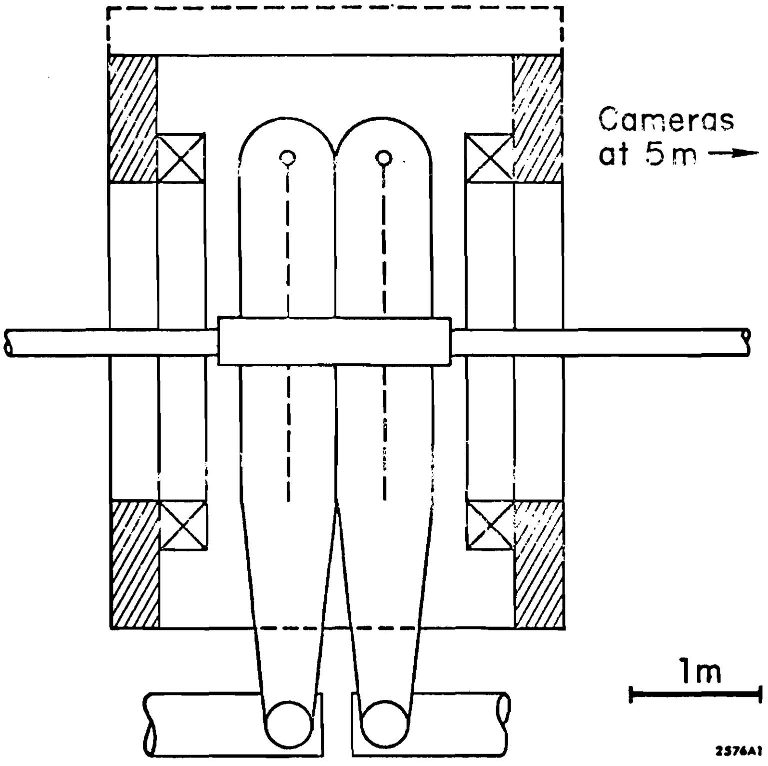

FIG. 1

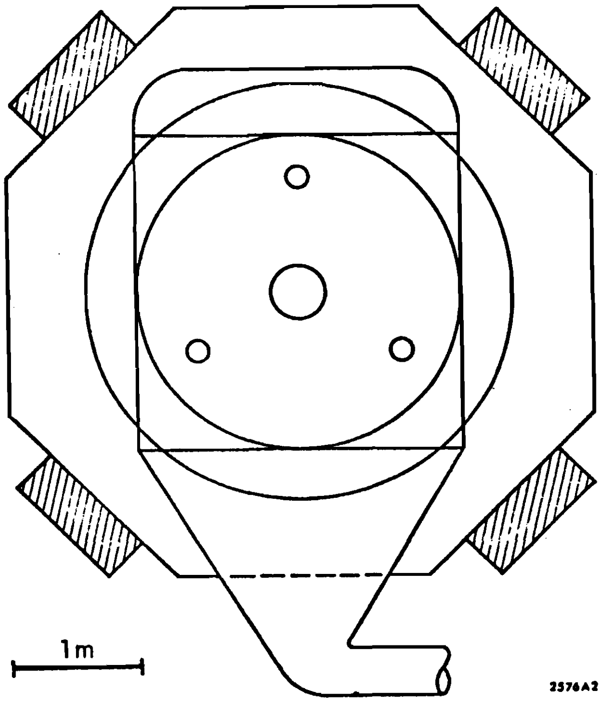

FIG. 2

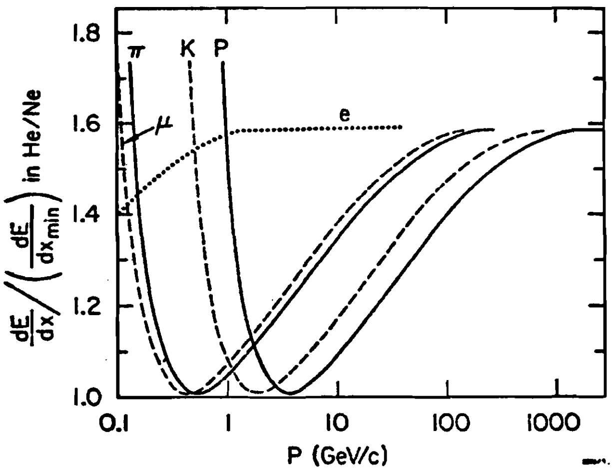

FIG. 3

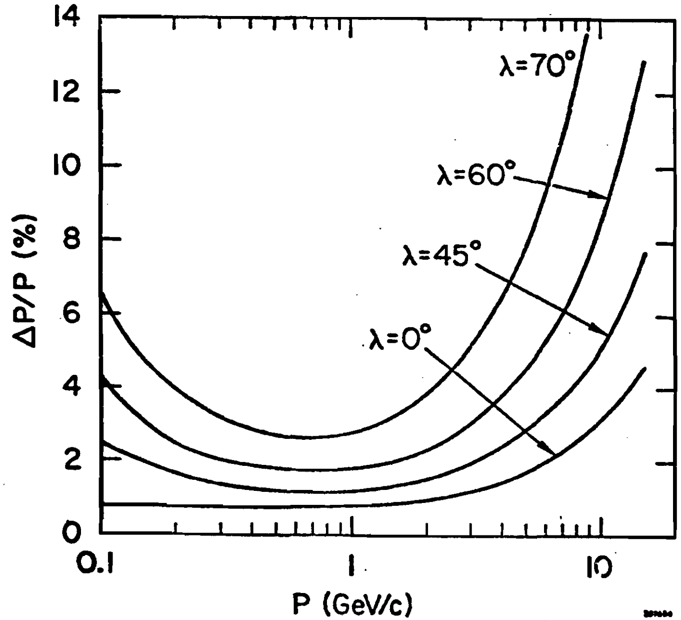

FIG. 4

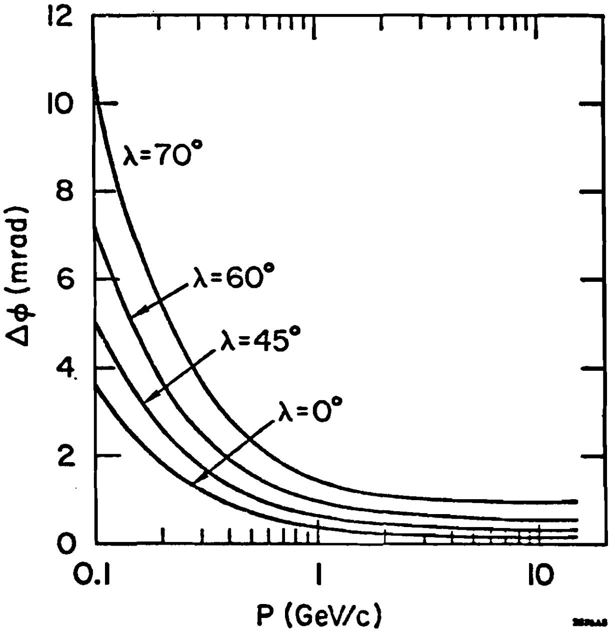

FIG. 5