High accuracy vertex detectors for the measurement of short living states, by K. Lanius

After the discovery of the charmed particles and the τ-lepton, there was a strong motivation to improve the spatial resolution of vertex detectors, to the point where the tracks of all particles could be observed and the decay vertex spatially separated from the production vertex for each event.

The problem of vertex identification and the correct association of final state particles to the decay vertices is dominated by transverse separation tracks rather than the longitudinal separation of the vertices. To a first approximation the problem becomes independent of the particle momentum since the transverse separation is:

$$\langle \Delta y \rangle \simeq \theta \cdot \ell_{decay} = \frac{p_\perp}{p} \cdot \ell_{decay} = \frac{p_\perp}{mc} (c \cdot \tau) \simeq c \cdot \tau$$

1) Nuclear emulsion

The only well established technique providing spatial resolution in the micron range is nuclear emulsion.

Emulsion, with a position resolution of better than one micron, permits direct observation of particle decays with lifetimes as short as $2 \cdot 10^{-15}$ seconds. In order to localize the events in some extent the emulsions are tagged with electronic spectrometers.

One event which could be interpreted as a charmed particle production in neutrino-nucleus interaction has been observed in an experiment utilizing nuclear emulsions and an electronic tagging system [1].

The advantage of emulsion is clearly resolution but the limitations are considerable:

a) No time resolution. Events cannot be selected using the precise timing information.

b) High event density. All events are recorded in the emulsion because of (a). Therefore in one experiment only a small number of events can be analysed (about 100 - 1000 events).

c) Very time consuming scanning and measuring work.

2) High resolution bubble chambers

As was shown by Fisher et al. [2] a spectrometer containing as its vertex detector a small rapid cycling hydrogen bubble chamber could be used for studying short living particles.

Bubbles begin small (diameter $d < 1\,\mu m$) grow at least until recompression sets in, with $d \sim \sqrt{t}$, where t is the time. Thus by triggering the flash after 10 - 50 μsec bubbles of size $\sim 10\,\mu m$ are produced. The depth of field for an optical system with resolving power of $10\,\mu m$ is $\lesssim 1$ mm. Such a system can in principle be constructed without too much difficulty, provided that the area of the beam plane over which it is required that interactions be seen is about 10 cm.

In order to allow high resolution with reasonable depth of field a possible way could be the use of holography.

In order to achieve a reasonable number of triggered events the cycling rate has to be sufficient. Bubble chambers which cycle at frequencies up to ~ 50 Hz are currently used or under construction. In the case of a small bubble chamber the extension of the technique by using ultrasonic expansion systems could allow cycling rates in the kilohertz region. The limitation of the cycling rate would be probably the thermal diffusion for recompressed bubbles in liquid hydrogen.

A small heavy liquid bubble chamber was recently tested by Hahn et al. [3]. The chamber operated at a bubble density of 300 bubbles/cm and an apparent bubble size of 30 μm in real space.

3) High resolution streamer chamber

Typical spatial resolution for atmospheric pressure streamer chambers is ~300 μm. The principle used by Sandweiss et al. [4] in designing the high resolution chamber is a scaling rule for avalanche formation in gases. If the gas pressure and the electric field are scaled by a factor s the streamer diameter is reduced by about the same factor s.

At Yale a small high pressure streamer chamber (Ne/He 90/10) at 20 atmospheres was constructed. The streamer diameter is ~50 µm and the width of a track is 150 µm because of diffusion of the seed electron during the time delay between the passage of a particle and the application of the high voltage pulse.

The depth of field for an optical system with resolving power of 50 µm is ~2 mm. In order to reduce flares the chamber was operated at slow avalanche and streamer growth rates. Therefore image intensifier have been used.

Work is in progress in order to get track width ~50 µm by depth of field ~ 2,5 mm with higher pressure (~100 at) and laser firing.

A possible way for future development is the use of laser induced liquid streamer chambers with track width as small as 2 µm. The depth of field for an optical system for a real image of ~2 µm is ~100 µm. Larger depth of focus may be obtained with holographic methods.

4) Liquid argon ionization chamber

An alternative approach which leads to high spatial resolution and which possess all the advantages of electronic detectors is the use of liquid filled chamber. The advantage of the liquid arises from the ~ 800-fold increase in density over that of gas, permitting the use of much smaller thickness, larger ionization statistics, and reduced effect of electron diffusion.

A measurement of the spatial resolution of a small gap liquid argon filled chamber was performed with minimum ionizing particles by Derenzo et al. [5]. Two multistrip chambers with 20 μm strip spacing operating in the ionization mode were used. The anode metallic pattern was done using standard integrated circuit techniques. Under the best conditions, the spatial resolution for a single strip was measured to be better than 20 μm rms with an efficiency of nearly 100 %.

At present a system of small-gap (2 mm) and wide-gap (up to 35 mm) liquid argon chambers is tested by a Berlin-CERN Collaboration [6].

5) Solid state micro-detector

Solid state detectors have been used mainly in high resolution nuclear experiments. Kanofsky [7] proposed a solid state detector in which the strips along the crystal are built using the standard integrated circuit techniques. The electrodes would be doped in columns along the crystal length so as to make conducting and nonconducting regions. These columns could be $\leq$ 100 μm in width, and electrodes would be attached at the crystal surface.

A system of very thin micro-detector planes is proposed for the detection of short living particles.

6) Liquid xenon drift chamber

A liquid xenon drift chamber with an electron drift space of 13 mm was constructed and tested by Doke and Kubota [8]. A spatial resolution of about 20 μm was achieved using an alpha particle source.

In liquid xenon the electron drift velocity is almost constant if the electric field is $>$ 3 kV/cm. For measuring the electron drift time, the scintillation pulse directly produced by an alpha particle was used as a trigger signal and the proportional scintillation pulse was used as an arrival signal of the drifting electrons.

For minimum ionizing particles it is expected that the spatial resolution is in the order of several microns except multiple scattering effects. Therefore the authors are testing now a multi-wire liquid xenon drift chamber.

References

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