LIMITS AND POSSIBILITIES FOR VERTEX DETECTORS

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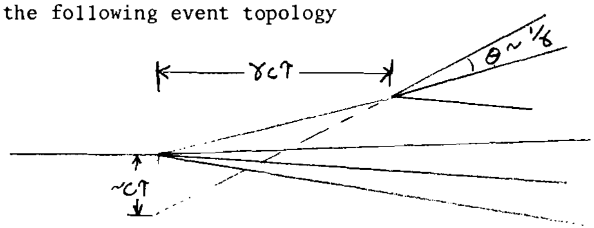
The purpose of this paper is to examine needs and limitations of vertex detectors used for lifetime tagging, measurement, and triggering in fixed target machines. As a context for our analysis we consider the following event topology



this results in an impact parameter for downstream decays of $c\tau$, independent of γ. The analysis breaks down where effects of vertex uncertainty and measurement angles become important. We also assume that the downstream spectrometer allows some level of event selection (Kaon ID, lepton ID), such that $\sim 3\sigma$ separation from 0 impact parameter is sufficient to identify the event.

The following impact parameter analysis we imagine measuring m points, each with equal errors (this is not strictly true due to multiple scattering). We then extrapolate to the vertex plane to find the impact parameter, b, the error in this extrapolation is:

$$\overline{\Delta b}^2 = \frac{\sigma^2}{n} + \frac{\sigma^2}{\sigma^2 + n\overline{x}} (x - \overline{x})^2$$

n = number of measurements
x = extrapolated point
$\overline{x}$ = average of measured points

A detector with finite resolution then needs a minimum number of measured points to resolve the required lifetime. For most detectors the basic limit on the number of measured points is multiple scattering in the detector elements. If we limit the useful length of our detector to the length at which the measurement resolution is equal to the multiple scattering errors we can estimate the hit density required in various detectors. These limits are shown in table 1 for measurement errors of 10 μm for various detector types

Table 1

Material	σ = 10 μm
Silicon	80 hits/cm
Germanium	166 hits/cm
Propane	37 hits/cm
Hydrogen	18 hits/cm
Emulsion	125 hits/cm

and for particle momentum of 10 GeV. Bubble chambers and emulsions can easily achieve the hit densities required. Solid state detectors are marginal for resolutions of $\leq$ 10 μm.

Semiconductor detectors are an important "new" technology for high energy physics. In this context it is important to examine their possibilities and limitations in some detail. Silicon intrinsically has the highest information content of any electronic detector. There are 80 electron hole pairs produced per micron by a minimum ionizing particle. In any one dimensional projective detector such as the silicon strip detectors developed at CERN the detector needs $\sim$300 μm of depletion ($\sim$30,000 electrons) to overcome the amplifier noise. This noise is proportional to the detector capacitance. A detector based on the charged coupled device needs slightly less depletion because of smaller element capacitance. This necessity for $\sim$300 μm per depletion projected point leads to a maximum hit density of $\sim$30/cm and limits the ultimate lifetime resolution for silicon strip detectors.

There are, however, devices which propose to use the intrinsic information density in a bulk semiconductor to increase the hit density by orders of magnitude. Examples of these devices are the indium coupled CCD by Alan Bross at LBL and the negative electron affinity device proposed by Pavel Rehak at Brookhaven.[2] Such a device would provide a two dimensional projection of an event on a surface of the semiconductor. The limits on resolution of these devices are set by electron of diffusion in the silicon.

$$\sigma_{\text{diffusion}} = \sqrt{2Dt},\ D = \mu\frac{kt}{q}$$

where D = diffusion constant
μ = electron (or hole) mobility
T = temperature
t = time
q = electron charge

if a axial magnetic field is employed the diffusion is reduced by a factor

$$\frac{1}{\sqrt{1+(\mu B)^2}}$$

where B = applied magnetic field so:

$$\sigma = \frac{1}{\sqrt{1+(\mu b)^2}} \frac{\sqrt{2kTd}}{qE}$$

where E = applied electric field
d = drift distance.

Table 2 contains the diffusion for a drift distance of 5mm under various conditions.

Table II

Temperature	Electric field	Magnetic field	σ(diffusion)
300°K	10 KV/m	0	160 μm
300°K	100 KV/m	0	50 μm
300°K	100 KV/m	10T	4 μm
70°K	10 KV/m	0	78 μm
70°K	100 KV/m	0	24 μm
70°K	100 KV/m	10T	1 μm

-Electron diffusion in silicon for a 5 mm drift under various conditions.

It is possible, under certain conditions to attain 1 μm resolution with these devices. There are also effects due to space charge repulsion in the ionization column, which may become significant for high resolutions and long drifts. It is more probable, however that high hit density 5-10 μm resolution devices can be built.