Vertex detection at LEP

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1. Introduction

Vertex detection at LEP will be important for understanding event topologies. Vertex and impact parameter measurements will be used for the determination of particle lifetimes and the identification of heavy flavors. All four LEP experiments studied the example of the b-lifetime in response to questions put by the LEPC in 1982, and the result [1] was that lifetimes of order $5 \cdot 10^{-14}$s will be measurable. Parts of the decay chain $t \to b \to c \to s$ can be tagged by reconstructing displaced verticies because of the "long" lifetimes of the b ($c\tau \simeq 360$ μm), c ($c\tau \simeq 120$ to 280 μm), and s ($c\tau \simeq 2.7$ cm for K_S^0) quarks and of the τ lepton ($c\tau \simeq 100$ μm). The LEP experiments should be able to detect these with good efficiency (~1% to 10%), as the discussion below will show.

Events with 5 or 6 verticies will occur often: running on the Z^0 will yield 3% $Z^0 \to t\bar{t}$ (m_t=40 GeV), 15% $Z^0 \to b\bar{b}$, and 12% $Z^0 \to c\bar{c}$ at a Z^0 event rate of ~0.3 Hz. The huge statistics will allow selective cutting so that a few percent detection efficiency is adequate for many studies.

We cite a few examples of physics for vertex detectors. The lifetimes of new particles must be measured. Also some lifetimes of "standard" particles may need measuring when LEP starts; e.g., ~10% differences in lifetimes of B mesons can occur. Large mixing is expected in the B_S^0-$\bar{B}_S^0$ system, and the main signature for this is like-sign high-p_t dilepton events. That the mixing is in the B_S^0 sector might be established by identifying $F^{\pm}$ mesons from the semileptonic decay of the B_S^0 or $\bar{B}_S^0$. Vertex detectors can help tag the $F^{\pm}$ mesons and measure the lifetimes of the B_S^0 so found. Identifying heavy flavors or heavy leptons is necessary for measuring the Z^0 coupling to these fermions (cross-section, forward-backward asymmetry), for the hunting of the Higgs ($H^0 \rightarrow$heaviest fermions), for studying single-quark decays in toponium, and so on.

2. Vertex Detection Efficiency

It is impossible to give general numbers for vertex-finding efficiency because of detector differences. However, to understand the ingredients, a simple model for measuring the impact parameter as seen in fig. 1 is useful. The error is

$$\delta^2 \simeq \left[\frac{\sigma_c}{L_c}\cdot L_v\right]^2 + \left[\frac{\sigma_v}{L_c}\cdot (L_v + L_c)\right]^2 + \left[\frac{.015\ \mathrm{GeV/c}}{p\beta}\cdot\sqrt{x_r}\cdot L_v\right]^2$$

Typical values might be $\sigma_v = 0.010$ mm, $L_v = 90$ mm
$\sigma_c = 0.100$ mm, $L_c = 500$ mm
$x_r = 0.02$ radiation lengths

so that

$$\delta \simeq \sqrt{(0.022)^2 + \left(\frac{0.190}{p}\right)^2}\ \text{(mm) (p in GeV/c).}$$

The impact parameter is then measured to an accuracy of 190, 44, 29, and 22 μm at p = 1, 5, 10 and 100 GeV/c respectively.

As shown in fig. 2, the impact parameter is directly proportional to the particle lifetime and equal to $c\tau$ on average (to the 0^{th} approximation). Thus, the measuring accuracy is smaller than particle lifetimes (see above) for p > several GeV/c, so it is in the right ball park for these $c\tau$ measurements. Going through the exercise of using the impact parameter measurement of high-p_t leptons from b-decays to determine the b-lifetime, one finds that a year of running (10^7 s) gives the b-lifetime to better than 1% statistically, which is small compared to systematic effects one can expect.

The accuracy of and resulting efficiency for reconstructing a vertex with several tracks emanating from it depends strongly on the decay mode and on the detectors, but to get a feeling for these numbers, we can go to some examples. The vertex reconstruction accuracy has recently been estimated for Aleph [3], for which the vertex detector will measure to ~10 μm in $r\varphi$ just outside the beam pipe. The longitudinal vertex resolution σ for two examples $D \rightarrow K\pi\pi$ and $B \rightarrow (D\pi\rightarrow)K\pi\pi$ (1 vertex) is seen as a function of D or B momentum in fig. 3. In fig. 4 we show the detection efficiency as a function of the vertex measuring error, given in the form of the number of the above standard deviations σ needed to clearly identify it. The detection efficiency is presented this way because the measuring accuracy in real life may be n times larger than the design value σ in fig. 3 due to systematic effects, due to the presence of other verticies nearby, or because the decay topology is more complicated than the simple cases $D \rightarrow K\pi\pi$ or $B \rightarrow K\pi\pi$. The cases chosen are (underlined):

$$Z^0 \rightarrow t\bar{t} \rightarrow \text{Tmeson} + X$$
$$\hookrightarrow \underline{\text{Bmeson}}$$
$$Z^0 \rightarrow b\bar{b} \rightarrow \underline{\text{Bmeson}} + X$$
$$Z^0 \rightarrow b\bar{b} \rightarrow B_s^0\text{meson} + X$$
$$\hookrightarrow \underline{\text{Fmeson}}$$
$$Z^0 \rightarrow c\bar{c} \rightarrow \underline{\text{Dmeson}} + X$$

The Lund Monte Carlo was used to calculate the momentum distribution of produced heavy mesons in each case and this was folded with the corresponding curve in fig. 3 to determine the average percentage of mesons living longer than $n\sigma$. The lifetime used for each meson is indicated in fig. 4. Also given is average momentum from the Lund generator, whereby mesons with momentum < 10 GeV/c have been cut out to reduce multiple-scattering effects. One sees that a reasonable fraction of vertices that occur is reconstructable over a large range of n. The worst case here is $F^{\pm}$ coming from B_s^0 decay due to the low momentum and short lifetime of the F's; still of order 1% of those with 3-charged-body decay mode should be findable (the curve for $D \rightarrow K\pi\pi$ in fig. 3 was used for the F).

References

[1] G. Wolf, CERN/LEPC/82-41; Aleph, CERN/LEPC/82-24; Delphi, CERN/LEPC 82-58; L3,CERN/LEPC 82-26; Opal, CERN/LEPC 82-17 and CERN/LEPC 82-28.

[2] A. Ali and C. Jarlskog, Phys. Lett. 144B, 266 (1984).

[3] L. Bosisio, L. Foa, E. Focardi, M. Giorgi, G. Tonelli, G. Triggiani, H. Dietl, R. Hoffmann, G. Lutz, E. Milotti, R. Settles; Aleph Note 84/130.

Figure Captions

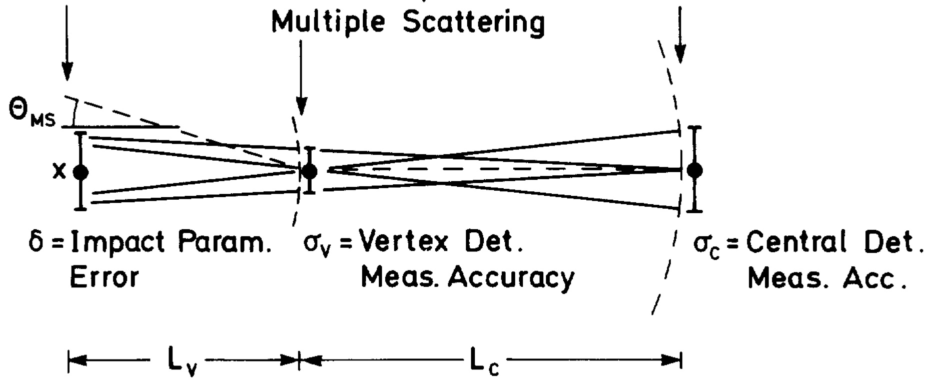
Figure 1. A simple model to calculate the accuracy of measuring the impact parameter.

Figure 2. Kinematics of the impact parameter of a particle from a decay.

Figure 3. Vertex reconstruction accuracy for Aleph for two examples of D and B decays.

Figure 4. Vertex detection efficiency for several examples, using fig. 3 and the Lund Monte Carlo.

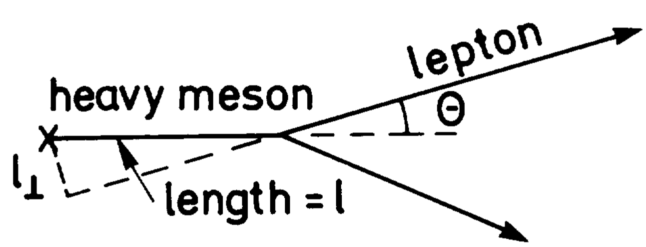
Simple Model for Impact Parameter Measurement



- Vertex detector measuring accuracy lumped together at distance L_V from interaction point.
- Central detector measuring accuracy lumped together at distance L_C from vertex detector.
- Multiple scattering lumped together at beam pipe and vertex detector.

Fig. 1

Impact Parameter $l_\perp$



$$l_\perp = l\Theta \qquad l = \frac{p}{m} c\tau \qquad \Theta \simeq \frac{m/2}{p/2} = \frac{m}{p}$$

$$\boxed{l_\perp \simeq c\tau}$$

Fig. 2

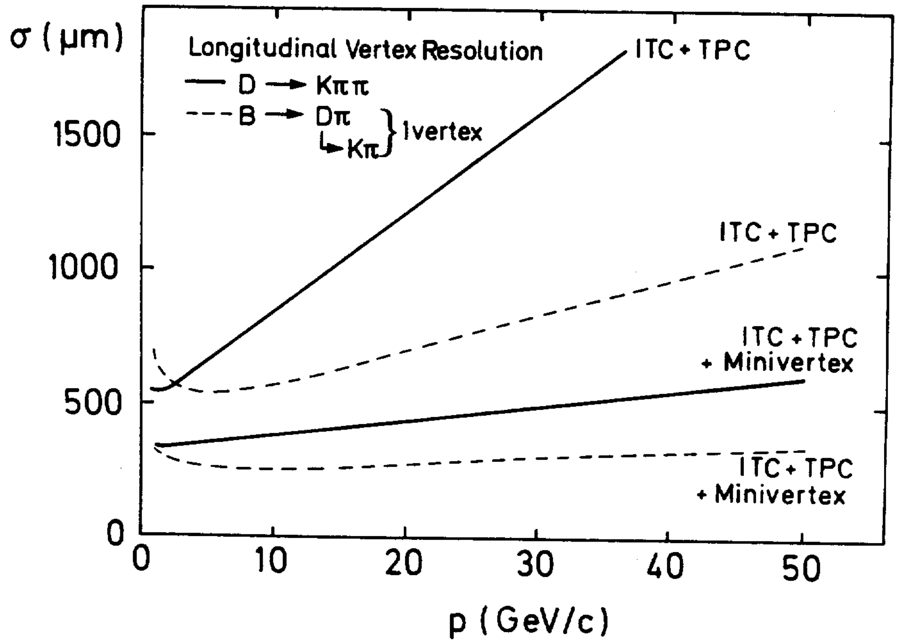
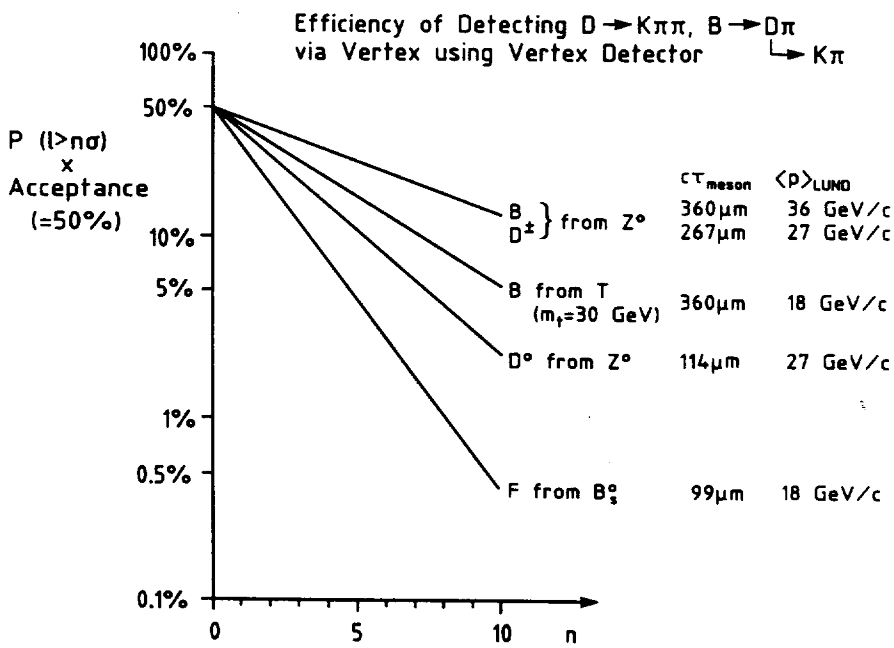


Fig. 3



$$P\ (l>n\sigma) = e^{-n\sigma / \frac{p}{m} c\tau_{meson}}$$

$$l = \frac{\langle P_{meson} \rangle}{m_{meson}} c\tau_{meson}$$

σ from Aleph - Note 84/130 for D → Kππ
or B → Dπ └→ Kπ } 1 vertex

Fig. 4