5 ALEPH

When you have completed the 'Lifetime' exercise, click the Next button in the text window to move onto the next section. Or select 'Aleph' from the Options menu. Either way the text window for 'Aleph' will appear.

Aim: to present 'real data' from an ongoing particle physics experiment. At this stage you should be more familiar with the terminology, formulas and visual presentation that physicists use in order to characterise new particles.

ALEPH: the Apparatus for Lep Physics is one of four detector arrays at the Large Electron-Positron machine (LEP) at CERN. CERN is the European Laboratory for Particle Physics, on the outskirts of Geneva. The LEP tunnel is 27 Km in circumference and lies underground, straddling the French/Swiss border. Within the tunnel is a ring of magnets which guide bunches of electrons and positrons, in opposite directions, on a circular path around a narrow pipe (see Section 2). The particles are accelerated up to the desired energy and then their paths are allowed to cross at four points in the ring, where the detectors are located. Some of those electrons and positrons, in the bunches, approach close enough to annihilate. Each detector measures different characteristics of the debris from the annihilation, in ways very similar to those encountered in these exercises. To do this requires apparatus which surrounds the annihilation point. The detectors are wrapped in layers around the beam pipe, where the annihilations occur, and so appear like huge cylinders as shown in Figure 5.1.

The first layer of the detector, closest to the incident beams, reveals the tracks of charged particles. A large electromagnet provides a magnetic field to bend these tracks, so that a particle's momentum can be calculated from its radius of curvature in a similar way to the exercise in section 3. Outside the tracking detectors is a layer of dense material, such as lead, which traps all the electrons, positrons and photons. This layer is interleaved with detectors which measure the energy that the particles lose as they plough into the lead and come to a halt. The aim is to create an *electromagnetic calorimeter* that measures all the energy of the electrons, positrons and photons. This helps in identifying certain neutral particles, which leave no tracks in the inner detectors, but reveal their presence by converting into photons.

It is from the information provided by the detector that physicists can reconstruct what happened immediately after an annihilation or *'event'*, and from this build up a picture of the underlying physical processes.

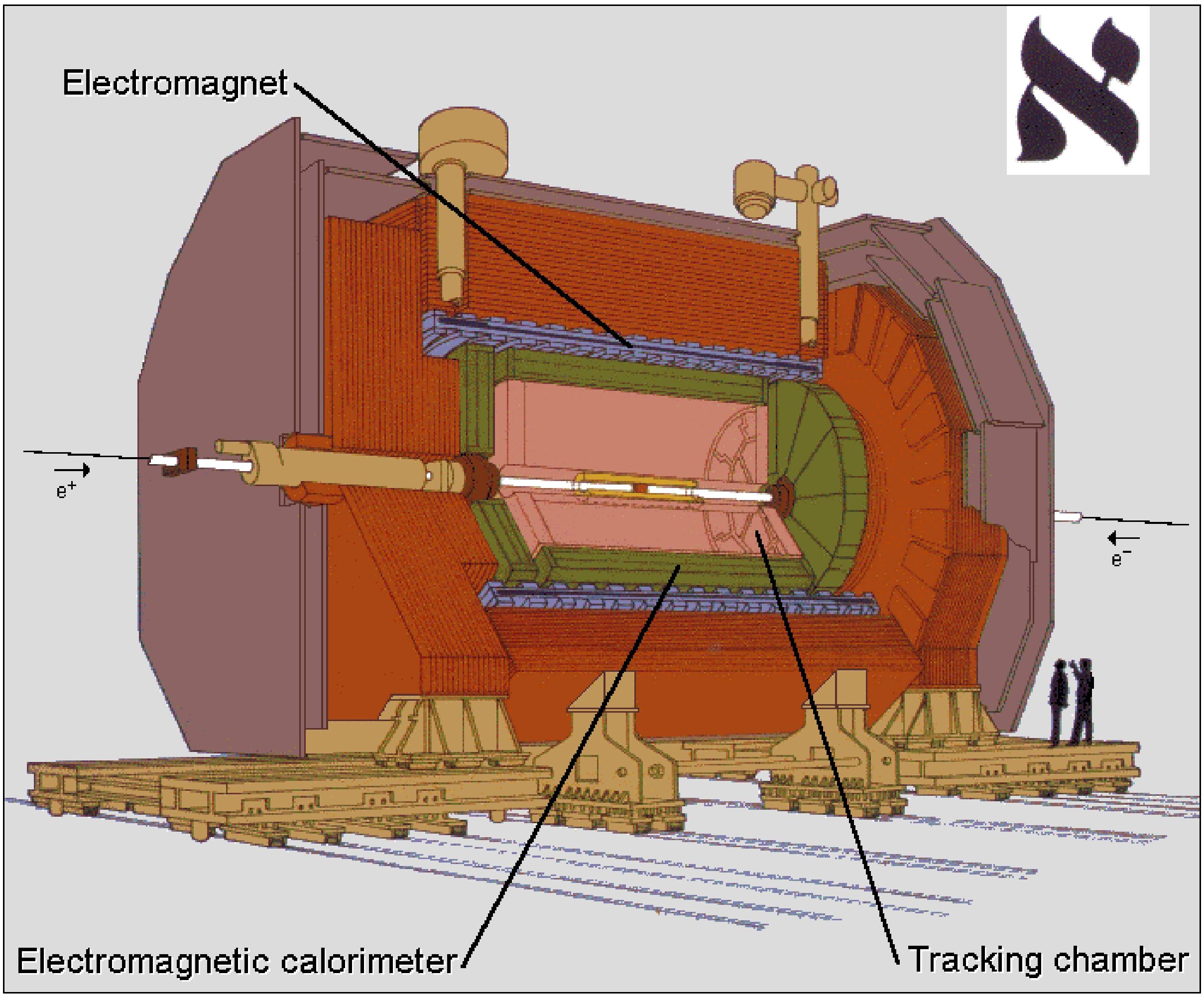

Figure 5.1 'The ALEPH Detector'

Click the Graphics button in the text window to display the graphics window as shown in Figure 5.2. This shows the familiar cross-sectional view of the ALEPH detector; compare with Figure 5.1. As before the graphics are simplified by displaying them in two dimensions, compared to the actual annihilations which will inevitably occur in three dimensions. The electron and positron beams travel along the axis of the accelerator, or into and out-of the screen; they meet and annihilate in the centre of this view at the origin of the x, y axes. In the real detector this view is several meters across; see scale on the bottom of the graphics viewport. Included in this view, in addition to the previous graphics, is the calorimeter as shown by the two large outer circles.

Click the Fire button in the graphics window this will simulate a *real* electron-positron annihilation event that took place at LEP; shown by the actual 'Run' and 'Event' numbers, in the top right hand corner of the graphics viewport (see Figure 5.2). Notice that there are many particle tracks, this is typical of most events and makes particle identification difficult.

Therefore, in order to clarify the picture, the main charged particle groups have been colour coded as follows:

Blue =	pions (individual p^+ or p^- particles)
Green =	electrons (e^+, e^-)
Purple =	kaons (K^+, K^-)
Red =	protons ($p, \bar{p}$ Proton, Antiproton)
Black =	pion <u>pairs</u> (p^+, p^-) from K^0 decays (see 'Lifetime' exercise)
Dark Yellow =	muons (m^+, m^-)

Across the bottom of the graphics window are three Option buttons. Each option groups together 'types' of events which have similar characteristics. Several events are contained in each option; these can be viewed, sequentially, by repeatedly clicking the <u>F</u>ire button. Each option button has a brief title which describes the events; on opening the graphics window the default setting is the '2 Jet Events'. Different Options are selected by clicking on the round buttons, adjacent to the titles, with your mouse pointer. When selected a dot appears inside the option button. The various options are described in more detail in section 5.1.

All these events have Incident beam energies of 45 GeV, in a uniform magnetic field of 1.5 T. These are <u>high</u> <u>energy</u> <u>annihilations</u> therefore <u>all</u> the events in each option have a similar chance of occurring. For lower beam energies there would be a hierarchy of events. Those requiring more energy, in order to create more particles or ones with greater mass, being less probable and some events not being allowed at all.

The calorimeter in addition to measuring the energy of photons, electrons and positrons also indicates their direction of motion. This is useful for photons which have zero electrical charge and so leave <u>no</u> tracks and travel in straight lines. Only the calorimeter information indicates their presence and direction of motion. A particle 'hit' in the calorimeter is indicated by Yellow/Red circles: Light Yellow circles represent the lowest energy photons/electrons/positrons (about 0.5 GeV), increasing to Red for the highest energy photons/electrons/positrons (several GeV).

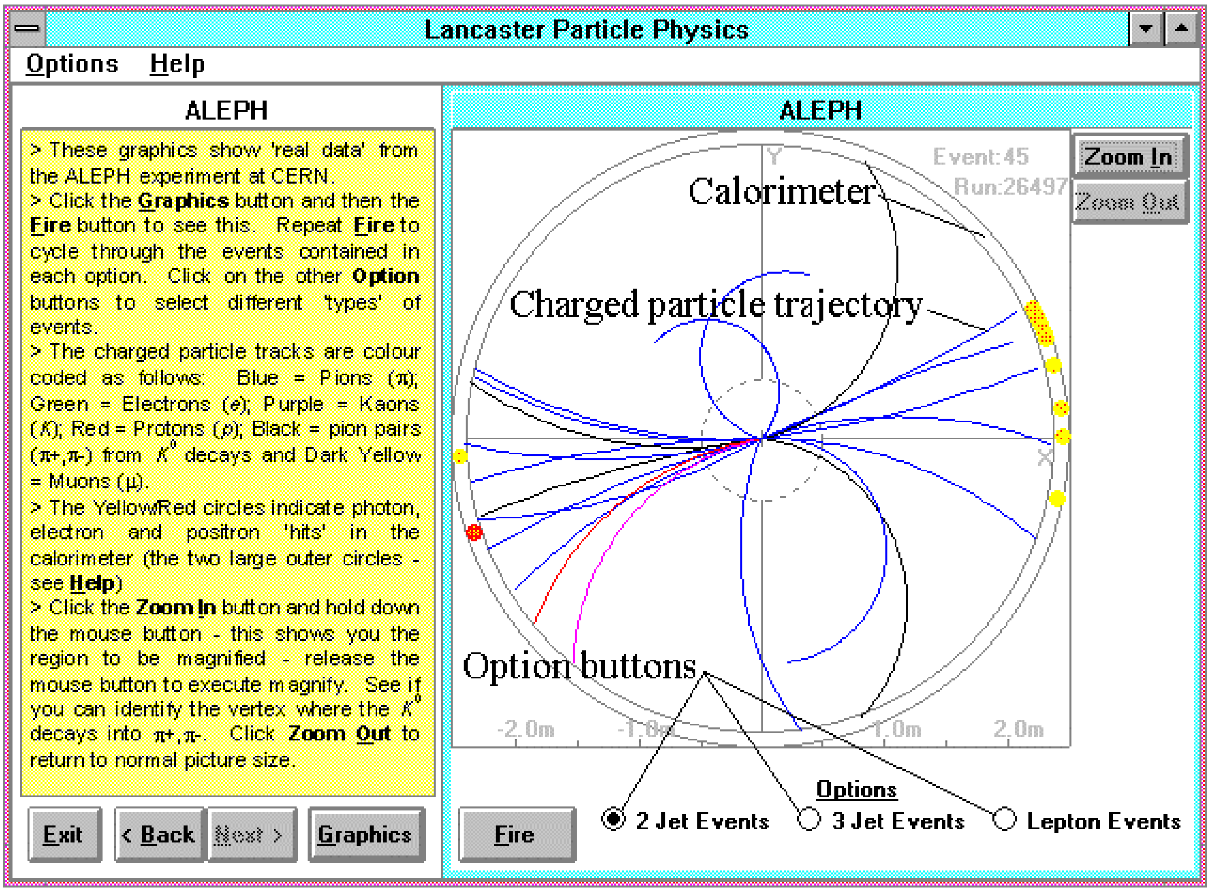

Figure 5.2 'A typical 2 Jet Event'

The Zoom In button gives a ×5 magnification of the centre of the annihilation picture. This is useful for observing the fine structure of events and in particular for identifying the vertex of a K^0 decay, into a p^+, p^- pair (see section 5.1). These usually occur close to the annihilation site near the origin of the x, y axes, making them difficult to distinguish on normal view. To magnify the view click the Zoom In button with your mouse pointer - Note: if you press and hold down the left-hand mouse button, when selecting Zoom In, the region to be magnified is highlighted in red (see Figure 5.3). Upon releasing the mouse button the magnification is executed. Once in the magnified view the scale changes appropriately and the Fire and options buttons can be selected to look at any event in ×5 magnification (see Figure 5.6). To exit the magnified view and return to the normal view, click on the Zoom Out button with your mouse pointer.

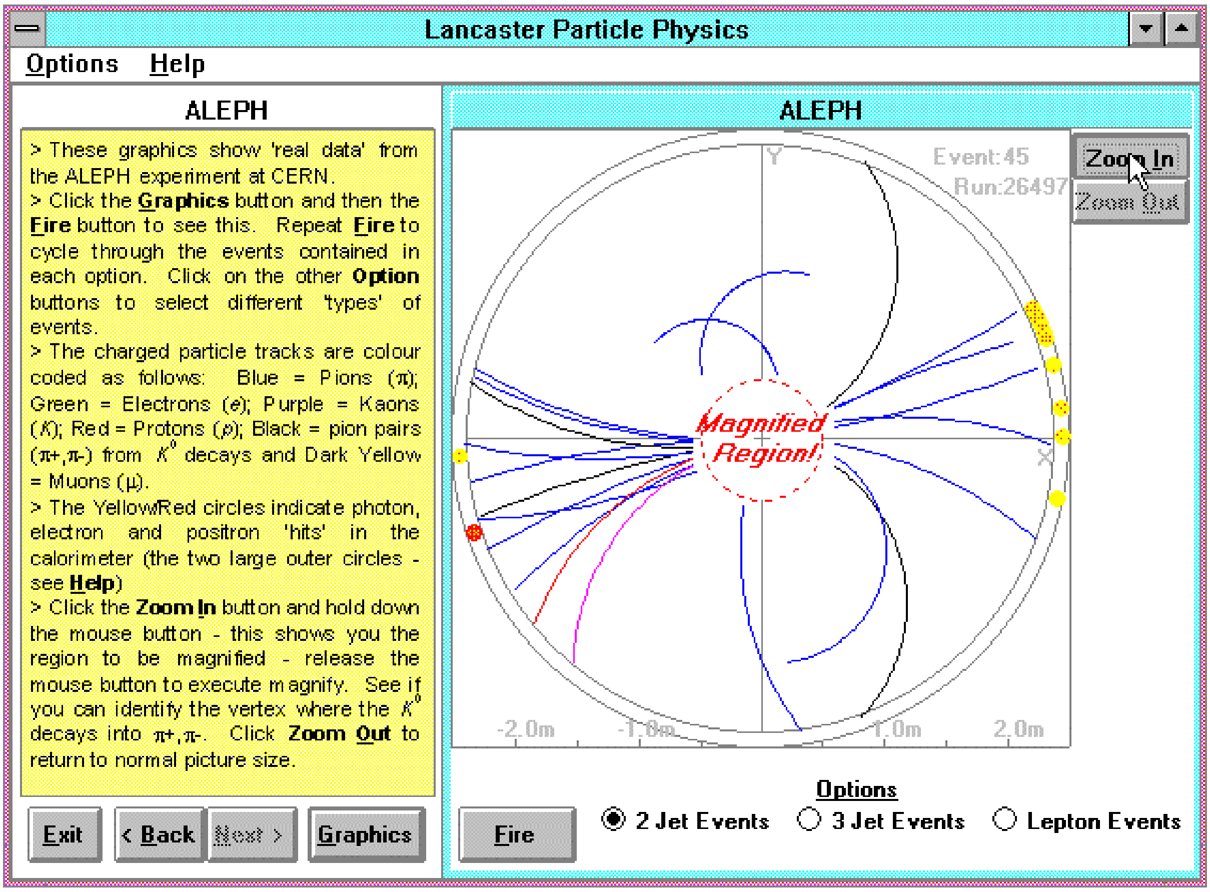

Figure 5.3 ‘Press and hold Zoom In to highlight magnified region’

5.1 Options

2 Jet Events: All the events contained in the options are collectively called Z^0 *decays*. This is because the annihilating e^+, e^- produces a heavy Z^0 particle which can immediately decay in a variety of ways. For the 2 Jet Events the Z^0 decays into a quark-antiquark pair.The quark and antiquark move off in opposite directions to conserve momentum. However neither can exist in isolation and some of their energy is converted into a cascade of particles, mainly pions (quark-antiquark pairs), which form two jets. The jets are produced ‘back-to-back’, in the same direction as that taken by the initial quarks.

The event can be represented with a Feynman Diagram as shown in Figure 5.4. The diagrams do not show details of the particles trajectories; the lengths of lines or the angles at which they meet are not important, only which particles they are connected to is significant. A time arrow has been included, in the diagram, to show that the reaction proceeds left to right. Next to this diagram has been drawn a simplified laboratory view; showing the general form of the annihilation debris for this type of reaction.

These events are often described as ‘fragmentation of quarks into hadronic jets’. Can you see the two jets in the real data? As expected from the conservation of momentum, most of the photons also lie in the same general direction as the common line of flight taken by the Jets.

Feynman Diagram *Lab View*

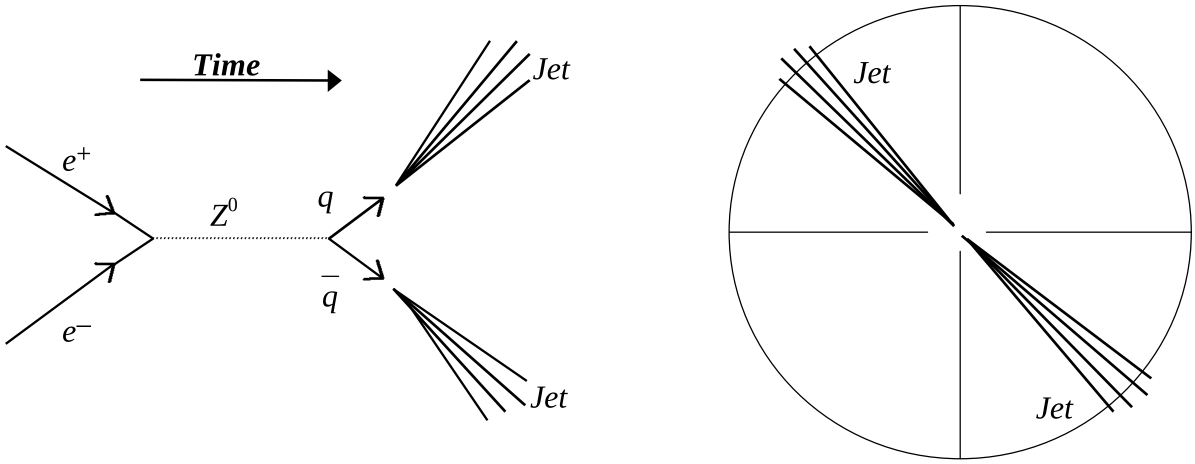

Figure 5.4

3 Jet Events: Z^0 decay. Following the Z^0 decay into a quark-antiquark pair one quark <u>may</u> radiate an energetic gluon. The gluon mediates the strong interactions between quarks, *i.e.* ‘*glues’* them together; it has zero rest mass and zero electrical charge. In this reaction it carries perhaps half of the quark energy. As with the 2 Jet events the gluon and each quark produce separate hadronic jets, resulting in <u>three</u> jets - see Figure 5.5. Can you see the three jets in the real data?

In some of the two and three jet events you may see a K^0 decaying into two pions (p^+, p^-), as in the ‘Lifetime’ exercise. Because the K^0 has no charge it leaves no track, only the *vertex* where the two charged pion tracks start from, indicates a K^0 decay. Often this decay occurs very close to the annihilation point and can only be seen by using the Zoom In button, to increase the magnification of the view (see Figure 5.6).

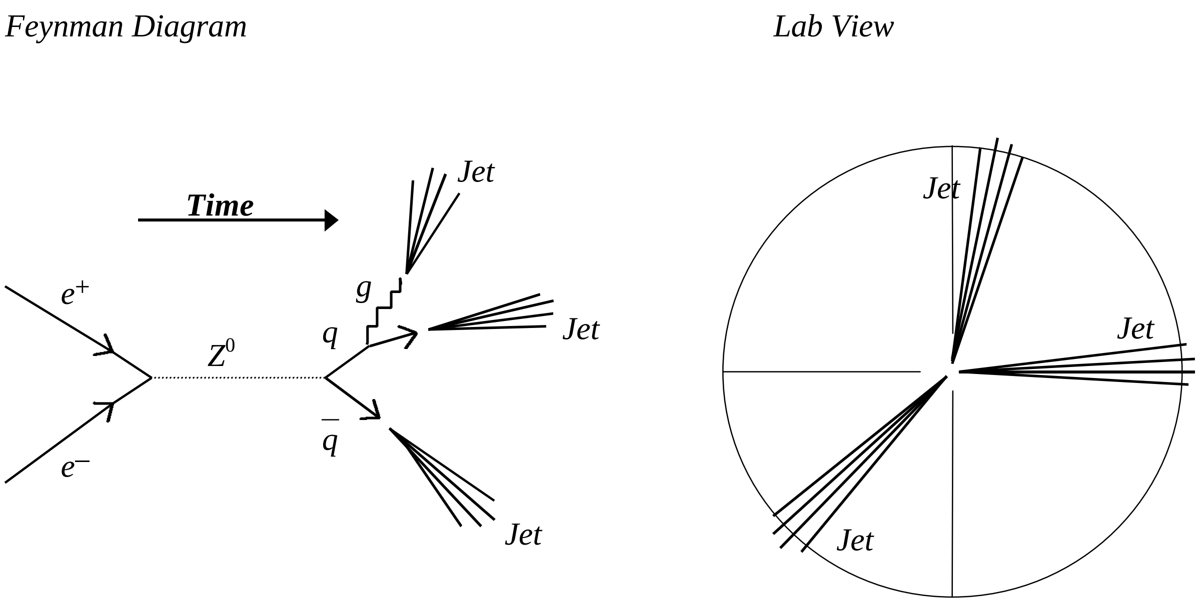

Figure 5.5

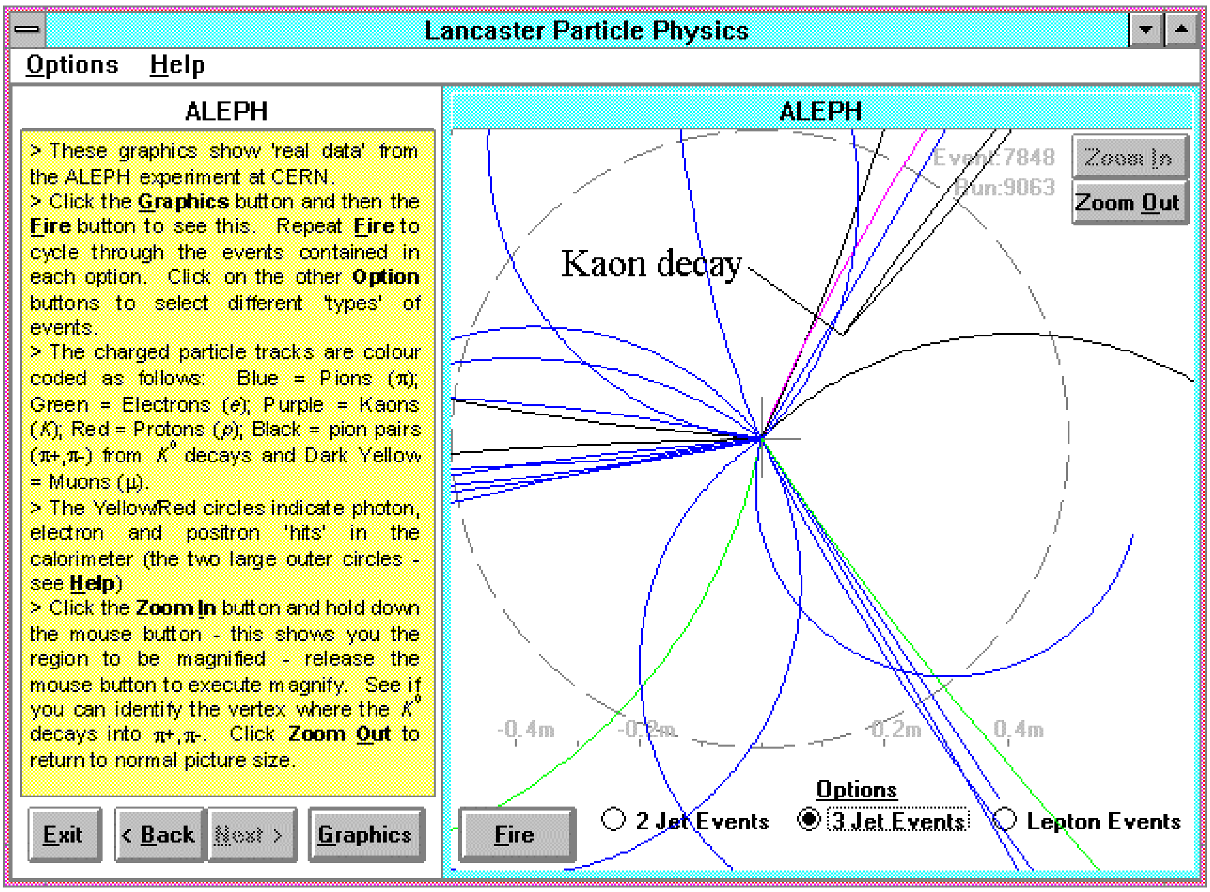

Figure 5.6 Showing the vertex of a K^0 decay, after clicking Zoom In

Lepton Events: Z^0 decay. The annihilating e^+, e^- produce a heavy Z^0 particle which can immediately decay into a Lepton pair: e^+, e^- (electron pair) or m^+, m^- (muon pair) or t^+, t^- (tau pair). Each lepton is currently believed to be a fundamental particle. At high beam energies each pair has a similar chance of being produced. (For lower beam energies the electron pair, being the lightest in mass, would be the most probable outcome, while tau pair formation would be the least likely due to their large mass). See Figure 5.7 for e^+, e^- and m^+, m^- events and compare with the real data.

Feynman Diagram *Lab View*

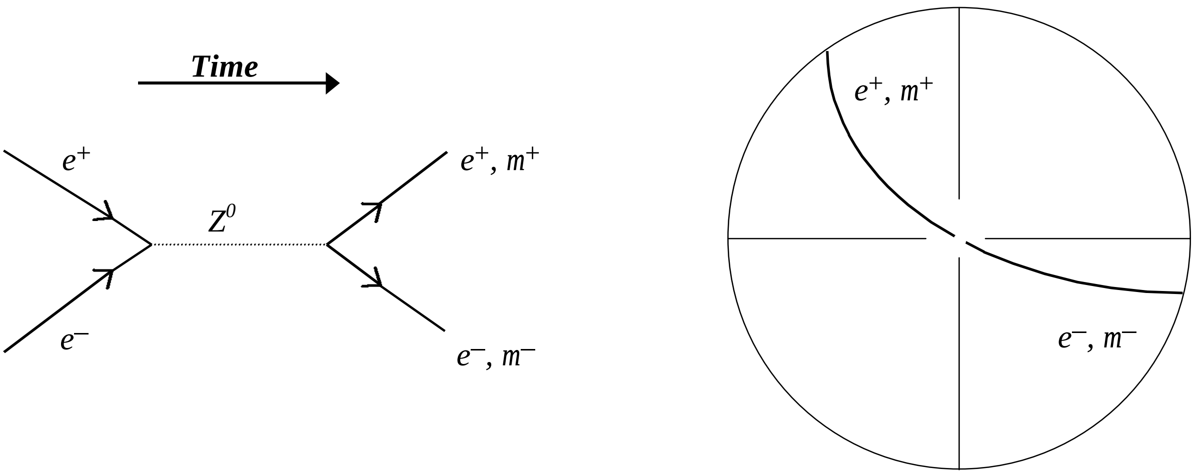

Figure 5.7 (Event 3)

The tau pair rapidly undergoes a further decay via the weak interaction into several hadrons and/or leptons, often producing a 'three plus one' formation, see Figure 5.8 and compare with the real data. The t lepton has many different decay modes. Among the most frequent are

1. $t^- \rightarrow e^- + \bar{n}_e + n_t$ (or $t^+ \rightarrow e^+ + n_e + \bar{n}_t$)
2. $t^- \rightarrow m^- + \bar{n}_m + n_t$ (or $t^+ \rightarrow m^+ + n_m + \bar{n}_t$)
3. $t^- \rightarrow p^+ + p^- + p^- + n_t$ (or $t^+ \rightarrow p^- + p^+ + p^+ + \bar{n}_t$)

The tau lifetime is so short that the decay products appear to come from the point where the e^+, e^- annihilation took place. In each case the neutrinos cannot be seen in the detector (can you recall why this is?).

Feynman Diagram *Lab View*

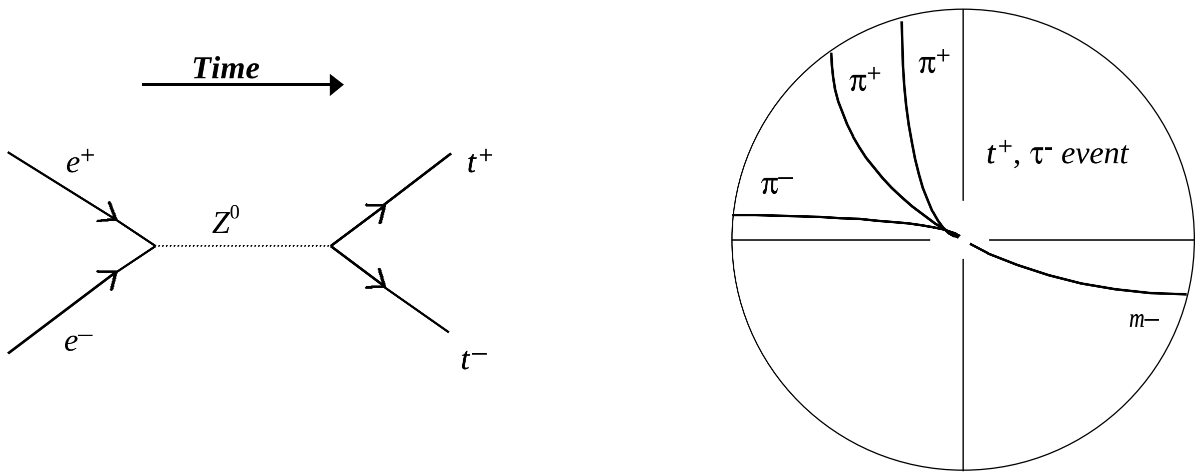

Figure 5.8 (Event 3)

We have listed, below, all the lepton events shown in the programme. The actual event numbers are shown in brackets so you can identify them.

Event 1 (1850):

$$e^+ + e^- \rightarrow t^+ + t^-$$
$$\text{then } t^+ \rightarrow m^+ + n_m + \overline{n}_t$$
$$t^- \rightarrow p^+ + p^- + p^- + n_t$$

Event 2 (1896):

$$e^+ + e^- \rightarrow t^+ + t^-$$
$$\text{then } t^+ \rightarrow m^+ + n_m + \overline{n}_t$$
$$t^- \rightarrow e^- + \overline{n}_e + n_t$$

Event 3 (2594):

$$e^+ + e^- \rightarrow t^+ + t^-$$
$$\text{then } t^+ \rightarrow p^+ + p^+ + p^- + \overline{n}_t$$
$$t^- \rightarrow m^- + \overline{n}_m + n_t$$

Event 4 (2669):

$$e^+ + e^- \rightarrow m^+ + m^-$$

Event 5 (4417):

$$e^+ + e^- \rightarrow e^+ + e^-$$

Lancaster Particle Physics

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Acknowledgement

The authors are grateful to the Particle Physics and Astronomy Research Council for the financial support received from a Public Understanding of Science and Technology award.