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SOME DETECTOR ARRANGEMENTS AT LEP

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Abstract

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The tasks to be performed at LEP by different specialized detectors are worked out and discussed in connection with presently available instrumentation. These specialized detectors include: a detector for lepton pairs, a detector for photon final states, a detector for measurements of mean life of short-lived particles, a calorimetric detector for hadron final states, and a detector for studies of flavour mixing.

The main functions of a "universal" detector, capable of analyzing complete events, are discussed and compared to the techniques presently available.

1. Introduction

It is generally expected that LEP will be a source of exciting physics for a large community of physicists, and that, hence, a large number of experiments is desirable. Will these experiments be done using large universal detectors or can at least some be better performed by small, specialized detectors?

LEP will have eight intersections of which only four may be available during the initial phase of operation. During the later stages of LEP operation aiming, for example, at the detection of W^+W^- pairs,

considerations of power consumption may lead to limiting the number of circulating bunches to one per beam and hence, the number of interaction regions to any two out of eight.

The number of large, universal detectors which will remain in place for long periods will therefore be small.

At the e^+e^- storage rings presently operating event rate considerations have led to a trend of trying to measure as many details as possible of each event and hence of building universal detectors.

At LEP, operating at the Z^0 pole, the event rates are expected to be large [1]. Table I gives events per day for a luminosity of $5 \times 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$. Short experiments using small, specialized detectors may therefore become a possibility. Section 2 is devoted to a discussion of specialized detectors and their tasks.

Specialized detectors can only be designed for known physics questions, e.g., for measurements of the parity violating angular asymmetry of lepton pairs as a function of energy. To discover the unforeseen and to search for rare events, more than one large, universal detector, combining many functions may be required, taking over the traditional role bubble chambers play as fixed target accelerators. Section 3 is devoted to a discussion of the main functions to be combined in such a universal detector.

The design of advanced detector apparatus involves choices concerning different techniques presently available. Some choices will be discussed, others only made. In both cases they will have to be backed up by feasibility studies before these detectors can be designed with some confidence. Some shortcomings of present day instrumentation are summarized in Section 4 which also contains some conclusions.

The discussions concentrate on central detectors; forward detectors for studies of reactions proceeding by two-photon exchange have been discussed at this conference by C. Berger [2].

2. Specialized Detectors

2.1 Selection of multi-hadron events

The ratio of cross-sections for e^+e^- annihilation and for two-photon exchange is known [1] to decrease faster than s^{-1} , where s is the square of the centre-of-mass energy. At $\sqrt{s} \sim 100$ GeV we expect a ratio

$$\frac{\sigma_{1\gamma}}{\sigma_{2\gamma}} \sim 3 \times 10^{-4}$$

Both processes can produce multi-hadron final states. It is therefore of great importance to separate these two processes by the differences in their kinematics. Annihilation events are characterized by the equality of the total energies of the colliding e^+e^- initial and of the hadron final state, whereas in two-photon exchange, in general only a small fraction of the initial (e^+e^-) energy is transferred to the final state.

A measurement of the visible energy of the final state requires detection of all particles, charged and neutral over a large fraction of the total solid angle of 4π , a cut in energy or momentum measurement of tracks as low as possible and an inclusive trigger. This could be achieved by a calorimeter.

Due to holes at the ends of cylindrical detectors, and to neutral particles, (e.g., K_L^0) some overlap between the two processes remains. It can be largely eliminated by a measurement of the longitudinal momentum balance, e.g., of

$$B_L = \frac{1}{E_{\text{vis}}} \sum p_i \cos \theta_i$$

$$E_{\text{vis}} = \sum E_i$$

where p_i , E_i , θ_i are the momentum, energy and angle of a track, i . For annihilation events $B_L = 0$; in actual measurements resolution effects and the unbalance due to undetected particles tend to broaden this result to a band of, e.g., $-0.5 < B_L < 0.5$. In two-photon exchange processes, in general $|B_L| > 0$.

A measurement of the longitudinal momentum balance B_L requires a detector capable of measuring the angles and momenta of all tracks, e.g., a central cylindrical drift chamber in an axial magnetic field. The question whether the angles and energies of neutral pions have to be detected as well will be discussed in Section 3.2.

An example of selection of $e^+e^- \rightarrow \text{multi-hadron}$ events at $\sqrt{s} = 27.7$ GeV, obtained using the JADE detector [3] at PETRA, is shown in Fig. 1. An accumulation of events at low E_{vis} and large B_L , seen in Fig. 1a, is typical of two-photon exchange processes. Selecting events with $|B_L| < 0.5$, a clear separation of the two processes is achieved by a cut at $E_{\text{vis}} > 13$ GeV. The remaining background is estimated at $\sim 1\%$.

2.2 A detector for lepton pairs

All experimental information presently available supports the view that the time-like electromagnetic and weak current couples directly to pointlike fermions, e.g., in the reactions

$$e^+e^- \rightarrow \ell^+\ell^- \tag{1}$$

where ℓ stands for e , μ and τ . Therefore, these channels are best suited for a study of weak-electromagnetic interference effects, for instance, by measuring the relative cross-sections at the Z^0 pole to determine the relative weak neutral current coupling constants of the three leptons, or by measuring the forward-backward asymmetry as a function of energy and making a comparison with the expectation of the electro-weak theory of Salam and Weinberg, as depicted in Fig. 2. An excellent review of this topic can be found in a report by J. Ellis and M.K. Gaillard [4].

An experimental study [5] of the angular distribution of reaction (1) requires a measurement of the electric charge of the outgoing leptons, to separate fermions and antifermions, identification of the lepton (e , μ or τ) and a measurement of the angles of the leptons with respect to the colliding e^+ and e^- beams. These measurements have to be made over a large fraction ($> 90\%$) of the full 4π solid angle.

A detector which is capable of these measurements can also give interesting physics results in different domains, e.g., in the search for heavy charged leptons by detecting $e\mu$ pairs

$$L^+L^- \rightarrow e + \mu + 4\nu. \quad (2)$$

The polarization of τ leptons may be determined by measuring the spectrum of electrons and muons from τ decay. A sensitive search for the hypothetical scalar Higgs meson produced in the reaction [4]

$$e^+e^- \rightarrow \mu^+\mu^-H \quad (3)$$

may be performed by measuring the invariant mass of the μ pair and searching for a peak in the missing mass due to the H meson.

A detector consisting of a solenoid of 3 m length and 1 m radius, with a field of 10 kG and a set of cylindrical drift chambers for measuring

50 track coordinates would give a transverse momentum resolution of $\Delta p_T/p_T = \pm 0.24 p_T$ or 12% at 50 GeV/c, adequate to determine the charge of a track and to reject background, e.g., from two-photon exchange. A design [5] elaborated during the LEP Summer Study 1978 is shown in Fig. 3. A shower detector is foreseen outside the thin coil for detection of e^+e^- final states. The shower counter would be 20 radiation lengths deep and would be segmented into two sections in depths, e.g., $5X_0$ and $15X_0$, to separate pions and electrons using well-known techniques of early shower development. Together with a comparison of the shower energy E and the momentum p measured by deflection, this technique will reduce the hadron contamination to the level of 1%.

The return yoke of the magnet (2 m of Fe) followed by four layers of muon detectors (e.g., drift tubes [6] or streamer tubes [7]) is used as a muon identifier. The cylindrical part of the detectors have to be completed by end-cap detectors to cover a large fraction of the solid angle.

π/μ separation would be limited to a few percent, mainly due to hadron punch-through and to π/K decays. A Monte Carlo simulation [8] of decays in flight over a volume of 3.6 m diameter and 6 m length gives a background of 0.01 muons with $p_\mu > 2$ GeV/c per event. The background rapidly decreases at higher momentum. At $p_\mu > 10$ GeV/c the background is 0.001 μ /event or $0.005 \times R$.

2.3 A detector for photon final states

Reactions with single photons play an interesting role in e^+e^- physics.

The reaction

$$e^+e^- \rightarrow \gamma Z^0 \quad (4)$$

can be used to count the number N_ν of neutrino types. Decays $Z^0 \rightarrow \nu\bar{\nu}$ can be recognized by choosing an energy of about 10 GeV above the Z^0 pole and measuring the γ spectrum in the reaction

$$e^+e^- \rightarrow \gamma + \text{nothing} \quad (4a)$$

The photon energy spectrum shows a peak at $\sqrt{s} - m_{Z^0}$ and the cross-section is directly related to N_ν [9].

Annihilation into a pair of photons

$$e^+e^- \rightarrow 2\gamma \quad (5)$$

is a reaction which allows a QED test of the electron propagator for q^2 up to $2 \times 10^4 \text{ GeV}^2$, since weak contributions have been shown [10] to be small ($\lesssim 10^{-3}$). Annihilation to three photons is a good study ground for weak-electromagnetic interference.

Many radiative cascade decays of the radial excitations of narrow $Q\bar{Q}$ states exist and have been successfully investigated in the J/ψ region using a dedicated photon detector ("The Crystal Ball") at SPEAR [11] specialized in detecting photons with energies lower than 1 GeV. This detector has as its principal component a 16 radiation length thick, highly segmented shell of NaI (Tl) surrounding cylindrical track chambers. The main Ball and various elements of the central chambers cover 94% of 4π sr. Segmented end-cap (NaI (Tl) detectors supplement the main Ball and increase the covered solid angle to 98% of 4π sr. The polar and azimuthal angle covered by one of the 612 triangular segments is 60 mrad, on average.

A detector specializing in the study of these reactions has to measure photon energies and angles over a large dynamic range, from 0.05 - 50 GeV. It has to discriminate between single γ and π^0 and hence has to solve the γ - γ overlap problem at LEP energies. A measurement of visible energy has to be performed over the "full" solid angle, in particular, for reaction (4).

The segmentation required at LEP to solve the γ - γ overlap problem has been studied in some detail by P.G. Innocenti et al. [12]. The reaction

$$e^+e^- \rightarrow q\bar{q} \rightarrow 2 \text{ jets} \quad (6)$$

has been simulated at $\sqrt{s} = 100$ GeV following the work of Feynman and Field. Figure 4 shows the cumulative distribution of the shortest distance between two photon impact points at a radius of 1.8 m. At small distances the contributions from the same jet become larger than those from the same π^0 . Using a segmentation of 4 cm, corresponding to $\Delta\psi \approx 20$ mrad leaves 4.4% unresolved π^0 of high energy. It should be noted that a detector of $e^+e^- \rightarrow 1\gamma, 2\gamma$ or 3γ alone does not encounter these overlap problems.

Several γ -barrels of large dimensions have been built: a large liquid argon barrel for TASSO [13] at PETRA; a lead glass barrel for JADE at PETRA [14]; lead-scintillator sandwiches with wavelength shifting light guides for UA2 at the CERN $\bar{p}$ - p collider and for ARGUS at DORIS. For unambiguous photon energy assignment, a segmentation into towers is preferred over segmentation into strips. It has been shown to provide better efficiency at low photon energies [15].

These existing γ -barrels cannot be scaled up for economical reasons to the dimensions and segmentation required at LEP. A new design is required; the one recently developed at CERN by Fischer and Ullaland, the time projection quantameter [16], may solve the problem. This device is based on a large volume converter, a drift space and a pick-up chamber (see Fig. 5). The converter is a laminated stack of perforated metal sheets, separated by thin insulating layers. The holes in the stacked plates form a long drift channel, with its axis oriented perpendicular to the incident photon or electron trajectory. The drift field is shaped

by connecting each insulated plate to an external voltage divider. The material thickness between drift channels and the overall density determine the sampling properties of the device. For the application discussed here good energy resolution is required, and hence thin converter plates and good separation of neighbouring showers, and hence high density. The pick-up chamber is a multiwire proportional chamber with anode wires and cathode strip readout. For a cylindrical barrel of 1.8 m radius several axial pick-up chambers would be required to limit the drift distances to $\lesssim 50$ cm. Cathode strips would sample azimuthally and add up the shower energy; anode wires would sample the shower development radially (see Fig. 6). The coordinate along the axis of the cylinder is obtained by measuring the drifted charge in small time windows. For drift holes of 10 mm diameter and lead plates of $1/3$ radiation length thickness, a resolution of

$$\frac{\Delta E}{E} = \frac{20\%}{\sqrt{E}}$$

is expected. A device with copper plates gave a resolution of $30\%/\sqrt{E}$, as expected, and for a mean density of $\bar{\rho} = 2 \text{ g/cm}^3$ a measured shower width [17] at 1 GeV of ~ 3 cm (see Fig. 7).

Also, digital calorimeters using Geiger tubes to measure the presence of shower electrons in small cells are being developed [18] and may be suitable for large γ -barrels.

2.4 A detector for lifetime measurements of short-lived particles

LEP operating at the Z^0 pole is a copious source of τ leptons (3300 pairs per day) and of B mesons (14,000 pairs per day) containing the bottom

quark of 5.28 GeV mass. Precise measurements of their mean lifetime are of great importance. A measurement of the lifetime of the τ lepton would determine the coupling constant to the charged weak current and answer the question of the universality of e , μ and τ coupling. The lifetime of B mesons is related to the coupling constant to the charged weak current and to weak flavour mixing angles. The values of these mixing angles can be estimated separately by studying the cascade of semileptonic decays of mesons containing heavy quarks (e.g., b and t , see Section 2.6). The combination of angles in the expression of the lifetime, e.g.,

$$\tau_B = \frac{4 \times 10^{-15} \text{ s}}{\sin^2 \theta_2 + \sin^2 \theta_3 + 2 \sin \theta_2 \sin \theta_3 \cos \delta} \quad (7)$$

can probably be measured with better precision.

One of the advantages of measuring the lifetime of τ produced in e^+e^- annihilations is the known τ energy. At 50 GeV beam energy $\gamma_\tau = 28$ and the mean flight path is expected to be $\lambda_{\text{lab}} = 2.5 \text{ mm}$. $\tau^+\tau^-$ production can be tagged by requiring one τ to decay leptonically and selecting events with nothing but a single lepton (e or μ) in one hemisphere (see Fig. 8) and the other τ to decay into $\nu_\tau A_1$,

$$\tau^+\tau^- \rightarrow (\mu^+\bar{\nu}_\mu \nu_\tau)(\bar{\nu}_\tau \pi^-\pi^+\pi^-) \quad (8)$$

Selecting events with an angle $\theta < 45^\circ$ between the τ flight line and the three-pion momentum vector provides good accuracy in determining the decay point by the 3π vertex. High resolution drift chambers with a precision of $\sim 50\mu$ per coordinate can be built. The production point can be determined by the vertex of events without leptons. The accuracy which can be obtained is, to first approximation, energy independent, because the angles between the 3π in reaction (8) decrease as $\sim 1/\gamma$ while the flight path

increase as γ . The advantage at LEP energies comes mainly from the large τ production at the Z^0 pole.

The specialized, high-resolution vertex detector may also be part of a universal detector capable of lepton identification and pion momentum measurement.

2.5 A calorimetric detector for hadronic final states

The mass of the Z^0 pole is predicted by the standard model in terms of the Glashow-Salam-Weinberg mixing angle:

$$m_{Z^0} = \frac{37.4 \text{ GeV}}{\sin\theta_w \cos\theta_w} \quad (9)$$

With a value of $\sin^2\theta_w = 1/4$, $m_{Z^0} \sim 90 \text{ GeV}$.

It is believed [19] that the absolute machine energy can be determined to a precision of $\sim 10^{-4}$. A detector capable of measuring the rate of annihilations as a function of energy to obtain $m_{Z^0} \pm 10 \text{ MeV}$ and $\Gamma_{Z^0} \pm 10 \text{ MeV}$ has to cover the angular range from 5° to 175° to measure the visible energy with a variance of 5%. A compact detector combining a hadron calorimeter for high energy tracks and a small solenoid with a 0.4 T magnetic field and a central cylindrical drift chamber for the dominant low energy tracks may be sufficient to perform these measurements. A detector designed by Albrow, Grote and Jarlskog [20] is shown schematically in Fig. 9.

The central solenoid of 1.5 m diameter and 2 m length has a field of 0.4 T; a cylindrical drift chamber measures the momentum of charged particles of low energy. Electromagnetic energy is measured in a separate calorimeter preceding the hadron calorimeter. Forty-five tons of iron

are shaped to form a segmented sampling calorimeter. Each segment is a tower oriented towards the intersection point. The performance of this detector in measuring the invariant mass of 2 jets has been studied using Monte Carlo methods. Assuming a hadron energy resolution of

$$\frac{\sigma(E)}{E} \approx \frac{0.3}{\sqrt{E}} \quad (10)$$

a mass resolution between 1 - 2 GeV has been found, similar to the performance of the calorimeter and a small solenoid detector, as shown in Fig. 10. It should be noted, however, that the resolution in Eq. (10) can only be achieved using uranium plates. Sampling plates of 5 cm Fe would give a resolution of $\sigma/E \approx 0.75/\sqrt{E}$ and a mass resolution without magnet between 2.5 and 5 GeV. All details of the event configuration is lost; individual tracks cannot be resolved.

An interesting application of this technique has been studied for the detection of W pairs,

$$e^+e^- \rightarrow W^+W^- \quad (11)$$

The invariant mass of the final state

$$W \rightarrow q\bar{q} \rightarrow 2 \text{ jets} \quad (12)$$

as measured by the uranium plate calorimeter (Eq. (10)) has been calculated by Monte Carlo methods [20]. The result is shown in Fig. 11. If the four jets of reaction(11) can be separated and their energies and angles calculated as in this simulation, there is no doubt that the reaction can be separated from the background.

Another interesting application of this detector is in the search for Higgs mesons; produced in the reaction

$$e^+e^- \rightarrow Z^0 H \quad \downarrow \quad q\bar{q} \rightarrow 2 \text{ jets} \quad (13)$$

2.6 A detector for studies of flavour mixing

The weak current between "up" and "down" quarks in a model with three generations of fermions has the form

$$J_\mu = (\bar{u}, \bar{c}, \bar{t})(1 + \gamma_5)\{M\} \begin{bmatrix} d \\ s \\ b \end{bmatrix}, \quad (14)$$

$\{M\}$, the mixing matrix of Kobayashi and Maskawa [21], is written in terms of three mixing angles and a CP violating phase angle, δ . The values of these mixing angles determine the decay modes of mesons built with heavy quarks. Comparison of the rates for different degrees of flavour changing in their semileptonic cascade decays gives a measurement of the mixing angles, e.g.,

$$\begin{aligned} \Gamma(b \rightarrow \ell \nu c) &\propto (\sin\theta_3 - \sin\theta_2 \cos\delta)^2 \\ \Gamma(b \rightarrow \ell \nu u) &\propto \sin^2\theta_1 + \sin^2\theta_3 \end{aligned} \quad (15)$$

Decays to the next flavour in mass value are expected to be Cabibbo - allowed, the others are expected to be suppressed.

An experiment has been sketched [22] in which the transverse momentum of the lepton with respect to the jet axis is used as a measure of the mass difference [23] between the primary and the secondary quark. A simulation of the decay of a hypothetical heavy quark h is shown in Fig. 12.

Production of a heavy quark pair can be tagged by requiring detection of three charged leptons, e.g., from the decay of t quarks on one side of the final state, as sketched in Fig. 13; one then obtains a sample of unbiased $\bar{t}$ decays on the opposite side which can be studied.

A detector for semileptonic decays has to identify muons and electrons in a background of hadron tracks, has to resolve the overlap problems occurring in jets and has to measure the lepton momenta to assign events to the different decay modes.

The segmentation required to solve the $\pi^\pm/\gamma$ overlap problem for π/e discrimination has been studied by Innocenti et al. [12] using a Monte Carlo simulation of 2 jet events. Figure 14 shows a scatter plot of the energies of photons and charged pions with impact points within 8 cm distance and within 4 cm distance at a radius of 1.8 m where an electromagnetic shower detector would start. One-hundred events have been generated. The overlap probability for a segmentation of 4 cm limits the π/e discrimination at the level of 1%. Additional rejection could be achieved by ionization measurements (see Section 3.1).

3. A Universal Detector

A universal detector combining many functions is, for example, required for spectroscopy of $(Q\bar{Q})$ mesons, (Qqq) baryons, for search of rare decay modes and for measurements of angular asymmetry in the reaction $e^+e^- \rightarrow q\bar{q}$ [24].

The detector has to have the capability:

- to separate the tracks of particles in jets and to measure their vector momenta;
- to identify pions, kaons and protons;
- to separate photons from charged particles and to measure their angles and energies.

The size of the detector [25] is determined by the requirements of particle identification. The magnetic field is chosen next to obtain good invariant mass resolution.

3.1 Particle identification

Particle identification by ionization sampling in proportional wire chambers has been proven already in existing detectors (JADE, CLEO, EPI) and is under construction in the TPC Project and for UA1 at the CERN $\bar{p}p$ collider.

The design goal for LEP is a 3 standard deviation separation of the ionization of pions and kaons for momenta up to 45 GeV/c. A detailed discussion of results obtained using this technique has been given at this conference [26]. The total track length required to achieve this goal is 5 m in argon under atmospheric pressure. The accuracy of the ionization measurement scales as

$$\sigma \sim \frac{1}{\sqrt{L} \times P} \quad (16)$$

where L is the track length and P the pressure. The Jetchamber [26] of JADE operates at 4 atm. pressure to reduce the track length. A large pressure tank is required and it has been found [26] that part of the ionization may be lost at high density. A simple, although costly, solution is the use of xenon gas. A track length of 1.5 m in xenon is expected to give a resolution of $\sigma \sim 4\%$, as shown in Fig. 15. With a beam pipe of 20 cm diameter and lost track length due to overlap, this fixes the outer radius of the central chamber to 1.8 m.

The spacing between particles in jets is momentum dependent [25]. Requiring a track length of 1.25 m without overlap defines a cell size for ionization measurement of $\Delta R = 1$ cm, $\Delta Z = 6$ cm, as calculated by Ekelöf and Grote [27] (see Fig. 16). Ninety-five percent of all simulated events have more than 1.25 m unobscured track length for all charged particles.

A full-scale test of a sector of a chamber filled with xenon may be required to check the predictions of Fig. 15 and the drift properties of this gas.

3.2 Solid angle coverage and detection of neutrals

It is quite instructive to investigate the effect of holes in the detection of particles [27]. Figure 17 shows the invariant mass of events

$$W \rightarrow q\bar{q} \rightarrow 2 \text{ jets} \quad (17)$$

with $m_W = 78 \text{ GeV}$, for all particles detected in the angular range from 10° to 170° . The tail at low invariant mass values is due to the holes of the detector. A cut at $M^* > 70 \text{ GeV}$ gives an average efficiency of $\sim 60\%$. A universal detector should therefore aim for good solid angle coverage.

The effect of undetected neutral particles on the invariant mass of reaction (17) is even more pronounced [28]. Figure 18 shows the invariant mass of all charged particles detected in the angular range $10^\circ - 170^\circ$. There seems to be no event without a neutral particle. Including neutral pions but excluding neutral kaons gives the invariant mass spectrum shown in Fig. 19. It seems therefore indicated to equip a universal detector with an electromagnetic calorimeter for π^0 detection and with a hadron calorimeter for K_L^0 and neutron detection.

3.3 Choice of the magnetic field

Having fixed the radial dimensions of the central cylindrical chambers and assuming that 100 coordinates are measured per track with $\sigma = 0.2 \text{ mm}$

in $R \times \Delta\phi$, the choice of the magnetic field strength fixes the momentum resolution and the invariant mass resolution. A field of 7.5 kG will provide a momentum resolution of

$$\frac{\Delta p}{p^2} \approx 0.1\% / \text{GeV}/c$$

and a momentum cut-off at $R = 10$ cm of 250 MeV/c. Increasing the field further will give more problems with spiralling tracks [29]. At 7.5 kG and 15° polar angle, 30% of the tracks spiral; at 90° , 5% of the tracks spiral. This fraction depends almost linearly on the field strength. A field strength of 7.5 kG can be obtained, e.g., using a thick Al coil or using a superconducting coil. The choice to be made will be influenced by questions about power consumption and reliability.

The mass resolution [30] for states decaying into charged particles only is around 30 MeV for all track combinations up to 15 GeV mass. The sensitivity for searching mesons containing a heavy quark, e.g., $(q\bar{t})$ depends on the mass resolution, because of the large combinatorial background in the presence of many tracks in the final state. We require that a resonant signal, to be significant, has to be ten times above this combinatorial background over three times the mass resolution $\sigma(M)$. Working at $\sqrt{s} = 100$ GeV, in the vicinity of the Z^0 pole, we expect a value of $R = 45$ and $R = 5$ for a new flavour of charge $2/3$. The background requirement leads then to a minimum branching ratio for a given decay mode, as shown in Fig. 20. With a rate of $40 \times R$ or 200 events per day going to $(q\bar{t})$ the counting rate is a more severe limit to the sensitivity than the mass resolution.

3.4 The central detector

A detailed discussion of central detectors has been given by A. Wagner [26] at this conference. The cylindrical part required for a universal detector, as discussed here, has a radius of 1.8 m and a length of 6 m, to limit the angle between tracks and wires to $\theta > 10^\circ$. The hole has to be filled by end caps.

Momentum measurement and ionization sampling of tracks require ~ 100 samples, and a cell size of $\Delta R = 1$ cm, $\Delta\phi \times R = 1$ cm and $\Delta Z = 6$ cm by charge division. Two possibilities of drift geometry exist, azimuthal drift, as in the JADE detector, or axial drift, as in the Time Projection Chamber. Azimuthal drift geometries give smaller drift paths and are therefore simpler to build and to operate. A schematic view of a sector of such a chamber with 5760 sense-wires is shown in Fig. 21. The maximum drift length is 12.5 cm and the maximum drift time is 2.5 μ s. The inner part of the central detector is a multiwire proportional chamber used for triggering.

Figure 22 illustrates the full detector combining the solenoid, the central charged particle detector, an electromagnetic shower detector, the iron return yoke organized as a hadron calorimeter and serving also as a muon identifier, and finally, tubes for muon detection outside.

4. Summary

Summarizing this discussion, there seem to be several ways of performing experiments by small, specialized detectors. There are also some shortcomings in the present status of instrumentation and some difficult choices which will have to be backed up by feasibility tests. Some questions and requirements are again listed here:

- γ -barrels of large surface with higher density and better energy resolution;
- high resolution drift chambers of large size;
- can individual tracks be resolved in calorimeters?
- can the theoretical resolution in ionization sampling be reached?

A large universal detector is needed, combining many functions and can probably be built.

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Table I

Event rates at the Z^0 pole for $L = 5 \cdot 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$

Fermion pairs (per family)	Events/day
$L^+ L^-$	3320
$\nu_L \bar{\nu}_L$	6640
$u\bar{u} \ (q = 2/3)$	11066
$d\bar{d} \ (q = 1/3)$	14387

Figure Captions

Fig. 1 : Selection of e^+e^- annihilation to multi-hadron events using the JADE detector at PETRA at $\sqrt{s} = 27.7$ GeV.

a) Scatter plot of visible energy (E_{vis}) and longitudinal momentum balance, $B_L = \sum_i p_i \cos \theta_i / E_{\text{vis}}$.

b) Distribution of E_{vis} for $|B_L| < 0.5$. A cut at $E_{\text{vis}} > \sqrt{s}/2$ leaves $\sim 1\%$ two-photon exchange events.

Fig. 2 : Expected forward-backward asymmetry of the reaction $e^+e^- \rightarrow f^+f^-$ for the three different families of fermions, assuming $\sin^2 \theta_W = 0.25$.

Fig. 3 : A lepton pair detector consisting of a 10kG solenoid, drift chambers, an electromagnetic calorimeter to detect (e^+e^-) final states and a muon filter and detector. The radius of the coil is 1 m.

Fig. 4 : Cumulative distribution of the distance of the impact points of two photons belonging to the same jet and originating from the same π^0 .

Fig. 5 : Schematic view of a time projection quantameter.

Fig. 6 : Schematic view of the pick-up chamber geometry of a cylindrical time projection quantameter.

Fig. 7 : Width of 1 GeV electron showers as a function of the depth measured in a time projection quantameter [17] of mean density $\bar{\rho} = 2 \text{ g/cm}^3$.

Fig. 8 : Schematic view of the τ lifetime experiment.

- Fig. 9 : Schematic view of a calorimetric detector [20]. A central solenoid of 1.5 m diameter, 2 m length produces a magnetic field of 0.4 T. It is surrounded by an electromagnetic calorimeter and by using a hadron calorimeter using the iron of the return yoke.
- Fig. 10 : Resolution in invariant mass of 2 jets, measured by a calorimeter with $\sigma/E = 0.3/\sqrt{E}$ using uranium plates (crosses) and with an additional small solenoidal magnet (open circles).
- Fig. 11 : Invariant mass of $W \rightarrow q\bar{q} \rightarrow 2$ jets detected by a hadron calorimeter with uranium plates giving a resolution of $\sigma/E \approx 0.3/\sqrt{E}$.
- Fig. 12 : Transverse momentum distribution [23] of leptons from Cabibbo-allowed and forbidden semileptonic decays of a heavy quark h .
- Fig. 13 : Decay of a $t\bar{t}$ final state. It is tagged by requiring on one side three charged leptons (ℓ) from cascade decay. On the other side, a sample of unbiased $\bar{t}$ decays is obtained for studying decay rates involving different degrees of flavour change.
- Fig. 14 : Scatter plot of the energies of photons and of charged pions with impact points within a) 8 cm, b) 4 cm at a radial distance of 1.8 m for 100 2 jet events at $\sqrt{s} = 140$ GeV.
- Fig. 15 : Separation of particle pairs in units of resolution σ for 1.5 m track length in argon at 4 atm. (left scale) and in xenon at 1 atm. (right scale).

- Fig. 16 : Average unobscured track length L versus particle momentum for different azimuthal cell sizes [27].
- Fig. 17 : Detected mass spectrum of all hadrons from $W \rightarrow q\bar{q} \rightarrow 2$ jets from $m_W = 78$ GeV.
- Fig. 18 : Detected mass spectrum of charged particles from $W \rightarrow q\bar{q} \rightarrow 2$ jets.
- Fig. 19 : Detected mass spectrum of charged particles and π^0 but no K^0 from $W \rightarrow q\bar{q} \rightarrow 2$ jets.
- Fig. 20 : Branching ratio of heavy mesons decaying into charged particles only required to give a signal 10 times above the combinatorial background over $3\sigma(M)$.
- Fig. 21 : Schematic view of a sector of the cylindrical drift chamber of a universal detector, looking into the beams. The inner part is a multiwire proportional chamber for triggering. The sense wires of the drift chamber are not at constant azimuthal angle to avoid ambiguity problems.
- Fig. 22 : Two views, a) from the side, b) into the crossing beams of a universal detector.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

TAGGING SIDE

Fig. 8

Fig. 9

Fig. 10

Fig. 11

Fig. 12

Fig. 13

Fig. 14

Fig. 15

Fig. 16

Fig. 17

Fig. 18

Fig. 19

Fig. 21

Fig. 20

Fig. 22