Experience with the L3 Vertex Drift Chamber at LEP

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The vertex drift chamber of the L3 Experiment at LEP, based on the **time expansion** principle, was in operation from the start-up of LEP in 1989 until the shutdown of LEP in 2000. The gas mixture used was 80% CO_2 and 20% $i - C_4H_{10}$ at a pressure of 1200 mbar. We present the design of the chamber, the infrastructure and the performance during the 11 years of operation. The total radiation received on the anode wires was $\sim 10^{-4}$ C/cm. No degradation of the anode pulse amplitude, wire efficiencies and resolution was observed for the whole running period.

Presented by B. Betev

1. Introduction

The L3 vertex drift chamber is a high resolution Time Expansion Chamber (TEC). Its basic operational principle was proposed in [1] and the chamber was built after extensive R&D studies [2]. The physics goals set for this chamber in the L3 experiment [4] were:
- detection of charged particles and precise measurement of their trajectories;
- determination of the transverse momentum and the sign of the charge for particles up to 50 GeV/c;
- reconstruction of the interaction point (primary vertex) and secondary vertices for particles with lifetime greater than $10^{-13}s$;
- reconstruction of the impact point for charged particles at the entrance of the electromagnetic calorimeter (BGO detector) with precision of ~ 5 mm;
- determination of the charge multiplicity of the events;
- minimal material between the interaction point and the BGO detector for clear separation of photon from electron showers in the BGO;
- a double track resolution better than 500 μm.

The space available for these tasks was a cylinder with radius of ~ 450 mm and lever arm for coordinate measurements of ~ 370 mm.

We present in this report a description of the construction and infrastructure as well as the operational history and performance during the 11 years of operation at LEP.

2. TEC construction

A Time Expansion Chamber has two regions; one with high electrical field, containing a plane of sense (anode) and focus wires separated by a grid wire plane at zero potential from the low electrical field region formed by a cathode wire plane. In the L3 experiment, the TEC [5] is configured as two concentric cylindrical drift chambers. The Inner TEC consists of 12 sectors, each with 8 sense wires, whereas the Outer TEC consists of 24 sectors, each with 54 sense wires. All sectors are in a common gas volume and are electrically independent.

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The TEC cylinder (diameter 913 mm) is closed by two Aluminum end plates (mean thickness 28 mm, max thickness 45 mm) with 10 μm precision holes for special feed-throughs, which keep all 1392 anode, 1428 focus and 3948 cathode wires in position with precision $\leq$ 10 μm. The anodes are 20 μm Tungsten (W:Rh= 97:3%) wires, the focus, cathode and grid wires are 100 μm Copper-Beryllium (Cu:Be=98:1.8 % + 0.2 % Ni,Co) wires. All wires are gold-plated.

To achieve low diffusion and low drift velocity of the electron component of the ionization we have chosen a mixture of 80% CO_2 and 20% $i - C_4H_{10}$ at a pressure of 1200 mbar. This gas mixture has a linear dependence of the drift velocity on the electric field, E, the gas temperature, T, the inverse pressure, $1/p$ and the ratio R of the $i - C_4H_{10}$ to CO_2 content: $v \sim E \cdot T \cdot R/p$.

The lever arm available for coordinate measurements is $\sim$ $370mm$ and the drift distances range up to 53 mm. To meet the requirement for charge identification of particles of 50 GeV/c momentum with ~50 coordinate measurement, the single-wire resolution has to be $\leq 50\mu$m. This requires stability of the drift velocity to better than 0.1% which translates to a stability of the electrical field $\delta E/E < 0.1\%$, gas temperature $\delta T/T < 0.3^oC$, gas pressure $\delta p/p < 0.1\%$, and $i-C_4H_{10}$ content $\delta R/R < 0.1\%$.

All elements in the chamber, except the wires, were cleaned with isopropyl alcohol. No surface treatment was applied for the Aluminum endplates, the outer Aluminum cylinder and the inner Beryllium beam pipe. The chamber was wired and assembled in an CLASS 1000 clean room.

3. TEC infrastructure

3.1. The gas system

To meet the stability requirements of the gas parameters the TEC gas system works in a closed loop. This guarantees the long-term stability of the pressure and gas quality. The gas system (figure 1) consists of three main parts: the mixing circuit, the purification circuit with a flux of about 600 l/h and the TEC chamber circuit of about 150 l/h, which exchanges the TEC volume in about 6 hours. The pressure is measured by several high precision gauges and regulated to a constant value within about 0.03% by opening and closing valves at the inlet and outlet of the TEC chamber.

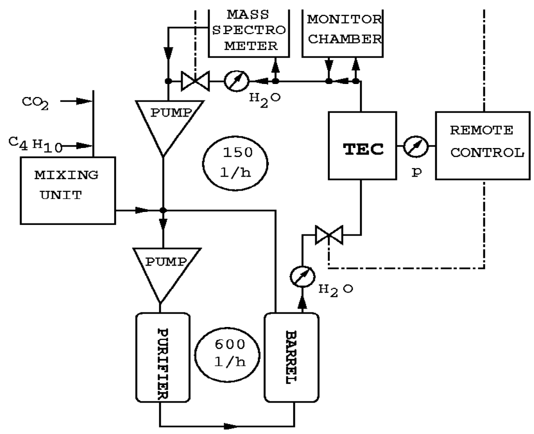

Figure 1. Simplified block diagram of the TEC gas system.

The gas mixture is produced in a 40 l mixing vessel which is initially evacuated, then filled first with $i - C_4H_{10}$ of purity 99.95% to a pressure of 1.9 bar and then with CO_2 of purity 99.998% up to 9.5 bar. The stability of the gas mixture to better than $\pm$0.1% is obtained by carefully measuring and correcting for temperature effects and by using an additional flux loop such that the two components of the drift gas are well mixed when filling it into the main gas system. An Oxisorb filter in the purification circuit absorbs the O_2 impurity to less than 1.5 ppm and the H_2O content to a level of less than 0.7 ppm. A 50 nm micro-filter in the TEC chamber circuit removes fine grain dust particles. All tubing of the gas system is made of copper of refrigerator quality avoiding possible outgassing of organic molecules by plastic tubing. Several instruments are used to monitor the gas quality. The most effective and accurate instrument is the gas test chamber, flushed by the same gas entering the TEC (see figure 1). It is a drift chamber, operated like the TEC in time expansion mode. It measures the drift speed directly by means of two ^{90}Sr sources with an activity of about 3 MBq that illuminate the chamber via collimators of 1 mm (entrance) and 2 mm (exit) diameter. The two sources are placed at distances of 7.5 mm and 47.5 mm, respectively. Using the same 100 MHz digitizing electronics as for the TEC, one measures two peaks in the drift time spectrum due to both radioactive sources with a time difference of 7.1 μs. Fitting the peak positions one can deduce the drift speed with a precision of better than $\pm 0.05\%$ in a 10 min measurement. As an example, figure 2 shows daily average values of the drift speed measured by the gas test chamber in the year 1997. The drift speed was kept constant within $\pm 0.1\%$. On some occasions a deviation of the drift speed of more than $\pm 0.1\%$ was observed for a few hours which originated from a leak in the gas system or component malfunction such as the Oxisorb filter. In these cases, the gas test chamber turned out to be the most sensitive and most reliable instrument for indicating a failure of the gas system and enabled an early repair of the system.

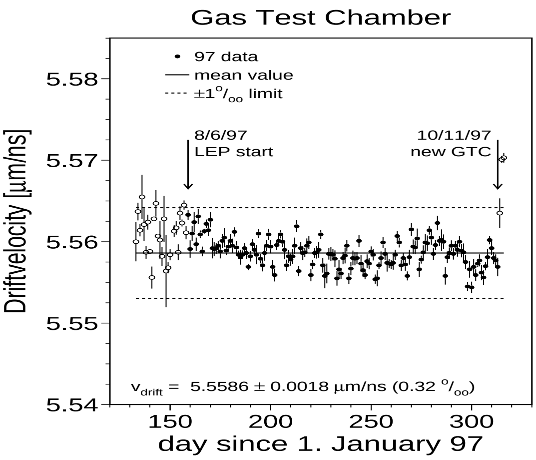

Figure 2. The drift velocity measured by the gas test chamber during data taking in 1997.

3.2. The high voltage system

The chamber has two independent high voltage subsystems: Positive HV for anode and focus wires based on a CAEN SY127 main frame and Negative HV for the cathode wires. The anode and focus wires of each TEC sector are powered independently. The negative HV subsystem is based on Novelec HV power supplies. The segmentation is by quarters of sectors. Both subsystems were run in a current trip mode. The current trip setting for the anode-focus frame was set to 20 μA for the inner TEC sectors and 30 μA for the outer sectors. The high degree of segmentation of the positive subsystem was very important for fast reaction in case of corona discharge or high current due to bad beam conditions. The long-term stability of the electrical field in the drift regions (negative HV) subsystem was better than 0.05% over the whole 11 year running period.

3.3. The temperature system

A system of water cooling of the front-end electronics and active heating was controlled and regulated by large array of sensors on the TEC endplates, connected to a microprocessor. The temperature on the TEC end plates was set to 18^{o}C. The long-term stability was $< 0.2^o$C.

3.4. Analog readout and data acquisition

The front-end preamplifiers for the anode signal were current-sensitive with a gain 280 mV/pC. Their output signals were fed into shaping amplifiers at a distance of $\sim$ 40m. The gain of the shaping amplifier is $\sim$100. It cuts the ion tail of the anode pulse and shapes the signal to a Gaussian-like pulse.

The data acquisition system (DAQ)[3] is a multi-branch, multi-crate VME system with two main elements: 2016 flash analog-to-digital converters (FADC) with a 6-bit ADC chip, which digitizes analog signals in time intervals of 10.24 μs in bins of 10ns, and data reduction processors (DRP) for compression and reduction of the data. The DRP computes the pulse parameters, including the drift time, using the center of gravity method for Gaussian-like anode pulse. A hadronic jet data event is shown in figure 3 to demonstrate the performance of the DAQ and the very low noise of the L3 TEC.

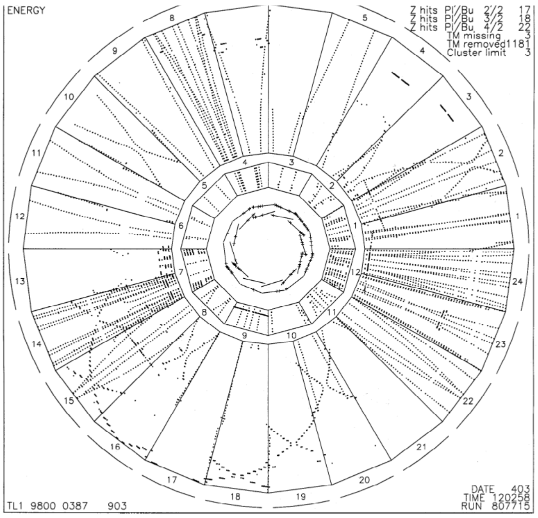

Figure 3. Online jet raw data event in $r\phi$ plane.

4. Calibration and resolution

The TEC calibration is performed using data collected by the L3 detector during normal running or in dedicated runs at the Z boson resonance. The method is based on tracks, for which the precise trajectories through the chamber can be determined from external information [6]. In the L3 magnetic field the trajectory of a charged particle is an arc of a circle and thus it is totally defined by the knowledge of two well measured points and the curvature. We use $\mu^+\mu^-$ or e^+e^- pairs produced in e^+e^- collisions without hard photon radiation. These tracks are practically collinear and we can assume that they form just a single arc with a fixed curvature. At the Z boson peak the pairs observed in the central part of the detector, which traverse the full length of the TEC sectors, provide a copious source of TEC-independent high precision spatial information. For LEP2 running this is not sufficient and we use a second copious data source – e^+e^- pairs which are produced dominantly in the forward region closer to the incoming beams, both from dedicated Z pole runs and from the usual high energy data. In this way the angular acceptance is extended from $|\cos\theta\,| \leq 0.74$ to $|\cos\theta\,| \leq 0.91$. The absolute value of the curvature is determined by the measurement of the momentum in the L3 muon chambers or the energy in the electromagnetic calorimeter at the percent level. For $\mu^+\mu^-$ events the sign of the curvature is also taken from the L3 muon chambers. For e^+e^- events we have to determine the sign from the TEC information itself, which is done by a method developed specially for the L3 geometry [5,8]. It is also sufficient to find points in two opposite sectors in the Silicon Micro-strip Detector (SMD) [7] to establish a high precision trajectory for the lepton pair.

By fitting the space-time curve, we can precisely determine the parameters of the Drift Distance to Time (DDT) relation for each region on the left and on the right of the wire (each anode has two signal collecting sides which are not symmetric due to the Lorentz angle).

The single-wire efficiency and resolution after TEC calibration are shown in Table 1. The results are stable: an efficiency of $\sim 95.5\%$ and a resolution between 49 μm and 51 μm on average for all years from 1995 to 2000. The single-wire resolutions and efficiencies are determined at the beginning of each year and stored in the L3 database. The spatial track resolution at the interaction point is 103-115 μm from the drift chamber alone (see e.g. figure 4). The results shown in figure 4 confirm the stable performance of the hardware and the calibration/alignment procedures over time. For tracks with associated SMD hits the resolution improves to $\sim$ 30 μm. The transverse momentum resolution is

$$\mathrm{dp_t}/\mathrm{p_t^2} = 0.018\ (\mathrm{GeV})^{-1}$$

and improves to a value of 0.010 $(GeV)^{-1}$ when SMD information is used.

Before the start of the 2000 run the negative high voltage of the *whole* TEC was lowered to 88% for safety reasons. This is equivalent to a new working point, expected to change the dependence of the single-wire resolution on the drift

Table 1
TEC efficiency and resolutions at a drift distance of 10 mm from 1995 Z peak and 1997-2000 high energy runs.

Year	Wire Efficiency [%]	Wire Resolution [μm]	Track resolution at origin [μm]
1995	95.8	50.3	102.7
1997	95.6	50.4	104.6
1998	94.2	48.7	102.7
1999	95.8	51.2	106.9
2000	96.0	50.4	115.5

distance. The drift velocity is reduced by approximately 12%, increasing the time expansion and the resolution. At the same time the diffusion in the TEC gas increases, reducing the resolution. Both factors nearly compensate each other, keeping the single-wire resolution unchanged [9].

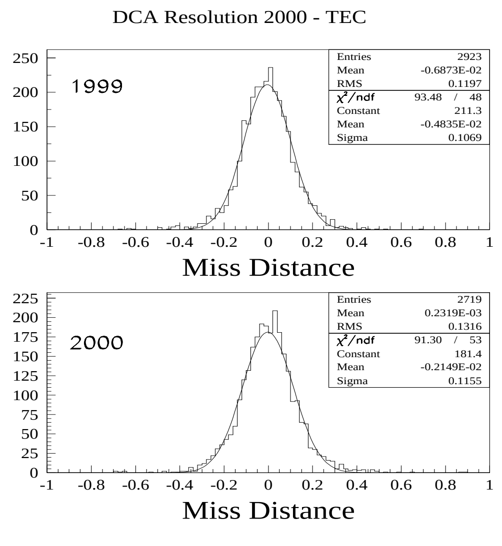

Figure 4. Spatial track resolution of the TEC in mm obtained from the distance of closest approach to the interaction point in 1999 and 2000.

Hardware and software efforts allowed us to take full advantage of the central tracker potential during running at LEP1 and LEP2. The required tracking efficiency and resolution under all running conditions were achieved, and the performance was stable even after substantial changes in the operating parameters.

5. Radiation and backgrounds at LEP

The radiation in LEP at Point 2 is measured by the L3 radiation monitor. The integrated radiation dose for 11 years in the central region of L3, where the TEC is situated, is estimated to about 2300 rad. The daily and integrated dose for the year 2000 is shown in figure 5. Similar pictures for the integrated and daily dose were observed in all 11 years for the L3 experiment.

The daily peaks seen in figure 5 are normally due to partial beam loss in the central region of L3. Such losses very often induced a trip or corona discharge in one or several TEC sectors.

The radiation received on the anode wires, estimated from their integrated counting and track rates, the initial number of electrons from the acceptance region (~ 30) and the gas amplification (~ 50000) is $\sim 10^{-4}\ C/cm$ for the whole running period of 11 years.

6. Anode pulse amplitude

From the Z peak data events we extract the pulse amplitude of each hit on the reconstructed track. The average pulse amplitude per sector are compared for the years 1997 to 2000. The result in figure 6 for the 24 sectors of the outer TEC shows that the pulse amplitude remains almost constant throughout the years. The same effect is observed in the inner TEC.

This fact together with the unchanged single-wire efficiency and resolution (table 1) demonstrates that no aging is observed in the TEC.

7. Summary

A drift chamber based on the time expansion principle was designed, built and used in the period 1990-2000 as a vertex track detector of the L3 experiment at LEP. The gas mixture used was 80% CO_2 and 20% $i-C_4H_{10}$ at a pressure of 1200 mb. The chamber has single-wire resolution of 50 μm, double track resolution of 500 μm and ver-

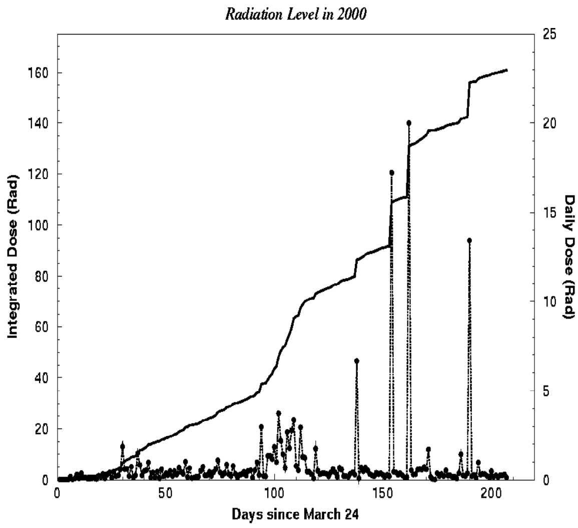

Figure 5. Daily and integrated radiation dose in the central region of L3 Experiment for year 2000.

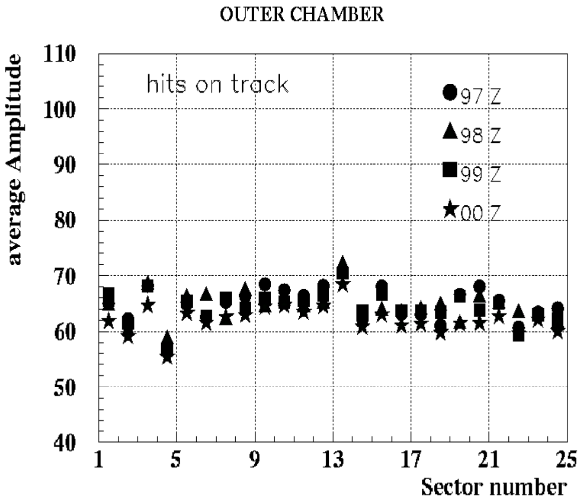

Figure 6. Anode pulse amplitude for outer TEC sectors.

tex (DCA) resolution of 110 μm. The transverse momentum resolution is

$$\mathrm{dp_t}/\mathrm{p_t^2} = 0.018\ (\mathrm{GeV})^{-1}.$$

The drift velocity stability and thereby the time to space relationship were maintained at a level of 0.1% over the entire 11 year running period. The total radiation dose received on anode wires is estimated to be $\sim 10^{-4}\ C/cm$ for the running period of 11 years. In this period, based on measured anode pulse amplitude and wire efficiencies. There were no indications of aging in the chamber.

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