COMMISSIONING AND OPERATING EXPERIENCE WITH THE INTERACTION RATE AND BACKGROUND MONITORS OF THE LEP e^+e^- COLLIDER

G.P. Ferri, M. Glaser, G.von Holtey and F. Lemeilleur.
European Organization for Nuclear Research (CERN), CH-1211 Geneva 23, Switzerland

Abstract

For optimizing luminosities and particle backgrounds the four interaction points in LEP have been equipped with compact silicon-tungsten calorimeters. We are reporting about their design, assembling, testing and operational performance.

1. INTRODUCTION

The interaction rate and background monitors (Bhabha monitors) have been built for LEP in order to optimize the bunch overlapping and to monitor the luminosity evolution during coasting beams. The detection of elastic e+ e- Bhabha scattering events have been chosen for this purpose. The Bhabha rate R_B at a given beam energy E_o is related to the luminosity L by the monitor constant σ_D, the Bhabha cross-section integrated over the acceptance $\Delta\Omega$ of the monitors:

$$R_B = L \bullet \sigma_D \text{ with } \sigma_D = \frac{8.29 \bullet 10^{-32}}{E_o^2} \iint_{\Delta\Omega} \frac{d\theta d\varphi}{\theta^3}$$

For not interferring with the LEP experiment detectors and due to the fact that the Bhabha cross-section is very peaked forward, the monitors are incorporated into the pits of the horizontal background collimators at 15 meters from the interaction points (IP) where they can be moved close to the beams during data taking. Chapter 2 is dealing with the elastic scattered e+ e- trajectories and the monitor acceptances. The monitors are compact silicon-tungsten (Si-W) sampling calorimeters made of silicon pad detectors for measuring the e+ e- energies and of silicon strip detectors for detecting the lateral shower positions and for fast trigger purposes. The assembling of the calorimeters and their performances are reported in Chapter 3. Their associated electronics are described in Chapter 4. The trigger is treated in Chapter 5 and data acquisitions in Chapter 6. The last chapter reports on first achieved results and the behaviour of the detectors in the LEP environment.

2. MONITOR LAYOUT AND ACCEPTANCES

The design of the monitors was performed in order to achieve sufficient Bhabha rates, high protection against Synchrotron Radiation (S.R.) out of the long straight sections and efficiency for the different operational low-beta optics. The detector layout as shown in Fig.1 was optimized by tracking Bhabha pairs through the LEP IP-optics [1] and photon background simulation [2]. Four calorimeters forming 2 independant monitors are incorporated in the mobile jaws of the horizontal collimators symmetrically located at 15 meters from the IP. Elastically scattered e+ e- trajectories for the back-up (β^*_V = 20 cm) and for the low beta (β^*_V = 7 cm) optics are indicated in Fig. 1 taking into account the magnetic fields of the insertion quadrupoles. Due to optic considerations the rates are much higher in the horizontal planes than in the vertical one [1]. The movable collimator jaws will be adjusted as close to the circulating beams as the photon background situation allows. When closed to 10 sigmas of the horizontal beam width the monitors intercept Bhabha electrons down to scattering angles of 2 mrad.

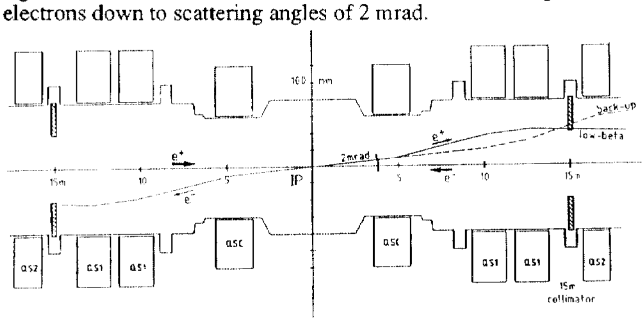

Fig. 1 Lay-out around an IP

Figure 2 shows the cross-section of a mobile collimator jaw with the incorporated 15 radiation lengths (r.l.) Si-W calorimeter (see Section 3) separated from the vacuum by a 1 mm stainless steel window. The back side of the calorimeter is protected from the S.R. and off-momentum particles by 30 r.l. of tungsten. A 2 mm lead shielding around the calorimeters has been added later to absorb part of the S.R. background.

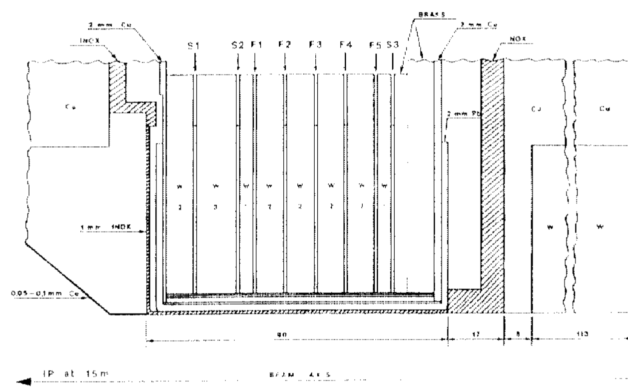

Fig.2 Cross-section of a 15 m horizontal collimator with a calorimeter embedded in its pit.

The detector cross-section σ_D seen by a monitor as function of its distance X_o from the beam axis is given in Figure 3 for back-up and low-beta optics at 51.5 GeV beam energy [3]. The sharp fall beyond 70 mm is caused by the acceptance limitations of the upstream vacuum chamber. Typical operational distances X_o for optimum photon background reduction are 45 to 50 mm for the β^*_V = 7 cm low beta optics.

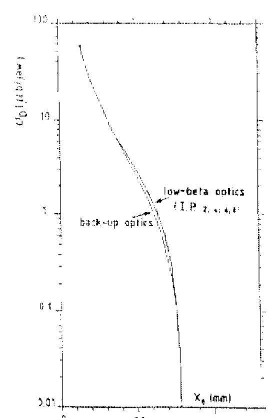

Fig.3 Monitor Bhabha cross-section σ_D versus beam distance X_o

3. CALORIMETERS

Silicon detectors as active material and tungsten as absorber have been chosen for compactness. The 15 r.l. depth calorimeter embedded in a Cu container can fit in the limited size of the collimator pit (86 mm length and 61 mm width).

The operational performance of a compact Si-W sampling e.m. calorimeter has been demonstrated [4] giving a linear energy response to better than 1 % and an energy resolution of

(17.6± 0.3) % $\sqrt{\tau}$/E with τ the sampling frequency in r.l. For a Bhabha detector which has to identify beam energy electrons, a limited energy resolution can be accepted. Consequently a limited number of sensitive planes has been chosen and their repartition in the absorbing material is shown in Figure 2.

Five silicon pad detectors (F1-F5) for measuring the e+ e- energies are placed between 6 and 14 r.l. of W with a frequency of 2 r.l. Three silicon strip detectors S1 (behind 2 r.l.), S2 (behind 5 r.l.) and S3 (behind 15 r.l.) aim to the following functions : for measuring the photon background flux after different absorption thicknesses (S1 & S2), for reconstruction of the lateral shower positions (S2) and for trigger purposes (S2 and S3).

The 300 µm thickness ion implanted silicon detectors are used fully depleted. Their operational voltages vary from 30 to 55 Volts depending upon their resistivities and their initial diode reverse currents varied between 0.3 and 0.6 µA at room temperature. The silicon oxide surrounding their active area has been reduced to 0.5 mm on the edge facing the beams in order to detect particles at the smallest scattered angles as possible.

The area of the silicon pad detectors is 50 • 50 mm2. The silicon strip detectors (40 • 40 mm2 area) have 16 strips (8 with a pitch of 1 mm situated close to the beams and 8 with a pitch of 4 mm). This configuration was chosen in order to limit the number of channels to be read out and to reconstruct accurately the lateral shower position on the edge of the calorimeter.

The detectors are embeded into W plates specially machined. The total gap beetwen 2 W plates where a detector is inserted is no more than 1.3 mm.

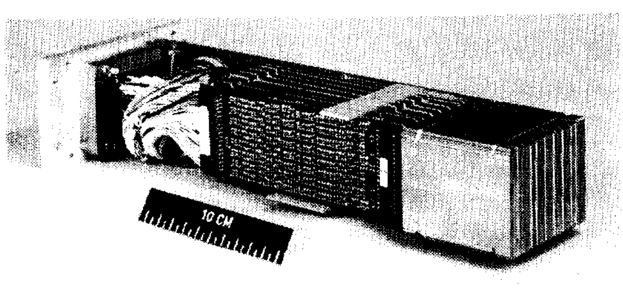

Fig. 4 Final Calorimeter with associated Electronics

A final calorimeter, seen in Fig. 4, has been tested using electron beams from the CERN SPS [3 and 5]. For fully contained showers an energy resolution of 64 % $\sqrt{E}$ between 25 and 60 GeV was obtained. For particles impinging on the edge of the calorimeter, which is the case for most of the Bhabha scattered particles, part of the shower energy is escaping radially. The measured fraction of deposited energy from 49 GeV incident electrons versus the impact distance d from the edge of the calorimeter is shown in Figure 5. The impact position d for each electron shower is found with cluster algorithms specially adapted to the S2 strip plane lay-out.

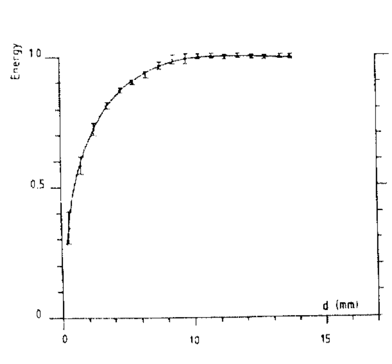

Fig.5 Fraction of deposited energy in a calorimeter by 49 GeV electrons versus impact d from the calorimeter edge

4. ELECTRONICS

Electronic cards for biasing the detectors, for calibration charge injections, for charge amplification and shaping are closely connected to the silicon detectors. The signals transmitted through 60-80 m of twisted pair cables are stored into Integrated-Hold (I-H) modules which also have the function of summing fast signals for trigger purposes. The analogue integrated charges are sequentially digitized by four 12-bit ADC's (3 µs digitizing time) working in parallel (see Fig. 6).

The CES 8150 VME module contains a sequencer for the control of the multiplexer and of the ADC timing sequences. It performs the reading and the storage into a 512 word FIFO intermediate buffer memory of the digital data from the ADC output registers and from a TAG register which identifies an event (see part 5). The programmable DSP processor ensures the data flow and the storage in a 32 kword DRAM buffer memory. A batch of events is stored in the DRAM awaiting to be read by the VME microprocessor.

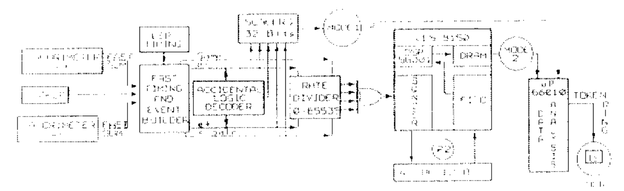

Fig. 6 Trigger and acquisition chain

Each monitor is controlled via the LEP Token Ring on which are connected, through the Process Control Assembly (PCA), the Equipment Control Assembly (ECA) containing the VME microprocessor (µP) and the following dedicated modules:

- a 16 channel voltage module for detector biasing,
- a 4 channel programmable Threshold Discriminator for trigger purposes,
- an I/O module to ensure the requested bunch and trigger selections, to select the type of events to be recorded and to fix the acquisition time period,
- a 16 channel programmable Delay Module (PDM) to provide the various time sequences needed in synchronism with bunch passages.

The electronic pedestals are obtained from dedicated runs for which the I-H acquisition gates are shifted in time between the bunch crossings. The gain calibration of each channel is realized by sending electronic charges on the back planes of the detectors.

5. TRIGGER

For each bunch passage the timing T_0 (see Fig. 6) is initiated by signals from beam pick-up's placed at 65 m apart from each IP. T_0 opens the gates for the I-H. The fast sum signal of SD2 for each calorimeter passes through the programmable discriminator the threshold of which is adjusted to trigger for high energy e^+e^- detected. The coincidences between these discriminated signals and T_0 enter the Beam Timing Selection (BTS) module which provides the event tagging stored in the TAG register.

The BTS is programmable to select the event trigger, to fix the frequency at which a specific event has to be acquired (via rate dividers) and to start and stop the time window of the data acquisition period. The BTS also contains the logic to measure the accidental pairs by delaying the signal trigger of one calorimeter by one LEP turn.

6. DATA ACQUISITION

6.1 Scaler mode

In this simple mode the data rely on the SD2 discriminated signals only. For each bunch passage the outputs of the BTS are sent to the inputs of VME scalers in which the specific events are accumulated : S.R. background (no trigger in either of the two calorimeters), e^+ and e^- backgrounds, e^+e^- pairs and accidentals.

The Bhabha rates are obtained by substracting the accidentals from the pairs.

6.2 ADC mode

The batches of events stored in the DRAM are transferred to the µP's which for each event performs the pedestal substractions and the gain calibrations for each ADC channel.

The S.R. and the e^+e^- background profiles from the strip detectors are stored in the local ECA's.

The relative luminosity rates are obtained by selecting Bhabha events from the e^+e^- recorded pairs. This is performed by the µP's which reconstruct the shower cluster positions, correct the e^+e^- measured energies for the edge effect, select the e^+e^- pairs with energies equivalent to the beam energies and retain collinear events.

7. RESULTS

The data stored in the local ECA's for the 8 monitors are sent to the LEP control room on request. The potentialities of the monitors are still not fully exploited and preliminary results are given below.

The deposited energy from a 46 GeV Bhabha pair event measured in the different silicon detectors of the two conjugate calorimeters forming a monitor is given in Fig. 7, showing the correct detection of the e.m. showers in the ADC acquisition mode.

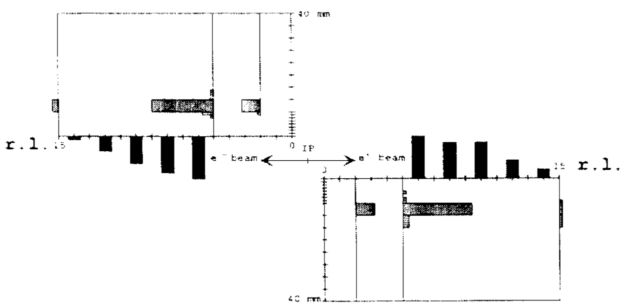

Fig.7 Deposited energy in the two conjugate calorimeters of a monitor by a Bhabha event for 46 GeV beams

The monitors were used to verify the exact crossing of the e^+e^- bunches in all four LEP interacting points by monitoring the Bhabha rates versus total vertical beam separations obtained with electrostatic field separators (Fig.8).These scans were done with 46 GeV beams and with a $\beta^*{}_V = 7$ cm low beta optics. The acquisition time per data point was 15 minutes.

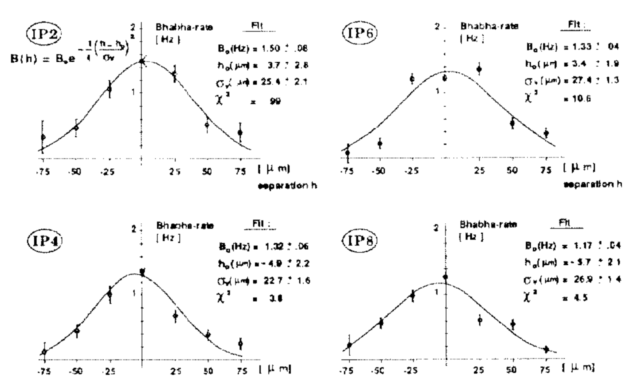

Fig.8 Relative Luminosity rates versus vertical beam-beam steerings in the 4 IP's

The relative luminosity evolution during a coasting beam run is shown in Figure 9.

The results presented in the last two figures are obtained by means of the scaler acquisition mode. The accidental rates represent 60-80 % of the e^+e^- pair rates.

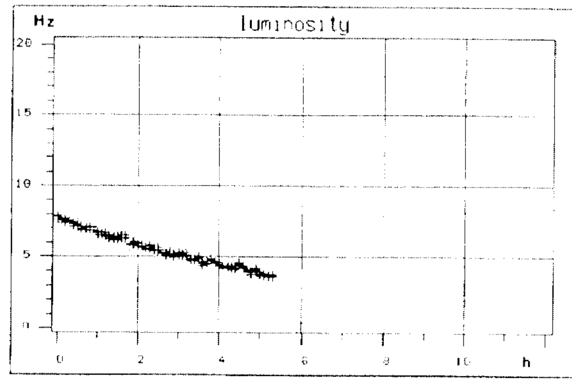

Fig.9 Relative luminosity versus time during a coasting beam run

During commissioning of LEP, the silicon detectors suffered from an alarming increase of their diode reverse currents. The fact that these currents recovered when the beams are stopped for several days suggests phenomena of positive charge accumulation induced by S.R. background in the detector silicon oxide. This was in great part overcome by introducing a few millimeters of lead shielding around the calorimeters (at the expense of Bhabha counting rates) and by biasing on the detectors only during data acquisition. The detectors also profited from greatly reduced closed orbits amplitudes around the IP's reducing the S.R. background.

8. CONCLUSION

The 16 Si-W calorimeters installed in the 4 IP's, their associated electronics and their data acquisition performed well. The behaviour of the silicon detectors are under control. The monitors have shown their capabilities of measuring the relative luminosities during LEP parameter adjustments and during coasting beam runs.

ACKNOWLEDGEMENTS

The authors wish to thank D. Azzedine, P. Buksh, B. Halvarsson and K. Unser for their contributions to electronic developments, E. Heijne and P. Jarron for their advises, H. Schmickler for data treatment and C. Bovet and R. Jung for their support.

REFERENCES

[1] G. von Holtey, "Proposal for an Interaction Rate Monitor at LEP", LEP Note 462 (1983).

[2] P. Münger and G. von Holtey, "Simulation Studies of S.R. Backgrounds to LEP Experiments", (1985), unpublished.

[3] J.Y. Hemery, F. Lemeilleur and G. von Holtey, "An Interaction Rate Monitor for LEP", CERN/LEP-BI/86-5.

[4] G. Barbiellini, G. Cecchet, J.Y. Hemery, F. Lemeilleur, C. Leroy, G. Levman, P.G. Rancoita and A. Seidman, "Energy Resolution and longitudinal Shower Development in a Si/W electromagnetic Calorimeter", N.I.M. A235 (1985),55-60.

5] J. Bjarne, "Beam Monitoring in LEP", Thesis, University of Lund, LUNFD6/(NFFL-7049), 1988.