EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

European Laboratory for Particle Physics

CERN - SL DIVISION

CERN–SL-97-72 (BI)

Luminosity measurements at LEP

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Abstract

Fast luminosity measurements are vital for the optimisation of the machine conditions needed for physics. At LEP this has been achieved since the startup by means of 16 small tungsten-silicon calorimeters measuring the rate of Bhabha scattering events. To increase the counting rate the detectors are placed close to the beams and mounted on collimator jaws. The rate of Bhabha scattering is calculated using the rate of coincidental detections of e^- and e^+ at both sides of the interaction point. The correction term arising from accidental off-momentum particle coincidences is calculated from the background rates. This technique could be successfully used at beam energies around 45 GeV since the correction term was small.

Starting in '95 however, the energy of LEP has been increased up to 91.5 GeV per beam. In these conditions the background event rate almost doubles while the Bhabha cross section decreases by a factor four. More refined background rejection techniques are therefore needed. The solution adopted and presented in this paper consists of checking the collinearity in the vertical plane of the particle tracks. This is obtained by measuring the vertical centre position of the showers inside the calorimeters using silicon strip detectors.

Paper presented at the third European Workshop on Beam Diagnostics and Instrumentation for particle Accelerators (DIPAC 97), Frascati, Italy 12-14 October 1997

Geneva, Switzerland
December, 1997

Introduction

The on-line LEP luminosity monitors are designed to give fast and precise relative luminosity measurements at each of the four collision points of the collider. This scope is achieved by measuring the elastic e^+e^- scattering (Bhabha scattering) rate.

The detection is carried out by means of 16 small calorimeters placed on either side of the interaction points. To increase the counting rate the detectors are installed near to the beam mounted on collimator jaws. The cross section decreases rapidly with the increase of the scattering angle θ. For angles $\theta < 50$ mrad it can be approximated by: [1]

$$\frac{d\sigma}{d\Omega} \simeq \frac{4\alpha^2(\hbar c)^2}{E^2\theta^4}$$

with E beam energy and α the fine structure constant.

The setup of the luminosity monitors is depicted in Fig. 1. Each interaction point (IP) is equipped with two identical monitors each of them composed of two calorimeters: one located in the internal part of the ring (Int) and the other in the external part (Ext). Monitor 1 internal and monitor 2 external collect electrons while the other two collect positrons. The detectors are placed downstream from the superconducting insertion quadrupoles with respect to the interaction region. This implies that the scattered particles are bent before arriving at the detectors reducing the lower observation angle in the horizontal plane and the upper in the vertical one. The resulting angular acceptance is $2 < \theta < 5$ mrad in the horizontal plane (the detectors can be moved in the horizontal direction since they are mounted on collimator jaws, this angle correspond to the closest position to the beam of $X_{coll} = 30$ mm) and $-2.5 < \theta < 2.5$ mrad in the vertical.

Using the counting of events the Bhabha rate can be computed as: [2]

$$\dot{N}_b = \dot{N}_{pair} - \frac{\dot{N}_{ext}\dot{N}_{int}}{\dot{N}_{void}}$$

And the associated error as:

$$\Delta\dot{N}_b = \frac{1}{\dot{N}_{void}^2\sqrt{\Delta t}}[\dot{N}_{ext}^2\dot{N}_{int}(\dot{N}_{void} + \dot{N}_{int})^2 + \dot{N}_{ext}\dot{N}_{int}^2(\dot{N}_{void} + \dot{N}_{ext})^2 + \dot{N}_{pair}(\dot{N}_{void}^2 - \dot{N}_{ext}\dot{N}_{int})^2]^{\frac{1}{2}}$$

where

$\dot{N}_b$	rate of Bhabha events
$\dot{N}_{int}$	rate of particle in the internal monitor only
$\dot{N}_{ext}$	rate of particle in the external monitor only
$\dot{N}_{void}$	rate of events (bunch crossings) with no particles in the detectors

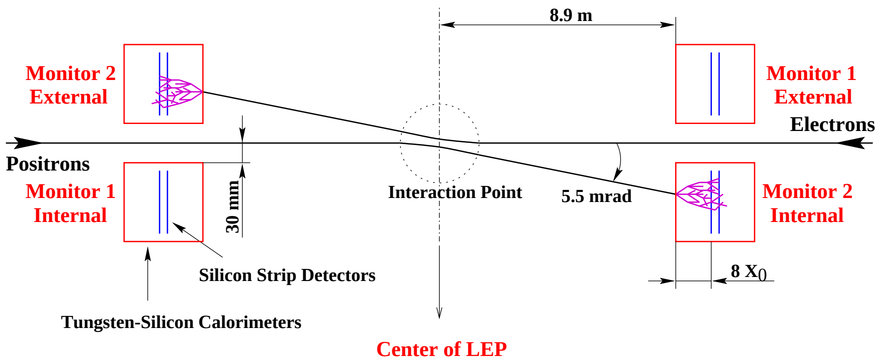


Figure 1: LEP luminosity monitors layout. Each installation is provided with two monitors, monitor 1 and monitor 2, in order to reduce the statistic error of the measurement.

At beam energies of 45 GeV, corresponding to the Z^0 resonance peak, and typical luminosities value for LEP of 10^{31}, the Bhabha rate is of the order of 60 Hz per monitor corresponding to 50% of the measured coincidence rate. The remaining 50% is coming from off-momentum particles [3]. A statistical error of 5% is thus obtained in a few seconds. Increasing the beam energy to 91.5 GeV with the same luminosity implies a reduction of the Bhabha rate by a factor four and an increase of the background by a factor two. The error associated with the measurement grows due to both the reduced statistical sample and the smaller Bhabha to background ratio. As a consequence the measuring time has to be extended and a better background discrimination technique is required. The latter is obtained by looking at the correlation of the vertical centre position of the showers generated by the particles in the internal and external calorimeters. Background events have no correlation and are mainly concentrated around the origin. Bhabha particles, on the other hand, are collinear and the shower positions are correlated.

Detectors

The calorimeters used for luminosity measurement at LEP consist of a tungsten block in which thin silicon strip detectors are inserted. The particles interact with the tungsten forming a shower. The silicon planes placed at a distance of 8 radiation lengths from the surface collect the charge of these secondary particles. The resulting signals are then amplified and read by the counting electronics.
The strips are oriented in the horizontal direction thus measuring the vertical position of the shower. To reduce the number of channels and keep a sufficient resolution, the strips have different widths depending on their positions. The pattern is symmetric, from the centre to the outside it consists of five 1 mm

strips followed by two 2 mm strips and one 4 mm strip. In total there are 16 channels per detector.
At low energy LEP is operated with four trains of bunches with two bunches each (family A and B). Each train is separated by 22 μs while the separation between bunches in the same train is 316 ns. The electronics processes the two families separately. At high energy however only one bunch per train is used which leads to a simplification of the electronics needed for background discrimination since only one family has to be processed.

Data acquisition

The data acquisition is split in two paths as can be seen in Fig. 2. In the first path the 16 channels of each detector are summed up and used for fast time arrival coincidence detection. This module consists of a Motorola MVME 162 CPU (68040 + IP bus) which houses on-board the ADCs (HiADC) and an I/O unit (IP-Digital 24) both produced by Green Spring. This block provides the counting of events as described above (Int, Ext, Pair and Void) as well as trigger and timing signals for the position correlation check described below. The CPU board can be configured with a memory buffer accessible from the VME bus which is used by the master luminosity CPU to read the results of each measurement cycle. Every 22 μs the eight sum signals of the four calorimeters (two families) are converted and compared with threshold values.

In the second path the vertical position of the showers is calculated using the strip signals. The calculation is performed only as a consequence of coincidence event detection. This is because the computation takes longer than the time interval between two bunch crossings, it is therefore impossible, and of little use, to convert every single event. Cuts are then applied to reject the background and counters are updated. The system uses the same kind of CPU and on-board ADCs as mentioned before. The two ports buffer is used again to read the counters at the end of each measure cycle. In this case the Bhabha event rate is given by the formula:

$$\dot{N}_b = \frac{\dot{N}}{p_B} \frac{P_{coll} - P_e P_i p_b}{1 - P_e P_i p_b}$$

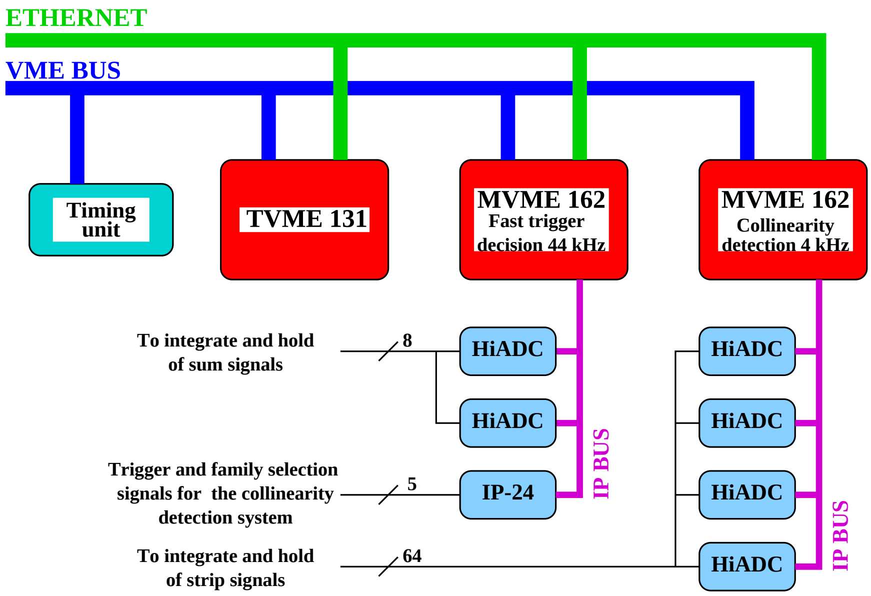
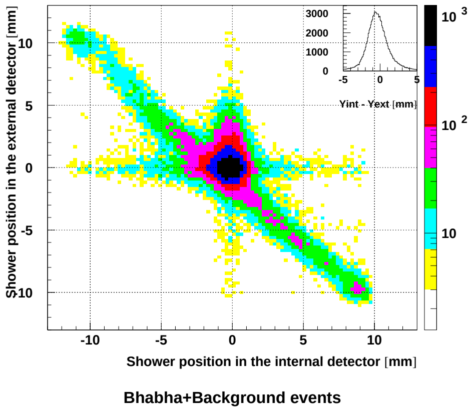


Figure 2: Data acquisition system for the LEP luminosity monitors. Two intercomunicating CPUs provide a fast event selection and a slow collinearity check. A third CPU is used to synchronise and control the whole system.

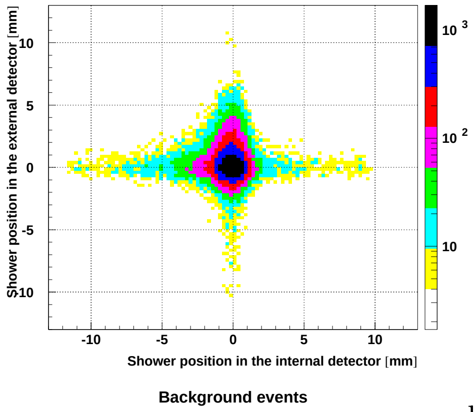
where

$\dot{N}$	Bunch crossing rate
p_B	Probability that a Bhabha event satisfies the cuts
$P_{coll} = \frac{\dot{N}_{coll}}{\dot{N}}$	Probability to have a coincidence event which satisfies the cuts
$P_e = \frac{\dot{N}_{ext}}{\dot{N}_{void}+\dot{N}_{ext}}$	Probability to have a background particle in the external detector
$P_i = \frac{\dot{N}_{int}}{\dot{N}_{void}+\dot{N}_{int}}$	Probability to have a background particle in the internal detector
p_b	Probability that a background event satisfies the cuts.

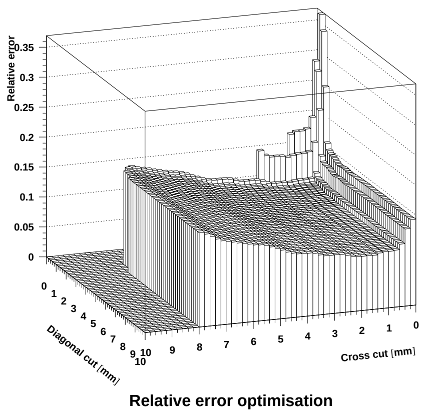
In Fig. 3a,b it is possible to see the differences between background and Bhabha events as shown by the monitors. In order to minimise the errors, two cut parameters are adjusted: one named “cross” requires that the impact parameters on both hit detectors is larger than a certain amount (exclusion of background region), the second one named “diagonal” requires that the difference between the two impact parameters is less than a certain value (acceptance of Bhabha). In Fig. 3c a lego plot of the relative error as a function of those two parameters is plotted. In the plot it is possible to see how the relative error of 14.5% corresponding to the old measurement setup can be brought down to 9% by op-



a)



b)



c)

Figure 3: Impact parameters in the internal and external detectors in case of a) concidence (Bhabha + background) events b) background events. c) Relative error as a function of the cuts parameters. The situation without collinearity check correspond to the bottom right corner (10; 0).

timal cut settings. This means a reduction of $\sim$40% of the relative error or, in other words, to a reduction of the measurement time by a factor 2.8 for the same relative error.

A third CPU board in the same VME crate (acting as master CPU) then reads the buffers from the two port memories and computes the Bhabha rates, the associated errors and the background levels. This unit is also responsible for the synchronisation and control of the other two. The computed values are sent to the LEP control room via the network and are used there in the on-line displays and machine optimisation routines.

Conclusions

The experience gained during the 1997 LEP run allowed us to understand the system better and find a procedure to minimise the measurement error by optimising the parameters of the cuts. A fully operational system was installed at one of the four collision points (DELPHI) and operated in parallel with the old system. It was found that a reduction of the measurement error by almost 40% was possible with these techniques as shown in Fig. 3c.

Due to the positive results obtained with the pilot installation we plan to replace the existing luminosity DAQ systems in all the four experimental interaction region of LEP with this new one during the ongoing shutdown.

References

[1] G. Altarelli, R. Kleiss , C. Verzegnassi, *"Z Physics at LEP 1"*, CERN Yellow report 89-08, Vol.1 (1989)

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