NORMALIZATION IN L3

L3 Luminosity Monitor Group
(M. Athanas et al.)

Abstract

The design of the L3 luminosity monitor is presented. Its expected performance for the absolute luminosity measurement is given. The influence on the relative luminosity measurement of the uncertainty in the variation of the bunch parameters from bunch to bunch is estimated.

1. DESIGN DESCRIPTION

The L3 luminosity monitor device was designed specifically for reliable luminosity measurements in the Z energy range at LEP [1]. It is located in an angular region forward enough to become independent of the Z exchange and yet not too far forward so as to allow easy Bhabha event selection unaffected by systematics. It consists of a charge tracking device to achieve good position resolution, followed by a highly segmented BGO array to measure precisely the showering energy as well as to assure good radiation hardness properties.

With this system shown in Fig. 1, one will be able to study in great detail the Bhabha process including the radiative tail. A carefully designed trigger [2] will permit the measurement and removal of background events like beam-gas. Furthermore, one can apply a sophisticated analysis to remove any Bhabha events that develop only a fraction of their energy in the BGO detector but otherwise pass the trigger condition. Thus, by comparing the tracking information with the energy profile deposited in the crystal array, one can define a very precise geometrical acceptance region. Lastly, an off-line asymmetric trigger can be easily implemented to further reduce systematics.

For the tracking device, it has been decided to use Proportional Inclined Chambers (PIC) [3], [4]. They will have a tilt against the vertical of 30° and a wire spacing of 2 mm. Each chamber (which in turn consists of two half

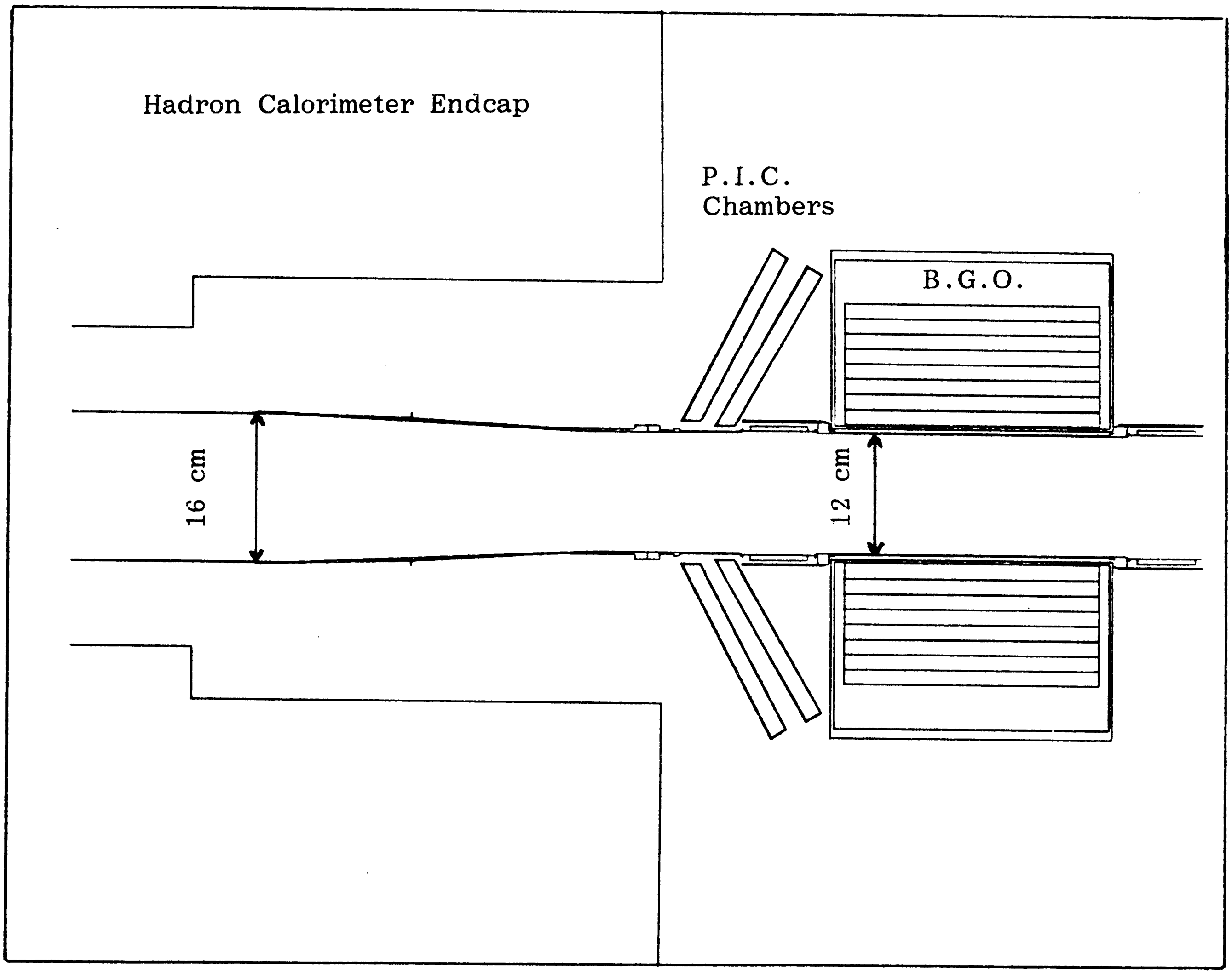


Figure 1

The L3 Luminosity Monitor Region

chambers) will be composed of 8 sectors covering 45° each in azimuth. The wires extend over four sectors at a time, stretched over combs to guide them across sectors. In addition, cathode strips are provided with a width of about 3° in order to measure the azimuth. The tracking device consists of two PIC chambers per arm located less than 10 cm away from the BGO array and rotated by 22.5° relative to each other to guard against possible inefficiencies near the combs.

The BGO array is cylindrically symmetric. The crystals are arranged in eight rings, as shown in Fig. 2, each covering 15 mm radially, parallel to the beampipe. Azimuthally, they are arranged in sixteen sectors of 22.5° each. Each sector consists of 19 crystals of different sizes. To ensure optimum

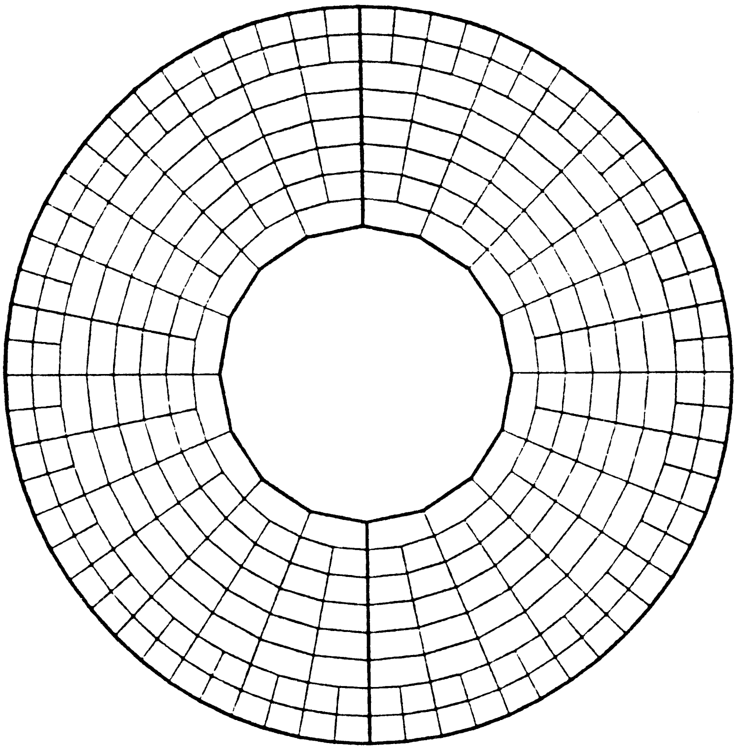


Figure 2

The BGO Crystal Array

shower containment, a software trigger condition is defined that limits the acceptance to the inner six of the eight rings. This also matches the full efficiency range of the PIC chambers. The BGO array is split into two halves that separate during each filling of the LEP ring. A hydraulic device with a measured positioning accuracy of 10 microns will close the array again for a run. A lead shield between BGO and beampipe provides for further radiation protection. In addition, any possible radiation damage and recovery will be monitored by LED pulsing. The main characteristics of the L3 Luminosity Monitoring System are summarized in Table 1.

The trigger consists of two sub-triggers. Apart from an energy trigger responsible for large amounts of energy deposited in total in the two BGO arrays (e.g. for tags in two-gamma physics), there will be a geometrical trigger that requires the observation of a minimum amount of energy (e.g. half the beam energy) in each of the two BGO arrays, in coincidence. The azimuthal width of the overlap region for the coincidence is defined as two BGO sectors, i.e. 45°. This trigger scheme allows the observation of radiative (and non

Table 1

Main characteristics of the L3 Monitoring System

Distance from the Interaction Point $Z_{min} - Z_{max}$ (m)	2.65 - 2.9
Amount of material in front (X_0)	0.10 - 0.15
Beam pipe radius (cm)	6.0
Radial extent of physical BGO array $R_{min} - R_{max}$ (cm)	6.8 - 19.0
Radial extent of acceptance area $R_{min} - R_{max}$ (cm)	8.5 - 17.5
Effective polar angle coverage $\Theta_{min} - \Theta_{max}$ (mrad)	30 - 62
Effective Bhabha cross-section σ(nb)	100
Length of BGO crystal (cm)	26.0
Length of BGO crystal (X_0)	24
Tracking chamber resolutions (entire track)	
* ΔR (μm)	< 300
$\Delta\Theta$ (mrad)	< 0.12
* $\Delta\Phi$ (degrees)	0.8
Calorimetry	
* $\Delta E/E$(%)	0.5 - 1.0
* ΔR (μm)	< 800
$\Delta\Theta$ (mrad)	< 0.3
* $\Delta\Phi$ (degrees)	< 0.6

* has been measured in a 50 GeV electron test beam

radiative) Bhabha events as well as of background interactions. Software event studies will then control the amount of background to be admitted into the luminosity event sample. The tracking chambers are not included in the trigger scheme.

2. PRECISION GOALS FOR THE L3 LUMINOSITY MONITOR

The Luminosity Monitor will accept an angular region of about 30 to 62 milliradians with full efficiency. This corresponds to an effective Bhabha cross-section $\sigma \simeq 100$ nb. Assuming an average luminosity of 10^{31} $cm^{-2}s^{-1}$, a trigger rate of about 1 Hz will result. It has to be compared to the

0.25 - 0.3 Hz expected rate from Z events. Thus, a statistical error of about 1% on the luminosity will be achieved in a 2.5 - 3 hour run.

We aim at a precision of better than 2% on the absolute luminosity on a run to run basis. The main limitation will then come from systematic errors which can be separated into four major sections as follows :

2.1 Theoretical uncertainties.

These include uncertainties in the Bhabha cross-section, e.g. weak interaction effects, vacuum polarization, or multiple photon emission beyond order α^3. These errors are being studied and are at present estimated to contribute about 1% to the systematic errors.

2.2 Detector performance

The basic features of the luminosity detector have been listed above. The inherent limitations are expected to contribute to the systematics well below the percent level. In particular, the loose total energy trigger and the requirement of good lateral shower containment will produce no significant loss of Bhabha events. Longitudinal shower containment is almost complete in 24 radiation lengths and can be ignored against the more incomplete lateral containment. The tracking chamber resolution of better than 300 microns, taken at the critical inner radius R = 8.5 cm, produces a luminosity error of less than 0.6% per event and this will be reduced to zero by the statistics of a three hour run. Chamber production tolerances, as well as final alignment and survey, should be below the 100 micron level and thus contribute 0.2% to the systematics. The chambers will be mounted in a fixed position on the beampipe, and they will be surveyed with respect to the LEP quadrupoles. Chamber efficiencies have probably the most critical effect in the systematics. They are required to be known to better than 1% per wire, and also stable at that level. When requiring 8 out of 10 wires per track, a drop by 1% in all wire efficiencies would translate into a systematic effect of 0.1%, whereas a requirement of 3 out of 4 wires (near the comb regions where the chambers are inefficient) would produce 0.3% in systematics.

Thus, by carefully monitoring any wire inefficiencies, especially near the onset of full efficiency at R = 8.5 cm, one should be able to control their effect to well below the percent level.

2.3 LEP beam backgrounds

Minor contributions to the systematics come from non Bhabha interactions mixed into the event sample. Synchrotron radiation induced events are easily removed by a suitable energy threshold in the trigger. Off-momentum electrons resulting in beam gas or beam wall interactions will be studied as part of the event sample. They are identifiable as highly acoplanar events which violate the geometric trigger but which manage to be accepted by the energy trigger. A study of these events will permit a reliable background subtraction accurate to better than the percent level.

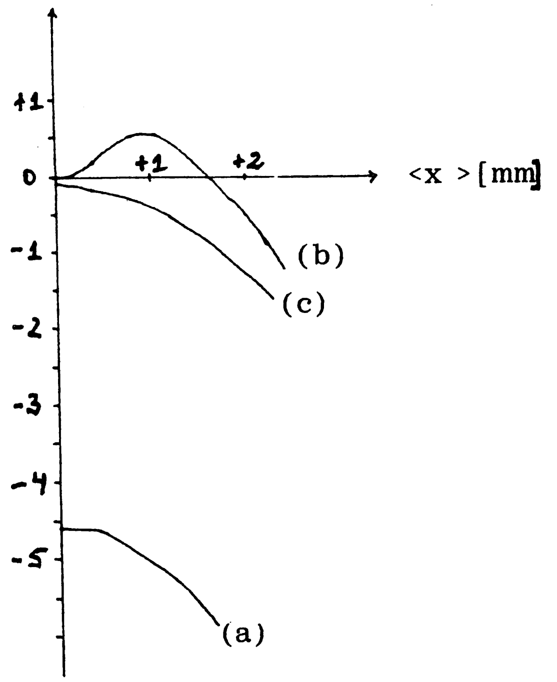
2.4 LEP beam parameters

One of the most difficult obstacles to keep luminosity systematics below the percent level is the dependence of the observed Bhabha rates on variations of the beam parameters at the interaction point. In addition, the parameters are predictions by the LEP staff for values at the I.P. derived from single separated beam measurements, and some parameters are thus difficult to quote. Hence, a major effort was undertaken to largely eliminate the dependence of the Bhabha calibration on the precise values of the beam parameters. After consultation with the LEP instrumentation group, the following parameters were picked as the most essential to control [5] :

I.P. position	$(\langle x\rangle, \langle y\rangle, \langle z\rangle)$
I.P. width	$(\langle\sigma_x\rangle, \langle\sigma_y\rangle, \langle\sigma_z\rangle)$
Beam dispersion	$(\langle\sigma_{x'}\rangle, \langle\sigma_{y'}\rangle)$
Angular beam offset	$(\langle x'\rangle, \langle y'\rangle)$ called "Beam Tilt".

A Monte-Carlo study was undertaken to investigate the effects of beam parameter values, in combination with the trigger design and event selection [2].

From the start, the L3 luminosity monitor has foreseen the use of a (software) asymmetric trigger [6] : only one of the two detector arms requires the nominal geometrical trigger between 30 to 62 milliradians, whereas the other arm has to satisfy the geometrical trigger within a loosened angular range from 30-d to 62+d milliradians, with "d" a parameter to be suitably chosen. As an example, the event rates drop almost linearly with $\langle x\rangle$ when $d = 0$. With increasing d, the dependency becomes parabolic until for a particular value of d, there is no more dependency for a wide range of $\langle x\rangle$ values. With still larger d values, one obtains even a rise in rate with $\langle x\rangle$ for small



a) d = 0, σ_x , σ_y , σ_z as for (c).

b) d = .6 mrad, σ_x = σ_y = σ_z = 0

c) d = .6 mrad, σ_x = 0.3 mm, σ_y = 0.012 mm, σ_z = 33 mm

Figure 3

Effect of asymmetric trigger

Calibration change (%)

values of <x>. This behaviour is illustrated in Fig. 3. In order to guarantee an absolute luminosity systematic error below 1% for a wide range of beam parameter values, a value of d = 0.6 milliradians has been chosen which is in this sense overcompensating.

During the study, a value of 400 microns for the chamber resolution has been used. The energy showers were not simulated, but lateral non-fluctuating shower spreading has been allowed for. The trigger as explained in section (1) has been simulated with an energy trigger threshold of 78% of beam energy per arm. The events themselves were produced by a standard generator [7] including first order radiative events.

It is important to realize that the results from the study on the systematic error apply only in case that a particular beam parameter setting cannot be measured (or predicted). If a parameter can be measured (e.g. by the central detector), it can clearly be corrected for and its effects on systematics removed. A study will be undertaken to investigate the feasibility of measuring beam parameters (beam spot offset, beam width, beam tilt, ..) with the luminosity monitor itself. Hence, the stated results are worst case only. Table 2 shows "typical values" for the parameters as they have been estimated by the LEP instrumentation group [5]. The column labelled "absolute change" shows the corresponding change in the luminosity calibration, in per mille.

In conclusion, it can be stated that the systematic error, due to ignorance of beam parameter settings, on the absolute luminosity can be kept below the percent level for values several times larger than the column labelled "Typical Value" in Table 2 hereafter, using a value of d = 0.6 milliradians.

Table 2

Systematic Uncertainties in relative luminosity measurement

Parameter at I.P.	Typical Value	Known to	Absolute Change in $^{\circ}/_{\circ\circ}$ for Typical Value	Systematic* Uncert. $^{\circ}/_{\circ\circ}$
$<x>$	100 μm	15 μm	0.1	0.10
σ_x	300 μm	10 μm	1.5	0.05
$<y>$	100 μm	5 μm	0.1	0.03
σ_y	12 μm	1 μm	0.06	0.01
$<z>$	1 mm	0.7 mm	0.1	0.11
σ_z	33 mm	0.5 mm	1.5	0.08
$<x'>$	0	2 μrad	0	0.01
$\sigma_{x'}$	175 μrad	5 μrad	0.05	0.01
$<y'>$	0	10 μrad	0	0.04
$\sigma_{y'}$	175 μrad	5 μrad	0.05	0.01
Total				0.45

* these errors $\Delta(L)/L$ are obtained under the assumption that all distributions are gaussian.

3. BUNCH TO BUNCH NORMALIZATION FOR L3

For the purpose of this report, it is not of vital importance to ensure a systematic error below 1% in the absolute luminosity. As demonstrated in the introduction to chapter "Normalization" in these proceedings [8], it is relevant instead to control the relative luminosity systematics between different bunch collisions to the per mille level. All of the systematic errors listed in sections 2.1, 2.2 and 2.3 will cancel in a relative luminosity measurement. Thus, one has only to reevaluate the Monte Carlo study of 2.4 for bunch-to-bunch parameter variations. The results are listed in Table 2.

The last column lists the per mille change in the Bhabha rate upon a variation of a parameter by the "Known to .." amount around the "Typical Value" setting [5], all remaining parameters being fixed at their respective nominal values. In particular, this means that the study lists results when the beam spot widths were at their nominal values. If one were to set the beam spot width artificially to zero, the systematics for the beam spot position, beam tilt, etc.., would be much more severe. However, σ_x, and σ_y, were set to zero when not taken as parameter under study.

Under these conditions, the final figure of $\Delta(L)/L$ was obtained by adding linearly the various contributions :

$$\frac{\Delta(L)}{L} \approx 0.4°/_{\circ\circ}$$

is the error in luminosity calibration due to unknown and uncontrollable fluctuations in the geometric parameters as listed in Table 2. In order to arrive at the "bunch to bunch" luminosity systematics as used in the introduction, one has to set :

$$\Delta(\frac{Li}{Lj}) = \sqrt{2} * \frac{\Delta(L)}{L} \approx 0.6°/_{\circ\circ}$$

to obtain the relative error in calibration between two different bunch collision classes.

In conclusion, the L3 luminosity monitor will collect Bhabha statistics at a rate fourfold higher than the Z events. Given a polarization programme at LEP, it appears that, under the conditions specified in the text, it could control the relative luminosity measurement from bunch to bunch with the required accuracy.

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References

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