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BACKGROUND AND LUMINOSITY MONITORING AT THE CERN ISR

J-Y. Hemery, F. Lemeilleur, R. Olsen, K. Potter
CERN, 1211 Geneva 23, Switzerland

1. Introduction

At the CERN ISR the luminosity and background conditions are monitored in the intersection regions by means of simple scintillation counter hodoscopes. The information from the counters is used to optimise machine conditions for the various physics experiments. The many factors influencing the accuracy of luminosity monitoring at the ISR have been investigated and the results are described.

2. Hardware and data handling

All eight ISR intersections are equipped with a standard detector system consisting of eight scintillation counters, two upstream and two downstream of the crossing point on each beam (Figure 1). The exact geo-

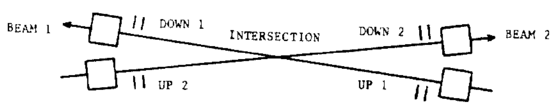

Fig. 1 - Standard Monitor Layout

metrical lay-out, however, varies because of the different high-energy physics experimental equipment. In particular in two intersections equipped with low-β insertions the downstream telescopes accept large-angle secondaries outside the insertion quadrupoles.

The scintillation counters (25cm x 20cm x 0.6cm), which are equipped with light diodes for test purposes, feed signals to NIM electronics in four auxiliary buildings, but high voltages and the light diode system can be controlled from the main control room (SRC). This allows the counters to be switched off during machine operations likely to produce excessive particle rates.

The fast logic (Figure 2) produces six signals

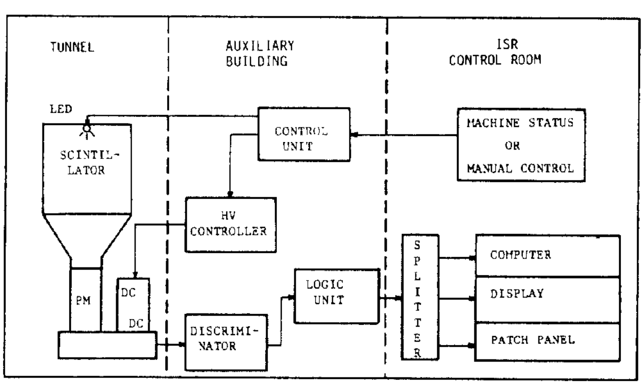

Fig. 2 - Block Diagram of Detector System

from each intersection, two backgrounds on each beam from the upstream and downstream telescopes and luminosity and accidentals from the two downstream telescopes placed in coincidence. The signals are sent to the SRC (100-700 m) using special line drivers where they are scaled by the ISR control computer, displayed on bargraph ratemeters (backgrounds) and are also available for test purposes. Selected rates can be sent to paper chart recorders by means of a μ-processor controlled selection system.

In intersection 5, four scintillation counter telescopes are installed to provide a more precise measurement of the luminosity. Each telescope, one above and one below each beam, consists of three 20 cm x 20 cm x 1 cm scintillation counters. Signals from the system (reference monitor) are processed by a stand alone μP-system to give a continuous display of the luminosity with automatic selection of the energy dependent monitor acceptance and integration time. An independent set of large acceptance counters is also available in this intersection for low luminosity runs.

Additional information on background conditions, as seen by the different physics experiments, is provided by means of signals coming from the experiments themselves. The combination of standardised and specialised background information is invaluable for ISR operation.

3. Background monitoring

Apart from the injection optimisation and filling processes giving rise to direct particle losses and induced radioactivity, a major problem is the control, the measurement and hence the limitation of background in the intersections during physics data taking.

The protons of a coasting beam experience nuclear scattering on the residual gas [1], giving rise to particle current losses all around the ring. At the ISR, with an average gauge pressure of 3×10^{-12} torr and currents of 30 Amps (6×10^{14} circulating protons), the average losses per metre are 3.5×10^2 protons per second. For the straight section upstream of an intersection, this corresponds to less than 1 per cent of the beam-beam rate.

More important is the flux of protons scattered out from the beam halo hitting aperture limitations. This halo develops from transverse beam blow up processes during the run and is due to intra beam scattering [2], to multiple scattering on residual gas and to particle motion disturbances created by magnetic field instabilities and resonances. At the ISR, the residual gas pressure is so low that with a correctly tuned machine, the main contribution comes from intra beam scattering. The beam height increases at a rate of about 10^{-2} per hour with 30 A beams, which is in good agreement with the calculated rate due to intra-beam scattering alone.

In order to avoid scattered protons reaching the sensitive high energy physics detectors, the beam aperture is limited by a set of movable collimators [3] which concentrate the losses in the beam dump region. The aperture is defined in both the horizontal and vertical planes by primary collimator blocks. Secondary collimators are placed downstream at $\pi/2$, π and $3\pi/2$ betatron phase advance, in order to intercept the particles scattered from these blocks. Collimators are adjusted at the beginning and during stable beam runs by reference to the upstream and downstream scintillation counter signals, permanently recorded in the main control room.

Background to beam-beam ratios of a few per cent are generally achieved for several hours. When necessary, beam cleaning is performed using scrapers. A typical rate of current loss during a high intensity physics run is 10 ppm.mn-1.

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4. Beam-Beam Optimisation

After filling and before physics data-taking periods, the beams are vertically steered in each intersection under computer control to obtain maximum luminosity.

The beams are displaced in 0.5 mm steps (ΔZ) in all intersections simultaneously using horizontal field magnet adjustments (Section 6). For each step, the beam-beam rate in each intersection, R_M (ΔZ) is measured. The integration time is automatically adjusted in such a way that the statistical error is less than 5 %. The two first steps indicate the relative position of the beams and the directions of the movements are reversed if necessary to go in the right direction. When the maximum R_M has been passed, parabola fits are performed on the three last steps to define the position in each intersection where R_M is a maximum. The approximation of fast parabola fits of gaussians is accurate enough to achieve optimum positions within $\pm$ 0.1 mm, for heff = 4 mm and ΔZ = 0.5 mm, corresponding to maximum luminosities within $\pm$ 0.5 %. The program continuously monitors power supply settings and beam current losses.

Full computerisation of this process which is needed before every run has saved a lot of time. All eight intersections can now be optimised in about ten minutes.

5. Luminosity Calibration and Monitoring

The measurement of luminosity is crucial since the knowledge of the absolute values of the measured cross sections depend on it.

For two beams of intensity I1 and I2 colliding head-on with a horizontal angle ψ , the luminosity [1] is:

$$L_o = 1.3 \times 10^{27} \frac{I1\ I2\ (\text{Amps})}{\text{tg}\ \psi/2.\text{heff(cm)}} \tag{1}$$

where the effective height heff depending on the vertical beam densities $\rho_1(z)$ and $\rho_2(z)$ is :

$$\text{heff} = \frac{\int \rho1(z)dz \ \int \rho2(z)dz}{\int \rho1(z)\ \rho2(z)dz} \tag{2}$$

Since I1 and I2 are known from an accurate current transformer [4], the luminosity depends only on heff which is normally measured by the Van der Meer method[5]. It consists of recording the event rates R_M (ΔZ) = σ_M.L(ΔZ) in monitors, with σ_M acceptances, while displacing the two beams vertically relative to one another in steps of ΔZ. Fig. 3 shows the results of

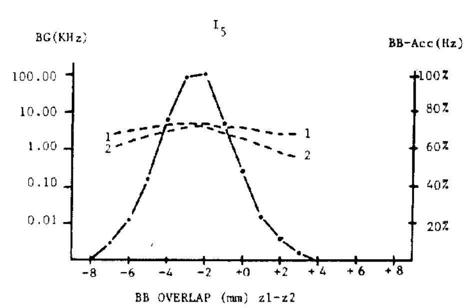

Fig. 3 - Luminosity Calibration Curve

such a measurement. Integrating this equation with L and heff of equations (1) and (2), we get (for details see Ref. 5) :

$$\int_{-\infty}^{+\infty} R_M\ (\Delta Z)d\ (\Delta Z) = \sigma_M.L.\text{heff} \tag{3}$$

and then

$$\text{heff} = \frac{\int_{-\infty}^{+\infty} R_M\ (\Delta Z)\ d\ (\Delta Z)}{R_M\ (\Delta Z = 0)} \tag{4}$$

that is the area of the curve of Fig. 3 divided by the rate at the optimum position. Each monitor acceptance can be deduced ($\sigma_M = R_M/L$) and used for luminosity monitoring during data taking periods.The accuracy of the measurement depends on the vertical beam displacement calibration and reproducibility (see Section 6) and on the monitor acceptance dependence over stack positions.

A monitor integrates events coming from different angles and momenta :

$$R_M\ \alpha \int_{\theta 1}^{\theta 2} \int_{\phi 1}^{\phi 2} \int_{p1}^{p2} \frac{d^2\ \sigma pp}{d\ \Omega\ dp}\ \sin\theta\ d\theta\ d\phi\ dp \tag{5}$$

Fig. 4 shows the strong momentum dependence of the reference monitor σ_M. A calibration is needed at each operational beam momentum.

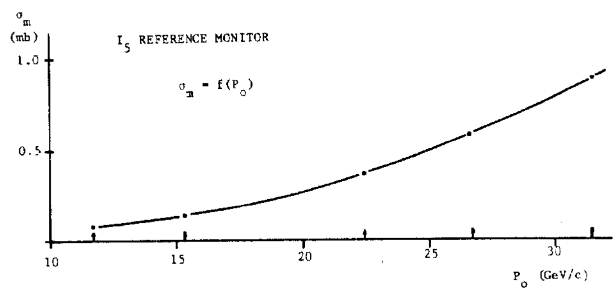

Fig. 4 - Variation of the Reference Monitor Acceptance with Momentum

For high intensity physics runs, the stacks extend over the full aperture of the ISR and the rates R_M depend on the vertex positions inside the interaction diamond. The p-p elastic events, whose collinearity gives rise to a strong geometrical dependence in the monitor acceptance, must be avoided. Measurements made with small stacks at various radial positions, with the reference monitor placed at a small angle in the forward direction, have shown that σ_M varies by up to 20 % at 11.8 GeV/c when accepting all elastic and inelastic events. Selecting the inelastic events only, limits the vertex dependence of the σ_M's. The radial dependence measurements performed with the reference and the standard monitors give variations of 1 to 5 % for σ_M's when measured for inner and outer stacks compared to those obtained for centred stacks. The σ_M dependences over the vertical diamond displacements vary from 0.5 to 3 % per millimetre. Generally, the radial and vertical σ_M dependences can be reduced by using large area scintillators accepting beam-beam scattered particles at not too small angles.
The rather large acceptance variations of the standard monitors are due to the fact that small size scintillators are used in places where they do not interfere with the large high energy physics detectors. Consequently, for high intensity stacks, the luminosity monitoring with the standard monitors is not better than a few per cent.

6. Vertical bump calibration

As described in Section 5, the Van der Meer method of measuring the ISR luminosity consists of determining an effective height in terms of beam displacements.

These displacements are made by exciting four horizontal field magnets placed symmetrically about the intersection region. Two of these magnets at around $\pi/2$ from the crossing point are used to make an approximately local closed orbit distortion while the similar magnets for adjacent regions are used as correction elements to ensure that the orbit distortion is as perfectly local as possible. As there is no non-destructive method of measuring the vertical position of the DC ISR beam to sufficient accuracy, the currents in these four magnets are used to define the beam displacement.

Errors can arise from a number of sources :

1) Calculation errors in determining the field required to obtain a beam displacement. This calculation requires an exact knowledge of vertical β values and relative phases.

2) Setting errors in the current through each of the four magnets.

3) Errors in the magnetic measurements used to establish the relationship between current and magnetic field.

4) Magnetic hysteresis which makes the relationship between current and magnetic field dependent upon the recent history of the magnet.

All these sources of error have been carefully investigated and checked by calibrating the beam displacements using a scraper driven by a high precision screw [6]. The method is destructive and hence is only capable of measuring the vertical position of successive pulses but an accuracy of better than ± 10 µm has been consistently obtained. Early results showed that the effects of magnetic hysteresis are appreciable, non-reproducible errors of up to 0.08 mm can occur in displacements of a few millimetres. A correction procedure has been established based on a model of the hysteresis loop [7].

The success of this correction is illustrated in Figure 5, where the difference between the scraper measured beam position and the nominal position is plotted as a function of nominal position. The measurements are reproducible and lie on a straight line, the scatter being characterised by σ_s = 6 µm. However, as can be seen from the slope of the fitted line, there is a linear difference between the scraper scale and the beam displacements of 1,5 %. The source of this error has not been established but must result from a combination of the possible errors outlined above.

The calibration measurements are made with single pulses (~150 mA) on central orbit, while luminosity calibrations are generally made with small stacks of a few amperes, hence other errors could be introduced. A space charge effect has been calculated as a function of the coherent Q_v shift [8], but is negligible (~ 0,1 %) for stacks of up to 5 A, when the beam is moved in one intersection region alone. Small stacks also have a momentum spread and a range of mean horizontal orbits. Beam displacements have been measured as a function of radial position but, since the dependence is small and approximately linear any errors are negligible for well-centred stacks.

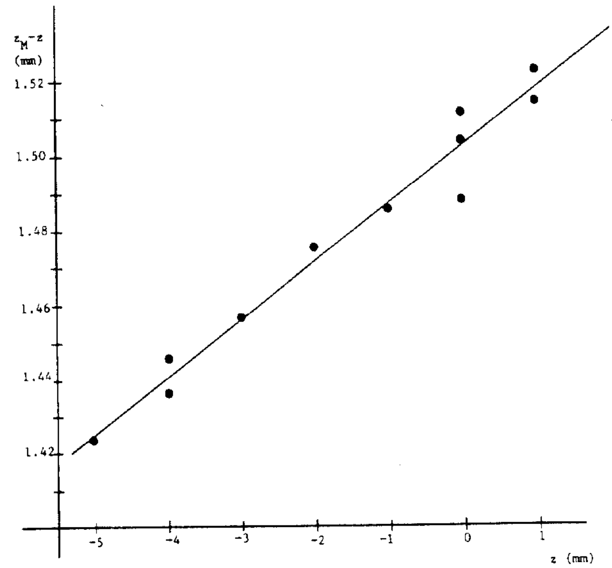

Fig. 5 – The Difference between the Vertical Centre of the Beam Measured with Scrapers (Z_M) and the Nominal position (z) plotted as a Function of the Nominal Position.

Using the smallest possible limits on power supply setting errors, a hysteresis correction and very careful control of all other relevant machine parameters it is expected that in the future it will be possible to maintain the errors in the beam displacement scale to less than ± 0.5 % for individual luminosity calibrations. This is particularly important for the ISR experiments currently engaged in measuring the $p\bar{p}$ total cross section and the pp-$p\bar{p}$ total cross section difference. To this end precision scrapers are being used to verify the beam displacements in the same intersection region and machine conditions as the total cross-section measurements.

References

1. G. Guignard, CERN 77-10
2. A. Piwinski, Intra beam scattering, Proc. IXth Int. Conf. on High Energy Accelerators, Stanford, 1974, 665-679
3. T. Risselada et al., The CERN ISR Collimator System, IEEE Transaction on Nuclear Science, NS-26, No3, 4131, June 79
4. K. Unser, A torroidal DC Beam current transformer with high resolution, these proceedings
5. G. Giacomelli and M. Jacob, Physics at the CERN-ISR, Physics Reports, 55(1), 1-132 (1979)
6. K. Potter, S. Turner, High precision scrapers for ISR luminosity measurements, IEEE Transactions on Nuclear Science, Vol. NS-22 No 3, 1589, June 75
7. T. Taylor, Private Communication
8. P. Bryant, J-P. Gourber, Experimental Investigation of Single Beam and Beam-Beam Space Charge Effects. Proc. IXth Int. Conf. on High Energy Accelerators, Stanford, p 87, 1974