EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
CERN – EST

CERN EST/2001-003 (LEA)

A luminosity monitor for the Large Hadron Collider

Anne-Laure Perrot

CERN/EST-LEA, Meyrin CH 1211Geneve 23
IPHE Université de Lausanne CH 1015 Dorigny

Abstract

The LHC luminosity will reach 10^{34} $cm^{-2}s^{-1}$ but special runs at 10^{28} cm^{-2} s^{-1} are foreseen. Thus a luminosity monitor must have a dynamic range of six orders of magnitude. A good tolerance to radiation is also required. A detector using both ionisation and secondary emission techniques has been studied in this context. Its design is based on monitors used previously at the CERN PS and SPS machines. Special attention was devoted to minimize leakage currents. Linearity in both Secondary Emission Counter (SEC) and Ionisation Chamber (IC) modes has been tested from ~10^4 incident particles to ~10^8 incident particles. SEC is linear above ~3 x 10^6 incident particles while IC is linear over the full studied range. However, because of the radiation environment at the LHC, the SEC mode is much preferred at high intensity. A solution actually foreseen is to switch from IC to SEC mode when the incident current on the monitor is ~10^{-13} A corresponding to an LHC luminosity of ~10^{31} cm^{-2} s^{-1}.

Paper presented at the "2000 IEEE Nuclear Science Symposium and Medical Imaging Conference"

Geneva, Switzerland
June 2001

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The LHC luminosity will reach 10^{34} $cm^{-2}s^{-1}$ but special runs at 10^{28} cm^{-2} s^{-1} are foreseen. Thus a luminosity monitor must have a dynamic range of six orders of magnitude. A good tolerance to radiation is also required. A detector using both ionisation and secondary emission techniques has been studied in this context. Its design is based on monitors used previously at the CERN PS and SPS machines. Special attention was devoted to minimize leakage currents. Linearity in both Secondary Emission Counter (SEC) and Ionisation Chamber (IC) modes has been tested from ~10^4 incident particles to ~10^8 incident particles. SEC is linear above ~3 x 10^6 incident particles while IC is linear over the full studied range. However, because of the radiation environment at the LHC, the SEC mode is much preferred at high intensity. A solution actually foreseen is to switch from IC to SEC mode when the incident current on the monitor is ~10^{-13} A corresponding to an LHC luminosity of ~10^{31} $cm^{-2}s^{-1}$.

I. INTRODUCTION

CERN is building a new accelerator, the Large Hadron Collider (LHC). It will give high luminosities to experiments to study very rare processes. However, the precise measurement of the luminosity, L, is difficult on this p-p (proton-proton) collider. A direct evaluation with the beam parameters (intensity and emittance) [1] or with the "van der Meer method" [2] will lead to a great uncertainty. TOTEM (TOTal and Elastic Measurement) will measure the p-p cross-section with high precision using the "luminosity independent method "[3], [4]. This will allow the calibration of the luminosity monitor at L ~10^{28} $cm^{-2}s^{-1}$.

The challenge for a luminosity monitor at the LHC is the dynamic range of six orders of magnitude (L between 10^{28} $cm^{-2}s^{-1}$ and 10^{34} $cm^{-2}s^{-1}$). Being close to the interaction point it also requires a good tolerance to radiation. These requirements are not fulfilled by detectors currently in use. It is proposed to study if a detector based on the concepts of Secondary Emission Chamber (SEC) and Ionisation Chamber (IC) developed years ago and still in use at CERN could be a luminosity monitor for the LHC. After a short introduction to IC and SEC principles, the design and performance of a prototype are reported.

II. IC AND SEC PRINCIPLES

An IC belongs to the family of ionisation detectors which are based on the direct collection of the electrons and ions produced by an ionising particle in the gas [5], [6]. A basic configuration is a pair of metallic plates surrounded by gas (see figure 1). A voltage difference is applied between the plates. An incident particle between the plates creates along its path a number of ion-electron pairs proportional to its path length in the gas. The electrons and positive ions move toward the anode and the cathode respectively, where they are collected. As the voltage is increased, the recombination forces are overcome and the current begins to rise as more and more of the electrons are collected. At some point, all created electrons will be collected. This is the IC mode in which we want to operate.

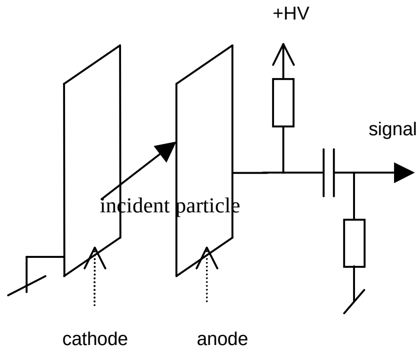

Figure 1: Sketch of an ionisation detector

For many years SEC have been used as standard intensity monitors in proton external beam lines. It is a simple and radiation hard detector. The SEC operation is based on the Secondary Electron Emission (SEE) process [7]. This latter can be divided into three steps [8]. First, the interaction of incident particles with target foils and the corresponding excitation of electrons. Some of these electrons receive enough energy to be knocked out from the atoms. Second, the diffusion of the electrons toward the foil surface with energy loss through inelastic collisions. The probability of reaching the surface decreases with the depth at which the electrons are excited. Finally, some of the electrons can pass the surface potential barrier. The SEE due to incident charged particles of high energy is a surface phenomenon independent of the target thickness. The principle of operation of a SEC is very simple (see figure 2). When a charged particle passes through a thin foil of metal, SEE occurs (its accompanying electromagnetic field interacts with the peripheral electrons on the foil surface atoms, as well as with the free electrons of the metal, providing some of them with enough energy to be ejected from the atoms and to escape from the surface). The foil surface is then an electron emitter. Another foil positively biased will collect these electrons. Collection is optimised when in vacuum.

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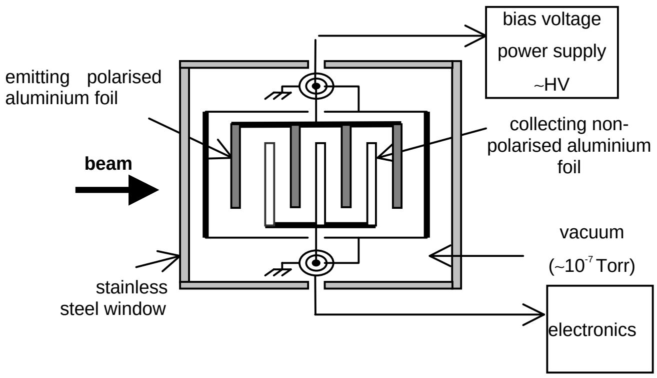


Figure 2: Principle of Secondary Emission Chamber

III. Construction of the New Prototype

The conception and design of the new monitor are based on those of SECs used at the PS (Proton Synchrotron) and SPS (Super Proton Synchrotron) [9]. The overall mass of the foils and windows has to be kept to a minimum. It determines the monitor dimension, the foil material and the window material. The SEC has to be bakeable, in order to reduce outgassing to obtain high vacuum and clean surfaces. Finally, it has to present good resistance to radiation damage. The conversion SEC to IC is simply done by filling the chamber with argon. Before presenting the monitor construction and introducing briefly the associated electronics, the improvements of the new prototype are pointed out.

A. Improvement of basic configuration

Our prototype differs from previous SECs used at CERN in two main characteristics. First, the addition of a ground insulated stainless steel cylinder inside the vacuum tank (see figure 3). Second, the use of triaxial connections. The aim is to minimise leakage currents, mass loops and noise pick-ups. The external tank acts now as a Faraday cage, it isolates the monitor electrodes (aluminium foils) from the external electromagnetic noise while the internal cylinder acts as a "floating" shield.

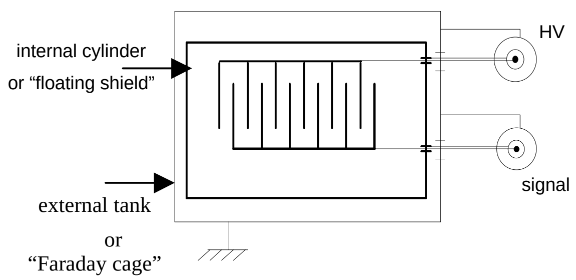


Figure 3: Triaxial configuration of the new prototype

B. Construction of the new prototype

It can be divided into four main steps. **Step1**: aluminium foils are mounted on circular stainless steel frames. They form the monitor electrodes (see figure 4). **Step 2**: twenty one electrodes are piled up on six support bars (see figures 5 and 6). In the final state, each collecting electrode is surrounded by two emitting ones. **Step 3**: introduction of the "electrodes block" in a stainless steel cylinder which will act as a floating shield (see figure 7). **Step 4**: the overall assembly is inserted inside an external stainless steel tank which will act as a Faraday cage (see figure 8). In SEC mode, the vacuum inside the chamber is around 10^{-7} Torr. In IC mode, the chamber is filled with argon at atmospheric pressure. Table 1 reports some technical specifications of the monitor.

Figure 4: Aluminium foil on a stainless steel frame

Figure 5: Electrode pile-up: intermediate step

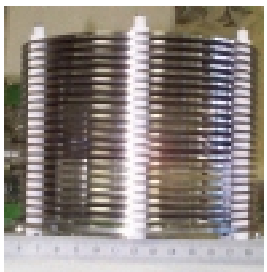


Figure 6: Electrode pile-up: final step

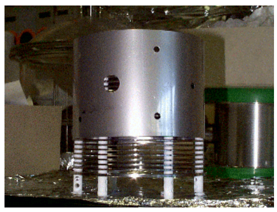


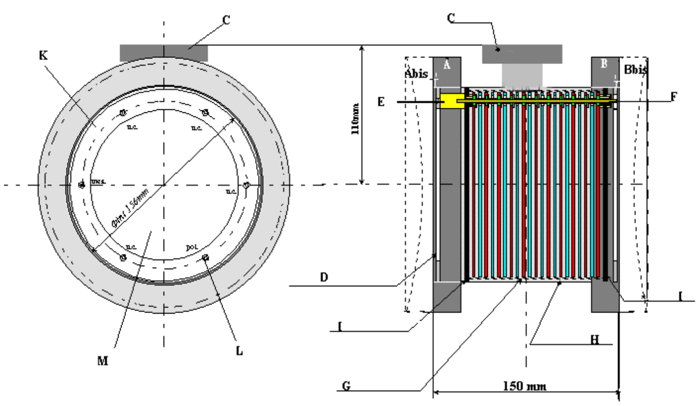
Figure 7: Insertion inside the internal cylinder

Figure 8: Insertion inside the external tank

The chamber is presented in figure 9. It is a flanged stainless steel cylinder. Each of the two external flanges include a foil window (curved dotted line) made of stainless steel 25 µm thick. They make the vacuum sealing. The chamber components are chosen to withstand a bake-out temperature of the order of 250°C. On the top of the external tank a "four-ways" cross allows the signal output, the polarisation input and the vacuum system connections. Two prototypes have been built. They differ in the insulation mode between two consecutive electrodes. In the first prototype, insulation is assured by ceramic while vacuum or gas is used in the second prototype. The resistivity is increased in this last version, thus minimizing the leakage current. The choice of aluminium as electrode material results from a compromise between radiation hardness and efficiency [10].

Table 1
Monitor technical specifications

foils	21 (11 emitting electrodes 10 collecting electrodes) Al (99% purity) thickness: 10 µm used diameter: 120 mm spacing: 5 mm
insulation	ceramic (macor and alumine Al_2O_3), thickness: 3 mm
other pieces	stainless steel (304 L type)



Front view Side view

A,B: internal flanges Abis, Bbis: external flanges
C: "4-ways" flange D: triaxial support
E: insulator cylinder F: stainles steel bar
G: internal cylinderH: external tank
I: electrode assembly support
K: Al foil frame L: stainless steel bar position
M: Al foil

Figure 9: New prototype

C. Associated electronic

As already mentioned, the monitor will work at luminosity between 10^{28} $cm^{-2}s^{-1}$ and 10^{34} $cm^{-2}s^{-1}$. Estimations of the monitor output current (or electronic input current) in SEC mode give values between 10^{-15} A and 10^{-9} A respectively. In ionisation mode the current is three orders of magnitude higher. The electromagnetic noise becomes important below 10^{-12} A and limits the signal detection. The

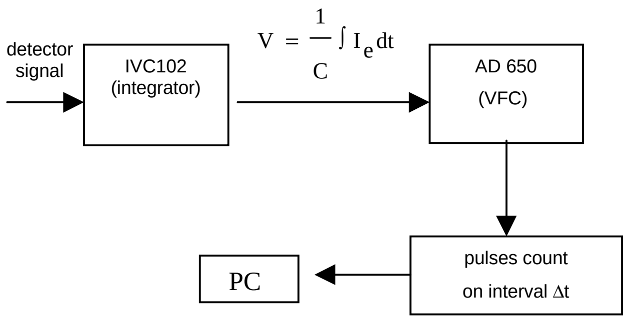


Figure 10: Sketch of the electronic chain

electronic components were chosen with the lowest intrinsic noise. A sketch of the electronic chain is presented in figure 10. The two main components of the circuit are a precision switched integrator transimpedance amplifier IVC102 by Burr-Brown [11] and a voltage to frequency converter (VFC) AD650 by Analog Devices [12]. The acquisition gate is activated by a trigger. IVC102 output voltage increases linearly with the integrated charge. After a fixed delay the gate is closed and the read-out is activated. The output voltage is converted into frequency by the AD650 and sent to a counter unit. At the end of the reading the system is reset. Then the IVC102 output voltage is set to zero. This represents a complete acquisition and reading cycle.

IV. PERFORMANCES

The performances of the monitor in both SEC and IC mode were determined comparing the response with a reference detector. The tests were carried out at CERN on the PS-T11 and the SPS-H6 extraction beam lines. The reference detector is a pair of scintillator-photomultipliers in coincidence in PS-T11 and a Precision Ionisation Chamber in SPS-H6, placed upstream of the luminosity monitor. The beam intensity could be adjusted with collimators. Before each extraction burst, the PS and SPS machines deliver a prepulse acting as trigger for the electronic readout.

A first series of tests performed during summer and fall 1998 allowed to specify the detection threshold of a previous SEC built around 1970. The background noise, electronic mass loops and pick-up limited the SEC detection to a current of around 10^{-12} A. The simulations show that the monitor in the LHC conditions must detect currents between 10^{-9} A and 10^{-15} A, thus a new SEC prototype was built. Its linearity tests were performed during 1999 and 2000 with intensities ranging from 3 x 10^4 to 6 x 10^7 incident particles per burst (see figure 11). This range corresponds to the intensities of the available PS and SPS beam lines.

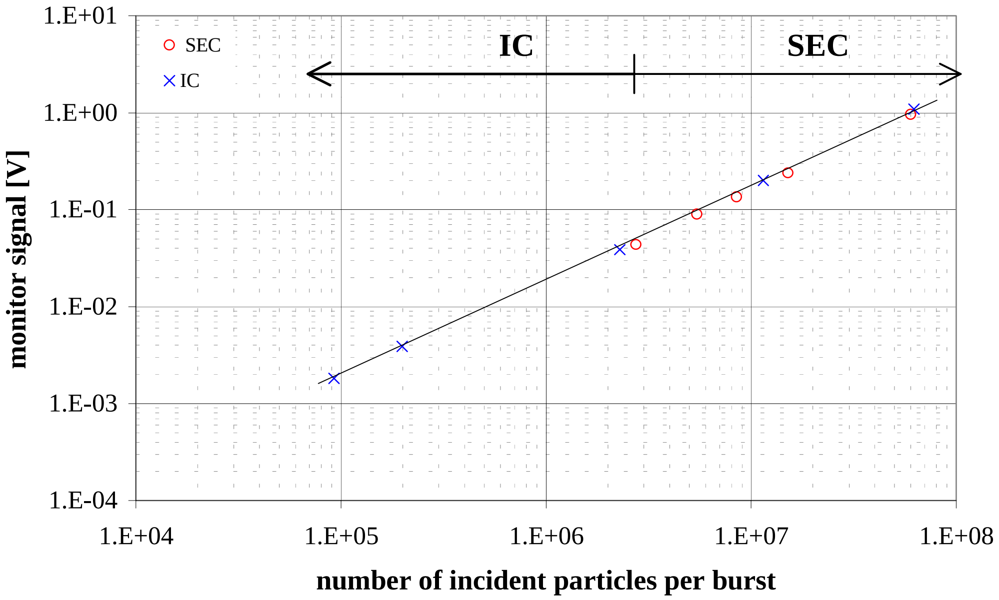


Figure 11: SEC-IC response versus the number of incident particle

Above ~ 3 10^6 incident particles per burst the SEC response is a linear function of the number of incident particles within 1%. We then deduce that at the LHC the SEC will be able to measure luminosity with a precision of ~3% for an integration time of 1 s, for luminosity above 10^{31} cm^{-2} s^{-1}. A conversion of the SEC into Ionisation Chamber (IC) is proposed to cover the LHC low luminosity region. We have transformed the SEC into IC by filling the chamber with argon at atmospheric pressure. The IC response is linear at the 1% level over the full experimental range of incident particles available. Its uncertainty during our tests is less than 2%. The IC could be used to measure the LHC luminosity from 10^{28} $cm^{-2}s^{-1}$. At high intensity, the LHC induced radiation may activate the inner gas of the IC which will result in the distortion of the IC response. The present idea is to use the monitor in IC mode at low LHC luminosity and in SEC mode at high LHC luminosity with a switch for a luminosity of 10^{31} cm^{-2} s^{-1}.

V. Acknowledgments

I wish to express my thanks to S. Weisz (CERN/EST-LEA) and Prof. A. Bay (IPHE, Lausanne university) for much helpful advice and discussions throughout the course of this work. I am very grateful to G. Molinari, J. Bosser and the CERN/PS-BD team for their assistance and help in the construction, setting-up and perfomance tests of the monitor. I would also like to thank K. Potter, CERN/EST-LEA group leader and W. Kienzle of the TOTEM collaboration for their encouragement and stimulation.

VI. References

[1] K. Piotrzkowski, Experimental aspects of the luminosity measurement in the Zeus experiment, internal report DESY F 35D–93-06, 1993.
[2] S. van der Meer, Calibration of the effective beam height in the ISR, CERN-ISR-PO/68-31, 1968.
[3] The TOTEM collaboration, Letter of intent, CERN/LHCC 97-49, LHCC/I11, p1, p30-31, fig.1 p9.
[4] M. Bozzo et al, Measurement of the proton-antiproton total and elastic cross-sections at the CERN SPS collider, Phys. Lett. 147B, p392, 1984.
[5] W. R. Leo, Techniques for nuclear and particle physics experiments, Springer-Verlag, chap.6, p119-127.
[6] K. Kleinknecht, Detectors for particle radiation, Cambridge University Press, chaps.1 and 2.
[7] V.Agoritsas and R. L. Witkover, Tests of SEC stability in high flux proton beams, IEEE Transactions on Nuclear Science, vol. NS-26 No 3, June 1979.
[8] The encyclopedia of physics, 2nd ed., edited by Robert M. Besançon, Van Nostrand Reinhold Company, p825.
[9] V. Agoritsas, Secondary Emission Chambers for monitoring the CPS ejected beams, Symposium on beam intensity measurement, Daresbury, proceedings edited by V. W. Hatton and S.A. Lowndes, DNPL/R1, 22-26 April 1968.
[10] G. Ferioli, R. Jung, Evolution of the Secondary Emission Efficiencies of various materials measured in the CERN SPS secondary beam lines, CERN-SL-97-71 (BI), 1997.
[11] Burr-Brown, email: http://www.burr-brown.com
[12] Analog Devices, email: http://www.analogdevices.com