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Design and Tests of a New Rest Gas Ionisation Profile Monitor Installed in the SPS as a Prototype for the LHC

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Based on the encouraging results obtained with a Rest Gas Ionization Profile Monitor of a first generation, a new monitor was designed and then installed in the SPS at the beginning of 2002. Its design fulfills all the requirements for a future installation in the LHC where four such monitors are foreseen. After the initial tests performed during the run of 2002, a few upgrading steps appeared necessary mainly in order to cope with the nominal LHC beam characteristics. They were implemented during the subsequent winter stop and the operation of the monitor was resumed in 2003 under various conditions of beam, ranging from a LHC pilot bunch up to beams having in the SPS nominal distributions in bunch number, intensity and energy for injection into the LHC. After a description of the monitor design, the measurements performed with the instrument during these last two years are discussed with the difficulties encountered and the corresponding implemented cures. Data acquired in 2003 on the whole spectrum of LHC beam characteristics are presented and the modifications made to prepare the 2004 campaign in a view to still improve the performance are also discussed.

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INTRODUCTION

A prototype gas ionization beam profile monitor was installed and under test in the SPS since 1999. The device, provided by DESY, was initially designed to exploit the ion signal produced by the ionization of the residual gas on the beam passage. It was adapted and inserted within a magnet with increased gap, and the electron signal used instead, the resolution obtained with the electron signal being generally better. Encouraging results were reported on several occasions, [1]. In particular, it was verified that useful information can be supplied in fast acquisition mode by measuring on consecutive turns, for example to perform injection matching tuning, as well as by integrating the signal on several beam passages in order to measure beam transverse distributions with a high precision.

Based on these results, it has been decided to equip the SPS and the LHC with such monitors for continuous transverse distribution measurements. A new monitor, working in the vertical plane, was then developed and installed in the SPS before the 2002 run. Its innovative design is compatible with incorporation in the LHC, for the start-up of 2007. Such issues as compactness, easier maintainability and optical tuning are tackled. The monitor commissioning in 2002, with the resulting steps taken, is reported and some measurements made in 2003 are mentioned and discussed. The perspectives for the year 2004 are also presented.

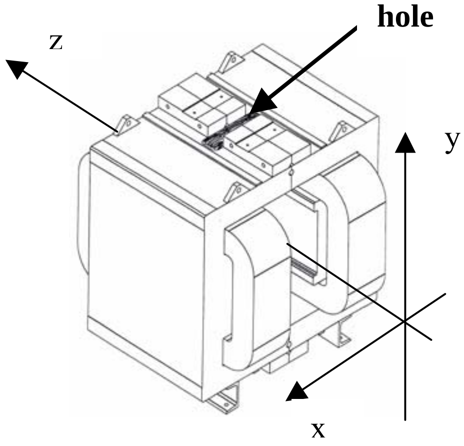
THE NEW MONITOR

In the LHC most of the beam instrumentation, apart from the Beam Position Monitors, will be incorporated on ambient temperature vacuum chambers sections, where transverse space contingencies are severe in the horizontal plane due to the proximity of the two beam vacuum chambers. A location has been reserved where 360 mm are available for the monitor section half dimension.

Another requirement of the LHC is to keep the vacuum chamber impedance budget to a minimum. This is achieved by avoiding abrupt steps in the vacuum chamber section, adding small angle transition pieces to connect parts having different cross section.

The Magnet

For the production of the magnetic field necessary to avoid the electron signal divergence, conventional magnets are used. They are recuperated from the former LEP wigglers and match nicely the space requirements with a section of 681x 646 mm^2. These magnets produce a magnetic field $B = 0.240$ T at maximum current ($I_{MAX} = 55$ A). Figure 1 gives a sketch of such a magnet with the basic geometrical parameters.



I_{MAX}	55	A
B_{MAX}	0.240	T
Strength	0.14	Tm
Gap width	200 x 200	mm^2
Section	681 x 646	mm^2
Overall length	680	mm

FIGURE 1. Sketch of the magnet used for the Gas Monitor with some basic parameters. The location of the hole through the yoke is also indicated.

A gap of 200 x 200 mm^2 is available between the yokes for the incorporation of the monitor tank. As represented in Figure 1, a racetrack shaped hole has been drilled through the magnet yoke to vertically extract the light signal coming from the monitor. The shape of the hole is such that while extracting on the left-hand side the signal coming from the ionization of the rest gas related to the vertical beam size, as explained hereafter, it is also possible to look, on the right-hand side, at the signal coming from the luminescence of the gas, and providing the horizontal beam size.

Magnetic measurements performed after the hole implementation have shown that the magnetic field quality in the useful part of the magnet is only marginally affected by the presence of the hole: the linearity remains very good even up to 60 A as shown in Figure 2 and the field relative variation on ± 40 mm from the magnet center along the three directions is less than 1 per mil as represented for the z direction in Figure 3.

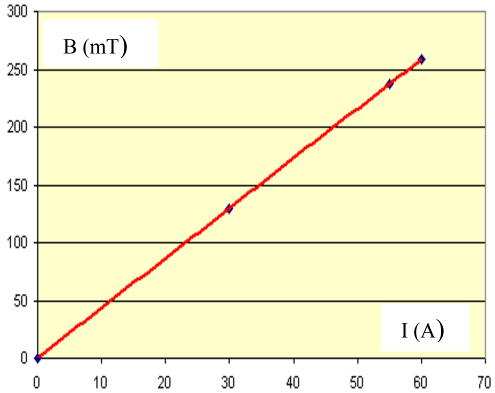


FIGURE 2. Magnet linearity in the presence of the hole

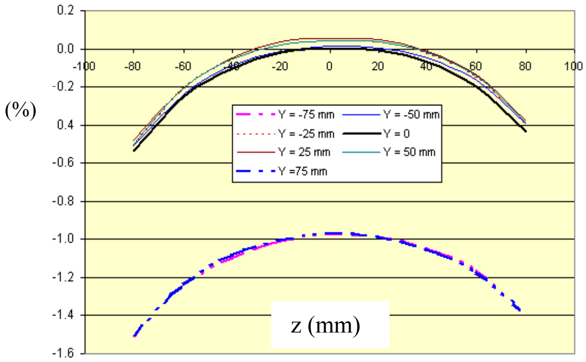


FIGURE 3. Relative variation of B along z at x = 0, for different y values

The Central Detector

In Figure 4 a), a cross section of the central detector is sketched. The two HV electrodes, normally set at ± 1 kV during operation, are spaced by 84 mm and are in the shadow of the 83 mm (internal diameter) vacuum chamber. The electrons are attracted to the input face of a Micro Channel Plate, (MCP), which is set at the positive voltage, are multiplied within the MCP, and finally sent, at the MCP output, to the entrance face of a prism, phosphor coated, set at a high positive voltage (anode).

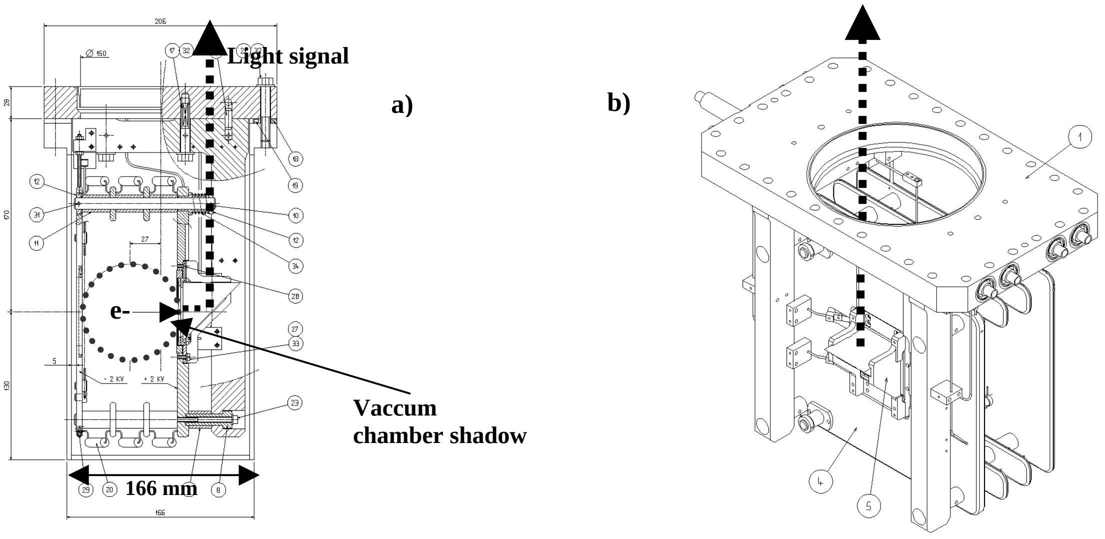


FIGURE 4. The central detector: a) Cross section view - b) 3-D view

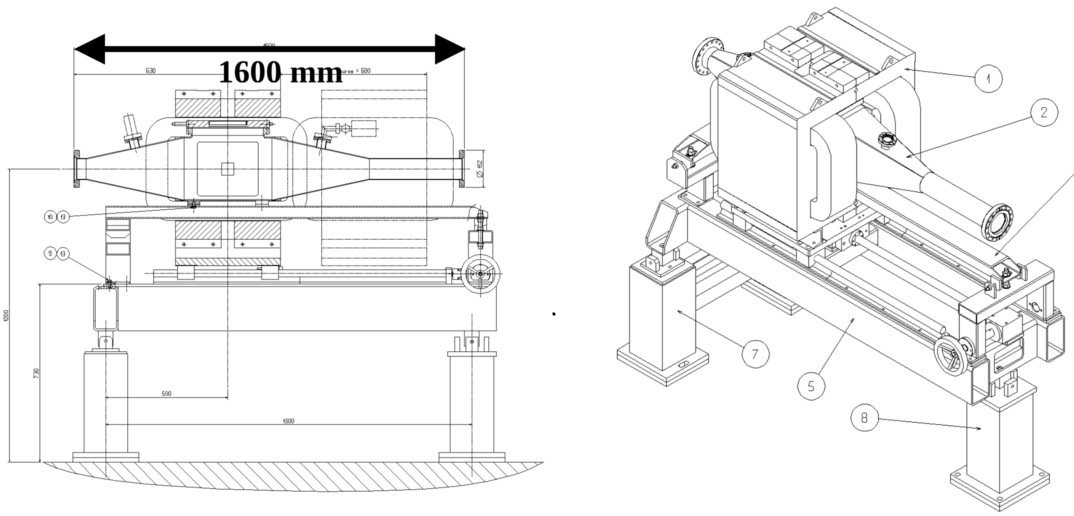
The light produced traverses the prism and, onto its back face, is reflected vertically to the outside, (Figure 4 a)). It then leaves the vacuum chamber through a large fused silica viewing port incorporated within a specially designed rectangular vacuum flange which supports the whole detector assembly, (Figure 4 b)). The electron signal conversion and light extraction assembly occupies transversally 55 mm.

The purpose of the two small lateral field shaping electrodes appearing at the top and at the bottom on the central detector 3-D view (Figure 4 b)) is to avoid electric field distortion.

The Monitor Tank

The monitor tank, made out of 316 LN stainless steel, fulfills two major requirements: it must become integrated within the magnet gap and, in order to not deteriorate the machine impedance budget, it should not present any discontinuity with respect to the normal vacuum chamber section. For this reason, its central part is terminated on each side by a fifteen degrees transition piece which permits to recuperate smoothly the normal section of 83 mm, (Figure 5 a)). An extra 500 mm vacuum chamber length, with normal aperture, is left available on the right-hand side, (Figure 5 a) and b)). This allows the magnet to slide along two rails, Figure 5 b)), when access is needed to the supporting flange in order to remove the detector from the tank. The whole assembly occupies a longitudinal space of 1600 mm

A valve and a vacuum gauge feed-through, are visible on each side on the two transition ends. They have been implemented in order to control the injection of Nitrogen and hence increase the pressure inside the detector. This is needed in the present SPS monitor to obtain a signal from luminescence, to measure the radial beam dimension, and could be required in the LHC where the rest gas pressure is expected to be only around 10^{-11} hPa at the monitor location.



a) Front view **b) 3-D representation**

FIGURE 5. Sketch of the Monitor tank: a) front view, b) 3-D representation of the whole monitor assembly.

COMMISSIONING IN 2002

The first tests started during the SPS operation period in the summer 2002 with two main problems generating important perturbations and a high noise level on the detector signal.

The first of these parasitic effects was electron cloud generation within the detector [2], a mechanism which starts to show up in the SPS machine when the beam structure approaches the nominal parameters required for the LHC, and which is still under investigation. Via this mechanism, secondary electrons are produced within the chamber. Under given conditions of bunch charge and bunch spacing this signal is steadily amplified and generates beam instabilities. In the SPS, the effect usually appears during the injection of the third batch, out of four composing the nominal LHC beam. The vacuum pressure is seen to increase. The gas monitor signal exhibited the same behavior, (Figure 8), and large fluctuations of the electrode DC voltage, and hence of the signal, were observed.

Other perturbations were induced by the high frequency modes generated by the beam structure inside the detector: the resulting high voltage instabilities could lead to complete signal loss due to vanishing gain.

During the subsequent stop several actions were taken. The high voltage electrodes were coated with a Non Evaporable Getter (NEG) layer, a treatment which is applied for vacuum getter pumping but which also reduces the secondary emission yield of the treated components, and hence their ability to generate electron cloud.

RF absorbers were also added close to the high voltage power supplies to filter the high frequencies.

Finally a conducting cover plate, leaving a reduced window, was installed on the view port for better conduction of the beam image current.

THE 2003 CAMPAIGN

Problems and Cures

In order to activate the NEG layer coating applied on the electrodes, a bake out to 200 degrees is necessary. This was performed after the monitor re-installation in 2003 with the result that electrical contacts were lost due to materials thermal expansion, in particular on the phosphor screen. In order to cope with these effects, thin frames, made of Copper-Beryllium, equipped with peripheral flexible contacts, were inserted within the detector assembly for better elasticity.

A fast but less sensitive phosphor was installed to try to test the feasibility of individual bunch measurement at 40 MHz. As a consequence, the MCP was used with high gain and premature aging of its central part, corresponding to the beam area, was observed. To overcome this problem, an image intensifier was added to the camera and a local orbit bump was applied in order to use another part of the MCP.

However, the addition of the intensifier generated other drawbacks. First, the resolution of the optical system was somewhat deteriorated. Reducing the camera lens diaphragm opening by 50% brought some improvement. Secondly, the intensifier appeared to be sensitive to the stray-field escaping from the magnet hole where the light is extracted. Hence, the intensifier was shielded with several layers of μ metal. Furthermore, the magnet was used at only 50 % of its maximum excitation.

Some parasitic lightening was still observed on the phosphor screen, at the end of the acceleration cycle when the bunch length was shrunk. This effect was overcome by removing the series resistors added close the monitor HV feed-throughs, which probably reflected back to the inside the RF modes generated by the beam.

Results

In spite of the above listed difficulties, interesting results were obtained last year. Some of them are discussed here but a more comprehensive study will be published soon [3]. Vertical profiles were measured over the whole intensity and energy ranges of LHC type beams, i.e. from single pilot bunches of 5 10^{9} protons, to nominal beams of 3.5 10^{13} protons, (288 bunches of 1.15 10^{11} protons each), and from the injection energy into the SPS of 26 GeV up to 450 GeV which will be the injection energy into the LHC. On Figure 6, profiles and 2-D pictures of a pilot bunch recorded at 26 GeV and at 450 GeV are shown. The data quality is improved, as seen on the lower one of the two profile curves, by subtraction of the fixed background pattern.

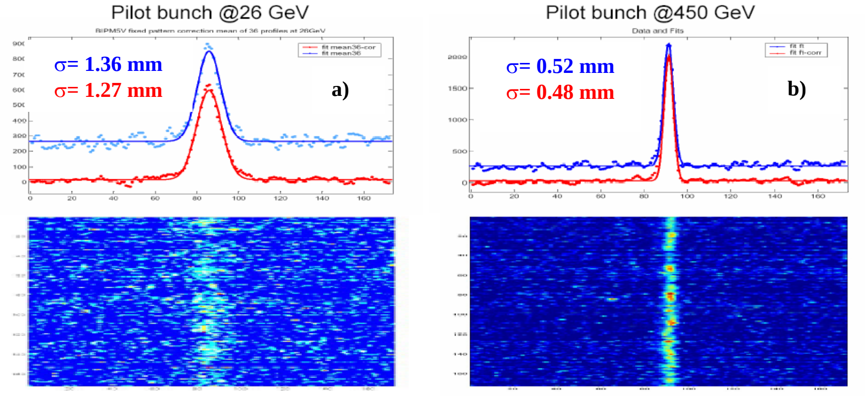


FIGURE 6. Vertical profiles and 2-D pictures of 5.10^{9} protons: a) 26 GeV, b) 450 GeV. Removing the background pattern improves the data (lower curve).

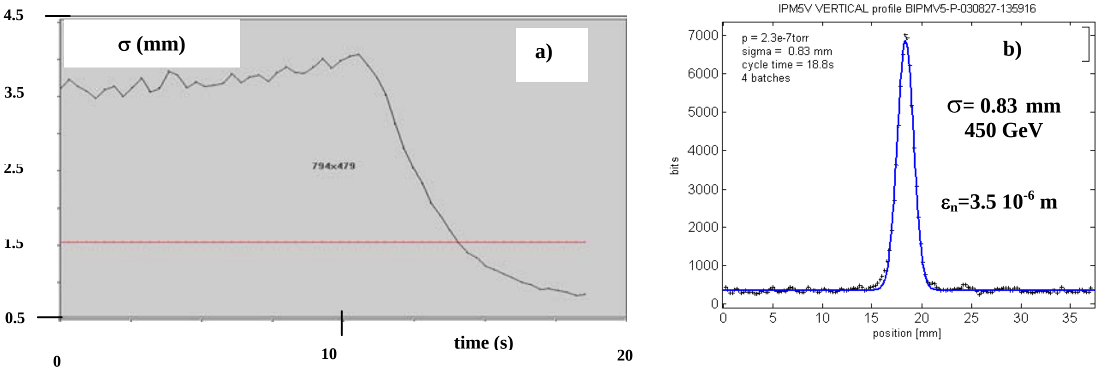


FIGURE 7. Vertical distribution of a nominal LHC beam of $3.5.10^{13}$ protons:
a) Evolution from 26 GeV to 450 GeV, b) vertical profile at 450 GeV

Figure 7 a) gives an example of the vertical rms value evolution of a nominal LHC beam throughout a complete SPS acceleration cycle with the corresponding profile obtained at the end, at 450 GeV, (Figure 7 b)). During the 10.8 seconds flat bottom at 26 GeV, needed for the injection of 4 batches of 72 bunches each, the rms value is constant and starts to slightly increase between 8 and 10.8 seconds, when the third batch is injected. The injection of the fourth batch occurs at t=10.8 s and then the acceleration from 26 GeV to 450 GeV starts. The rms value shrinks down to 0.83 mm while the energy is progressively increased to 450 GeV.

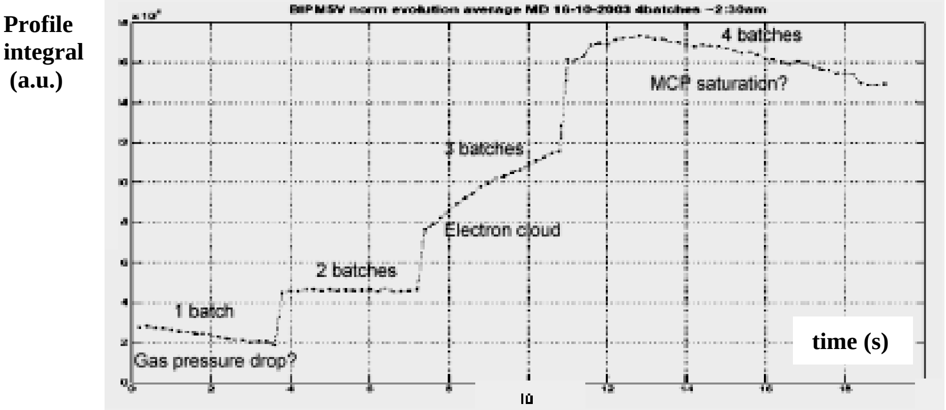


FIGURE 8. Profile integral evolution of a nominal LHC beam of $3.5.10^{13}$ protons

Figure 8 shows the evolution of the beam profile integral along the SPS cycle. The steady signal increase observed after injection of the third batch is the signature of an electron cloud effect mechanism, reduced but still showing-up within the detector, in spite of the NEG coating applied on the electrodes.

During acceleration from 26 GeV to 450 GeV, between 10.8 s and 19 s, the profile integral decreases, whereas, without beam loss, it is expected to remain constant. This may indicate a saturation effect within the monitor, possibly at the level of the MCP.

The monitor was also operated with beams having a normalized emittance value much lower than the nominal LHC beam normalized emittance of 3.5 10^{-6} m. Comparisons with the wire scanners were made and the results are presented in Figure 9. The agreement is good at 26 GeV but when the beam rms value decreases during acceleration to values lower than 0.7 mm the gas monitor data become more and more pessimistic with discrepancies increasing for the lowest emittances. The contribution of the monitor resolution limit to the measured rms value is of the order of 0.35 mm.

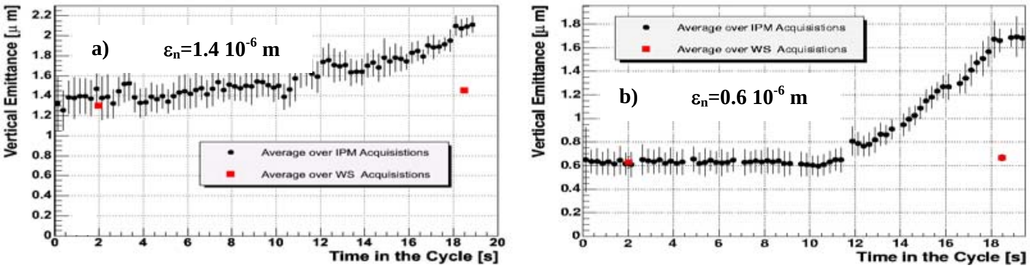


FIGURE 9. Profile integral evolution of low emittance beams: a) ε_n = 1.4 10^{-6} m, b) ε_n = 0.6 10^{-6} m, • Gas monitor data, 🟥 comparative wire scanner data.

MODIFICATIONS AND PERSPECTIVES FOR 2004

Based on the 2003 data, some modifications have been implemented for 2004.

After some feasibility tests, the input face of the new MCP has also been coated with NEG to reduce further the electron cloud effect within the detector.

Several steps have been implemented to improve the resolution of the monitor:

- A few components will be replaced: a single new MCP will replace the previous chevron stacked MCP amplification system for better S/N ratio and resolution. A new $Y_3Al_5O_{12}$:Ce (P46) phosphor coating, replacing the previous CdS:In, will be used at the entrance face of the prism, less demanding from the MCP for the same signal amplitude. A reflective Aluminium layer has been deposited onto the prism back face extracting the light to the outside, to ensure total internal reflection and hence, a more homogeneous signal distribution.
- For high precision measurements, the detector will be coupled to a new Low Light Level camera with low noise, higher resolution and which is expected to be insensitive to magnetic fields. The optics placed in front of the camera has also been reconsidered for an improved aperture. A splitter has been incorporated to add a signal path used by the fast turn-by-turn system equipped with a 32-channel photomultiplier tube.
- On the cathode grid, the number of wires has been reduced by a factor of 3 in a view to reduce their contribution to tail distributions, via secondary electron emission, and to RF field generation.
- A non-reflective treatment was applied at the surface of relevant detector supporting parts to suppress parasitic reflections.

New RF absorbers have been installed close to the HV supplies for better noise filtering and the possibility to vary the MCP gain during the beam acceleration cycle, in order to stay below the saturation level, is now foreseen in the HV control program.

Hence, a performance improvement is anticipated. With upgrades of the control software, the monitor is expected to reach soon an operational stage for the LHC era.

ACKNOWLEDGMENTS

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