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# IONISATION PROFILE MONITOR TESTS IN THE SPS

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## Abstract

A beam profile monitor, from DESY, based on the ionisation of the rest gas, was installed in the SPS in 1997. Horizontal beam profiles obtained from the extracted positive ions are presented. It is known that in this case some broadening affects the signal, which limits the monitor resolution. This broadening results from the transverse momentum that the ions gain within the space charge field of the circulating beam.
In order to improve the resolution for LHC applications, the monitor was modified during the 1998/99 winter stop. A magnetic focusing was incorporated. The aim is to analyse the signal provided by collecting the electrons, rather than the ions, of the ionised rest gas. The details of this new set-up and the expectations for the resolution limit will be compared to the measurement results.

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# IONISATION PROFILE MONITOR TESTS IN THE SPS

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## *Abstract*

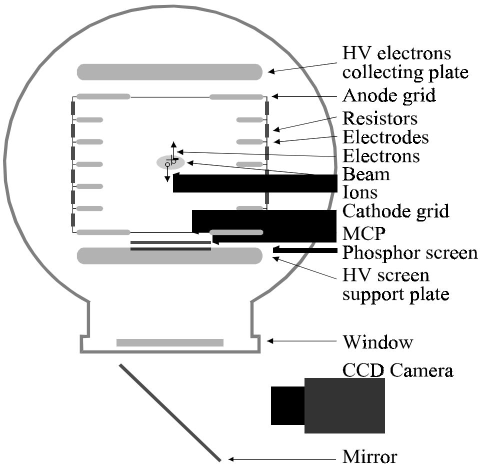
A beam profile monitor, from DESY, based on the ionisation of the rest gas, was installed in the SPS in 1997. Horizontal beam profiles obtained from the extracted positive ions are presented. It is known that in this case some broadening affects the signal, which limits the monitor resolution. This broadening results from the transverse momentum that the ions gain within the space charge field of the circulating beam.

In order to improve the resolution for LHC applications, the monitor was modified during the 1998/99 winter stop. A magnetic focusing was incorporated. The aim is to analyse the signal provided by collecting the electrons, rather than the ions, of the ionised rest gas. The details of this new set-up and the expectations for the resolution limit will be compared to the measurement results.

## 1. INTRODUCTION

Rest gas monitors are used in many high energy accelerators in order to reconstruct transverse beam distributions [1], [2], [3]. The signal which is used results from the collection of either the ions or the electrons produced by the ionisation of the rest gas due to the circulating beam passage. This type of device is used so far to analyse beam RMS dimensions larger than one millimetre. Ions or electrons are produced with a given transverse velocity. During part of their drift to the analysing device, they also experience space charge effects from the circulating beam, and their transverse momentum is enhanced. With their much larger rigidity, ions are less sensitive to these counteracting phenomena although their drift time through the beam space charge forces is longer. But a resolution better than 1 mm is difficult to achieve.

Such a device, obtained from DESY [1], was installed in the SPS in 1997. Tests were performed on proton beams. Figure 1 recapitulates the fundamentals of this monitor suited to work in the horizontal transverse plane. Two grids symmetrically positioned at 50 mm above and underneath the beam orbit, are set at inverse voltages, with a possible amplitude up to 5 kV. Ions and electrons are extracted in opposite directions, depending on the grid voltage polarity. In the basic configuration, positive ions are extracted towards the detection chain. They are then accelerated to a Multi-Channel Plate, which acts as a signal amplifier. The MCP gain can be adjusted by varying the voltage difference between input and output up to 1 kV. Electrons extracted from the MCP are accelerated, by potential differences up to 12 kV, to a high voltage plate supporting a phosphorescent screen. The transmitted light is reflected on a mirror to a CCD camera.



## 2. RESULTS WITH IONS

Profiles of $10^{13}$ proton beams were recorded during entire SPS super-cycles, from 26 GeV to 450 GeV, by looking at the signal provided by ions. Results are in Figures 2 and 3.

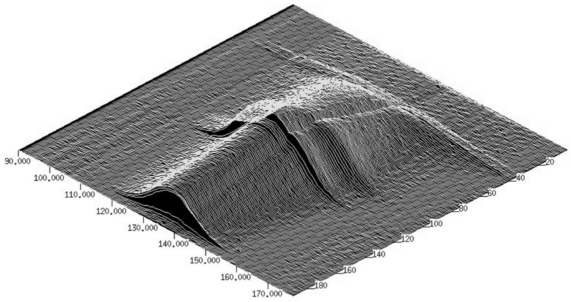


**Figure 2**: Proton beam horizontal profiles, measured from 26 GeV to 450 GeV using the signal from ions.

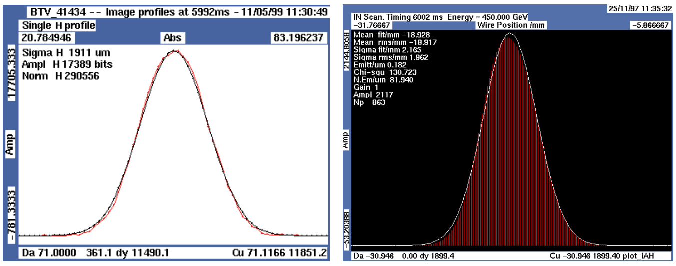


**Figure 3**: Horizontal proton beam profiles, with gaussian fit, at 450 GeV, taken with the IPM (left) and the wire scanner (right).

Figure 3 shows that both the IPM and the wire scanner monitor, which is our reference, provide a similar proton beam RMS value, respectively 1.9 mm and 2.1 mm. However, considering the ratio of the amplitude function values at the two monitor locations, the IPM should measure a narrower beam by a factor of 1.9, i.e. around 1mm. In this case, an enlargement of the signal of 100 % is observed when using the ion signal. This is not satisfactory to evaluate RMS dimensions below 2 mm.

## 3. THE IPM IN ELECTRON MODE

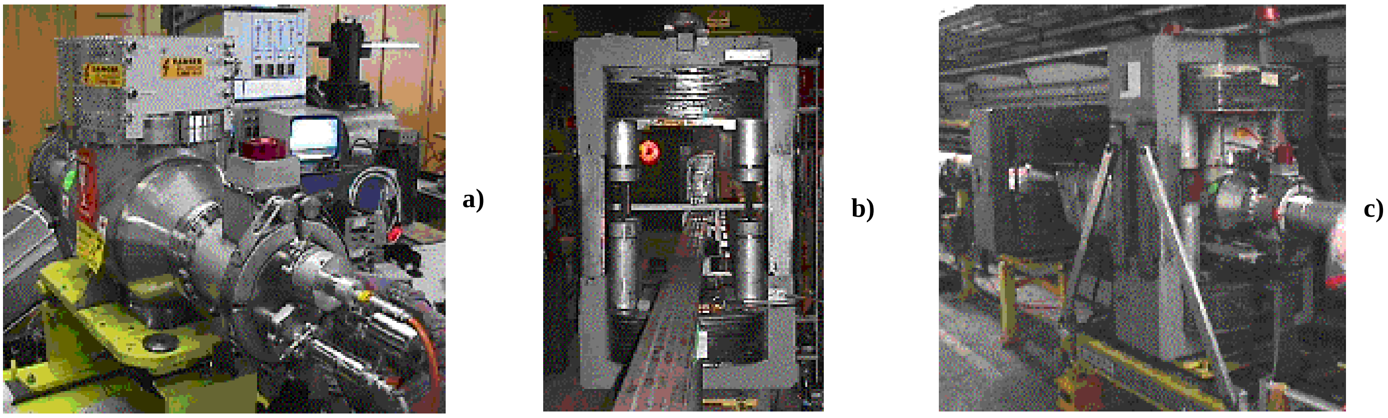


**Figure 4**: a) the monitor before insertion within the magnet b) the modified magnet on the measuring bench with the two wedges increasing its gap, c) the assembly installed, with, in the back, the orbit distortion correction magnet.

Resolutions far below 1mm are requested for the LHC era, both in the SPS and in the LHC; RMS beam dimensions of this order are expected at 450 GeV. At 450 GeV, the possibility to exploit synchrotron radiation is not established in the LHC yet. An IPM monitor is one of the candidates to measure transverse beam distributions. Looking at the signal of electrons instead of ions should permit to improve the resolution. With their much smaller mass, electrons also experience the parasitic transverse kicks mentioned for the ions, but they are also much easier to channel along a magnetic field with very short precession radius. As mentioned in previous estimations [2], only a few per cent of the electrons are generated with transverse momentum larger than 500 eV. This corresponds to a Larmor radius of 0.375 mm in a magnetic field of 0.2 T.

During the 1998/99 winter stop, the IPM was adapted to make possible the exploitation of the signal from electrons. The adequate polarities were set to the plates providing the accelerating voltages. After a few investigations, the solution retained to generate the magnetic field was to incorporate the monitor within the gap of an available dipole. The monitor height was first reduced, (Figure 4a)), by modifying at the top the different high voltage connections, and at the bottom, by a new design of the extraction system of the light transmitted from the phosphorescent screen. An overall height of 700 mm was achieved. The magnet gap was increased accordingly by a factor of 3 from its initial value of 224mm. This was performed by the insertion, between the two magnet halves, of two steel wedges, as shown in Figure 4b). From the nominal field of 0.24 T, 0.077 T was expected by linear scaling. Magnetic measurements performed on the modified magnet revealed that in the central active part of the monitor a field of 0.060 T was actually produced: stray field effects are slightly enhanced with the larger magnet gap. However, the electron transverse momentum distribution is such that this field should permit the evaluation of beam RMS values of 1 mm with less than 10% of aberration effects. The field variation across the active monitor region is around 5%. Within the SPS supercycle, the magnet is pulsed only during the proton cycle, without acting on leptons.

The integrated field was measured to evaluate the perturbation generated on the beam closed orbit. Results were in accordance with expectations. To compensate for the kick introduced by the magnet, a similar magnet, with standard gap, was installed immediately upstream of it, (Figure 4c)). The resulting local calculated closed orbit distorsion is 2 mm at 14 GeV and becomes negligible throughout the acceleration to 450 GeV. This has been confirmed by measurements.

## 4. RESULTS WITH ELECTRONS

Preliminary tests of the modified monitor could be performed on proton beams this year during the first two weeks of the SPS setting-up. Starting without the magnetic field, observations were made of a beam of $10^{13}$ protons injected at 14 GeV and accelerated to 450 GeV. Results are presented in Figures 5, 6 and 7. Corresponding profiles acquired with the wire scanner monitor are also displayed.

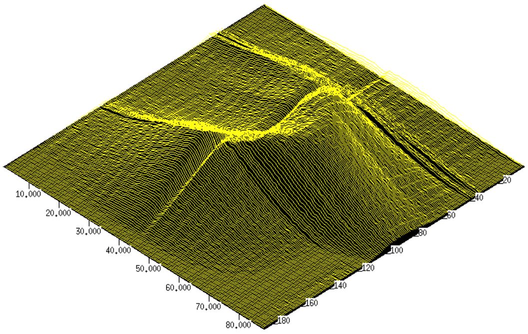


**Figure 5**: Horizontal profiles recorded using the signal from electrons, without magnetic field, of $10^{13}$ protons, accelerated from 14 GeV to 450 GeV.

At 14 GeV, a RMS value of 2.815 mm is obtained, (Figure 6), from the IPM. By comparison, the horizontal RMS value provided by the wire scanner is 6.225 mm; by scaling according to the machine optics parameters, one should get 3.28 mm at the IPM. The measured fitted value is 14 % smaller.

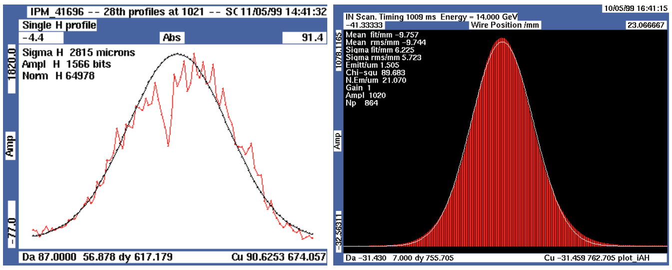


**Figure 6**: Horizontal profile taken on $10^{13}$ protons at 14 GeV, with the IPM in $e^-$ mode (left), and the wire scanner (right). B = 0 T

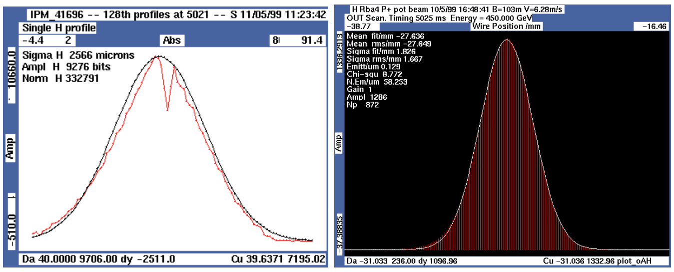


**Figure 7**: Corresponding profiles measured at 450 GeV during the same acceleration cycle.

The same data taken at 450 GeV are displayed in Figure 7. The beam has shrunk and RMS values of respectively 2.566 mm (IPM), and 1.826 mm (wire scanner), are measured. Again, by scaling with the wire scanner data, a value of 0.960 mm should be observed at the IPM: hence a quadratic enlargement exceeding 200% affects the expected results.

Finally, the magnetic field was switched ON in the monitor, and beams of around 1.6 $10^{13}$ protons were investigated from 14 GeV to 450 GeV. Two magnetic field levels were considered, 0.018 T and 0.036 T. Data measured with the latter value are presented in Figure 8 and Figure 9.

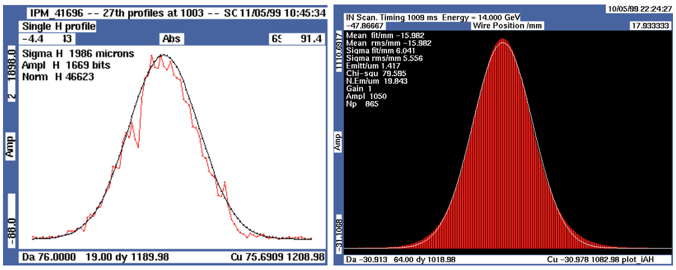


**Figure 8**: Horizontal profile of 1.6 $10^{13}$ protons at 14 GeV, with the electron signal (left), and the wire scanner (right). B = 0.036 T

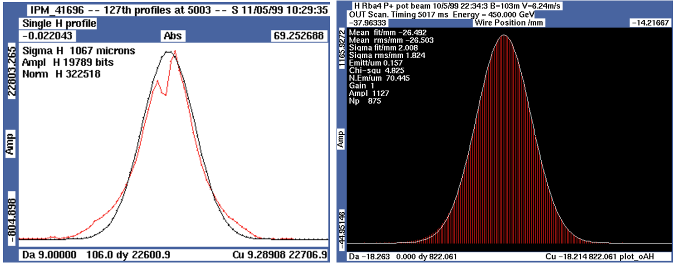


**Figure 9**: Corresponding profiles measured at 450 GeV.

At 14 GeV, a fitted RMS value of 1.986 mm is obtained from the IPM profile, (Figure 8). With the wire scanner, the corresponding fitted beam width is 6.041 mm, and the resulting RMS width at the IPM should be 3.180 mm. A relative shrinking of 35% is again observed at the IPM. This discrepancy will be investigated later. So far, not enough time was available to clarify it. The same observation was made at the lower field level.

However, looking at the 450 GeV data, an RMS beam width of 1.067 mm is provided from the IPM profile. This fits very well the RMS wire scanner value of 2.008 mm when scaling with the optics. The same conclusion is relevant for the data recorded with a magnetic field of 0.018 T. Thus, RMS dimensions of 1 mm can apparently be measured within a few per cent even with a modest magnetic field. The small fraction of electrons with large transverse momentum, and hence large precession radius, probably appear in the tails which are ignored by the fit, (Figure 9).

## 5. CONCLUSION

The IPM monitor installed in the SPS has been adapted to analyse the signal provided by the electrons. With the nominal vacuum, the signal to noise ratio is entirely satisfactory. More study remains to be done to fully understand the observations. However, the preliminary observations made recently are very promising. Without magnetic focusing, a signal enlargement of around 2 mm is observed on RMS values of 1 mm. This is slightly worse than what is observed with ions. Obviously, the behaviour difference between ions and electrons depends on space charge forces which, during our tests, were limited by moderate beam intensity.

With the addition of a magnetic field, even set at rather low values, RMS dimensions of 1 mm have been measured with an accuracy of a few per cent. An improved knowledge of the instrument, will hopefully allow us to refine, in the near future, the determination of this resolution limit.

## ACKNOWLEDGMENTS

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## REFERENCES

[1] K. Wittenburg, Emittance Measurement in the Proton Accelerator in DESY, Emittance in Circ. Accel., KEK 95-7, Sept. 95.

[2] R. Connolly et Al., A Prototype Ionisation Profile Monitor for RHIC, Proceedings of PAC 1997, Vancouver, p 2152.

[3] J.R. Zagel et Al., FERMILAB Main Ring Ion Profile Monitor System, Proc. of PAC 1997, Vancouver, p 2166.