COMPARATIVE TRANSVERSE DISTRIBUTION MEASUREMENTS BETWEEN THE NEW SPS REST GAS IONISATION MONITOR AND THE WIRE SCANNER MONITORS.

C. Fischer, B. Dehning, J. Koopman, D. Kramer, F. Roncarolo, CERN, Geneva, Switzerland.

Abstract

During the past two years, a new Ionization Profile Monitor was installed and tested in the CERN SPS. In parallel modifications were made on various wire scanner monitors. The aim is to develop instruments performing reliable measurements of transverse beam distributions in the SPS and in the LHC, in order to control the stringent emittance preservation requirements. Measurements made with the two types of monitors were performed under various conditions of LHC type beams, ranging from a pilot bunch up to beams having in the SPS nominal distributions in bunch number, intensity and energy for injection into the LHC. The data provided by the two types of instruments are compared. In the case of discrepancies, an analysis of the possible reasons is made. The cures implemented and the improvements foreseen are discussed.

INTRODUCTION

A newly designed rest gas monitor (IPMV) was installed in the SPS in 2002 to measure vertical transverse beam distributions. Following its installation and initial tests, a few upgrading steps were applied prior to the machine start-up in 2003 [1]. Interesting results were obtained subsequently in 2003 under different conditions of beam currents and emittances. Measurements were performed on beams ranging from an individual LHC pilot bunch of 5 10^9 protons, having a normalised emittance of 0.6 10^{-6} m (1 σ), to beams with the nominal characteristics foreseen for injection into the LHC, i.e. 288 bunches of 1.15 10^{11} protons each, with an emittance of 3.5 10^{-6} m.

Wire scanners are so far the main tools to measure transverse distributions in the SPS and they are also used as the absolute reference to cross-calibrate the other devices. However SPS wire scanners needed modifications in order to withstand LHC type beams, and a vast upgrading campaign was progressively applied these last two years. Their accuracy has been recently investigated [2] by comparing synchronized measurements made with different scanners. The agreement between the different monitors is within 5 10^{-2} on the normalized emittance, therefore 2.5 10^{-2} on the beam size. In Figure 7, the plot scale is such that the error bars, indicating the spread of measurements made with the wire scanner, are hardly visible.

Measurements on the whole range of SPS beams circulating in 2003 were performed with the two types of instruments. When synchronised, they can be compared. The observed discrepancies are analysed and the remedies necessary to improve the performance are mentioned.

FIXED TARGET BEAM

The set-up and the calibration of the rest gas monitor are made at the beginning of each period when the SPS is in fixed target mode, during physics data taking. This beam, consisting of 4000 bunches of less than 10^{10} protons, with a spacing of 5 ns, suits well for this purpose as no harmful effect is observed for this bunch population.

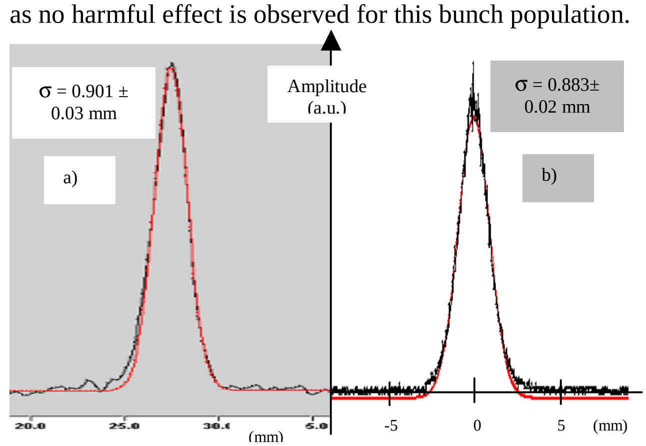

Figure 1: Vertical distribution of a fixed target beam of 4.5 10^{12} protons at 400 GeV measured: a): with the IPMV, b) with wire scanner 51731.

Figure 1 gives the profiles of the same fixed target beam recorded at 400 GeV with a) the rest gas monitor and b) the wire scanner located near to it. The indicated rms values are the fit results averaged on five acquisitions made with the two devices. The IPMV is 2% more pessimistic whereas, according to the optics scaling at the monitor locations, it should provide 5% lower rms values.

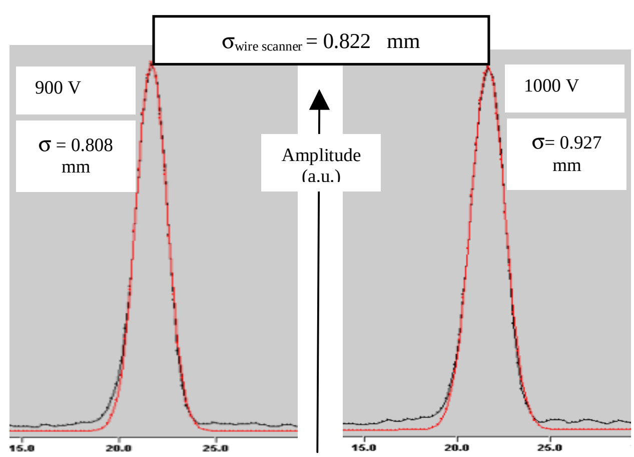

Figure 2: Vertical distribution of a fixed target beam of 25 10^{12} protons measured with the IPMV for two different gains.

A factor of discrepancy is illustrated in Figure 2. Two profiles of a fixed target beam are measured at 400 GeV for two different gains of the IPMV. The gain is controlled by varying the differential voltage between the input and output faces of the micro-channel plate (MCP), to amplify the primary electron signal. Increasing the gain by 100 volts induces saturation effects inside the MCP: the agreement with the wire scanner is within 2% on the left profile and is worse than 12% on the right one. Hence it is mandatory to calibrate carefully the IPMV.

LHC TYPE BEAMS

Vertical distributions of LHC type beams, ranging from pilot bunches of 5 10^{9} protons, to beams of 3.5 10^{13} protons distributed in 288 bunches each of 1.1 10^{11} protons, were investigated in the SPS with the IPMV, and compared with those provided by a wire scanner.

Nominal beams

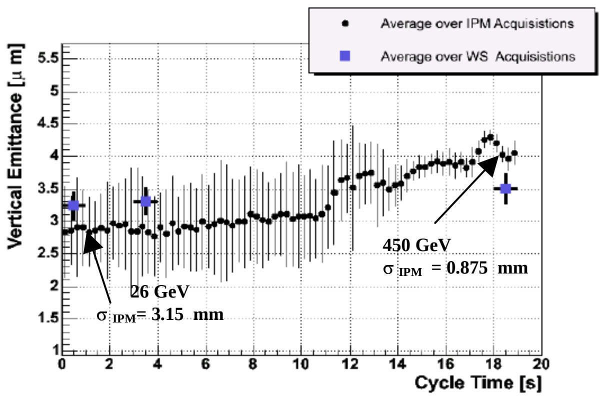

Figure 3: Normalised vertical emittance evolution measured with the IPMV and the wire scanner (square dots) of nominal LHC beams of 3.5 10^{13} protons during their acceleration from 26 GeV to 450 GeV

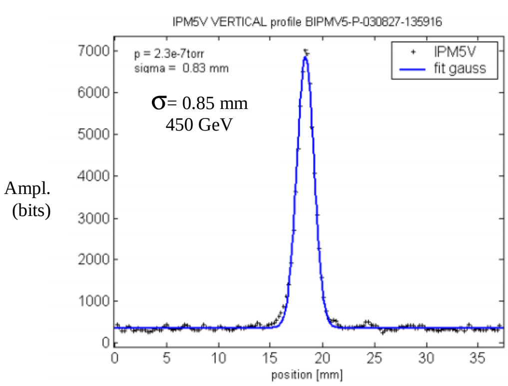

Figure 4: Vertical profile at 450 GeV of a nominal LHC beam measured with the IPMV.

Figure 3 shows how the normalised emittance of nominal LHC beams, measured with the IPMV every 250 ms, develops throughout the acceleration from 26 GeV to 450 GeV in the SPS. The error bars indicate the spread of the data and include eventual beam instabilities. During the first 10.8 seconds, four different batches are injected at 26 GeV, before the acceleration takes place between 10.8 s and 19 s. Each data is the result of an averaging on 15 cycles. A corresponding profile measured with the IPMV at 450 GeV is shown in Figure 4. At three different times during each cycle, profiles were also measured with a wire scanner. The corresponding emittance values are indicated by the square dots on the plot.

At 26 GeV, the agreement between the two instruments is about 10% on the emittance, 5% on the rms value, and within the error bars. There is a tendency for the IPMV to be more optimistic than the wire scanner.

The start of the acceleration, at 10.8 s, is accompanied by a step of the IPMV data, (Figure 3). This results either from saturation effects, already illustrated in the previous section, or from a limited resolution of the IPMV optics. These effects start to show-up when the beam dimension suddenly shrinks due to the energy increase. At 450 GeV, the IPMV provides an emittance value 14% larger, corresponding to a measured rms value in excess by 7 % when compared to the wire scanner data.

Low emittance 75 ns beams

The same exercise was repeated with a beam having a bunch separation of 75 ns, instead of the nominal 25 ns one foreseen in the LHC, hence a lower current and a normalised emittance of 1.4 10^{-6} m instead of 3 10^{-6} m. The results are presented in Figure 5. The agreement at 26 GeV is very good.

During acceleration, from 10.8 s, an emittance growth is again visible. It is smoother but larger than in the previous case. Saturation effects within the monitor should have less importance in this case due to the lower beam current, and hence due to the lower signal amplitude. In this case, the growth is probably more related to the limited monitor resolution.

At 450 GeV, the measured rms value is 0.64 mm, 20% larger than the expected one which would perfectly agree with the wire scanner data (square dot).

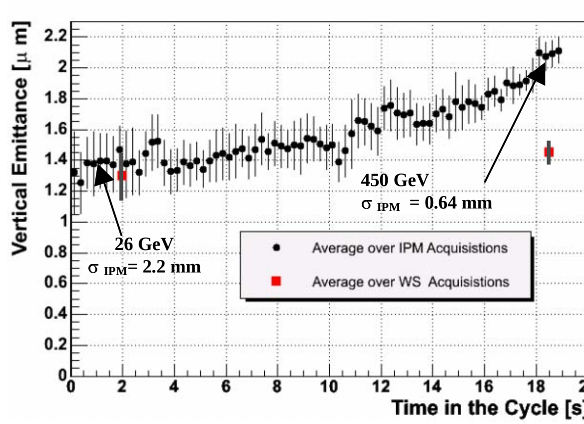

Figure 5: Normalised vertical emittance evolution measured with the IPMV and the wire scanner (square dots) of 75 ns LHC beams during their acceleration from 26 GeV to 450 GeV.

Pilot beams

Similar studies have been performed on pilot bunches of 5 10^9 protons, the expected smallest injected current in the LHC. The normalised emittance was 0.6 10^{-6} m.

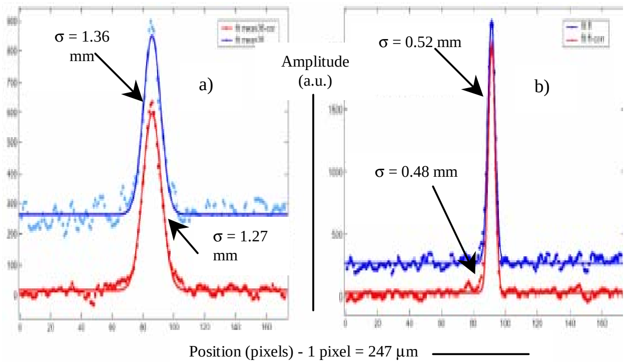

Figure 6: Profiles of a 5 10^9 proton bunch measured with the IPMV: a) 26 GeV, b) 450 GeV. Removing the background pattern improves the data (lower curve).

At such a low beam current, the IPMV data are sensitive to the signal to noise ratio. It is shown in Figure 6 how they improve both at injection energy and at 450 GeV when the background is subtracted (lower curve).

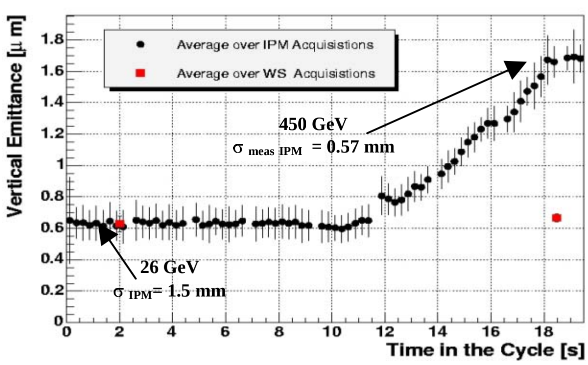

Figure 7: Normalised vertical emittance evolution measured with the IPMV and the wire scanner (square dots) of pilot bunches LHC during their acceleration from 26 GeV to 450 GeV.

Figure 7 depicts again the evolution of the transverse normalised emittance of pilot bunches, measured by the IPMV along the SPS acceleration cycle, and by the wire scanner at injection energy and at 450 GeV.

The two monitors are once more in good agreement at 26 GeV. During the acceleration, the emittance measured with the wire scanner is preserved while the IPMV measures again a blow-up. It provides an rms value of 0.57 mm at 450 GeV instead of 0.36 mm, the value which would agree with the wire scanner data. This corroborates the fact that the IPMV resolution was limited. The IPMV camera optics calibration factor was 0.247 mm/pixel. Therefore 1.5 point/ σ was available to reconstruct the profile of these pilot bunches. Analytical considerations and simulations predict a systematic increase of only 2 % of the rms value due to this granularity [2].

DISCUSSION AND SUMMARY

On fixed target beams, the agreement between the two instruments is better than 5% on the rms value as long as one makes sure to avoid saturation effects within the micro channel plate (MCP) of the gas monitor. Hence, a careful calibration with the wire scanner is needed.

Concerning LHC type beams, good agreement is obtained at injection energy. During the acceleration discrepancies show up progressively in the gas monitor data. Their relative effect at 450 GeV depends on the beam dimensions, increasing from 7 % for beams having rms values of 0.8 mm, to 60 % for beam of very low emittance. A contribution between 350 mm and 400 mm, adds-up quadratically to the expected rms value.

The IPMV data measured on nominal LHC beams are affected by saturation effects during the acceleration and its corresponding beam shrinking. Indeed, the same gain setting cannot cover properly the necessary dynamic of a full cycle, with the injection of four batches, an additional signal enhancement due to the electron cloud effect, and the subsequent acceleration. For this reason, the possibility to vary the gain during the cycle will be implemented for the run of 2004. NEG coating of more detector components will also be continued.

For rms beam dimensions below 0.8 mm, and even at reduced beam intensity, which excludes the eventual contribution of space charge effects, the discrepancies between the IPMV and the wire scanner data are due to the limited resolution of the instrument. Several contributing factors have been identified:

- an intensifier added in front of the camera for improved sensitivity deteriorated the resolution.
- this intensifier appeared to be affected by the magnetic field of the monitor. A residual tilt of the 2D beam image was observed and the distribution profile got by projection was enlarged.
- tails resulting from aberrations effects in some components of the optics could be attenuated by reducing the camera lens opening by 50%. However they were not completely removed. Their relative effect on the results depends on the fitting strategy.

The monitor optics has been completely reconsidered and a new Low Light Level electron multiplied camera installed for the next run. The aim is to reach an overall resolution close to 100µm with the IPMV. This would permit to monitor beams up to 7 TeV in the LHC.

Finally, using the same fitting routine on the wire scanner and on the IPMV data would provide better consistency. This is not the case at the moment.

REFERENCES

[1] C. Fischer et al., "Design and Tests of a New Rest Gas Ionisation Profile Monitor Installed in the SPS as a Prototype for the LHC", BIW04, 3-6 May 2004, Knoxville, Tennessee, and CERN-AB-2004-031.

[2] F. Roncarolo et al., "Accuracy of profile monitors and LHC emittance measurements." These proceedings.