THE LUMINESCENCE PROFILE MONITOR OF THE CERN SPS

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Abstract

The SPS luminescence monitor is the first device of this type to be used in a high energy accelerator, from 14 to 450 GeV, where up till now the light production was considered to be insufficient. It uses Nitrogen at pressures as low as 4 10^{-6} Pa as the scintillation medium. Light production, spectrum and decay times have been measured and compared with theory and existing low energy data. They are important factors for the design of such monitors for other machines, for example LHC.

1 INTRODUCTION

This development was initiated in the framework of the LHC project where the emittance conservation over the whole chain of CERN accelerators is of vital importance.

The check of the matching between the accelerators will be performed with dedicated monitors [1] to minimise emittance blow-up after filamentation. The emittance preservation along the acceleration cycles will then have to be checked with a non-intercepting monitor. This can be achieved with Synchrotron Radiation monitors at high energies in both SPS and LHC. Below 300 GeV in SPS and 2 TeV in LHC, the machine dipole monitors won't be able to provide beam size measurements because the light production will not be sufficient in the sensitivity region of usual detectors.

Monitors based on the luminescence of gas excited by the passage of the beam are one of the possibilities to perform this task in an energy range going from SPS injection energy at 14 GeV to LHC top energy at 7 TeV.

2 LIGHT PRODUCTION

The monitor uses the light emitted by gas molecules returning to their ground state after having been excited by the beam. Nitrogen is a very good candidate for this type of monitor, because it has a large cross-section for photon production, emits at the lower end of the visible spectrum for which many detectors are available, has short decay times compatible with the resolutions contemplated and is easily pumped away by the vacuum system. Luminescence has been studied in detail in connection with the auroral phenomena, especially for Nitrogen. Unfortunately, the studies concerning the cross section and the decay time have only been made for low energy particles [2]. It is hence necessary to extrapolate the available data from 200 keV to the range 14 GeV to 2 TeV, i.e. over 5 to 7 orders of magnitude. If the photon production is proportional to the beam energy loss, then this extrapolation can be made by using the Bethe-Bloch equation. In that case, the photon production will be lower by a factor more than 200 in the considered range with respect to the 200 keV case. This large difference explains probably why [3] at higher energies there has only been a preliminary test at the CERN ISR [4] and a proposal for HERA [5], whereas there are a few monitors at low energy facilities [6,7].

3 THE SPS MONITOR

Considering the present state of the detector technology and assuming the validity of the light cross-section extrapolation with the Bethe-Bloch equation, a preliminary estimation and tests were performed at the SPS in 1998 [8]. As the tests looked promising, a monitor was built and installed in 1999 and improved in 2000. The monitor consists of a six-port vacuum tank, 450 mm long with 160 mm diameter tubes, where two ports are used for the beam passage, three are equipped with quartz viewing ports, and the last one is equipped with a retractable screen for in-situ geometrical calibration: see Figure 1. Gas can be injected through a remote controlled leak valve. The pressure bump is restricted to the monitor area by two 400 l/s sputter ion pumps installed at ±4m from the monitor and interlocks protect the SPS vacuum system from an excessive pressure bump.

The three observation ports are fitted with an optical transport line, comprised of 80mm diameter achromats of various focal lengths, which collects a maximum of photons and images the light cylinder generated by the passage of the beam onto the detectors. These are located far enough from the beam plane to be protected from background particles. The top optics images the light cylinder onto a Photo-Multiplier to measure photon productions and temporal characteristics. The lower and side optics image bottom and side views of the beam onto 2-stage MCP intensifiers coupled to Peltier-cell cooled CCDs, with scaling factors of 285 and 180 μm/pixel for horizontal and vertical profiles. Different magnifications have been chosen for the two planes as β_h is nearly twice β_v. Chromatic filters can be inserted, and gating can be achieved as well as amplification with the MCP high voltage. This is particularly necessary as the beam dimension changes by a factor four during the acceleration cycle. The beam image is acquired by an 8 bit video frame grabber or a 12 bit slow scan digitiser, both compatible with an acceleration rate of 1 GeV/25ms, and are in the VME standard. Local data processing will perform a gaussian fit on the beam projection, and beam images in 3D (the light density is the 3rd dimension), 2D and projections can be displayed.

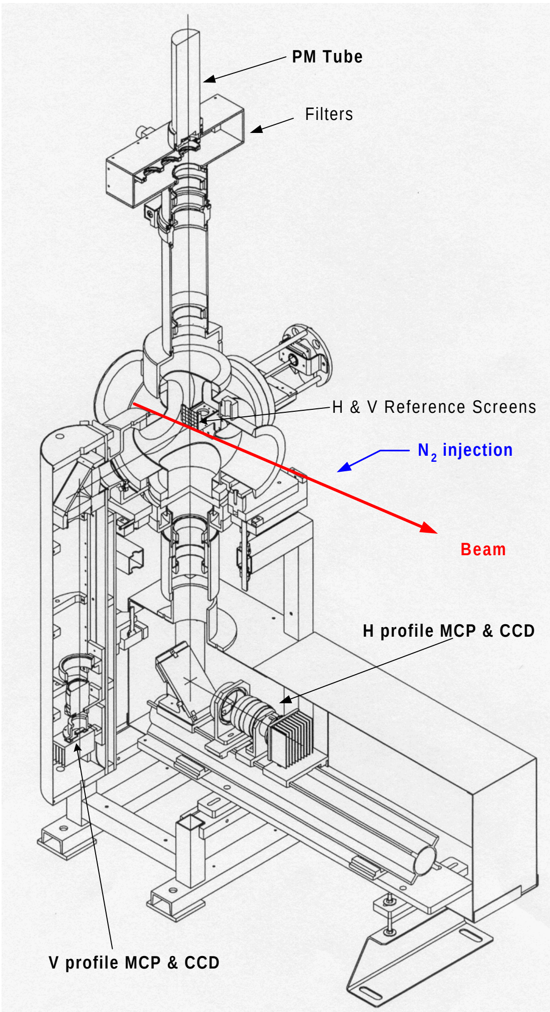

Figure 1 : The SPS Luminescence monitor: the side and bottom optics are used for vertical and horizontal profile measurements, the top one for intensity and time structure evaluations.

4 RESULTS WITH PROTONS AND IONS

4.1 Light observation with the PM set-up

The first test was to measure the light level as a function of energy from 14 to 450 GeV. It was confirmed that the light production, and hence the cross-section follows the trend of the Bethe-Bloch equation. The level measured is a factor 2 to 4 lower than calculated and can be accounted for by uncertainties on the pressure and non isotropic light emission.

The second test was to determine the light production spectrum with 70 and 35 nm FWHM interference filters. It is compatible with that of the first negative system of N_2^+ [2] with its 391.4 nm dominant line, see Figure 2.

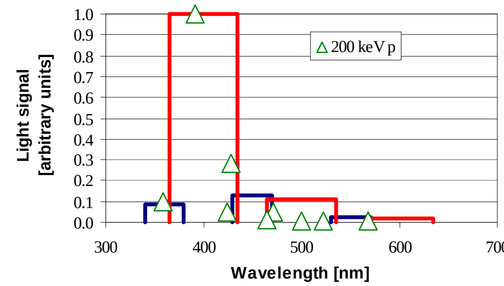

Figure 2: Light production measured with 70 and 35 nm FWHM interference filters. Indicated by triangles are the intensities measured at 200 keV in [2].

The next test was to measure the photon production as a function of Nitrogen pressure. It is linear with pressure, see Figure 3, indicating that the light is produced in a one step process, with hence a short decay time, which makes it suitable for precise profile measurements. Pressure can also be used in the explored range to adapt the dynamic range of the monitor to the beam conditions.

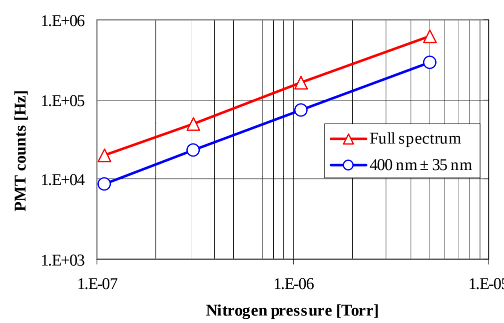

Figure 3: Light production as a function of N_2 pressure of the full spectrum and at 400 nm ± 35 nm.

Finally the time structure of the light production was estimated, confirming a decay time around 60 ns [9] for the main spectral band around 400 nm, with slower components (at several µs) at other wavelengths.

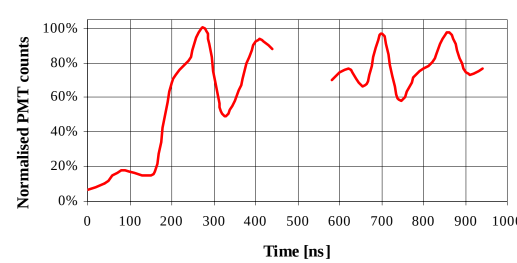

Figure 4: Time structure of the light emitted at 5 10^{-5} Pa by a batch of Lead ion bunches spaced by 131 ns.

As the light is emitted by N_2^+ ions, these ions will move during this latency under the influence of the beam space charge, which will produce a profile broadening. Simulations have shown that this broadening will be limited to 50 µm FWHM for a 60 ns decay time.

4.2 Profile measurements with protons

As this monitor is to be used essentially at low energies where the beams are four times larger than at top energy, the monitor was first optimised for large beam sizes. The beam profiles were in general measured in single shot mode over 870 turns, i.e. over 20 ms, at pressures around $6\ 10^{-5}$ Pa, see Figure 5.

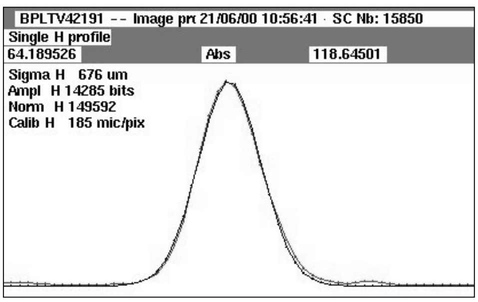

Figure 5: Single shot vertical profile and fit of a $2\text{x}10^{13}$ proton beam at 450 GeV and $6\ 10^{-5}$ Pa, σ = 676 µm.

For pressures reduced to $4\ 10^{-6}$ Pa or less dense beams, images were acquired over 10 SPS cycles, the corresponding image matrices averaged, projections calculated by summing the columns, a first gaussian fit calculated by a χ^2 minimisation, from which the noise was subtracted before calculating a second gaussian fit. The method gives consistent results with the single shot method while operating with much lower pressures.

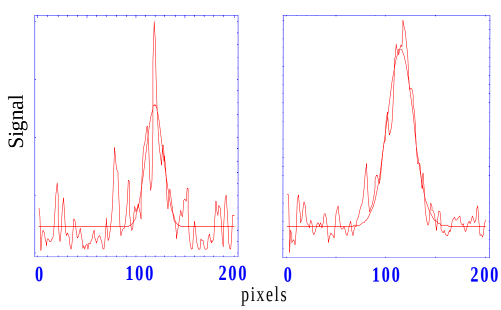

Figure 6: Single shot (left) and statistically processed data (right) with gaussian fits for a 14 GeV horizontal profile taken at $6\ 10^{-6}$ Pa, σ= 4 700 µm.

In both cases, it is possible to obtain the beam size evolution over a full acceleration cycle. Cross calibrations were performed with a wire scanner located at 244 m from the monitor. The difference with this reference monitor is -17%±2%. The mean offset can come from differences between calculated and real optics functions. The smallest measured beam sizes had a σ of 580 µm.

To follow the blow-up of the accelerated beam, it is best to plot a normalised beam size. In Figure 7, the beam size for a fixed target cycle is normalised to the beam size at injection by $\sqrt{\gamma/\gamma_{14}}$. In this particular case, the vertical emittance is blown-up by a factor 2.5.

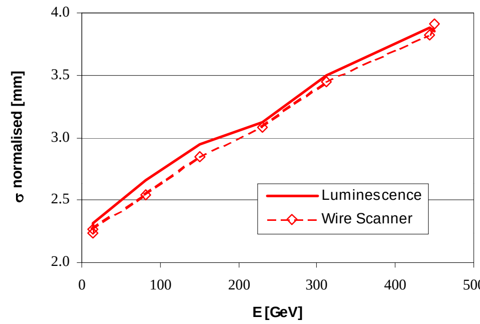

Figure 7: Normalised Vertical beam size evolution during acceleration from 14 to 450 GeV. The beam size measured by a reference Wire Scanner is also given.

4.3 Profile measurements with Lead ions

Profile measurements have also been made with fully stripped Lead ion beams of $8\ 10^{8}$ ions up to 156 GeV/amu. The light level follows the expected Z^2 law from the Bethe-Bloch equation. In general it appeared that the Signal/Noise ratio and the beam tails were of better quality than with proton beams.

5 CONCLUSION

Profile monitors based on N_2 luminescence have given good results in the SPS. The agreement with a reference wire scanner is around 17%±2%, which makes this type of monitor suitable for emittance evolution checking during the acceleration ramps, both in the SPS and LHC.

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