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SCREENS VERSUS SEM GRIDS FOR SINGLE PASS MEASUREMENTS IN SPS, LEP AND LHC

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Abstract

When the transfer channels of the SPS and LEP were designed in the 70's and early 80's, it was foreseen to use screens to observe qualitatively the beam positions and shapes and Secondary Emission Grids and Split Foils to perform precision profile and position measurements. Foils covering the whole aperture were installed for measuring the beam intensities. The original screens were 1 mm thick, which blows up the low energy beams and limits the number of screens which can be used simultaneously. With the use of different screen materials, image acquisition hardware and processing software, the TV screens are now competing with the SEM Grids for precision measurements. The screens are simpler in construction, have a large spatial resolution, typically 10^5 points, and are more sensitive. The use of fast luminescent material and thin Optical Transition Radiation screens are extending the screen monitor field to bunch length and time structure measurements.

Limitations of Secondary Emission Monitors and results obtained with screens with hadrons and leptons are reported. Future applications are considered.

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Screens versus SEM Grids for single pass measurements in SPS, LEP and LHC

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I. INTRODUCTION

The CERN SPS handles a large variety of beams, from 3.5 GeV leptons and 14 GeV protons at injection to 20 GeV leptons and 450 GeV protons at ejection, and more recently 158 GeV/u Lead ions. When the transfer channels of the SPS and LEP were designed in the 70's and early 80's, it was foreseen to use screens to observe qualitatively the beam positions and shapes and Secondary Emission Grids and Split Foils to perform precision profile and position measurements. Foils covering the whole aperture were installed for measuring the beam intensities. The original screens were 1 mm thick, which blows up the low energy beams and limits the number of screens which can be used simultaneously. With the use of different screen materials, image acquisition hardware and processing software, the TV screens are now competing with the SEM Grids for precision profile measurements. The screens are simpler in construction, have a large spatial resolution, typically 10^5 points, and are more sensitive. The use of fast luminescent material and thin Optical Transition Radiation screens are extending the screen monitor field to bunch length and time structure measurements.

II. Secondary Emission Monitors

About 180 Secondary Emission Monitors (SEM) are used in the transfer lines to and from the SPS and 4 in LEP. Their large number in the SPS demonstrates their historical importance as a precise instrument for measuring beam characteristics. They are used for Intensity (BSI), Position (BSP) and Profile (BSG) monitoring. The monitors have either two defined positions, IN and OUT of beam, or can be moved to any desired position with the help of stepping motors. The foils are made of either Aluminium of 25 or 5 µm thickness, or Titanium of 8 or 12 µm thickness. These foils have an average Secondary Emission Efficiency (SEE) of 4.7 %. For the Oxygen and Sulphur low intensity runs in the SPS, thin 500 nm CsI coatings have been deposited onto Aluminium foils to increase the SEE by a factor of twenty [1]. Bias foils are placed at 10 mm on each side of the foils to trap the emitted electrons and define as precisely as possible the SEE. The signals coming from the foils are integrated at intervals defined by timing signals and are processed with 10 bit resolution. Their main limitations have always been the finite spatial and temporal resolutions due to their mechanical construction and their signal processing electronics based on signal integration. The grids in current use in the SPS domain have a spatial resolution between 0.5 and 5 mm, depending on the beam size at the monitor location, with a total number of 16 or 32 channels. The outer foils are wider so as to cover the whole beam aperture.

Two further limitations, related to the SEE, appeared when using these monitors. For lepton transfers, it was noted that the monitors have lower SEEs with electrons than with positrons or protons. This was related to the beam potential which generates much higher electrical fields than the usual bias voltage. The measured efficiencies for electrons are plotted in Fig. 1 as a function of bias voltage. It can be seen that the bias voltage for electrons should be made larger than 700 V to reach efficiencies comparable to the ones for positrons or protons where a plateau is already reached after 30 V.

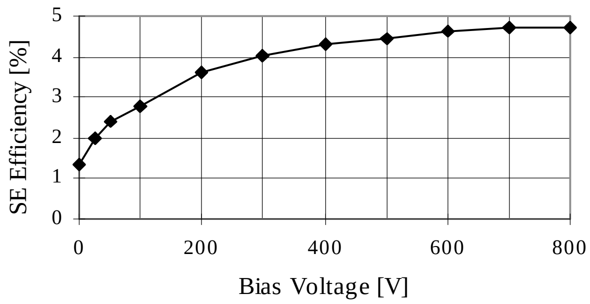

Fig. 1: Secondary Emission Efficiency as a function of bias voltage measured with bunches of 10^{11} electrons.

The second limitation was found when the high intensity transfers to the neutrino line where restarted in 1994 with 10^{13} p per pulse. It was noted that the integrated beam given to this line seemed to decrease rapidly in time. It was found, that the foil measuring the intensity in front of the target had a significant SEE drop in the beam impact area [2]. Comparative measurements on foils in various beam lines, and scanning the foil surface with the beam, demonstrated that the efficiency changed by more than 20% after the passage of a total beam of about 10^{19} p, more or less independent of the time span over which this occurred. This is demonstrated in Fig. 2, where the signals coming from a rarely utilised BSI used as reference, from a permanently used one, from the two strips of a BSP moved across the beam and their sum, are plotted as a function of the BSP position. This ageing effect is being studied systematically after the installation in early 1995 of two BSI monitor heads (Fig. 4) with four foils: two Aluminium and two Titanium, one of each uncoated and the other coated with a thin layer of evaporated Gold. These detectors are put regularly in the beam and their SEEs noted over time. The results are given in Table 1.

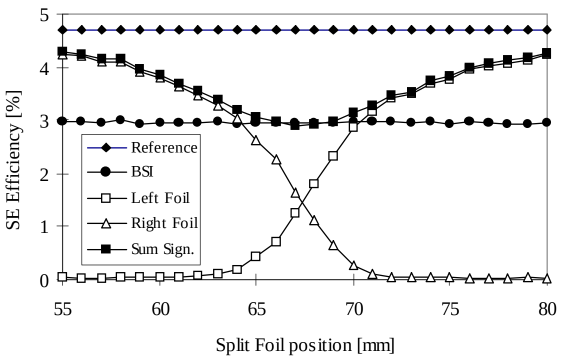

Fig. 2: SE Efficiencies from a reference BSI, a permanently used BSI, the two strips of a BSP and their Sum signal, as a function of the BSP position.

Table 1: Relative Secondary Emission Efficiencies as a function of total charge passed through various foils

	Al	Ti	Al + Au	Ti + Au
New	100%	52%	98%	96%
$1.4x10^{18}$ p	89%	50%	98%	96%
$\sim 10^{19}$ p	64%			

It is noted that new uncoated Aluminium and Titanium foils have very different SEEs, despite the close values of their Work Functions, whereas the Gold coated foils have similar SEEs. The difference may come from the manufacturing process of the foils, the Titanium foils having been annealed during their fabrication. Only $1.4x10^{18}$ protons passed up to now through the foils. The SEE of the Titanium and Gold plated foils has not changed significantly, whereas the Aluminium foil experiences a decrease of 11% of its SEE. The SEE for the 10^{19} case is taken from an old foil. For the moment, the only possibility to overcome this ageing effect is to regularly check the SEE. The SEE is calibrated when appropriate against a reference foil or current transformers, taking into account the calibration problems of single pass current transformers. The influence on measured profiles has been estimated to result in a maximum size increase of 5%. The actual increase is smaller, as the grids are not in permanent use. A typical measured profile is given in Fig. 3.

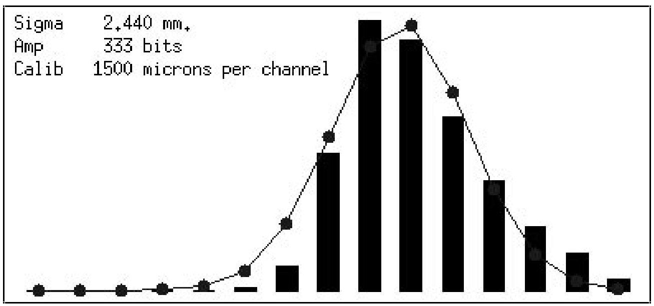

Fig 3: Profile measured with a BSG and fitted gaussian.

III. Screen Monitors

Thirty-seven screen monitors are available in the SPS area and 26 in LEP [3]. The use of different screen materials and the availability of CCD cameras, fast ADCs, large inexpensive memories and processing capabilities, is rejuvenating the screen monitors and is promoting them to precision beam profile instruments. These monitors have a four position mechanism for inserting three screens in the beam and a position for free passage of the beam [1]. Depending on the location, the expected beam density and the measurements to be done, the mechanism is equipped with Al_2O_3(Cr), CsI(Tl), Lithium glass (Ce) or Quartz screens. The emission spectra and sensitivities can be found in [1]. More recently, Optical Transition Radiation (OTR) screens have been installed in five locations: Fig. 4 They are presently made of 25 μm Mylar foils coated with 30 nm of Aluminium on each side, but can be made thinner.

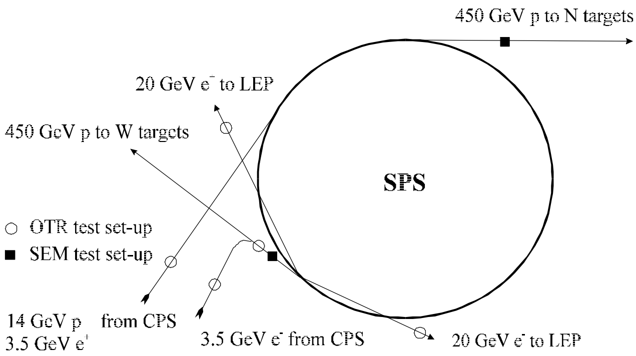

Fig. 4: SEM and OTR test stations in the SPS domain

Comparative sensitivity measurements were made. Leptons at injection and after ejection and accelerated protons can be observed with OTR screens. The 20 GeV injected protons have not yet been seen. An intensifier will be needed to observe them. The relative sensitivities are listed in Table 2.

Table 2: Sensitivities of the various screens for usual optics and beam sizes in the SPS transfer channels.

	CsI(Tl)	Al_2O_3(Cr)	Quartz	OTR
leptons	$7x10^4$	$2x10^6$	$1x10^8$	$1x10^9$

The CCIR standard video signals are acquired and digitised over 8 bits in a VME card and the horizontal and vertical projections are calculated every 40 ms and are stored on the card. A windowing function reduces altogether the integrated noise level on the calculated projections, the memory size for the stored 2D image and the data to be treated and it increases the number of projections which are stored on the card. The use of intensifiers extends these ranges to a few protons per pixel for CsI(Tl) screens [1] and probably to the 10^{13}

injected protons at 20 GeV for OTR screens. A typical profile obtained with screens is given in Fig. 5.

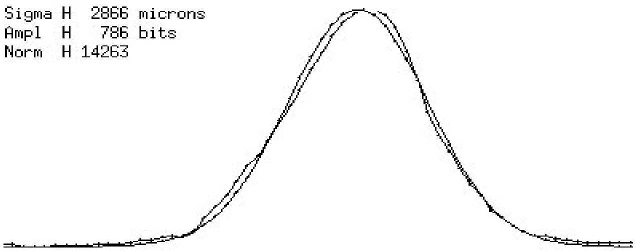

Fig. 5: Horizontal beam projection obtained with a screen and fitted gaussian.

This profile has to be compared to the one measured with a SEM-Grid given in Fig. 3. The screens give up to 400 points per projection compared to the 16 points per profile of the SEM-G. The resolution is perfectly defined with CCD cameras, where the pixel size is fixed at the Silicon level and matched to the beam size by the optics. Next to the high resolution and the 25 Hz measuring frequency, the availability of 2-Dimensional representations and thepossibility to observe them in real time on a TV monitor are major advantages of screens over SEM Grids.

The Al_2O_3(Cr) screens have several drawbacks. They are slow, with hundreds of milliseconds decay times, which don't allow fine time structure analysis, but are appreciated by operators for visual observation on TV monitors. They have a radiation length of about 7 cm which gives an appreciable blow-up when used in the standard thickness of 1mm on low energy beams. But due to their good mechanical properties, they can be thinned.

The CsI(Tl) screens are fast, with a 1µs decay time, more sensitive, but have a lower radiation length of 1.9 cm. The softness of CsI limits their size to disks of 80 to 100 mm diameter at 1 mm thickness. They are extensively used for low density beams and for time structure analysis above the microsecond range. Their major disadvantage is the beam blow-up.

The Quartz screens are fast, with nanoseconds decay time, and are the least sensitive. They are used on high density beams for time structure analysis with Photo-Multipliers. They can be thinned to less than 1 mm.

All these screens give an increase of the measured beam size due to depth of field effects. This effect was reduced in LEP by having the screens perpendicular to the beam trajectory and observing the light through a mirror at 45° [3]. Another possibility is to thin down the screens when mechanically possible.

The OTR screens generate light which reproduces the time structure of the beam. They do not blow-up significantly the beams in our range of energies and emittances. Their disadvantage is the low intensity for the 20 GeV protons in the injection channels and the narrow angular light pattern with leptons. The diffraction is negligible for protons, but is measurable for lepton beams. A correction strategy similar to the one used for the LEP Synchrotron Light telescopes will be applied [4].

Ageing effects with screens have not been observed in normal operating conditions in SPS and LEP.

IV. FUTURE PROSPECTS

The studies of the variations of the SEE will be pursued. It is intended to restrict in future the use of SEMs to areas where screens are not practical, i.e. locations with limited space available on the beam lines or high radiation areas, like extraction septa and targets.

Due to the high spatial resolution and signal-to-noise ratio and good temporal sampling achievable, the screens will be used whenever possible for measuring beam profiles and temporal structure. Luminescent Screens are adequate on all our beam lines and CsI(Tl) screens are the preferred ones. The only disadvantage is the beam blow-up, mainly of the lepton beams, which prohibits their permanent use in the lepton injection lines. OTR screens give little beam disturbance and can be used on all lepton lines. Several screens can be put in the beam path without affecting seriously the emittance. The beam size increase due to diffraction and depth of field will be further studied. It is intended to install more OTR screens in the SPS transfer lines and to replace the four BSPs upstream of the LEP injection by two OTR screens for permanent monitoring. A fast acquisition similar to the one described in [4] is being considered. This will permit individual measurement of all the bunches, separated by at least one LEP turn of 89 µs, injected into LEP during one SPS cycle. For LHC it is intended to install OTR screens for the 450 GeV proton transfer lines between the SPS and LHC. A moderate light amplification will be necessary for the visualisation of the low intensity 10^9 p pilot beams.

V. ACKNOWLEDGEMENTS

J. Mann helped with optics, J. Provost participated in the design of the video acquisition system and M. Sillanoli in the mechanical design and fabrication of the special detectors. The Operations teams provided helpful observations and access to the accelerators.

Their contributions are greatly acknowledged.

VI. REFERENCES

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