Beam loss monitoring system inside Elettra Storage Ring

K.Casarin, E. Benfatto, M.Folla, S.Sbarra, G.Tromba, A.Vascotto

Elettra - Sincrotrone Trieste S.C.p.A., Strada Statale 14 - km 163.5, 34149, Basovizza, Trieste, Italy

Abstract

Elettra is a Synchrotron Light Source based on a 2.4 GeV full-energy injector.
From 2008, top-up mode is operative and permits to keep quasi-constant at the maximum value the current stored inside the ring and consequently the photon flux for the users.
Top-up injections are carried out with beamlines' stoppers open, therefore a great attention is devoted to minimize beam losses inside the ring tunnel. To improve the capability of locating beam losses, a network of 95 Bergoz PIN diode detectors has been installed around the storage ring and a specific software has been developed for detectors' data acquisition.
This paper describes the system layout and characteristics, together with some operational results.

1. Introduction

Elettra facility consists of a 100 MeV pre-injector, a maximum 2.5 GeV booster and a storage ring (SR).
The SR typically operates at two energy values: 2.0 GeV with 310 mA stored current or 2.4 GeV with 140 mA stored current. The booster construction has been completed in 2008, and from 2010 the storage ring routinely operates in top-up mode during users' shifts.

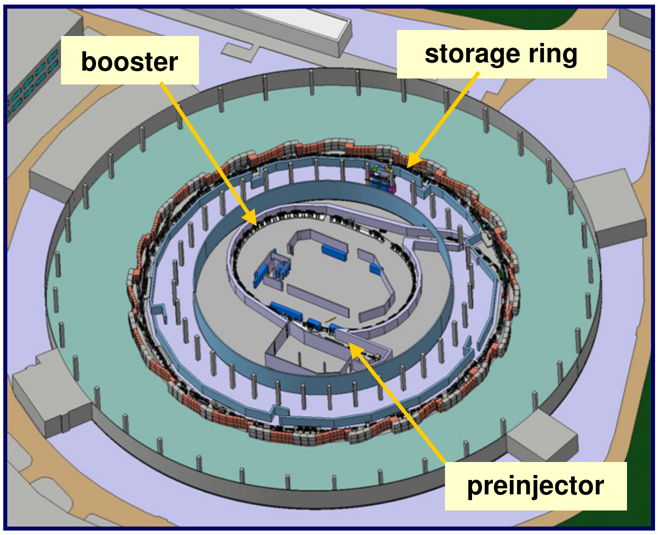


Fig.1 - Elettra facility sketch.

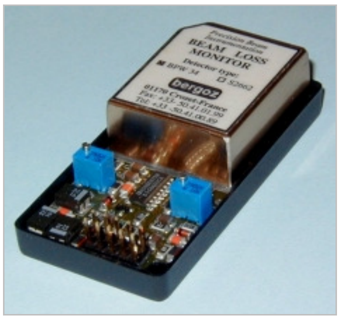
Up to 2008, the beam loss monitoring system installed inside the storage ring consisted of a network of 24 PIN photodiodes BPW34, with a front-end electronics developed in house, based on a charge amplifier.
The charge produced by beam losses was integrated through a charge sensitive amplifier, opportunely amplified, and then sent to a 8-bit ADC. The ADC output was transmitted to a server and plotted on a bar chart at disposal of the control room operator.
The detector electronics was synchronized with the injection trigger to optimize the signal-to-noise ratio and to maximize the detection efficiency during beam injection.
Nevertheless, the detector dynamic range was not suitable to detect small beam losses produced during top-up injection.

In 2008, in view of the top-up mode introduction, an upgrade of the storage ring beam loss monitoring system started.
The requirements for the new beam loss monitoring system included high sensitivity, large dynamic range and high modularity (i.e. possibility to easily add beam loss detectors and acquisition boards to increase the system performance). A graphical user interface was also needed, in order to manage easily the information

coming from the detectors, and a historical database had to be forecast, in order to permit data retrieval for offline analysis.

2. The new beam loss monitoring system installed in the storage ring

In order to upgrade the beam loss monitoring system, a network of Bergoz BLMs [1], [2], [3], [4] was installed around the 260 m circumference storage ring. The network initially consisted of 16 detectors, that became then 48 and finally 95 in 2012.
Each Bergoz detector (Fig.2) consists of two photodiodes, mounted face-to-face: they produce voltage pulses when the photodiode active area is struck by minimum ionizing particles (MIPs), i.e. particles generated when the electron beam strikes the residual gas molecules or a beam pipe obstruction.
The signals coming from the two photodiodes are analyzed through a coincidence electronics: the detector functioning is based on the idea that a MIP crosses both PIN-photodiodes, producing current flow in both detectors, whereas a synchrotron radiation photon is stopped by either PIN-diode, and does not cause a coincidence. Therefore, through a coincidence technique applied in the circuit, it is possible to discriminate MIPs from synchrotron radiation, normally produced inside the storage ring.



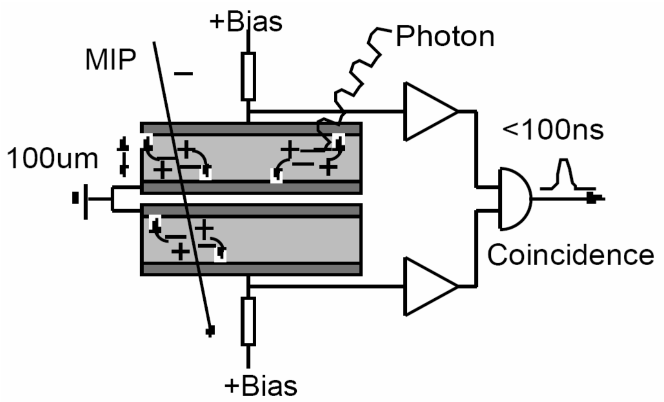


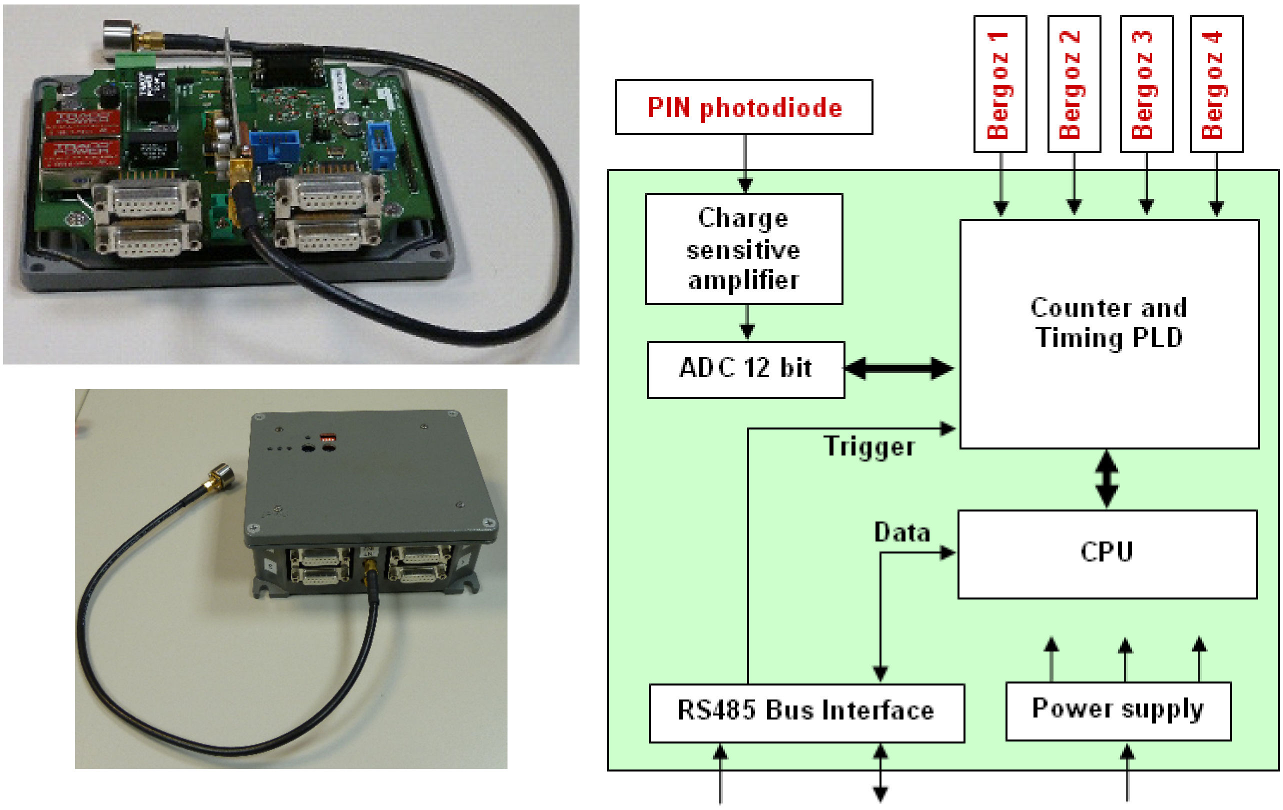
Fig.2 - Bergoz detector and operating principle.

The detectors' specifications are listed in Table 1.

Bergoz BLM specifications	
Single particle detection efficiency:	>30%
Size:	69 x 34 x 18 mm
PIN-photodiode surface:	7.34 mm^2
dE/dx in Si:	3.7 MeV/cm
Spurious count rate:	<0.1 Hz
Maximum count rate:	>10 MHz
Fast:	~5 ns
Sensitivity:	~50 $nC/rad/cm^2$
Output:	positive TTL 50Ω

Table 1 - Bergoz BLMs' specifications.

The TTL signals coming from the Bergoz BLMs are acquired through an electronics which has been developed in-house (see Fig.3). The same electronics is utilized to acquire the output of the old-type synchronized PIN photodiodes; up to 4 Bergoz BLMs and 1 old-type PIN photodiode can be connected to the same reader.



(a) (b)

Fig.3 - BLMs' reader.

As shown in Fig.3b, the TTL signals coming from the Bergoz BLMs are counted by a PLD and then sent to a CPU which is in charge of data processing. The CPU output is transmitted to the server via RS485 Bus Interface.

The charge produced by the beam loss in the old-type PIN photodiode is integrated by a charge sensitive amplifier and then sent to a 12 bit ADC, triggered by the injection timing. Data retrieval from the ADC is synchronized with data acquisition from the Bergoz through the same PLD.

The final beam loss monitoring network consists of 24 readers, 95 Bergoz BLMs and 24 PIN photodiodes, as shown in Fig.4.

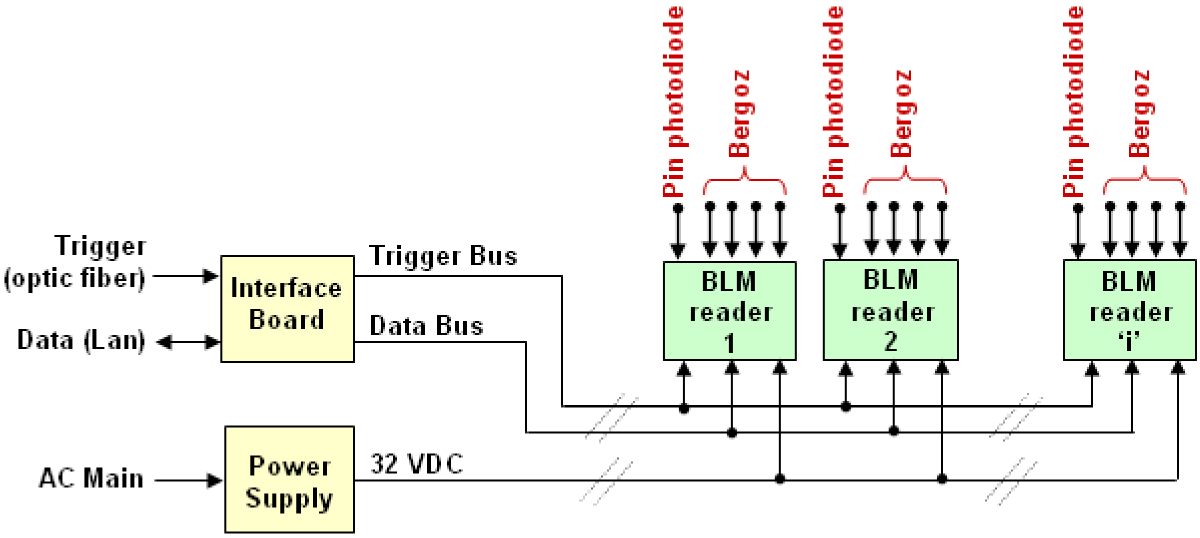
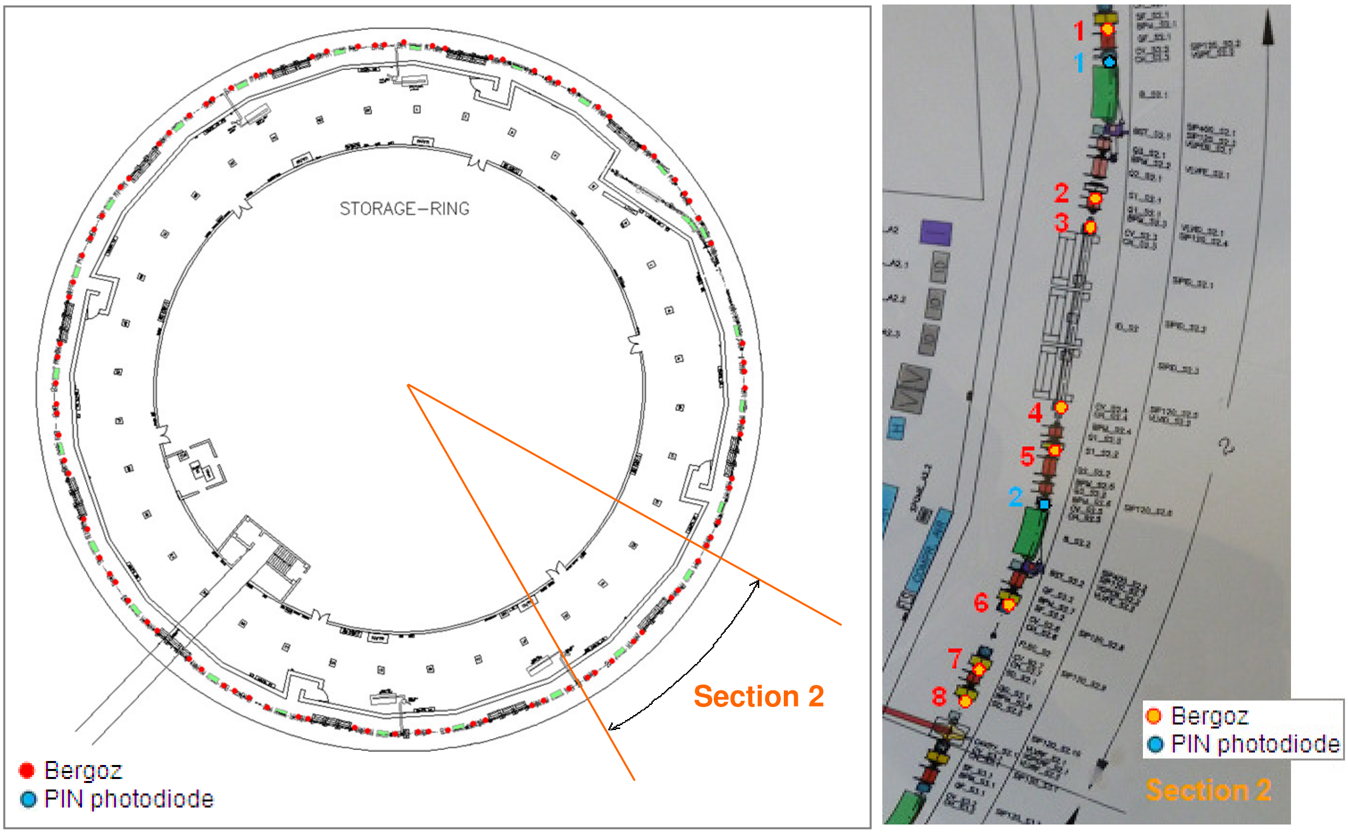


Fig.4 - Block diagram of BLMs' network.

The position of the detectors along the storage ring is indicated in Fig.5a; a detailed view of Section 2 is shown in Fig.5b as an example.



(a) **(b)**

Fig.5 - BLMs position along Elettra storage ring (a). Detail of BLMs position in Section 2.

The choice of the measurements points for the BLMs positioning is performed taking into account different parameters, such as the available space near the vacuum chamber, the vertical aperture of the vacuum chamber itself, some machine parameters such as the dispersion, and the points affected by major beam losses identified on the basis of the induced radioactivity distribution measured during shutdown surveys.
To maximize detectors' sensitivity, the BLMs were positioned directly on the vacuum chamber (as close as possible to the beam axis), with the active area perpendicular to the beam direction.

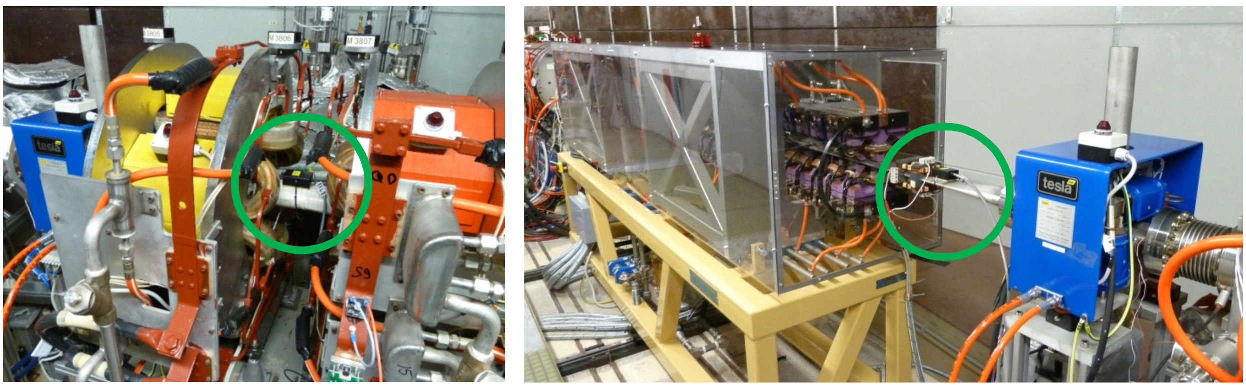


Fig.6 - Photos of some Bergoz detectors positioned inside the Elettra storage ring tunnel.

A graphical user interface was developed in-house (using Qtango libraries) and fully integrated with the machine control system (Tango Control System), in order to provide a handy tool both for machine trouble

shooting diagnosis and for routine operation. A Tango historical database (HDB) was developed to permit data retrieval for further offline analysis.
Fig.7 shows the real-time bar-chart display at disposal of the control room operator for beam loss monitoring. The abscissa indicates the position of the monitor (which corresponds to the name of the machine component installed just upstream of the detector), and the ordinate shows the detector count rate, expressed in counts per second.

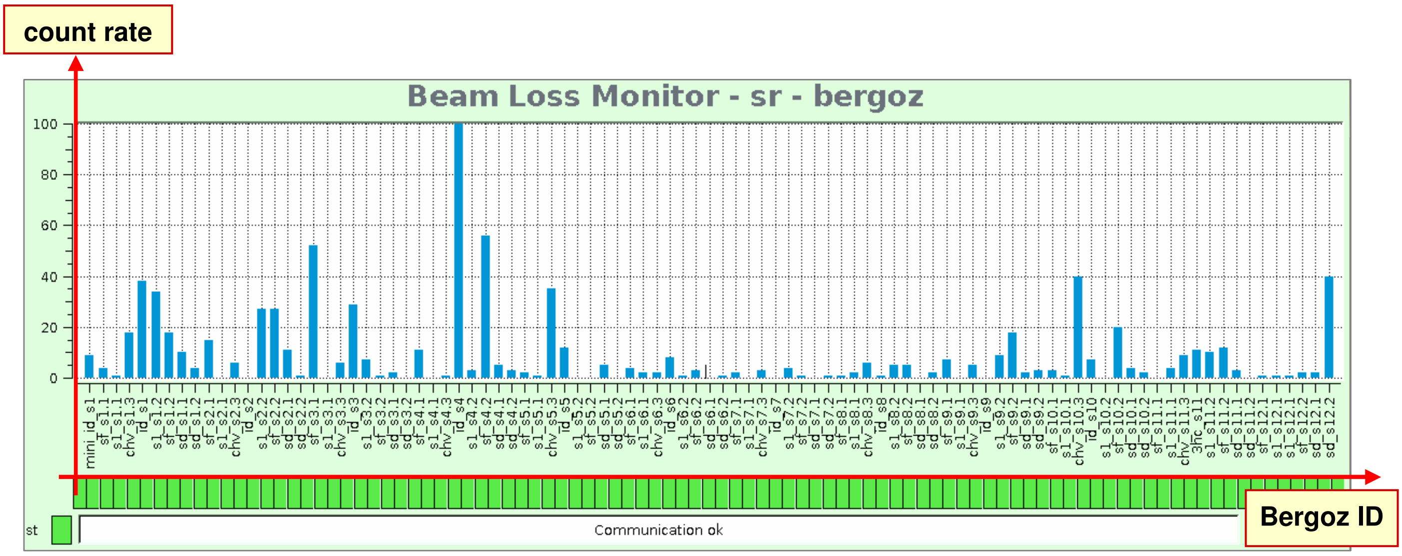


Fig.7 - Real-time bar-chart display of the Bergoz beam loss monitoring system.

3. Measurements

<u>Case#1</u>

Case#1 refers to an anomalous beam loss detected on March 18th, 2013, during injection operation, by the BLM positioned just downstream of the insertion device installed in section 4 of the storage ring.
Fig.8 shows a screenshot of the Bergoz bar-chart at 20:05:16, referred to the first 6 sections of the storage ring (from Section1 to Section 6).

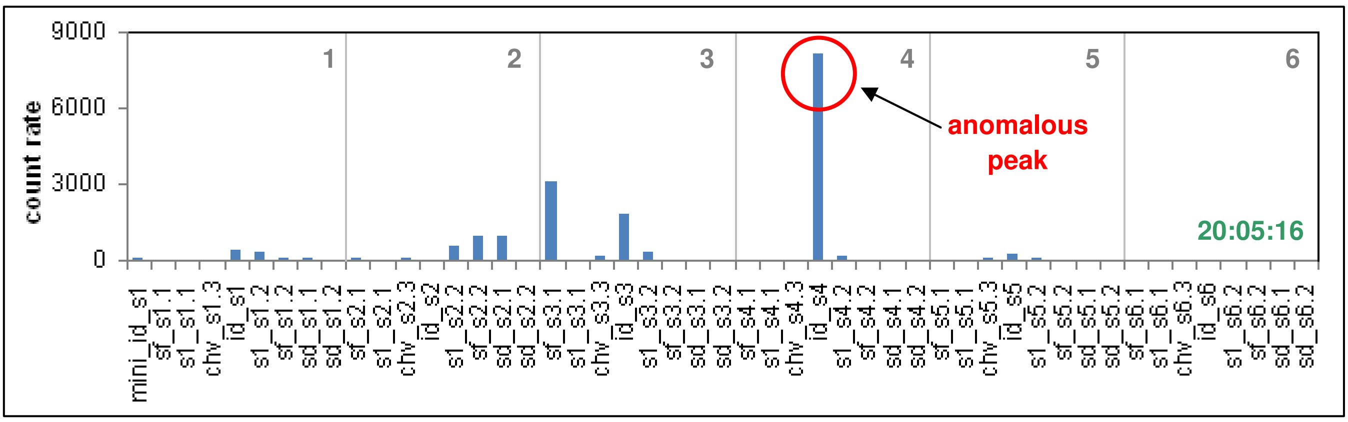


Fig.8 - Real-time bar-chart display of the Bergoz beam loss monitoring system.

The analysis of the data retrieved from the historical archive showed that the beam loss was present not only during injection (Fig.9), but also when top-up operation mode was activated (Fig.10), and between a top-up injection and another (Fig.11), with different intensity.

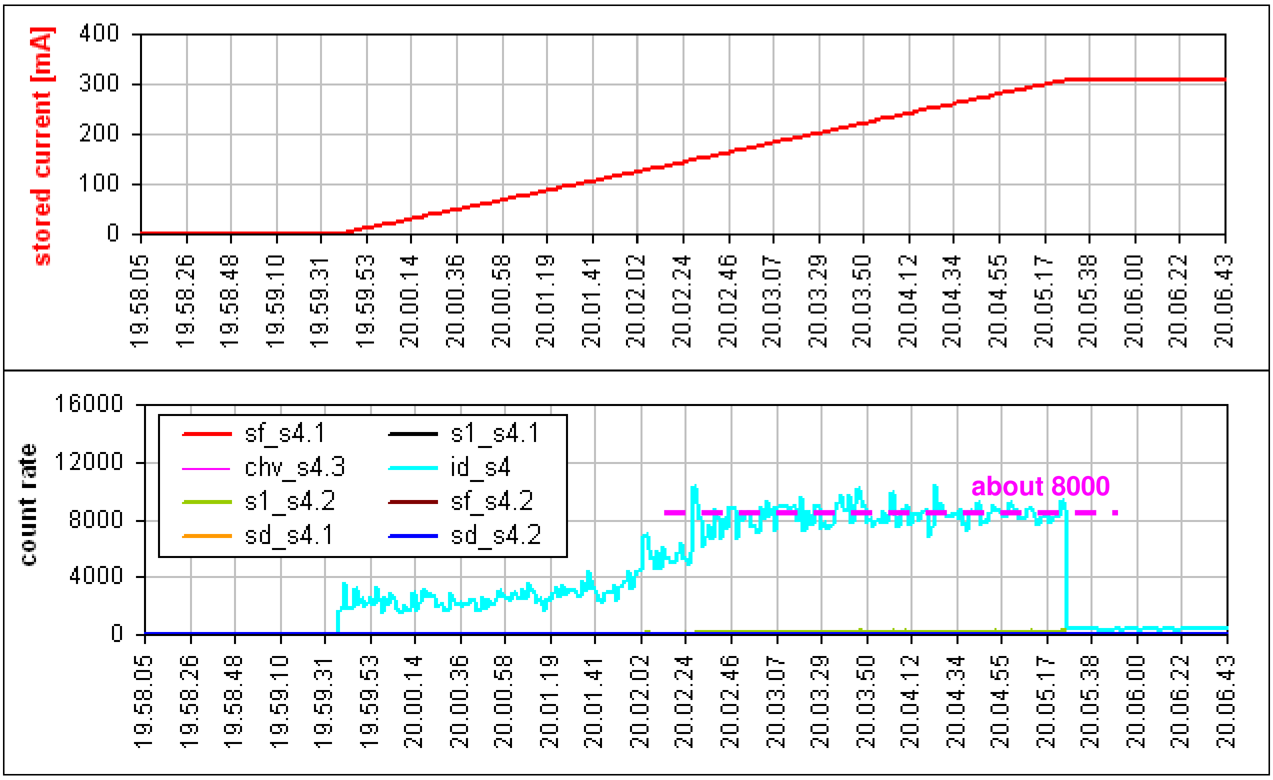


Fig.9 - Plot of the storage ring current and of the count rate measured by the Bergoz detectors installed in section 4 of the storage ring, during 18 March injection, as a function of time.

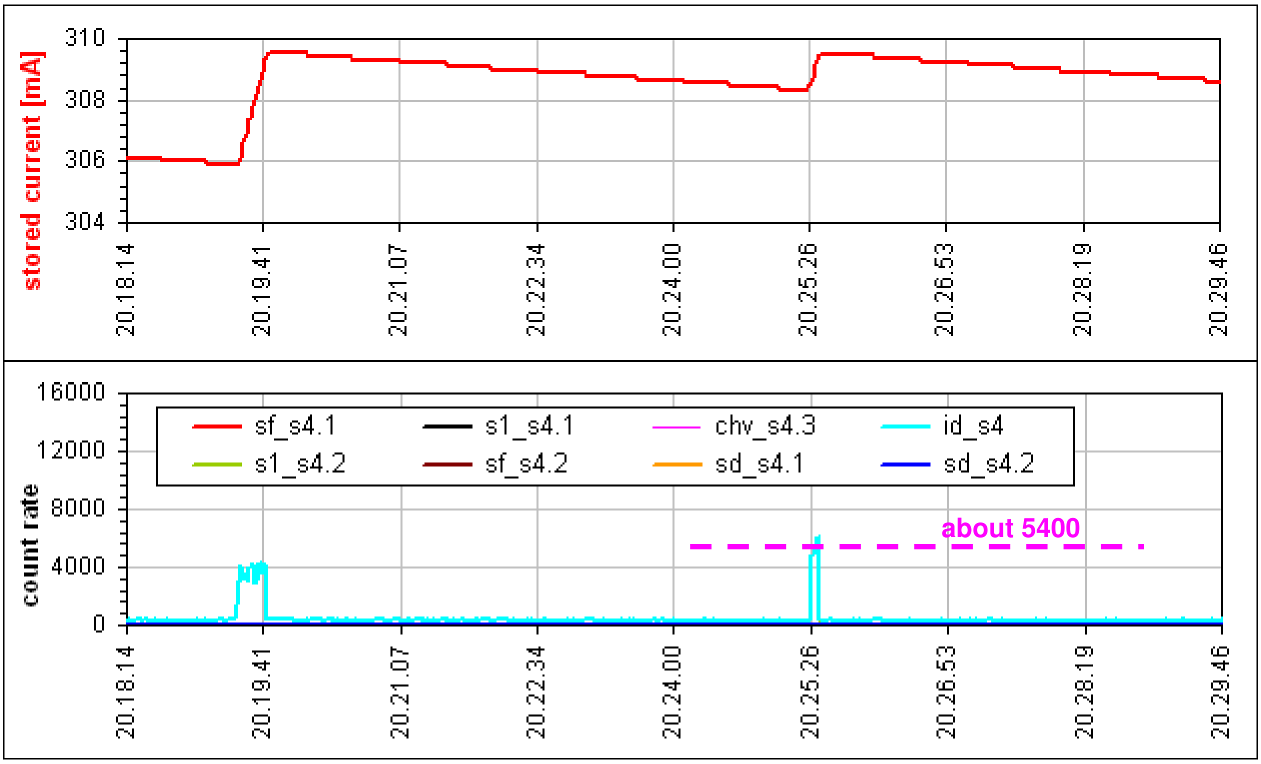


Fig.10 - Plot of the storage ring current and of the count rate measured by the Bergoz detectors installed in section 4 of the storage ring, in top-up mode, as a function of time.

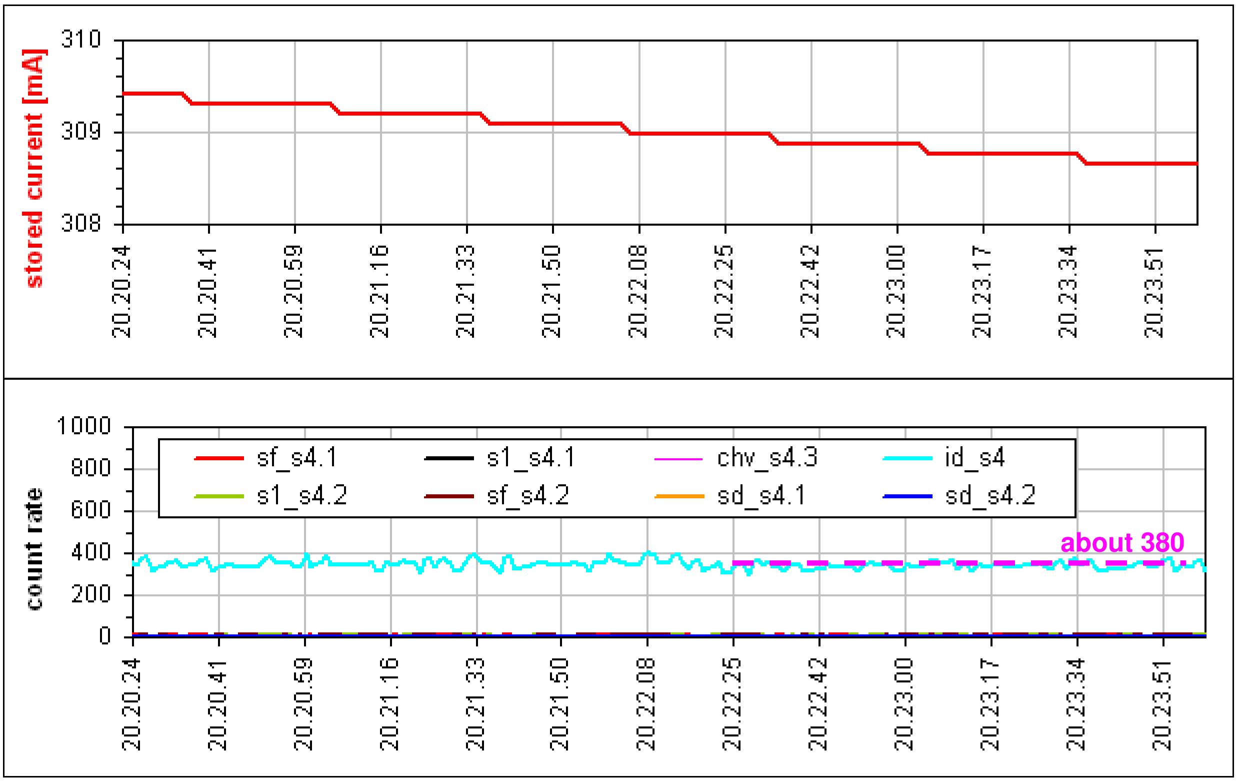


Fig.11 - Plot of the storage ring current and of the count rate measured by the Bergoz detectors installed in section 4 of the storage ring between two top-up injections (decay mode), as a function of time.

Investigation of the beam loss cause permitted to identify a focalization problem: it was found out that the beam loss could be decreased by increasing the current of the quadrupole placed just upstream of the ID4. Fig.12 shows in detail the position of the Bergoz BLMs in Section 4 (blue arrow), the position of the Bergoz BLM which detected the beam loss (red arrow) and the position of the quadrupole whose current had to be corrected to decrease the beam loss (yellow frame).

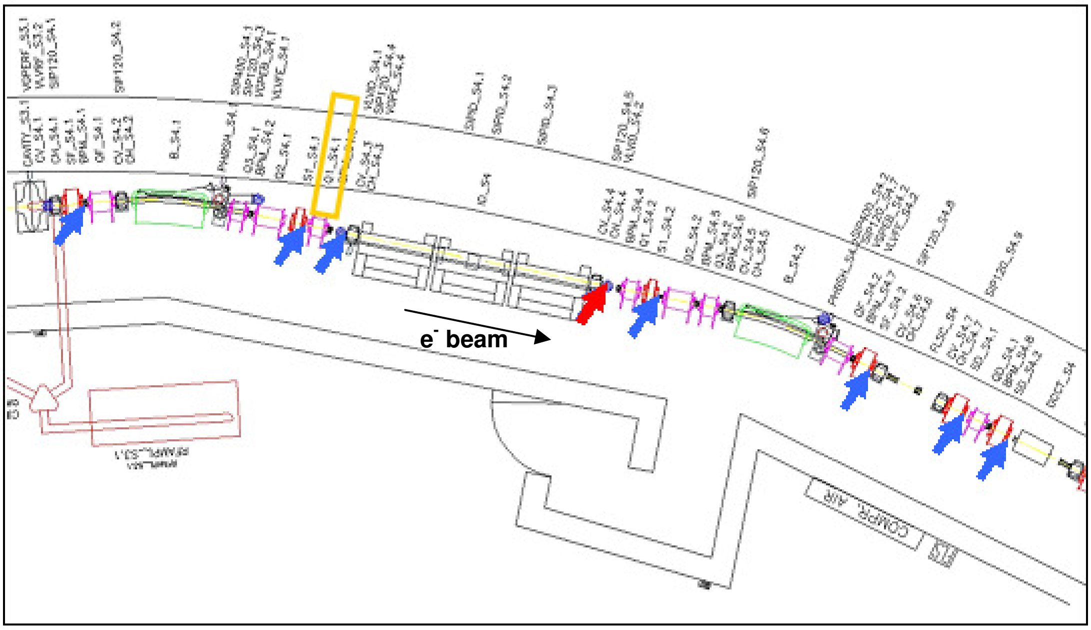


Fig.12 - Detail of Section 4, with the position of the Bergoz BLMs (blue arrow), the position of the Bergoz BLM which detected the beam loss (red arrow) and the position of the quadrupole whose current was correlated to the beam loss intensity.

Case#2

Case#2 refers to an anomalous current drift of a quadrupole (Q3_S10) positioned just after the insertion device installed in section 10 of the storage ring, detected during a users' shift in top-up mode.
The drift caused a decrease in the electron beam lifetime from 18 to 15 hours (indicated in blue in Fig.13) and an increase of the count rate measured by the Bergoz BLM called "id_s10S (Fig.14), placed just downstream of the insertion device.

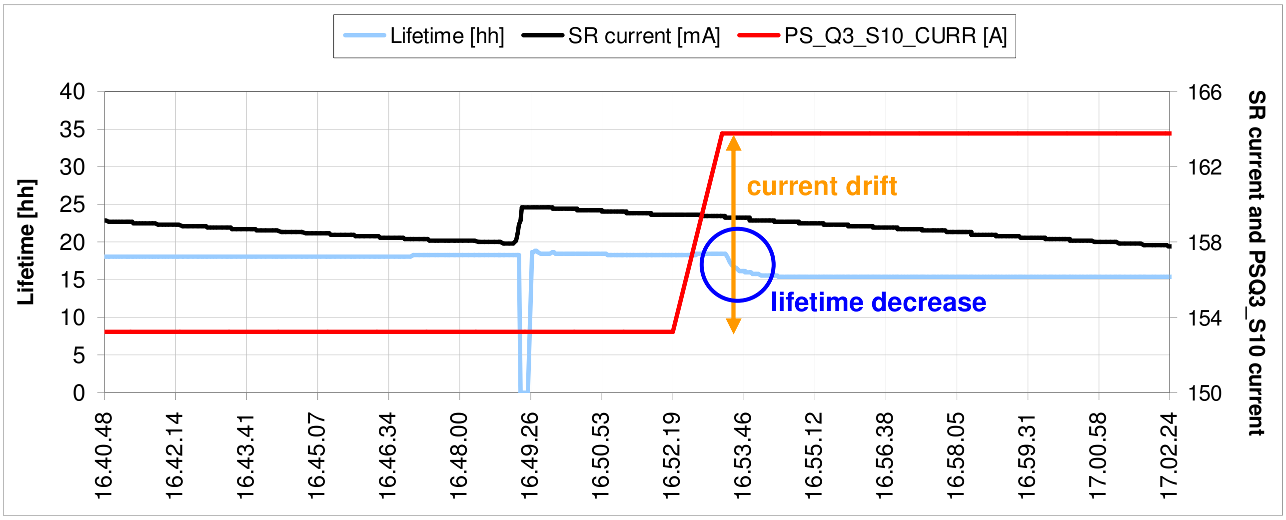


Fig.13 - Plot of electron beam lifetime, storage ring current and quadrupole Q3_S10 current as a function of time. The quadrupole current drift and the lifetime decrease are pointed out in yellow and blue respectively.

Data retrieval from the historical archive permitted to understand the correlation between the two events and to calculate the Bergoz BLM count rate increase (about a factor 3).

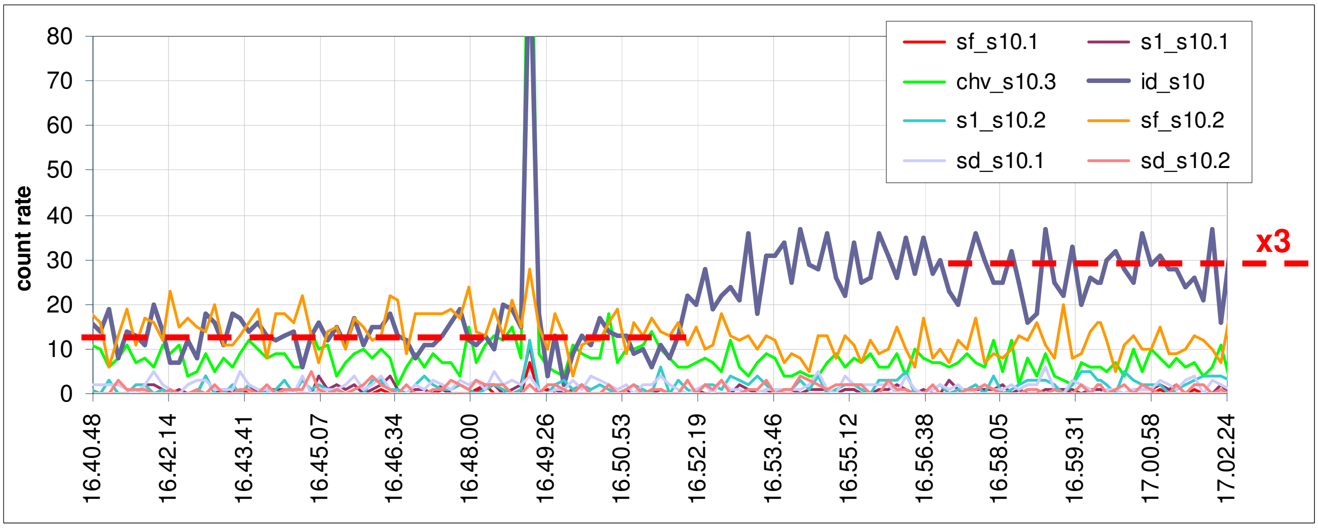
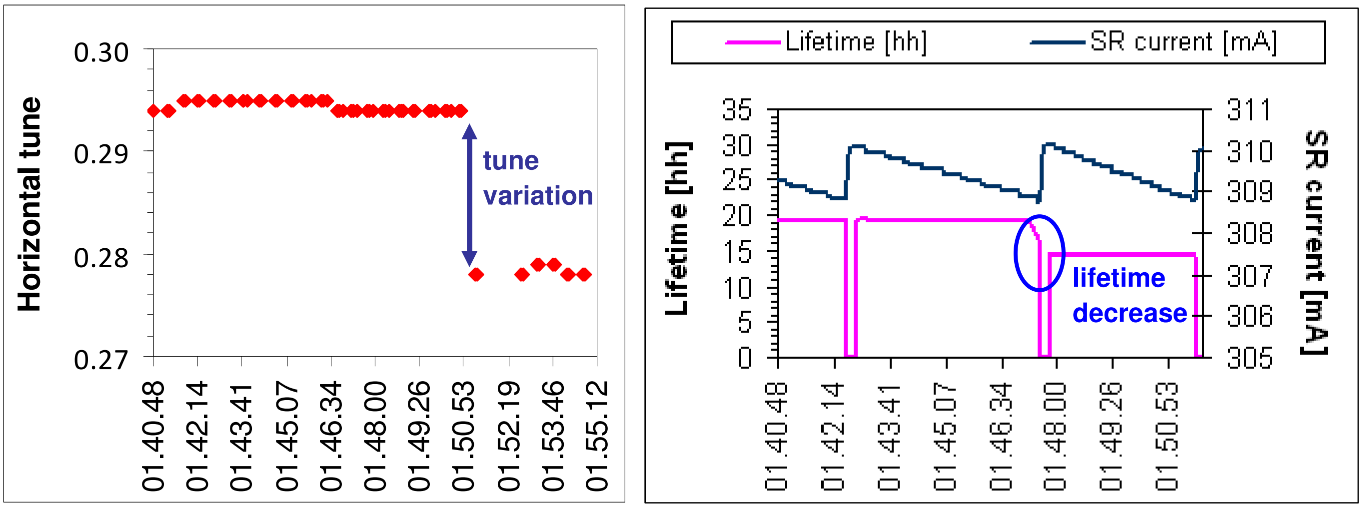


Fig.14 - Plot of count-rate of the Bergoz BLMs installed in Section 10 of the storage ring.

Case#3

Case#3 refers to a “strong” variation of the horizontal tune (see Fig.15a), registered on April 28th, 2013, during a users’shift in top-up mode, due to a phase variation in the insertion device installed in section 9 of the storage ring.

The tune variation caused a global perturbation of the beam orbit, with a decrease in the electron beam lifetime (from 19.2 to 14.5 hours, as shown in Fig.15b) and a general increase in the count rate recorded by the Bergoz BLMs’ monitoring system (Fig.16).



(a) (b)

Fig.15 - Tune variation during a users’shift (a) and consequent decrease in the electron beam lifetime (b).

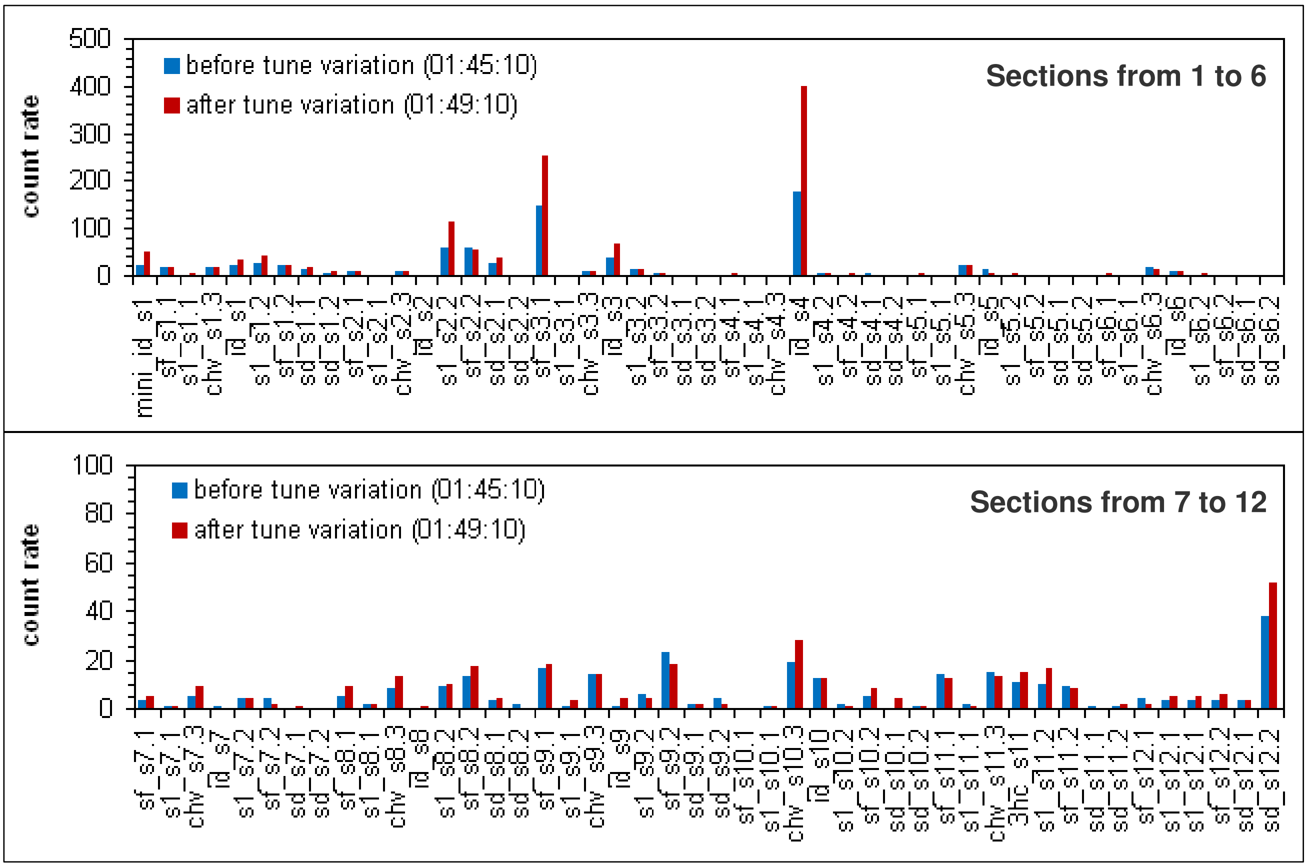


Fig.16 - Bergoz BLMs’ count rate on two different instants, before and after tune variation.

Case#4

In Case#4, a set of beam dumps was intentionally produced inside the storage ring, with different values of stored current, switching off the RF cavities radiofrequency, in order to study beam loss distribution.
Results are shown in Fig.17. In general, graphs confirm that the beam losses are more probable where the vacuum chamber vertical gap is smaller.
Nevertheless, the intensity of Bergoz count rate does not increase linearly with the value of stored current, suggesting that this kind of detectors could be not completely adequate to detect short beam losses (e.g. beam losses produced during beam dumps).

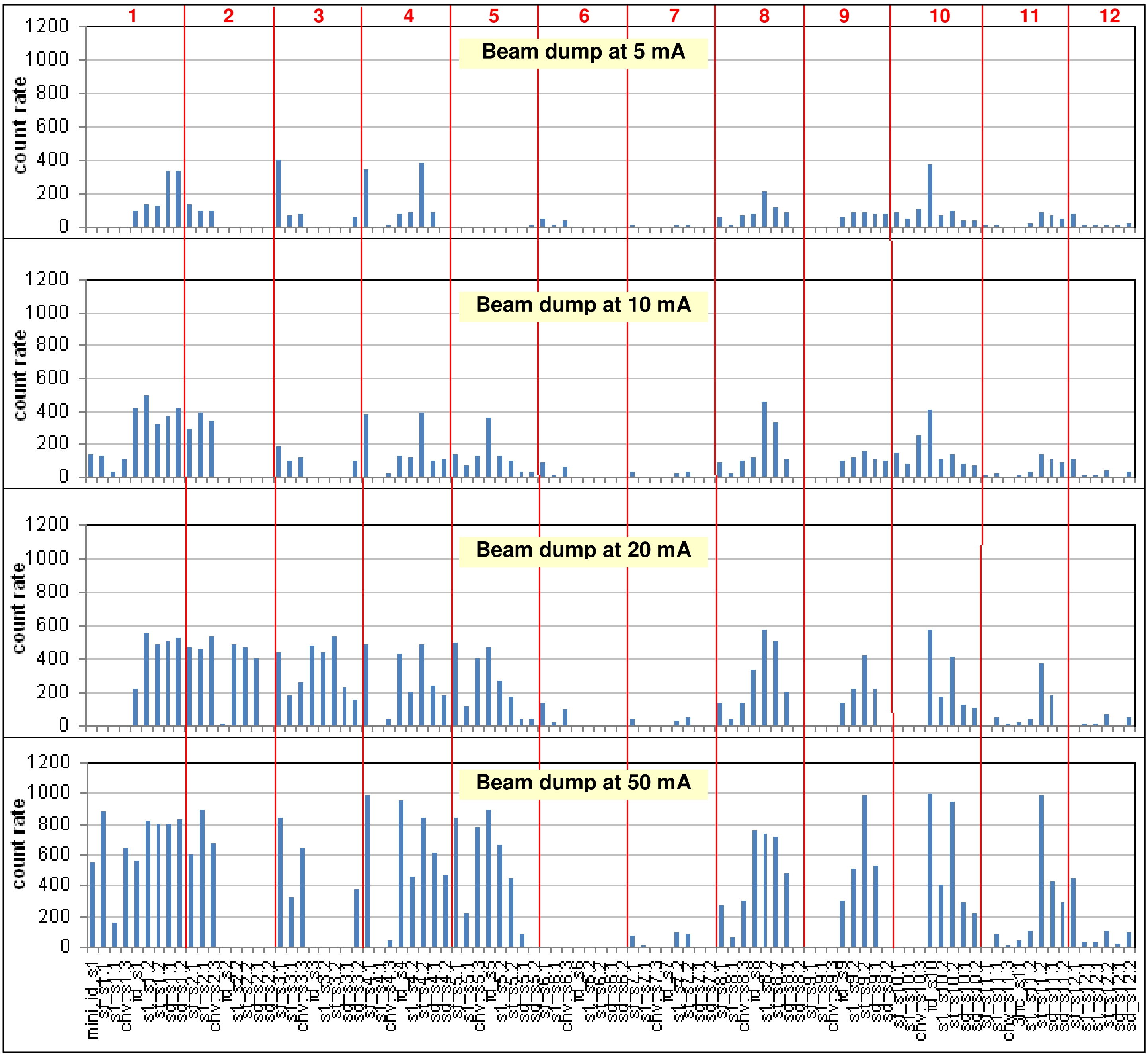


Fig.17 - Bergoz detectors' count rate in correspondence to the beam dumps, with different stored current.

Case#5

Case#5 shows the response of the BLM monitoring system when the electron beam, coming from the booster, hits one of the storage ring fluorescent screen. In the first set of measurements, the electron beam impinged on the fluorescent screen installed in Section 2 of the storage ring, called FLSC2.
The position of the FLSC2, together with the position of the old-type photodiode named "ch_3.2" and of the 4 Bergoz BLMs ("sf_S2.2", "sd_s2.1", "sd_s2.2" and "sf_s3.1") installed in the area of beam loss, is shown in Fig.18.

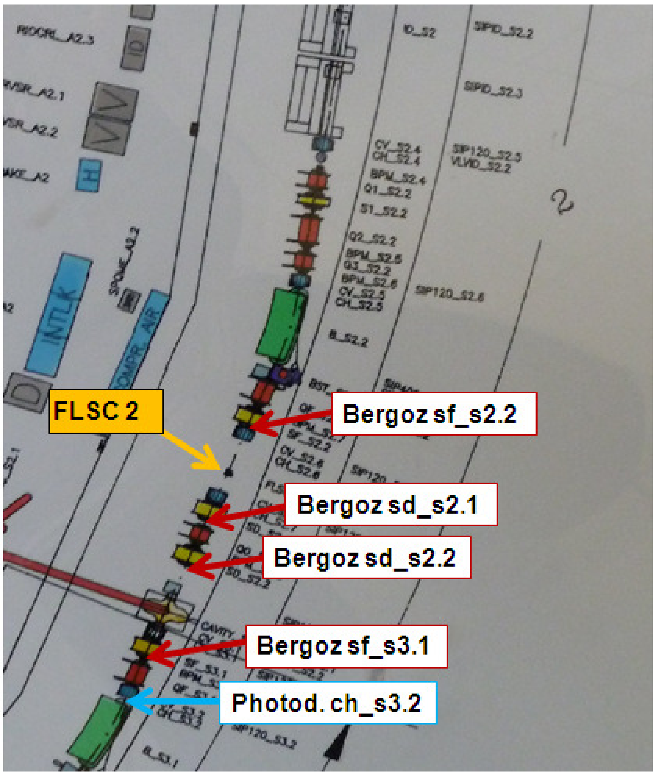


Fig.18 - Position of the fluorescent screen in section 2 (FLSC2) and of the BLMs installed in the same area.

A screenshot of the graphical panel developed for the old-type PIN photodiodes is shown in Fig.19. A peak is detected in correspondence to the PIN photodiode named "ch_S3.2", indicating a saturation of the charge amplifier.

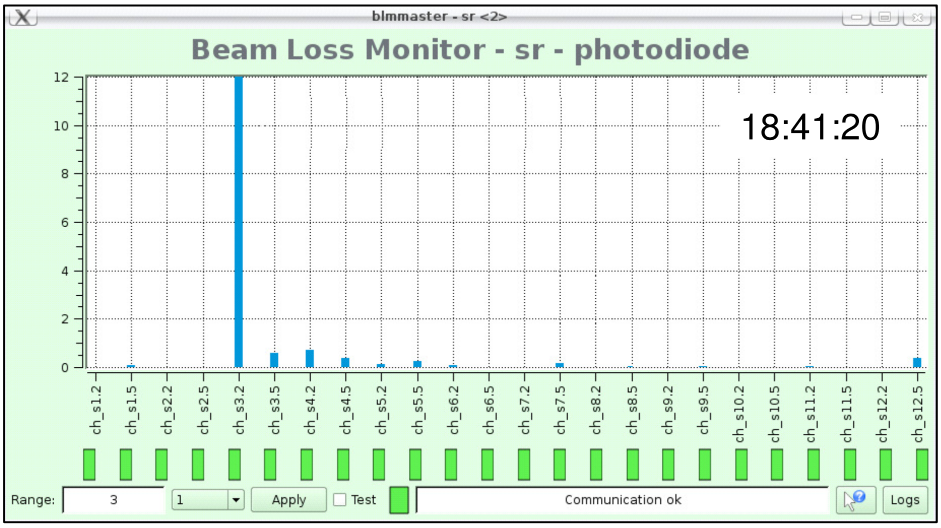


Fig.19 - Data from old-type PIN photodiodes at 18:41:20.

Data recorded by from the 4 Bergoz BLMS installed in the region of beam loss are plotted in Fig.20 and do not show any increase in count rate (the green arrow indicates the time of the screenshot of the panel shown in Fig.19, recording the peak) .
The Bergoz BLMs' response of the is reasonably due to the fact that the current pulse coming from the booster and impinging on the FLSC is very short (100 ns) and consequently the MIPs produced by the interaction of the booster pulse with the ring FLSC is detected as a single coincidence event. This represents a limit in the capability of these detectors to detect pulsed beam loss.
The experiment was repeated with all the storage ring FLSCs (installed in Section n° 4, 6, 8, 10), producing the same results.

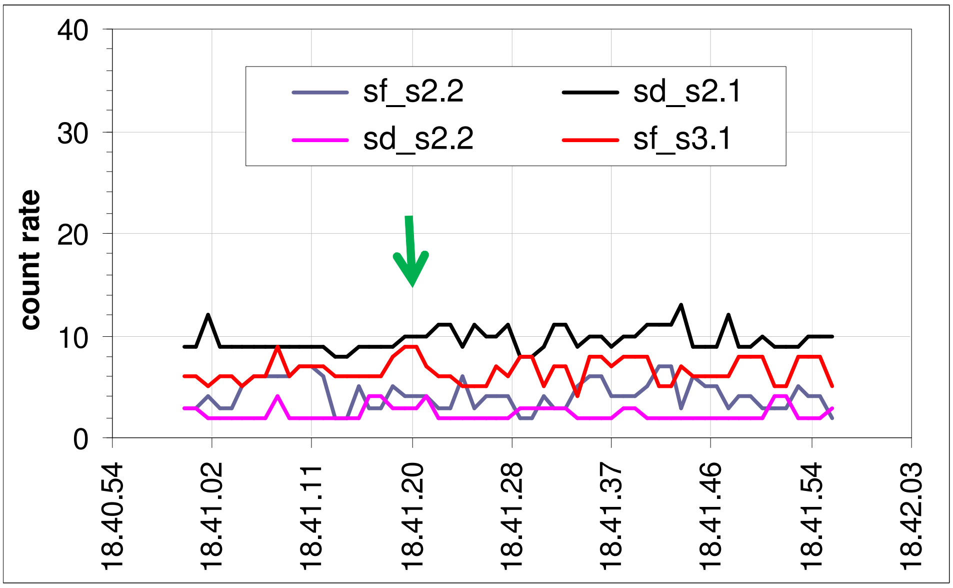


Fig.20 - Plot of data from Bergoz BLMs installed in the area of beam loss.

4. A further development

Starting from the experience gained with the Elettra beam loss monitoring system, the project of a new BLMs' reader was developed, in order to increase the dynamic range and the beam loss detection sensitivity. The general idea was to develop a widespread, low cost, beam loss detection system, to be used in the optimization of the electron beam transport inside the new facility FERMI@elettra [5], [6].

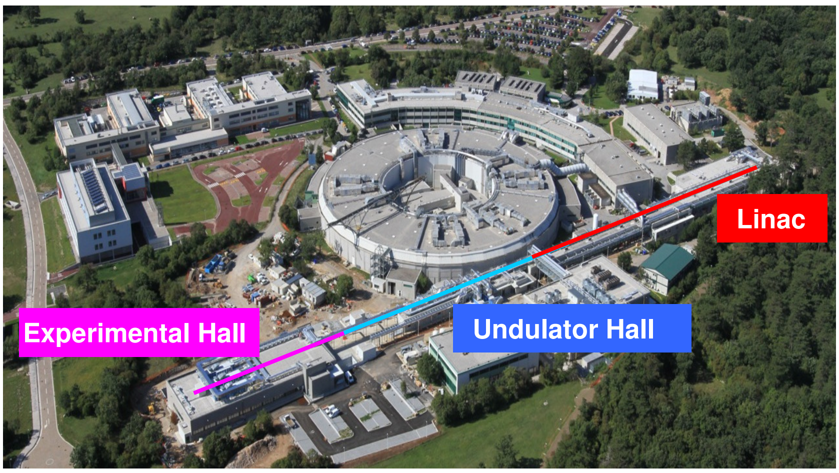


Fig.21 - FERMI@elettra accelerator.

FERMI@elettra is a free electron laser facility consisting of a 200 m Linac, a 100 m Undulator Hall and a 50 m Experimental Hall. The electron beam, produced and accelerated inside the Linac, is transported in the Undulator Hall, and guided along one undulator chain (named FEL1) or the other (named FEL2).
The facility is projected to produce two FEL beams, that cover different spectral regions: FEL1 covers the spectral range from ~100 nm down to 20nm, FEL2 from 20 to ~4 nm. The max charge produced by the Linac is 500 pC at 1.2-1.5 GeV, with a maximum repetition rate of 50 Hz.

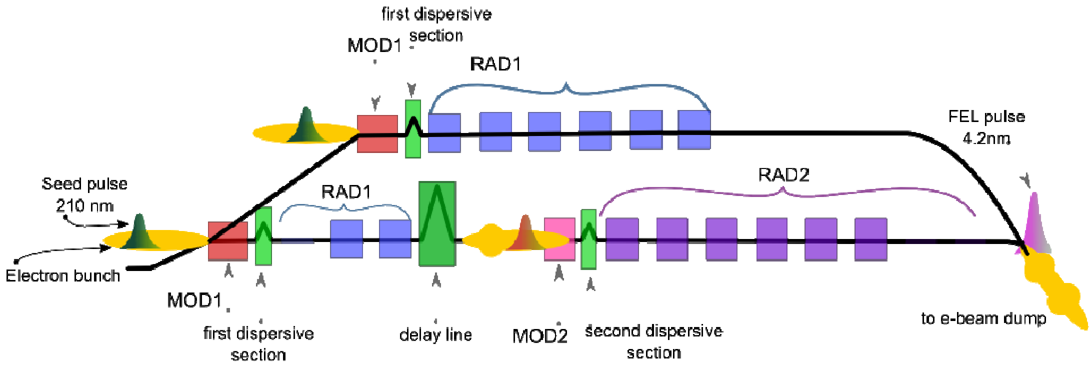


Fig.22 - FERMI@elettra layout inside the Undulator Hall.

The BLMs' reader developed for FERMI are still based on BPW34 photodiodes (as the old-type storage ring detectors), synchronized with the injection trigger, but the front-end electronic was completely revised and substituted by a dual input, wide dynamic range, charge-digitizing Analog-to-Digital Converter with 20-bit resolution (Fig.23).
The new electronic permits to select the integration capacitor and therefore the input range, from about 0.02 pC to 1 nC. The device functionality can be checked through the "Test" channel.

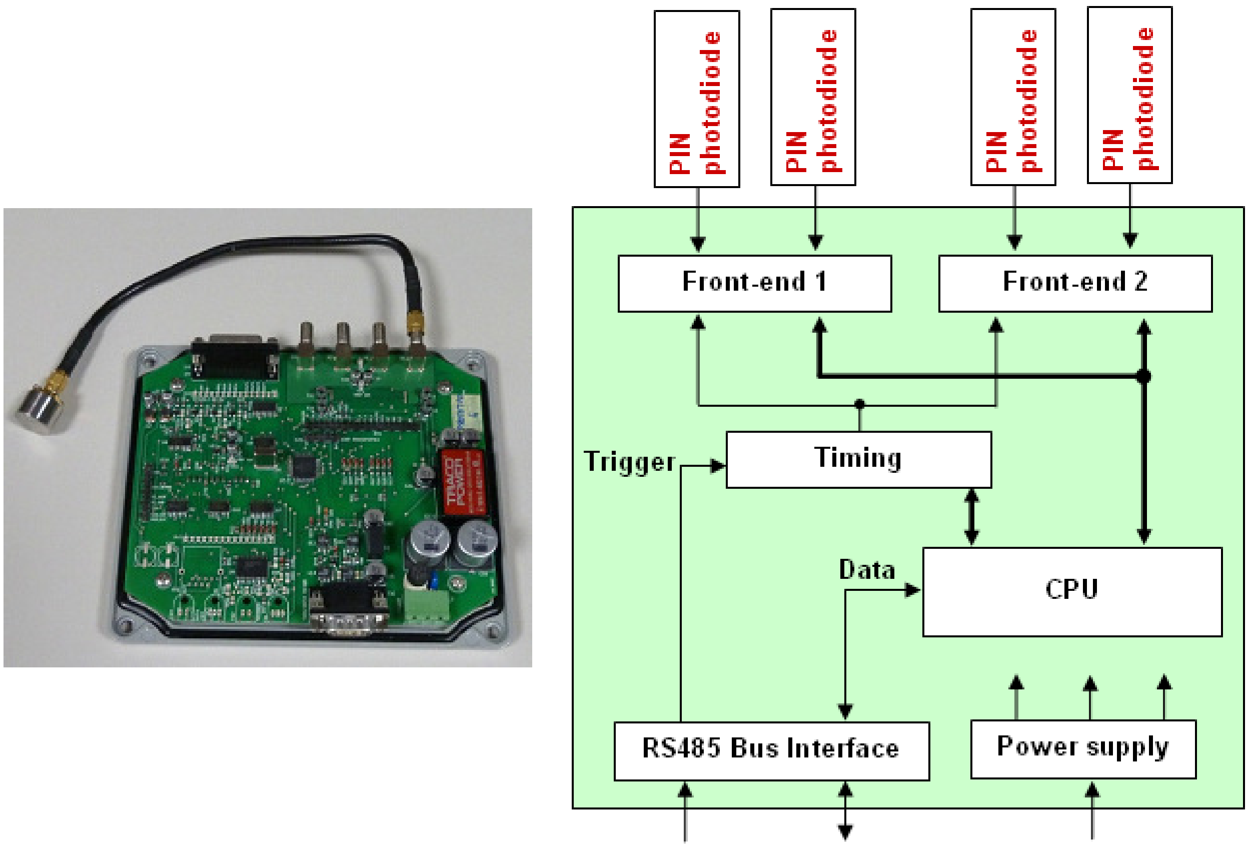
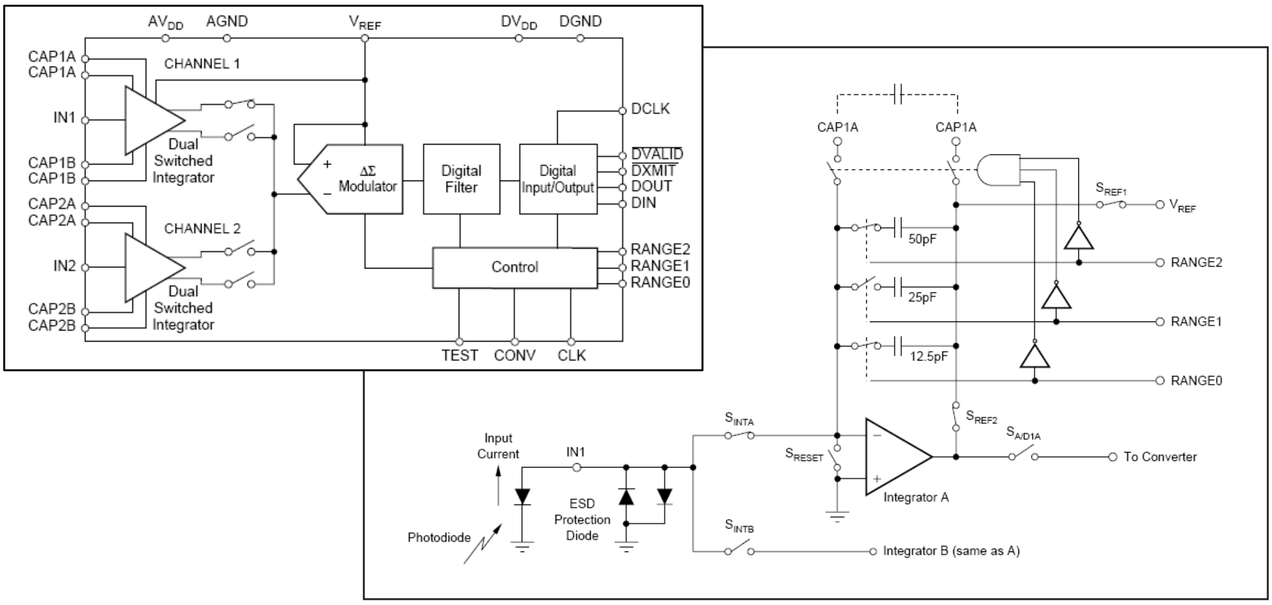


Fig.23 - The new BLMs' reader.

The front-end stage electronics of the new BLMs'reader is shown in Fig.24.



Basic Integrator Configuration for Input 1 Shown with a 250pC (C_F = 62.5pF) Input Range.

Fig.24 - The front-end stage electronics of the new BLMs'reader.

Some photos of some BLMs installed inside FERMI@elettra machine tunnel are shown in Fig.25.

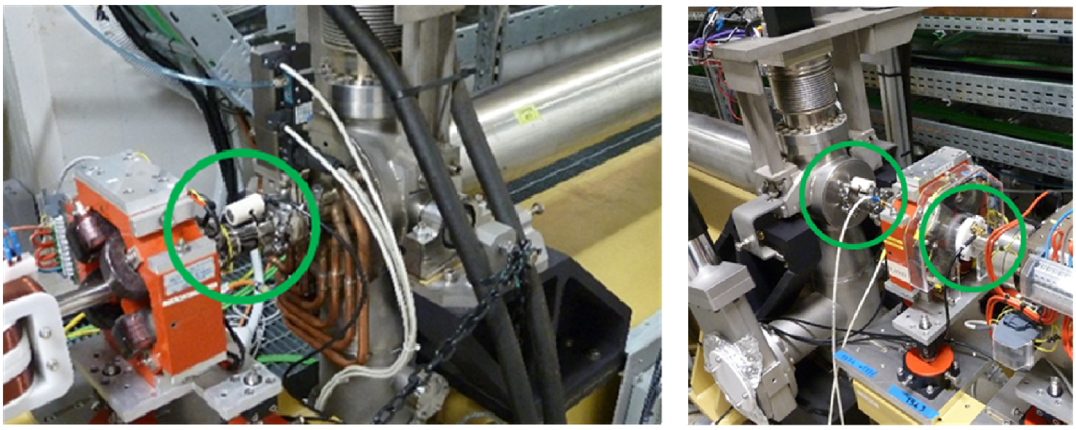


Fig.25 - Photos of some BLMs installed inside the FERMI@elettra machine tunnel.

Three networks have been installed inside the machine tunnel, two for the Linac and one for the Undulator Hall, with a total of 67 readers (45 in Linac and 22 in UH) and 236 PIN photodiodes (127 in Linac, 57 along FEL1 and 52 along FEL2). A block of each BLMs' network is shown in Fig.26.

Inside the Undulator Hall, another beam loss monitoring system interlocked with the Machine Protection System was already present [7], [8], to keep under control the beam losses produced along the undulator chains.

A graphical users'interface was developed for the new detectors, on the basys of the one already realized for the storage ring BLMs.

The beam loss detection system turned out to be very useful in the optimization of electron beam transport during FERMI commissioning and operations.

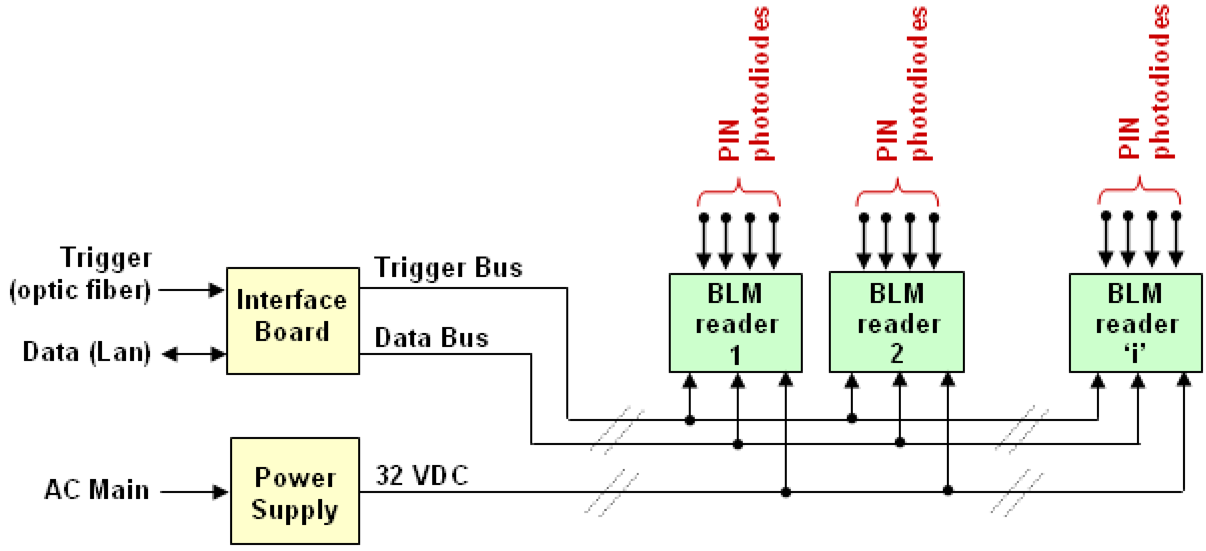


Fig.26 - Block diagram of each BLMs' network in FERMI@elettra.

5. Conclusions

In general, the monitoring of the accelerator parameters, including beam losses, during machine operation provides an important tool for diagnostic purposes.
A beam loss monitoring system inside machine tunnel permits to easily locate beam losses, focusing attention on precise ring sections. This can facilitate machine physicists' work (e.g. in the optimization of the beam optics and trajectory), providing a useful real-time feedback to their choices.
Moreover, if the beam loss monitoring system is sensitive enough, it permits to locate even small beam losses (due to vacuum leakage, optics mismatching, etc.) and to intervene before problem becomes critic.
Last but not least, the detection of beam losses (above all if protracted for long) can provide important indications also about which area of the storage ring may be affected by induced radioactivity. This permits to evaluate better the radiological risk for the personnel who needs to enter the machine tunnel during the RUN (e.g. in case of fault), and also helps the Radiation Protection Group in the radiation surveys carried out inside the machine tunnel at the beginning of the shutdown periods.

Acknowledgements

A special thanks to the Machine Physicists and Control Room Operators of Elettra facility for their precious collaboration during measurements.

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