TEST OF DIFFERENT BEAM LOSS DETECTORS AT THE GSI HEAVY ION SYNCHROTRON

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Abstract

For the sensitive process of slow extraction from a synchrotron a reliable control of the beam losses is needed. We have tested several types of particle detectors mounted at the extraction path of the SIS: A BF_3-tube for pure neutron detection, a liquid and a plastic scintillator detecting neutrons, gammas and charged particles and an Ar filled ionization chamber mainly sensitive to charged particles. While the count rate is quite different, the time evolution of all detector signals during the spill are similar, but the plastic scintillator has the highest dynamic range. This type is going to be used for beam alignment.

1 DEMAND FOR LOSS MONITORS

To control the beam losses during the beam alignment and operation of an accelerator it is an important issue to prevent permanent activation. At the GSI heavy ion synchrotron SIS all heavy ions can be accelerated from 11.4 MeV/u to a variable final energy up to $\sim$ 1.5 GeV/u. During the last years a large increase of beam current up to a factor of 100 in particular for heavy specious was possible due to the installation of an electron cooler and an upgrade of the LINAC [1]. Most of the experiments are using third order resonance extraction having an extraction time of several seconds. Most of the losses occur during this extraction, some of them are unavoidable, others should be minimized by careful setting of the accelerator parameters like tune changes, focusing, steering angles, in particular of the septa etc. The highest activation is measured around the electrostatic septum (mostly due to 'unavoidable' losses for slow extraction), the following dipole magnet inside the SIS and the magnetic septa due to their small acceptance (here the right orientation of the transverse emittance is needed). Compared to other large accelerators there are some differences concerning the loss: Firstly the currents in terms of particles per second are relatively low due to the long cycle time using slow extraction. Secondly different ions with a wide span of current and final energy are accelerated. Thirdly the detectors should be used for the alignment procedure and not for creating an emergency interlock (like used elsewhere for quench-protection of superconduction magnets).

The cross section of the production of secondary particles is not well known for heavy ions. The energy of the colliding nuclear system is comparable to the energy of it constituents leading to a more complex reaction mechanism, as used e.g. for high energy protons [2]. Moreover, the penetration depth is in the order of several cm, and the assumption of a 'thick target' can not be applied for particles hitting the vacuum chamber. Some investigations using heavy ions have been made to measure the cross section, scaling laws and angular distribution [3], but not all needed parameters (ion specious and energy) are covered. In addition the charged primary or secondary particles loose a noticeable amount of energy in the target due to electronic stopping. Therefore the main secondary particles reaching the detector are expected to be neutrons from fragmentation and spallation processes. The angular distribution is peaked in forward direction inside a cone having an opening angle of several degrees with a strong depending on the primary ion's energy [3]. Due to all these dependences, an absolute dose cannot be generated from the data.

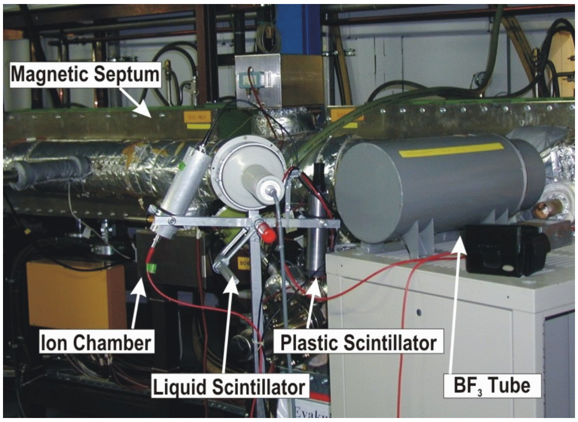

Figure 1: The detectors installed at the SIS-extraction.

2 TYPES OF DETECTORS

Different detectors have been tested at the SIS in a distance of $\sim$3 m and an angle of $\sim 20^o$ from the magnetic septa, see Fig. 1. One of them is only sensitive to neutrons, while the others have different sensitivity to other secondary particles, see below. For the purpose of beam alignment, a high dynamic range i.e. large count-rate capability and a background free operation is needed. General demands are an easy and hazard-free installation and a stable operation.

Liquid scintillator: An older device form Nuclear Enterprise containing NE 213 liquid scintillator (decay time 3.2 ns [4]) in a cylinder container of 1 l was installed. The light generation is based on collisions of the neutrons with hydrogen atoms of the polymers (elastic n+p-reaction), the proton's electronic stopping leads the scintillation. For other charged particles the electronic stopping creates directly the scintillation [4]. To have the possibility of pulse shape discrimination (i.e. the discrimination between γ and neutrons) an integrating pre-amp is attached to the photomultiplier output, restricting the maximum count-rate to $\sim$ 30 kHz. This discrimination is not used here. The material is sensitive to γ, n, e^- and charged hadrons. Care has to be taken due to the flamability of the solvent.

Plastic scintillator: Like in the liquid scintillator, the elastic n+p-reaction creates the scintillation light for neutrons, and direct energy loss is measured for charged particles. We use a block of $20 \times 20 \times 50\,\text{mm}^3$ BC400 standard plastic material (decay time 2.4 ns [4]) coupled to a fast photomultiplier (Philips XP2972) having a voltage of 1500 V. A counting mode is used via standard discriminators (LeCroy 4608C) to get high dynamic range up to several MHz. The material is sensitive to γ, n, e^- and charged hadrons. The pulse height distribution shows a broad distribution due to the different detected particles and their energy deposition.

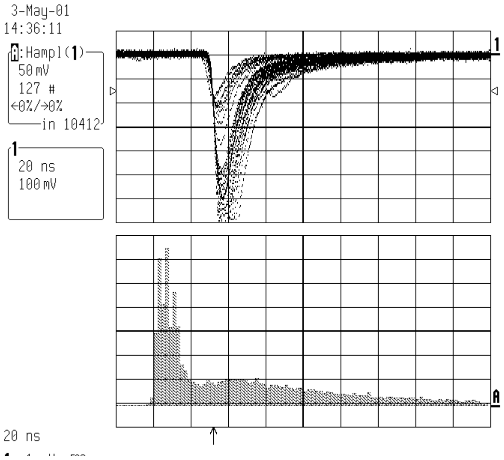

Figure 2: Typical pulses from the plastic scintillator (top, 100 mV/div and 20 ns/div) and their pulse height distribution (bottom, 50 mV/div).

BF$_3$ proportional tubes: To have the possibility to measure only neutrons a cylindrical proportional tube (diameter 15 mm, length 400 mm) filled with BF$_3$ is installed. For thermal neutrons the reaction B+n $\rightarrow$ Li + α has a high cross section ($\sim$ 1 kbarn) and is exothermic (Q-value of 2.3 MeV) [4]. To slow down the fast neutrons form the primary beam interaction concentric layers of polyethylene with an outer diameter of 220 mm surround the proportional tube. Special precaution are done to get a flat detection efficiency as a function of the angle. Normally these detectors are used at nuclear power plants for neutrons with energy up to 10 MeV, but the thermalization yield of the neutrons can be extrapolated at least up to 100 MeV.

Ionization chamber: In contradiction to the BF$_3$-tube, an IC is not sensitive to neutrons and has a low efficiency for γ, only charged hadrons and electrons are detected. A type of IC routinely used at Brookhaven RHIC [5] is build of a sealed 100 mm long cylinder with outer diameter of 38 mm filled with pure Ar at $\sim$ 970 mbar. The readout is done in the current mode using a current-to-frequency converter with the range of 100fA equals one count, i.e. a resolution of 1 pA for the current is reached [6]. This current is directly proportional to the absorbed dose.

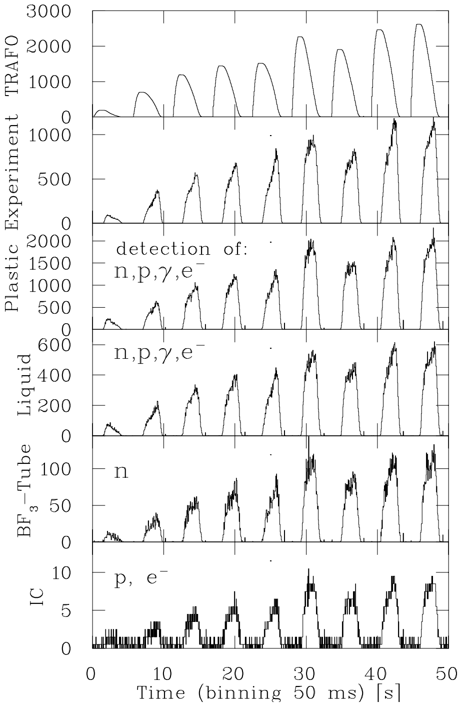

Figure 3: Typical example from different beam loss monitors for a O^{8+} beam at 800 MeV/u with up to 4 $\times$ 10^{10} particles per spill.

Solid state detector: At the most accelerators PIN-diodes are used [7]. We installed a PIN-diode of size $10 \times 10\,\text{mm}^2$ and a thickness of 300 μm. An integrating pre-amp and a spectroscopy-amp is used for a good energy resolution. But the measured pulse height distribution is a comparable to the one of the plastic scintillator. This type is sensitive only to charged hadrons. For the application of beam alignment, the count-rate of this small active volume is too low.

3 COMPARISON OF THE DETECTORS

To fulfill the requirements described above test with typical beam parameter were taken with the detectors installed at the magnetic extraction septum at the SIS. A typical example is shown in Fig. 3 for a O^{8+} beam accelerated from 11.4 MeV/u to 800 MeV/u and then extracted slowly within 3 s. The maximum number of stored particles was 4 $\times$ 10^{10}, which is close to the incoherent space charge limit. The signal as a function of time seen at the figure is displayed together with the signal for the synchrotron dc-transformer (top, arbitrary units) and a signal proportional to the extracted current measured at the experiment location (second plot, using a secondary electron monitor in arbitrary units [8]). The general feature is, that the signals for the different loss monitors are showing the same time behavior. This is not directly evident due to the different detection mechanisms. This shows the predominant role of the 'prompt' radiation (prompt within a time scale of ms) what ever the type of secondary radiation consists of. The signals of all detectors are background-free, showing the minor role of permanent activation compared to the signals induced during the spill.

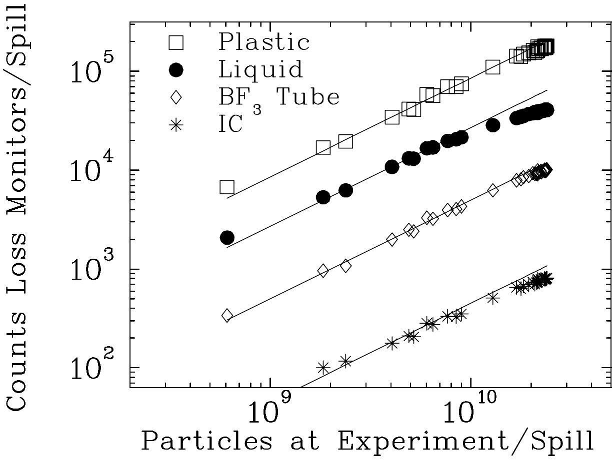

Figure 4: Linearity of the loss monitors as a function of the current at the experiment, with the beam parameters as Fig 3. The lines are linear fits.

The linearity of the different detectors is better seen in Fig. 4 where the total counts for one spill are shown as a function of the current detected at the experiment. The count-rate is quite different: The plastic scintillator shows the maximum rate, about a factor of 30 more than the BF_3-tube, due to the detection of more categories of secondary particles. The liquid scintillator shows a lower rate; the saturation for the highest rate is due to the slow integrating per-amp. The IC is lower by a factor of 200 as compared to the plastic scintillator. The dynamic range needed for the optimization procedure is highest at the plastic scintillator, making this type a preferable choice for our application. With this high rate the losses during the spill can be reduced e.g. by changing the extraction angle during the spill.

More tests were done using other primary ions from d to U having different final energies. The count-rate varies much with the ion specious, but no significant change in the ratio of the detector's count-rate has been seen as a function of the ions nuclear charge. The radiation hardness of the plastic scintillator was not yet investigated.

4 BEAM ALIGNMENT USING THE PLASTIC SCINTILLATORS

Using the plastic scintillator a first test has been done to minimize the losses close to the septa. We installed them each left and right close to the extraction devices at five different places to examine the capability for the alignment. As an example, Fig. 5 shows the rate for a d beam at 250 MeV/u with 2×10^{11} particles. The voltage on the electrostatic septum is varied yielding a slightly different extraction angle. The losses varied due to this correction at the sensitive locations, while the current measured at the experiment shows no significant change. To monitor the losses instead of the transmitted current is a more sensitive method due to the direct determination. In addition, the installation of several devices at the sensitive location can be done easily. The large dynamic range of plastic scintillators guarantee a linear signal behavior even in the case of large differences in the left/right count-rate. More investigations have to be done to proof the capability for the alignment for the operating of the SIS.

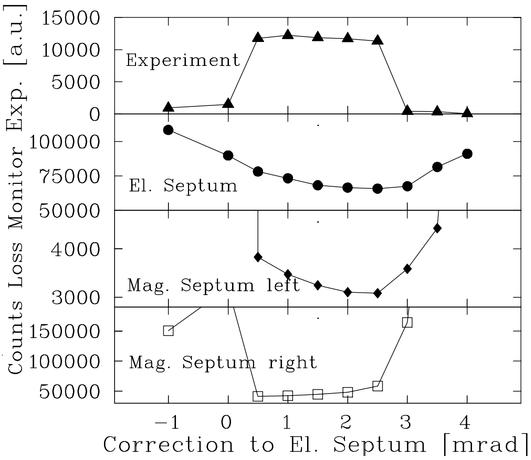

Figure 5: Counts per spill from three loss monitor locations and the current at the experiment averaged over 10 spills as a function of the angle electrostatic septum for a 250 MeV/u d beam.

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