Intensity Measurements of Heavy Ion Beams from SIS

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Abstract

The heavy ion synchrotron SIS at GSI, in regular operation since 1990, accelerates all elements up to uranium to final energies up to 2 GeV/u. For this energy range new beam diagnostic devices have to be developed. Up to now plastic scintillation counters and secondary electron monitors are installed for intensity measurements of slowly extracted SIS beams. The performance and the calibration of these detectors are discussed.

1 INTRODUCTION

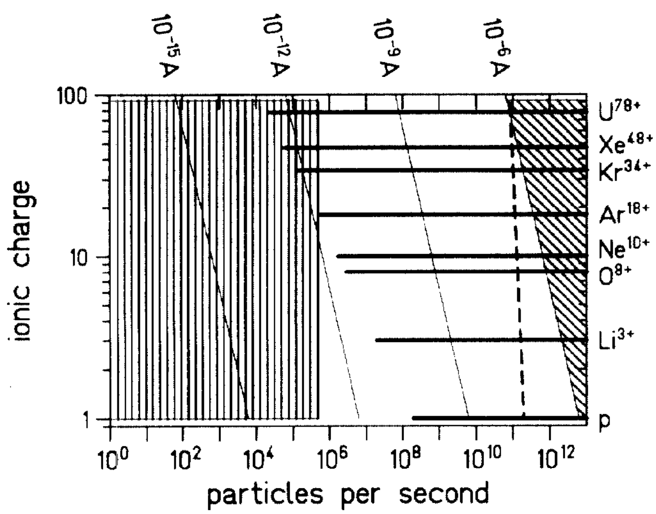

Fig.1 Working ranges of different detector concepts: Particle counters are used up to 10^6 pps (vertically hetched). The range of SEMs is indicated by horizontal bars for different ion species, the lower limit corresponding to a secondary current of 1 pA. A vertical dashed line marks the maximum number of ions per spill from SIS. Beam current transformers work only at higher intensities (diagonally hetched).

1.1 The Current Range of Heavy Ion Beams from SIS

The maximum number of ions per acceleration cycle of SIS imposed by space charge limitations is of the order of 10^{11} [1]. As the slow extraction mode usually lasts a few seconds, this number is also the upper intensity limit in particles per second (pps), corresponding to an electric current of about 100 nA. The experiments however require different intensities usually between 10^4 pps and 10^8 pps, and above all during the tuning of the beam even lower intensities have to be measured.

Finally the monitoring of radioactive beams is not possible without devices which are able to detect a few particles per second.

Non intercepting detectors (capacitive or inductive pick-ups) work only at much higher, especially at pulsed beam currents, e.g. in the synchrotron and are not subject of this article. Intensity measurements of slowly extracted SIS beams are therefore only possible by making use of the energy loss of the beam particles in matter.

1.2 Energy Loss in Particle Counters

The stopping power of a heavy ion with energy E, mass m and nuclear charge Z in a given material is approximately proportional to $Z^2(E/m)^{-1}$. With Z varying from 1 to 92 and E/m from about 100 to more than 1000 MeV/u, the specific energy loss of heavy ions from SIS covers a range from 0.002 to 50 MeV/(mg/cm^2) [2].

The aim of measuring beam intensities from single particles to 10^{11} pps, by means of the particles energy loss which varies by several orders of magnitude, can probably not be realized using a single detector. For instance, the operation of a massive Faraday cup able to stop any kind of SIS ion beams would cause several technical problems, one of which is the production of energetic secondary particles. The intensity measuring devices presently in use or in development are therefore relatively thin and cause only small energy losses. Nevertheless they are intercepting devices in the sense that the resulting broadening of the transverse beam emittance by small angle scattering is usually not tolerable in the beam lines.

Up to now the intensity range below 10^6 pps is covered by particle counters, and for higher intensities secondary electron monitors are in use (fig. 1).

2 PARTICLE COUNTERS

For the counting of primary beam particles plastic scintillation detectors are used, as this type of detector is very fast, easy to handle and relatively inexpensive. The scintillation material and the photomultiplier tube of the detectors used at GSI have pulse duration times of less than 3 ns, the multiplier base being optimized for maximum counting rate. The energy loss in the about 1 mm thick scintillator sheet is sufficient to detect even the lightest and fastest ions. To avoid a limitation of the maximum counting rate by the high light output of heavier ions, the optical coupling between scintillator and multiplier can be adjusted by means of a diaphragm. A further reduction of the anode current is possible in the usual way by reducing the high voltage. A computer controlled adjustment of the high voltage according to species and energy of the particles is planned. Depending on the stopping power of the beam particles the maximum count rate amounts to about 10^6 pps[1]. For these intensities, scintillation detectors have become a reliable tool in routine operation.

Little is known about the radiation resistance of plastic scintillation material when irradiated by heavy ions. It is reported that serious degradations in light output occur after irradiation of several 10^4 Gy by a ^{60}Co gamma source [3]; recent investigations indicate that the attenuation length of the plastic material is much more affected than the amount of originally emitted light [4]. This dose corresponds to the passage of 10^{12} 2 GeV/u Ne ions or 10^{10} 400 MeV/u U ions, numbers which normally are not attained during some minutes of beam adjustment. If nevertheless a slight degradation in light output occurs, this will not influence the measured count rate.

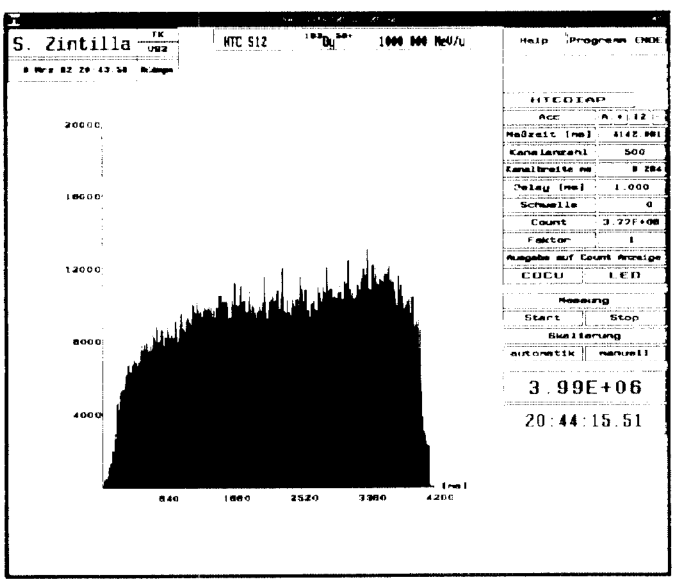

Fig.2 Graph of a slowly extracted 1000 MeV/u $^{163}Dy^{53+}$ beam spill, produced by the fast reading out of scintillation counters. In this example $4 \cdot 10^6$ particles have been detected during the extraction time of 4s.

The electronics connected to the detectors contain fast counters which are read out by the control system. For low beam intensities it is thus possible, apart from random coincidences, to determine the number of particles in a choosen time interval exactly. A particularly useful application is the graphic representation of the beam intensity as function of time, which in routine operation is necessary for shaping the spill structure according to the experimental requirements (fig. 2). For this purpose the counters are read out in time intervals down to 1 ms.

Plastic scintillation detectors, put into special shapes, are also well suited for getting a rough estimate of the beam's profile.

3 SECONDARY ELECTRON MONITORS

In its simplest version, a SEM consists of one electron emitting foil put between two positively biased collecting and screening foils and connected to a current measurement circuit. The yield of secondary electrons produced by a heavy ion traversing a thin metal foil is approximately proportional to the specific energy loss of the ion in the foil material (and does not depend on its thickness). For precise intensity measurements, SEMs are calibrated at low intensities using particle counters. From fig. 1 it is clear that especially for light nuclides the overlap with the linear counting range of particle counters becomes very small (note that the arbitrarily chosen sensitivity limit of 1 pA can be improved at the expense of the bandwidth). As shown in fig. 3 for an 220 MeV/u $^{40}Ar^{18+}$beam, for heavier ions the overlap is sufficient.

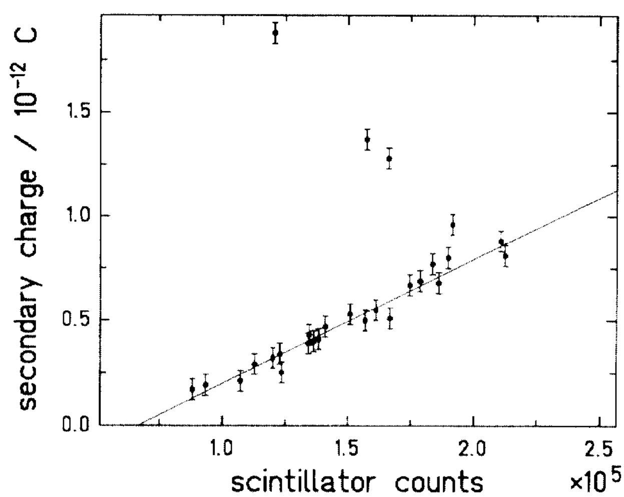

Fig.3 SEM calibration curve for a 220 MeV/u $^{40}Ar^{18+}$beam. The charge per spill collected by a SEM consisting of 3 10μm thick aluminum foils is plottet against the counting rate of a relatively thick (5 mm) plastic scintillator [5]. The dependence is linear up to $2 \cdot 10^5$ particles per spill, then the curve bends back due to saturation effects of the scintillation counter.

A development using a stack of foils is in progress to improve the sensitivity. The number of foils is limited by the fact that the detector capacity increases with decreasing distance between the foils. Care is taken to avoid vibrations of the foils which could interfere with the current signal. The current measuring circuit is designed to resolve <1 pA at a bandwidth of 1 kHz.

[1] The possibility of extending the measurable intensity range to higher values by reading out the photomultipliers in current mode is presently investigated.

One approach to extend the measurable intensity range of SEMs down to single particles per second is the project SEEBEAM [6], a detector which will use channeltrons to multiply the secondary electron yield.

4 OTHER DETECTORS

4.1 Ionization Chambers

In contrast to SEMs, the output of ionization chambers is a direct measure of the absolute energy loss of the traversing particles. This allows high accuracy intensity measurements with only one calibration. At SIS energies the energy loss even in thick entrance windows (0.1 mm stainless steel) does not influence the result of the measurement. A prototype is being built at present at GSI to investigate properties like the limits of the linear range, the influence of secondary electrons, and others. The aim is to measure moderate intensities exceeding the range of particle counters. For the simultaneous determination of the beam profile segmented electrodes can be used.

Further investigations are planned concerning a universal gas filled chamber which works in pulse mode at low and in current mode at moderate intensities and which can be evacuated to become a SEM at high intensities.

4.2 Position Sensitive Detectors

For profile measurements of high energy, low intensity heavy ion beams multiwire proportional counters are in operation [7], with a lower sensitivity limit of about 100 pps in current mode. A less complex and more compact alternative is again the use of plastic scintillation material. Two prototypes of position sensitive detectors are under construction actually: a grid of scintillating fibers, and a thin scintillator foil (10...100 μm), an image of which is made onto the cathode of a position sensitive PM tube by an optical system. Both detector types could registrate single pps.

5 CONCLUSION

As a consequence of the possibility to accelerate all elements within relatively wide ranges of final energies and intensities, beam diagnostic devices for slowly extracted SIS beams have to process a great dynamics of counting rates and amplitudes of the incoming signals which is not possible with a single detector principle. At GSI, the intensity ranges of plastic scintillators and SEMs complement each other, and effort is made to increase the overlap. Multimode detectors like SEMs with variable electron multiplication or ionization chambers which can be operated as SEM could play an important role in future applications.

6 REFERENCES

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