BEAM-BASED TESTS OF INTERCEPTING TRANSVERSE PROFILE DIAGNOSTICS FOR FAIR*

P. Forck[1#], C. Andre[1], C. Dorn[1], W. Ensinger[2], R. Haseitl[1], A. Lieberwirth[1,2], S. Lederer[1,2], S. Löchner[1], A. Reiter[1], M. Schwickert[1], T. Sieber[1], B. Walasek-Höhne[1], M.Witthaus[1]
[1] GSI Helmholtz-Zentrum für Schwerionenforschung, Darmstadt, Germany
[2] Technical University Darmstadt, Institute for Material Science, Germany

Abstract

FAIR will serve as a versatile accelerator for ions of energies between 200 MeV/u and 29 GeV/u (FAIR start version) with an intensity variation from some 10^3 to 10^{13} ppp. In the transport lines the transverse profile determination will be mainly based on intercepting methods: Scintillation screens, SEM-Grids and gas filled MWPCs. These devices are tested at the existing GSI-SIS18 where ions are extracted either in fast mode within ≈ 1 µs or slow mode within ≈ 0.3 s. The imaging properties of scintillation screens were investigated. Over intensities 10^7 to 10^9 ppp the light output for the screens is linear with respect to the ion intensity. Wire-based methods using SEM-Grids and MWPCs are discussed.

DESIGN OF FAIR HEBT DIAGNOSTICS

The upcoming Facility for Antiproton and Ion Research (FAIR) is dedicated to the acceleration of high intensity protons to heavy ions in the range from about 200 MeV/u to 29 GeV/u (for protons, value for FAIR start version) as well as the production and storage of rare isotopes and anti-protons [1]. A two-step installation for the facility is foreseen: the so called 'start version' and 'final version'. Fast extraction from the planned synchrotron SIS100 will be performed with the design values for proton intensity of 2.5×10^{13} particle per pulse (ppp) within a single bunch of $\sigma \approx 25$ ns duration and the design intensity for U^{28+} of 4×10^{11} ppp within bunch duration of about $\sigma \approx 50$ ns. Slow extraction within a time range 0.1 to 10 s for high intensity beams will serve fixed target experiments. Low intensities of anti-protons and rare isotope beams down to some thousand ions per pulse will be transported between the production targets and the experimental targets and storage rings.

The High Energy Beam Transport (HEBT) lines connecting the synchrotrons, storage rings, production targets and experimental locations have a length of about 1.5 km for the start version and 2.4 km for the final version [1]. For transverse beam profile determination of typically $\sigma \approx 1$ to 30 mm beam width, five different beam diagnostic devices are foreseen to cover the extremely large dynamic range as given by the ion species, intensities, energies and time structure; the amount of instruments and their application are summarized in Table 1.

Scintillation screens [2] as used for fast and slow extraction give a direct two dimensional beam image. They offer an inexpensive technical realization but must be investigated concerning the dynamic range, radiation hardness and image reproduction. For the HEBT lines they are foreseen for low and intermediate intensity beams from 10^3 to about 10^9 ppp.

Wire-based detectors offer a large dynamic range as realized by the connected electronics. For fast extraction Secondary Electron Emission Grids (SEM-Grids) are widely used at the existing GSI facility. For slow extraction the signal strength is insufficient for a vacuum installation; instead Multi Wire Proportional Chambers (MWPC) are foreseen where the ionization along the particle trajectory in 1 bar Ar/CO_2 gas leads, in connection with a biasing voltage, to a moderate amplification. With the chosen electronics time resolved profiles down to the ms region can be recorded.

For the highest intensities and a non-destructive detection scheme Ionization Profile Monitor (IPM) [3,4] or Beam Induced Fluorescence (BIF) Monitor [5] are considered allowing online beam observation. A description of these methods is not subject of this paper.

This contribution describes recent test measurements performed at the existing ion synchrotron SIS18 at GSI with fast and slow extracted beams with the focus on scintillation screens. The aim is to determine the applicability for FAIR and to test prototypes. The available beam intensities during the experiments were at least a factor of hundred lower as foreseen for FAIR.

Table 1: Types of HEBT Detectors, Numbers for the Start and Final Version of FAIR and Usable Extraction Method

Detector type	Number start vers.	Number final vers.	Extraction type
Scintillation screen	16	31	fast & slow
SEM-Grid	49	73	fast
MWPC	34	47	slow
BIF or IPM	15	19	fast & slow

SCINTILLATION SCREEN

With beams extracted from the heavy ion synchrotron SIS18 at GSI the applicability of various scintillator screens for accurate profile measurement were tested. Single crystal YAG:Ce, phosphor screens P43 and P46 as well as ceramics Al_2O_3 and Al_2O_3:Cr were investigated, see Table 2. The scintillator screens were mounted on a

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#corresponding author: p.forck@gsi.de

target ladder on air in an angle of 45^0 with respect to the beam direction. The images were recorded by a standard CCD camera, for more details see [6,7]. Images from single beam pulses were analysed. For fast extraction the beam intensity is recorded by a resonant transformer with a detection threshold of 1.5×10^7 charges per pulse. For slow extraction the intensity is determined by an ionization chamber and a secondary electron monitor.

Table 2: Investigated Scintillation Screens, ∅ 5 to 8 cm

Name	Material	Thickness	Supplier
YAG:Ce	$Y_3Al_5O_{12}$:Ce	3000 µm	Crytur
P43	Gd_2O_2S:Tb	50 µm	ProxiVision
P46	$Y_3Al_5O_{12}$:Ce	50 µm	ProxiVision
P46	$Y_3Al_5O_{12}$:Ce	20 µm	Crytur
Alumina	Al_2O_3	800 µm	BCE
Chromox	Al_2O_3:Cr	800 µm	BCE

In the following the term 'light output' refers to the light recorded by the CCD camera. The term 'light yield Y' describes the light output per unit of energy loss dE/dx of an ion in the material; dE/dx is calculated using the code LISE [9]. In previous experimental campaigns [6-8], the properties of the scintillators were investigated with several ion species mainly for slow extraction from SIS18. The findings concerning light output and image width are in accordance with the measurements described in this contribution.

In the recent beam-time we compared the scintillator response for slow extraction within 0.2 to 0.3 s with fast extraction of four bunches within 1 µs. The beam intensity was varied at the LINAC with minimal influence on the extracted beam emittance. As an example for extensive investigations [10] the results of a Ni irradiation are illustrated in Fig. 1: The light output shows nearly the same value for both extraction types for the phosphor screen and the ceramics in accordance with previous results for Uranium beams [7]. It is remarkable that even for the five orders of magnitude shorter beam delivery no significant saturation effect of the scintillation process occurred. Only for the single crystal YAG:Ce the light output differs by a factor of ≈ 2 between the two extraction types.

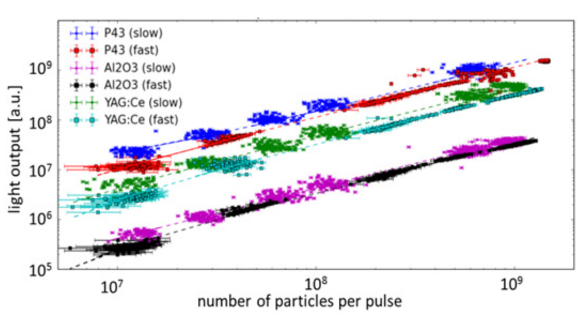

Figure 1: Light output from scintillation screens irradiated with a Ni beam for fast (energy 297 MeV/u) and slow (energy 290 MeV/u) extraction; lines are linear fits [10].

The profile width is calculated from each image and displayed in Fig. 2 for both extraction types. For each extraction type the phosphor screens and the ceramics show constant beam width independent of the beam intensity within the expected reproducibility of the beam acceleration. In particular for fast extraction this result was unexpected and proves the absence of intensity dependent saturation effects. The YAG:Ce might show some intensity dependent image broadening, which will be investigated in future.

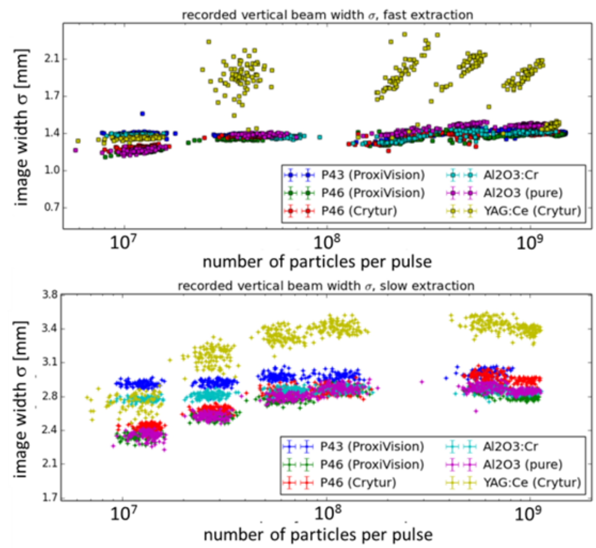

Figure 2: Vertical image width (one standard deviation) for scintillation screens irradiated by a Ni-beam using fast extraction (top, 297 MeV/u) and slow extraction (bottom, 290 MeV/u).

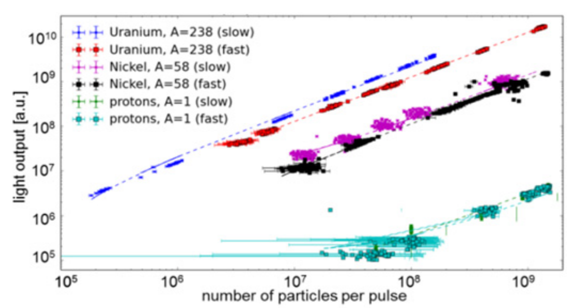

Figure 3: Light output from a P43 phosphor screen for fast and slow extraction irradiation by protons (fast 299.8 MeV, slow 299.4 MeV), Nickel (fast 297 MeV/u, slow 290 MeV/u) and Uranium (fast 340 MeV/u, slow 320 MeV/u). The vertical error bars for fast extraction of protons are related to the current transformer detection threshold of 1.5×10^7 ppp.

The light outputs were determined for different ion species [10]; an example is displayed in Fig. 3 for the phosphor P43. It shows again a light output basically independent of the extraction type for protons, Nickel and Uranium. From these measurements the light yield Y_{Ion} for different ion species can be estimated: for the displayed data the ratio is $Y_p \approx 1.4\cdot Y_{Ni} \approx 2.7\cdot Y_U$ [10]. This confirms previous findings for slow extraction [8].

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Investigations concerning possible degradation of the scintillation efficiency were performed for different ion species and an integrated particle number of about 5×10^{11} as available during a reasonable irradiation time, see [6,7]. Neither the light output for the phosphor screens degrades drastically nor does the profile shape deform significantly. Further results for different ion species in connection to the related wavelength spectra from the scintillation process will be reported elsewhere [10]. The time constant of the scintillation process, sometimes referred to as 'afterglow', is a subject of investigations.

For the FAIR layout we can conclude that scintillation screens are suited for the profile measurements at low and medium intensities and the investigated phosphor screens could be an appropriate choice. High intensities, as foreseen for FAIR are presently not available and therefore the radiation hardness tests cannot be conducted up to the projected fluence.

SEM-GRID AND MWPC

For high intensity fast extracted beams SEM-Grids will serve as the standard detector. Our design comprises up to 64 W-Re alloy wires per plane of ∅ 100 µm with an application dependent spacing of 0.8 to 2 mm. For digitalization a current-to-frequency scheme (see below) has been successfully tested [11]. For precise profile determination, the emitted secondary electrons must be completely removed from the SEM-Grid wires to prevent for unbalanced electron transfer between wires. It has been simulated and experimentally verified [12] that clearing electrodes biased to about +50 V e.g. realized by an arrangement of diamond-shaped wires is sufficient for this electron removal.

For slow extracted beams MWPC with 64 wires per plane and 1 to 2 mm spacing will be used. They provide a gas-amplification of ≈ 15 at 1200 V. An example of recorded profile data is shown in Fig. 4. The display of time resolved profiles is very useful for the alignment of the synchrotron's extraction parameters. Using electronics described in the next section, dead-time free measurements with a time resolution down to 100 µs are possible [11].

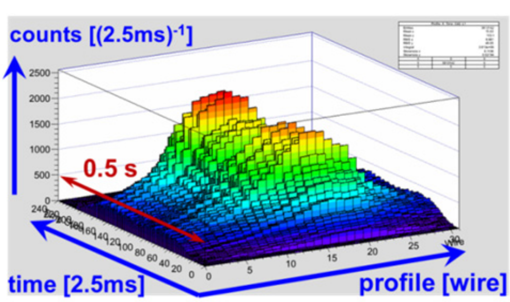

Figure 4: Time resolved profiles from a MWPC for a slow extraction of 0.5 s duration recorded with 2.5 ms time frames; beam 300 MeV/u U^{73+} beam with 10^8 ppp.

GRID-DETECTOR DIGITALIZATION

The readout of the SEM-Grid and MWPC at FAIR will be performed by current-to-frequency conversion as realized by a dedicated ASIC and related digitalization called POLAND (PrOfiLe Acquisition Network Digitizer) [10]. The highest sensitivity is 0.25 pC/count and the maximal frequency is 40 MHz. Each front-end module contains 32 channels. The radiation hardness of the front-end part was tested by proton irradiation [13] with no single event offset for a dose of 750 Gy (SiO_2 equivalent). This should be sufficient for the installation in the HEBT tunnel. For fast extraction in connection with SEM-Grids a passive pulse stretcher proving a capacitance of some nF was successfully tested. The final hardware and software version will be operational by end of 2014.

CONCLUSION AND OUTLOOK

Detailed tests of the beam instrumentation were performed with comparable beam parameters as expected for FAIR but only lower intensities were available. By comparing the light output for fast and slow extraction, an unexpected large dynamic range was determined for some scintillator screens. Phosphor screens P43 and P46 show good performance. SEM-Grids and MWPCs in connection with the POLAND electronics are well suited. For a precise profile determination a careful detector design (e.g. using biased clearing wires for SEM-Grids) is required. Encouraged by experimental results at 11.4 MeV/u [14], investigations for OTR photon emission with highly charged but barely relativistic ions with a Lorentz-factor $\gamma \approx 2$ will be performed in near future.

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