2D-CHARACTERIZATION OF ION BEAMS USING VIEWING SCREENS

A. Peters, H. Eickhoff, T. Haberer, A. Weiss, GSI, Darmstadt, Germany, e-mail: a.peters@gsi.de

Abstract

Three different systems using viewing screens are currently under development at GSI's heavy ion facility to measure transverse beam profiles for all ion species with energies in the range from 20 MeV/u to 2 GeV/u, in particular for the planned therapy accelerator facility HICAT [1, 2]. The first device will be established for a complete 2D-characterization of slowly extracted beams from synchrotrons. The second system was built up to measure the beam spot in the so-called isocentre position of a gantry section test stand. The third detector will be used to check the homogeneity of area scans applied in cancer treatment with proton and carbon beams.

1 IMPROVEMENT OF EXISTING VIEWING SCREEN SYSTEMS

Up to now the viewing screens used at GSI to observe the slowly extracted ion beams from the heavy ion synchrotron are equipped with Chromox targets [3], which have a good sensitivity, a high radiation hardness and are UHV-compatible as well. But a major disadvantage is their long-lasting afterglow up to some minutes. Therefore they can not be used for exact measurements of beam movements in the millisecond region as well as changes of beam profile widths from spill to spill. Because of these facts multi-wire proportional chambers (MWPCs) are mainly used when precision measurements are necessary. But these MWPC systems are rather expensive due to the large number of analog electronics and projections deliver only two one-dimensional profiles of the beam.

Table 1: Target material characteristics

Material	Composition	Maxim. Emission	Decay Time (10%)	Rel. Yield of light
Chromox	Al_2O_3: Ce	700 nm	~ 1 s	1.0
P43	Gd_2O_2S: Tb	545 nm	1 ms	1.46
P46	$Y_3Al_5O_{12}$:Ce	530 nm	300 ns	0.2

In addition to the modernization of the image acquisition system (see below) the main task was to test more suitable target materials. Several screens made of heavy inorganic scintillators have been investigated and their behaviour concerning sensitivity, saturation and timing performance was evaluated.

A comprehensive study [4] showed that commercially available phosphor screens [5] - prepared by sedimentation of phosphor grains on a glass or metal substrate - should have the appropriate parameters (see table 1).

Both phosphor screens (P43, P46) have reasonable decay times as well as their maximum light output lies in the green region (about 540 nm) which fits to the sensitivity of monochrome CCD sensors.

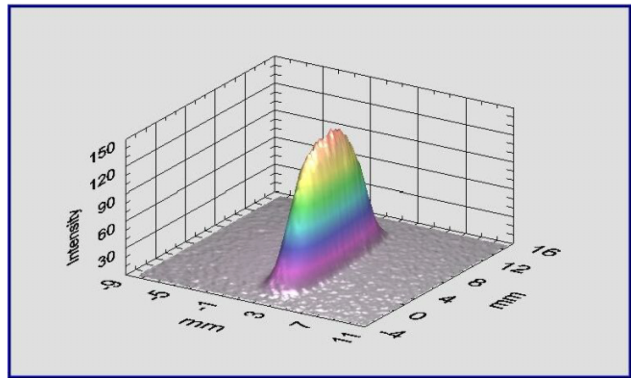

Figure 1: Intensity plot of a 356 Mev/u $^{12}C^{6+}$-beam on a P43 target

All screens were tested with protons and carbon ions, the main beam species foreseen for the cancer therapy facility. Fig. 1 shows a typical example of a beam spot image. No differences in size are observed due to the target material, but the yield of light differs by a factor of about 7 between P43 and P46. The last column of Table 1 shows the values of the summarized surface luminosity relative to Chromox. All measurements were taken with the same camera settings with a 356 MeV/u $^{12}C^{6+}$-beam of 10^7 - 10^8 particles per second, a proton beam of 200 MeV showed similar results.

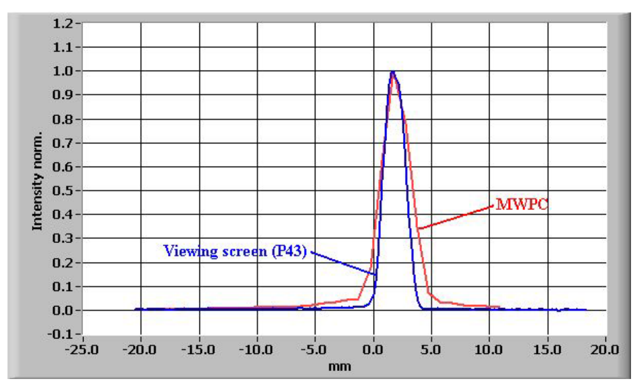

Figure 2: Horizontal profile of a 356 Mev/u $^{12}C^{6+}$ -beam on a P43 target in comparison to a MWPC measurement

No saturation was found in our experiments with up to 4×10^8 carbon ions per second, even at lower energies (80 MeV/u), which lead to higher energy loss in the target.

In comparison to MWPCs smaller profile widths are measured by viewing screens, see Fig. 2. This effect was yet observed by irradiation of films to verify the homogeneity of area scans for therapy - see below.

From these measurements it can be deduced that viewing screen images generate a more realistic picture of the beam spot size and give a complete 2D-characterization of the beam instead of only two profiles (horizontal and vertical).

2 DIGITAL IMAGE DATA ACQUISITION USING IEEE 1394

Most CCD cameras today transmit the captured images as an analog TV-signal which is digitized afterwards with a framegrabber. This technique has three main disadvantages: the multiple AD-conversions and vice versa, the signal-loss due to noise and reflections on the analog cables and reduced possibilities in changing the exposure time.

A new approach in industrial automation is to use the IEEE 1394 high-speed serial bus [6], also known as "FireWire (Apple)" or "i.link (Sony)". Unlike normal camcorders, which send highly compressed video data, industrial digital cameras for image processing must deliver uncompressed data. For this purposes the DCAM specification [7] was set up. This standard has several advantages for beam diagnostic measurement systems:

- a complete digital data path without any loss of image quality,
- a single bus with up to 63 nodes, which can be bridged to other segments,
- multiple cameras with different properties, e.g. resolutions on the same bus,
- isochronous and asynchronous data transfer, with a throughput up to 400 Mb/s (and up to 3.2 Gb/s in the future by IEEE 1394b),
- standardized and inexpensive PC interfaces, cables, hubs and repeaters for the bus infrastructure. Up to now the cable length is limited to 4.5 meters between the individual nodes without repeaters, but bus extenders using glass optical fibres for longer distances exist [8], and the next IEEE 1394b specification will include standards for longer cable lengths.

For the above mentioned target measurements a prototype camera (type A302fs from Basler, [9]) was used which is capable to take 30 frames per second (maximum) with exposure times of up to 80 ms. The software package was written in LabVIEW using the IEEE 1394 driver for IMAQ to acquire the images and IMAQ Vision for image processing. For the viewing screen tests the camera works reliable and with the pronounced parameters.

3 BEAM DIAGNOSTICS FOR THE TESTS OF THE GANTRY SECTION

For the cancer therapy facility at the clinics of Heidelberg (HICAT) a light ion gantry system is foreseen, that is compact and fulfils the requirements of the "intensity-controlled" raster scan procedure. A section of this gantry including the scanner-magnets and the 90° bending magnet has been constructed and built up at GSI (see Fig. 3). The diagnostic part consists of a diagnostic box in front of the scanner magnets with a viewing screen and a MWPC (for comparison) as well as an ionisation chamber and a scintillator for current measurements. At the so-called isocentre – the position where the tumors will be irradiated – a large area viewing screen (220×300 mm^2) is mounted.

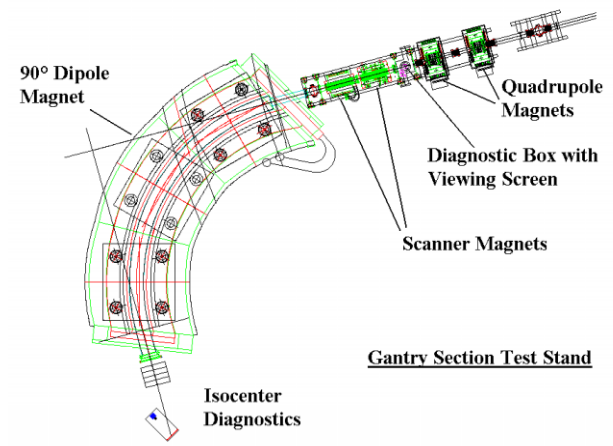

Figure 3: Equipment of the gantry section test stand (schematic view)

The viewing screen mounted inside the diagnostic box is fixed to a feed-through to move into the beam. It has a diameter of 100 mm, the target material is P43 with a thickness of 100 µm. The CCD camera from Basler (type A301f, 75 fps, 640×480 pixels) is installed perpendicular to the beam axis. Through a vacuum window the screen is viewed which has an angle of 45° both to the CCD camera and the beam axis. To align the whole setting including the optics it was necessary to place markers on the border of the target. For this purpose a vacuum suitable graphite lacquer (graphite grains solved in isopropanol) was sprayed through a mask onto the soft, granular phosphor material. The set-up at the isocentre position is mounted on air because there is a vacuum window directly at the end of 90° bending magnet. The large viewing screen is also manufactured from P43 phoshor, but the thickness is about 180 µm to get a higher light output. To reach a good spatial precision in the order of 0.3 mm a high resolution CCD camera from Hamamatsu (Orca 1394, 1280×1024 pixels, max. 12 fps, possible exposure time up to 10 s, [10]) was installed. While the beam hits the target under 45°, the camera is mounted perpendicular to the screen to avoid problems with a varying depth of focus. The whole system is wrapped by a black foil to prevent from background light.

The both CCD cameras are connected to a Firewire network which is linked to a PC in the control room by an optical fibre extender. The data acquisition and online analysis programme is nearly the same, a screen shot of the isocentre version is shown in Fig. 4. The images were taken during the first short test run in April 2002. While the beam has a perfect shape near the beam axis, the beam spot shows a slightly asymmetric behaviour if it is deflected by the scanner magnets to the border of the irradiati-

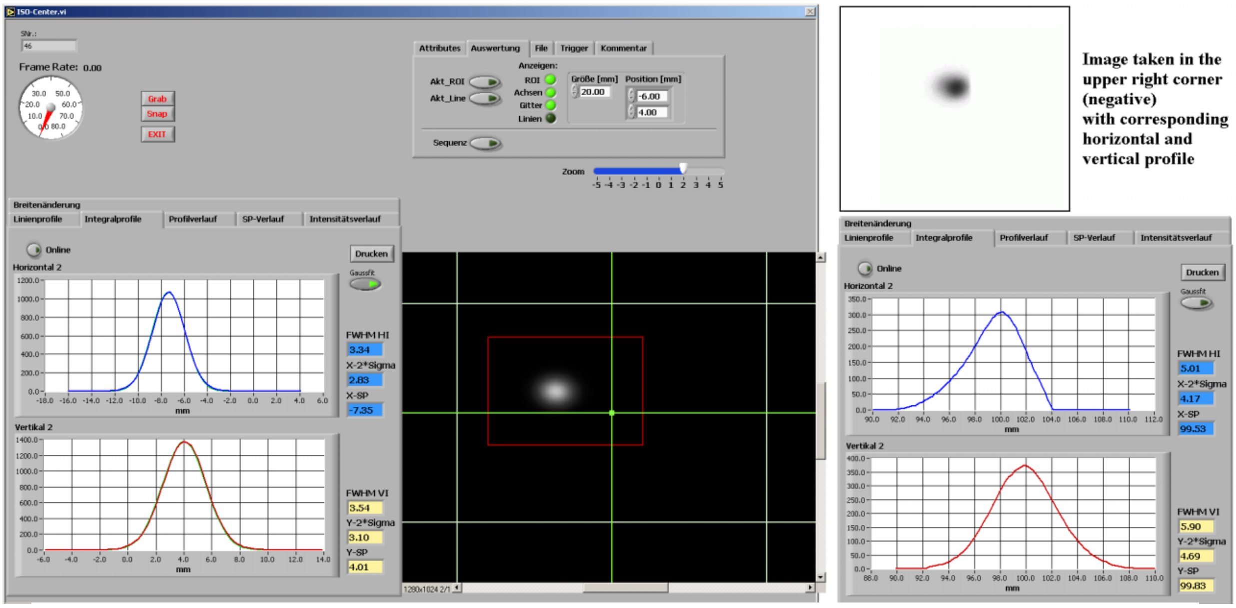

Figure 4: Screenshot of the data acquisition and online analysis programme (left) – beam spot and profiles measured near the centre of the screen. A second image (right side with accompanying profiles) taken with both scanner magnets excited to 90% of the maximum field.

on field. But further optimizations of the beam optics are foreseen that will be tested in further beam times until end of 2002.

4 FLUORESCENT SCREENS FOR DOSE VERIFICATION

The results presented above have stimulated new investigations whether fluorescent screens can be used for dose verification in the conformal carbon ion radiotherapy at GSI. In contrast to other radiation detectors (e.g. films) fluorescent screens allow an *online* verification of the application dose distribution with high spatial resolution.

But dosimetry with these radiation detectors is a complex task, because the response differs for particles of

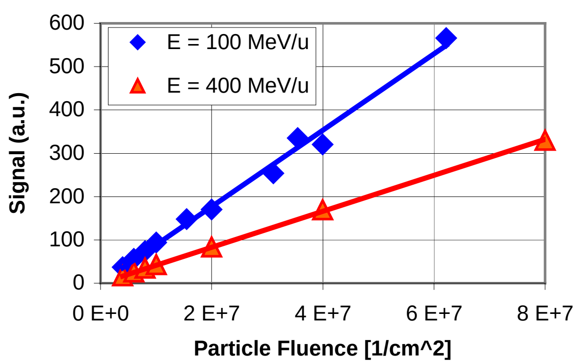

Figure 5: Viewing Screen characteristic line for carbon beams; lens aperture for all measurements fixed to 5.6

different atomic number Z and energies [11]. First experiments have been performed to study the energy dependence of the fluorescent signal for high energy carbon ions.

For these experiments exactly the same setup of target material and CCD camera has been used as for the iscocenter diagnostics described above. Fig. 5 shows the measured data for two different energies (100 and 400 MeV/u). The results up to now illustrate a linear response, no saturation has been found.

In this regard, further experiments are necessary to investigate the detector´s response in a wider range of energies, atomic numbers Z and fluences. An optimization of the viewing screen system according to the therapy relevant beam parameters and timing requirements is foreseen. A first step will be the use of a thicker target material to get a higher light output. Additionally, an efficiently cooled (-60°C) CCD camera with a high quantum efficiency (> 70%) will lead to a more sensitive device.

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