# DIAGNOSTICS OF THE PROSCAN PROTON-THERAPY BEAM LINES

R. Dölling, PSI, Villigen, Switzerland

*Abstract*

PROSCAN, an extended medical facility using proton beams for the treatment of deep seated tumours and eye melanoma, is in preparation at PSI [1]. An overview is given on the beam line diagnostics now under development, with emphasis on beam profile measurement.

## INTRODUCTION

In the PROSCAN facility (Fig. 1) a 250 MeV proton beam of 1 to 500 nA will be extracted from the COMET cyclotron. After degradation to the range of 230 to 70 MeV it can be delivered (at a maximum current of 10 nA) into one of four areas: Two gantries, an eye treatment room and a material irradiation area. Fast changes of beam energy are foreseen for the spot-scanning treatment of deep-seated tumours in the new gantry 2. Several diagnostics will be used to control the beam parameters in different modes of operation. At present most of the components are under development and prototypes will be tested in the next half year.

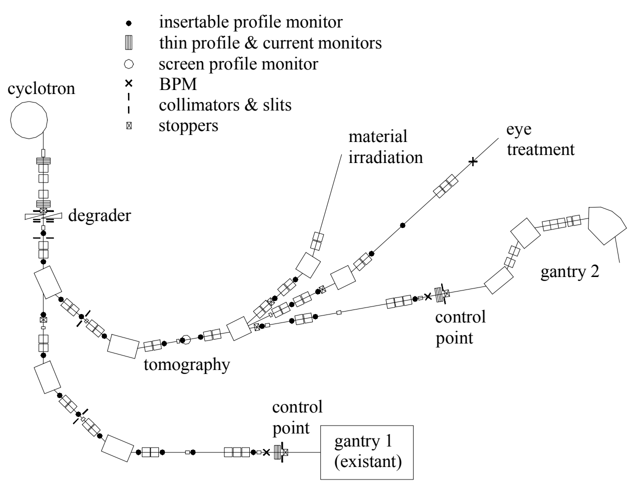


Figure 1: Overview of beam lines.

## INSERTABLE PROFILE MONITORS

Insertable monitors, successively introduced into the beam, yield the input information for the calculation of a beam envelope with the "Transport" code [2]. Each single monitor allows the measurement of the temporal development of a beam profile. Since these monitors are not thin, only a measurement at one location at a time is possible.

Multi-strip ionisation chambers (MSIC) are used to obtain enough signal from the small beam current (0.1 to 40 nA). All ionisation chambers are filled with ambient air. Metallized ceramic 0.63 mm thick boards separated by 4 mm wide air gaps provide the strip pattern and high-voltage electrodes in order to measure (the projections of) the vertical and horizontal beam profiles (Fig. 2). The pitch of the metallized strips varies from 0.5 to 1 and 2 mm (plus one broader strip at each side). 2x 68 strips are fed to the outside by flexible-printed-circuit cables.

With two exchangeable printed circuit boards placed in an electrically shielded box at the top of the profile-monitor feed-through the signals are routed to the 2x 16 channels of the electronics. With this arrangement, a strip pitch of 0.5, 1, 1.5, 2, 3 or 4 mm can be chosen for a "1 broader + 14 regular + 1 broader"-strip arrangement in each plane. This variability allows for the adaptation of the strip pitch to the expected range of beam profile width. This is required due to the limited number of only 16 channels per plane that is foreseen for most of the monitors. Simulations [3] indicate that for 16 channels beam position and width can be measured accurately if the FWHM beam width is in the range 1x to 10x strip pitch and the profile is of conventional shape. A pattern with varying strip pitch can also be chosen to further enlarge the range of possible beam profile width of a fixed configuration.

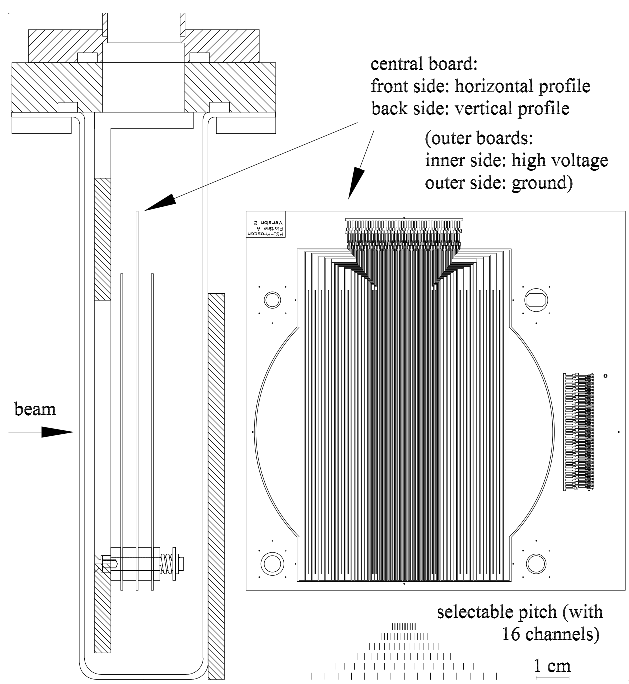


Figure 2: Insertable profile monitor.

At three successive locations, a higher resolution is foreseen for beam tomography. A "1 broader + 30 regular + 1 broader"-strip arrangement in each plane will be realised by doubling the number of cables and electronic modules. At these locations, the available strip pitch is 0.5, 1 or 2 mm. For the tomography measurements also an additional insertable screen monitor is also foreseen. It will be observed via a mirror using a concrete shielded CCD-camera.

A shielded 40-wire twisted-pair cable is used to transport the signals to the electronics located some 40 meters away outside of the concrete shielding.

+0.6 kV power supplies with low ripple feed the HV-electrodes via an RC-filter. With one exception, the electric field is sufficient to suppress the effect of recombination (calculated according to [4]) on the measured currents to below 10 % at the expected beam current densities and beam energies.

The MSIC is placed in a box filled with ambient air and moved into the beam by a pressured-air actuator. No attempt has been made to make the monitor thin. (Thinner ceramic board is available, but usually less flat.) On the contrary the wall thickness of the box (2x 1 mm) is enlarged by an attached square of aluminium of 5 mm thickness in order to further degrade the beam and prevent its transportation through the gantry. This eliminates the possibility of patient irradiation with a disturbed beam in the case of a profile monitor placed erroneously in the beam.

The strip pattern will be adjusted in the directions transversal to the beam to the requested accuracy of 0.1 mm to the reference given by the flange of the vacuum box.

## THIN PROFILE MONITORS AND CURRENT MONITORS

In front of the degrader and at the "control point" in front of the gantries, MSICs are inserted permanently in the beam. These must be very thin to prevent excessive scattering of the beam. Titanium foils of 6 μm thickness are used for the strip-planes and HV-planes. Two ionisation chambers (IC) for the redundant measurement of the integral current are formed by additional foils (2 HV and 2 measurement). The ratio of the currents at both locations is rapidly monitored as a safety measure.

A "1 broader + 30 regular + 1 broader"-strip pattern with 1 mm pitch is used. The alternating measurement and HV-planes are separated by a gap of only 2 mm. A bias of +2 kV is applied. The high electric field counteracts the non-linearity due to recombination and reduces the charge collection time (~15 μs). For the expected beam parameters under standard operation, recombination effects should be below 5 %. Nevertheless, with smaller beam diameters, recombination effects are dominant at higher beam currents.

The pre-tensioned foils (full or with the etched strip pattern) will be mounted on the supporting frames made from thick-film plated ceramic board (Fig. 3). This is done using non-conducting glue while electrical connection to the printed circuit pattern is done with small strings of conducting glue. As an alternative, soldering will be tested, which requires a thin sputtered silver coating of the outer parts of the foil. A flexible-printed-circuit cable is used for the connection to the outside terminal.

The integrity of the strips can be checked by capacitively coupling a voltage pulse or AC-signal to the strip ends opposed to the read-out.

The measurement head is separated from the vacuum by a box with thin (35 μm) titanium windows, which are clamped between flanges [5]. A similar but insertable monitor of this type is used shortly after the cyclotron.

In order to get signals not compromised by recombination at higher beam currents, the same devices are placed in vacuum and used as multi-strip secondary emission monitors (MSSEM) and current monitors (SEM) at the locations near the cyclotron and in front of the degrader. (Nevertheless, at low beam current the signal is too low for the electronics used.) Titanium is known for the stability of its secondary emission coefficient against ageing [6].

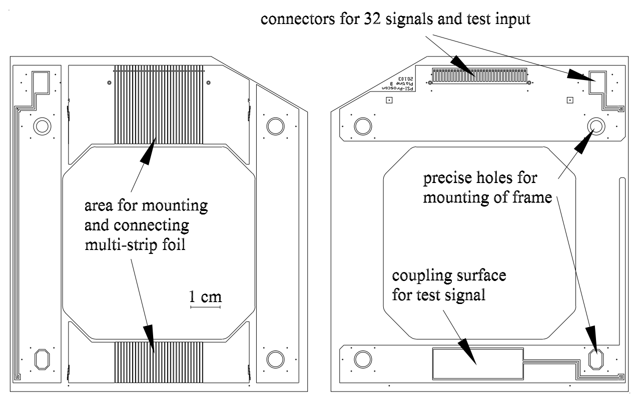


Figure 3: Supporting frame for multi-strip foil.

## HALO MONITORS AND IONISATION CHAMBERS

Standard external ionisation chambers are located behind the dipoles close to the beam pipe. Only losses close to an air-filled chamber generate enough signal for the electronics used. More sensitive "halo-monitors" are placed around modified bellows adjacent to the quadrupole doublets and triplets (Fig. 4). These 4-segment ionisation chambers, which protrude circumferentially 5 mm into the beam pipe of 90 mm diameter, give enough signal to detect traversing beam current fractions of below 1 pA. This should also give an online control of the stability of the beam settings.

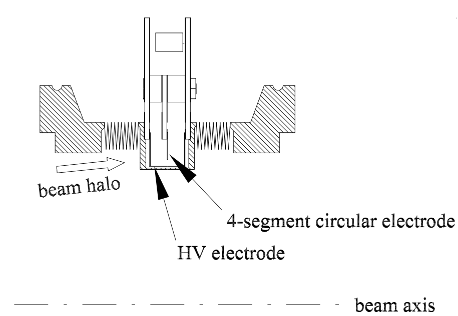


Figure 4: Halo monitor.

## BPMS

Stripline-BPMs with a Q of ~180 are planned as an online control of the beam angle upstream of the "control point" in front of the gantries and the eye treatment room [7]. At the "control point", the beam passes through an air gap of ~20 cm where the above mentioned thin MSIC and IC, a collimator with ~0.8 cm diameter, and a fast stopper are located. We are also considering placing a thin 4-segment ionisation chamber for a fast control of the beam position at this location.

## ELECTRONICS AND SHIELDING

All currents from MSIC, MSSEM, IC, SEM, halo monitors, external ionisation chambers, stoppers and slits are measured with multi-channel logarithmic-amplifier modules. In the first phase, a 16-channel CAMAC-module will be used with a current range of 10 pA to >200 μA. It allows single channel readout as well as the measurement of up to 4096 profiles with a minimum time step of 1 ms. Algorithms for data evaluation and the generation of interlocks can be implemented. A trigger input allows the observation of time dependent machine behaviour by simultaneous operation of several modules [8]. In the later phases, this will be replaced by 32-channel and 4x4-channel (4 separate isolated grounds) VME-modules, which are under development. The high voltage for MSIC, MSSEM, IC, SEM, halo monitors, external ionisation chambers and suppressor electrodes of faraday cups will be delivered by VME-modules also under development.

The very low signal levels require the omission of ground loops. Therefore, the internal shield and "ground" of the analogue amplifier electronics is only grounded via the internal shield of the measurement-cable (and in the case of the 40-wire cable by 8 wires), which is grounded at the diagnostic head at the beam line. The ground of the digital electronics refers to the CAMAC- or VME-crate ground. The ground transition for the signals is provided by a differential amplifier. This is the standard technique used at our lab and applies as well to the HV-modules. Additional shielding is provided by enclosing measurement- and HV-cables from one diagnostic head together in a second shield (copper braid) which is grounded at many locations along the way. The diagnostic cables are placed on its own support, separate from magnet cables and water pipes in order to reduce electromagnetic and microphonic noise.

## VACUUM BOXES

The vacuum boxes for profile monitors, stoppers, moving slits, etc. are individually adjustable on a (already nearly accurately placed) girder of several meters length (Fig. 5). The box design allows an inexpensive production using water cutting, brazing and only minimal machining of the stainless steel parts [9]. The main flange of the box includes 4 "ears" with precision holes. Its adjustment can be surveyed with or without the diagnostic head installed. The head with drive is pre-adjusted on a corresponding gauge.

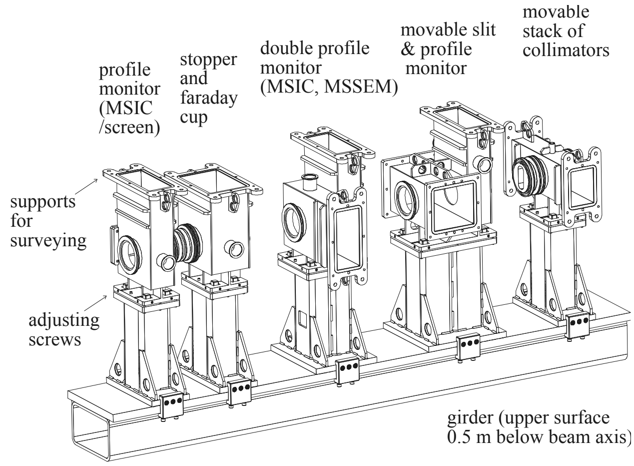


Figure 5: Vacuum boxes with support.

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