A Scintillator based Halo-Detector for Beam Position Monitoring

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Abstract

For the cancer therapy project with C^{6+} ions and energies between 80 and 430 MeV/u extracted from the synchrotron SIS at the GSI, Darmstadt, a detector system is developed for an online monitoring of the focal parameters of the beam . Four stepping motor driven scintillator paddles will detect 0.1-1 % of the particles from the beam halo. Informations on the centre-of-mass, the width and the intensity can be deduced by this sensitive, nearly non-destructive method. The mechanical and electronic design, as well as a test measurement is described.

1 INTRODUCTION

The synchrotron SIS delivers relativistic heavy ion beams with intensities up to about 10^{11} particles per second (pps) in the slow extraction mode which usually lasts several seconds. The detector system described here is dedicated for the online, non-destructive beam position and intensity control. It is designed especially for the use in the cancer therapy beam-line with carbon beams of $10^6 - 10^8$ pps and energies between 80 and 430 MeV/u [1]. To diagnose these beams a detection system has been designed for the following purposes:

- precision measurements of the beam profile, especially at the extremities of the intensity distribution
- investigation of changes in position and profile during the extraction period
- detection of possible misalignments of the beam
- generation of a fast interlock signal to stop the extraction within milliseconds in the case of a non-acceptable change in any beam parameters.

It is clear that a non-destructive detection method is necessary for online control. The only non-destructive device to measure heavy ion beam profiles, the residual gas monitor, is not sensitive enough for the use in the extraction beam lines. Therefore the basic idea is to install 2 horizontal and 2 vertical scintillator paddles scratching at the edge of the beam profile, each of them driven individually by a stepping motor with a spatial resolution of 0.1 mm. For profile measurements the count rate can be registered as a function of the paddle position. A position is chosen which corresponds to a certain, very small fraction of the integral count rate, e.g. 1 % to 0.1 %. Deviations from this value are an indication for the quality of the beam parameters. A multitude of informations can be deduced from the different count rates of the 4 scintillator: their dependence on the time, their sums and differences, ratios etc.

Detector	
scintillation material	NE102A
dimensions	25 x 50 x 5 mm^3
Light-guide	
cross section reduction	Perspex strips
guide	cylindrical rod
length	650 mm
diameter	17 mm
multiplier	Philips XP2972
Feedthrough	
stroke	100 mm
step	0.1 mm
max. speed	15 mm/s

Table 1: Properties of the detector-feedthrough unit

As no plastic material was allowed in the beam line vacuum, different kinds of glass (NE901[2] and M-382[3]) were used as scintillation medium in the first prototypes, and the light guides were made either from glass (internal reflexion) or from metal (hollow guide with highly polished aluminium surfaces). However the glass scintillators used are too slow (several hundred ns fall-time) to prevent pile ups at the intended count rate up to 10^5 pps. In addition, the transmission of the metal light guide was not satisfactory. Therefore the actual version consists of plastic scintillators outside of the vacuum, connected to a photomultiplier by a Perspex strip light guide encapsulated in a metal container.

2 MECHANICAL DESIGN

For the medical application, the requirements to the mechanics are:

- Nearly all particles of the beam should continue their path, without being influenced by the detector, in order not to spoil the quality of the beam which reaches the target.
- All particles farer than a given distance from the beam centre should be detected and stopped. No particle should pass the detector position with a modified energy or flight direction.

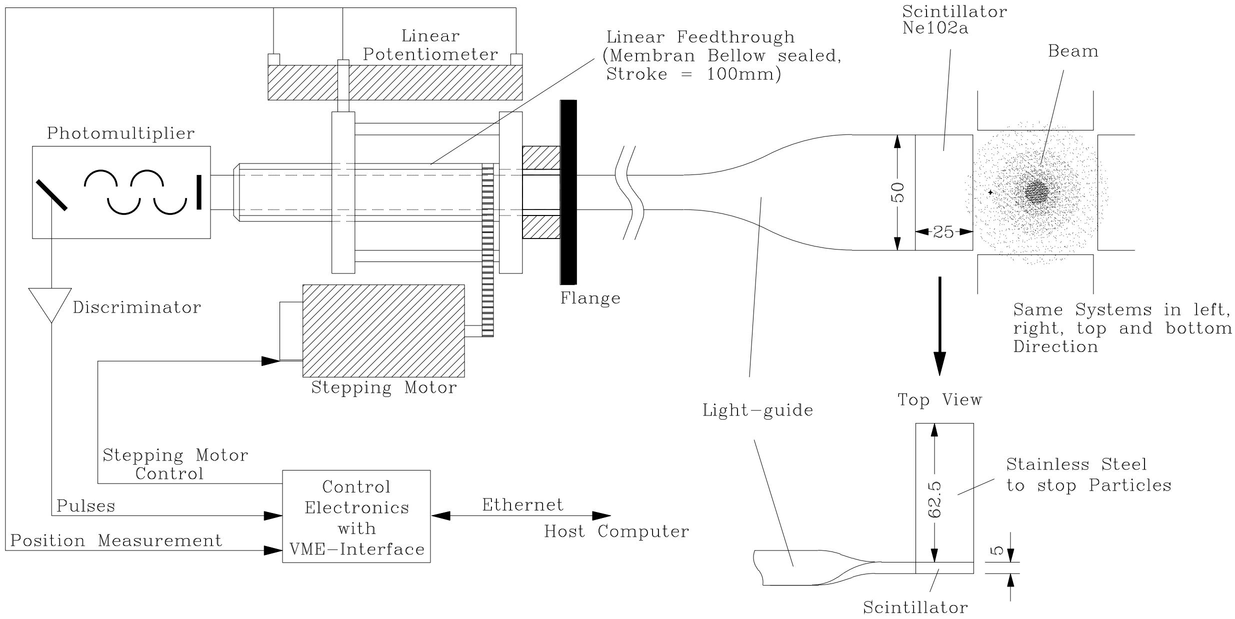

Figure 1: Mechanical setup of the halo-detector system

- The amount of particles stopped without being detected should be as small as possible.

To fulfil the last requirement, a wall thickness of only 0.2 mm has been realized at the scratching side of the container.

The main part of the detector is the scintillator sheet inside the stainless steel housing, see Fig. 1 and Table 1. To fulfil the requirements mentioned above, the beam particles have to traverse an entrance window with a thickness of 2 mm which is thin enough for 80 MeV/u carbon ions, the plastic scintillator sheet with a thickness of 5 mm and a stainless steel absorber of 56.5 mm to stop even the fastest beam particles. Inside the metal containment the cross section of the scintillator sheet is reduced to a circular one by means of a perspex strip light guide. The detector head is mounted onto the stepping motor feedthrough.

The system is mounted inside the beam lines, about 15 m upstream from the iso-centre (i.e. the patient location). Three quadrupoles, one dipole and the scanning magnets are in between. The relation of the beam stability at the iso-centre and at the detector position is given by the beam line optics, which might be energy dependent.

3 ELECTRONICS

The analog signals are converted to NIM pulses by fast discriminators and counted with 24 bit counters. An ALTERA programmable logic device [4], triggered by the start of the extraction, is used to store the data in buffers with programmable time slices of about 100 ms, see Fig. 2. The differences and sums of the counters can be calculated directly. They will be compared to reference data for each

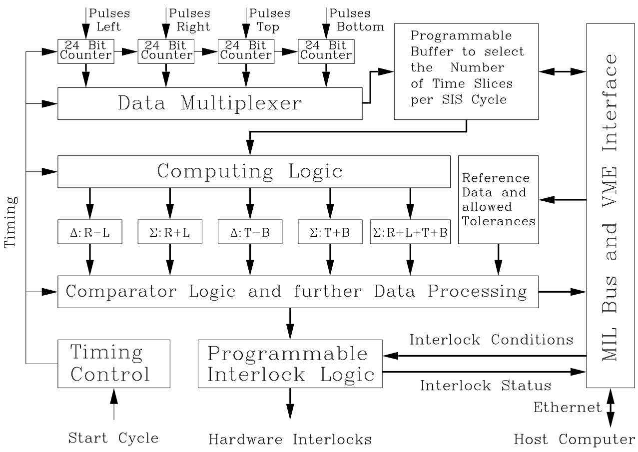

Figure 2: Schematic diagram of signal processing

time slice by a digital comparator. These references will be measured and stored in a test run with the same ion beam conditions before the patient irradiation. The tolerances for the deviations with respect to the reference can be programmed and an interlock can be generated.

4 COUNT RATE CONSIDERATIONS

The measured count rate of one detector paddle for example in the positive horizontal direction $C(x_{det})$, corresponds to the beam intensity distribution $F(x, y)$ integrated over the scintillator area 25x50 mm^2 starting at the position

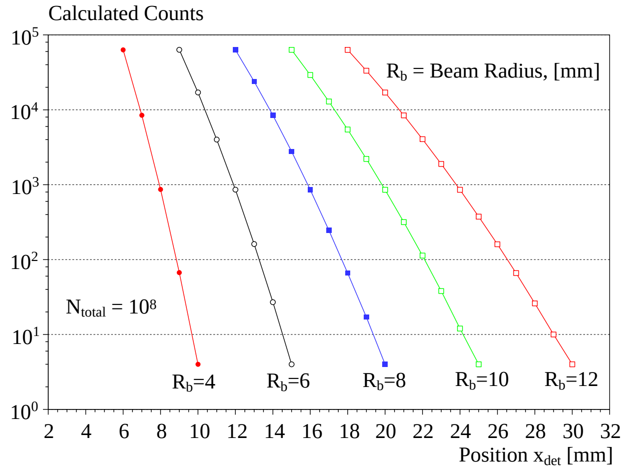

Figure 3: Dependence of the count rate from the position of one paddle calculated for various beam radii R_b. For the simulation, a centred beam of 10^8 particles is assumed.

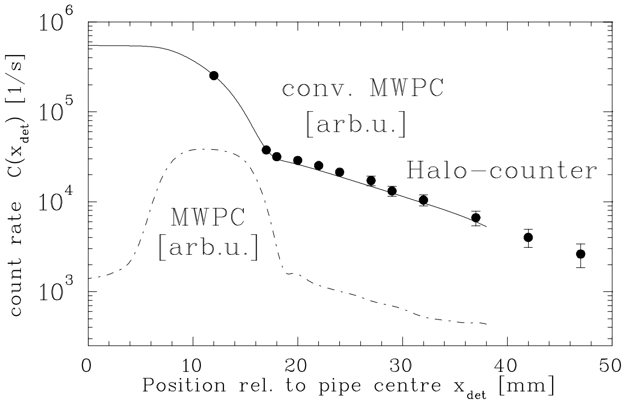

Figure 4: Comparison between the measured count rate of the halo-counter and the convoluted signal from the profile grid (MWPC) for an extraction time window of 200 ms. In addition the original MWPC signal is shown.

of the edge of the scintillator, x_{det}:

$$C(x_{det}) = N \int_{x_{det}}^{x_{det}+25} \int_{-25}^{25} F(x,y)dydx \qquad (1)$$

N being the total intensity. Calculations are done with a Gaussian intensity distribution of the form

$$F(x,y) = \frac{1}{\sqrt{2\pi}\sigma_x} e^{-\frac{(x-X_0)^2}{2\sigma_x^2}} \cdot \frac{1}{\sqrt{2\pi}\sigma_y} e^{-\frac{(y-Y_0)^2}{2\sigma_y^2}} \qquad (2)$$

with X_0, Y_0 and σ_x, σ_y the position and width of the beam in horizontal and vertical direction, respectively. The expected dependence of the count rate on the position x_{det} for different beam parameters is displayed in Fig. 3. A steep increase of the count rate with x_{det} is visible even for larger values of R_b up to one order of magnitude per mm. Therefore small changes of the beam parameters can be detected, but a careful positioning is necessary.

5 TEST MEASUREMENT

A first test was performed with one paddle installed in the horizontal plane at a beam energy of 367 MeV/u and an extraction time of 2 s. The data shown in Fig. 4 were taken in a 200 ms time window during the spill. The paddle position is scanned across the beam profile, having a width of $R_b \simeq 7$ mm and a centre-of-mass at 12 mm with respect to the beam-pipe centre. The high count rate close to the wall of the beam pipe indicates an unexpected large beam halo. The dependence of the scintillator counts is compared to the transverse profile determined with a multi wire proportional chamber (MWPC), convoluted with the 25 mm width of the scintillator. There is a good agreement between both measurements. The plot shows the high sensitivity of the halo-counter to any changes of the beam parameters. When putting it to the edge of the sharp rise of the signal (in this case at about 16 mm), the count rate increases by a factor of 2 per mm in reasonable agreement with the calculation in Fig. 3. The sensitivity (i.e. the deviation $dC(x_{det})/dx_{det}$) varies with the position and can therefore be chosen to an optimal value.

For the comparison with the MWPC only data from a 200 ms time window were considered to be independent on spatial beam drifts. In principle a time independent alignment is possible [1], but was not realized for the test measurement.

6 CONCLUSION

A detector has been developed which is able to determine the tails of the beam profile distribution with a high precision using only a small fraction of the beam particles. It can be used advantageously for the online stability control of spatial beam parameters. Multiple informations can be obtained from the 4 count rates. A first test with one detector paddle proved the good functioning of the detector-feedthrough-unit. The results of the profile measurement are in agreement with MWPC data. All four paddles are installed now and have to be tested. The next step of the development will be the realization of the data evaluation hardware and software. It is planned to use this device as an interlock unit, as well as a direct online display for the beam quality.

7 REFERENCES

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