Synoptic Report on Beam Profile Monitors supported by HIPPI WP5

R. Tölle[1]

1) Forschungszentrum Jülich, Jülich, Germany

Abstract

Within the HIPPI project three laboratories took the chance to develop diagnostic tools suitable for pulsed high intensity beams in a common work package. A survey of the achievements is given covering goals, design, and tests.

Introduction

Pushing the limits of acceleration technology is in itself intimately connected to advances in diagnostic techniques to fulfill and verify new requirements to beam quality. Within the HIPPI framework and driven by their individual application 3 laboratories developed diagnostic devices with genuine properties suitable for high power beams. They will be referred to as:

- CHD-CERN = Chopping and Halo detector (CERN)
- BIF-GSI = Beam Induced Fluorescence monitor (GSI)
- BIF-Jülich = Beam Induced Fluorescence monitor (Forschungszentrum Jülich)

1. Designed properties

	CHD-CERN	BIF-GSI	BIF-Jülich
Purpose	3 MeV chopped H^- beam, time structure and transverse beam profile incl. Halo	transverse beam profile measurements at FAIR (several ion species, pbar)	transverse beam profile measurements at COSY and HESR (p, d, pbar)
Target material	thin carbon foil, intercepting ~2% of the beam	residual gas, additional gas load if necessary	residual gas, additional gas load if necessary
Average beam current	60 µA	various currents of several ion species from 3.5 to 750 MeV/u	n / a
Peak beam current	70 mA		n / a
Detection steps prior to data analysis	guide secondary electrons to phosphor screen gated by acceleration grids, light guide, detect photons using a thermo-electrically cooled CCD camera	optically collect fluorescence light, convert to electrons intensify via multi channel plates, gate the electrons if desired, convert to photons, record with CCD camera	optically collect fluorescence light, detect with multi-array photo multiplier tube
Time resolution	$\Delta t \approx 1$ ns	100 ns	< 100 ns
Spatial resolution	$\Delta x \approx 2$ mm	down to 0.2 mm	n / a
Active area	40 mm x 40 mm (transverse)	50 mm long segment of the beam	45 mm long segment of the beam
Dynamical range	$> 10^5$		
Remarks	Device with major in-house made components	Maximized usage of industrial components	Device with major in-house made components

2. Sketch of detector with main components

2.1. CHD-CERN

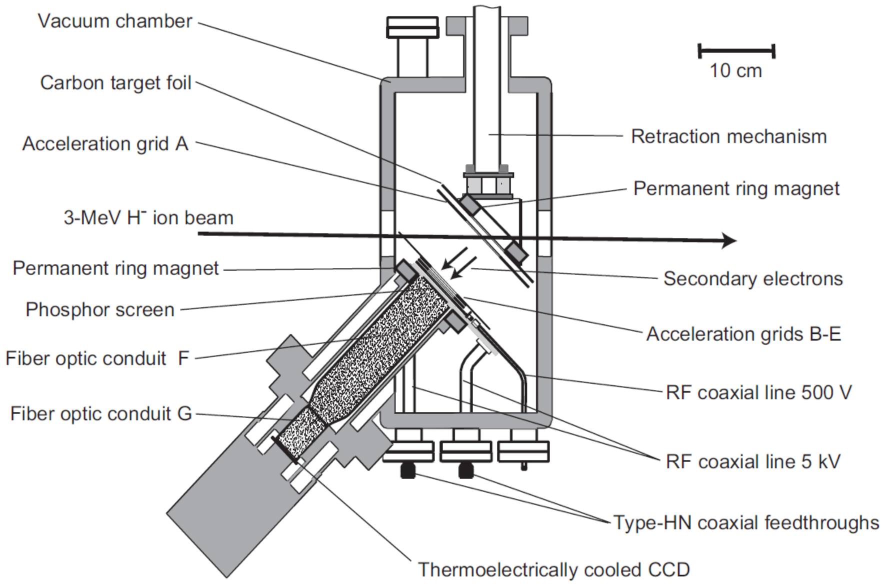

Fig. 1: Schematic layout of the beam profile monitor. Incident H^- ions of energy E = 3MeV struck a carbon target foil. Secondary electrons emitted from the foil were accelerated by grids A–E and struck a phosphor screen. The fluorescence image was transported by fiber optic conduits F and G to a CCD.

2.2. BIF-GSI

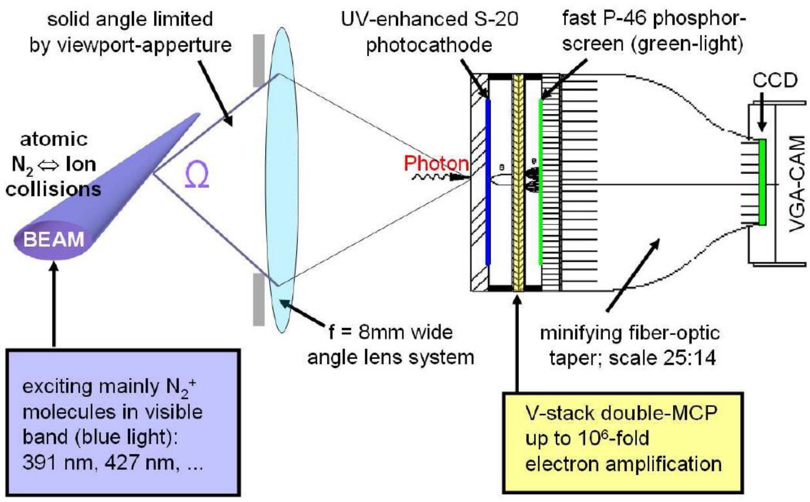

Fig. 2: BIF-principle and the scheme of an image intensifier.

2.3. BIF-Jülich

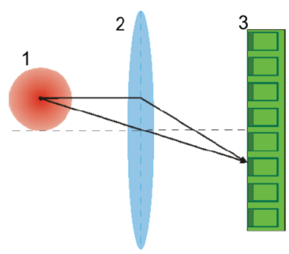

Fig. 3: Measurement Principle (not to scale): The light from the beam (1) is focused with a glass lens (2) onto the multichannel photomultiplier (3).

3. Beam tests with charged particle beams

3.1. CHD-CERN

A thorough description of the detector with all its details is given in [1]. Apart from tests described here tests with laser beams are reported in [1], special focus on timing behavior. Performance dependence on parameters of acceleration grids is not included here.

3.1.1. Description of beam
momentum 3 MeV, TANDEM at IPN, Orsay, micro bunches with 5×10^4 protons, micro bunch length 5 ns, repetition rate 10 MHz

3.1.2. measurement conditions
integration over $10^2 – 10^3$ micro bunches

3.1.3. measured profile

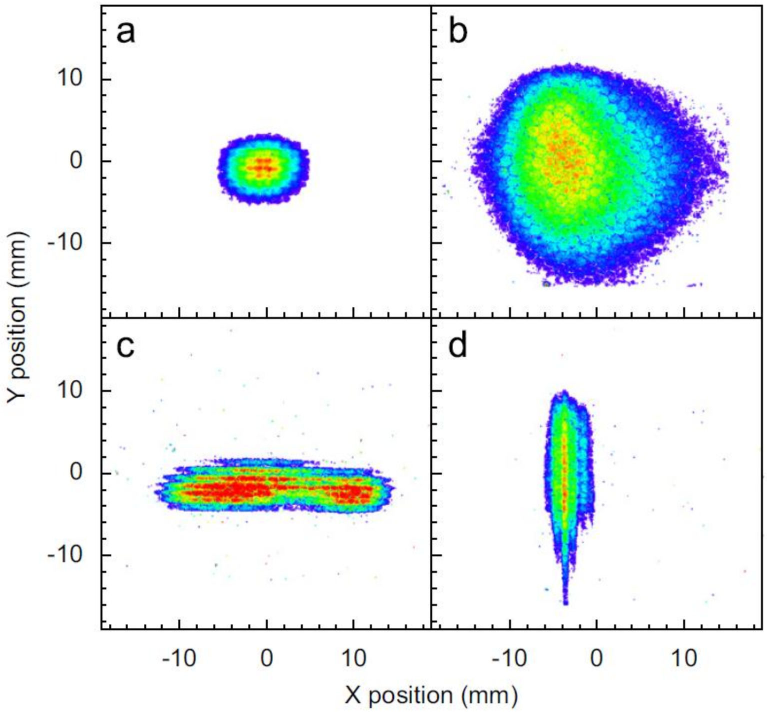

Fig. 4: Spatial profiles of the 3-MeV tandem beam containing $N_p = 5\times10^4$ protons per micro bunch, measured for circular beams of diameter d = 5mm (a) and 15mm (b), and beams that were horizontally (c) and vertically (d) elongated. The measurements were made by integrating the signals from 120 micro-bunches on the CCD.

The detector showed a linear response to the number of protons per bunch between 10 protons per micro bunch and 6×10^4 protons per micro bunch. Laser based experiments indicate an even wider linear range for intensity measurements.

Gating of the secondary electrons by the acceleration grids with duration of 1 ns could be achieved.

3.2. BIF-GSI

The measurements were confirmed by independent diagnostic instruments.

3.2.1. Description of beams
UNILAC: Energy from 3.5 MeV/u to 11.4 MeV/u, various ions from Ar to U, peak current range from 10 µA to 10 mA, macro pulse length from 0.1 to 5 ms
Extracted from SIS: Energy from 60 MeV/u to 750 MeV/u, various ions from Xe to U, current from 10^8 particles per pulse to 10^{11} particles per pulse, fast and slow extraction

3.2.2. Measurement conditions
Vacuum pressure 10^{-7} to 10^{-2} mbar of N_2, optics and geometry chosen for a resolution of 300 µm per pixel.

3.2.3. Measured profile

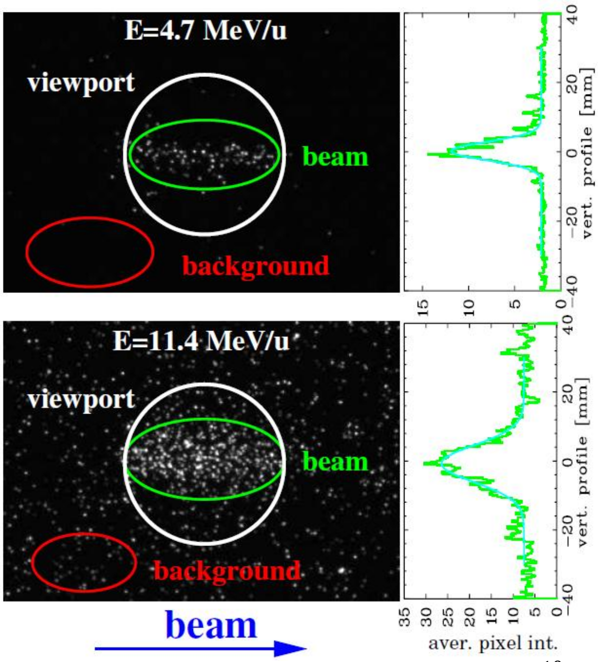

Fig. 5: The two dimensional image from the intensifier of an Ar^{10+} beam at 4.7 MeV/u as well as 11.4 MeV/u and I_{beam} = 2.5 mA recorded during *one* 250 µs long macropulse with a vacuum pressure of about 10^{-5} mbar. The projections for the vertical beam profiles (right) are shown.

Some recordings show noticeable background fluctuations which can be suppressed by integration of several (e.g. 32) macro pulses. Further methods of background suppression were successfully investigated.

By gating of the electrons in the multi channel plates, 20 µs fractions of the UNILAC pulse could be measured.

Correct choice of focal length and iris diameter is crucial for meaningful measurements.

The functionality of the BIF principle was demonstrated under various beam conditions. A reliable technical realization was produced. This setup is installed at several locations along the UNILAC for routine profile measurements under high current conditions.

3.3. BIF-Jülich

All measurements are confirmed by independent diagnostic instruments.

3.3.1. Single pass experiment at 1.35 GeV/c

3.3.1.1. Description of beam
Momentum 1.35 GeV/c, extracted beam at COSY, bunch with 10^{10} protons, bunch length 100 ns

3.3.1.2. Measurement conditions
Beam diameter at monitor ≈ 40 mm, distance beam – PMT 50 cm, local pressure varied between 10^{-1} and 10^{3} mbar N_2, integration time 100 ns

3.3.1.3. Measured profile

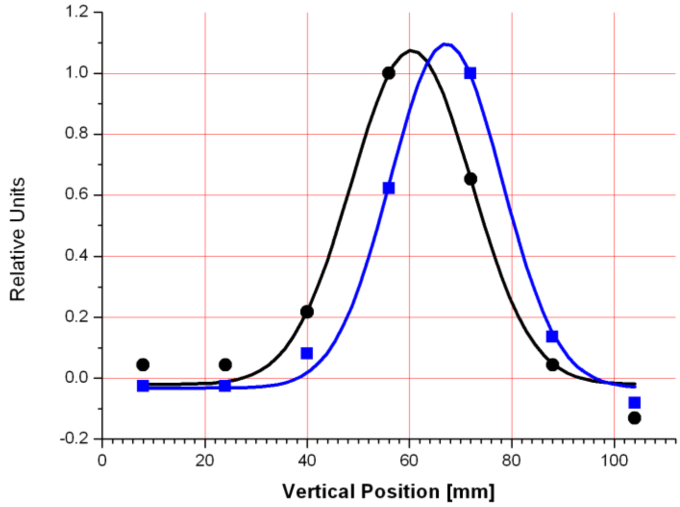

Fig. 6: Vertical profile of extracted COSY beam, 10^{10} protons, 1.35 GeV/c, 10 mbar local pressure, direct beam (black) and shifted beam (blue), data (dots, boxes) and Gaussian fit (lines).

3.3.2. Single pass experiment at 3.14 MeV

3.3.2.1. Description of beam
Energy 3.14 MeV, cyclotron DC beam at iThemba Labs, 100 μA

3.3.2.2. Description of results
Detector is working reliably under routine conditions in radiative environment. Further investigation is needed to allow measuring extremely large beam diameters and beam diameters behind narrow collimators.

3.3.3. Multi pass experiment (synchrotron)

3.3.3.1. Description of beam
Momentum 1.7 GeV/c, coasting beam in COSY, 5×10^{9} protons, frequency 1.426 MHz

3.3.3.2. measurement conditions
Local pressure 10^{-7} mbar mainly H_2, integration time 4 seconds

3.3.3.3. measured profile

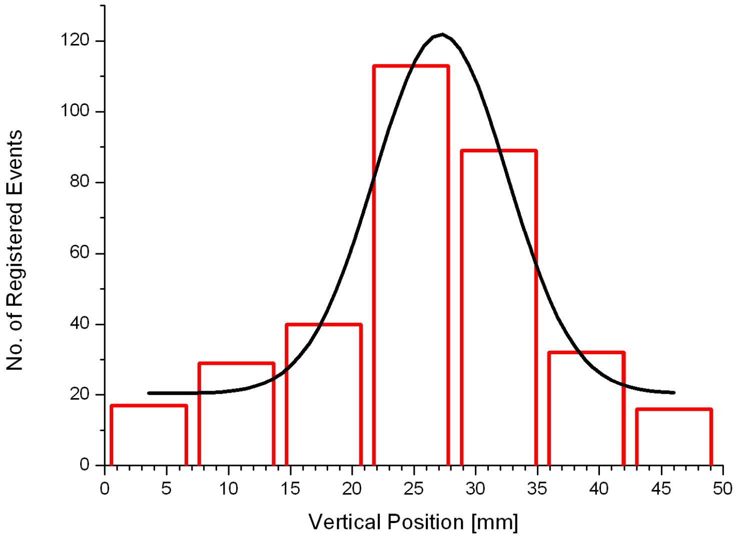

Fig. 7: vertical profile of circulating COSY beam, 5×10^9 protons, 1.7 GeV/c, 10^{-7} mbar local pressure mainly H_2, acquired during 4 seconds, PMT channel data (red) and Gaussian fit (black)

4. References

For a full description of the devices check the references given below:

- CHD-CERN:
  [1] http://dx.doi.org/10.1016/j.nima.2008.01.078
- BIF-GSI:
  [2] http://irfu.cea.fr/Phocea/file.php?class=std&&file=Doc/Care/care-report-07-016.pdf
  [3] F. Becker et al., Proc. DIPAC 2007, Venice (2007)
  [4] F. Becker et al., Proc. BIW 2008, Lake Tahoe (2008)
- BIF-Jülich:
  [5] http://irfu.cea.fr/Phocea/file.php?class=std&&file=Doc/Care/care-report-07-029.pdf

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