Beam Induced Fluorescence (BIF) Monitors as a Standard Operating Tool

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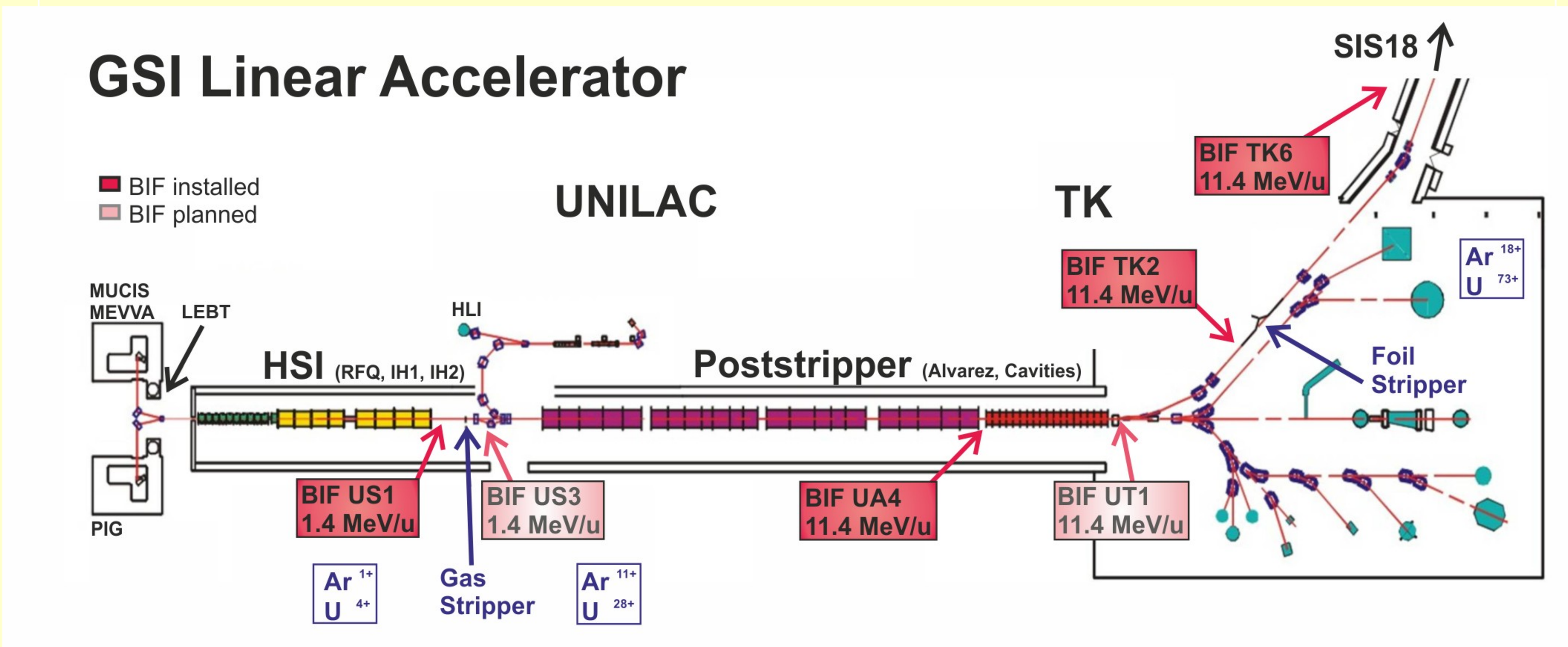
Abstract

The Beam Induced Fluorescence Monitor was developed as a non-intercepting optical measurement device, dedicated for transverse beam profile monitoring at high current operation at the GSI Heavy Ion Linear Accelerator UNILAC. Nowadays, BIF monitors are installed at four different locations and handed over to the operating team as a standard diagnostic tool.

BIF Installations at GSI



Installed BIF monitors along the linear accelerator with typical beam energies and charge states

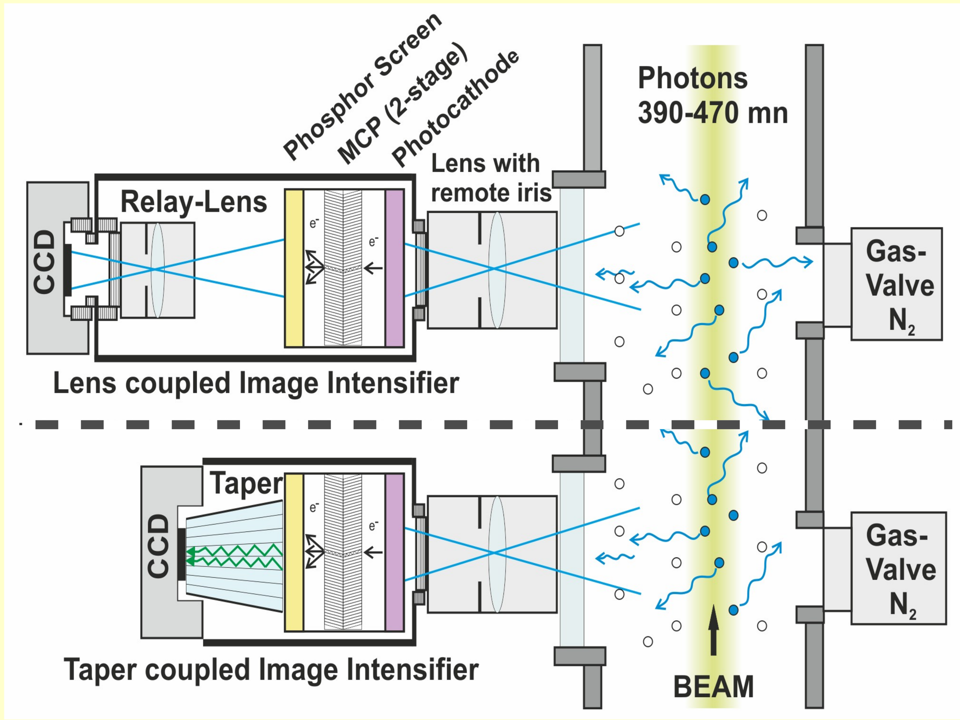
BIF Detection Principle

The BIF principle is based on the observation of fluorescence photons emitted by excited nitrogen molecules. Depending on the energy loss of the interaction between ions and gaseous nitrogen molecules, different excited states are possible, mostly emitting photons in the range of 390–470 nm.

A rough scaling for the photon yield Y for UNILAC energies is:

$$Y \propto \frac{q^2}{E_{kin}} \cdot p_{gas}$$

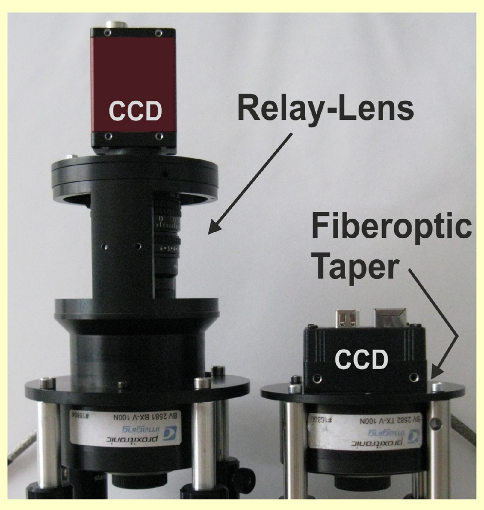
q : ionic charge
E_{kin}: kinetic energy
p_{gas}: gas pressure



BIF detection principle with Relay-coupled (top) and Taper coupled (bottom) CCD camera

Experimental Setup

For UNILAC operation, a single shot measurement at the lowest possible gas pressure is required. Hence, the optical system is optimized for single photon detection.



Relay- and Taper coupled camera system

Fiberoptic Taper (25:14)

Image Intensified Camera System

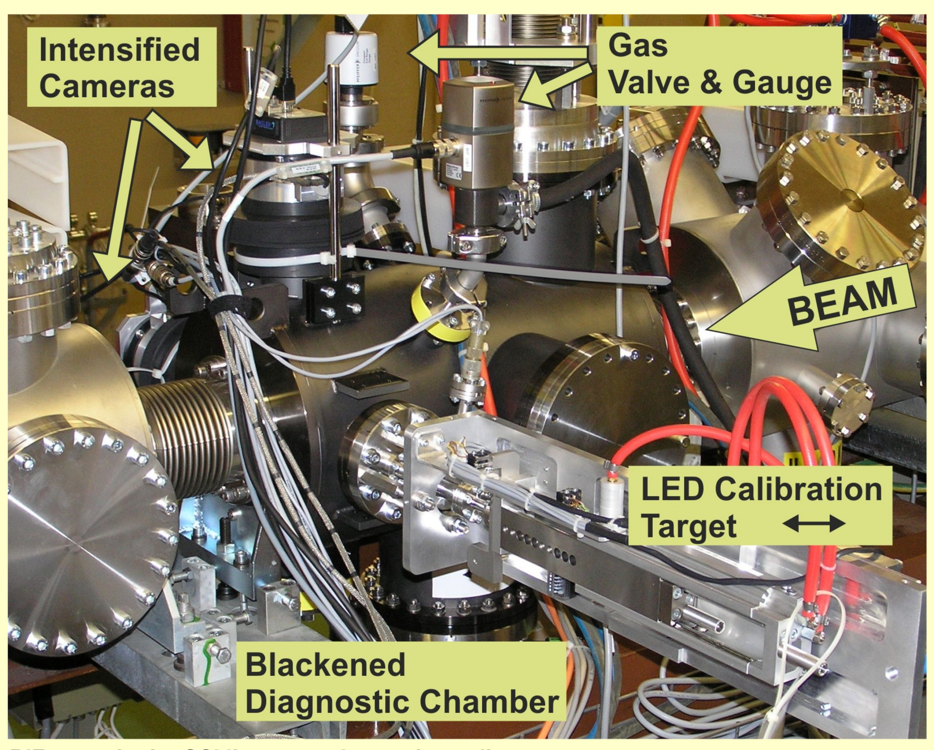
- Proxitronic BV 2582 BX-V 100N
- Bialkali photocathode with a QE of 15-20% at 390-470nm
- 2-stage MCP in V-stack assembly, magnification of up to 10^6
- P46 phosphor screen with decay time of 300 ns and max. emission at 530 nm
- Taper- (25:14) or Relay-coupling (Schneider Componon lens 35/2.8, magn.=0.6)
- Firewire CCD, ½' Sony ICX414 chip, VGA resolution and max. 60 fps (full frame)
- High voltage power supply: high voltage remote controllable up to 2 kV, gated with a minimum of 100 ns

Imaging Lens: Pentax C1416ER

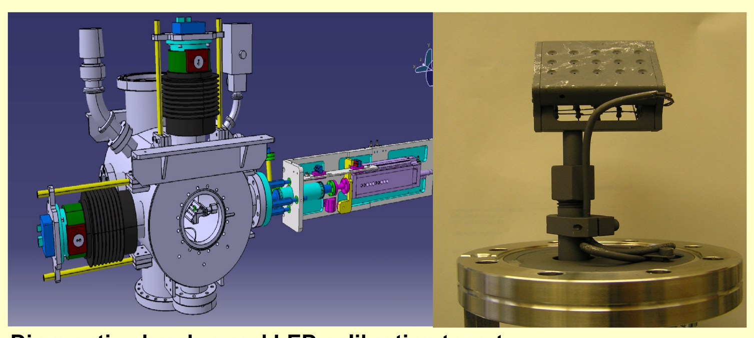
- Focal length 16 mm
- Remote controllable iris to extend the dynamic range of the system and to adapt the depth of field

Pfeiffer Vacuum Gas Control System

- Control unit RVC300, remote access
- Dual gauge PKR261 (cold cathode & Pirani)
- Needle valve EVR 116



BIF setup in the GSI linear accelerator beam line



Diagnostic chamber and LED calibration target

LED Calibration Target on Pneumatic Drive

- For system calibration and adjustment to beam axis.
- 15 LEDs are arranged to the cameras in 45°
- Depth of field can be controlled

⟶ **Optical setup gives a resolution of ~4.5 pixel/mm and a depth of field of ~40 mm**

BIF Signal Control

The signal strength and the profile quality obtained by the BIF monitor depend on many factors. Thus, for an optimized signal the profiles have to be evaluated from case to case and settings have to be adopted. Remote controllable parameters are:

- Control of the iris
- Gain of the MCP and the phosphor screen
- Gas pressure

} adjustable by a slow control voltage controlled via Ethernet command

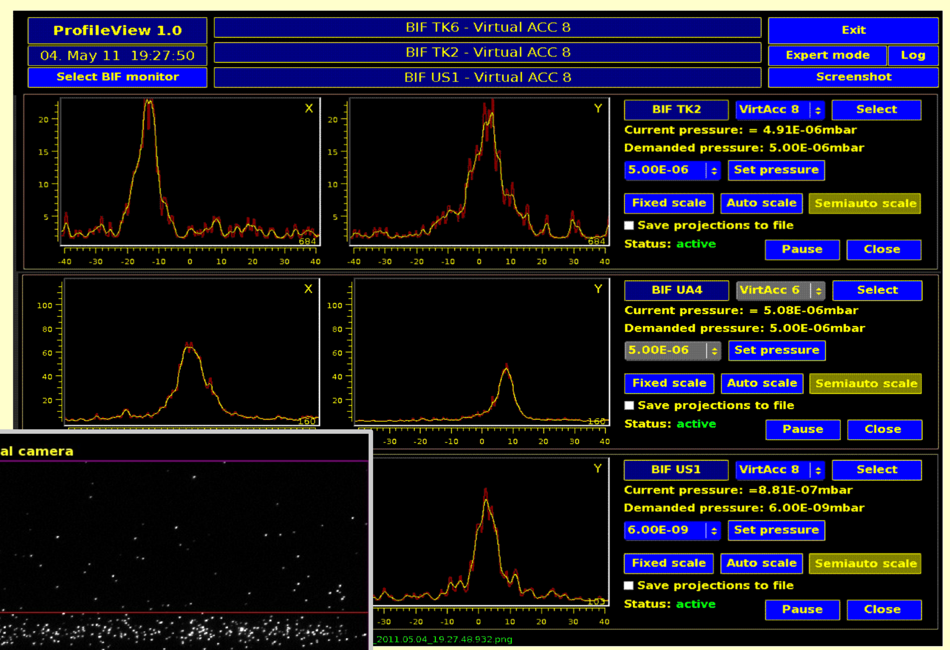
The slow control voltages are applied by a Siemens PLC driven DAC (SM332: 12 bit/ 4 analogue outputs). Additionally, a relay (SM322: 8 digital outputs) is used for remote power control of all electronics near the beam line.

BIF Usage

For operating of the BIF monitors, the new software 'ProfileView' was designed. It automatically controls the camera communication, timing, slow controls and gas pressure and shows profiles, images and calculations in a GUI.

ProfieView 'User Mode'

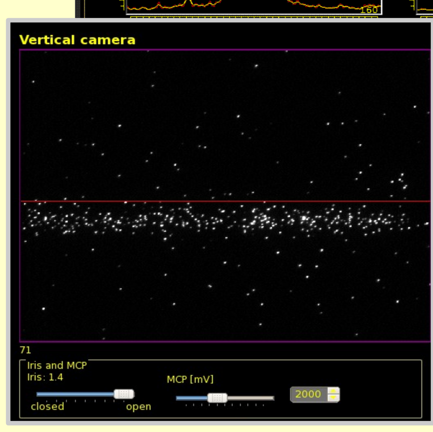
- Easy-to-use mode for operation
- Profiles of up to three BIF monitors
- Nitrogen pressure as a free control parameter for adjustment of the signal strength
- All other settings are pre-defined
- Save profiles option



ProfileView 'User Mode'

Profile View 'Expert Mode'

- For experienced users, debugging and research experiments
- Original images can be displayed and saved
- All remote devices and slow controls can be set manually



ProfileView 'Expert Mode'

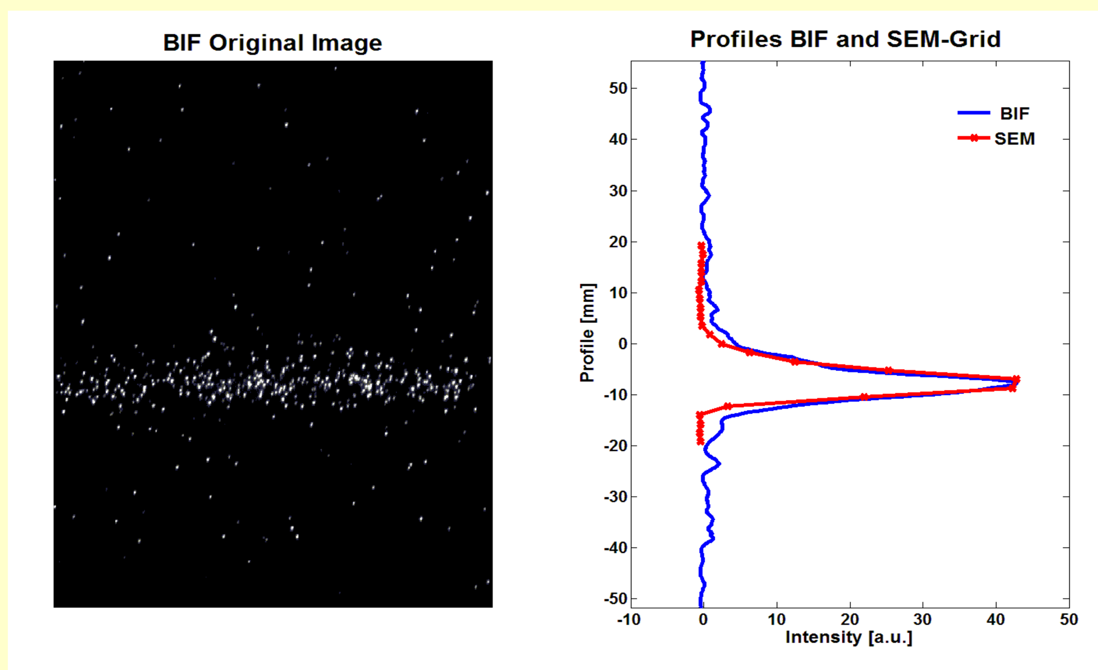
Experiences and Results

The standard measurement devices at GSI used for transverse beam profile determination are beam intercepting Secondary Electron Emission grids (SEM).
BIF was destined to replace these intercepting diagnostics for high current operation, due to these advantages:

- BIF is a non-intercepting beam diagnostic device
- 100 x 80 mm² field of view at a resolution of ~4.5 pixel/mm
- The full beam pulse can be observed as well as a defined time window of min.100 ns
- Images can be accumulated and smoothing or binning algorithms can be applied
- Particle losses due to the beam-gas interaction are negligible
- No charge changing processes were detected yet

As a prove of principle before handover to the operation crew, BIF projections were compared to the profiles simultaneously measured by a SEM grid.

As an example, a single shot BIF image and calculated profiles are shown, taken at UNILAC section UA4 at 11.4 MeV/u of an U^{39+} beam with $4 \cdot 10^{10}$ particles per pulse (ppp) and $5 \cdot 10^{-6}$ mbar N_2. The profiles of BIF and SEM grid measurement are compared and show a good agreement.



Energy [MeV/u]	Ion and Charge state	Particles per pulse (ppp)
1.4	Ar $^{1+}$	$2 \cdot 10^{12}$
11.4	Ar $^{11+}$	$2.8 \cdot 10^{11}$
1.4	Ta $^{3+}$	$2 \cdot 10^{11}$
1.4	U $^{4+}$	$7 \cdot 10^{11}$
11.4	U $^{39+}$	$3.6 \cdot 10^{10}$

A rough estimation of beam parameters where good signals with BIF were achieved is shown in the table. For all measurements, a local gas pressure of $5 \cdot 10^{-6}$ mbar was used. The measurements were done under user conditions and no expert optimization was performed. Some of the profiles are shown in the ProfileView 'User Mode' figure above.

Conclusion & Outlook

The BIF monitors are working as a reliable diagnostic tool to be used by the operating crew. The functionality has been proved under daily conditions and measured profiles were compared to SEM grid measurements. Further monitors will be installed at GSI UNILAC, also in special areas e.g. at charge separation. At the new FAIR facility, several BIF monitors are foreseen in the HEBT lines.

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