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FAIR @ GSI	Detailed Specification for Scintillating Screens for HEBT	F-DS-BD-16e_ OptProfile_SCR_T	Page1 of 36

Document Title:	**Detailed Specification for Scintillating Screens for HEBT** **F-DS-BD-16e_OptProfile_SCR_T**
Description:	**This document contains the Detailed Specification of the beam diagnostic component "Scintillating Screens for HEBT". This document covers all items of psp-code 2.3.6.5.2.**
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1. Purpose

The purpose of this document is to specify the technical requirements of the Beam Diagnostic (BD) component "Scintillating Screens" for optical beam profile measurement in the High Energy Beam Transport lines (HEBT) [2] of FAIR [1]. It is the most detailed document in the hierarchy of beam diagnostic documentation to specify all rules and information for the planned technical realization of this system.

The Detailed Specification serves as an entry point for third parties to get an overview of the required functionalities of a beam diagnostic component, to evaluate the scope of the instrument, to learn about the achievements reached with existing realizations at GSI and to understand the questions to be solved in the course of device fabrication for the FAIR project.
Whenever regulations and requirements are specified in the General Specifications [3], Technical Guidelines or Common Specifications for Beam Diagnostics [4] they are only referenced in the present document. The related documents are listed in Appendix II.

No legal or contractual conditions are treated in this document. All related information is given in the General Specifications for FAIR [3].

Appendix IV contains a list of abbreviations used in this document.

2. Scope

The optical beam profile system described here is intended for usage in HEBT beam lines.

Throughout the FAIR project individual technical components are unambiguously identified by their unique PSP code (project structure plan). Moreover the sub-structure of beam diagnostic equipment is also reflected by detailed PSP codes for BD sub-components.

The present document covers the following PSP code:

PSP	BD Component	FAIR Section
2.3.6.5.2	Scintillating Screens	HEBT

Civil construction and building issues are specifically **not** covered in the present document.

3. Responsibilities

The responsibilities with respect to changes and modifications of the present document are entirely in the hands of the Beam Instrumentation Department (BI) of the GSI Helmholtz Centre for Heavy Ion Research GmbH (GSI) Darmstadt.

4. General Functionalities

4.1. Overview

Scintillating Screens are intercepting devices to measure a 2-dimensional intensity distribution of the ion beam in the transversal plane. In contrast to methods implying direct projections (such as SEM-Grids and MWPCs), screens deliver a true 2-dimensional image of the impinging intensity distribution. Beam-profile projections along the vertical and horizontal axis can be derived later from the 2D image, as well as center of mass or higher statistical moments of the distribution.
Driven by the differential energy loss of the ion beam, scintillating screens are excited to fluorescence levels. Important parameters like the light output, the decay time and the radiation hardness are characteristic material properties of the scintillator and depend on the actual beam parameters.

Scintillating Screens are typically used for low to medium current applications in transport sections or as a first turn diagnostics in synchrotrons or storage rings and whenever a two-dimensional intensity distribution is important for machine operation. A schematic drawing of a typical scintillating screen setup with its major components is shown in Figure 1.

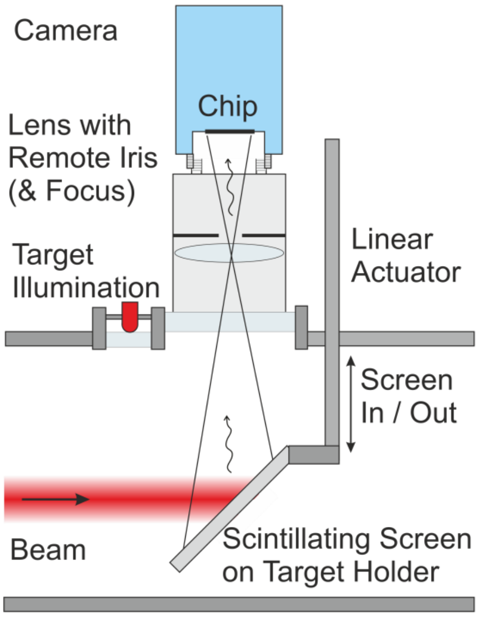

Figure 1: Scheme of an intercepting scintillating screen setup; Screen mounted in 45° with respect to the beam and the camera.

4.1.1. Measurand / Quantity to be measured

The measured quantity is the position-dependent (in transverse coordinates) light output emitted by the scintillator under ion impact from which the intensity distribution of the particle beam is extracted.

This beam diagnostics device has to deliver the following information:

- Complete 2 dimensional beam distribution (raw image data)
- Background corrected horizontal and vertical beam distribution (beam profiles)
- Statistical moments (e.g. beam position & center, beam width, correlation coefficients etc.)
- Light intensity histogram

4.1.2. Physical Measurement Principle

Ions that impinge on the scintillator lose energy in the material according to their specific energy loss which is a function of the particle type, its energy, its charge, and the chosen type of scintillating material. In a scintillator a part of the energy loss is converted into a number of isotropically emitted photons, typically in the optical wavelength range.

Via an appropriate optical lens system, the photons are transported to a digital camera and output the beam profile in pixel space. Applying a calibration factor (to convert pixel separation into coordinate space), the physical size of the beam spot can be determined, and hence an image of the real beam distribution. The image calibration depends on the specific optical system. Reference marks on the screen holder allow an in-situ calibration.

4.1.3. Measurement Challenges

Scintillating material

The light output of a scintillator depends on several parameters such as the specific energy loss or the particle flux (number of particles per unit area). Material ageing, quenching effects and damage mechanisms differ between scintillator types. Due to the the variety of beam types and intensities at the FAIR facility, different scintillating materials are required for the HEBT setups, depending on the location. A careful choice has to be made according to signal estimates derived from simulated beam spot sizes, beam parameters and detector design parameters.

Optics: Depth of field

For typical sizes of HEBT screens about 100 – 120 mm in diameter, the scintillating screens are mounted in an angle of 45° with respect to the beam axis and the camera, as shown in Figure 1. Here, the path length from the screen to the camera differs, depending on the impact position of the particle on the screen. This setup demands for a large depth of field.

Optics
Spectral matching of the scintillator emission spectrum, the transmission through the glass flange and the optical lens system, and the quantum efficiency of the digital camera is very important in order to avoid unnecessary signal losses.

Radiation damage to cameras
In some areas around the beam lines stray radiation, created by injection or extraction processes or by unwanted particle losses, may be a critical design factor. Cameras have to be chosen carefully in respect to radiation hardness and tested.

Dynamic range of the optical system
Due to the wide range of ions and particle numbers, attended by a huge variation in light output of the scintillating screen, the camera and the lens system have to cover a large dynamic range.

Camera timing
The spill lengths of a particle beam extracted from the FAIR synchrotron can differ from 25 ns during fast extraction up to about a few seconds during slow extraction. The digital camera used for screen observation must be adjustable over a large range of integration times. For long integration times, the intrinsic camera noise may limit the system sensitivity. The shortest integration time is in principle defined by the decay time τ of the excited states in the scintillator; in practice this may be the minimum integration time of the camera.

4.2. Foreseen Component Setup

In order to comply with the measurement task as described in the previous sections, GSI Beam Instrumentation Department defines the technical solution for installations at FAIR as described in the following sections.

The diagnostic component as specified in the present document is the product of previous R&D work within GSI BI department. It is important to note that minor changes of the parameters given here might become necessary during the course of project realization. Any contributor shall account for the fact that limited alterations of the technical realization as described here will be communicated by GSI BI department (see section 3) as soon as the modification is approved by GSI and agreed upon by the responsible persons at FAIR.

The intent of the present specification is to give a coherent overview of the present planning for the BD component, which was already exemplarily build and operated as a prototype (see section 5.6. and 6.5). Technical aspects and parameters, e.g. in sections 4.3 or 12, which are partly still under discussion are clearly marked as being preliminary throughout the document.

Important topics of research activities have been:

- Investigation of various scintillator properties with high energy ion beams
- Definition of the necessary active area of the screens at all installation locations through ion optical simulations
- Compilation of the expected dynamic range of energy loss (and hence light output) to optimise the choice of scintillator (type and thickness)

- Radiation hardness of digital camera and system components
- Dose simulations at installation locations (transfer tunnels or synchrotron areas) to investigate possible radiation shielding for the experimental setups
- Tests with a radiation-hard camera to achieve a reasonable operating live-time

The results of this research strongly influenced the proposed setup.

4.2.1. System Schematic

Figure 2 illustrates a general scheme of the demanded scintillating screen setup for optical beam profile measurements. The scintillator is mounted inside the vacuum chamber on a target holder, driven by a linear actuator (mechanical drive) to be moved in and out of the beam path. A digital camera with an appropriate lens system observes the screen through a viewport. The light intensity at the camera can be regulated by the remote-controlled iris of the lens system. A Siemens PLC [20] with a slow control unit for iris control, LED power control and drive control is typically not installed in the direct vicinity of the beam line, rather in a radiation save area. The required analogue voltage control signals can be supplied by standard industry solutions over long distances. For calibration purposes, a remote-controlled Light Emitting Diode (LED), integrated into the vacuum flange, provides an independent screen illumination to calibrate the camera image in-situ via reference marks on the target holder of the screen. The digital camera has to be equipped with an external trigger-input to start the image acquisition on demand. The image data is transferred to the DAQ System, analysed and displayed in a User GUI for operation. Typical derived quantities are beam position and beam width. An interface to control the camera I/O (e.g. integration window) and a remote-reset option for the camera power are required.

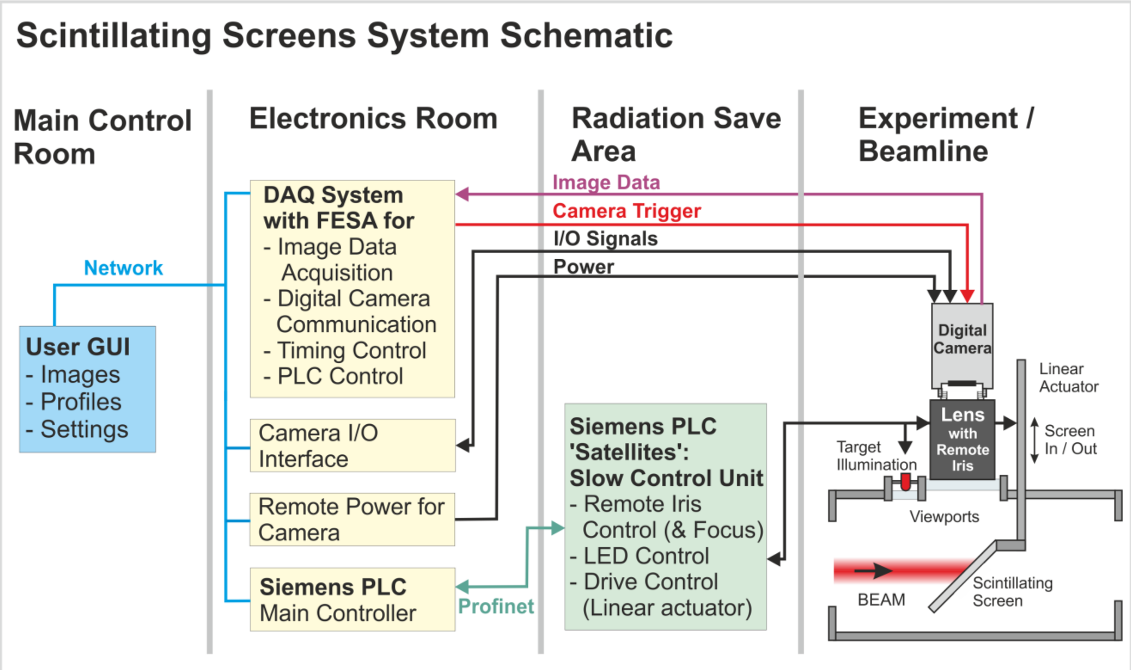

Figure 2: Scheme of a Scintillating Screen Setup.

4.2.2. Constituents of the BD Component

The BD component ‘Scintillating Screen’ consists of the parts assigned in the schematic drawings in Figure 1 and Figure 2:

- Scintillating screen mounted on a target holder, driven by a linear actuator. The target holder must have permanent alignment marks outside the active material area.
- Linear actuator (mechanical drive) to move the target holder and screen in and out of the beam
- Vacuum chamber to house and mount all the required components
- Viewports with appropriate spectral transmission and optical quality
- Lens system with remote-controlled iris (remote focus optional) and an appropriate fixed focal length to match the reproduction scale of the setup
- Digital camera system with external trigger, adjustable parameters (gain, integration times, etc.) and appropriate interface for image data (e.g. Gigabit Ethernet)
- Remote-reset camera power supply
- Optical shielding for the camera-system to avoid incidence of ambient light
- LED for target illumination, used for calibration issues
- Electronics and DAQ according to requirements of the BI department

4.3. Basic Component Parameters

Number of elements		**31 (16 in FAIR module 0-3)**
Installation details		
Overall length of chamber	mm	460 - 790 *
Horizontal aperture	mm	150
Vertical aperture	mm	150
Scintillator		
Scintillating material		Al_2O_3:Cr (Chromox) as the standard P43 or YAG:Ce for low light applications **
Active area (typical)	mm^2	Ø 100 mm / Ø 120 mm
Spatial resolution of the optical system (typical)	mm	0.4
Camera requirements		
Type		CMOS digital camera, monochrome as the standard. CID video cameras (monochrome) for special installations, where high radiation hardness is necessary **.
Data interface		Gigabit Ethernet for the standard (CMOS) cameras. For special radiation hard cameras (CID), other interfaces have to be discussed**.
Chip size	inch	min. ½''
Chip resolution	pixel	min. 640 x 480 (VGA)
Refresh rate	fps	min. 30
Dynamic range (ADC)		min. 8 bit, preferred 10 bit
Gain (ADC)		min. 0 - 12 dB
Integration time		min. 10 µs – 2 sec
Sensor latency		max. 40 µs
Camera features		external trigger input, gain control, global shutter (CMOS), integration enable output signal
Requested properties		low noise, high sensitivity, definable region of interest (ROI) & binning, preferably good radiation hardness
Lens system requirements		
Lens type		Fixed focal length, VIS wavelength range
Relative lens aperture (f-number)		min. 1:1,8 (for f= 16 mm / 25 mm)
Lens features		Remote controllable iris (stepper motor with encoder or voltage defined aperture setting), optional remote controllable focus
Requested properties		low distortion and good optical quality

*Length of diagnostic chamber depends on number of BD components in chamber at defined position.
** In written agreement with the GSI beam instrumentation department

Table 1: Basic component parameters for HEBT

4.4. Installation Locations and Special Requirements

The present document covers the parameters for the BD component Scintillating Screens foreseen for installation in the FAIR section HEBT.

The technical parameters for the given HEBT locations differ in:

- Special solution due to beam line bake-out required at following positions: T1X1 and T3C1,
- In the following positions high radiation levels due to beam losses are expected: T1X1, T8DU, T1D1 and T3D1. This requires appropriate protection of the camera system or/ and radiation hard cameras.

5. Mechanical Setup

5.1. Overview

Scintillating screens are a direct, but intercepting, method to observe transverse beam profiles. A measurement can hardly be more intuitive than to see a beam spot right in the centre of a scintillating screen. One typical realization is schematically shown in Figure 1. The scintillating screen is inserted into the beam under an angle of 45°. Through a viewport, located at 90° with respect to the beam, a camera observes the screen.

The drawing of the Scintillating Screen setup on a flange with a target under 45° in respect to the beam is shown in Figure 3.

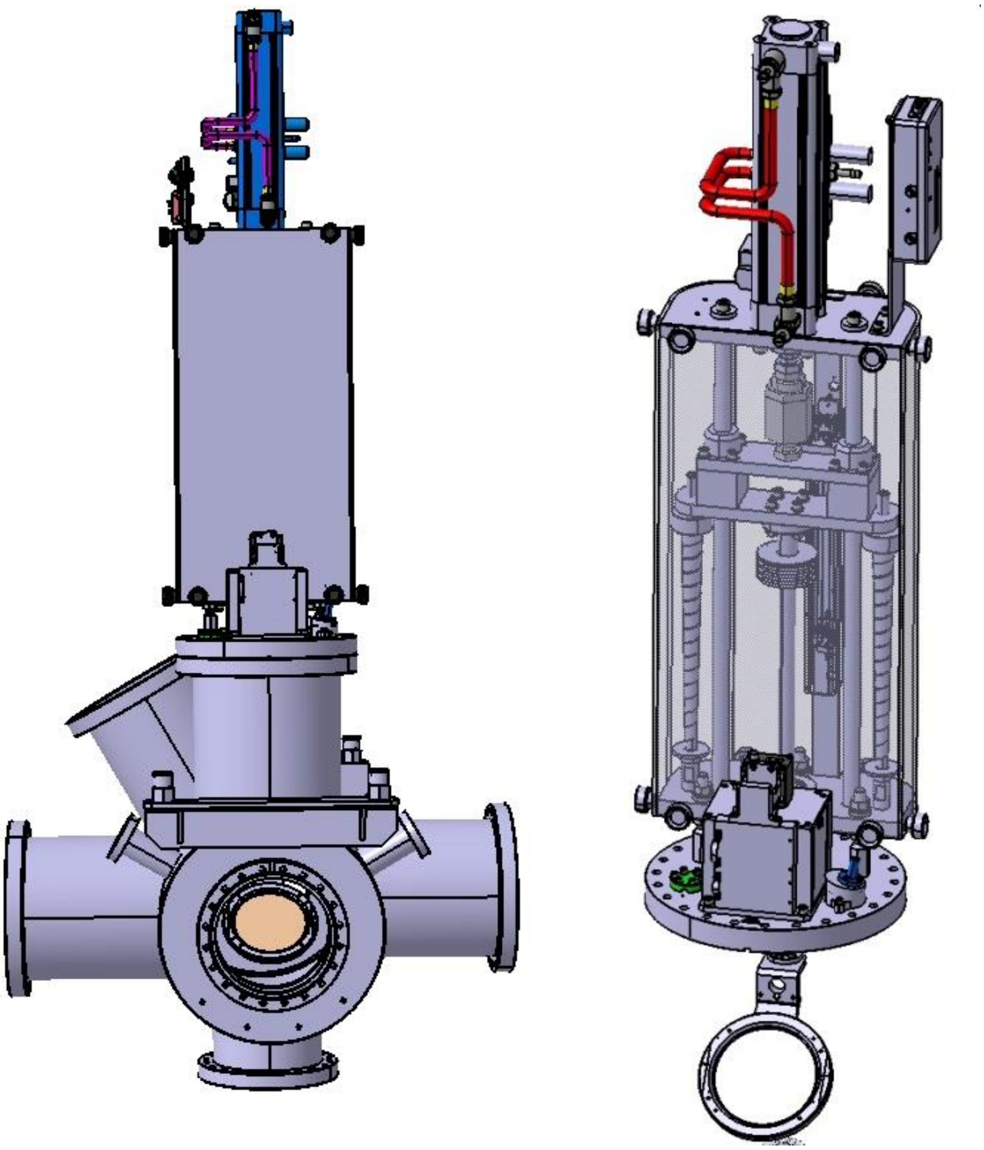

Figure 3: 3D model for prototypes of vacuum chamber and mechanics for HEBT scintillating screens.

5.1.1. Mechanic Constituents of the BD Component

The mechanical constituents of one Scintillating Screen Setup (Figure 3) are the following parts:

- Detector consisting of scintillating screen and target holder.
- Pneumatic driven linear actuator, see [21].
- Diagnostic chamber for installation of linear actuators, see [23].
- Additional parts for detector installation on linear actuator.

The standard scintillating screen setup has to comply with the technical guidelines [100], [105], [106], [107], [108], [109], [110], [111], [112], [113] and [114].

For installations where bake-out is required, the following technical guidelines [101], [102], [103] and [104] have to be applied in addition.

Detector

The detector consists of the scintillating screen (target) and the target holder. The scintillating screen is a round disk of scintillating material (solid or coated material), fixed in a holder with permanent alignment marks outside the active area.

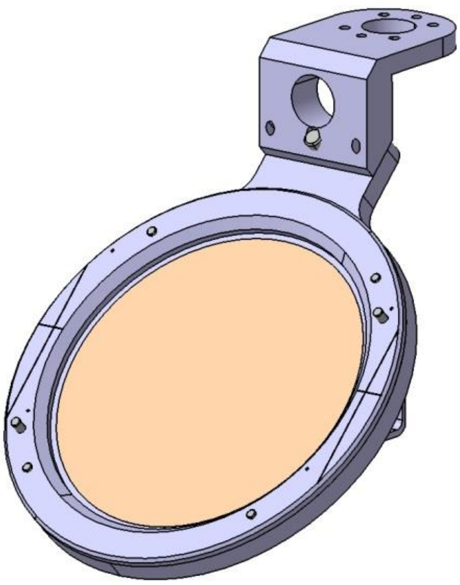

Figure 4: Scintillating screen on target holder

Material	**Type**	**Application**
Al2O3:Cr (Chromox)	Solid target material	Standard light applications
Gd_2O_2S:Tb (P43)	Coated on a plate	Low light applications
YAG:Ce	Solid target material	Low light applications

Table 2: Scintillating Screen Material

In the HEBT lines, two different detector sizes are used with an active area of Ø 100 mm and Ø 120 mm, respectively.

Type number: Detector	Detector size (active area)	Bake-out	Drawing number
FT-DF 2010	D100	No	BD-1018552-A-000
FT-DF 2011	D100	Yes	BD-1018926-A-000
FT-DF 2020	D120	No	BD-1017884-A-000
FT-DF 2021	D120	Yes	BD-1018471-A-000

Table 3: Drawings of Detectors

Pneumatic Driven Linear Actuator

The linear actuator moves the detector (scintillating screen and holder) into the beam center and out of the beam, see [21]. The four different detectors listed in Table 3 correspond to four different linear actuators in Table 4.

Type number: Detector	Distance Flange-Beam center [mm]	Stroke [mm]	Bake-out	Type number: Linear actuator	Drawing number
FT-DF 2010	270	150	No	FT-DL 2210	BD-1018821-A-000
FT-DF 2011	270	150	Yes	FT-DL 2220	BD-1018881-A-000
FT-DF 2020	370	200	No	FT-DL 2230	BD-1014852-A-000
FT-DF 2021	370	200	Yes	FT-DL 2240	BD-1018450-A-000

Table 4: Drawings of Linear Actuators

Diagnostic Chamber

In the HEBT, different types (different sizes, bake-out or no bake-out) of diagnostic chambers are used; see Detailed Specification [23].

Additional Parts / Assembly

Additional parts for the beam diagnostic assembly and setup are

- Viewports for Camera and LED
- Holder for camera and lens system
- Holder for LED (target illumination)
- Optical shielding for the camera-system and LED
- Fixing options for connector box or cables

The following drawings show the parts and material to assemble the detector on the linear actuator.

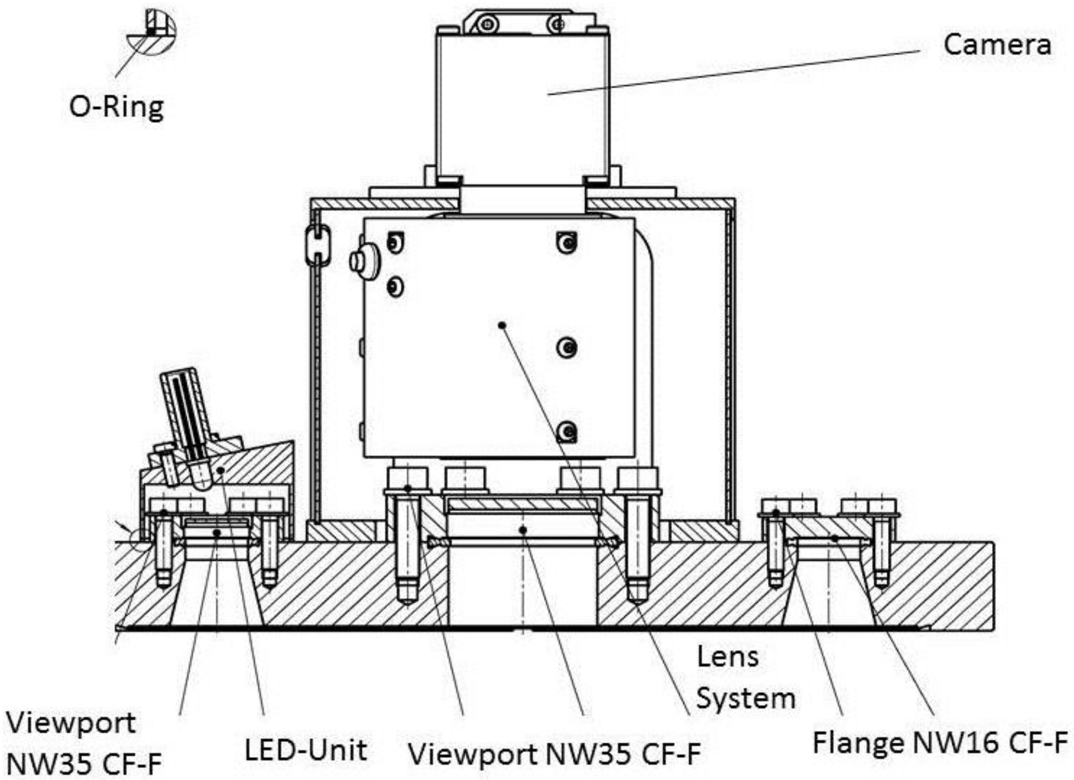

Figure 5: Assembly of additional parts of the scintillating screen setup

Type number: Detector	**Type number: Linear actuator**	**Type number: Additional parts of the detector**	**Drawing number**
FT-DF 2010	FT-DL 2210	FT-DZ 2211	BD-1018825-A-000
FT-DF 2011	FT-DL 2220	FT-DZ 2221	BD-1018966-A-000
FT-DF 2020	FT-DL 2230	FT-DZ 2231	BD-1015663-A-000
FT-DF 2021	FT-DL 2240	FT-DZ 2241	BD-1018484-A-000

Table 5: Drawings of additional parts of detector assembly

5.2. Vacuum Parts

The components installed in the vacuum are

- Diagnostic chamber
- The scintillating screen material and its support structure (target holder)
- Linear actuator
- Viewports (for camera and LED).

These components have to fulfil the following requirements

Working pressure	down to 10^{-9} mbar
Ultimate pressure	lower than 1 x 10^{-8} mbar 24h after start of pump down
Working temperature	15°C ≤ T ≤ 50°C

Integral leak rate	< 1 x 10^{-10} mbar·l/s
Residual gas composition	sum of detected hydrocarbon partial pressures (masses >36 u) smaller 1% of total pressure
Surface related outgassing rate	max. 5 x 10^{-10} mbar·l/s·cm^2

Table 6: Vacuum Parts Requirements

At special locations, e.g. at SIS100 injection and extraction, all vacuum parts must be suited for bake-out up to 300°C. Here, the assembly of the viewports requires silver coated, soft-annealed copper gaskets.

5.3. Non-Vacuum Parts and Supports

The non-vacuum parts and support constituents of one Scintillating Screen installation are the following:

- Holder for camera and lens system
- Holder for LED
- Optical shielding for the camera-system
- Fixing options for connector box or cables

5.4. Optical Setup

The optical constituents of one Scintillating Screen are the following parts:

- Screen material (defines the wavelength range of the detected signal)
- Viewports of sufficient optical quality
- Lens system with remote-controlled iris
- Digital camera system with external trigger and adjustable integration times
- Optical shielding for the camera-system to avoid incidence of ambient light

5.5. Mechanical and Optical Alignment

A fine alignment using a theodolite will guarantee the screen to be adjusted centred to the diagnostic chamber, as well as tilted by 45 degrees, as depicted in Figure 1.

The diagnostic chamber has to be aligned to beam axes defined by the centers of entrance and exit flanges of the chamber.

The camera with the lens system can be focussed, aligned and calibrated using the permanent alignment marks on the target holder. The required reproduction scale can be derived from geometric optics formulas.

5.6. Exemplary Realization at GSI

Prototypes of the FAIR vacuum chamber including a scintillating screen setup were installed in different locations of GSI high energy beam transport lines (HEBT).

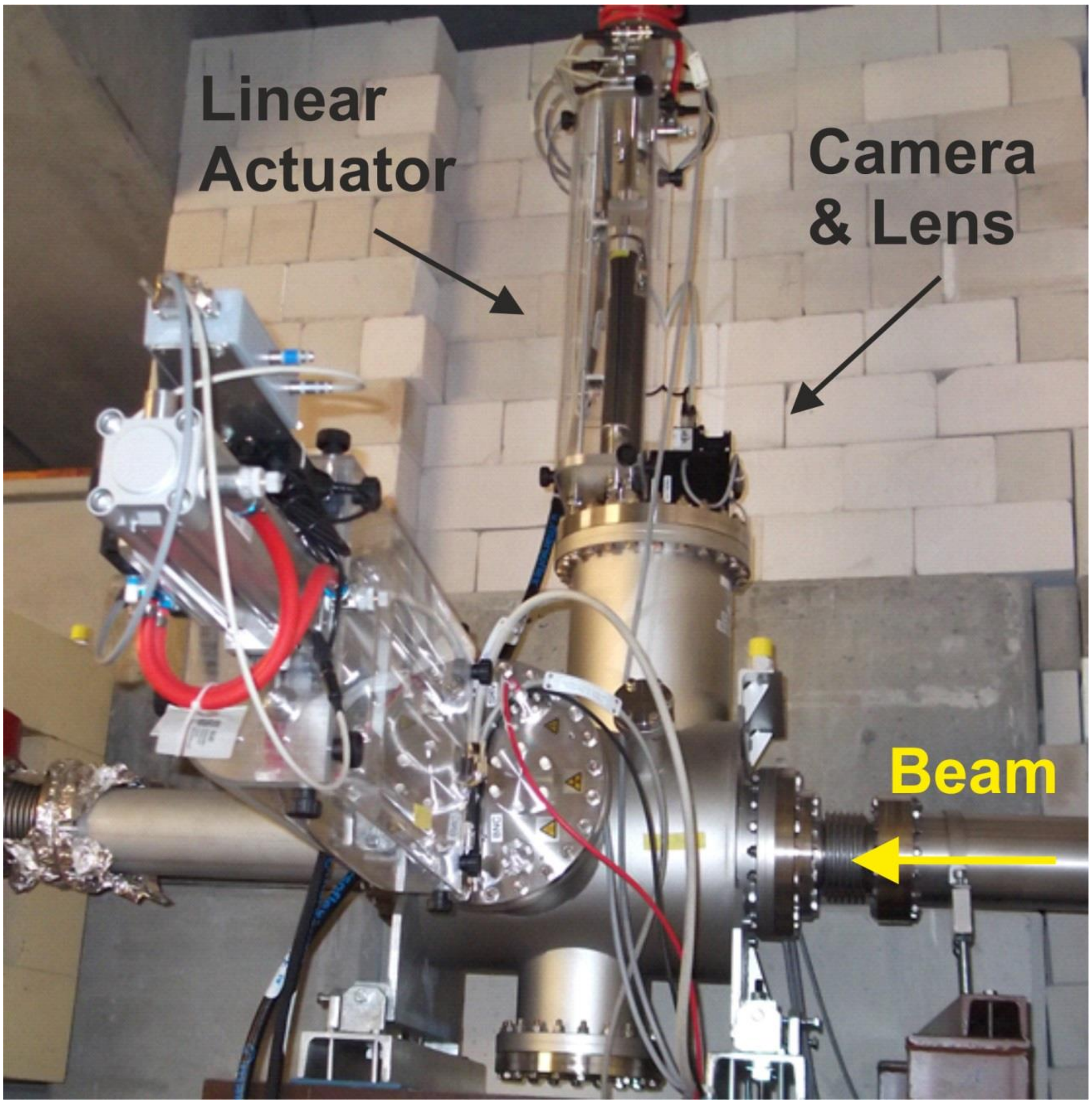

Figure 6: Scintillation screen installation in a GSI HEBT line

As the scintillating materials, a P43 target (ProxiVision) and a Chromox (BCE Ceramics) target were tested with different ion beams and intensities. To observe the signal, a CMOS camera (IDS µEye UI-5240SE-M [300]) and a remote controlled lens system (Linos / Qioptiq MeVis-Cm 1.6/16 [303]) were used. The mechanics to hold the screen, the camera and the LED are built according to the drawings given in chapter 5.1.1.

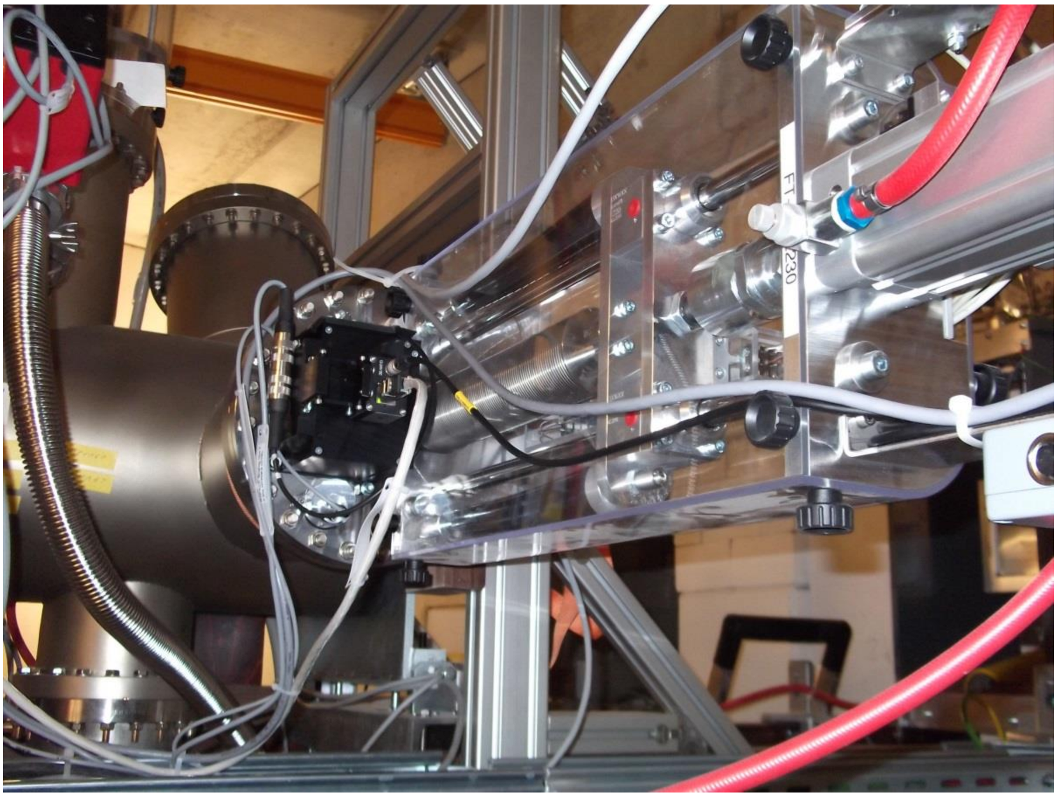

Figure 7: Linear actuator with scintillation screen and camera installations

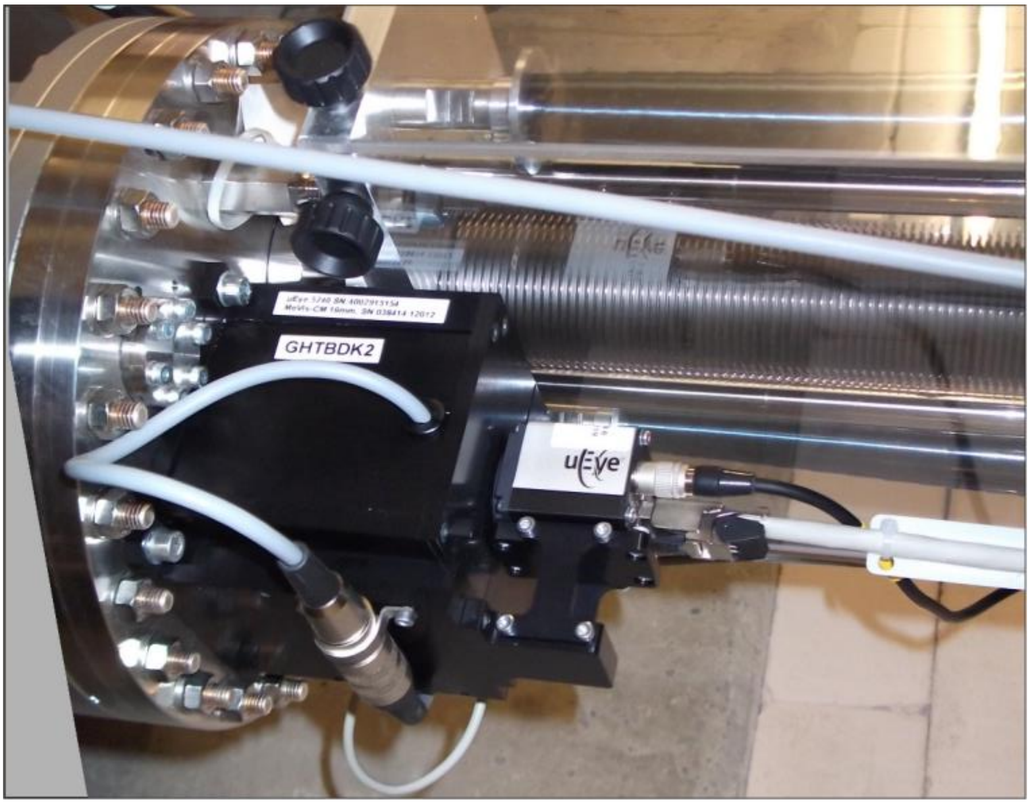

Figure 8: Linear actuator with mounted camera, lens system and optical shielding

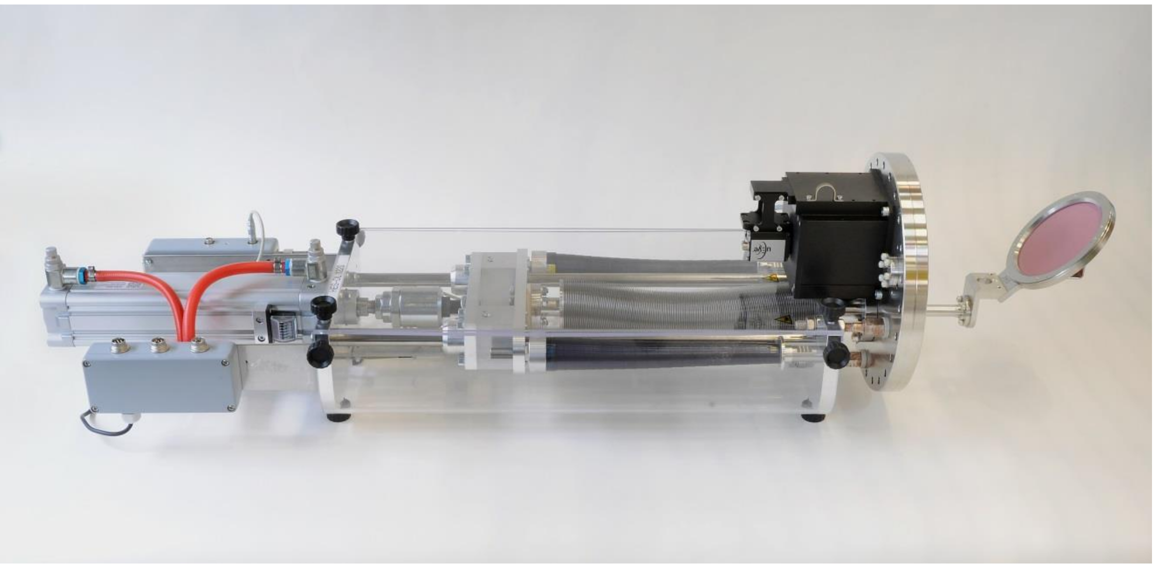

Figure 9: Linear actuator with camera setup and Chromox screen

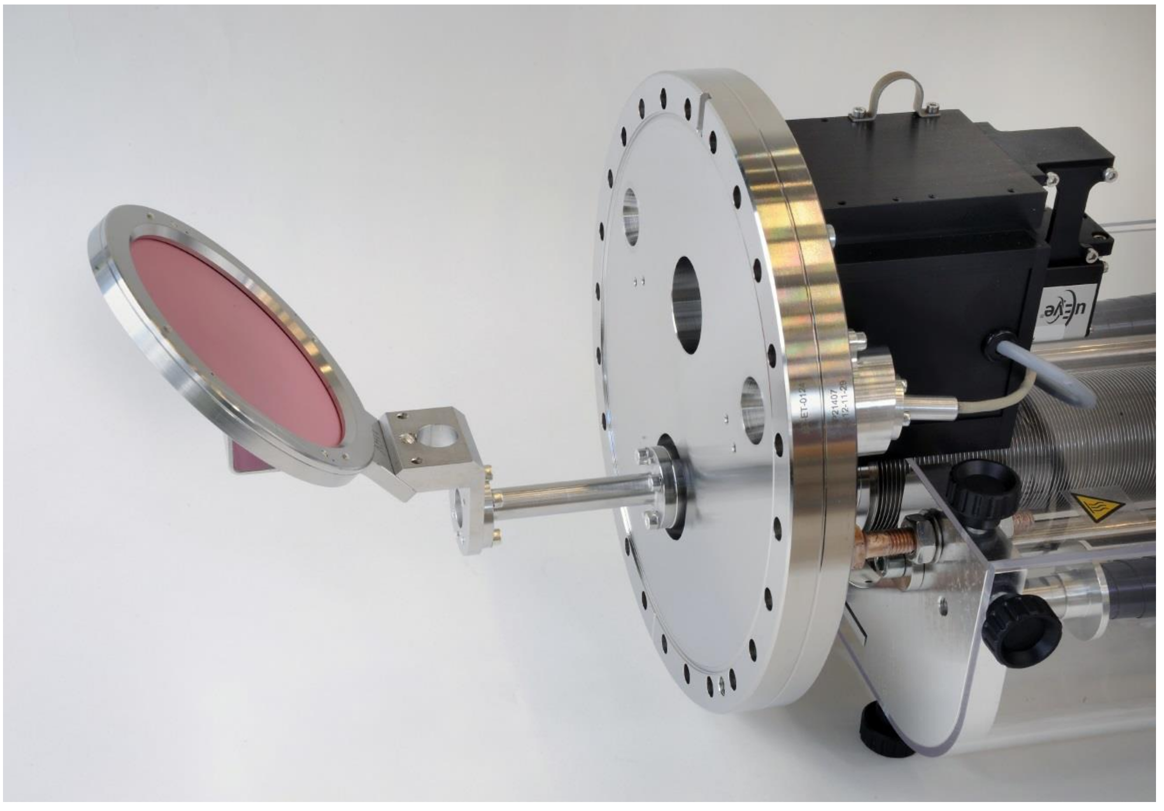

Figure 10: Camera setup and Chromox screen

6. Electronics and Data Acquisition

6.1. Overview

As shown in the system schematic in Figure 2, the electronic constituents of one scintillating screen setup are positioned in different areas. During beam operation and a certain time after, there is no access to the experimental area due to radiation. Therefore, all devices near the beam line have to be remote controllable and preferably radiation hard. Between the experiment and the radiation safe area or the electronics room, long cable distances have to be considered.

6.1.1. Electronic Constituents of the BD Component

The electronic constituent of one Scintillating Screen consists of the following parts:

Digital camera	• CMOS type as the standard • CID for special installations with high radiation levels • FESA compliant camera interface and controls protocol (GigE interface as the standard, others to be discussed with GSI BI department) • External trigger interface ➢ Further camera requirements see chapter 12
Camera I/O interface	• To send and receive I/O signals to / from the digital camera, (e.g. external camera trigger, camera integration window)
DAQ system	• Industrial PC (will be specified in DAQ detailed specification [20])
Timing	• FAIR-timing compliant timing interface • Independent selectable trigger for each camera, use of splitters to be discussed in written agreement with the GSI beam instrumentation department ➢ Further information is given in chapter 7
Slow controls	The Siemens PLC slow control system comprises of a PLC main control unit and PLC satellites. • PLC for slow control of the iris (& optional of the focus) and to power the target illumination for calibration issues. • PLC to control the linear actuator [24]
Camera Remote Power	• Remote-reset opportunity for the camera power supply

Table 7: Summary of electronics

6.2. Beam line Electronics

For all the components installed in the beam line a radiation tolerant design or an effective shielding has to be considered. Whenever it is possible, sensitive electronics has to be moved into the electronic rooms and will be connected via signal and supply cables. However, some of the components have to be installed in the beam line:

- The digital camera with network based interface (e.g. GigE)

6.3. Parts in Electronic Rooms

Installations in a radiation-safe area (medium distance to the beam line) are:
- Slow control unit (PLC satellite) to control the iris, the LED and the linear actuator

Installations in an electronic room (possibly long distance to the beam line) are:
- DAQ system with image acquisition module
- Camera I/O interface and appropriate hardware for timing monitoring
- Remote power opportunities for all devices at the beam line, especially the camera power (hardware reset possibility)
- Timing interface

6.4. Cabling

Cables and numbers stated here are indicative and depend on the chosen hardware realisation. As the case may be, single connections can be combined in multicore cables. Final and exact cable lengths have to be specified.

Number of cables per system	**Type**	**Purpose**
Cables between the radiation safe area and the beam line		
3	Multicore cable	From PLC satellites to beam line devices for slow control of iris (& focus), LED power, linear actuator
Cables between the electronics room and the beam line		
1	Data transfer cable	Image data and camera control (depending on the type and interface of the camera)
1	Power cable	Camera Remote Power
1	Trigger cable	Camera trigger
1	Multicore cable	Camera I/O signals
Cables between the electronics room and the radiation-safe area		
1	Profinet	Connection Siemens PLC main unit and satellites

Table 8: Short summary of cabling

6.5. Exemplary Realization at GSI

At GSI, a complete prototype system for scintillating screens was developed and installed in several positions of the HEBT line behind SIS18. The mechanics of the prototype is described in section 5.6.

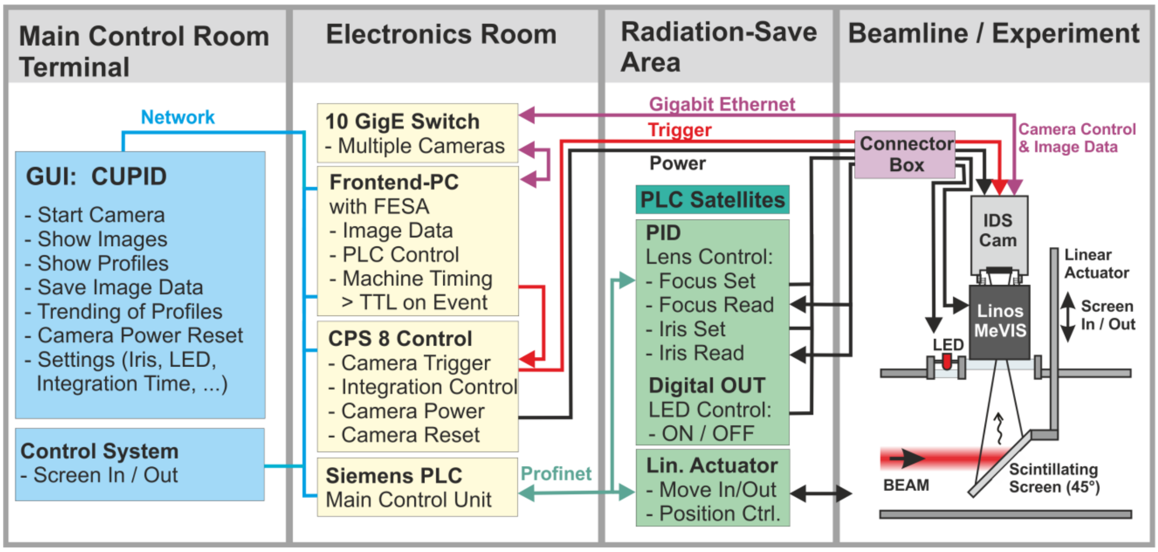

Figure 11: Communication scheme of GSI prototype installations

Camera (standard applications)	IDS µEye UI-5240SE-M [300] With radiation tested e2v CMOS sensor Sapphire EV76C560 (monochrome) [301] and GigE interface
Radiation hard camera	Thermo Scientific MegaRad3 (8726DX7) CID (Charge Injection Device) camera [302] Video camera, monochrome
Lens system	Linos / Qioptiq MeVis-Cm 1.6/16 [303] Motorized iris and focus with position feedback, 16 mm fixed focal length
DAQ system	• Industrial PC (Frontend-PC) • GigE switch for image data & camera control of the digital camera • Frame grabber card for the radiation hard video camera • Timing interface (here: 'CERN-type')
CPS8 Control	GSI in-house developed Camera Power Supply Controller (for up to 8 cameras) • Control of the camera I/O's (send camera trigger, read integration window) • Camera power reset for the camera
Siemens PLC	• PLC main control unit • PLC satellite for slow control of the lens system (iris & focus) and the calibration LED. • PLC for linear actuator control and position inspection
Connector box	GSI custom development to patch multiple cables

Table 9: Electronic devices of the GSI prototype system

Camera Control, Data Acquisition and GUI

CUPID (Control Unit for Profile and Image Data) [304] is a new system for scintillating screen imaging, which is based on the data acquisition framework for FAIR. It includes digital image acquisition, remote control of the optical system (focus and iris; camera setup and power), control of the linear actuator (pneumatic drive) and a graphical user interface (GUI). With the exception of the pneumatic drives, the direct hardware access is based on FESA, the CERN Front-End Software Architecture [20][116].

Image acquisition, lens control and camera power are implemented as different FESA classes. Because CUPID is designed to work with different imaging hardware like GigE cameras or video cameras using frame grabber cards, a dedicated image acquisition FESA class is written for each imaging system supported. Using the inheritance mechanism in FESA a new imaging device can be easily incorporated in the system. The imaging base class contains all common code, like image manipulation (rotation, mirroring) and computations (profiles, intensity histogram, moments of the intensity distribution). It also provides the code to save raw images to disk (local or via network) as standard bitmap files. In addition, it enforces the common interface between the imaging FESA class and the CUPID GUI. The derived FESA class for the specific imaging device only implements the specific code to set up the device and acquire the images.

The standard camera installed is the IDS uEye UI-5240SEM, which is a digital GigE camera equipped with the radiation tested e2v CMOS sensor with 1280 by 1024 pixel. A camera internal area-of-interest limits the image to the size of the scintillating screen and reduces the amount of data transferred already in the camera. Grouped according to their location, the cameras are connected via a HP Procurve 10 Gigabit Ethernet switch to a Kontron PCI 761 Industrial PC. The PC is equipped with an additional 10 Gigabit network adapter to provide a private network for the camera readout. The PC also runs the FESA classes and provides the link via the accelerator network to the GUI. The performance of the system reached more than 15 frames per second at full resolution with one active camera and a single connected client. Power supply and remote reset for up to eight digital cameras are realized by the in-house developed Camera Power Supply controller CPS8. The CPS8 is based on an Arduino single-board microcontroller and controlled via Ethernet. By sending simple ASCII commands the controlling FESA class sets the power of any attached camera. It can also obtain the power status of each connected camera. In addition, the CPS8 distributes hardware triggers to the cameras either from an external input or self-generated. The standard installation for CUPID uses a Linos MeVis-Cm lens with 16 mm focal length, motorized iris and lens control with potentiometers to read back actual positions. A Siemens PLC (main unit and satellites) handles control of focus and iris motors, read and set by a PID controller (FM355C). In addition, digital outputs (SM322) of the PLC control the LED to illuminate the target for calibration issues. A dedicated FESA class using the CERN IEPLC [305] library provides access to the PLC from the CUPID GUI. Conforming to FAIR requirements, the GUI is written in Java. It displays the acquired image (corrected for camera orientation), the profiles, the intensity histogram as well as integral data like total brightness, center of intensity in the reference coordinate system and full-width-half maximum of the profiles. The GUI is also responsible for the conversion of pixels into millimeters. The corresponding conversion factors are stored with the FESA class and sent to the GUI with each profile or image. Because the scintillating screen is tilted 45° with respect to the camera's optical axis, the image suffers from perspective distortion. The GUI provides the possibility to overlay a grid with 5 mm line spacing over the image. In addition, the coordinates of any pixel under the mouse cursor are displayed not only in pixels but also in mm. For basic operation the camera controls are reduced to changing the opening of the iris and switching on or off the illuminating LED. An expert mode provides more detailed control like changing the exposure time, the binning of the image or requesting the raw images to be automatically saved to disk by the FESA class. It also allows changing the acquisition mode. The CUPID system provides three acquisition modes, which may either be realized in hardware or in software by the FESA class. The two most important ones are 'free run' and 'triggered'. In 'free run' the camera continuously acquires images with the specified exposure time and frame rate. The acquired images are displayed in the GUI as they arrive in real time. In the 'triggered' mode, the image acquisition is triggered by a machine event of the accelerator (for example at beam extraction). At the time of the trigger, a single image is acquired by the FESA class and displayed by the GUI. An extension of the 'triggered' mode is the 'sequence' mode, which acquires a predefined number of images with the specified frame rate after a trigger is received.

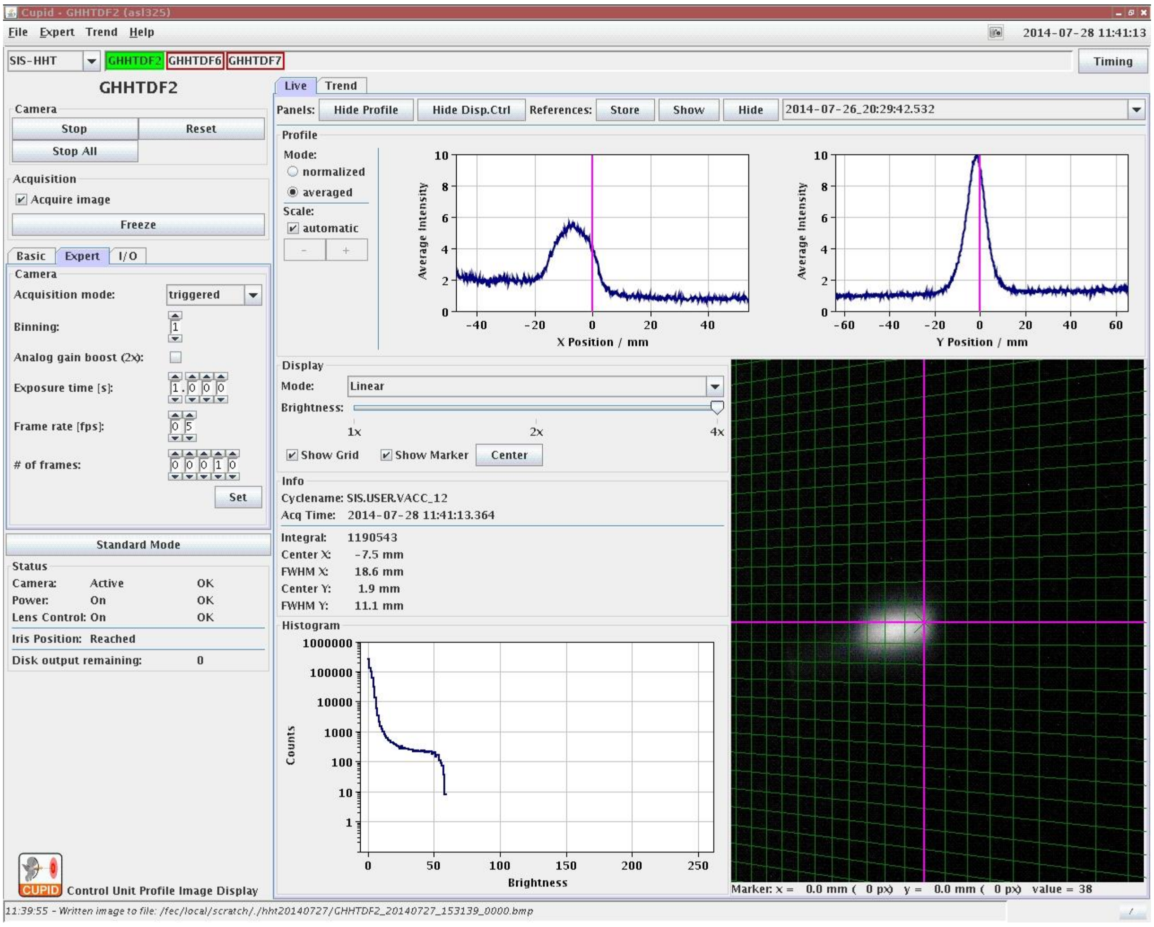

Figure 12: CUPID GUI

Near SIS18 extraction, where a high radiation level is observed, a radiation-hardened solid-state CID (Charge Injection Device) based camera from Thermo Fischer Scientific, the CCIR MegaRad3 (8726DX7), was installed. According to the manufacturer [302] this device is tolerant to gammas, neutrons, high energy electrons and proton radiation to at least 3 MRad. Only in tests up to 14 MRad a noticeable degradation in the image quality has been reported by the manufacturer. Tests at GSI SIS18 extraction with the MegaRad3 camera have shown, that within 15 months of operation and accumulated doses of 130 Sv neutrons and 82 Sv gammas, no significant change in camera performance was observed [306].

Currently, a FESA class is under development to acquire images from a frame grabber card to be used with the radiation hardened camera.

7. Timing Requirements

All DAQ systems requiring machine timing or related trigger and gate functionalities must use the FAIR timing system based on the White Rabbit protocol [26]. Timing receiver hardware [27] will be available in following form factors:

- AMC (e.g. µTCA)
- PCIe
- VME
- PMC
- Stand-alone system

The trigger functionality of the camera must be able to cope with fast extracted beams of 25 ns or slow extracted beams of several seconds duration. Camera integration times of 10 µs up to 2 seconds have to be covered.

Timing	
Start Trigger	External triggers for a camera (for beam pulse and background)
Stop Trigger	External acquisition stop
Other	Selectable trigger FESA controlled

Table 10: Short summary of timing

8. Data Acquisition Software

8.1. General Requirements

Beam diagnostic data acquisition software must be based on the CERN-built FESA system including the GSI-specific extensions. The FESA version to be used must be the latest actual version released at GSI. For details of the FESA system see Detailed Specification for Data Acquisition [20].
So-called FESA classes interact directly with the hardware, handle hardware settings and publish acquired data to remote clients (i.e. graphical user interfaces) via a defined interface. The interface must comply with the 'Guideline for designing FESA equipment software at the GSI and the FAIR facility' [116] and the 'Guideline for Connecting new Equipment to the Accelerator Control System' [117]. This guideline details the naming conventions and interface parts (like Status, Setting and Acquisition properties) which are mandatory for FESA software to be used in the accelerator control system. Furthermore GSI FESA template classes have to be used as base for the class development. They are provided to ensure seamless integration of the FESA class into the control system.
The concepts for FESA based DAQ systems shall be discussed and agreed on with GSI experts before the main programming work has started. In addition a code review before final integration into the Accelerator Control System (ACS) is foreseen. An iterative development style based on frequent feedback and demonstration of the present status of work is mandatory.

The following list gives a broad but not necessarily exhaustive overview over the general requirements of a FESA class (the final version 'Guideline for designing FESA equipment software at the GSI and the FAIR facility' which specifies the binding requirements).

- Property data has to be as far as possible self-contained, which means it has to contain all information needed to use the data for different purposes including
  - Displaying
  - Archiving
  - Correlation

  without access to other data-sources e.g. databases, FESA classes, etc.
- Property data has to represent values in SI units if applicable (i.e. Ampere, Volt, Particles/sec, etc.). The physical unit has to be sent with the data.
- Acquisition data must contain information on the timing context (cycle stamp (timestamp of cycle start), cycle name, acquisition time) at which it was acquired.
- Measurement values have to contain information about their quality. An alarm when leaving a tolerance band must be raised.
- Supervision of the device status must be supported
- FESA classes must provide all functionality to integrate with other parts of the control system like
  - Alarm system

  - Post-mortem system
  - Data archiving and logging

If applicable, FESA classes for beam diagnostics must also provide functionality for

- Equipment self-test and calibration
  Logging and archiving for offline analysis of all data (in general to disk) on demand either manual or triggered by ACS independent on the above mentioned archiving and logging system of the ACS

Software	
Driver Level	Linux drivers for chosen camera type
Front End Level	Linux, Front End FESA
Manual Control	FESA Navigator
Data Structure	compliant to FESA
Control System Interface	Front End: Linux with RT Patch and Intel CPUs with according FESA class

Table 11: Short summary of software

8.2. General Functionality

The main purpose of the scintillating screen system is the measurement of transverse beam distributions and their statistical moments.

8.3. Operational Modes

Different trigger modes have to be implemented in the software to allow for commissioning and maintenance, as well as standard operation:

- Manual trigger mode: acquisition is started/stopped by software command
- ACS trigger mode: acquisition is started/stopped by the timing system

The data acquisition software shall provide the following acquisition modes:

- Single shot (one start, possibly one stop trigger)
- Cyclic mode (repetitive start with start/stop trigger)
- Free-running mode

The following operational modes are required:

- Online data (raw data, horizontal and vertical profiles)
- Trending (position and statistical moments vs. time)
- Alarm/Interlock (alarm generation when crossing tolerance band)

Operating mode	Description
Single image	Acquisition of a single image (with/ without external trigger)
Image sequence (Automatic)	Acquisition of one or more images by the camera with the configured image rate
Image sequence (Trigger)	Acquisition of one or more images by the camera via external trigger
Calibration	Verification of calibration factors (mm/pixel) and origin of coordinate system through acquisition of a calibration image that includes the reference marks on the actuator

Table 12: Typical operating modes of the optical beam profile system

8.4. Required I/O settings

To control the measurement the following I/O-channels have to be provided:

- Set all hardware parameters (camera gain, camera integration time, iris aperture, etc.)
- Provide camera output signal ‘integration enable’ for timing control
- Set to self-test or calibration

8.5. Required Beam Information

In order to provide the required functionality the following beam parameters have to be supplied to the DAQ system via timing system, LSA [25] or databases (not on front-end level):

- Ion charge state
- Ion species, defined by atomic number Z and atomic mass A
- Ion energy in units of MeV/u
- Nominal particle number
- Information about slow or fast extraction mode and nominal duration of extraction (spill duration)

8.6. Online Display and Control

In general the software shall supply the complete set of information about the measurement device to the client application.
The basic requirements for the online display and control are:

- Plot of actual and background corrected profiles an positions at min. 5 Hz repetition rate
- Display of original data (raw image)
- Display of the complete device status
- Display of alarm when leaving tolerance band
- Setting of self-test / calibration mode
- Setting of values for tolerance band
- Switching of operational modes
- Start/stop saving data (raw image and profiles)

8.7. Data for Logging and Offline Analysis and Archiving

For logging and offline analysis the following functions are required:

- Generation of data files on demand (manual/automated by ACS)
- Further definition of file format
- Generation of log-files (controlled by ACS)
- Post-mortem functionality (set and triggered by ACS)

8.8. Special Issues and boundary Conditions

Some additional features have to be implemented in the data acquisition software:

- The ACS has to supply the predicted beam intensity (for automated camera and lens parameters).

9. Related Subsystems

This detailed specification contains two subsystems that are already specified in separate detailed specifications and are listed in this document just for the sake of completeness.

9.1. Pneumatic Drive

For standard scintillating screens as discussed in Chapter 6.3, the linear actuator with two positions (In / Out) shall be realized in a reliable design, using a pneumatic drive which is specified as a subsystem [21], [24].

9.2. Optical Iris Control

A lens system with remote-controlled iris is required in order to adjust the amount of light that impinges onto the digital camera sensor. Note that the iris setting affects the depth of field.
The remote control can be done by setting a defined analogue input voltage as a set value for the iris opening (as used for Pentax ER-type lenses, now phased out). Another solution can be a lens system with an external attached stepping motor for the iris setting, equipped with an analogue position output (as used for Linos MeVIS-Cm series, see [303]). This allows a PLC based feedback control system as described in chapter 6.5.

10. Quality Assurance, Tests, and Acceptance

All the information concerning Quality Assurance aspects are included in [4].

11. Scope of Work and Delivery

Manufacturing and testing of scintillating screens has to be performed as described in the documents delivered by GSI/ FAIR.

11.1. Scope of Work

Definition of the final setup in agreement with the GSI BI department, regarding all requirements described in the detailed specification.

- Final definition of the system details, according to mechanics, electronics, optics, data acquisition and subsystems (system realization in agreement with GSI BI department).
- Manufacture and tests of mechanical parts and supports, as described in chapter 5 and 10.
- Delivery of all purchase components (e.g. camera, iris, viewports, DAQ components & hardware).
- Development and production of special electronics (e.g. timing receivers, slow control units).
- Development of software for camera control & readout, timing, subsystems (e.g. slow control) and GUI, as described in chapter 6, 7, 8 and 9.
- Assembly of pre-series and tests, according to chapter 10.
- Assembly of the complete setups and tests, according to chapter 10.
- Commissioning of the setups with software in the FAIR facility.

11.2. Scope of Delivery

The scope of delivery is the complete Scintillating Screen setup, consisting of all components described in the detailed specification, concerning

- Mechanics
- Hardware components
- Electronics & Data Acquisition
- Software

The components have to be delivered to GSI. The Scintillating screen setups have to be assembled, tested and integrated into the FAIR HEBT beam line, as well as commissioned with the software.

Each Scintillating Screen setup has to be labelled with component ID (CID) codes provided by GSI, see [118].

12. Technical Parameter List

This technical parameter list is a draft version until now and has to be modified and completed substantially, as soon as the relevant calculations are performed.

Number of elements		**31 (16 in FAIR module 0-3)**
Installation details		
Overall length of chamber	mm	460 - 790
Horizontal aperture	mm	150
Vertical aperture	mm	150
Scintillator		
Scintillating material		Al_2O_3:Cr (Chromox) as the standard. P43 or YAG:Ce for low light applications **.
Active area (typical)	mm^2	Ø 100 mm / Ø 120 mm
Spatial resolution of the optical system (typical)	mm	0.4
Camera requirements		
Type		CMOS digital camera, monochrome as the standard. CID video cameras (monochrome) for special installations, where high radiation hardness is necessary **.
Data interface		Gigabit Ethernet for the standard (CMOS) cameras. For special radiation hard cameras (CID), other interfaces have to be discussed**.
Chip size	inch	min. ½’’
Chip resolution	pixel	min. 640 x 480 (VGA)
Refresh rate	fps	min. 30
Dynamic range (ADC)		min. 8 bit, preferred 10 bit
Gain (ADC)		min. 0 - 12 dB
Integration time		min. 10 µs – 2 sec
Sensor latency		max. 40 µs
Camera features		external trigger input, gain control, global shutter (CMOS), integration enable output signal
Requested properties		low noise, high sensitivity, definable region of interest (ROI) & binning, preferably good radiation hardness
Lens system requirements		
Lens type		Fixed focal length, VIS wavelength range
Relative lens aperture (f-number)		min. 1:1,8 (for f= 16 mm / 25 mm)
Lens features		remote controllable iris (stepper motor with encoder or voltage defined aperture setting), optional remote controllable focus
Requested properties		low distortion and good optical quality

*Length of diagnostic chamber depends on number of BD components in chamber at defined position.
** In written agreement with the GSI beam instrumentation department

Table 13: Technical parameter list for HEBT

13. Open Issues / Questions

There are no open questions and issues.

I. Attached Documents

No documents attached.

II. Related Documentation

The list below represents the documents referenced in the text.

The first paragraph contains all design reports and the General and Common Specifications of FAIR and the GSI-BI-department. The second paragraph is devoted to the Detailed Specifications of the Beam Instrumentation work package, whereas the third paragraph lists all relevant Technical Guidelines. Paragraph four contains documents that are specific for the present Detailed Specification.

General Documents [1...19]

[1] FAIR Baseline Technical Report
[2] Technical Design Report HEBT
[3] F-GS-F-01e General Specification of the FAIR Accelerator Facility Project
[4] F-CS-BD-01e Common Specifications Beam Diagnostics for FAIR

Detailed Specifications Beam Diagnostics [20...99]

[20] F-DS-BD-40e DAQ
[21] F-DS-BD-43e Mech+MechanicalDrives
[22] F-DS-BD-41e SubSys+StepperMotor
[23] F-DS-BD-44e Mech+VacuumChambers HEBT
[24] F-DS-BD-47e SubSys+PneumaticDrive
[25] F-DS-C-03e Settings-Management-System
[26] F-DS-C-05e General-Machine-Timing-System
[27] F-DS-C-06e Timing-Receivers

Technical Guidelines [100...199]

[100] F-TG-V-2.1e Stainless Steel for Beam Vacuum Chambers
[101] F-TG-V-2.5e Vacuum Firing for Hydrogen Degassing of Materials and UHV Chambers
[102] F-TG-V-2.6e Material for Bakeable CF Flanges
[103] F-TG-V-2.23e Bolts Studs Nuts and Washers for bakeable UHV Components
[104] F-TG-V-2.25e Forged Blanks for Vacuum Applications Material 1.4429 / ESU
[105] F-TG-V-2.36e Bolts Studs Nuts and Washers for Non-Bakeable UHV Components
[106] F-TG-V-3.42e Copper Gaskets for CF Flanges
[107] F-TG-V-5.1e Surface Properties of Vacuum Chambers
[108] F-TG-V-6.1e Cleaning of UHV Components of Stainless Steel
[109] F-TG-V-6.2e Cleaning of Standard Vacuum Components
[110] F-TG-V-7.1e Mechanical Acceptance Test for Beam Vacuum Components
[111] F-TG-V-7.2e Vacuum Properties Acceptance Test without Bake-out
[112] F-TG-V-7.15e Record for Factory Acceptance Test (FAT) of Vacuum Components
[113] F-TG-V-9.1e Transport and Packaging of Vacuum Components
[114] F-TG-V-13.1e Assembly Instructions for Knife-Edge UHV Flanges
[115] F-TG-C-02e Control System Equipment Interfaces
[116] F-DG-C-01e FESA Development Guideline
[117] F-DG-C-04e Equipment Integration Guideline
[118] F-TG-B-0.5e-CID and Barcode

Special Documents and Technical Notes [300...]

[300] IDS Imaging https://en.ids-imaging.com
[301] E2v image sensors http://www.e2v.com
[302] Radiation hard CID Cameras http://www.thermoscientific.com

[303] MeVis Lenses: http://www.qioptiq-shop.com/en/Precision-Optics/LINOS-Machine-Vision-Solutions/LINOS-Machine-Vision-Lenses/MeVis-Cm-motorized.html
[304] B. Walasek-Höhne et al.," CUPID: New System for Scintillating Screen Based Diagnostics", IBIC 2014, Monterey, USA;
[305] F. Locci et al., "IEPLC framework, automated communication in a heterogeneous control system environment" ICALEPCS 2013, http://www.JACoW.org/
[306] B. Walasek-Höhne et. Al., "Radiation-hard camera tests near SIS18 extraction", GSI Annual Reports 2014

III. Document Information

III.1. Document History

Version	Date	Description	Author	Review / Approval
0.1	2010-12-06	Draft Version	A. Reiter	1st version
0.2	2012-07-10	Draft Version	B. Walasek-Höhne	2nd version
0.3	2013-02-14	Draft Version	R. Lonsing B. Walasek-Höhne C. Dorn	
0.4	2013-03-15	Draft Version	C. Andre P. Forck	4th version
0.5	2013-04-09	Draft Version	B. Walasek-Höhne A. Reiter T. Hoffmann	
1.0	2013-04-22	Draft Version	B. Walasek-Höhne	
1.1	2015-04-01	Final Version	C. Andre	TH, CD, BWH
1.2	2015-10-16	Final Version	C. Andre	Changes after Rejections

IV. Abbreviations

µTCA	Micro Telecom Computing Architecture
ACS	Accelerator Control System
ADC	Analog-to-Digital Converter
AMC	Advanced Mezzanine Card
BI	Beam Instrumentation
BIF	Beam Induced Fluorescence Monitor
CCD	Charge Coupled Device
CID	Charge Injection Device
CMOS	Complementary Metal Oxide Semiconductor
CERN	Conseil Européen pour la Recherche Nucléair (European Organization for Nuclear Research)
CF-Flange	ConFlat-flanges
CPU	Central Processing Unit
DAQ	Data Acquisition
EDMS	Engineering & Equipment Data Management Service
FAIR	Facility for Antiproton and Ion Research
FESA	Front-End Software Architecture
FPGA	Field Programmable Gate Array
GigE	Gigabit Ethernet (Camera Interface Standard)
GSI	GSI Helmholtzzentrum für Schwerionenforschung GMBH
GUI	Graphical User Interface
HEBT	High Energy Beam Transport
I/O	Input / Output
IPM	Ionization Profile Monitor
IRIS	Iris

LAN	Local Area Network
LED	Light Emitting Diode
LHC	Large Hadron Collider
LINAC	Linear Accelerator
LOBI	LINAC & Operations Beam Instrumentation
LSA	LHC Software Architecture
PC	Personal Computer
PCI	Peripheral Component Interconnect
PCIE	Peripheral Component Interconnect Express
PID	Proportional-Integral-Derivative Controller
PLC	Programmable Logic Control
PMC	PCI Mezzanine Card
PSP	Project Structure Plan (code number in cost book)
SCR	Scintillating Screen
SEM-Grid	Secondary Electron Emission Grid
SI-System	International System of Units
TCP/IP	Transmission Control Protocol/Internet Protocol
TG	Technical Guideline
TTL	Transistor-Transistor Logic
UHV	Ultra High Vacuum
VME	Versa Module Eurocard
XML	eXtensible Markup Language