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| Requirement Specification | |
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| Revision | 0 |
| State | Preliminary |

# icBLM Specifications

## Table of Contents

# 1. INTRODUCTION, NUMBER OF DETECTORS

The BLM system is one of the primary diagnostic system of the ESS LINAC for beam tuning and equipment protection. The system is designed to prevent hardware destructions, to avoid cavity quenches and/or degradation, in SC section of LINAC and to provide quantitative loss values. icBLM stands for ionization chamber Beam Loss Monitor, which is sued for continuous surveillance of particle losses. Ionization chambers are a compromise among high dynamic range to able to detect fast and slow losses, time resolution, RAMI (reliability, availability, maintainability, inspectability), radiation hardness and cost.

The icBLM system is one component of a diverse and redundant suite of iinstrumentation to diagnose and protect against beam losses. The other systems include the neutron BLM (nBLM) system and the BCM system. Additions to this suite may be considered after commissioning. These potential additions include Cherenkov detectors, phase and position monitors, and other advanced techniques and systems.

# 2. TECHNICAL REQUIREMENTS

ESS requirements are divided into top-down requirements and interface requirements. Top down requirements are named by a level number, and are section - specific. The icBLM instrumentation is a level 5 component, and is formally a part of the level 4 accelerator discipline "PBI", proton beam instrumentation. Accelerator sections, e.g. SPK or MBL, are level 3.

The level 4 requirements are set by the Beam Physics section onto all proton beam instrumentation in the specific section. They are maintained in the ESS requirement database DOORS. This document contains copies of the relevant requirements.

Level 5 requirements are requirements on specific implementations of the instruments, in this case the icBLM. The level 5 requirements are defined in this document.

Interface requirements between the icBLM and other accelerator disciplines can be found in DOORS. This document contains copies of the relevant requirements with.

In case of conflict between different sources, DOORS take precedence over this document for level 4 and interface documents. This document takes precedence for all L5 requirements.

## 2.1 icBLM L4 requirements

The L4 requirements are extracted from ESS-0078645: “PBI L4 Requirements 2016-11-21.xslx” and summarized in the table below for the icBLM over the entire LINAC.

| DOORS-ID | Name | Description | Clarification | Traced Up To | Verify Method | Development Phase |
|---|---|---|---|---|---|---|
| 15176, 15223, 15275, 15327, 15371, 15422, 15478 | PBI energy range | Proton beam instrumentation shall function over a proton beam energy range of 3.0 MeV - 2100 MeV | Sufficient tolerances shall be added on the instrument level | | Inspection | Design, operation |
| 15177, 15224, 15276, 15328, 15372, 15424, 15479 | PBI peak current range | Proton beam instrumentation shall function over a peak beam current range of 3 mA to 65 mA | Sufficient tolerance shall be added on the instrument level | | Inspection | Design, operation |
| 15178, 15225, 15277, 15329, 15373, 15425, 15480 | PBI pulse length range | Proton beam shall function over a proton beam pulse length range of 5µs to 2.980 ms | Sufficient tolerance shall be added on the instrument level | | Inspection | Design, operation |
| 15179, 15226, 15278, 15330, 15374, 15426, 15481 | PBI pulse-by-pulse measurement update rate | Unless specifically stated, all instrumentation shall be able to perform the measurements and report the relevant PV data at a repetition rate of 14 Hz | Sufficient tolerance shall be added on the instrument level | | Inspection | Design, operation |
| 15180, 15227, 15279, 15331, 15375, 15427, 15482 | PBI measurement error limit definition | Unless specifically stated, instrumentation shall be designed so that less than 1 measurement in 2.4e8 is allowed to be outside the specified allowed error limits for each requirement | This is one pulse per year. The limits correspond to hard limits of a uniform distribution, or a margin of approximately 6 sigma for a two sided interval of a normal distribution | | Inspection, analysis | Design, operation |

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| 15182, 15229, 15281, 15333, 15377, 15429, 15484 | PBI damaging beam detection and mitigation | Beam conditions that are potentially damaging to machine components shall be detected by the instrumentation and reported fast enough so that the conditions can be mitigated before damage occurs | | | Inspection | Design, operation |
| 15183, 15230, 15282, 15334, 15378, 15430, 15485 | PBI beam start up measurements | Proton beam instrumentation shall be capable of measuring all beam parameters needed that allow for a safe startup of beam power, from no beam to the full nominal beam | The different beam modes are described in ESS-0038258R2 | | Inspection | Design, operation |
| 15221, 15273, 15325, 15369, 15420, 15476, 15518 | beam loss measurement | The beam loss shall be measured | | | Inspection, analysis | Design, operation |
| 15222, 15274, 15326, 15370, 15421, 15477, 15519 | beam loss measurement sensitivity | A beam current loss of 10 mW/m shall be detected | | | Inspection, measurement | Design, operation |

## 2.2 Interface Requirements

This category includes all system interfaces related to machine protection, temperature, radiation, timing.

| DOORS-ID | Name | Description | Clarification | Traced Up To | Verify Method | Development Phase |
|---|---|---|---|---|---|---|
| | Alarms | The BLM shall provide graded alarms prior to beam inhibit. | Operators can then intervene prior to trip and thus avoid downtime. Implies measurement precision that is better than that required for MPS. | | Inspection, demonstration | |
| | Beam inhibit | Protect from damaging beam loss. Inhibit beam production via the Beam Interlock System when damaging beam loss is detected | The interface to the BIS shall be provided by ICS and include an FPGA module with an industry standard interface to the protection function. The protection function is provided by beam diagnostics. This is a 2 ways interface: the icBLM system sends out its own status and receives information from the BIS | | Inspection, demonstration | |
| | Post Mortem | Acquire and analyze data surrounding Machine Protection System trips. Tools shall allow detailed analysis of losses within a pulse, variations from other pulses, trends, correlation with other measurements, determination of root cause, etc. The processed waveforms just before the comparator in the protection module shall be available for inspection after a trip | This should be supported by the data on demand feature | | Inspection, demonstration | |

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| | Timing | Signal acquisition triggering shall be provided by the ESS timing interface | Triggers are produced by the Event Receiver that is provided by ICS. | | Inspection, demonstration | |
| | Temperature | The icBLM electronics shall be operated under the temperature conditions described by AD WP15 | Temperature stabilization in the racks is specified at +/- 5 degC | | Inspection, demonstration | |
| | Radiation: ionization chambers | The ionization chambers shall be operated under radiation conditions described in ESS-0060208 | Refer to ESS-0060208 for loss map in the ESS LINAC | | Inspection | |

## 2.3 System level Requirements

| DOORS-ID | Name | Description | Clarification | Traced Up To | Verify Method | Development Phase |
|---|---|---|---|---|---|---|
| | Reliability | The BLM system design shall respond to the reliability requirements defined by the Machine Protection group | | | Inspection, demonstration | |
| | Safety | Relevant hazards shall be identified and adressed in the system design | The icBLM system shall be compliant with ESS internal regulations and the relevant laws of Sweden | | Inspection, demonstration | |

# 3. IONIZATION CHAMBERS SPECIFICATIONS

| Name | Description | Clarification | Traced Up To | Verify Method | Development Phase |
|---|---|---|---|---|---|
| Dynamic range | Chamber's current is $10^8$, in range 50 pA to 0.5 mA | | | Inspection, Measurement | |
| Energy Cut-off | Particle above this level start to deposit energy in detector | *Protons, neutrons ~ 30 MeV<br>*Electrons, photons ~ 2 MeV | | Inspection, Measurement | |
| Dark current | Leakage current | Less than 1 pA | | Measurement | |
| Electron and Ion drift time | Where ions and electrons travel the largest available distance | Electrons:<br>1/e fit of max is ~ 50 ns,<br>all electrons collected is ~300ns<br>Ions:<br>1/e fit of max is ~ 83 microsec,<br>all ions collected is ~300 microsec | | | |
| Conversion factor | Charge – energy deposition | 5.25 E-5 C/Gy | | | |
| Mechanical parameters | Length -60 cm, active volume - 50 cm, diameter – 9 cm, volume – 1.5 l, filling – N2 at 1.1 bar, HV – 1.5 kV | | | | |
| Reliability | Tolerance failure rate | $10^{-7}$ per hour per channel | | | |
| Stabilization of HV input | The low pass filter is mounted on the chamber feed throughs | R=1 MOhm and C=0.5 microF | | | |

The response function for the ionization chambers, as simulated at CERN, is illustrated on Figure 1:

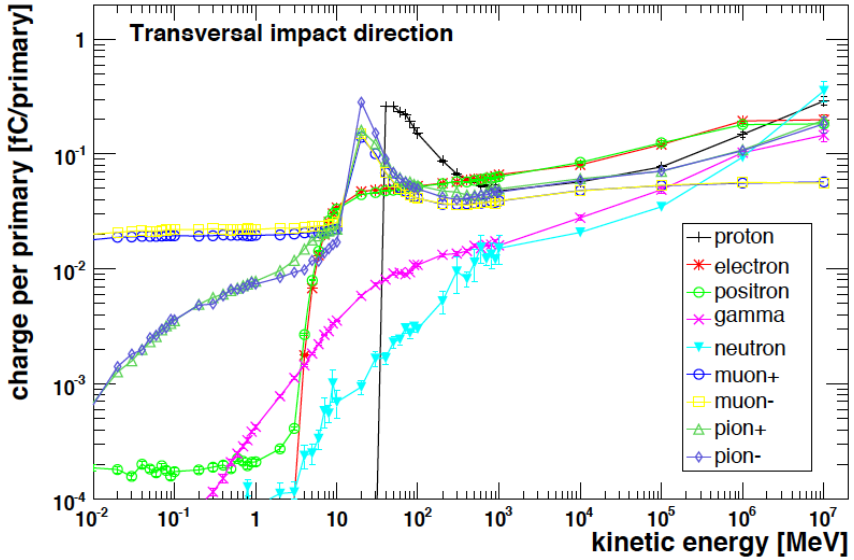


Figure 1: Ionization chamber response function

# 4. ICBLM ELECTRONICS SPECIFICATIONS

| Name | Description | Clarification | Traced Up To | Verify Method | Development Phase |
|---|---|---|---|---|---|
| High Voltage Supply: Modulation | Self-testing the ion chamber channels by modulating HV bias voltage shall be possible<br>Modulation requirements here | A pulse or a continuous modulation could be used. This produces a signal by coupling through the capacitance of the ion chamber. The signal is acquired in the usual manner by the acquisition electronics. Optionally, the configuration of the MPS processing chain could be modified to produce a trip | | Inspection, measurement | |
| High Voltage Supply: output voltage rating | The High voltage power supply providing the polarizing voltage to the ion chamber electrodes shall be able to provide a positive voltage of at least 3 kV | the use of “positive polarity” will minimize saturation effects under high dose rates | | Inspection, measurement | |
| High Voltage Supply: output power | The High voltage power supply should feature a maximum output power of at least 5 W | | | Inspection, measurement | |
| High Voltage Supply: output voltage ripple | The High voltage power supply should feature an output voltage ripple below 4 ppm pk-pk/FS | | | Inspection, measurement | |
| High Voltage Supply: noise figure | The High voltage bias supply noise figure shall be compatible with that of the signal acquisition board. This includes temperature induced noise | | | Inspection, measurement | |

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| Signal acquisition: Dynamic range | Input current dynamic range: 10 nA to 10 mA. | Two separate ranges shall therefore be used: the low end set by the condition that the operators must be able to tune on beam loss measurements down to 10 mW/m, while the high end shall allow recording of total beam loss during faults and machine studies | BLM is required to be able to measure at least 1% of 1W/m loss during normal operation and up to 1% of the total beam loss. | Inspection, measurement | |
| Signal acquisition: Response time | NC LINAC: Calculated melting time values of 3-4 us<br>SC LINAC: 10 us<br>The signal acquisition car shall therefore feature a bandwidth of at least 300 KHz and a minimum sampling rate of 1MSPS | The response time of the BLM system is a sum of:<br>"Particle time" - PT: time between the onset of beam loss (the primary is lost) and the moment particle (primary or secondary) hits the detector.<br>Detection time: time needed for the detector signal to develop and to collect enough hits/current<br>Processing time: from the output of the detector to the BIS output on the FPGA | | Inspection, measurement | |
| Signal acquisition: resolution | The signal acquisition card shall have a resolution of at least 20 bits | | | Inspection, measurement | |
| Signal acquisition: noise figure | The signal acquisition card shall have a typical noise better than 10 nA in its lowest range, including temperature induced noise | | | Inspection, measurement | |

# 5. CABLES SPECIFICATIONS

| Name | Description | Clarification | Traced Up To | Verify Method | Development Phase |
|---|---|---|---|---|---|
| Signal cable | The signal cables shall be triaxial cables, complying with the ESS rules for the selection of materials in cables: document ESS-0034035 on CHESS. | Triaxial BNC connectors should be used with signal icBLM cables | | Inspection | |
| HV cable | The High Voltage cables shall be coaxial cables, complying with the ESS rules for the selection of materials in cables: document ESS-0034035 on CHESS. | SHV connectors should be used with HV icBLM cables | | Inspection | |

# 6. ICBLM SOFTWARE AND FIRMWARE SPECIFIC FUNCTIONS

| Name | Description | Clarification | Traced Up To | Verify Method | Development Phase |
|---|---|---|---|---|---|
| Log dose history | Dose should be logged for reporting purposes and future analysis | Once per second statistics. For convenient retrieval, some statistics accumulated over longer time periods should also be logged | | Inspection, demonstration | |
| Loss map comfort display | Control room display, updated once per second and graphically displaying max and min loss per pulse, one second average loss per pulse, and MPS thresholds | | | Inspection, demonstration | |
| Loss per pulse – Real time | Provide real time correlation plot of loss per pulse vs arbitrary parameter that is being tuned | Should work for all beam modes | | Inspection, demonstration | |
| Subtract background signal | Measure and subtract background that is not due to beam loss | This is primarily due to X-ray emission from cavities with a small contribution from residual activation | | Inspection, demonstration | |
| Intra-pulse data logging | Periodically and/or on demand, log intra-pulse waveforms that can be correlated with waveforms from other systems | | | Inspection, demonstration | |

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| Accelerator regions integrated dose | Calculate integrated dose to regions of the accelerator. Integration time in this case is on the order of hours to months | This data is useful for identifying hot spots that may lead to early equipment failure or to elevated worker dose during maintenance activities. Data should be correlated with in-tunnel surveys and corrected to provide rough predictions of dose rates after beam is turned off | | Inspection, demonstration | |
| Protect from beam loss over thermal time constant of components | These time constants depend on the device: from milliseconds to minutes. | Integrated loss should be filtered based on a simple thermal model (similar to superconducting magnet protection) before thresholding. BIS would be used for second/minute timescales, but alarm system could be used alone for human time scales. | | Inspection, demonstration | |
| Protect from unanticipated variations in beam properties | The systems should look for pulses with properties that vary significantly from previous (or nominal) pulses and provide a graded response | Graded response: update a "figure of merit" PV, produce an alarm, produce a trigger that can initiate data acquisition, or inhibit beam via the BIS | | Inspection, demonstration | |
| Real time data link | The electronics shall support real time communication of loss signals to allow the protection function to utilize signals from multiple detectors | Latency shall be less than 1 microsecond plus the cable/fiber delay between nodes | | Inspection, demonstration | |
| Time-independent protection | The system shall provide some basic protection by continuously monitoring losses without depending on timing events. | | | Inspection, demonstration | |
| Support data on demand | Continuously buffer measurements and upon receipt of timing system event, report data from before and after the event | Buffer depth will be determined based on operational needs | | Inspection, demonstration | |

# 7. ICBLM LOCATION AND RADIATION FIELDS

icBLM detectors positions are chosen in accordance with maximum beam loss locations, and to minimize crosstalk. Because the ionization chambers are nearly point detectors, their location must be chosen to allow full coverage without blind spots. For diagnostic use, the detector layout should also allow determination of the loss originOperational and accidental losses are based on ESS-0044760: "A guideline to operational and accidental absorbed dose rates in the ESS accelerator tunnel" by Lali Tchelidze.

Detectors will be installed outside cryostats and will have an option as mounting flexibility (mobile monitors).

Normal operational 1 W/m proton beam loss was considered. This was derived from hands-on maintenance criteria for high intensity proton machines and was adopted at ESS as a maximum allowable operational beam loss. The beam loss was simulated as a homogeneous uniform loss around and across the vacuum beam pipe, with a shallow angle.

Additionally, a full point beam loss was considered for 2 GeV on a vacuum beam pipe as an accidental beam loss.

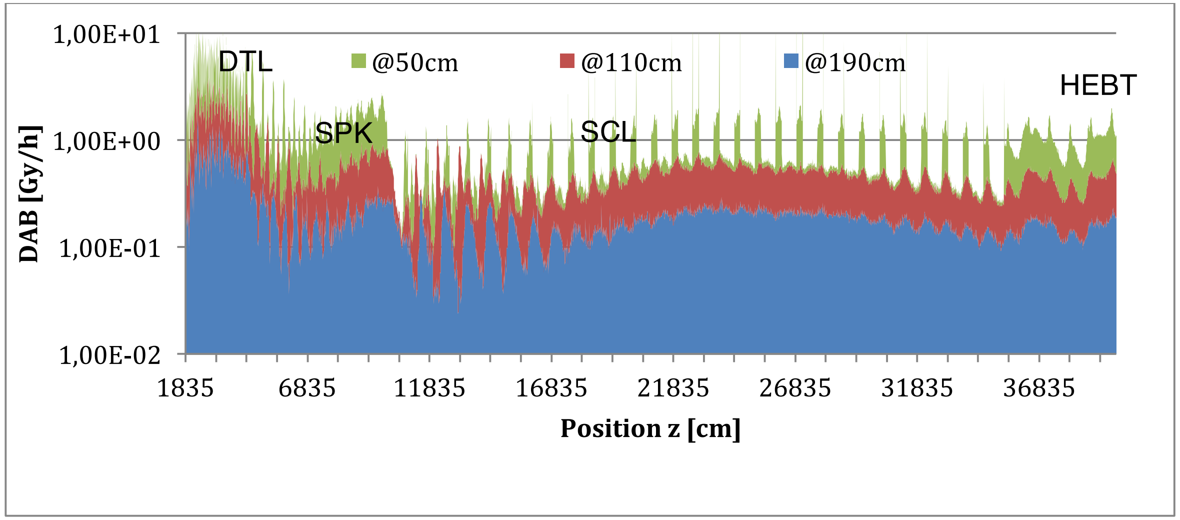

Figure 2 - Absorbed dose maps for 50, 110 and 190 cm from the beam centre [Gy/h]

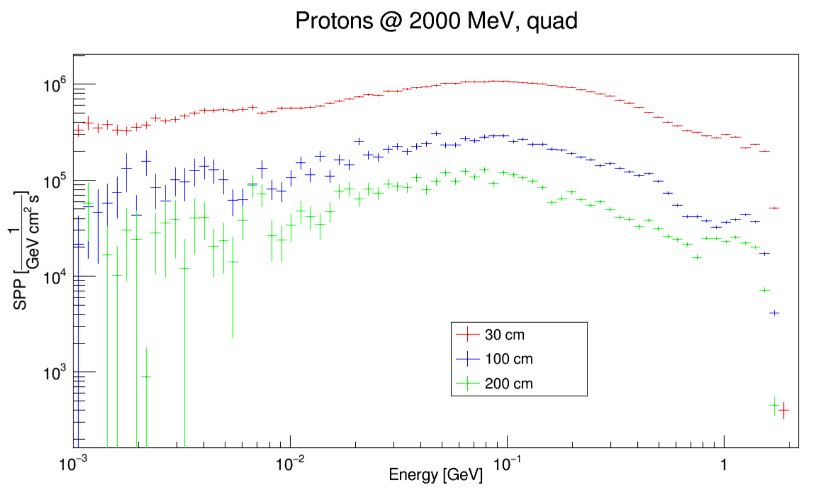


Figure 3 - Proton spectra around the quadrupole at various distances from the beam at 2000 MeV [1/Gev/cm^2/s]

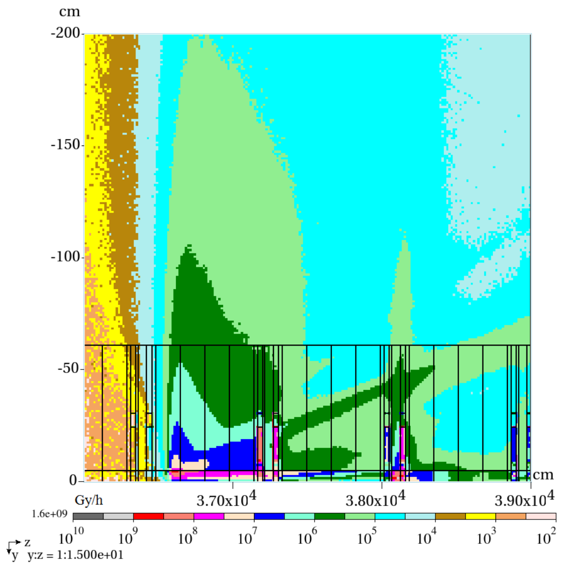


Figure 4: Absorbed dose rates for the 5 MW point beam loss [Gy/h]