Overview of ESS Beam Loss Monitoring System

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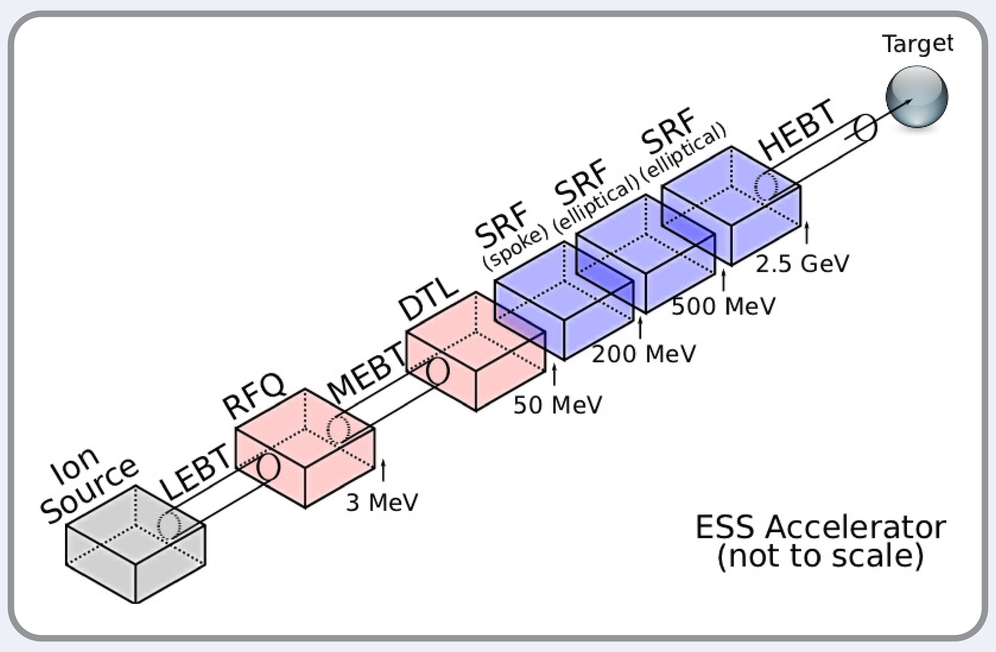
Introduction

The European Spallation Source (to be built in Lund, Sweden) will be a 5 MW proton linear accelerator with the following beam parameters: beam energy 2.5 GeV, beam macro-pulse duration 2.86 ms, average pulse current 50 mA and repetition rate 14 Hz.



System Requirements

- The BLM (beam loss monitoring) system should give in-real-time loss information for the entire accelerator. It should be a part of the machine protection system and must shut the beam off if the losses exceed the predefined limits.
- Baseline is 8.94×10^{14} protons/pulse, the design is made for 1.34×10^{15} protons/pulse.
- Sensitivity > 70 nC/Rad [1, 2].
- Time response < 2 - 3 μs [2, 3].
- Dynamic range > 10^6 - 10^7 [1].

Ion collection time

- The current BLM system at SNS (Spallation Neutron Source, Oak Ridge, Tennessee) is designed so that it's able to produce the stop-the-beam signal in less than 10 μs [3]. The ESS will operate at around 3-5 times higher power, which requires to improve the time response of the detector by the same factor.
- The improvement was done based on the following ion collection time considerations. The positive ion collection time in an ionization chamber is given by [4]

$$t = \frac{d^2}{\mu_0 (P_0/P)}$$

where μ_0 is the ion mobility at standard temperature and pressure, V is an applied voltage, P_0 is an atmospheric pressure, P is a working pressure and d is an effective electrode separation. For cylindrical geometry the effective gap between the electrodes

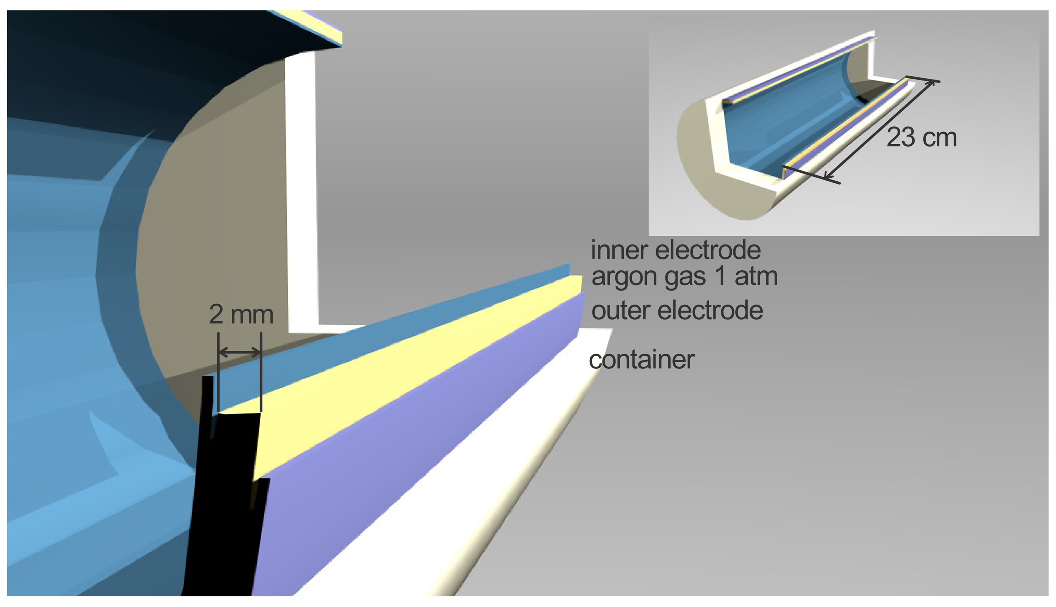
$$d = \left((R^2 - r^2) \frac{\ln R/r}{2} \right)^{1/2}$$

where R and r are the outer and inner radii of the electrodes respectively.

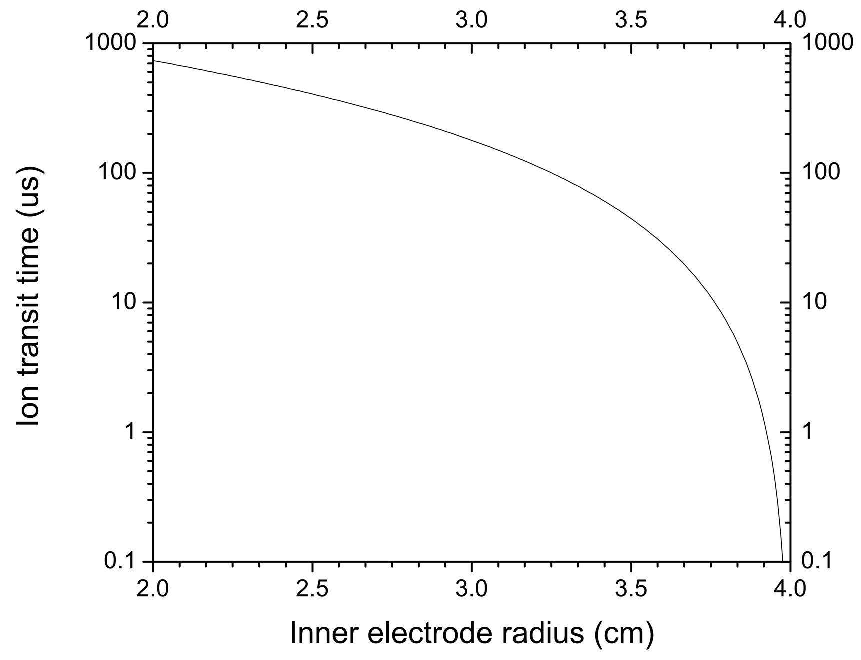
- By adjusting the radii of the electrodes one can change the ion transit time in the detector. This technique was used to decrease the current SNS loss detector response time by almost a factor of 10. The length of the detector was increased to keep the same sensitivity and thus the volume of the Argon gas [5] (110 cm^3 [1]) in between the electrodes.

Choice of Detector

At the ESS the main beam loss detector is chosen to be an ioniziation chamber. The SNS loss detector (cylindrical ionization chamber) was modified to meet the requirement of faster collection time. The new design of the detector is shown below. Also a graph of ion transit time is given as a function of the inner electrode radius, for a fixed outer electrode radius $R = 4$ cm and applied voltage $V = 3$ kV. The plot was used to find an optimal inner electrode radius and length of the detector to meet the response time requirements.

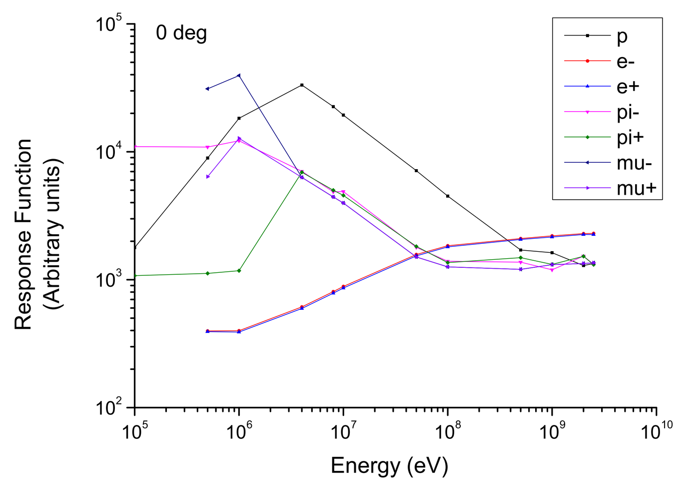


The new ESS loss monitor prototype design.

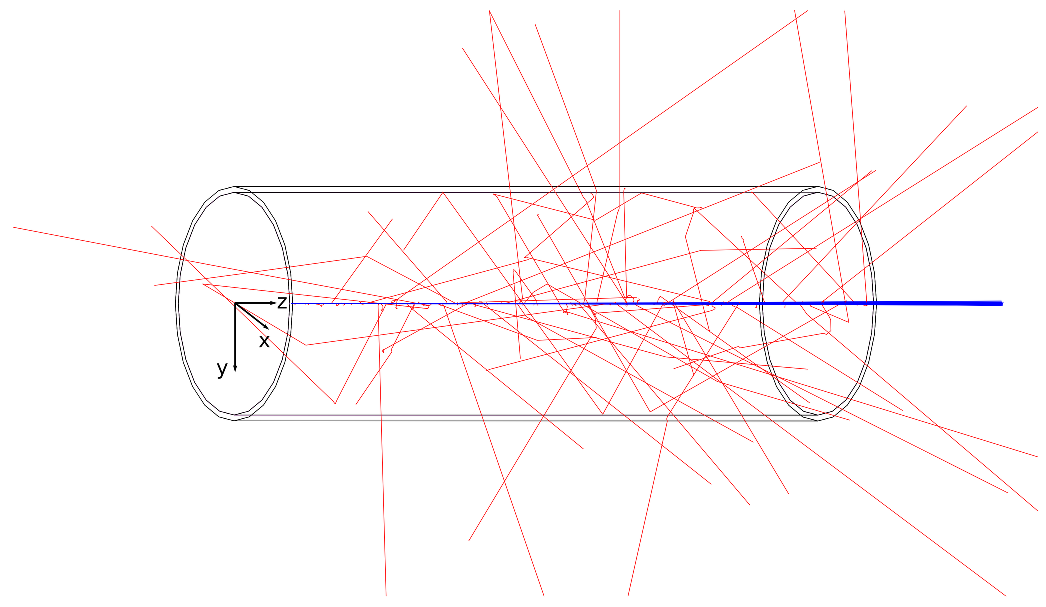


Results

The response functions were calculated for the new ionization chamber. The particle transport code MARS was used [6, 7]. The total power density was calculated in the Argon gas of the detector and it was assumed that the response function is proportional to it.



ESS prototype ionization chamber response functions as a function of incident particle type and energy. For zero incident angle.



Ar gas between coaxial cylinders. Blue - primary protons, red - secondary electrons. For 100 MeV protons.

Part of ESS	Number of IC
DTL	30
SRF (spoke)	45
SRF (elliptical, low beta)	30
SRF (elliptical, high beta)	42
HEBT	22

ESS main beam loss distribution [8].

The positioning of the loss detectors is currently determined to be at every quadrupole magnet across the accelerator. Later, once the primary loss maps are generated, the secondary showers will be simulated using the MARS and Geant4 simulation codes and the locations will be modified accordingly.

Other detectors

Several other detectors are considered to be used in addition to the main ionization chamber. These are an ionization chamber at cryogenic temperatures, in case we need to place the detectors inside cryomodules; fast scintillator detectors, when we need to look at the micro-structure of the pulse and neutron detectors when the other detectors are not sensitive enough to see any signal. Diamond detectors are considered also as a possible loss monitor at both room and cryogenic temperatures.

Summary

A new faster detector is designed for the ESS compared to the existing one used at SNS. A conceptual design of the new prototype ionization chamber is given and the response functions of the detector are calculated as a function of incident particle type, energy and angle.

The ion collection time is improved by almost a factor of 10 while keeping the sensitivity of the detector unchanged. The further tests will verify the expected response time and the response functions of the detector.

References

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