μ-LOSS DETECTOR FOR IFMIF-EVEDA

J. Marroncle, P. Abbon, J. Egberts*, CEA/DSM/IRFU, 91191 Gif-sur-Yvette Cedex, France
M. Pomorski, CEA/DRT/LIST/DCSI/LCD, 91191 Gif-sur-Yvette Cedex, France

Abstract

For the IFMIF-EVEDA project, a prototype accelerator is being built in Europe and installed at Rokkasho (Japan). It is designed to accelerate 125 mA CW Deuteron up to 9 MeV. The very high space charge and high power (1.125 MW) of the beam make this accelerator very challenging.

For hands-on maintenance requirements, losses must be well less than 1W/m, i.e.10^{-6} of the beam. That is why, in the 5-9 MeV superconducting Linac, beam dynamics physicists search to tune the beam by minimizing the very external part of the halo. For that, the need is to be able to measure very tiny beam losses, called μ-losses, at all the focusing magnets. Only neutrons and γ escape from the beam pipe due to low deuteron energy. Thus such beam loss detectors have to be sensitive to neutrons, but rather insensitive to X-rays and γ in order to decrease their contributions coming from super-conducting cavity emission. They must be radiation hardness qualified, and capable to work at cryogenic temperature. Single CVD diamonds ($4\times4\times0.5$ mm^3) are studied for these purposes and first results seem to fulfill the requirements so far.

INTRODUCTION

The International Fusion Materials Irradiation Facility (IFMIF), a project involving Japan and Europe in the framework of the "Broader Approach", aims at producing an intense flux of neutrons (~14 MeV), in order to characterize materials envisaged for future fusion reactors. That should be done with 2 deuteron beam accelerators (125 mA - 40 MeV) impinging a liquid lithium target, producing a huge neutron flux (10^{17} neutrons/s).

In a first step called EVEDA (Engineering Validation and Engineering Design Activities), this project includes the construction of a prototype accelerator with the same characteristics as IFMIF, but at a lower energy of 9 MeV.

Such a high power accelerator has to cope with many challenges. All the envisaged solutions should be validated on the prototype prior to be applied to the final accelerators. In this paper, we will focus on the very low beam loss requirements. First we will present the beam dynamics motivations, where is defined what we call "μ-losses". Then the different specifications are progressively listed, leading to the choice of diamond detectors. First simulations and cryogenic tests are presented as well as perspectives, and finally preliminary conclusions.

MOTIVATION

The high beam intensity induces a high space charge regime making particle dynamics behaviors strongly non-linear. Halo formation and sudden particle losses drastically rise, and at the same time their modelisation is less precise. But high beam intensity also means high power, and that induces harmful material activation, especially when the beam energy is over 5 MeV. In the case of Mega-Watt power as IFMIF, the hands-on maintenance requirement of well less than 1W/m loss corresponds to well less than 1 deuteron particle over 1 million. We call these losses "μ-losses".

We are clearly in the presence of conflicting issues. On the one hand, important loss mechanisms that are modelised with a poor precision, and on the other hand, tiny loss tolerance that should be controlled with a very high precision. Faced with that, an uncommon strategy has been employed [1]: a) beam dynamics optimisations are exclusively performed in the way that can be reproduced by on-line fine tuning b) optimisations aim at minimising μ-losses and not rms values like beam envelope or emittance.

This strategy can be fully implemented only if numerous μ-loss detectors are available along the beam line, at least around all focusing magnets where losses mainly occur. They must be as close to the beam axis as possible in order to inform on loss location. They will be used very frequently, automatically, at full current, in a time response about a second. As the most critical components to protect against losses are the cryomodules of the SRF-Linac (Superconducting-Radio-Frequnecy Linac), μ-loss detectors should in addition work at cryogenic temperatures and be very compact, seen the extreme compactness of the cryomodules, another consequence of high beam current.

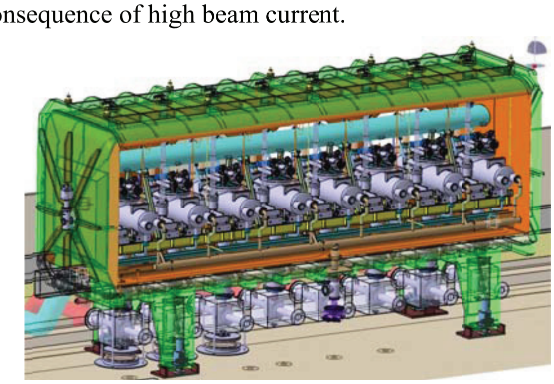

Figure 1: Cryostat with its 8 ensembles.

DIAMOND AS μ-LOSS DETECTOR

In the prototype accelerator, the SRF-Linac is composed of only 1 cryomodule. Downstream of the RFQ and the MEBT, it transports and accelerates particles from 5 to 9 MeV. It is made of 8 periods, each one consisting in 1 Half-Wave Resonator for acceleration, 1 Solenoid for

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focusing, equipped with steerers, and 1 Beam Position Monitor. µ-loss detectors are planned to be installed around the solenoid helium vessel. Note that there is no beam shape diagnostics. All the components are maintained at 4.2 K in a 5 m long cryostat (Fig. 1).

µ-losses are due to deuteron particles, mainly in the beam halo, impacting the beam pipe wall. That produces particles of which charged ones are stopped inside the structure while only neutrons and γ can escape. To detect them, the requirements should be as follows:

- good neutron sensitivity and the least sensitive to γ for avoiding confusion between γ losses and X-rays to γ spectra radiated by accelerating cavities,
- good radiation hardness,
- compactness: cryostat is very crowded,
- working range down to cryogenic temperature.

Neutron and γ spectra (Fig. 2) were simulated for 1 W/m beam losses in the cryostat, for deuteron energies between 5 and 9 MeV, roughly taking into account materials crossed by particles like in the solenoids. During the accelerator commissioning, the SRF-Linac tuning will be done following µ-loss detector information (counting rates and energy deposit).

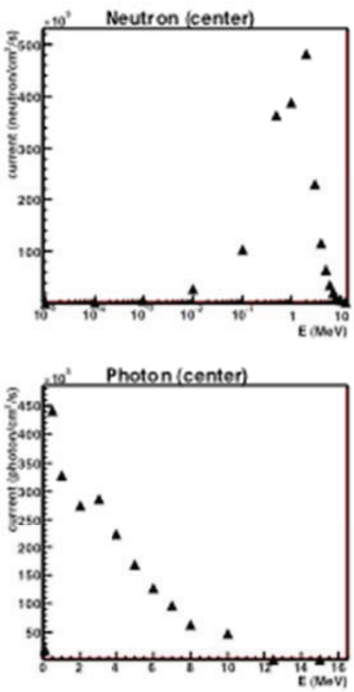

Figure 2: Incoming neutron (top) and γ fluxes (bottom) at the µ-loss detector place.

Diamond Detector

Detection principle of a diamond: it acts as a solid-state ionization chamber with its opposite metalized faces polarized around 1 V/µm. When neutrons interact with carbon nuclei (scattering, nuclear reactions), the energy released under recoil or particle emission ionizes the medium producing electron-hole pairs that drift under the applied electric field.

Nowadays, Chemical Vapour Deposition (CVD) is a technique commonly used to manufacture single crystal diamonds [2]. The main characteristics of diamond are summarized in Table 1.

Table 1: Some Diamond Characteristics

Density	3.52 g/cm^3
Resistivity	10^{13} - 10^{16} Ω.m
ε_r	~5.7
e/hole pair energy production	~13.2 eV
Intrinsic charge transit time (at 1 V/µm)	~ 1 ns for 100 µm
Energy resolution	~ 18 keV
Band-gap	5.5 eV
Radiation hardness	~500 Mrad for 24 GeV proton

The single CVD diamond characteristics are compatible with the requirements. Thus we foresee to use single diamonds of 4×4×0.5 mm^3. For 1 MeV neutrons, the expected rate is about 200 Hz per diamond fixed on the solenoid for 1 W/m loss in nominal beam conditions. The neutron interaction probability with 0.5 mm thick diamond is about 1%. Radiation hardness is good as reported in [3]. Diamond is nearly transparent for γ and a combination of thin layers of lead and copper should shield X-rays emitted by cavities. These layers can be used to make a very compact box (Faraday cage) inside which diamond will be placed.

Nevertheless, for the last requirement concerning the diamond ability to work at cryogenic temperature, there is no data available.

DIAMOND DETECTOR BEHAVIOR IN LIQUID NITROGEN

As a first step, it was decided to check that diamond could be used as detector at the liquid nitrogen temperature (77 K).

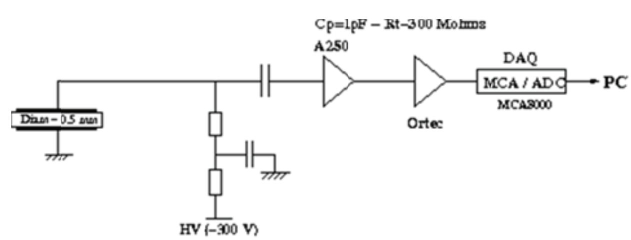

Figure 3: Electronics sketch.

In December 2010, a diamond detector was plunged in a Dewar filled of LN_2 while a ^{232}Cf source (delivering γ and fission neutrons) glued outside the Dewar wall which irradiates the whole. A sketch of the electronics is depicted in Fig. 3 consisting mainly in an Amptek charge sensitive amplifier (A250) followed by an Ortec shaping amplifier; then data are digitized by a pocket MCA8000. The diamond detector was polarized at 300 V. Special care was taken to insure the electric contact at room and LN_2 temperature.

Three combinations of data were taken:
- ^{232}Cf and diamond in LN_2
- ^{232}Cf and diamond in air
- diamond in air for a background evaluation.

For the 2 first tests, the ^{232}Cf source and the diamond detector remain in the same position, but liquid nitrogen evaporates in the meanwhile.

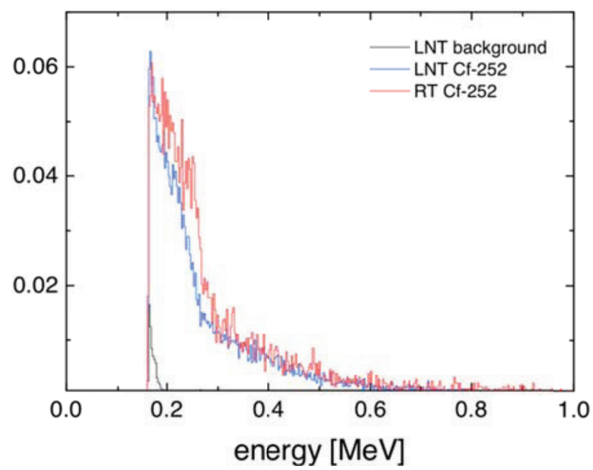

Figure 4: Diamond detector test at LN_2 temperature.

The results are depicted in Fig. 4, showing the normalized rate versus the deposited energy in the diamond. The three coloured curves correspond to:
- in blue: ^{232}Cf and diamond plunged in LN_2
- in red: ^{232}Cf and diamond in air
- in black: diamond in air with no ^{232}Cf source.

The 2 first spectra are quite similar except attenuation in counting rate and a little shift in energy. Both effects are probably due to the different amount of matter between these 2 configurations. Indeed particles encounter more matter in the first case where they scatter on the LN_2 while it is replaced by few air molecules in the second case.

Thus the conclusion is that diamond detector works with unchanged characteristics down to 77 K.

PERSPECTIVES

For the near future, a diamond detector will be tested at liquid helium temperature (4.2 K). Results will be reported during the poster session.

Beam tests are scheduled for the end of June. We will use a neutron beam delivered by the Van der Graaff accelerator of Bruyère-le-Châtel CEA, covering a large energy range from 30 keV to 20 MeV. During that period, calibrations and electronics tests will be planned.

Due to its very low capacitance (~1 pF), diamond should be read-out with an electronics set as close as possible to the detector, especially for charge sensitive electronics. Radiation in the IFMIF-EVEDA accelerator hall should be quite important, thus leading to a solution at remote distance (> 30 m). A priori, the use of current or/and transimpedance amplifiers could be suitable and will be tested.

Tuning the beam will impose to locate the µ-losses with a precision better than the solenoid length. Our idea is to put 3 diamonds on each solenoid to have also information on the transverse losses spread, as well as to improve the reliability. Indeed the cryostat will be closed quite definitively, thus if one diamond would be damaged, 2 others could be used anyway.

CONCLUSION

For high beam intensity, the beam fine-tuning can be done using the µ-loss information. CVD diamond detector was proposed as a solution for µ-loss detectors.

We have shown for the first time that diamond detector works at temperature as low as liquid nitrogen (77 K). Soon, a test at 4.2 K will tell us if diamond is suitable for µ-loss detectors fixed directly on the cryogenic solenoids.

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