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Beam Profile Monitor Design for a Multipurpose Beam Diagnostics System

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Abstract

Beam diagnostic tools are the key component of any accelerator. They provide the way to measure beam parameters in order to monitor the accelerator performance. The beam profile is a bridge to other beam parameters such as transverse position, size, divergence and emittance. Depending on the characteristics of the beam, there are different tools and methods for monitoring the beam profile. A suitable diagnostic tool for measuring the beam profile with high resolution is scintillator view screens which is one of the oldest and most precise tools. This paper presents the beam profile monitor design for a multipurpose beam diagnostic system. This system is aimed to measure the beam profile, transverse parameter, energy spectrum and current. The concerning issues in the beam profile monitor design such as image resolution, radiation damage and scintillator temperature distribution have been discussed.

PROFILE MONITORING DESIGN

The design procedure includes, scintillator material selection, handling the thermal and charge accumulation issues and estimation and improvement of the measurement resolution.

Selection of scintillation material:

For the scintillation material high light yield, resistance to radiation damage, vacuum compatibility, linear response and lower temperature sensitivity is demanded, YAG:Ce is a trade-off choice since it presents good scintillation yield and radiation damage resistance and low temperature dependence[1].

Radiation Damage:

Cavity and atomic displacement are the main types of radiation damage in scintillation crystals[2].These lattice damage alters the energy of the crystal bond. As a result, optical parameters such as the yield and frequency of scintillation output light change[3].The damage of the electron beams is generally small compared to the ion beams due to their mass[4].

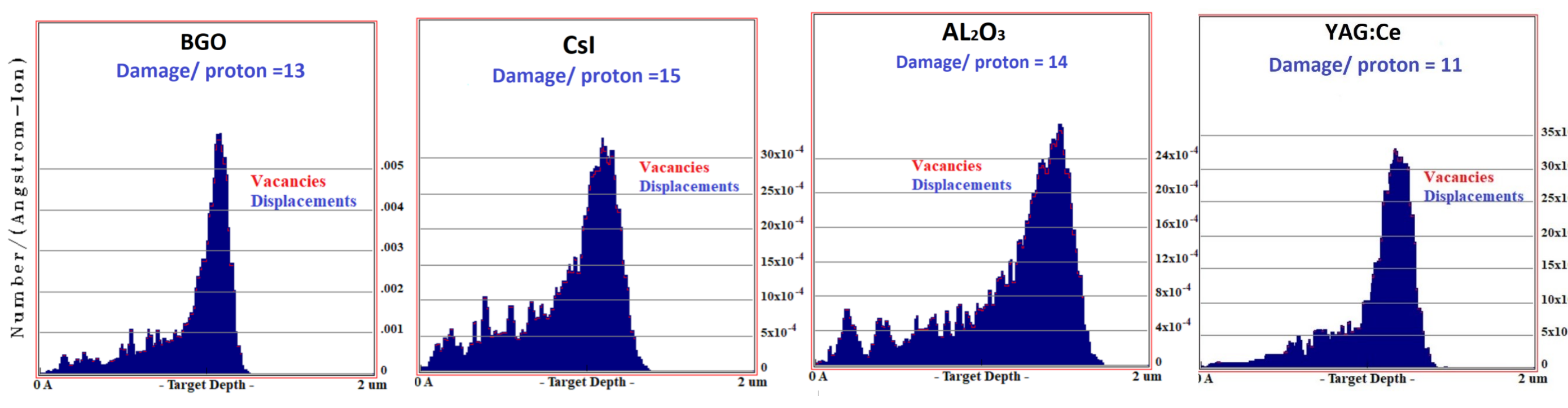

Figure 1: Comparison of radiation damage of scintillators caused by a 200 keV proton.

The scintillation damage caused by a 200 keV proton beam in conventional scintillators are simulated using TRIM software. According to the Fig.1, the YAG scintillator is the most resistant material to be used as a beam diagnostic tool with the minimum amount of cavities and displacement created (11 damage per collision). This result is consistent with the experimental data obtained by Simon et al., which emphasizes the high resistance of the YAG scintillation to proton radiation[5].

Temperature distribution:

As the proton beam strikes the surface of the scintillator, its temperature increases and resulting in degradation of its optical response[2]. Bachmann et al. calculated the effect of temperature changes on the intensity of the YAG scintillation yield[3].The results are shown in Fig. 2, where the light intensity of YAG is reduced by about half the maximum value at a temperature of about 600 K ($T_{1/2}$). This temperature is conventionally selected as the maximum allowable temperature of the scintillator. To calculate the final temperature of the scintillator, we simulated the temperature distribution using Comsol software (as shown in Fig.3) and obtained the final temperature of the YAG:Ce scintillator for different beam powers. If the scintillator has no substrate, the scintillator temperature at high powers will reach to 600 K (T1/2). The average final scintillation temperature for different beam powers is shown in Fig. 7 . Information about the simulated problem is given in Table 1.

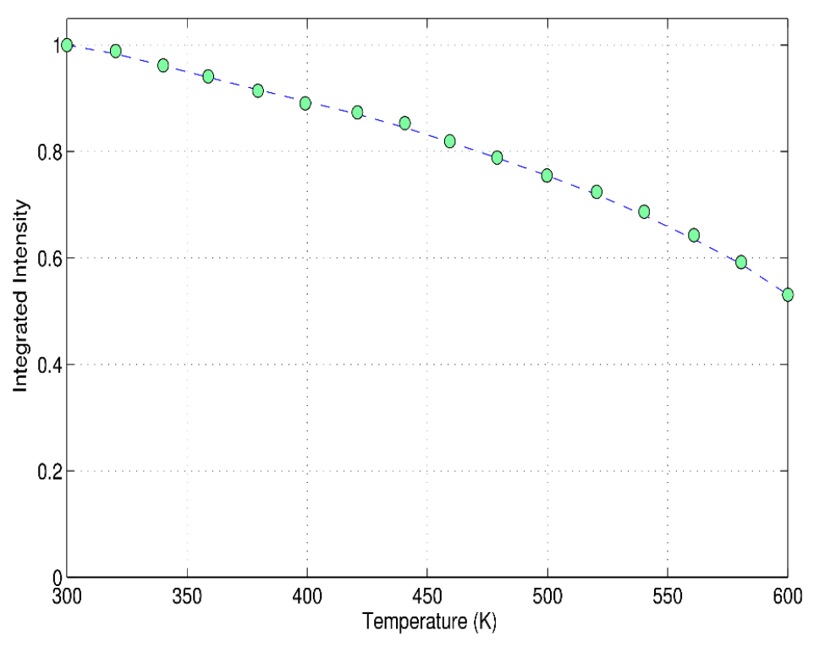

Figure 2: The temperature dependence of YAG yield[6].

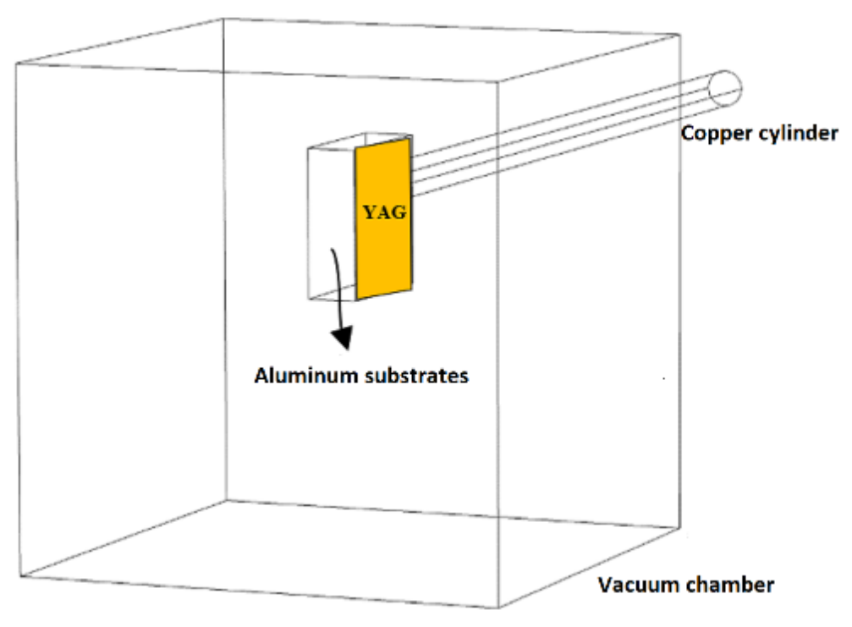

Figure 3: Schematic of the simulated problem.

Table 1: Simulated problem information.

YAG (30*30mm*50 um)	scintillator
Al (30*30mm*10 mm)	substrate
Copper cylinder (R=5 m , h=200 mm)	holder
10 mm	Beam radius
From 0.1 to 10 W	Beam power

As you can see in Fig. 4, at a beam power of 5 W, the temperature of the scintillator has reached above the $T_{1/2}$, also the temperature difference between the center of the scintillator and the sides reaches 300 K which affects the linearity of the scintillator response. In fact, the presence of temperature differences leads to changes in the optical efficiency of different points of the scintillator compared to the ideal state and this can disrupt the beam profile[6]. Using MATLAB software, we simulated the change of the beam profile for different powers. An example of a 1D beam profile for a 5W beam power is shown in Figure 5. The presence of a temperature difference of scintillator causes a 17% increase in the width (RMS) of the beam. As a result, the profile of the measured beam has changed and the final shape of the beam has been disturbed.

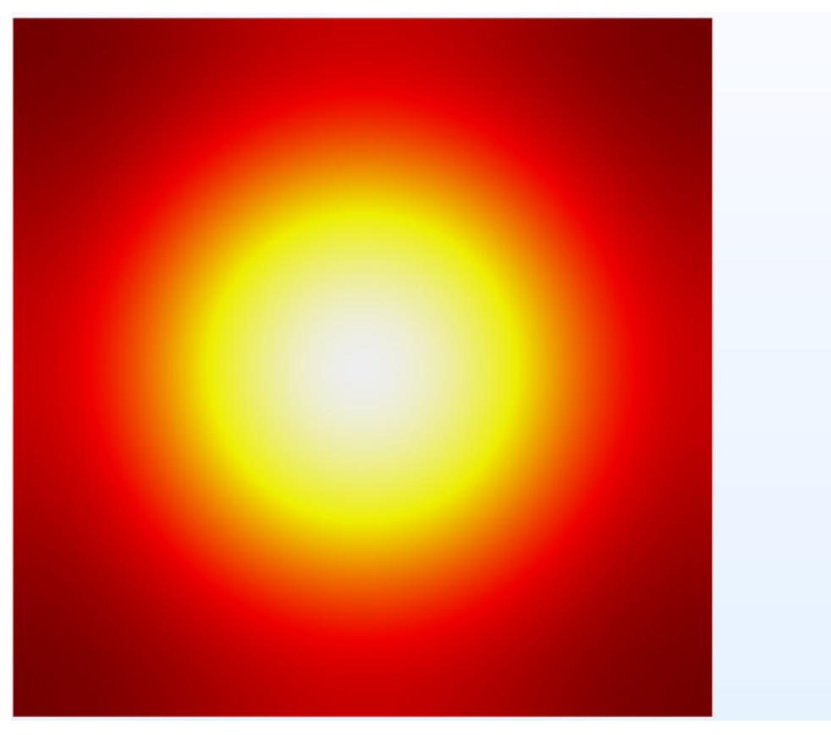

Figure 4 Temperature profile of YAG for 5 W beam power.

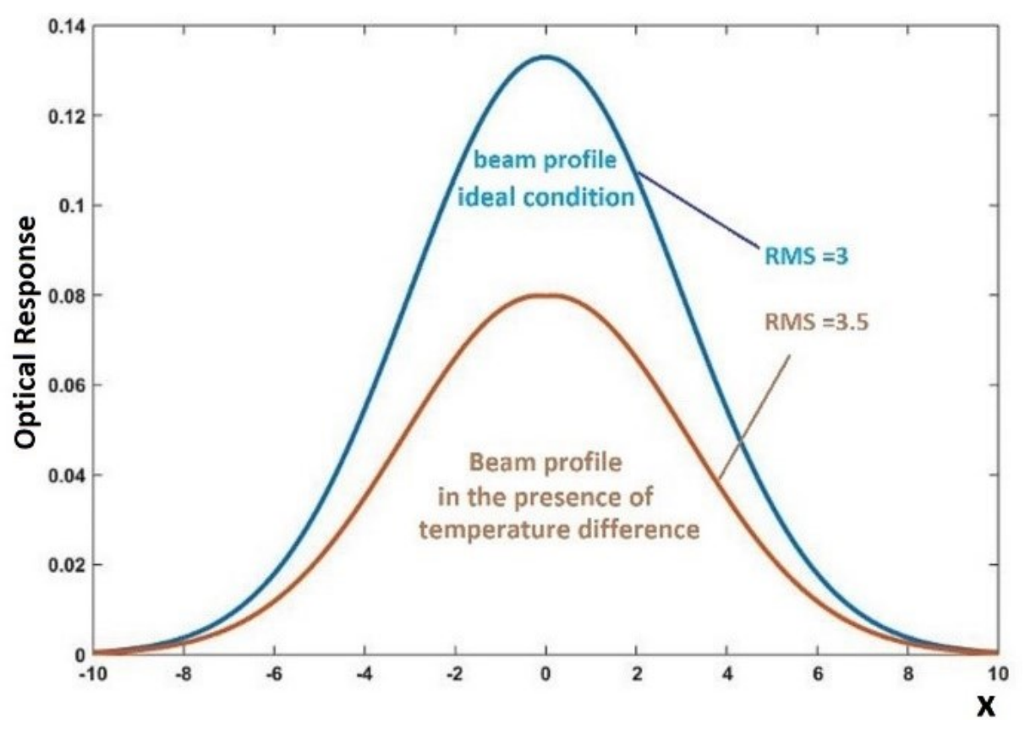

Figure 5: 1D beam profile for 5 W beam power
(blue diagram: no temperature difference in scintillation,
brown diagram: 300 K temperature difference).

According to the simulation results shown in Fig. 6, by placing the aluminum substrate and copper holder, better heat transfer has taken place in the scintillator and the temperature of the scintillator has reached below the allowable temperature $T_{1/2}$. On the other hand, the temperature difference between the center of the scintillator and the sides is reduced significantly, and therefore there is no significant change in the ratio of the light output of the scintillator and the width of the beam. Also, by connecting the aluminum substrate to the ground (as shown in fig.7), the charge accumulation in the scintillator and damage caused by sparks to the scintillator is prevented.

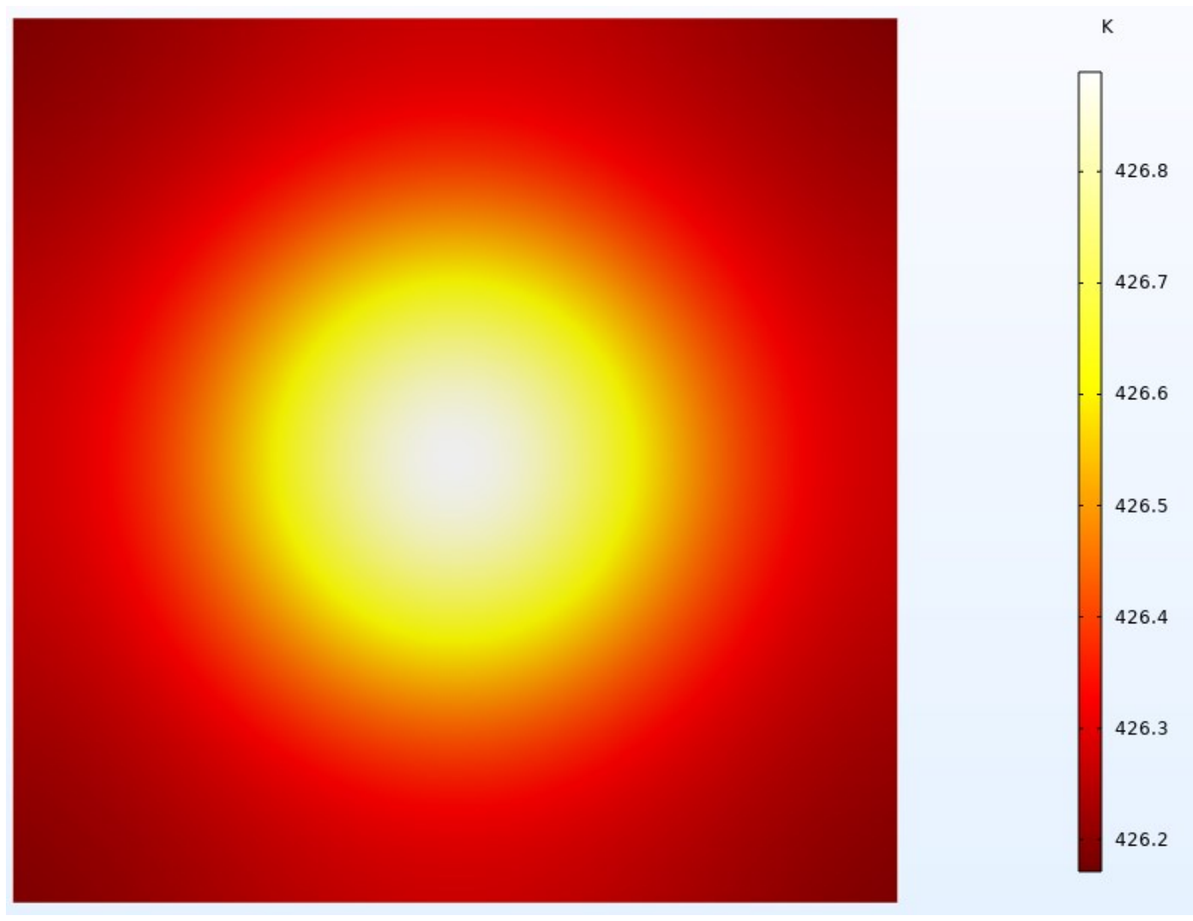

Figure6: Temperature profile of YAG for 5W beam power in the presence of aluminum substrate.

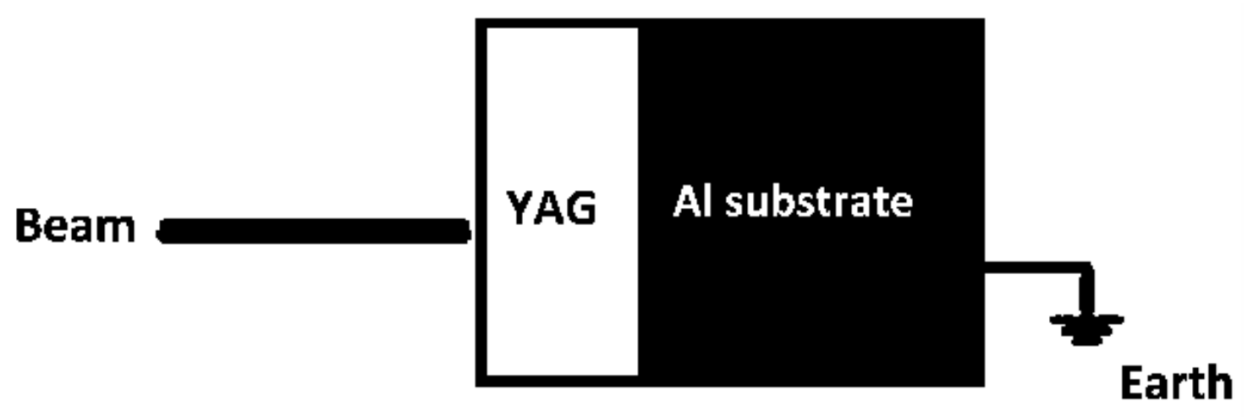

Figure 7: Prevent the accumulation of charge on the scintillator by adding an aluminum substrate.

Image resolution:

In order to estimate the image resolution limits due to coulomb scattering, the Geant 4 Monte Carlo code is used. We simulate the collision of an ideal zero-dimensional beam with the YAG scintillator screen. Due to multiple scattering within the scintillator, an area of the scintillator is illuminated. The dimensions of this area is a measure of the resolution of the scintillator. As shown in the Fig. 8, the RMS for a 200 keV proton beam is less than 0.1 μm (RMS =72 nm) with an error of less than 2%, which indicates the very high resolution of the YAG scintillator To benchmark the results, we simulated the problem with the MCNP code, which resulted in a difference of less than 2% compared to the Geant4 code. This difference is due to the different methods of problem solving by the codes.

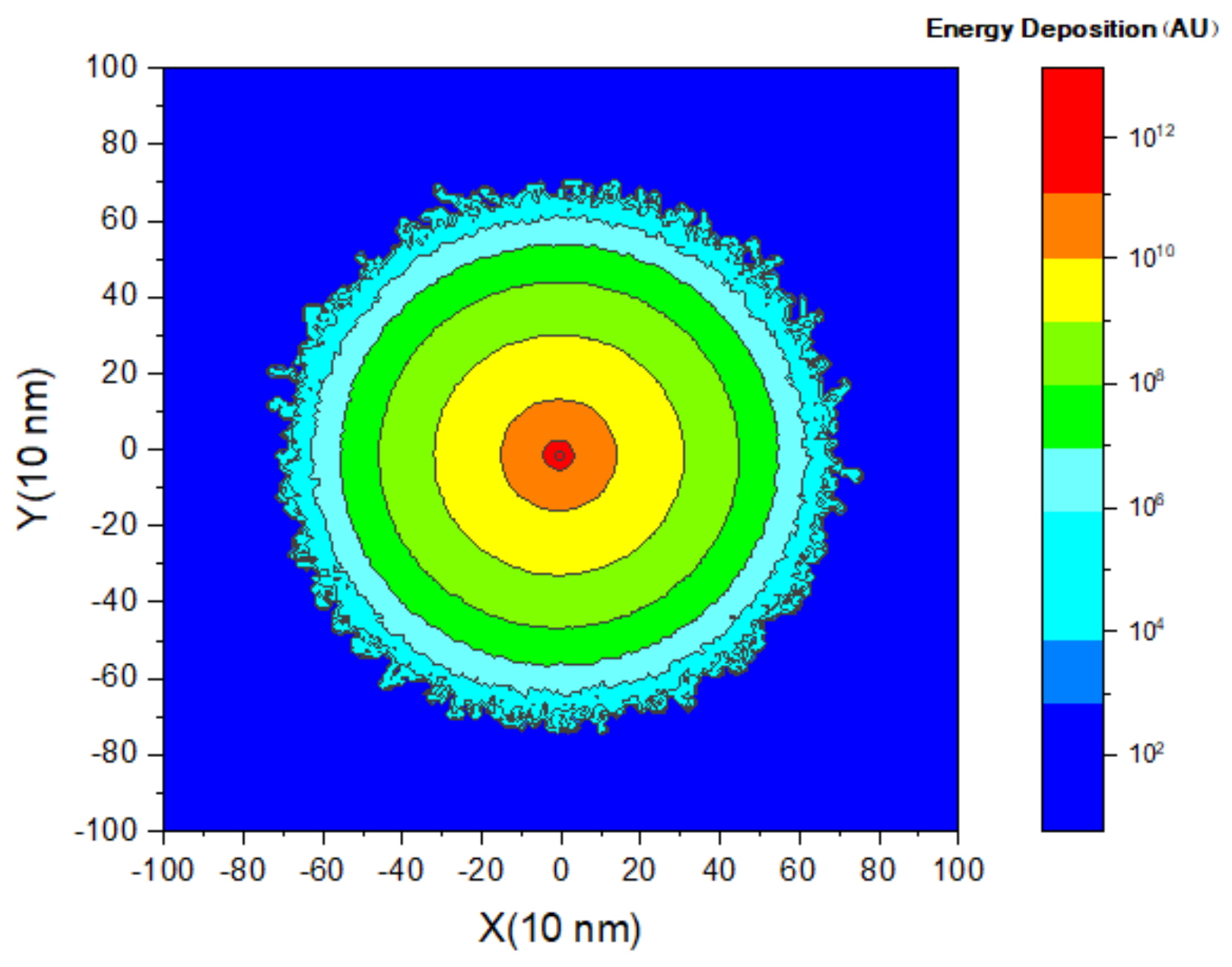

Figure 8: The profile of the 200keV proton beam on the YAG scintillation target.

CONCLUSION

In this paper, the design procedure includes, scintillator material selection, handling the thermal and charge accumulation issues and estimation and improvement of the measurement resolution have been studied. In order to select the resistant scintillator material, the scintillation damage caused by a 200 keV proton beam in conventional scintillators are simulated using TRIM software and the YAG scintillator was the most resistant material to be used as a beam diagnostic tool with the minimum amount of cavities and displacement created (11 damage per collision). The effects of scintillation temperature changes on the beam profile were also investigated. At 5 W, the temperature difference between different points of the scintillation, affects the linearity of the scintillator response and causes a 17% increase in the width (RMS) of the beam. To reduce these damaging effects on the beam profile, it was suggested to place an aluminum substrate behind the scintillator. Finally, using Geant 4 Monte Carlo code, we simulated the collision of an ideal 200 kV proton beam with the YAG: Ce scintillator and obtained the beam transverse distribution (beam profile). By calculating the RMS (root mean square) of the beam profile, we obtained a measure of the resolution of the YAG: Ce scintillator, which was less than 0.1 microns, and confirmed the proper resolution of the YAG: Ce scintillator for use as diagnostic tool.

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