WEPP38

IBIC '20 International Beam Instrumentation Conference

ENERGY GAIN MEASUREMENT FOR ELECTRONS ACCELERATED IN A SINGLE-CYCLE THZ STRUCTURE

euclid TECHLABS

Sergey Kuzikov, Sergey Antipov, Pavel Avrakhov, Ernie Knight, Yubin Zhao, Euclid Techlabs LLC, Bolingbrook, IL, USA
John Gorham Power, ANL, Lemont, Illinois, USALLC, Bolingbrook, IL, USA

Abstract: Beam halo measurement is important, because novel x-ray free electron lasers like LCLS-II have very high repetition rates, and the average power in the halo can become destructive to a beamline. Diamond quad detectors were previously used for electron beam halo measurements at KEK. Diamond is the radiation hard material which can be used to measure the flux of passing particles based on a particle-induced conductivity effect. However, the quad detectors have metallic contacts for charge collection. Their performance degrades over time due to the deterioration of the contacts under electron impact. We recently demonstrated a diamond electrodeless x-ray flux monitor based on a microwave measurement of the change in the resonator coupling and eigen frequency. We propose similar measurements with a diamond put in a resonator that intercepts the halo. Without electrodes, such a device is more radiation resistant. By measuring the change in RF properties of the resonator, one can infer the beam halo parameters. In a similar manner to traditional beam halo monitors, the diamond plate can be scanned across the beam to map its transverse distribution.

DIAMOND BLADE CONCEPT

Beam halo has a relatively low charge density. However, for high intensity beams, the actual number of particles in the halo is typically quite large. For this reason, the halo is associated with an uncontrolled beam loss, and must be monitored and mitigated. It is difficult to use typical fluorescent screens to monitor beam halo, since the core of the beam will produce a high signal that can leave the halo signal too small to differentiate. The wire scanners allow beam profile characterization its transverse distribution. Even though refractory metals such as tungsten are used for the wires, they must be replaced from time to time due to beam damage. We consider the use of diamond for a sensing material, because of its extraordinary mechanical, electrical, and thermal properties. Large bandgap, radiation hardness, high saturated carrier velocities, and low atomic number make diamond an attractive candidate for the detection of ionizing radiation and charged particles. Diamond quadrant detectors have been successfully used to measure beam halo at KEK. We propose an electrodeless measurement of the chargedarticle-induced conductivity of the diamond by means of a microwave resonator reflection measurement. A diamond blade will be used to intercept electrons. The blade will be inside a critically coupled resonator, i.e., when fed microwaves at the resonant frequency, there will be no reflection from the resonator. Due to electron interactions with the diamond, the diamond will become weakly conductive.

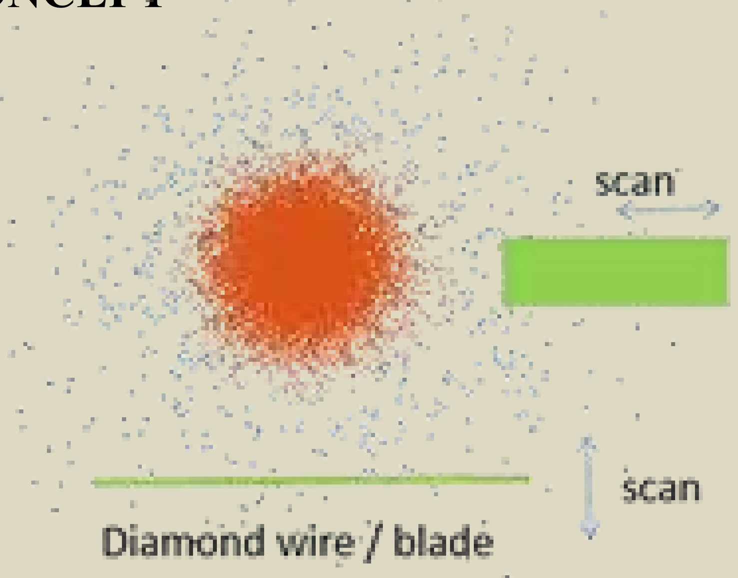

Figure 1: Diamond blade beam halo scanning.

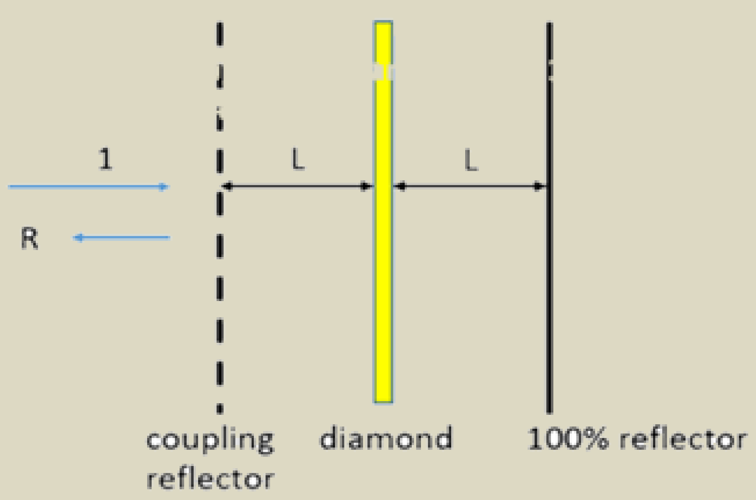

Figure 2: Simulation of resonator S_{11} for beam and no beam for the initial near to critical coupling.

Because of that, the microwave properties of the resonator will change, and it will start to reflect power at the resonant frequency, a signal whose amplitude will be correlated to the intercepted charge from the halo. We propose a reflection-based measurement to detect beam halo (Figure 1). A diamond blade/wire scans across the beam. The signal recorded is resonator coupling change due to particle-induced conductivity in diamond. The role of charged particles is to promote bound electrons into the conduction band across the band gap.

Simulations for scanning diamond blade scrapper monitor

To simulate the response of the device to different current densities in the beam halo, we utilized a simple model of a diamond blade positioned between a 100% reflector and a variable reflector (Figure 2). We can adjust the reflectivity of the second reflector to provide critical coupling to this simple resonator. When the coupling is tuned to critical, we can demonstrate a sharp resonance (see Figure 3). If we change the concentration of electrons in the conduction band from 0 to 10^{12} cm^{-3}, the coupling is significantly reduced, i.e., there is a strong reflection from the device. This reflection can be used to measure of the charge passing through the diamond blade. Following results from, we assume that there is no dependence on electron beam energy (between MeV and GeV) on how many electrons are promoted into conduction band when electrons pass through diamond.

If we scan the effective concentration of carriers in the conduction band of the diamond, N_e, and plot the reflection signal as a function of time (see Figure 4), we observe generally nonlinear response of the resonator. To measure such high concentrations with the test resonator, we first note that the quality factor of this resonator is completely dominated by the conductivity losses in the diamond blade. Therefore, the decay time of a transient measurement (Figure 4) is fully governed by the relaxation time of the diamond's conductivity.

We take a 5-ns relaxation time as a representative time for diamond. The concentration (N_e) evolves as $N_0 \times exp(-t/\tau)$, where τ is the relaxation time. Therefore, during relaxation, N_e decreases and enters a linear region. That is why one can take several test resonator signal points, where the response is linear, for several subsequent times t_1, t_2, t_3. This would allow one to determine τ as well as N_e at $t=0$.

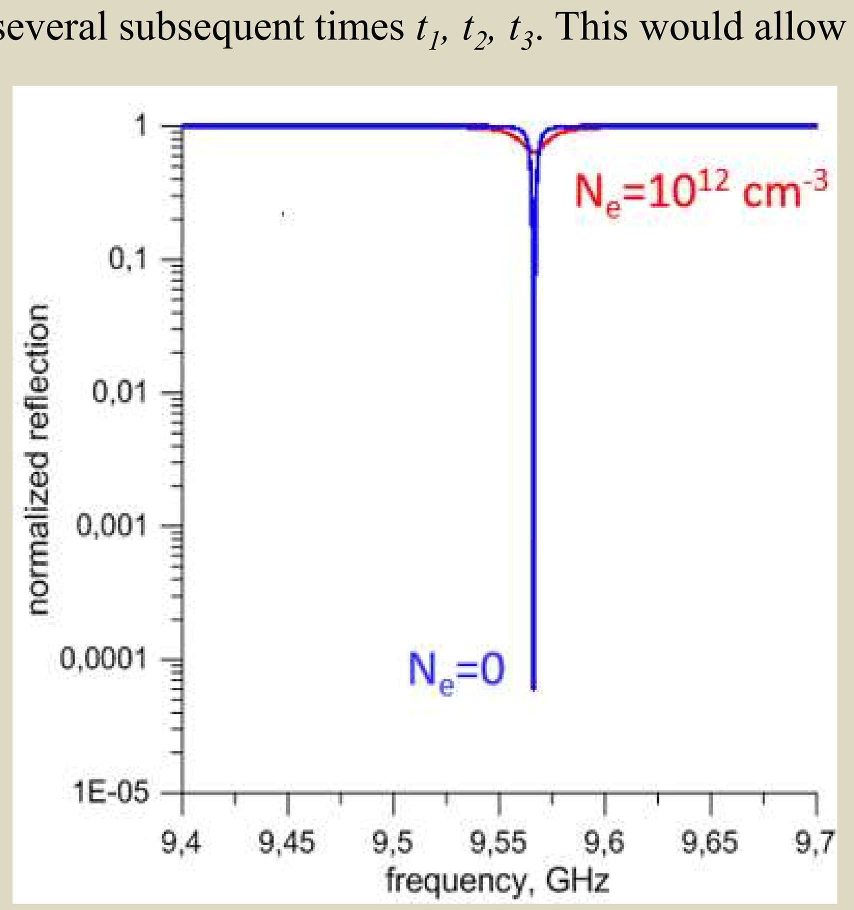

Figure 3: Simulation of resonator S_{11} for beam and no beam for the initial near to critical coupling.

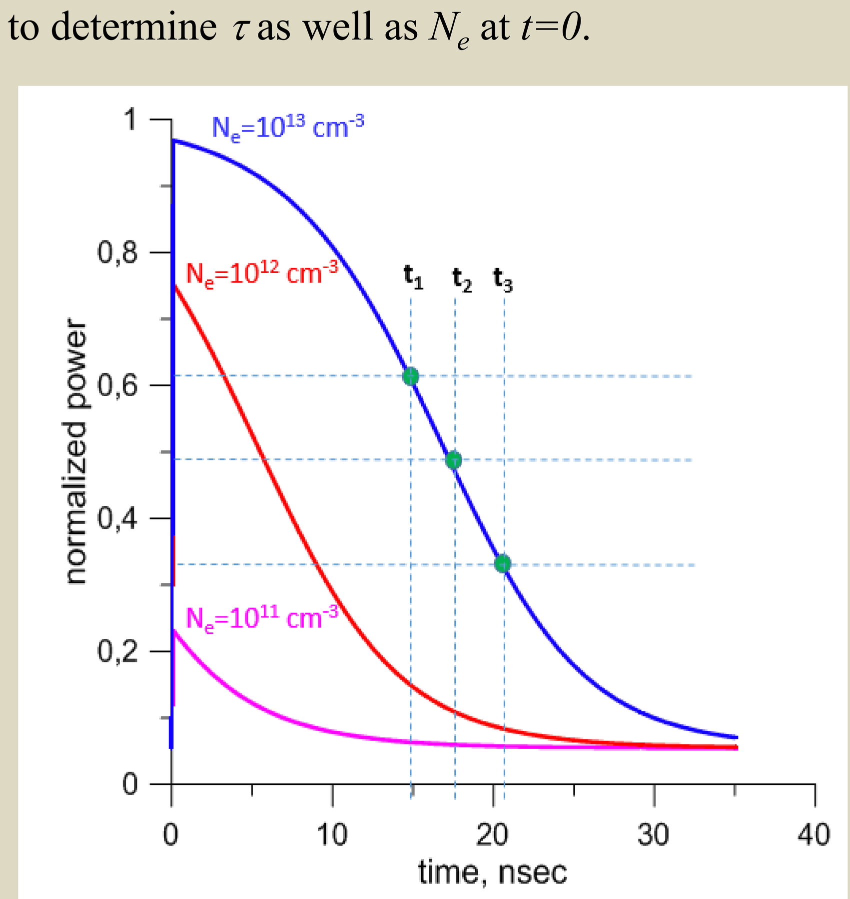

Figure 4: Time response of resonator for different carrier concentrations.

BEAM TEST OF DIAMOND SAMPLES

Figure 5: Diamond samples: a – CVD electronic grade sample from Applied Diamonds Inc., b – detector grade CVD diamond from II-VI, detector grade single crystal diamond from ElementSix.

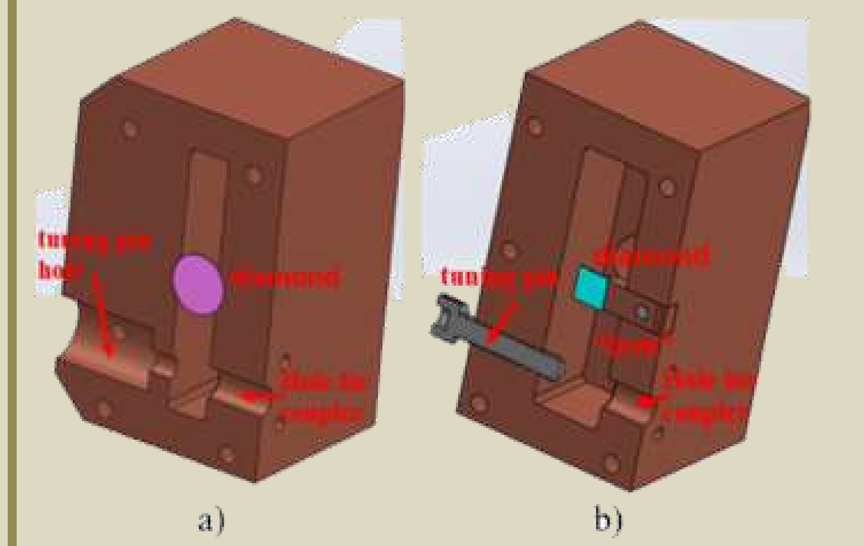

Figure 6: Test resonators: a – resonator to accommodate circular diamond sample of II-VI, b – resonator to accommodate square samples of Applied Diamond and ElementSix.

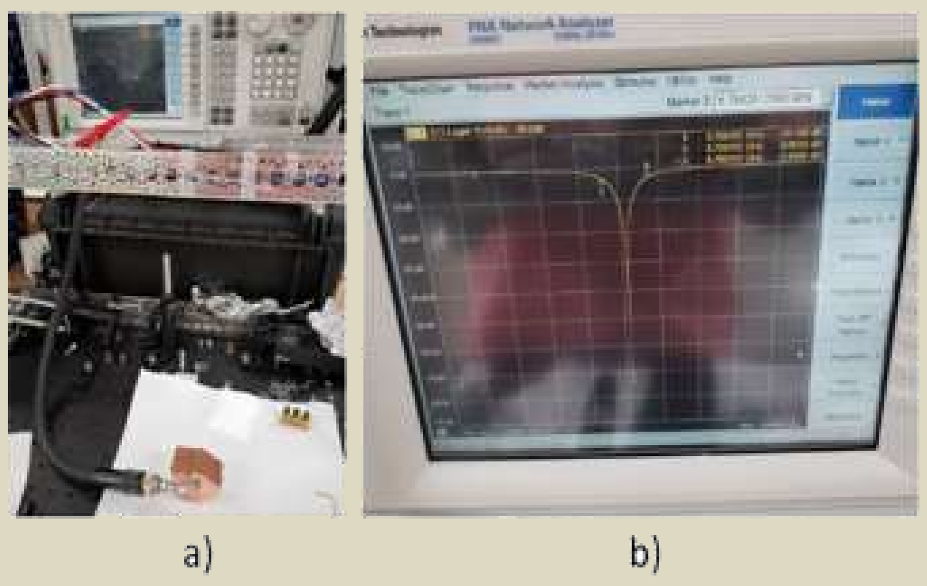

Figure 7: Tuning of copper resonator with built-in diamond sample (Element6) before installation at VBS: a – network measurement setup, b – final curve for the tuned resonator.

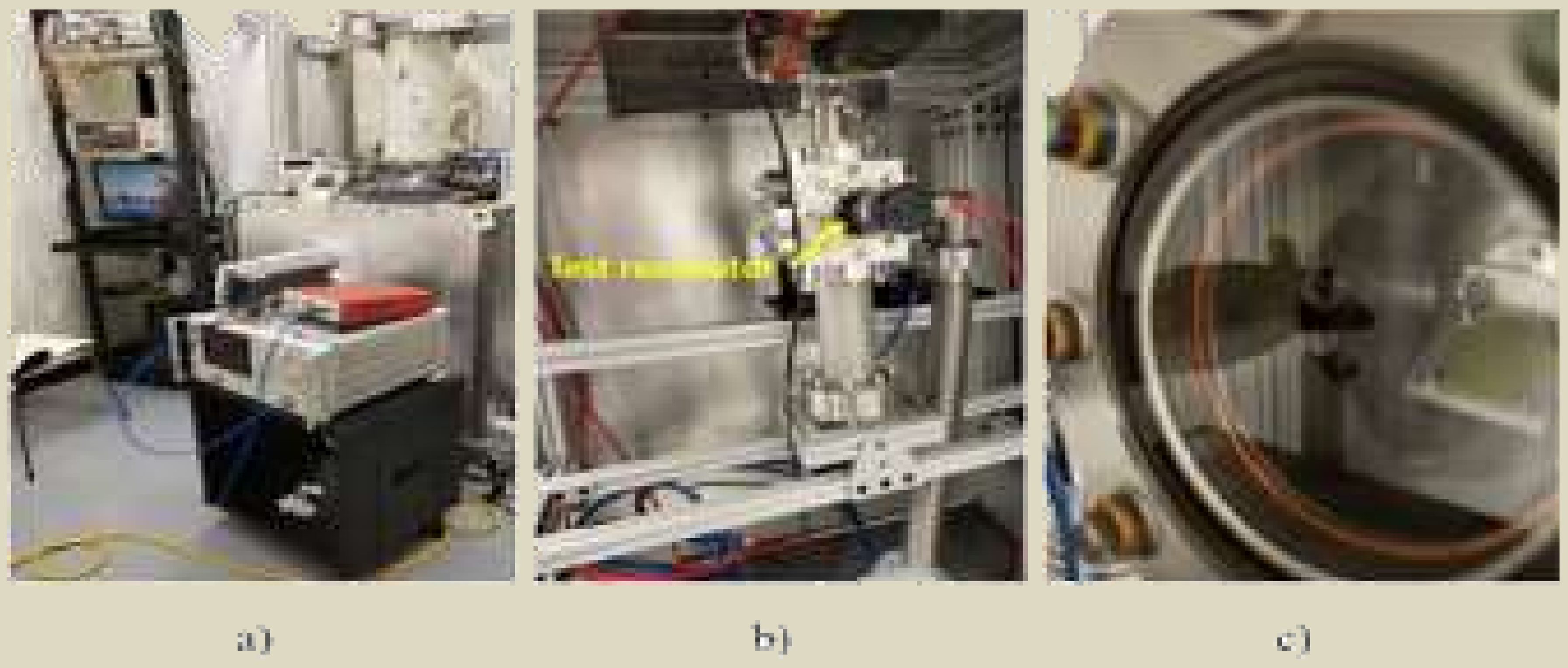

Figure 8: VBS test stand with installed test resonator: a – overall view, b – test resonator in vacuum chamber, c – view through quartz window to YAG-screen.

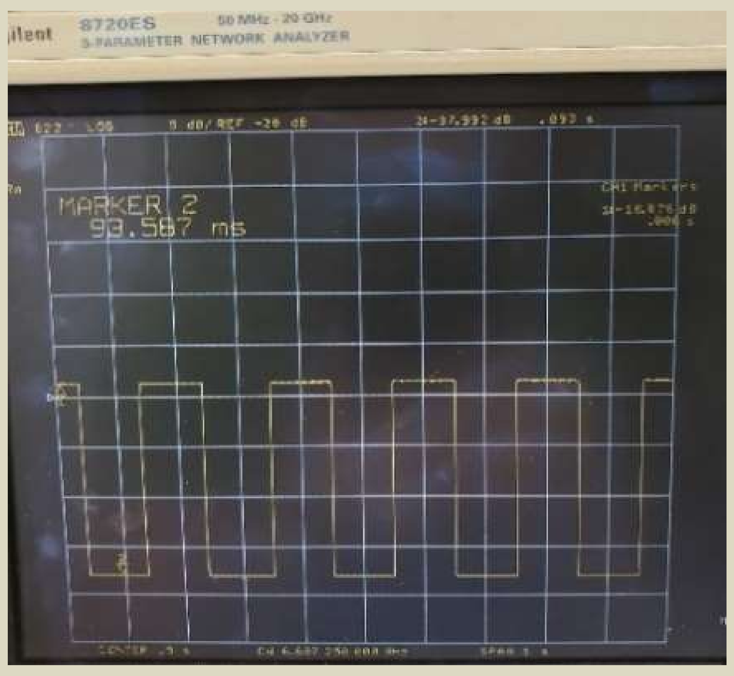

Figure 9: Monitor time response for 5 Hz steered beam.

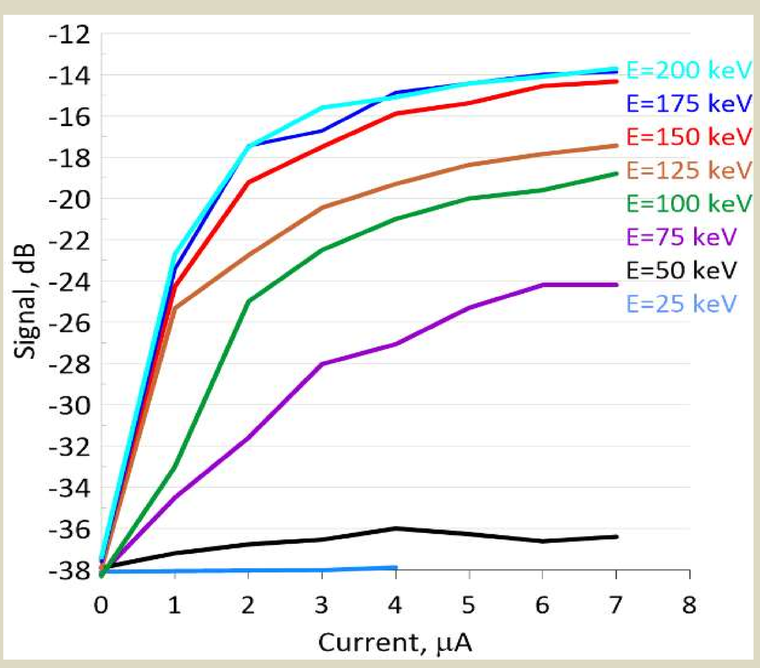

Figure 10: Experimental plot of beam monitor response amplitude vs beam current for several beam energies.

DESIGN OF HALO MONITOR FOR TEST IN AWA

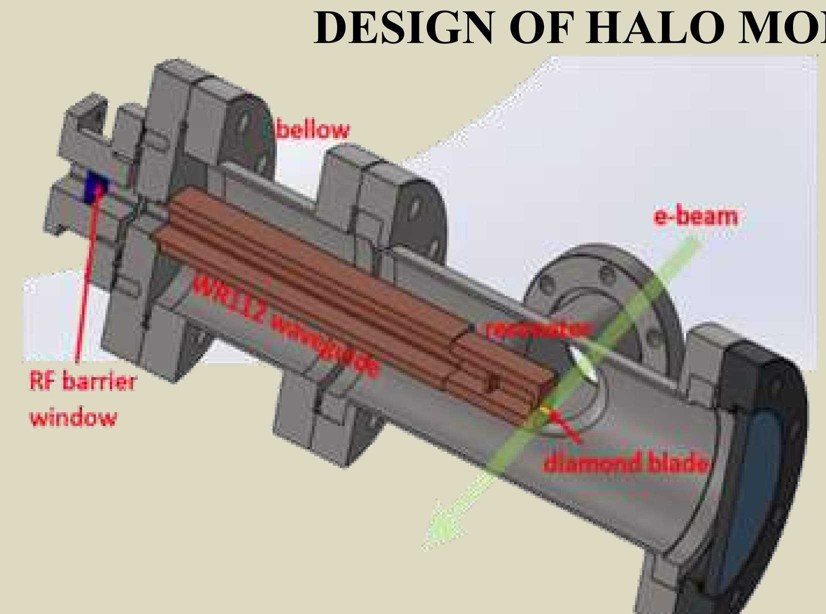

Figure 11: Engineering design of scanning diamond blade scraper halo monitor based on motorized bellow for tests at AWA.

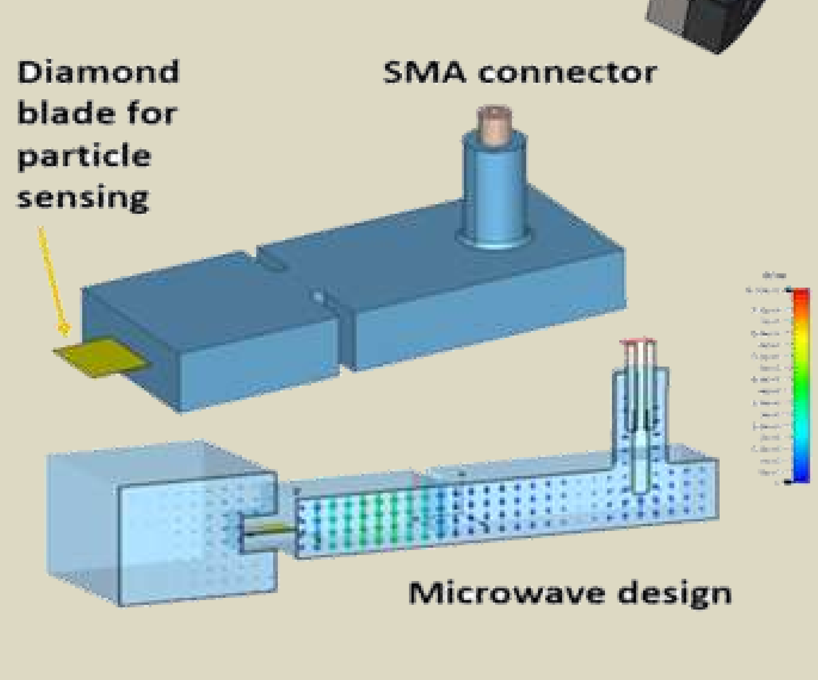

Figure 12: RF design of a diamond blade halo detector resonator with RF connector.

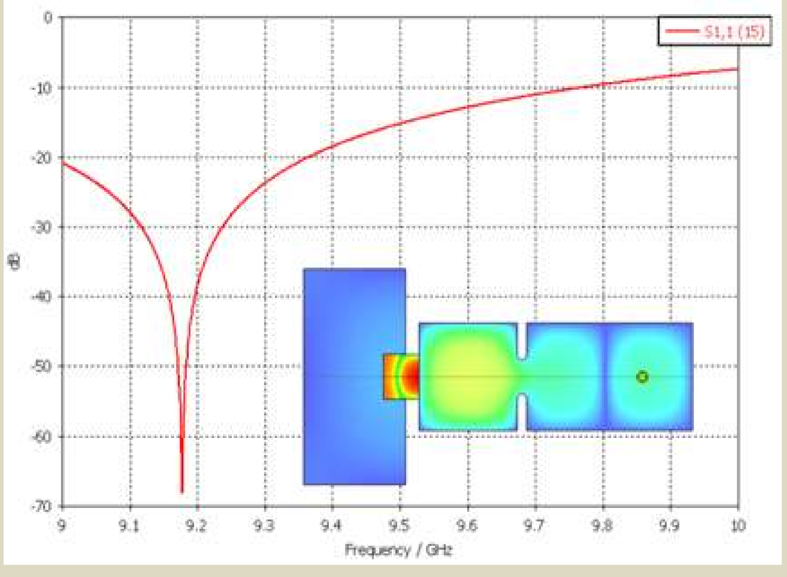

Figure 13: Reflection simulation and field distribution in the resonator.