



An Electrodeless Diamond Beam Monitor

Sergey Kuzikov, Pavel Avrakhov, Ernest Knight, Yubin Zhao, Euclid TechLabs, Solon,
Ohio

Chunguang Jing, ANL, Lemont, Illinois; Euclid Beamlabs, Bolingbrook; Euclid TechLabs,
Solon, Ohio

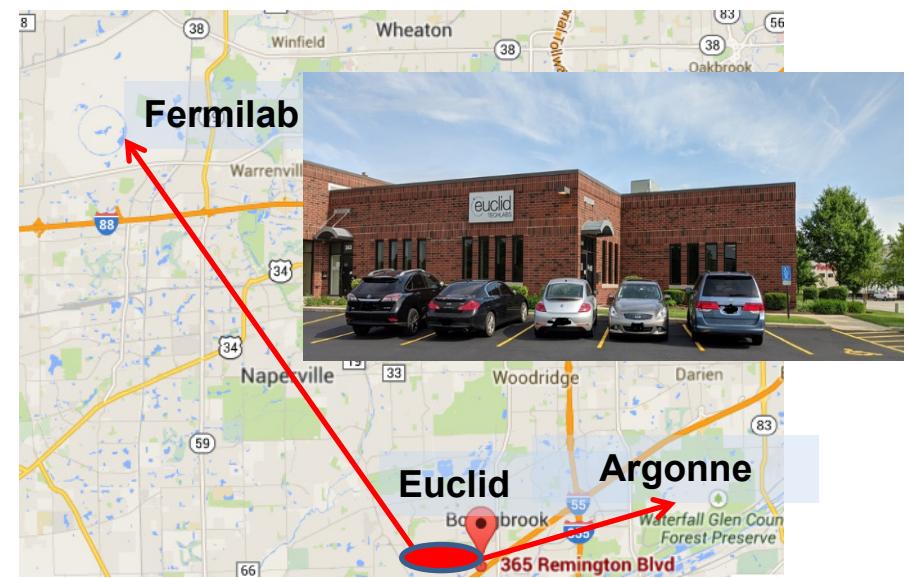
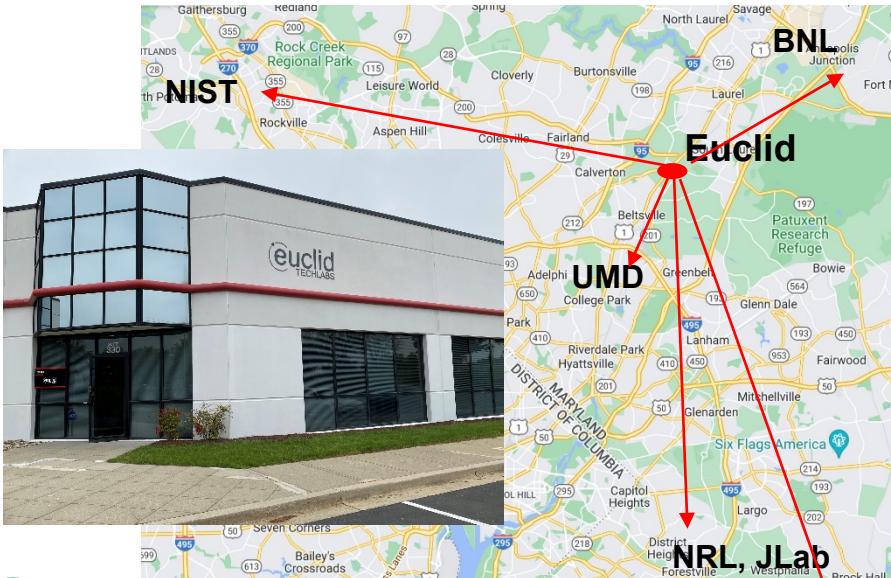
John Power, Doran Scott, Eric Wisniewski, ANL, Lemont, USA

This work was supported by DoE SBIR grant # DE-SC0019642.

08/11/2022

Euclid Techlabs/Euclid Beamlabs

Euclid Techlabs, LLC is a research and development company specializing in linear particle accelerators, ultrafast electron microscopy, and advanced material technologies. The company was formed in 2003. Euclid Beamlabs LLC, formed in the winter of 2014, is a sister (spin-off) company of Euclid Techlabs LLC, particularly to commercialize industrial accelerator and related advanced material technologies developed at Euclid Techlabs. Euclid has developed expertise and products in several innovative technologies: time-resolved ultra-fast electron microscopy; ultra-compact linear accelerators; electron guns with thermionic, field emission or photo-emission cathodes; fast tuners for SRF cavities; advanced dielectric materials; HPHT and CVD diamond growth and applications; thin-film for accelerator technologies; Present: 27 people research staff (researchers, engineers, technicians) and 5 administrative. 16 PhDs in accelerator physics and material science, 32 staff. 2 labs: Bolingbrook, IL (accelerator R&D lab) and Beltsville, MD (material science lab). Long term collaborations with National Labs and Institutes: ANL, Fermilab, BNL, Jlab, LBL, SLAC, LANL, NIST, NIU, IIT, etc.



Products & Capabilities Snapshot

Products

- UltraFast Pulser (UFP™) for TEM
- Dislocation free diamond for Xray optics
- Compact X-Ray Source
- NCRF and SRF electron sources
- Low loss ceramics (linear and non-linear)
- LINAC
- RF window
- In flange BPM

Capabilities

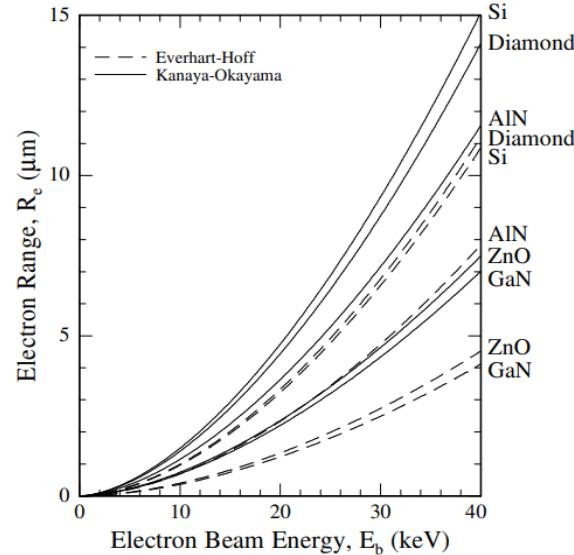
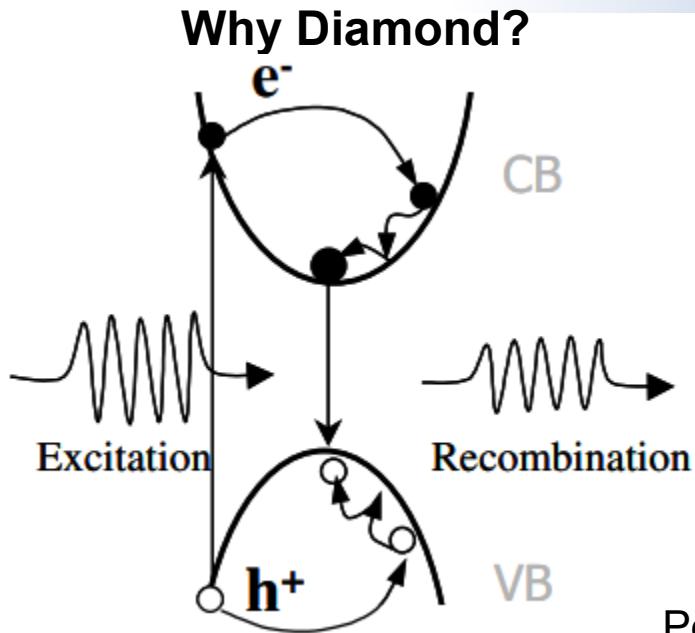
- Femtosecond Laser Ablation System
- Thin Film Deposition Lab
- EM Testing Lab
- Radiation Shielding/Testing Lab



2019
R&D
100
WINNER

Dielectric permittivity depends on concentration n_e of free electrons and holes:

$$\epsilon = \epsilon_0 - \frac{2\pi e n_e (\mu_e + \mu_h)}{\omega} i$$

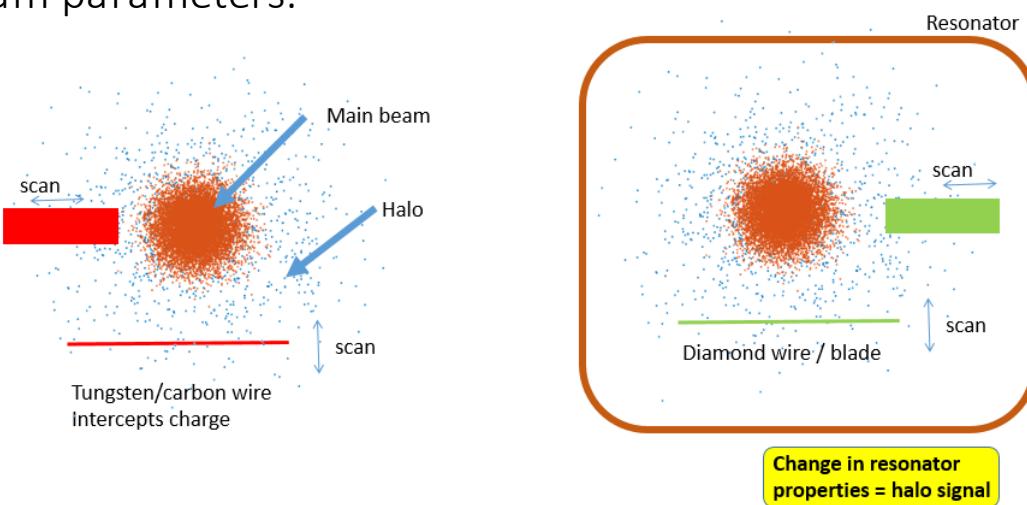


Penetration depth vs beam energy

- Diamond is a wide-bandgap semiconductor ($E_g = 5.5$ eV). $\Re=5.7$, $\tan\Re\sim 10^{-4}$ in X-band.
- Carrier lifetimes of more than 2 μ s have been measured in single-crystal CVD diamond.
- Diamond exhibits the highest predicted breakdown field (E_{br}) of any semiconductor with values in the range 5–10 MVcm⁻¹.
- Diamond has the highest thermal conductivity of any material known.
- Radiation hardness, high saturated carrier velocities, and low atomic number.

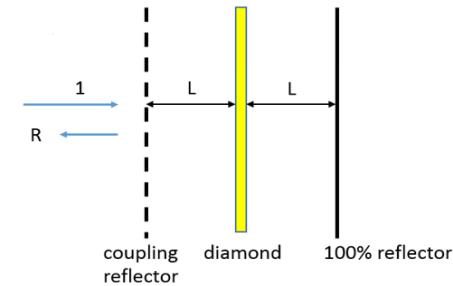
Concept of Electrodeless Beam Halo Monitor

Halo monitor is based on a thin piece of diamond (blade) placed in an open high-quality microwave resonator. The blade partially intercepts the beam. By measuring the change in RF properties of the resonator, one could infer the beam parameters.

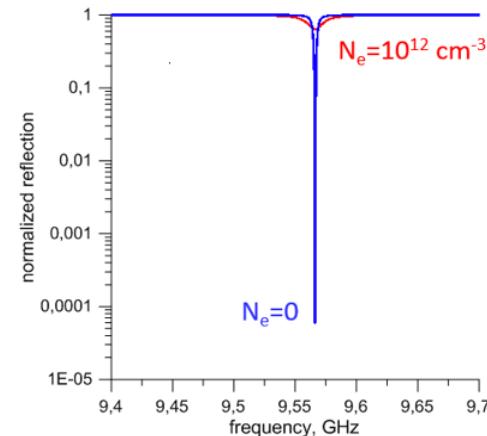


Left: standard wire / blade beam halo scan.

Right: Proposed diamond blade beam halo scanning.

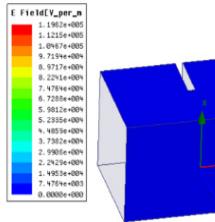


Model of the resonator with inserted in it diamond sample.

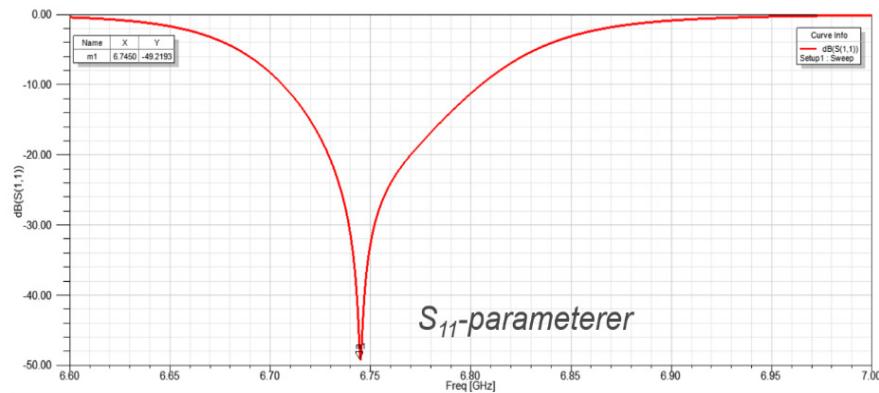


Simulation of S_{11} for beam and no beam for the resonator with critical coupling.

RF Design of 6.7 GHz Halo Monitor



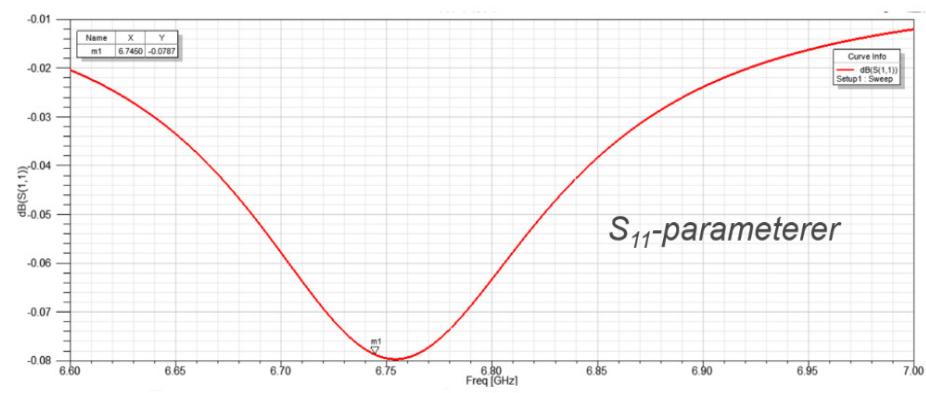
Field structure at 6.745



S_{11} parameter of the resonator with diamond not exposed by beam ($N_e = 0 \text{ cm}^{-3}$, $\tan\delta = 10^{-3}$).



Field structure at 6.745 GHz

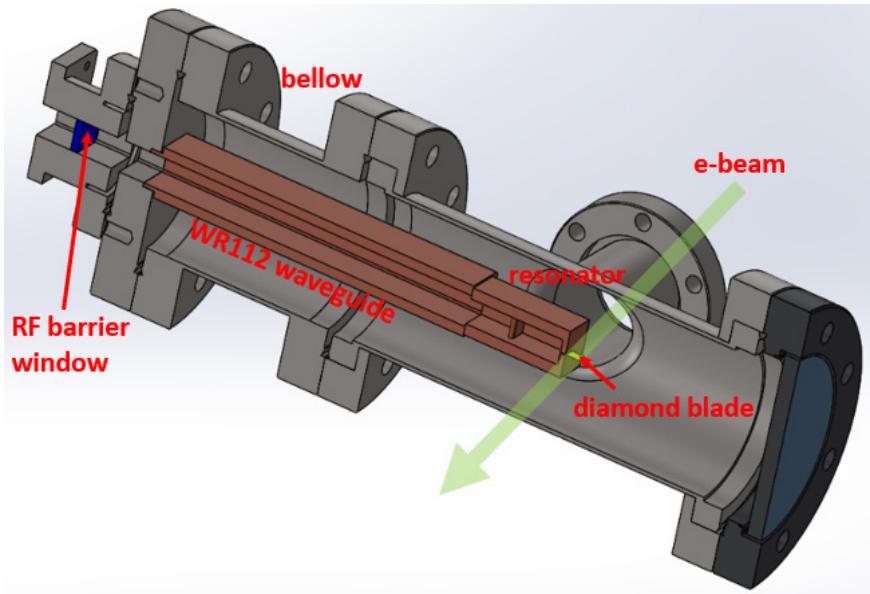


S_{11} parameter of the resonator with diamond exposed by beam ($N_e = 10^{14} \text{ cm}^{-3}$, $\tan\delta = 0.3$).

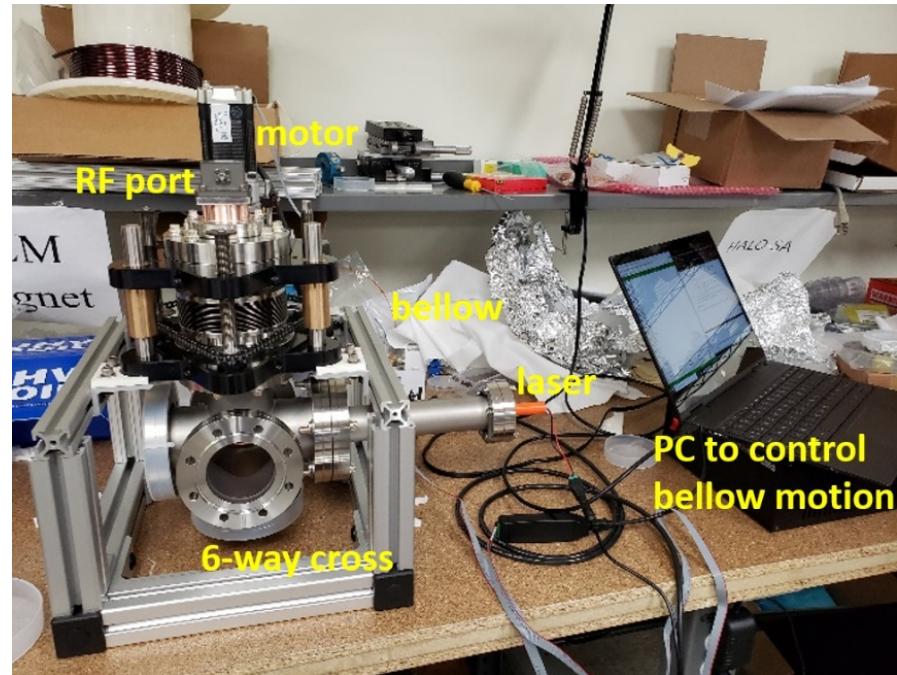
1D Scanning Halo Monitor



Diamond samples

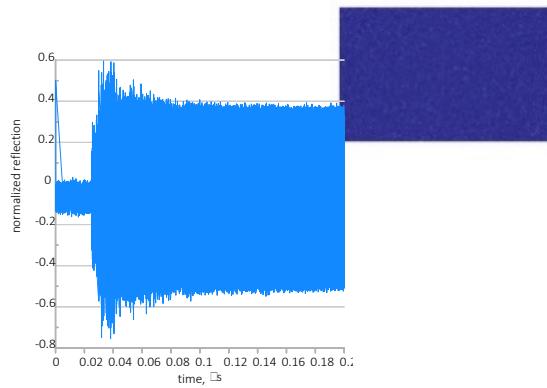


Sketch of scanning halo monitor with diamond blade and motorized bellow.

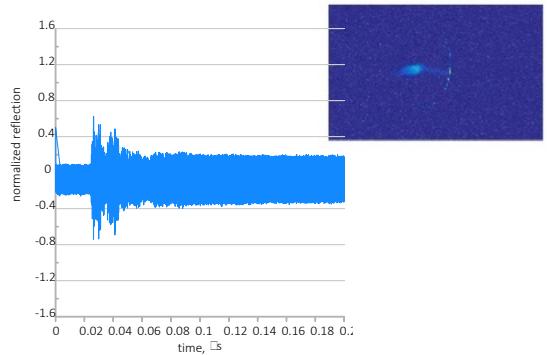


1D scanning monitor under mechanical test.

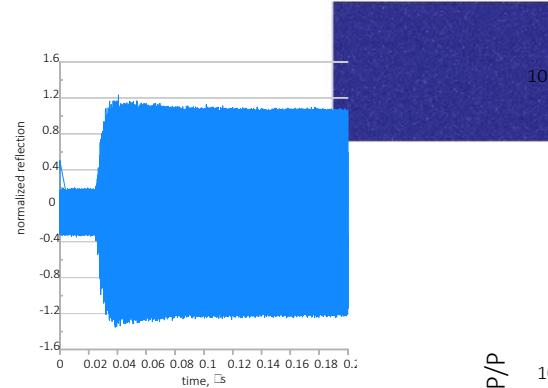
Measurement with Beam Located in Center and Resonator Moved Across Pipe



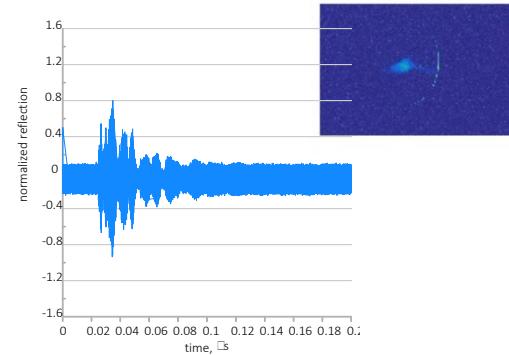
Charge 47 pC, position $x=0$ mm



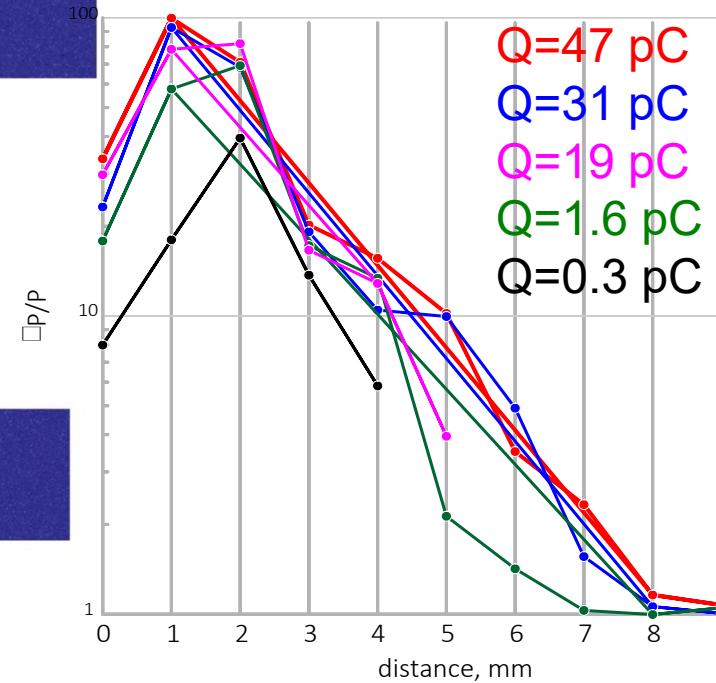
Charge 47 pC, position $x=6$ mm



Charge 47 pC, position $x=3$ mm

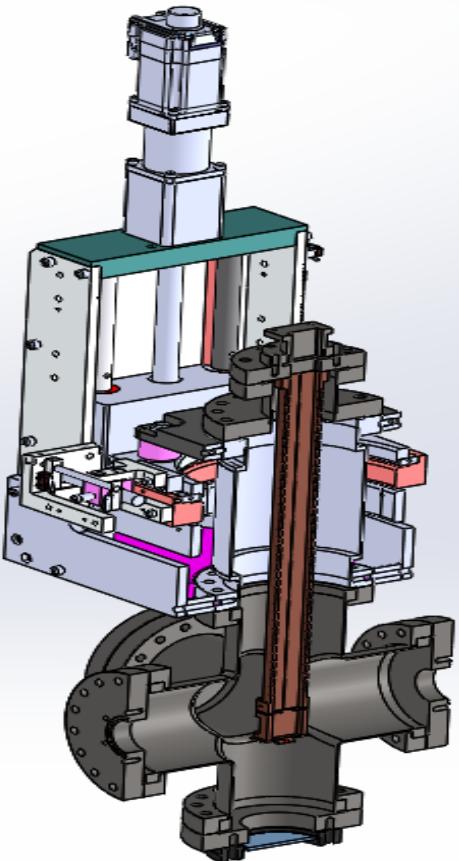


Charge 47 pC, position $x=9$ mm

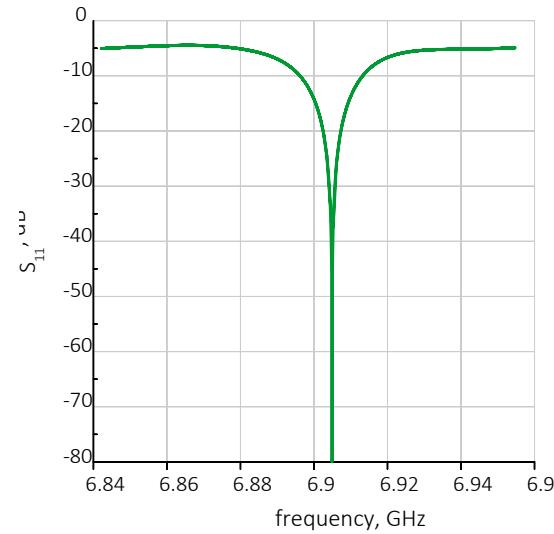
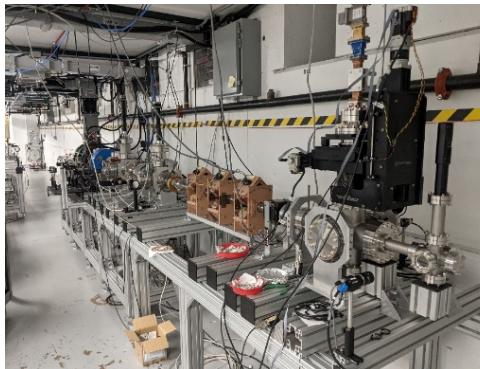
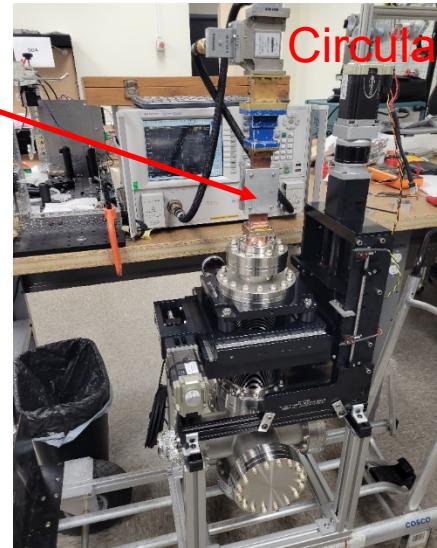


Beam halo monitor response vs transverse shift of diamond blade.

2D Diamond Beam Halo Monitor



Stub tuner Circulator

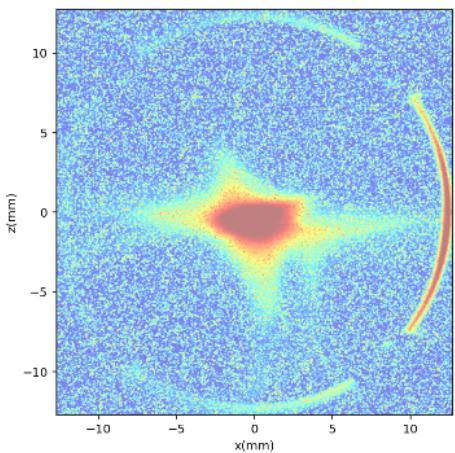


S_{11} parameter vs frequency

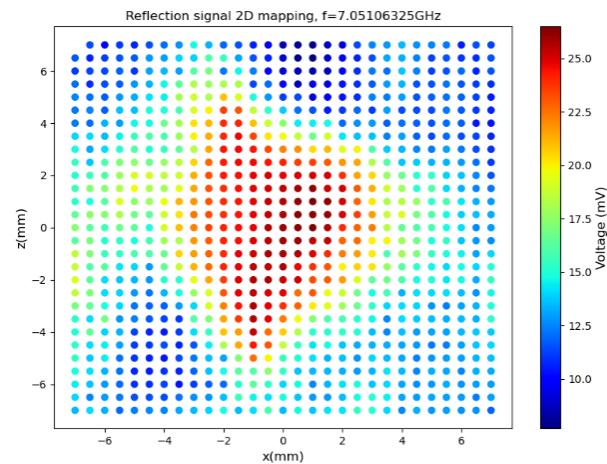
Halo monitor at AWA beamline

2D Maps of Electron Beam

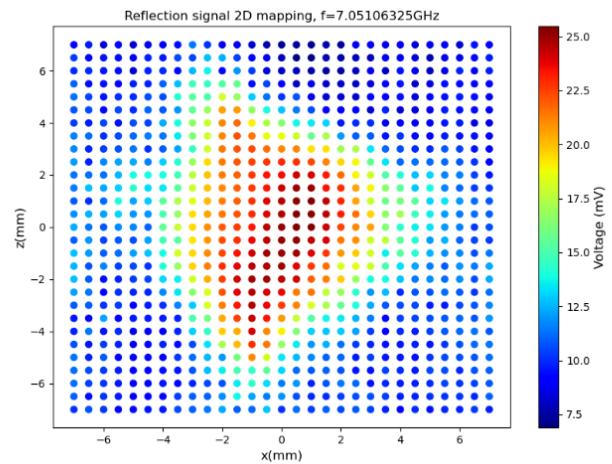
Halo monitor was capable to show so small signals that were not visible for the conventional YAG screen!



YAG screen image.

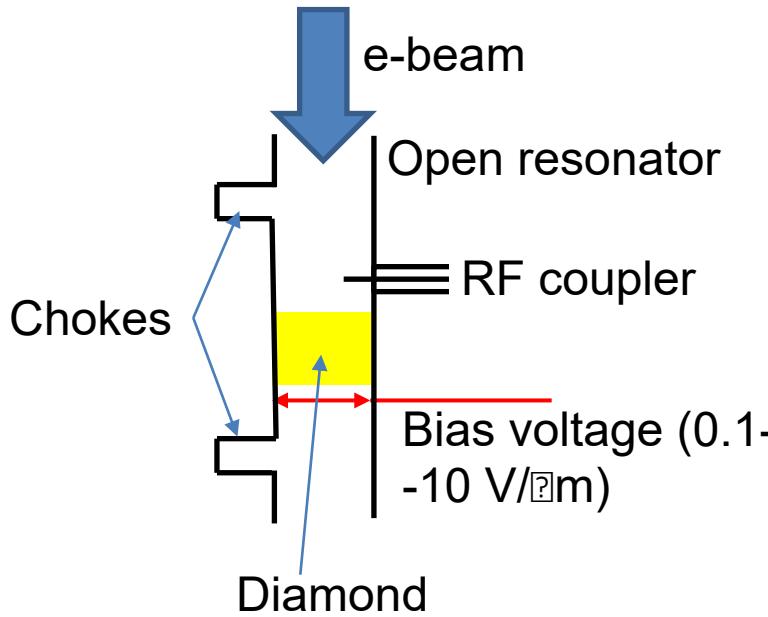


2D map of the same beam plotted by means of the halo monitor.



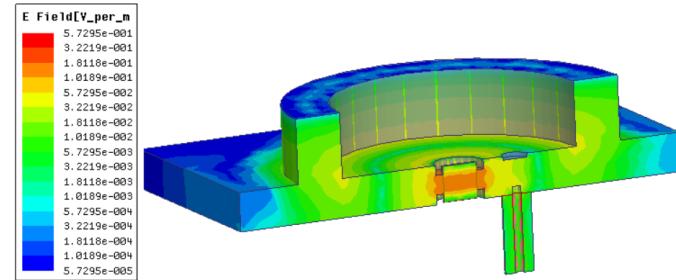
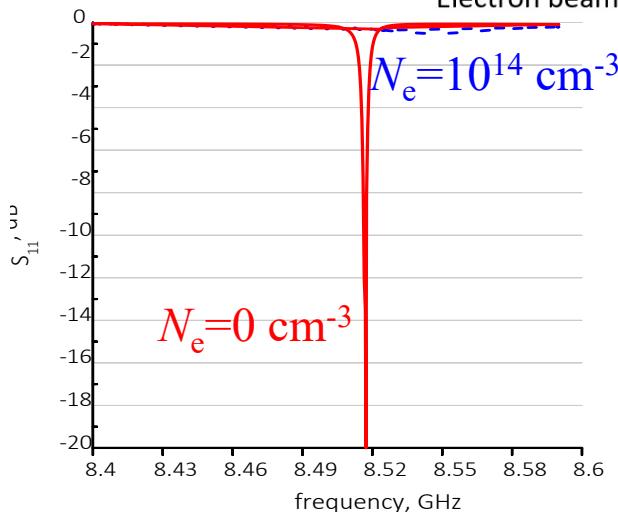
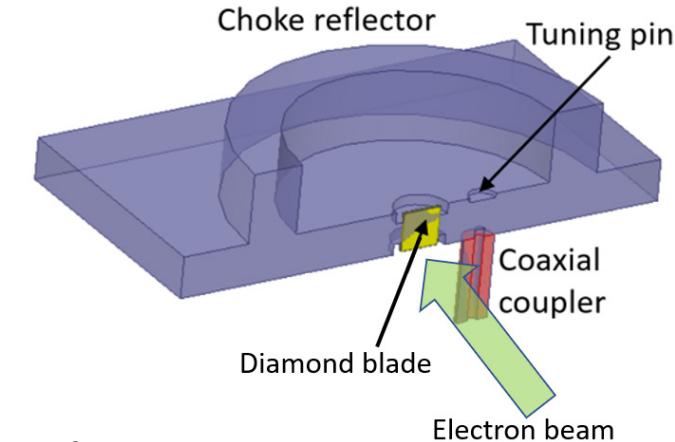
After background subtraction.

Avalanche Diamond Beam Monitor (ADBm)



- If one induced free carriers in diamond and forced its to drift in DC electric field, these particles due to collisions could create new secondary particles. These scenario is considered as an avalanche that can involve much higher concentration of the particles in comparison with the non-biased case.
- Biased diamond detectors exist and show \sim 10 times sensitivity enhancement. Applying of a bias voltage makes sense for electrodeless detectors as well.
- We plan to show an enhanced sensitivity of the avalanche monitor in comparison with the classical quad detectors and the non-biased diamond electrodeless detectors previously developed by Euclid Techlabs

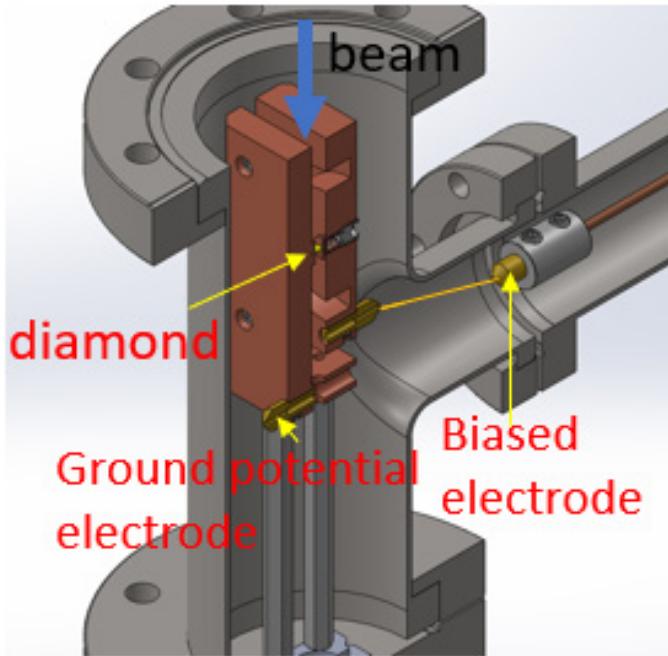
8.5 GHz ADBM RF Design



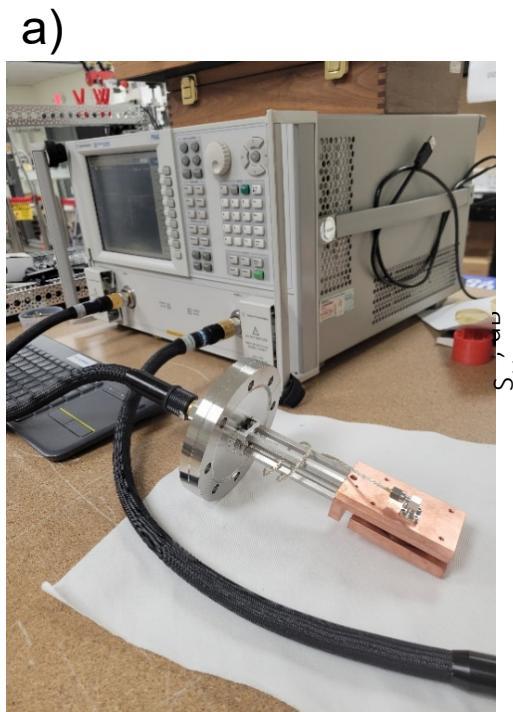
E-field structure at resonant frequency when no beam (logarithmic scale).

S_{11} parameter when no beam (solid red) and with beam exposure (dashed blue).

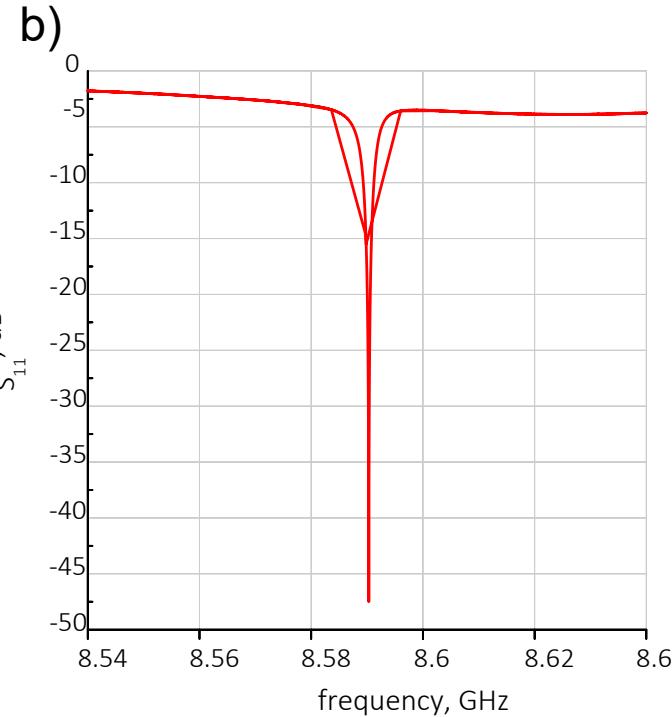
8.5 GHz ADBM Engineering Design



ADBM cut view.



Measurements of S_{11} parameter for ADBM: a – test setup, b – the measured S_{11} parameter (b).

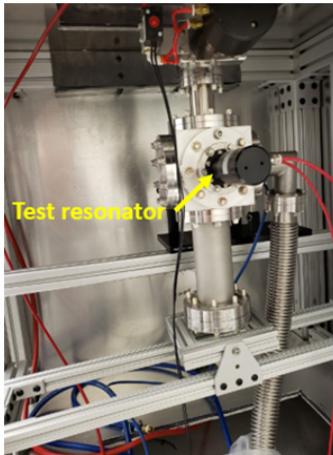


Vertical Beam Stand (VBS)

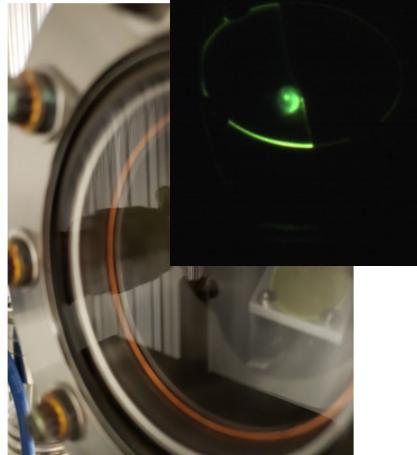
VBS delivers a DC or modulated electron beam of the 20-200 keV energy with the current 1-50 μ A.



a)



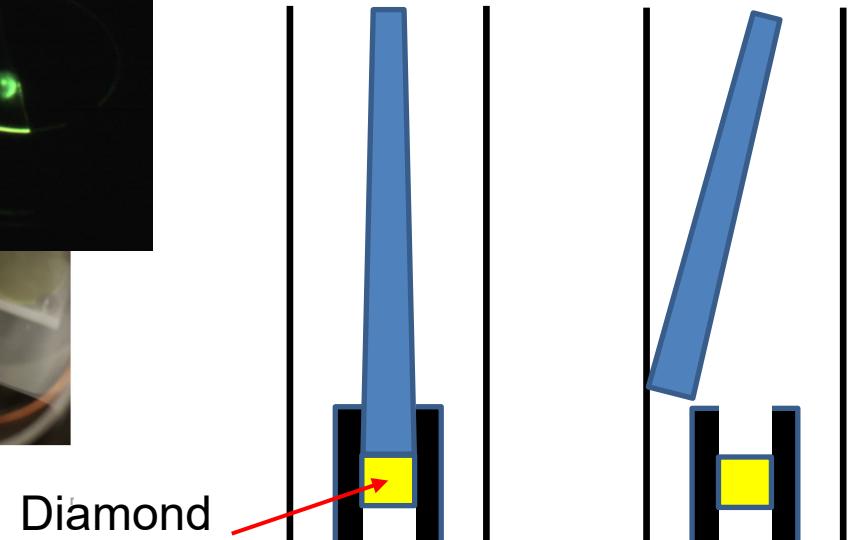
b)



c)

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

Electron beam Electron beam



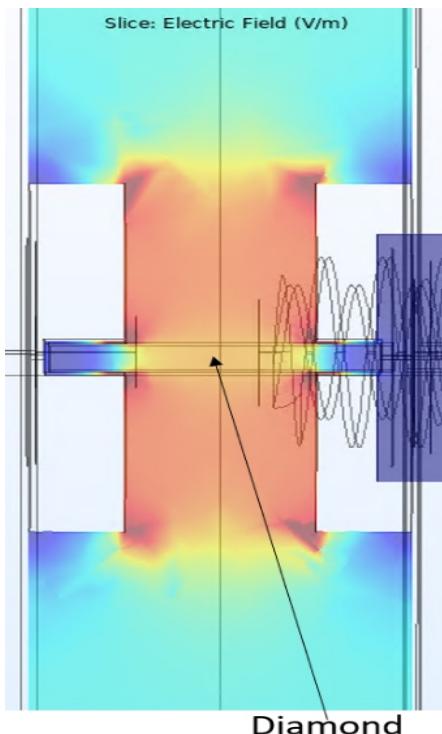
Beam on
(50% of time)

Beam off
(50% of time)

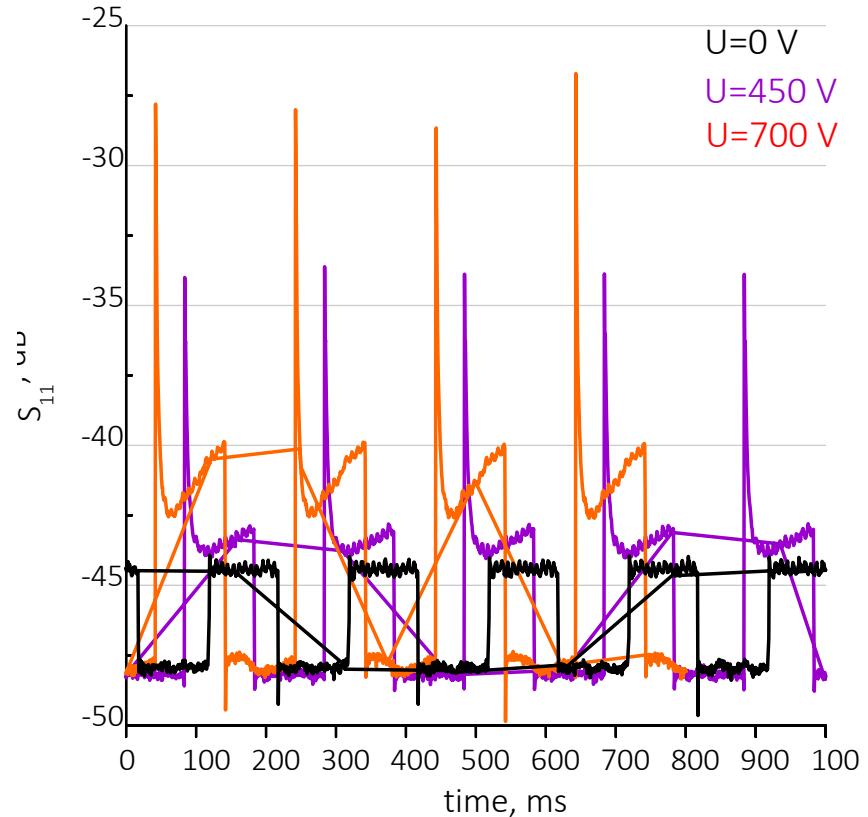
VBS beam modulation (5 Hz)

First VBS Test with 8.5 GHz ADBM

We observed frequent breakdown events when voltage exceeded 400 V.



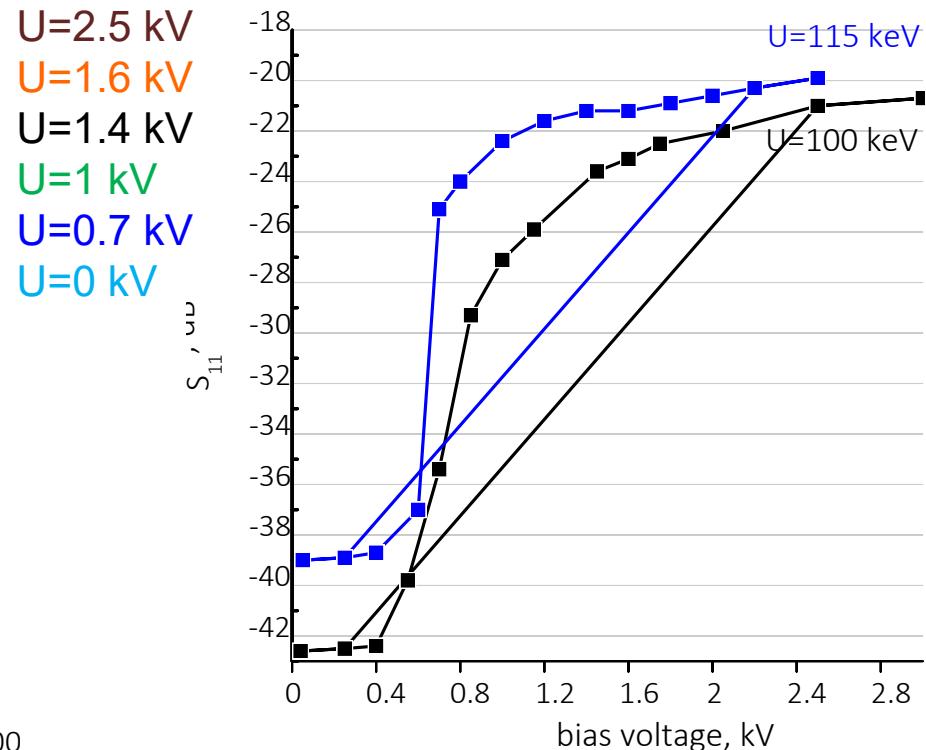
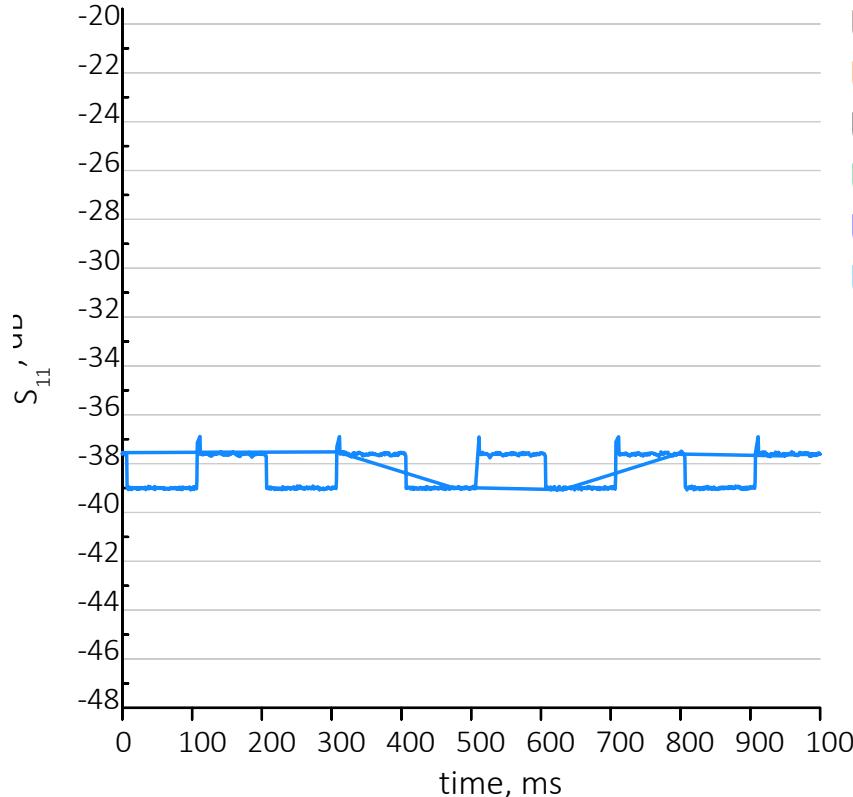
DC electric field map for ADBM



ADBM response to the modulated beam exposure for different applied bias voltage

Experiment at VBS with ADBM Biased with AC Voltage

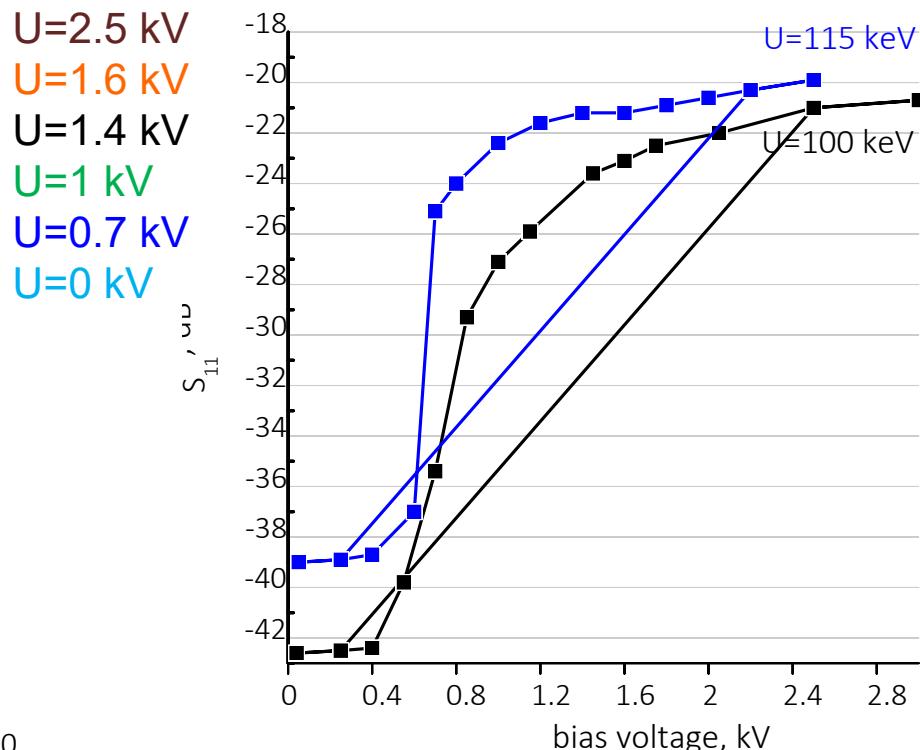
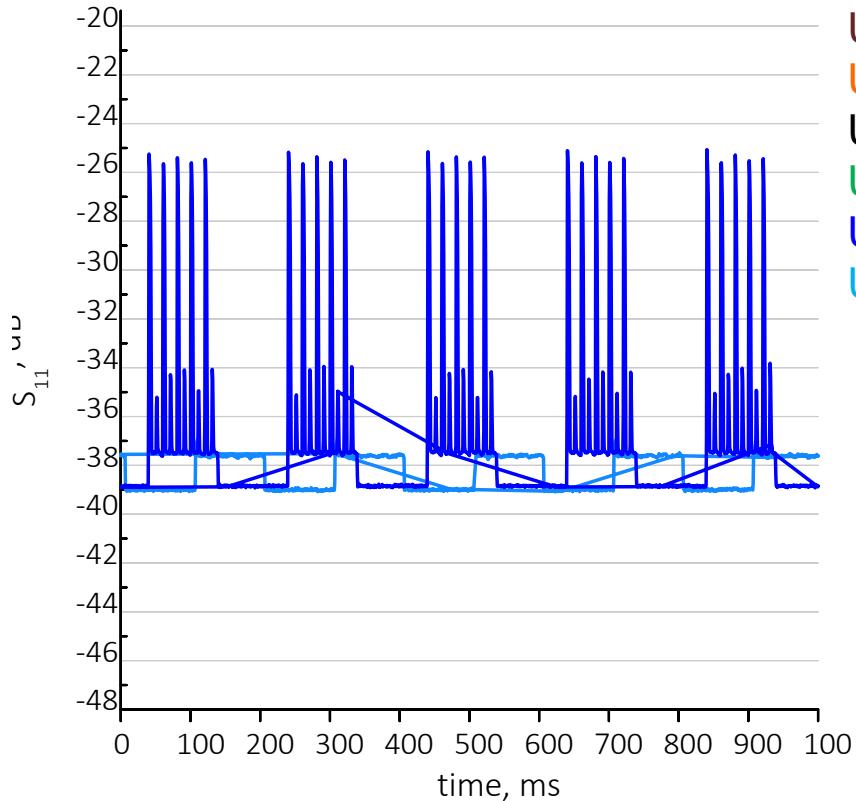
No breakdown observed!



Beam monitor response signal
vs applied bias voltage.

Experiment at VBS with ADBM Biased with AC Voltage

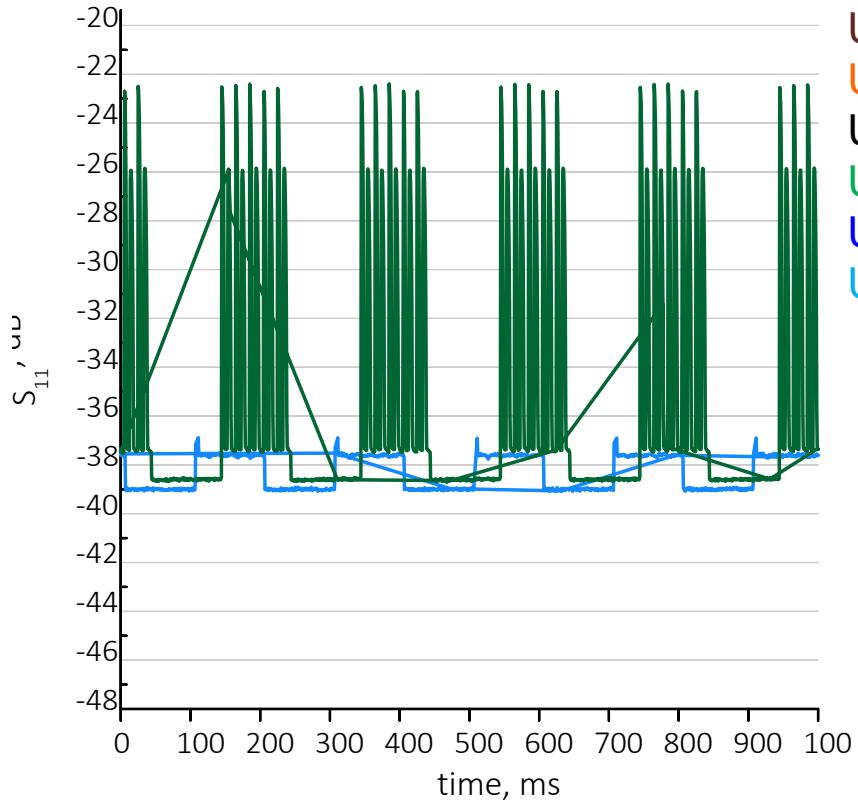
No breakdown observed!



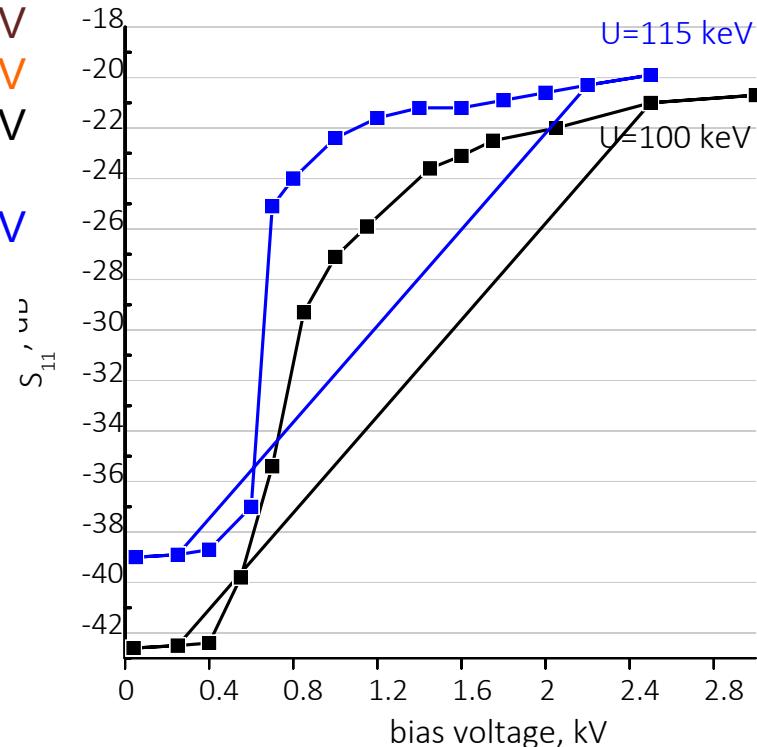
Beam monitor response signal
vs applied bias voltage.

Experiment at VBS with ADBM Biased with AC Voltage

No breakdown observed!



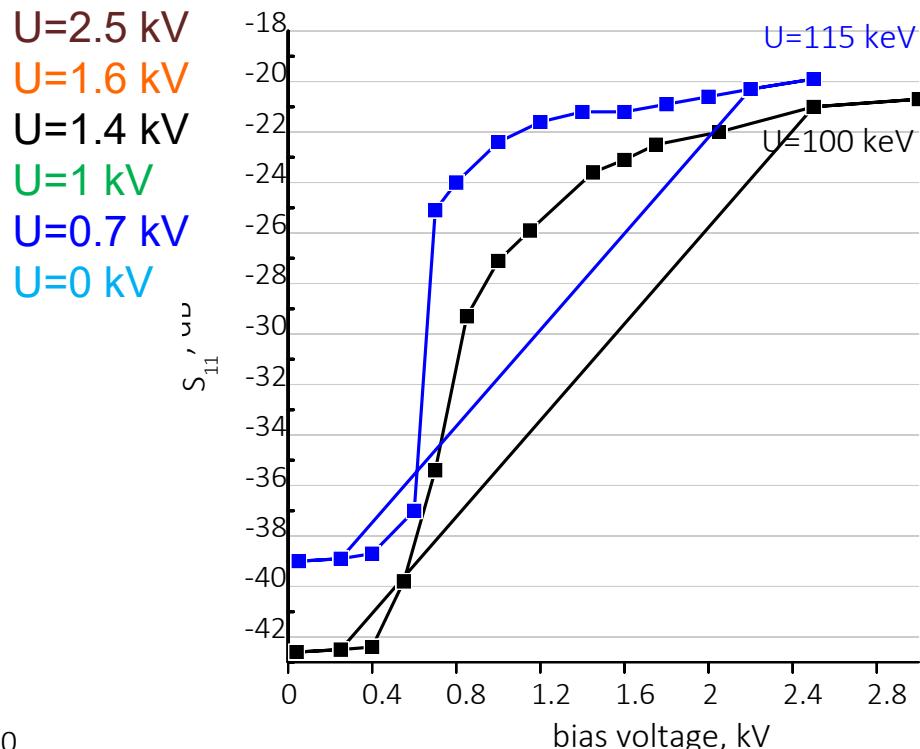
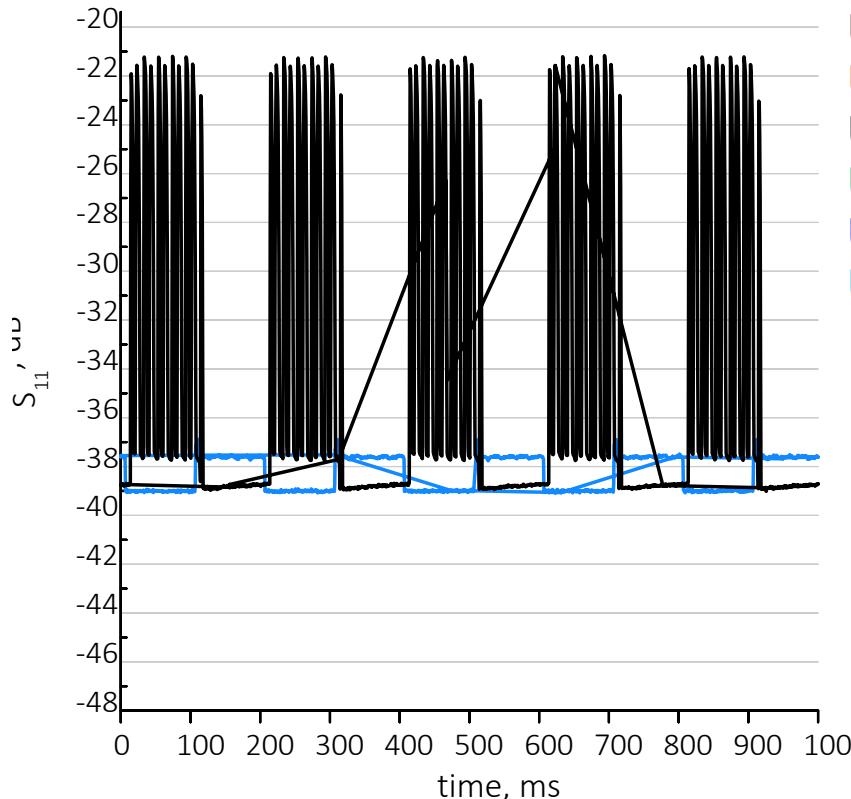
$U=2.5 \text{ kV}$
 $U=1.6 \text{ kV}$
 $U=1.4 \text{ kV}$
 $U=1 \text{ kV}$
 $U=0.7 \text{ kV}$
 $U=0 \text{ kV}$



Beam monitor response signal
vs applied bias voltage.

Experiment at VBS with ADBM Biased with AC Voltage

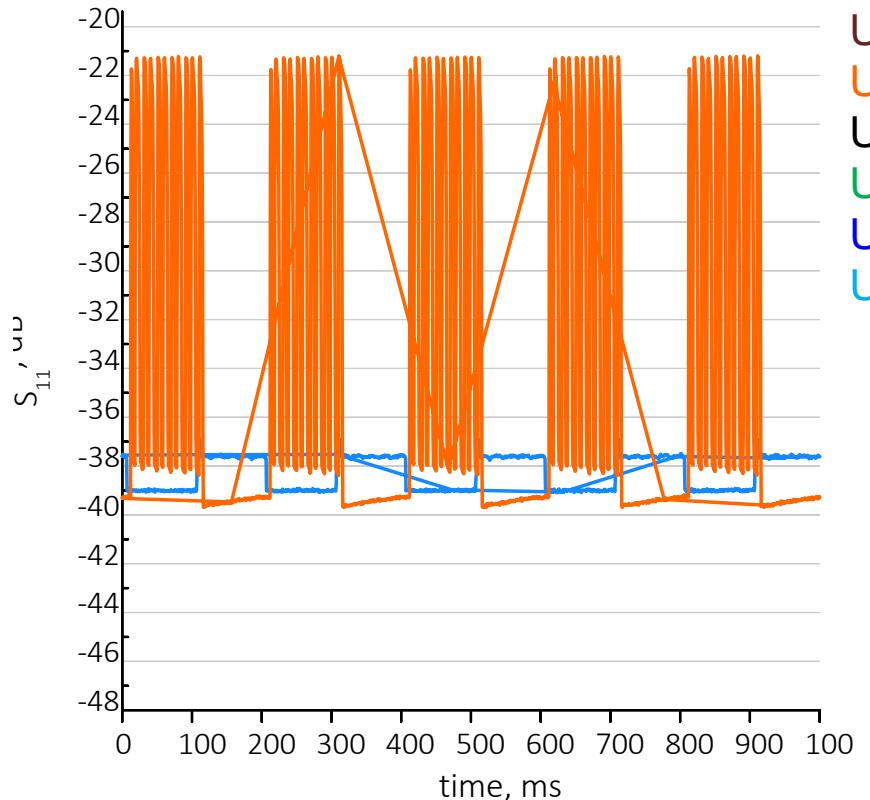
No breakdown observed!



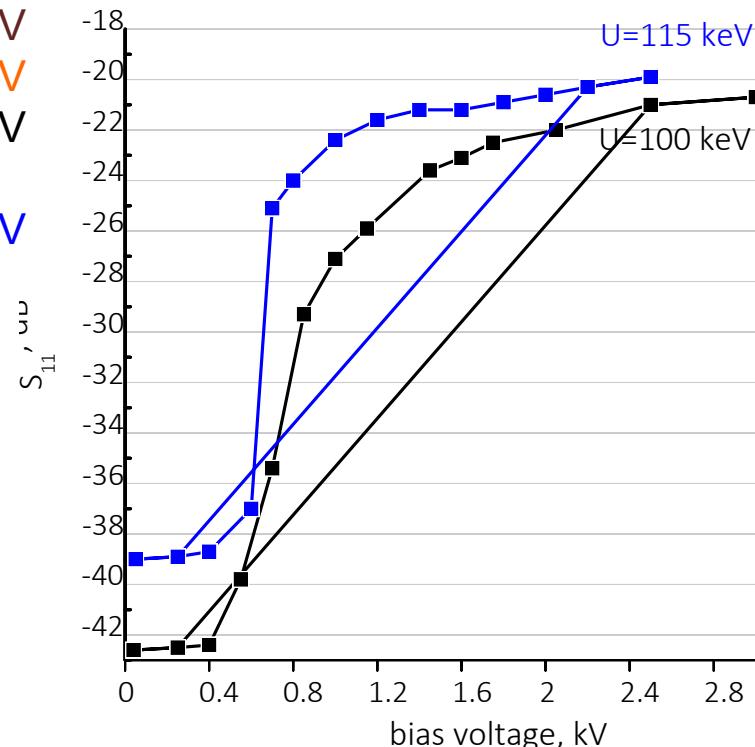
Beam monitor response signal
vs applied bias voltage.

Experiment at VBS with ADBM Biased with AC Voltage

No breakdown observed!



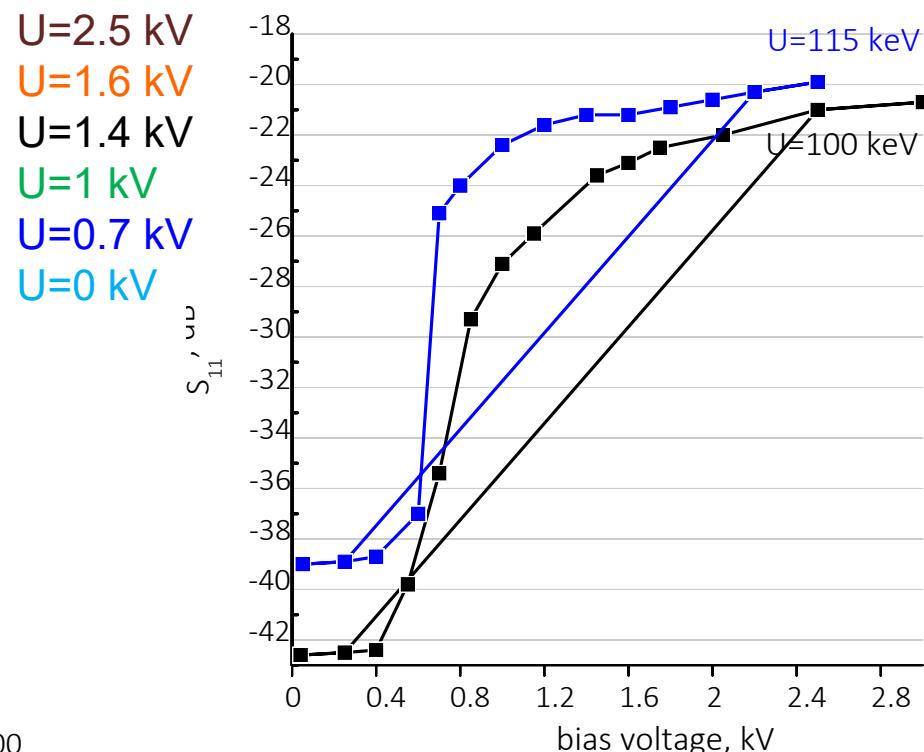
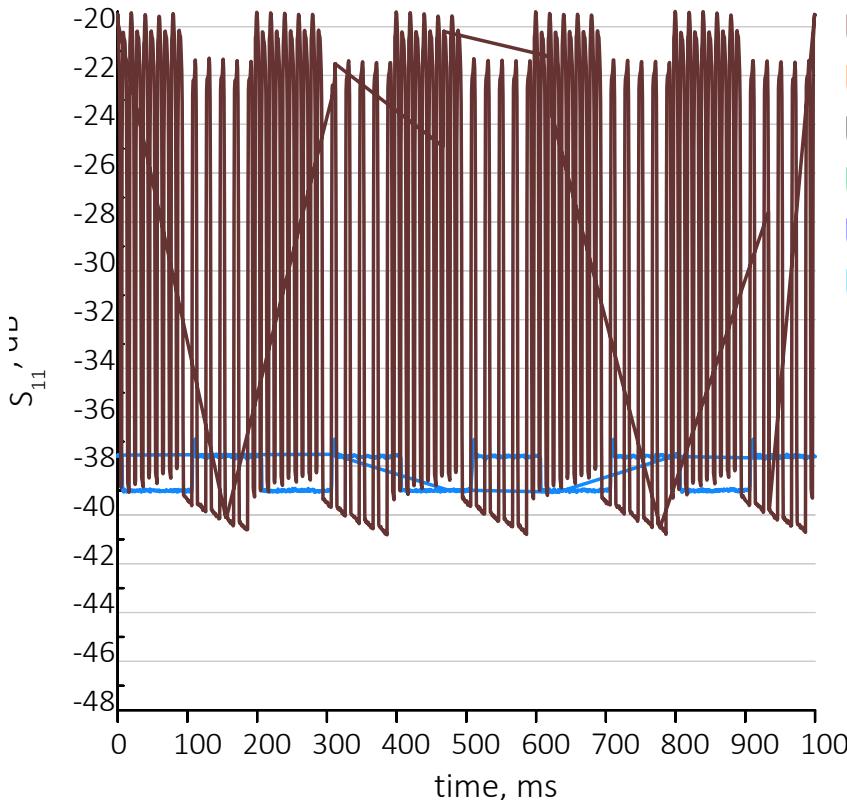
U=2.5 kV
U=1.6 kV
U=1.4 kV
U=1 kV
U=0.7 kV
U=0 kV



Beam monitor response signal
vs applied bias voltage.

Experiment at VBS with ADBM Biased with AC Voltage

No breakdown observed!



Beam monitor response signal
vs applied bias voltage.

Conclusion

1. We carried out tests with the 2D beam halo monitor (2D BHM) and plotted 2D maps of AWA beam. We have shown that the monitor had high enough sensitivity to monitor beam halo.
2. In the experiment with the avalanche monitor (ADBM) biased with ~ 3 kV AC voltage we have shown that the sensitivity of the diamond detector based on RF technology could be increased by factor ~ 100 times in comparison with the non-biased device.
3. We plan to design and test at AWA a new modification for the 2D BHM in order to allow bias voltage at diamond.