PROGRESS AND CHALLENGES OF DIELECTRIC BASED ACCELERTORS

C. Jing for Euclid Techlabs

High Gradient Workshop, April. 2012

Outline

- Introduction
- Experimental Reports Since the last HG workshop (Nov. 2011, LBL)
  - ➢ High Power RF Test of a SW DLA Structure at NRL
  - ➢ High Gradient Wakefield Test of a Diamond Slab Structure at AWA
- A Novel DWA based THz Source
- More Experiments in the Queue of 2012
- Summary

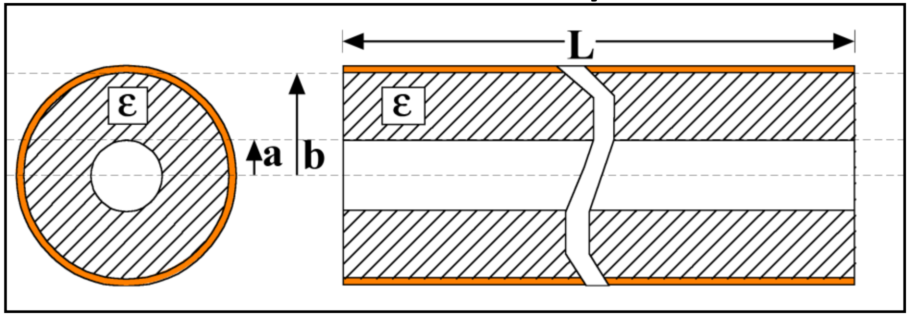
Introduction

Dielectric-Loaded Accelerating (DLA) Structures

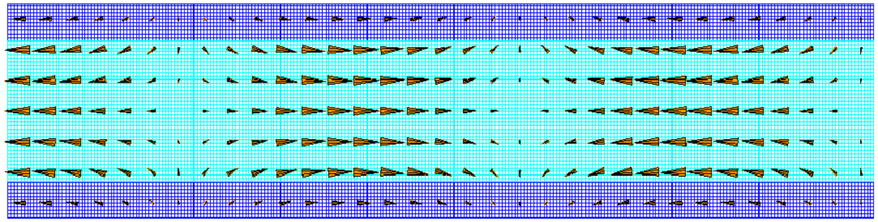
→Euclid, ANL, NRL, SLAC, BNL, UCLA Collaboration

→Program Goals: Demonstration of high gradient, practical dielectric accelerators

Geometry



Electric Field Vectors



Advantages

- Simple geometry
- No field enhancements on irises
- High gradient potential
- Comparable shunt impedance
- Easy to damp HOM

Major concerns

- Multipactor
- Breakdown

External rf powered or beam wakefield driven

Statistics in the Past 5 Years

✓ 6 DoE SBIR Phase I and 3 Phase II related to the work were awarded and completed.

✓10 X-band TW and 1 SW External DLA structures were made and tested.

✓ 5 wakefield high gradient DLA structures were made and tested.

✓ 4 different dielectric materials were tested.

✓ 2 different multipactor suppression techniques were tested.

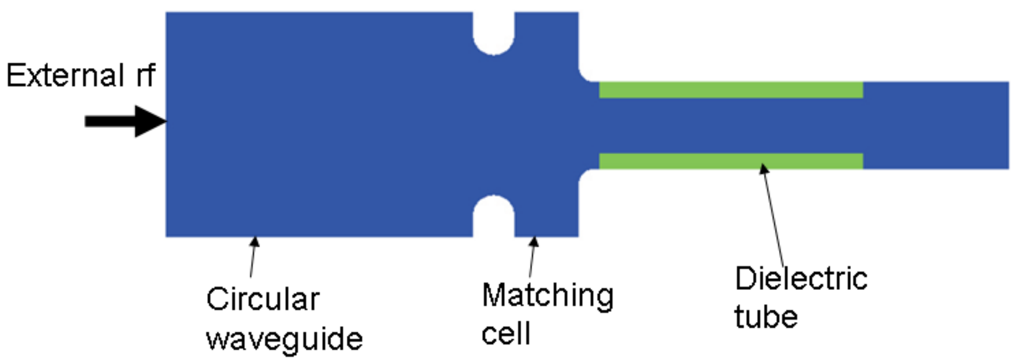
Currently Available RF or Beam resources for Euclid's Experiments.

Facility	Main parameters
ANL/AWA	15MeV/ 75 MeV, σ_z = 1-2 mm, Q = 10-100 nC, yielding ~ 100-300 MV/m at 10-30 GHz or ~GW beam power; TBA;
NRL/Magnicon	11.4GHz, 10~20MW, >200ns, rf station; 5MeV, 50mA (5pC/bunch), Xband rf injector;
BNL/ATF	60 MeV, tunable σ_z = 100 um-1.5mm, σ_r~100um, 0.3-0.5 nC, 0.3-0.8 THz
SLAC/ASTA, Klystron	11.4GHz, >50MW, 50~400ns, rf test stations
SLAC/FACET	23 GeV, σ_z = 20-30 um, σ_r ~ 10 um , Q = 1-3 nC, 0,5-1,0 THz frequency, 1-10 GV/m

Experimental Report on A New Standing Wave DLA Structure

(DoE SBIR Phase I project, 2011)

Design Parameters



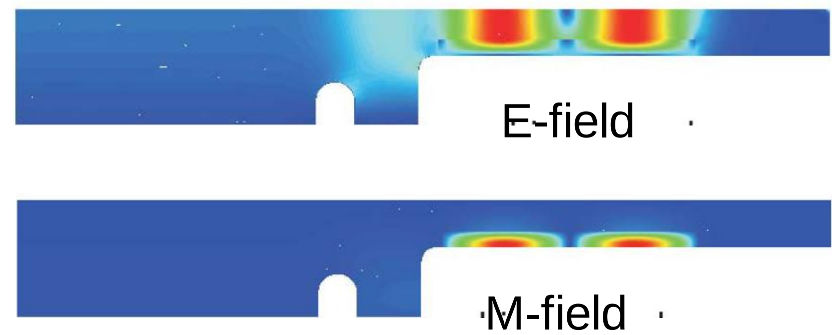
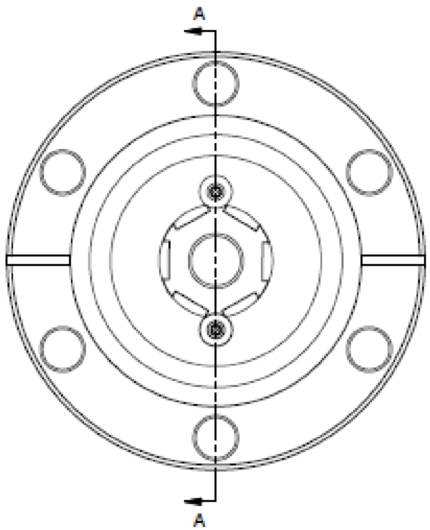
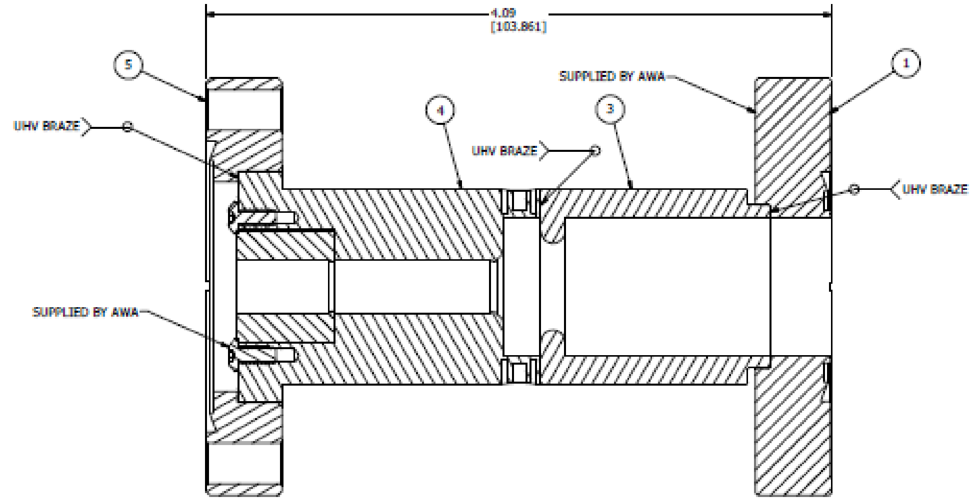


TABLE 1. Parameters of 11.424 GHz SW DLA Structure

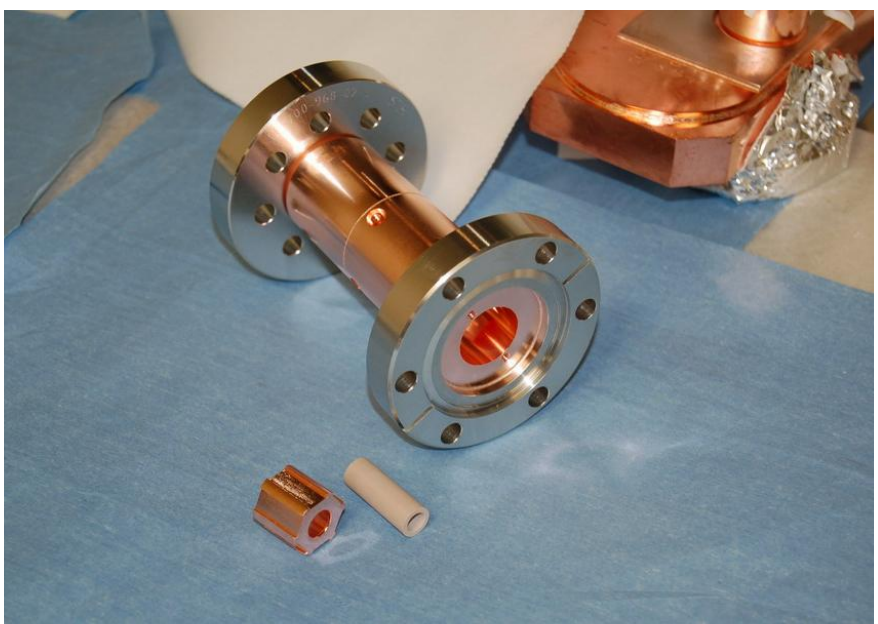
Geometric and accelerating parameters	Value
ID/OD	6 mm /9.134 mm
Dielectric constant	20
Length of dielectric tubes	25.8 mm
Synchronous frequency of TM_{011}mode	11.424 GHz
R/Q of TM_{011} mode	8.8 (kW/m)
Q of TM_{011} mode	2249
Gradient per 10MW input	120MV/m

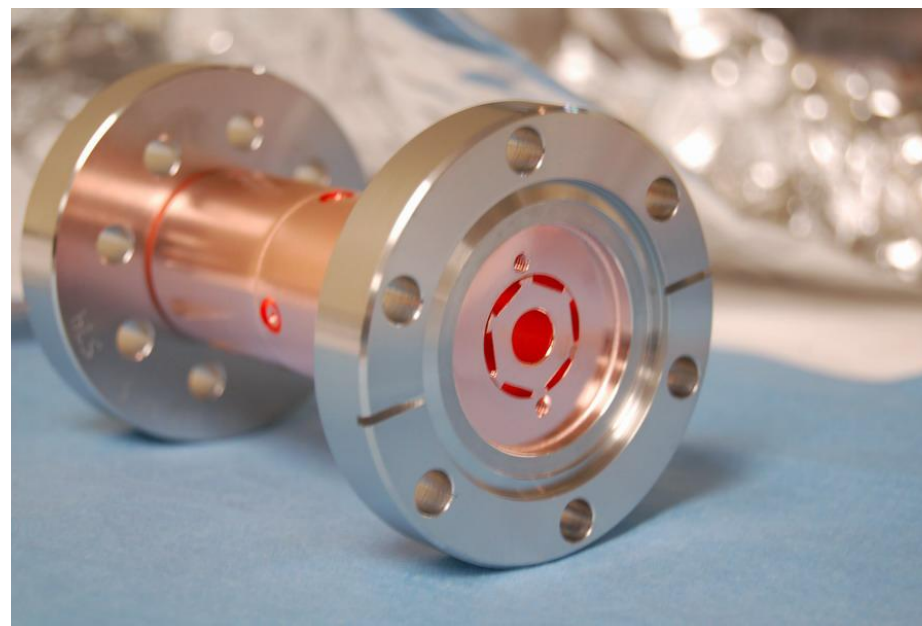
Mechanical Design and Fabrication





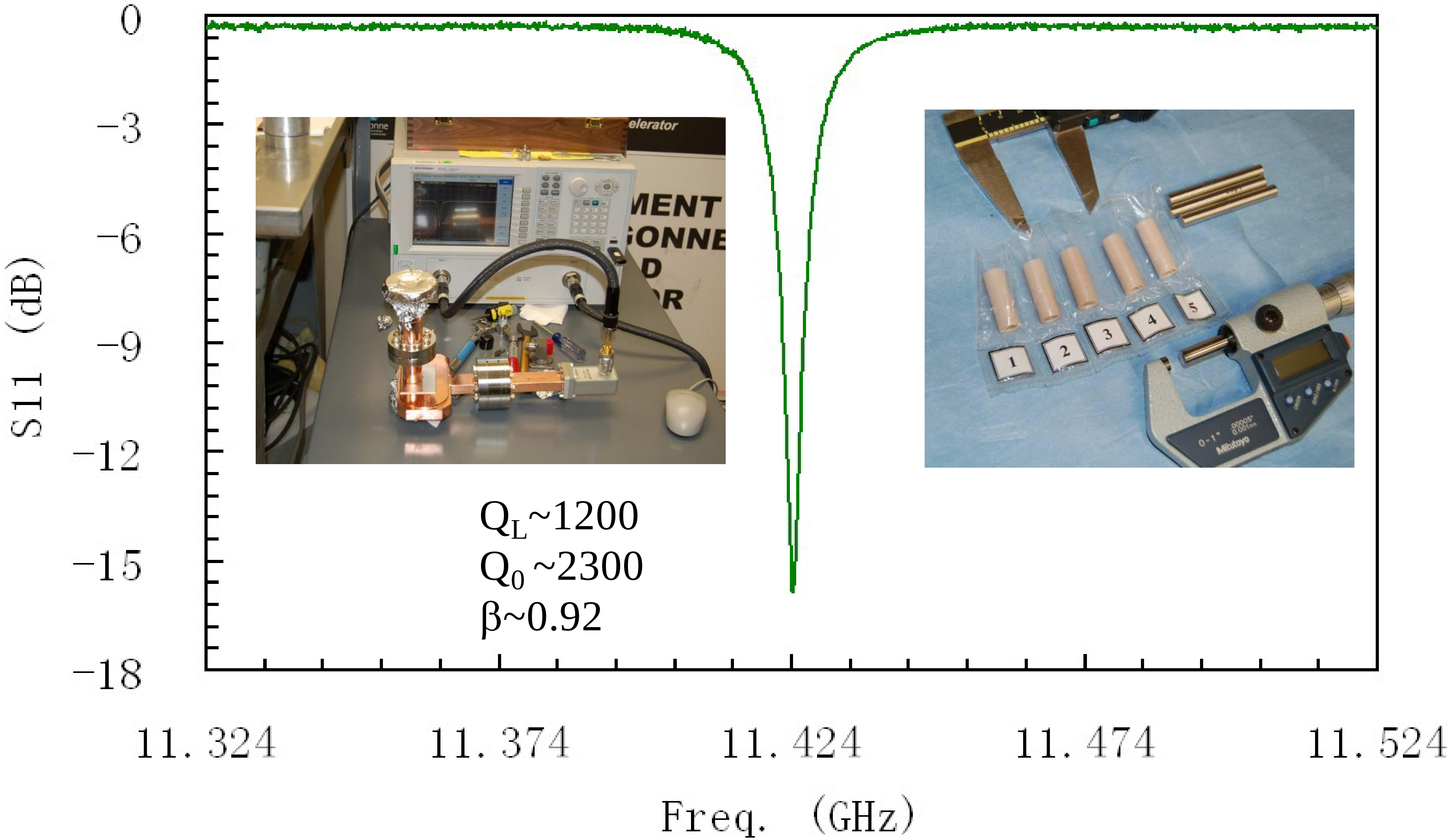
SECTION A-A
SCALE 2 : 1



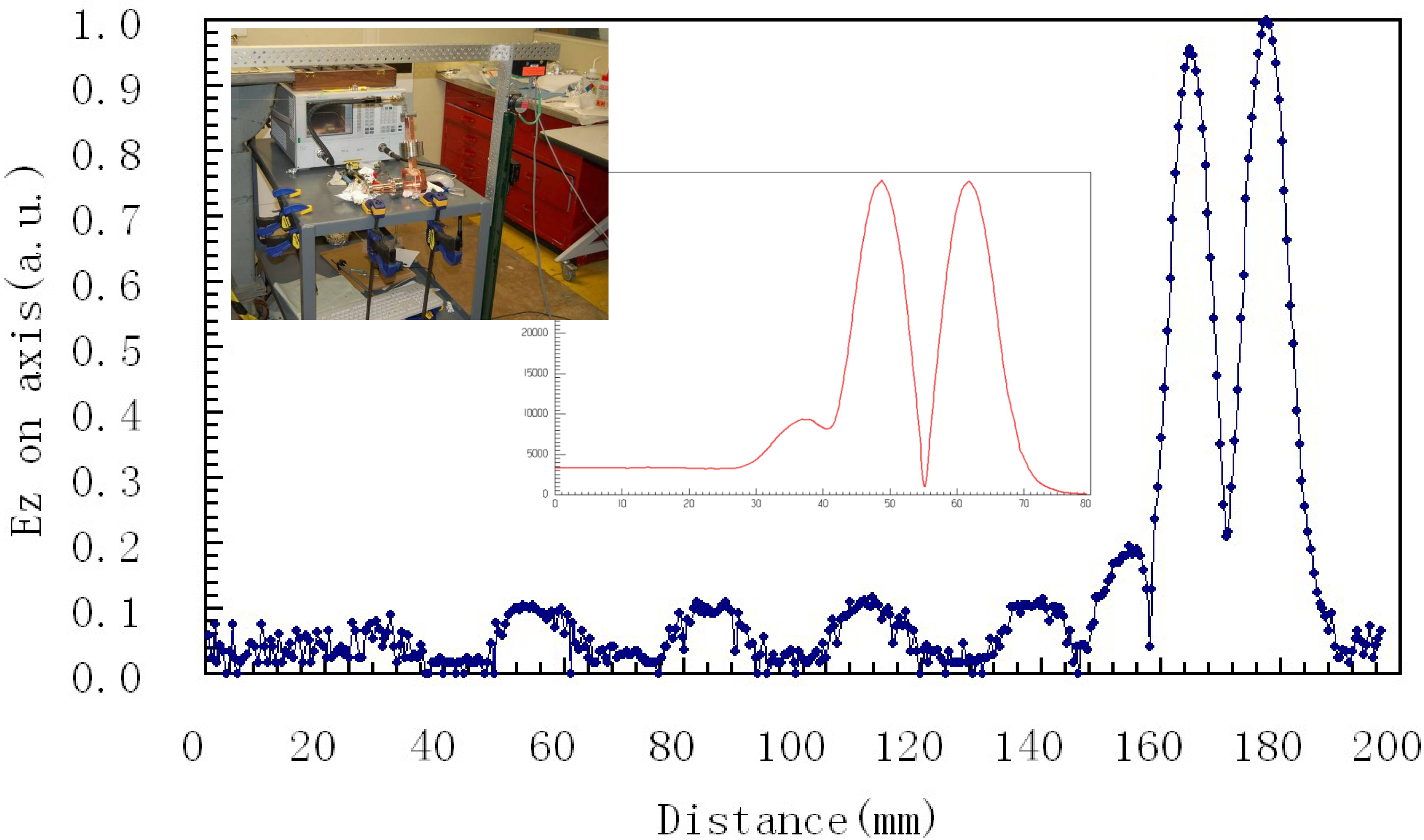


Bench Test

We thank Sami Tantawi for providing us two rf couplers.

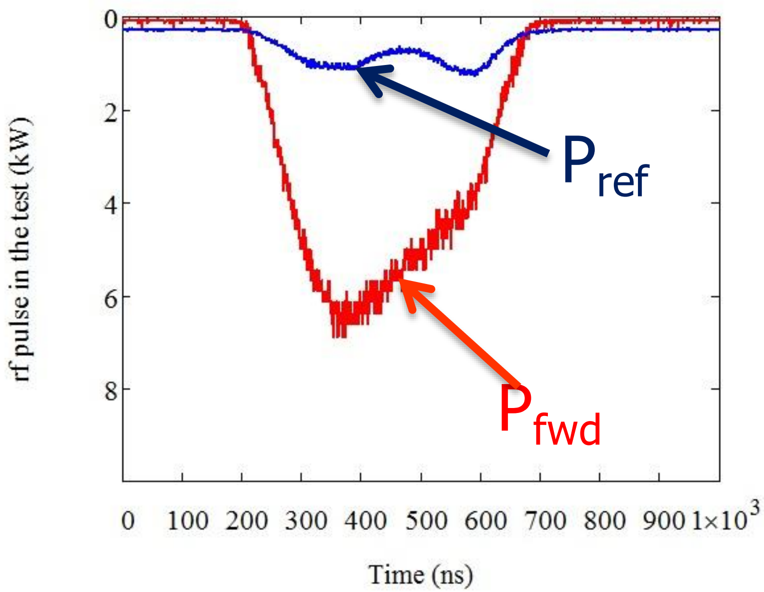


Beadpull

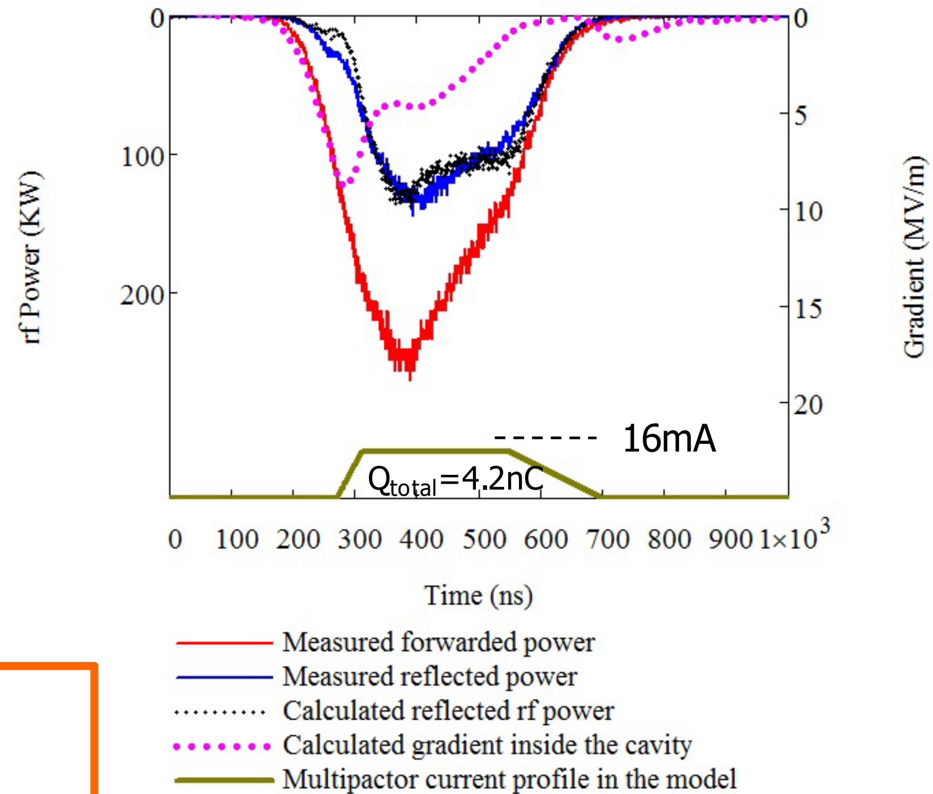

Ez on axis(a.u.)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
20
40
60
80
100
120
140
160
180
200
Distance(mm)
20000
15000
10000
5000
0
0
10
20
30
40
50
60
70
80

High Power RF Test at NRL

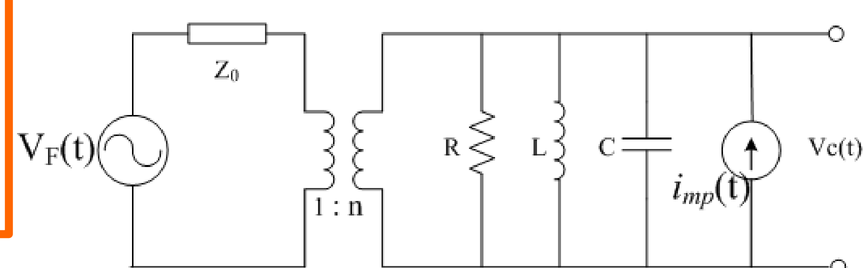
No Dielectric multipactor



Dielectric multipactor kicks in



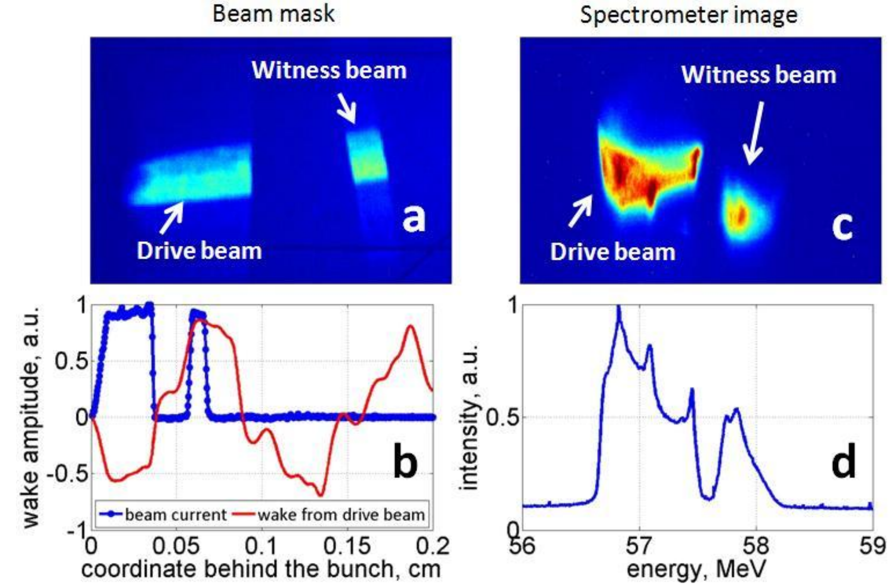
- ➢ Multipactor drives the structure off resonance and absorbs rf power.
- ➢ Improved structure design and new experimental implementation (solenoid + coating to cure the multipactor; a rf probe is added to monitor field) is proposed in Phase II.

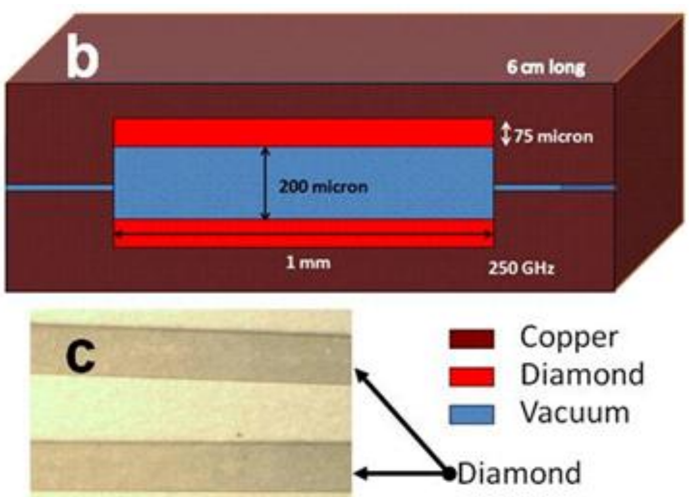


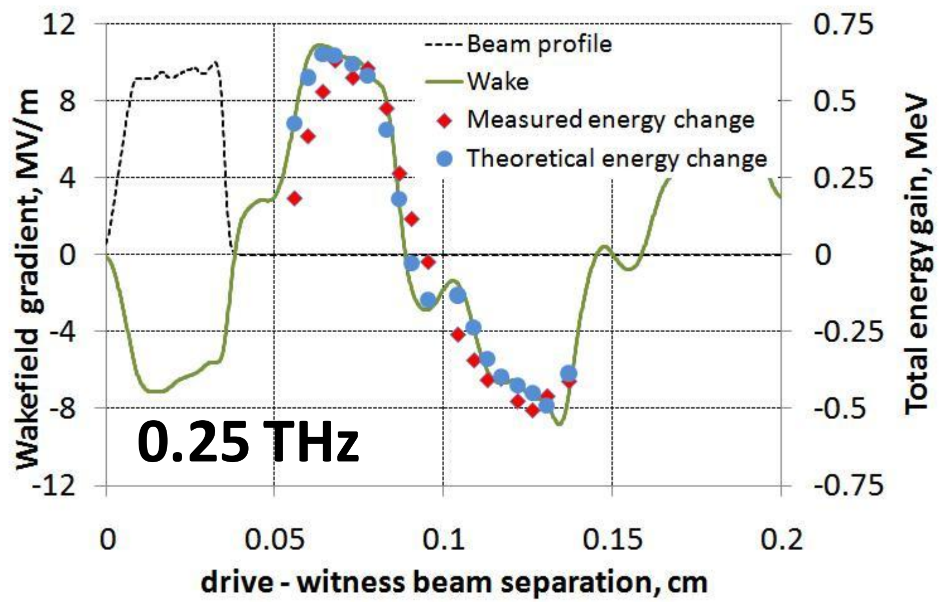
Experimental Report on A Diamond Based Wakefield Structure (DoE SBIR ext. Phase II project, 2012)

Wakefield Mapping of a Diamond Slab Structure at BNL/ ATF

- 1st wakefield mapping experiment in THz regime (June 2011).
- 1st wakefield acceleration observed in THz regime.
- S. Antipov, *et al, App. Phy. Lett. March* 2012.

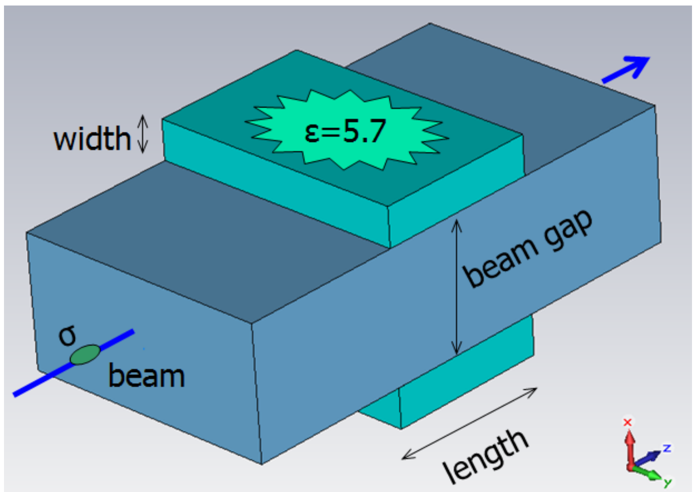




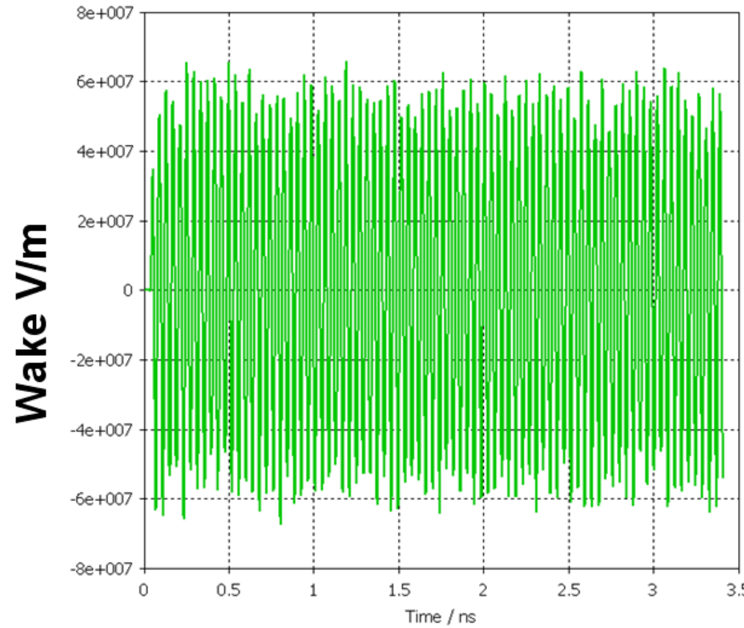


High Grad. Breakdown Study of A Diamond Slab Structure @ ANL/ ATF

Our goal is to perform first WF experiment with Diamond-based DLA, test for breakdown



50MV/m per 50 nC beam



Bunch length	**2~2.5 mm**
Beam gap	**4.0 mm**
D thickness	**1.2 mm**
width	**8 mm**
length	**5.0 mm**

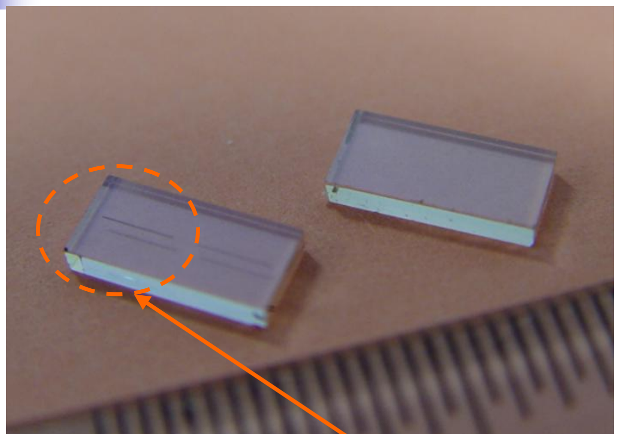
***AWA facility can generate up to 100nC beam with σ_z = 2.5 mm (14 MeV)**

Structure is short, TM_{110} – based

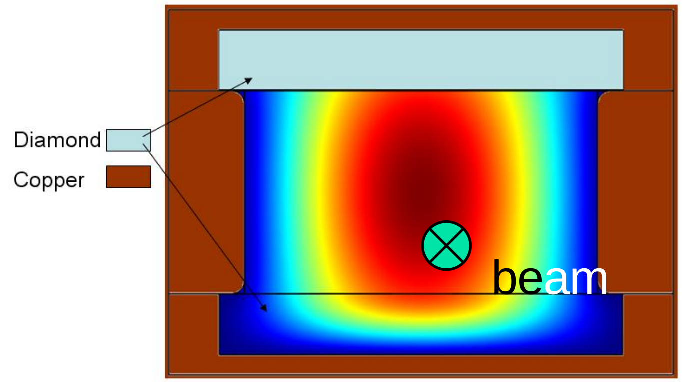
Wake is a single mode at ~ 26 GHz

Q = 2800 (→decay time τ~35ns)

Field Enhancement in the scratch

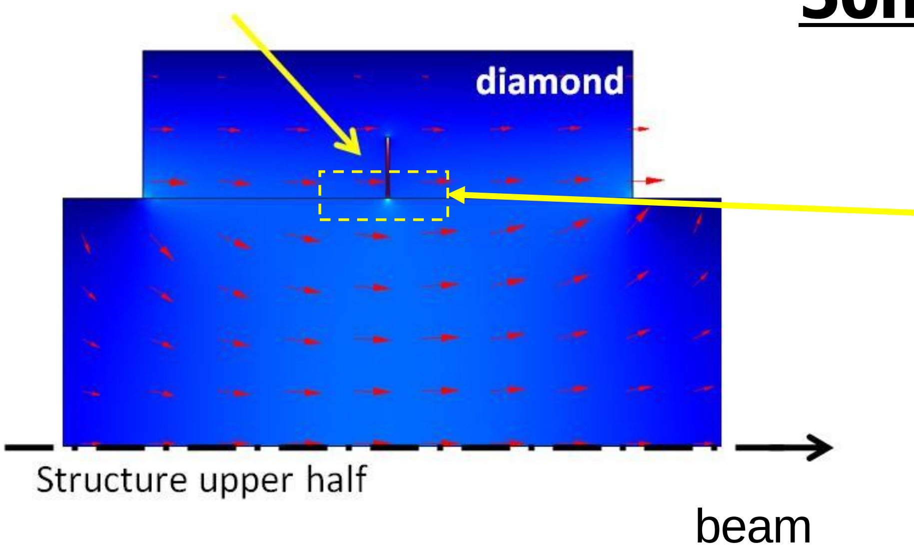


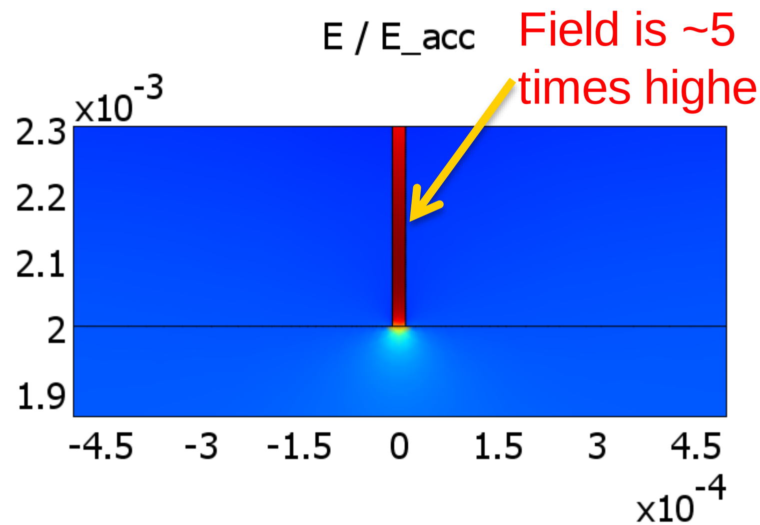
Diamonds (E6) ...**scratched**



Avoiding hot spots on diamond holder

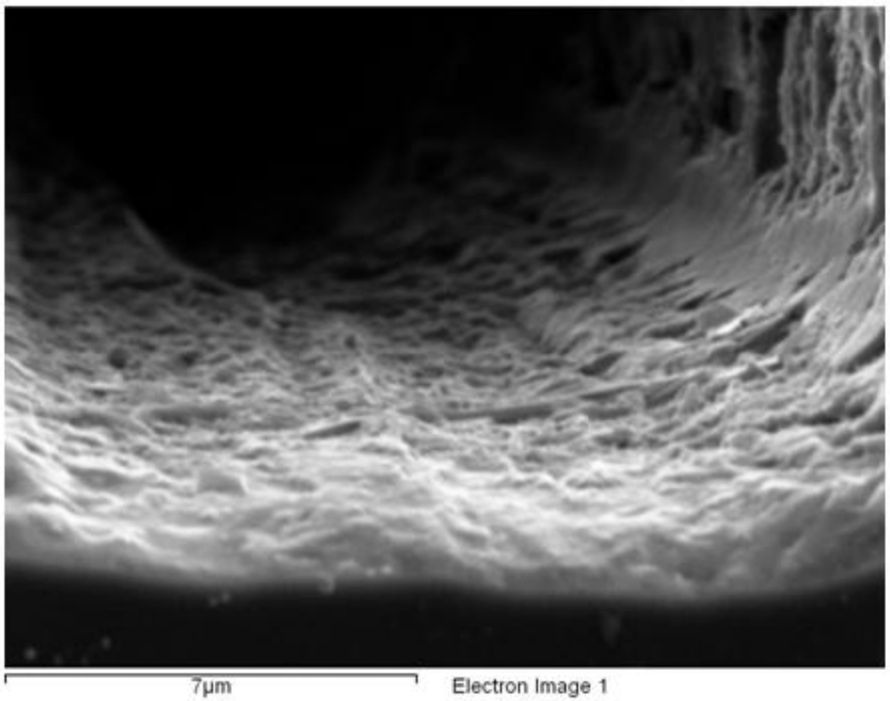
50nC → 250 MV/m

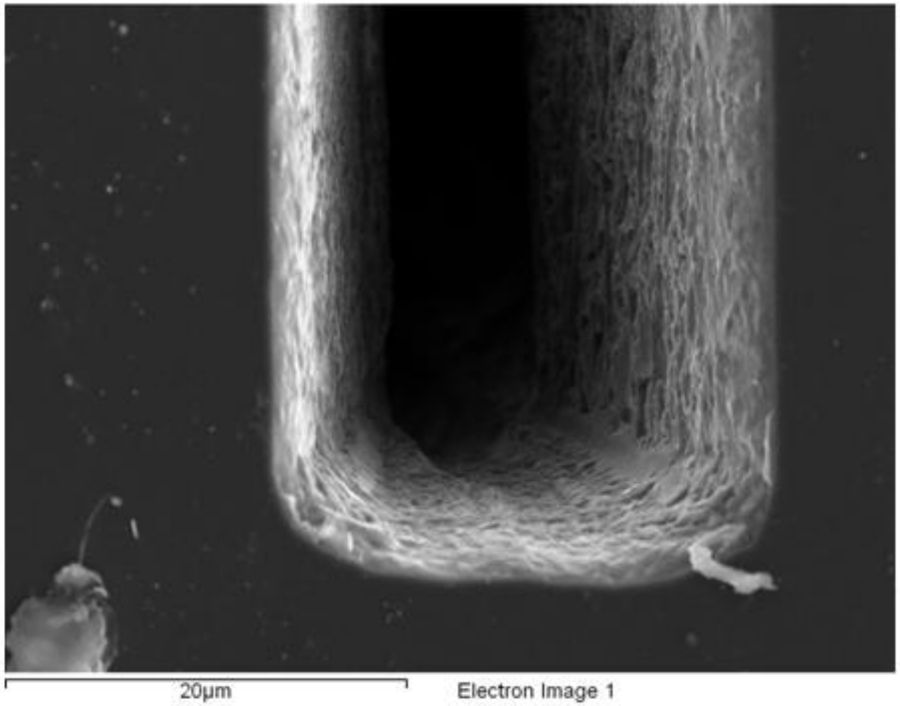




Diamond groove SEM image

Image: “BEFORE”

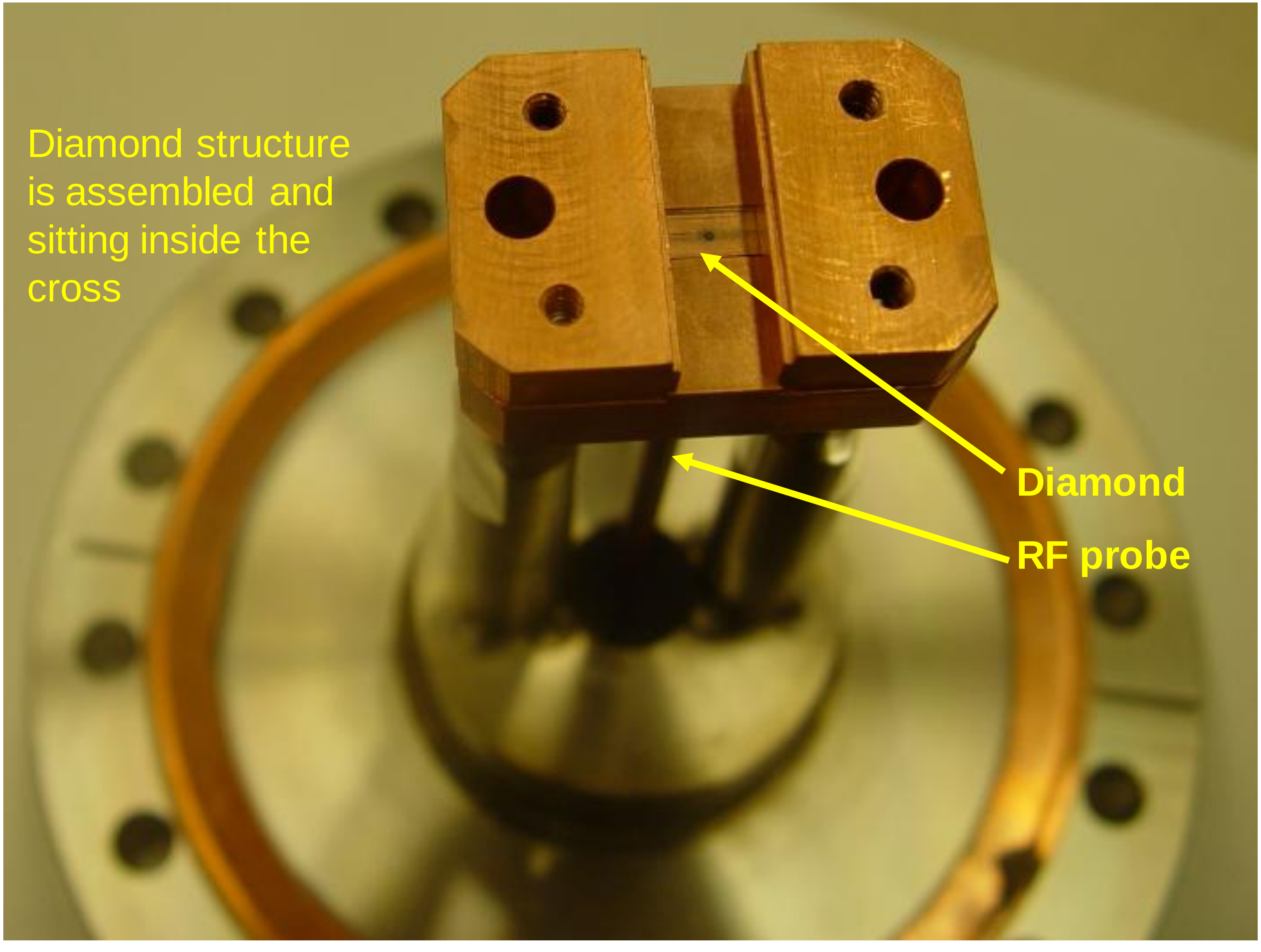




SEM: Z. Yusof (AWA)

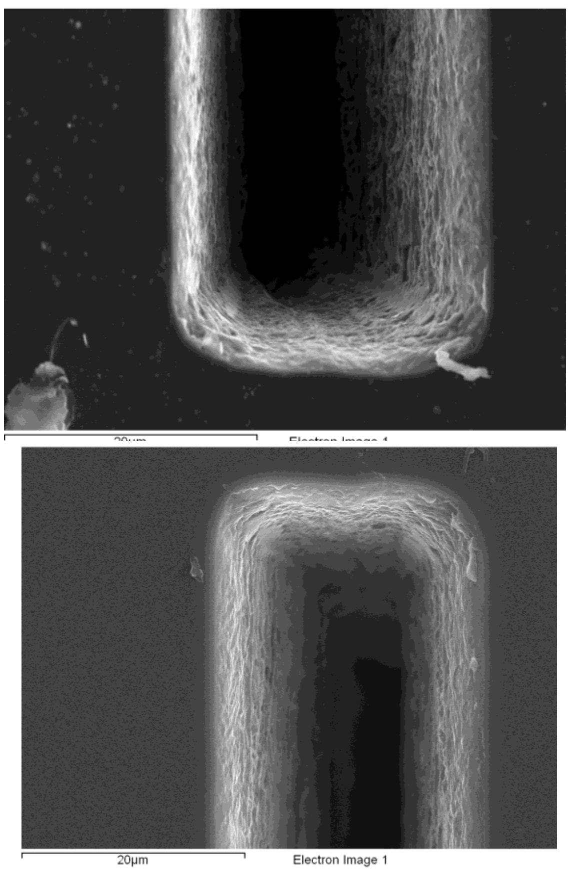
Cut: J. Butler (NRL)

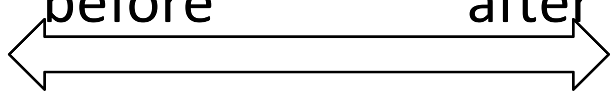
Diamond Holder

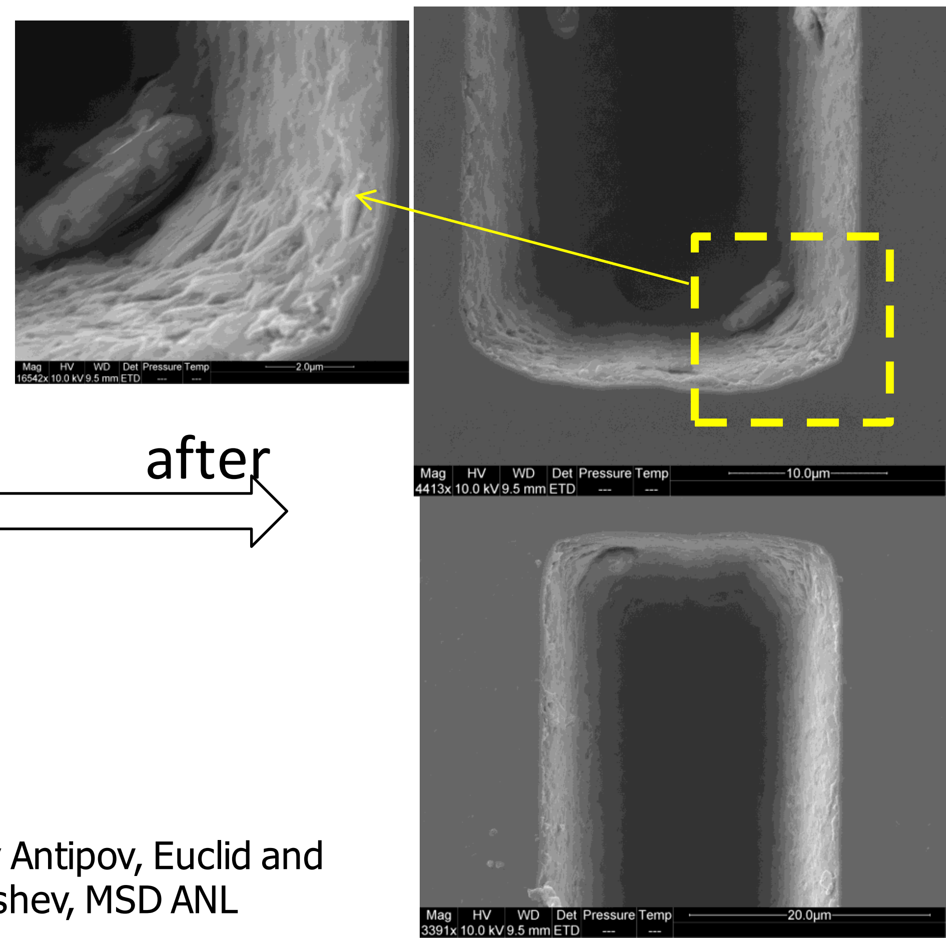


comparison

- 72nC (σ_z=2.5mm) went through which is *eqv*. to **~300 MV/m** gradient on axis for (decay time **~35ns**).
- Preliminary examination shows **No** evidence of breakdowns during the beam test. More examinations or additional test will be carried out.







SEM: Sergey Antipov, Euclid and Sergey Baryshev, MSD ANL

A Novel DWA based THz Source

Self-Bunched CCR (Coherent Cherenkov Radiation) THz Source

BNL, ATF: S. Antipov, C. Jing et. al. Phys. Rev. Lett. 108, 144801 (2012)

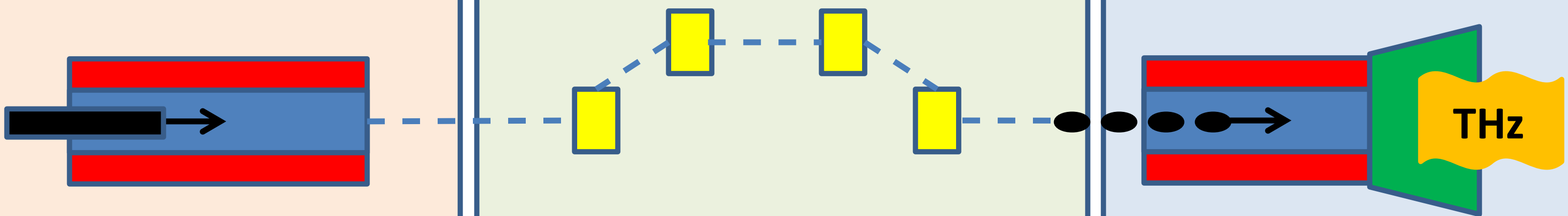
SLAC, NLCTA: D. Xiang et. al. Phys. Rev. Lett. 108, 024802 (2012)

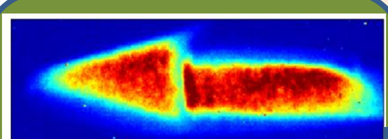
BNL, ATF: G. Andonian et. al. Appl. Phys. Lett. 98, 202901 (2011)

Energy modulation via self-wakefield

Chicane energy modulation conversion to bunch train

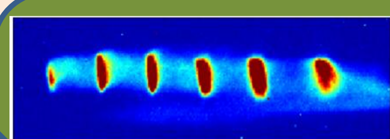
THz radiation wakefield structure





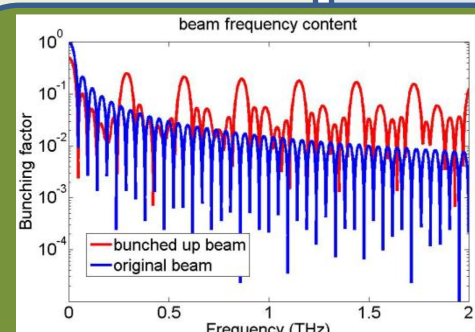
Measured beam spectrum

Energy chirped rectangular beam



Measured beam spectrum

Energy modulated rectangular beam



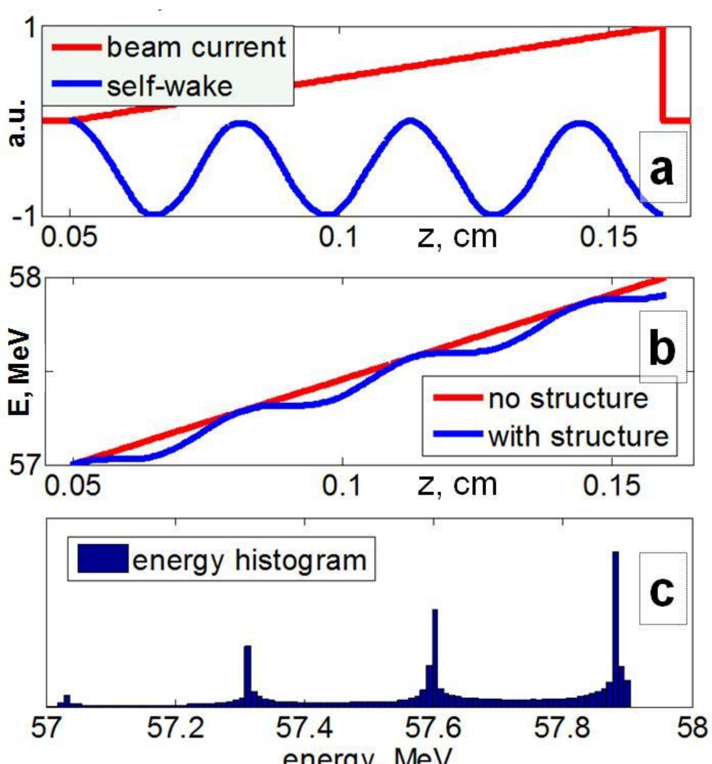
Bunch train frequency content

Tunable 10% source:
Range: 0.3-1.5 THz
Pulse bandwidth: 1%
Energy in pulse: ~ mJ

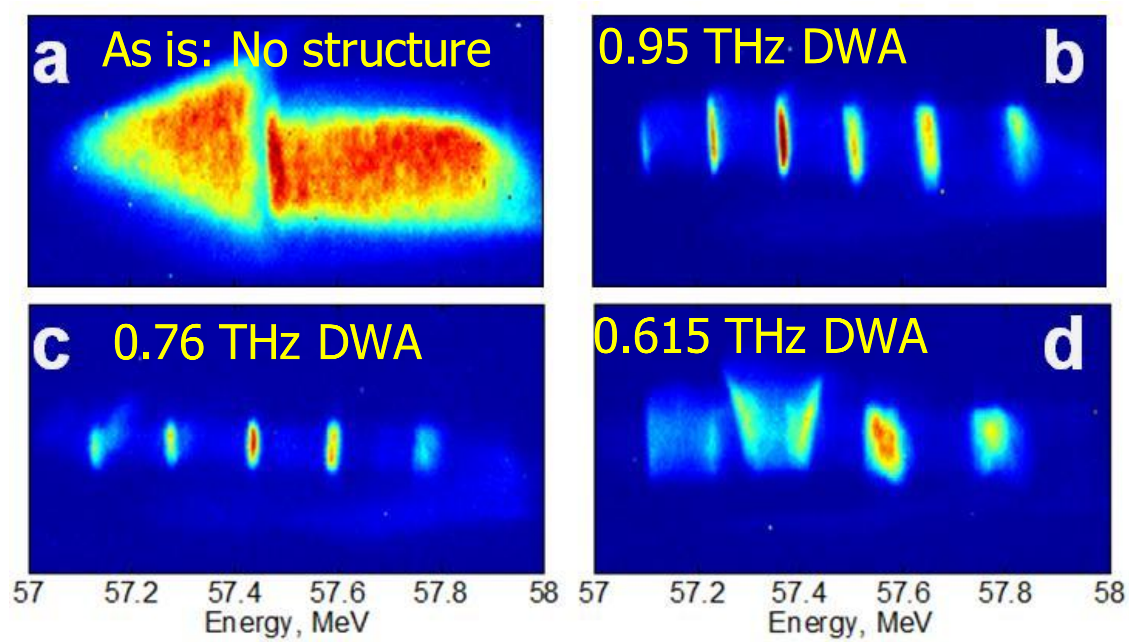
Flexible: each step has a tuning range

Observation of Self Energy Modulation (Exp. @BNL/ATF in Oct. 2011)

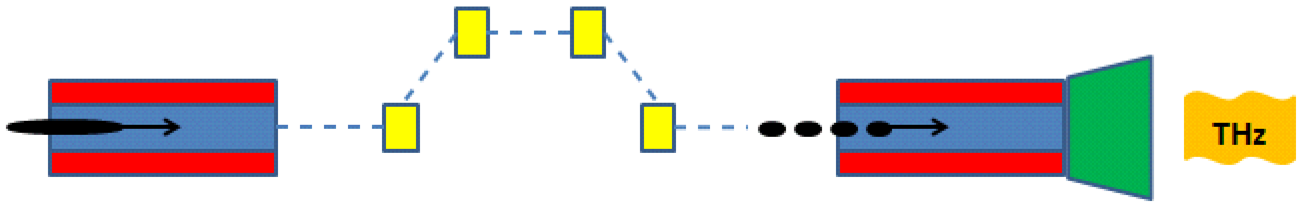
- A shaped (triangular or rectangular) bunch with an initial energy chirp will form strong energy bandgaps while passing through a wakefield device.
- Experiment by Euclid has been done at BNL/ATF ; a paper been published at *Phy. Rev. Lett.* April 2012.
- The next step to use a chicane to convert the energy modulation to density modulation forming the micro bunchlets is planned at ATF this year.



Spectrometer images



Expected THz Radiation in Different Scenarios



DWA structure	Beam @ the entrance	THz Radiation @ the exit
1mm / 1.2mm Quartz 10cm long	(AWA beam) 6.3mm, 10nC rectangular	0.5 GW peak, 0.3THz, 320ps pulse, 1%BW, 155mJ per pulse
0.3mm / 0.4mm Quartz 3cm long	(ATF beam) 2.4mm, 0.8nC rectangular	6 MW peak, 0.7THz, 161ps pulse, 0.9%BW, 1.4mJ per pulse

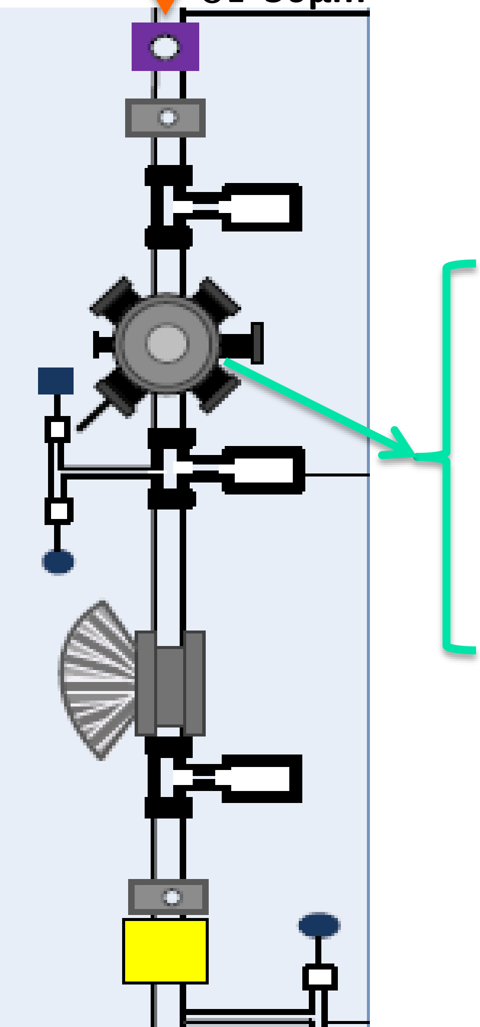
More Euclid DLA Experiments planned in 2012

- THz DWA at FACET /SLAC (April 2012)
- X-band dielectric PETS at SLAC (May or June 2012?)
- K-band dielectric PETS at AWA/ANL (July 2012)
- THz DWA test at ATF/BNL (fall 2012)
- X-band external powered DLA beam test at NRL (fall 2012)
- 2nd X-band SW DLA structure test at NRL (winter 2012)

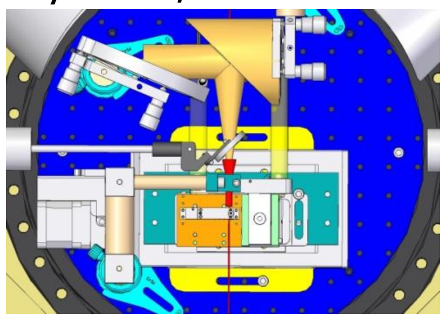
Euclid THz DWA structures at FACET Run 2a (4/19-4/24, 2012)

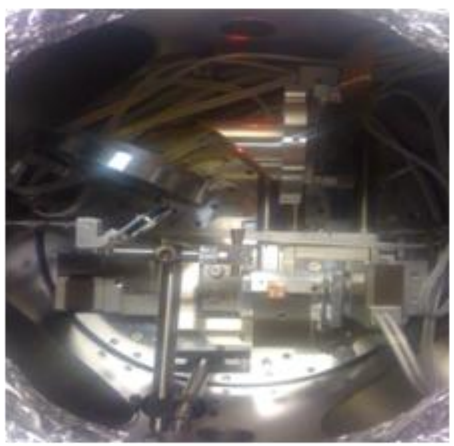
Through Collaboration E201 (UCLA/SLAC/Euclid, etc.)

e^- **23GeV, 3nC, σr~10μm, σz~30μm**



Kraken Chamber
by UCLA/SLAC



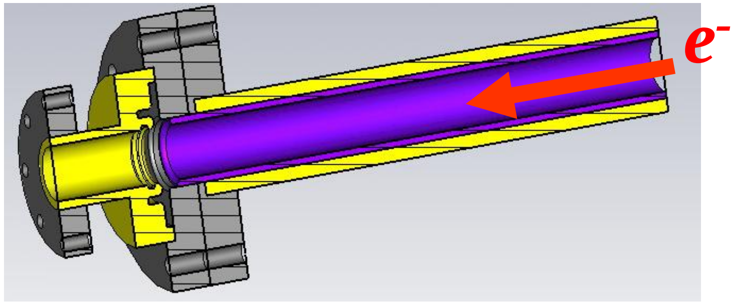


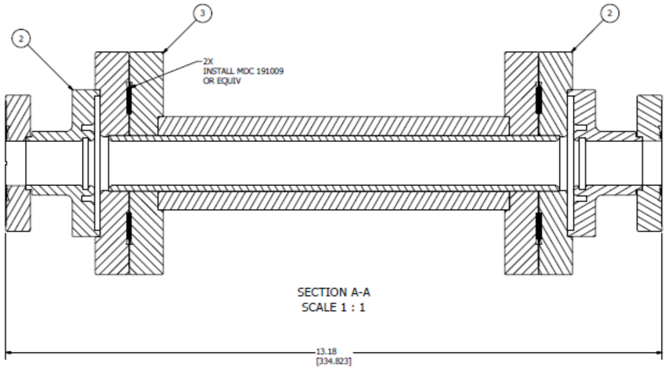
Euclid Structure	Dimensions	Exp. Grad. (3nC, σz~30μm)
Quartz tube 1	400μm ID 550μm OD	1.6GV/m ~0.6THz
Quartz tube 2	300μm ID 415μm OD	2.5GV/m ~0.63THz
Alumina tube	508μm ID 790μm OD	0.9GV/m multimode
Sapphire tube	790μm ID 1090μm OD	0.5GV/m multimode
Diamond slab	150μm gap 90μm thickness	1GV/m multimode
Diamond tube	105μm ID 165μm OD	8.8GV/m ~1THz

Test of an X-band Quartz-Based Power Extractor

(summer 2012)

- 11.4GHz version is in the queue of high power rf test at SLAC.
- 12GHz dielectric PETS w/ the transverse mode damping is under construction.

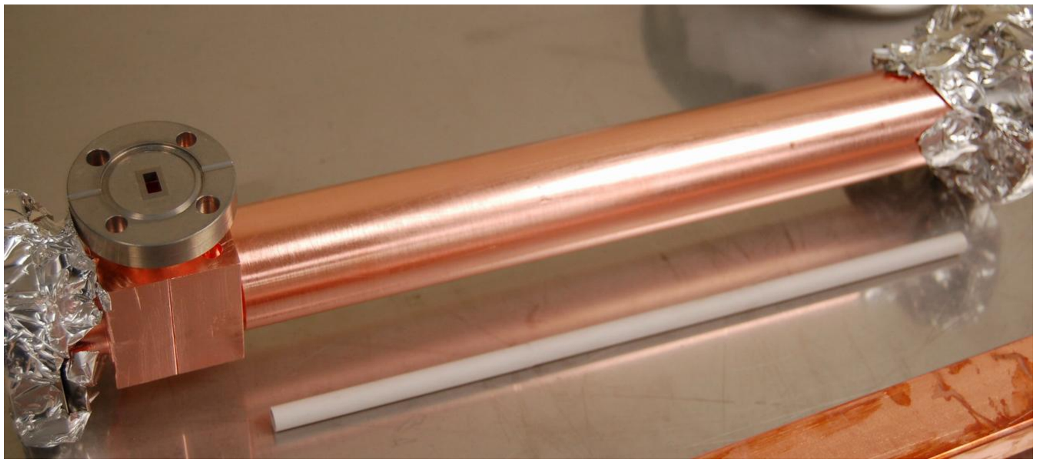




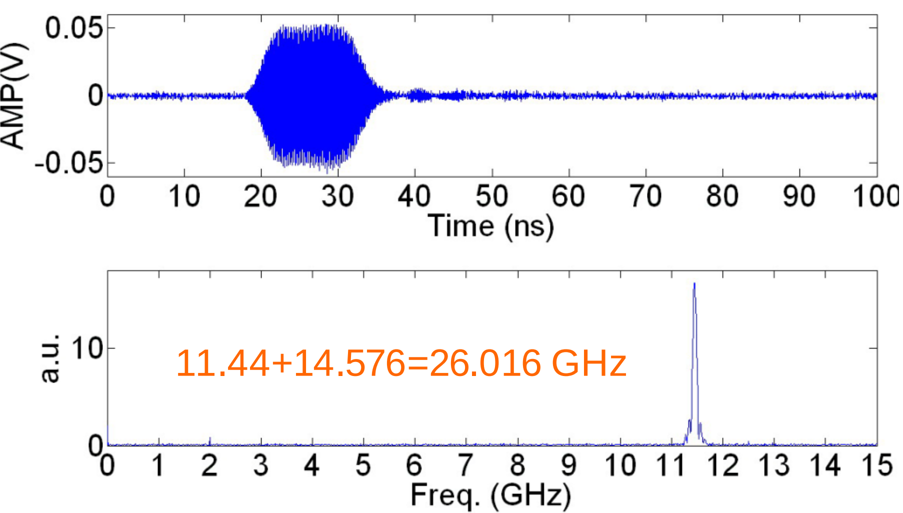
Freq	11.994GHz
Effective Length	23cm
Beam channel	23mm
Dielectric wall thickness	2.582mm
Dielectric const.	3.75(Quartz)
Q	7318
R/Q	2.171kΩ/m
Vg	0.4846c
Peak surface Gradient	$E_{\parallel}$=12.65MV/m; $E_{\perp}$=18.28MV/m
Steady Power	142MW

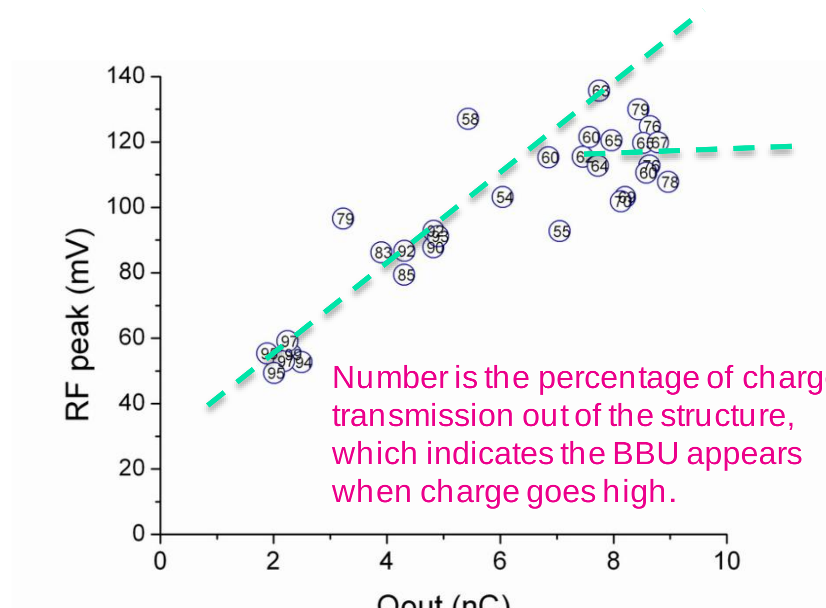
2^{nd} test of the 26GHz dielectric power extractor at AWA

(June ~July 2012)

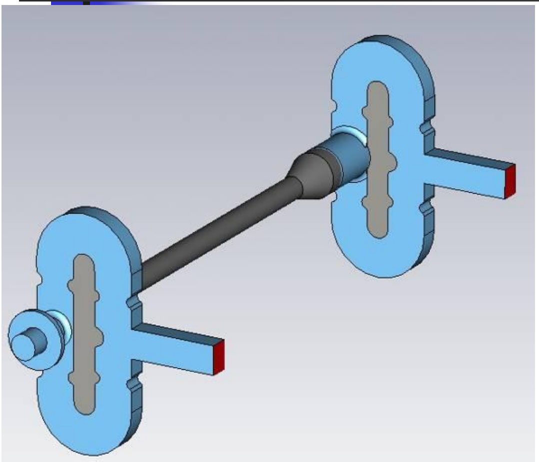


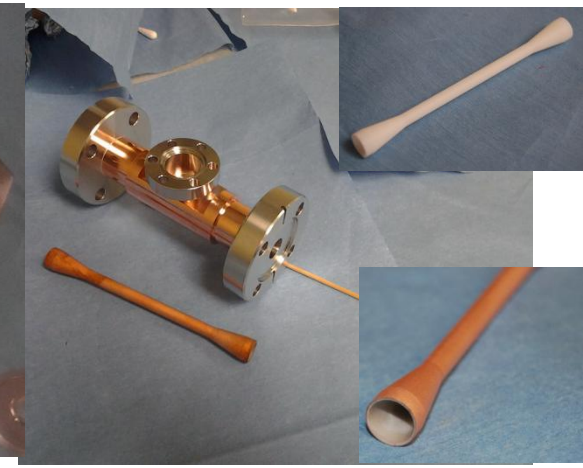
- ~20MW was measured in the first run 2009.
- BBU was observed. Simulation shows it can be cured by a 1T solenoid field.
- Solenoid arrived. 2^{nd} test will be in June or July 2012.





A 26GHz Short Pulse DLA Structure to be Tested

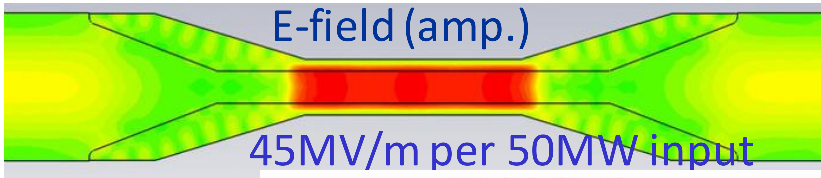


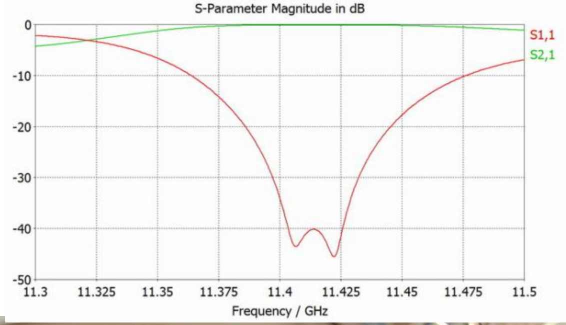


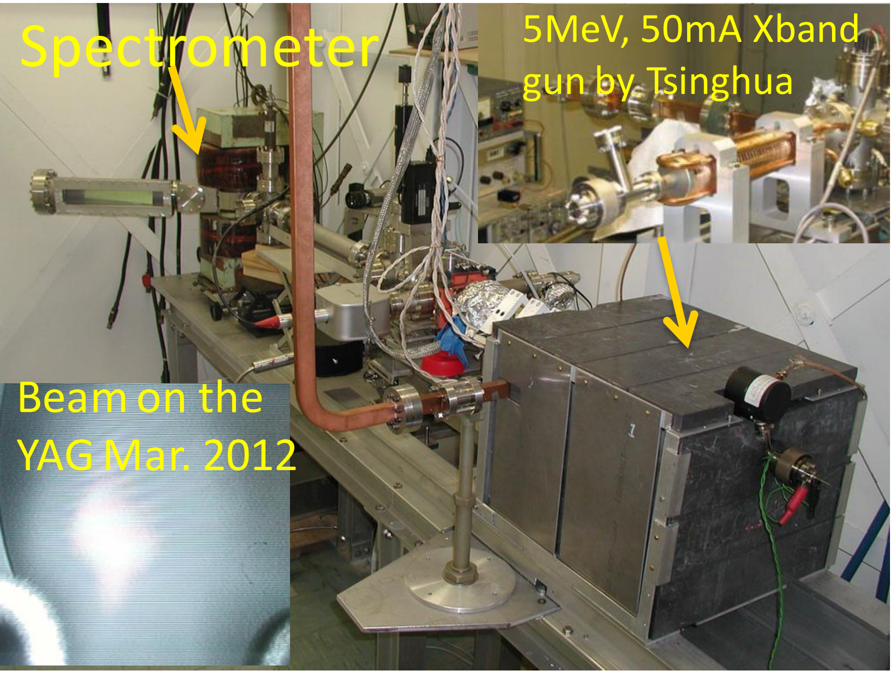
Geometric and accelerating parameters	value
ID / OD of dielectric tube	3 mm /5.025 mm
Dielectric constant	9.7
Length of dielectric tubes	300 mm
Vg	11.13%c
T_{fill}	9ns
R/Q	21.98 kΩ/m
Q (loss tan=10^-4)	2295
Shunt impedance	50.44 MΩ/m
$BW_{\_3dB}$ of the requested coupler	120 MHz
E_{acc} for 1.26GW input	316 MV/m unloaded/ 267MV/m loaded

1st beam test of an X-band external powered DLA at NRL

- The X-band injector beamline will be available soon.
- We expect to have the 1st beam test of DLA structure in 2012.







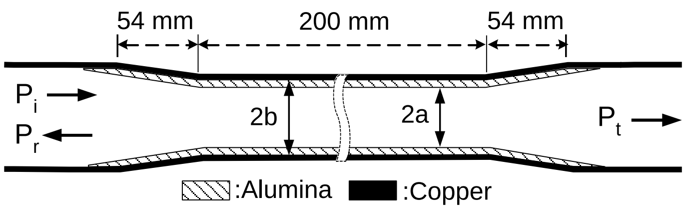
Summary

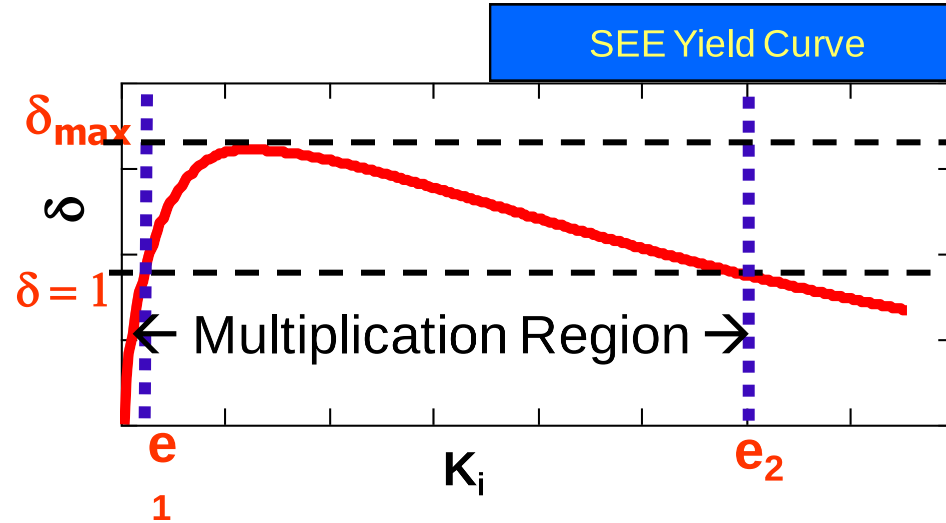
- Progress on the development of external DLA structures continue, experimentally and theoretically.
- More DLA structures have been developed, currently under construction, or to be developed soon, as well as more experiments on the way.
- Ultimately goal→ a mature high gradient DLA structure

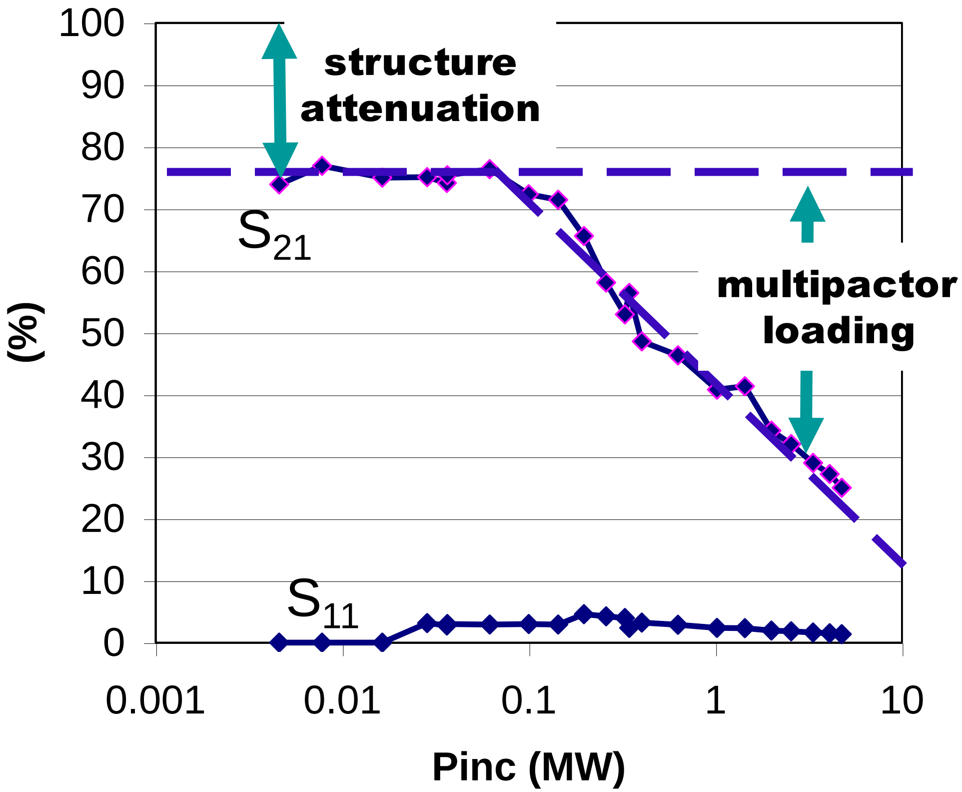
Thanks to supports from the DoE SBIR program and all our collaborators!

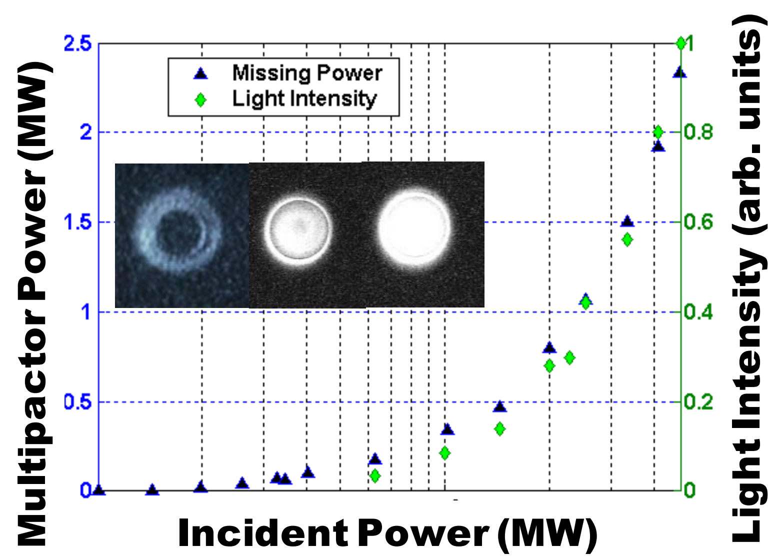
A New Multipactor Suppression Technique *(Backup slides)*

Multipactor



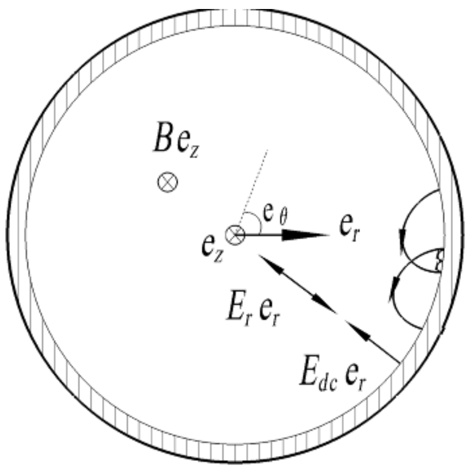


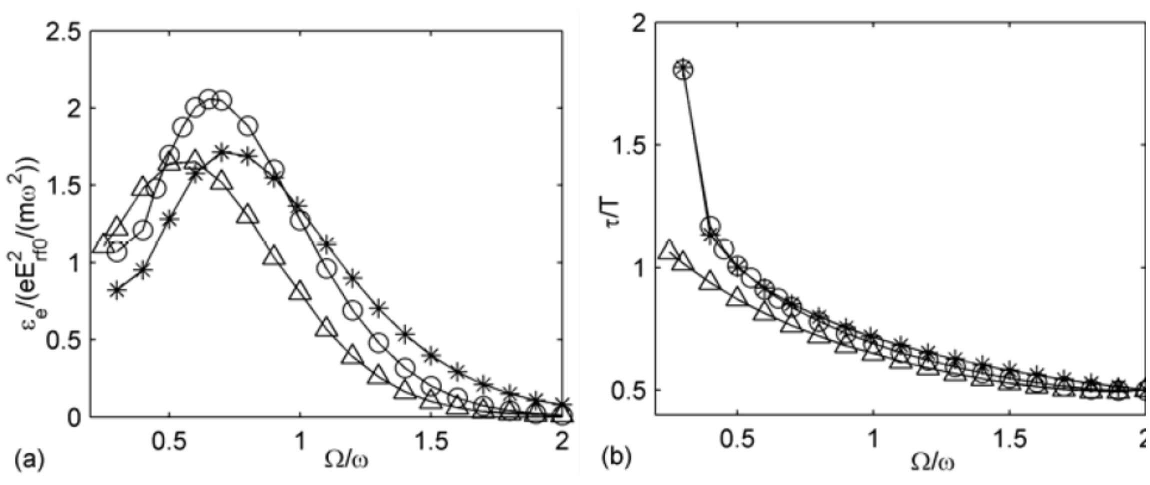


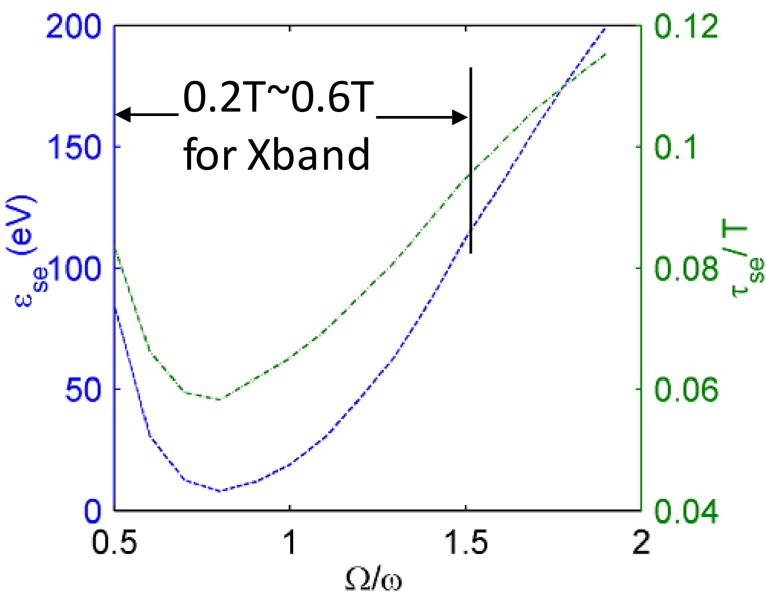


A new approach proposed by C. Chang at SLAC: Solenoid field

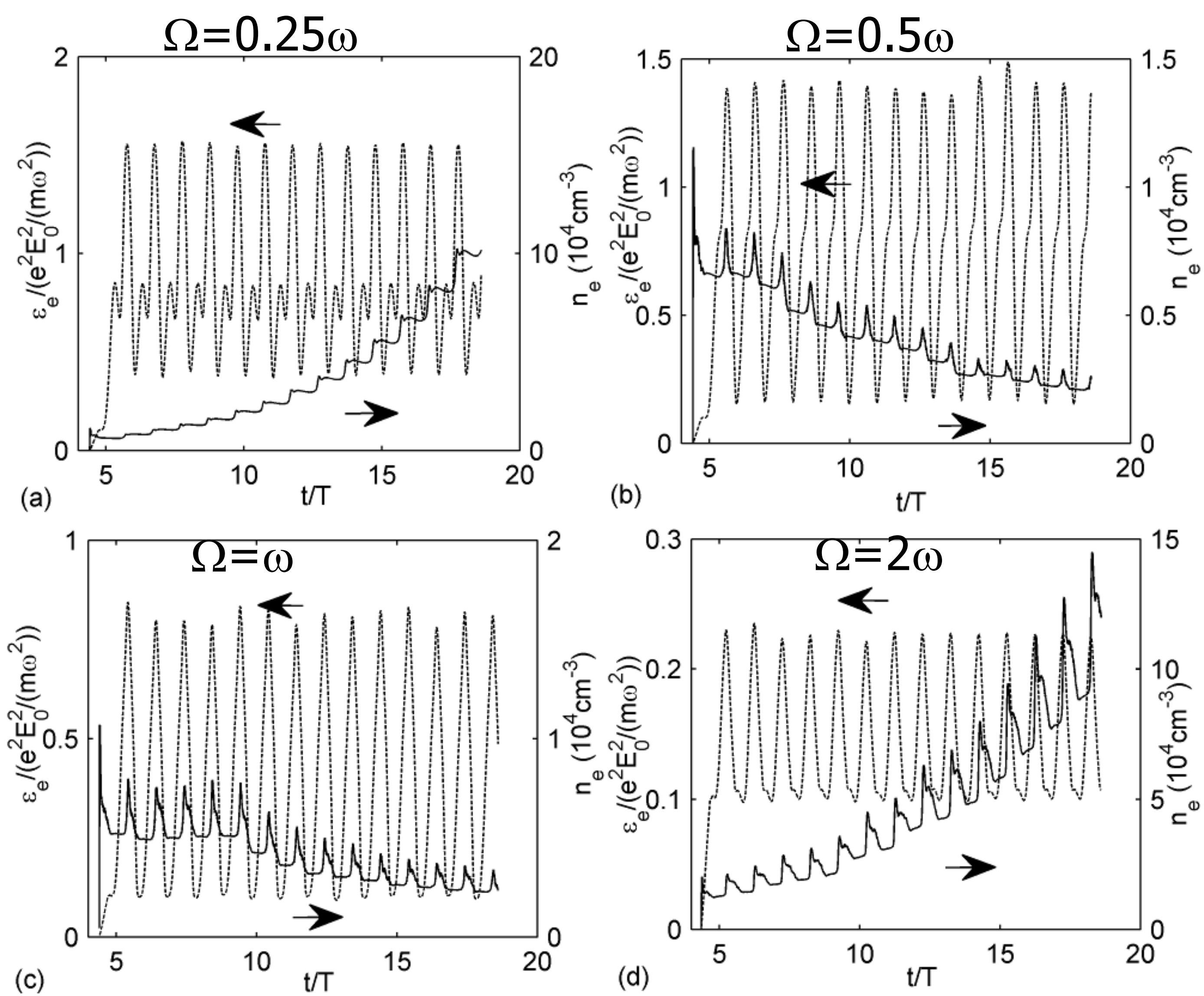
Principle: the introduced Bz can effectively alter the transit time τ of secondary electrons. A proper strength of Bz makes τ in the range of (T/2,T) so that Er is always pushing electrons back to the dielectric surface, leading to a very small impact energy, then SEE<1.







Impact energy and particle numbers for different strength of the solenoid field



A few X-band DLA structures for the proposed experiments on the multipactor suppression

TABLE 1. Some parameters of X-band DLA structures for the proposed experiments.

Parameters	**Structure 1**	**Structure 2**	**Structure 3**
Radii a / b of straight section	0.059" /0.255"	0.168" /0.255"	0.098" /0.171"
Radius of taper matching section	0.446"	0.446"	0.446"
Dielectric constant	3.75	9.7	15.7
Loss tangent	6×10^{-5}	1×10^{-4}	1×10^{-4}
Length of dielectric tubes	5.5"	5.5"	5.5"
Synchronous frequency of TM_{01} mode	11.424 GHz	11.424 GHz	11.424 GHz
Group velocity	0.267c	0.12c	0.066c
R/Q of TM_{01} mode	15 (kW/m)	8 (kW/m)	11 (W/m)
Q of TM_{01} mode	6004	3103	2550
Gradient per 50 MW input	26 MV/m	28 MV/m	44.5 MV/m