THz Diamond Based DLA for Microbunch High Gradient Cherenkov Generation

A.Kanareykin

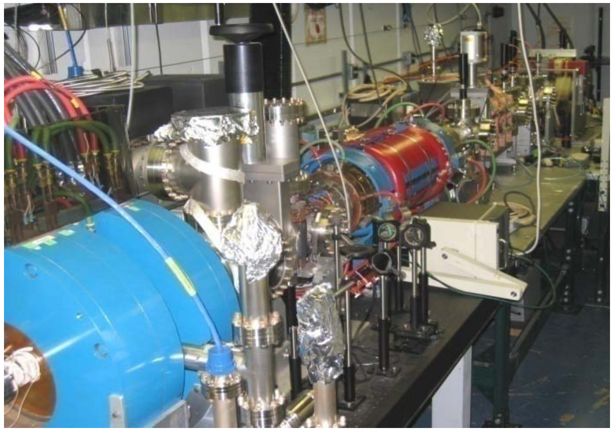
Euclid TechLabs LLC, Rockville, MD

Outline

- Why diamond based DLA ?
  - Idea
  - Technology
  - Current status on diamond structures fabrication
- THz Cylindrical and Rectangular Structures
  - Analytical estimates
  - Electromagnetic simulations (Waveguide^{TM})
  - BBU estimates for cylindrical and planar structures
  - Comparison of the cylindrical and planar THz structure parameters
- Perspectives

Euclid Techlabs LLC: DLA collaborations

AWA of Argonne Nat. Lab, Chicago:
Argonne Wakefield Accelerator:
M.Conde, J.G.Power, R.Conecny, Z.Yusof and W.Gai



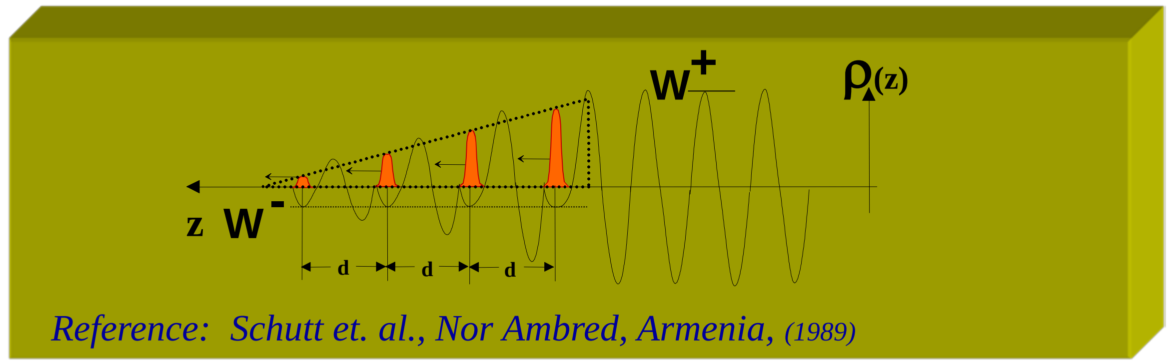
Euclid Techlabs, Rockville, MD:
C.Jing, S.Antipov, P.Schoessow, and A.Kanareykin
- P. Avrakhov (FNAL)

Euclid efforts in the WF experiments at AWA

- **Experiment of 26GHz dielectric wakefield power extractor in 2009**
  - ☑ 16ns,1MW & 6ns, 20MW 26GHz rf pulse were measured. BBU was observed.
- **Experiments of transformer ratio enhancement in 2007, 2010**
  - ☑ Successfully enhanced the transformer ratio to 3.4 by using ramped bunch train technique (2 bunches).
- **The 2nd test of 26GHz DWPE. BBU control and mitigation.**
  - ☐ The 1st test of 26GHz DWPE successfully generated ~20MW 26GHz rf pulse. We plan to run the 2nd test to achieve higher rf power with help of better beam control. BBU experiments.
- **The planned test of tunable DLA**
  - ☐ Developed the tunable DLA structure and finished bench test. It will be tested in the fall 2010.
- **The planned test of the GHz diamond structure**
  - ☐ Finished simulation and engineering design. Material has been ordered. It will be constructed and tested by the end of 2010. Progress on cylindrical structure development.

Transformer Ratio Experiment by joint effort from Euclid Techlabs and AWA

$R_2=3.4$



PRL **98,** 144801 (2007) PHYSICAL REVIEW LETTERS week ending 6 APRIL 2007

Observation of Enhanced Transformer Ratio in Collinear Wakefield Acceleration

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One approach to future high energy particle accelerators is based on the wakefield principle: a leading high-charge *drive* bunch is used to excite fields in an accelerating structure or plasma that in turn accelerates a trailing low-charge *witness* bunch. The transformer ratio R is defined as the ratio of the maximum energy gain of the witness bunch to the maximum energy loss of the drive bunch. In general, $R < 2$ for this configuration. A number of techniques have been proposed to overcome the transformer ratio limitation. We report here the first experimental study of the ramped bunch train (RBT) technique in a dielectric based accelerating structure. A single drive bunch was replaced by two bunches with charge ratio of 1:2.5 and a separation of 10.5 wavelengths of the fundamental mode. An average measured transformer ratio enhancement by a factor of 1.31 over the single drive bunch case was obtained.

DOI: 10.1103/PhysRevLett.98.144801 PACS numbers: 29.17.+w, 41.60.−m, 41.85.Ct

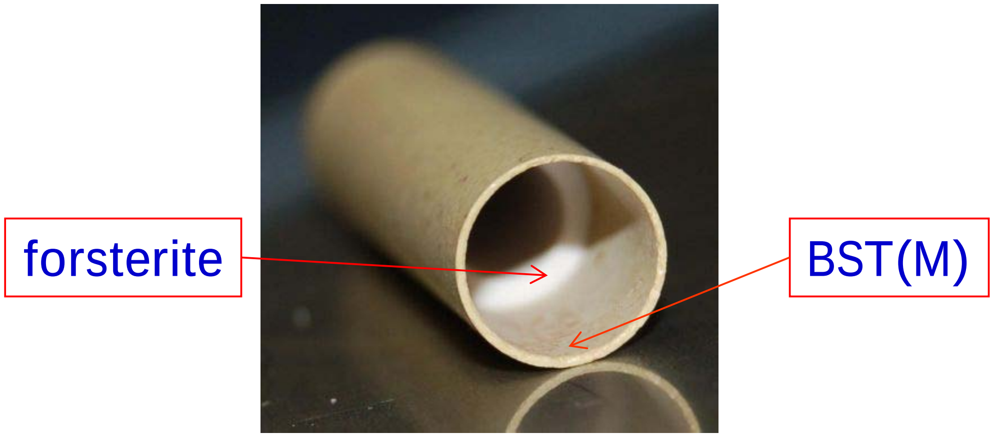
In a wakefield accelerator, the fields generated by a leading, high-charge *drive* bunch (either a single drive bunch or a train of drive bunches) are used to accelerate a trailing, low-charge *witness* bunch. An important pa- transformer ratio enhancement has been fully discussed in Refs. [14,15], which emphasized that the two key parameters necessary to adjust in order to effect the transformer ratio enhancement are the optimized charge ratios

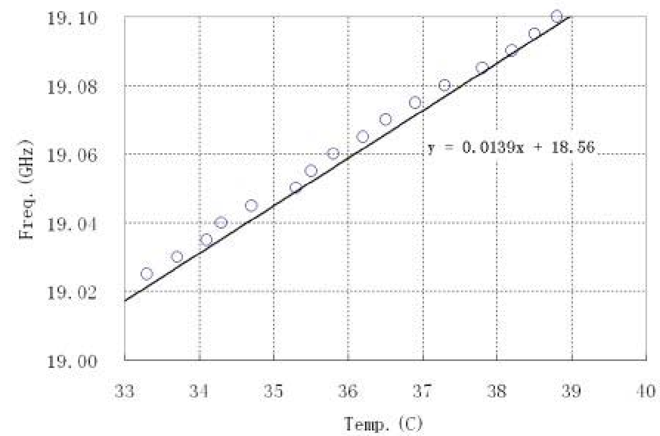
Measured Enhancement factor of $R_2/R_1=1.31$

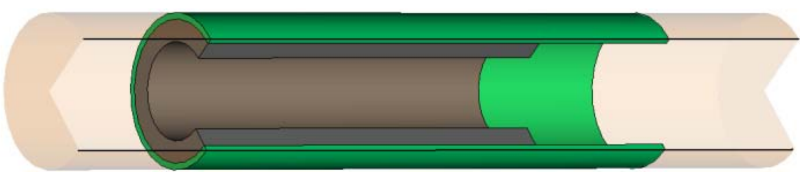
Inferred $R_2=2.3$

(2007)

Temperature Tuning Effects in Dielectric-Based Accelerator





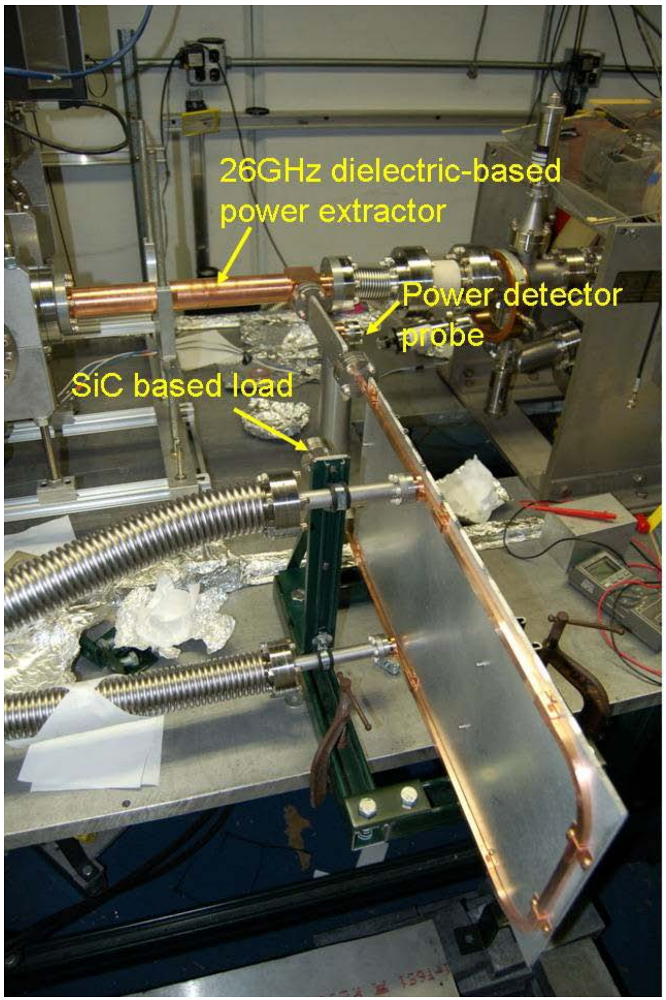


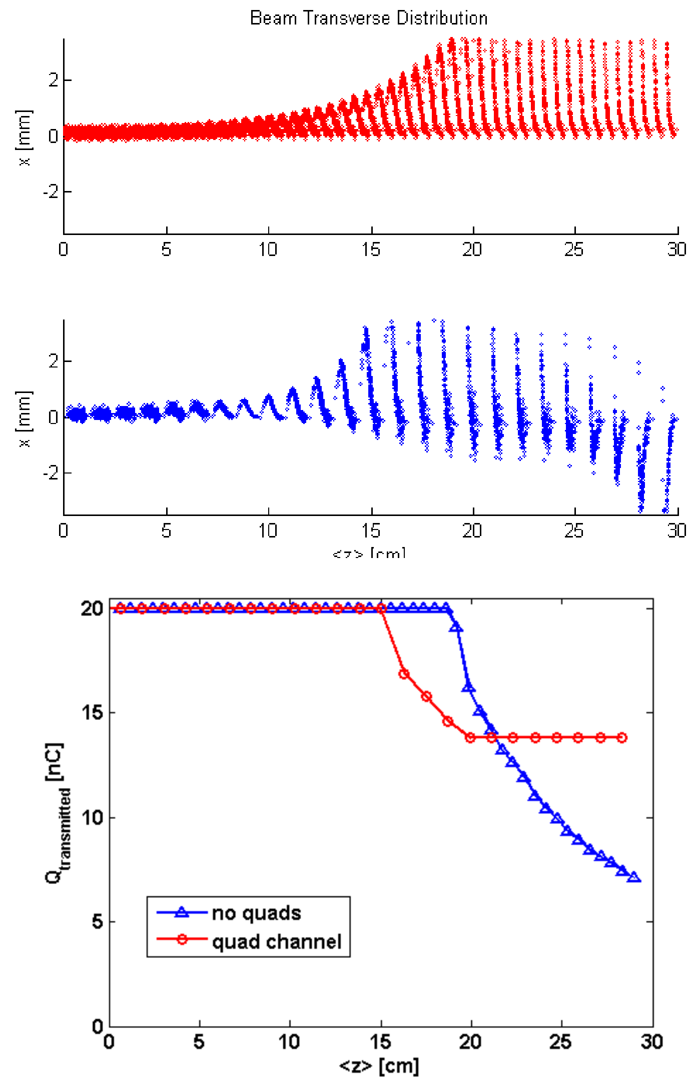
ε(E) for ferroelectric dielectric composite

Temperature tuning of 14 MHz/^{0}K

BBU Experiment: 2010/11
Quads FODO Focusing

BBU mitigation with quadrupole channel





20 nC beam; tapered F-D-F quad array

Projects

- ❑ **Development of a Dielectric-Based Short RF Pulse Two Beam Accelerator Prototype Module** Unlike the most of the present accelerator designs pulse with lengths of 150-400 ns and gradients ~100 MV/m as the operational parameters, we propose a short pulse (~20 ns), high repetition rate (>1 kHz), high gradient (>200 MV/m) accelerator technology.

- ❑ **THz Dielectric Wakefield Accelerating Structure.** This project will develop a manufacturing technology of artificial diamond fiber to be used in dielectric loaded accelerating structures. When developed, this structure will sustain a record high accelerating gradient in THz frequency range.

- ❑ **Development Of A 12 GHz Dielectric-Based Wakefield Power Extractor for Potential CLIC Applications** Dielectric based high power radio frequency (rf) generator offers the possibility of reduced cost and higher efficiency for applications in the next generation high energy physics machine to meet the particular requirements of CLIC.

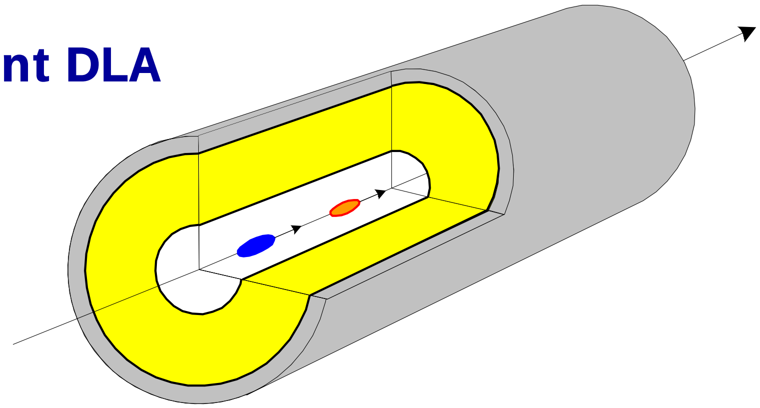
- ❑ **Multipactor Suppression In Dielectric Loaded Accelerating Structures Using Vacuum Channel Surface Modification** This project will study ways to eliminate a form of energy absorption that is currently the main obstruction to widespread use of the dielectric based particle accelerators.

- ❑ **Dielectric Collimators for Linear Collider Beam Delivery** this project will develop a special device to control electron bunch of the future linear collider. The use of new software and materials that our company has developed is expected to lead to improved performance and efficiency.

A

What can be used from the DLA ATF studies ?

- **Drive Beam – Beam Train - High Gradient DLA**
- **Dielectric Material Beam Tests**
- Dielectric - Wakefield Power Extractor
- Tunable Dielectric Based Accelerator
- Energy Transfer: High Transformer Ratio
- **Beam Handling, Beam Breakup (BBU)**



Dielectric Based Accelerator issues: high gradient – drive beam, power extraction, tuning, efficiency, beam control (BBU).

Motivation for CVD Diamond for DLA

CVD DIAMOND PROPERTIES:

- DC BREAKDOWN THRESHOLD OF ~ 2 GV/m
- LOSS FACTOR DOWN TO 5-9 x10^{-5} AT 30-140 GHz
- HIGHEST THERMAL CONDUCTIVITY
- MULTIPACTING CAN BE SUPPRESSED

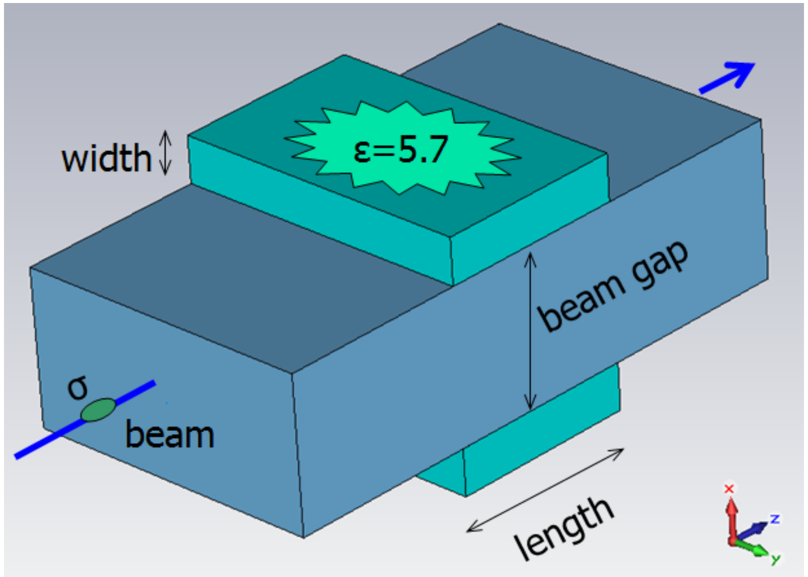
and

CVD DEPOSITION NOW CAN BE USED TO FORM CYLINDRICAL WAVEGUIDES

Element Six

Element Six

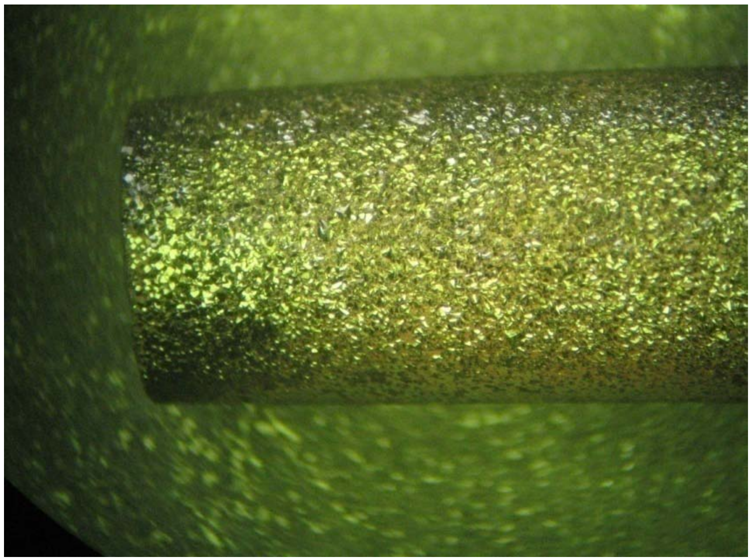
Rectangular diamond structure

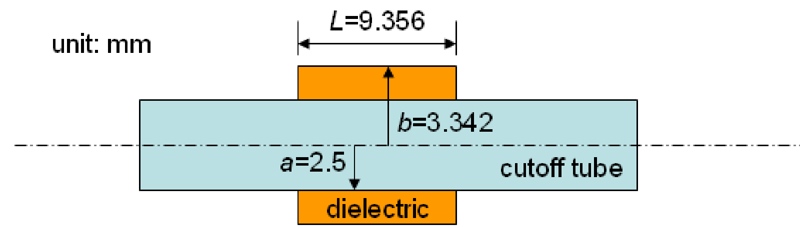


Experiment at AWA

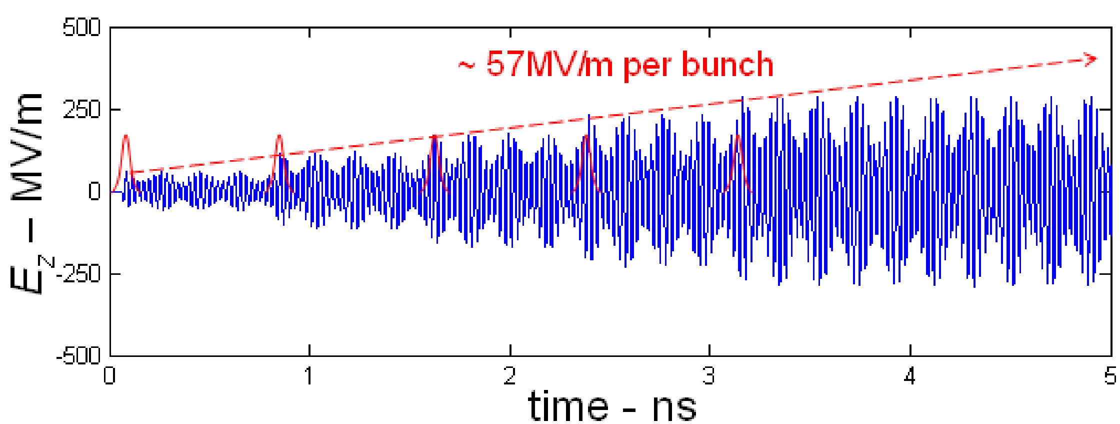
- First CVD diamond in a dielectric accelerating structure
- >~ 100 MV/m gradient using AWA beam
- Breakdown test using 20 micron – wide artificial scratch on the diamond surface (0.5 GV/m level fields)

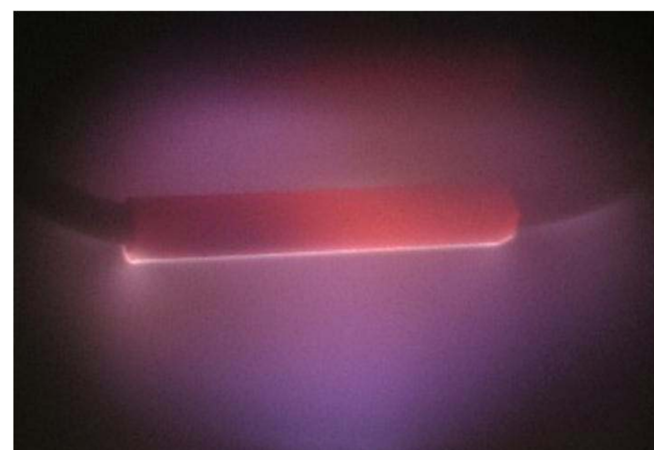
35 GHz Diamond Based DLA Structure





CVD diamond tube fabrication





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Diamond Based DLA Structure Material Characterization

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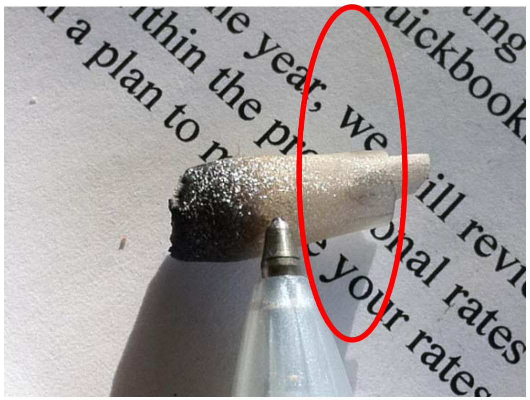
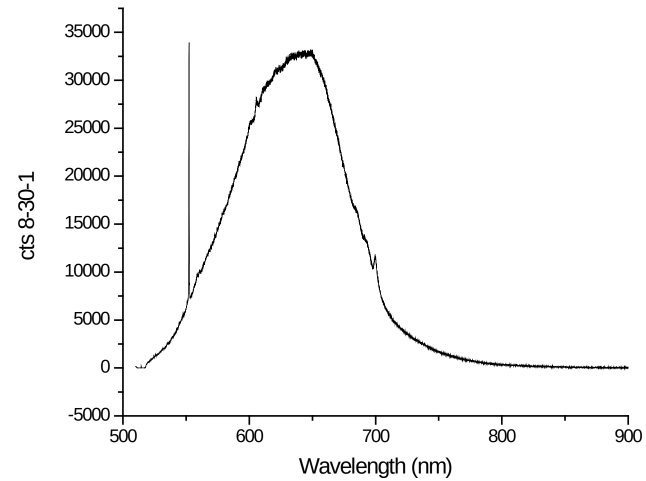
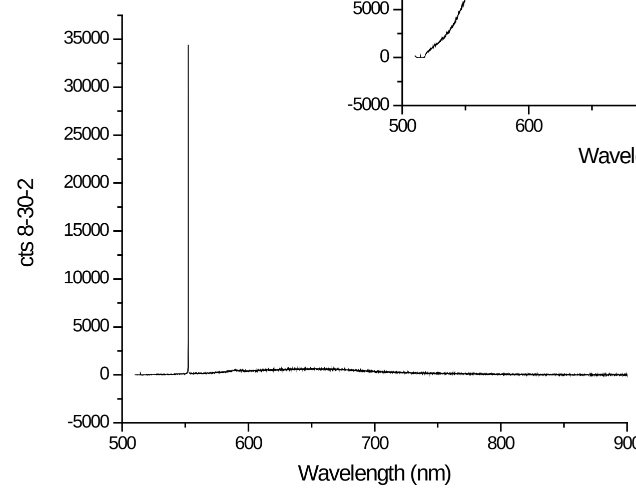
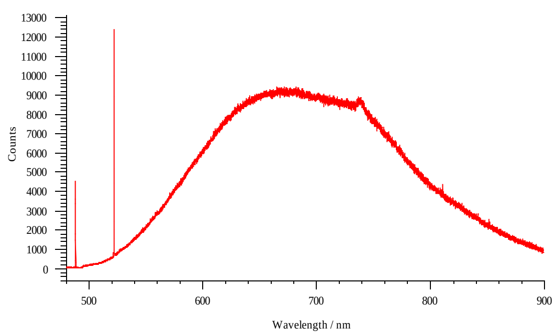
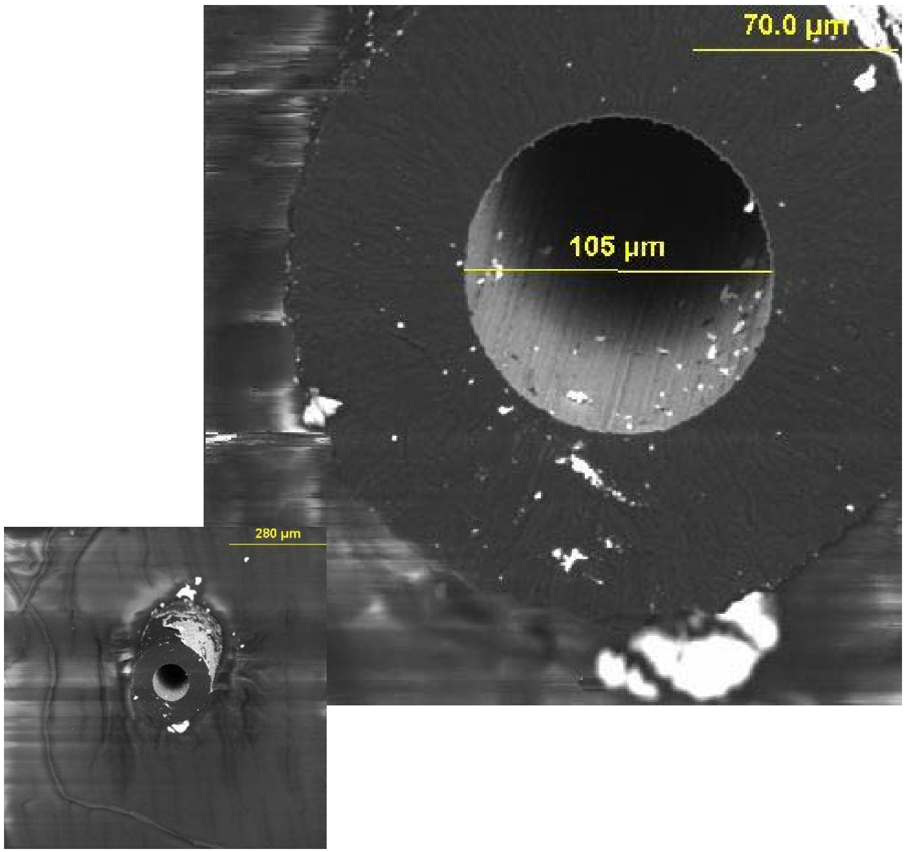








THz Diamond Tubes

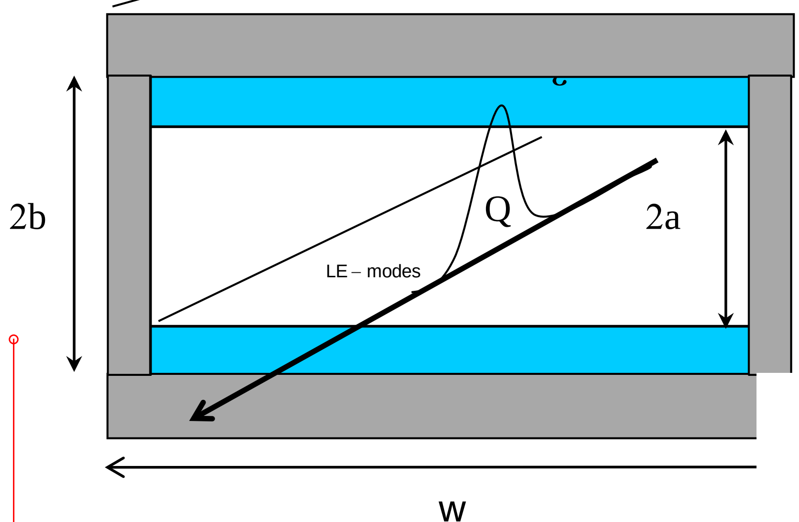


Scanning electron microscope images of a THz diamond microstructure produced using the hot wire deposition technique.

THz diamond structure:
ID = 100 µm, thickness 70 µm, 1 cm long

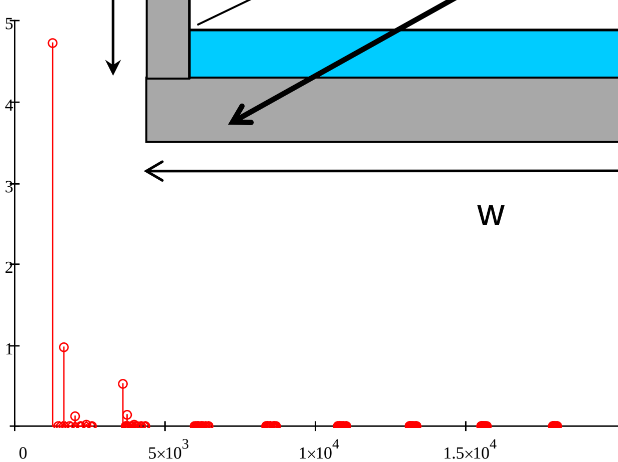
(Bristol University, UK)

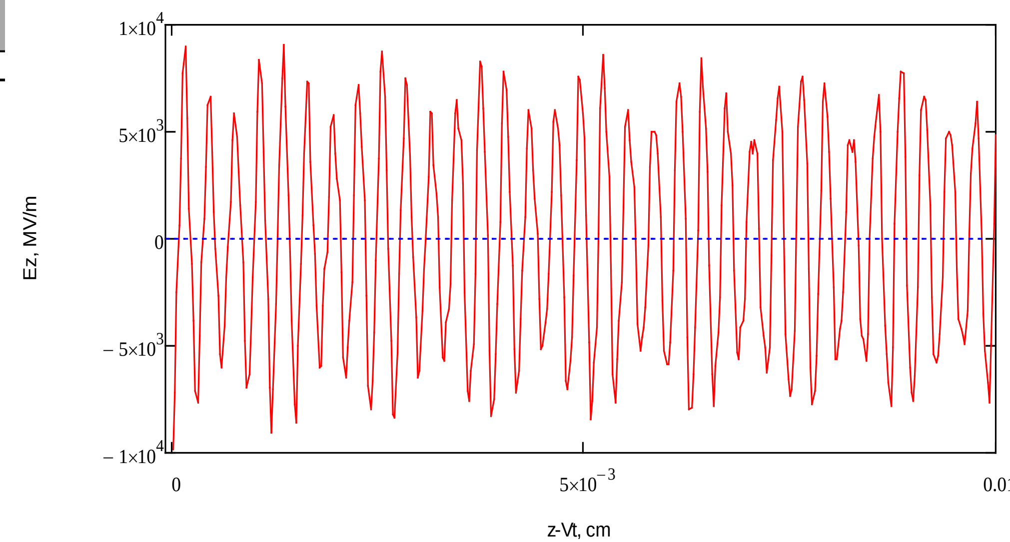
THz Planar Diamond Based DLA



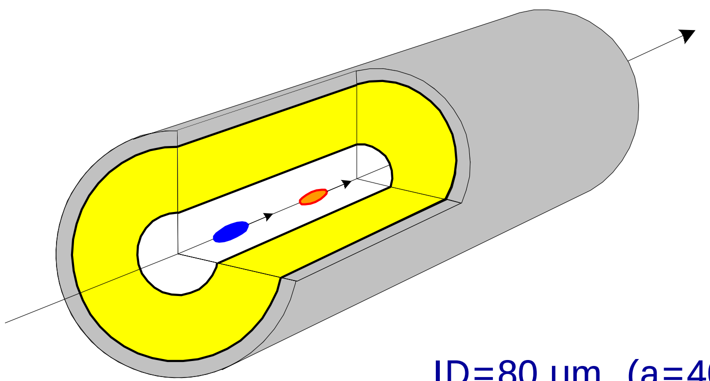
w= 300 μm
a= 40 μm, 2a=80 μm
b= 70 μm
b-a= 30 μm
(diamond thickness)

~2 GV/m/nC ⇒ **0.7 GV/m ATF**

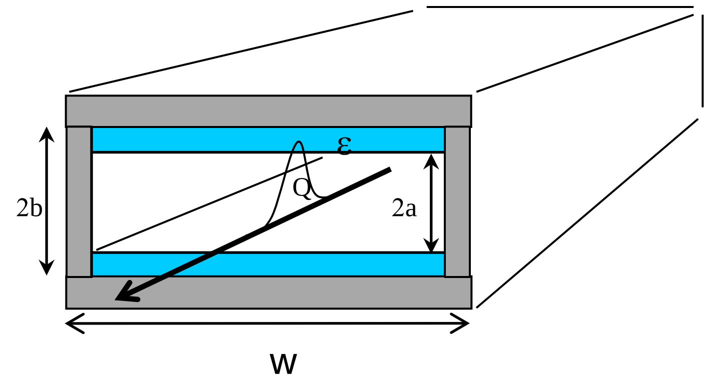




Planar or Cylindrical THz DLA ? Gradient

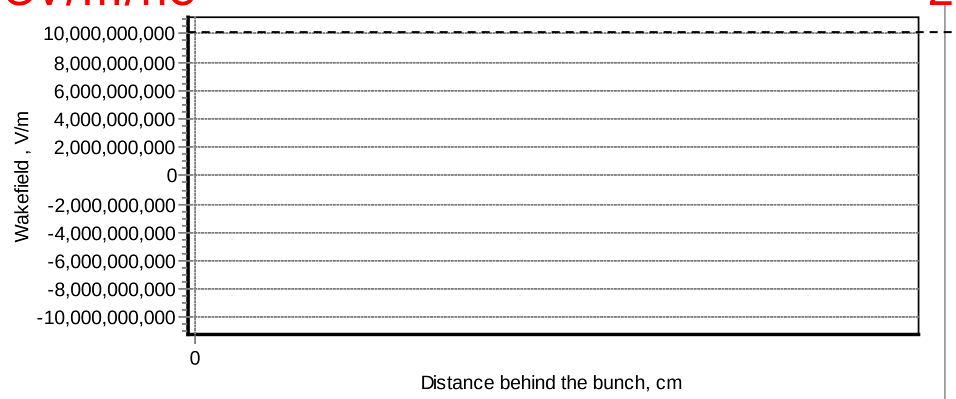


ID=80 μm (a=40 μm)
OD= 152 μm (b=76 μm)
b - a= 30 μm (diamond thickness)

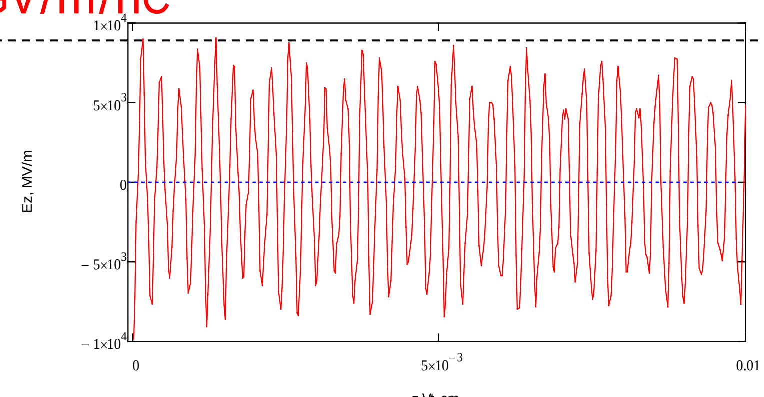


2a=80 μm, a= 40 μm, b= 70 μm
b - a= 30 μm (diamond thickness)
w= 300 μm

2 GV/m/nC



2 GV/m/nC



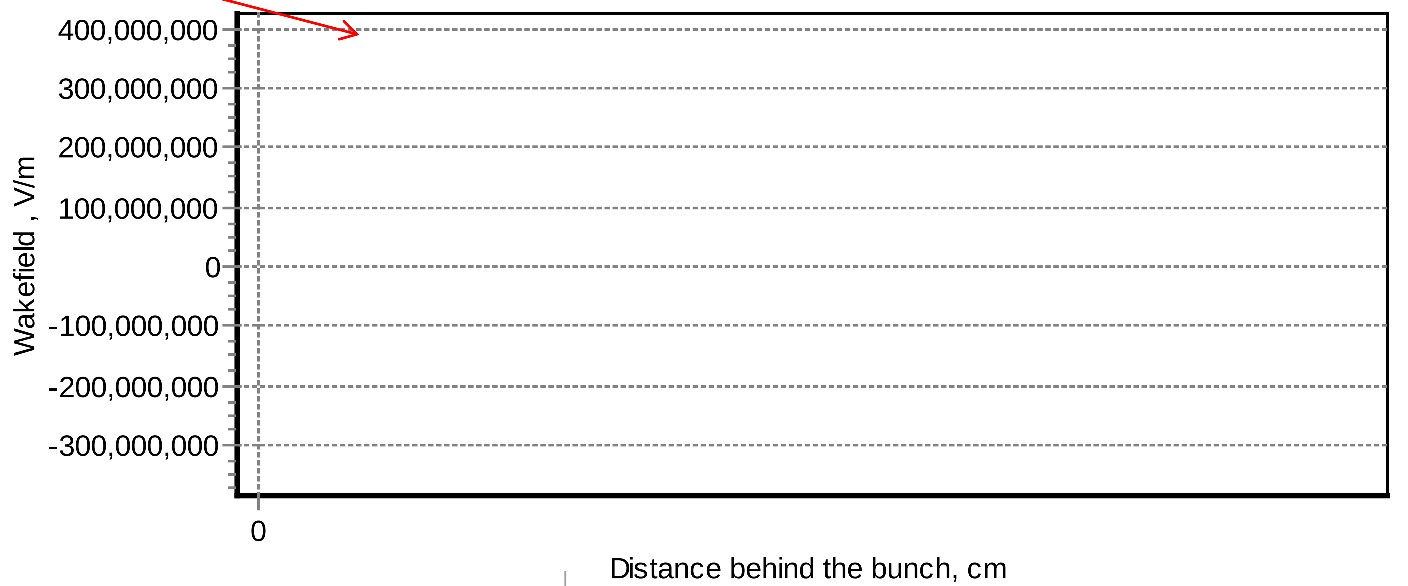
Both structures ~ 2 GV/m/nC

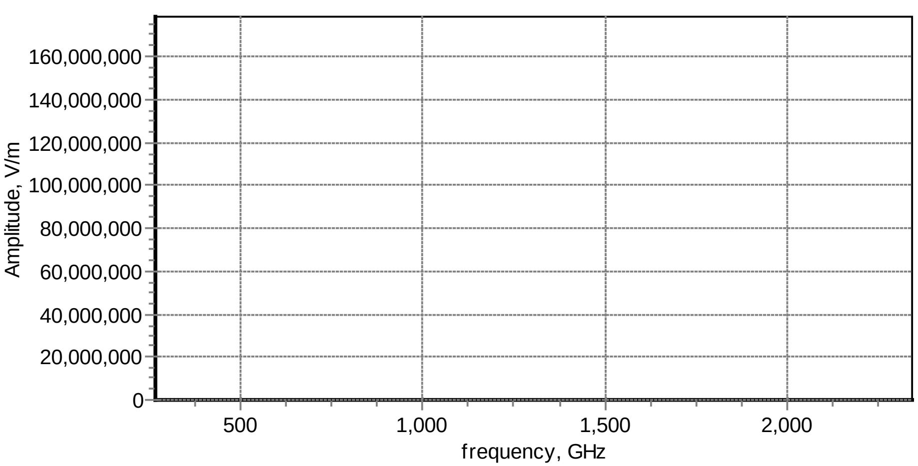
A. Kanareykin, Euclid Techlabs LLC, ATF Users Meeting 2010

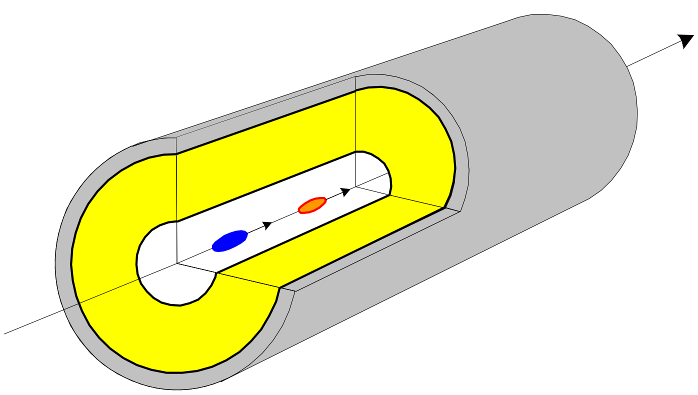
Cylindrical Structure

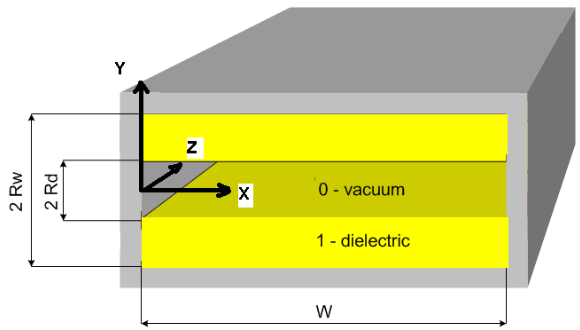
400 MV/m

a=100 μm
σ=50μm
Q=500pC
f=400 GHz







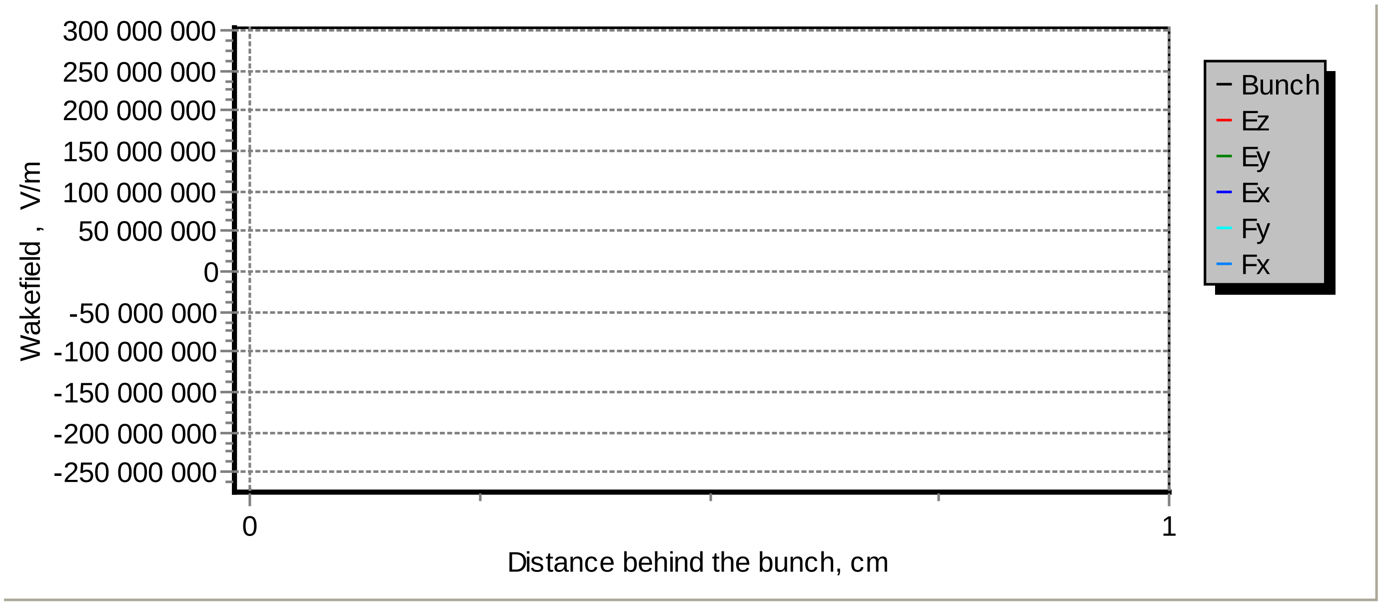


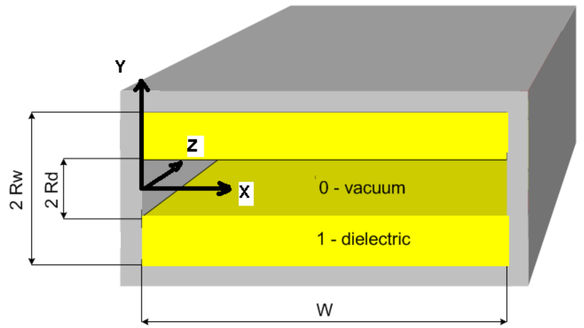
Planar Structure

a=100 μm
σ=50μm
Q=500pC
f=400 GHz

f,GHz	Rd, μm	Rw,μm	eps	W, μm	Q, pC	σ z,μm
400	100	177	5.7	500	500	50

300 MV/m



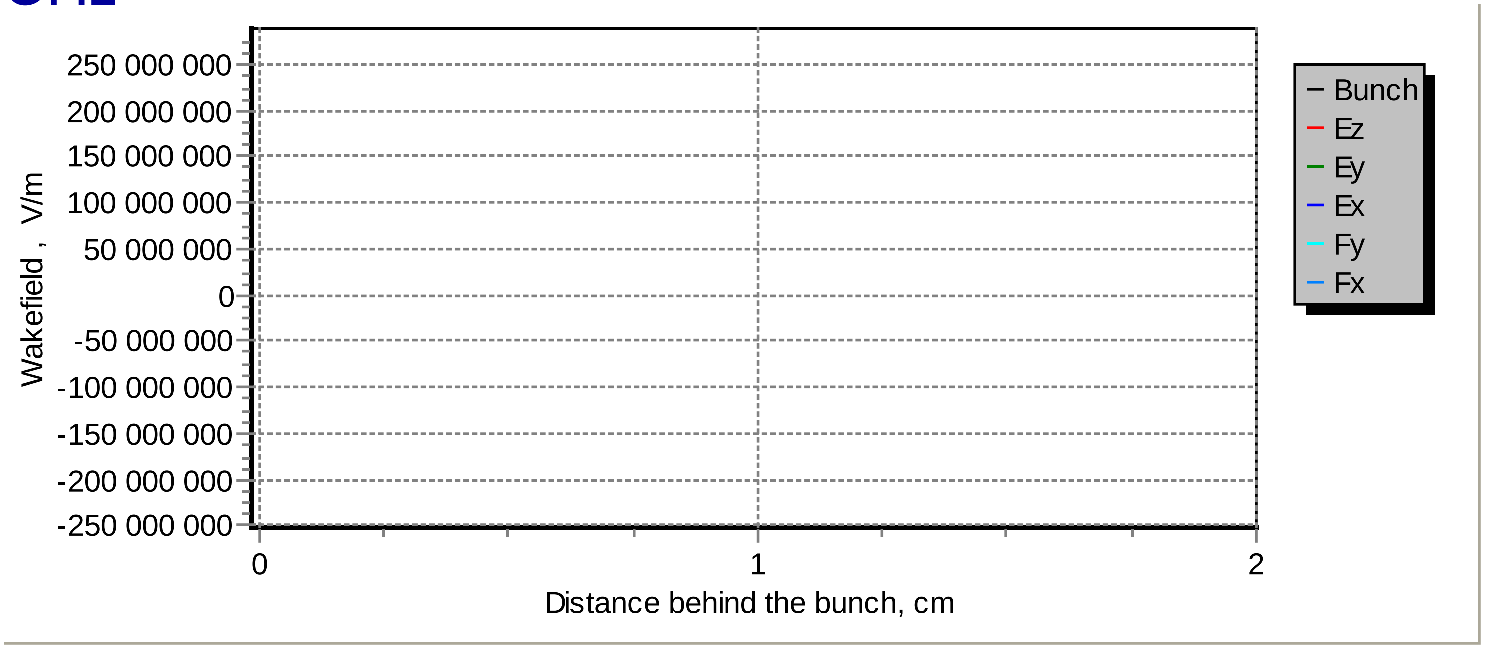


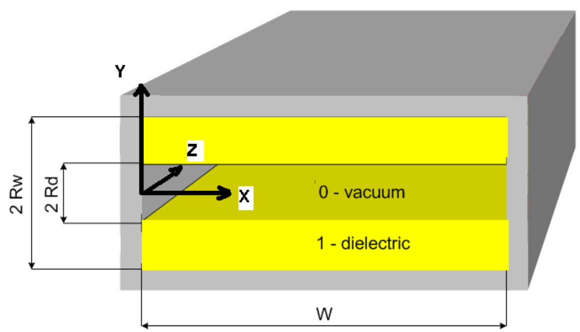
Planar Structure

a=100 μm
σ=50μm
Q=500pC
f=400 GHz

f,GHz	Rd, μm	Rw,μm	eps	W, mm	Q, pC	σ z,μm
400	100	171	5.7	1	500	50

250 MV/m



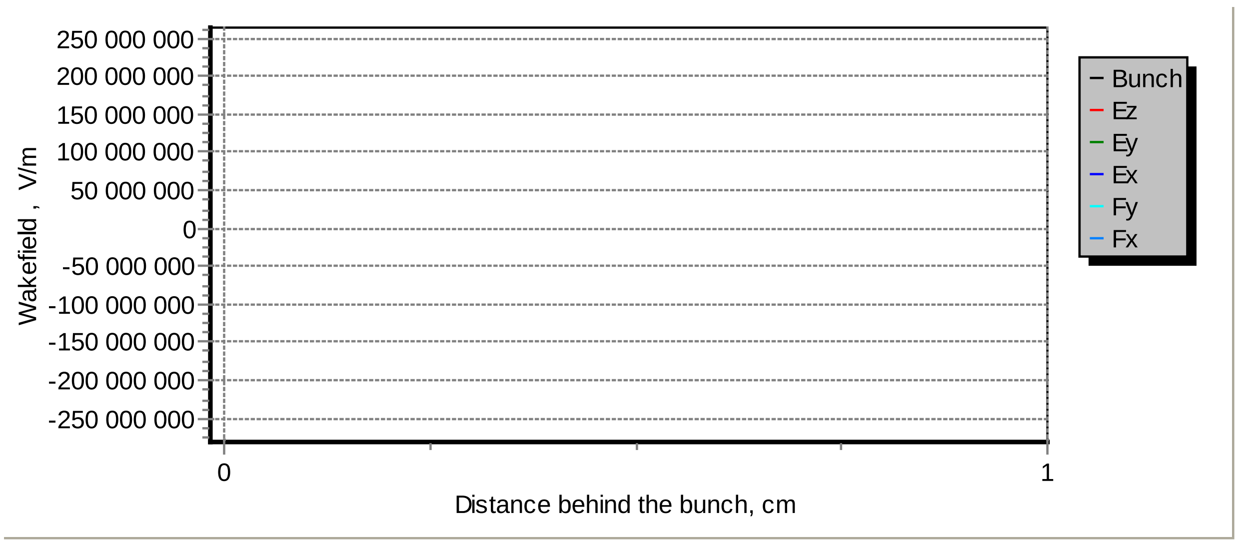


Planar Structure

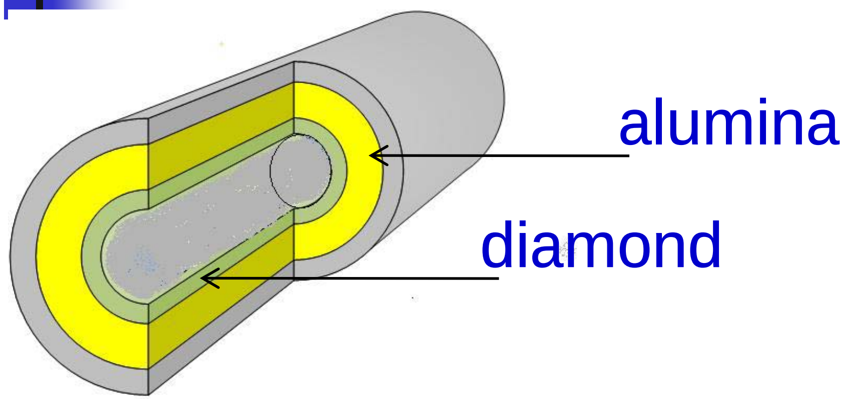
a=100 μm
σ=50μm
Q=500pC
f=300 GHz

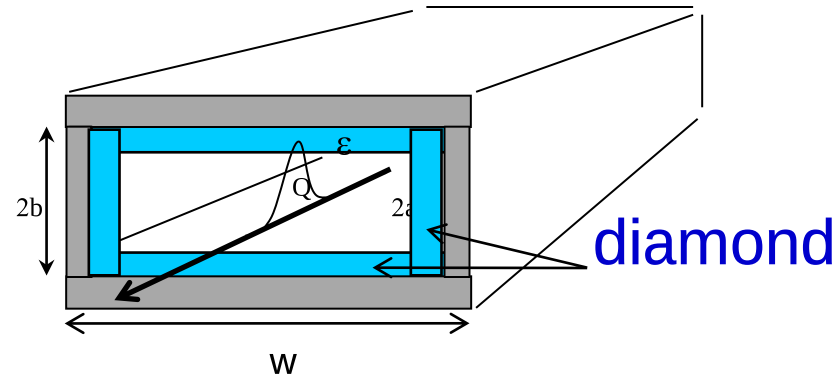
f,GHz	Rd, μm	Rw,μm	eps	W, μm	Q, pC	σ z,μm
300	100	215	5.7	500	500	50

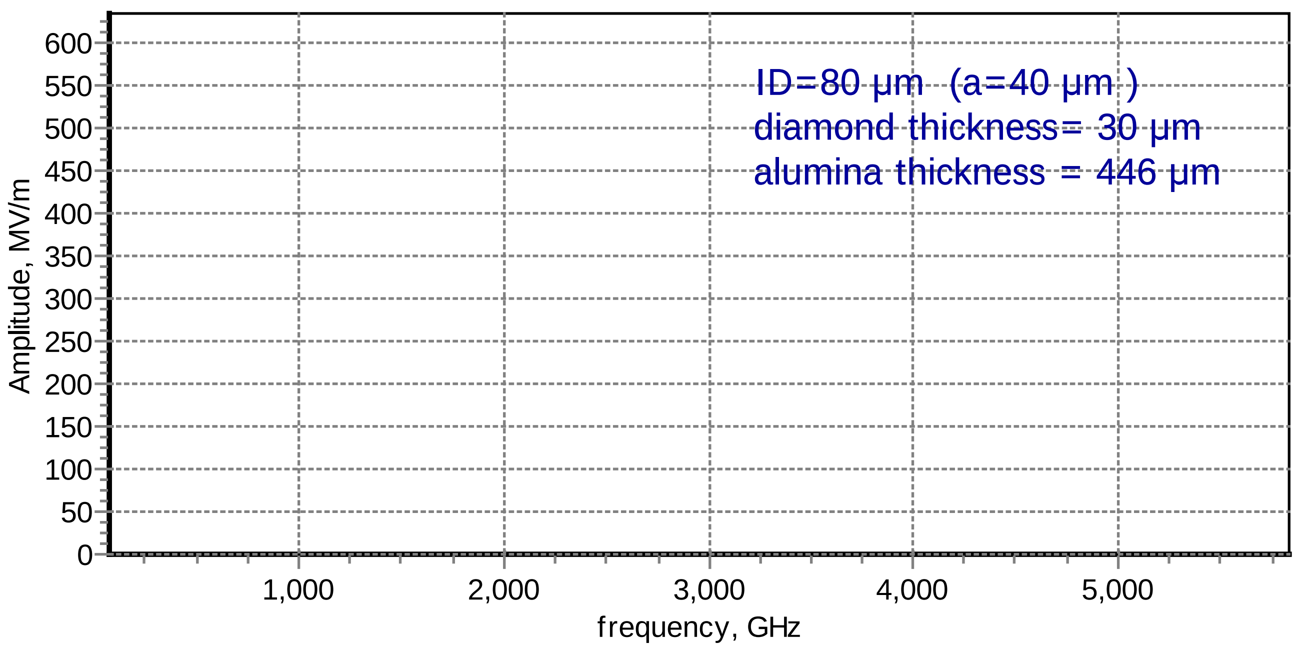
250 MV/m



Dual Layer Diamond-Alumina Structure (Multimode Dielectric Cladding)





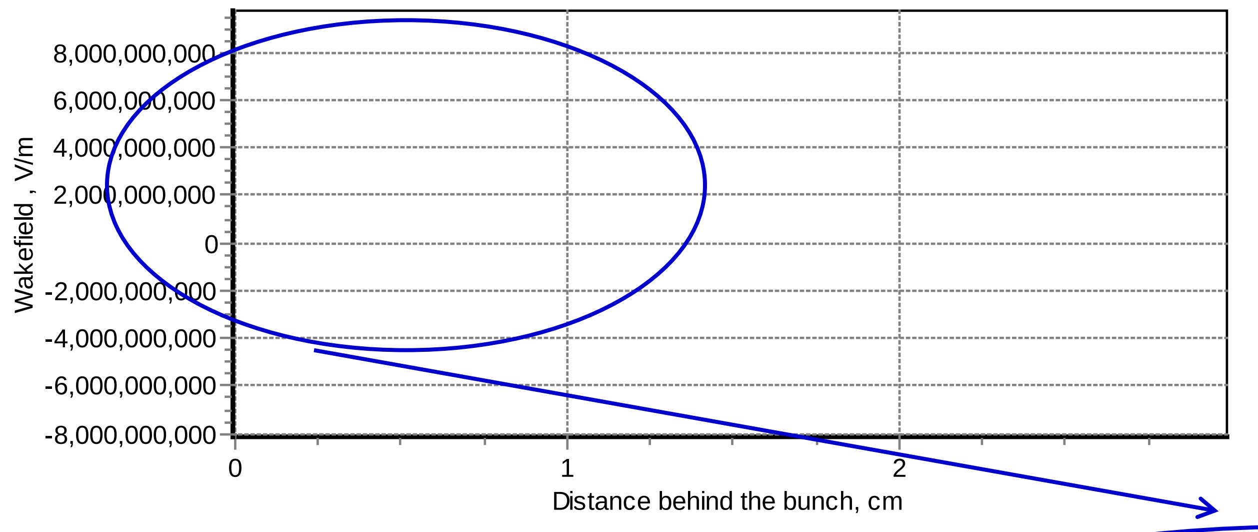


gradient ?

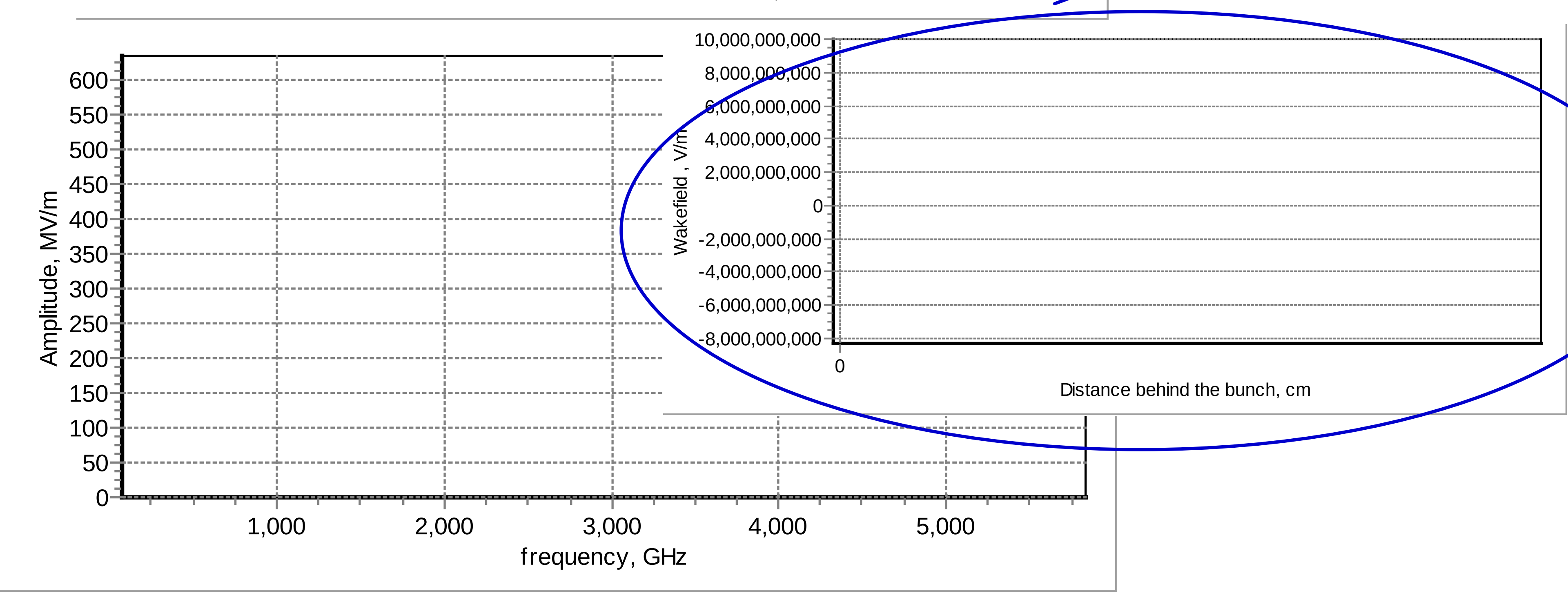
T-B. Zhang et al, Phys. Rev. E 1997

J.G. Power et al. Phys.Rev., ST-AB, 2000.

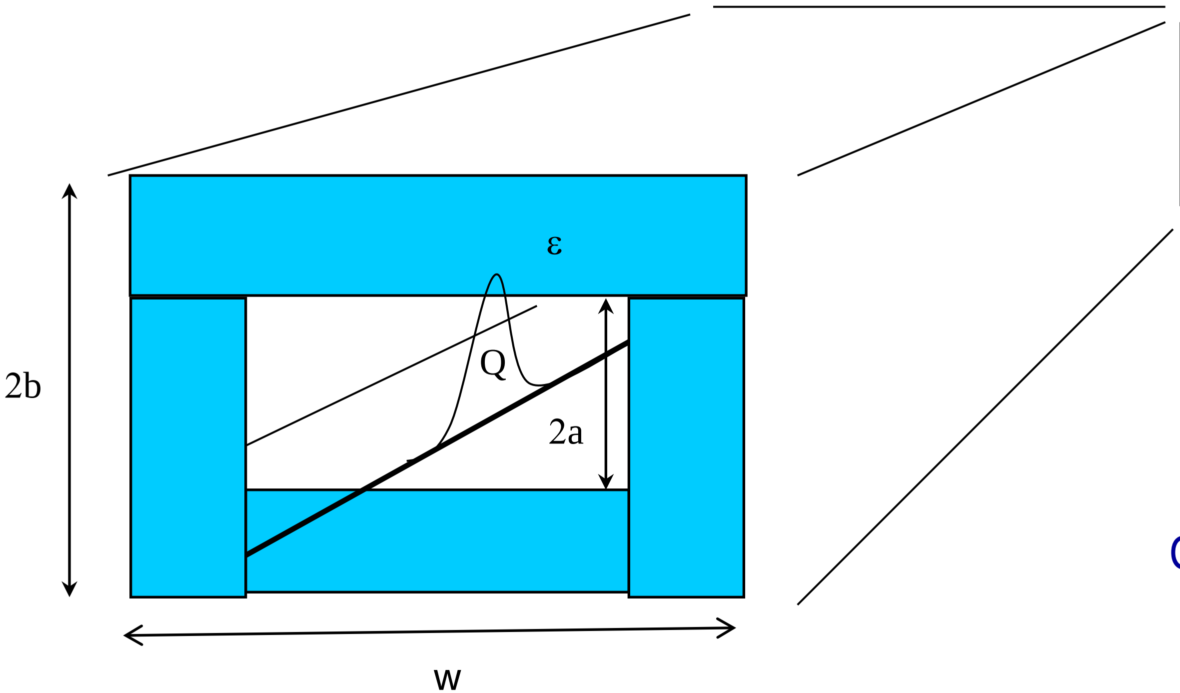
Dual Layer Diamond-Alumina Structure (Thermo-conducting Cladding)



2 GV/m/nC

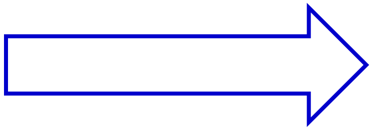


All-Diamond Planar THz DLA



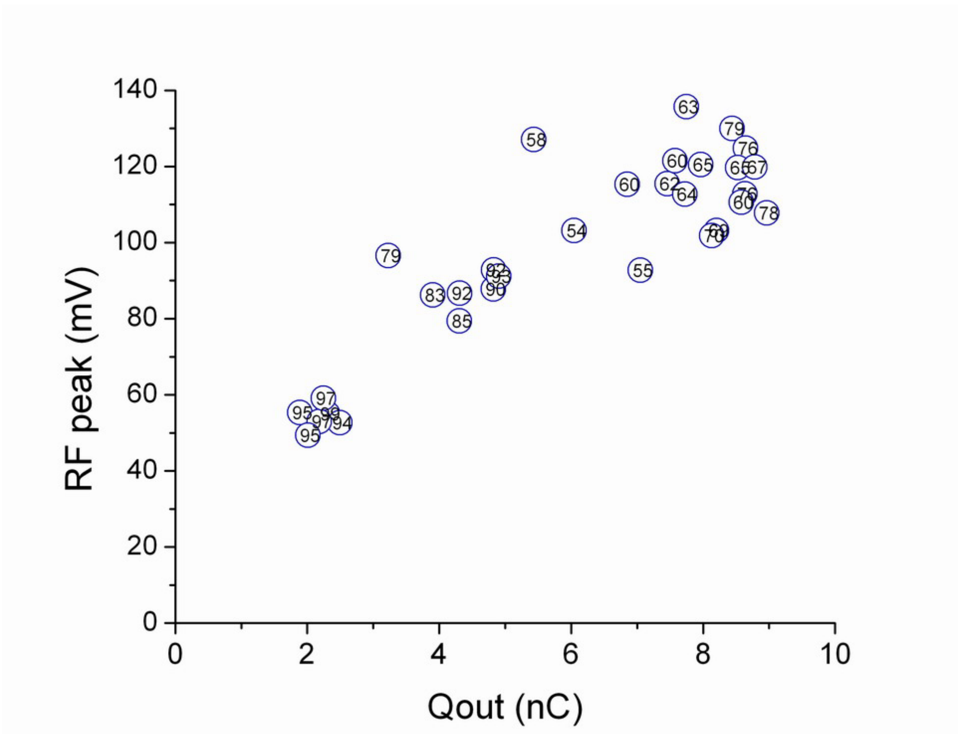
w= 300 μm
a= 40 μm, 2a=80 μm
b= 70 μm, 2b=140 μm

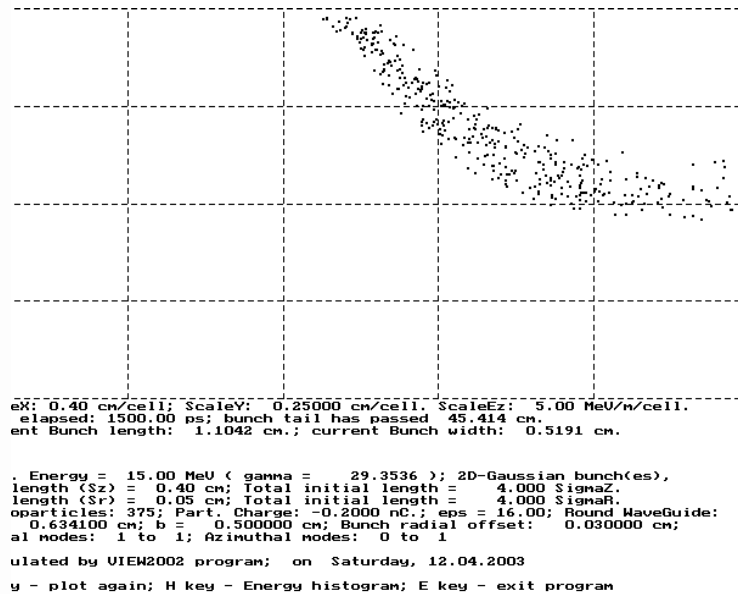
Cylindrical structure



ID=80 μm (a=40 μm)
diamond thickness= 30 μm
alumina thickness = 446 μm

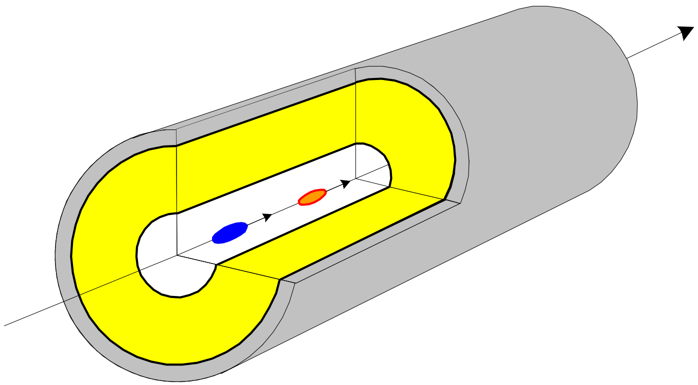
BBU at Dielectric Accelerator

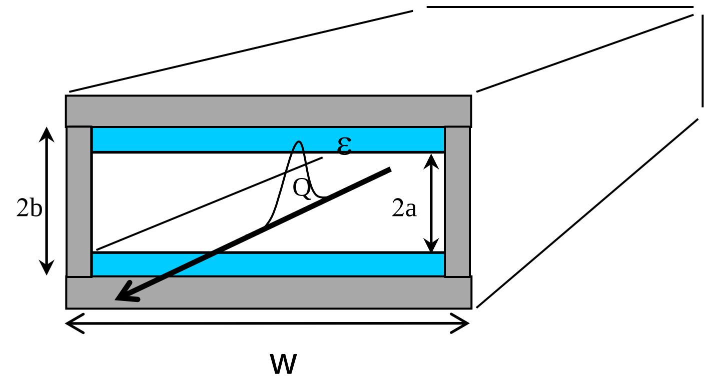


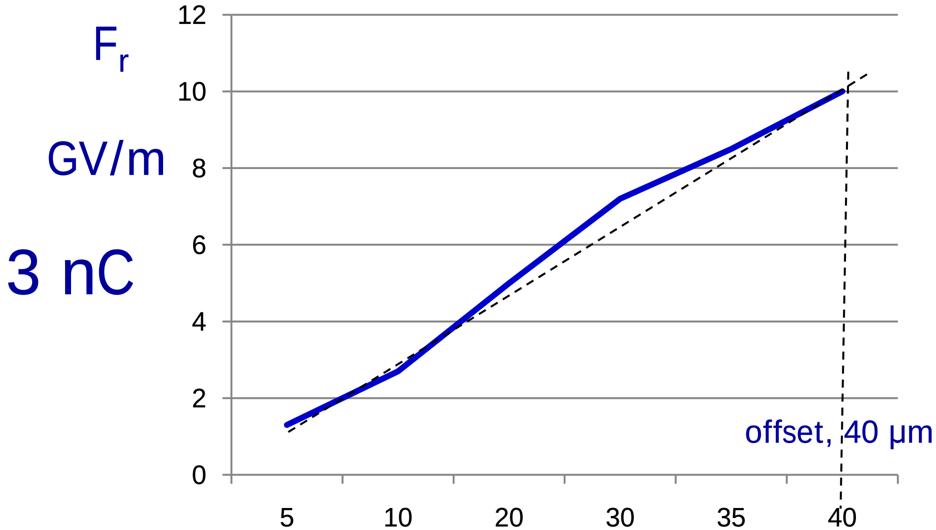


- Deflection of bunch tail by transverse wakefields from head
- Amplification of injection errors as beam propagates
- Especially significant for the high charge bunches used for wakefield acceleration-

Planar or Cylindrical THz DLA ?
BBU comparison







3 GV/m/nC

F

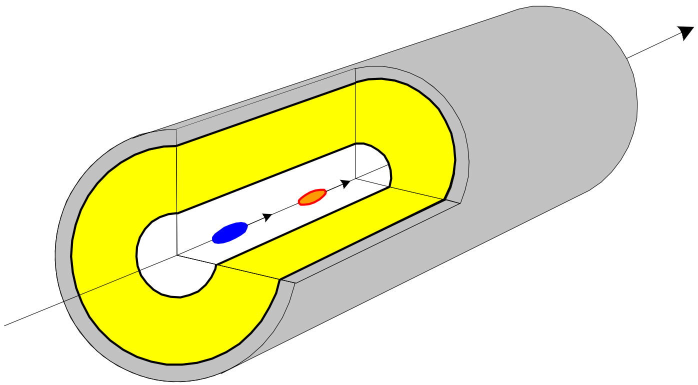
y

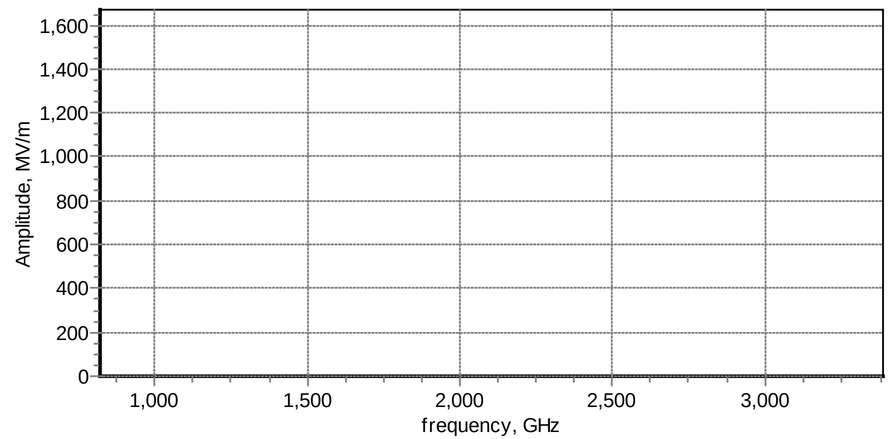
0.7 GV/m/nC

40 μm

5 μm

Dipole modes and Deflection Fields





0.8 GV/m/nC deflecting force

ID=80 μm (a=40 μm)
OD= 152 μm (b=76 μm)
b - a= 30 μm (diamond thickness)

10 μm offset

ATF Beam BBU, Planar Structure, Transverse Deflection

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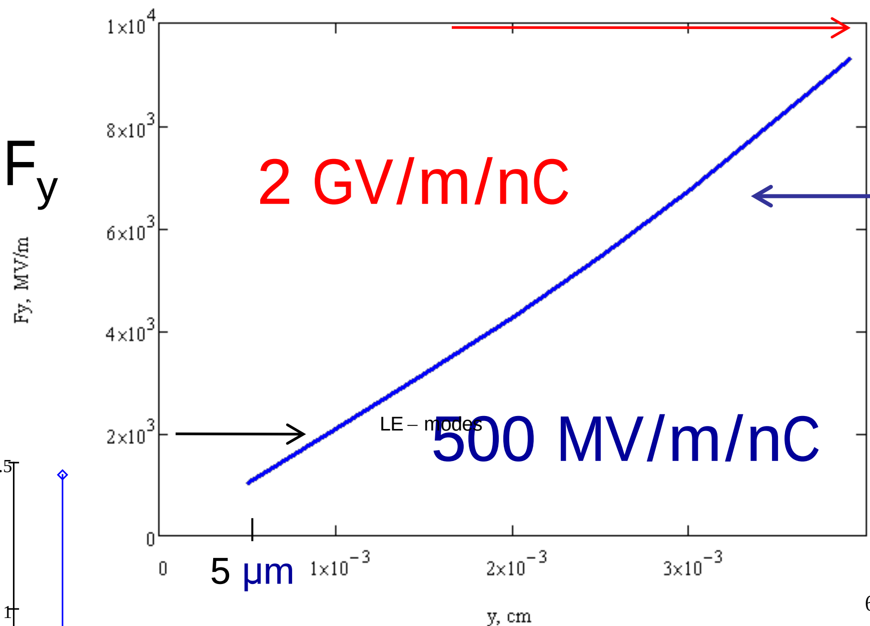
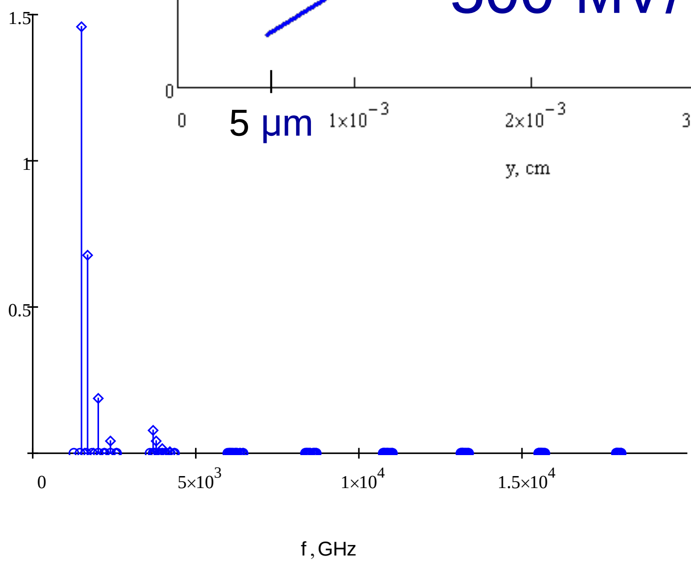
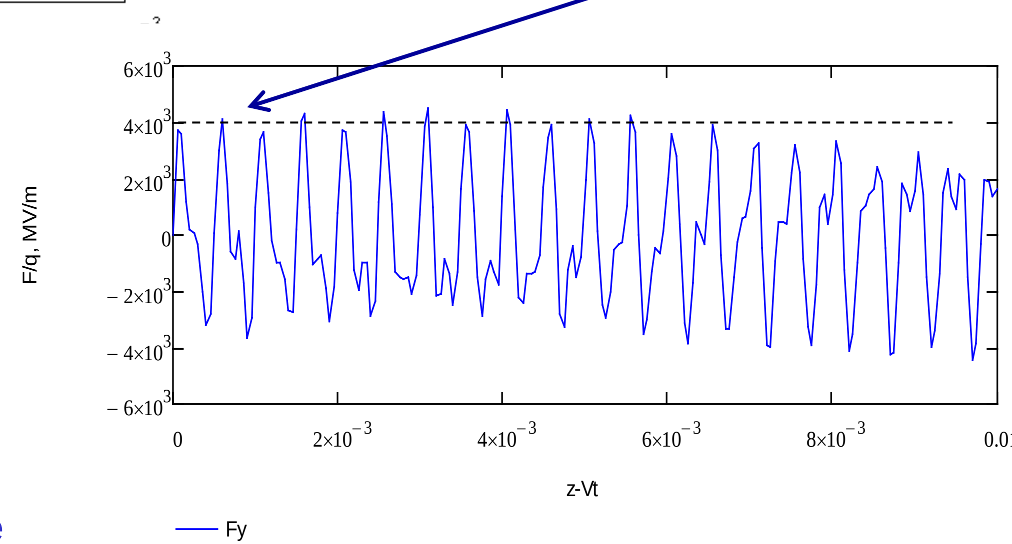
Deflecting force vs. offset
5 μm – 40 μm

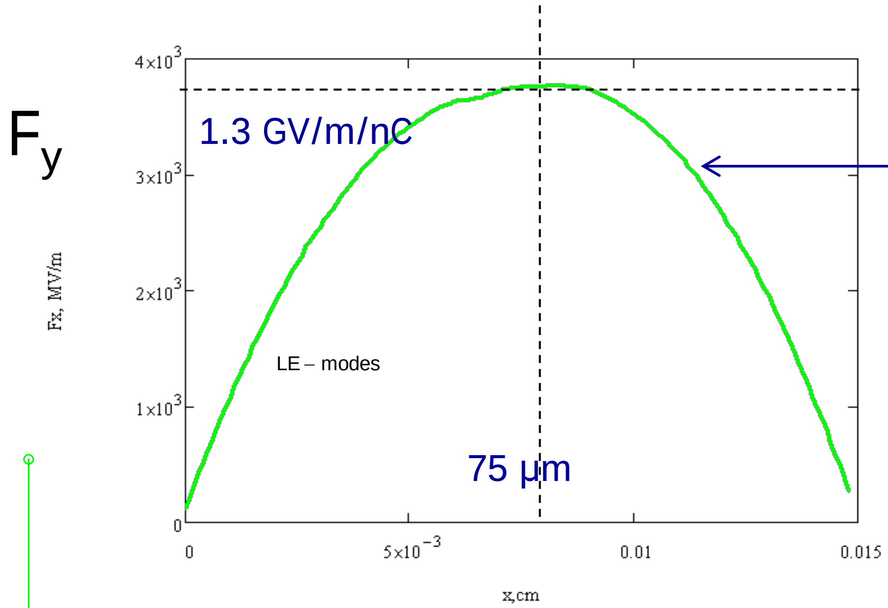




offset 20 μm, F_y = 1.3 GV/m/nC

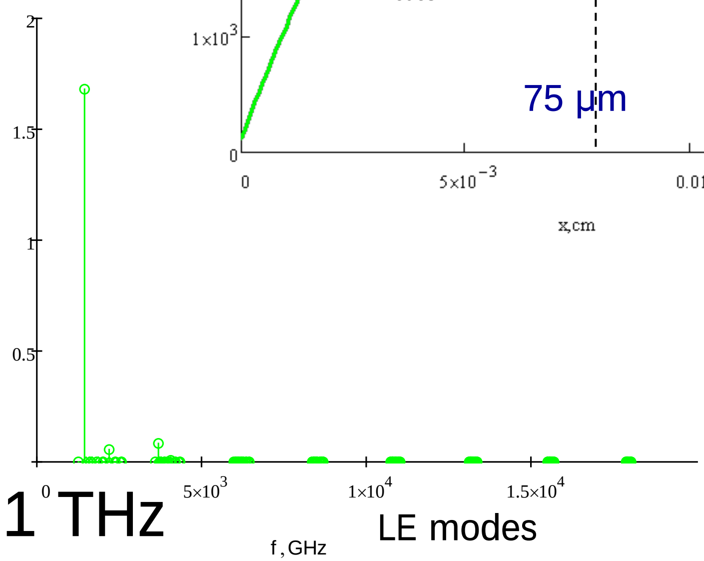


ATF Beam BBU, Planar Structure, Parallel Deflection



150 μm

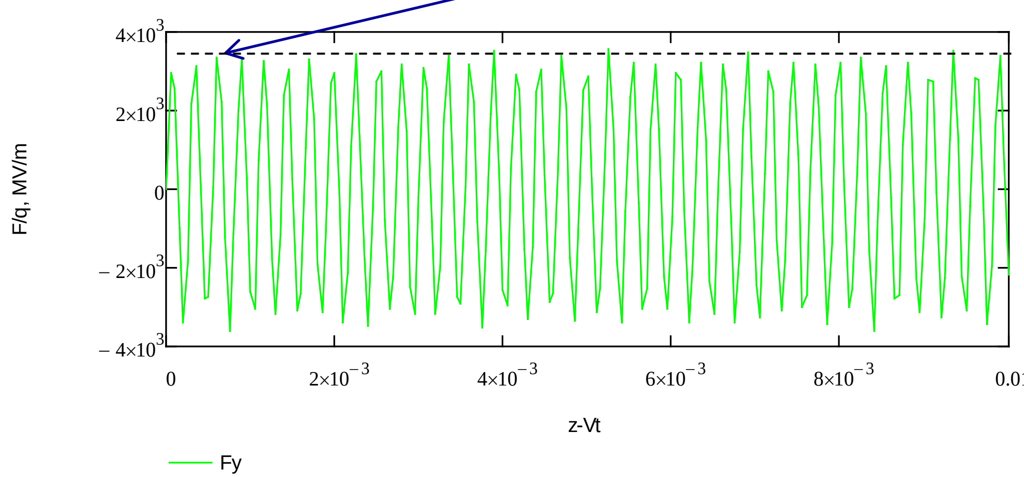
Deflecting force vs. offset 0 μm – 150 μm



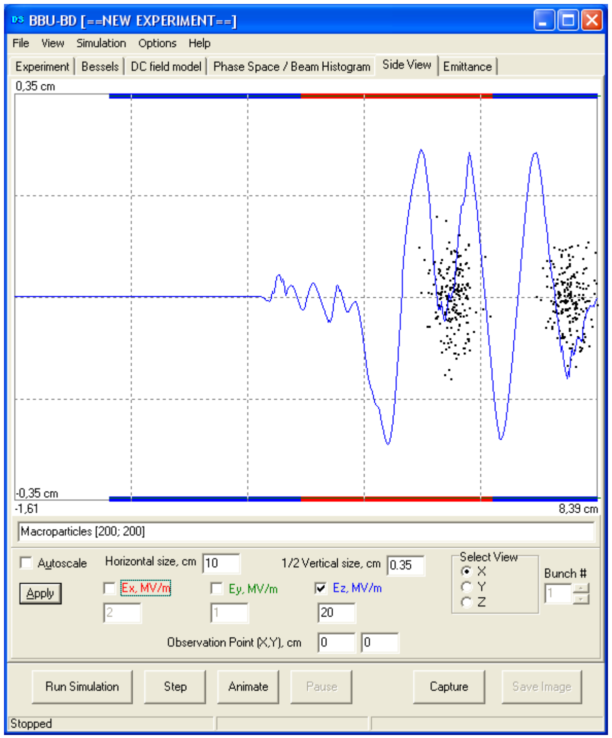
1 THz

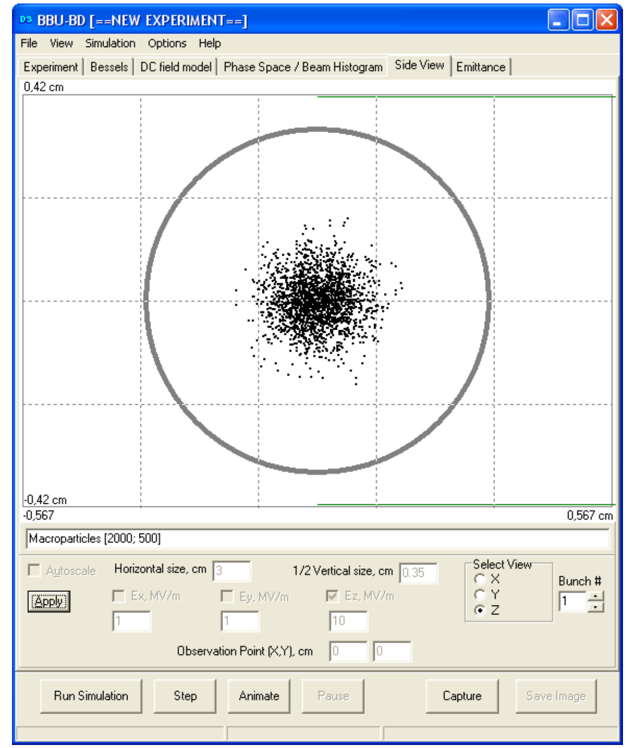
LE modes

offset 75 μm, F_y = 1.3 GV/m/nC



BBU-3000 Code Development for Dielectric Accelerator





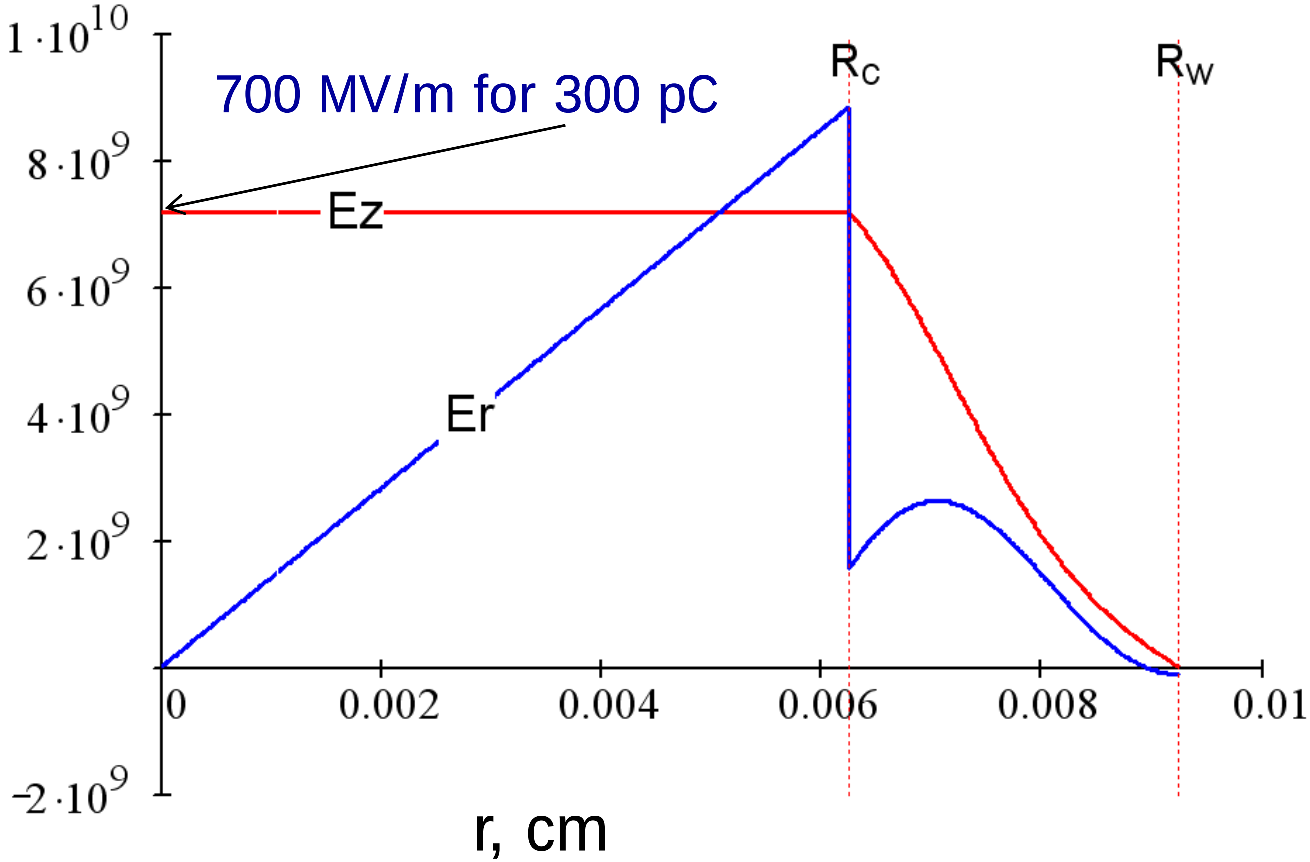
BBU-3000 will be used for THz Structure optimization

Focusing quads (in this case in the *x*-*x*' plane) are plotted with a solid blue line. Defocusing quadrupoles are shown with a solid red line.

Cross-section view (*x*-*y* plane), Gaussian distribution

BBU Simulation for 3 nC beam

Field profiles

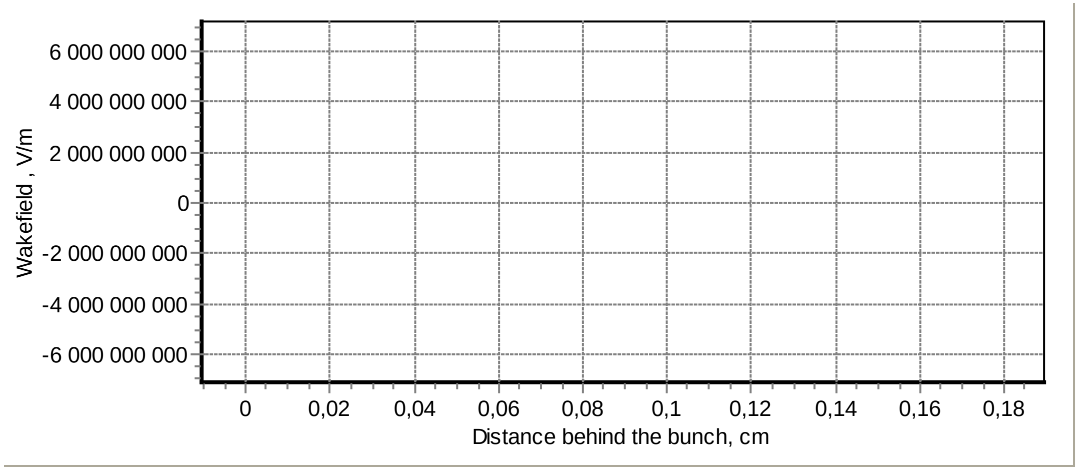


Structure:

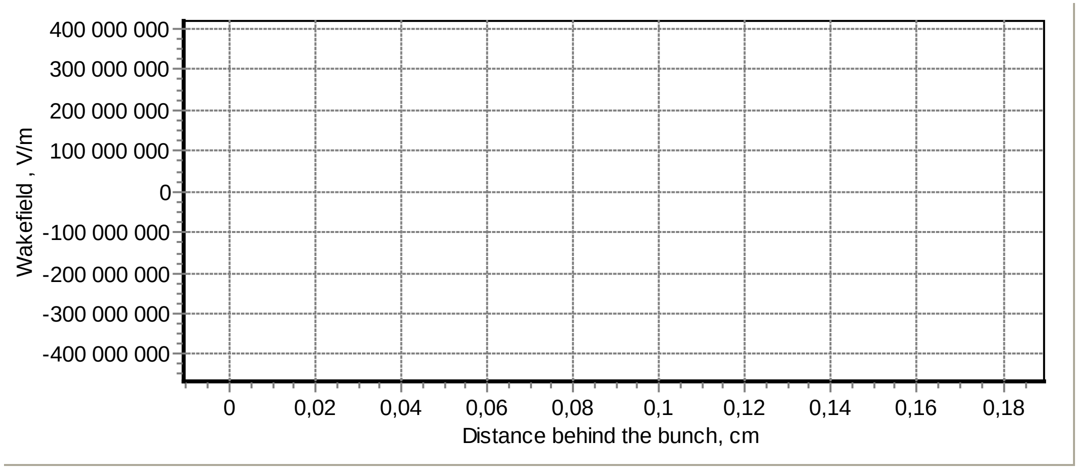
- iR = 62.5 μ
- oR = 92.5 μ
- ε = 5.7
- 3 nC; σ_r = 5 μ; **offset =5 μ**
- σ_z = 30 μ;

E_z (ATF)=E_z/10

Wakefields, 3 nC



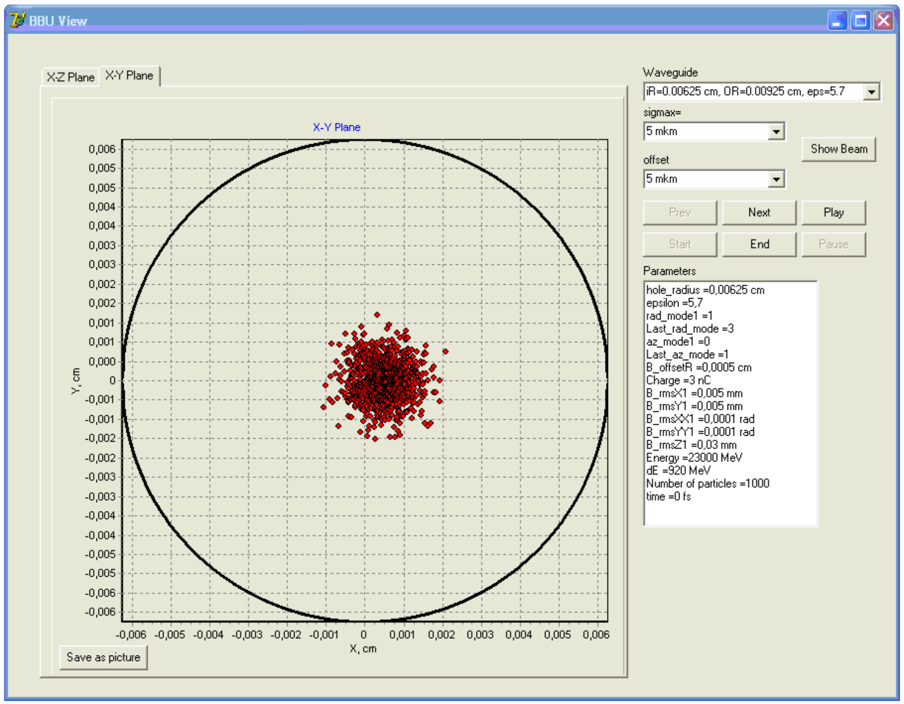
E_z ~ 2.3 GV/m/nC

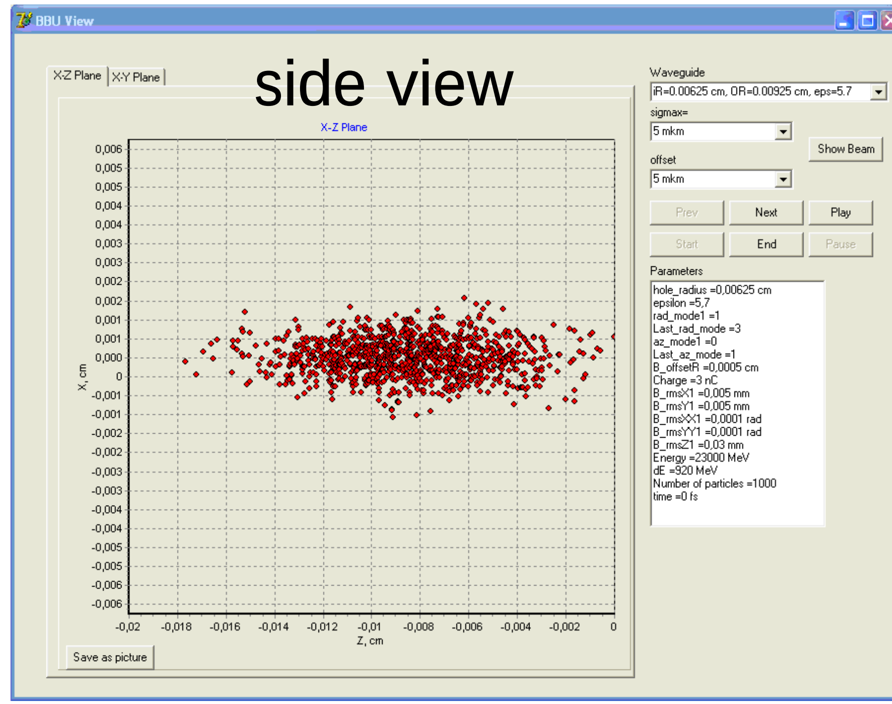


$F_\perp$ ~ 130 MV/m/nC

Initial offset 5 μ

BBU Simulation





E_z ~ 2.3 GV/m/nC.

The deflecting gradient grows from 130 MV/m/nC (for initial 5 μ offset) as the beam is deflected.

Conclusions

- Diamond structure is a promising solution for ATF (and future for FACET) experiments because of the highest breakdown threshold and highest thermo-conductivity
- A high quality CVD diamond cylindrical tube with ID ~ 100-200 um is under development; no physics and technology limitations though, 100 um ID all diamond tube has been fabricated and to be tested at the first available ATF or FACET experiment.
- The planar (rectangular) diamond based structure made of best quality single crystal diamond can be fabricated as well, required 30-100 um thick diamond plates are available commercially.
- Gradient and BBUs of this planar structure have been studied numerically; values found to be comparable with those of the cylindrical all-diamond structure of the same ~ 100 um aperture.
- Dielectric thermo-conducting cladding (diamond and alumina both) have been studied, ~ 3 GV/m/nC gradients can be expected due to the coherent multimode superposition for the 80 um aperture structure.