Dielectric Based HG Structures II: Diamond Structures; BBU and Multipactor

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Workshop on Novel Concepts for Linear Accelerators and Colliders
SLAC 7.10.09

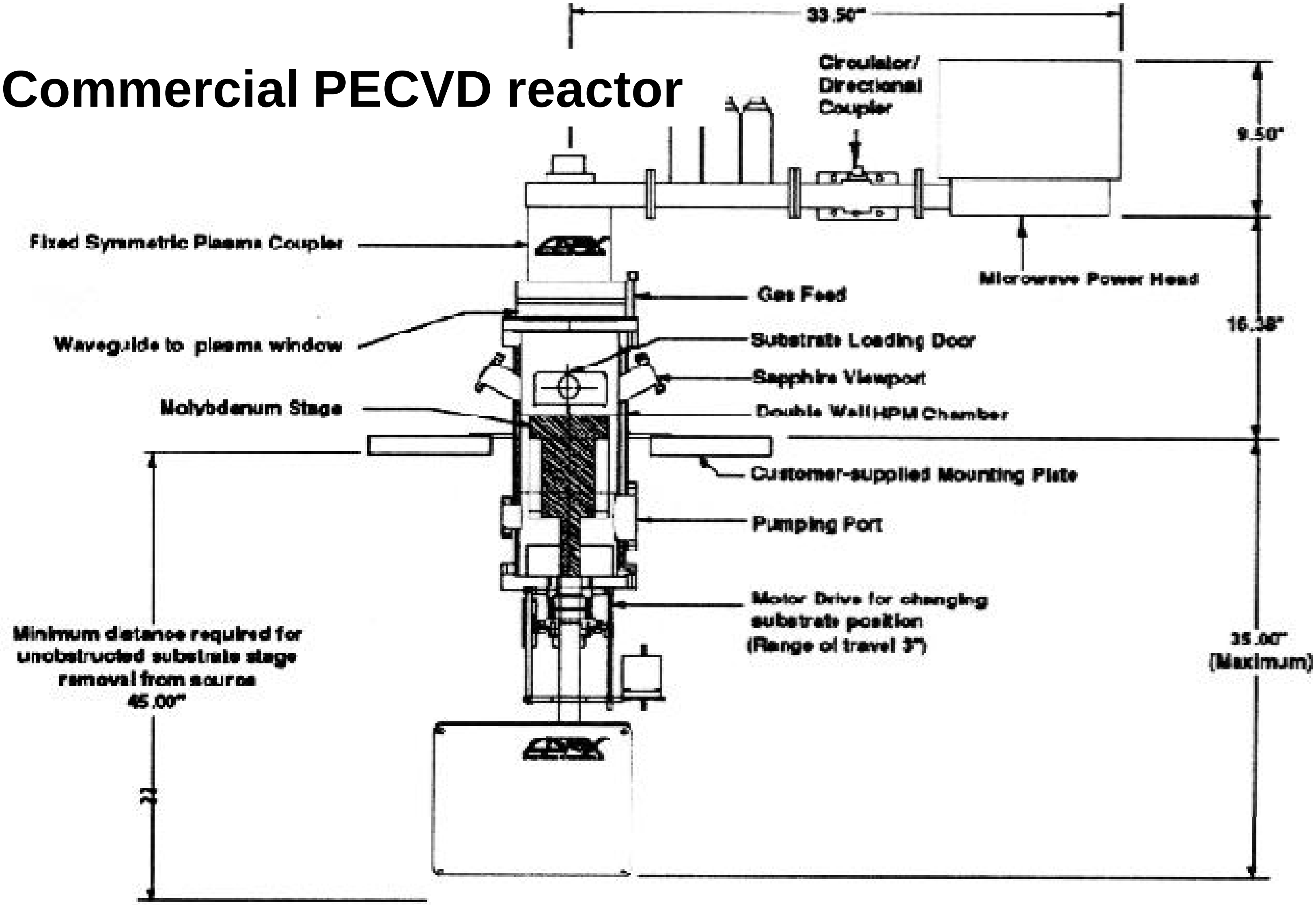
More DLA Research Activities at Euclid

1. Advances in diamond structure fabrication
2. Beam breakup in dielectric structures
3. Multipactor studies in rf driven DLAs

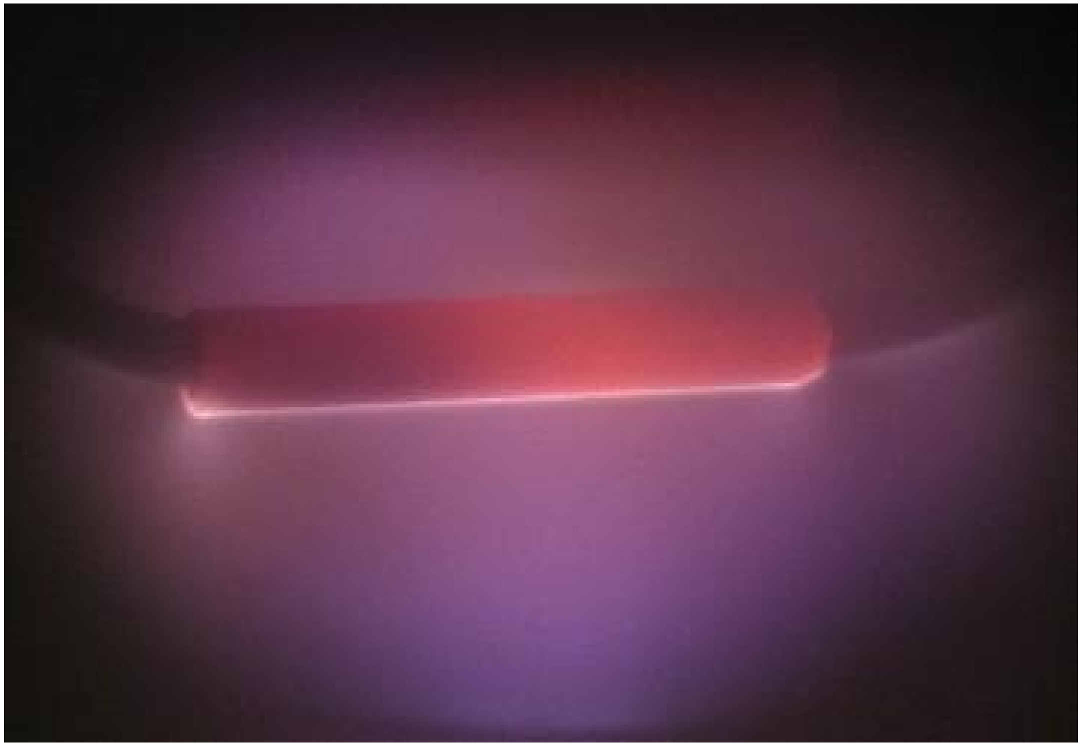
1. Progress in diamond structure development

- The electrical and mechanical properties of diamond make it an ideal candidate material for use in dielectric accelerating structures:
  - permittivity=5.7
  - high RF breakdown level (GV/m),
  - extremely low dielectric losses (tan $\delta<10^{-4}$)
  - highest thermoconductive coefficient available ($2\times10^{3}\ W m^{-1} K^{-1}$) .
- The method we are using for fabrication of the diamond tubes is based on CVD (Chemical Vapor Deposition).
- Predicted sustained accelerating gradient is larger than 600 MV/m

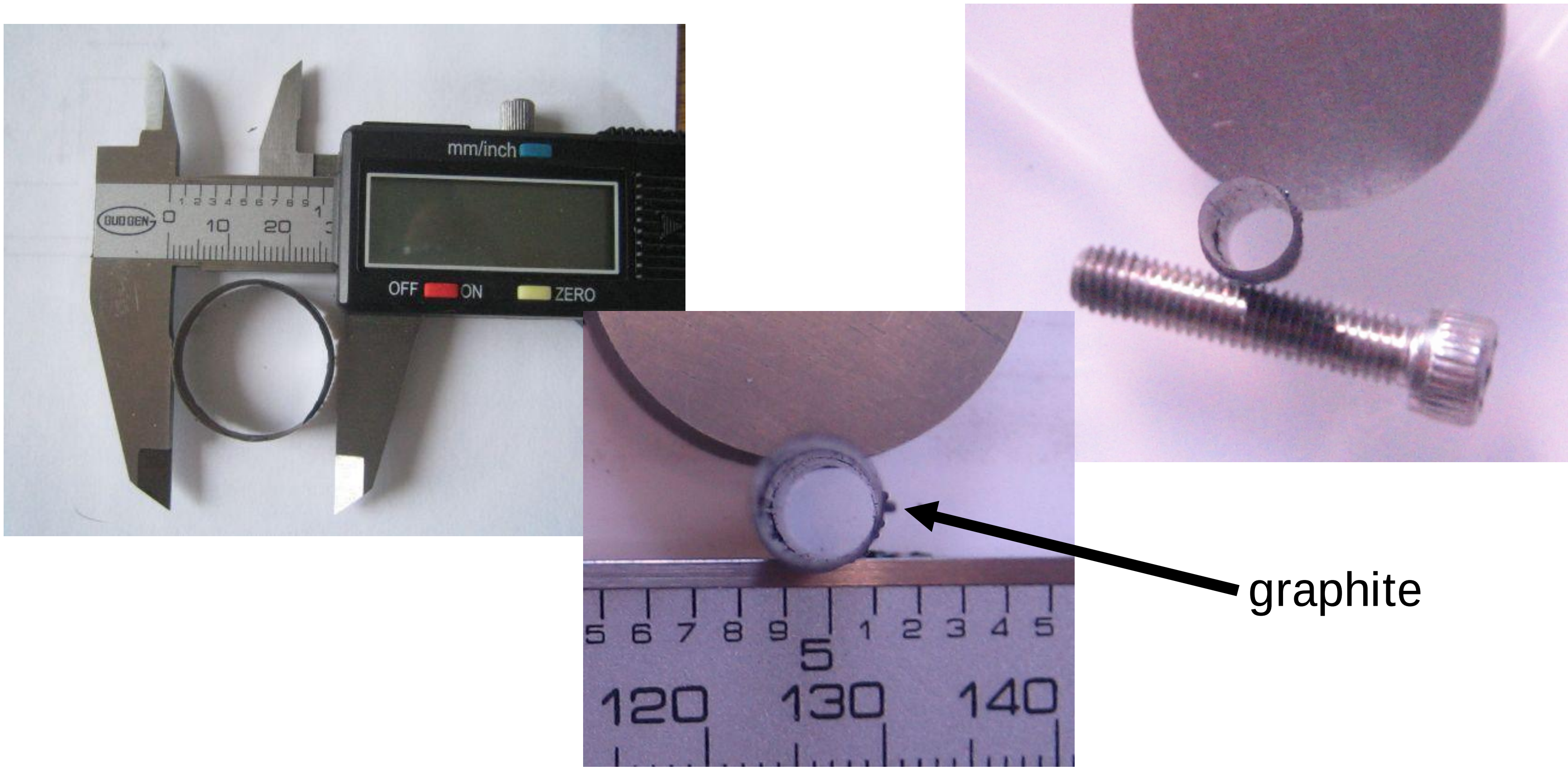
Commercial PECVD reactor



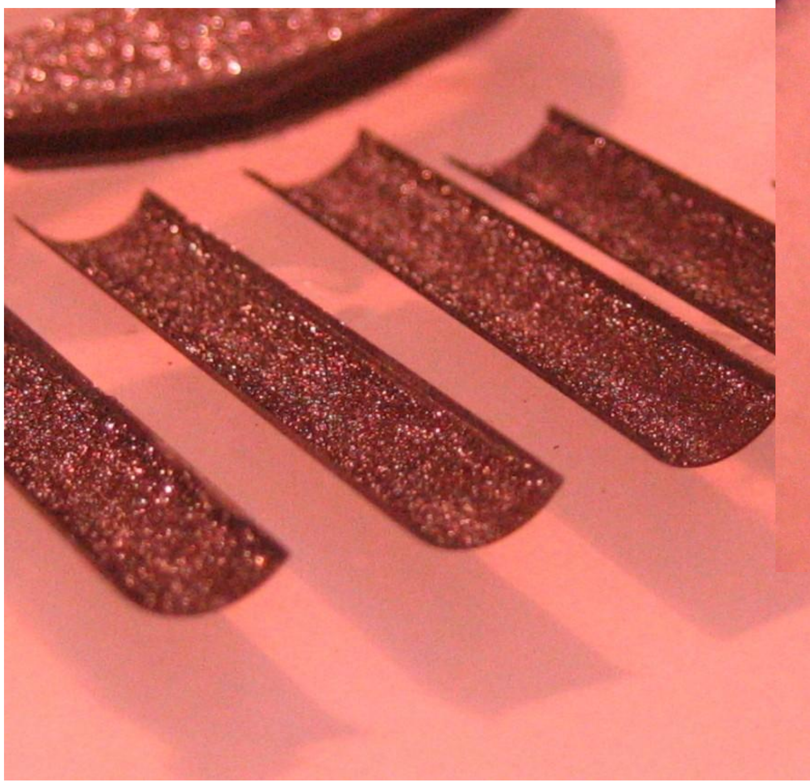
Ceramic Substrate in Plasma Chamber

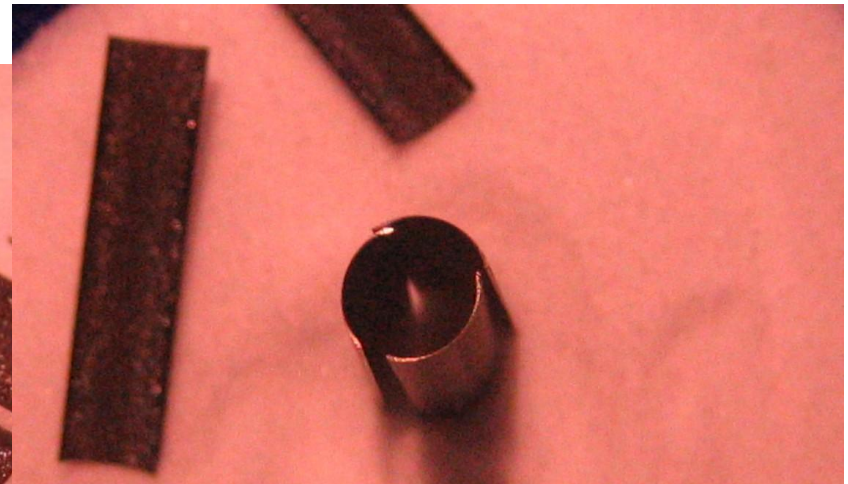


Early CVD Diamond Structure Prototype



Segmented Structures



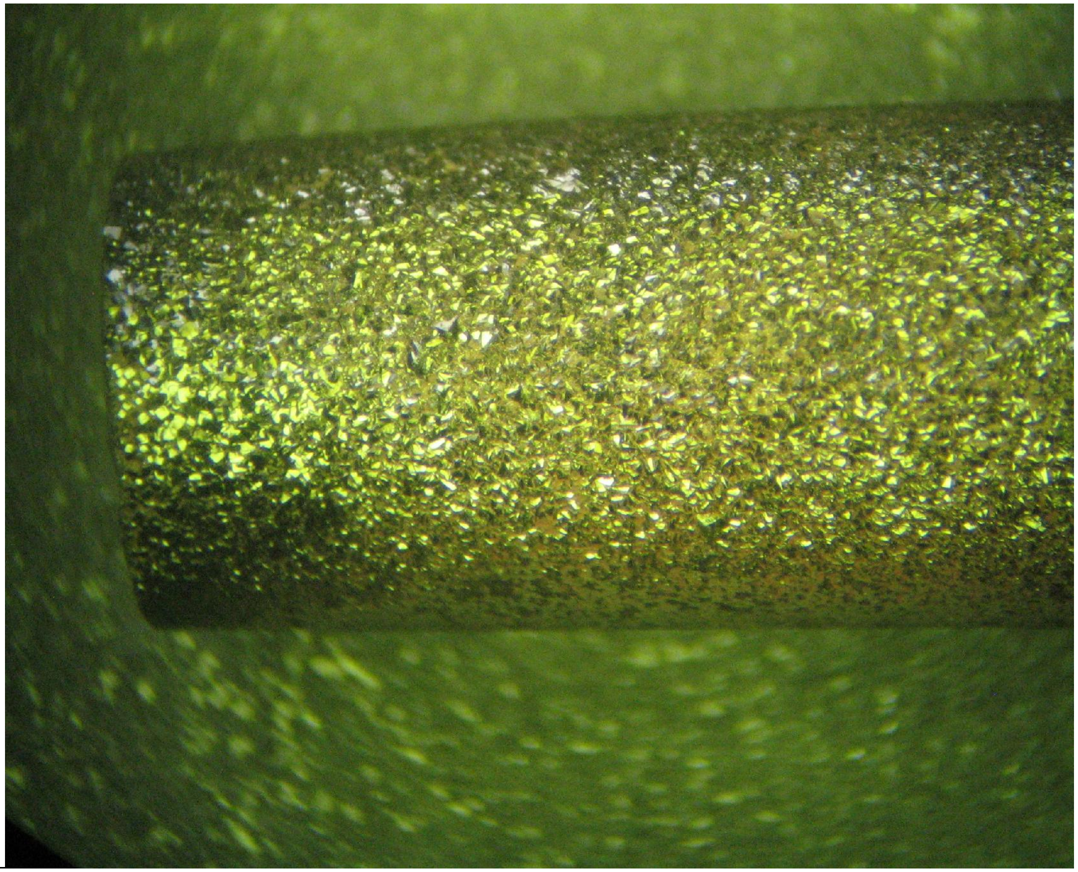


- High diamond quality achieved with this process
- Manufacture of complex surfaces
- No Eφ component in TM01
- Complications with edge machining and joining

Recent results

Photograph of new CVD diamond tube developed by our collaboration. Tube parameters are: 5 mm inner diameter, 2.5 cm length and ~ 500 μm thickness.

Close-up of the 5 mm ID diamond tube. Light reflects off the naturally smooth individual facets of diamond crystals comprising the polycrystalline aggregate. Large crystals generally exhibit better dielectric properties.

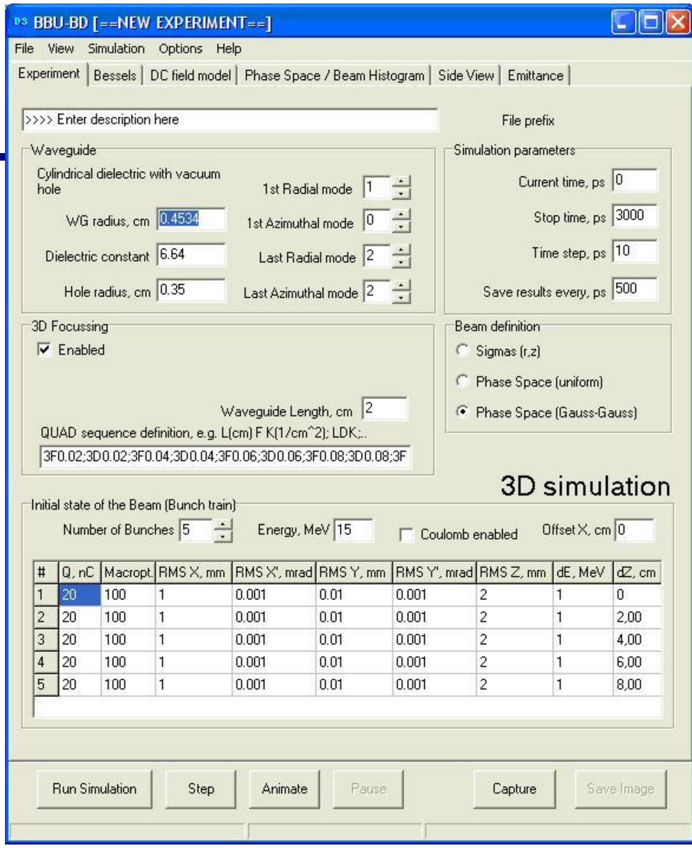


Summary (Diamonds)

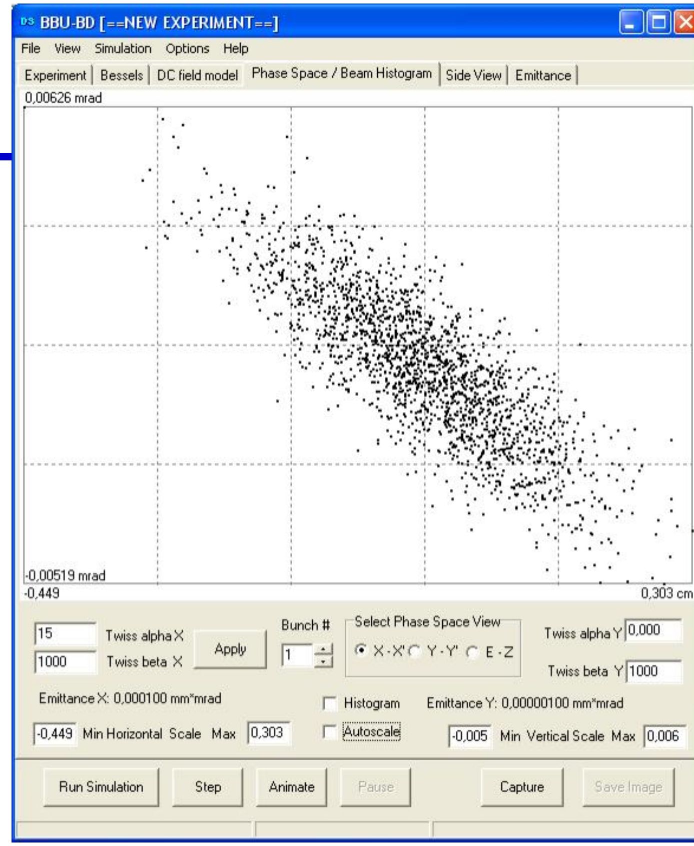
- Use of CVD (Chemical Vapor Deposition) diamond as a DLA will allow high accelerating gradients up to 0.5-1.0 GV/m assuming 1-2 GV/m breakdown rf field.
- CVD process technology is rapidly developing; the CVD diamond fabrication process is becoming fast and inexpensive.
- Multipacting performance of the CVD diamond is expected to be suppressed by diamond surface dehydrogenation through annealing or chemical treatment.

2. DLA BBU Studies

- Experiments: BBU measurements in a number of high gradient and high transformer ratio wakefield devices.
- Numerics: particle-Green's function beam dynamics code (BBU-3000) development. The code allows simulation of beam breakup effects in linear accelerators, emphasis on DLAs.
  - 2D/3D
  - Complementary to PIC approach
  - Heuristic group velocity effects for multibunches
  - Beam Dynamics Simulation Platform; access software via web browser, parallelism (cluster/multicore)
  - Efficiency improvement
  - space charge



#	Q, nC	Macropt.	RMS X, mm	RMS X', mrad	RMS Y, mm	RMS Y', mrad	RMS Z, mm	dE, MeV	dZ, cm
1	20	100	1	0.001	0.01	0.001	2	1	0
2	20	100	1	0.001	0.01	0.001	2	1	2,00
3	20	100	1	0.001	0.01	0.001	2	1	4,00
4	20	100	1	0.001	0.01	0.001	2	1	6,00
5	20	100	1	0.001	0.01	0.001	2	1	8,00



Main screen of the user interface is used for experiment setup definition. Current version allows specifying 3D beams in Phase Space as upright Twiss ellipses, uniform and Gaussian initial macroparticle distributions are supported.

BBU: Planned AWA Experiments

	a (mm)	b (mm)	L (cm)	ε	Beam
26 GHz Power Extractor (underway)	3.5	4.534	30	6.64	*20 nC BUNCH TRAIN, SPACING = 23.1 CM*
Ramped Bunch Train	3	3.667	40	16	*5-15-25-35 nC TRAIN, SPACING=23.1 CM*
High Gradient	1.5	7.49	25.4	3.78	*SINGLE 100 nC BUNCH*

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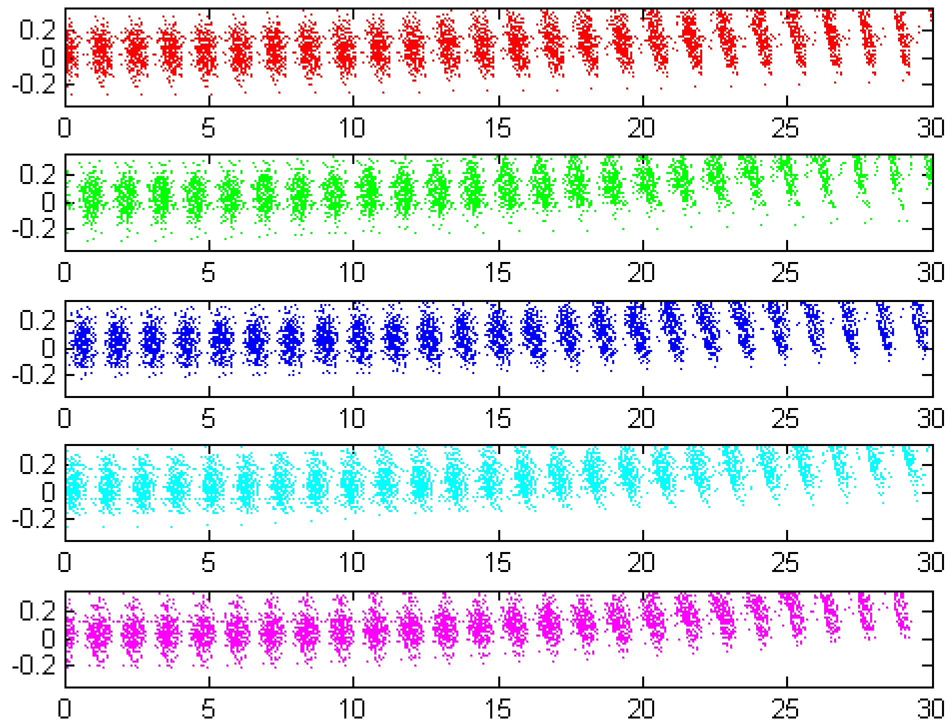
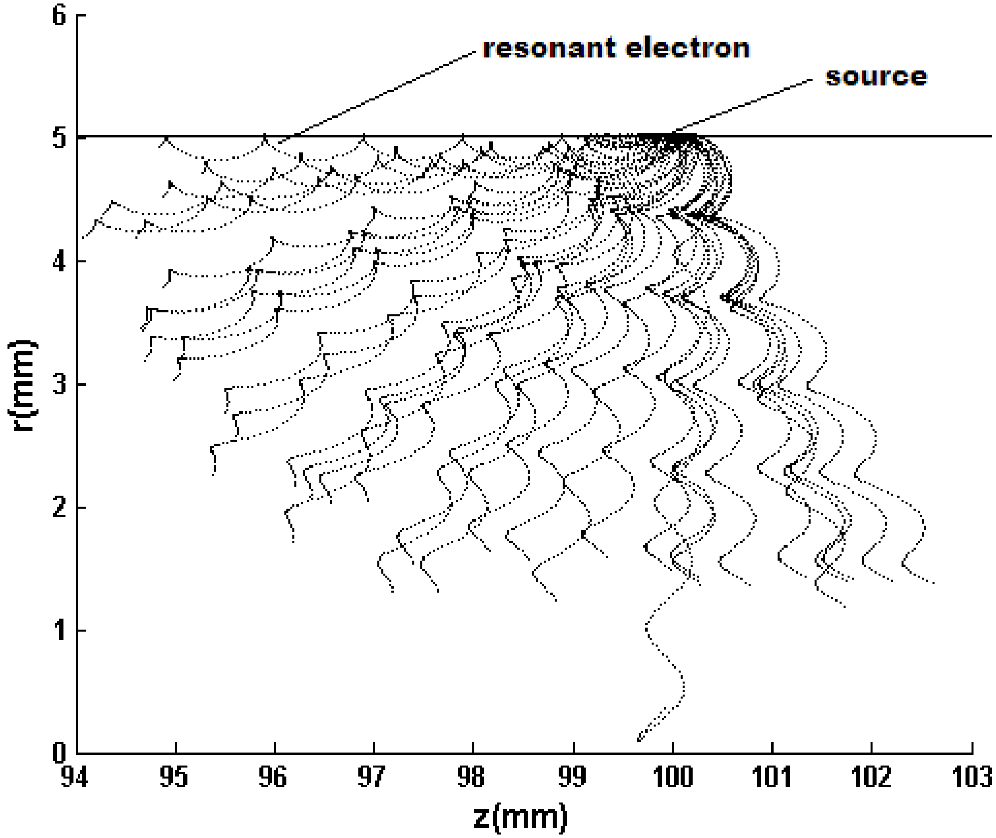
26 GHz Power Extractor

Snapshots of the electron distributions in the x-z plane traversing the 26GHz decelerator (five-bunch train computed using BBU-3000). The frames top to bottom show bunches 1-5 at 40ps intervals. The bunches are injected with an initial offset of 0.4mm in the positive x direction. Initial energy of each bunch is 20MeV. Distances in cm; the vertical extent of each plot corresponds to the width of the vacuum channel (±0.35 cm).



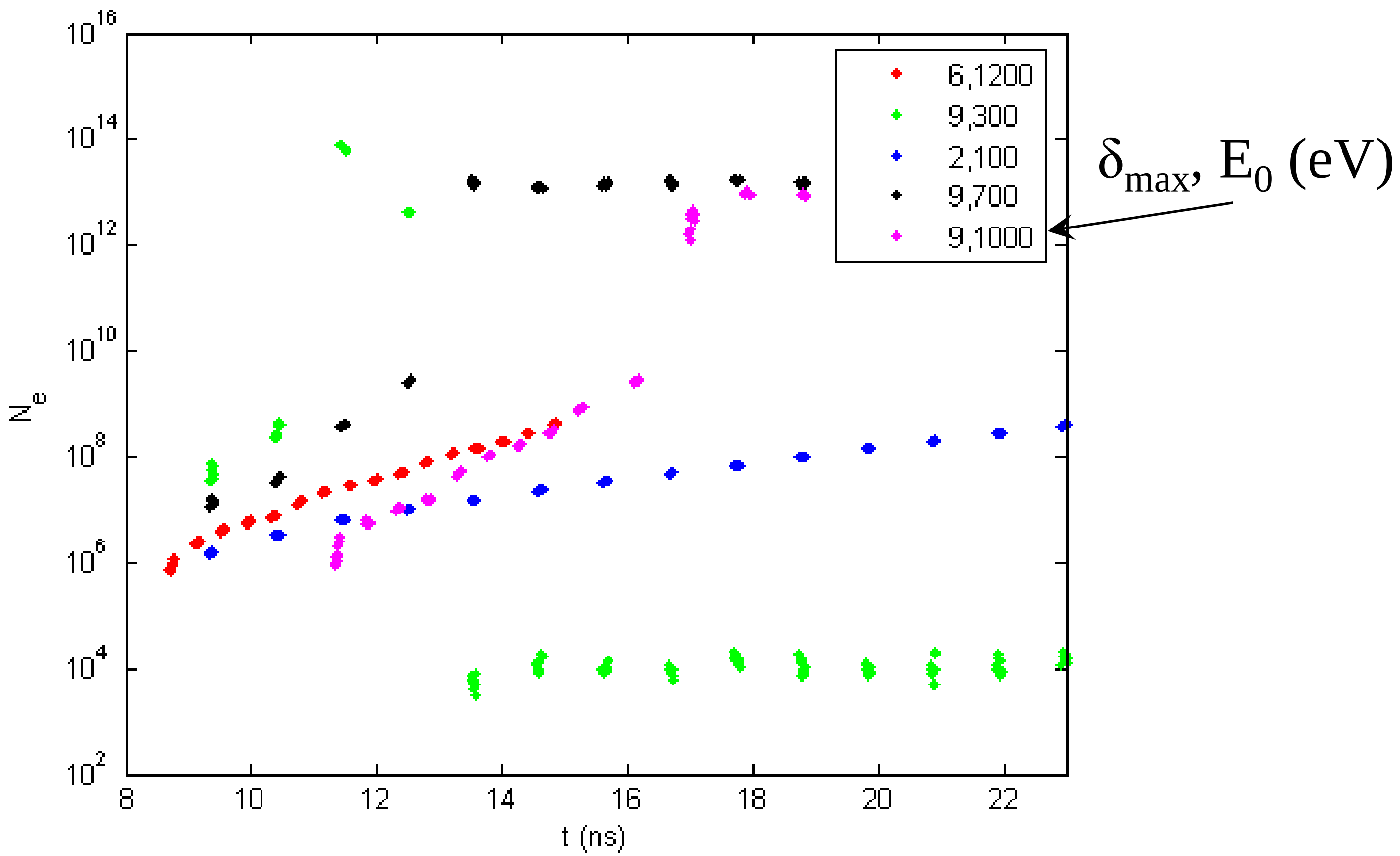
3. Multipactor Simulations

- OOPIC Pro, 2½-D FDTD PIC code
- electrons originate at a field emission site at the dielectric-vacuum boundary
- Trajectories of low energy electrons emitted over 1 rf period in an 11.4 GHz structure.
- only one electron in this particular ensemble is resonantly captured by the TM_{01} accelerating mode
- these electrons (and their daughter electrons) are responsible for single surface multipactor.



Multipactor Discharge Intensity

(P=1 MW, Vaughan Parameter Dependence)



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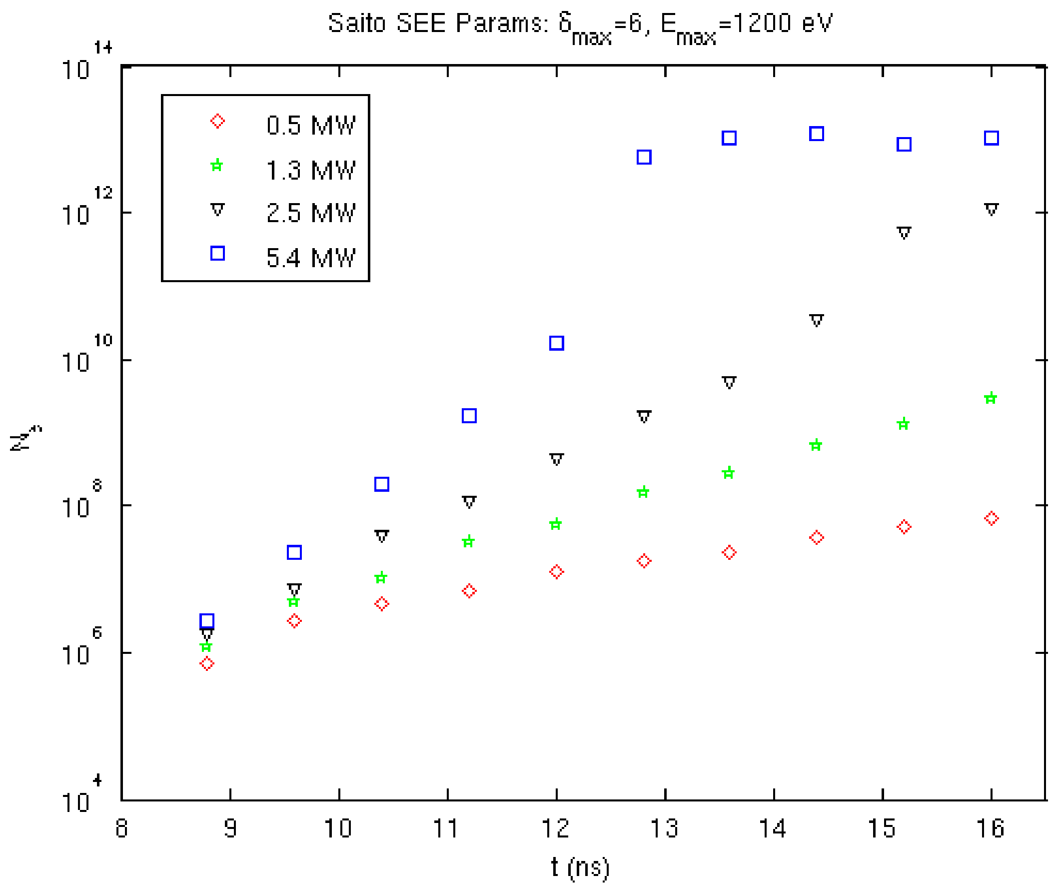
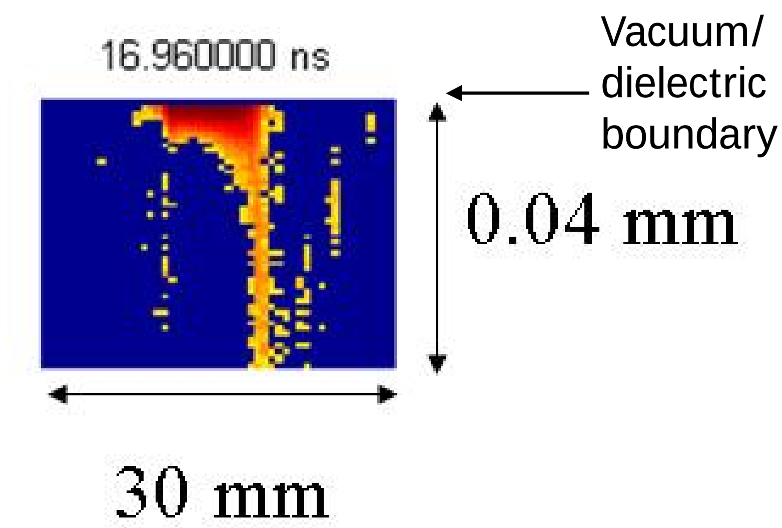
Time Dependence of Discharge Intensity



Challenges

Discharge forms in thin layer at dielectric boundary, requires fine mesh to resolve

- Adaptive space charge mesh?
- FE or FDTD or electrostatic (Sinitsyn/UMD)



(10^{11} dynamic range)

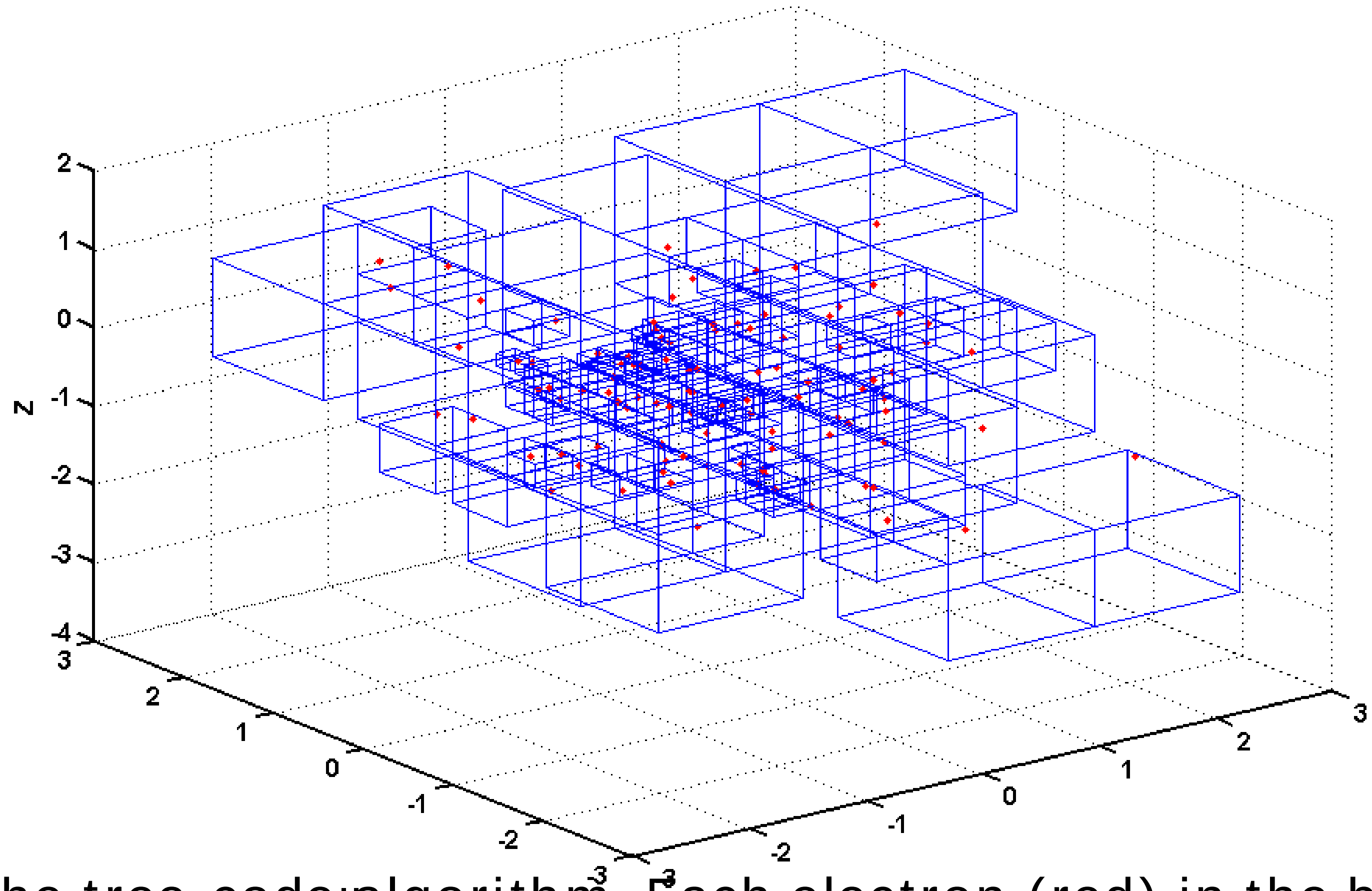
EXTRAS

CVD Diamond Manufacture

- CVD diamond is made when a dilute mixture of methane (CH_4) in hydrogen is chemically excited to produce atomic hydrogen and hydrocarbon radicals.
  - Diamond bond (sp^3) slightly more stable under hydrogen bombardment than the graphitic (sp^2).
- In most commercial systems excitation is performed using microwave radiation; hot filaments also used
- Microwaves partly ionize and cause intense heating of the gas mixture up to 4000°C. The diamond film forms on a surface held at about 900°C in proximity to the excited gas. Typical pressures are sub-atmospheric (100 Torr), film growth rates ~1-10 μm/hr depending on reactor design and power.
- Turnkey microwave reactors capable of unattended diamond deposition over areas of up to 12” in diameter are commercially available

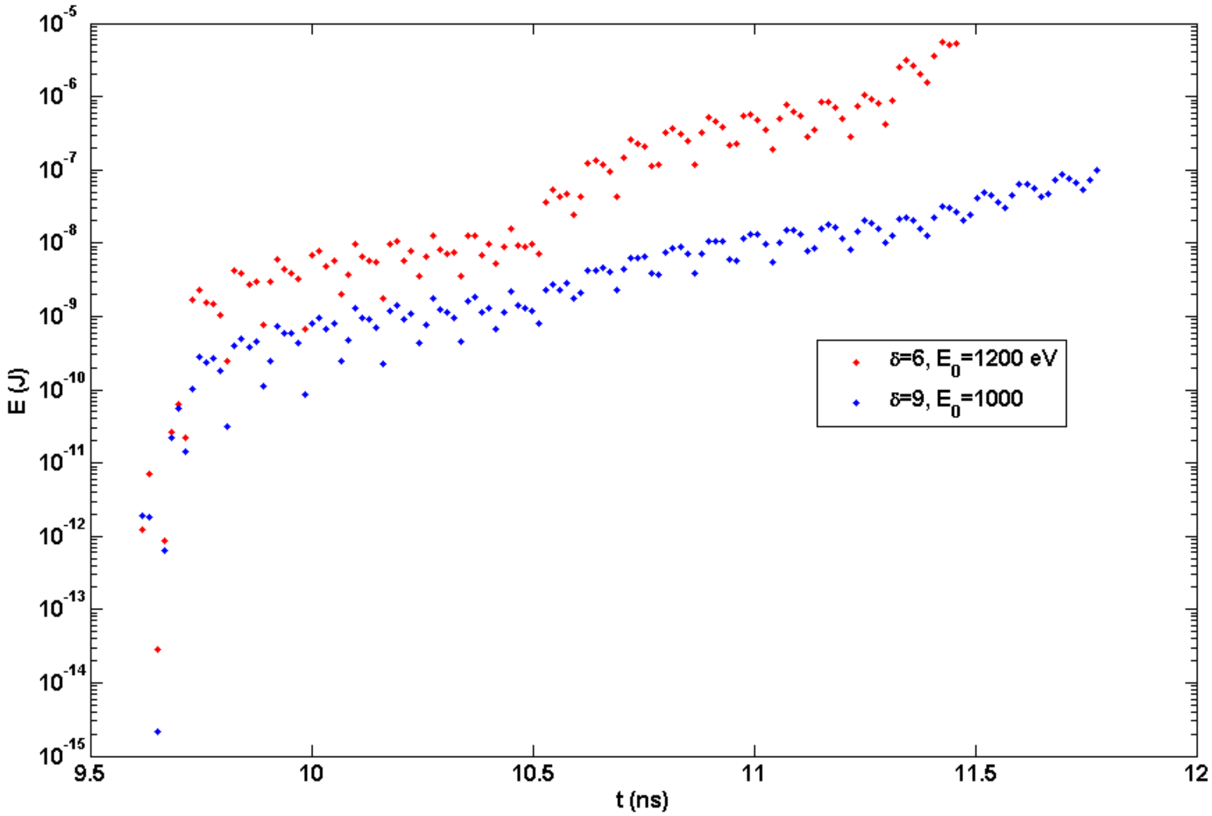
Efficiency Improvements to BBU-3000

- The present algorithm used in BBU-3000 computes pairwise particle interactions at each time step to determine the forces on each electron in the simulation. This algorithm scales as $O(N^2)$ where N is the number of particles used. While for small particle numbers this is not problematic, larger scale problems (particularly ramped bunch train and other multibunch) require a large number of particles and hence can become very inefficient.
- We are investigating to what extent this can be improved. The most promising approaches are based on a set of algorithms developed in recent years that factor particle-particle interactions into short and long range components. Interactions between particles in close proximity are computed as in the existing code. Forces on a given electron resulting from clusters of electrons at longer separations are handled by replacing the individual cluster particles in the force calculation by a single particle with effective properties computed through the use of spatial averaging.
- Two of the possible algorithms being considered are known as the *Tree-code* algorithm and the *Fast Multipole Method*. Both of these techniques were originally developed for Poisson-type problems involving static charge distributions or many body gravitational dynamics. It is expected that these methods can be adapted to the dynamics of a relativistic beam and will also simplify the implementation of the space charge calculation.

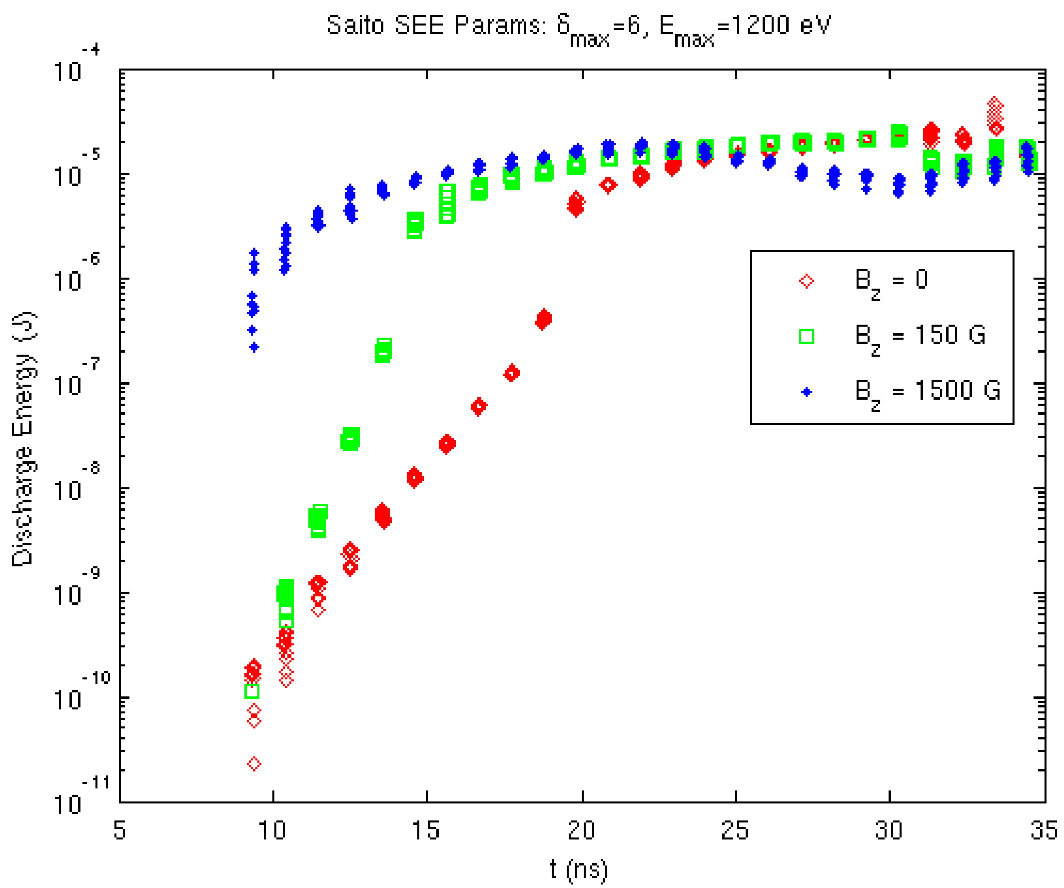


Test of the tree-code algorithm. Each electron (red) in the bunch is assigned a place in a hierarchy of cubic cells (blue). Only the final level of cells, each containing a single electron is shown. The total number of macroparticles in this example is 100.

Discharge Energy at Early Times



Multipactor Discharge, Axial Magnetic Field



Time Dependence of Discharge Energy