Recent Experiments of Dielectric Structures and Preparation of Breakdown Study at AWA

Chunguang Jing

High Gradient Workshop, June 2013

Outline

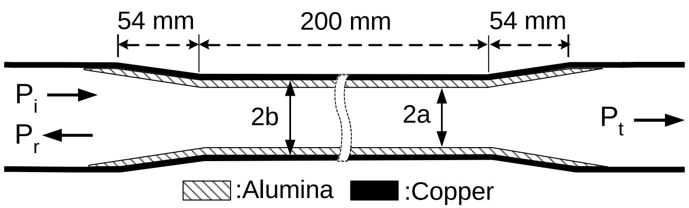
- Experimental Reports
  - Multipactor Suppression of DLA Structure at NRL
  - Test of Dielectric PETS at SLAC
- Planned Experiments at AWA
- Laser Triggered BD Study at AWA
- Summary

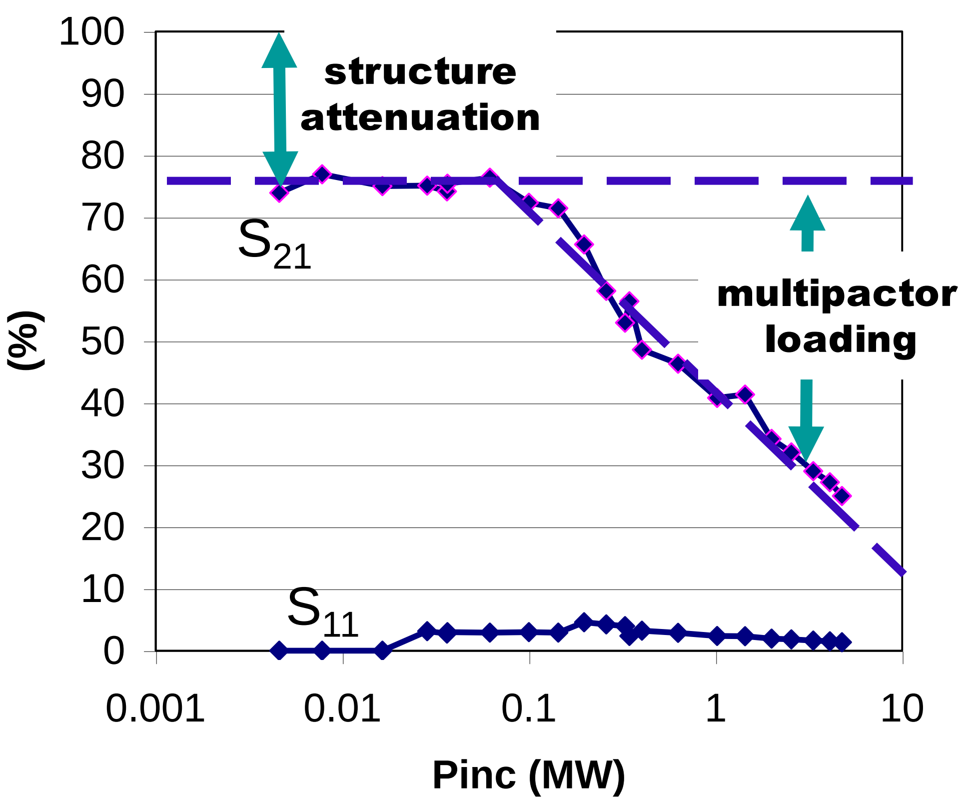
Currently Available RF or Beam resources for testing dielectric structures

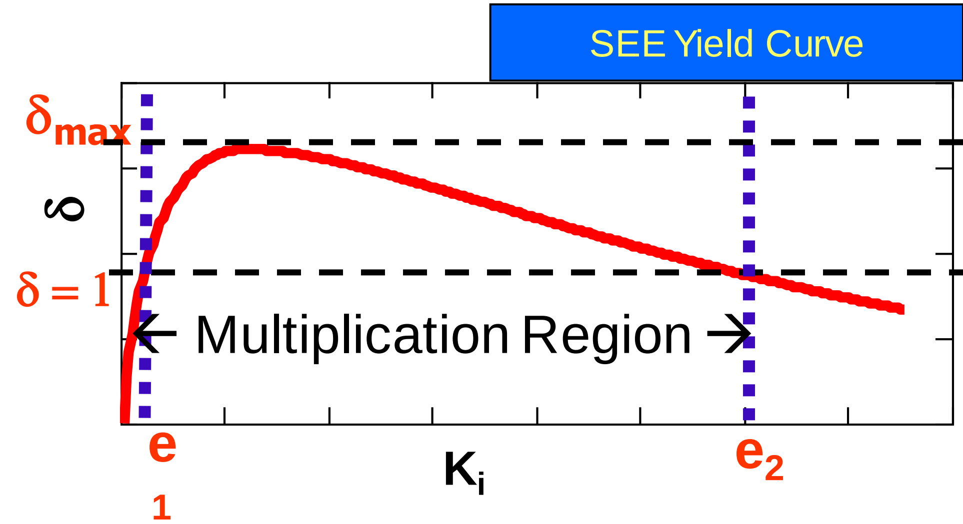
Facility	Main parameters
ANL/AWA	15MeV/ 75 MeV, σ_z = 1-2 mm, Q = 10-100 nC, yielding ~ 100-300 MV/m at 10-30 GHz or ~GW beam power; TBA;
NRL/Magnicon	11.4GHz, 10~20MW, >200ns, rf station; 5MeV, 50mA (5pC/bunch), Xband rf injector;
BNL/ATF	60 MeV, tunable σ_z = 100 um-1.5mm, σ_r~100um, 0.3-0.5 nC, 0.3-0.8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

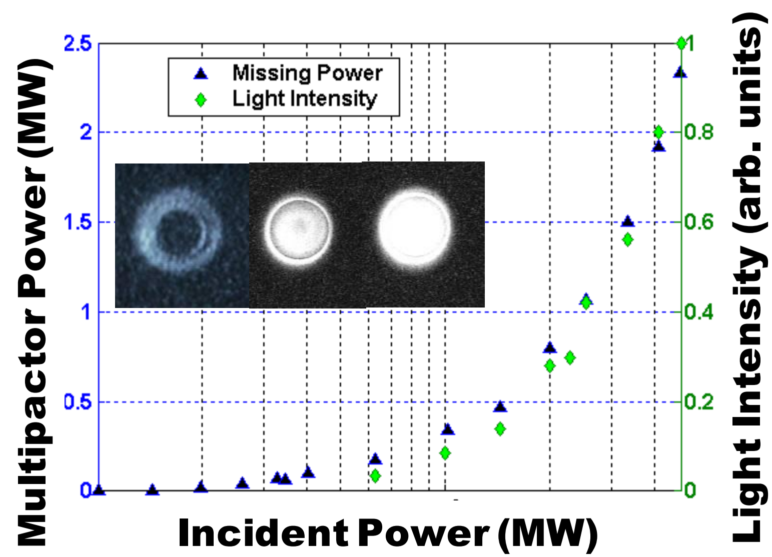
Experimental Report on Multipactor Suppression of DLA Structure using a Solenoid (US SBIR funded Project)

Multipactor

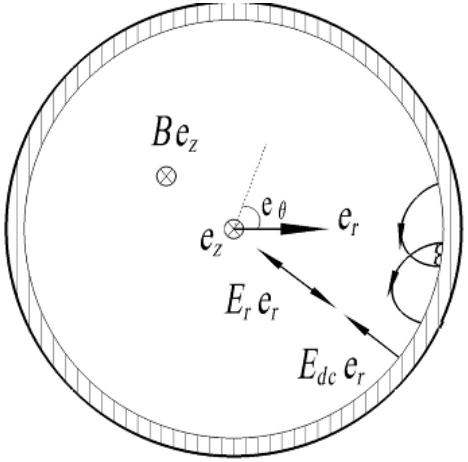




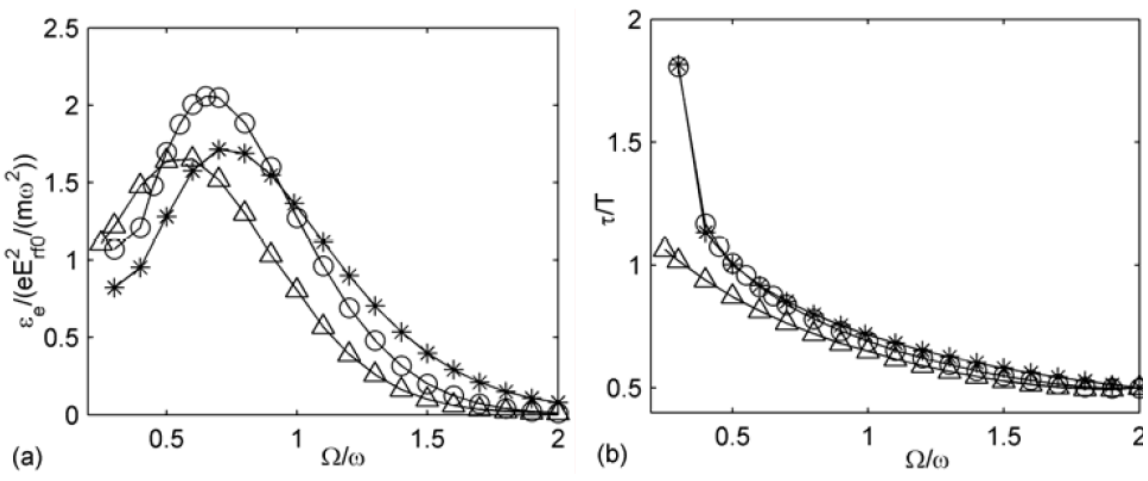


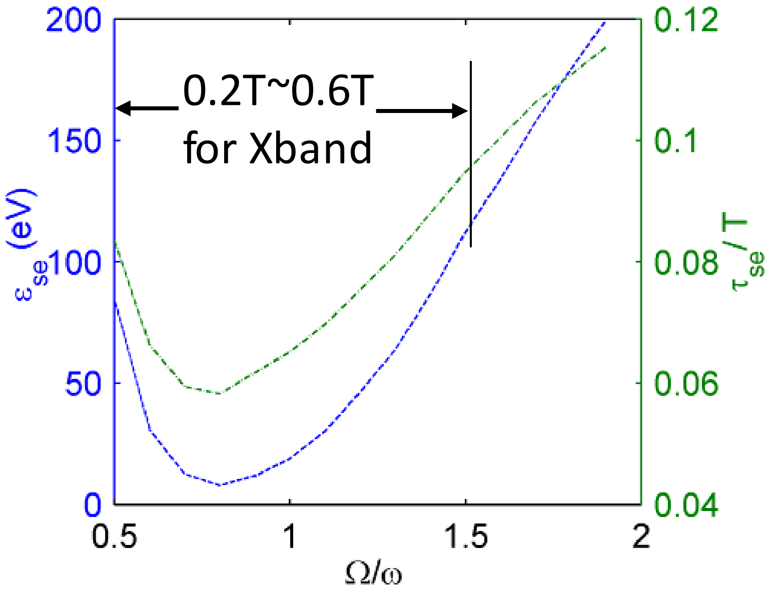


A New Approach to block Multipactor : Solenoid field

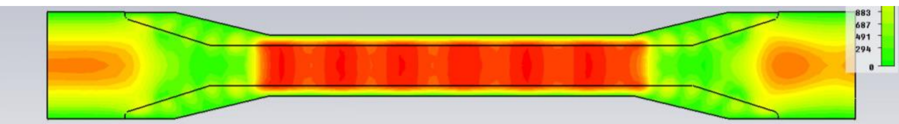


Principle: the introduced Bz can effectively alter the transit time τ of secondary electrons. A proper strength of Bz makes τ in the range of (T/2,T) so that Er is always pushing electrons back to the dielectric surface, leading to a very small impact energy, then SEE<1.



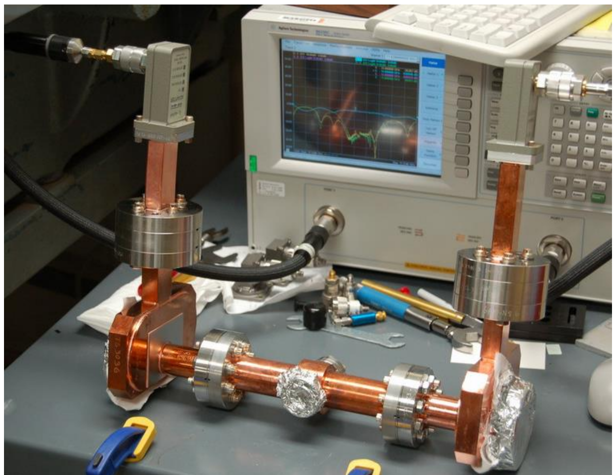


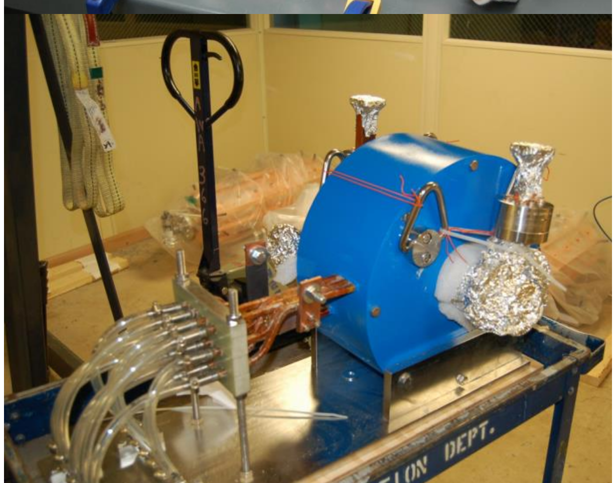
Two X-band DLA structures for experiments on the multipactor suppression



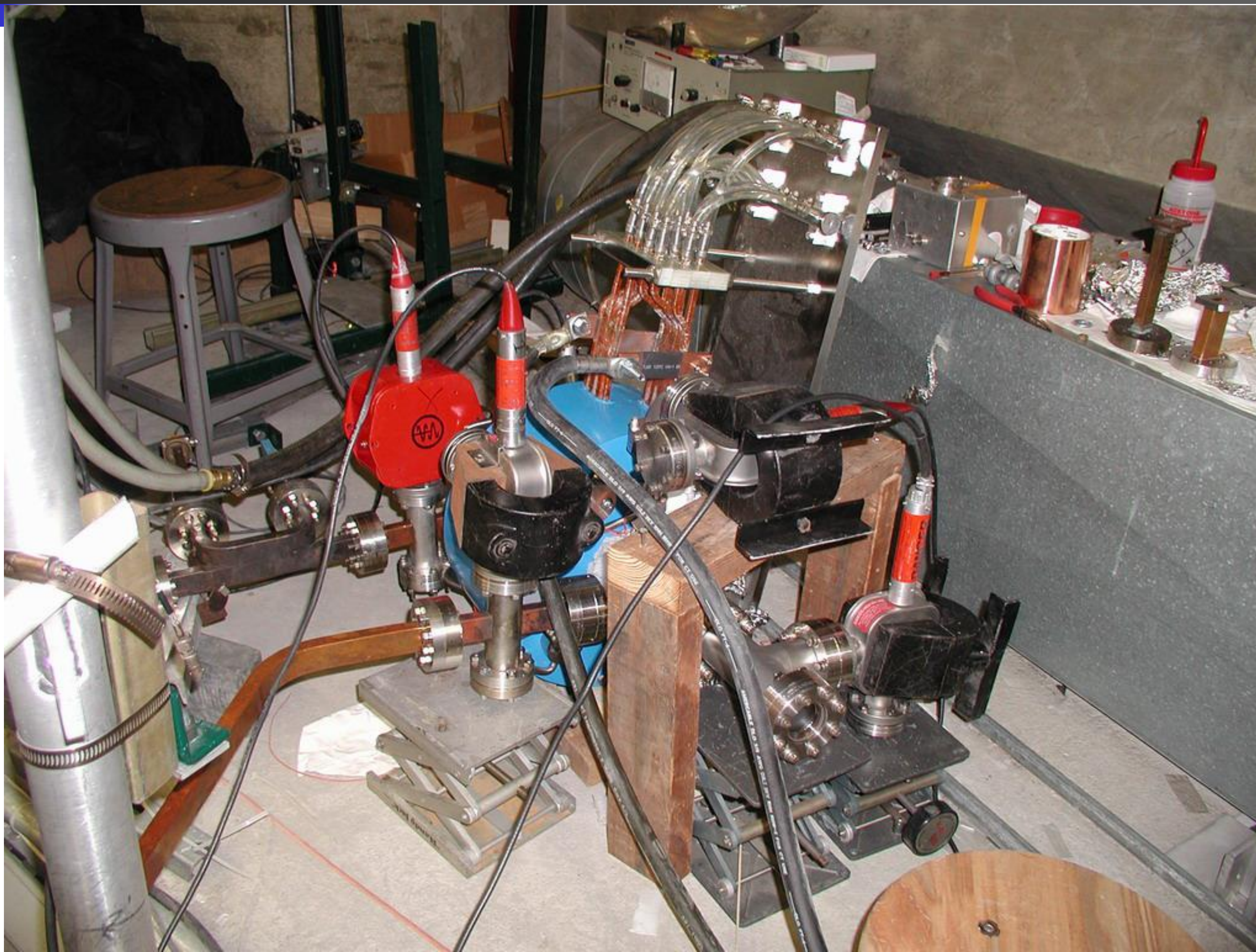
Parameters	Structure 1	Structure 2
Radii a / b of straight section	0.059” /0.255”	0.168” /0.255”
Radius of taper matching section	0.446”	0.446”
Dielectric constant	3.75	9.7
Loss tangent	6×10^{-5}	1×10^{-4}
Length of dielectric tubes	5.5”	5.5”
Synchronous frequency of TM_{01} mode	11.424 GHz	11.424 GHz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

Bench Test @ AWA

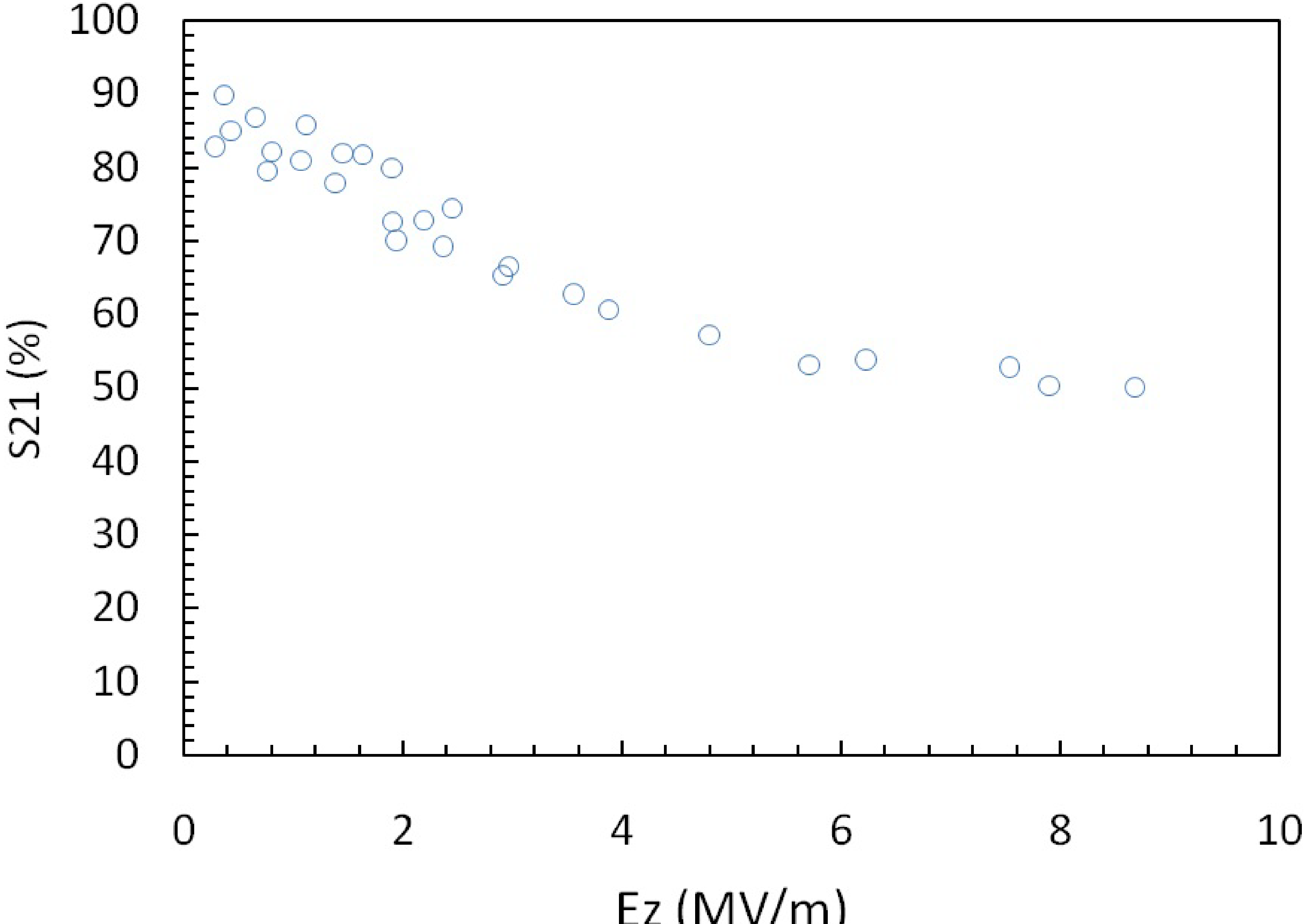




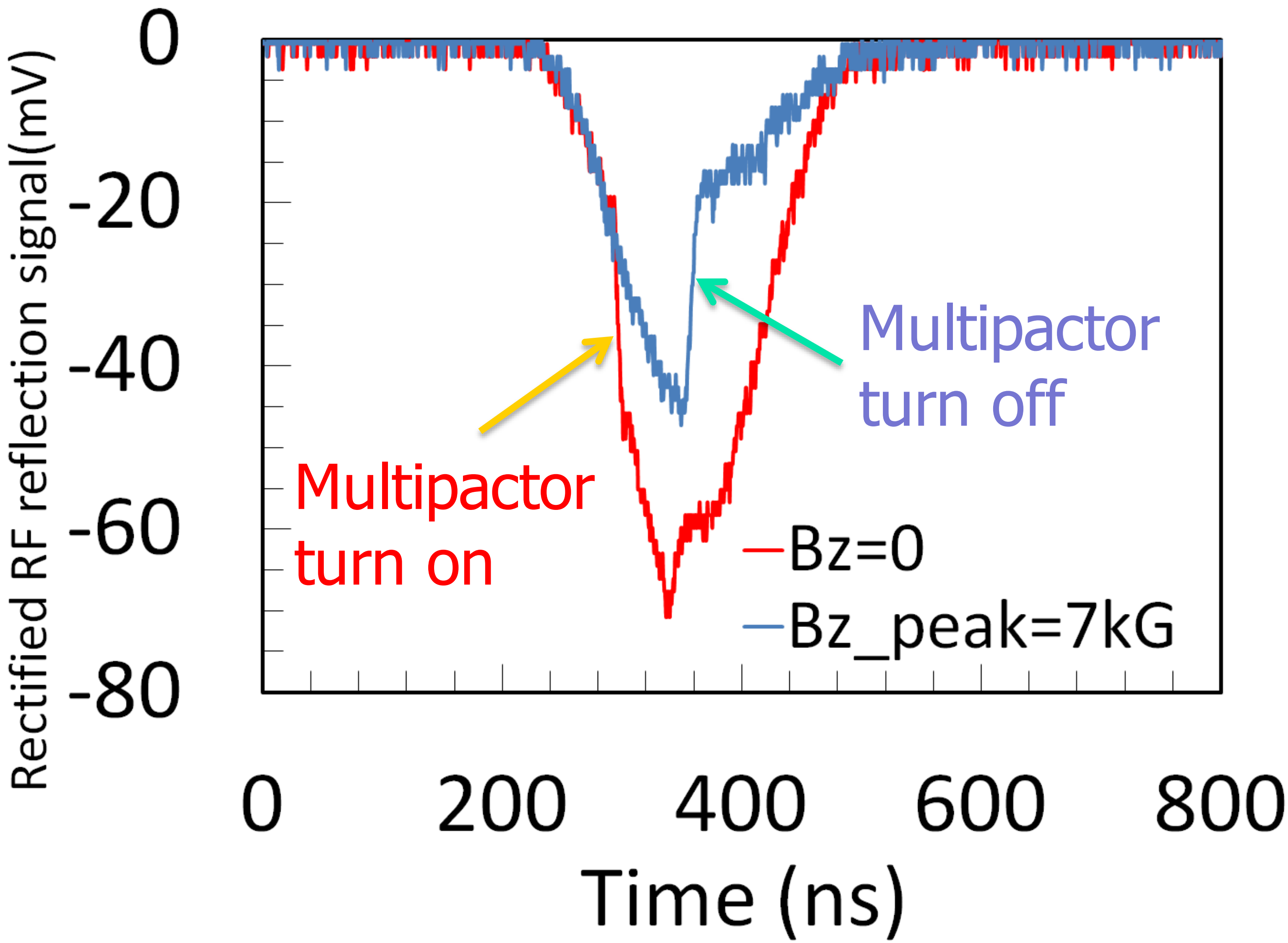
High Power RF Test @ NRL



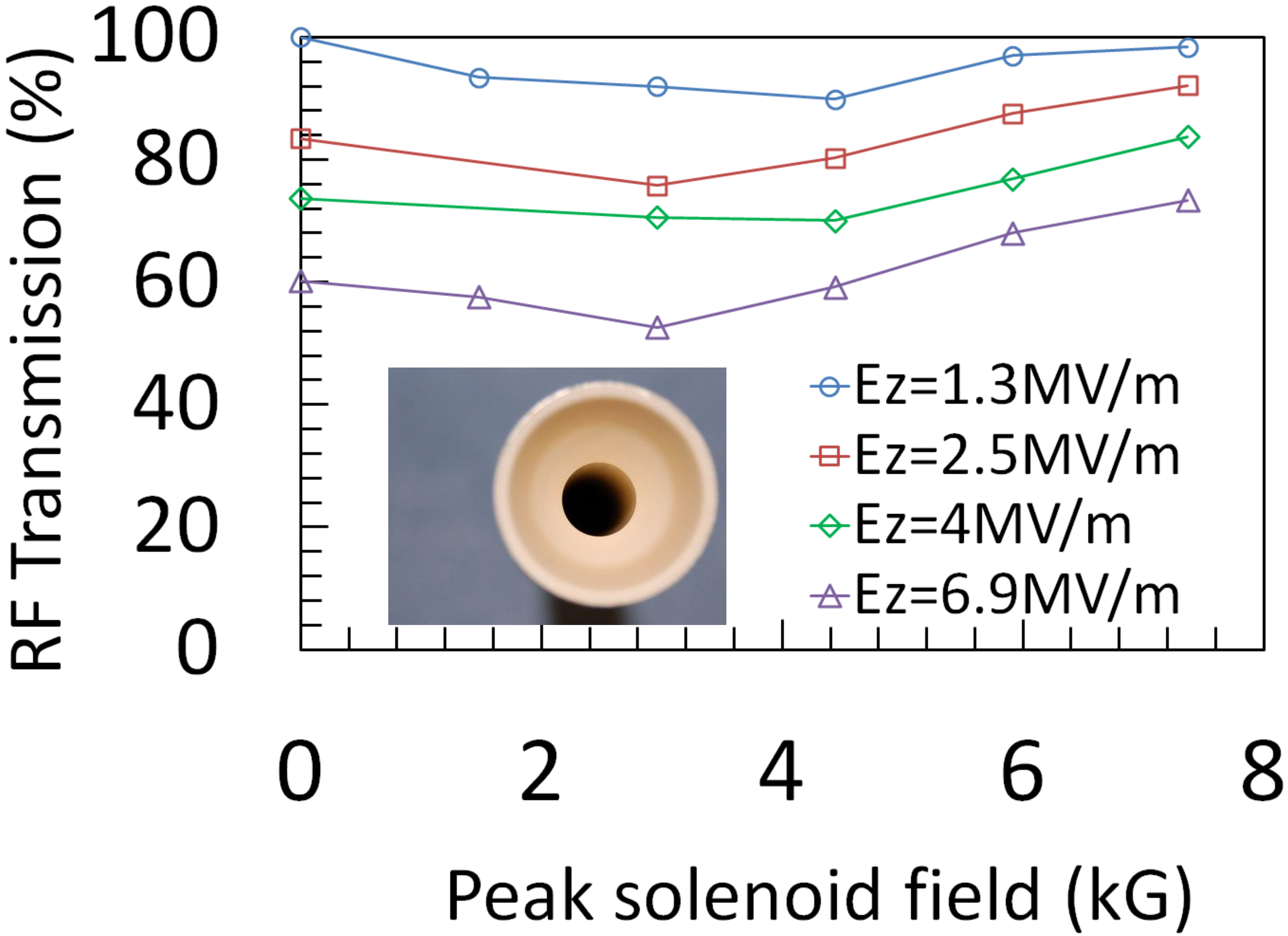
RF Transmission without External Bz



Rectified RF traces w/ and w/o External Bz



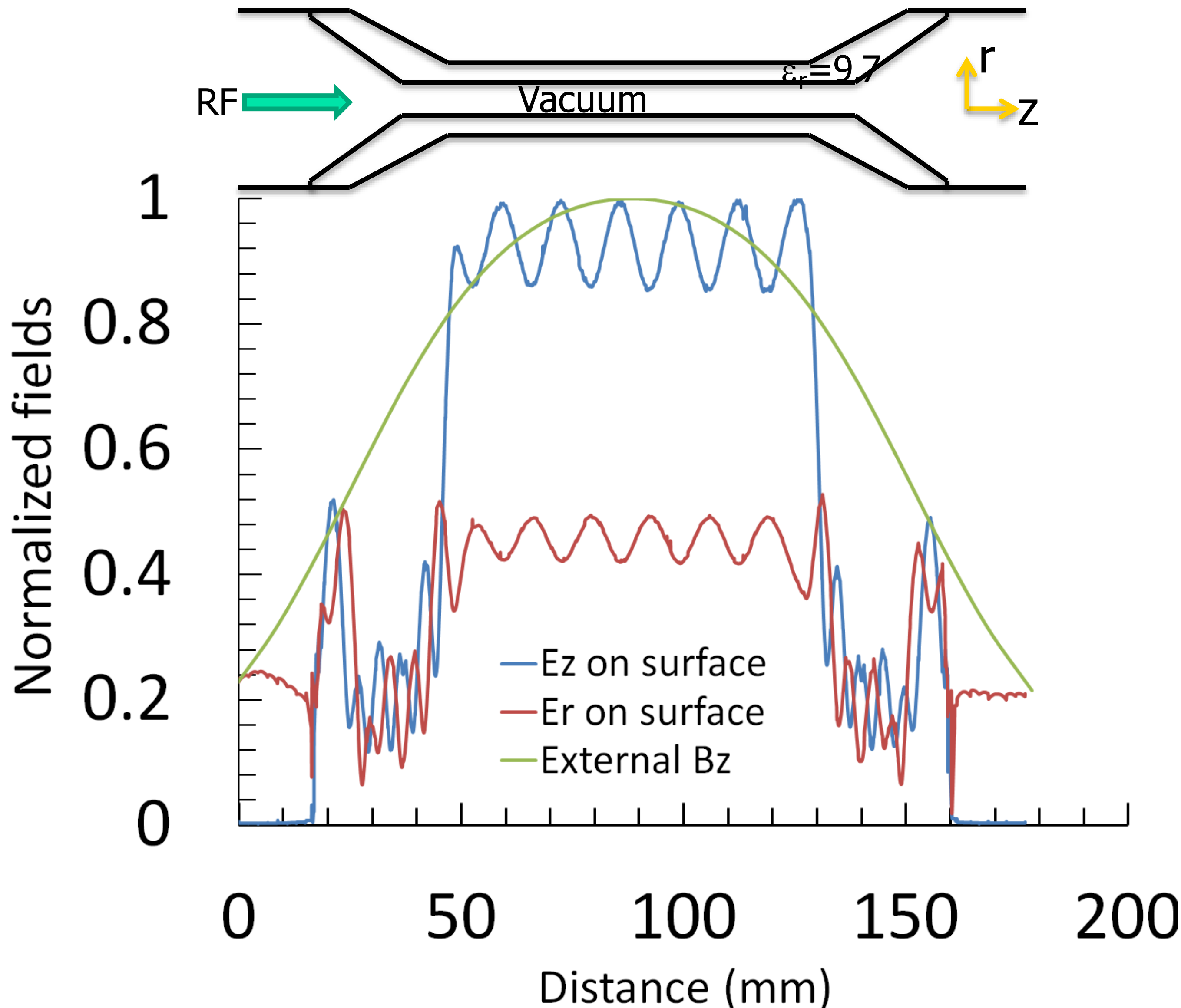
Bz sweeping for different Ez



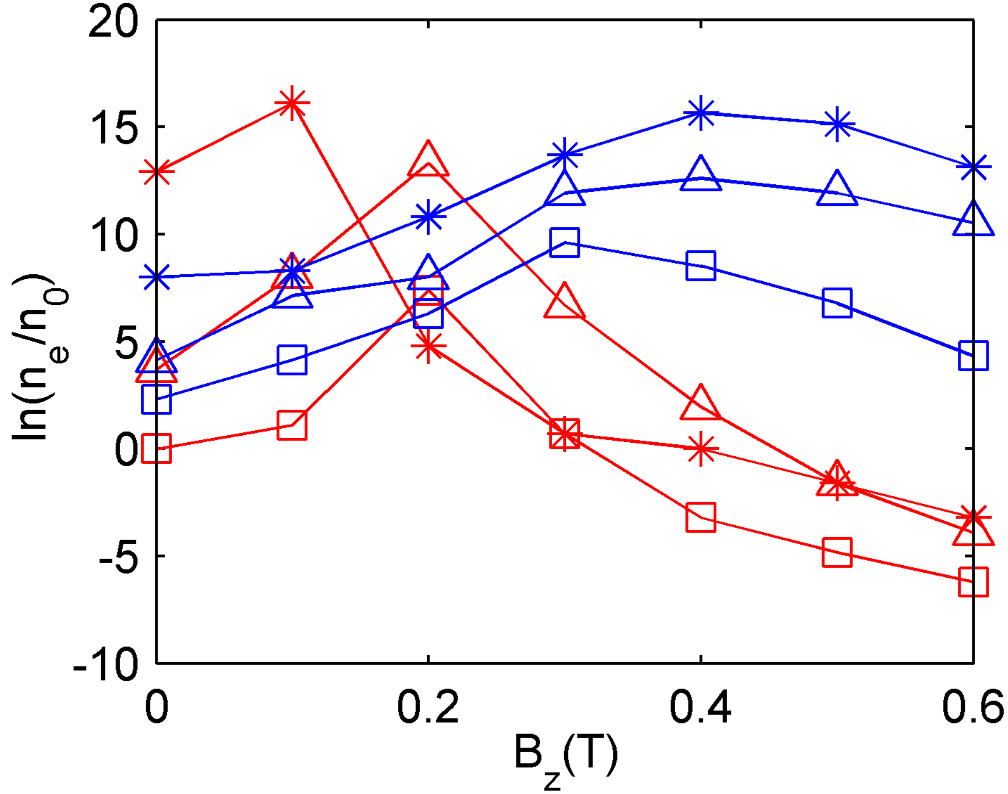
Observations in the Experiment

- Certain level of Solenoid field makes the MP light disappearing and S11 improves dramatically, which are signatures of multipactor being suppressed very effectively.
- However, the S21 was not improved much accordingly. Also, the vacuum readings monitored at both ends of structure increased dramatically when Bz applied.
- Discolored rings at both ends of dielectric tapers indicate the serious electron bombardment occurred.

Non-uniform fields distribution along the structure



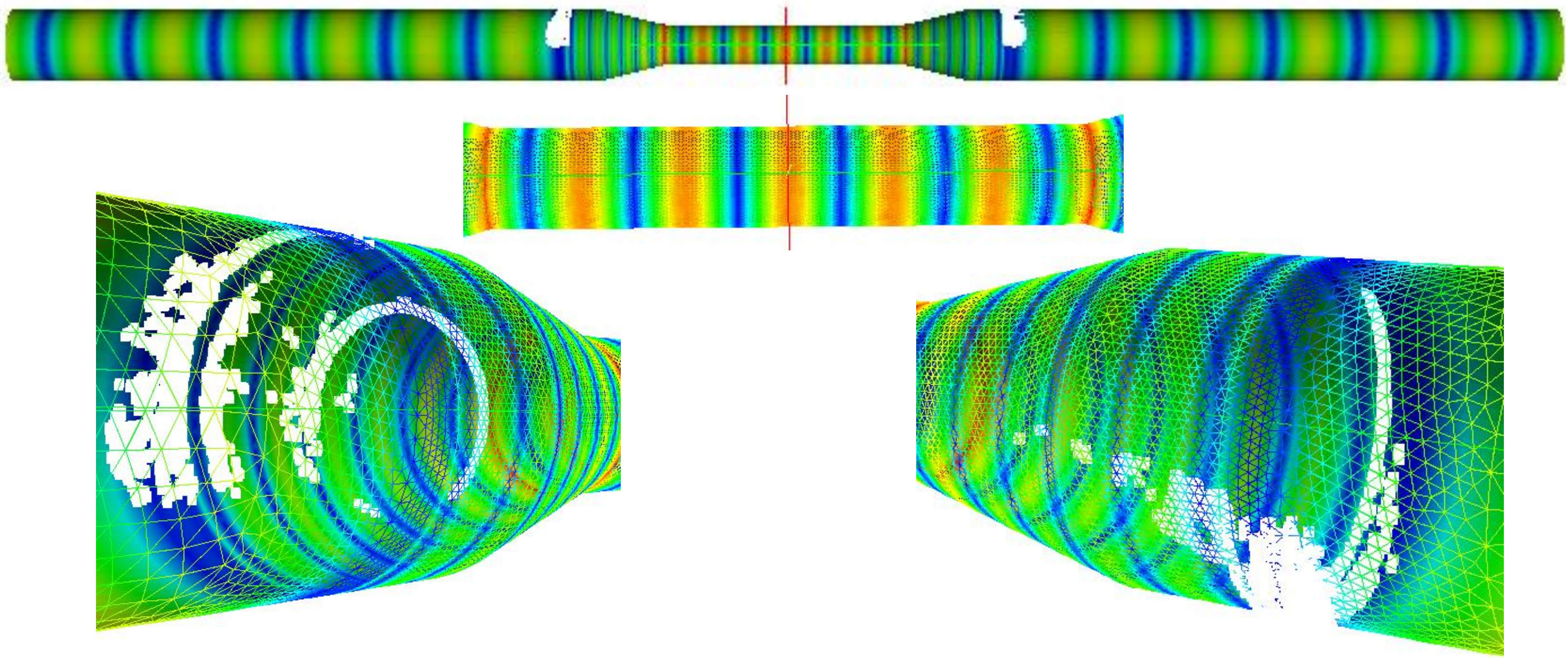
3-D PIC simulation



Variation of electron density n_e with external magnetic field B_z and RF field E_z in the dielectric waveguide (Red curves) and at taper (Blue curves) with $B_r=0.5*B_t$ ('*' for E_z=6.9MV/m, '△' for E_z=2.5MV/m, '□' for E_z=1.3MV/m) (Note: the magnetic field and electric field at taper are the values in the central DLA waveguide, that is to say, the real magnetic value at the taper has been divided by 0.6, and the real RF field at the taper has been divided by 0.6)

Secondary Electron Tracking with SLAC Track3P code

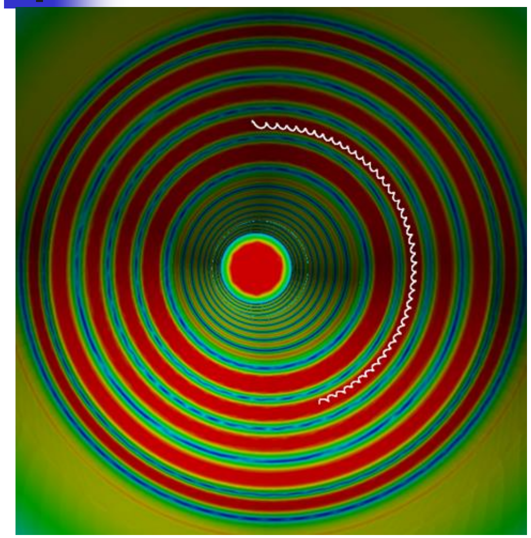
MP Impact Locations with External B-field @

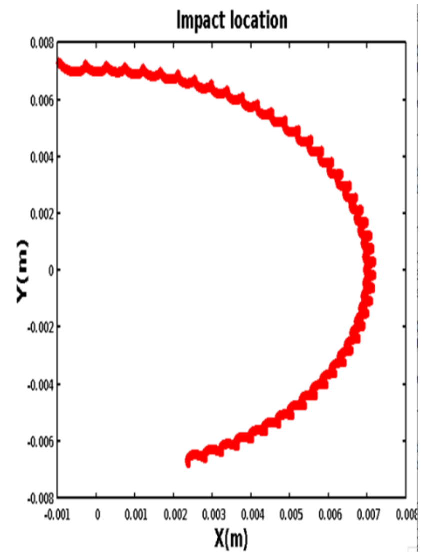


Emitting primary particles only on the Alumina Surface

- Adding external B-field=0.5T, the MP activities locate at the tapers. There is no MP at the straight section of the tube.

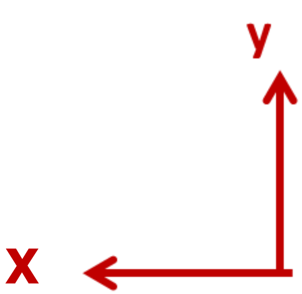
MP Trajectories with External B-field @ 0.5T

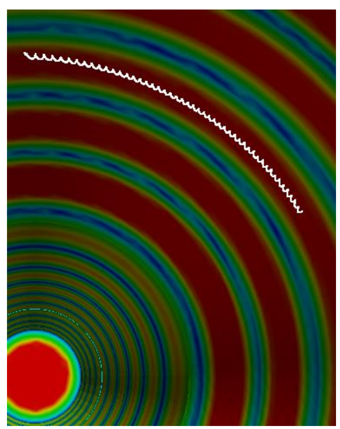


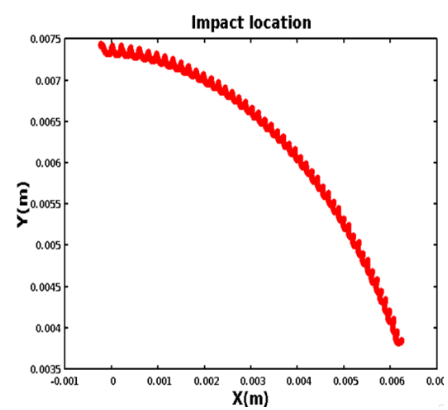


1. One point 1st order MP.
2. Impact energy: 600 eV ~ 700 eV
3. 46 RF cycles

One Typical Resonant Particle's Trajectory @ E=3.75MV/m







1. One point 1st order MP.
2. Impact energy: 100 eV.
3. 49 RF cycles

One Typical Resonant Particle's Trajectory @ E=1MV/m

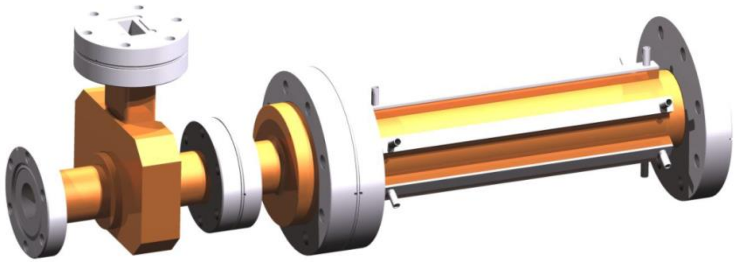
Summary of the Experiment

- Successfully demonstrate the multipactor suppression with an external solenoid field.

- Another experiment is planned with a uniform Bz and a different impedance matching design.

Experimental Report on test of Dielectric PETS (US SBIR funded Project)

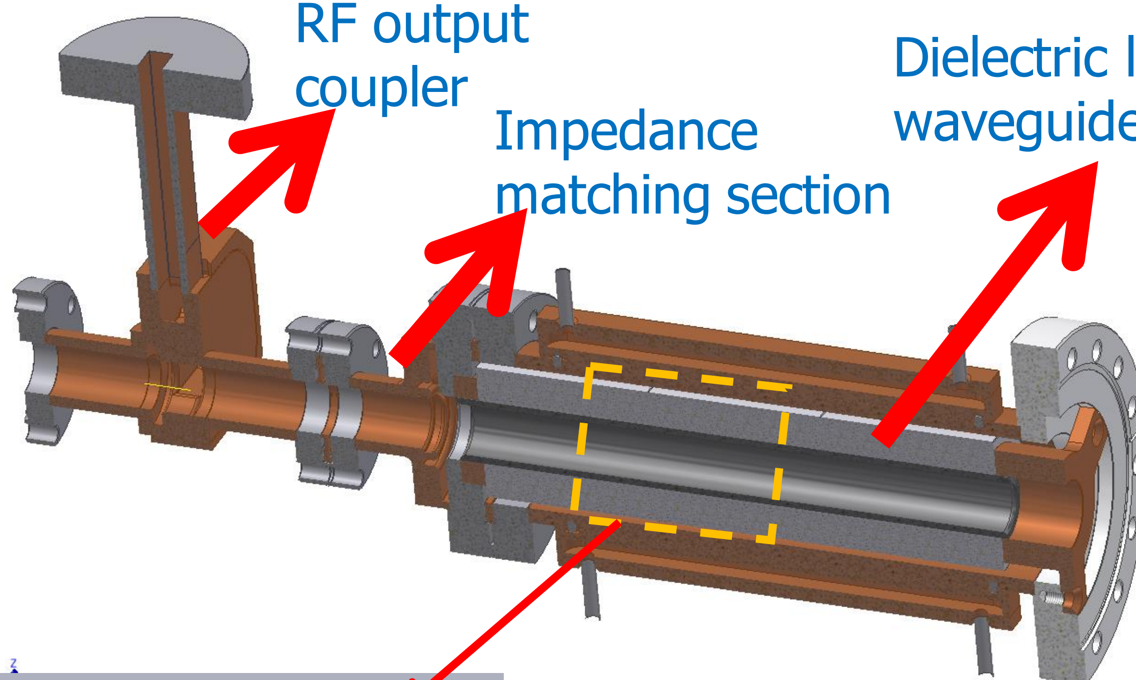
Dielectric PETS Parameters



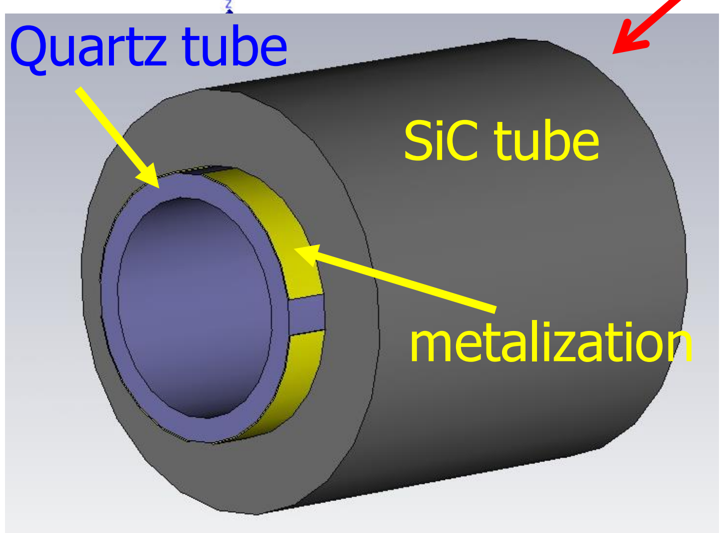
Using CLIC Beam: σz=1mm, Q=8.4nC, Tb=83ps

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

Engineering Design



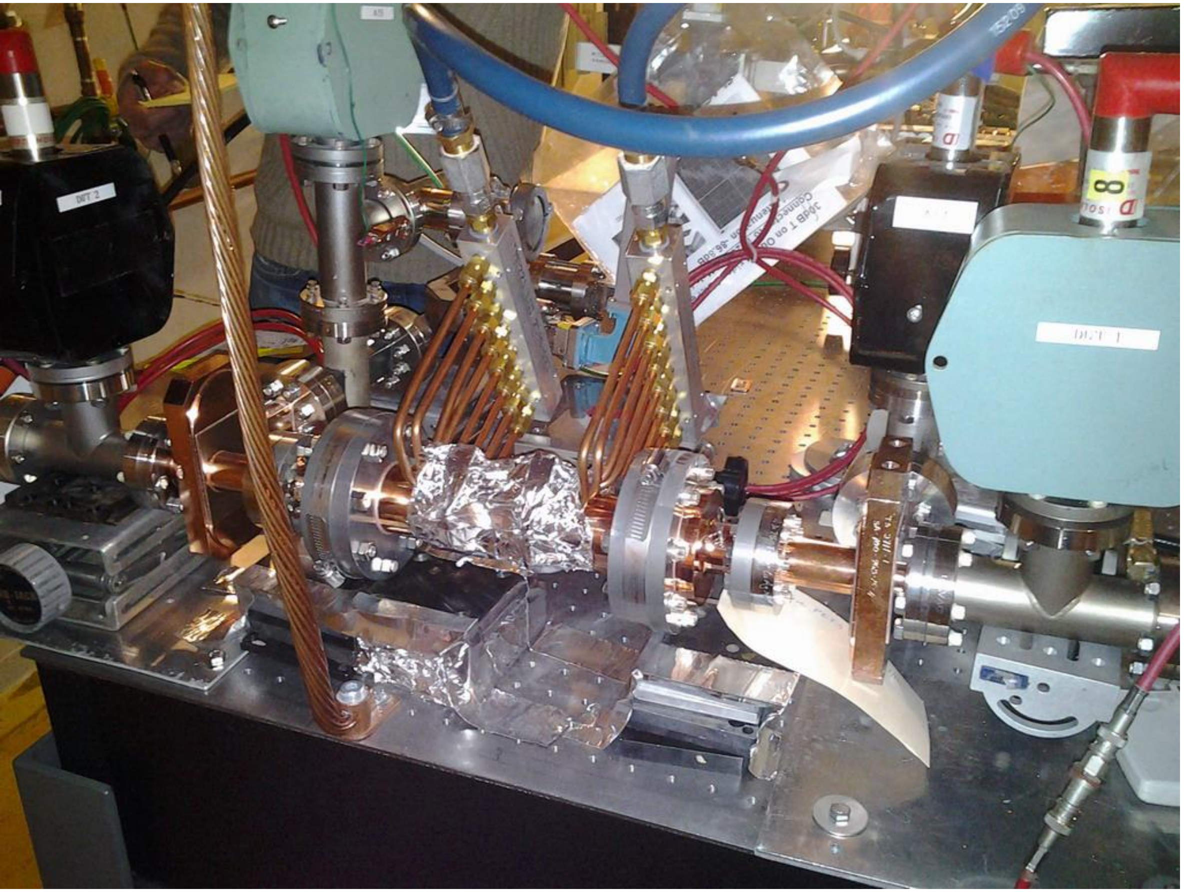
Transverse mode damping

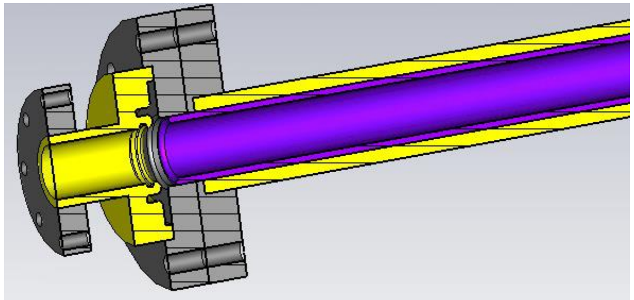


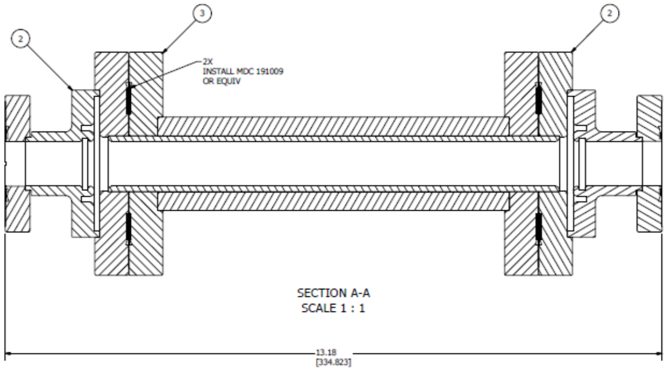
Fabrication

11.4GHz version is under high power rf test at SLAC

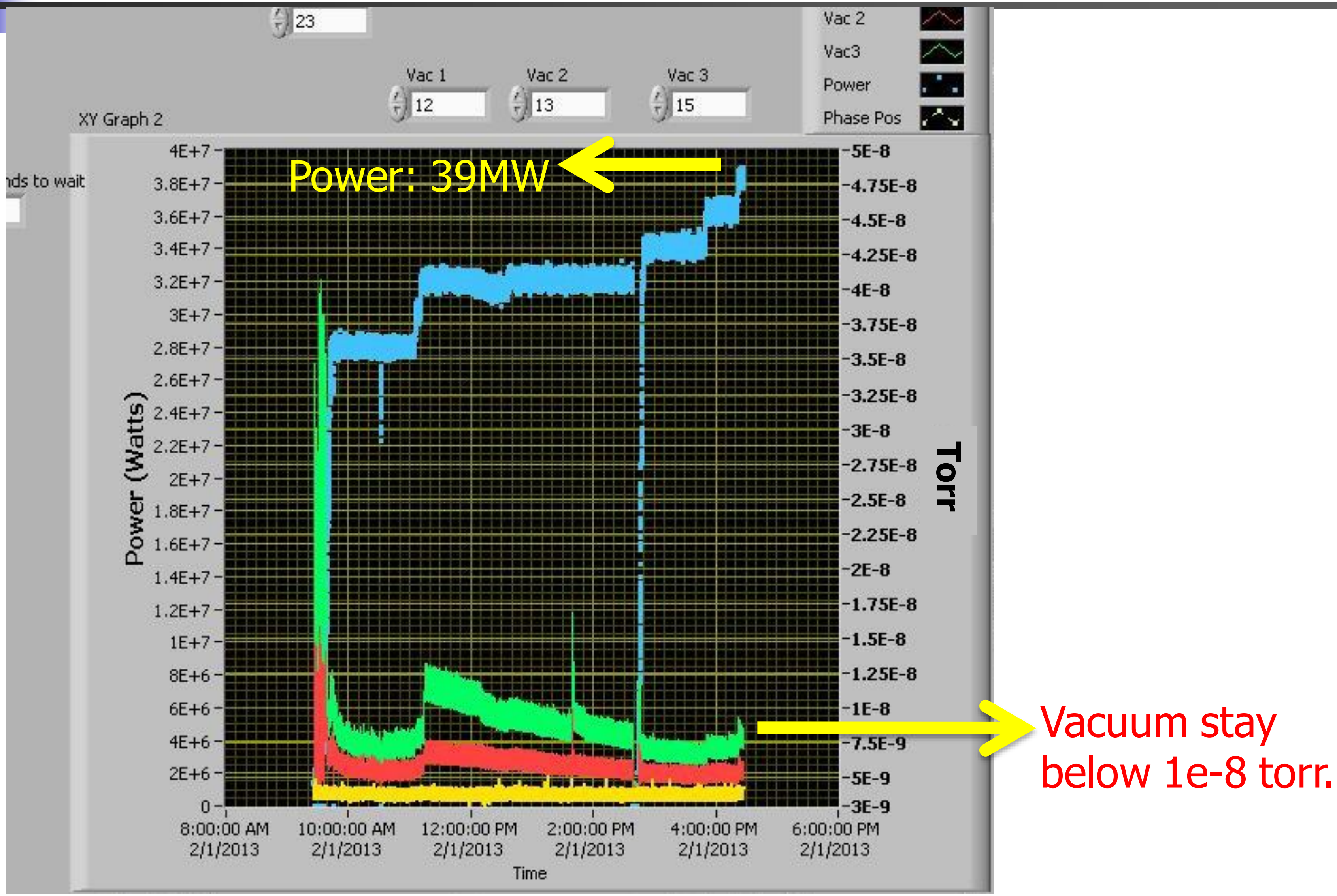
Setup at SLAC ASTA facility







Testing data on 2/1/2013 (100ns flat pulse)



Summary of the Experiment

- Successfully demonstrate the potential of dielectric PETS.
- Beam experiment is planned at AWA.

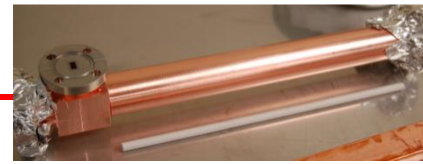
The Coming Experiments at AWA

Planned Two beam acceleration experiment @AWA

75MeV drive beam
- 16 bunches x 60nC/per bunch
- σz=2mm

26GHz Stage I DWPE

a=3.5mm; b=4.53mm;
eps=6.64; L=30cm



65MeV drive beam
(10MeV loss)

RF Power Generation
- 767MW x15ns
- 26GHz rf

witness (10 MeV)
Q=1nC, σz=1mm, ε=1.5 um

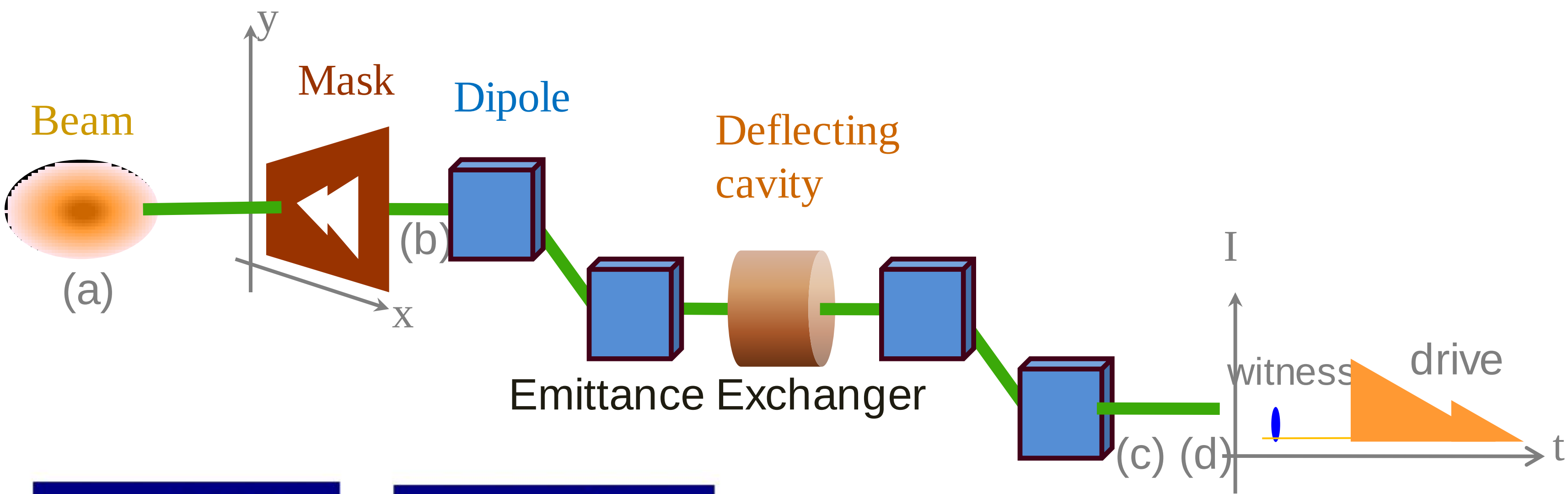
26GHz Stage II DLA

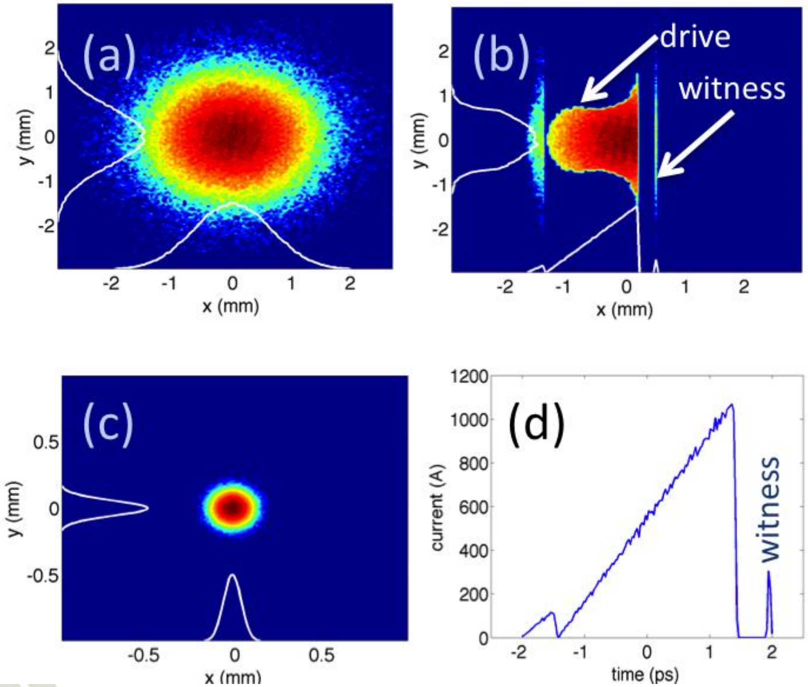
a=3mm; b=5.03mm;
eps=9.7; Vg=11%c; L=30cm

Ez = 250MV/m

witness (85 MeV)

Bunch shaping for high transformer ratio

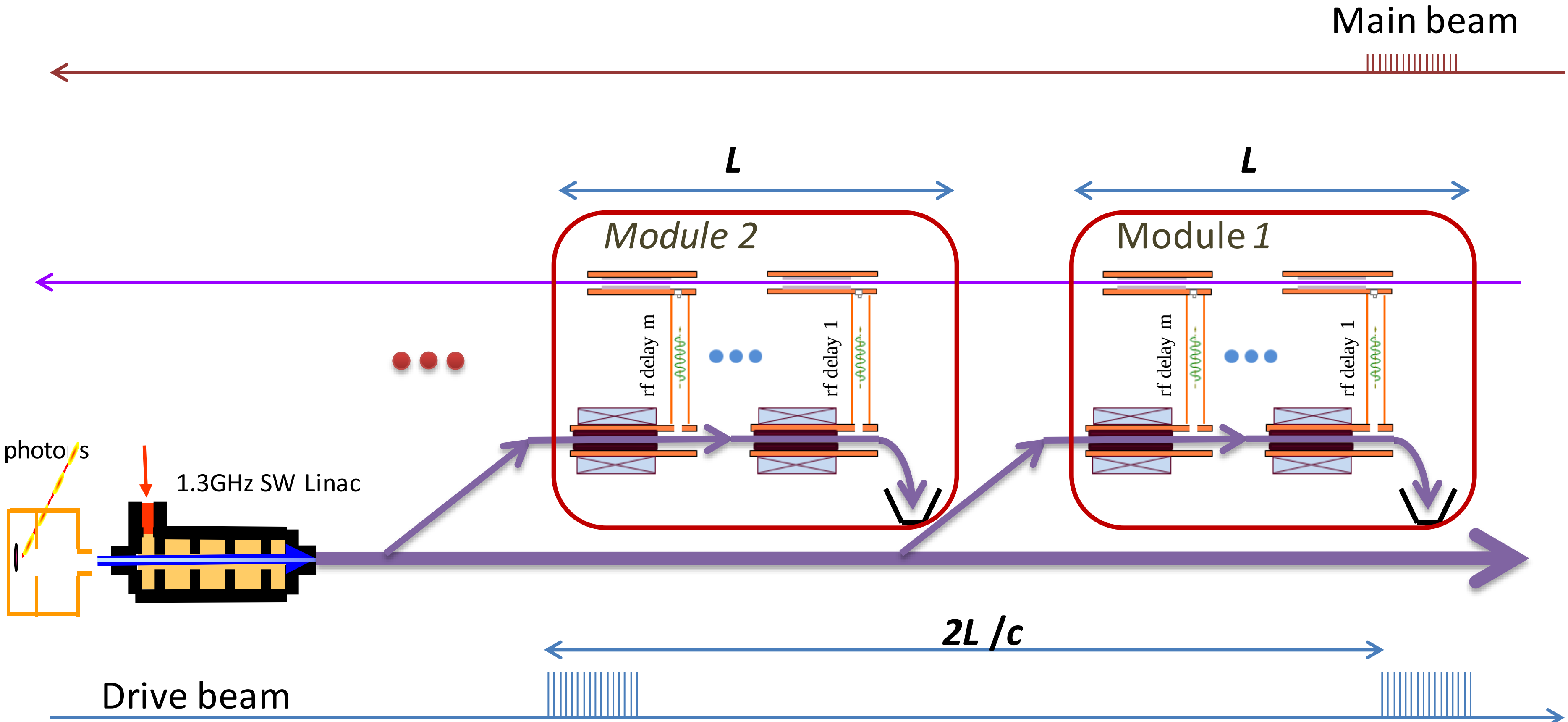




- Works well for a few nC charge after mask;
- flexible with mask shape
- witness bunch can be produced with the same mask to avoid the timing jitter;

Simulation by P. Piot (NIU)

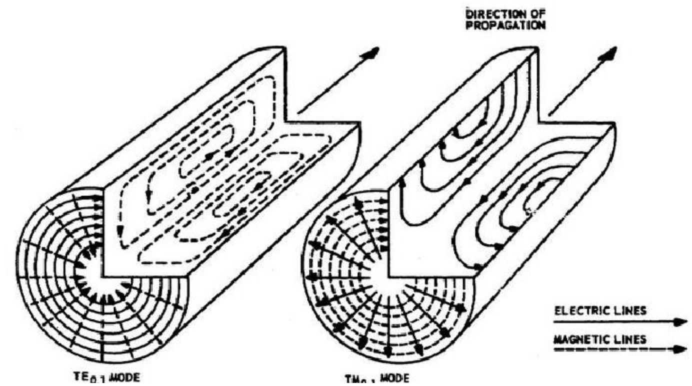
New Scheme to avoid 180 degree drive beam bend (using rf delay to obtain a sync timing)



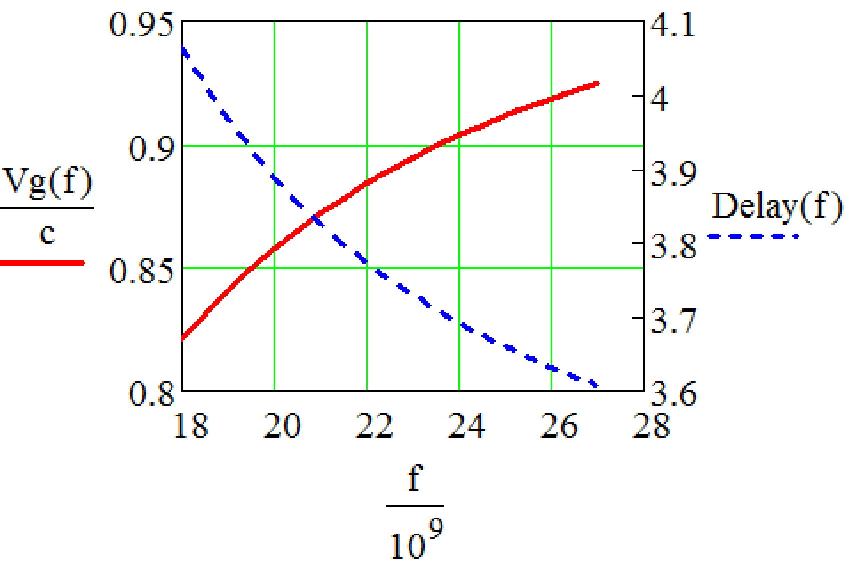
rf delay1=0;
rf delay2=$2L_s/c$;
rf delay m=$2*(m-1)*L_s/c$,
m is the # of structures in each stage,
L_s is the length of a single structure.

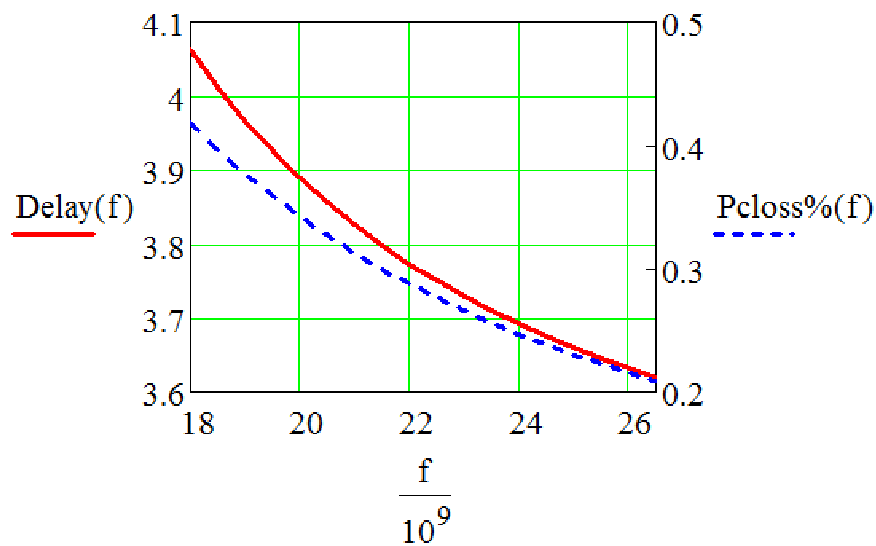
Example: Using parameters in the original design, we have 38 30cm-long structures in one module; then the requested shortest delay is $2*0.3m/c=$ **2*ns***; the longest delay is 2* (38-1)*0.3*m*/*c* =***74ns.***

In order to reduce rf loss in the delay line, let's consider the most commonly used a circular overmoded waveguide w/ TE01 mode (air filled, copper wall, a=0.7", f=26GHz): **delay=3.6ns/m; power loss=0.22%/m**

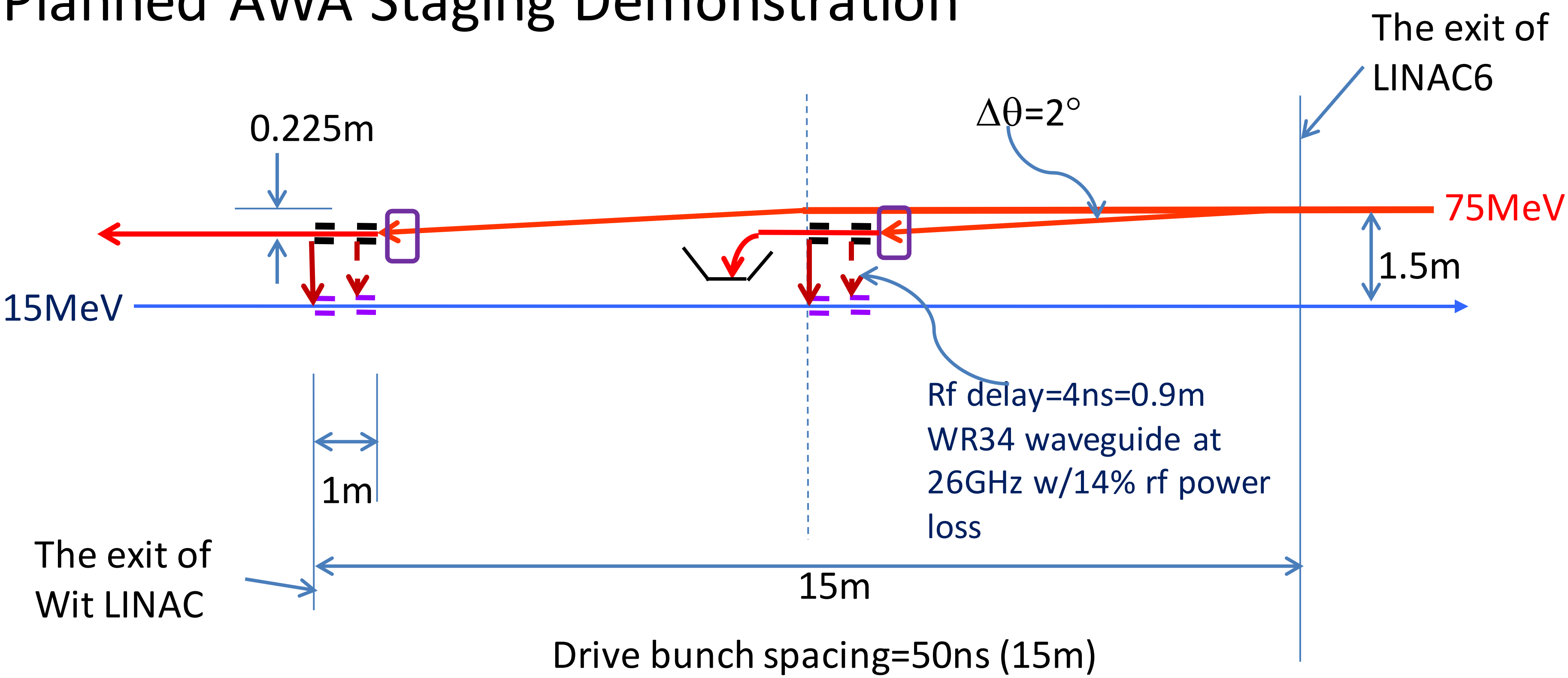


Then the longest delay line is 74ns/3.6ns=**20.6m**
The rf loss is 0.22%*20.6=**4.5%**





Planned AWA Staging Demonstration

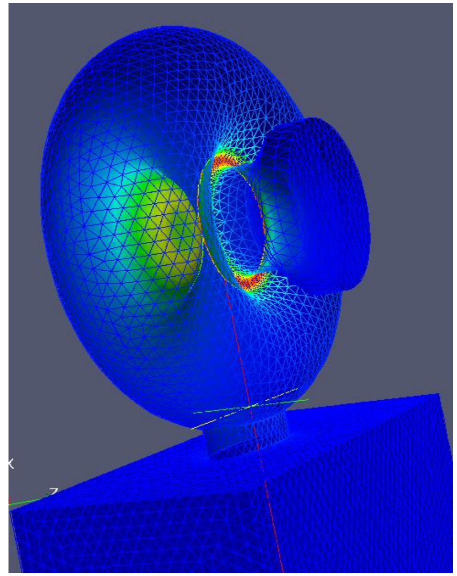
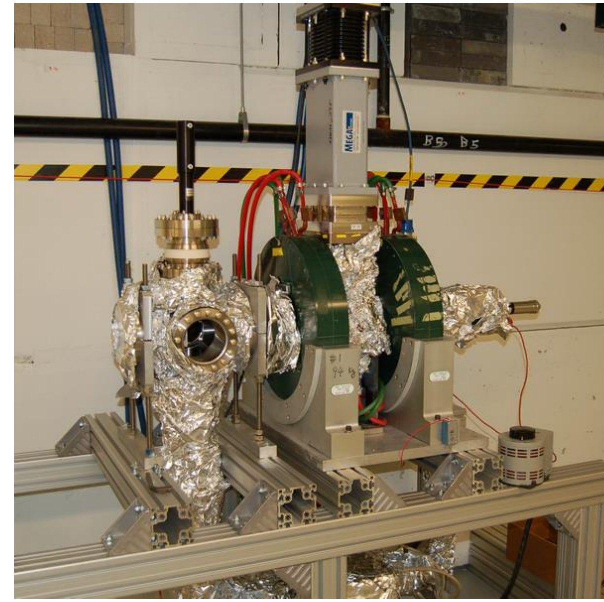


p_0 (MeV/c)	$\Delta\theta$ (mrad)	$\Delta p_\perp$ (MeV/c)	T_{rise} (ns)	TW Deflector Power, Length
75	**34.9**	**2.62**	**50**	**29.6MW, 0.3m**

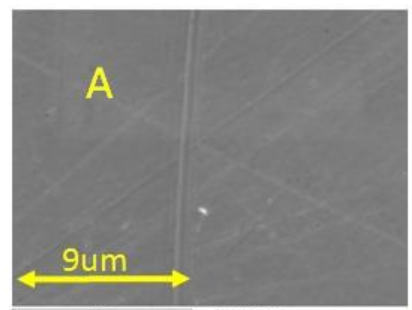
Laser Triggered Breakdown Study at AWA (in collaboration with Faya Wang of SLAC and Tsinghua University)

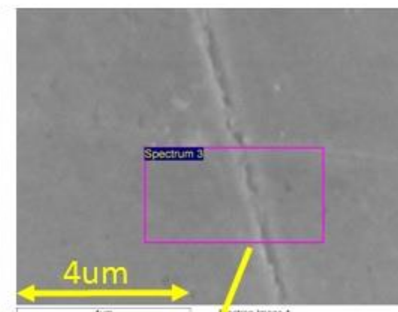
AWA G1B photo-gun

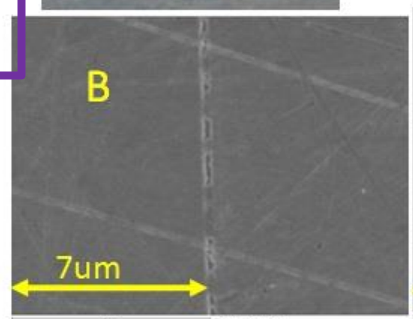
- ½ cell 2MeV gun
- β=1.5
- was conditioned to 120MV/m
- new simulation by Omega3P shows 3MW→147MV/m.

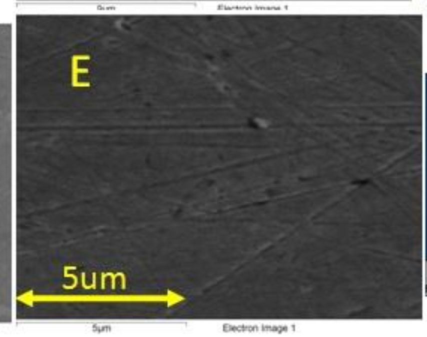



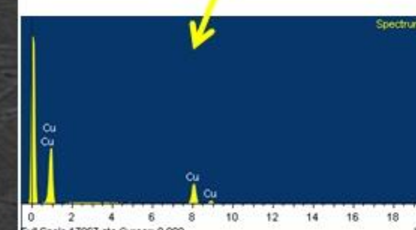
- copper cathode after the machine polish with 1um or 0.25um water based diamond powder

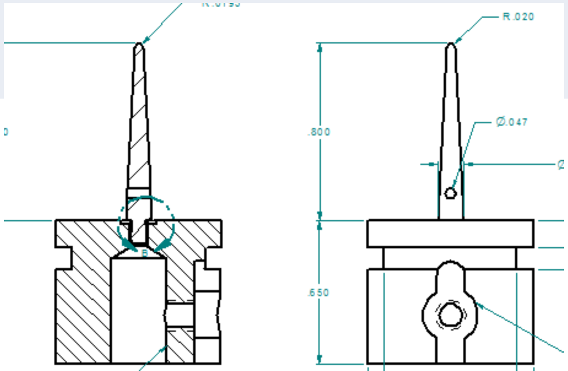






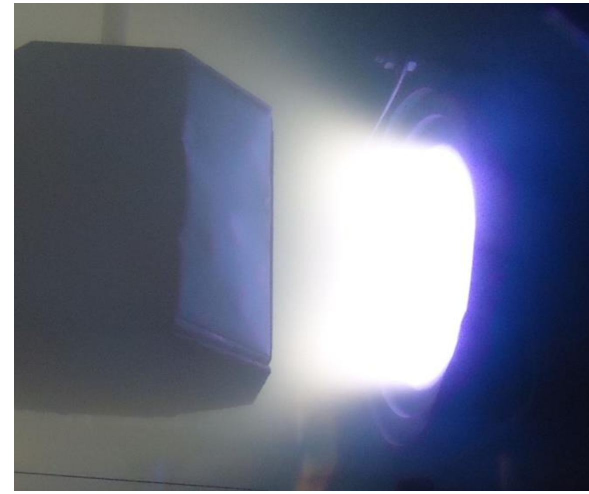


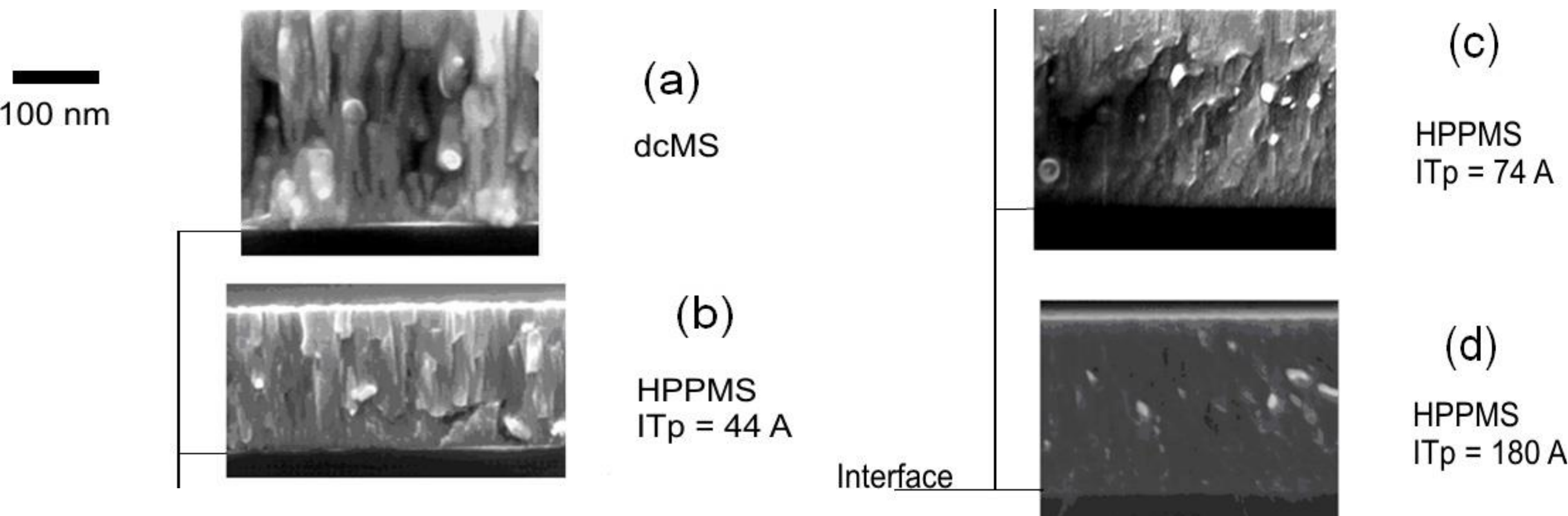


steps	What we measure
Rf conditioning G1B back to 120MV/m level	Measure dark current; record breakdown events using rf probe
Take out the cathode	SEM and comparison
Re-polish the cathode and put it back for re-conditioning	Record breakdown events on the cathode using rf probe and camera
Put back the plasma treated cathode and re-conditioning	Record breakdown events on the cathode.
Laser (Red and UV) and RF triggered breakdown study on the untreated copper cathode	Cathode imaging; rf probe;…..
RF breakdown study using field enhancement cathode	

Plasma treatment of the metal surface---- High-Power Impulse Sputtering (HiPIS); work w/ SwRI

- •Low repetition rate pulse
- •High current in the pulse to cause surface melting
- •High ionization rate
- •Negative bias make the copper ions back to the surface





Final Remarks

- 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