AWA Needs and Opportunities Workshop

chaired by Manoel Conde (Argonne), John Power (Argonne National Lab)

from Wednesday, August 21, 2019 at **13:00** to Friday, August 23, 2019 at **12:00** (US/Central)
at **Argonne, Building 360 (A-224)**

Structure-Based Beam-Driven Accelerator

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Research sponsored by NSF Award#1632588

Yale University

Omega-P R&D, Inc.
Accelerator Physics & Technology

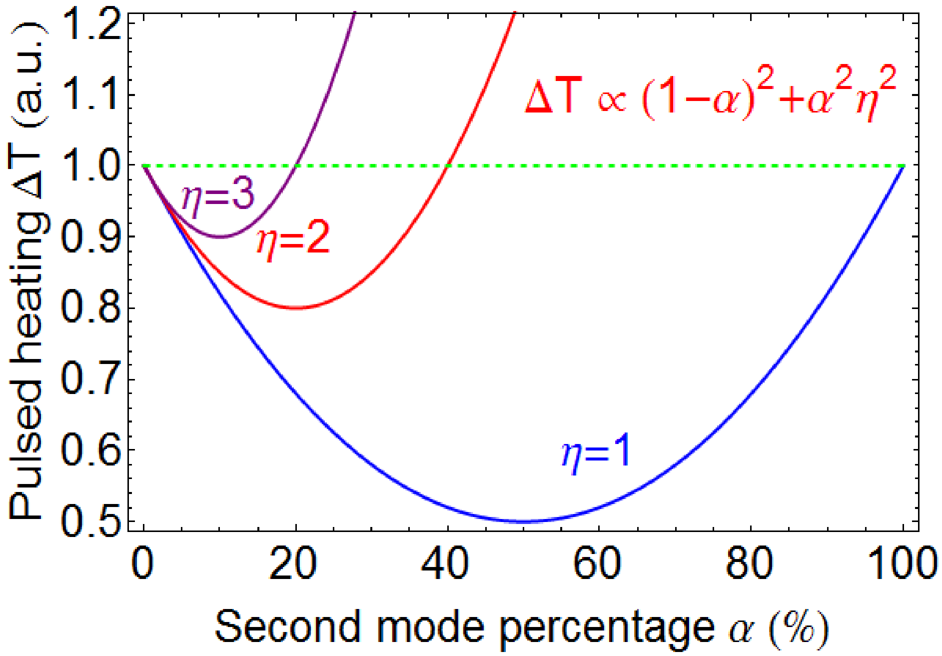
(AWA) to provide

1) number of bunches = 300 or about;
2) charge per bunch = 80 nC;
3) bunch size, transverse < Ø 4mm;
4) bunch size, longitudinal < 2 - 3 mm;
5) bunch energy spread, Pk-Pk < 10%;
6) frequency = 1.3 GHz for bunch spacing;
7) bunch energy = 3 - 10 MeV;
8) total beam power, peak ~ 0.3 - 1 GW;
9) beam power, average ~ 80 - 240 W @ 1Hz;
10)conservative number of klystrons at 100 MW = 4 - 12;

(Omega-P R&D) note: the frequency of our structure = 10.4 or 11.7 GHz (+ third harmonic, by design);

Suppression of Surface Pulsed Heating

"Quadratic Dependence" Effect



$$E_{total} = (1-\alpha)E_1 + \alpha E_2$$

$$H_{total} = (1-\alpha)H_1 + \alpha H_2$$

E_1 , E_2 normalized to the same acceleration gradient

α is the percentage of the 2nd mode

$$\Delta T \propto (1-\alpha)^2 < H_1^2 > +\alpha^2\sqrt{f_2/f_1} < H_2^2 > = < H_1^2 > [(1-\alpha)^2 + \alpha^2\eta^2]$$

where $\eta = \sqrt{(f_2/f_1)^{1/2} < H_2^2 > / < H_1^2 >}$

$\exists\alpha$ $\quad (1-\alpha)^2 + \alpha^2\eta^2 < 1$

also, modified Poynting vector S_c and total RF power P_{total} are reduced.

Two harmonic mode superposition could suppress pulsed heating – a* possible *precursor to breakdown.

TM_{010}+TM_{012} Cavity

a/λ=0.10 π mode standing wave effective gradient E_{acc}=100 MV/m	 TM_{010} + TM_{012} Bimodal Cavity			 Pillbox A	 Pillbox B	 Nose-cone
	1^{st} harmonic alone	3^{rd} harmonic alone	84% 1^{st} +16% 3^{rd}	1^{st} harmonic only	1^{st} harmonic only	1^{st} harmonic only
frequency (GHz)	11.9942	35.9826		11.9942	11.9942	11.9942
effective shunt impedance (MΩ/m)	100.73	24.65	▲ 124.19	100.43	99.18	127.7
transit time factor	0.753	0.633		0.762	0.758	0.749
max E_{surf} (MV/m)	209.8	359.2	▼ 178.0	206.7	178.0	218.6
max H_{surf} (MA/m)	0.309	0.776	0.339	0.309	0.309	0.267
max S_c (W/μm²)	2.365	9.700	▼ 1.670	3.190	3.181	3.68
max ΔT (K) @ 200ns pulse length	24.46	261.8	▼ 19.15	24.46	24.46	17.65
wall loss (MW)	1.241	5.069	▼ 1.006	1.244	1.260	0.979

2-mode superposition compared to fundamental mode alone in the same cavity :

- ◊ pulsed heating temperature ↓22%
- ◊ effect shunt impedance ↑23%
- ◊ peak surface E-field ↓19.4%
- ◊ modified Poynting vector ↓30%
- ◊ total RF power ↓ 19%

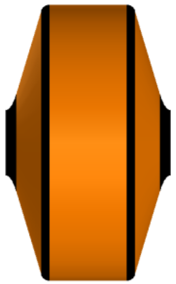
	Bimodal (16%)	Nose-cone	
effective gradient E_a	150	150	MV/m
effective shunt impedance	124.2	127.7	MΩ/m
max E_{surf}	267	327.9	MV/m
max H_{surf}	0.509	0.401	MA/m
max S_c	3.76	8.28	W/μm²
max ΔT @ 200ns pulse length	43.1	39.7	K
wall loss	2.26	2.20	MW

Bimodal Cavity for Pulsed Heating Suppression

TM_{010}+TM_{012} (f + 3*f*)

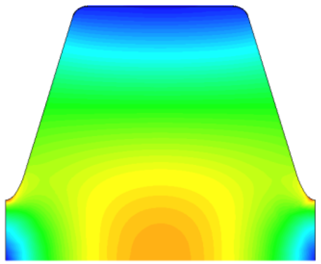
elliptical cavity

$a/\lambda=0.1$



TM_{010} 12 GHz

E



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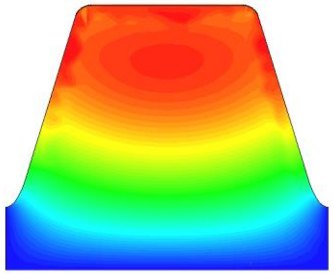
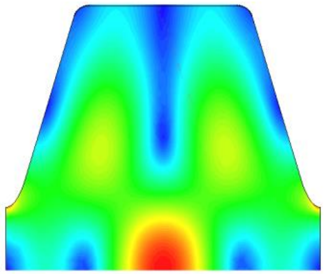


TM_{012} 36 GHz

E



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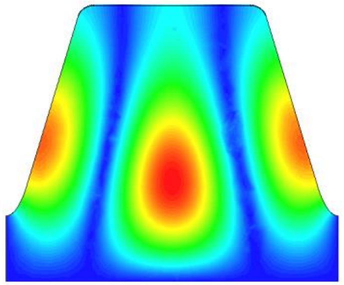
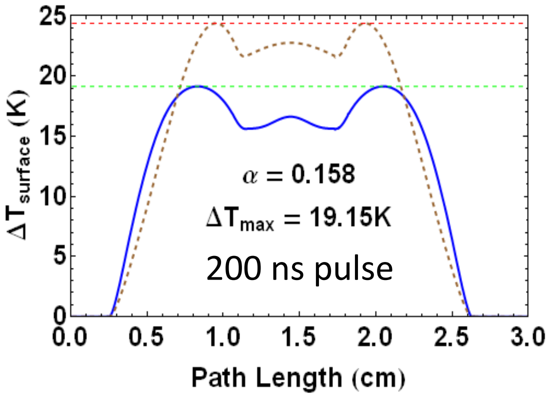
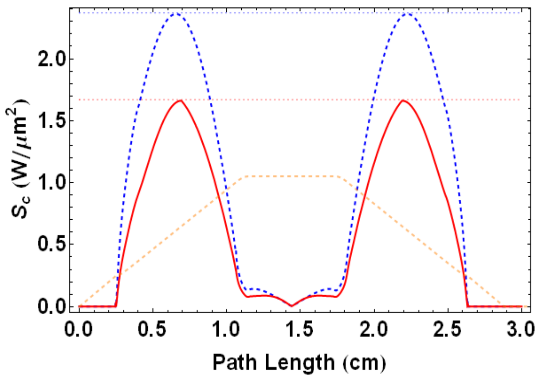


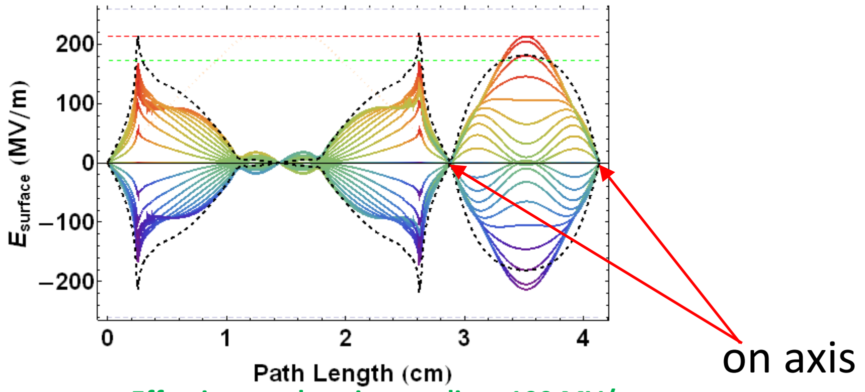
pulsed heating temperature



modified Poynting vector S_c



surface E-field along periphery

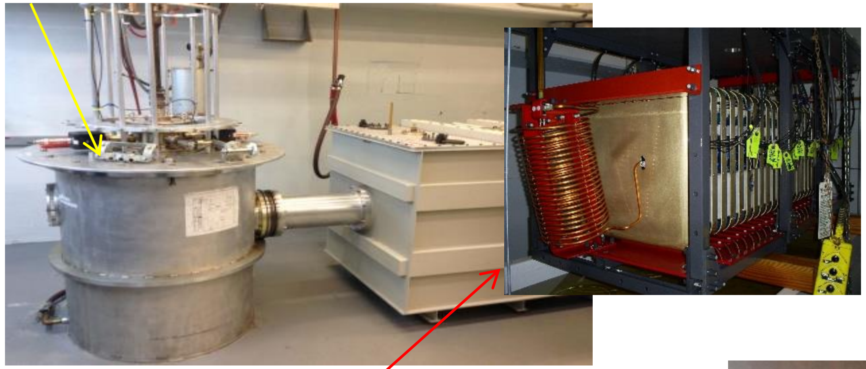


Effective acceleration gradient 100 MV/m

2-mode superposition compared to fundamental mode alone in the same MHC :

- ◊ pulsed heating temperature ↓22
- ◊ peak surface E-field ↓19.4%
- ◊ total RF power ↓ 19%
- ◊ effect shunt impedance ↑23%
- ◊ modified Poynting vector ↓30%

Electron Gun 350-500kV; 129-220 A

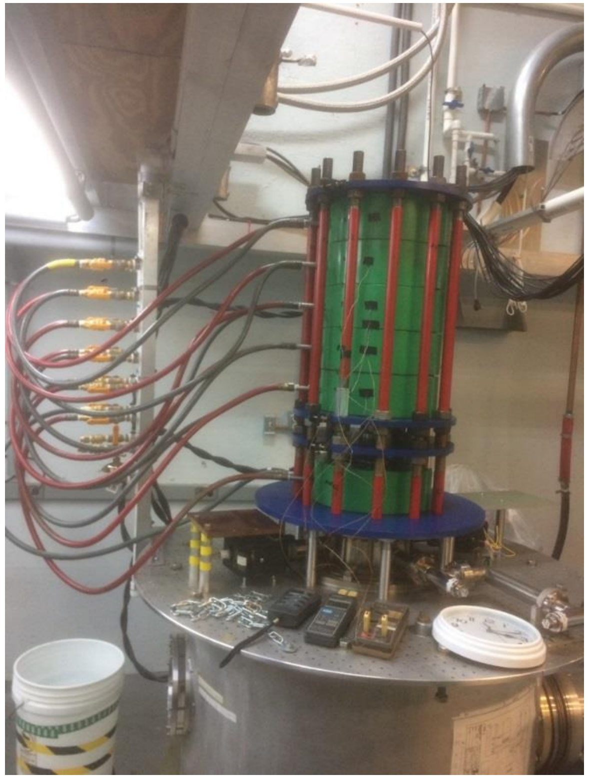


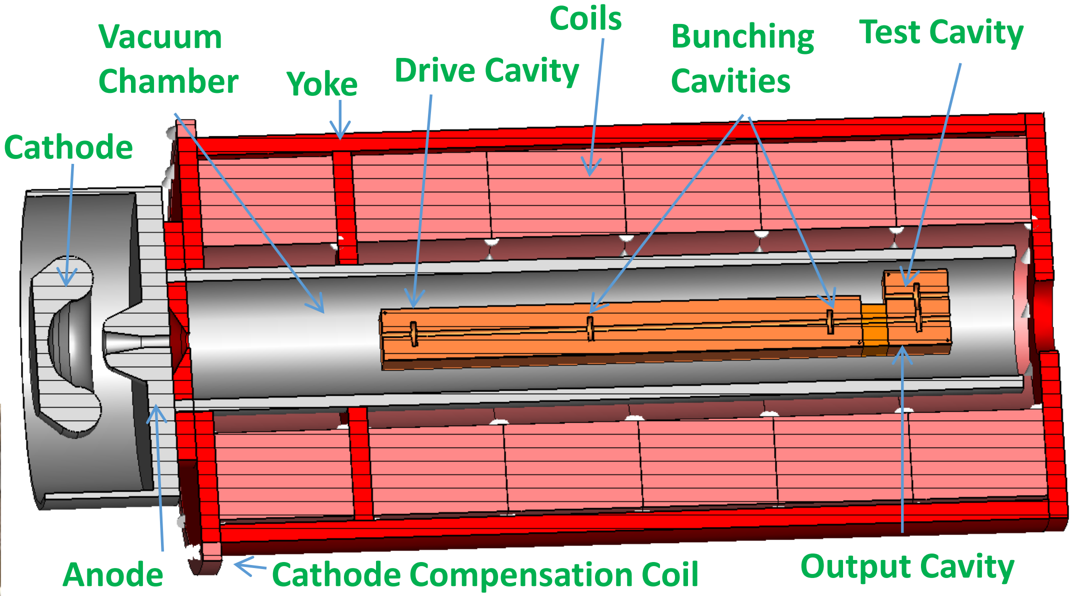
Solid State Marx Modulator

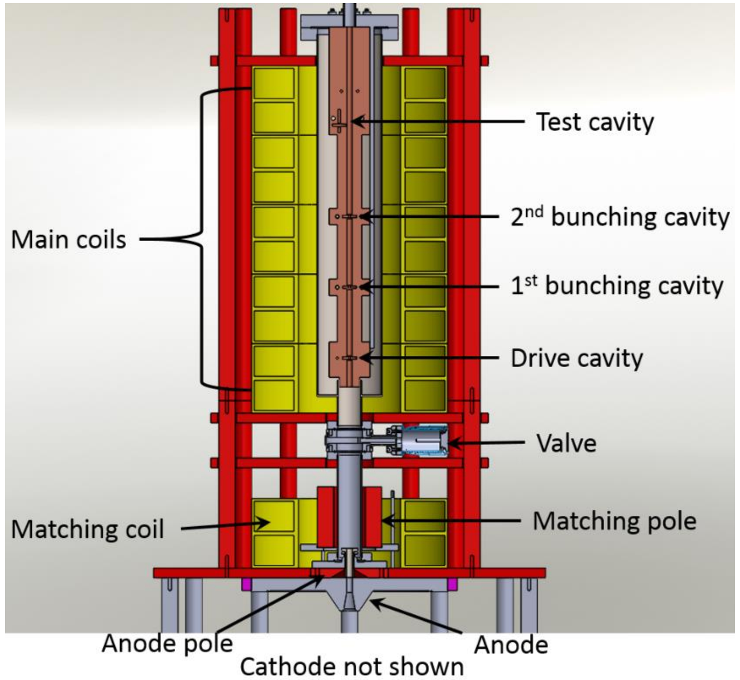
500kV, 250 A, 1.2 μs, 5 Hz

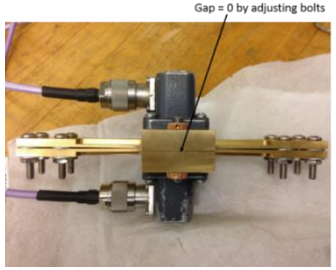
Challenge: High Current Drive Beam
Solution: Thermionic Beam using Klystron-like Bunching without actual X-band Klystron

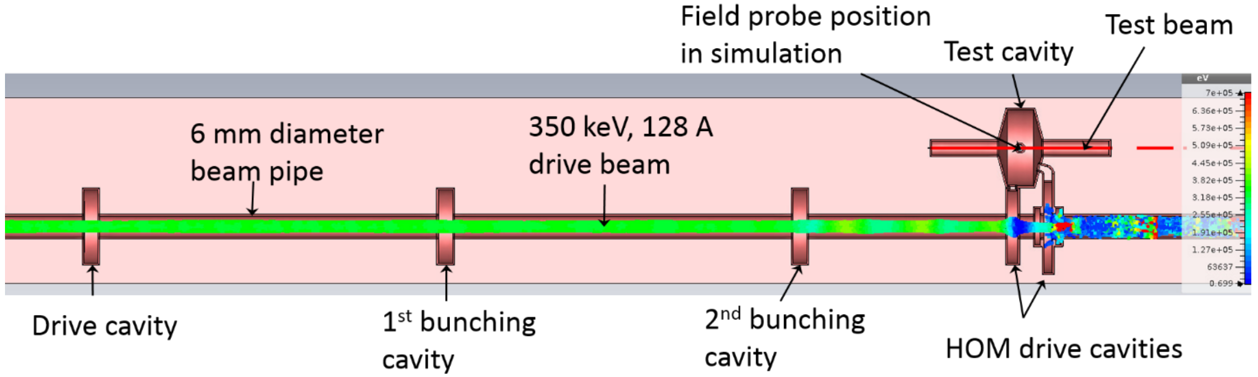
Challenge: Low Energy Drive Beam (0.5 MeV) can be reflected by high field (1.8 MeV loss)
Solution: add a two-frequency output cavity and couple to test cavity



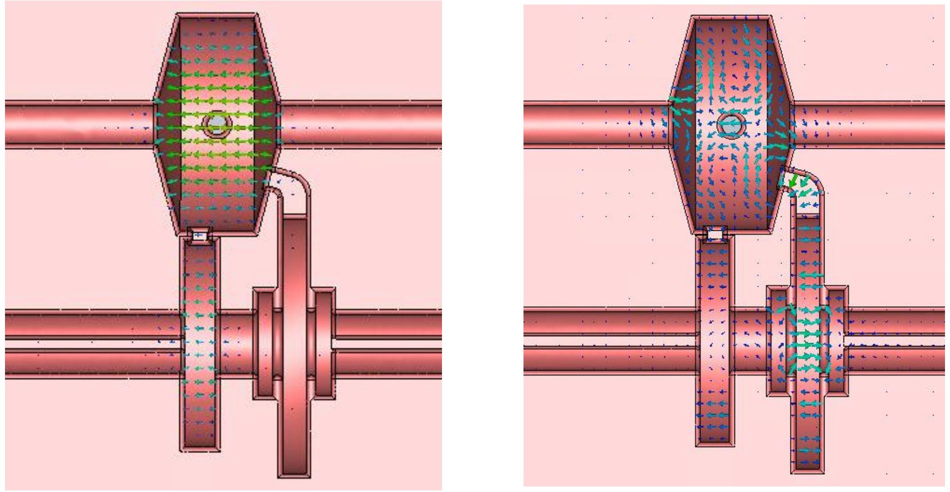




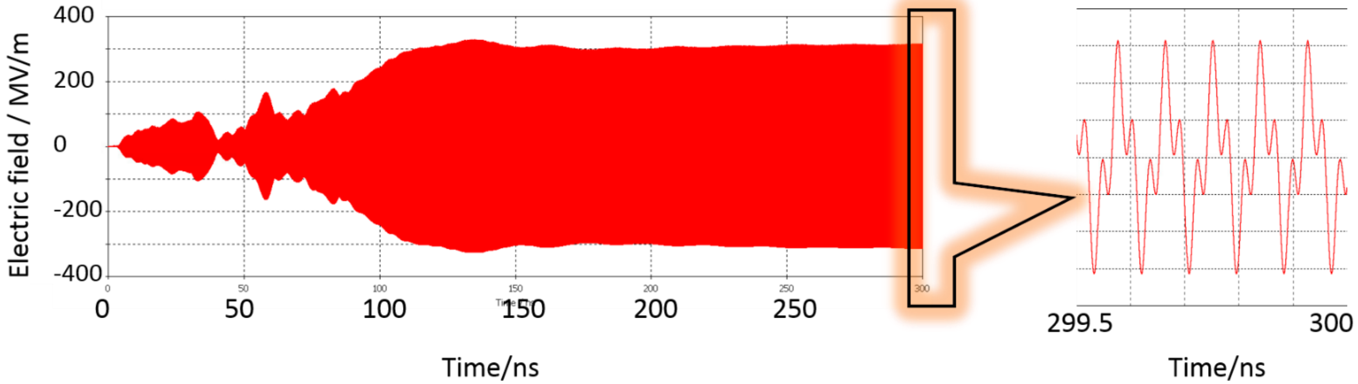




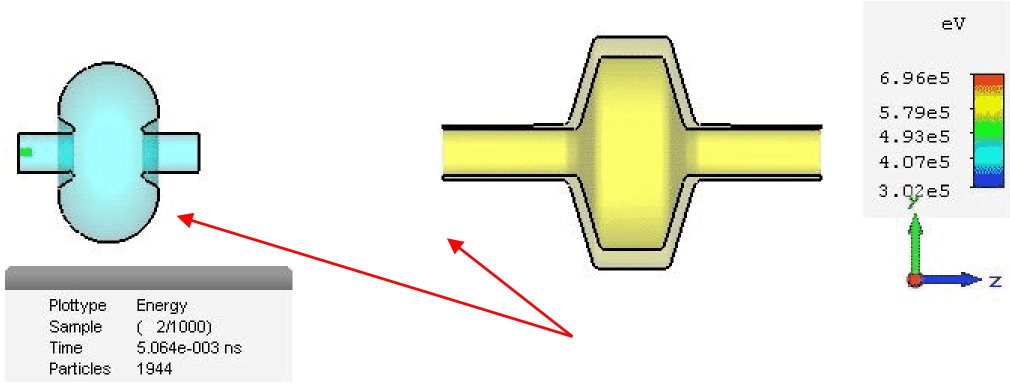
Steady state of a 350 keV, 128A beam going through the system. Drive power in drive cavity is 30 W, beam radius is 2 mm, and longitudinal magnetic field is 3000 G. A high energy (100 MeV), negligible current (1 pA), and small size (0.4 mm diameter) test beam is sent through the test cavity to test the acceleration.

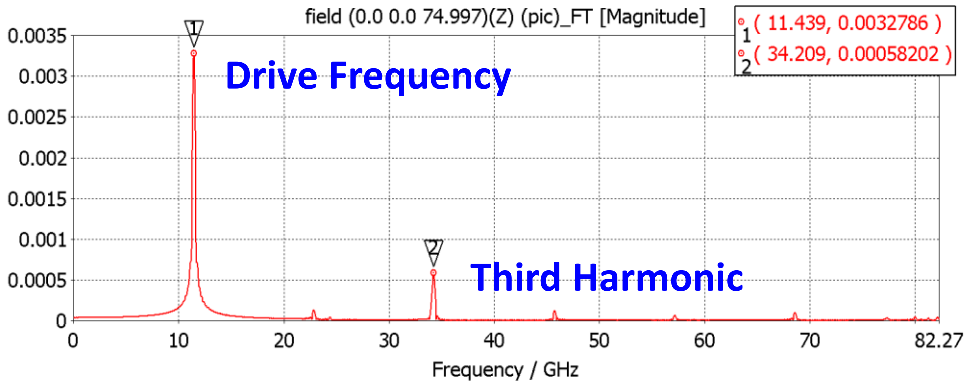


Left: Fundamental mode field pattern.
Right: 3rd HOM field pattern.



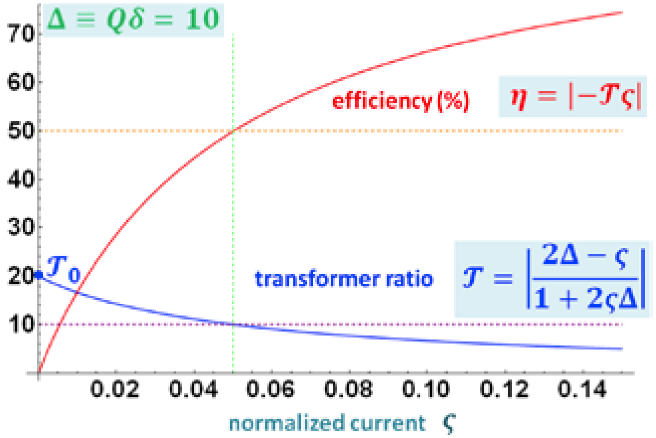
Electric field vs. time at probe location of figure 11. The peak field reaches 313 MV/m. The peak energy gain of the test beam is 1.92 MeV.

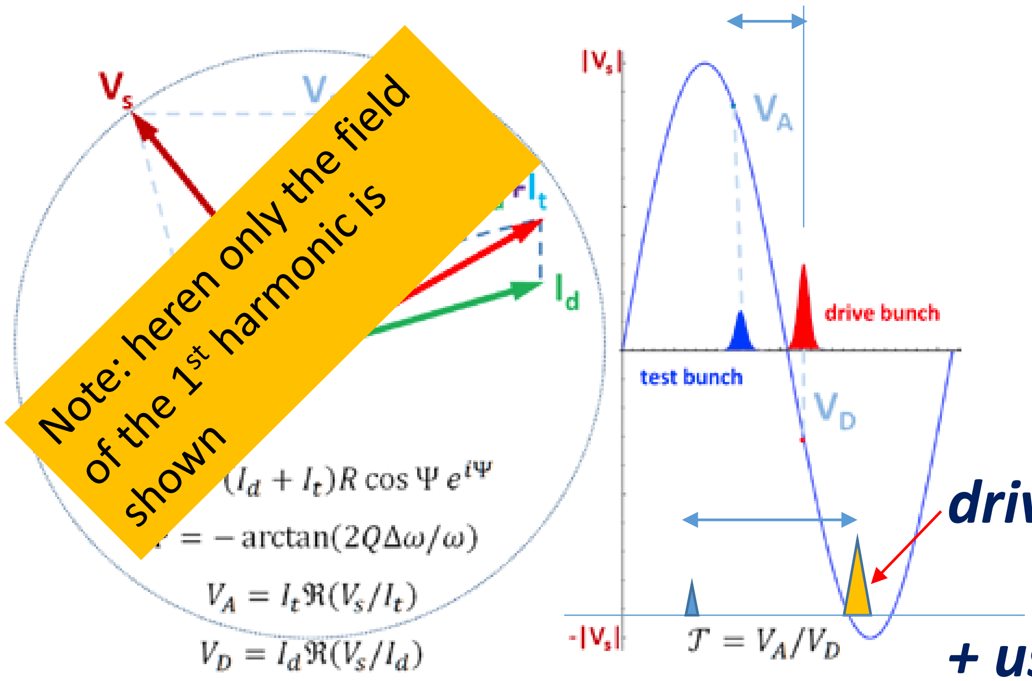




to test these directly… we need something else;

recall: special case ΔΦ (drive-to-test) = 90°





drive here → low detuning → lesser drive charge is needed

+ use a variable ΔΦ to map the accelerating/decelerating fields on axis

lesser drive
same gradients
same wall fields
almost no test bunch – low beam loading (low efficiency), but we can…

…demonstrate that BDR is reduced (as the 1st step);
+ we can use a small test charge to map the fields on axis to show that they are a real combo of the 1st and 3rd harmonics

1) number of bunches = **300 or about**;
2) charge per bunch = **10 nC;**
3) bunch size, transverse < Ø 4mm;
4) bunch size, longitudinal < 2 - 3 mm;
5) bunch energy spread, Pk-Pk < 10%;
6) frequency = 1.3 GHz for bunch spacing;
7) bunch energy = 3 - 10 MeV;
8) total beam power, peak ~ 40 - 120 MW;
9) beam power, average ~ 10 - 30 W @ 1Hz;
10) conservative number of klystrons at **30 MW** = 2 - 4;