Novel Collinear Two Beam Accelerator Structures for CLIC Applications

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OUTLINE OF TALK:

I. Cavity detuning for collinear acceleration

II. Multi-harmonic cavities

III. Multi-harmonic collinear accelerator structure

IV. Conclusions

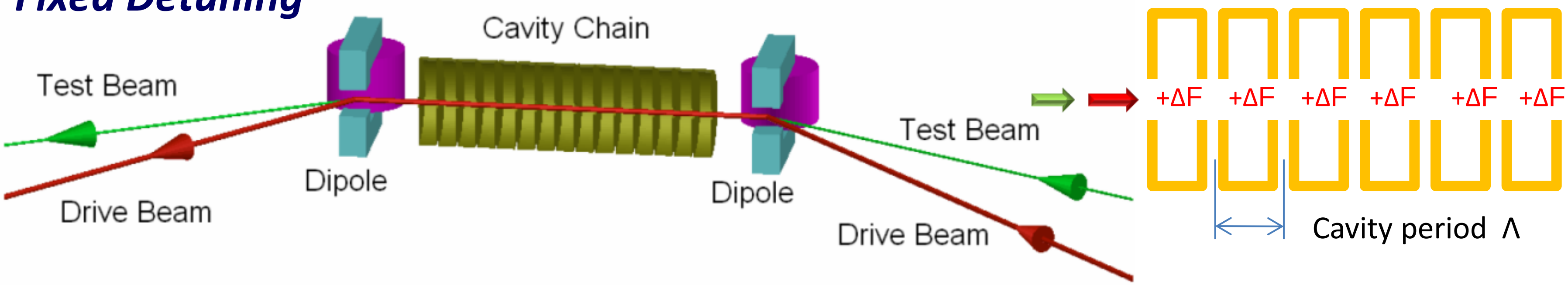
I.I Cavity detuning for collinear acceleration

Monopole Mode Detuning

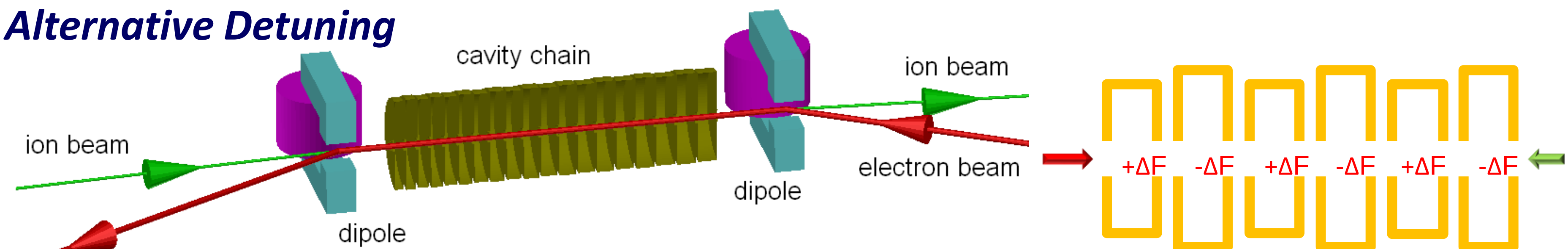
- Detuned cavities allow for collinear beams
- Phase shift, $\varphi = \mathrm{ArcTan}(-2Q\delta)$ causes drive bunch to see low decelerating field.
- Test bunch phased to arrive $\pi/2$ later, sees high accelerating field.
- Transformer Ratio, T is the ratio of test bunch field to drive bunch field, $T \gg 1$
- Can be shown that $T = -2Q\delta$ for unloaded case, Q is the cavity quality factor, δ is the magnitude of detuning.

I.II - Beam Excitation: Detuned-Cavity Two-Beam Accelerator

Fixed Detuning



Alternative Detuning



Every other cavity, detuning flips sign

Details in "High-gradient two-beam accelerator structure", S. Yu Kazakov, S.V. Kuzikov, Y. Jiang, and J. L. Hirshfield, PRSTAB 13, 071303 (2010)

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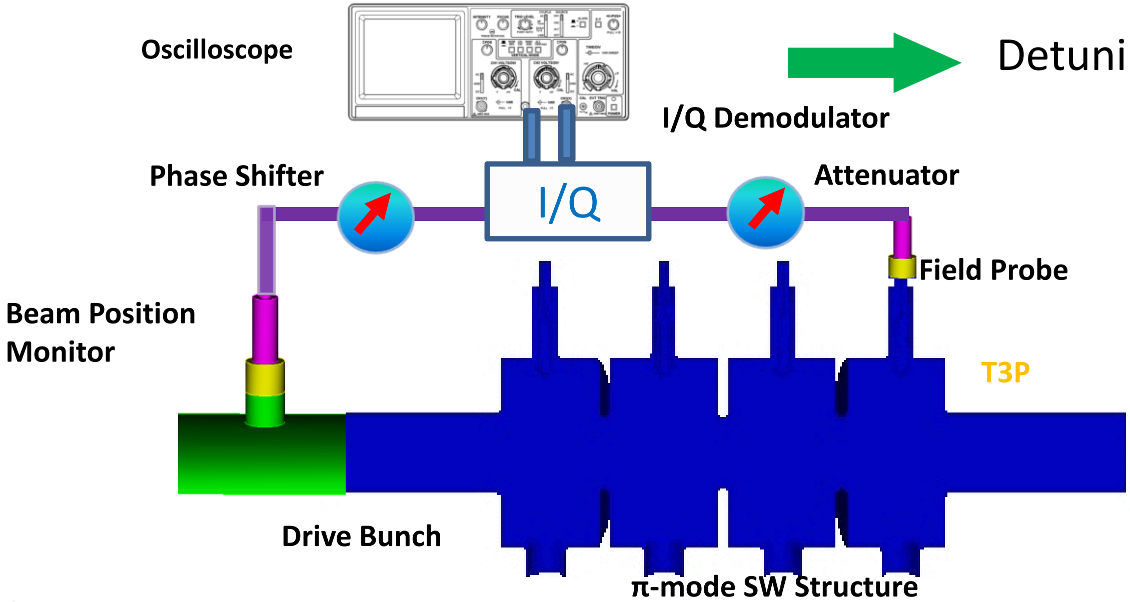
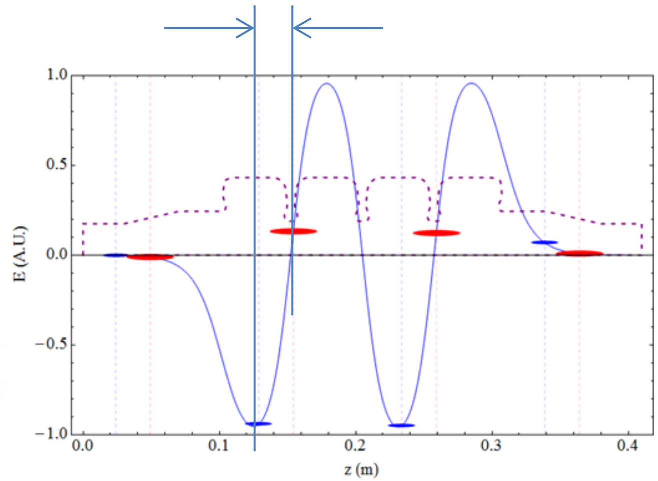
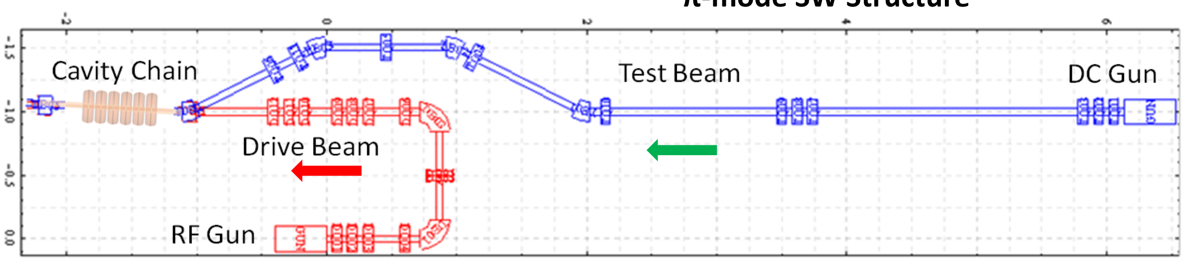
I.III - Single Mode TBA Experimental Plan



Detuning angle $\Delta\theta=\phi$ $T=\frac{A}{D}=\tan\phi=-2Q\delta$

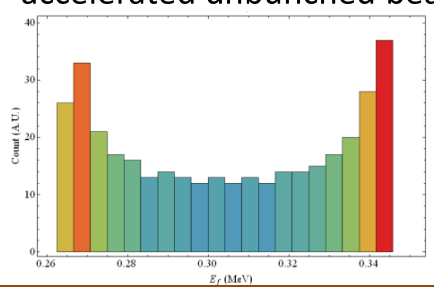


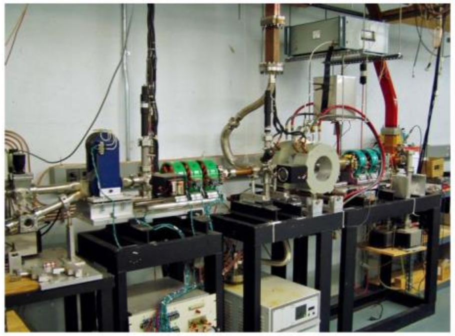


(1) To measure the transformer ratio by measuring the phase relationship between the drive bunch and the excited wakefield in the detuned accelerator structure.

(2) To measure the acceleration gradient by measuring the final energy distribution of DC test beam.

final energy spread of accelerated unbunched beam

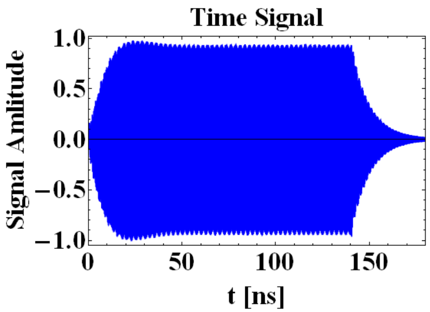




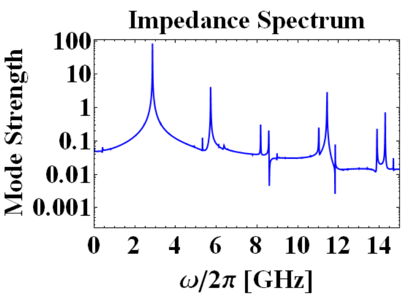
Slide courtesy of Y.Jiang

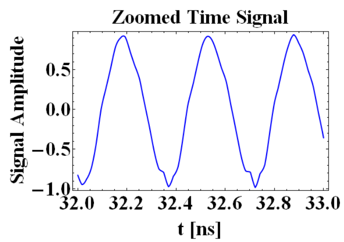
BPM

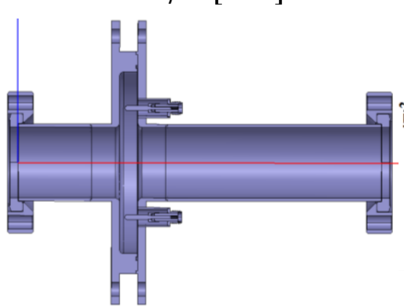
- Timing mechanism required for detuned experiment.
- Low Q (125) required to minimize the filling time of the cavity.
- Cold test results (bottom right) confirm simulation. Awaiting beam line test.

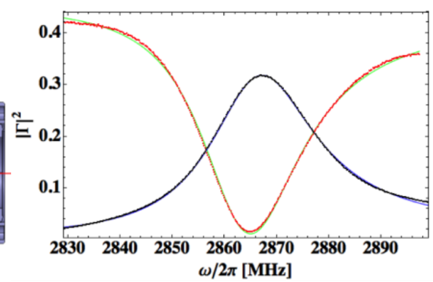


Time signal from on axis bunch train with σz=1.5mm, q=0.175nC and bunch frequency 2.856 GHz.



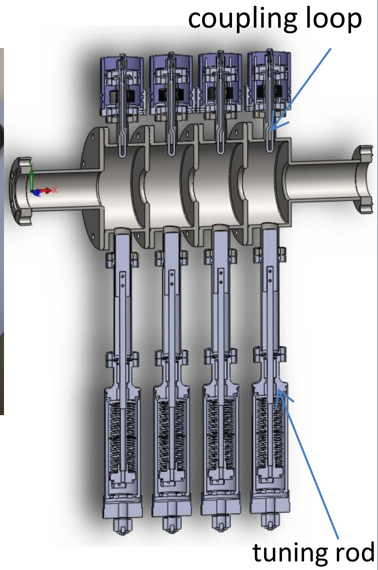


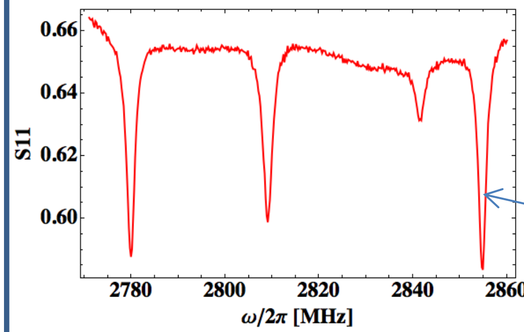




Detuned Pillbox Four Cell Structure

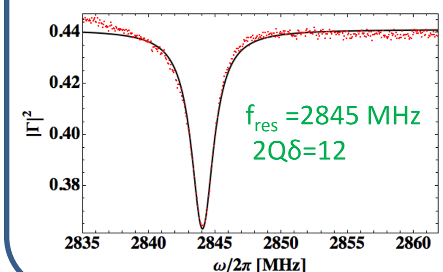
Constructed and Cold-Testing

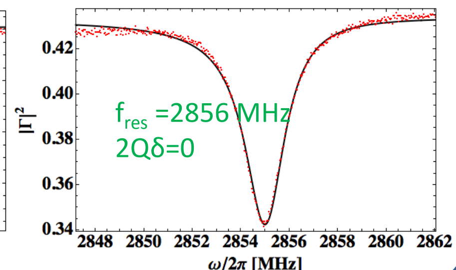




Operating π-mode Q_L ~ 1400

wide-range tunable Q and frequency with different tuner and coupler position





II. Multi Harmonic Cavities

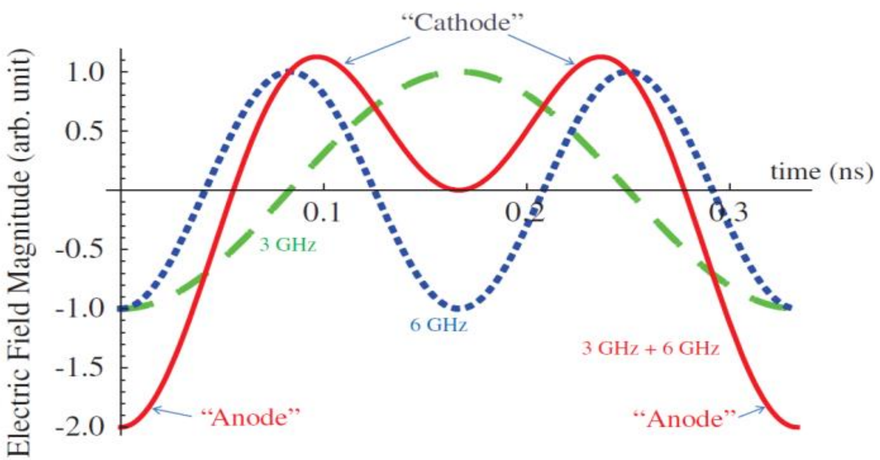
Dual mode excitation

- TM010 + TM020 could reduce onset of rf breakdown due to anode cathode effect.
- TM010 + TM011 could reduce effects from pulsed surface heating.
- Dual mode rf source being developed at Yale University.

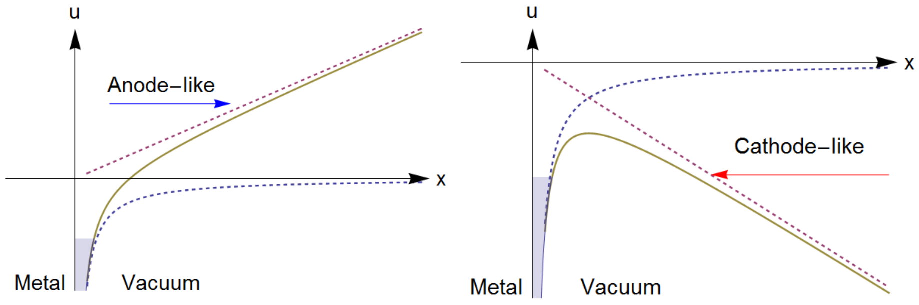
II.I - Motivation: Why excite multiple harmonics?

Superimposing harmonically-related modes

• Anode – Cathode effect: Electric fields that point into metallic cavity surfaces (cathode-like) can be smaller than fields that point away from the surfaces (anode-like), thereby inhibiting field emission and potentially preventing onset of rf breakdown.



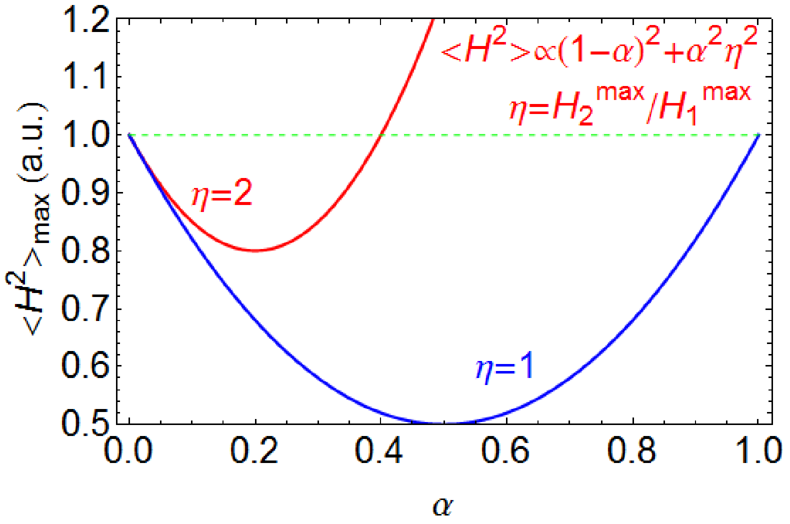
Potential energy **u** of an electron near the surface of a metal with **x** the distance of electron from surface.



• may lower the pulsed surface heating. By superimposing two modes $\tilde{H} = (1-\alpha)\tilde{H}_1 + \alpha\tilde{H}_2$

$$\Delta T \propto \langle \tilde{H}^2 \rangle = \langle \tilde{H}_1^2 \rangle \left[(1-\alpha)^2 + \alpha^2 \langle \tilde{H}_2^2 \rangle / \langle \tilde{H}_1^2 \rangle \right] < \langle \tilde{H}_1^2 \rangle$$

(Ideal pillbox $\eta = H_2^{max}/H_1^{max} = 2$)



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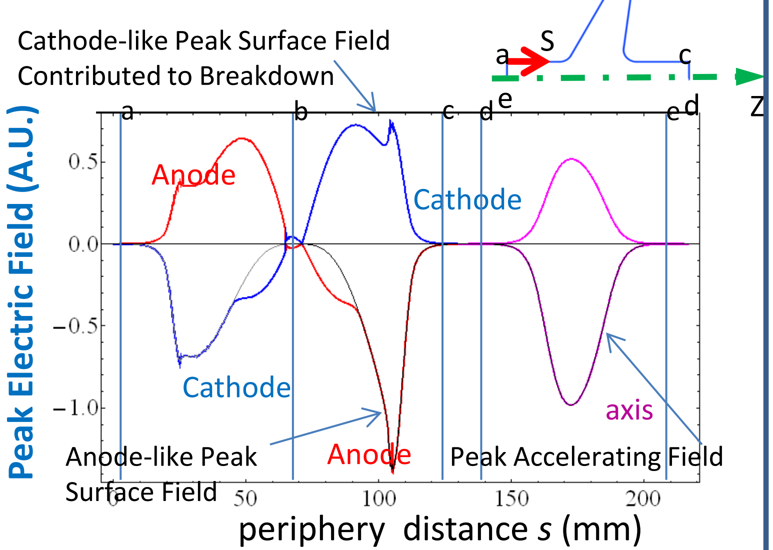
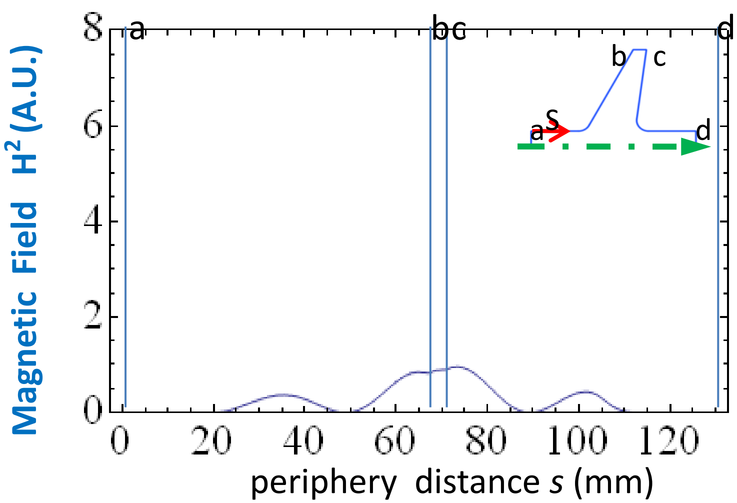
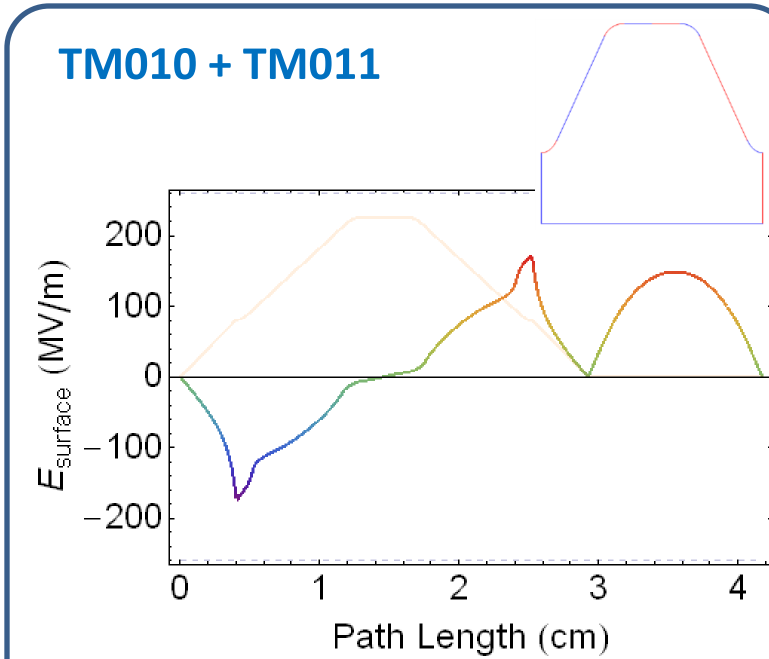
II.II - Field profiles in dual-harmonic cavities

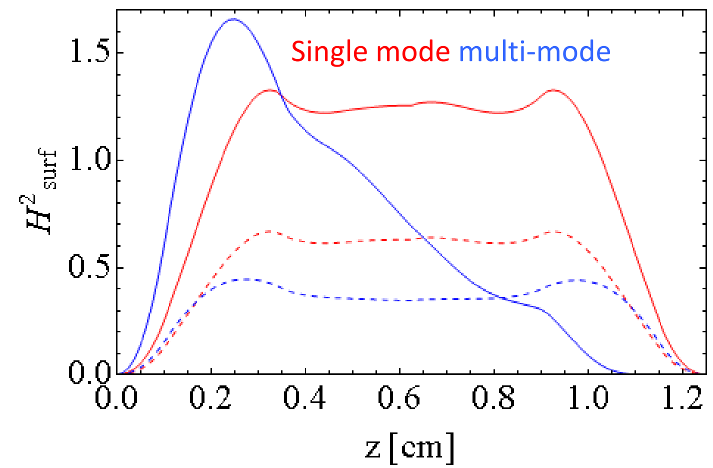
TM010 + TM020



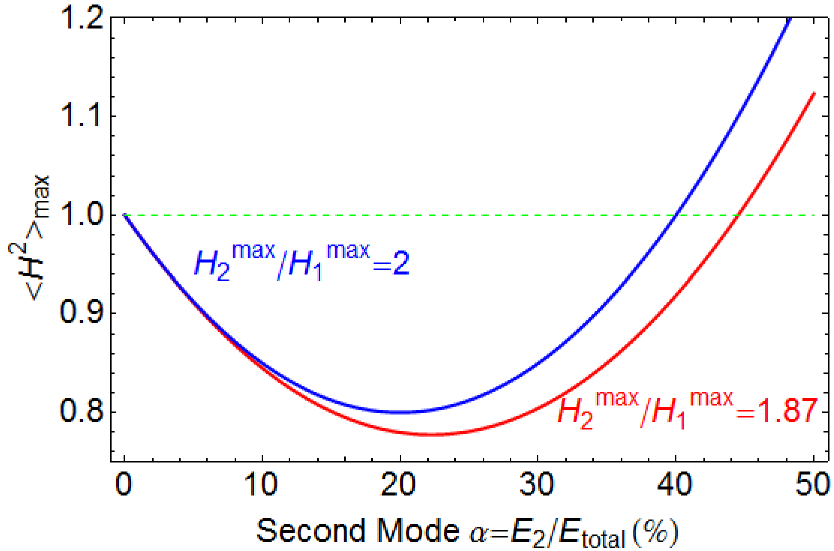


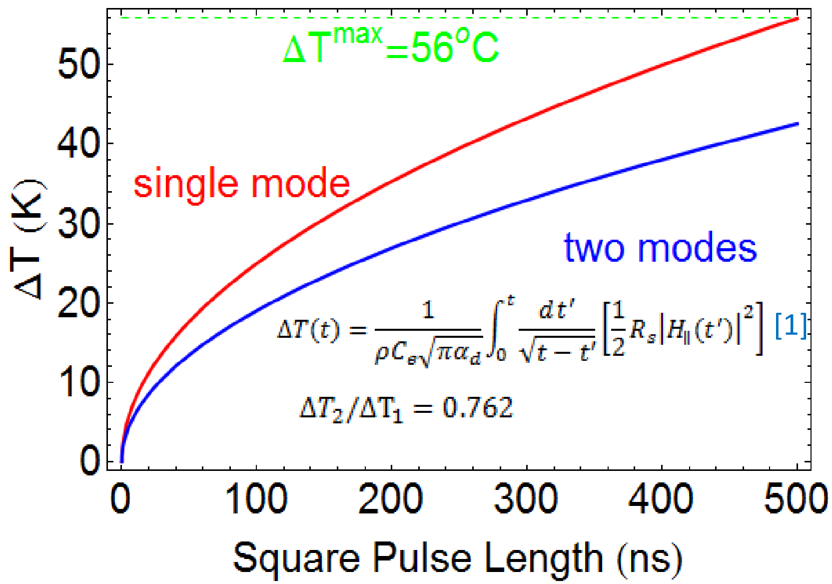
TM010 + TM011





II.III - Pulsed Surface Heating Reduction





Single mode and two mode superposition

$$\tilde{E}=(1-\alpha)\tilde{E}_1+\alpha\tilde{E}_2$$

$$\tilde{E}_{max}=\tilde{E}_{1,max}\left[(1-\alpha)+\alpha\tilde{E}_{2,max}/\tilde{E}_{1,max}\right]$$

$$\langle\tilde{H}^2\rangle=\langle\tilde{H}_1^2\rangle\left[(1-\alpha)^2+\alpha^2\langle\tilde{H}_2^2\rangle/\langle\tilde{H}_1^2\rangle\right]$$

normalized at the same acceleration gradient 100 MV/m

The preliminary design shows it can lower the pulse heating by about 20% at the cost of increasing maximum electric field by 20%, and satisfy the constraint:

(1) surface electric field $Max(E_{surf})<260$ MV/m
(2) pulsed surface heating $\Delta T^{max}<56^oC$

Optimisation Goals:

(1) minimize the ratio of peak magnetic fields and the ratio of peak electric fields
(2) maximize the ratio of shunt impedances between the second mode to the first one
and balanced with design goal for both harmonics
(3) minimize peak magnetic field and peak electric field
(4) maximize the shunt impedance

[1] Details in “RF Pulsed Surface Heating”, David Pritzkau - Thesis, ARDB271 (2001)

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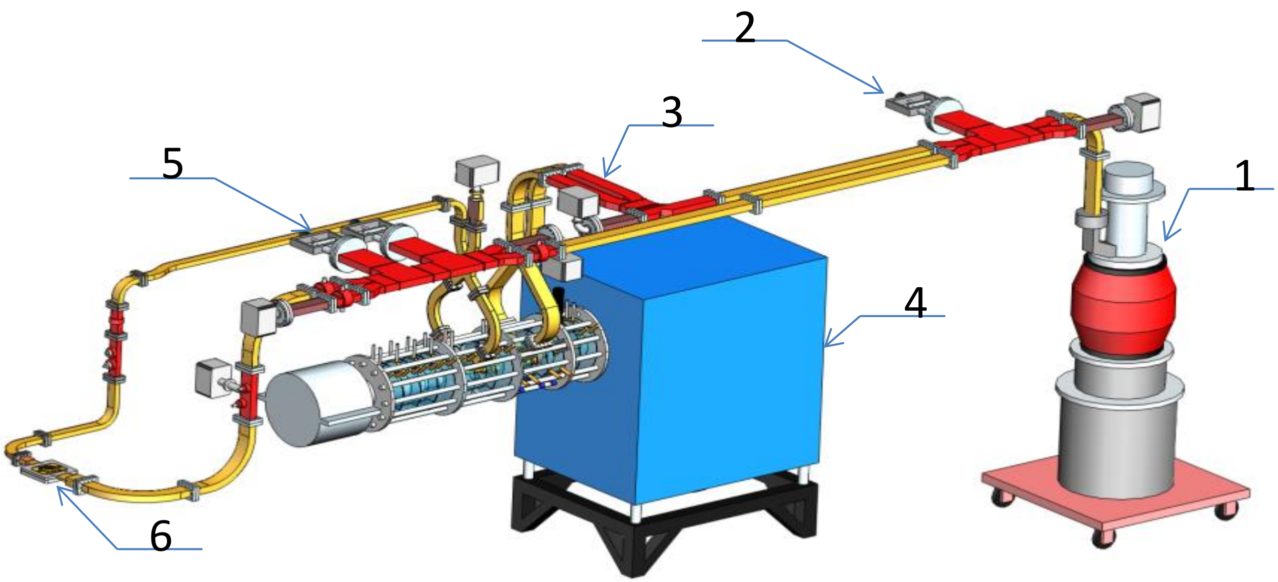
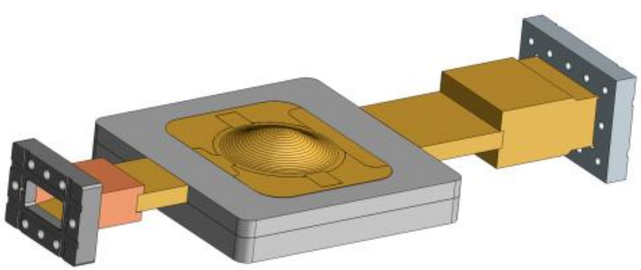
II.IV - Dual-Frequency RF Source at Yale University

- Power splitting into each frequency component with adjustable amplitude and phase
- Two sources automatically phase-locked
- No new modulator or C-band driver needed.

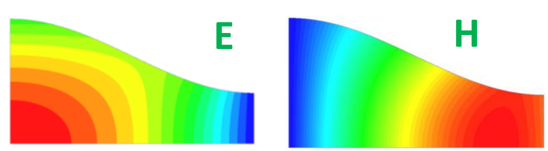


Layout of dual-frequency RF source, shown feeding a bimodal test cavity.
1 – S-band klystron;
2 – variable power splitter;
3 – 3-dB hybrid splitter;
4 – 250-kV gun tank;
5 – variable power splitter and phase shifter;
6 - bimodal test cavity.

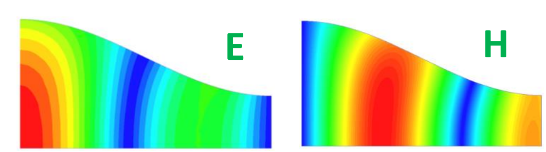
Test of anode-cathode effect: Demountable Bimodal Cavity



TM_{010} 2.856 GHz



TM_{020} 5.712 GHz



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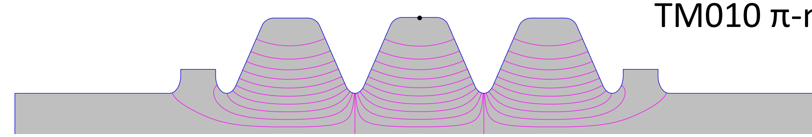
III. Multi Harmonic Accelerator Structure

Beam driven accelerating cavity

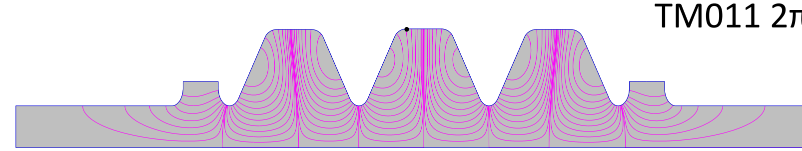
- Cavity parameters and HOM’s
- Longitudinal and Transverse Wakefield
- Ongoing simulations on Transformer Ratio and Pulsed Surface heating.

III.I - Beam driven multi-harmonic structure

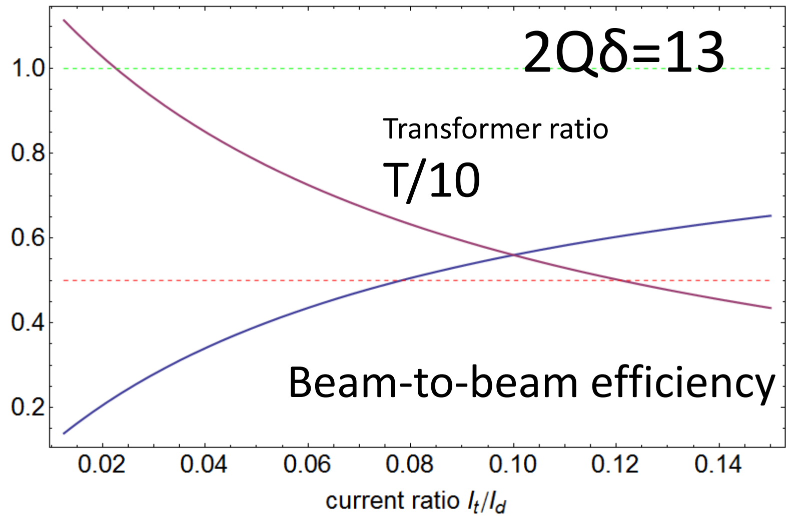
- The drive frequency is 11.9942 GHz
- Detuning angle is 85.58 degree, $2Q\delta=12.9$
- The chokes at either end of the structure
- Each mode normalised to 100MV/m



TM010 π-mode



TM011 2π-mode



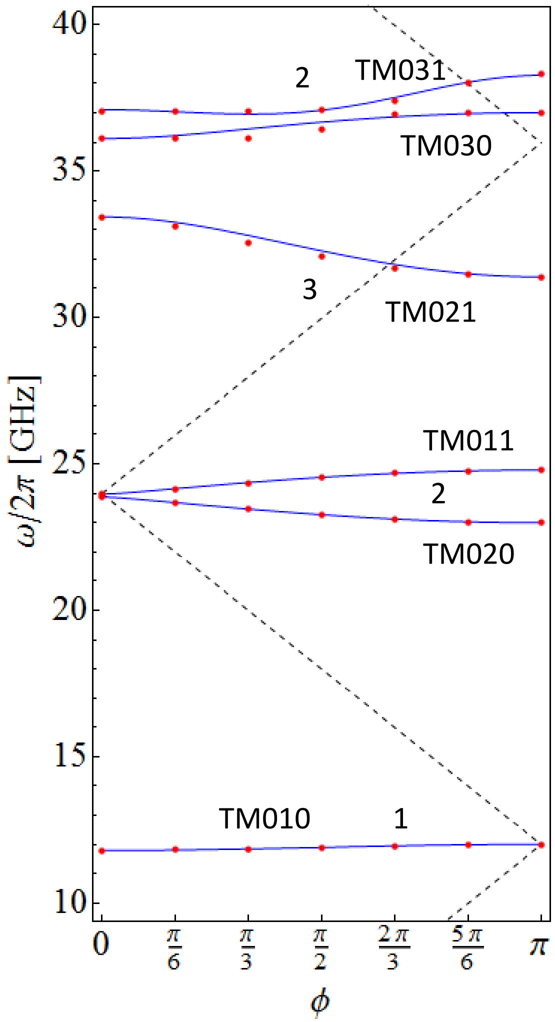
	Fundamental TM010	Second Harmonic TM011	Unit
Frequency	12003	24003	MHz
Transit-time factor	0.77	0.78	
Power dissipation	818	2257	kW
Q	8827	10328	
Shunt impedance	64.3	22.5	MOhm/m
r/Q	53.9	16.7	Ohm
Maximum H	364283	681209	A/m
Maximum E	207.4	351.4	MV/m

Single cell rf parameters.

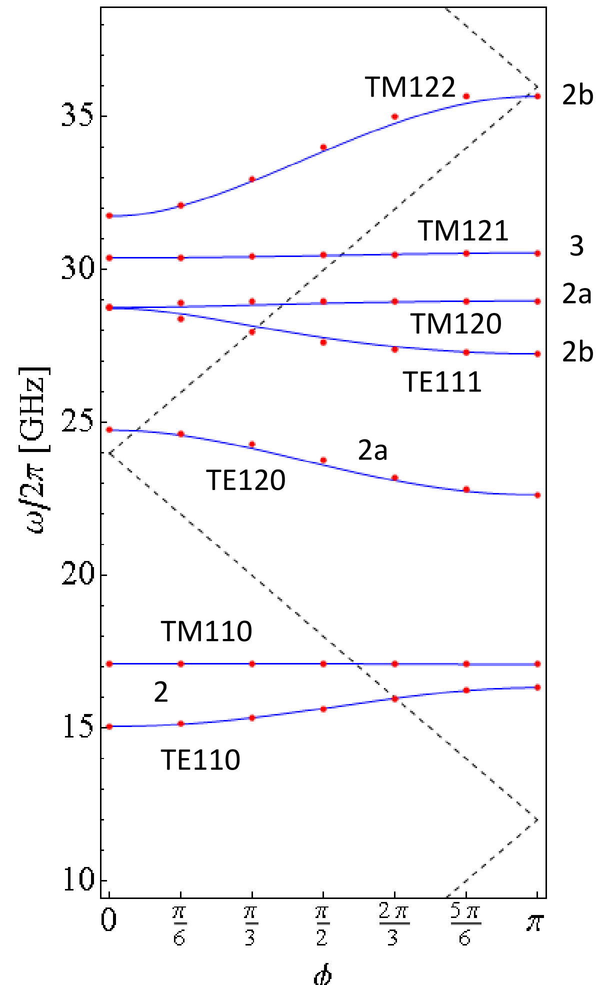
- With $a/\lambda=0.15$, the drive current needs to be 17 A to have 100 MV/m acceleration gradient with drive bunch length of 0.5 mm , or 25 A to have 150 MV/m. *New TBA paradigm?*
- Third harmonic can also be excited for pulsed surface heating reduction. See Y.Jiang MEVARC talk ‘Multi-harmonic accelerating cavities for rf breakdown studies’ (2013)

III.II - Dispersion Curves

Monopole Mode



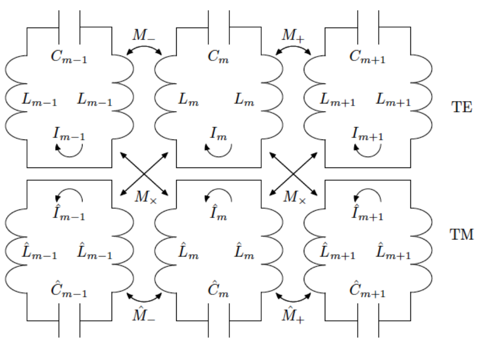
Dipole Mode



1 = Nearest neighbour coupling

2= Mode coupling

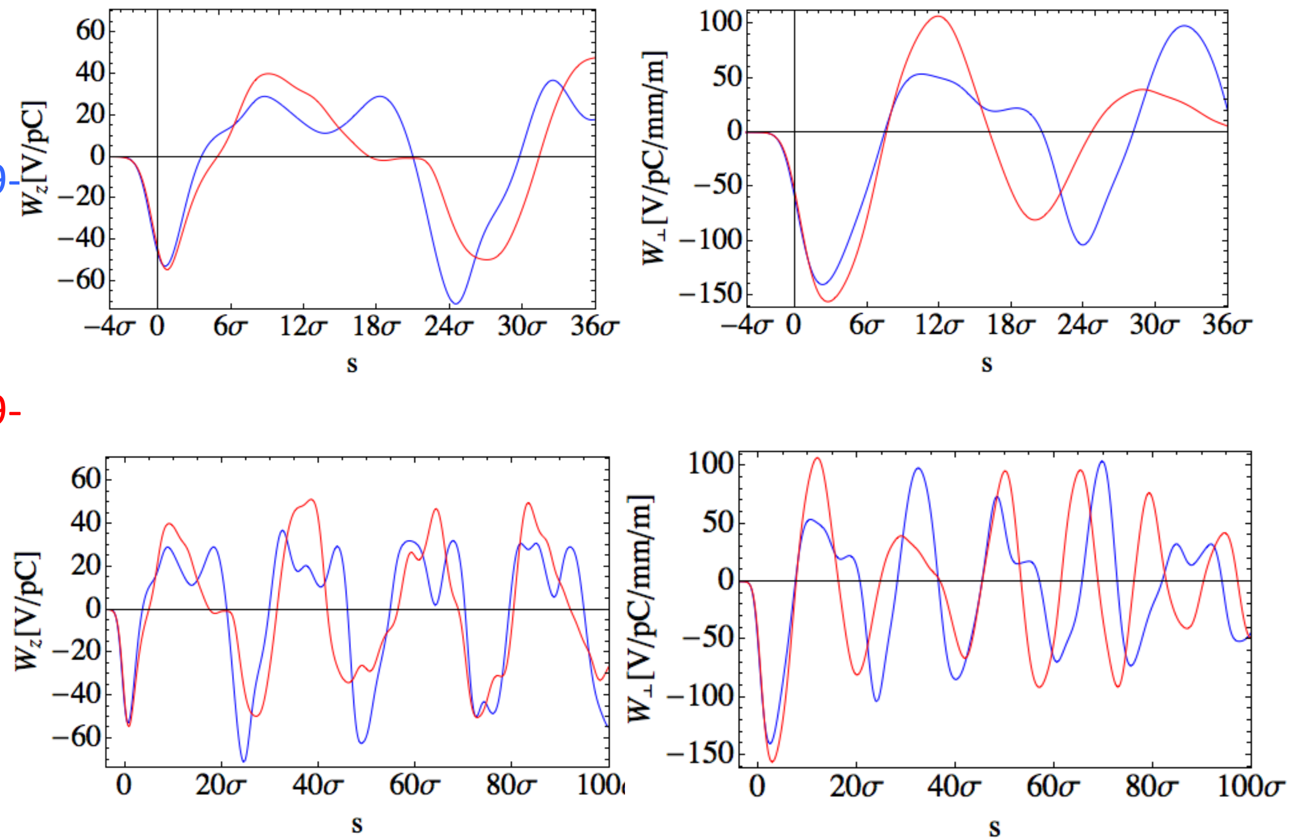
3= Next nearest neighbour coupling



- Red points are single cell simulation results, blue curves are circuit model prediction. The dashed line is the light line.
- The indices give the type of coupling used for best fit.

III.III - Wakefields

Longitudinal | Transverse

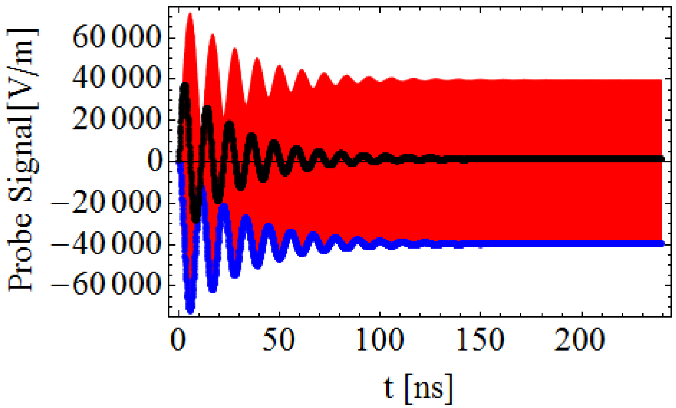


- σ_z=1mm, Q=1pC
- GdfidL simulation for 9-cell multi-harmonic structure.
- GdfidL simulation for 9-cell pillbox of same length and fundamental frequency.

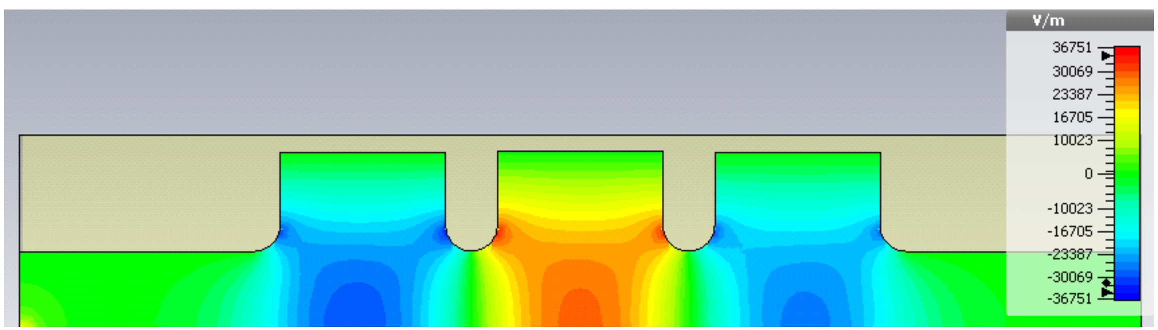
- Wakefield for test bunch with 10% charge of drive bunch will be extremely high due to bunch spacing of 0.25 RF Cycles.
- **The transverse wakefield due to drive bunch is a significant issue which merits further study.**

III.IV - Ongoing Study: Time Domain Simulations

- Time domain simulations using PIC solver in CST and (soon to be) ACE3P.
- Excite multi-harmonic structure with both long bunches (fundamental mode only) and short bunches (multi-harmonic excitation).



- Black points drive bunches, blue points test bunches. Also allows detuning angle to be measured.
- Bunch spacing can be varied to see Transformer Ratio behaviour.



- Peak gradient can be scaled to 100MV/m, allowing for surface heating comparison between single and multi-mode

Medium term plan: Fundamental physics on rf breakdown and pulsed surface heating.
Long term plan: New accelerator design.

IV. Conclusions

•Dual-harmonic operation of acceleration cavities may allow suppression of RF breakdown and possible increase in acceleration gradient.

(1) TM010+TM020, exhibits anode-cathode effect that could increase acceleration gradient without raising the surface cathode field.

(2) TM010+TM011, exhibits smaller surface pulsed heating than TM010 alone.

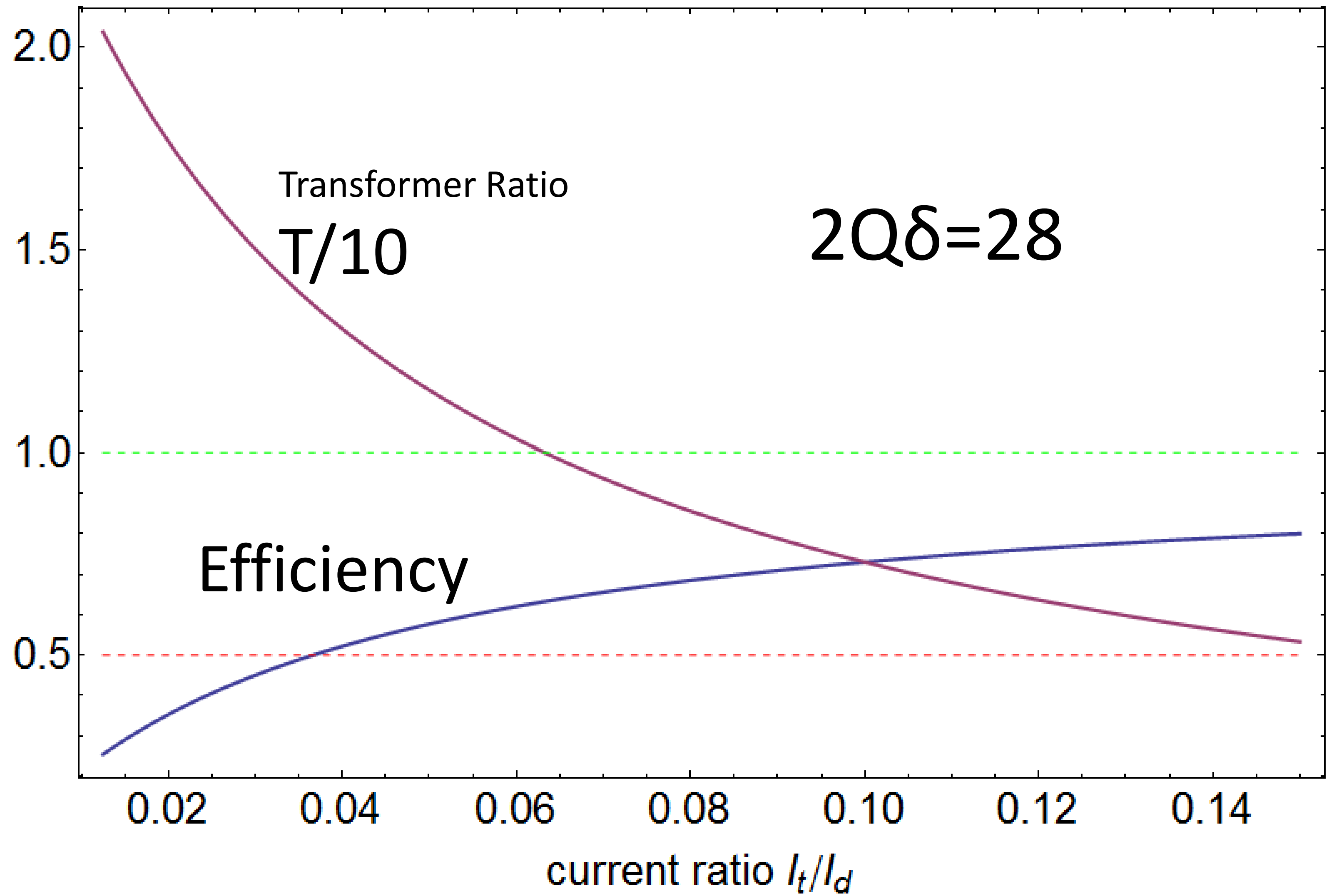
•Detuned single-mode collinear structure shows high transformer ratio, and high beam-to-beam efficiency. Detuned bimodal cavity two-beam structure could have the same virtues with the additional benefit of reduced surface pulsed heating.

•Lower drive beam current (17A *vs* 100A) for 100 MV/m acceleration gradient could lead to a new paradigm for a collinear TBA.

•Time domain and wakefield studies are underway to determine effect of HOM's and bunch spacing on the transformer ratio.

•Optimisation software currently being created in order to design a structure with the greatest benefit.

backup


Transformer Ratio
T/10
2Qδ=28
Efficiency
2.0
1.5
1.0
0.5
0.02
0.04
0.06
0.08
0.10
0.12
0.14
current ratio I_t/I_d