Traveling-wave buncher for the CLIC drive beam injector

CLIC Workshop 2015

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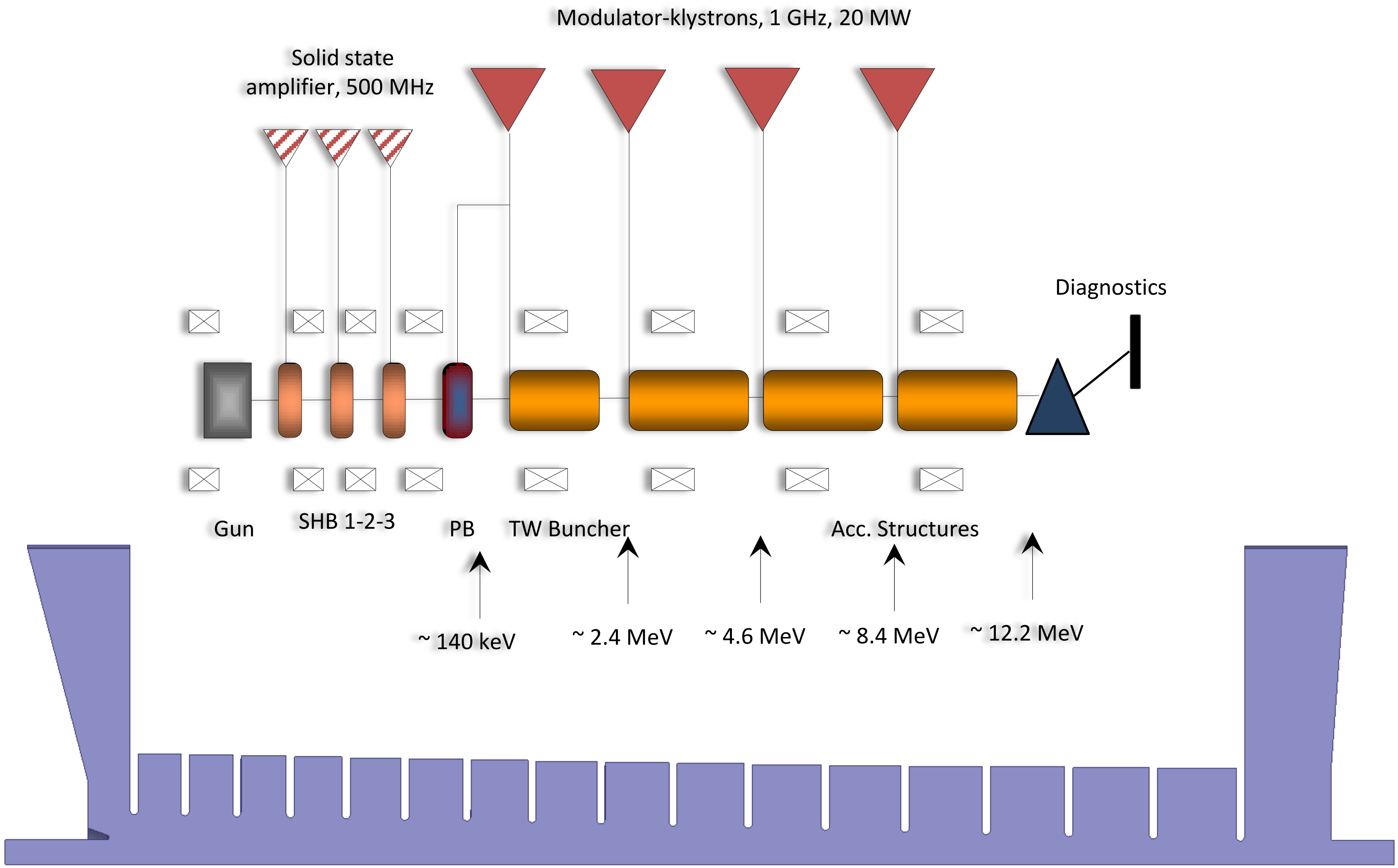
Drive Beam Front-End layout



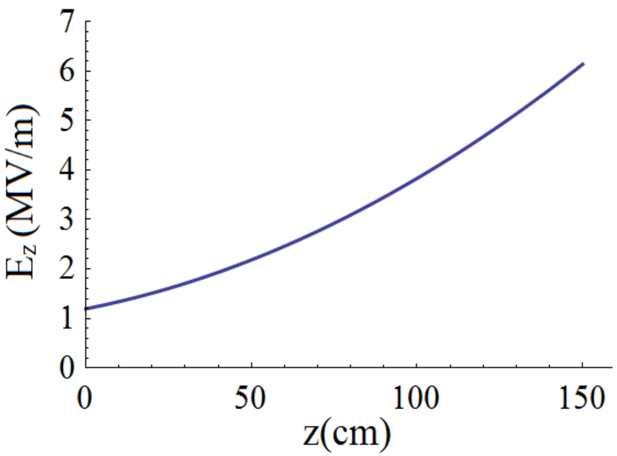
Ideas behind the TW buncher design

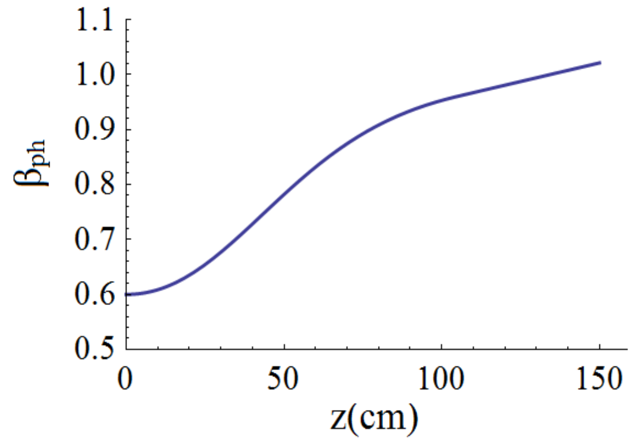
- A buncher bunches and accelerates the bunches simultaneously.
- A buncher behaves like a damping oscillator then for a good bunching:
  - Bunches should enter close to zero crossing and the phase should increase smoothly toward crest along the buncher.
  - Electric field at the beginning should be comparatively low to avoid kicking out particles and should increase smoothly along the buncher.
- In most design cases, when beam loss is not so critical, the bunching mechanism is less paid attention and bunches travel near the crest but in our case we need a good bunching to reduce beam loss and satellite population.

Interesting subjects compared to contemporary bunching systems:

- Critical bunching optimization to reduce satellite population and beam loss.
- Reactive beam loading effect due to off-crest traveling and high current (5A) beam.
- Interesting HOM's effects study due to non-relativistic/relativistic beam and tapering structure.

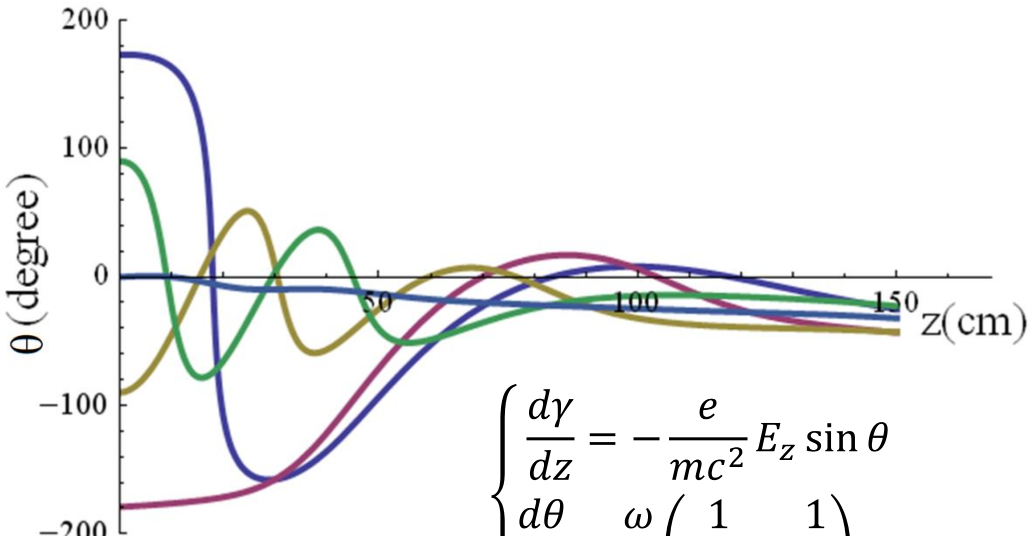
Optimization procedure - I





Different axial electric fields and bunch phases are tested by particle tracking to:

- Minimise the bunch length
- Minimize the energy spread



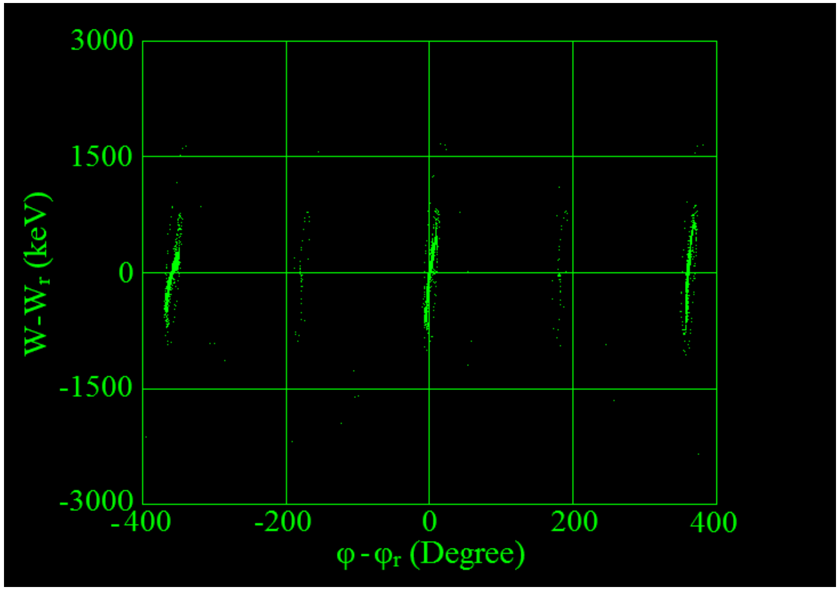
$$\begin{cases} E_z(z) = E_0 + E_1 z + E_2 z^2 \\ \theta_s(z) = \theta_1 z \\ \dfrac{d}{dz}\dfrac{1}{\sqrt{1-\beta_{ph}^2}} = -\dfrac{e}{mc^2} E_z(z) \sin\theta_s(z) \end{cases}$$

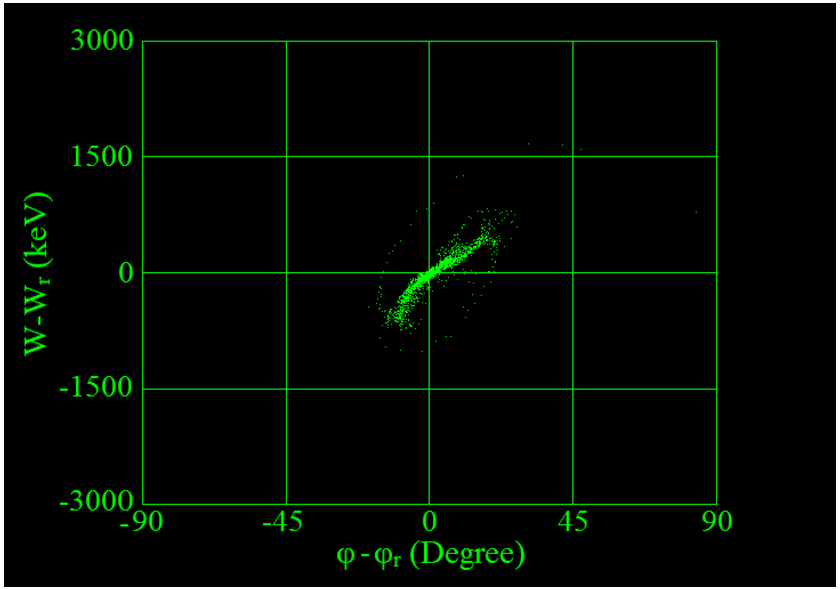
$$\begin{cases} \dfrac{d\gamma}{dz} = -\dfrac{e}{mc^2} E_z \sin\theta \\ \dfrac{d\theta}{dz} = \dfrac{\omega}{c}\left(\dfrac{1}{\beta_{ph}} - \dfrac{1}{\beta}\right) \end{cases}$$

Done by Shahin

Optimization procedure - II

Parameter	Value
$\sigma_L(mm)$	7.23
$\sigma_W(MeV)$	0.317
$W_{av}(MeV)$	2.38
Satellite(%)	2.8





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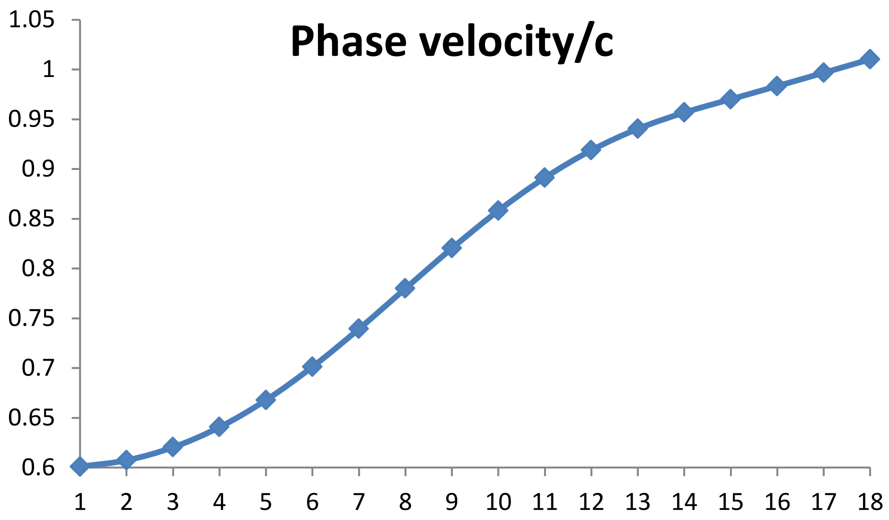
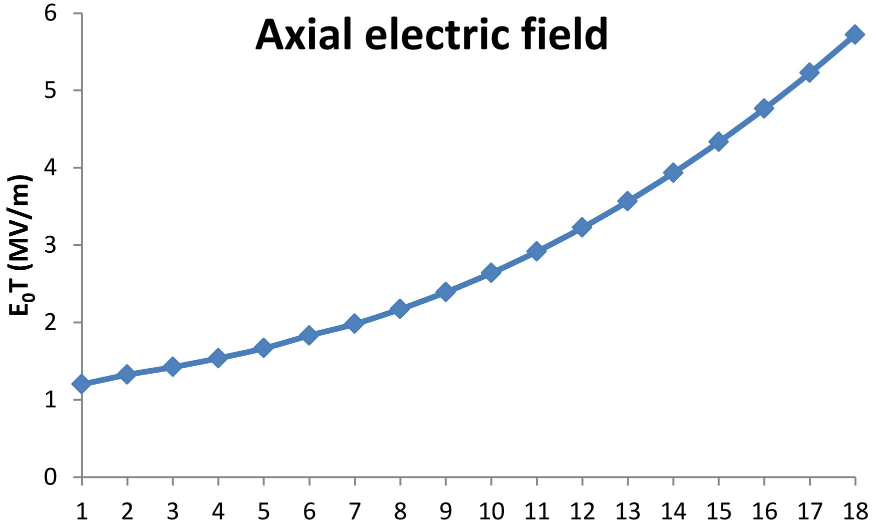
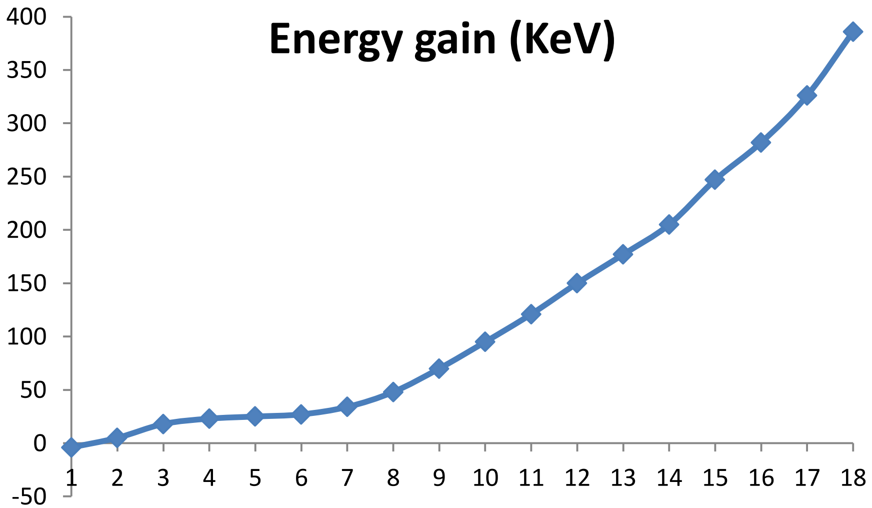
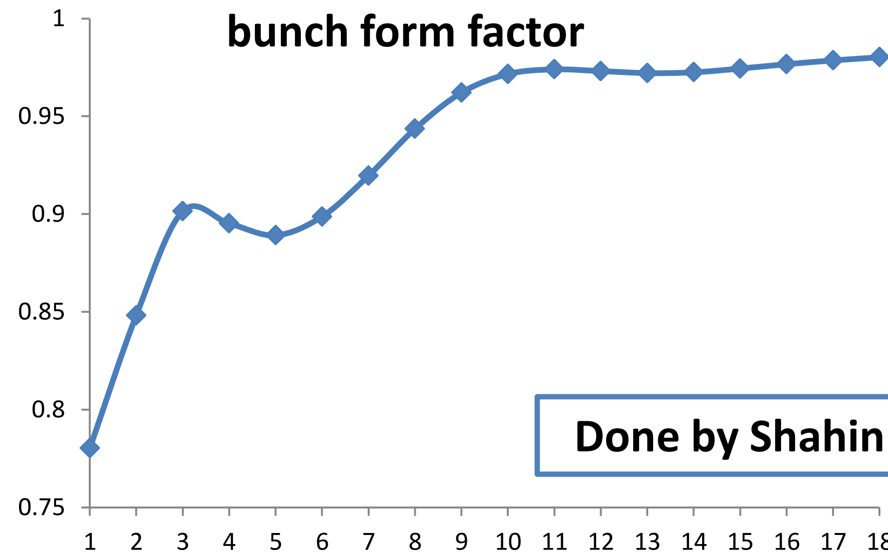
Optimization procedure - III









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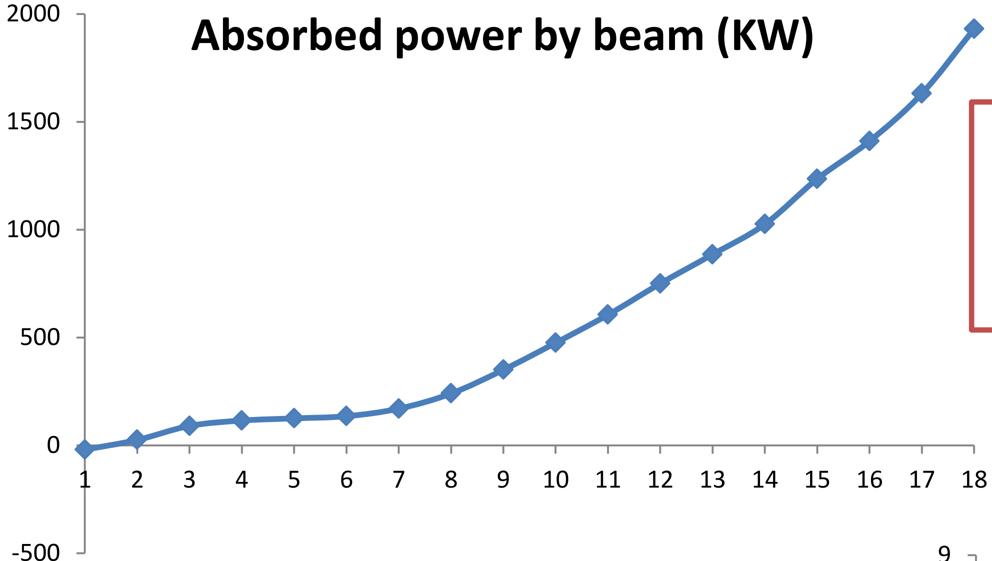
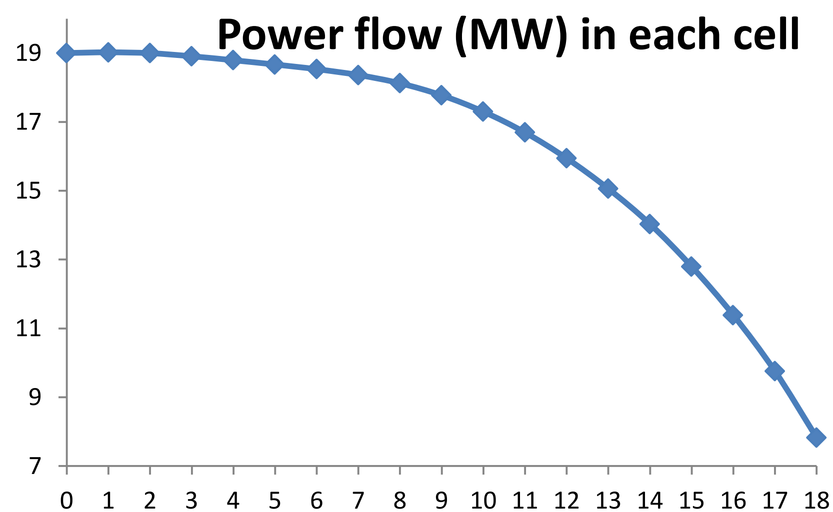
Normalized electric field

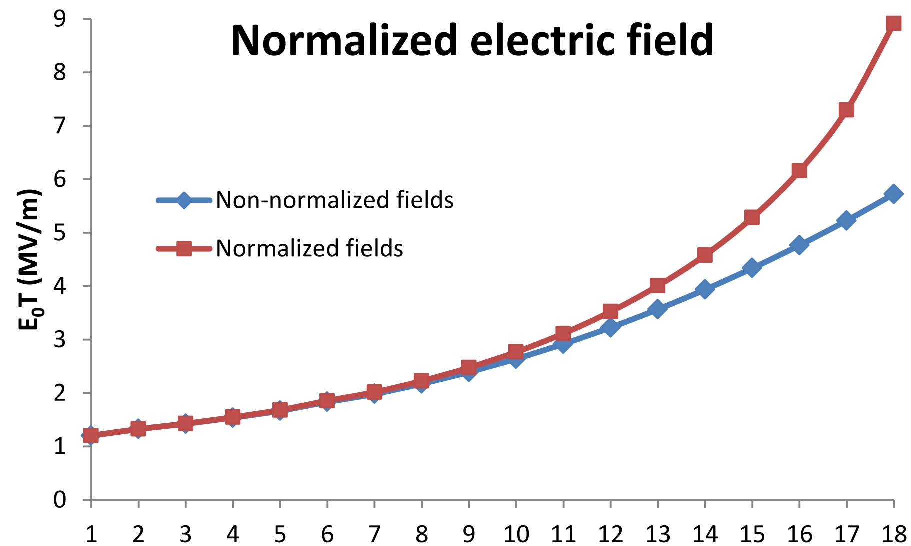


Power absorbed= Energy gain * I

Normalized field= $\sqrt{\frac{P_0}{P}} \times$ Non-normalized field.

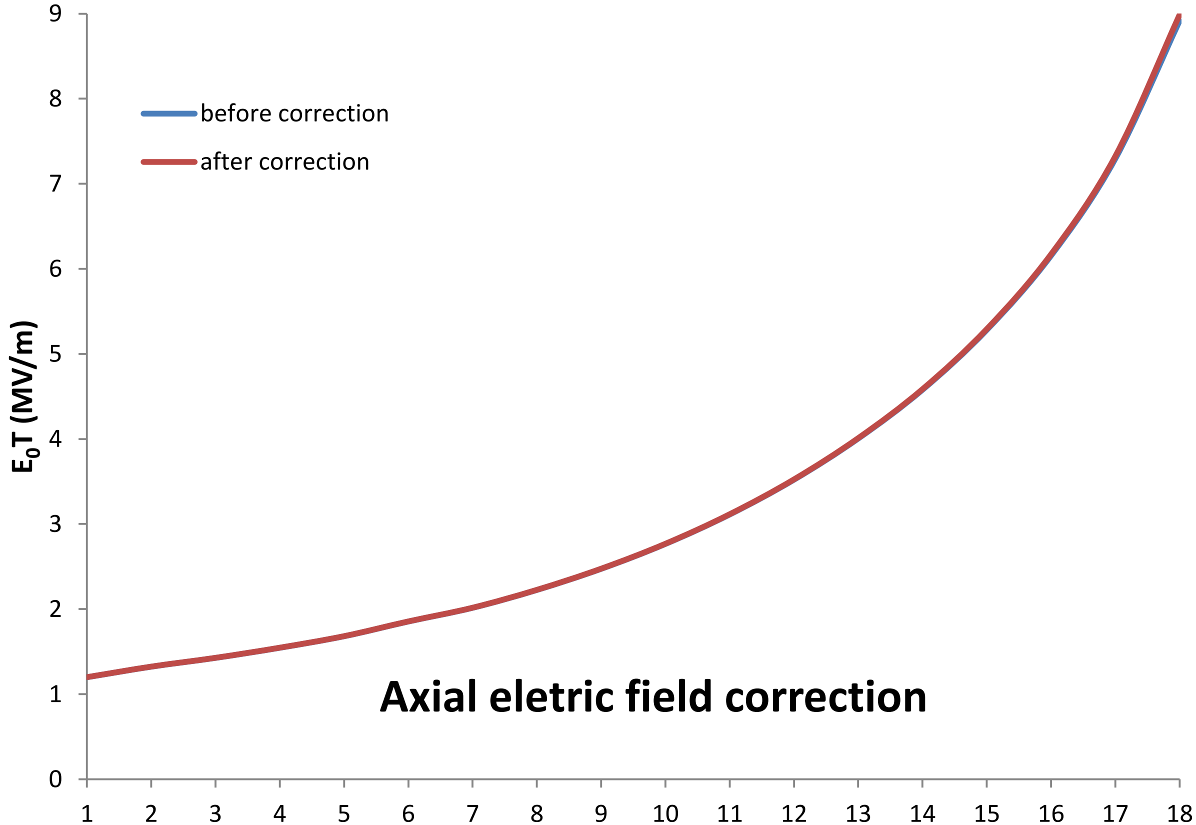
P_0=19MW. I= 5A





Electric field correction based on the attenuation

$$\begin{cases} \dfrac{dP}{P} = -2\alpha dz \\ \alpha = \dfrac{\omega}{2Q_0 v_g} \end{cases}$$

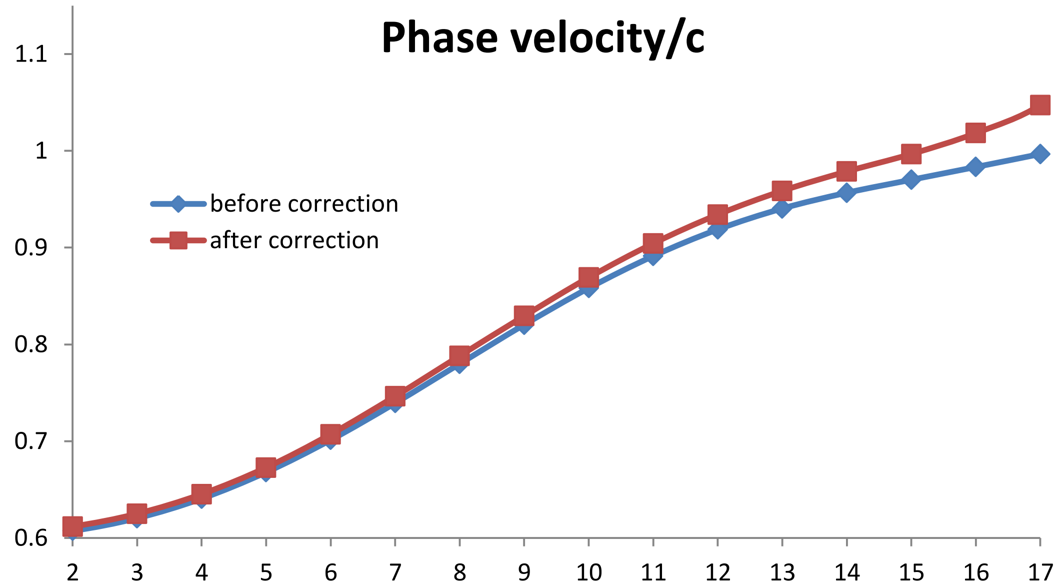


Total power loss on the surface is about 0.7 MW (≈ 3.8%). Absorbed power by the beam is about 11.2 MW (≈ 59 %).

Phase velocity correction based on the fundamental mode reactive beam loading

A correction is required based on the reactive beam loading of the fundamental mode. This effect is emerged because of the off-crest bunch traveling*.

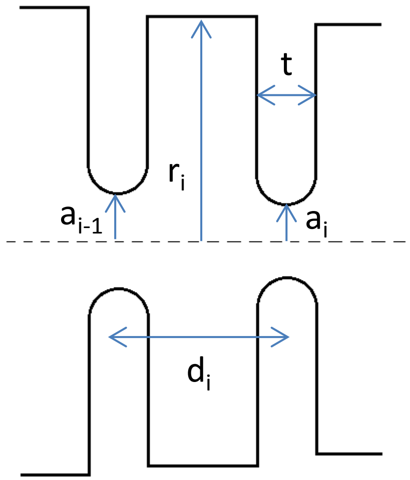
$$\begin{cases} \dfrac{\frac{1}{v_e}-\frac{1}{v_p}}{\frac{1}{v_g}-\frac{1}{v_e}} = -\dfrac{1}{2\pi}\dfrac{E_{b0}\sin(\varphi_b)}{E_g} \\ E_{b0} = -F\dfrac{\omega_0}{2}\dfrac{r}{Q_0}q \approx -\pi F\dfrac{r}{Q_0}I \end{cases}$$



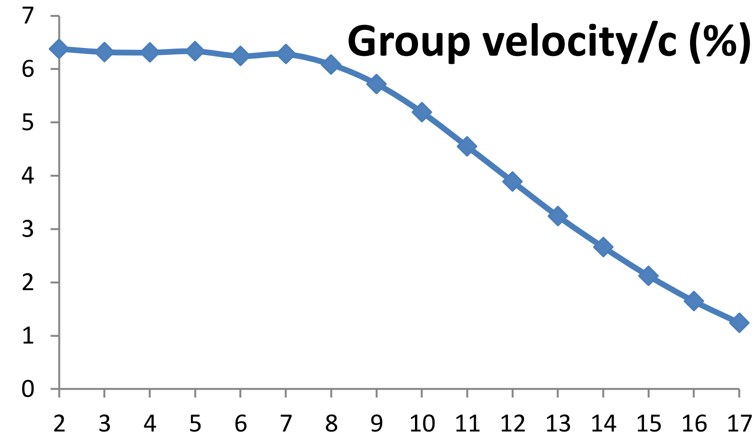
The amount of required detuning for a traveling wave structure is equal to a standing wave case done by P. B. Wilson with this assumption that the beam excites the mode that its phase velocity is equal to the beam velocity.

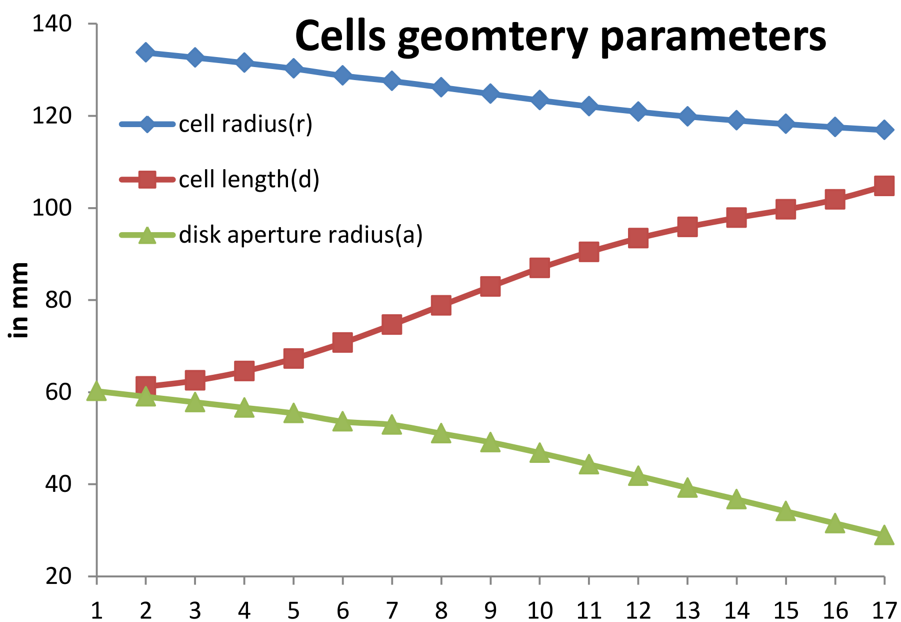
* General Beam Loading Compensation in a Traveling Wave Structure", H. Shaker et al., IPAC13

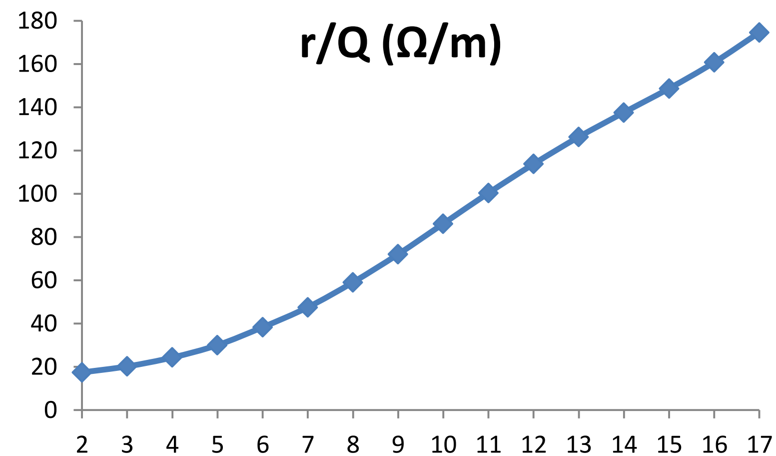
Cells design



$$d = \frac{v_p}{f} \times \frac{\varphi}{2\pi} = \frac{\beta_p c}{f} \times \frac{\varphi}{2\pi}$$

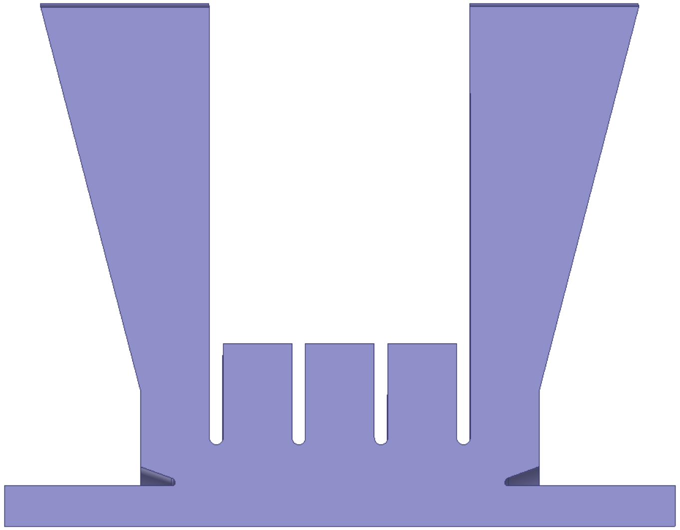






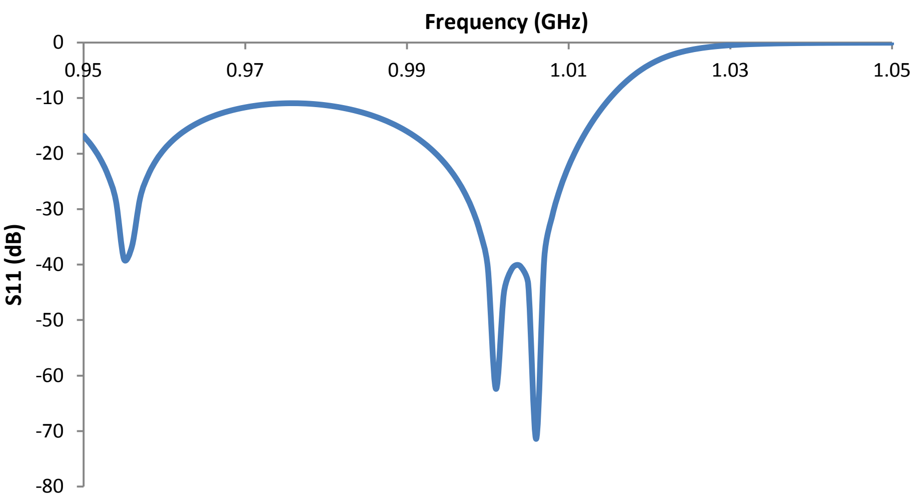
Power couplers- tuning method

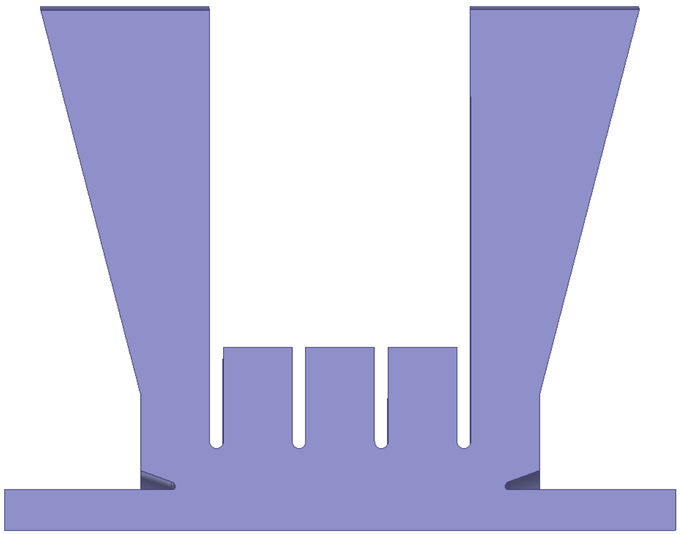
To connect the WR975 rectangular waveguide to the TW buncher we should design the power couplers. A tapered waveguide connected the WR975 waveguide to the coupler cell and a slot is opened to let the RF wave enters the coupler cell. Now, a proper slot size and the coupler cell radius should be found to match these two structures and to avoid any internal reflections.

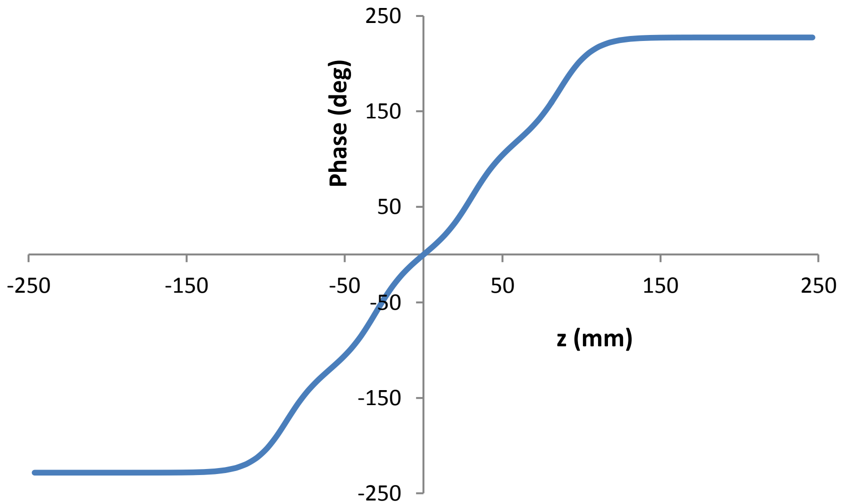


Three similar setups are used with different number for the intermediate cells (three, four and five).For each slot size and the coupler cell radius, these three setups are simulated to find the reflection (S11) of each dimension. The reason to use three setups is to avoid the low S11 due to partial cancelation of two reflecting waves from the input and output couplers. Then for each dimension, the maximum S11 between these three setups are taken. The best dimension is the one with the lowest S11.

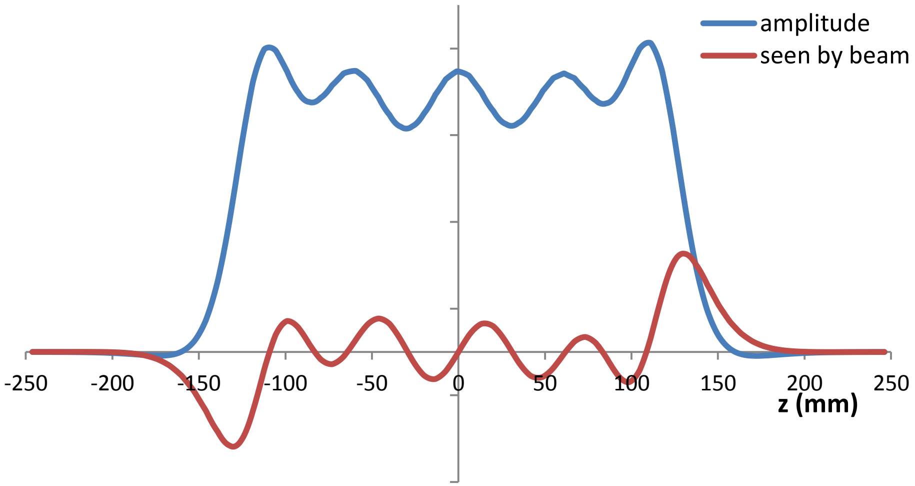
Input coupler





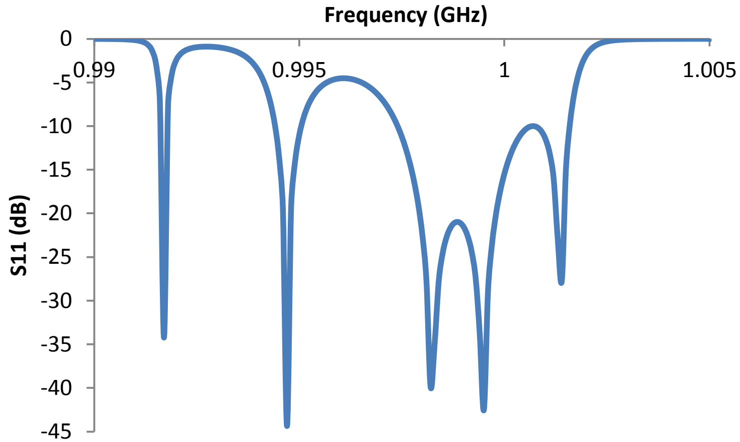


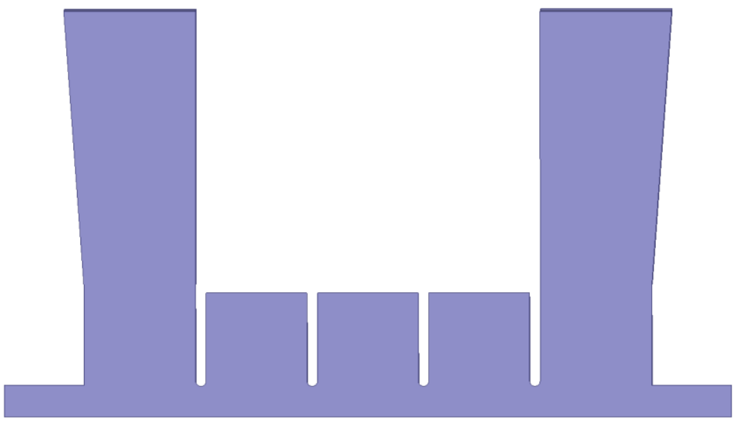
Axial electric field phase

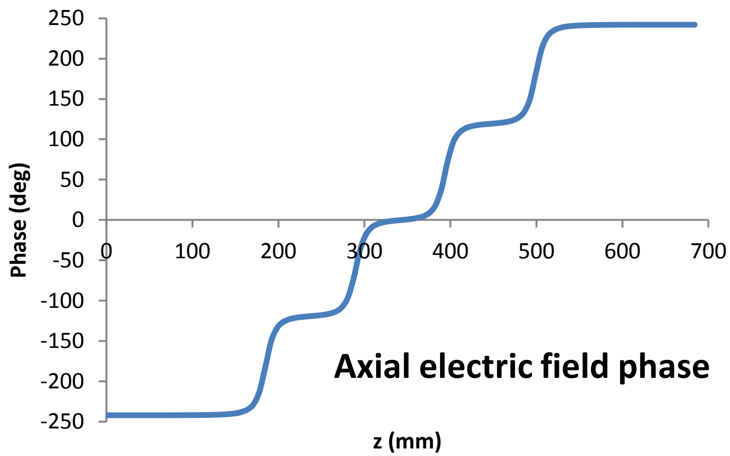


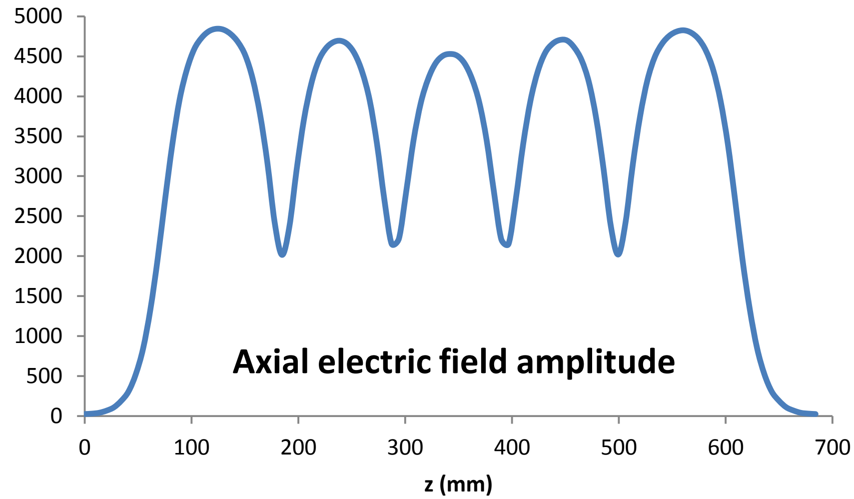
Axial electric field amplitude

Output coupler

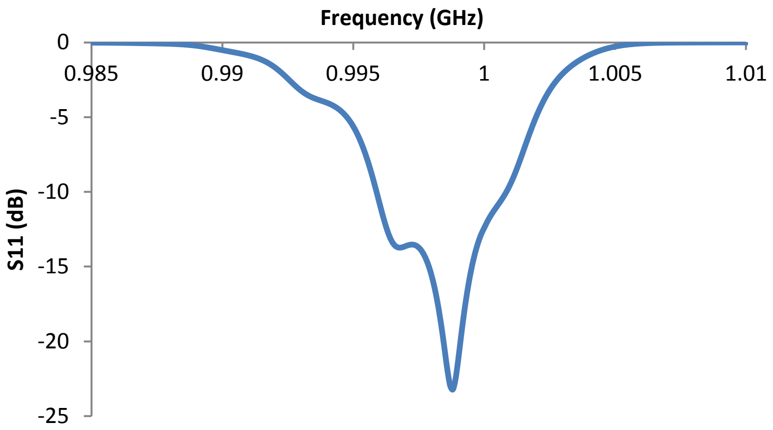


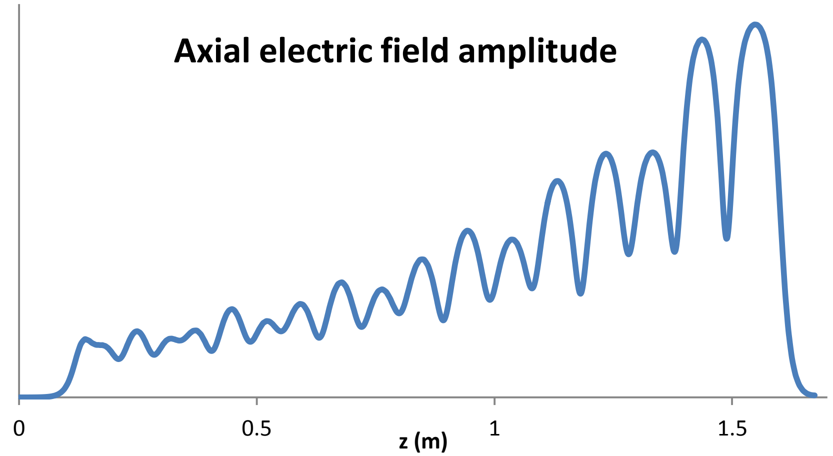


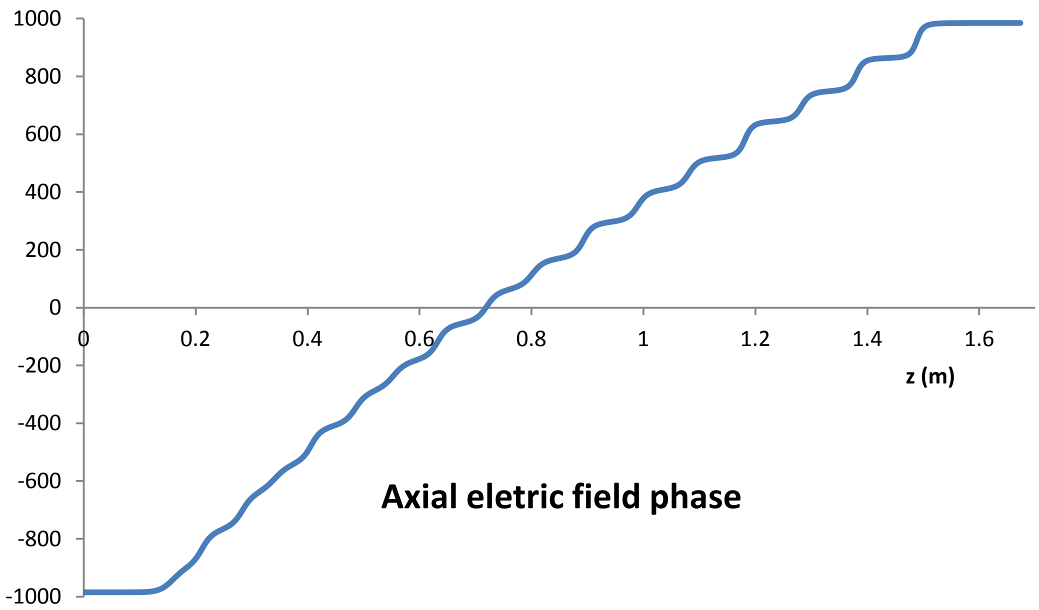




Full structure

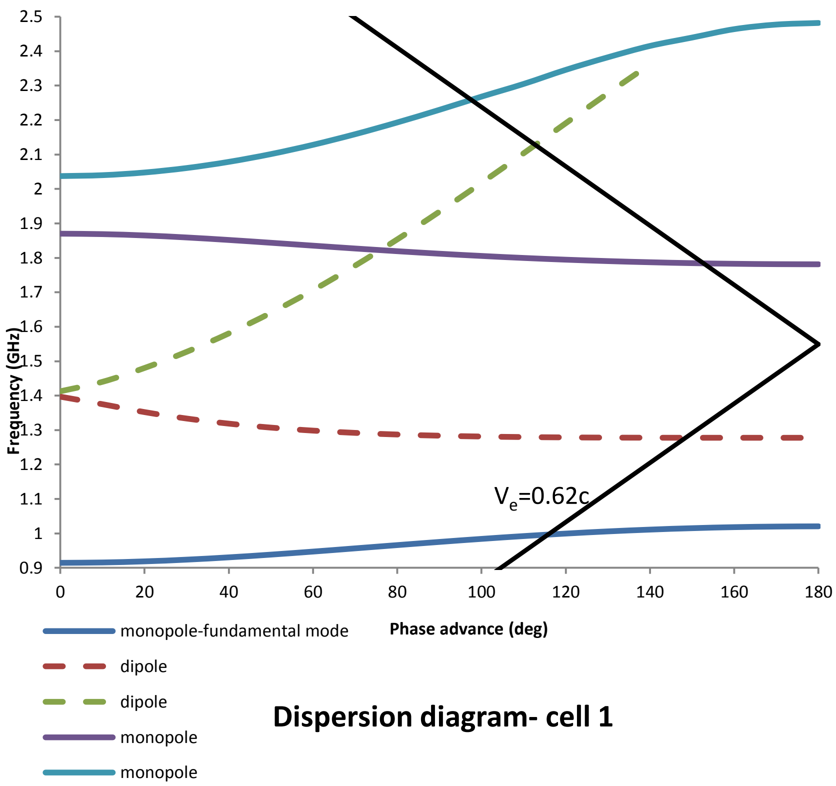




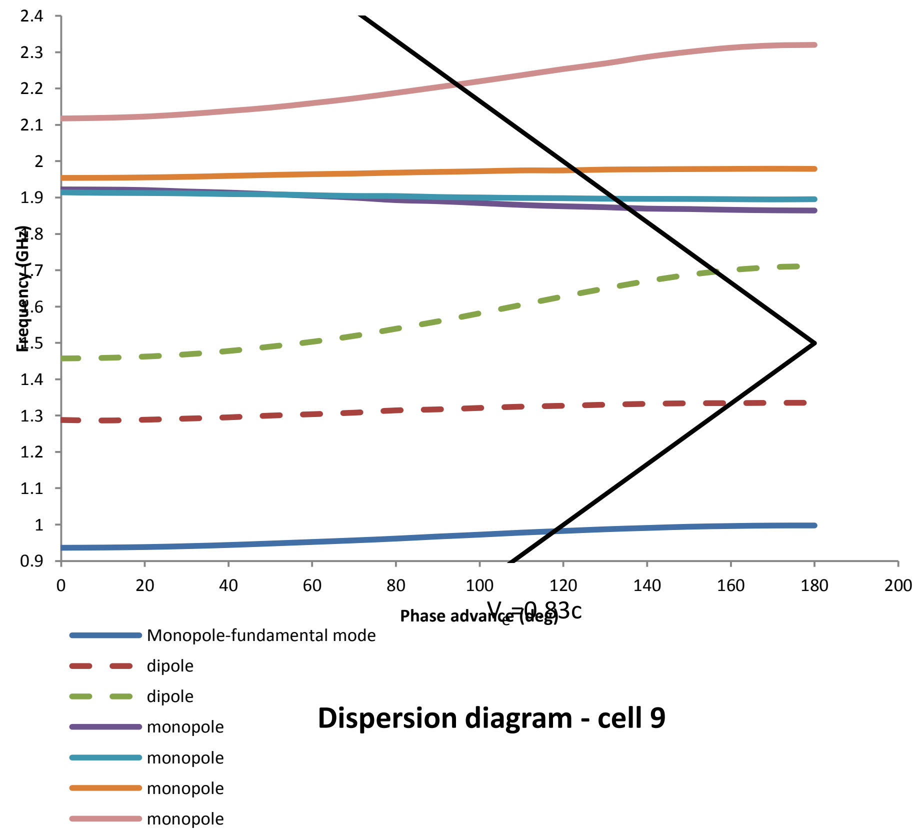


Because of tapering structure, some local reflection is unavoidable but the result could be better by retuning a few intermediate cells and re-matching the couplers. Another option is to remove the one or two last cells. It decreases the local reflection with a minor effect on the beam properties.

HOMs study - I



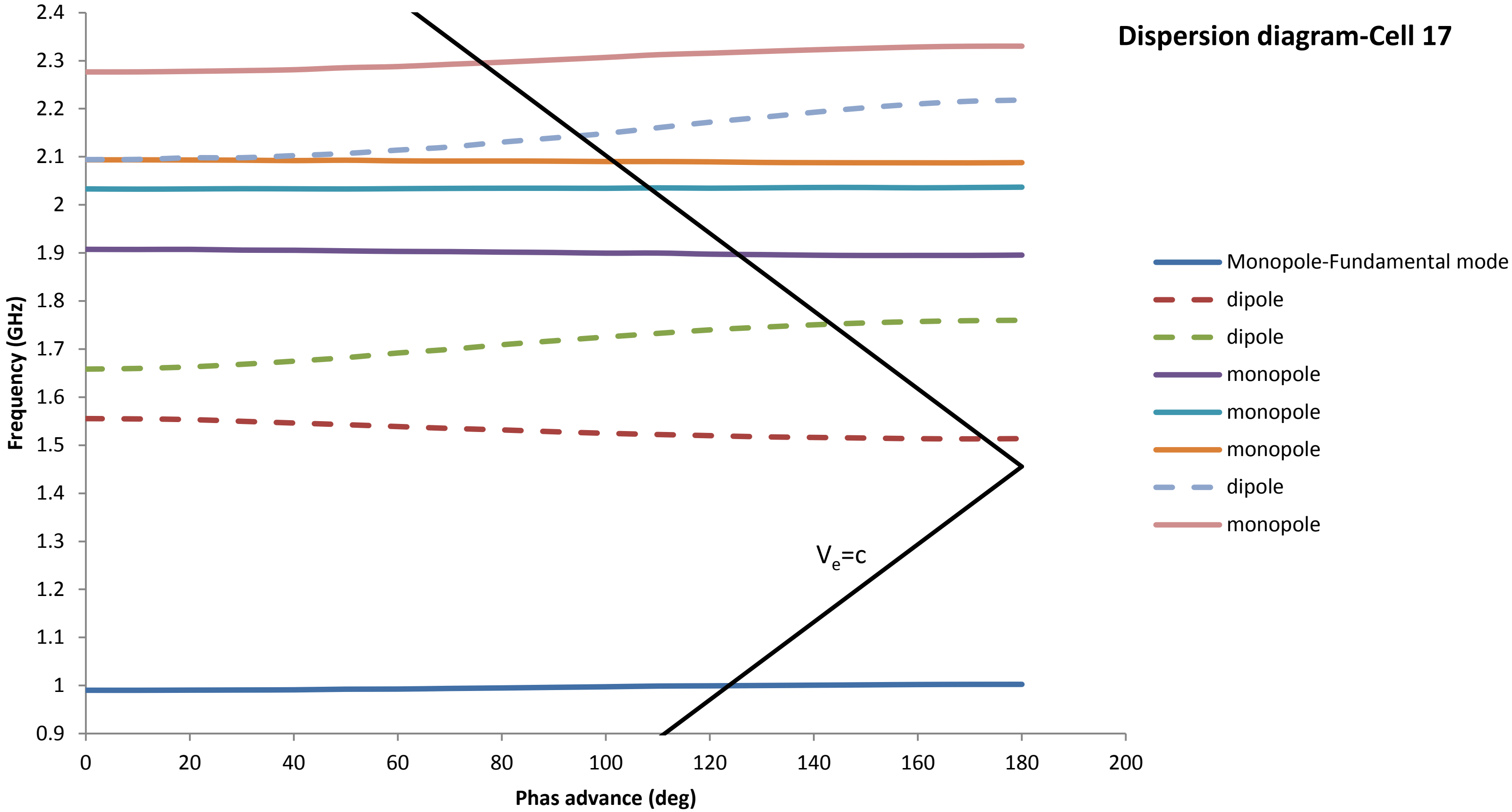
Dispersion diagram- cell 1



Dispersion diagram - cell 9

The beam excited mostly the modes that their phase velocity is equal to the beam velocity. These modes could be dangerous for the bunches if their frequency is close to 0.5 GHZ (beam frequency) or an integer multiplication of it. The structure is heavily tapered then there is natural detuning between modes excited in each cells.

HOMs study-II



The study is continued.

Thanks for your attention

First Sub Harmonic Buncher under fabrication