Microwave accelerating structures: an innovative parallel coupled electron LINAC

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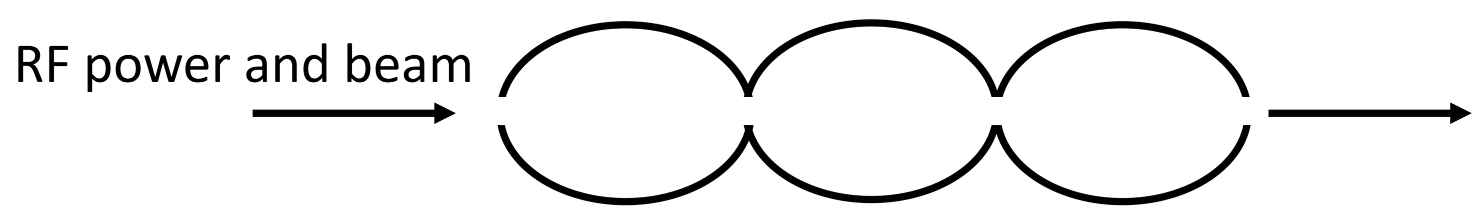
Motivation

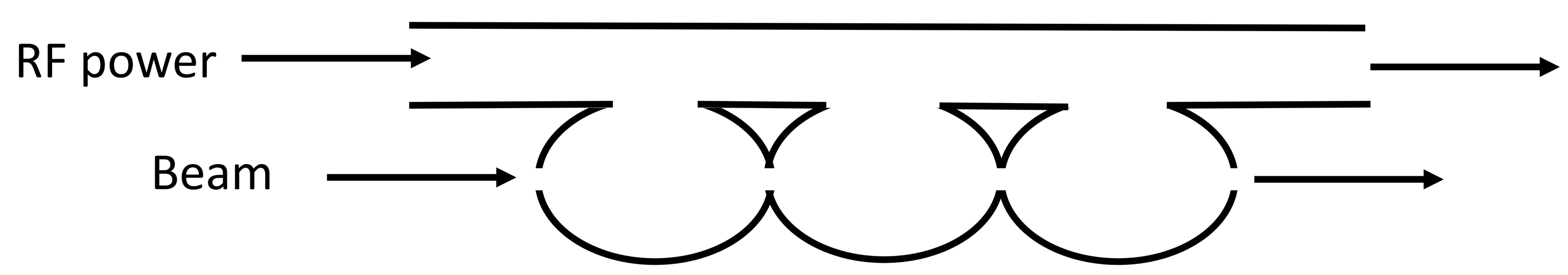
High gradient LINACs can considerably increase the energy gain per unit length in particle colliders or lead to more compact, table top, accelerator for industrial or medical application. The physics phenomena which limits the increase of the accelerating gradient is the RF breakdown.

In traditional on axis LINAC both beam and RF power propagate on the same trajectory. The RF power is coupled through serial way from cell to cell.



During a breakdown event the normal operation of the accelerating structures is compromised by the reflected RF power from the cell where the arc has occurred up to the klystron. A large fraction of the stored energy is involved in the process. This destructive event can lead to a permanent deformation of the coupling iris between two adjacent cells. The accelerating section is therefore detuned and the performance are degraded. Moreover, in on axis coupling configuration, leftovers of the arcs explosion have to be pumped out through many cells with a small aperture.

In parallel coupled accelerating structures RF power and beam propagation are located in two different axis.

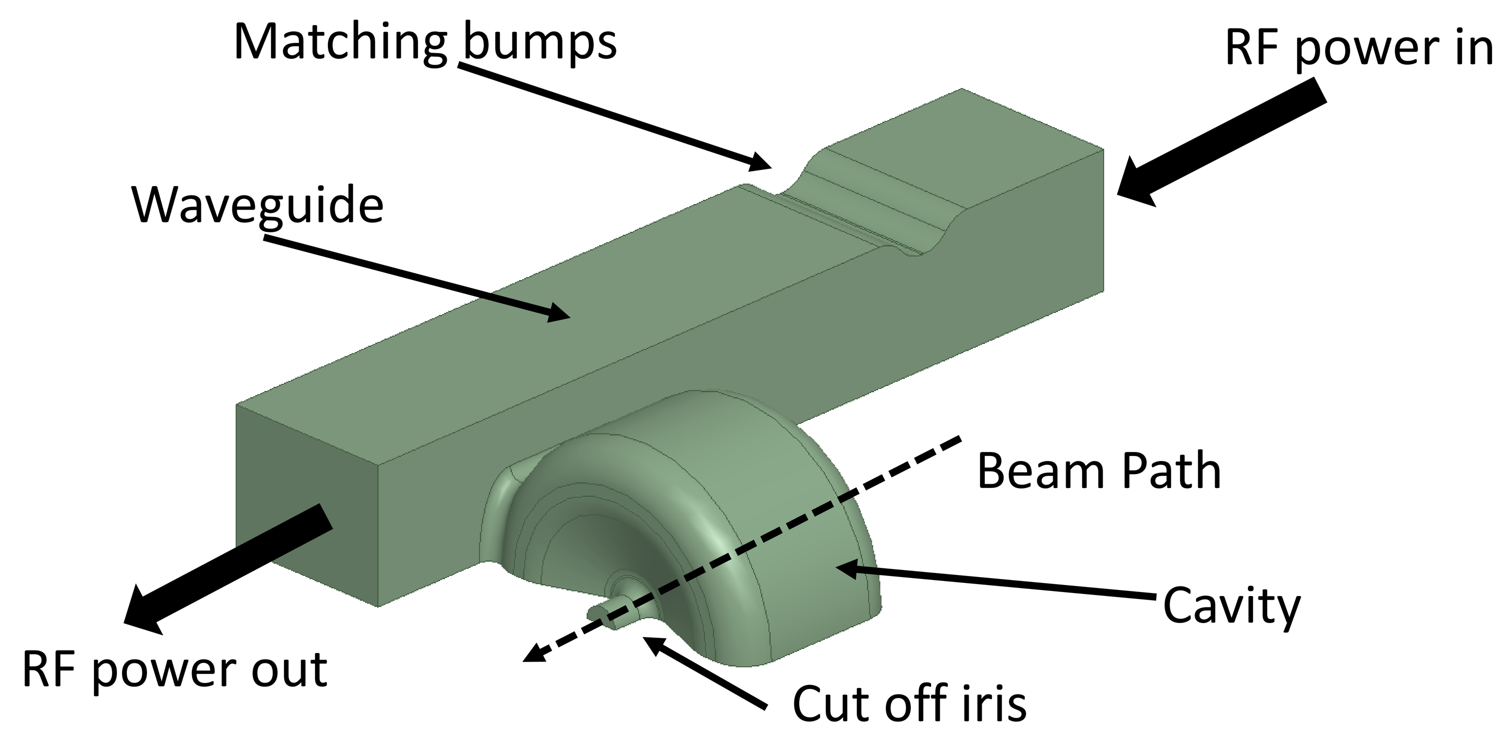


The decoupling of RF power and beam propagation axis leads to several advantages [1]:

- For each breakdown event only the energy stored in a single cell is involved,
- The arc damage is lesser due to the fewer energy involved,
- Only one cell per breakdown event is shorted: the normal operation is preserved and only a small fraction of the final energy is lost,
- Leftovers of arc explosions are pumped out through a large aperture.

Design of the Structure

The elementary cell is shown below. The main parts of the cell are the cavity for acceleration of the particles, the waveguide for the RF power propagation and the inductive matching bumps for mode stabilization.



The inductive matching bumps cancel the reflected wave. Therefore only the forward wave is present. In this regime the modes separation and the power flow is optimized [2].

For efficient acceleration three parameters should be optimized:

1) Resonant frequency of the accelerating cavity,
2) Phase advance per cell,
3) Group velocity of the RF pulse.

The three above quantities can be tuned by the cavity radius, the larger side of the waveguide and the coupling hole respectively.

For a rectangular waveguide the phase velocity and the larger side of its are related:

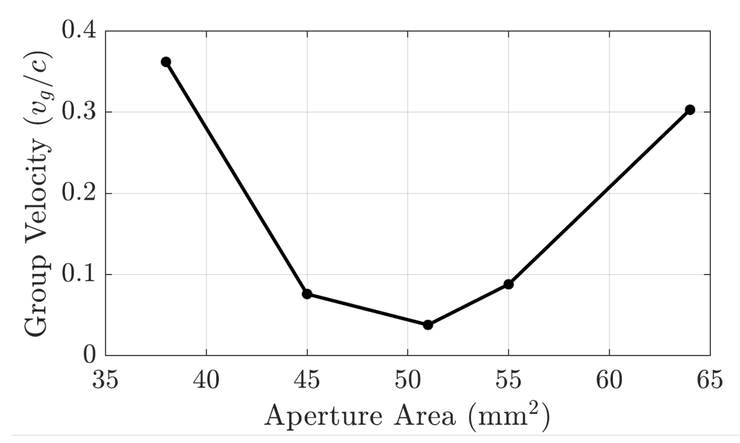
$$v_{ph} = \frac{c}{\sqrt{1-\left(\frac{2}{2af}\right)^2}}$$

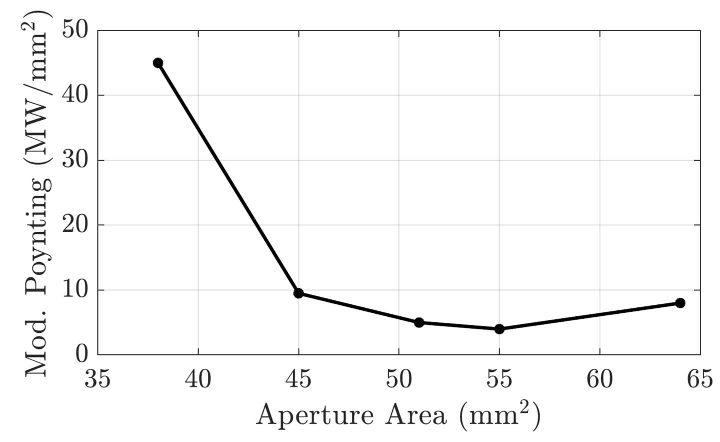
which can be used as guidance to tune the phase velocity of the structure.

The dependence of the group velocity versus the coupling hole has been studied by means of numerical results. The group velocity for periodic structure is given by the ratio of the power flowing and the stored energy per unit length inside the structure [3]:

$$v_g = \frac{P_{in}}{w}$$

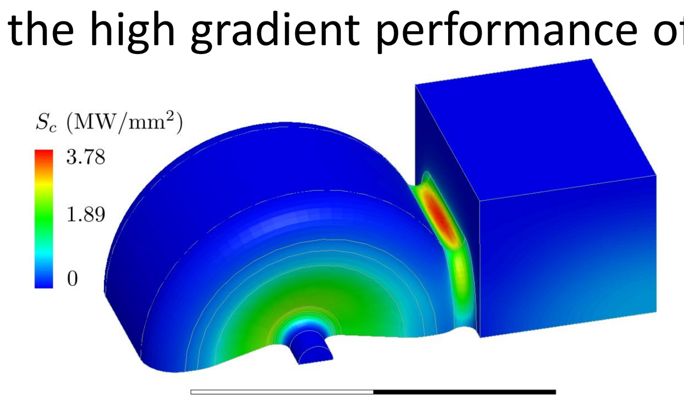
The coupling hole fillet is a region of high magnetic field due to the inductive power coupling between waveguide and cavity. Therefore a compromise between the high gradient performance and the required group velocity should be find.



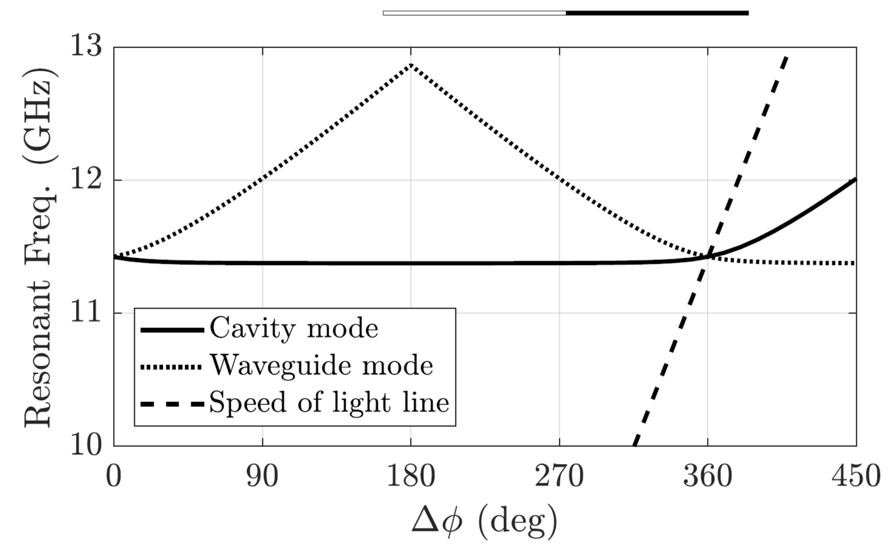


The modified Poynting vector (S_c), along with the maximum value of the electric and magnetic field, provides an estimation of the high gradient performance of the structure.

The chosen value for the coupling hole minimizes the modified Poynting vector (shown in the side figure) while keeps sufficiently low the group velocity.



The dispersion curve for this structure has the characteristic behavior of the accelerating structures stabilized by resonant coupling [2].



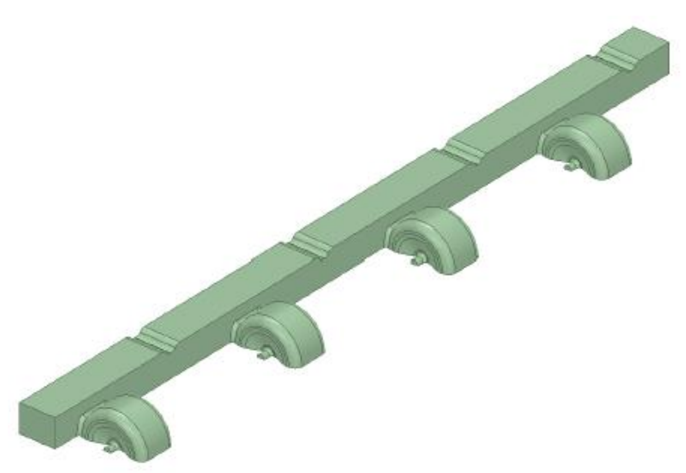
RF Parameters

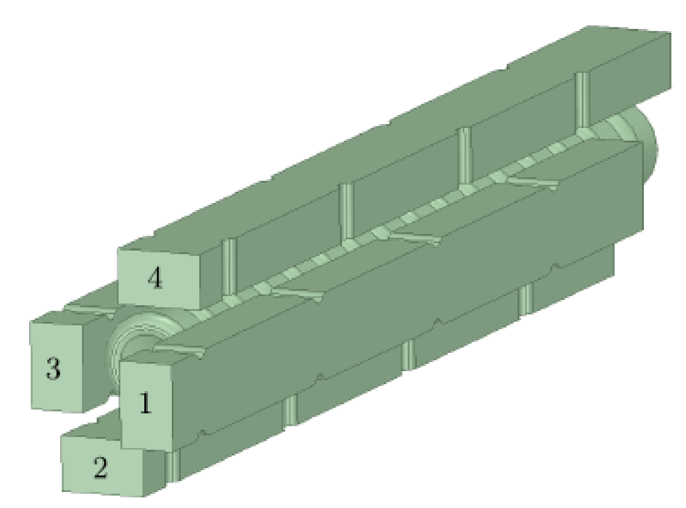
The main RF parameters of the single cell are reported in the following table:

Parameter	Value	Parameter	Value
Average Gradient	80 MV/m	Quality Factor	8200
Iris radius	1 mm	Shunt Impedance	160 Ω/m
a/λ	0.038	R over Q	19600 Ω
Phase Advance in cell	π	Peak Input Power	152 MW
Group Velocity	9% of *c*	Max. Electric Field	272 MV/m
Section Length	2 m	Max. Pulse Heating	42 K (200 ns pulse)
Attenuation	0.33	Max Mod. Poynting	3.99 MW/mm^2

Complete Accelerating Section

The complete section of the accelerating structure can be obtained with a repetition of the single cell along the propagation axis. The structure obtained is a single arm of the complete accelerating section (left image). From the interpolation of four arms with the appropriate shift in the z-axis it is possible to obtain the final structure (right image).





[1] Brezhnev, O. N., et al. "Parallel-coupled accelerating structures." Proceedings of LINAC. 2002.
[2] Wangler, Thomas P. RF Linear accelerators. John Wiley & Sons, 2008.
[3] Chen, Parry Y., et al. "Group velocity in lossy periodic structured media." *Physical Review A* 82.5 (2010): 053825.