Crab Cavities for High Energy Colliders

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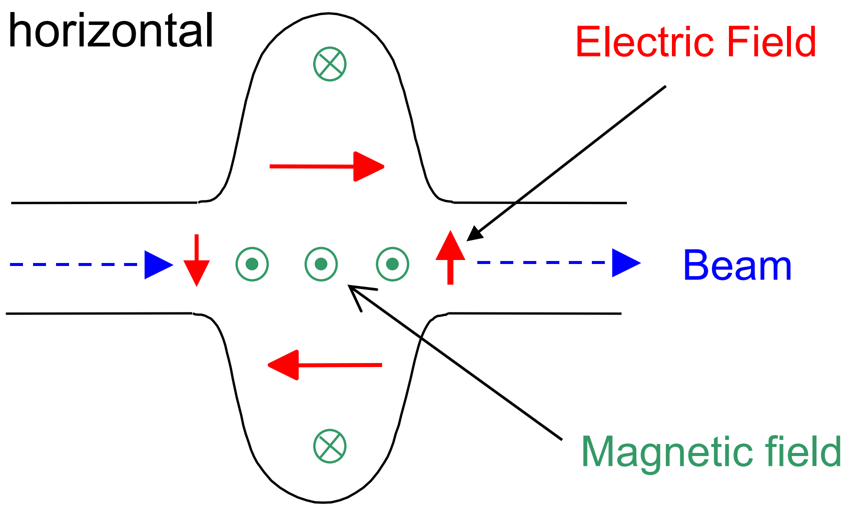
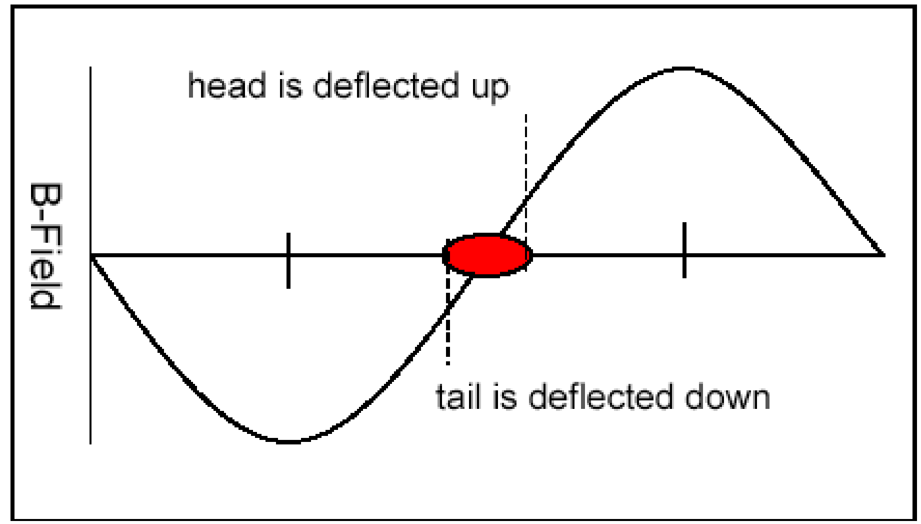
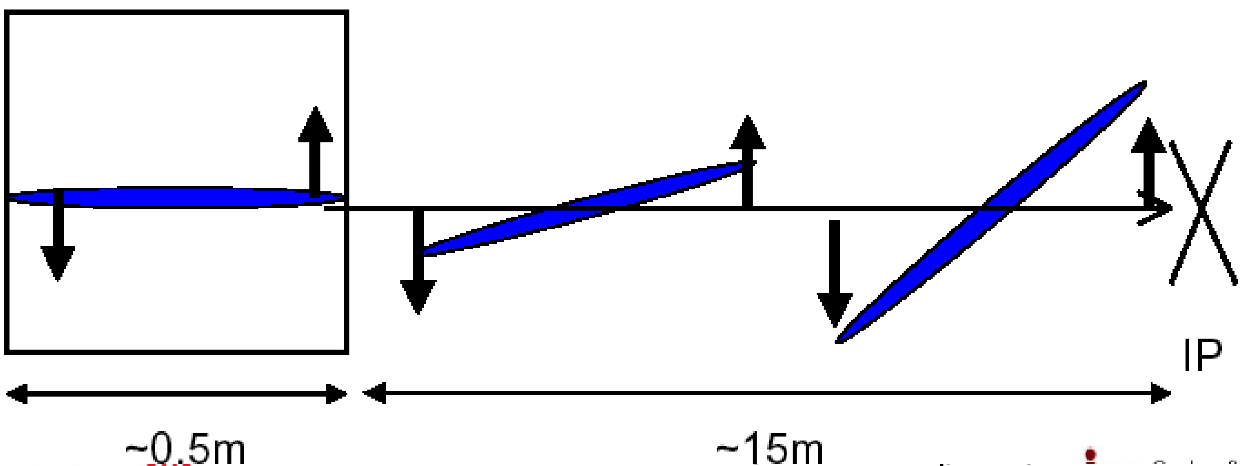
IoP NPPD April 2011

Crab Cavities

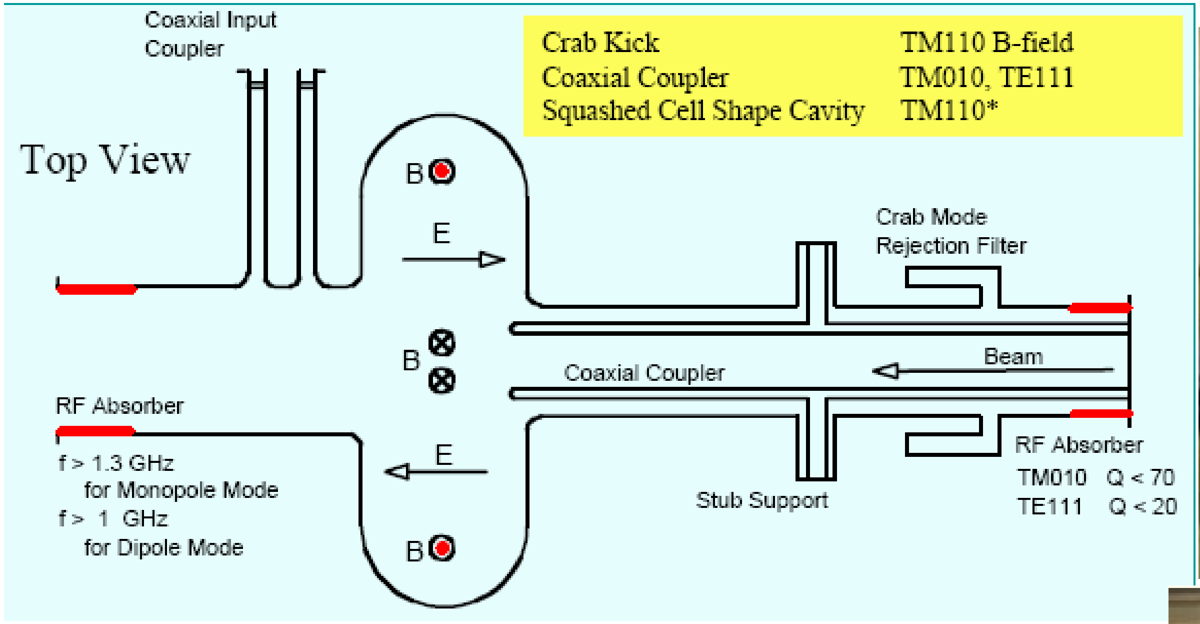






Crab cavities are RF cavities designed to rotate bunches of charged particles

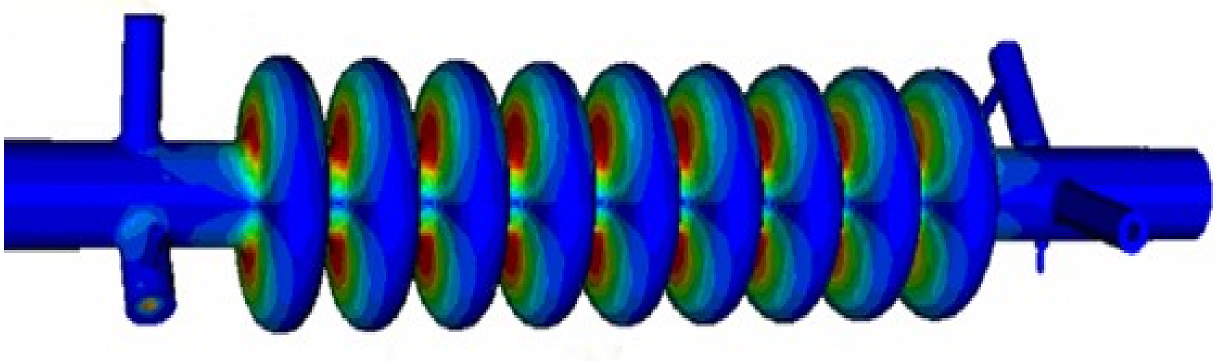
KEK-B Crab cavity

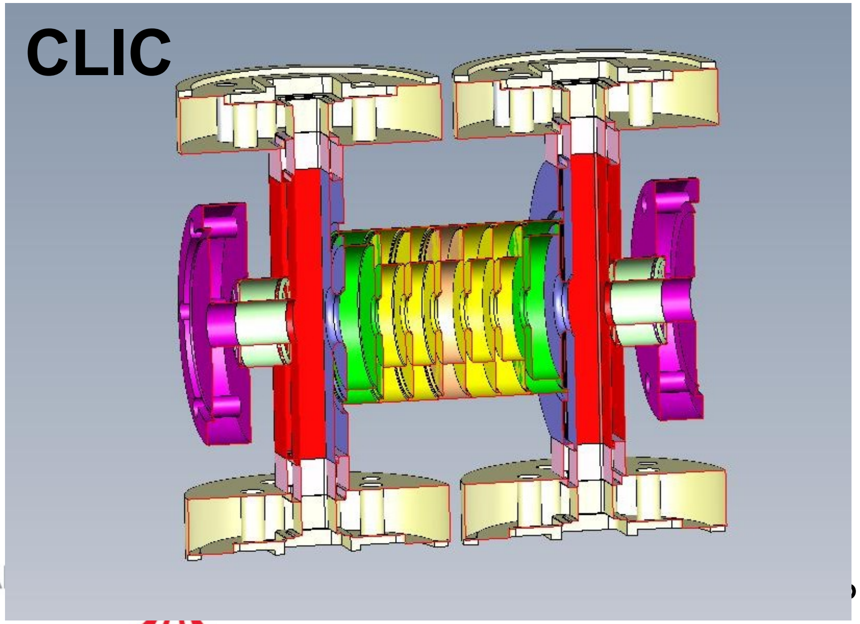


- More recently there has been a lot of attention paid to the KEKB crab cavities.
- These 508.9 MHz single cell Nb cavities operate at 1.44 MV and have special hollow coaxial dampers to deal with the monopole mode (LOM) of the cavity.

Crab Cavities Developed at Lancaster

International Linear Collider (ILC)





Large Hadron Collider (LHC)

Crab Parameters

Simpler design required

Huge beam loading and wakes

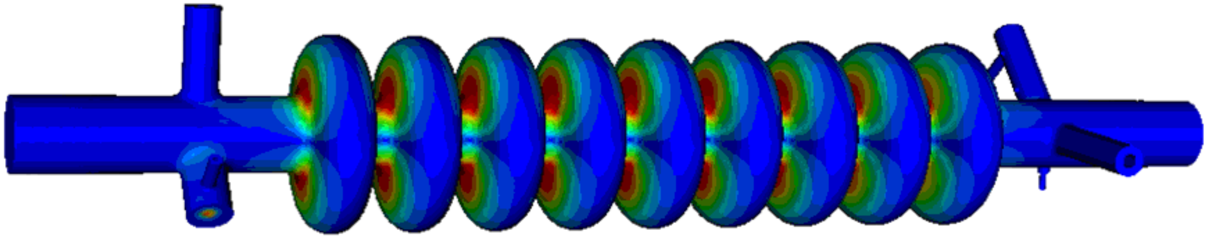
	Beam Energy	Bunch Charge	Bunch Repitition	Crab peak Power	Bunch Length
ILC	0.5 TeV	3.2 nC	3 MHz	1.24 kW	300 μm
CLIC	1.5 TeV	0.6 nC	2 GHz	288 kW	100 μm
LHC	7 TeV	18.4 nC	40 MHz	12.7 kW	7.55 cm

Stiff beam, needs a large voltage and/or small crossing angle

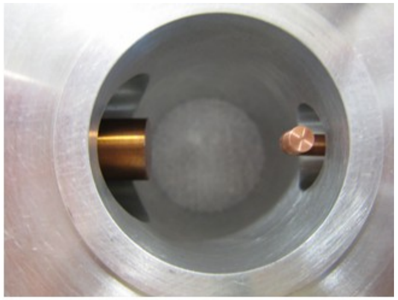
Short timescales, high current

Long bunch = low frequency to avoid non-linear kick

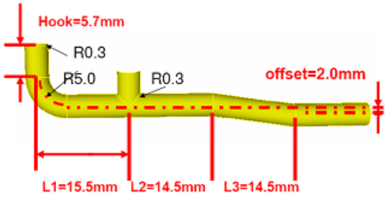
ILC Crab Cavity

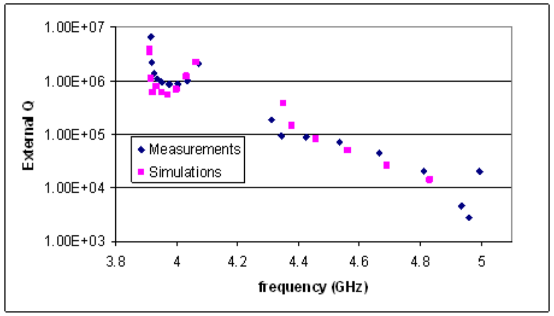


The ILC cavity is a 9 cell superconducting cavity at 3.9 GHz, similar to the FLASH 3rd harmonic cavity.



The LOM coupler was found to give good agreement with both MWS and Omega3P simulations.





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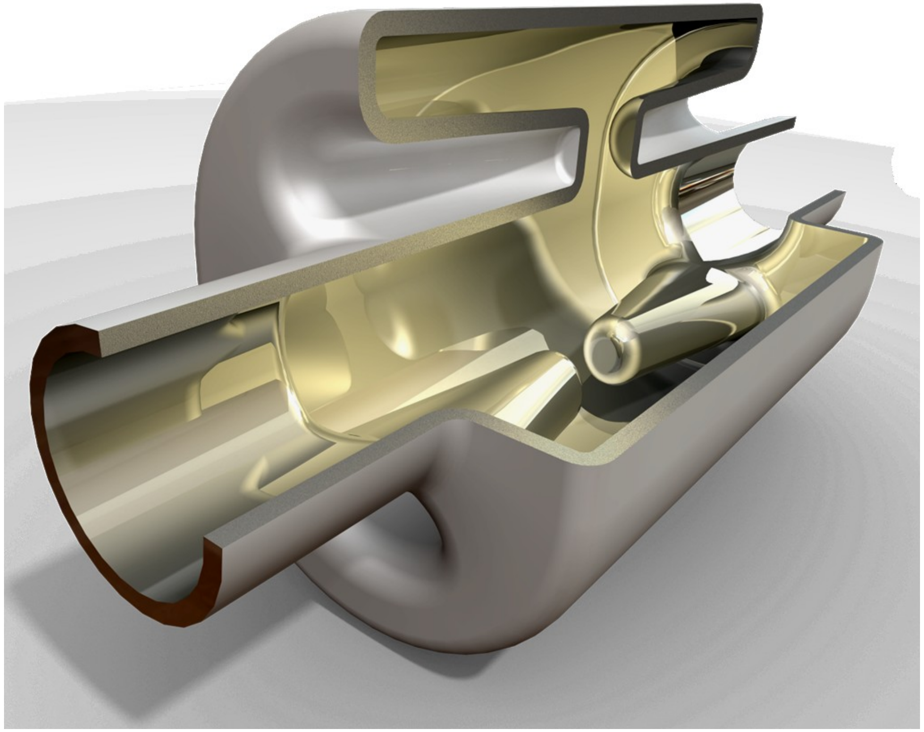
LHC Crab Cavity



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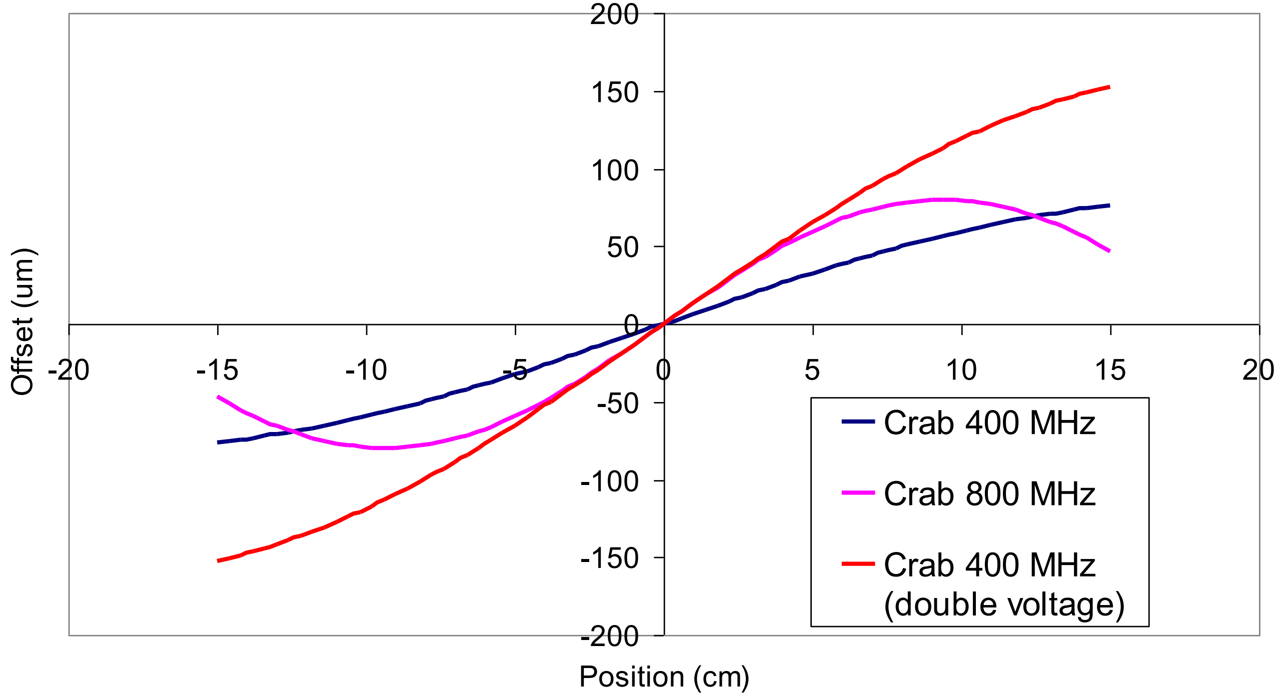
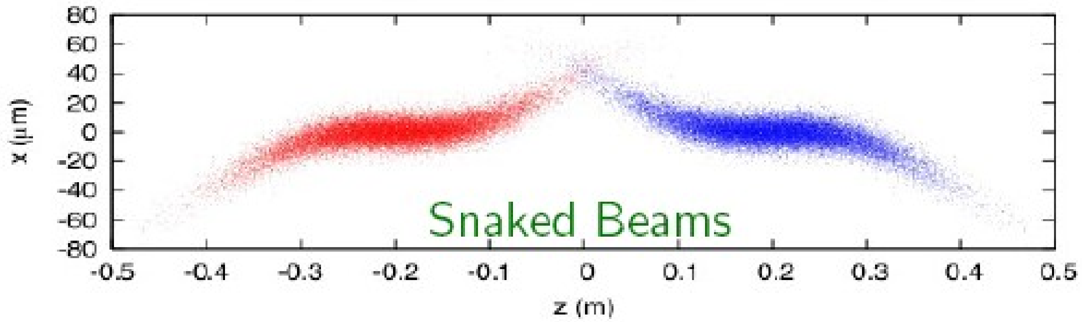
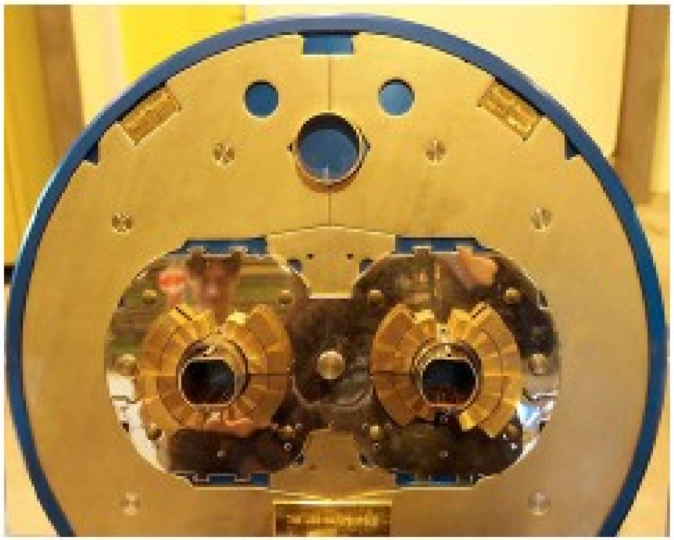
LHC frequency

As the crabbing voltages vary sinusoidally the long LHC bunch length necessitates a large crab wavelength (hence a low frequency)

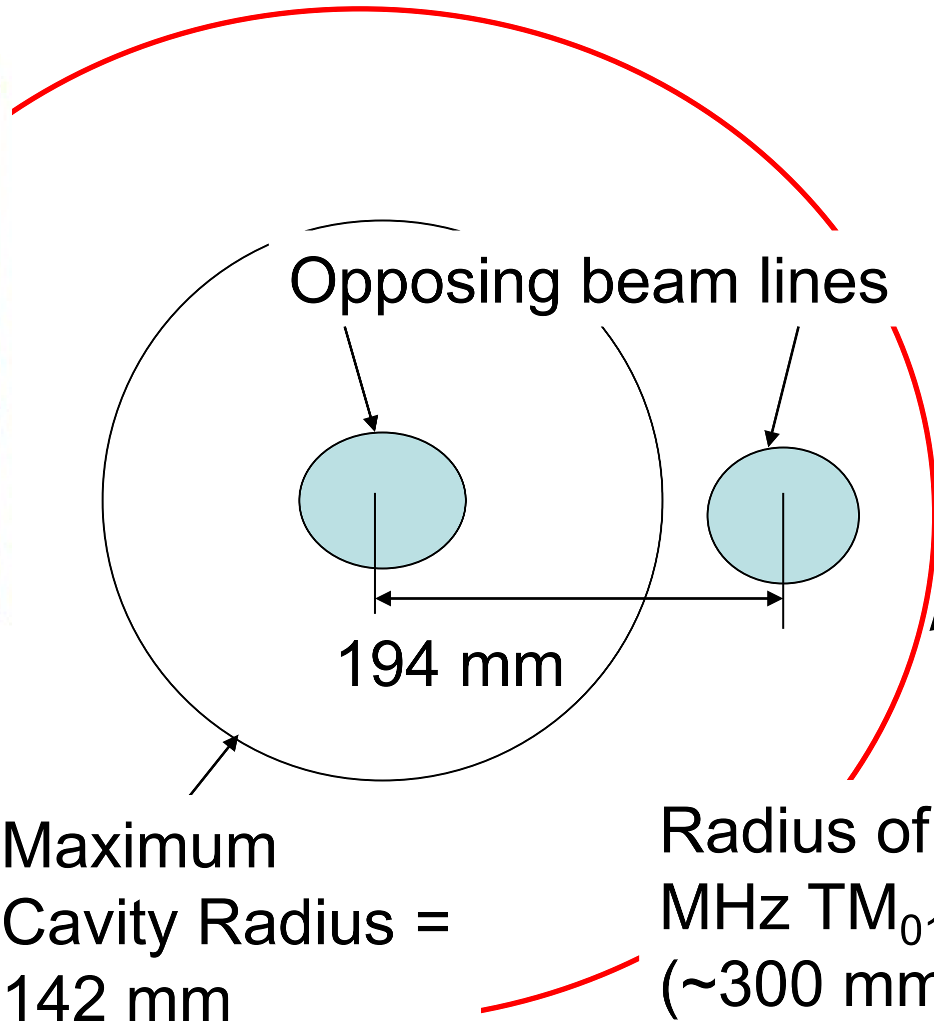




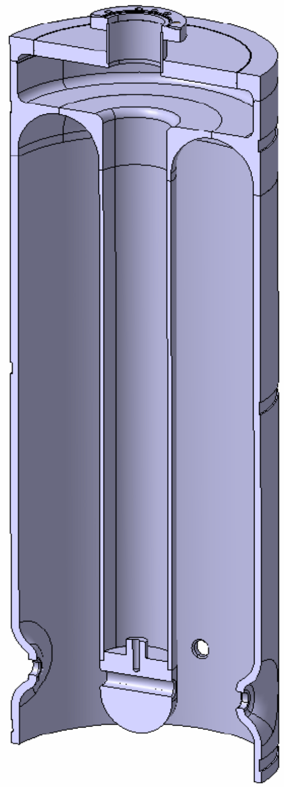
Cavity Size



A standard TM_{010} mode cavity will not fit between the two beam lines.



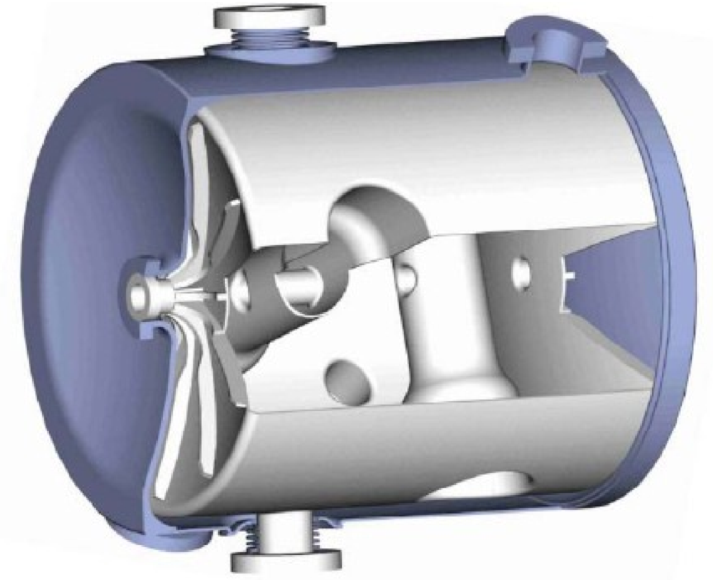
TEM Mode Cavities



If we require low frequency accelerating cavities we use TEM mode cavities.

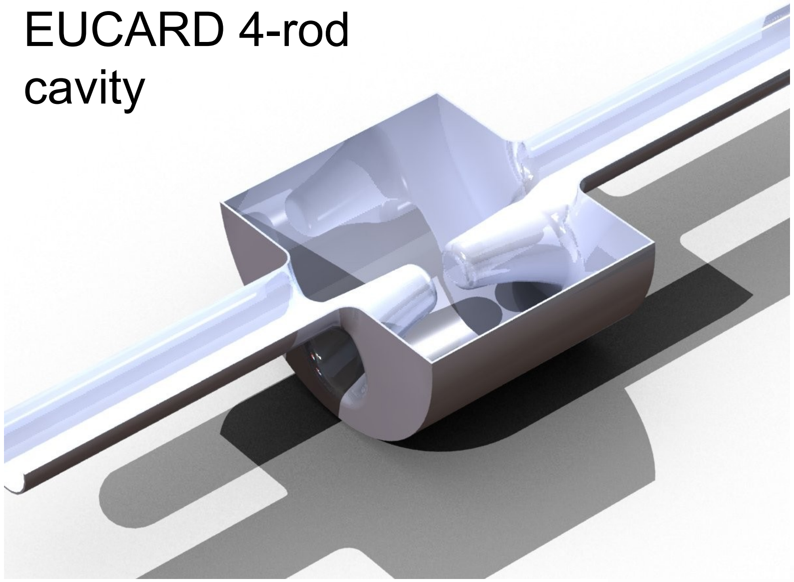
These require two separate conductors to support the TEM mode.

Either coaxial line, stripline or parallel lines can be used to support a TEM wave.

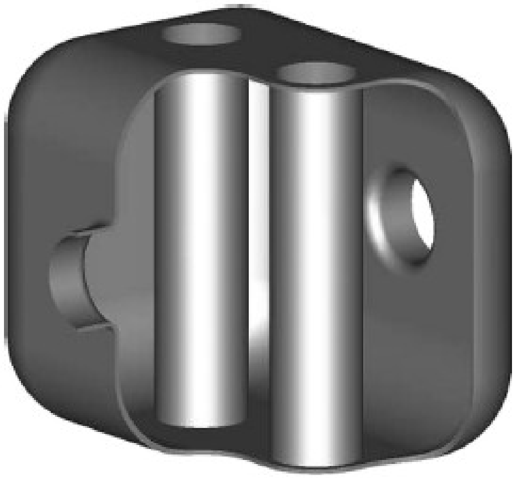


Compact Cavity Designs

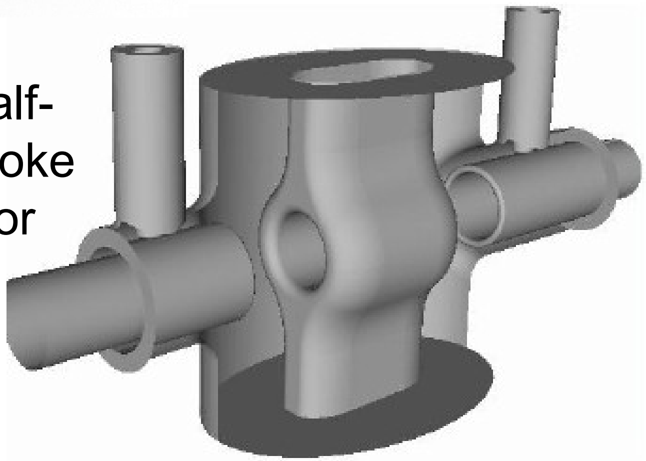
EUCARD 4-rod cavity



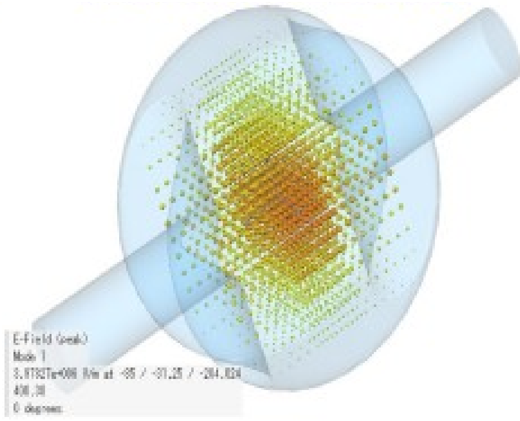
ODU Parallel Bar Cavity



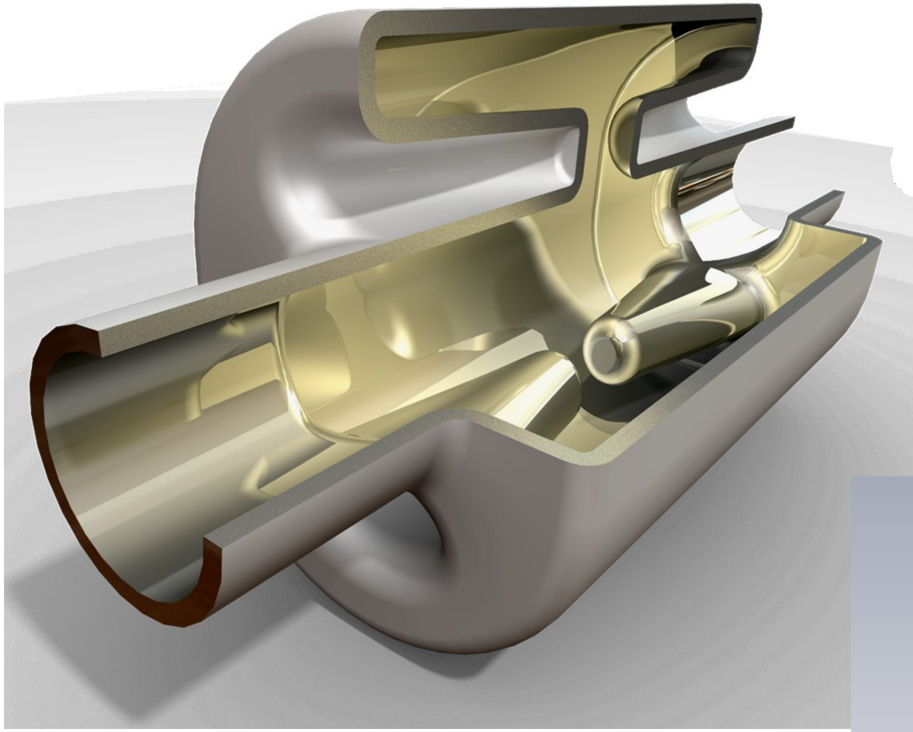
SLAC Half-wave Spoke Resonator



KEK Kota Cavity

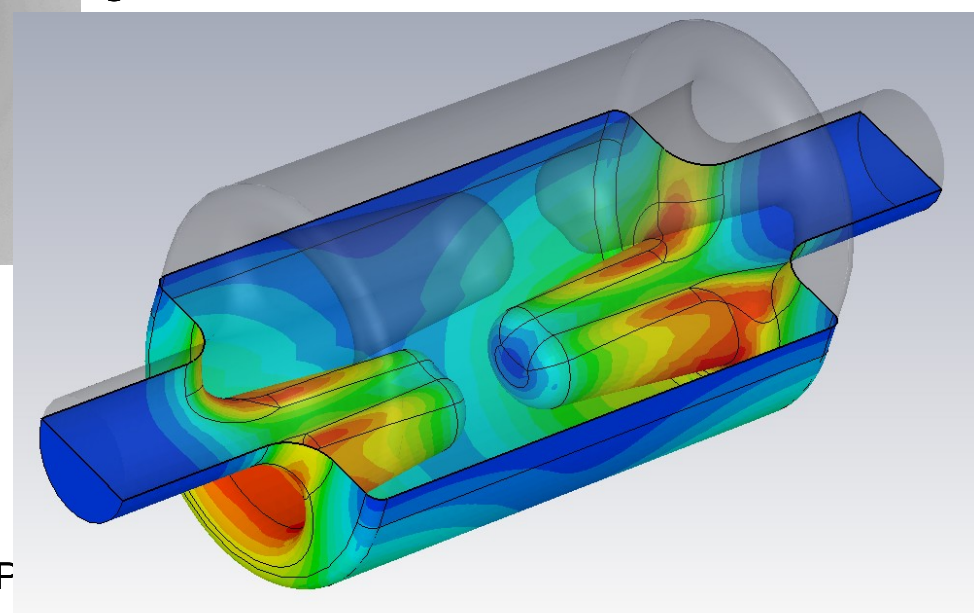


LHC Crab Cavity



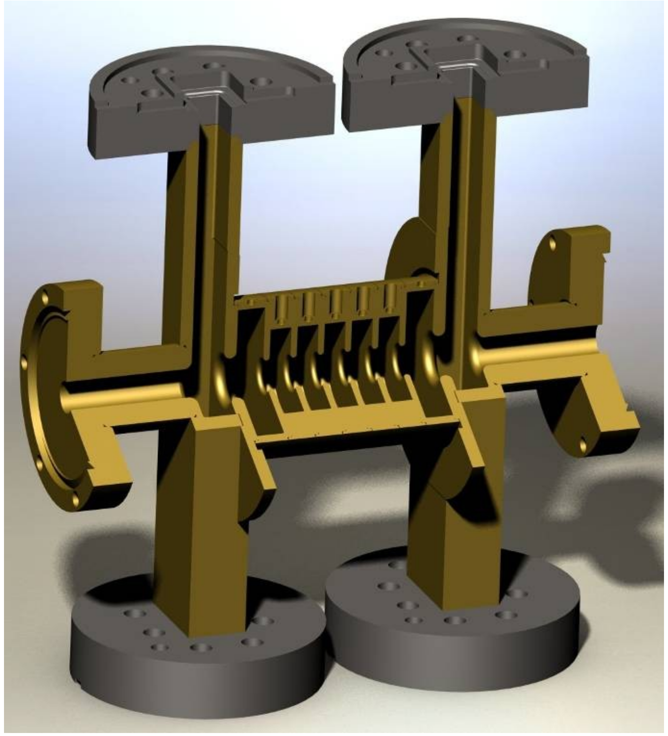
The cavity design includes a 280mm / 230 mm diameter squashing to increase coupling to the LOM when a coupler is included.

Cavity fits in all LHC scenarios (90mm aperture) and meets design gradient.



The EUCARD design is based on parallel lines

CLIC Crab Cavity



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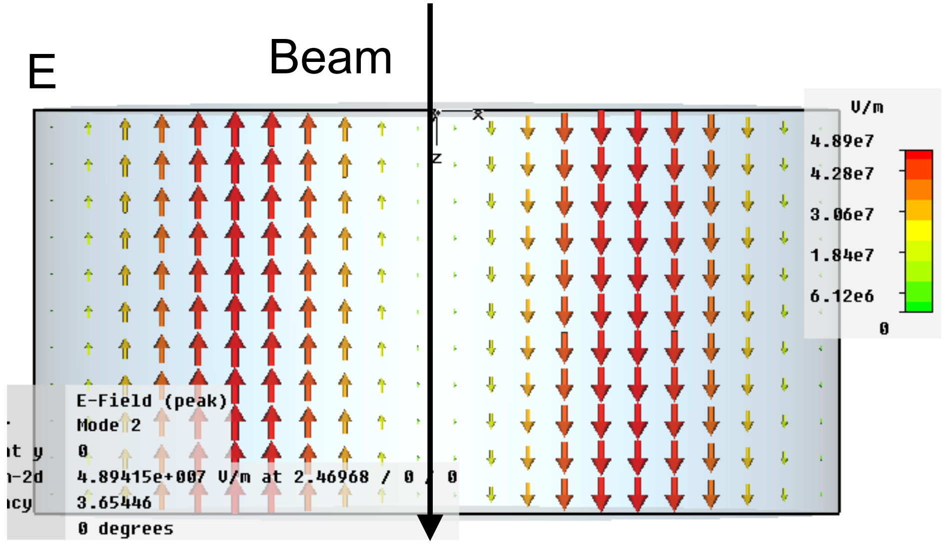
Beam Loading

- As the electric field in dipole cavities vary with offset the beam-loading changes with time and cannot be predicted.
- The beam is too short for feedback.
- Need to design to minimise the effect (increase convection or dissipation)



For each cell solve energy equation

$$\frac{dU_n}{dt} = \frac{(U_{n-1} - U_n)}{L_{cell}} v_g \quad - \quad U_n \frac{\omega}{Q} \quad - \quad q\, f_{rep}\, \delta x\, \omega \sqrt{\frac{\omega}{c} \frac{R}{Q} U_n} \qquad (n > 1)$$

convection - dissipation - beamloading

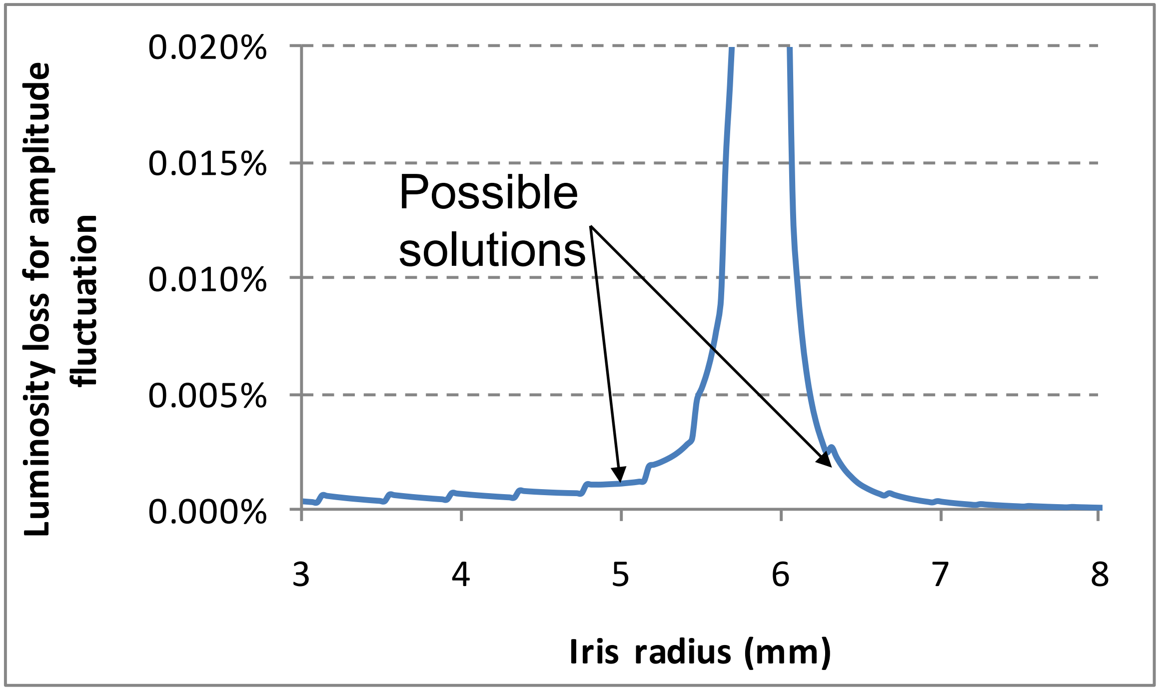
Luminosity loss from beamloading

Increasing dissipation increases heating, this is not recommended

We can increase power convection by increasing the structure group velocity.

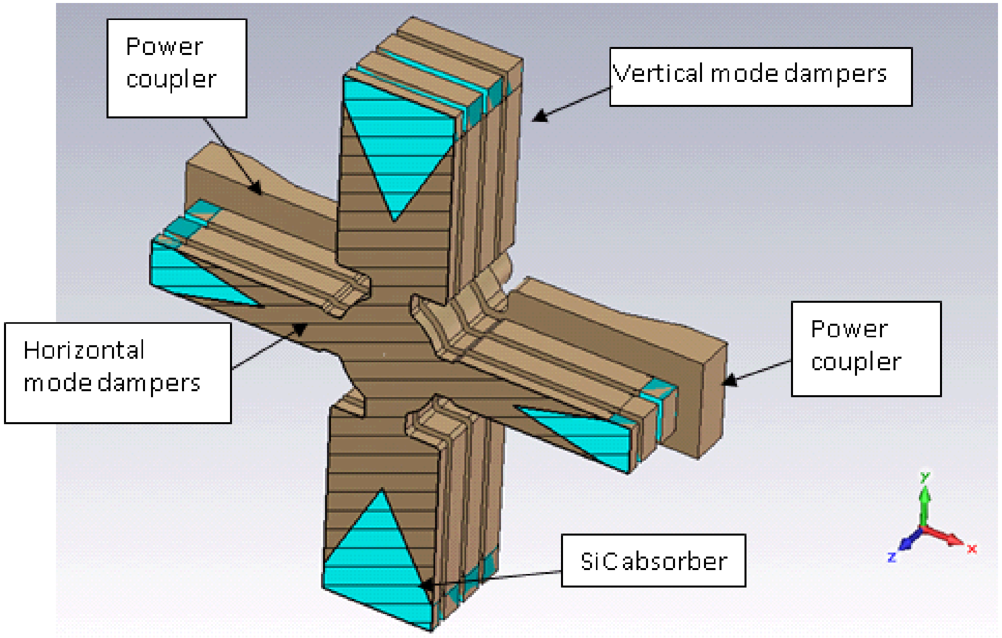
The group velocity is dependant on the iris radius.

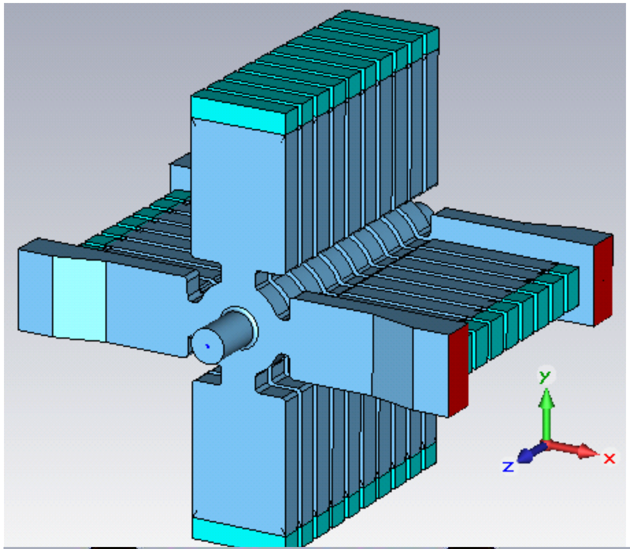
However we have limited power (20 MW) so we can only increase the convection so much.

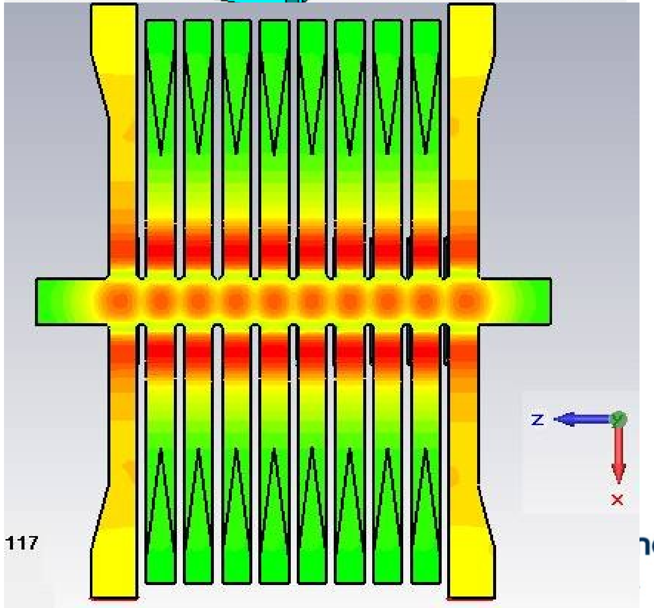


Luminosity loss for a beam offset of 0.125 mm

Final Cavity Design

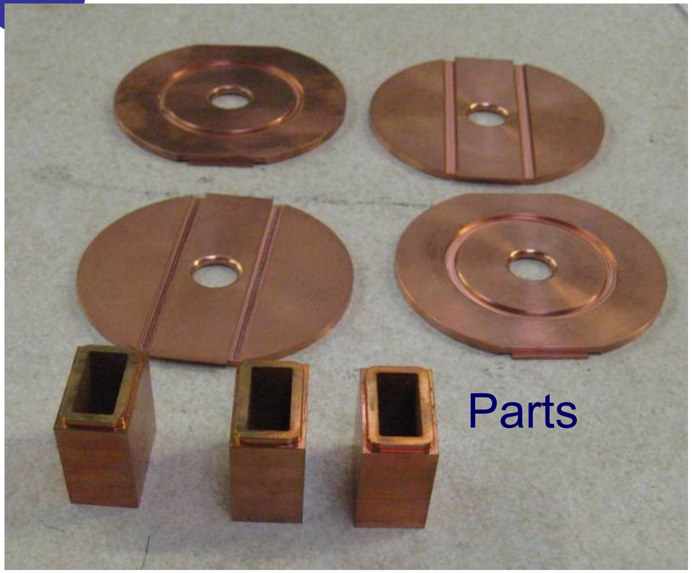




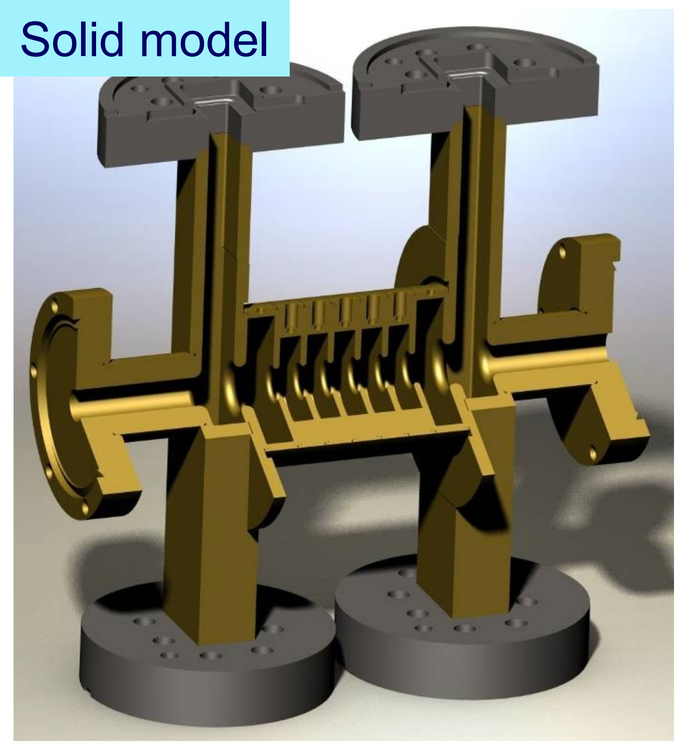


cell length	8.3375	mm
iris thickness	2.0	mm
iris radius	5.0	mm
equator radius	14.09	mm
group velocity	2.95 %	of c
R/Q per cell	53.92	Ω
E_{max} / E_{trans}	3.55	
H_{max} / E_{trans}	0.012	S

Test Cavity



As CLIC has a beam energy of 1.5 TeV the beam requires a large voltage kick to rotate it.



A collaborative program has been developed with SLAC and CERN to build and develop a number of prototypes which can be tested at high gradients to verify the crab design.

Thank You