RF Deflecting Mode Cavities Lecture II – Issues and cavity designs

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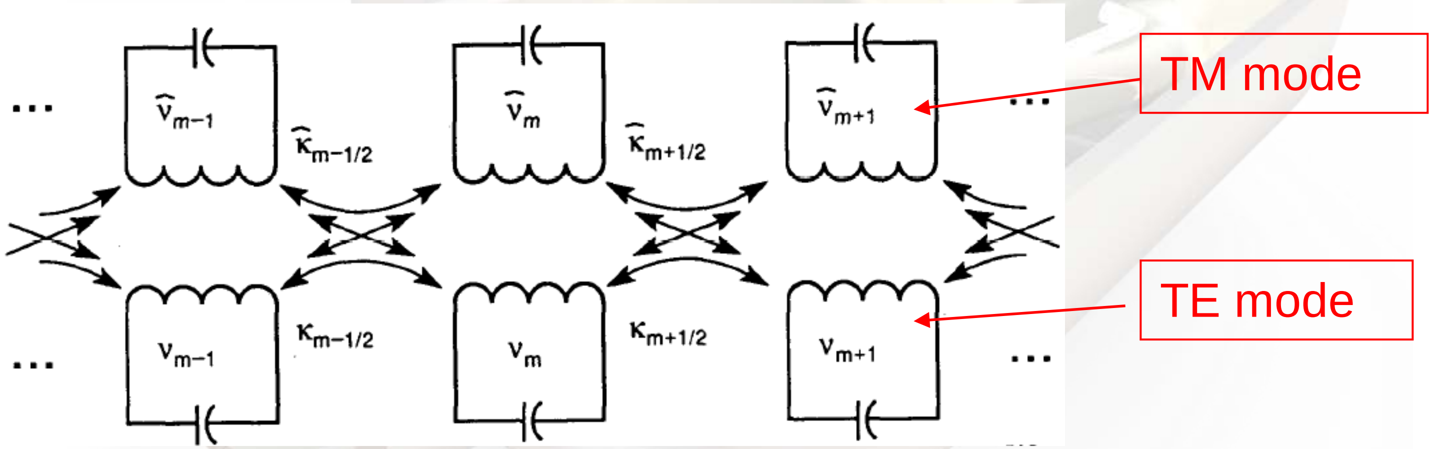
Equivalent Circuit

- To find the dispersion of the deflecting cavity an equivalent circuit can be constructed.
- In order to obtain accurate results we need to include the TE mode as well as the TM mode in the cavity. This leads to a two-chain model

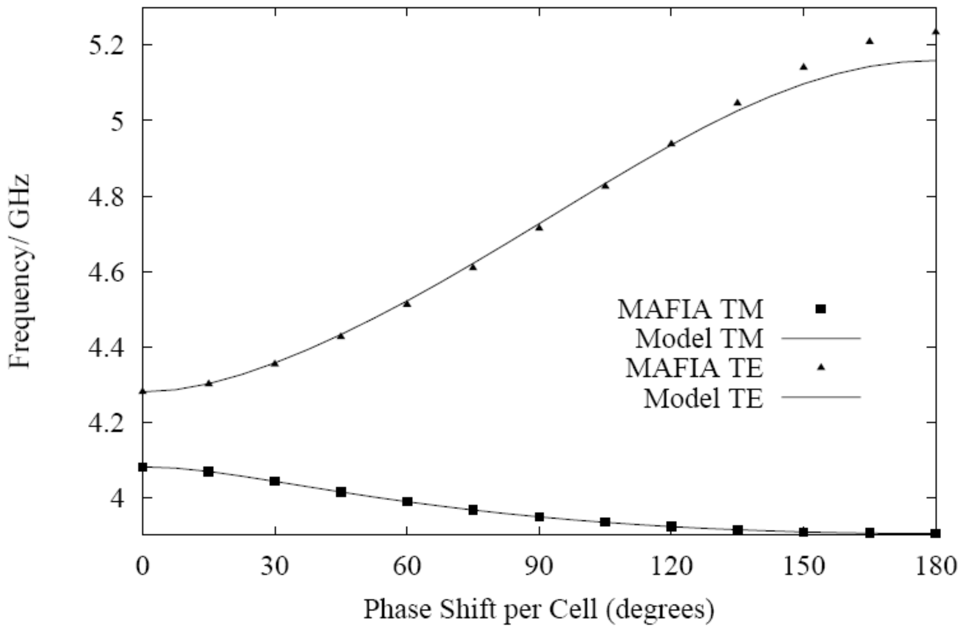


Each mode couples to its nearest neighbour of both modes

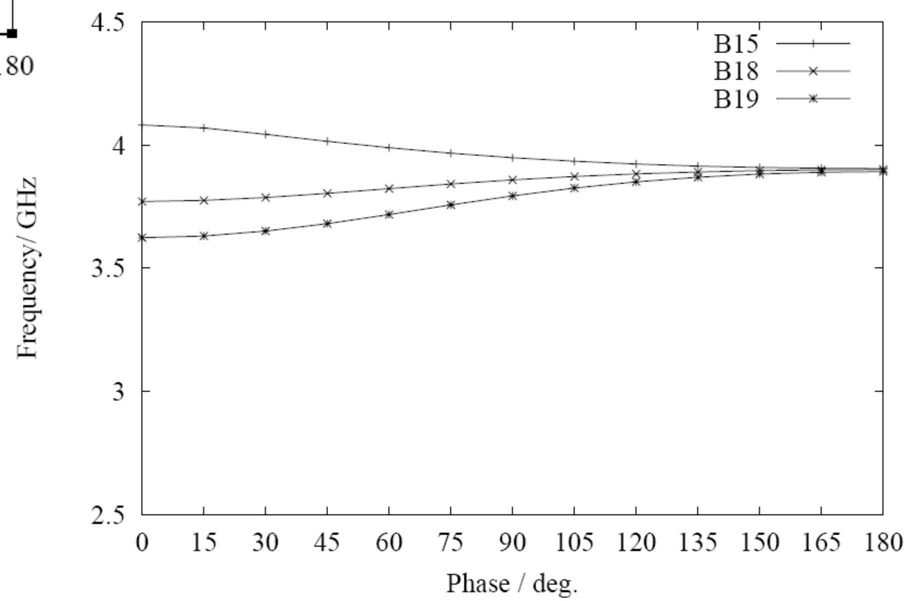
$$\left(\frac{1}{\nu^2}-\lambda\right) f_m - \frac{\kappa}{2} f_{m+1} - \frac{\kappa}{2} f_{m-1} = -\frac{\sqrt{\kappa\overline{\kappa}}}{2} f_{m+1} + \frac{\sqrt{\kappa\overline{\kappa}}}{2} f_{m-1}$$

$$\left(\frac{1}{\overline{\nu}^2}-\lambda\right) \overline{f}_m - \frac{\overline{\kappa}}{2} \overline{f}_{m+1} - \frac{\overline{\kappa}}{2} \overline{f}_{m-1} = \frac{\sqrt{\kappa\overline{\kappa}}}{2} \overline{f}_{m+1} - \frac{\sqrt{\kappa\overline{\kappa}}}{2} \overline{f}_{m-1}$$

Dispersion Diagram

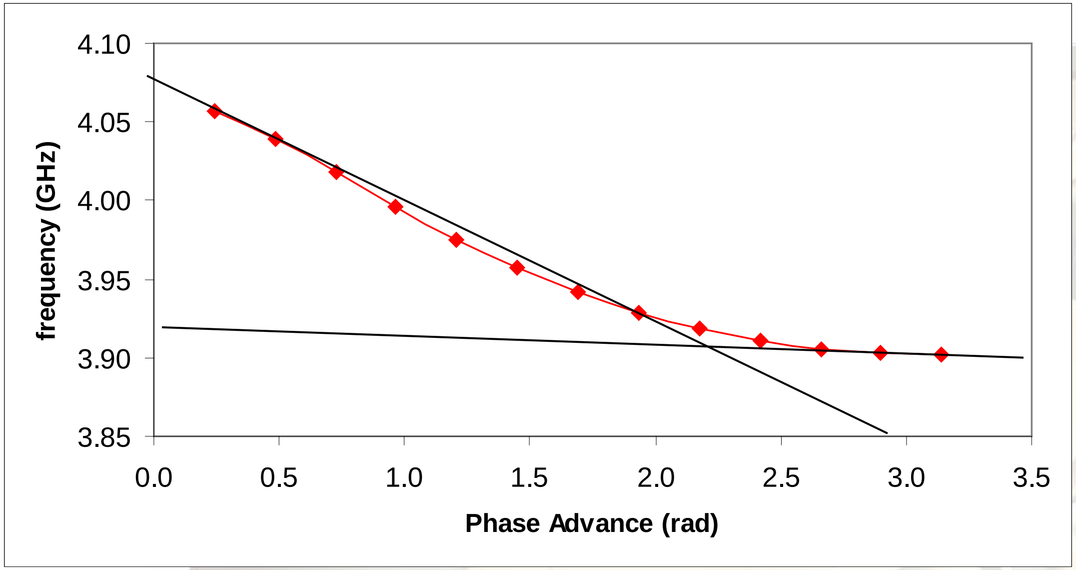


The two-chain model creates two eigenmode passbands, a TM-like hybrid and a TE-like hybrid. Neither has an exact sinusoidal dependence due to the TM-TE mixing.



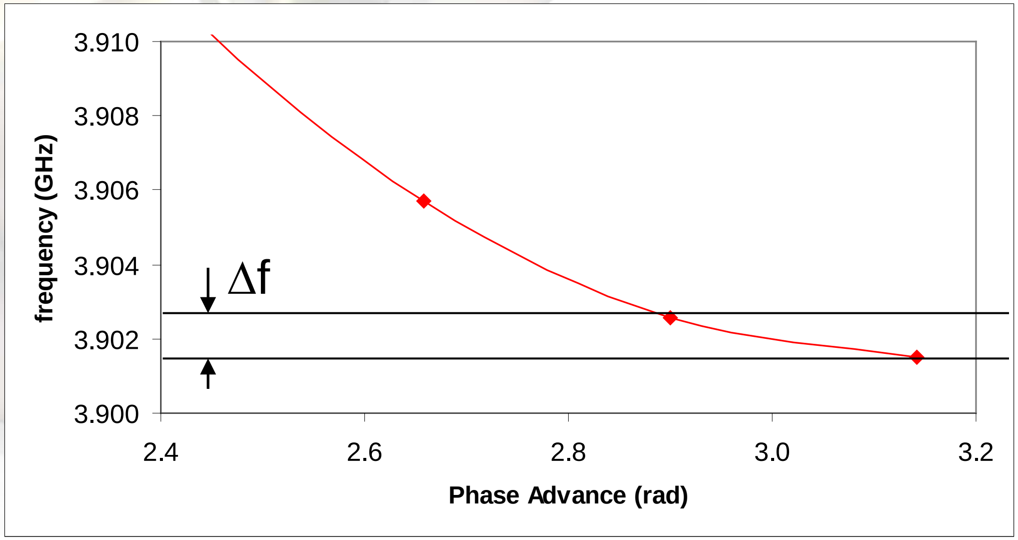
As the cell to cell coupling of the eigenmode can occur via the TE mode, the cell-to-cell coupling parameter can be capacitive or inductive depending on the exact dimensions.

Other modes in the Passband



The mixing of TE and TM modes causes the cell-to-cell coupling to vary.

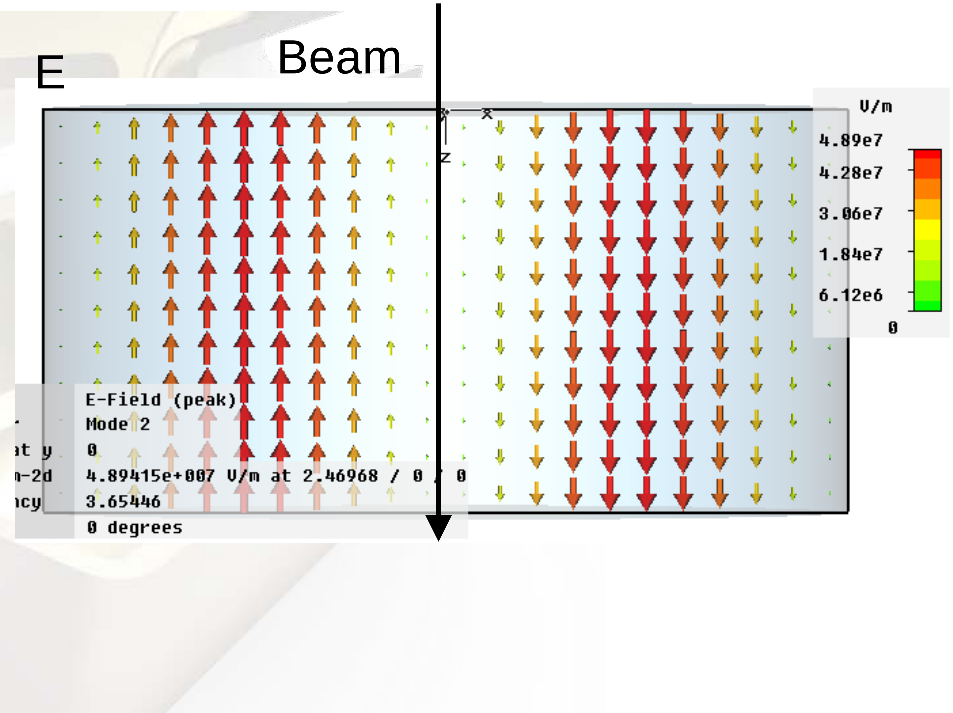
The frequency separation between the π mode and its nearest neighbour is very small in dipole cavities which limits the total number of cells.



Beam-loading

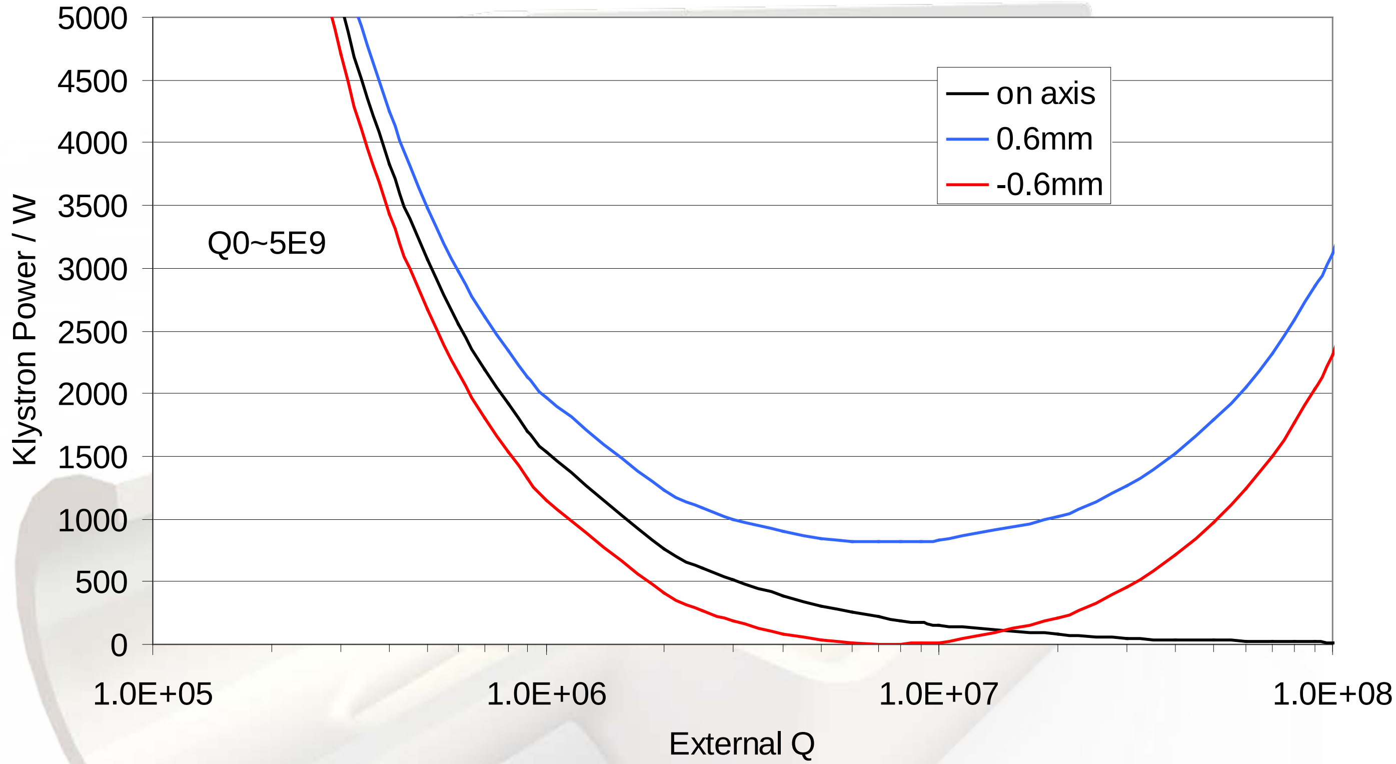
As pointed out by Panofsky and Wenzel in 1956, deflection from *E* and *B* in a TM mode add - but this means large E_Z near but not at cavity center axis.

As the Ez field is zero on axis the beam-loading is zero on axis but like the Ez field it varies linearly as the beam goes off-axis. The beam-loading can be either positive or negative depending on the beam position.



The decelerating field is 90 degrees out of phase with the deflecting field. Hence the beam-loading in deflecting phase is zero, but is maximum when in crabbing phase.

Dipole Beam-loading



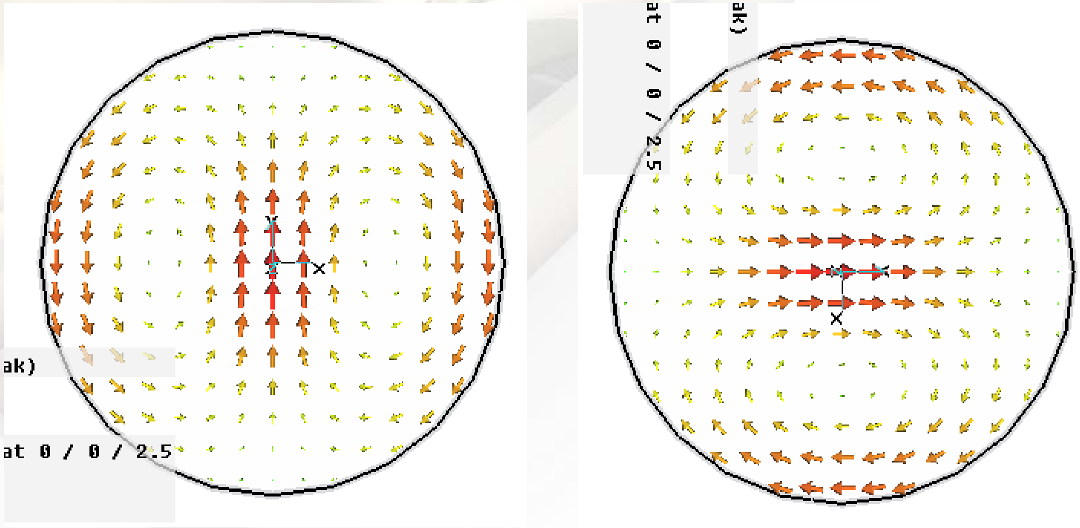
As the beam-loading can be positive or negative, the beam can either give or take power from the cavity. This makes control hard as the beam position jitters.

It could even be possible to run the cavity without an RF amplifier using an offset beam.

Mode Polarisation

- Dipole modes have a distinct polarisation ie the field points in a given direction and the kick is in one plane.
- In a cylindrically symmetric cavity this polarisation could take any angle.
- In order to set the polarisation we make the cavity slightly asymmetric.
- This will set up two dipole modes in the cavity each at 90 degrees to each other.

One mode will be the operating mode, the other is refered to as the same order mode (SOM) and is unwanted.



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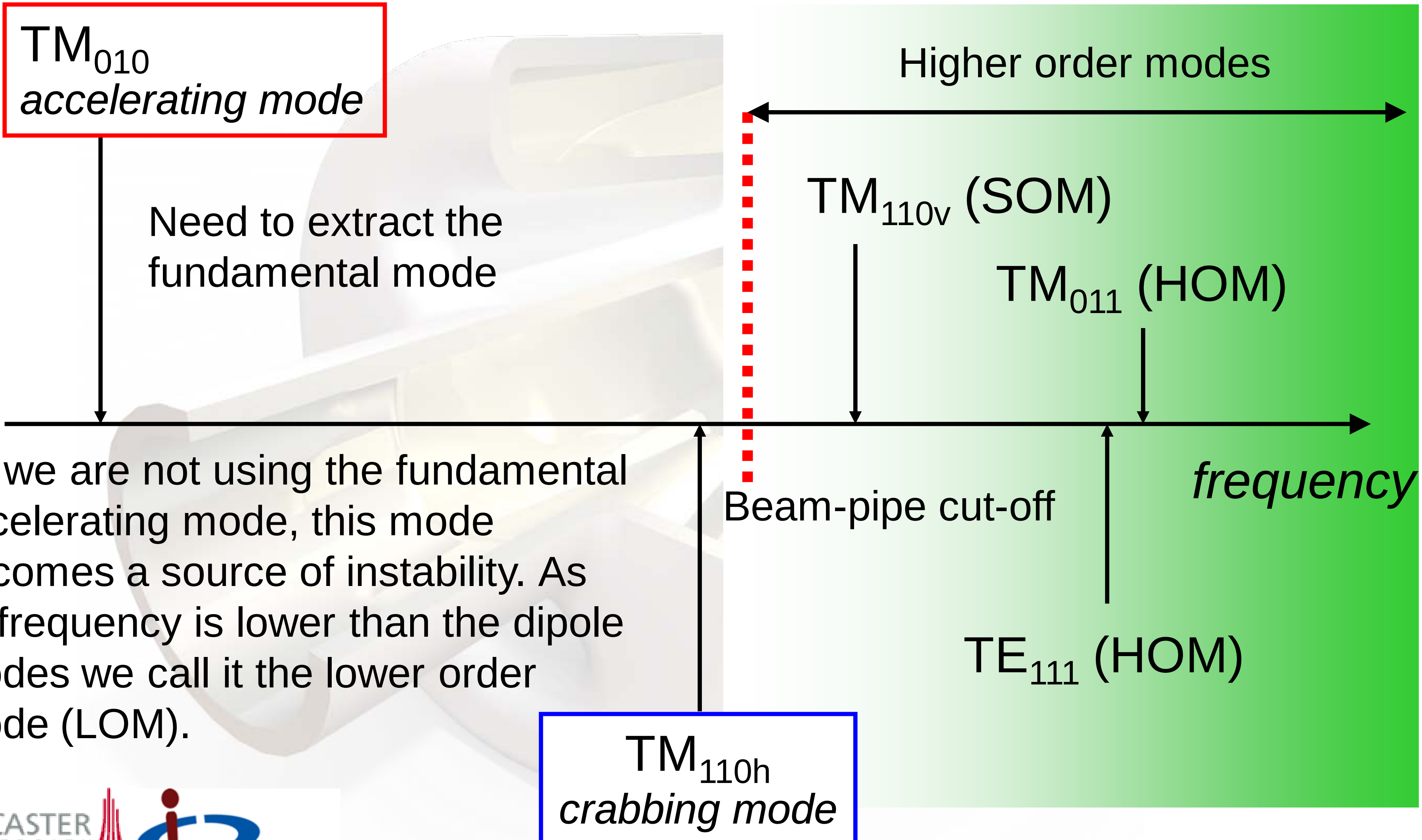
Lower and Higher Order Modes



As we are not using the fundamental accelerating mode, this mode becomes a source of instability. As its frequency is lower than the dipole modes we call it the lower order mode (LOM).

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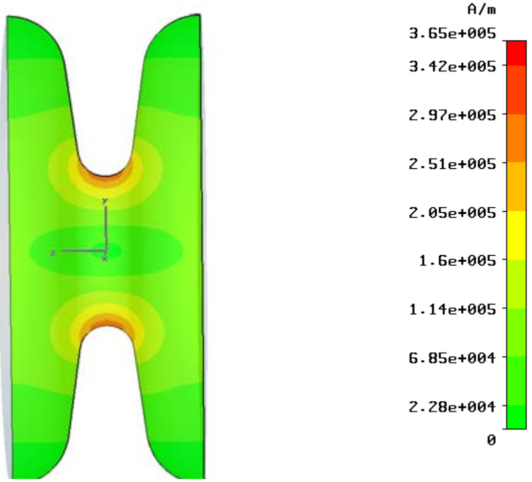
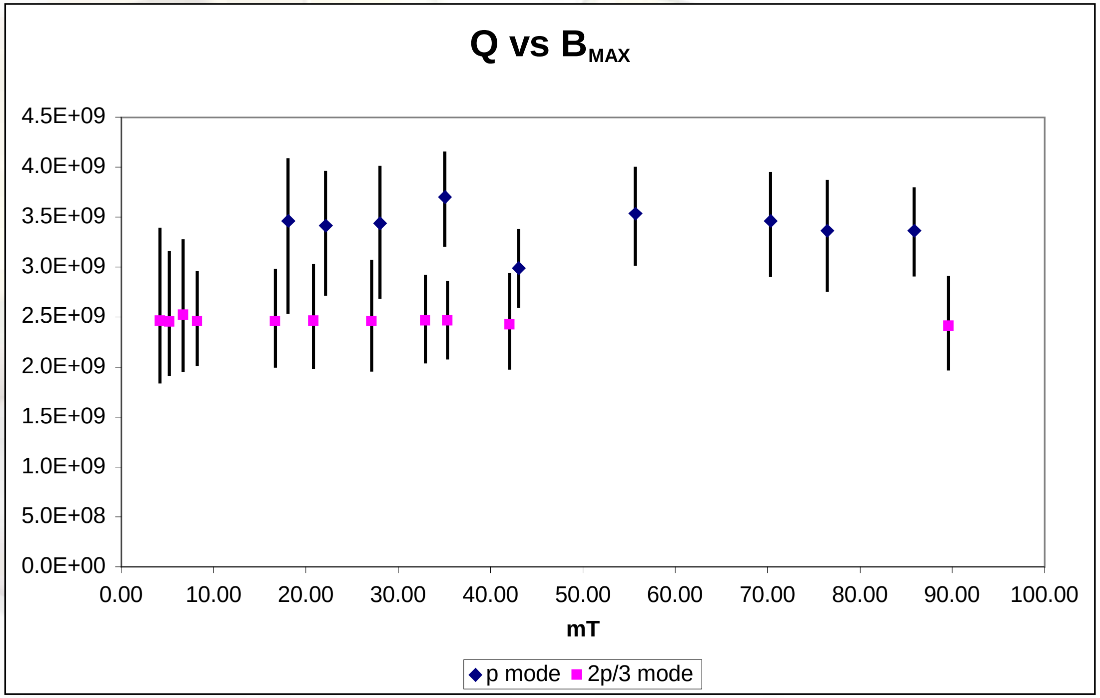
Peak Fields



Cavity type	mode	Frequency GHz	B_{max} mT	E_{max} MV/m
TESLA	TM010	1.3	105	50
CKM	TM110	3.9	80	18.5

Dipole cavities have much larger peak surface magnetic fields than surface electric fields.

This leads to a much smaller Q drop due to field emission as the deflecting gradient increases.



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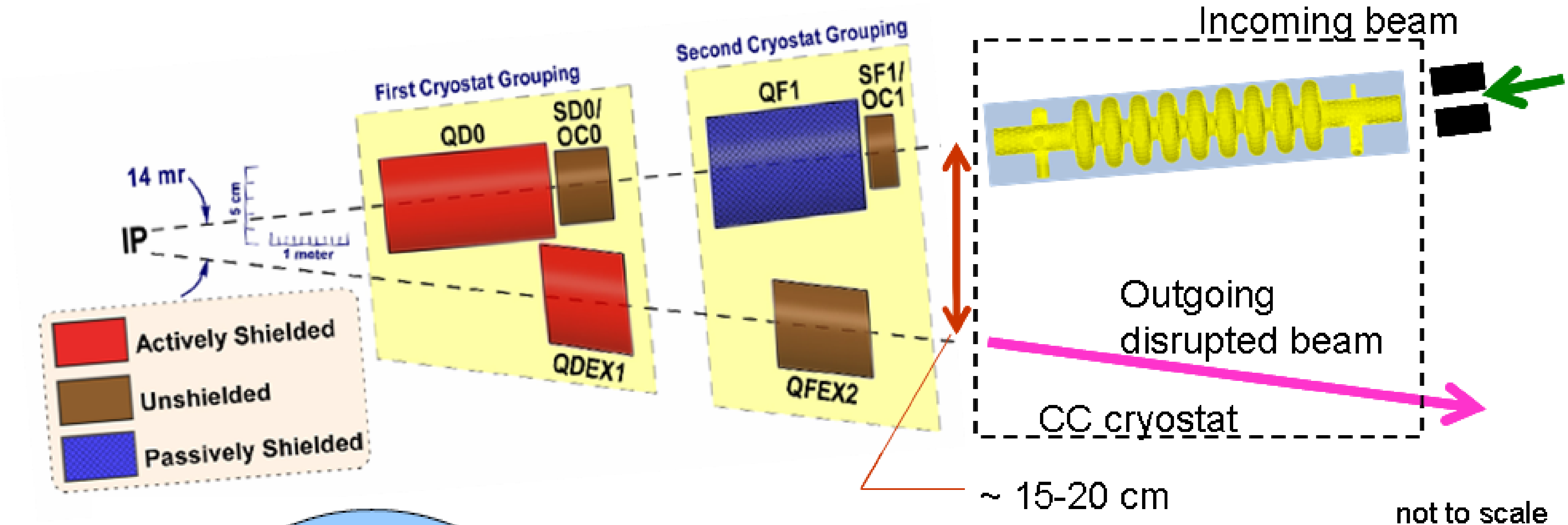
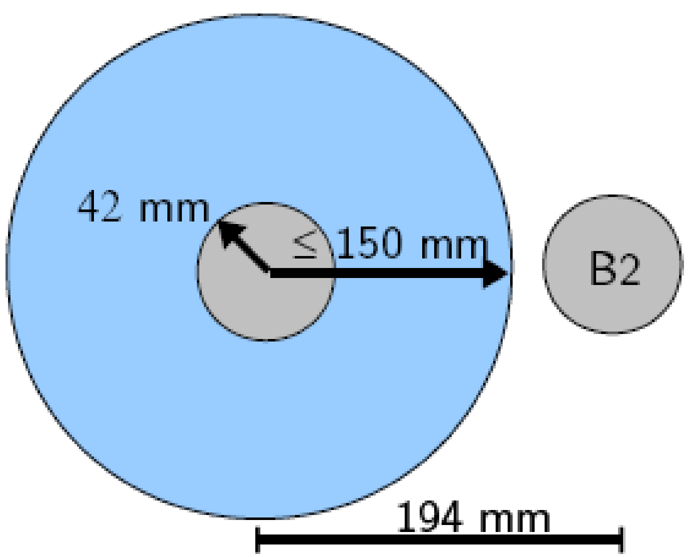
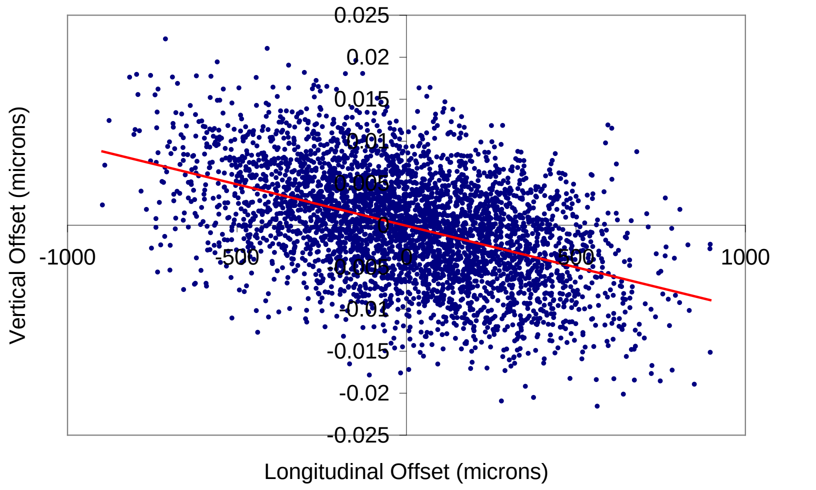
Space Constraints

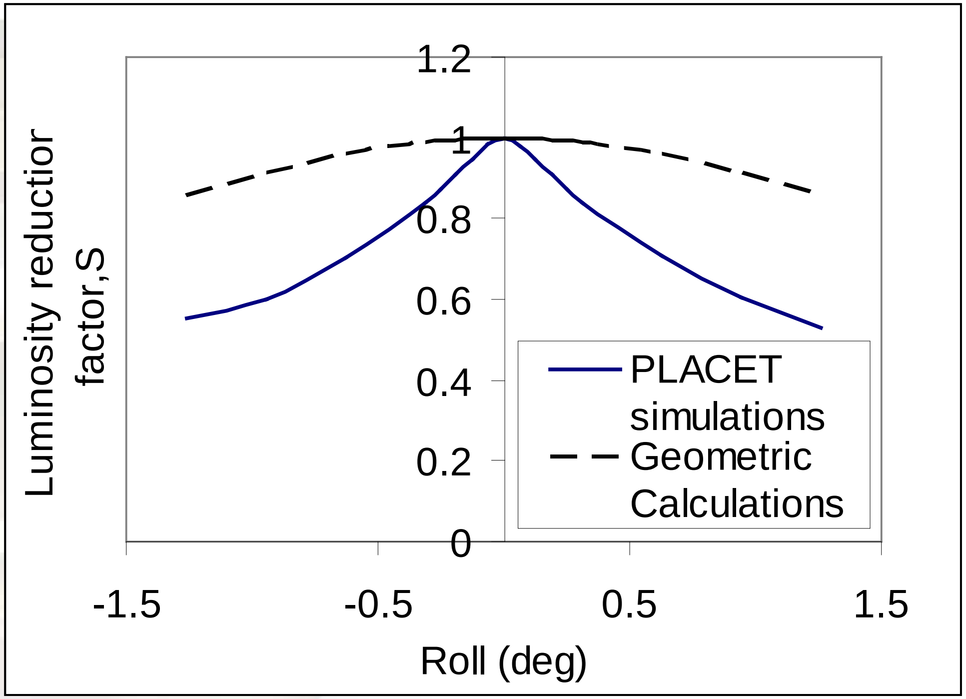




- Crab cavity just behind the Final Doublet
- Limit for couplers outputs oriented toward outgoing beampipe
- Outgoing beam (~17MW, highly disrupted) goes through crab cryostat

Cavity Alignment





If the cavity has a roll misalignment it will cause a small crossing angle in the vertical plane.

This will significantly reduce the luminosity if the vertical beam size is significantly smaller than the horizontal beam size

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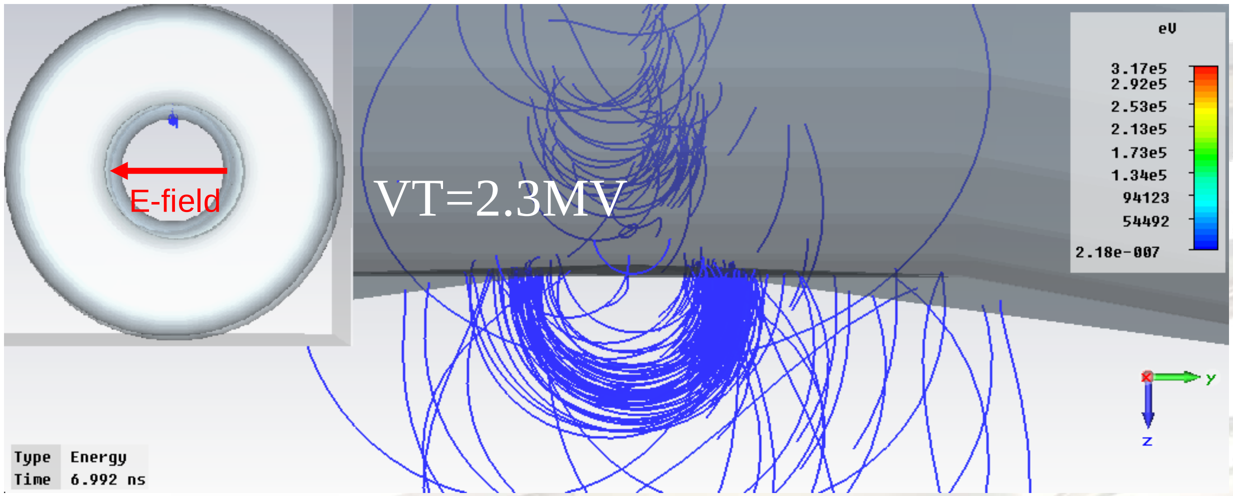
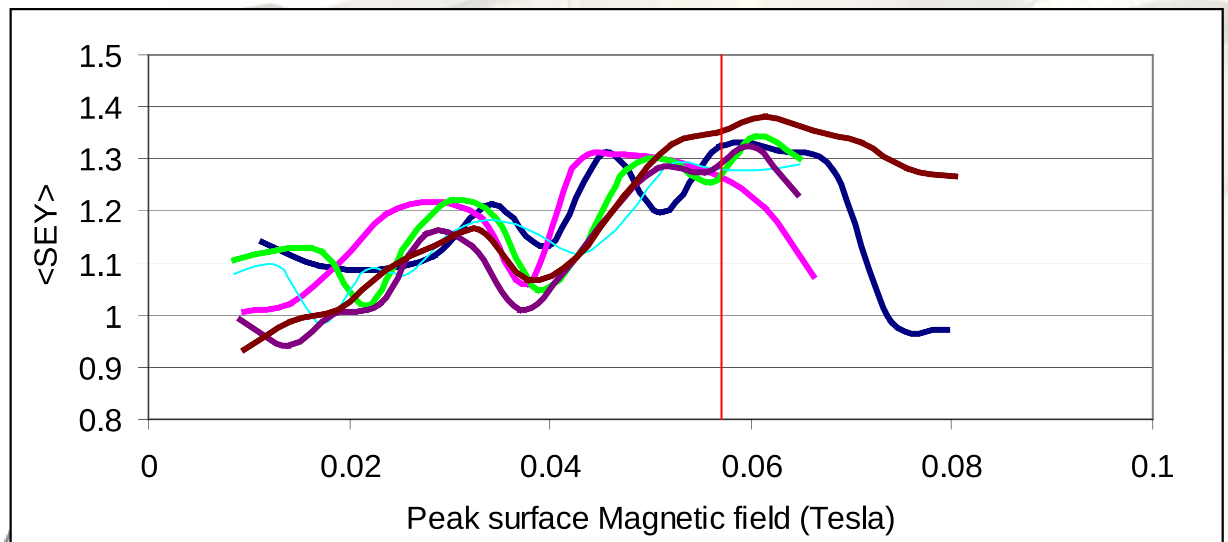
Multipacting





CST-PS simulations clearly show that the multipactor in the iris is directly linked to the cyclotron frequency.

MP always peaks at 57 mT.

Hence low magnetic field structures suppress multipactor. This means that lower frequency cavities are more likely to multipact as a lower magnetic field is required to have the cyclotron frequency double the RF frequency.

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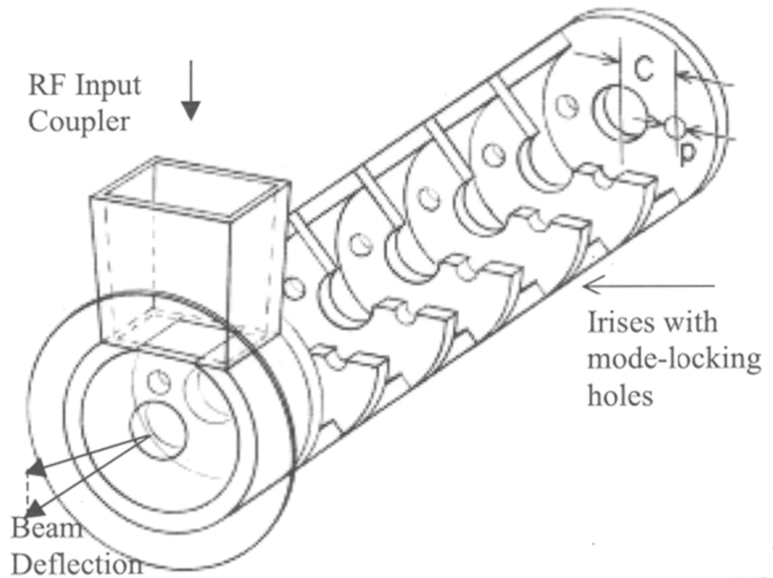
Travelling wave Cavities

- Like accelerating cavities we can also use travelling wave deflecting cavities.
- These cavities are less sensitive to temperature, can have more cells per cavity and fill faster.
- The down side is they require more RF power.
- Most diagnostic cavities and fast separators are travelling wave to take advantage of fast filling times.



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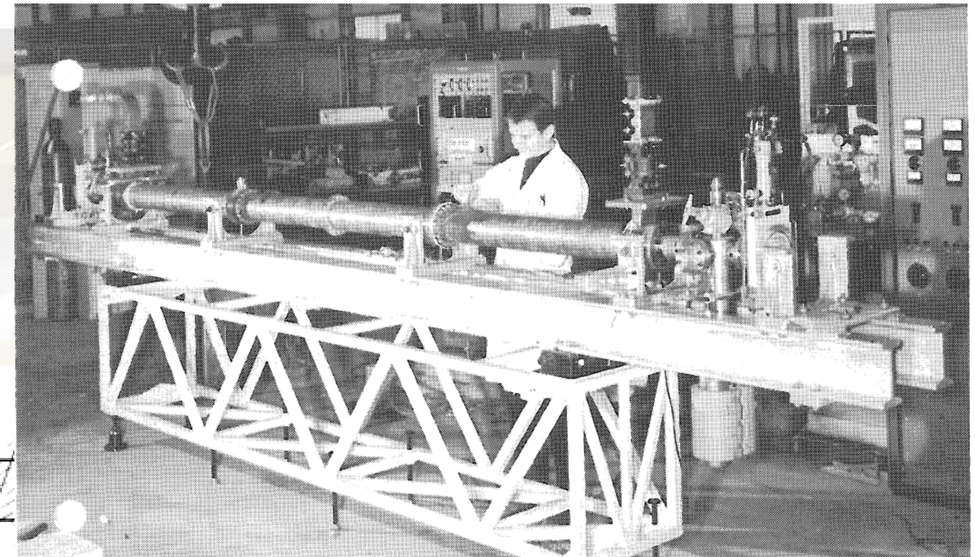
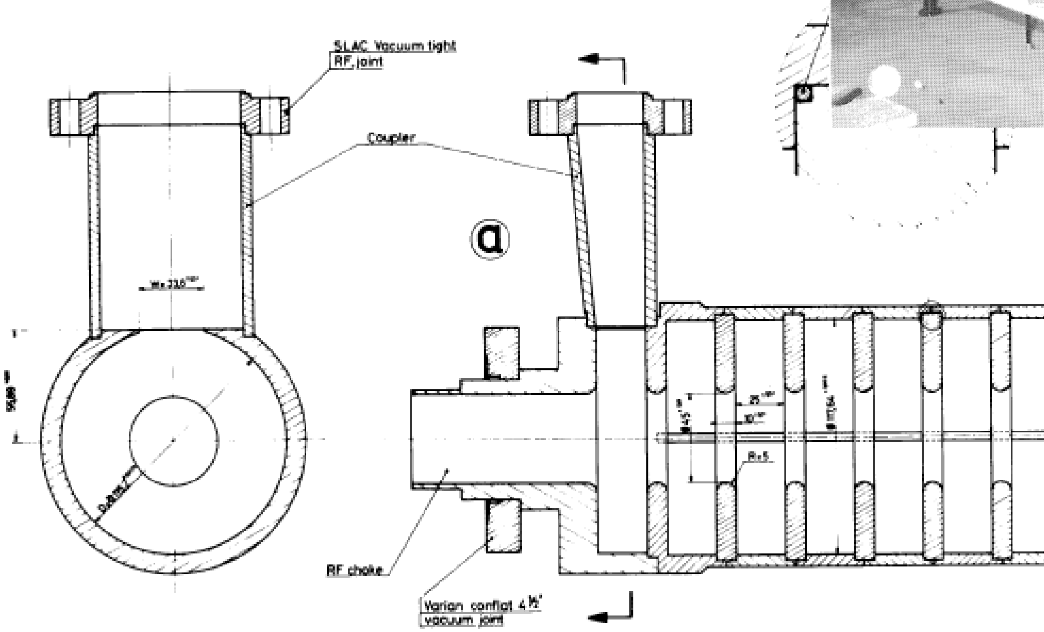
CERN RF Separators

- Montague Jan 1965
- Bernard and Lengler 1969
- $2\pi/3$ 2855 MHz 100 Cells





The first RF deflectors were all travelling wave structures with a phase advance of 120 degrees.

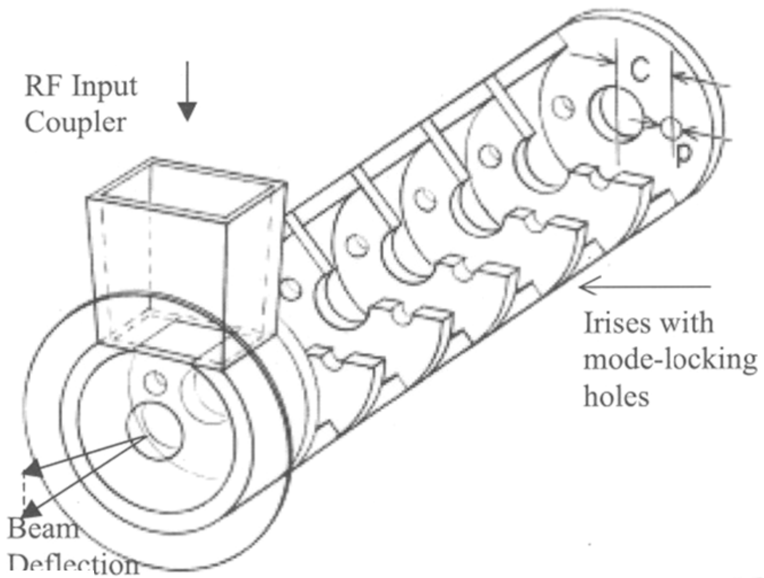
They generally had a large number of cells.

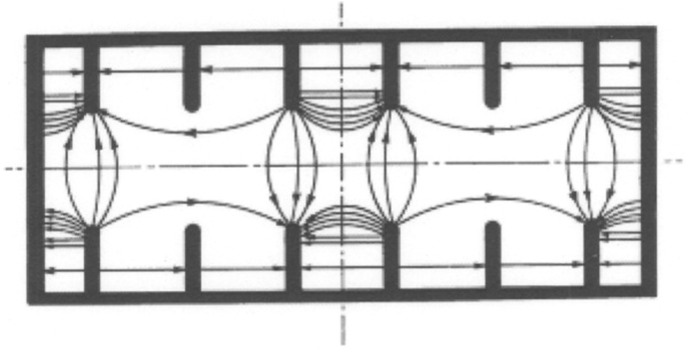
SLAC S-Band Deflector (LOLA II & III)

Loew 1965

$2\pi/3$ mode traveling wave

Frequency=2856 MHz

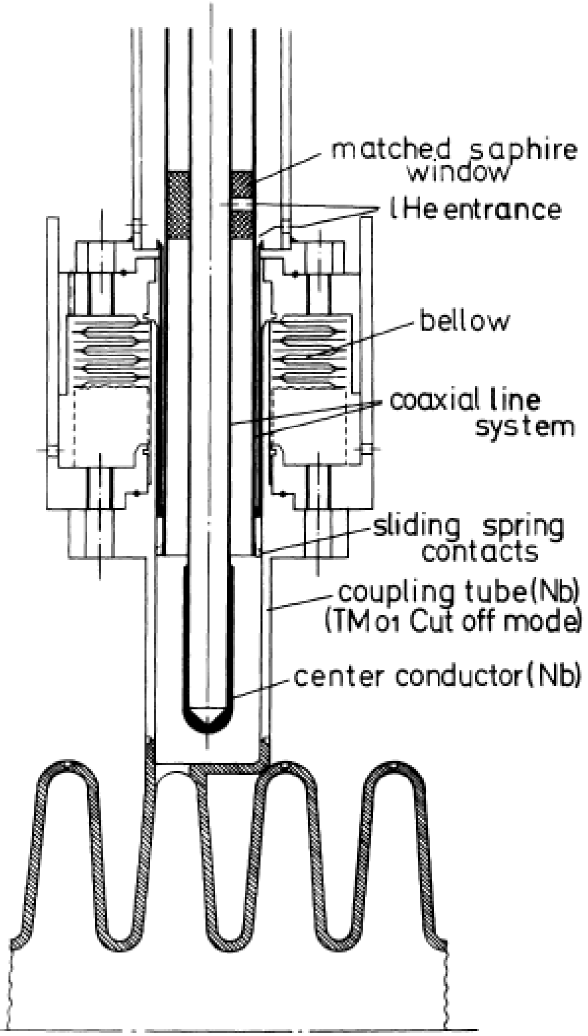


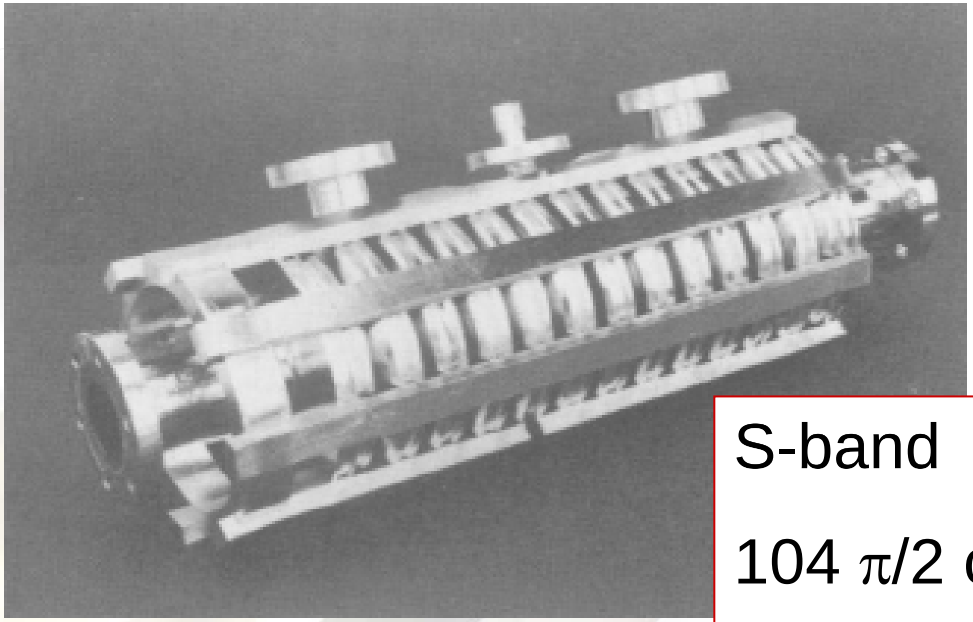


The LOLA family of deflectors are commonly used for bunch length diagnostics.

Holes in the irises are used to lock the mode polarisation.

CERN-Karlsruhe cavity [1970]





S-band

104 $\pi/2$ cells

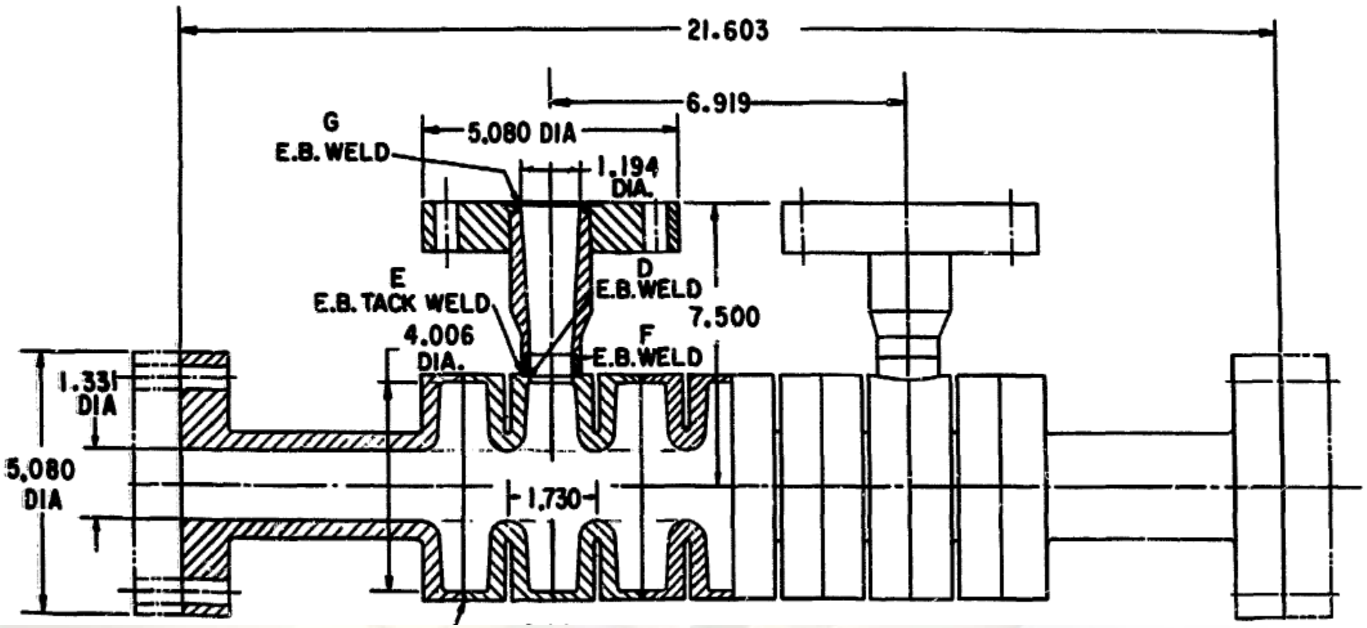
Kick= 2 MV/m

The CERN-Karlsruhe separator was one of the 1st Nb cavities constructed.

The cavity uses a standing wave $\pi/2$ mode to avoid e-beam welds in high field regions

This cavity is still in use at IHEP

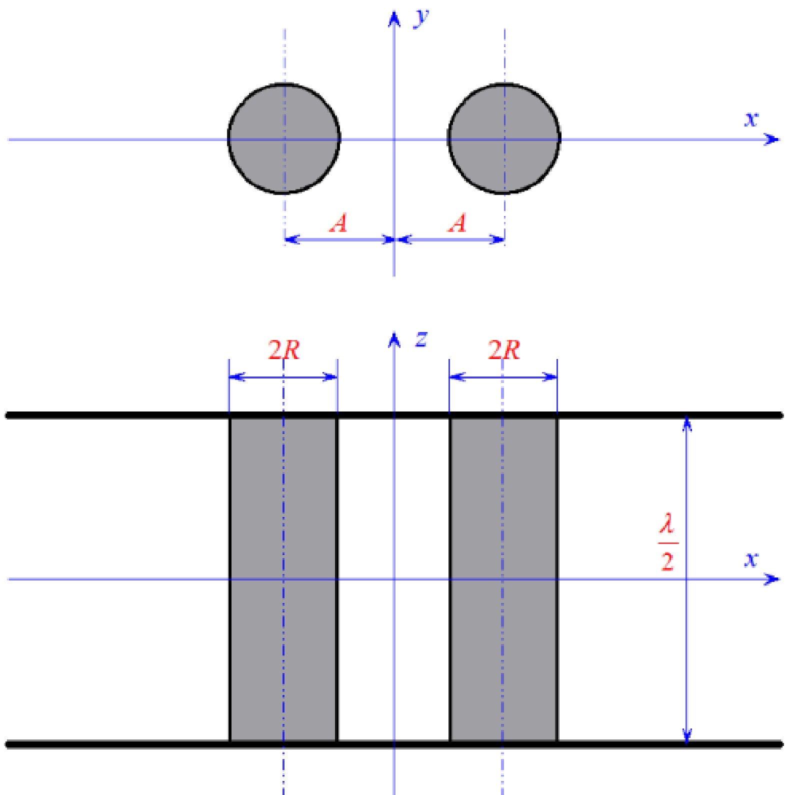
BNL SRF Deflector [1973]



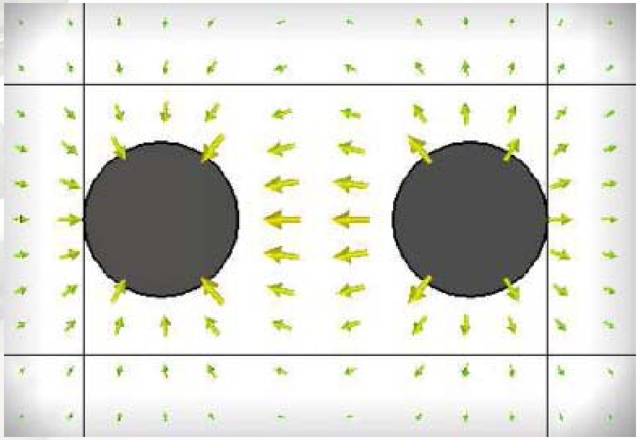
- BNL made the first p mode SRF deflector by machining the parts from solid Niobium.
- The frequency was 8.665 GHz (would have a high BSC resistance)
- Not much consideration of LOM.
- Elliptical cross section to polarise the cavity

Parallel Bar Transmission Lines

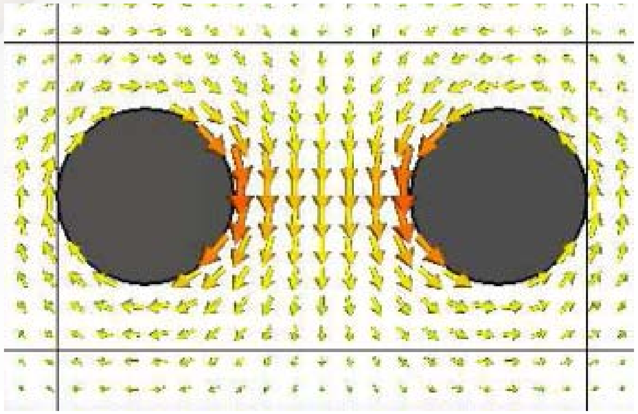
- Just like a coaxial line can support TEM modes, so can a set of parallel bars.
- Their geometry is more suitable for deflectors than coax.



Electric Field

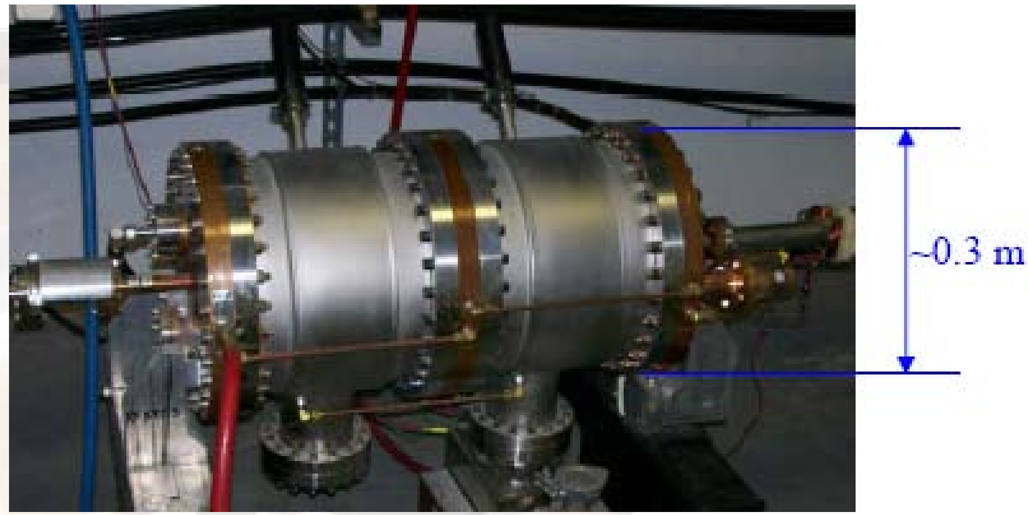


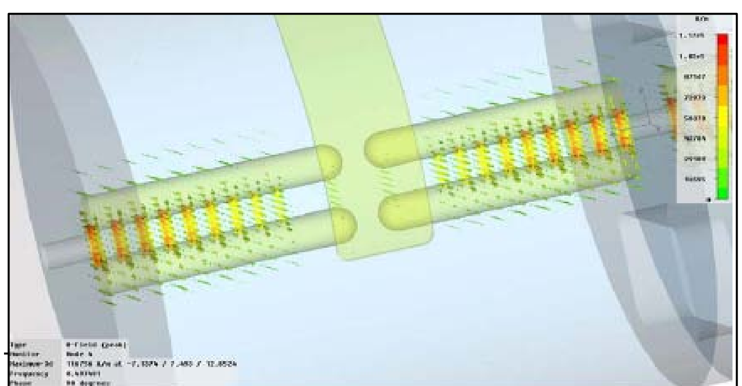
Magnetic Field

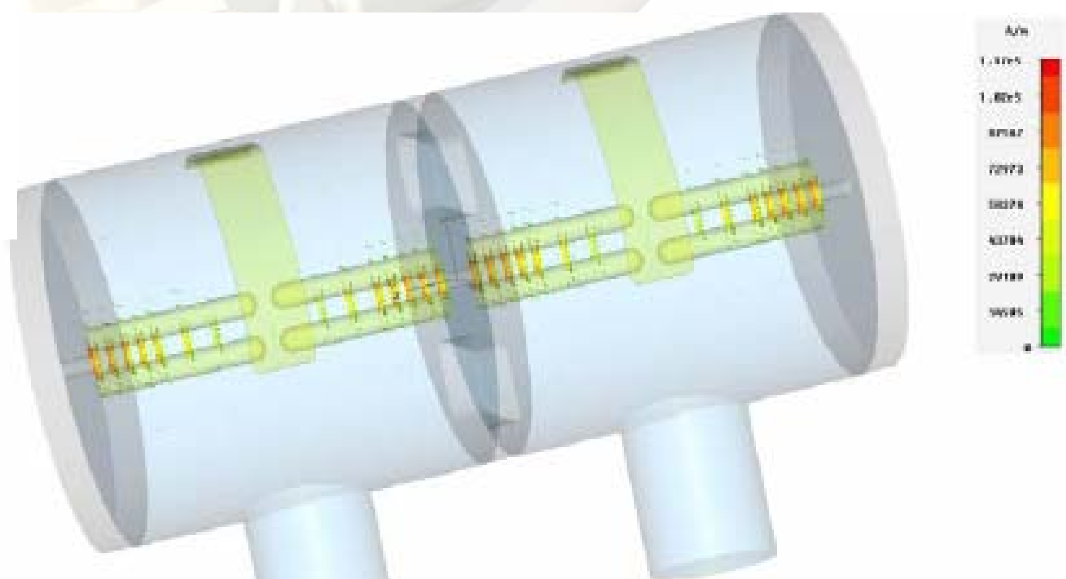


CEBAF Cavity (1993)

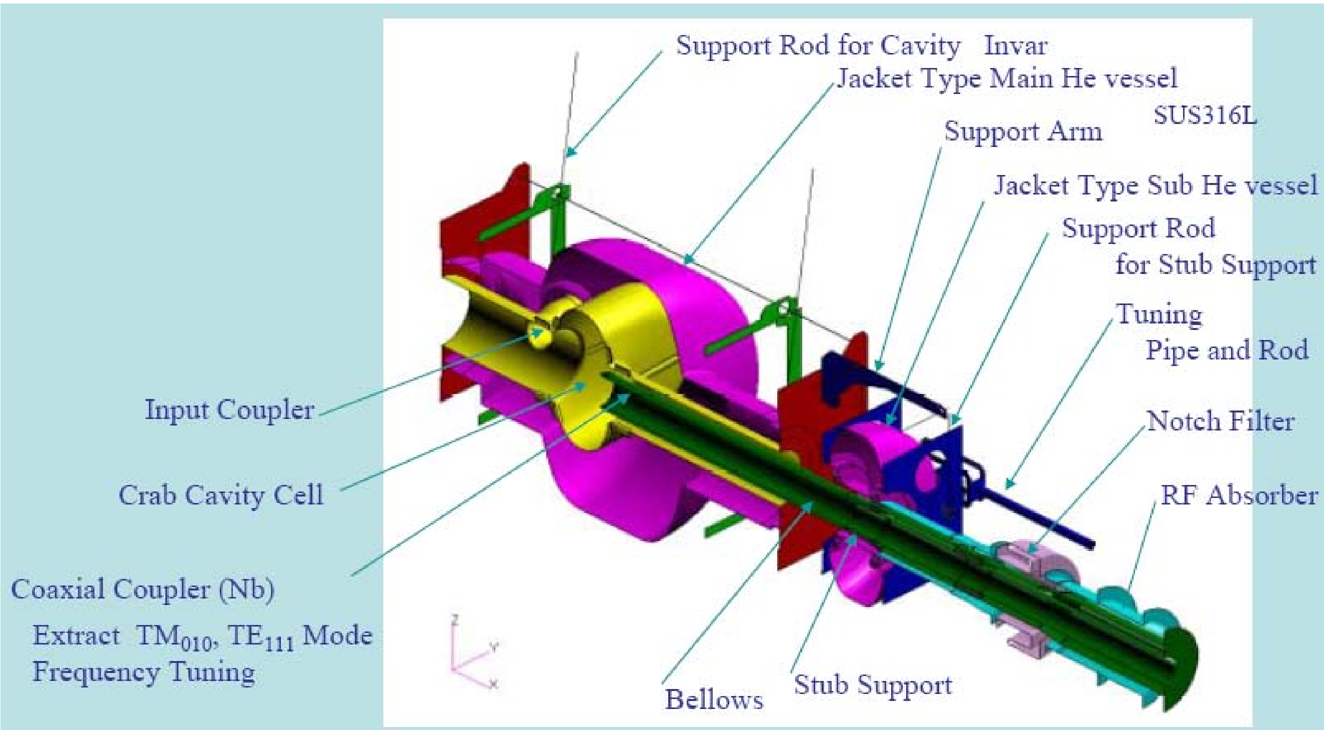
- CEBAF currently uses a compact normal conducting separator.
- It operates using the TEM mode of four parallel rods (two sets of two co-linear rods).
- To provide the transverse deflection a capacitive gap is placed between the two co-linear rods
- 30 cm diameter at 500 MHz





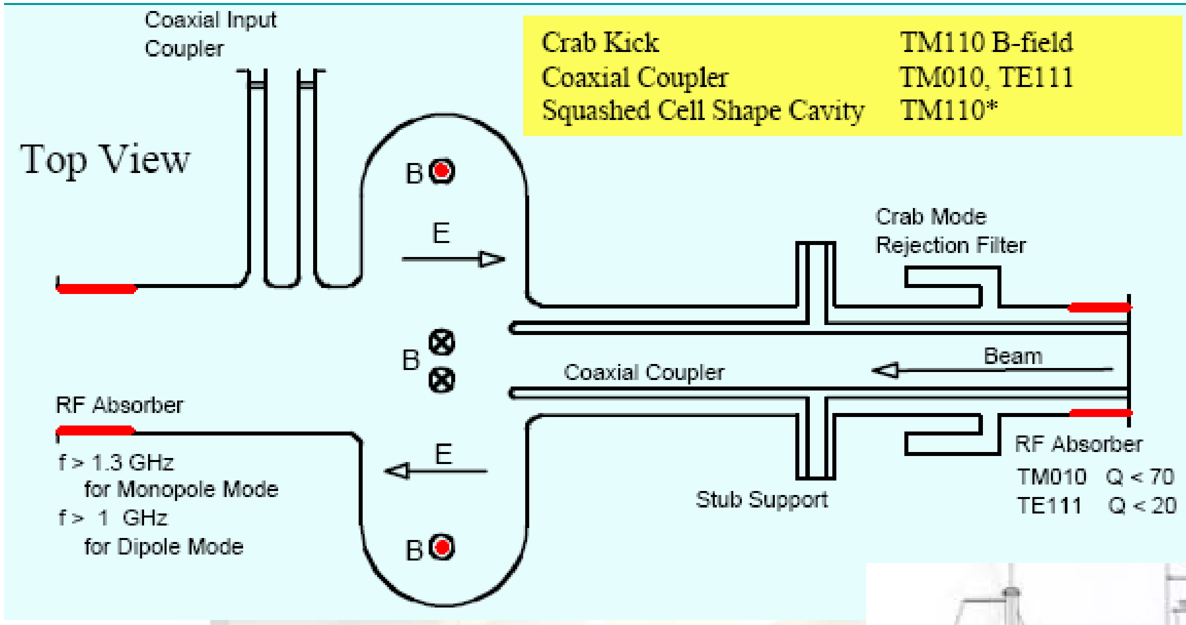


KEK-B Crab cavity (1991-2009)



- 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

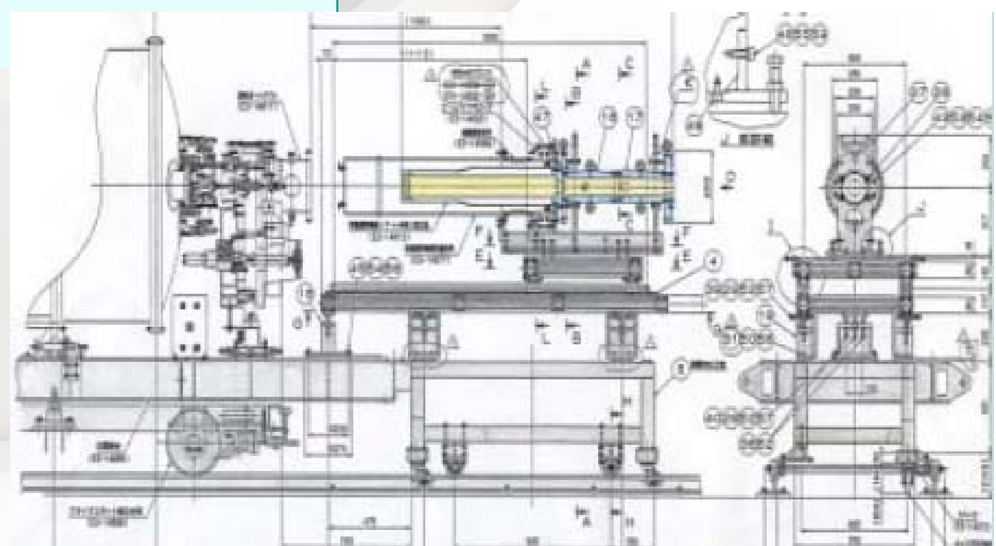
Coaxial Damper



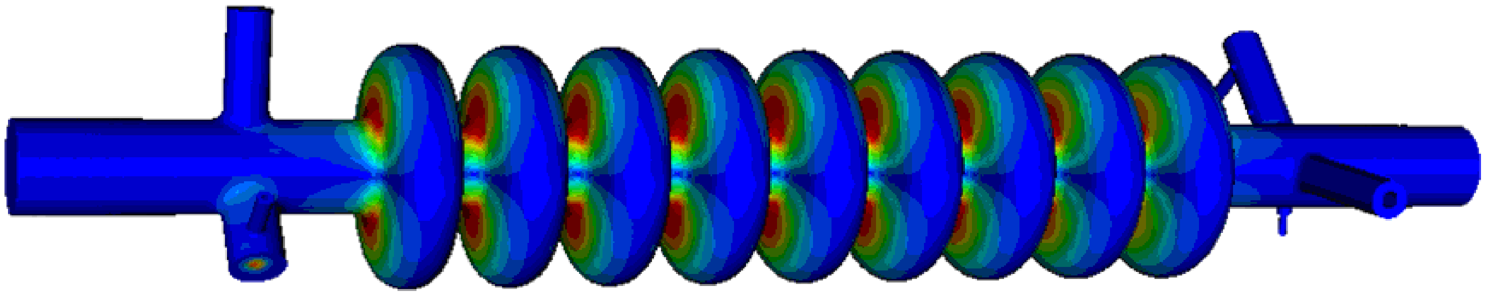
- The cavity has special hollow coaxial dampers to deal with the monopole mode (LOM) of the cavity.
- If the coax is centred it will not couple to the dipole mode as the dipole modes are cut-off in the beam-pipe. Only the TEM mode exists.

If the coax is off centre the crab mode can couple to the TEM coax mode, hence a rejection filter is used.

Alignment is not easy with such a long coupler.



CKM / ILC Crab Cavity

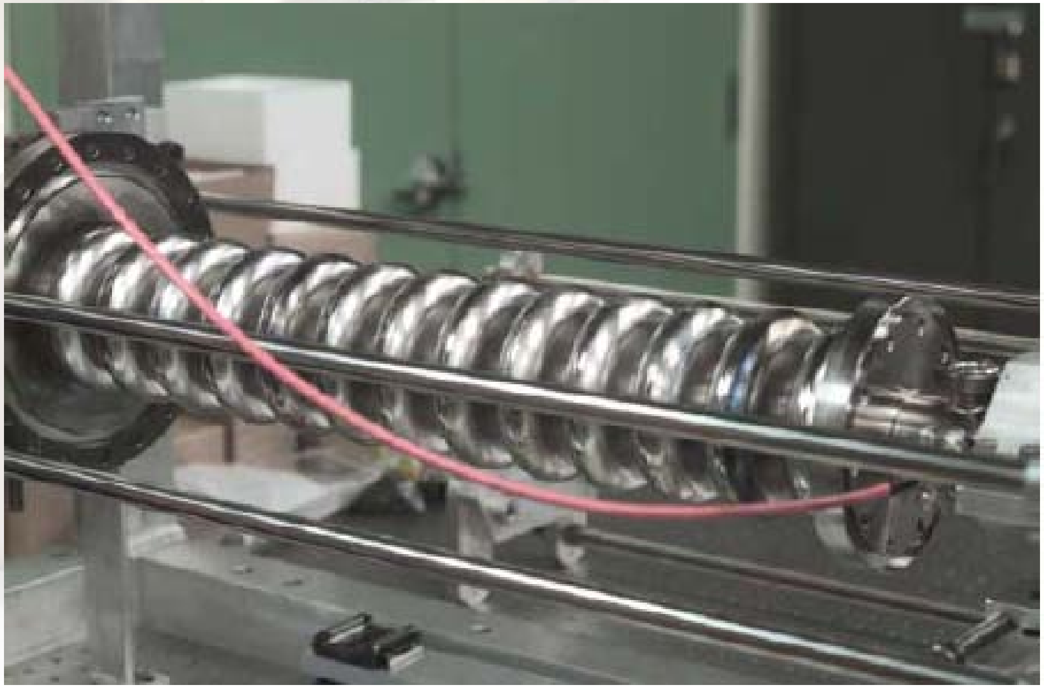


There is also interest in a 9 cell S-band cavity for the ILC.

This cavity is based on the FNAL 13-cell S-band CKM cavity.

A novel hook-type coupler is utilised for strong coupling to the lower order accelerating mode (LOM).

Designed to operate at 5 MV/m deflecting voltage and 73 mT B_{peak}.



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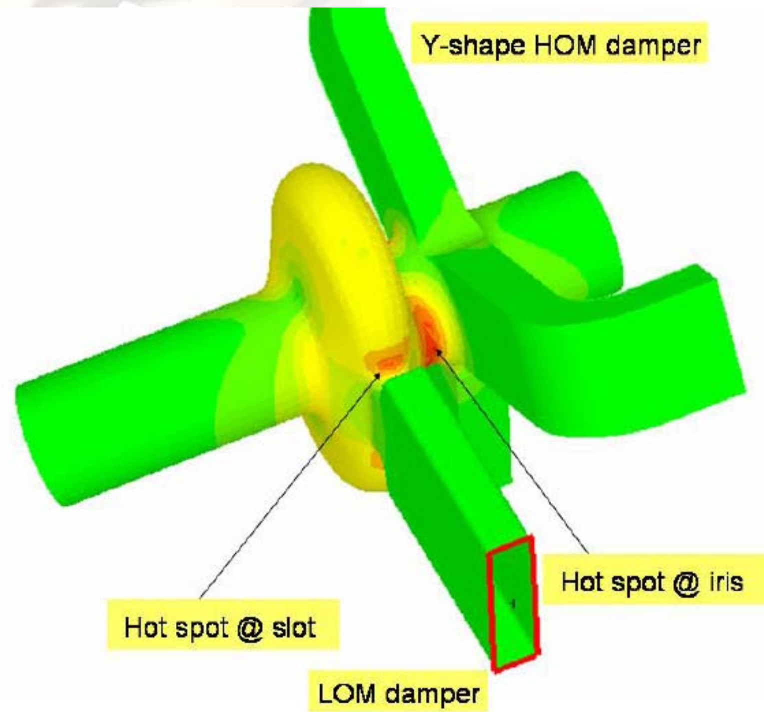
ANL Crab with On-Cell damping

On-cell damping involves coupling directly into the cavity cell as opposed to the beam-pipe as is common in most elliptical cavities.

This is not possible for accelerating modes due to the high surface currents but in crab cavities the fields and currents are zero perpendicular to the mode polarisation.

Jlab have constructed a single cell Nb prototype of the ANL crab cavity with an on-cell waveguide damper.



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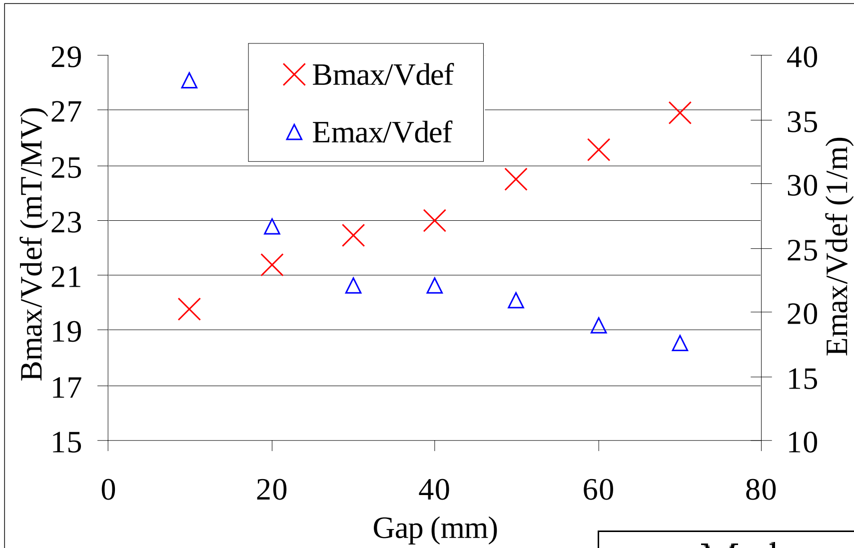
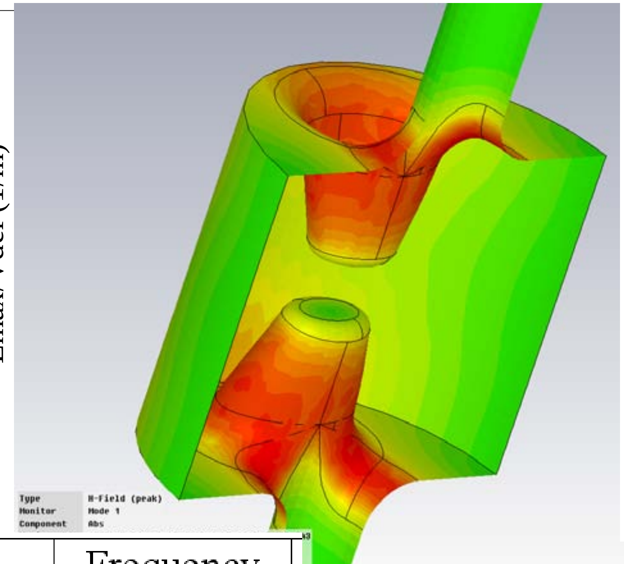
New Shapes - Compact Cavities

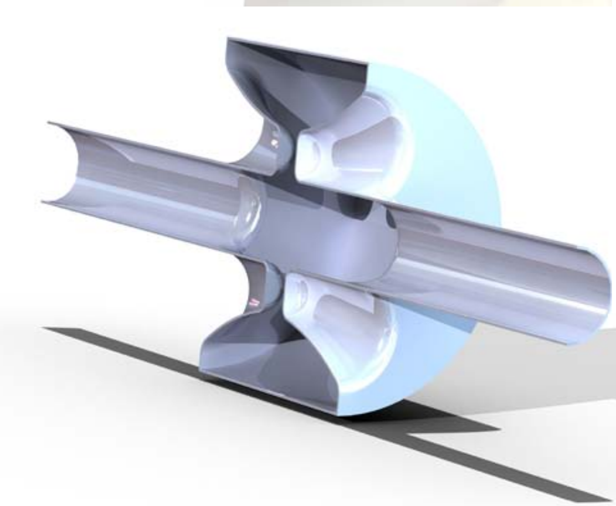
- Many crab cavities operate in areas where space is limited such as the IP of a collider.
- As crab cavities or often larger than accelerating cavities this poses a problem.
- A number of smaller cavities utiling TEM modes have been developed in recent years, similar to the CEBAF cavity concept.

Four Rod Parallel Bar Cavity





A SRF version of the CEBAF cavity is being pursued. This design will require significantly thicker con-cal rods to reduce microphonics.



Mode	Frequency (GHz)
LOM	0.3356
Operating mode	0.4000
1st dipole HOM	0.4866
1st monopole HOM	0.5178

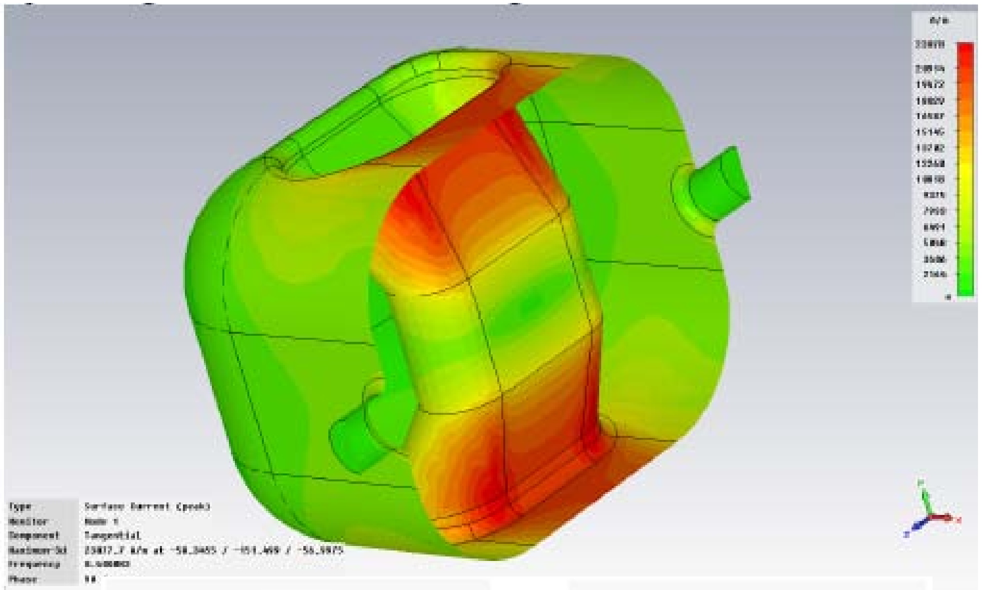
The low fields on the outer can allows couplers to be added easily and a low RRR Nb can be used for the outer can with high RRR for the rods.

At 3 MV we achieve

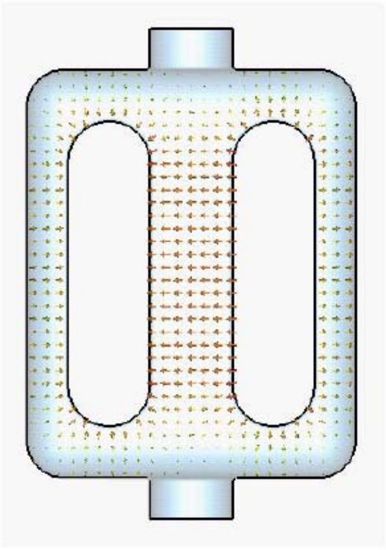
E_{peak}=40 MV/m

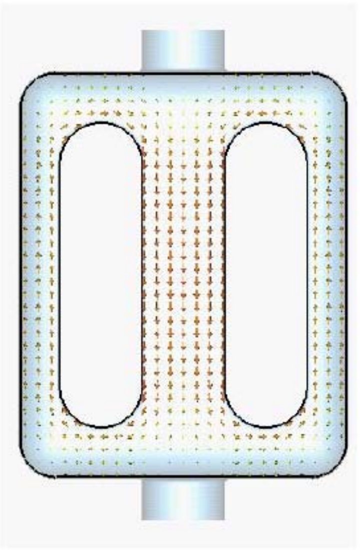
B_{peak}=53 mT

Parallel bar cavity (THPPO023)

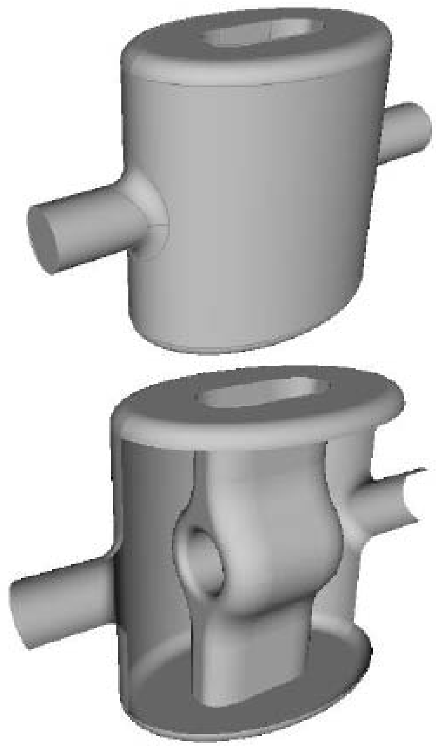


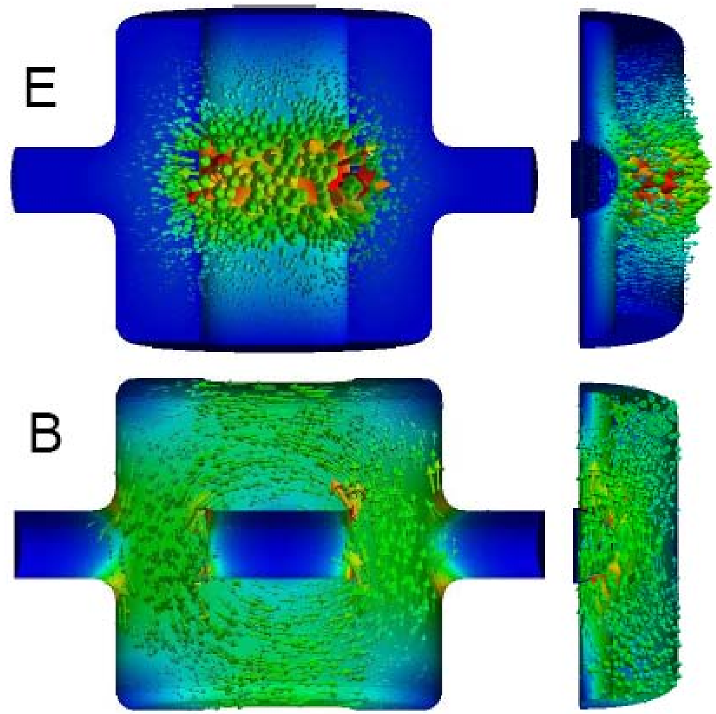
- Another variant of the CEBAF cavity is the Parallel bar cavity.
- This design doesn't need the capacitive gap as the beam travels perpendicular to the rods.
- This means that the peak surface currents is not near the beam-pipes significantly reducing surface fields (22.8 MV/m and 59.4 mT at 10 MV/m kick).





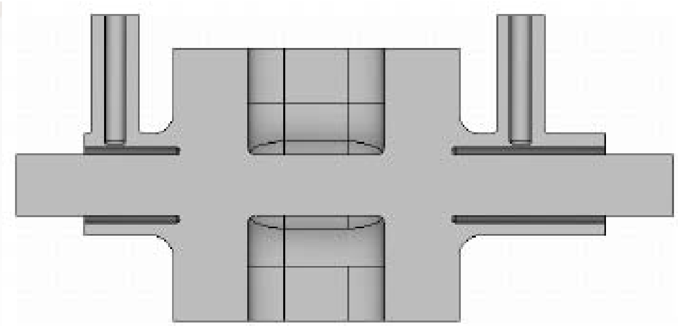
Half Wave Spoke Resonator



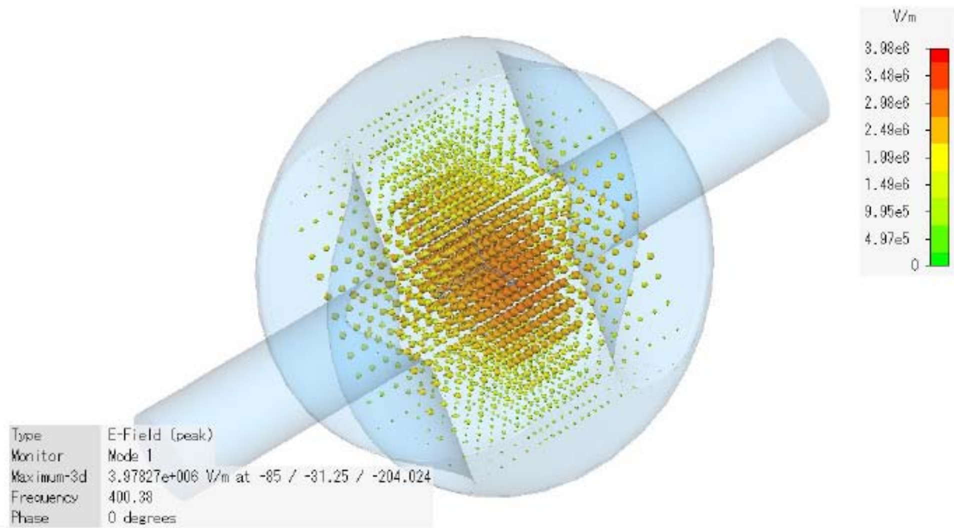


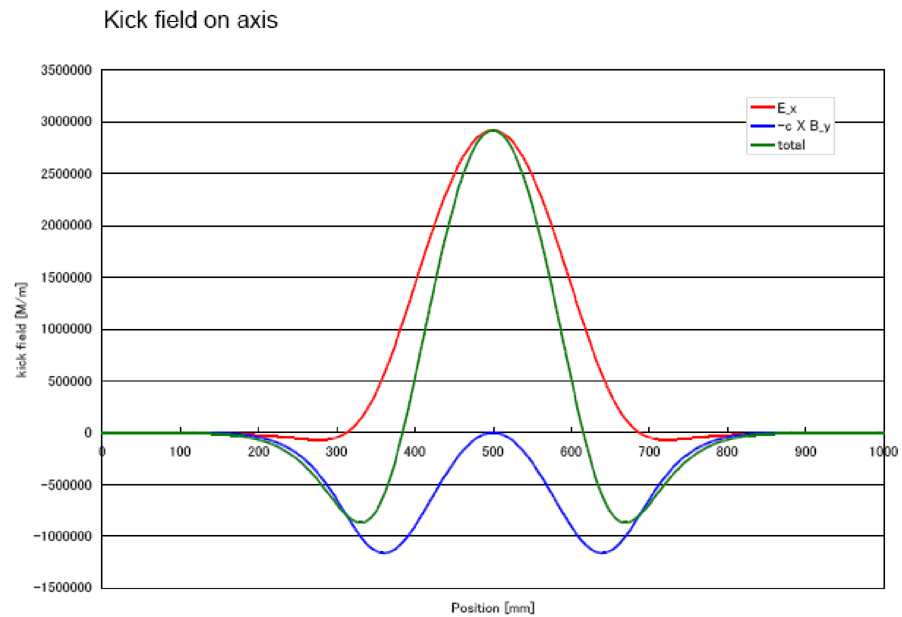
For damping the LOM a coax-coax beampipe coupler is utilised.

This allows the benefit of the beam-pipe coax without the problems of a long coupler

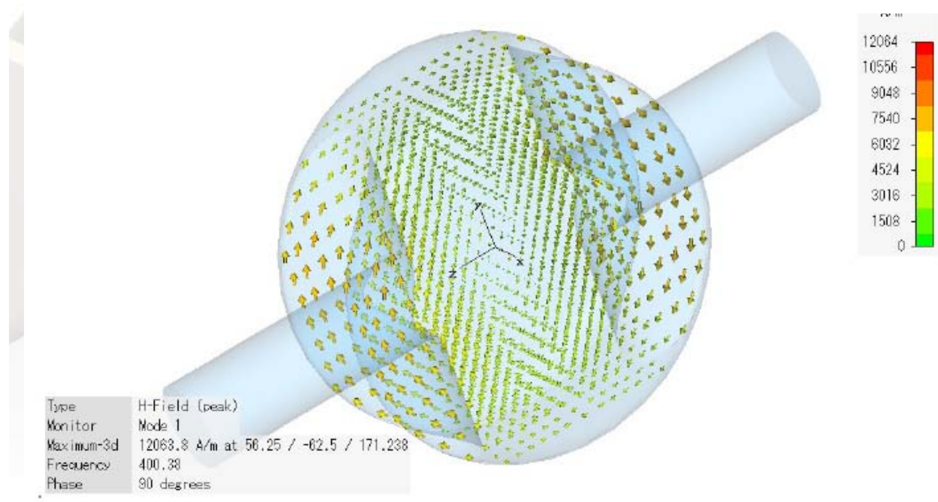


KEK Kota Cavity

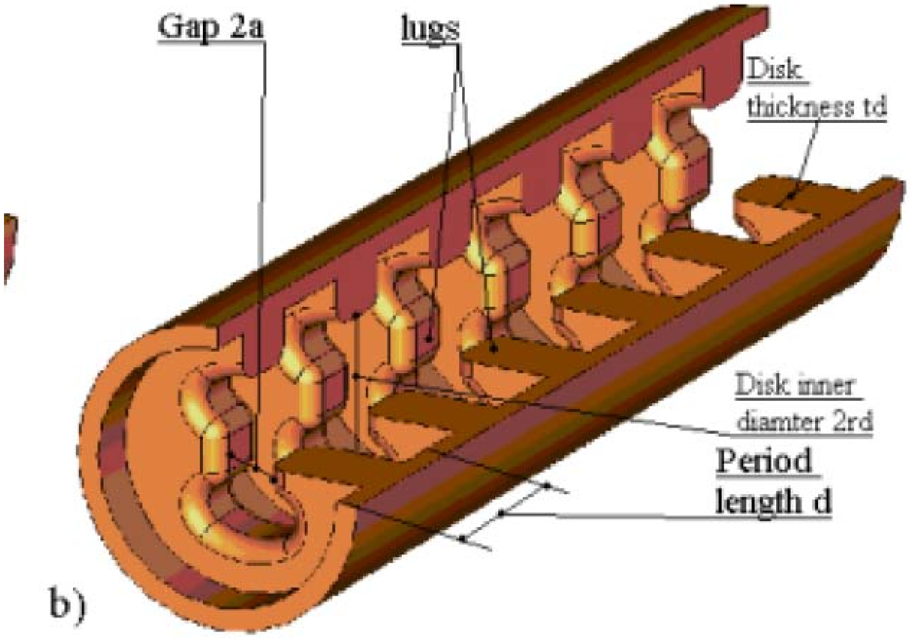


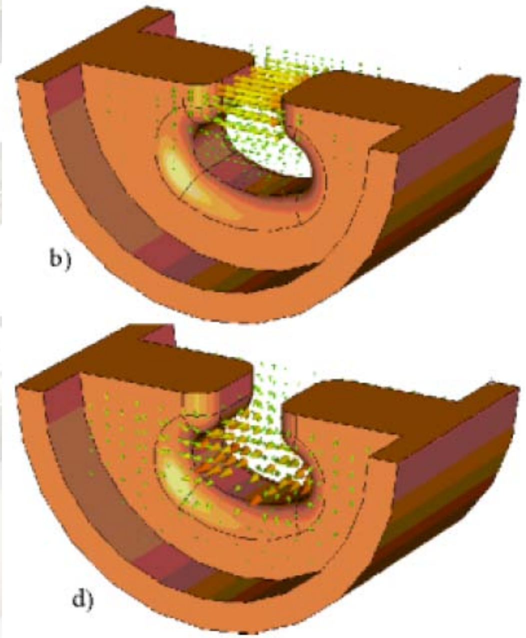


- The KEK Kota cavity is a novel twist on this concept by having the beam travel transversely.
- Normally the E and B field cancel each other out but by using special nose-cones the B field can be shielded.
- For 1.13 MV kick the surface magnetic field is 84.3 mT.



Paramonov Cavity





- A recent cavity proposal ustilises a periodic ridged waveguide loaded cavity to reduce the cavity diameter by a factor of two.
- This structure is designed to be a π mode standing wave cavity.

Summary

- Deflecting mode cavity research is having a resurgence due to crabbing applications.
- There is still a need for deflecting cavities for diagnostic and separation applications.
- Major issues are space, LOM/SOM damping, beam-loading and separation of other modes in the dipole passband.

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