

# R&D on Crab Cavity

Presented by  
by Andrei Seryi  
(SLAC)  
on behalf of Crab Cavity collaboration

*October 27, 2008*

# Crab cavity r&d

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- \* Very active collaboration
  - BNL, LBNL, FNAL, SLAC, JLAB, UK, China, KEK, etc
- \* About a year of focused work
  - Since ~November 2007
- \* Many ideas, cross-fertilization
- \* Come close to selection of a version 0.1 of baseline design
- \* Other ideas will be continued to be developed, as alternative versions
- \* Next, illustrate r&d with slides from KEK, UK, and other colleagues (who could not come in person)

# Suggestions for Contribution for Crab-Cavity R&D from KEK

Kazunori Akai, Kenji Hosoyama,  
Yoshiyuki Morita, Kota Nakanishi,  
Katsunobu Oide

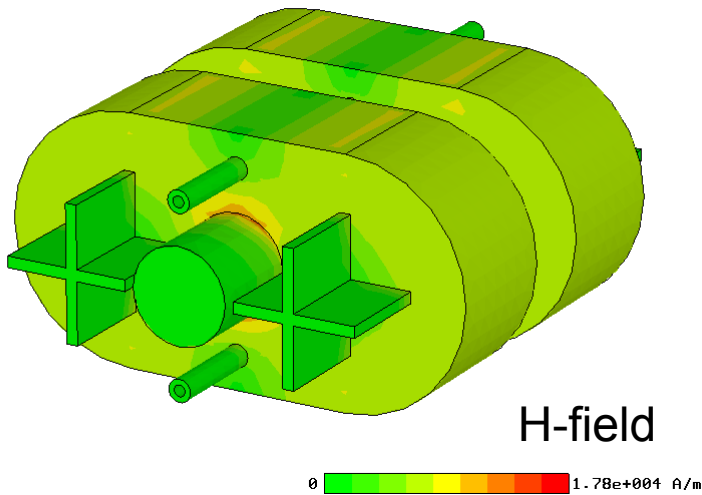
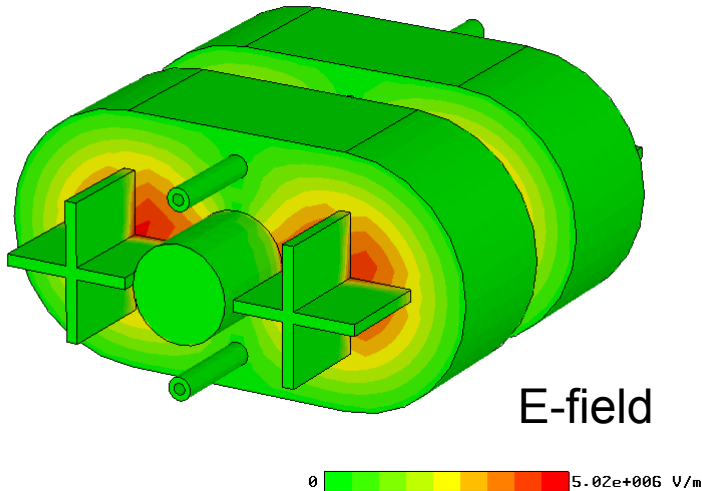
# Conceivable contributions

Not yet founded !!

- Fabrication of prototype CC at KEKB
  - Cavity design: US-LARP design
  - Fabrication of cavity cell
  - Surface treatments (Heat treatment, EP, HPR)
  - Vertical cold test at KEK
  - Fabrication of cryomodule: FNAL/KEK collaboration
- S-KEKB type cavity proposal
  - 2-cell cavity
  - Not really for LHC CC
  - Multipacting simulation
- New design for the compact crab cavity
  - “Kota” cavity

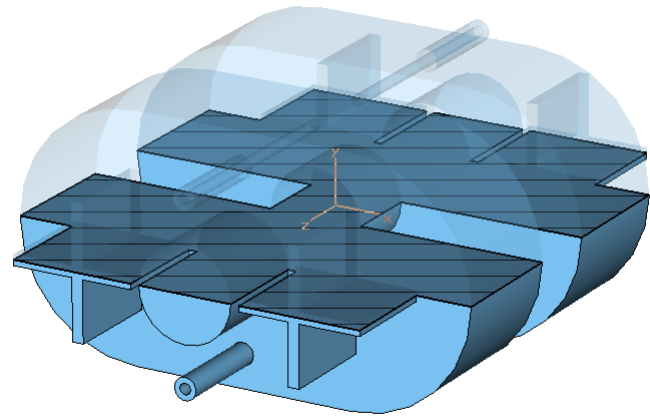
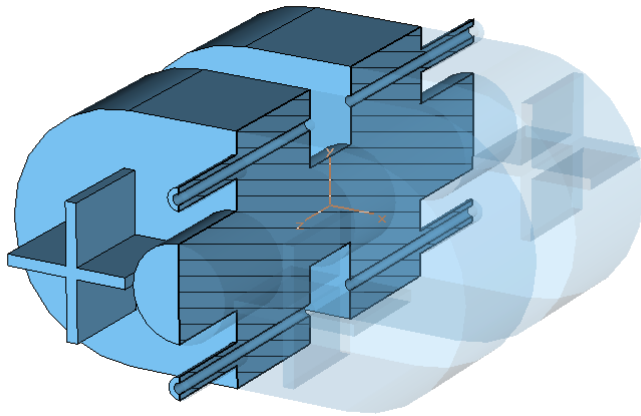
# Two-cell S-KEKB type crab cavity

- Originally designed for S-KEKB
- Coaxial couplers
  - LOM damping ( $Q \sim 50$ )
- Wave guides
  - HOM damping



Frequency	800 MHz
# of Cells	2
R/Q	$\sim 120$
LOM frequency	690 MHz
$Q_{\text{LOM}}$	$\sim 50$

# Cross sections



# Morita-san's comments

- First we have a plan to fabricate the LHC crab cavity, because we have a lot of experiences for crab cavity fabrications. The US-LARP designs the cavity shape. We will fabricate the cavity cell, and surface treatments (heat treatment, electro-polishing, high pressure rinsing). We also test the cavity in the vertical cryostat. We have to collaborate with FNAL to fabricate a cryomodule. Hosoyama-san has made cost estimation; however, this plan is not founded yet. Japanese LHC group want to contribute to the LHC upgrade, not only for the detector upgrade but also for the accelerator upgrade. LHC crab cavity will be included in the Japanese upgrade plan. Oide-san is proposing this plan to be funded.

# Morita-san's comments

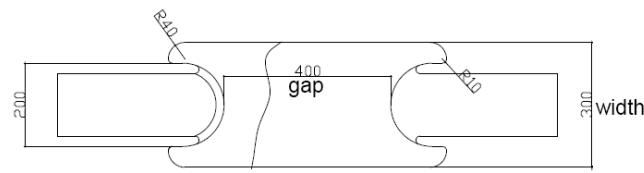
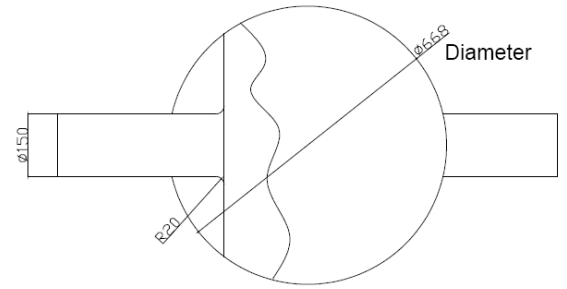
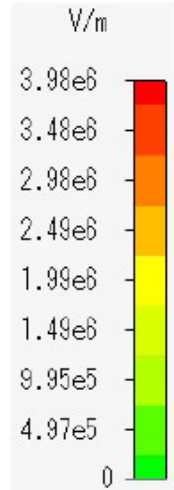
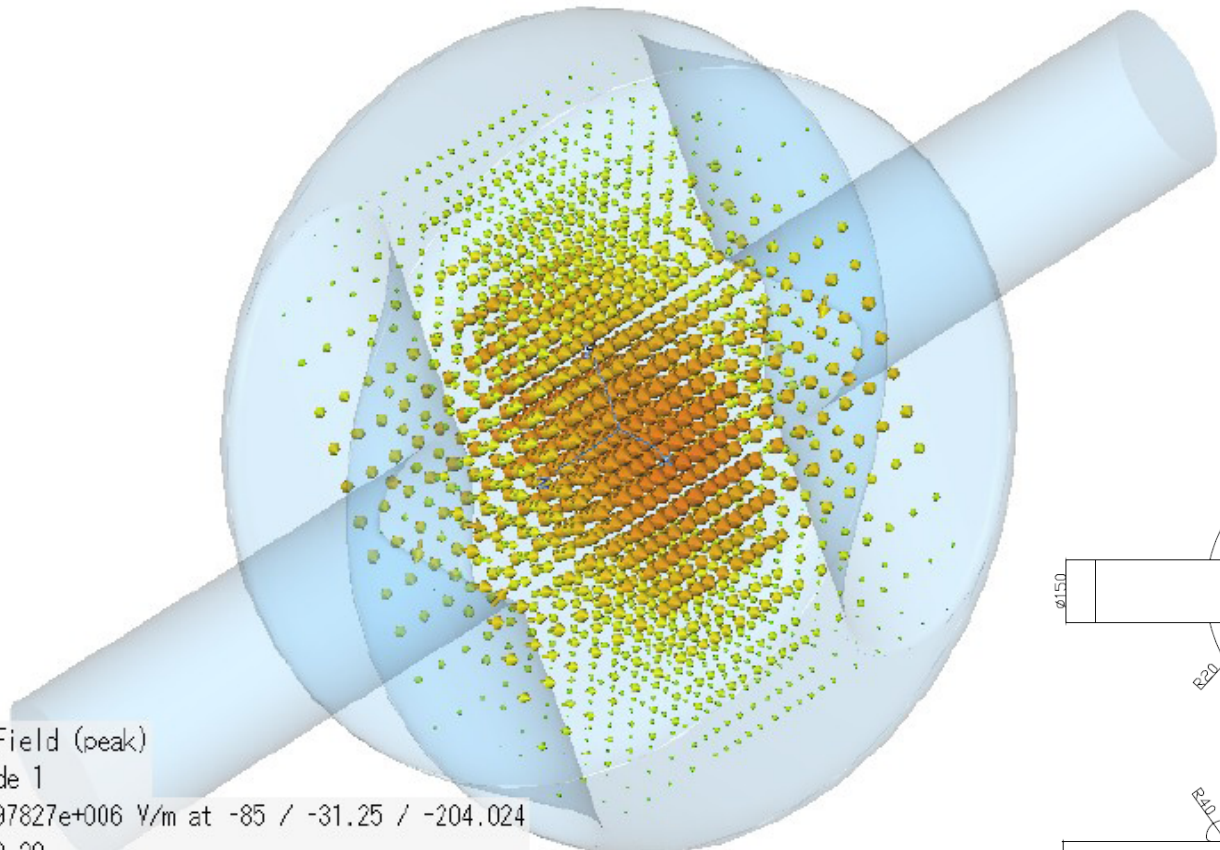
- We will propose 2-cell cavity which was designed for the super KEKB. The super KEKB type cavity has a single cell and a resonant frequency of 1GHz, but it is easy to design 2-cell cavity that has a resonant frequency of 800 MHz. This cavity is not really for the LHC-CC. We have to check the multipacting phenomenon in this cavity. The US-LARP group has a specialist for multipacting simulation. We hope a specialist can check multipacting. I am making an optimization for the cavity shape.
- Compact cavity is very attractive for the future local crabbing scheme. Kota Nakanishi has an idea. We propose his cavity for the compact crab cavity R&D. He will send you some slides.



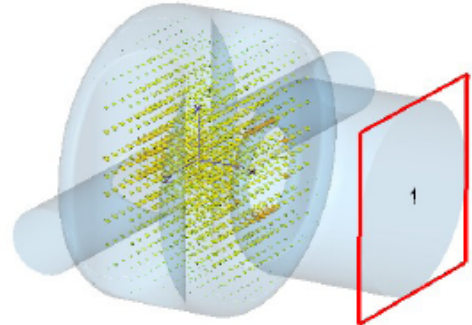
# Kota Nakanishi Concept

- Use lowest mode.
  - The KEKB crab cavity is more complicated than the acc cavity, because of the attached coaxial coupler. The single mode cavity for lowest mode technique is well developed.
- Use the electric field.
  - In the pillbox cavity, both of electric and magnetic field can kick the beam, but the directions are opposite. The magnetic field should be shielded by nose-cone like structure. There is no longitudinal electric field on the beam axis.
- Simple is better.
  - Superconducting cavity require very clean surface. Simple shape is very helpful to make that.

Type	E-Field (peak)
Monitor	Mode 1
Maximum-3d	3.97827e+006 V/m at -85 / -31.25 / -204.024
Frequency	400.38
Phase	0 degrees



With HOM dumping port →





# LHC-CC in the UK

P McIntosh (STFC) on behalf of  
the LHC-CC EUCARD Team

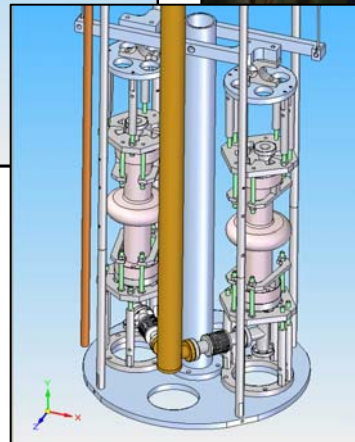
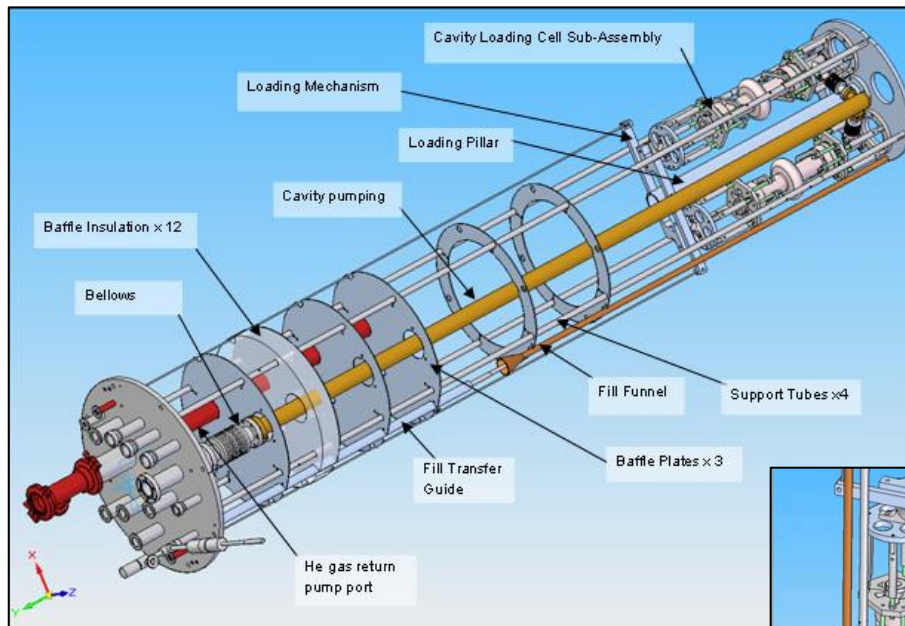


# UK EUCARD (LHC-CC) Proposal

- UK has led crab cavity and associated LLRF system developments for ILC over the past 3-4 years.
- Full integrated testing of these systems is happening right now.
- The UK EUCARD CC proposal targets the fundamental synergies for the design of crab cavity systems:
  - not only for RF structure design and wakefield suppression,
  - but also the RF system control
  - and full system integration and validation.
- **Our EUCARD proposal combines both LHC and CLIC CC R&D.**
- For LHC:
  - Global system preferred:
    - Transverse beam separation restrictions,
    - Frequency limited to 400 - 600 MHz.
  - Emittance growth is a major concern:
    - $\sim 0.010^\circ$  phase tolerance required @ 400 MHz with 300  $\mu$ rad crossing.

# ILC-CC System Tests (Aug 2008)

- Aim: to verify LLRF and synchronisation of 2 x 3.9 GHz SRF crab cavities.







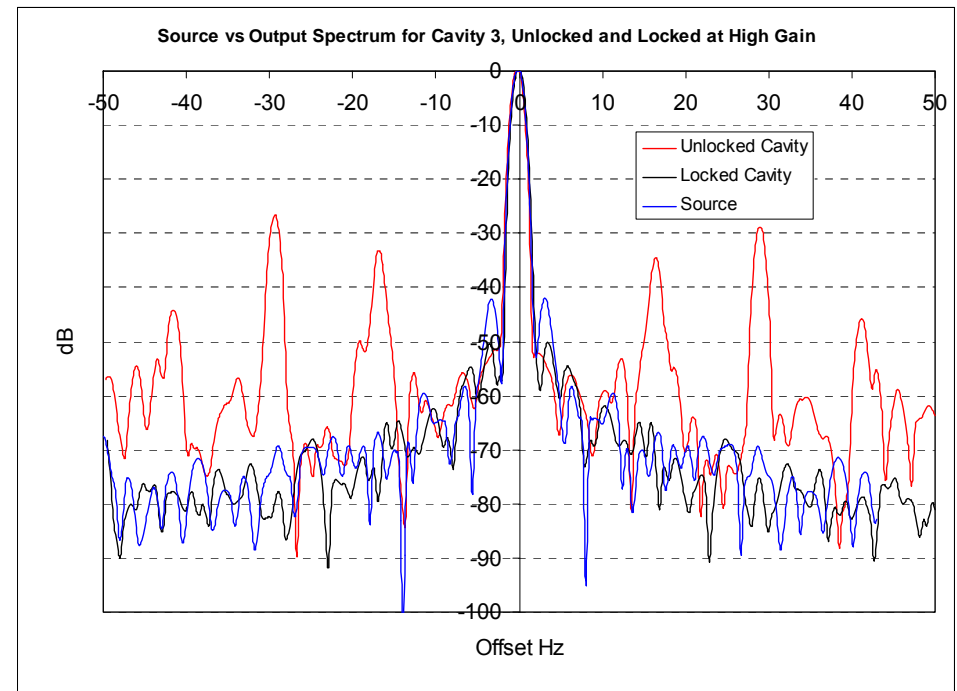
## Peter's comments

- Three single-cell 3.9 GHz dipole mode cavities fabricated at Niowave Inc. and validated to 6-7 MV/m at Niowave in Nov 2007. Vertical tests at Daresbury have utilised two of these cavities in a vertical cryostat to evaluate the DSP/FPGA LLRF system developed in reaching the ILC stability spec of 0.12deg.
- Tests performed in Aug 08 have both cavities tuned close in frequency via the tuning assemblies for each cavity. Both cavities could easily be phase locked to the 3.9 GHz source oscillator, however the noise for this device was excessive at ~0.1deg.
- Synchronising both cavities to each other highlighted the major sources of noise in the system, the source being the most dominant. Improvements are being implemented to improve the noise performance of the system and a further test is scheduled for next month.



# ILC-CC System Tests (Aug 2008)

- Independent phase lock achieved for both cavities:
  - Unlocked  $\Rightarrow 10^\circ$  r.m.s.
  - Locked  $\Rightarrow 0.14^\circ$  r.m.s.
- Performance limited by:
  - Source noise (dominant)
  - ADC noise
  - Measurement noise
  - Cavity frequency drift
  - Microphonics
- Improvements being made.
- Next test:
  - to verify synchronisation of both cavities to  $< 0.12^\circ$  r.m.s.
- Scheduled for Nov 2008.





## UK EUCARD (LHC-CC) Request

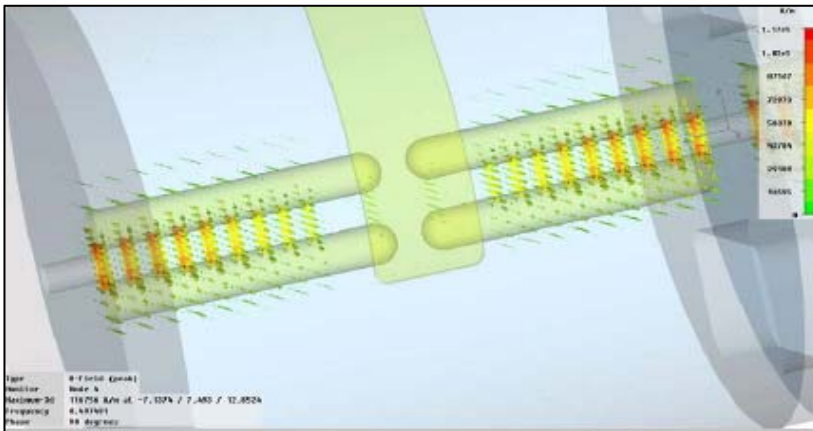
- STFC, CI-Lancaster University and CERN.
- Proposal underwent several cuts, resulting in:
  - Total staffing: 1.5 FTE/yr (over 3 years)
  - Total capital, consumables etc: 72k€
    - Model tests of cavity/couplers and LLRF
  - Total LHC proposal cost: 677k€
    - EU to provide 30%
  - Deliverables:
    - LHC-CC cavity, couplers and tuners designed and verified
    - LLRF system verified
    - Integrated system performance verified (limited by funds)





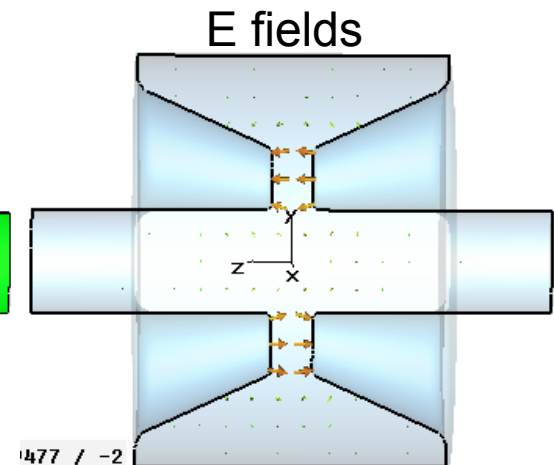
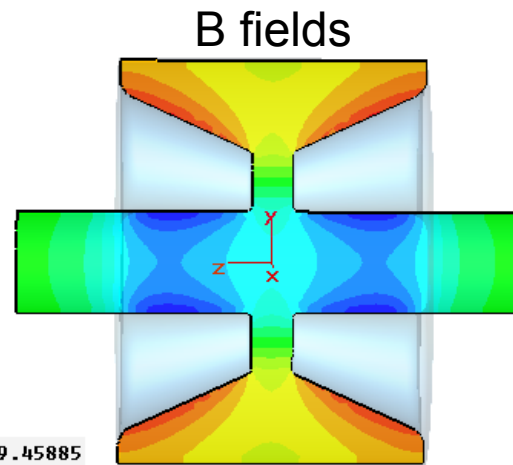
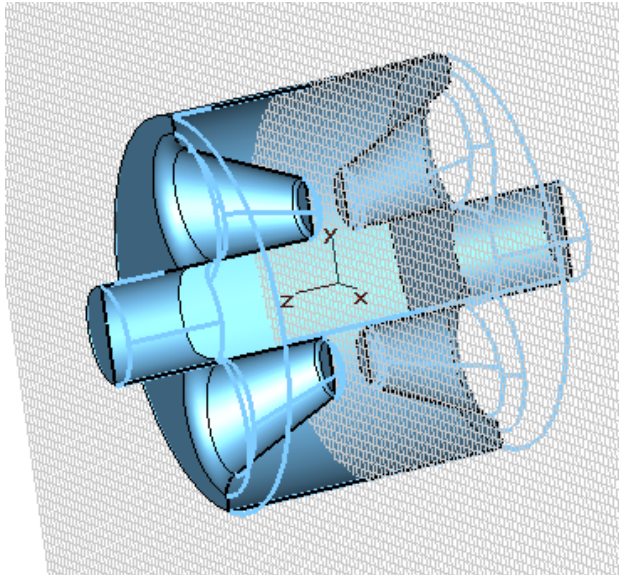
# Initial Studies for a Compact CC

- Modification of existing CEBAF 2-rod separator cavity (collaboration with J Delayen at JLab):
  - Has 200 MHz and 400 MHz options,
  - Has a 10 cm diameter beampipe,
  - Has 40 cm diameter for both frequencies.
- CEBAF separator cavity is:
  - 499 MHz,
  - 2-cell,
  - $\sim\lambda$  long
  - $\sim 0.3$  m diameter,
  - can produce 400kV deflecting voltage with 1.5kW input RF power.
- $Q_{cu}$  is only  $\sim 5000$  (structure wise), the stainless steel cylinder only takes less than 5% of total loss.
- The maximum surface magnetic field at the rod ends is  $\sim 14.3$  mT.
- Water cooling needed on the rods.
- If Nb used for this type of cavity, the  $V_{\perp}$  is  $\approx$  KEKB CC.
- Microphonics and fabrication issues to be resolved.





# Modified 2-Rod Design

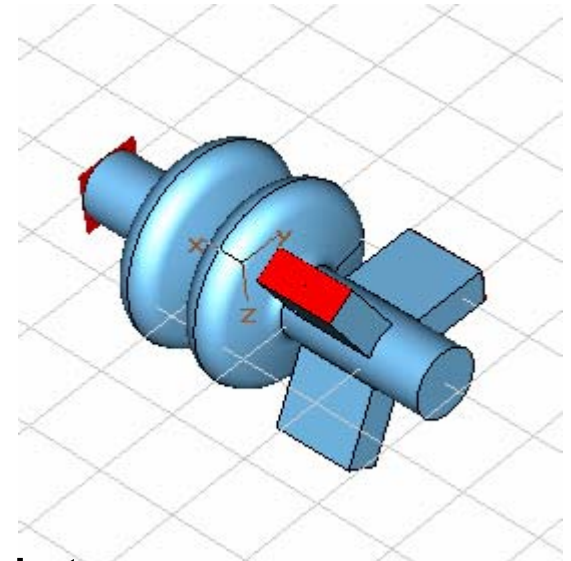
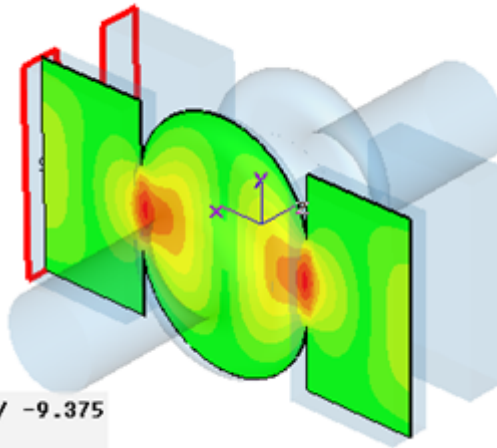


- At 400 MHz, and  $V_{\perp} = 3$  MV:
  - single cell (length = 30 cm)
  - $R/Q = 700$  Ohms
  - $E_{\text{max}} = 90$  MV/m
  - $B_{\text{max}} = 120$  mT
- At 200 MHz, and  $V_{\perp} = 5$  MV:
  - single cell (length = 80 cm)
  - $R/Q = 2800$  Ohms
  - $E_{\text{max}} = 50$  MV/m
  - $B_{\text{max}} = 60$  mT

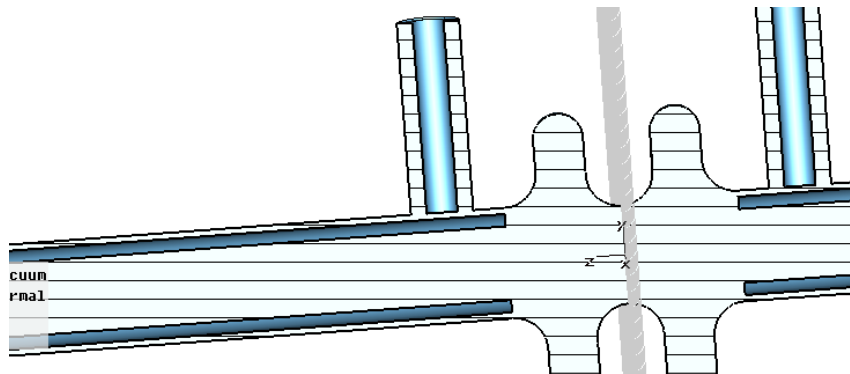
# Mode Damping Studies

The CI are simulating a wide variety of damping schemes to evaluate optimum designs.

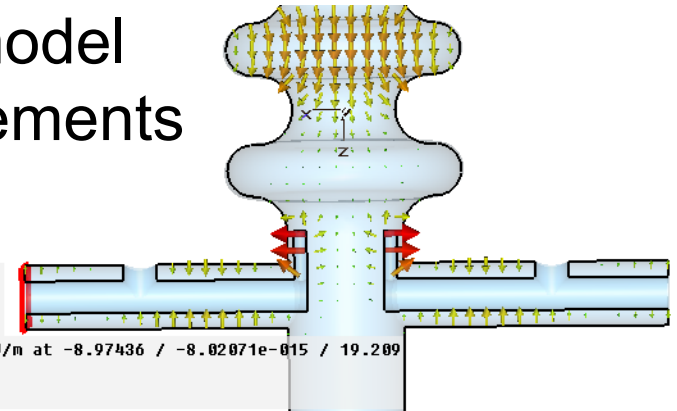
Type	E-Field (peak)
Monitor	Mode 1
Component	Abs
Plane at z	-9
Maximum-2d	7.54623e+006 V/m at 17.661 / 0 / -9.375
Frequency	0.802207
Phase	0 degrees

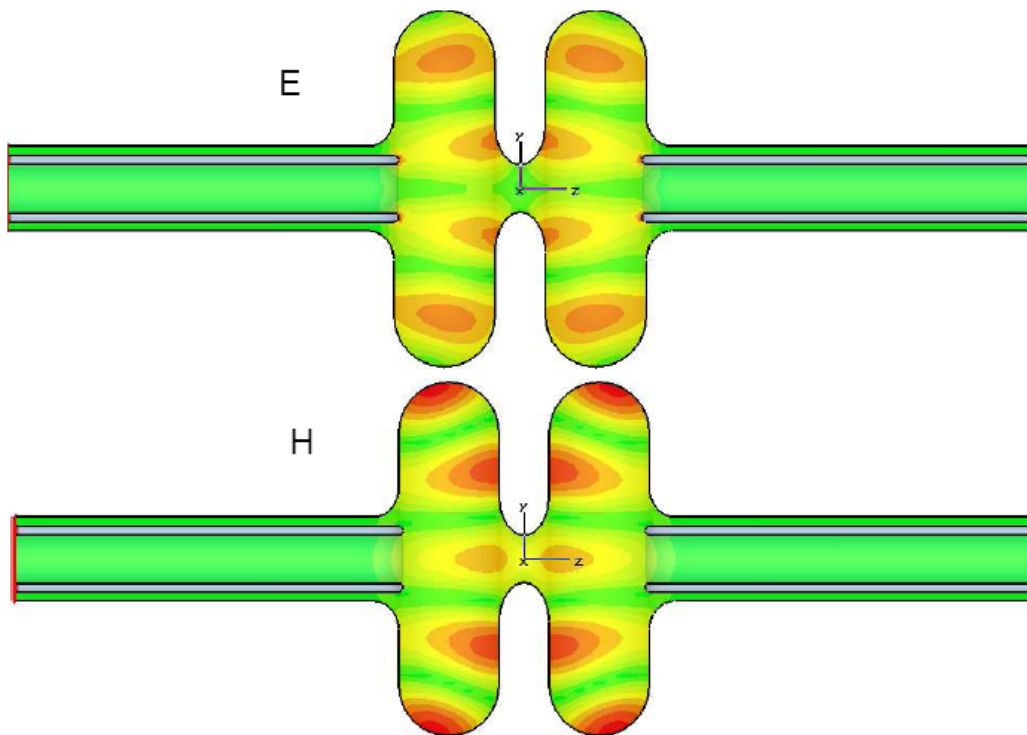
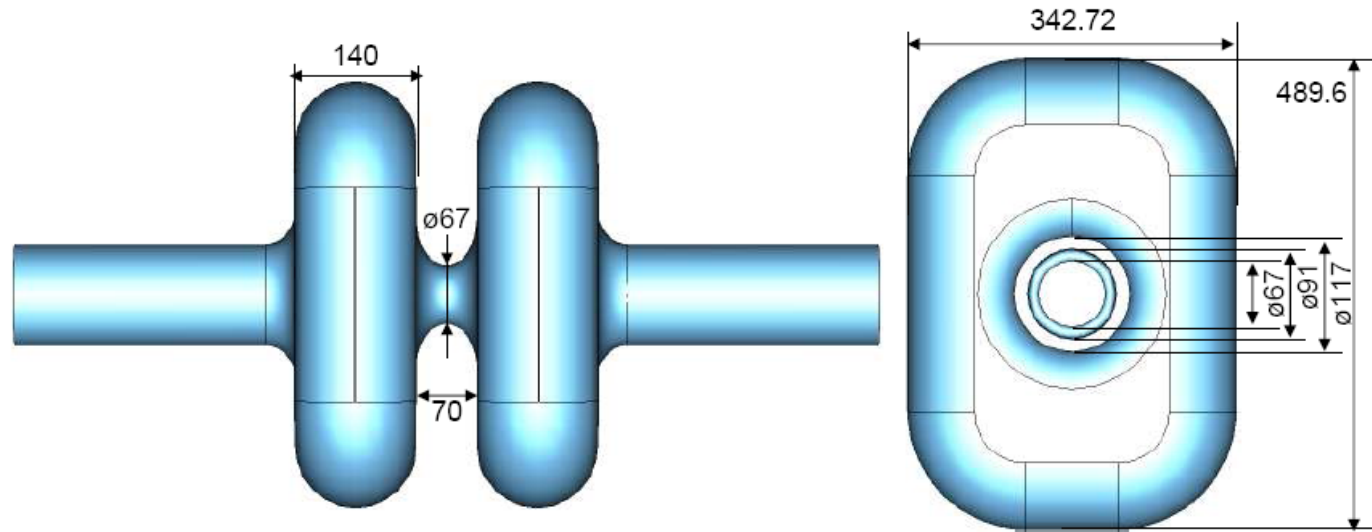


Plan to validate  
with model  
measurements



Type	E-Field (peak)
Monitor	Mode 2
Plane at y	0
Maximum-2d	1.04082e+007 V/m at -8.97436 / -8.02071e-015 / 19.209
Frequency	0.652383
Phase	0 degrees





LHC CRAB CAVITY FOR GLOBAL  
SCHEME.  
FNAL Update

I. Gonin, N. Solyak, and V. Yakovlev  
FNAL

Crab Cavity Webex meeting, July, 16

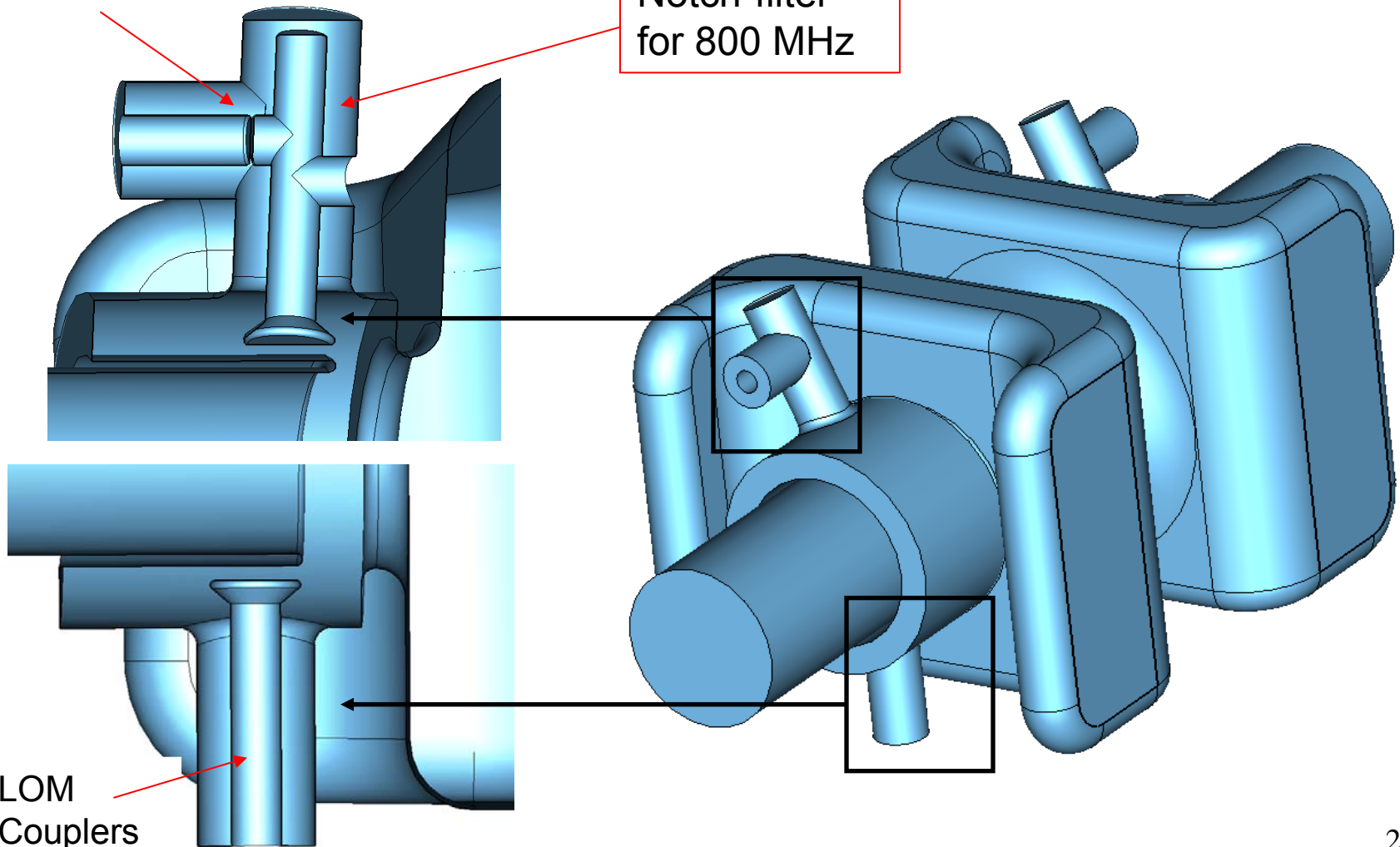
Electric and Magnetic fields distribution for  $TM_{120,0}$  mode.

$F=1366.1$ ,  $R/Q=146 \text{ } \Omega/\text{m}$ ,  $Q=32000$ ,  $R=4.6 \text{ M}\Omega$ .

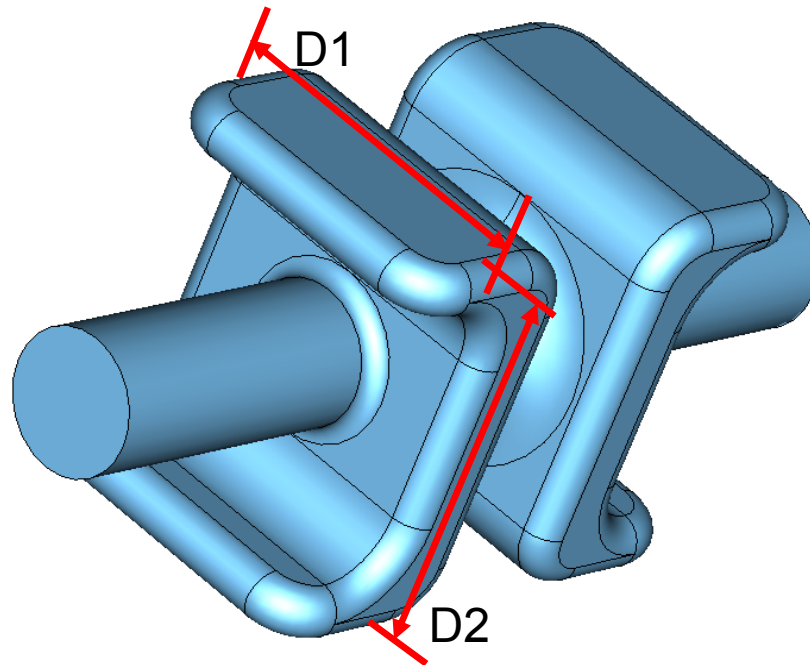
# FNAL CRAB CAVITY WITH QUARTEWAVE COUPLERS (alternative compact design)

HOM and FP Couplers

Notch-filter  
for 800 MHz



## RESULTS OF FIRST 3D OPTIMIZATION



Monopole modes

F, MHz	Q	R/Q, Ohm
661.2	38	186
664.6	37	12.9
1052	1500	1.2
1055	1510	35.2

$P < 2 \text{ kW}$

$P = 2.5 \text{ kW}$

a	50
b	60
A	50
B	45
$L_{\text{gap}}$	125
D1/D2	294/350

$V_{\perp}^*$ , MV	2.5
$B_{\text{peak}}$ , mT	77.4
$E_{\text{peak}}$ MV/m	31.7
$R_{\perp}/Q$ , Ohms	52.5

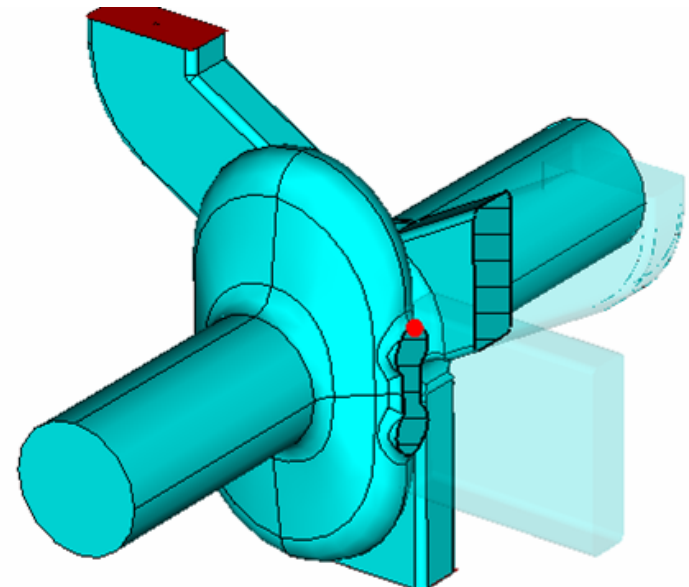
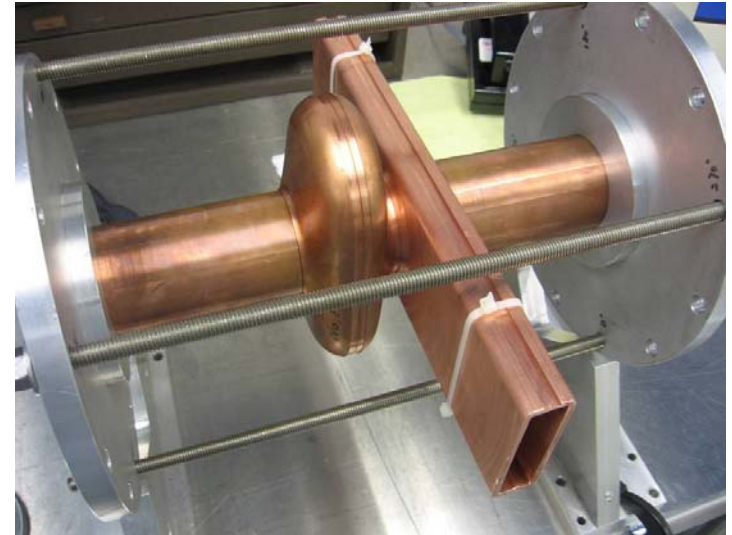
\*  $V_{\perp} = \Delta p_{\perp} c / e$

Dimensions (in mm) and main parameters of FNAL Crab cavity

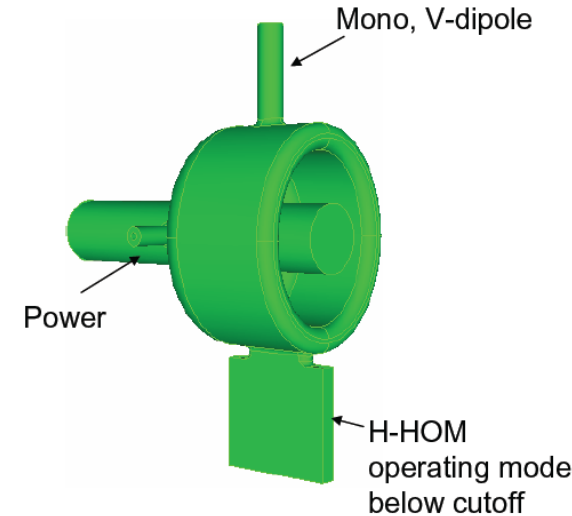
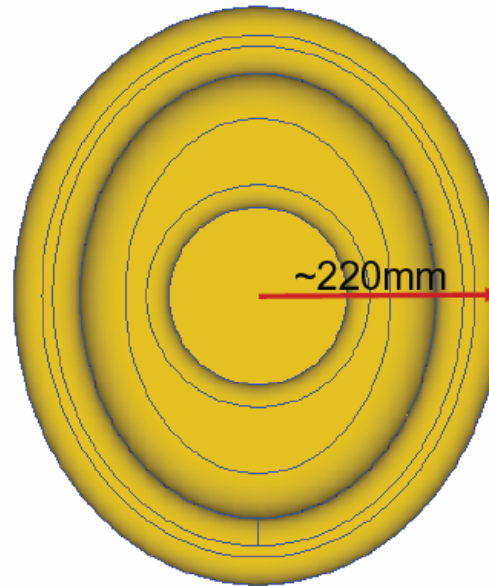
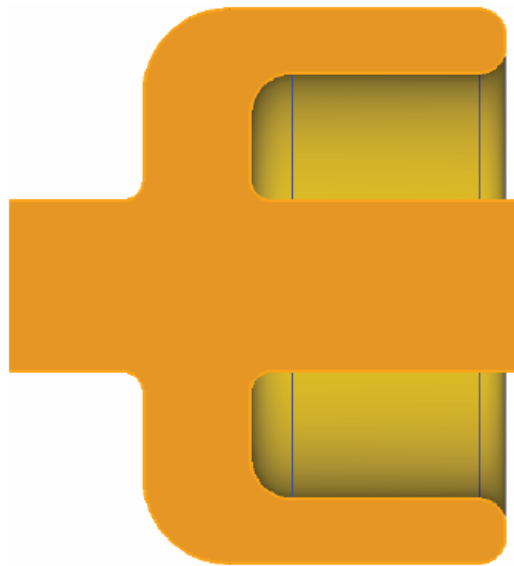


# HOM/LOM Coupling

- Recent progress....
  - Squashed cavity
    - Reduced magnetic field
    - Degenerate mode separation
  - On-beam-pipe damping
    - Simulation and experiment shows stub coupling promising. With an optimized stub length, get  $Q_{\text{ext}} \sim 200$
  - On-cell damping
    - Field enhancement acceptable
    - $Q_{\text{ext}}$  low to several tens
    - Need to check multipacting
  - Multi-cell
    - Cell-to-cell coupling studied
    - 2-cell/4-cell structure
- Effort highly leveraged on existing programs



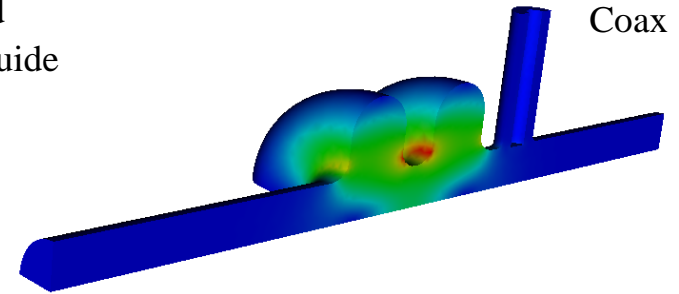
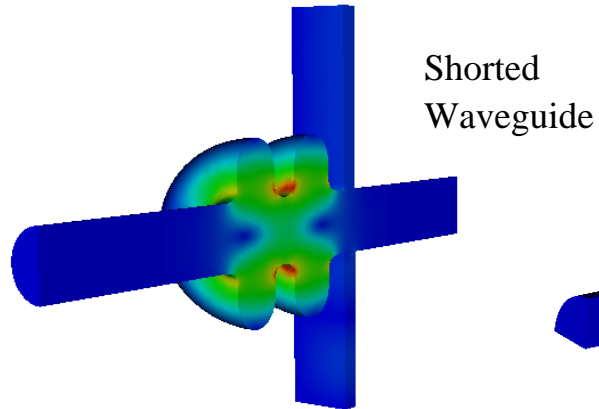
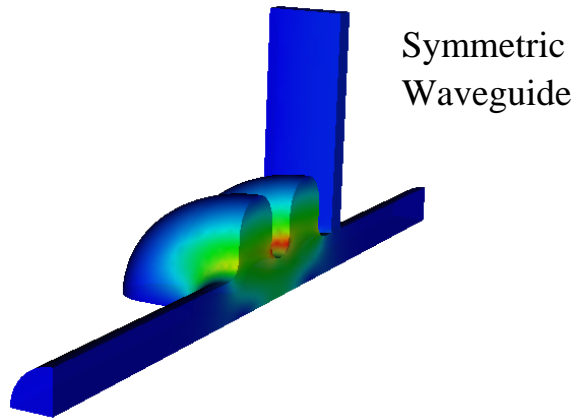
# 400 MHz Half-Wave Resonator Crab Cavity



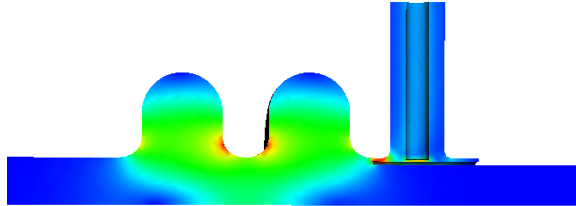
- Crabbing voltage needed doubles as compared with 800MHz cavity
- One gap per cavity
- 3-4 cavities needed per beam



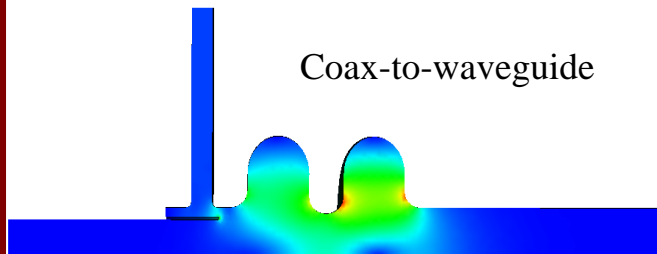
# LHC Crab Cavity Conceptual Design at SLAC



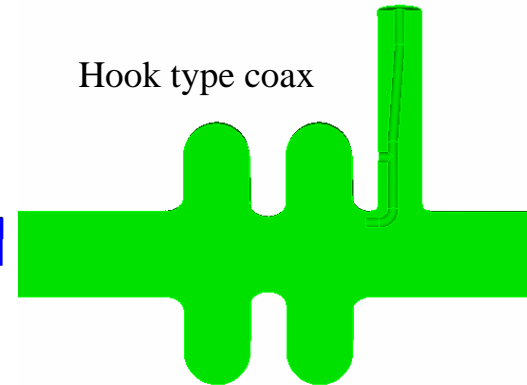
Coax-to-coax



Coax-to-waveguide



Hook type coax



*Liling Xiao, Zenghai Li*

Advanced Computations Department, SLAC

# Draft merit table for design comparison

Parameter	Version baseline	Version alternative 1 ...
Epk		
Bpk		
R/Q		
cell-to-cell coupling		
Beam pipe radius		
Transverse size (Equator Radius)		
Loss factor (longitudinal)		
Transverse loss factor		
LOM, R/Q, Qext		
SOM: R/Q, Qext		
Multipacting		
Fabrication		
Chemistry complexity		
Cryostat complexity		
Assembly & associated components		