Science & Technology Facilities Council
ASTeC

Prospects of Compact Crab Cavities for LHC

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LHC-CC Workshop, CERN
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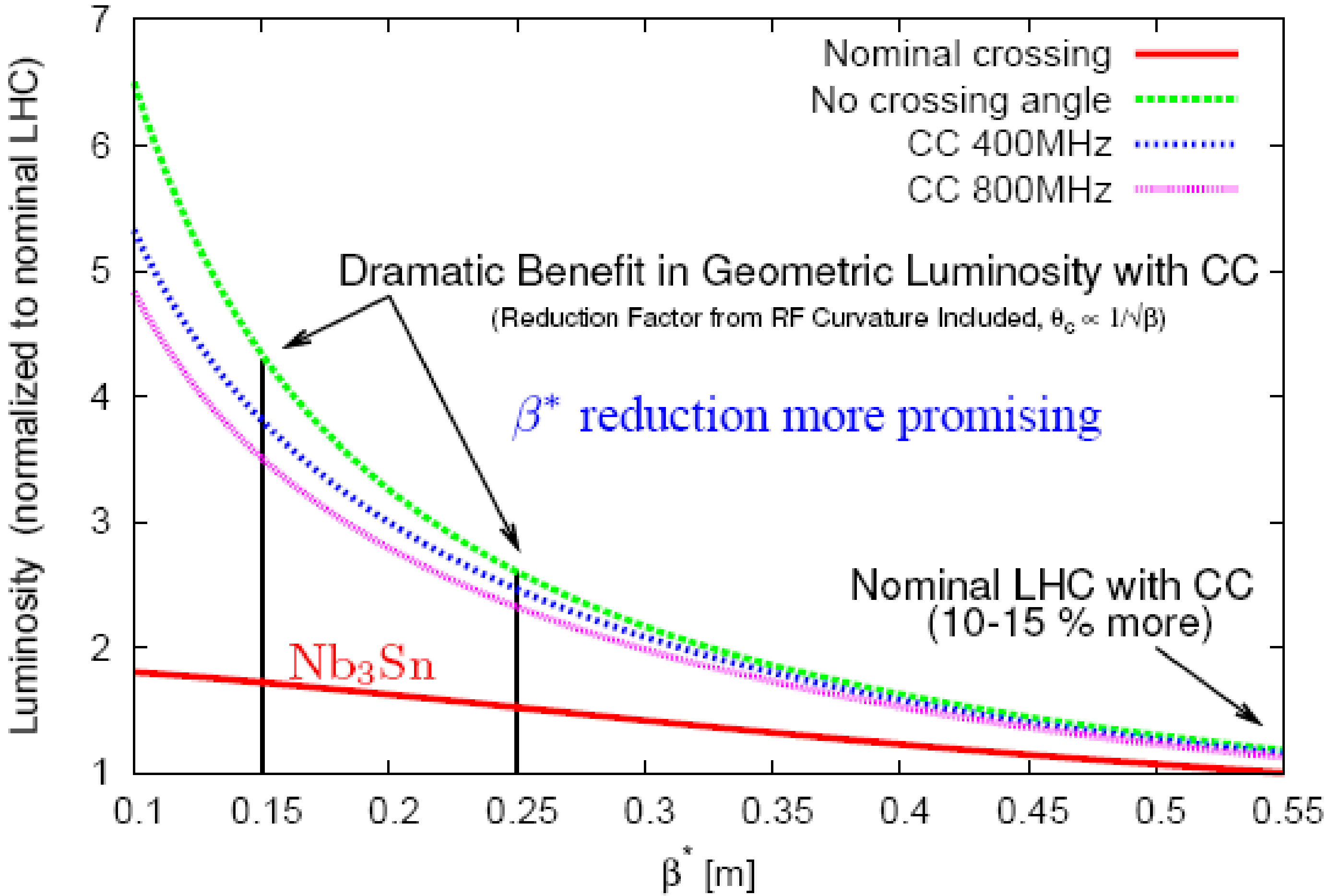
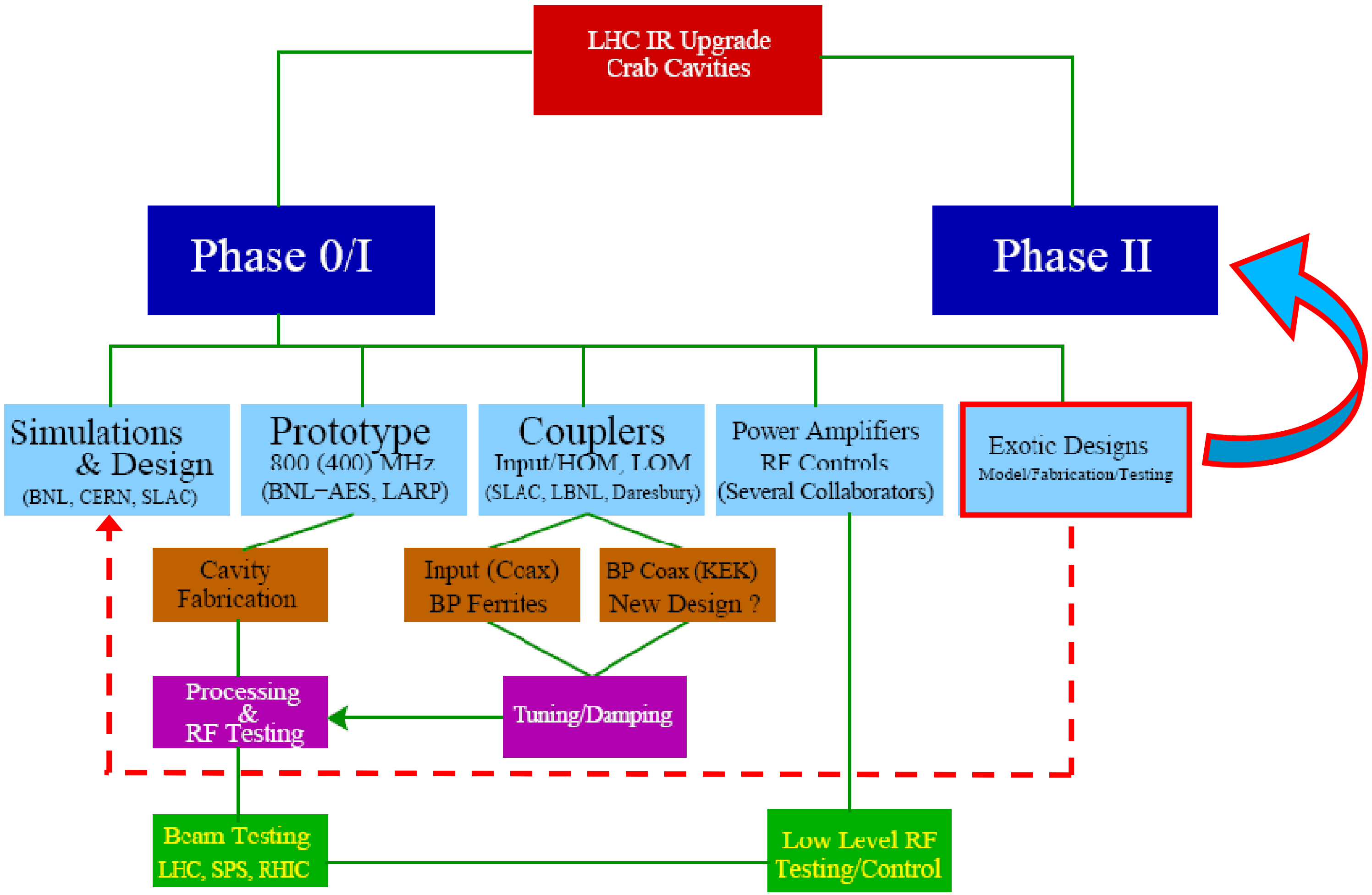
Overview

- CC Advantages for LHC
- LHC Constraints
- Local vs Global
- Compact CC R&D Underway
- Conclusions

CC Advantages for LHC

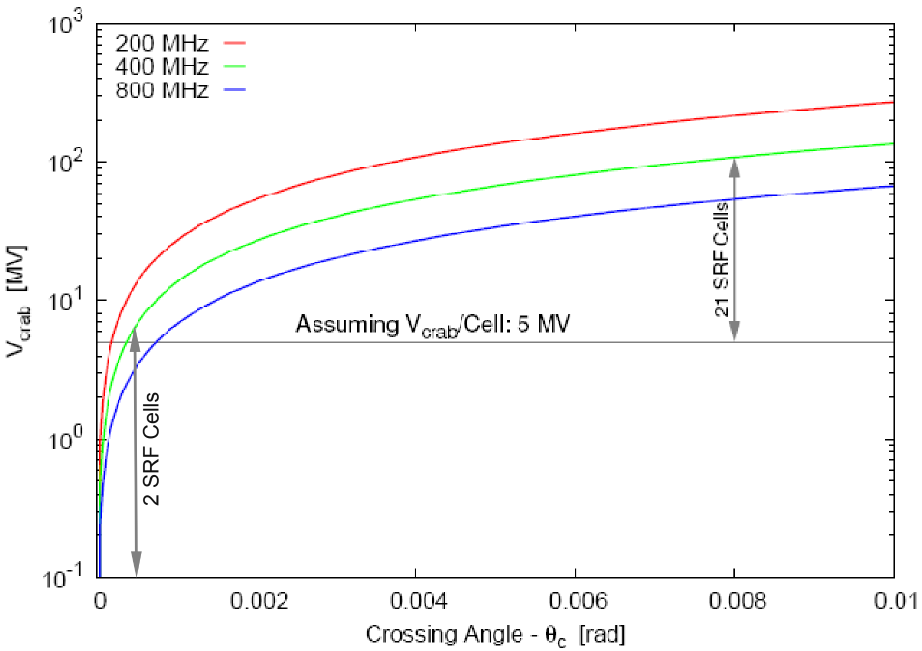


LHC CC R&D Plan



From LHC-CC08 BNL, 25-26 Feb 2008

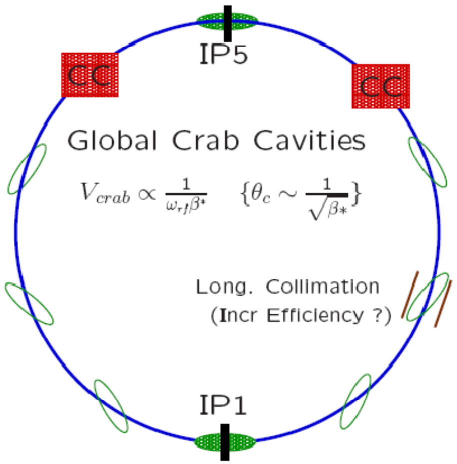
LHC CC Voltage Requirement



$$V_{crab} = \frac{cE_0 \tan(\theta_C/2)}{\omega_{RF}\sqrt{\beta_{crab}\beta^*}} \quad \{\sigma_z \ll \lambda_{RF}\}$$

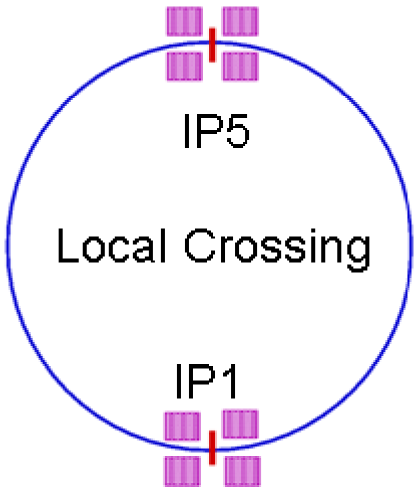
- For LHC:
  - Bunch length = 7.55 cm
  - Crossing angle ≈ 0.3 - 0.5 mrad
- RF voltages required:
  - 3 – 7 MV (deflecting)
- At 800 MHz:
  - 1 module of the BNL/SLAC elliptical cavities (2-cell Cavity)
- At 400 MHz:
  - 2 modules of the various compact CC designs
- Longitudinal Space ~ 5 m
- A flat beam option will give an extra degree of freedom for voltage delivered.

Local vs Global



- Small crossing angle (~0.5 mrad):
- Global crab scheme is ideal choice for prototype Phase-I:
  - Test feasibility of crab crossing in hadron colliders,
  - Address all RF and beam dynamic issues,
  - Small orbit excursion and tune shifts,
  - Compatible with nominal and upgrade options to recover the geometric luminosity loss,
  - Collimation optimisation!
  - These cavities are feasible using available technology and the gradient requirements are within reach of current technology.

- Local crab crossing preferable (Phase-II):
  - Independent control at IPs,
  - Avoid collimation/impedance issues.
- The only local crossing scheme feasible with current technology requires VV crossing (see R. Calaga's talk).
- Need compact cavities to fit in the IR region of the ring.
- Lower frequency hopefully!



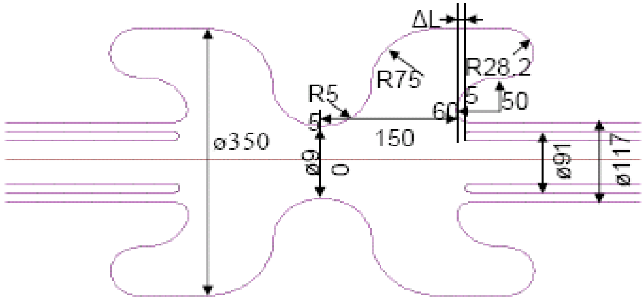
Compact CC Constraints

- Two key LHC constraints
  - Transverse beam-line separation (19 - 25 cm)
  - Bunch length = 7.55 cm, 800 MHz ok (400 MHz preferred!)
- Local crab crossing scheme preferred to avoid problems with collimation & impedance issues.
- Parallel R&D for compact CC's along with elliptical cavity development.
- Find best substitute for elliptical cavities among the several ideas.
- Copper and/or Niobium prototype to test SRF features.

Compact Cavity R&D Underway

- FNAL mushroom cavity (N Solyak)
- BNL offset TM_{010} cavity (R Calaga)
- SLAC spoke cavity (Z Li)
- JLab rod cavity (H Wang)
- SLAC half wave resonator (Z Li)
- CI figure-8 cavity (G Burt)

FNAL Mushroom Cavity



dimensions are in mm

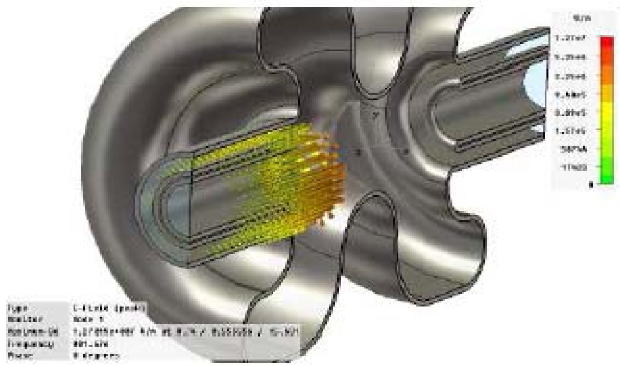
Monopole modes

Freq MHz	FF*(R/Q) Ohm	Q
520.6	20	440
520.7	73	420
1087.2	2.1	330
1087.2	6.8	350

Dipole modes

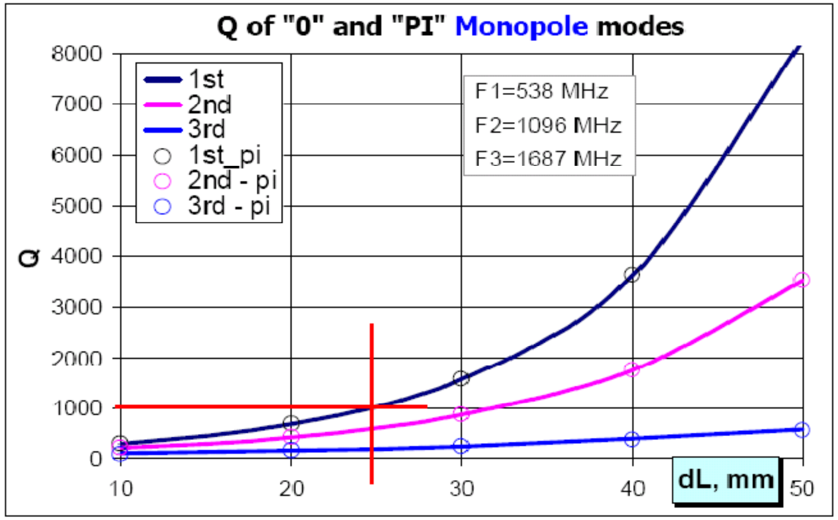
Freq MHz	FF*(R/Q) Ohm	Q
800	26.4	~10^7
~900	0.17	~1000
1144.6	0.01	61
1144.9+	0.6	60
1285.5	1.3	509
1291.4+	1.4	150
1302	0.05	18.8
1309+	0.22	18.4

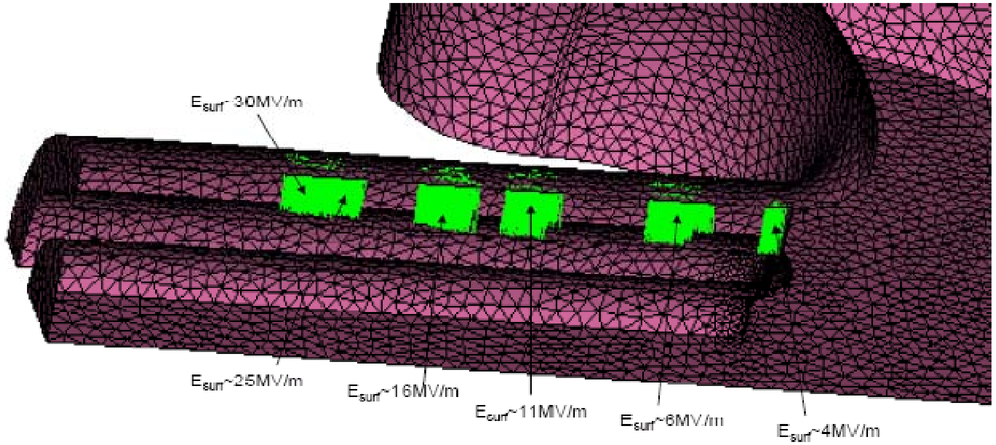
- Coaxial coupler penetration adjusted for optimised damping.
- Aperture increased to 117 mm diameter.
- Reduced E-fields in coaxial line, avoid multipactor.

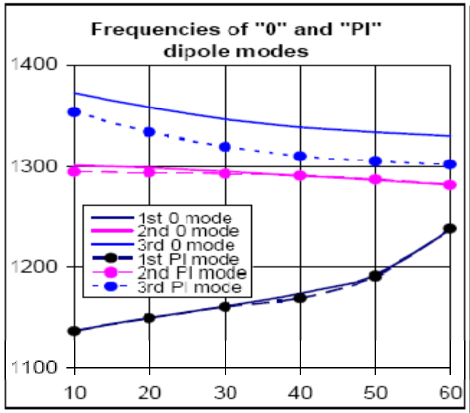


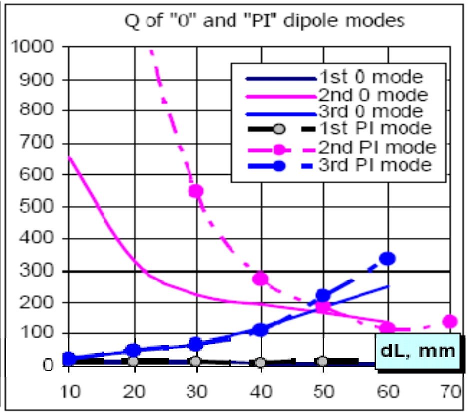
- Target Q_{ext} < 1000 for all inactive modes.

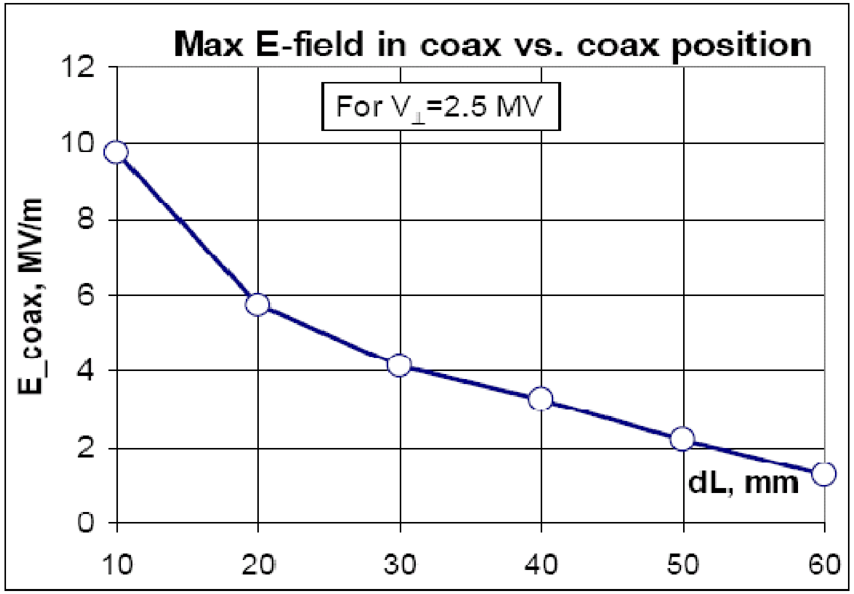
FNAL Mushroom Cavity (Cont'd)



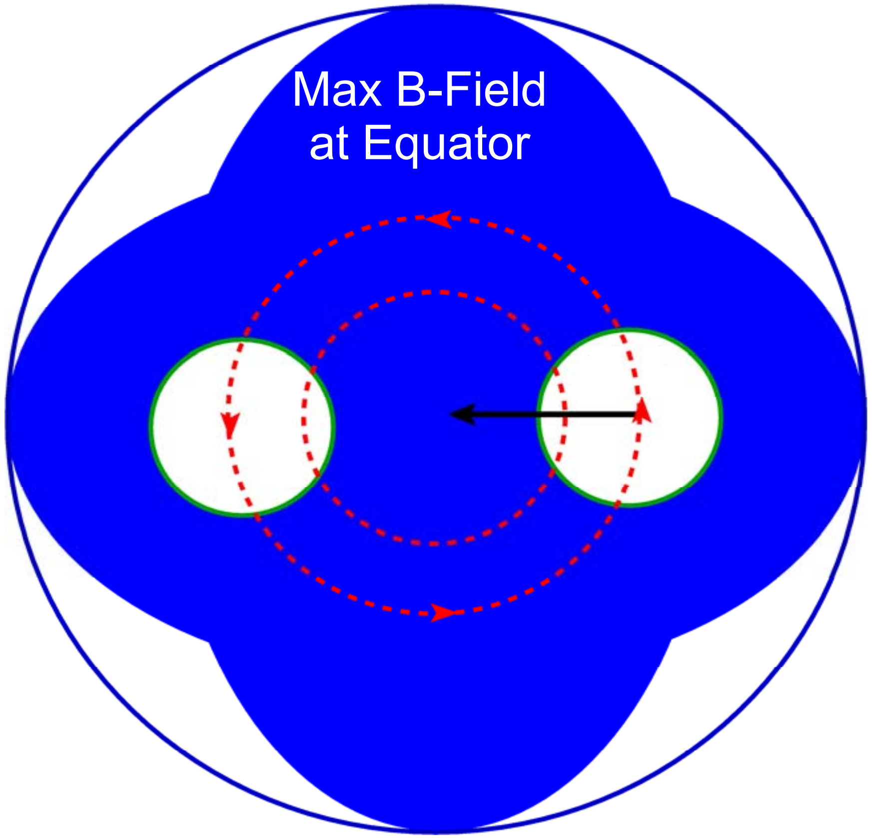






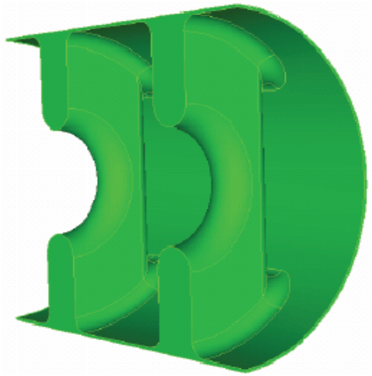


BNL TM_{010} Cavity (SRF)



- TM_{010} is the lowest mode in pillbox cavity with largest R/Q.
- Transverse space becomes a non-issue even for 400 MHz.
- HOM damping becomes trivial:
  - No LOM to damp!
- Smaller peak surface fields compared to TM_{110}.
- Large transverse offset will increase coupling to beam with HOMs, need to evaluate impedance effects.
- Multipacting & non-zero beam loading needs evaluating to see if this design is attractive.

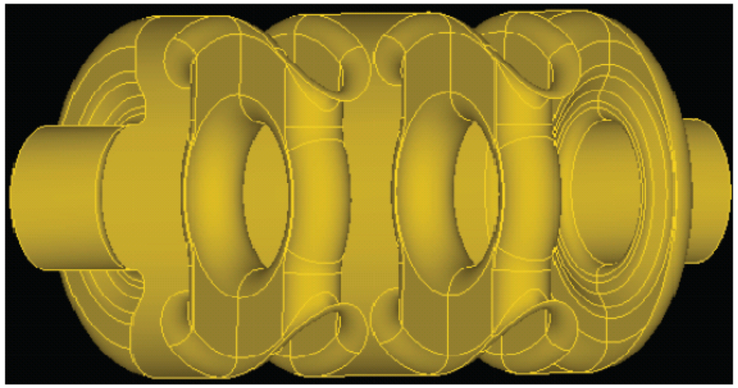
SLAC Spoke Cavity



spoke-cell

- 0.3 m diameter
- Minimum iris radius of 60 mm needed, for effective cell-to-cell coupling.

Cavity radius: 150 mm

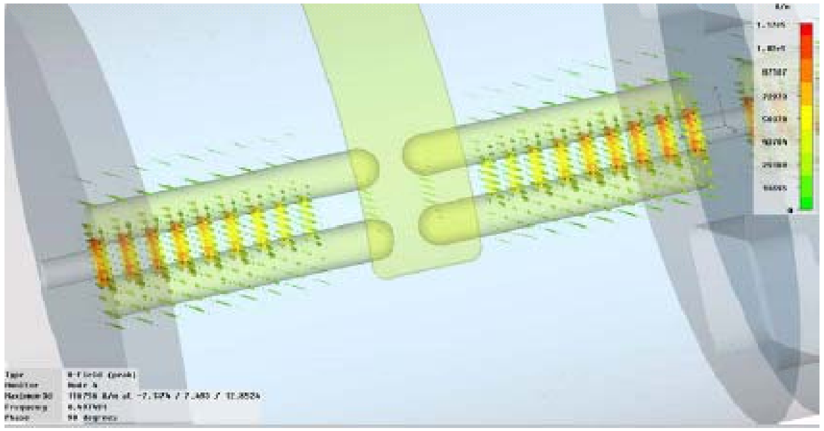


spoke with end-cap

ModelD	Frequency	RoQT(ohm/cavity)
0	7.91E+08	2.2
1	8.18E+08	121.4
2	1.03E+09	9.6
3	1.13E+09	2.9
4	1.20E+09	10.6

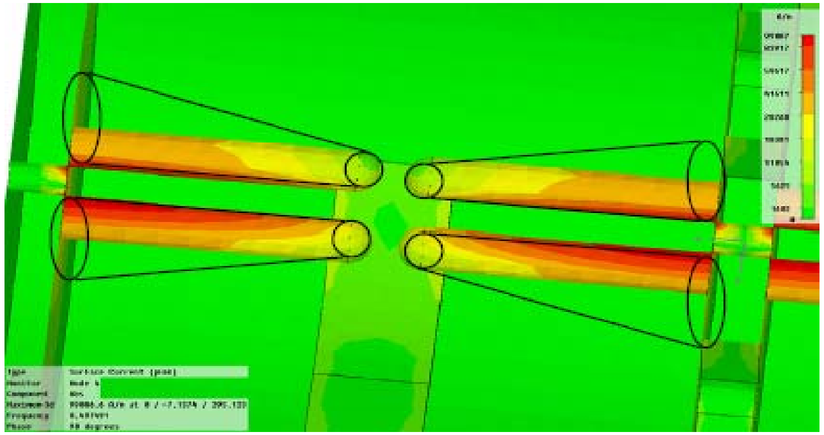
- Damping optimisation with input coupler required.

JLab Rod Cavity (NC)



- 2-rod separator cavity operating on CEBAF.
- Q_{cu} is only ~5000 (structure wise), the stainless steel cylinder only takes less than 5% of total loss.
- Each cavity is:
  - 499 MHz,
  - 2-cell,
  - ~λ long
  - ~0.3 m diameter,
  - can produce 400kV deflecting voltage with 1.5kW input RF power.
- The maximum surface magnetic field at the rod ends is ~14.3 mT.
- Water cooling needed on the rods.
- If Nb used for this type of cavity, the $V_{\perp}$ is ≈ KEKB CC.
- Microphonics and fabrication

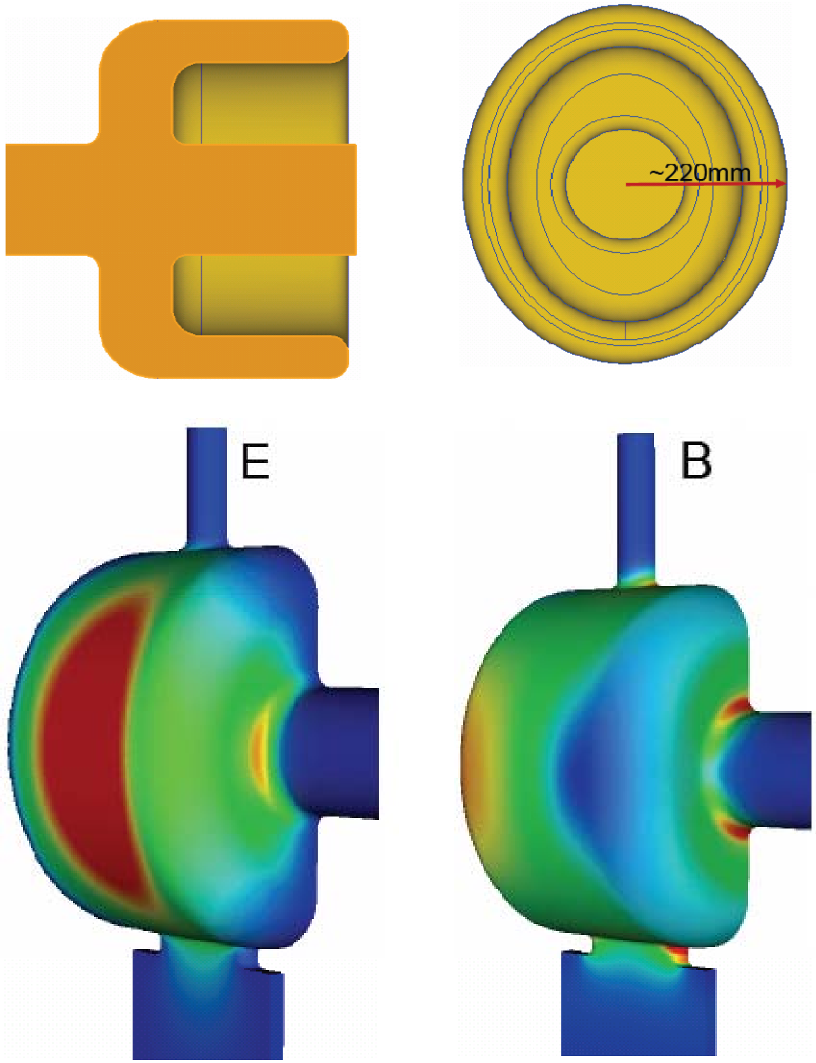
JLab Rod Cavity (SRF)



- There are both magnetic and electric fields providing deflecting kick, $E_{\perp} \approx B_{\perp}$.
- The cavity tuner is in low field region. No field enhancement there.
- As rod separation increases, the B_x and E_y fields drop quickly.

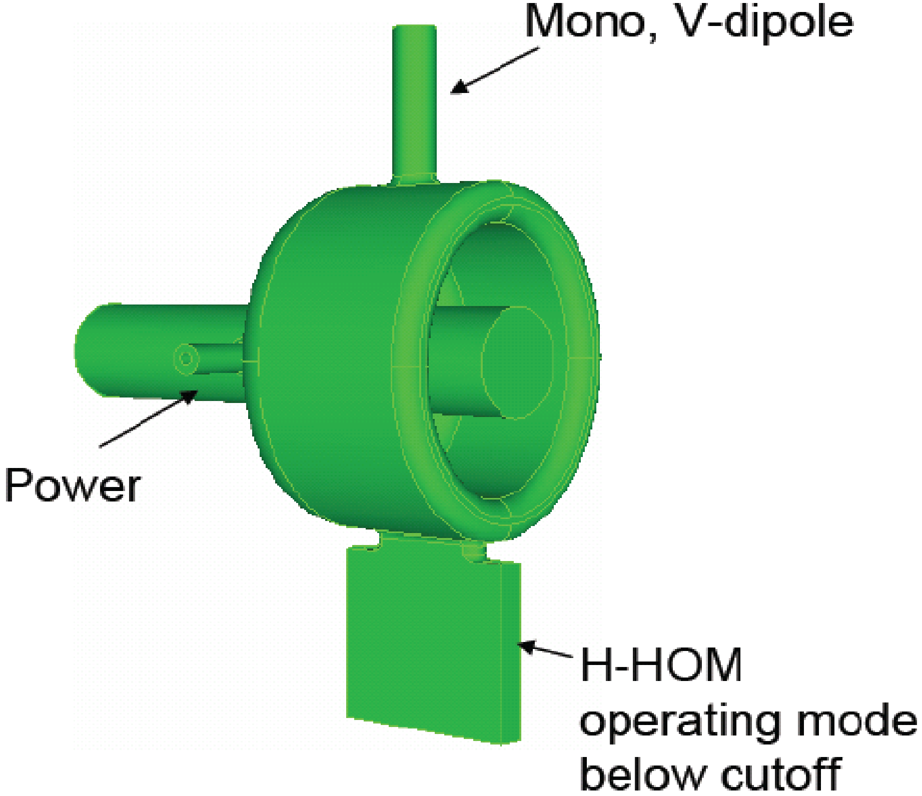
- Use “π” mode for separating three beams in CEBAF.
- No LOM damping required since the deflecting mode is the fundamental mode.
- Can a SRF version be made to work?
- Need to reduce the surface magnetic field at the rod ends.
- Need high B/E field near the beam path.
- Using cone shape electrodes can certainly reduce rod vibration and microphonics.
- Since there is a low loss on the cylinder can:
  - could make cavity cylinder in low RRR Nb, with rods in high RRR Nb?

SLAC Half Wave Cavity



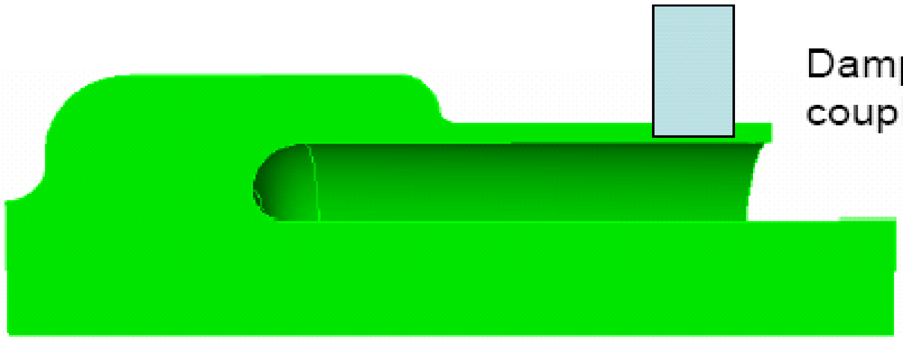
- 400 MHz operating frequency.
- Crabbing voltage doubles c.f. 800 MHz.
- Single gap per cavity.
- Requiring 3-4 cavities per beam for small crossing angles ($V_{\perp}$ = 1.25 MV).
- Multipactor studies needed and damping optimisations verified.

SLAC Half Wave Cavity

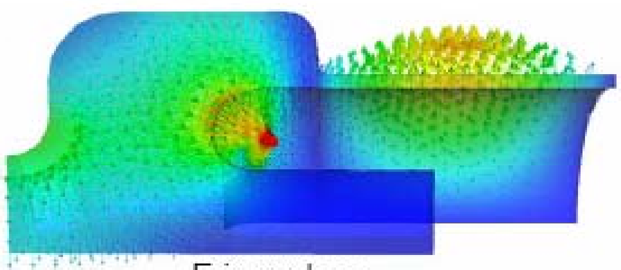


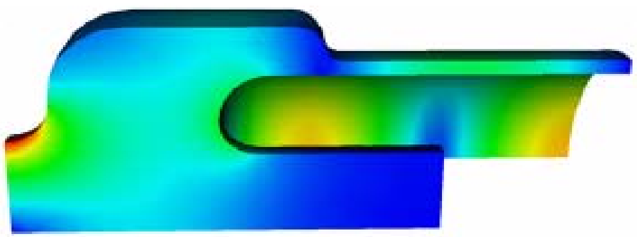
F (MHz)	Qext	Type
400.00		Operating
577.40	181.9	h q
746.92	165.6	h d2
779.88	53.3	h d+s
928.02	131.6	h q
989.84	24.4	h o
1011.76	36383.3	h d-TE
1021.78	3957.2	h d-TE
1103.91	1957.1	h s
1106.62	170.6	h s
242.08	122.3	mono
374.20	30.4	v d
560.48	15.1	v m+q
590.56	334.7	v m+d
706.99	25.7	v d2
783.93	25.0	v d-q
910.03	32.2	v
940.80	273.3	v
992.43	19.8	v d-s
996.94	547.4	v o
1013.85	193467.5	v d-TE
1107.69	66.6	v s

SLAC Coaxial Input Coupler



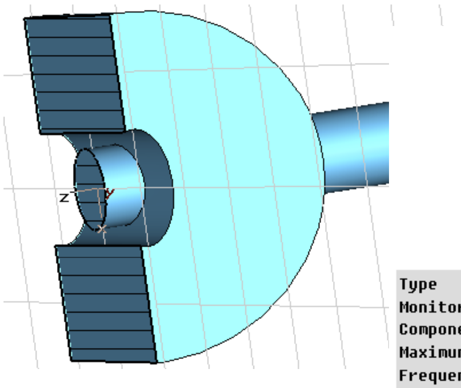
- Position of inner conductor of coaxial beampipe adjusted to tune cavity frequency
- Coax-coax or coax-waveguide damping for LOM/SOM/HOM

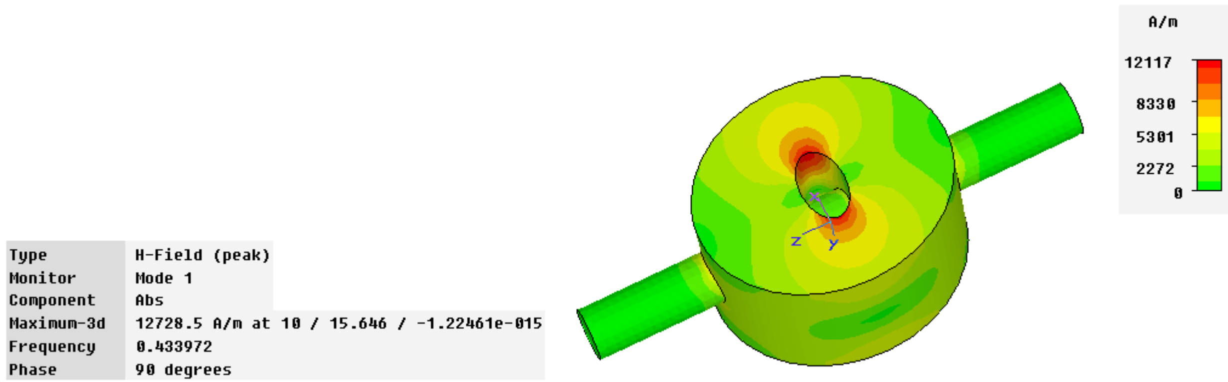

E in x-plane


B in y-plane

- Transverse dimension much smaller than regular cavity (< 170mm)
- R/Q and surface fields are being optimized

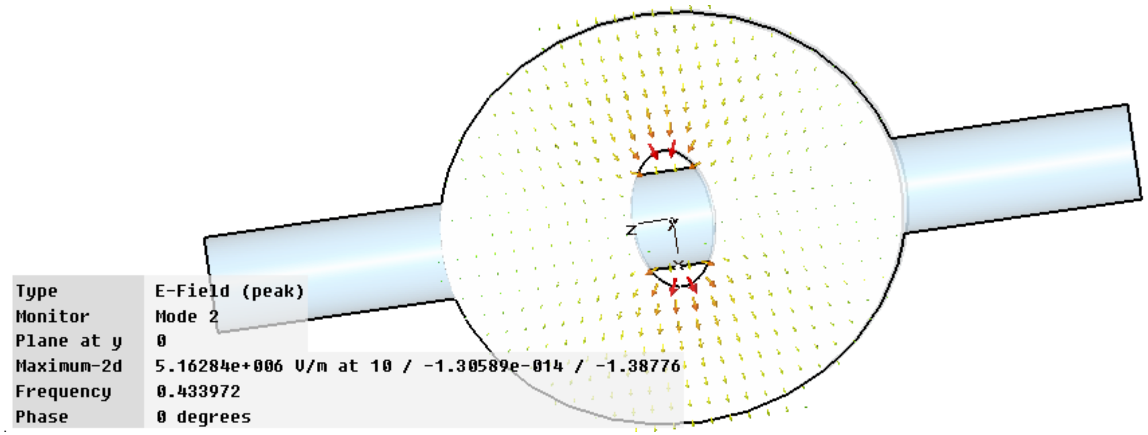
CI Figure-8 Cavity





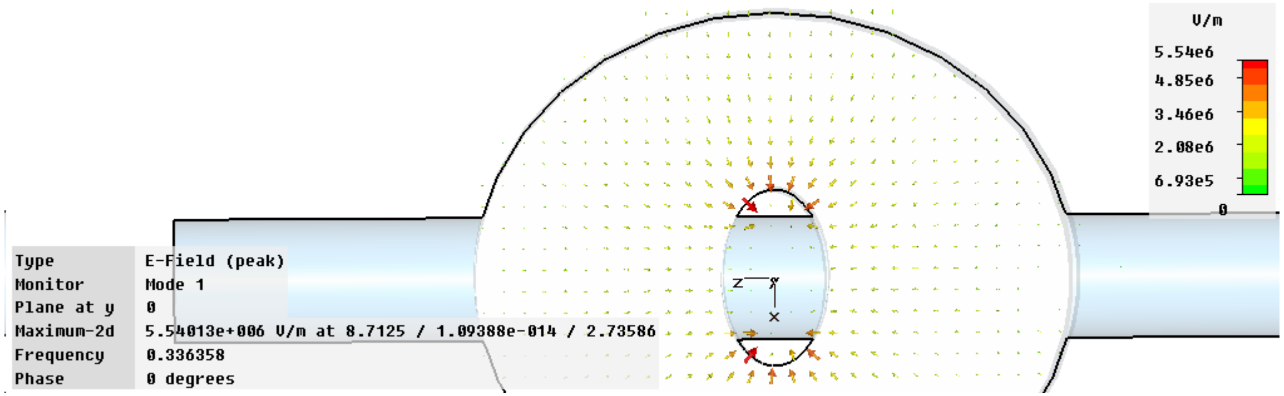
A Figure-8 cavity allows a very compact cavity size (0.25 - 0.3 m radius @ 400 MHz). Further optimisation will lead to a better field profile.

Peak magnetic fields are 150 mT at $V_{\perp}$ = 5 MV.

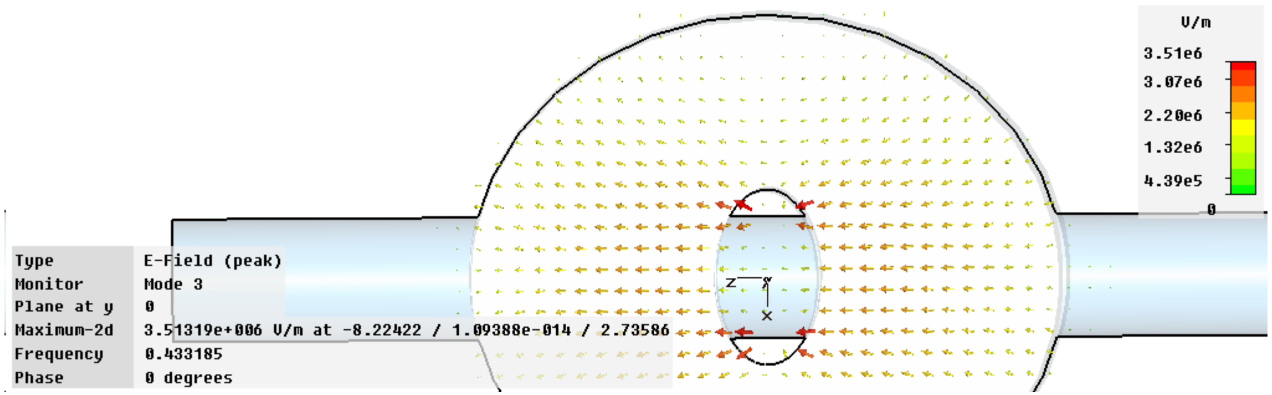


CI Figure-8 Cavity

The cavity has the two LOMs close to the operating mode at 336 MHz and 433 MHz.



The mode at 433 MHz has a low R/Q as the fields cancel.



Coupler optimisations ongoing.

SRF fabrication process to be determined.

Conclusions

- Luminosity improvements with CCs clear … even at nominal β^* parameters.
- Substantial increases predicted for lower β^*.
- Lower frequency CC preferred for LHC.
- Space constraints for local crossing make lower frequency solution more difficult.
- Many compact cavity designs being pursued.
- Cavity optimisations, mode damping and multipactor studies ongoing.
- Very promising that a viable solution can be achieved.
- Need coordinated effort to focus R&D for compact CC design.