WP4 Highlight Talk: Compact Crab Cavities for HL-LHC

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Acknowledgements

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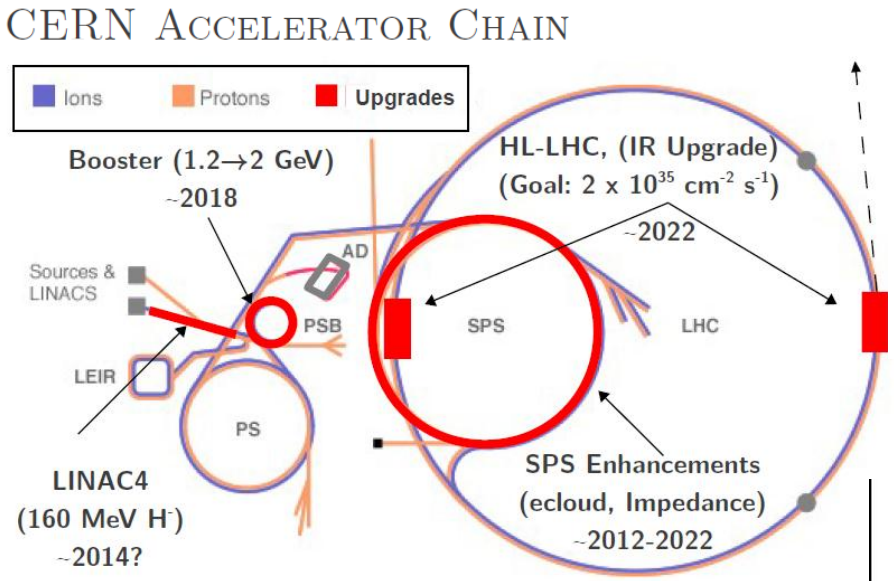
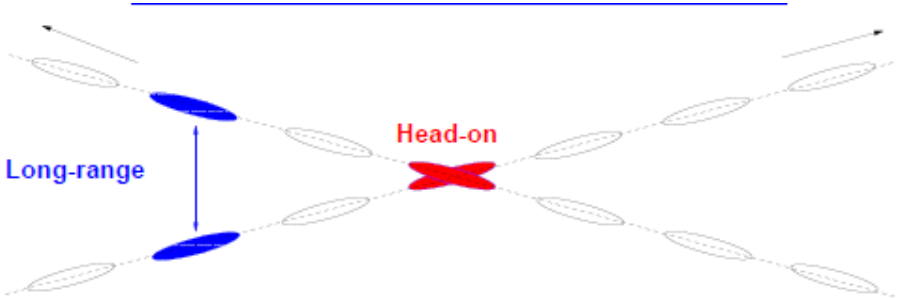
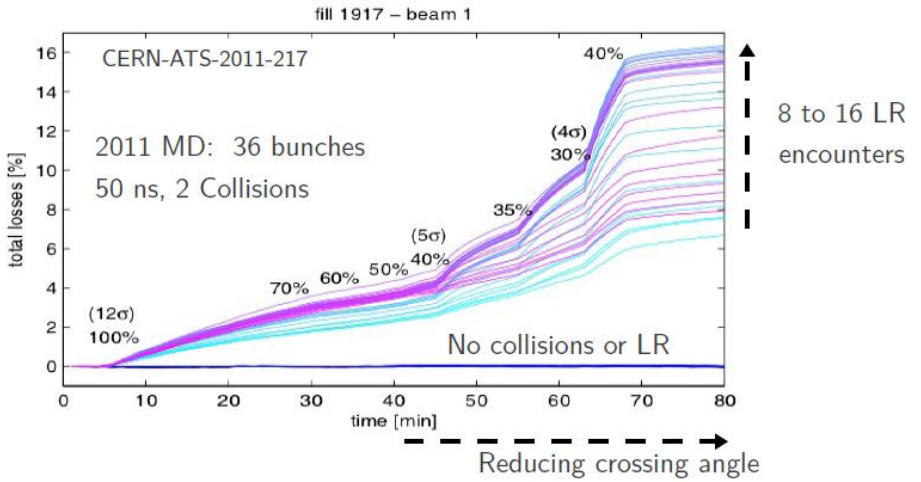
HL-LHC Upgrade IR problem





- The LHC HL upgrade will have a smaller B*.
- This will increase the long range effect at the IR.



Nominal → 4 IRs, 120(+) parasitic encounters

Sufficiently large crossing angle inevitable (8-12σ sep)

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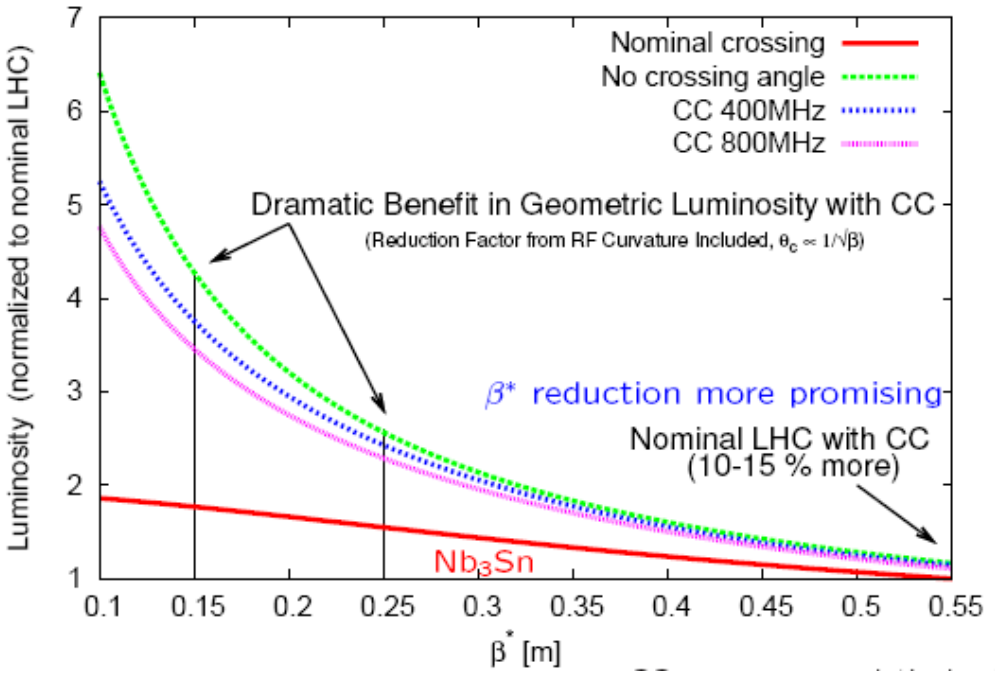
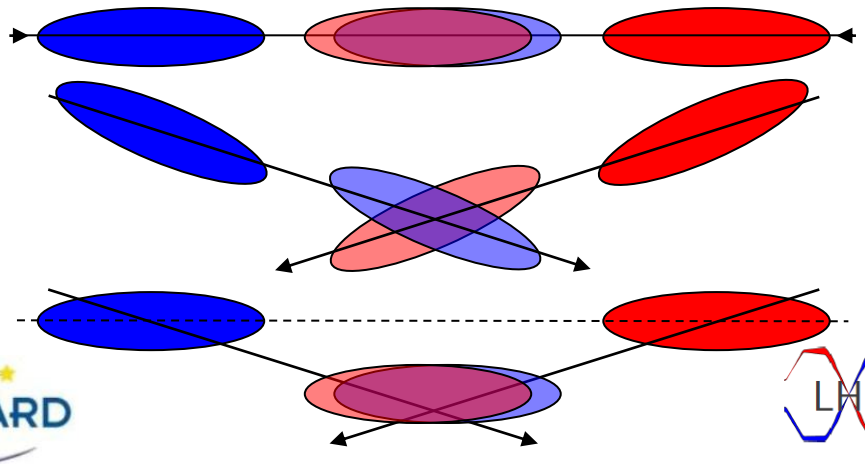
Crab cavities

- Increasing the crossing angle decreases the long range effect but decreases geometric overlap.
- Rotating the bunches with crab cavities before and after collision can reduce this.

$$L \propto \frac{N_b^{\,2}}{\sigma^{\,2}} / R_{\Phi} F_{RF}$$



	2011	2012	after LS1	after LS3
Energy	3.5 TeV	4 TeV	7 TeV	7 TeV
β* [cm]	100	60	55	15
2ϕ [μrad]	260	313	247	473
$R_{\Phi}(\sigma_z = 7.55\text{cm})$	0.94	0.85	0.82	0.37
$R_{\Phi}(\sigma_z = 10.1\text{cm})$		0.76	0.74	0.28



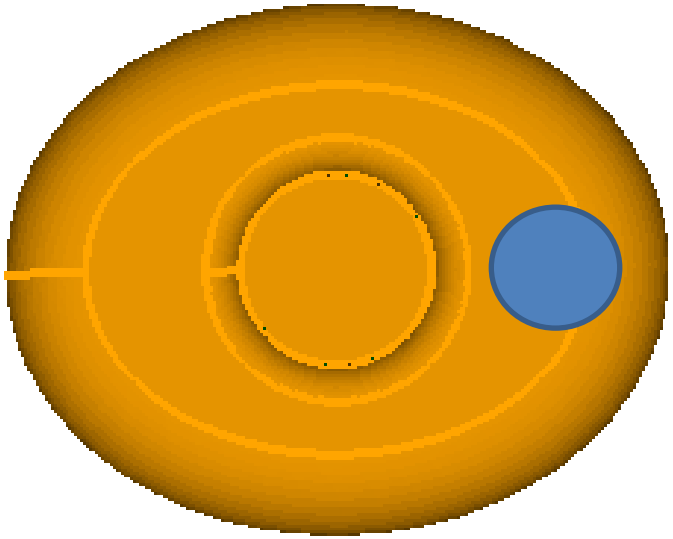
ARD

LHC

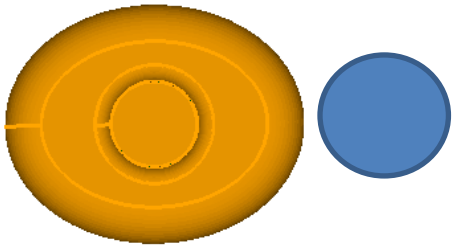
Why do we require compact cavities?

There is limited space for the crab cavities due to the opposing beamline. The cavity must within a 143 mm radius.

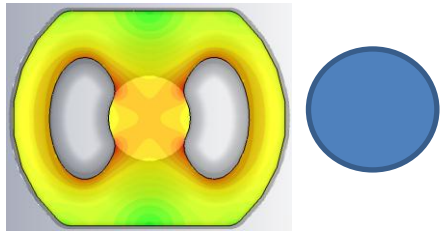
$$L \propto \frac{N_b^{\,2}}{\sigma^2} / R_{\Phi} F_{RF}$$



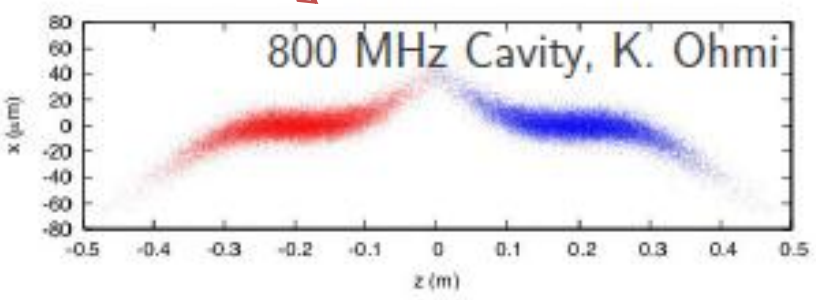
400 MHz elliptical



800 MHz elliptical



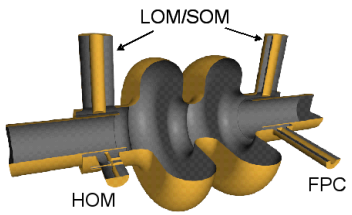
400 MHz elliptical

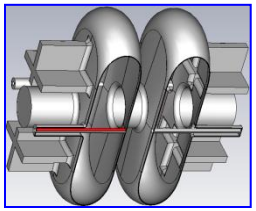
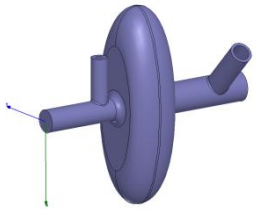
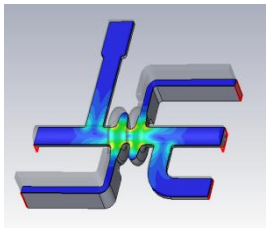
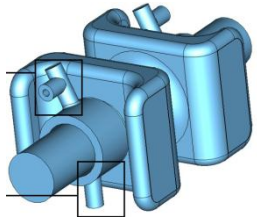
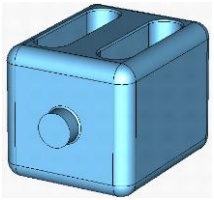
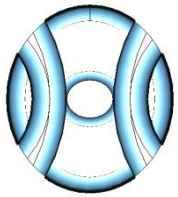
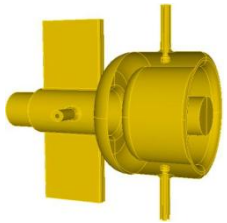
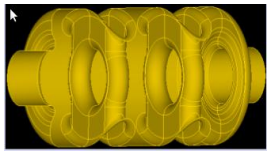
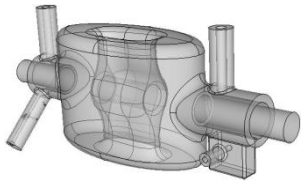
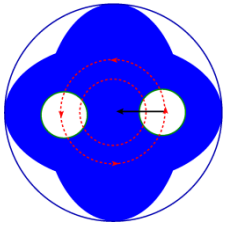
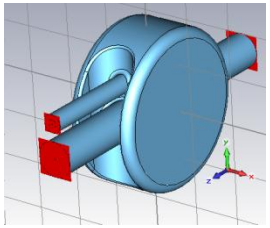
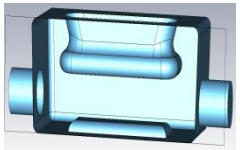
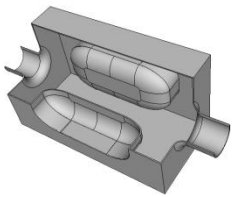
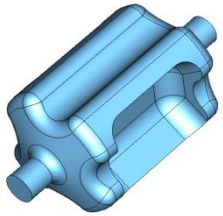
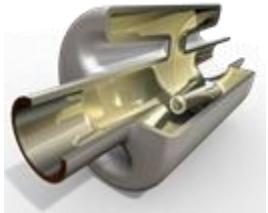
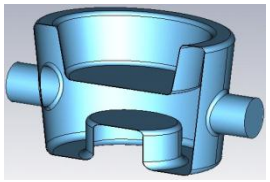
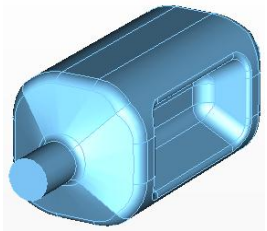


Using 800 MHz RF causes a S-shaped bunch which reduces luminosity hence a 400 MHz compact cavity is desired

CC Down selection (CC'11)

R. Calaga, Chamonix '12



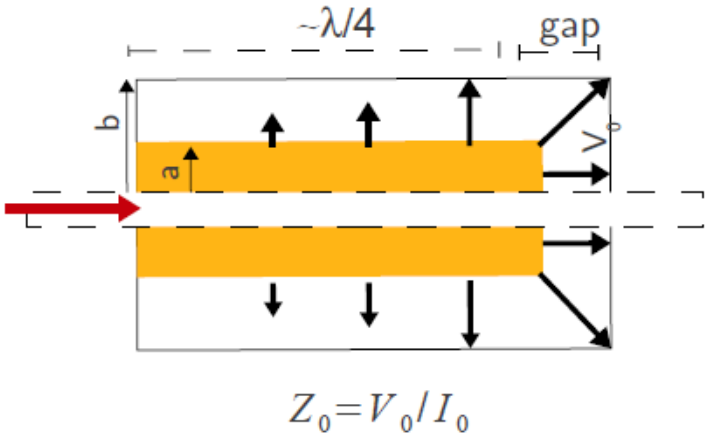


















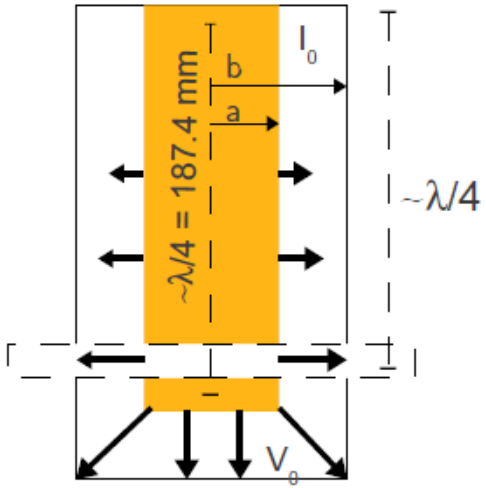
~4yr of design evolution

Exciting development of new concepts

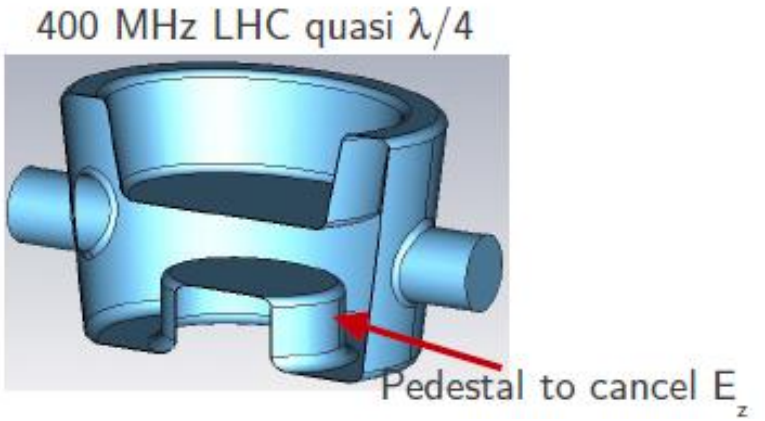
(BNL, CERN, CI-JLAB, FNAL, KEK, ODU/JLAB, SLAC)

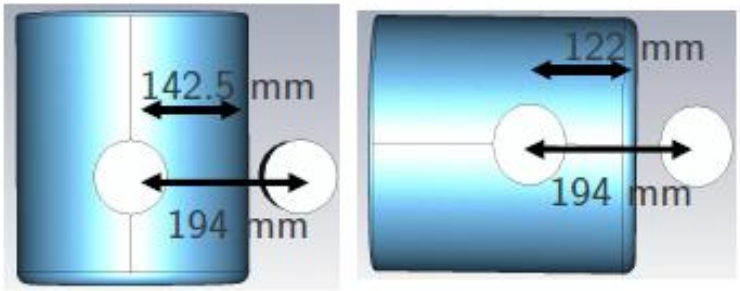
λ/4 TEM Cavity – BNL (Ilan Ben-Zvi)



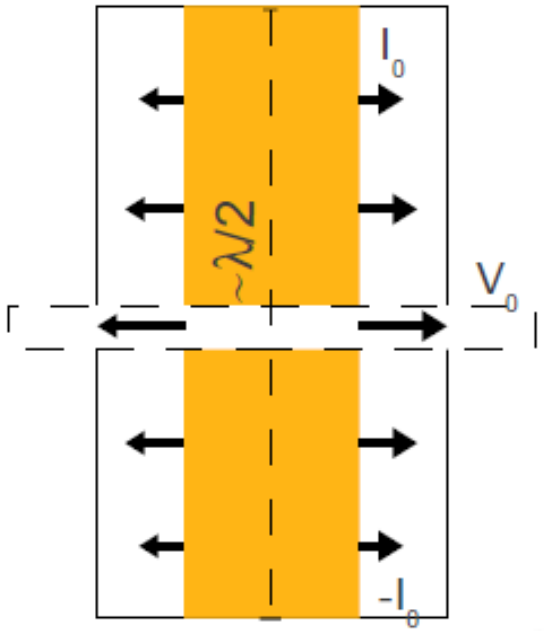


- Cavity is very short in the direction of opposing beamline.
- Nearest HOM is far away.

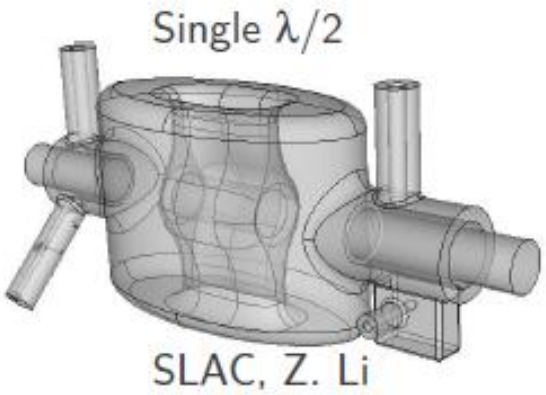


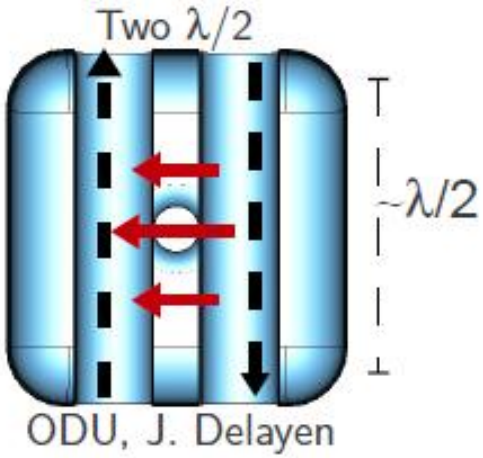


λ/2 TEM Cavity – ODU and SLAC

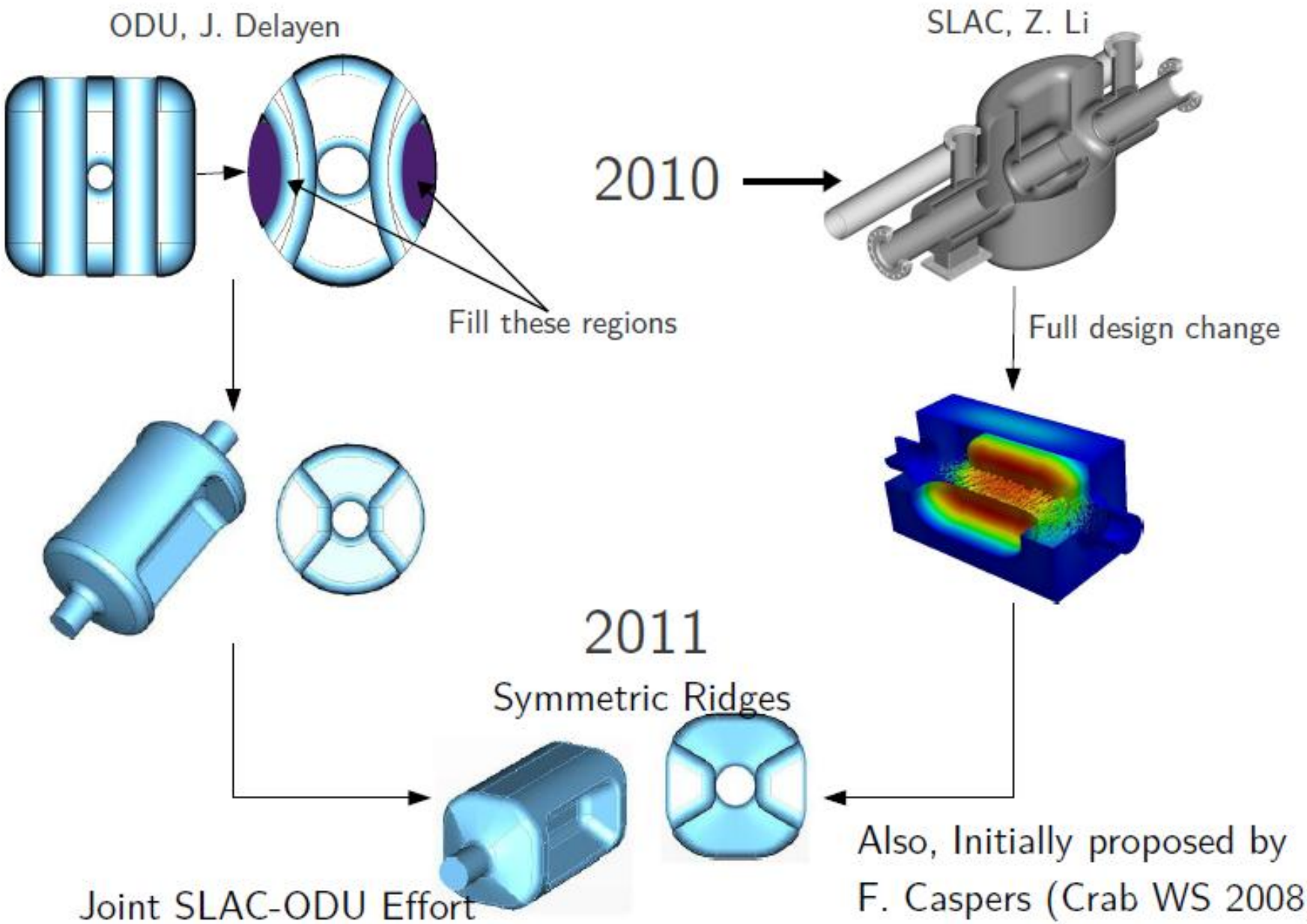


- Using a ½ wave cavity removes any monopole and quadrupole components.
- However it then is only compact in one direction (LHC may need both planes).
- Also has another monopole mode nearby.

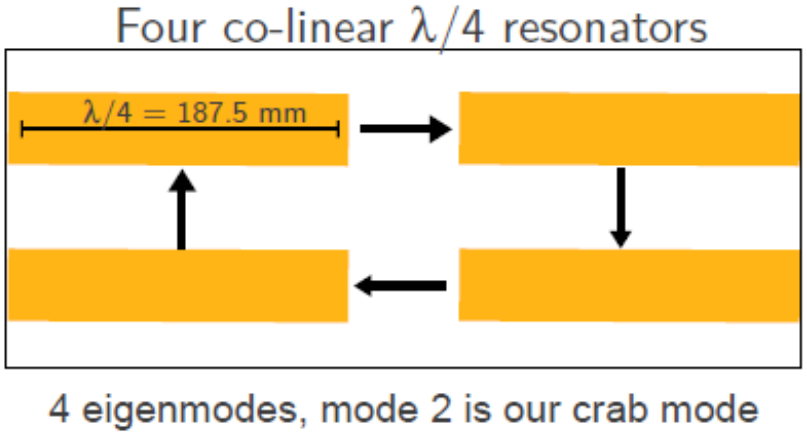




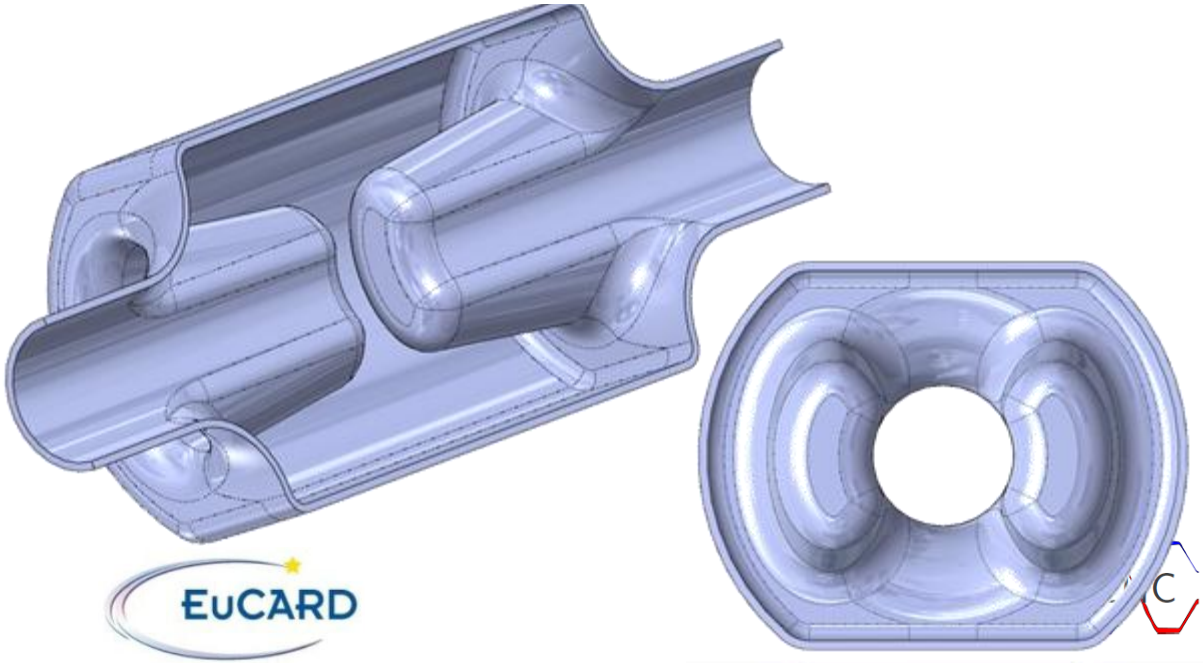
λ/2 TEM Resonator



4R crab cavity – Cockcroft - Jlab



- The 4 R cavity is ultra compact as it has its half wavelength in the longitudinal plane.
- CEBAF have a normal conducting version as a separator.
- Has a lower order mode but less HOM's.



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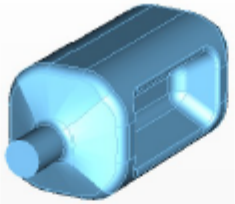
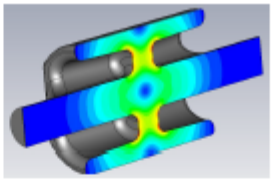
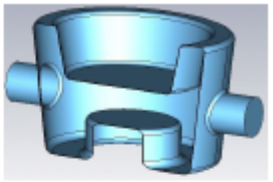
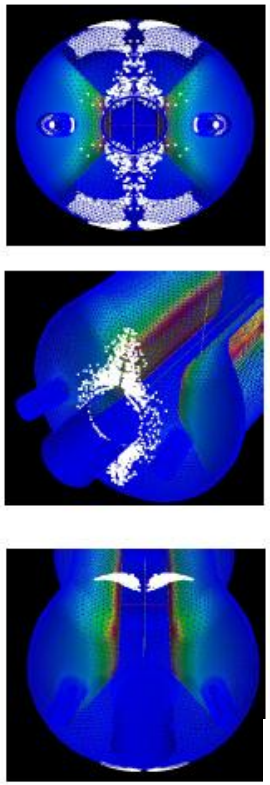
400 MHz Cavity Comparison

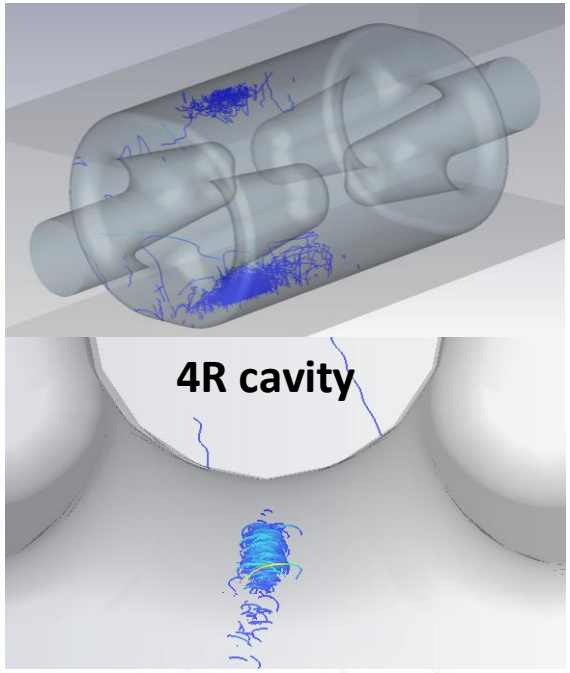




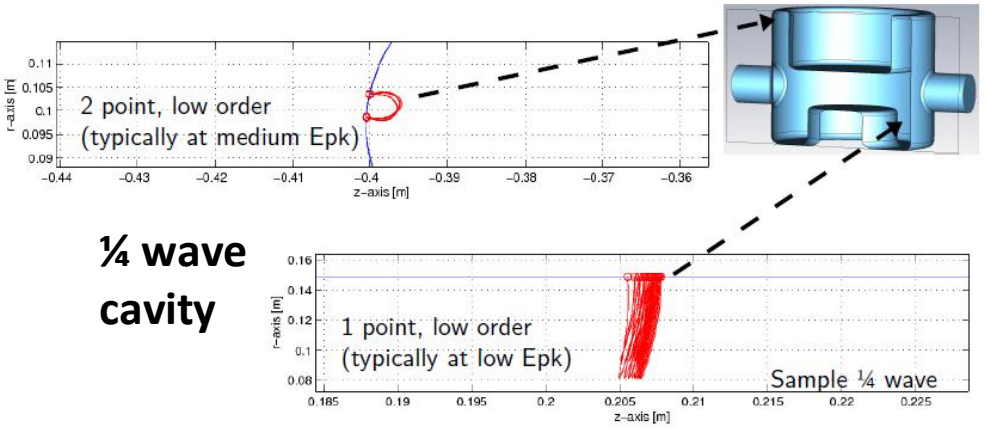
	Modified PB (ODU)	4-Rod (UK)	¼ Wave (BNL)
Cavity Radius [mm]	**147.5**	**143/118**	**142/122**
Cavity length [mm]	597	300	380
Beam Pipe [mm]	84	84	84
Peak E-Field	33	32	47
Peak B-Field	56	60.5	71
R_T/Q	287	915	318
Nearest Mode	584	371-378	575

Multipactor Simulations



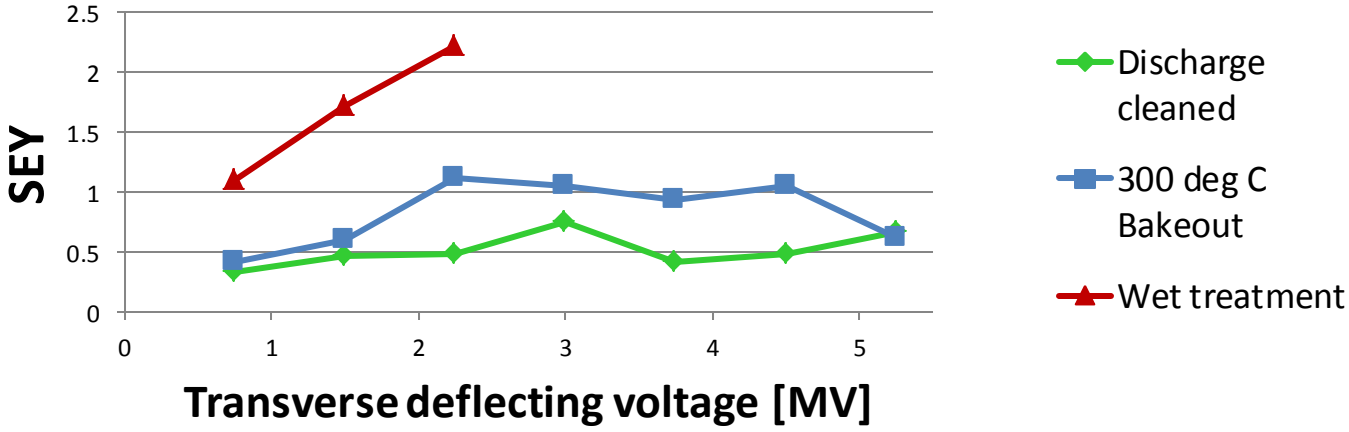
Doubled ridged cavity





¼ wave cavity

Multipactor has been modelled in all three cavities. Although multipactor is found it disappears for clean surfaces suggesting it can be processed through.



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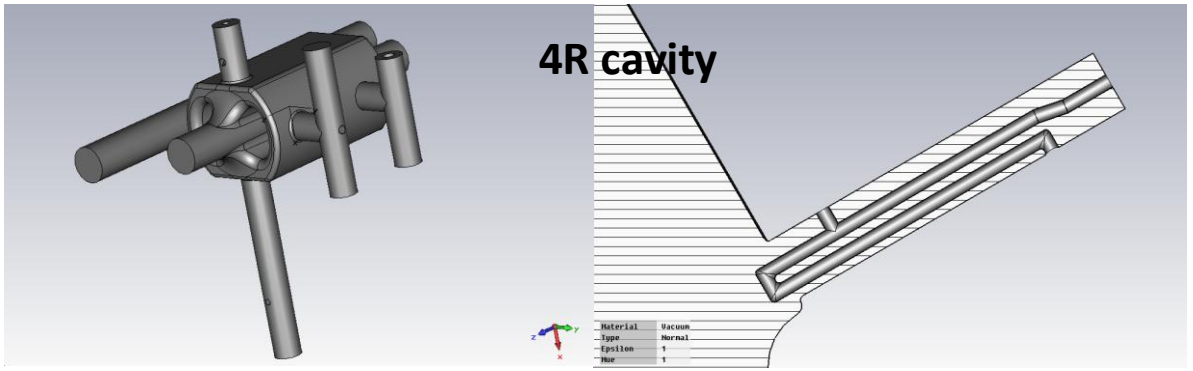
LHC

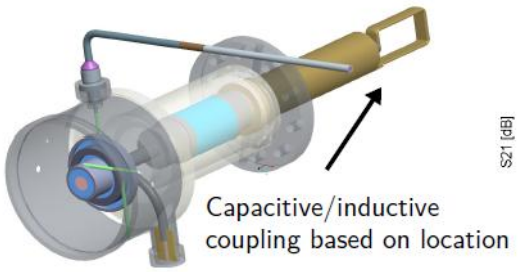
HOM damping

- The HOMs (and LOM's) need significant damping due to their location in LHC.

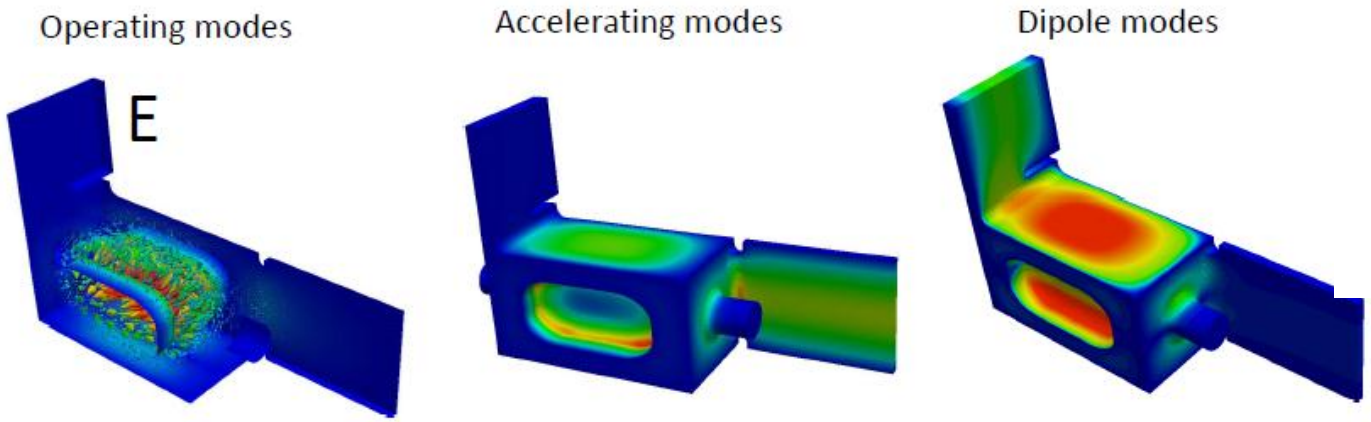
- The lowest monopole mode will need a Q ~ 100 and may have up to 6 kW in the HOM/LOM coupler.

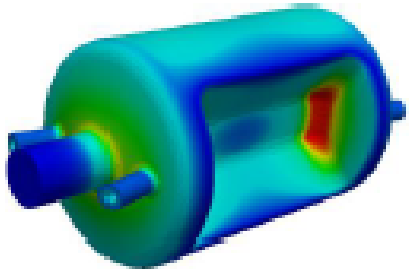


¼ wave cavity



Each cavity has its own set of couplers, although each set probably works for all cavities.

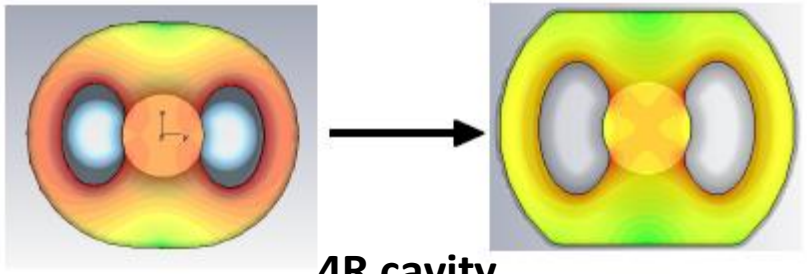




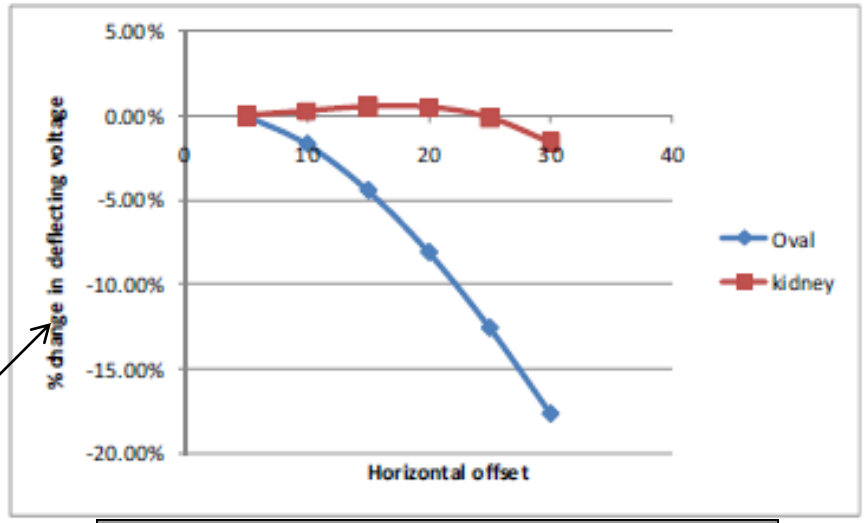
Double ridged cavity

RF Field Non-Linearity

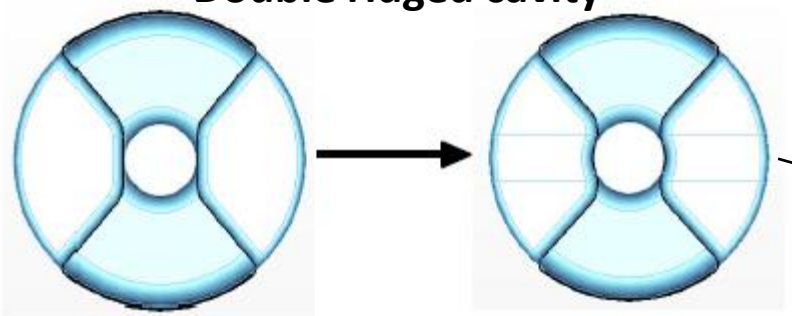
The cavity fields in these complex shapes are not pure dipole. Large sextupole components are also found in the cavity fields.

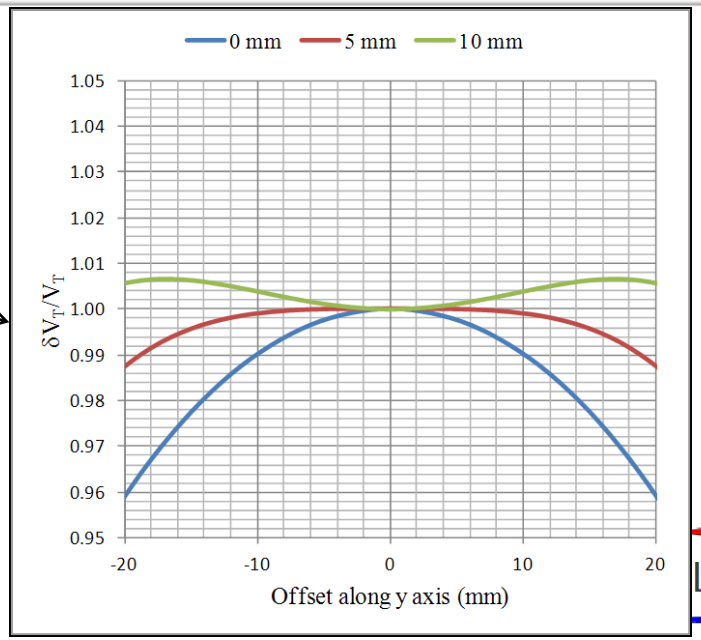


4R cavity



Double ridged cavity





Altering the shape of the rods in each of the cavities can reduce the sextupole component.

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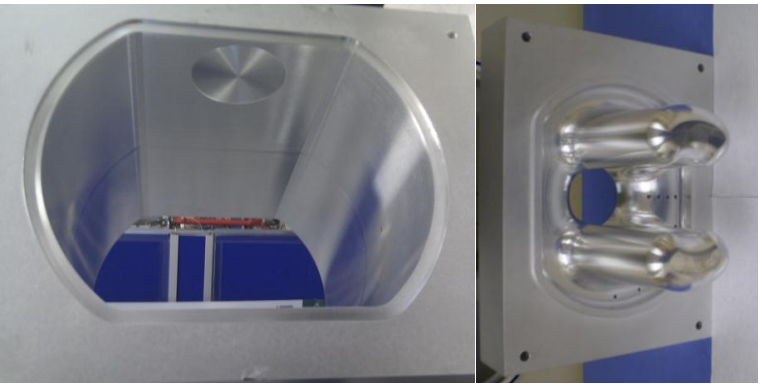
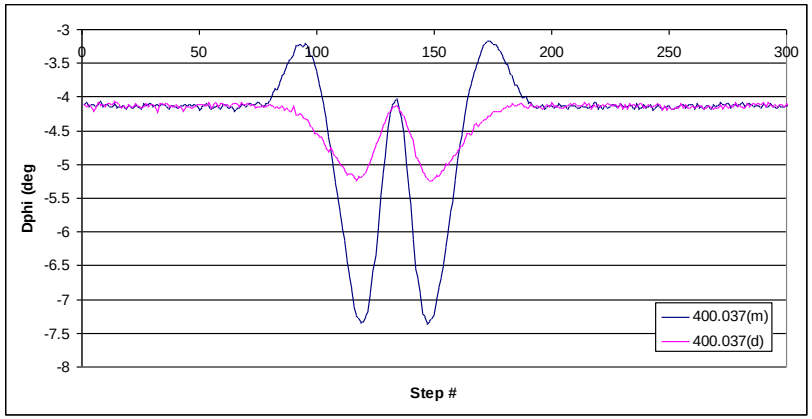
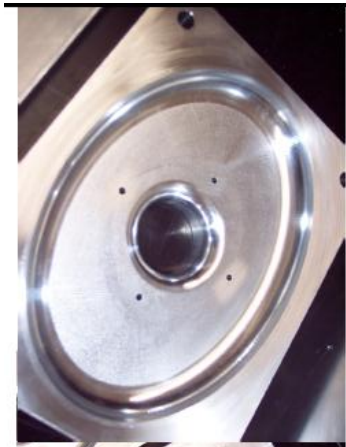
EuCARD

LHC

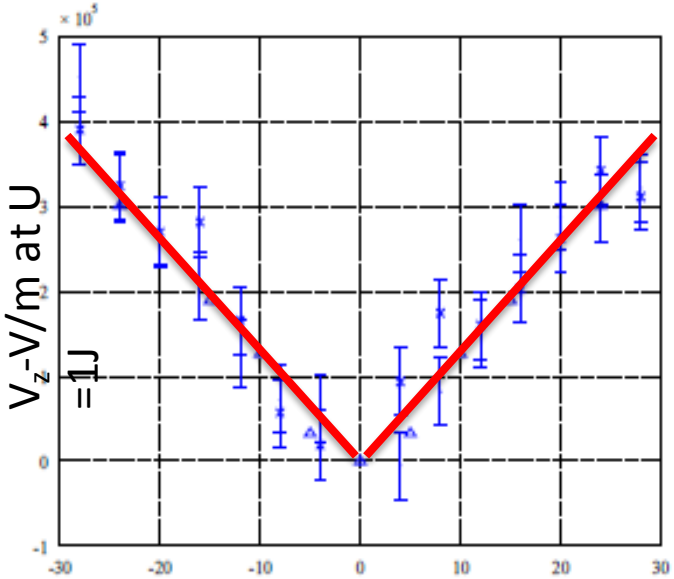
Aluminium prototype cavities





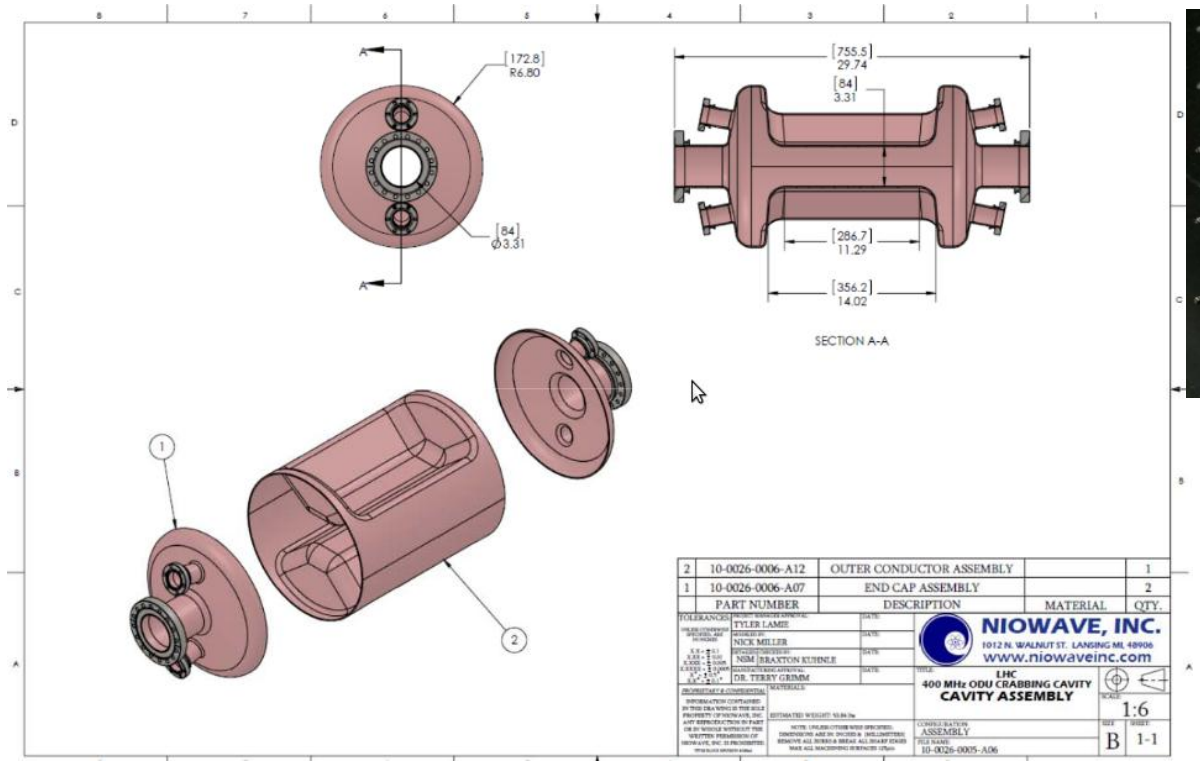


- Aluminium prototypes have been made of the 4R cavity and an earlier version of the ODU cavity.
- The improved linearity of the field is proven.



EuCARD

Double ridge prototype, Nov. 2011



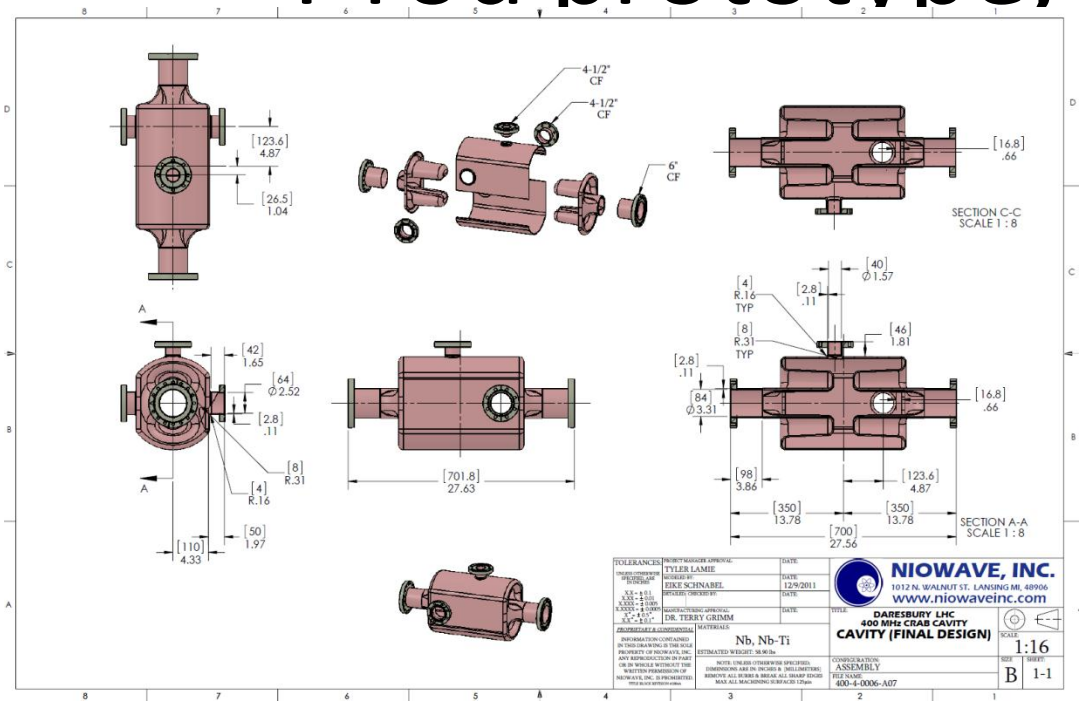
Niowave, Inc, STTR Phase I/II (DoE)
Cavity ready for testing (JLAB)
April 2012 (now!)

The Cockcroft Institute of Accelerator Science and Technology

EuCARD

LHC

4-rod prototype, Dec. 2011



The Cockcroft Institute
of Accelerator Science and Technology

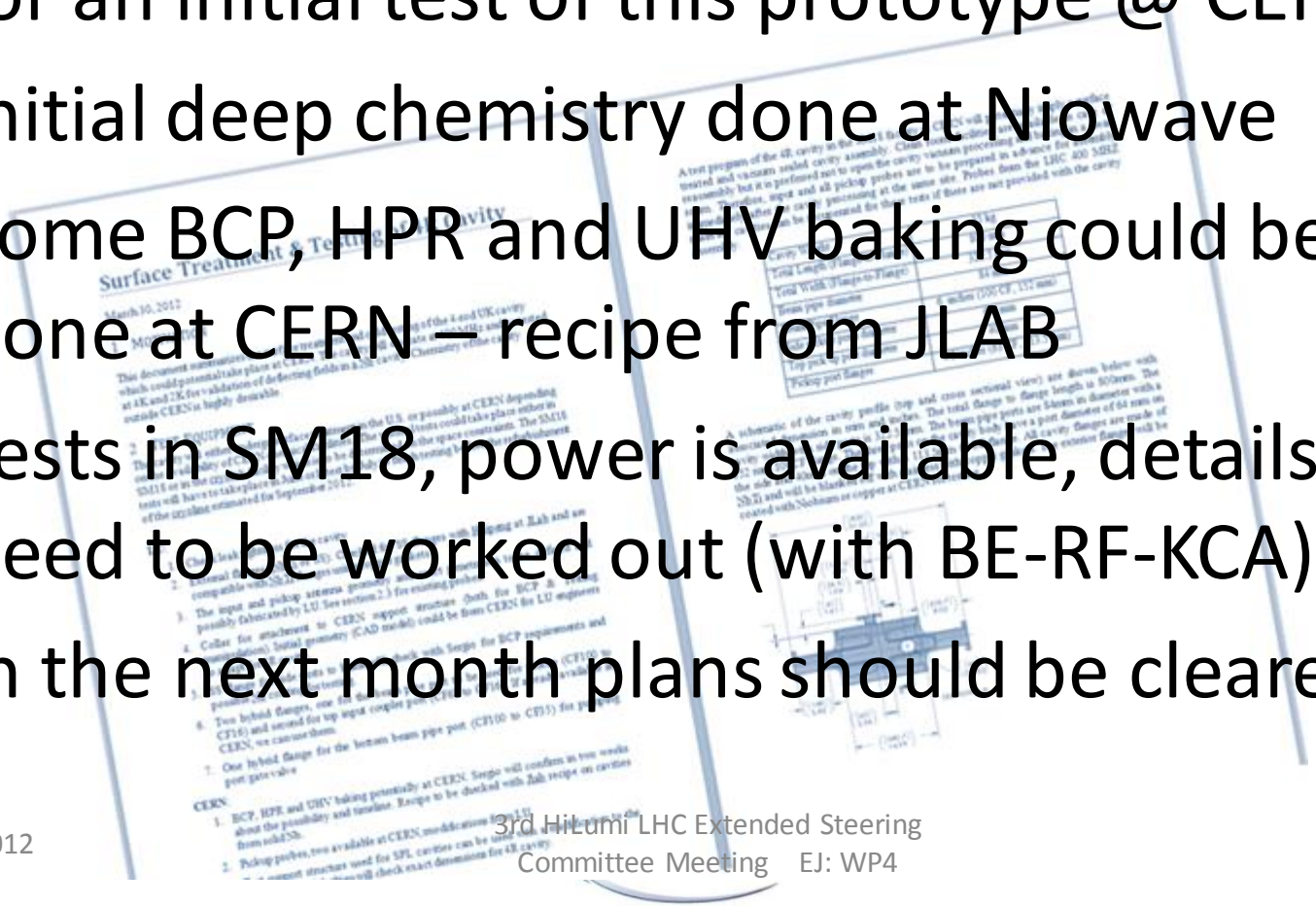
EuCARD

4 Rod prototype built

Double Ridge cavity prototype built

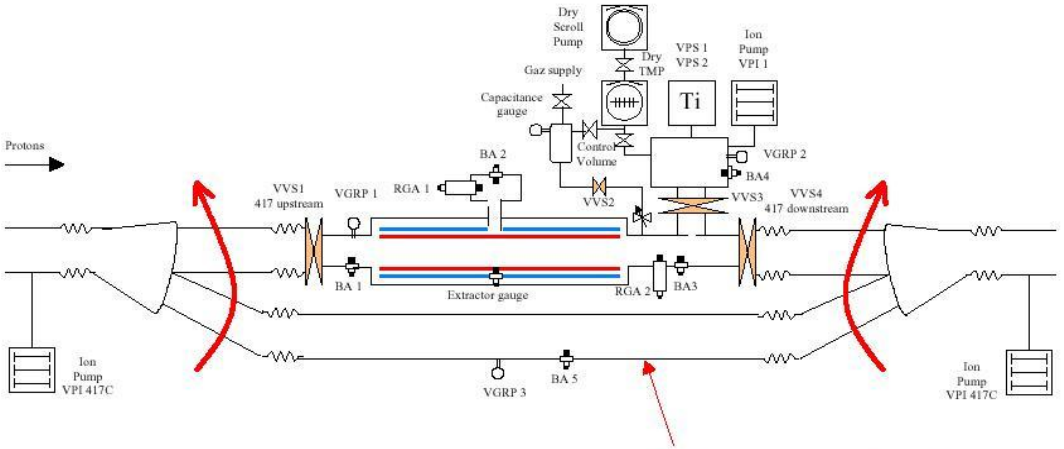
Initial cavity test at CERN ?

- We’re now in the process of devising a plan for an initial test of this prototype @ CERN
- Initial deep chemistry done at Niowave
- Some BCP, HPR and UHV baking could be done at CERN – recipe from JLAB
- Tests in SM18, power is available, details need to be worked out (with BE-RF-KCA)
- In the next month plans should be clearer.



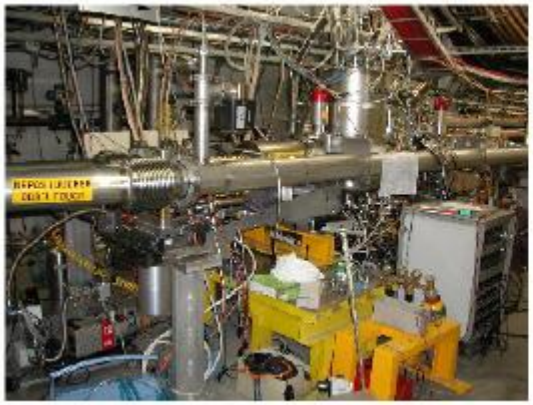
Preparing for beam test SPS

Crabs have never been tested on hadron beams and LHC is not a testbed.
COLDEX location in the SPS has a bypass line that could serve as a hadron crab cavity test location prior to LHC.



Goals of SPS test (before LS2):

- Cavity validation with beam (field, ramping, RF controls, impedance)
- Collimation, machine protection, cavity transparency
- RF noise, emittance growth, non-linearities,
- Instrumentation & interlocks



Conclusion

- Four years of effort has been put into the design of compact crab cavities for HL-LHC.
- Three compact crab cavity designs are in the advanced stages of design.
- Niobium prototypes exist of two designs and the third is expected to be ordered soon.
- Testing at 4.2 K and then 2K will being mid-summer 2012.
- Testing with beam is proposed in SPS COLDEX in 2015.