Compact  Cavities

Erk Jensen, CERN BE-RF

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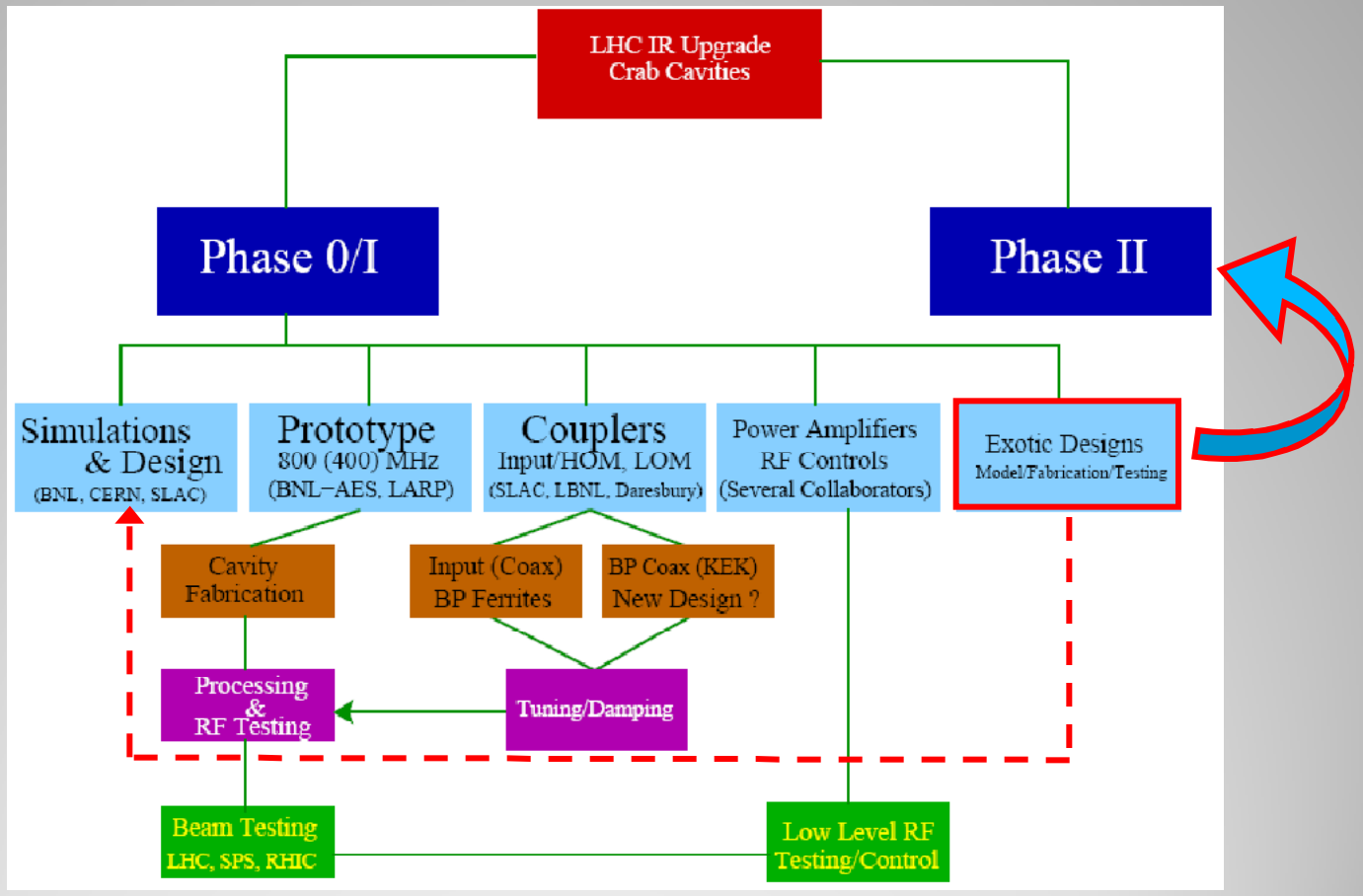
Introductory remarks

- I'm not an expert on Crab Cavities.
- I will not pretend to be!
- My interest was aroused at last year's Mini-Workshop on "Crab Cavity Validation" @ CERN (21-Aug-2008)
- My main concern:
  The validation with a global scheme and a (non-compact) CC near point 4 may be incompatible with LHC operations.

Planned phases

Last year, Peter McIntosh showed this diagram (HHH LHC CC validation workshop, 21-Aug-2008). Compact Crab Cavities are considered "exotic".



From LHC-CC08 Summary

Some speculations

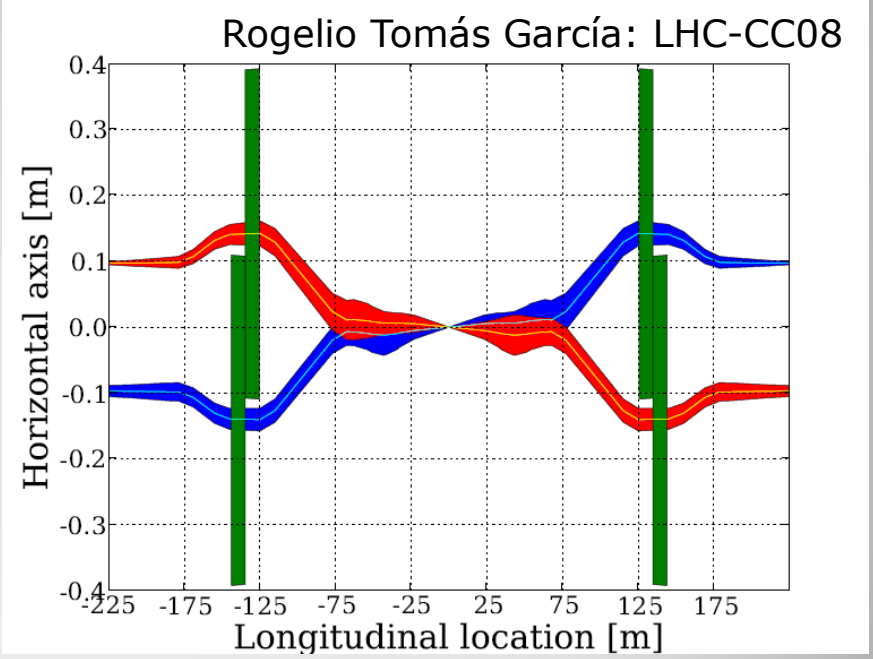
- After successful (re-)start-up of the LHC later this year, it will take some time to ramp it up in both energy and luminosity.
- Highest priority then will be given to HEP (… they have already been waiting for one year longer!)
- Unless the case is very strong*), how likely is the OK for a test-cavity in the LHC by say 2011?
- *) **not perturbing HEP**, at the same time able to **demonstrate significant gain**. *DANGER*
- If all this happens and the test will be a success, the result should be **relevant**! (correct beam separation, frequency, …)

Why compact cavity?

- For significant luminosity gain, **local** crab cavities around each IP would be desired.
- The global scheme uses enlarged beam separation near point 4 (420 mm) – local crab cavities can't rely on this luxury!
- Also, the areas around point 4 will eventually be used by other RF systems and will not remain available (200 MHz capture system/transverse damper upgrade ?)!

Which beam separation?

- LHC normal beam separation: 194 mm.
- With "D1-D2 separation optics" (Fartoukh, Tomás), the parameters could be:
  - Beam separation: ≈ 27 cm
  - Available length: ≈ 20 m on each side of IP (between D11 and D12)
  - Beam apertures:
    - H: > 106 mm,
    - V: > 70 mm.

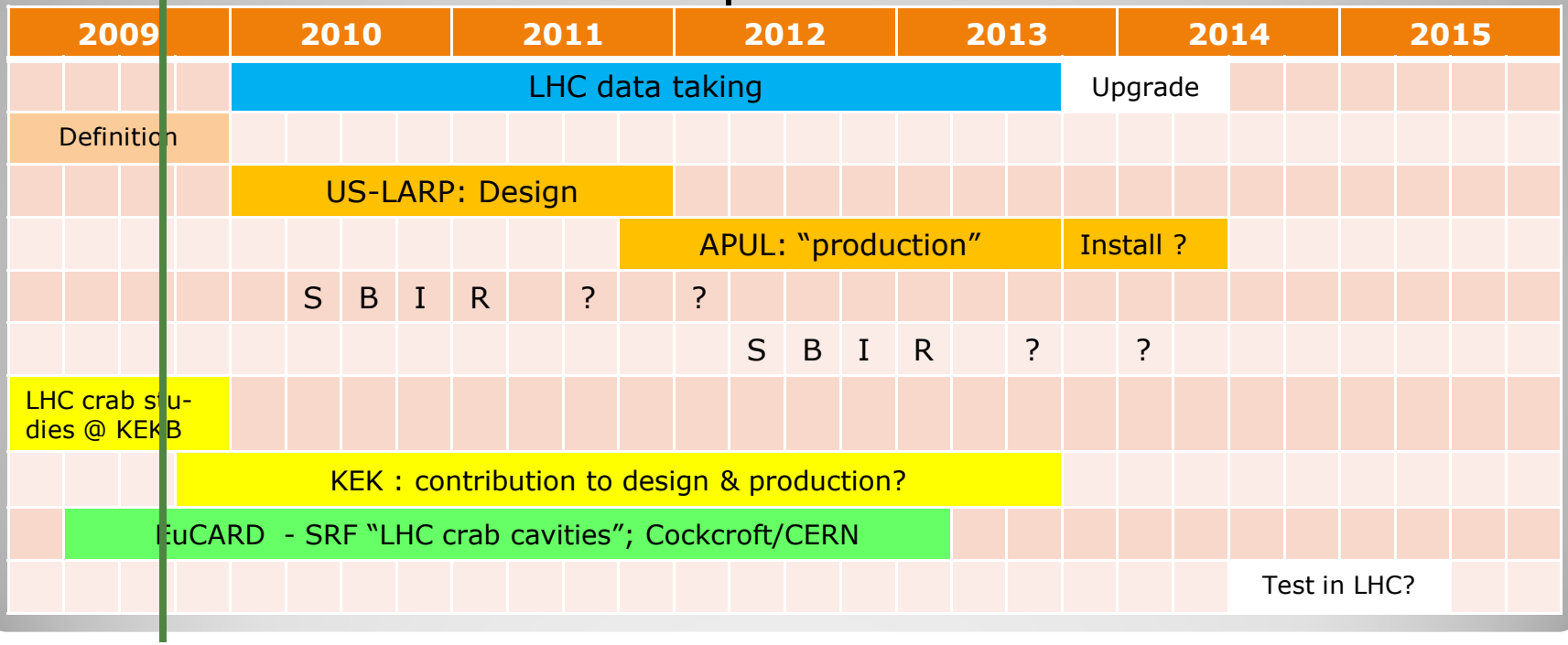


Green boxes sketch the possible CCs vessels.

My main statement:

- Considering all of the above, I would personally recommend to concentrate R&D effort on
  - a **local scheme**,
  - **compact crab cavities** that fit LHC constraints,
  - the technological issues which result from this choice.

some ideas on a possible time-line:



Frequency?

- Any integer multiple of 40 MHz is possible (for any bunch spacing integer multiples of 25 ns)
- Need for compact size favours higher frequencies
- However, single high frequency gives nonlinear kick force
  - ... this can be eased with multi-*f* approach at the cost of more voltage.
- HOM- (LOM-, SOM-) damping more difficult with smaller cavities?
- Characterizing the "compactness" with r/λ, and with cavity radius < 22 cm (beam separation – aperture radius), what minimum frequency could one imagine?

$$f_{\min} = \left(\frac{r}{\lambda}\right) \cdot 1364\ \mathrm{MHz}$$

for 400 MHz, one needs $r/\lambda < 0.29$,
for 800 MHz, one needs $r/\lambda < 0.58$.

There are ideas around …

- In the following, some*) ideas about topologies that may lead to compact crab cavities.

*) Not a complete list!

Two "classes" of compact  cavities

1. TM type

   $E_z(x) = -E_z(-x)$ ➔ Kick force dominated by $v \times B_y$

   - Variations of elliptical cavity …
   - Half-wave resonator (SLAC, Zenghai Li)
   - Mushroom cavity (FNAL, Nikolay Solyak)
   - Longitudinal rods (JLAB, H. Wang/CI, G. Burt)

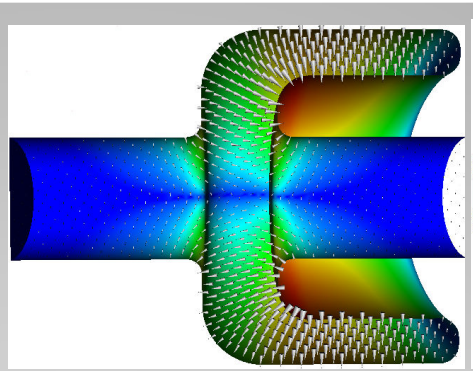
2. TE type (Panofsky-Wenzel: $j\omega \vec{F}_\perp = \nabla_\perp F_z$!)

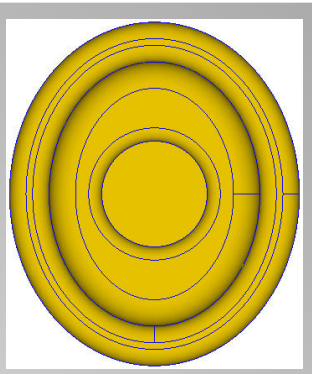
   $B_y = 0$ ➔ Kick force dominated by E_x

   - "transverse pillbox" (Kota Nakanishi)
   - Parallel bars or spokes:
     - Figure-of-8 (CI, Graeme Burt, Peter McIntosh)
     - Spoke cavity (SLAC, Zenghai Li)
     - Parallel bar cavity (JLAB, Jean Delayen)

SLAC Half-wave Resonator

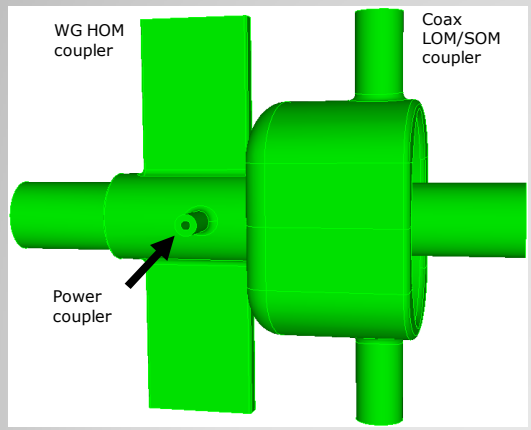
Operating mode Frequency	400 MHz
Operating Mode	TM11
Same-Order Mode Frequency	342 MHz
Iris aperture (diameter)	160 mm
Transverse Shunt Impedance	47 ohm/cavity
Deflecting voltage per cavity	1.25 MV
Peak surface magnetic field	74 mT
Peak surface electric field	35 MV/m

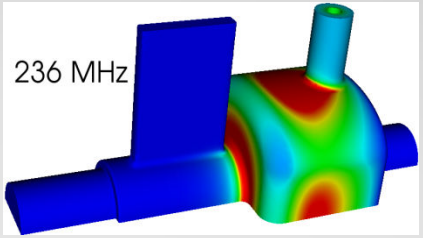


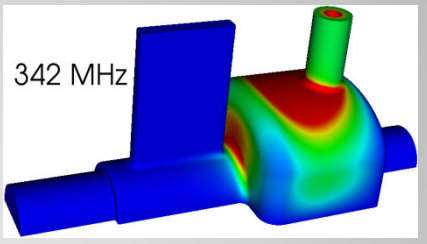


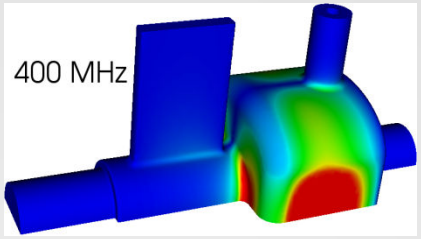
$r \approx 0.3\ \lambda$

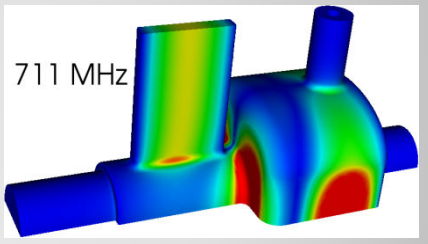
LOM, SOM & HOM damping:





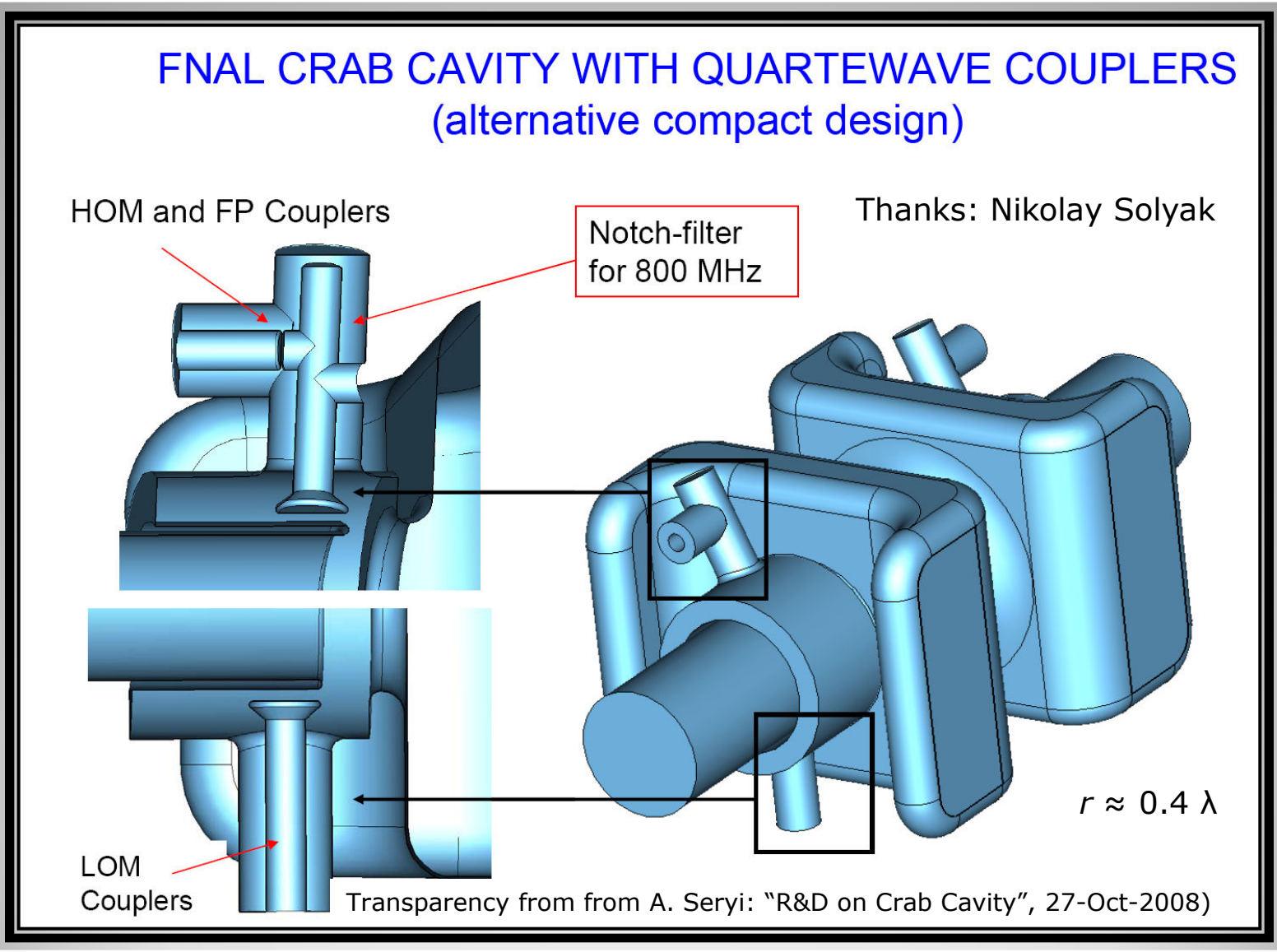






Thanks: Zenghai Li (pictures from PAC09 poster)!

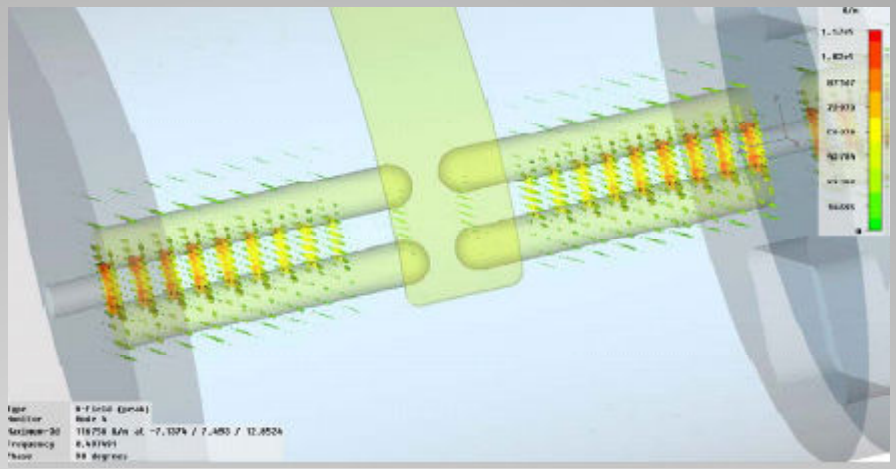
Mushroom cavity



Longitudinal rods

Original JLAB concept:

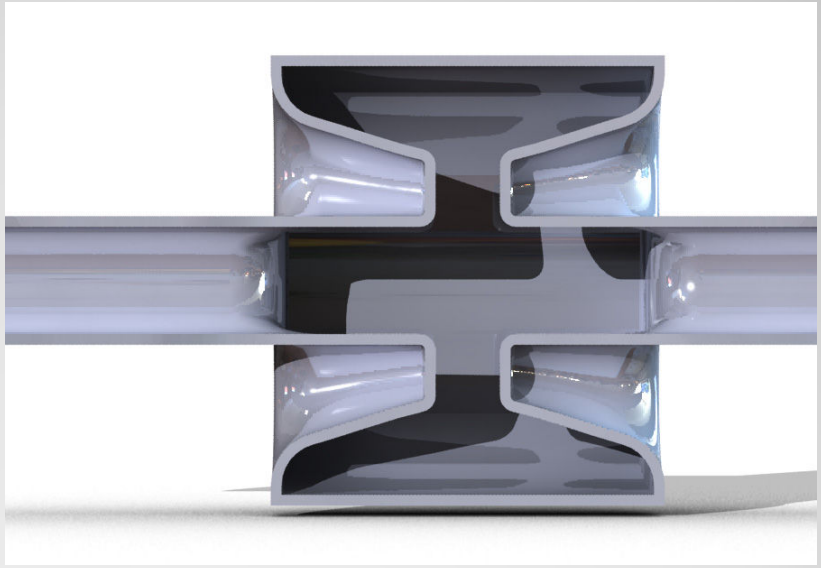
Thanks: H Wang



Thanks: Peter McIntosh (HHH LHC CC validation workshop, 21-Aug-2008)

CI's evolution of the scheme:

... this study is also supported by FP7



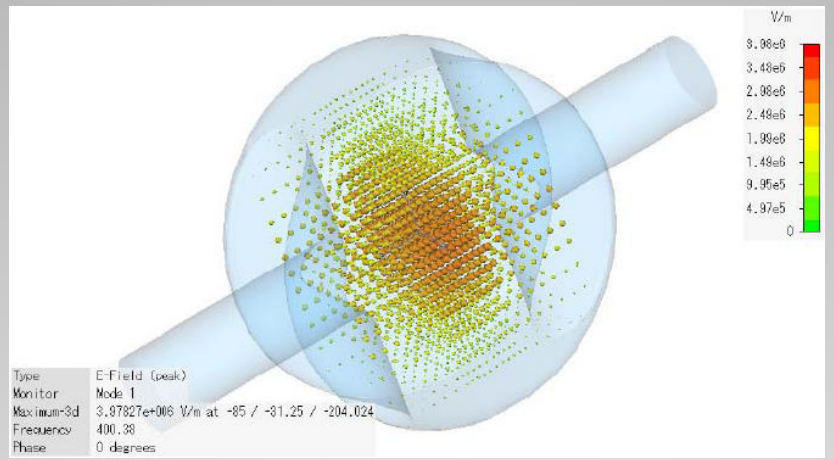
$r \approx 0.26\ \lambda$

Thanks: Graeme Burt, CI/U-Lanc.

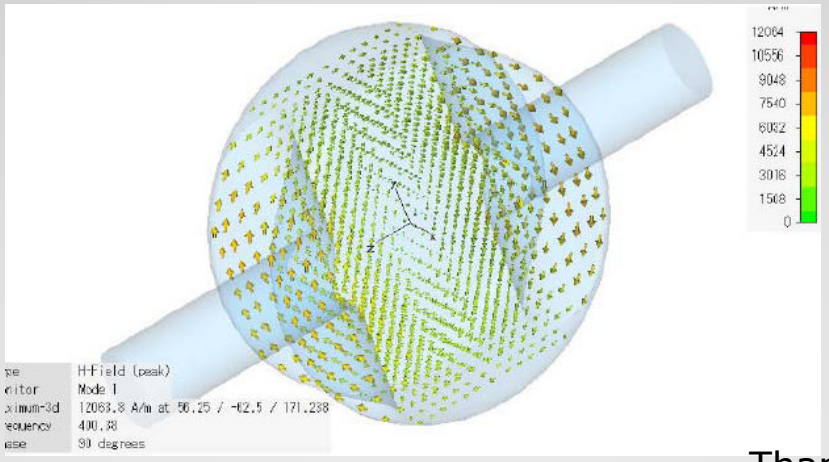
"Kota-cavity"

- Kota Nakanishi's idea to use a "transverse pillbox":

E-field:



B-field:

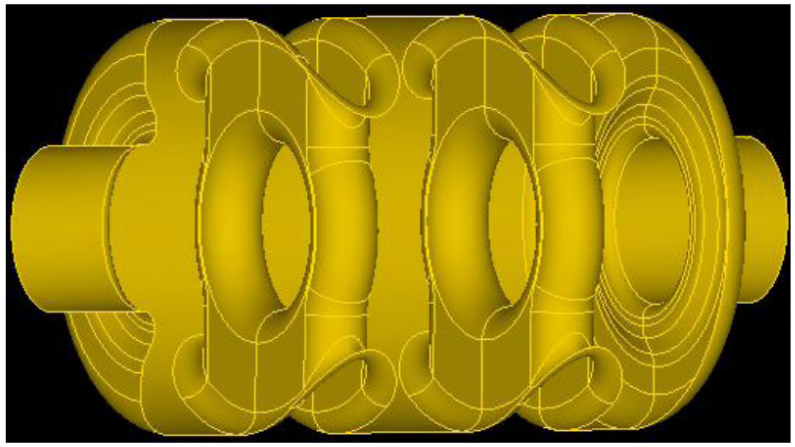


$r \approx 0.2\ \lambda$

Thanks: Kota Nakanishi, KEK, pictures from G. Burt

Spoke cavity

800-MHz Spoke Cavity



Cavity radius: 150 mm

$r \approx 0.4\ \lambda$

ModeID	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

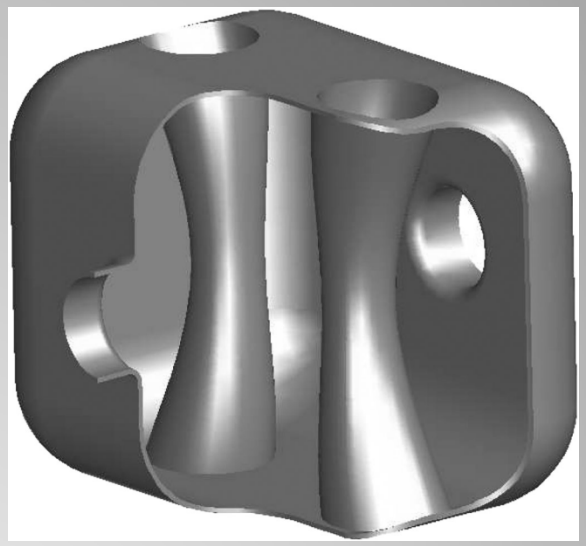
Verticle Modes

ModeID	Frequency	RoQT(ohm/cavity)
0	1.03E+09	9.10E+00
1	1.11E+09	1.02E+02
2	1.15E+09	3.55E+01
3	1.17E+09	4.54E-01
4	1.32E+09	6.71E-01

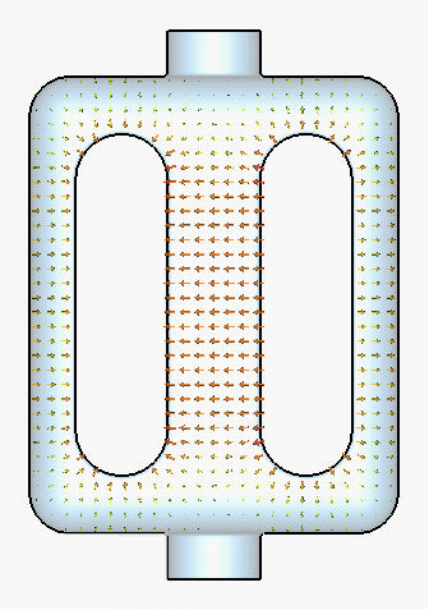
Thanks: Zenghai Li!

Parallel Bar Cavity

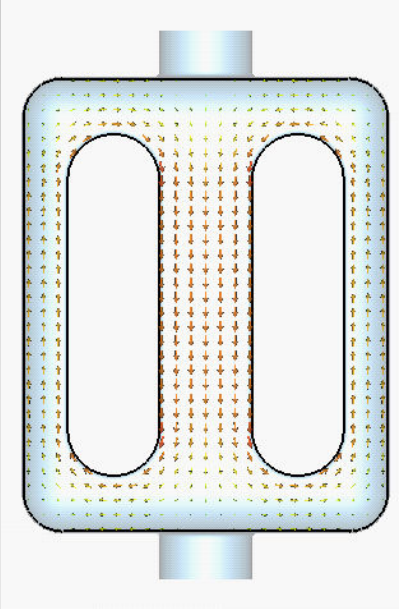
Delayen & Wang:
"New compact TEM-type deflecting and crabbing rf structure"
PRST-AB **12**, 062002 (2009)



400 MHz version



E-field in the mid plane



H-field in the top plane

$r \approx 0.27\ \lambda$

Thanks: Jean Delayen, JLAB and Old Dominion University

… but a lot of issues remain!

- High kick field required; surface electric and magnetic fields!
- Fabrication technology (e-beam welding, cleaning, HP water rinsing, ...)
- HOM, LOM (SOM) damping
- Machine impedance
- Multipactor
- Microphonics
- ...

Conclusions

- There is a risk that a validation test with a global scheme and a (non-compact) CC near point 4 may be incompatible with LHC operations.
- Only Compact Crab Cavities are compatible with a Local Scheme.
- In my personal view, one should intensify R&D on Compact Crab Cavities.
- In order to have a chance of success, this R&D must be significant and well coordinated – many issues are unsolved!

Acknowledgement:
I took material from many of you and would like to express my thanks. In particular I acknowledge the quick help from Peter McIntosh, Graeme Burt, Jean Delayen and Zenghai Li!

Not-so-compact vs. compact crab