EUROPEAN SPALLATION SOURCE

Multiple cavity effects (Field emission & eigenmodes)

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HOM Issues in the ESS Linac

Sept 22nd, 2011

Multiple cavity effects

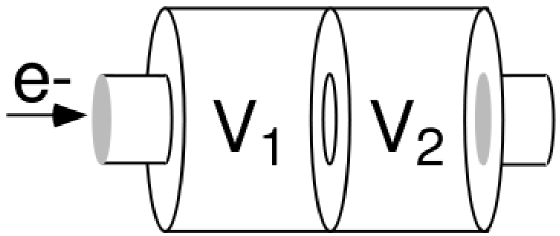
- Cavities are coupled by beampipes
    - This may prevent cavities being viewed in isolation
  - Signals/particles in one cavity may propagate
- Inter-cavity design is crucial
    - Length, bellows, taper, coupler location, …
  - Feeds into lattice & cryomodule design
  - Beampipe, coupler, etc., modes with high R/Q
- Heavy duty simulation
  - Large number of simulation elements
    - Mesh points & particles

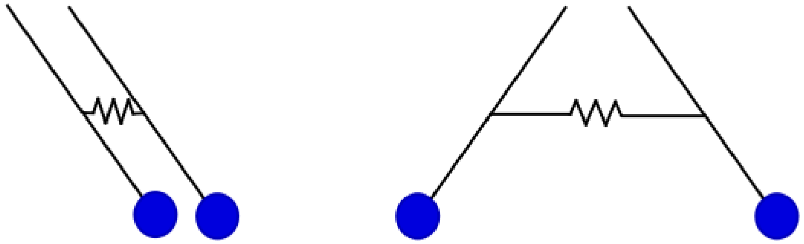
Cell-cell → cavity-cavity coupling

- Single cells have the usual mode spectrum
  - TE_{mnp}, TM_{mnp}
- Couple cells together to form a multi-cell cavity
  - Single-cell modes then split into passbands
  - Each oscillation characterised by phase advance per cell
    - EM codes allow modeling a single cell with the phase advance on the boundaries specified
- Now, connect multiple cavities into a cryomodule
  - Modes below beam-pipe cutoff, so disregarded
    - But this is identical to the multi-cell cavity case!
    - Cavity irises are below cutoff

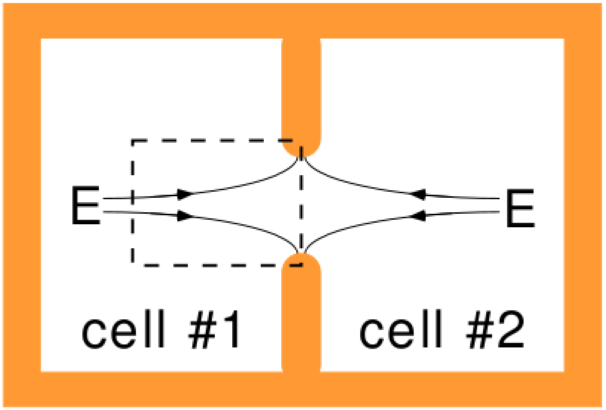
– Coupling is evanescent

Coupled oscillators

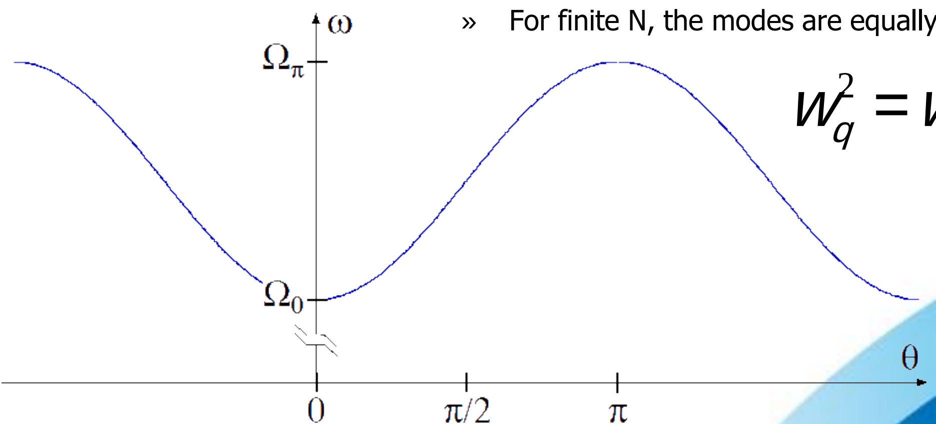




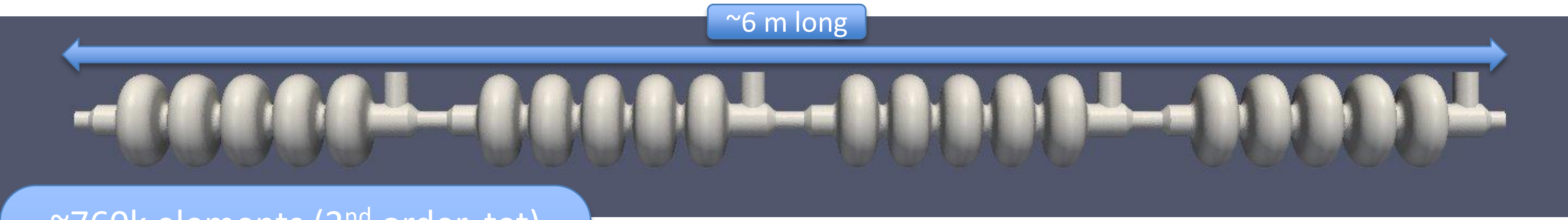
- Eigenmodes of coupled oscillators split according to the phase difference
    - "0-mode", "π-mode", etc.
- For N+1 coupled oscillators
    - iπ/N radians phase advance (i=0,1,…N)
  - Frequency also splits
    - Depends on the coupling strength
      - » Think about the stiffness of a spring coupling two pendulums
    - Each new mode may be plot on a Brillouin curve
      - » For finite N, the modes are equally spaced along the curve



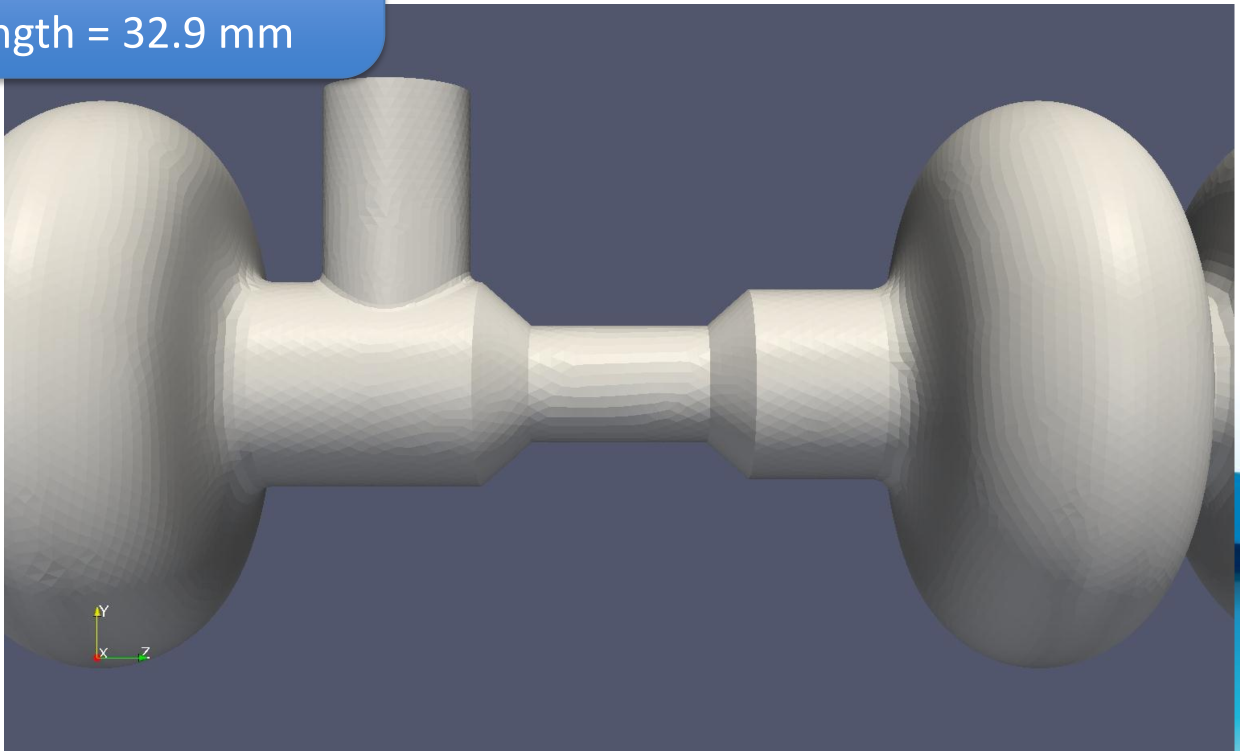
$$w_q^2 = w_{p/2}^2 \left(1 - k\cos(q)\right)$$



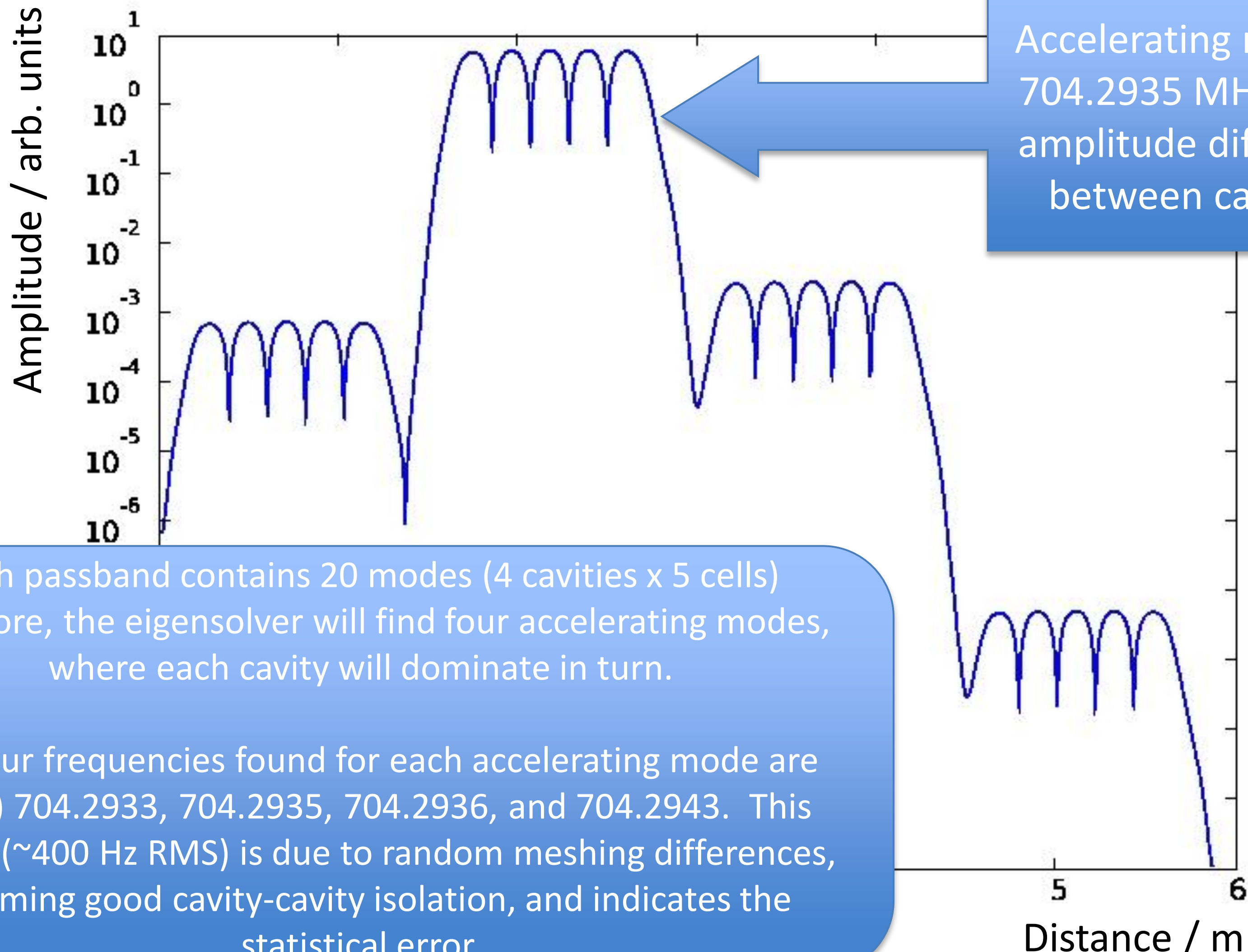
Eigensolve 4 full cavities (half cryomodule, SPL-CEA β=1.0)



~760k elements (2nd order, tet)
Average volume = 4.5×10^{-7} m^{-3}
Min edge length = 1.4 mm
Max edge length = 32.9 mm



Eigenmodes exist across all cavities



Accelerating mode at 704.2935 MHz. ~10^4 amplitude difference between cavities.

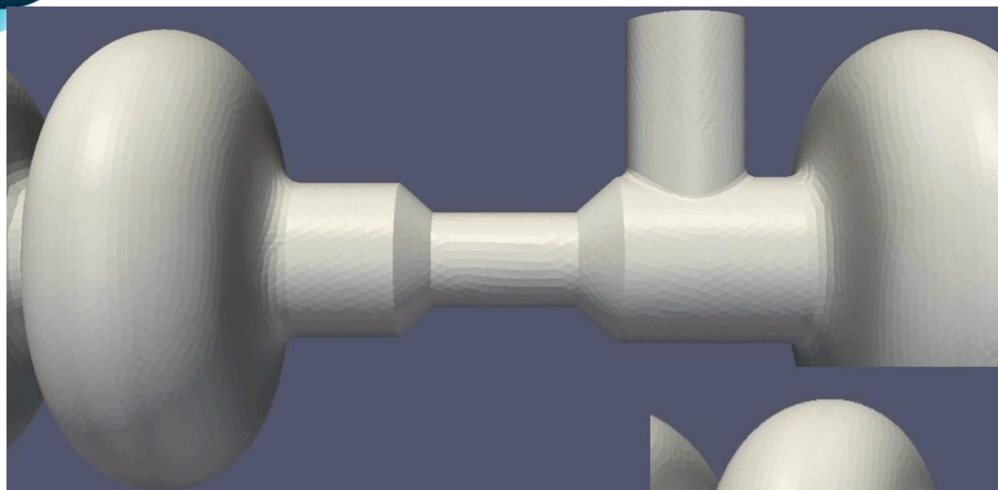
Each passband contains 20 modes (4 cavities x 5 cells) Therefore, the eigensolver will find four accelerating modes, where each cavity will dominate in turn.

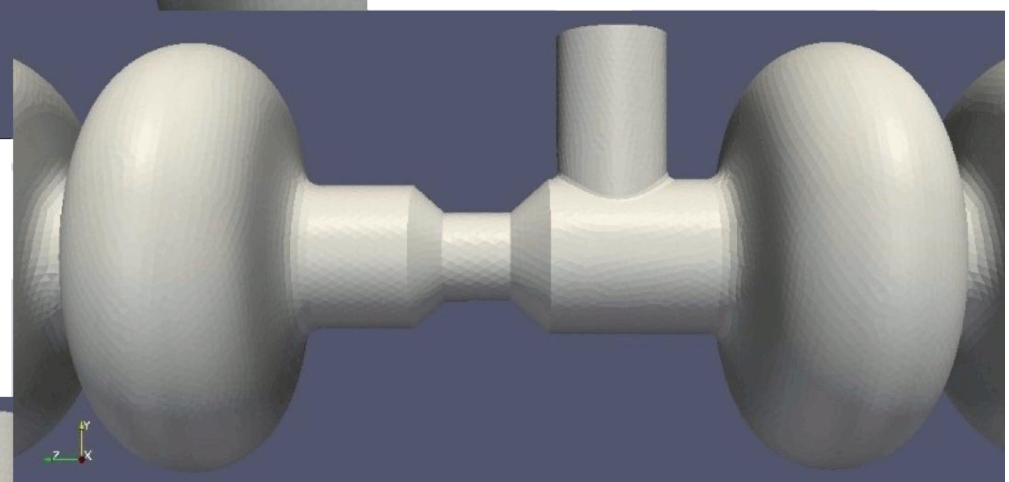
The four frequencies found for each accelerating mode are (MHz) 704.2933, 704.2935, 704.2936, and 704.2943. This scatter (~400 Hz RMS) is due to random meshing differences, assuming good cavity-cavity isolation, and indicates the statistical error.

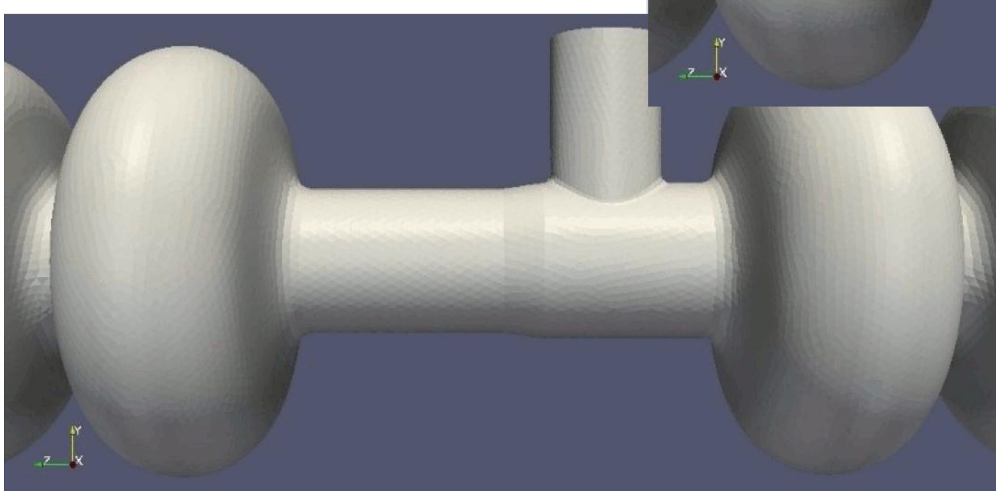
Cavity-cavity coupling

- Each cavity mode will be found four times
  - One for each cavity
  - A single cavity will dominate each mode, however the evanescent field allows coupling
    - Beam → Field coupling in one cavity will excite fields in all others
  - Expect coupling to increase (non-trivially) with frequency
- Use eigensolver to determine coupling
  - Frequency spread of passband modes
  - $w_q^2 = w_{p/2}^2 \left(1 - k \cos\left(q\right)\right)$
- Theory can give some insight
  - QM "particle in box" calculations…

Geometries







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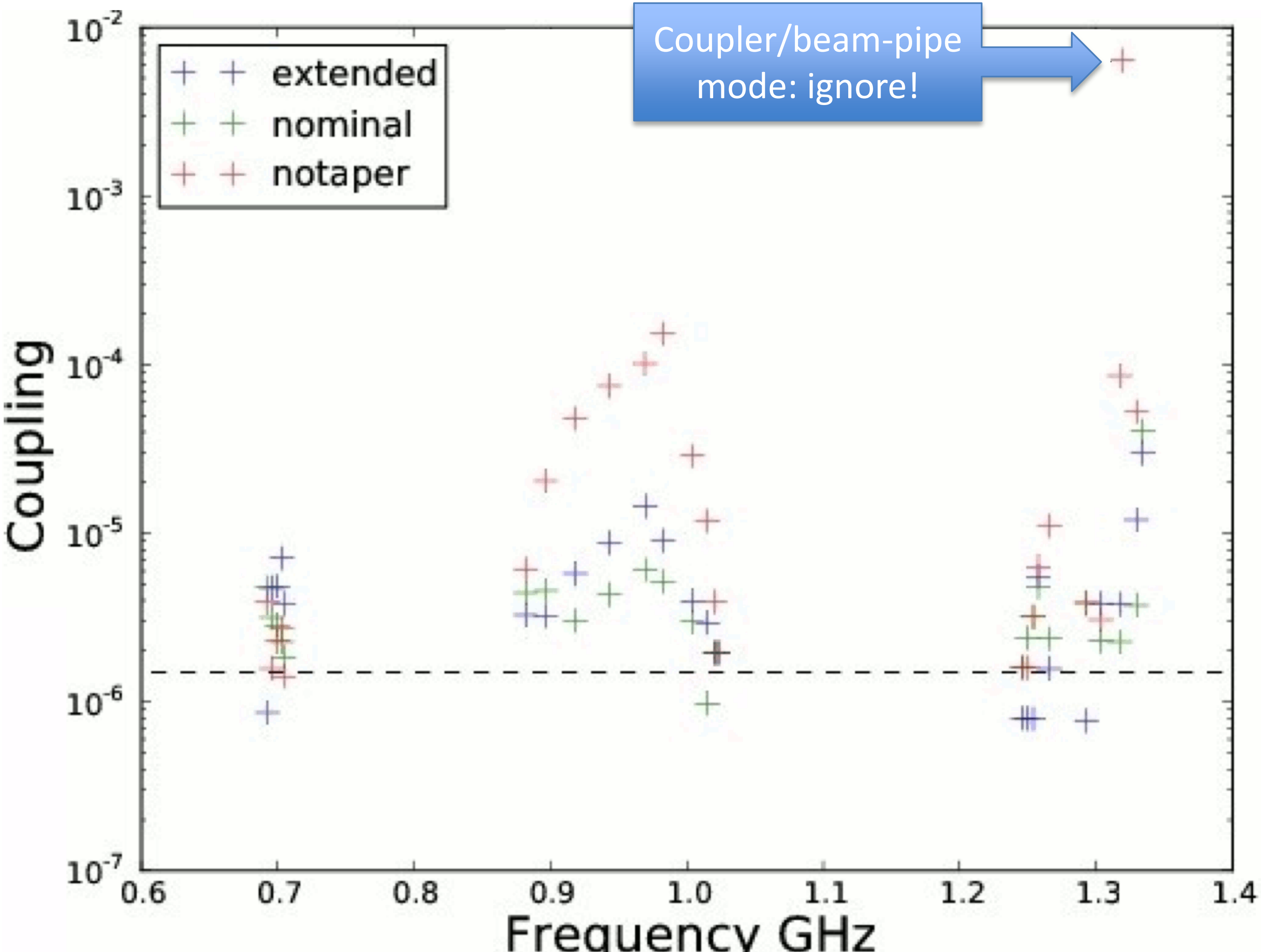
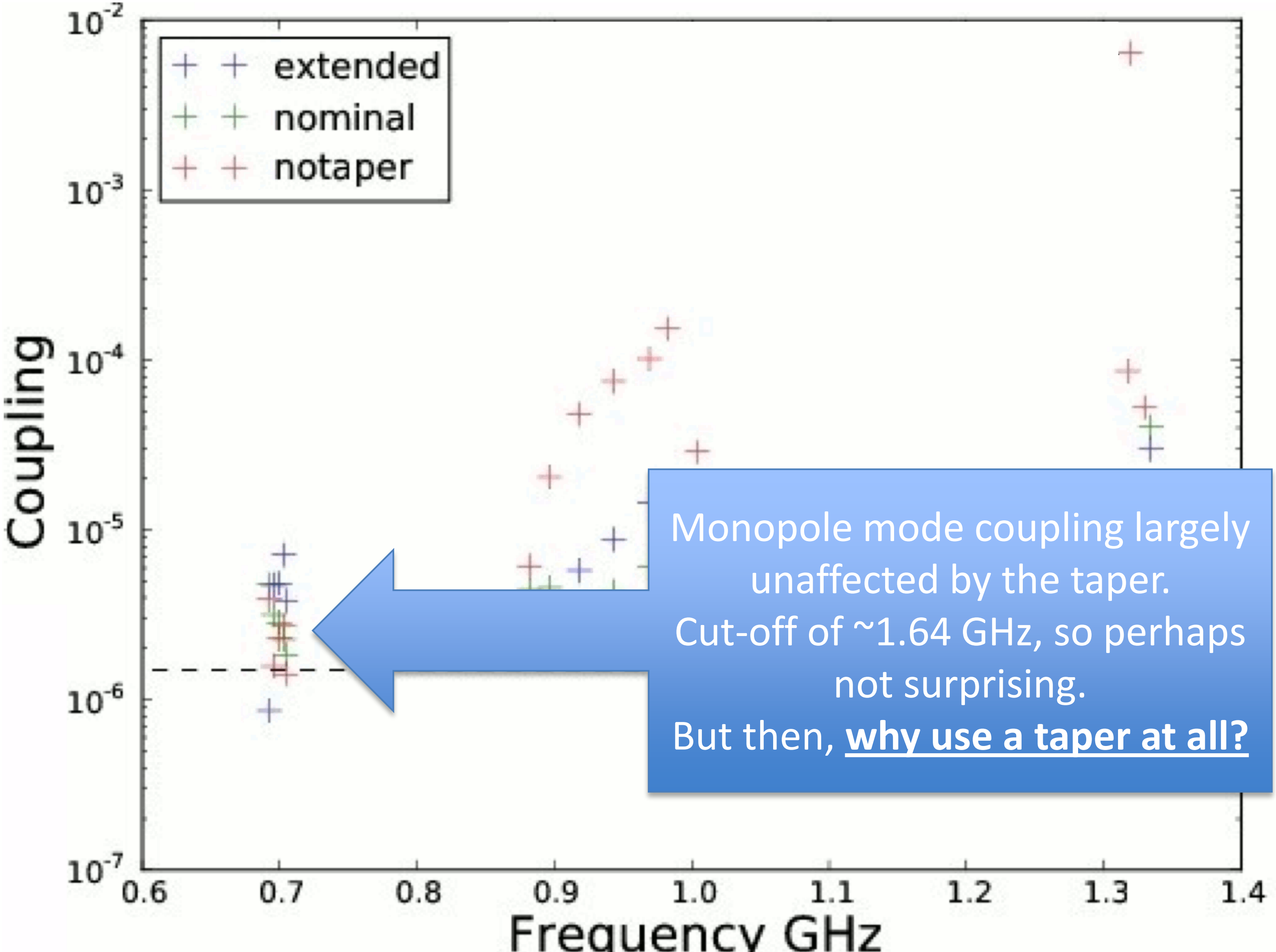
Coupling

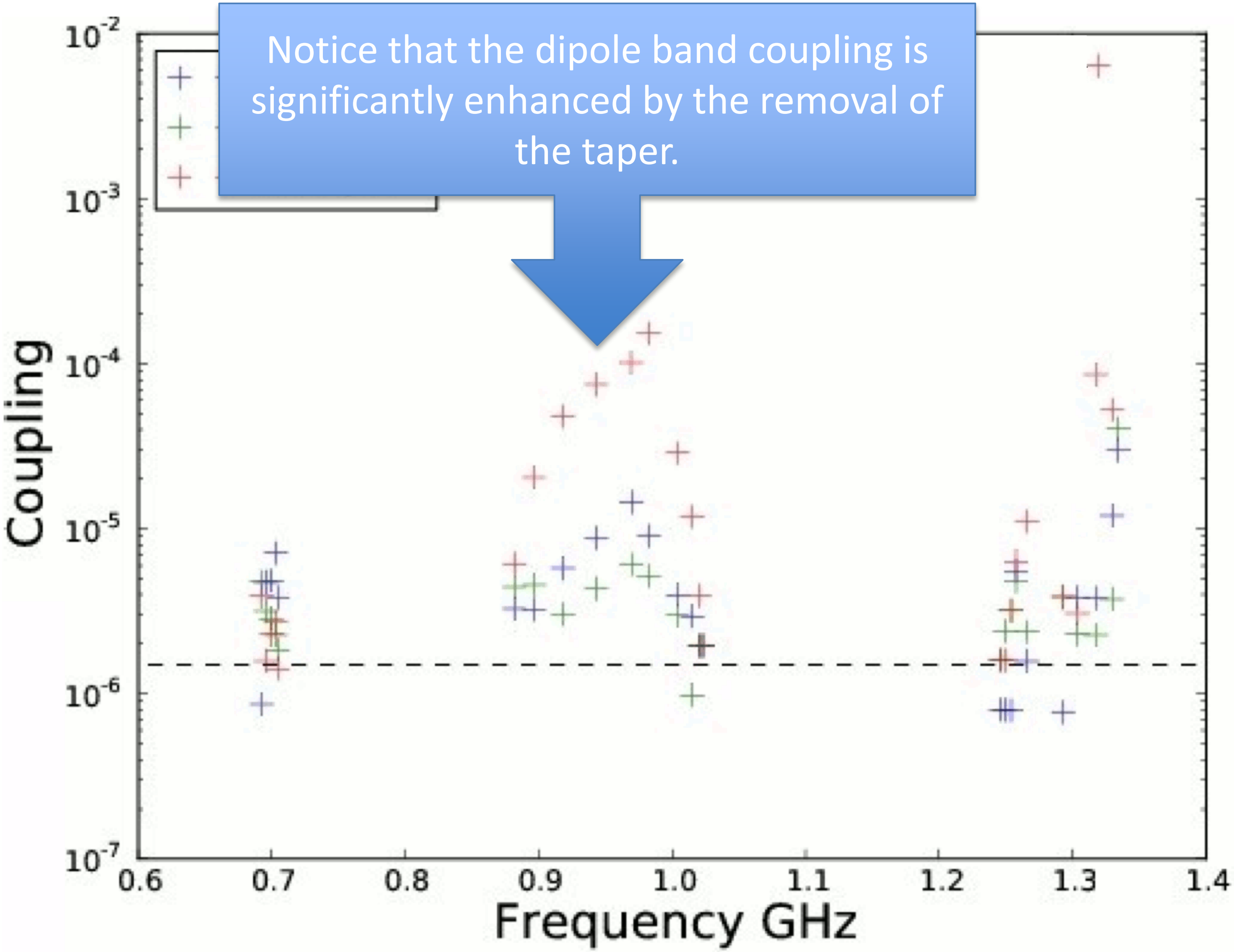


Coupling



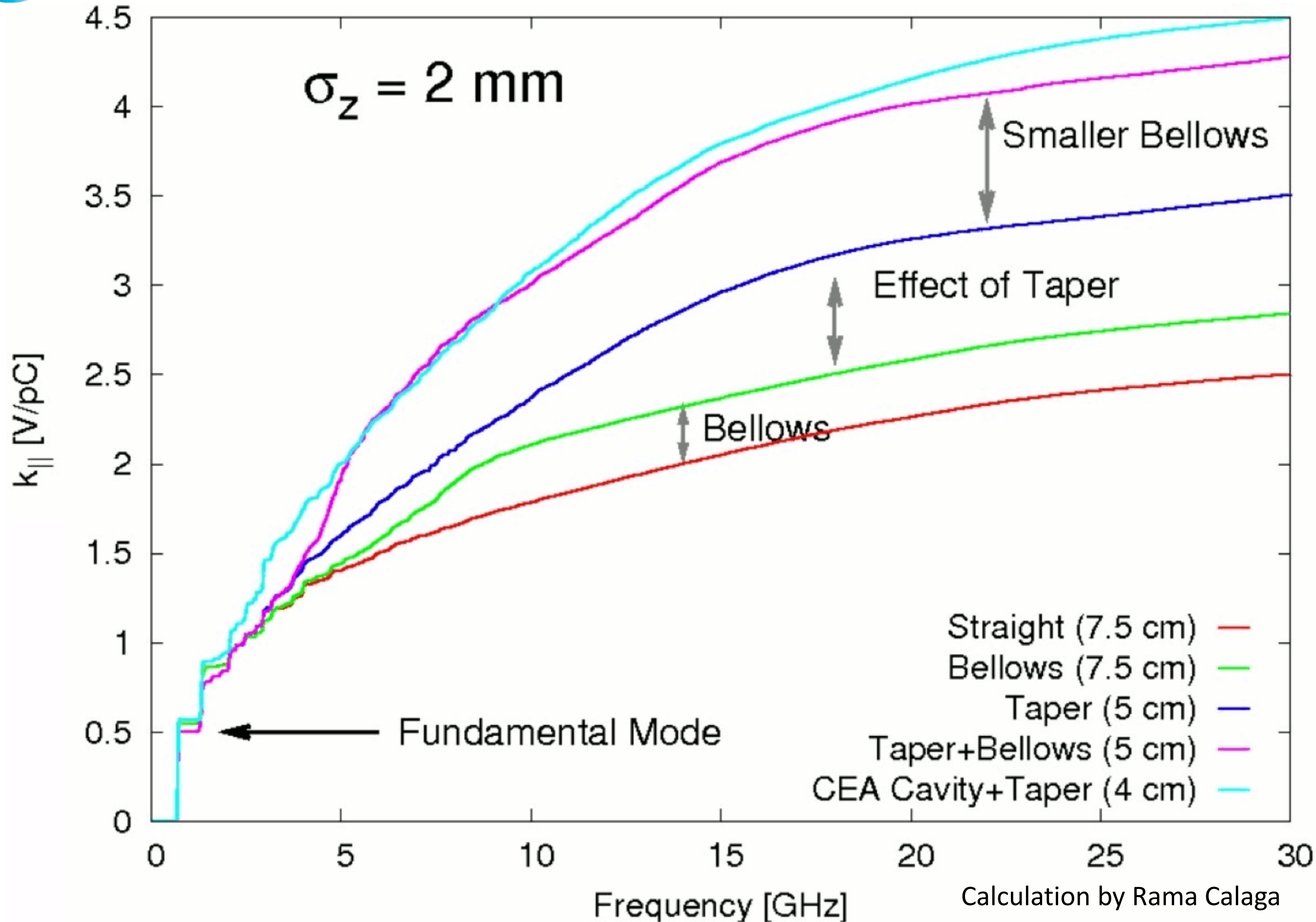
Monopole mode coupling largely unaffected by the taper.
Cut-off of ~1.64 GHz, so perhaps not surprising.
But then, **why use a taper at all?**

Coupling



Notice that the dipole band coupling is significantly enhanced by the removal of the taper.
Coupling
Frequency GHz
10-2
10-3
10-4
10-5
10-6
10-7
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4

Impact of the taper – loss factor



Calculation by Rama Calaga

Impact of taper

- No effect on fundamental mode isolation
- Increased loss factor
    - Perturbation of the beam
- Decreases dipole coupling
    - Is this desirable?
  - Decreased coupling → lower amplitude
  - Lower amplitude → decreased efficiency of HOM coupler
- Is a taper necessary?

I. E. Campisi, F. Casagrande, M. T. Crofford, Y. W. Kang, S. H. Kim, others, PAC07, 2511 (2007).

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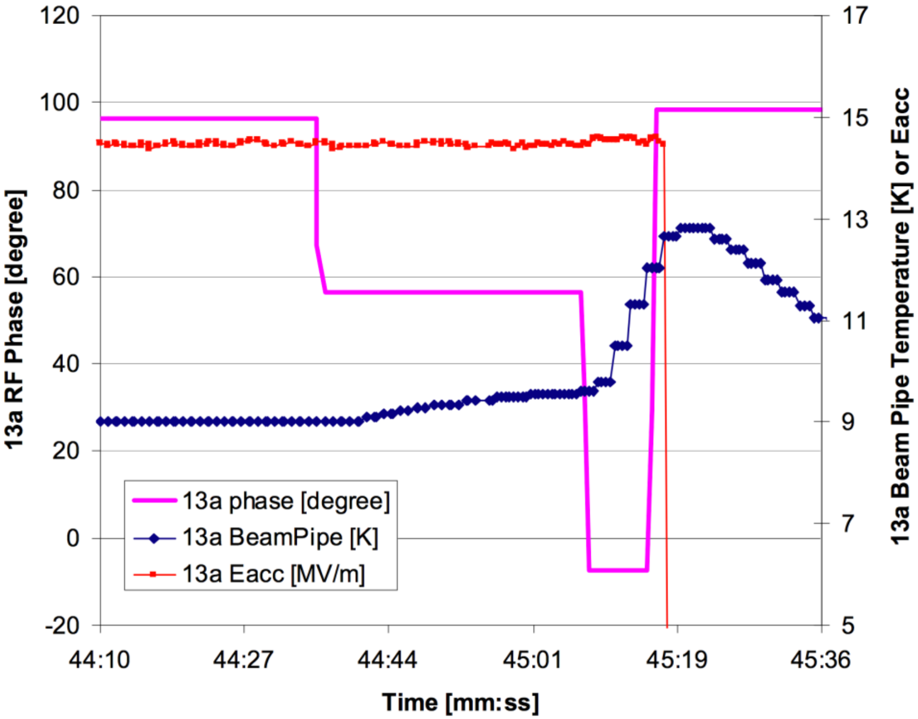
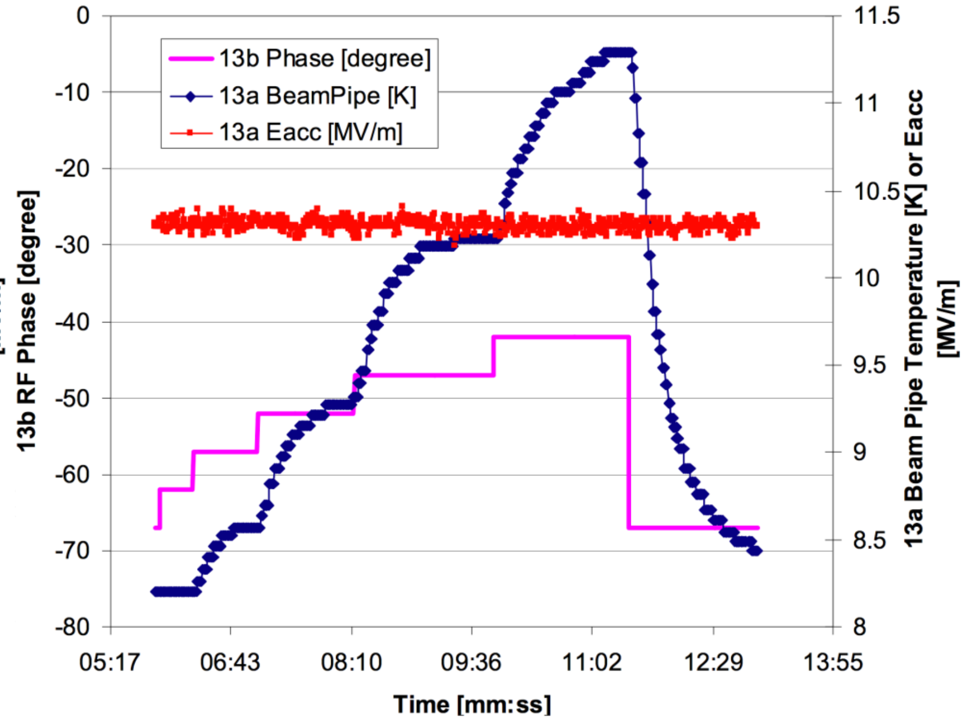
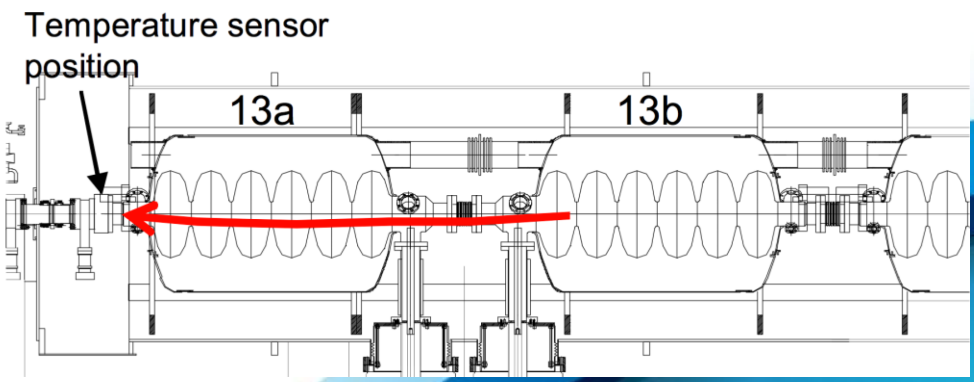
Field emission – multi-cavity phenomenon

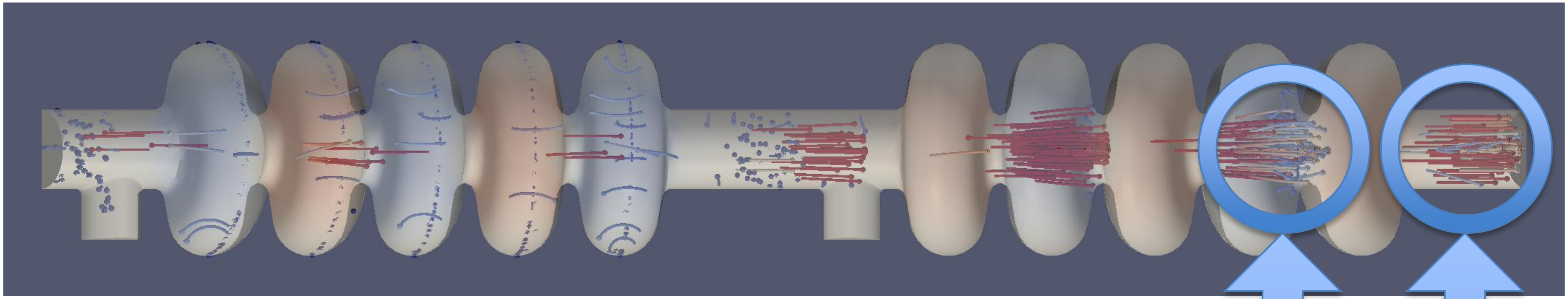




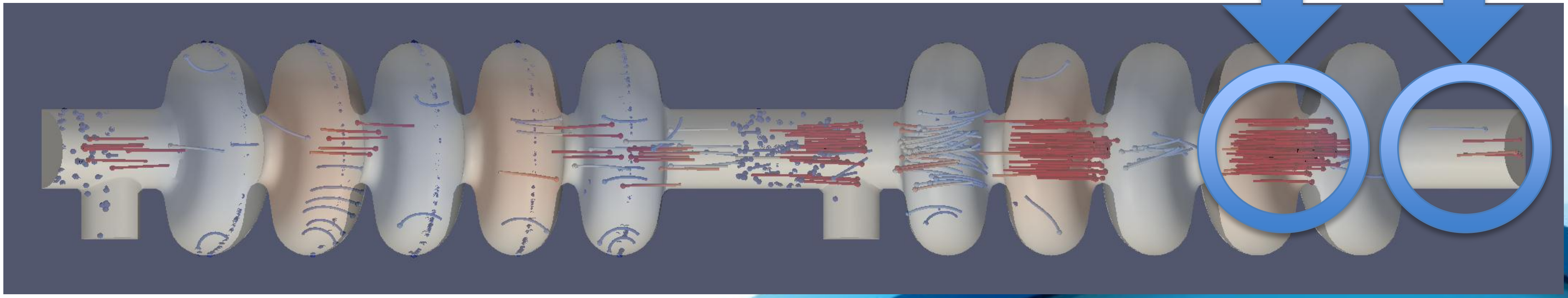


Can we simulate this?

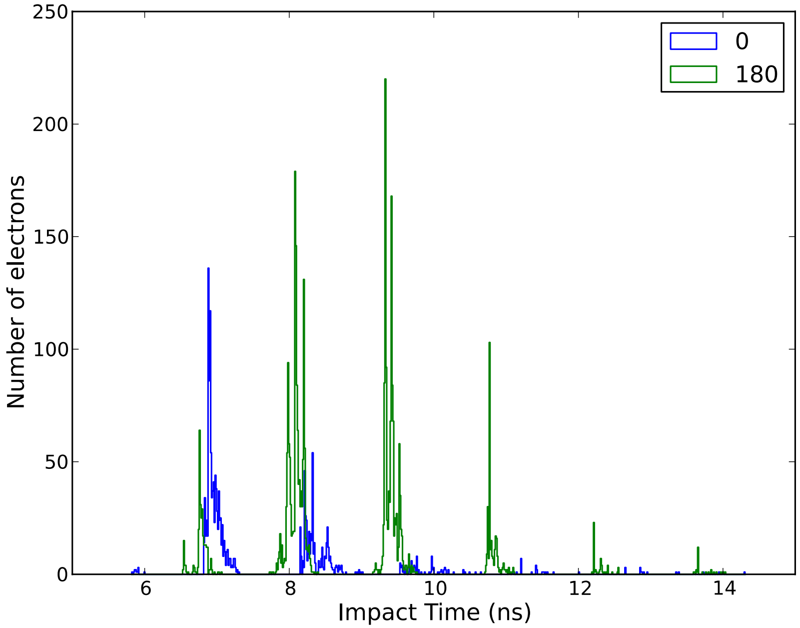
- Instantaneous phase difference = 0°

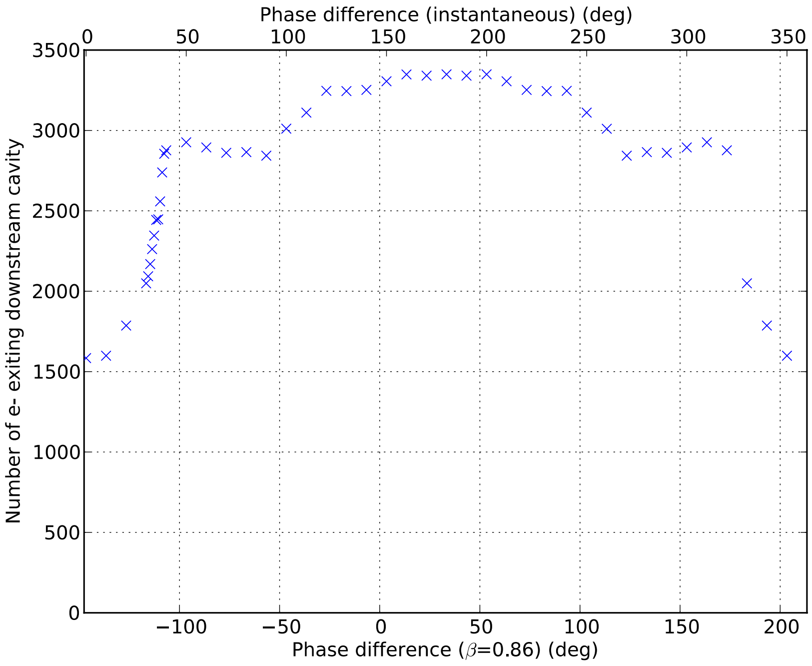


- Instantaneous phase difference = 180°



FE current is dependent on cavity phase relationship





Inter-cavity transition section design is important

- Mode coupling
  - Are we trying to limit fundamental coupling?
  - Promoting coupling of HOMs?
- FE electrons
  - Attempt to limit their propagation?
- Loss factor
  - High frequency beam perturbations?
- What studies are necessary?
  - Software tools?
  - Experimental studies?