

HOM simulations: Single cavities and cryomodules

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Steve Molloy, Rob Ainsworth
Royal Holloway, University of London

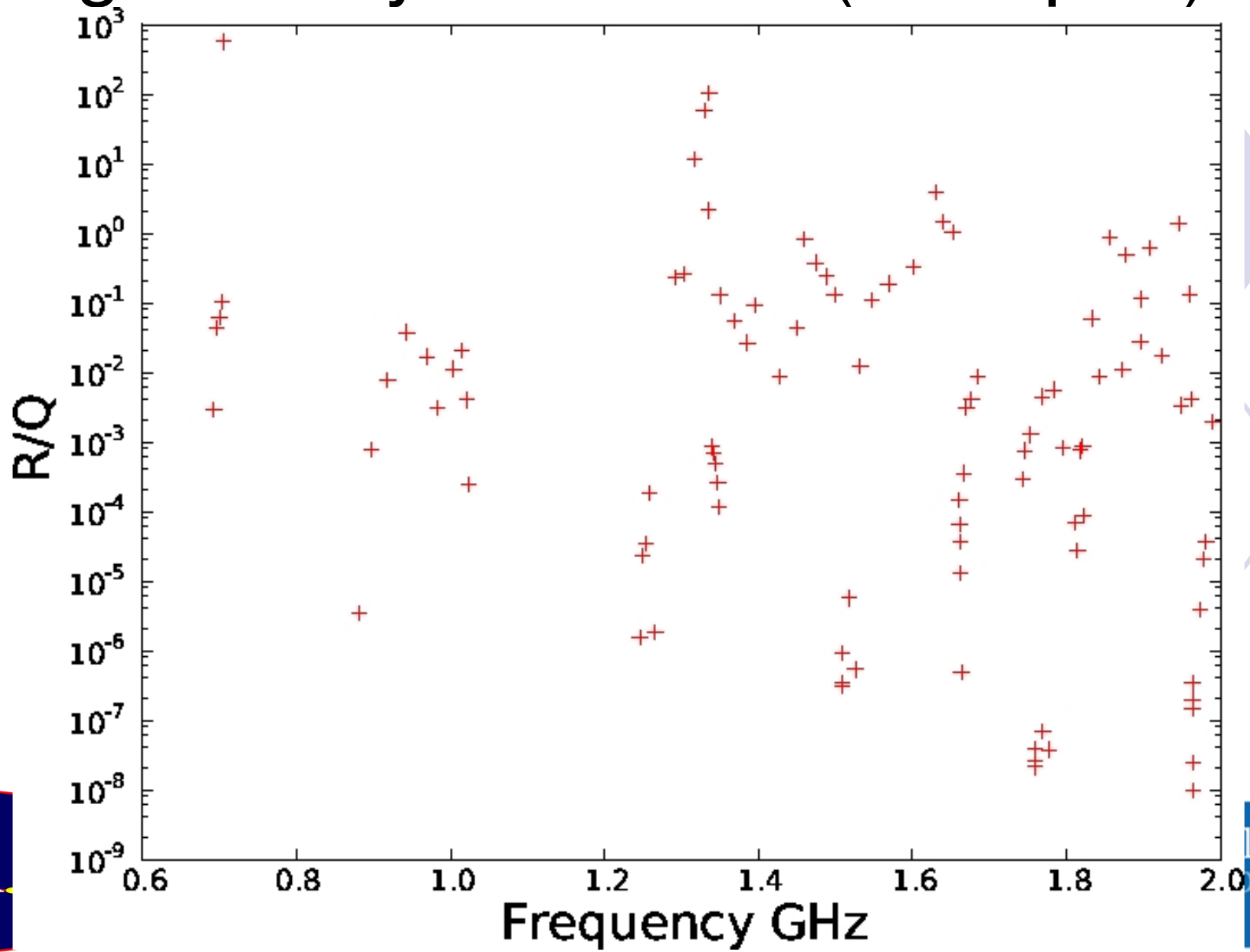


Outline

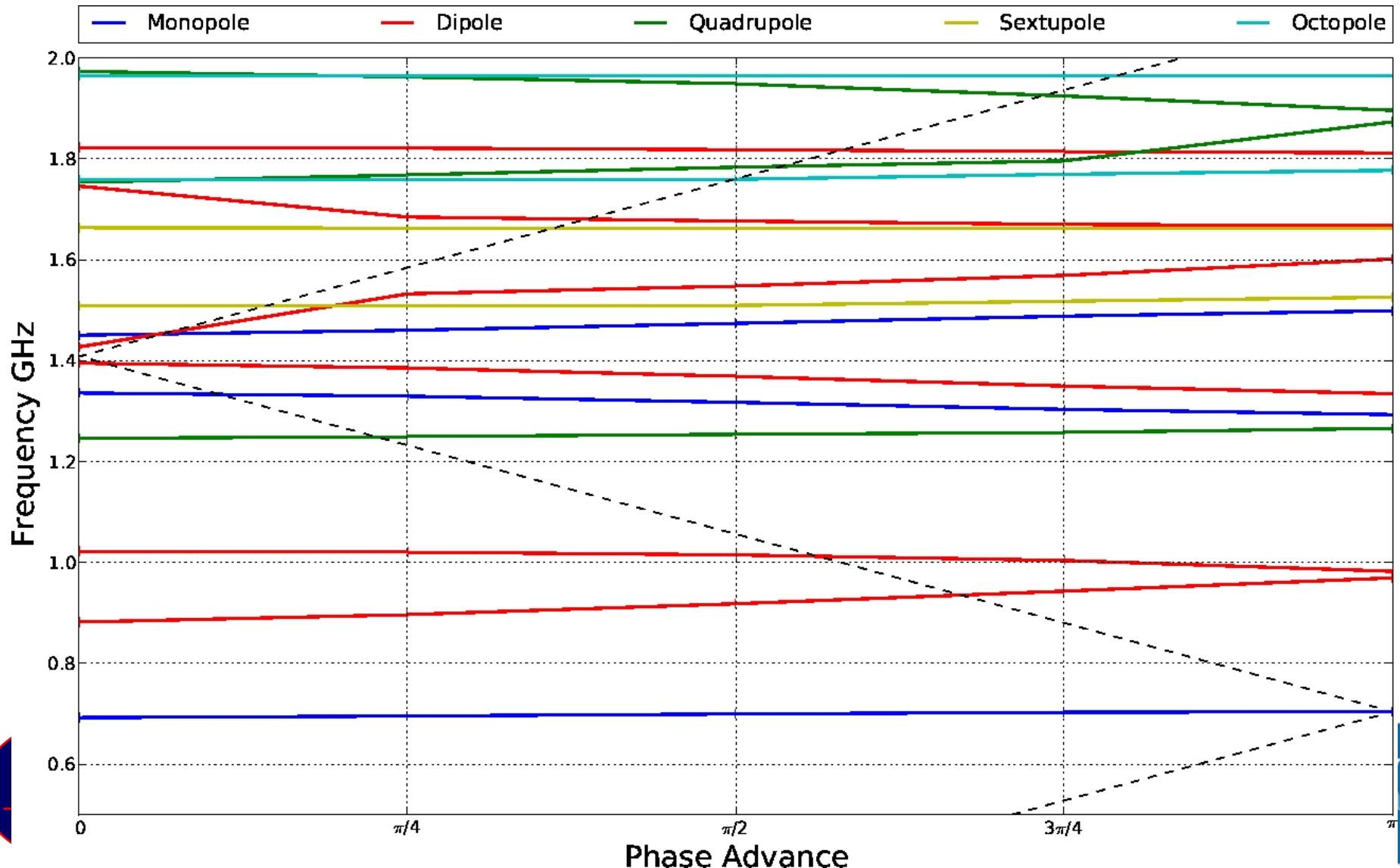
- Single cavity results (CEA $\beta=1$)
- Previous cryomodule simulations
 - Presented in Lund in June
 - **What we got wrong!**
- Correction to the method
 - Description of the theory
 - Calculations & simulations
 - Conclusions



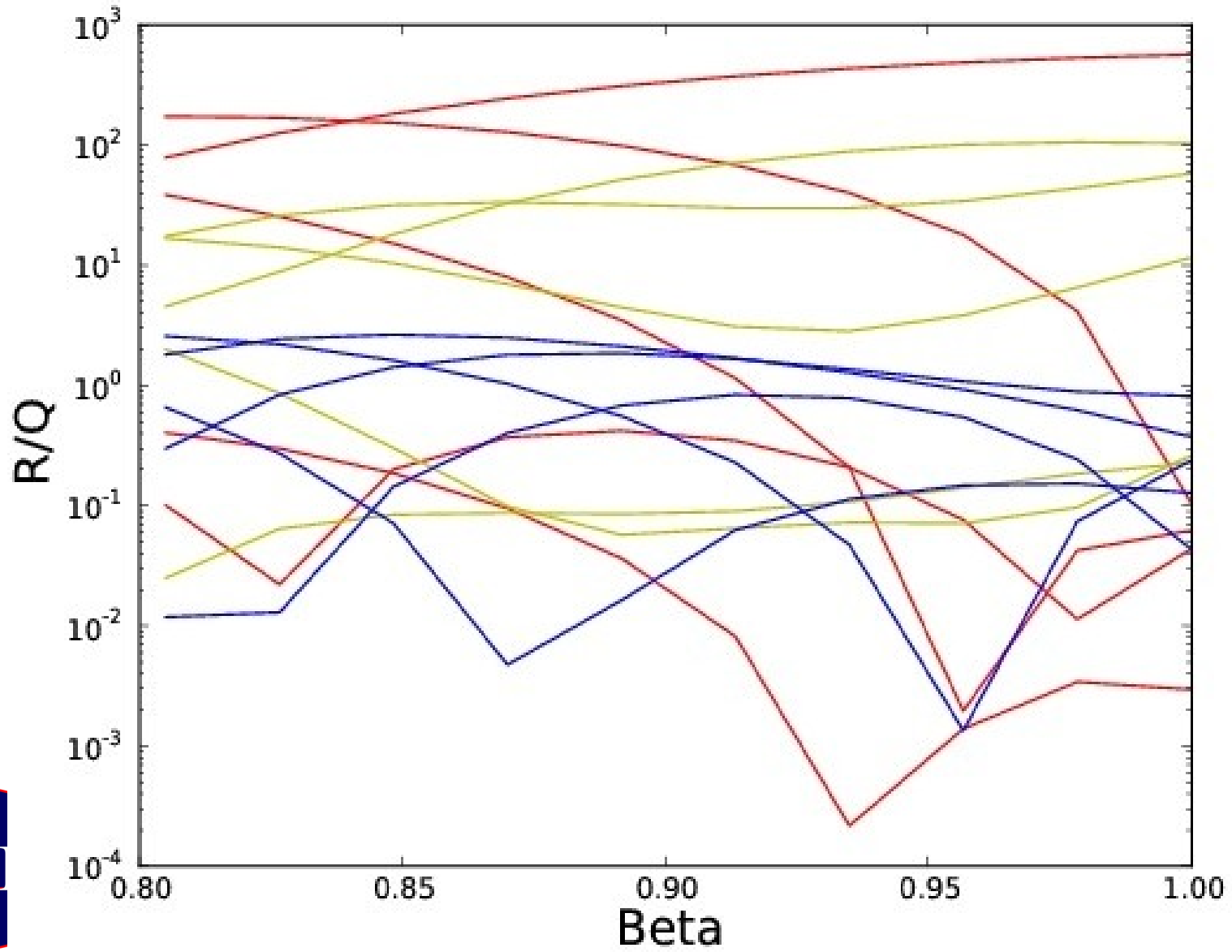
Single Cavity simulation (CEA $\beta=1$)



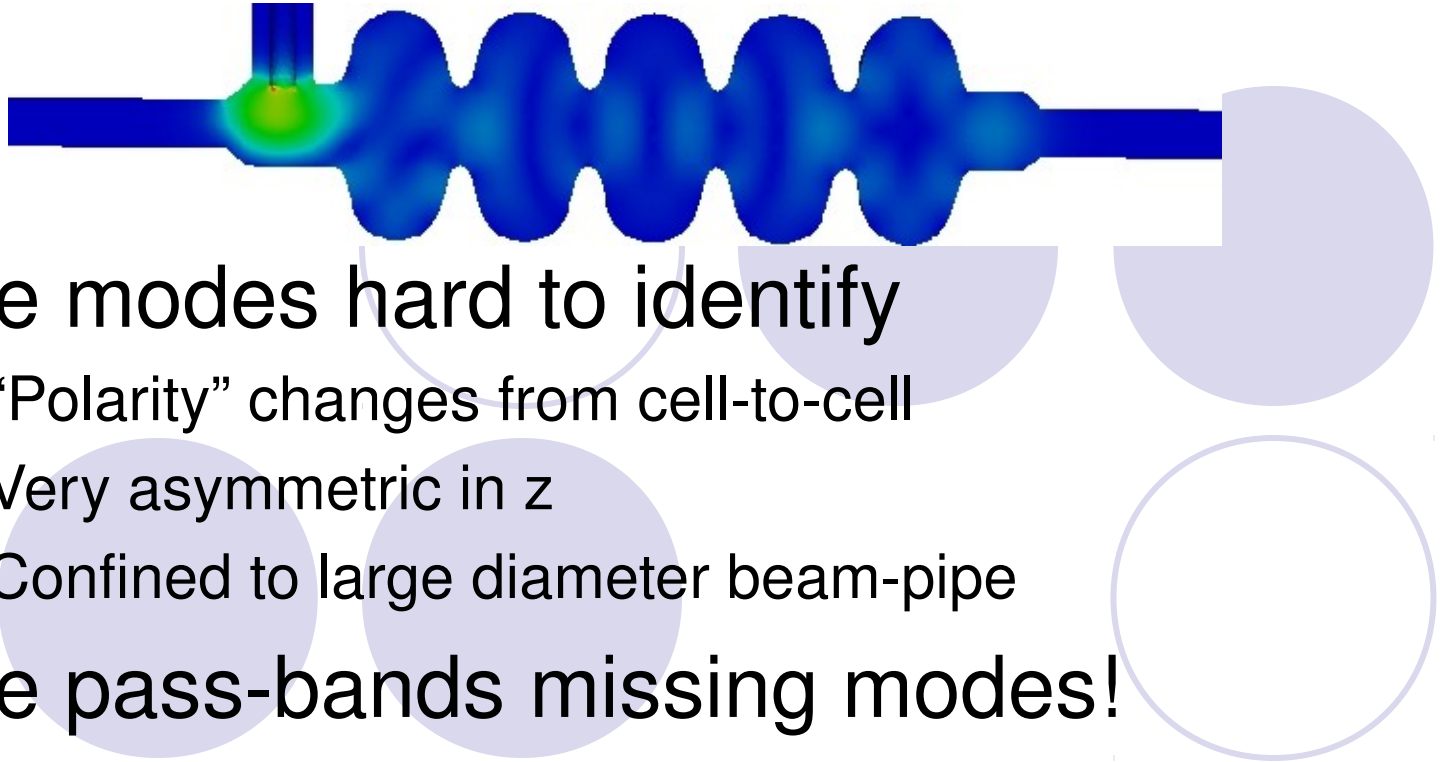
Dispersion curves for single cavity



Coupling vs beam velocity

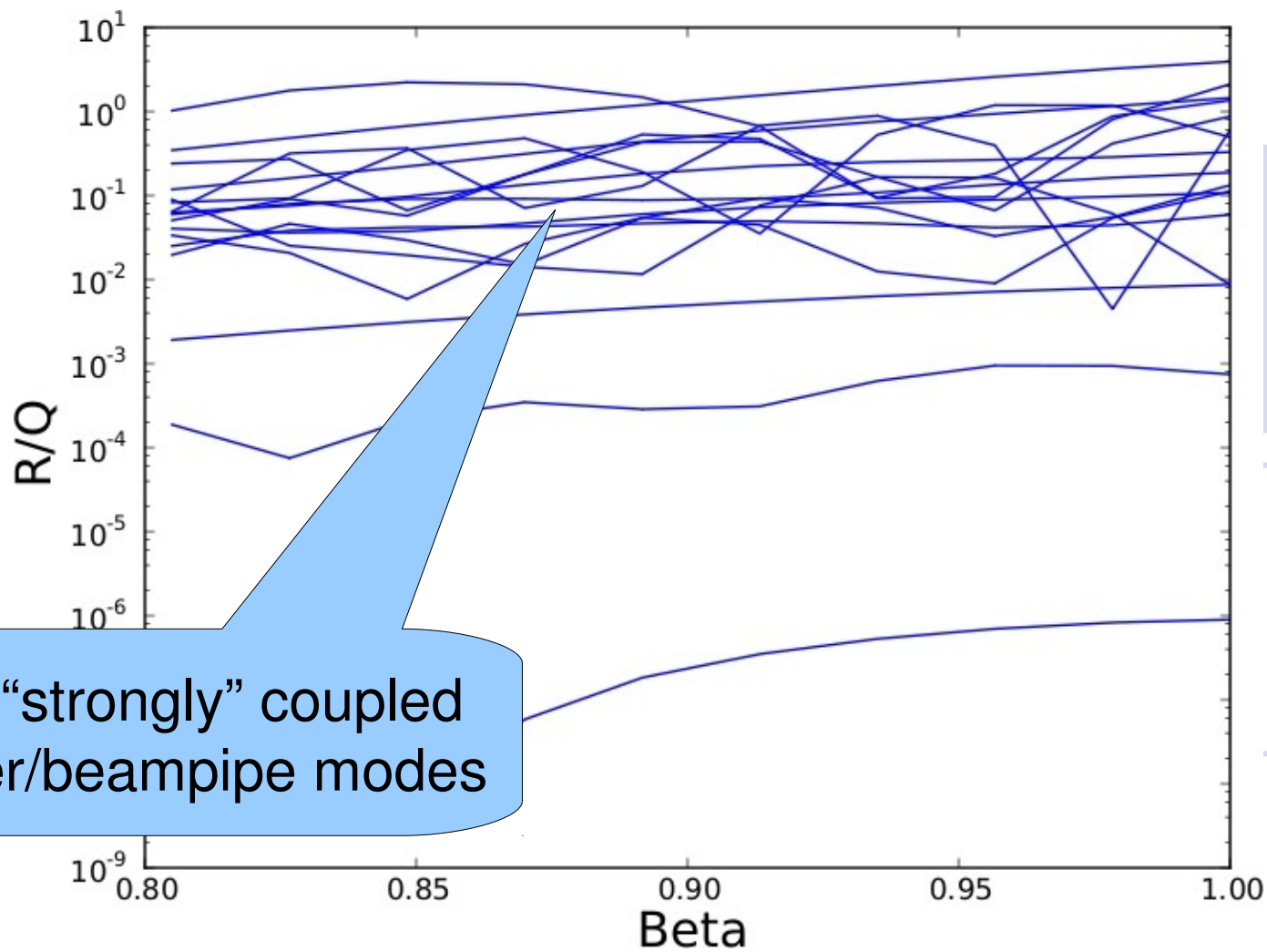


Beam-pipe, coupler, & hybrid modes



- Some modes hard to identify
 - “Polarity” changes from cell-to-cell
 - Very asymmetric in z
 - Confined to large diameter beam-pipe
- Some pass-bands missing modes!
 - 4/5 modes in passband identified
 - Remaining mode illusive
 - Mode at “right” frequency has “wrong” structure

Coupler/Beampipe modes



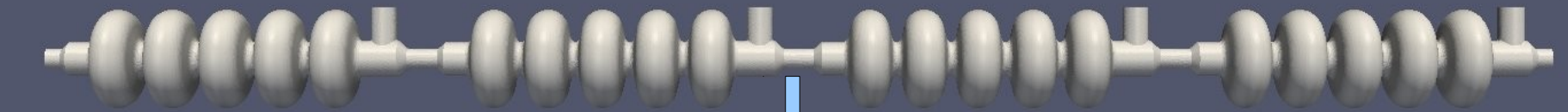
Multi-cavity coupling

- A single cell has the usual mode spectrum
 - TE_{mnp} , TM_{mnp}
- Coupled cells (e.g. in a multi-cell cavity)
 - Modes split into passbands
 - Each oscillation characterised by phase advance per cell
- Multicavity installations (i.e. a cryomodule)
 - Modes below beam-pipe cutoff, so disregarded
 - *But this neglects evanescent coupling!*

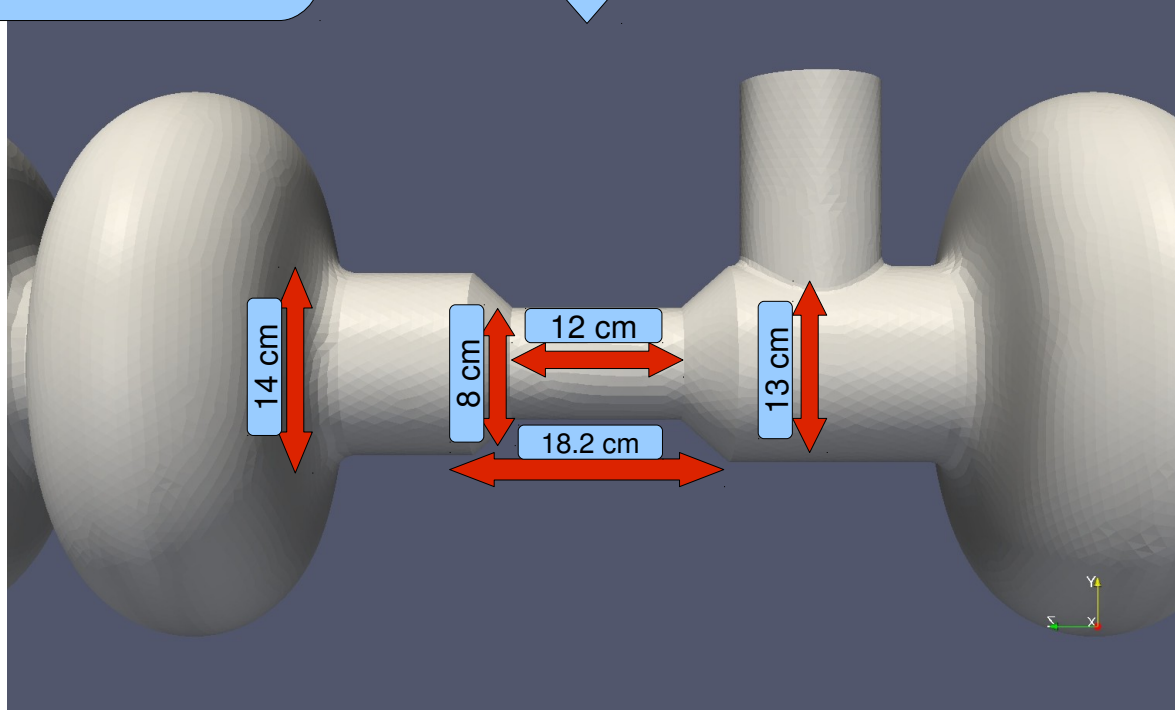


Eigen solve 4 full cavities

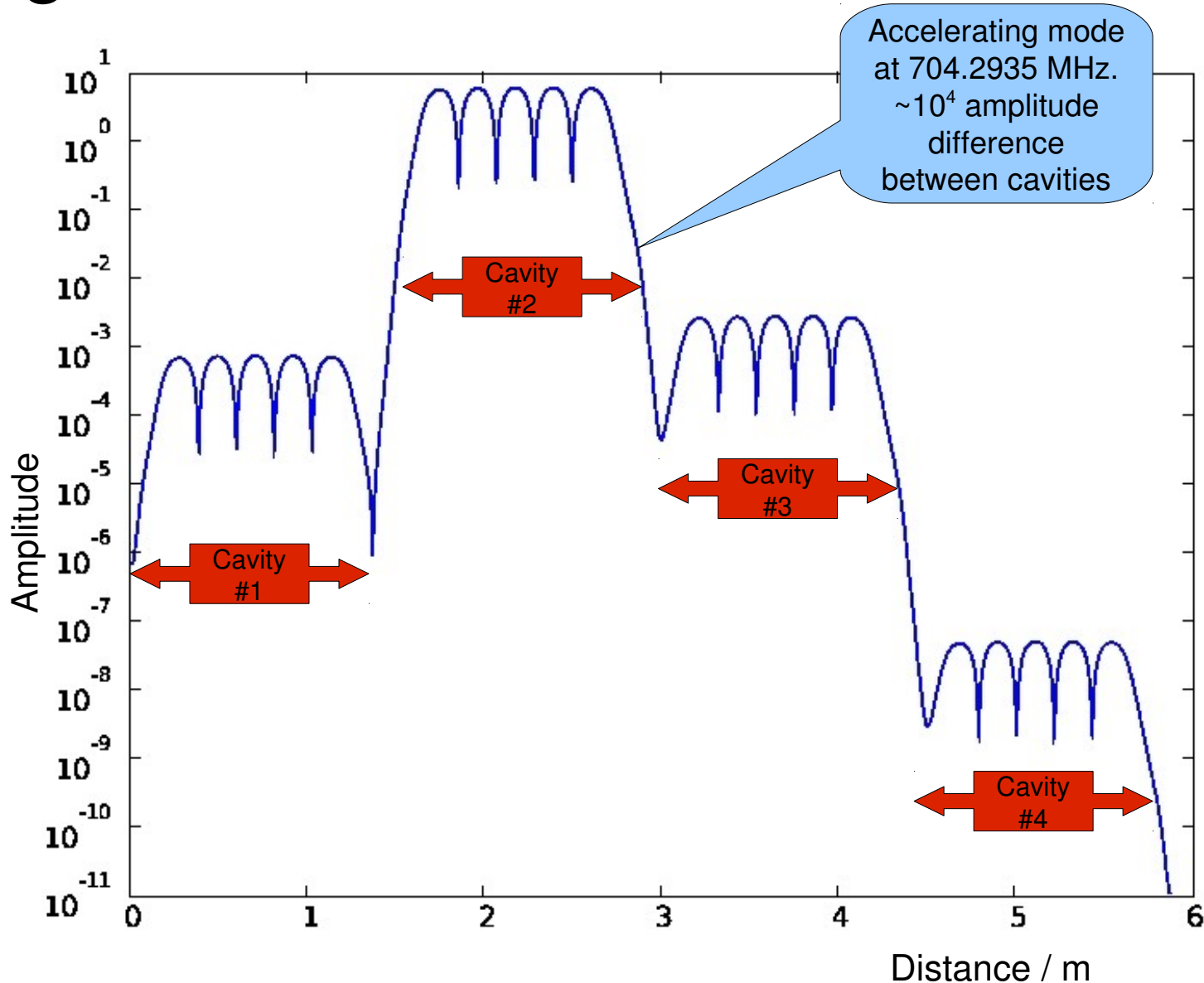
~6 m long



~760k elements
Average volume = $4.5 \times 10^{-7} \text{ m}^3$
Min edge length = 1.4 mm
Max edge length = 32.9 mm



Eigenmodes exist in **all** cavities

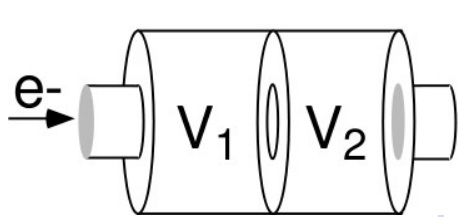


Intra-cavity coupling

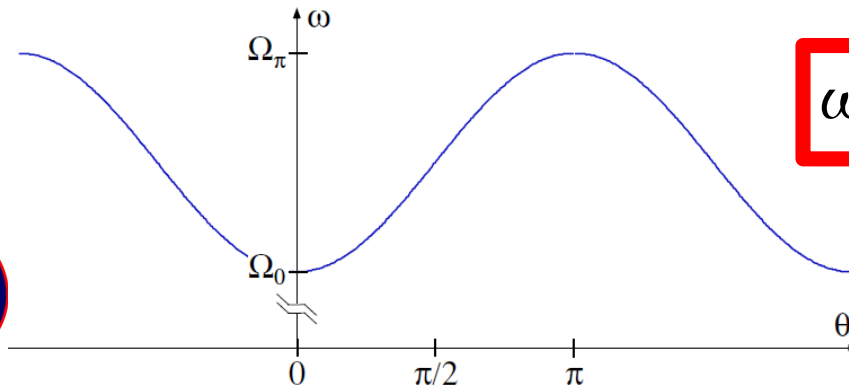
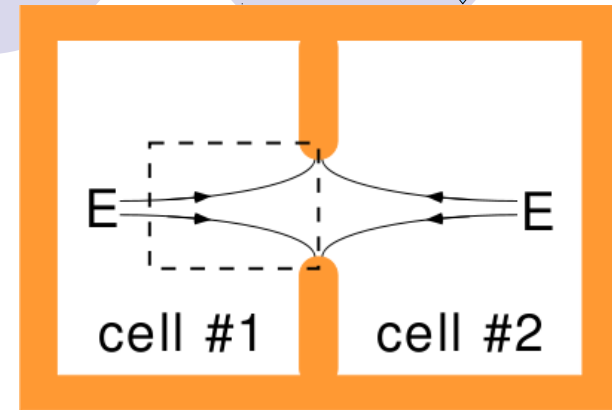
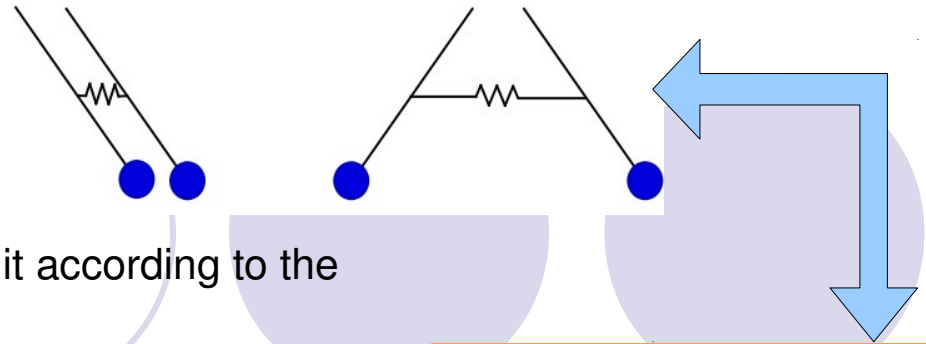
- Each cavity mode will be found four times
 - One for each cavity
 - A single cavity will dominate each mode, however the evanescent field allows coupling.
 - Beam → Field coupling in one cavity will excite fields in all others.
 - Expect coupling to increase (non-trivially) with frequency
- Extract intra-cavity coupling from simulation
 - Ratio of field amplitude between each cavity and its neighbour



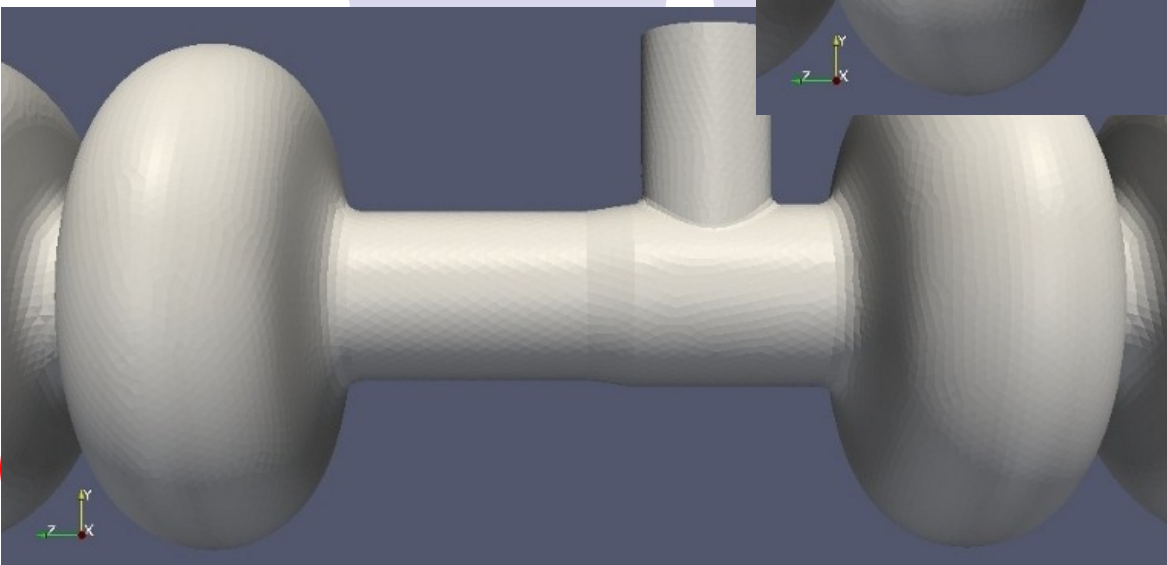
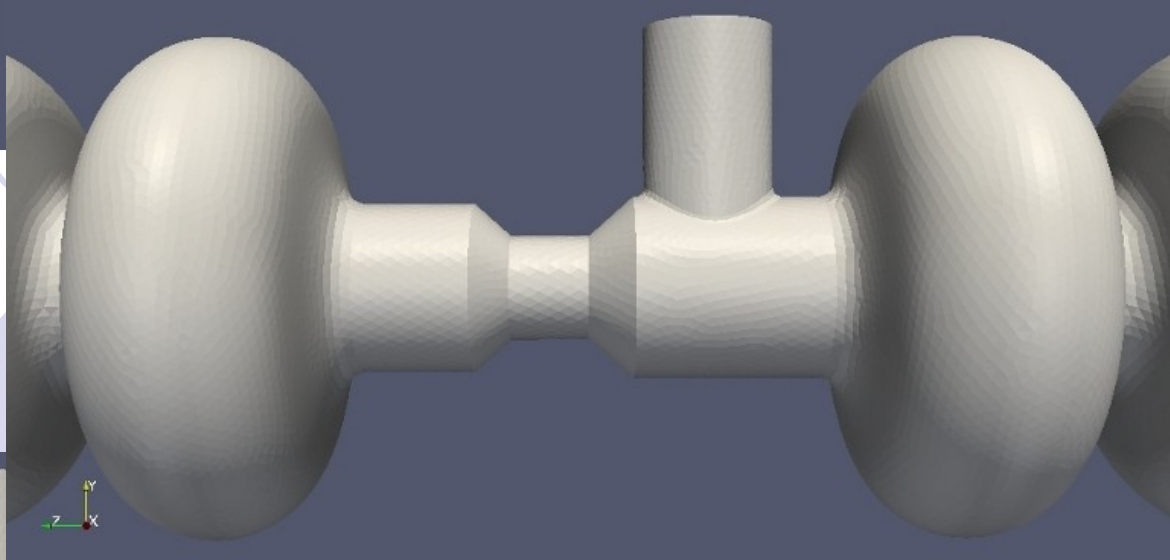
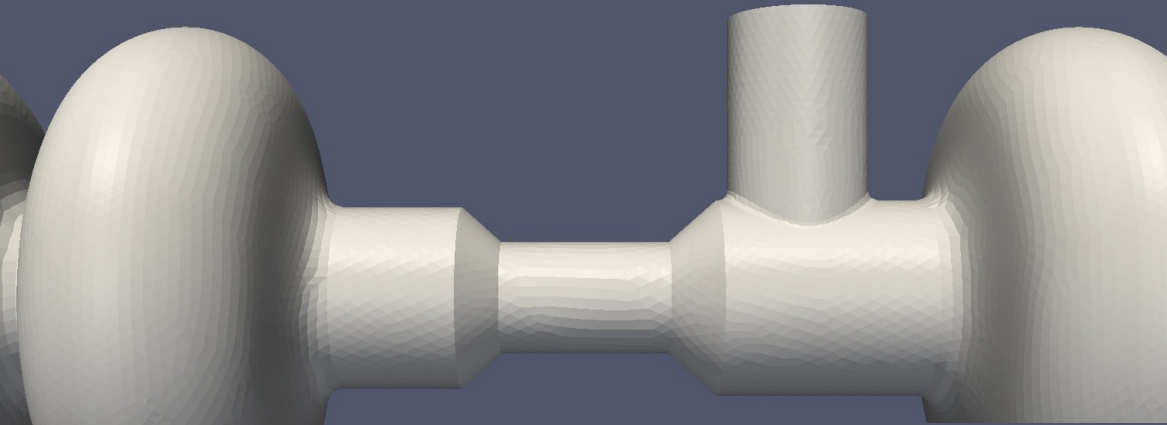
Coupled oscillators



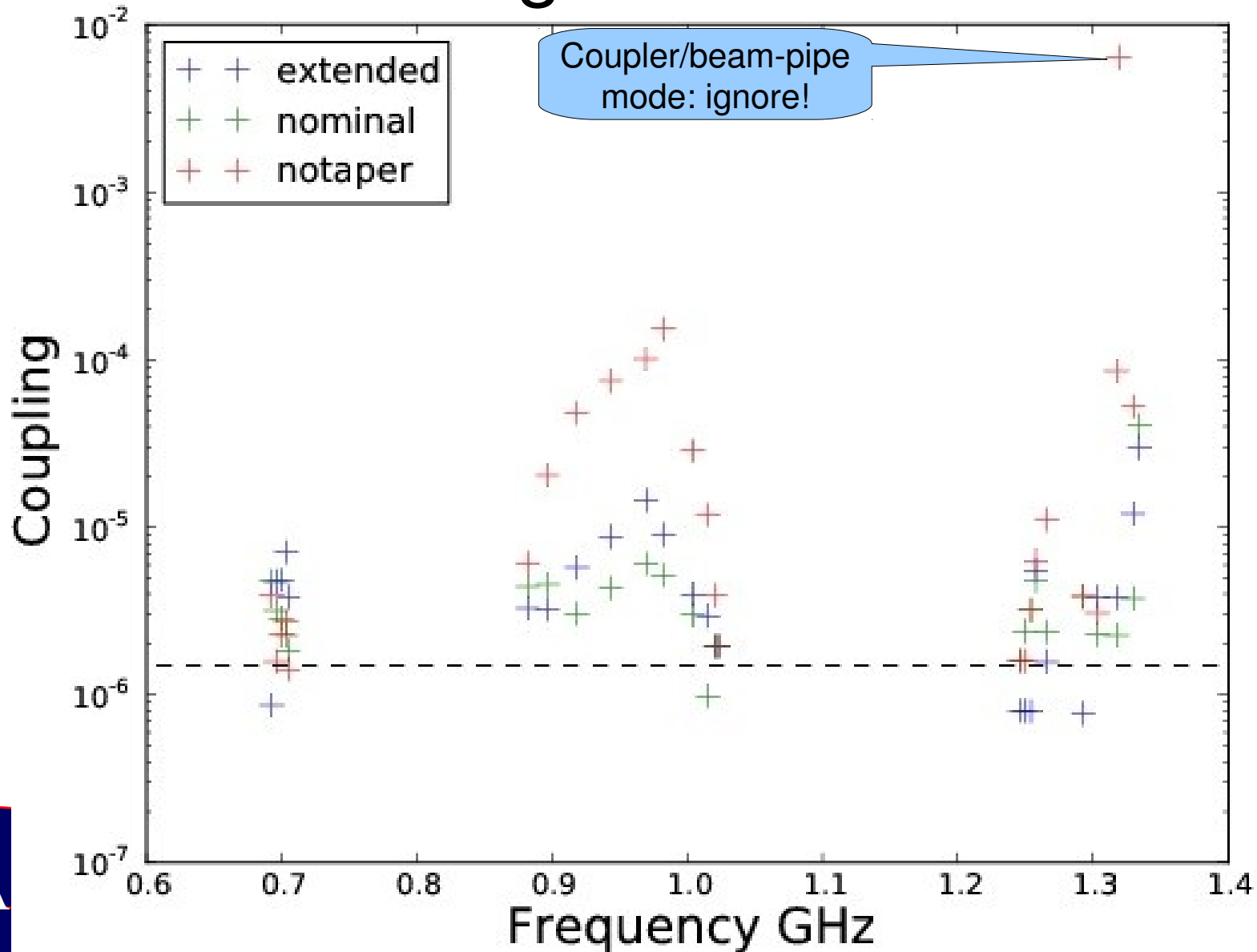
- Eigenmodes of coupled oscillators split according to the phase difference
 - “0-mode”, “ π -mode”, etc.
- For $N+1$ coupled oscillators
 - $i\pi/N$ radians phase advance ($i=0,1,\dots,N$)
 - Frequency also splits
 - Dependent on the coupling strength
 - Each new mode may be plotted on a Brillouin curve
 - For $N \ll \infty$ the modes are equally spaced along the curve



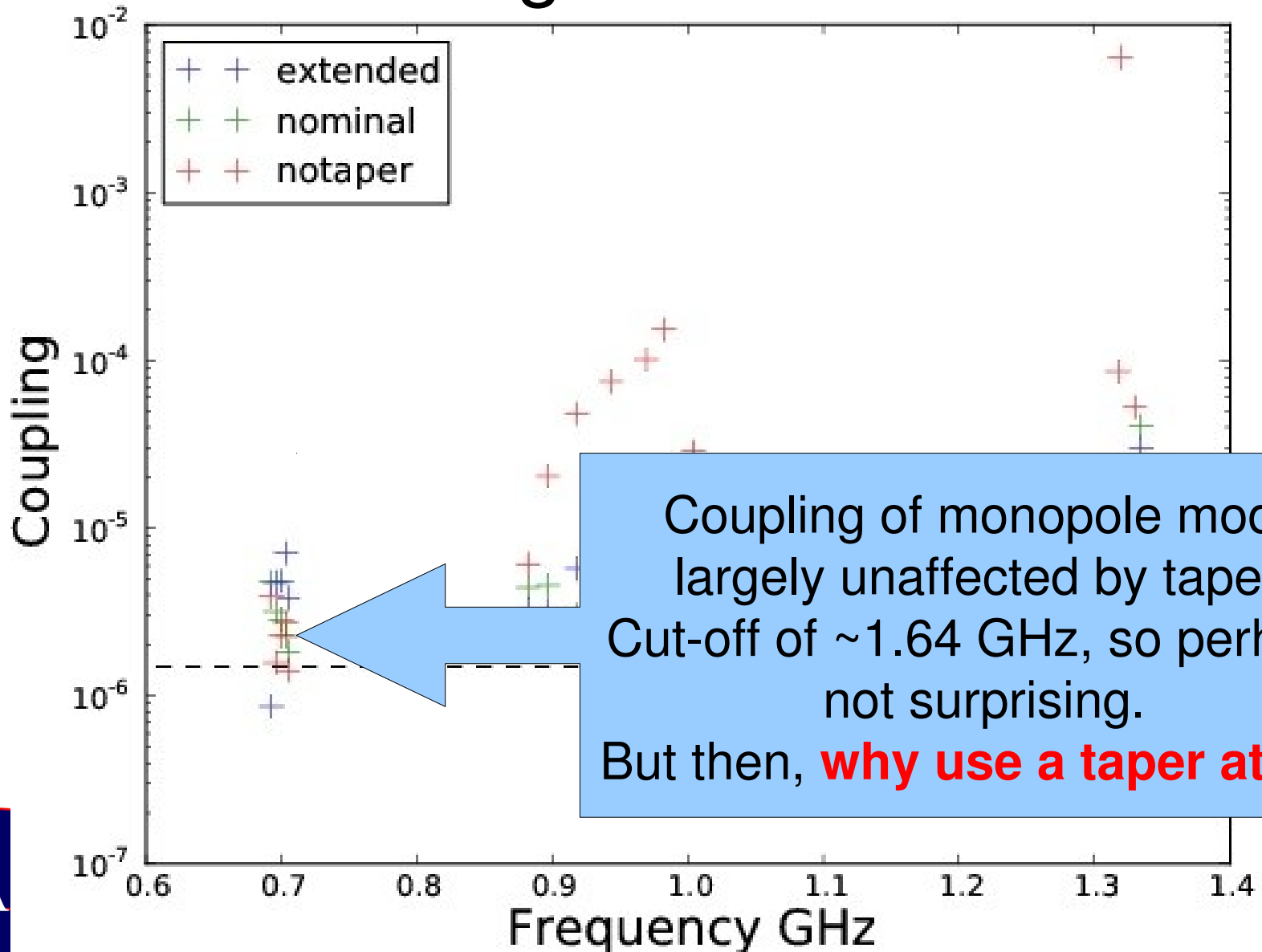
$$\omega_{\theta}^2 = \omega_{\pi/2}^2 (1 - \kappa \cos(\theta))$$



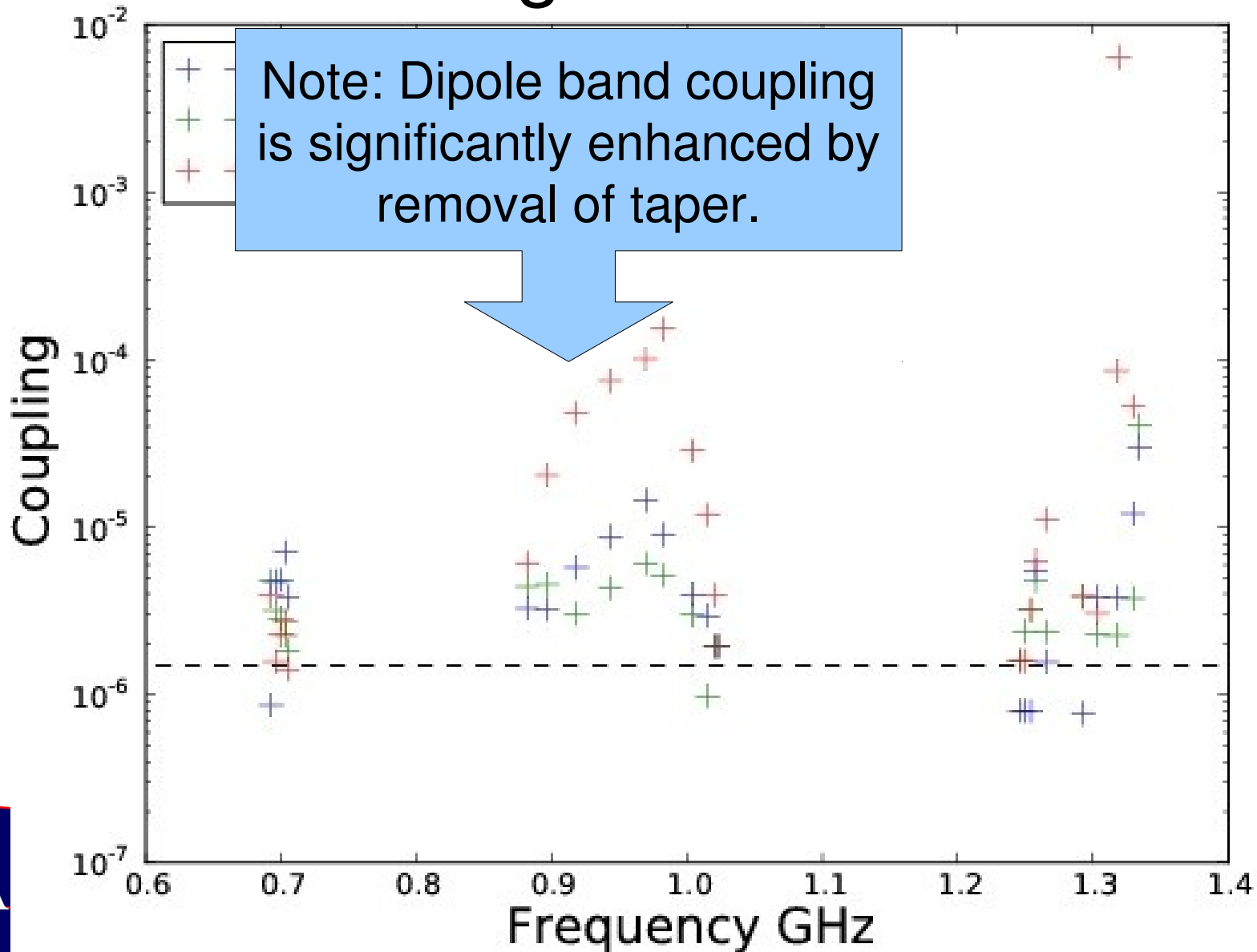
Three different geometries



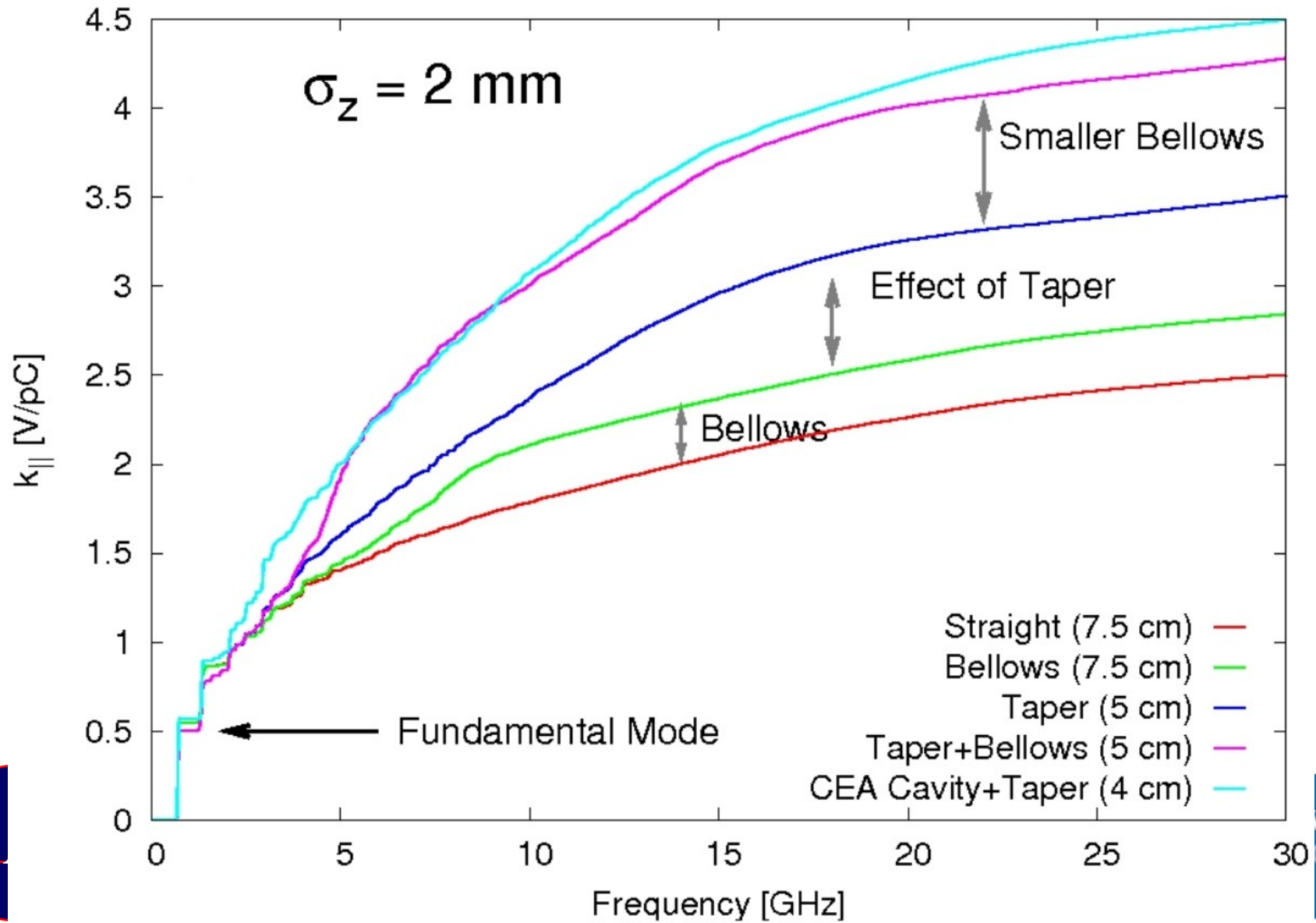
Three different geometries



Three different geometries



Impact of taper – loss factor



Impact of taper

- No effect on monopole coupling
- Perturbs beam due to increased loss factor
- Decreases dipole coupling
 - But is this desirable?
 - Decreased coupling → lower amplitude
 - Lower amplitude → decreased efficiency of HOM coupler
- **Is a taper necessary?**



Summary & Conclusions

- R/Q vs β
 - R/Q of 2nd mono passband comparable to TM₀₁₀
- Coupler/beampipe modes
 - Normally ignored for H⁺/H⁻ machines
 - R/Q > 1 Ω (@ 1 mm)
 - Is this a concern? Further investigation necessary?
- Cavity-to-cavity coupling – necessity of taper?
 - Coupling calculation corrected
 - Negligible effect on monopole coupling
 - Adds to loss factor
 - Necessary?

