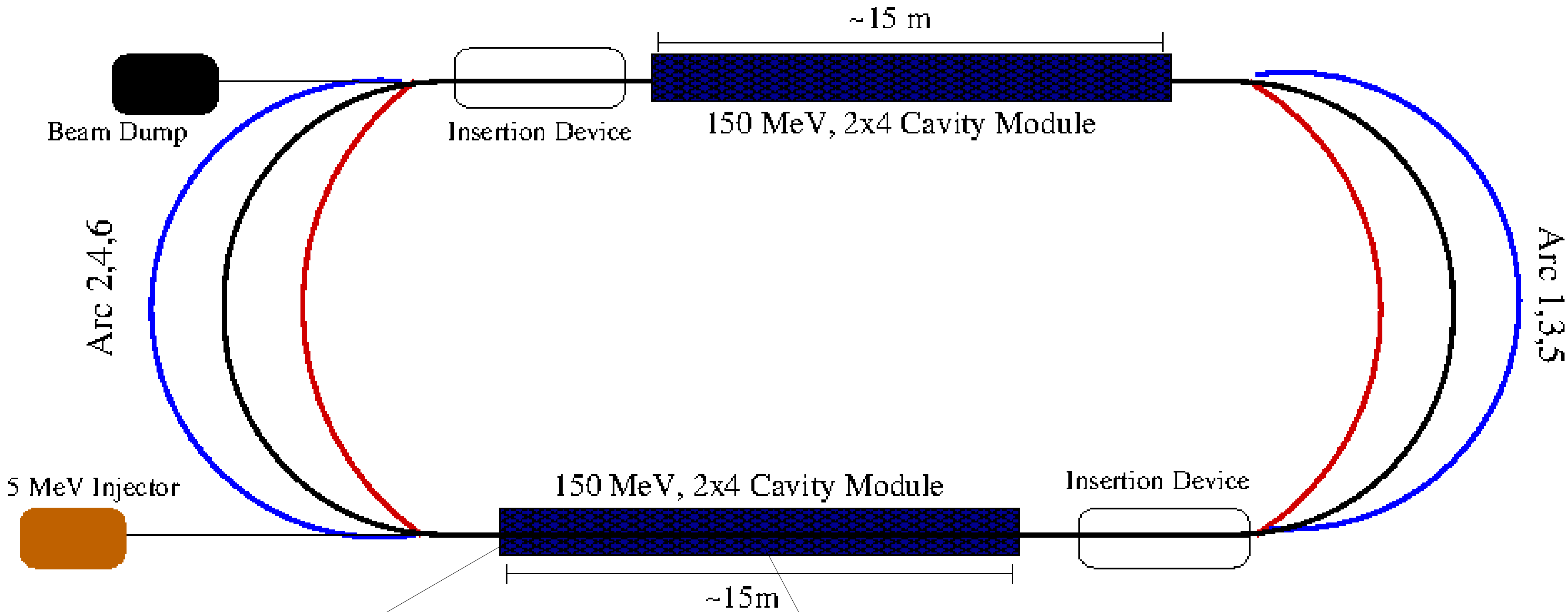
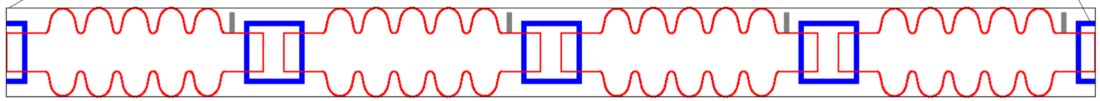
ERL Facility Cavities

R. Calaga, CERN, Jun 25, 2015

A quantum jump from zero to 60 GeV ERL is unlikely





Basic unit: 5-cell cavity into 4-cavity module

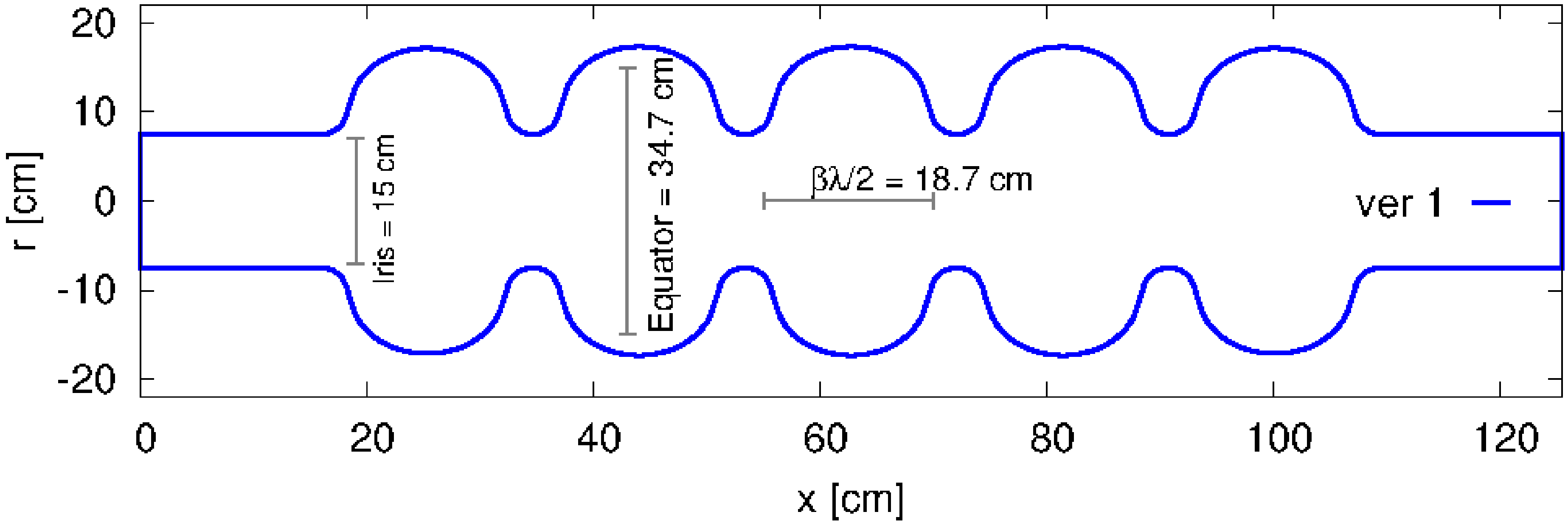
Energy: 150, 450, 900 MeV

Frequency: 801.58 MHz (h=20)

Voltage: 18.7 MV/cavity

Design Considerations

Scaled from a 704 MHz SPL-BNL design



- Initial design (2013) is already optimized
- Main aim: High Q, moderate-high gradient, strong cell-to-cell coupling, minimize input & HOM power
- No single cavity design optimum, choose a conservative & simple design

5-Cell RF Parameters

Parameter	Ver 1 (Scaled)	Ver 2
Frequency [MHz]	801.58	801.58
Number of cells	5	5
Active cavity length [mm]	935	935
Voltage [MV]	18.7	18.7
E_p [MV/m]	45.1	48.0
B_p [mT]	95.4	98.3
R/Q [Ω]	430	393
Cell-cell coupling (mid-cell)	4.47%	5.75%
Stored Energy [J]	154	141
Geometry Factor [Ω]	276	283
Field Flatness	97%	96%

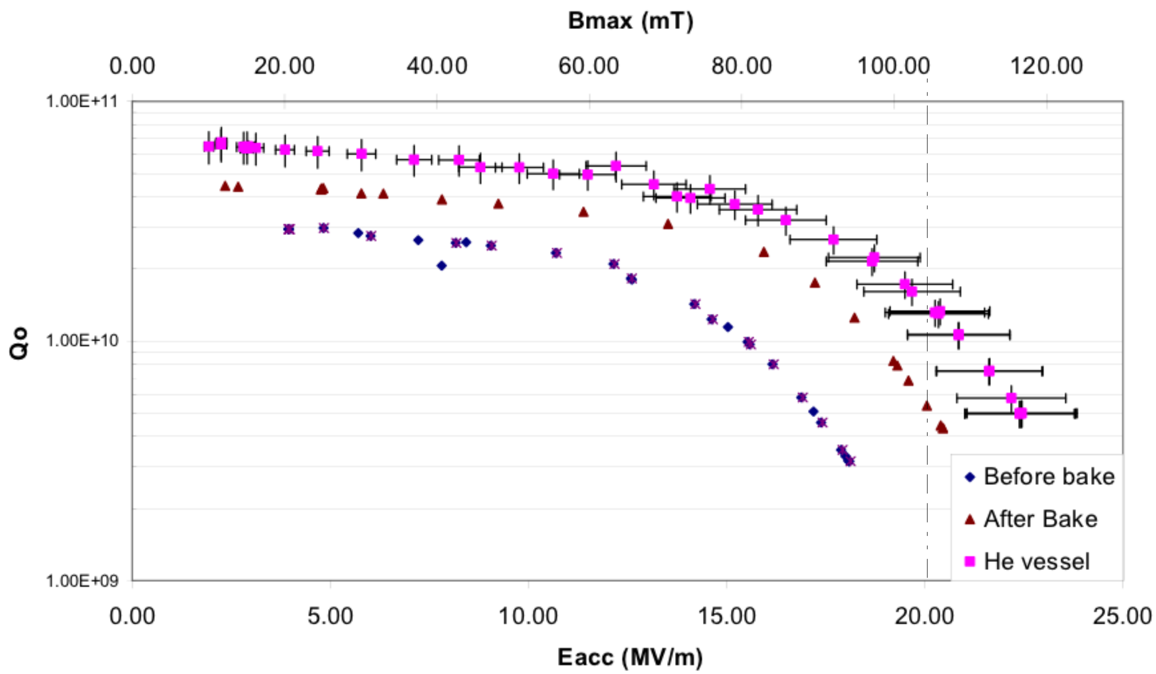
For example, at 18.7 MV/cavity :

Cavity dynamic losses (assume Rs = 7-10 nΩ): ~22-31 W

Gradient reach limited by heat load & extraction (~ 1W/cm2 for piping)

Lots to be gained from high Q than small improvements in cavity geometry

High Q0

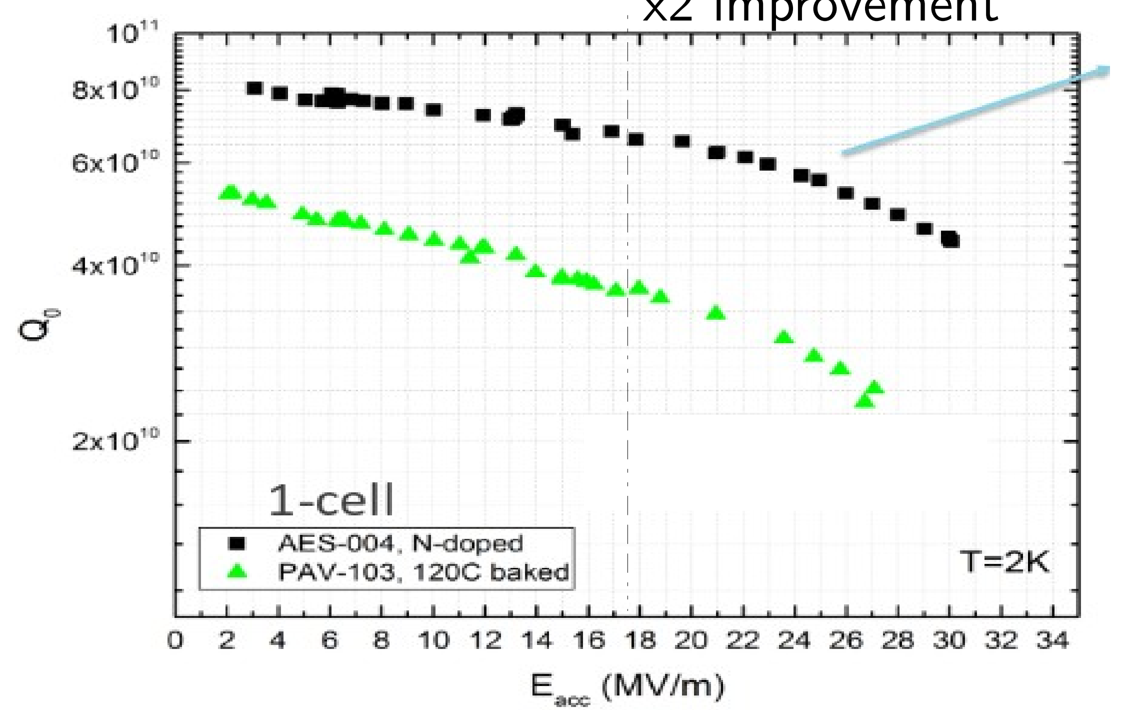


BNL 704 MHz 5-Cell

A. Burill et al., AP Note 376

(translates to ∼20 nΩ)

x2 improvement



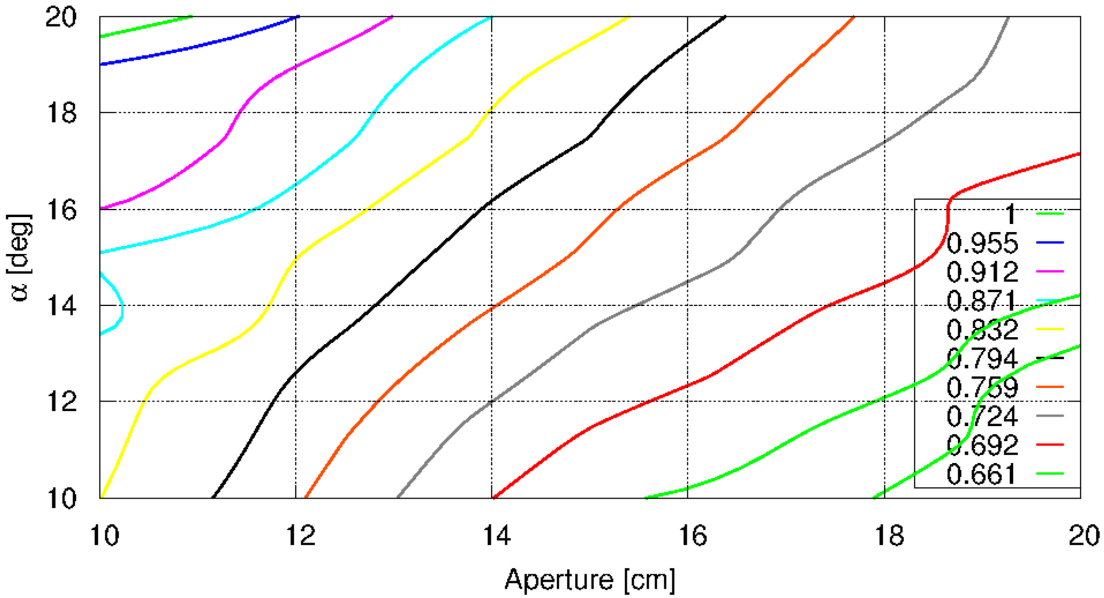
650 MHz, 1-cell: N-Doping

A. Romenenko et al., FCC Workshop

Washington, 2015

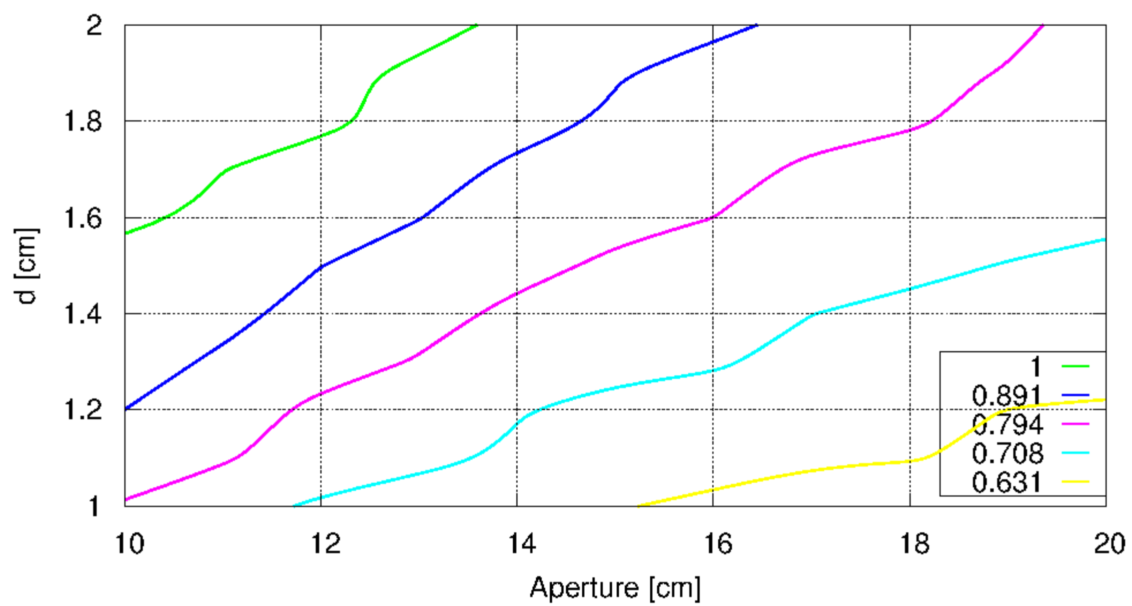
(translates to ∼4 nΩ)

Aperture Scans, Peak Fields

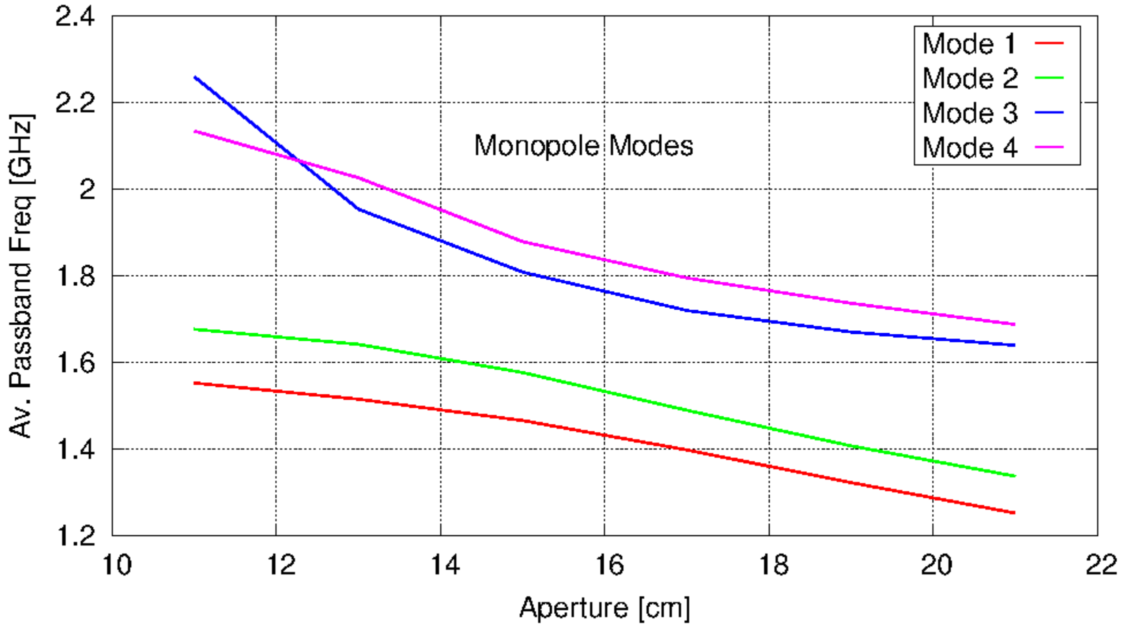


Goal was to find an improvement around the optimum point

Contours show the ratio of the peak fields

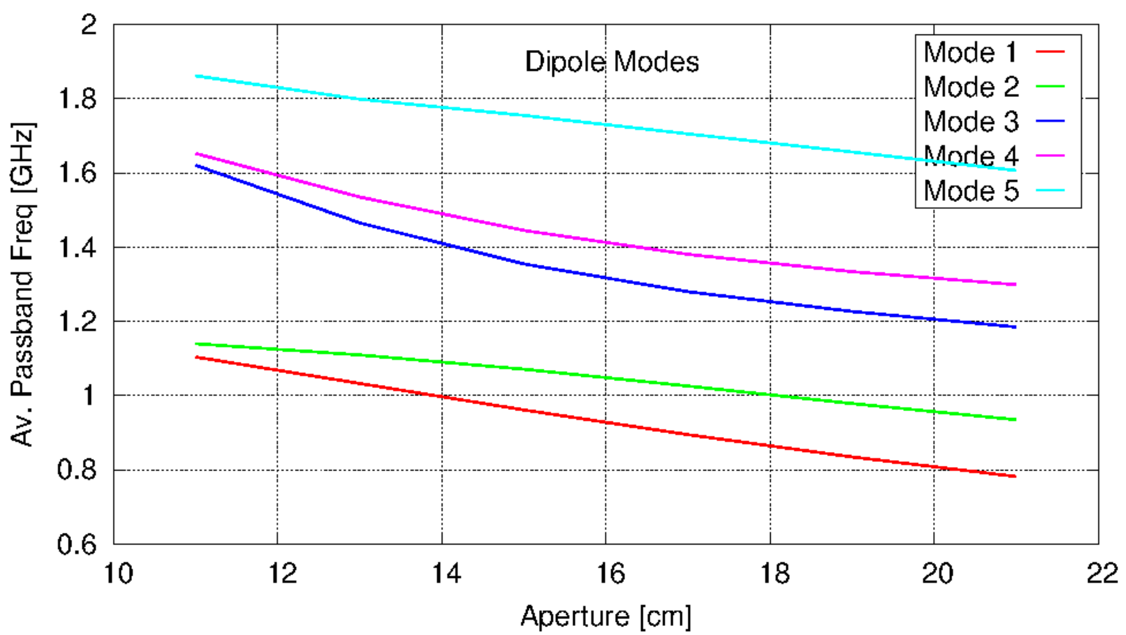


Aperture Scans, Frequencies

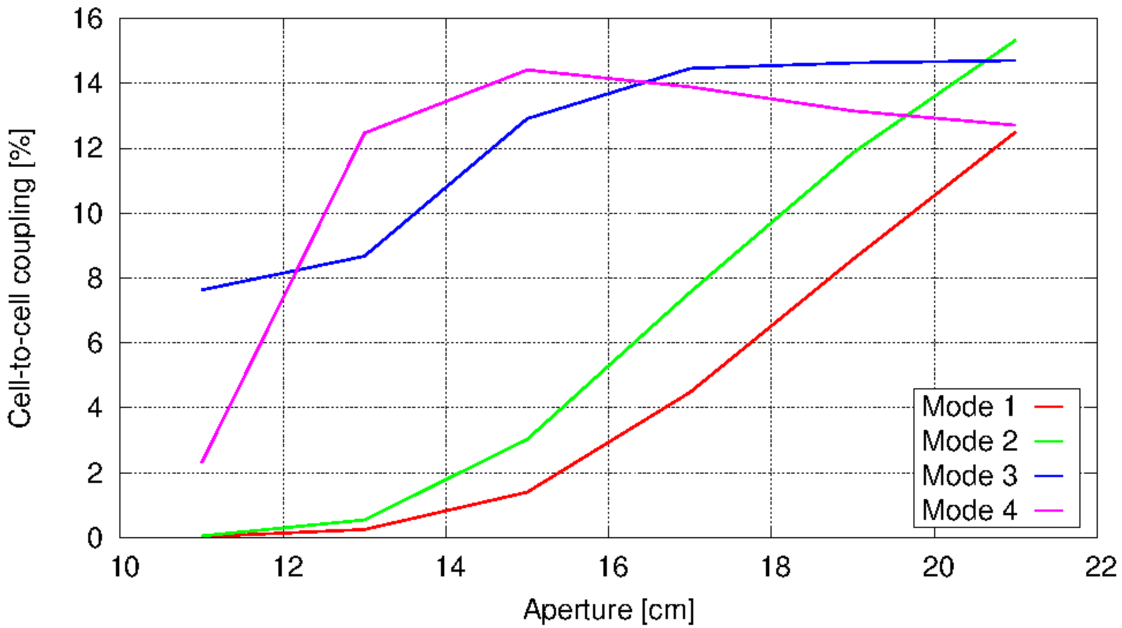


Find a good compromise between cut-off frequency and HOM passband frequency.

Avoid overlap with fundamental harmonics

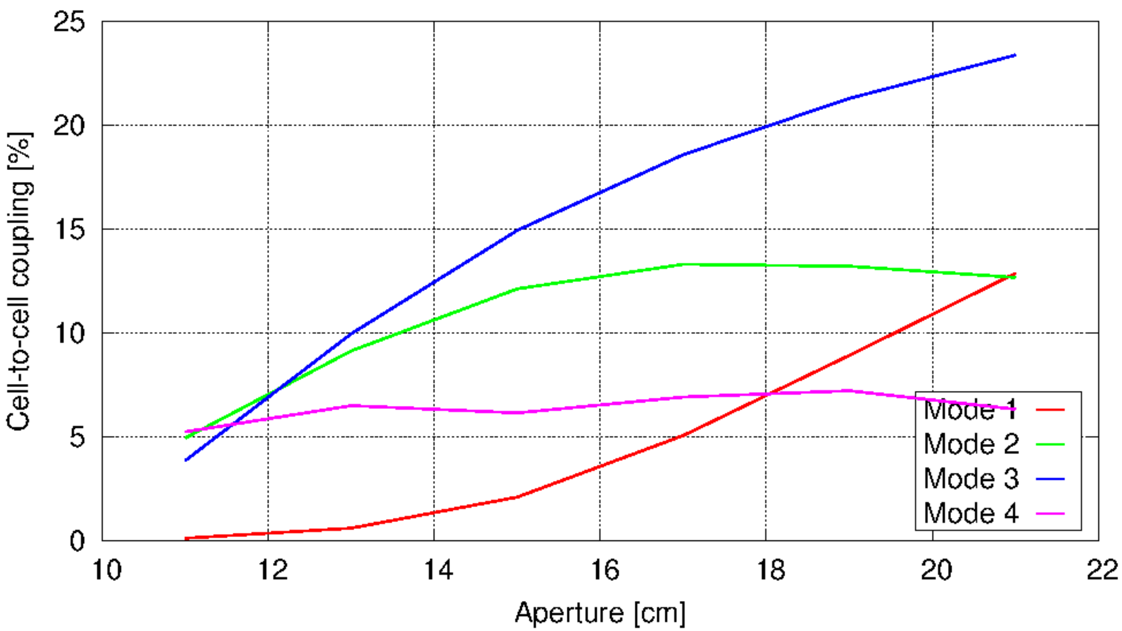


Aperture Scans, Coupling



More relaxed tolerance from fabrication errors for the accelerating mode

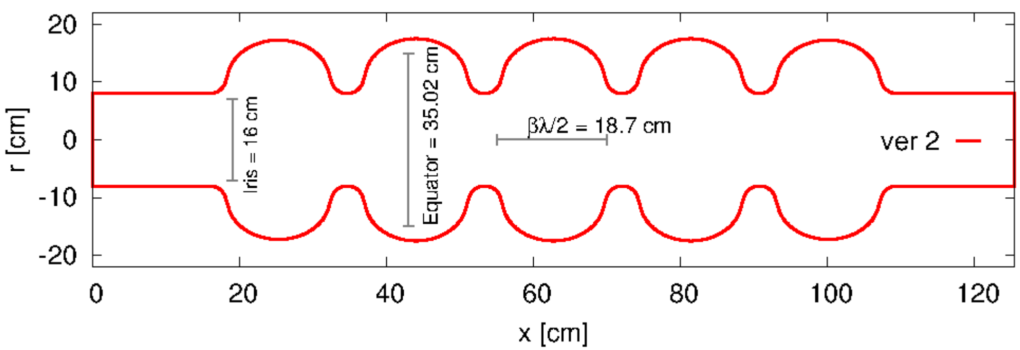
Improved coupling of HOMs to beam pipe for damping purposes



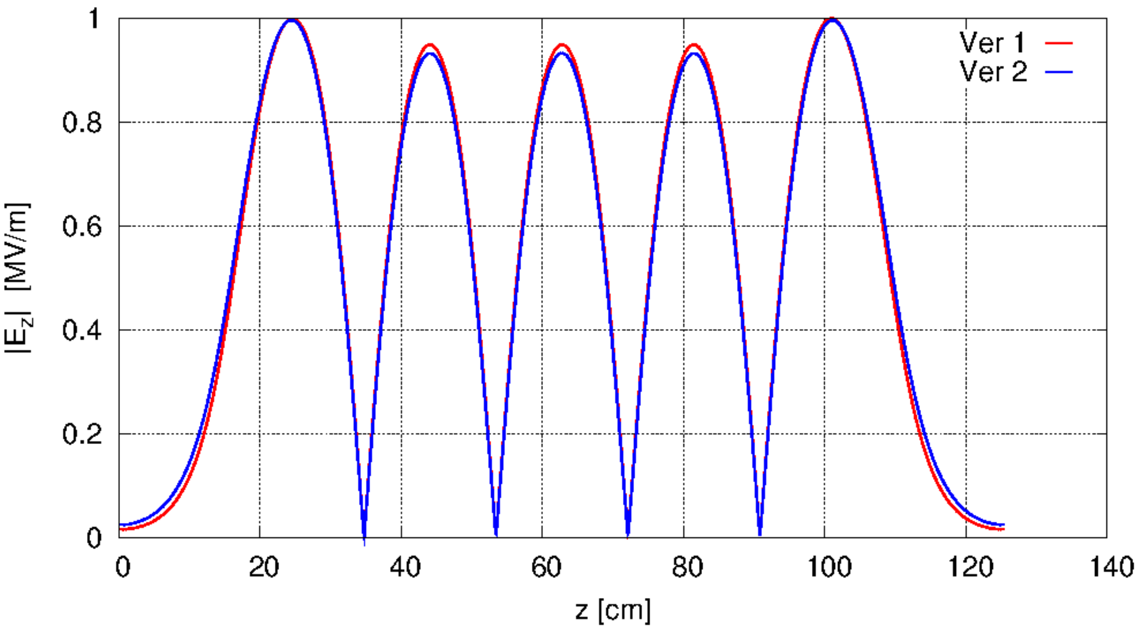
Five-Cell Cavity

Field flatness → Efficiency of acceleration

Large aperture → Strong cell-to-cell coupling (also for HOMs)



5-cells, a good compromise



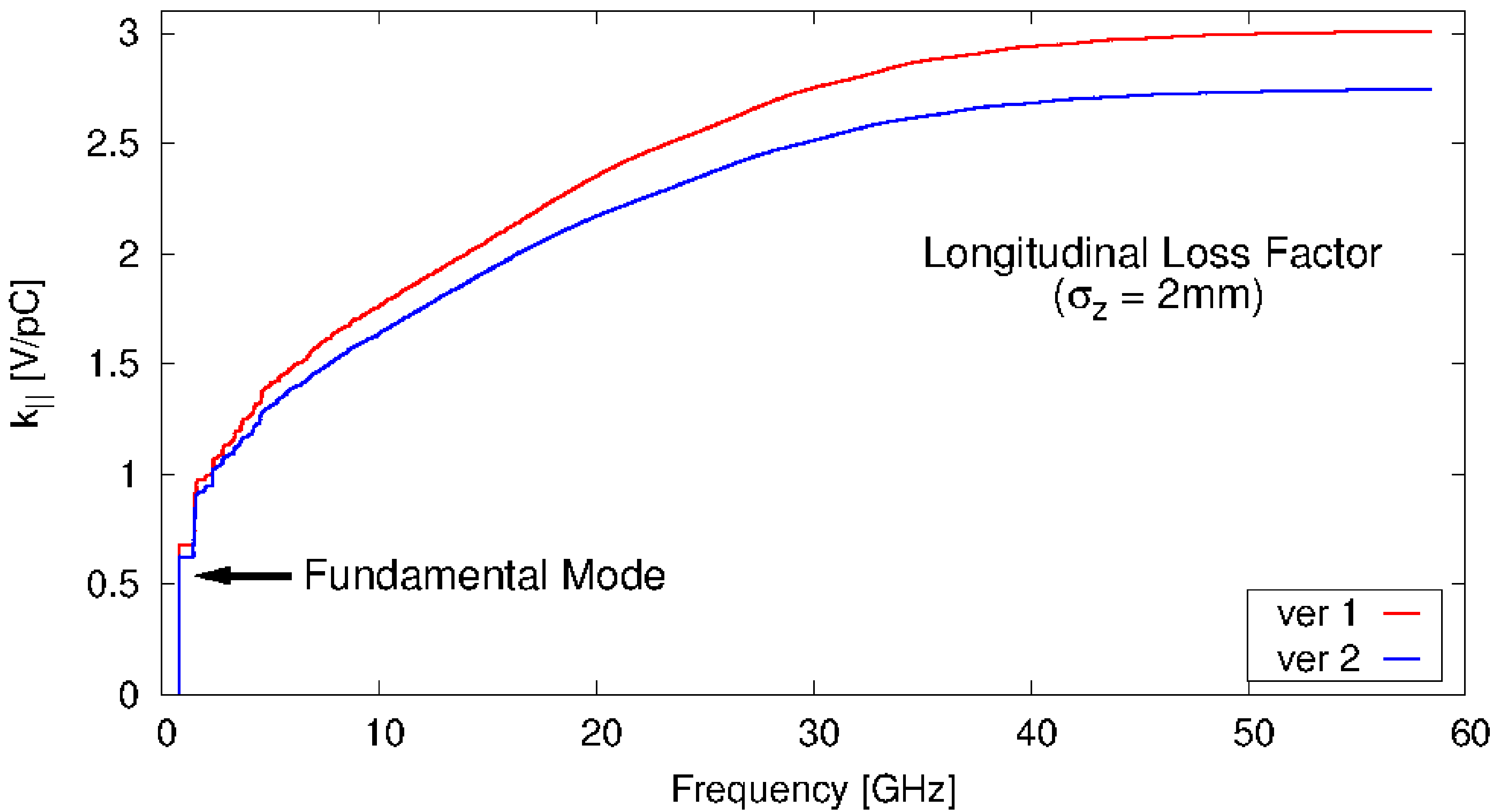
$$a = \frac{N^2}{k_{cc}}$$

Number of cells

Cell-to-cell coupling

The HOM loss factor scales ~√N

Longitudinal Loss Factor



Ver 1: $k_{||} = 2.89$ V/pC, $k_t = 2.73$ V/pC/m

Ver 2: $k_{||} = 2.63$ V/pC, $k_t = 2.18$ V/pC/m

HOMs, Longitudinal

$I_b = 77$ mA (3 passes + deceleration), $Q = 0.32$ nC

Total Average $P_{HOM} = k_{||}.Q.I_{beam}$ ($\sigma_z = 2$mm)

$k_{||} = 2.64$ V/pC $\rightarrow$ 65 W per cavity

(1.3GHz 9-cell is $\sim$ factor 3 larger HOM power)

Resonant excitation (R/Q=10Ω, $Q_{ext}=10^{4-5}$)

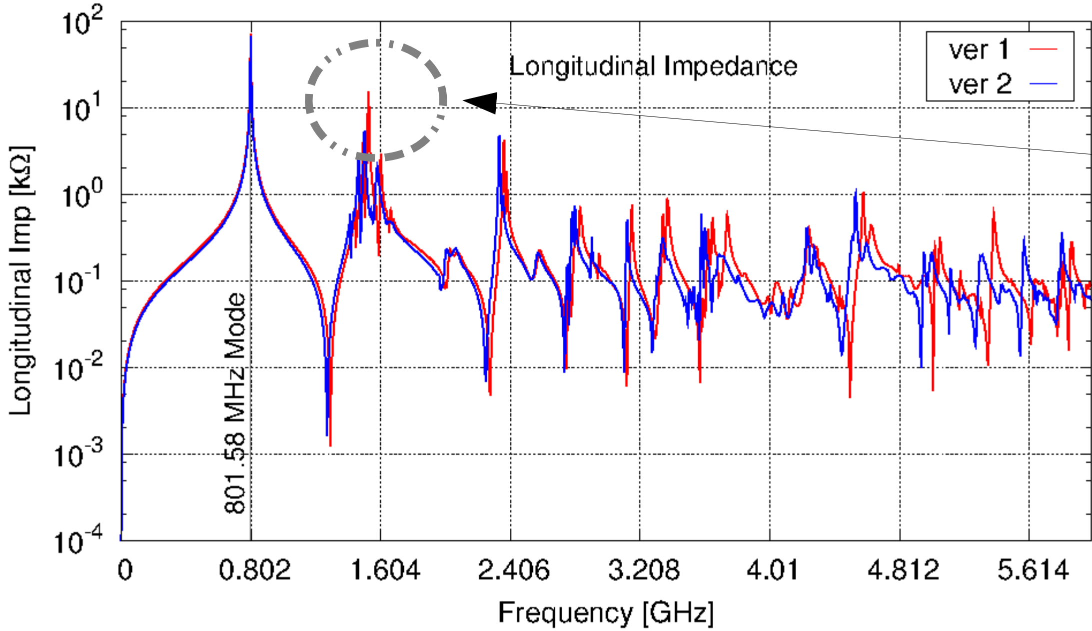
$P_{HOM} \rightarrow$ 0.6 - 6 kW!!

Energy Spread:

$$\frac{\delta E}{E} = \frac{k_L Q_b}{E_{gain}}$$

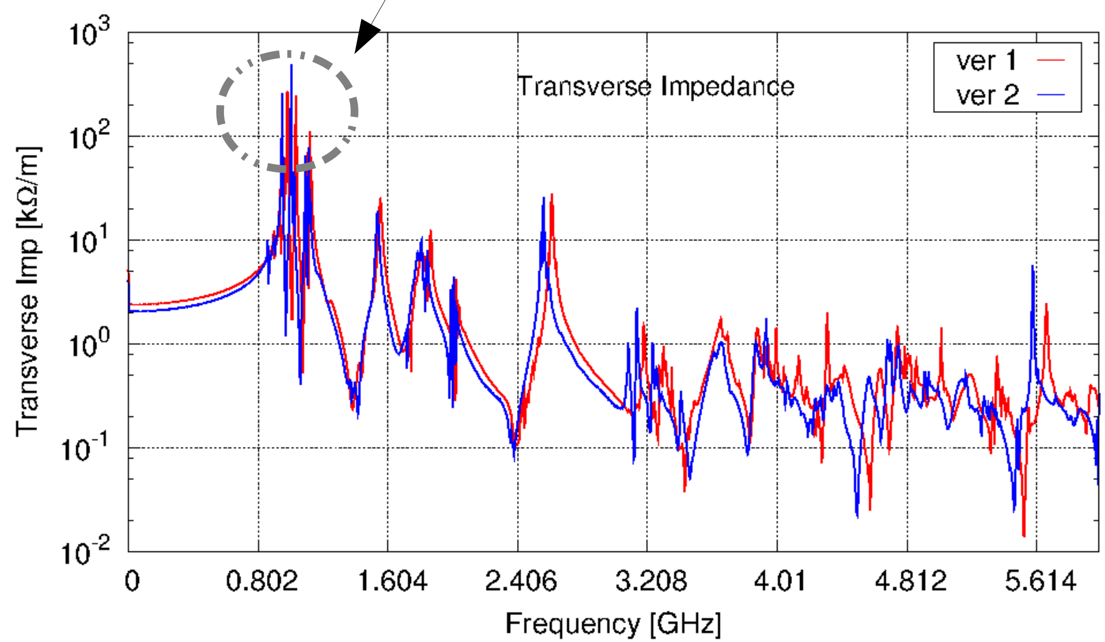
End of final turn: ~5 x 10^{-4} (4 cavities/turn, 3 passes)

Impedance Spectrum



First few passbands typically dangerous

Proximity to fundamental mode or harmonics



Targeted damping for the highest impedance mode & extraction of broadband HOM power

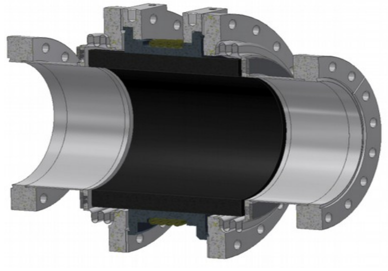
HOM Damping & Extraction

Ferrite Absorbers → Broadband room temp

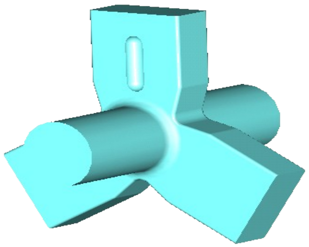
Waveguides → higher frequencies more suitable

Notch Filters → Narrow-band & targeted damping

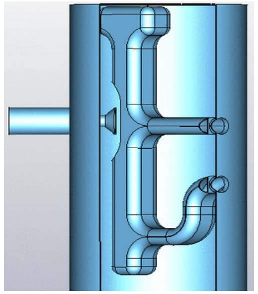
Ferrites



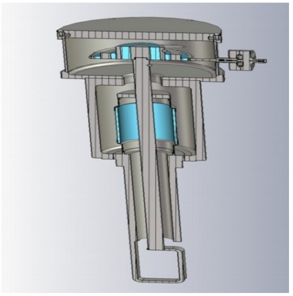
Waveguides



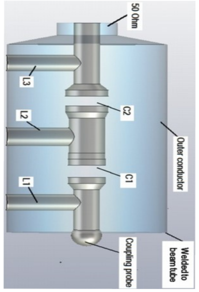
Notch filters



Band-Pass



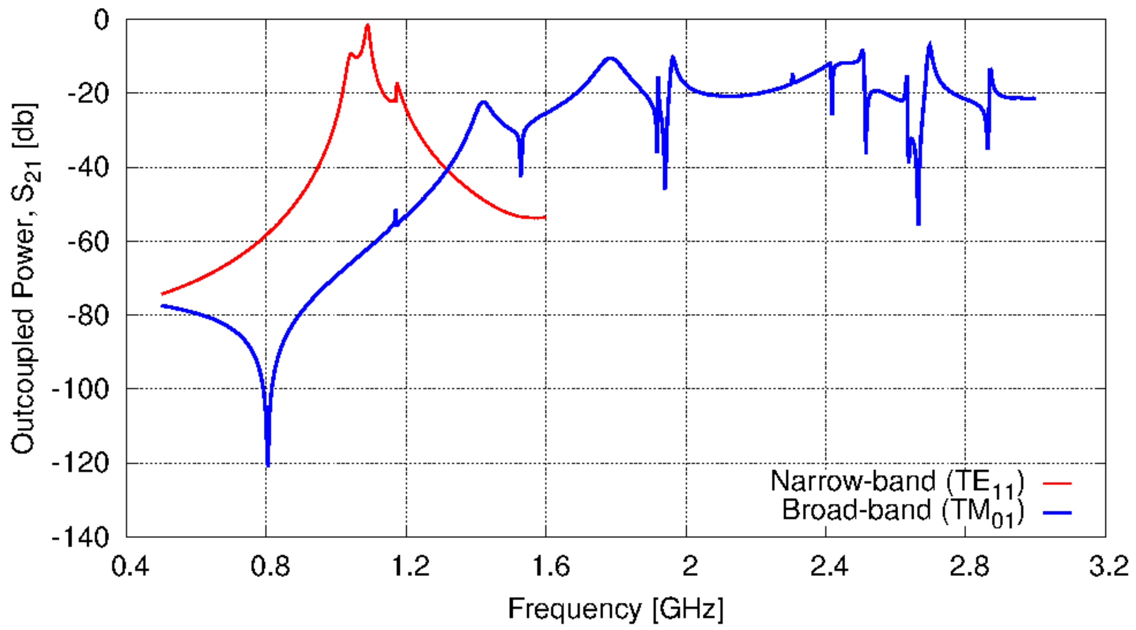
Double-Notch



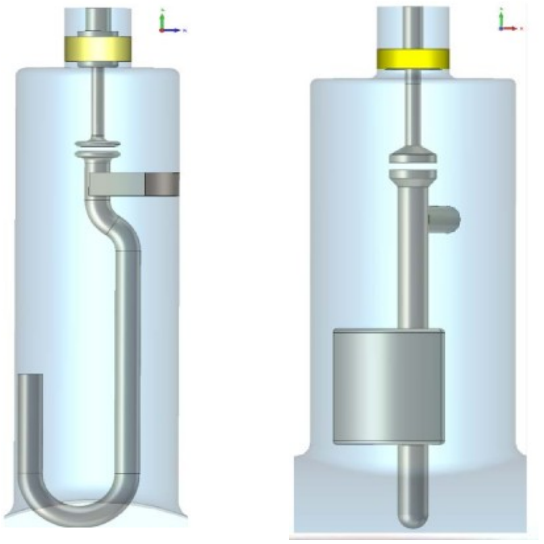
Multi-cavity cryomodule require broadband SC dampers!

But with a strong thermal bridge

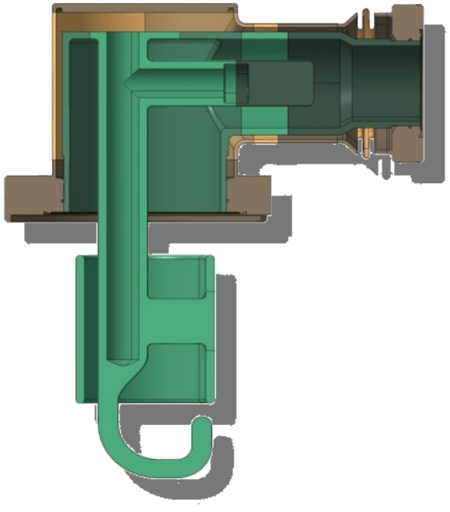
HOM Couplers



Use LHC-like dual concept



LHC crab cavity-like concept



Or a hybrid concept like the one being developed for LHC crab cavities

Studied ongoing to determine a simple configuration

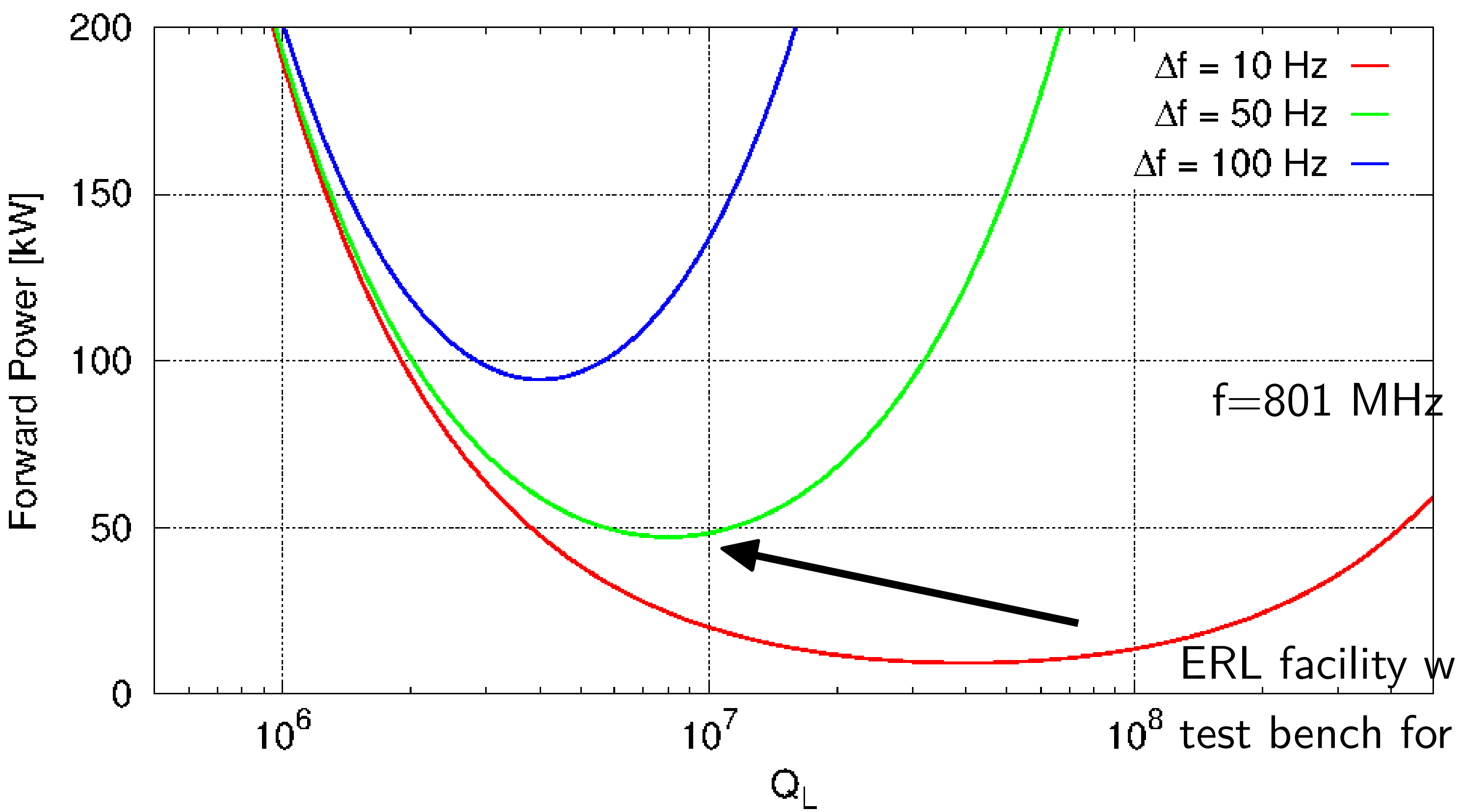
ERL, RF Power

"Zero" Beam Loading

Peak detuning

$$P_g = \frac{V^2}{R/Q} \cdot \frac{\Delta f}{f} \qquad \left\{ Q_{opt} = \frac{1}{2} \cdot \frac{\omega}{\Delta \omega} \right\}$$

Recall: static detuning w/o ER ~50 Hz, highest R/Q not essentially best



ERL facility will be excellent test bench for stable operation

SPS 800 MHz IOTs

800 MHz IOTs (~60 kW) for the SPS 3rd harmonic system

Chain of 8 IOTs installed powering two cavities in the SPS

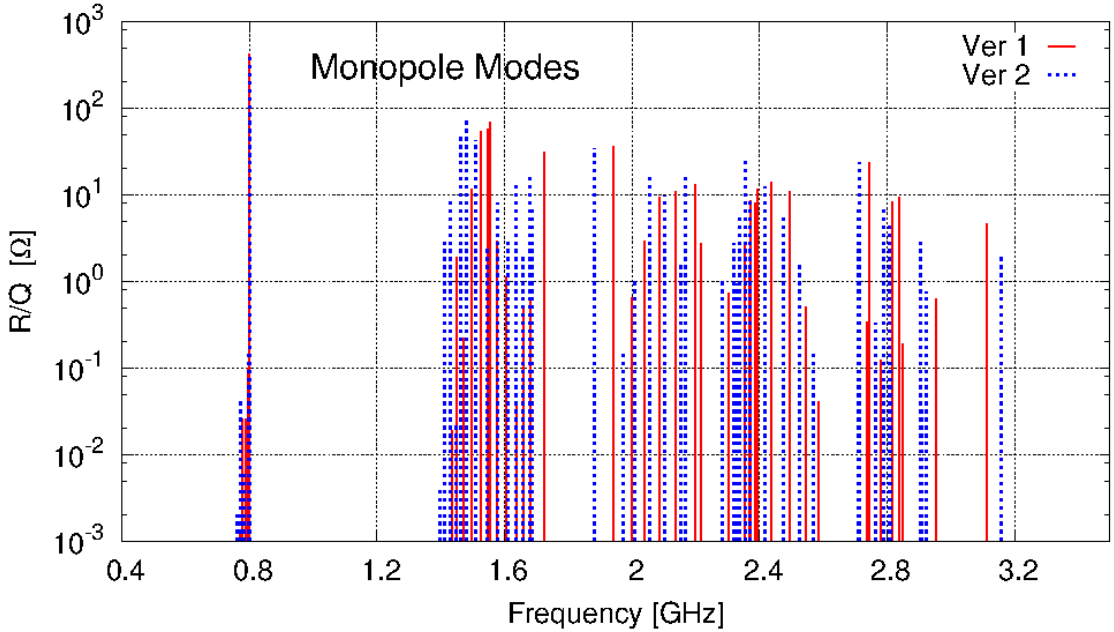
Next Steps

- Cavity(ies) designs mature and ready for prototyping
  - The collaboration with Jlab & SPL experience is
  - HOM damping requires further studies, but solutions available

- Recent high Q0 focus & results greatly boosts the ERL case
  - However, performance might be limited by accelerator environment
  - LCLSII & ERL facility experience will important input

- Good experience from SPS 800 MHz IOTs
  - ERL facility, important step to validate stable high Q_L operation

Higher Order Modes, R/Q's



Low frequency longitudinal modes with R/Q of few 10's of ohms