Optimizing Cavity Shape for ERLs

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Three Imp. Issues of ERL Cavities

HOMs, HOMs, HOMs !!!

Main Issues Contd.

- **Higher Order Modes**:
  - HOM Power & Kick ($k_{||}$, $k_{\perp}$)

$$P_{avg} = 2k_{||}IQ$$

  - Trapped Modes ($k_{cell-cell}$, N_{cells}, Q_{ext})

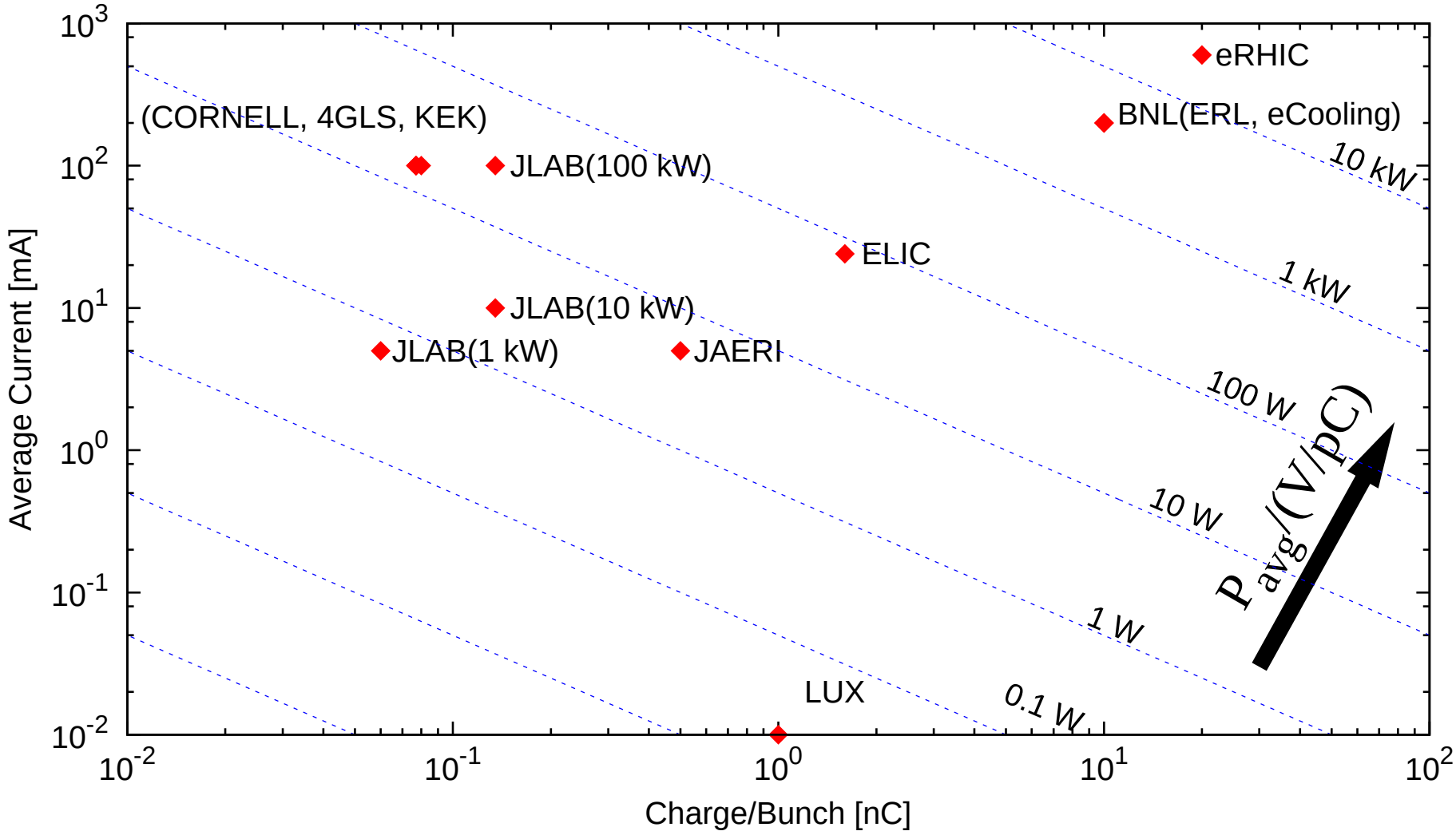
$$I_{thr} = \frac{-2p_r c}{e\left(\frac{R}{Q}\right)Q_e k_m M_{12} sin(\omega_m t_r) e^{-\frac{\omega_m}{2Q_e}t_r}}$$

  - Efficient extraction of HOMs (Cryo Losses)

- **Fundamental Mode**:

$$\frac{E_{peak}}{E_{acc}}\ (\downarrow),\ \frac{H_{peak}}{E_{acc}}\ (\downarrow),\ \frac{R_s}{(R/Q)G}\ (\downarrow)$$

Existing & Future ERLs

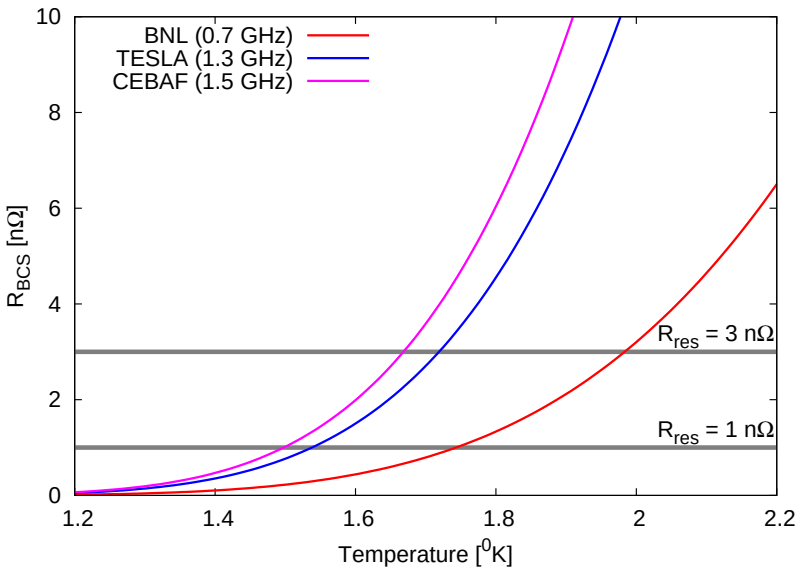


*** Avg. Power Normalized to 1 V/pC

Design Criteria: Approx. Scaling Factors

Fund. Mode:

- $P_{cav} \propto \frac{Rs}{(R/Q)G}$
- $R_s \propto \omega^2 \ (R_s = R_{BCS} + R_{res})$
- $\frac{R}{Q}G \propto const. \ (E_{acc} \propto \omega)$
- $a \propto \frac{N^2}{k_{cc}}$ (field sensitivity)



Loss Factor:

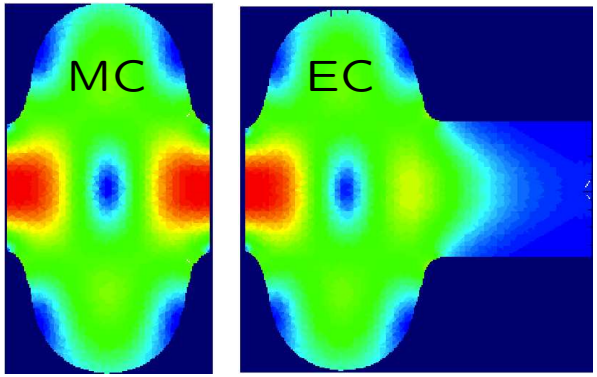
- $k_{||} \propto \frac{1}{\mathbf{R_{iris}}}\sqrt{\frac{d}{\sigma_z}}\sqrt{N_c}$
- $k_{||} \propto \omega^2 \ (Q_b \propto \omega^{-1})$
- $k_{\perp} \propto \frac{1}{R_{iris}^3}\sqrt{d\sigma_z N_c}$
- $\delta E \propto k_{||}Q, \quad \gamma\delta\epsilon \propto k_{\perp}Q$

Threshold Current:

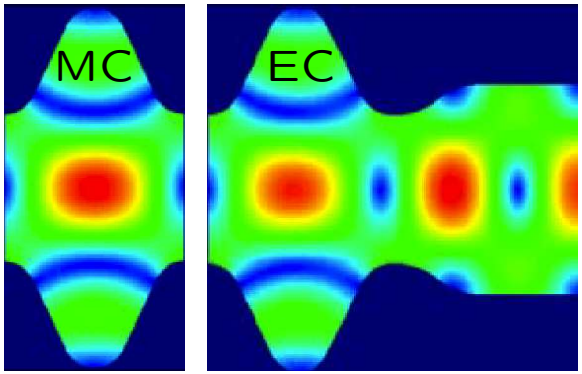
- $I_{thr} \propto \frac{1}{\omega e^{-\frac{\omega}{2Q}t_r}}$
- $I_{thr} \propto \frac{1}{\left(\frac{R}{Q}\right)\mathbf{Q_{ext}}}$
- $k_{cc}(\downarrow) \ \Rightarrow$ trapped modes

Design Criteria: Trapped Modes

Frequency Difference

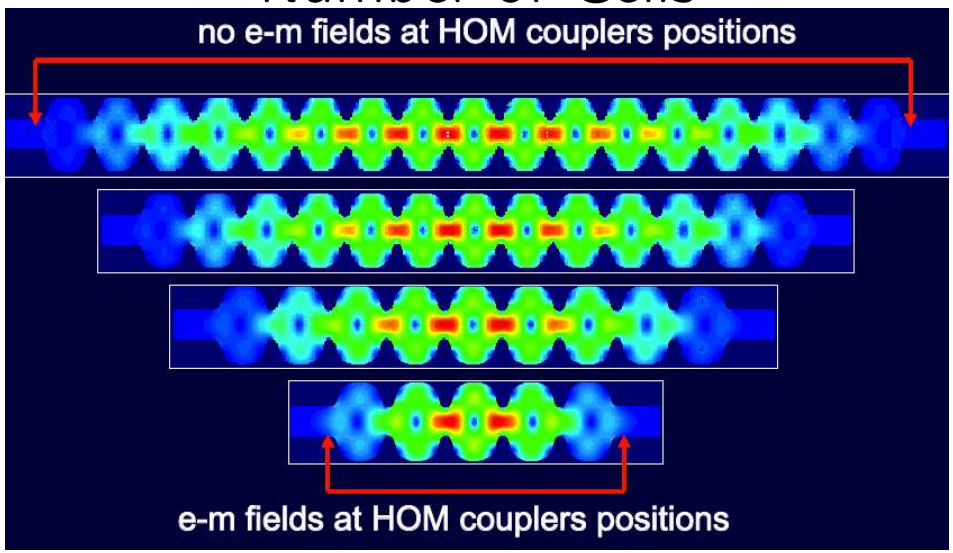


$\Delta f = 30MHz$ (2.4 GHz)



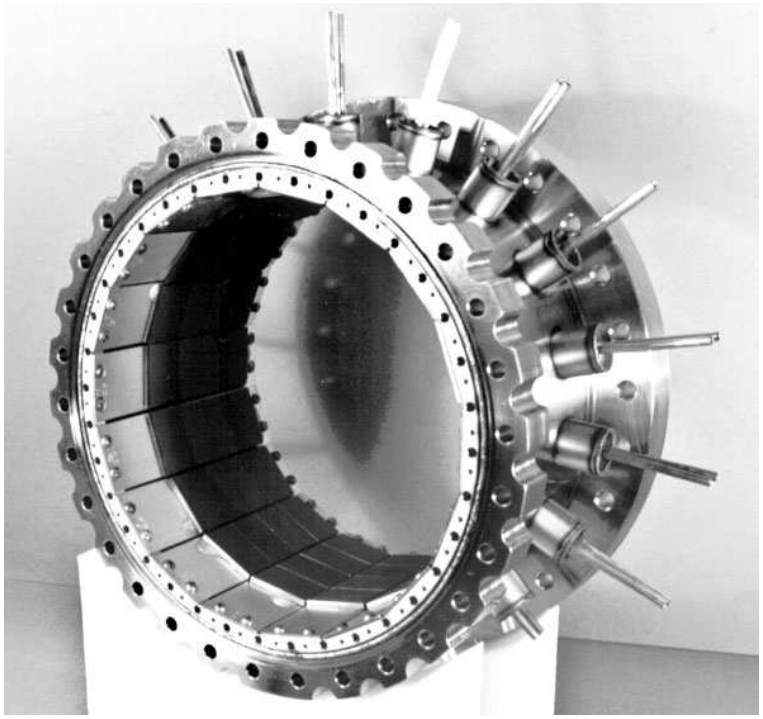
$\Delta f = 13MHz$ (1.4 GHz)

Number of Cells



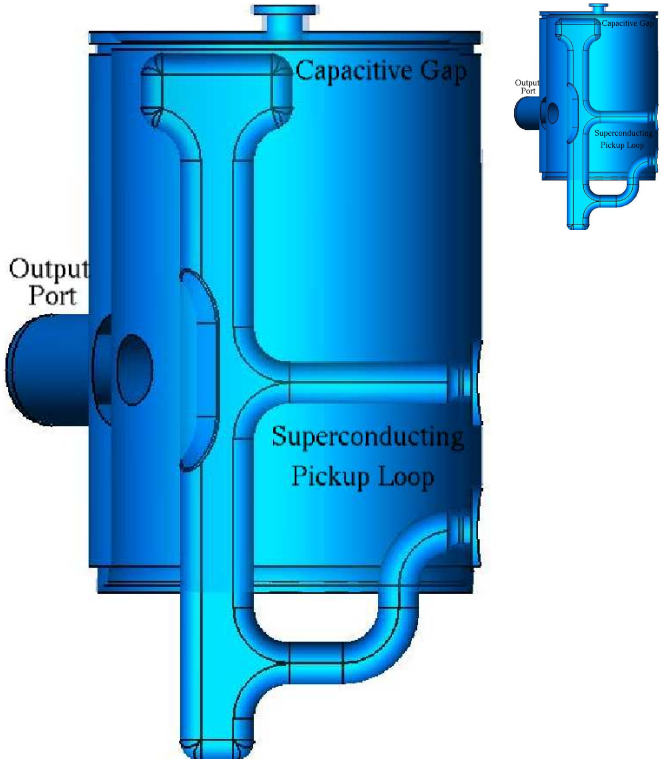
HOM Extraction & Damping

Ferrite Absorbers
Broadband (300 K)



(CORNELL)

Loop Couplers
Resonant Ciruit (4 K)



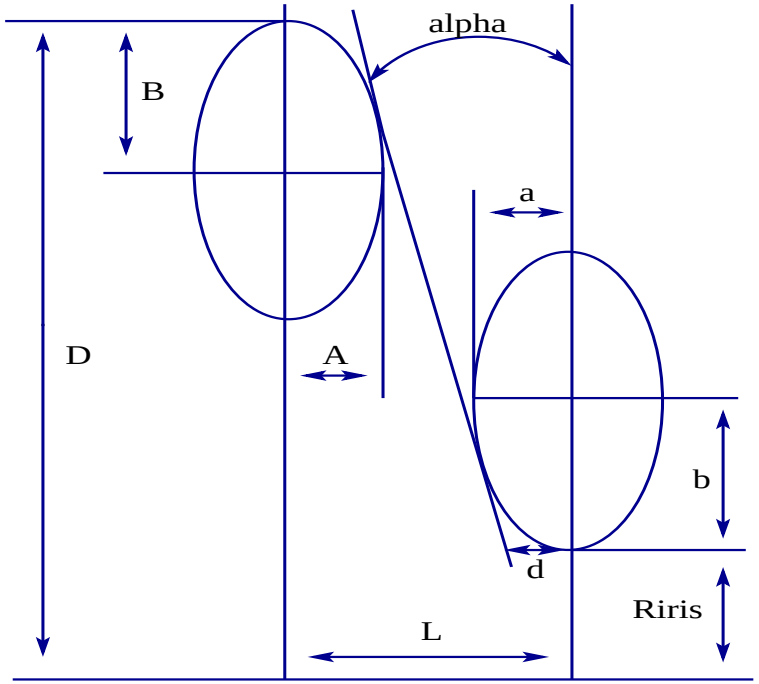
(TESLA)

Comparison of RF Parameters

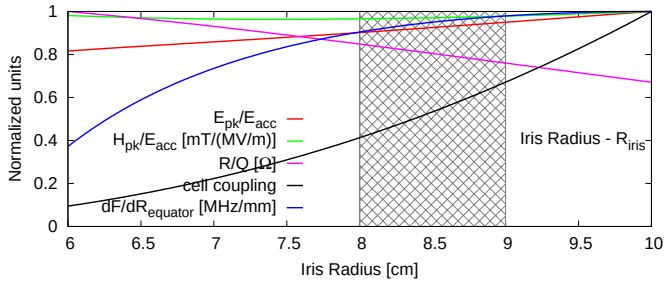
Parameter	BNL(HC)	CEBAF(HG)	TESLA(HG)
Frequency [MHz]	703.75	1497	1300
Number of cells	5	7	9
$(R/Q) * G$ [Ω^2]	9×10^4	2.1×10^5	2.8×10^5
$k_{\|\|}$ $(\sigma_z - 1mm)$ [V/pC]	4.25	10.71	13.14
$k_\perp$ $(\sigma_z - 1mm)$ [V/pC/m]	0.1	2.24	2.07
Q_{ext} (Dipole)	$10^2 - 10^4$	$10^3 - 10^6$	$10^3 - 10^7$
E_p/E_a	1.97	1.96	1.98
H_p/E_a $[mT/MV/m]$	5.78	4.15	4.15
cell to cell coupling (k_{cc})	3%	1.89%	1.87%
Sensitivity Factor ($\frac{N^2}{\beta k_{cc}}$)	8.3×10^2	2.6×10^3	4.1×10^3
Lorz. Det. Coeff $[Hz/(MV/m)^2]$	1.2 (UnStiff)	2	1

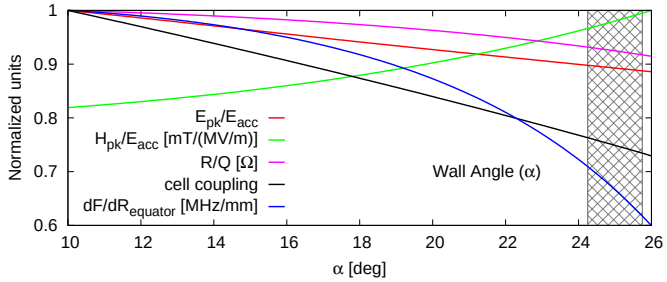
BNL Cavity Example

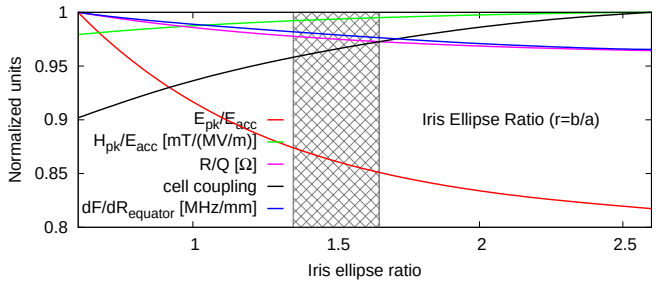
Cavity Design (Build Cavity)

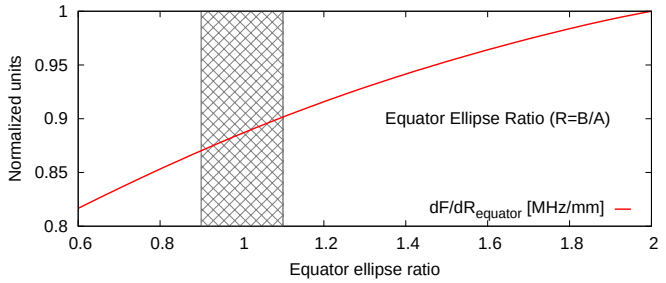


Iris Radius, R_{iris}	8.5 [cm]
Wall Angle, α	25 [deg]
Equatorial Ellipse, $R = \frac{B}{A}$	1.0
Iris Ellipse, $r = \frac{b}{a}$	1.1
Cav. wall to iris plane, d	2.5 [cm]
Half Cell Length, $L = \frac{\lambda\beta}{4}$	10.65 [cm]
$H = D - (R_{iris} + b + B)$	4.195 [cm]
Cavity Beta, $\beta = \frac{v}{c}$	1.0



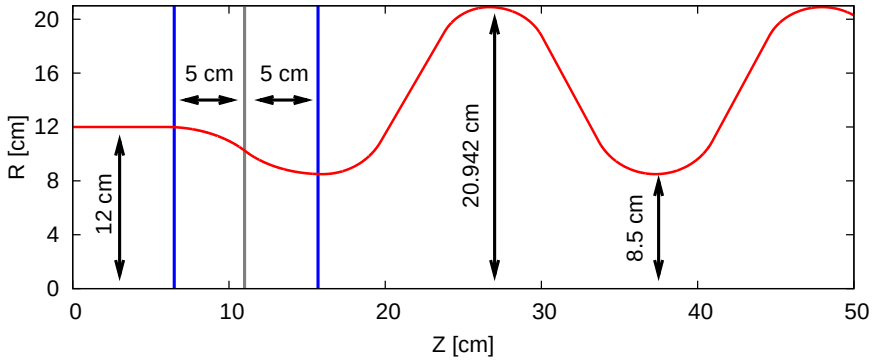


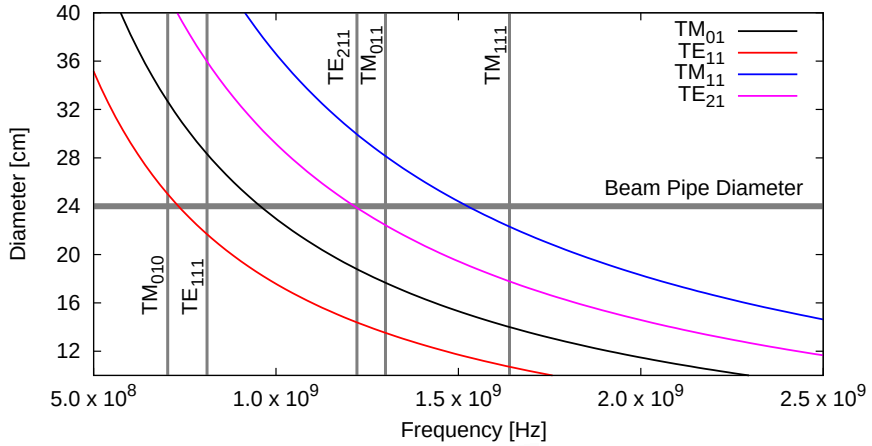


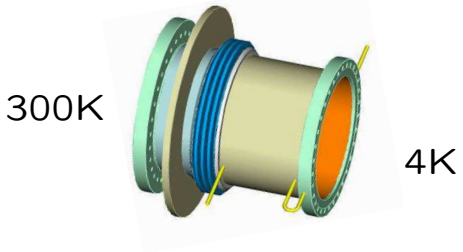


Beam Pipe Transition

- Damping HOMs
  - **Enlarged BP (KEK, BNL, CORNELL)**
  - Flutes (CORNELL)
  - Loop couplers (TESLA, CEBAF)
- Minimize fundamental leakage ($> 10\ W$).
- Minimize FPC kick
  - Enlarged BP (KEK, BNL)
  - Symm. couplers (CORNELL)
- Cold to warm transition (Counter Flow of He)



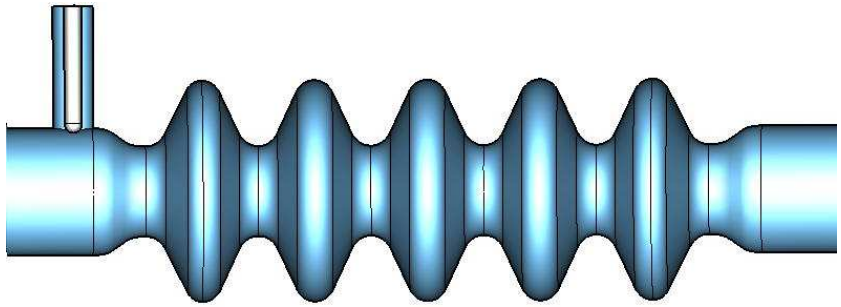




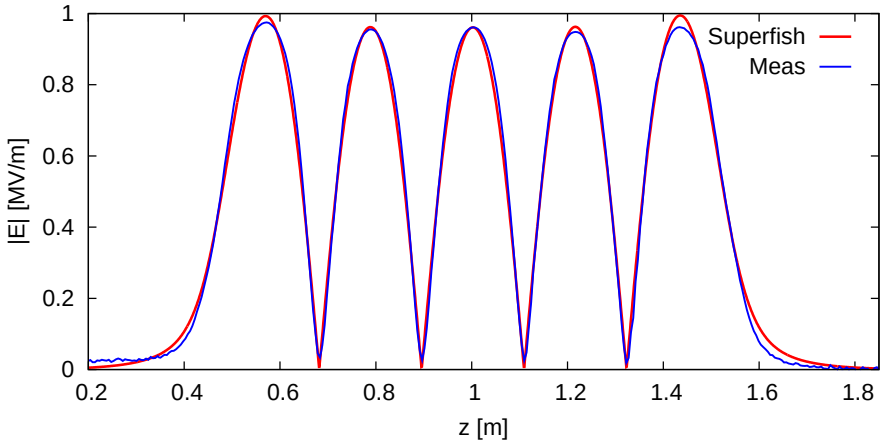
BNL High Current Cavity

Main Parameters:

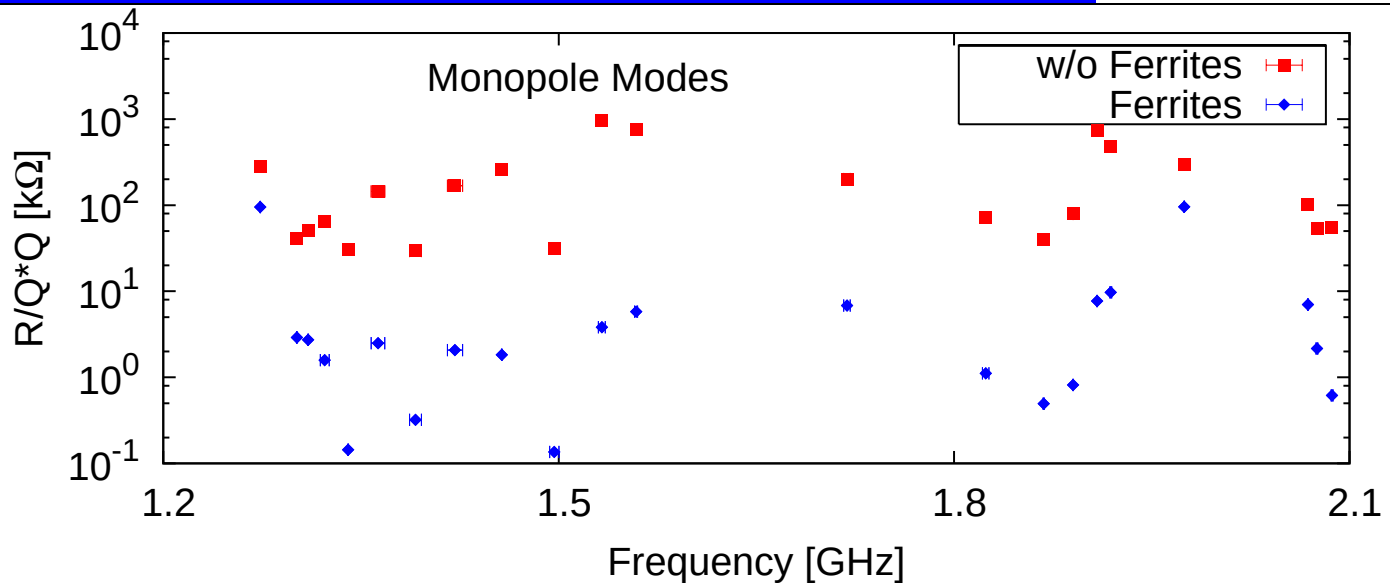
Frequency	703.75 [MHz]
RHIC Harmonic	25
Number of cells	5
Active cavity length	1.52 [m]
Iris Diameter	17 [cm]
Beam Pipe Diameter	24 [cm]
G (Ω)	225
R/Q	403.5 [Ω]
Q BCS @ 2K	4.5×10^{10}
Q_{ext}	3×10^{6}
E_p/E_a	1.97
H_p/E_a	5.78 [$mT/MV/m$]
cell to cell coupling	3%
Sensitivity Factor ($\frac{N^2}{\beta}$)	833
Field Flatness	96.5 %
Lorentz Detuning Coeff	1.2 [Hz/MV/m]
Lowest Mech. Resonance	96 [MHz]
$k_{\|\|}$ ($\sigma_z - 1cm$)	1.1 [V/pC]
$k_{\perp}$ ($\sigma_z - 1cm$)	3.1 [V/pC/m]
HOM Power (10-20 nC)	0.5-2.3 [kW]

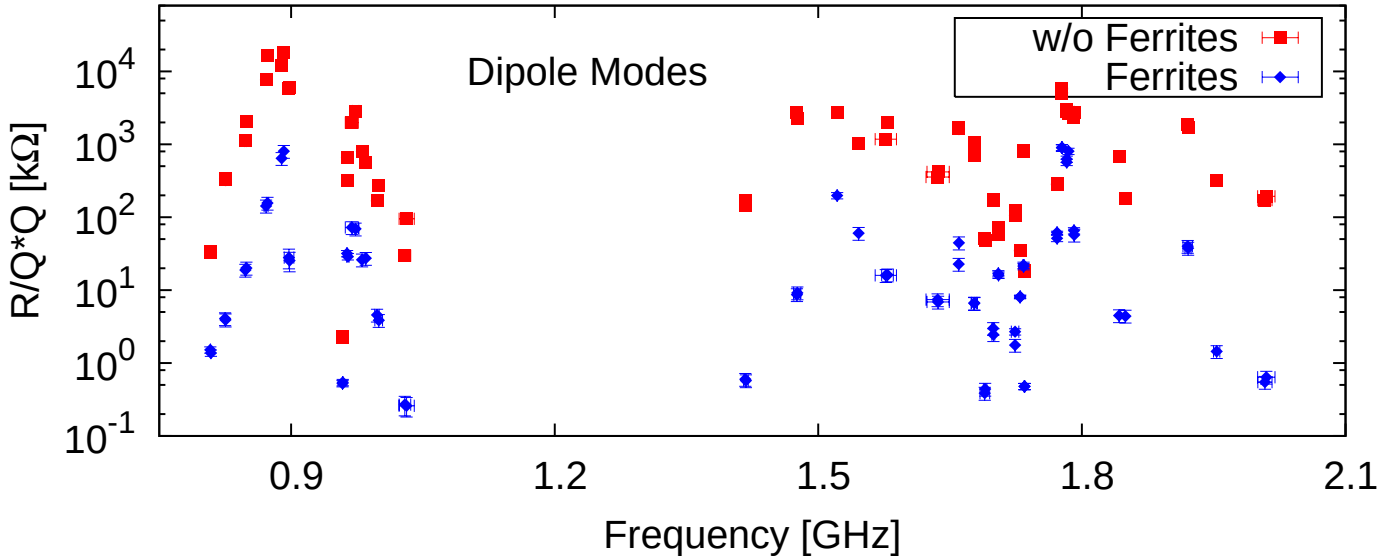


Field Flatness



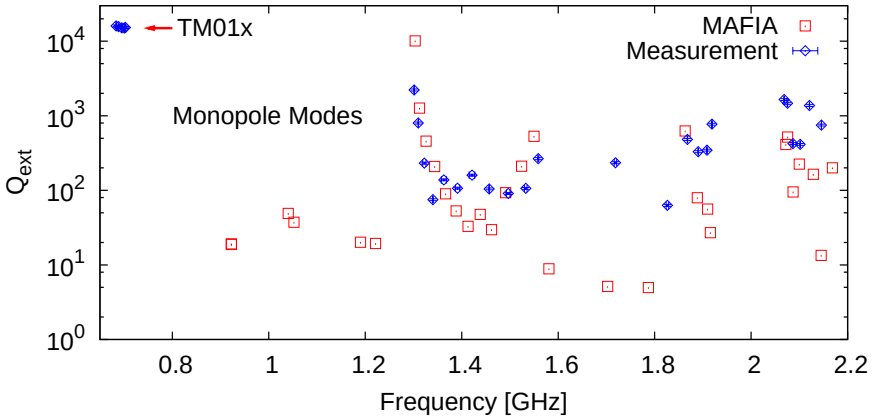
HOMs: Measurements from Cu Prototype

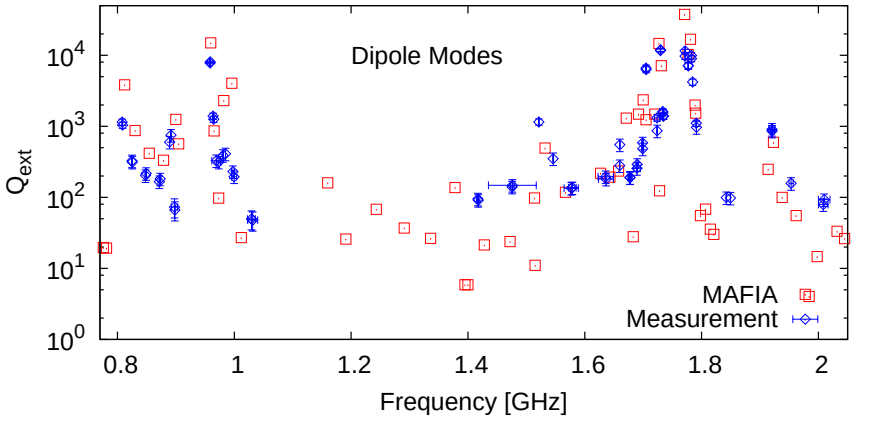




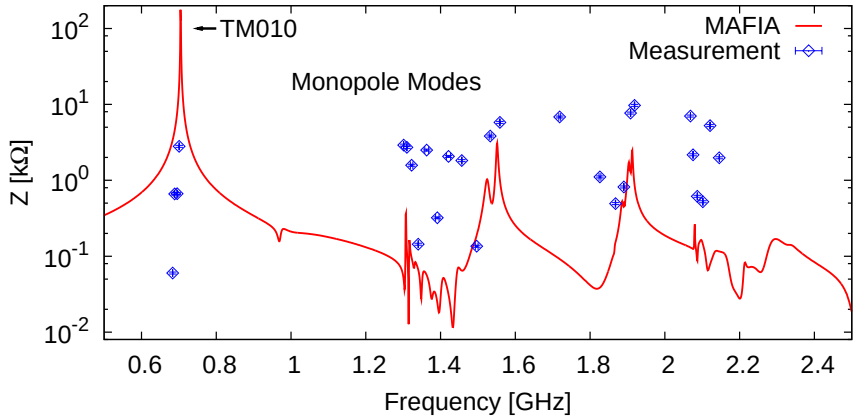
HOMs: Simulation & Measurements

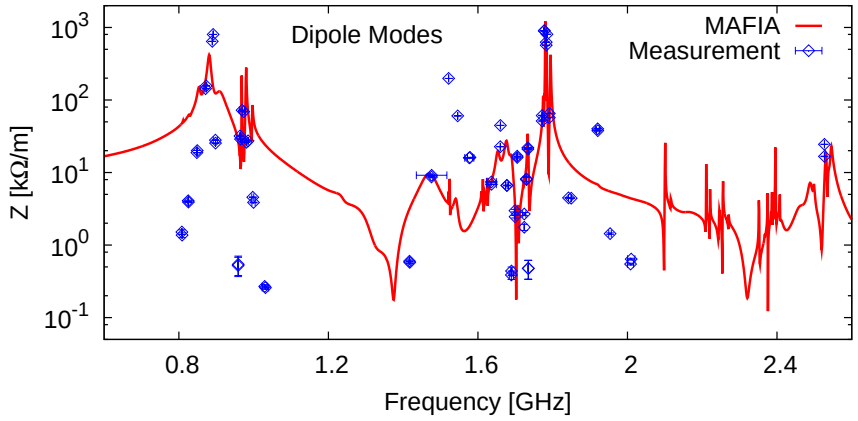
Frequency Domain





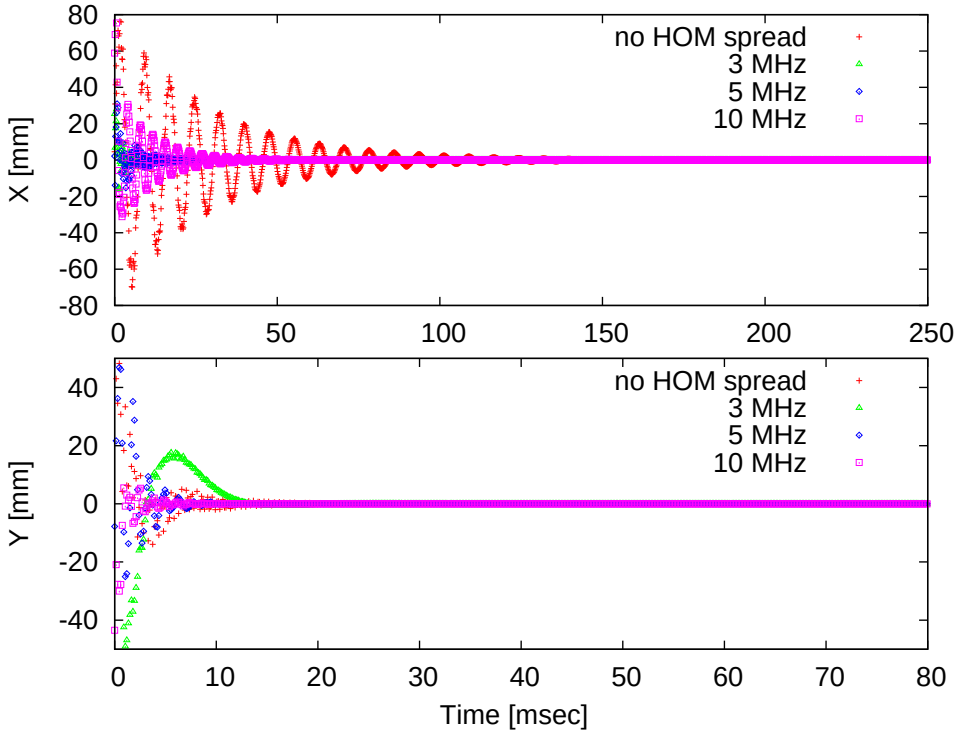
Time Domain



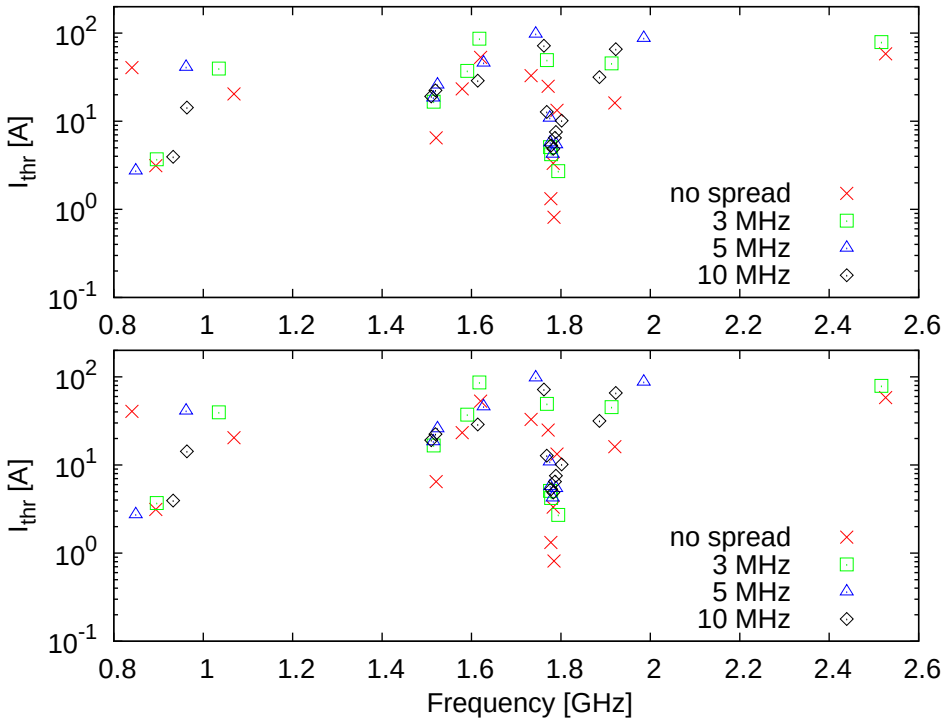


Multibunch BBU

TDBBU



MATBBU



Threshold Current > 2 Amps

BNL eCooling Configuration - 4 Cavities - 54 MeV

(Numerical Codes from JLAB)

Conclusion

- Future ERLs will operate at High Currents and some at High Bunch Charge
- Minimize P_{HOM} ($k_{||} \downarrow \Rightarrow\ \omega \downarrow,\ R_{iris} \uparrow$)
- Untrap all HOMs ($Q_{ext} \downarrow \Rightarrow\ k_{cc} \uparrow,\ N_c \downarrow$)
- Efficient extraction of HOM power (Propagate all HOMs)