SRF Cavities for High Current ERLs

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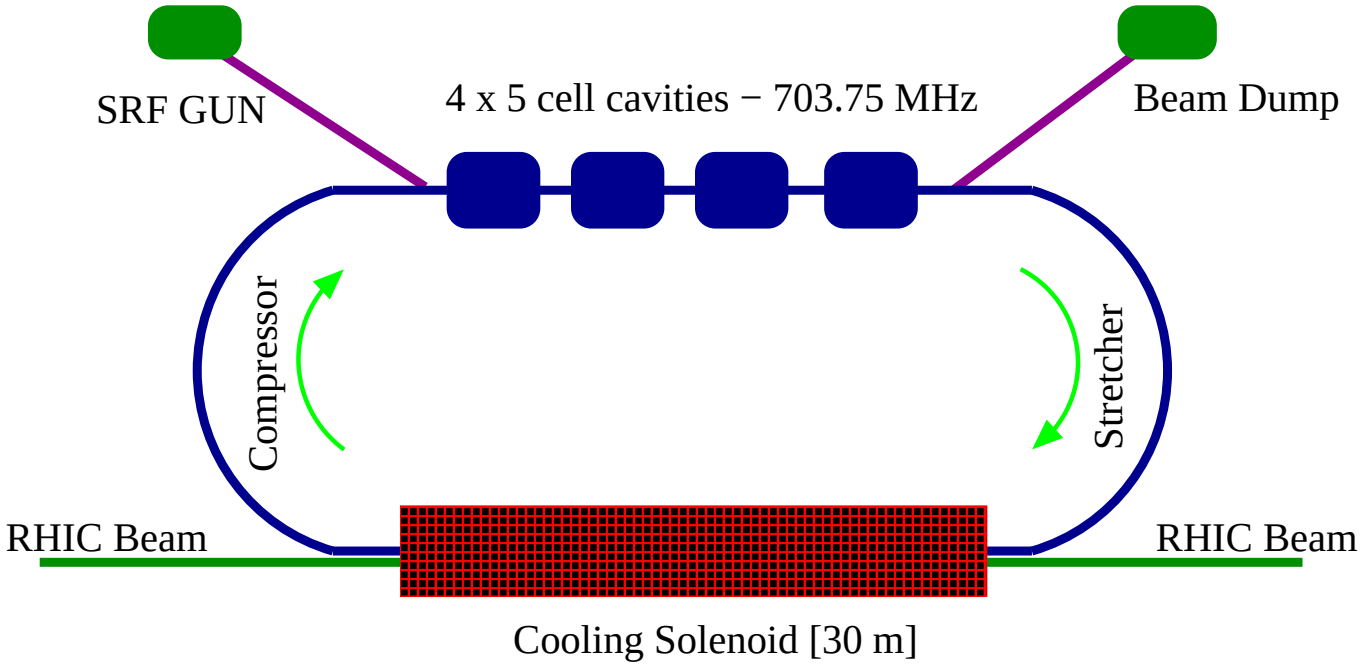
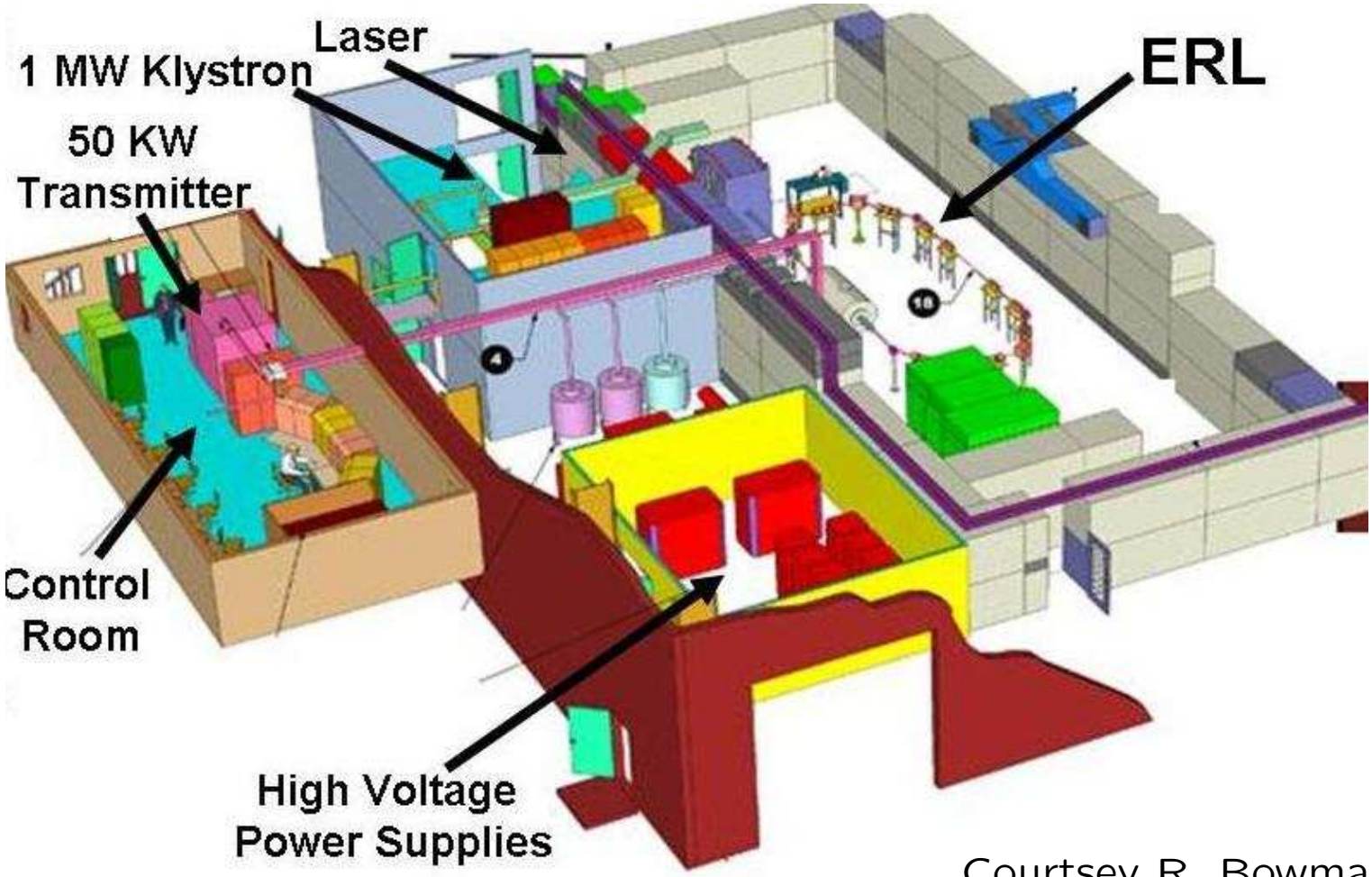
Motivation - ecooling@RHIC

- Cooling Au beams at 100 GeV requires $\sim$ 54 MeV e^-
- $\frac{dCooling}{dt} \propto \gamma^{\frac{5}{2}}$
- Low $\epsilon_{x/y}$, high current ($> 200mA$) and bunch charge (10-20 nC)
- Replenish e^- every cycle - energy recovery linac



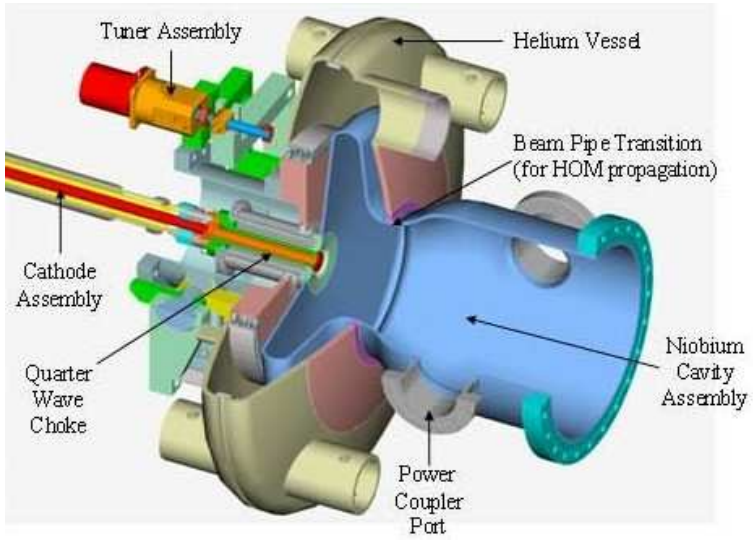
Prototype ERL - Proof of Principle



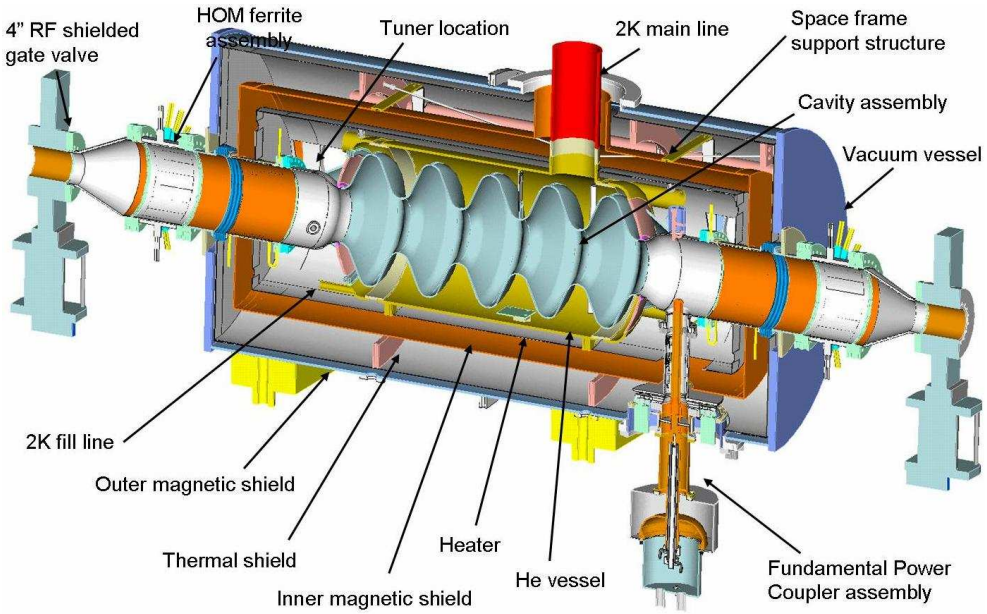
Courtsey R. Bowman

Injector & Linac

SRF Injector



SRF Cavity



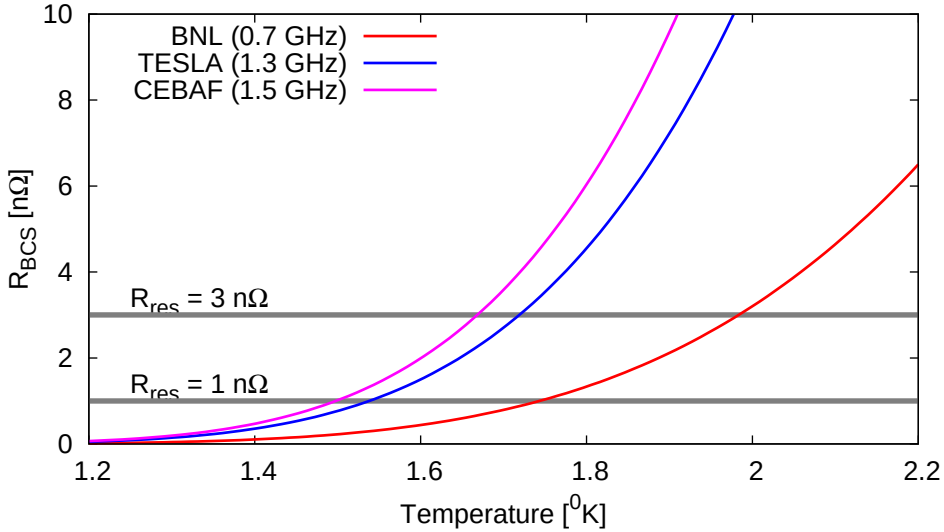
- Generation of ampere class beam CW
- Cathode Issues and Isolation
- E_z at the cathode
- Low $\epsilon_{x/y}$ & $\delta E/E$
- Strong Coupling $Q_{ext} \sim 10^4$

- High Q_{ext} $\Rightarrow$ Lorentz force detuning & microphonics
- HOM Power & extraction
- Multibunch Instabilities (x20 state-of-the-art)
- Field Emission (Q_0)

SRF Cavity Design Issues

Fundamental Mode - Main Issues

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



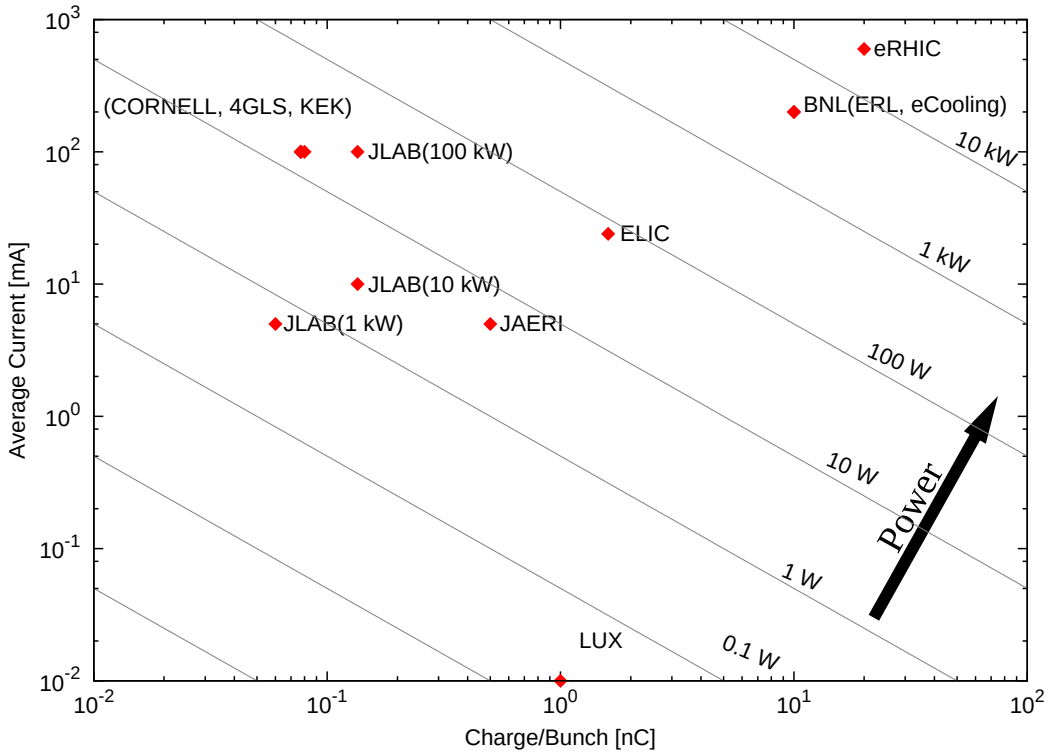
Par	BNL(HC)	CEBAF(HG)	TESLA(HG)
Freq. [MHz]	703.75	1497	1300
$\frac{R}{Q} * G$ [Ω^2]	9×10^4	2.1×10^5	2.8×10^5
E_p/E_a	1.97	1.96	1.98
H_p/E_a $[mT/MV/m]$	5.78	4.15	4.15
k_{cc}	3%	1.89%	1.87%
N_{cells}	5	7	9
$\frac{N^2}{\beta k_{cc}}$	8.3×10^2	2.6×10^3	4.1×10^3

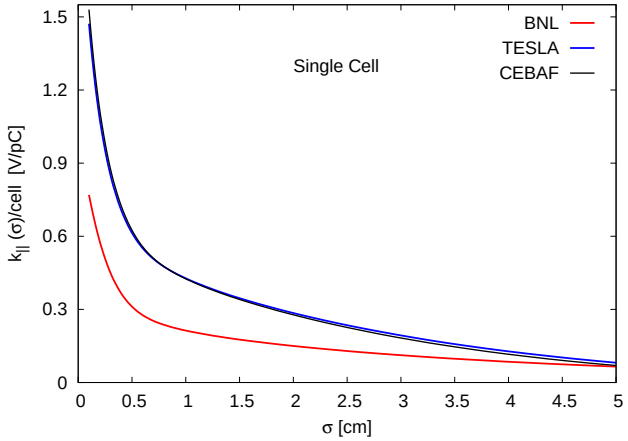
HOM Power & Extraction

HOM Power & Kick

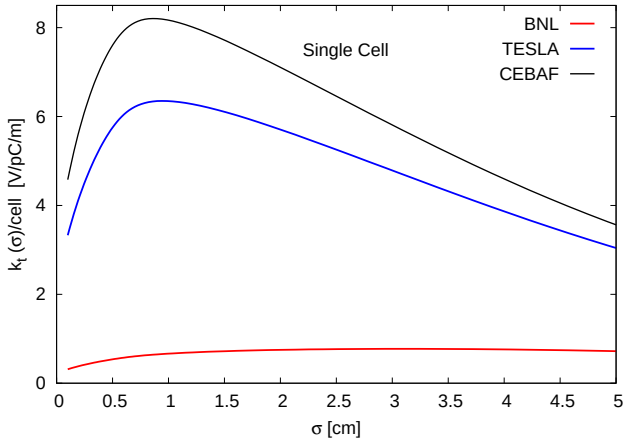
$$P_{avg} = 2k_{||}IQ$$

$$k_{||} \propto \frac{1}{\mathbf{R_{iris}}}\sqrt{\frac{d}{\sigma_z}}\sqrt{N_c}$$





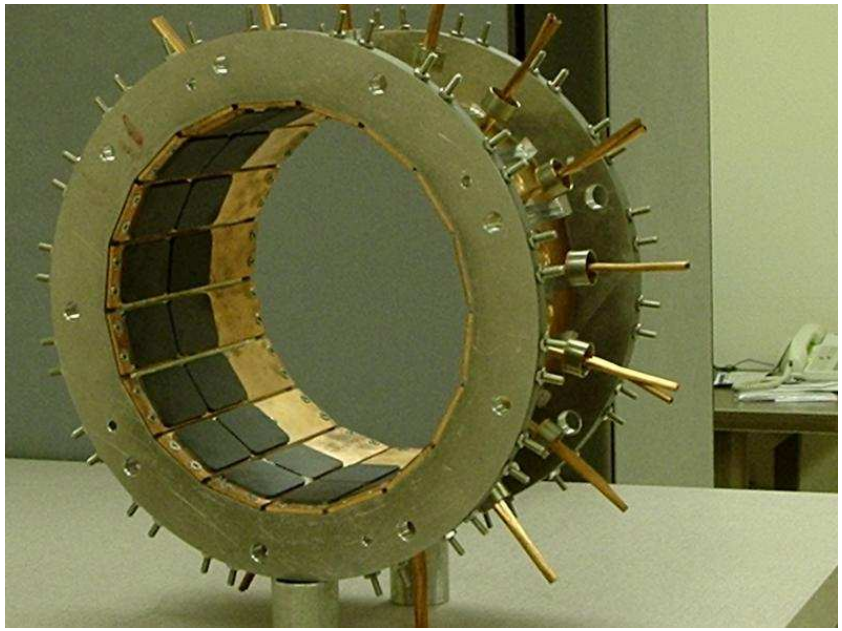
$$k_{\perp} \propto \frac{1}{R_{iris}^3}\sqrt{d\sigma_z N_c}$$



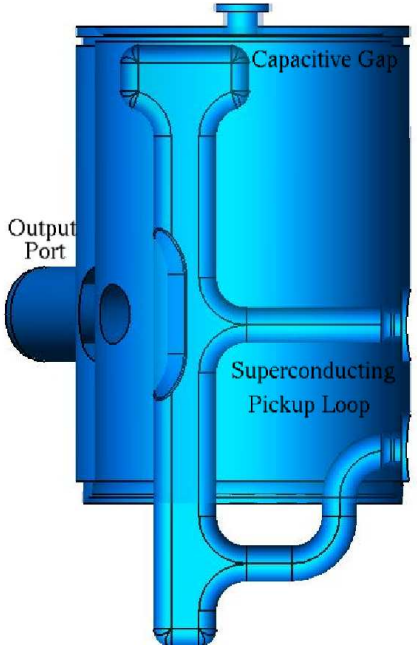
*** Avg. Power Normalized to 1 V/pC

HOM Extraction & Damping

Ferrite Absorbers
Broadband (300 K)



Loop Couplers
Resonant Ciruit (2 K)

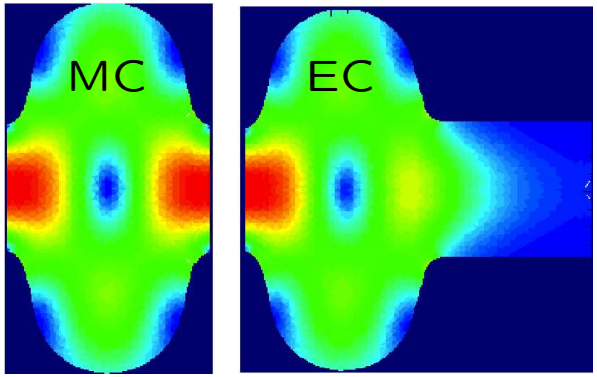


Parameter	BNL(HC)	CEBAF(HG)	TESLA(HG)
$k_{\|\|}$ $(\sigma_z - 1mm)$ [V/pC]	4.25	10.71	13.14
$k_{\perp}$ $(\sigma_z - 1mm)$ [V/pC/m]	0.1	2.24	2.07

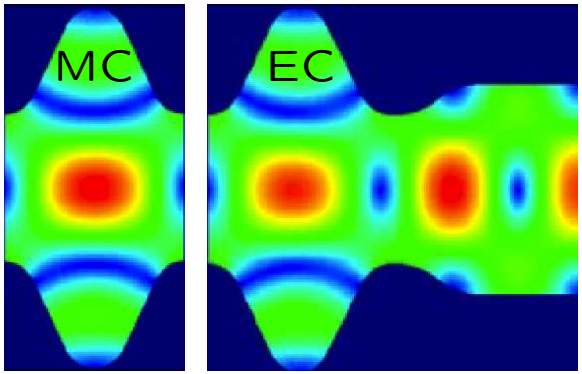
Trapped Modes

Design Criteria: Trapped Modes

Frequency Difference

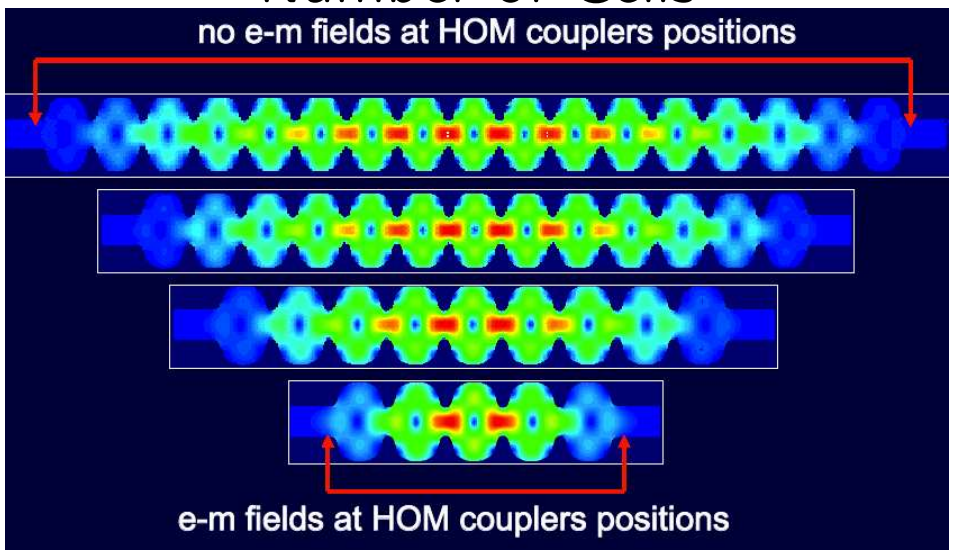


$\Delta f = 30MHz$ (2.4 GHz)

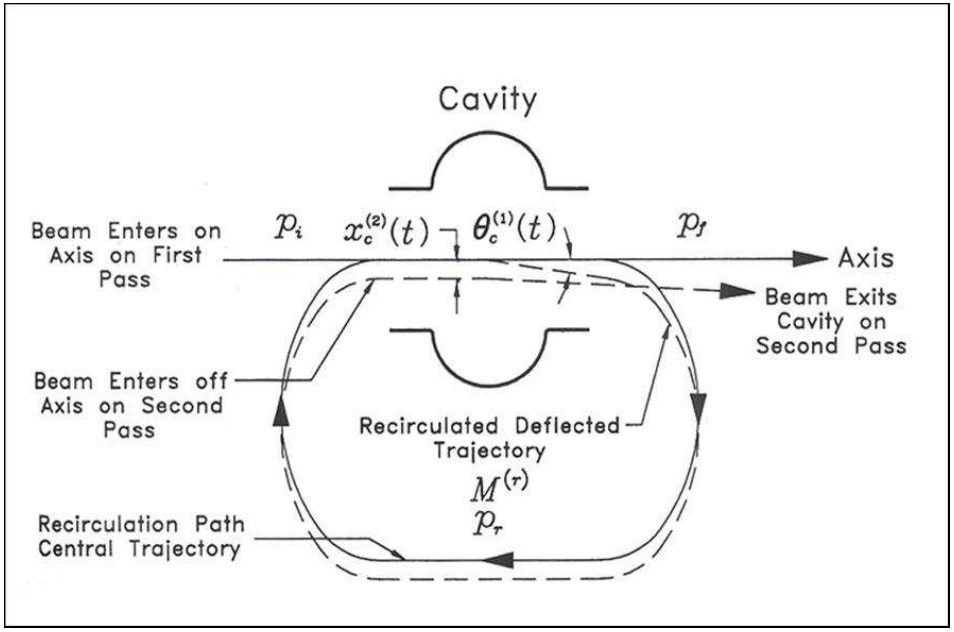


$\Delta f = 13MHz$ (1.4 GHz)

Number of Cells



HOMs - Multibunch BBU



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

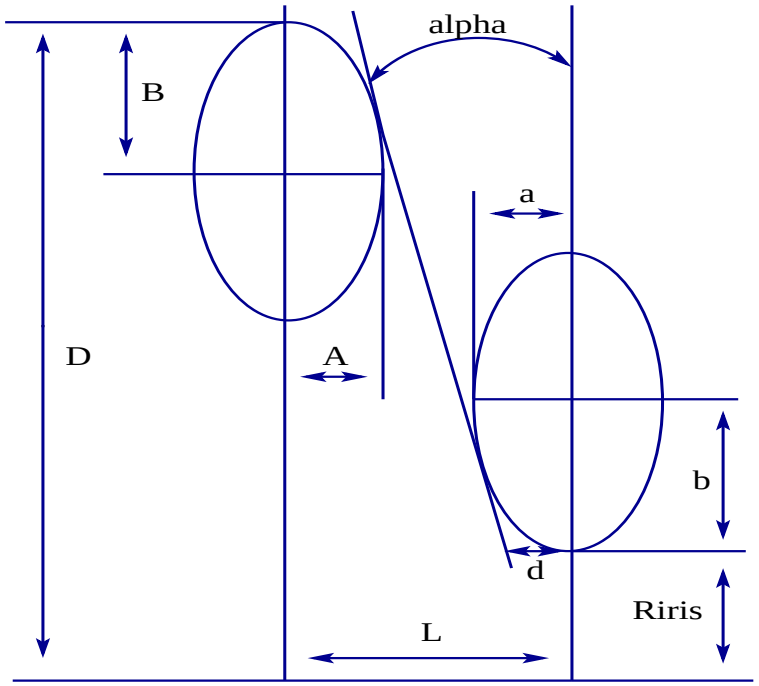
$$I_{thr} = \frac{-2p_r c}{e\left(\frac{R}{Q}\right)Q_e k_m M_{12} sin(\omega_m t_r) e^{-\frac{\omega_m}{2Q_e}t_r}}$$

Parameter	BNL(HC)	CEBAF(HG)	TESLA(HG)
$k_{\|\|}$ $(\sigma_z - 1mm)$ [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)	$10^2 - 10^4$	$10^3 - 10^6$	$10^3 - 10^7$

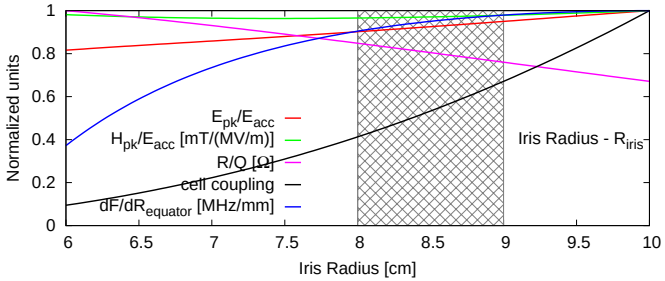
Single Pass (HG) Vs. Multiple Passes (HC + Magnets)

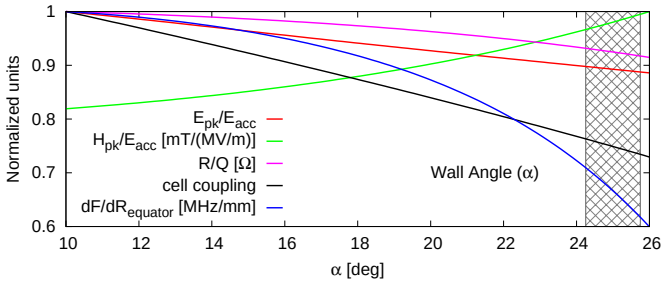
BNL Cavity

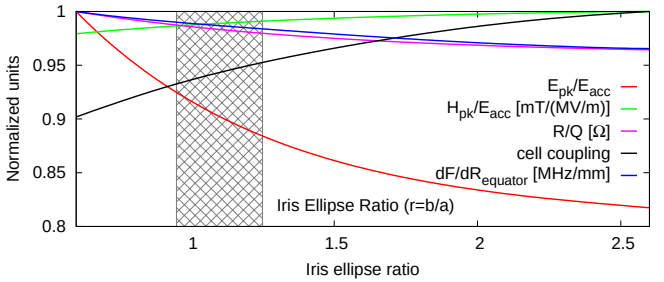
Cavity Design

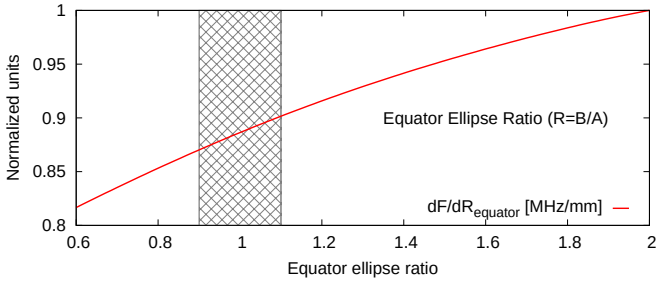


Iris Radius, R_{iris}	8.5 [cm]
Wall Angle, α	25 [deg]
Equatorial Ellipse, $R = \frac{B}{A}$	1.0
Iris Ellipse, $r = \frac{b}{a}$	1.1
Cav. wall to iris plane, d	2.5 [cm]
Half Cell Length, $L = \frac{\lambda\beta}{4}$	10.65 [cm]
$H = D - (R_{iris} + b + B)$	4.195 [cm]
Cavity Beta, $\beta = \frac{v}{c}$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



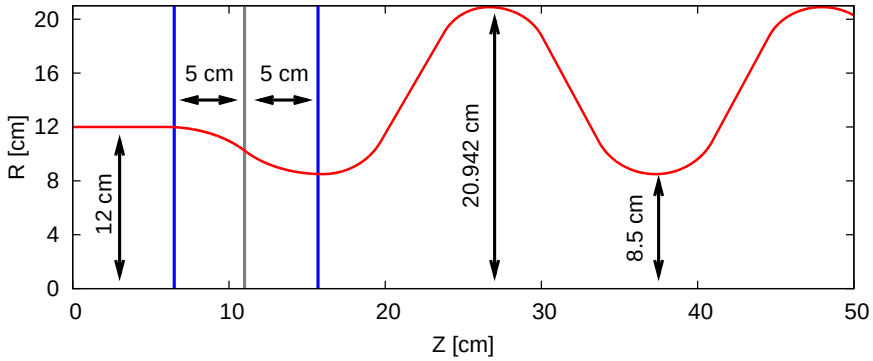


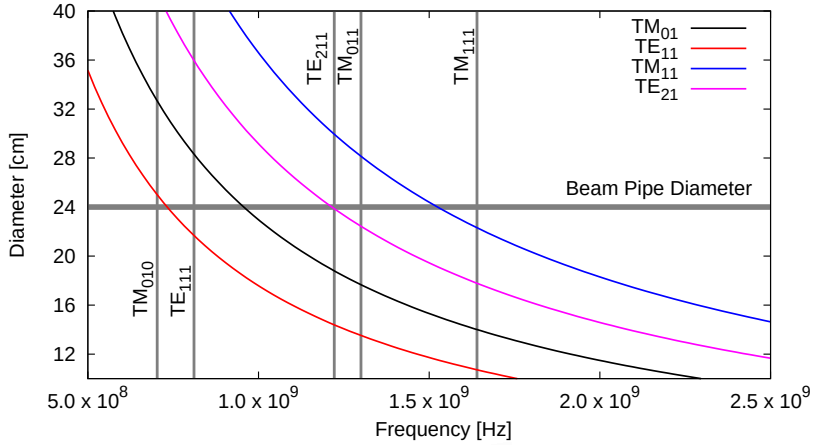


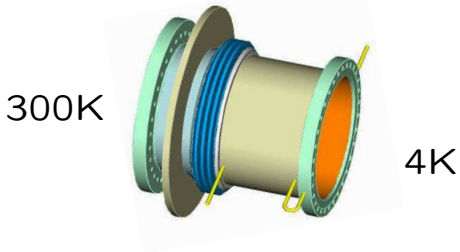


Beam Pipe Transition

- 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)



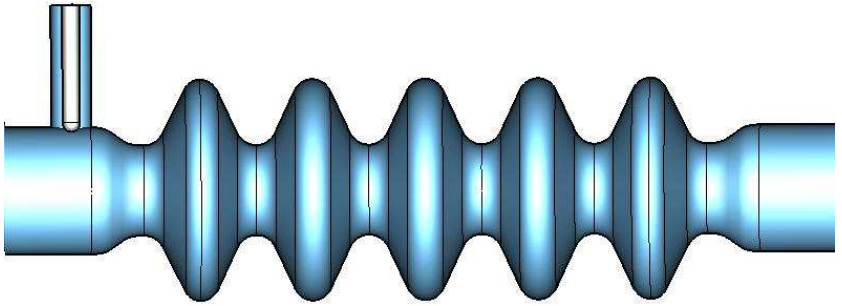




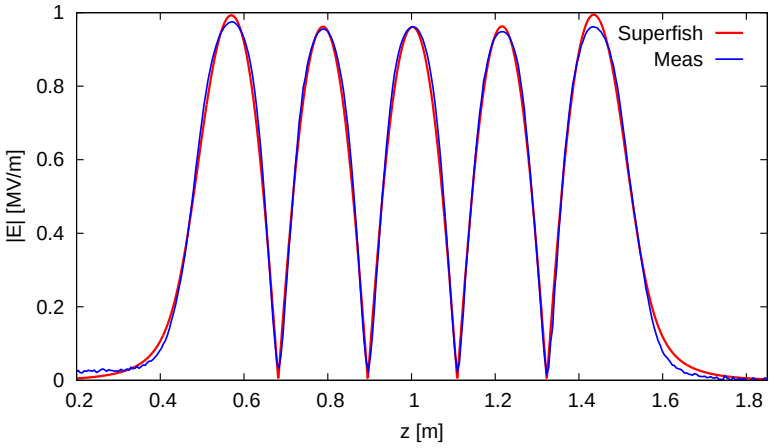
BNL High Current Cavity

Main Parameters:

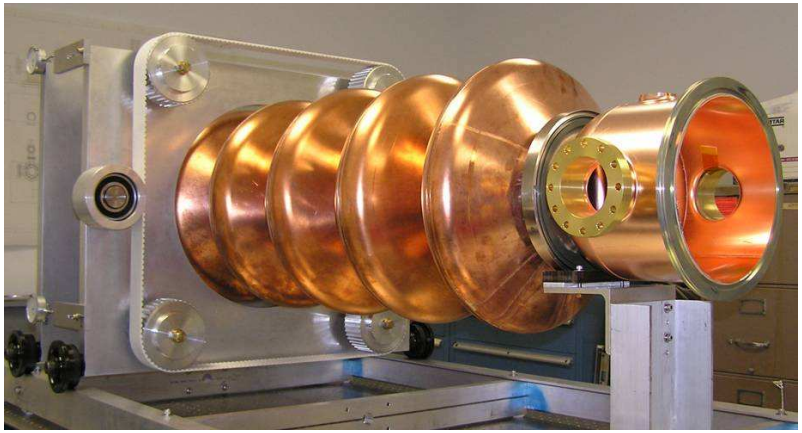
Frequency	703.75 [MHz]
RHIC Harmonic	25
Number of cells	5
Active cavity length	1.52 [m]
Iris Diameter	17 [cm]
Beam Pipe Diameter	24 [cm]
G (Ω)	225
R/Q	403.5 [Ω]
Q BCS @ 2K	4.5×10^{10}
Q_{ext}	3×10^6
E_p/E_a	1.97
H_p/E_a	5.78 $[mT/MV/m]$
cell to cell coupling	3%
Sensitivity Factor ($\frac{N^2}{\beta}$)	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]

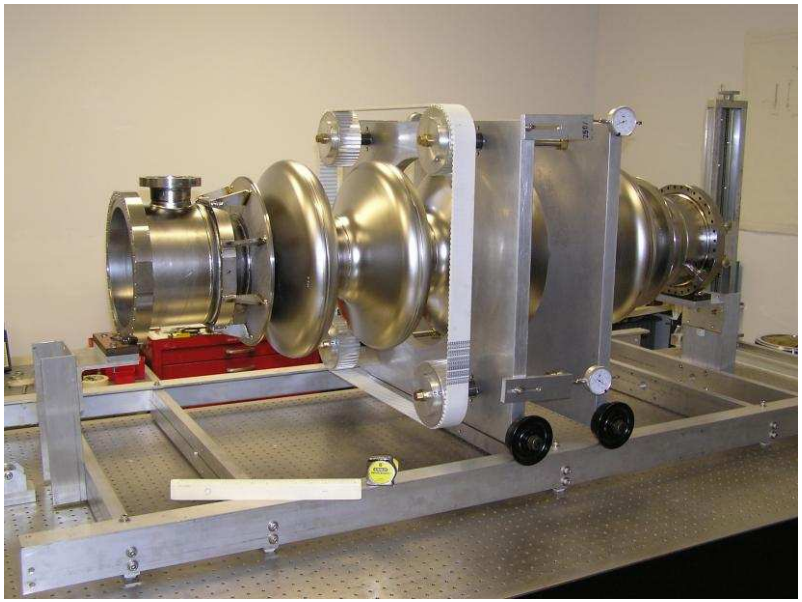


Field Flatness



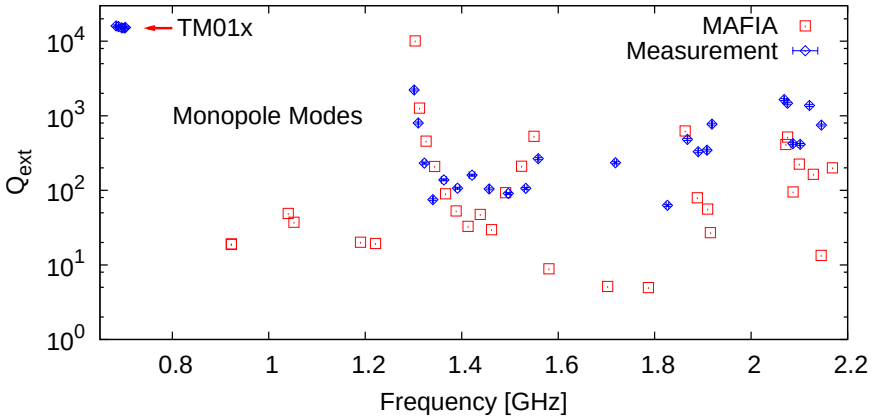
Cu Prototype & Nb Cavity

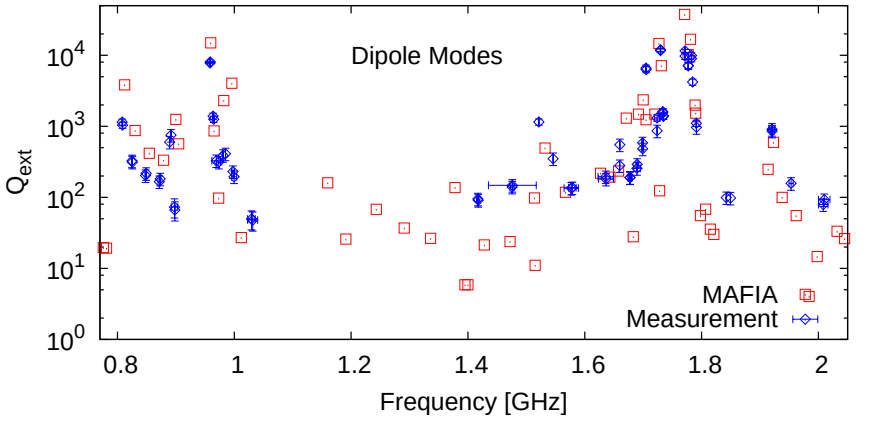




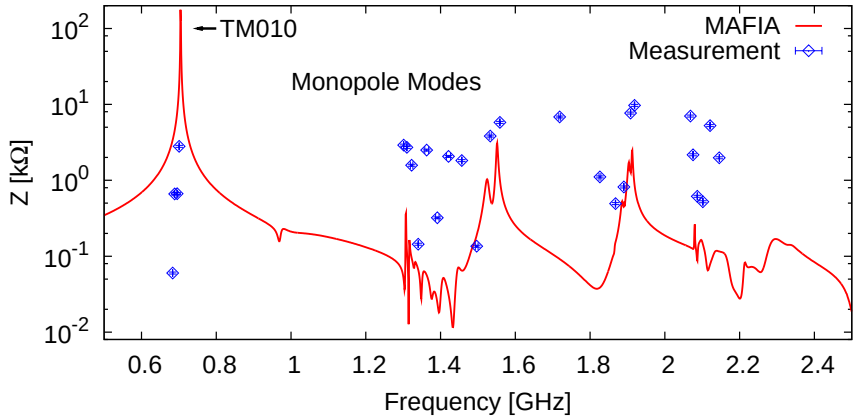
HOMs: Simulation & Measurements

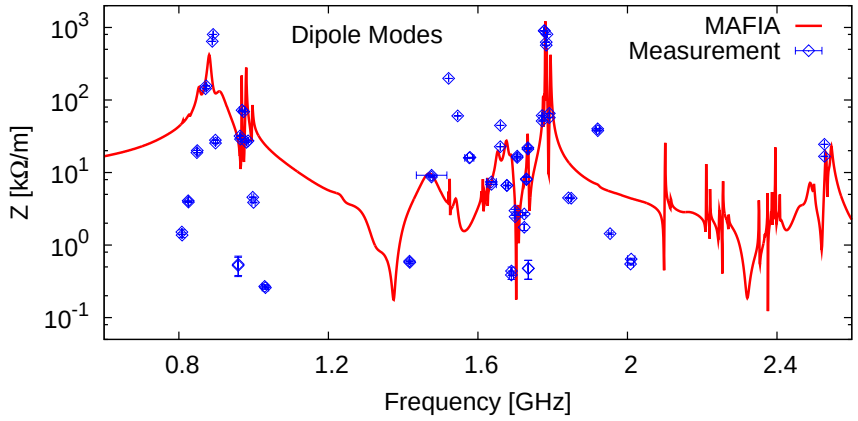
Frequency Domain





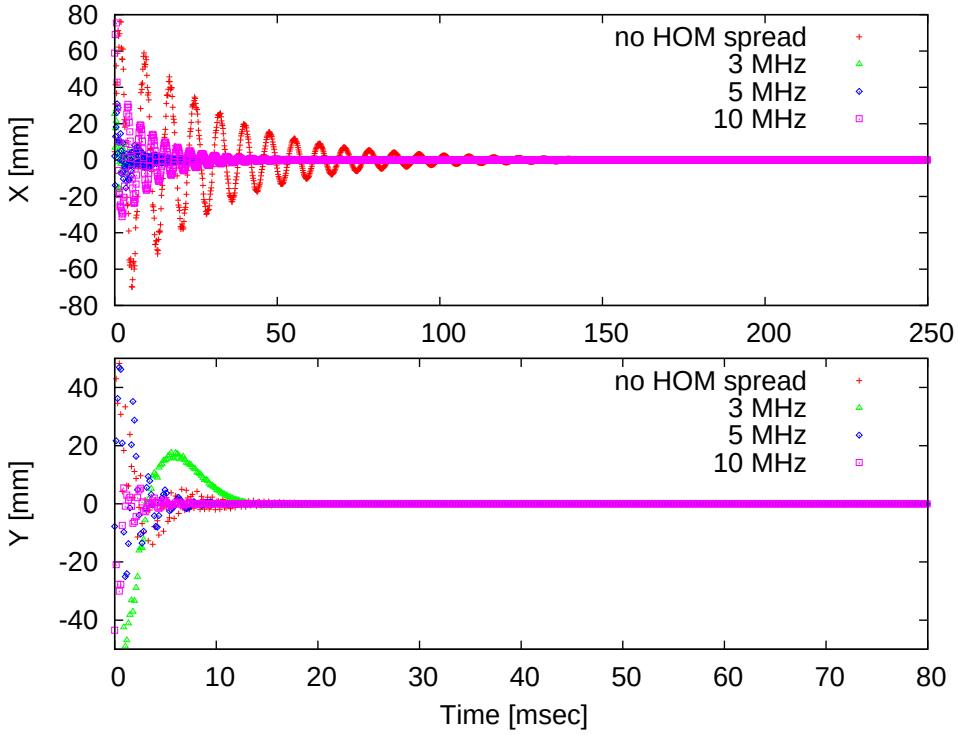
Time Domain



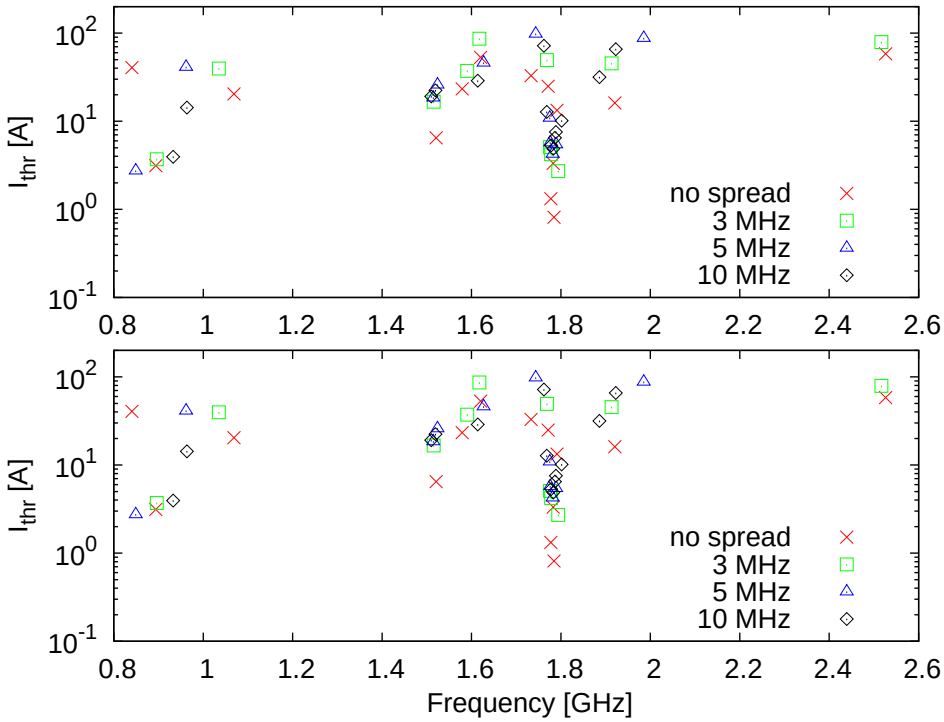


Multibunch BBU

TDBBU



MATBBU



Threshold Current > 2 Amps

BNL eCooling Configuration - 4 Cavities - 54 MeV

(Numerical Codes from JLAB)

Conclusion

- The cavity is being prepared for chemical treatment at JLAB
- Cryostat assembly and cold testing in 2006
- The SRF gun will finish fabrication end of 2006
- The 20 MeV prototype ERL will be operational sometime in 2007

THANKS & HAVE A NICE LUNCH