Damping Requirements in SRF Deflecting Cavities for Generation of Short X-ray Pulses in Storage Rings

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ANL

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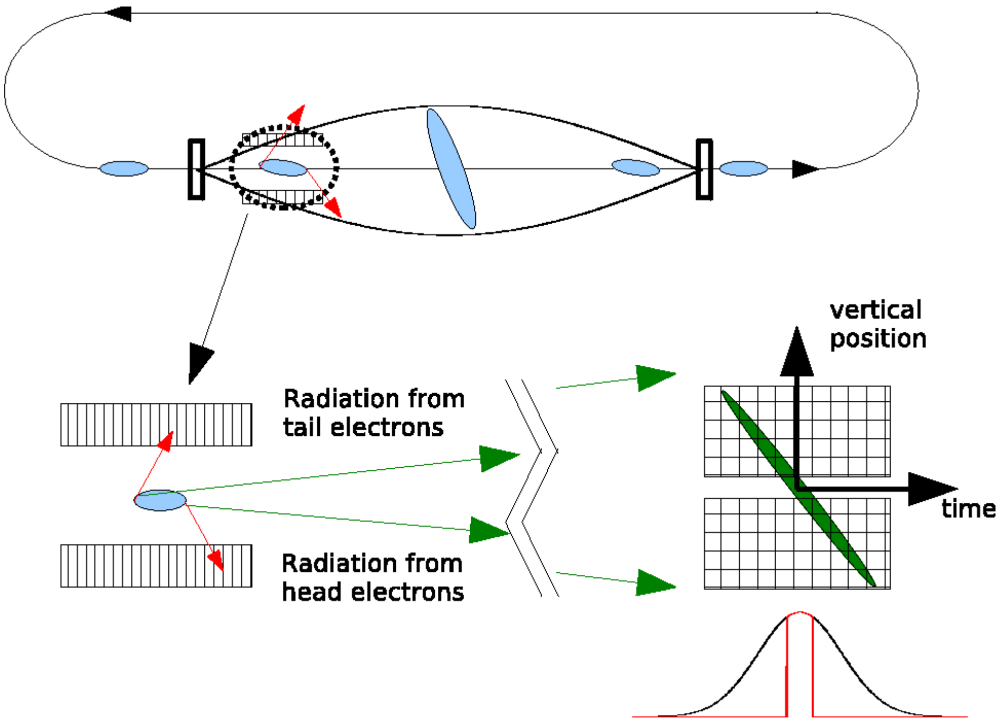
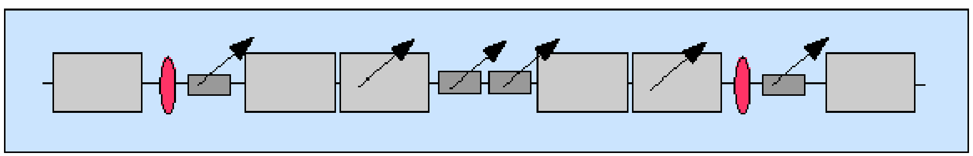
Outline

- Scheme
- Cavities performance requirements
- Summary

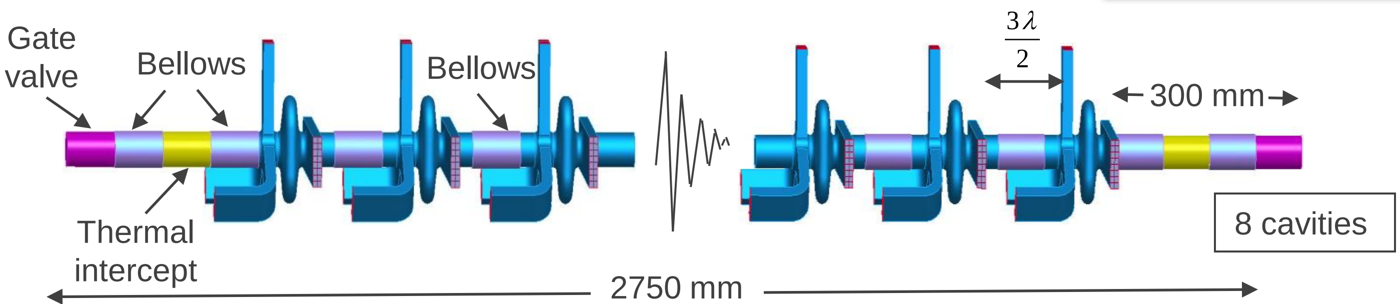
Scheme*

Pulse can be sliced or compressed





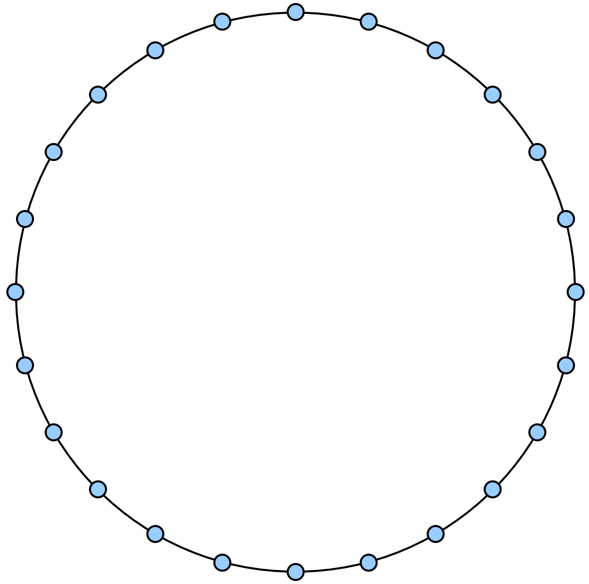
2 sector spacing
Two ID + Two BM



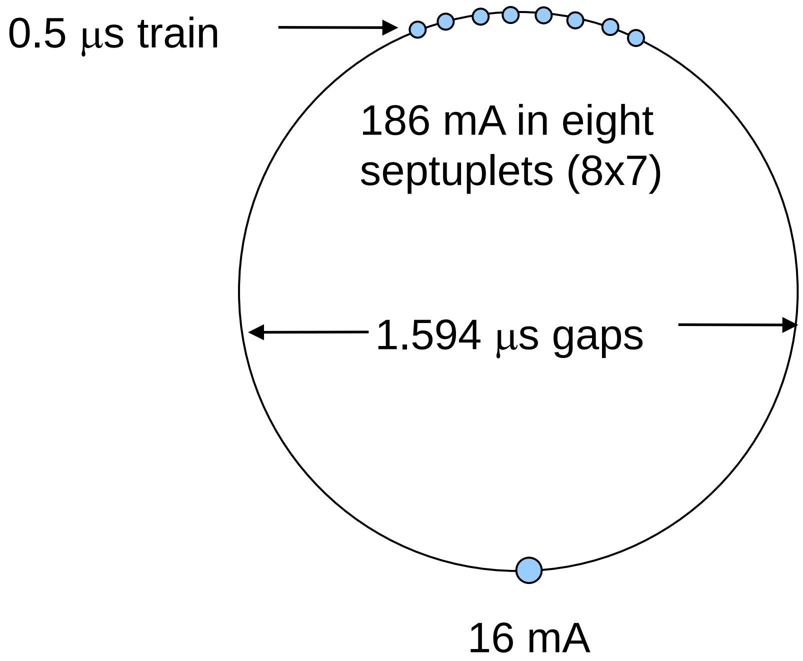
*A. Zholents, P. Heimann, M. Zolotorev, J. Byrd, NIM A 425(1999), 385

Bunch Patterns

Symmetric
202 mA in 24 bunches



Hybrid, i.e.
Single bunch plus a bunch train
202 mA in Hybrid: 1+ 8x7
Hybrid usually has higher growth rates



Beam Parameters

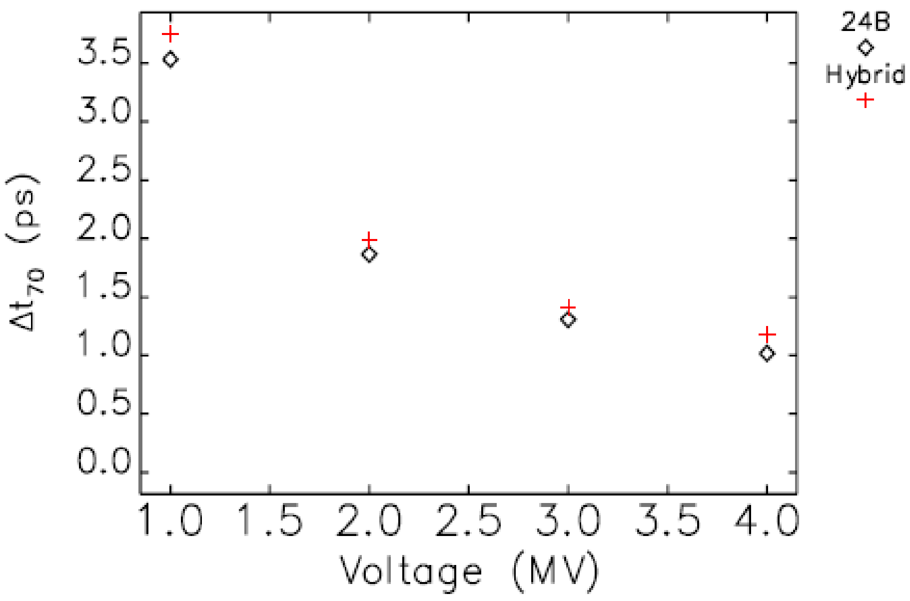
Operating total current	202 mA
Energy	7 Gev
Revolution frequency	271.55 kHz
Synchrotron frequency	2.1 kHz
Momentum compaction	2.8×10^{-4}
Cavity $\square_x$	22 m
Cavity $\square_y$	7.5 m
RMS bunch length for 2 mA	37 ps
Chromaticity	> 6

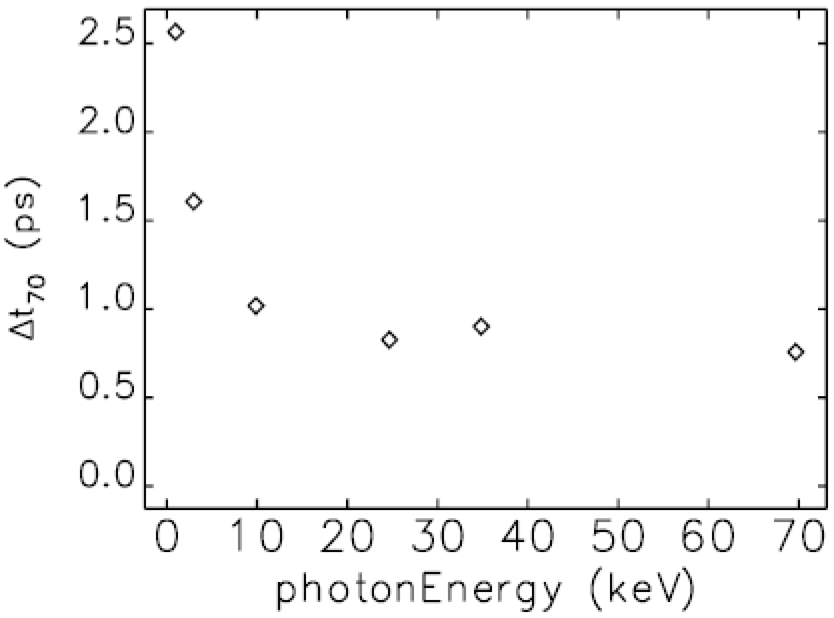
Damping rates

Planes	Synchrotron radiation	Coherent
Longitudinal	208 s^{-1}	208 s^{-1}
Horizontal	104 s^{-1}	> 600 s^{-1}
Vertical	104 s^{-1}	> 600 s^{-1}

SPX Fundamental Parameters

Beam current	**202 mA (24singlets)**
Beam energy	**7 GeV**
Revolution frequency	**271.55 kHz**
RF deflecting voltage	**2 MV (Initial implementation)**
Two cryomodules	
4 cavities/cryomodule	
RF deflecting voltage	**4 MV (Final implementation)**
Two cryomodules	
8 cavities/cryomodule	
RF frequency	**2815.4856 MHz (8th harm of SR frequency, 351.9357 MHz)**



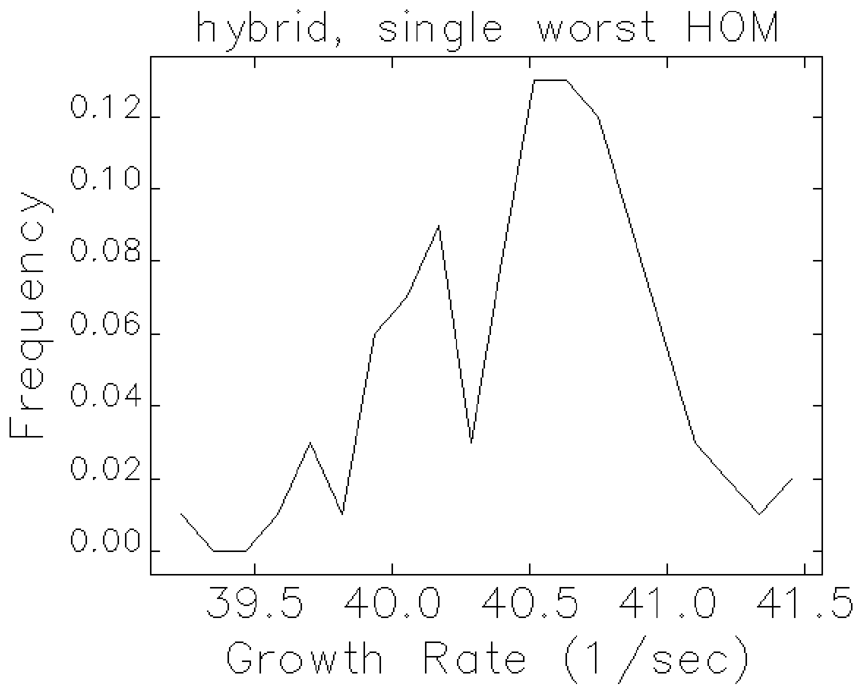


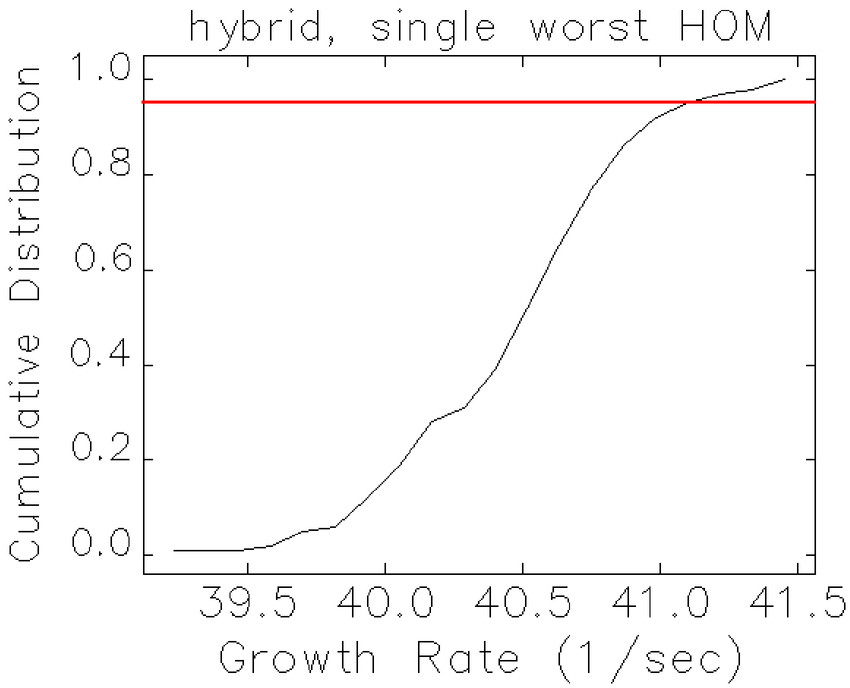
Example V-plane HOMs from One SC cavity with dampers

Frequency Hz	Q	RoverQ Ohm/m	ShuntImpedance Ohm/m	
2.82e+09	100000	1062	1.06e+08	← Deflecting mode
2.98e+09	43	66	2.84e+03	
3.01e+09	588	13	7.64e+03	
3.02e+09	68	878	5.97e+04	
3.06e+09	797	240	1.91e+05	← Dominant HOM
3.32e+09	16	0	1.60e-01	
3.38e+09	187	0	2.24e+01	
3.43e+09	144	448	6.45e+04	
3.70e+09	580	27	1.58e+04	
3.83e+09	1116	4	4.07e+03	
4.20e+09	67	20	1.34e+03	

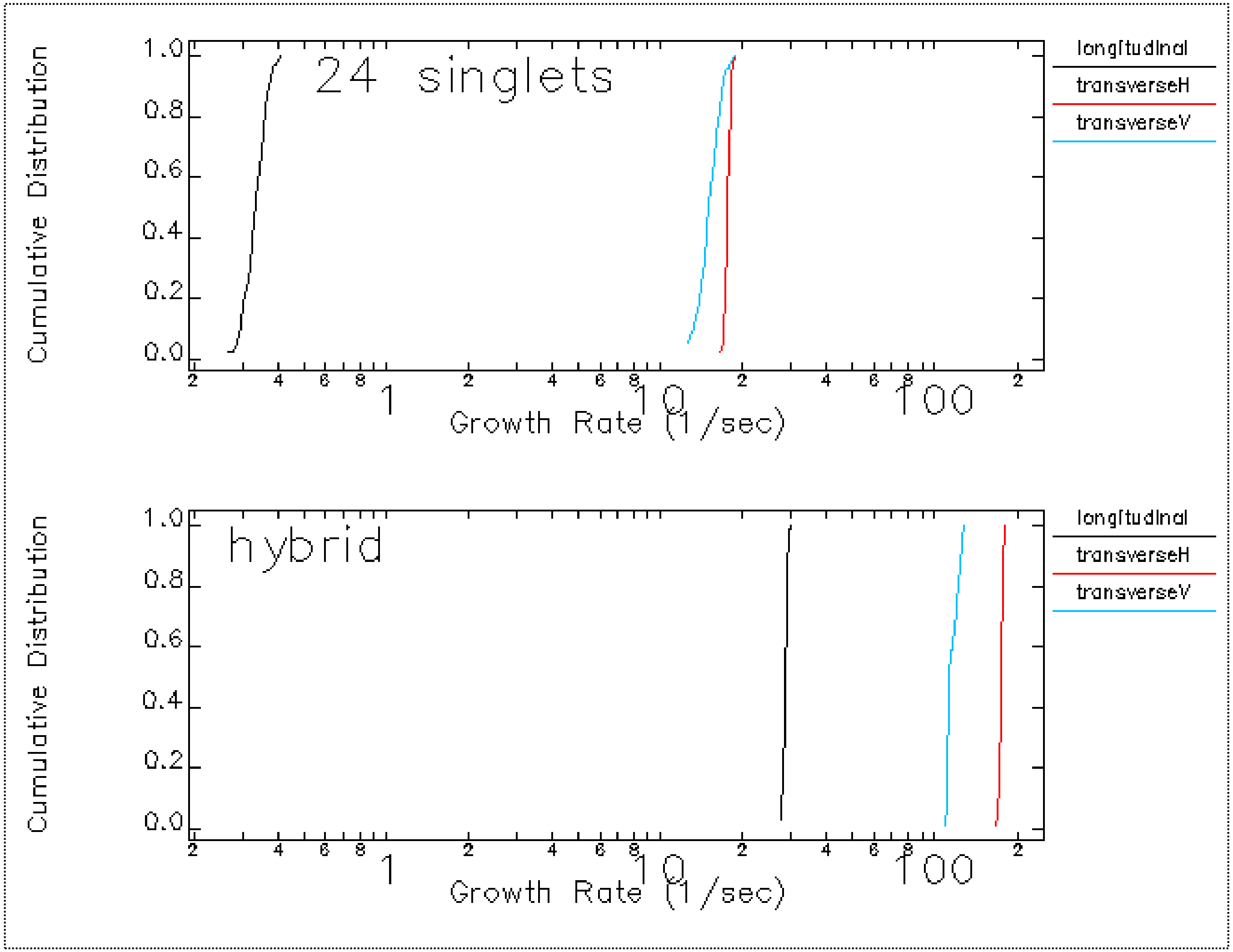
Data supplied by G. Waldschmidt

Monte Carlo Results for Hybrid Bunch Pattern, Single Worst HOM in V-plane





Results for all planes, all HOMs and two bunch patterns

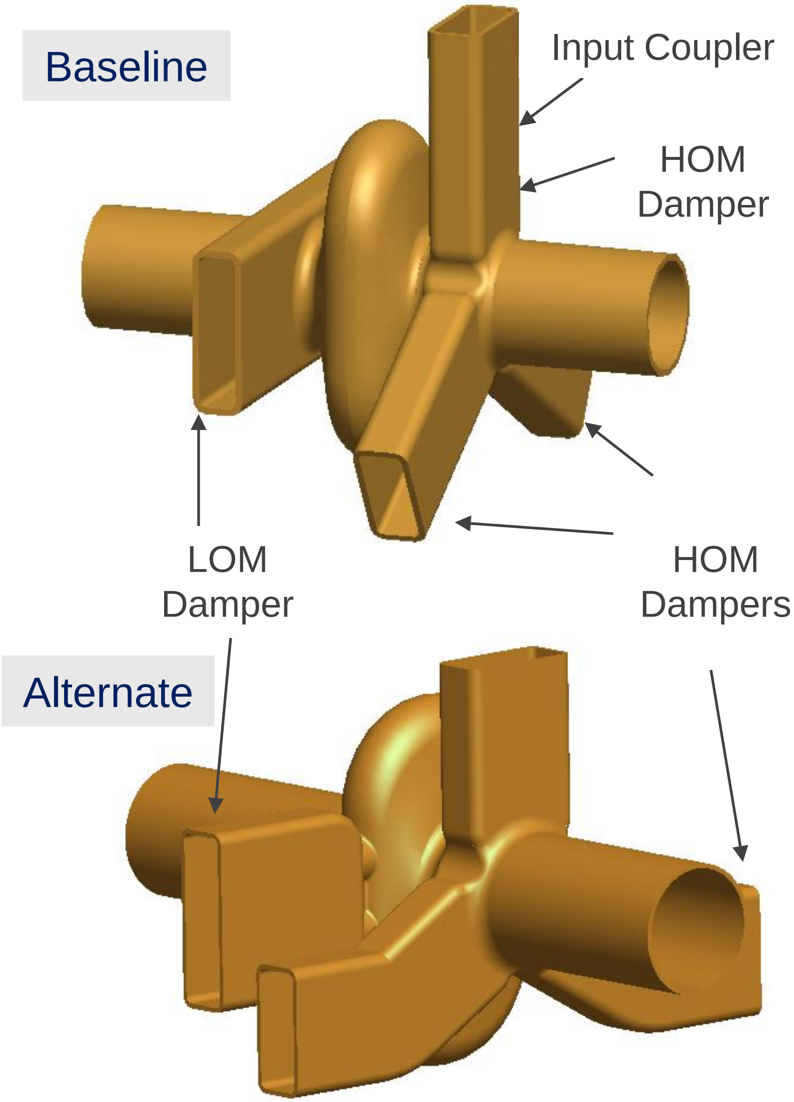


Stability Result

- Q's of longitudinal and transverse planes are very low (20-800)
- Transverse plane is stable with only synchrotron radiation

Plane	Growth Rate	Damping Rate		Comment
		Synchrotron Radiation	Coherent	
Longitudinal	30 s^{-1}	208 s^{-1}	Not applicable	Stable
Horizontal	180 s^{-1}	104 s^{-1}	> 600 s^{-1}	Probably stable
Vertical	125 s^{-1}	104 s^{-1}	> 600 s^{-1}	Probably stable

Single-Cell Storage Ring Cavity Options

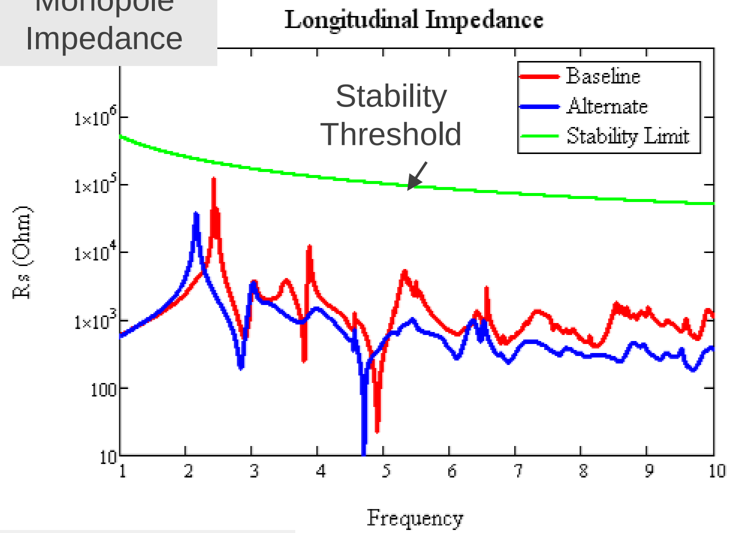


Frequency	2815	MHz
I_{beam}	200	mA
Q_{bunch}	30.7	nC
$f_{revolution}$	271	kHz
# of bunches per revolution	24	
Bunch length	40 (12)	ps (mm)
# of cavities	16	
# of Cryomodules	2	
$k_{\|\|}$ (baseline)	0.523	V/pC
$k_{\|\|}$ (alternate)	0.305	V/pC
Beam pipe radius	25	mm

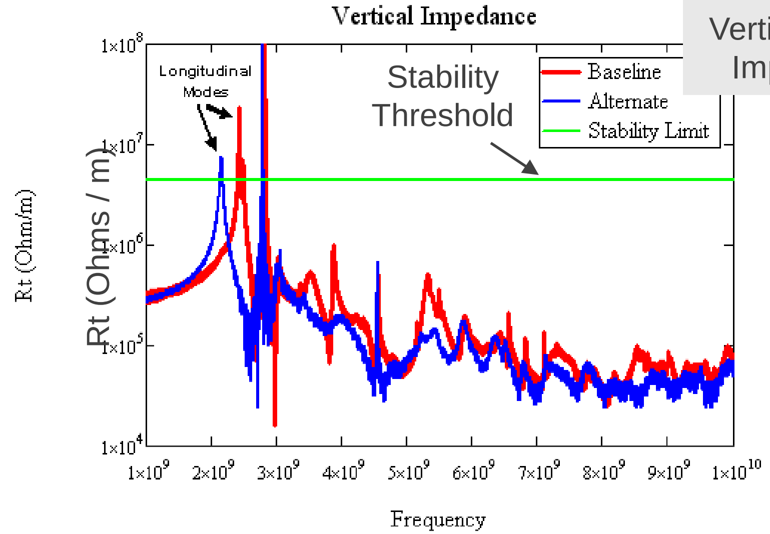
Cavity and bunch parameters

Longitudinal and Transverse Impedance

Monopole Impedance



Vertical Dipole Impedance



Monopole Stability Threshold

$$R_s * f_p < 0.5M\Omega - GHz \qquad R_s = \frac{V^2}{2P_l}$$

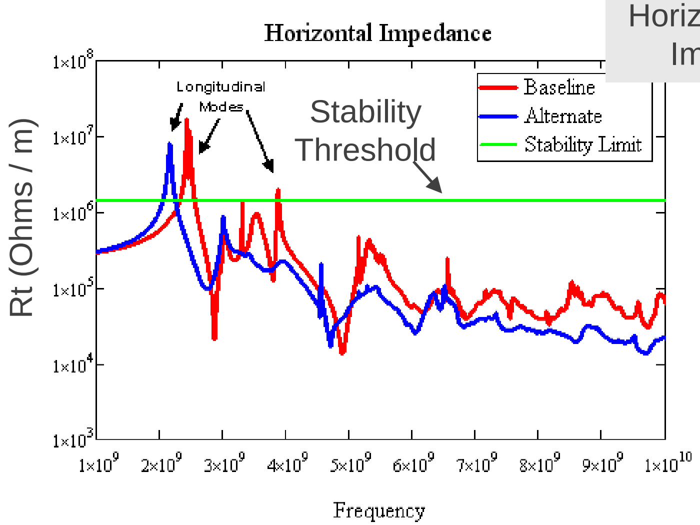
Dipole Stability Threshold

$R_t < 1.5M\Omega / m$ Horizontal dipole

$R_t < 4.5M\Omega / m$ Vertical dipole

$$R_t = \frac{V^2\Big|_{r=r_0}}{2\,P_l\,k\,r_0^2}$$

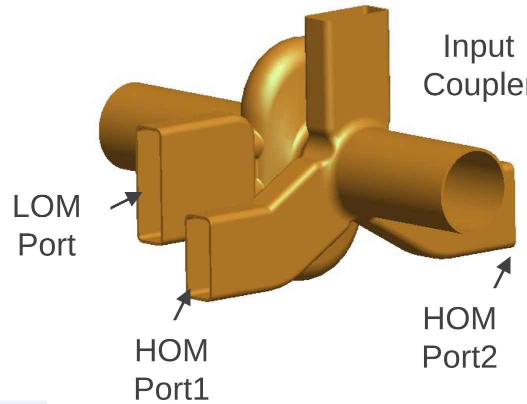
Horizontal Dipole Impedance



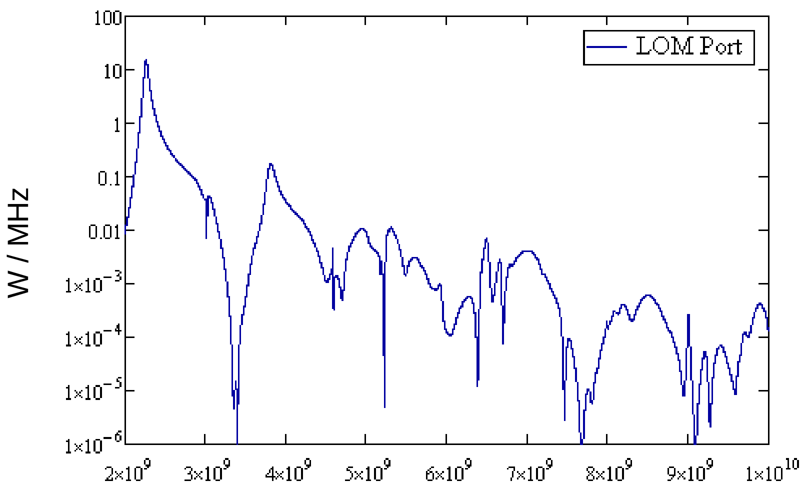
Representative 'alternate' cavity used for analysis

Power Loss Parameters for Alternate Design

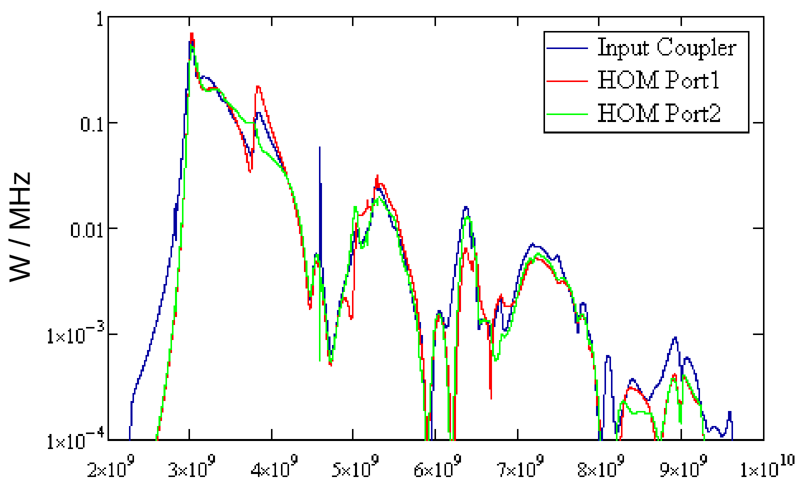
HOM power per cavity	1.9	kW
90% power level	3.5	GHz
$Q_{Monopole}$	500	
Q_{Dipole}	200	



LOM port



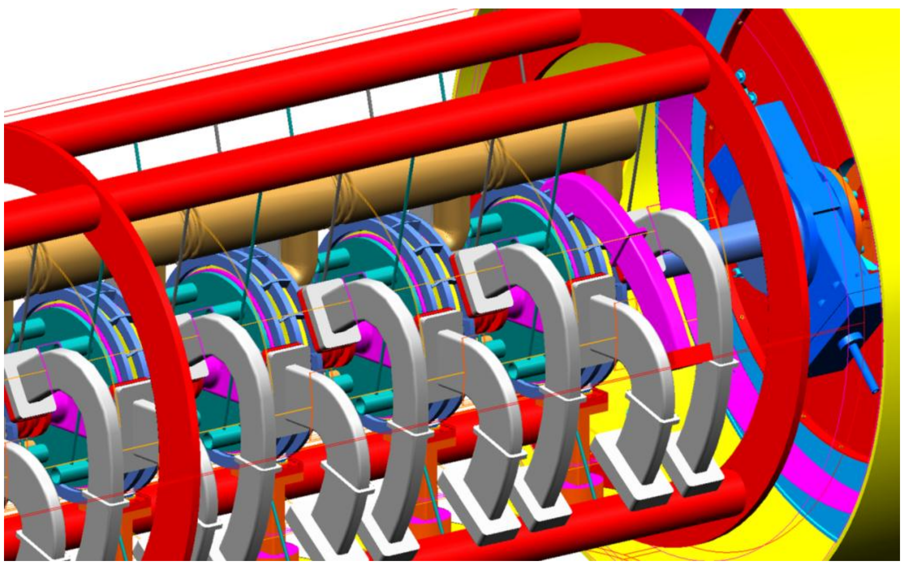
HOM / Coupler ports

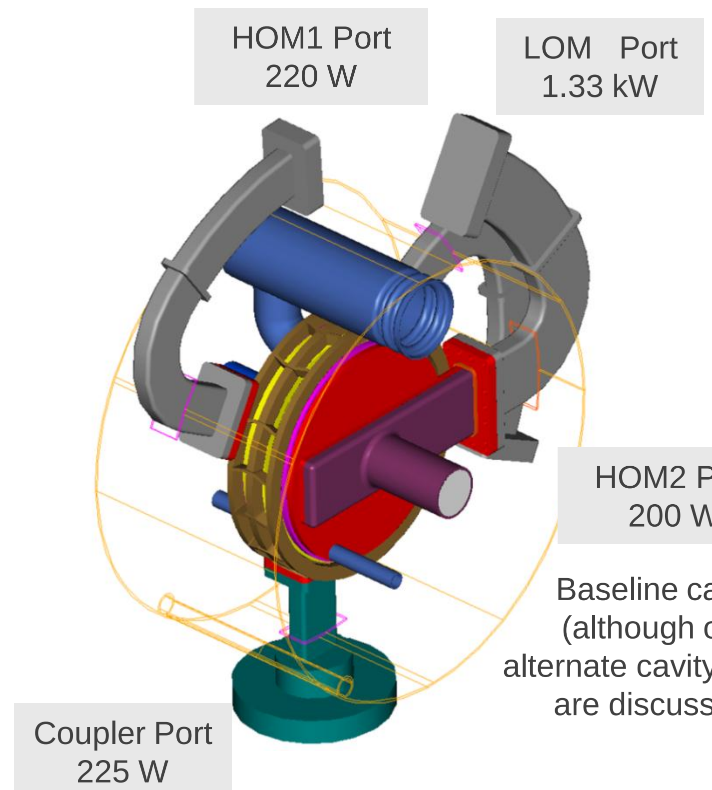


Power spectral density at each cavity port with 200 mA beam current

Power Loading Estimates in Alternate Cavity

- Total power loss into alternate cavity using loss factor is 1.87kW.
- Total power loss by performing a rough integration of the instantaneous power at each of the damper ports is 1.97kW.
- Actual power load into dampers is heavily dependent on final choice of cavity option and loss factor



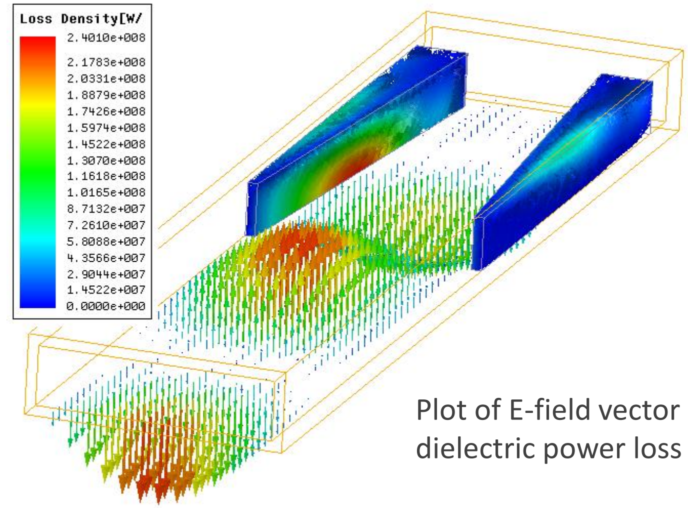


Baseline cavity (although only alternate cavity results are discussed)

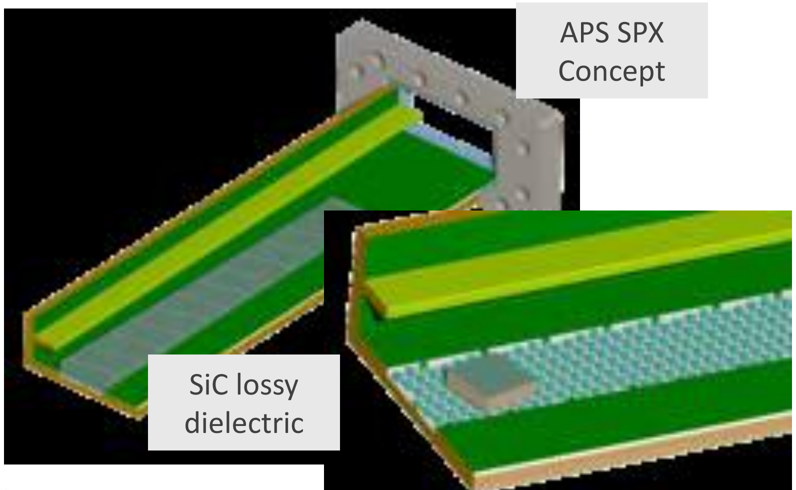
Courtesy: J. Henry (JLAB)

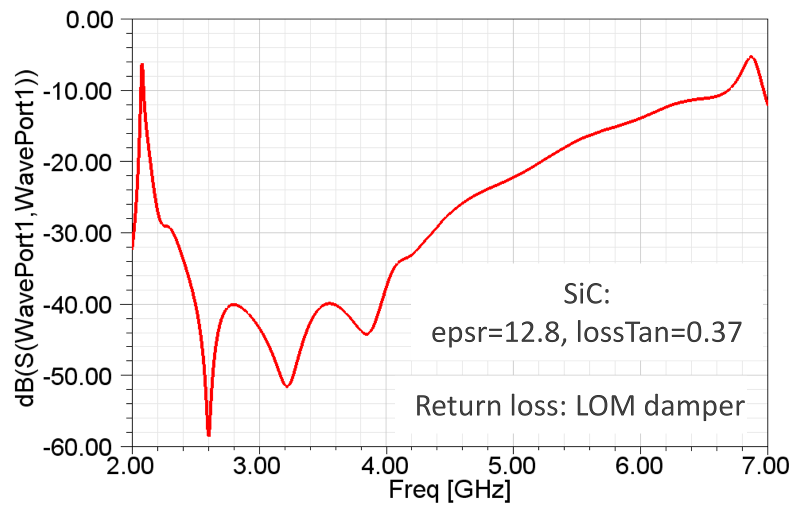
Damper Design Concept (JLAB design)

- JLAB has demonstrated good results for prototype, low-power SiC dampers.
- SiC electrical properties have been measured at room temperature and at low temperature.



Plot of E-field vector and dielectric power loss density





F. Marhauser. "Investigations on Absorber Materials at Cryogenic Temperatures"

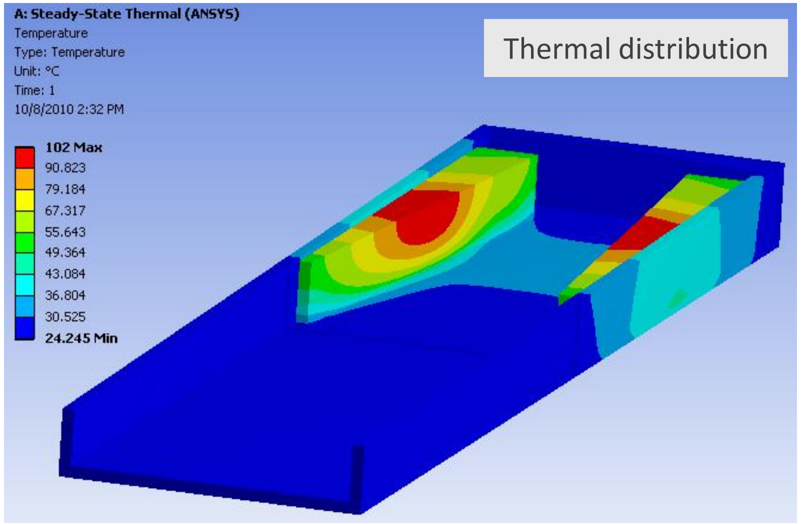
G. Chang: High-Power Damper Concept

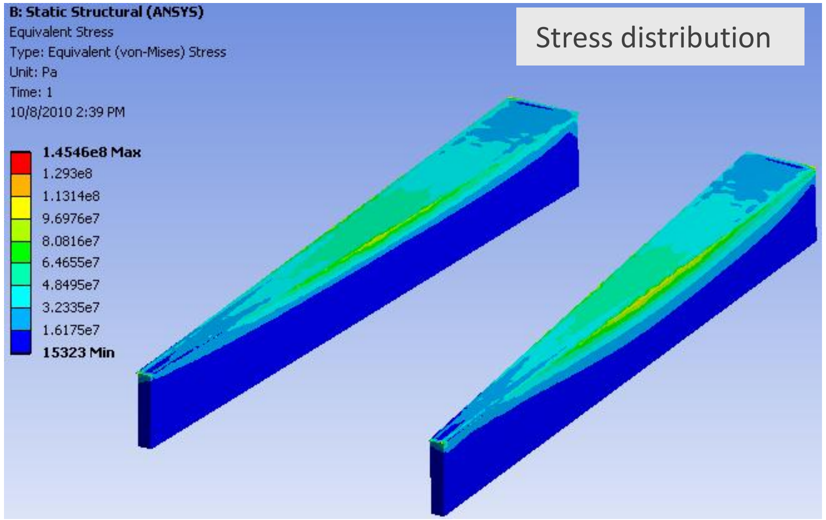
Damper Structural Preliminary Analysis

2 kW RF power

Thermal Conductivity	150	W / (m °C)
Young's Modulus	410	Gpa
Poison's Ratio	0.21	
CTE @ 22 °C	3.0E-6	1 / °C

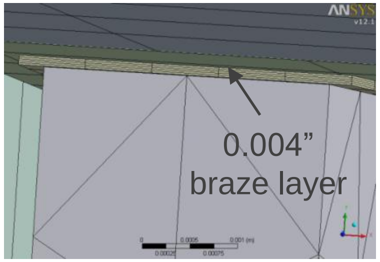
- The dampers are approximately 150mm long by 15mm by 15mm at its base.
- Ultimate strength of SiC exceeded in simulations.
- Stress relief copper posts and segmented SiC were not yet included.





Design and Analysis Issues

- Is it useful to perform a transient thermal analysis of the brazing operation?
- We modeled a 0.004" braze layer to possibly analyze the brazing operation from the solidus temperature.
  - Determine pre-stresses in a room temperature, brazed damper.
  - Determine the number of pieces to divide damper.
  - Determine number and size of stress-relieving posts.
  - Are useful mechanical parameters available for brazing material.



- Is SiC preferred to AlN although the CTE of AlN is closer to copper?
- Is soldering with Sn based material, such as S-Bond, compatible with ultra-high vacuum?
- If brazing is required, what process is preferred? What vendors are recommended for material and brazing?
- What is the knowledge base for material properties of damping material at 80K / 293K?
- What is the failure criteria for damping material, such as tensile yield strength?

SiC Material Properties

	Trade name	SC-DS(SC-30)	Ceralloy 146-IS		CRYSTAR CVD SiC
	Company name	CoorsTek, Inc	Ceradyne, Inc	Morgan	Saint Gobain
	Process used	Direct Sintered	Hot Press	CVD	CVD
Property	Units				
Purity			99.30%	99.9995%	
Density	gm/cc	3.15	3.15		3.21
Crystal Size, Average	MICRONS	5			
Color		Black			
Flexural Strength (MOR) at (T°)	MPa (psi X 103)	480 (70)	380		590
Elastic Modulus, at (T°)	GPa (psi X 106)	410 (59)	400		450
Poisson's Ratio, at (T°)		0.21	0.17		
Compressive Strength, at (T°)	MPa (psi X 103)	3500 (507)			
Hardness	GPa (kg/mm2)	26 (2500)	(2300)		26
Tensile Strength, at (T°)	MPa (psi X 103)	*			
Fracture Toughness,	MPa m1/2	4	2.5		
Thermal Conductivity, at (T°)	W/m K	150	115 @ 25°C		250
CTE, (T° range)	1X 10-6/ °C	4.4	4.8 (RT-1000 °C)		
Specific Heat, at (T°)	J/kg*K	800			
Thermal Shock Resistance, (ΔTc)	°C	300	164 *(caculated)		
Maximum Use Temp.	°C	1600			
Resistivity	log (ohm-cm)	< 10^5	< 10^6		4.0 x 10^{-6}
Dielectric constant k					
Relative Permeability					
Loss tangent					
Compatibility with UHV					