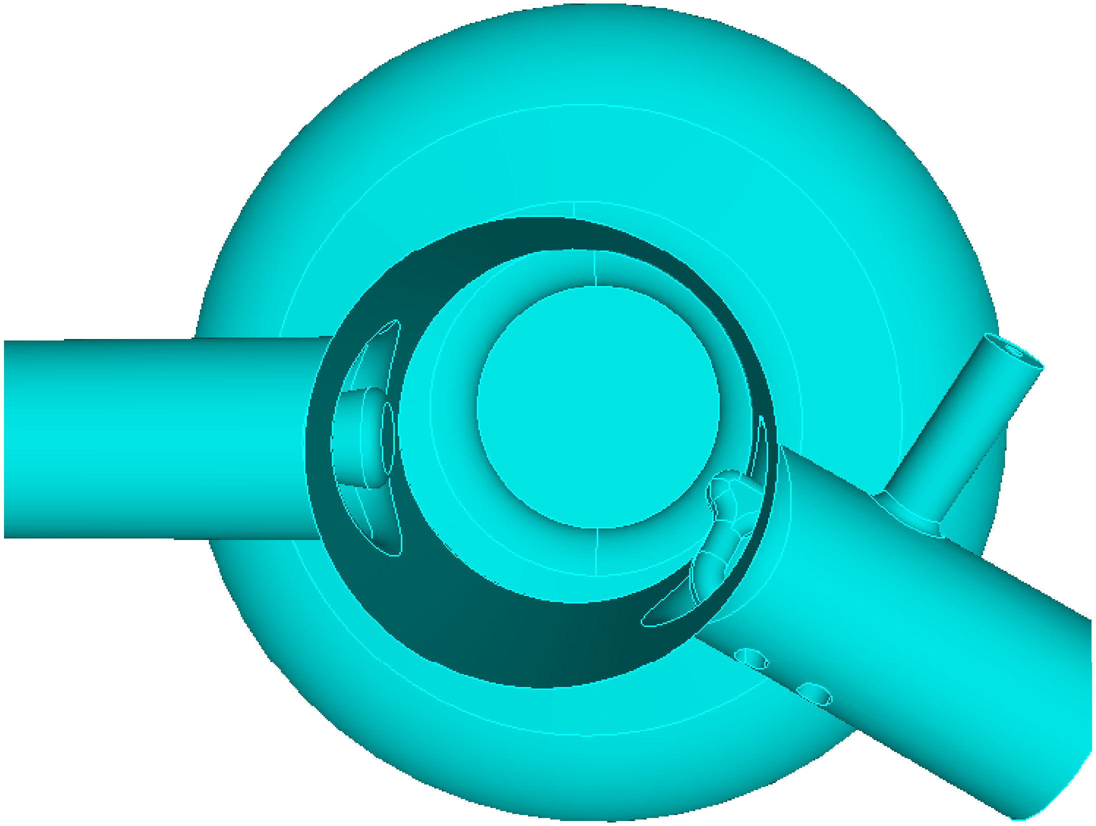
Summary of MLI Studies

Chris Adolphsen

GDE Meeting at Sendai, 3/14/08

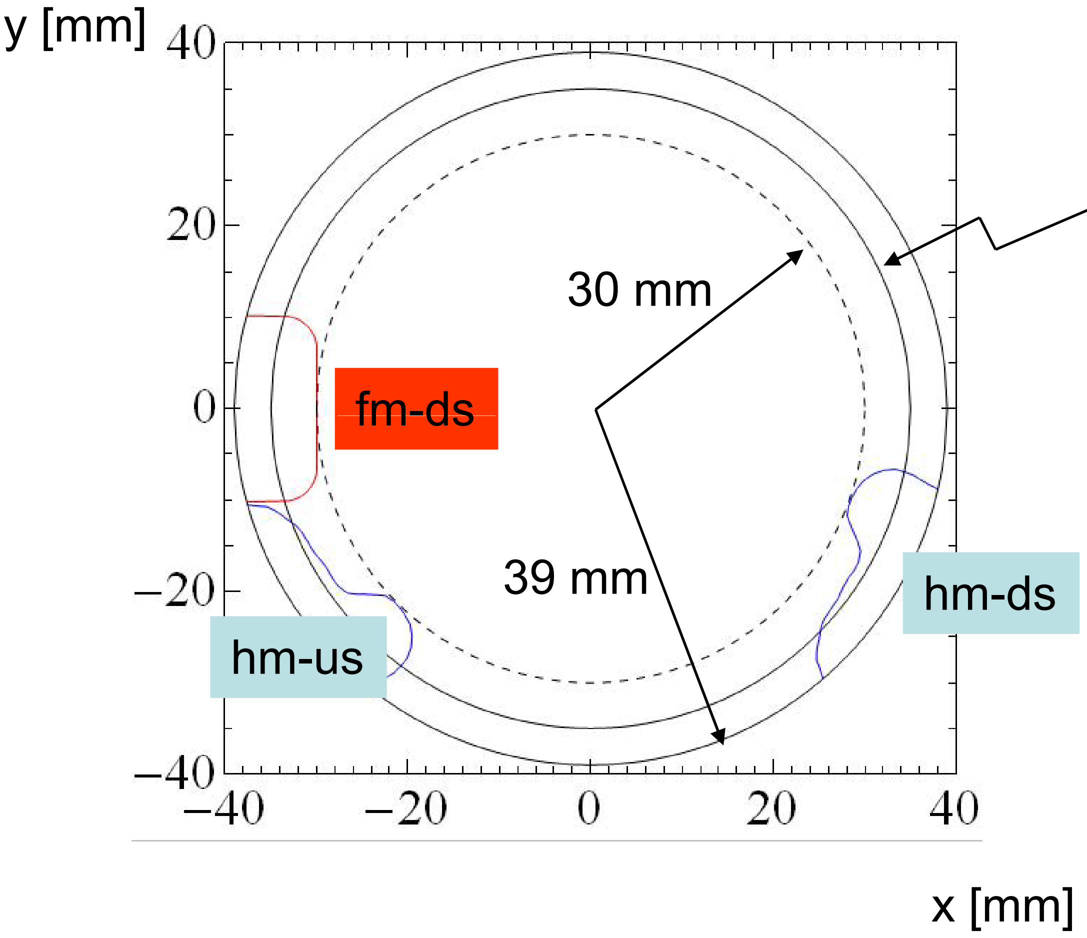
On Axis Wake Kicks

(I. Zagorodnov, V Yakovlev, Z. Li and K. Bane)



Detailed view of FM and HM couplers - note protrusion of couplers

End on view of coupler geometry (from downstream end)



Edge of irises (r= 35 mm)

30 mm

39 mm

fm-ds

hm-ds

hm-us

(fm—fundamental,
hm—higher mode,
ds—downstream,
us—upstream)

On-Axis Wake Due to Coupler Asymmetry

Numerical calculations performed in 3 steps: couplers in beam pipe, cavity with couplers, multiple cavities with couplers (I. Zagorodnov)

Wake varies along bunch; (k_x, k_y) are kicks averaged over beam; in calculations $\sigma_z = 1$ mm (due to mesh limitations)

- One set of couplers in beam pipe: $(k_x, k_y) = (-21, -19)$ V/nC; agrees well with analytical optical model with all elements at same z: (-21, -17) V/nC

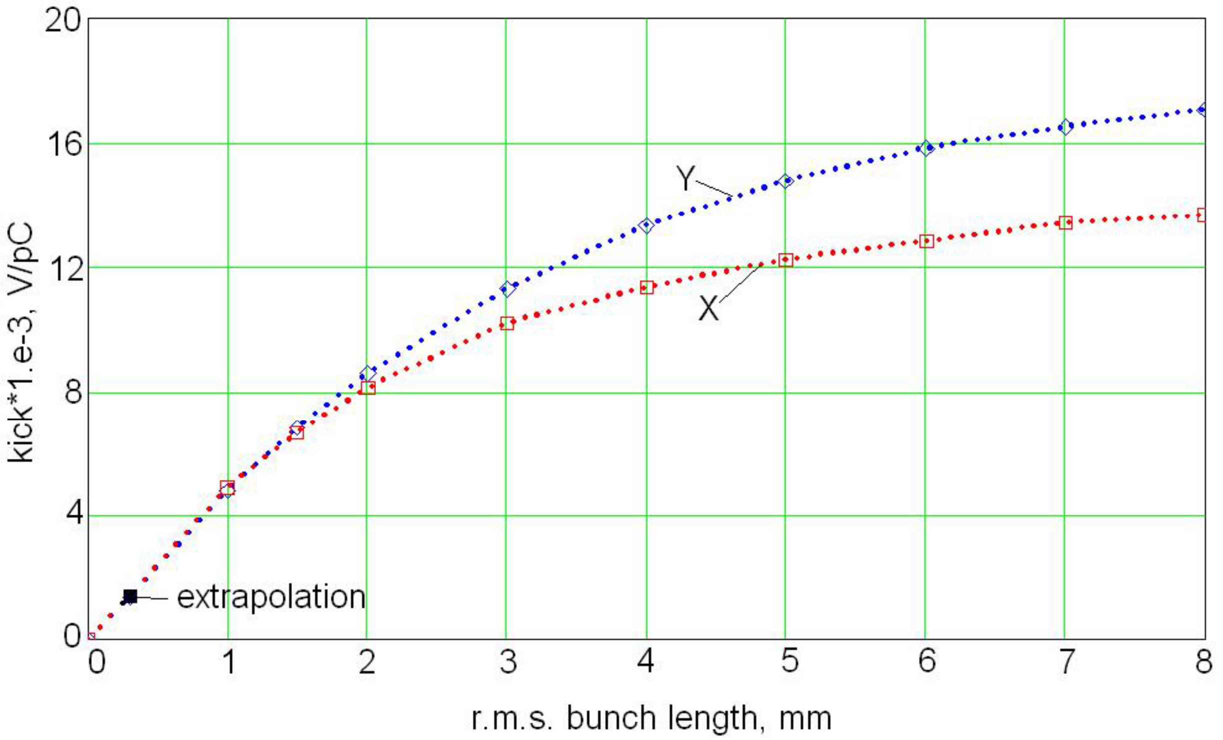
- One cavity with couplers: $(k_x, k_y) = (-11, -10)$ V/nC; agrees well with a z-independent optical model with iris shadowing with all elements at same z: (-13, -7) V/nC.

- Periodic solution: $(k_x, k_y) = (-7.6, -6.8)$ V/nC/m (reached after 2 cavities)

V. Yakovlev has also performed numerical calculations for 1 mm bunches that agree reasonably well (*e.g.* periodic solution ~-5 V/nC/m)

V. Yakovlev's Gdfidl Results

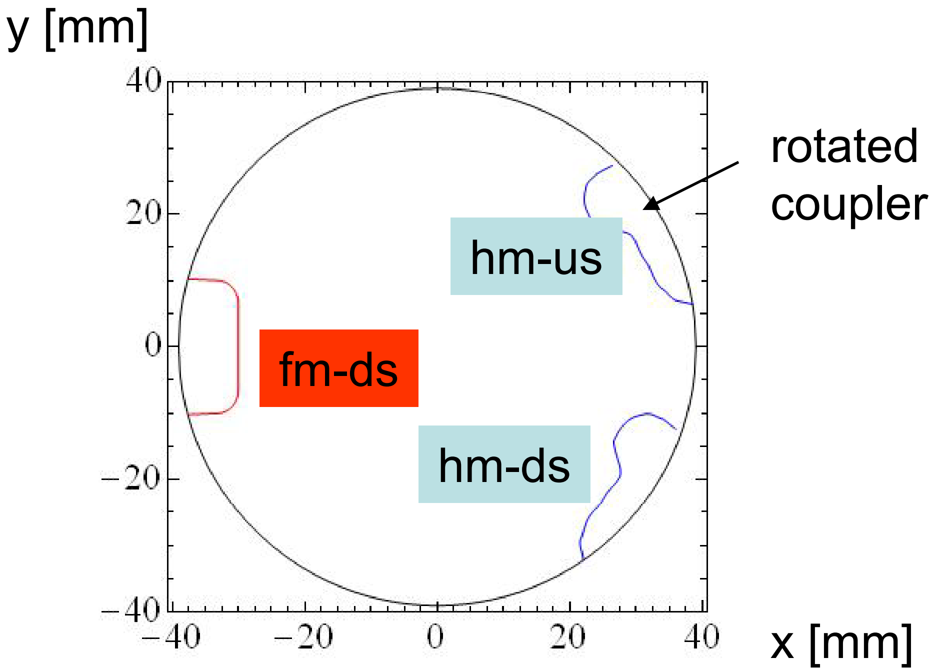
For σ_z= 0.3 mm the mesh needs to be finer, and more cavities are needed to reach periodic solution (~6) => large computer resources needed



Expectation is that the kick for the short bunch ~0.3 times the kick for σ_z= 1 mm

- T. Weiland's group is also working on this calculation

Symmetrizing Couplers



Z. Li proposes rotating upstream coupler by 180° to reduce wake =>

For one cavity with couplers, optical model + iris shadowing: (k_x, k_y)= (-2.5, 1.2) V/nC [was (-13, -7) V/nC]

Effect on Beam

Wake has two terms: an offset term and a slope term

Offset:

A constant driving term to the equation of motion generates a kind of dispersion => the closed orbit depends on (longitudinal) position in bunch;

model: $y'' + y/\beta^2 = e^2 N\, W(s)/E$ has solution

$$y = \beta^2 e^2 N\, W(s)/E + \text{betatron oscillation(s)}$$

Particles will perform free betatron oscillation about different centers, depending on *s*; projected emittance will oscillate; no real wake effect; average emittance will increase due to energy spread (filamentation) and normal cavity wake

Slope:

Numerical results for 3 couplers in beam pipe, *W*av~ 2.4 V/nC/mm/m; for periodic case should reduce a factor 2~3 to ~1 V/nC/mm/m, which is a factor 20 smaller than the normal cavity wake, so can be ignored

Estimated Emittance Growth

(analytical approximation)

Let eN = 3.2 nC, $\langle\beta\rangle$= 68 m, $\gamma\varepsilon_y$ = $2*10^{-8}$ m.

k [V/nC/m]	$(\varepsilon/\varepsilon_0)_{max}$	$(\varepsilon/\varepsilon_0)_{final}$
20	3.1	1.03
5	1.23	1.02
2	1.04	1.003

Bottom Line: For periodic solution the wake due to coupler asymmetry should not be a problem; with Z. Li's modification, the effect will be even less

Summary of RF Kicks (Z Li)

Eacc = 35 MV/m, I_Beam = 0.011A, Qext ~3.4E6

Accelerating Gradient = 31.5MV/m
Head-tail: +- 1 sigma_z
Kick unit: Volt

	X-centroid	Y-centroid	X-head-tail	Y-head-tail
TDR	-2106	-785	33	3.5
TDR-M	761	2621	24	4
TDR,TDR-RotX	609	-739	20	0.3
TDR-M,TDR-M-RotX	664	2606	11	~0
TDR-M,TDR-M-MirrorZ	664	15	11	4

Average over cavity pair

M = TDR with 180 deg rotation of HOM on non-FPC end
RotX = TDR rotated about x axis by 180 so FPC switches from up-stream to down-stream end and power feed direction changes.
MirrorZ = Up/Down end groups interchanged, power feed direction unchanged

Summary of RF Kicks (K Bane)

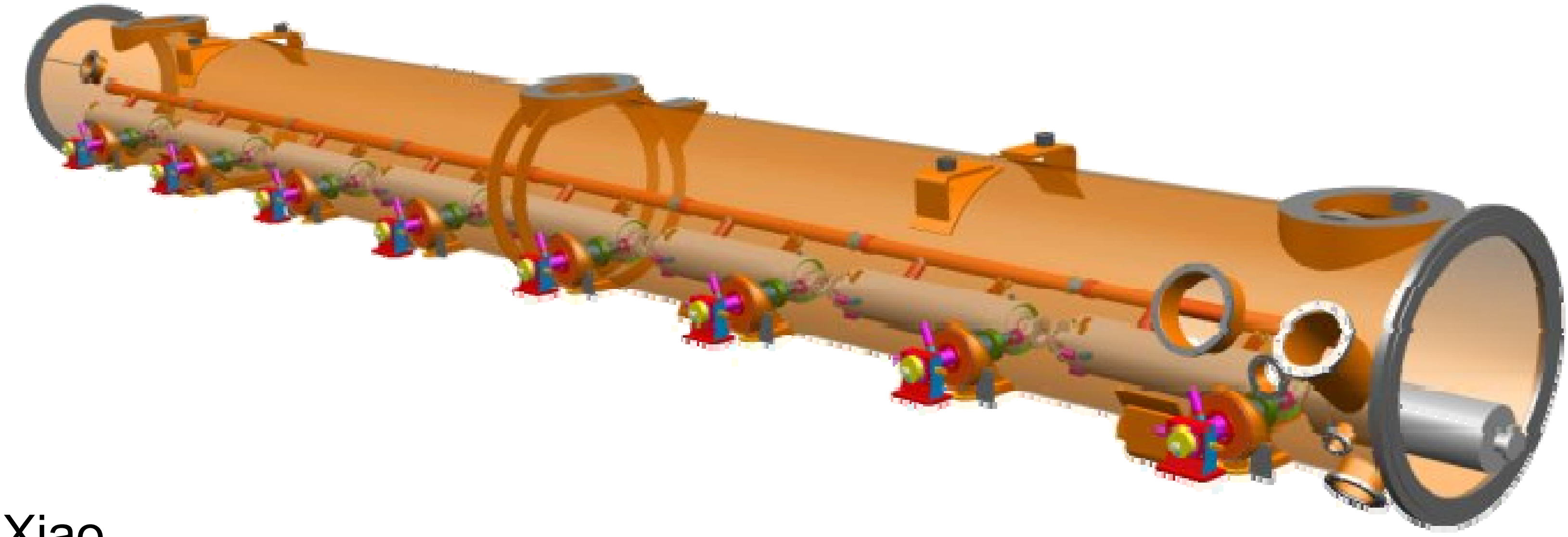
	SLAC		FNAL	
	$\langle k \rangle$ [V]	k_{rms} [V]	$\langle k \rangle$ [V]	k_{rms} [V]
x	-2000	17.	-3320	18.
y	-670	2.7	-230	2.9
ZLi_x	-650	13.	-1020	16.
ZLi_y	-2490	1.8	-2810	4.6

Average and rms of rf kicks experienced by the beam, according to SLAC and FNAL calculations. Here we assume V_{acc}*= 31.5 MV/m and* σ_z*= 0.3 mm. Given are the total kicks due to all couplers in one cavity as is, and also after Z. Li's symmetrization (the upstream coupler is rotated by 180 deg).*

Beamline Absorber Study Using T3P

1. Application (ILC, XFEL, ERL,…);
2. Simulation method (T3P);
3. Simulation results;

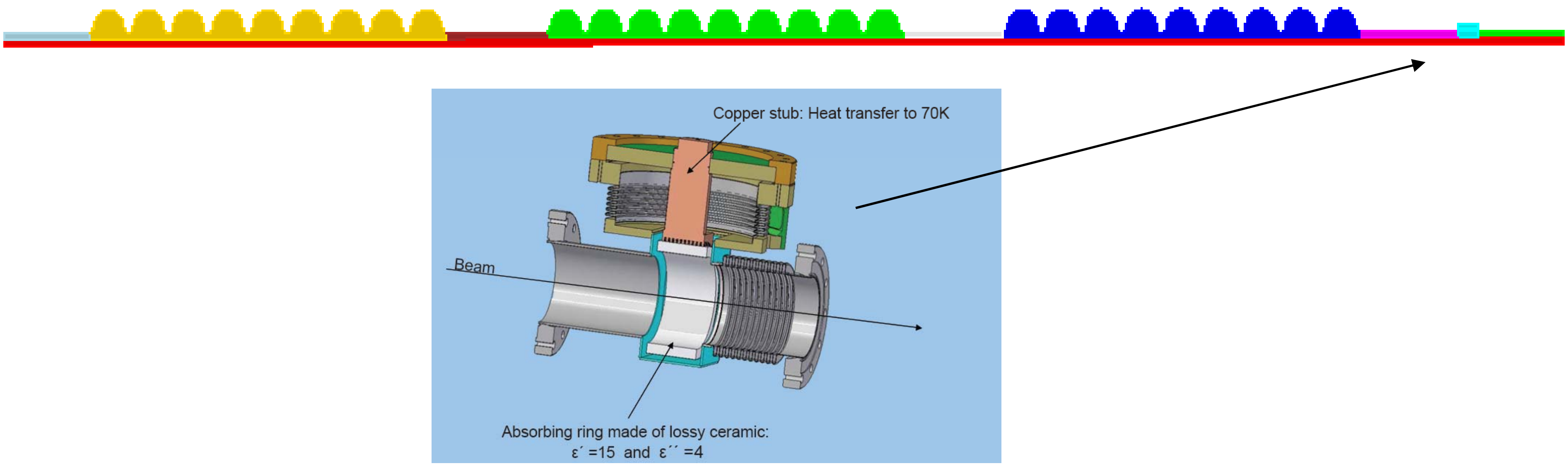
   (3D one TESLA cavity with couplers, 2D one cavity/two-cavity/three-cavity..)
4. Going to simulate multi-cavity with short bunch and taking account into dispersive medium;



Liling Xiao

Monopole Single Passage Losses for three cavities without couplers

One bunch Q=3.2nc, bunch length=10mm Loss factor (V/pc)=9.96V/pc	**Lossy dielectric conductivity σ_{eff}=0.6(s/m)** **Dielectric constant ε_r=15, within 80ns**
Total Energy Generated by Beam (J)	10.208e-5
Energy propagated into beam pipe (J)	*4.44e-6*
Energy dissipated in the absorber (J)	*7.0e-7*
Energy loss on the Non SC beampipe wall (J) around absorber	9.3e-10
Energy loss in intersection between two cavities (J)	1.3e-9 (cold copper conductivity=3500e6Simm/m)



Ratio of Dissipated Energy and Propagated Energy to Total HOM Energy

	1-cavity+absorber @200ns	1-cavity+absorber @80ns	2-cavity+absorber @80ns	3-cavity+absorber @80ns
left beampipe	***14.1%***	***12.4%***	***8.9%***	***6.6%***
right beampipe	***11.3%***	***10.3%***	***6.0%***	***4.5%***
absorber	***2.6%***	***2.1%***	***1.8%***	***1.7%***
Total	***28.0%***	***24.8%***	***16.7%***	***12.8%***
Absorber fraction	***9.4%***	***8.5%***	***10.8%***	***13.5%***

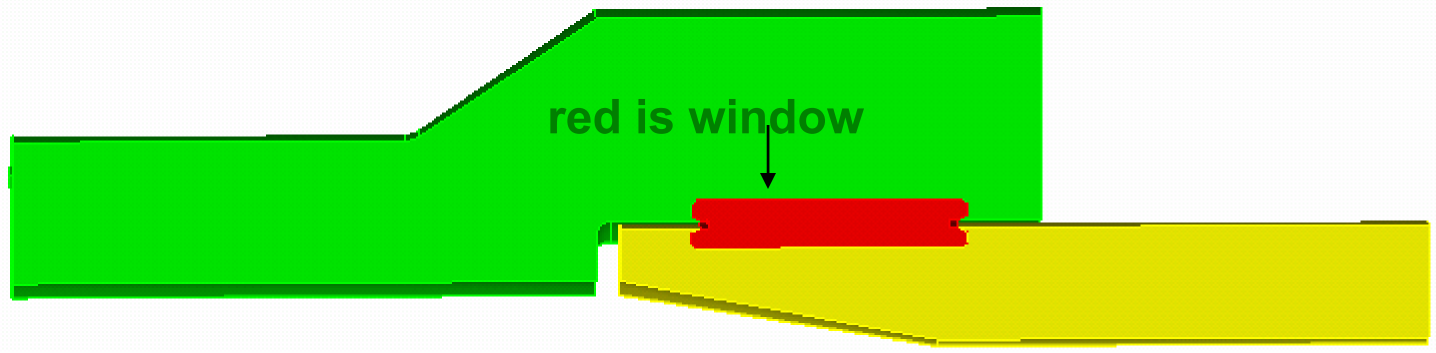
Beam Pipe Total for 3-cavity CM = 1.3e-9 * 2800 * 5 / (0.128 * 0.135) = 1.1 mW

Worse case for 8-cavity CM and 300 um bunch = 1.1 * (8/3) * (10/0.3) = 100 mW

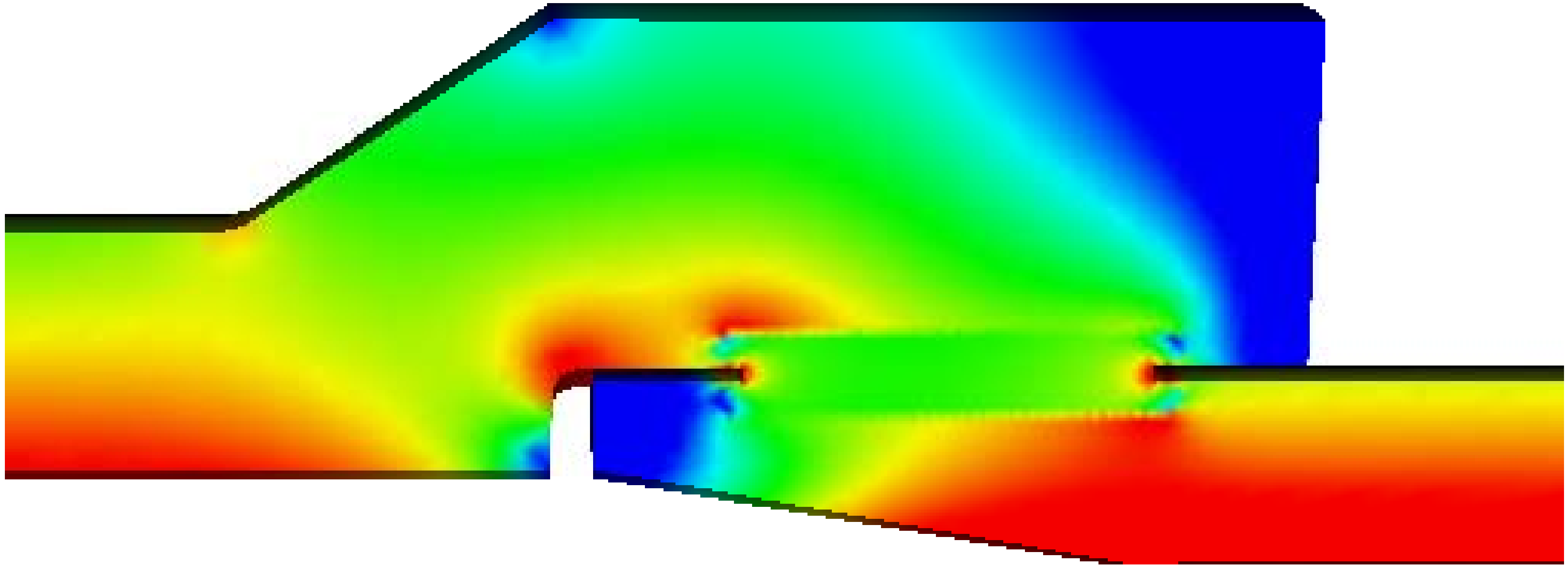
E-Field Strength at TTF3 Cold Coupler Window Region

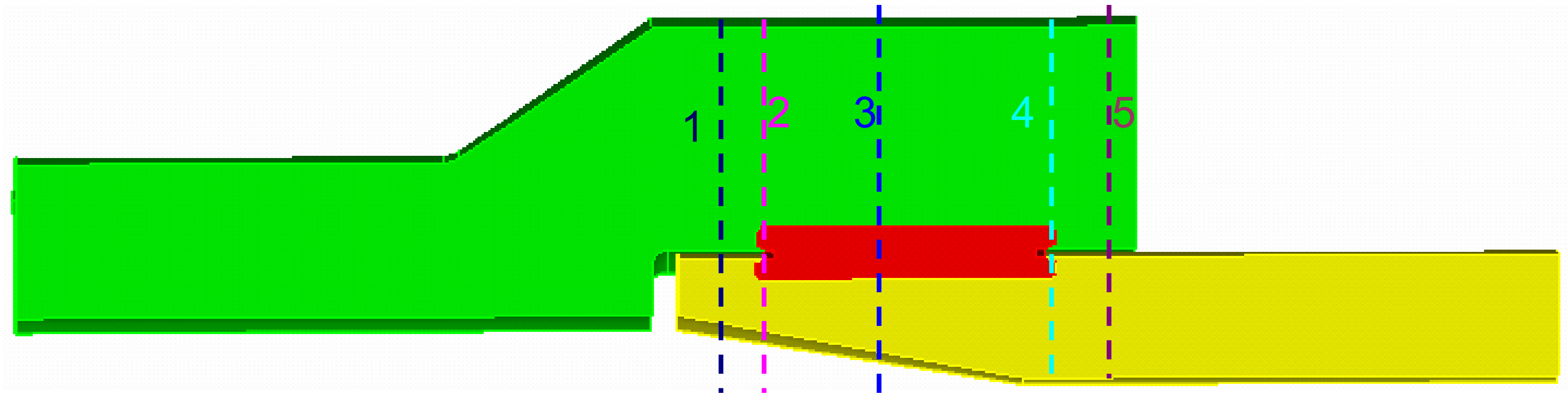
Lixin Ge, ACD Group at SLAC

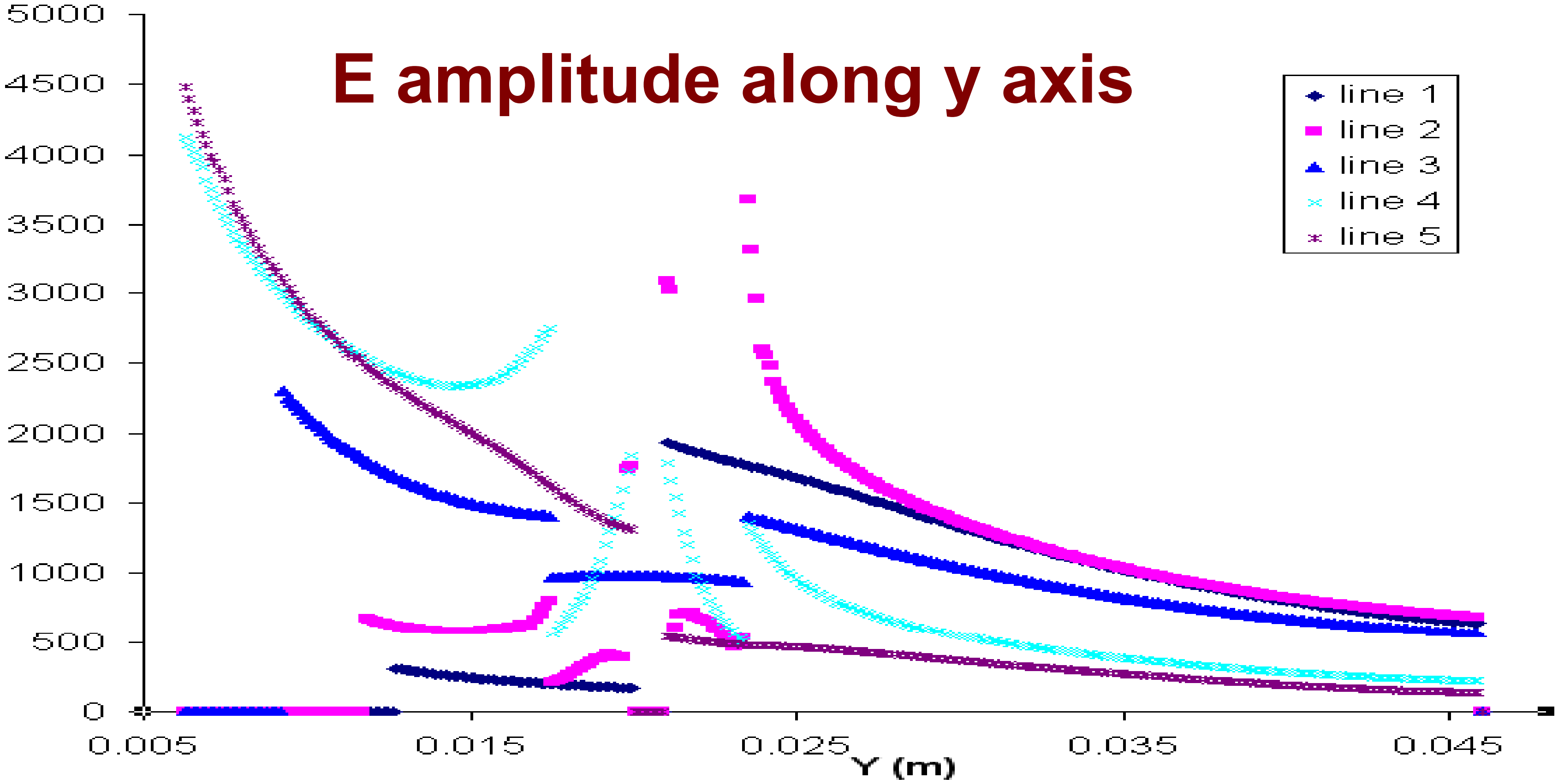
Model



E magnitude




1
2
3
4
5


E amplitude along y axis
◆ line 1
■ line 2
▲ line 3
× line 4
* line 5
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0.005
0.015
0.025
0.035
0.045
Y (m)

TTF HOM Measurement Data Analysis with Curve Fitting Method

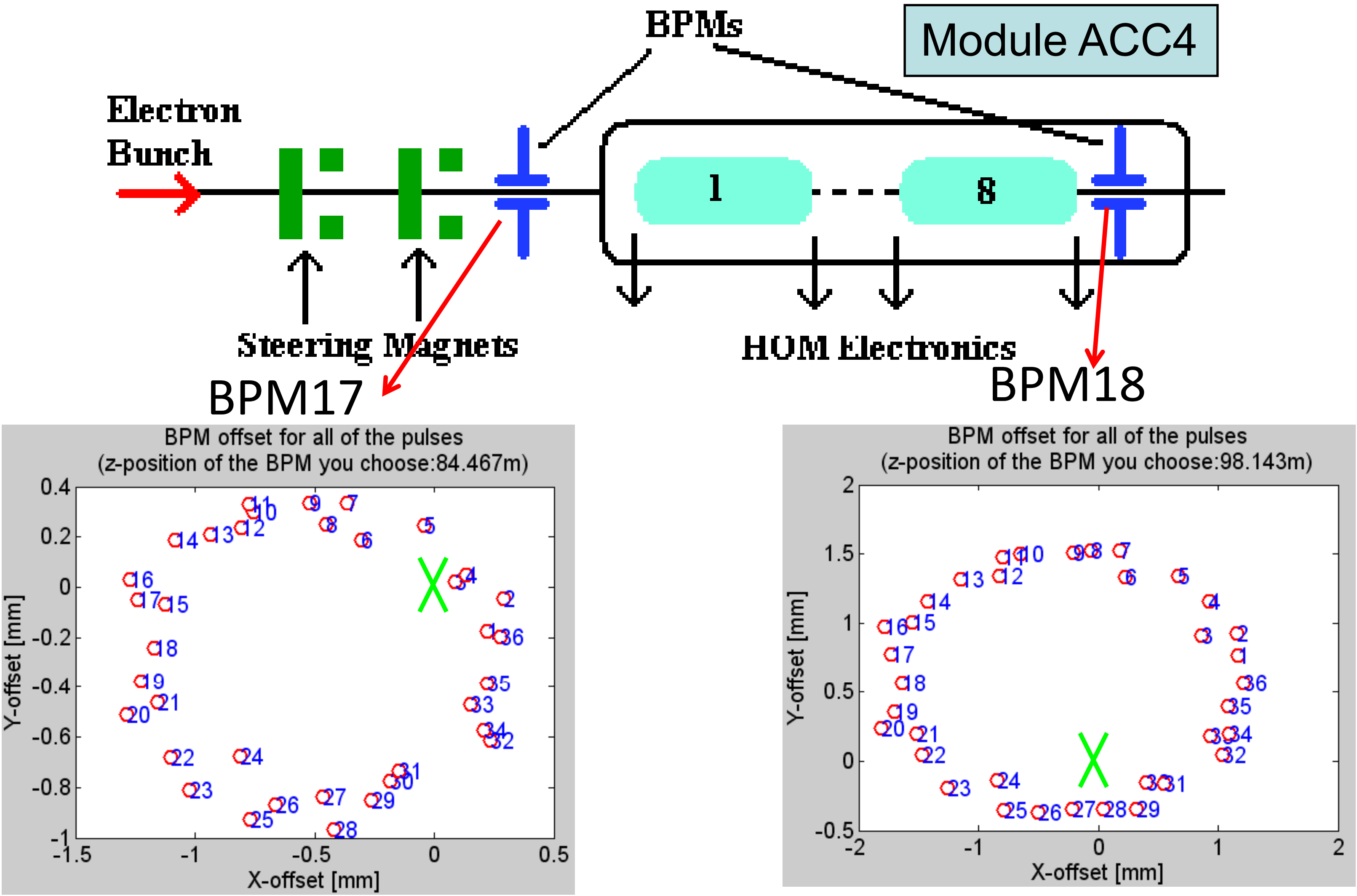
Shilun Pei

with

Chris Adolphsen, Zenghai Li, Karl L. Bane, et al.

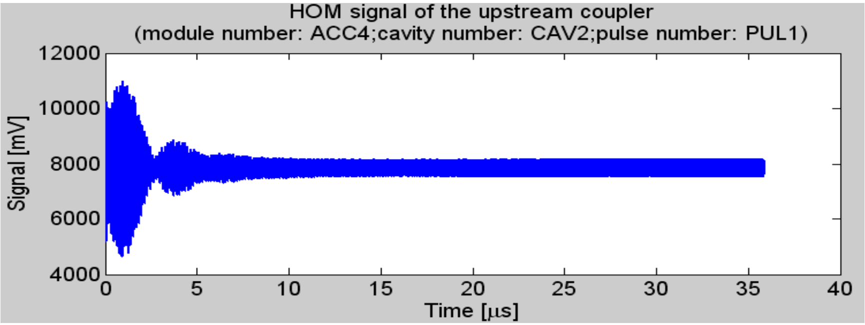
SLAC, Feb. 27, 2008

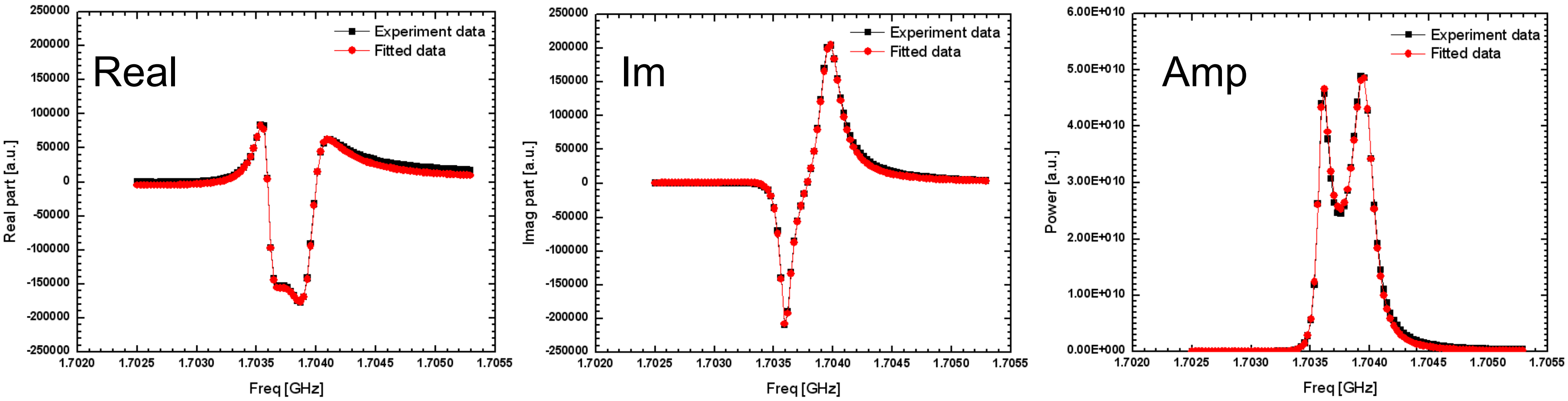
Steering setup



2007-01-22T091106.mat

Modal Analysis of Dipole Signals



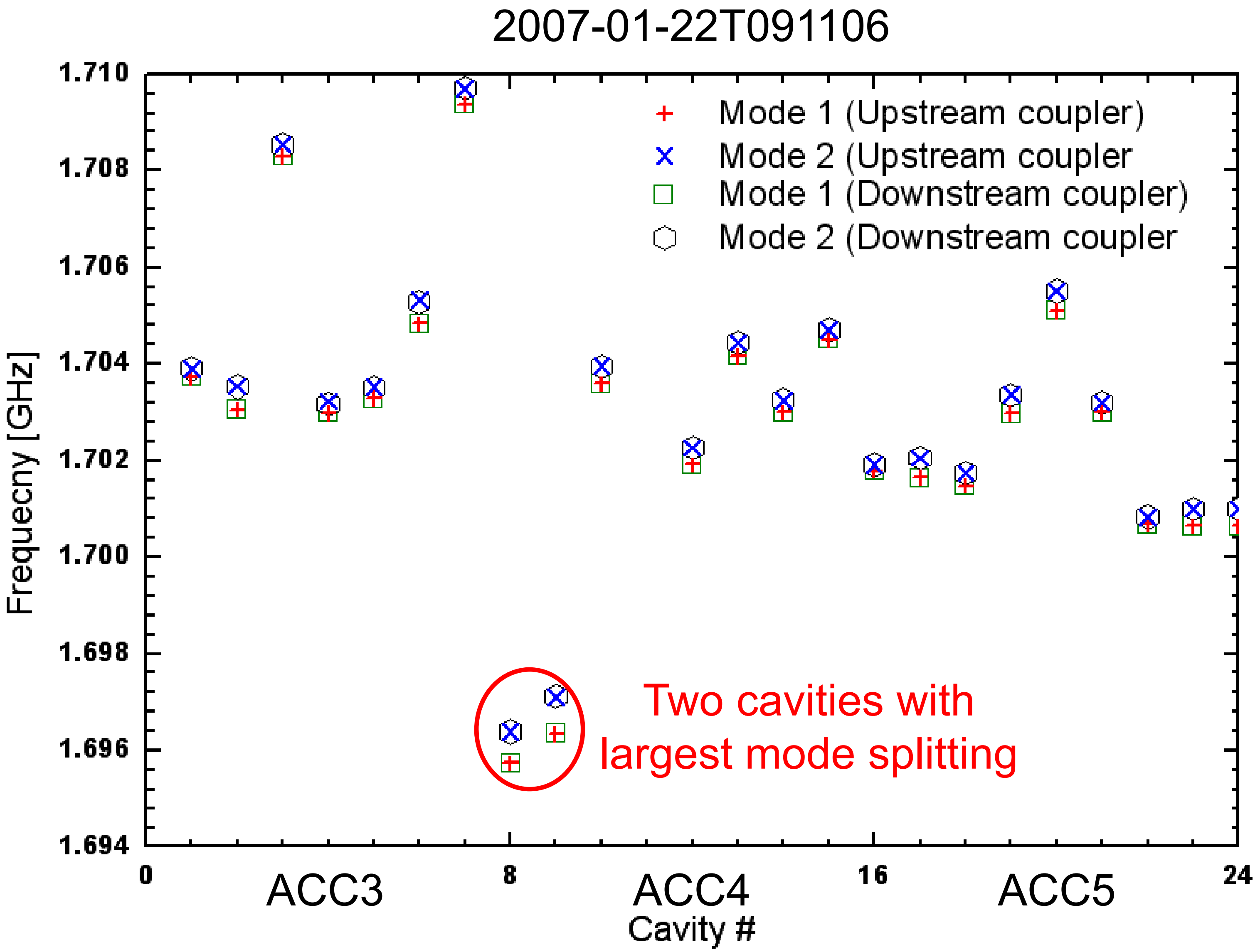


Fit frequency spectrum near 1.7 GHz
to sum of complex Lorentzians

$$\frac{A_n}{\omega - \omega_{0n} + \Gamma i}$$

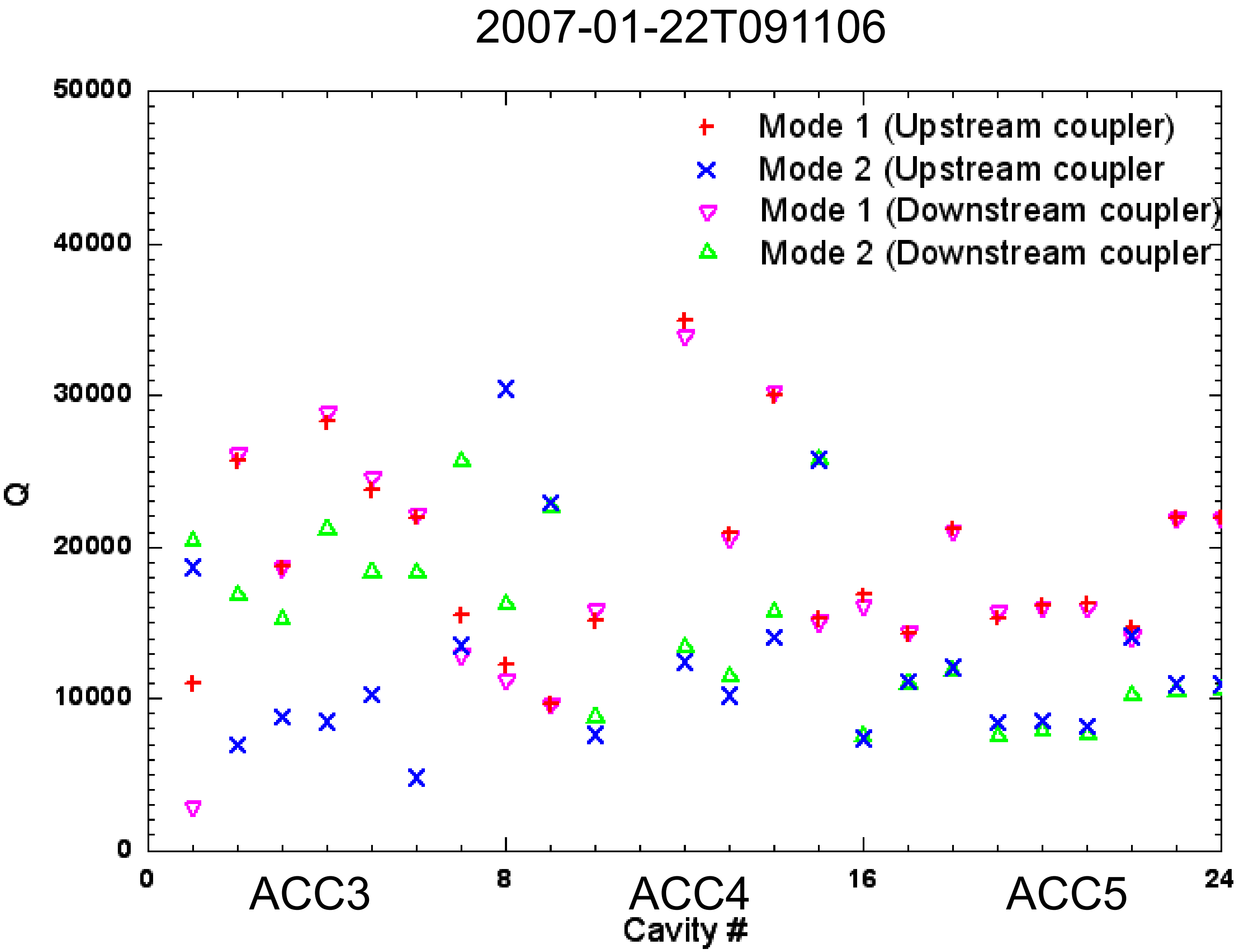
Derive frequency and Q of two polarizations from simultaneous fit to 36 orbits

Cavity Freq in ACC3/ACC4/ACC5



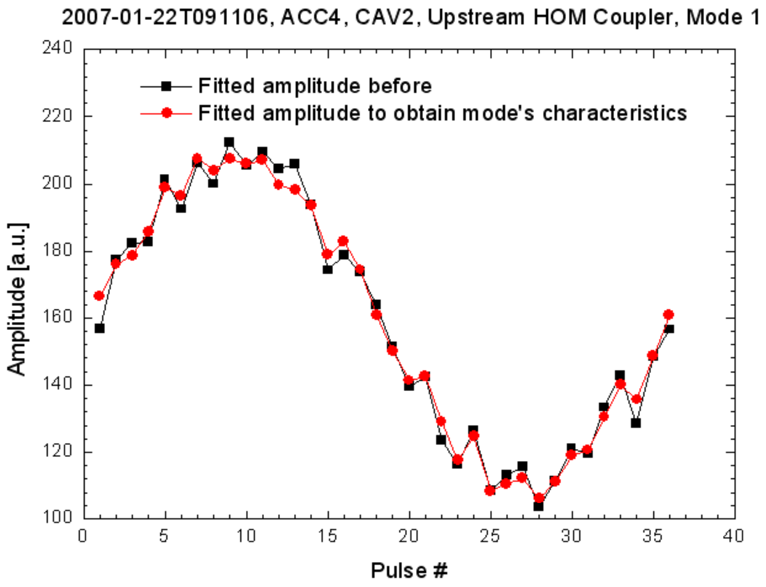
Two cavities with
largest mode splitting

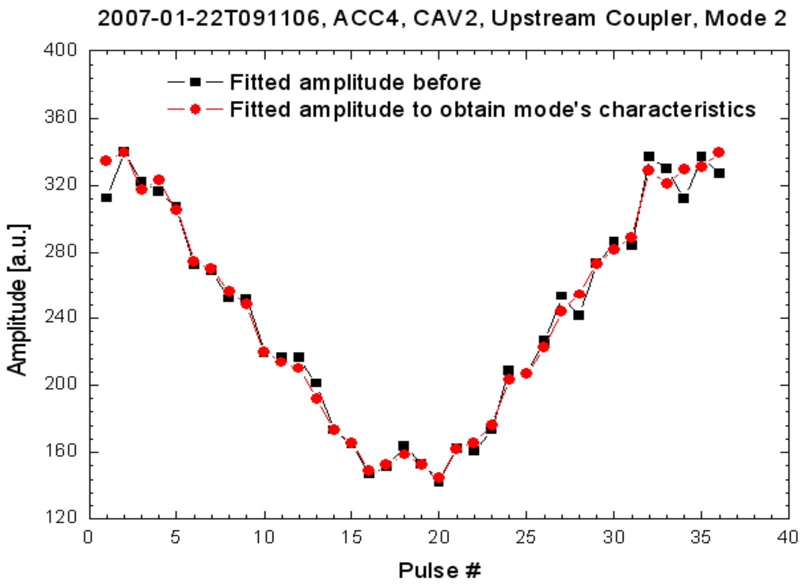
Cavity Q in ACC3/ACC4/ACC5



Fit of Amplitudes to BPM X and Y

- Ignoring the small out-of-phase (angle) contributions, the resulting mode amplitudes correlate well with the x and y positions inferred from the bpm data



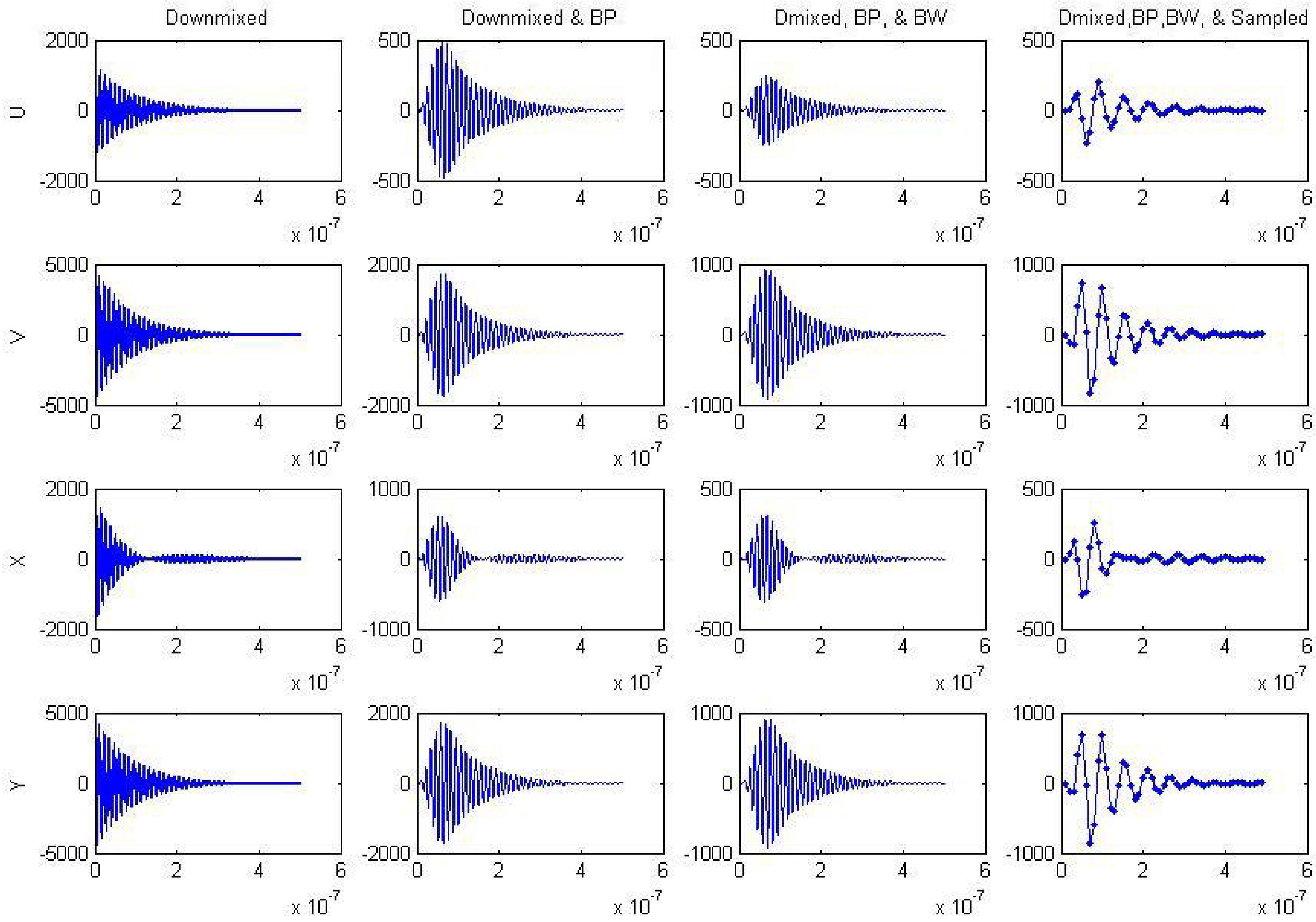


Mode Polarizations

2007-01-22T091106, ACC4

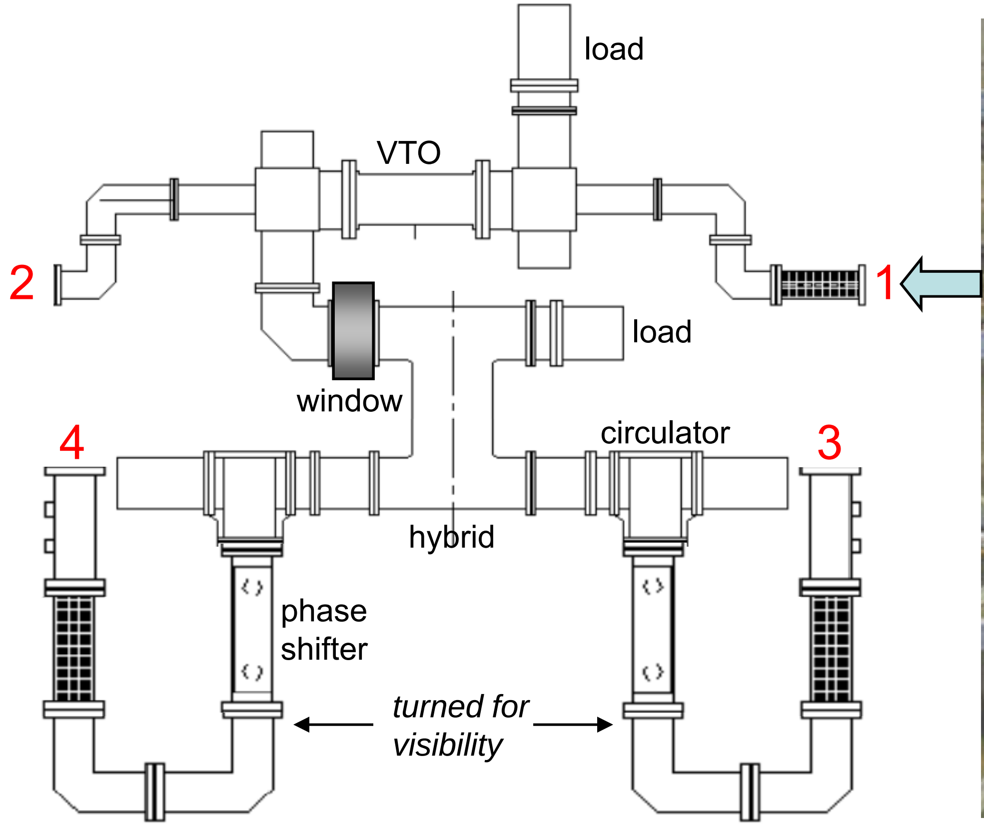
CAV #	**Mode 1 Pol. Angle**	**Mode 2 Pol. Angle**
2	3.03°	92.70°
4	21.62°	111.27°
5	2.85°	94.29°
6	4.10°	93.68°
7	-15.01°	72.47°
8	-23.76°	68.77°

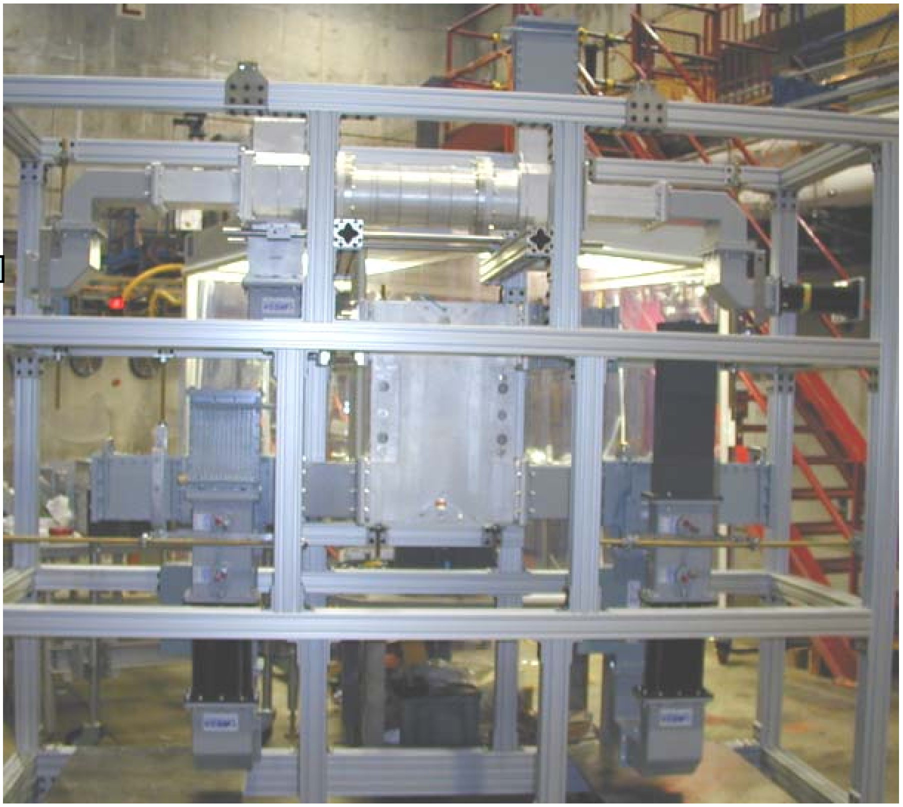
S-Band RF BPM Signal Simulations



Johnny Ng

RF Distribution Module Cold Test





The first (of 4) 2-cavity module of our RF power distribution system for Fermilab’s first NML cryomodule is assembled and cold tested and ready for high-power testing.

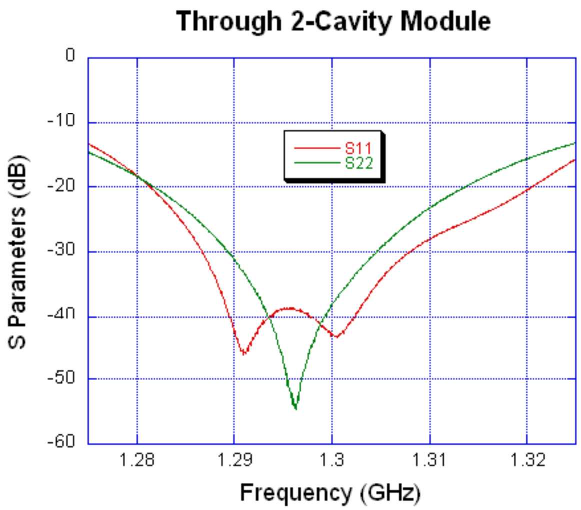
It incorporates:

SLAC VTO and hybrid
IBFM window (for pressurization of high-power volume)
S.P.A. Ferrite isolators and loads
Mega bends and flex guides (and dir. cplrs. while awaiting S.P.A. pieces)

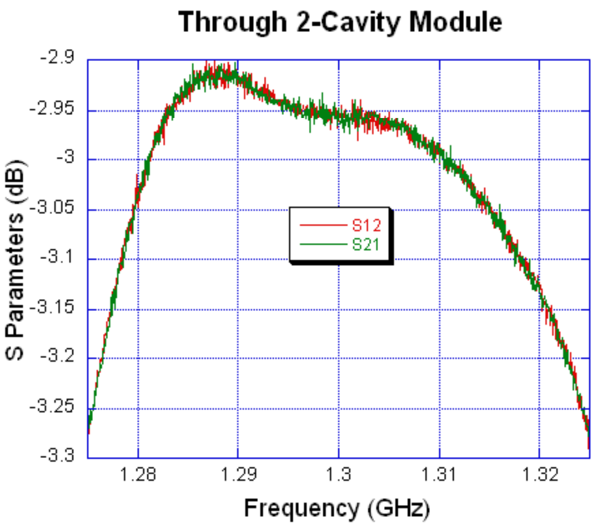
C. Nantista

COLD TEST RESULTS:

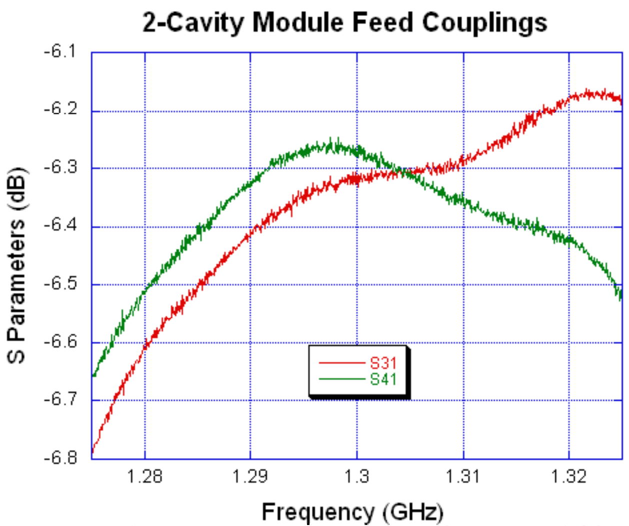
VTO set for 2nd to last cavity pair (~3 dB).



S_{11} = -43.0 dB (0.005%)



S_{21} = -2.948 dB (50.72%)



S_{31} = -6.318 dB (23.35%)

S_{41} = -6.276 dB (23.57%)

POWER

2.36% of power missing (-0.104 dB) ⇨ Expect roughly:

Bends:		0.41%
VTO:		0.446%
Window:	0.493×0.088% =	0.043%
Hybrid:	0.493×0.42% =	0.207%
Circulators:	0.493×1.78% =	0.878%
Phase shifters:	0.493×0.55% =	0.271%
Flex guides:	0.62% + 0.493×0.62% =	0.926%
		~3.18%

Pair power division equal to within 1%.

Slightly more than ½ power sent through to allow for downstream losses.

PHASE

Phases of S_{31} and S_{41} initially within 1.7° of each other (adjustable with phase shifter).

Module through phase error = ~-6.7° (easily absorbed in next modules phase shifters).

SPACING

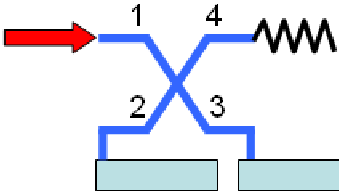
Feed spacing measures ~1.3827m, compared to 1.3837m coupler spacing.

Module length measures ~2.7674m, exact to measurement resolution.

C. Nantista

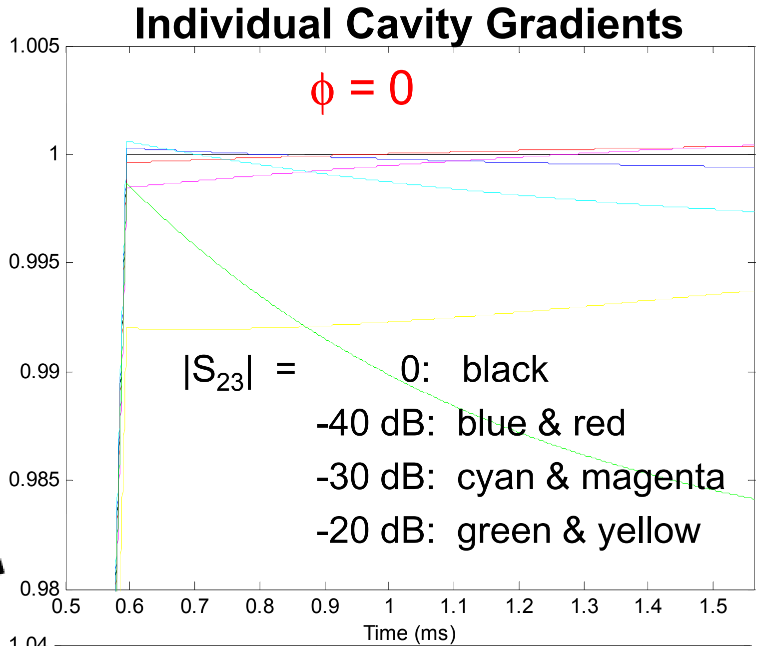
Simulation of Cavity Pair Coupling Through Hybrid w/o Circulators

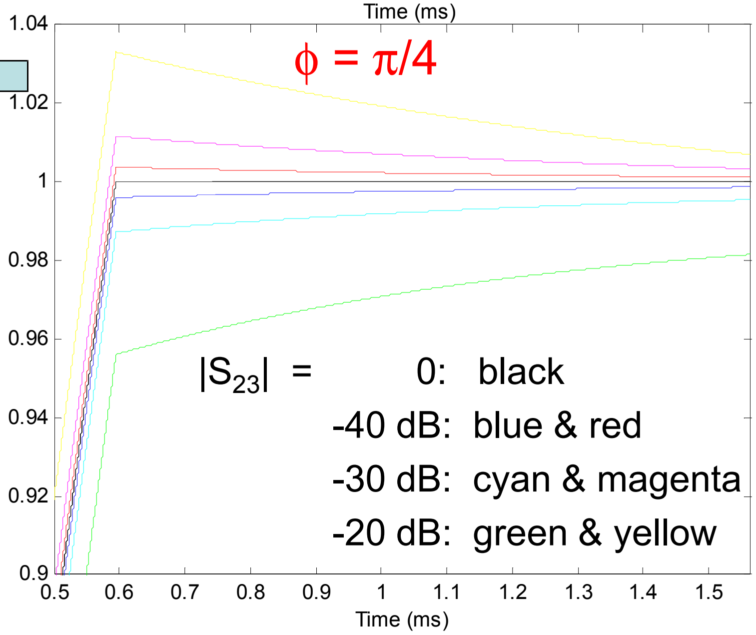
Assumed identical cavities and lossless, symmetric coupling network with equal coupling but imperfect port isolation.



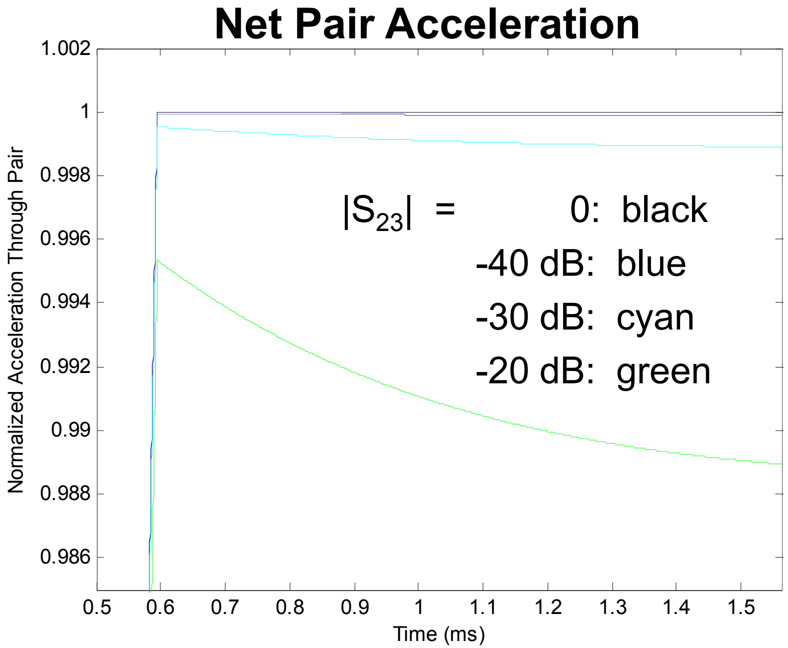
ϕ is the phase length from the hybrid ports to the cavities (with $\angle S_{23}$ set to 0).

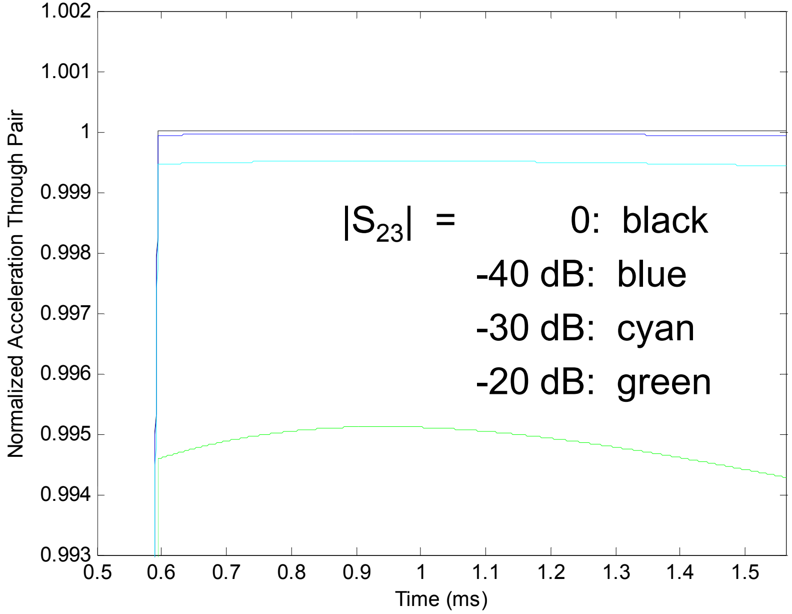
Individual Cavity Gradients





Net Pair Acceleration

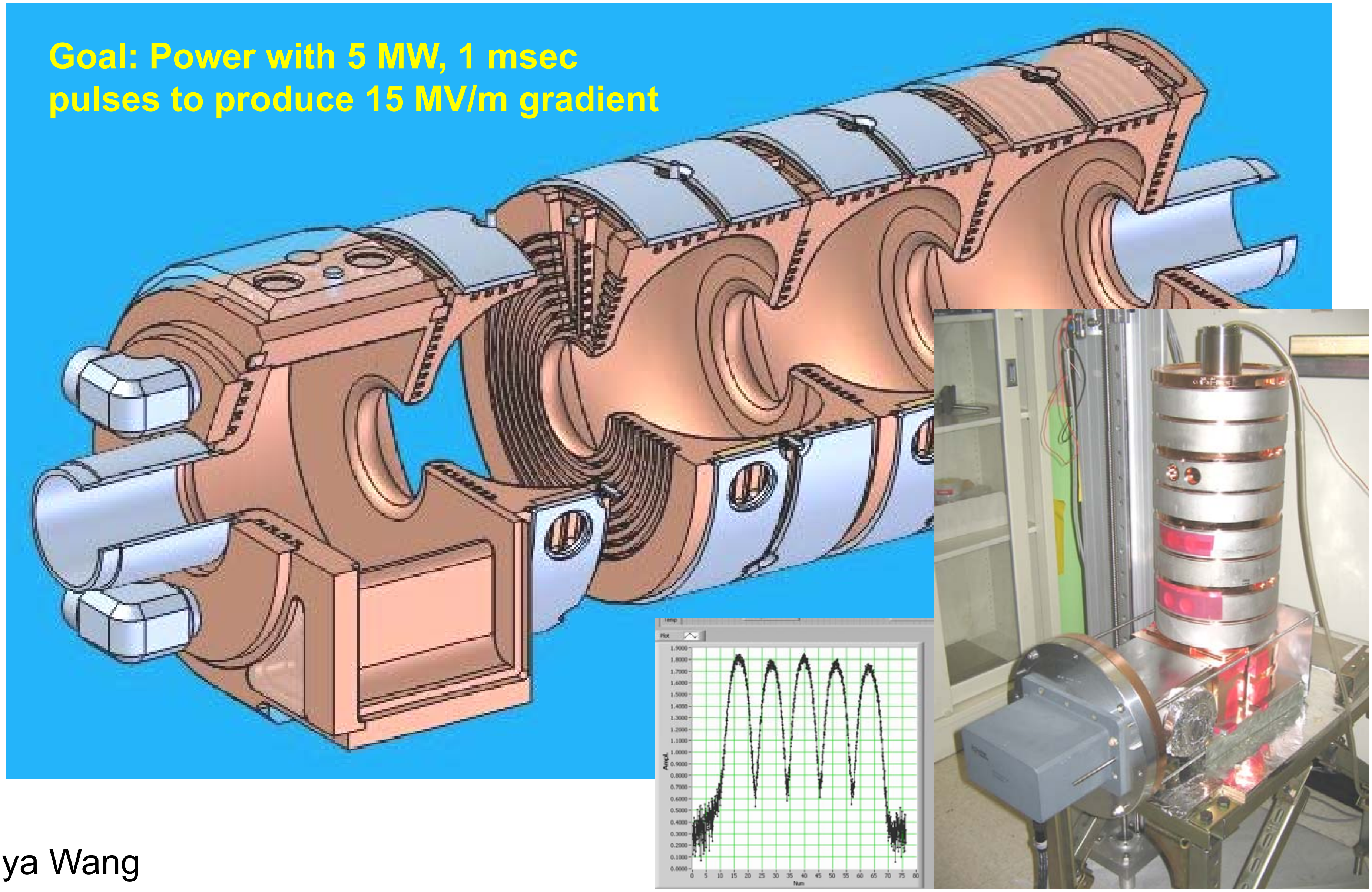




Typical measured isolation: -42—48 dB → gradient variation << 0.1%

C. Nantista

ILC Positron Capture Cavity Prototype

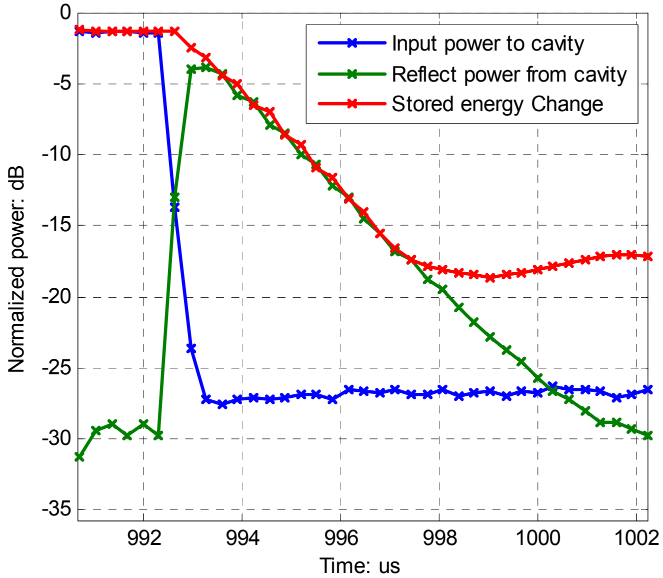


Goal: Power with 5 MW, 1 msec pulses to produce 15 MV/m gradient

Faya Wang

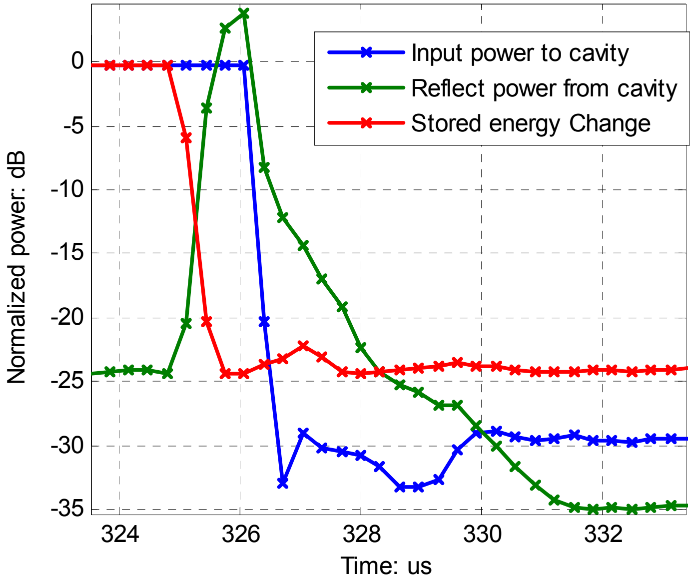
RF waveforms are calibrated in these cases

Normal Off

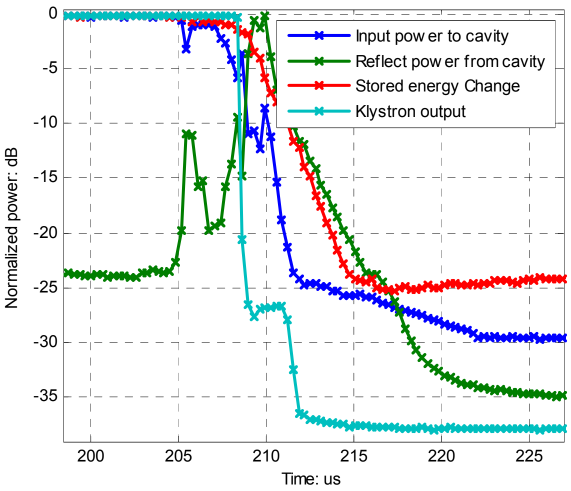


Hard Events

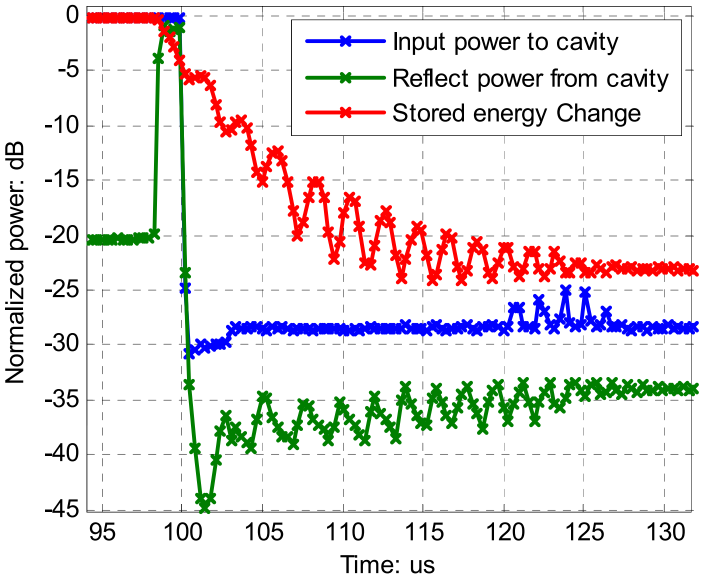
Breakdown in Cavity



Breakdown in Waveguide

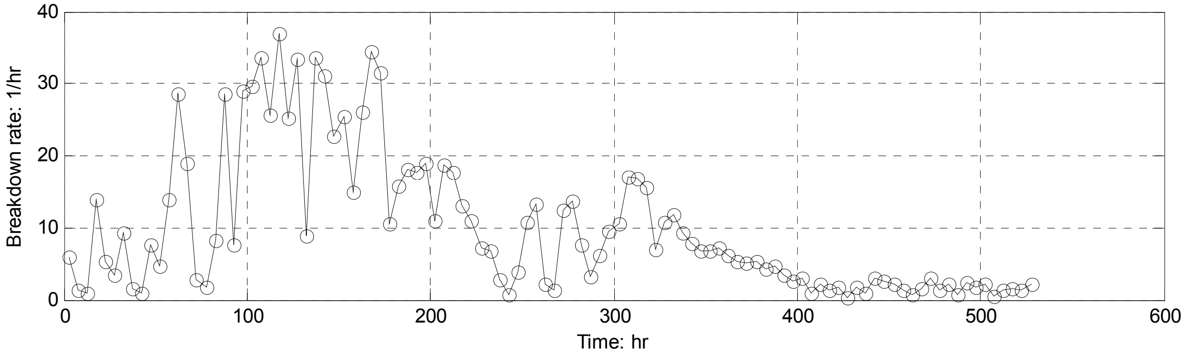


Soft Events

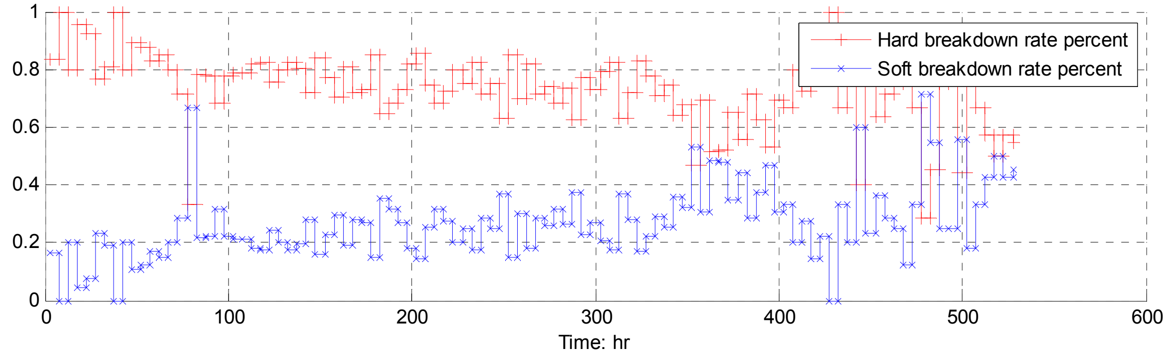


Breakdown Data During Processing

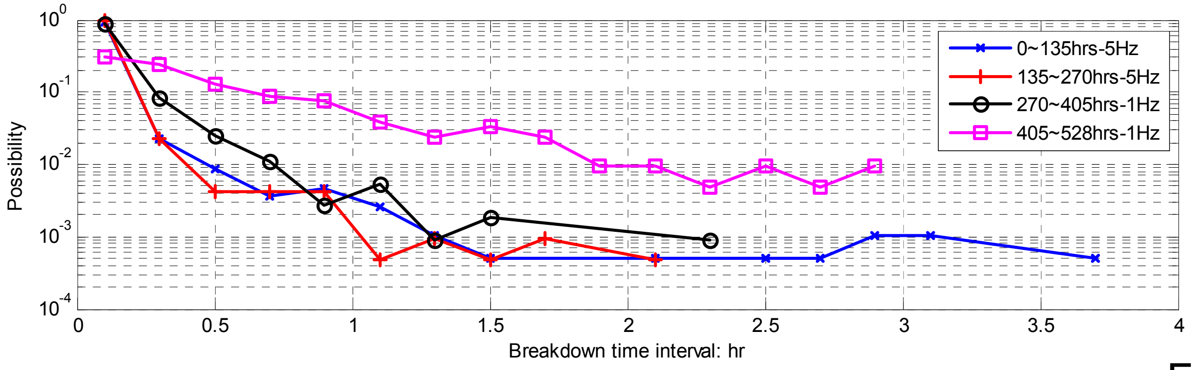
Rate (1/hr) vs Time (hr)



Fraction of Hard and Soft Events vs Time (hr)

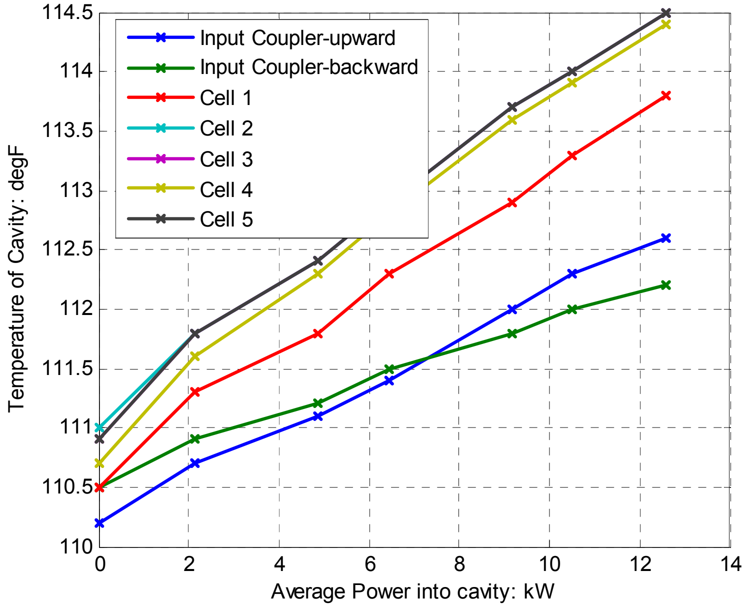


Distribution of Time Between Breakdowns for Different Processing Periods

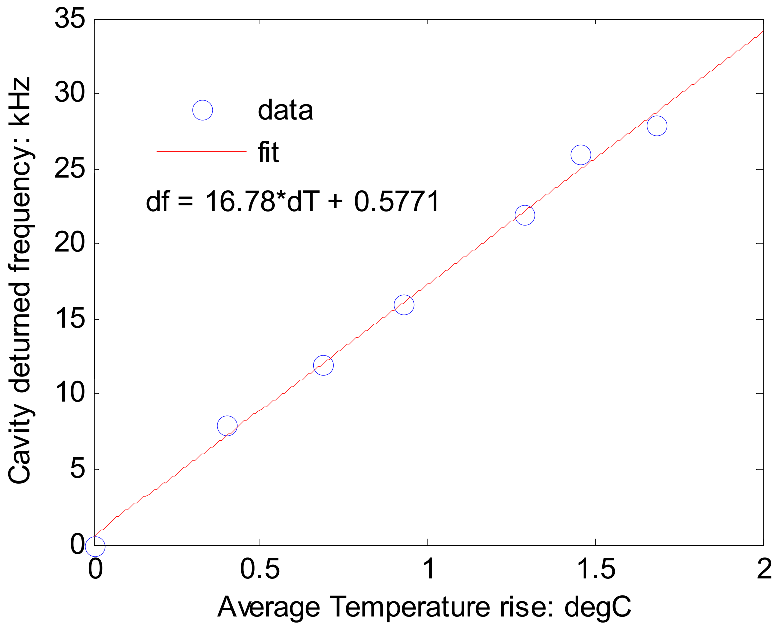


F. Wang

Temperature vs Cavity Input Power (with 28 gpm cooling)



Cavity Detuning vs Temperature (slope near that expected)



Cavity Gradient Measurements with Beam

(Worlds first L-band cavity operation in an X-band Linac)