HOM Measurement of ACC39

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Outline

- Motivation
- Single cavity and module-based analysis
- First HOM measurement with beam of ACC39 at FLASH
- First HOM dependence on beam offset observed on ACC39 at FLASH

Motivation

- **Higher order modes (HOMs) are excited by charge particles in cavity**

  - influence the beam both longitudinally and transversely

  - non-monopole modes excited by particle off-axis

- **Dipole modes dominate transverse wake potentials**

$$(Amplitude)_m \sim W_\perp^{\ m} \sim \left(\frac{r}{a}\right)^m$$ (*r*: offset, *a*: iris radius)

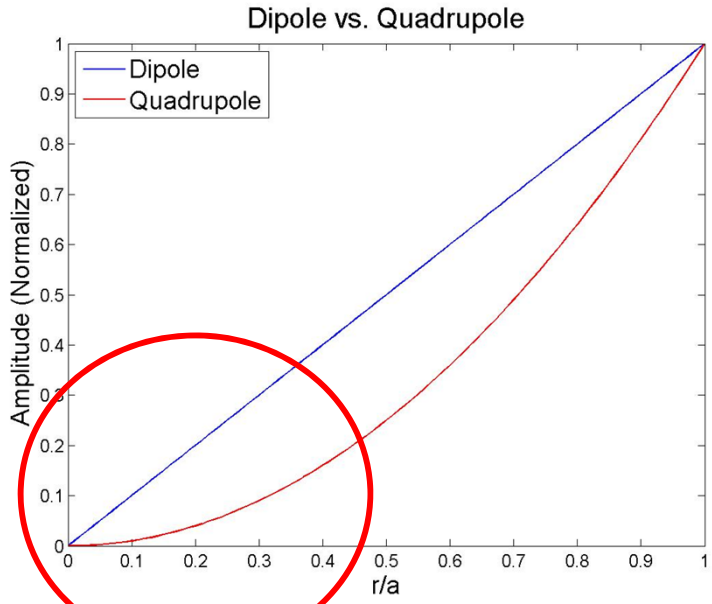
m=1, dipole; *m*=2, quadrupole

- **Use HOMs (non-monopole modes) to**

  - align the beam to the electric center

  - monitor beam position (HOM-BPM)

Principle proved in 1.3GHz Tesla cavity



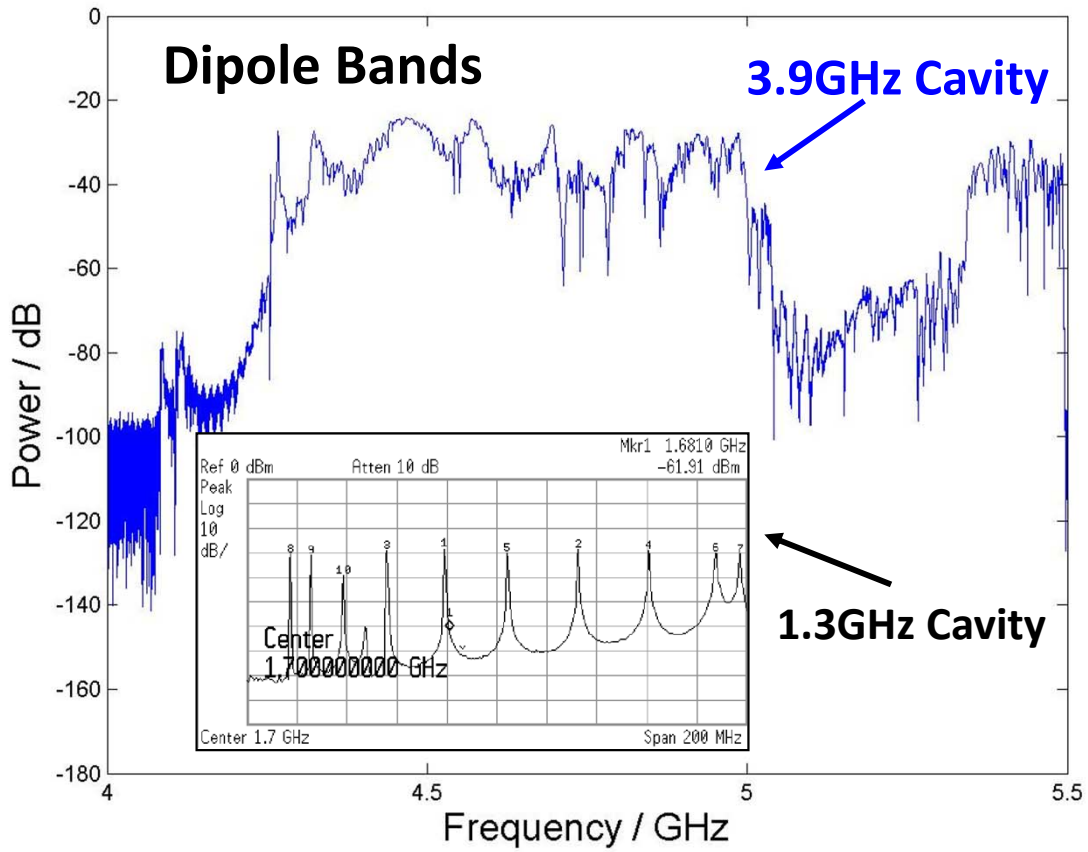
Normally in this region

Motivation (Cont'd)

- Considerably larger wake fields (compared to 1.3GHz cavity)

$$w_{//} \sim \lambda^{-2}, \qquad w_{\perp} \sim \lambda^{-3}$$ (λ is structure scaling factor)

- HOMs propagate through attached beampipes (cut off of dipole: 4.39GHz)
- HOMs shift from single cavity modes and hard to identify



- 1.3GHz cavity
  multi-cell, single cavity modes
- 3.9GHz cavity
  multi-cavity modes

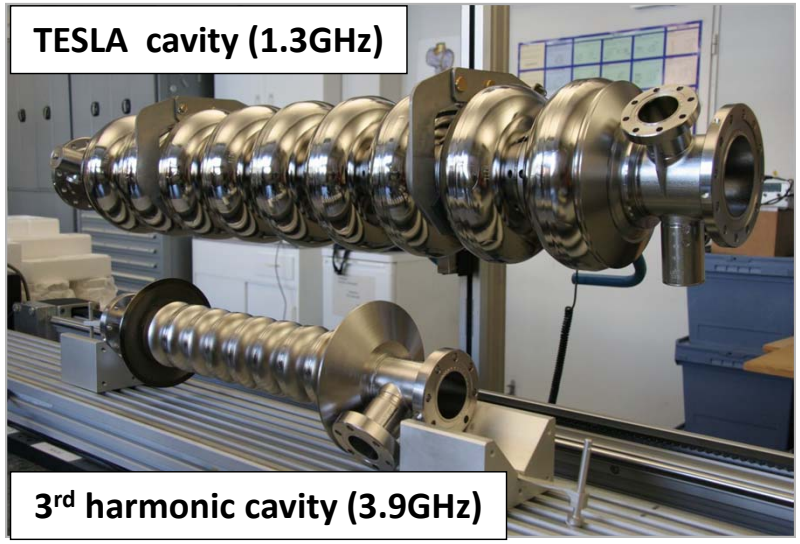
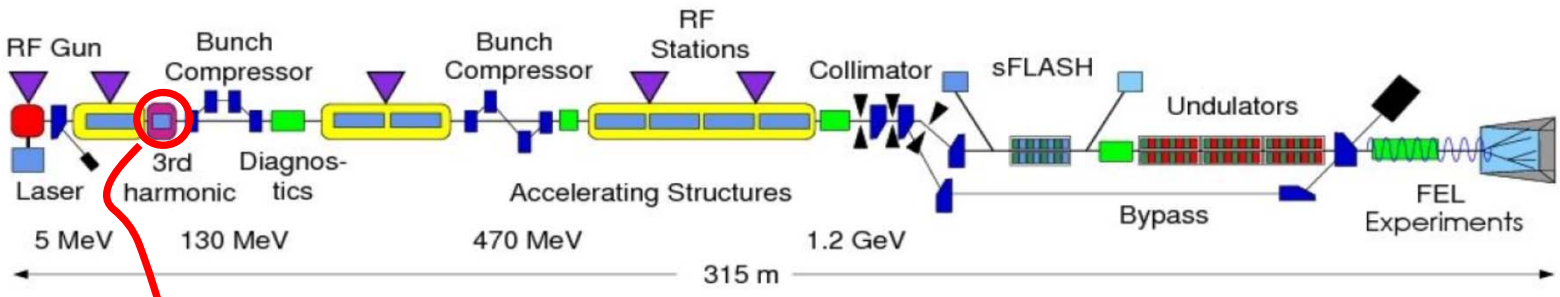
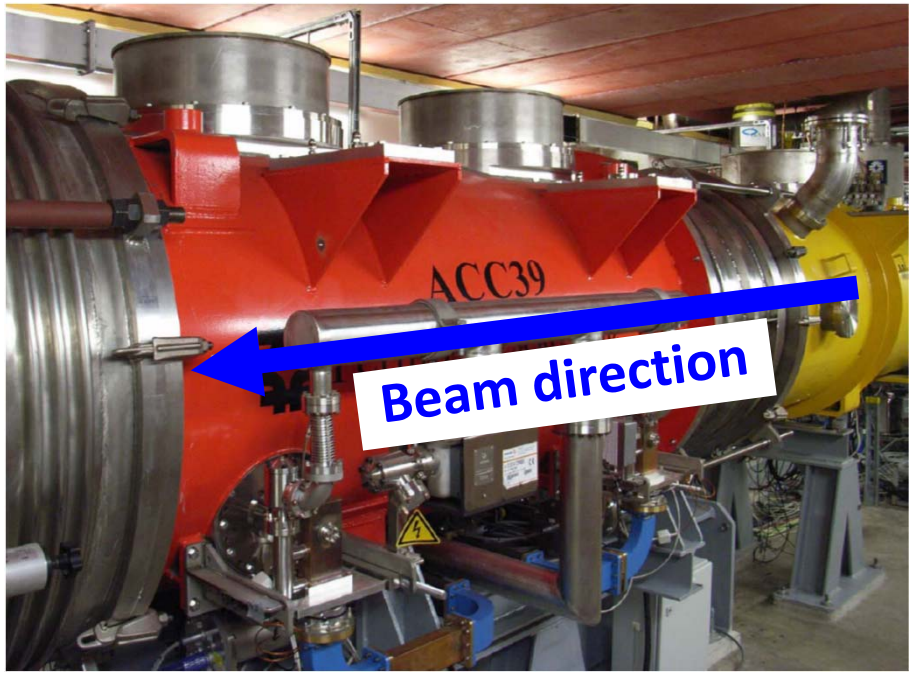
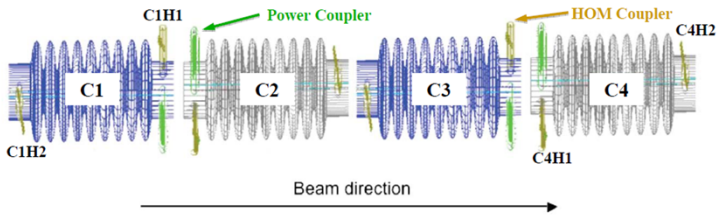


Photo courtesy E. Vogel & DESY

ACC39 @ FLASH





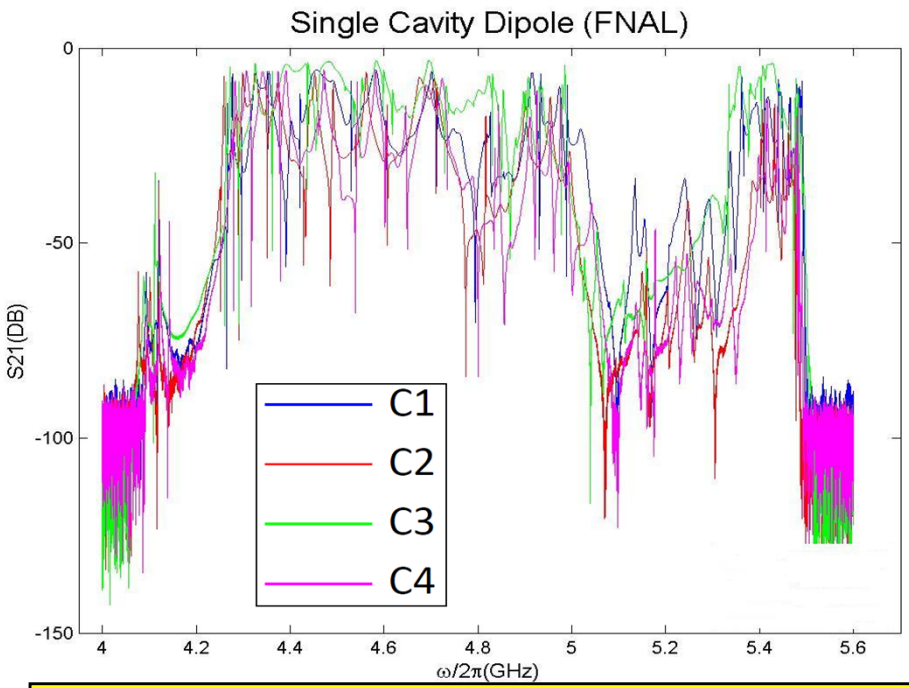


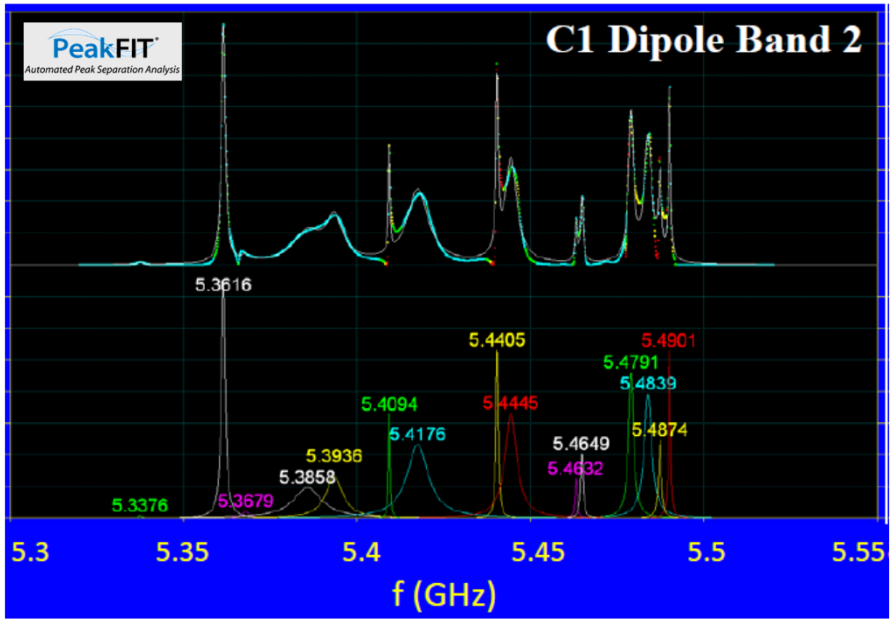
Number of cavities	4
Cavity length	0.346 m
Design gradient	14 MV/m
Phase	-179°
Cavity frequency ($\omega/2\pi$)	3.9 GHz
R/Q ($V^2/(2\omega U)$) [5]	373 Ω
E_{peak}/E_{acc}	2.26
B_{peak} (E_{acc}=14MV/m)	68 mT
Loaded Q_L	1.3×10^6
Max dipole R/Q at $\omega/2\pi$	50.20 Ω/cm^2, 4.831 GHz

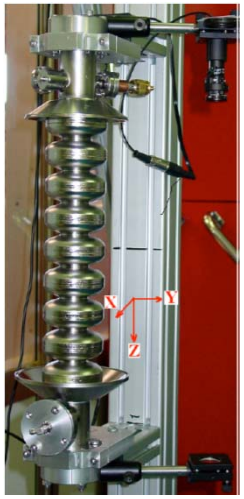
Measurement Status

Date	Measurement Info.	Beam info.	Location
2008	Single cavity (cold, not tuned)	w/o beam	FNAL
Oct. 2009	CMTB (cold, tuned)	w/o beam	DESY
Apr. 2010	ACC39 panel (cold, tuned)	w/o beam	
Jul. 2010	1st parasitic beam measurement	w/ beam	
Nov. 2010	2nd parasitic beam measurement	w/ beam	
Jan. 2011	1st **dedicated** beam measurement	w/ beam	

Single Cavity Analysis

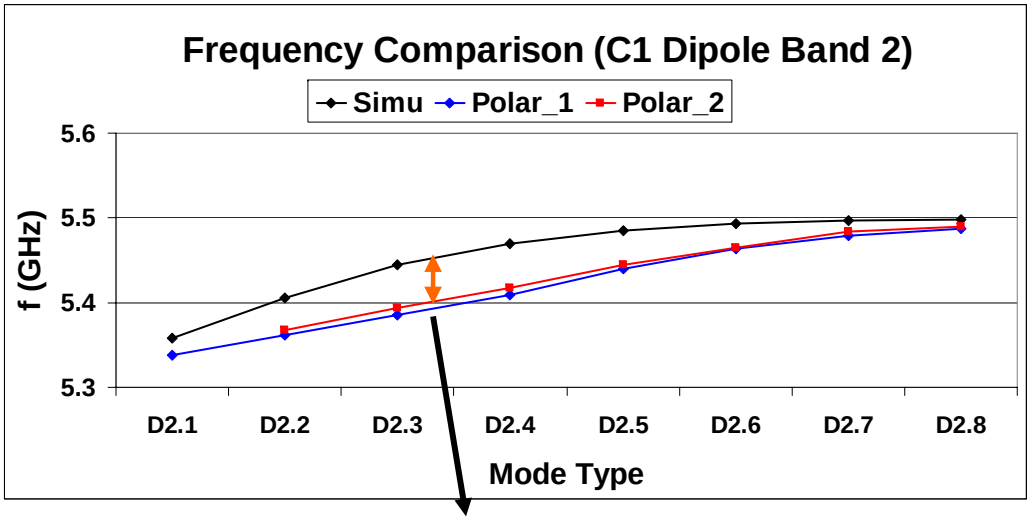




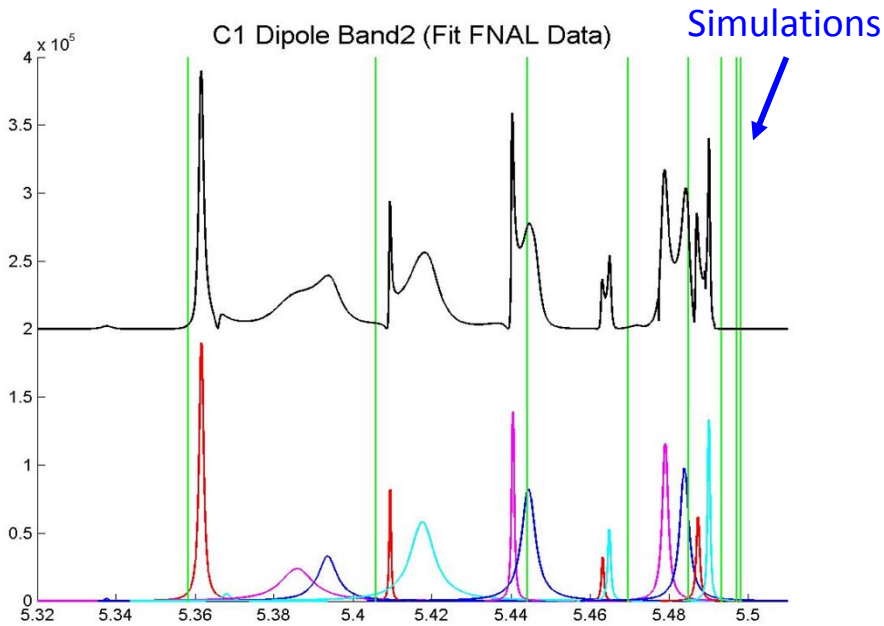


Not tuned !

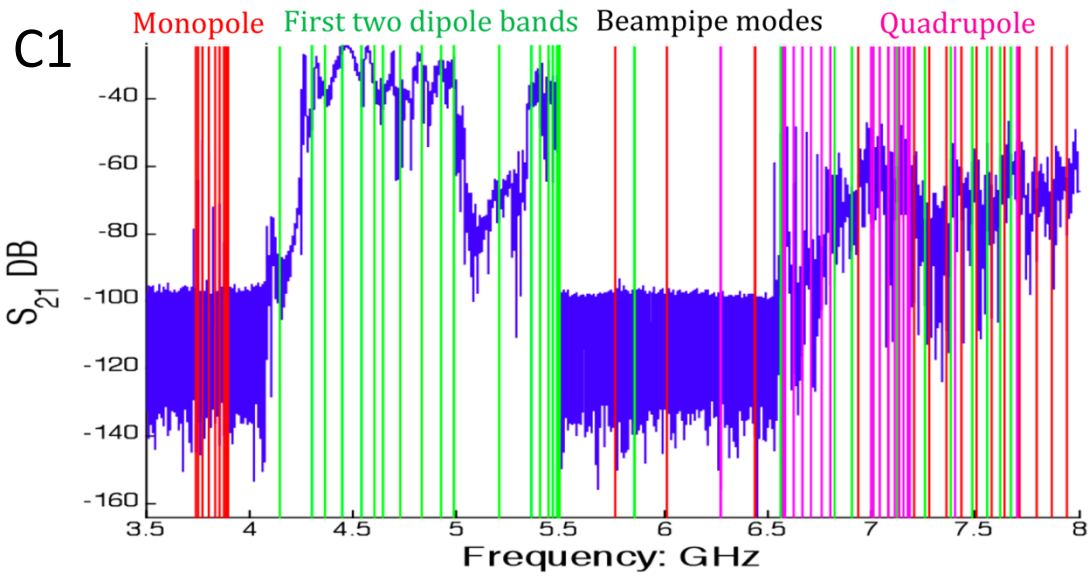
Cavities are not coupling with each other, yet !

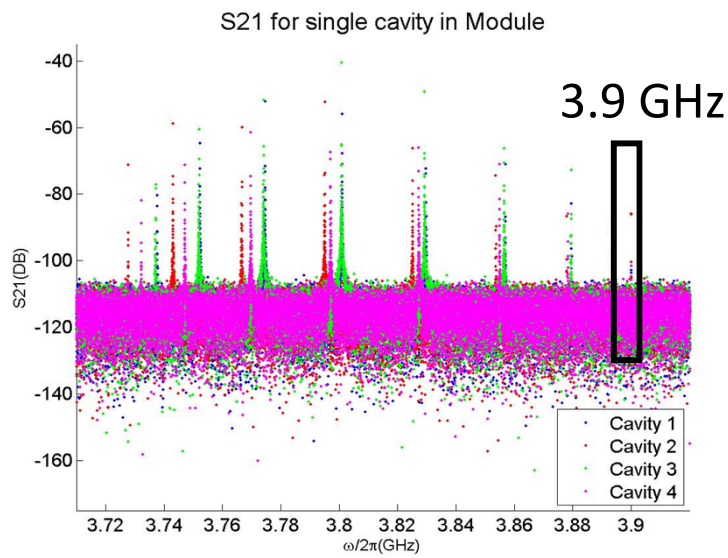


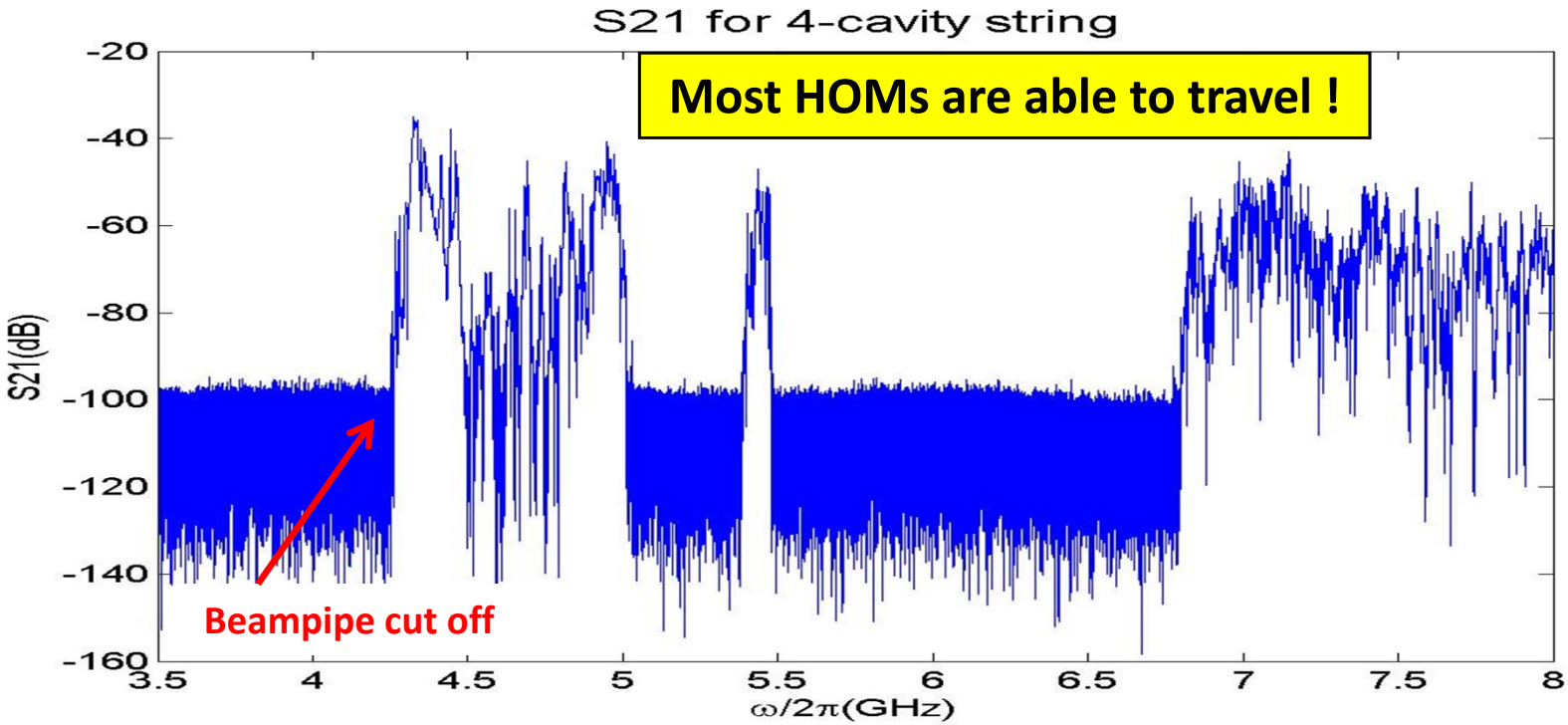
Might due to ideal cavity simulations, couplers not included, …



Module-based Analysis

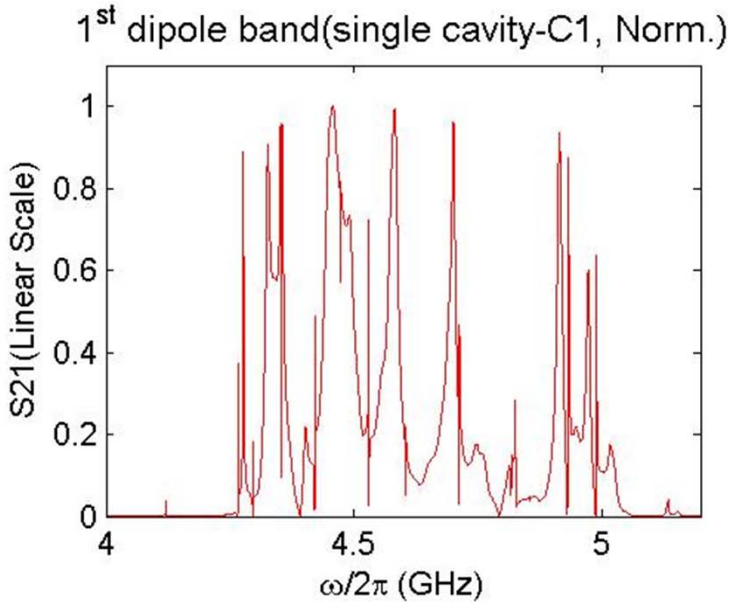


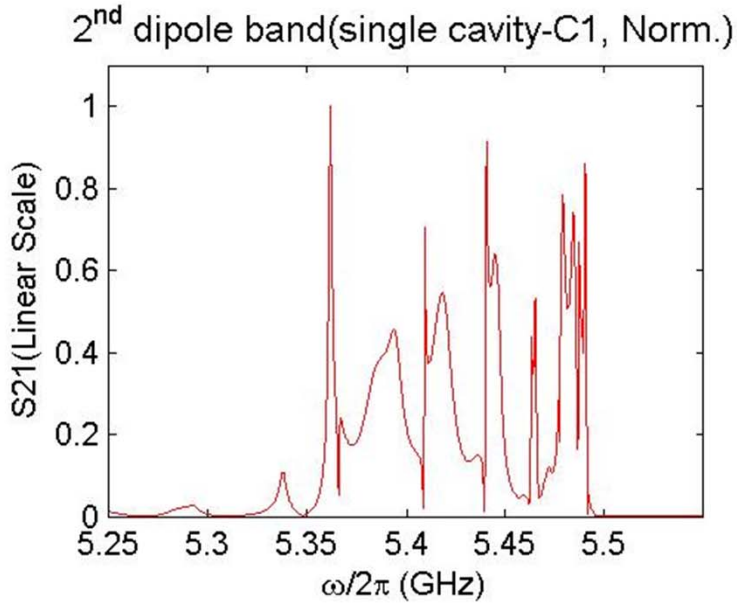




Non-local Modes - Coupling

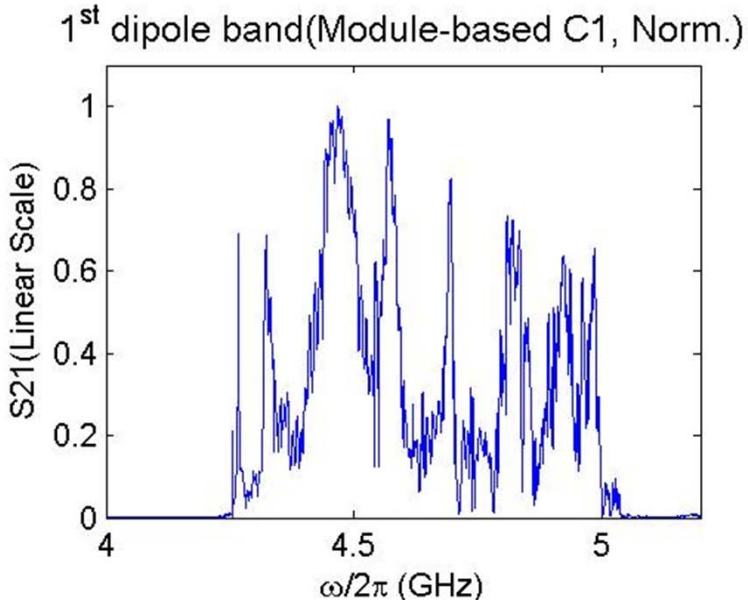
Single Cavity

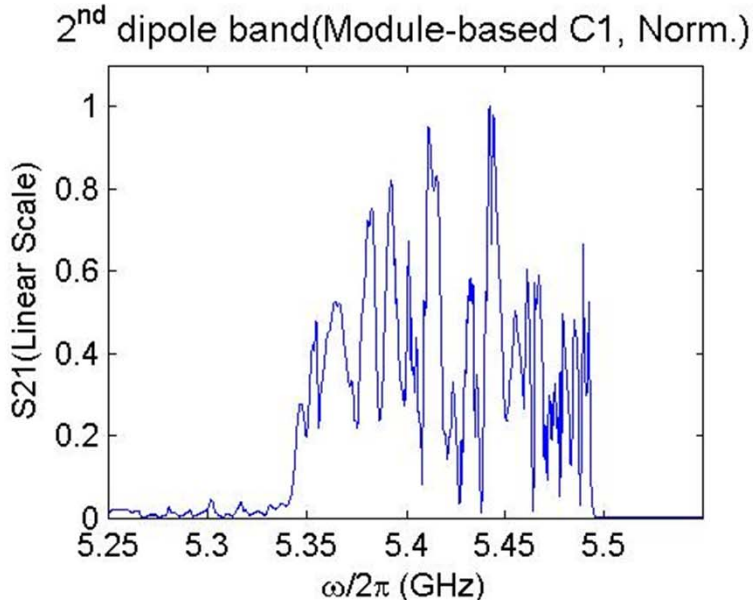




Couplings of all cavities show up !

Module-based





First Beam Spectra of ACC39

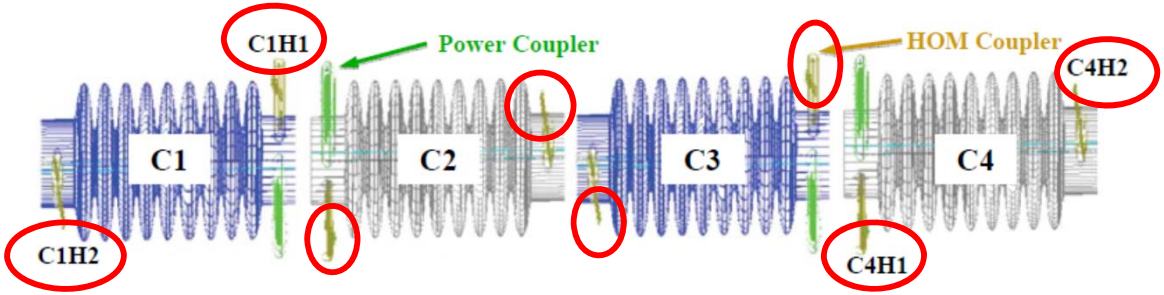
Monopole

Dipole

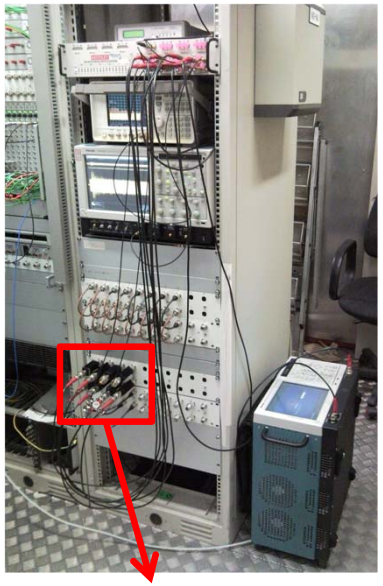
Quadrupole

Jul 2010

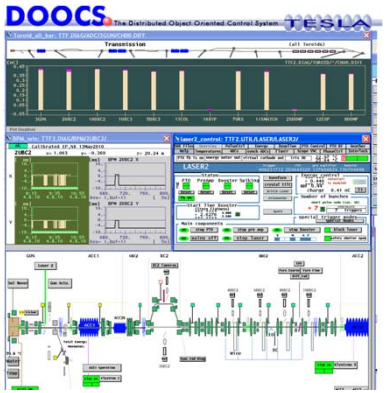
Measurement Setup



Beam direction



ACC39 HOM panel



Bpm, Current, …

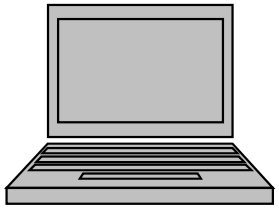
MATLAB®

Multiplexer

Oscilloscope

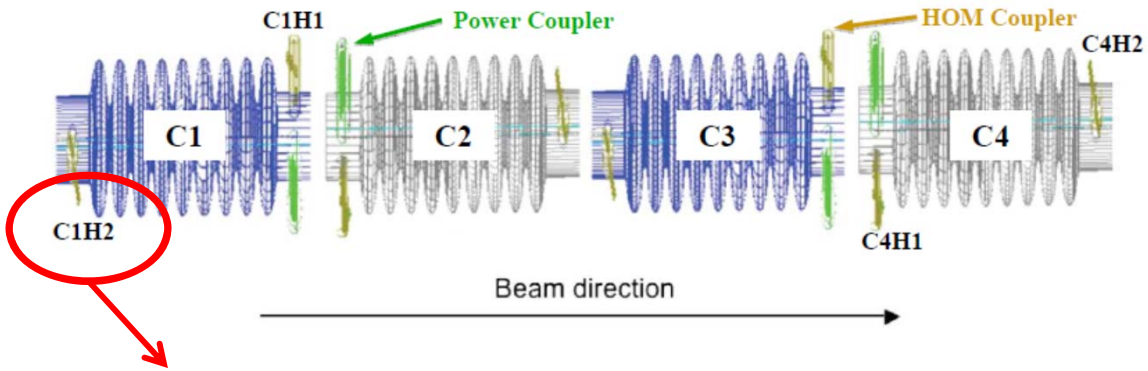
MATLAB®
Instrument Control Toolbox™

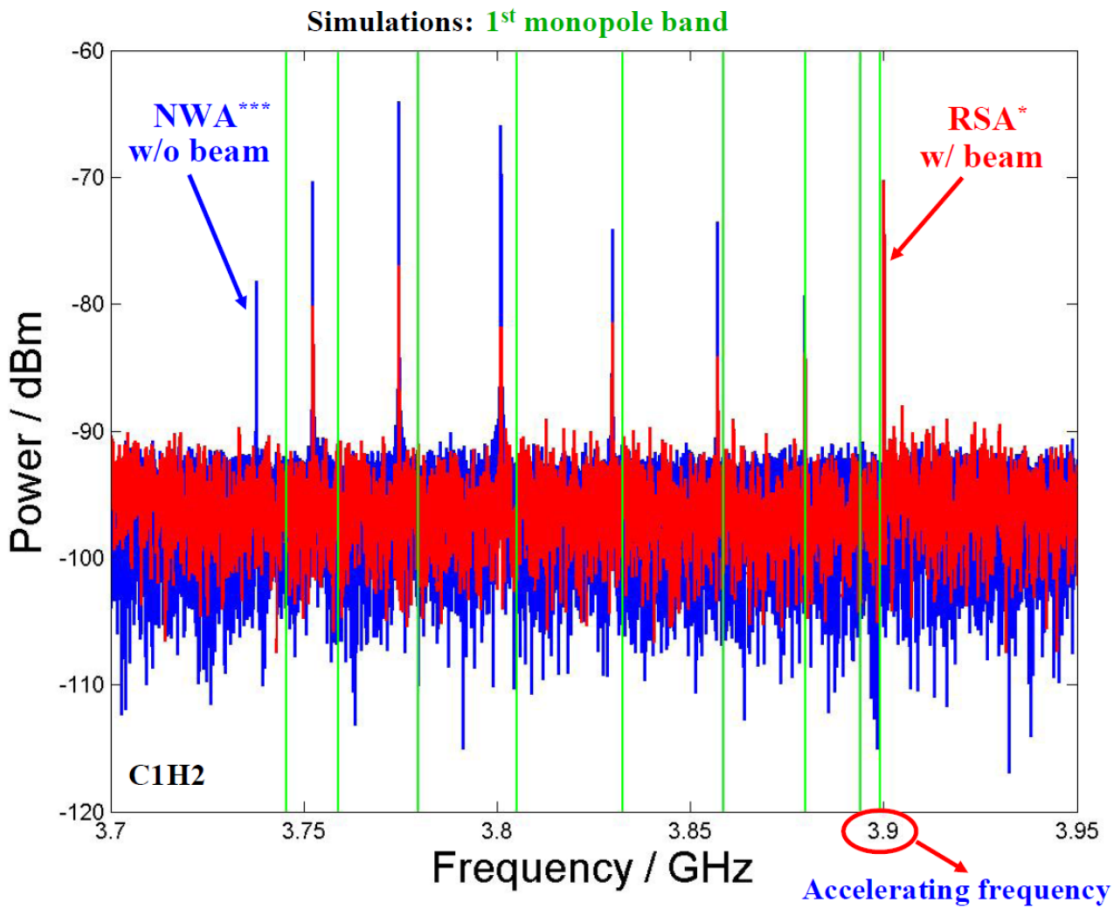
VISA-TCPIP-GPIB



Trigger (10Hz)

Monopole w/ & w/o Beam





NWA

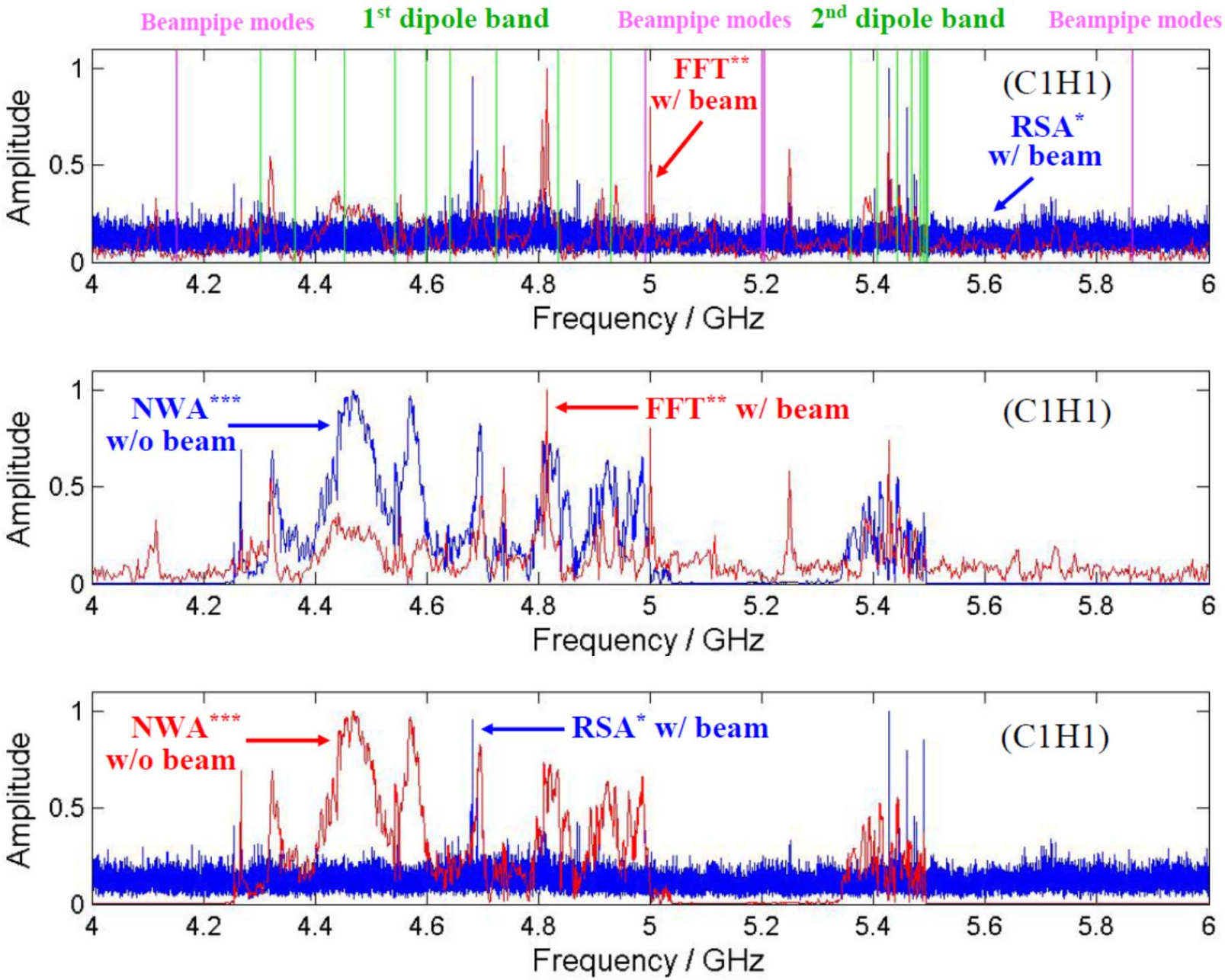
transmission measurement w/o beam

RSA

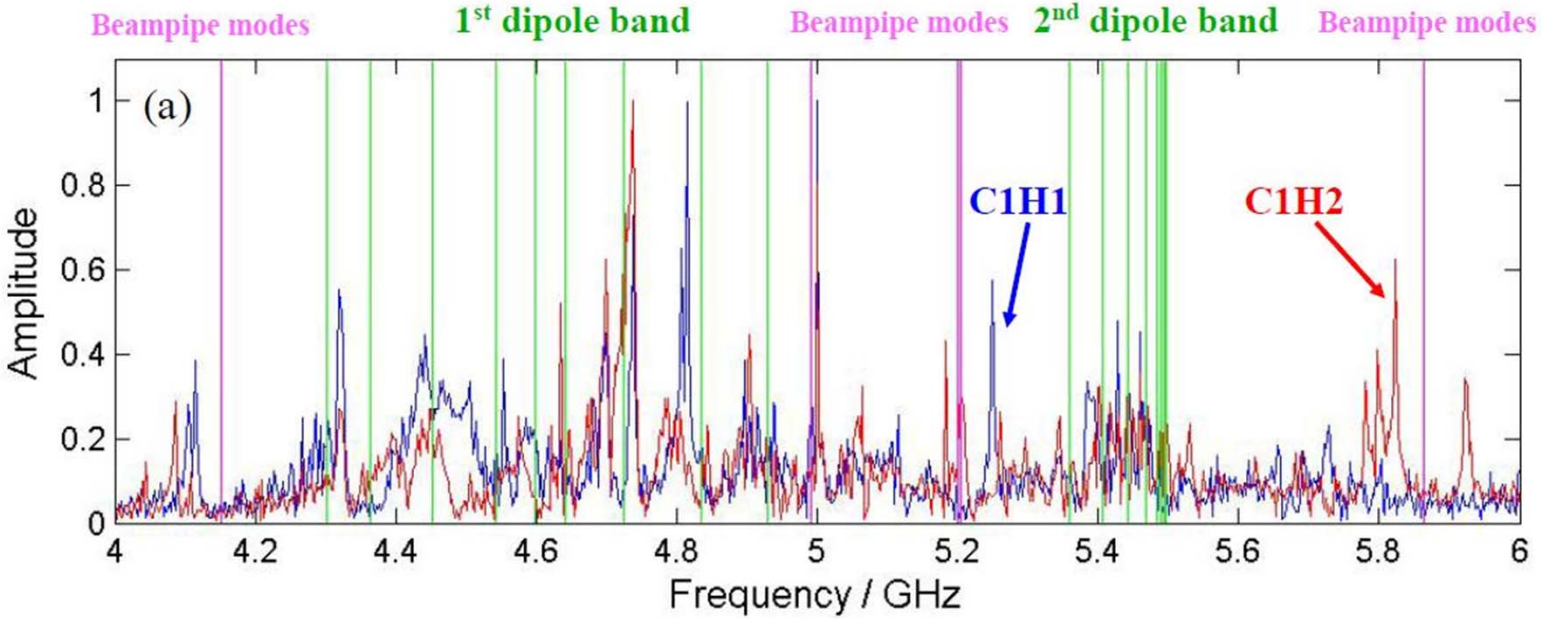
beam-excited HOM measurement

Fit Well !

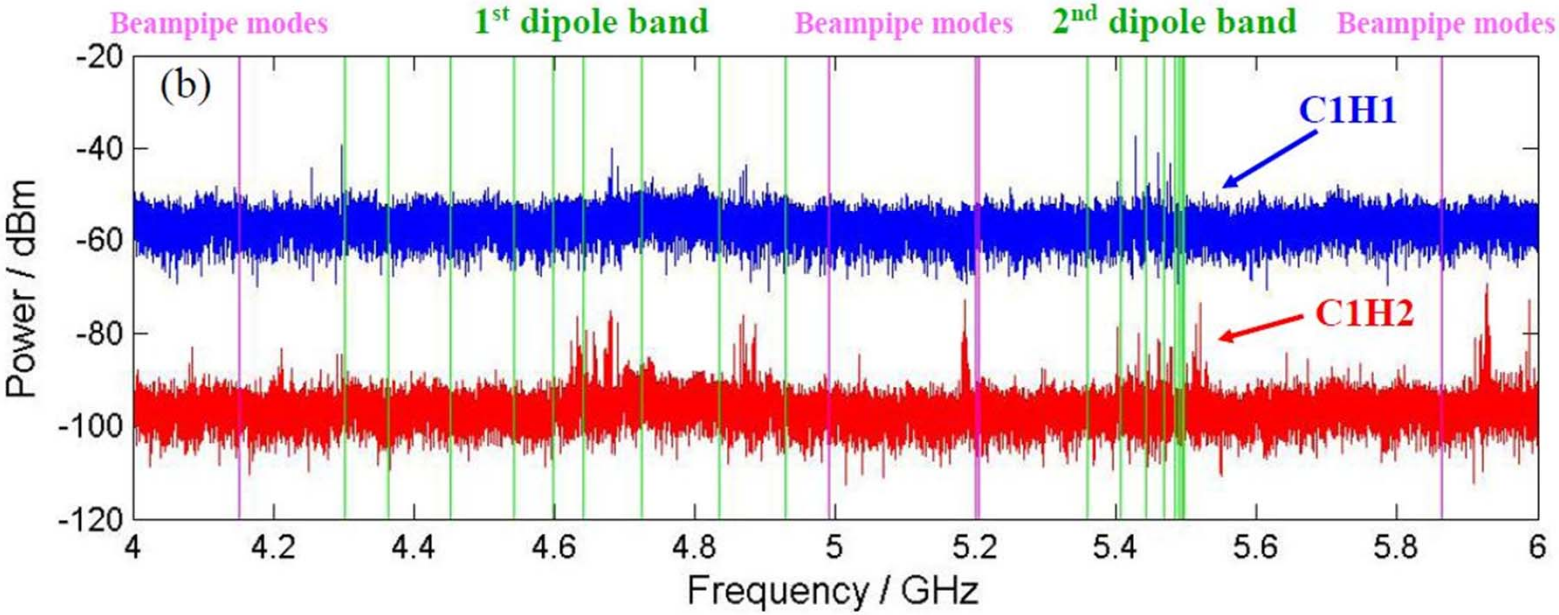
Dipole w/ & w/o Beam



Coupler Responses to HOMs

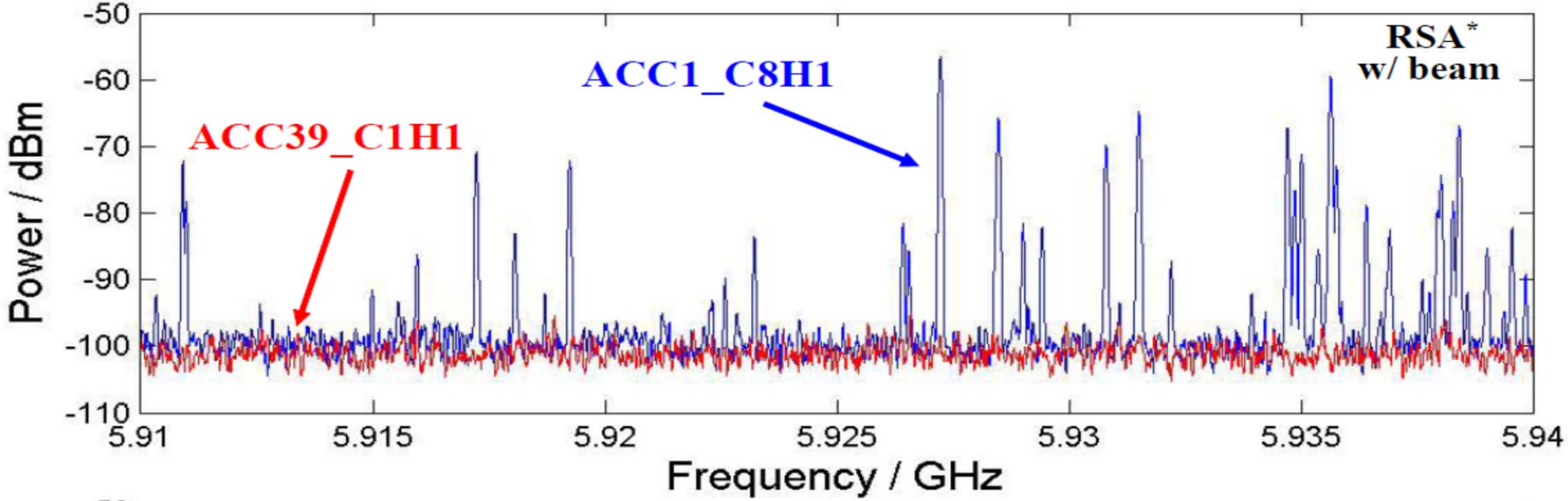


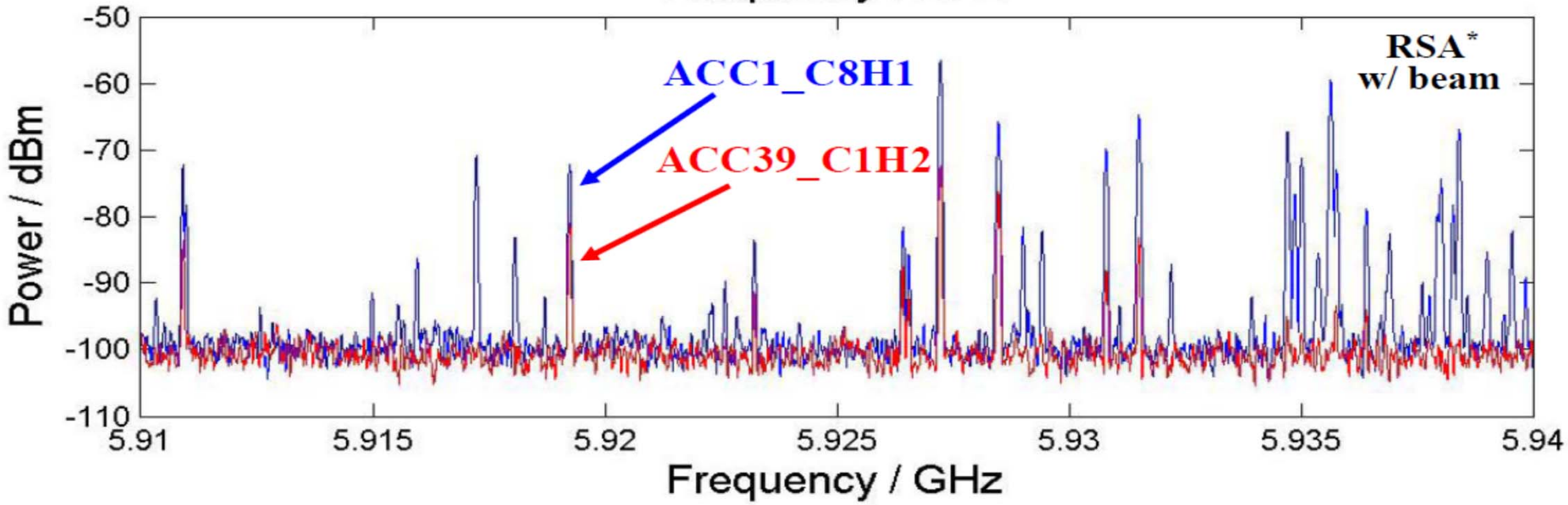
FFT



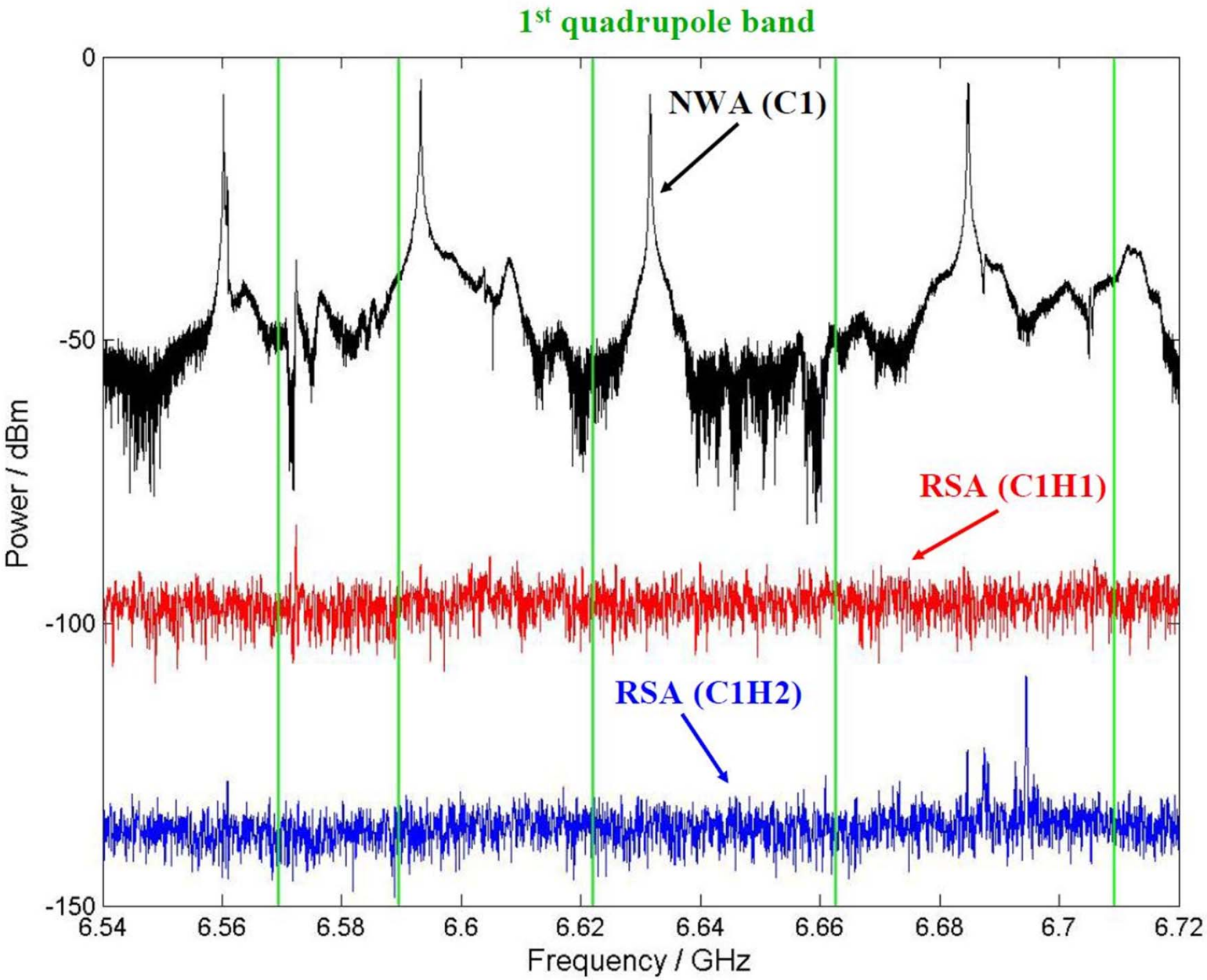
RSA

Transmission from ACC1 to ACC39





Quadrupole w/ & w/o Beam

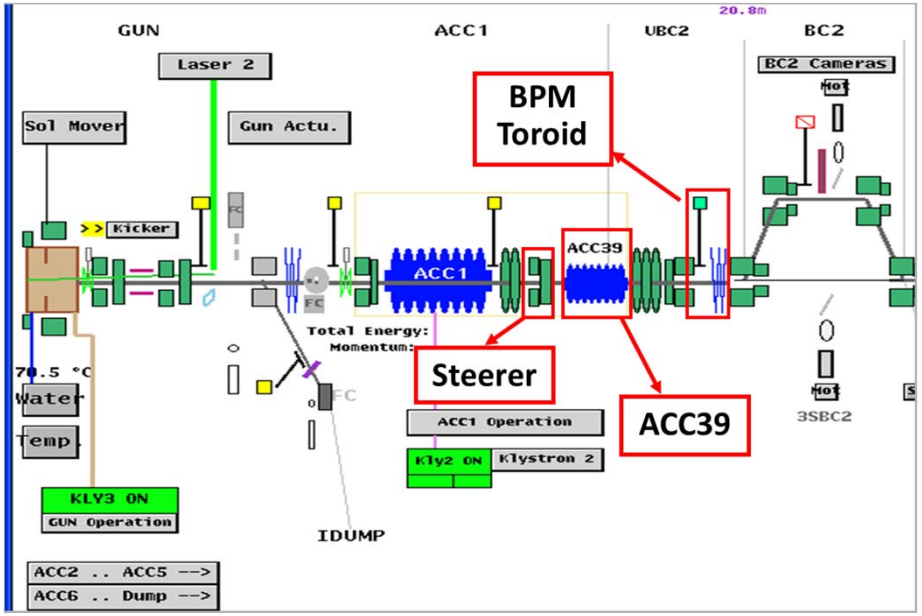


Closer Look at HOMs

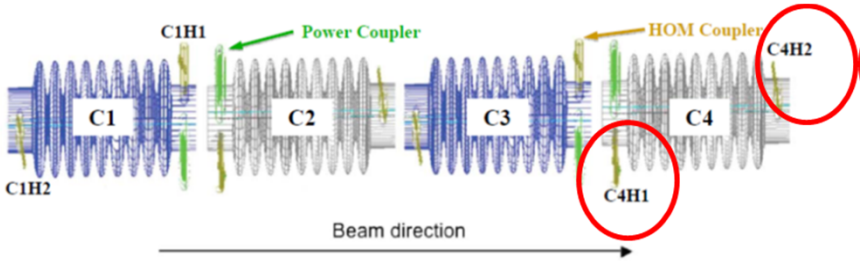
- **Dipole modes below beampipe cutoff (w/o multi-cavity coupling)**

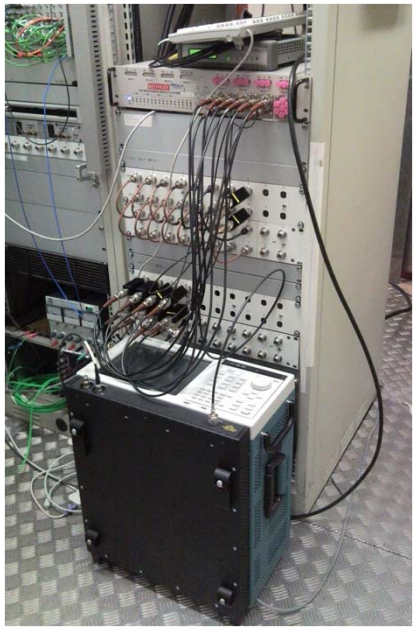
Nov 2010

Measurement Scheme



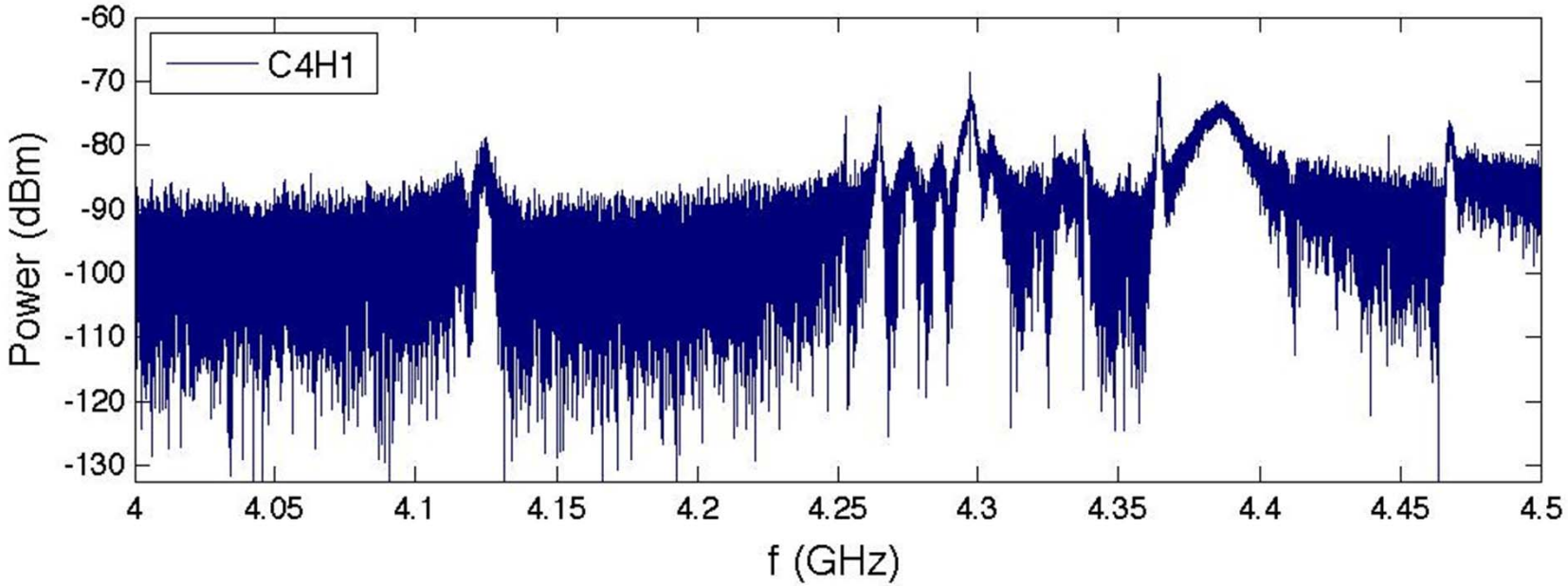
Beampipe Cut off
4.39GHz (theory)

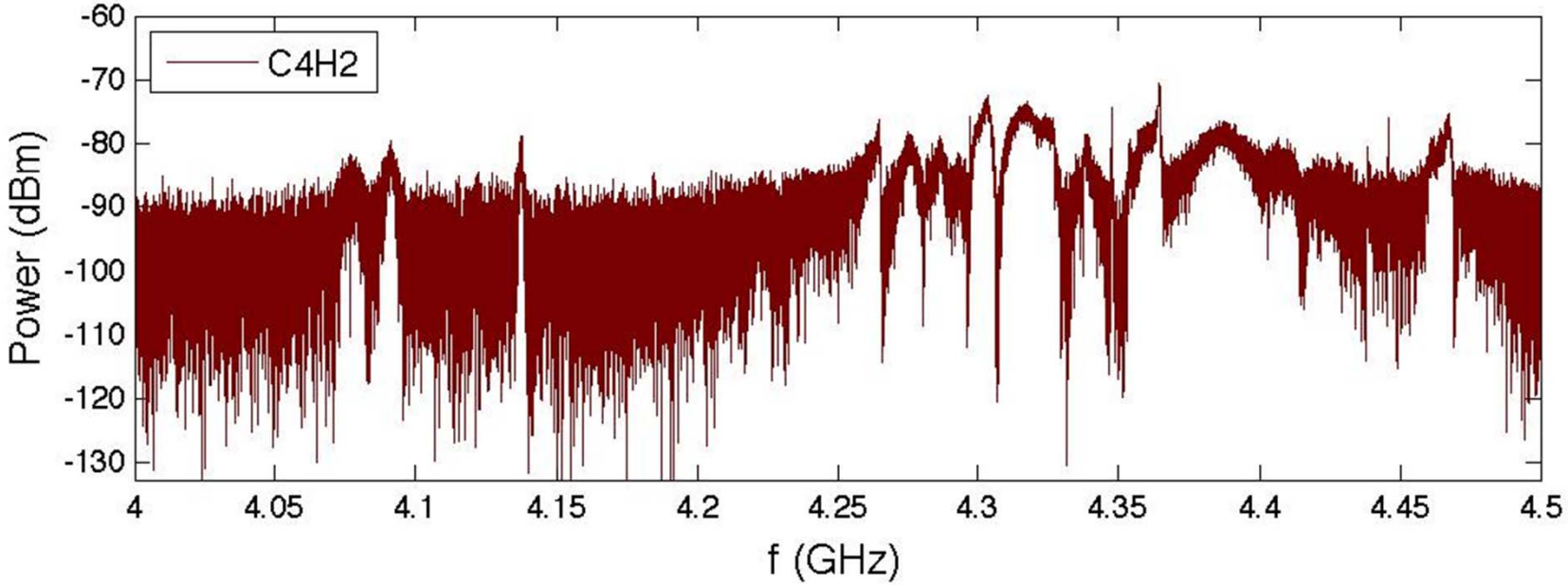




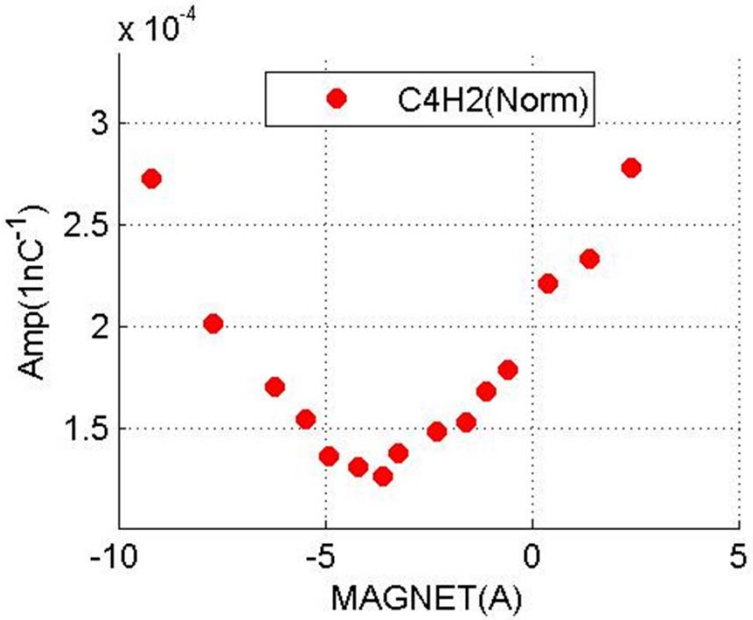
Couplers measured	C4H1, C4H2
Frequency range	4.0GHz ~ 4.5GHz
Resolution bandwidth	22kHz
Horizontal move	**15** beam positions
	-6.680mm ~ 7.208mm
Vertical move	**13** beam positions
	-6.039mm ~ 7.000mm

RSA Spectra

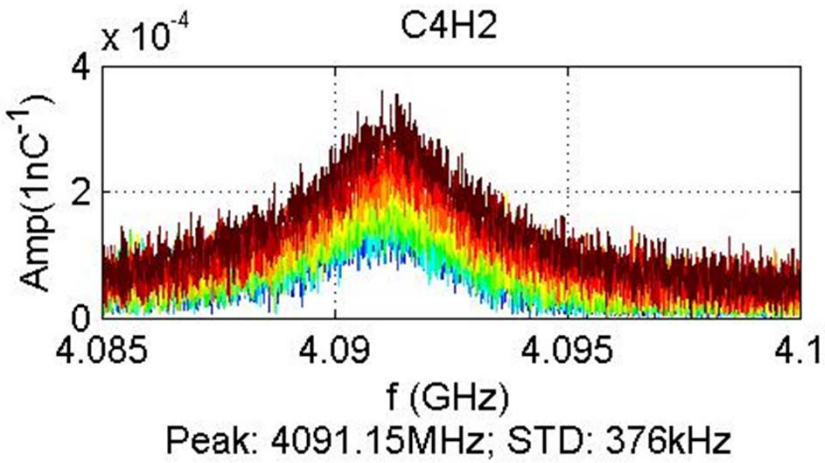

C4H1
Power (dBm)
-60
-70
-80
-90
-100
-110
-120
-130
4
4.05
4.1
4.15
4.2
4.25
4.3
4.35
4.4
4.45
4.5
f (GHz)

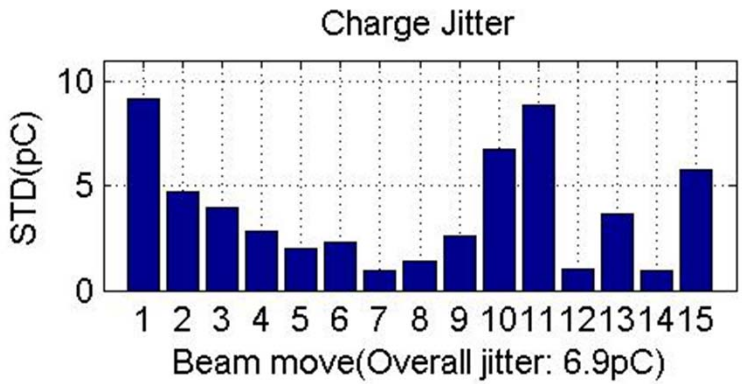

C4H2
Power (dBm)
-60
-70
-80
-90
-100
-110
-120
-130
4
4.05
4.1
4.15
4.2
4.25
4.3
4.35
4.4
4.45
4.5
f (GHz)

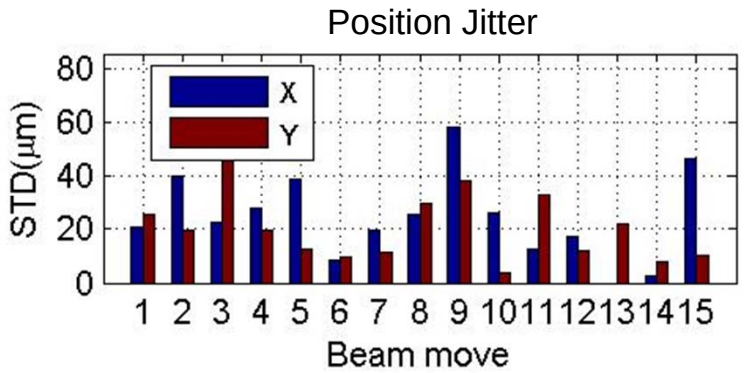
Horizontal Move

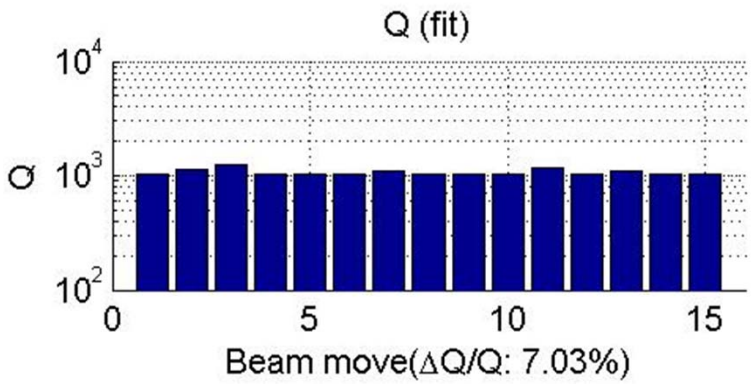


***f* = 4091.1420MHz**

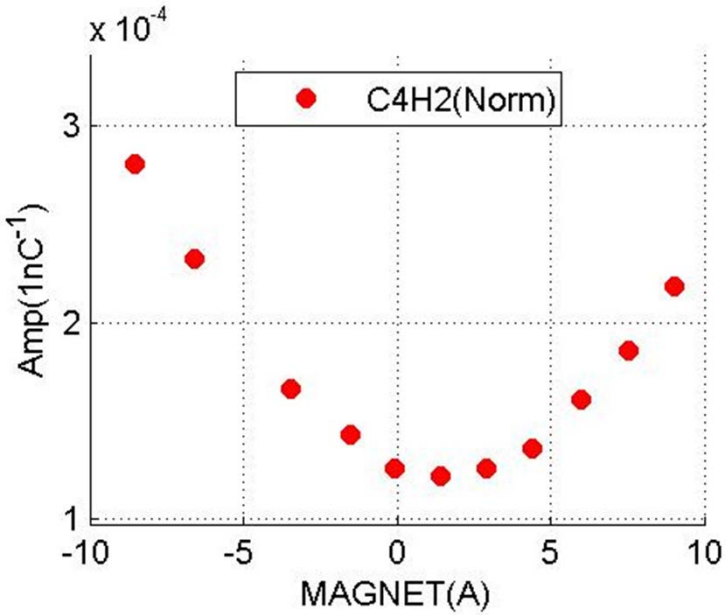


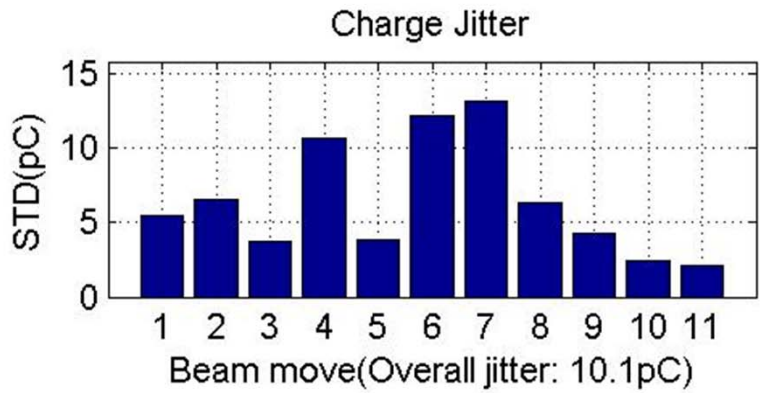


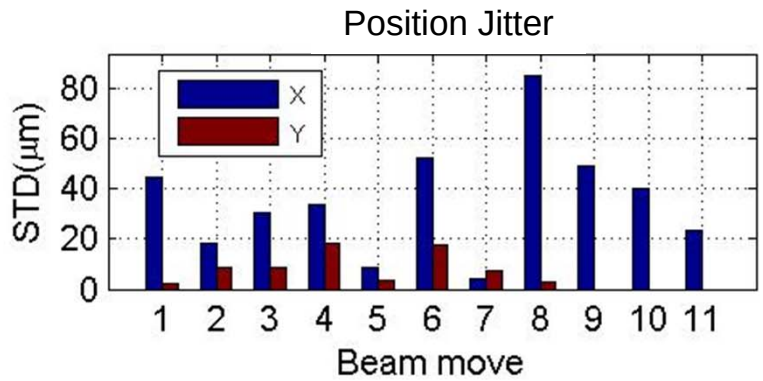




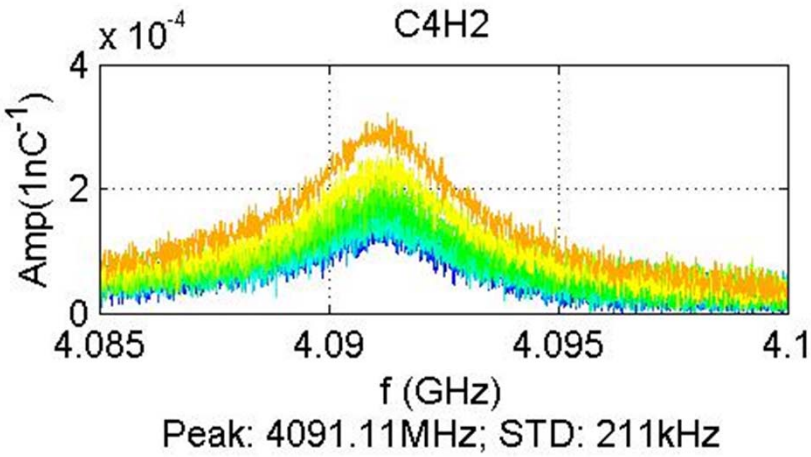
Vertical Move

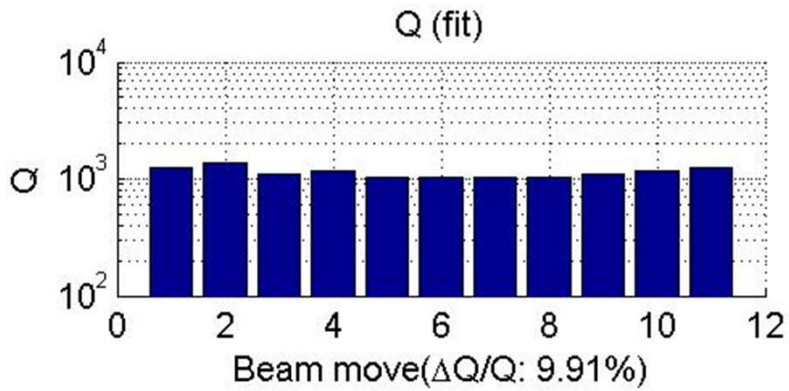




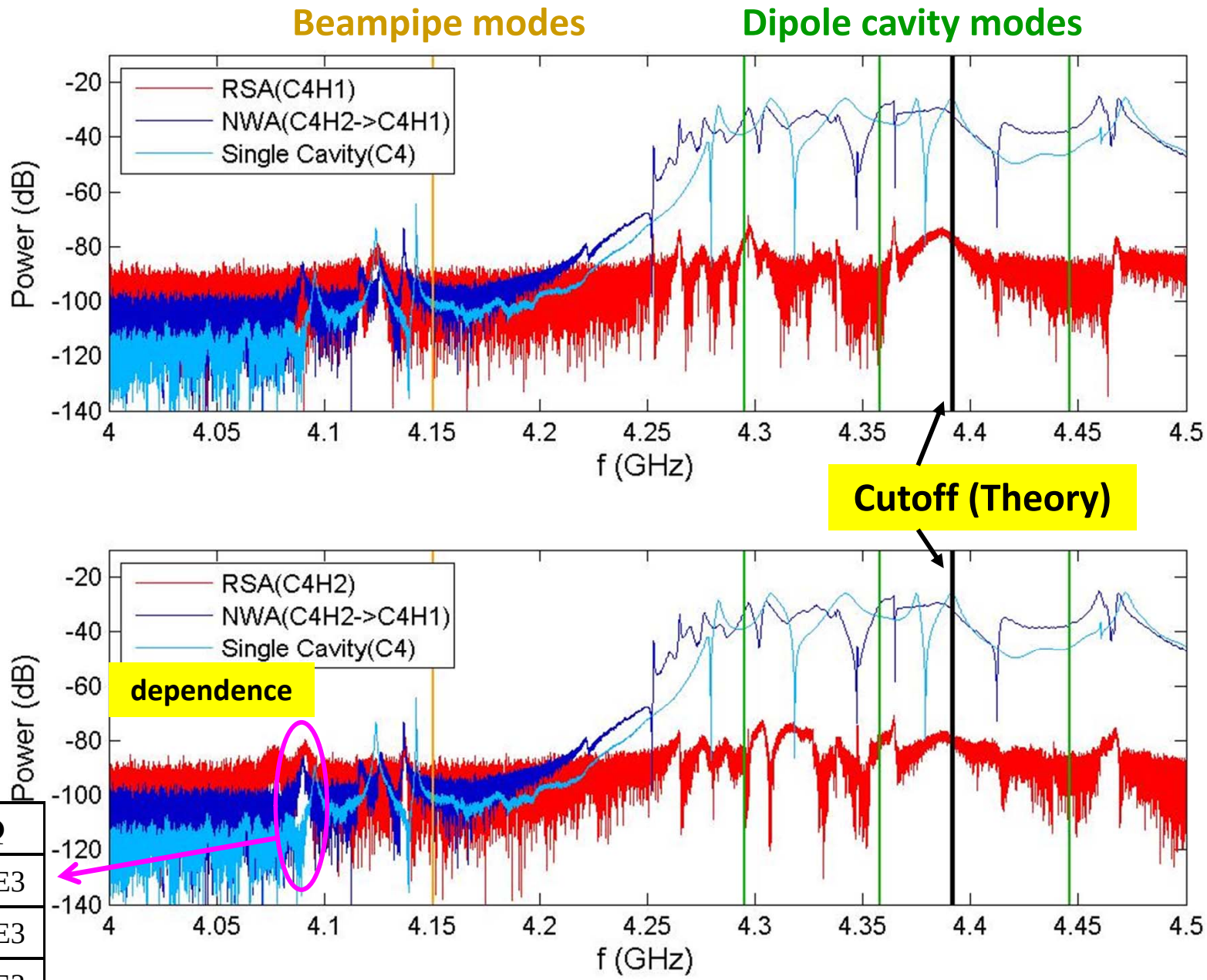


***f* = 4091.1420MHz**





RSA, NWA and Single Cavity

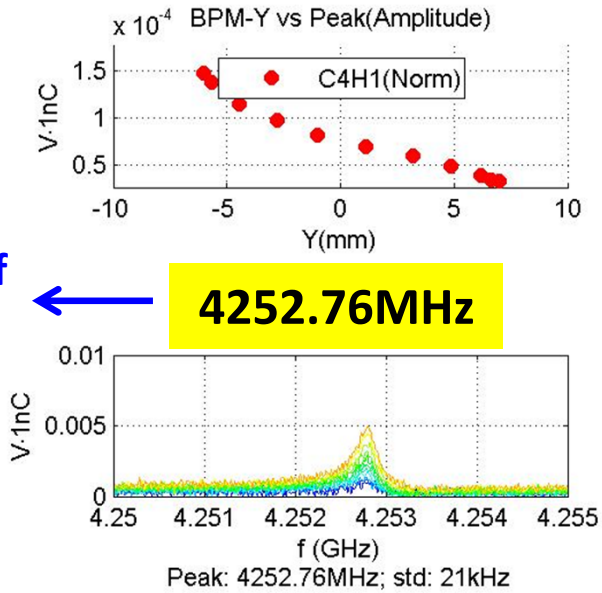


- Single cavity: not tuned!
- NWA, RSA: tuned!

	f (MHz)	Q
NWA	**4090**	~2E3
RSA	**4091**	~1E3
Single	**4096**	~3E3

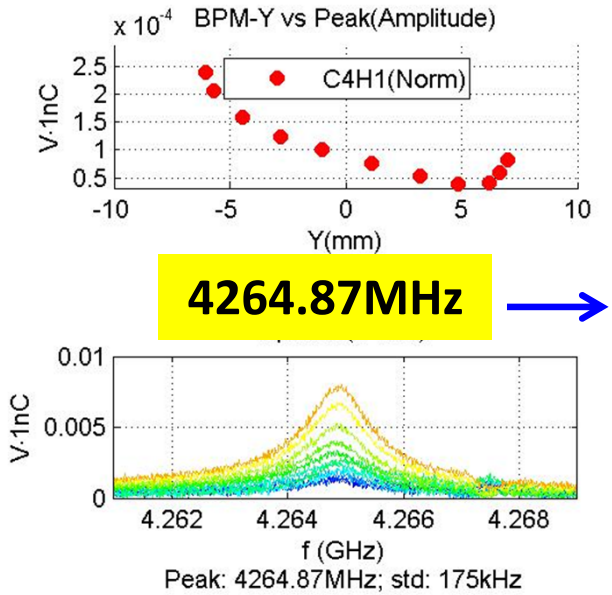
More Dependences (C4H1)

Y



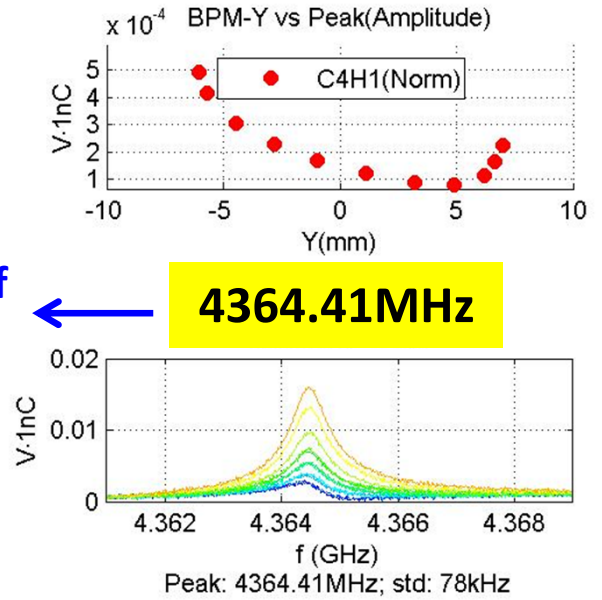
Below cutoff (theory) ← **4252.76MHz**

Y



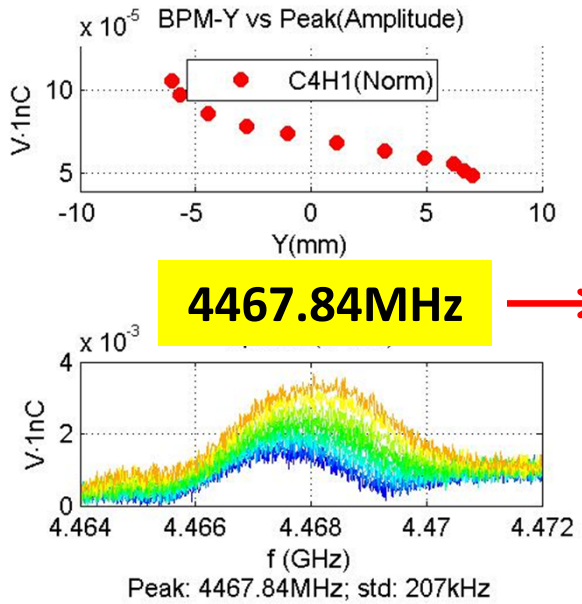
4264.87MHz → Below cutoff (theory)

Y



Below cutoff (theory) ← **4364.41MHz**

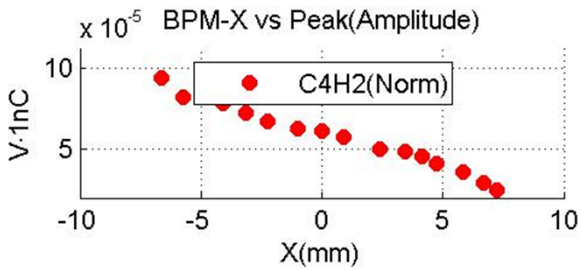
Y



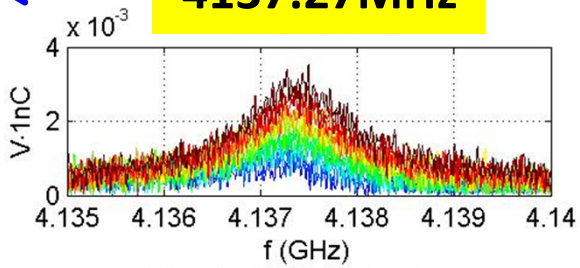
4467.84MHz → Above cutoff (theory)

More Dependences (C4H2)

X

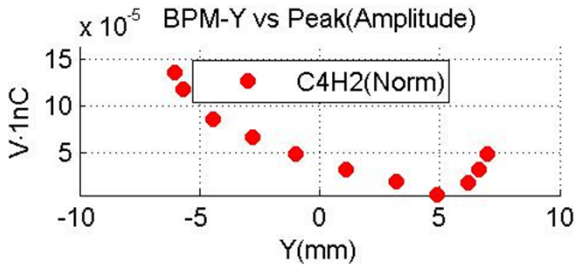


Below cutoff (theory) ← **4137.27MHz**

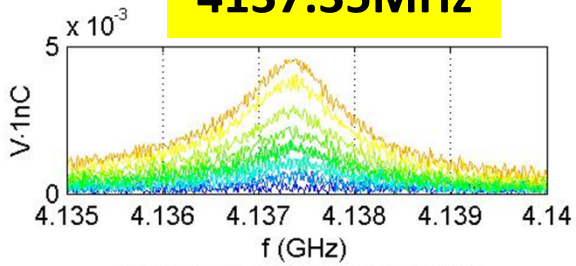


Peak: 4137.27MHz; std: 115kHz

Y

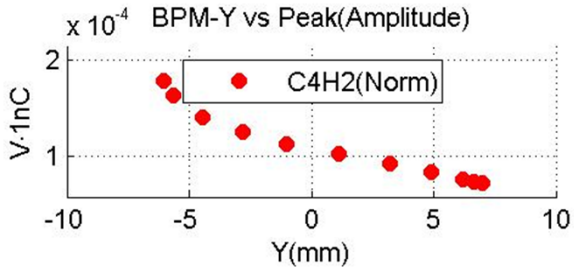


4137.35MHz → **Below cutoff (theory)**

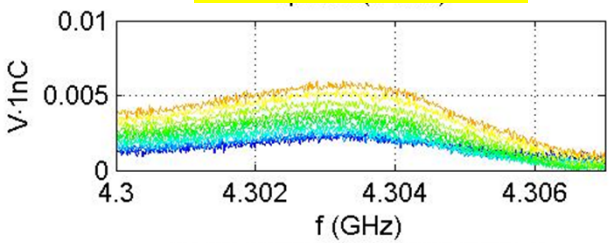


Peak: 4137.35MHz; std: 35kHz

Y

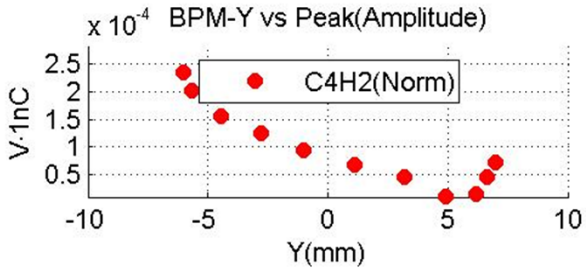


Below cutoff (theory) ← **4302.82MHz**

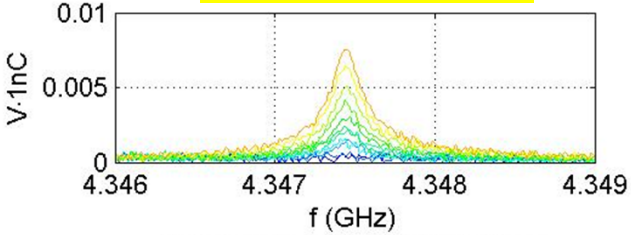


Peak: 4302.82MHz; std: 143kHz

Y



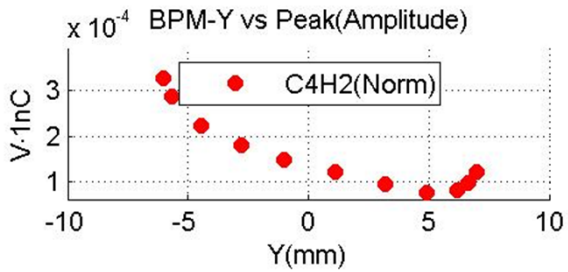
4347.36MHz → **Below cutoff (theory)**



Peak: 4347.36MHz; std: 190kHz

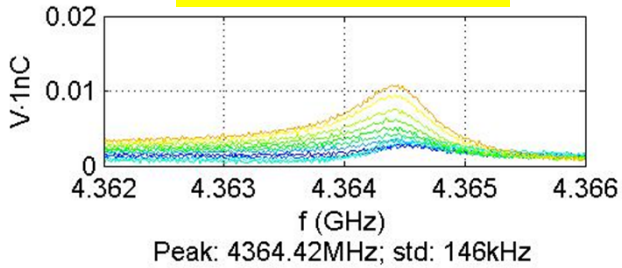
More Dependences (C4H2)

Y

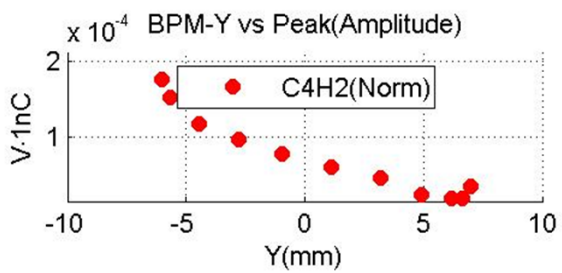


Below cutoff (theory)

4364.42MHz

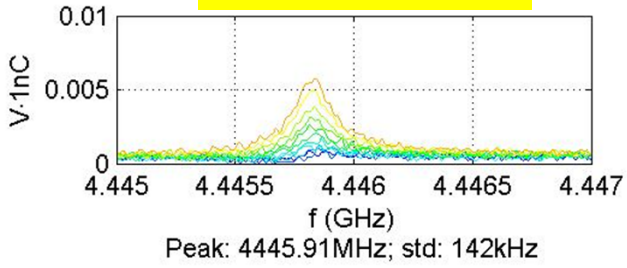


Y

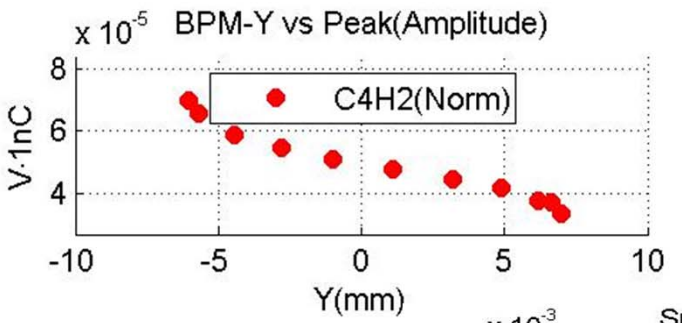


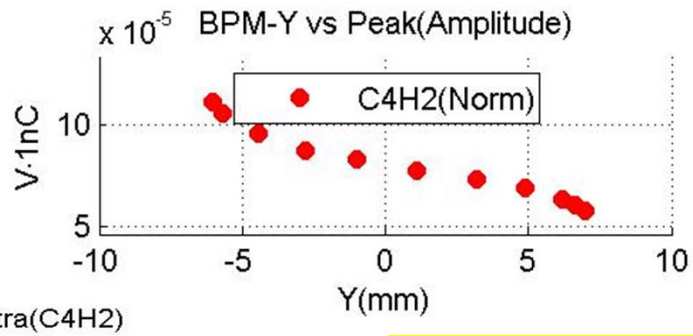
4445.91MHz

Above cutoff (theory)



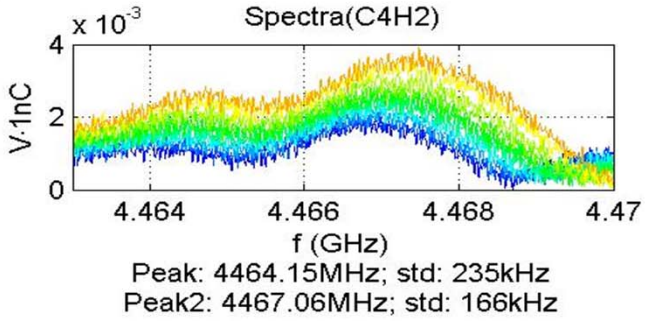
Y





4464.15MHz

Above cutoff (theory)



4467.06MHz

Above cutoff (theory)

Summary & Outlook

- **Single cavity and module-based analysis w/o beam**
- **First beam measurement on ACC39 performed**

  - HOM signal recorded (RSA, Scope)

  - beam-excited monopole, dipole and quadrupole observed

  - transmission from other accelerating module observed
- **First HOM dependence on beam offset observed**
- **Detailed beam measurement required**

  - investigate suitable mode(s) for diagnostics electronics

  - design electronics for HOM-BPM

BK: Measurement Scheme

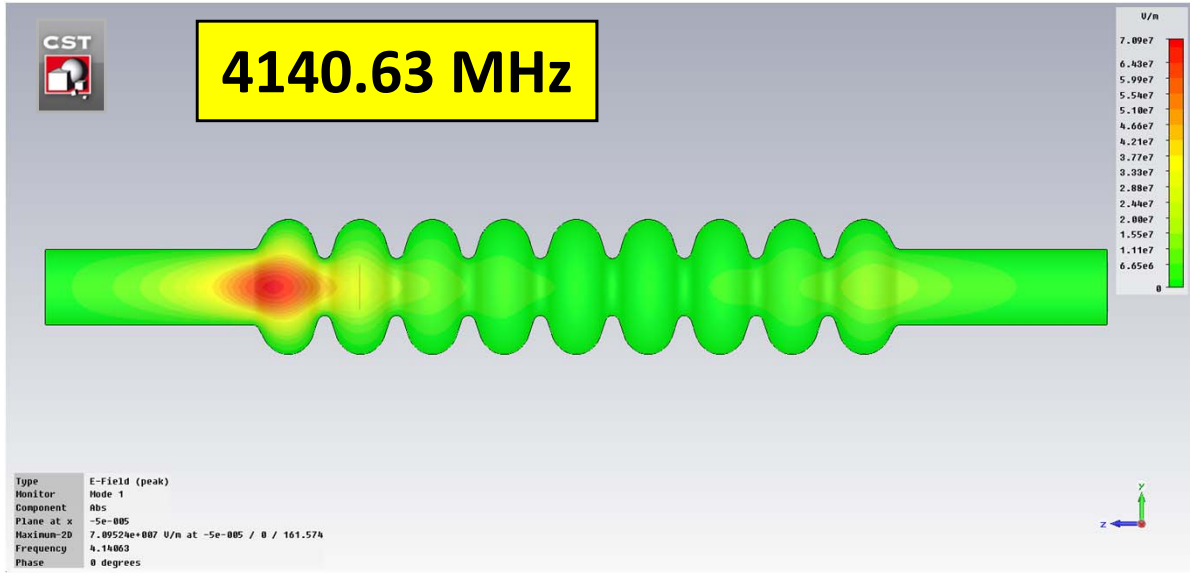
Couplers measured	C4H1, C4H2
Frequency range	4.0GHz ~ 4.5GHz
Frequency interval	50MHz
RBW	22kHz
Frequency step	5kHz

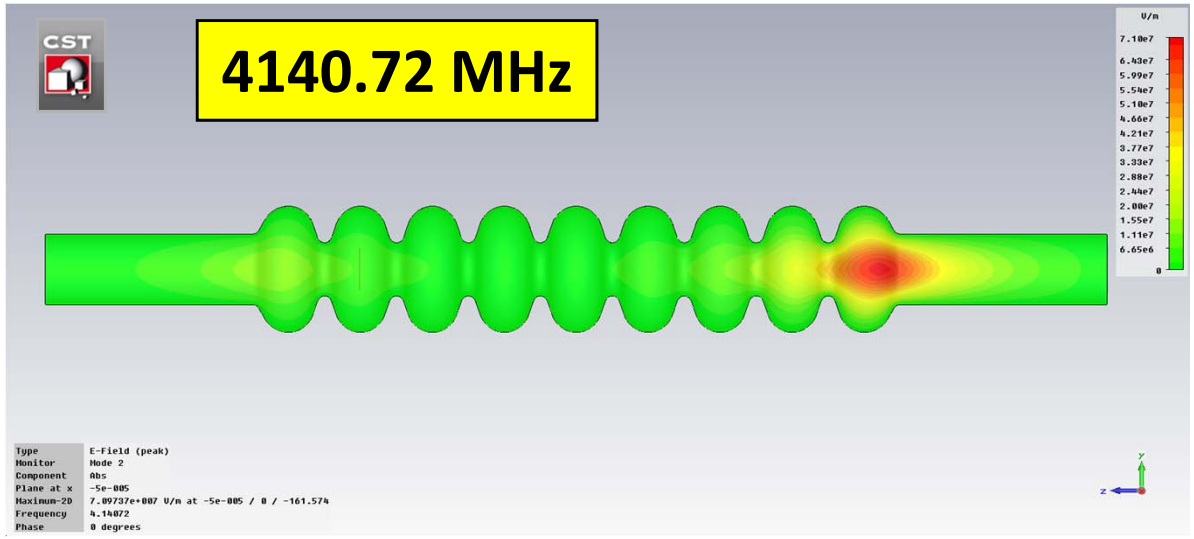
Beampipe Cutoff
4.39GHz

Horizontal move	**15** beam positions
BpmX move range	-6.680mm ~ 7.208mm
Total X move	13.9mm
Average separation	~ 0.9mm
BpmX jitter	< 60µm (~ 7%)
BpmY jitter	< 45µm
Time (incl. magnet move)	25 min.

Vertical move	**13** beam positions
BpmY move range	-6.039mm ~ 7.000mm
Total X move	13.0mm
Average separation	~ 1.0mm
BpmX jitter	< 65µm
BpmY jitter	< 20µm (~ 2%)
Time (incl. magnet move)	5 min.

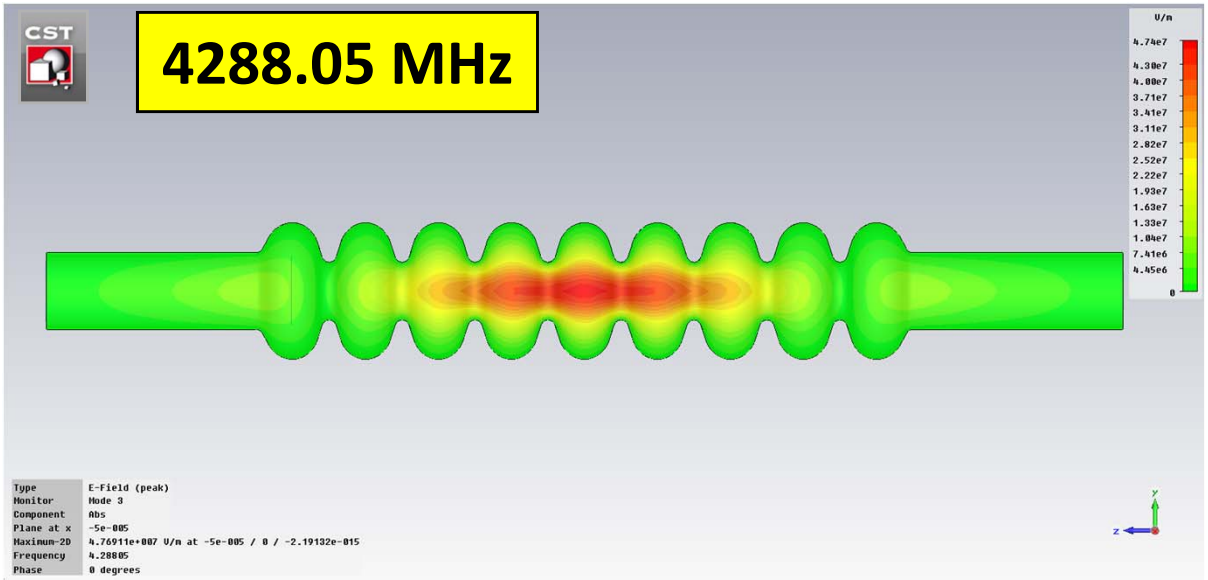
BK: Beampipe Modes

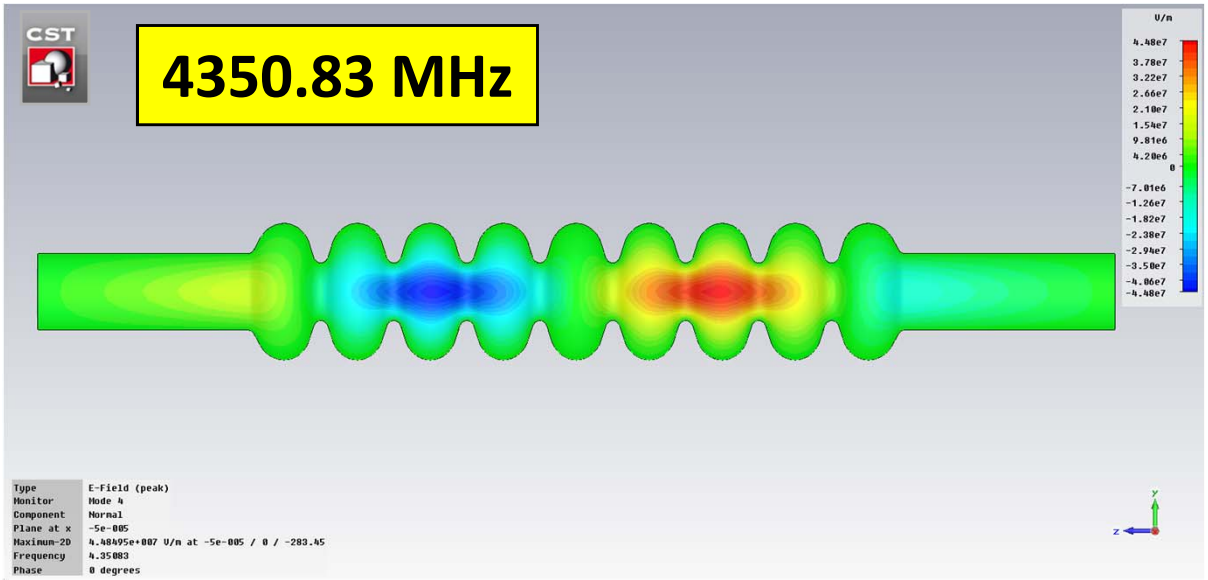




Mode	*f* (MHz)	R/Q (Ω/cm^2)
BP1	4140.63	0.558
BP2	4140.72	0.977

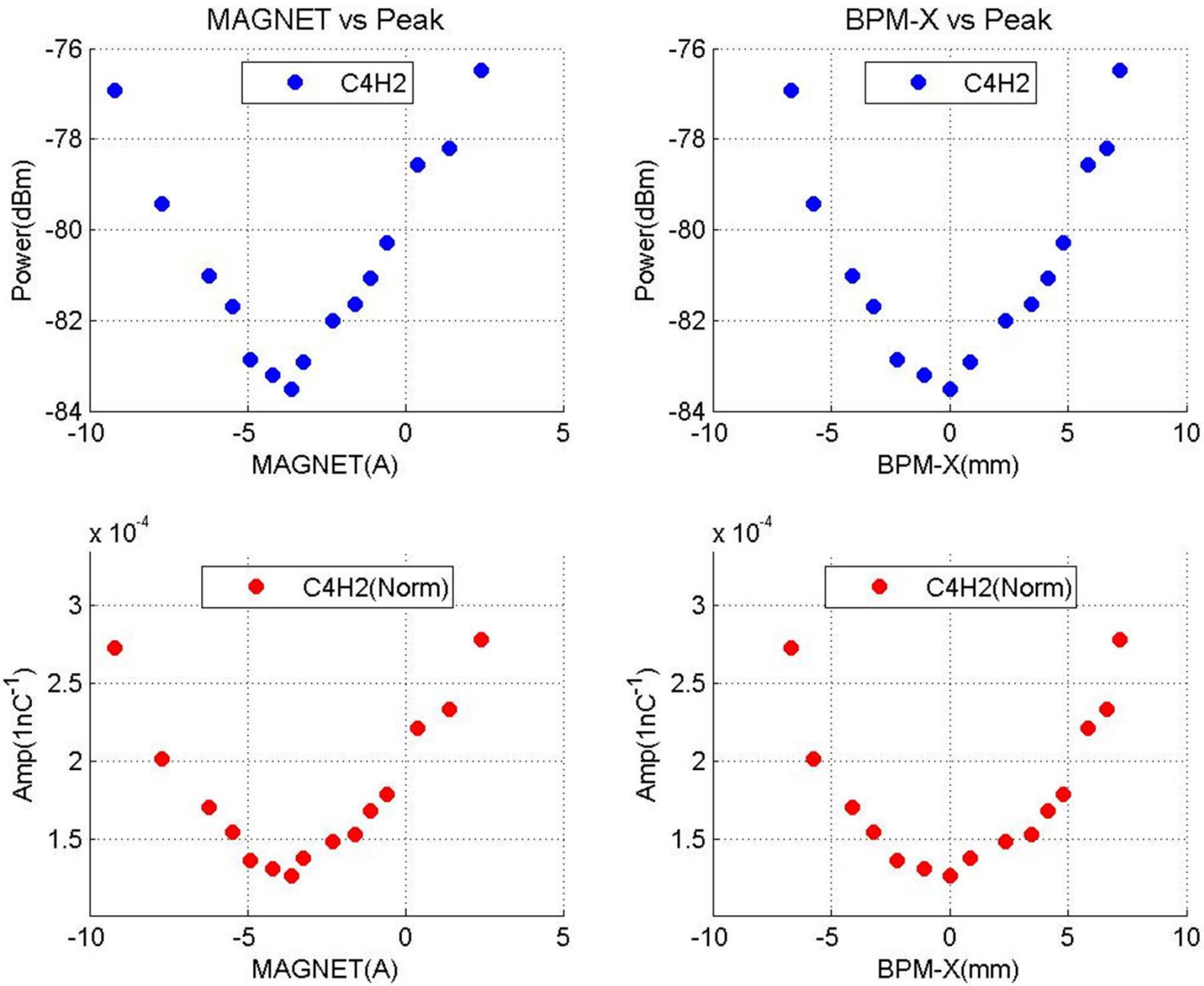
BK: Dipole Modes Below Cutoff



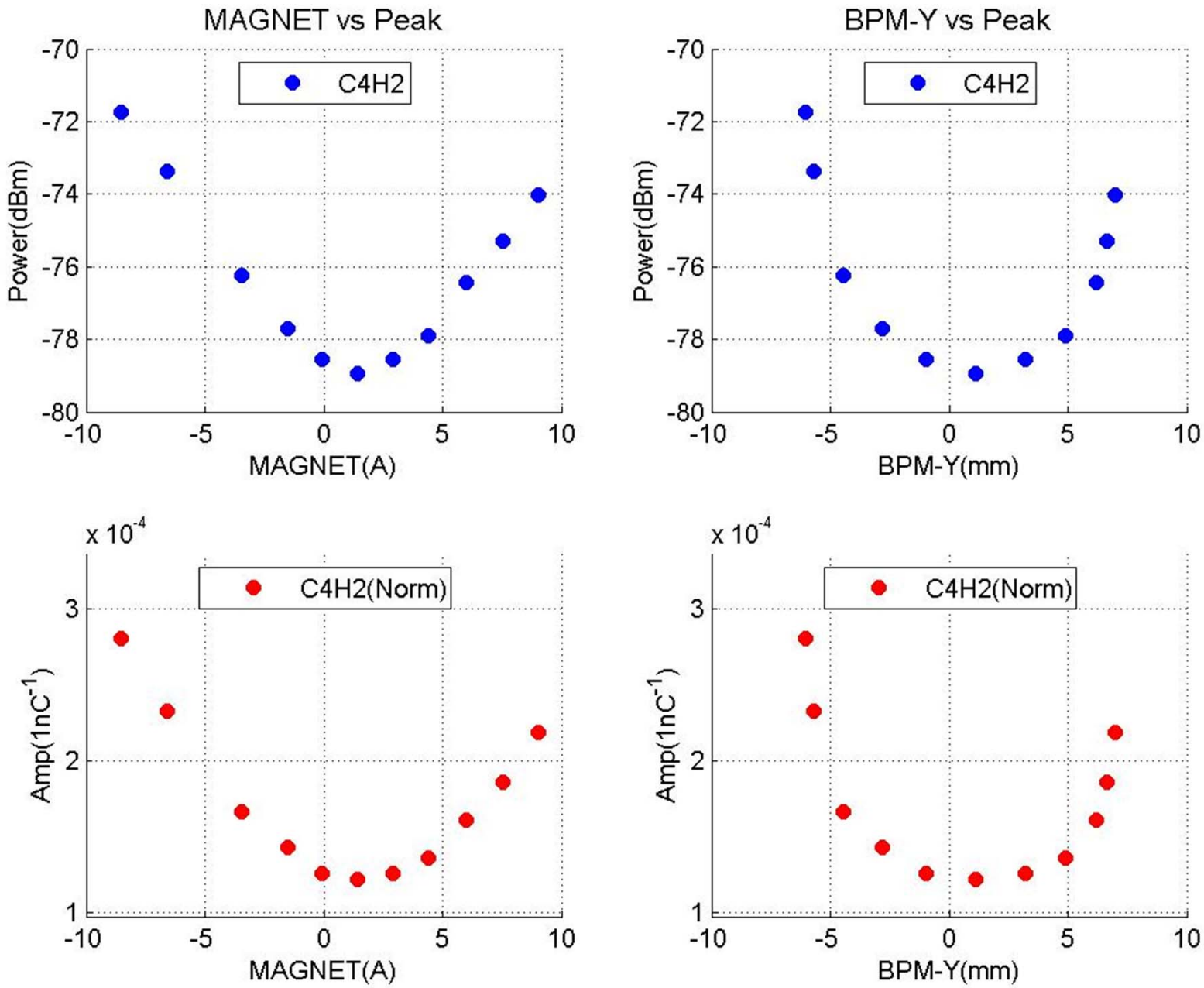


Mode	*f* (MHz)	R/Q (Ω/cm^2)
BP1	4140.63	0.558
BP2	4140.72	0.977
D1	4288.05	0.002
D2	4350.83	0.292

BK: Magnet Current vs. BPM-X



BK: Magnet Current vs. BPM-Y



BK: BPM Saturation