Cavity Higher-Order-Mode Analysis

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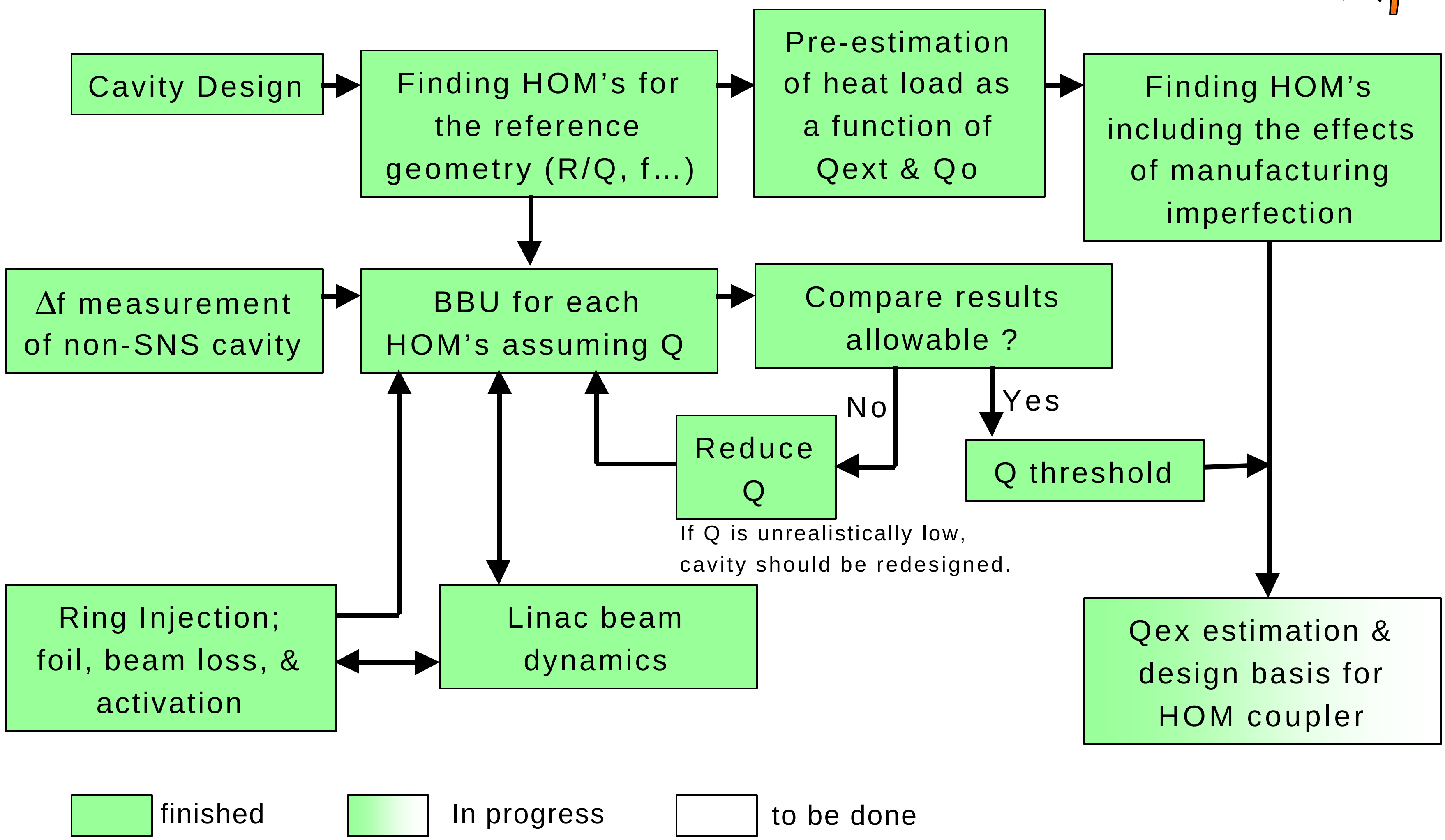
Outlines

- HOM issues
  - Beam breakup (BBU)
    - Transverse
    - Longitudinal
  - HOM power

- Objectives
  - Figuring out HOM's and trapped modes
    - R/Q, f, field profile…
  - Beam Breakup (BBU) simulation due to HOM's
    - Establish Q limits for each HOM
  - Heat Loads estimation
    - To HOM couplers and cavities
  - Design Basis for HOM coupler
    - Estimating damping levels and finding trapped modes including cavity manufacturing imperfection

HOM Analysis



Principal Participants

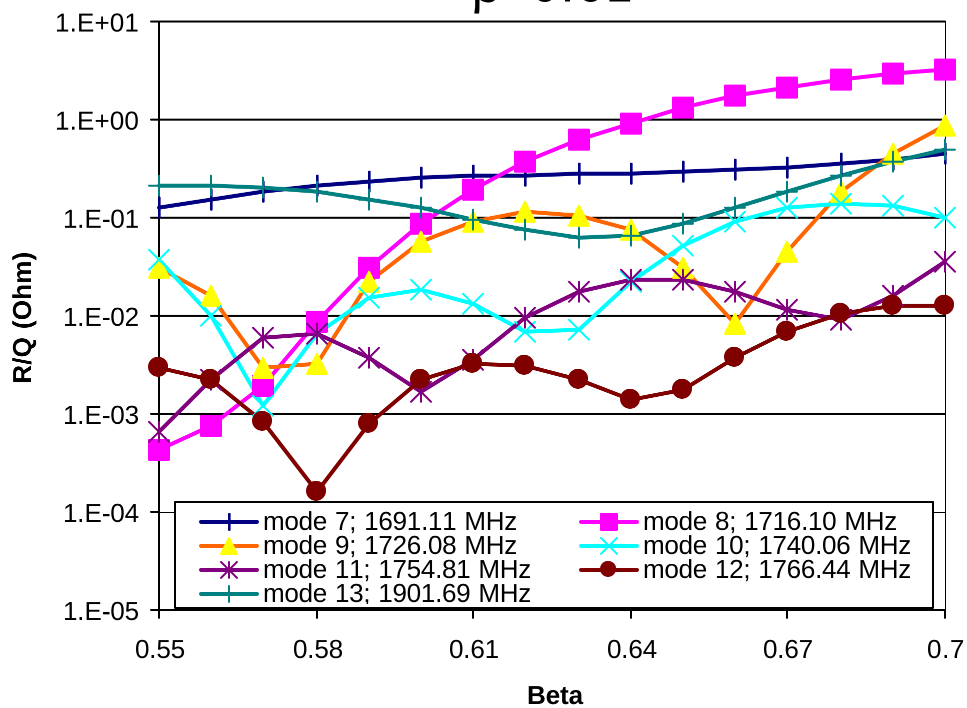
- Ron Sundelin
  - Transverse BBU
  - Longitudinal BBU
  - HOM power
- Dong-o Jeon
  - Transverse BBU
  - Longitudinal BBU
- Sang-ho Kim & Marc Doleans
  - Finding HOM's
    - R/Q, Stored Energy, Mechanical imperfection effect..
  - HOM power
  - Qex estimation for each HOM (to be done)

HOM vs. b

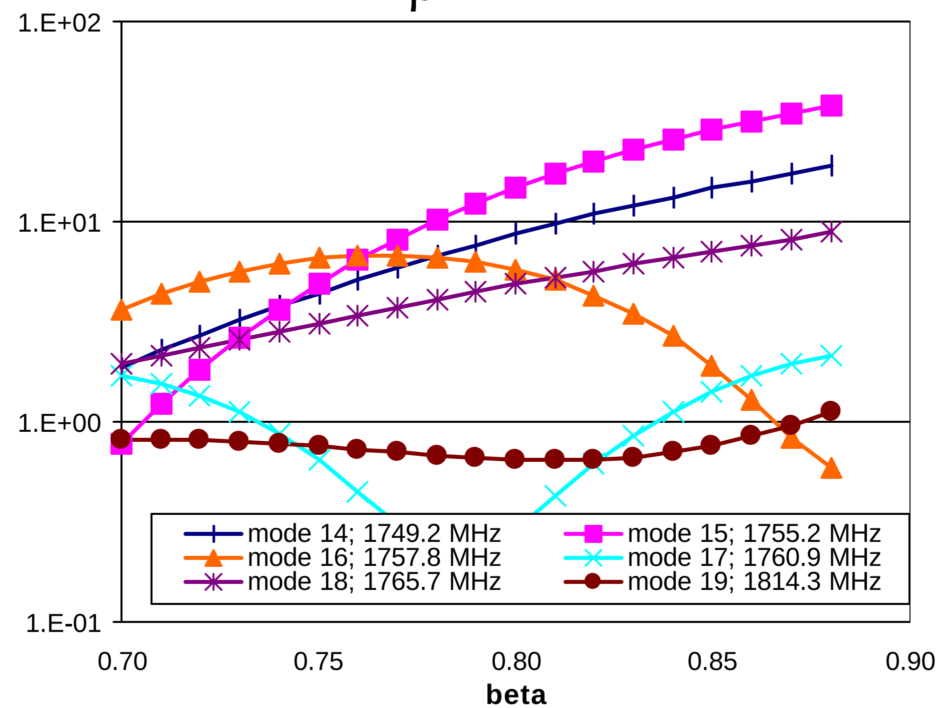
R/Q vs β; TM monopoles (40), Dipole (45), Quadrupoles (30), and Sextupoles (18) for each betas

Examples (TM monopoles)

β=0.61

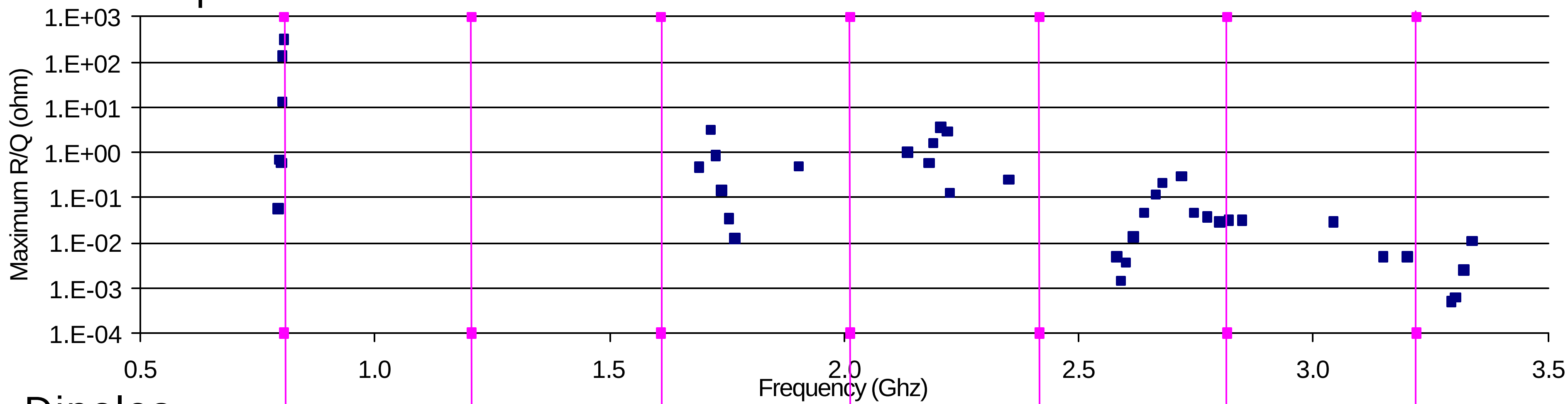


β=0.81

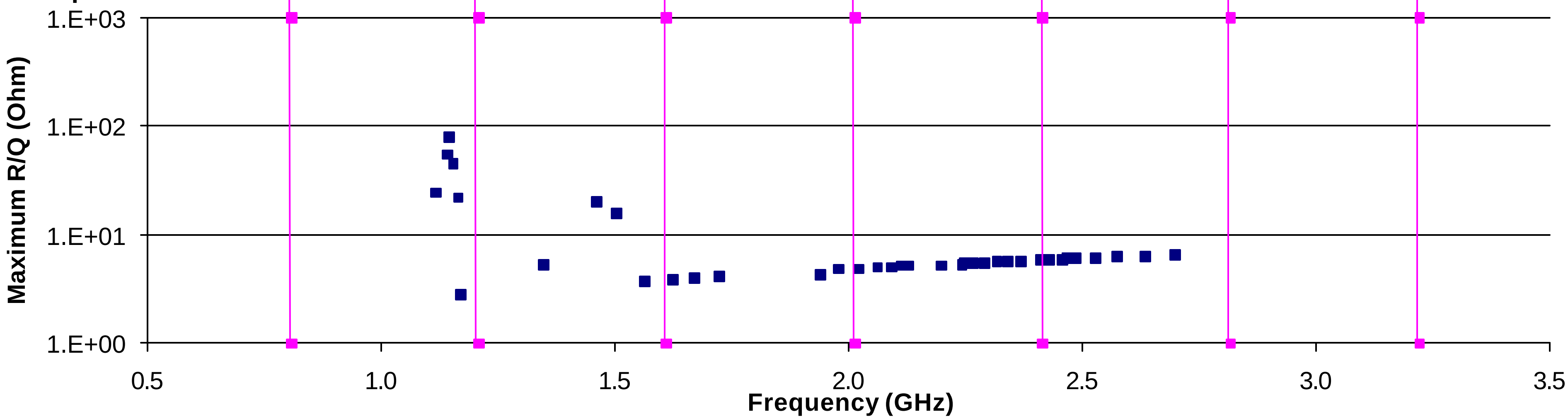


HOM Distribution (ex. medium beta cavity)

TM Monopoles



Dipoles



Trapped Modes (ex. High beta cavity)

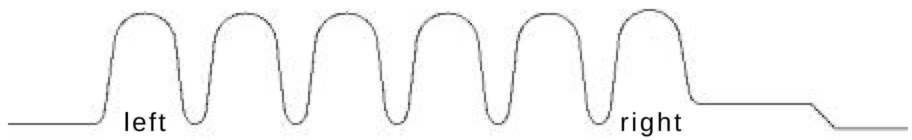
- Trapped mode; difficult to extract by the HOM coupler
  for monopole; stored energy in both end cell combined<0.1 %
  for multipoles; stored energy in each end cell<0.1 % (2 polarization)
- Two HOM couplers are planned for each cavity (one at each end)
- Including manufacturing imperfection

TM Monopoles (possibly trapped)

mode no.	frequency	total %
15	1.7546E+09	2.54E-01
16	1.7588E+09	8.91E-01

Dipoles

mode no.	frequency	right %	left %	total %
1	1.1037E+09	9.97E+01	**1.26E-08**	9.97E+01
13	1.4848E+09	9.74E+01	**9.58E-05**	9.74E+01
19	1.8176E+09	9.33E+01	**8.99E-04**	9.33E+01
20	1.8363E+09	**2.47E-08**	9.78E+01	9.78E+01
27	2.0800E+09	3.23E+01	**3.03E-03**	3.23E+01
32	2.1161E+09	**2.37E-02**	8.16E+01	8.16E+01
33	2.1243E+09	9.25E+01	**7.75E-04**	9.25E+01
34	2.1865E+09	4.63E+01	**1.95E-03**	4.64E+01



Quadrupoles

mode no.	frequency	right %	left %	total %
1	1.52443E+09	9.99E+01	**3.32E-09**	9.99E+01
2	1.55870E+09	**5.80E-02**	2.38E+00	2.43E+00
6	1.56571E+09	**2.37E-02**	3.59E+01	3.59E+01
7	1.60687E+09	9.88E+01	**4.42E-07**	9.88E+01
8	1.66181E+09	**9.54E-02**	1.57E+00	1.67E+00
12	1.67829E+09	**4.21E-04**	7.86E+01	7.86E+01
13	2.07735E+09	9.98E+01	**4.16E-07**	9.98E+01
19	2.24853E+09	8.83E+01	**1.90E-02**	8.84E+01
20	2.37723E+09	9.93E+01	**2.78E-04**	9.93E+01

Sextupoles; all modes are trapped

HOM frequency properties

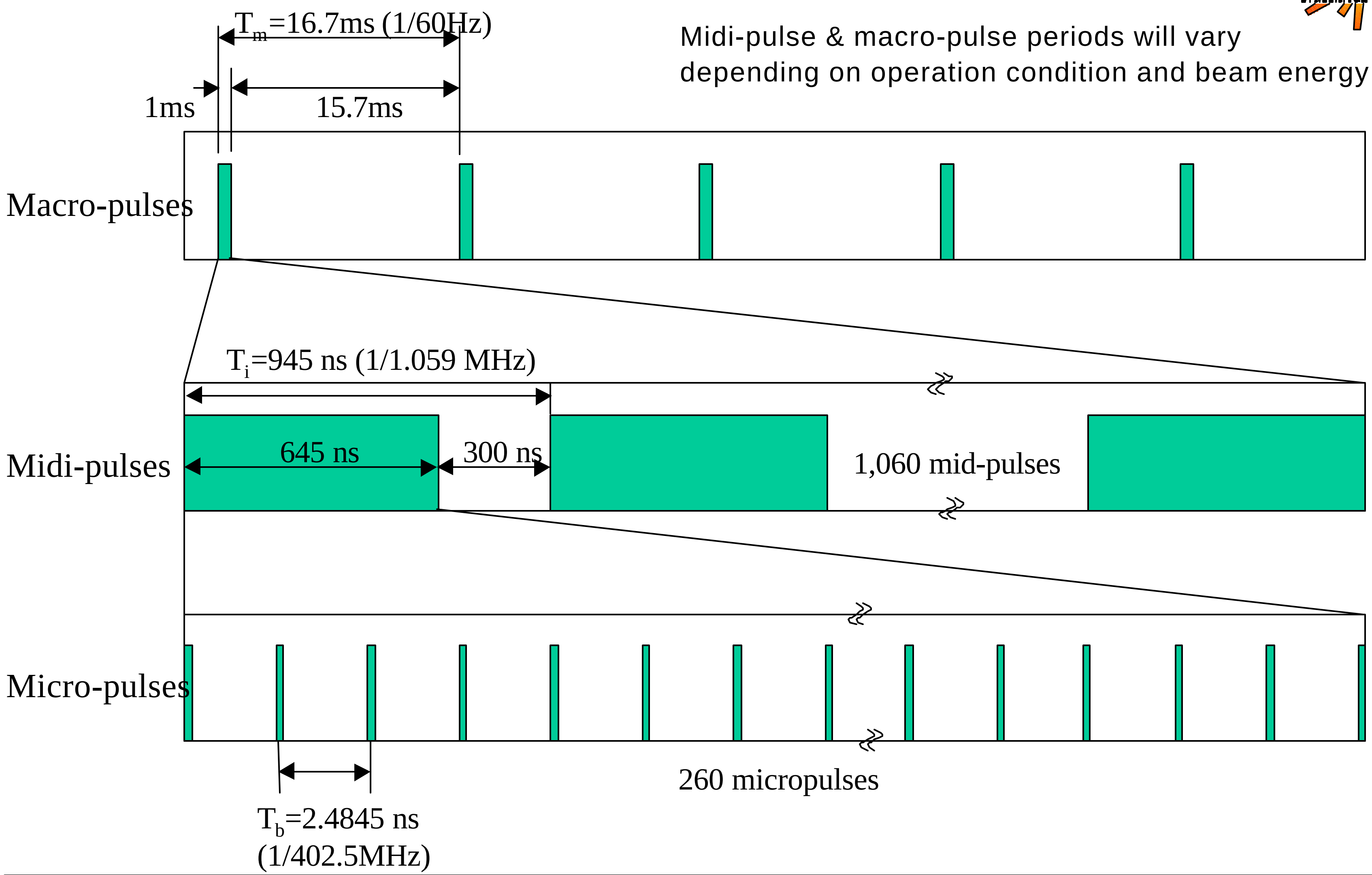
- Frequency spreads (cavity to cavity) reduce beam dynamics problem
  - Results from Cornell study with tuned fundamental mode
    - $\sigma=0.00109*|f_n-f_o|$, here 0.2 x σ is used for frequency spread
- Differences between measured frequency centroids and calculations
  - HOMs
    - $\pm$0.00376 maximum fractional error (from Cornell study)
    - $\pm$0.008 maximum is used for SNS (more possibility to hit the resonance line; will be mentioned later)
  - Other fundamental passband members (from Cornell study)

$$\left| \frac{f_{meas.} - f_{calc.}}{f_{calc.}} \cdot \frac{f_{Pi.}}{f_{Pi.} - f_{passband}} \right| \leq 0.027$$

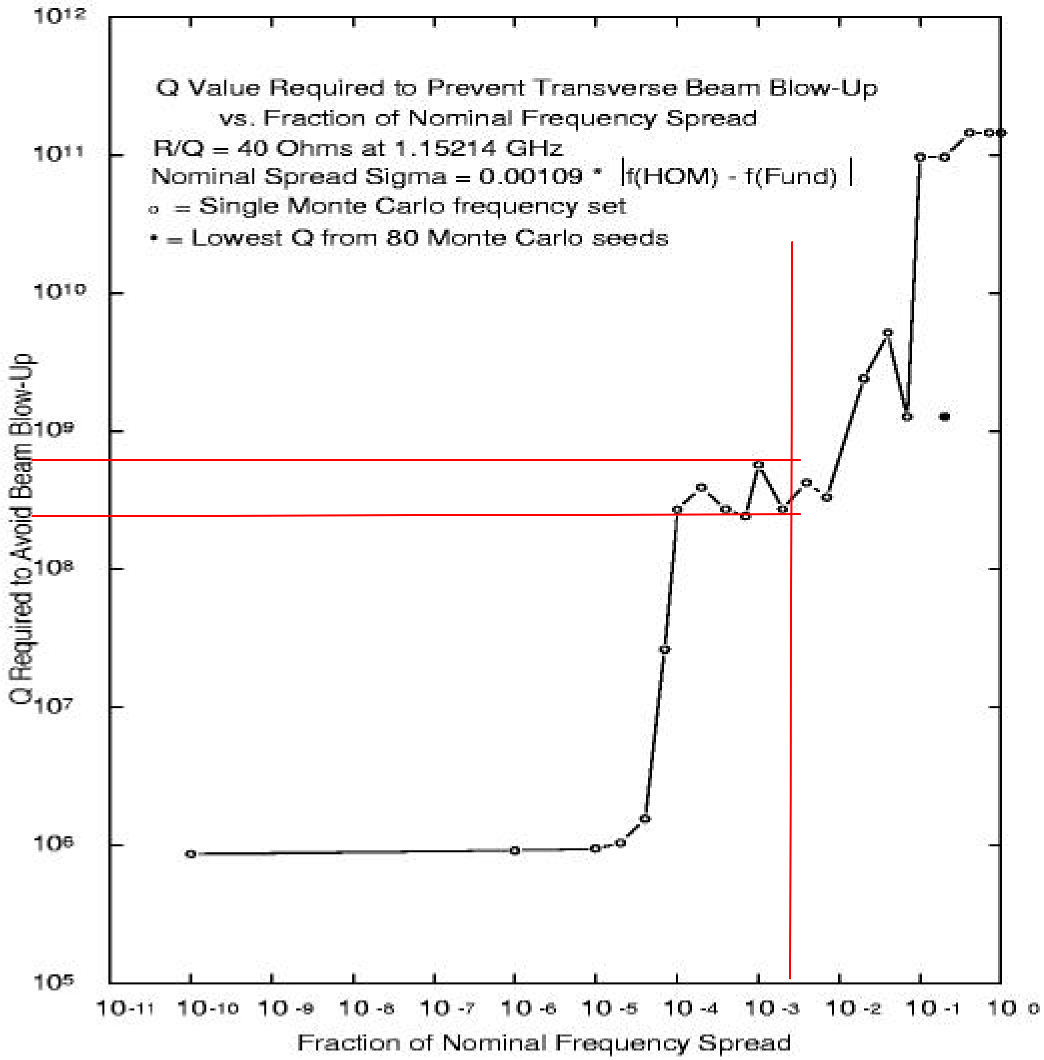
2.5 times is used for SNS

Time structure of SNS beam (for 1 GeV operation)

Midi-pulse & macro-pulse periods will vary depending on operation condition and beam energy



Transverse BBU (I)



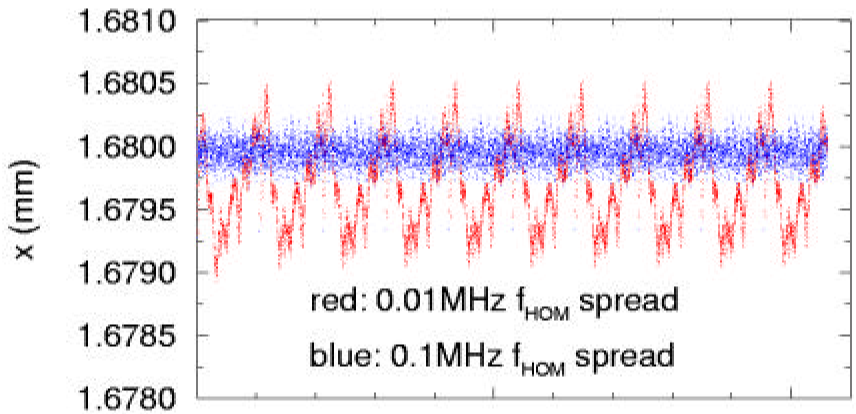
Threshold Q to avoid beam Blow-up;

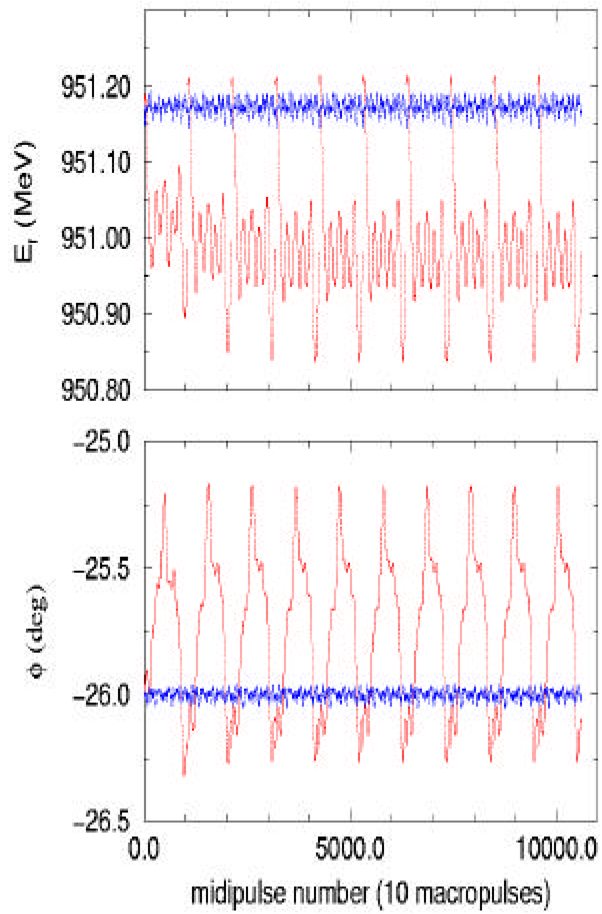
R/Q=40 Ohm for all cavities (high & medium)

Same frequency centroid for high and medium beta

Q<10^8, & 0.00109 nominal Frequency spread ; No beam blow-up

Transverse BBU (II)





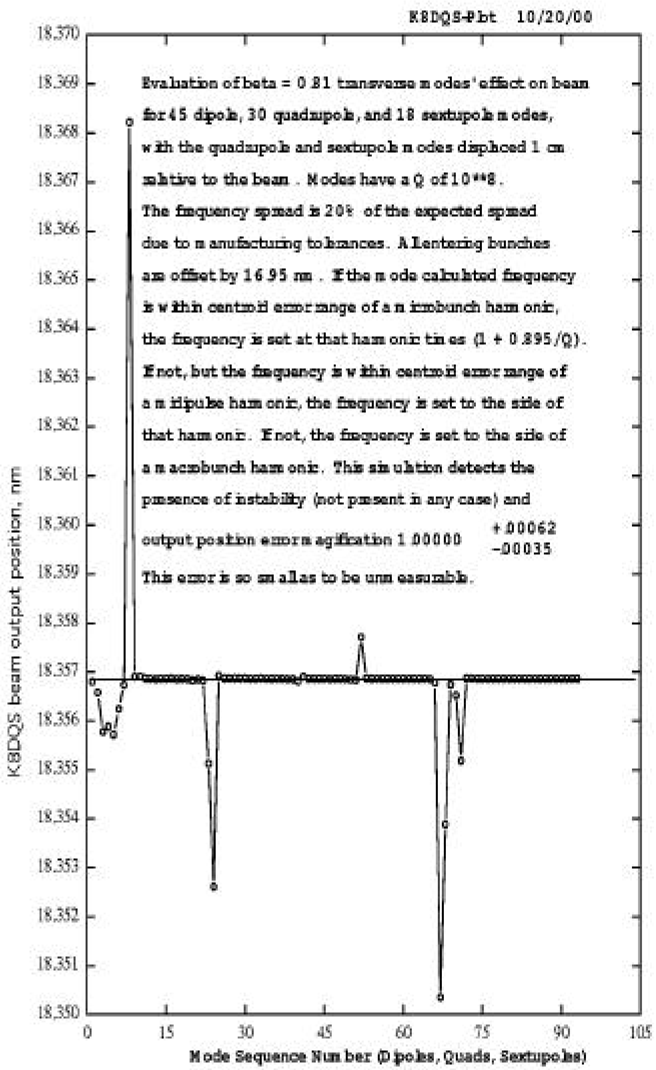
Five most dangerous modes with Qex=10^8

20% of nominal frequency spread of 2.5 GHz ;~0.35 MHz

Even with about 6 % of nominal frequency spread

→No measurable transverse instability

Transverse BBU (III)



Input;

Q=10^8,

Frequency spread; 20 % of nominal value,

45 dipoles, 30 quadrupoles, 18 sextupoles with calculated R/Q(β)

entering bunch offset; 16.95 nm

Frequency centroid shift ; to resonance frequency

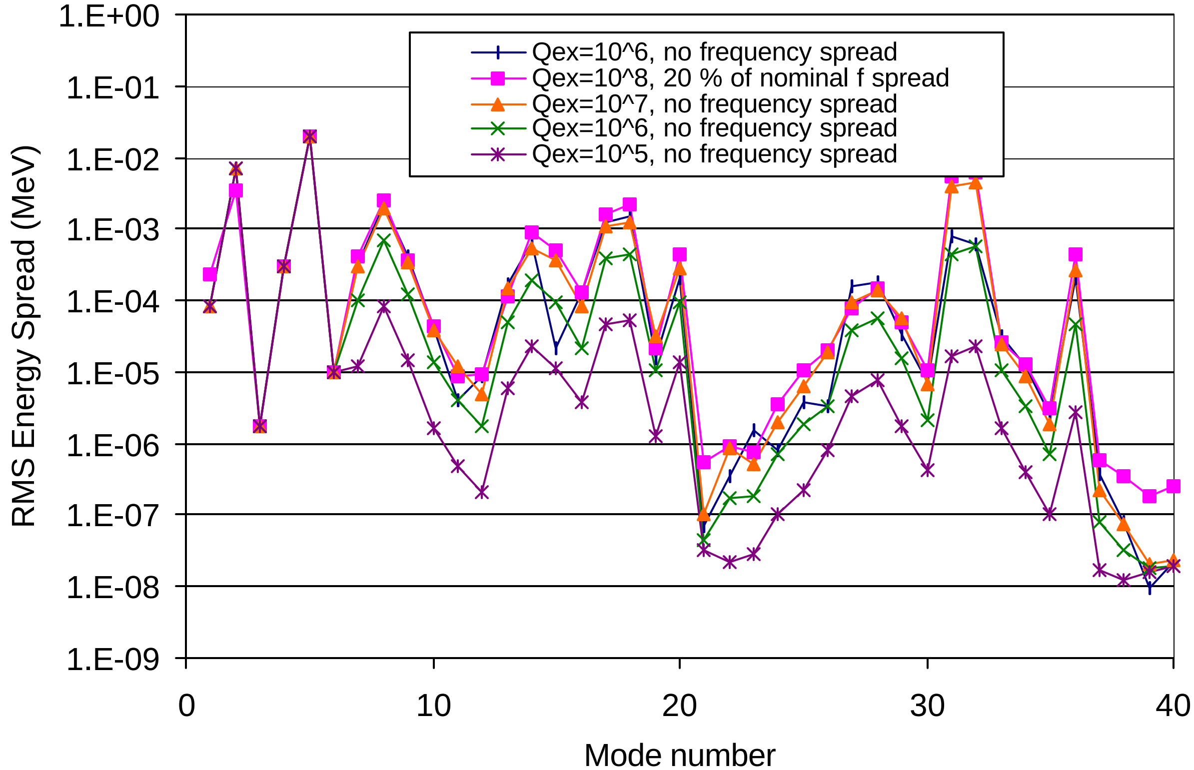
Result;

output position error; 1.00000+0.00062 -0.00035

(unmeasurable)

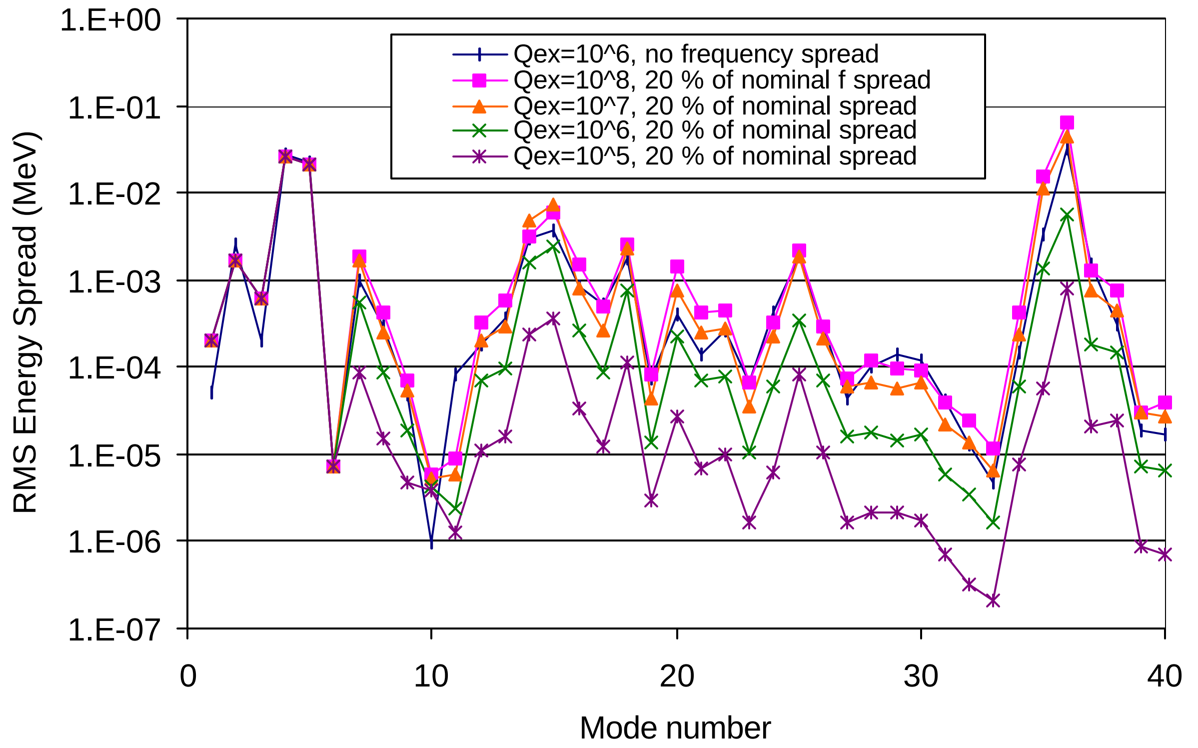
Longitudinal BBU (I)

Medium Beta; No instability was found until Qex=10^8
& 20% of nominal frequency spread



Longitudinal BBU (II)

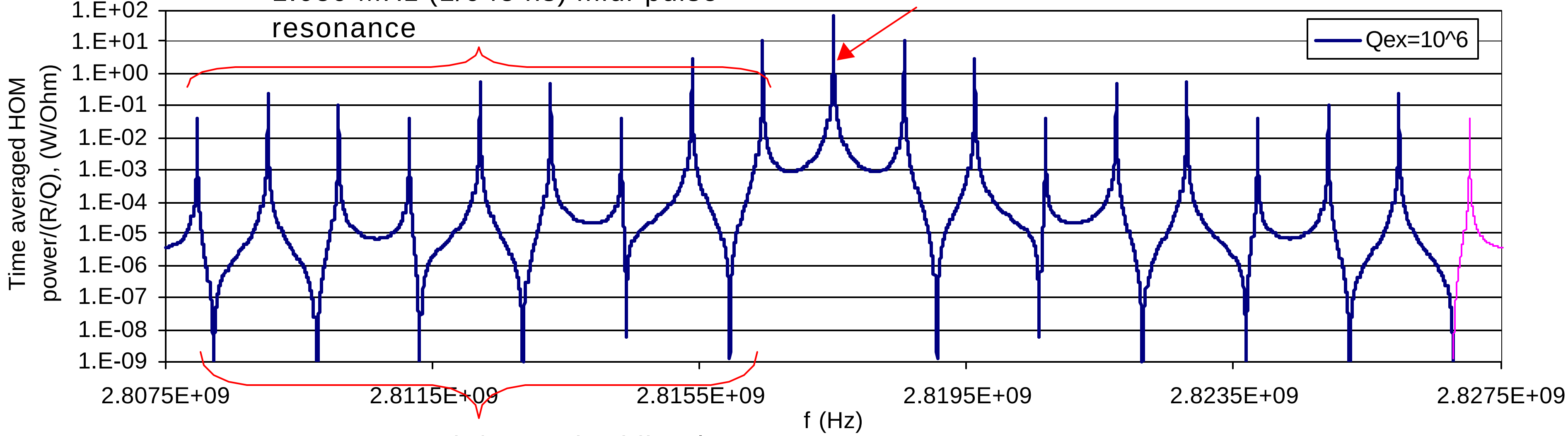
High Beta; No instability was found until Qex=10^8
& 20% of nominal frequency spread



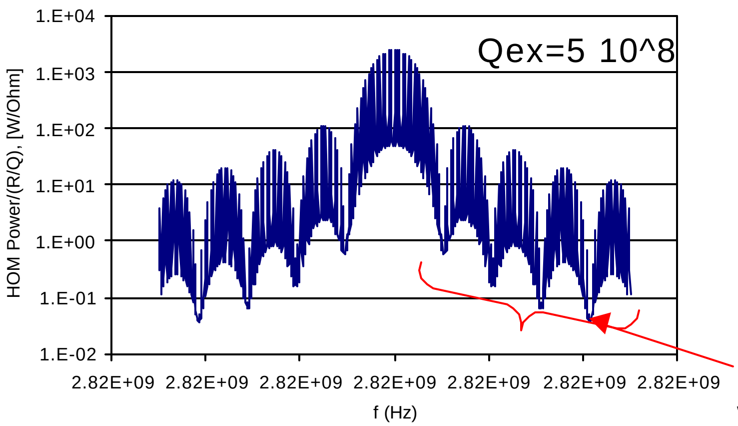
Frequency dependencies of HOM power

1.059 MHz (1/945 ns) midi-pulse resonance

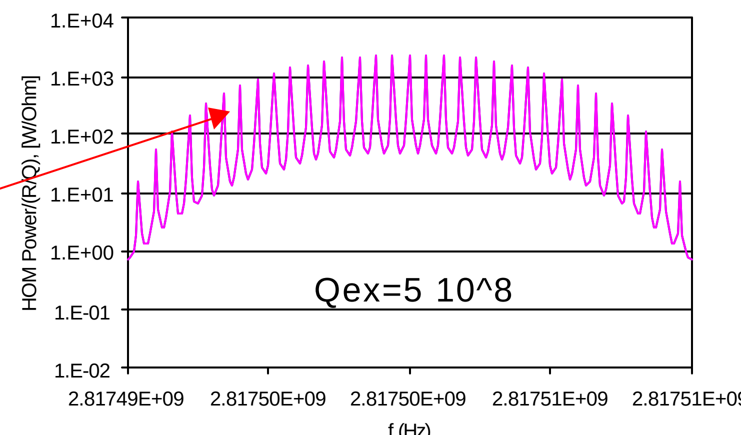
402.5 MHz micro-bunch resonance



1.55 MHz (1/645 ns) midi-pulse without gap anti-resonance

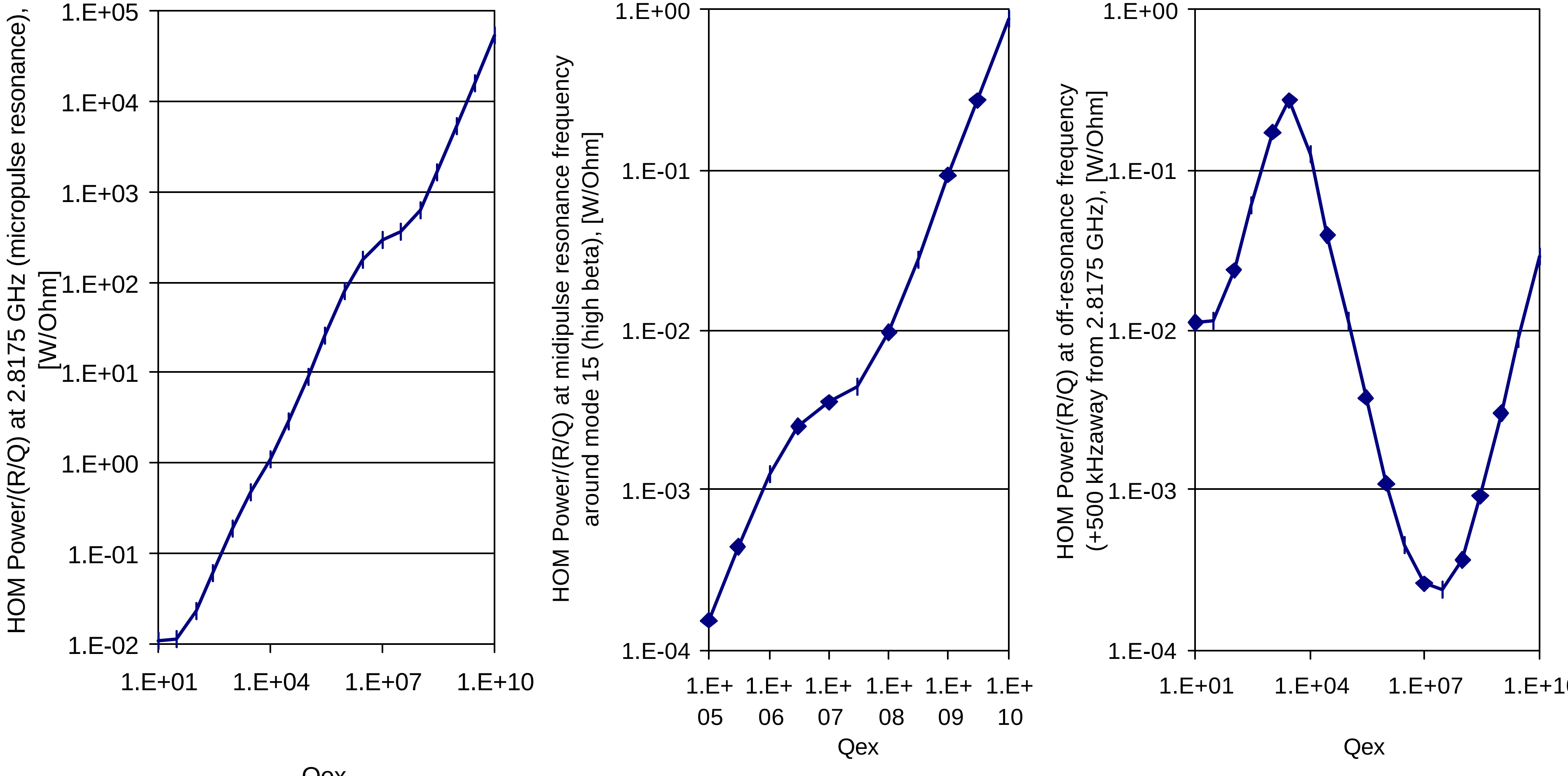


60 Hz (1/16.7ms) Macro-pulse resonance



1 kHz (1/1ms) macro-pulse without gap anti-resonance

Q dependencies of HOM power

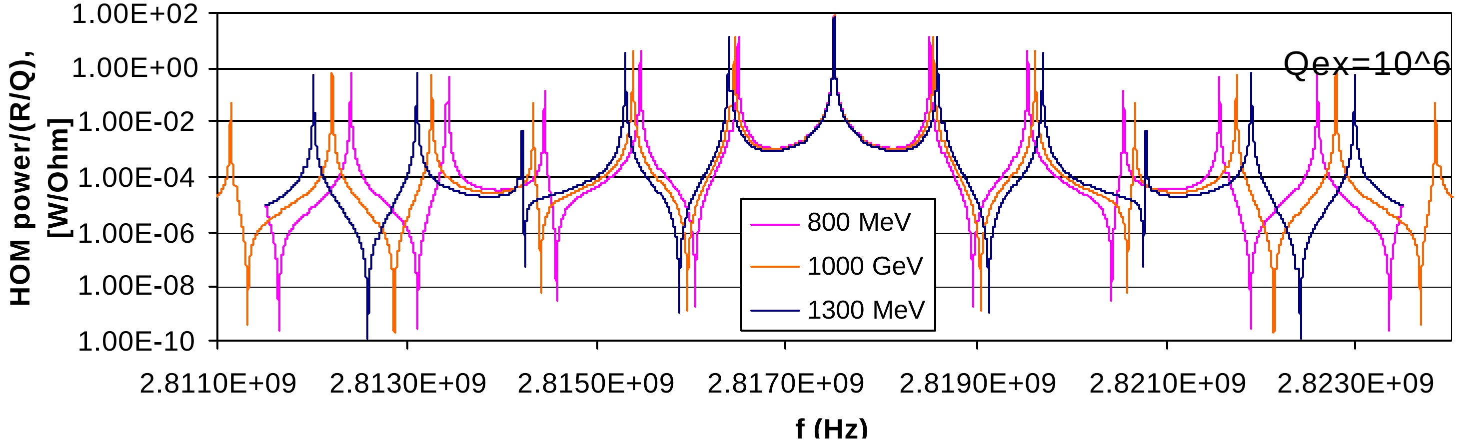


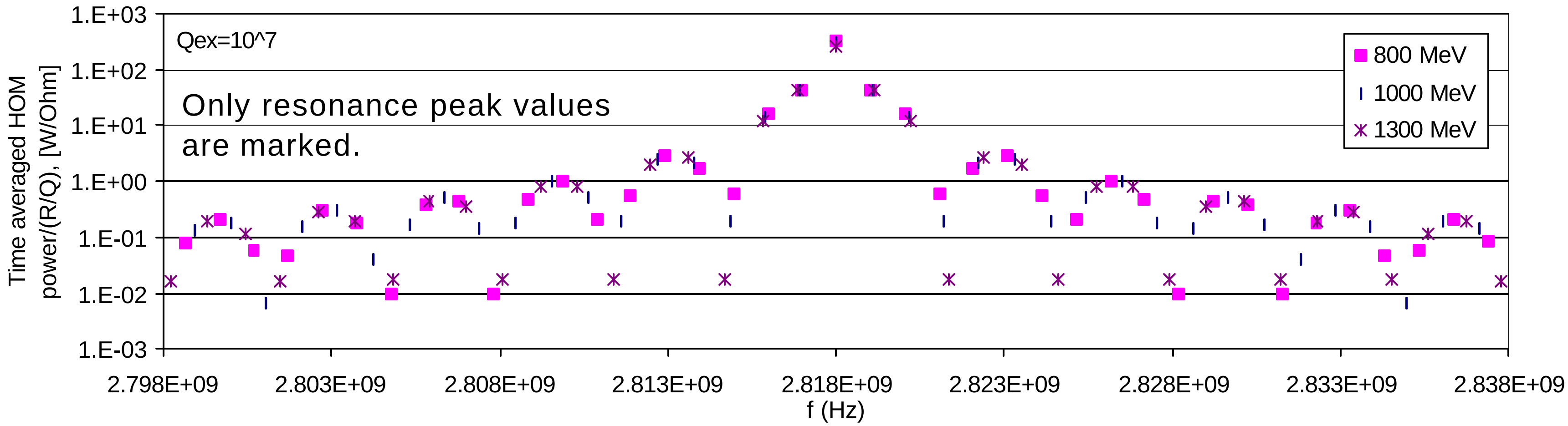
Micro-pulse resonance

Midi-pulse resonance
Around trapped mode

Far away from any resonance

Effect of time structure change





Midi-pulse period is determined by the ring revolution time.

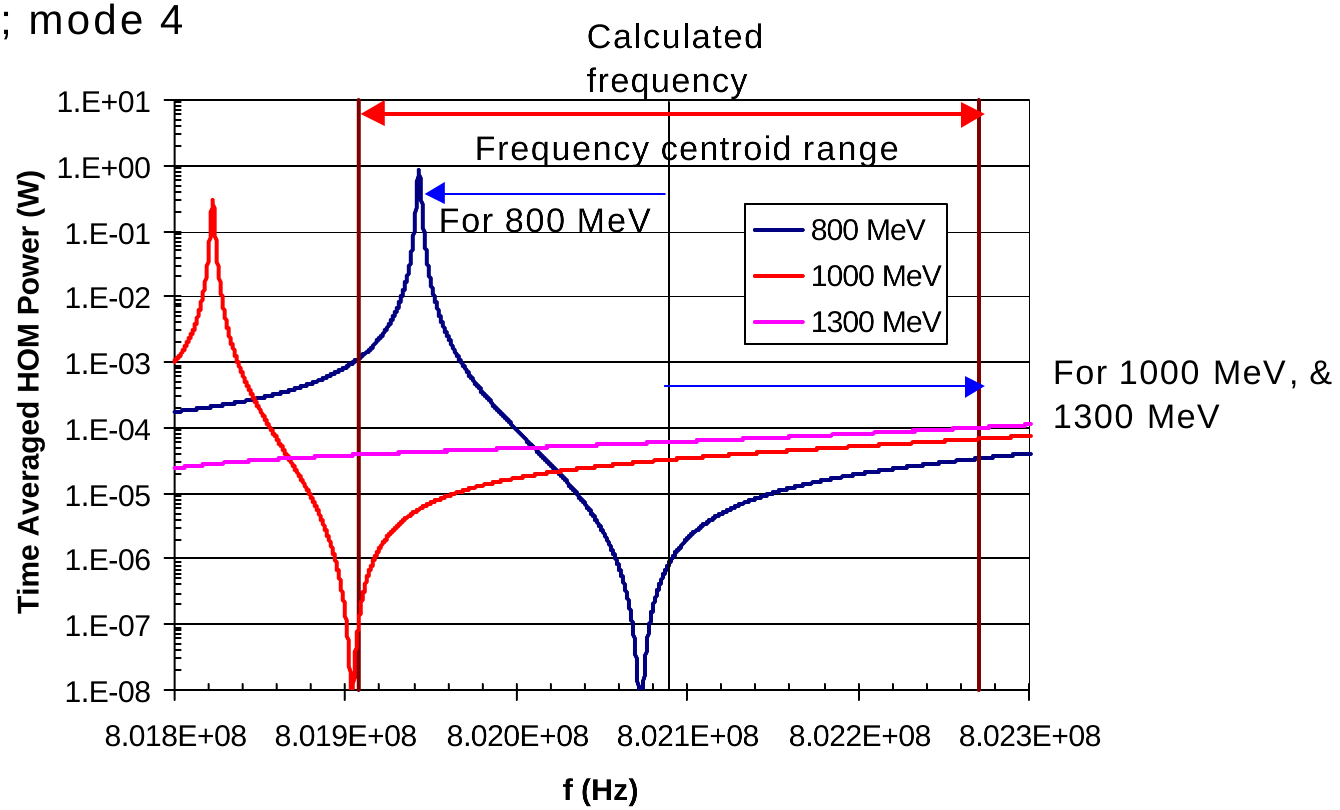
The probabilities to hit the resonance line will increase (not at the same time).

But heights of midipulse resonances decrease exponentially from the micropulse resonance.

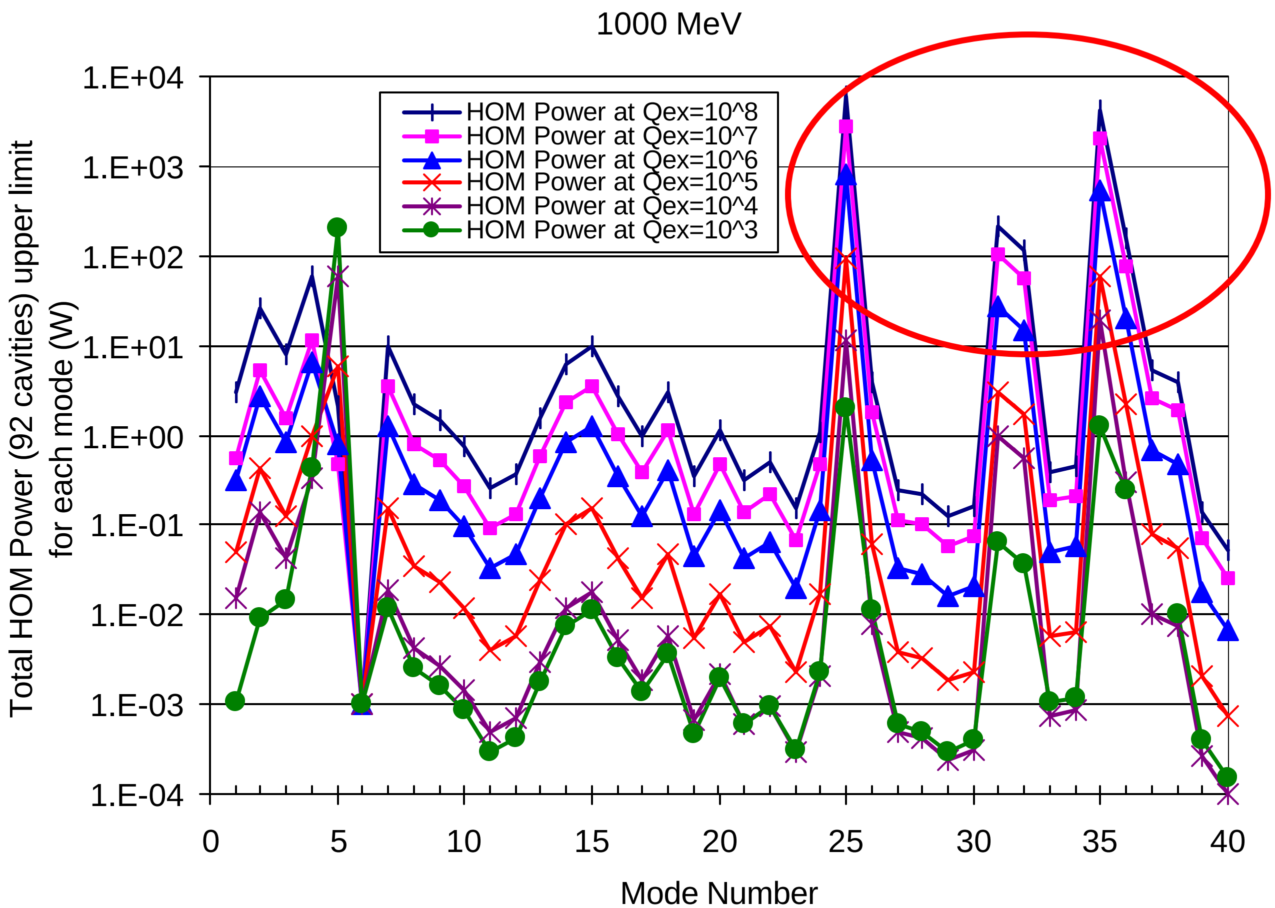
HOM Power (I)

Worst movement of the frequency centroids & without frequency spread ; can provide upper limit of HOM power

Example ; mode 4



HOM Power (II)

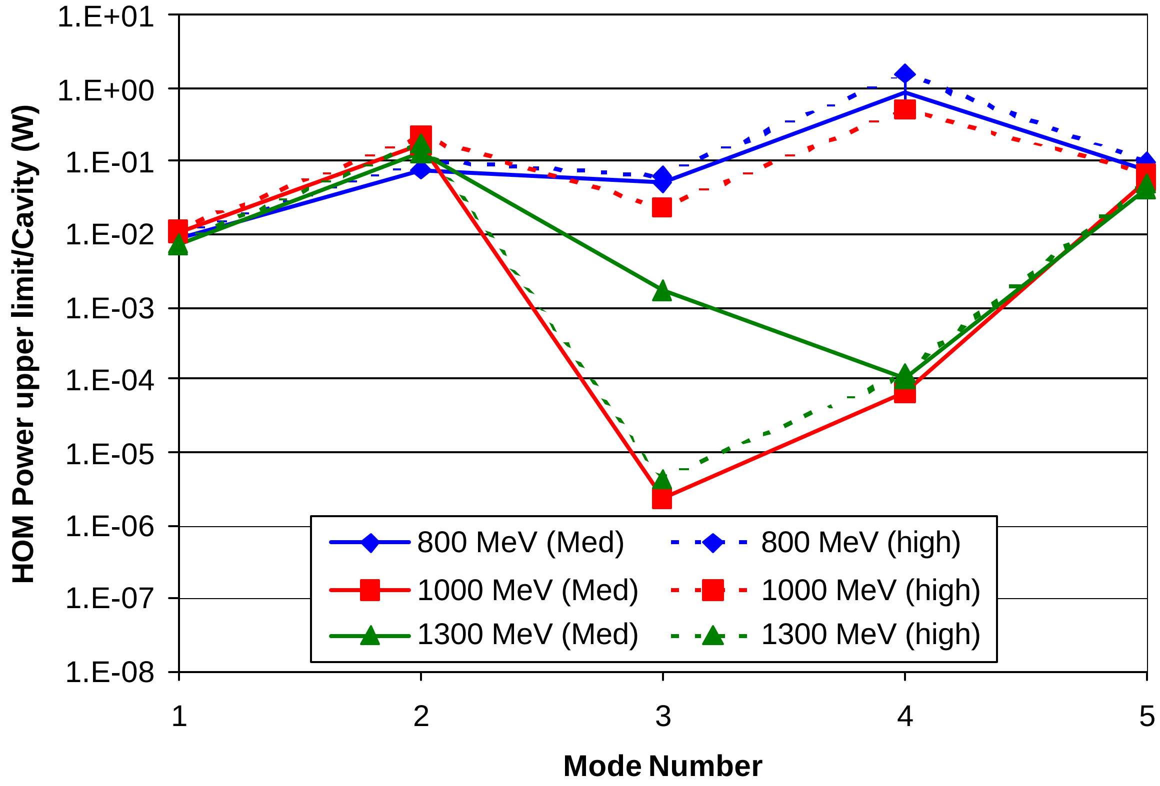


These main peaks come from the micro-pulse resonance.

Micro-pulse resonance bandwidth ; ~ kHz (low probability)

5~6 modes can produce large HOM power. Behaviors are same for different time structures.
Total HOM power decreases by factor of 20~30 with 20 % of nominal frequency spread.

HOM Power of other fundamental passband members



Q's are provided by fundamental power coupler.

(end-cell stored energy ratio comparison with fundamental mode)

It is very important for 5th mode not to hit the resonance line. (high R/Q~140)

SUMMARY

- HOM's for both medium and high beta cavity of reference geometry are identified.
- Transverse BBU
  - $Q<10^8$ and +/-20 % of nominal cavity-to-cavity frequency spread ;no beam blow-up for both medium- and high-beta cavity
- Longitudinal BBU
  - $Q<10^8$ and +/-20 % of nominal cavity-to-cavity frequency spread ; no instability was found.
- Upper limit of HOM power is calculated with very conservative assumption. Damping is required at certain case. (especially for 5 modes near micro-pulse resonance line)
- Coupler development is in progress.
  - Baseline; 2 TESLA HOM couplers per cavity.
  - Damping levels of TESLA HOM coupler will be calculated with MAFIA.
  - Associated power will be determined.