Cornell University

Experience with Microphonics

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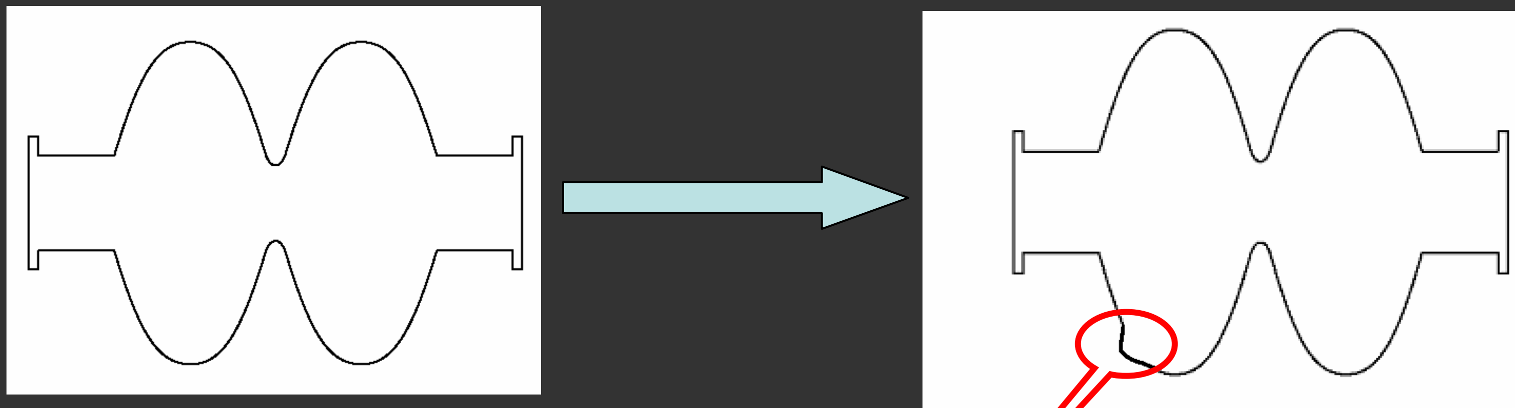
<u>Outline:</u>

- **Microphonics**
- **Why does it matter?**
- **What we know today…**
- **What we don't know…**
- **Outlook**

Microphonics

Deformation of cavity shape:



$\Rightarrow$ Shift in cavity resonance frequency:

(see J.C. Slater, Microwave Electronics, 1950)

$$\frac{\Delta f}{f} \approx \frac{1}{4U} \int_{\Delta V} \left(\mu_0 |H|^2 - \varepsilon_0 |E|^2 \right) dv$$

U: unperturbed stored energy; *E*, *H* cavity field amplitudes

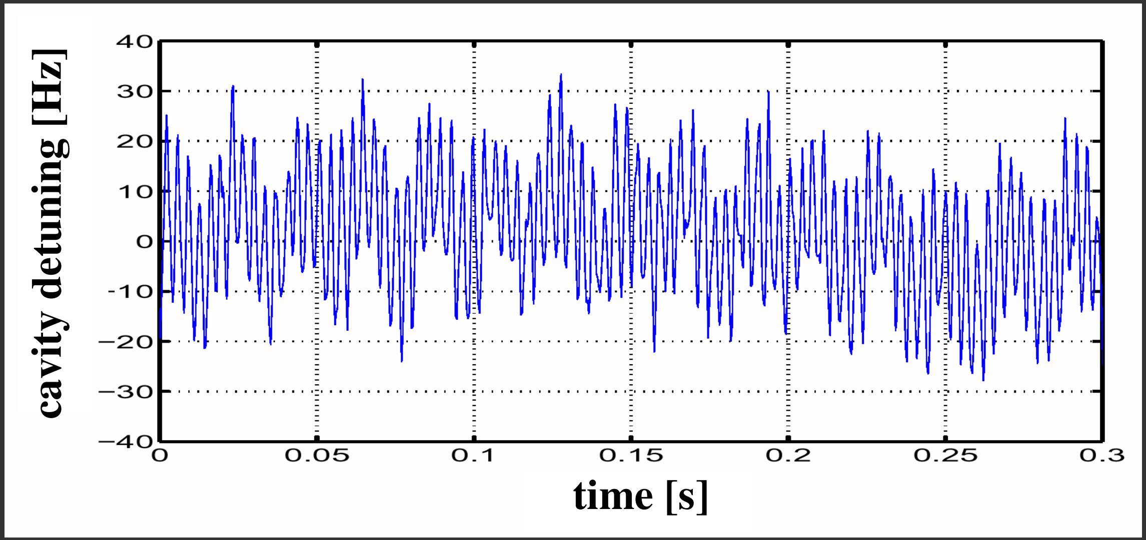
Sources: Microphonics (cavity vibration), Lorentz-force detuning

Microphonics

- *Microphonics:* modulation of resonance frequency by external mechanical disturbances
- thin wall thickness and small bandwidth of superconducting cavities

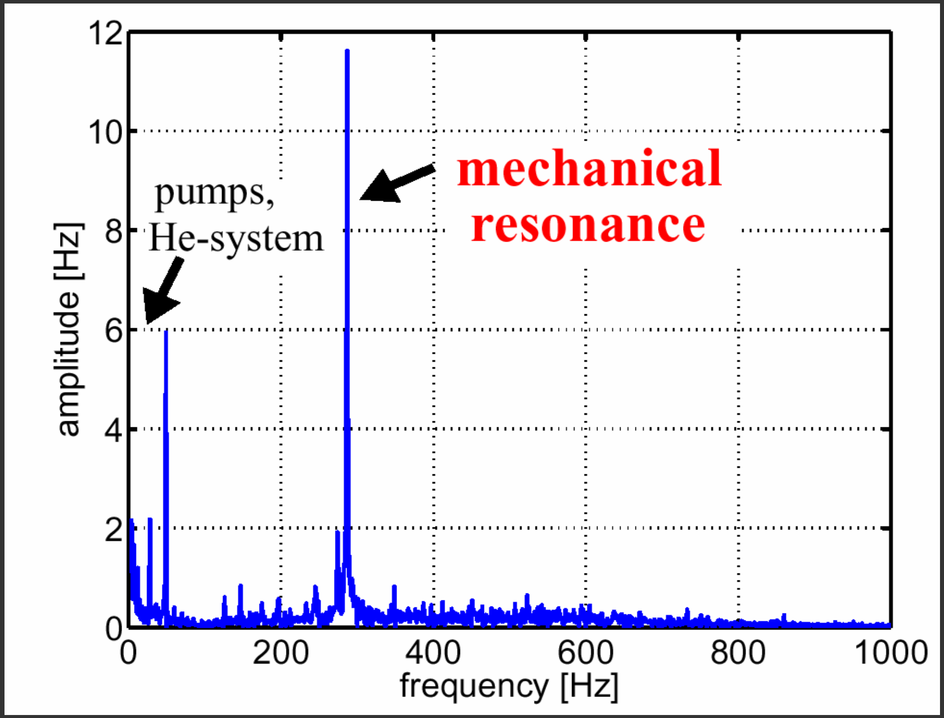
$\Rightarrow$ sensitive to microphonics

Example: TTF 9-cell cavity in a horizontal test cryostat (cw operation)



Microphonics

Example: TTF 9-cell cavity in a horizontal test cryostat (cw operation)

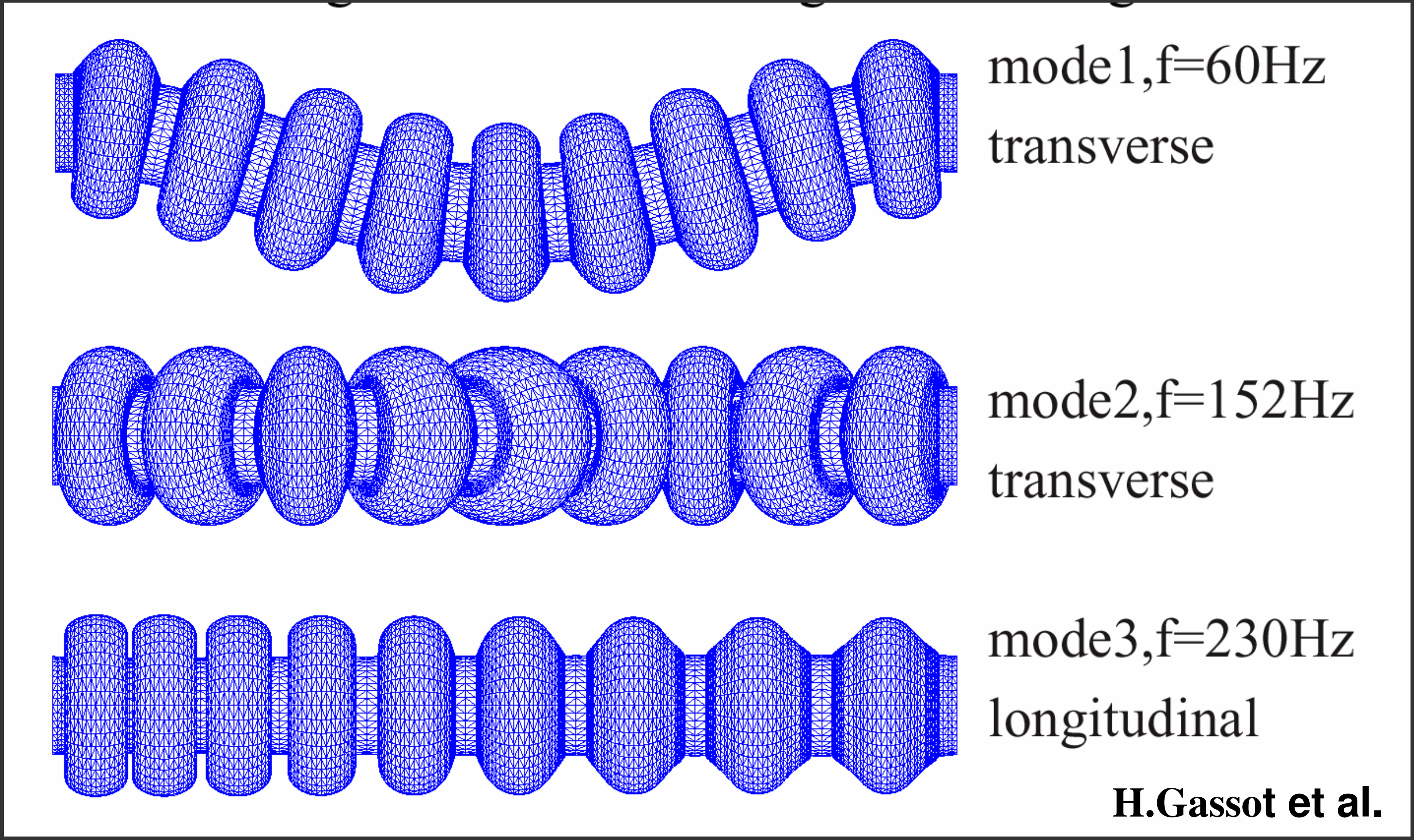


Microphonics spectrum reflects:

- frequency of vibration sources
- mechanical resonances of the system

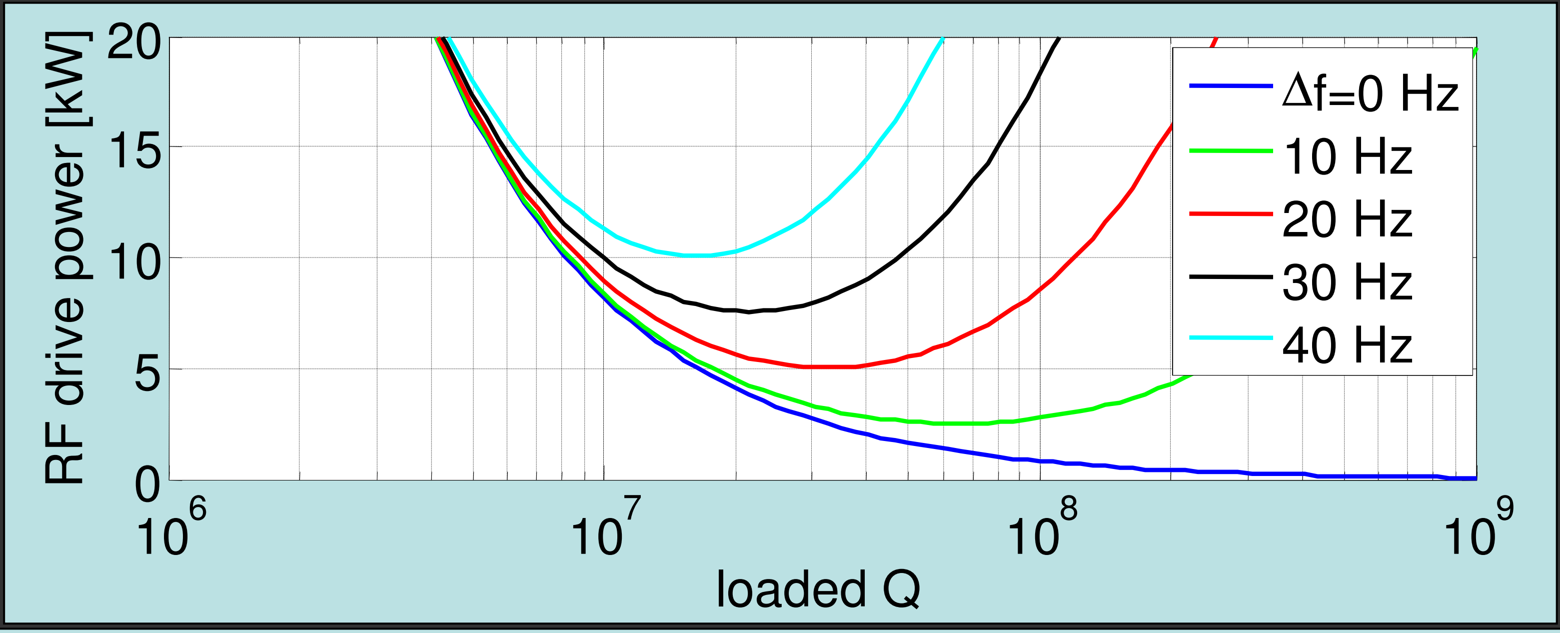
Microphonics

Example: TTF 9-cell cavity



Microphonics
Why does it matter?

In an main linac ERL cavity, the required peak drive power is proportional to the peak microphonics detuning!



$$P_g = \frac{V^2}{8\frac{r}{Q}Q_L}\left(1+\left(\frac{\Delta f}{f_{1/2}}\right)^2\right)$$

$$Q_{opt} = \frac{1}{2}\frac{f_0}{\Delta f}$$

$$P_{g,\min} = \frac{V_{acc}^2}{2r/Q}\frac{\Delta f}{f}$$

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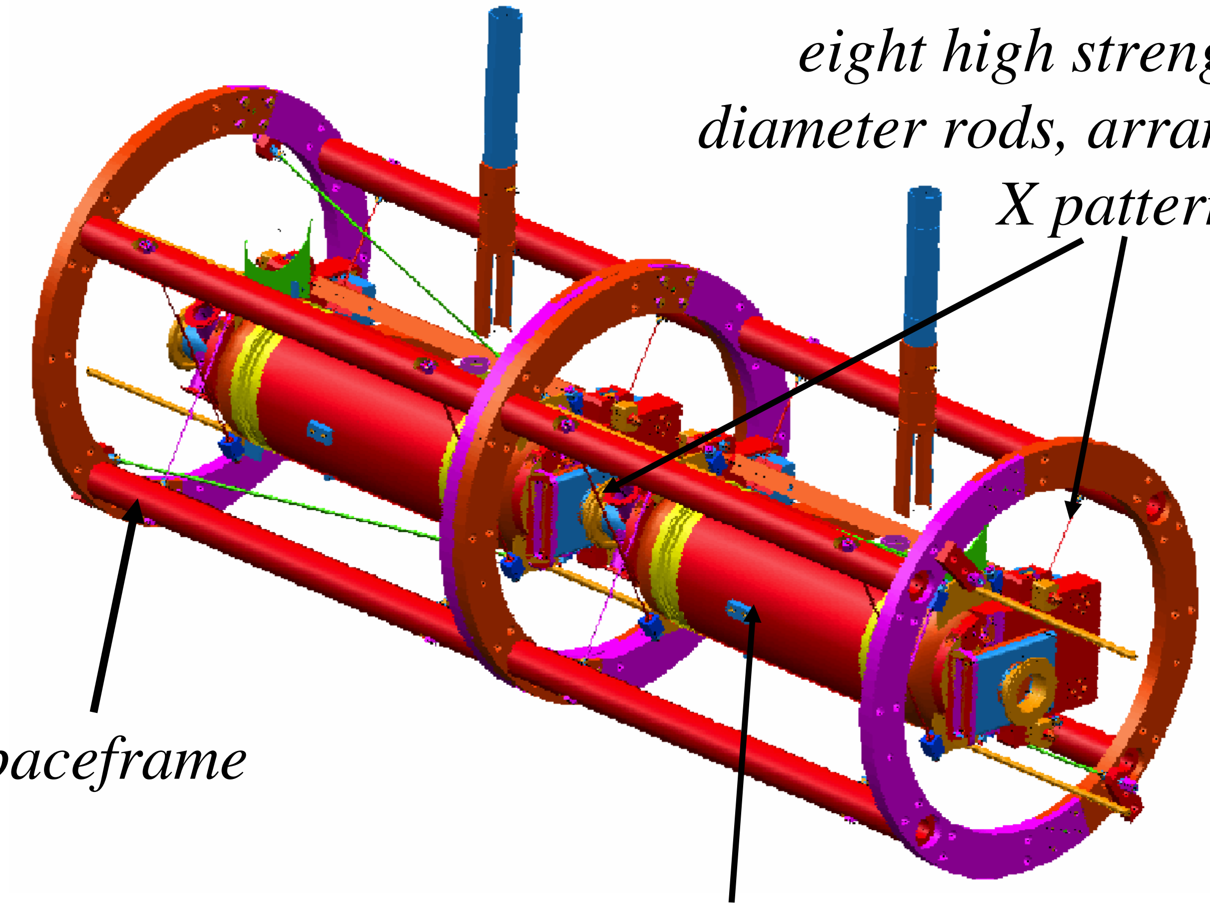
Why does it matter?

- The **peak detuning** determines how much RF drive power needs to be installed/available!
- If the cavity is detuned too much, not enough drive power is available to stabilize the RF field, and the cavity **trips**.
- But: In designing a new machine, what number should one assume as peak detuning?
- Some papers use 6σ as **peak detuning**. But what is a good number for the detuning σ? Let's look at some existing linacs…

What we know today… CEBAF

- **measured:**
  - **σ = 2 Hz average!**
  - **peak to peak 20 Hz (average!)**
  - **$\Rightarrow$ average $6\sigma \approx 15$ Hz**
  - **But: Substantial differences between cavities!**

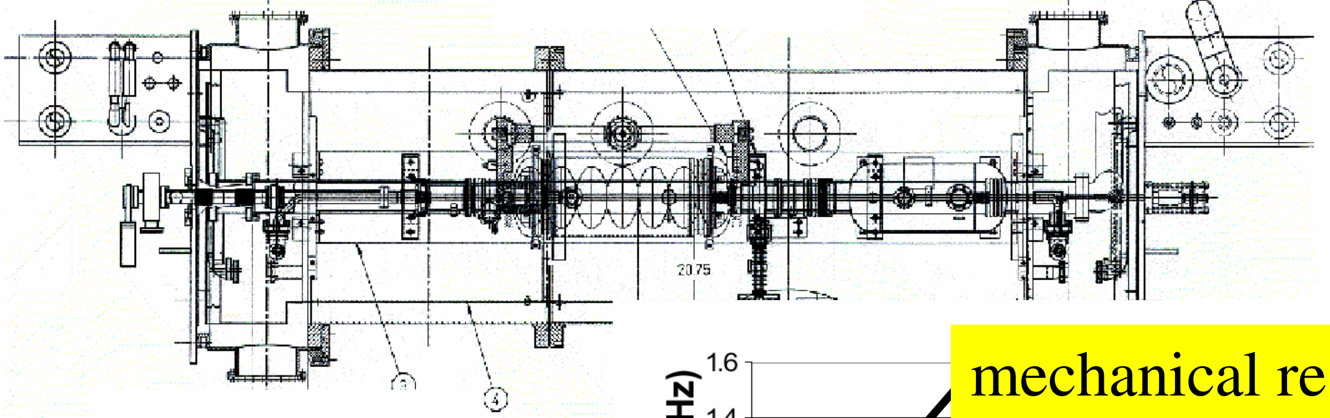
What we know today…
CEBAF Upgrade/ UV FEL

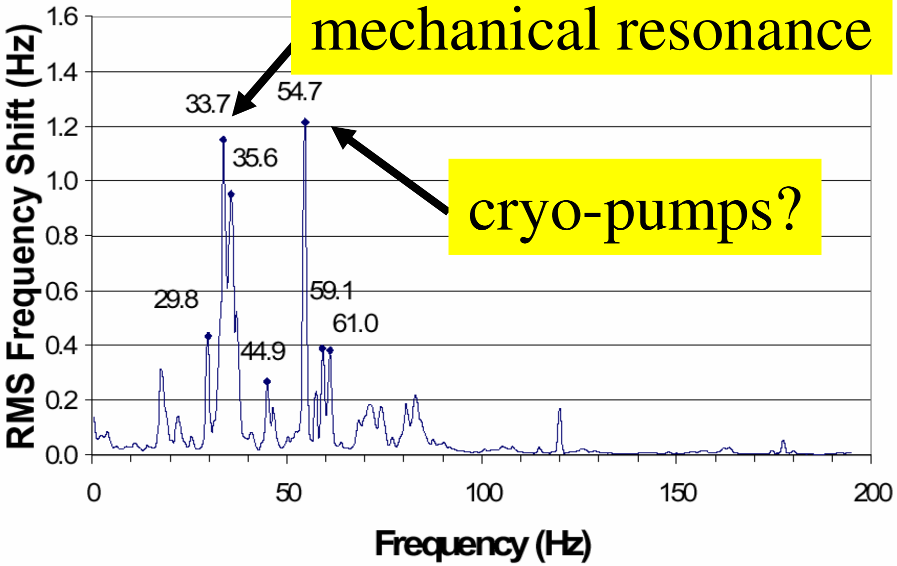


J. Hogan et al.

What we know today…
CEBAF Upgrade

CEBAF upgrade horizontal test bed cryostat:





measured:

σ = 2 to 2.5 Hz

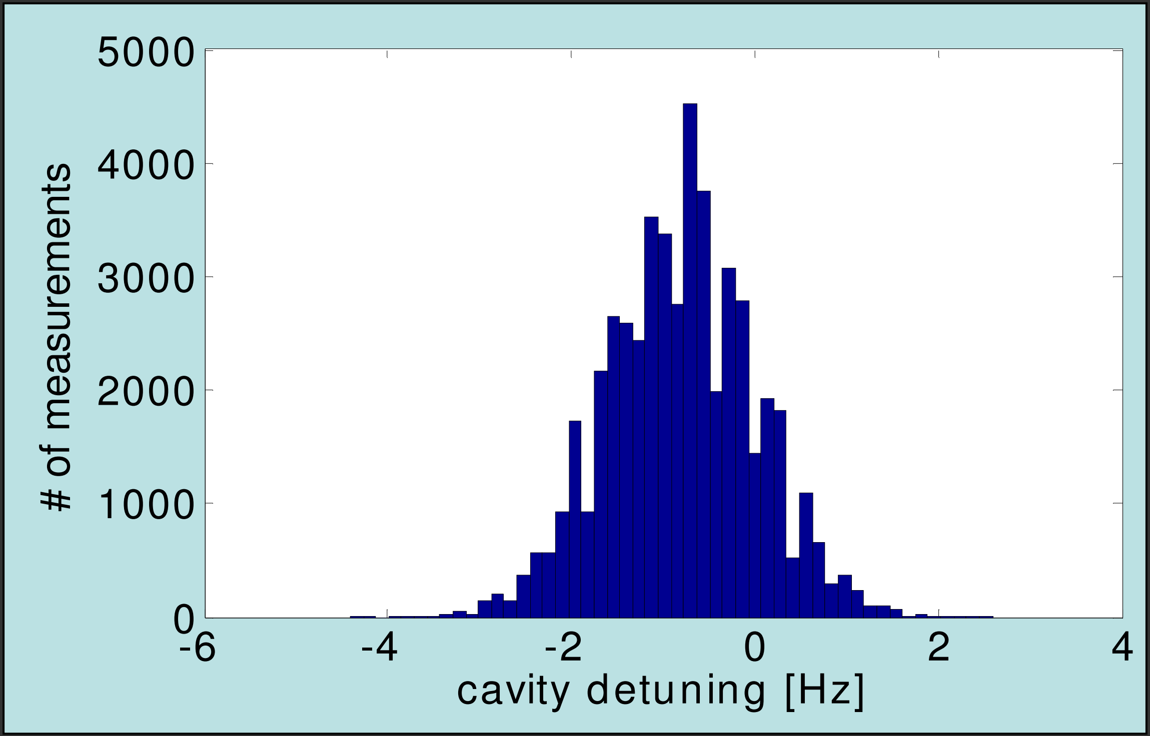
$\Rightarrow 6\sigma \approx$ 15 Hz

What we know today… JLAB FEL

measured:

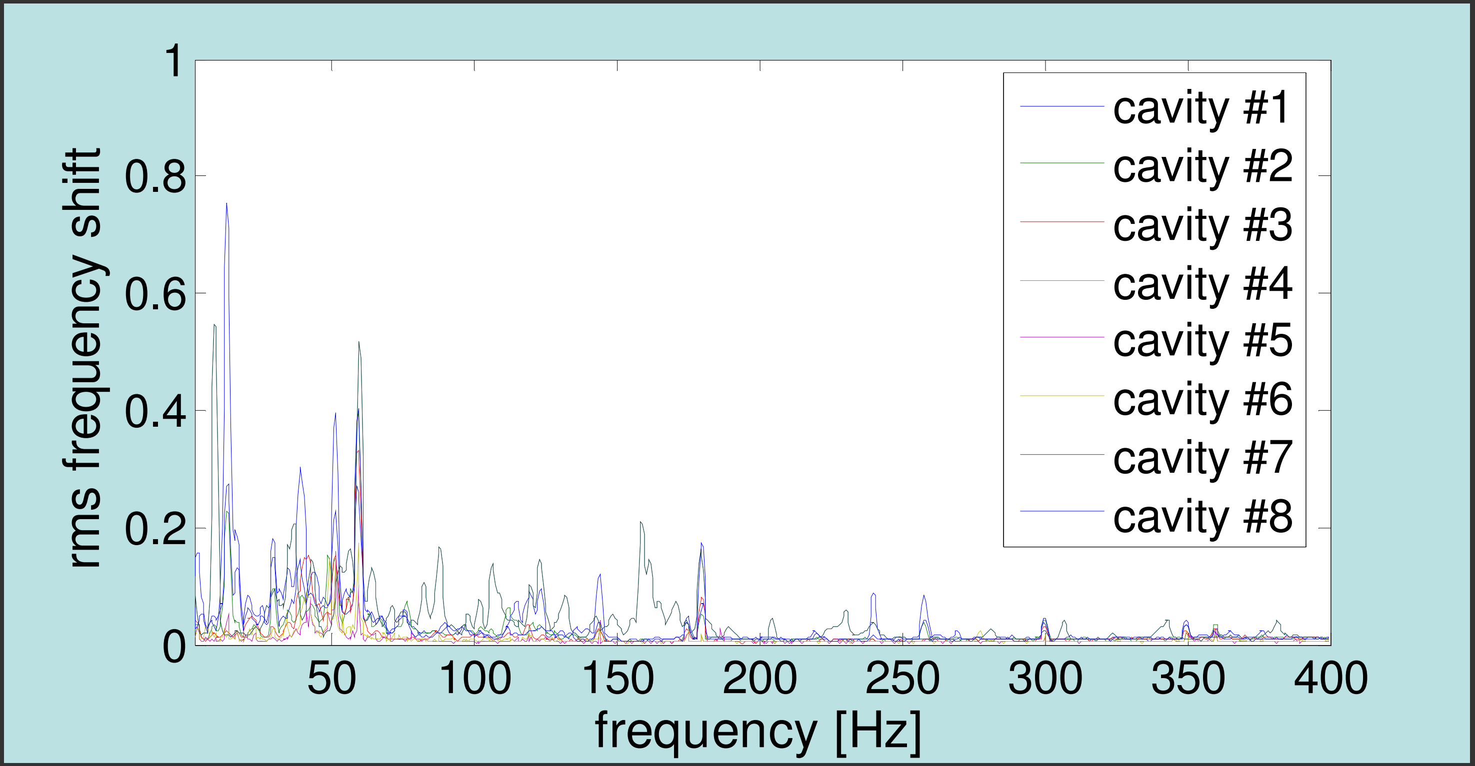
$\sigma \approx 1$ Hz

$\Rightarrow 6\sigma \approx 6$ Hz



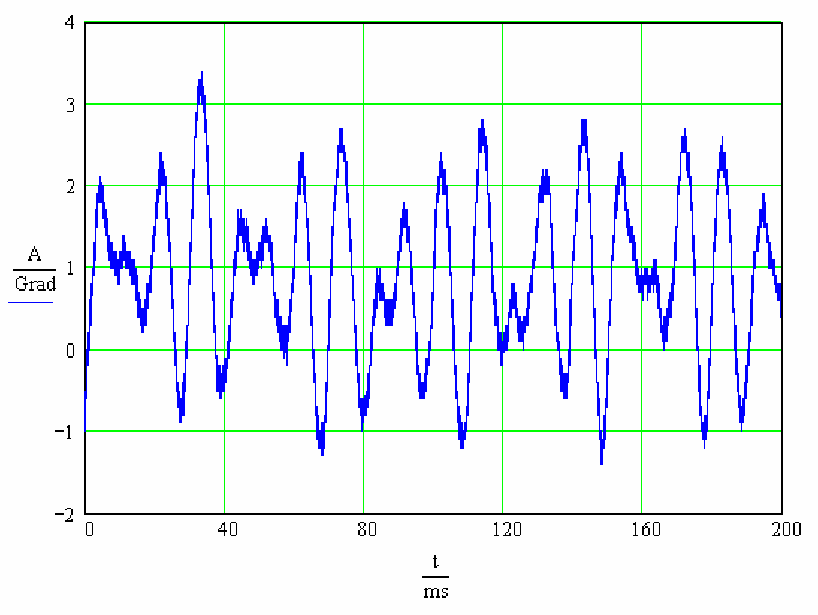
cavity #	1	2	3	4	5	6	7	8
σ [Hz]	1.3	0.8	0.8	0.7	0.6	0.7	1.1	1.0
6σ [Hz]	7.6	4.9	4.5	4.4	3.7	4.3	6.8	6.2

What we know today…
JLAB FEL

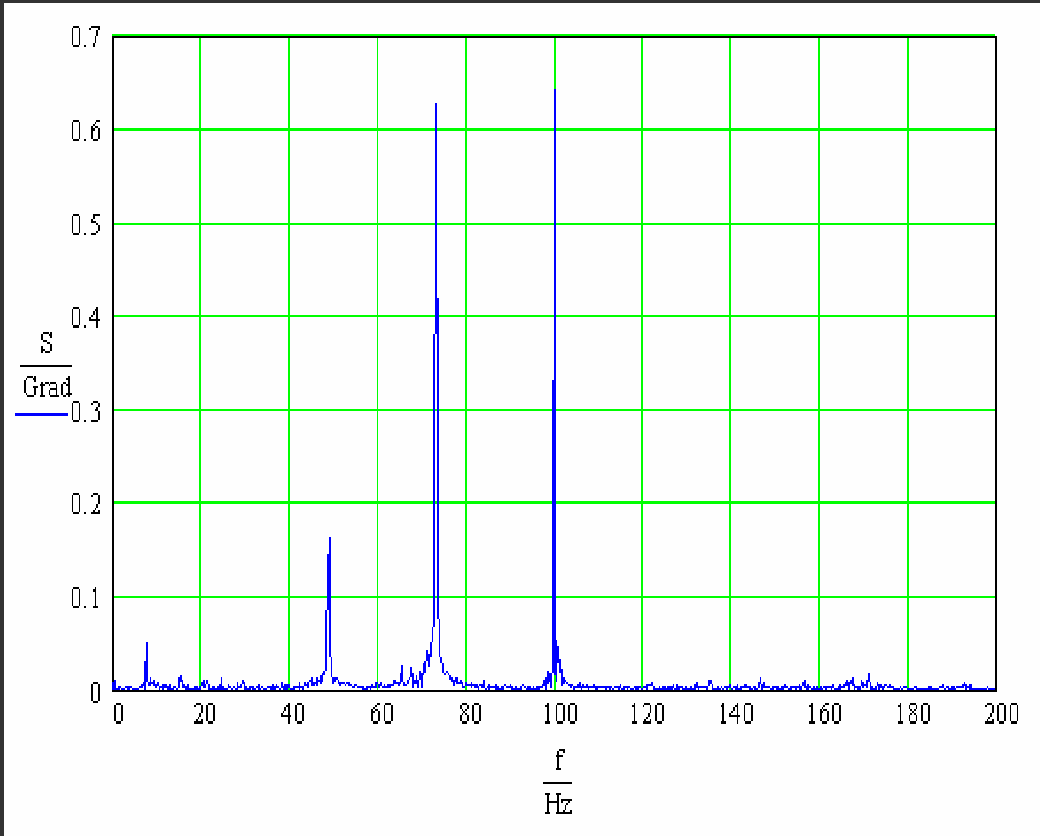


Again, most of the relevant vibration is at frequencies below ≈ 150 Hz…

What we know today…
ELBE



Open Loop Phase Noise



Open Loop Phase Noise Spectrum

measured:

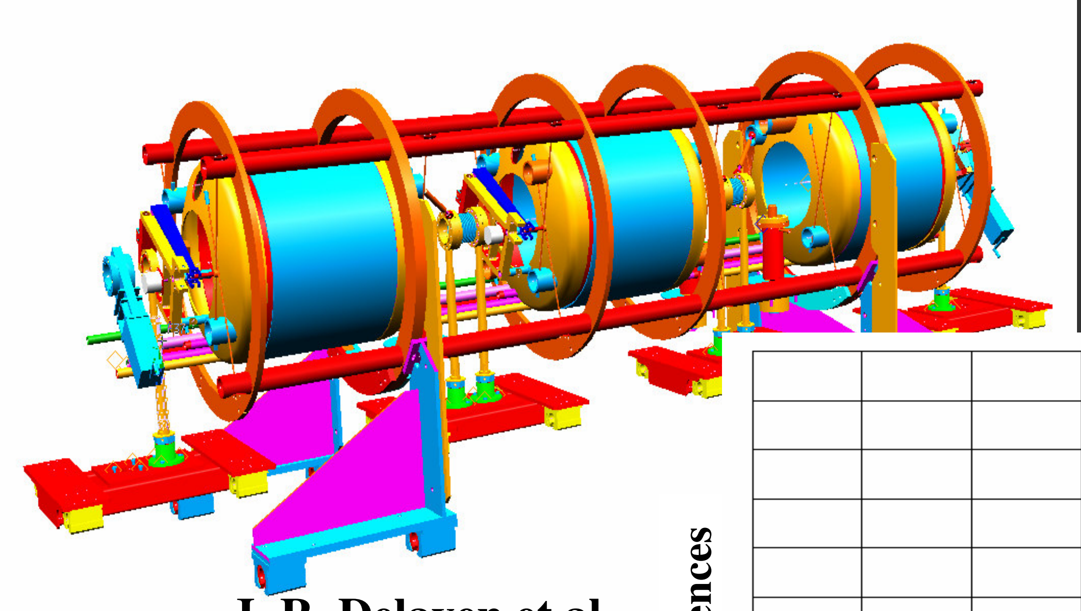
σ ≈ 1 Hz

⇒ 6σ ≈ 6 Hz

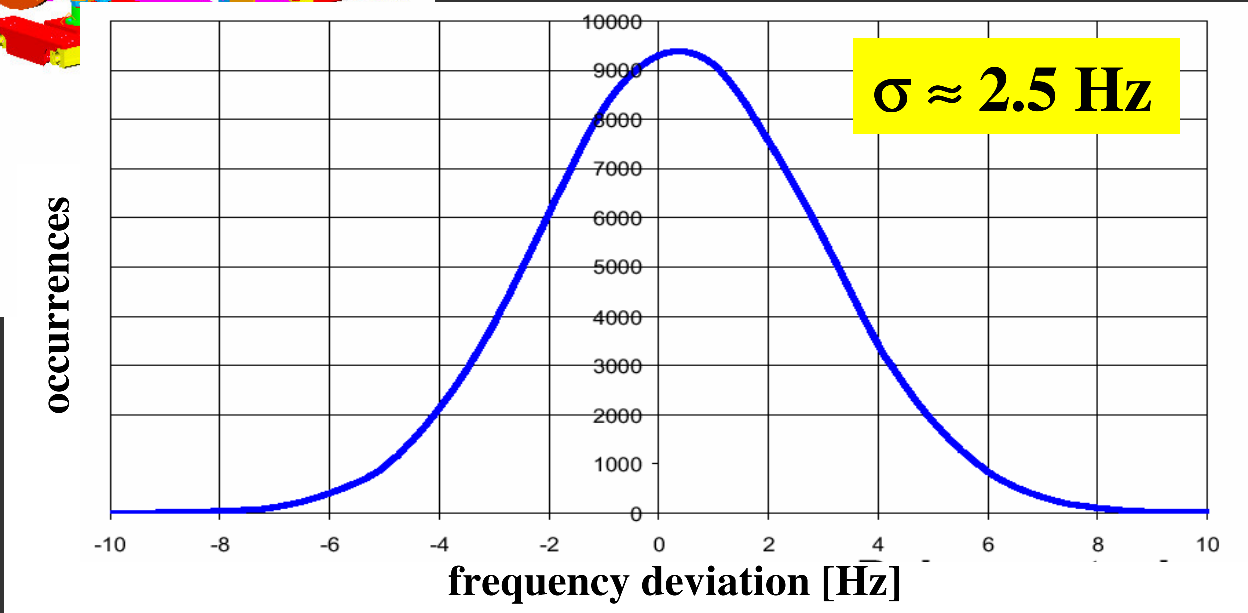
Again, all relevant vibration below ≈ 150 Hz…

What we know today…
SNS

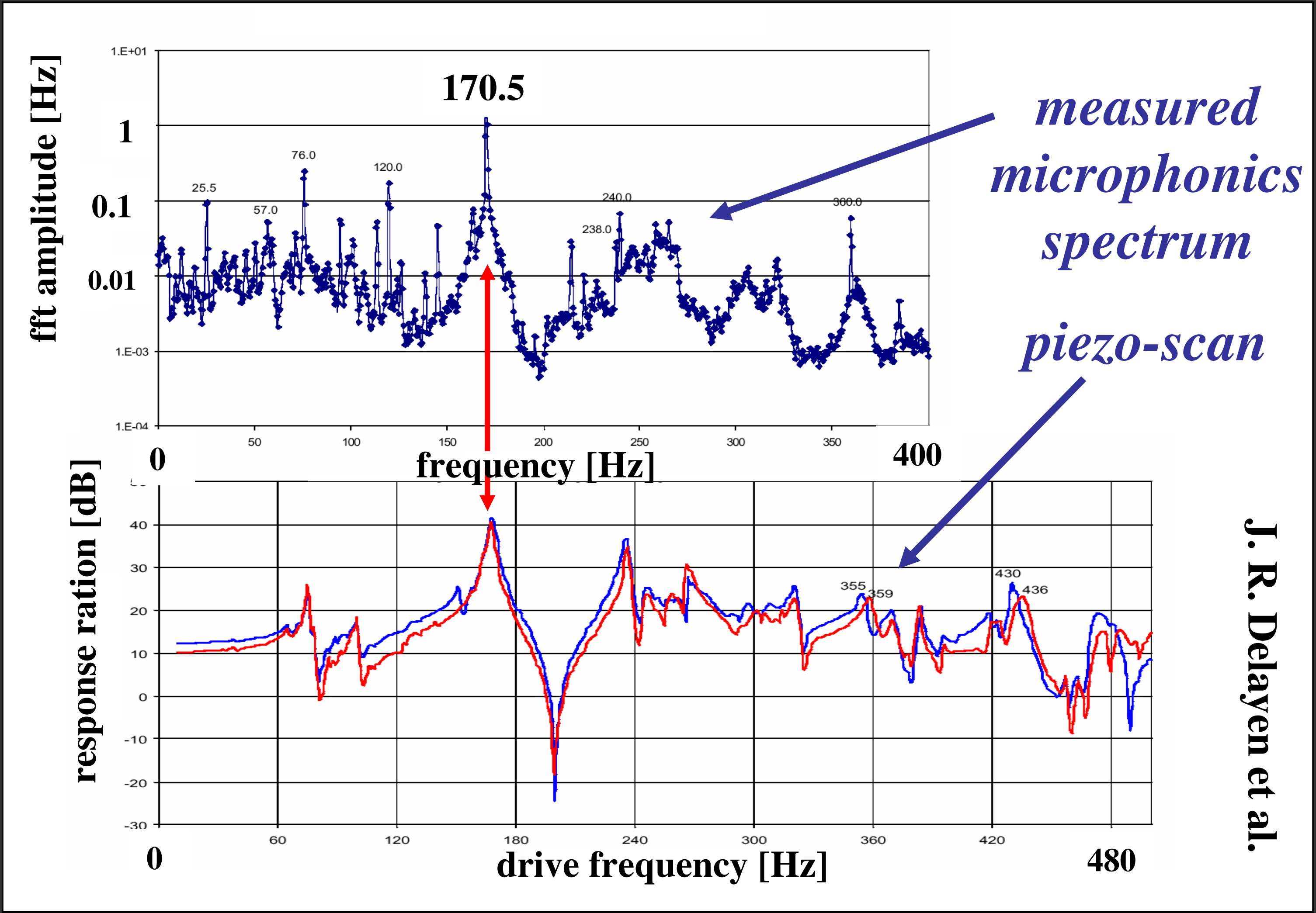
SNS low beta (0.61) prototype cryostat:



J. R. Delayen et al.



What we know today… SNS



What we know today… SNS

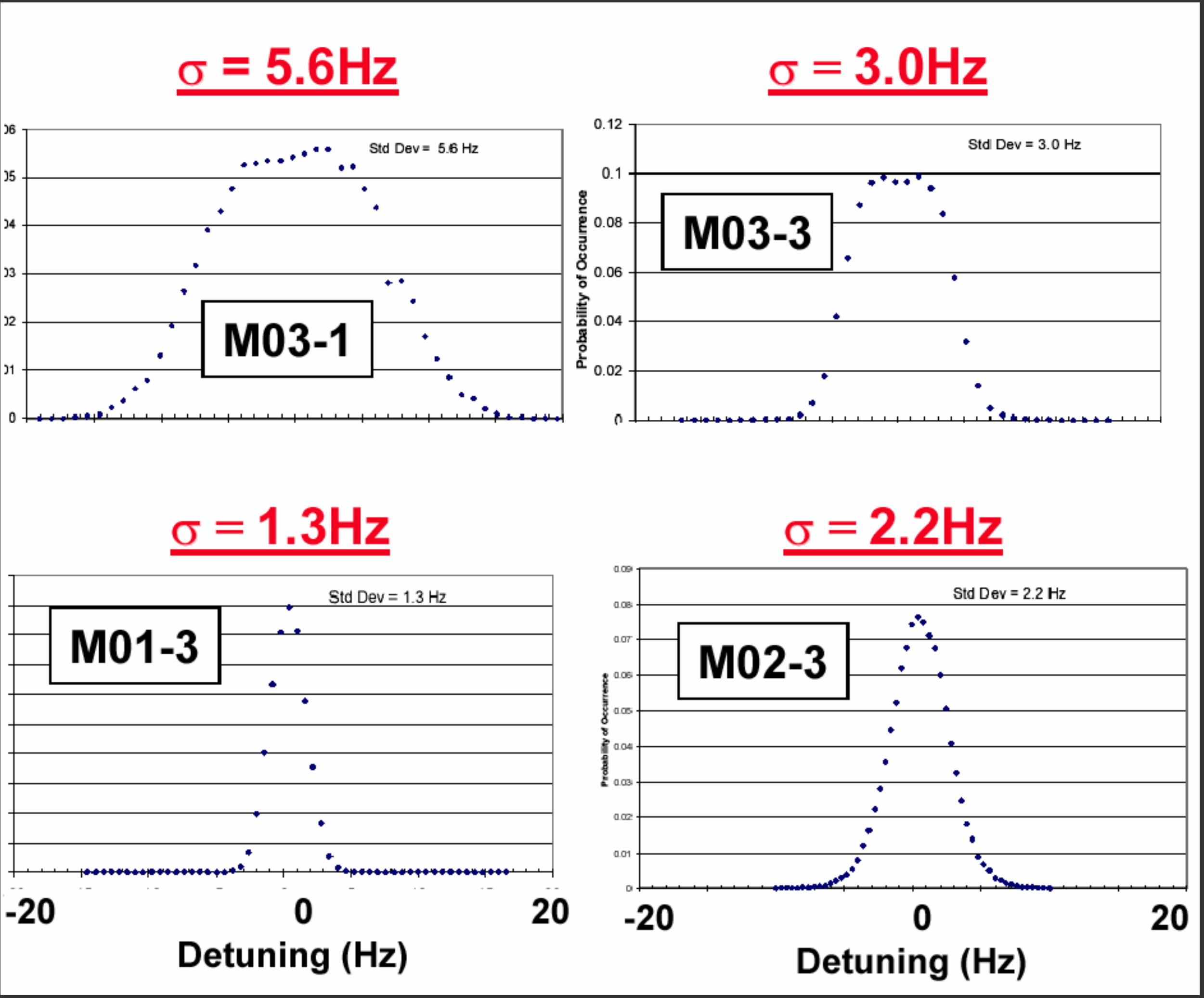
Substantial differences!

- **Between cavities**
- **Temporal**

measured:

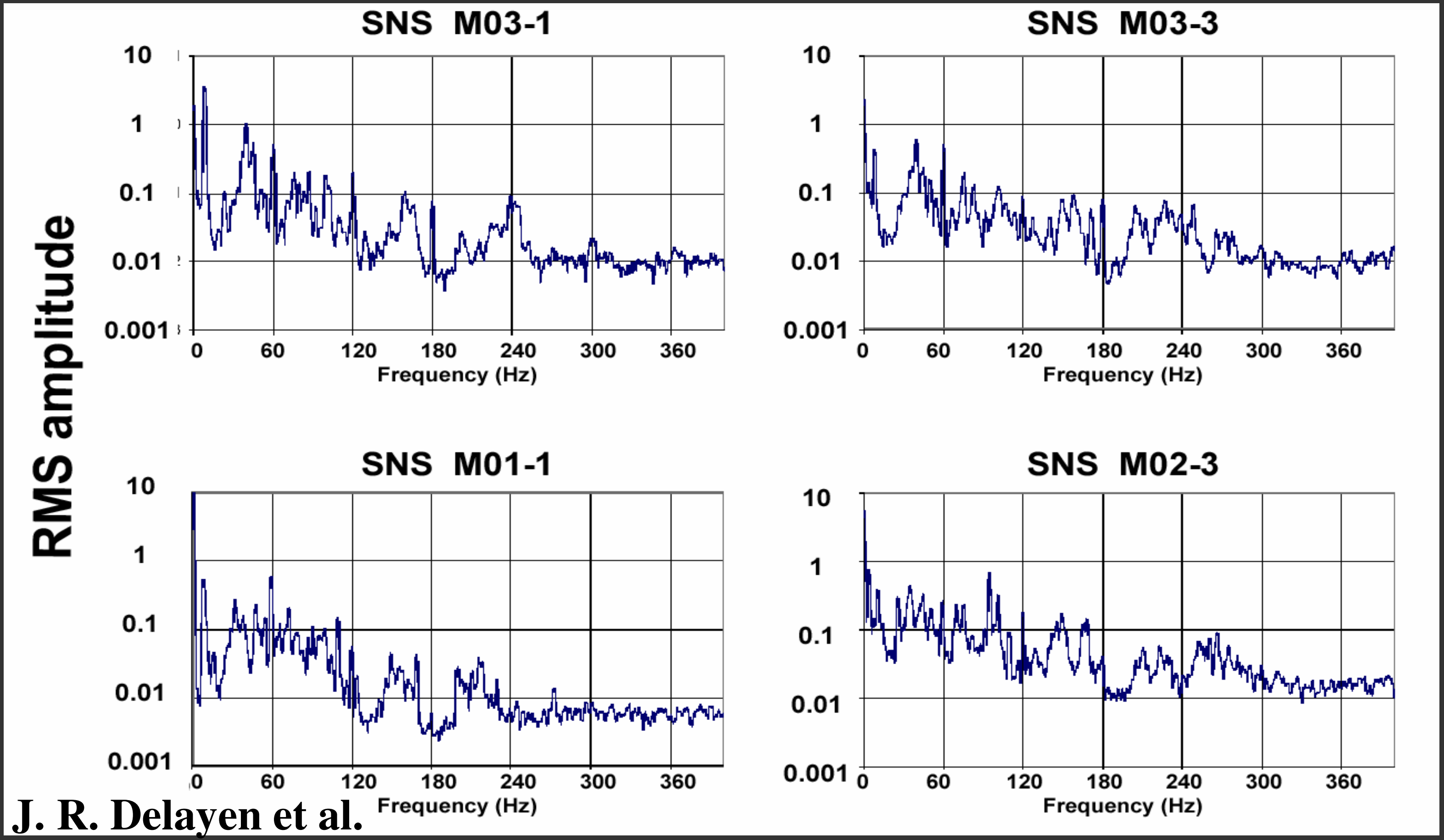
σ = 1 to 6 Hz

⇒ 6σ ≈ 8 to 35 Hz



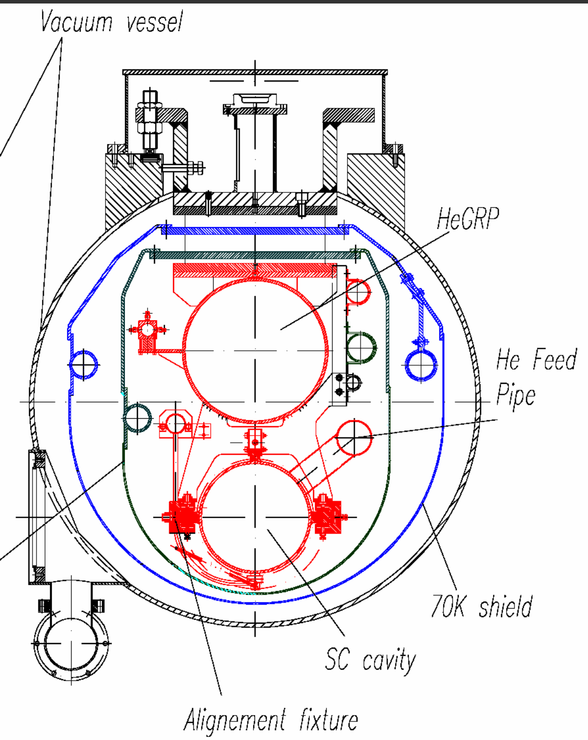
J. R. Delayen et al.

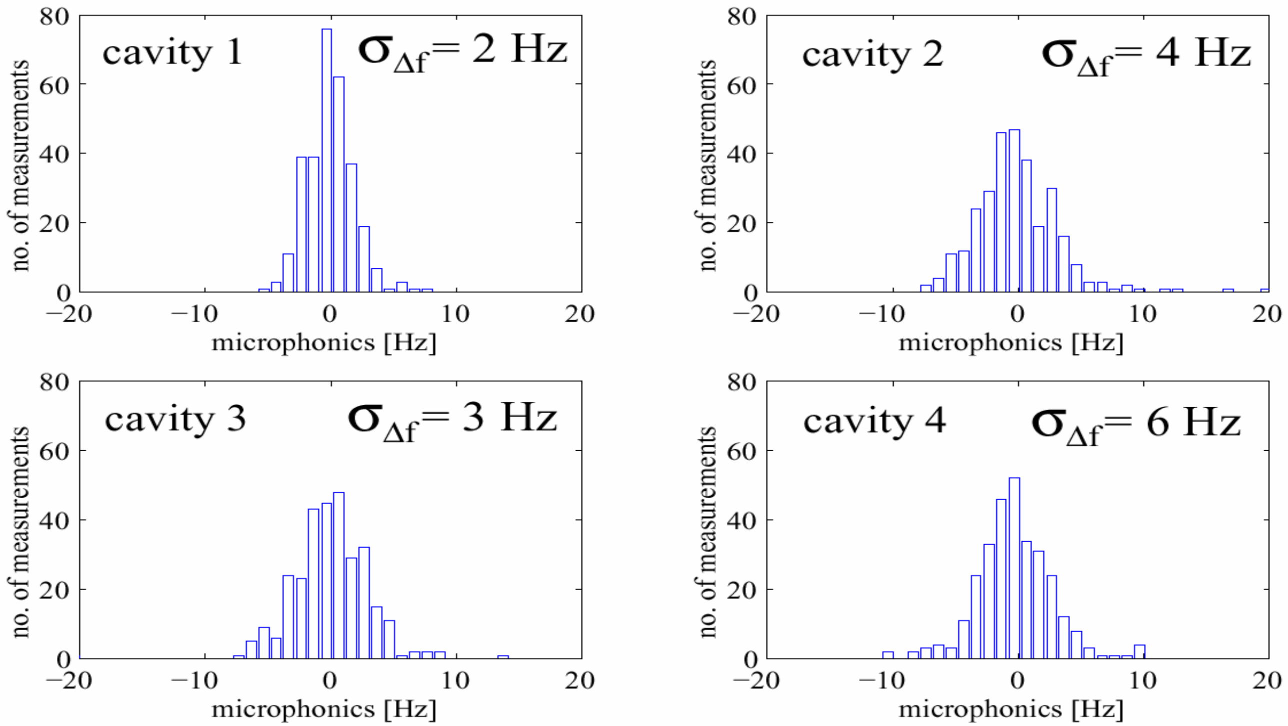
What we know today… SNS



Most of the relevant vibration is at frequencies below ≈ 200 Hz…

What we know today… TTF





Substantial differences!

- **Between cavities**
- **Temporal**

measured (*pulsed*!):

σ = 2 to 7 Hz

$\Rightarrow 6\sigma \approx$ 12 to 42 Hz

Microphonics
What we don't know (well)…

- What are the dominating sources of microphonics?
- How do they couple to the cavity?
- Why is there often a significant variation in microphonics from cavity to cavity within the same linac?
- Is microphonics completely uncorrelated from cavity to cavity?
- Is 6σ the right number to define peak detuning? What does this really mean in trips/hour (i.e. $\Delta f > 6\sigma$)?

Outlook
What does this mean?

What do we know today?

- Microphonics can be low: $\sigma < 2$ Hz , 6 $\sigma < 10$Hz have been demonstrated in real linacs!
- But: Significant differences from cavity to cavity in same linac.
- Most of the relevant vibration is at frequencies below 200 Hz.

What do we need to do?

- Need to understand sources of microphonics and coupling to cavities in more detail.
- Need to improve on reliability and uniformity.
- With some work (cryostat design, active and passive damping) we can do even better…

Stay tuned!