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# INTERMEDIATE-VELOCITY SUPERCONDUCTING ACCELERATING STRUCTURES

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# Applications of medium-β superconducting structures

| | High Current | Medium/Low Current |
|---|---|---|
| CW | Accelerator driven systems<br>waste transmutation<br>energy production | Production of radioactive ions |
| Pulsed | Pulsed spallation sources | |

# High-current cw accelerators

- Beam: p, $H^-$, d
- Technical issues and challenges
  - —Beam losses (~ 1 W/m)
  - —Activation
  - —High cw rf power
  - —Higher order modes
  - —Cryogenics losses
- Implications for SRF technology
  - —Cavities with high acceptance
  - —Development of high cw power couplers
  - —Extraction of HOM power
  - —Cavities with high shunt impedance

# High-current pulsed accelerators

- **Beam: p, $H^-$**
- **Technical issues and challenges**
  - **Beam losses (~ 1 W/m)**
  - **Activation**
  - **Higher order modes**
  - **High peak rf power**
  - **Dynamic Lorentz detuning**
- **Implications for SRF technology**
  - **Cavities with high acceptance**
  - **Development of high peak power couplers**
  - **Extraction of HOM power**
  - **Development of active compensation of dynamic Lorentz detuning**

# Medium to low current cw accelerators

- **Beam; p to U**
- **Technical issues and challenges**
  - **—Microphonics, frequency control**
  - **—Cryogenic losses**
  - **—Wide charge to mass ratio**
  - **—Multicharged state acceleration**
  - **—Activation**
- **Implications for SRF technology**
  - **—Cavities with low sensitivity to vibration**
  - **—Development of microphonics compensation**
  - **—Cavities with high shunt impedance**
  - **—Cavities with large velocity acceptance (few cells)**
  - **—Cavities with large beam acceptance (low frequency, small frequency transitions)**

# Common considerations (I)

- **Intermediate velocity applications usually do not require (or cannot afford) very high gradients**

- **Operational and practical gradients are limited by**
  - —**Cryogenics losses (cw applications)**
  - —**Rf power to control microphonics (low current applications)**
  - —**Rf power couplers (high-current applications)**

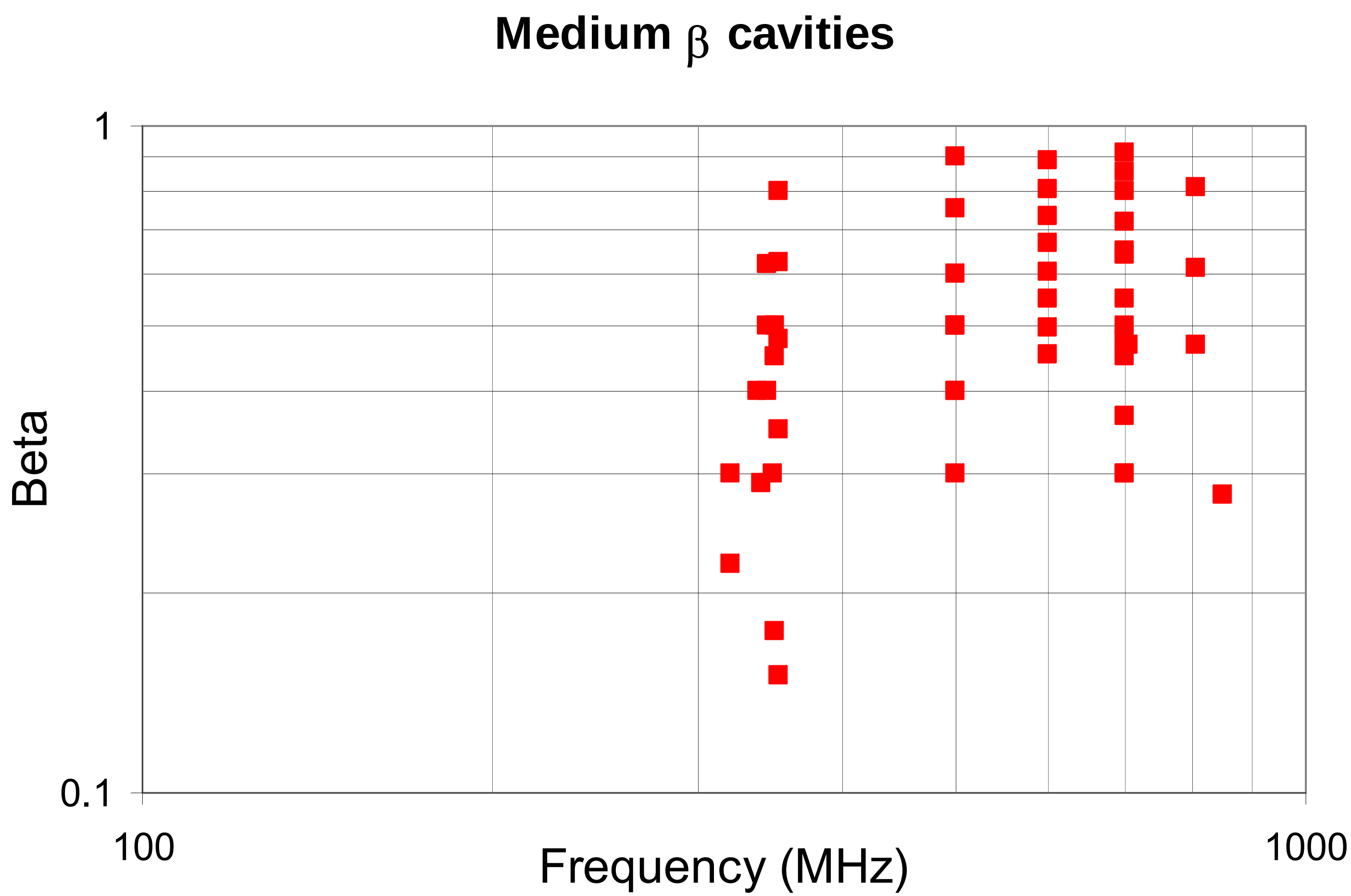
- **High shunt impedance is often more important**

- **To various degrees, beam losses and activation are a consideration**

# Common considerations (II)

- **Superconducting accelerators in the medium velocity range are mostly used for the production of secondary species**
  - —Neutrons (spallation sources)
  - —Exotic ions (radioactive beam facilities)
- **Medium power (100s kW) to high power (~MW) primary impinging on a target**
- **Thermal properties and dynamics of the target are important considerations in the design of the accelerator (frequency, duration, recovery from beam trips)**
- **Some implications:**
  - —Operate cavities sufficiently far from the edge
  - —Provide an ample frequency control window

# Medium β cavities



# Basic Structure Geometries

- **Resonant Transmission Lines (TEM-class)**

  $\lambda/4$

  - Quarter-wave
  - Split-ring
  - Twin quarter-wave
  - Lollipop

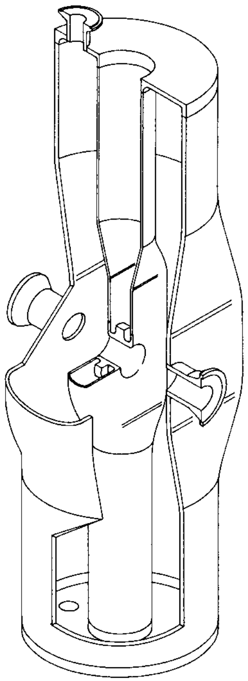
  $\lambda/2$

  - **Coaxial half-wave**
  - **Spoke**
  - **H-types**

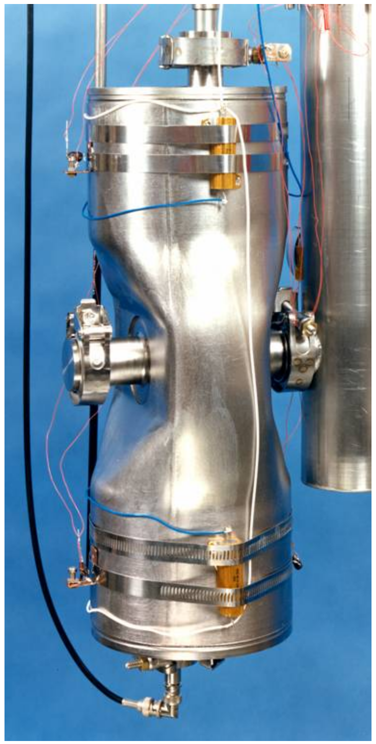
- **TM-class**
  - **Elliptical**
  - Reentrant

- Other
  - Alvarez
  - Slotted-iris

# TEM-class geometries (λ/2 coaxial half-wave)

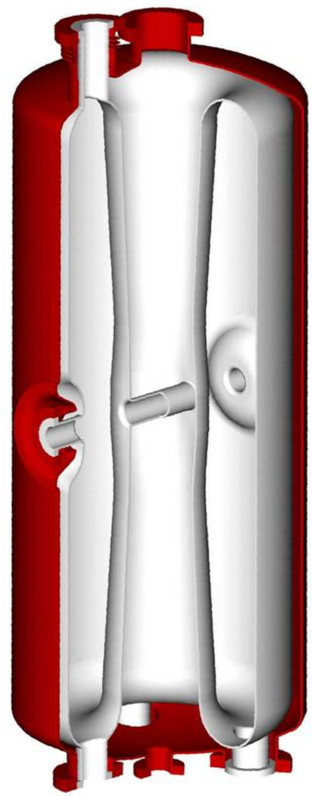


ANL 1988



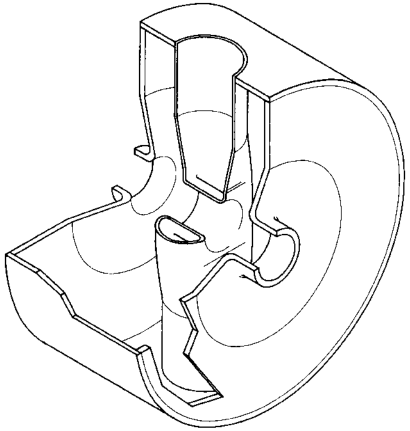
ANL 1990

MSU 2003



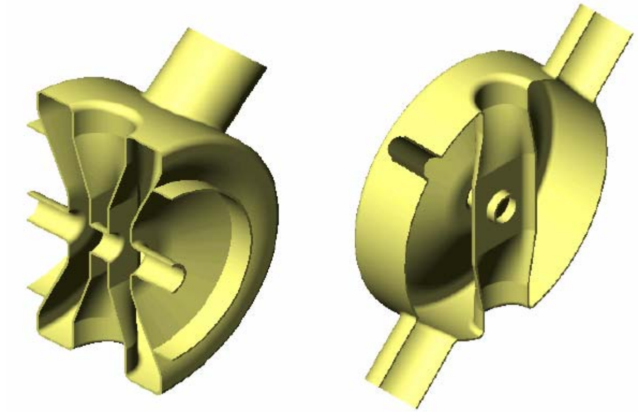
ANL 2003

# TEM-class geometries (λ/2 single spoke)



ANL 1988

ANL 1991

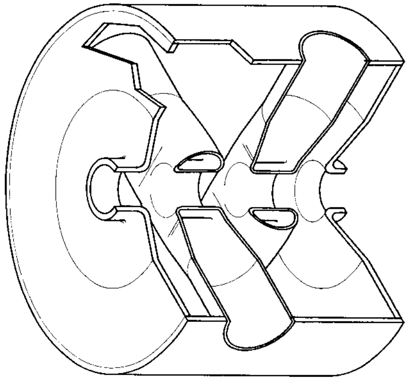


LANL 2001

ANL 1998

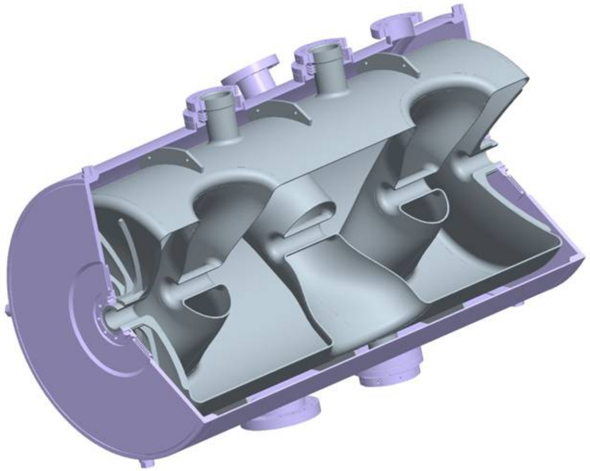
Orsay 2002

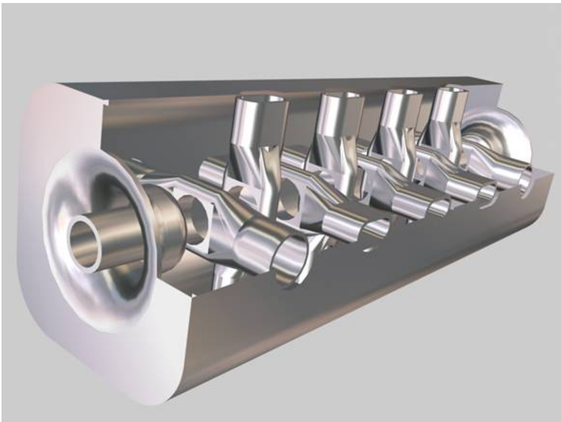
# TEM-class geometries (λ/2 multi-spoke)



ANL 1988

ANL 2003



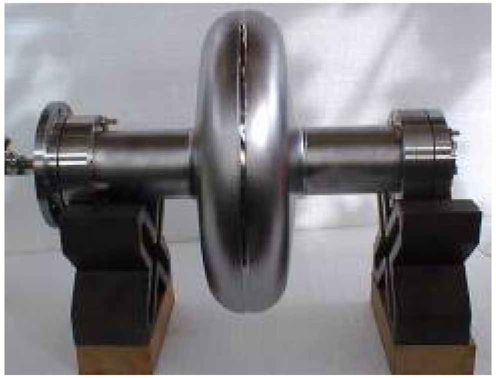


Juelich 2001

Juelich 2003

ANL 2004

# TM-class geometries (single cell)



Saclay 1999

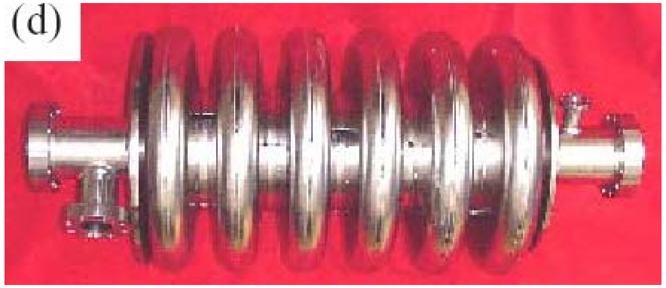
CERN 1997

INFN 2001

JLab/MSU 2001

# TM-class geometries (multi-cell)

JLab/SNS 2001




JLab/MSU 2001

Orsay 2003

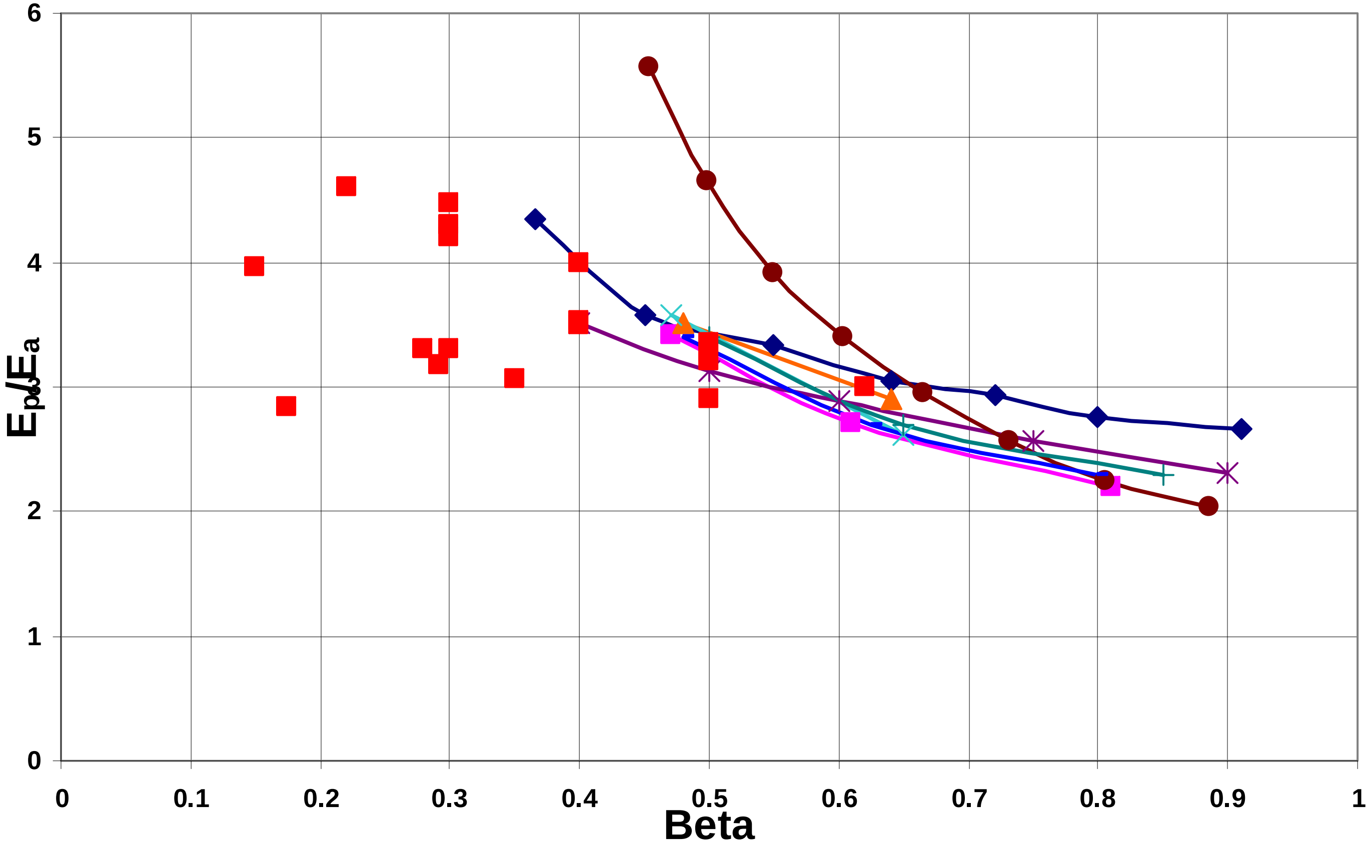
KEK/JAERI 2003

LANL 2001

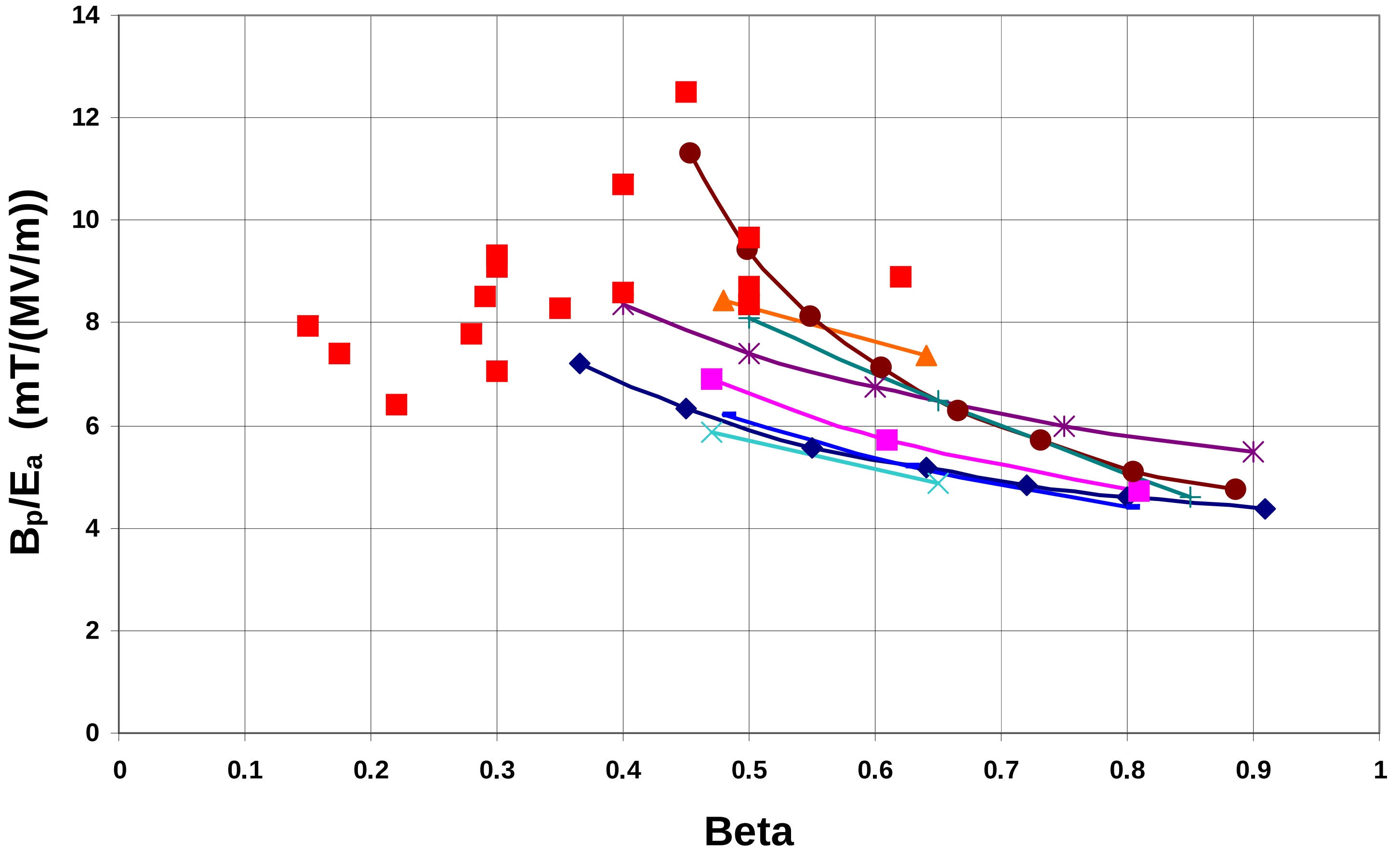
# Design considerations

- Low cryogenics losses
  - — High $QR_s$ * $R_{sh}/Q$
  - — Low frequency
- High gradient
  - — Low $E_p/E_{acc}$
  - — Low $B_p/E_{acc}$
- Large velocity acceptance
  - — Small number of cells
  - — Low frequency
- Frequency control
  - — Low sensitivity to microphonics
  - — Low energy content
  - — Low Lorentz coefficient
- Large beam acceptance
  - — Large aperture (transverse acceptance)
  - — Low frequency (longitudinal acceptance)

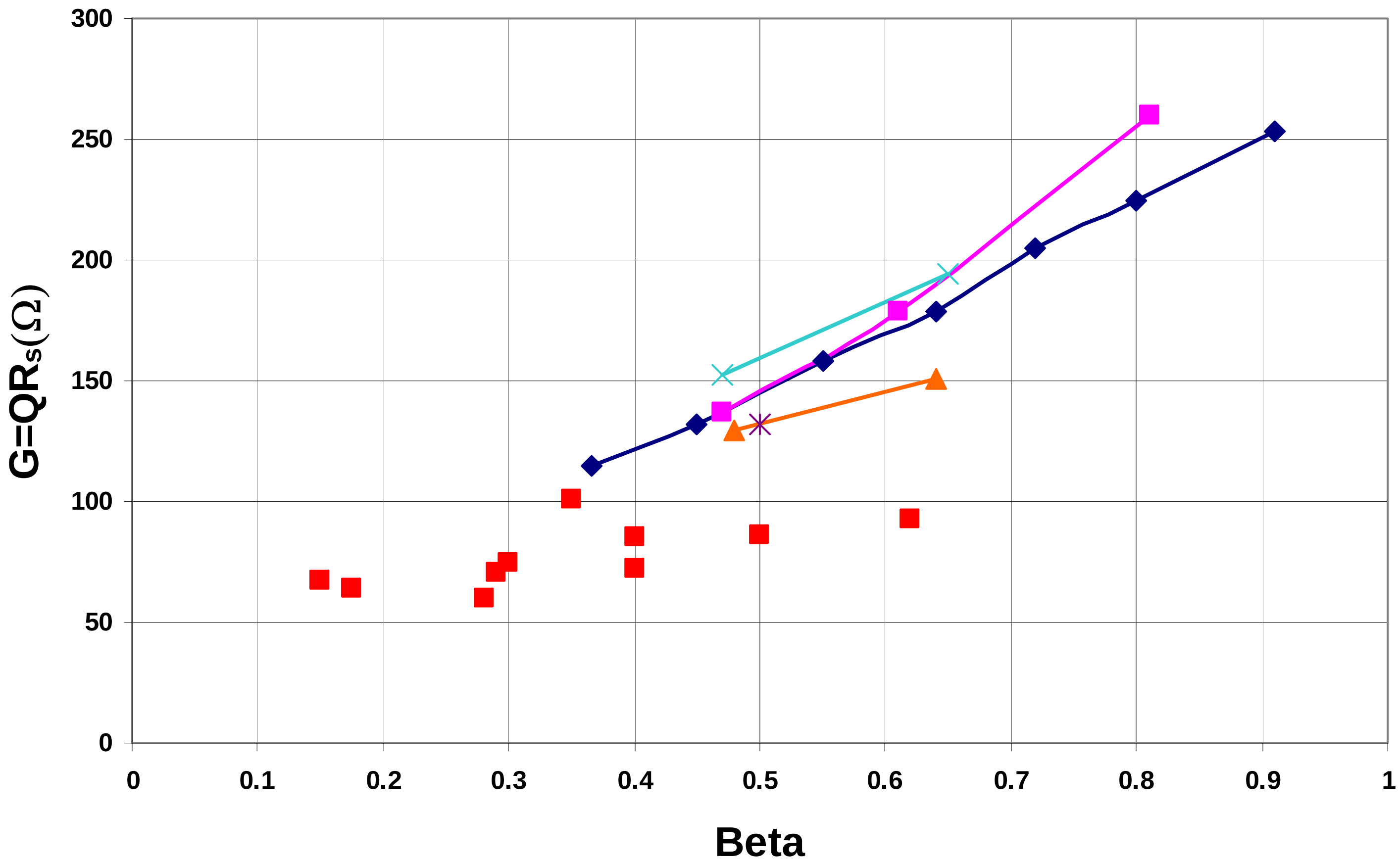
# Peak surface electric field



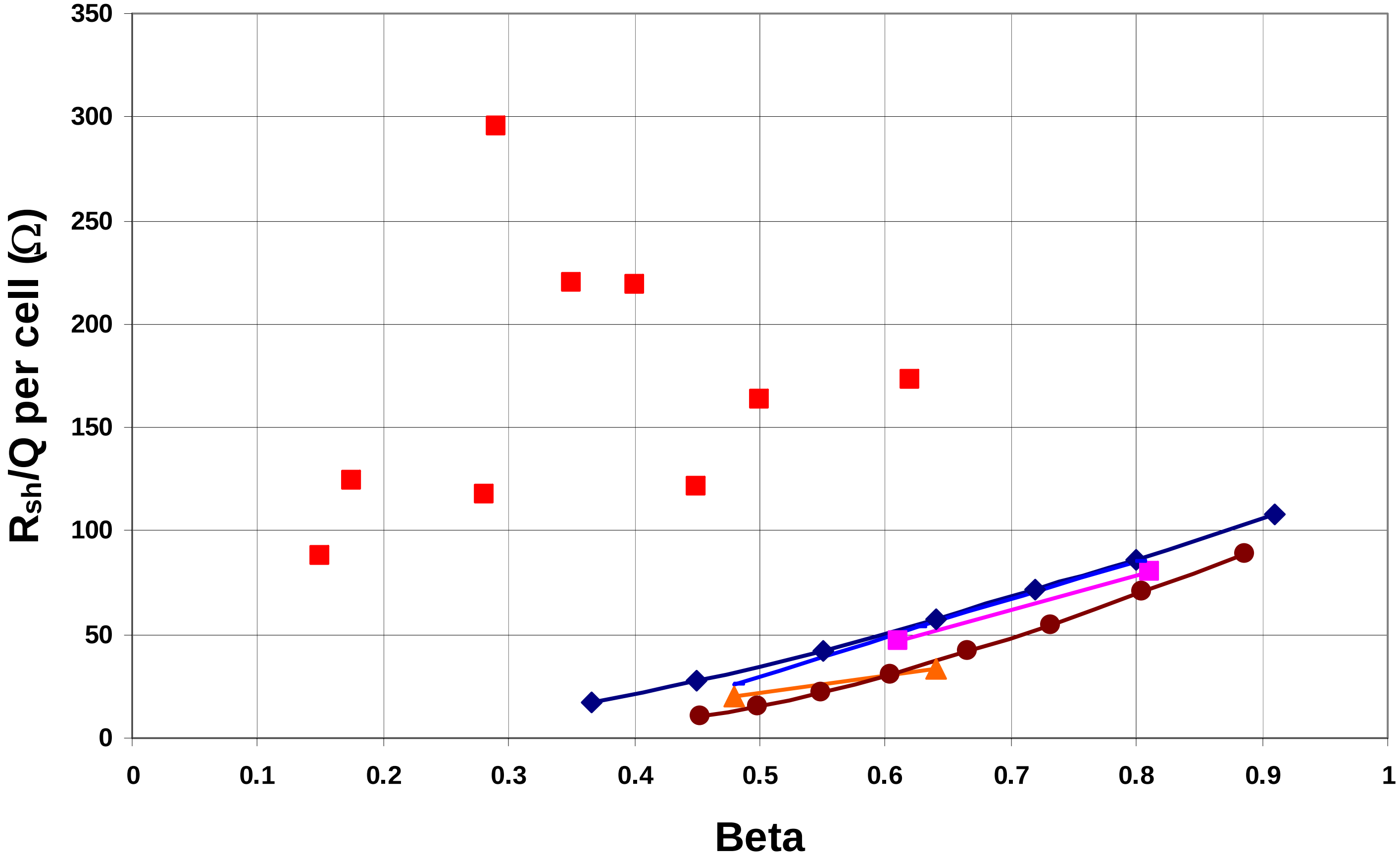
# Peak surface magnetic field



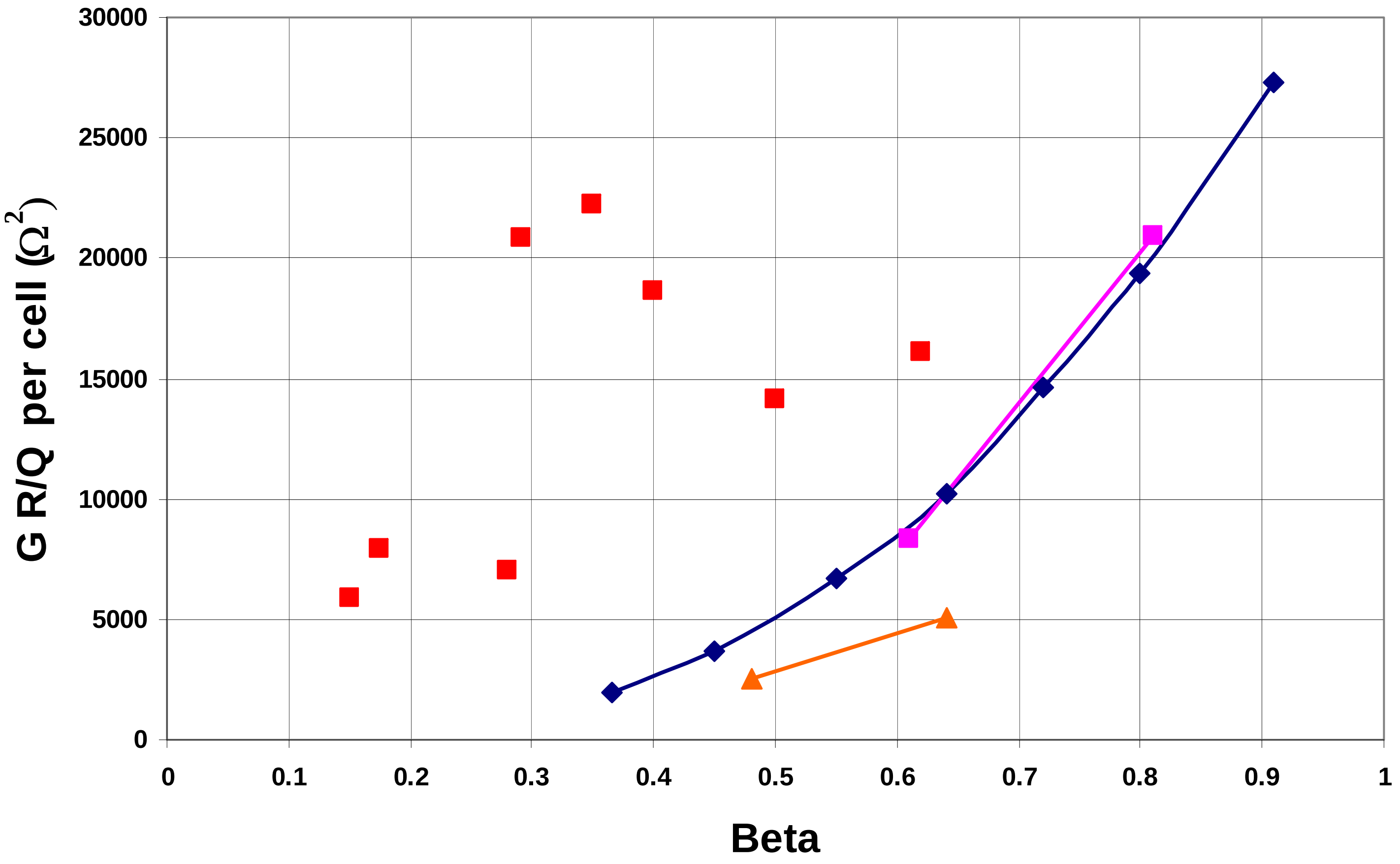
# Geometrical factor $G=QR_s$



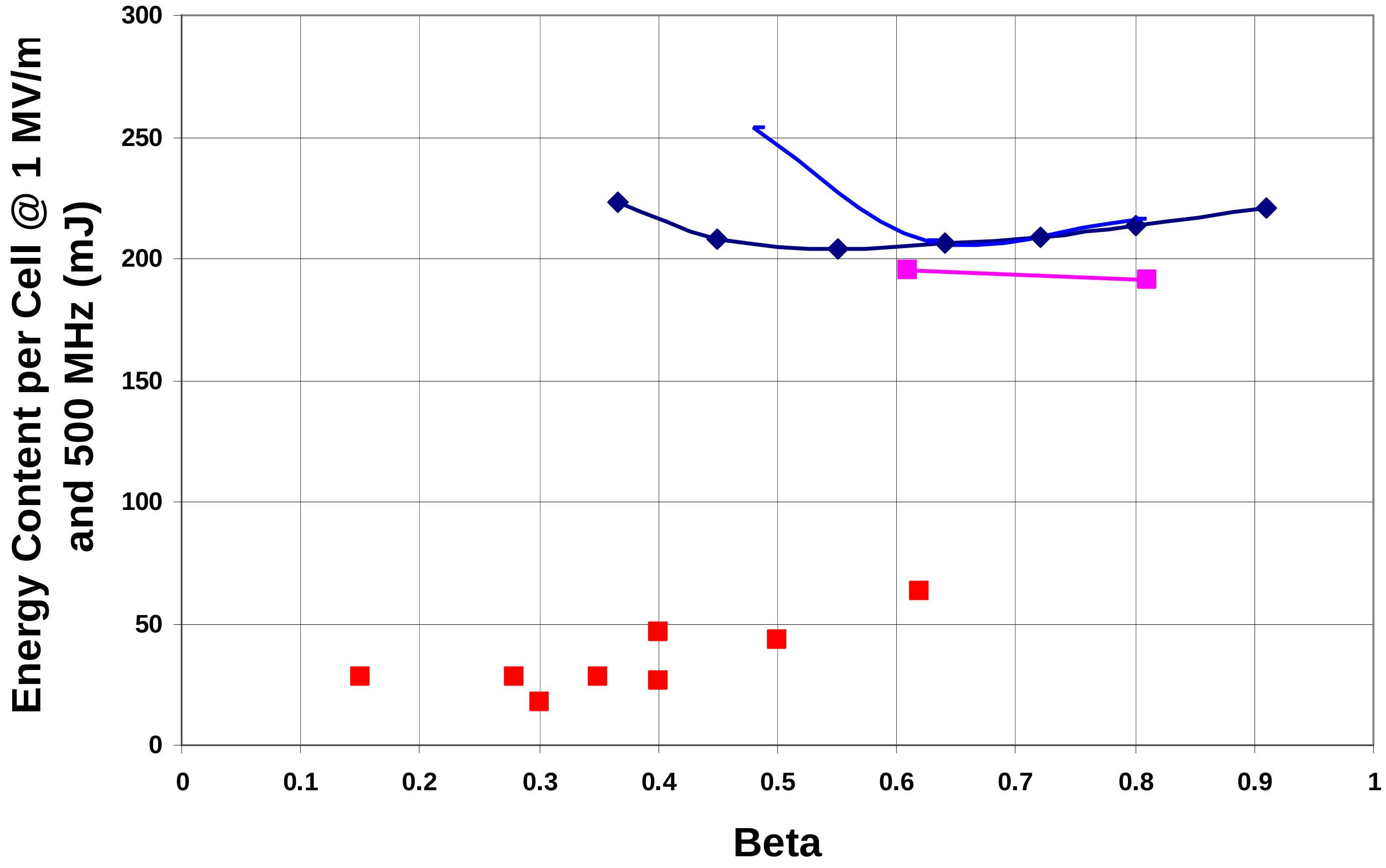
# $R_{sh}$/Q per cell



# $QR_s * R_{sh}/Q$ per cell

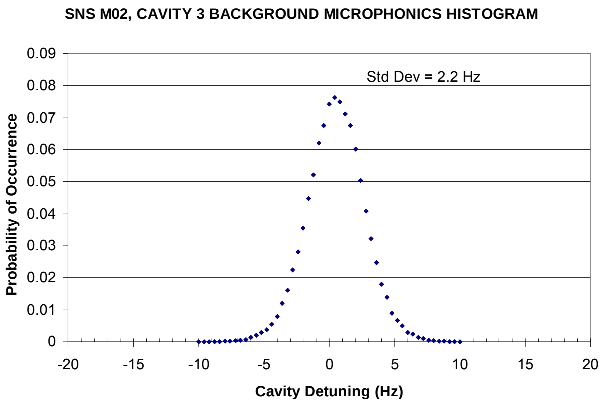


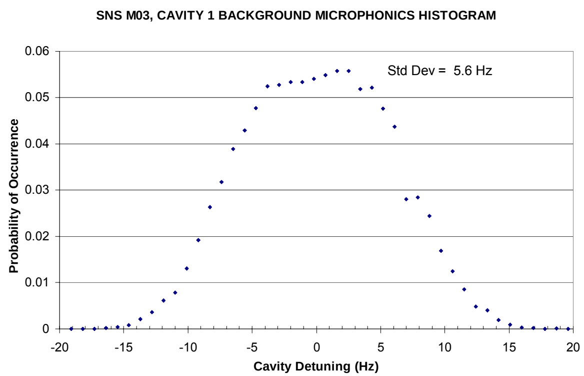
# Energy content per cell at 1 MV/m, 500 MHz

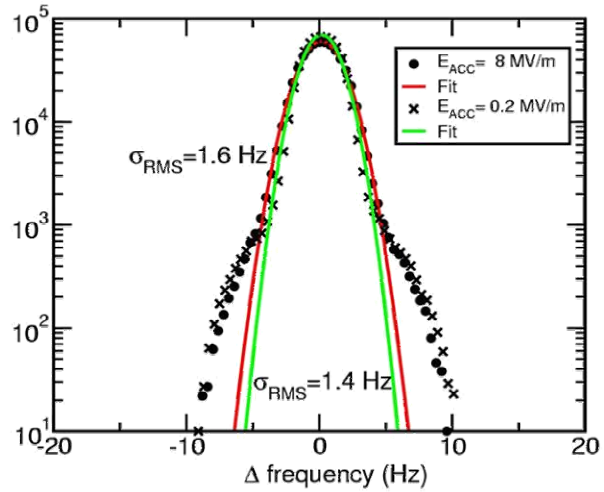


# Microphonics (probability density)

| Single gaussian | Bimodal | Multi-gaussian |
|---|---|---|
| Noise driven | Single-frequency driven | Non-stationary noise |



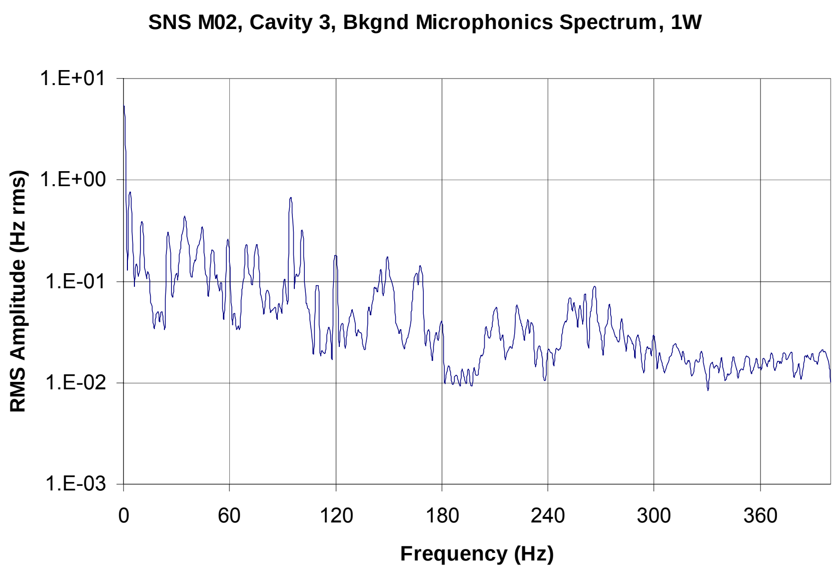



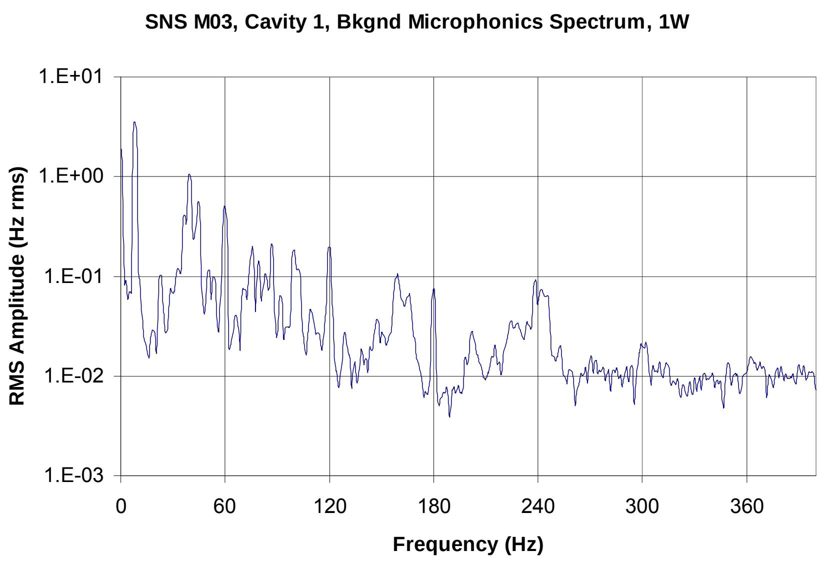

| 805 MHz TM | 805 MHz TM | 172 MHz TEM |
|---|---|---|

# Microphonics (frequency spectrum)

TM-class cavities (JLab, 6-cell elliptical, 805 MHz, $\beta$=0.61)

- Rich frequency spectrum from low to high frequencies
- Large variations between cavities



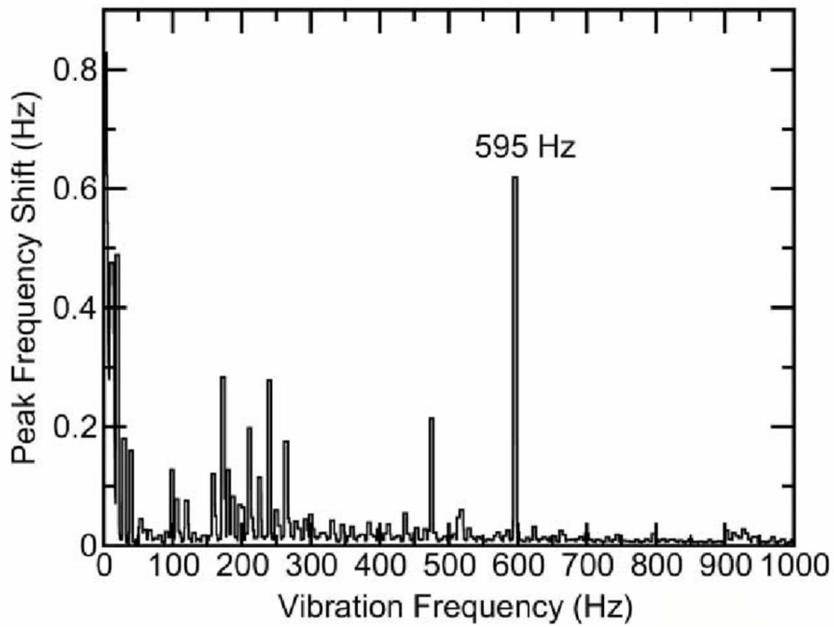



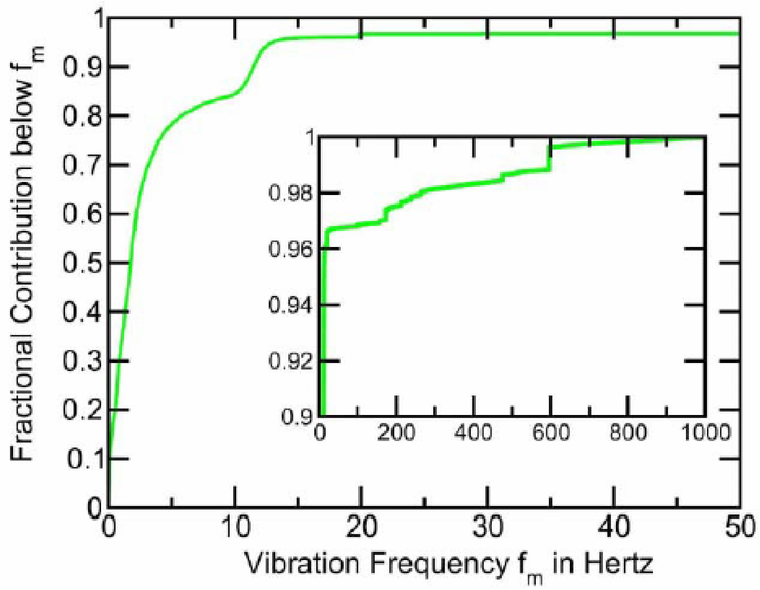
# Microphonics (frequency spectrum)

TEM-class cavities (ANL, single-spoke, 354 MHz, $\beta$=0.4)

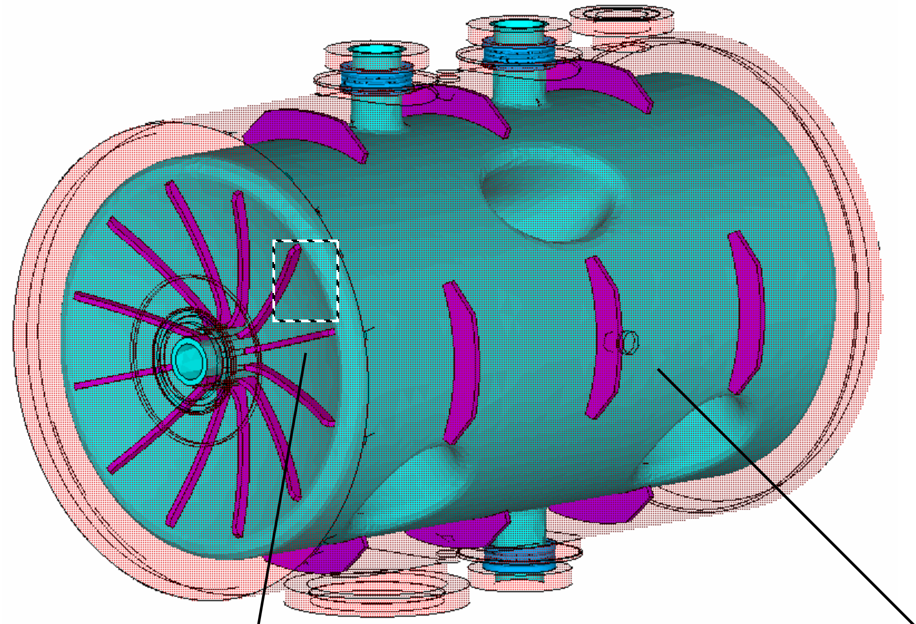
Few high frequency mechanical modes that contribute little to microphonics level.

Dominated by low frequency (<10 Hz) from pressure fluctuations (can and has been reduced by careful engineering )



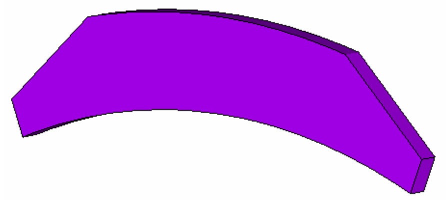



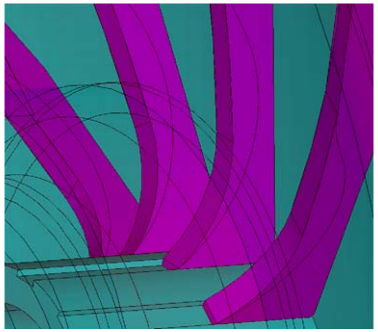
# Engineering reduction of pressure-fluctuation-induced microphonics



**Reduction of pressure fluctuation-induced microphonics by >10**

12 radial stiffeners





End stiffeners

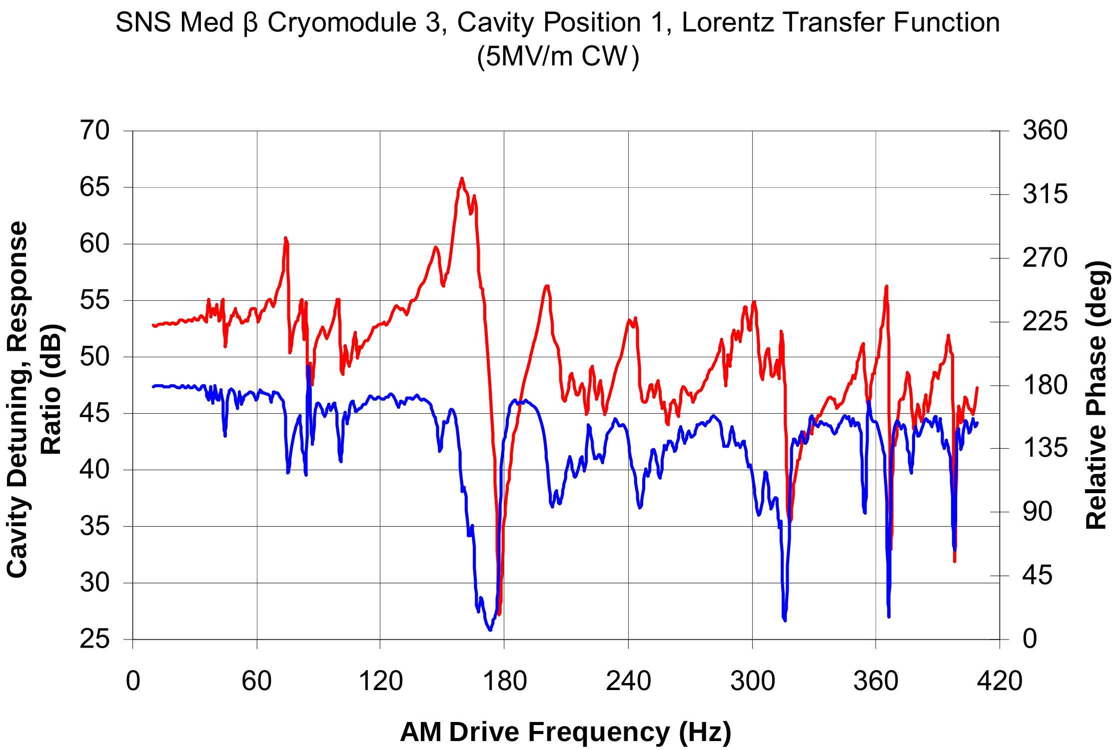
**ANL-AES**

# Lorentz transfer function

TM-class cavities (Jlab, 6-cell elliptical, 805 MHz, $\beta$=0.61)

Rich frequency spectrum from low to high frequencies

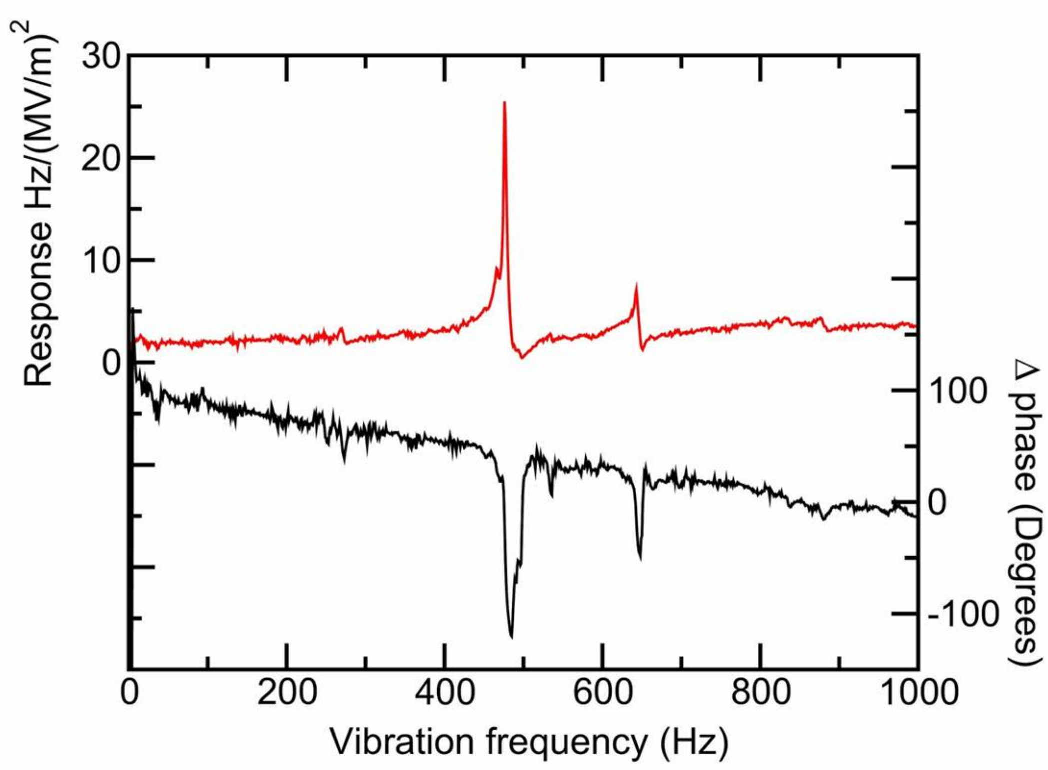
Large variations between cavities



# Lorentz transfer function

TEM-class cavities (ANL, single-spoke, 354 MHz, $\beta$=0.4)

simple spectrum with few modes

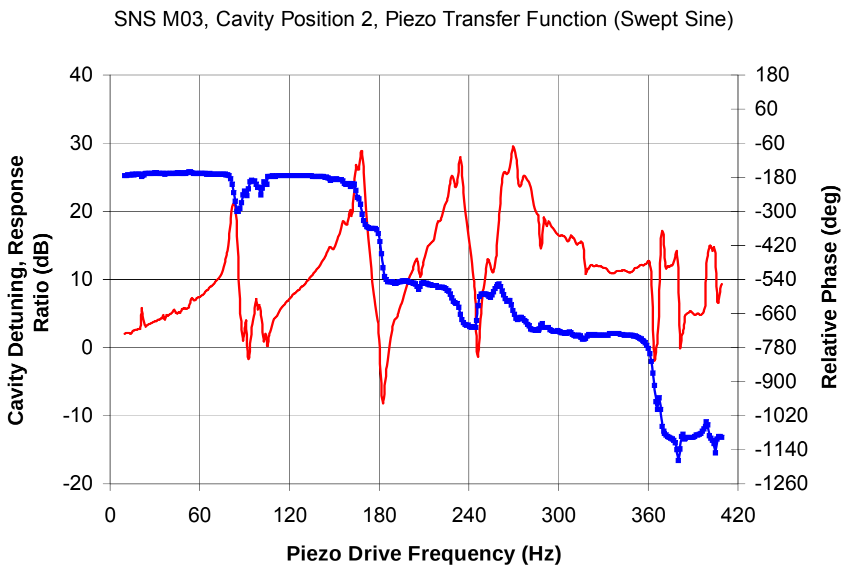


# Piezo tuner transfer function

Jlab, 6-cell elliptical, 805 MHz, $\beta$=0.61

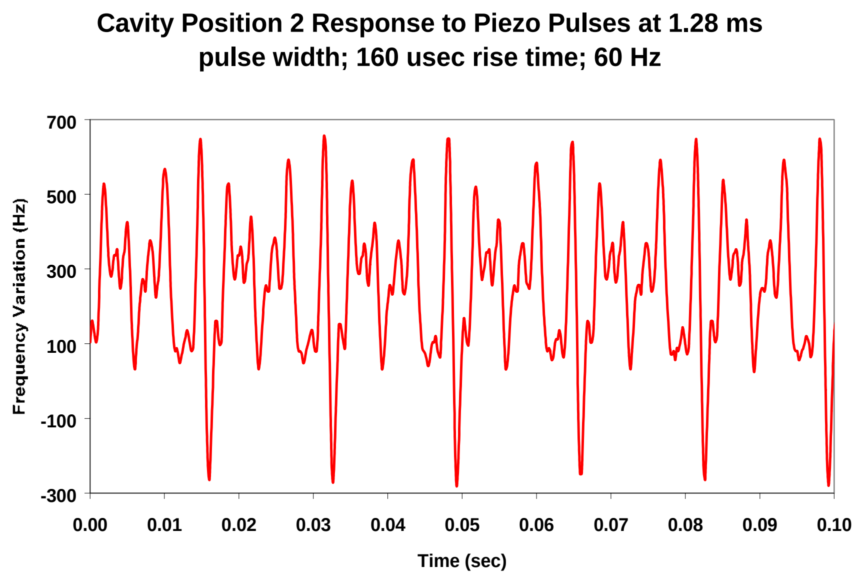
Sinusoidal excitation

Frequency domain




Pulsed excitation

Time domain



# Piezo control of microphonics

MSU, 6-cell elliptical 805 MHz, $\beta$=0.49

Adaptive feedforward compensation

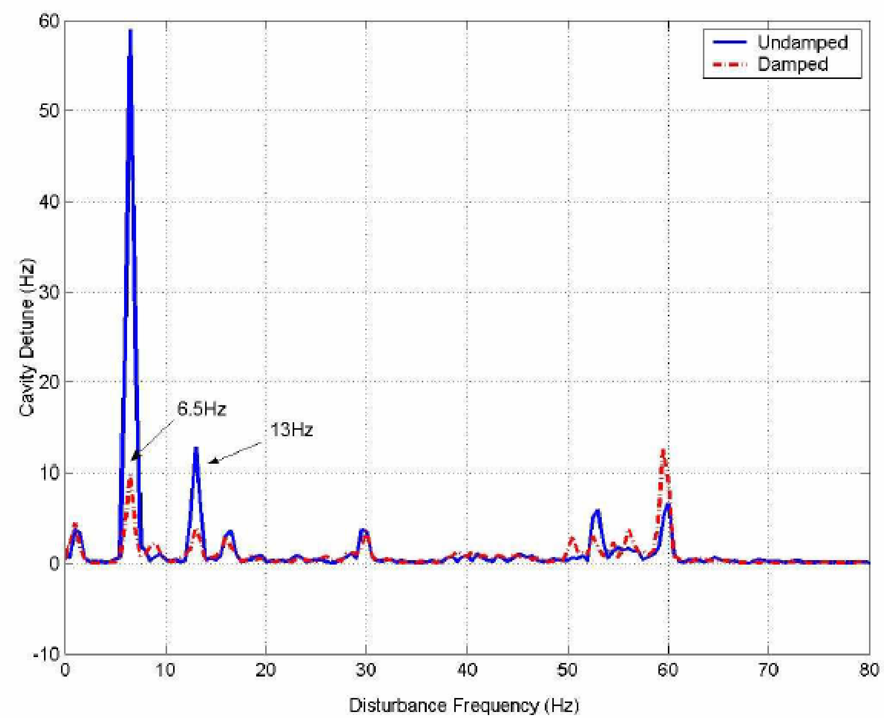



Figure 2. Active damping of helium oscillations at 2K.

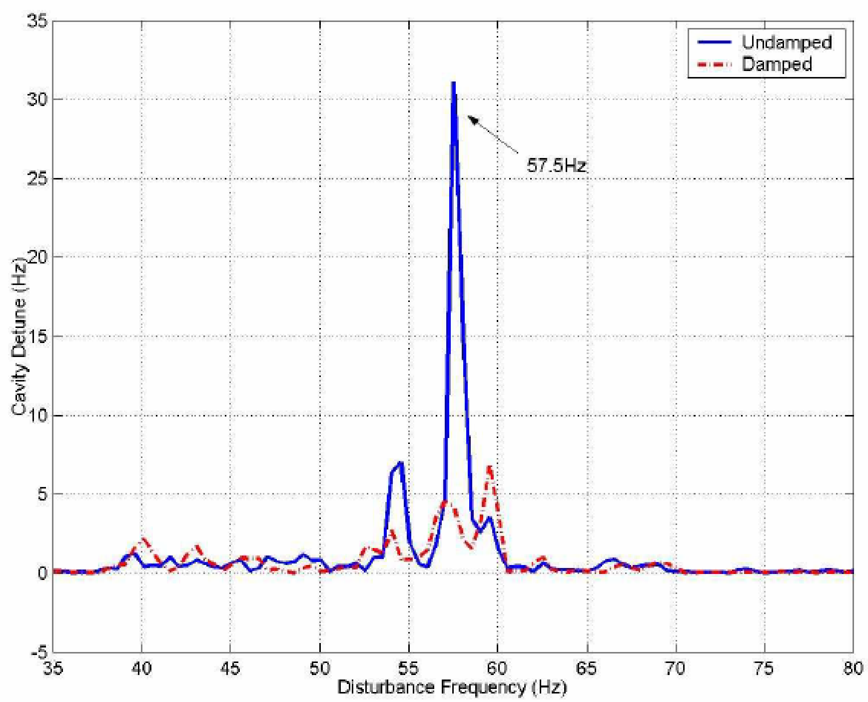
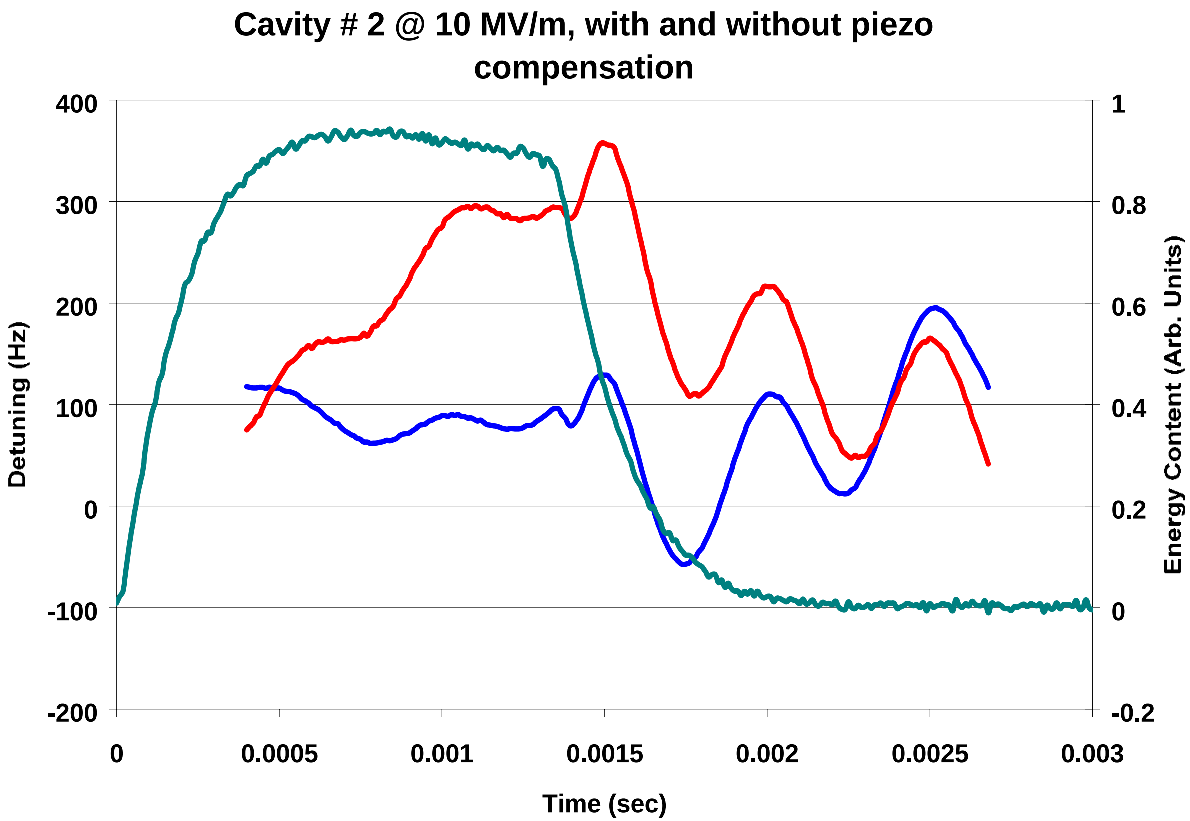



Figure 3. Active damping of external vibration at 2K.

# Piezo compensation of dynamic Lorentz detuning

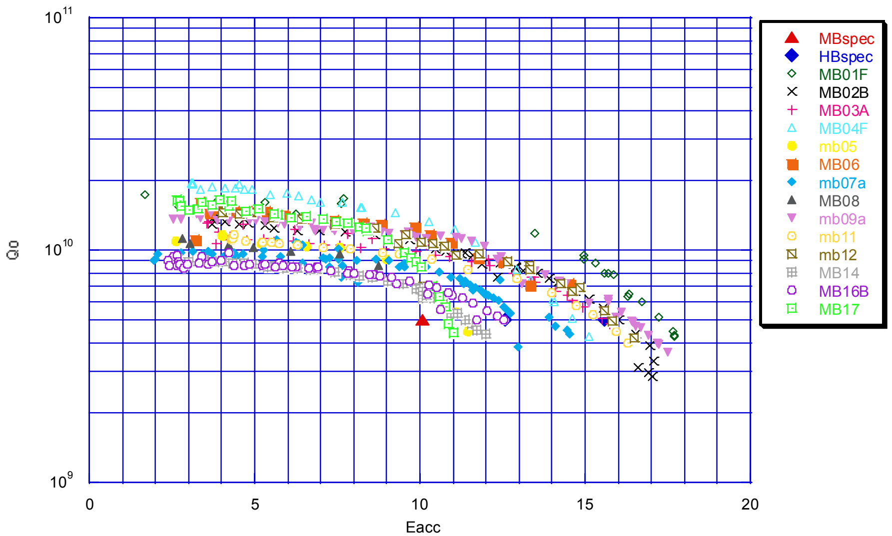
Jlab, 6-cell elliptical, 805 MHz, $\beta$=0.61



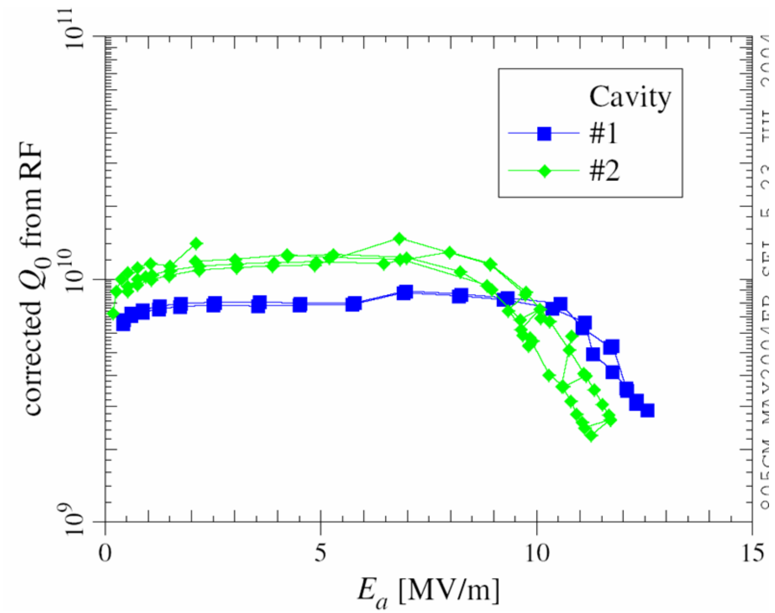
# Experimental results

## TM-class cavities

6-cell elliptical, 805 MHz, β=0.61
JLab tests of SNS cavities



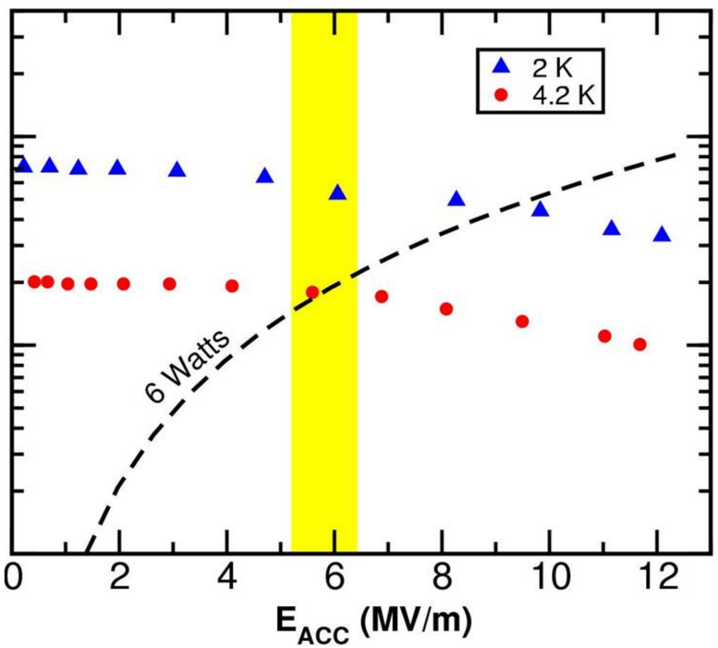

6-cell elliptical, 805 MHz, β=0.49
MSU



# Experimental results

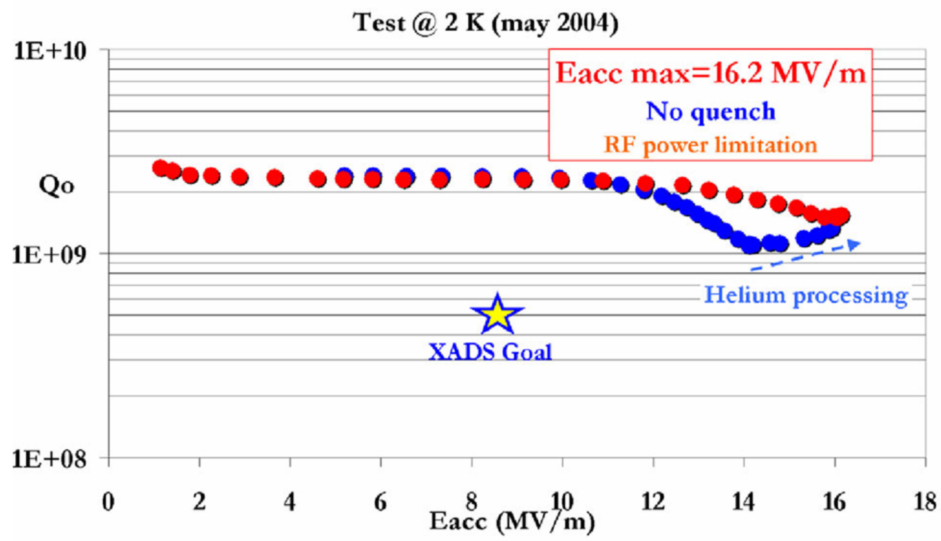
ANL

double-spoke, 345 MHz, β=0.4




Orsay

single-spoke, 352 MHz, β=0.35



# Summary

- **A large number of intermediate-velocity superconducting cavities are under development for a wide range of applications with different requirements.**
  - —Velocities from 0.2 to 0.8c
  - —Low and high currents
  - —Pulsed and cw operation
- **A variety of geometries are being explored**
- **Prototypes are demonstrating good performance**
  - —Requirements are being met
  - —No show-stoppers or surprises
- **Over the last 15 years, the gap between low and high velocity in the srf technology has been closed**
  - —The velocity space from <0.01c to c is now covered