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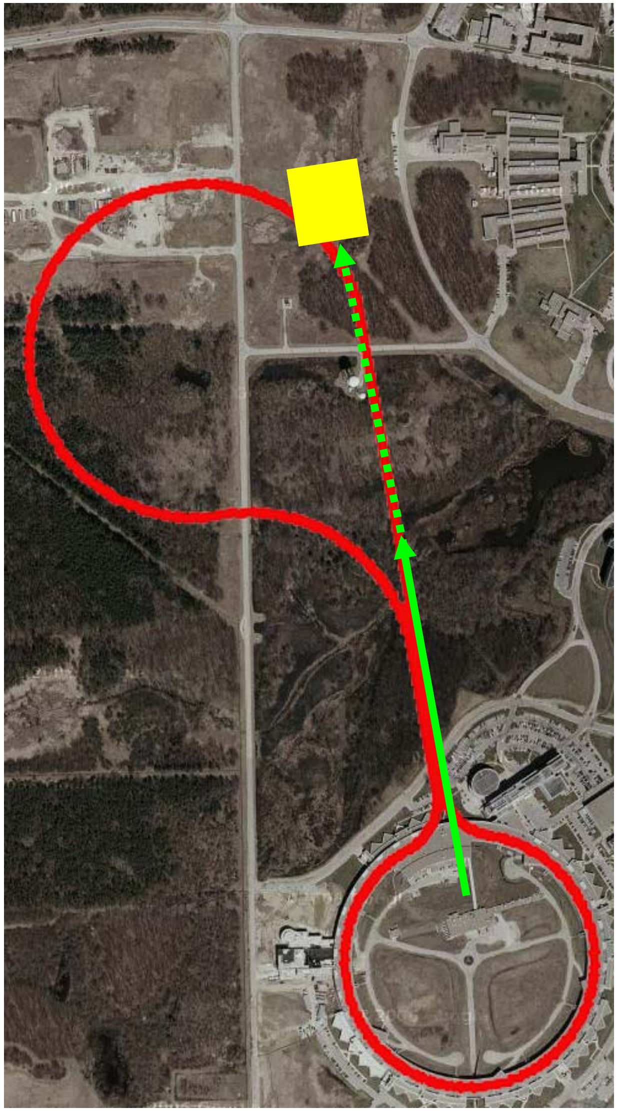
# *SRF R&D for ERL*



*Ali Nassiri*

*Accelerator Systems Division*

*Advanced Photon Source*

## *ESRF, Spring8, APS Three-Way Meeting (3WM08)*

U.S. Department of Energy

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U.S. DEPARTMENT OF ENERGY

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# *Key R&D*

- Achieving very high intrinsic $Q_0$ value
- Effective suppression of HOM
- Microphonics and optimal external $Q_e$
- Fundamental power coupler for the Injector linac
- Dedicated Test Facility

# Design Parameters Comparison

| | ILC[1] | Light Source ERL[2] | |
|---|---|---|---|
| Beam Energy | 500 COM | 5 – 8 | GeV |
| Average beam Current | 9.0 | 100 | mA |
| Bunch train repetition rate | 5 | $1.3\times10^{9}$ | Hz |
| RF duty factor | $7.5\times10^{-3}$ - $1\times10^{-2}$ | CW | |
| Average accelerating gradient | 31.5 | 20 | MV/m |
| Cavity Quality factor | $1\times10^{10}$ | $> 5\times10^{10}$ ($1\times10^{11}$) | |
| Beam pulse length | $9.5\times10^{-4}$ | $2\times10^{-12}$ | sec |
| Total AC power consumption | ~230 | ~ 50 | MW |

[1] Barry Barish, GDE/ACFA Closing Beijing 7/02/07

[2] Ali Nassiri, APS MAC, Nov. 15-16,2006

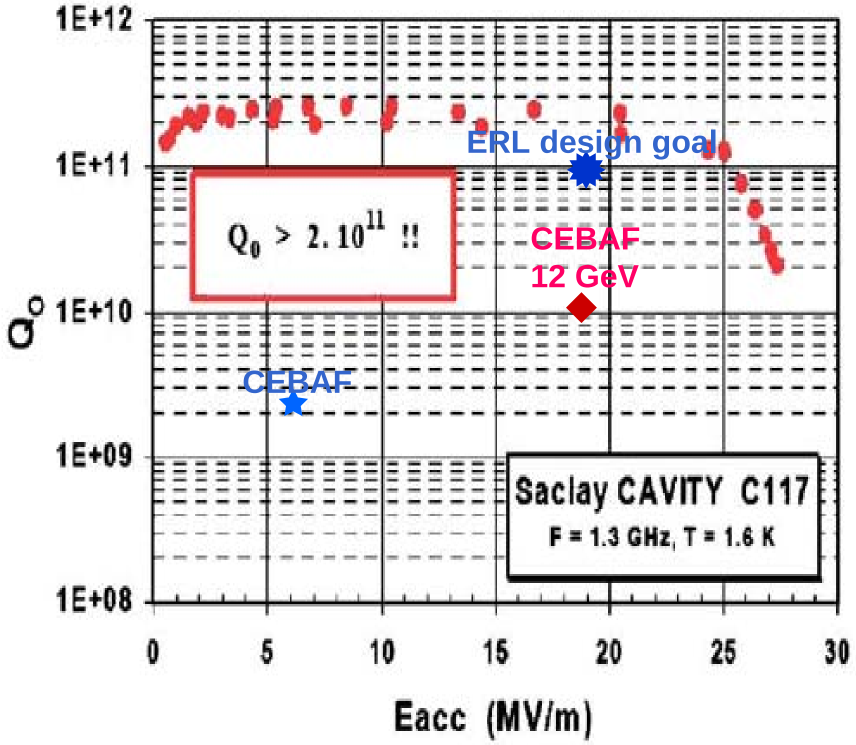
# SRF requirements

- 7 GeV single pass cw linac
- 400 multi-cell SRF cavities for main linac
- Roughly 400 meter of rf linac
- 10 MeV, 100 mA Injector linac ( 1 MW RF power)
- Roughly 45 kW total losses ( dynamic and static losses) at $2^0$K
  - Large complex
  - Extremely heavy cryogenic load
- Robust and reliable power couplers (FPC) and HOM dampers
- Complex low-level rf control for amplitude, phase stability and microphonics
- Acceptable RF systems reliability and availability for beam up time

# *High(er) $Q_0$*

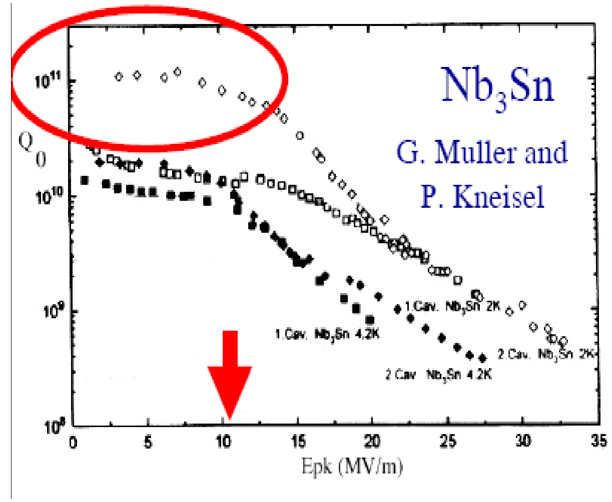
- Material Science for higher Q
  - $10^{10}$ is O.K., $5 \times 10^{10}$ is better, but $10^{11}$ is great
  - Refine surface processing
  - Large crystal
  - Single crystal

$P_{refrigeration} \propto 1/Q_0$




Single-cell 1.3 GHz cavity tested at 1.6K at Saclay

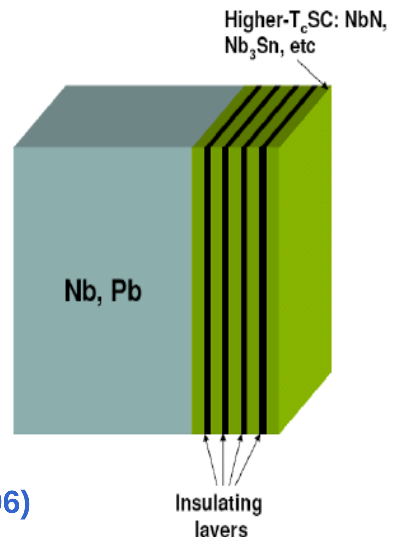
# High(er) $Q_0$ (2)

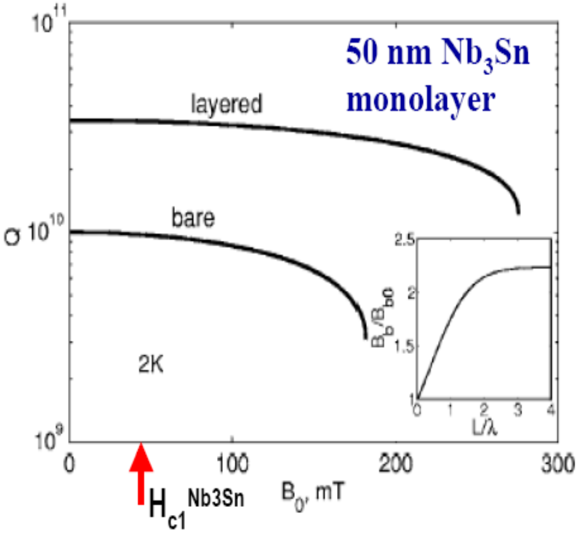



- Alternative materials
  - $Nb_3Sn$
  - NbN
  - $MgB_2$
  - YBCO
  - Stronger reduction of BCS resistance because of use SC layer with higher $\Delta$
  - $Nb_3Sn$ thin film coating may triple the breakdown field of Nb and increase Q by 3-10 times*

$$Q \sim exp\left(\frac{\Delta}{K_B T}\right)$$

$$\Delta_{Nb_3Sn} \approx 1.8 \Delta_{Nb}$$



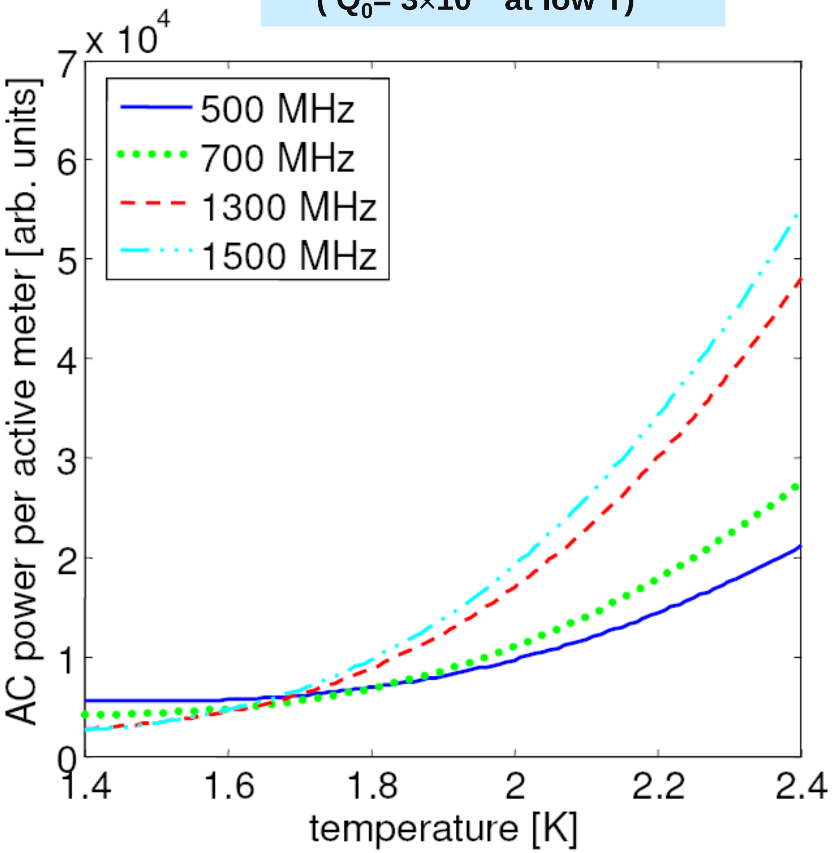

*A. Gurevich, App. Phys. Lett. 88, 012511 (2006)

# *Optimal Temperature*

- Effect of residual resistance on AC power consumption ( non-BCS surface resistance)*

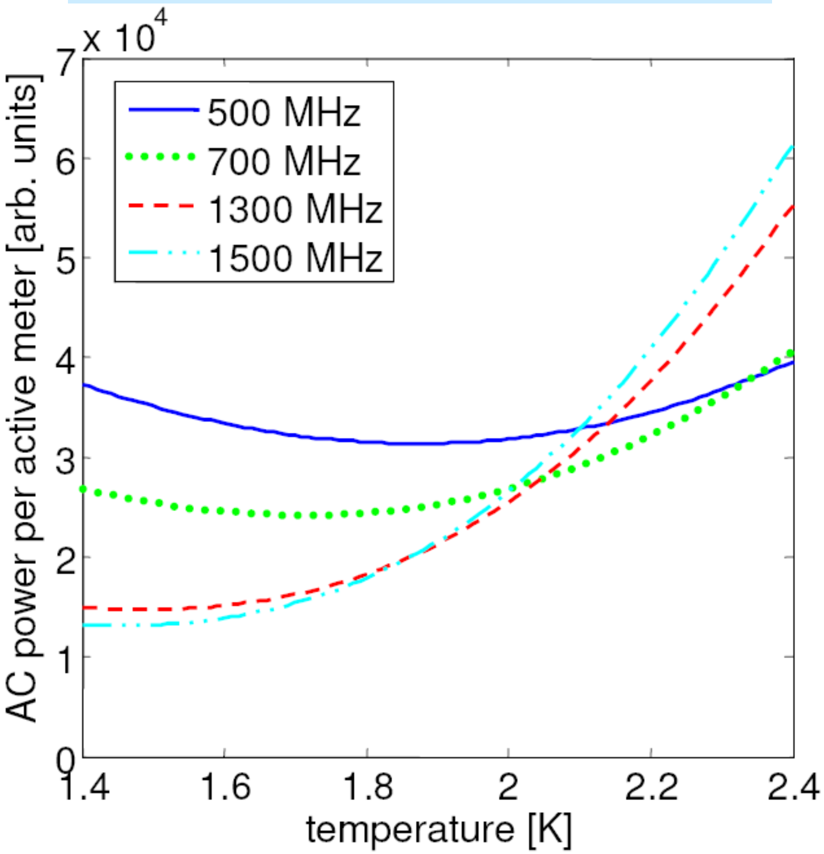
1 nΩ residual resistance

( $Q_0 = 3\times10^{11}$ at low T)




State-of-the-art 7 nΩ residual resistance

($Q_0 = 4 \times10^{10}$ at low T)




* Temperature dependent of Carnot efficiency of the cryoplant is included.

# HOM Suppression

- Multi-cell cavities with a larger number of cells would also improve linac packing factor, i.e., ratio of active length to total length
- This will reduce the cost of the ERL linac, BUT
- Strong HOM damping is essential with higher beam current which favors smaller number of cells

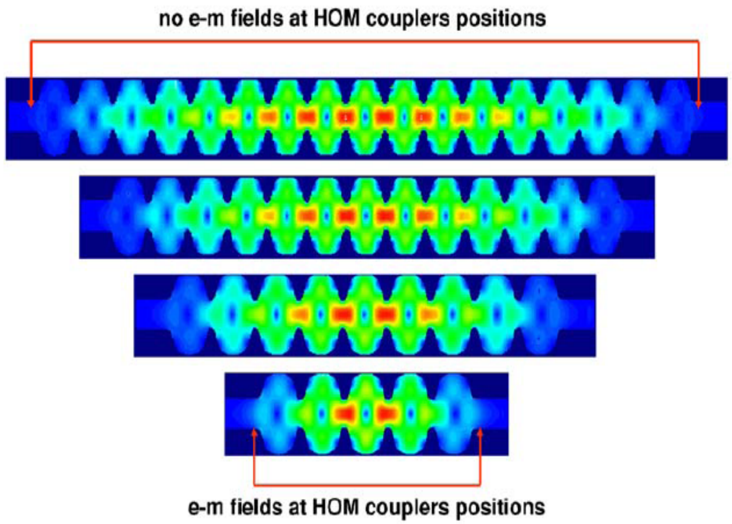
$$Q_b = 77\ pC$$

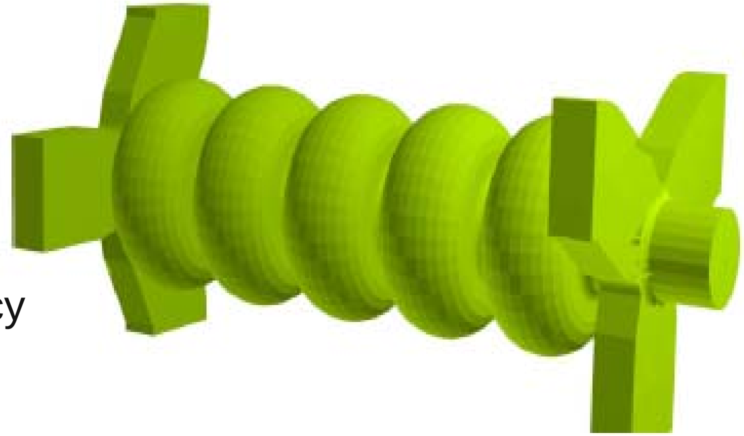
$$\kappa_{||} = 10\ \mathrm{V/pC}$$

$$f_{bunch} = 1300\ MHz\ (interbunch\ spacing\ 770\ ps)$$

$$P_{HOM} = 150\ W$$

(per cavity for two beams)

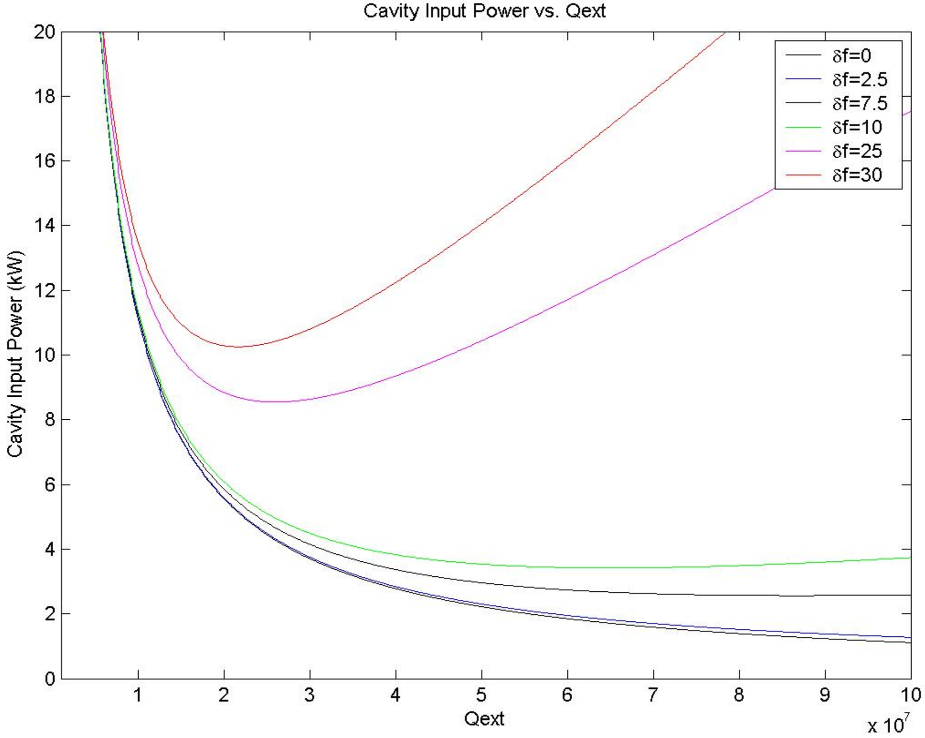


- HOM power dissipation at room temperature
- High-current optimized cell shape for good rf efficiency
- Cell Shape to have good HOM frequency spectrum

# Microphonics and External Q

- Cavity and cryostat should be designed for low microphonics
- Higher $Q_{ext}$ → less power is needed
- Detuning → more power is needed especially for large Q




$$Q_{L,\mathrm{optimal}} = \frac{1}{2}\frac{f_0}{\Delta f}$$

$$P_{g,\mathrm{minimal}} = \frac{V_{acc}^2}{2R/Q}\frac{\Delta f}{f_0}$$

RF Control:

- Operating at very high Q, ~108 (100 mA beam)
- Amplitude and phase fluctuation specs: $10^{-4}$ , 0.03º or better

- For 10 Hz detuning ( < 20 Hz peak): $Q_e = 7 \times 10^7$
- This minimizes average power but not the max power that needs to be available.

# FPC for the Injector Linac

- Power Coupler
  - No significant issue for the main linac
  - High power injector linac coupler needs to be developed
    - *Power handling > 150 kW cw*
    - *Variable coupling factor*
- Energy gain 5 to 15 MeV
- High cw current:
  - 100 mA ( 77 pC/bunch) @ 5MV, 500 kW, $\varepsilon$ ~ 1 mm-mrad
  - 100 mA (77 pC/bunch) @ 10 MV, 1000 kW, $\varepsilon$ ~1 mm-mrad
  - 33 mA (26 pC/bunch) @ 15 MV, 500 kW, $\varepsilon$ ~ 0.1 mm-mrad
- 1.4 GHz SRF 2-cell cavities:
  - Gradient ~ 15 MV/m ( ~ 3 MV)
  - Need three 2-cell cavities
  - Two couplers/ cavity ( Kick cancellation by symmetry)
  - FPCs need to be designed to handle power on the order of 150 kW or more

# *A Need for a Dedicated Test Facility*

- There is a definite need for a beam test facility to test and characterize components of a the full-size APS ERL
- This can be accomplished with a moderate electron beam energy ( ~200 MeV) and a low average current ( ~ 10 mA)
- The purpose of such facility is to characterize and understand issues such as:
  - Electron source
  - Injection scheme
  - Merger
  - Beam transport at injection energy
  - Ultra-low emittance beams generation and preservation
  - Power handling capabilities of the injector linac ( FPC performance)
  - System integration
  - Experience with SRF operation
  - Operational reliability