High Gradient Cavities: Cost and Operational Considerations

TDR: is it a Technical Design Report or a

TDR Time Domain Reflectometry
TDR Transfer Of Development Rights
TDR Time Domain Reflectometer
TDR Tokyo Disney Resort
TDR Transferable Development Rights
TDR The Death Race
TDR Tricom, S A
TDR Time Depth Recorder
TDR Transportation Discrepancy Report
TDR The Demonic Radicals
TDR Training Device Requirement
TDR The Dark Riders

TDR Test Discrepancy Report
TDR The Dirty Rag
TDR Contents of Arvid tape
TDR Transaction Data Repository
TDR Total Death Race
TDR Total Debt Restructuring
TDR Tasks, Duties, and Responsibilities
TDR Task Description Report
TDR Timmy Don't Read
TDR Technical Design Review
TDR Tom De Ridder
TDR Time Domain Reflectometry
TDR Technical Documentation Report

Chris Adolphsen

Cryomodule and Cryoplant Costs

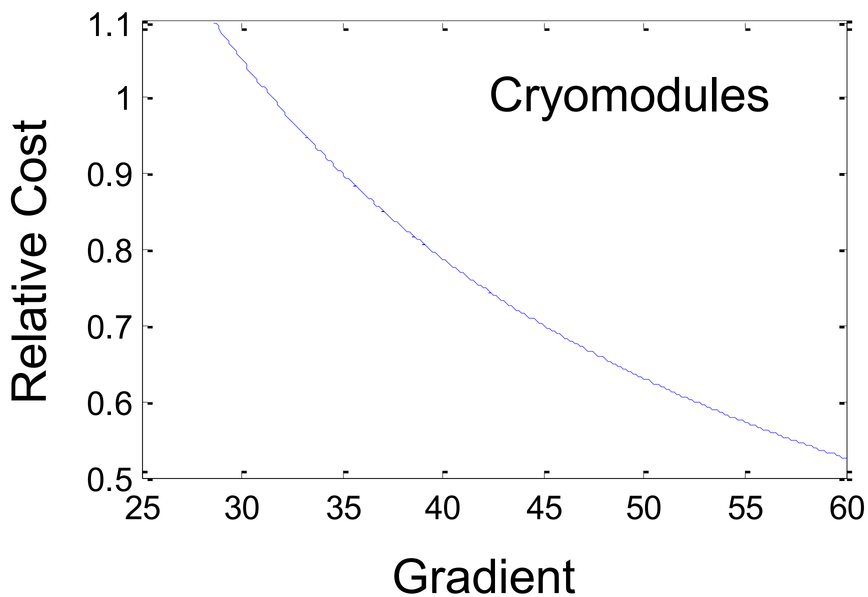
Pulse Length: Tfac = (Tb + Tfo*g/go) / (Tb + Tfo)

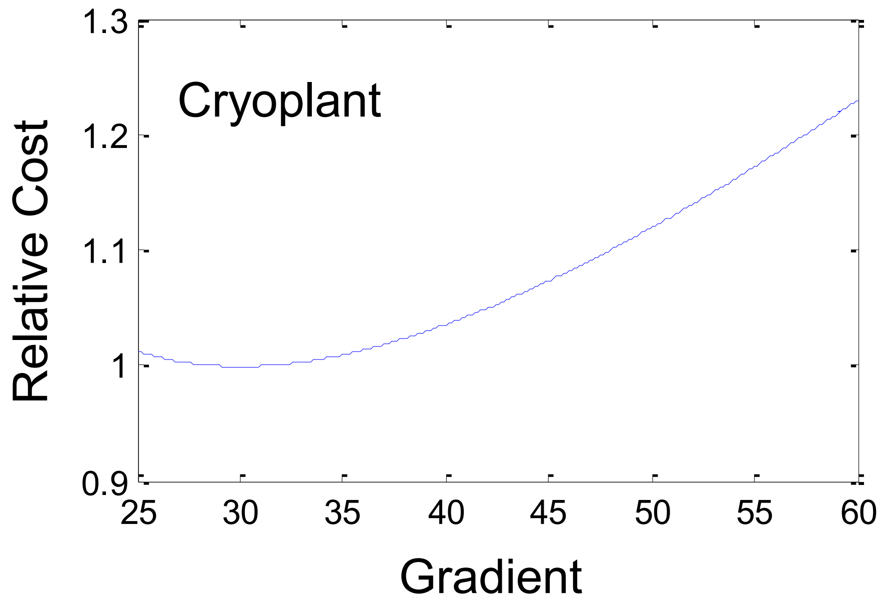
Coupler Cryo Load: Pfac = (g/go) * (Tb + 2*Tfo*g/go) / (Tb + 2*Tfo)

Cavity Cryo Load: Gfac = (g^2/go^2)*Qfac*(Tb + 1.1*Tfo*g/go)/(Tb + 1.1*Tfo)

Cryomodule Cost = (C_module + C_inst + C_vac) * (go/g)

Cryoplant Cost = (C_plant + C_dist)*[(0.52 + 0.10*Pfac + 0.38*Gfac)) * (go/g)]^0.6



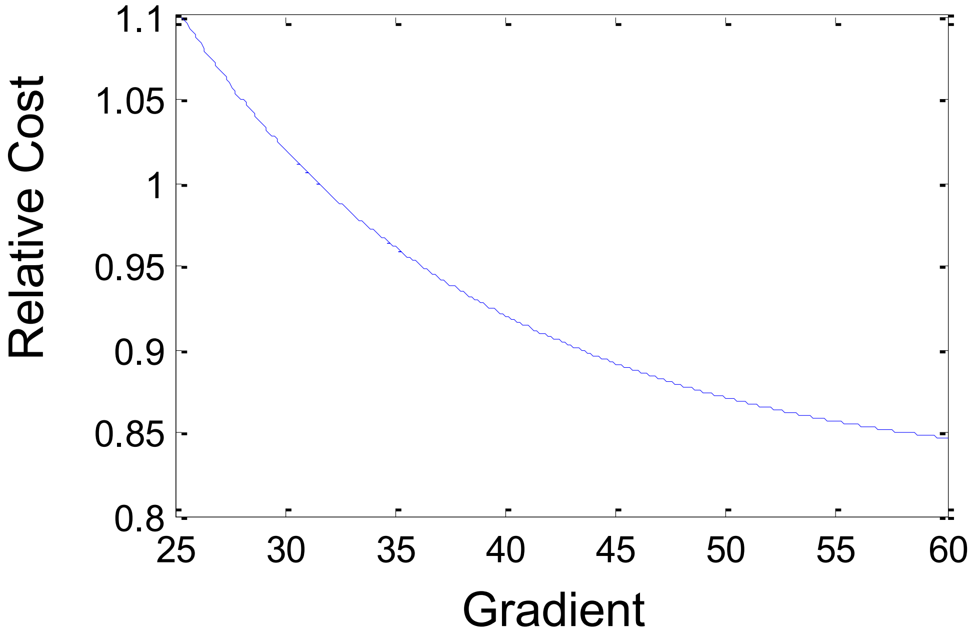


RF System Cost

Pulse Length: Tfac = (Tb + Tfo*g/go)/(Tb + Tfo)

Number of klystrons and modulators independent of gradient – number of cavities fed per klystron scale as go/g.

RF System Cost = C_mod * (0.45 + 0.55*Tfac) + C_kly * (0.74 + 0.26*Tfac) + (C_dist + C_llrf + C_global) *(go/g) + C_inst * (0.3 + 0.7*(go/g))



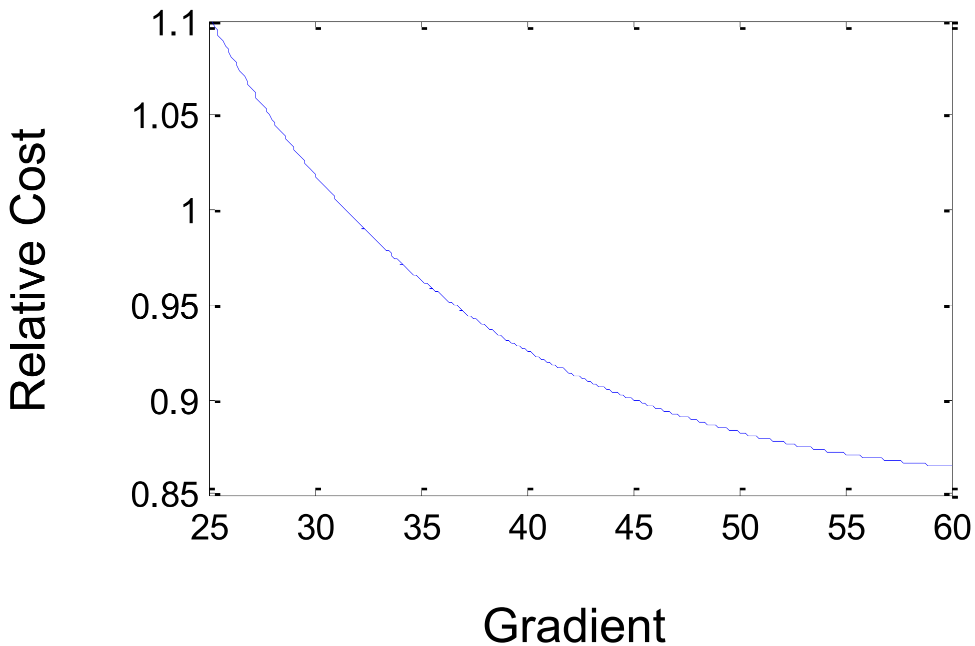
Civil Cost

Pulse Length: Tfac = (Tb + Tfo*g/go)/(Tb + Tfo);

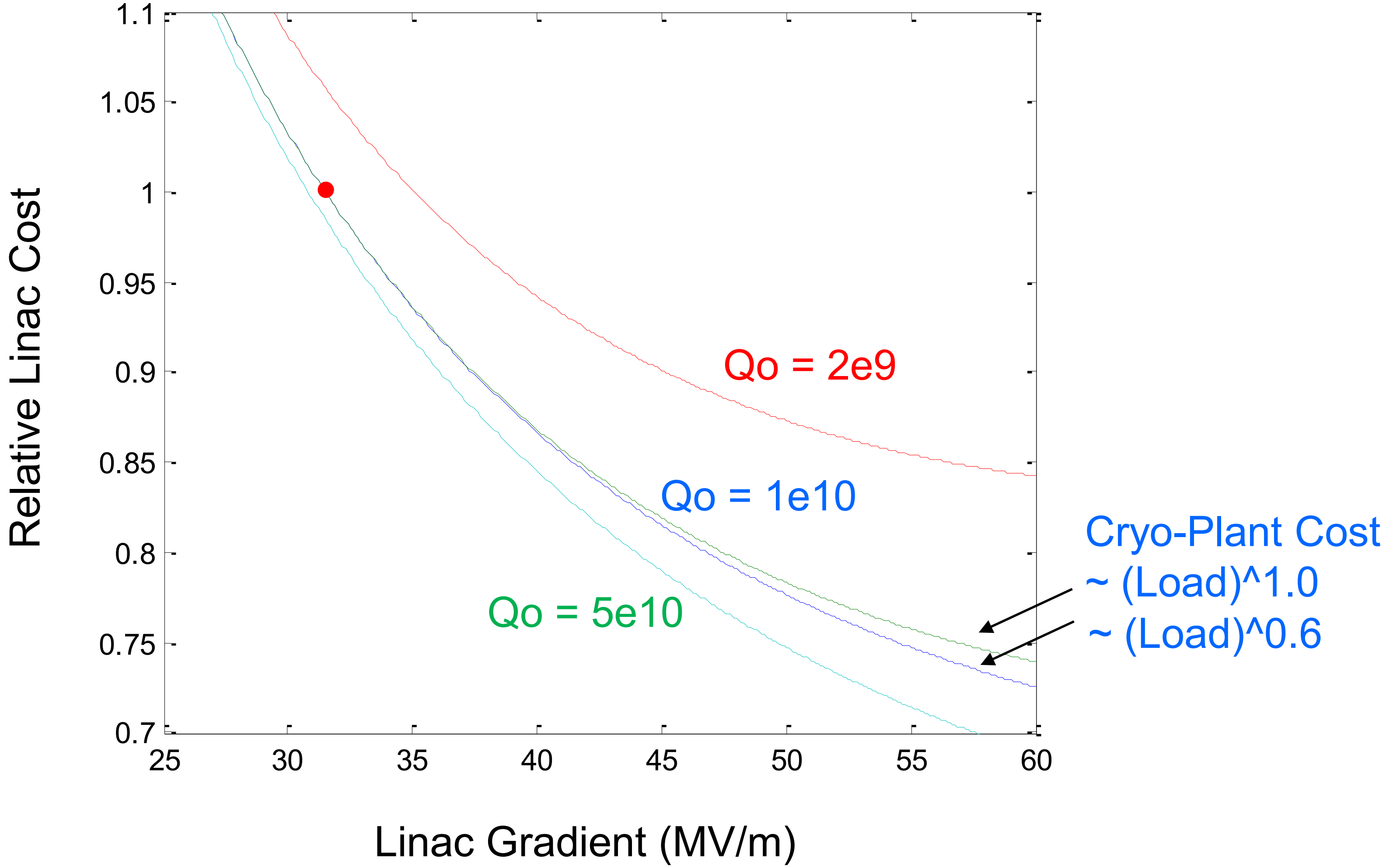
Assume electrical and cooling cost scale as load, number of shafts, and surface buildings constant

Civil Cost = C_shaft + C_tunnel *(go/g) + C_elect*Tfac

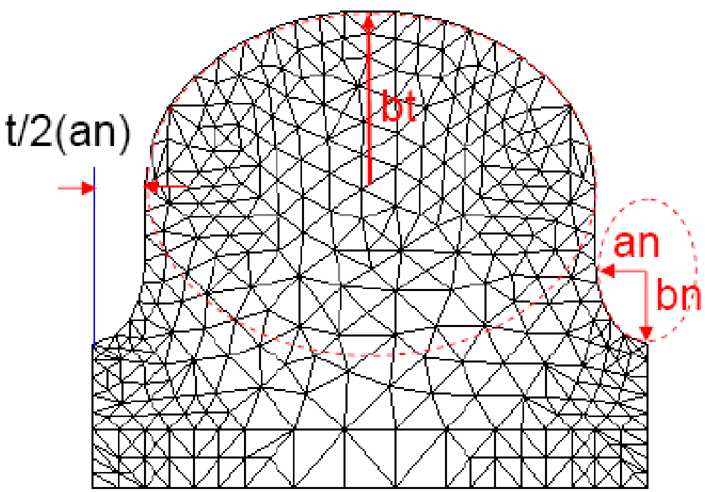
+ C_cooling*(0.22 + 0.78*Tfac)

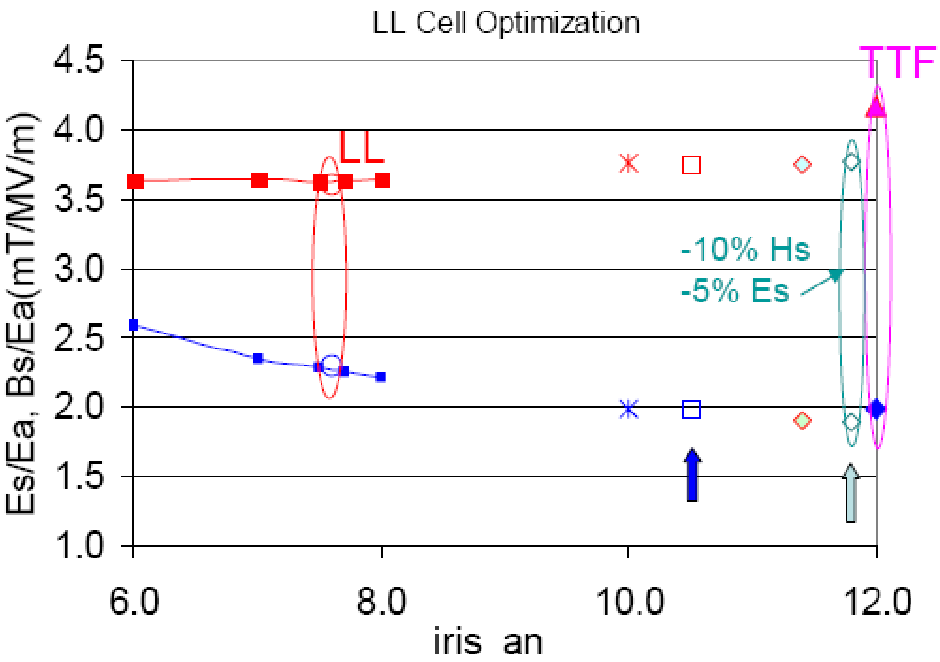


Americas ILC Linac Cost Versus Cavity Gradient and Qo



More Optimal 30 mm LL Cavity Design





	an	bn	Es/Ea	Hs/Ea	Bs/Ea (mT/(MV/m))	Ea ((MV/m)/180mT)
TTF cell (a=35mm)	12.00	19.00	1.984	0.00332	4.168	43.19
Original LL (a=30mm)	7.60	10.00	2.303	0.00287	3.608	49.88
opt-3 (a=30mm) 0mm slope	10.50	17.10	1.984	0.00295	3.712	48.49
a=30mm 0mm slope	11.80	20.80	1.894	0.00300	3.770	47.75

5% Es reduction
10% Hs reduction

Reduces cryoload by 10%, rf pulse length by 6%, and site power by ~ 4%, but short-range transverse wakes ~ 85% larger

High Gradient Operational Challenges

- Stronger Lorentz Force Detuning (LFD) to Cavity Bandwidth (BW) Ratio: For TESLA cavities:

Gradient (MV/m)	Current (mA)	Qext (10^6)	BW (Hz)	LFD (Hz)	LFD/BW
31.5	9.0	3.5	370	990	2.7
31.5	4.5	7.0	185	990	5.4
40	4.5	8.9	146	1600	11
50	4.5	11.1	117	2500	21

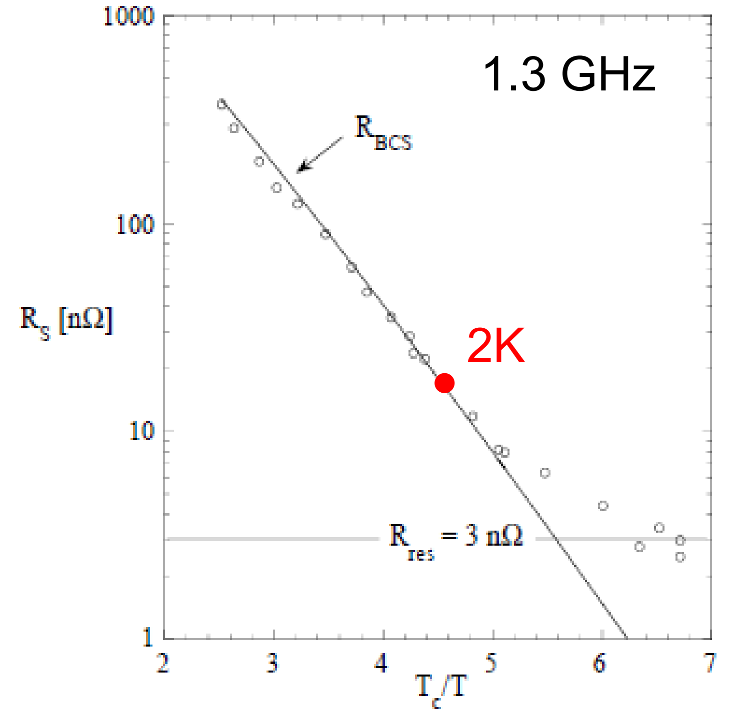
  – BW > 1e7 required for CW ERLs and proton linacs, but LFD is constant after slow ramp-up
  – Could stiffen cavity but constrained by thermal runaway if make the walls thicker

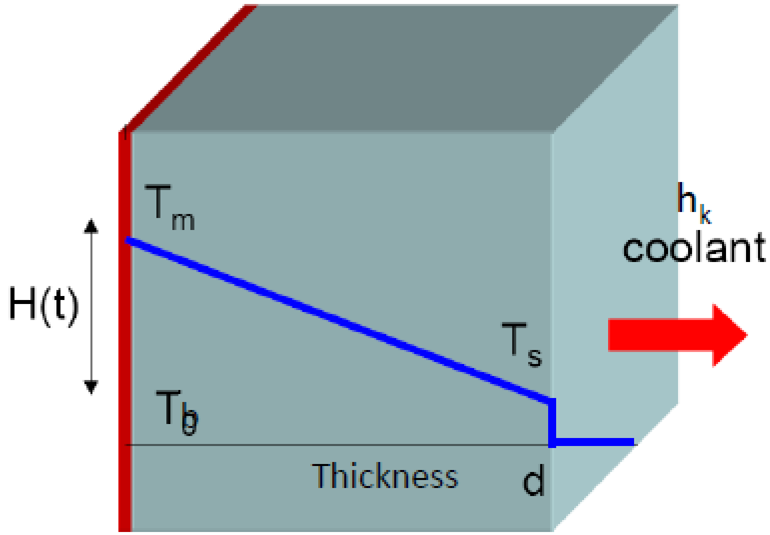
High Gradient Operational Challenges (cont)

- For same field emitters, much higher dark currents
  - Limited to 50 nA per cavity to keep loading < 0.1 W/m
  - However, reducing field emitters seems necessary to achieve high gradient, so this may not be a separate problem
- For same current, input power increases as gradient
  - At 9 mA and 31.5 MV/m, approaching power limits of couplers
  - However at 4.5 mA, the input power at 63 MV/m would be the same

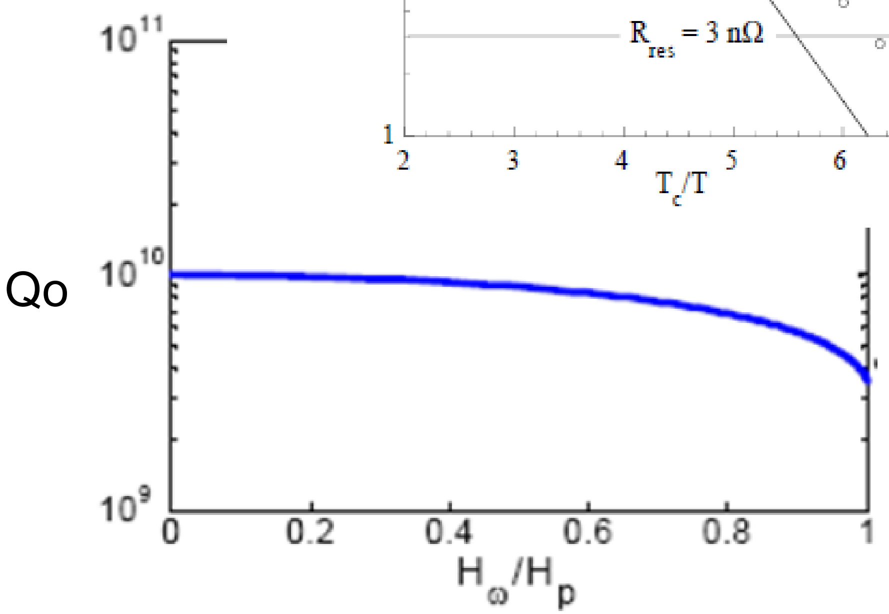
Higher Frequency Cavities

For same cavity wall thickness, gradient becomes limited by thermal run-away due to higher surface resistance, Rs, which scales as frequency^2

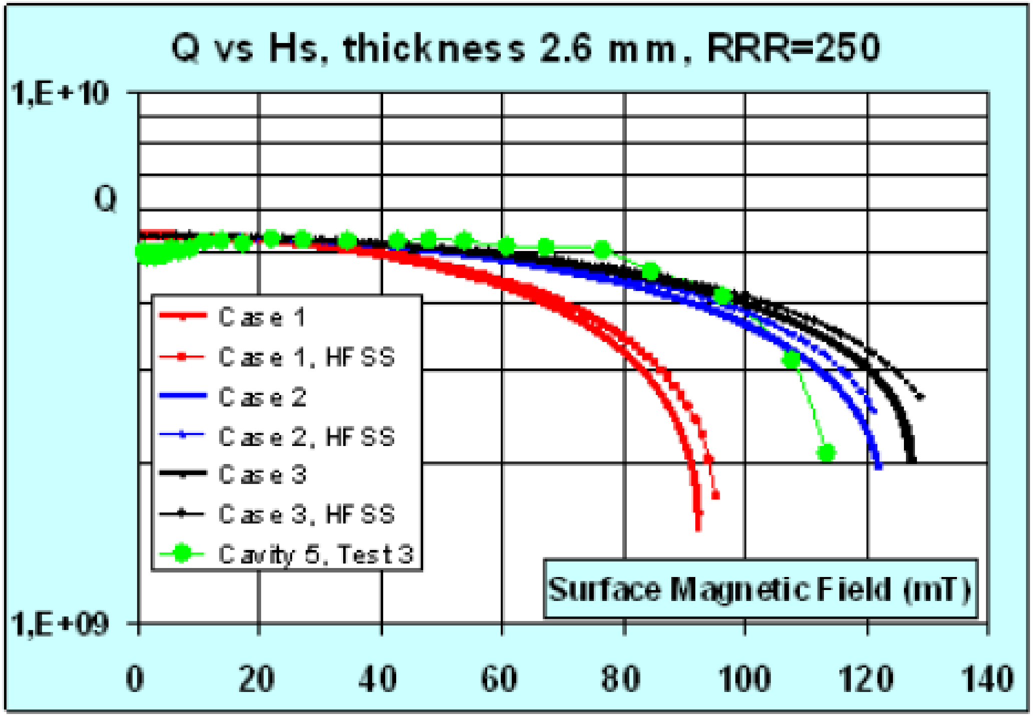


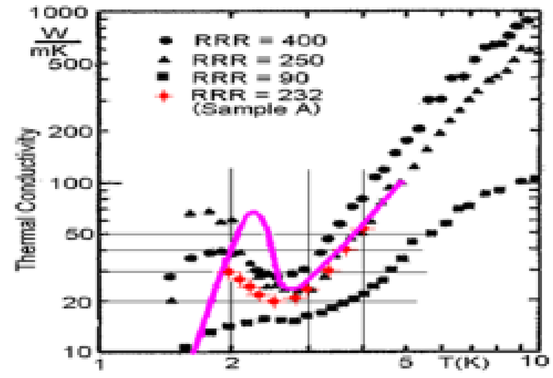


Cavity Wall

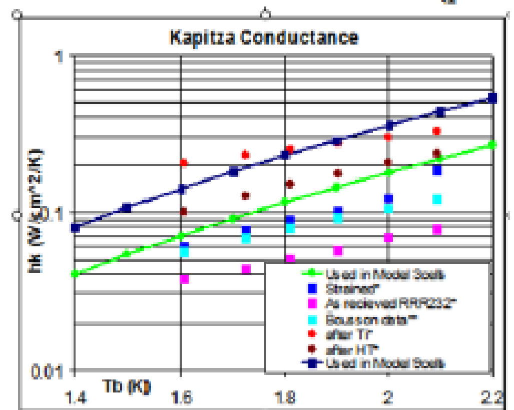


Thermal Breakdown Data and Simulation for the FNAL 3.9 GHz 'Linearizer' Cavities Built for FLASH

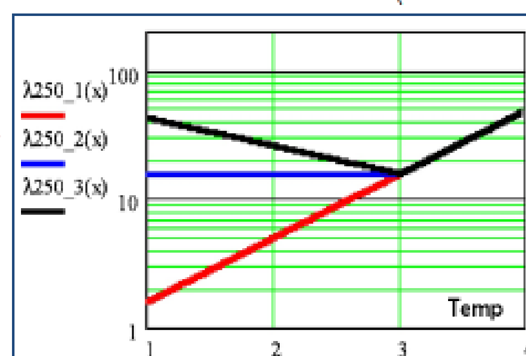




Measured thermal conductivity and values used in models (pink)



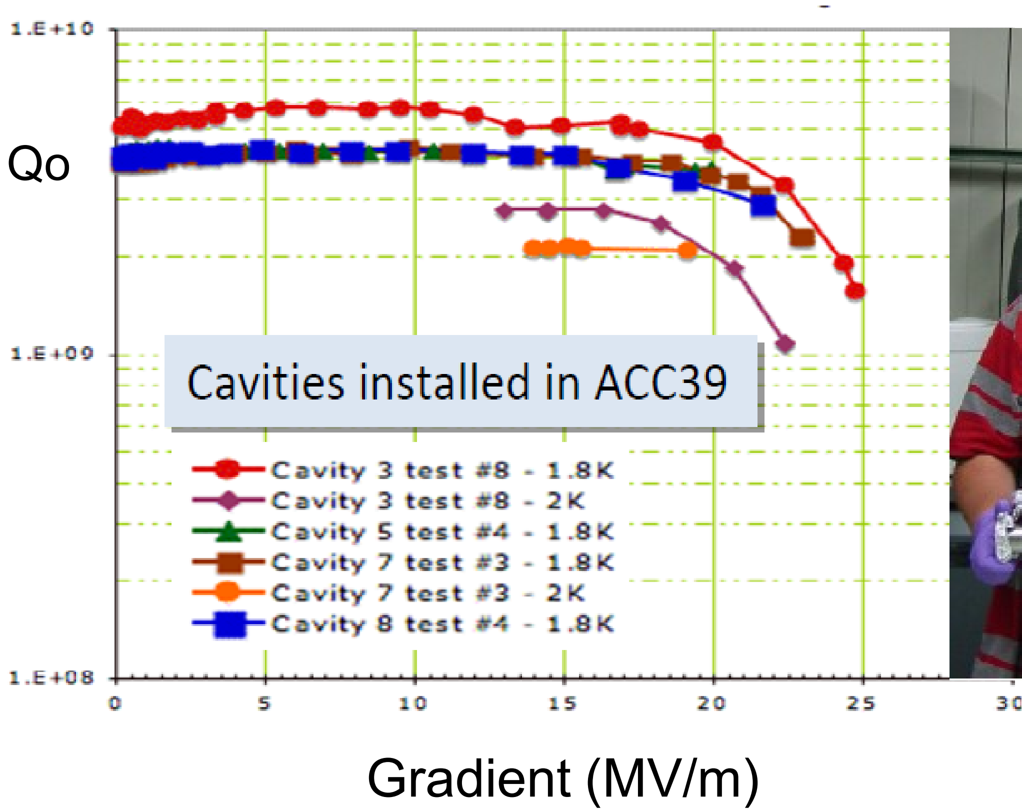
Measured values of Kapitza conductance and values used in model (solid lines)



Comparison of measured data for cavity #5 (dashed) with model for the three thermal cases.
Case 1 - RED, Case 2 - BLUE, Case 3 – BLACK.
Solid lines are for the constant surface magnetic field model, dotted for real fields calculated by HFSS.

h_k=0.3 W/cm^{2}K at 1.8K.

3.9 GHz Vertical Test Results: Qo vs Gradient



Bottom Line: Cavity and cryomodule costs likely lower at 2.6 GHz and 3.9 GHz, but need to optimize cavity wall thickness for thermal limit and LFD, and evaluate energy where increased wakes from the smaller aperture could be tolerated.

From 10/2007

Sergei Nagaitsev: What we will NOT learn from the ILC SRF Facilities by 2011

- It is likely that by end of 2010 neither facility [NML or STF] will have an rf unit with Type 4 CM's
- NML will not operate at 5 Hz rep rate.
- We (NML or STF) may have at least one CM operating at 31.5 MV/m
  - Need to verify gradient with beam – proof of ILC CM existence!
- Neither lab will have a separate CM test stand
  - Thus no rapid CM tests with pulsed rf power
- NML and STF will not validate system optimization for the best "value engineering", such as
  - Beam dynamics and quadrupoles system design
  - Cryomodule design with cryogenics system design

What we will NOT learn … (continued)

- Will not validate some interface parameters:
  - Plug compatibility
- We will have difficulties with:
  - Long-term reliability tests of CM components, such as tuners, piezos, couplers
  - Evaluating HOM absorption and propagation
    - Need to do it with an ILC CM's
  - Static and dynamic heat loads
    - NML temporary cryo system is not properly instrumented; wrong temperatures

From 10/2007

H. Weise: XFEL Components

- XFEL needs
  808 cavities for
  101 accelerator modules, i.e.
  808 frequency tuners,
  808 RF main input couplers,
  1616 HOM pick-ups,
  101 HOM absorbers
  etc.

First 5-10% of modules in 2010, majority in 2011 / 2012

Tunnel installation finished spring 2013

- Overall rate: 1 module per week for 2 years
- Orders will be placed not later than 2009, so the prices are known on the basis of 5% ILC
- Component tests start in Q3/2010

End of 2010 approx.	5 modules, 40+40 cavities, coupler, …
Mid of 2011 approx.	30 modules, 300 cavities, coupler …