Snowmass ILC WS: Superconducting Cavities

Personal Compressed Highlights of WG5 (Cavity)

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(figures ‘stolen’ (adapted) from presentations at Snowmass)

Hot Topic: ‘The’ Cavity Gradient (1)

Existence proof:

There are a few **cavities close to theoretical limit**, but many are still ‘somewhat away’ … -> **spread in E_{max}**

Problem: RF power for many (16, 24,..) cavities generated by common klystron and distributed ->

All cavities have the ‘same’ field:

worst cavity limits group performance

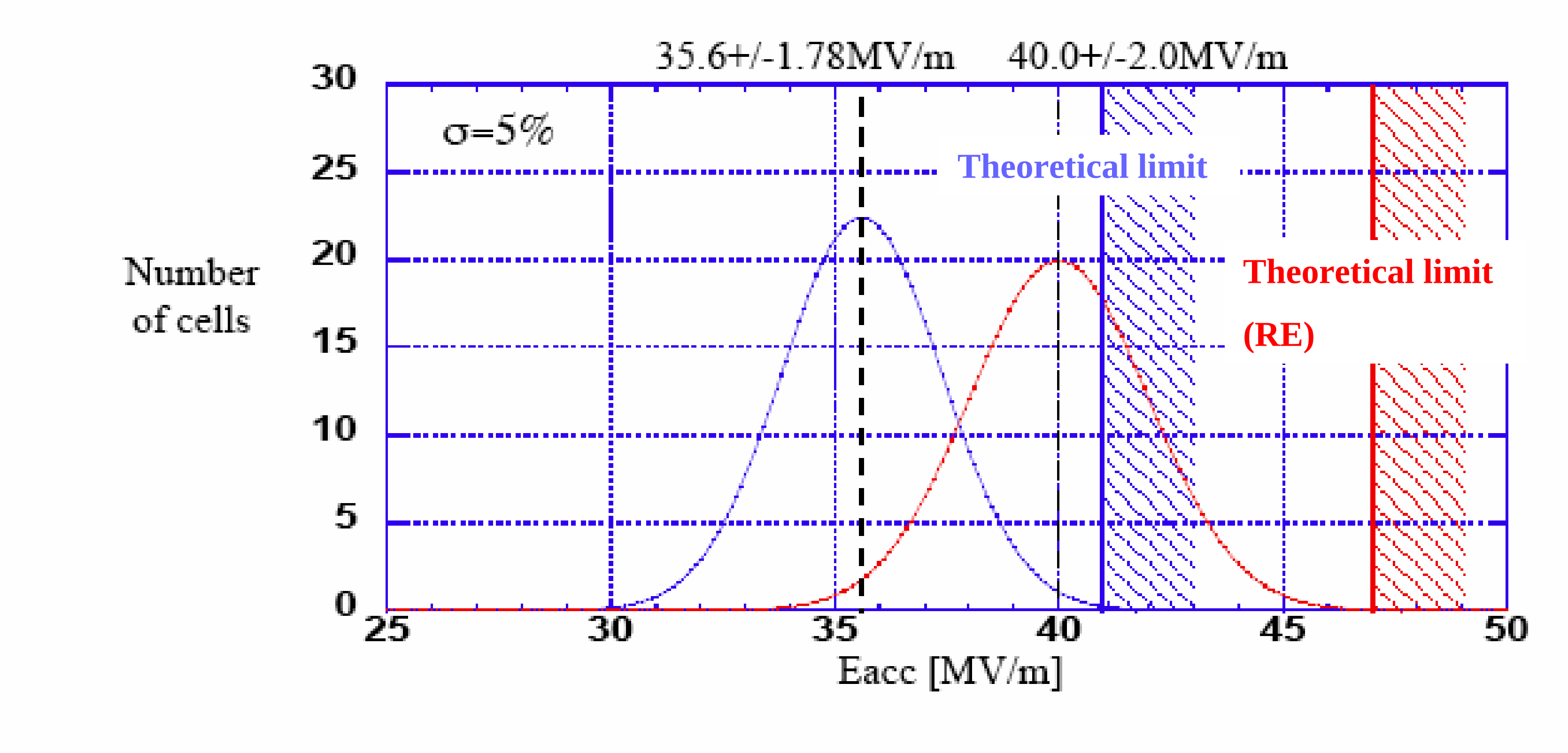
All RF-tricks to excite each cavity according it’s individual performance needs special expensive hardware, is very complex and work intensive to set up

…. and risk of ‘V_{acc}-slope’ along pulse (bunch train)

Hot Topic: ‘The’ Cavity Gradient (2)

Histogram TESLA cavities/cells (blue Gaussian) applying ‘standard’ (but complex!) fabrication and surface treatments

(red Gaussian: extrapolation to new cavity shapes - see later)



Hot Topic: ‘The’ Cavity Gradient (3)

WG5 proposal for design gradient (baseline):

Assume that, when machine is to be built in 20xx, all TESLA shape cavities can be produced to supply at least

35 MV/m individual cavity gradient in ILC

(in vertical test (if) and no degradation assumed on it’s way into cryomodule and accelerator: perfect handling)

Unavoidable scatter in the RF distribution system and Q_{ext} and operational range will need 10% margin ->

31.5 MV/m <cavity gradient>, $Q=1\cdot10^{10}$

Definition cavity gradient: $E_{acc} = V_{acc}/L(\text{cells})$!!!

The Real Estate Gradient

What really counts is the

real estate gradient: Linac end-energy / linac length

Reduce length of all non-accelerating components,

i.e. for the cavities:

-Cut-off tubes (limit: RF leaks to normal conducting parts)

-Tuning mechanisms

-Power coupler / HOM damper longitudinal space require.

-Superstructure = 2 joined (not welded, size of object!) cavities fed by a unique power coupler

Tuner: Nothing 100% ready on the shelf for high gradient (with piezo !) but 2 designs are close (and 2 more designs on their way)

- Saclay type : using lever arms (TTF3)
- INFN blade tuner: coaxial rotating construction

Lorentz force detuning compensation necessary at high gradients:

(fast !) piezo has to be incorporated , not yet ready

Hot discussion: Step-motor(s) and piezo inside cryostat (easier construction, less cryo losses) or outside (access) -> **'inside motor' exists and tested (TTF3), seems to be 'failsafe' enough** …

Power Coupler: Proven TTF3 design sufficient for baseline, will be used for XFEL (large scale test for ILC …)

Advanced options: KEK-Tristan variant or Capacitive (ring)

HOM Coupler ('low' frequency): TTF3 design sufficient for baseline. Advanced options: Modified capacitor, beam line capacitive

Beam line absorber (high frequency): not yet ready, existing design estimated sufficient for baseline. Advanced options: Modified capacitor, beam line capacitive.

Superstructure: Feed 2 cavities by one coupler, saving space and money (one coupler / 2 cavities).

'Missing link': Superconducting seal, all attempts failed

(except for 'split-ring cavities' at ANL …. ????)

Hot topic: New 'improved' cavity shapes (1)

'Today' progress approaches theoretical limit of <u>magnetic</u> field (185 mT for RF ? -> 41 MV/m TESLA shape)

For the same E_{acc}:

- **Modify cavity shape to have lower B_{peak} (cell equator)**

BUT: peak electric field (close to iris) increases

Today each 2nd sc. cavity is limited by field emission (dark current) from high electric field regions ….

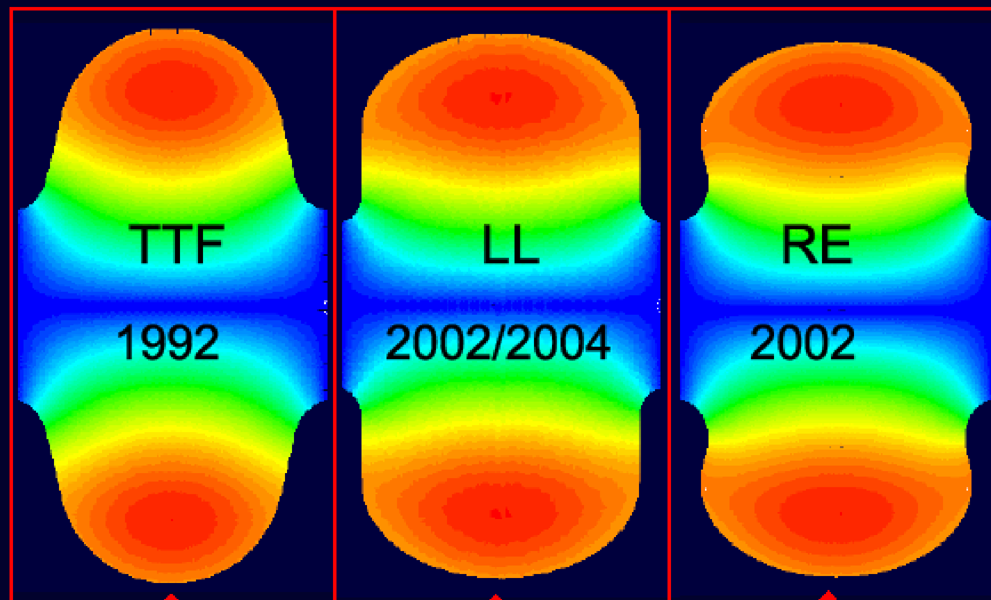
- **Decrease cavity iris diameter, decreases B_{peak} and E_{peak}**

But: wake fields (impedance) increases and cell-to-cell coupling decreases (field flatness in multi-cells)

(• Minimize RF-losses = cryogenic consumption (LL))

Hot topic: New 'improved' cavity shapes (2)

Example: 1.3 GHz inner cells for TESLA and ILC



		TTF	LL	RE	
r_{irisb}	[mm]	35	30	33	
k_{cc}	[%]	1.9	1.52	1.8	field flatness
E_{peak}/E_{acc}	-	1.98	2.36	2.21	max gradient (E limit)
B_{peak}/E_{acc}	[mT/(MV/m)]	4.15	3.61	3.76	max gradient (B limit)
R/Q	[Ω]	113.8	133.7	126.8	stored energy
G	[Ω]	271	284	277	dissipation
R/Q*G	[Ω*Ω]	30840	37970	35123	dissipation (Cryo limit)

Hottest parameter: B_{peak}, E_{peak}, iris diameter

Hot topic: New ‘improved’ cavity shapes (3)

- Before considering new shapes: Field-emission has to be ‘eliminated’ (up to 120 MV/m surface field) ->

Top priority R&D (advanced) |[1]

- First checks from beam dynamics: **wakes** after reduction to r=30 mm iris should be **acceptable for ILC**

- ‘re-entrant’ shape (RE): Problems with rinsing liquids, might spoil cavity Q-value and favour field emission (shape in past ‘unthinkable’ …) -> **R&D**

|[1] The problem is 100 years old (e.g. high power switches) but no easy solution has been found

Material and Surface Improvements

Standard Material Choice (for mechanical properties):

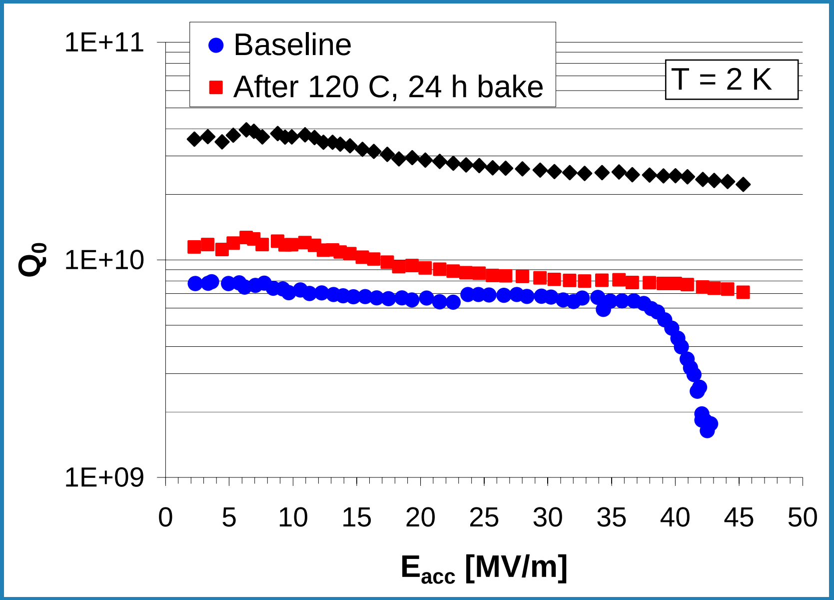
Fine grain niobium, high thermal conductivity (RRR)

Grain boundaries are the 'junk-yard': Try using large grain material or single crystal (less/no g.b.)

First test single crystal slice

(at 2.2 GHz, available crystal size)

Best: 45 MV/m, 2nd limited by field emission



Extrapolate Q to 1.3 GHz: signific. better than 'standard'

There seems to be a bright light at the end of the tunnel ….

R&D

Summary: Baseline

- The WG is convinced that at ‘time of delivery’ cavities with operational <cavity gradient> of **31.5 MV/m** can be supplied

(This assumes that by continued R&D production can be improved **reducing the spread in E_{acc}**)

- Cheaper fabrication (hydro forming of entire 9-cell …) and surface treatment (avoid electro-polish …) to be pursued

- Ancillaries as power couplers, HOM dampers, tuners are either ready or on the way for finalization; XFEL will be a technology test-bed ‘free of charge’ for ILC …

Summary: Advanced

• New cavity shapes increase the potential of the technology by ≈10% in gradient; however, the problem of **field emission (dark currents)** has to be eliminated by aggressive R&D

• Large grain / single crystal niobium has shown significantly improved performance in gradient and Q in ‘reduced size’ tests.

R&D should **confirm results** at 1.3 GHz (any shape); perhaps allows to get away with **cheaper surface treatment methods**