Re-entrant Cavity Geometry for Increasing Gradients

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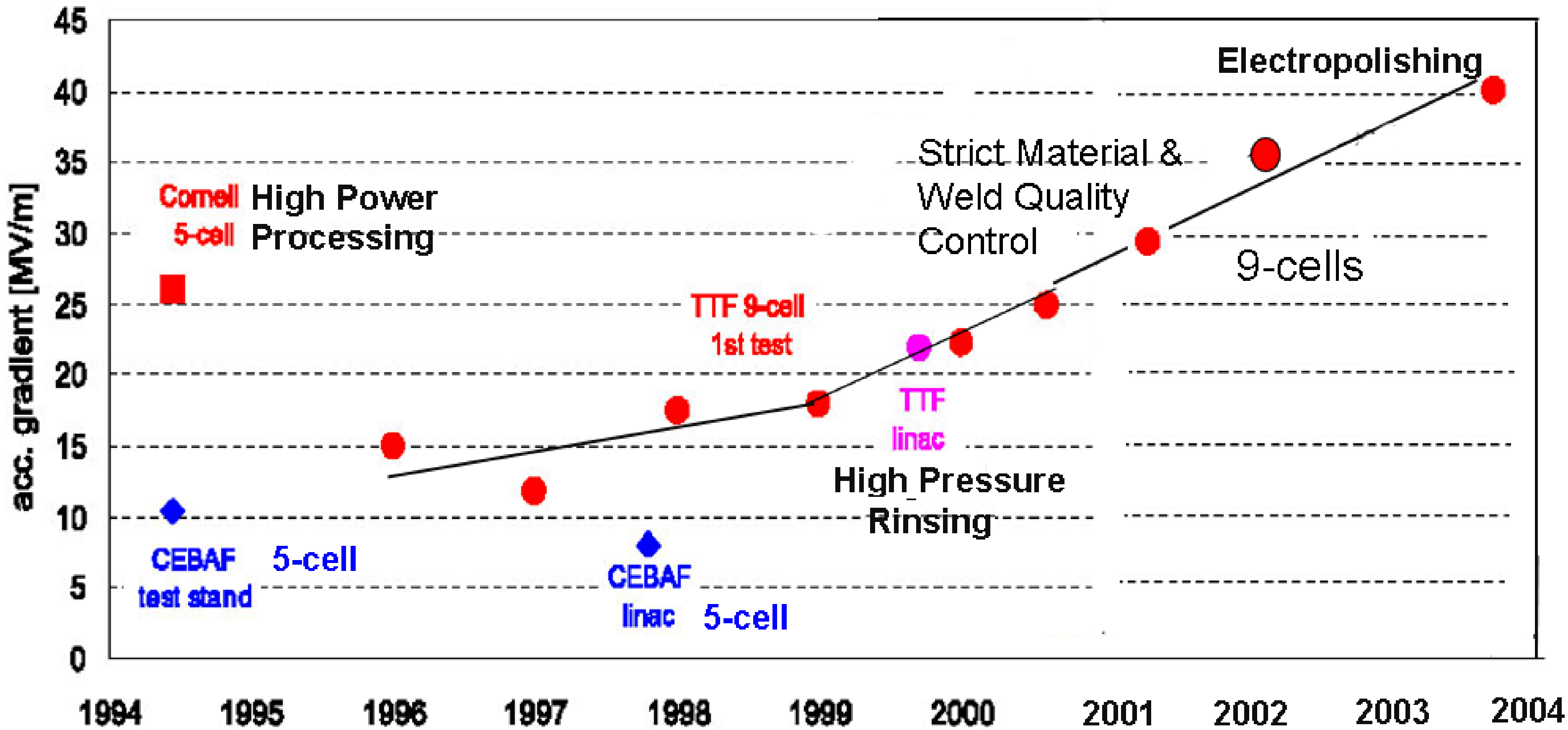
Continuing SRF for Higher Gradients: Issues, Challenges and Benefits

- SRF performance has been rising every decade
- SRF installations for HEP (and other applications, e.g. NP, spallation, light sources, ADS) have been rising steadily
- With strong support, SRF can continue to make major impact on future HEP accelerators
  - ILC, TeV upgrade, Superbeams for Neutrinos, Neutrino Factory, Muon Collider, Multi-TeV colliders
- This provides important spinoff for
  - Nuclear Physics colliders (e.g. eRHIC)
  - Spallation sources (e.g. ESS)
  - Light sources (e.g. x-ray ERL)
  - Accelerator Driven Systems (ADS) energy sources and transmutation of nuclear waste.

Increase of SRF Gradients Multi-cells, 1995 – 2006 => 42 MV/m



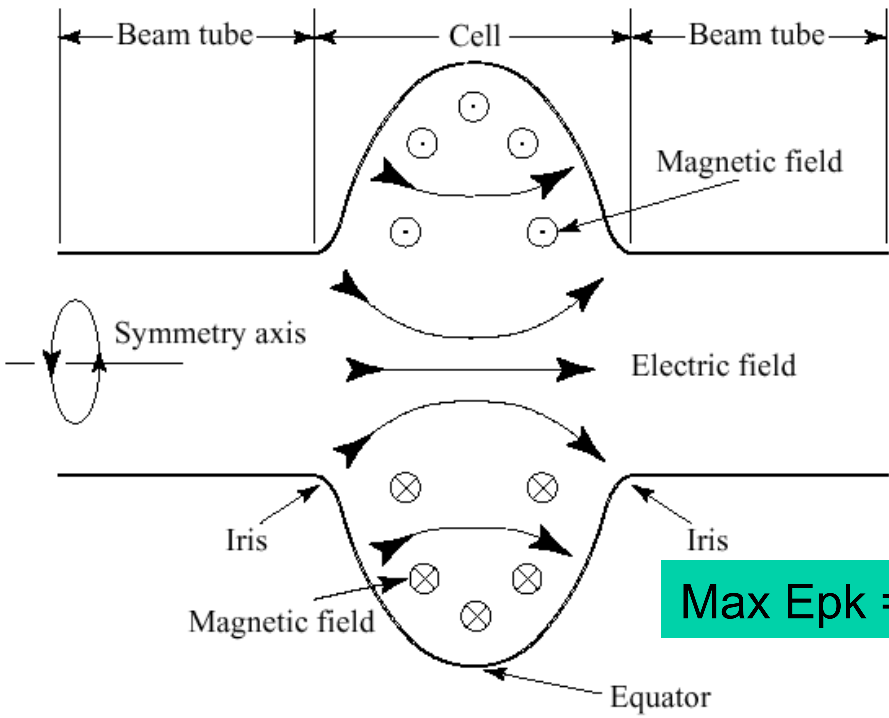
Background

- Accelerating gradients in superconducting cavities have increased from 5 MV/m to over 45 MV/m over the past 35 years. How much higher can the fields be pushed?

- The maximum attainable gradient is limited by the critical magnetic field on the surface of the cavity. At this field, superconductivity breaks down.

Surface Magnetic and Electric Fields

1 MV/m Accelerating Field



Max Epk = 2 MV/m

Max Hpk = 4.2 mT

Theory:

RF critical magnetic field =

Superheating critical field = 0.23 T for Nb

=> 54 MV/m for standard (TESLA) shape cavity, as shown here

Best achieved in single cell cavity of this shape = 45 MV/m =80% theoretical

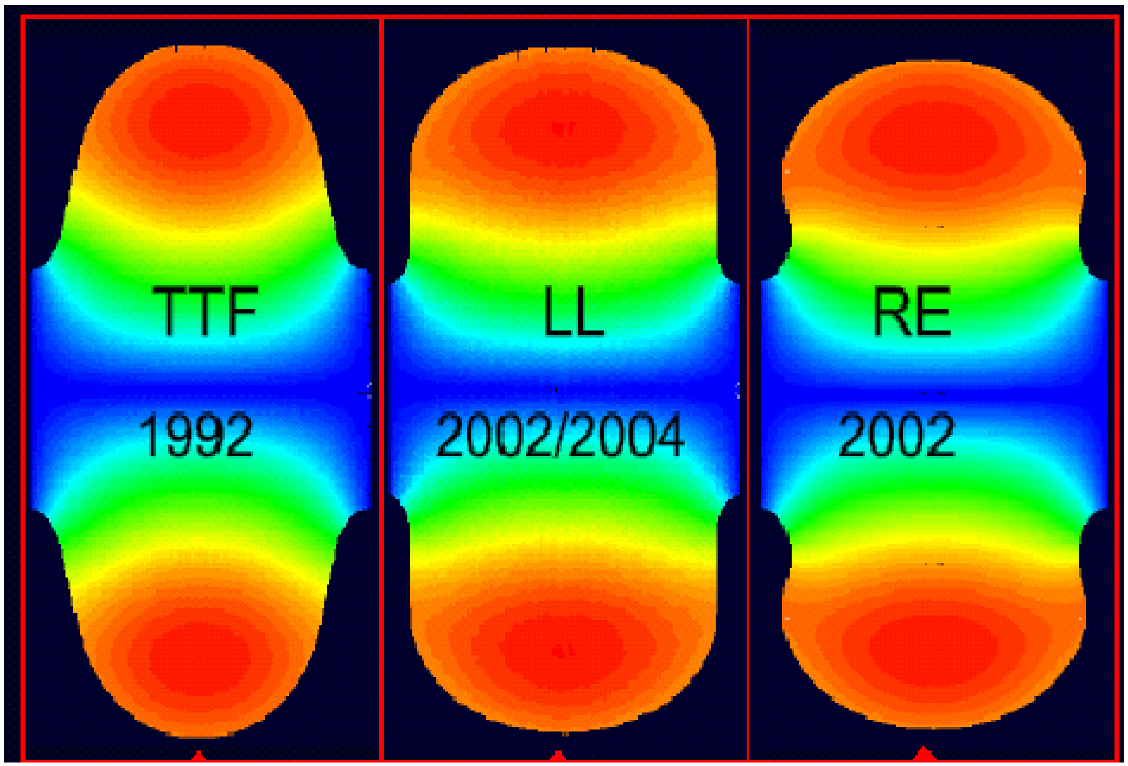
Two strategies

a) Improve geometry

b) Increase surface field by better treatments

Philosophy:

• Critical magnetic field at equator region is a brick wall.
• Losses from field emission can be reduced by HPR and HPP
-> Lower Hpk for desired Eacc
Even if we must raise Epk

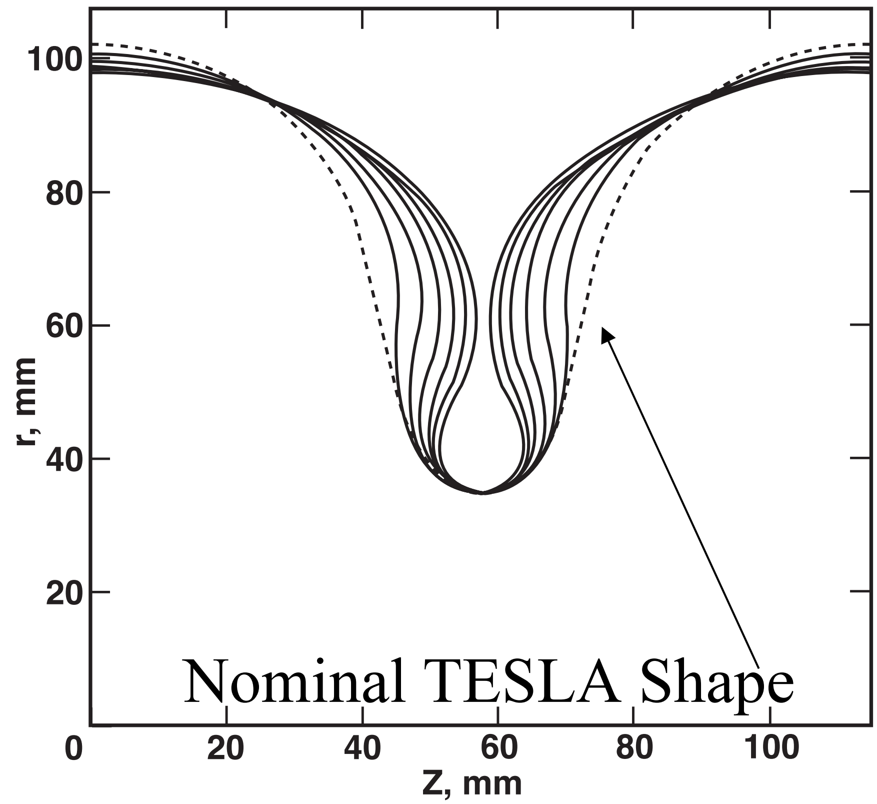


+ Variations

Comparison

Single cell, 1.3 GHz niobium cavities of various shapes
(a) TTF-like
(b) KEK, Low-loss (ICHIRO) 60 mm aperture
(c) Cornell Re-entrant 70 mm aperture
(d) Cornell Re-entrant 60 mm aperture.

Re-entrant Shape #1: Keep the 70 mm TESLA Aperture for Low Wakes



Philosophy:

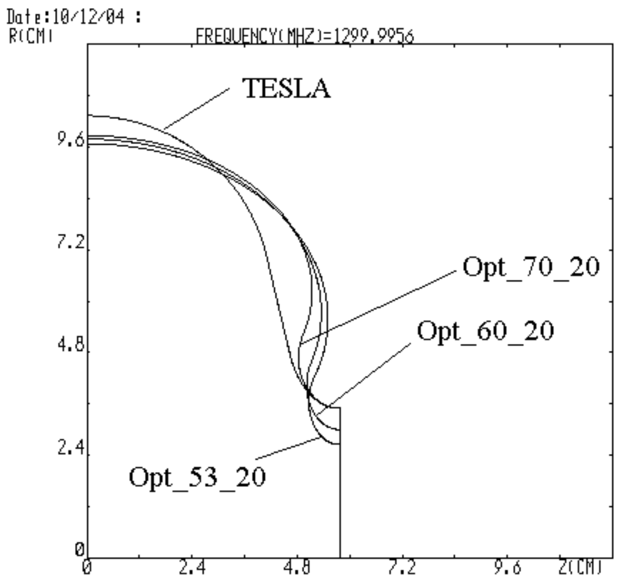
- RF Critical magnetic field is a brick wall (fundamental limit).
- -> Lower Hpk

Even if we must raise Epk

δe, %	δh, %
0	-5.07
+ 10	-7.92
+20	-10.00
+30	-11.36
+40	-12.30
+50	-12.99

Chosen Geometry

Details of Optimization



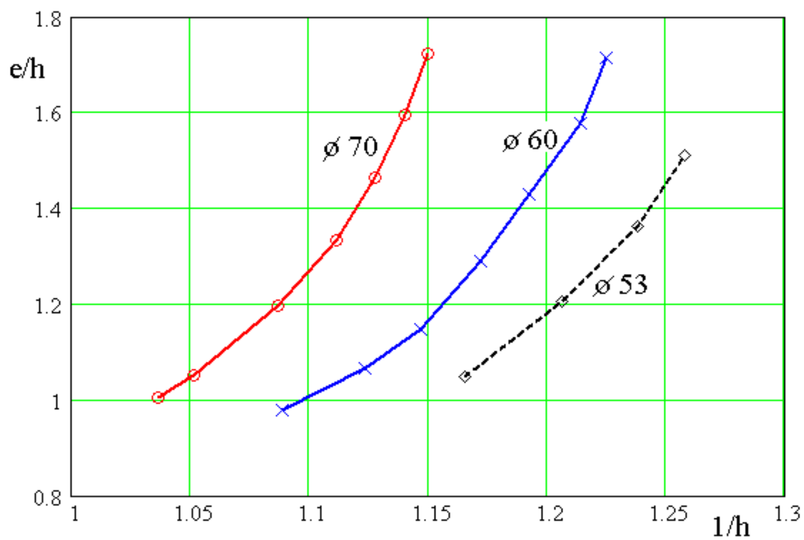
Opt_70_20 - reentrant cavity with aperture 70 mm, electric field 20 % higher than in TESLA, magnetic field 10 % less than in TESLA, at the same acceleration.

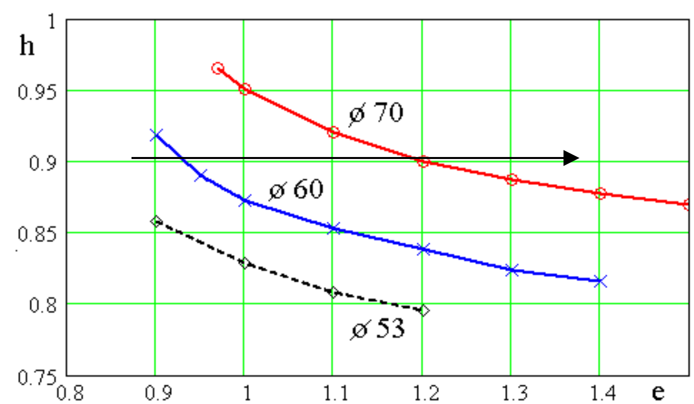
Opt_60_20 - aperture 60 mm, el. field: +20 %, mag. field: - 16.1 %.

Opt_53_20- aperture 53 mm, el. field: +20 %, mag. field: - 20 %.

e = Epk/2 Eacc
h = Hpk/42Eacc
for TESLA e = 1, h = 1.

e/h = Epk/Epk(TESLA)
1/h = Eacc/Eacc(TESLA)





TESLA, LL, and RE cavity

	TTF	RE-1	LL	RE-2
Ra/mm	70	70	61*	60
$\frac{H_{pk}/E_{acc}}{4.15mT/(MV/m)}$	1	0.91	0.87	0.85
$\frac{E_{pk}/E_{acc}}{1.98}$	1	1.21	1.19	1.15
$\frac{GR/Q}{30840\Omega^2}$	1	1.09	1.23	1.34
Cell coupling	1.9%	2.38%	1.52%	1.57%
$\alpha°$	103°	72.93°	98°	75.75°

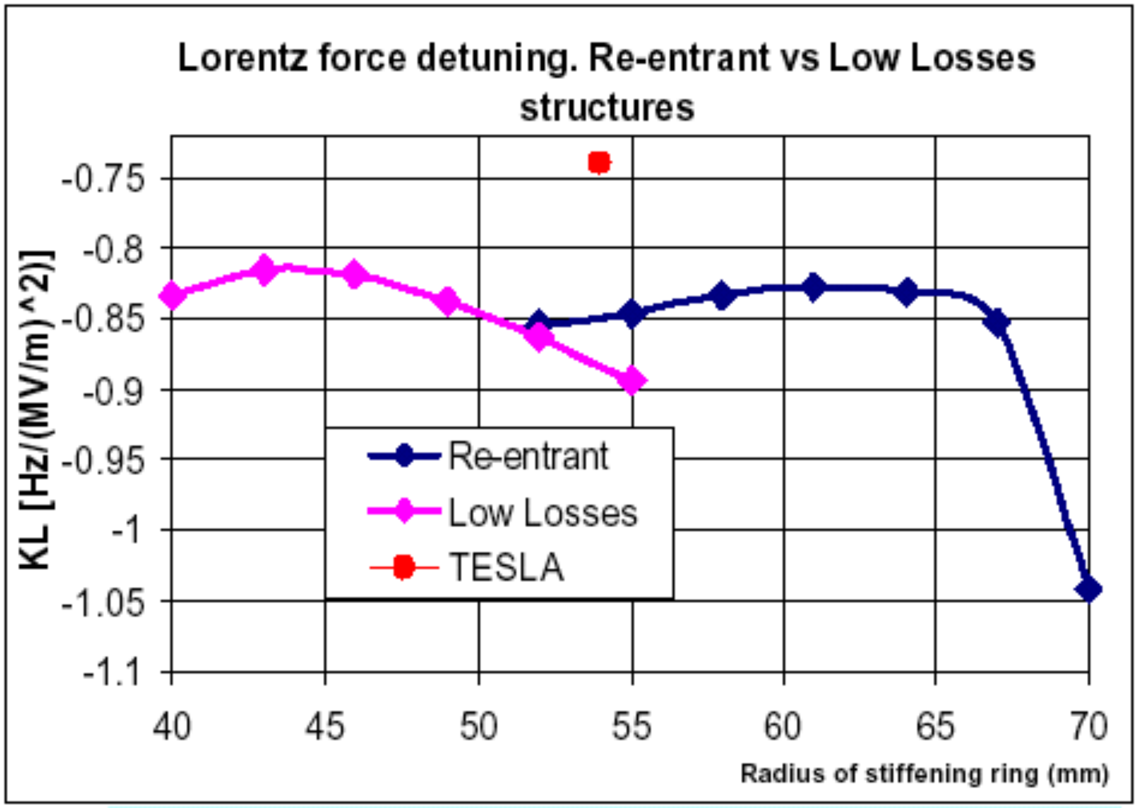
***recalculated to 1300 MHz (actually 1500)**

Downsides of Smaller (60 mm) Aperture

- Higher wakefields
  - LL shape : k_l up 20%, k_t up 70%
  - RE shape : same as TESLA shape
- Smaller cell-to-cell coupling LL shape
  - More sensitivity to mechanical tolerances
  - 1.5% instead of TTF 1.9%
- Higher R/Q
  - Lower cryogenic losses by 20%
- LL and RE
  - Slightly higher Lorentz-Force detuning
    - See next slide

Fermilab

Mechanical properties. Lorentz forces (2)



TESLA(wall=2.8mm) ΔF(wo/w ring) = - 801/-463 Hz for 25 MV/m

Low Losses(2.8mm) ΔF(wo/w ring) = - 871/-509 Hz for 25 MV/m

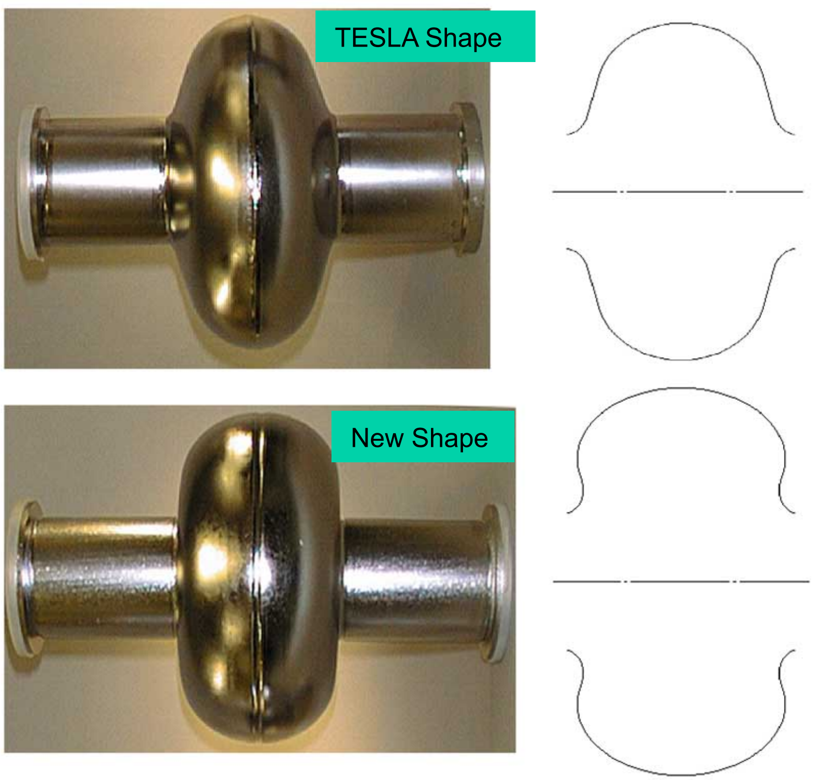
Re-entrant(2.8mm) ΔF(wo/w ring) = - 860/-517 Hz for 25 MV/m

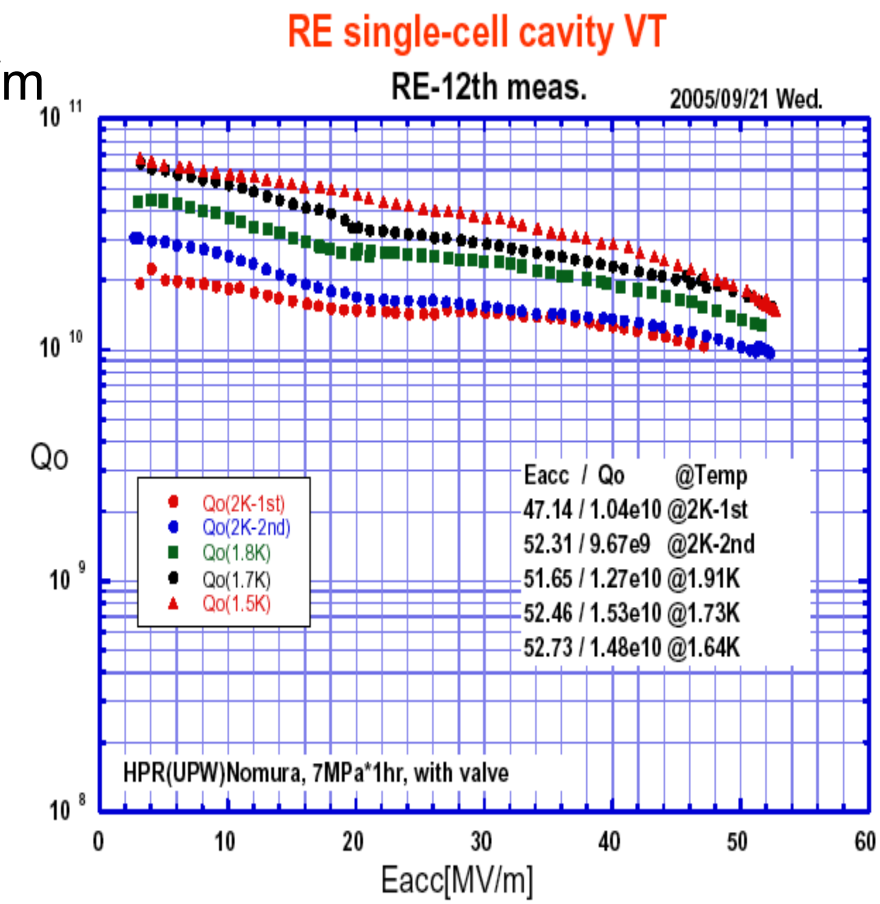
Improved Treatments Applied to Raise Surface Fields to 0.2 T

- New treatments
  - Post-purified to RRR >600 (at Cornell)
  - Centrifugal Barrel Polish at KEK
    - to smooth welds
- EP and H-degassing at KEK
- HPR at KEK

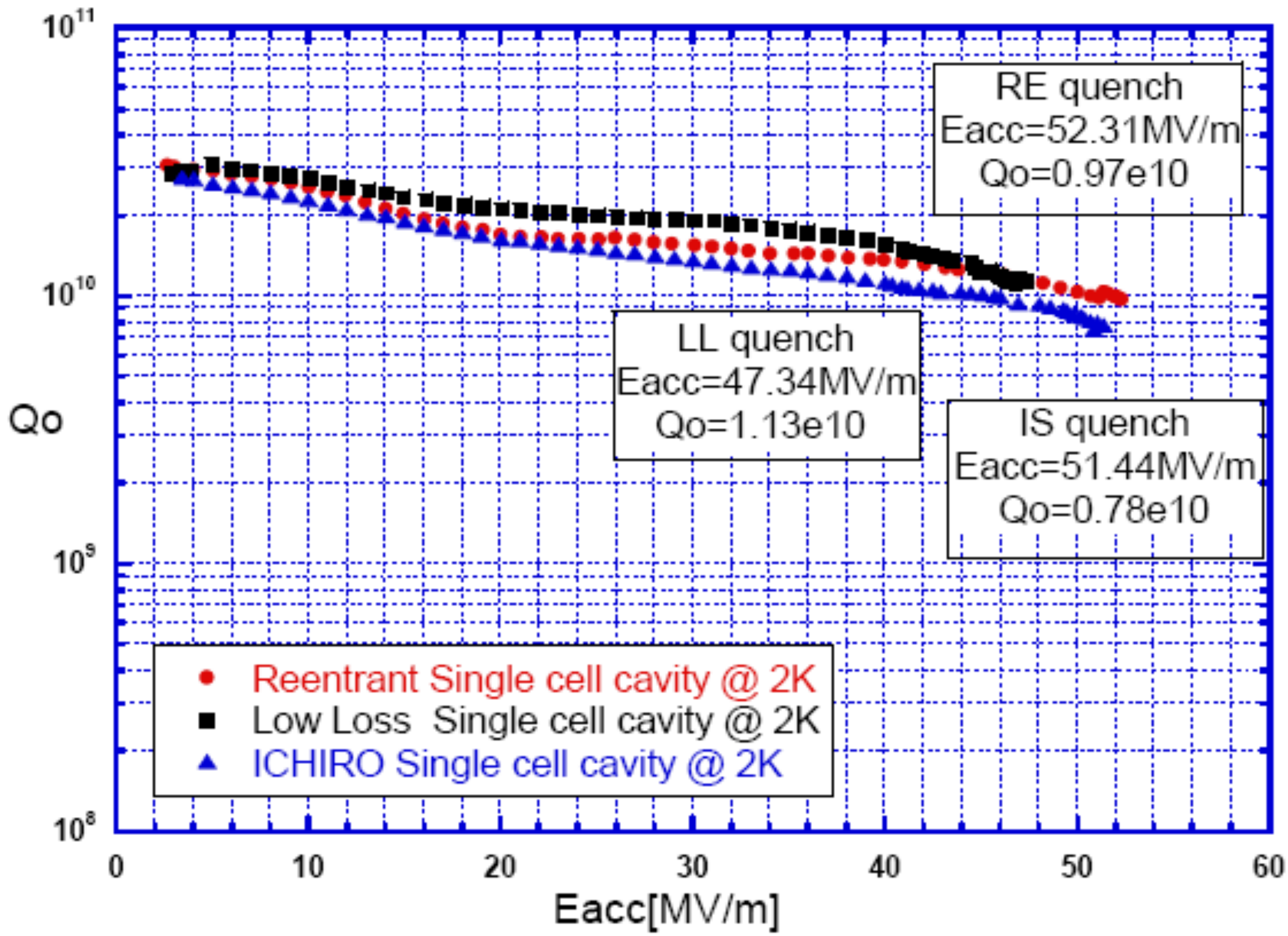
First Re-Entrant Cavity 70 mm aperture (2005 - 2006)

- Cornell fabricated and purified new-shape cavity
- KEK processed and tested cavity
- World record (2006) Eacc = 53 MV/m



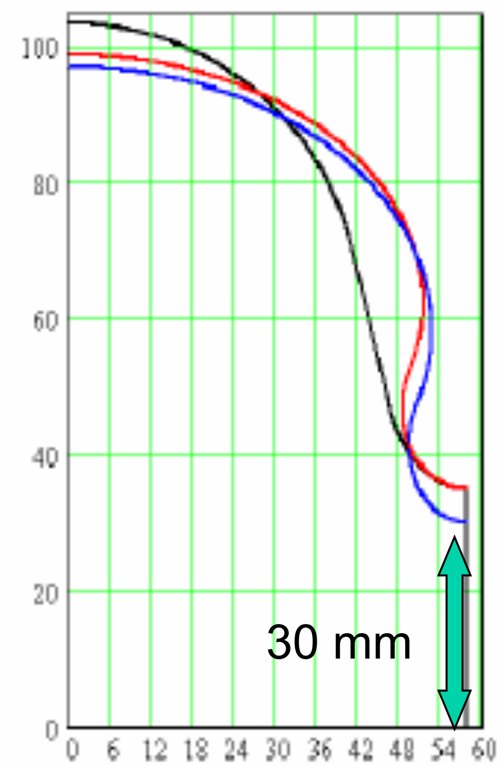


Compare Performance to LL and IS



Reentrant Shape #2 (60mm) and Preparation

- Aperture of re-entrant cavity reduced from 70 mm (Tesla-shape) to 60 mm (like LL shape) to reduce Hpk/Eacc for RE cavity from 3.8 to 3.5 mT/(MV/m)
- Cavity fabricated and post purified (RRR > 600) at Cornell, sent to KEK
- Centrifugal Barrel Polishing and Horizontal EP at KEK, HPR
  - Tests at KEK limited by field emission to 45 MV/m, due to water quality at Nomura Plating.

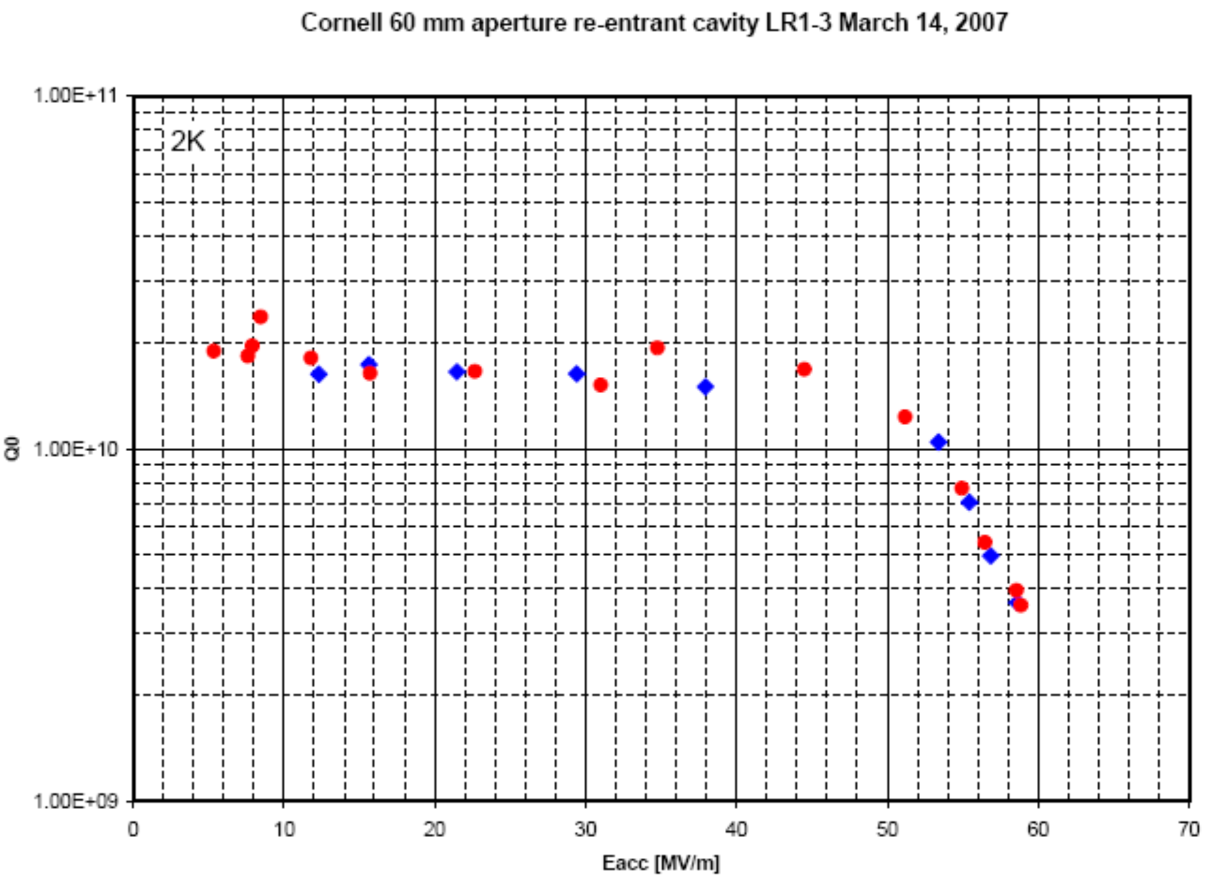


- Return to Cornell
- HPR 2 hours and test

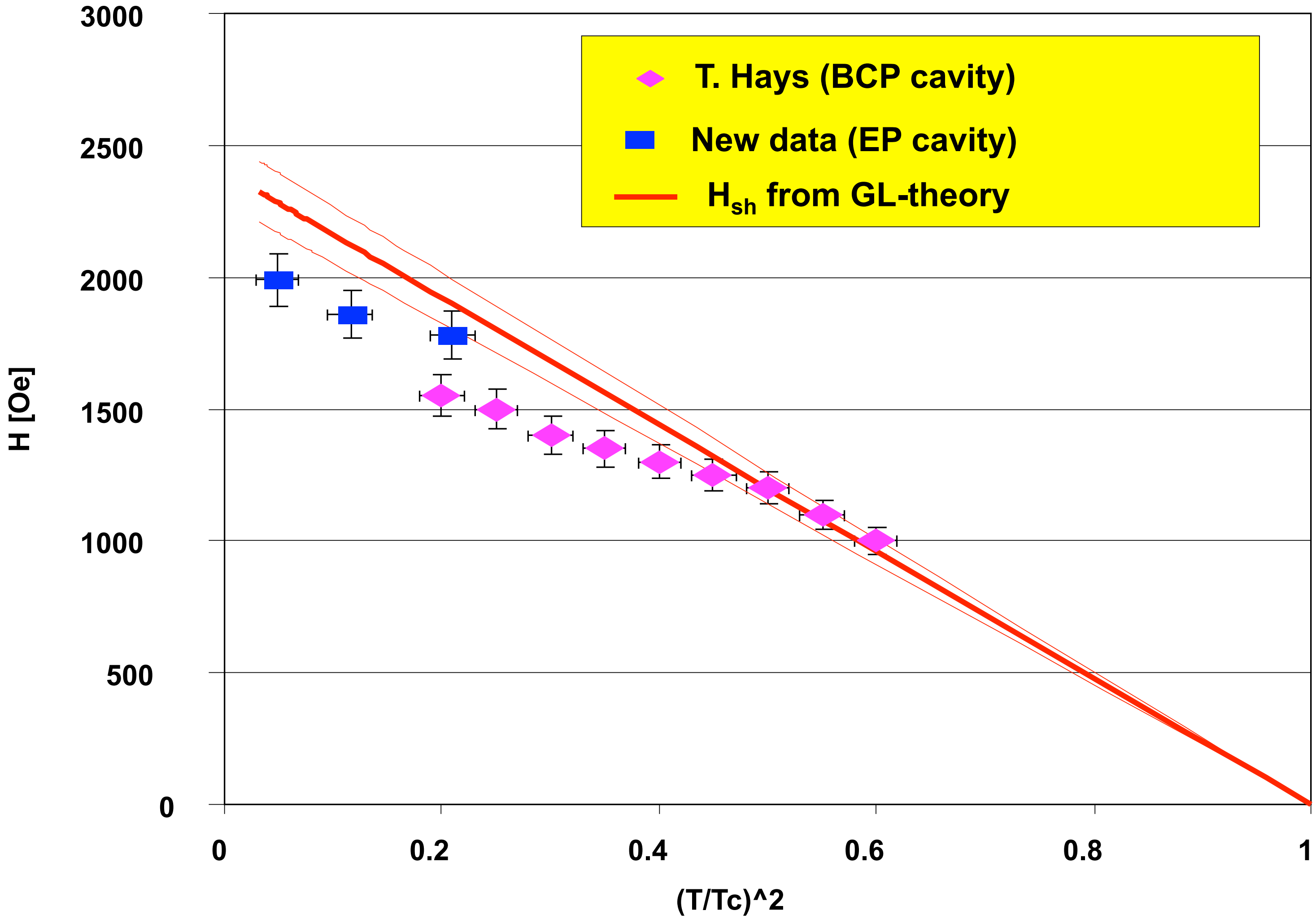
60mm-Aperture Re-entrant Cavity 58 MV/m! KEK/Cornell

- Cornell: fabrication and purification

RE-LR1-3

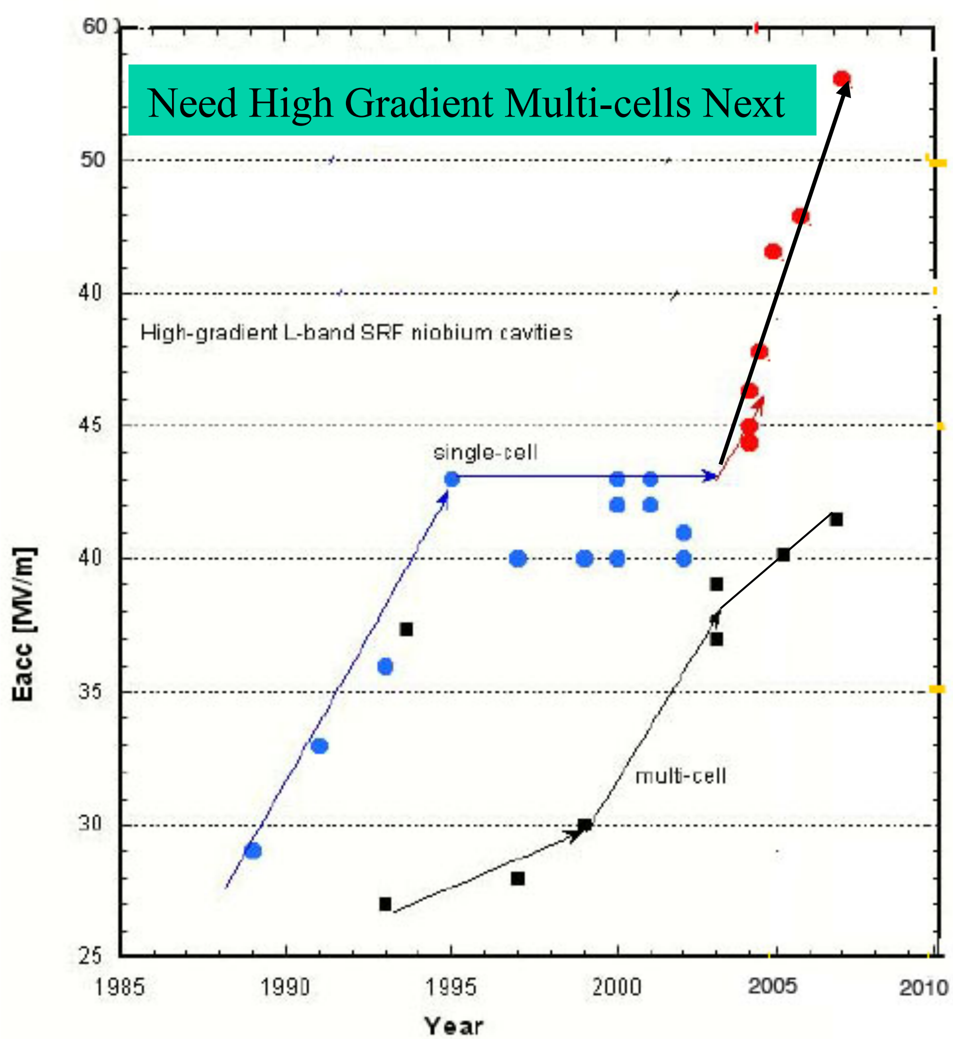


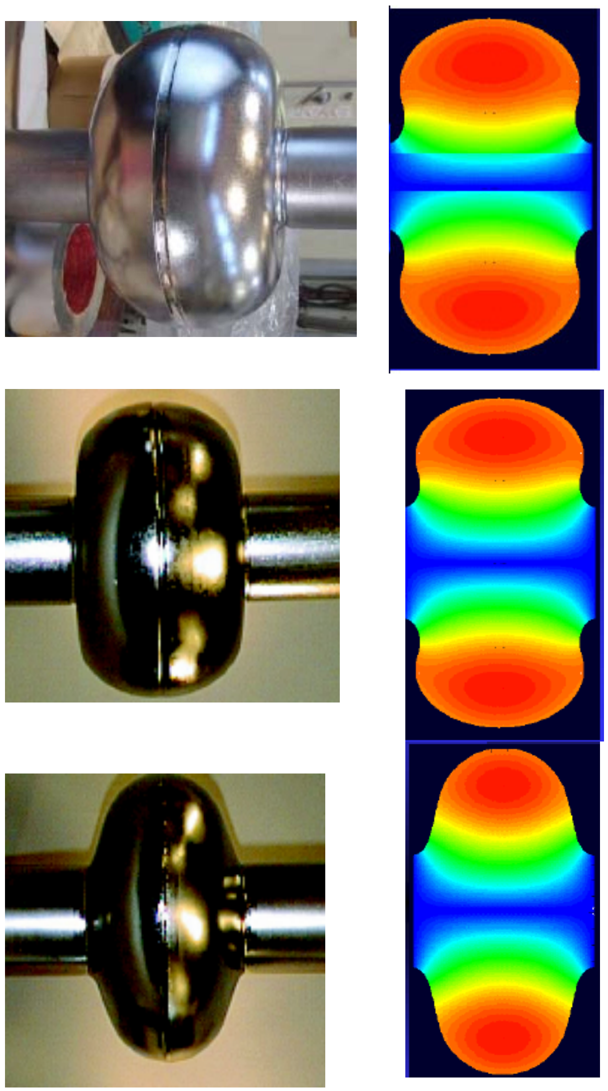
Surface Reaches 0.2 T (closer to $H_{superheating}$) (equiv. Eacc = 56.5 MV/m)



Cornell University
Laboratory for Elementary-Particle Physics

Re-entrant Shapes Reach 58 MV/m in Single Cells !





60 mm
Re-
entrant

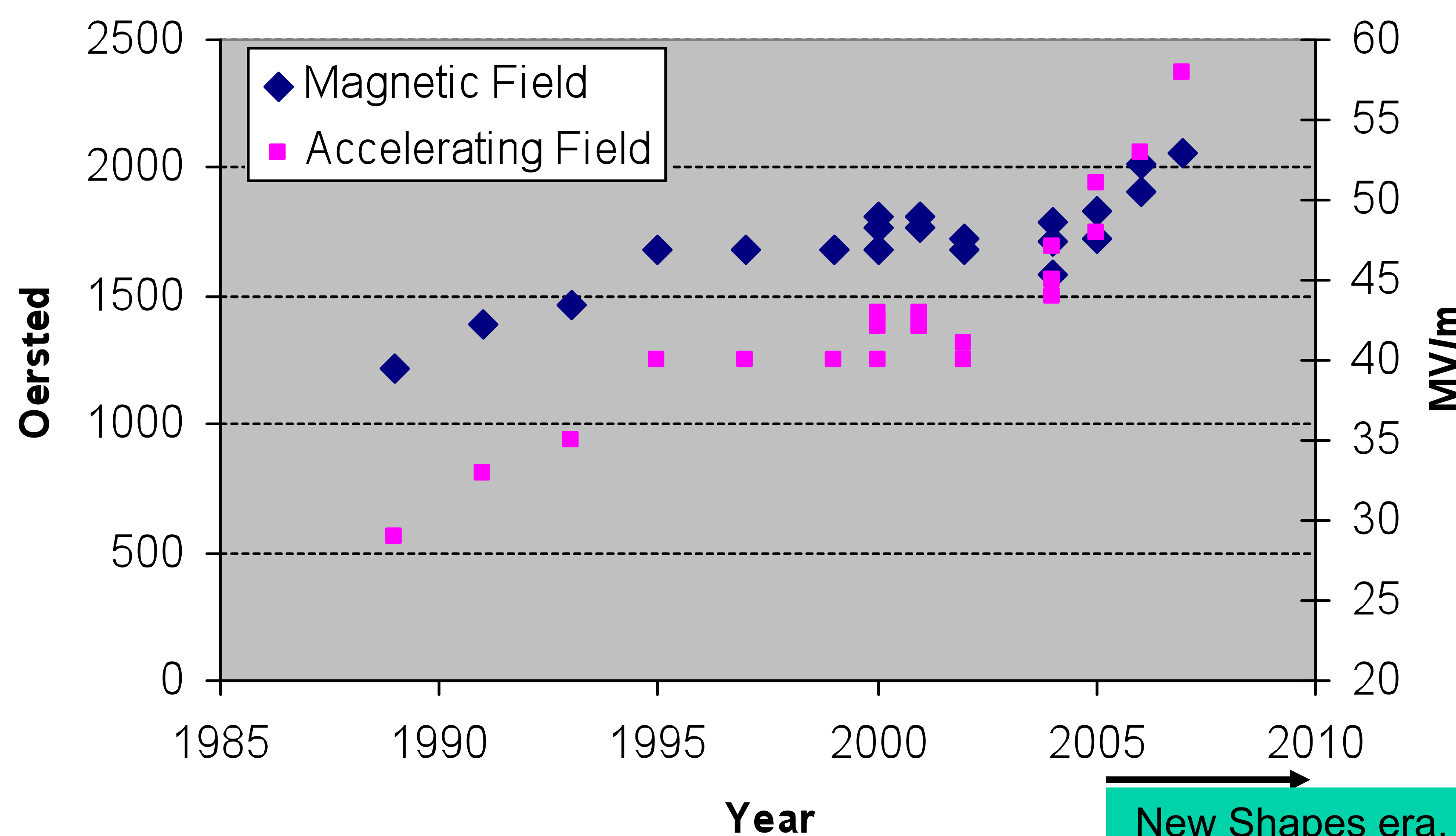
Cornell
KEK

70 mm
Re-
entrant

Cornell
KEK

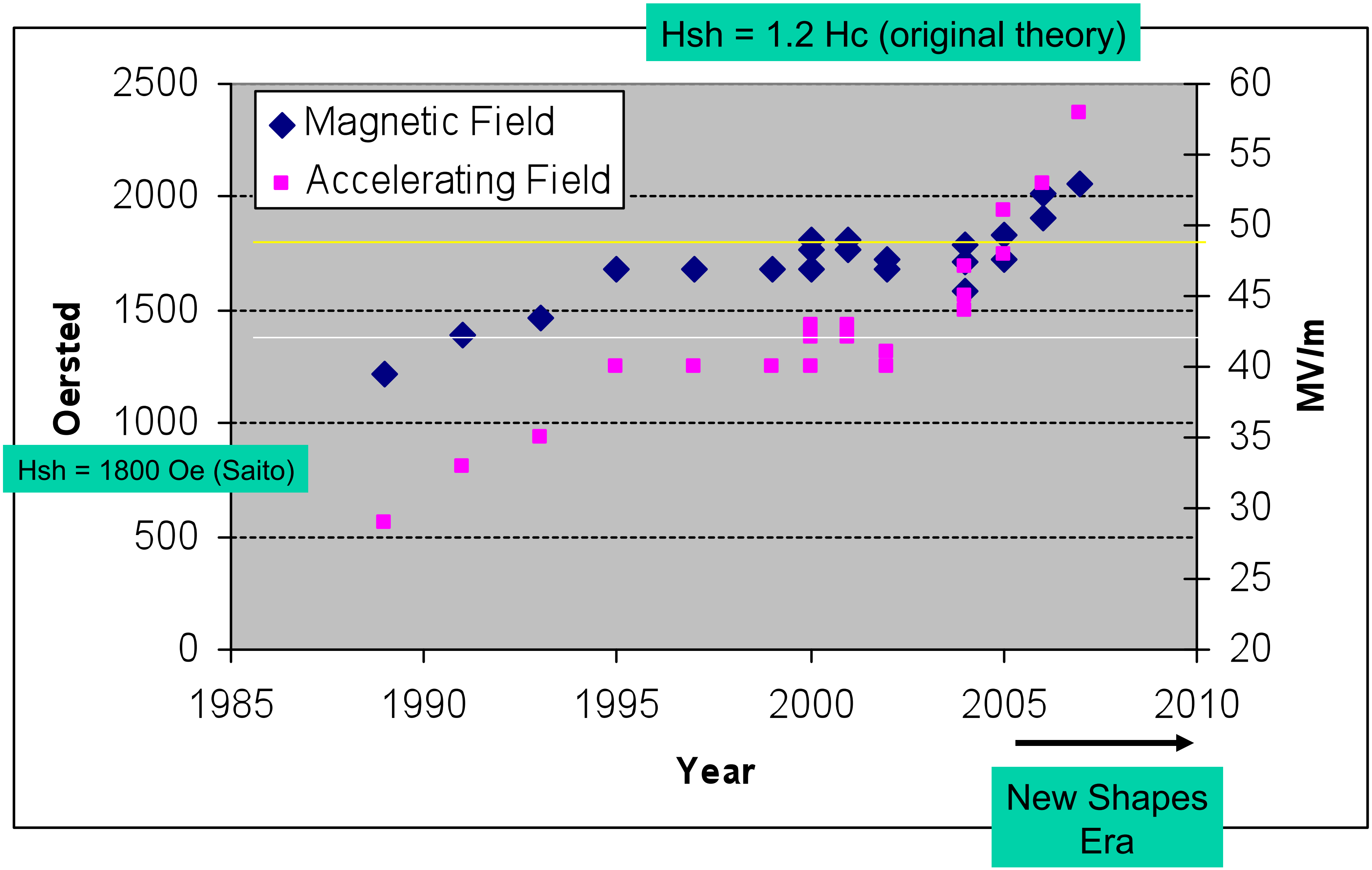
70 mm
Tesla
Shape

Evolution of Accelerating and Surface Magnetic Fields



New Shapes era, LL and RE

Compare to Theories for RF Critical Field



AES Re-Entrant 9-cell, First Test
July 07

Preparation: 36 micrometers removed by VEP after fabrication.

Half cells were electropolished 100 microns before fabrication.

No H degas.
120 degree x 48 hour bake.

Quench

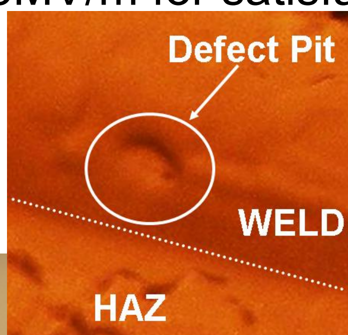
Need more EP to remove machining damage

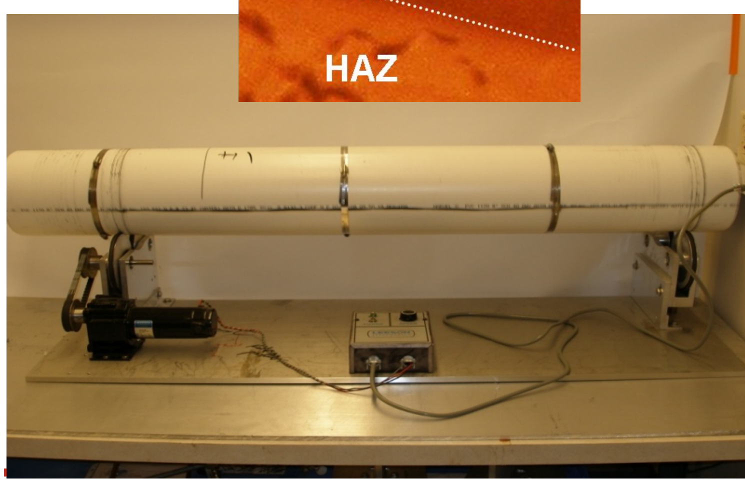
Cavity repair by tumbling

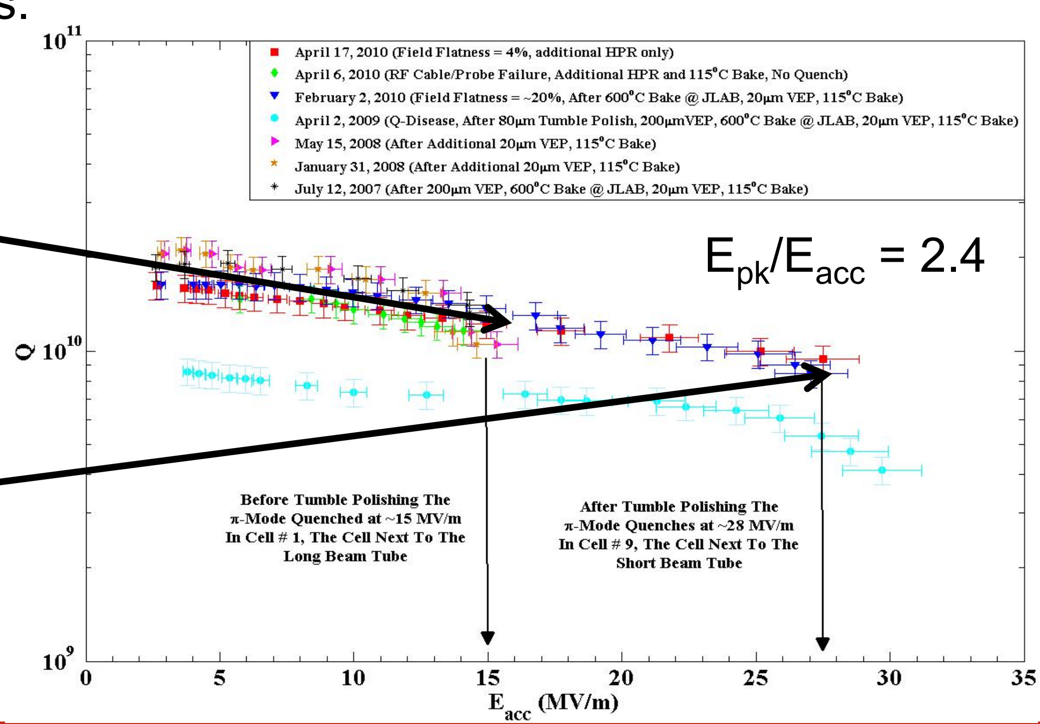
1) Large Pit Defect located with second sound
2) Tumbling to repair, and reprocessing E_{acc} > 30MV/m in the repaired cell.
3) When excited in the 5π/9-mode, E_{acc} = 37 MV/m in the center cell.
4) Reduced Q was repaired by additional 2h, 800C baking.

Conclusions:

1) Tumbling is an effective option to repair weld defects, e.g. pits.
2) Individual cells in cavities processed with VEP can reach fields exceeding 35MV/m for satisfactory Q values.





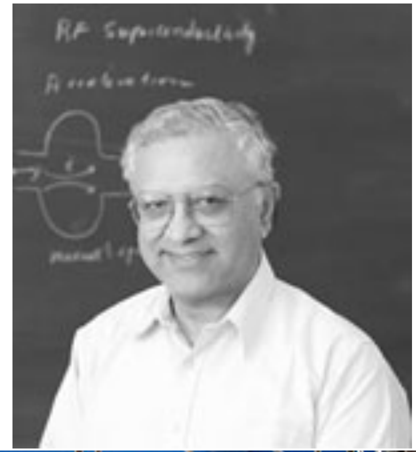


Further Re-entrant Cavity Developments

- Study single cells of both shapes
  - 53 and 58 MV/m (small aperture) records
- Continue Multicell re-entrant cavities
  - Stiffen 9-cell fabricated by AES
  - Apply post purification (used for record fields in single cells)
  - Fabricate 3-cell re-entrant and 5-cell re-entrant in house

Acknowledgements

- Thanks to Hasan Padamsee who lead the reentrant development and provided graphs and information of this presentation.



- Thanks to Rongli Geng, who managed much of the project and tested the RE cavity at Cornell.

- Thanks to Valery Shemelin who optimized the shape of the RE cavity.