High Gradient Cryomodule

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ILC IDT WG2 Meeting

November 2022

HGC Collaborators:

Fermilab, Jefferson Lab, DESY., cea, Cornell University, KEK-JAPAN, Argonne NATIONAL LABORATORY, TRIUMF

High Gradient Cryomodule (HGC)

- Present **ILC** spec 31.5 MV/m (per TDR)
- Many new advances in SRF technology since ILC TDR. **New treatments** may **enable significant reduction** in ILC cost: flux expulsion, 75/120 two-step bake C, cold EP (processing sequence stays similar)
- Supported by ILC Cost Reduction R&D funds from DOE, Fermilab plans to assemble a cryomodule with cavities with new treatments.
- Goal is to reach higher gradient than has ever been demonstrated in CM test
- Aim will be 38 MV/m average gradient with Q_0 >1.0x10^{10} and a stretch goal of 40 MV/m
- Achieving this would be a key demonstration of the potential for cost reduction for ILC
- Will reuse CM1, the first SRF cryomodule assembled at Fermilab in 2007 – as a part of a collaboration between Fermilab, DESY, and LASA

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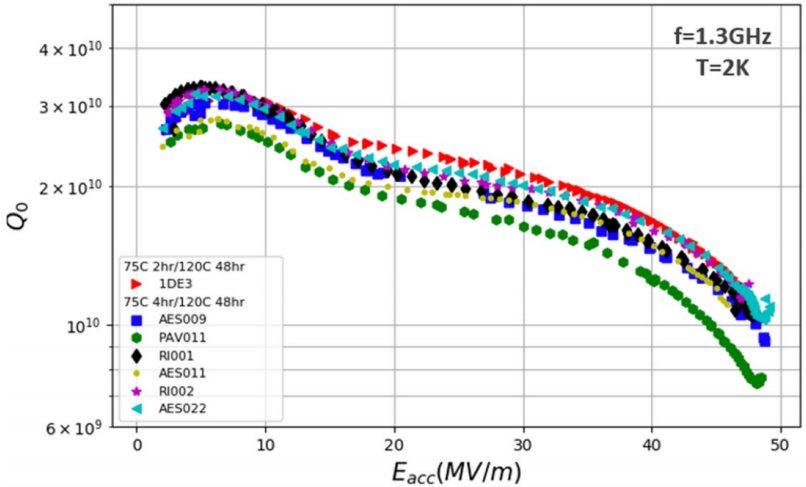
75/120 C Bake

- Single cell cavities treated with 75/120 C bake have reached unprecedented accelerating gradients ~48-50 MV/m (~ 210 mT, TESLA shape)
- 75 C for ~4 hours, plus standard 48 hour 120 C bake – consistent results in single cells, still studying origin, possibly linked to hydrides
- 50 MV/m cavity sent around for confirmation studies: Cornell, JLab, KEK, DESY



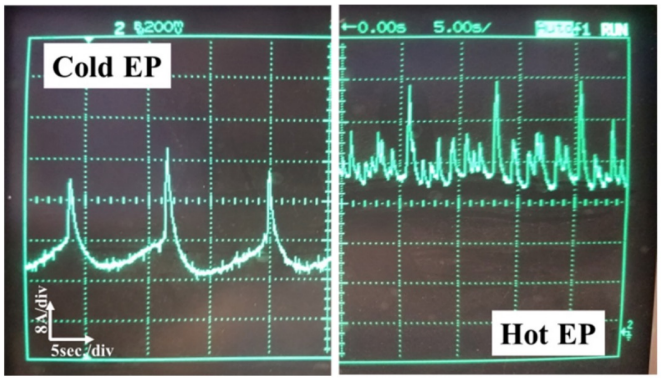
See Grassellino et al. arXiv:1806.09824

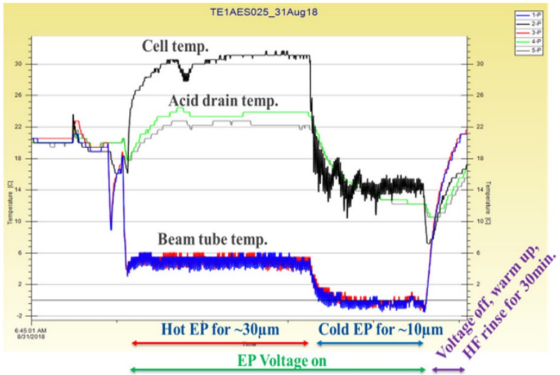
Fermilab

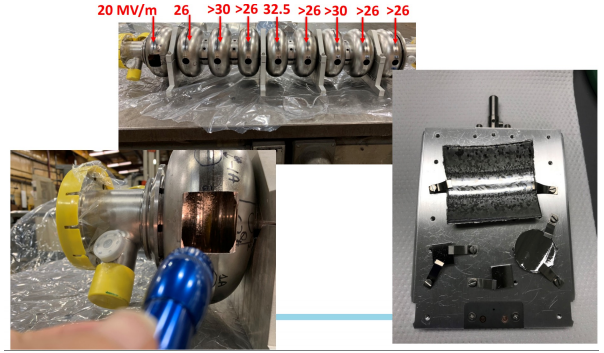
Cold Electropolishing

- In Fermilab's single cell EP facility, it was found that keeping the electrolyte cold (~12°C) would result in less heating, lower flow, and strong current oscillations
- When rough surfaces were found in nitrogen doped cavities, cold EP was implemented, and found to substantially improve surface quality
- Does cold EP improve also non-doped cavity surfaces?
- Studies needed to evaluate and improve understanding

[See Furuta et al. TUP022, SRF 2019]







[See Grassellino et al. TUFUA2, SRF 2019 and Palczewski et al. TUFUA3, SRF 2019]

Fermilab

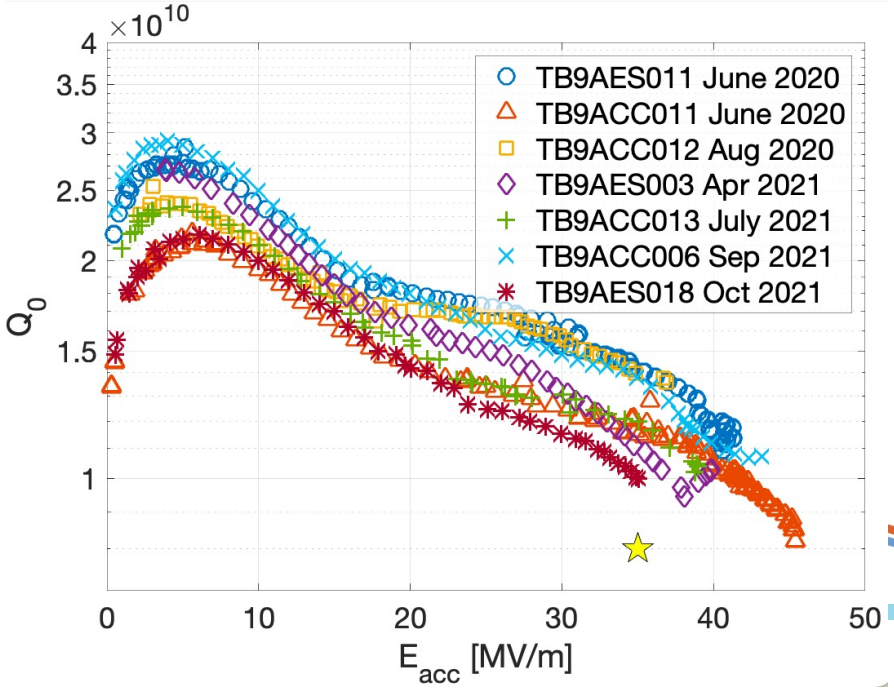
VTS Testing of Cavities for HGC @ FNAL

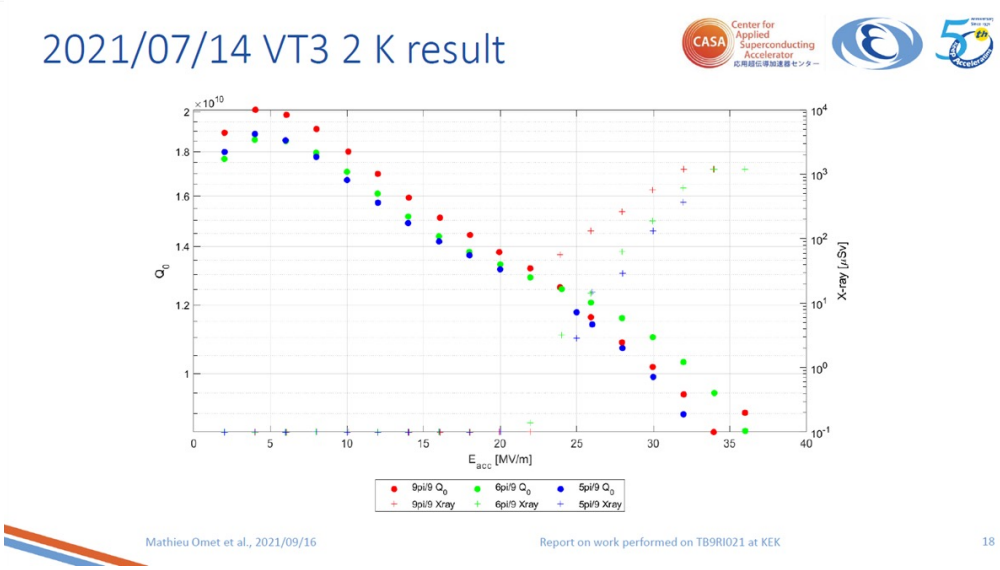
- The cavities we are working with are cavities that had achieved ILC specifications and been set aside ~10 years ago for future modules. The cavity have been subjected to the new treatment plan:
  - 900 C bake
  - Cold EP
  - 2-step 75/120 C bake
- 8 cavities so far at least conditionally qualified:

Cavity #	Cavity Name	Maximum Gradient E_{acc}
1	TB9AES011	41.3 MV/m
2	TB9ACC011	45.4 MV/m
3	TB9ACC012	36.9 MV/m
4	TB9AES003	39.8 MV/m
5	TB9ACC013	39.0 MV/m
6	TB9ACC006	43.2 MV/m
7	TB9AES018	35.0 MV/m
8	TB9RI021 (treated and tested at KEK)	36.0 MV/m
	AVERAGE	**39.6 MV/m**

HGC Cavities – Vertical Testing Results

- 7 cavities treated & tested at Fermilab, 1 at KEK (Omet, Umemori, et al.)
- Continued efforts on additional cavities at FNAL, JLab, & CEA, but 8 already with average gradient 39.6 MV/m





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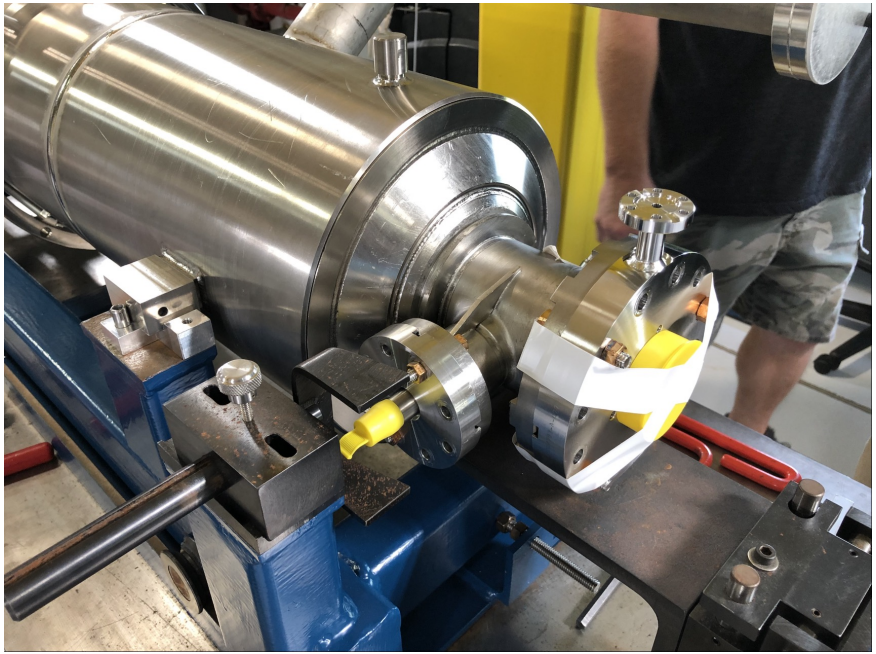
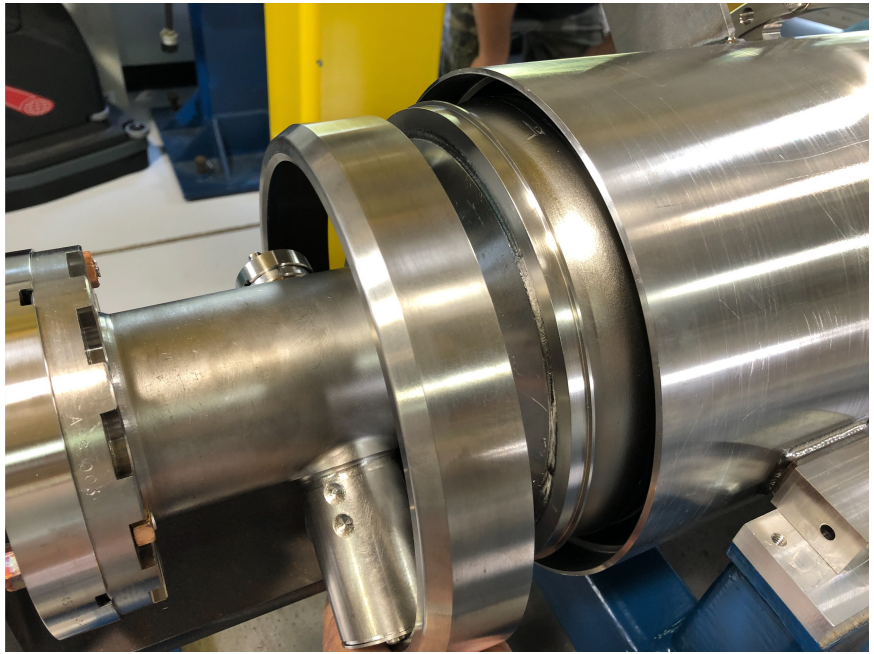
Start of Tank Welding – TB9AES003

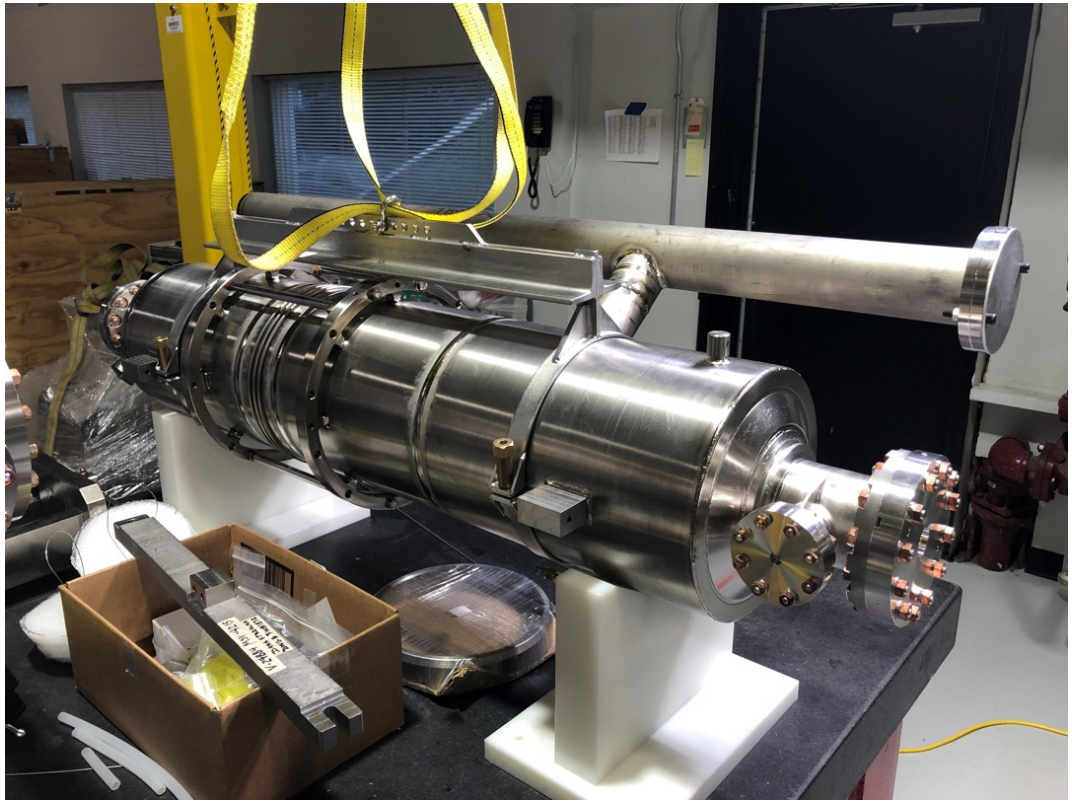
- First 9-cell tank welding in a while (since LCLS-II pCM? Different tank design also)





Start of Tank Welding – TB9AES003

- TB9AES003, maximum gradient in vertical test prior to tank welding: 39.8 MV/m



Module Disassembly Status

- “CM01” vacuum vessel and upper cold mass removed (or will be soon)
- Will bring cavity string into MP9 cleanroom facility
- Couplers to be re-used: remove cold ends in cleanroom environment
- 6 couplers look good, 2 maybe re-evaluate
- Many key items are re-usable from CM01, others will be replaced
- Use old FNAL stock of ILC He vessels (central bellows) and tuners (blade tuners), replace piezos/motors

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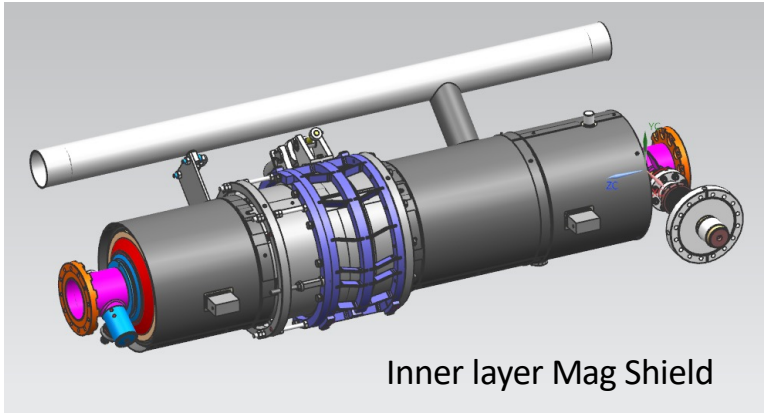
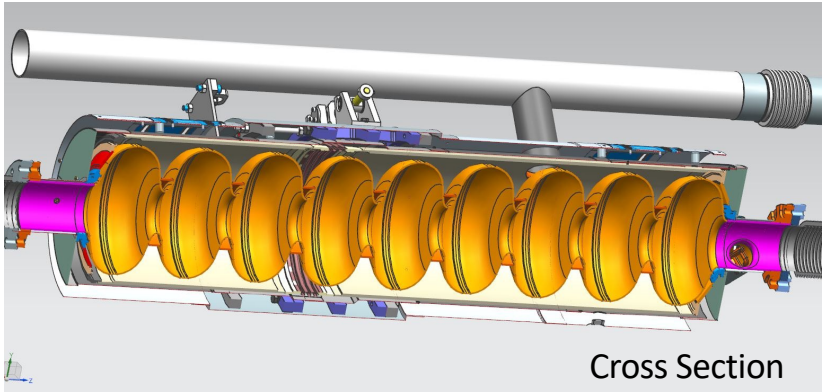
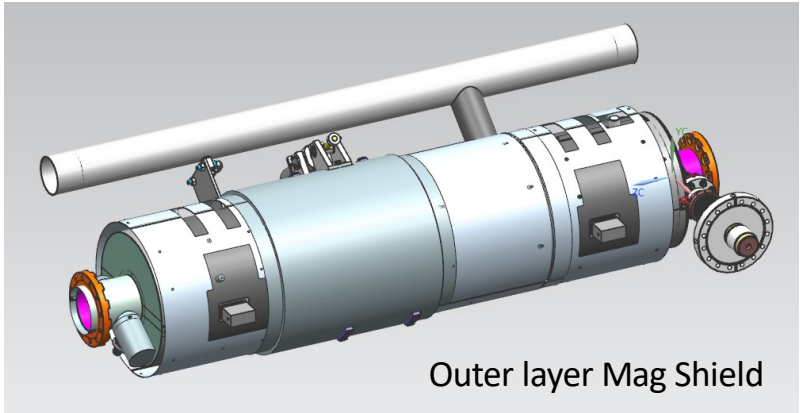
Second Layer Magnetic Shielding

- Design by Yuriy Orlov, FNAL
- Procurement of 4 inner shields by CEA in French industry (thanks to Oliver Napoly!)
- Evaluate performance of 4 cavities with inner shields compared to 4 without


Inner layer Mag Shield


Cross Section


Outer layer Mag Shield

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Cleanroom Assembly

- Tentative timing: March 2022 (need to qualify all dressed cavities in VT, and set up string assembly)
- Collaboration planned with CEA to use COBOT for robotic assistance in cleanroom for assembly
- No quadrupole magnet: will likely use either dummy or just spool piece

Cobot in Saclay ISO4 Clean Room

High Gradient Cryomodule (HGC)

- Encouraging international participation in HGC. Contributions under discussion:
  - Cavities, cavity performance R&D, advanced cleanroom assembly techniques, magnetic shielding, cryomodule testing, and more
- Labs involved to date:

Fermilab

Jefferson Lab

DESY.

cea

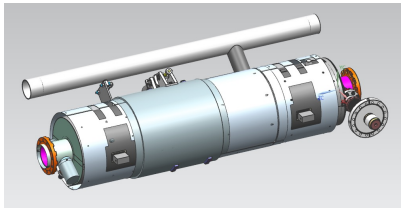
CORNELL UNIVERSITY FOUNDED A.D. 1865

KEK-JAPAN

Argonne* NATIONAL LABORATORY

TRIUMF

*Cavities treated at joint FNAL-ANL cavity treatment facility



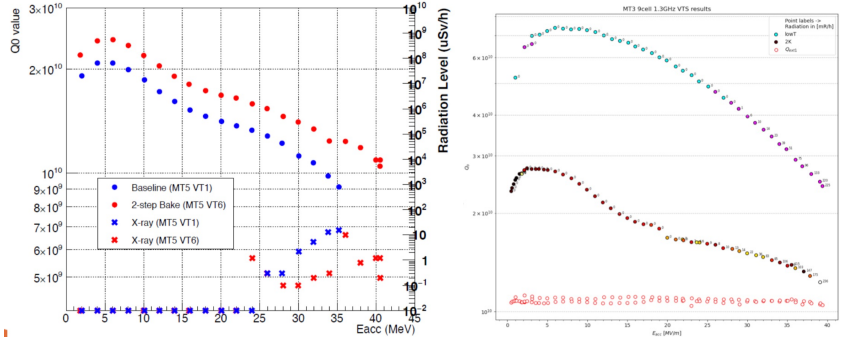
Cobot in Saclay ISO4 Clean Room

1) Mag shield procurement, 2) cleanroom robotics, 3) cavity treatment + test

Jefferson Lab

R&D on cold EP/2-step bake/900 C – cavity qualification for HGC

KEK-JAPAN



R&D on cold EP/2-step bake/900 C – cavity qualification for HGC

CORNELL UNIVERSITY FOUNDED A.D. 1865

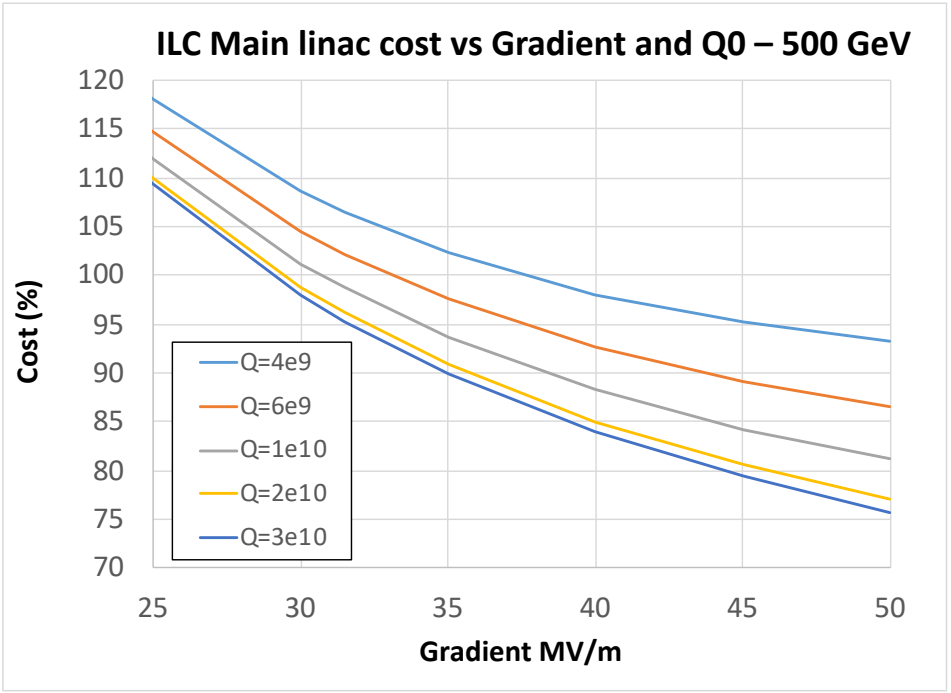
R&D on cold EP/2-step bake/900 C

DESY.

Original “CM01” kit, 2007

High Gradient Cryomodule (HGC)

- Testing HGC will be interesting for many technical aspects:
  - Maximum gradient: with 8 cavities qualified in vertical test, can we maintain ~38 MV/m or higher in cryomodule
  - Cryogenic factors: e.g. how do external magnetic fields and cooldown impact Q_0? This was key for LCLS-II
  - RF: experience with driving cryomodule at higher gradient and evaluating scalability, resonance control



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Summary

Supported in US by DOE HEP
ILC Cost Reduction Funds

- High Gradient Cryomodule (HGC) – effort to demonstrate ability of recent SRF R&D to increase E_{acc} in a real module, evaluate CM test in high gradient regime
- Inherits from efforts in ~2005-2010: re-uses existing cryomodule CM01 equipment, takes earlier ILC R&D cavities and attempts to treat them with new processes
- 8 cavities now show 39.6 MV/m average gradient – conditionally qualified
- International, multi-institutional participation has been excellent so far
- Working towards assembly – tentatively starting in March 2022
- Tentative plan is to test cryomodule at Fermilab's FAST facility where 1.3 GHz multi-MW klystron is already available, avoids conflicts with LCLS-II-HE & PIP-II