Status of Cornell SRF R&D

Fumio Furuta
Cornell University

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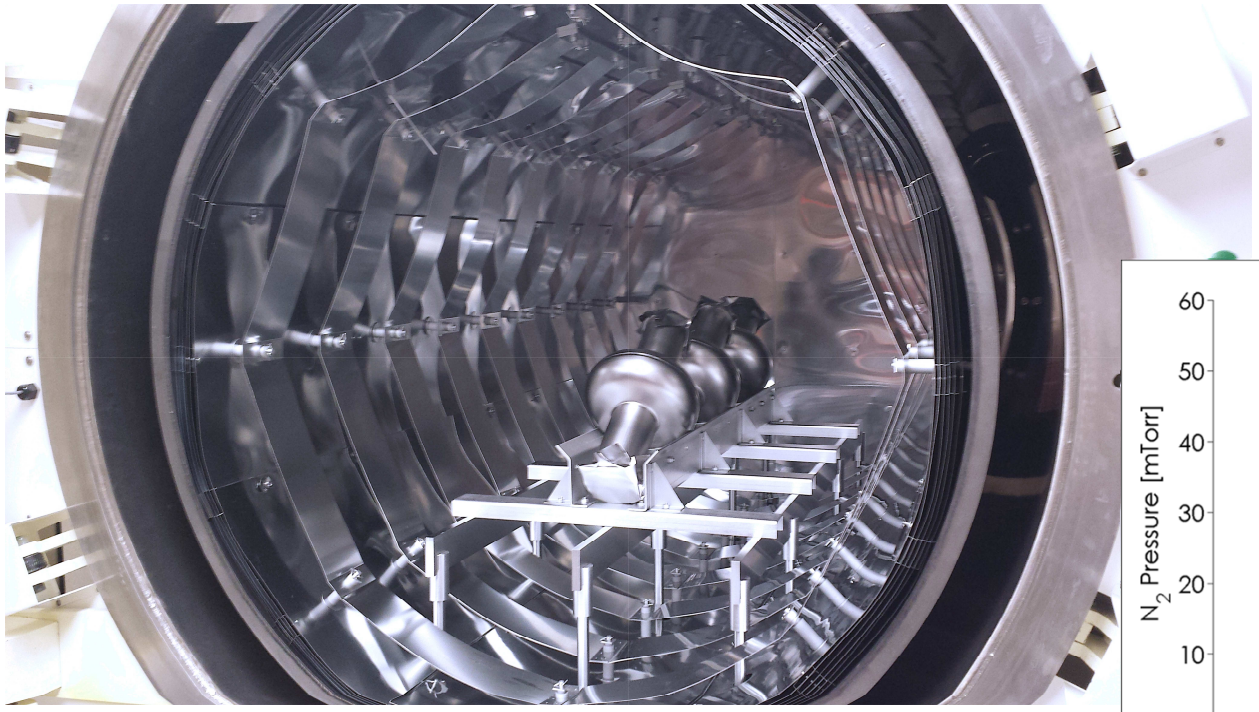
LCLS-II high-Q work at Cornell

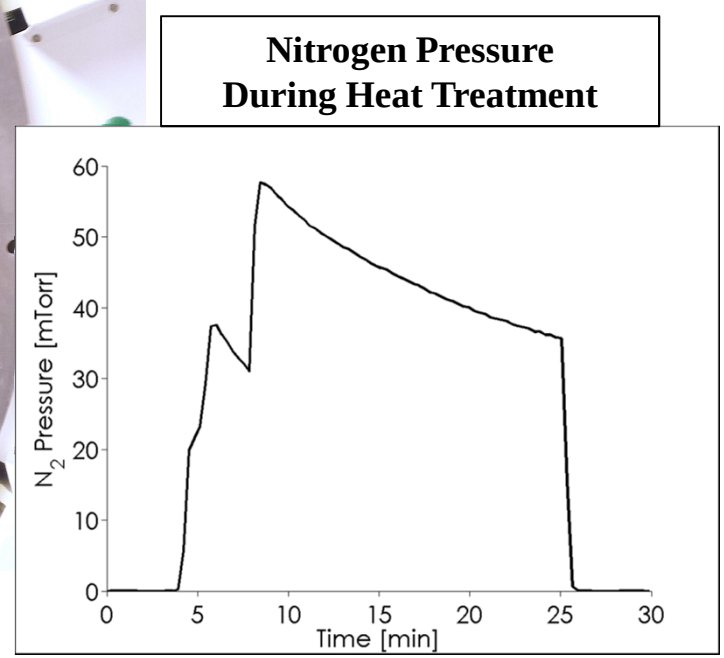
Milestones

Milestone	Target date	Actual date completed
Begin single-cell cavity fabrication	17 Feb 2014	17 Feb 2014
Singe-cell cavity set complete	28 Mar 2014	26 Mar 2014
Initial single cell parametric study complete (5 individual cavities/ 10 tests)	20 Jun 2014	10 July 2014
N-treatment protocol ready for 9-cell	30 Jun 2014	7 July 2014
Final single cell parametric study complete (8 tests)	30 Sep 2014	
Receive 2 as-fabricated 9-cell cavities from FNAL	21 Mar 2014	19 Mar 2014
Receive 2 as-fabricated 9-cell cavities from FNAL	4 Apr 2014	10 Apr 2014
Test of two 9-cell cavities complete	13 Jun 2014	7 July 2014
Test of two additional 9-cell cavities complete	5 Sep 2014	23 Aug 2014
Receive 2 as-fabricated 9-cell cavities from FNAL	18 Aug 2014	28 July 2014
Test of two additional 9-cell cavities complete	14 Nov 2014	18 Sept 2014
First HTC test complete (ACC012)	31 Jul 2014	31 July 2014
Second HTC test complete (ACC011)	23 Sep 2014	3 Oct 2014
Third HTC test complete	14 Nov 2014	

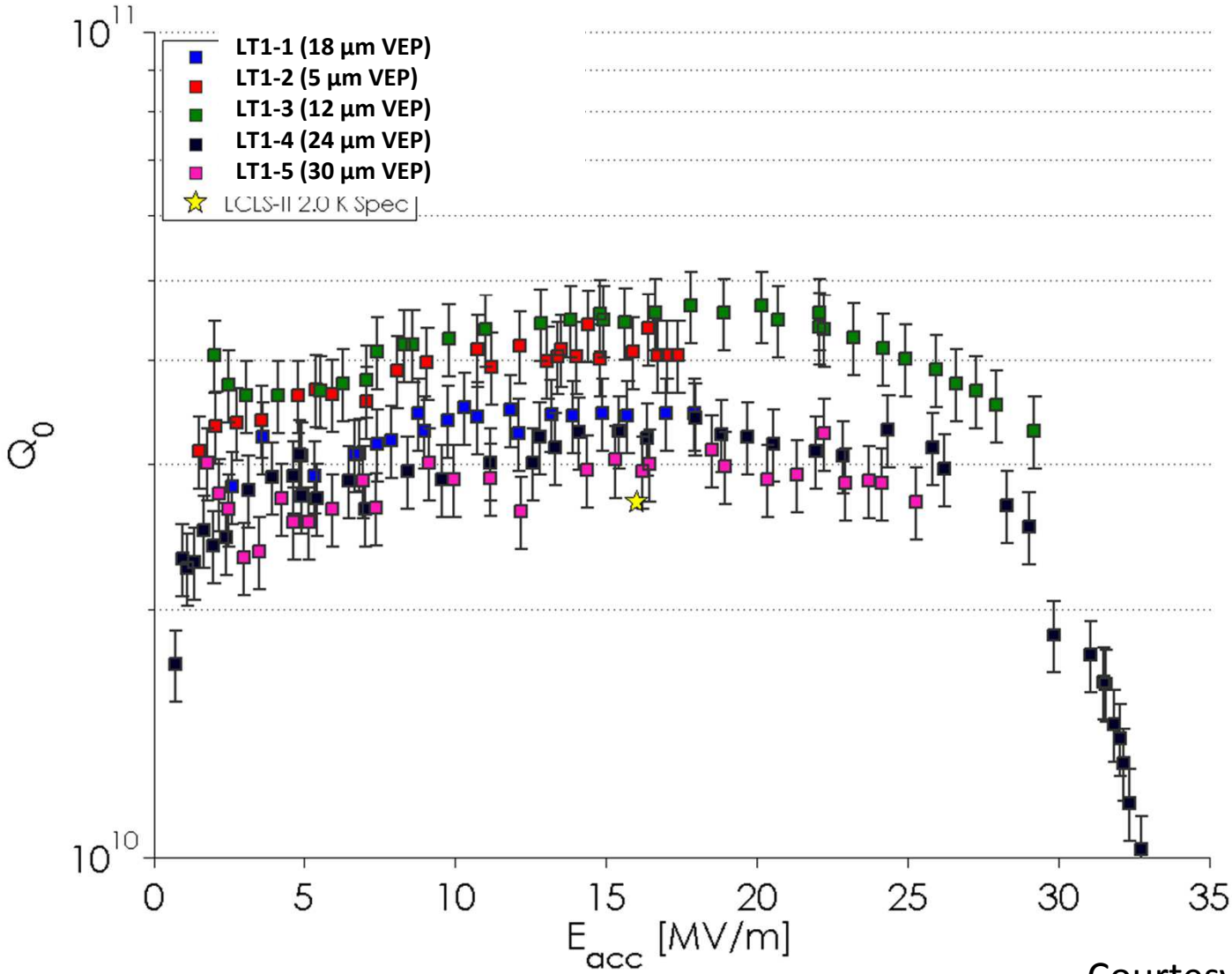
N-doped cavity preparation

- **Surface prep. ; Bulk VEP(120um) + Degas + N-dope + light VEP**
- **1st study on single cell: same N-treatment (800C; 20 min in N_2 followed by 30 min in vacuum), but different final VEP amounts**





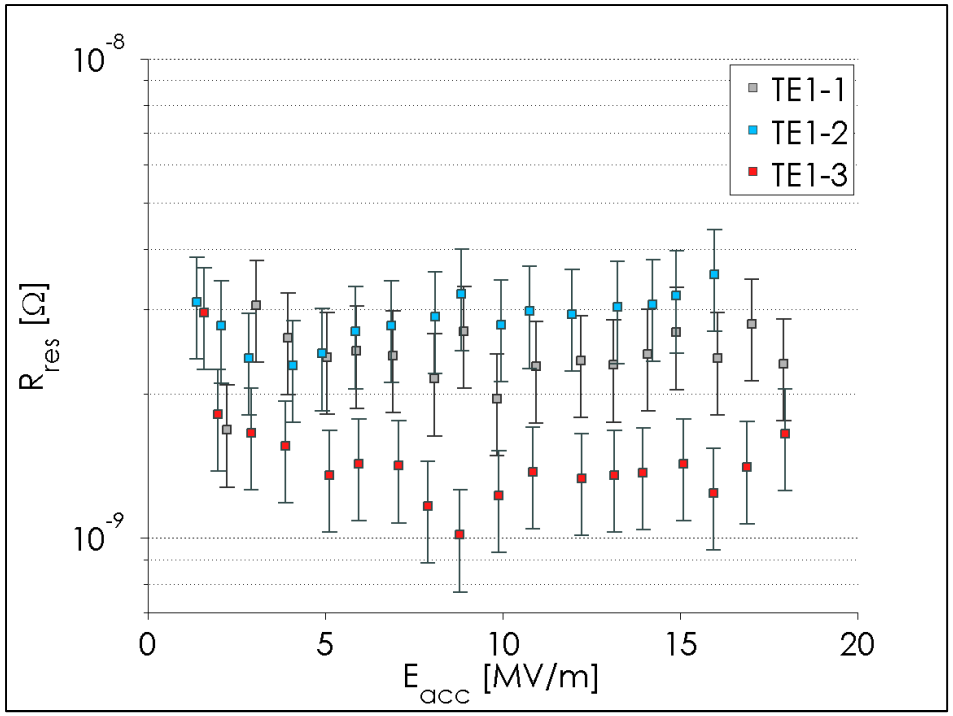
N-doped single-cell VT results at 2K



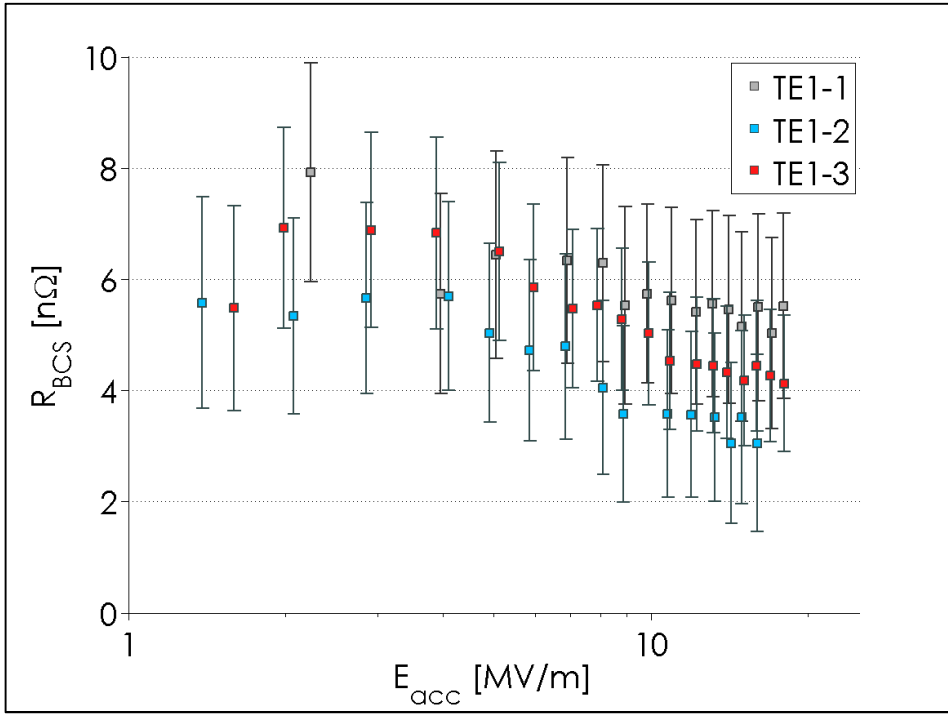
Courtesy of Dan Gonnella

N-doped Single cell analysis

R_{res}



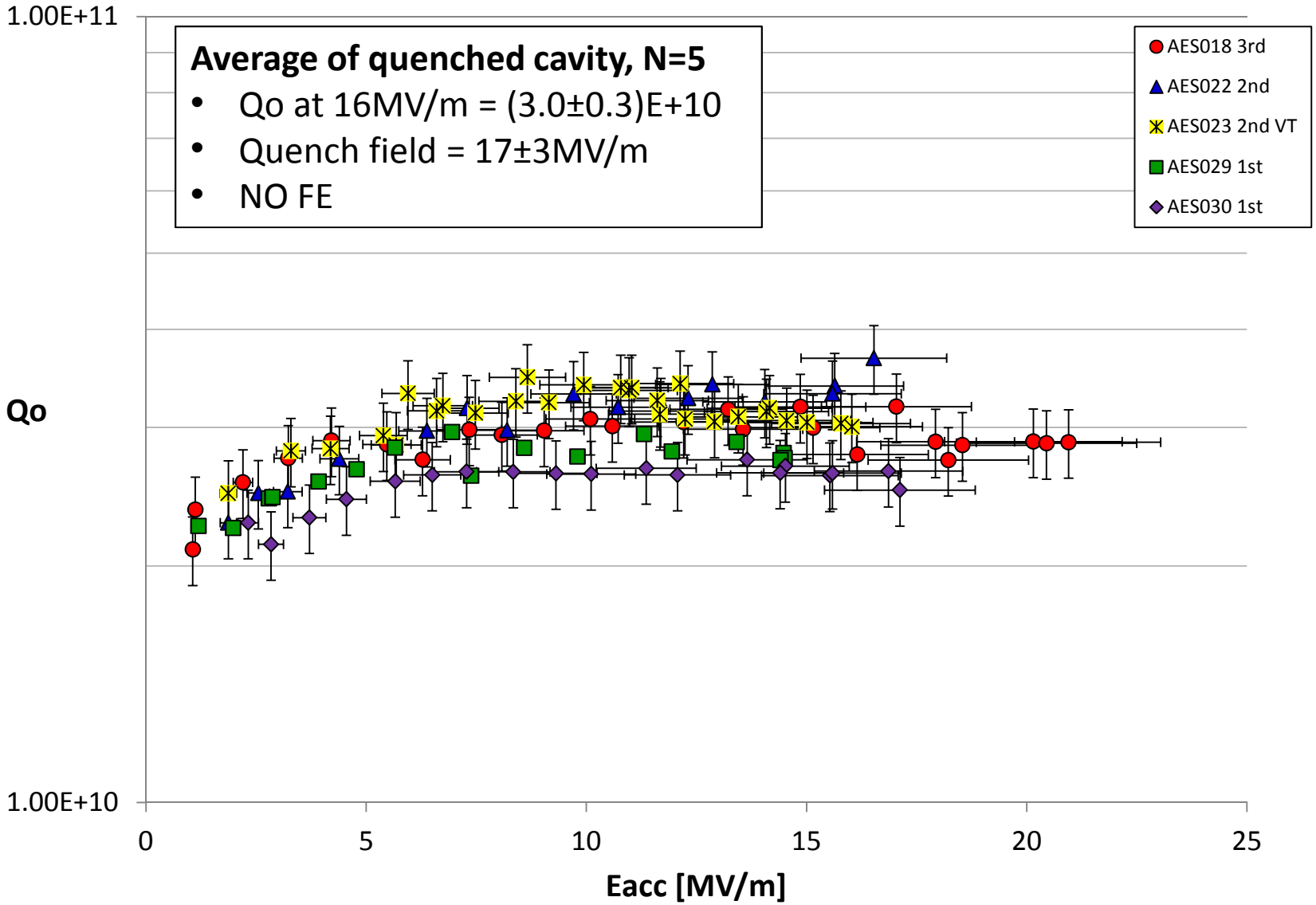
R_{BCS}



Decreasing BCS resistance results in anti-Q slope.

Courtesy of Dan Gonnella

N-doped 9-cell VT results at 2K



N-doped 9-cell VT summary

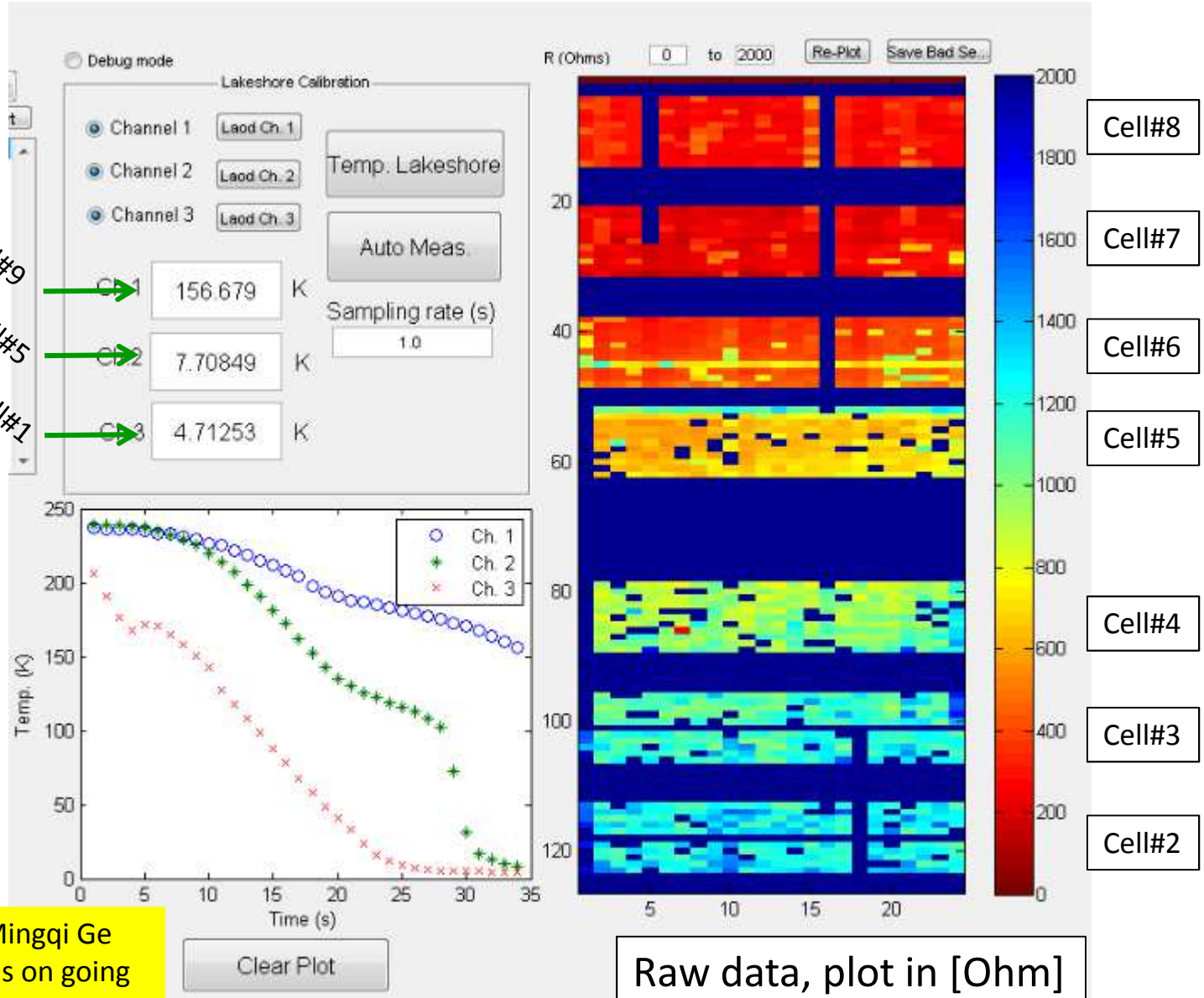
N-Doped 9-cell	1st Pass *	2nd Pass **	Qo at 16MV/m, 2K	Quench	Status
AES018	Done	Done (post re-VEP)	2.3E10 (2nd) 3.2E10 (3rd)	28MV/m 21MV/m	FE Quench
AES022	Done	Done (post re-HPR)	2.0E10 (1st) 3.4E10 (2nd)	24MV/m 17MV/m	FE Quench
AES023	Done	Done (post re-VEP)	3.4E10 (1st) 3.0E10 (2nd)	14MV/m 16MV/m	Quench Quench
AES029	Done		2.7E10	15MV/m	
AES030	Done	Planed next week	2.7E10	17MV/m	Cold leak at 1.8K, re-test after HPR

* 1st Pass; VT after bulk VEP + N2-dope + light VEP.
** 2nd Pass; VT after re-HPR or additional light VEP.

HF treated 9-cell	1st Pass *	2nd Pass **	Qo at 16MV/m, 2K	Quench	Status
AES025	Done		1.9E10	33MV/m	FE limit

* 1st Pass; VT after bulk BCP + 850C bake + light VEP + 120C bake + HF rinse.

T-map meas. during fast cool



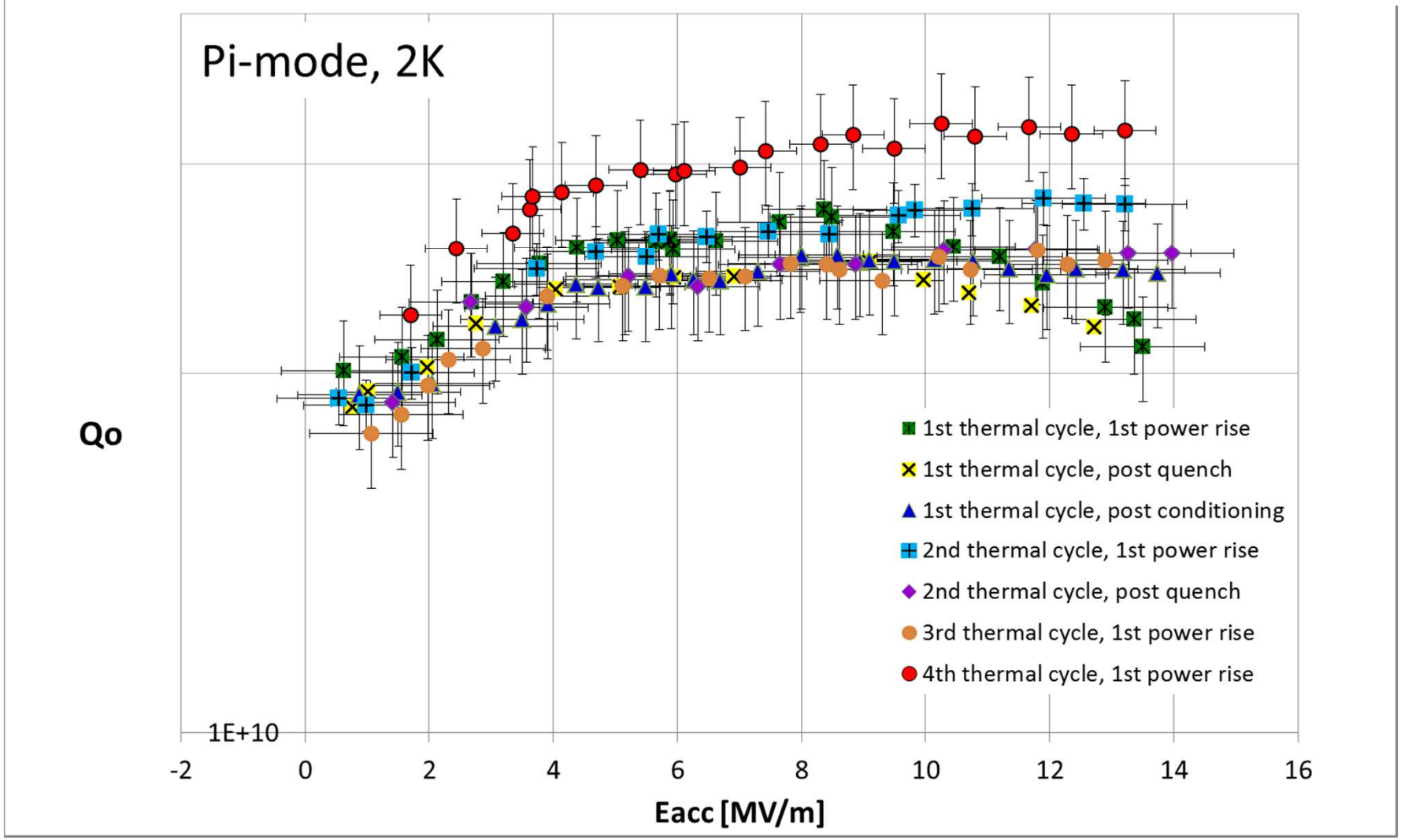
Courtesy of Mingqi Ge
Data analysis is on going

Raw data, plot in [Ohm]
Tc is 1000~1500[Ohm]

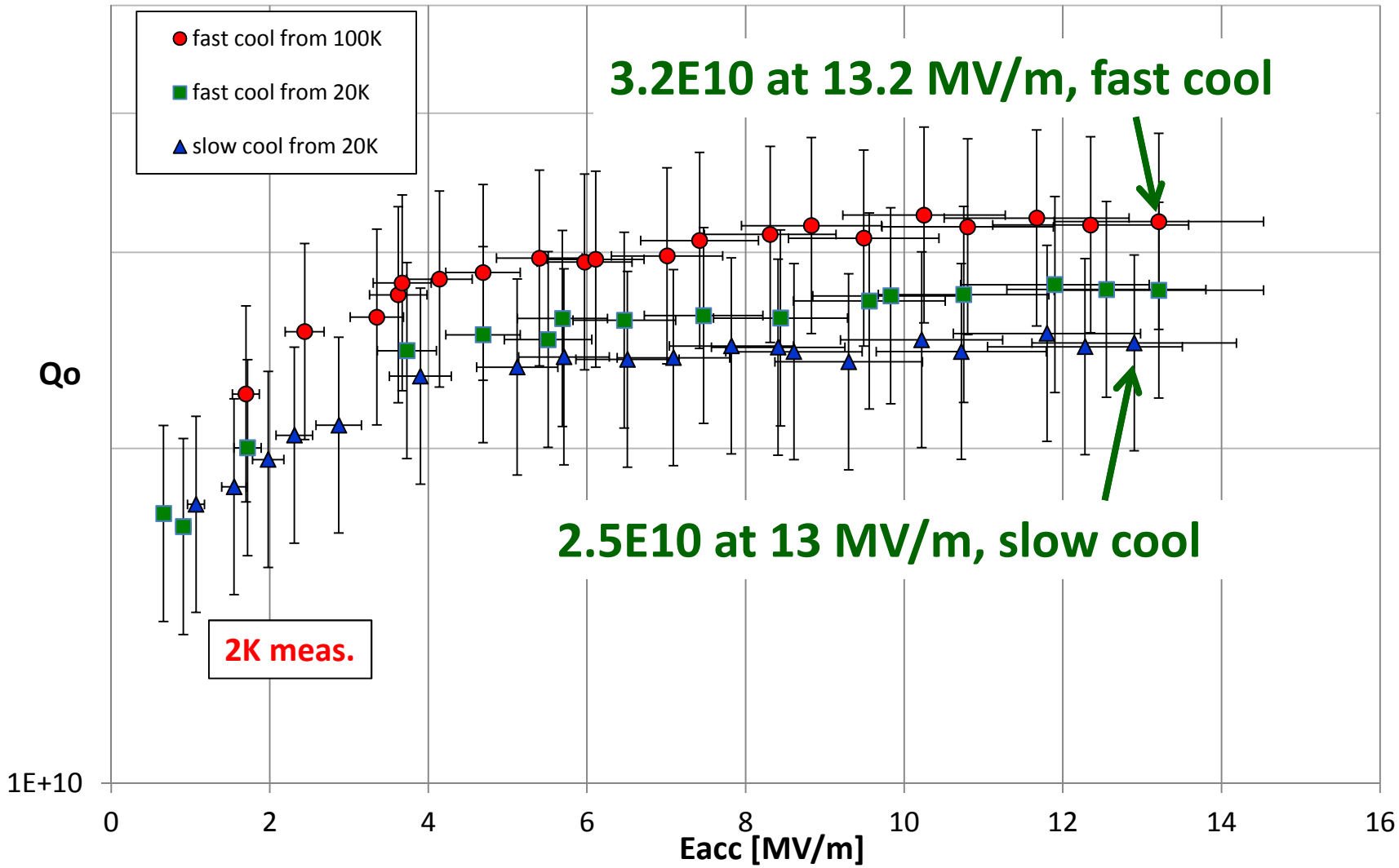
Cornell HTC Test on N-doped 9-cell

HTC Test #1, Q vs. Eacc at 2K

Cavity:ACC012



HTC Test #1, fast/slow cool effect



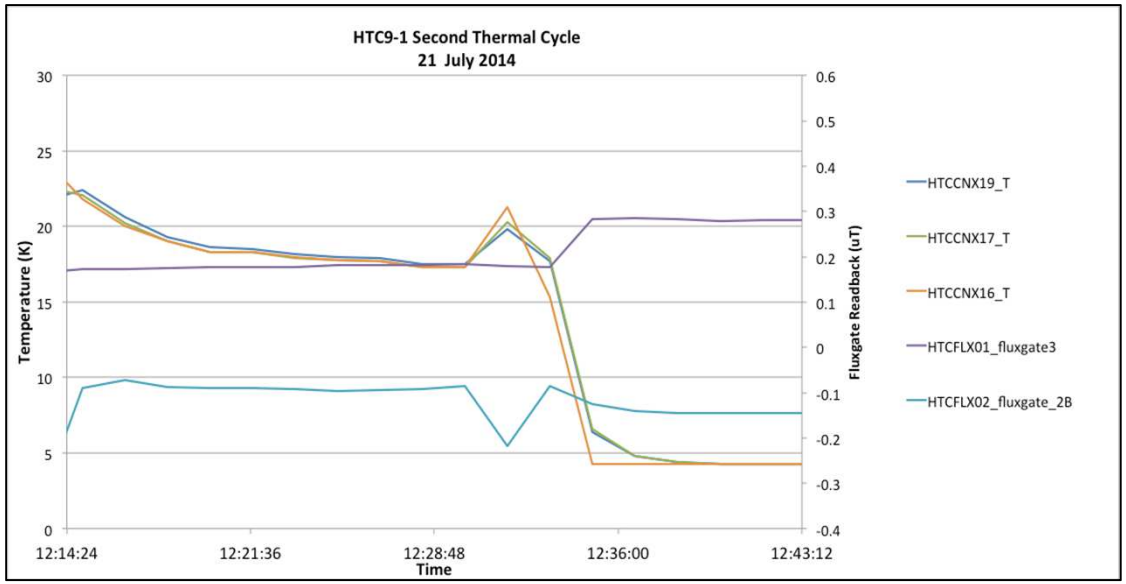
HTC Test #1 Summary, ACC012

Title	Cool down	Results
Initial cool down	~0.5K/min, dT~2.5K (below 25K)	Low field Q meas.,2.6e10 at 5MV/m. Calibrations accomplished.
1st thermal cycle	Warm up to 15K Fast cool from 15K, ~5K/min, dT~5K	FE conditioning in 8/9pi-mode. Eacc=14MV/m, Qo=2.5e10 at 2K (post quench and conditioning).
2nd thermal cycle	Warm up to 25K Fast cool from 20K, ~7K/min, dT~3K	Eacc=14MV/m, Qo=2.8e10 at 2K. Quench degraded Qo from 2.8e10 to 2.5e10 at 2K.
3rd thermal cycle	Warm up to 35K Slow cool from 20K, ~0.04K/min. dT~0.3K	Eacc=14MV/m, Qo=2.5e10 at 2K.
4th thermal cycle	Warm up to 300K Fast cool from 100K, dT~20K near Tc	Eacc=14MV/m, Qo=3.2e10 at 2K. Qo=8e10 at 1.6K, Rres~2nOhm.

HTC Test #1, 2nd and 3rd thermal cycle

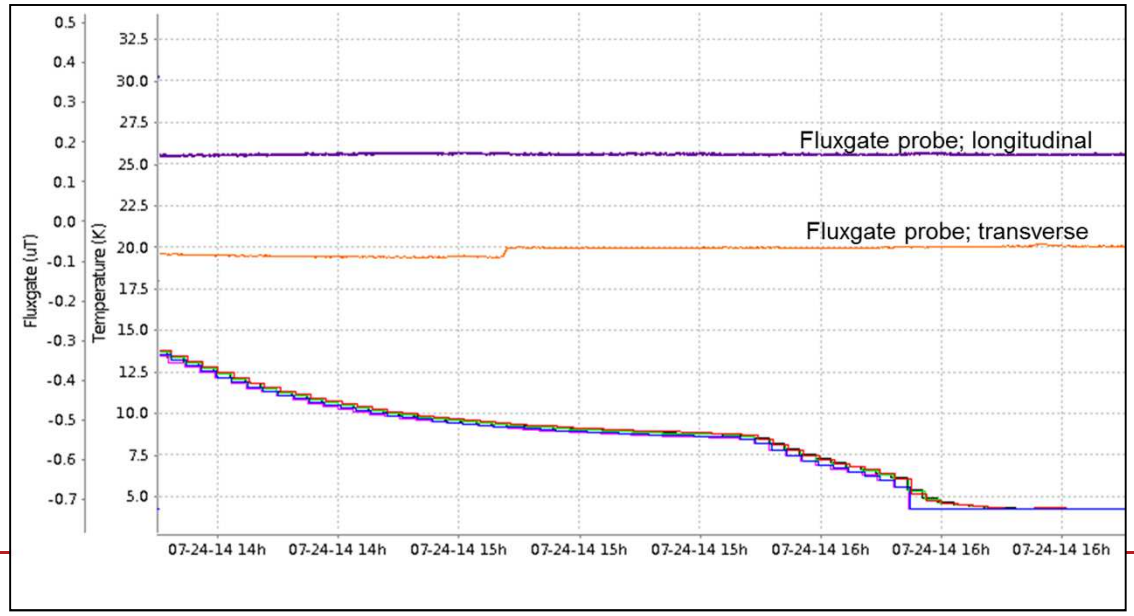
2nd Thermal cycle

- fast cool from 20K
- ~7K/min near Tc
- ~3K gradient over cavity



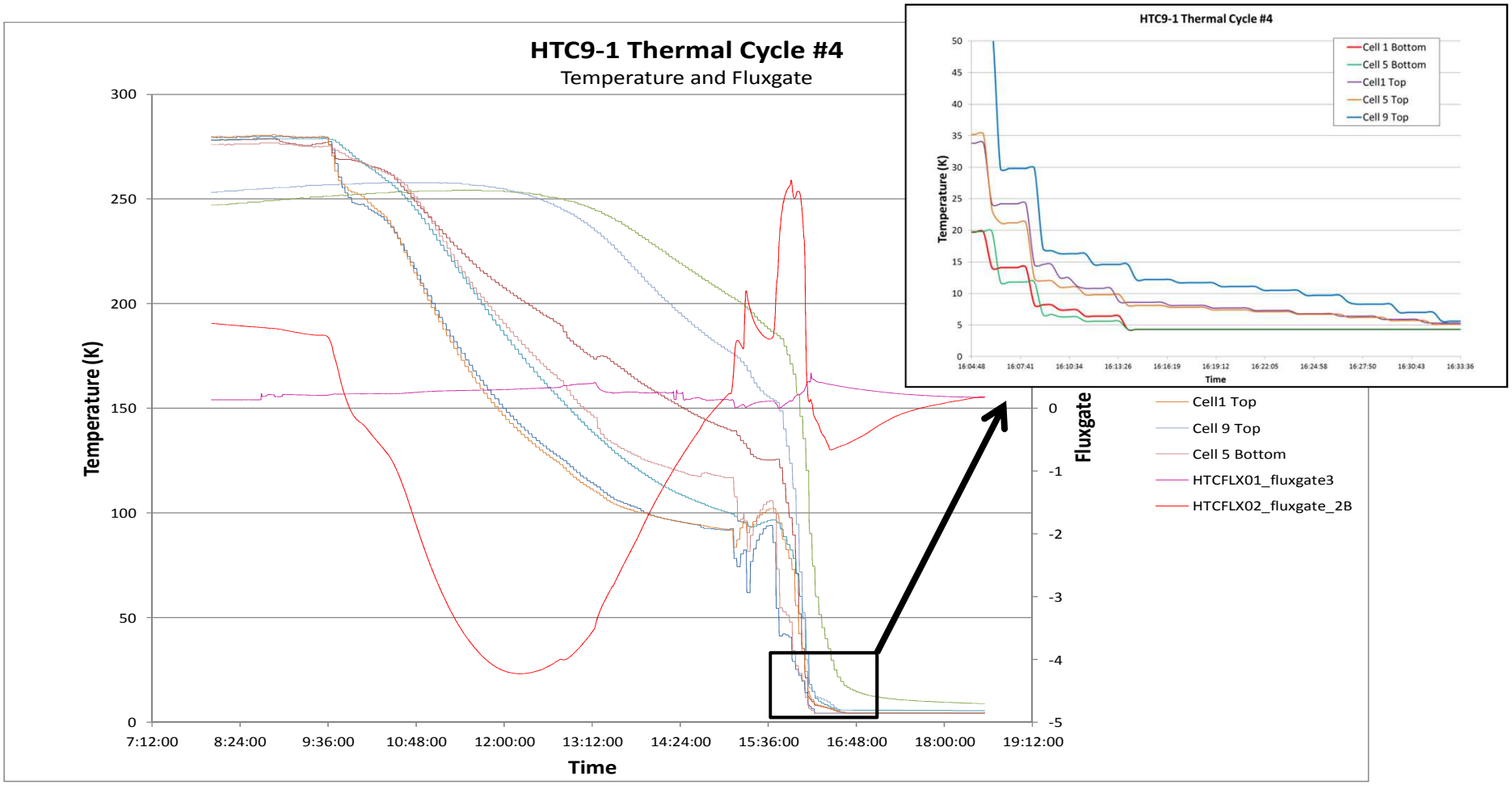
3rd Thermal cycle

- slow cool from 20K
- ~0.04K/min near Tc
- ~0.3K gradient over cavity

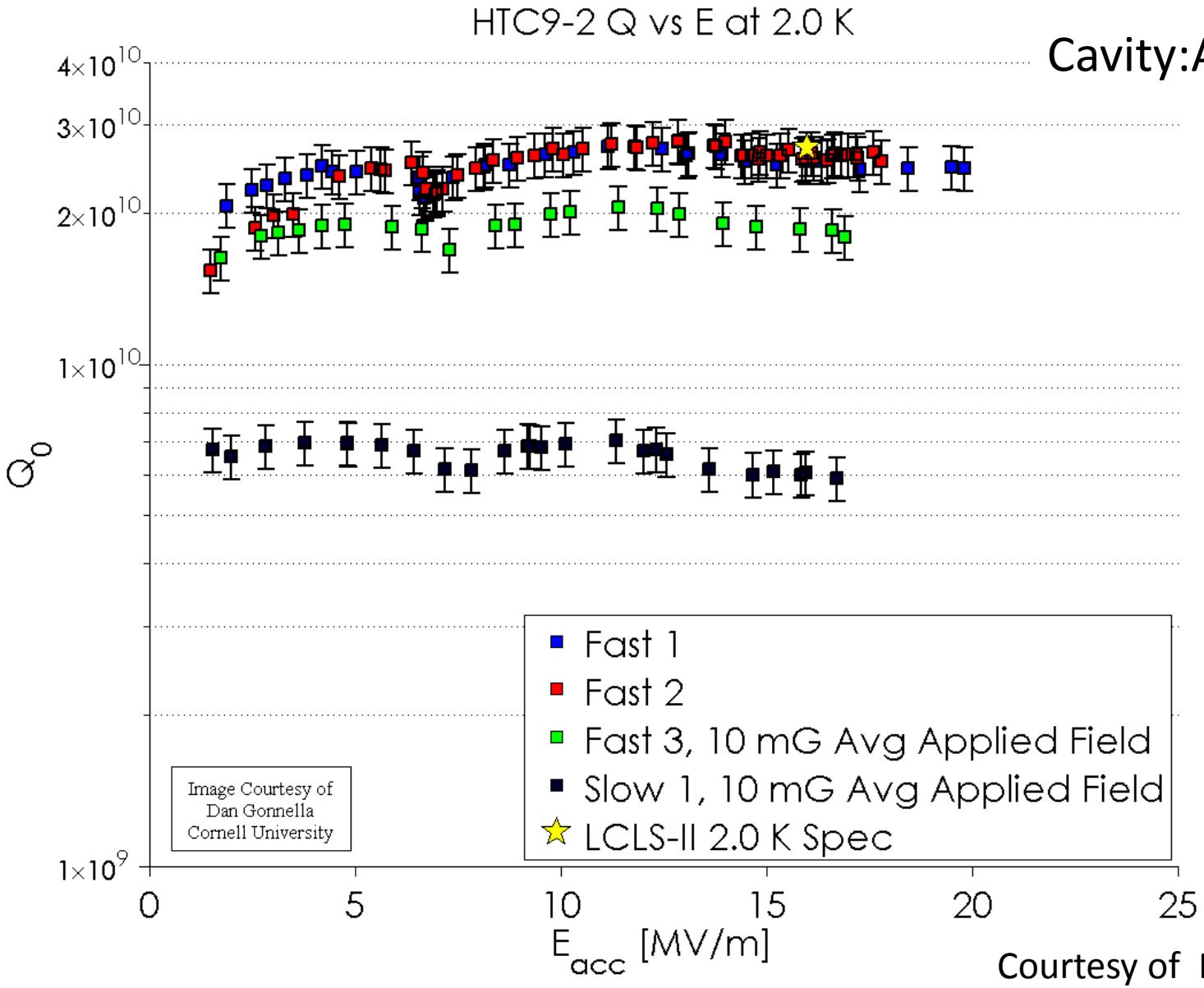


HTC Test #1, 4th thermal cycle

Warmed up to 300K, fast cool from 100K
~20K gradient over cavity near Tc.



HTC Test #2, Q vs. Eacc at 2K



Courtesy of Dan Gonnella

HTC Test #2 status

- **1st cool-down:** fast in low ambient magnetic field
  - Max dT/dt=1.2 K/min, Max ΔT=6.3 K, ~2 mG
- **2nd cool-down:** fast in low ambient magnetic field with somewhat larger temperature gradients over the cavity
  - Max dT/dt=1.3 K/min, Max ΔT=8.9 K, ~2 mG
- **3rd cool-down:** fast in high ambient magnetic field produced by solenoid around the cavity
  - Max dT/dt=1.3 K/min, Max ΔT=7.0 K, $B_{applied}$~10 mG
- **4th cool-down:** slow in high ambient magnetic field produced by solenoid around the cavity
  - ~0.1 K/min (data not completely analyzed), $B_{applied}$~10 mG

- Additional cool down and test is on going.

Summary on LCLS-II work

- Single cell achievement.
  - All 5 single cells (LT1-1~5) successfully achieved and exceeded LCLS-II specs. in 1st VT, no additional process was needed.
  - Q_0 > 3E10 at 2K, 16 MV/m for wide range of final VEP removal (5 to 30 µm). Ave. Qo at 16MV/m, 2K is (3.7±0.6)E10.
  - Quench fields of 18 to 33 MV/m.
  - Established highly reliable High-Q recipe with VEP+N2-dope
  - Decreasing BCS resistance results in anti-Q slope.

- Un-dressed 9-cells achievement.
  - 5 N-doped 9-cells have been tested successfully and achieved LCLS-II specs., Average Qo is 3.0E10 at 16MV/m, 2K. Quench at 21MV/m.
  - Demonstrated availability of VEP for high-Q 9-cell prep.

- Dressed 9-cells achievements in HTC.
  - 1st HTC test on ACC012 exceeds intrinsic quality factor specification in cryomodule for the first time., Qo is 3.2E10 at 14MV/m, quench at 14MV/m.
  - Fast cool down with temp. gradient of ~20K near Tc gave best results with Q~3.2e10 at 2 K and 8e10 at 1.6 K (~2 nOhms of residual) during 1st HTC test.
  - 2nd HTC test on ACC011 is on going, Qo of 2.6E+10 at 16MV/m, 2K has achieved so far.

Cornell ERL
Main Linac Cryomodule

Cornell ERL 7-cell and MLC

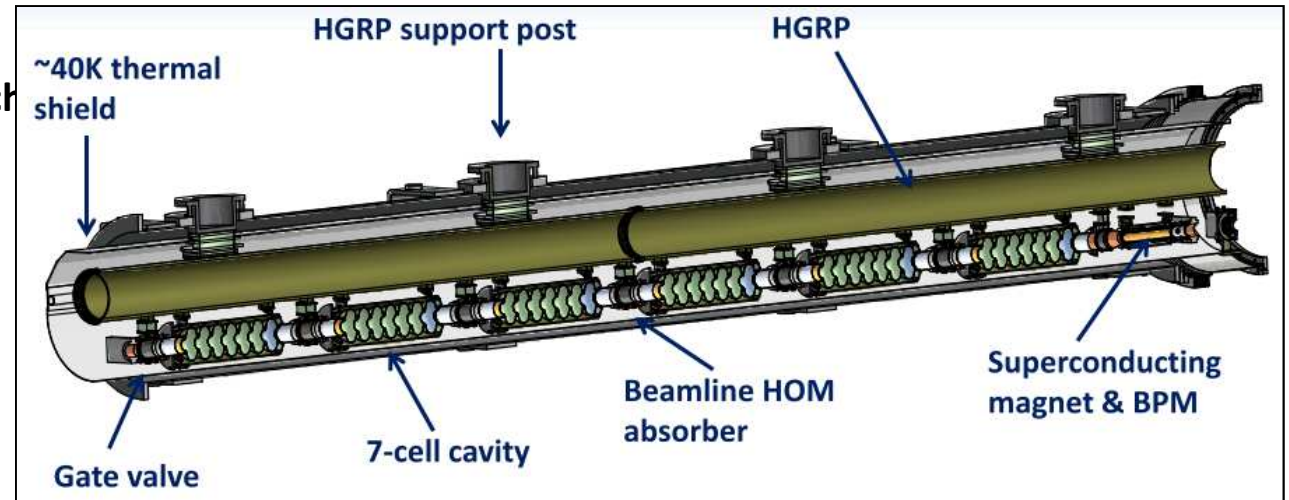
ERL 7cell surface preparations

1. Fabrication
2. Bulk BCP (140um)
3. Degassing (650C*4days)
4. Freq. and flatness Tuning
5. light BCP (10um)
6. 120C*48hrs bake
7. HF rinse
8. VT w/ T-map
9. He vessel welding, final mach
10. String assembly

Cavity specification values in vertical test dewar

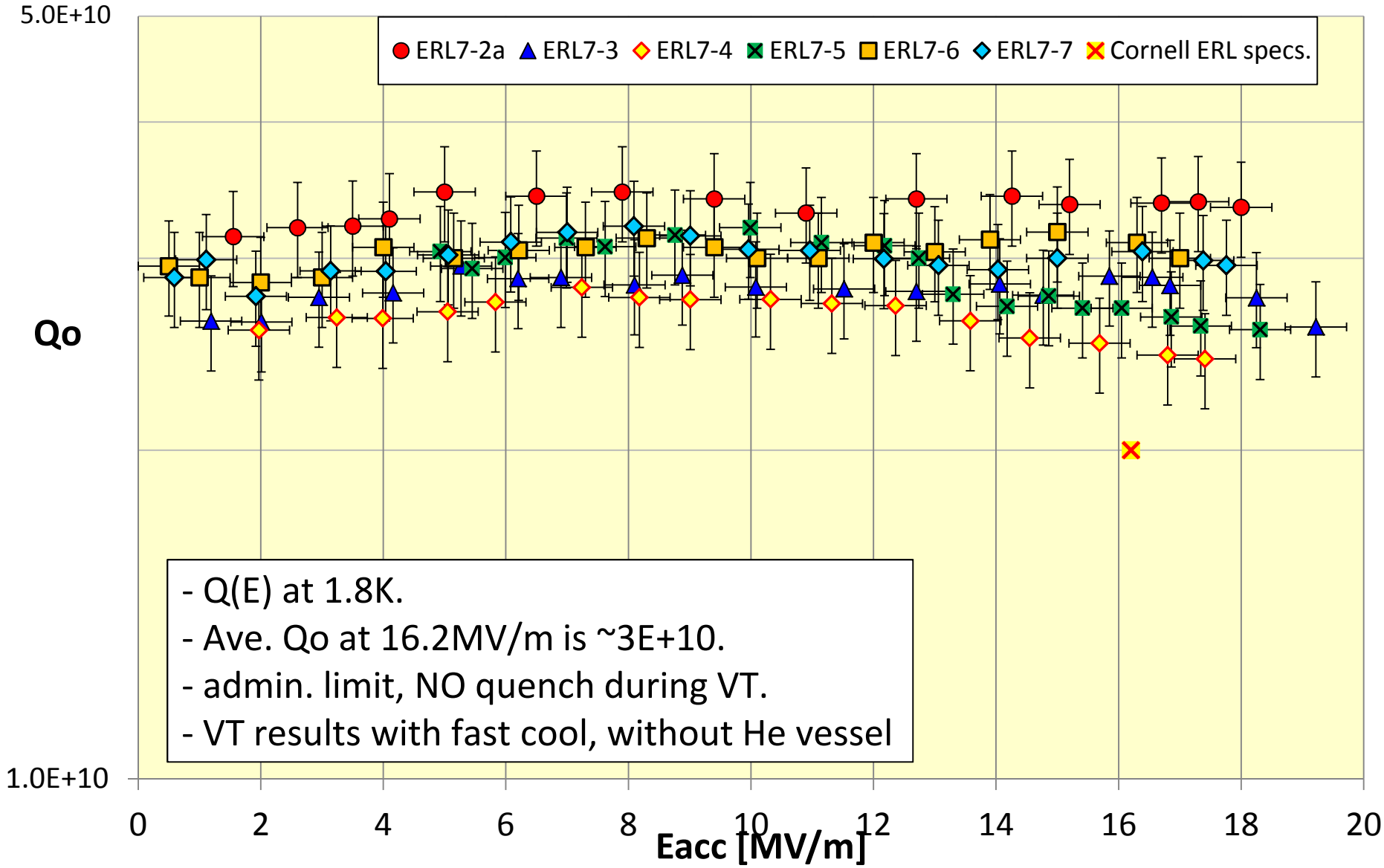
- Eacc=16.2MV/m
- Qo=2.0e10 at 1.8K

Image of Cornell ERL Main Linac Cryomodule



- Number of 7-cell cavities 6
- Acceleration gradient 16.2 MV/m
- R/Q (linac definition) 774 Ohm
- Qext 6.5×10^{7}
- Total 2K / 5K / 80K loads: 76W / 70W / 1500W
- Number of HOM loads 7
- HOM power per cavity 200 W
- Couplers per cavity 1
- RF power per cavity 5 kW
- Amplitude/phase stability 10^{-4} / 0.05° (rms)
- Module length 9.8 m

7-cell VT results at 1.8K



- Q(E) at 1.8K.
- Ave. Qo at 16.2MV/m is ~3E+10.
- admin. limit, NO quench during VT.
- VT results with fast cool, without He vessel

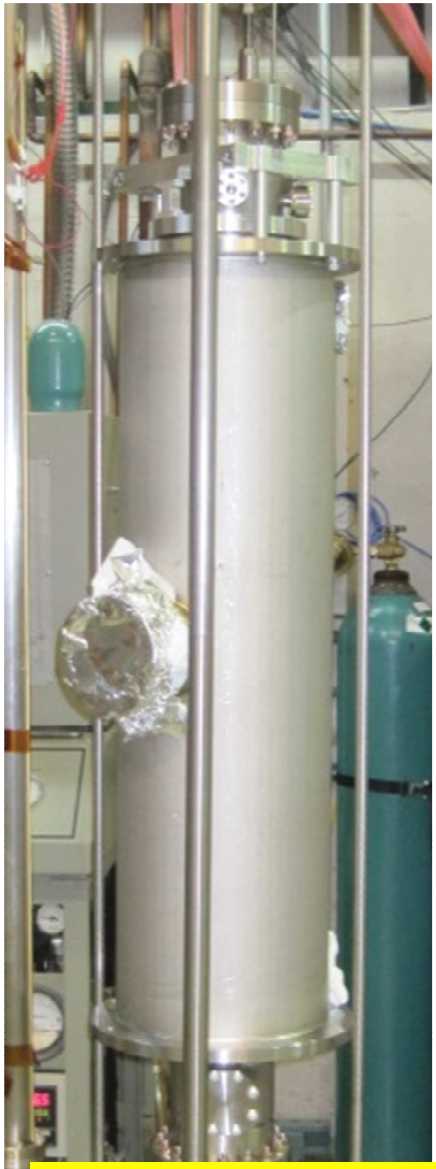
Processes and VT summary of 7-cell

	ERL7-2(a)	ERL7-3	ERL7-4	ERL7-5	ERL7-6	ERL7-7
	Un-stiffened cavity			Stiffened cavity		
Bulk BCP (target removal)	80±5 um (80)	138±5 um (140)	132±7 um (140)	114±8 um (120)	132±5 um (140)	118±5 um (120)
Degassing	TM-furnace 650C*1days 850C*3days	TM-furnace 650C*4days	TM-furnace 650C*4days	TM-furnace 650C*4days	TM-furnace 650C*4days	TM-furnace 650C*4days
Post tuning, flatness and cavity length	97% 1160.80mm	91% 1163.56 mm	92% 1162.09 mm	94% 1158.35 mm	94% 1159.06 mm	94% 1159.31 mm
light BCP	10 um	10 um	10 um	10 um	10 um	10 um
120C bake	TM-furnace	TM-furnace	TM-furnace	TM-furnace	TM-furnace	On insert
HF rinse	Yes	Yes	Yes	Yes	Yes	Yes
Additional Mag. shield on cavity during VT	Yes	No	No	No	Yes	Yes
1st VT	Achieved specs.	FE limit	Achieved specs.	Achieved specs.	Achieved specs.	Achieved specs.
2nd VT		Achieved specs.				
Qo at 16.2MV/m, 1.8K (design=2.0e10)	3.37e10	2.90e10	2.45e10	2.70e10	3.10e10	3.04e10
Final Results at 1.8K	18MV/m 3.34e10	17MV/m 2.8e10	17.4MV/m 2.4e10	18.3MV/m 2.6e10	17MV/m 3e10	17.8MV/m 2.95e10

Notes; * all data shown on table were taken with fast cool, no He vessel on cavity.
* ERL7-3 was re-processed with light BCP +120C bake +HF rinse before 2nd VT.
* some cavities were measured again after He vessel welding.

Cavity on VT insert

Bare, w/ T-map

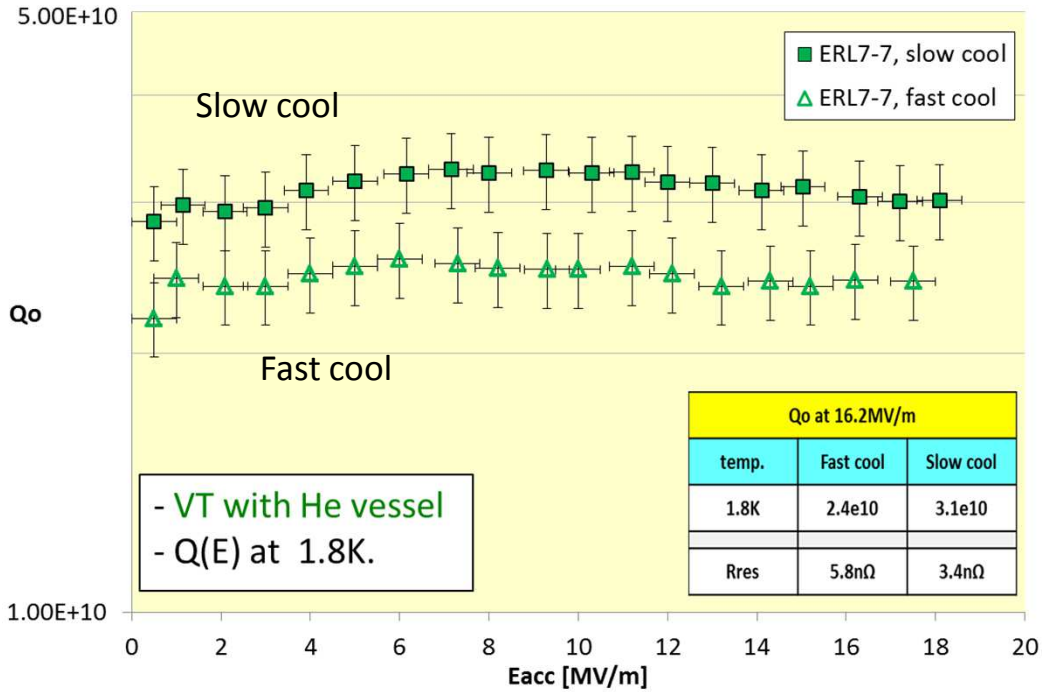


w/ He vessel

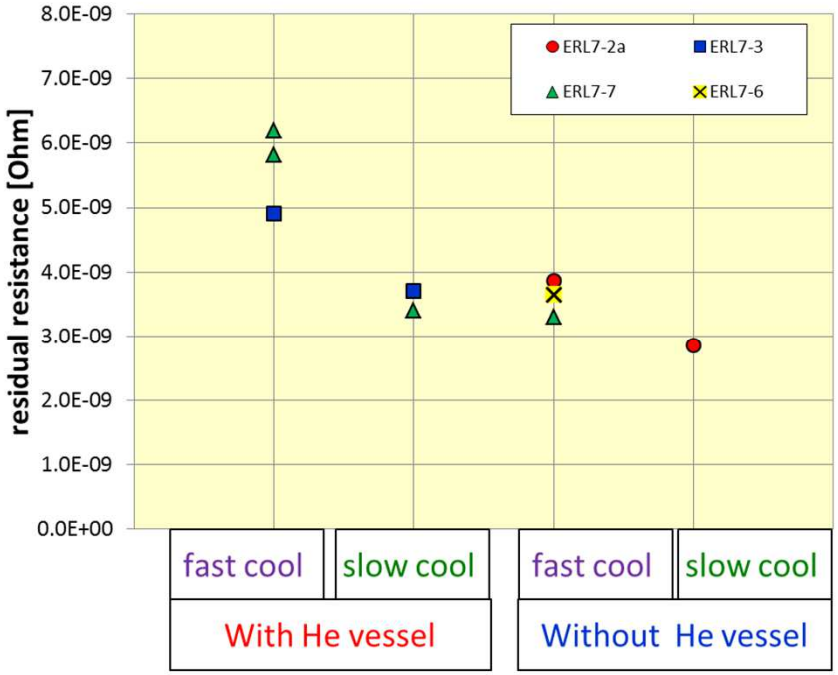
w/ additional mag. shield

R&D on fast/slow cool VT

Fast cool; dT over cavity ~100K near Tc.
Slow cool; dT over cavity ~0.1K near Tc.

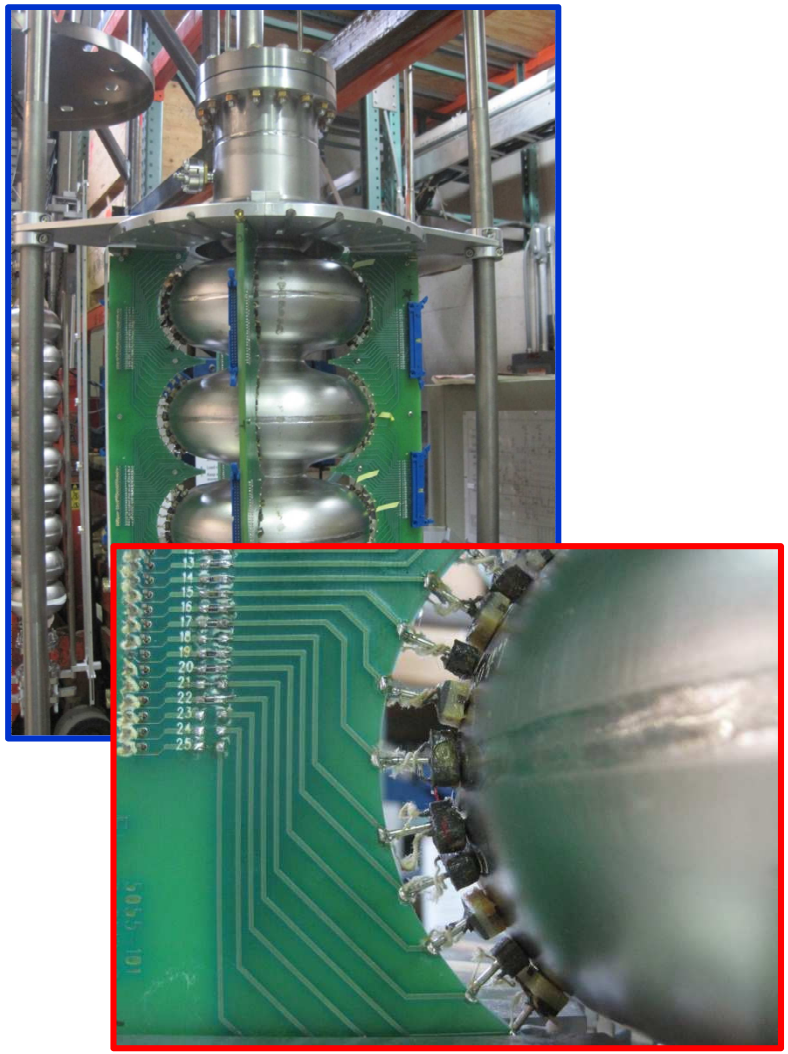


Qo at 16.2MV/m		
temp.	Fast cool	Slow cool
1.8K	2.4e10	3.1e10
Rres	5.8nΩ	3.4nΩ

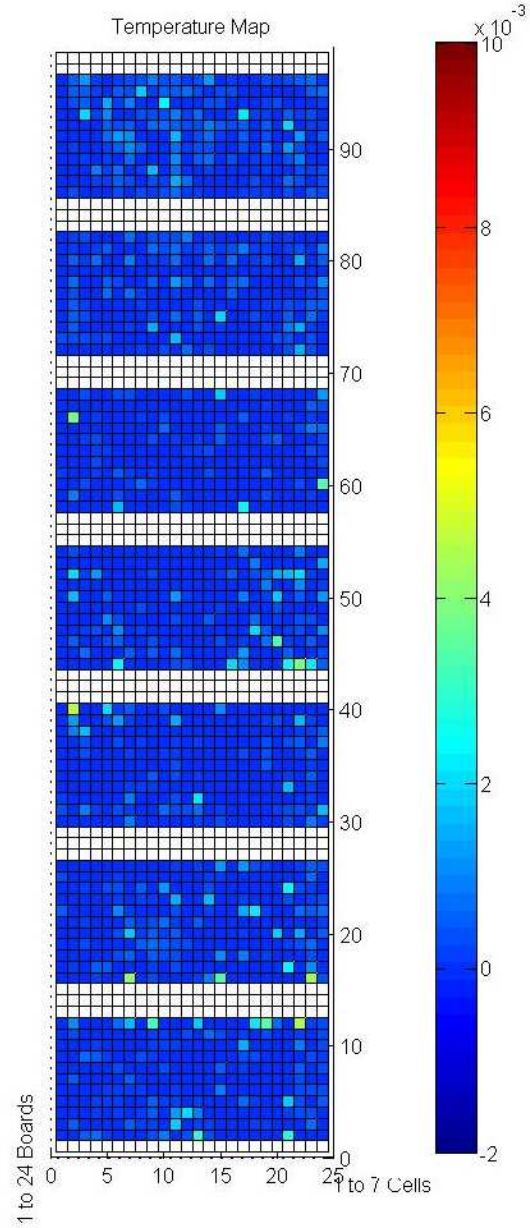


Slow cool gave higher Qo than fast cool during VT of 7-cells.

T-map meas. Durign VT



An example of 7-cell T-map data
ERL 7-5, Eacc=17MV/m, Qo=1.7e10, at 2K.
Courtesy of Mingqi Ge



String and cold mass assembly

MLC assembly

Summary on Cornell ERL MLC

- The Cornell ERL 7-cell cavities for Main Linac Cryomodule, six 7-cells in total, had been fabricated, processed, and tested in CLASSE vertical test dewar.
- All cavities have surpassed the specification values of Eacc=16.2MV/m w/ Qo of 2.0e10 at 1.8K. Achieved Qo during vertical test were much higher than specs, the average of Qo is almost 3e10 at 1.8K.
- Through these 7-cell VTs, we have successfully demonstrated our high reliability of fabrication, high reproducibility of processes, and high yield of the results.
- MLC assembly is on going, cold mass was slid into vac. bessel last week.