Gradient Status from the S0 perspective

C.M. Ginsburg (Fermilab)

On behalf of the S0/S1 Task Force

EDR Cavities Kick-off meeting
DESY Hamburg
September 19, 2007

Outline

- S0 charge and goals
  - The what and the why
- Results for S0
  - S0-related cavity test results – focus on gradients
  - Global data analysis
- Summary and plans

Gradient Task Force Charge

- The RDB is asked to set up a Task Force to carry out a closely coordinated global execution of the work leading to the achievement of the accelerating gradient specified in the ILC Baseline.
- A definition of the goals for the cavity performance in terms of gradient and yield and a plan for achieving them should be proposed by this group, which should take account of the global resources available and how they may be used most rapidly and efficiently.
- The accelerating gradient performance and yield should be specified both for an individual 9-cell cavity and for an individual cryomodule, and the plan should cover the demonstration of this performance in both cases.
- The GDE will facilitate the coordination at the global level to achieve this vital goal as soon as possible.

S0 Task Force, Goal & Plan

- S0 task force membership
  - Hitoshi Hayano (KEK), Toshiyasu Higo (KEK), Lutz Lilje (DESY), John Mammosser (SNS), Hasan Padamsee (Cornell), Phil Pfund (FNAL), Marc Ross (FNAL), Kenji Saito (KEK), Bill Willis (Columbia), Camille Ginsburg (FNAL)
- Goal for cavity performance in vertical test
  - ILC baseline (RDR): $E_{acc} \geq 35$ MV/m, $Q_0 \geq 0.8 \times 10^{10}$
  - Proof of principle: $E_{acc} \geq 35$ MV/m and $Q_0 \geq 10^{10}$, with yield > 90% for >100 cycles
- Plan for achieving goal
  - Two steps
    - S0.1: Tight loop to improve "final preparation" yield
      - Process and test few cavities repeatedly; test of processing
    - S0.2: Production-like activities to determine overall yield for cavity materials, fabrication and full cavity processing
      - Process and test batches of 10's of cavities; test of full cycle including fabrication, surface processing, assembly
  - Closely coordinated global execution
    - Reproducibility from lab to lab
      - Complete description of preparation and testing processes
      - Common minimum test procedure and reporting of results
      - Compare regional preparation setup performance
    - Time scale should be commensurate with completion of the EDR (mid 2009)

Basic Assumptions

- **The basic recipe for highest gradients is known: Electropolishing, High Pressure Water Rinse and In-situ Bakeout (120 C)**
  - **Results are not fully reproducible**
  - **Field emission is a major problem**
  - **Some contaminants have been identified**
- **Fine-tuning the surface preparation parameters is needed**
  - **Need to separate the surface preparation process from the potential fabrication errors by new vendors**
- **Need to get a statistically meaningful sample for the overall cavity fabrication and preparation**
  - **The cavity performance is influenced by the fabrication process and surface preparation process.**
  - **Large number of cavities from several regions in a production-like mode eventually**
  - **The yield for the number of successful cavities of the final production batch should be > 80% in the first test. After re-processing the 20% underperforming cavities the yield should go up to (80%+80%*20%) >95%. This is consistent with the assumption in the RDR costing exercise.**

S0 Tight-loop Status

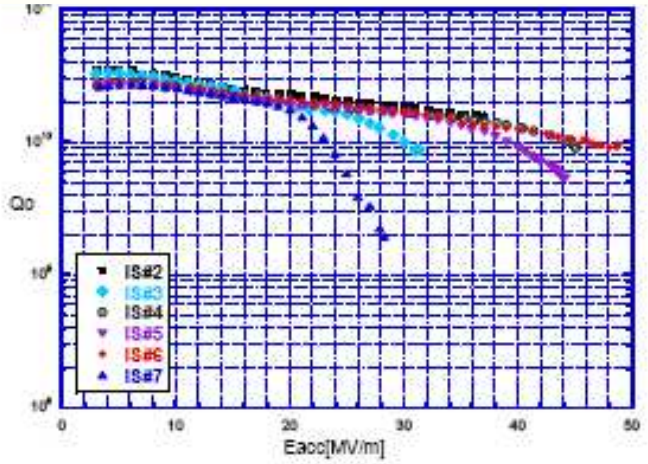
- **Tight-loop**
  - **Basic assumption: cavity preparation is the critical step**
  - **Definition: Test minor variations in the final surface preparation**
  - **Main goal: Demonstrate 80% yield in first acceptance test, then 95% with second try**
  - **Detailed goals:**
    - **Conduct a dedicated single-cell program**
    - **Demonstrate multi-cell handling**
    - **Cavity exchange to ensure complete processing and test-stand description**
    - **Compare regional preparation setup performance**
    - **Demonstrate optimized treatment in a second cycle**
- **Results**
  - **R&D on Single-cells**
    - **Comparison of final preparation methods (mostly at KEK) <- see data**
    - **Yield already one strong candidate for these processes: 'fresh acid'**
  - **R&D on Multi-cells**
    - **Promising process: Ultrasound degrease (mostly at JLab), H2O2 (KEK)**
  - **First tight-loop results from established (already-qualified) vendors <- see data**

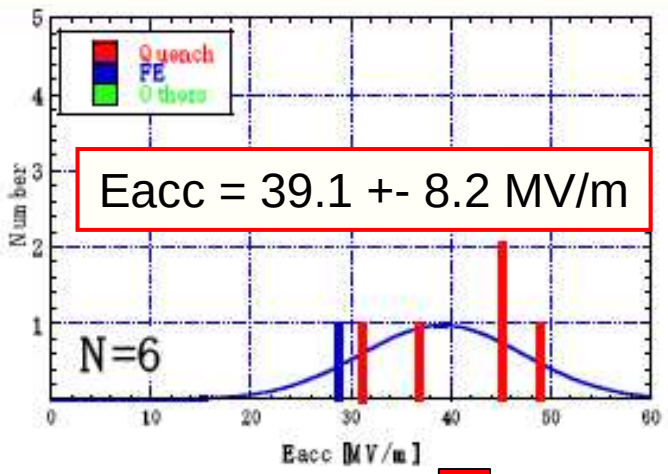
R&D on single cells

Comparison of final preparation methods: KEK data

KEK (high-grad group) process R&D

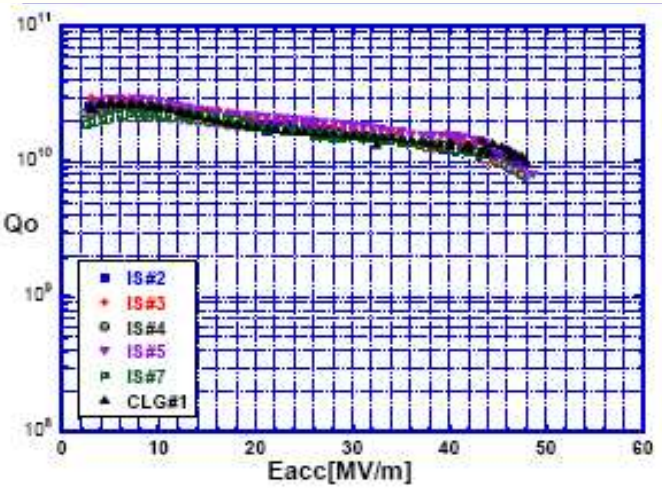
K. Saito, TTC Meeting at Fermilab, April 2007

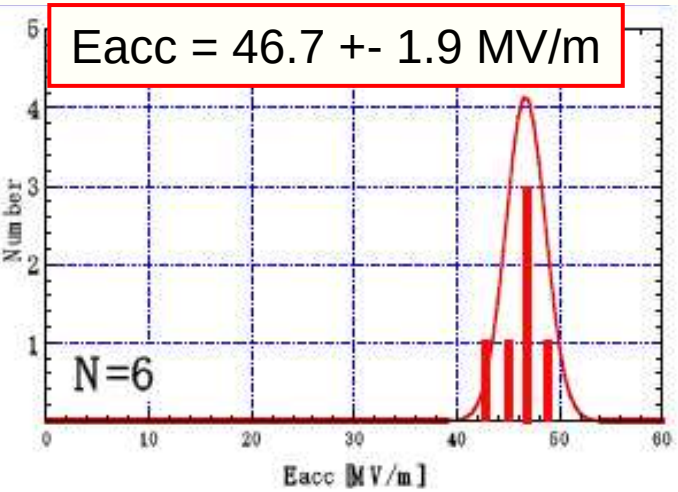




Eacc = 39.1 +- 8.2 MV/m

Add fresh/closed 3 μm EP





Eacc = 46.7 +- 1.9 MV/m

- **Single-cell Ichiro shape**
- **Standard treatment**
  CBP+CP+Anneal+ EP(80 μm) + HPR + bake (120C*48hrs)
- **Improvement in gradient and *spread* by the addition of fresh/closed 3 μm etch**
- **Raises gradient for onset of field emission (FE)**
- **cannot be certain whether the final quench is caused by FE or by defect**

KEK (high-grad group) process R&D

Same data, more details

cavity	test status	measurement date	cavity treatment includes…	Eacc [MV/m]	Q0 [E10]	x-ray start [MV/m]	FE onset [MV/m]
IS#2	quench	11/29/2005	EP(80)	36.90	1.5	24	35
IS#3	FE	11/21/2005	EP(80)	31.4	0.866	19	25
IS#4	quench	11/22/2005	EP(80)	45.1	0.907	33	38
IS#5	quench	11/28/2005	EP(80)	44.2	0.538	20	37
IS#6	quench	12/12/2005	EP(80)	48.8	0.964	37	no
IS#7	FE	12/14/2005	EP(80)	28.3	0.194	15	20
IS#2	quench	4/4/2006	EP(20+3, closed)	47.07	1.06	37	no
IS#3	quench-FE	4/12/2006	EP(20+3,closed)+HF	44.67	0.98	37	43
IS#4	quench	4/19/2006	EP(20+3,closed)	47.82	0.78	30	45
IS#6	quench	1/25/2007	EP(20+3,closed)+HF	48.60	0.80	31	N/A
IS#7	quench	4/15/2006	EP(20+3,closed)+HF	43.93	1.17	no	no
CLG#1	quench	1/26/2007	EP(20+3,closed)+HF	47.90	1.0	30	N/A

Source: K. Saito TTC@Fermilab April 2007 + F. Furuta, private communication

- **“X-ray start” is the gradient at which the x-ray flux above the cryostat top plate exceeds 0.3 μSv/hr**
- **“FE onset” is the gradient at which the FE-loading starts increasing, approximately the shoulder in the Q vs. E curve (more info available if desired)**

Established Cavity Vendors

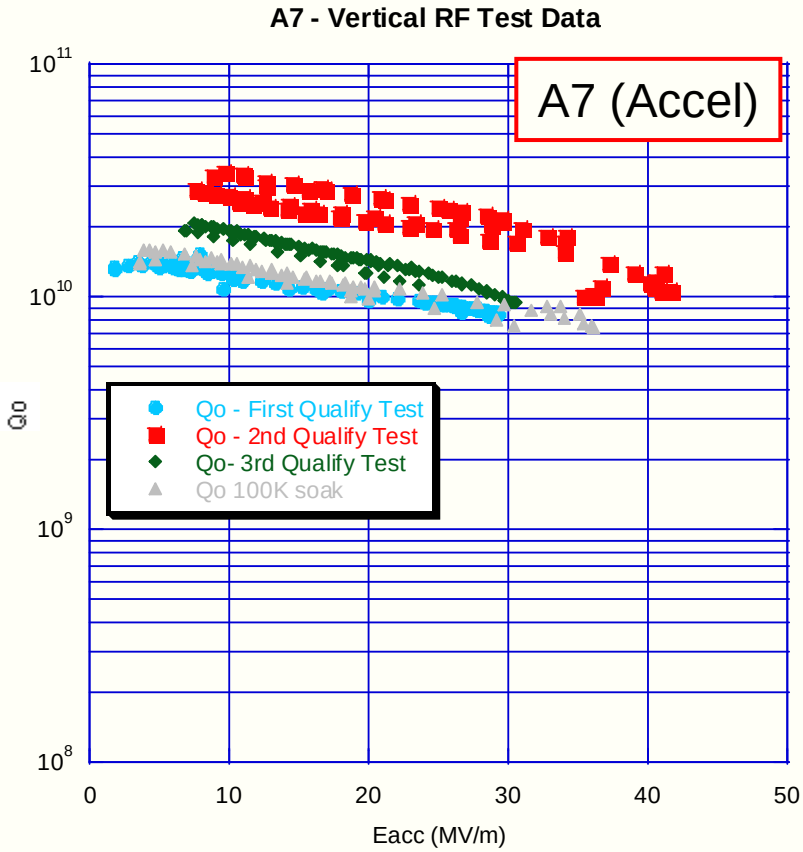
Tight-loop results from already qualified vendors

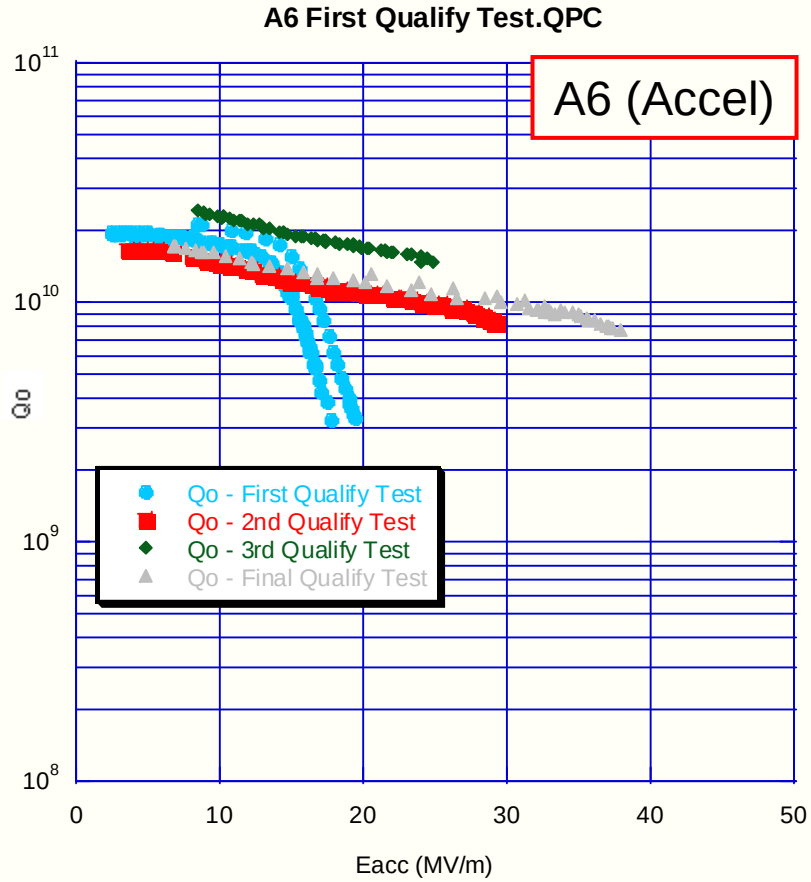
- Only testing the processing

JLab: Process reproducibility

J. Mammosser, TTC Meeting at Fermilab, April 2007

- **Accel cavities – already qualified vendor, same treatment for all cavities**
- **All curves but one limited by quench; A6 final test limited by FE**
- **Large distribution of quench gradients with multiple tests of same cavity**





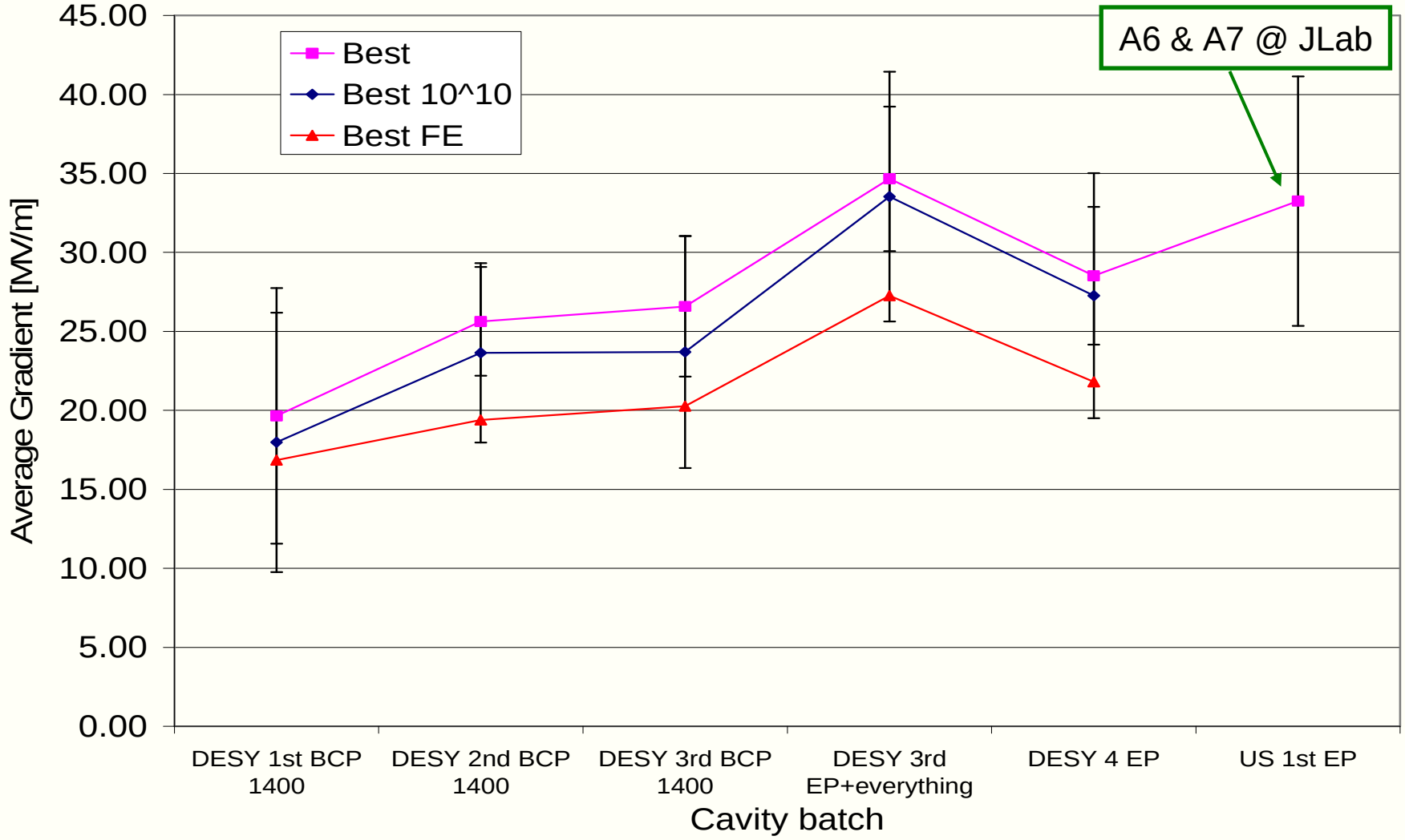
JLab: Process reproducibility

J. Mammosser, TTC Meeting at Fermilab, April 2007

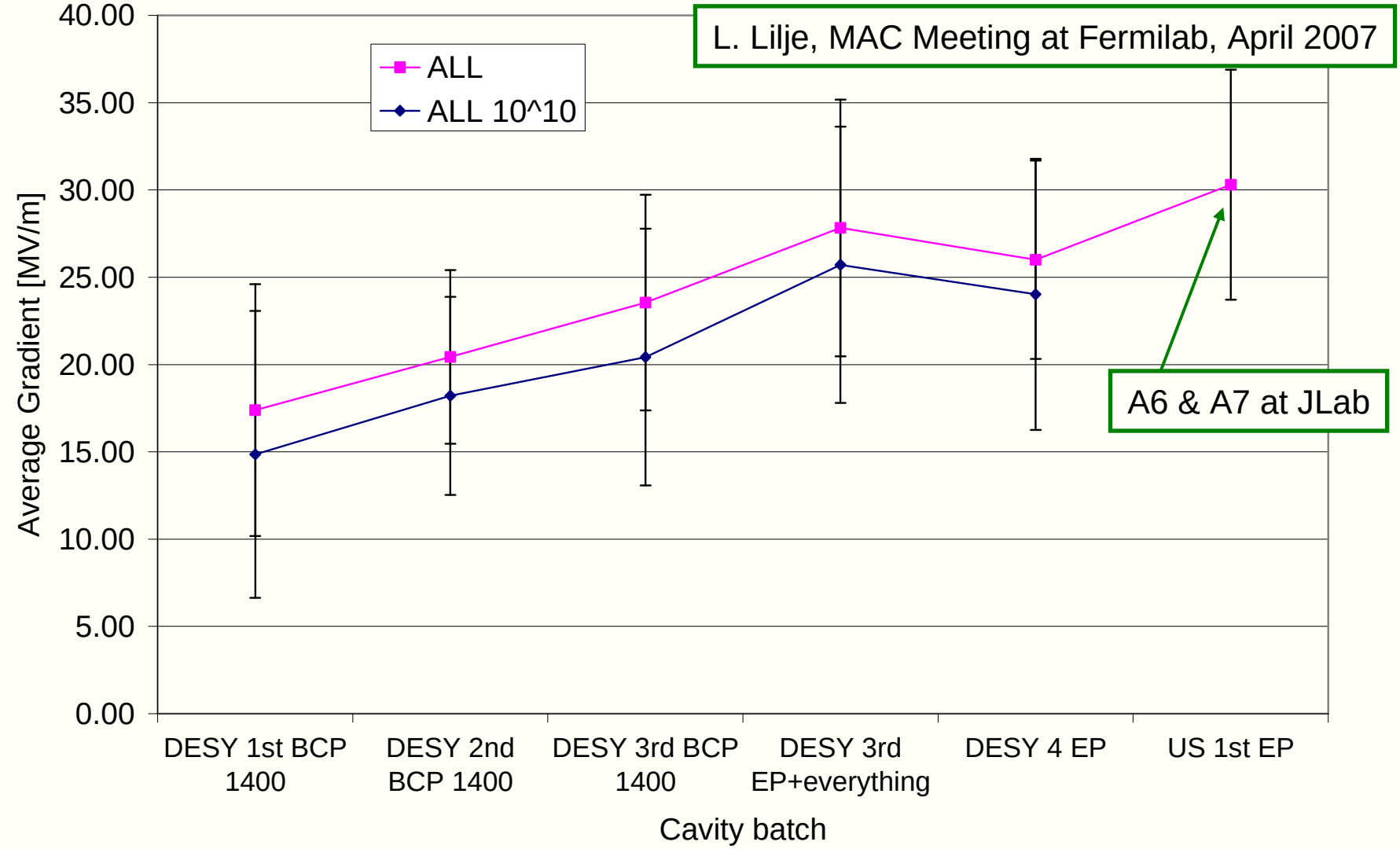
- **JLab processing recipe**
  - **Degrease**
  - **Electropolishing (20 μm)**
  - **Degrease**
  - **First HPR+dry**
  - **First cleanroom assembly**
  - **Second HPR+dry**
  - **Final cleanroom assembly**
  - **Evacuation and leak check**
  - **Low temperature (110 C) bake**
- **RF test at 2K**

Summary of 'Already-Qualified' Vendors
DESY & JLab Best Test Results

L. Lilje, MAC Meeting at Fermilab, April 2007



Summary of 'Already-Qualified' Vendors
DESY & JLab All Test Results



S0 'Production-like' Process Status

- **Production-like tests**
  - **Determine yield of full production chain**
    - **fabrication, process, ass'y, test**
    - **includes cavity fabrication variations**
      - **Cavity fabrication by new vendors will be tested**
  - **Several cavities treated in the same manner**
    - **specify yield in more detail**
- **Results**
  - **KEK new vendor MHI (Mitsubishi Heavy Industries) <- see data**
    - **(TESLA-like cavities)**
  - **US new vendor AES (Advanced Energy Systems, Inc.) <- see data**

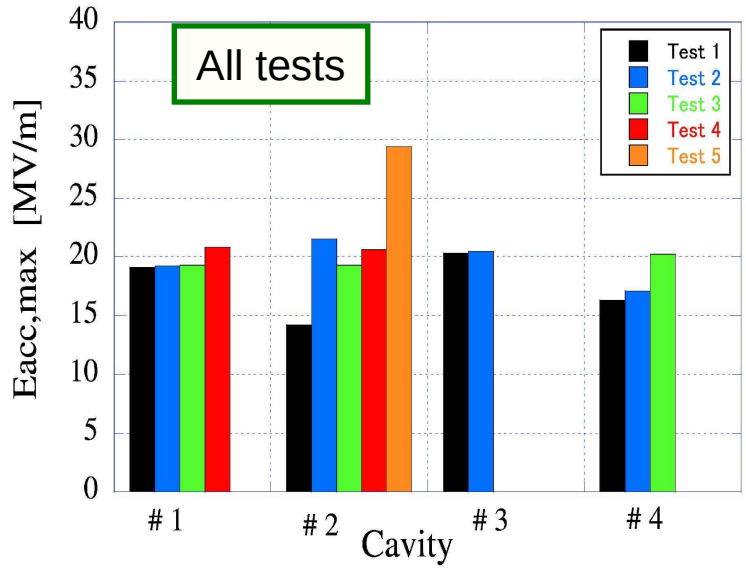
S0 Production-like Status

Qualification of new cavity vendors

KEK Tesla-style cavities

KEK baseline-gradient group data

- **Tesla-style cavities for STF phase 1.0 cryomodule**
  - **Improved stiffness**
  - **Larger diameter input coupler port and beamtube**
- **New cavity vendor: MHI**
- **Standard KEK surface treatment**
- **Results**
  - **Gradient summary: 20.1 +- 3.6 MV/m**
  - **Best cavity test 29 MV/m**
  - **Tighter QC for future production runs will be implemented**
  - **Mode measurements very useful**

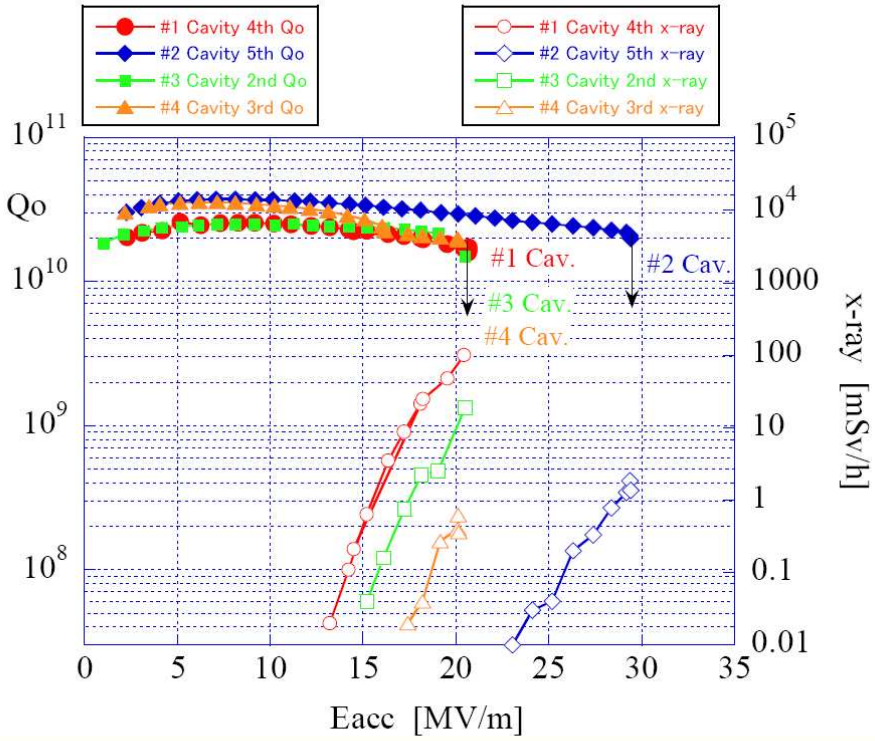


E. Kako, priv. comm.

KEK Tesla-style cavities

E. Kako, TTC Meeting at Fermilab, April 2007

Final Performance in Vertical Tests



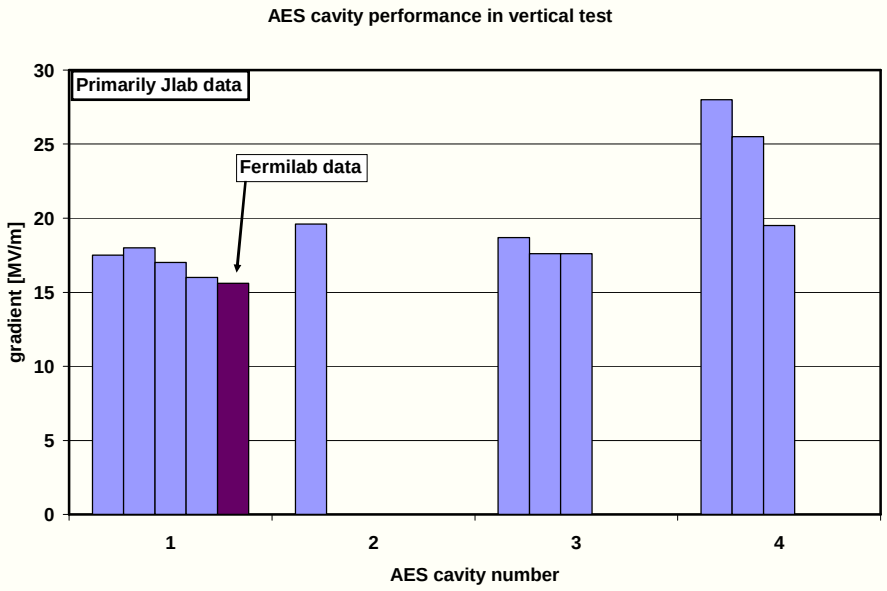
Eacc,max

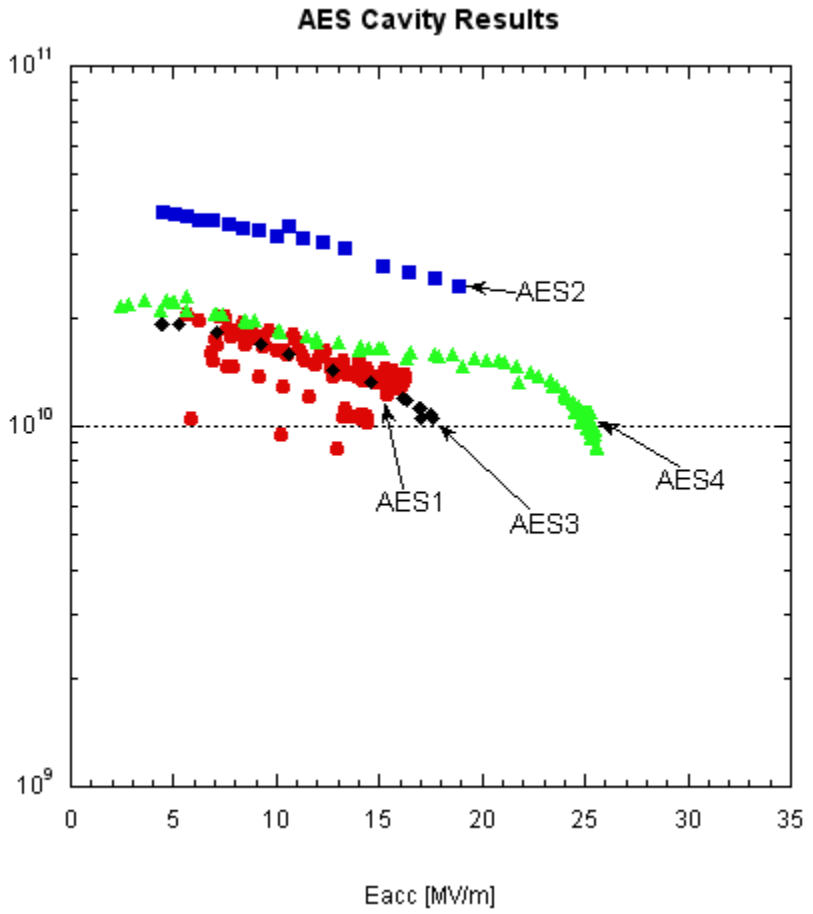
#1 20.8 MV/m
#2 29.4 MV/m
#3 20.5 MV/m
#4 20.2 MV/m

high Qo > 10^{10}

JLab: qualification of new vendor

R. Geng, AES Meeting at Jlab, Aug 2007





- New cavity vendor: AES
- Standard JLab surface treatment
- Results
  - Gradient summary: 19.2 +- 3.8 MV/m
  - Best cavity at 28 MV/m
  - Mode measurements very useful

S0 data coordination

Global data analysis

S0 9-cell test definition

- **Goal: define a test procedure which results in a data set comparable among the laboratories**
- **Due to the significant differences in infrastructures the test procedures differ significantly**
- **A standard set of data from a vertical, low-power 9-cell cavity test contains**
  - **A check for hydrogen contamination of the niobium material (Q-disease)**
    - **Stay at 100K for 8 hours during cooldown; provide temperature vs. time data**
    - **As this test significantly extends the testing time for some labs, can be omitted once confident that processes do not contaminate niobium with hydrogen**
  - **Q vs.T measurement for residual resistance**
  - **All 9 passband modes measurement**
    - **Deformation would lead to a unusable information from the passband modes measurement**
    - **Field flatness data required for proper interpretation**
    - **Checks of frequency spectrum**
  - **Quench location: thermometry, mode measurements, x-ray detection etc.**
  - **Further information to be provided with the data above include**
    - **Continuous pumping during test or closed valve; provide pressure data**
    - **Temperature difference over cavity (top to bottom) during cooldown**
    - **Method of low-power processing – pulsed or cw**
    - **Coupler type: fixed or variable**

Issues associated with this definition

- KEK and Cornell rely on portable LHe dewars
  - Minimizing test duration and LHe usage are critical
- Only DESY and KEK have variable input couplers, which are almost necessary for mode measurements
- Quench detection is time consuming, requiring at least two cooldowns: one to localize quench via mode measurements, and one to attach thermometry
  - Current thermometry systems are too time consuming for every test, and only measure one cell
- Field emission measurement numerically not comparable among test stands
  - Different amounts of material between cavity and detector
  - Different locations of detector with respect to cavity
  - Different detectors with different acceptance for different energies and different trigger time window
- Only DESY has a publicly available data management system
  - Still not everything desirable is available
  - Rely on experimental groups to provide results

S0 cavity tracking

P. Pfund, update August 31 2007

The Cavity Report

Cavity_Listing_2007-08-31.xls

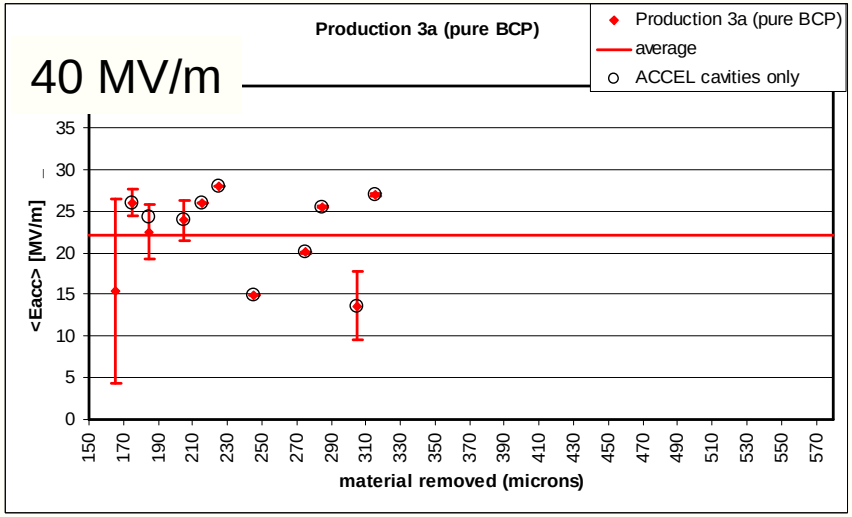
Lab	Cavity Name	Current	Current	Designated	Reported	Comments
	AC 7	At Jlab	Tested	S0 testing	31.9 MV/m (Jlab)	Selected for S0. Will probably be sent to Fermilab first, before being sent to KEK for S0 testing.
	AC 8	At Jlab	to be tested	S0 testing	25 MV/m (Cornell) 22 MV/m (Jlab) first test.	Selected for S0. Sent to Jlab after testing at Cornell.
KEK	KEK Tesla Type #5	Being fabricated		S0 testing		(as of 06Aug07) Expect to be available Dec07.
KEK	KEK Tesla Type #6	Being fabricated		S0 testing		(as of 06Aug07) Expect to be available Jan08.
KEK	Ichiro #0	At KEK		S0 testing		
KEK	Ichiro #2	At KEK		S0 testing		
KEK	New Ichiro #5	At Jlab	S0 testing	STF 1.5		(as of 20Aug07) New Ichiro 35 arrived at Jlab. Rongli Geng and Kenji Saito are working on a plan for processing and testing.
PAL	New Ichiro #6	At KEK	S0 testing	STF 1.5		
DESY	AC115			S0 testing		Selected by DESY for S0 testing. Processing will begin at DESY Sep07 or later.
DESY	AC118			S0 testing		Selected by DESY for S0 testing. Schedule for processing and testing is still under discussion at DESY.
DESY	AC116			S0 testing		Tentatively selected by DESY for S0 testing but this needs to be confirmed by DESY and the schedule is uncertain.

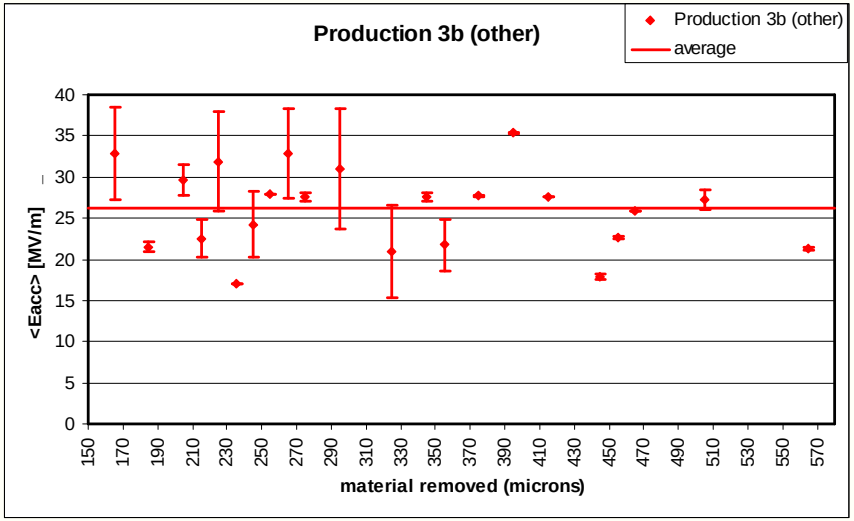
http://tdserver1.fnal.gov/project/ILC/S0/S0_coord.html
Selection showing cavities designated for S0
First cavities have been identified for global swaps

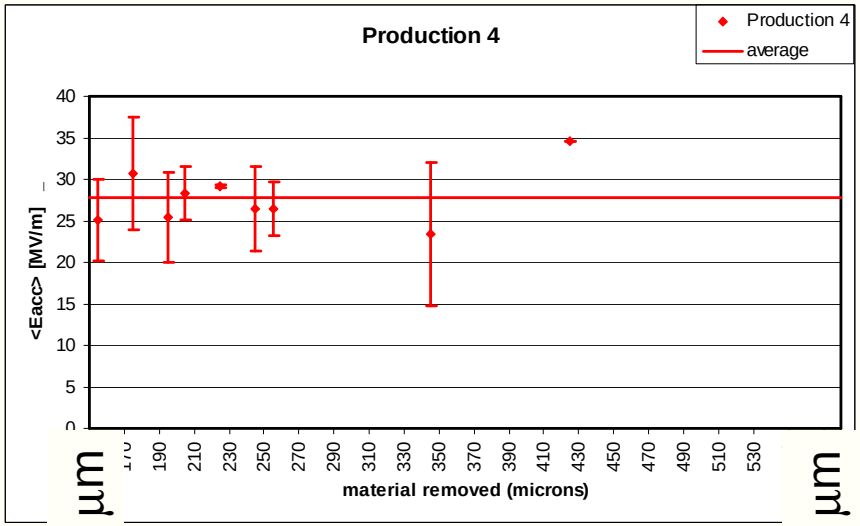
Material Removal Study (1)

- Study quench gradient development as a function of material removal
- Dataset: DESY/TTF vertical test data from cavity Production Batches 3 (split) and 4
  - Production 3a: BCP
  - Production 3b: other
  - Production 4: mostly EP
  - 9-cell cavities only
  - Removed material thickness is estimated from processes
- Underlying assumption: all cavities are equivalent, and only variable of interest is material removal
  - A data point is one test-process-test cycle
  - One cavity can show up in multiple data points

Material Removal Study (2)





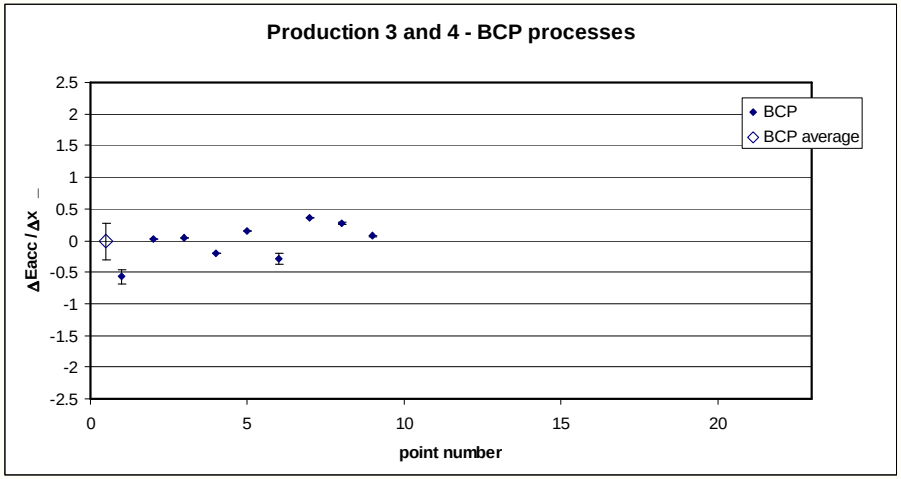


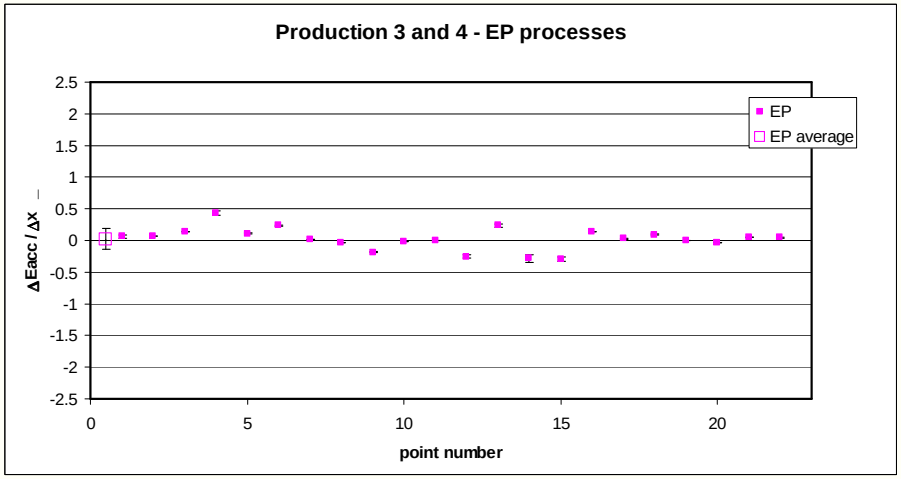
150 µm

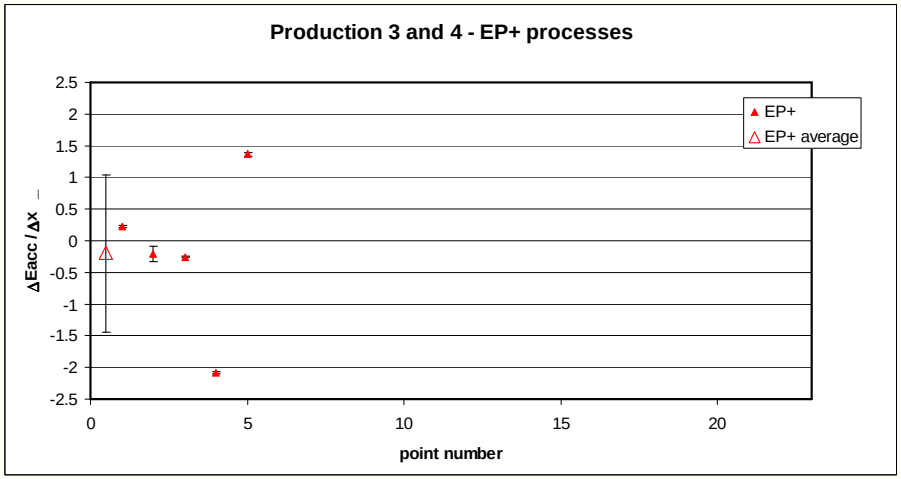
570 µm

- **average quench gradient [MV/m] is shown for a given amount of removed material [µm]**
- **solid line is average quench gradient**
- **open circles in top plot are average quench gradient in the bin, when including only ACCEL cavities**
- **No dependence of gradient on material removal is seen**

Material Removal Study (3)







- Data separated by treatment types
- Plots show change in quench gradient per amount of material removed: $\Delta Eacc / \Delta x$
- Point number is a meaningless counter
- average and standard deviation of all points are shown by the large open point
- Data are consistent with no change of gradient with material removal, i.e., $\Delta Eacc / \Delta x = 0$

Material Removal Study (4)

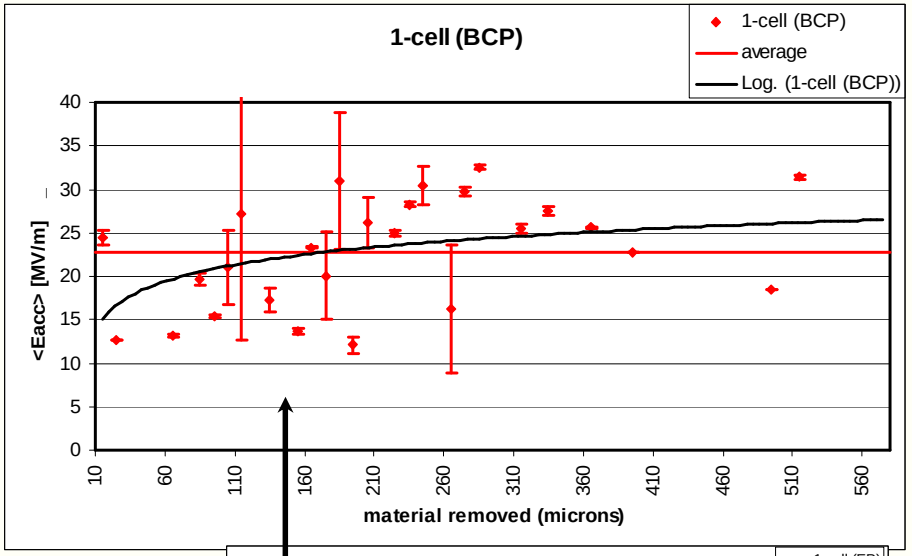
- The quench gradient change does not depend on the amount of material removal, independent of processing type
- The quench gradient does not improve or degrade, on average, with additional processing*
- Possibilities I can think of:
  - Maybe too much material is already removed to make a difference? We start with a minimum of 150 μm
    - Would imply the thesis "only variable of interest is material removal" is wrong
  - Well performing cavities may not be reprocessed. Cavities are weighted in this analysis by the number of processes, which may favor bad ones
    - Would imply the thesis "all cavities are equivalent" is wrong
  - This is all the data, warts and all. I did not remove any cavities because I knew they were "bad"
    - Would imply the thesis "all cavities are equivalent" is wrong, which in some cases we known to be true

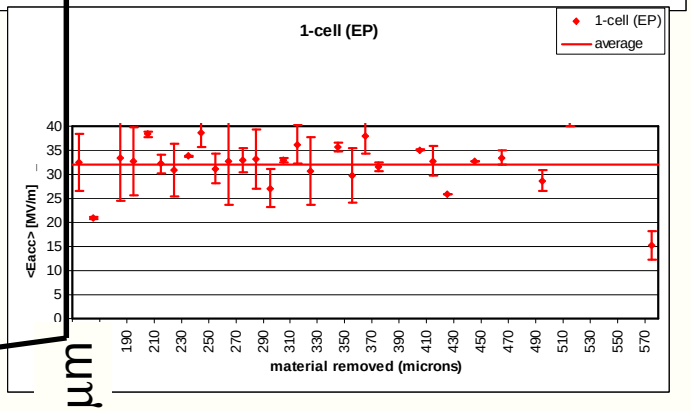
* D. Reschke shows an improvement from first to final gradient in a subset of cavities – not necessarily inconsistent, due to different analysis method, but must be understood

Material Removal Study (5)

- What about single-cells? More data from tests with less material removal
- Only DESY/BCP process data available with statistics for material removal less than ~150 μm
  - Lots of old exp'tl cavities included
  - Maybe a dependence below ~200 μm?
  - DESY/EP process data included for completeness
- KEK (Ichiro) data show no dependence

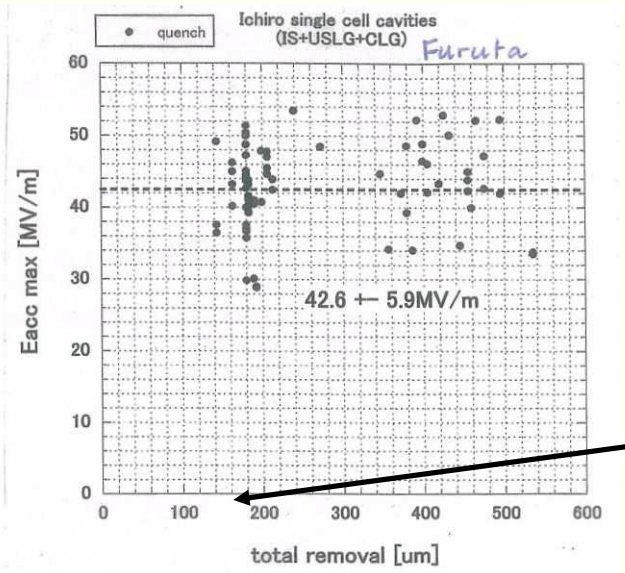
DESY single-cell data





150 μm

KEK (Ichiro) single-cell data



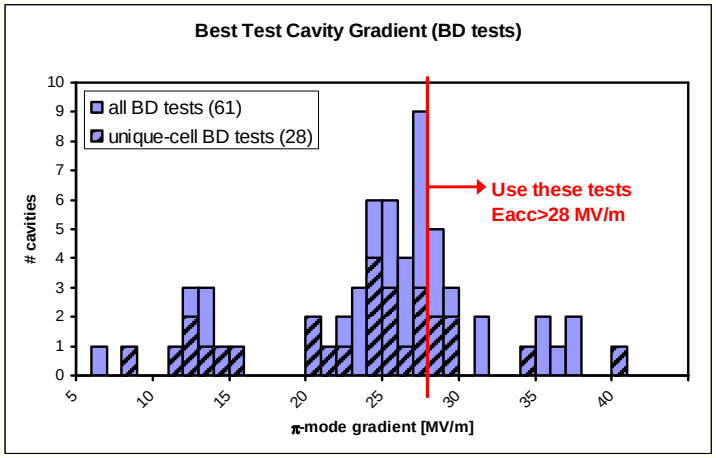
F. Furuta, priv. comm.

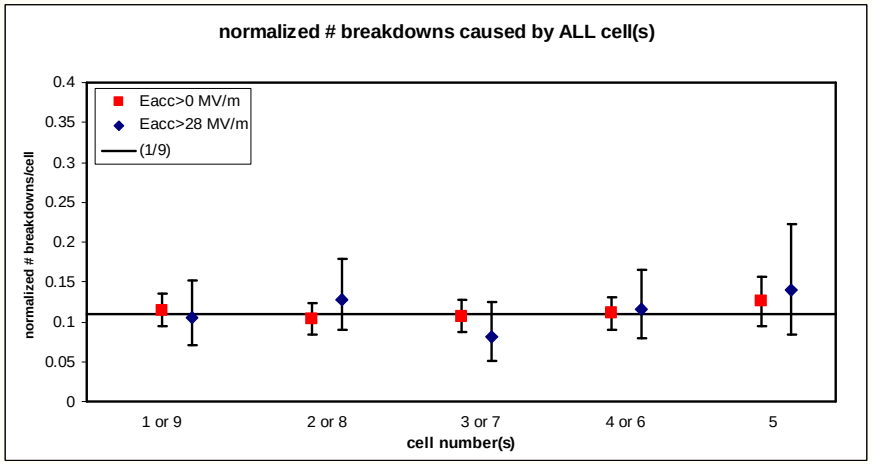
Mode Measurement Study (1)

- Analyzed DESY/TTF/Vertical (CW) passband mode data to determine whether any cell pair (or cell 5) showed a statistically higher probability to cause cavity breakdown than others
  - Could show systematic contamination during assembly
- Data sample: 105 “Best” tests of all 117 cavities from Production Batches 1, 2, 3, and 4; data extracted July 24, 2006
  - http://tesla-new.desy.de/content/cavitydatabank/index_eng.html
- Mode measurement method:
  - For each mode, the gradient measured by the pick-up probe is that seen by the end-cell
  - Gradient seen by pairs of cells (or cell 5) determined by scaling measured gradient in the end-cell by the relevant E_{cell} factor
  - Maximum gradient seen by pairs of cells (or cell 5), determined in this manner, in any mode measurement, is recorded in the database.
  - Assume the lowest maximum gradient in a pair of cells (or cell 5) indicates that the cause of the limitation is physically located in that pair of cells (or cell 5)
  - Completeness of this analysis depends on the assumption of field flatness in all cells
  - In many cases, the lowest maximum gradient was evident in more than one pair of cells (or cell 5).

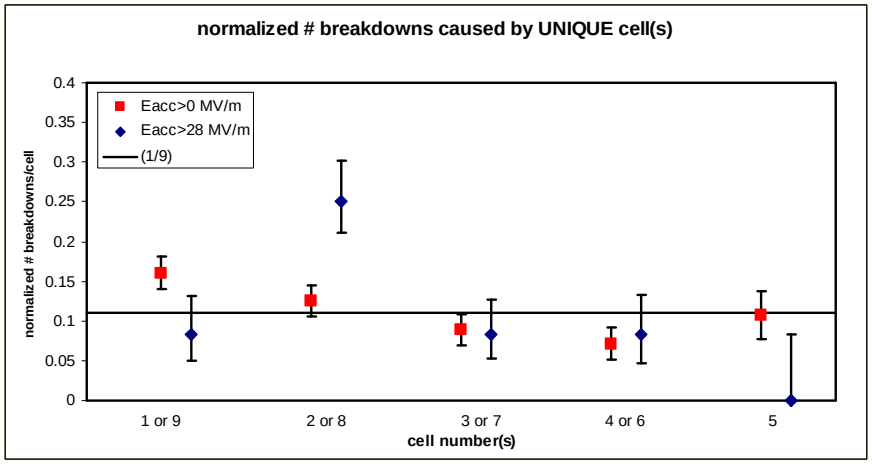
Mode Measurement Study (2)

DESY data





- **Data shown are:**
  - **All tests (red squares)**
  - **Tests with gradient >28 MV/m (blue diamonds)**
- **Results**
  - **Very consistent with random breakdown location for the (correlated) datasets**
  - **No evidence of systematic contamination during assembly**



S0 Summary and Plans

- First S0 results
  - Tight-loop
    - good candidates for improved cavity surface treatment
      - Fresh acid at KEK (single cells)
      - Ultrasound degrease at JLab (9 cells)
    - New data from qualified vendor Accel with gradient up to 40 MV/m (low statistics)
      - Accel cavities at JLab perform comparably to Accel DESY production 4 cavities
    - First cavities have been identified for global swaps
  - Production-like
    - Qualification of new vendors with gradients around 20 MV/m (low statistics)
      - KEK data with four MHI cavities
      - JLab(Fermilab) data with four AES cavities
  - Global data analysis
    - Thank you to my colleagues who generously shared their data and expertise - special thanks to KEK and DESY for the hospitality
    - An excellent testbed for international collaboration

- Facilities are coming online
  - New Fermilab vertical test stand now operational

- High priority technical items requiring manpower – for discussion
  - Improve data availability and communication, for improved worldwide test comparability
  - Thermometry and other diagnostics
  - All within the bounds of limited resources