Global Cavity Data Analysis for S0 with Application to a Global Database

C.M. Ginsburg (Fermilab)

This work was done in collaboration with and on behalf of the ILC GDE S0/S1 Task Force

Tesla Technology Collaboration Meeting
DESY Hamburg
January 16, 2008

Contributors and Content

- **S0 Task Force**
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- **DESY, JLab, KEK, (Cornell)**
  - 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

- **I report on my ~one-year experience in S0, with emphasis on which data have been of interest, and how I accessed those data**
  - the opinions expressed and the errors introduced are my own

S0 Task Force Goal & Plan

- **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**
      - **Basic assumption: cavity preparation is the critical step**
    - **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**

I will show several examples

Focus today is on data sharing

R&D on single cells

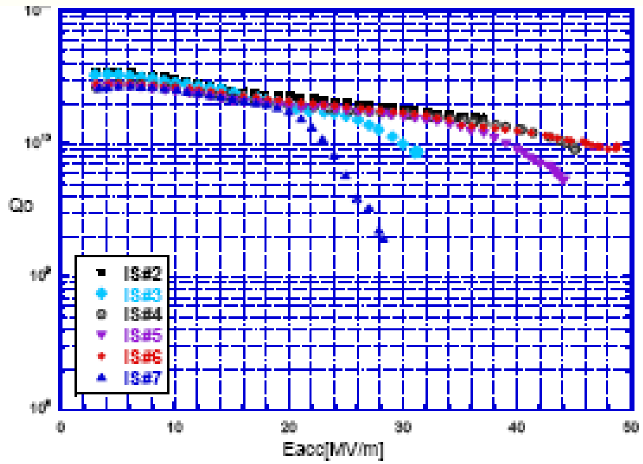
S0.1: Tight loop to improve “final preparation” yield

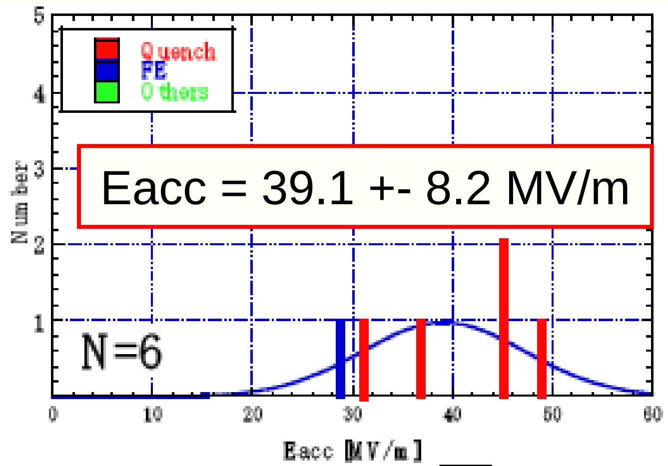
Example 1: Comparison of final preparation methods

KEK (high-gradient group) data

KEK (high-grad group) process R&D

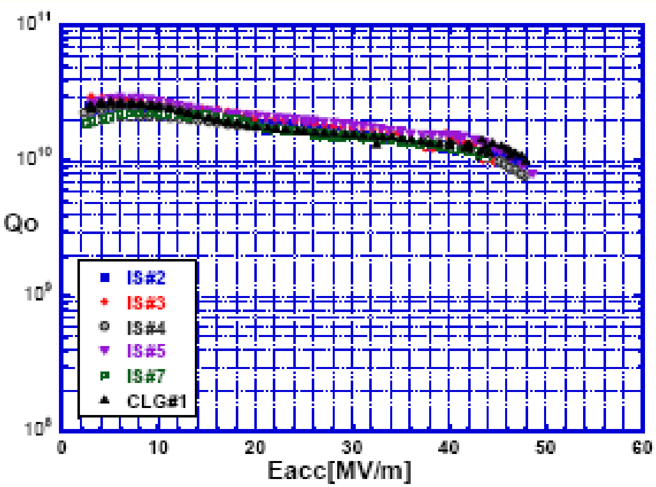
K. Saito, TTC Meeting at Fermilab, April 2007

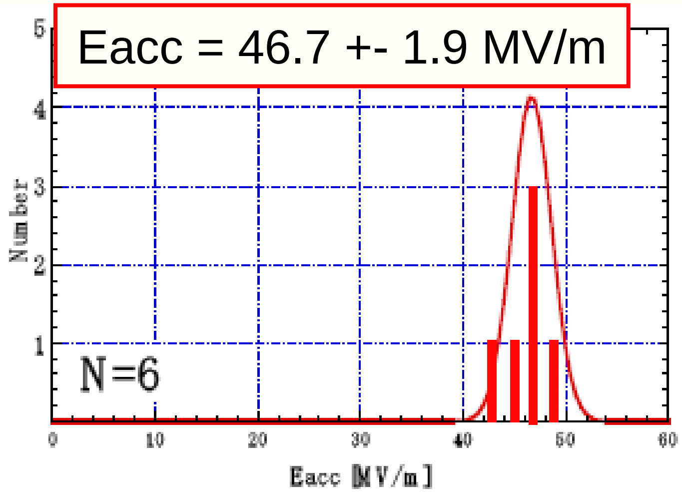




Eacc = 39.1 +- 8.2 MV/m

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 EP**
- **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

K. Saito, TTC Meeting at Fermilab, April 2007
and K. Saito, private communication
and F. Furuta, private communication

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)**

I can reproduce these histograms (p.5) and did make this table from F. Furuta spreadsheet and private communication

Established Cavity Vendors

S0.1: Tight loop to improve "final preparation" yield

Example 2: Tight-loop results from already qualified vendors

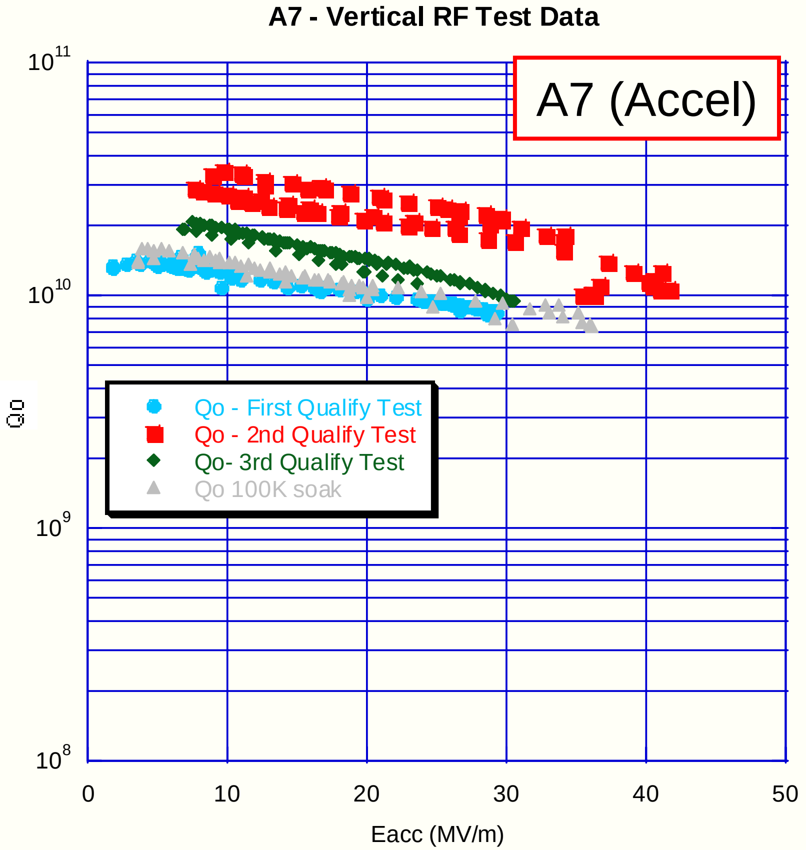
- **Only testing the processing**

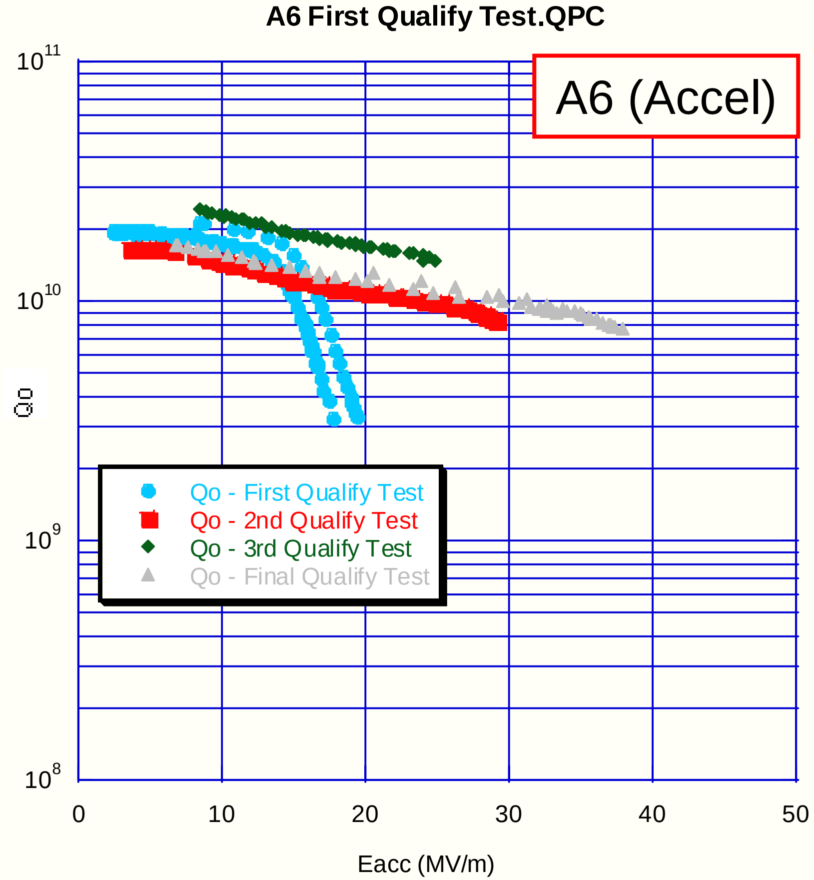
DESY and JLab data

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





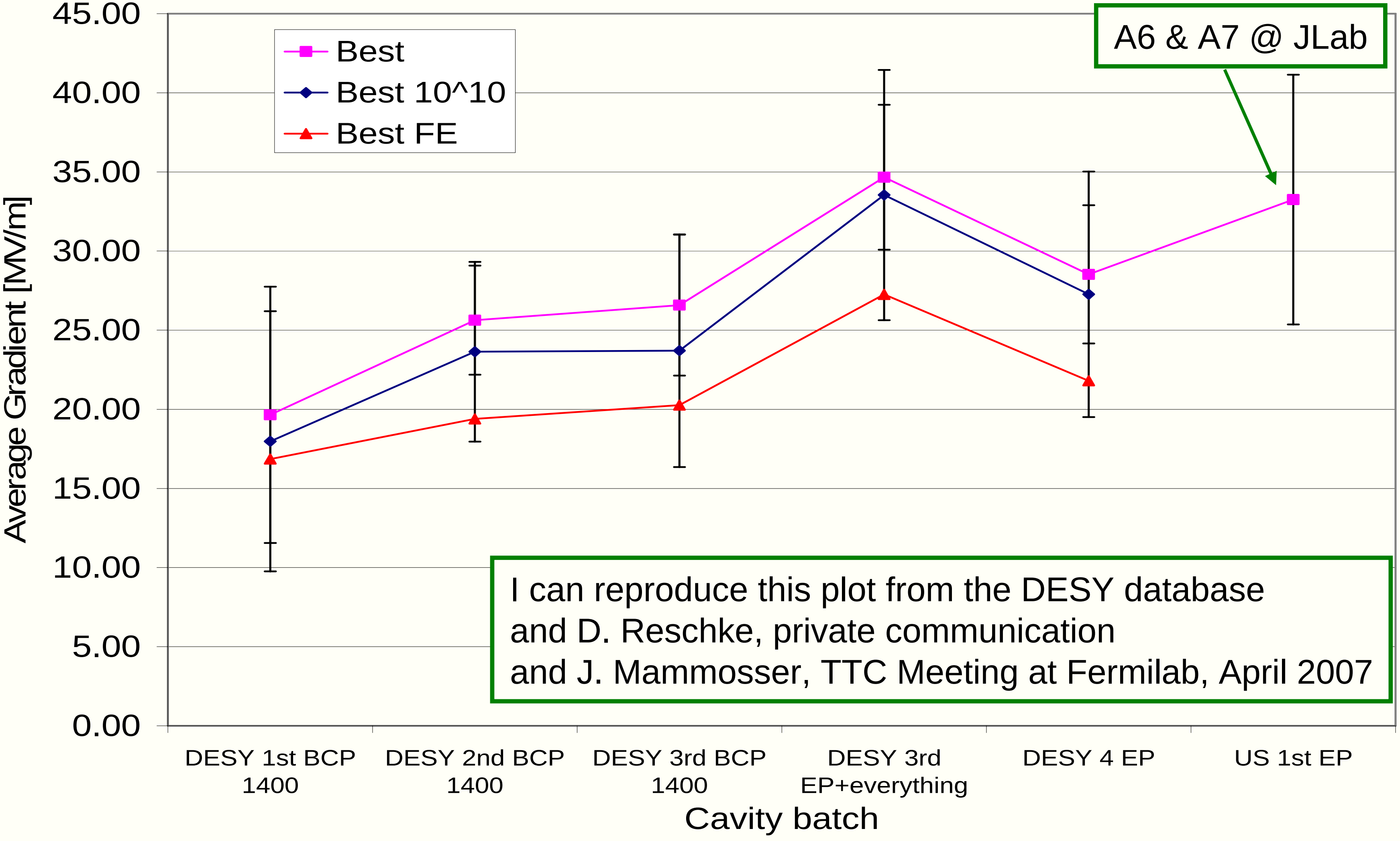
JLab: Process reproducibility

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**

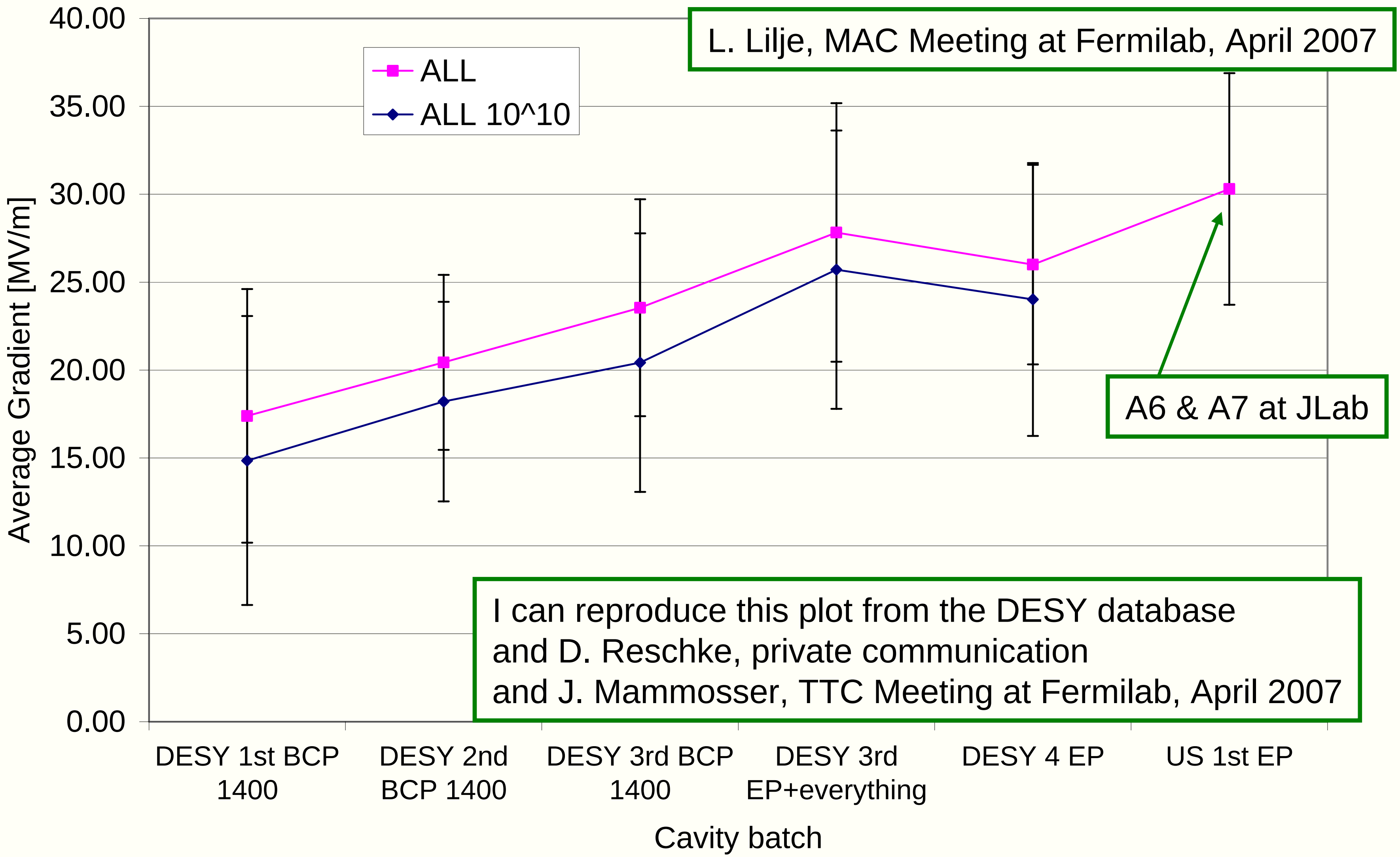
Summary of 'Already-Qualified' Vendors DESY & JLab Best Test Results

L. Lilje, MAC Meeting at Fermilab, April 2007



I can reproduce this plot from the DESY database
and D. Reschke, private communication
and J. Mammosser, TTC Meeting at Fermilab, April 2007

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



S0 Production-like Status

S0.2: Production-like activities to determine overall yield for cavity materials, fabrication and full cavity processing

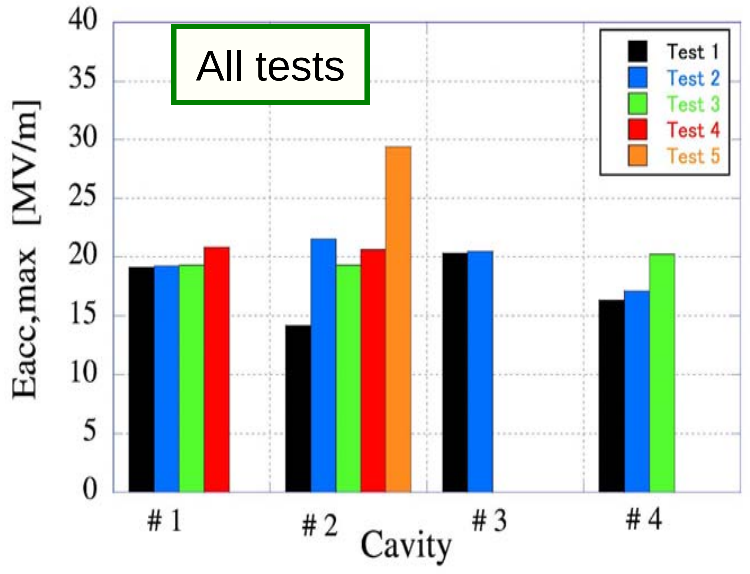
Qualification of new cavity vendors

KEK (baseline group) and JLab and Fermilab data

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 (Mitsubishi Heavy Industries)
- 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



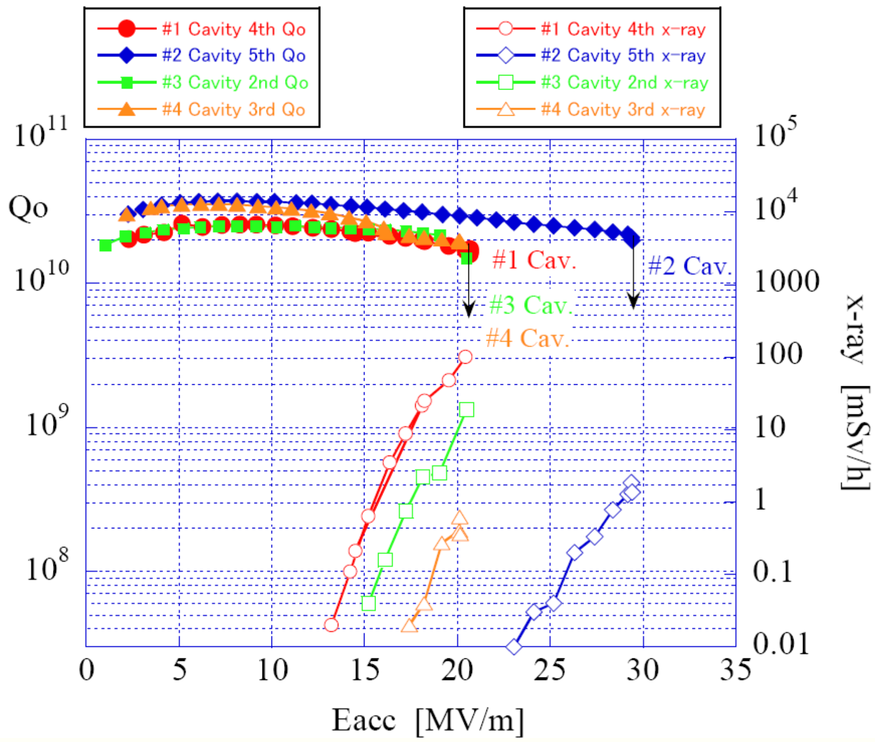
E. Kako, priv. comm.

I could reproduce this histogram from my study of KEK baseline-gradient group logbooks

KEK Tesla-style cavities

E. Kako, TTC Meeting at Fermilab, April 2007

Final Performance in Vertical Tests

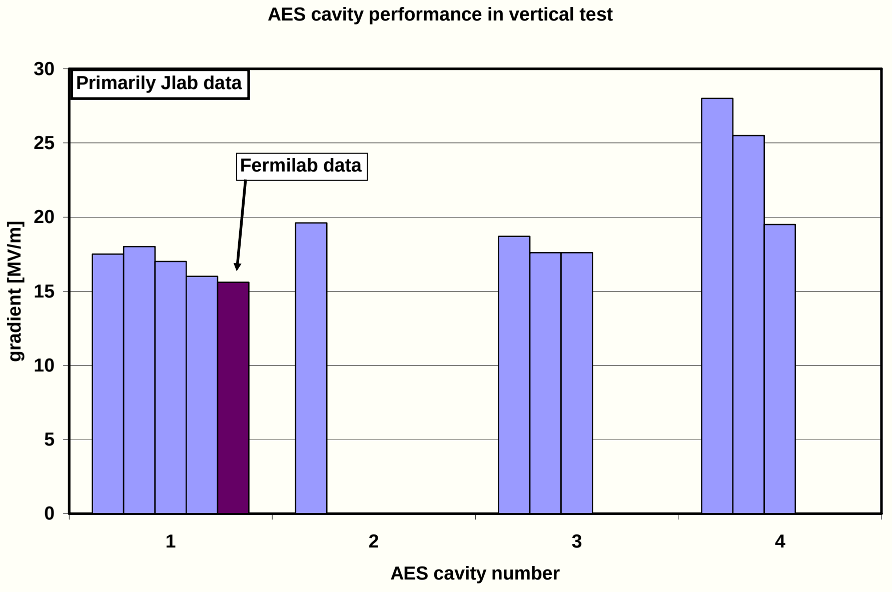


Eacc,max

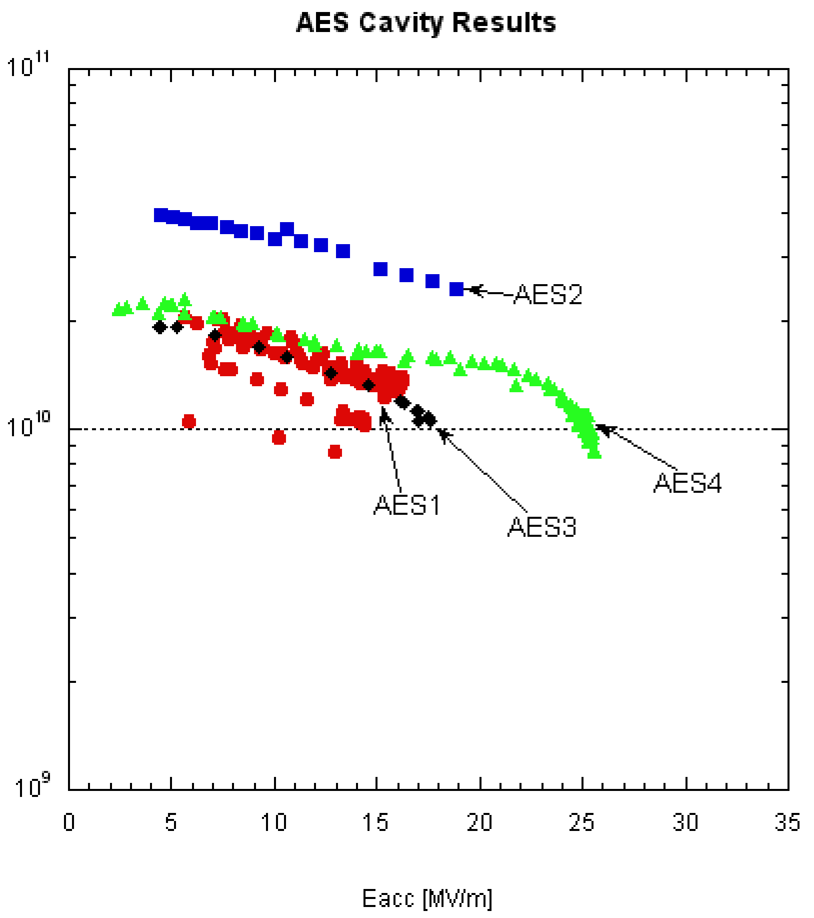
#1 20.8 MV/m
#2 29.4 MV/m
#3 20.5 MV/m
#4 20.2 MV/m

high Qo > 10^{10}

JLab: qualification of new vendor



R. Geng, AES Meeting at Jlab, Aug 2007



- New cavity vendor: AES (Advanced Energy Systems, Inc.)
- 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

Closely coordinated global execution

S0 cavity tracking

The Cavity Report

Cavity_Listing_2007-12-03.xls

Lab	Cavity Name	Current Location	Current Use	Designated Use
FNAL	AES001	enroute to KEK		
FNAL	AES002	at Jlab	Under test	
FNAL	AES003	at Jlab	Under test	
FNAL	AES004	at Jlab	Under test	
FNAL	AC 6	At Jlab	Tested	Dressed, high gradient testing (S1).
FNAL	AC 7	At Jlab	Tested	Dressed, high gradient testing (S1).
FNAL	AC 8	At Jlab	Under test	NML-CM2
FNAL	ACC010	At ACCEL being fabricated.	First tight-loop processing and testing will be at Jlab.	S0 testing
FNAL	ACC011	At ACCEL being fabricated.	First tight-loop processing and testing will be at Jlab.	S0 testing
FNAL	ACC012	At ACCEL being fabricated.	First tight-loop processing and testing will be at Jlab.	S0 testing
FNAL	ACC013	At ACCEL being fabricated.		Production mode processing at Jlab.
FNAL	ACC014	At ACCEL being fabricated.		Production mode processing at Jlab.
FNAL	ACC015	At ACCEL being fabricated.		Production mode processing at Jlab.
FNAL	ACC016	At ACCEL being fabricated.		Production mode processing at Jlab.
FNAL	ACC017	At ACCEL being fabricated.		Production mode processing at Jlab.
FNAL	AES005	At AES being fabricated.	First processing will be at Cornell.	
FNAL	AES006	At AES being fabricated.	First processing will be at Cornell.	
FNAL	AES007	At AES being fabricated.	First processing will be at Cornell.	
FNAL	AES008	At AES being fabricated.	First processing will be at Cornell.	
FNAL	AES009	At AES being fabricated.	First processing at ANL and testing at Fermilab.	
FNAL	AES010	At AES being fabricated.	First processing at ANL and testing at Fermilab.	
KEK	BL-#1 (KEK Tesla Type #1)	At KEK		STF 1.0
KEK	BL-#2 (KEK Tesla Type #2)	At KEK		STF 1.0
KEK	BL-#3 (KEK Tesla Type #3)	At KEK	STF 0.5	STF 1.0
KEK	BL-#4 (KEK Tesla Type #4)	At KEK		STF 1.0
KEK	BL-#5 (KEK Tesla Type #5)	Being fabricated		S0 testing
KEK	BL-#6 (KEK Tesla Type #6)	Being fabricated		S0 testing
KEK	LL-#0 (Ichiro #0)	At KEK		S0 testing
KEK	LL-#2 (Ichiro #2)	At KEK		S0 testing
KEK	LL-#5 (New Ichiro #5)	At Jlab	S0 testing	STF 1.5
PAL	LL-#6 (New Ichiro #6)	At KEK	S0 testing	STF 1.5
DESY	AC115			S0 testing
DESY	AC118			S0 testing
DESY	AC116			S0 testing

P. Pfund, update December 3, 2007

http://tdserver1.fnal.gov/project/ILC/S0/S0_coord.html

Selection showing cavities designated for global swaps; see webpage for complete information

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 TM010 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 cavity vacuum 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 (Fermilab soon), which are almost necessary for mode measurements
- Quench location is time consuming, requiring at least two cooldowns: one to localize quench via mode measurements, and one to attach thermometry
  - Current thermometry system assemblies are too time consuming for every test, and frequently only measure one cell
    - except KEK baseline group (see Y. Yamamoto talk)
- 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
    - KEK baseline group photodiode array maybe more comparable (see Y. Yamamoto talk)
- Only DESY has a publicly available data management system
  - Still not everything desirable is available
  - Rely on experimental groups to provide results

S0 data coordination

Global data analysis:

Example 1: Quench gradient development as a function of material removal

Example 2: From mode measurements,

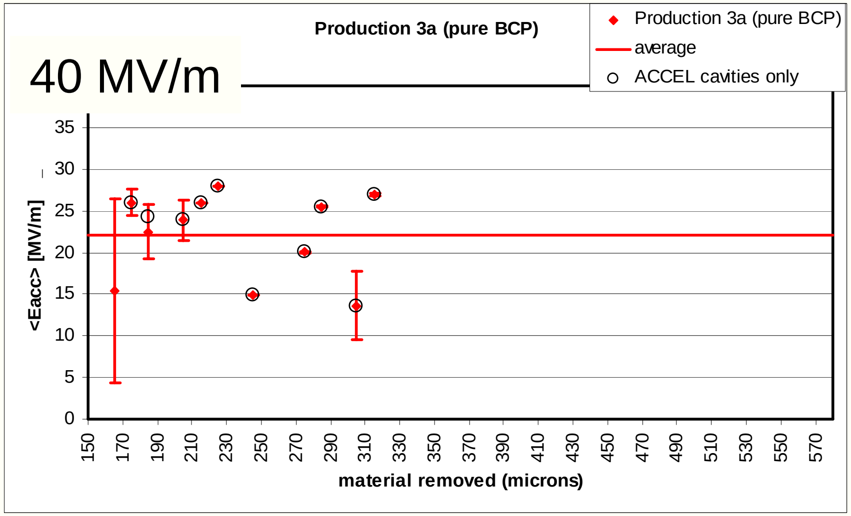
determine whether any cells showed a statistically higher probability to cause cavity breakdown (quench) than others

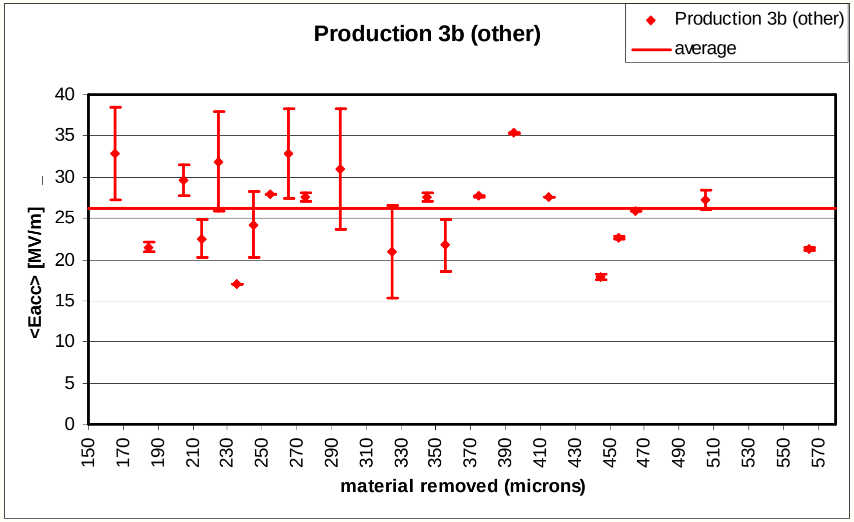
DESY and KEK data

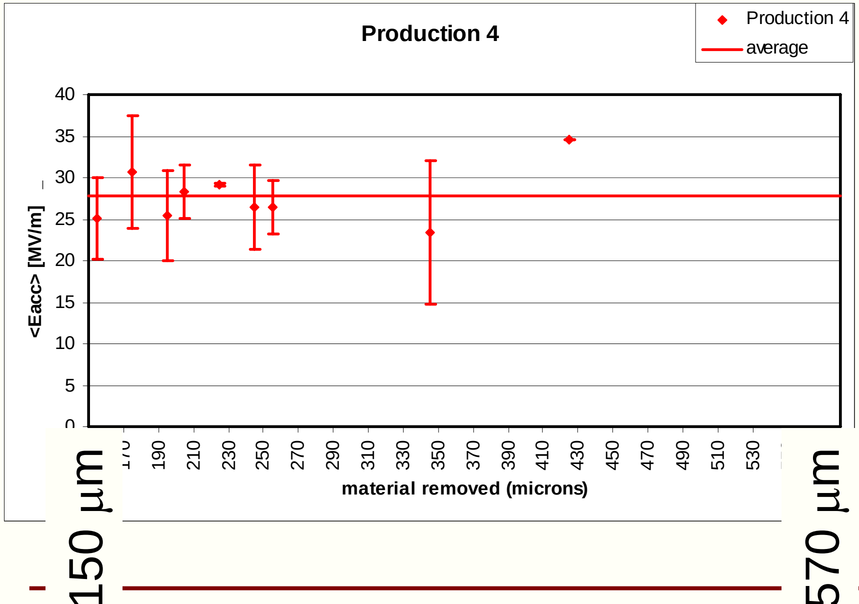
Material Removal Study (1)

- **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)

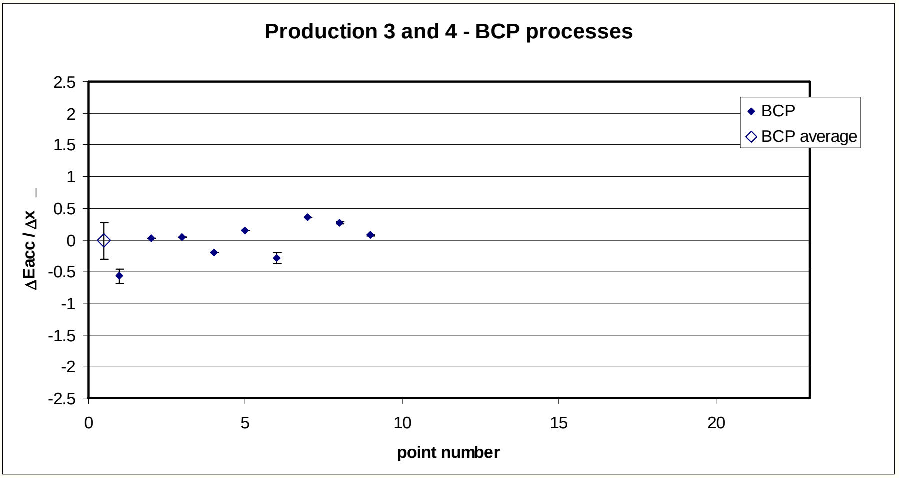


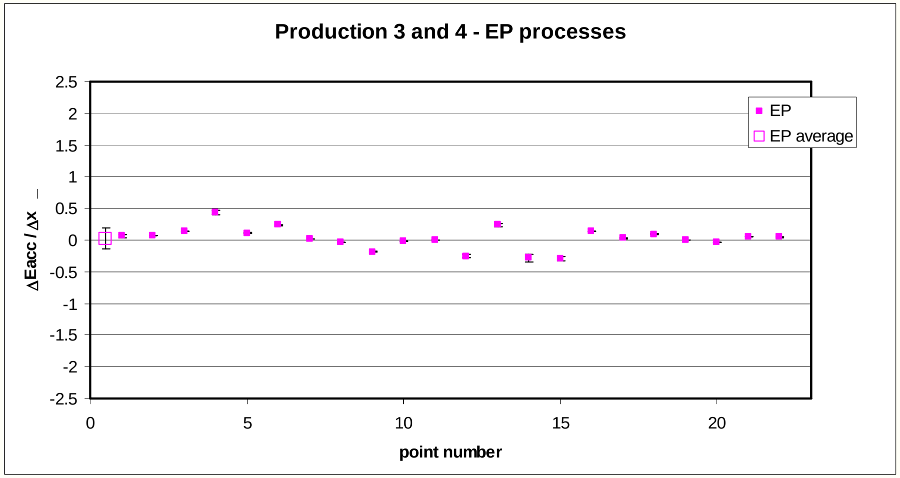


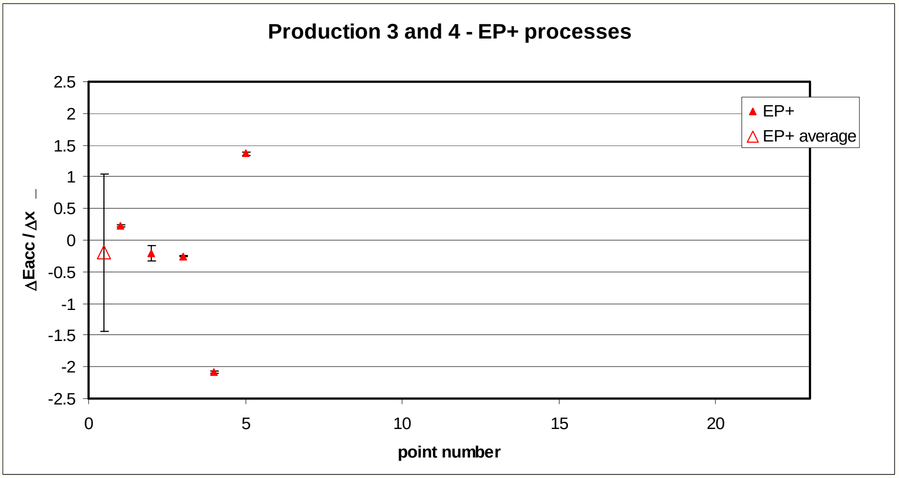


- average quench gradient [MV/m] is shown for a given amount of removed material [µm]
- solid line is average quench gradient
- open circles in top plot are average quench gradient in the bin, when including only ACCEL cavities
- No dependence of gradient on material removal is seen

Material Removal Study (3)







- Data separated by treatment types
- Plots show change in quench gradient per amount of material removed: ΔEacc / Δx
- 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., ΔEacc / Δx = 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

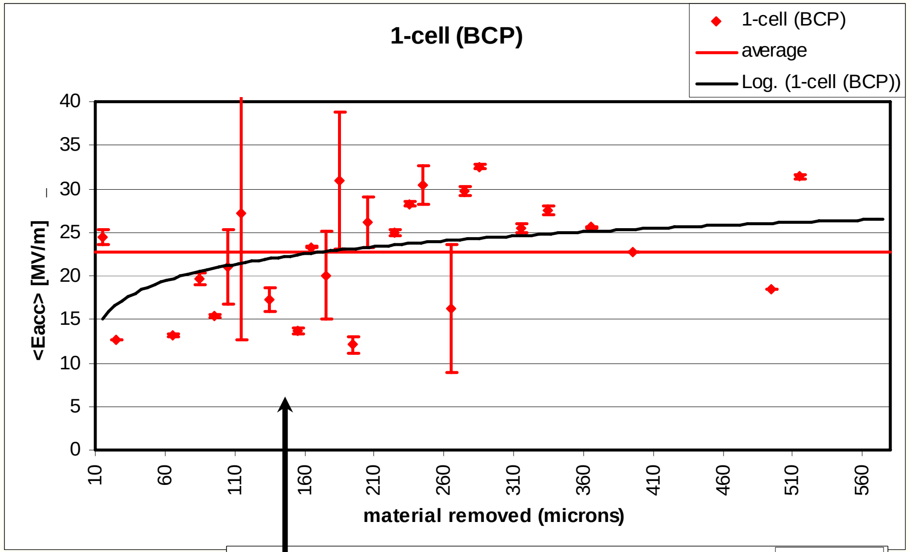
* D. Reschke shows an improvement from first to final gradient in a subset of cavities – not necessarily inconsistent, due to different analysis method, but must be understood.

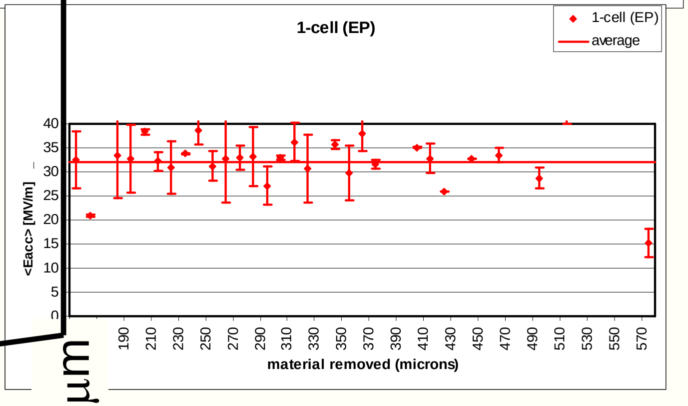
It is not possible to do such an analysis, even with the wonderful DESY database, without expert intervention

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

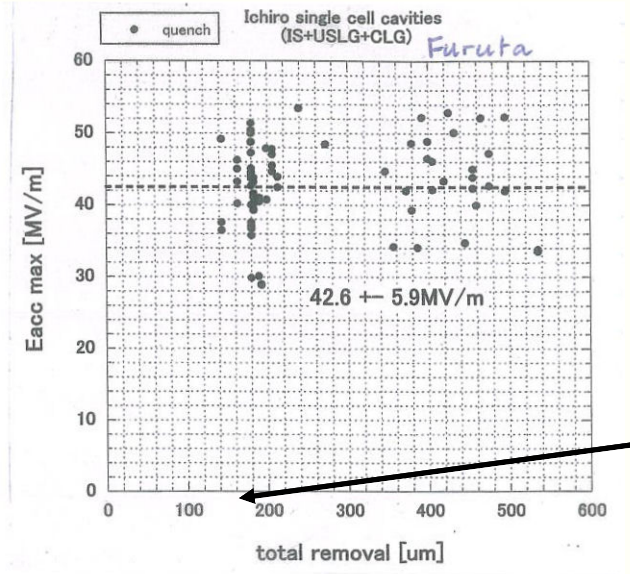
DESY single-cell data





150 μm

KEK (Ichiro) single-cell data



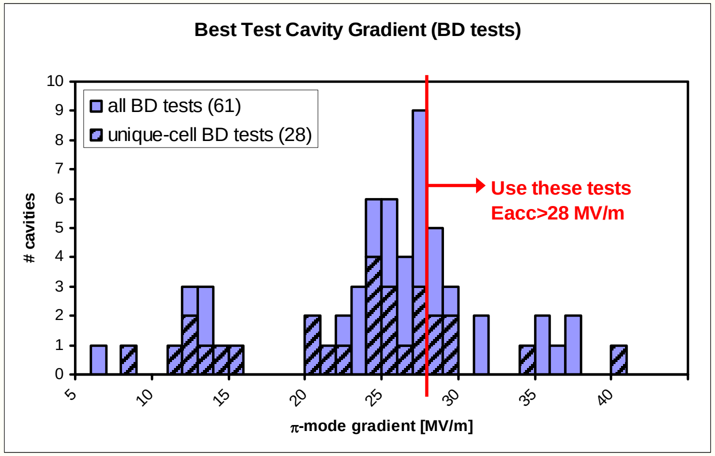
F. Furuta, priv. comm.

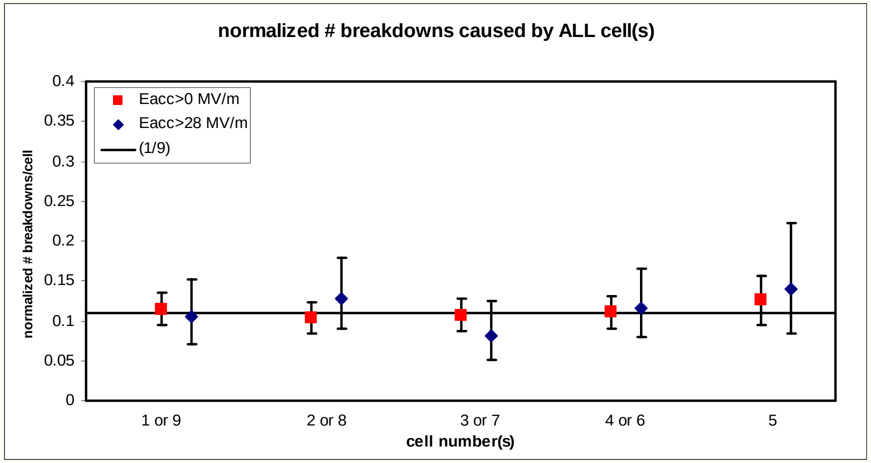
Mode Measurement Study (1)

- 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).

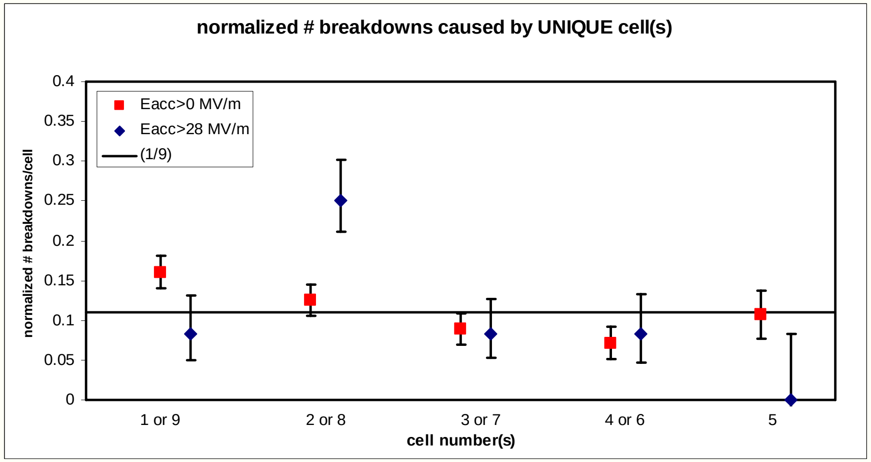
Mode Measurement Study (2)

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**

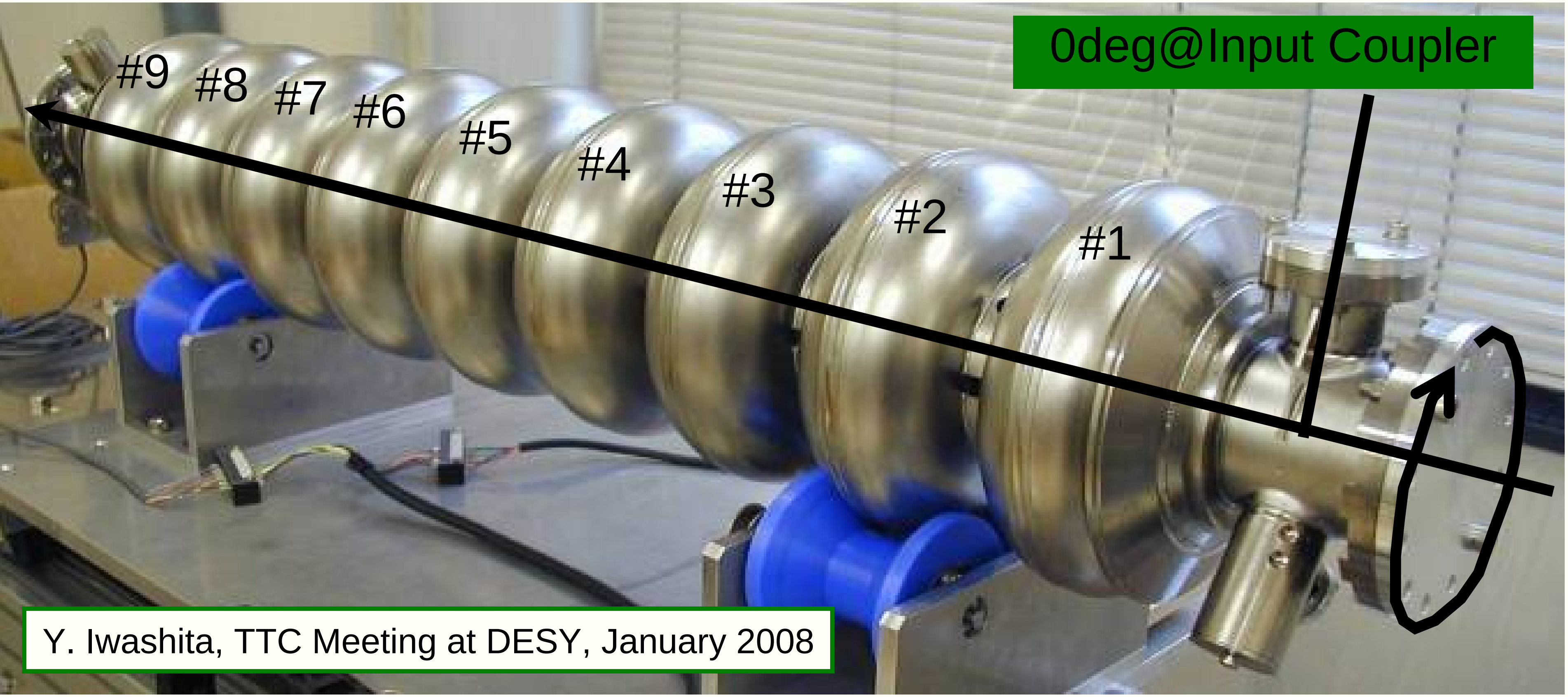


S0 summary

- First S0 results
  - Tight-loop
    - good candidates for improved cavity surface treatment
      - Fresh acid (3 um, closed) at KEK (single cells) was shown
    - 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
    - Several 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
    - Assuming all cavities are equivalent, no dependence of quench gradient on material removal
    - No systematic cell dependence of quenches

- Facilities are coming online
  - New Fermilab vertical test stand now operational, KEK STF in Feb.2008

Global Data Coordinate System



- Let’s choose a common coordinate system
- Most of the ILC baseline-shape cavity data have this one
- We have to overcome this inconvenience

Global data analysis issues

- **High priority technical items requiring manpower – for discussion**
  - **Establish a common coordinate system**
  - **Improve data availability and communication, for improved worldwide test comparability (this Working Group)**
    - **As in any collaboration, system experts will always be needed for details**
  - **Thermometry and other diagnostics (Working Group 2)**
    - **How to compare the results?**
  - **How to include the global coordination aspects, e.g., cavity location and status?**
  - **All within the bounds of limited resources**