Update on S0, S1

for ILC R&D

H. Padamsee, Cornell

For the S0/S1 Task Force

S0/S1 Task Force

- Hitoshi Hayano (KEK)
- Toshiyasu Higo (KEK)
- John Mammosser (JLab)
- Hasan Padamsee (Cornell)
- Marc Ross (FNAL)
- Kenji Saito (KEK)
- Lutz Lilje (DESY) Chair

Outline

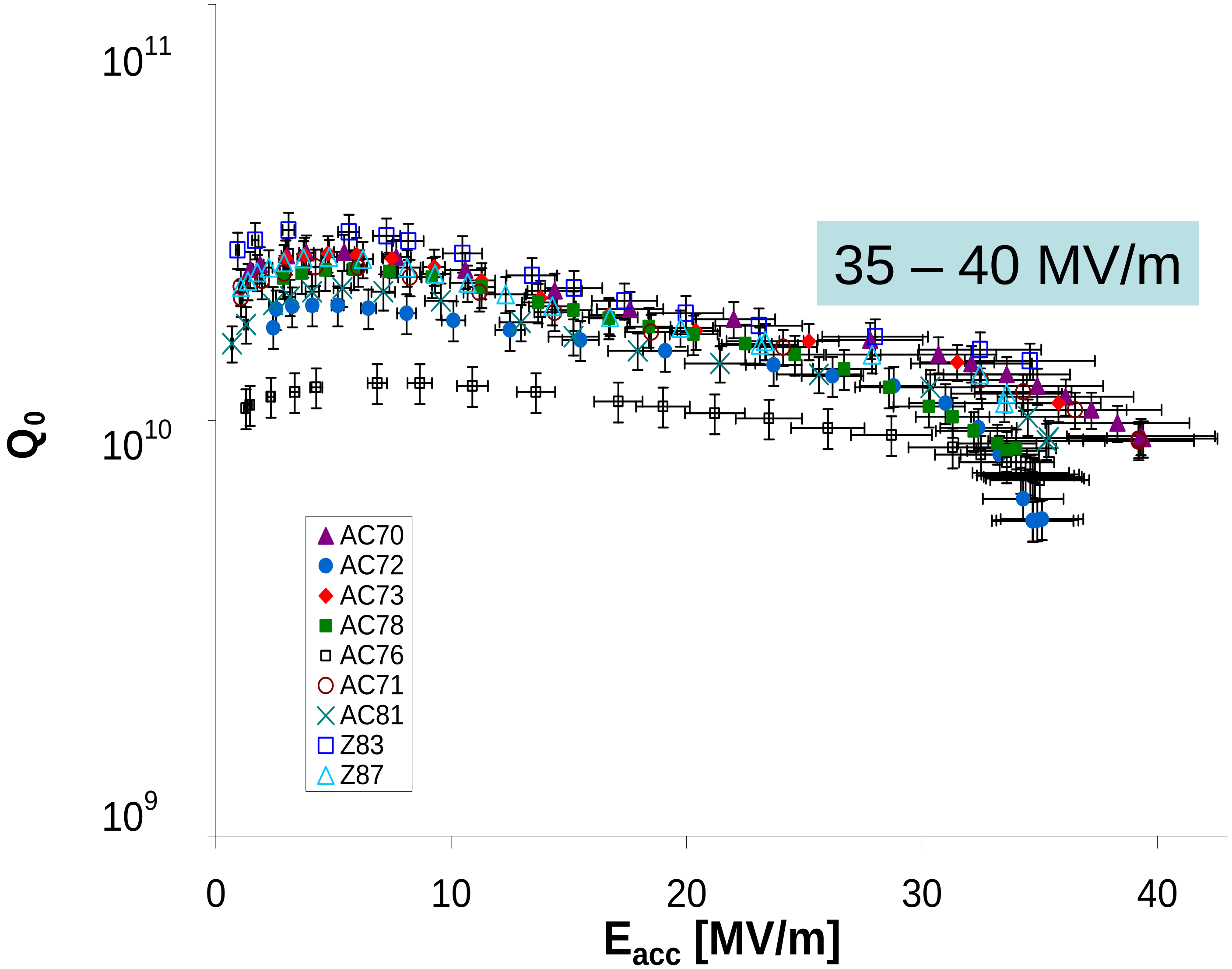
- Brief review of goals for S0
- Plan for S0 (several relevant documents are published)
  - S0.1 Tight-loop
  - S0.2 Production-like effort
  - ACD and Long-range performance R&D
- Status of S0 activities

- Brief review of goals for S1
- Plan for S1 (under final discussion)
- Status of S1 activities
- Resources to carry out S0/S1 ?
- Conclusions

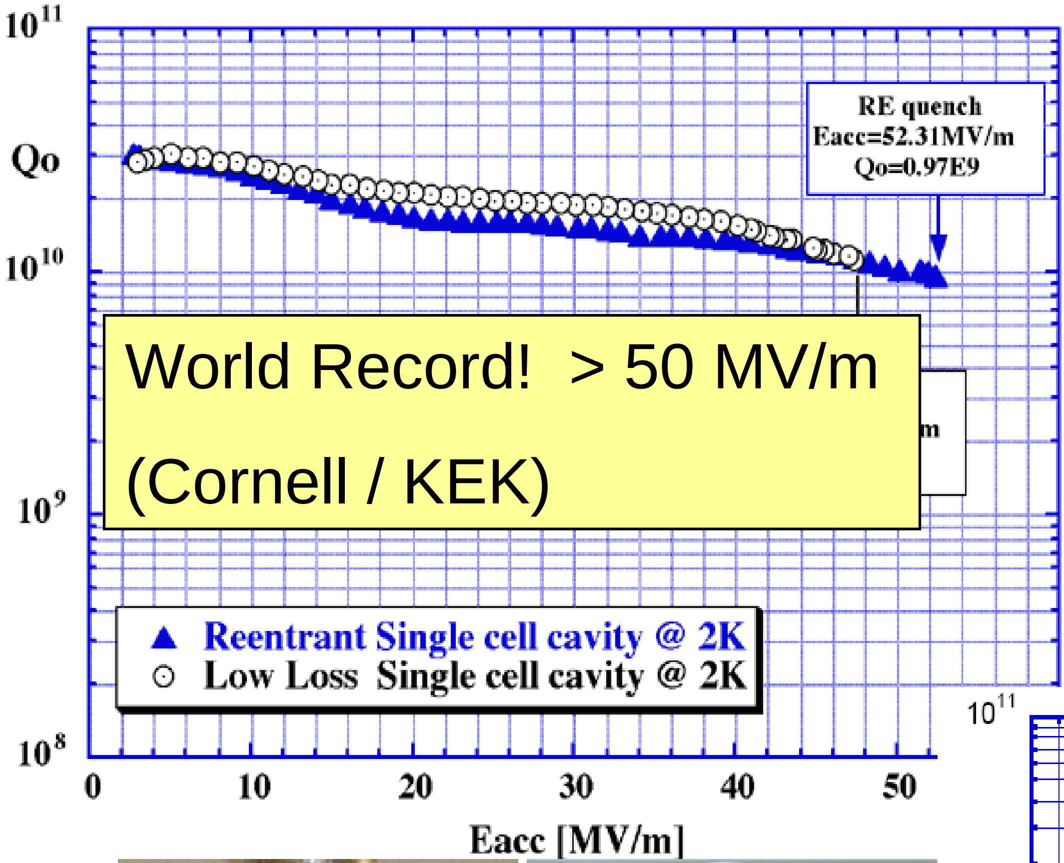
Main Topic of S0 Task Force

- Improve the yield for cavity gradients
- The situation before us :
  - Proof of principle for 35- 40 MV/m exist
  - Single cell results (40 - 50 MV/m) show that baseline preparation procedures are in hand
  - But low yield for 35 MV/m in 9-cells
    - See the following slides from TTF experience

TESLA Nine-Cells: (Proof-of-Principle)
9 Best Cavities (Vertical Test Results @low power)



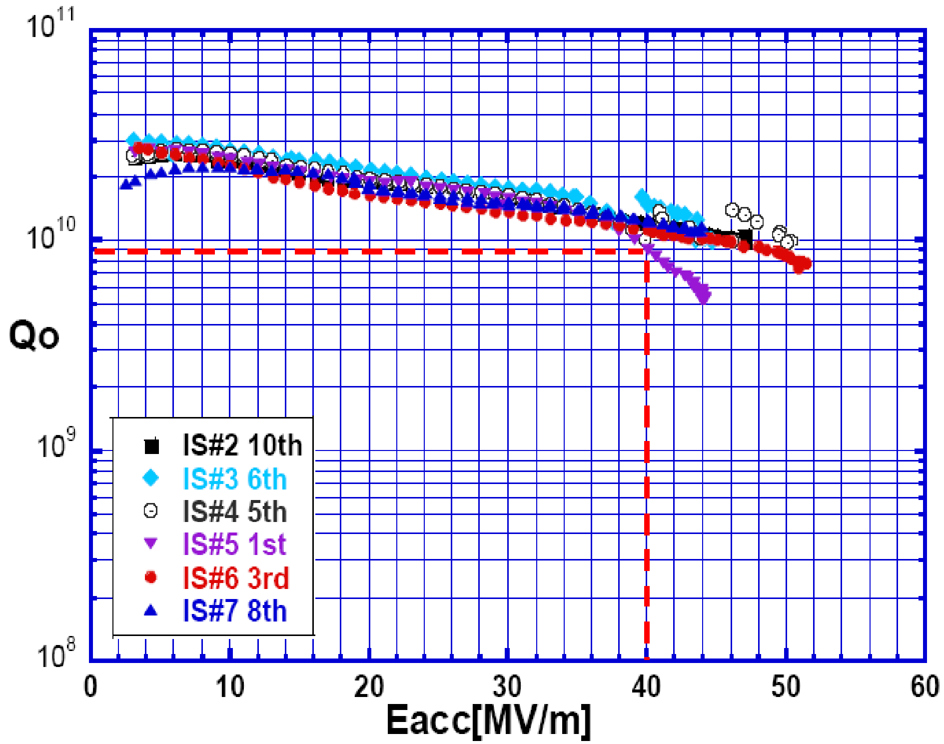
Basic Process Works !



World Record! > 50 MV/m

(Cornell / KEK)

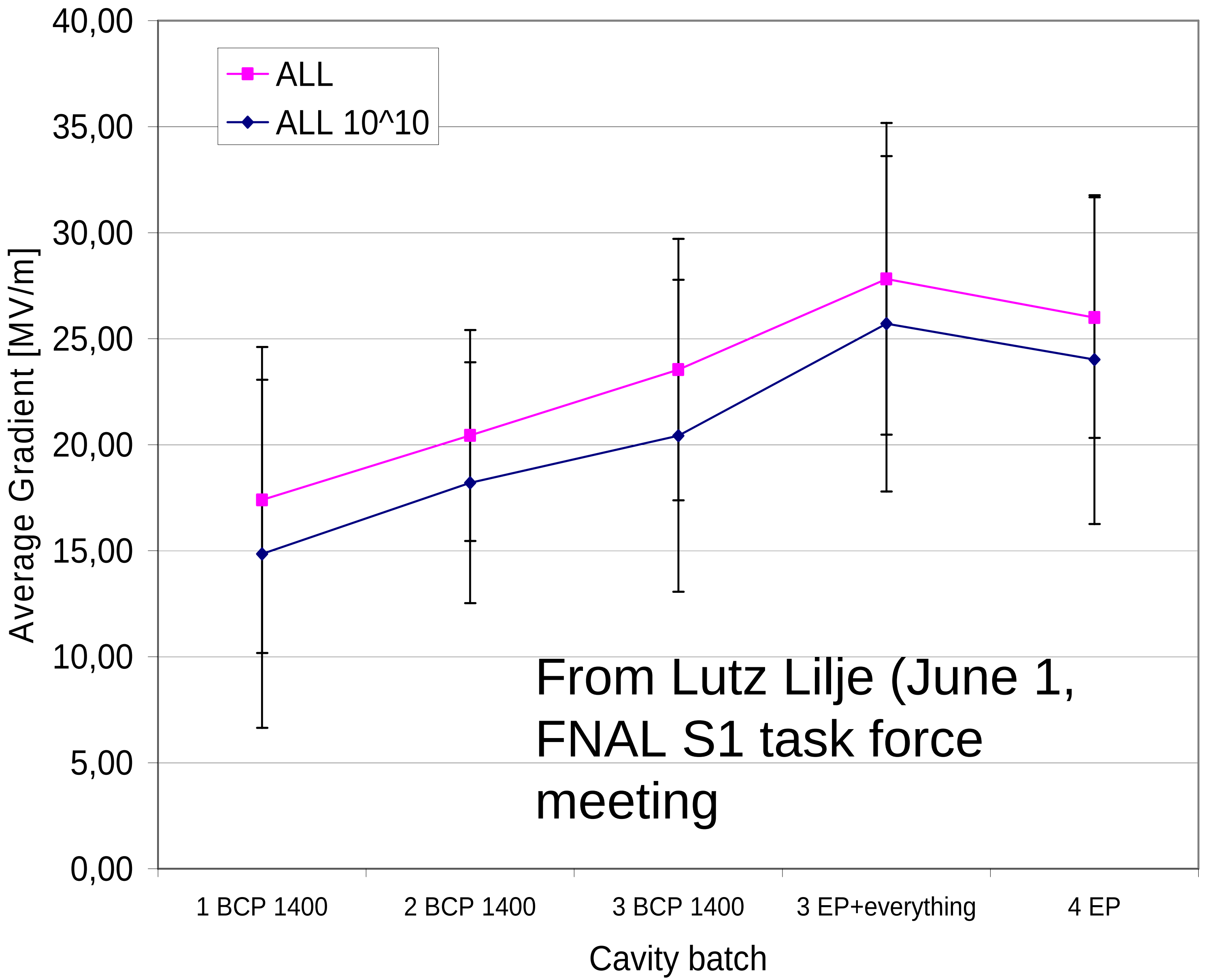
Several cavities achieved more than 45 MV/m at high Q! (KEK)



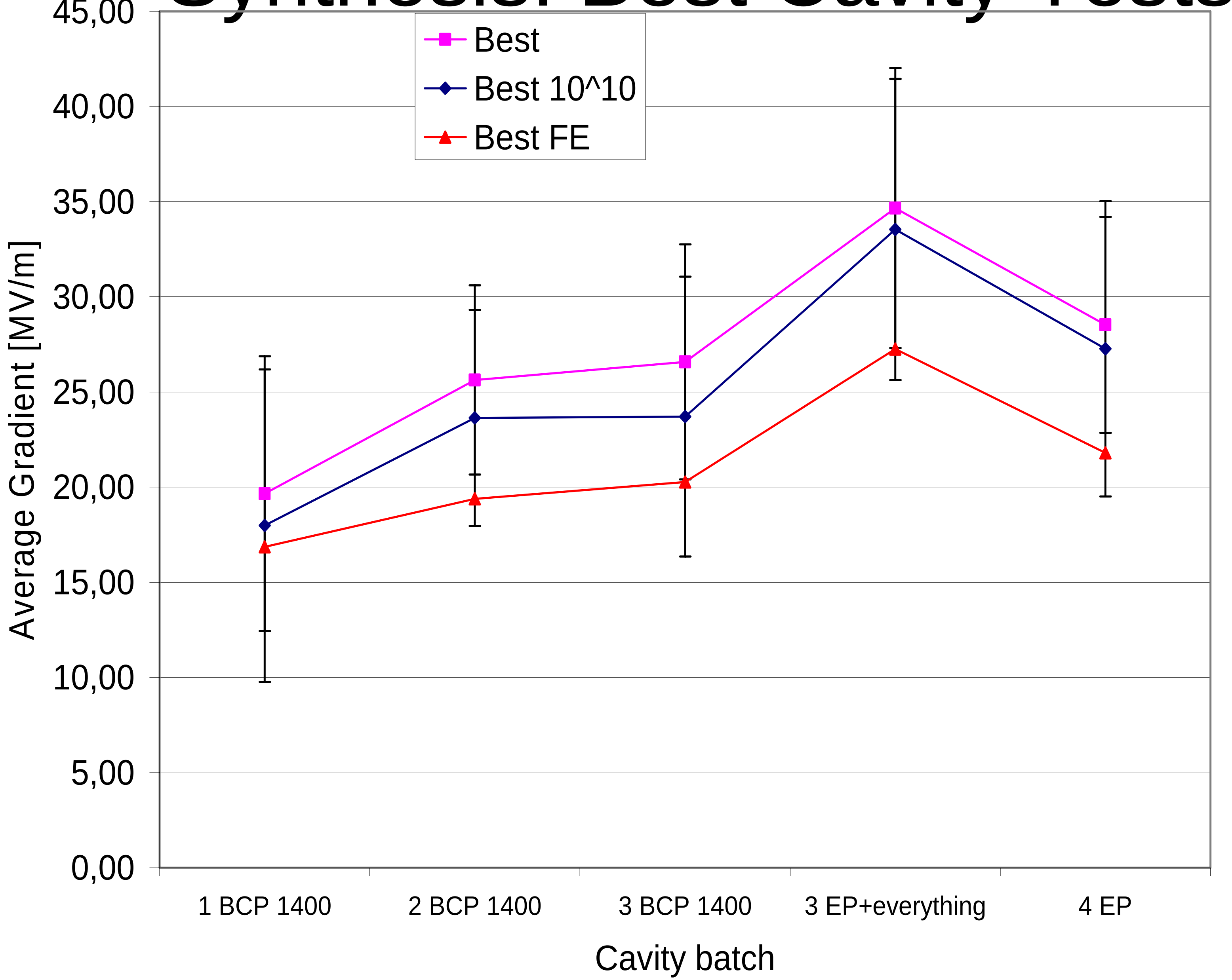
The situation before us : TTF Results

- Over the last 11 years, DESY carried out 450 prep/test cycles on 100 cavities, average 40 cycles per year
- Important: There are many variables in this data set
  - Goals
    - Cavity gradients, cryomodules, Projects: ILC, TTF-I, TTF-II, XFEL
  - Materials suppliers
    - Heraeus, WahChang, Cabot, TokyoDenkai
  - Cavity Vendors
    - Dornier, ACCEL, CERCA, Zanon
  - Processes
    - BCP + 1400 C, BCP + 800 C, EP + 800C, EP + 1400 C, Rinsing parameters, Bake, No-Bake
- Number of tests/cavity to reach gradients
  - For BCP
    - finally a nearly production-like operation was achieved in the 3rd production batch of TTF cavities,
    - => fewer tests per cavity were needed to achieve 25MV/m+
  - For EP
    - First an R&D phase, many tests per cavity
    - First production run ongoing, spread still too large, many cavities not yet treated second time

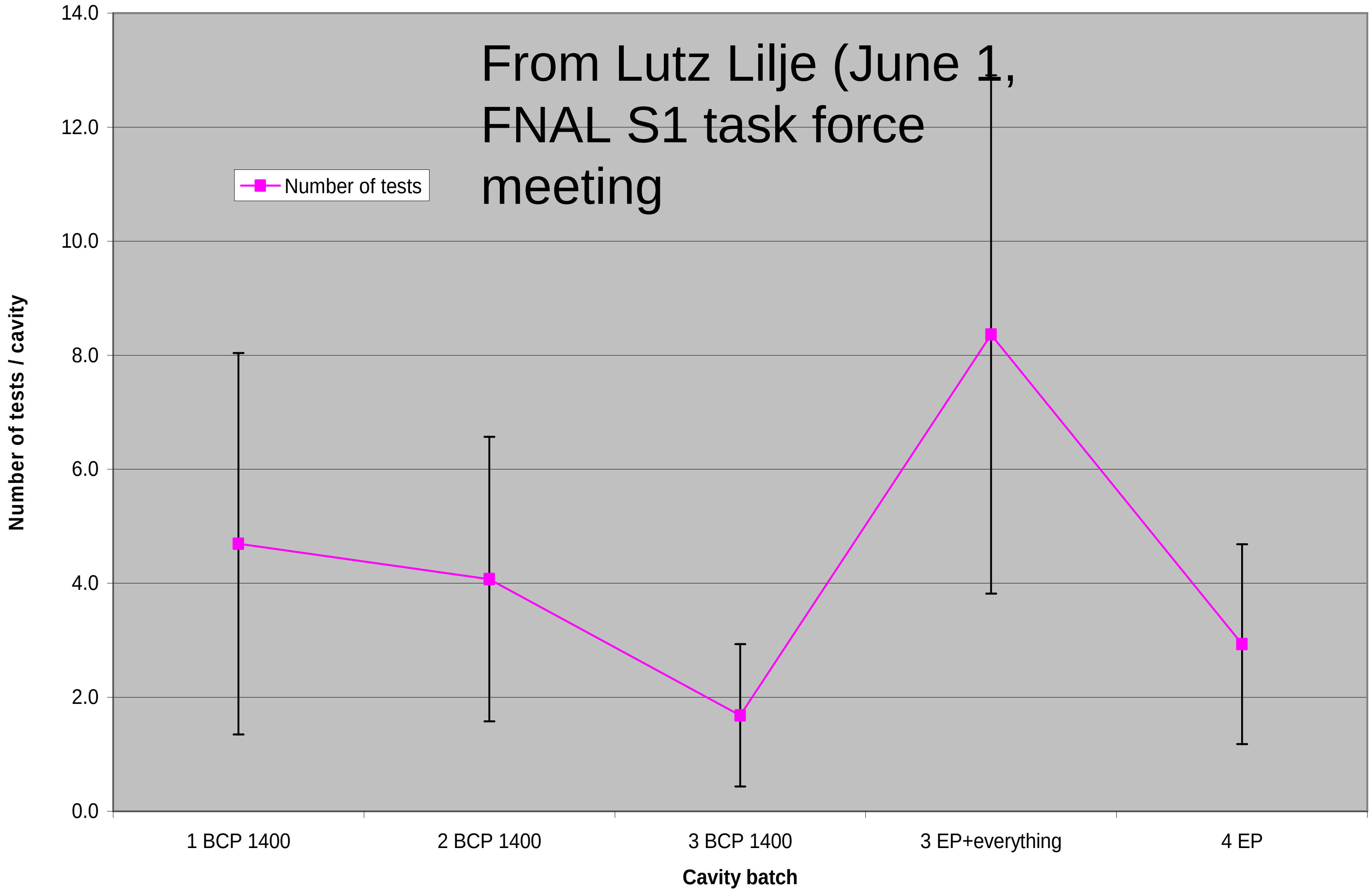
Synthesis: All Cavity Tests



Synthesis: Best Cavity Tests



Average Number of Prep/Test Cycles to Reach Gradient Goal



Where are we now with EP-treated cavities?

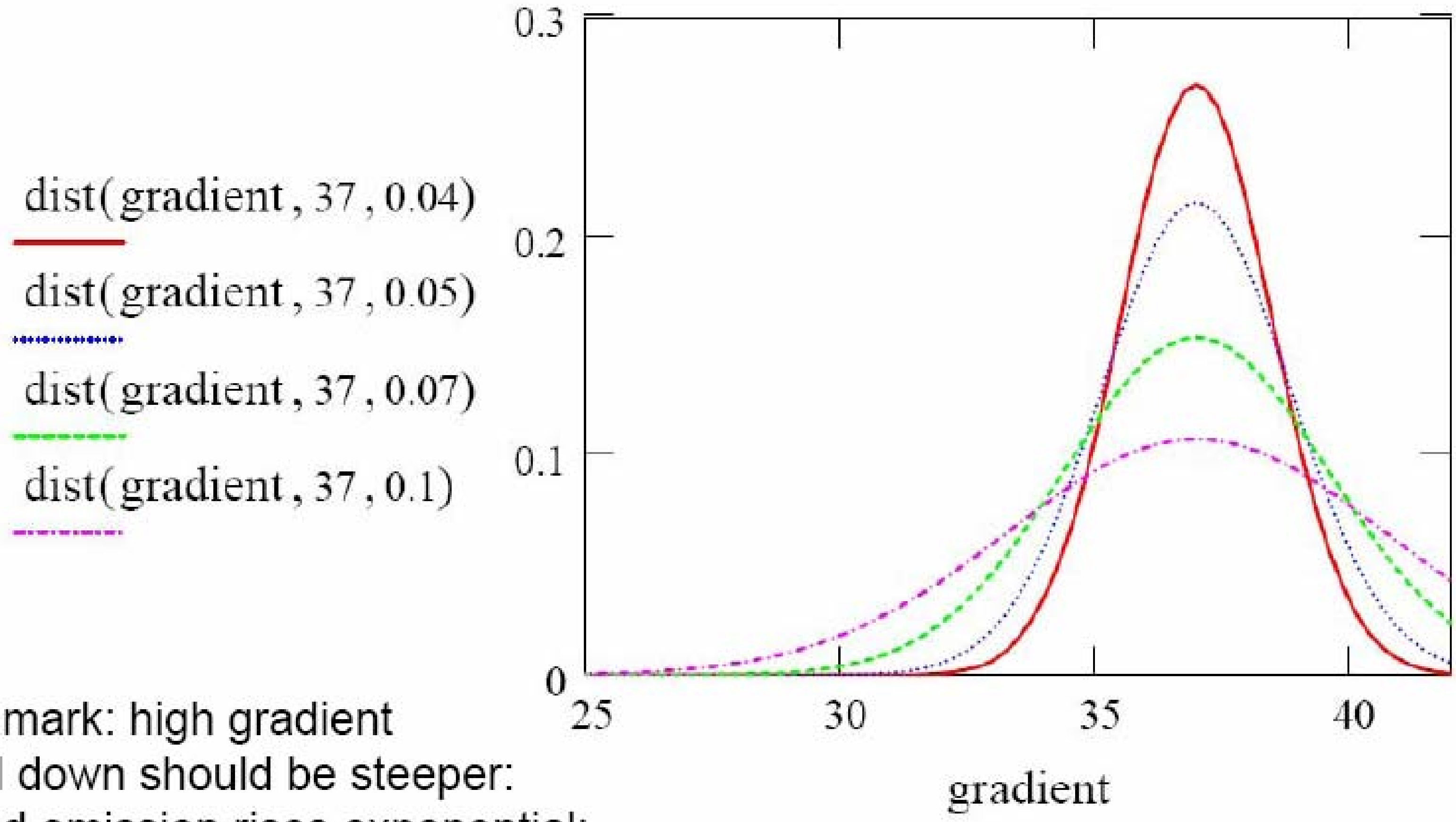
Best tests: above 34 MV/m +- 25%

Last tests: about 27 MV/m +- 25%

Where would be like to be?

Ultimate Goal Drafted at BCD

Assumption: Gaussian distribution of cavity performance
Center is at Eacc = 37 MV7m, width from 4% to 10 %

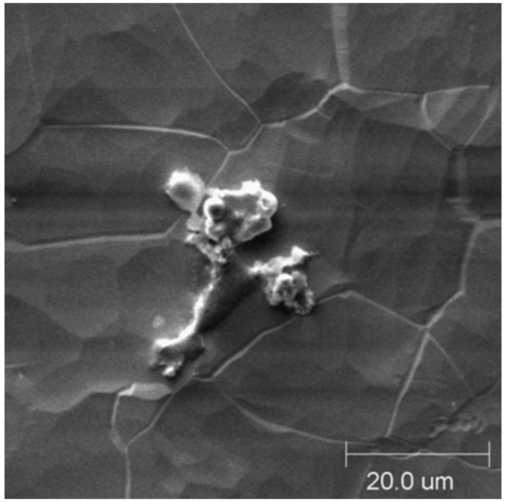


Remark: high gradient
roll down should be steeper:
field emission rises exponential;
also magnetic limitation is a barrier

Reformulation of BCD - Ultimate Yield Goal

- 80% of cavities reach 35 MV/m on first test
- With 80% yield on second test , the total number failing is < 5 %
- Need a sufficiently large “final batch” of cavities to get a statistically meaningful result

Present Yield Limitations



- Many tests are still limited by field emission
- Some by quench
- Few by the H-Q disease
- Example Variables to address
  - Preparation related
    - EP parameters (V, I, S, H…)
    - Rinsing parameters (time, pressure, water quality)
    - Particulate contamination (assembly procedures)
  - Fabrication Related
    - Cavity production parameters, e-beam welds, insufficient quality control
    - Nb material quality (RRR, grain size, defects, insufficient quality control…)

S0 Goals

- Several tasks before us
  - Improve reproducibility of cavity processing
    - 80% yield in first test (95% in two tests)
  - Carry out coupled R&D programs in parallel to improve processes
    - multi-cell tests with diagnostics, single cells prep/tests, preparation R&D, materials R&D, diagnostics and QA on EP, HPR…systems
  - Valuable input from TTC community on R&D
  - Results from R&D programs feed into 9-cell activities
  - Establish final best recipe to use for subsequent productions
  - All institutions should converge to similar preparation and test procedures to establish comparable data for 9-cells
- Need to make substantial progress towards these goals by mid to end of 2008, and complete S0 by mid-2009
  - Could impact final choice of gradient for TDR (due end of 2009)
- Yield improvement effort is equally important to XFEL and ILC

A Phased Program for S0 With Intermediate Goals

- Separate the task of improving the yield into two parts:

1. Improve Yield of Final preparation process
    - Final EP 10 - 20 um
    - HPR
    - Bake 100- 120 C
    - Test
2. Improve cavity fabrication yield (with bulk processing steps included)
    - Address gradient limitations from materials
    - Address gradient limitations from fabrication errors

Implementation of S0 Part 1
Stage 1: Define Baseline Yield (by mid-2007)

- Find best 9 cavities for tight loop
  - Need 9 - 20 cavities at start because yield is < 0.5
- Send 3 best to lab in each region with existing full set of facilities
  - EP-horizontal, H-removal furnace, tuning, HPR, test
  - DESY, KEK, Jlab
- Step 1: Qualify HPR and Test stand
  - HPR, Assemble & Test one high gradient cavity several times
  - If not reproducible, improve HPR, cleanliness…
- Step 2: Establish baseline for Tight-Loop
  - EP/HPR/test, 3 cavities, 3 tests, 3 locations
  - Total an 27 tests
  - Determine spread
- Step 3: exchange 1 - 3 cavities between regions for calibration
- Total > 30 tests after qualification

- **Use same final preparation procedure at different sites**
  - **(fixed at TTC –KEK)**
- **Use same testing protocol at different sites**
  - **(fixed at TTC- KEK)**

Implementation of S0 - Part 1
Stage 2 : Apply Process Improvements (by mid-08)

- Inject process improvements from parallel R&D program
  - see later slides
- Repeat 3 x 3 = 27 tests
- Compare yield with first set of tests
- Repeat above as necessary

Parallel-Coupled R&D Plan

- To determine methods that will improve the yield
- Many Arenas of R&D Coupled to S0
  - Discussed at TTC, Plans Developed…
- Single cell prep/tests
  - Focus is to remove identified contaminants efficiently (e.g. sulphur)
  - Rinsing studies (e.g. ethanol, ultrasound degrease, peroxide, short etch, HF…)
  - Labs have proposed to participate: KEK, Cornell, CEA Saclay, JLab (inder discussion)
- Improved quality control to be implemented
  - Process monitoring
    - » Acid, water QC
  - Thermometry diagnostics
  - Qualify HPR systems with force sensor system by INFN

Additional Studies

– S-deposition studies in control set ups
– H- contamination studies
– Field emission studies
– Material studies

Existing Proposals for Studies on Electropolishing (TTC,SMTF)

Nb CAVITY EP SUMMARY AS OF DECEMBER 2005

Tsuyoshi Tajima* for the Working Groups at TTC and SMTF meetings

Abstract

This document presents an outcome of the discussions at the TTC meeting at Frascati on 5-7 December 2005, which was a continuation from the SMTF meeting held at FNAL on 5-7 October 2005. Our goal was to identify the cause of the results spread of EPed 9-cell Nb cavities that have been tested mostly at DESY. While the spread might not have been caused only by the EP itself, the fact that the spread is larger than BCPed cavities may suggest that the EP process or EP-related contamination due to such as sulfur may be the cause of the problem. After the discussions on EP parameters and current issues, we suggest that the following be carried out with R&D efforts as highest priority items: 1) further study how important it is to control HF content and what is an appropriate range, 2) establish the best way to eliminate sulfur, a reaction product while EP and is insoluble to water, 3) study how

KEK	High Energy Accelerator Research Organization, Japan
QA	Quality Assurance
SMTF	Superconducting Module Test Facility
TTC	TESLA Technology Collaboration
WG	Working Group

Proposal for an R&D Plan towards better Understanding of the Electropolishing of Niobium Cavities

P. Kneisel, K. Saito, D. Reschke

Jan. 17, 2006

During the last year issues concerning the electropolishing of niobium cavities have been discussed at various meetings such as the TTC meeting at DESY in March 2005, the ILC Snowmass workshop, the SMTF workshop at FNAL in October 2005 and now at the TTC meeting in Frascati.

A summary report about Electropolishing activities worldwide will be published in the near future [1]

It has become very clear that the major problems have to do with contamination of the electropolished surfaces as well as with unpredictable hydrogen dissolution, resulting in some cases in "Q-disease". Better "on line" monitoring of the process seems to be a desirable QA/QC activity.

Single-cell Prioritized Program (TTC)

Problem	Proposed Activity	Priority
Contamination Field Emission	Rinsing studies with samples (XPS,SIMS…) Rinsing studies with single cell cavities	1
Non-reproducible appearance of Q-disease	Test any electropolished cavity for Q-disease Can overheating during initial rinsing cause Q-disease? Optimizing studies for cathode/screening geometry	1 2 2
Monitoring and control	Implementation of "on line" monitoring and data logging of polarization curves and HF concentrations Exploitation of EP simulation program Investigation of the cause for non-uniform material removal	1 1 2
Acid composition/ decomposition	Chemical analysis of acid mixture (nominally equal) Polarization curves on samples	2

P. Kneisel,
D. Reschke,
K. Saito

S0 – Part 2
Work on the Production Yield

- Cavity production yield can be < 1 due to
  - Fabrication errors (e.g. poor welds)
  - Material problems (e.g inclusions)
  - Troubles with bulk processing stages
    - 120 um EP, 800 C hydrogen removal…
- Especially important if goals include new vendor development
- May need to decouple if we are tight on cavity funding, but will have long-range impact
  - not enough qualified cavity vendors

Plan for S0- Part 2

- Plan for ‘production'-like processing of batches of about 50 cavities each (with some time delay between them)
- For a batch of 50 cavities, statistical error is about 15%
- The staging of these batches should allow for process improvements obtained from parallel R&D programs, as discussed earlier
- During the first production run it is expected that several tests (up to 3-4) would be necessary to qualify a cavity to 35 MV/m
- In the second and the following ones, the maximum number of re-test should become progressively lower
- Until the final goal (a total of 1-2 tests per cavity) is achieved.
- Plan to reach ultimate goal by mid-2009 (if resources available)

Implementation of S0- Part 2

- Order a large number of cavities starting as soon as possible (takes about 9 months to fabricate)
  - US is preparing to order > 50 cavities by end of FY 07
  - Globally: Order > 50 in 07 and > 50 + 50 cavities by early 08
- Start processing first batch after mid-07 with best procedure available from tight loop and basic R&D studies (Part I)
- Plan for 2-3 production cycles until end 2008
- ‘Final Production’ batch of 50 cavities (finish mid-2009)
- Use cavities > 35 MV/m to populate cryomodules for S1 (later) and S2 (next talk)
- How many cryomodules and RF units can we prepare?

Additional Scope for Improving Yield for S0- Part 2

- Some labs will work on reject cavities with diagnostics
  - Determine nature of defects: weld, material
- Feedback to cavity production to improve yield
- Proposals from LANL and MSU

Global Capacity for Prep and Testing

No. of Prep/Tests	Jlab	Cornell	ANL/ FNAL	KEK	DESY	Total Prep/ Tests	Tight Loop Tests	Production Tests
2006	6	3	0	10	10	29	9	20
2007	30	10	20	40	10	110	54	56
2008	40	10	40	40	10	140	27	113
2009	50	10	40	40	10	150	0	150
Totals	126	33	100	130	40	429	90	339

Note: DESY rate is lower because cavities which pass 28 MV/m are removed from the cycle for XFEL

Total number of prep/test cycles till end of 2009 > 420

Tight loop : 90 (3 rounds of 30 tests)

Production-like : 330

Furthur Comments on Capacity

- Competing demand for existing processing facilities for other projects
  - XFEL, JLAB Upgrade, ERL…
  - Single cell R&D activities
- Add parallel test stands to increase capacity
- An increase in the preparation capacity especially on the EP is needed in early stage.
- In addition to the JLab facility a new EP facility will be brought online at ANL/FNAL. The timely installation of this facility is of great importance to increase the overall turnaround on surface preparations.
- At Cornell a vertical EP facility has been assembled for 9-cells and is presently under test.
- In Europe it is expected that industry will be building nine-cell EP facilities for the first (pre-furnace) EP step. This would considerably increase the capacity for the final EP at the existing setup at DESY.
- Consider exchange of cavities between US (cavity fabrication) and KEK (cavity treatment) to get results quickly

Yield Model
and Number of Cavities

	Production	Process Yield	Fabrication	No. of Cavity	Min. No. of Cavities	
	Tests	Assumption	Yield	> 35 MV/m	to be available	
2006	20	0.25	0.7	3	4	
2007	56	0.33	0.8	15	18	
2008	113	0.5	0.8	45	57	
2009	150	0.8	0.8	96	120	
Totals	339			159	199	
					20	Tight loop
					220	

Globally: 64 good cavities by end of 08 can be used to populate 8 crymodules in 09 = 2 + RF units in 2010

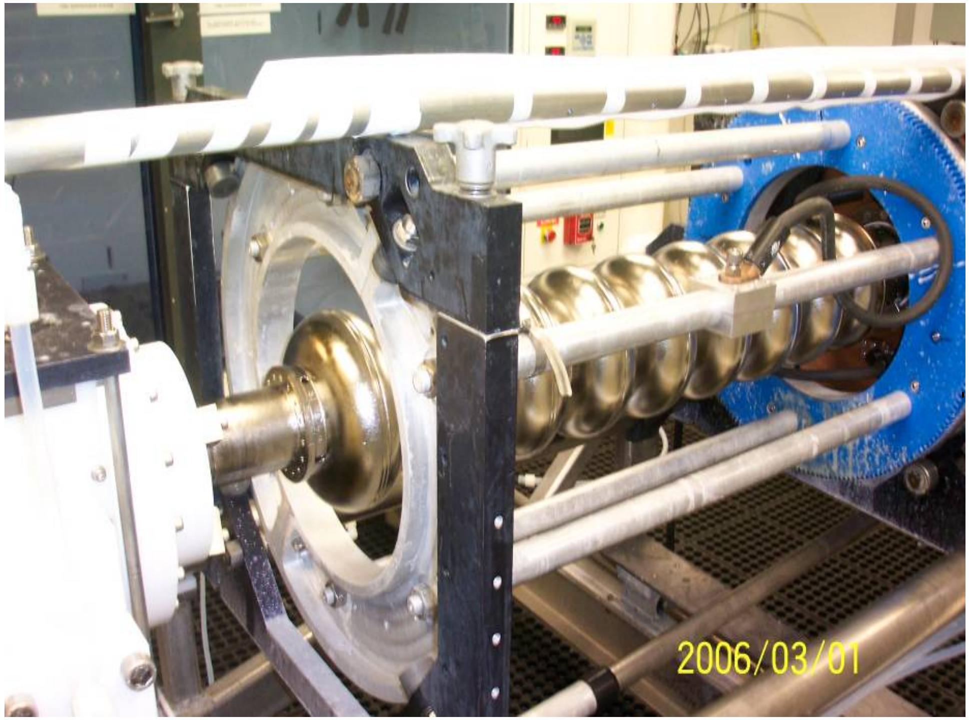
S0 Activities Status

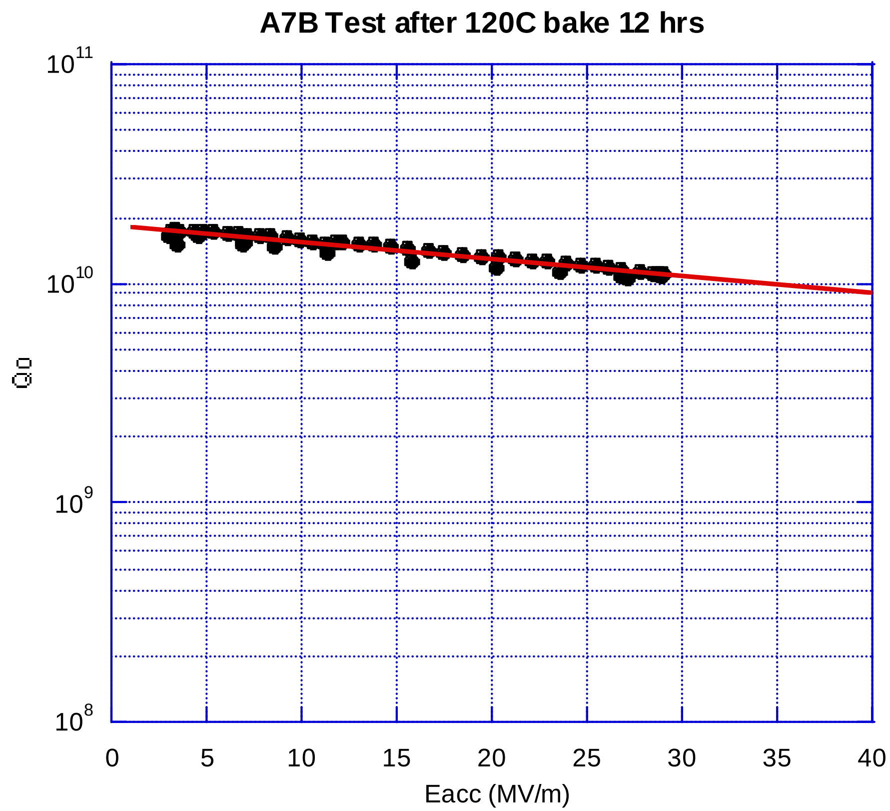
US: Cavity Fabrication

- US has ordered (or will order soon) following cavities (>50) .
  - FY05: 4 Cavities (ACCEL) (TESLA Length)
  - FY06:
    - Phase 1: 4 Cavities (AES), 4 (Jlab) (TESLA Length)
    - Phase 2: 6 Cavities (AES), 9 (Qualified Vendor) (ILC Length)
  - FY07: 24 Cavities will be ordered in next several weeks. (Last cavities to be delivered mid 07)
- S0-1 (US Cavities)
  - 3 Cavities from ACCEL is already part of tight loop at Jlab
  - 3 Cavities from Qualified Vendor (FY06-P2) will be part of tight loop at KEK/DESY
- Rest will be part of first phase of cavity yield studies, Vendor development, S0-S1 and S2 etc.

EP and Vertical Testing at Jlab

- Jlab has commissioned the EP, HPR, Bake and Vertical Testing for the 1.3 GHz cavities.
- Jlab will be the center of the S0-1 “Tight Loop” actives in USA.





Cornell: BCP and Vertical Test of ACCEL Cavity

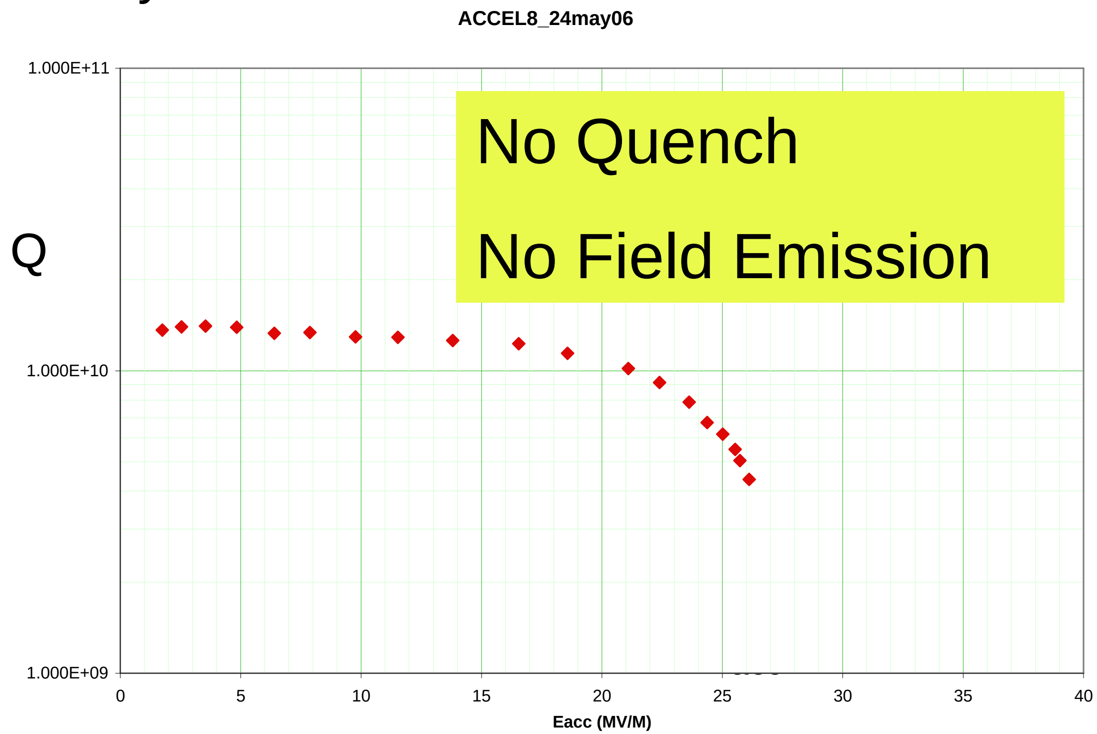
BCP (Etching)

50 + 60 µm BCP + 50 µm at ACCEL + HPR

No Heat treatment at 800 Deg C

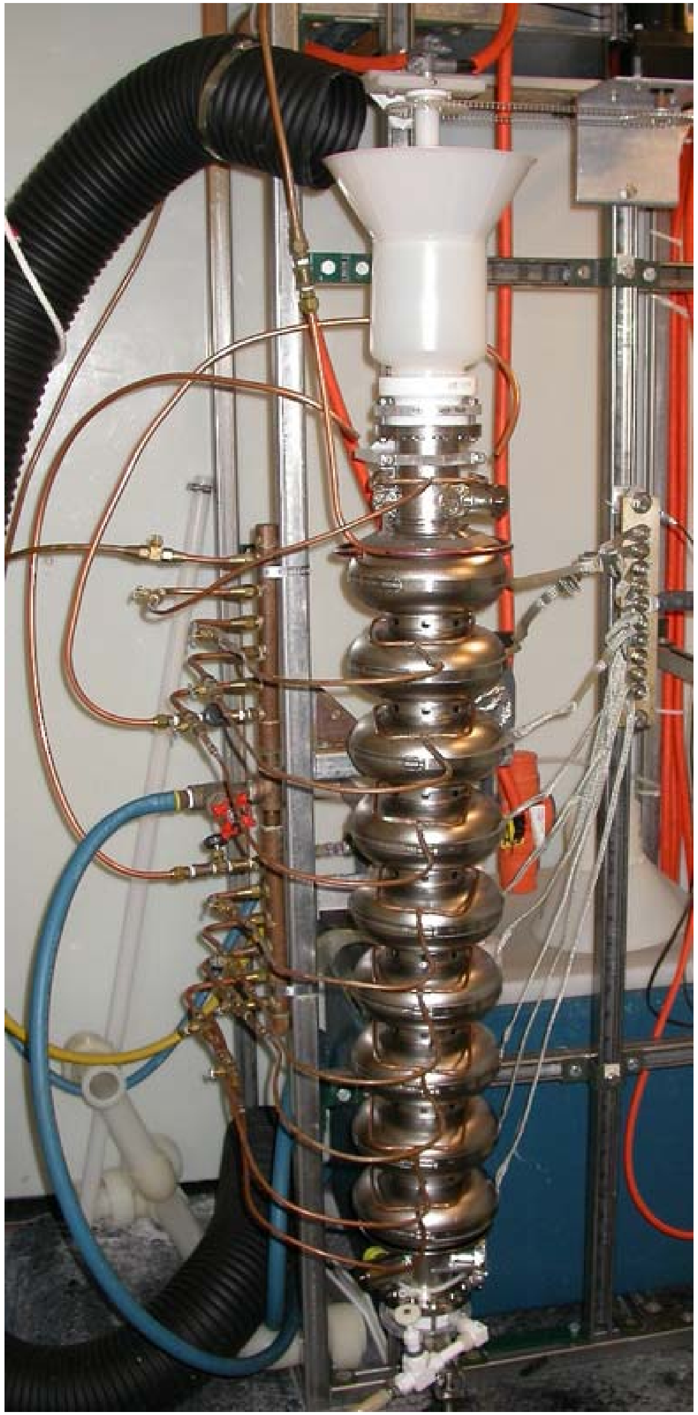
Maximum field = 26 MV/m (high field Q-slope)

Two cycles to reach best field for classical BCP



Vertical EP Underway

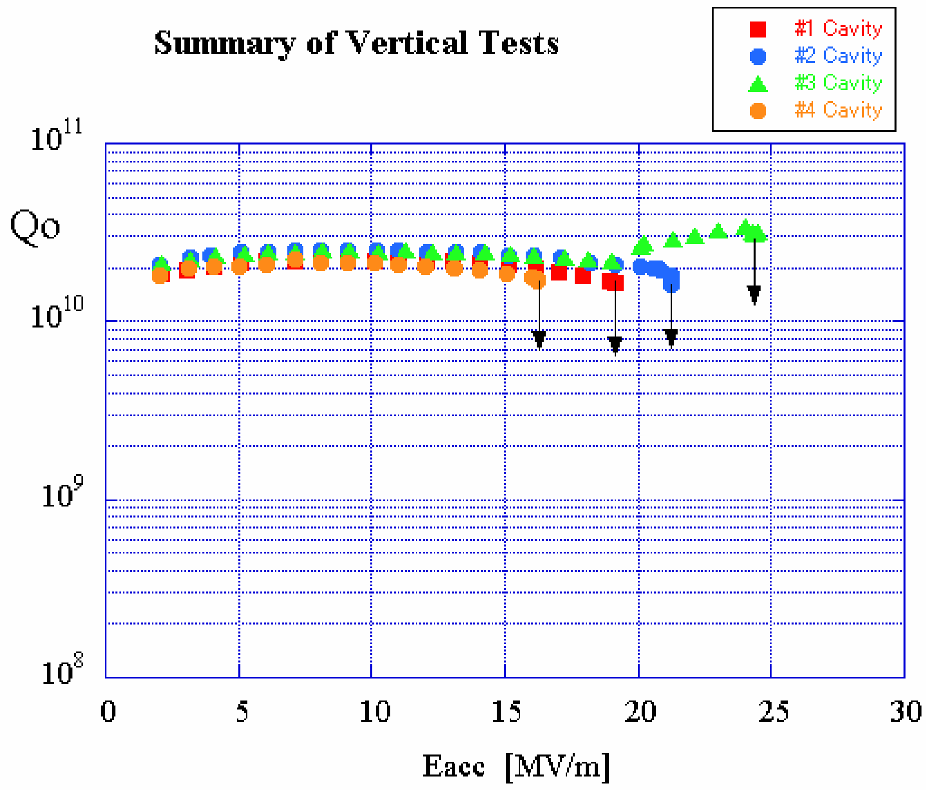
- 120 um EP complete
- 600 C, 12 hour bake at Jlab to remove H
- HPR & test underway



KEK: Vertical Tests of TESLA style Cavities

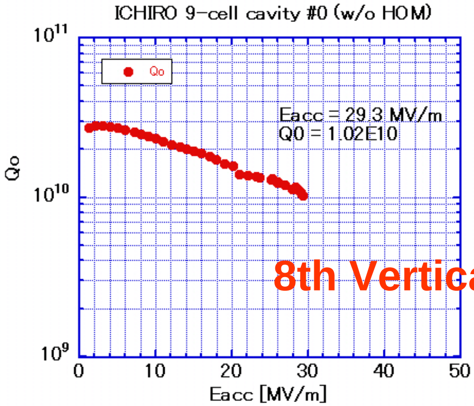
Up to now, 9 tests for 4 cavities.

#1 cavity : 3 tests (max 19.2MV/m)
#2 cavity : 2 tests (max 20.3MV/m)
#3 cavity : 3 tests (max 24.5MV/m)
#4 cavity : 1 test (max 17.1MV/m)



LL-type Ichiro 9-cell Cavity Vertical Test

#0 : without HOM /input port



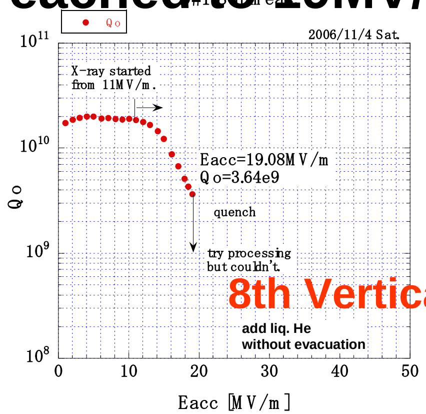
4 EP, 16 measurement -> reached to 30MV/m,

Now under modification of end-group.

#1 : with HOM /input port

4 EP, 8 measurement

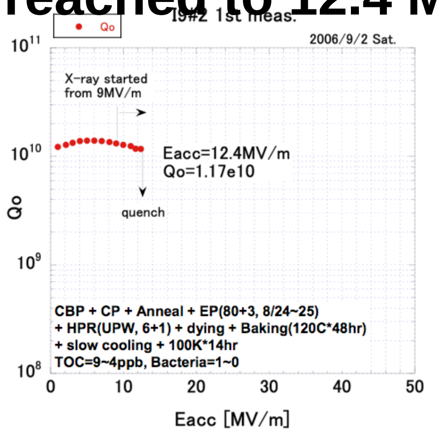
-> reached to 19MV/m



#2 : with HOM /input port

1st measurement

-> reached to 12.4 MV/m



Single-Cell Work Well Advanced at KEK and DESY

Single-cells: Compare Maximum Magnetic Field between KEK and DESY (F. Furuta)

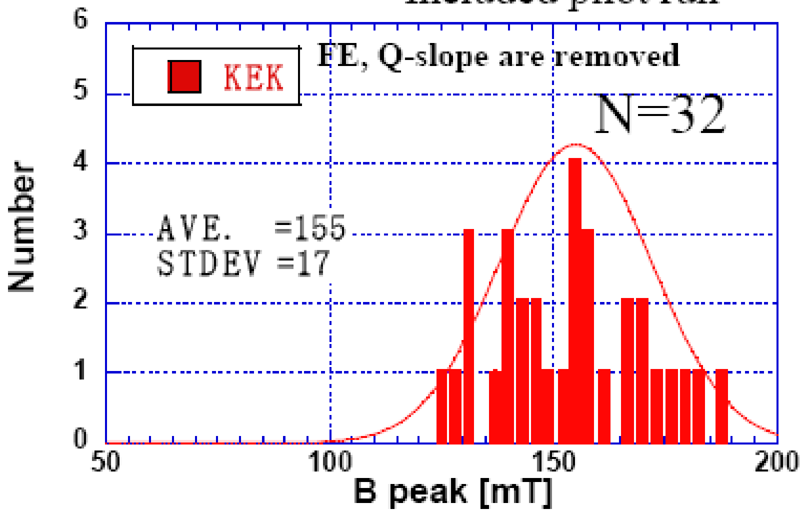
- Comparison of KEK and DESY single-cells
  - KEK
    - CBP + CP + Anneal + EP + HPR + Baking
    - Ichiro / LL shape
    - Single source of niobium, same manufacturer
    - EP at Nomura company
  - DESY
    - EP + Anneal + EP + HPR + Baking
    - TESLA shape
    - Various types of niobium, various manufacturers
    - EP at Henkel company

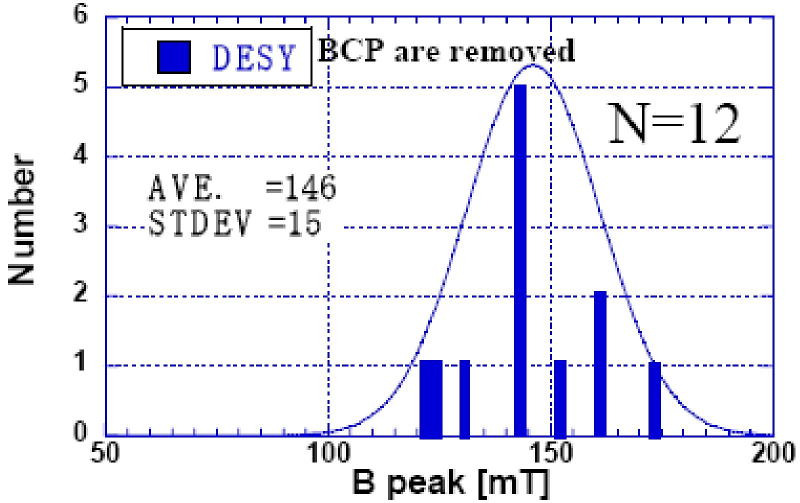
- Results:
  - KEK
    - E_{acc} = 43.5 +/- 4.8MV/m for ICHIRO
    - If normalized to TESLA shape:
    - E_{acc} = 37.3 +/- 4.1MV/m
  - DESY
    - E_{acc} = 35.2 +/- 3.6MV/m for TESLA

- Small difference (~6%) in average value and spread of the magnetic field
  - Very comparable results although different recipes

- Accelerating gradient is larger in the Ichiro-shape
  - One nine-cell achieved 29 MV/m

Included pilot run





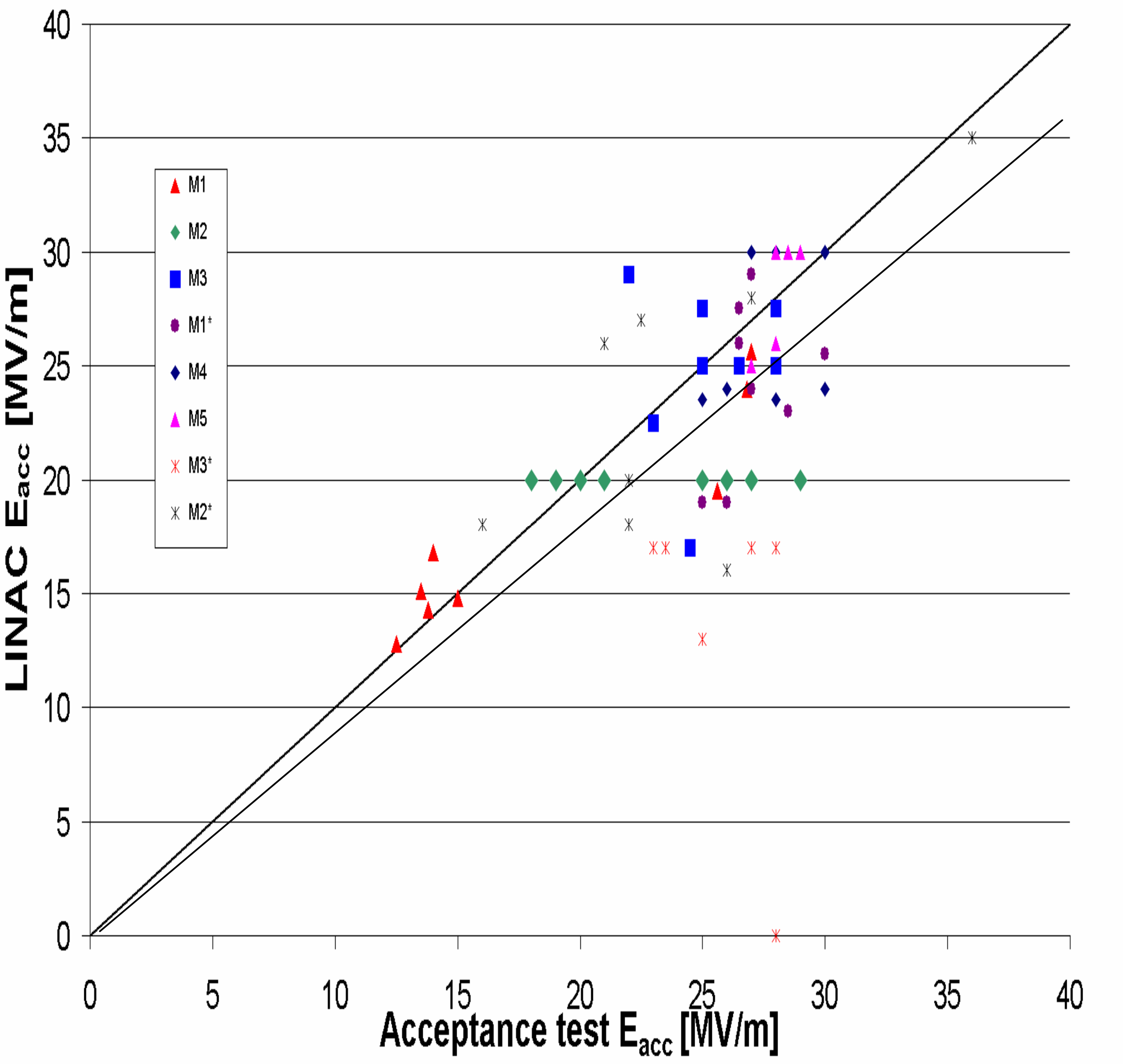
Using DESY/ Detlef Reschke's data.

S1- Goals

- Achieve 31.5 MV/m (< 10% drop) at a Q0=10^10 as operational gradient as specified in the BCD in more than one module of 8 cavities
  - including e.g. fast tuner operation and other features that could affect gradient performance
- At least three modules should achieve this performance. This could include re-assemblies of cryostats (e.g. exchange of cavities). It does not need to be final module design. An operation for a few weeks should be performed.
- Intermediate goal
  - Achieve 31.5 MV/m average operational accelerating gradient in a single cryomodule as a proof-of- existence. In case of cavities performing below the average, this could be achieved by tweaking the RF distribution accordingly.

LINAC vs. Vertical (Individual Cavities)

- Some cavities power limited
  - Esp. M5
- Coupler limited
  - M2
  - M4
- Only module measurement available
  - M2



Status of S1

35MV/m Single Cavity in Cryomodule Test at TTF (in 2004)

AC72: one of **five** high-performance EP cavities

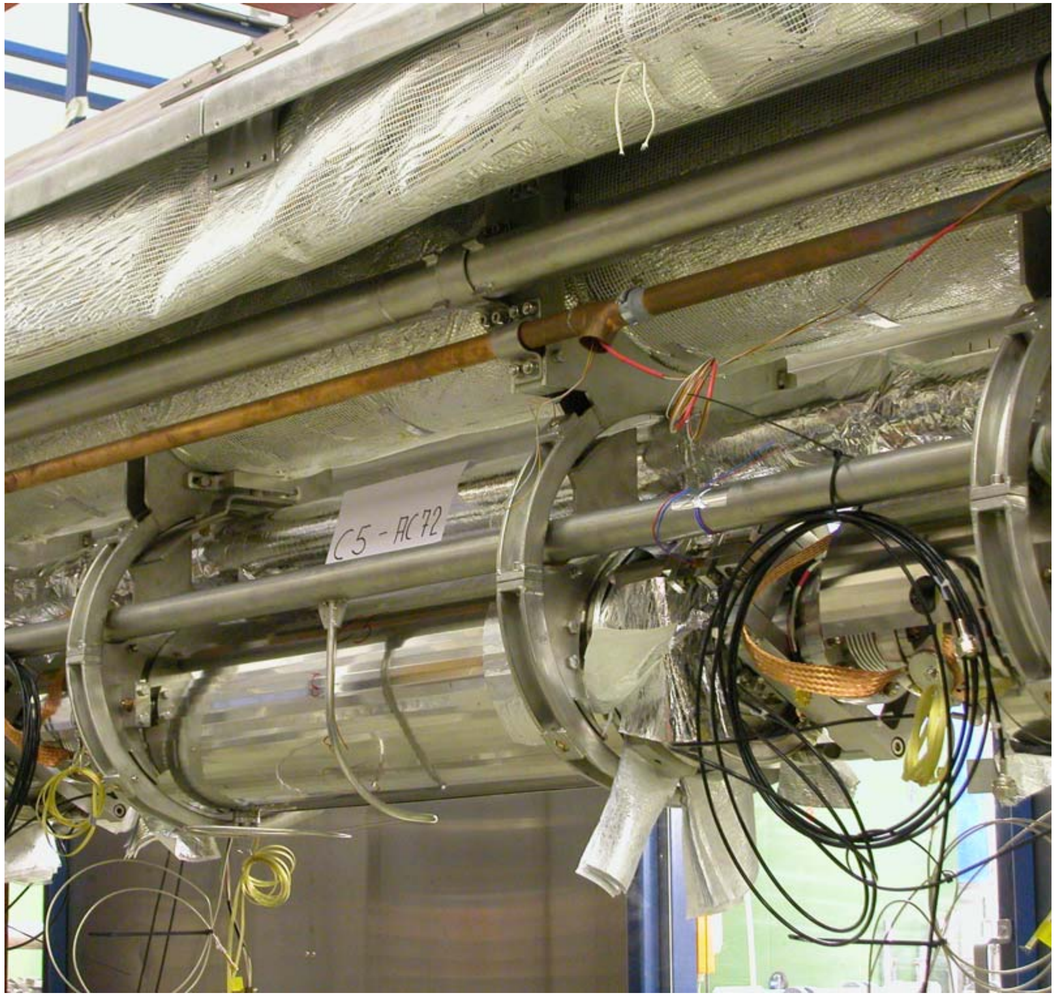
Acceptance test in vertical cryostat

↓ Transferred to

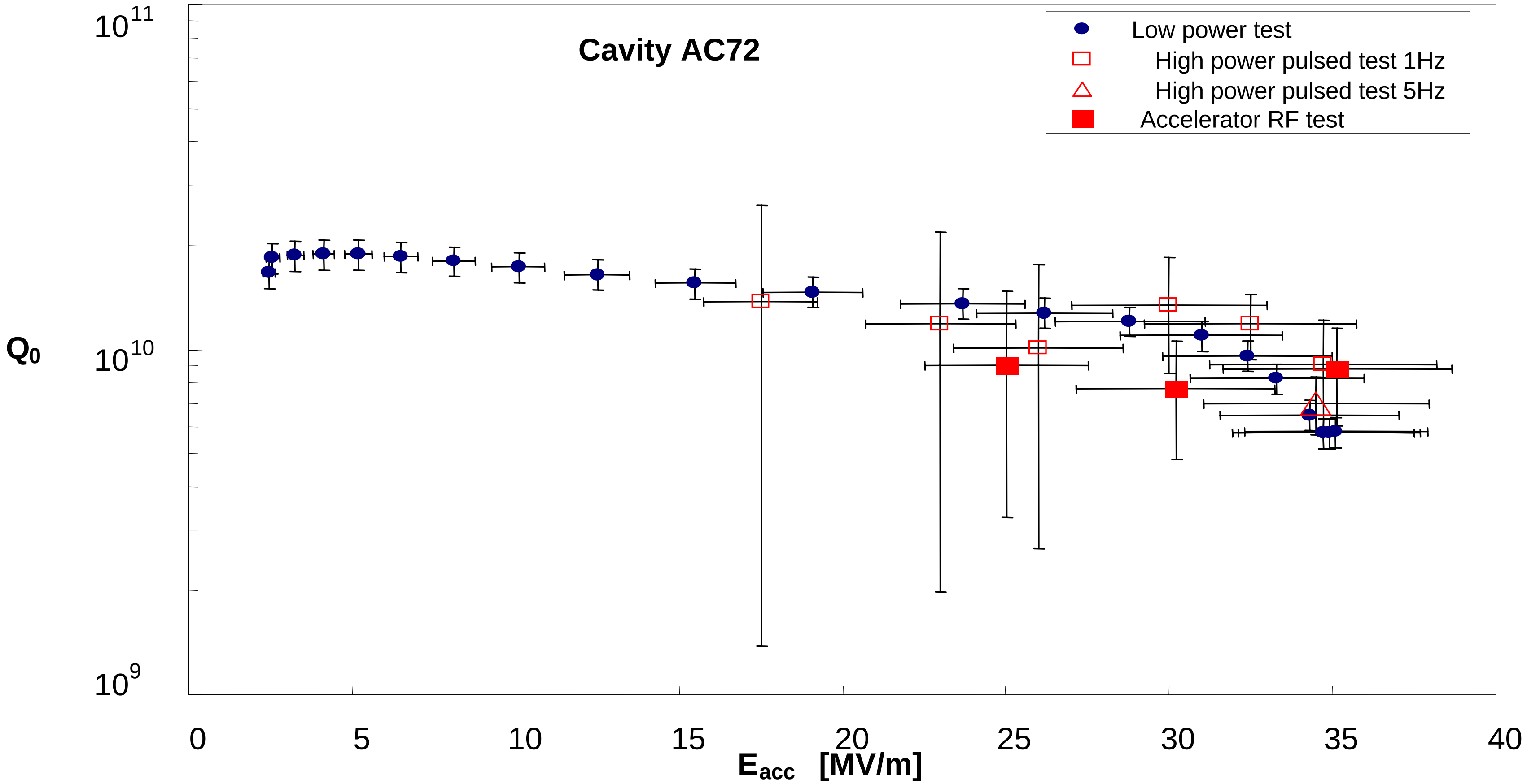
Full 1/8th CM horizontal test (CHECHIA)

↓ Transferred to

Full 8 string CM TTF

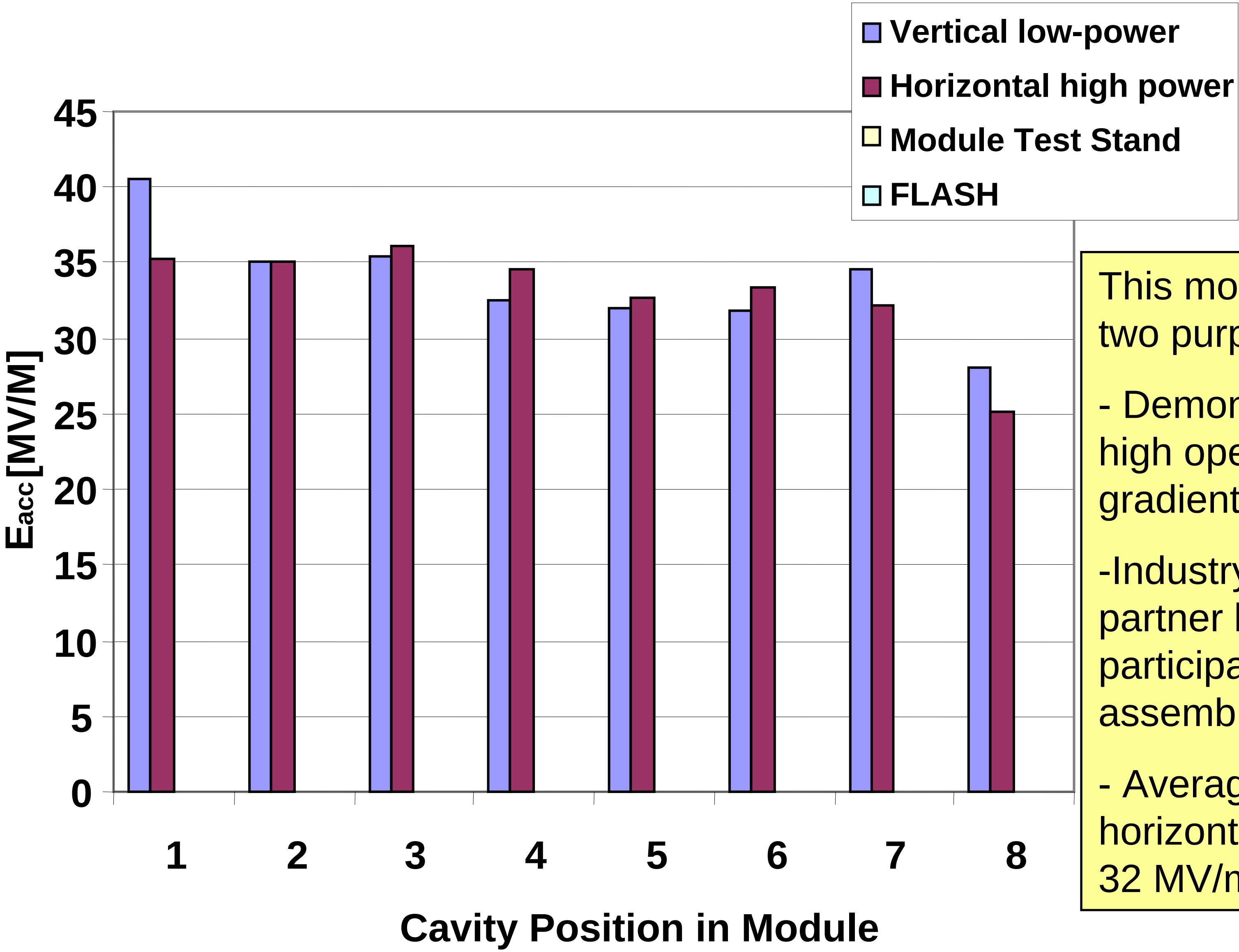


Cavity Test Inside a Module



- One of the electropolished cavities (AC72) was installed into an accelerating module for the VUV-FEL
- Very low cryogenic losses as in high power tests
- Standard X-ray radiation measurement indicates no radiation up to 35 MV/m

2006: FLASH Module 6: High Gradient Module



This module serves two purposes:

- Demonstration of high operational gradient

-Industry and partner labs to participate in assembly process

- Average of horizontal tests > 32 MV/m

DESY **C**ryo **M**odule **T**est **B**ench (CMTB)

Test of module 6 will start in October (week 41)

Cryogenic systems commissioned

Now: Installation of module 6 on CMTB

RF interlock tests scheduled for 10.10.06

Don't Forget We Need to Continue R&D on ACD Topics

"ACD is part of the BCD" …

- ACD Examples from BCD document
  - Large grain Nb material and cavities
  - Alternate shape cavities
    - LL and RE
- Important Long-Range R&D
  - Address field emission as a long-range issue
  - Aggressive quality control for EP, rinsing, assembly
  - In-situ processing of emitters
  - Re-visit : High Pulsed Power processing
  - Other Cost reduction ideas

Conclusions

- S0, S1 goals defined
- Work plans exist (S0, Single-cells) or are being formulated (S1)
- Tight loop Work started in Japan and US
  - DESY is in a production-mode, tight-loop options being discussed
- R&D for improved process on-going in all regions
- Next steps for S0 Task Force
  - Compare cavity plans worldwide with target scope
  - Resolve gaps
    - Stretch schedule to 2010 : TDR impact
    - Reduce scope : end up with larger spread than target
    - Get more R&D support with help from GDE.
  - R&D Board is discussing options for tracking progress of S0/S1
    - e.g. full-time person for
    - tracking, data integration, communication, comparing systems performance, supporting process improvements over lab boundaries
  - Evaluate cost/performance benefits of S0/S1