Cavity R&D Program

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GDE

Overview

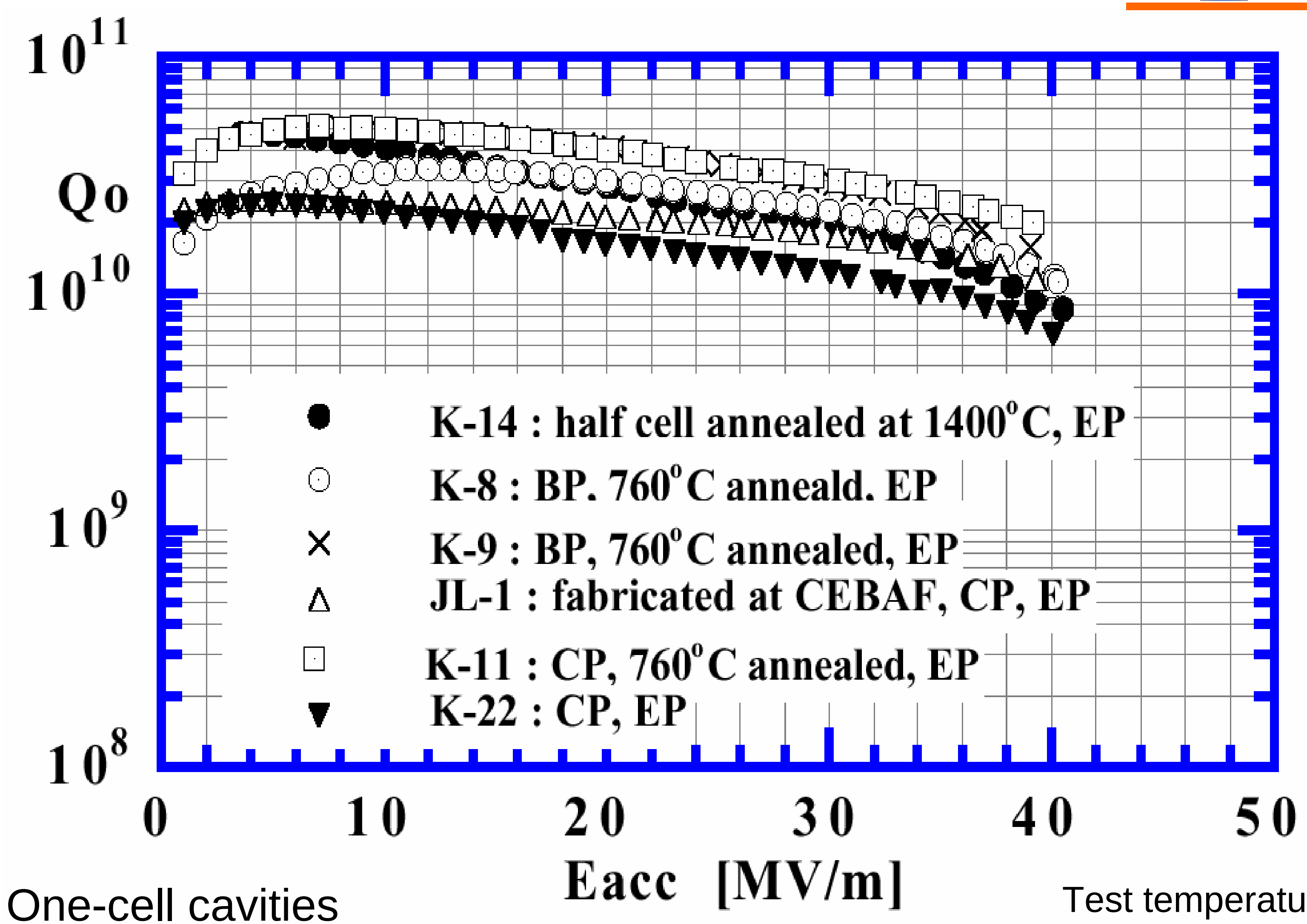
- ILC R&D framework
  - **What has been shown? What not?**
- 'S'-issues
  - **What are they?**
- Gradient Task Force Charge
- ILC Program on high gradient cavities

What has been achieved?

- Data for ILC-like cavities available on
  - **Individual cavities**
    - Single-cells
    - Multi-cells
  - **Full accelerator modules**
    - TTF experience so far on etched cavities
    - First EP Module going to test stand

Electropolished 1,3 GHz Elliptical Niobium Cavities

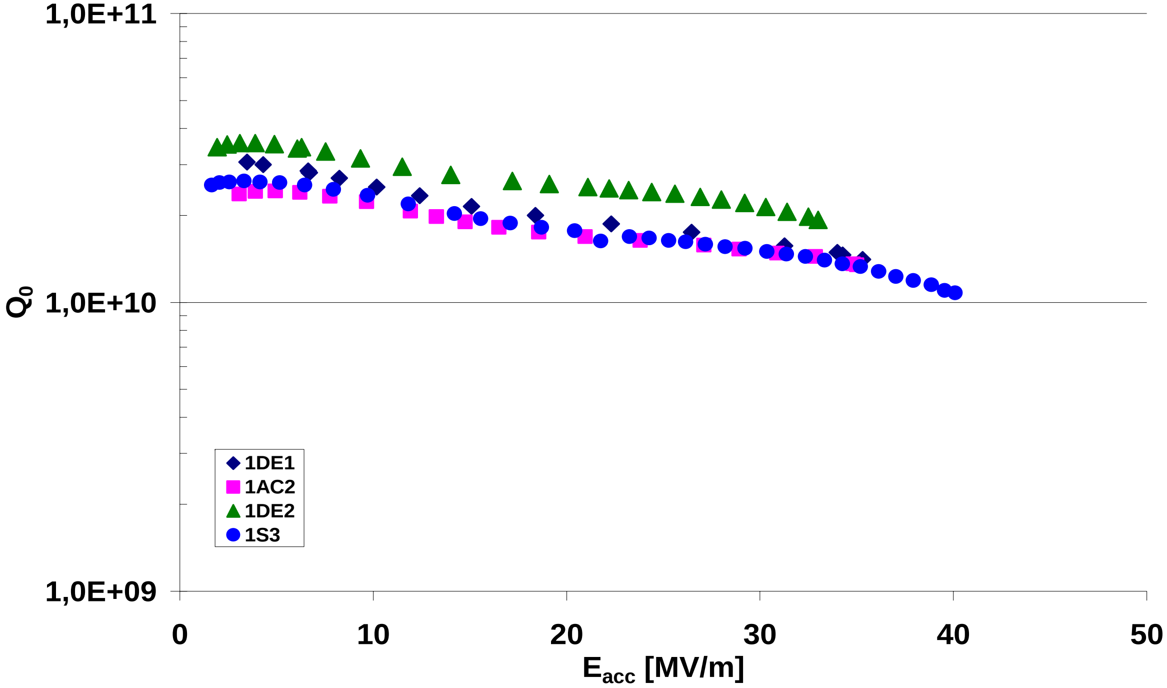
K. Saito et al. KEK 1998/1999



One-cell cavities

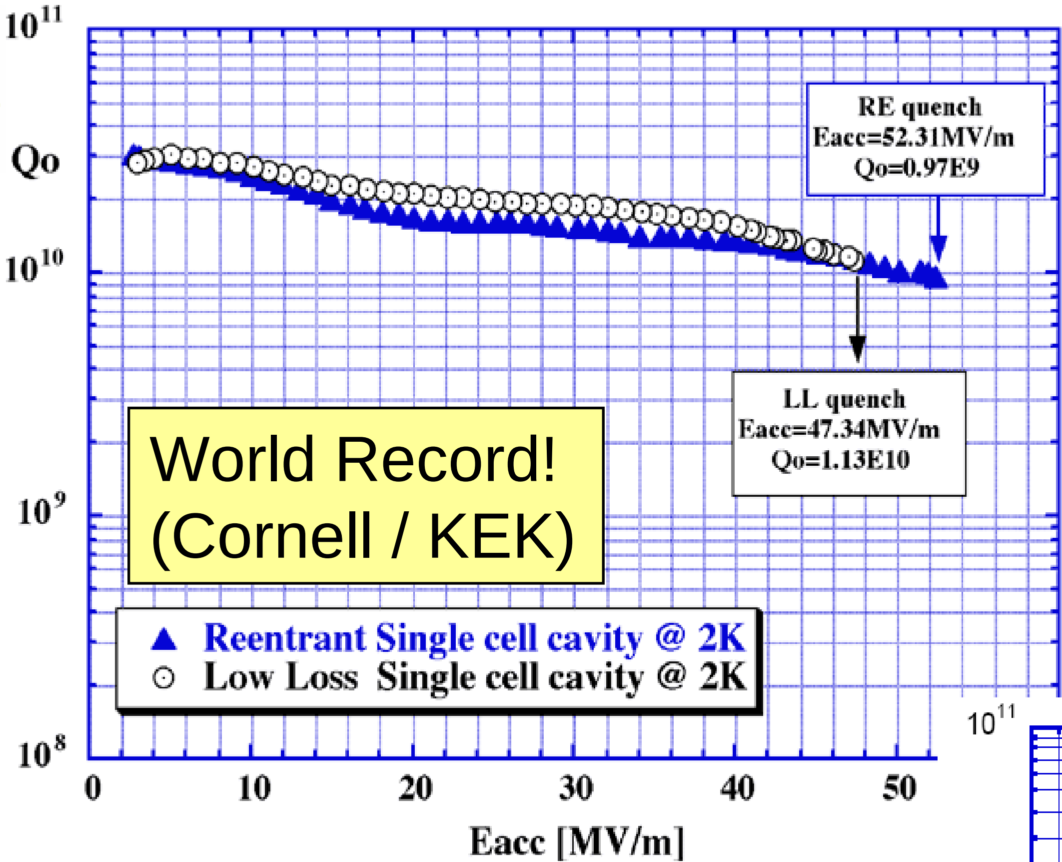
Test temperature: 1.6 K

Example of XFEL Industrialization: Henkel

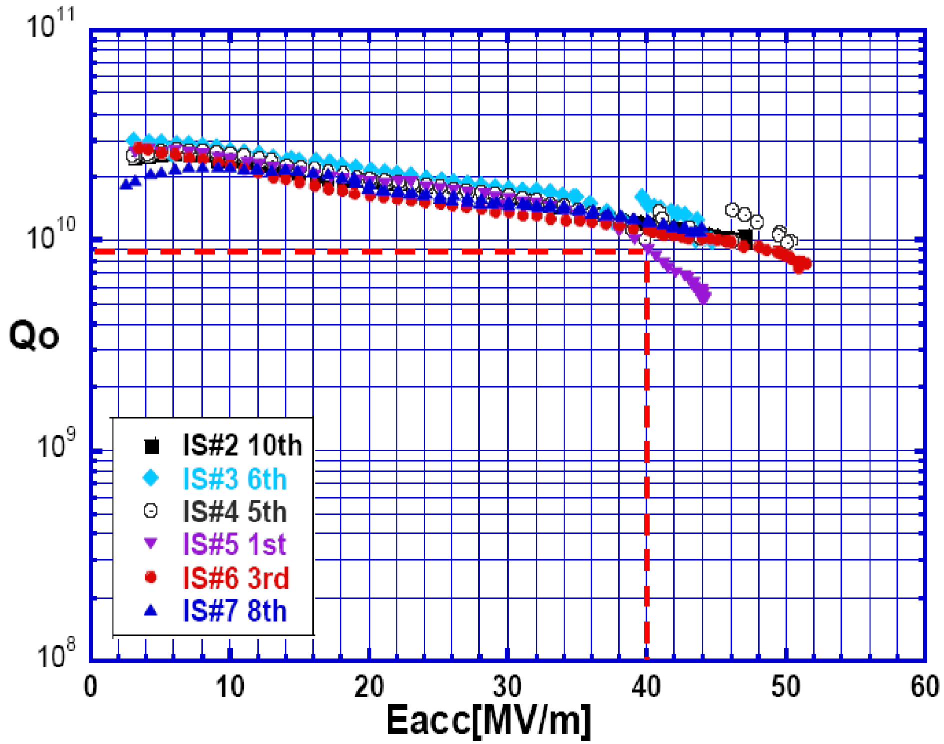


- Very high gradient (up to 40 MV/m), high Q_0 single-cell cavities have been prepared
- Study on improved quality control measures at DESY and Henkel
  - **E.g. Improved parameter-control of electrolytes**
- Up to three-cell 1.3 GHz cavities can be treated currently

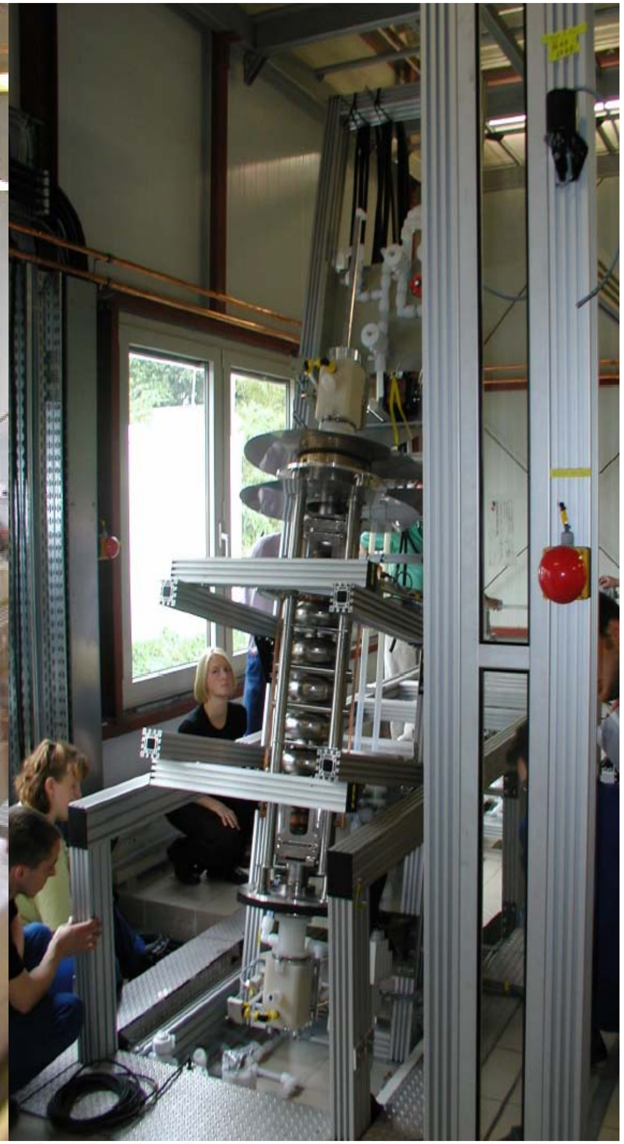
Single-Cells: Other Shapes



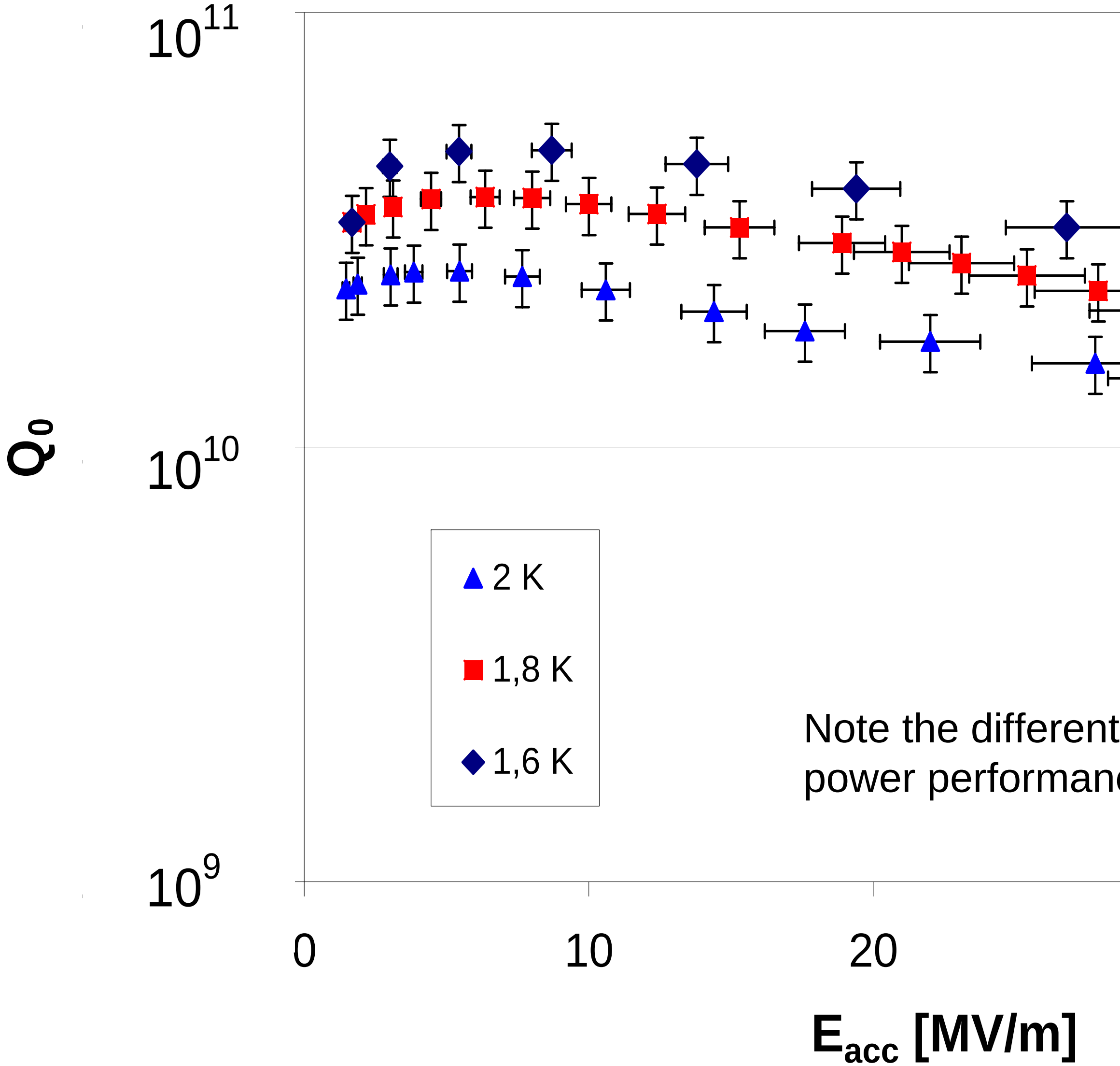
Several cavities achieved more than 45 MV/m at high Q! (KEK)

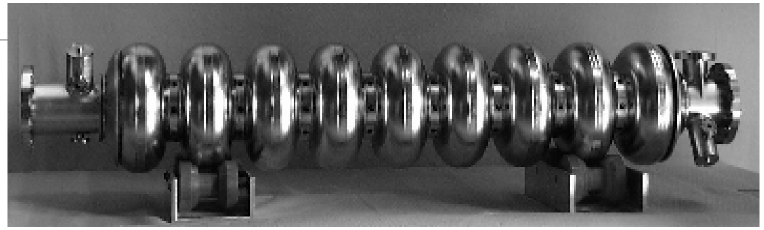


Electropolishing Setup at DESY



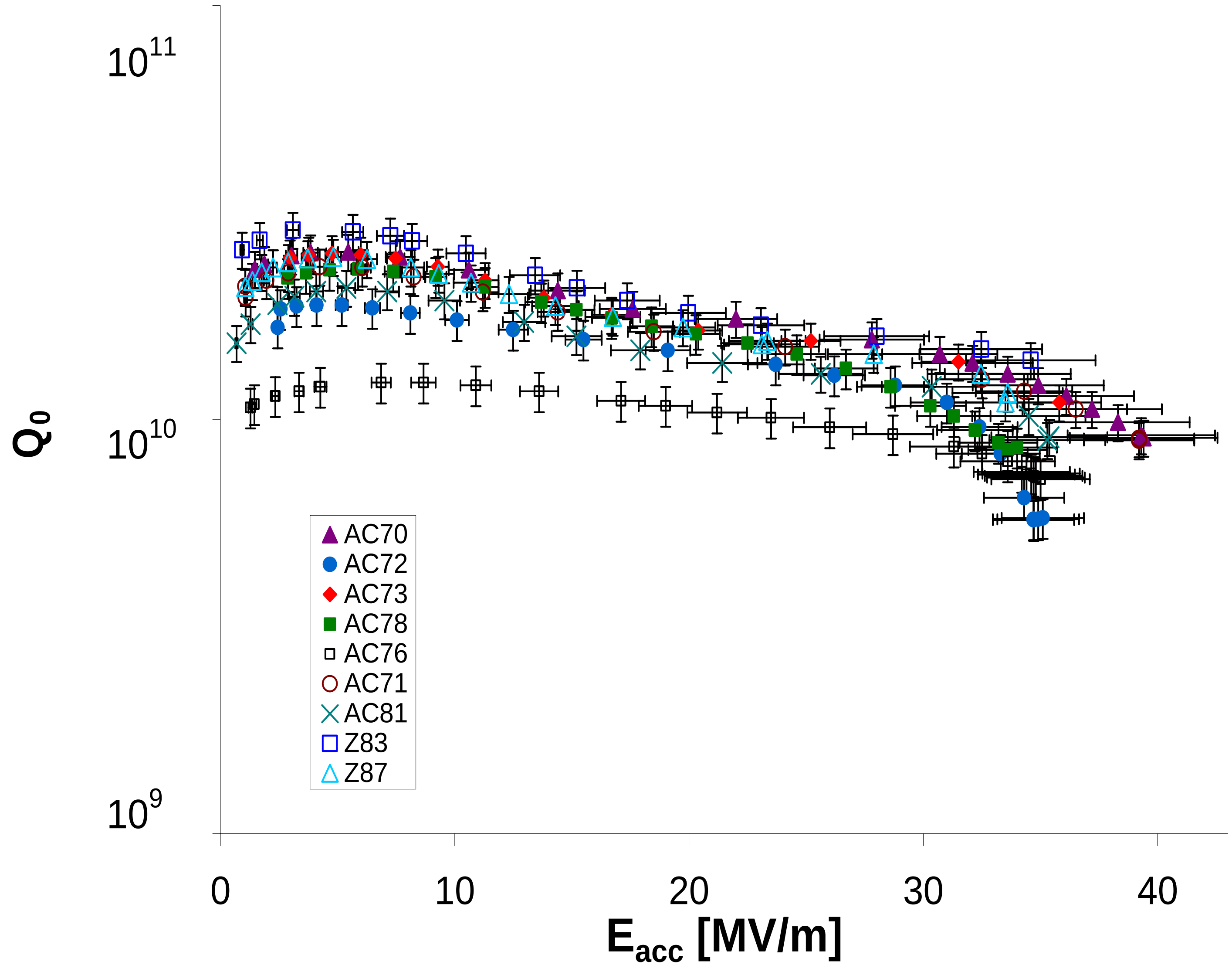
Proof-of-Principle: TESLA Nine-cell Test (ILC Baseline Cavity)



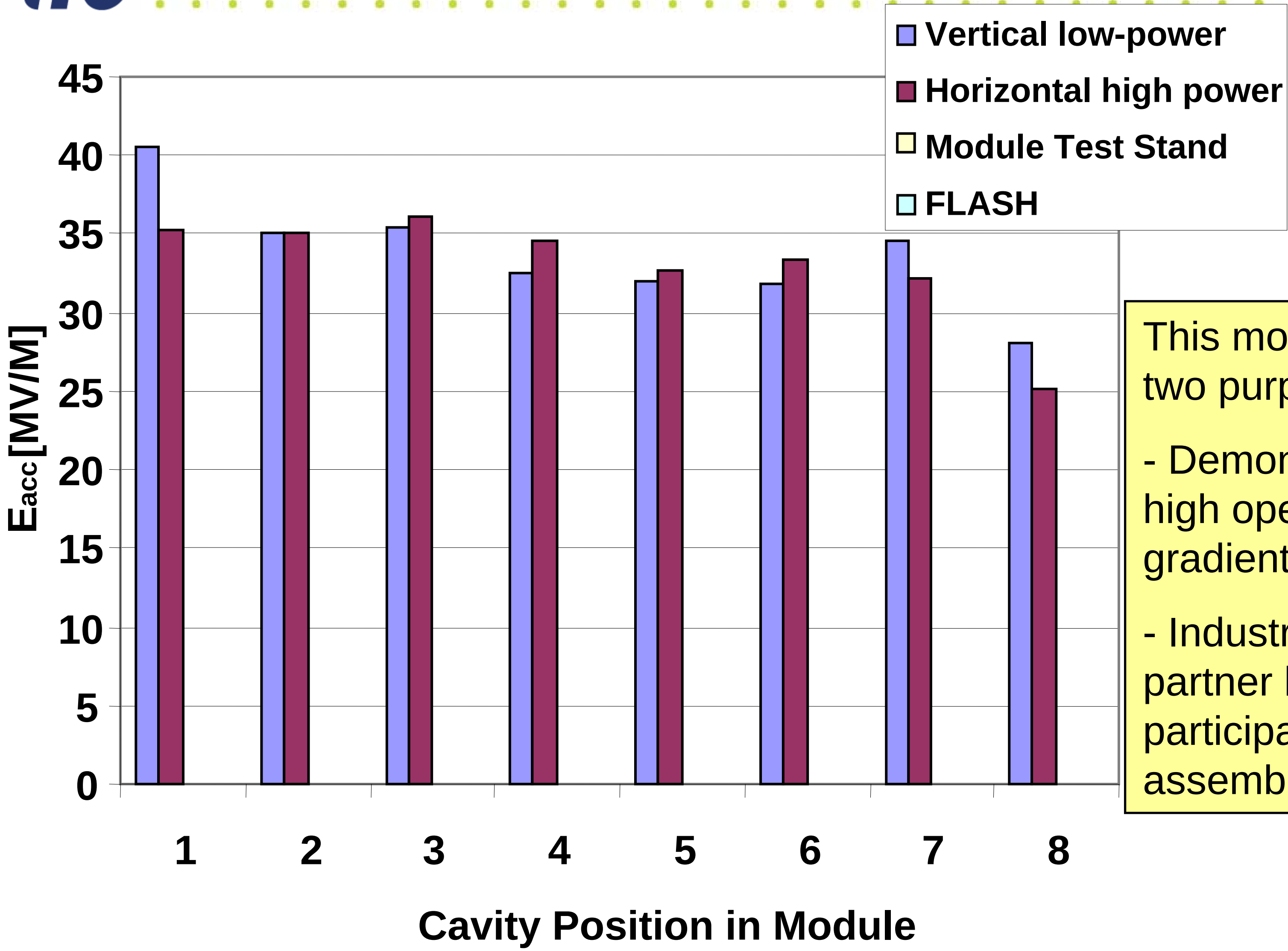


Note the different test temperature in this low power performance test: 1.6 K –2K

TESLA Nine-Cells: Low-Power Results



FLASH Module 6: High Gradient Module

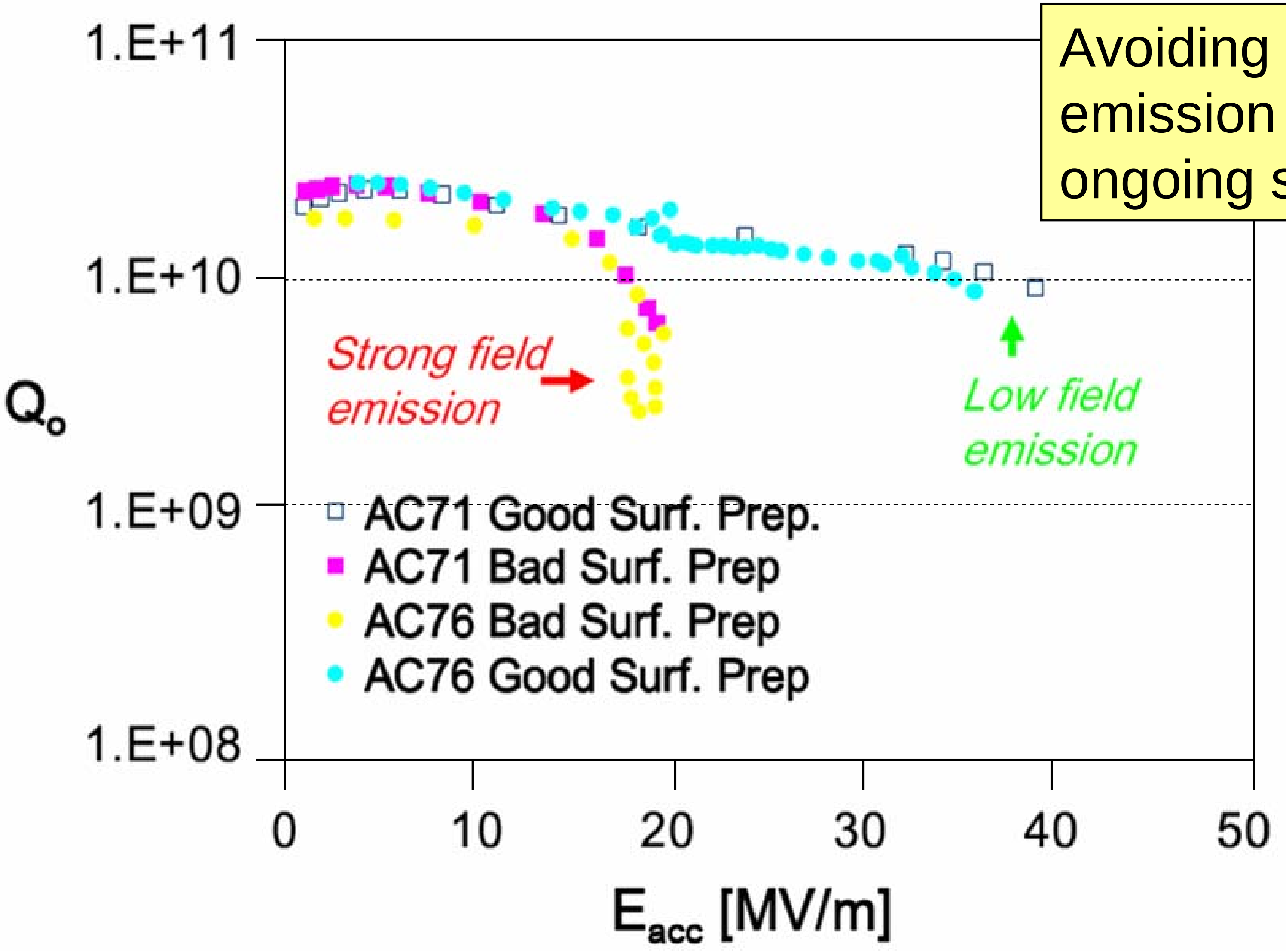


This module serves two purposes:

- Demonstration of high operational gradient

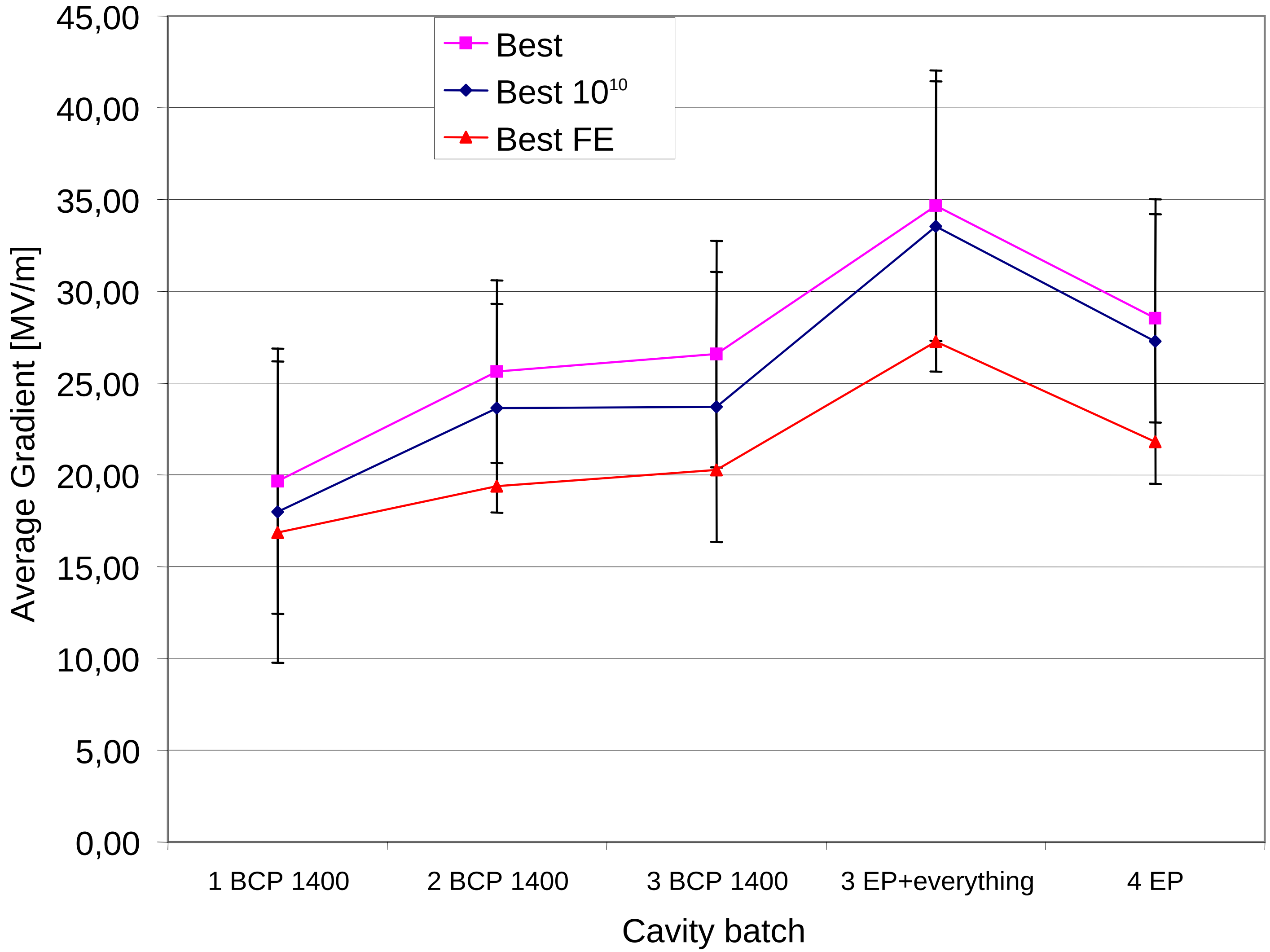
- Industry and partner labs to participate in assembly process

Work needed: Reproducibility in the Processes

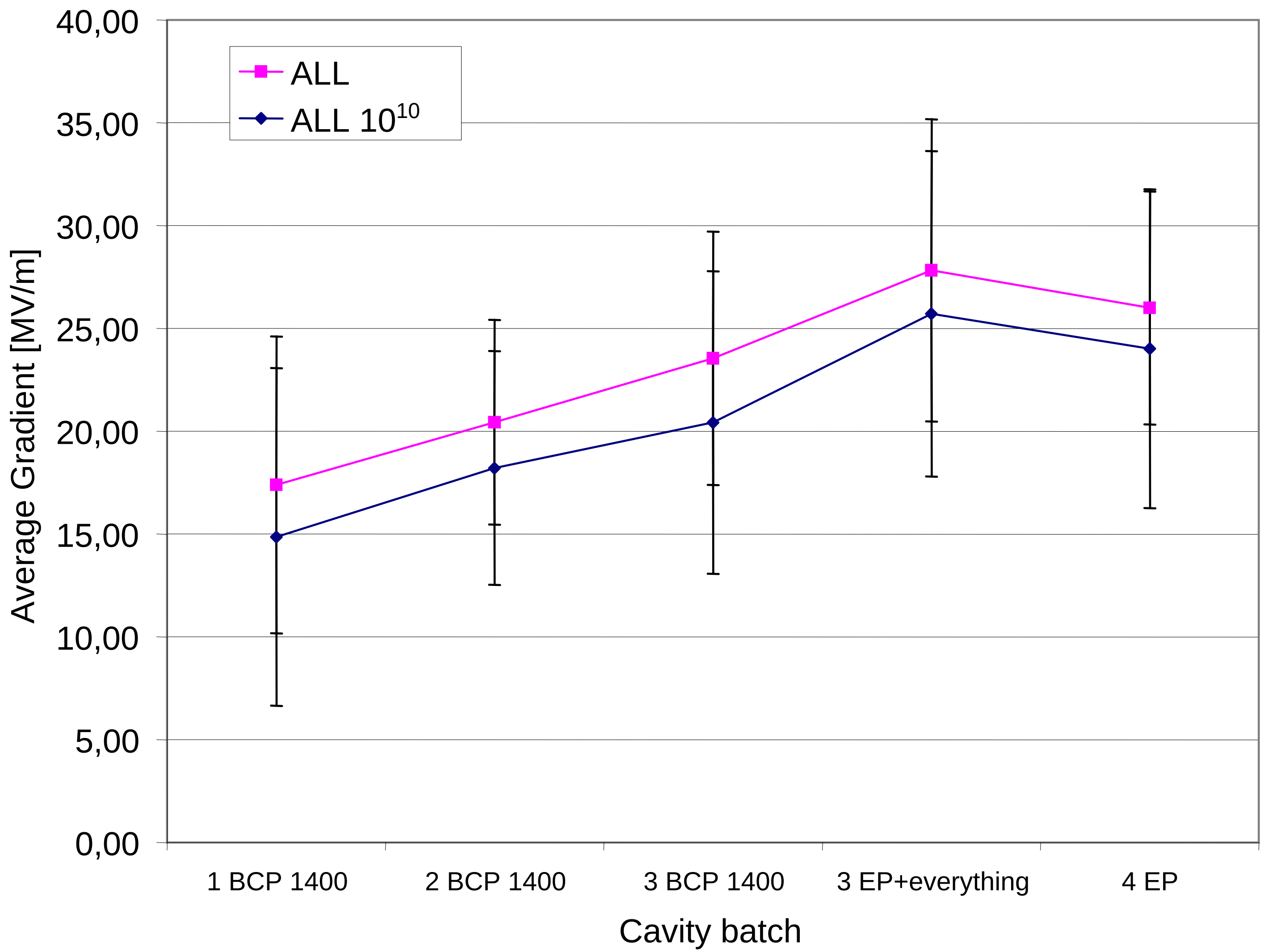


Avoiding field emission is an ongoing struggle !

TTF Productions: Best Test Results



TTF Productions: All Test Results



Main Sources of Reproducibility Problems

- Imperfections in final surface treatment,
  - **e.g. electropolishing (EP)**
  - **final rinsing**
- Field Emission from particle contamination
  - **e.g. assembly processes**
  - **sulphurus from EP acid**
- Thermal breakdown of superconductivity from material or manufacturing defects
  - **Weld Problems at new industry**
    - Deviation from specification
    - Insufficient quality control

ILC R&D Framework

- The need of making gradients more reproducible is a top priority
- Single-cell cavities in various labs and also from industry obtain very high performance
  - **Yield rates vary slightly between labs**
  - **Probably we are not far away from the good parameter set**
- Looking at the history of TTF some significant effort is needed to transfer results to multi-cells
  - **Three cavity production cycles (20-30 each) were done to improve the gradient from the level of 5-10 MV/m to 25 MV/m with classical etching**
    - This included especially the training of companies to provide the required niobium and electron beam weld quality
  - **Currently, we are in EP Production cycle No.1 at DESY**
  - **Other regions are in the process of being able to do research, it is not yet a production cycle**
- A dedicated facility in each region with sufficient redundancy and flexibility is desirable to have fast turn-around of cavity tests.
  - **Waiting for the repair of infrastructure is painful**
  - **From the TTF experience the bottleneck is typically the cavity preparation, not the cryogenic testing**

'S'-issues: Overview

- S0
  - Achieve 35 MV/m in 9-cell cavity in vertical dewar tests (low-power) with a sufficient yield
  - Staged approach with intermediate goals to track progress
- S1
  - Achieve 31.5 operational as specified in the BCD in more than one accelerating module
  - … and enough overhead as described in the BCD.
- S2
  - a string of N modules with full xyz...by date ...
  - Need for a linac ?
  - Endurance testing

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/S1 Task Force

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

Basic Assumptions

- The basic recipe for highest gradients is known: Electropolishing, High Pressure Water Rinse and In-situ Bakeout
  - 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
  - Large number of cavities from several regions in a production-like mode eventually

S0 Ultimate Goals

- The cavity performance is influenced by the fabrication process and surface preparation process.
  - **Effort in all the regions to qualify further vendors for cavities**
- Preparation process and vertical test yield for 35 MV/m at $Q_0 = 10^{10}$ should be greater than 90% for a sufficiently large number (greater than 100) of preparation and test cycles.
  - **There should be a complete description of the preparation and testing processes (reproducibility in other places). The time scale should be commensurate with the completion of the TDR (middle of 2009).**

S0 Ultimate Goals

- After a viable cavity process has been determined through a series of preparations and vertical tests on a significant number of cavities, achieve 35 MV/m at $Q_0 = 10^{10}$ in a sufficiently large final sample (greater than 30) of nine-cell cavities in the low-power vertical dewar testing in a production-like operation e.g. all cavities get the same treatment.
  - **The yield for the number of successful cavities of the final production batch should be larger than 80% in the first test. After re-processing the 20 % underperforming cavities the yield should go up to 95%. This is consistent with the assumption in the RDR costing exercise.**

S1 Ultimate Goals

- Final goal (following the BCD definition):
  - **Achieve 31.5 MV/m at a $Q_0=10^{10}$ 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**
  - **All cavities built into modules perform at 31.5 MV/m including enough overhead as described in the BCD. The cavities accepted in the low-power test should achieve 35 MV/m at $Q_0 = 10^{10}$ with a yield as described in the S0 definition (80% after first test, 95% after re-preparation).**
  - **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.**

Refining the R&D Process

- Need for Intermediate Milestones
  - **Ultimate Goals are long-term**
  - **allow for tracking of progress in cavity preparation cycle**
- Describe work plan with four elements which are interconnected
  - **'Tight-loop':**
    - A few cavities over again, demonstrate that spread of process is small
    - Qualification of infrastructure and processes
    - Finally, the full process chain must be looped through
  - **'Production-like'**
    - Batches of cavities treated in same manner
  - **Single-cell R&D**
    - Define single-cell measurements where they are useful
      - Programme must be integrated into nine-cell effort
  - **General R&D**
    - Leave room for alternatives (e.g. large-grain material)
- Define measurement best practice to make results comparable e.g.
    - Passband mode measurements
    - Check for hydrogen contamination ('Q-disease')
    - Temperature-mapping of the niobium surface for multi-cells in all regions
- Need estimation of capacities for testing and cavity production
  - **Overall testing capacity will be limited**
  - **A lot of the testing needs to be done on multi-cell cavities as assemblies and procedures are different for single-cells and multi-cells**

Problematic Issues

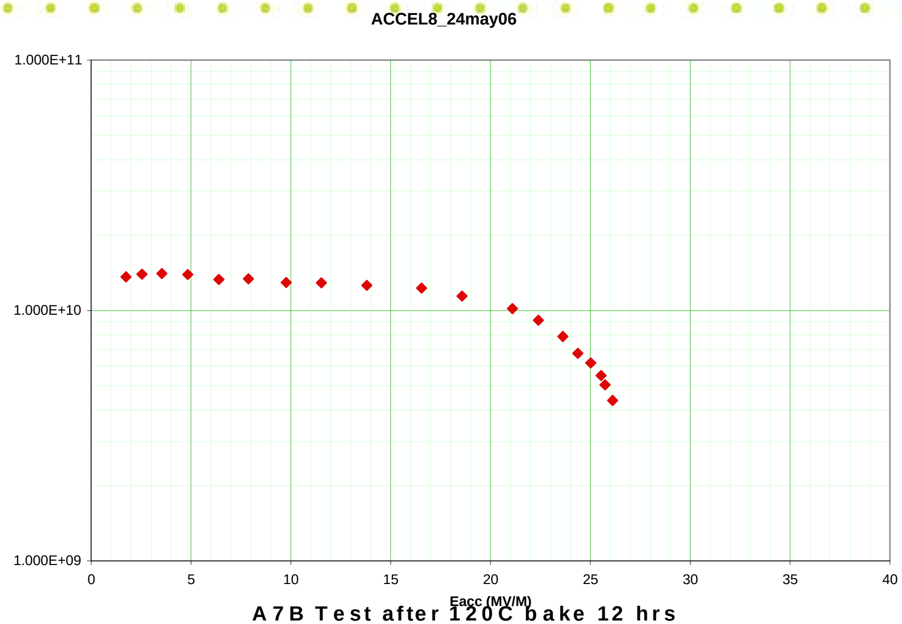
- Variety of cavity types is not helpful in the long-run
  - **Various lengths, flange systems, magnetic shielding, HOM damping etc.**
  - **For the ultimate goal a single cavity type is needed**
    - Can be built and treated in different regions in parallel provided processes are transferable
- Variety of recipes and setups
  - **Must develop protocols that guarantee transferable results**
    - Monitoring of parameters should make processes more transparent (e.g. HF content)
    - Exchanging cavities can facilitate
  - **Setups need to be qualified first (tight-loop)**
- Many process steps from niobium to cavity in accelerating module
  - **New vendors will have to learn**
  - **separate final process reproducibility from cavity reproducibility (includes fabrication)**
- Cavity development is ongoing
  - **Staging of cavity production is necessary to allow for evolution in cavity design and process improvements**
- Ultimately the number of cavities being built and treated will be small compared to the ILC number of cavities

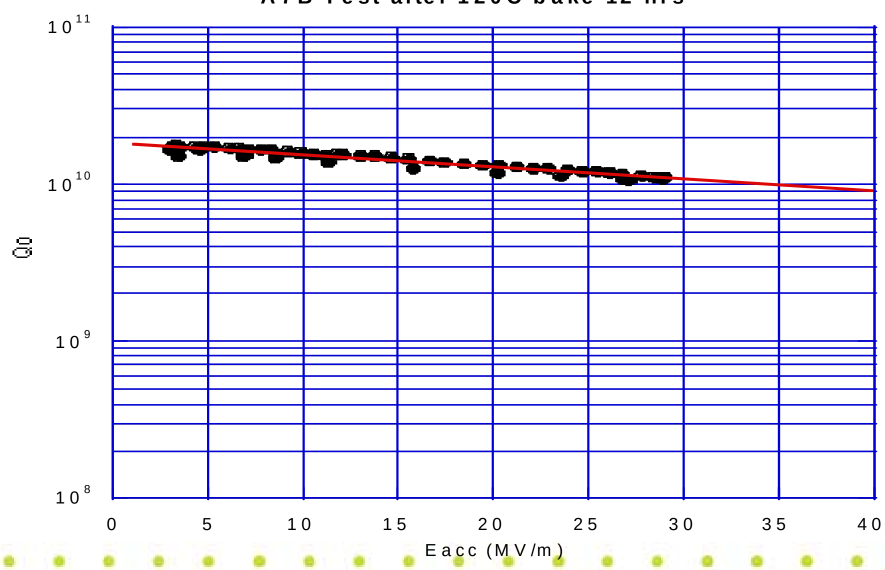
Tight-loop experiments

- Needed for
  - **Qualification of infrastructure and processes**
    - Focus is on the final EP (10-30 um), HPR and bakeout
    - Has started in now
  - **Comparison of processes between labs**
  - **Demonstrate improvements suggested by parallel single-cell R&D**
  - **Important intermediate milestone**
    - … be an improvement over the TTF experience with EP production cycle 1
    - … provide data for a decision on the baseline gradient
- Implementation
  - **A few cavities over and over again, demonstrate that spread of process is small**
  - **Two Phases**
    - Phase 1 (until mid-end 2007)
      - Select best 9 cavities of available cavities today (3 per region)
        - » To avoid manufacturing defects
      - Repeat preparation three times in home region
      - Send to other regions, each region to prepare and test three times
    - Phase 2 (until mid-end 2008)
      - After improvements from parallel single-cell are implemented, repeat above sequence
  - **Resources**
    - Cavities and testing capacity need to be made available

New Cavity Preparation Infrastructure in the US: First results (Data from H. Padamsee and J. Mammosser)

- May 06: Cornell BCP
  - **26 MV/m, no field emission, limited by high-field Q-slope due to BCP, EP on the way.**
- Sept 06: Jlab EP/bake
  - **29 MV/m, no field emission, limited by quench**
  - **Test stand needs improvement:**
    - Higher power amplifier (on the way)
    - Variable coupling





Single-cell R&D on Surface Preparation

- Needed to optimize the parameters for surface rinses
  - **Candidates are Oxipolish, Degrease, Alcohol**
  - **HPR should be pursued more systematically**
- Timeline:
  - **Results needed by mid/end 2007 for inclusion in 'tight-loop' experiments**
  - **Later results could still be useful for improvements in production mode**
- Implementation
  - **Proposal to invite TTC to implement single-cell program with ILC support**
    - TTC's role is exactly that. Excerpt from mission statement:
      - The mission of the TESLA Technology Collaboration (the Collaboration) is to advance SCRF technology R & D and related accelerator studies across the broad diversity of scientific applications, and to keep open and provide a bridge for communication and sharing of ideas, developments, and testing across associated projects.
  - **Task force proposes to profit from this and work together with TTC on a R&D program focused on ILC issues by making very specific requests for information and experiments.**

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

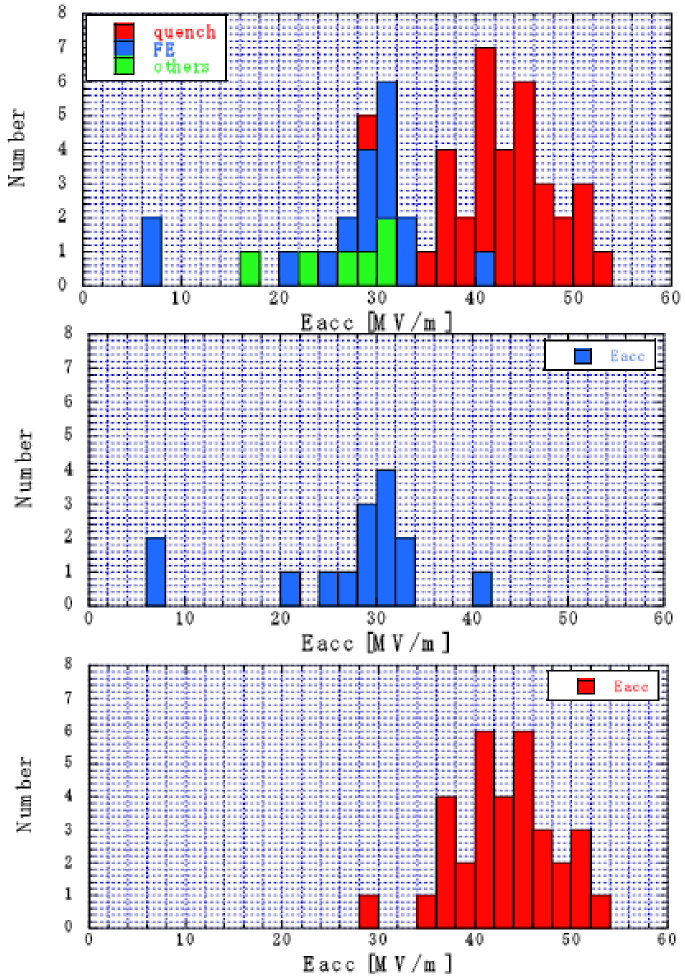
Analysis of KEK single-cells (F. Furuta)

IS series Histogram

IS cavities results (All)
AVE. Eacc = 37 MV/m.
STDEV = 10 MV/m.

IS cavities results (FE)
AVE. Eacc = 27 MV/m.
STDEV = 9 MV/m.

IS cavities results (quench)
AVE. Eacc = 43 MV/m.
STDEV = 5 MV/m.

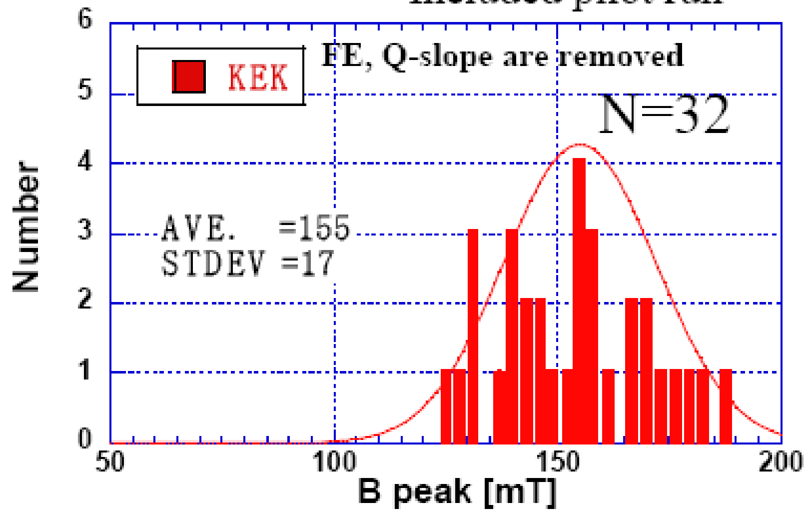


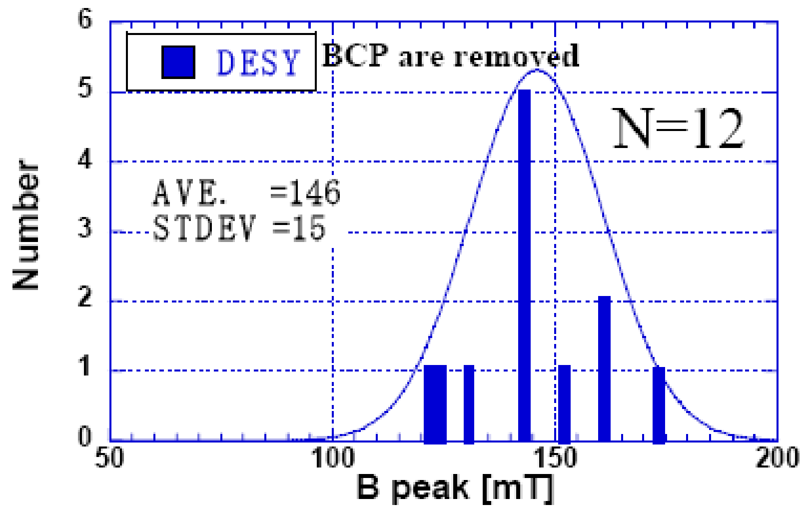
- Ichiro-shape
  - **Alternative shape**
    - Very similar to Low-loss
- Data from a series of experiments with slightly varying parameters

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.

Production-like experiments

- **Needed for**
  - Qualifying vendors
  - Full process yield including material and fabrication
  - Giving finally the production yield to demonstrate ultimate goals (S0)
    - Large number needed to get statistics right
  - Assembly of modules (S1) and later (S2) (goals under discussion)
- **Implementation**
  - Batches of cavities treated in same process once or twice
  - Improvements in the processing will come from single-cells and tight-loop effort
  - Phases
    - Stage 3 'Production-like' (start now)
      - Order batches of cavities
      - According to first assessment, the total number of cavities in hand by end of 2007 could be ~50-60.
    - Stage 4 'Final Production' (finish mid-2009)
      - » Carry out full treatment. Apply best recipe from Stage 2 to the large batch of cavities
- **Resources**
  - Overall cavity number is low
  - Especially in 2008, see next slide
  - Eventually these cavities have to go to the module assembly

Cavities available/needed

- Task force recommends to increase overall number of cavities
- 2007
  - **KEK**
    - Current plan: 4+4(+2) STF 1; Order 4+4 STF 1.5
    - Qualifying vendors can endanger good cavity yield
    - Proposal: At least 10 cavities beyond the STF Phase 1.5 being purchased for production-like experiment
      - Proposed shape under discussion, exchangibility essential
  - **XFEL:**
    - 15 underway; 30 on order
    - Important data point: Vendor qualification, fabrication yield
    - How much can we influence the recipe still?
  - **Americas**
    - Productions started
      - 4 ACCEL, 2 JLab, 4 AES; On order 6 AES, 8 to be decided
    - Qualifying vendors can endanger good cavity yield
    - Preparation studies urgent, new setups
    - Module production poses schedule limitations
    - 24 cavities in FY07 will arrive rather late (probably 2008)
- 2008
  - **XFEL: under discussion**
    - Clearly training industry becomes more and more important
  - **KEK: Currently 24 for STF Phase2 planned**
  - **Americas: 48 planned**
  - **Task force recommends at least 160 world wide (under discussion)**
    - 128 from qualified manufacturers
    - 32 for new manufacturers

Cavity Preparation Capacity

- Overall cavity preparation capacity is limited
  - **Conflicts for resources with other projects**
  - **R&D-like setups**
    - Lot of down-time for maintenance
    - No redundancy
  - **Involvement of industry is small in EP process**
    - XFEL effort to get industry involved on the way, other regions?
  - **A next step could be the development of a next generation facility**
    - Implement improvements from the process
    - Include redundancy
    - Could serve a pre-production type operation
      - Scale needs definition
    - Task force tentatively suggests discussion in 2007 when process becomes clearer -> recommendation end 2007?

Vertical Test Capacity

- Testing capacity is also an issue
  - **Conflicts for resources with other projects**
  - **Standardized tests desirable**
    - Passband mode measurement
    - Check Hydrogen contamination etc.
  - **Diagnostics must be made available (T-map!)**
  - **Production-like operation necessitates fast turnaround**
    - Increases need for testing significantly
  - **Estimates**
    - Tight-loop: ~100 tests
    - Production-like: ~300 tests
    - Single-cell needs are difficult to estimate now but is large
  - **Available (without considering other projects)**
    - A fully equipped facility (e.g. TTF, STF or similar) could do about 50 tests including preparations per year
      - Rough estimate, probably on the optimistic side
    - Existing (neglecting other projects!)
      - JLab, STF, DESY: 50/year= 300 total
      - FNAL (1 ½ years - under construction): 75 total
      - Cornell: 12/year = 24 total
    - **Sum** **400 total**
      - Options:
        - » Second teststands at JLab and KEK: 200 total
    - Diagnostics or special tests capacity is too small
      - Could be given to specialized labs

General R&D

- The task force will produce a statement to alternatives and other R&D issues in the near future
  - **Potential topics**
    - High-peak power processing
      - Understand field emission which is the main limiting effect
      - Potential remedy for curing accidents in main linac
    - Alternatives:
      - Material, Shapes etc.

Summary and Outlook

- Several multi-cell cavities have met ILC specifications
  - **In production mode yield of multi-cells is not yet sufficient**
  - **Single-cells have achieved much higher gradients**
  - **Fine-tuning of parameters needed**
    - Avoidance of contaminants
    - Improved quality control
- Program to address this issue is being developed i.e.
  - **Defined goals**
  - **Make Results more comparable**
  - **Develop common set of parameters**
  - **Assess global capabilities**
  - **Synchronize efforts**
- Task force has prepared a work plan for Tight-loop, Single-cell R&D, Production-like (nearly there)
  - **These elements are linked to each other (see talk)**
  - **R&D plan will take stock of TTC for an efficient use of resources**
  - **Statement on other R&D e.g. alternatives to follow**
- Outcome should give confidence for the technical design phase
  - **Staging i.e. intermediate goals can help to account for progress**
  - **Overall cavity count and test capacity for R&D program is small compared to ILC numbers**
- This should demonstrate an effective model of international coordination of R&D efforts
  - **Long-term management of this effort will need resources**
    - Follow progress of the experiments
    - Assess data