S0S1 Taskforce

High-Gradient SC Cavities

Lutz Lilje

GDE

Outline

- Recapitulation
  - **S0S1 charge**
  - **S0S1 goals**
- Executing the S0S1 Plan
  - **First results**
  - **Further refinements**
  - **Estimation of resources**

- Alternatives (in second part of the talk)

‘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)

- Will add dedicated manpower to the taskforce:
  - **project engineer for coordination**
    - coordinating cavity exchange, keeping track of tests
    - implementation of standard data sets
  - **scientific investigator**
    - data evaluation
    - improve data consistency

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 EDR (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.**

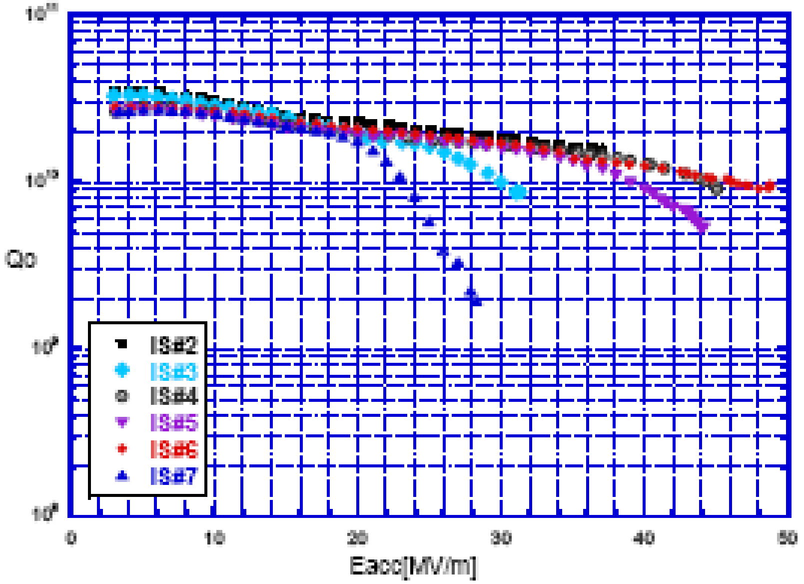
S0S1 'Tight-Loop': Improvement of the Cavity Preparation Process

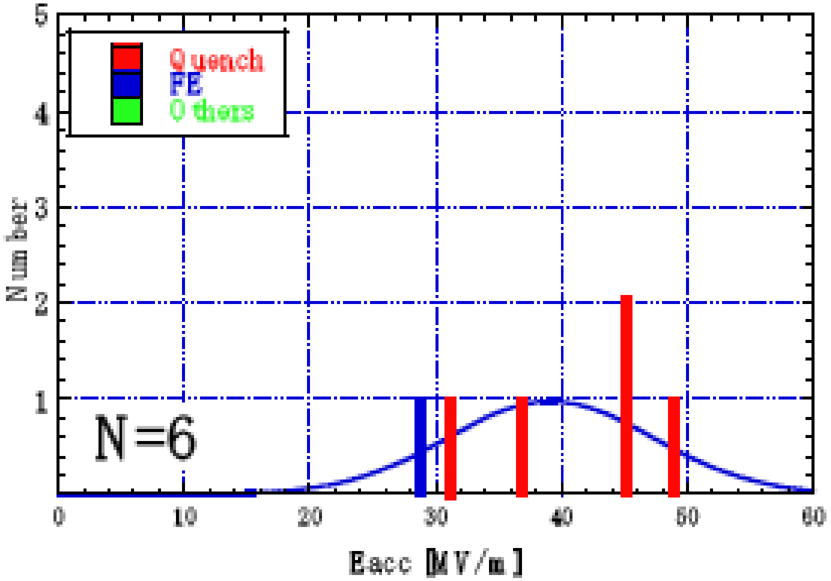
- Basic assumptions
  - **Preparation is the critical step**
- Main goal:
  - **Demonstrate 80% yield in first acceptance test, then 95% with second try**
- Tight-loop
  - **Test minor variations in the final surface preparation**
    - Conduct a dedicated single-cell program
    - cavity exchange
  - **Demonstrate multi-cell handling**
  - **Compare regional preparation setup performance**
  - **Demonstrate optimized treatment in a second cycle**
- R&D results
  - **Single-cells**
    - Comparison of final preparation methods (mostly at KEK)
    - Yield already one strong candidate for these processes: 'fresh acid'
  - **Multi-cells**
    - First tight-loop experiments
    - Two candidate processes: Ultrasound degrease and H2O2

S0-Single cell study @ KEK

	Eacc, max[MV/m] / Qo@Eacc max								Ave.Eacc
recipe	IS#2	IS#3	IS#4	IS#5	IS#6	IS#7	CLG#1	CLG#2	
(A) CBP+CP+AN +EP(80) +HPR+Bake	36.90	31.40	45.10	44.20	48.80	28.30			39.1±8.2
	1.53e10	8.66e9	9.07e9	5.38e9	9.64e9	1.94e9			
(B) CBP+CP+AN +EP(80+3)+HF +HPR+Bake		42.00	46.10	44.70	34.25	39.30		43.80	41.7±4.4
		9.72e9	9.47e9	1.08e10	8.56e9	1.03e10		3.46e9	
(C) +EP(20) +HPR+Bake	47.24	52.44	52.91	31.10	48.92	46.54			46.5 ±8.0
	5.98e9	1.51e10	5.23e9	5.21e9	7.56e9	9.03e9			
(D) +EP(20+3)+HF* +HPR+Bake	47.07	44.67*	47.82		48.60*	43.93*	47.90*		46.7 ±1.9
	1.06e10	0.98e10	0.78e10		0.80e10	1.17e10	1.0e10		
(E) +EP(20)+H_2O_2 +HPR+Bake	Now on going								
(F) +EP(20)+Degrease +HPR+Bake									

(A) CBP+CP+Anneal+EP(80μm) +HPR+Baking(120C*48hrs)



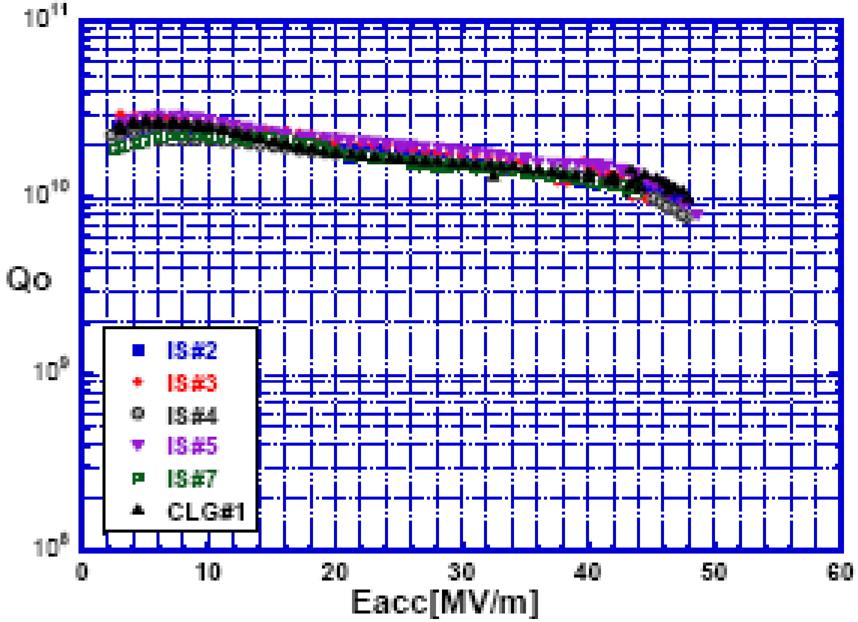


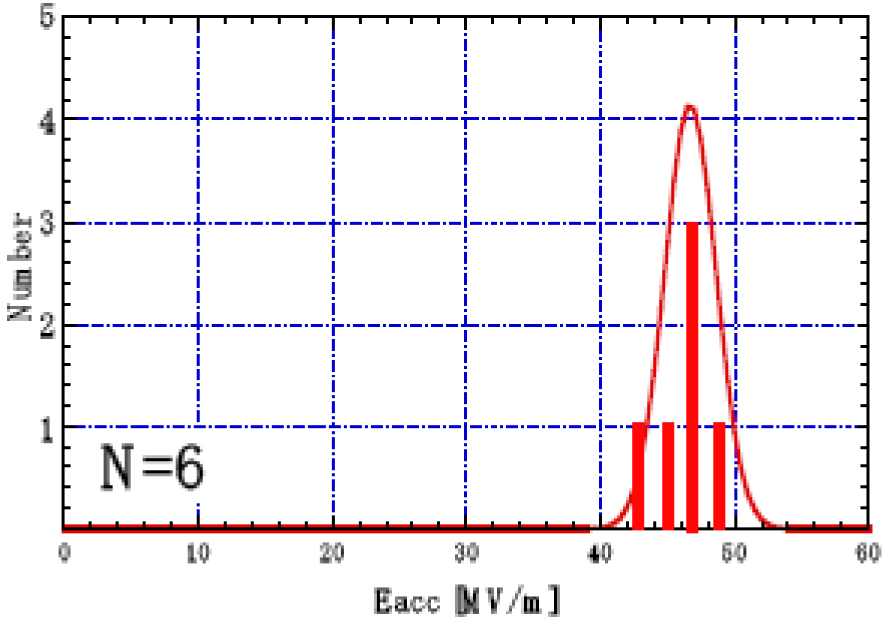
Ave. Eacc=39.1±8.2MV/m

Scattering:20%, Acceptability@40MV/m(ACD):50%

		IS#2	IS#3	IS#4	IS#5	IS#6	IS#7
EP(80)	Eacc	36.90	31.40	45.10	44.20	48.80	28.30
	Qo	1.53e10	8.66e9	9.07e9	5.38e9	9.64e9	1.94e9

(D) +EP(20μm)+EP(3μm, fresh, closed) +HF* +HPR+Baking (120C*48hrs)





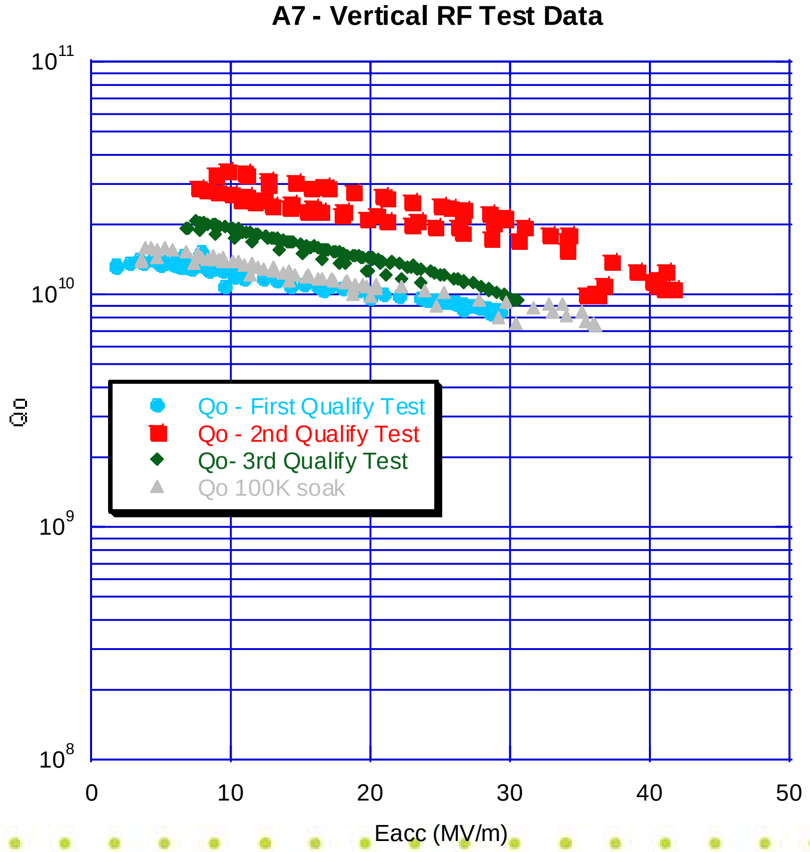
Ave. Eacc=46.7±1.9MV/m

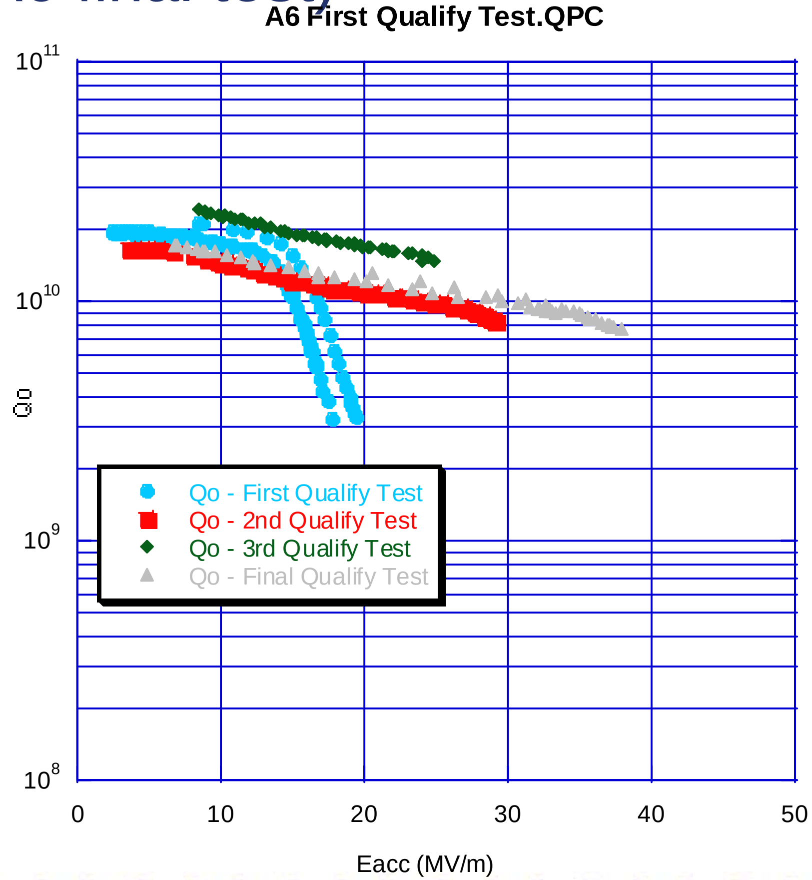
Scattering:4%, Acceptability@40MV/m(ACD):100%

		IS#2	IS#3	IS#4	IS#6	IS#7	CLG#1
+EP(20+3) +HF*	Eacc	47.07	44.67*	47.82	48.60*	43.93*	47.90*
	Qo	1.06e10	0.98e10	0.78e10	0.80e10	1.17e10	1.0e10

JLab Multi-cells: Second Alternative Rinse

- Second candidate rinse
- All curves but one limited by quench
- Field emission in one test (A6 final test)



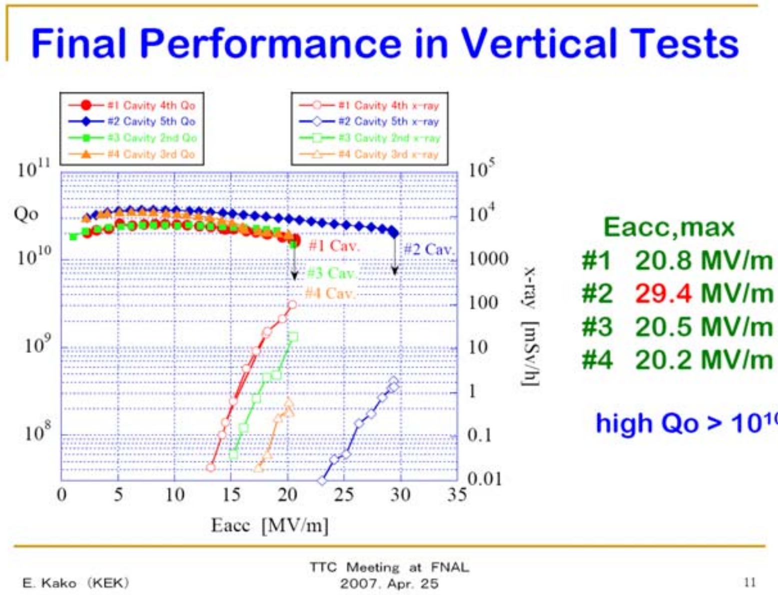


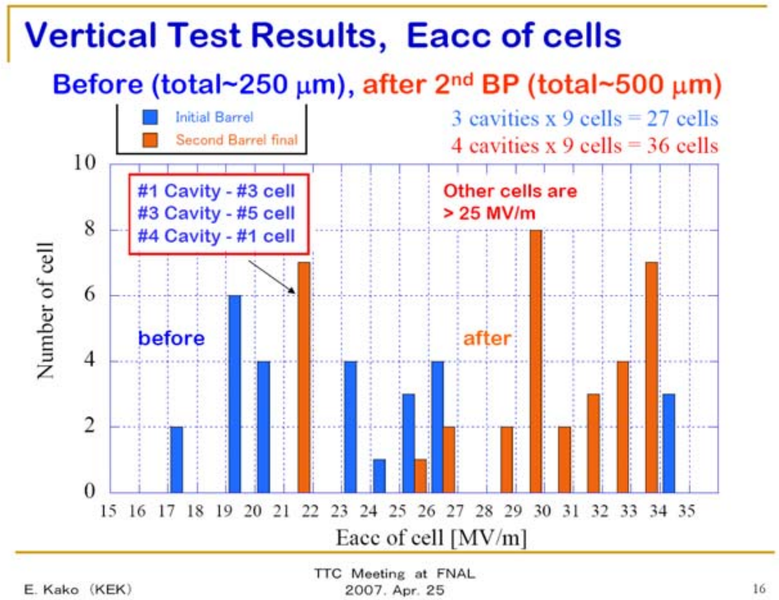
S0S1 'Production-like': Determine the Yield of the Full Production Chain

- Production-like tests
  - **Several cavities are treated in the same manner**
    - demonstrate full yield of the fabrication and preparation process
    - specify yield in more detail
    - includes cavity fabrication errors
      - New vendors will be tested
- R&D results
  - **KEK first try at new vendor (TESLA-like cavities)**
  - **US results on a qualified vendor**
    - Both JLab and Cornell results
  - **Update on Statistics**
    - Reference batch:
      - 3rd production DESY
      - R&D batch: several processings
    - Recent DESY results
      - 4th production
      - Real Production mode

KEK TESLA-type Multi-Cells

- New cavity vendor
- Surface treatment at 'standard' company
- Results
  - **Field emission in first processing**
  - **Only few cells are limited at low field ~21 MV/m**
  - **Similar to first 2 production runs at TTF few bad cells, but larger number gaussian distribution at higher gradient**
  - **Tighter QC for future production runs will be implemented**

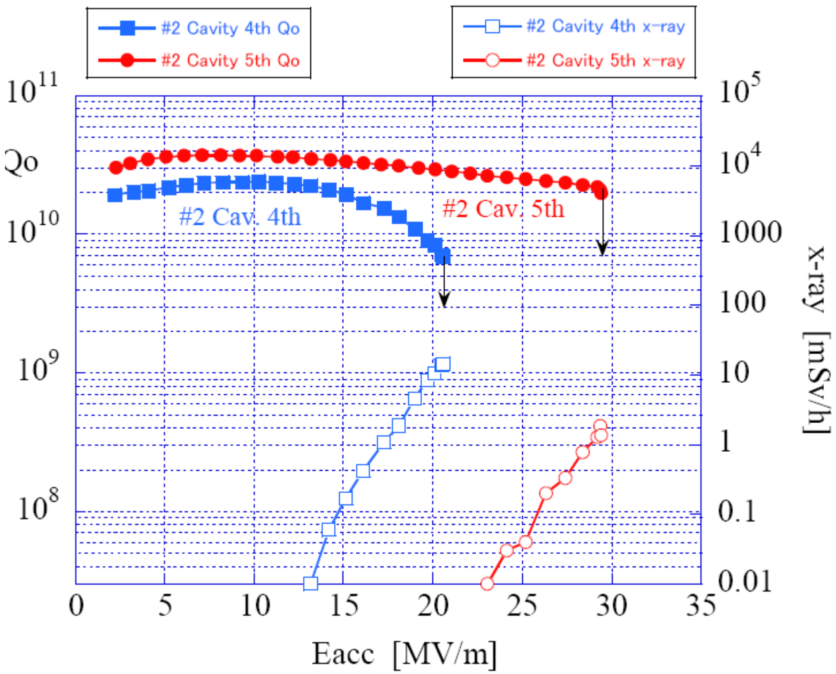




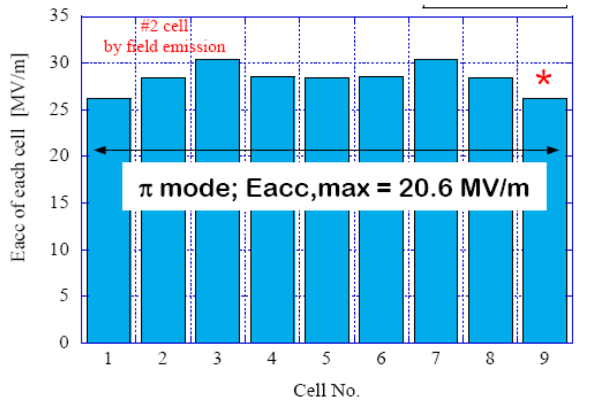
Vertical Test Results, #2 Cavity

#2 Cavity ; 4th and 5th Test

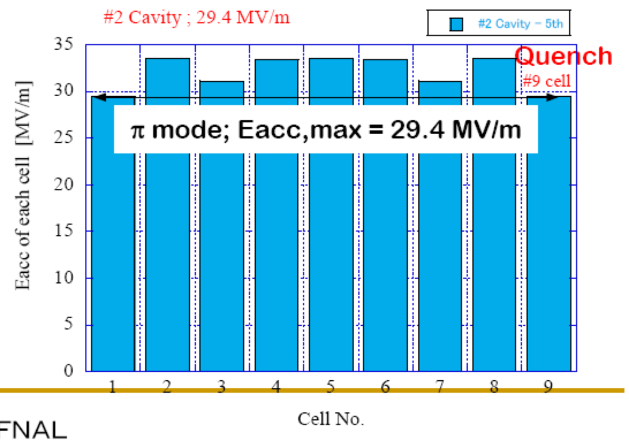
+ EP 20μm, H_2O_2 Rinse 1h, Hot Rinse 1h, HPR 16h



#2 Cav. 4th aft. 2nd Barrel Polishing



#2 Cav. 5th

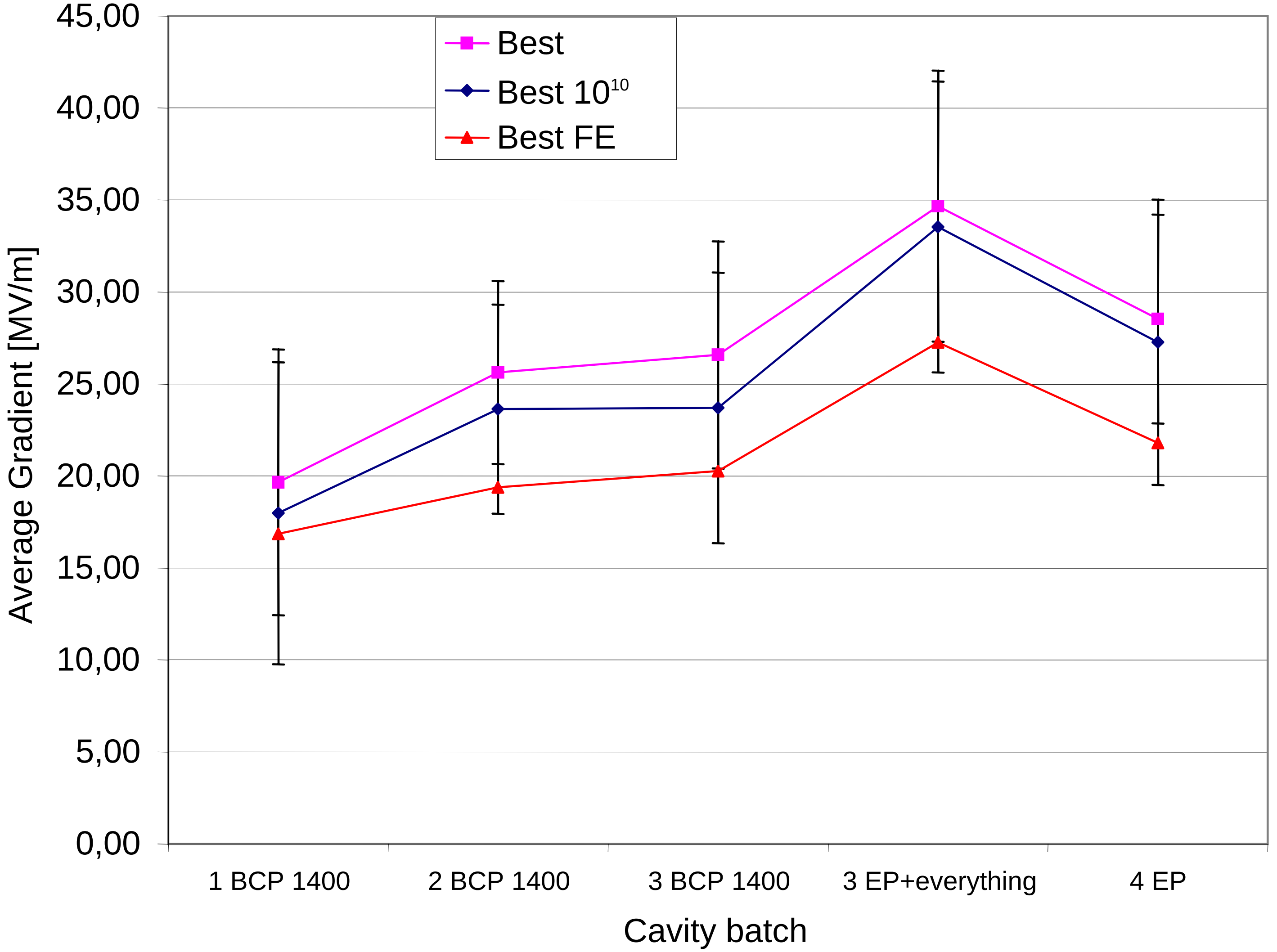


Comparison of qualified vendors: DESY and US Data

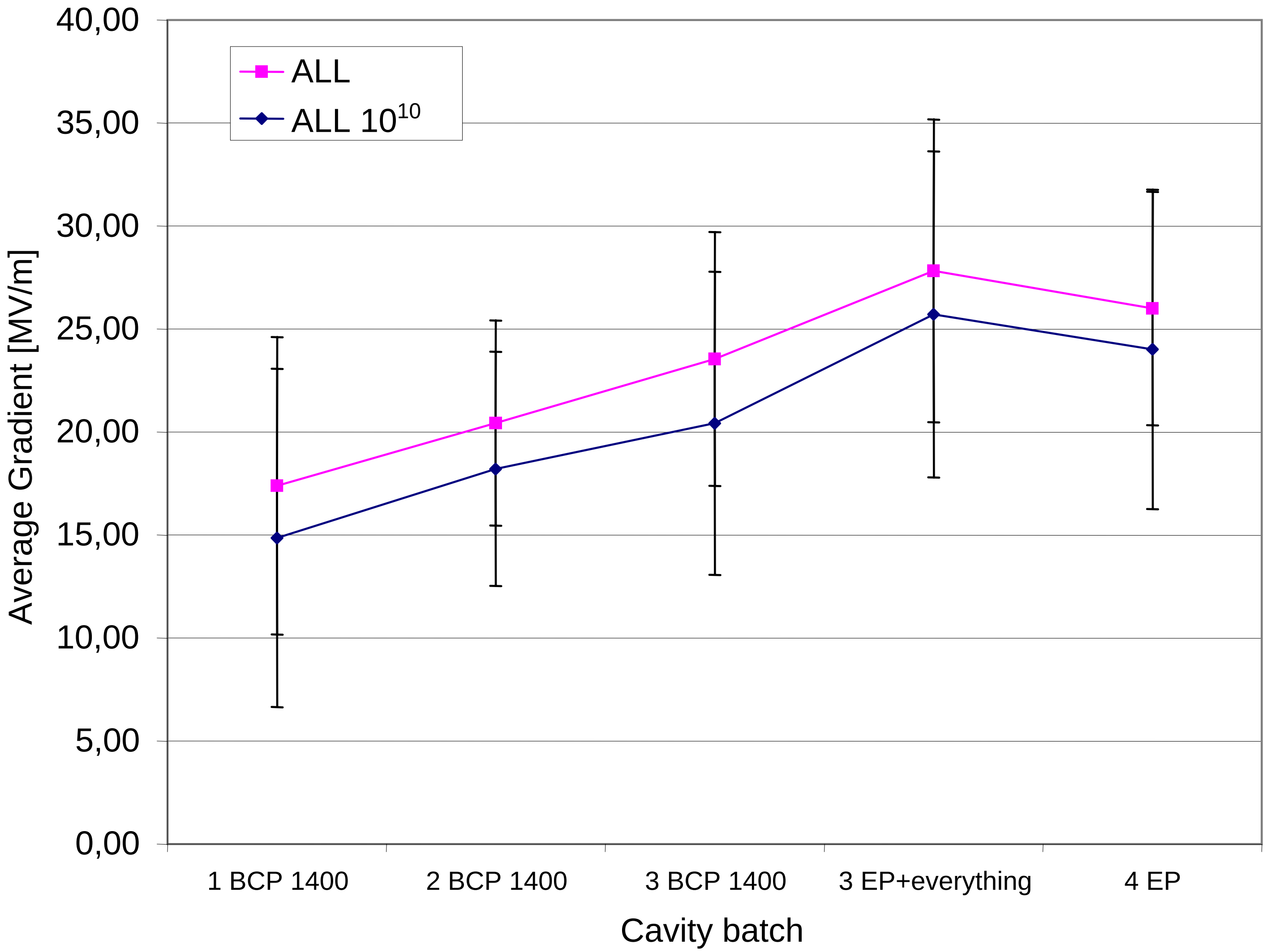
- DESY
  - **24-30 cavities each**
  - **reference: 3rd production**
  - **real production: 4th**
- US
  - **4 cavities total**
  - **Surface treatment**
    - Baseline: Horizontal EP at Jlab
    - Alternative: Vertical EP at Cornell
- So far average over those 4 cavities
  - **best: ~33 +/- 7.8 MV/m**
  - **all tests: ~30 +/- 6.5 MV/m**

- Make plot!!!!

TTF Productions: Best Test Results

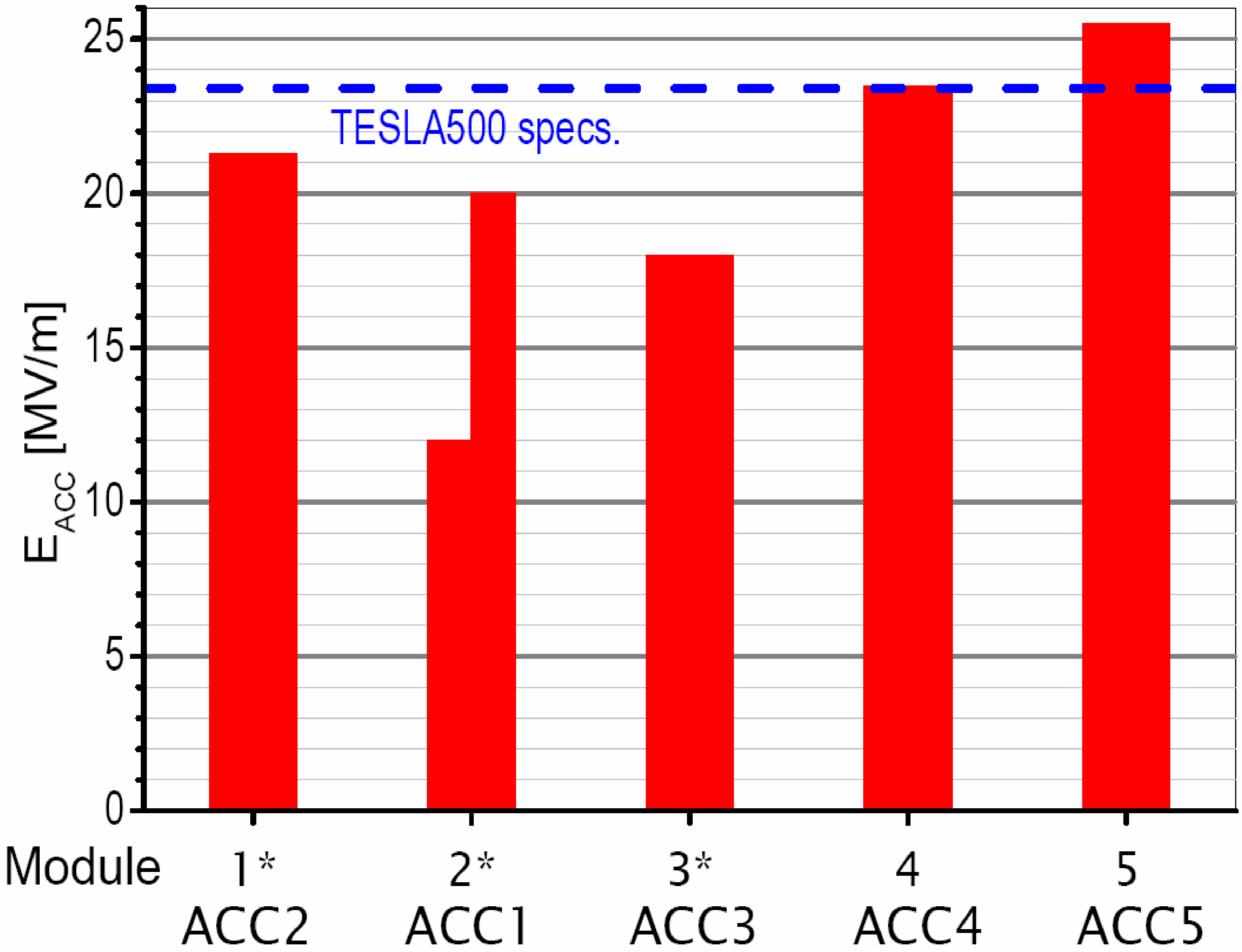


TTF Productions: All Test Results



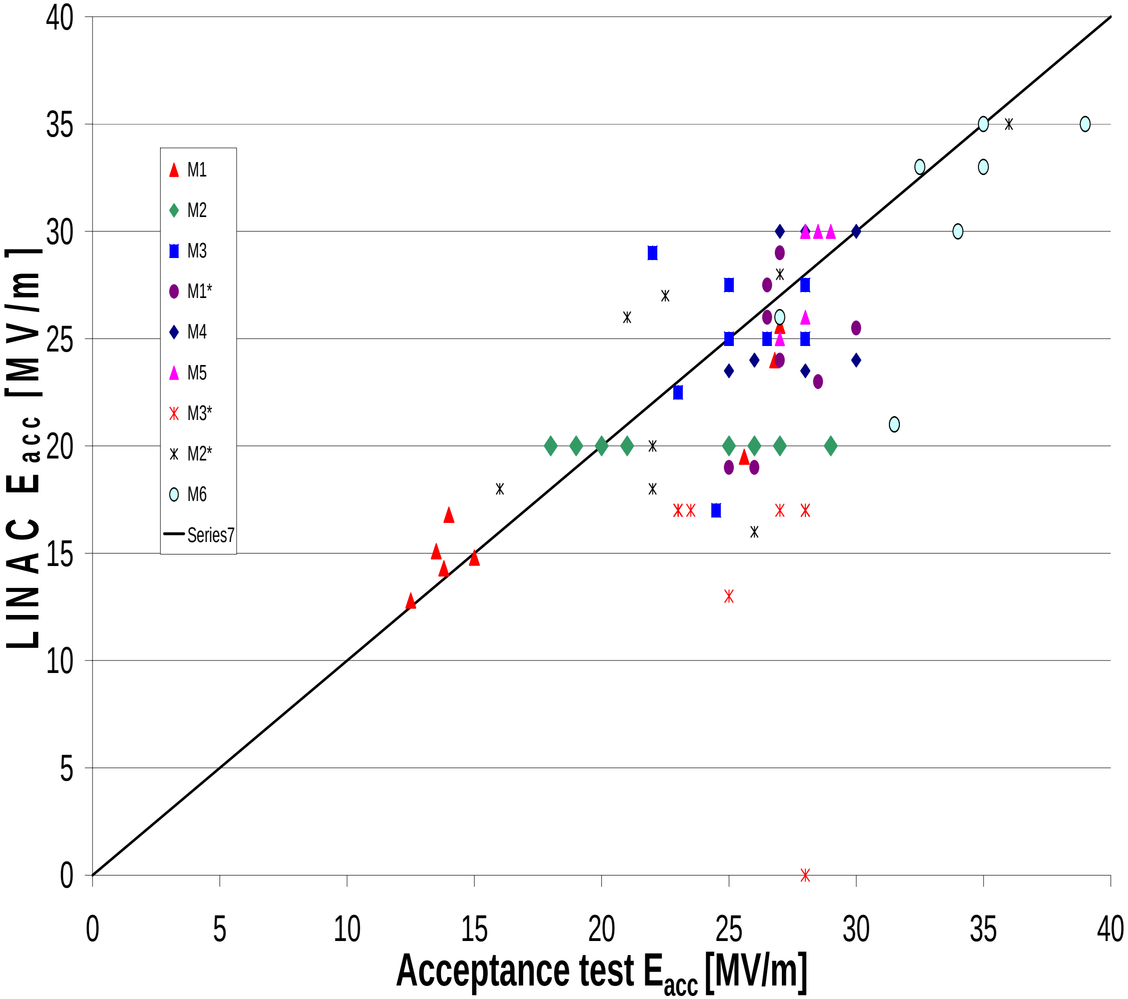
S1

- Module tests (S1)
  - **History of earlier modules**
    - M4 and M5 both much closer agreement between VTA and module performance
  - **M6**
    - Gradient
    - Couplers
    - Tuners
    - Thermal cycling
    - Vibration studies
    - ‘Excuses’....
      - try to focus on the ‘normal’-performing cavities
      - ‘handicapped’ module due to time pressure

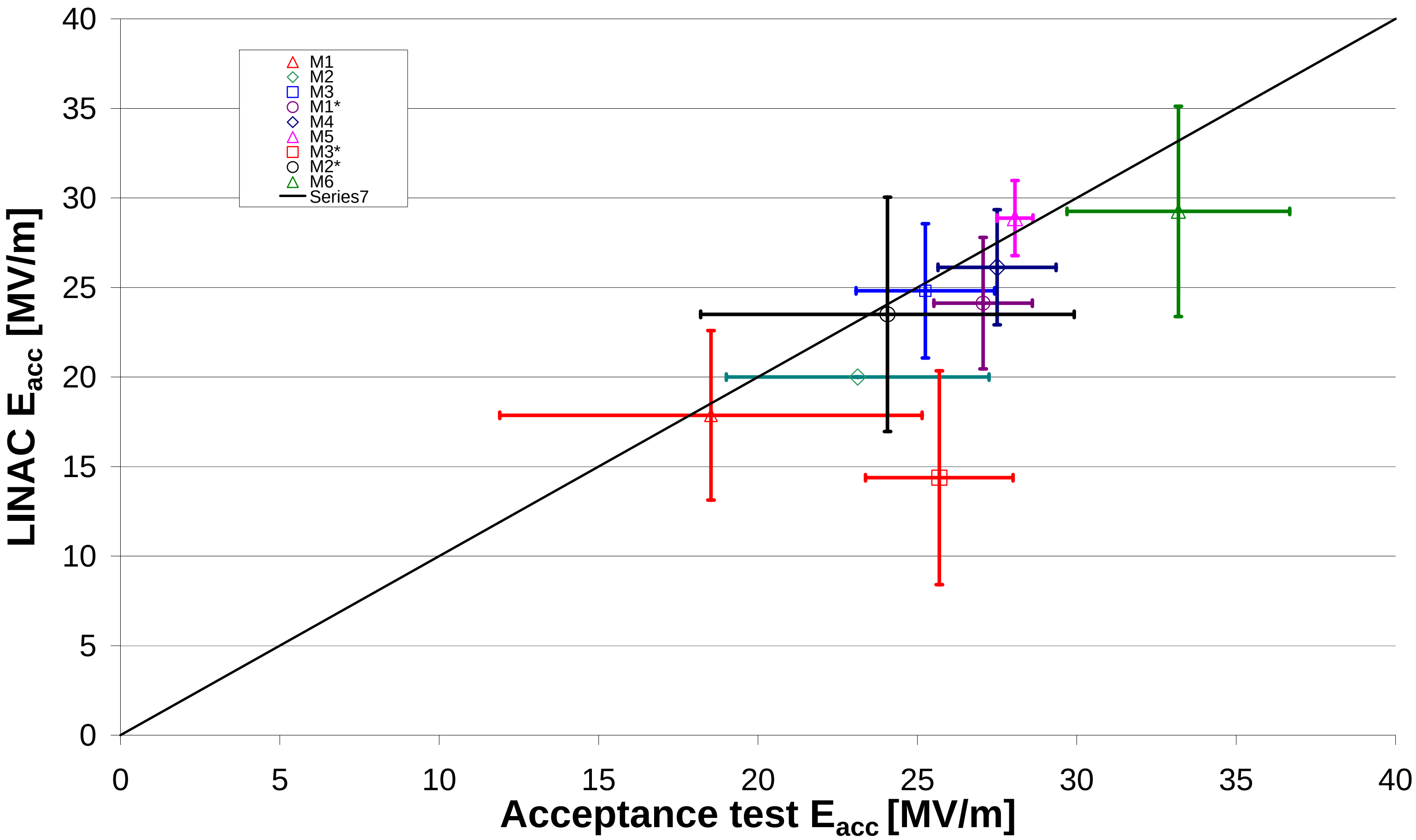

TESLA500 specs.
E_{ACC} [MV/m]
25
20
15
10
5
0
Module
1*
ACC2
2*
ACC1
3*
ACC3
4
ACC4
5
ACC5

LINAC vs. Vertical (Individual Cavities)

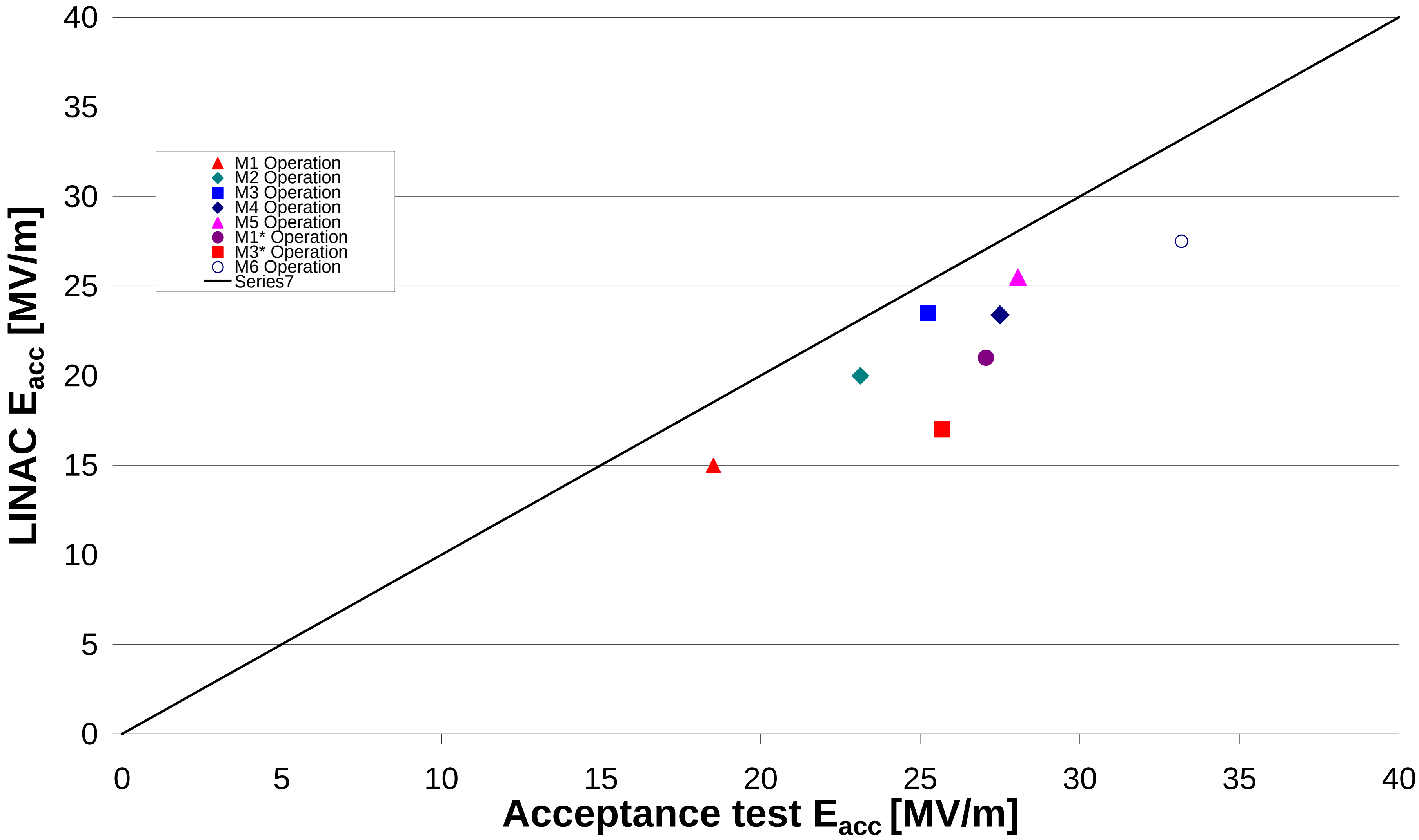
- Some cavities power limited
  - Esp. M5
- Coupler limited
  - M2
  - M4/C3
- Only module measurement available
  - M2



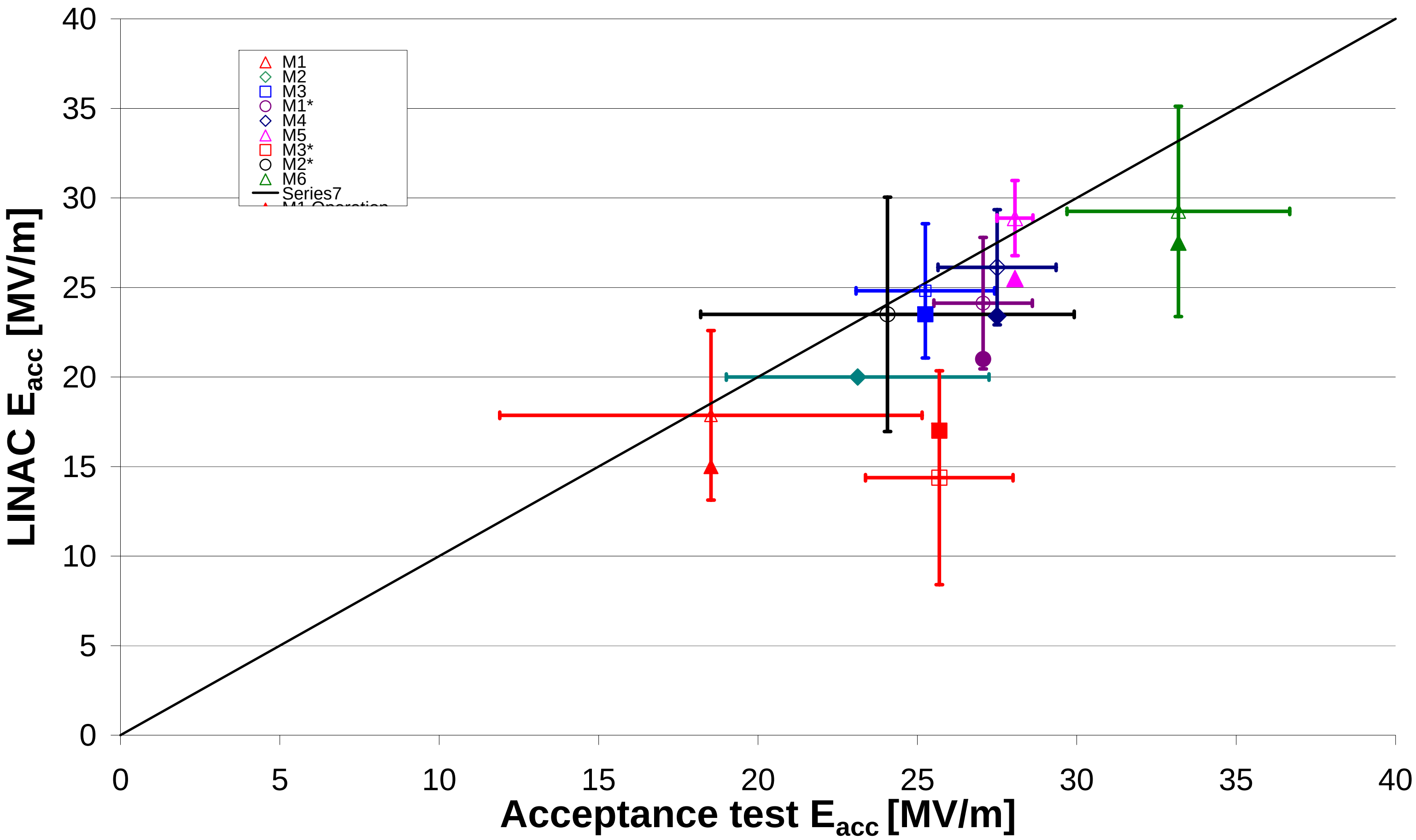
LINAC vs. Vertical (Cavity Average Gradients)



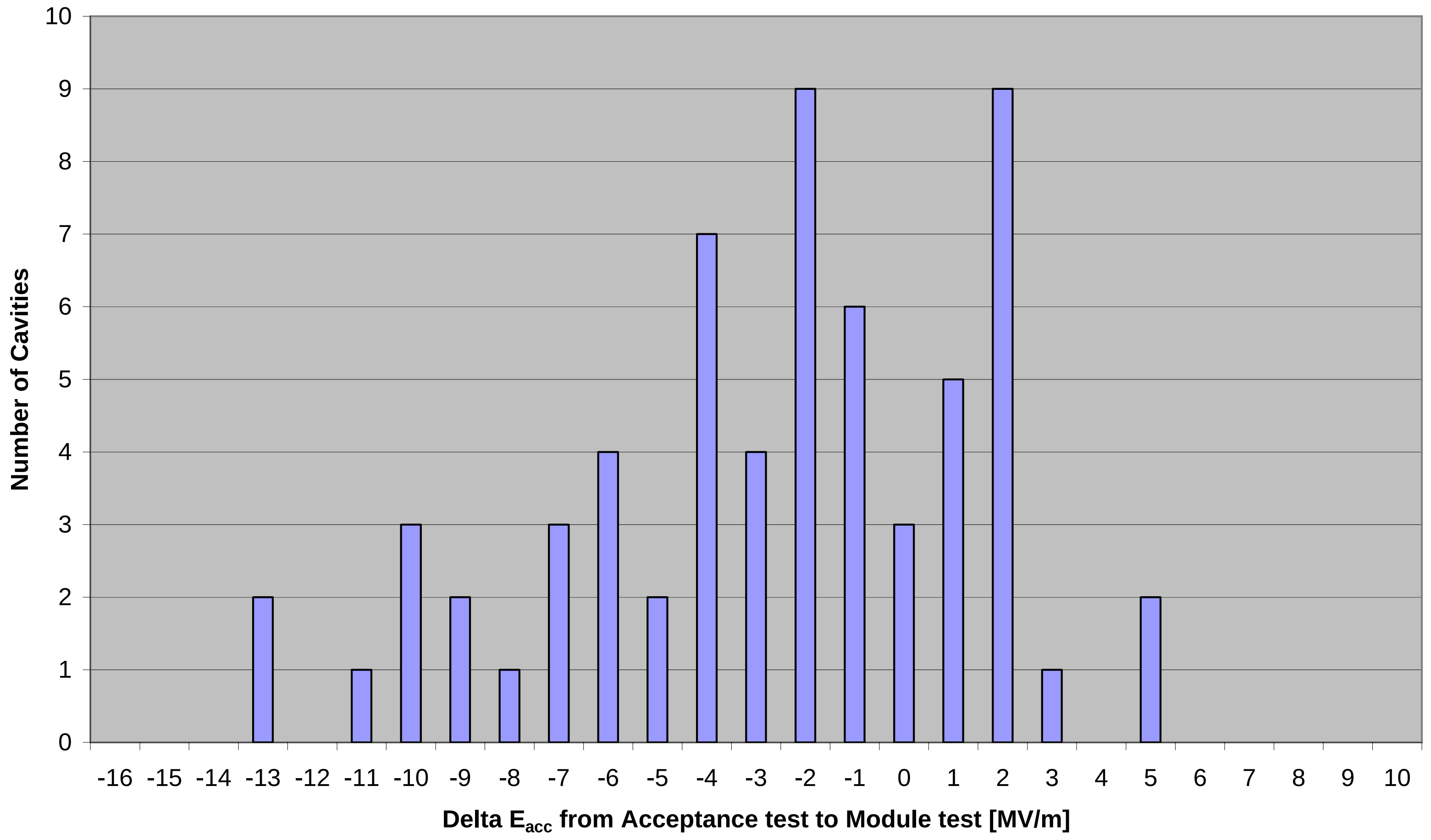
LINAC vs. Vertical (Module Max. Operational Gradient)



LINAC vs. Vertical (Cavity Average and Module Max. Operational)



Compare Acceptance Test with Module Operational Accelerating Gradient



INSERT M6 Tests Details here

Plan S1

- Planned until 2009
  - **DESY**
    - M7
      - not 31
    - M9
      - need statement on gradient from DESY
      - probably no slow-down due to cherry-picking
    - M10
    - Could pool cavities cavities from regions to assemble a cryomodule
      - e.g. x cavities from another region (US that is) in exchange for XFEL cavities
      - support from task force
  - **US**
    - 2007
      - Kit
        - » not 31
    - 2008
      - 1st
      - 2nd
        - » T4CM
        - » this would be delayed for cherry-picking
    - 2009
      - 2 more T4CM
  - **Japan**
    - STF Phase 1
- Evaluate Hasan's model on cavity production
  - **consistent with yielding enough cavities by end 2008?**
- Strategy
  - **to focus on a fast-track module with cavities from several regions**

S0S1 Planning: Estimation of Resources

- Estimate impact on whole project
  - What is the penalty for taking a cavity performance distribution of today?
- Estimate R&D cost (material and manpower)
  - cavity production is an expensive R&D item
  - include processing
  - Need continuous flow of smaller production batches as this allows to continuously improve processes and QC
    - will be used for estimation of final batch size
  - Develop 3 scenarios
    - Optimistic case
    - Realistic case
    - Pessimistic case
- Timeline for the S0S1 plan

Ultimate S0 Production experiment

- For the ultimate experiment
  - **only qualified vendors**
  - **only qualified preparation infrastructure**
  - **will start end 2009**
    - would be post-EDR
  - **Number of cavities should be A x 30 where A is greater or equal to 1**
  - **could take into account further results from parallel R&D effort (single-cell and tight-loop)**

ILC Cost for lower average gradients (following C. Adolphsen)

- Assume a distribution of gradients of a current cavity production with a large spread
  - average 28 MV/m ranging from 22-34 MV/m, flat distribution
    - e.g. DESY 4th production
  - tweak power distribution
  - reduce overhead a bit
    - due to a small loss in the efficiency of the RF unit
  - increases linac length by 12.5 %
  - yields 7% increase of total project cost ~500 MILCU
- Thus a major cost risk is associated with the average gradient.
  - As long as a wide range of gradients can be accomodated only the average gradient matters.

Backup Original Slide from Chris: Linac Operation with Variable Tap-Offs (VTOs) and Large Gradient Spread

Chris Adolphsen, SLAC

- Assume cavities produced with flat distribution of sustainable gradients (G) from 22 MV/m to 34 MV/m with <G> = 28 MV/m
- With Qeo optimized for Go = <G>, achieve flat cavity field at G with
  - **Qe = Qeo * ln(2) / ln (1 + G/Go * Qeo/Qe)**
  - **Input Power = Po * (1/4) * (1 + G/Go * Qeo/Qe)^2 * (Qe/Qeo)**
- Requires on average 6.8% more power per rf unit
- Maintain rf unit layout but increase linac length by 31.5/28 -1 = 12.5%
- At 31 MV/m, which is a 3-sigma variation in the mean gradient of an half rf unit, have same 16% tuning overhead as present design at 33 MV/m.
- Considering all changes, ILC cost increases by about 7%

What precision on the width of the distribution is needed?

- Calculate the precision on ‚faulty' cavities
  - **N= number of cavities in a production-like effort**
    - cavities
      - from one manufacturer
      - processes once or twice
  - **take delta e = sqrt(e*(1-e)/N)**
  - **calculate cost increase for the project**
    - if N=100, e=20% then delta e = 4 %
    - thus worst case need 4% more cavities
      - 30 MILCU
    - if N=60, e=20% then delta e= 5.1 %
      - 38 MILCU
    - if N=30, e=20% then delta e= 7,3 %
      - 54 MILCU
- This should be probed by a final batch of N cavities
  - **Time-line**
    - post-EDR
  - **N is a cost issues**
- Nonetheless one can already learn a lot looking at three scenarios for cavity productions
  - **takes into existing plans in the regions**
  - **includes pessimistic, realistic, optimistic planning (due to avaliable resources)**

Scenarios Cavity Production

- Pessimistic case
  - **EU**
    - ‚only' XFEL
      - limit processing to XFEL gradient (~28 MV/m)
  - **Japan flat budget**
  - **US flat budget**
- Realistic scenario
  - **EU**
    - XFEL
      - limit processing
    - 30 cavities from FP7
      - ILC processing
  - **Japan**
    - Flat
  - **US**
    - Minor increase in cavity numbers
- Optimistic scenario
  - **EU**
    - XFEL
    - 30 cavities from FP7
    - Additional high-gradient programme at DESY
  - **Japan**
    - flat (+20%)
  - **US**
    - roughly double number of cavities in 2009: 48

Cost for these Scenarios

- calculate the cost fabrication and one process cycle
- assumes the existance of cavity preparation infrastructure
  - **infrastructure development is not considered as part of S0 production**
  - **nonetheless it is closely related to the tight-loop**
  - **need to include number of preparation cycles (second preparation) for full cost estimate**
- need to add process cost for tight-loop
  - **30000 k$ per process**
  - **81 processes in first loop**
  - **27+ processes in second loop**
  - **roughly 3.5 MILCU**
- need to add the final batch for S0 production
  - **30 cavities**
  - **roughly 3 MILCU**
- EUR =$ on this slide

		KEK			**US**			**EU**						
		2007	2008	2009	2007	2008	2009	2007	2008	2009	Sum over 2007-2009	Cost Fabrication	Cost Processing	Cost Sum
	pessimistic	8		24	14	20	20	30	20	30	166	12450000	5810000	18.260.000,00 €
	realistic	8		24	14	24	30	30	30	60	220	16500000	7700000	24.200.000,00 €
S0	**optimistic**	10		24	14	24	48	30	30	60	240	18000000	8400000	26.400.000,00 €

Value added from these scenarios

- Get an estimate
  - **on average gradient**
    - see 4th DESY production
  - **on spread of the gradient**
    - see 4th production again
- Even the pessimistic scenario will improve this to
  - **an average gradient**
    - which is based on many more cavities
    - additional capacity for cavity fabrication (new vendors) and preparation (added infrastructure at labs)
  - **a gradient spread with an error of ... %**
- thus this information will be submitted with a recommendation for the final gradient of the ILC

Evaluation of the pessimistic scenario

- Roughly 160 cavities total up to 2009
  - **about 80 will be put through a mature infrastructure for the final preparation step (EU)**
    - tighter quality control at the vendors
    - this might differ from the final ILC preparation process
  - **the other 80 will be partially from qualified vendors and new vendors**
    - use new infrastructure tailored to the final ILC preparation process
- The fabrication yield can be estimated from this data set at least to exclude major fabrication problems
- This scenario will provide a lower boundary of the average gradient
  - **minimum expectation is a gradient level of the 4th production at DESY ~27 MV/m (TBC) with a spread of ... MV/m (TBC)**
  - **with an optimized process available in the other regions an improvement of the average gradient should be demonstrated**

Evaluation from the other scenarios

- More cavities are put through the optimised ILC process assumed to be available by mid 2008
  - **assumes new vendors**
  - **pessimistic scenario: 64 cavities**
  - **additional in 2008/09**
    - the numbers of cavities which could be subjected to a new process increases to 108(126) cavities in the realistic (optimistic) scenarios
  - **this is the demonstration of a higher average gradient with better statistics**
    - due to improved preparation steps
    - results available for the EDR

Final cost table

- Optimistic with final batch + tight-loop
  - **33 MILCU**
- compare to the risk of the width
  - **this half of what be the final cost impact on the project**
- relation of the average gradient to the 500 MILCU

Seperate out XFEL relation

- Material issues
  - **scanning for a large batch of material**
  - **qualifying more vendors**
- continuous production of cavities in line of preparation improvements
  - **is a significant part of the cavity data set**
- pre-series will start 2008
  - **EP is becoming industry process from autumn**
- Design for manufacturing for the cavities
  - **weldings**
- Quality assurance
  - **defining a reasonable and affordable QC procedure**
- (Coupler industrialisation)

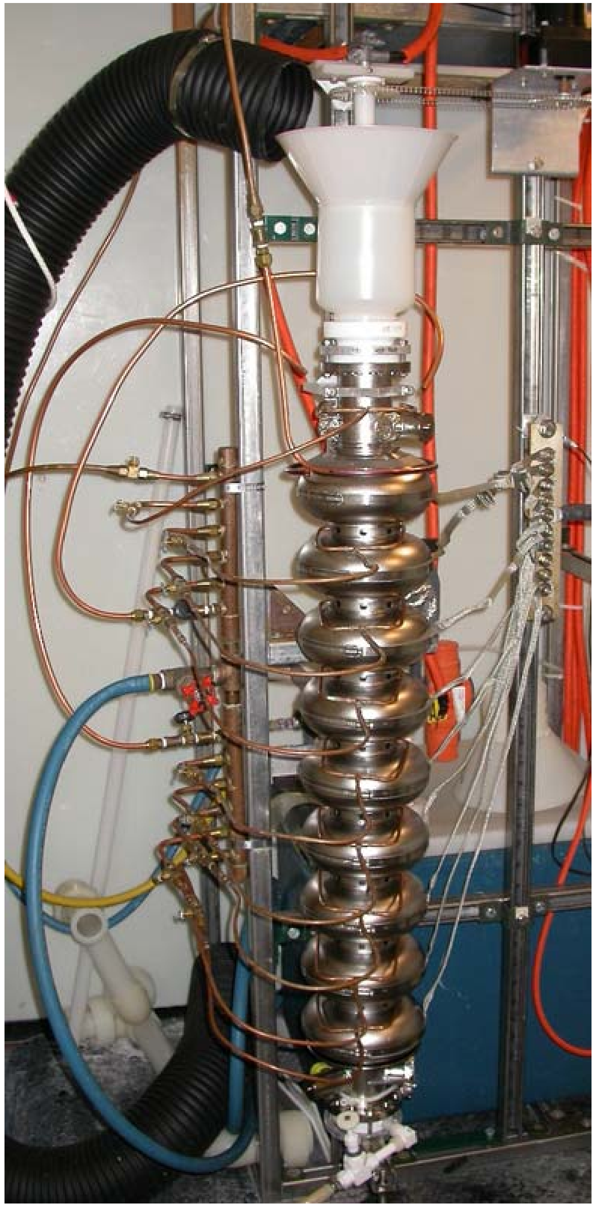
- Module design has been reviewed by industry

Alternatives

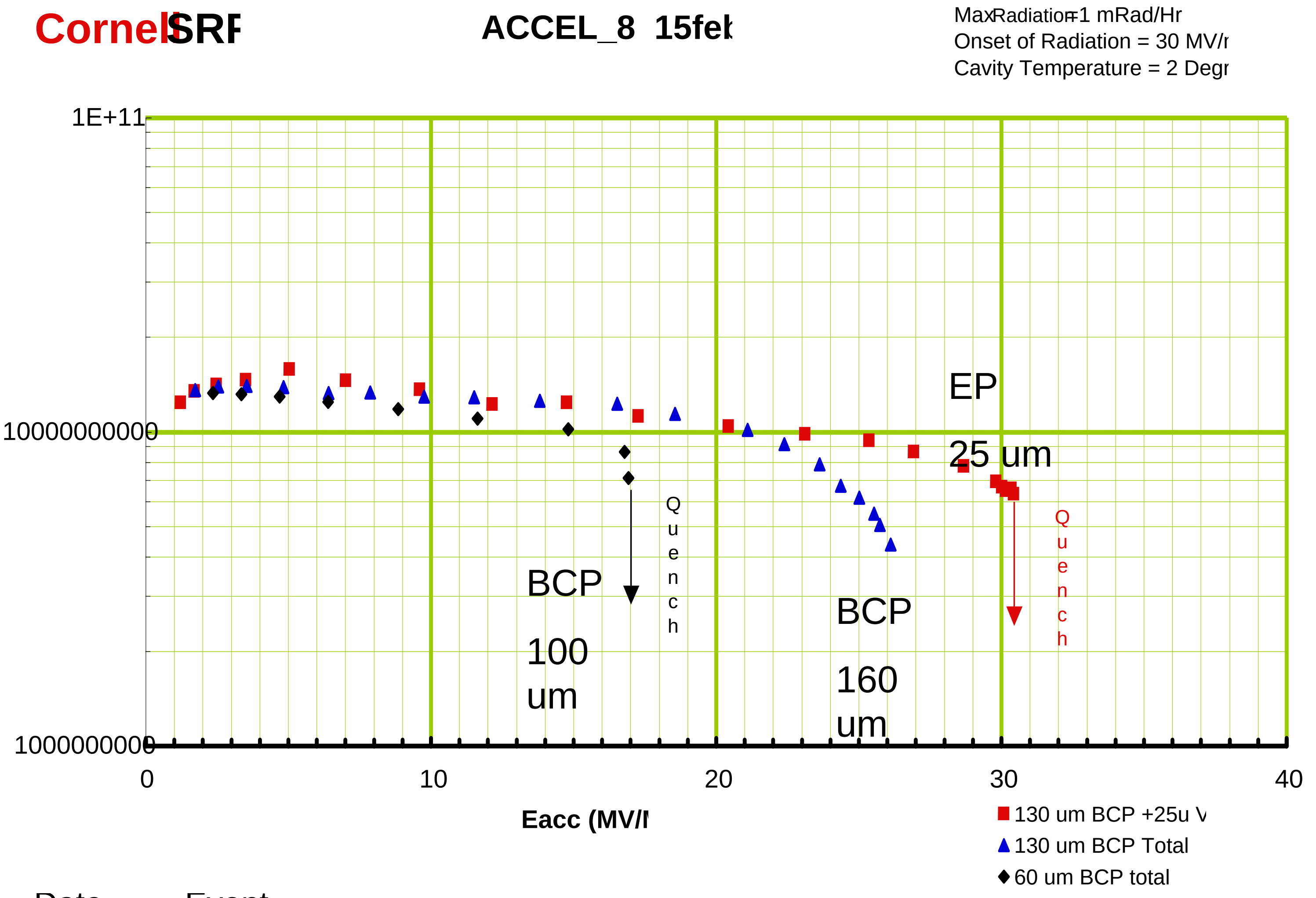
- LL, Re-entrant
- Vertical EP
- Large-grain with and without EP

Vertical Electropolishing Set-up

- Possible benefits
- Simpler
  - No large acid barrel, no plumbing, valves, no acid heat exchanger…
- Less expensive to reproduce many systems
- Possible disadvantage
  - more exposure to H
  - 600 - 800 C, H degassing required



Vertical EP Moves Forward
ACCEL- 8 Test Results



Date Event

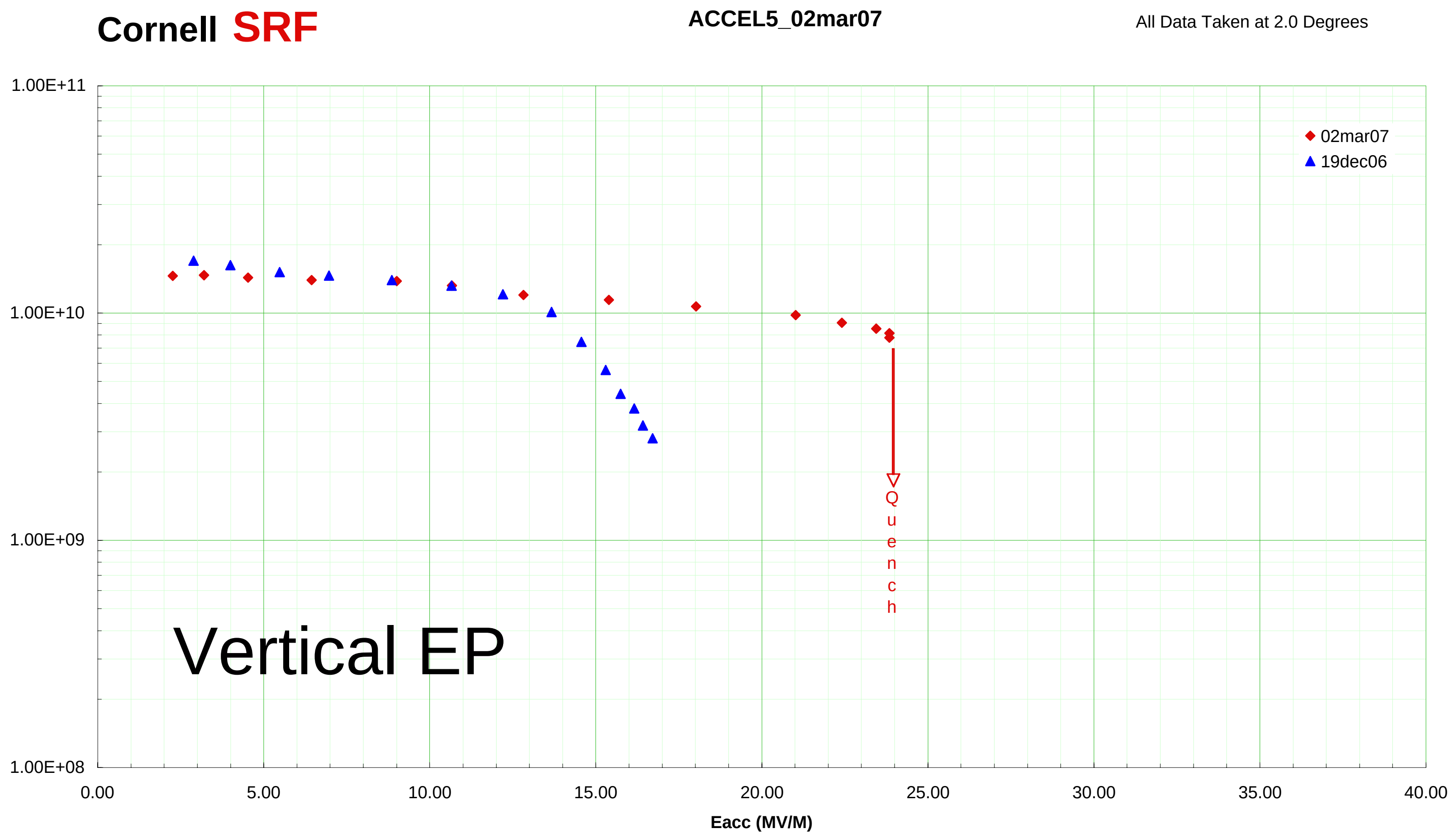
ACCEL 8 Treatment Details

- BCP 110 μm (+ 50 μm on parts at ACCEL) + HPR
- No Heat treatment at 800 Deg C
- Eacc = 26 MV/m (Limit : high field Q-slope)
- Vertical EP, 25 microns, bake 110 C, 48 hours
- Eacc = 30 MV/m
  - No field emission
  - Limit: quench
- Vertical EP: 70 microns
  - Sent to Jlab for H outgassing

ACCEL- 5 Treatments

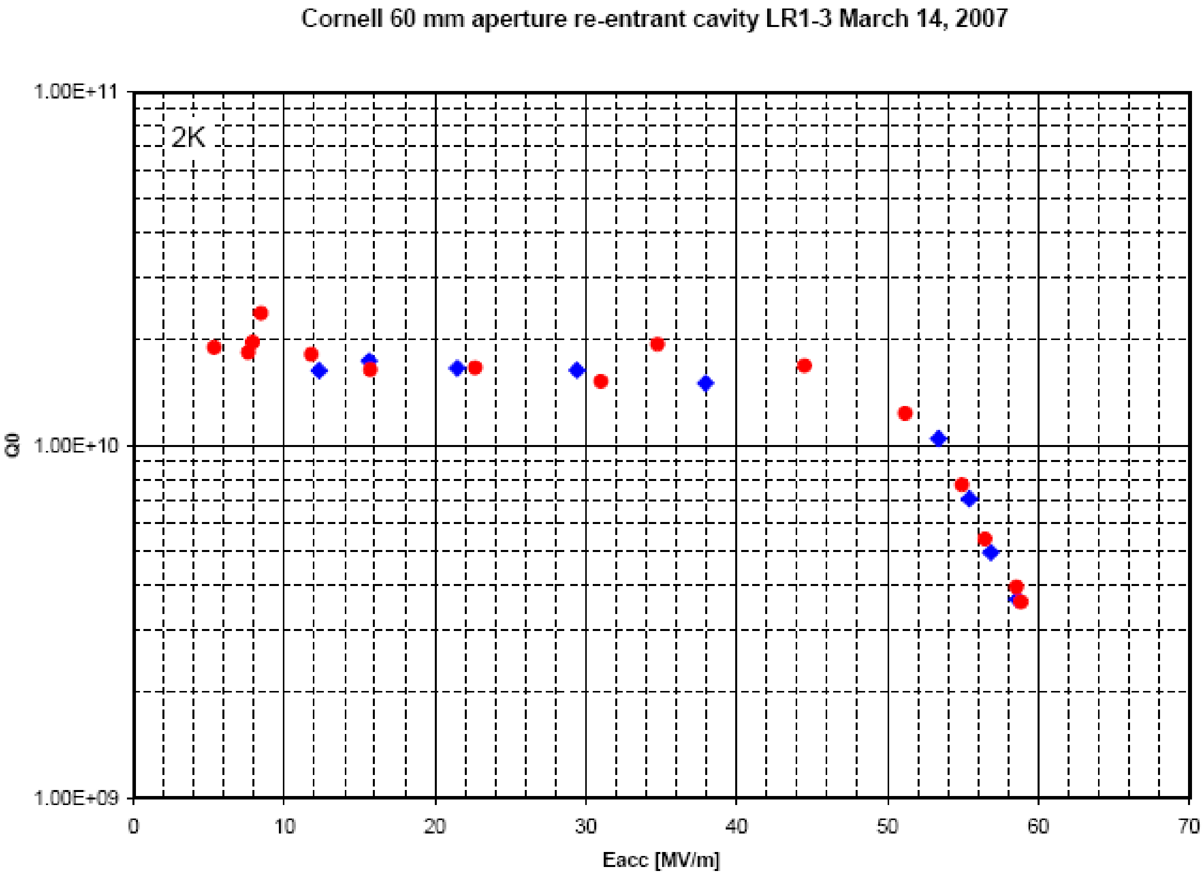
- Vertical EP : 120 micron
- 600 C, 12 hour bake at Jlab to remove H
- Flash BCP (< 10 microns) + HPR & test
- Eacc = 17 MV/m (max)
  - No field emission
- Need more material removal after furnace bake
- Vertical EP, 25 microns
- Eacc = 24 MV/m, Flat Q vs E, Quench
- Remove another 105 microns, sent to Fermilab for H outgassing

Vertical EP - ACCEL-5

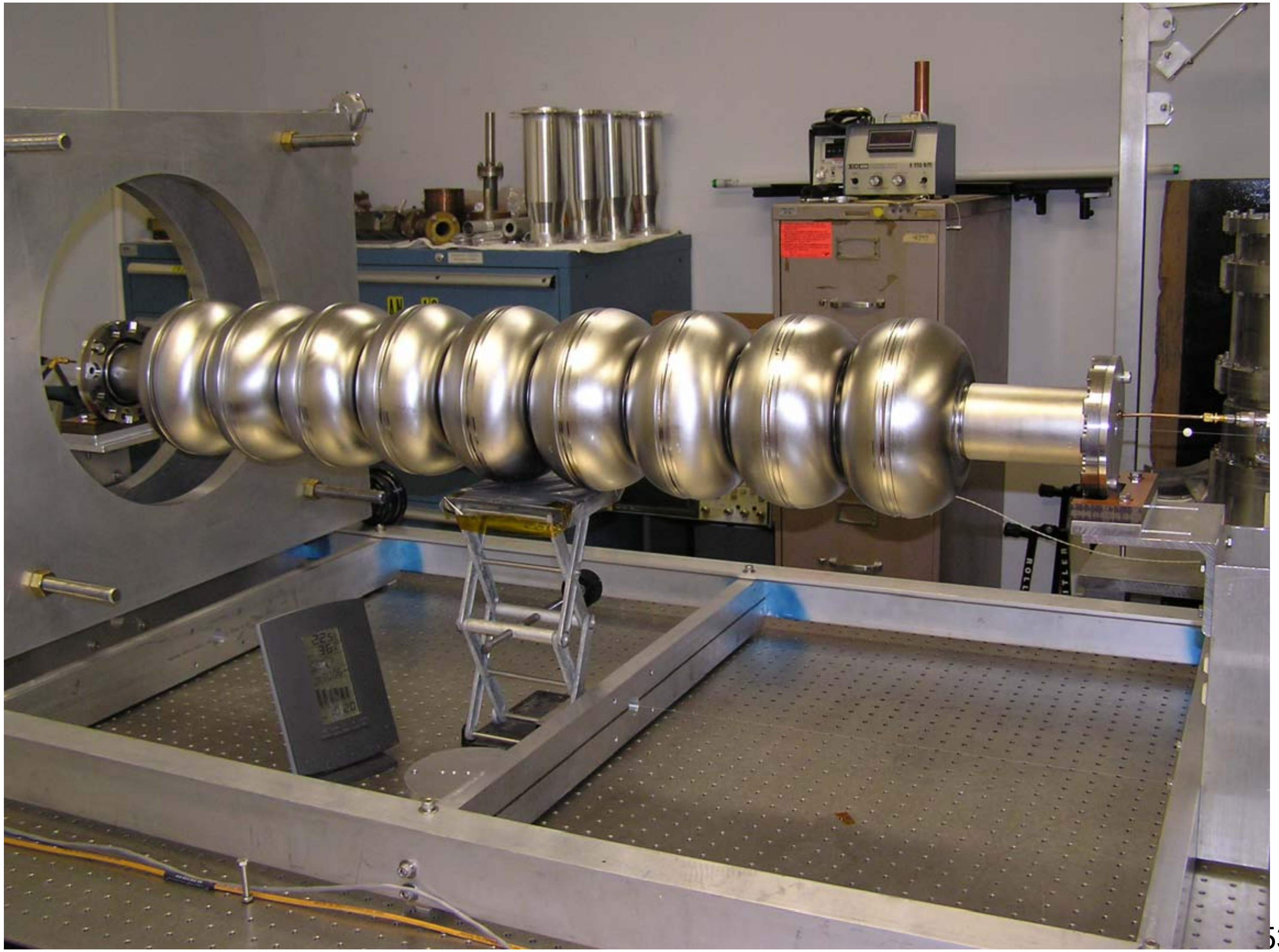


60mm-Aperture Re-Entrant Cavity
Best Eacc = 59 MV/m

RE-LR1-3



ACD: AES (Medford, NY)
Built and Tuned 9-cell Re-Entrant Cavity (70 mm aperture)



Major Milestones

- Ongoing cavity exchange
  - **first cavities have been identified**
    - KEK-US and vice-versa
      - cavities will go to DESY
    - DESY-KEK
      - at least one direction
    - results are partially available by end of this year (2007)
      - a third of those tests by end of the year
    - first loop finished by mid 2008
    - second loop by beginning 2009
  - **Production-like**
    - will have tested ACCEL cavities in the US
      - will have tested the AES cavities
    - 8 (10) cavities at Japan
    - will have tested 15 ACCEL TESLA-short
    - will have tested the 6th production at DESY
  - **S1**
    - tests of M7, M8 (FNAL), M9, STF Phase1
    - M10 as a dream module?
    - Aquisition of further modules
      - 2 in 2008 (1st US, 1st T4CM)
      - 2 in 2009 (2nd T4CM, T4CM9)

Next steps

- Interfacing S2
- enhanced
- Coherent data sets

Bottom Line

- S0 Plan has started
  - **Tight-loop started**
    - hot candidates
      - Fresh acid
      - Ultrsound degrease
        - » Multi-cells at JLab
- Production-like
  - **Resource-intensive**
  - **several batches is underway**
  - **a plan becomes more realistic**
    - scenarios have been developped
- Facilities are becoming online
  - **Jlab**
  - **others as well**
- Alternatives
  - **Single-cells**
  - **Vertical EP**
  - **Large-grain material**

Bottom line II

- S1
  - **M6 important**
  - **Needs more work**
  - **Resource-intensive**
  - **Long lead times**
    - propose to built proof-of-principle across regions
- Plan
  - **becomes much clearer as resources are known better**
  - **Worst case**
    - Even then a lot of data available for a educated decision for the EDR
  - **Best case**
    - Still final full production-like assessment will be later than the EDR
  - **Cost effectiveness...**
- XFEL
  - **several points of connection have been discussed and are critical to the success of the ILC R&D program**