SCRF Cavity R&D Progress
and Preperation for
ILC-ML Gradient Decision

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R. Geng, and C.M. Ginsburg
with thanks to the SCRF R&D team

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- Summary of TILC09-AAP Review, for Cavity

- SCRF Cavity Status
- 'Global Database' effort
- Gradient w/ respect to the RDR and SB2009
- Current R&D Efforts

- SB2009 / Gradient Integration Topics

- *NOTE: The SCRF Cavity R&D Status and plan will be the subject of a separate discussion in the GDE meeting, Beijing, March 2010 (tbc) and beyond.*
  - ***This talk is a status report to prepare for further discussion***

R&D Current Status:

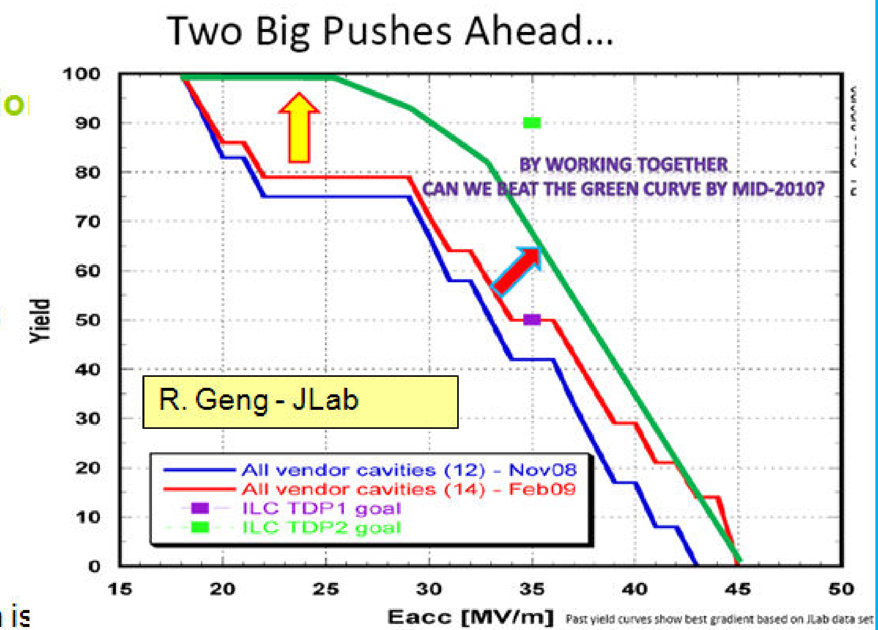
- Americas
  - **Successful preparations at JLab**
    - Most recent production
  - **Startup of the facility at FNAL**
  - **Second sound**
  - **T-map at LANL**
  - **New vendor Qualification**
- Asia
  - **STF**
    - Pulsed tests
    - Vertical Tests online
    - EP online
  - **Vendor qualification**
  - **Optical inspection system development**
    - Guided repair as an option to recover faulty cavities
- Europe
  - **Preparation for mass production**
  - **Development optical inspection**
  - **HiGrade**

TILC09-AAP Review

Reported by L. Lilje

Strategy to Improve Performance

- The lower gradient part
  - **Vendor qualification**
  - **Improvement of fabricatio and weld quality**
  - **Typically larger defects, ‚easily‘ detectable**
- The higher gradient part
  - **More systematic studies needed**
- Tools are available
  - **Surface Mapping**
    - T-Map
    - Second Sound
  - **Optical inspection**
    - Common data evaluation is the way
- In addition:
  - **Study repair options**
    - Local grinding
    - Tumbling



19.4.2009 TILC09 AAP Review
Lutz Lilje

Global Design Effort

35

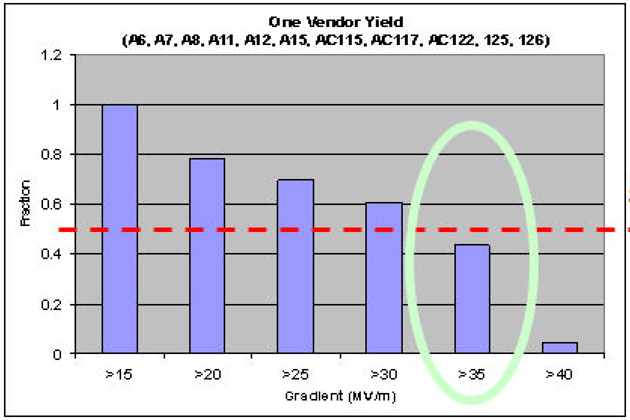
R&D Plan in TDP

- R&D subjects and what will be expected
  - Improve the yield of the preparation process
    - Vertical test yield not yet sufficient
      - Subsets of certain vendors do pass
    - Module integration (cavity assembly) will be investigated
  - Improve weld quality
    - PMs have visited the various cavity manufacturers
    - Training for manufacturers is important
  - Alternatives not to be forgotten
    - Large-grain
    - Low-loss shape
- Time-line
  - Beginning 2010
    - Revise choice of the gradient if necessary
- Resources
  - Ongoing cavity fabrication in the three regions
    - ~60 tests targeted at ILC in TDP1
    - parallel startup of XFEL with 800 cavities on order

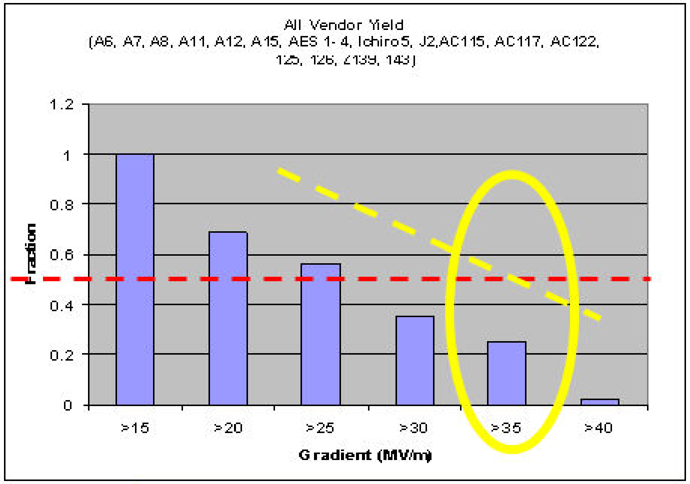
19.4.2009 TILC09 AAP Review
Lutz Lilje
Global Design Effort
36

Global Yield of Cavities (November 2008) and Expectation

23 tests, 11 cavities	48 Tests, 19 cavities
One Vendor	ACCEL, AES, Zanon, Ichiro, Jlab



50%



45% yield at 35 MV/m being achieved by cavities with a qualified vendor

H. Padamsee, TTC-08 (IUAC), ILC-08 (Chicago)

2009.4.19 AAP-SCRF-Summary 4

A Summary of TILC09-AAP Review

SCRF

The committee is very impressed by the progress made in the gradient yield toward TDP 1 goals. New final rinse techniques have significantly reduced field emission problems. There has been substantial progress in understanding some of the causes of gradient limitations by developing effective thermometry-based diagnostic tools, 2nd sound quench detection tools, and optical examination tools. Several methods of cavity repair are under exploration with already encouraging results. Companion studies are underway to understand the origin of gradient limitations. Efforts continue at all laboratories to understand and improve process reproducibility. These tools raise the prospects of continued improvement in gradient yield towards the TDP 1 goals of 50% process yield. Prospects are high for achieving good statistics with more than 90 tests available by 2010.

The path towards the TDP 2 goal of 90% cavity yield in 2012 is under development with improved understanding of defects that limit performance, especially from new vendor cavities. Not counting the large XFEL production, more than 100 cavities will be available to collect good statistics. Valuable information from quench detection and corresponding inspection will be fed back to the vendors.

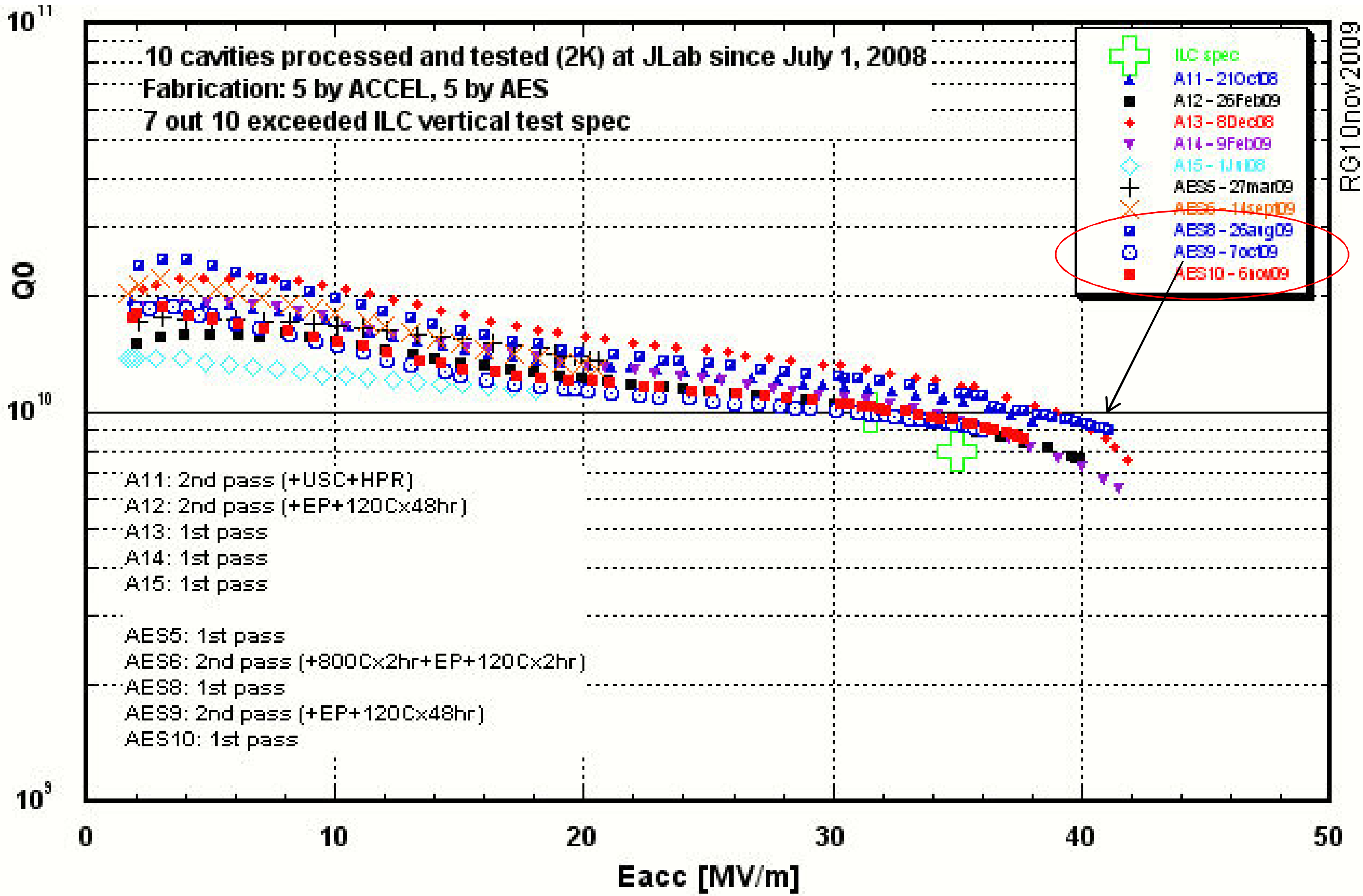
> *The AAP recommends a strong interaction between laboratory experts and new vendors during all stages of cavity fabrication.*
>
> *The AAP recommends that for the yield study further evaluation be made of the quality of cavities (Q-values) along with gradient. Electron loading and x-ray intensities at 35 MV/m should be closely monitored.*

There has been substantial progress in the two major new cryomodule assembly facilities at KEK and FNAL. The first 4-cavity cryomodule has been successfully tested at KEK at an average gradient around 24 MV/m with one cavity approaching 31.5 MV/m. The slide-jack tuner variant has been successfully developed for a stiffer cavity-He vessel system and successfully tested with Lorentz force compensation at 30 MV/m. The first cryomodule

ILC Gradient R&D – Global Progress

- First demonstration of 33 MV/m in, production-like, 9-cell cavity processing and testing at ANL/FNAL & KEK in CY09 Q4
  - Following DESY and JLab's successes
  - Global competence in ALL regions emerging
- Cavities (9-cell) manufactured by US industry exceeds 35 MV/m
  - 3 out of 5 AES 2nd production cavities 36-41 MV/m
  - Close information feedback between lab and industry
  - Following successes in European industry (ACCEL/RI & ZANON)
- Global cavity result database
  - First-pass yield 26% & second-pass yield 44% at 35 MV/m
    - July report was 22% and 33%, respectively.
  - ~60 9-cell cavities expected in TDP-1
- Improved understanding of gradient limits (more at Beijing GDE meeting)

FY09 Results from JLab/FNAL



Improved Understanding in Quench Limit

- Routine monitoring: 9-cell T-mapping and optical inspection
  - **9-cell T-mapping being commissioned by LANL**
  - **New 9 cell thermometry system in development at FNAL**
  - **New insights from pre-cursor heating studies at JLab**
  - **First predictive defect study at DESY**
  - **Cornell 2nd sound sensors, Cornell-OST's, will be available for labs for quench detections**
  - **Many labs use "Kyoto/KEK camera" (JLab just received a loan unit)**

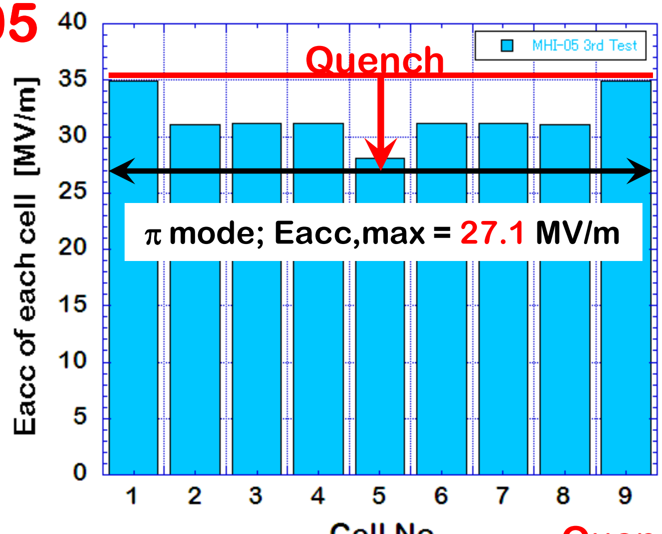
- New finding: many 9-cell is quench limited at 20-25 MV/m by only one defect in one cell with other superior cells already reaching 30-40 MV/m
  - **There may or may not be observable flaw in quench site**
  - **This seems to suggest we need to address material aspect besides processing and fabrication in TDP-2**
  - **This also suggests some local repairing is needed for efficient raise of 2nd pass gradient yield**

$Eacc_{max}$(cell) by Pass-bands modes Meas.

Reported by E. Kako (KEK), 0ct. 2009.

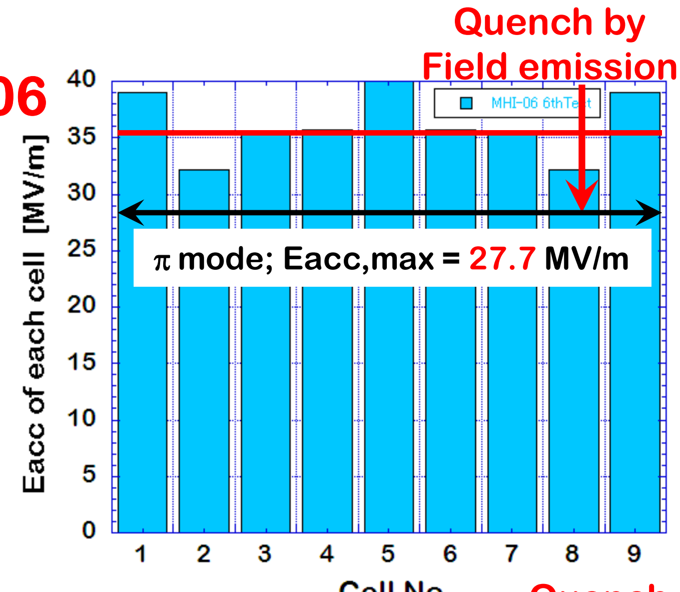
MHI-05
3rd

> 30. MV/m



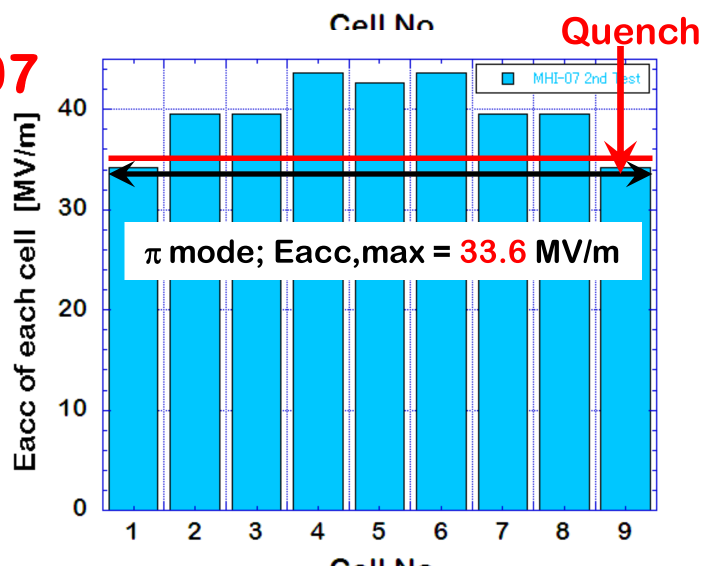
MHI-06
6th

> 35. MV/m



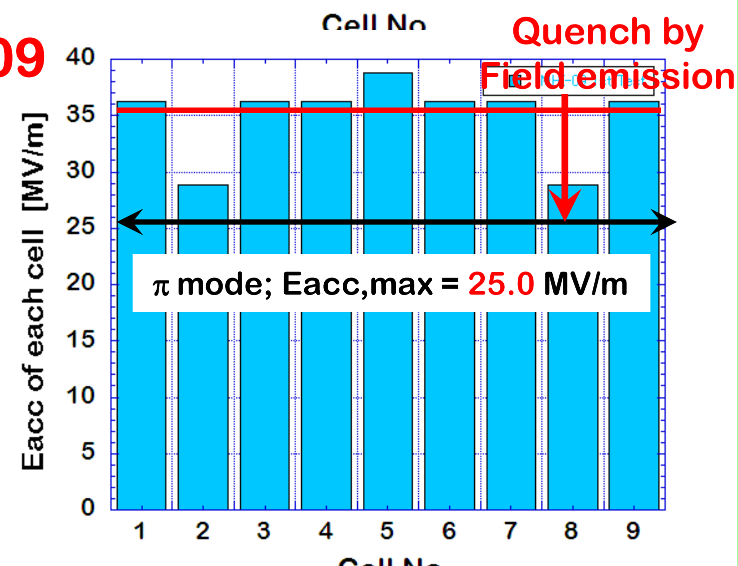
MHI-07
2nd

~ 40. MV/m



MHI-09
1st

> 35. MV/m



Global Plan for SCRF R&D

Year	07	2008	2009	2010	2011	2012
Phase	TDP-1			TDP-2		
Cavity Gradient in v. test to reach 35 MV/m	→ **Process** Yield 50%			→ **Production** Yield 90%		
Cavity-string to reach 31.5 MV/m, with one-cryomodule		Global effort for string assembly and test (DESY, FNAL, INFN, KEK)				
System Test with beam acceleration		FLASH (DESY) , NML (FNAL) STF2 (KEK, extend beyond 2012)				
Preparation for Industrialization			Production Technology R&D			

Global Database Effort

- Following the Spring ‘09 Reviews, the need to establish a global database was noted
  - **Common data sample, well defined data cuts**
  - **Easily reproducible plots**
  - **Data entry rules for reliable and reproducible results**
  - **Well defined data fields**
  - **No private/sensitive vendor data**
  - **Regular updates at predetermined times**

- As part of the S0 effort, a database team was established, and led by
  - **C.M. Ginsburg (FNAL) and including**
  - **S. Aderhold (DESY), Z. Conway (Cornell), R. Geng (S0 leader, Jlab), and K. Yamamoto (KEK) was established**

- A 6 month timeline for implementation was developed
- DESY management agreed to provide support

Cavities in the current dataset

- 27.Oct.2009 Excel spreadsheet contains data from all three regions, from the last few years
  - **KEK [5 cavities]: [MHI005:MHI009]**
  - **JLab, Cornell, Fermilab [18 cavities]: [A5: A9], [TB9ACC010:TB9ACC015], [AES001:AES004], [TB9AES005:TB9AES006], JLAB-2**
  - **DESY [53 cavities]: [AC112:AC129], [Z130:Z145], [AC146:150] (Production batches 5, 6, &7 are represented) and [Z88,Z93,Z97,Z98,Z100:Z104,Z106:Z110] (Production 4)**

- 11.Dec.2009 update
  - **Updates from all three regions**
  - **Americas [+4 cavities]: TB9AES008,TB9AES009,TB9AES010, TB9ACC016 1st pass**

Production Yield Plot - Method

- Database version 11.Dec.2009
- Cuts
  - **Cavity from vendors who have manufactured a cavity that has surpassed 35MV/m in vertical test:**
    - ACCEL or ZANON or (AES SN>=5)
  - **Fine-grain cavity**
  - **Use the first successful (= no system problem/limitation) test**
  - **Standard EP processing: no BCP, no experimental processes**
    - Defined as JLab#1, DESY#2 (weld tank before test), DESY #4 (weld tank after test)
    - Ethanol rinse and 120C bake required for DESY cavities
  - **(Ignore test limitation)**

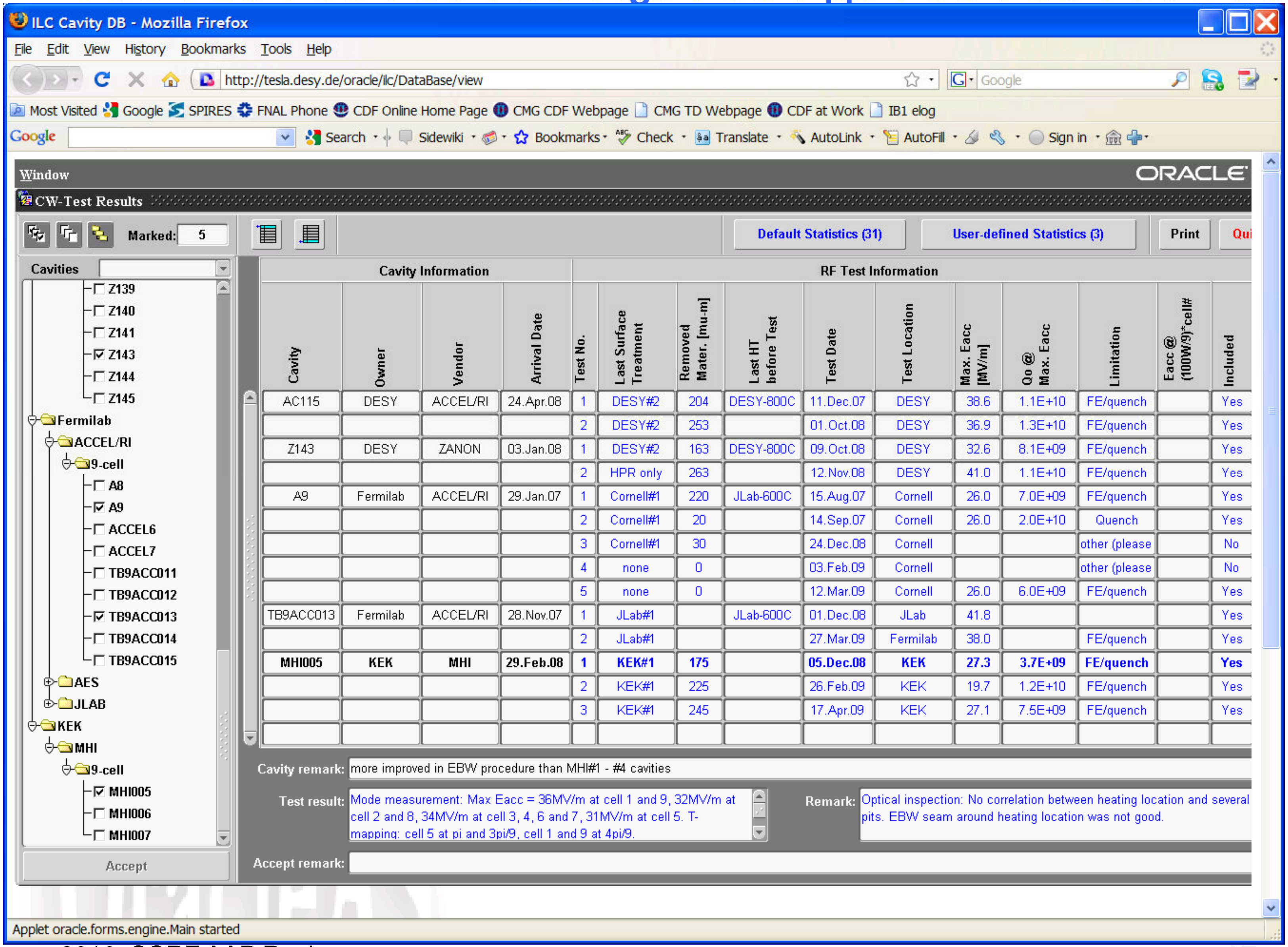
- Also known as “first-pass”
- Include binomial errors

"Up-to-second-pass" Production Yield Plot - Method

- Database version 11.Dec.2009
- Cuts
  - **Cavity from vendors who have manufactured a cavity that has surpassed 35MV/m in vertical test:**
    - ACCEL or ZANON or (AES SN>=5)
  - **Fine-grain cavity**
  - **Use the first successful (= no system problem) test**
  - **Standard EP processing: no BCP, no experimental processes**
    - Defined as JLab#1, DESY#2 (weld tank before test), DESY #4 (weld tank after test)
  - **(Ignore test limitation)**
  - **Second pass**
    - if (Eacc(1st successful test)<35 MV/m) then
      - if (2nd successful test exists) then
        - » plot 2nd test gradient
      - else
        - » plot nothing [assume 2nd test didn't happen yet]
      - endif
    - else
      - plot 1st successful test gradient
    - endif
- Include binomial errors

Database Snapshot

Acknowledge DESY support



Cavity	Owner	Vendor	Arrival Date	Test No.	Last Surface Treatment	Removed Mater. [mu-m]	Last HT before Test	Test Date	Test Location	Max. Eacc [MV/m]	Qo @ Max. Eacc	Limitation	Eacc @ (100W/9)*cell#	Included
AC115	DESY	ACCEL/RI	24.Apr.08	1	DESY#2	204	DESY-800C	11.Dec.07	DESY	38.6	1.1E+10	FE/quench		Yes
				2	DESY#2	253		01.Oct.08	DESY	36.9	1.3E+10	FE/quench		Yes
Z143	DESY	ZANON	03.Jan.08	1	DESY#2	163	DESY-800C	09.Oct.08	DESY	32.6	8.1E+09	FE/quench		Yes
				2	HPR only	263		12.Nov.08	DESY	41.0	1.1E+10	FE/quench		Yes
A9	Fermilab	ACCEL/RI	29.Jan.07	1	Cornell#1	220	JLab-600C	15.Aug.07	Cornell	26.0	7.0E+09	FE/quench		Yes
				2	Cornell#1	20		14.Sep.07	Cornell	26.0	2.0E+10	Quench		Yes
				3	Cornell#1	30		24.Dec.08	Cornell			other (please		No
				4	none	0		03.Feb.09	Cornell			other (please		No
				5	none	0		12.Mar.09	Cornell	26.0	6.0E+09	FE/quench		Yes
TB9ACC013	Fermilab	ACCEL/RI	28.Nov.07	1	JLab#1		JLab-600C	01.Dec.08	JLab	41.8				Yes
				2	JLab#1			27.Mar.09	Fermilab	38.0		FE/quench		Yes
MHI005	**KEK**	**MHI**	**29.Feb.08**	**1**	**KEK#1**	**175**		**05.Dec.08**	**KEK**	**27.3**	**3.7E+09**	**FE/quench**		**Yes**
				2	KEK#1	225		26.Feb.09	KEK	19.7	1.2E+10	FE/quench		Yes
				3	KEK#1	245		17.Apr.09	KEK	27.1	7.5E+09	FE/quench		Yes

Cavity remark: more improved in EBW procedure than MHI#1 - #4 cavities

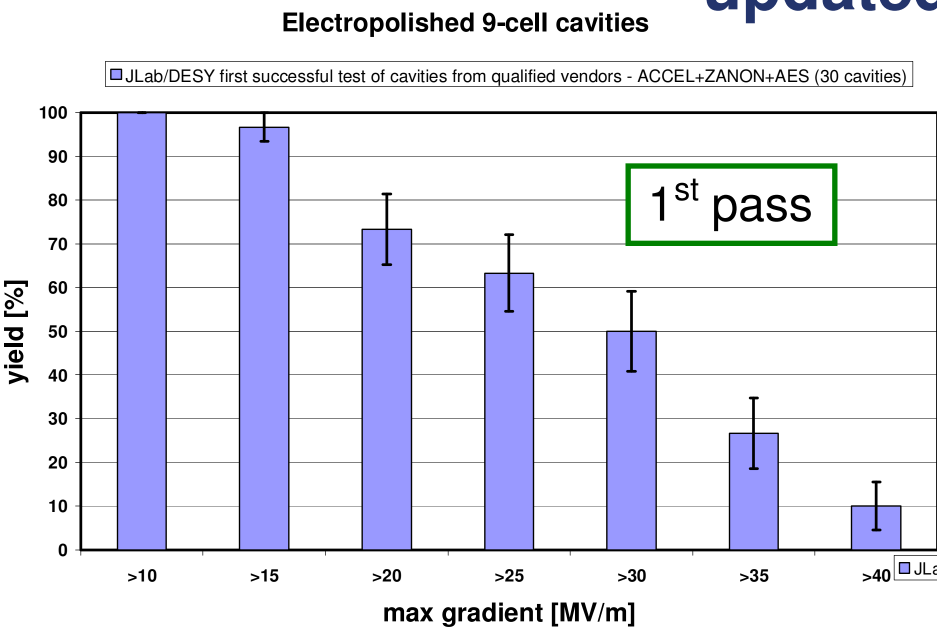
Test result: Mode measurement: Max Eacc = 36MV/m at cell 1 and 9, 32MV/m at cell 2 and 8, 34MV/m at cell 3, 4, 6 and 7, 31MV/m at cell 5. T-mapping: cell 5 at pi and 3pi/9, cell 1 and 9 at 4pi/9.

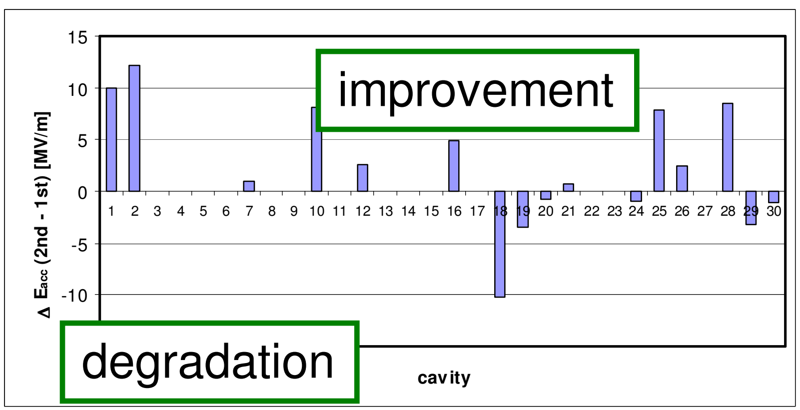
Remark: Optical inspection: No correlation between heating location and several pits. EBW seam around heating location was not good.

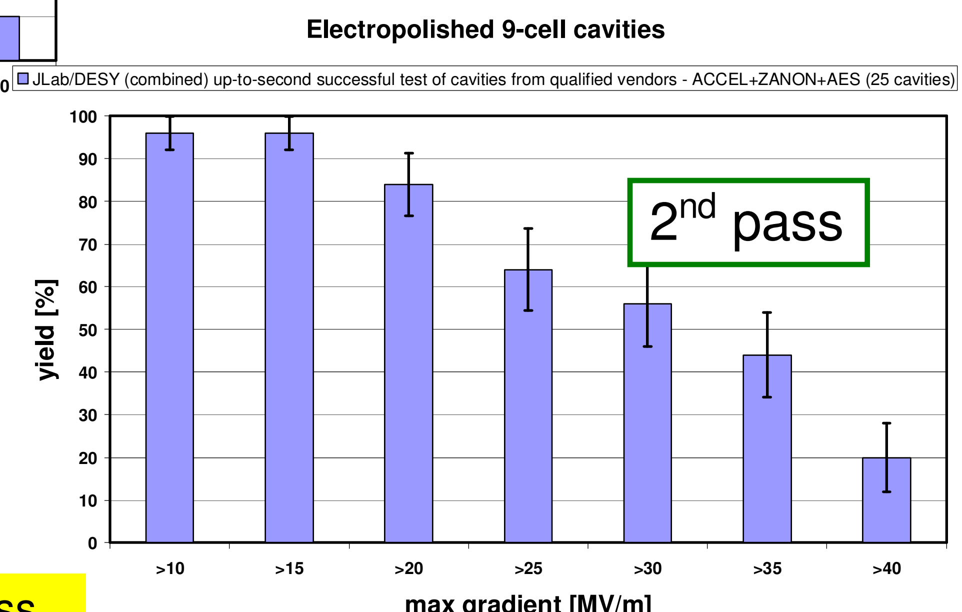
Accept remark:

Applet oracle.forms.engine.Main started

Compare 1st and 2nd pass yields updated, Dec. 2009







Performance typically improves after 2nd pass

Summary of Cavity Gradient Status

- Global Database has been created
  - **Consistent, reproducible plots incorporating worldwide data**
- Production, 2nd pass yield of 44% for vendors with a cavity >35MV/m in vertical test
  - **Q0 goals met by all cavities, >35MV/m--efforts will continue on this aspect as well**
- Considerable number of cavity tests coming in 2010
  - **Infrastructure, cavity orders in place**
  - **Fermilab completed 6 VTS test cycles in December**
- Continued push to TDP goals, through better control of fabrication and processing
  - **Better diagnostic equipment in place**
- Extension of understanding to maximize machine performance economically in final design
  - **Improved technical understanding and increased statistics provide basis for updating of industrialization model**

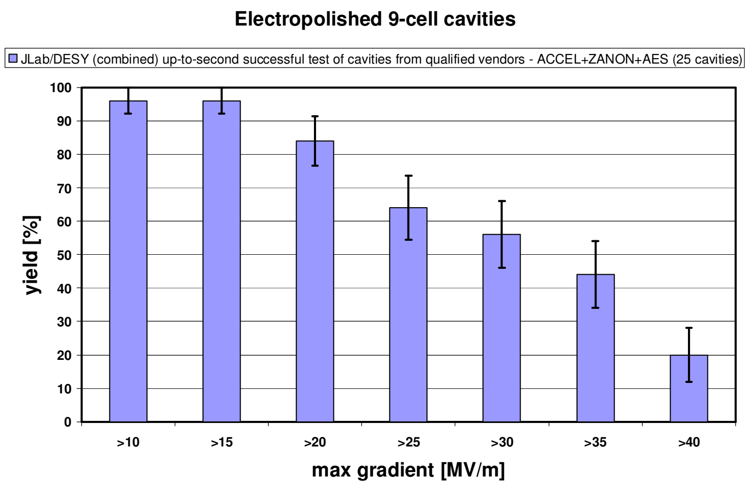
SCRF Cavity Gradient in SB2009 and
Preparation for ILC-ML Gradient Decision

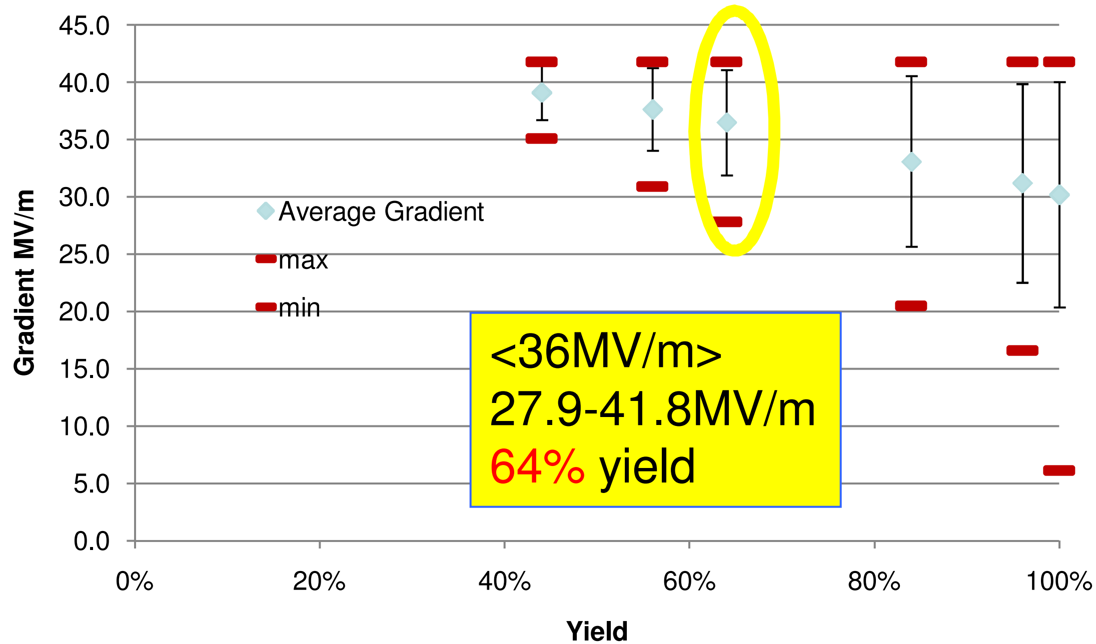
- Re-evaluation of the design accelerating gradient is required during TDP-2, based on
  - **Statistical cavity performance (R&D results), i.e. expected/projected yield for cost-optimized mass production**
  - **Required operational overhead of installed cavities in linac (under full beam loading)**
- SB2009 WA-1 is to maintain the RDR value of 31.5 MV/m ($Q_0 \geq 1\times10^{10}$) pending final and thorough review of R&D status
  - **Determines length of main linac, in SB2009 (CFS requirements)**
- Unlike RDR, propose to adopt variable power distribution for HLRF to allow for spread in accelerating gradient of individual cavities
  - **Maximize *average* accelerating gradient (better 'yield')**
  - **Has impact on required RF power overhead and efficiency**
  - **Overall cost benefit**
- Acceptable performance spread of cavities about the average still remains to be determined
  - **Expect approximately ±10~ 20%**

Alternative Yield Plot Analysis

originated by N. Walker

Dec 2009 Data:
1st +2nd Pass, 1st pass cut 35MV/m,
vendors w/ 1 cavity > 35MV/m





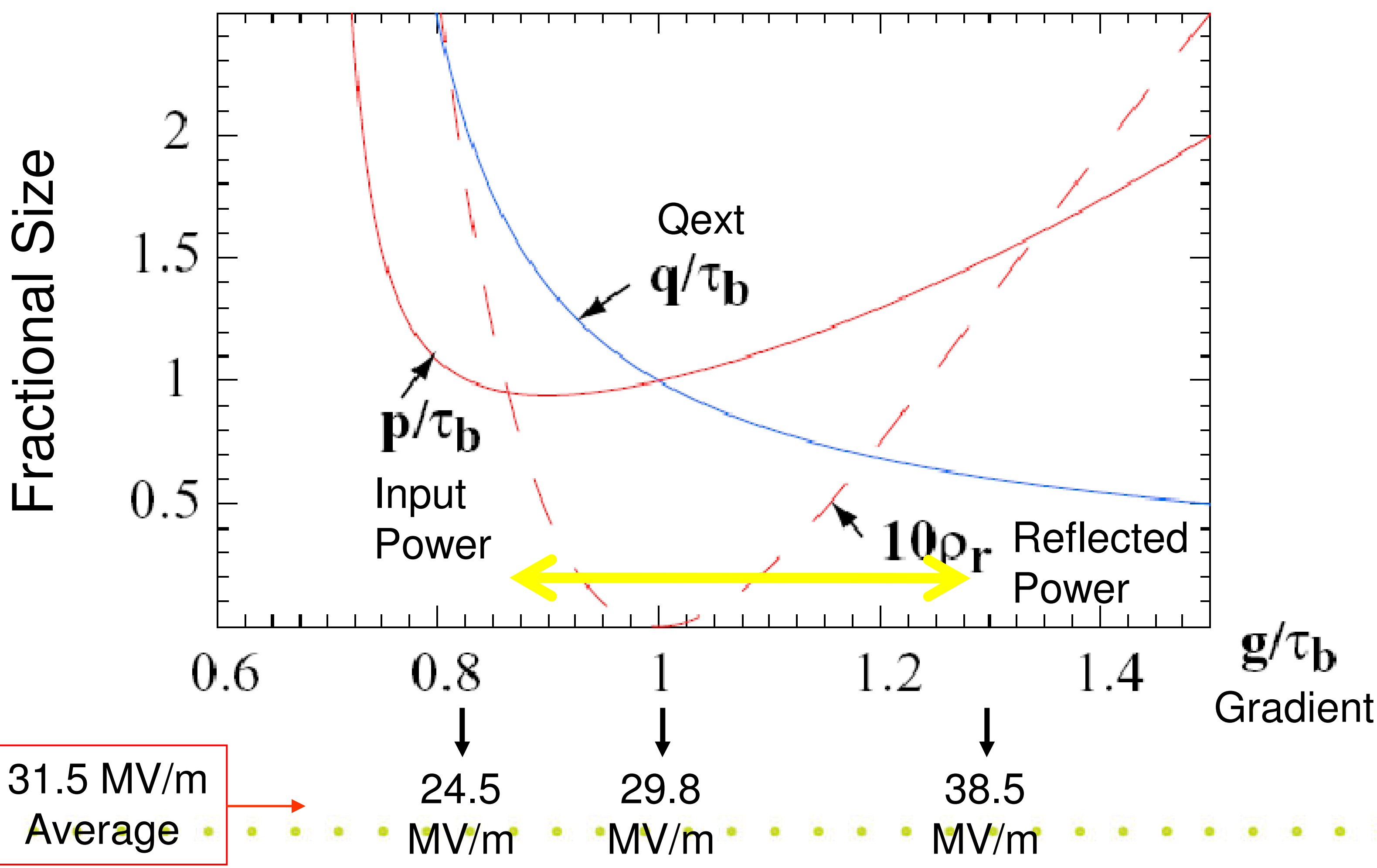
<36MV/m>
27.9-41.8MV/m
64% yield

>35MV/m
35-41.8MV/m
44% yield

-Yield: estimated assuming a specific lower cut-off in cavity performance, below which cavities are assumed 'rejected'.
- Error bar: +/- one RMS value (standard deviation of the population) of the remaining (accepted) cavities (gradient above cut-off).
- Additional bars (min, max) indicated the minimum and maximum gradients in the remaining cavities.

Flattop Operation with a Spread of Cavity Gradients

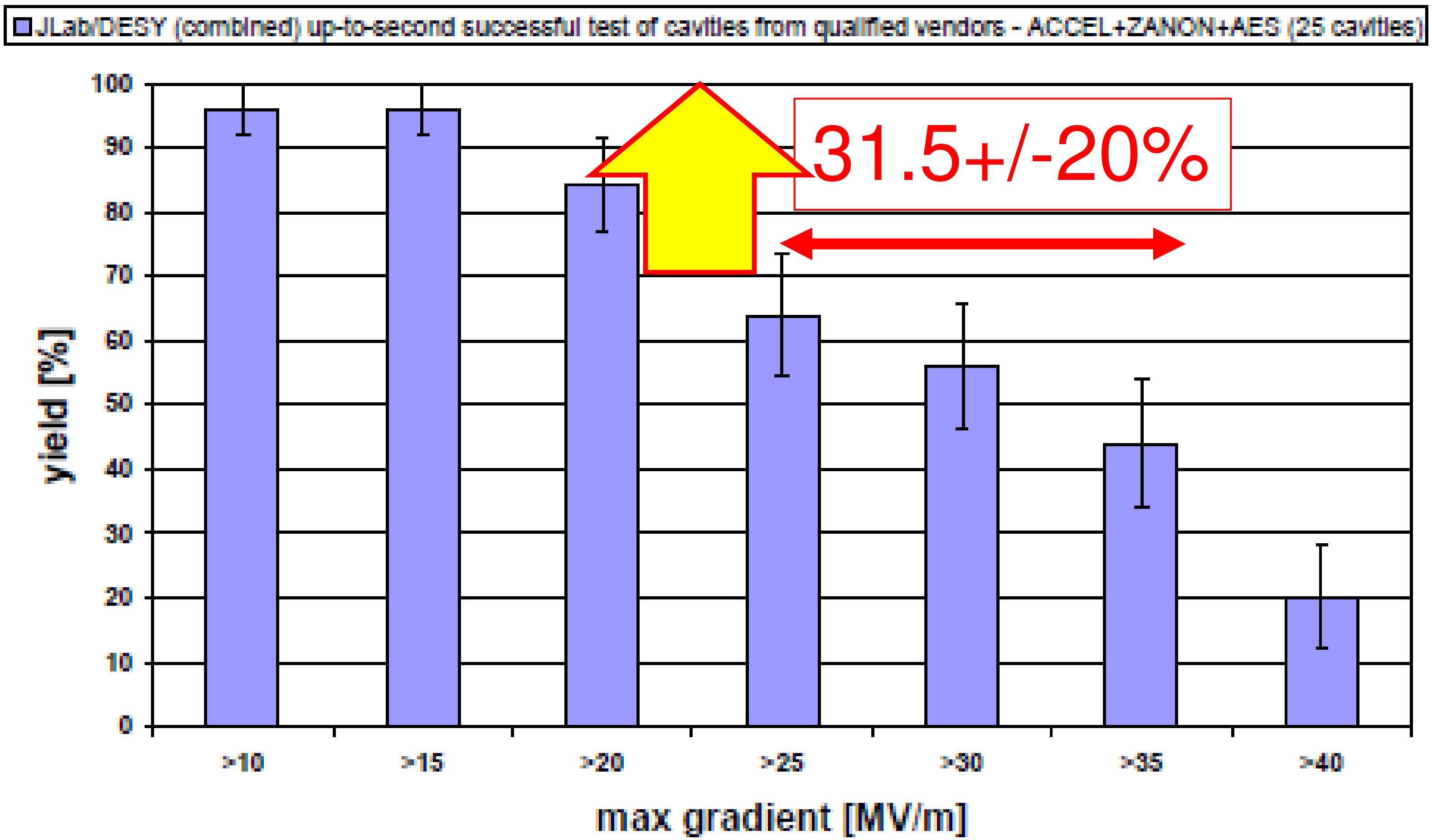
reported by C. Adolphsen



31.5 MV/m Average

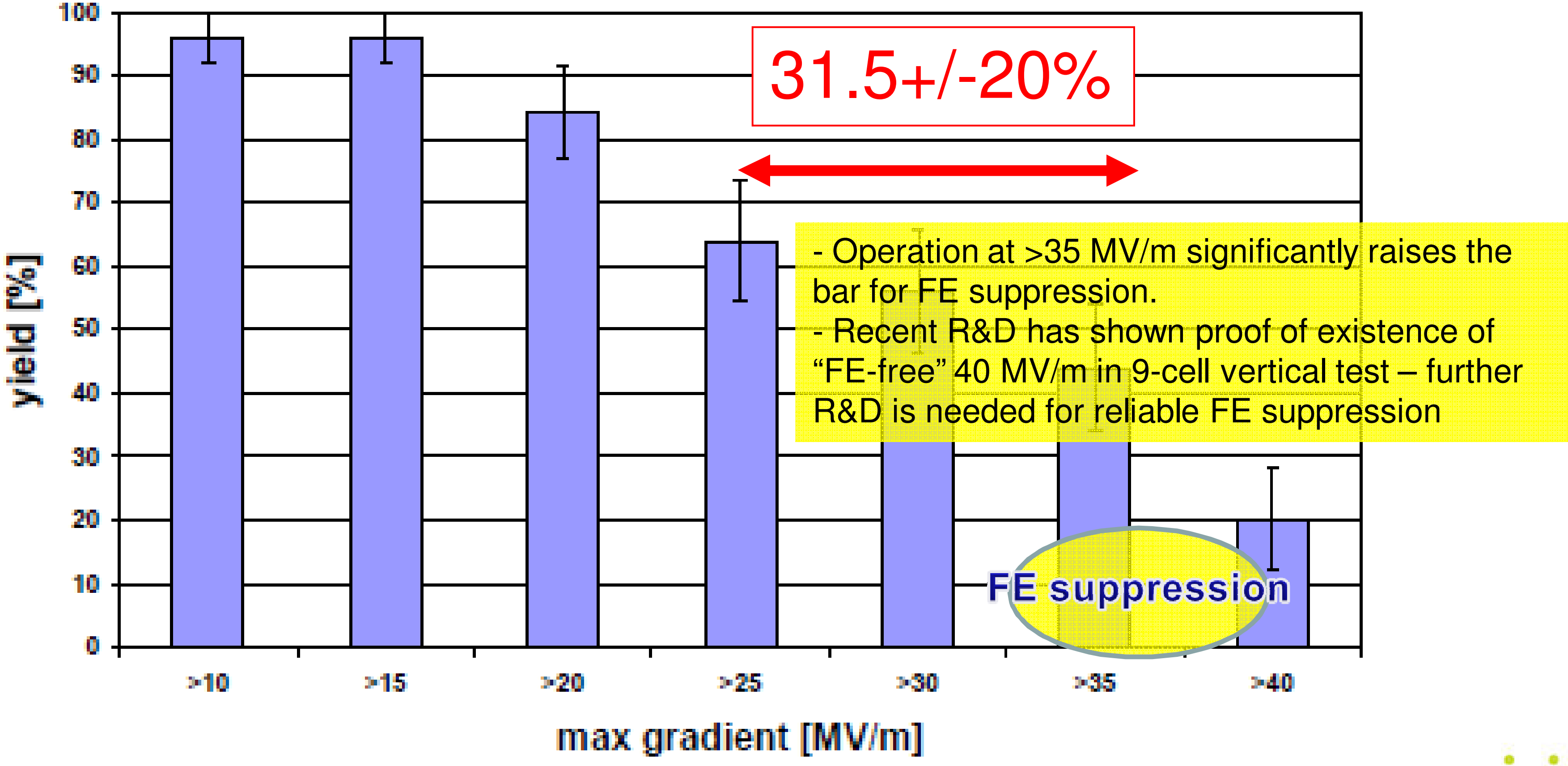
The Next Battles (1): Eliminate the Yield Drop near 20MV/m

Despite increased acceptance thanks to more flexible HLRF



The Next Battle (2): Further Reduce Field Emission up to 40 MV/m

Flexible HLRF opens up possibility of
some individual cavity operations up to 38 MV/m



Progress and Prospect of Cavity Gradient Yield Statistics

	PAC-09 Last/Best May 2009	FALC 1st Pass Jul 2009	ALCPG 2nd Pass Oct 2009	Current Dec 2009	Coming Prod/Test Jun 2010	Research cavities
DESY	9 (AC) 16 (ZA)	8 (AC) 7 (ZA)	14 (AC/ZA)	10-6 (Prod-4)	5	8 (large grain)
JLAB FNAL/ANL/ Cornell	8 (AC) 4 (AE) 1 (KE-LL5) 1 (JL-2)	7 (AC)	7 (AC)	5 (AE) 1 (AC)	12 (RI) 6 (AE) 2 (AC)	6 (NW) (including large-G)
KEK/IHEP /PKU			(4 -4:MH)	5 -5 (MH)	2 (MH)	~5 (LL) 1 (IHEP) 2 (PKU)
Sum	39	22	21	21 -11	27	~ **22**
G-Sum				42-11 = 31	69-11=58	

Statistics for Production Yield in Progress to reach ~ 60, within TDP-1.
We may need to have separate statistics for 'production' and for 'research',

R&D Goals & ILC Operational Gradient

- The RDR has a gradient goal of 35MV/m such that a machine performance based on 31.5MV/m (-10%) may be achieved
- The S1 and S2 goals are both set at 31.5MV/m

- This 10% reduction was assumed (in Snowmass, 2005)
  - **to include limitations due to both 'final assembly problems' and required 'machine operational overhead'**

- In addition to continued efforts on cavity performance, TDP-2 gives several opportunities to further investigate and quantify the actual required value, and thus the machine design
  - **FLASH**
  - **NML**
  - **STF2**
  - **Horizontal cavity tests**

S1 Goal: Achieved at DESY/XFEL

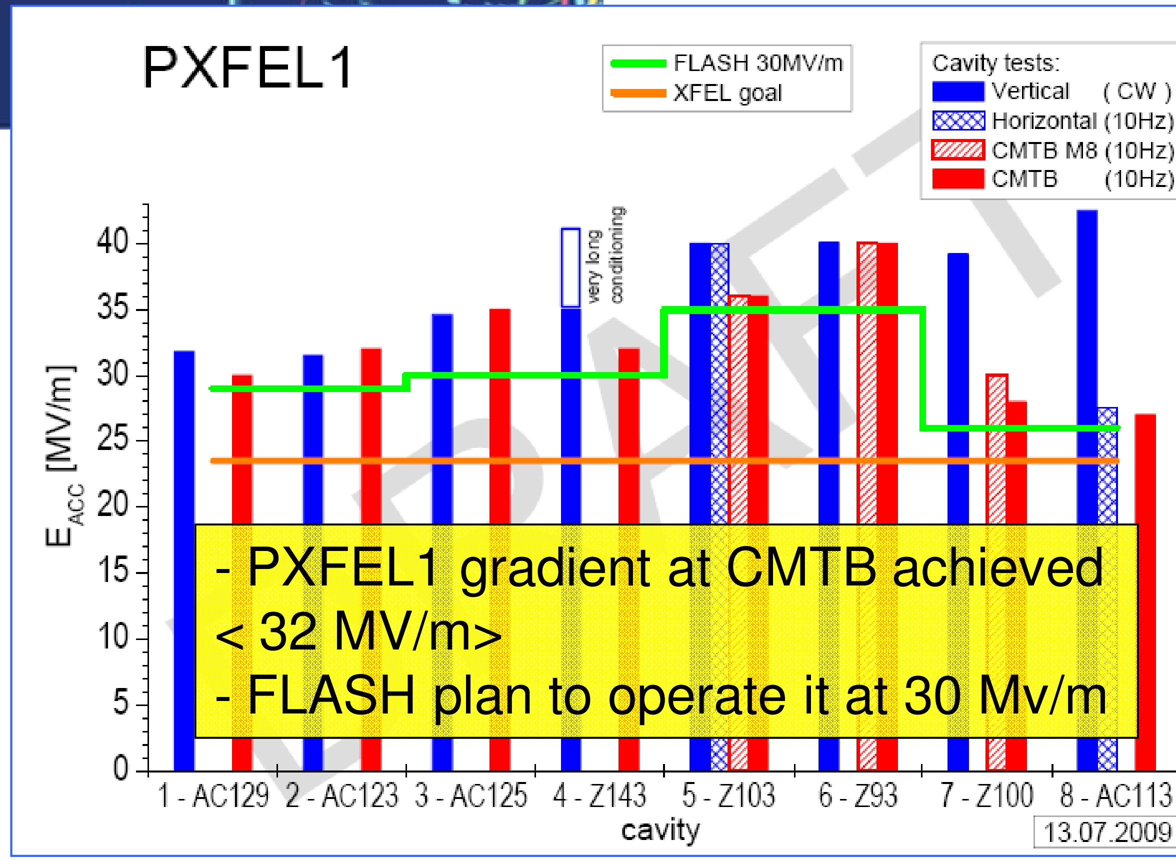
NewsLine

Around the World

Cryomodule surpasses ILC gradient test

European-XFEL cryomodule using SCRF technology sets new record

The cryomodule that set the world gradient record in the testbench at DESY



First XFEL prototype module **exceeds 31.5 MV/m average**
- Module will see beam in FLASH in 2010 (av. of 30MV/m)
- Cryostat (cryomodule cold-mass) contributed by IHEP, in cooperation with INFN

Subject to be studied in TDP-2

- Balance between R&D target values and Operational parameters
Will be reviewed after S1 experience
-System design should require reasonable margin for the individual component and the system operation

S1 (~ Component performance) > ILC-Acc. Operational Gradient

	RDR/SB2009	Re-optimization required with cautious, systematic design	
R&D goal: S0	35 (> 90%)	35 MV/m (> 90 %) *Keep it, and forward looking*	
S1 (w/o beam)	31.5 in av.	*need:* > 31.5 in av., to be further optimized	31.5 in av.
S2 (w/ beam acc.)	31.5 in av.	> 31.5 in av.	31.5 in av.
ILC: operational gradient	31.5 in av.	31.5 in av. (+/- 10 ~ 20 %)	*or:* < 31.5 in av,, to be further optimized

Summary

- In SB2009, ILC operational field gradient left unchanged
  - for CF&S study to enable to stay at 31 km in ML tunnel length and to be consistent with 250 GeV beam energy,
- SCRF cavity gradient R&D Goal
  - Kept to be 35 MV/m (at Q0 = 8E9) with the production yield of 90 %,
  - Global data base appreciated to continue for monitoring the progress,
- Spread of cavity gradient effective to be taken into account
  - to seek for the best cost effective cavity production and use,
  - Final acceptable range requires confirmation from RF effort,
- Re-optimization required, to decide ILC operational gradient
  - to have adequate balance/redundancy between the ‘R&D gradient-milestone’ and the ‘ILC operational gradient’ including ‘cryomodule operation margin’ and ‘HLRF/LLRF adjustability’ for stable and sufficiently high ‘availability’ with risk mitigation.

Additional Information

A Satellite Meeting at IPAC-2010

Industrialization of SCRF Cavities

Date : May 23, 2010, a full-day meeting, prior to IPAC-2010

Place: Int. Conf. Center, Kyoto, Japan

Organized by: ILC-GDE Project Managers,

Objectives and Plan:

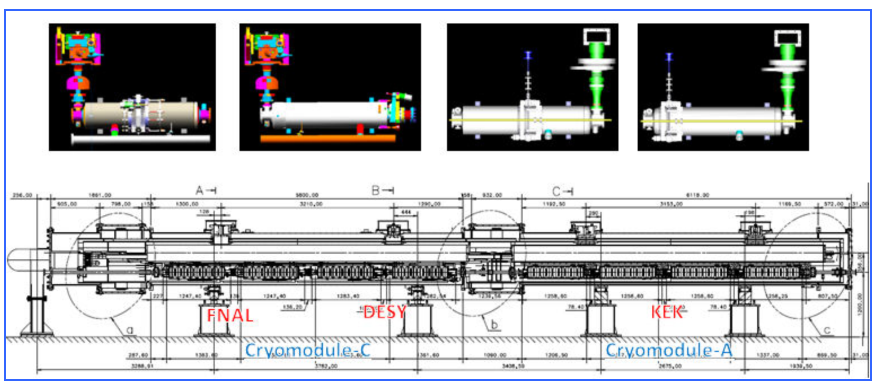
- To discuss and exchange information on preparation for the 'ILC SCRF Cavity' industrialization between industries and laboratories,
- Industrialization plan to be reported by laboratories, and comments/advices given by industries,

Announcement sent/made to major cavity vendors, RI, Zanon, AES, Niowave, PAVAC, MHI, other SCRF industries, and ILC-SCRF institutions,

Additional Report: S1-Global Progress

All Components arrive in Japan, Dec. 2009

- Global effort for cryomodule test
  - **INFN: Cryomodule**
  - **DESY: 2 cavities**
  - **FNAL/JLab: 2 cavities**
  - **KEK: 4 cavities, Cryomodule**



Delivered to KEK on Dec.25, 2009