Report for ILC-PAC

SCRF

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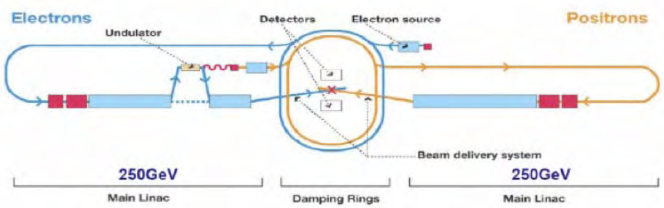
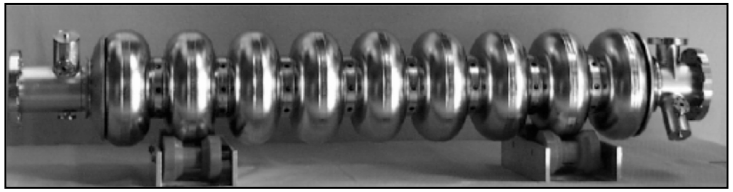
Prepared for ILC-PAC to be held at POSTECH, Nov. 2, 2009

SCRF Technology Required

Parameter	Value
C.M. Energy	500 GeV
Peak luminosity	$2x10^{34}$ $cm^{-2}s^{-1}$
Beam Rep. rate	5 Hz
Pulse time duration	1 ms
Average beam current	9 mA (in pulse)
Av. field gradient	**31.5 MV/m**
# 9-cell cavity	**14,560**
# cryomodule	**1,680**
# RF units	**560**





TDP Goals of ILC-SCRF R&D

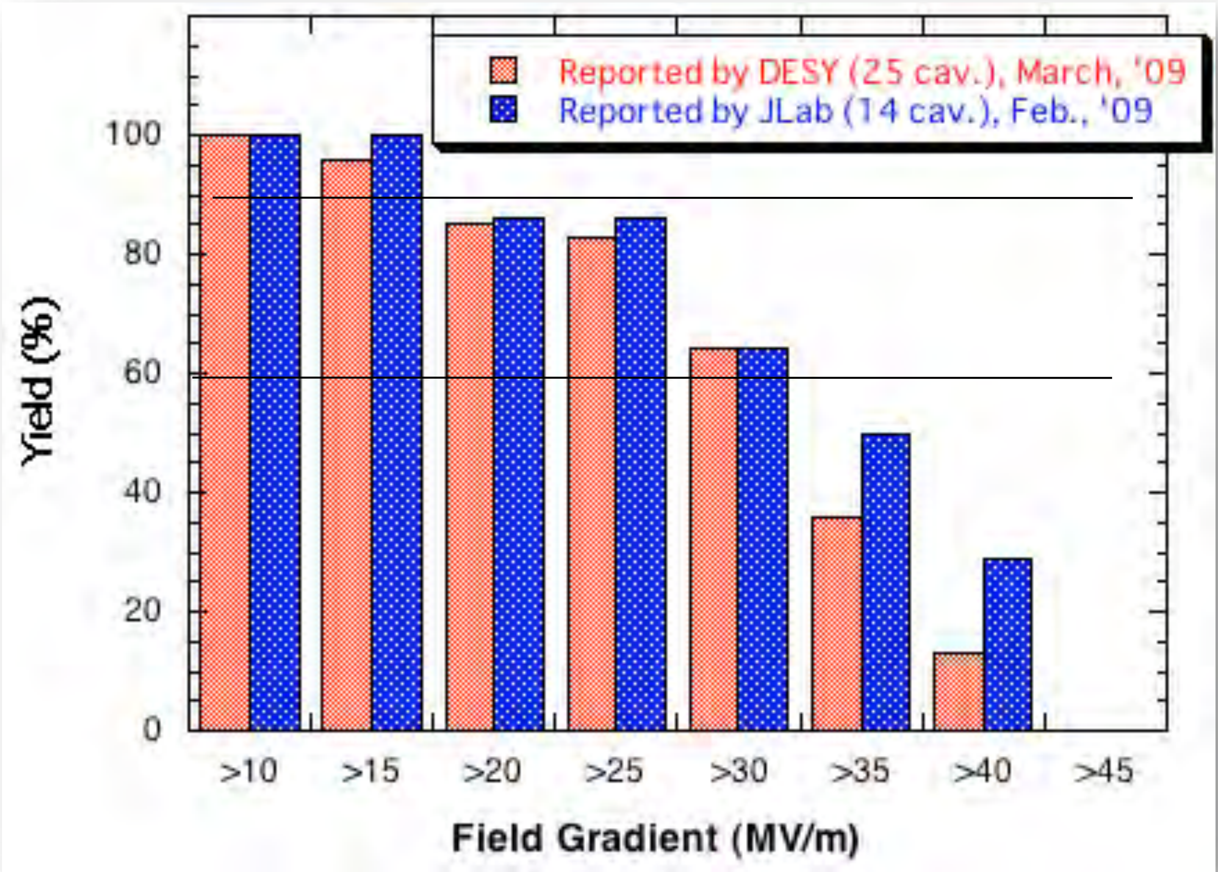
- **Cavity Field Gradient (S0)**
  - 35 MV/m in vertical test
- **Cavity-string Assembly in Cryomodule (S1)**
  - <31.5 MV/m> in cavity string test in cryomodule
    - To be re-evaluated in preparation for SB-2009 proposal.
  - Efficient R&D with “Plug-compatibility” for
    - improvement and ‘creative work’ in R&D (TDP) phase
- **Accelerator System with SCRF (S2)**
  - Beam Acceleration with SCRF Accelerator Unit
    - Need to discuss an reliable, operational field gradient including adequate HLRF/LLRF control margin for stable operation
- **Industrial Production R&D**
  - Preparing for production, quality control, cost saving
    - “Plug compatibility” for global sharing in production phase

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	→ Yield 50%			→ 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		

Progress Towards High-Gradient Yield

reported at PAC and ILC-PAC, Vancouver, May, 2009



Recent DESY/JLab "production" series.

Total 39 cavities (08/09)

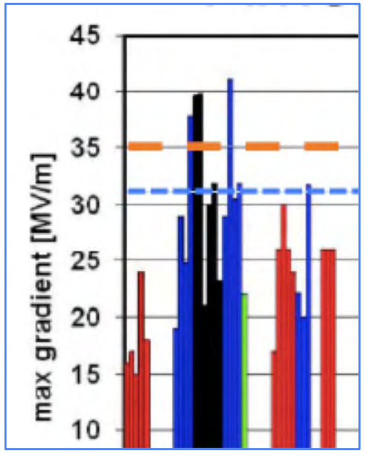
Field Emission greatly reduced (rinses)
→ identified RDR barrier

Baseline gradient re-evaluation (TDP1) expected to be based on sample of >60 cavities

Evaluation of the Cavity Performance

Original S0 concept and approach:

- Surface can be reset according to the EP process
  - **multiple processes may be integrated for statistics.**
- Several-year experiences, however, show:
  - **Repeating processes may cause degradation**
- Processing and Test recipe has been updated
  - **Complete the process and test only with the first cycle (in XFEL)**
    - no further processing if the results are acceptable



Revision required for the concept and 'yield' definition

- Production yield may be more important
- Common means for collection/evaluation of the data required

New effort started by the Global Database Team

- Try a new approach to be more appropriate
  - Production yield with the first/second pass RF test

Creation of a Global Database for Better Understanding of "Production Yield" in TDP-2

- Global Data Base Team formed:
  - **Camille Ginsburg (Fermilab)**
    - Team Leader & Data Coordination
  - **Rongli Geng (JLab)**
    - GDE-SCRF Cavity TA Group Leader
  - **Zack Conway (Cornell University)**
  - **Sebastian Aderhold (DESY)**
  - **Yasuchika Yamamoto (KEK)**

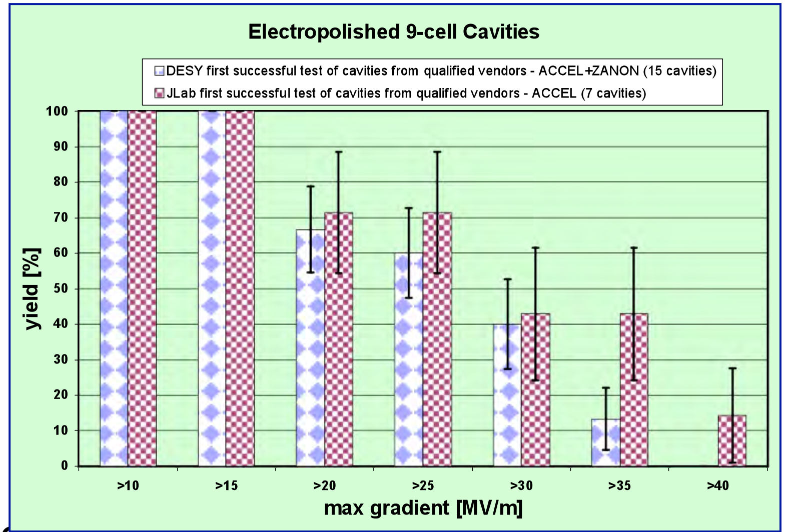
- Activity Plan/Schedule
  - **July 2009:**
    - **- Determine DESY-DB to be viable option,**
  - **Sept., 2009: (ALCPG/GDE)**
    - **- Dataset, web-based, support by FNAL-TD or DESY**
    - **- Some well-checked, easily explainable, and near-final plots, available,**
  - **Nov.- Dec., 2009:**
    - **- Finalize DB tool, web I/F, standard plots, with longer-term plans**

Standard Process Selected for Further Yield Plot

	Standard Cavity Recipe
Fabrication	Nb-sheet (Fine Grain)
	Component preparation
	Cavity assembly w/ EBW (w/ experienced venders)
Process	1st Electro-polishing (~150um)
	Ultrasonic degreasing with detergent, or ethanol rinse
	High-pressure pure-water rinsing
	Hydrogen degassing at > 600 C
	Field flatness tuning
	2nd Electro-polishing (~20um)
	Ultrasonic degreasing or ethanol
	High-pressure pure-water rinsing
	Antenna Assembly
	Baking at 120 C
Cold Test (vert. test)	Performance Test with temperature and mode measurement (1st / 2nd successful RF Test)

Example New Yield Plot from the 1st Successful Vertital RF Test

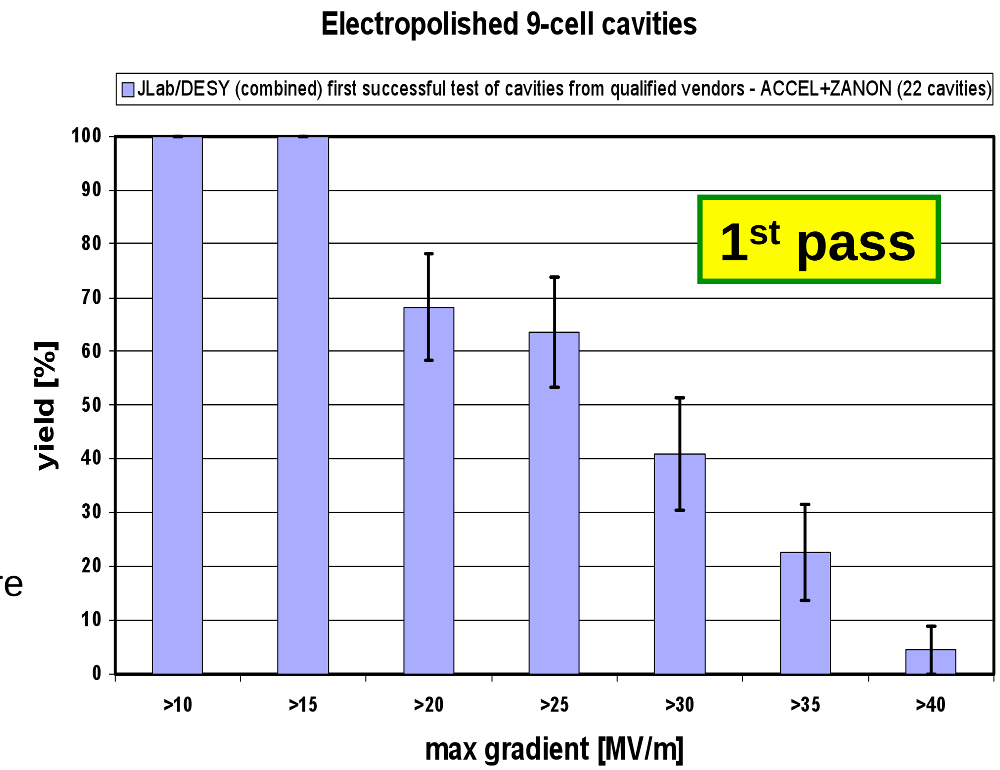
- Vertical axis: fraction of cavities satisfying criteria where:
  - **Denominator (logical and of the following):**
    - Fabricated by ACCEL or ZANON
    - Delivered to labs within last 2-3 years
    - Electro-polished at DESY and JLab
    - Fine-grain material
  - **Numerator (logical and of the following):**
    - Denominator
    - Accepted by the lab after incoming inspection
    - 1st successful vertical RF test,
      - excluding any test with system failure, has max gradient > (horizontal axis bin) MV/m;
      - ignore Q-disease and field emission (to be implemented in future)
- Horizontal axis: max gradient MV/m
- Exclude cavities which are work-in-progress, i.e., before rejection or 1st successful RF test



Note: These are results from the vertical CW test at DESY and JLab

Yield Plot from the 1st Vertical Test

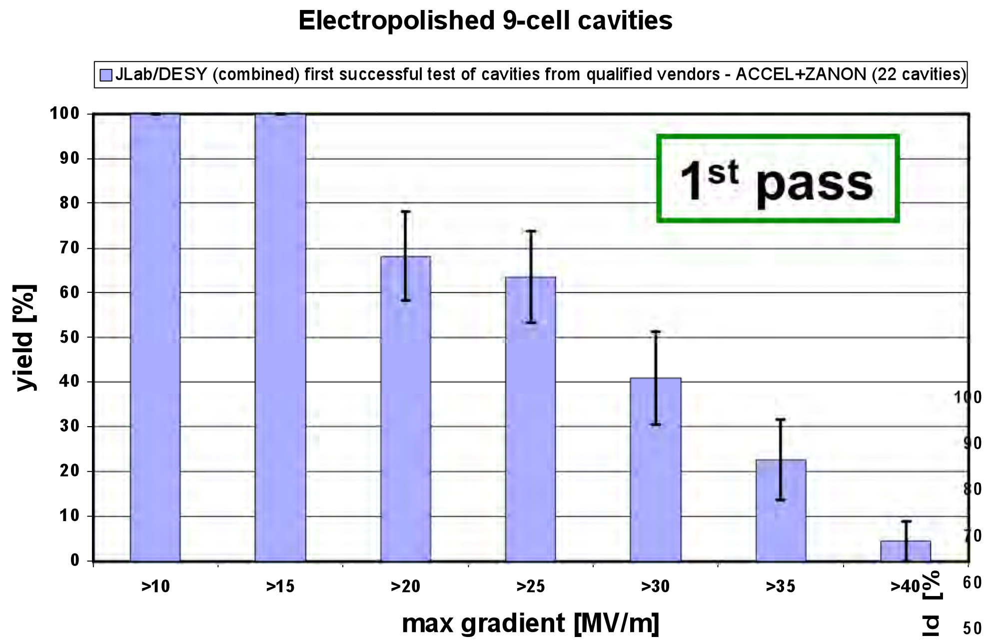
- V. axis: Successful Yield
  - **Denominator:**
    - Fabricated by ACCEL/ZANON
    - Delivered within last 2-3 years
    - EP'ed at DESY and JLab
    - Fine-grain material
  - **Numerator:**
    - Accepted by the lab
    - 1st successful vertical RF test,
      - excluding any test with system failure
      - ignore Q-disease and field emission
        - » (to be implemented in future)
- H. axis: Max. gradient (MV/m)



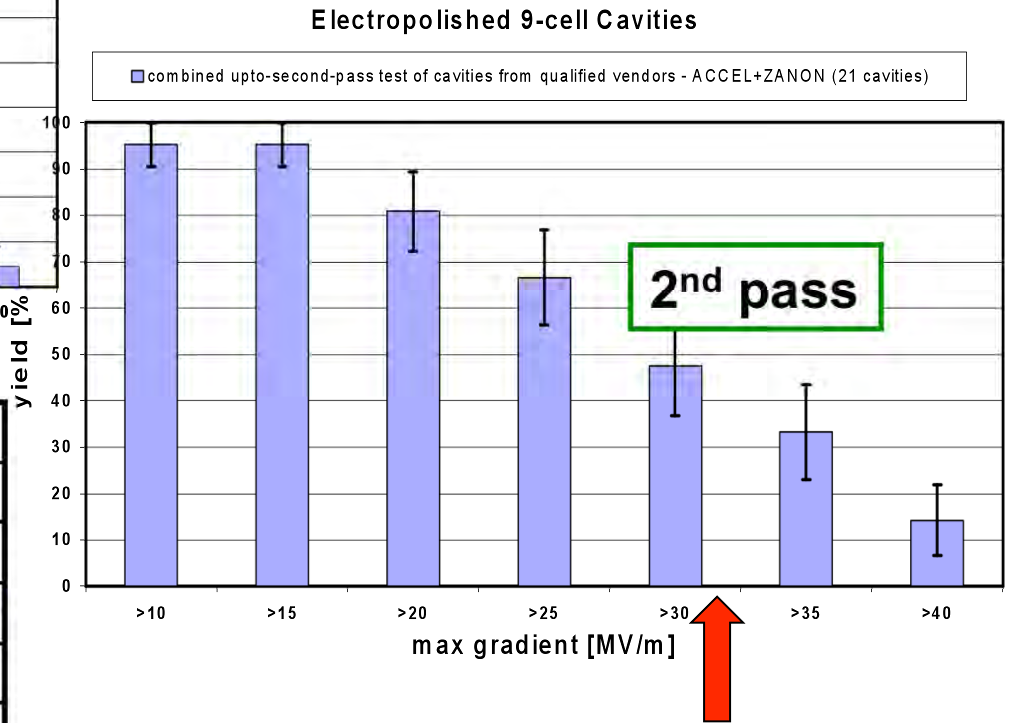
- Note:
  - **exclude cavities which are work-in-progress,**
  - **i.e., before rejection or 1st successful RF test**

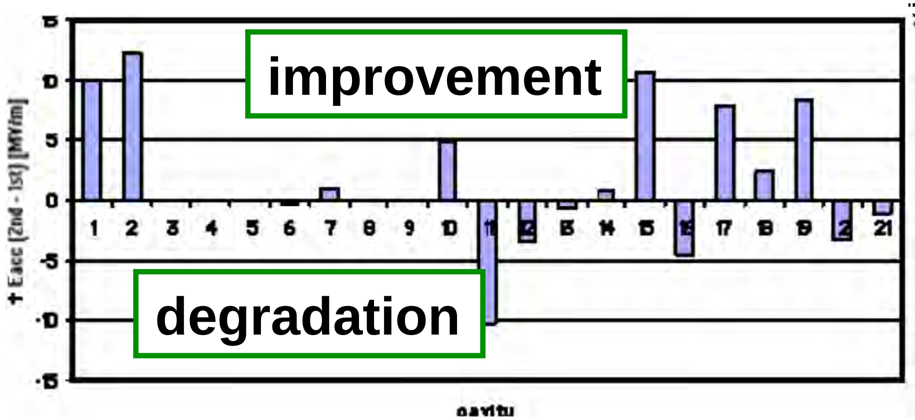
Note: CW test at DESY and JLab

New Production Yield after 1st and 2nd Pass (RF) Test



Yield at 35 MV/m:
22 % at 1st pass
33 % at up to 2nd pass

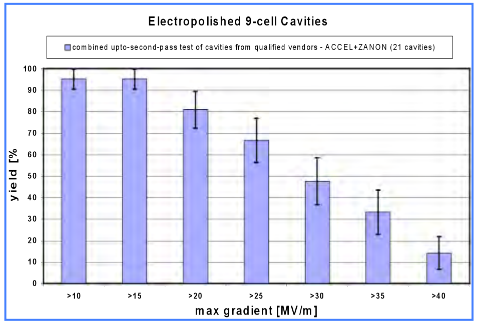


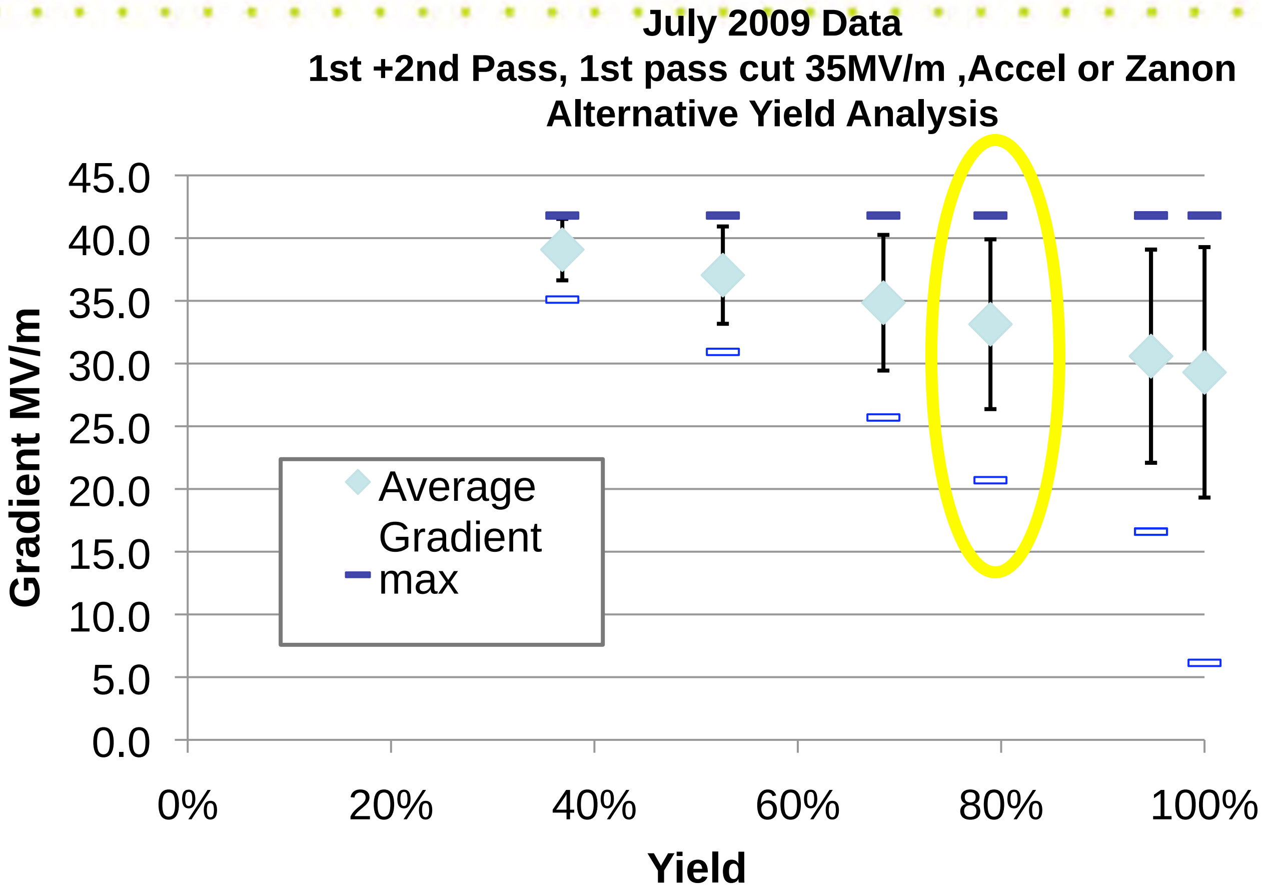


ILC Operation at <31.5 MV/m>
Yield reaching ~ 40 %

Reported by C. Ginsburg and GDB team

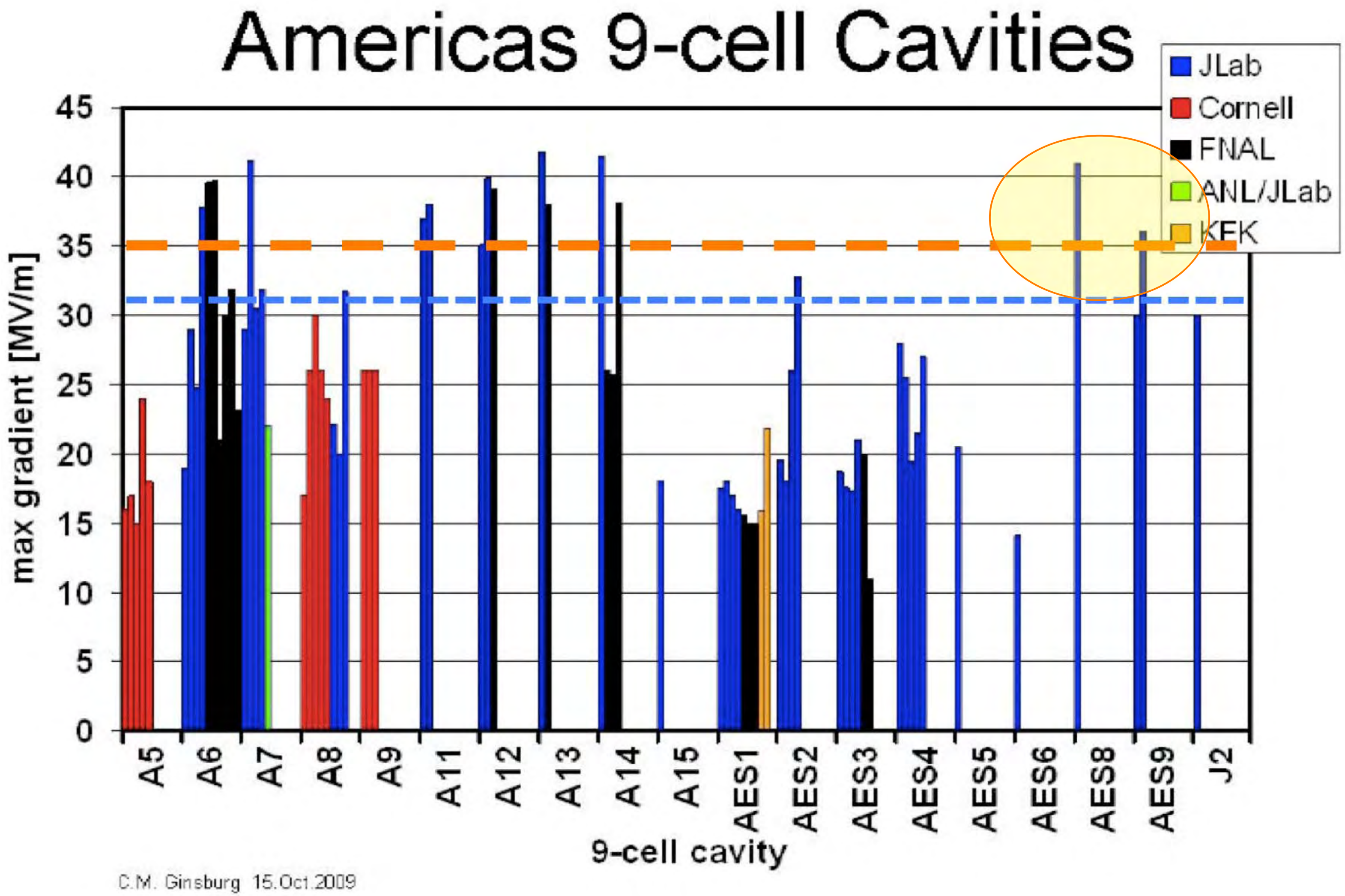
Alternate Yield Plot



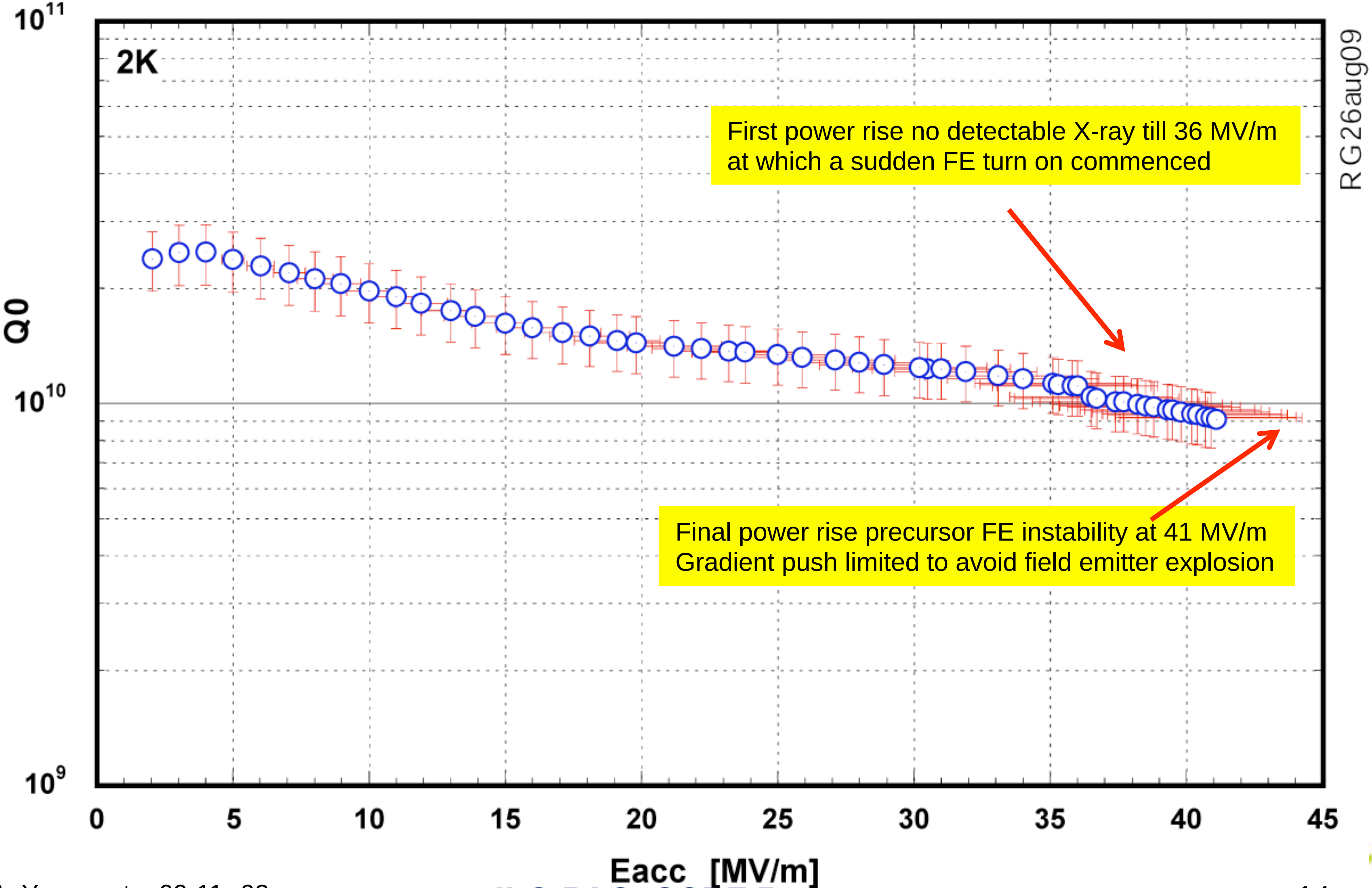


Yield is estimated assuming a specific lower cut-off in cavity performance, below which cavities are assumed 'rejected'.
Error bar is +/- one RMS value (standard deviation of the polulation) of the remaining (accepted) cavities (gradient above cut-off).
Additional bars (min, max) inidcated the minimum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

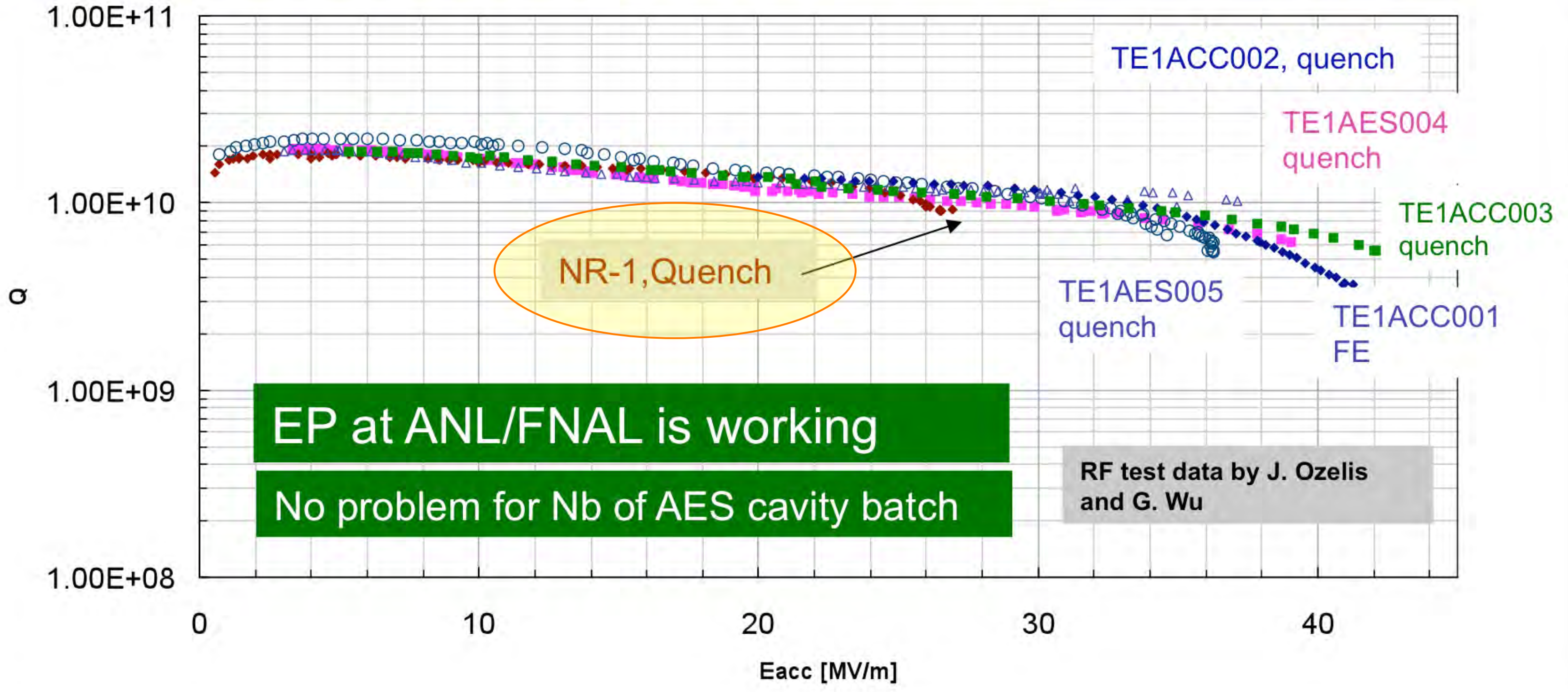
Progress in Americas



AES: 1st RF Test following (1^{st}) Light EP in the 2^{nd} Pass with JLab/FNAL Collaboration



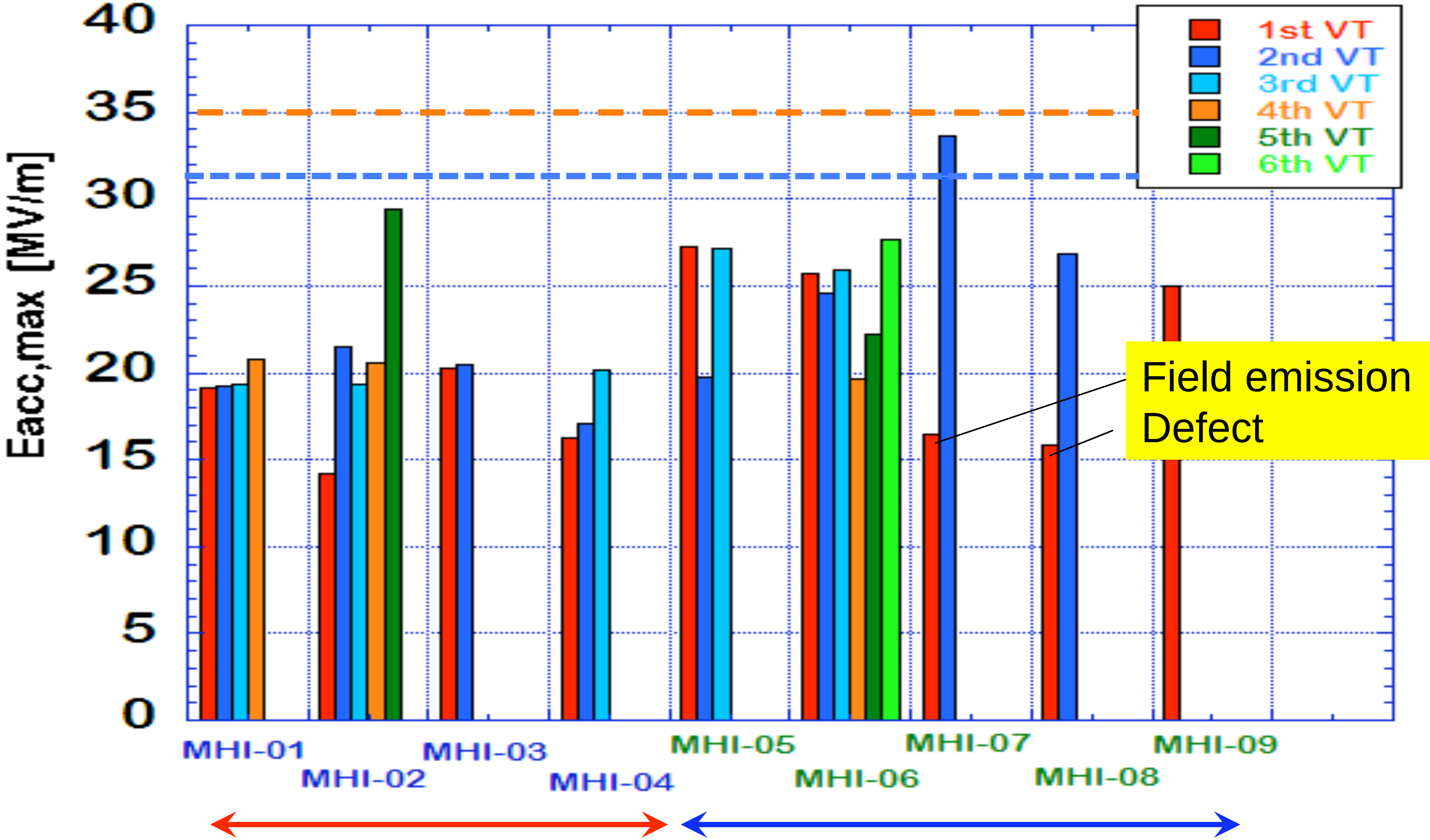
> 40 MV/m in 1-cells @ ANL/FNAL



	BCP*	EP	Ethanol	Eacc [MV/m]	Notes
NR-1	150	93		26.5	No distinguishing feature
TE1AES004	107	65		39.2	Equator large pit present
TE1AES005	104	100	Yes	36.3	Oxidation by HPR water
TE1ACC001		99	Yes	41.3	FE appeared due to vacuum handling
TE1ACC002		112		37.1	No distinguishing feature
TE1ACC003		119		42.1	Pits present

* BCP done at Cornell University

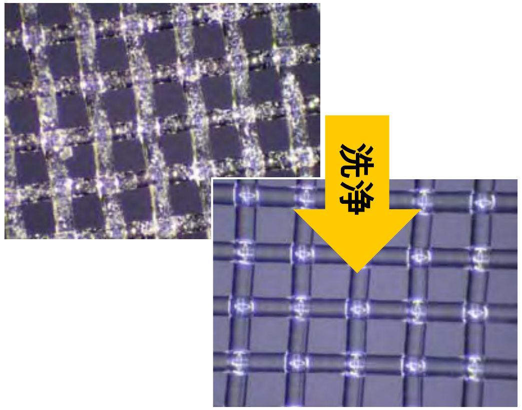
Progress at KEK/MHI Cavities

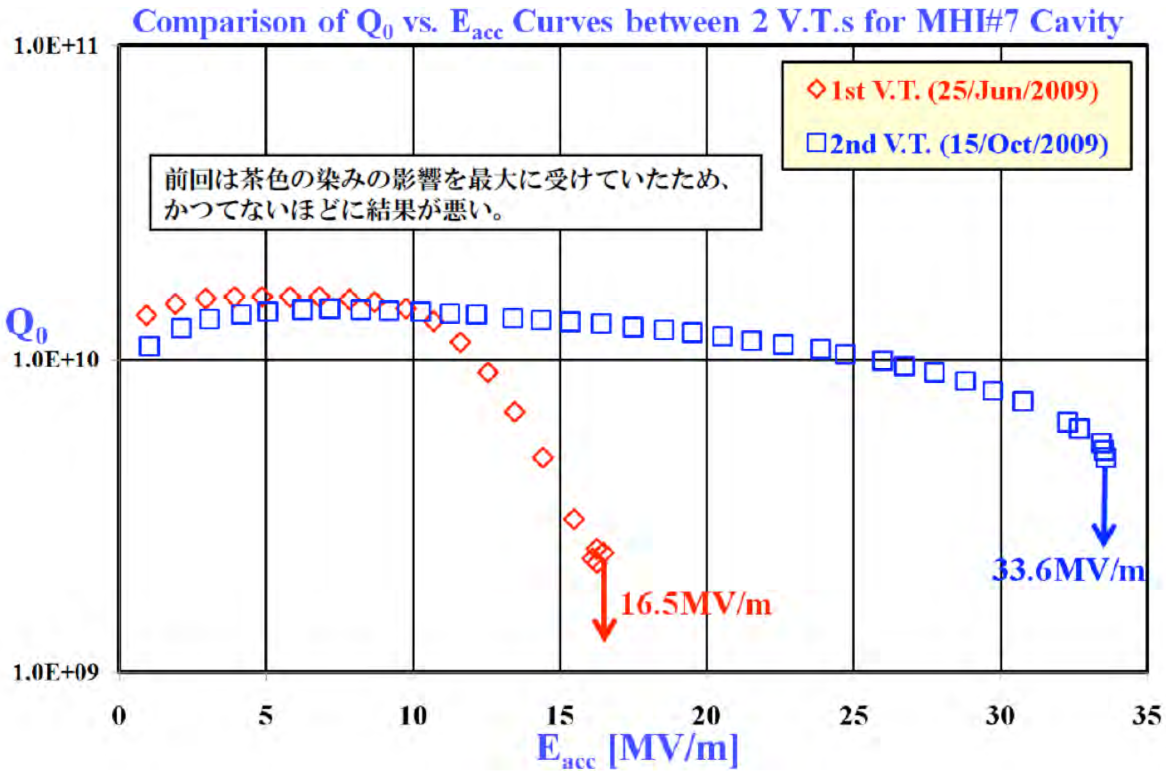


STF1: < 22.7 MV/m **S1-Global: <~28.0 MV/m >**

Achievement with Contribution of basic R&D for surface conditions

BL#6 #9-BP, t = 241 deg. -2

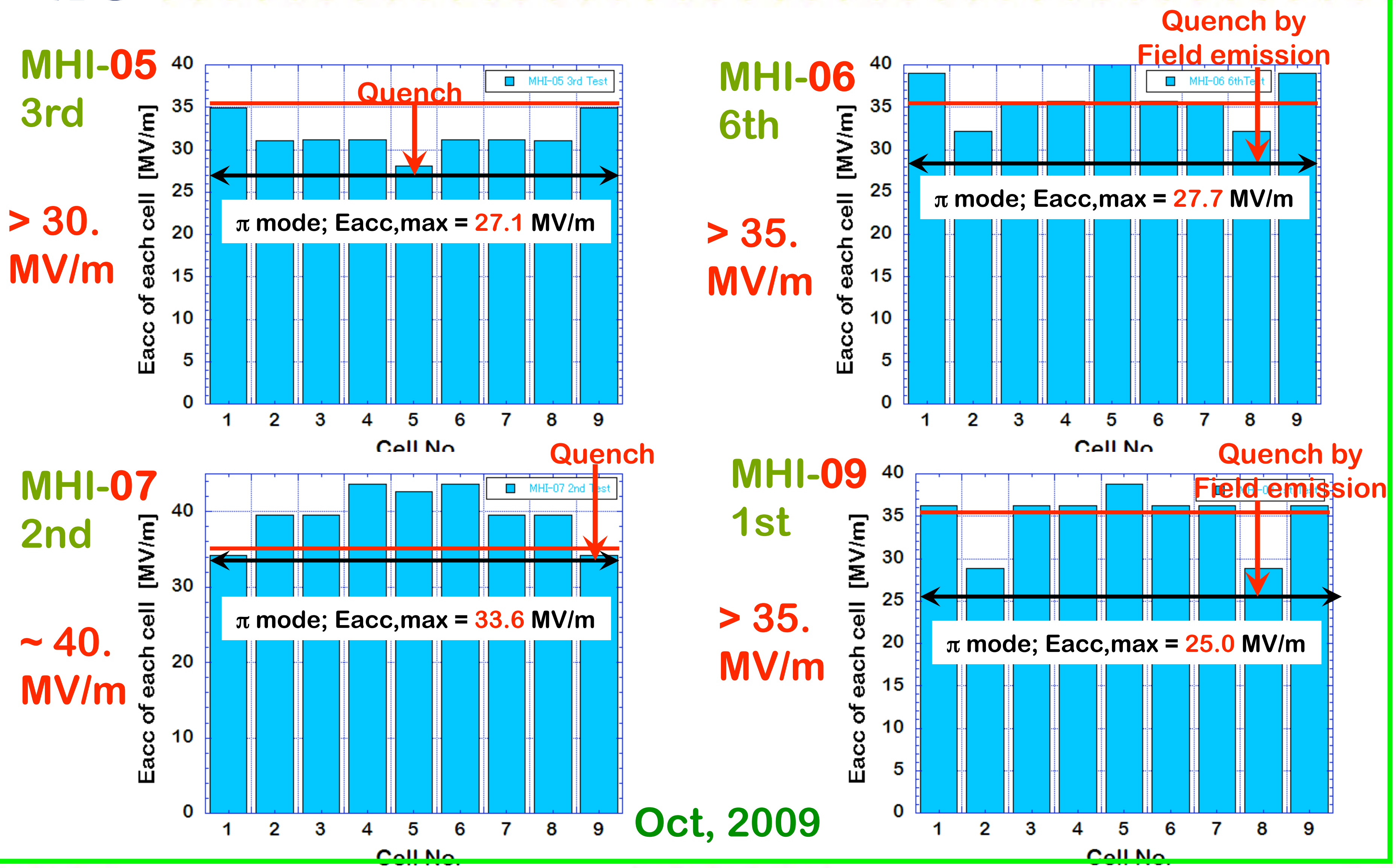




Possible reasons for improvement:

- Water rinsing (increased flow rate, time)
- Detergent rinsing .
- EP solution condition (aged) .

Eacc,max (cell) by Passbands modes Meas.



Oct, 2009

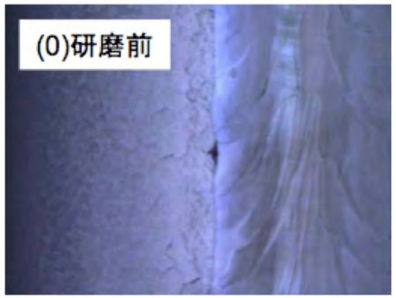
Emax spread 33.4 – 43.8 MV/m in n π / 9 Test

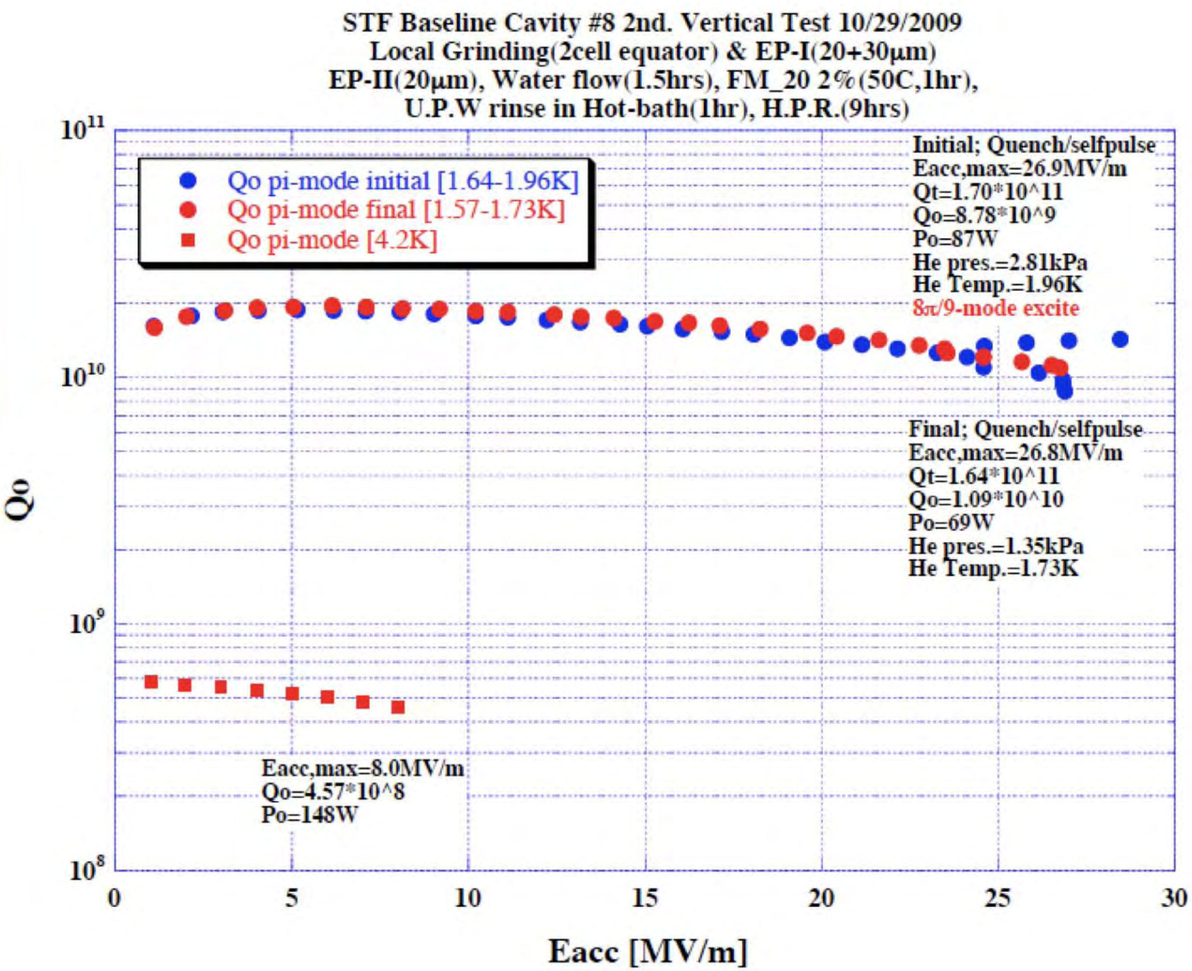
	Cell 1&9[MV/m]	Cell 2&8[MV/m]	Cell 3&7[MV/m]	Cell 4&6[MV/m]	Cell 5[MV/m]	Comment
π Initial	33.47	33.47	33.47	33.47	33.47	Radiation Limit : Heat@9cell Qo=4.79E9, Po=246W Xray over range
Final	33.59	33.59	33.59	33.59	33.59	Radiation Limit : Heat@9cell Qo=4.82E9, Po=247W Xray over range
8π/9	33.32	29.65	21.99	12.32	0	Quench/selfpulse : Heat@9cell Qo=5.51E9, Po=103W X-ray 4.38mSv/h
7π/9	34.19	18.12	6.84	26.33	36.58	Quench/selfpulse : Heat@9cell Qo=5.78E9, Po=114W X-ray 0.61mSv/h
6π/9	33.67	0	33.67	33.67	0	Quench/selfpulse : Heat@9cell Qo=5.42E9, Po=136W X-ray 0.62mSv/h
5π/9	33.51	22.79	39.54	6.70	42.56	Quench/selfpulse : Heat@5cell Qo=4.82E9, Po=191W X-ray 0.23mSv/h
4π/9	30.14	39.48	17.18	43.70	0	Power Limit : No heat Qo=3.96E9, Po=260W X-ray 0.95mSv/h
3π/9	17.45	34.90	17.45	17.45	34.90	Quench/selfpulse : Heat@5cell Qo=8.76E9, Po=65.7W X-ray 0.05mSv/h
Eacc,max	34.2	39.5	39.5	43.7	42.6	Ave. 39.6MV/m

- Emax limited by Cell 1 & 9

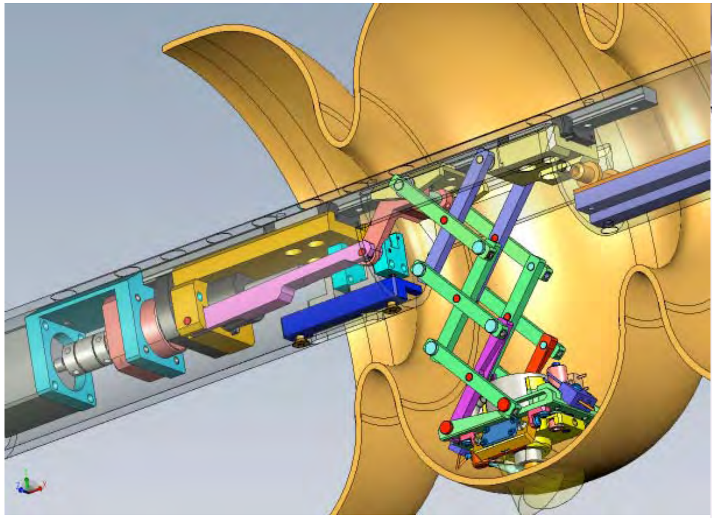
MHI-08: Latest Results from the 2nd Pass Test, Oct. 29, 2009

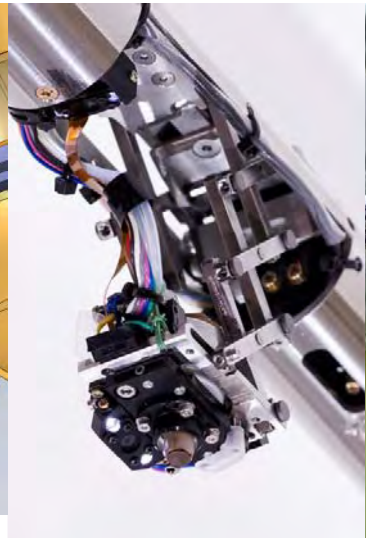
- Defect has been repaired using a grinding tool

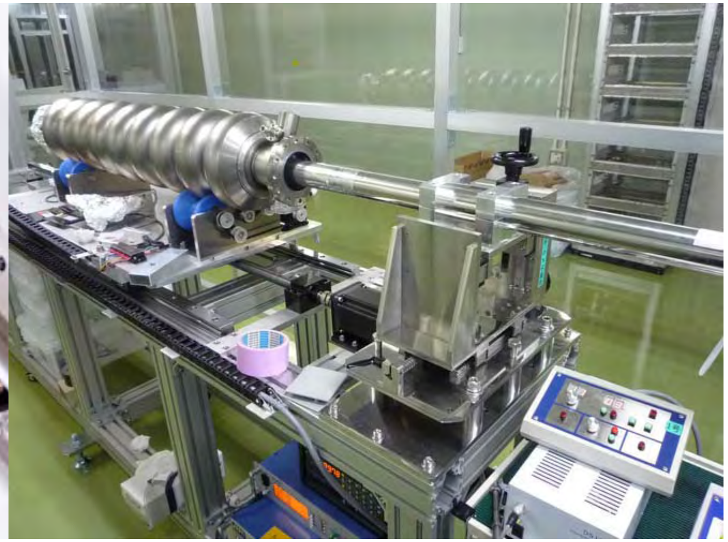




Local grinding for Surface Repairing



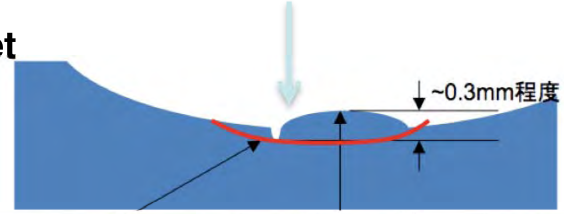


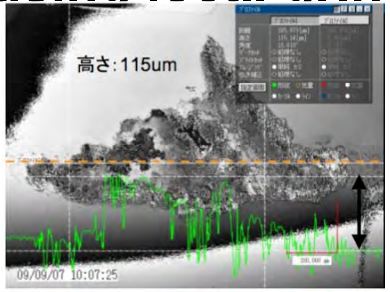


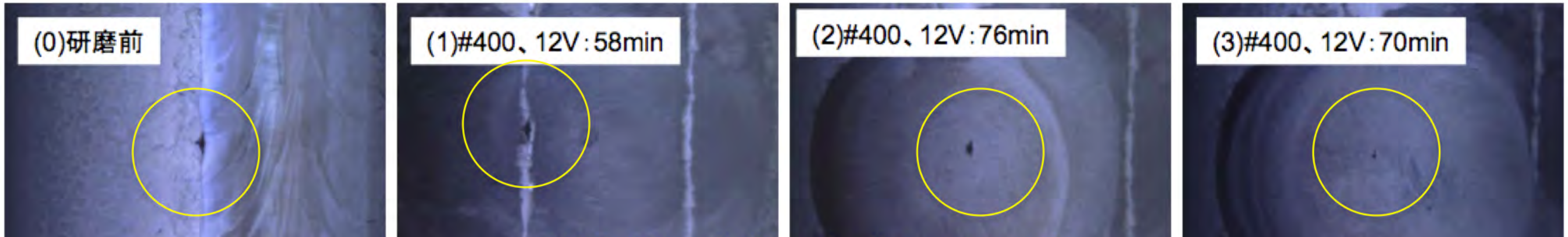
Defect removal test is under development using local grinder

use of special mechanics and diamond powder sheet together with pure water, in 9-cell cavity.

~115μm depth pit in MHI-08 cavity







MHI-08 cell #3 grinding example

Progress and Prospect of Cavity Gradient Yield Statistics

	PAC-09 Last/Best 2009-05	FALC 1st Pass 2009-07	ALCPG 2nd Pass 2009-10	To be added (2009-11)	Coming Prod. Y. (2010-06)	Research cavities
DESY	9 (AC) 16 (ZA)	8 (AC) 7 (ZA)	14 (AC/ZA)	10 (Prod-4)	5	8 (large G.)
JLAB FNAL/ ANL/ Cornell	8 (AC) 4 (AE) 1 (KE-LL5) 1 (JL-2)	7 (AC)	7 (AC)	~ 5 (AE)	12 (AC) 6 (AE)	6 (NW) (including large-G)
KEK/ IHEP				5 (MH)	2 (MH)	~5 (LL) 1 (IHEP)
Sum	39	22	21	20	25	**~ 20**
G-Sum				41	66	

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

Cavity Gradient Study - Summary

- Yield at 35 MV/m (w/ established vendors: **RI, Zanon**)
  - **22 % at 1st pass (statistics 22)**
  - **33 % at 2nd pass (statistics 21, as of 2009-07))**
    - Average Gradient reaching 30 MV/m
  - DESY Prod-4 data to be added, (10 more statistics)
- New statistics coming (w/ potential vendors)
  - **AES: to be counted from #5** (to be confirmed)
  - **MHI: to be counted from #5** (to be confirmed)
- Selecting statistics needed for 'Production Yield'
  - **to evaluate readiness of industrialization and cost**

Note: *Numbers of Cavities for 'gradient research': need to be separately counted.*

A Proposal for Re-baseline Cavity Gradient and Yield, in TDP-2

- Operational field of <31.5 MV/m> (@ Q0 = 1E10)
  - Keep it, as the 'averaged field gradient' in the ILC operational condition with cryomodule string, and
  - Accept the gradient distribution of (~ 20 % (b/w 25 – 38 MV/m) in operation (note: exact number to be further well discussed)
    - See the recent progress at DESY PXFEL cryomodule test result
- Maximum gradient of 35 MV/m (@ Q0 = 8E9) in vert. test
  - keep our R&D goal of the yield of 90 % at 35 MV/m, as a target, and
  - Recognize that the yield may be acceptable to be ~ 50 % with the +/-20 % distribution (i. e., b/w 28 and 42 MV/m) of the gradient.
- Production Yield
  - the yield of 90 % at the 28 MV/m, and 50 % at 35 MV/m may meet the the ILC operational field gradient with a margin of 10 % , by taking the above model with the distribution of +/- 20 %.

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	→ Yield 50%			→ 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			

S1 Goal: Achieved at DESY/XFEL

NewsLine

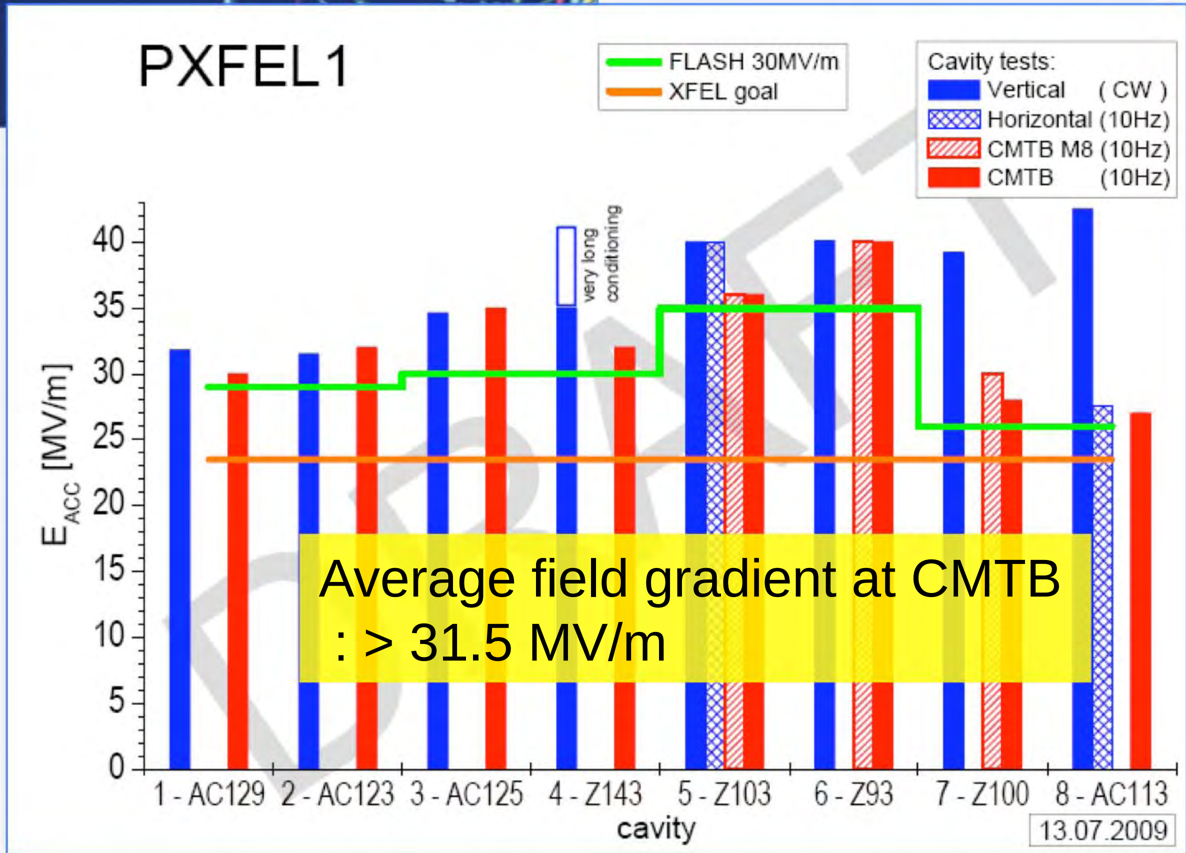
Around the World

Cryomodule surpasses ILC gradient test

European-XFEL cryomodule using SCRF technology sets new record

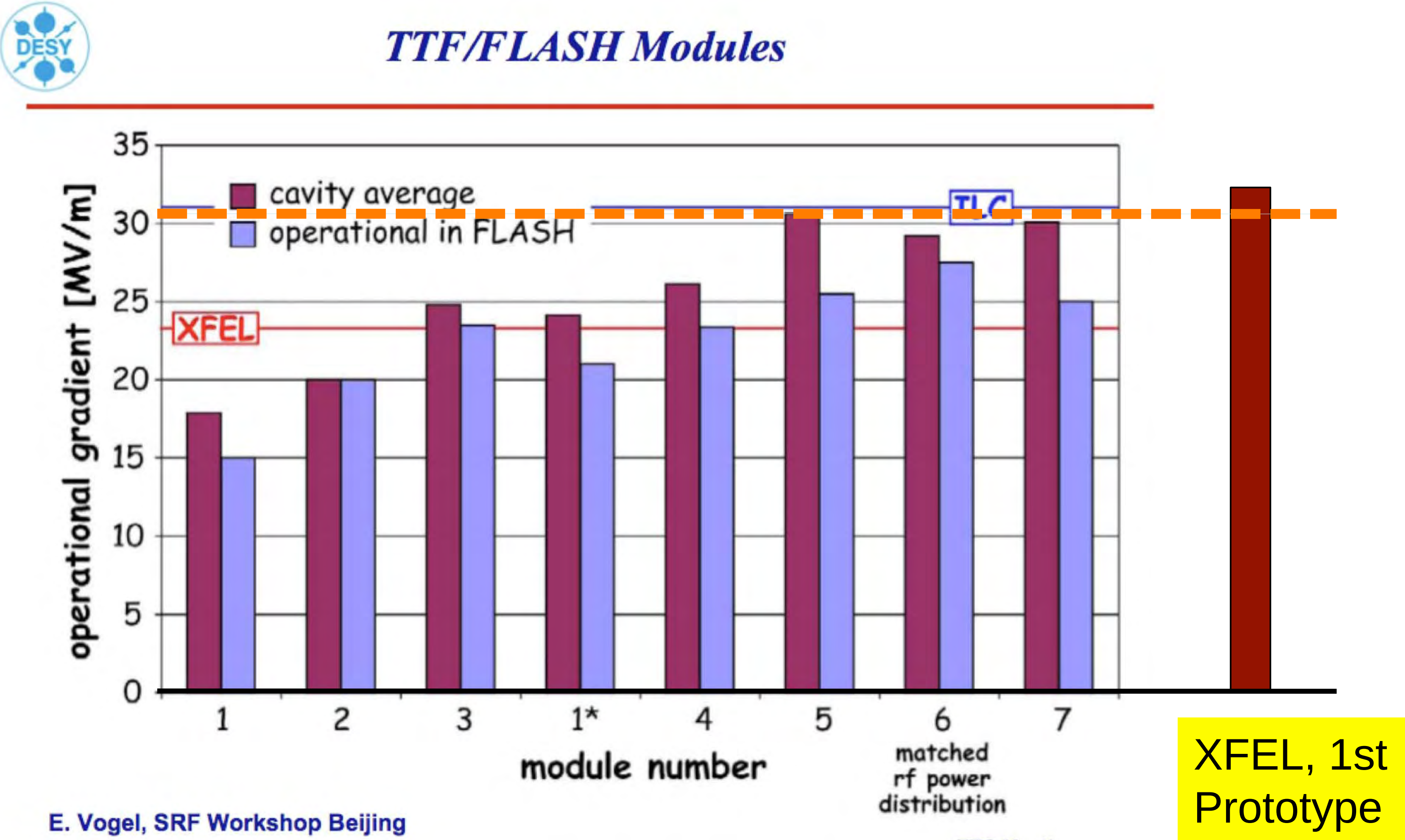
The cryomodule that set the world gradient record in the testbench at DESY

A cryomodule prototype for the European XFEL has set the world gradient record for cryomodules built with superconducting radiofrequency technology, reaching an average accelerating gradient of more than 32 megavolts per metre (MV/m) in recent



- 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

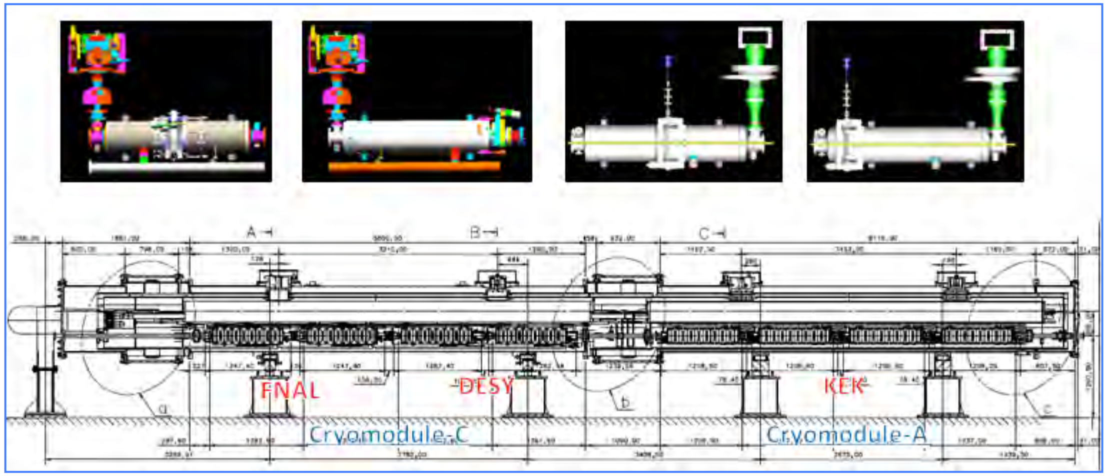
Progress at DESY & TTF/FLASH



S1-Global in Progress
INFN/ZANON Cryomodule Completed

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

INFN/KEK Crew at Zanon
S1, Global Cryomodule
Completion in Dec. 2009



Eight Candidate Cavities for S1-Global

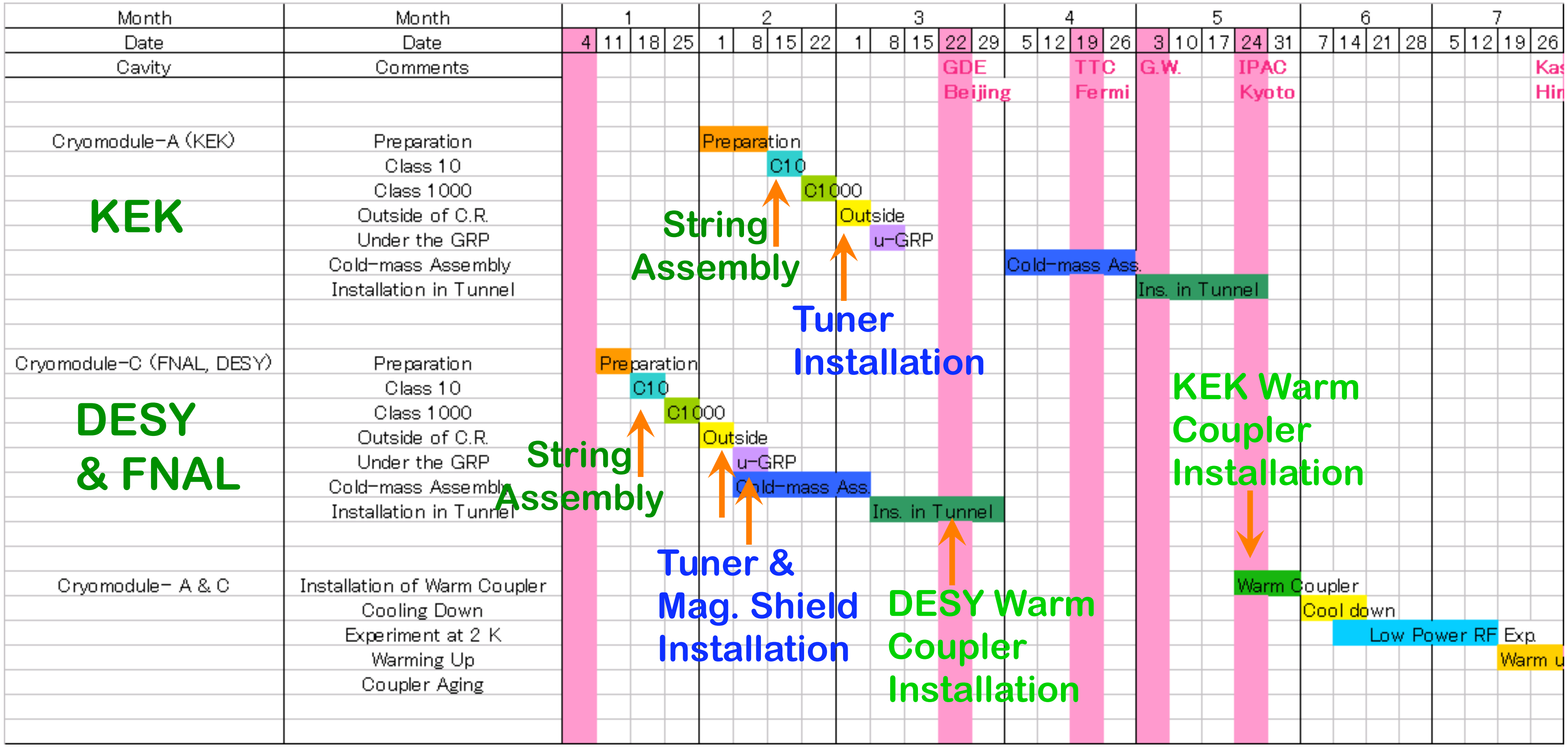
1. MHI-05 (27.1 MV/m) ; Slide-Jack tuner (center)
2. MHI-06 (27.7 MV/m) ; Slide-Jack tuner (center)
3. MHI-07 (33.6 MV/m) ; Slide-Jack tuner (end)
4. MHI-09/08 (25.0/?? MV/m) ; Slide-Jack tuner (end)
5. Zanon-108 (31.3 MV/m) ; Saclay tuner (end)
6. Zanon-109 (30.7 MV/m) ; Saclay tuner (end)
7. AES-002 ? (32.8 MV/m) ; Blade tuner (center)
8. ACCEL-8 ? (30.6 MV/m) ; Blade tuner (center)

Candidates considered, as of Oct. 26, 2009

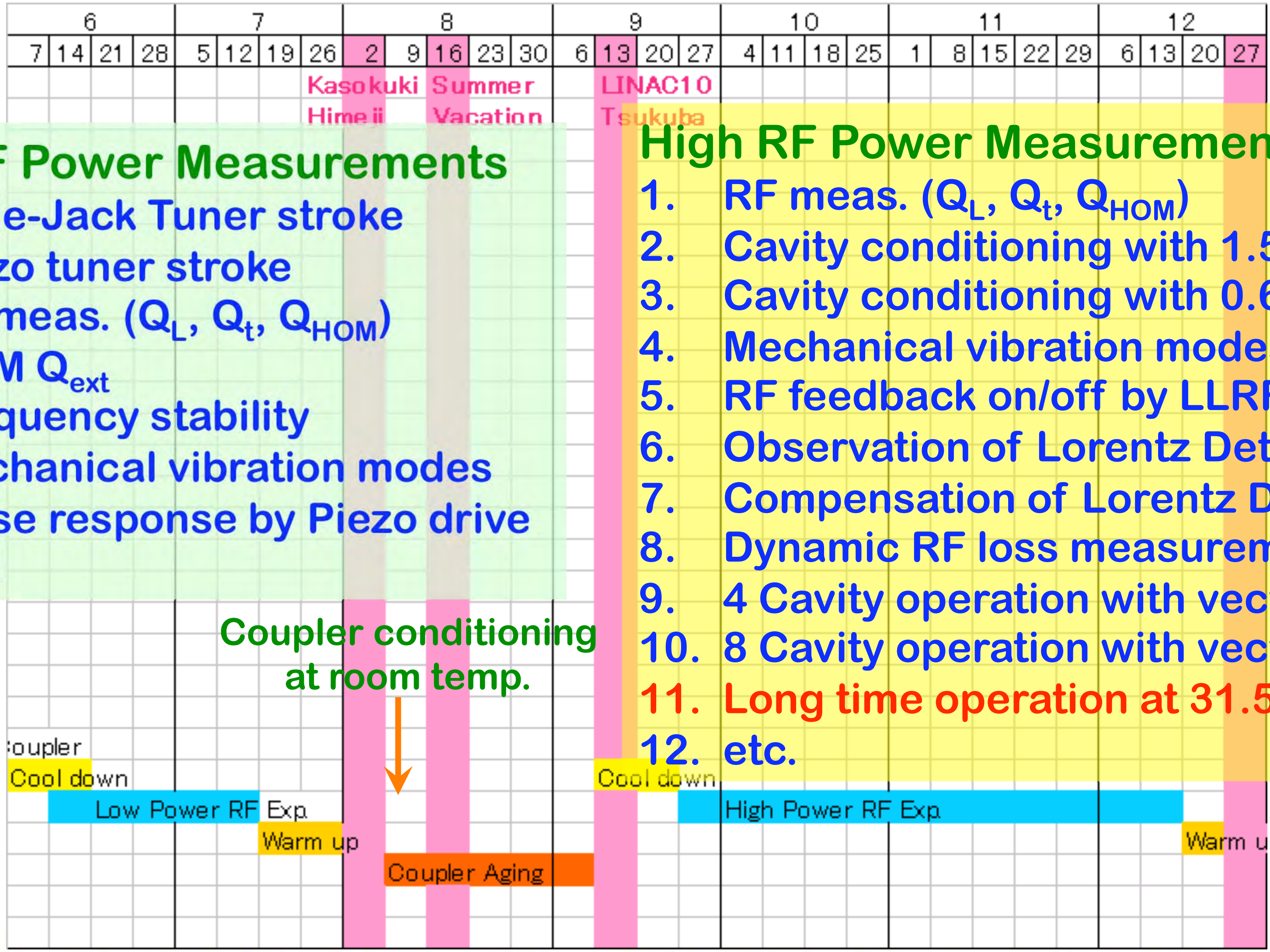
MHI (Japan), Zanon (Italy), AES (USA), ACCEL/RI (Germany)

Expected Average Gradient: ~ 30 MV/m

Cavity Assembly for S1-Global



Cryomodule Tests Objectives for S1-Global



Low RF Power Measurements

1. Slide-Jack Tuner stroke
2. Piezo tuner stroke
3. RF meas. (Q_L, Q_t, Q_{HOM})
4. HOM Q_{ext}
5. Frequency stability
6. Mechanical vibration modes
7. Pulse response by Piezo drive
8. etc.

High RF Power Measurements

1. RF meas. (Q_L, Q_t, Q_{HOM})
2. Cavity conditioning with 1.5 ms
3. Cavity conditioning with 0.6 ms
4. Mechanical vibration modes (5Hz)
5. RF feedback on/off by LLRF
6. Observation of Lorentz Detuning
7. Compensation of Lorentz Detuning
8. Dynamic RF loss measurement
9. 4 Cavity operation with vector-sum
10. 8 Cavity operation with vector-sum
11. Long time operation at 31.5 MV/m
12. etc.

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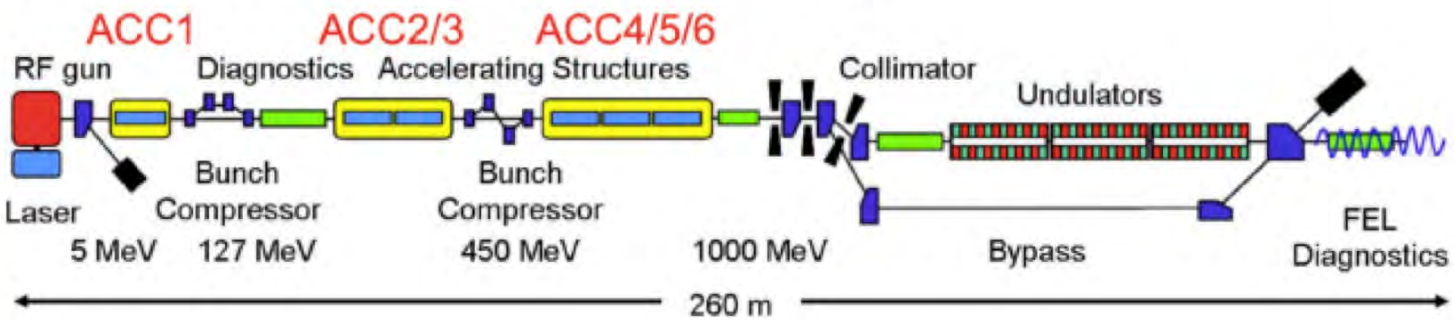
Preparation for Industrialization			Production Technology R&D			

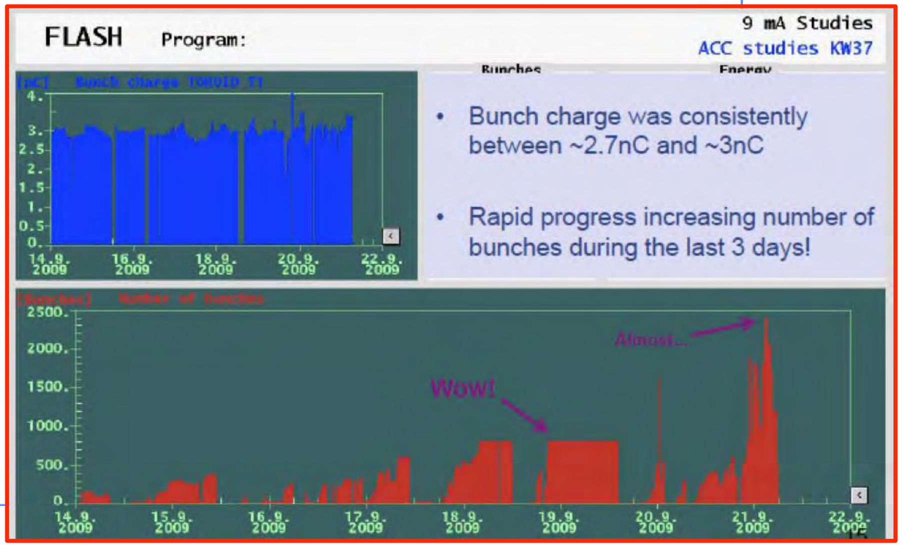
Global SCRF Technology: EUROPE

S2: TTF/FLASH 9mA Experiment

Full beam-loading long pulse operation → "S2"

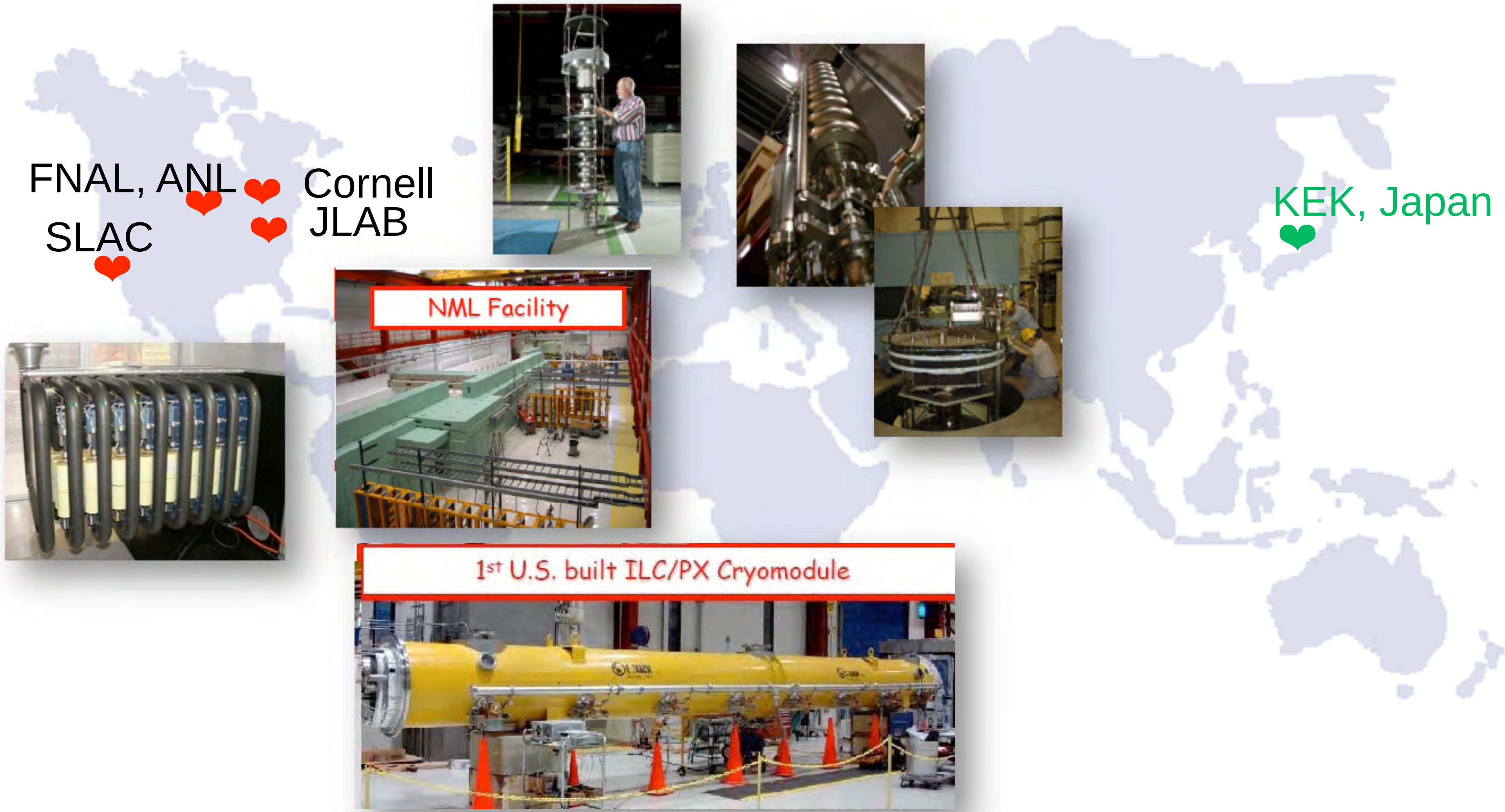


		XFEL	ILC	FLASH design	9mA studies
Bunch charge	nC	1	3.2	1	3
# bunches		3250	2625	7200*	2400
Pulse length	µs	650	970	800	800
Current	mA	5	9	9	9



- Successfully completed 2-week dedicated experiment

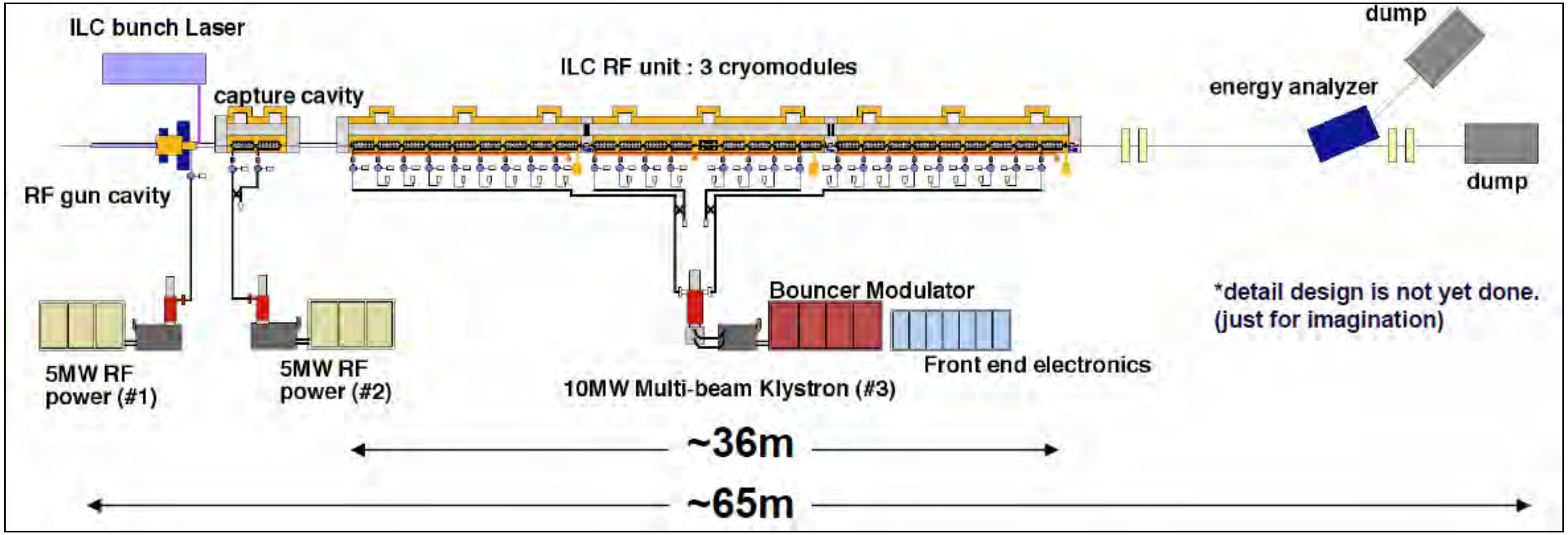
SCRF : AMERICAS



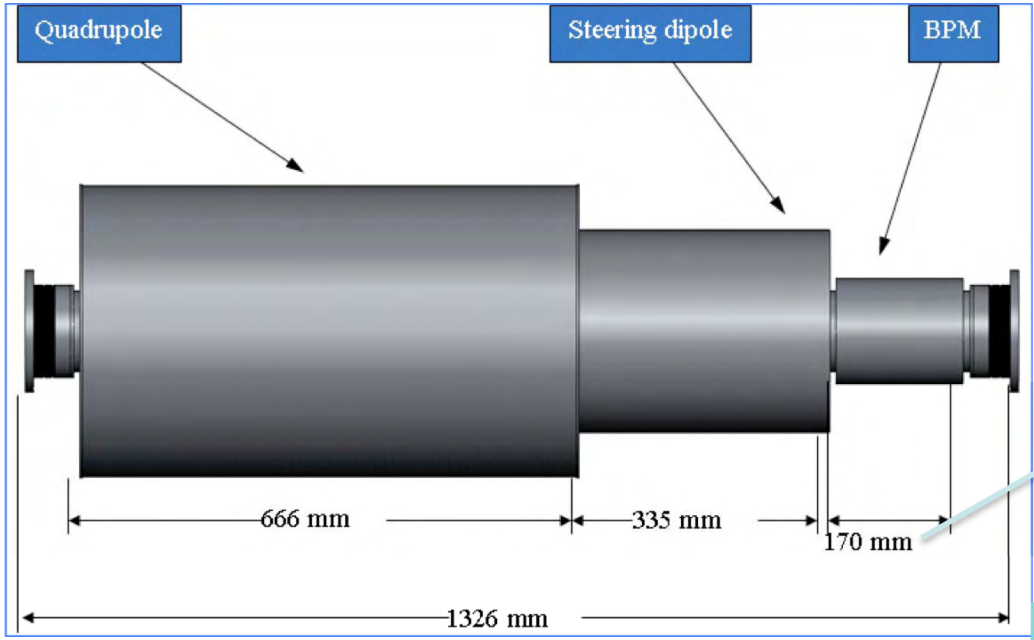
SCRF: ASIA

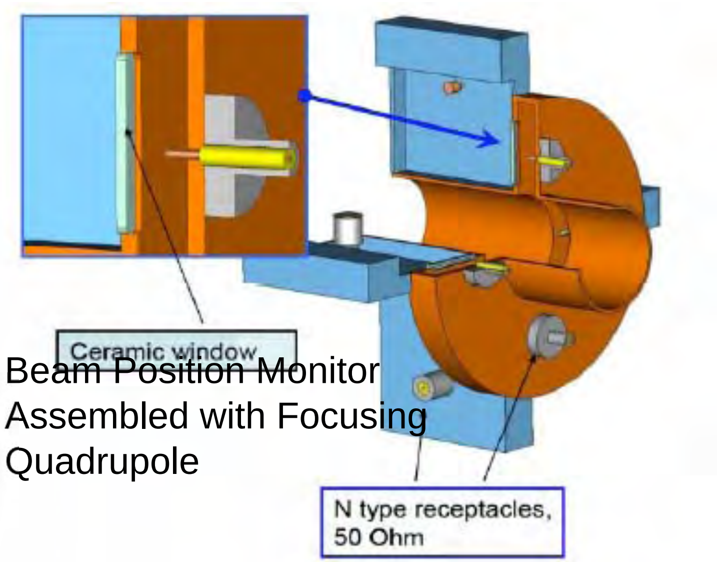
Beam Acceleration Test Plan

with RF unit at Fermilab and KEK in TDP-2

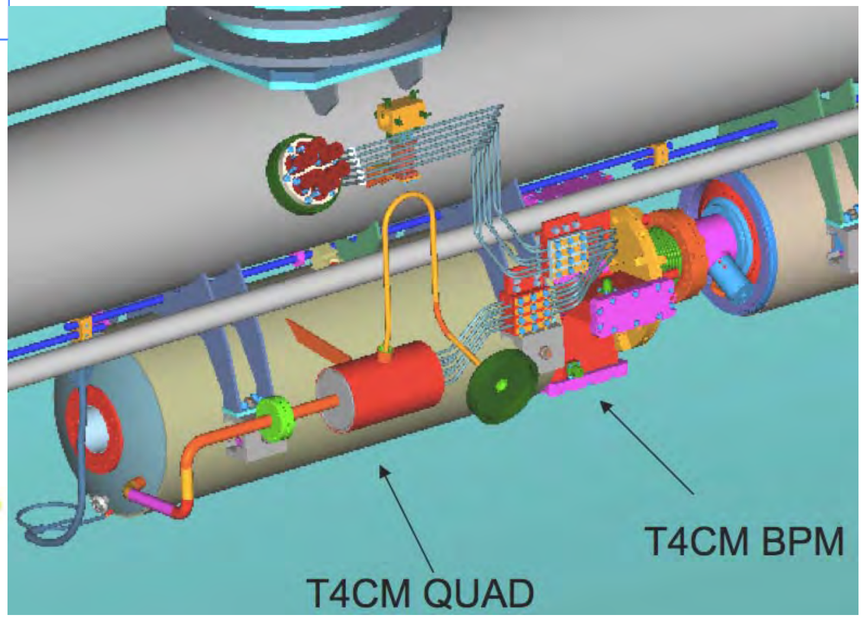


Quadrupole Development at FNAL - Conduction cooling -



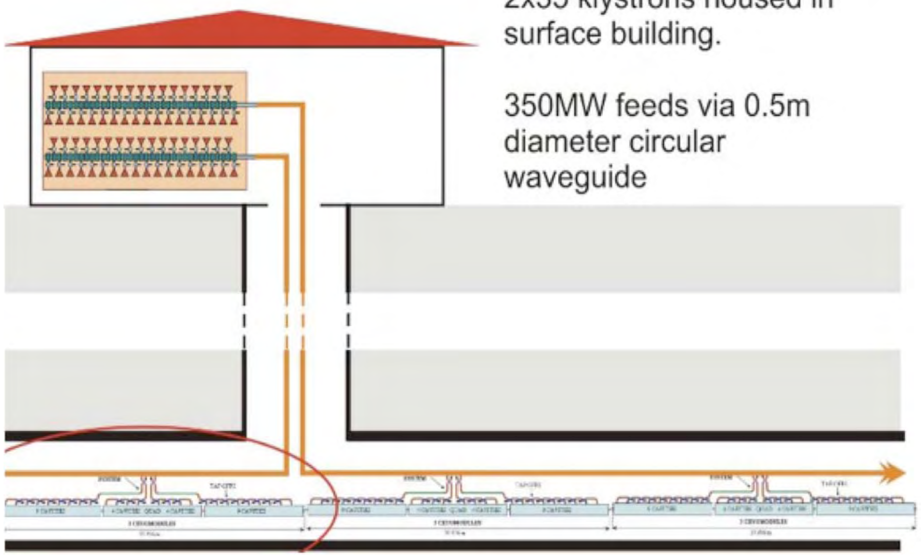


Beam Position Monitor Assembled with Focusing Quadrupole

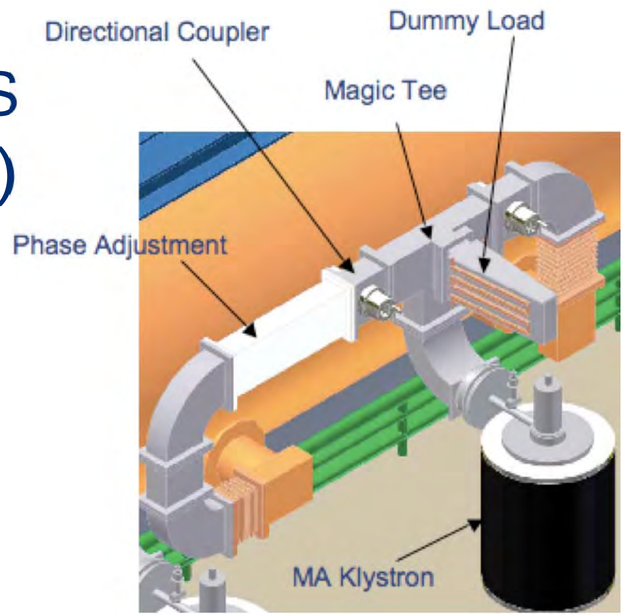


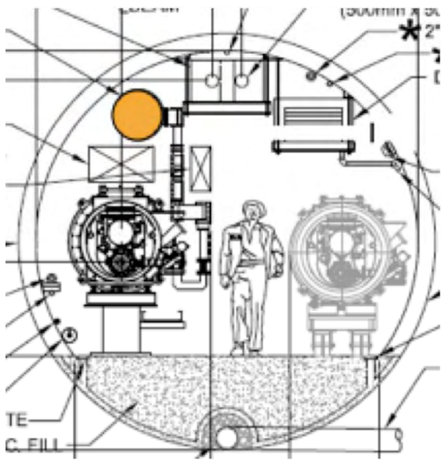
Note: Alternate effort with SLAC/SIEMAT collaboration progressed

Novel RF Distribution Concepts

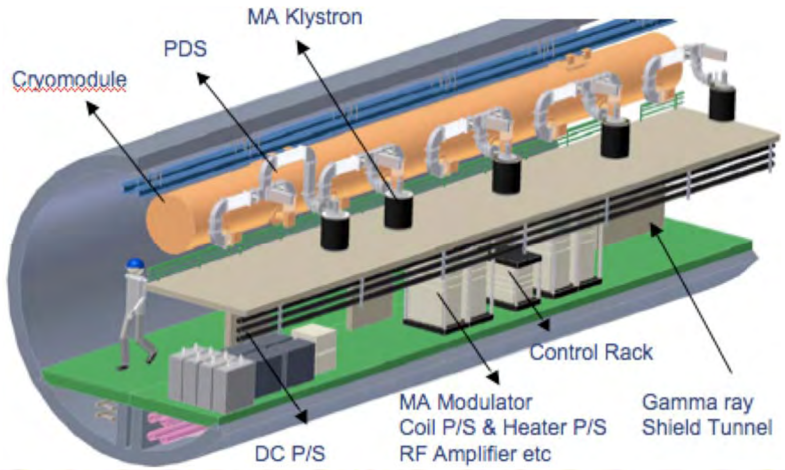


DRFS (KEK)





Klystron Cluster (SLAC)



Single Tunnel Solutions

SCRF R&D Plan at Fermilab

from P5 talk by S. Holmes

	FY08	FY09	FY10	FY11	FY12	FY13
ILC C+CM	CM1	CM2	CM3 (Type IV)		CM4 rf unit syst.tst	
ILC RF Power		MBK	PFN modulator			
SRF Infra.				NML complete		CAF complete (1 CM/month)
HINS				60 MeV beam tests		
Project X			CDR	FE decision Gradient decision baseline docs	rf unit sys.tst	
	CD-0		CD-1	CD-2/3a		

Cavity- and Cryomodule-String Program (S1G, S2) at KEK, Japan

C. Year	2008	2009	2010	2011	2012	2013	2014
Cavity String (S1-Global)	Cavity	>>	Ins / Test				
Cryomodule String Test (S2)	*High Pressure Code Regulation/Stamp to be applied						
Quant. Beam* (Compact L.S.)		Cavity	>>	Inst. / Test	Test		
Cryomodule 1*		Cavity	>>	>>	Ins & T	Ins & T	
Cryomodule 2,3*			Cavity	>>	>>	Ins	Ins & T
	Technical Design Phase					Development to be continued	

R&D/Prepare for Industrialization

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	→ Yield 50%			→ 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			Mass-Production Technology R&D			

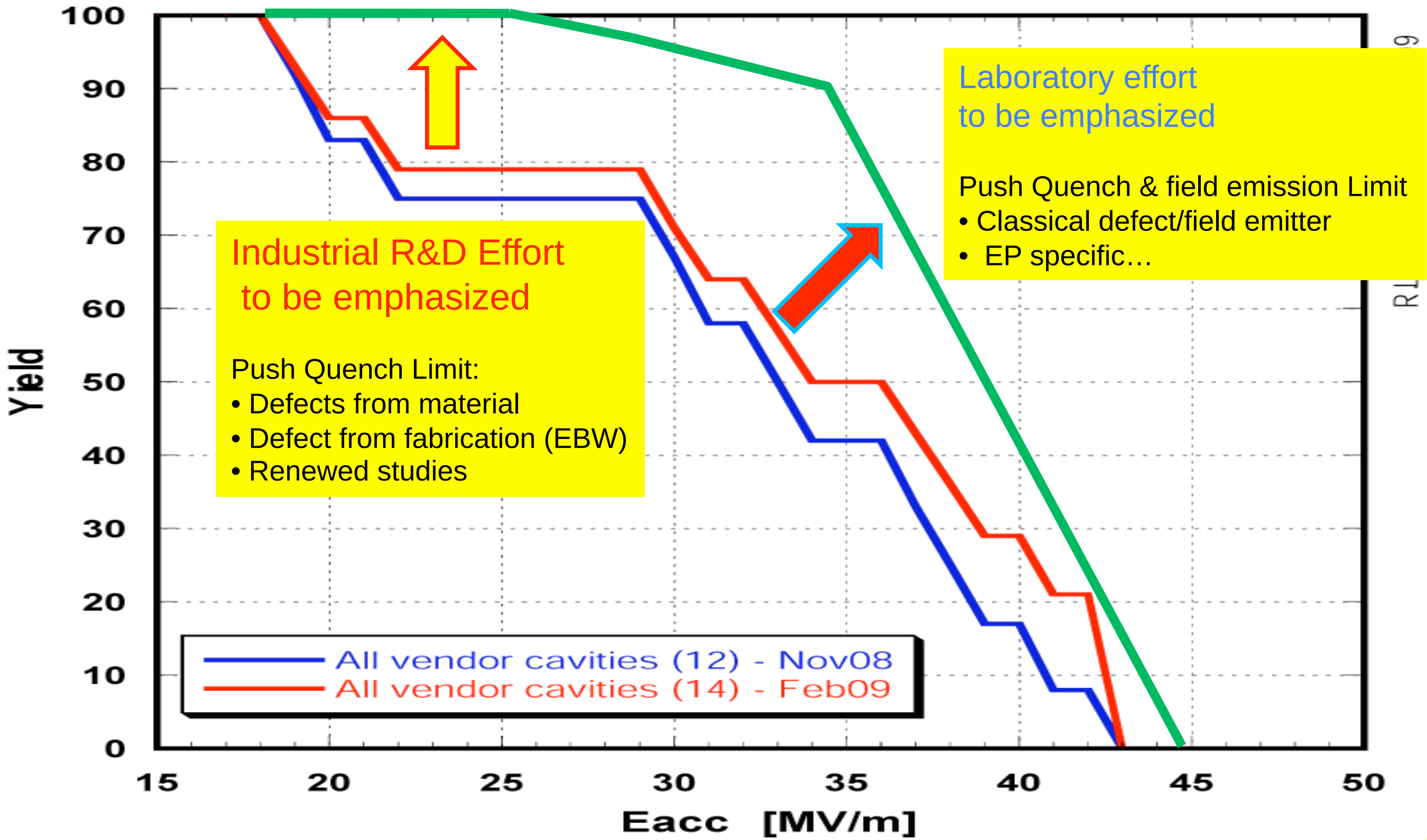
Toward Industrialization

- Global status of Industries
  - **Research Instruments (ACCEL) and Zanon in Europe**
  - **AES, Niowave, PAVAC in Americas**
  - **MHI in Asia**

Project Scope			
SNS	~ 110	3years	< ~ 1 cavity / week
Euro XFEL	~800	2 years	~1 cavity / day
Project X	~400	3 years	~2 cavities/ week
ILC	~15,500	4 years	~20 cavities / day
(÷ 3 regions			~7 cavities / day)

- Industrial Capacity: status and scope
  - **No company currently ready for the ILC capacity**
  - **Need to understand what is required (and cost) by 2012**

Two Pushes Ahead



SC Cavity Manufacturers: 2009

Europe:

RI (ACCEL)
ZANON

Americas:

AES
NIOWAVE
PAVAC

Asia

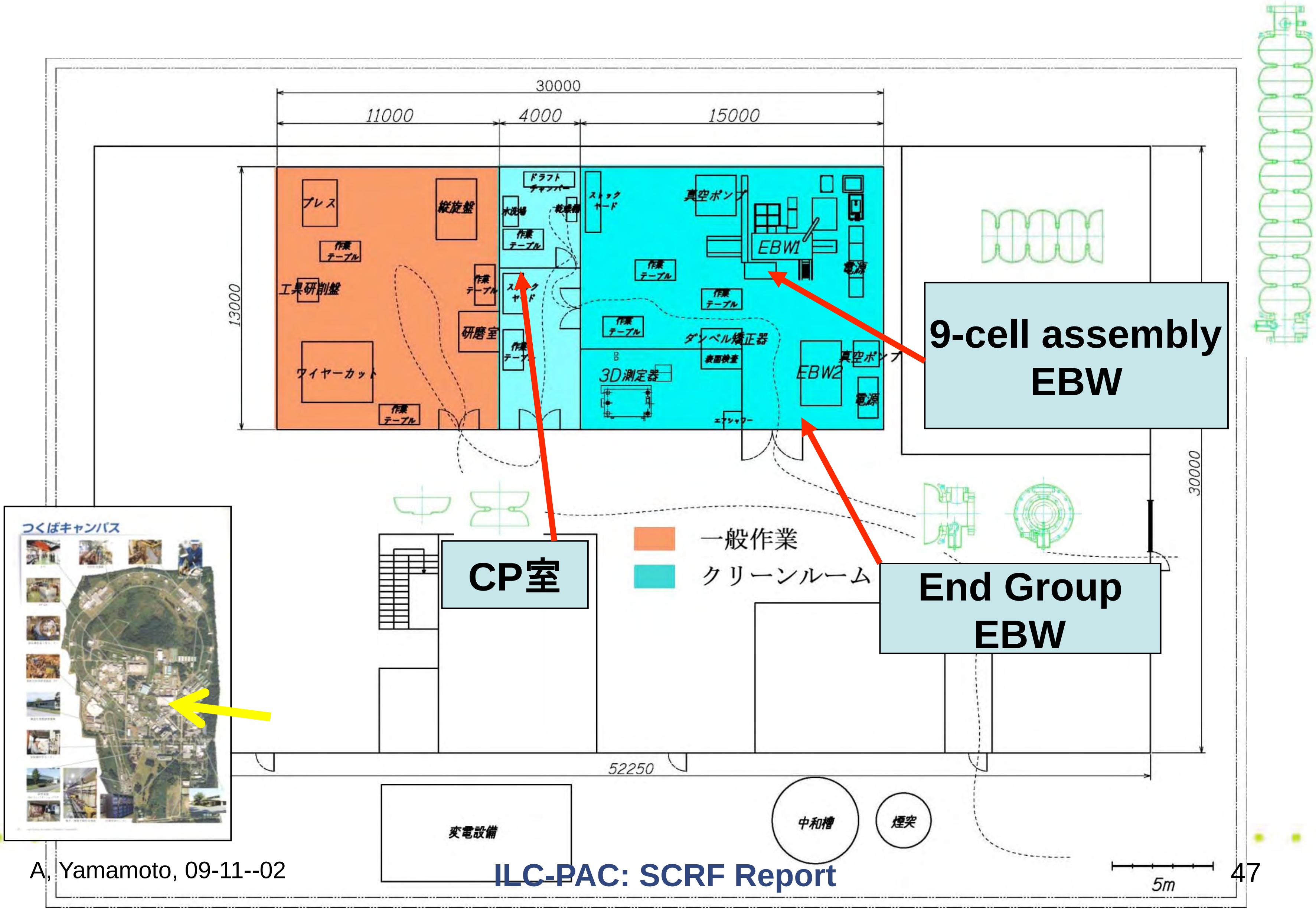
MHI
HITACHI (expected)
TOSHIBA (expected)

Notes:
AES: Advanced Energy Systems
RI: Research Instruments (previously, ACCEL)
MHI: Mitsubishi Heavy Industries

Prepare for ILC-scale Industrialization

- Learn previous efforts and current status:
  - Industrialization study for TESLA (1990's)
  - Recent R&D progress (in ~ 10 years)
  - Current status in industries (in progress)
- Learn industrialization at XFEL Project
- Prepare for ILC-scale industrialization
  - **Encourage Laboratory-hosted Pilot Facilities/Plant, particularly important at KEK,**
    - to study cost effective production and quality control with participation of industries,
  - **Prepare for cost-effective production and quality control in cooperation with industries,**

Plan Proposed for a Pilot Facility at KEK for SCRF Cavity Production R&D



Possible EBW Facility at KEK

Vertical
Electron beam gun

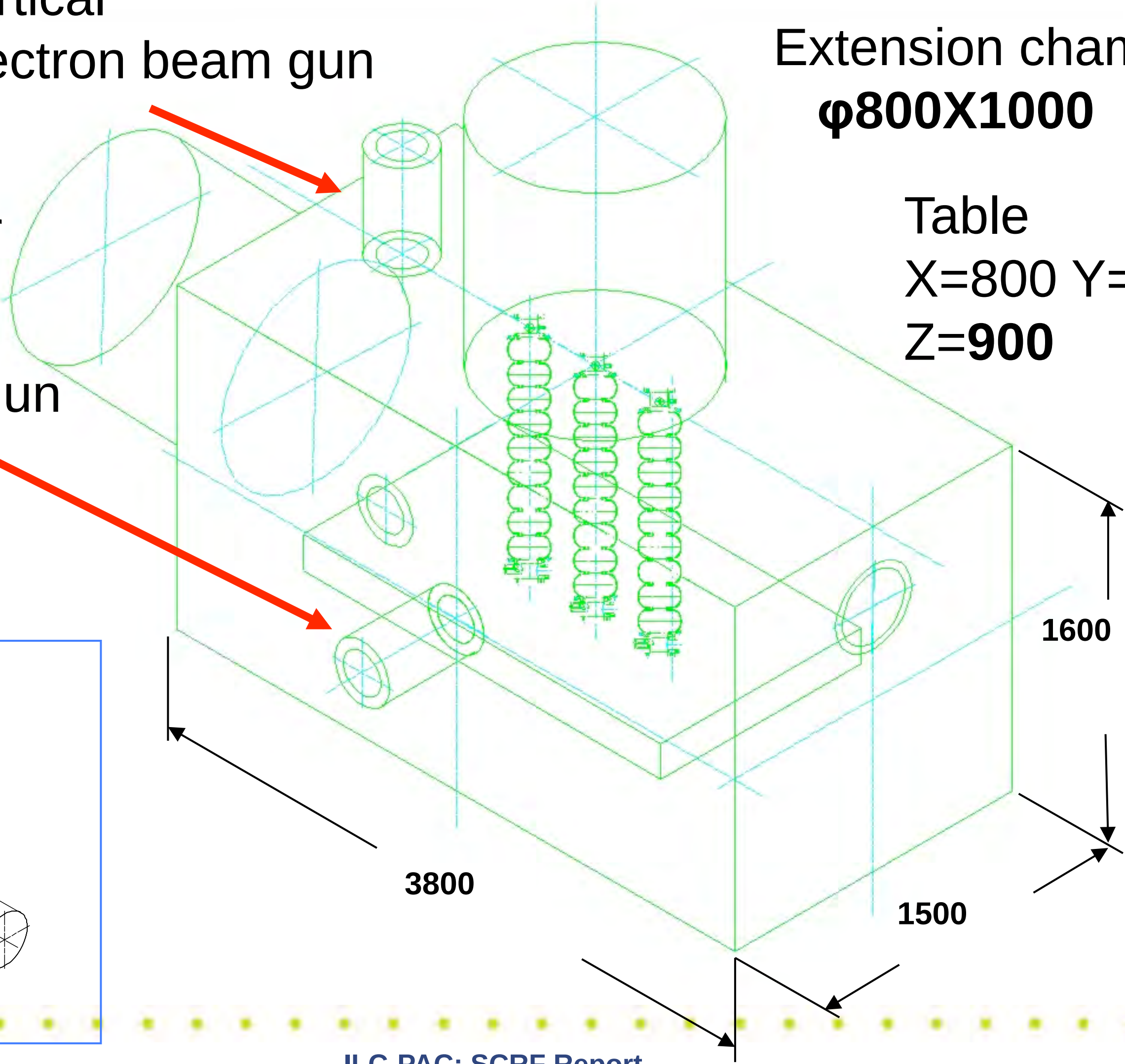
Extension chamber
φ800X1000

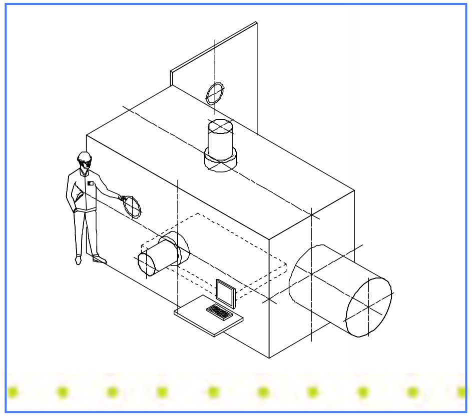
Extension
chamber

Table
X=800 Y=600,
Z=**900**

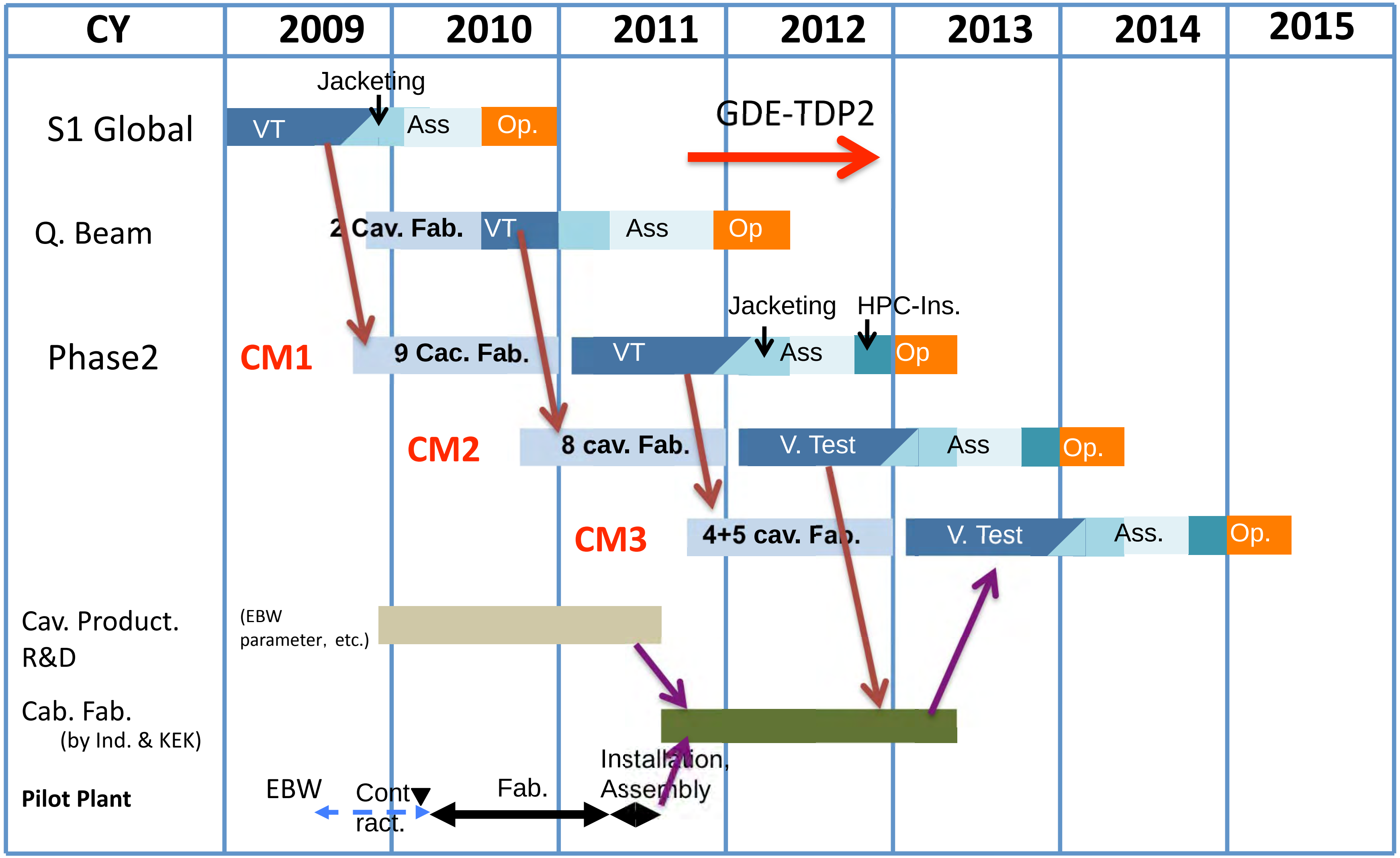
Horizontal
Electron beam gun

±200





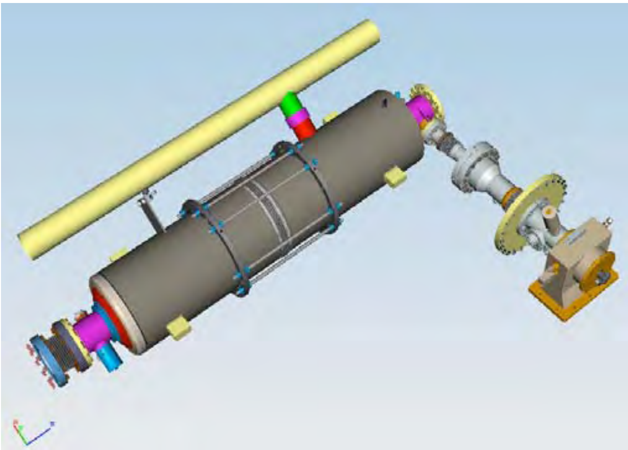
KEK-STF: Long Term Plan

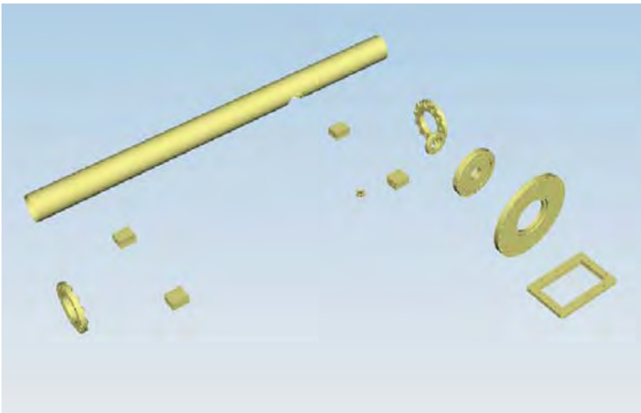


Plug-compatibility in R&D and Construction Phases

- **R&D Phase**
  - Creative work for further improvement with keeping replaceable condition,
  - Global cooperation and share for advanced technology
- **Construction Phase**
  - Prepare for various organization scheme for the ILC global collagoration including ‘in-kind contribution,
  - Keep competition with free market/multiple-suppliers, and effort for const-reduction, at least within a region
  - Maintain “intellectual” regional expertise base
  - Encourage regional centers for fabrication/test facilities with accepting regional features/constraints

Plug-compatible Conditions



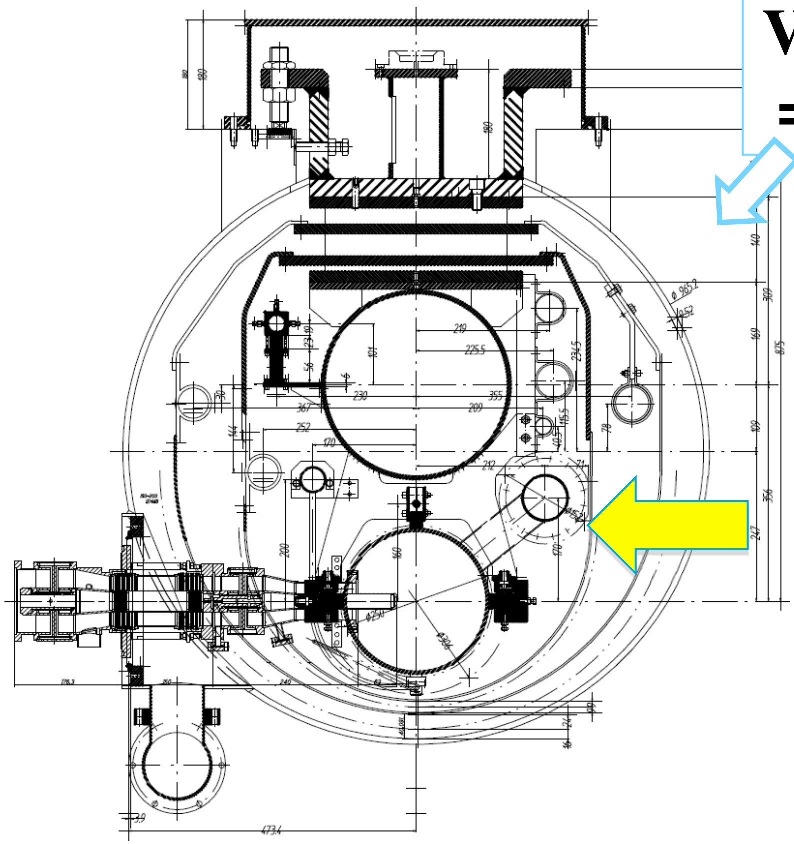


Item	Can be flexible	Plug-comp.
Cavity shape	TeSLA/ LL/RE	
Length		Fixed
Beam pipe flange		Fixed
Suspension pitch		Fixed
Tuner	Blade/Jack	
Coupler flange (warm end)		Fixed
Coupler pitch		fixed
He –in-line joint		TBD

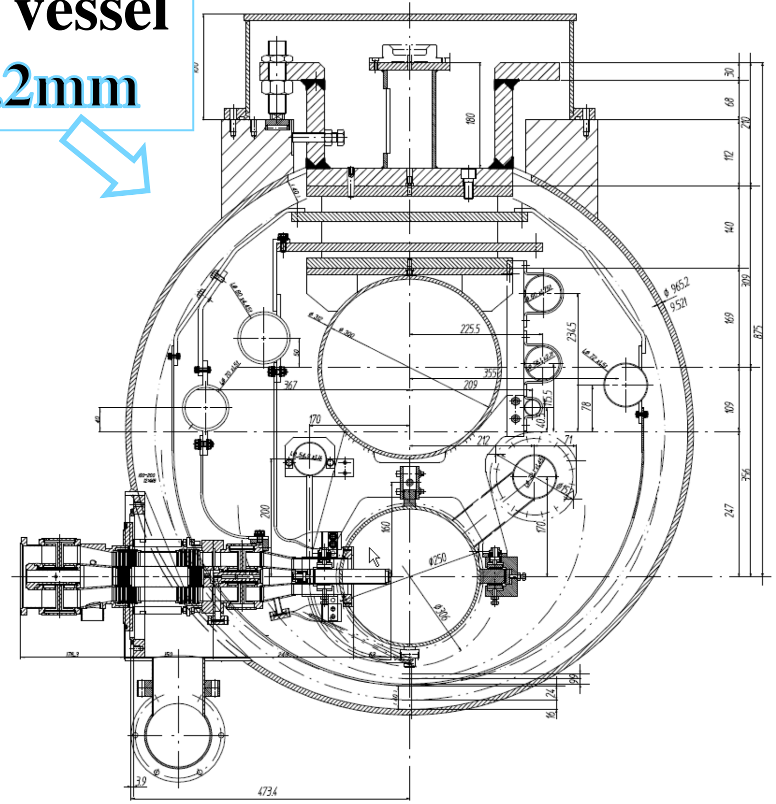
Plug-compatible interface nearly established

Study of the “plug-compatible” cryomodule cross-section

Vacuum vessel
= ϕ 965.2mm



Two shields model based on TTF-III

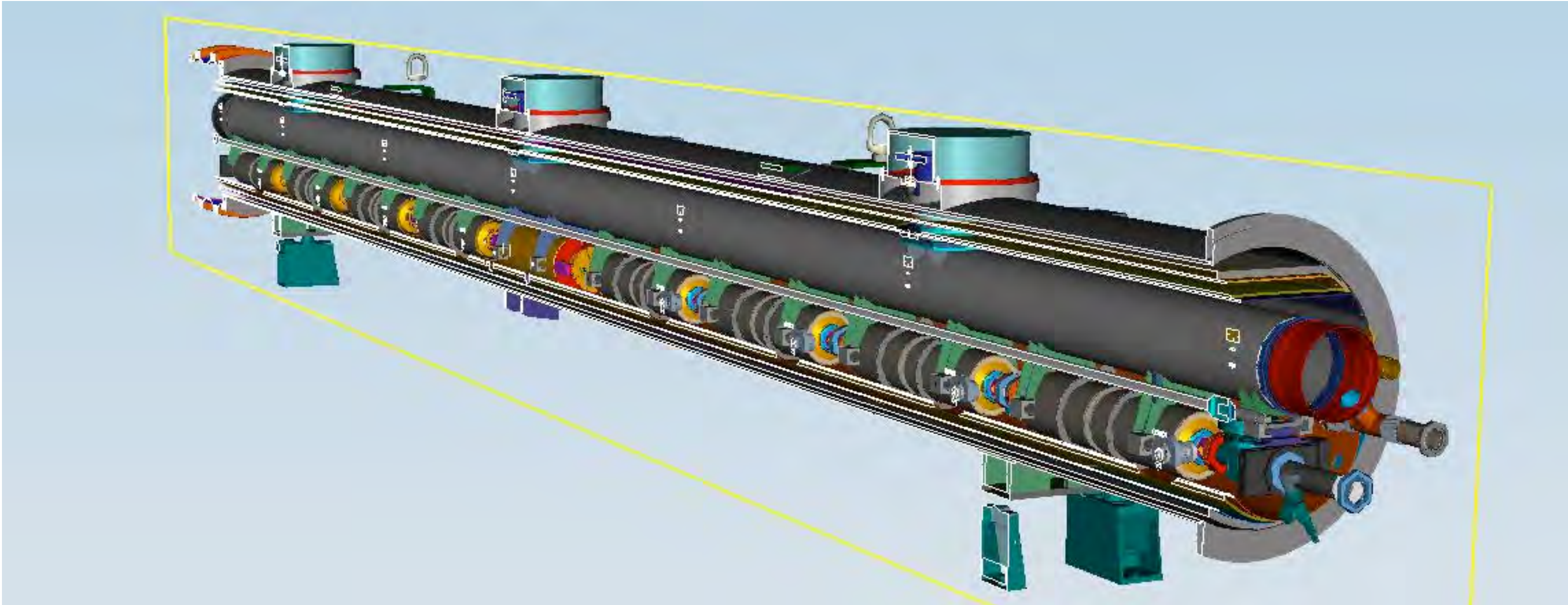


One shield model to save fabrication cost

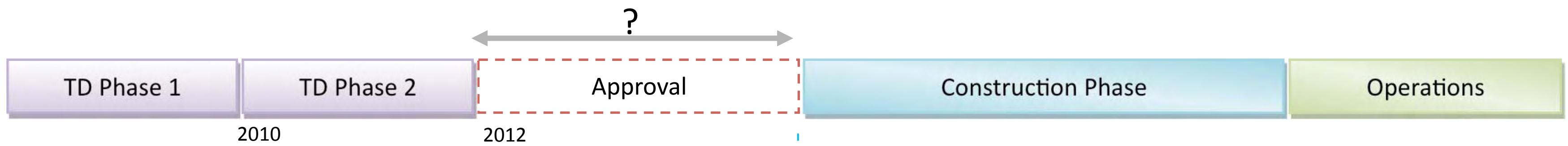
Plug-compatibility

- Plug Compatibility could be applied from a level of the whole cryomodule, to the smallest component.

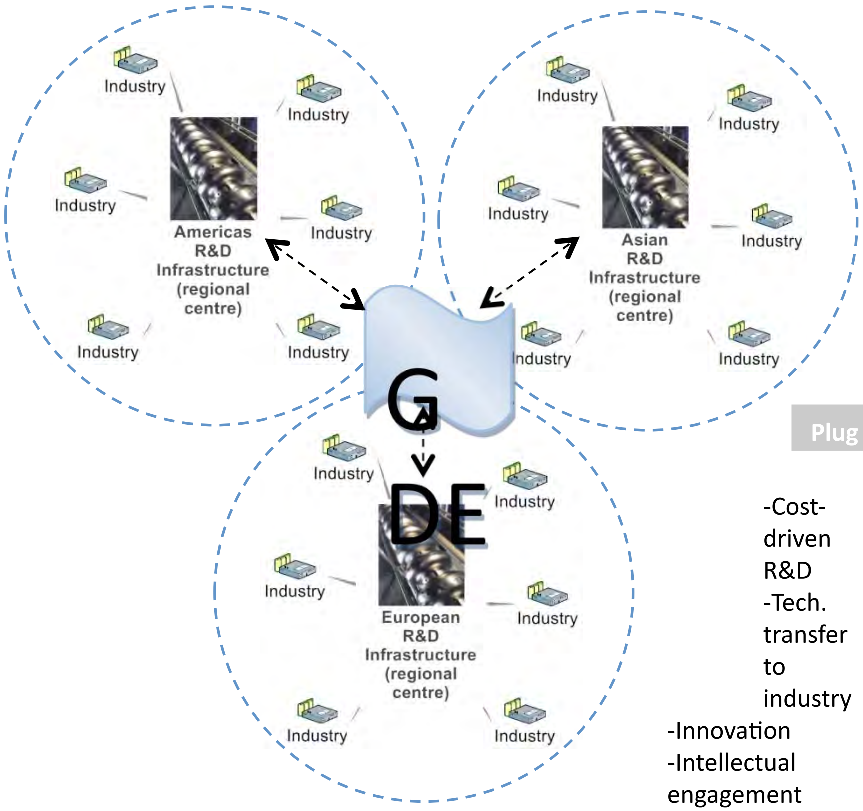
- During R&D, it is appropriate to set boundaries such that technical components can be most efficiently addressed.



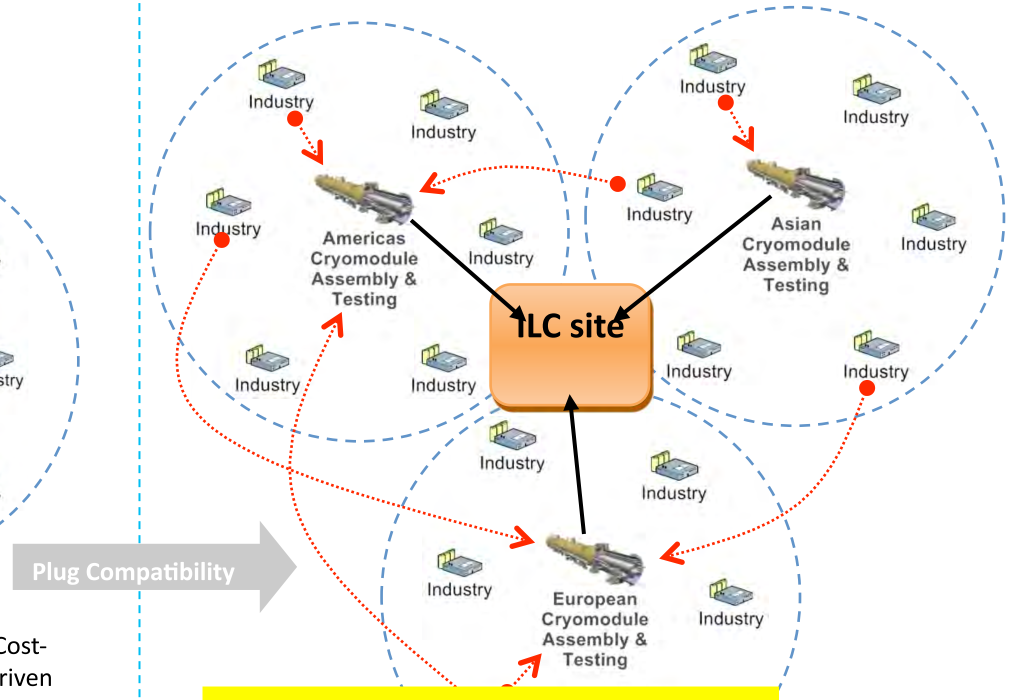
Transition to Construction Project



TDR documents submitted for approval



-Cost-driven R&D
-Tech. transfer to industry
-Innovation
-Intellectual engagement
-Expert base



Testing (QA/QC)

-Free 'global' market competition (lowest cost)
-Maintain 'intellectual' regional expertise base

-Adaptable for various collaboration scheme including in-kind contribution

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 venders, RI, Zanon, AES, Niowave, PAVAC, MHI, other SCRF industries, and ILC-SCRF institutions,

Summary

- Progress in Phase-1:
  - 35 MV/m with yield 50 % in surface process
    - 1st pass: 22 %, 2nd pass 33 % w/ established vendor's cavities,
    - Cavities with potential vendors are coming,
  - 31.5 MV/m with the cavity-string in a cryomodule
    - Achieved with FLASH Prototype Cryomodule Test (> 32 MV/m)
    - To be realized with a global effort (S1-Global): KEK, FNAL, DESY, INFN
- **Plan for Phase-2:**
  - 35 MV/m. to be kept as a R&D goal in vert. test,
  - Re-evaluation of the operational gradient for SB2009 proposal including adequate operational margin (H/LRF),
  - Beam acceleration with the operational field gradient,
- **We aim for**
  - Global R&D efforts **with keeping "plug-compatibility"**
  - Cooperation of world-wide Institutions and Industries
    - to prepare for industrialization: quality control and cost saving.