Advances in SRF Development for ILC

Akira Yamamoto

ILC-GDE and KEK

Prepared for SRF2011, Chicago, July 25, 2011

With sincere acknowledgment for all

ILC-GDE SCRF collaborators and global SCRF industrial partners

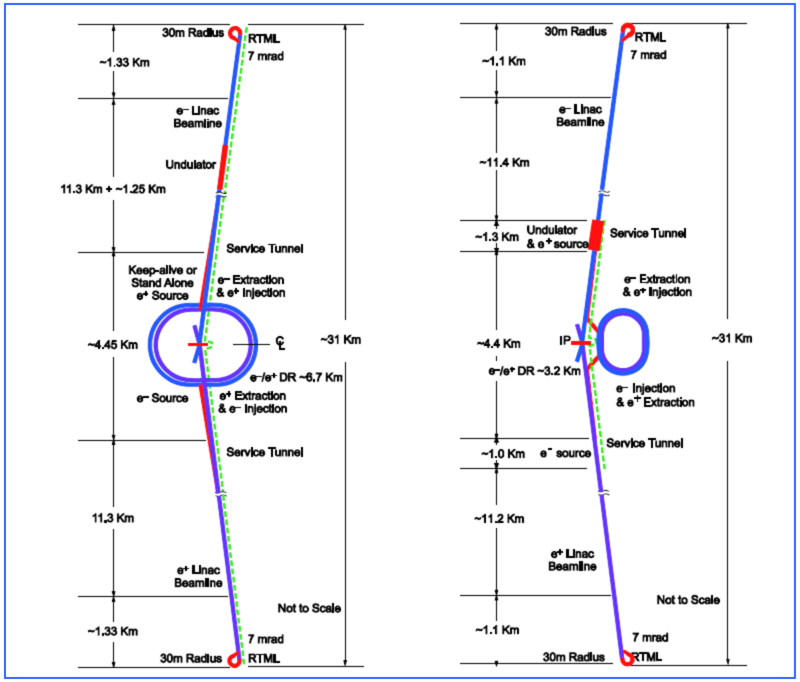
Special thanks for M. Ross, N. Walker, and R. Geng

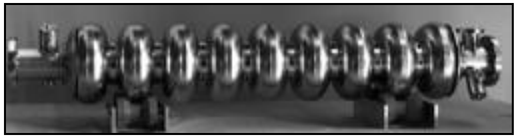
Design Update in SB2009

Motivation: Cost containment

- Single accelerator tunnel
- Smaller damping ring
- e+ target location at high-energy end,
- **SCRF:** Gradient variation of 31.5 MV/m +/- 20 %,
- **HLRF:** KCS and DRFS with RDR-RF unit as backup

RDR → SB2009





Global Plan for ILC Gradient 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, test start in 2013)				
Preparation for Industrialization			Production Technology R&D			

New baseline gradient:

Vertical acceptance: 35 MV/m average, allowing ±20% spread (28-42 MV/m)

Operational: 31.5 MV/m average, allowing ±20% spread (25-38 MV/m)

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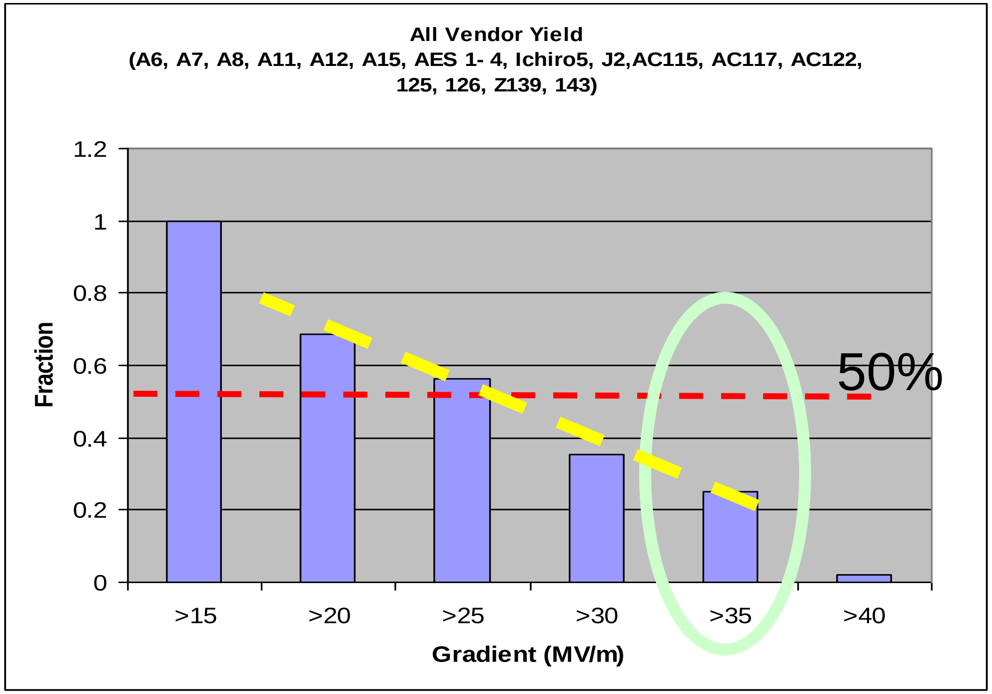
Global Yield of Cavities in 2008

tested at DESY and JLab

Originally reported by H. Padamsee



Process Yield: **~ 23 %** @ 35 MV/m, based on 48 Tests for19 cavities

Manufactured by ACCEL, AES, Zanon, KEK (Ichiro-type), and JLab

- Reported by H. Padamsee at TTC-08 (IUAC), and ILC-08, (Chicago), based on the status in 2008。

Definition for production yield, not established yet

Creation of a Global Database for
Better Understanding of "Production Yield"

- <u>Global Data Base Team</u> formed by:
  - **Camille Ginsburg (Fermilab), leader**
  - **Rongli Geng (JLab)**
  - **Zack Conway (Cornell University)**
  - **Sebastian Aderhold (DESY)**
  - **Yasuchika Yamamoto (KEK)**

- <u>Activity</u>
  - **July 2009:**
    - Determine DESY-DB to be viable option,
  - **Sept., 2009: (ALCPG/GDE)**
    - Dataset, web-based, support by FNAL/DESY
  - **Dec., 2009: (SB2009) : 1st update**
  - **March, 2010 (IW-ILC) : 2nd update**
  - **June, 2010 (End TDP-1) : 3rd update**
  - **March, 2011 (ILC-ALCPG): 4th update**
    RI, Zanon, AES, <u>MHI</u> manufactured
    Cavity data included.
    (3 region's data available)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Around the World

News from China on ILC collaboration

Vacuum vessel fabrication in factory

The effort towards realising the International Linear Collider is being carried out by global collaboration. Such efforts focus mainly on the technology development, but other aspects such as training the younger generation, are also important to ILC community. From 7 to 18 September China hosted the Fourth International Accelerator School for Linear Colliders in Beijing at Huairou. Among 69 students from 21 countries, there were 29 students from Asia, including 15 Chinese students. Since 2005, Chinese PhD students majoring in ILC-related topics are increasing

Feature Story

One sheet to plot them all
DESY database becomes standard tool for cavity research

The new worldwide ILC cavity database features only nine-cell, no single-cell cavities like the one held by Camille Ginsburg in this picture. Image: Fermilab.

<u>Production yield</u> allowing to:
- include the 2nd chemical process

Standard Procedure Established

for ILC-SCRF Cavity evaluation, in guidance of TTC

allow twice

	Standard Fabrication/Process
Fabrication	Nb-sheet purchasing
	Component Fabrication
	Cavity assembly with EBW
Process	EP-1 (~150um)
	Ultrasonic degreasing with detergent, or ethanol rinse
	High-pressure pure-water rinsing
	Hydrogen degassing at > 600 C
	Field flatness tuning
	EP-2 (~20um)
	Ultrasonic degreasing or ethanol (or EP 5 um with fresh acid)
	High-pressure pure-water rinsing
	Antenna Assembly
	Baking at 120 C
Cold Test (vertical test)	Performance Test with temperature and mode measurement

Key Process

Fabrication

- Material
- EBW
- Shape

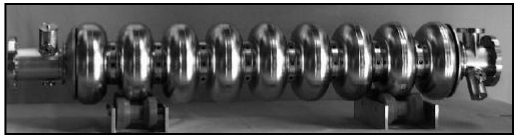
Process

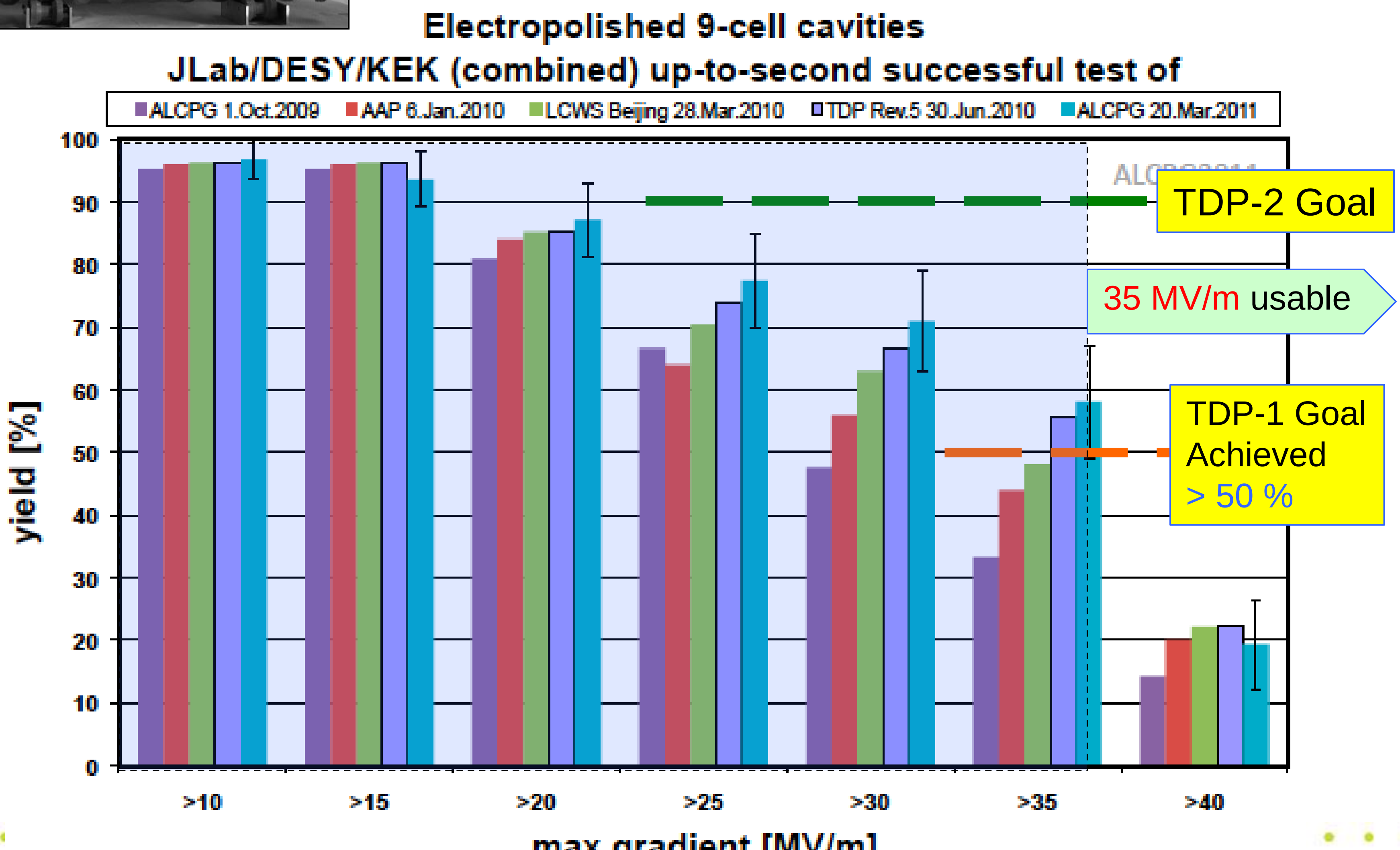
- Electro-Polishing
- Ethanol Rinsing or
- Ultra sonic. + Detergent Rins.
- High Pr. Pure Water cleaning

Global ILC Cavity Gradient Yield

Updated, March, 2011

Plot courtesy
Camille Ginsburg of FNAL





Global ILC Cavity Gradient Yield

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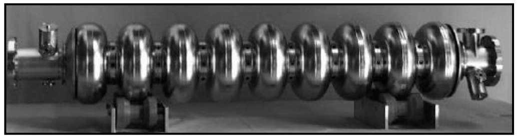
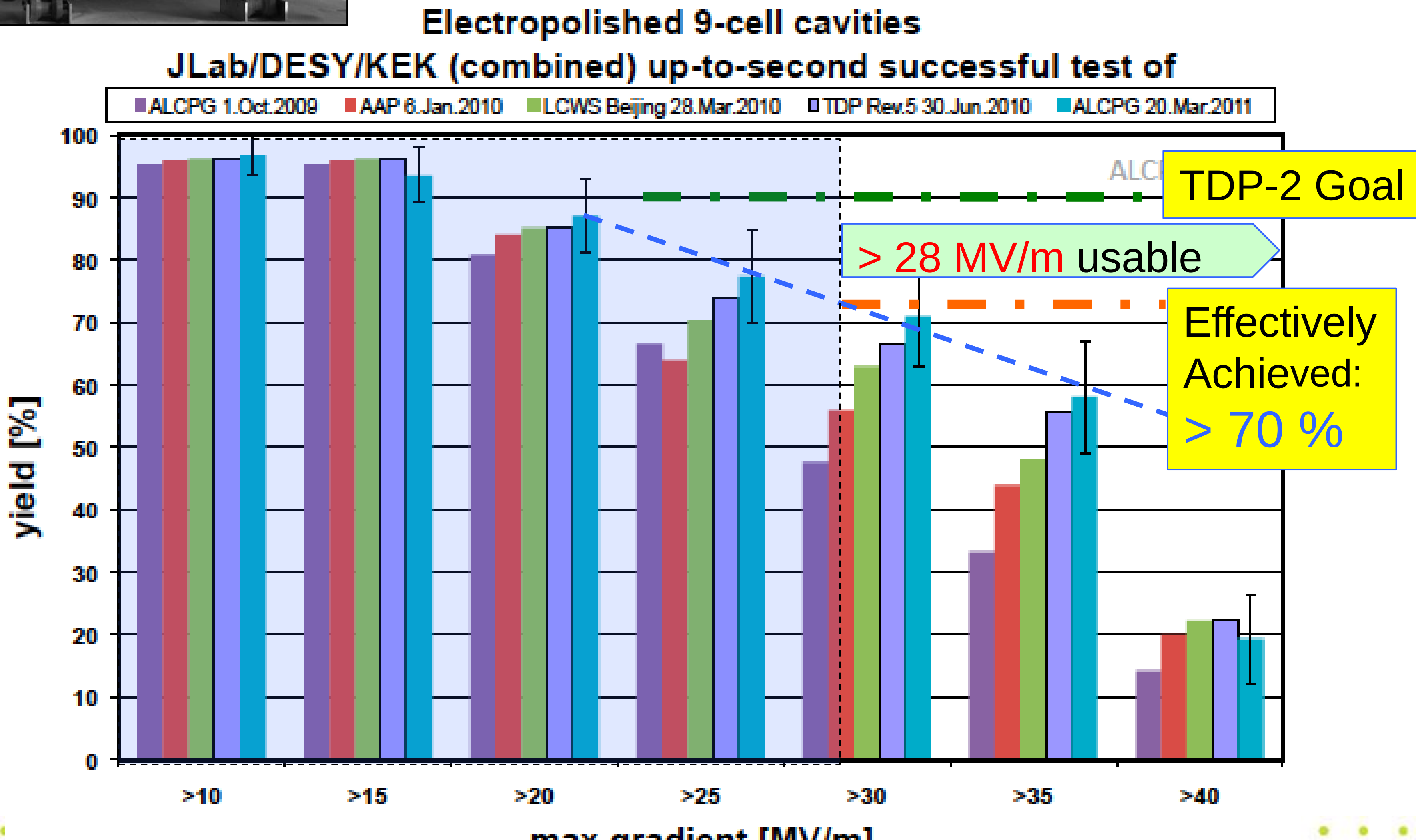
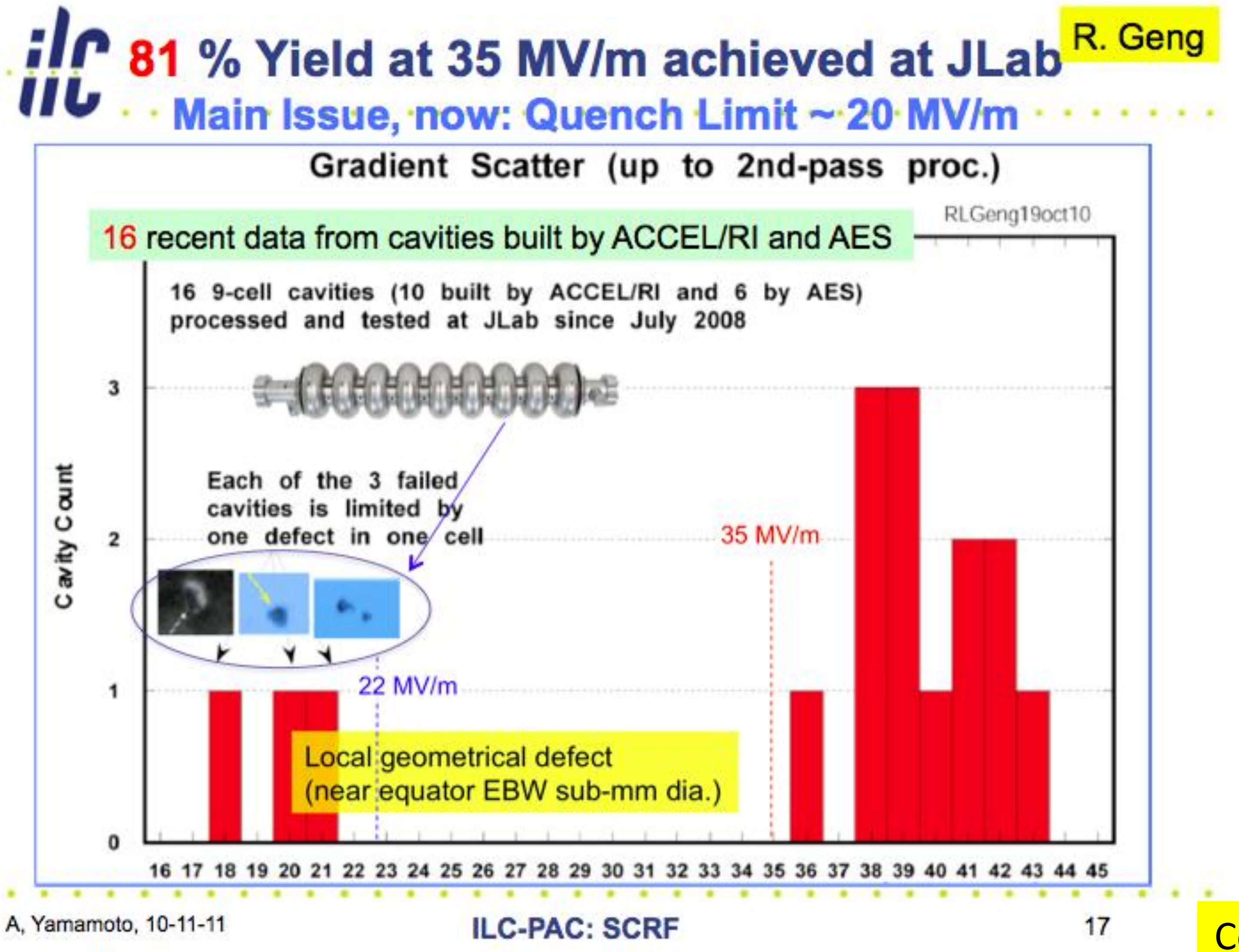




Impact of Mechanical Polishing

progress in Nov, 2010 ~ May, 2011



Courtesy: R. Geng

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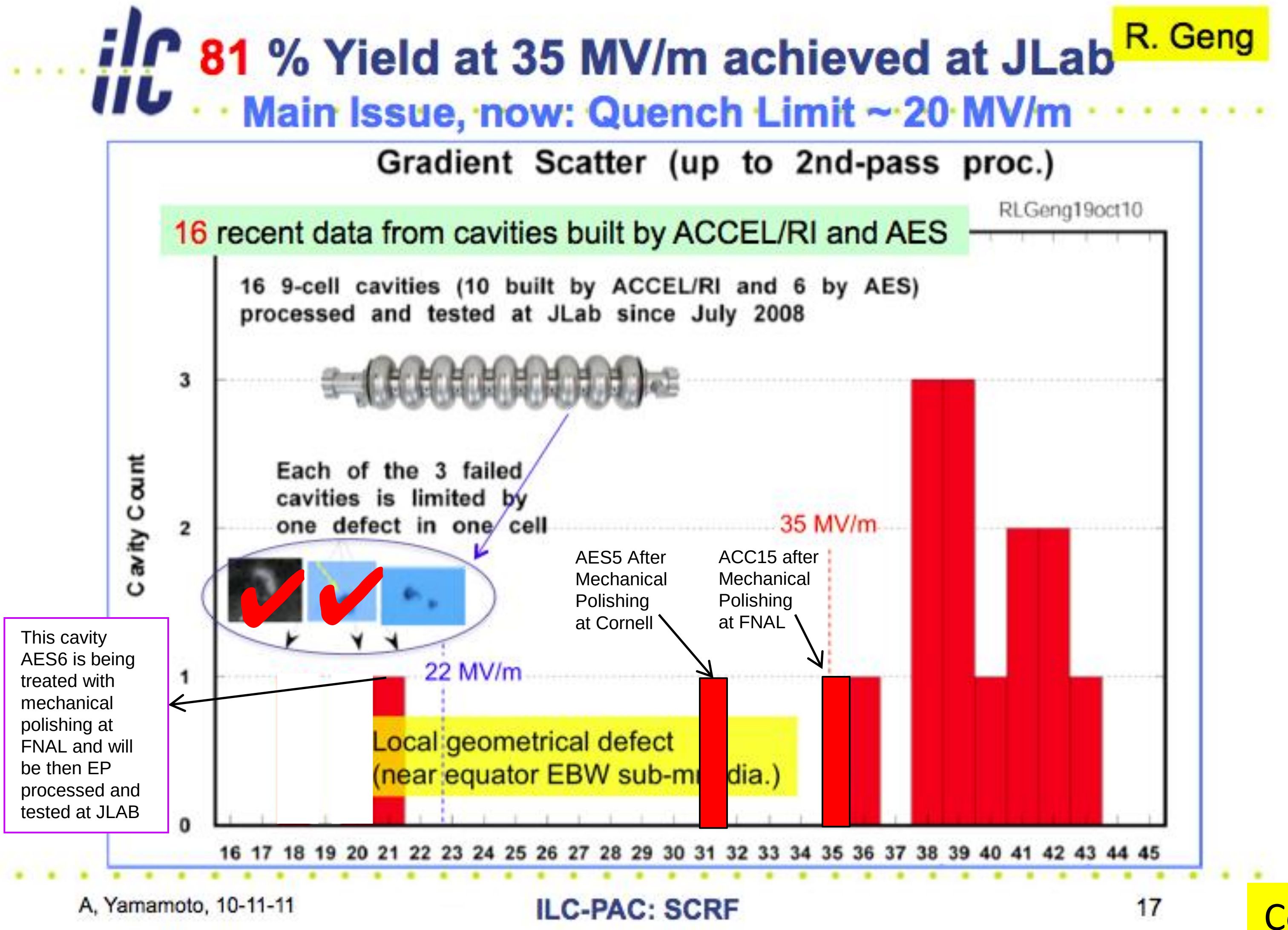

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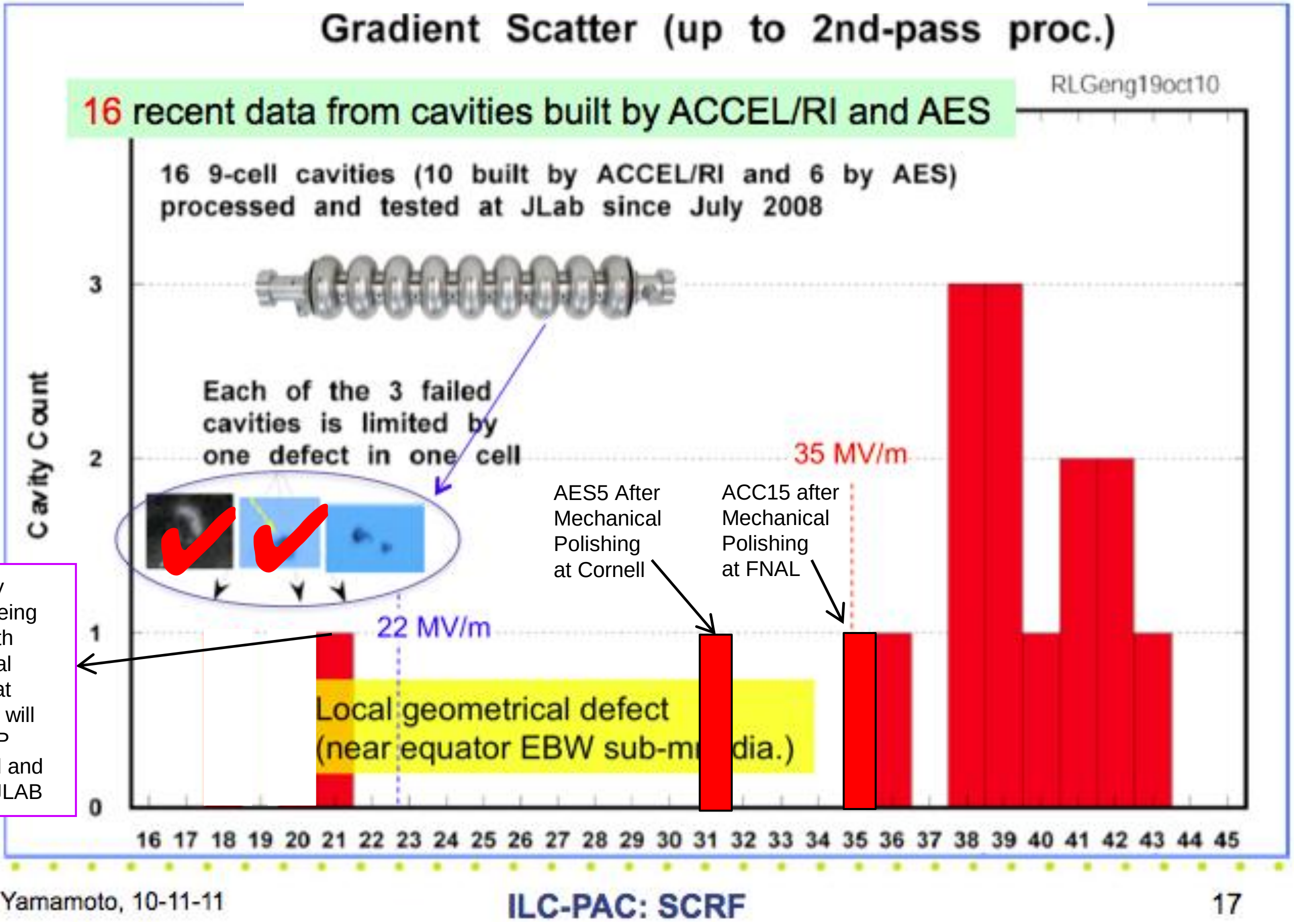
88% Yield at 35 MV/m achieved at JLAB + FNAL

Average gradient 39 MV/m



This cavity AES6 is being treated with mechanical polishing at FNAL and will be then EP processed and tested at JLAB

Courtesy: R. Geng

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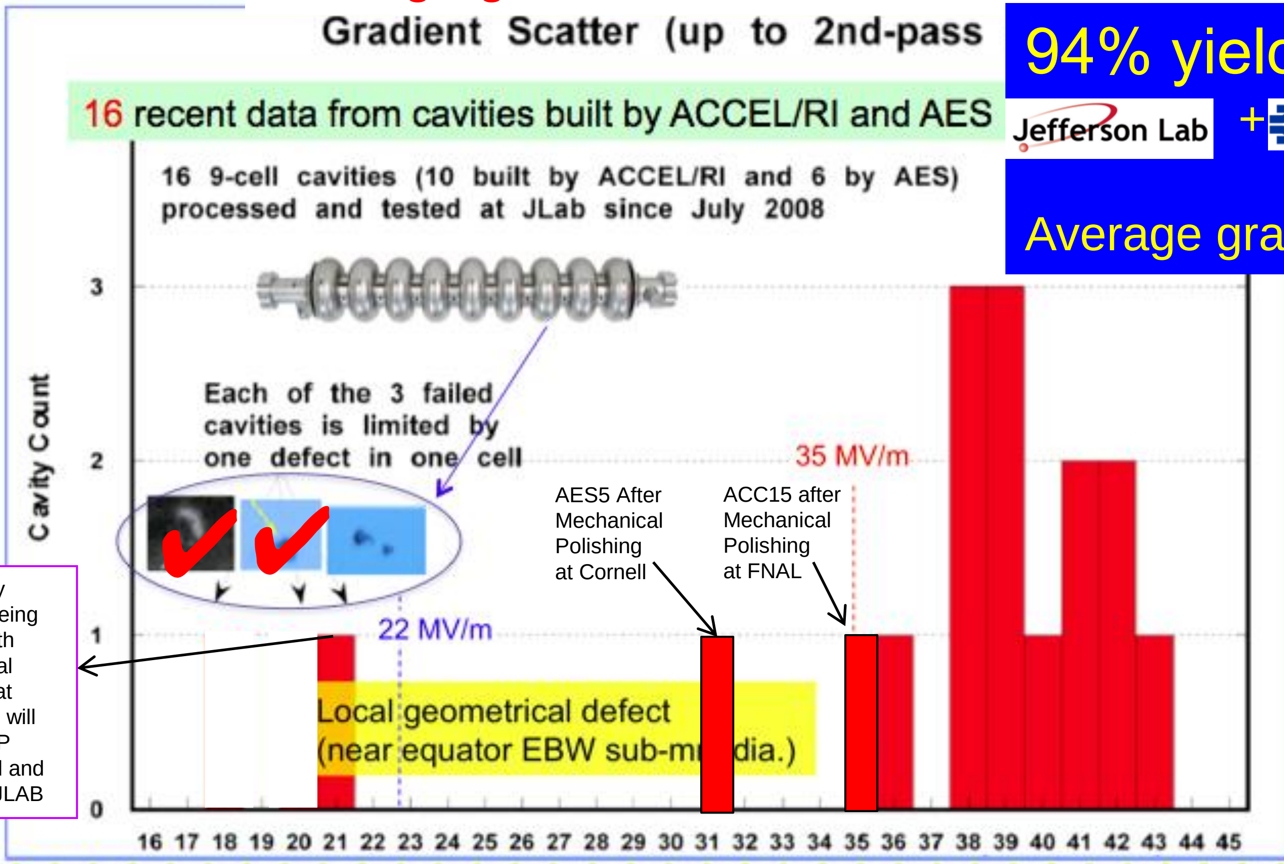
88% Yield at 35 MV/m achieved at JLAB + FNAL

Average gradient 39 MV/m

94% yield at ≥31 MV/m

Jefferson Lab + Fermilab + Cornell University

Average gradient 38.8 MV/m



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A, Yamamoto, 10-11-11 ILC-PAC: SCRF 17

Courtesy: R. Geng

Impact of Mechanical Polishing

as of July, 2011

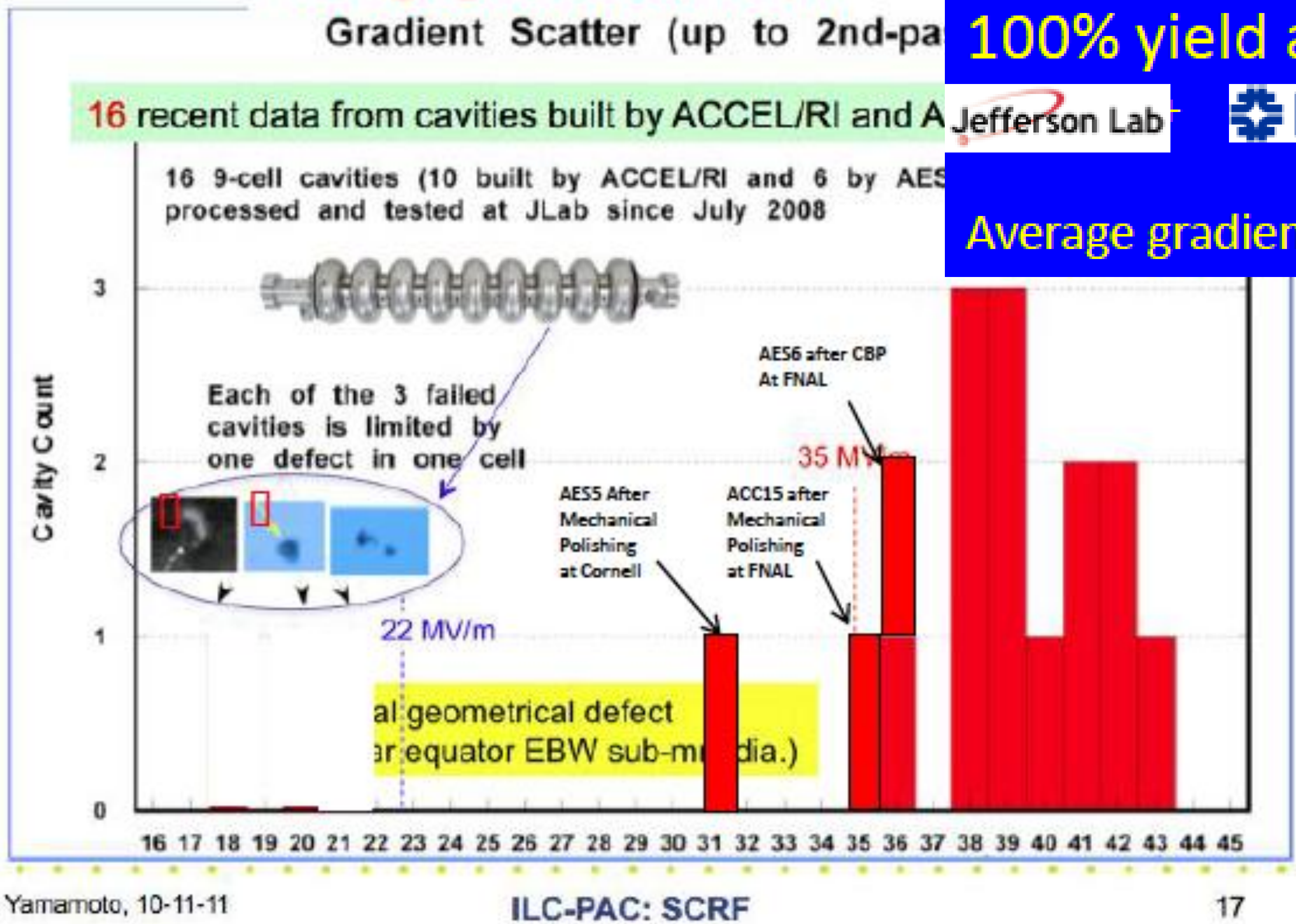
94% **Yield at 35 MV/m achieved at** JLAB + FNAL .

Average gradient 39 MV/m

100% yield at ≥31 MV/m

Jefferson Lab · Fermilab · Cornell University

Average gradient 39 MV/m



Courtesy: R. Geng

SCRF 9-Cell Cavity
Highlight: in 2010

Americas:

- **Niowave-Roark-FNAL: 1st** cavity reached 28.8 MV/m.
- **Jlab** set ~ 90% **yield** @ **35** MV/m (1 vendor, process at JLab
- **FNAL-KEK**: Cavity repaired, G improved from **11 to 30** MV/m

Asia:

- **IHEP-KEK**: 1st cavity (LL, large-grain, no-end) reached 20 MV/m,
- **PKU-JLab**: Cavity (Tesla, fine-grain) reached 28 MV/m,
- **Hitachi-KEK**: 1st cavity (Tesla-like, no-end) reached 35 MV/m
- **MHI-KEK**: Cavity (Tesla-like w/ end-HOM) reached 37 MV/m,
- ***MHI-KEK-S1-Global***: *cavity (Tesla-like) reached > 35 (40) MV/m*

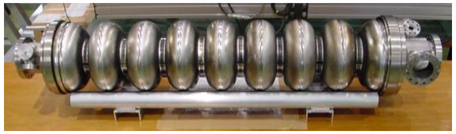
Europe:

- **E-XFEL / HG-FP7**: 600 cavity production order placed (2 vendors)

SRF Cavity and Gradient Highlights 2010~ 2011

- **Americas**
  - FNAL mechanical polishing improved 9-cell cavity ACC15 gradient from 19 MV/m to 35 MV/m

  - JLAB started processing and testing DESY seamless 9-cell cavity built from DESY 3-cell seamless units
  - 6 of AES 3rd production & 4 Niowave-Roark 1st production received by FNAL



- **Asia**
  - KEK MHI-12 reached 40.7 MV/m gradient at Q0 6.2E9
  - KEK-JLAB: ACD shape cavity ICHIRO7 reached 40 MV/m gradient at Q0 8E9

CBP(80μm)+ CP(10μm)+AN(750°C, 3hr)+EP(80μm)+HPR Bake+VT @ KEK, then sent Jlab.

- **Europe**
  - DESY large-grain 9-cell cavity AC155 reached 45 MV/m at Q0 > 1E10, and more reached in the next, …

Global Plan for SCRF R&D

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Preparation for Industrialization			**Production Technology R&D**			
Communication with industry:	2009: 1st step: Visit Vender (2009) 2010: 2nd step: Organize Workshop (2010) 2011: 3rd step: Send specification & receive response					

Integrated Systems Tests

2009 ~

FLASH (DESY)

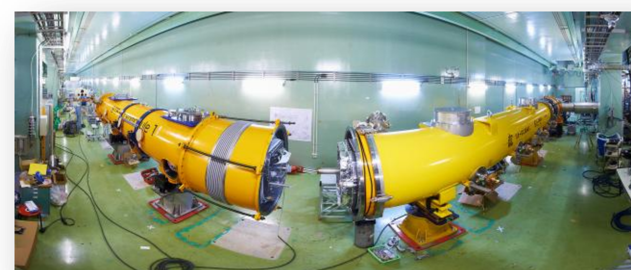
- TDP focus
- 7 CM → 1.2 GeV beam
- photon user facility

NML (FNAL)

- Under construction
- Up to 6 cryomodules
- Operation: end 2012
  - (3 CM)

STF (KEK)

- "Quantum Beam" experiment 2011
- 1 CM with beam 2013
- (2 CM 2015)



"9mA experiment" achieved ~1800 bunches at 9mA in 09.2009

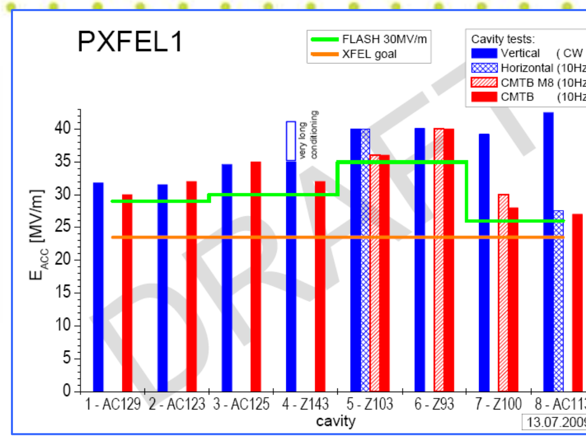
$\Delta E/E_{RMS}$ ~0.5% (@ 0.8 GeV)

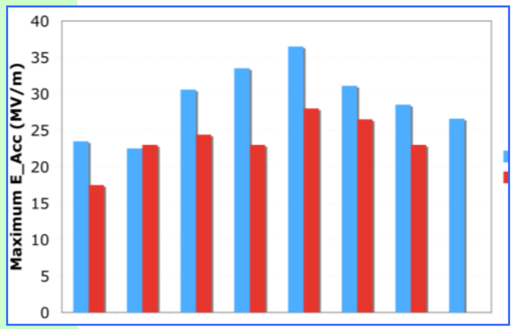
~0.1% within pulse

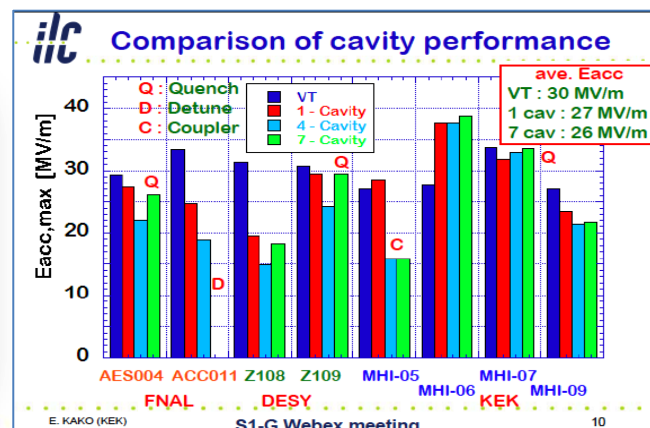
Full systems integration testing

Cryomodule Development & Test

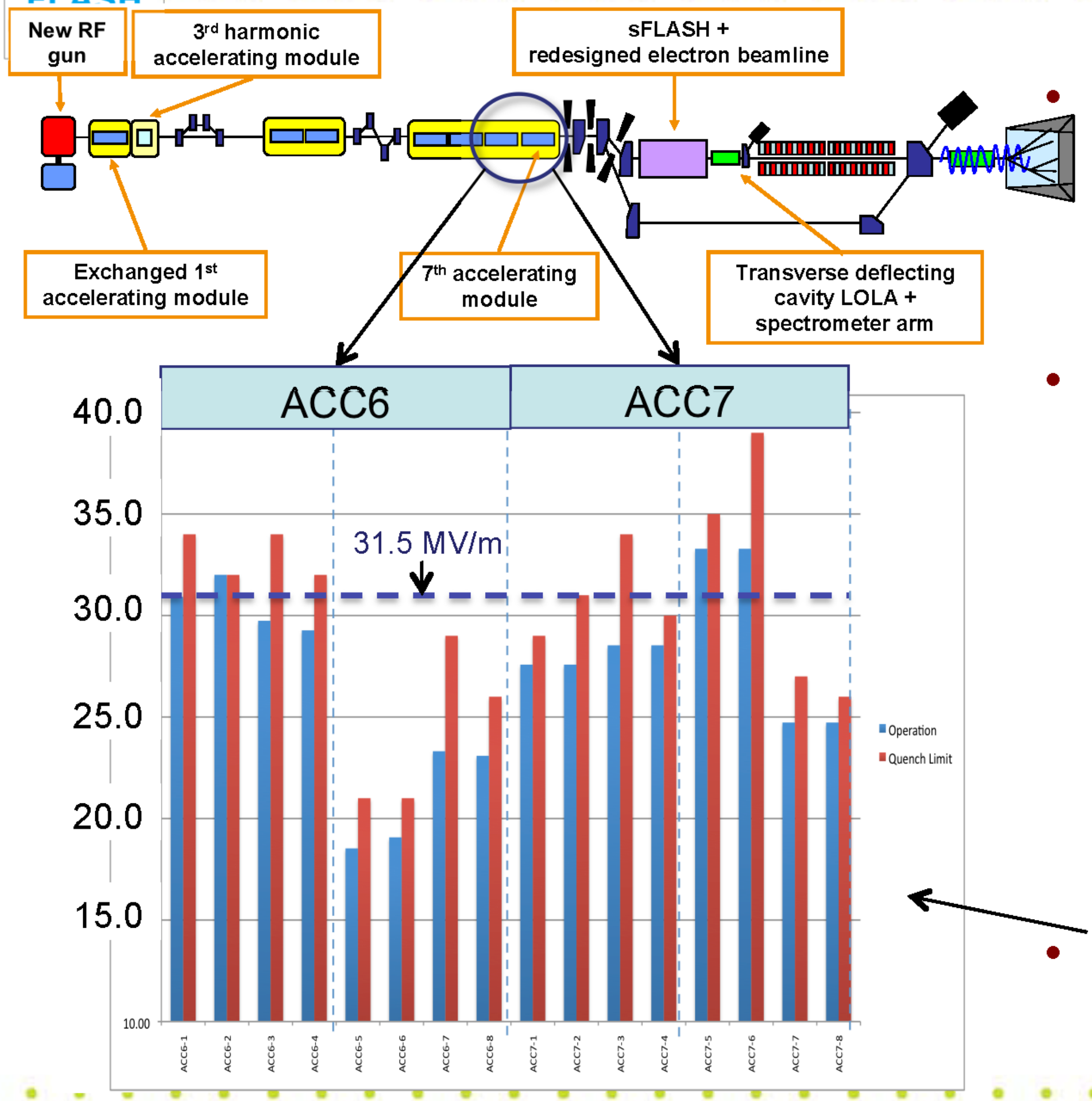
- FLASH (DESY)
  - **<32 MV/m> in CM operation, PXFEL-1**
  - **< 30 MV/m> in FLASH operation**
- NML-CM1 (Fermi)
  - **In progress**
- STF: S1-Global (KEK)
  - **Global effort**
    - DESY/INFN/FNAL/SLAC/KEK
  - **<26 MV/m> in CM operation**





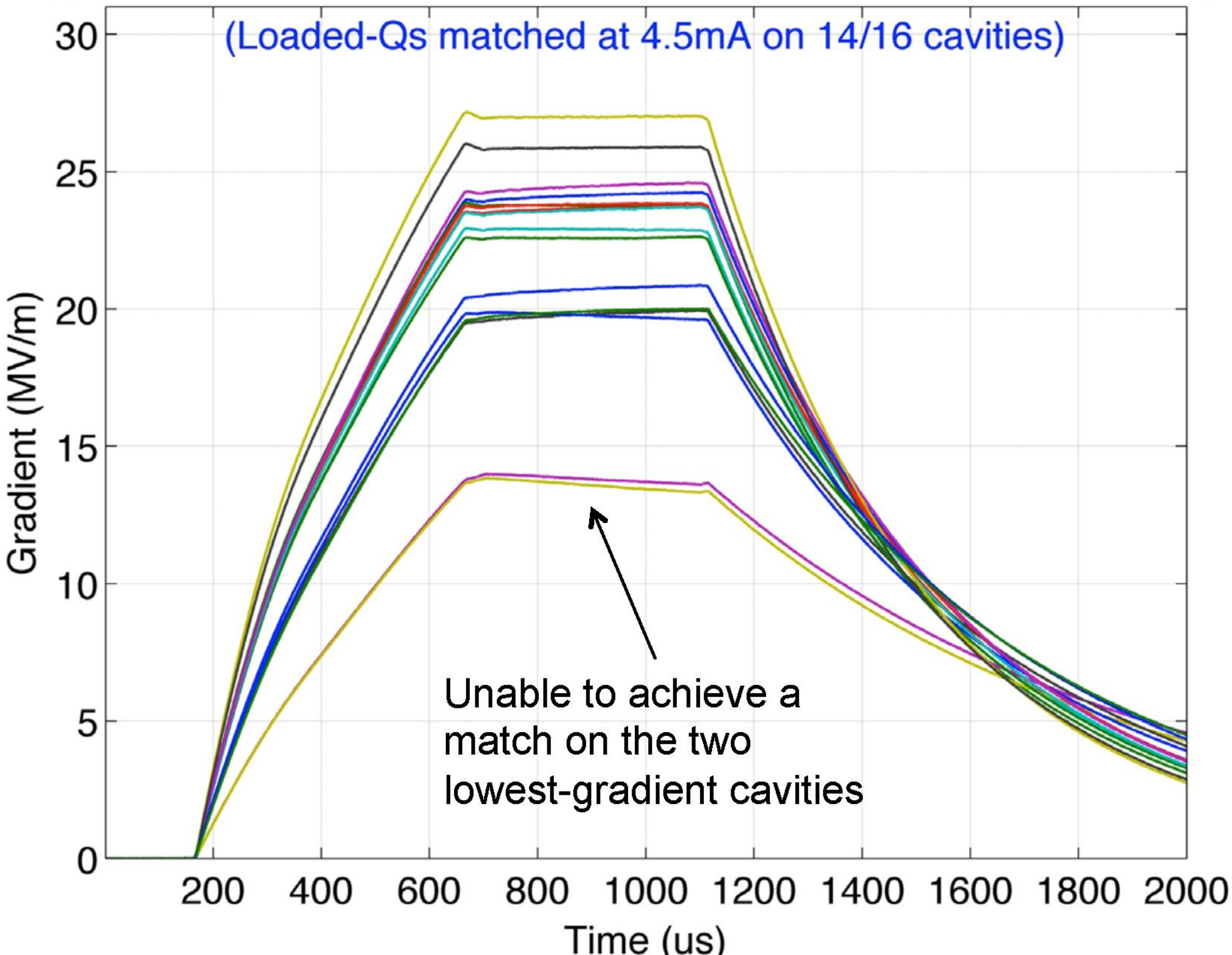


Main TDP R&D goal driving the 9mA studies in February 2011



- **Operation with <u>Gradient Spread</u>**
  - From single RF source
- **Specifically: achieving constant gradients <u>for each individual cavity</u> during beam pulse**
  - to within few percent
  - close to gradient limits
  - 'Effective usable gradient'
- **ACC67 modules at FLASH have operating gradient spread around +/-25%**

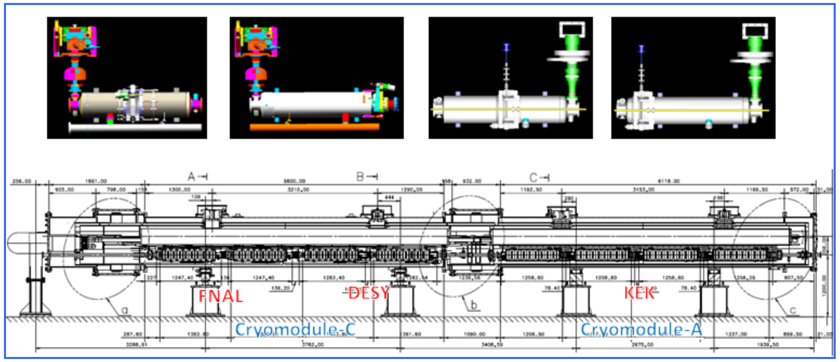
Flat gradient achieved at 360MV Vector Sum and beam current of 4.5mA (400us beam pulse)

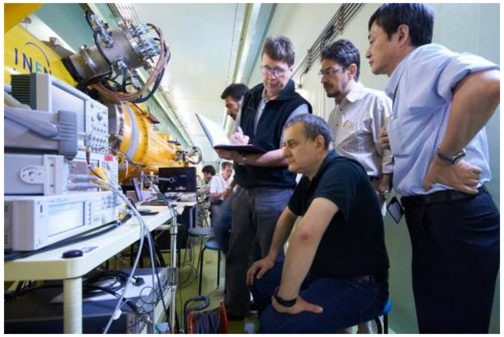


S1-Global Assembly/Test with Global Effort

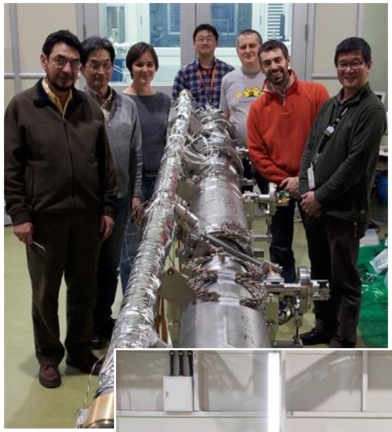
DESY, FNAL, Jan., 2010

DESY, Sept. 2010





FNAL & INFN, July, 2010



INFN and FNAL Feb. 2010

March, 2010

DESY, May, 2010

June, 2010 ~

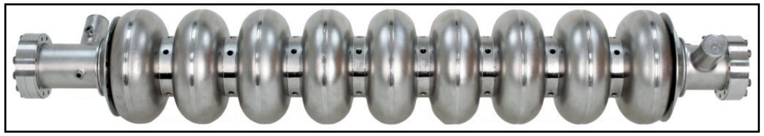
S1-Global High Power Test

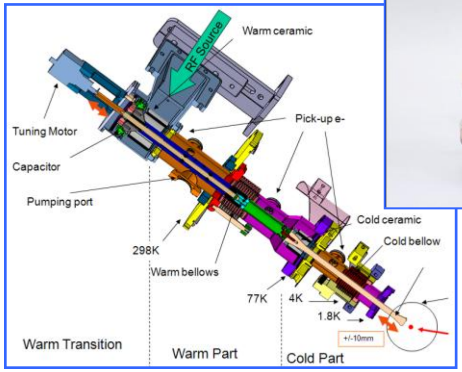
at STF/KEK, Sep., 2010 ~

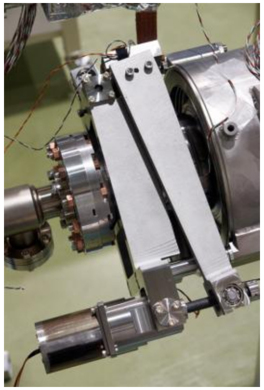
With
Denis Kostin
(DESY) Sept. 2010

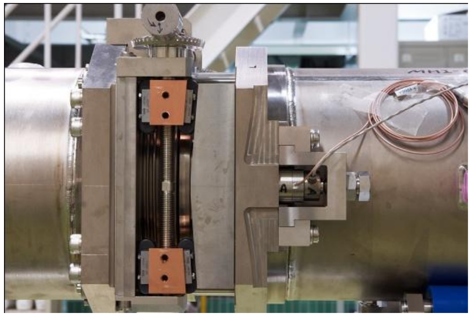
With
Yuriy Pischalnikov
Warren Schappert
(FNAL) Oct. 2010

S1-Global: Demonstrations/evaluation of Various Couplers and Tuners



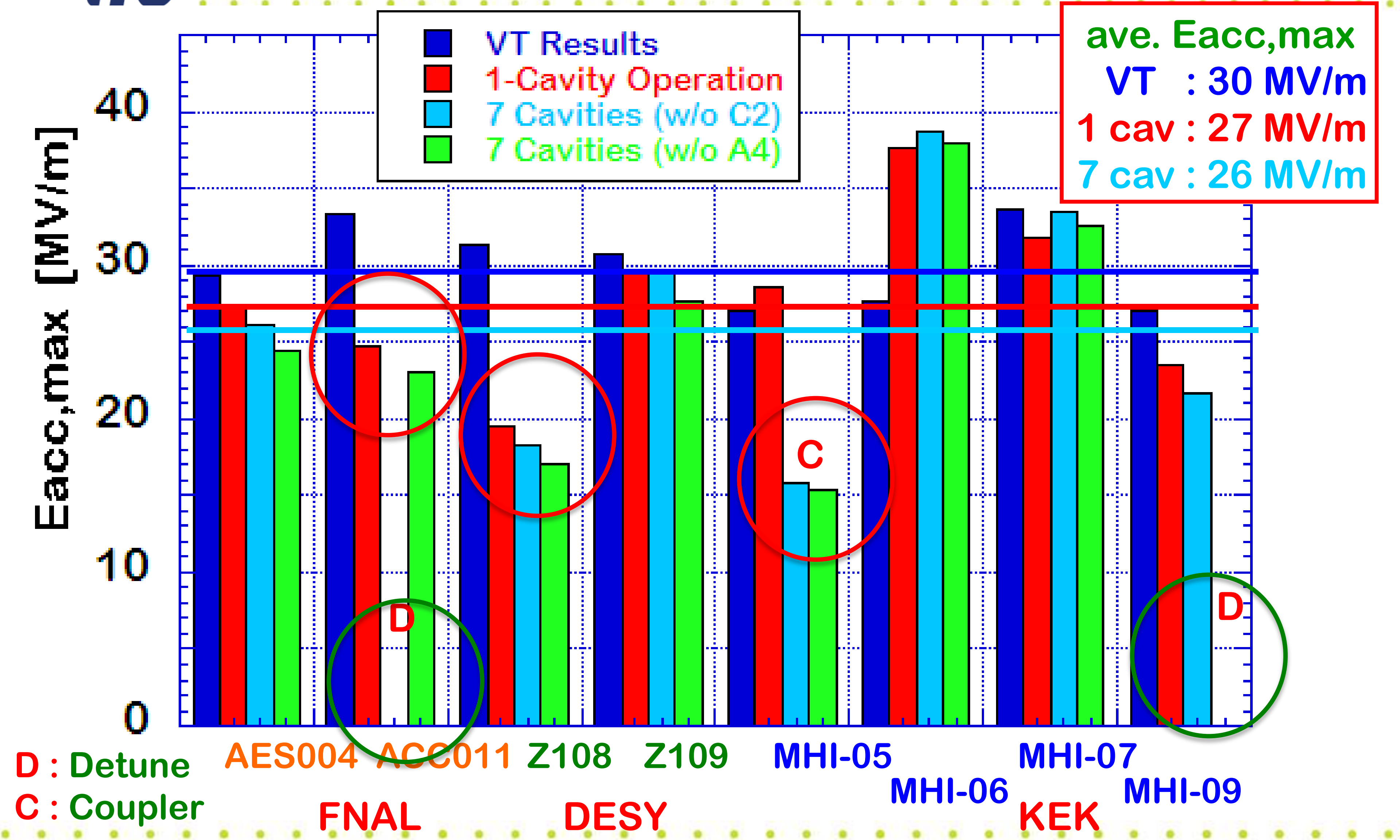






- Every coupler and tuner demonstrated, as expected, and be applicable for ILC cavities
- Finding various subjects to be further investigated and settled

Comparison of cavity performance

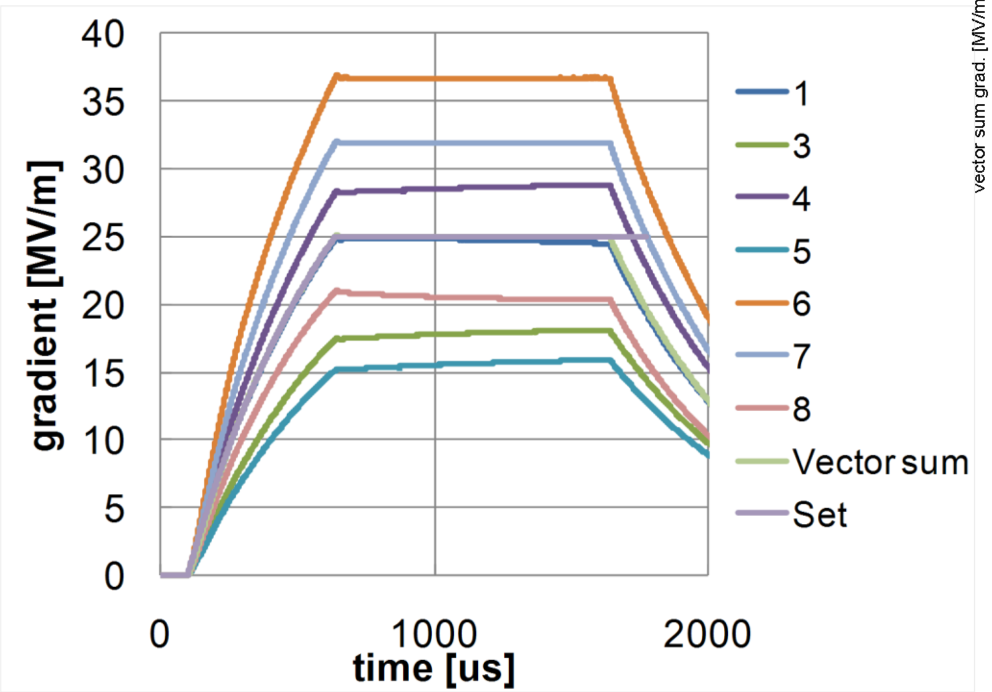


- Performance reduction in two cavities and one coupler
- Tuner mechanics trouble in two cavities

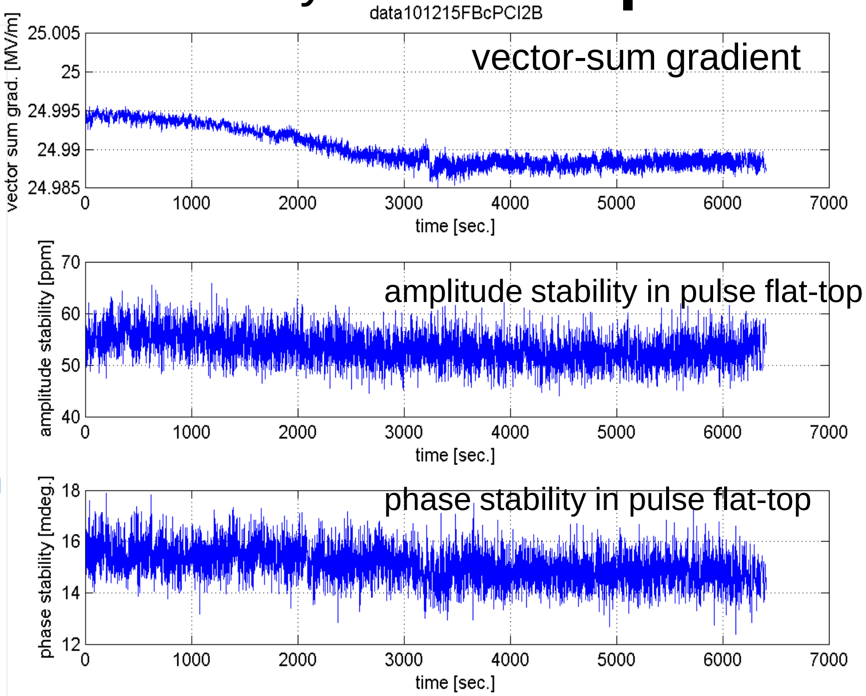
7-cavity operation by digital LLRF

LLRF stability study with 7 cavities operation at 25MV/m

Field Waveform of each cavity



Stability in 6300 sec.



- **Vector-sum stability: 24.995MV/m ~ 24.988MV/m (~0.03%)**
- **Amplitude stability in pulse flat-top: < 60ppm=0.006%rms**
- **Phase stability in pulse flat-top: < 0.0017 degree.rms**

Many Thanks for
Global Collaboration for S1-Global

A. Bosotti, C. Pagani, R. Paparella, P. Pierini,
INFN (Italy)
K. Jensch, D. Kostin, L. Lilje, A. Matheisen, W.-D. Moeller,
M. Schmoekel, P. Schilling, N. Walker, H. Weise,
DESY (Germany)
T. Arkan, S. Barbanotti, M. Battistoni, H. Carter,
M. Champion, A. Hocker, R. Kephart, J. Kerby, D. Mitchell,
Y. Pischalnikov, T.J. Peterson, M. Ross, W. Schappert,
B. Smith
FNAL (USA)
C. Adolphsen, C. Nantista, **SLAC (USA)**

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H. Nakai, H. Nakajima, K. Nakanishi, S.
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M. Satoh, T. Shishido, T. Shidara, T.
Takenaka, A. Terashima,
N. Toge, K. Tsuchiya, K. Watanabe, S.
Yamaguchi,
A. Yamamoto, Y. Yamamoto, K. Yokoya,
KEK (Japan)

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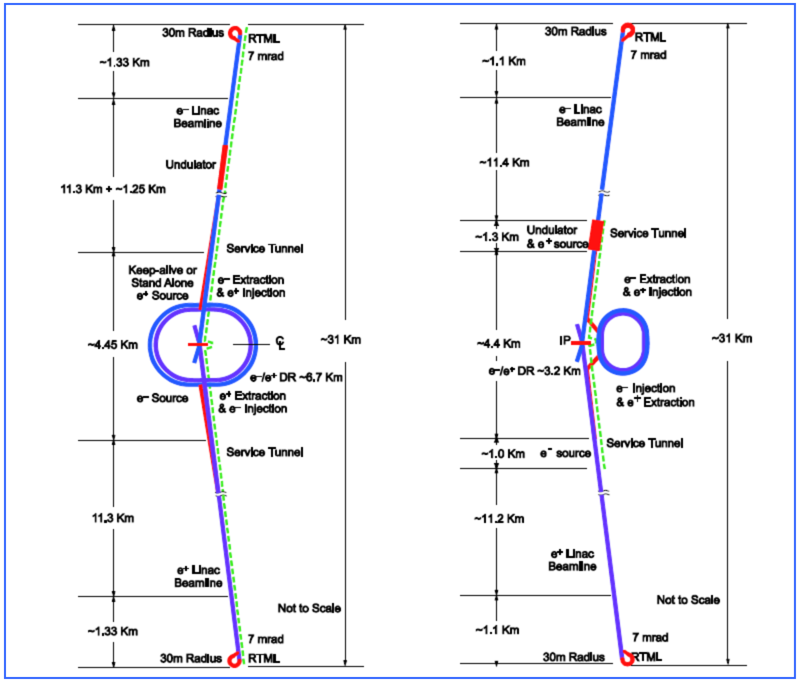
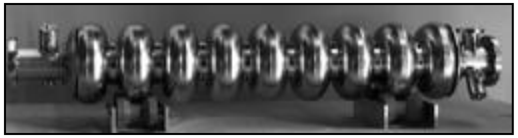
SCRF-ML Technology Required

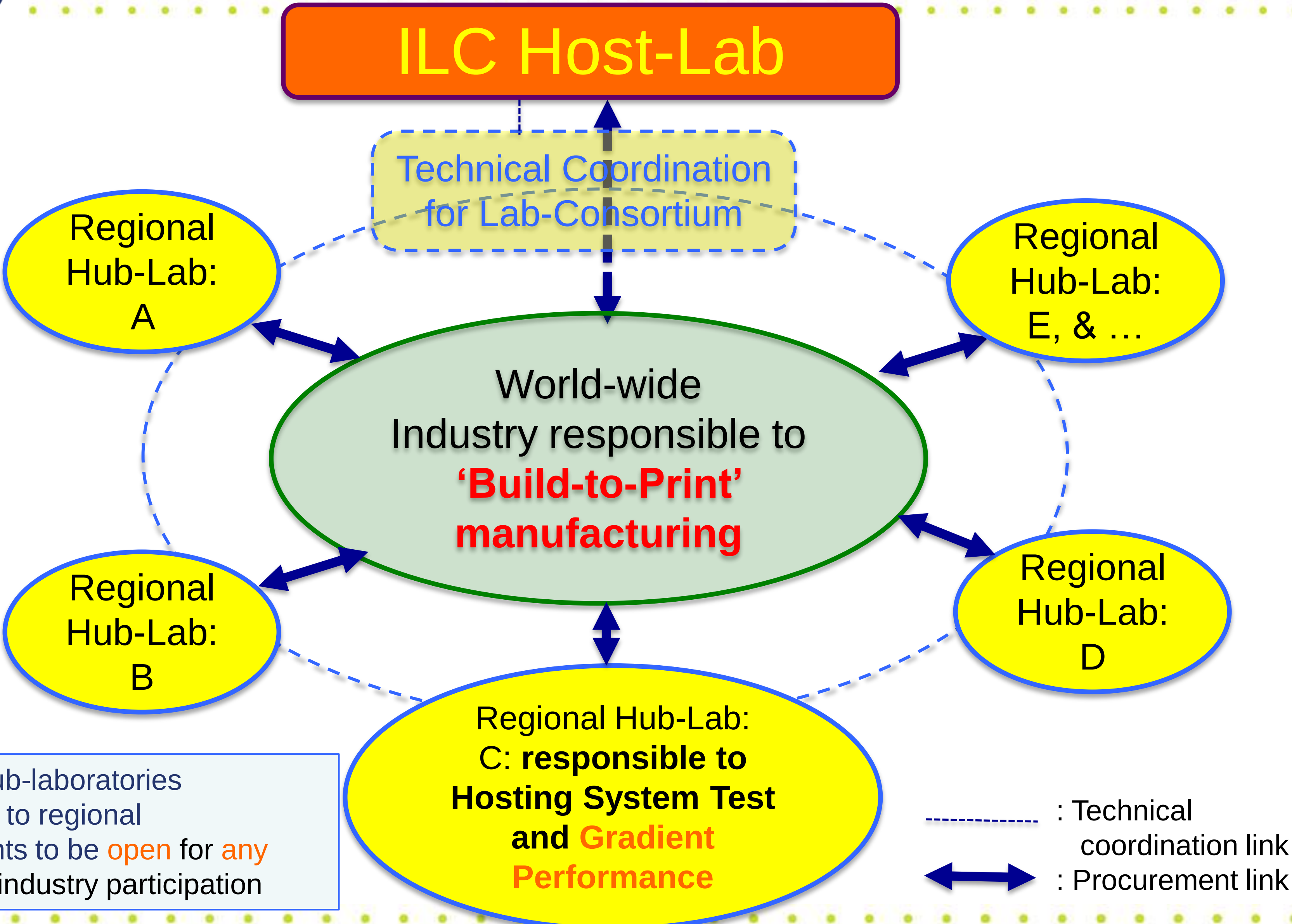
RDR Parameters	Value
C.M. Energy	500 GeV
Peak luminosity	2×10^{34} cm^{-2}s^{-1}
Beam Rep. rate	5 Hz
Pulse time duration	1 ms
Average beam current	9 mA (in pulse)
Av. field gradient	**31.5 MV/m**
# 9-cell cavity	**14,560**
# cryomodule	**1,680**
# RF units	**560**

RDR → SB2009





SCRF Procurement/Manufacturing Model



Regional hub-laboratories responsible to regional procurements to be open for any world-wide industry participation

Communication with Industry in 2011

- Visit factories, and Request for information
  - **Based on currently available manufacturing technology and available information with worldwide industry**
    - Assume the EXFEL 'build-to-print' specifications as a common reference, and
    - Allow 'plug-compatible' alternate designs with the cost equivalent or more effective production and/or better performance
- Requests for information to companies
  1. **Cost comparisons: 20/50/100 % in 3 or 6 year production ?**
  2. **Factory-site location: company or laboratory ?**
  3. **Sharing responsibilities for the cost-effective production ?**
  4. **Deliverables with 'build-to-print' fabrication?**
  5. **Consortium to be considered or not**

Visiting Companies in Progress
(and further plan)

	Date	Company	Place	Technical sbject
1	2/8	**Hitachi**	Tokyo (JP)	Cavity/Cryomodule
2	2/8	**Toshiba**	Yokohana (JP)	Cavity/Cryomodule, Magnet
3	2/9	**MHI**	Kobe (JP)	Cavity / (Cryomodule)
4	2/9	**Tokyo-Denkai**	Tokyo (JP)	Material (Nb)
5	2/18	**OTIC**	NingXia (CN)	Material (Nb, NbTi, Ti)
6	3/3	**(Zanon) mtg at INFN**	Verona (IT)	Cavity/(Cryomodule)
7	3/4	**RI**	Koeln (DE)	Cavity (Cryomodule)
8	3/14, (4/8)	**AES**	Medford, NY (US)	Cavity (Cryomodule)
9	3/15, (4/7)	**Niowave**	Lansing, MI (US)	Cavity/ (Cryomodule)
10	4/6	**PAVAC**	Vancouver (CA)	Cavity, EBW-machine
11	4/25	**ATI Wah-Chang**	Albany, OR (US)	Material (Nb, Nb-Ti, Ti)
12	4/27	**Plansee**	Ruette (AS)	Material (Nb, Nb-Ti, Ti)
13	5/24	**SDMS**	Sr. Romans (FR)	Cavity, Vessel, joint
14	7/6	**Heraeus**	Hanau (DE)	Material (Nb, Nb-Ti, Ti)
15	9/14	**Zanon**	Verona (IT)	Cryomodule
16	11/16	**SST**	Munchen (DE)	EBW-machine

The 2nd workshop on SCRF Technology and Industrialization for the ILC

as a satellite meeting of SRF 2011

- Date: July 24, 2011
- Place: Chicago
- Agenda:
  - **Introduction**
  - **Reports from SCRF cavity/cryomodule industry**
  - **Reports from SC material vendor**
  - **Comments from Potential Regional Hub-laboratory**
  - **Discussions on the ILC SCRF industrialization model**
- Note:
  - **Open for everybody,**
  - **Many Industrial participations acknowledged**

Workshop Objectives

- Exchange information:
  - efforts on cost-effective SCRF cavity/cryomodule **production** and quality control
- Discuss on:
  - optimum industrialization models for ILC including the scale, time, and site,
  - sharing responsibilities between industry and laboratories, and/or industry and industry,
  - how to manage industrial constraint/regulation and to coordination it in global scale
- Provide:
  - advices for the ILC TDR and cost-estimate.

R. Geng

Cavity R&D for ILC 1 TeV-Upgrade (continued)

- ILC SRF cavity R&D beyond 2012
  - **Importance**
    - Maintain "global" nature for coherence
    - Project oriented, targeted R&D, benchmarked progress
    - Resource sharing, cross-region experience exchange
  - **ILC: driver for high gradient SRF cavity technology**
    - Pursuit of ultimate gradient continues to motivate innovation
    - Gradient success continues to benefit SRF based accelerators

year	# of >35 MV/m 9-cell cavities	# of labs capable of 35 MV/m processing	# of Industrial manufacturers capable of 35 MV/m fabrication
2006	10	1 DESY	2 ACCEL, ZANON
2011	41	4 **DESY, JLAB, FNAL, KEK** **and others joining soon**	4 **RI, ZANON, AES, MHI,** **and others joining soon**

M. Ross

Cavity R&D to be extended

for possible ILC 1 TeV Upgrade

- High gradient
  - **Shape: LL/ICHIRO, RE, LSF – on going**
  - **Processing: Mechanical polishing – on going**
  - **Material**
    - Large grain – on going
    - Nb/Cu laminate – needs re-start
    - Multi-layer and material beyond Nb – to be encouraged
- High Q0
  - **Large grain – on going**
  - **ALD over coating – R&D started**
- Suppress field emission
  - **CO2 snow cleaning – on going**
  - **HOM can cleaning – R&D started**

Summary

Please refer further ILC related papers presented in SRF2011

- SRF 1.3 GHz cavity R&D progressed
  - **9-cell cavity Gradient R&D:**
    - Maximum gradient reaching > 45 MV/m (w/ large-grain)
    - Production-yield progressed in ILC Global data-base:
      - ~ 20 % at 35 MV/m in 2008 to ~ 60 % at 35 MV/m in 2011
  - **Cavity-string performance in Cryomodule**
    - FLASH/PXFEL-1: reached <32 MV/m>
    - NML: in progress
    - S1-Global: reached <26 MV/m> with 7 cavity-string
  - **Superconducting accelerator system test**
    - FLASH: progressing in acceleration for 9 mA demonstration
- Industrialization study in progress
  - **in close communication with industry**
- Further high-gradient R&D after TDR being prepared,
  - **for possible 1-TeV upgrade**