SRF Technical Status and Future R&D

Rong-Li Geng

Jefferson Lab & GDE

LCWS12 International Workshop on Future Linear Colliders

University of Texas at Arlington, USA

22–26 October 2012

Acknowledgement

Many thanks to the following colleagues for providing information to me in preparing the slides presented in this talk: Sebastian Aderhold(DESY), Andre Anders(LBNL), Claire Antoine(SACLAY), Lance Cooley(FNAL), Charlie Cooper(FNAL), Eckhard Elsen(DESY), Fabien Eozenou(SACLAY), Fumio Furuta(Cornell), Jie Gao(IHEP), J.K. Hao(PKU), Hitoshi Hayano(KEK), Georg Hoffsttatter(Cornell), Camille Ginsburg(FNAL), Kexin Liu(PKU),Olivier Napoly(SACLAY), Aliaksandr Navitski (DESY), Sam Posen(Cornell), Jiyuan Zhai(IHEP).

Recent reviews on the ILC SCRF technology and ILC main linac design have been given by Akira Yamamoto (GDE PM for SCRF). Some slides on ILC SRF status are borrowed from Akira's talks at LINAC12 and ASC12.

Outline

- **ILC SRF technical status**
  - Cavity gradient
  - Cryomodule system testing
  - Beam operation of cryomodules in SRF linacs
- **Future SRF R&D for linear collider**
  - Field emission understanding and control
  - Very high gradient with high Q0
  - Inexpensive SRF fabrication and processing
  - Fundamental issues
- **Summary**

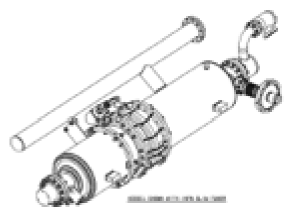
Outline

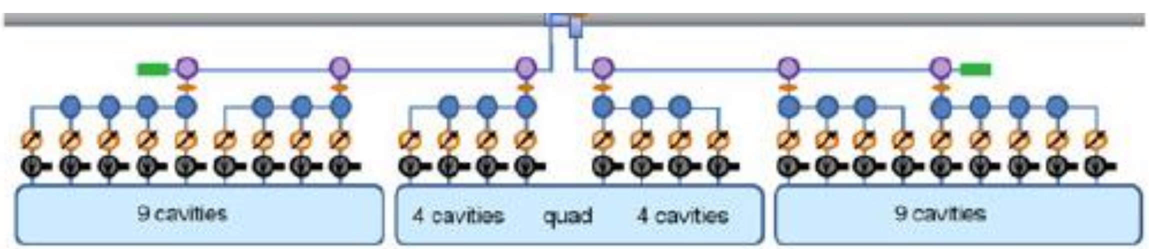
- **ILC SRF technical status**
  - Cavity gradient
  - Cryomodule system testing
  - Beam operation of cryomodules in SRF linacs
- **Future SRF R&D for linear collider**
  - Field emission understanding and control
  - Very high gradient with high Q0
  - Inexpensive SRF fabrication and processing
  - Fundamental issues
- **Summary**

SCRF Technology Required

Parameters	Value
C.M. Energy	500 GeV
Peak luminosity	2×10^{34} $cm^{-2}s^{-1}$
Beam Rep. rate	5 Hz
Pulse duration	1 ms
Average current	5.8 mA (in pulse)
Av. field gradient	31.5 MV/m +/-20%
# 9-cell cavity	16024 (x 1.1)
# cryomodule	1,855
# Klystron	~400

- Cavity Performance requirement:
  - **G = 35 MV/m +/- 20 %**
  - **Q0 = 0.8 E10**





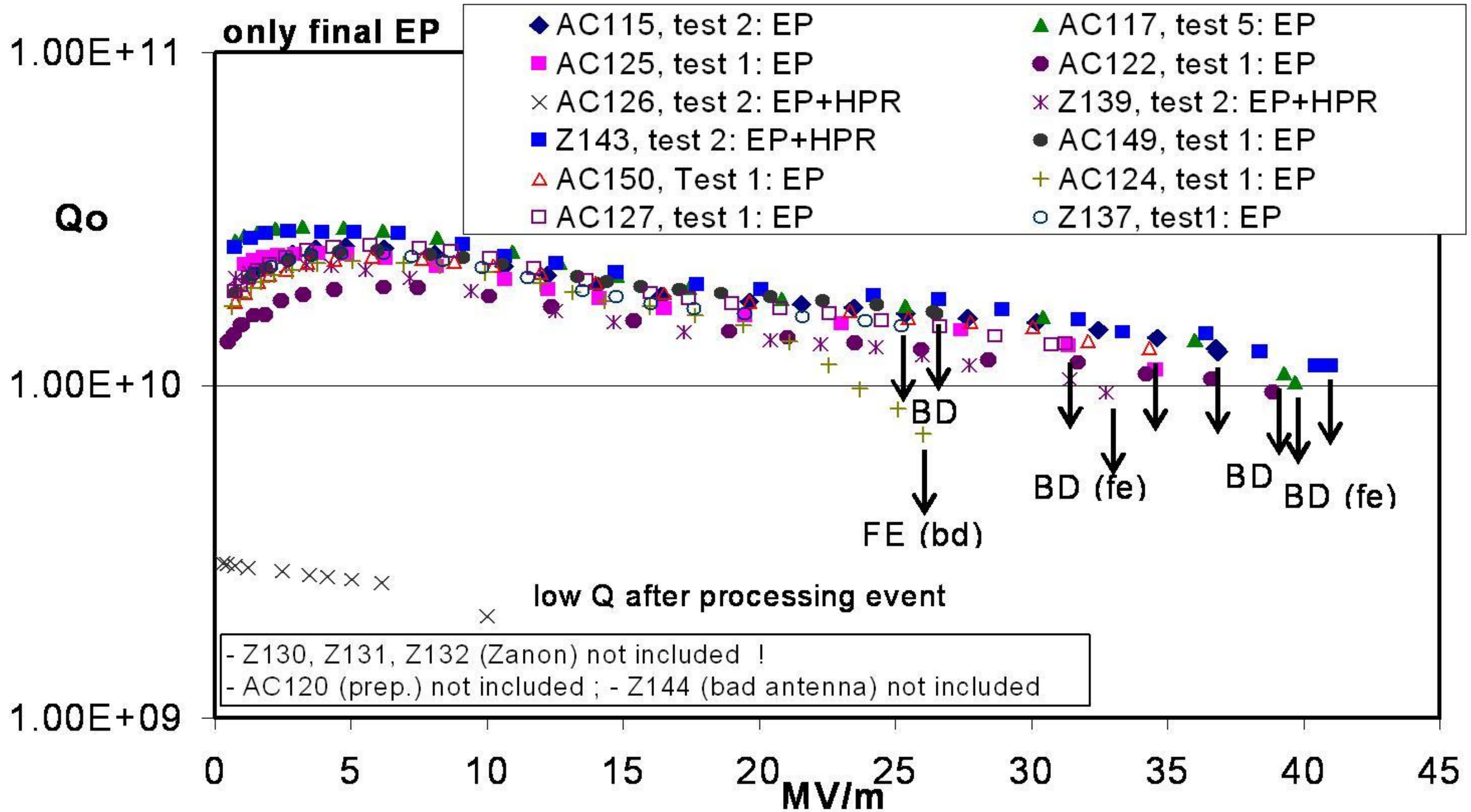
Technical Goals for TD Phase

- SCRF Technology
  - **Cavity: High Gradient R&D to:**
    - 35 MV/m with 50% yield by 2010 , and 90% by 2012 (TDR)
    - Manufacturing with cost effective design
  - **Cryomodule performance including HLRF, and LLRF**
- System Test with ILC-like Beam
  - **ILC-like beam acceleration**
    - 9 mA: FLASH
    - 1 ms: STF2 - Quantum Beam
    - Ultra-low beam emittance: Cesr-TA, ATF
    - Ultra-small beam size at Final FOcusing: ATF2

Global Plan for SCRF R&D

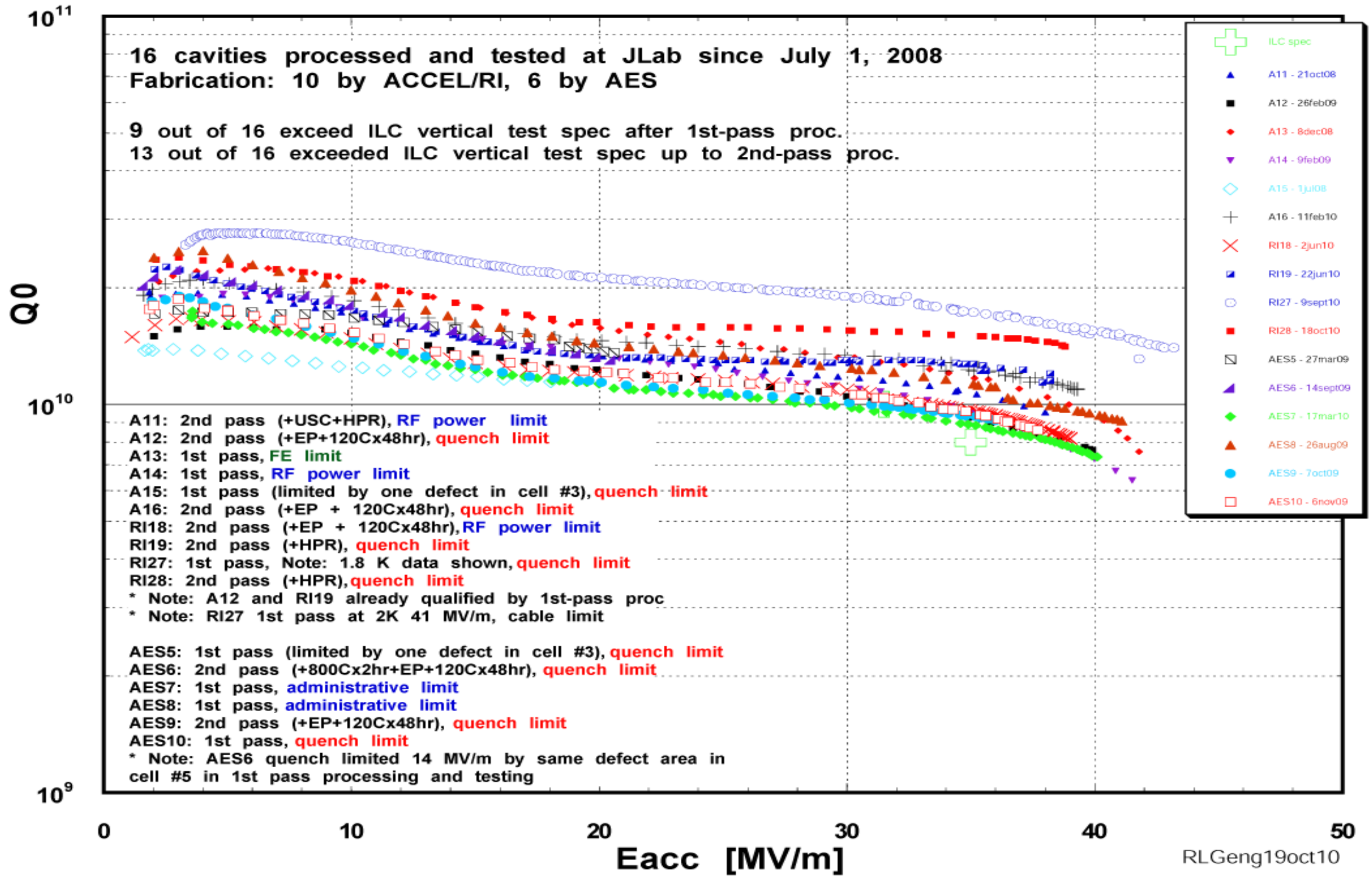
Year	07	2008	2009	2010	2011	2012
Phase	TDP-1			TDP-2		
Cavity Gradient in v. test to reach 35 MV/m	→ Yield 50%			→ Yield 90%		
Cavity-string to reach 31.5 MV/m, with one-cryomodule		Global effort for string assembly and test (DESY, FNAL, INFN, KEK)			We are here	
System Test with beam acceleration			FLASH (DESY) , NML/ASTA (FNAL) QB, STF2 (KEK)			
Preparation for Industrialization				Production Technology R&D		
Communication with industry:	1st Visit Venders (2009), Organize Workshop (2010) 2nd visit and communication, Organize 2nd workshop (2011) 3rd communication and study contracted with selected vender (2011-2012)					

Global Cavity Gradient Results - EU



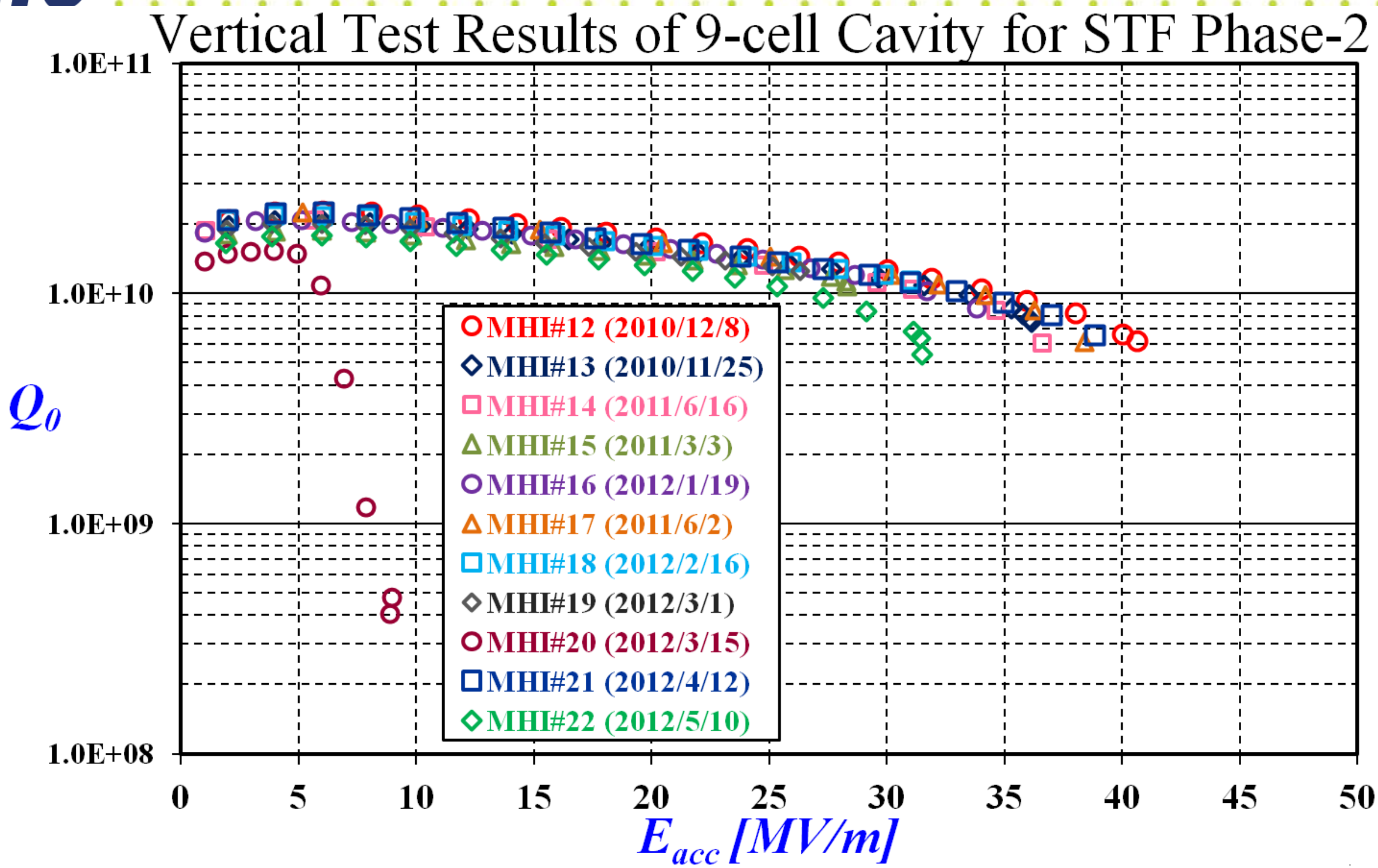
DESY data, D. Reschke et al., SRF2009, TUPPO051.

Global Cavity Gradient Results - Americas



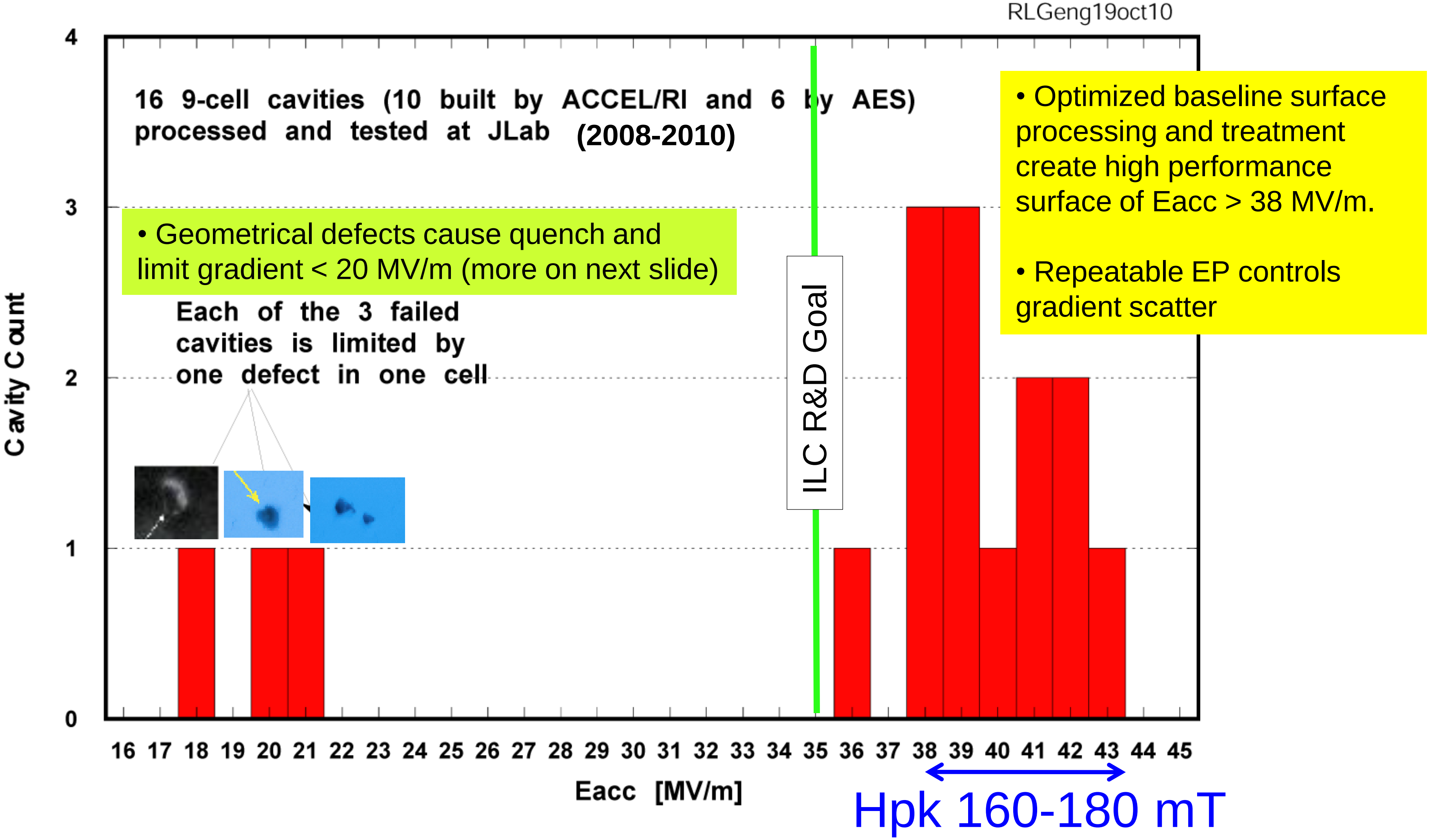
JLAB data, R.L. Geng et al., IPAC2011, MOPC111.

Global Cavity Gradient Results - Asia

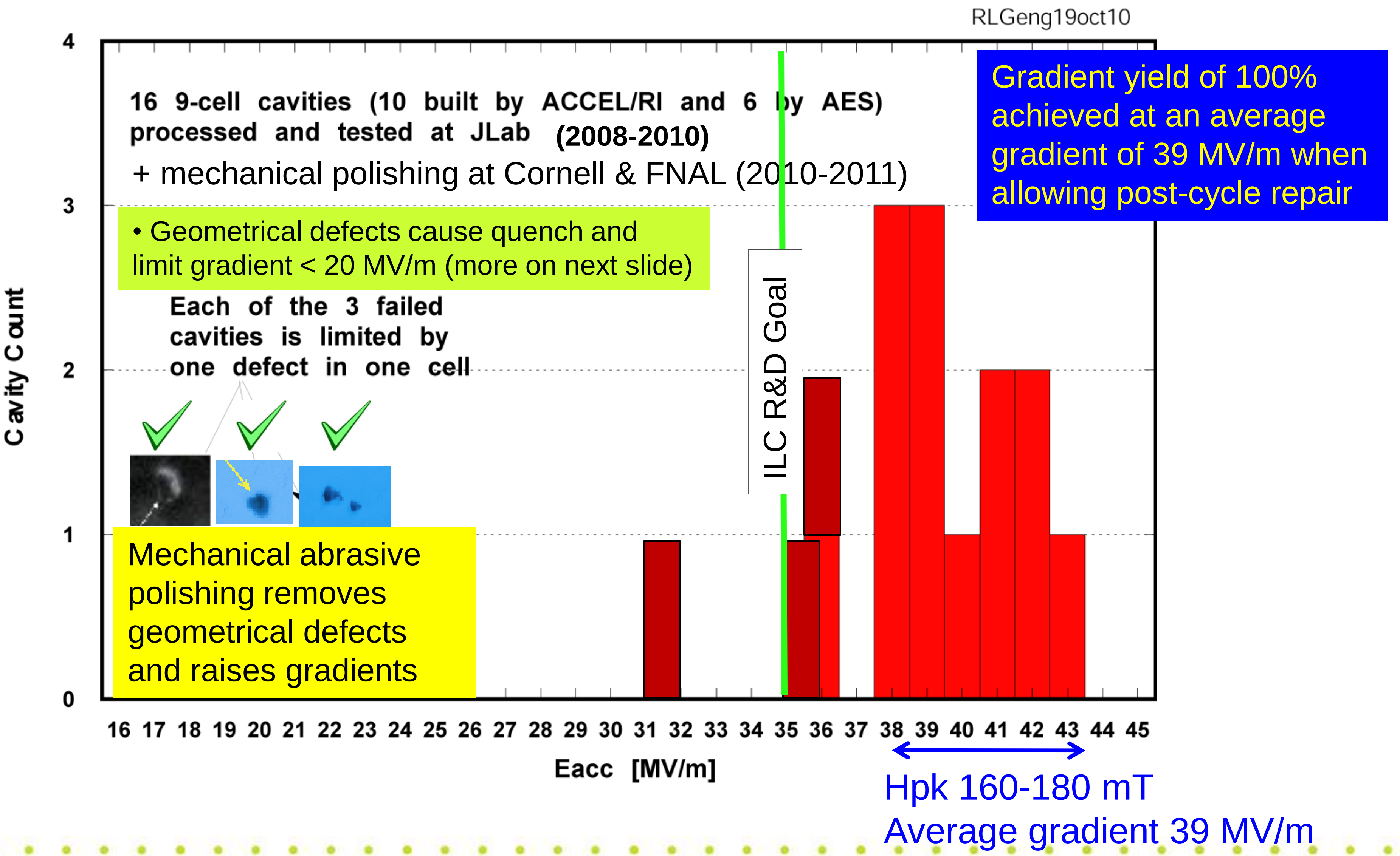


KEK data, Y. Yamamoto et al., IPAC2012, WEPPC013.

Gradient Limit Understanding and Control



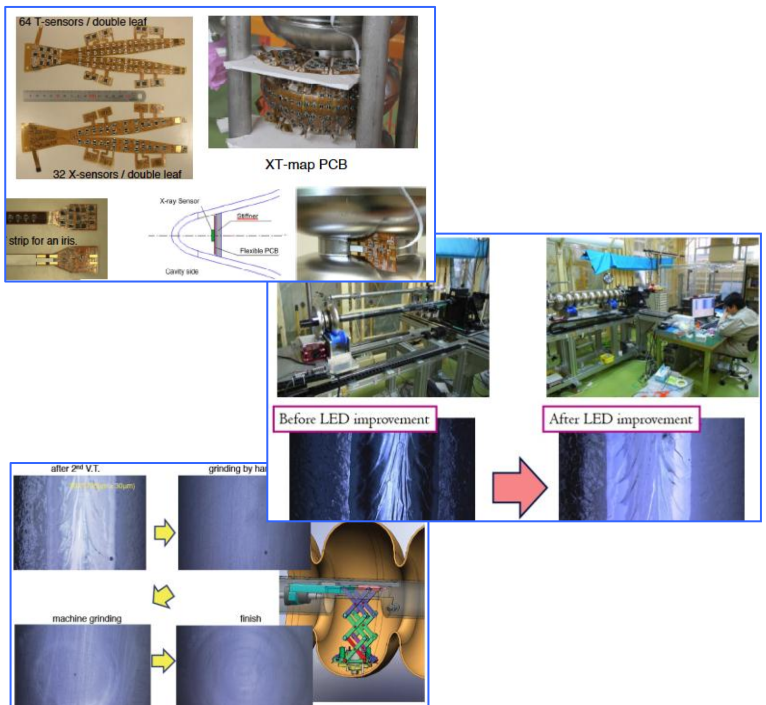
Gradient Limit Understanding and Control



Gradient Limit Understanding and Control

Technology in progress:

- Localization during test
  - + Optical inspection
  - + Local repairing



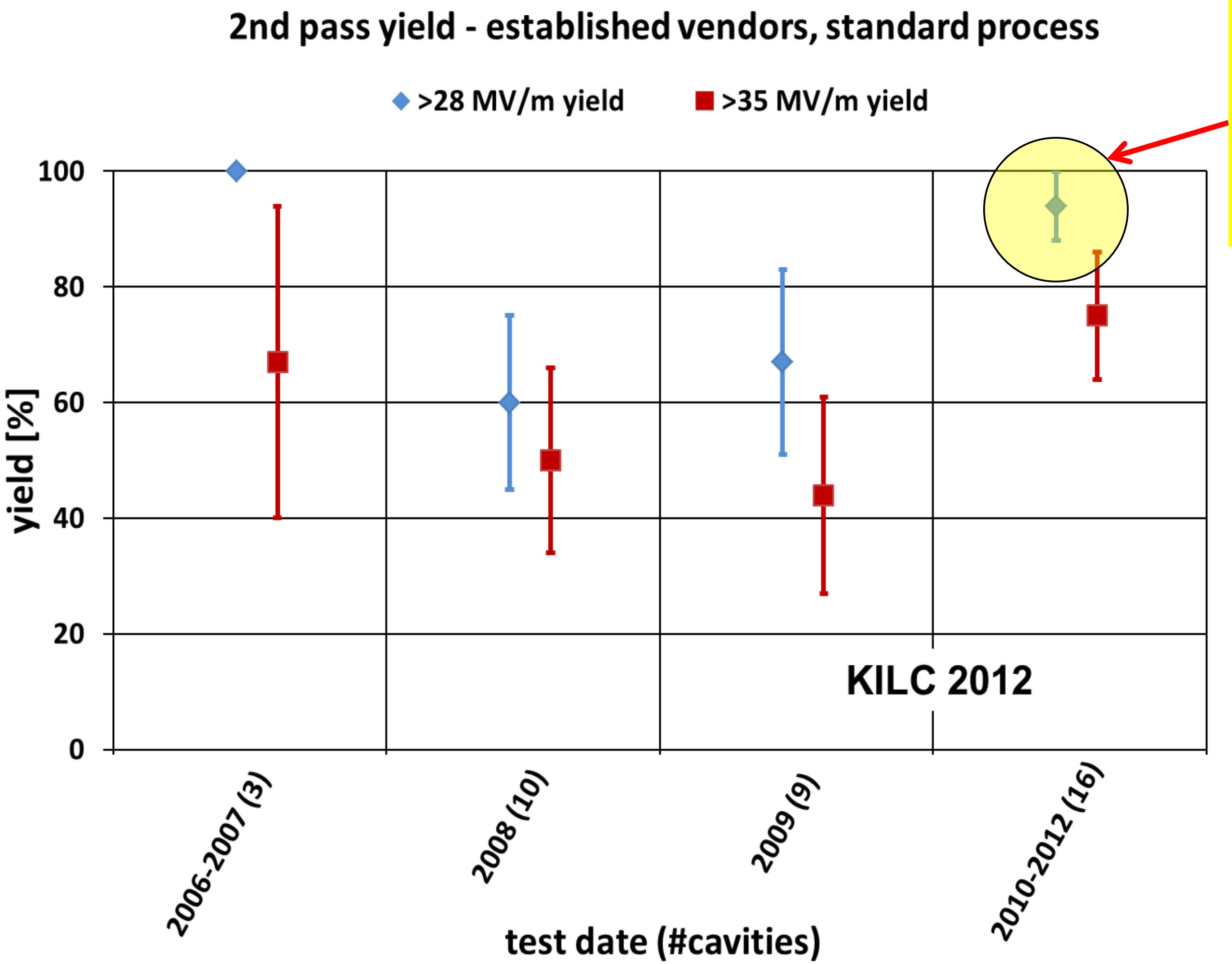
Guided repair at KEK

Cavity	Repaired at (EP/ MT/ LG)	Tested at	Bef.	Aft.	Year
MHI-08	KEK (LG)	KEK	16	27	2009
MHI-14	KEK (LG)	KEK	13	37	2011
MHI-15-1	KEK (LG)	KEK	23	33	2011
MHI-15-2	KEK (LG)	KEK	29	36	2011
MHI-15-3	KEK (LG)	KEK	18	36	2012
MHI-16	KEK (LG)	KEK	21	34	2012
MHI-19	KEK (LG)	KEK	26	37	2012
HIT-2	KEK (LG)	KEK	35	41	2012

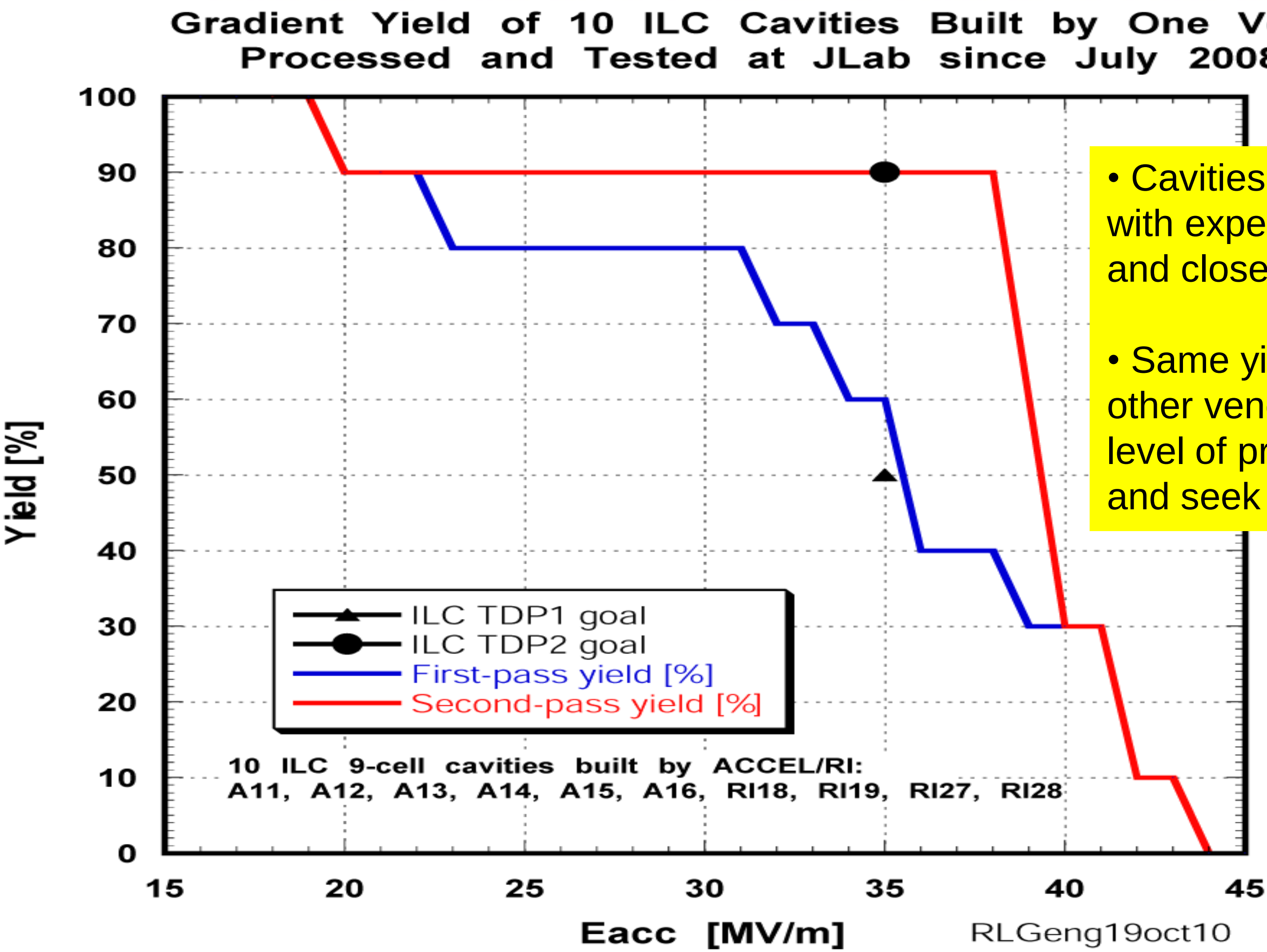
Blue: Repaired after the 1st cycle process
Red: Satisfy ILC requirements

Global Progress in Cavity Gradient Yield

(94+/-6)% acceptable for ILC mass production



Demonstration of 90% Yield at 38 MV/m w/ Q0 ≥ 8E9



- Cavities built by one vendor with experience of many cavities and close feedback with lab
- Same yield can be expected if other vendors are given similar level of practice in fabrication and seek feedback from labs

R.L. Geng et al., IPAC2011, MOPC111.

Global ILC 9-Cell Cavity R&D Experiences

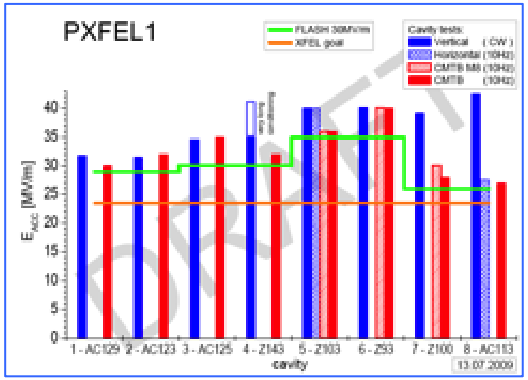
Labs	#9-cell cavities fabricated	Regional and world total
KEK	38	
IHEP	1 (2 new under fabrication)	
PKU	4	Asia total 43
FNAL	70 (80 ordered)	
JLab	7 (1 new under fabrication) In addition 112 7-cells	
Cornell	1	Americas total 78
DESY	200 (800 for XFEL)	EU total 200
		World total 321 (9-cell only) 433 (9-cell & 7-cell)

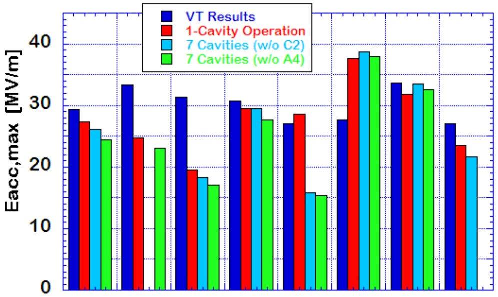
Gradient Summary

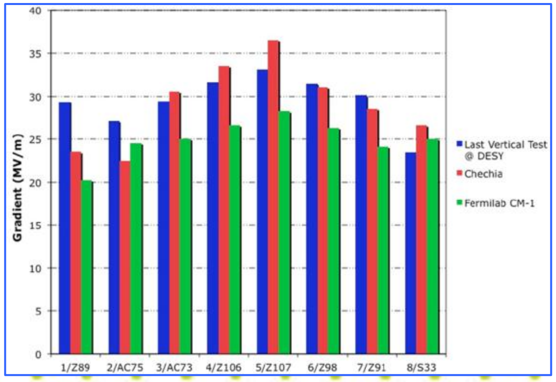
- **Baseline surface processing and handling procedure optimized and standardized.**
  - Added optical inspection for fabrication QA.
  - Allowed data-driven second-pass processing.
- **Steady gradient yield progress made in past 5 years on a global basis (tracked by Global Cavity Database).**
  - According to the current yield definition
    - 94% yield at gradient acceptable for ILC mass production (> =28 MV/m with average gradient AG=35 MV/m) on global basis.
  - Further yield improvement can be expected when allowing repair
    - 100% yield at >31 MV/m (w/ AG=39MV/m) demonstrated in Americas region
    - New progress being made with post-cycle local repair technology in Asia region
    - Repair can be included in procedure if cost effectiveness justified
- **Qualified vendors for cavity fabrication and labs for cavity processing in place in all regions**

Progress in SCRF System Tests

- DESY: FLASH
  - **SRF-CM string + Beam,**
    - ACC7/PXFEL1 < 32 MV/m >
  - **9 mA beam, 2009**
  - **800μs, 4.5mA beam, 2012**
- KEK: STF
  - **S1-Global: complete, 2010**
    - Cavity string : < 26 MV/m>
  - **Quantum Beam : 1 ms**
  - **CM1 + Beam, in 2014**
- FNAL: NML/ASTA
  - **CM1 test complete**
  - **CM2 operation, in 2012**
  - **CM2 + Beam, in 2013**







FLASH 9mA Expt achievements: 2009-mid 2012

High beam power and long bunch-trains *(Sept 2009)*

Metric	ILC Goal	Achieved
Macro-pulse current	9mA	9mA
Bunches per pulse	2400 x 3nC (3MHz)	1800 x 3nC 2400 x 2nC
Cavities operating at high gradients, close to quench	31.5MV/m +/-20%	4 cavities > 30MV/m

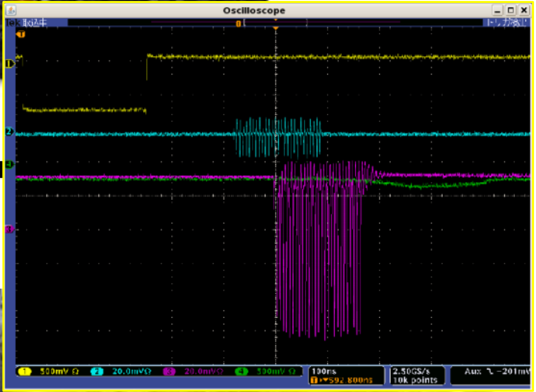
Gradient operating margins *(Feb 2012)*

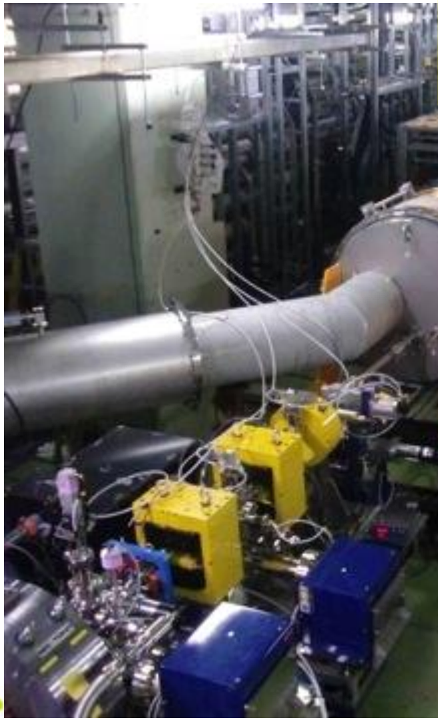
Metric	ILC Goal	Achieved
Cavity gradient flatness (all cavities in vector sum)	2% ΔV/V (800μs, 5.8mA) (800μs, 9mA)	<0.3% ΔV/V (800μs, 4.5mA) *First tests of automation for Pk/Ql control*
Gradient operating margin	All cavities operating within 3% of quench limits	Some cavities within ~5% of quench (800us, 4.5mA) *First tests of operations strategies for gradients close to quench*
Energy Stability	0.1% rms at 250GeV	<0.15% p-p (0.4ms) <0.02% rms (5Hz)

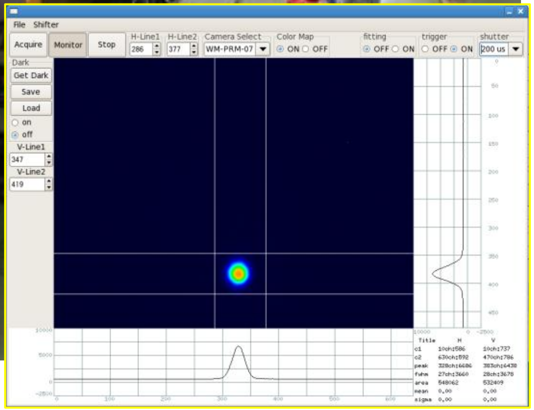
STF Quantum-Beam experiment

KEK-STF
Quantum-Beam Accelerator

Beam acceleration (40 MV) and transport for 1 ms, successful !
April, 2012



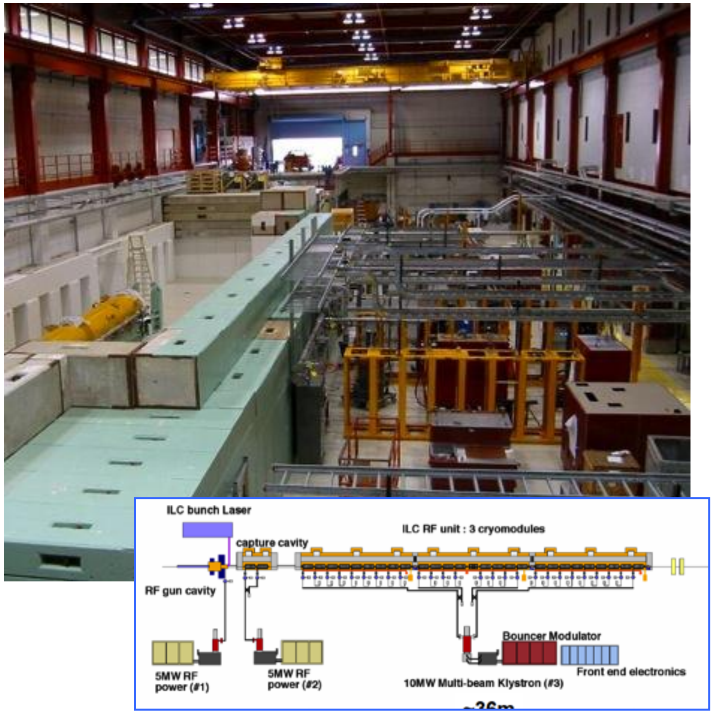


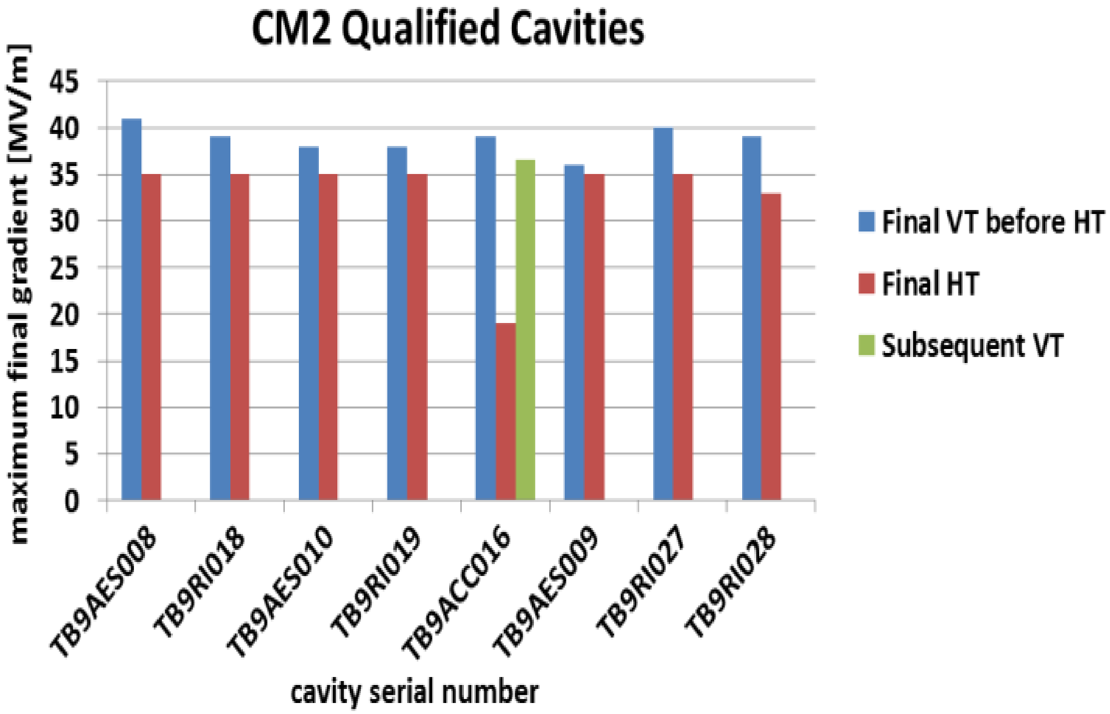


Target: 1.3 x 10^{10} photons/sec 1%bandwidth

2012. Feb : cool-down started,
April : beam acceleration

CM Test in Progress at Fermilab





- **CM-2 expected to reach the system test, in 2012**
  - 7 cavities reached > 35 MV/m in VT (Jlab), > 33 MV/m in HT (Fermi),
  - Expect > 30 MV/m on average in CM test

Progress in Industrial Participation to ILC Cavity Production

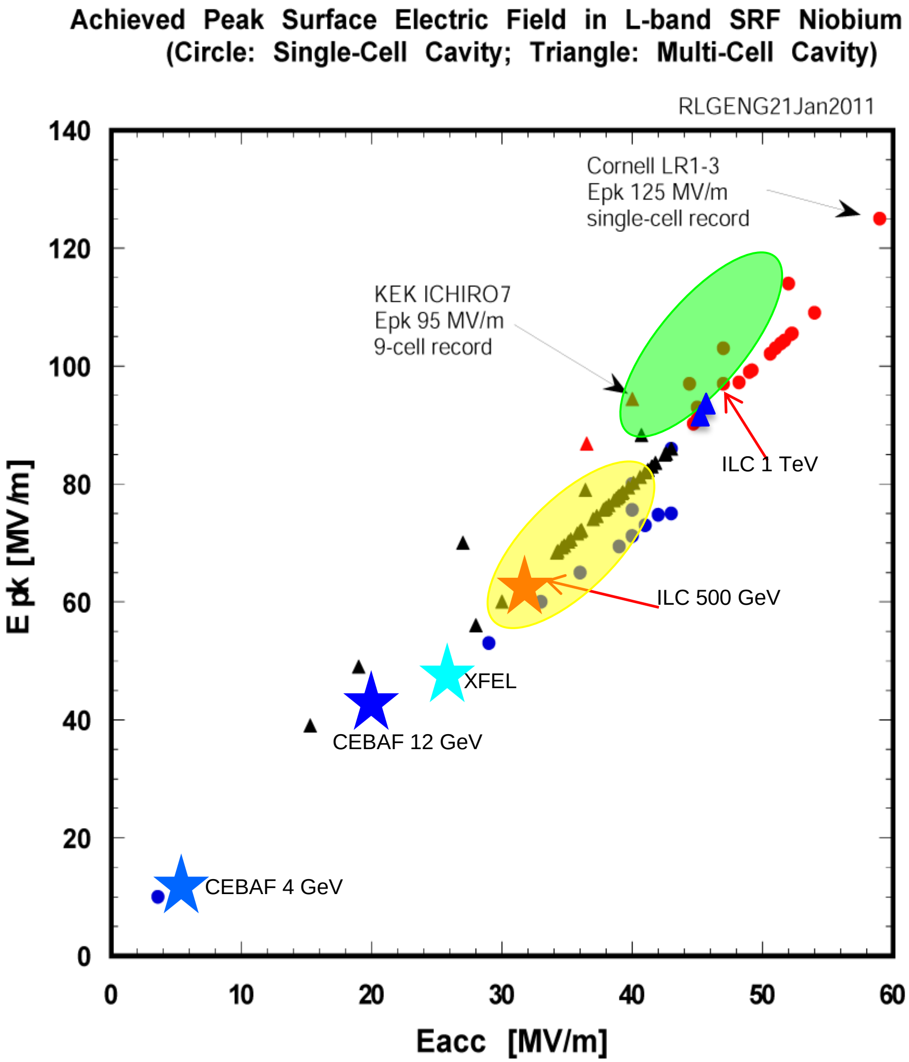
year	# 9-cell cavities qualified	# of Labs reaching 35 MV/m processing	# of Industrial manufacturers reaching 35 MV/m fabrication
2006	10	1 DESY	2 ACCEL, ZANON
2011	41	4 DESY, JLAB, FNAL, KEK	4 RI, ZANON, AES, MHI,
2012	(45)	5 DEY, JLAB, FNAL, KEK, Cornell	5 RI, ZANON, AES, MHI, Hitach

- Recent Progress in Industry/Lab
  - **Niowave-Roark/Fermilab (TB9NR004): reached 30 MV/m (Nov. 2011)**
  - **Hitachi/KEK (HIT02): reached 41 MV/m with HOM (April, 2012)**
  - **Toshiba/KEK (TOS-02): reached 35 MV/m w/o HOM (March 2011)**
  - **Accel (RI)/Cornell (A9) : reached 40 MV/m w/ HOM, vertical EP (April, 2012)**
  - **DESY (LG-) : reached > 45 MV/m w/ large-grain (2011~12)**
  - **IHEP-KEK: 1st cavity (LL, large-grain, no-end) reached 20 MV/m,**
  - **PKU-JLab: Cavity (Tesla, fine-grain) reached 28 MV/m,**
- Progress in EXFEL (updated by W. Singer : the 2nd EP at DESY, as of Sept. '12)
  - **RI: 4 reference cavities with Eacc > 28 MV/m, (~ 39 MV/m max.)**
  - **Zanon: 4 reference cavities with Eacc > 30 MV/m (~ 36 MV/m max.)**

Outline

- **ILC SRF technical status**
  - Cavity gradient
  - Cryomodule system testing
  - Beam operation of cryomodules in SRF linacs
- **Future SRF R&D for linear collider**
  - Field emission understanding and control
  - Very high gradient with high Q0
  - Inexpensive SRF fabrication and processing
  - Fundamental issues
- **Summary**

Field Emission Understanding and Control



- Intensive R&D in past years resulted in reduced field emission
  - Post-EP cleaning
  - No longer a main limit for vertical test
- But still not under complete control
  - Causes additional cryo loss
  - Risk increases rapidly with peak surface electric field due to exponential nature of the process

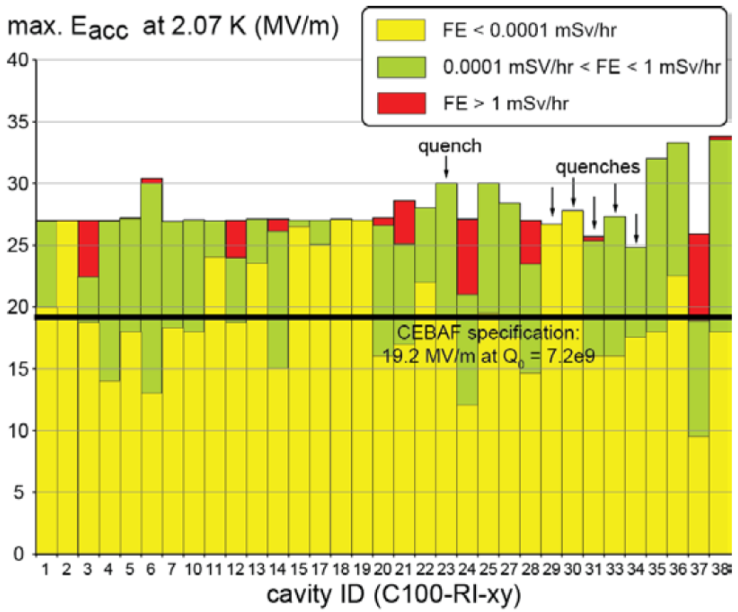
$$I_{\rm FN} = j_{\rm FN} A_{\rm FN} = A_{\rm FN} \frac{e^3 (\beta_{\rm FN} E)^2}{8\pi h \Phi t^2(y)} \exp\left(-\frac{8\pi\sqrt{2m_e \Phi^3}\, v(y)}{3he\beta_{\rm FN} E}\right)$$

- Critical issue for accelerator operation
  - Dark current
  - Radiation damage to electronics
  - Beam line activation from neutron
- For ILC operation Epk average 63 MV/m and up to 76 MV/m
  - For XFEL, Epk 47 MV/m
  - For CEBAF upgrade, Epk 42 MV/m

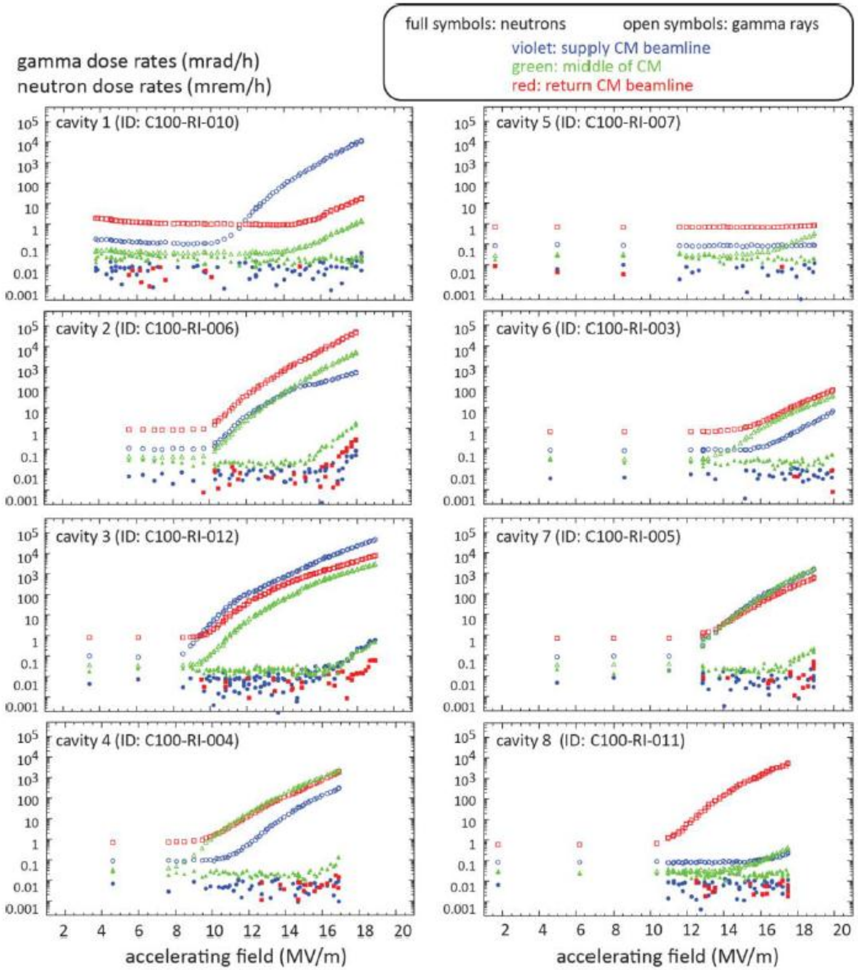
Field Emission Understanding and Control

CEBAF upgrade cavities: From vertical test to operation in accelerator tunnel

- Final surface processing essentially the same as that for ILC baseline
- Cavities and cryomodules met project spec
- Field emission recognized in some modules
  - ➢ Field emission onset change
  - ➢ Sometimes beam-line component activation
- Similar observations in other labs



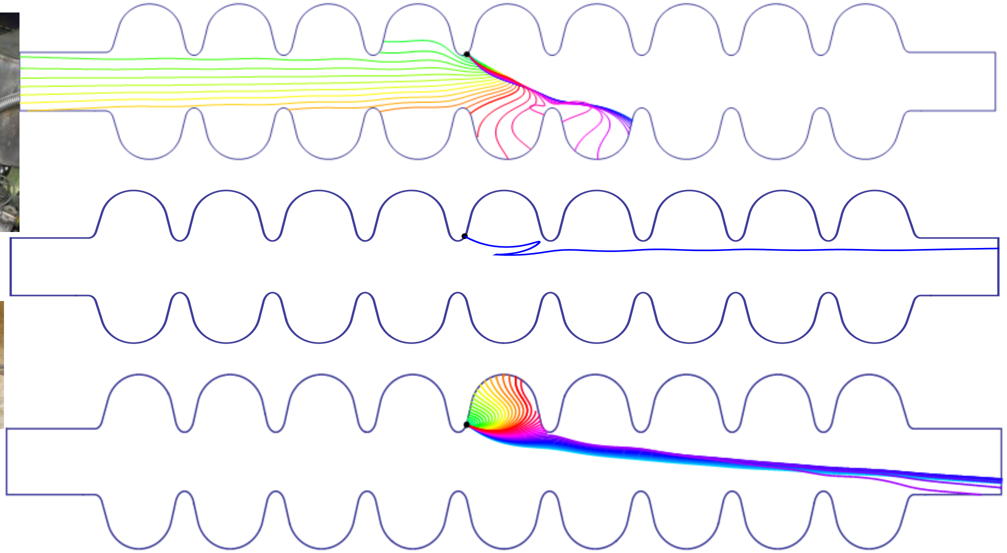
F. Marhauser, JLAB-TN-12-044



Future R&D on Field Emission

- Near term goal: Reduce field emission reliably up to a surface electric field of 80 MV/m in 9-cell cavity so as to insure operation of cryomodules at average gradient of 31.5 MV/m with acceptable field emission induced cryogenic loss and field emission induced radiation dose
  - **(Cryogenic loss due to FE) / (Cryogenic loss due to dynamic + static heat) per cryomodule < 10%**
  - **Dark current per cavity < 50 nA**
- Long term goal: Push the field emission onset gradient reliably beyond Epk = 50 MV/m in 9-cell cavities; Demonstrate Epk = 100-120 MV/m in 9-cell cavities
  - **Requires deeper fundamental understanding of FE phenomenon**
  - **Requires advanced surface processing**
    - “mirror finish”
    - In-situ processing

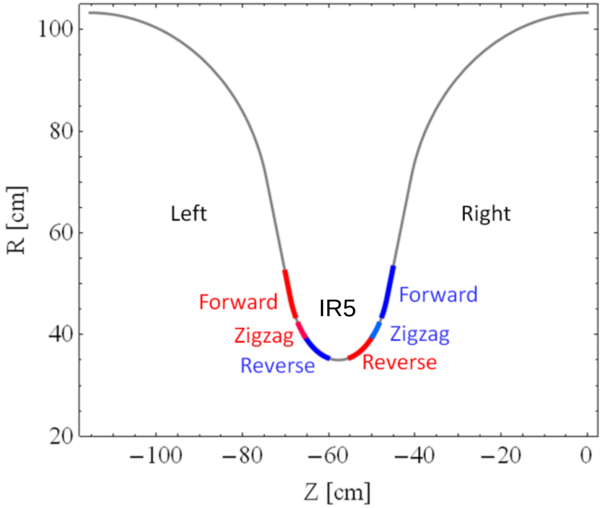
Locating Field Emitter in 9-cell Cavity

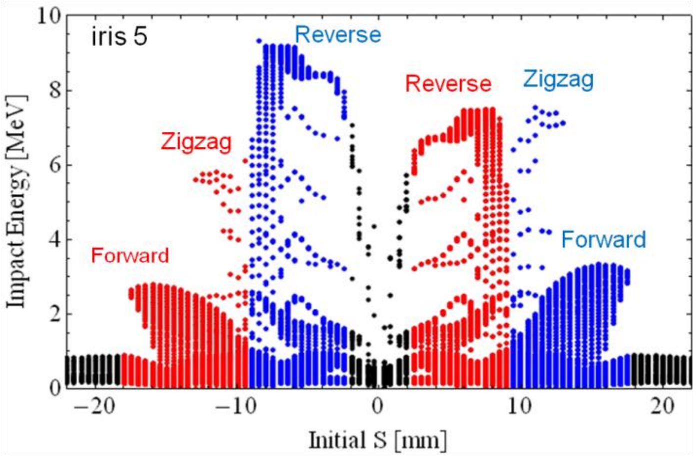


Emission in region
>>> "Reverse type"

Emission in region
>>> "Zigzag type"

Emission in region
>>> "Forward type"





Impact position VS impact energy distribution

Fundamental FE Studies

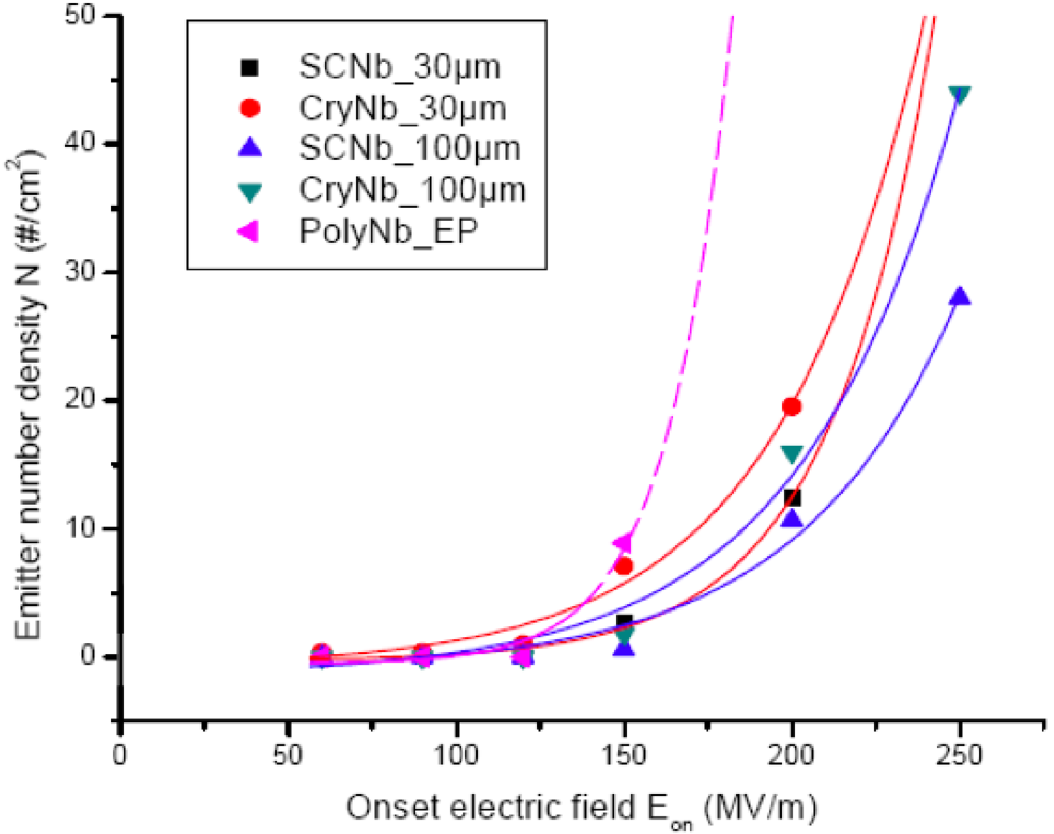
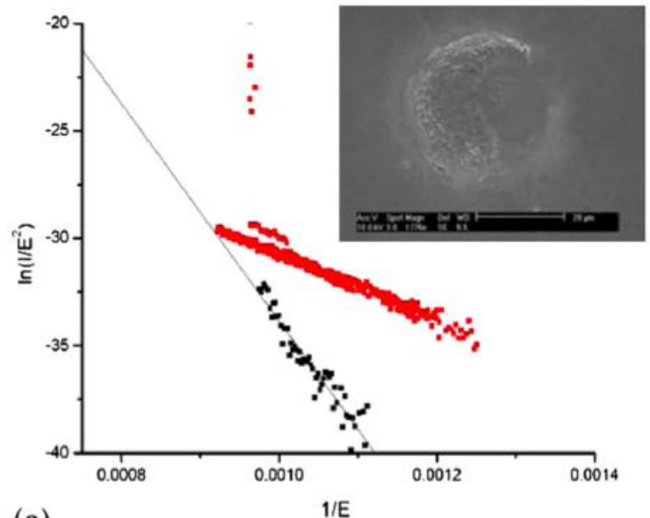


FIG. 3. (Color) Emitter number density vs applied electric field for different material removal. (Exponential fit lines: Red for 30 μm BCP, blue for 100 μm BCP, and magenta for EP polycrystalline Nb sample).

Difference between BCP and EP treated Nb surface

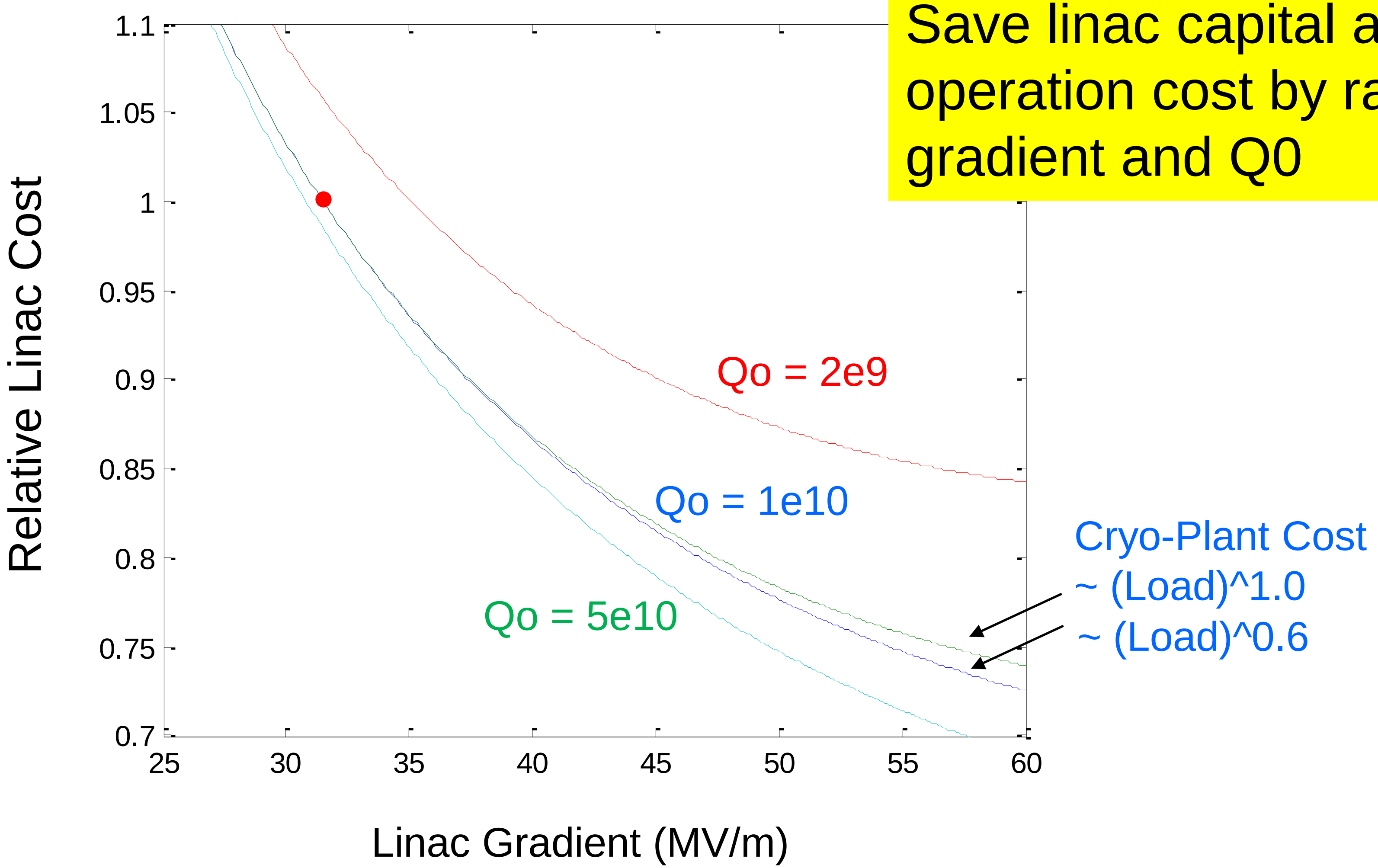
Creation of emitter by microdischarge



(a)

A. Dangwal Pandey et al., PRST-AB 12, 023501 (2009)

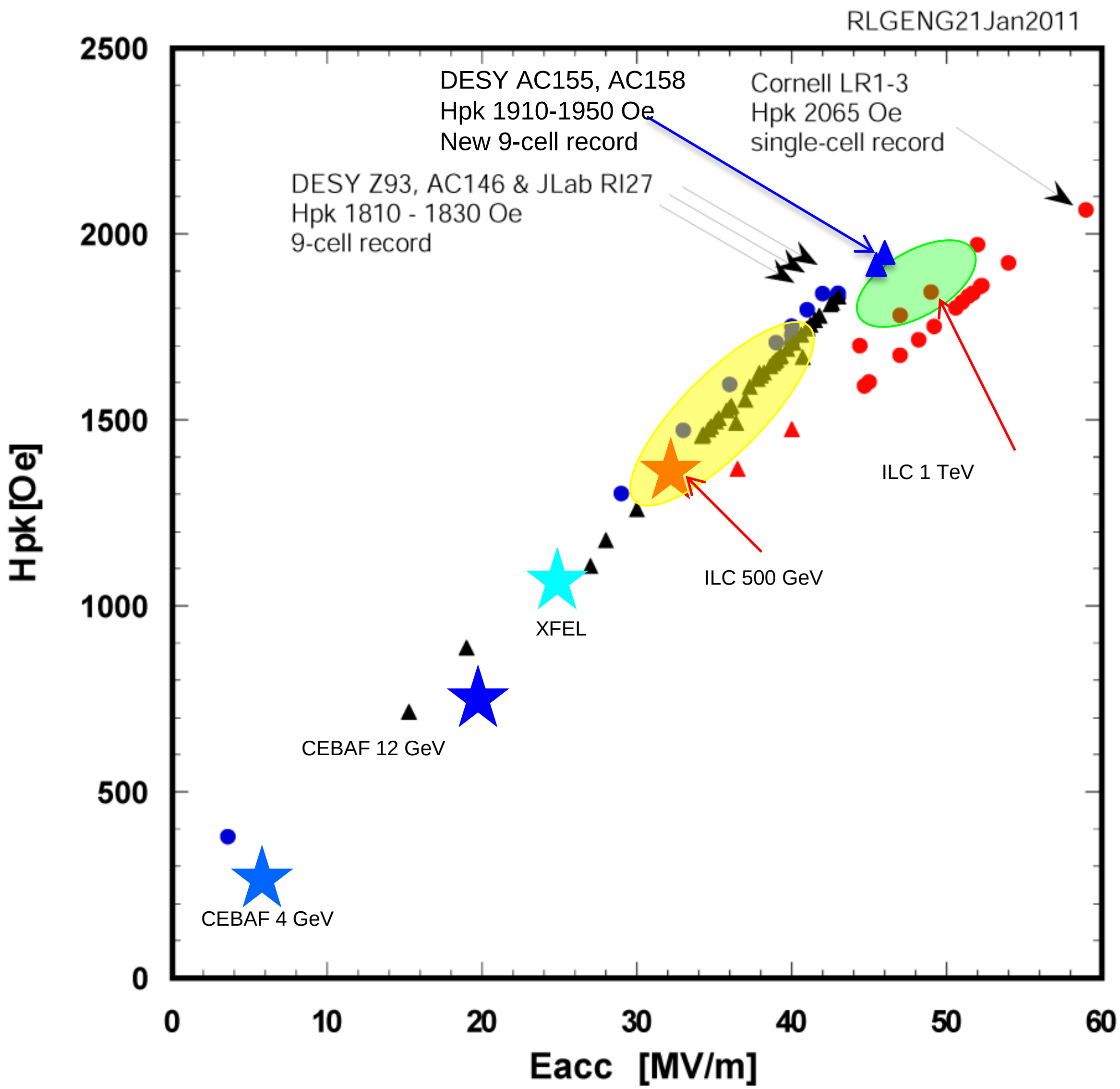
Very High Gradient with High Q0



Save linac capital and operation cost by raising gradient and Q0

Chris Adolphsen, ALCPG2011.

Achieved Peak Surface Magnetic Field in L-band SRF Niobium Cavities (Circle: Single-Cell Cavity; Triangle: Multi-Cell Cavity)



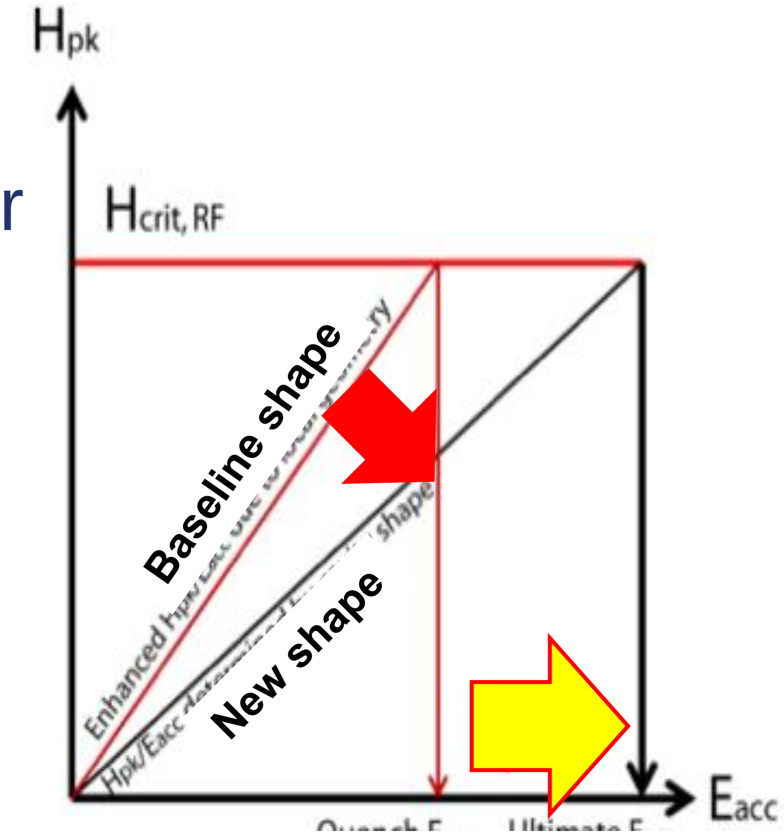
Recent cavity results established that a peak surface magnetic field of 190-200 mT is possible and practical

45 MV/m in TTF shape means effectively > 50 MV/m in Re-entrant, low-loss or ICHIRO, and Low-Surface-Field shape cavities

In fact, this is already shown in many 1-cell cavities

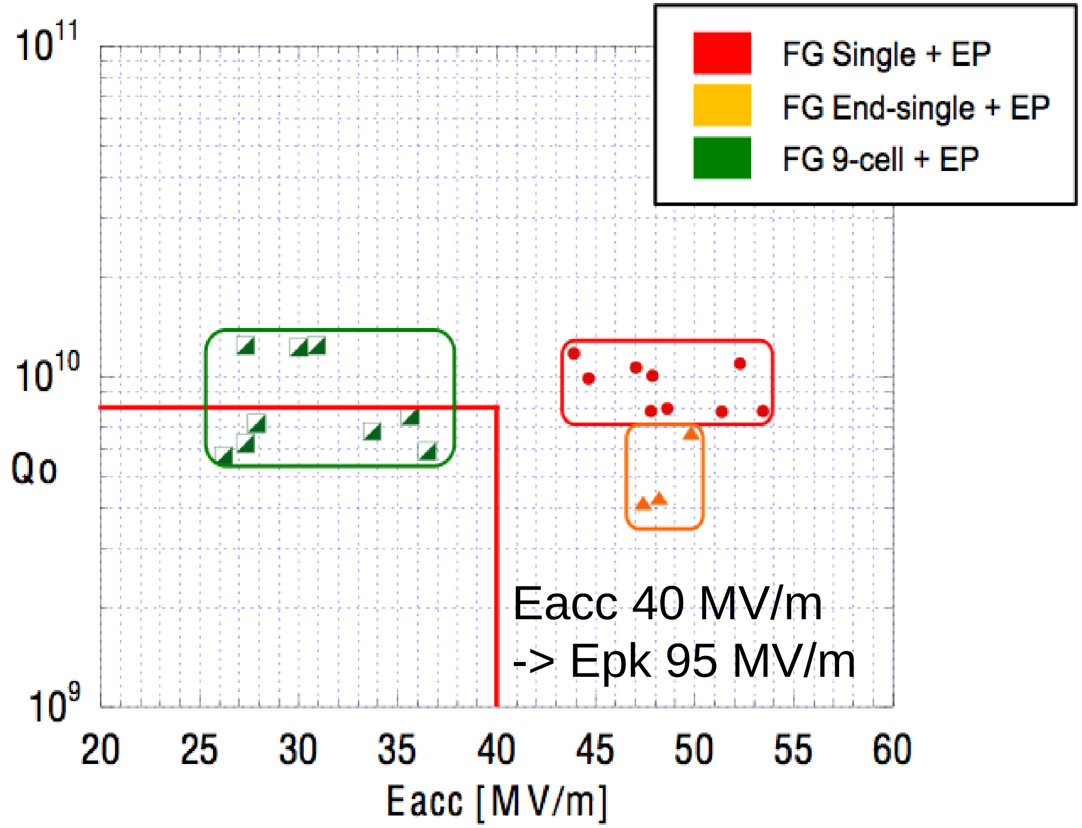
High Gradient via New Shapes

- Ratio of Hpk/Eacc solely determined by shape
- Lowering Hpk/Eacc for higher gradient up to critical RF magnetic field (material property)
- Three cavity shapes under evaluation
  - **Low-loss (KEK, JLab, IHEP)**
  - **Re-entrant (Cornell)**
  - **Low-Surface-Field (JLab/SLAC)**



KEK 9-cell cavity ICHIRO7 achieved 40 MV/m gradient (potential > 50 MV/m) under collaboration between KEK and JLab

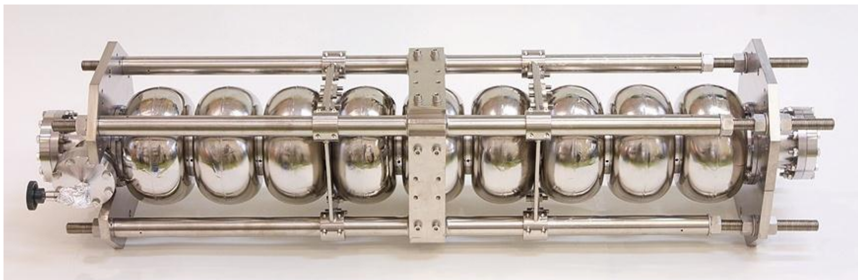
Current status of ICHIRO + EP

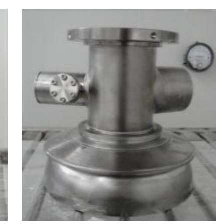


F. Furuta et al., SRF2011, TUPO014 (2011).

IHEP 1.3 GHz 9-cell Cavities

- Low-loss large grain cavity (w/o HOM)(IHEP-01)
  - **20 MV/m (CBP + CP), in collaboration with KEK and JLAB**

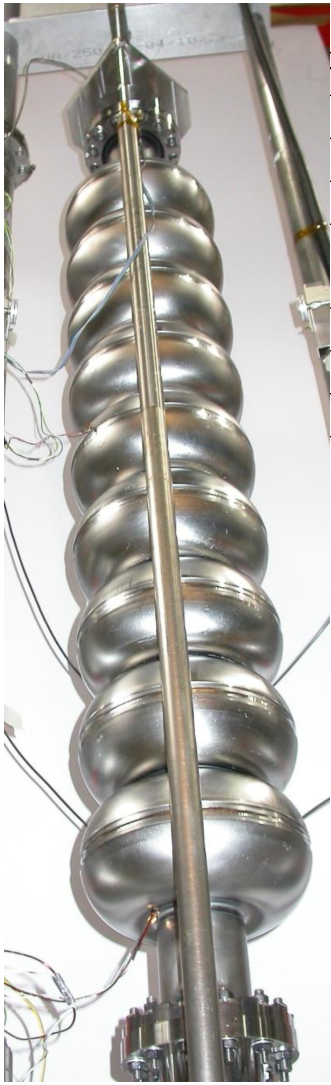




- Low-loss large grain cavity (IHEP-02)
  - **cold test in 2013, in collaboration with FNAL**
- TESLA-like fine grain cavity (IHEP-03)
  - **cold test in 2013, in collaboration with KEK**

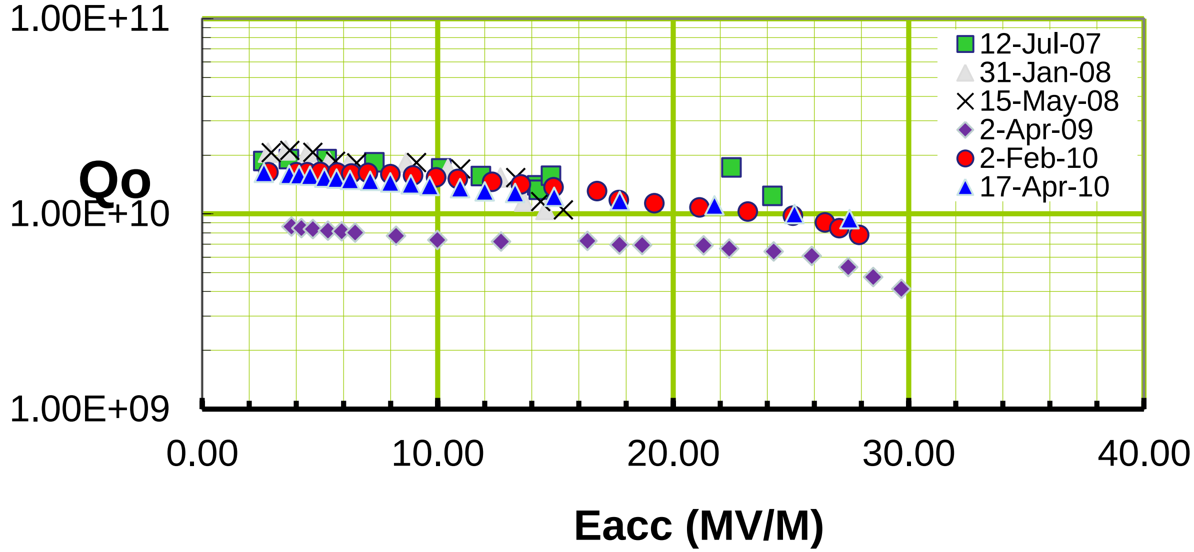
Courtesy: J.Y. Zhai, J. Gao
IHEP, CAS

High gradient R&D w/ Re-entrant 9cell at Cornell



History of Re-entrant 9-cell

cavity	date	Eacc max [MV/m]	Qo at Eacc max	process
LR9-1	12-Jul-07	24.23	1.23E+10	VEP200um, 600C bake(Jlab), VEP20um, 115C bake
LR9-1	31-Jan-08	14.59	1.05E+10	VEP20um, 115C bake
LR9-1	15-May-08	15.35	1.05E+10	VEP20um, 115C bake
LR9-1	2-Apr-09	29.70	4.12E+09	Tumbling80um, VEP200um, 600C bake(Jlab), VEP20um, 115C bake, Q-disease
LR9-1	2-Feb-10	27.49	9.39E+09	600C bake(Jlab), VEP, 115C bake
LR9-1	6-Apr-10	-	-	Re-HPR, 115C bake, RF cable/probe failure
LR9-1	17-Apr-10	27.91	7.80E+09	retune 4%, re-HPR only



Courtesy: F. Furuta, Cornell Univ.

First LSF 9-cell Cavity Fabrication at JLAB

LSF RF design by Z. Li, C. Adolphsen, SLAC

Feature:

- Lowering Hpk/Eacc without raising Epk/Eacc
- low cell-cell coupling
    - need better stiffening

First cavity test expected in 2013, Use proven JLAB high gradient procedure

High Gradient via Materials

- Ultimate gradient limit set by RF critical magnetic field
  - **Nb, 240 mT predicted by superheating theory**
    - Ultimate gradient 60 MV/m
    - ~210 mT (~90% theoretical limit) achieved
      - One 1-cell 1.3 GHz re-entrant cavity (R.L. Geng et al., PAC2007)
      - One 2-cell 1.3 GHz cavity (K. Watanabe et al., KEK cERL, 2012)
    - 195 mT (~80% theoretical limit) achieved
      - One 9-cell 1.3 GHz TTF-shape large grain cavity (D. Reschke et al., SRF2011)
  - **Nb_3Sn, 400 mT predicted by superheating theory**
    - Ultimate gradient 100 MV/m
    - Vapor diffusion
      - Was investigated 20 years ago
      - New efforts restarted at Cornell
        - » First 1-cell 1.3 GHz coating this month

Nb_3Sn Coating Chamber

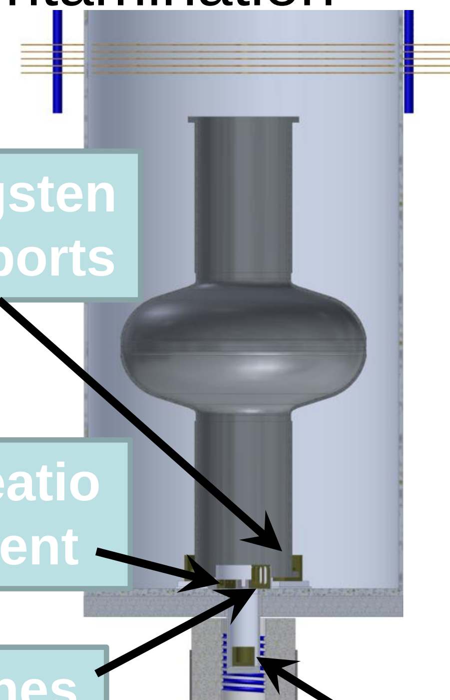
Cornell University

Coating chamber is inserted into UHV furnace. Separate vacuum system keeps furnace free from tin contamination

Cavity Temp Thermo - couples

Heater Power

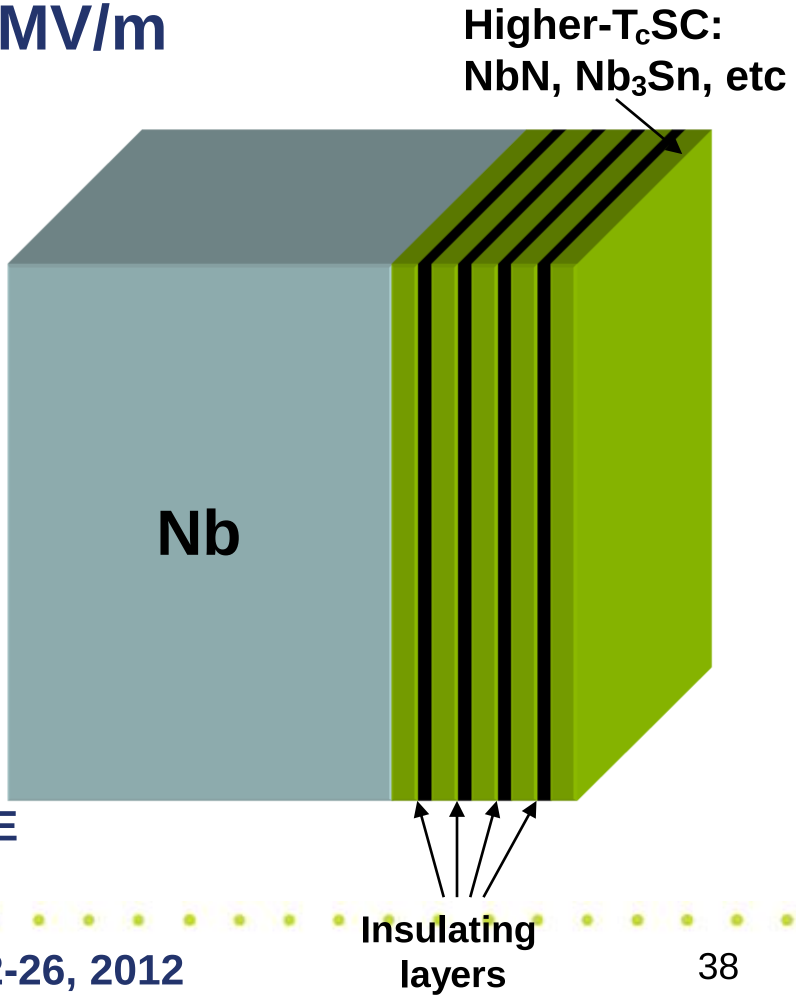
Heater Temp Thermo - couples



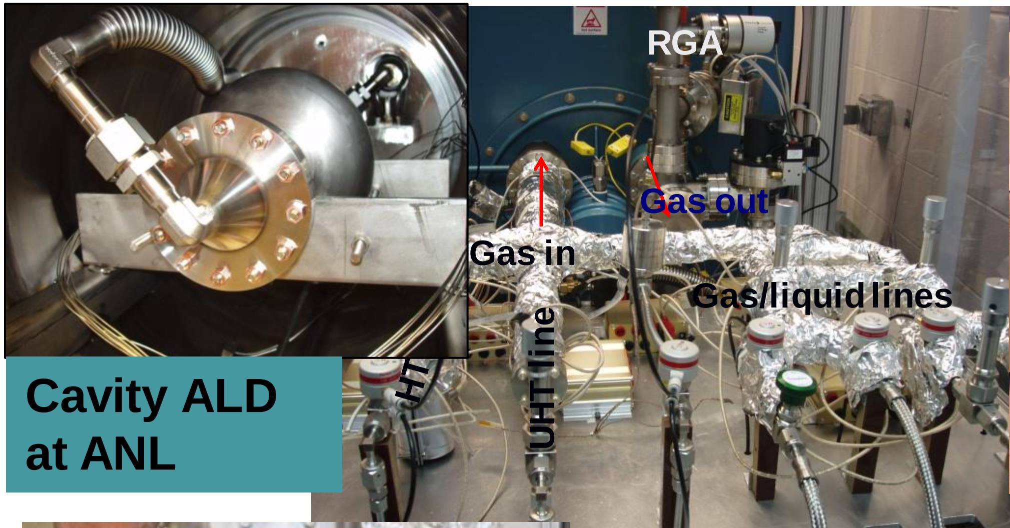
Courtesy Sam Posen, Cornell

High Gradient via Multi-Layer

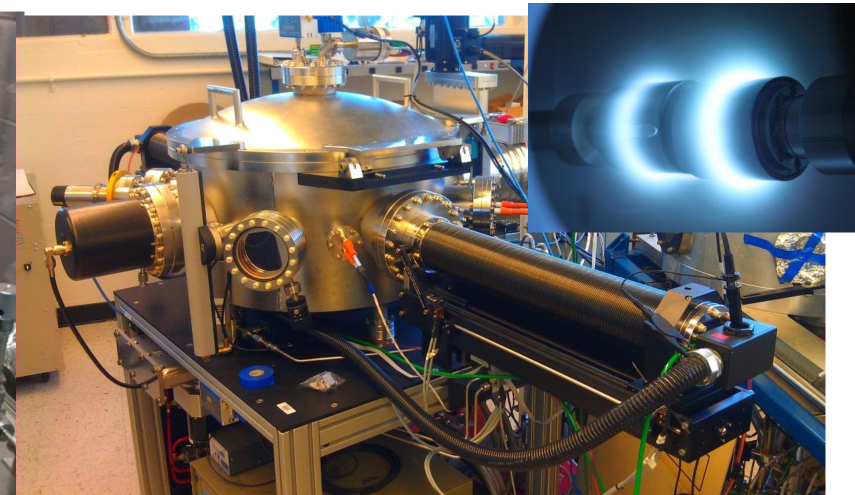
- Theory by Gurevich, APL 88, 012511(2006)
- Potential for magnetic limit 500-1000 mT
  - **Ultimate gradient up to 200 MV/m**
- Insulating layer nm thick
- Thin film coated cavities
- Coating techniques
  - **Several paths being explored at ANL (ALD), CERN (sputtering, HIPIMS), JLAB (ECR, CVD), LBNL (HIPIMS)**
- Requires RF evaluation of samples at low temperature
  - **Several apparatus being developed at CERN (Quadrupole resonator), Cornell (TE cavity), JLAB (SIC cavity)**



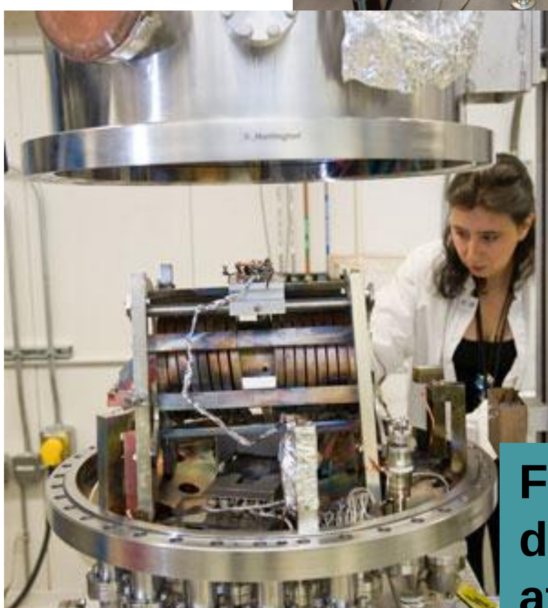
Coating Infrastructures



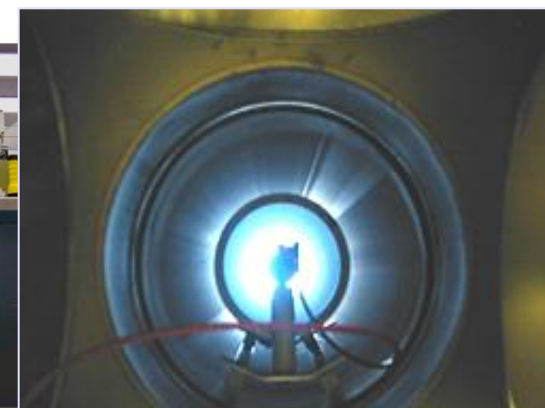
Cavity ALD at ANL



High-impulse deposition at LBNL

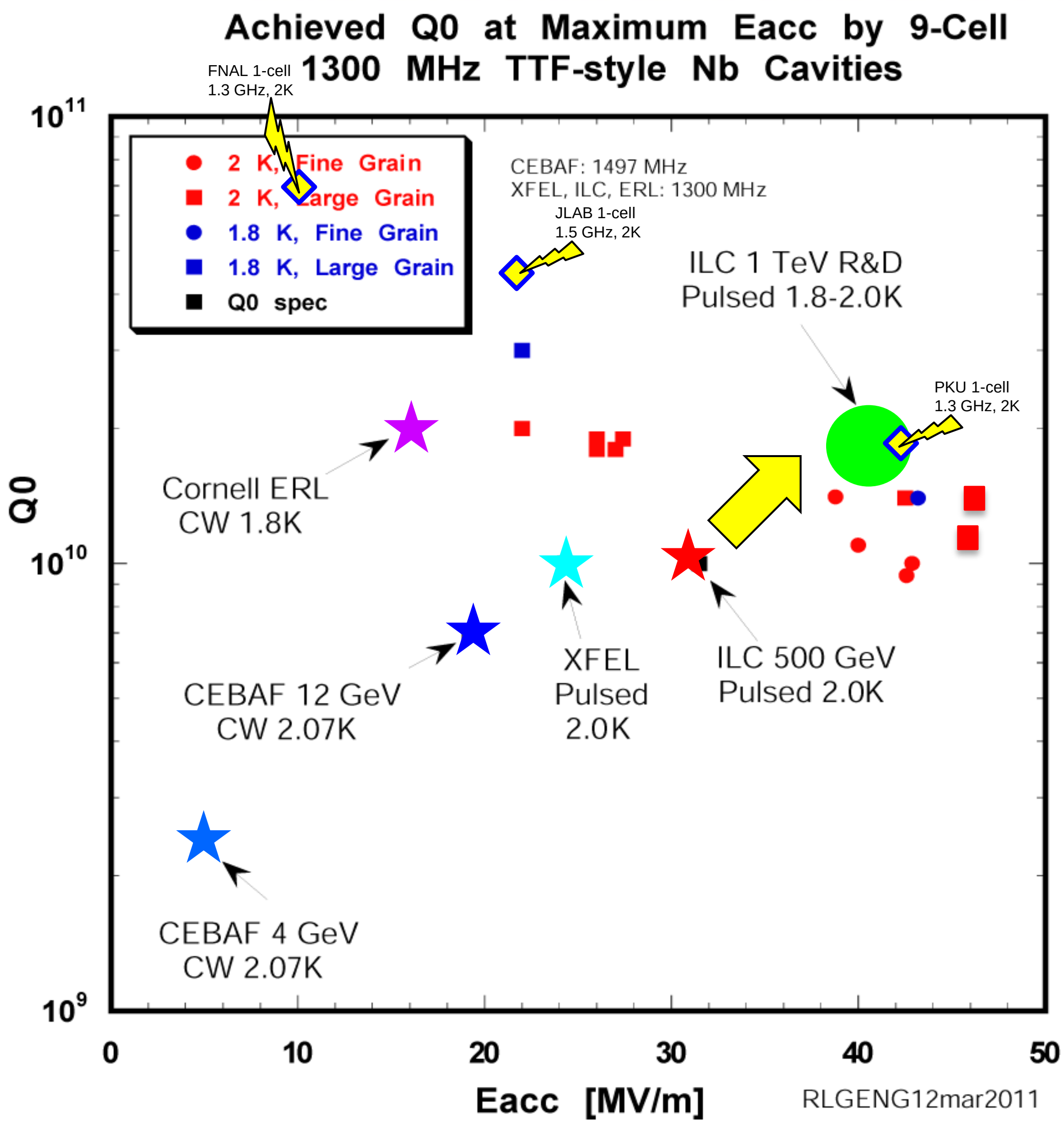


Film deposition at JLab



CED at AASC, 1^{st} coated Nb-Cu cavity in hand, 2012

Very High Gradient with High Q0



For 1 TeV upgrade, high gradient and high Q0 are required for lowering capital and operation cost Goal: G=45 MV/m @ Q0=2E10

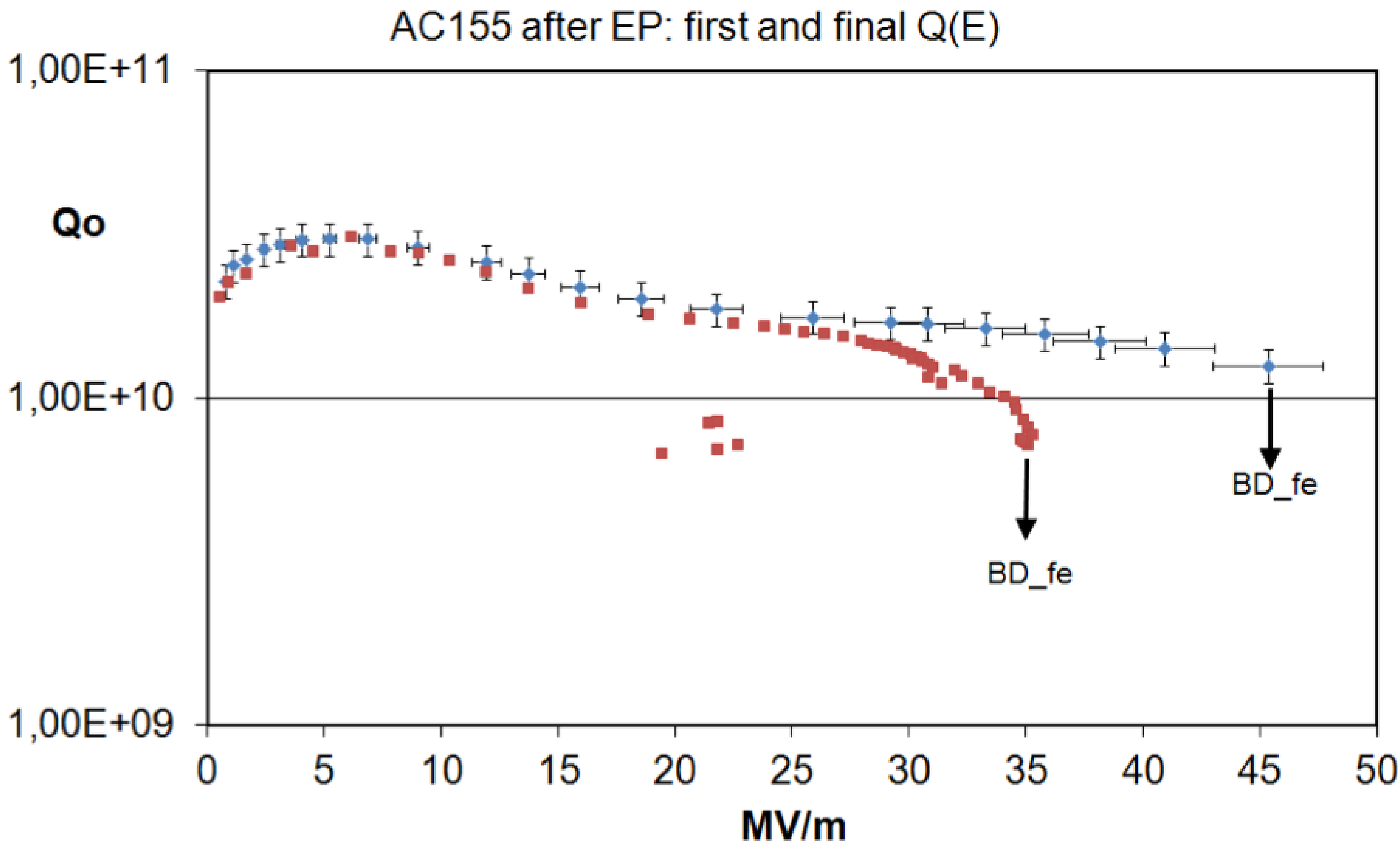
Several 1.3 GHz 9-cell Nb cavities have achieved Q0=1E10 for G= 40-45 MV/m

Large-grain Nb promises higher Q0

Recent L-band 1-cell Nb cavities demonstrated much higher Q0 after high temperature furnace treatments with various exposed media

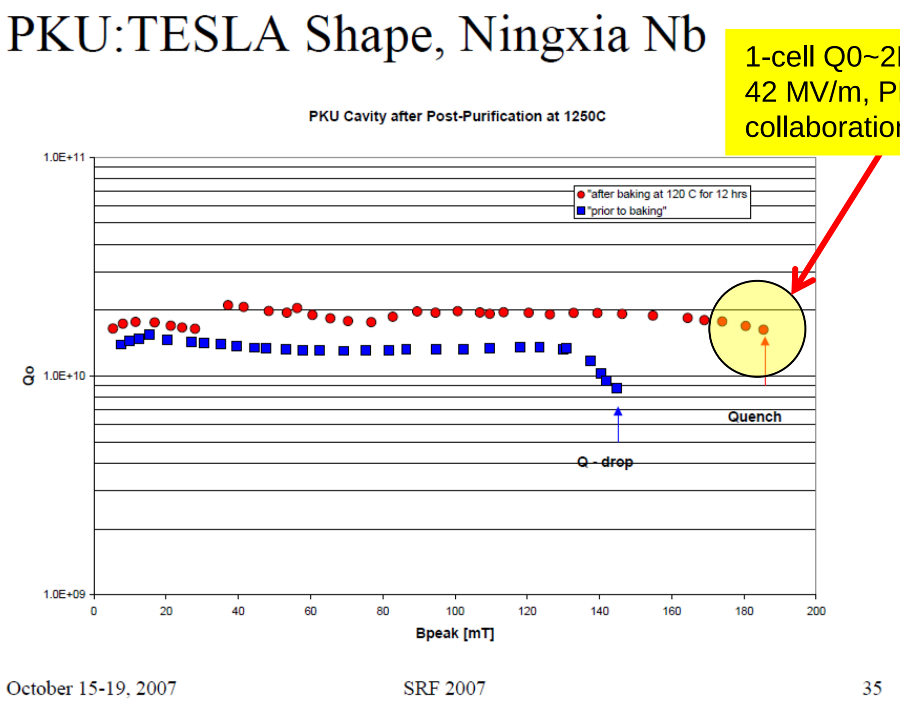
- 4.6E10 at 2K & Hpk=90 mT, 1.5 GHz, LG Nb at JLAB (P. Dhakal et al., IPAC2012)
- 7E10 at 2K & Hpk=42 mT, 1.3 GHz at FNAL (A. Grassellino, CW SRF linac w/s, 2012)

High Q0 via Large Grain Nb



D. Reschke et al., SRF2011, THPO046 (2011).

High Q0 via Large-Grain Nb

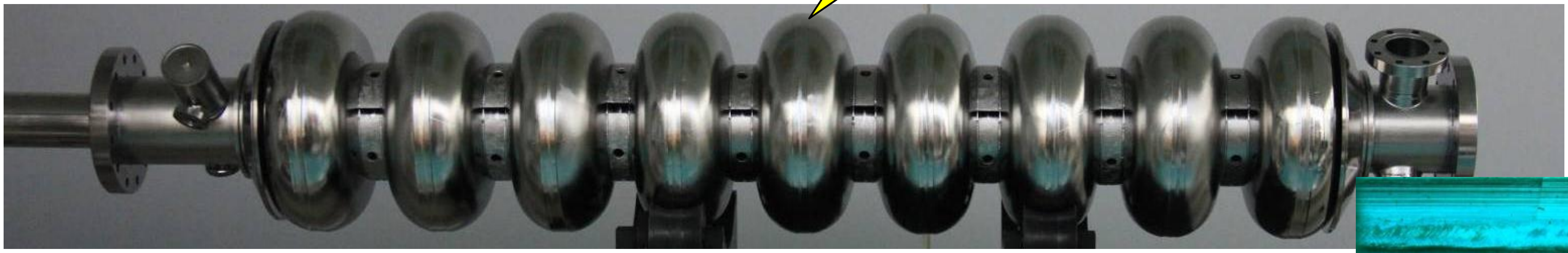


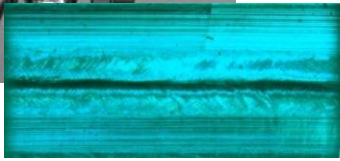
1-cell Q0~2E10 @ 2K & 42 MV/m, PKU/JLAB collaboration, 2007

9-cell PKU2 Q0=2E10 @ 2K & 20 MV/m, PKU/JLAB collaboration, 2010-2011

Cavity limited by quench due to fabrication defect

New 9-cell PKU4 with improved weld, 2012
To be processed and tested at KEK this year





Improved weld

Courtesy J.K. Hao, K.X. Liu, Peking University

Inexpensive SRF Fab. & Proc.

- SRF cost effectiveness expected to improve with the size of production volume
  - **Subject of ILC SRF industrialization**
  - **XFEL production unique opportunity for understanding**
    - Inspection QA/QC
    - Second-pass re-processing scheme
    - Percent of cavities needing “guided repair”
- Several paths being explored in terms of cavity fabrication and processing
  - **Seamless cavity**
  - **Mechanical abrasive polishing**
  - **Vertical electropolishing**

Goal of the R&D program @ DESY

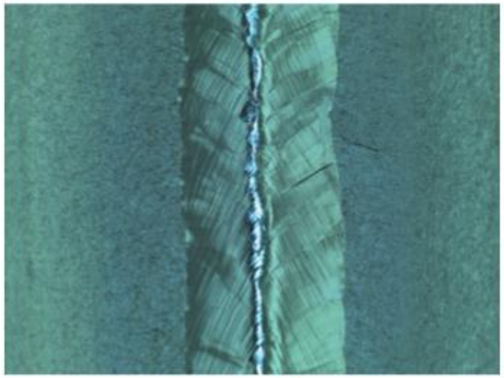
What do we want to reach:

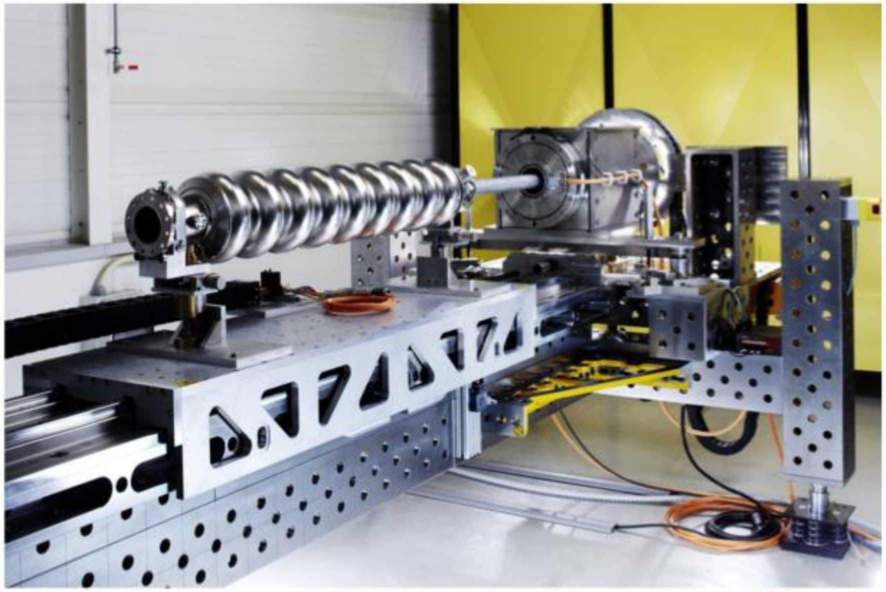
- Solid understanding/control of the industrial mass-production process
- **Influence/feedback** to the XFEL production
- Clear **identification** of the **gradient limiting factors**
- **Elaboration** of cavity **treatment** technique providing at least **E_{acc} > 35 MV/m** at production yield of **>90% in one pass**
- Aim for **3 world record modules** from the **24 ILC-HiGrade cavities**

Automated Optical Inspection

OBACHT – Optical Bench for Automated Cavity Inspection with High Resolution on Short Time Scales

- **Large amount** of cavities can be **inspected**: ILC-HiGrade, (European XFEL)
- **Fully automatic** (LabView) cavity inspection with Kyoto Camera System yields
  - 2790 pictures in ~8 hours: welding seems of equator (iris) every 4°(10°) + equator left/right
  - ~12 x 9 mm pictures (2488 x 2616 pixels, ~10 µm resolution) in *.bmp, *.png and/or *.jpg
- Movable sled with cavity (axial posit. ~10 µm) and Kyoto camera (angular posit. ~0.01°),
- Collision free movements assured by optical tests
- Fully **automatic** cavity **positioning**, **illumination**, and image **recording**
- **Automatic** image **processing** and possibly defect **recognition**





HELMHOLTZ ASSOCIATION

ilc higrade

SEVENTH FRAMEWORK PROGRAMME

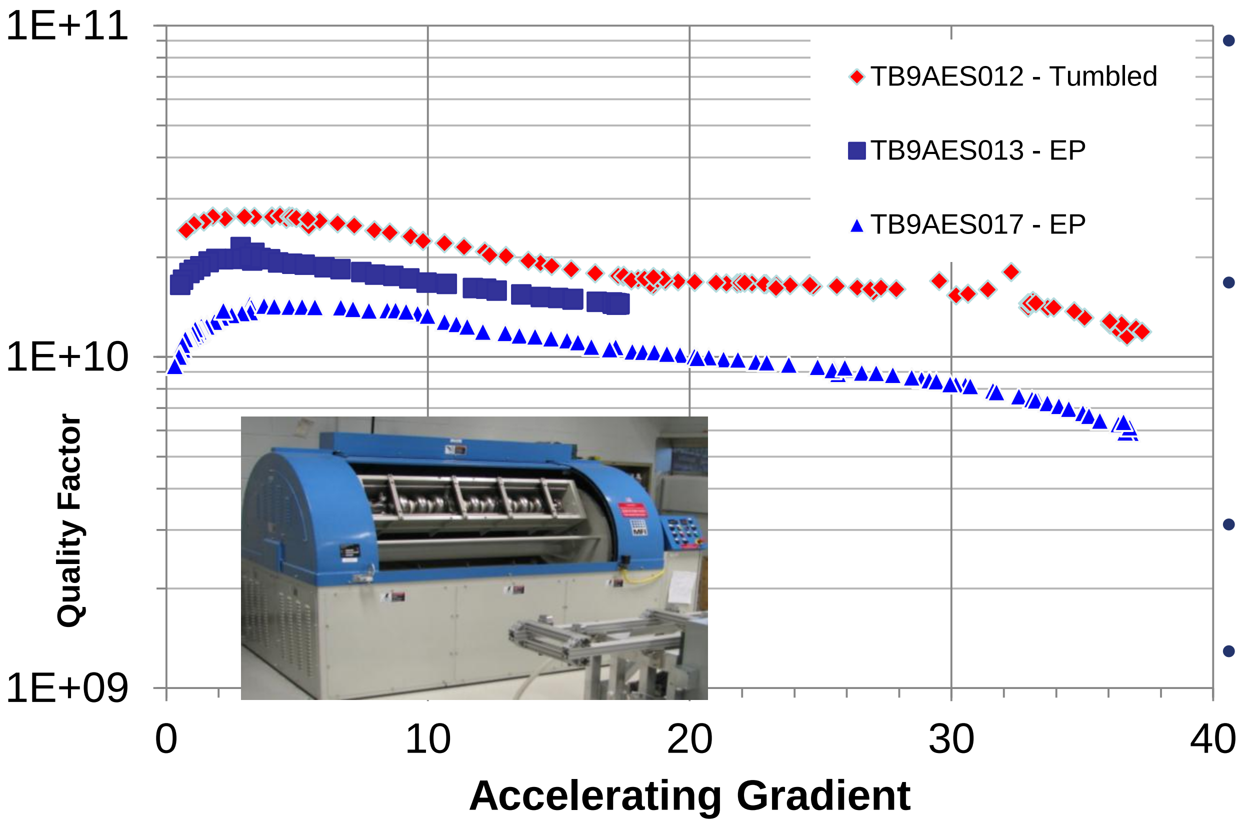
Aliaksandr Navitski, Eckhard Elsen
for International Workshop on Future Linear Colliders (LCWS12)

DESY

Seamless Cavity

- Initial work at DESY progressed over years
  - **Best 9-cell seamless cavity (by welding three 3-cell seamless units) Z164 reached 34 MV/m**
    - Limited by quench
    - Thorough instrumented testing has been done at JLab
    - Results being compared with welded cavities (talk to be presented November 2012 TTC meeting)
- Other labs (FNAL, JLAB, KEK) are interested in further development
- Cost saving by reducing number of EBW steps
- Further cost saving if technology is used for Nb-Cu clad material or copper in association with Nb coating
  - **Aligned interest with multi-layer (earlier slides)**
  - **Potential exists in US labs**

Mechanical Abrasive Polishing CBP

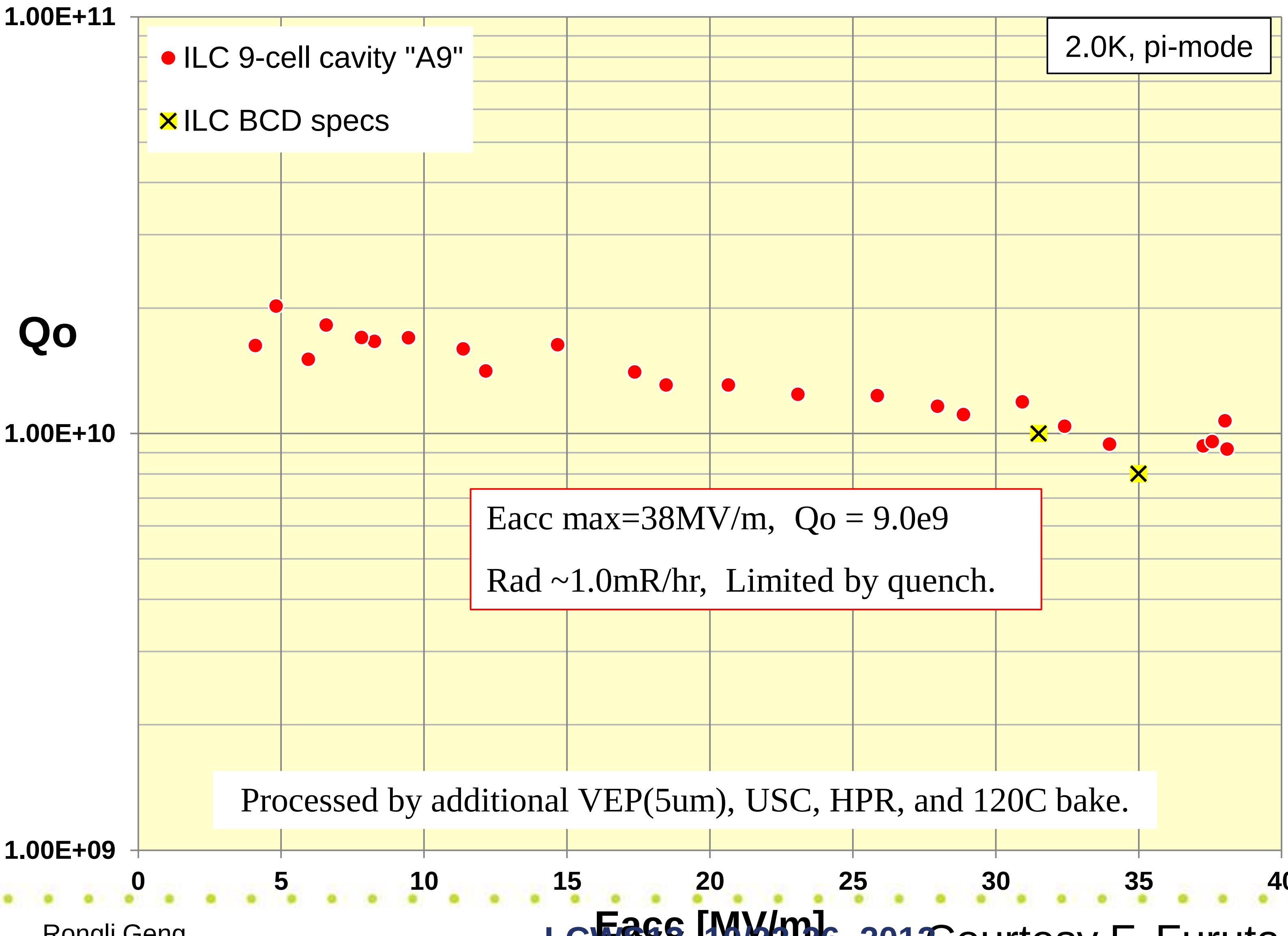


3rd AES production cavities baseline vs. CBP

Courtesy C. Cooper, FNAL

- Clear demonstration of effectiveness in repairing low performing cavity in hand
- 10 cavity set under process at FNAL to evaluate suitability for adoption as baseline
- “Mirror finish” achieved in 9-cell at FNAL and JLAB.
- R&D at FNAL aims for recipe of “zero chemistry” following CBP
- Same machine exists at Cornell, FNAL, JLAB, and U. Hamburg (available for DESY)

1st achievement of 40MV/m w/ VEP + TESLA 9-cell



Courtesy F. Furuta, Cornell U.

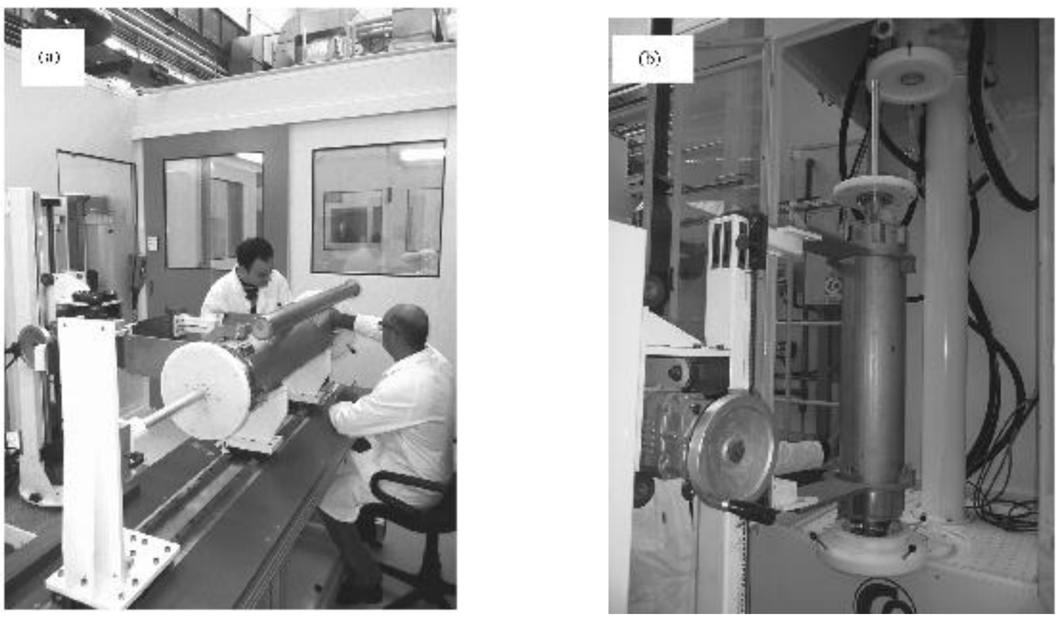
Vertical Electropolishing at SACLAY

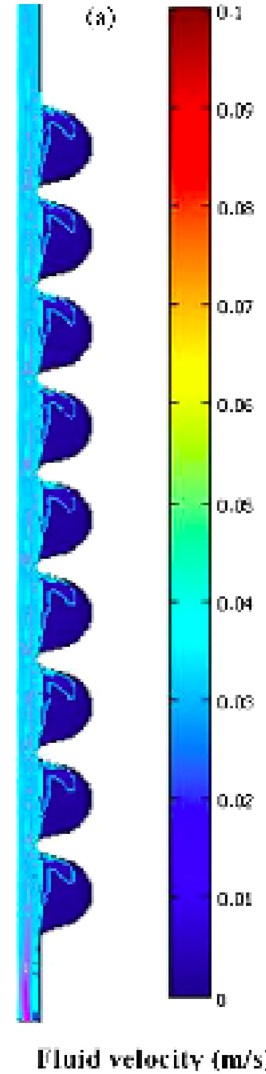
PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS
15, 083501 (2012)

Development of an advanced electropolishing setup for multicell high gradient niobium cavities

F. Éozénou,* S. Chel, Y. Gasser, C. Servouin, B. Visentin, and J-P. Charrier
CEA, Irfu, SACM, Centre de Saclay, F-91191 Gif-Sur-Yvette, France

Z. Wang
ENSAM ParisTech, F-75013 Paris, France
(Received 28 March 2012; published 3 August 2012)





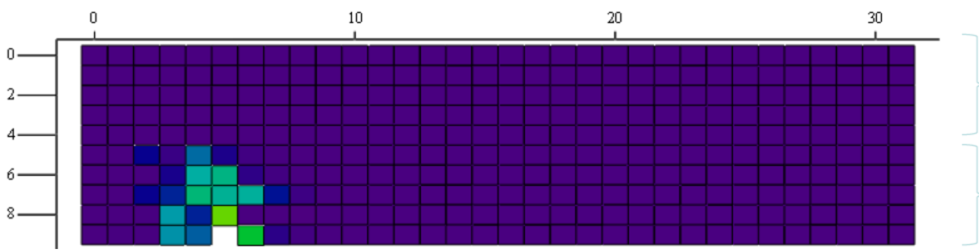
Fundamental SRF Issues

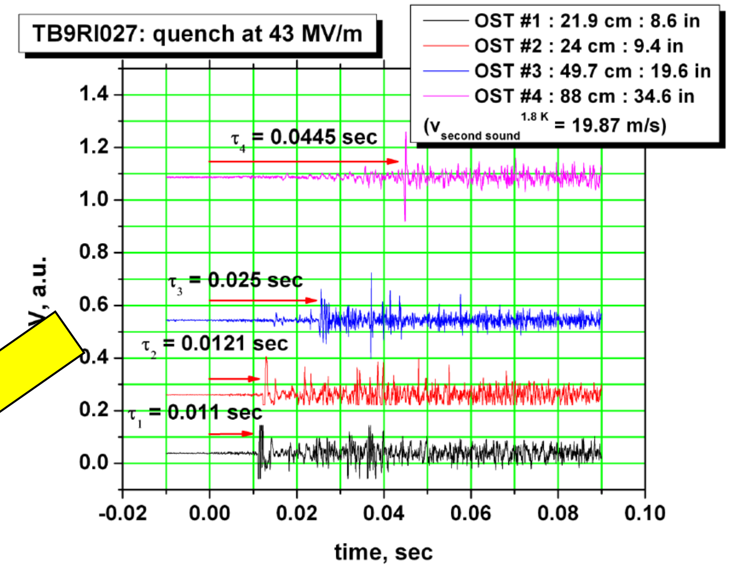
- Critical RF field
- Nature of quench below critical RF field
  - **Magnetic field enhancement effect**
  - **Role of flux entry?**
- Non-linear surface resistance (Q-drop)
- Origin of “residual resistance”
- Origin of field emitters and their behaviors under high electric RF field
- Other related issues at high gradient
  - **Higher order mode coupler multipacting**
  - **Lorentz force detuning**

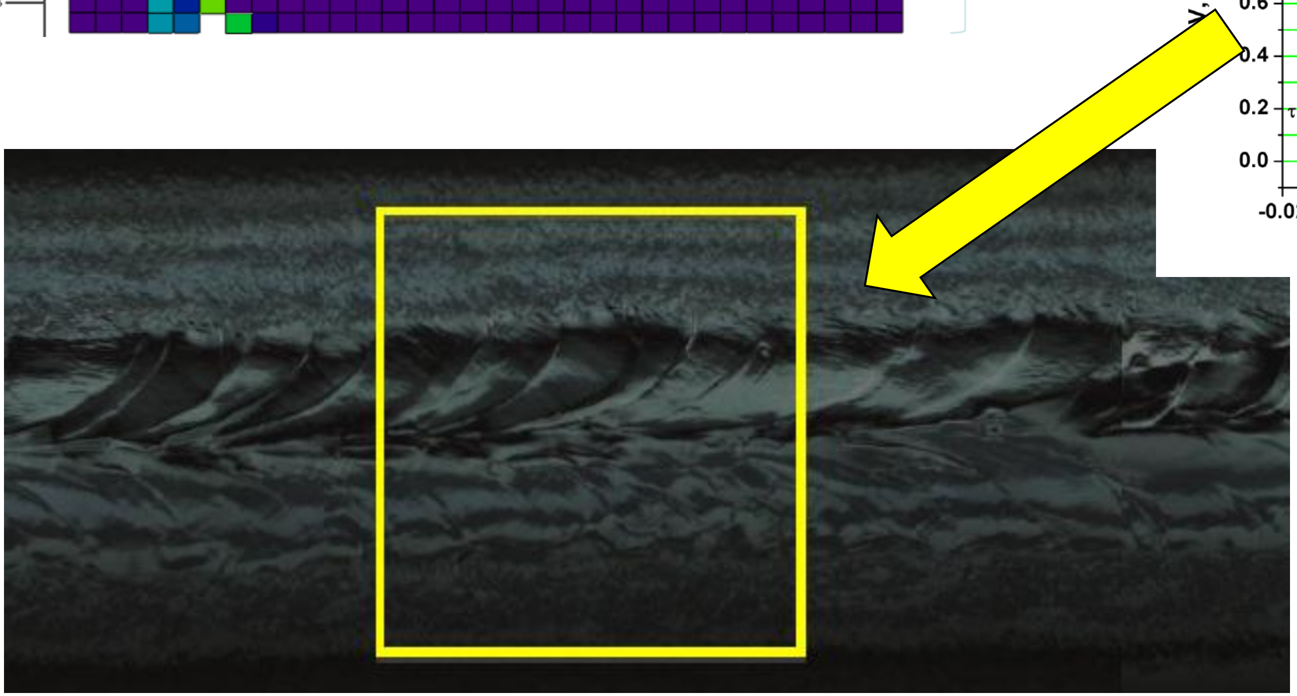
What Is Reason for Quench Limit in Gradient Range of 35-45 MV/m?

TB9RI027 : OST data

Cavity RI27 quench at 43 MV/m



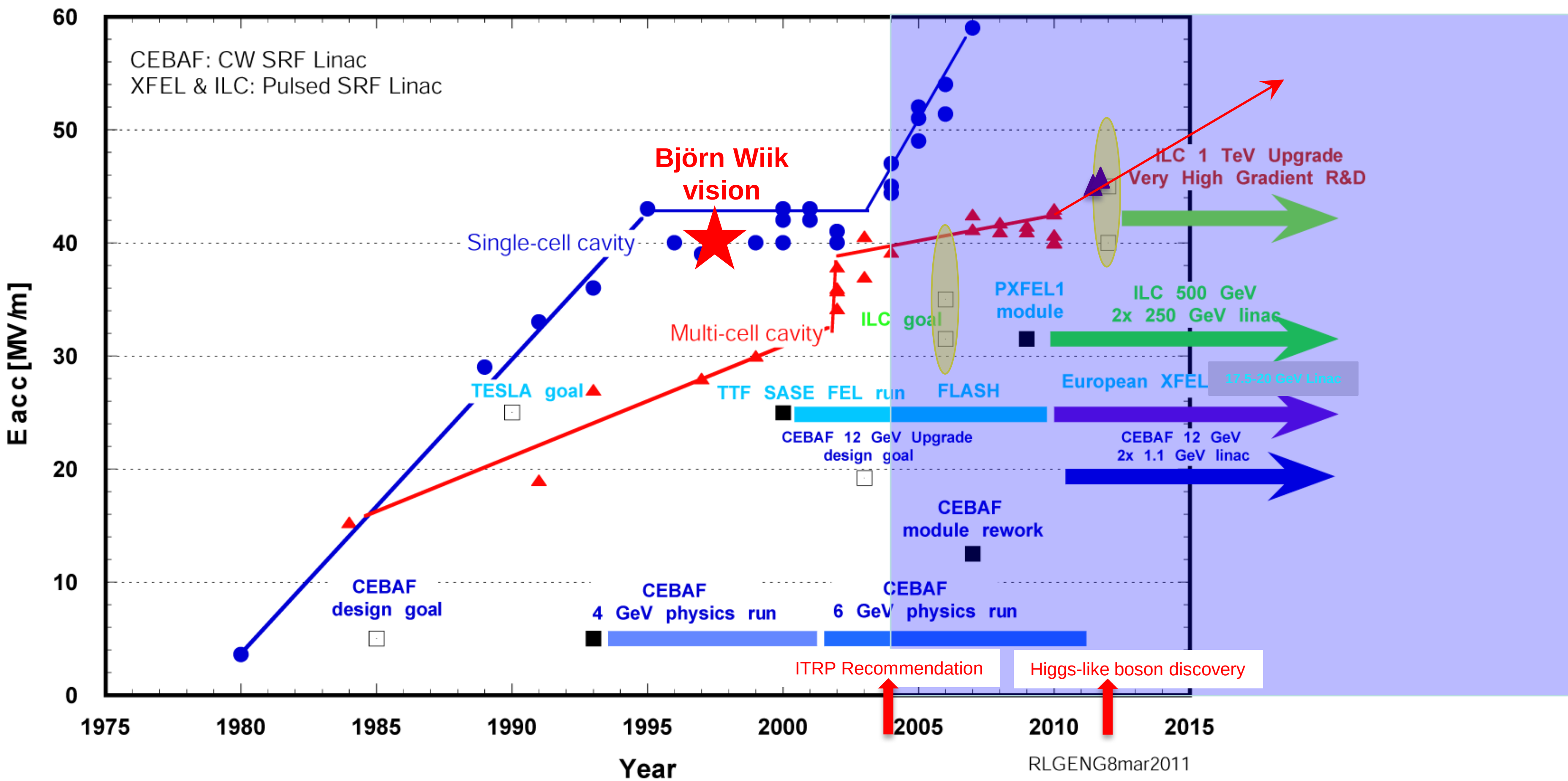




- OST predicted quench area shown in box
- No observable feature on site

Development since 2004 ITRP recommendation of SRF for ILC

L-Band SRF Niobium Cavity Gradient Envelope and Gradient R&D Impact to SRF Linacs



- Continued progress in SRF gradient : breakthrough of 45 MV/m in 1-cell, ~60 MV/m record; 45 MV/m in 9-cell
- GDE began in 2005. Since then, gradient yield at 35 MV/m steadily improved; ALSO steady progress in gradient envelope
- New SRF Test Facilities in operation: STF at KEK first beam; NML at Fermilab first US module expects testing at <35 MV/m>
- Upgrade of CEBAF to 12 GeV at JLAB, 80 cavities final process essentially ILC style, cryomodule w/ beam met spec
- FLASH operation and construction of European XFEL underway, cavity mass production started, 800 cavities total

Summary

- Understanding of gradient limitation and scattering much improved in past five years
- Progress has been made in gradient yield as well as in gradient envelope in 1-cell & 9-cell cavities
- ILC production cavity gradient yield goal now met
  - **90% at average 35 MV/m allowing +/-20%**
- ILC cryomodule operation gradient w/ beam now met
- Future SRF R&D identified
  - **Control field emission reliably**
  - **High gradient cavity with high Q0**
  - **Inexpensive SRF fabrication and processing**