Global R&D Effort of SCRF Cavity Development for the International Linear Collider

Akira Yamamoto, Marc Ross, and Nick Walker
Project Managers for
ILC Global Design Effort

To be presented during visiting SCRF cavity manufacturers
February/March, 2009

Acknowledgements

- *We would thank*
  - *your kind acceptance for our visiting here and the opportunity to learn your industrial efforts.*
- *We would thank*
  - *the ILC SCRF collaborators for their kind cooperation to prepare for this presentation.*

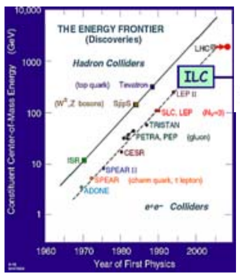
Objectives of Visiting

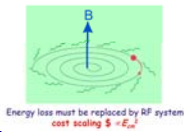
- Learn industrial status and possible future at cavity manufacturers, through visiting the factory, presentations and discussions with factory staff,
- Communicate TD-Phase R&D Plan, and inform necessary boundary conditions, "plug-compatibility", in the word-wide R&D stage,
- Request close collaboration with laboratories to further industrial R&D effort, particularly, to improve "field gradient" and "cost effective production" to prepare for the industrialization (mass production),
- Establish close communication and confident relationship between ILC-GDE and manufacturers.

Outline

- **Introduction**
- **R&D Status**
- **Plan for Technical Design Phase**
- **Global Plan and Project Management**
- **Summary**

Particle Accelerators
beyond limit of circular accelerators

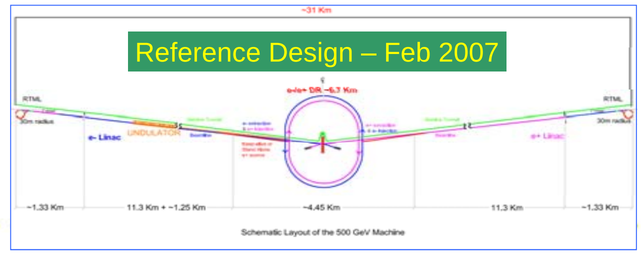




Electron machine
Ring accelerator
>> Linear Accelerator

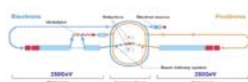
ILC Reference Design

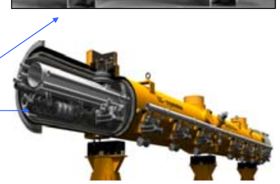
- **11km SC linacs operating at 31.5 MV/m for 500 GeV**
- **Centralized injector**
  - Circular damping rings for electrons and positrons
  - Undulator-based positron source
- **Single IR with 14 mrad crossing angle**
- **Dual tunnel configuration for safety and availability**



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**





Technical Design Report
to be completed by 2012


ILC Research and Development Plan for the Technical Design Phase

Release 2

June 2008

ILC Global Design Effort

Director: Barry Barish

Prepared by the Technical Design Phase Project Management

Project Managers: Marc Ross, Nick Walker, Akira Yamamoto

Reference Design, 2007 >> Technical Design Phase, 2008-2012
We are now at the stage of progressing from the RD to TD

Outline

- Introduction
- R&D Status
- Plan for Technical Design Phase
- Global Plan and Project Management
- Summary

Progress in Single Cell Cavity

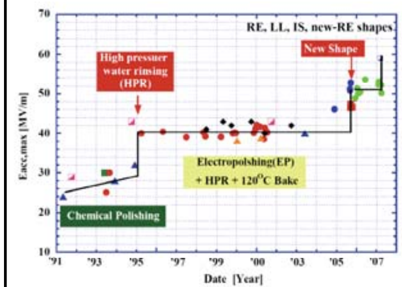
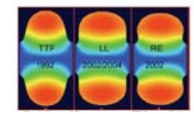


TABLE II. CAVITY SHAPES STUDIED FOR THE ILC.

Parameter	TESLA	LL/IS	RE
Iris aperture (mm)	70	60/61	66
E_{peak}/E_{acc}	1.98	2.36/2.02	2.21
B_{peak}/E_{acc} (mT/(MV/m))	4.15	3.61/3.56	3.76
Char. shunt impedance: R/Q (Ω)	114	134/138	127
Geometric factor: G (Ω)	271	284/285	277
G × R/Q (Ω × Ω × 10^5)	3.08	3.80/3.93	3.51



- Record of 59 MV/m achieved with the RE cavity with EP, BCP and pure-water rinsing with collaboration of Cornell and KEK

Standard Procedure Established

	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

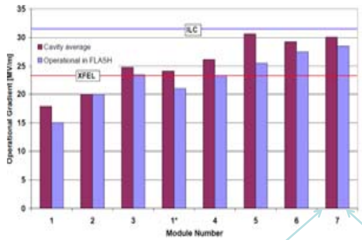
Fabrication
- Material
- EBW
- Shape

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

Status of 9-Cell Cavity

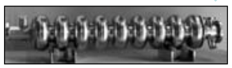
- **Europe (DESY, Saclay)**
  - **Gradient: > ~ 40 MV/m (max) ,**
  - **Industrial (bulk) EP demonstrated**
  - **Field emission reduced with ethanol rinsing**
  - **Surface process with baking in Ar-gas**
- **Americas (Jlab, Cornell, FNAL/ANL)**
  - **Gradient: > ~ 40 MV/m (max),**
  - **Field emission reduced w/ Ultrasonic Degreasing & Detergent**
- **Asia (KEK, IHEP, RRCAT)**
  - **Gradient: 36MV/m (LL, KEK-JLab), 32 MV/m (TESLA-like, KEK)**
  - **Global cooperation of Indian institutions with**
    - Fermilab, ANL, Jlab, DESY, and KEK

9-Cell and Cavity String Field Gradient Progress at TESLA



ILC operation :
- <31.5> MV/m

R&D Progress :
- ~ 28 MV/m to satisfy XFEL operation at 24.6 MV/m

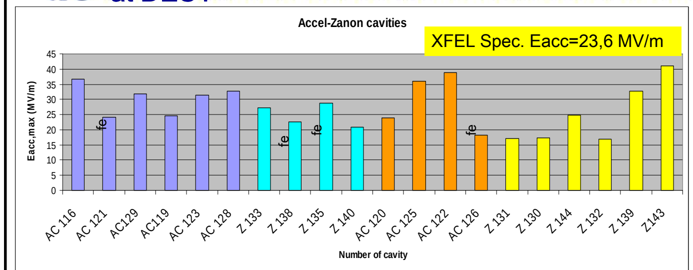


•20 % improvement required for ILC

13

090226 ILC-GDE SCRF

Preliminary RF statistic of 6th cavity fabrication at DESY



AC BCP Flash	Z BCP Flash	AC EP	Z EP E_{acc}=24,9+/-4,4
E_{acc}=30,2 +/- 4,9	E_{acc}=24,9 +/- 3,8	E_{acc}=29,3+/- 9,7	

- Max gradient, FE marked, if starts below 20 MV/m
- With He-vessel
- Without HOM pick up

Remark: some Z-Cavities might have suffered from fabrication problems so that the shown result could be independent of the final surface preparation process, i.e. wait for final analysis

Information provided by W. Singer

090226 ILC-GDE SCRF 14

DESY: Ethanol Rinse Effect

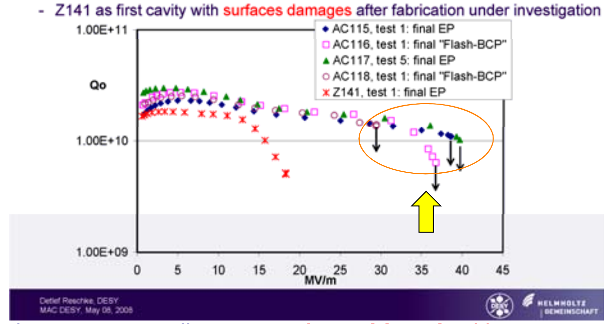
Cavity gradient may be improved by 'ethanol rinse', and Field emission significantly reduced.

090226 ILC-GDE SCRF 15

Industrial (EP) Effort in Europe

6th cavity production – rf results

- excellent + promising first results including first Plansee nine-cell (AC115)
- Z141 as first cavity with surfaces damages after fabrication under investigation

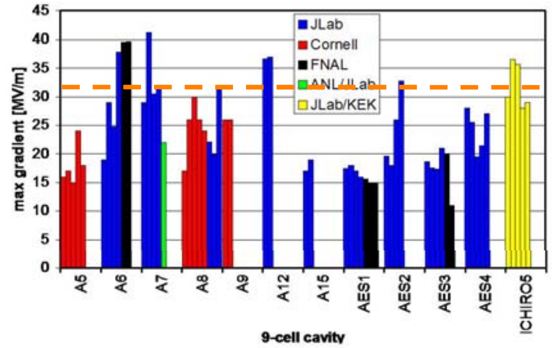


- The average gradient, **36 MV/m, achieved** with AC115-118

090226 ILC-GDE SCRF 16

9-cell Progress in Americas

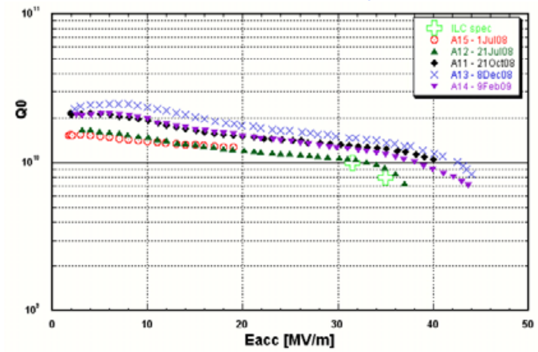
with Japanese contribution for ICHIRO-5



A (Accell), AES: TESLA shape, ICHIRO: LL shape

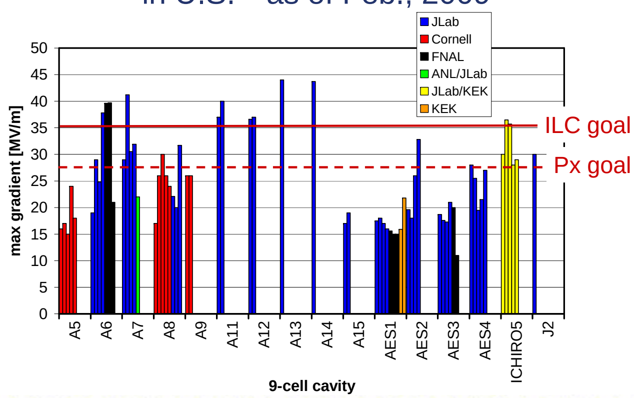
Most Updated Results from Jlab

as of Feb. 18, 2009



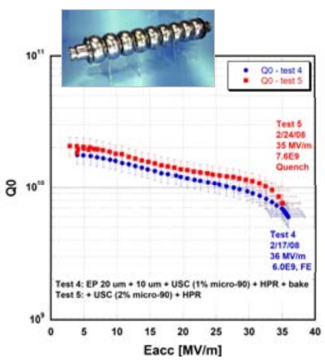
- Five 9-cell cavities: built by ACCEL, and processed/tested at Jlab.
- All of them processed with one bulk EP followed by one light EP and by ultrasonic pure-water cleaning with detergent (2%).

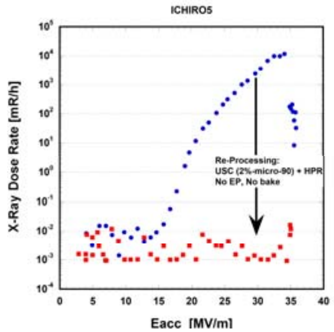
Summary of 9-cell Vertical Tests in U.S. as of Feb., 2009



JLab: Effective Ultrasonic Degreasing

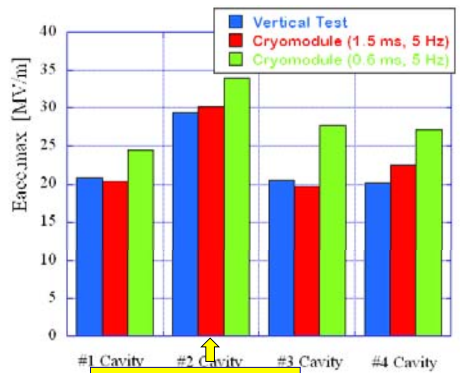
"KEK-ICHIRO-5" 9-cell cavity Processed/Tested at Jlab





Ultrasonic Cleaning with degreaser effective to reduce field emission

KEK: 9-cell Cavity in VT/Cryomodule



Finally reached 32 MV/m

high power test, one by one

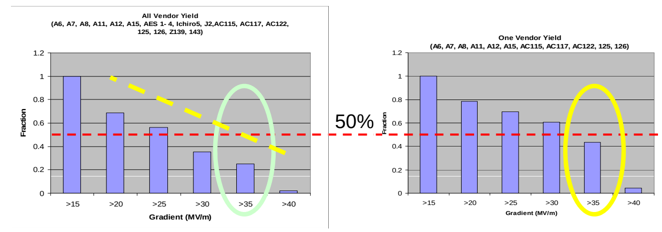
high power test, with 4 cavities

090226 ILC-GDE SCRF 21

Global Yield of Cavities Recently Tested at Jlab and DESY

48 Tests, 19 cavities
ACCEL, AES, Zanon, Ichiro, Jlab

23 tests, 11 cavities
One Vendor



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

A Summary from TTC-08 (IUAC), ILC-08 (Chicago) by H. Padamsee

090226 ILC-GDE SCRF 22

Outline

- Introduction
- R&D Status
- Plan for Technical Design Phase
- Global Plan and Project Management
- Summary

090226 ILC-GDE SCRF 23

TDP Goals of ILC-SCRF R&D

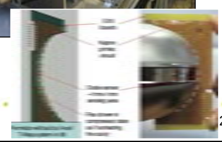
- **Field Gradient**
  - 35 MV/m for cavity performance in vertical test (S0)
  - 31.5 MV/m for operational gradient in cryomodule
    - to build two x 11 km SCRF main linacs
- **Cavity Integration with Cryomodule**
  - **"Plug-compatible" development to:**
    - Encourage "improvement" and creative work in R&D phase
    - Motivate practical 'Project Implementation' with sharing intellectual work in global effort
- **Accelerator System Engineering and Tests**
  - Cavity-string test in one cryomodule (S1, S1-global)
  - Cryomodule-string test with **Beam** Acceleration (S2)
    - With one RF-unit containing 3 crymodule

090226 ILC-GDE SCRF 24

What do we need to re-visit?

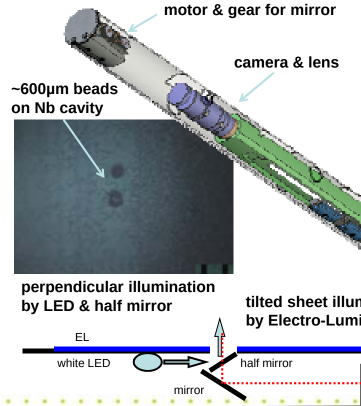
In Superconducting Cavity R&D

- Niobium Sheet metal cavity
- Fabrication:
  - Forming and welding (EBW)
  - Local repair
- Surface Process:
  - Chemical etching/polishing
  - Cleaning
- Inspection/Tests:
  - Optical Inspection (warm)
  - Surface Analysis (warm)
  - Thermometry (cold)



A New High Resolution, Optical Inspection

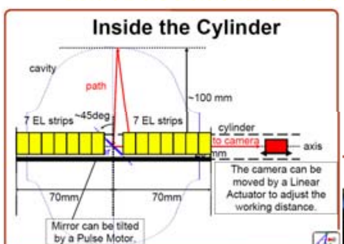
For visual inspection of cavity inner surface.

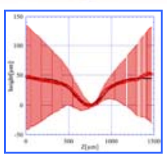


Camera system (7μm/pix) in 50mm diameter pipe.

DESY and FNAL starting to use this system in cooperation with KEK

Concept of Profile Measurement

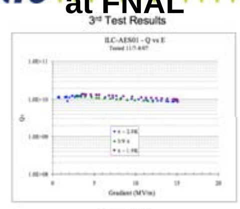


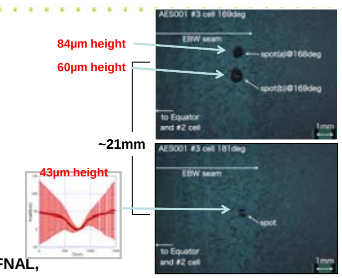


Stripe Illumination(SI)

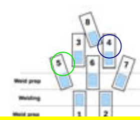
- Fourteen Electro-Luminescence(EL) strip sheets are 10mm in axial direction and cover 100mm in azimuthal direction.
- These fourteen strips can be turned ON/OFF one by one.
- Assuming that cavity's interior surface is a complete mirror, we can measure wall gradients of the cavity's interior surface with these ELs.

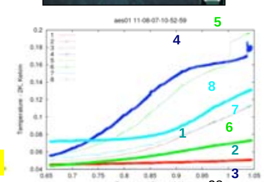
Consistent with Thermal Measurement at FNAL





AES01 has hard quench at 15MV/m, its location was identified by Cernox at FNAL, (M. Champion et al., ASC-08)



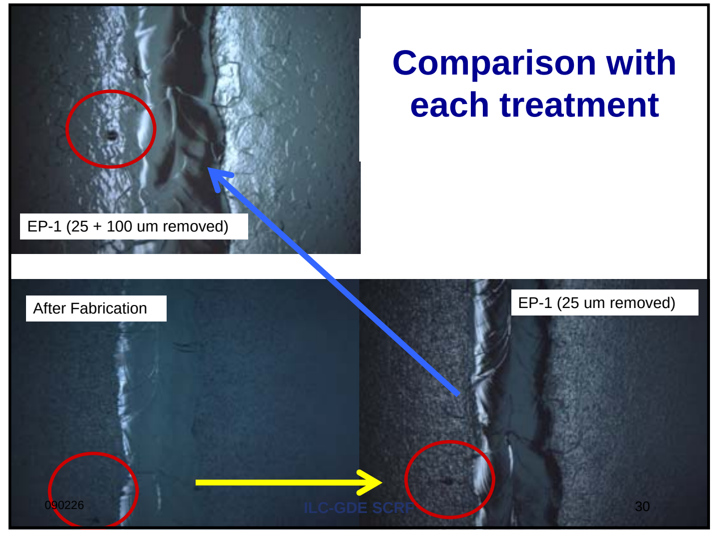


Kyoto-camera found 3 spots in their exact location

Guideline: Standard Procedure and Feedback Loop

	Standard Fabrication/Process	Acceptance Test/Inspection
Fabrication	Nb-sheet purchasing	Chemical component analysis
	Component Fabrication	Optical inspect., Eddy current
	Cavity assembly with EBW	Optical inspection
Process	EP-1 (~150um)	
	Ultrasonic degreasing with detergent, or ethanol rinse	
	High-pressure pure-water rinsing	Optical inspection
	Hydrogen degassing at 600 C	
	Field flatness tuning	
	EP-2 (~20um)	
	Ultrasonic degreasing or ethanol	
	High-pressure pure-water rinsing	
	General assembly	
	Baking at 120 C	
Cold Test (vertical test)	Performance Test with temperature and mode measurement	If cavity not meet specification Optical inspection

Comparison with each treatment

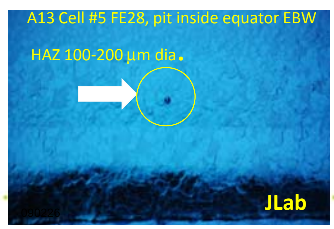


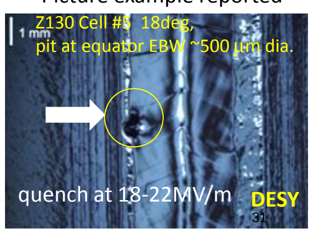
Understanding of Sources for Quench

From TTC-09a Summary (by H. Padamsee)

- Sources for quench below 25 MV/m have been identified
- Thermometry first used to locate quench regions followed by optical inspection.
- Quench sites are predominantly bumps and pits on the equator e-beam weld (EBW), or in the heat affected zone.

Picture example reported

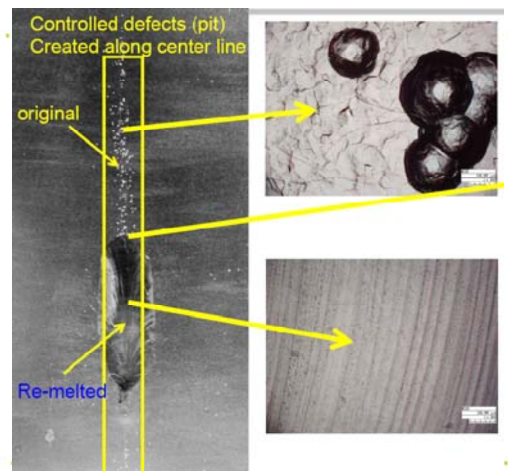




Jlab

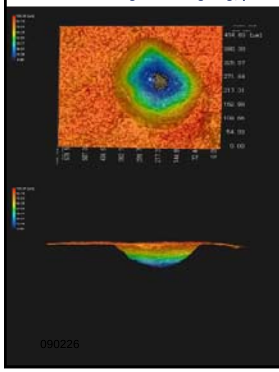
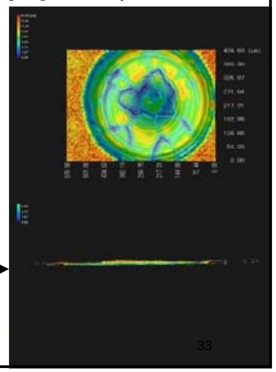
- E-beam melting to repair pits
- Try this on a single cell ?

A summary from TTC (H. Padamsee)

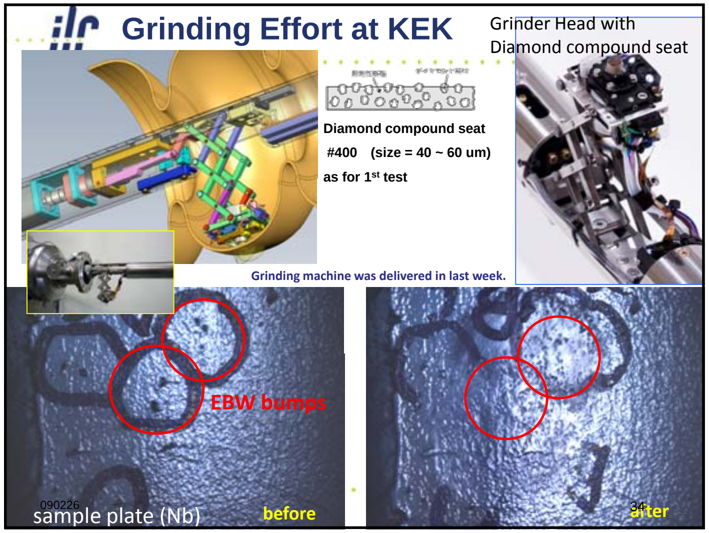


Laser Melting Shows Potential for Repair of Pits

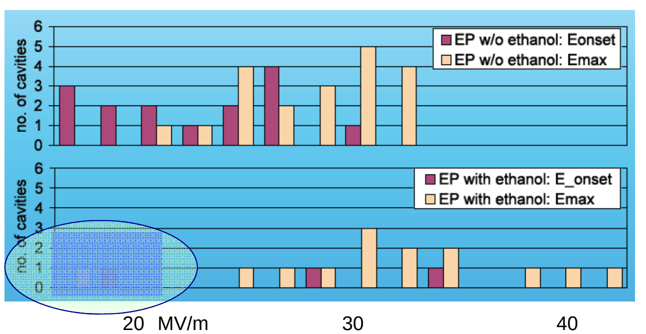
- A pit cannot be removed by BCP or EP, even after ~150 um removal, in recent investigations
- Laser melting experiments at Fermilab show potential for repair of pits:
  - **Irregular pit with depth ~100 um melted to form shallow circular pit of depth ~14 um**
  - **Investigations ongoing; plan to test repair method using single-cell cavity**

Grinding Effort at KEK

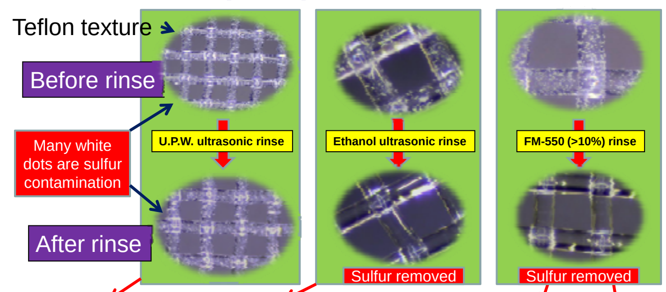


After Better Understanding To Exclude Mechanical Defect



Field gradient improved by 'ethanol rinse', and it may be more evident, if the "lowest sample" (limited due to different reasons) may be eliminated.

Rinse Effect to Remove Sulfur precipitation/contamination



	U.P.W. ultrasonic rinse	Ethanol rinse (vibration)	Ethanol ultrasonic rinse	Detergent FM-550 2 %	Detergent FM-550 5 %	Detergent FM-550 10 %	Detergent FM-550 20 %
Cleaning Result	×	△	○	△	△	○	○

Summary of R&D Efforts/Subjects

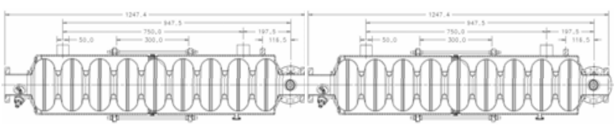
- Establish technology for defect-free production, with "quick" feedback using inspection camera results
  - Upgrade "inspection camera", and
  - Develop other inspection tools,
- Identify, more accurately, origin of field emission after surface treatment
  - Research and improve "surface-analysis": XPS, SEM ,,,
- Establish and Demonstrate countermeasures:
  - The final treatment to remove FE source such as sponge wipe, degreaser rinse, ethanol rise,
  - Repair method such as grinding tool for curing damaged cavities

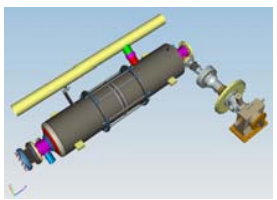
Importance of Plug-compatibility in Development Stage

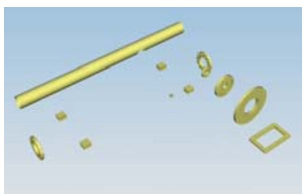
- Creative/Innovative work for further improvement with keeping "redundancy" and "replaceable >> plug-compatible" condition
- Seek for Cost-effective Fabrication for "mass production"
- Global cooperation and share for intellectual engagement
- "Plug-compatibility" essentially important

Plug-compatibly of Cavities

Important for Global Cooperation

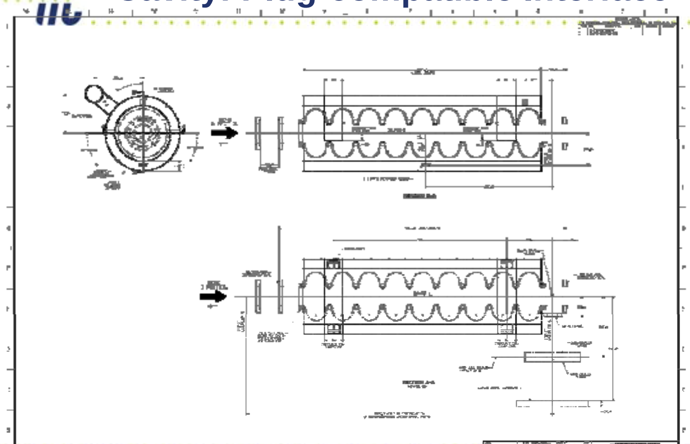






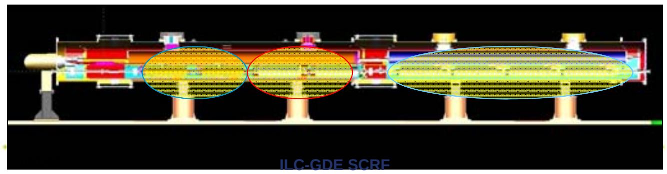
Plug-compatible interface being established

Cavity: Plug-compatible Interface



Cavity String Test in Cryomodule with Plug Compatibility

- Cavity integration and the String Test to be organized as a global cooperation (S1-Global):
  - 2 cavities from EU (DESY) and AMs (Fermilab)
  - 4 cavities from AS (KEK)
  - Cryomodules: from EU (INFN) and AS (KEK)
- A practice for the plug-compatible assembly



ILC-GDE SCRF

Outline

- Introduction
- R&D Status
- Plan for Technical Design Phase
- Global Plan and Project Management
- Summary

090226 ILC-GDE SCRF 42

ILC-GDE Organization in TDP

PAC - - - ILCSC - - FALC - - - FALC-RG

AAP - - - ILC-GDE Director

Director's Office
= ~ Central Team
= ~ EC

Regional Directors — Project Managers — Experts

	SCRF-ML	G-CFS	AS
EU			
AM			
AS			

Project. M. Office
- EDMS
- Cost & Schedule
- Machine Detector Interface
- ILC, XFEL, Project X liaison
- ILC Communications

090226 ILC-GDE SCRF 43

Project Plan in 2008-2010

- Field gradient (S0)
  - To be re-optimized, based on the R&D progress (2010),
- Plug-compatibility
  - Common interface conditions being fixed ,
  - Overview document published
- System engineering/test plan, (S1, S2)
  - Work sharing in cavity string in global effort (S1-Global)
  - Accelerator system test with beam
    - Necessary detailed study and re-coordination under limited resources, including schedule
- Effort for "minimum machine",
  - Cluster or Distributed RF power sources and distribution,
- Prepare for AAP Interium Review in April, 2009
- Global Communication and cooperation with Laboratories & Industries
  - Visit Industries: ACCEL, ZANON, AES, Niowave, MHI,

090226 ILC-GDE SCRF 44

Global Plan for SCRF R&D

Calender Year	2007	2008	2009	2010	2011	2012
Technical Design Phase	TDP-1				TDP-2	
Cavity Gradient R&D to reach 35 MV/m		Process Yield > 50%			Production Yield >90%	
Cavity-string test: with 1 cryomodule			Global collab. For <31.5 MV/m>			
System Test with beam 1 RF-unit (3-modulce)		FLASH (DESY)			STF2 (KEK) NML (FNAL)	

Summary

- **Technical Design Phase in progress:**
  - **Phase-1: Technical reality to be examined,**
    - 35 MV/m with yield 50 % in surface process and
    - 31.5 MV/m with the cavity-string in a cryomodule
  - **Phase-2: Technical credibility to be demonstrated**
    - 35 MV/m with the yield 90 % for 9-cell in manufacturing
    - Beam acceleration with the field gradient 31.5 MV/m.
- **We aim for**
  - Global R&D efforts with various efforts keeping "plug-compatibility" concept.
  - Cooperation of world-wide Institutions and Industries would be crucially important and expected.

Information and References

General INformation

- ILC
  - http://www.linearcollider.org
  - http://www.linearcollider.org/cms/?pid=1000613
- This presentation (Cavity Manufacturer visiting, Feb./March, 2009)
  - http://ilc-edmsdirect.desy.de/ilc-edmsdirect/file.jsp?edmsid=*868405

ILC-GDE Reports

- Reference Design Report
  - http://www.linearcollider.org/cms/?pid=1000437
- TDP R&D Plan, Release 3
  - http://ilc-edmsdirect.desy.de/ilc-edmsdirect/file.jsp?edmsid=*813385

Public Presentations/Proceedings:

- "Global R&D effort for the ILC linac technology", presented by A. Yamamoto, at EPAC08,
  - http://ilc-edmsdirect.desy.de/ilc-edmsdirect/file.jsp?edmsid=*868435
- "Superconducting RF cavity development for the International Linear Collider", presented by A. Yamamoto, at ASC08, to be published in IEEE Trans. Applied Superconductivity,
  - http://ilc-edmsdirect.desy.de/ilc-edmsdirect/file.jsp?edmsid=*868465

URL site prepared for visiting

SCRF Cavity Manufacturers

ILC Global Design Effort Project Manager visit to SCRF ca... http://www.linearcollider.org/cms/?pid=1000

international linear collider

ILC Global Design Effort Project Manager visit to SCRF cavity manufacturers

February - March 2009

In early 2009 the ILC Global Design Effort Project Managers (Akira Yamamoto, Marc Ross, and Nick Walker) visited and were graciously hosted by many of the world's top superconducting RF cavity manufacturers. The objective of the visit was to:

1. Learn industrial status and possible future at cavity manufacturers.
2. Communicate the ILC GDE Technical Design Phase R&D Plan.
3. Request further industrial R&D effort, particularly to improve "field gradient" and "cost effective production" in order to prepare for the industrialization (mass production).
4. Establish close communication and a confident relationship between ILC GDE and vendors.

This web page is intended to capture the material presented to vendors and to include key references.

Global R&D Effort of SCRF Cavity Development for the International Linear Collider (pdf, 5Mb)
Akira Yamamoto, Marc Ross, and Nick Walker - Project Managers for the ILC Global Design Effort, **material presented to each of the SCRF cavity manufacturers.**

Superconducting RF Cavity Development for the International Linear Collider (pdf, 4Mb)
Akira Yamamoto for the ILC Global Design Effort, **paper presented at Applied Superconductivity Conference 2008 (ASC 2008).**

Global R&D effort for the ILC linac technology (pdf, 4Mb)
Akira Yamamoto for the ILC Global Design Effort, **paper presented to EPAC 2008.**

Reference Design Report
Download the full report
Volume 3 - Accelerator: Download the pdf (20MB)

ILC Research and Development Plan for the Technical Design Phase
Download the pdf

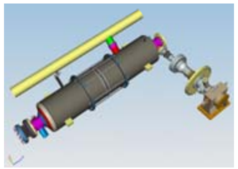
(Last updated: 25 February 2009)

Technical Questions to be Discussed

- Manufacturing process and capacity?
  - **How we may improve "field gradient", and how we may establish "quality control = stable performace"?**
    - Material, forming, chemical process, packaging
  - **Capability for Full production process by yourself and/or any specific collaboration with other companies in specific process?**
  - **Quality assurance program?**
    - License/authorization for high pressure vessel manufacturing
  - **Capacity in production: status and plan?**
- Any requests/questions to ILC-GDE?

Backup for Discussions

Plug-compatible Conditions

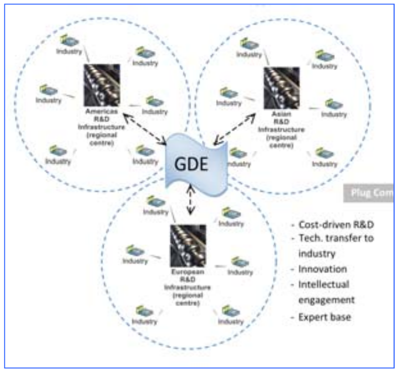


Item	Can be flexible	Plug-comp.
Cavity shape	TeSLA/LL/RE	
Length		Fixed
Beam pipe flange		Fixed
Suspension pitch		Fixed
Tuner	Blade/Jack	
Coupler flange (warm end)		Fixed
Coupler pitch		fixed
He –in-line joint		TBD

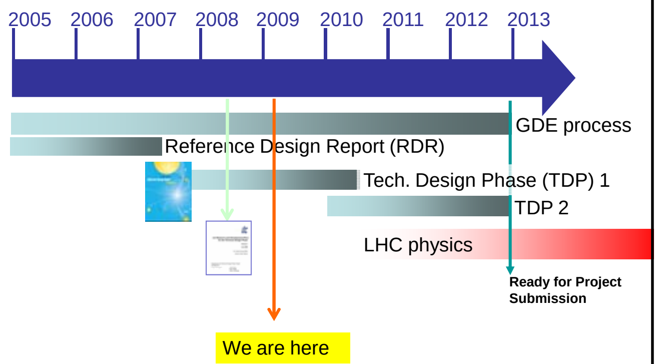
Plug-compatible interface being established

Global Cooperation: Plug-compatible Design and R&D

- Cost driven R & D process
- Innovative and Intellectual engagement
- Technology transfer to Industry
- Expert base



GDE: ILC Timeline



Cooperation with EuroXFEL and Further SCRF Acc. Projects

European X-ray Free Electron Laser Facility

- **EuroXFEL SRF design gradient : 23.6 MV/m**
- **Machine designed: 28 MV/m**
- **~ 100 SCRF cryomodule, based on the experience at TTF,DESY,**
- **Leading SCRF industrialization (scale: 1/20 of ILC, in 5 years)**
- **Keep close cooperation with XFEL, on-going project.**

Further SCRF Accelerator Project Plans:

- **Project X at FNAL, SC Proton Linac at CERN, ERL at KEK, Indian Accelerator Project**
- **Best effort for common design and cost-effective design**

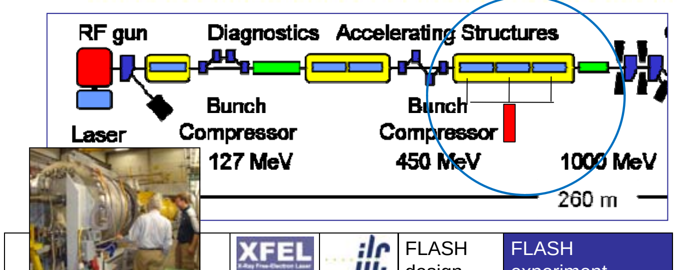
SRF Test Facilities

NML facility
Under construction
first beam 2010
ILC RF unit test

TTF/FLASH
~1 GeV
ILC-like beam
ILC RF unit
(* lower gradient)

STF (phase I & II)
Under construction
first beam 2011
ILC RF unit test

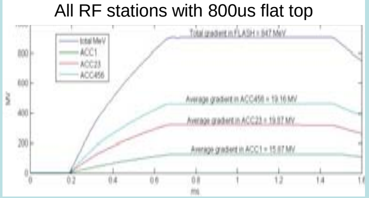
9mA Experiments in TTF/FLASH



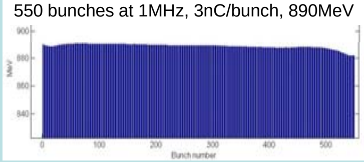
		XFEL	ILC	FLASH design	FLASH experiment
Bunch charge	nC	1	3.2	1	3
# bunches		3250*	2625	7200*	2400
Pulse length	μs	650	970	800	800
Current	mA	5	9	9	9

Preliminary Results (2008)

All RF stations with 800us flat top



550 bunches at 1MHz, 3nC/bunch, 890MeV



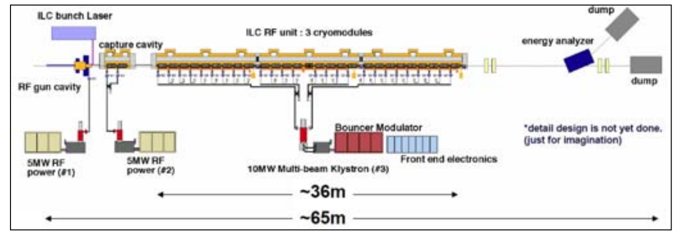
FLASH operations records

- Long bunch trains with 3nC per bunch:
  - **550 bunches at 1MHz**
  - **300 bunches at 500KHz**
  - **890MeV linac energy**
- All modules running with 800us flat-top and 1GeV total gradient

- Limited to 1MHz (3mA) during first (preparatory) experiments
- 6 kW achieved
- 2009 goal: 36 kW (9mA)

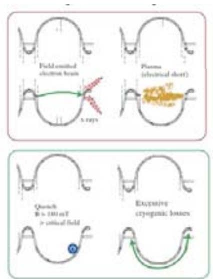
Beam Acceleration Test Plan

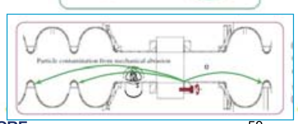
with RF unit at Fermilab and KEK in TDP-2



Field Gradient Limit in SC Cavity Current Status

- **Field Emission**
  - **due to high electric field**
    - around "Iris"
- **Quench**
  - **caused by surface heating from dark current, or**
  - **magnetic field penetration.**
    - around "Equator"
- **Contamination**
  - **during assembly**

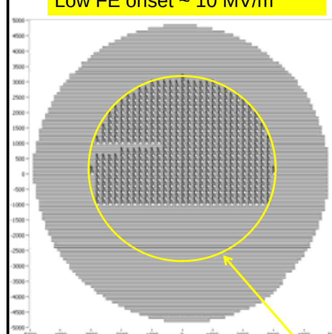


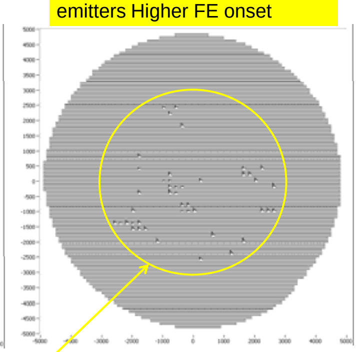


Filed scanning on the Nb-sample surface

Sample#1: many field emitters Low FE onset ~ 10 MV/m

Sample#2: much less field emitters Higher FE onset

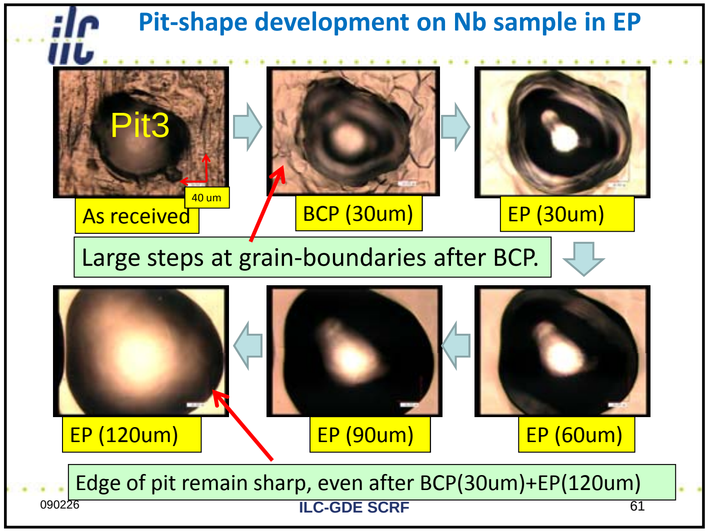


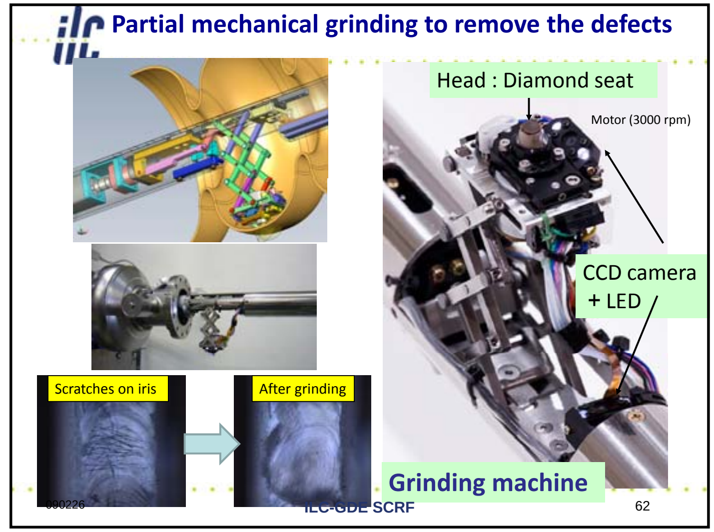


EP(70 um)

EP(70 um) + Sponge cleaning

Area inside circle is scanned


Pit-shape development on Nb sample in EP
Pit3
40 um
As received
BCP (30um)
EP (30um)
Large steps at grain-boundaries after BCP.
EP (120um)
EP (90um)
EP (60um)
Edge of pit remain sharp, even after BCP(30um)+EP(120um)
090226
ILC-GDE SCRF
61


Partial mechanical grinding to remove the defects
Head : Diamond seat
Motor (3000 rpm)
CCD camera
+ LED
Scratches on iris
After grinding
Grinding machine
090226
ILC-GDE SCRF
62