Status of ILC

A. Yamamoto, M. Ross, and N. Walker

ILC-GDE Project Managers

An invited talk at LINAC12, Tel-Aviv, 2012-09-13

Acknowledgements

- *We would thank*
  - *World-wide collaborators for their cooperation to proceed global design and R&D efforts, and to realize the ILC.*

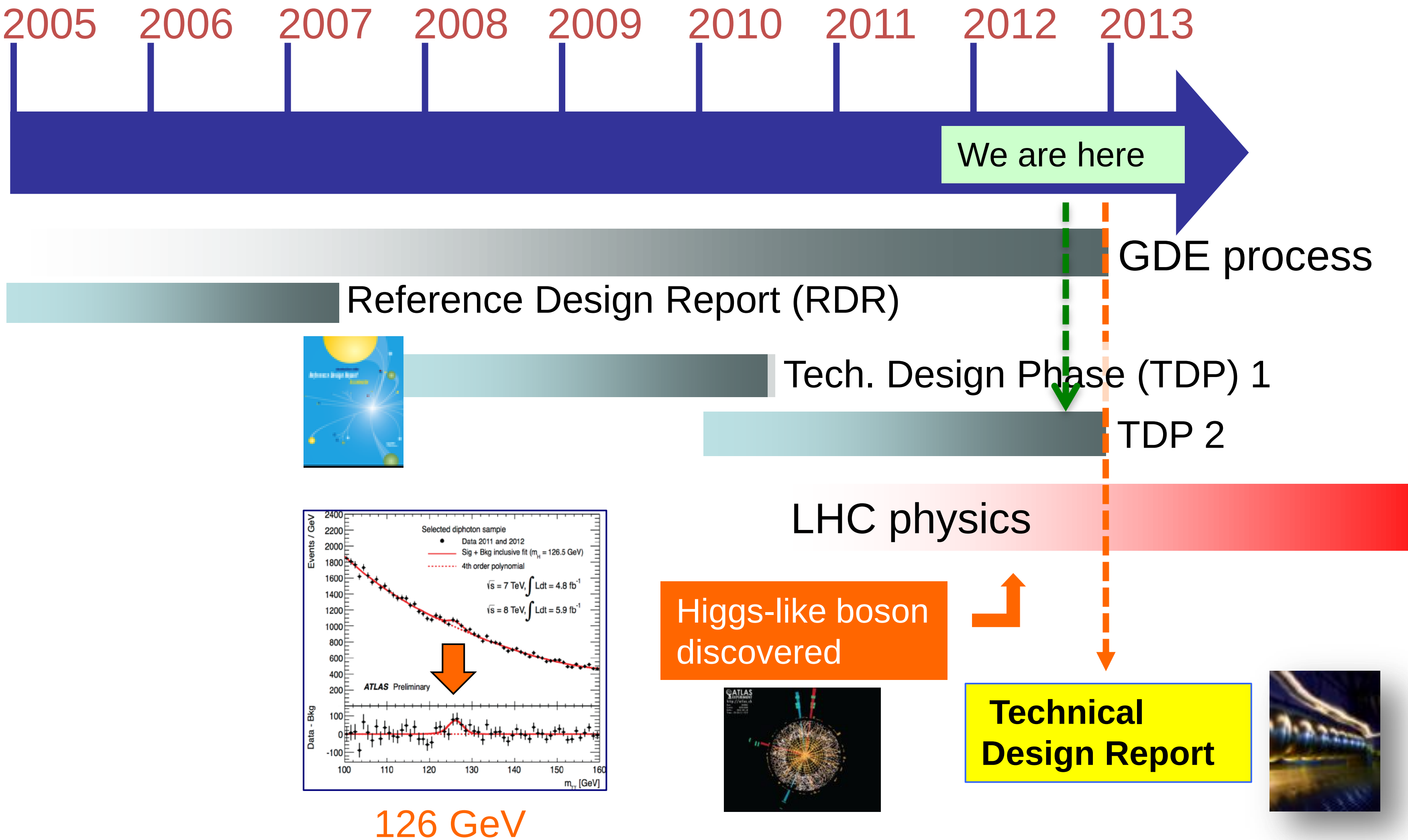
- Further presentations at LINAC12, related to “Status of ILC”
  - *V. Yakovlev* (MO1A03): SRF Linac Technology Development”
  - *C. Adolphsen* (MOPB044) : “ILC RF Development Summary”
  - *C. Ginsburg* (MOPB052): “Fermilab 1.3GHz SCRF cavity and … “
  - *Y. Iwashita* (MOPB053): “Non-distructive Inspection ...”
  - *E. Harms* (MOPB054): Test Results of Tesla-style Cryomodule …”
  - *A. Grassellino* (MOPB078): “High Q Studies for Nb Cavities …”
  - *Y. Fuwa* (TUPB090): “Development of Permanent Magnet Focusing …”
  - *M. Kemp* (WE2A02): Solid State Marx Modulators for …”
  - *H. Hayano* (TH1A01): Results achieved by the S1-Global Collab. …”

Outline

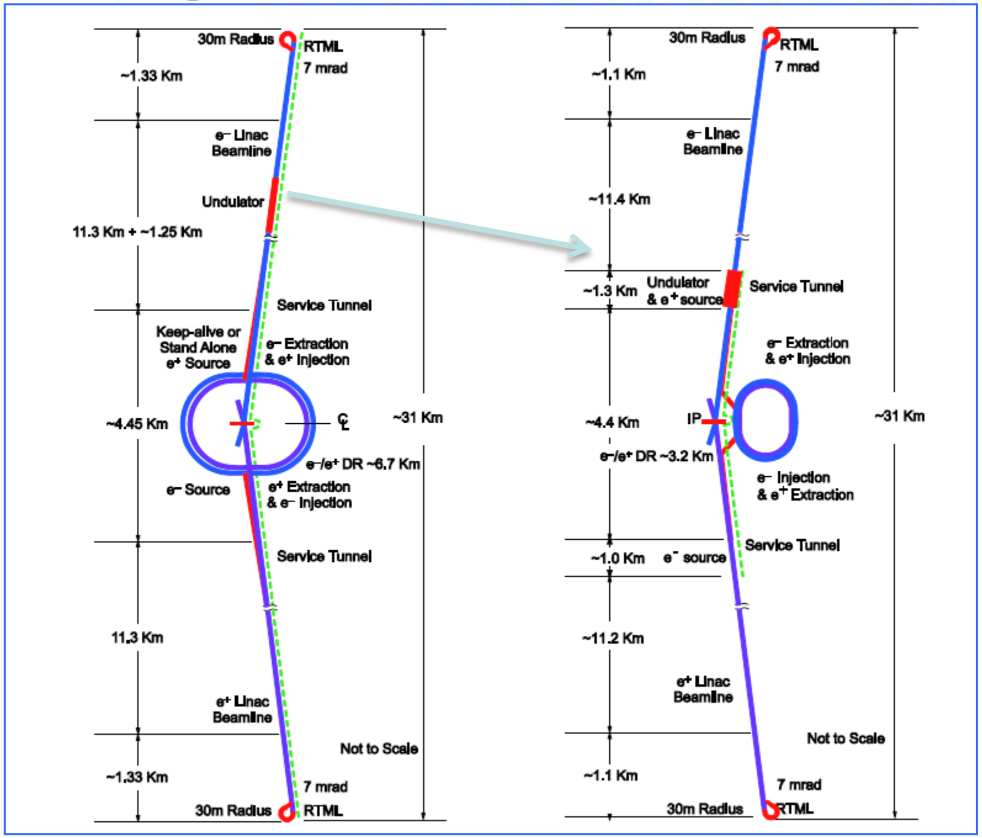
- **Introduction:**
  - ILC GDE: What we planned, and where we are ?
  - Design updates: Baseline for Technical Design 2012
- **Progress in Technical Design Phase**
  - Cavity Gradient R&D: DESY, JLab, Fermilab, Cornell, KEK
  - System Test: FLASH, STF/S1-Global/QB, NML/ASTA
    - An additional progress in conduction-cooling Q magnet
  - Preparation for industrialization
  - Technical Design Report (TDR)
- **Summary**

- **Scope beyond TDR (in case of questions)**
  - Technical effort beyond TDR (2012)

ILC-GDE Timeline

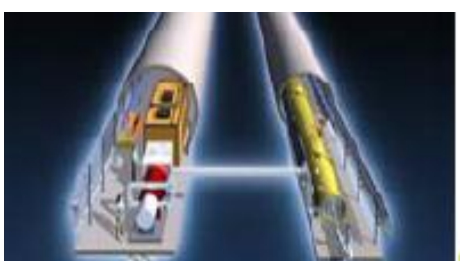


Configuration: RDR to TDR

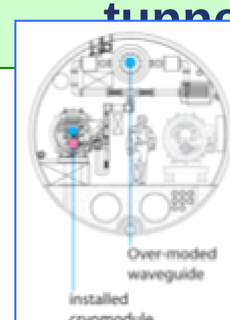


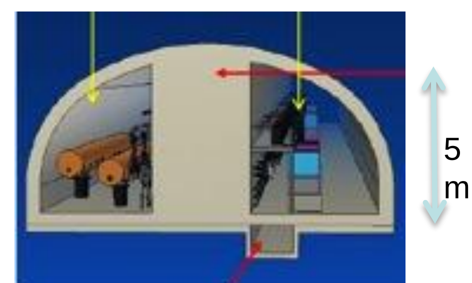
<u>Cost containment Motivation:</u>

- **Single** accelerator tunnel
- **Smaller** damping ring
- **e+ target** at high-energy end,
- **Cavity** G. 31.5 MV/m +/- 20 %,
- **HLRF and tunnel layout:**
  - **Klystron-Cluster on surface (KCS), or**
  - **Distributed Klystron in tunnel (DKS)**



RDR-2007 → TDR-2012



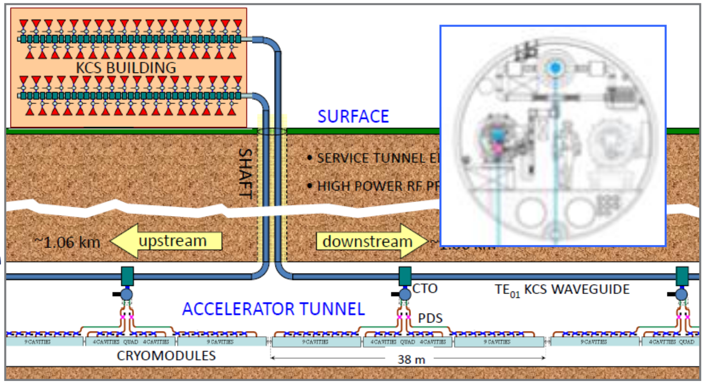


Flat-land or Mountainous Tunnel Design

HLRF Power Distribution Design

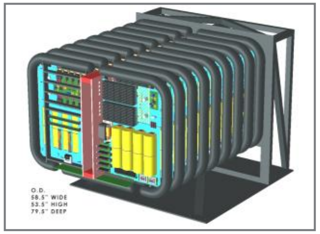
Klystron Cluster Scheme (KCS)

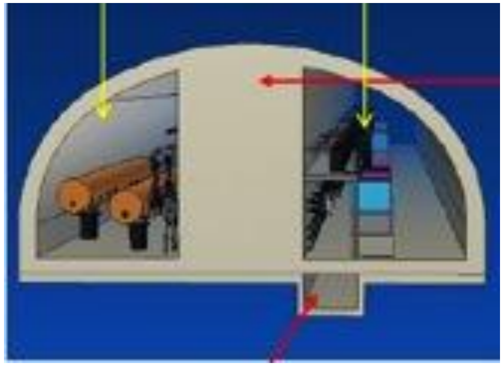
- Marx Modulators
- Clusters of klystrons
  (2 × ~ 30 10-MW MBK) on surface
- RF power distribution via major waveguide (300 MW)



Distributed Klystron Scheme (DKS)

- Marx modulator
- 10-MW MBK per 39 cavities
- Everything in tunnel





C. Adolphsen (MOPB044): *ILC RF development*
M. Kemp (WE2A02): *Solid State Marx Modulators*

Technical Goals for TD Phase

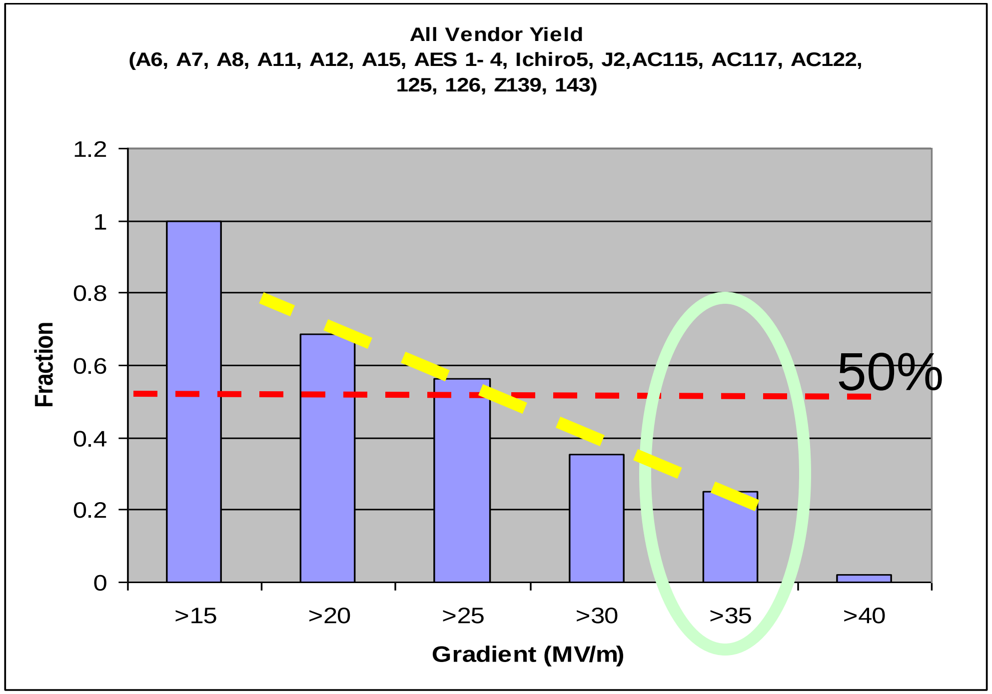
- **SCRF Technology**
  - Cavity: High Gradient R&D to:
    - 35 MV/m with 50% yield by 2010 , and 90% by 2012 (TDR)
    - Manufacturing with cost effective design
  - Cryomodule performance including HLRF, and LLRF
- **System Test with ILC-like Beam**
  - ILC-like beam acceleration
    - 9 mA: FLASH
    - 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 Vendors (2009), Organize Workshop (2010) 2nd visit and communication, Organize 2nd workshop (2011) 3rd communication and study contracted with selected vendors (2011-2012)					

Global Yield of Cavities in 2008

-- where we were ? --



Tested at DESY and JLab

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

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

Originallypresented by H. Padamsee, TTC-08 (IUAC)

Definition for production yield, not established yet

Standard Procedure Established

for ILC-SCRF Cavity evaluation, in guidance of TTC

	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

allow twice

Key Process

Fabrication

- Material
- EBW
- Shape

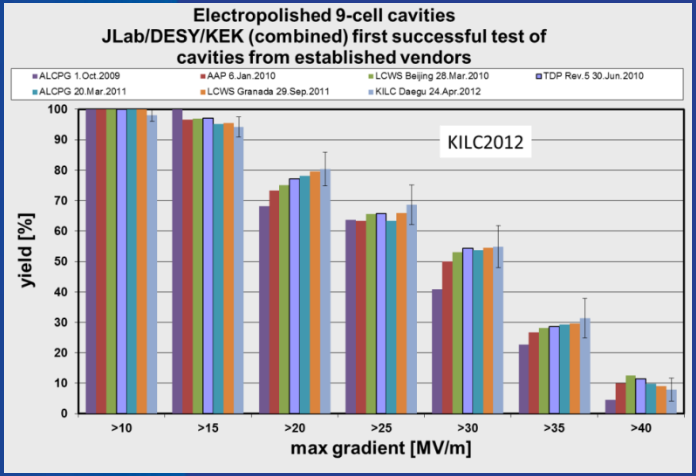
Process

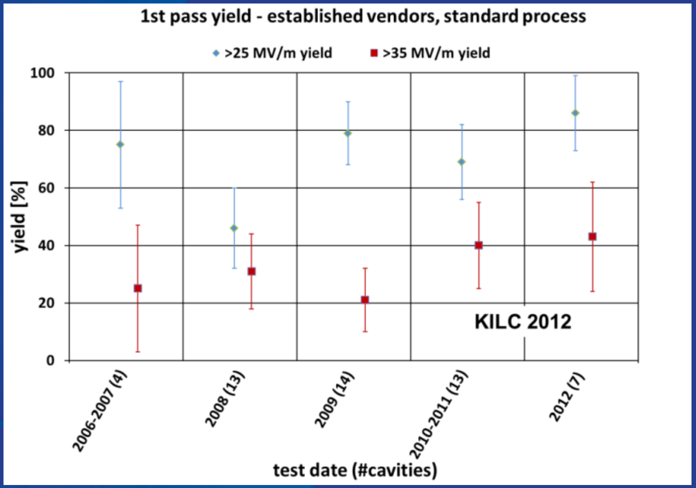
- Electro-Polishing
- Ethanol Rinsing or
- Ultra sonic. + Detergent Rins.
- High Pr. Pure Water cleaning

C. Ginsburg (MOPB052)

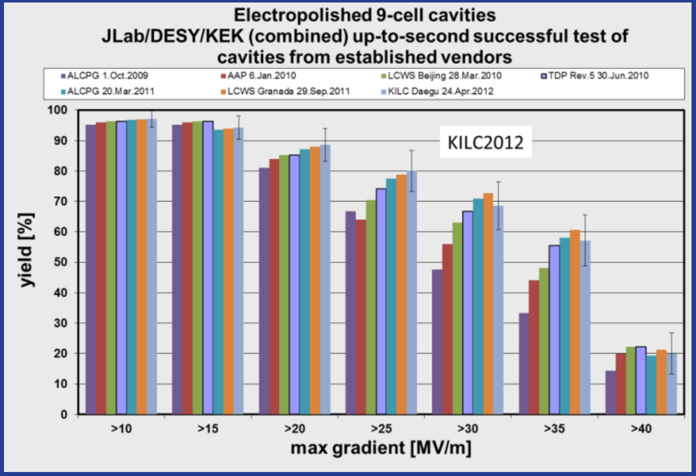
ILC 1.3 GHz Cavity Performance Benchmark

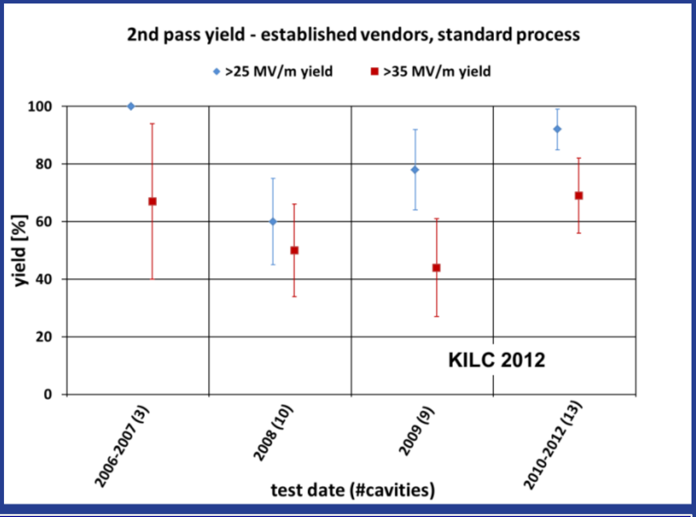
1st pass





2nd pass





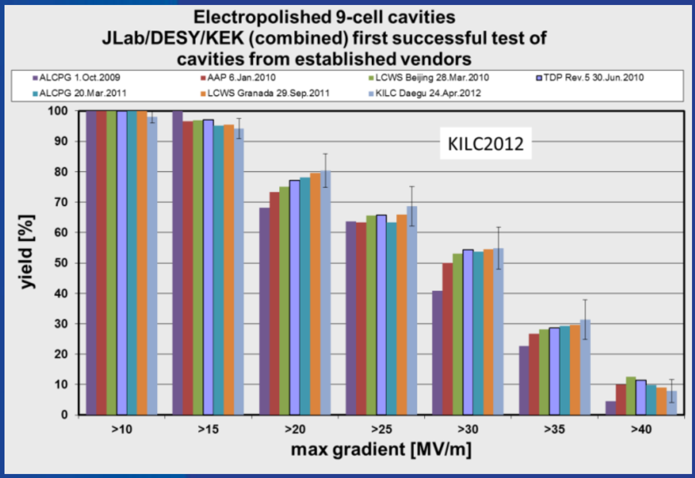
C.M. GInsburg et al., KILC12, Daegu, S. Korea
http://ilcagenda.linearcollider.org/contributionDisplay.py?contribId=85&sessionId=36&confId=541

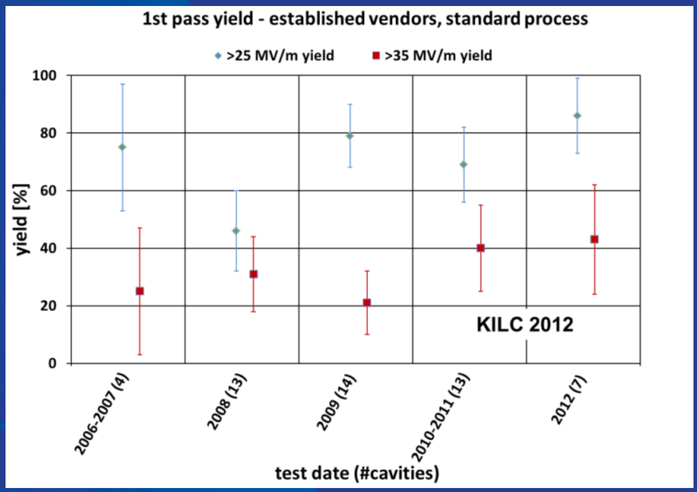
- ILC-GDE Cavity Data Base Team formed by: C. Ginsburg, R. Geng, Z. Conway/F. Furuta, S. Aderhold, Y. Yamamoto since 2009.
- Data updated, every year (6 times) and latest update at April. 2012.

C. Ginsburg

ILC 1.3 GHz Cavity Performance Benchmark

1st pass





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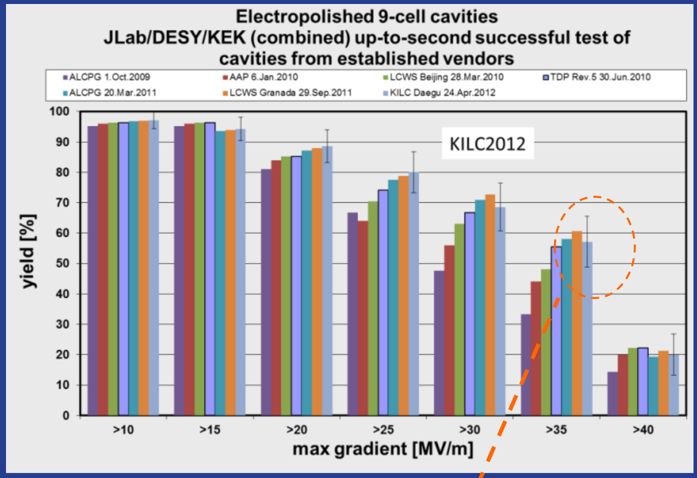

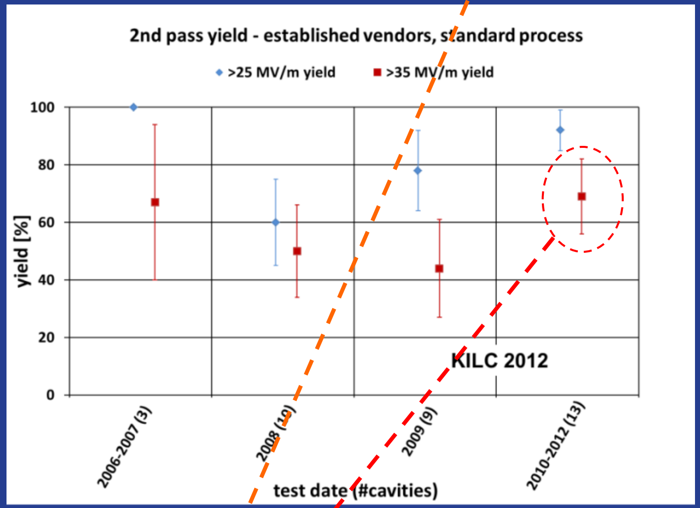

C.M. Ginsburg et al., KILC12, Daegu, S. Korea
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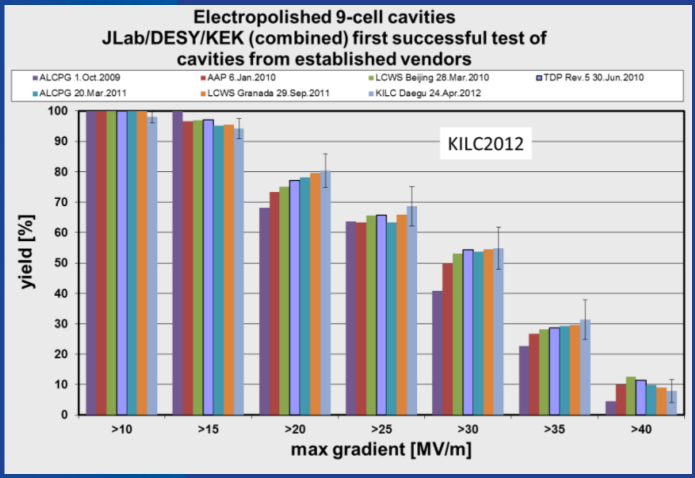
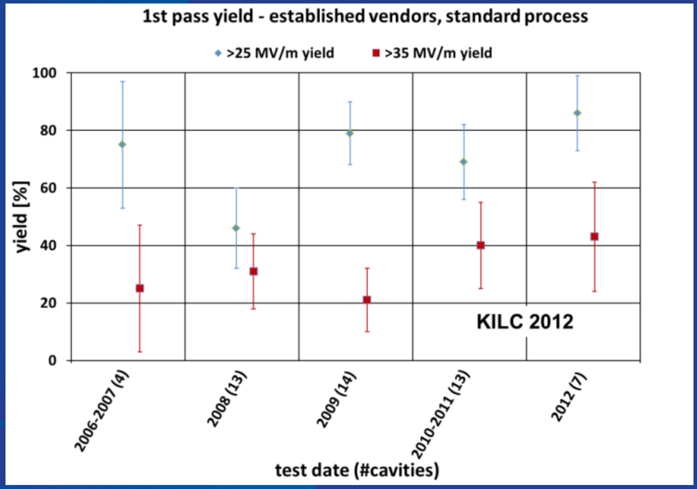
International cavities from established vendors using established processes
2nd pass yield for **>35 MV/m** for integrated sample is (57 +- 8)%
for 2010-2012 alone is (69 +- 13)%

C. Ginsburg

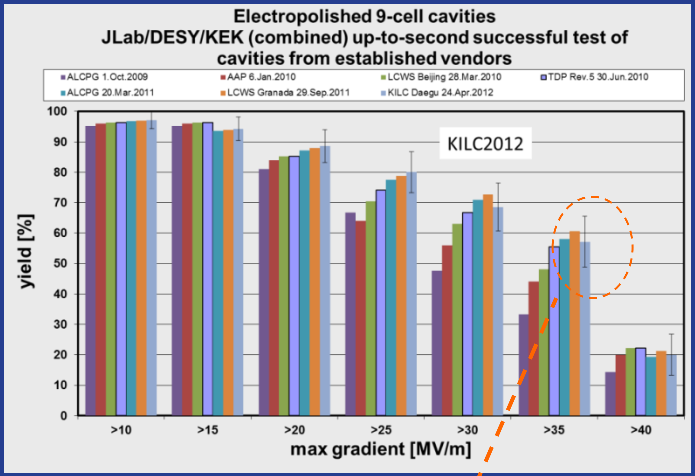
ILC 1.3 GHz Cavity Performance Benchmark

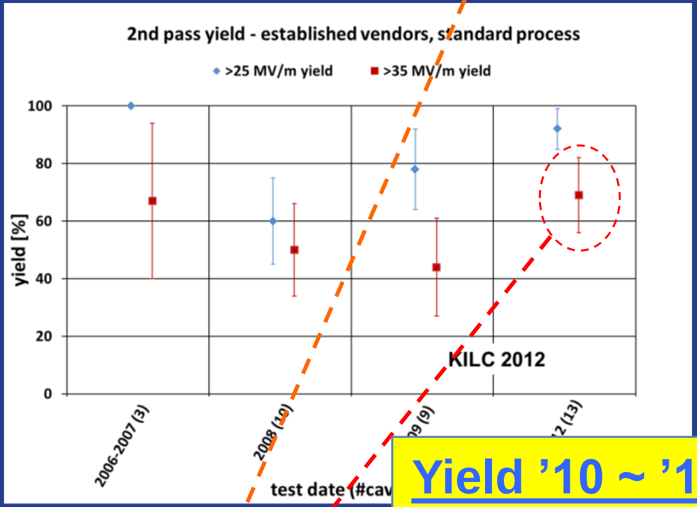
1st pass





2nd pass





et al., KILC12, Daegu, S. Korea
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Yield '10 ~ '12:

> 90% @ 25 MV/m

~ 80% @ 28 MV/m

~ 70% @ 35 MV/m

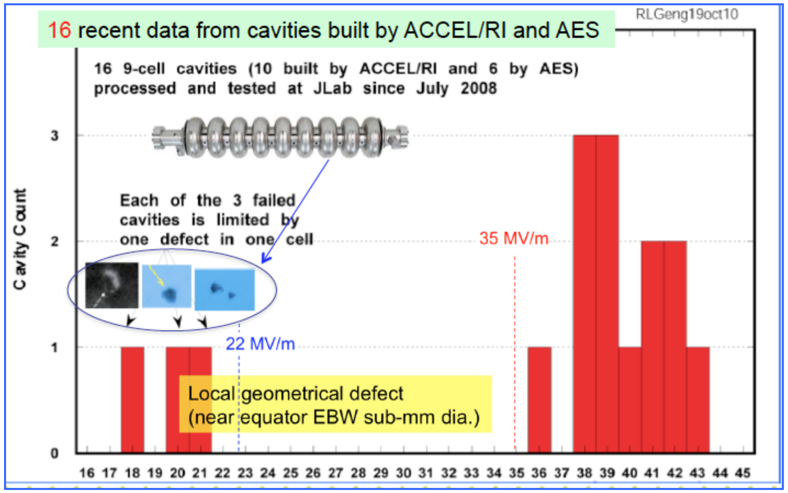
International cavities from established vendors using established

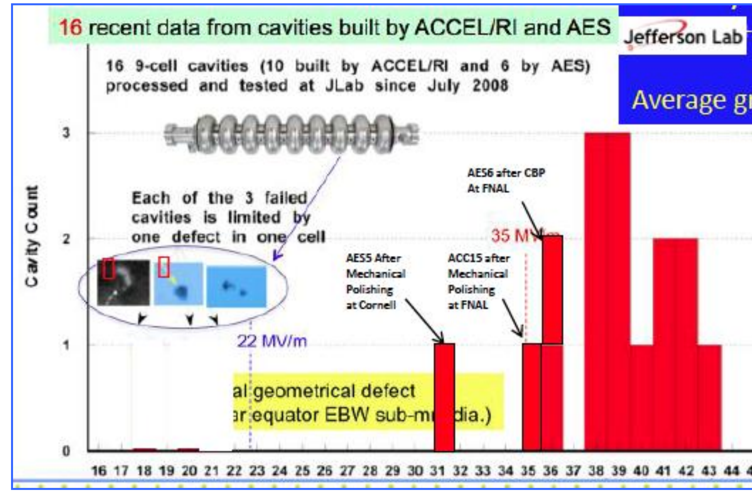
2nd pass yield for **>35 MV/m** for integrated sample is (57 +- 8)%

for 2010-2012 alone is (69 +- 13)%

R. Geng

Experiences from JLab, Fermilab, Cornell Collaboration





R. Geng, SRF11, tupo-029

- Type-I: quench limit occurs at a gradient > 25 MV/m.
  - Normally <u>no observable</u> feature at the quench site
  - Often, <u>a second EP effectively improves</u> the quench limit to > 30 MV/m.
- Type-II: quench limit occurs in a gradient range of 15-25 MV/m.
  - Often correlated with <u>sub-mm sized geometrical defects</u> (mostly pits but bumps are also observable) at or near the equator EB welding.
  - Repeated EP has no or little effect in improving the quench limit, <u>suggesting the permanent nature</u> of these defects.

How we may achieve the 90 % yield?

Overcome: Limit at E< 25 MV/m

- **QC at manufacturing process (at vendor)**
  - Material quality/uniformity including near surface
    - Need to find novel inspection and acceptance criteria
      - Optical, X-ray, Eddy current: acceptance criteria,
  - Welding quality control
    - Need to find clear inspection and acceptance criteria
      - Optical, X-ray, others,
  - Repair technique
    - Local grinding, melting, …
- **QC at further assembly process (to eliminate contamination)**

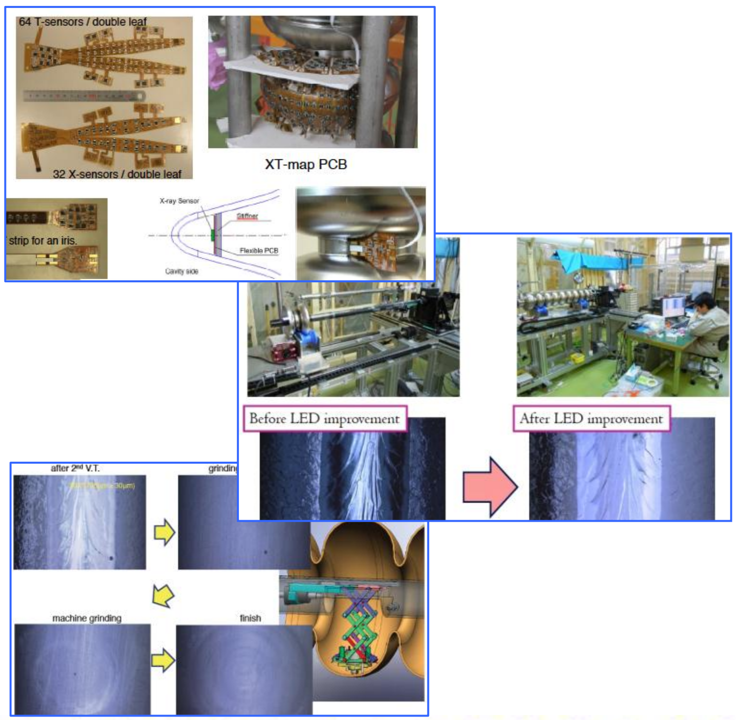
Improve Gradient toward E > 35 MV/m

- **QC at surface preparation process (at vendor and/or laboratory)**
  - Suppress field emission
    - Need much more research effort to understand surface and to establish quality control in chemical process and cleaning

Inspection and Repair Technology may improve the Yield

Technology in progress:

- Localization during test
  + Optical inspection
    + Local repairing



Cavity	Repaired at (EP/ MT/ LG)	Tested at	Bef.	Aft.	Year
AES-5	Cornell (EP)	JLab	20	31	2010
AES-6	FNAL (Tumbling)	JLab	21	36	2011
ACC-15	FNAL (Tumbling)	J / Fnal	18	35	2011?
LG#1	JLab-KEK (LG)	JLab	31	(42)	2010?
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

A. Yamamoto, LINAC12, 120913-b

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)
- **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.)

Global Plan for SCRF R&D

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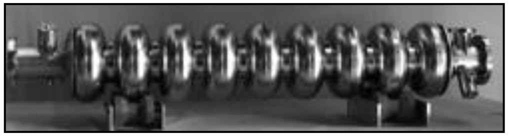
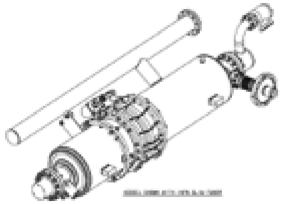
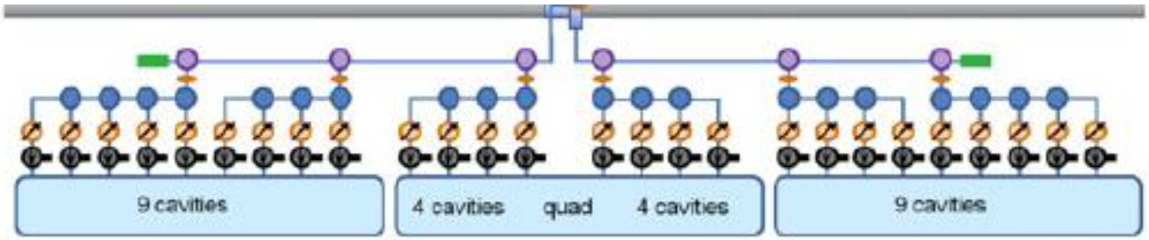
SCRF Technology Required

Parameters	Value
C.M. Energy	500 GeV
Peak luminosity	1.5×10^{34} $cm^{-2}s^{-1}$
Beam Rep. rate	5 Hz
Pulse duration	0.73 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**

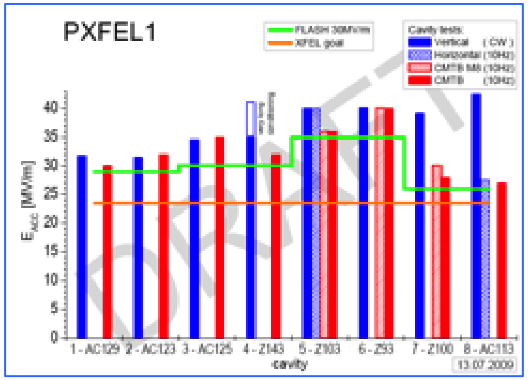


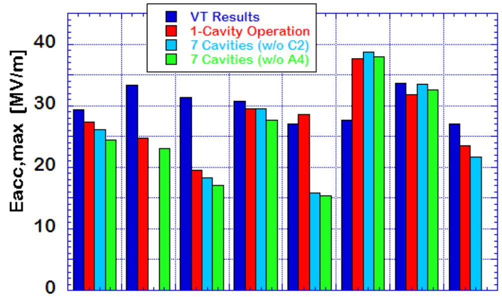


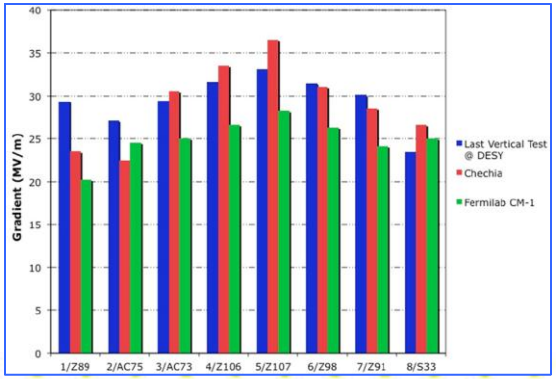


Progress in SCRF System Tests

- **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, beyond 2013







FLASH 9mA Expt achievements: 2009-mid 2012

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

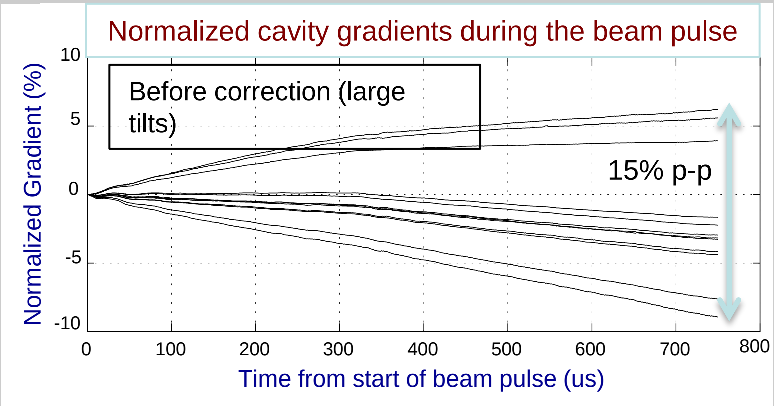
Metric	ILC Goal	Achieved
Macro-pulse current	9mA	9mA
Bunches per pulse	2400 x 3nC (3MHz)	1800 x 3nC 2400 x 2nC
Cavities operating at high gradients, close to quench	31.5MV/m +/-20%	4 cavities > 30MV/m

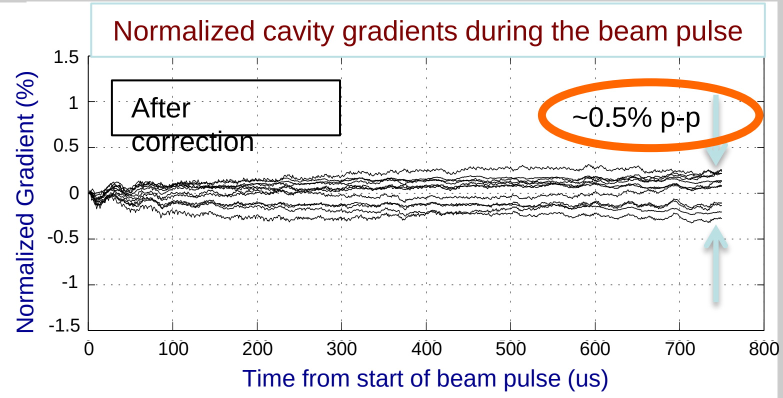
Gradient operating margins *(Feb 2012)*

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)

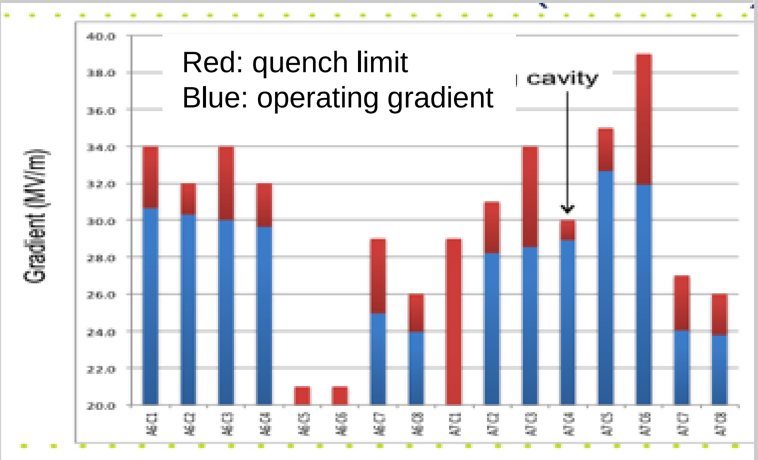
FLASH 9mA Studies: beam operation close to cavity gradient limits (4.5mA/800us bunch trains)

Tailored cavity Loaded-Qs to cancel beam-loading induced gradient tilts





Operation at 380MeV on ACC67 (13 cavities)

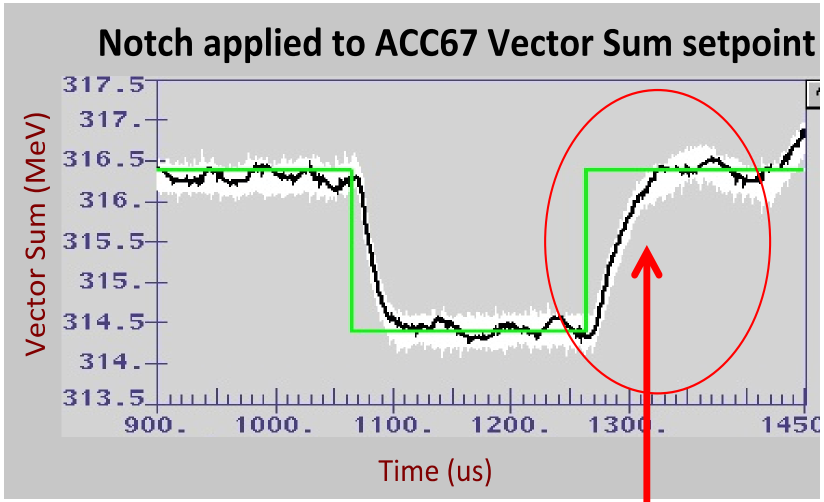


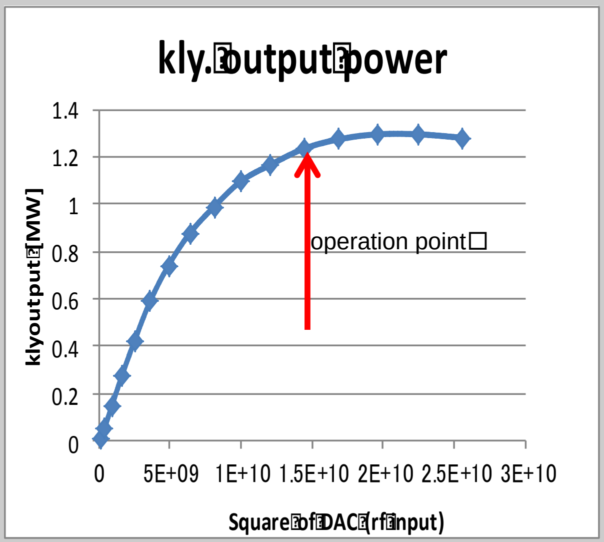
The limiting cavity is within 5% of quench

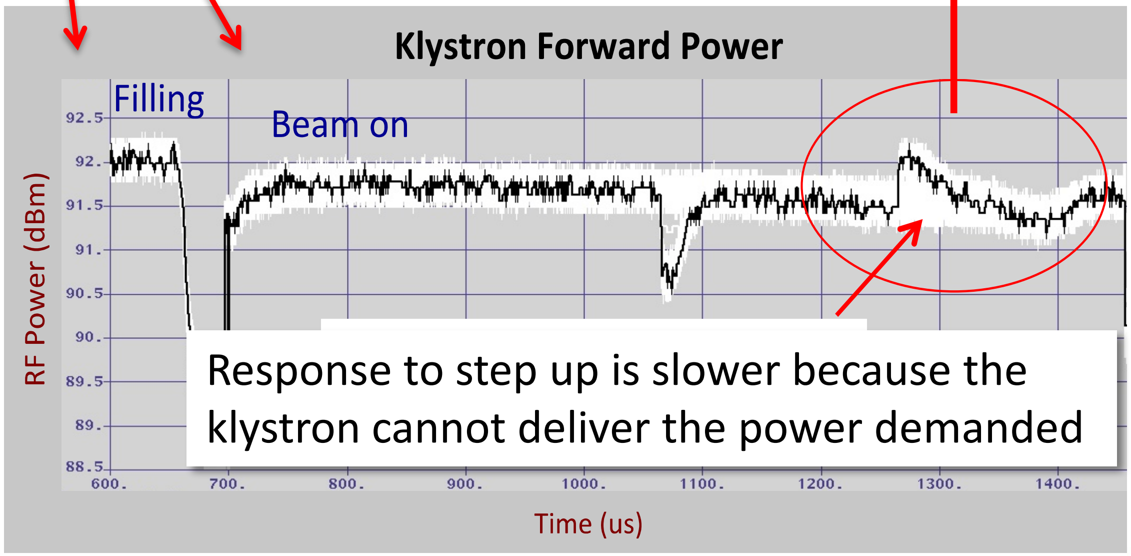
- Flattened individual gradients to **<<1% p-p**
- Several cavities within 10% of quench
- 'Crash test': very rapid recovery of 800us / 4.5mA after beam trip
- Ramped up current from ~zero to 4.5mA with ACC67 gradients approaching quench
- 'Cavity gradient limiter' to dynamically prevent quenching without turning off the rf

9mA Studies: evaluating rf power overhead requirements (4.5mA/800us bunch trains)

- Klystron high voltage was reduced from 108KV to 86.5KV so that the rf output just saturated during the fill
- The required beam-on power ended up being ~7% below saturation



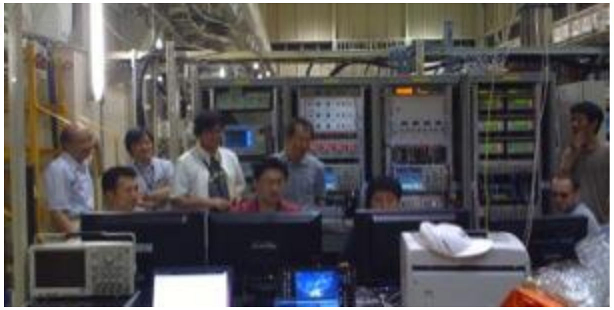




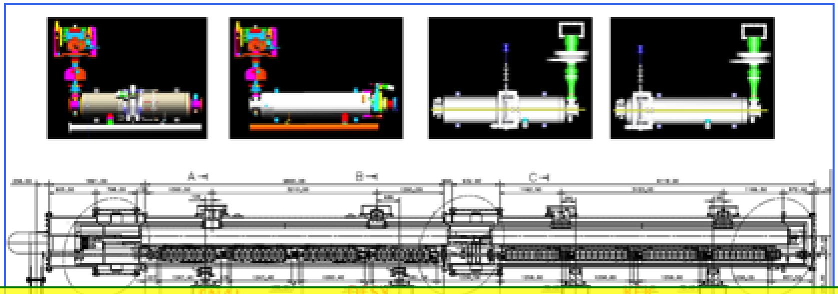
H. Hayano (TH1A01):

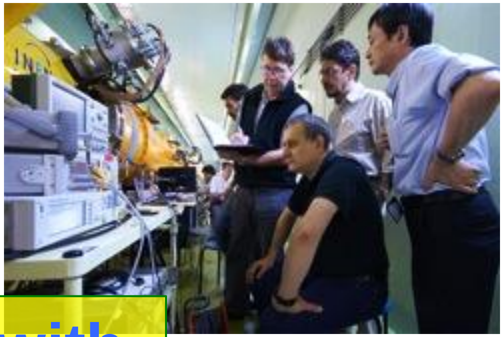
S1-Global Assembly/Test with Global Effort

DESY, FNAL, Jan., 2010

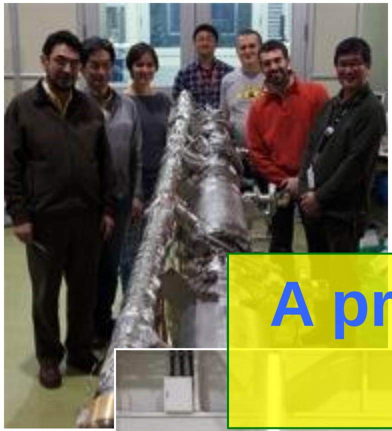


DESY, Sept. 2010





FNAL, INFN, July, 2010



INFN and FNAL Feb. 2010

A practice for Global Cooperation with Plug-compatibility !

March, 2010

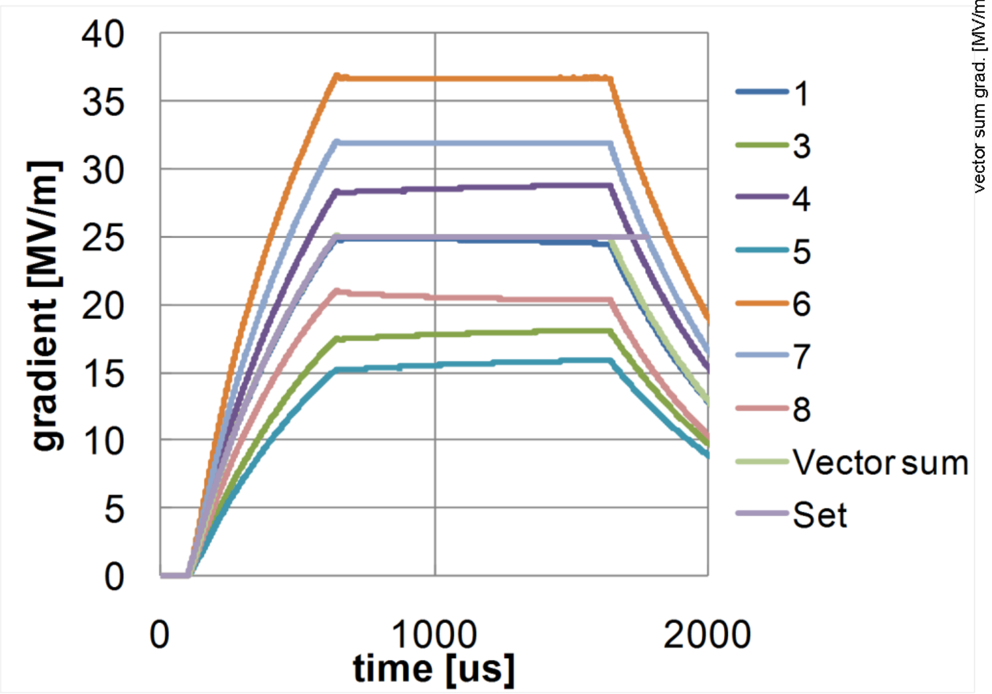
DESY, May, 2010

June, 2010 ~

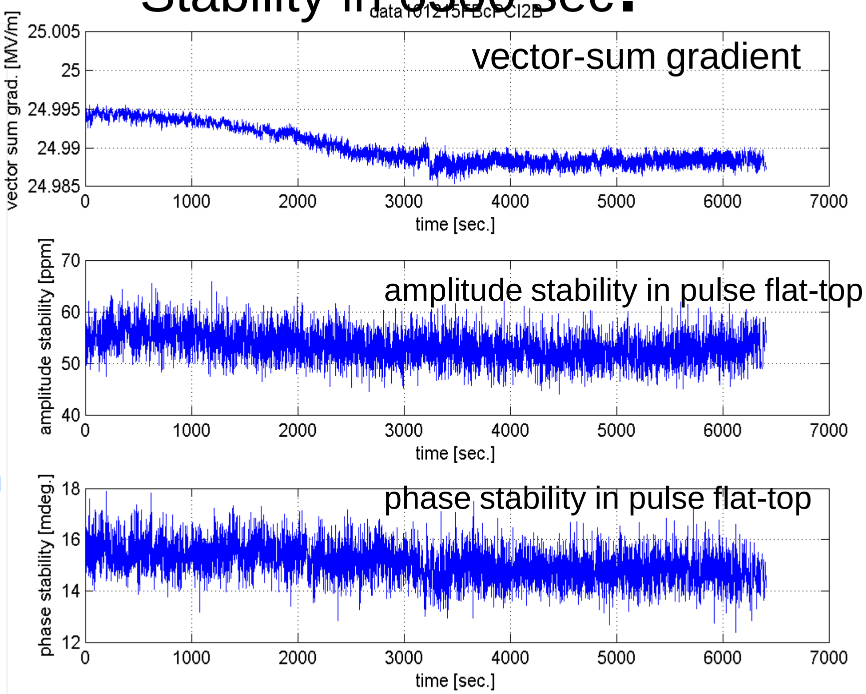
7-cavity operation by digital LLRF

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

Field Waveform of each cavity



Stability in 6300 sec.

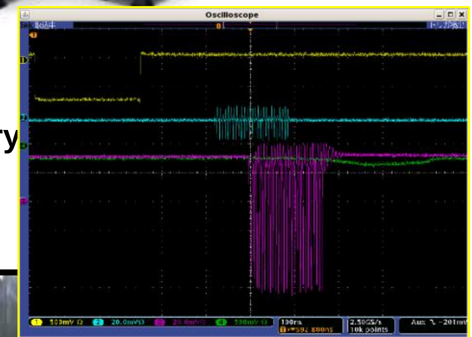


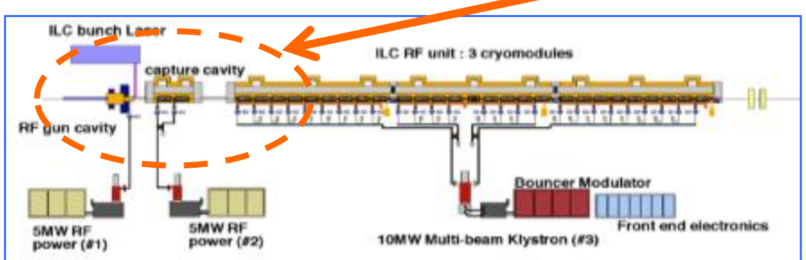
- **Vector-sum stability: 24.995MV/m ~ 24.988MV/m (~0.03%)**
- **Amplitude stability in pulse flat-top: < 60ppm=0.006%rms**
- **Phase stability in pulse flat-top: < 0.0017 degree.rms**

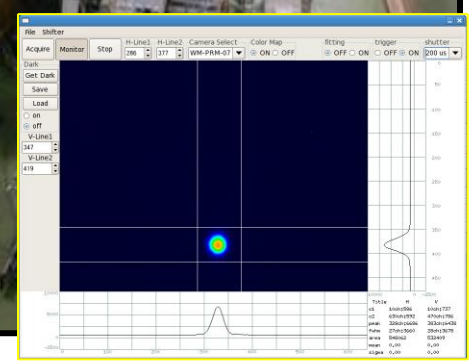
STF Quantum-Beam experiment

Quantum-Beam Accelerator
Starting as starting of KEK-STF-2

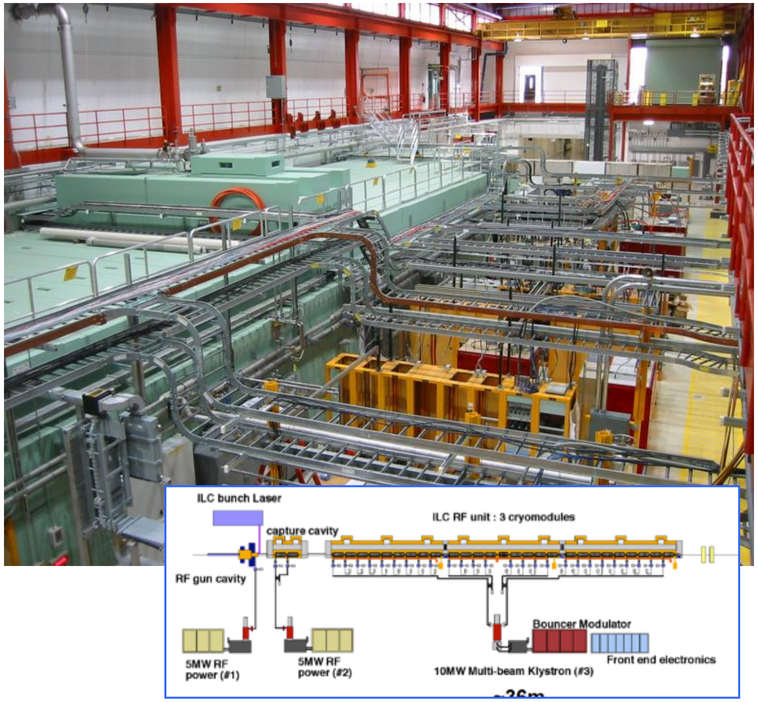
Beam acceleration (40 MV) and transport for 1 ms, successful !
April, 2012

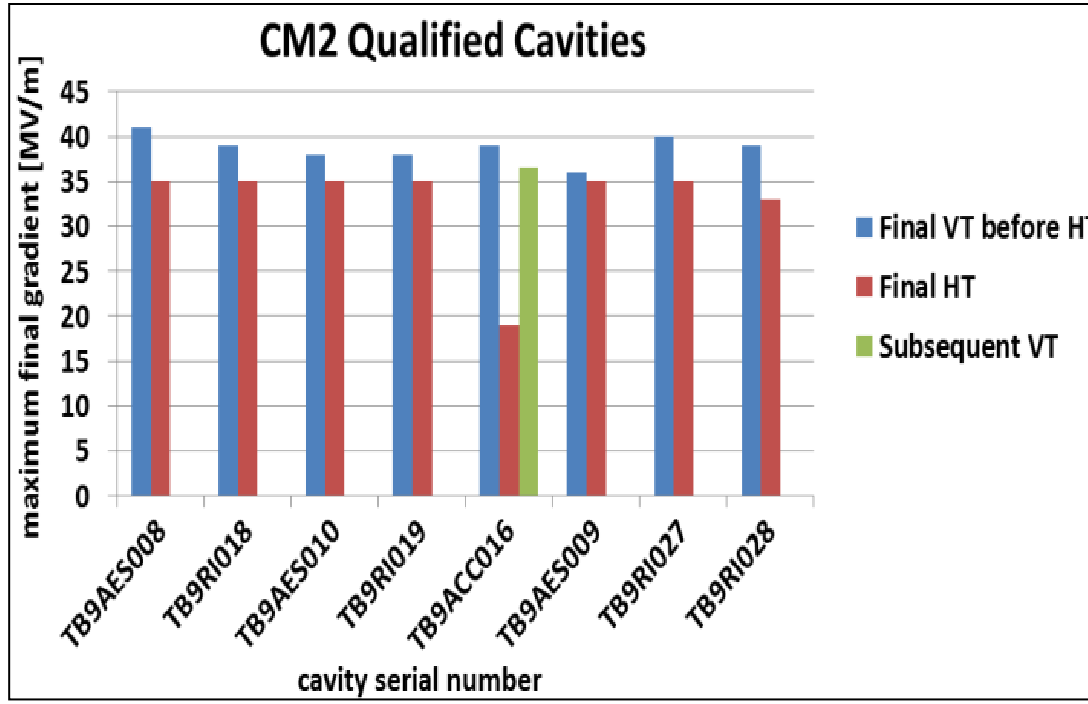






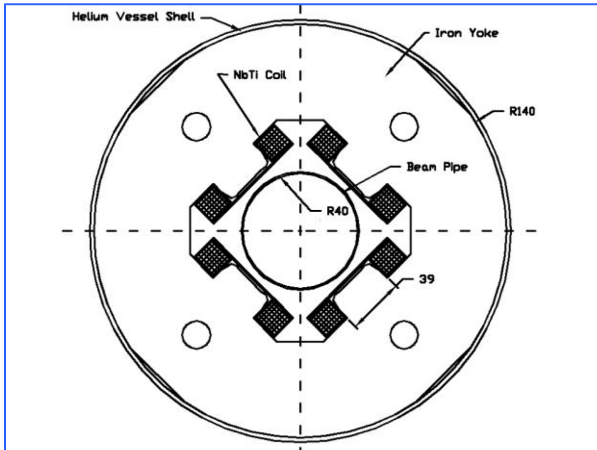
CM Test in Progress at Fermilab





- **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 Conduction-cooled, Split-able Quadrupole Magnet R&D



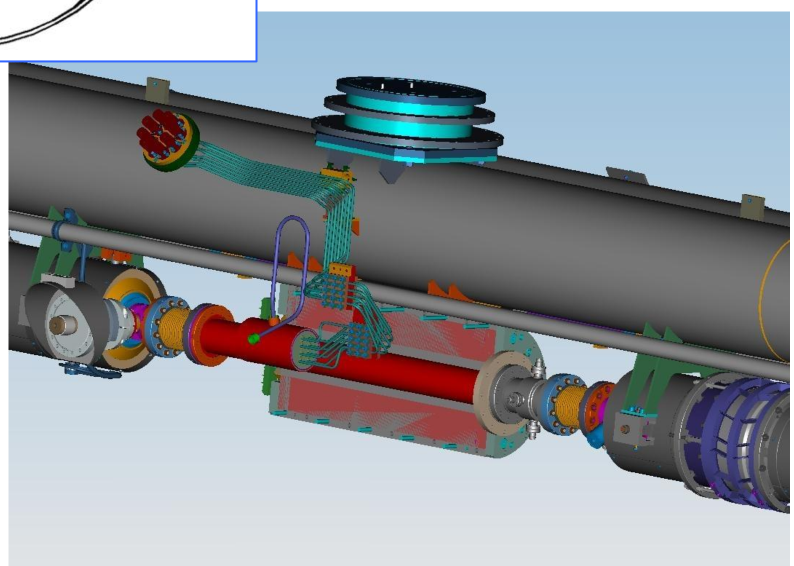
V. Kashikhin

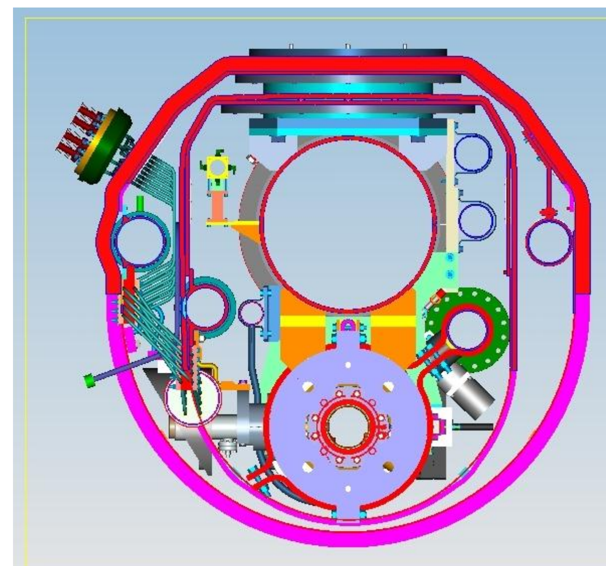
Advantages;

- Q-magnet may be assembled separately,
- Keep "best clean" during cavity string assembly
- No additional cryostat and cryogenics
- Highly accurate alignment without LHe vessel

Collaboration;
Fermilab:
- magnet

KEK:
- Cooling

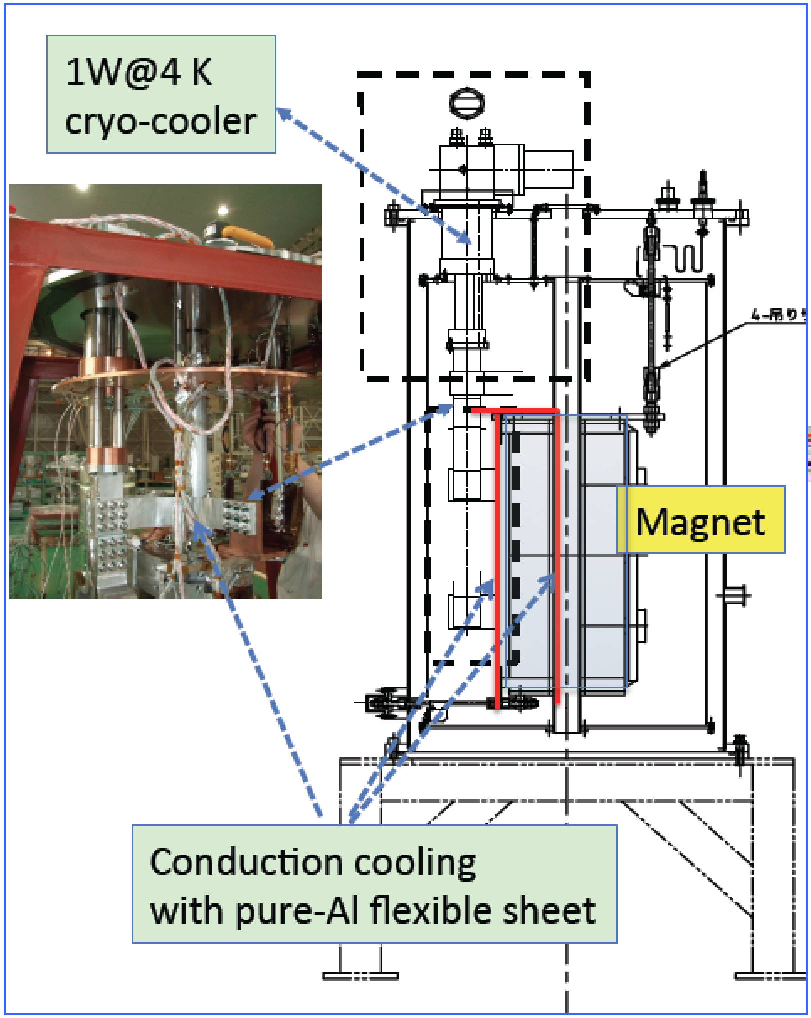




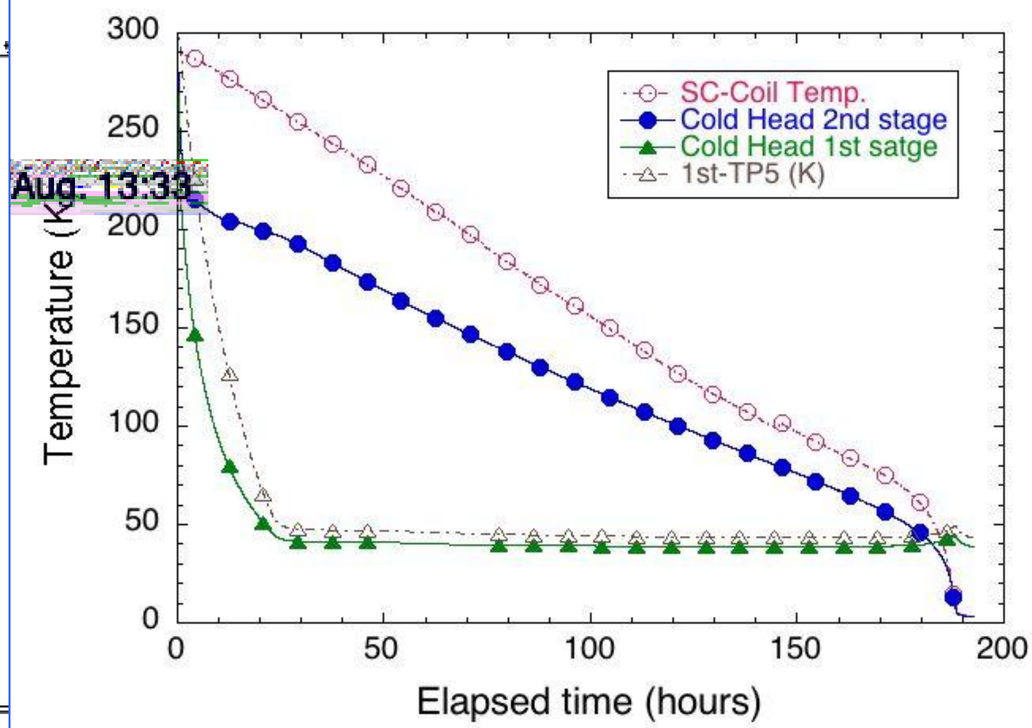
Conduction cooling through Al-strips

Kimura, Kashikhin, Tartaglia

Conduction Cooling Test using Cryo-Cooler held at KEK, Aug-Sept. 2012

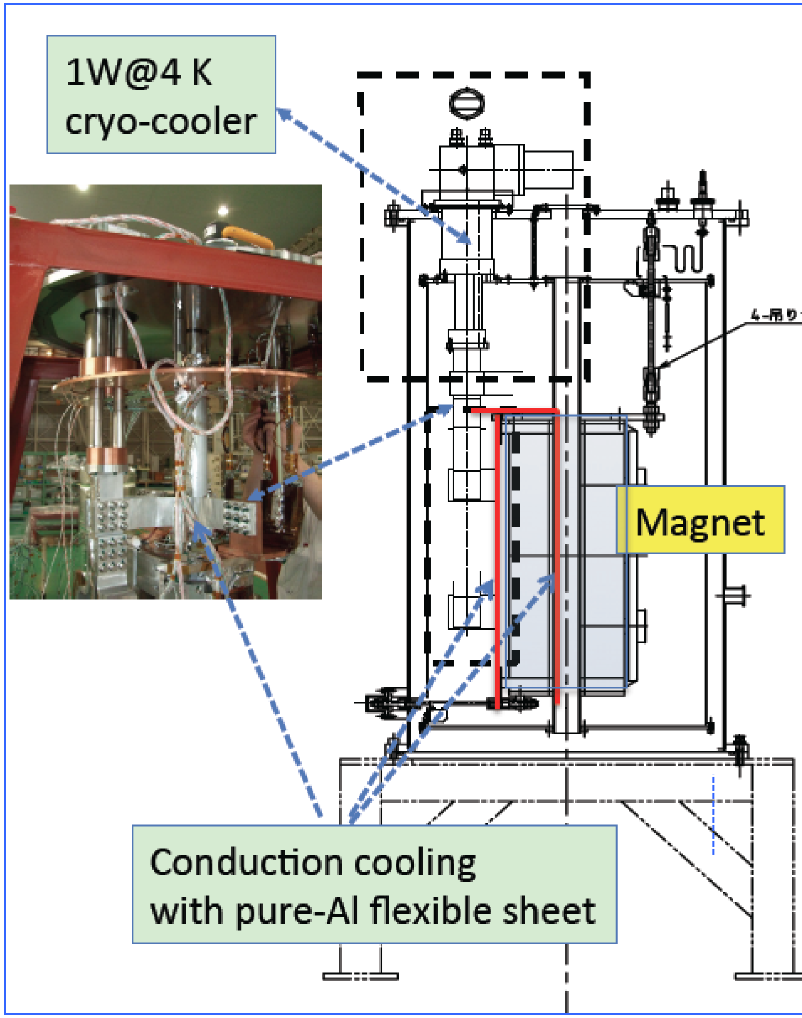


Cold mass weight: ~ 400 kg
Cryo-cooler capacity: 1 W @ 4 K
Cool-down: 8 days to reach 4K

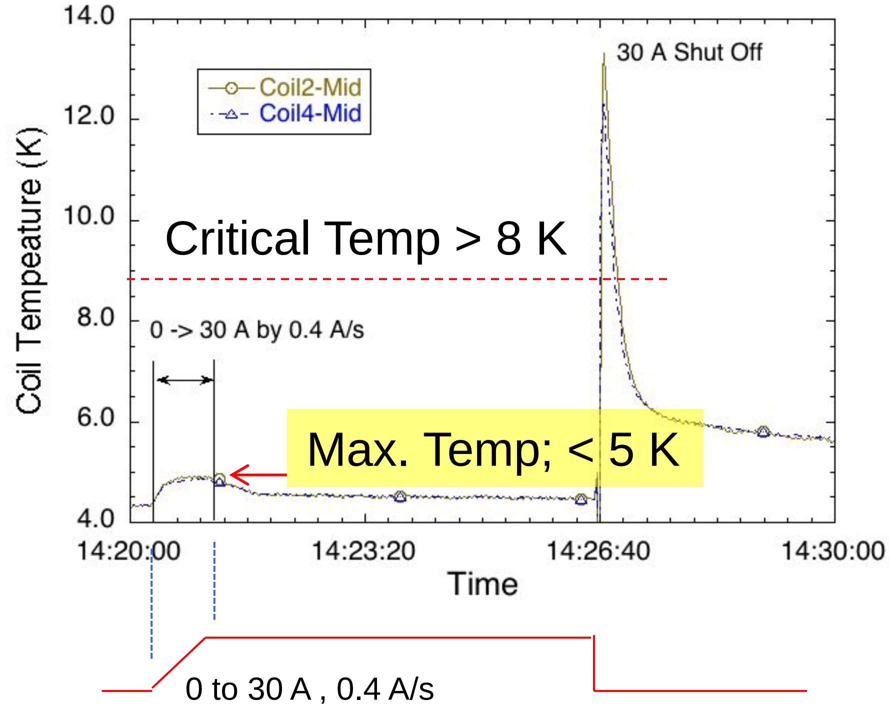


Kimura, Kashikhin, Tartaglia

Conduction Cooling Test using Cryo-Cooler held at KEK, Aug-Sept. 2012



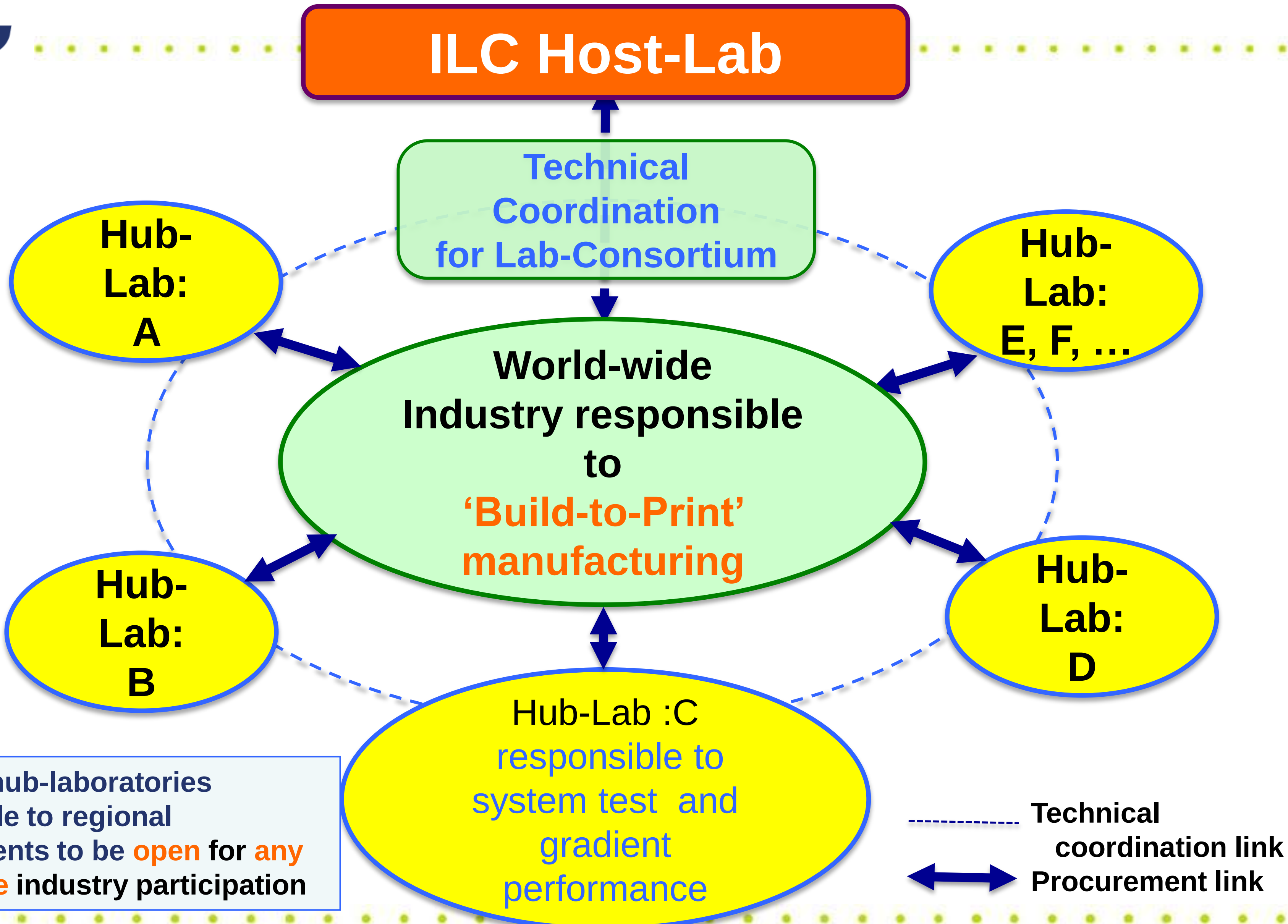
Excitation test up to 30 A (30%)
Ramp rate test : 0.4 A/s
(x 40 faster than ILC-ML op.)
Temperature rise : ~ 0.5 K



Global Plan for SCRF R&D

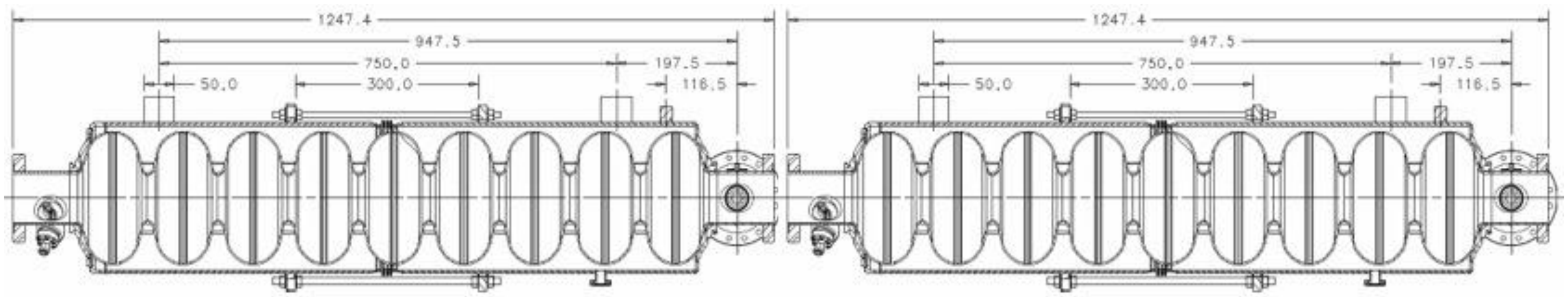
Year	07	2008	2009	2010	2011	2012
Phase	TDP-1				TDP-2	
Cavity Gradient in v. test to reach 35 MV/m	→ Yield 50%				→ Yield 90%	
Cavity-string to reach 31.5 MV/m, with one-cryomodule		Global effort for string assembly and test (DESY, FNAL, INFN, KEK)			We are here	
System Test with beam acceleration		FLASH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

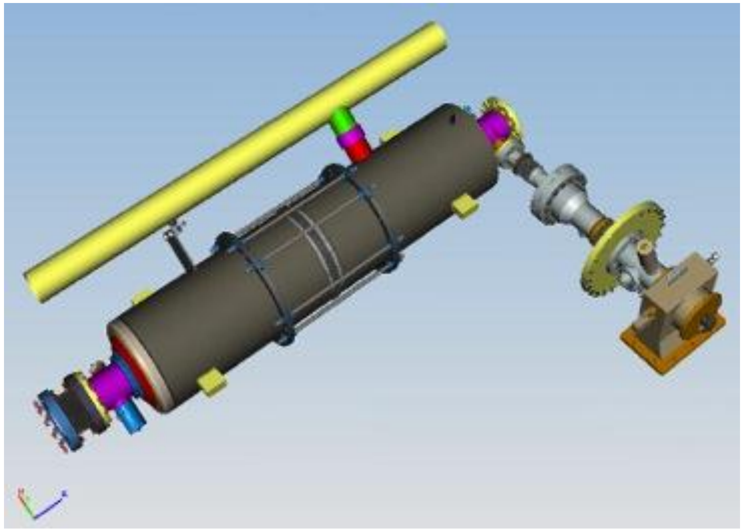
ILC Procurement/Manufacturing Model

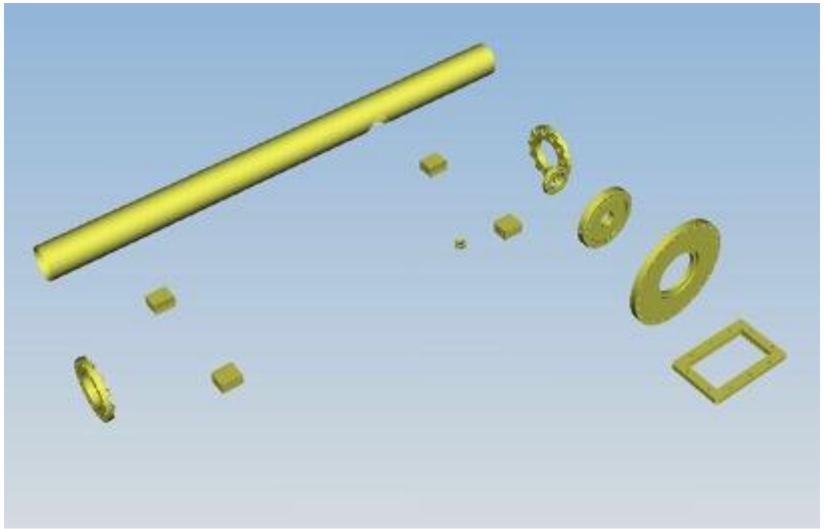


Regional hub-laboratories responsible to regional procurements to be open for any world-wide industry participation

Plug-compatibly of Cavities
Important for Global Cooperation







Plug-compatible interface need to be established

The 3rd Cycle Communication with Companies

Further studies with some contracts in 2011-2012

	Year	Company	Place	Technical subject
1	2011~2012	Hitachi (KEK)	Tokyo (JP)	Cavity/Cryomodule (CM)
2	2011~2012	Toshiba (KEK)	Yokohama (JP)	Cavity/CM, SC Quadrupole
3	2011~2012	MHI (KEK)	Kobe (JP)	Cavity / CM
4	2011~2012	Tokyo Denkai	Tokyo (JP)	SC Material
5	2011	OTIC	NingXia (CN)	SC Material
6	2011	Zanon	Schio (IT)	Cavity/CM
7	2011~2012	RI (DESY)	Koeln (DE)	Cavity, Coupler
8	2011~2012	AES (Fermilab)	Medford, NY (US)	Cavity
9	2011	Niowave	Lansing, MI (US)	Cavity/CM
10	2011	PAVAC	Vancouver (CA)	Cavity
11	2011	ATI Wah-Chang	Albany, OR (US)	SC Material
12	2011	Plansee	Ruette (AS)	SC Material
13	2011	SDMS	Sr. Romans (FR)	Cavity
14	2011~2012	Heraeus	Hanau (DE)	SC Material
15	2011~2012	Babcock-Noell (CERN)	Wurzburg (DE)	CM assembly
16	2011	SST	Maisach (DE)	EBW
17	2012	Tokyo Electron-Tube	Nasu (JP)	HLRF (Klystron, Coupler)
18	2012	Thales	Velccy Villacoublay (FR)	HLRF (Klystron)

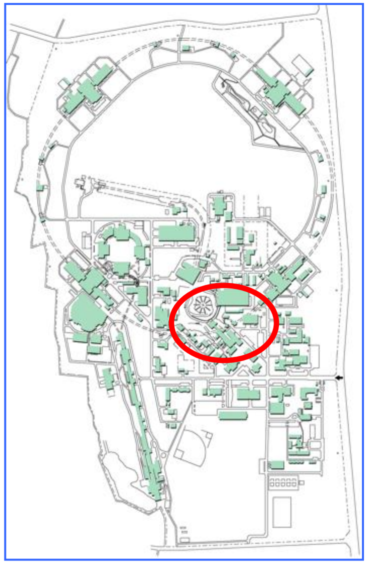
Mass-Production Studies

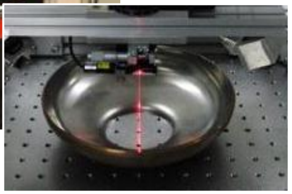
in contracts

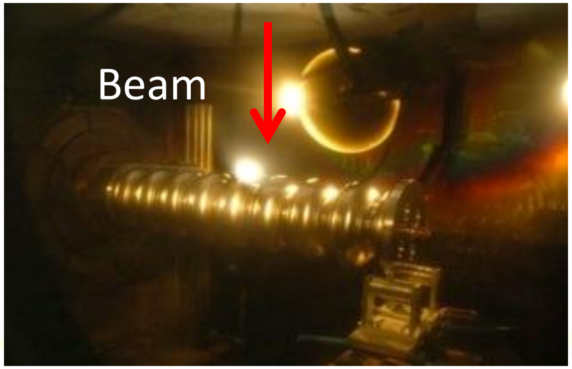
	Company	Mass production model	Contract funded/hosted by
Cavity	RI	100%. 50%	DESY
	AES	20 %	DOE/Fermilab
	MHI	20, 50, 100%	KEK
Quadrupole	Toshiba	100 %	KEK
CM and assembly	Hitachi	20, 50, 100%	KEK
	AES	25%	DOE/Fermilab
CM assembly	BN	100, 33 %	CERN

In parallel, EXFEL experience kindly informed by DESY, INFN, CEA/Saclay , and CERN is contributing to SCRF and CFS, based on LHC experience

Cavity Fabrication Facility at KEK
As a laboratory's production R&D effort







TDR Technical Volumes

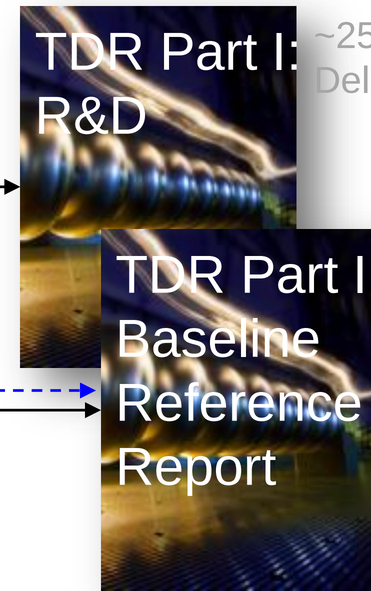
2007

2011

2013*

ILC Technical Progress Report ("*interim report*")

AD&I



~250 pages
Deliverable 2

~300 pages
Deliverables 1,3 and 4

Technical Design Report

Reference Design Report

* end of 2012 – formal publication early 2013

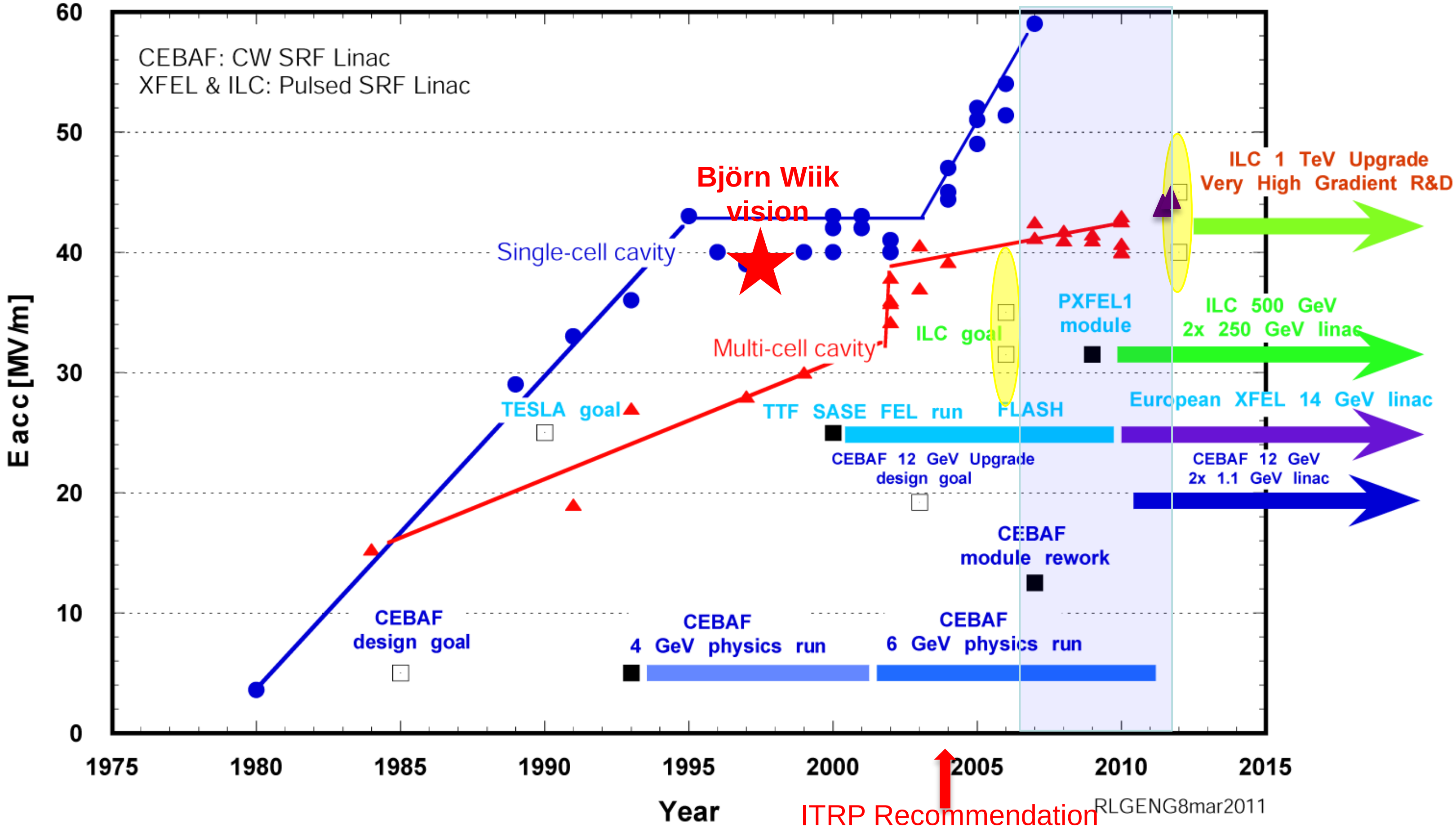
Technical Efforts beyond TDR

- **Extended Basic R&D efforts:**
  - Cavity: High-gradient and high Q development as well as higher yield for mass production
  - CM: Less degradation after CM assembly
  - Superconducting accelerator: operational experience

- **Cost effective production/industrialization studies**
  - With plug-compatible cavity design and fabrication

Courtesy: R. Geng

SCRF Cavity Gradient Progress



- 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: produce a design for ILC and coordinate worldwide R&D efforts
- New SRF Test Facilities in operation: STF at KEK and NML at Fermilab
- Upgrade of CEBAF to 12 GeV underway at Jefferson Lab (80 cavities)
- FLASH operation and construction of European XFEL underway (640 cavities)

Summary

- **ILC can be built, based on the TDR technology.**
- **Multiple scenarios may be considered:**
  - Realize Full energy (500 GeV) machine, extendable up to 1 TeV,
  - Staging to reach 500 GeV, and extendable up to 1 TeV
  - ILC construction requires 10 years. Start of the construction in coming 5 year will be anticipated to realize the ILC by end of 2020's (before 2030).
- **Further works beyond TDR**
  - Industrialization to be further prepared in communication with industry
  - Basice R&Ds extended for cost-effective construction/production, and for 1 TeV upgrade capability

Appendix

ML Beam Parameters for Various Operating Scenarios

Parameter	Unit					TDR baseline	Luminosity upgrade	Energy upgrade	
Center-of-mass energy	GeV	200	230	250	350	500	500	1000	1000
Beam energy	GeV	100	115	125	175	250	250	500	500
Collision rate	Hz	5	5	5	5	5	5	4	4
Electron linac rate	Hz	10	10	10	5	5	5	4	4
Number of bunches		1312	1312	1312	1312	1312	2625	2450	2450
Electrons/bunch	$\times 10^{10}$	2.0	2.0	2.0	2.0	2.0	2.0	1.74	1.74
Positrons/bunch	$\times 10^{10}$	2.0	2.0	2.0	2.0	2.0	2.0	1.74	1.74
Bunch separation	ns	554	554	554	554	554	366	366	366
Bunch separation $\times \lambda_{RF}$		720	720	720	720	720	476	476	476
Pulse current	mA	5.8	5.8	5.8	5.8	5.8	8.75	7.6	7.6
RMS bunch length	mm	0.3	0.3	0.3	0.3	0.3	0.3	0.250	0.225

Baseline ML Beam Parameters for 500 GeV CMS operation

Parameter	Value	Unit
Initial beam energy	15	GeV
Final beam energy	250	GeV
Particles per bunch	2.0×10^{10}	
Beam current	5.8	mA
Bunch spacing	554	ns
Bunch train length	727	µs
Number of bunches	1312	
Pulse repetition rate	5	Hz
Initial $\gamma\epsilon_x$	8.4	µm
Final $\gamma\epsilon_x$	9.4	µm
Initial $\gamma\epsilon_y$	24	nm
Final $\gamma\epsilon_y$	34	nm
σ_z	0.3	mm
Initial σ_E/E	1.6	%
Final σ_E/E	0.11	%
Bunch phase relative to RF crest	5	degrees

ILC possible timeline

B. Barish, KILC12