Status of ADS and Superconducting Cavity Development in Japan

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in cooperation with

Hiroyuki Oigawa and Kazufumi Tsujimoto (JAEA)

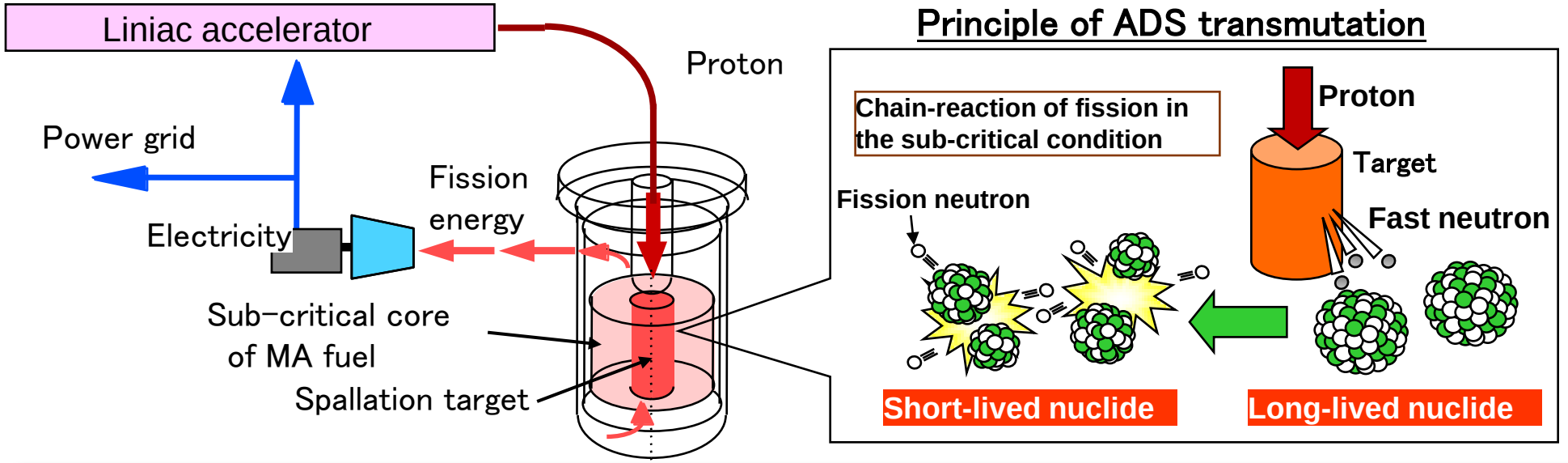
To be presented in the 2nd Int. Workshop on ADS and Thorium Utilization, held at BARC, Mumbai, 2011

Outline

- ADS development in Japan
  - Progress in J-PARC ADS
- Superconducting RF Cavity Development
  - Global Effort: ILC/GDE-KEK cooperation
  - KEK's effort: cERL and SCRF Cavity Technology development in house

Courtesy: Tsujimoto, Oigawa

Accelerator-Driven System (ADS)



Mechanism of ADS

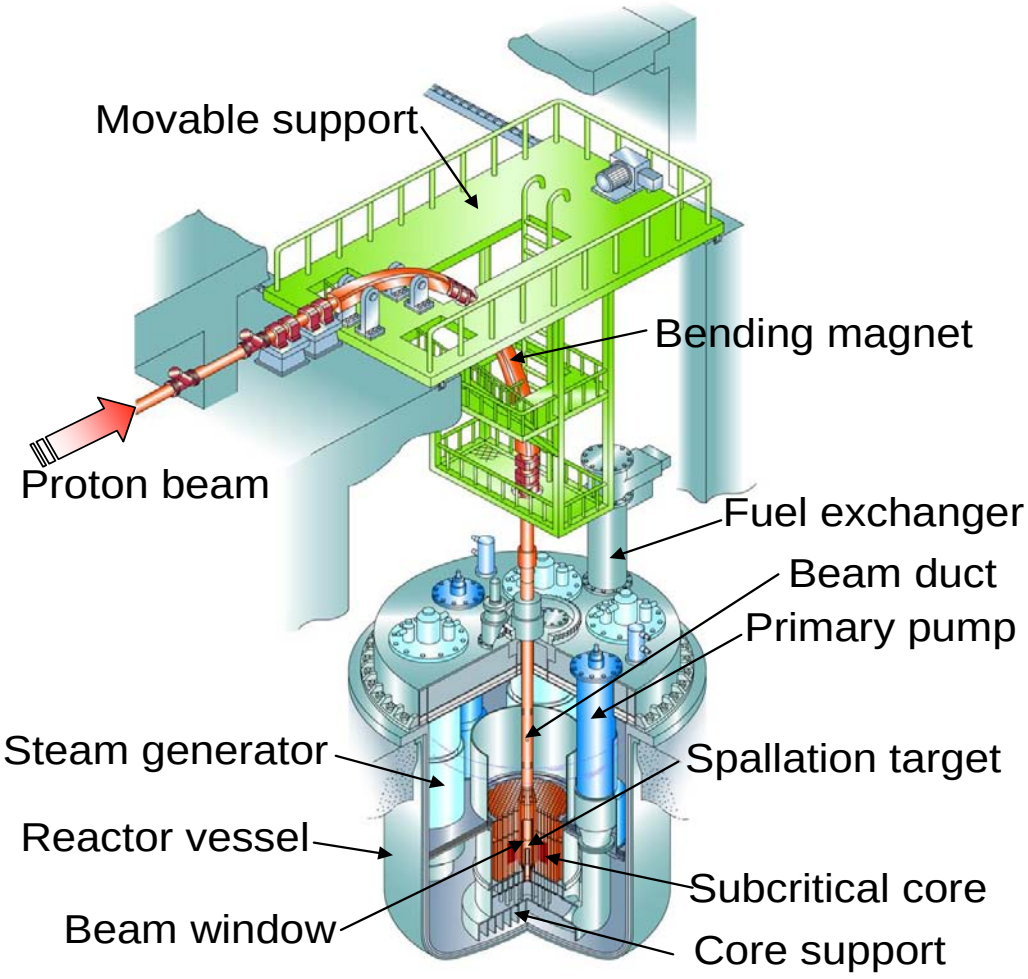
- Proton beam which is accelerated by the **superconducting LINAC** is injected to ADS.
- High intensity proton generates massive neutrons by **spallation reaction** with **heavy metal target** (~30neutrons/proton).
- Fission reactions of **MA** are caused by spallation neutrons. Neutrons by fission reactions lead to the next transmutation.

  →Number of neutron is increased 20-times by the **chain-reaction**.

Courtesy: Tsujimoto, Oigawa

Design Concept of ADS for Transmutation

- The design study for ADS in JAEA has been concentrated on the concept of a "commercial-size" one with the thermal power of 800 MWth.
- In the reference design, a superconducting linear accelerator (SC-LINAC) is adopted to deliver a 30 MW (maximum value) proton beam.
- Lead-bismuth eutectic (LBE) is used as the core coolant and the spallation target.
- The spallation target and the accelerator are separated by a beam duct and a beam window inserted down to the active core.
- Dedicated nitride fuel (MA, Pu)N + ZrN, where nitrogen is enriched up to 99 % with ^{15}N, is a primary candidate, which can be recycled by a pyrochemical process with recovering ^{15}N.



Concept of JAEA's 800MWth ADS

Courtesy: Tsujimoto, Oigawa

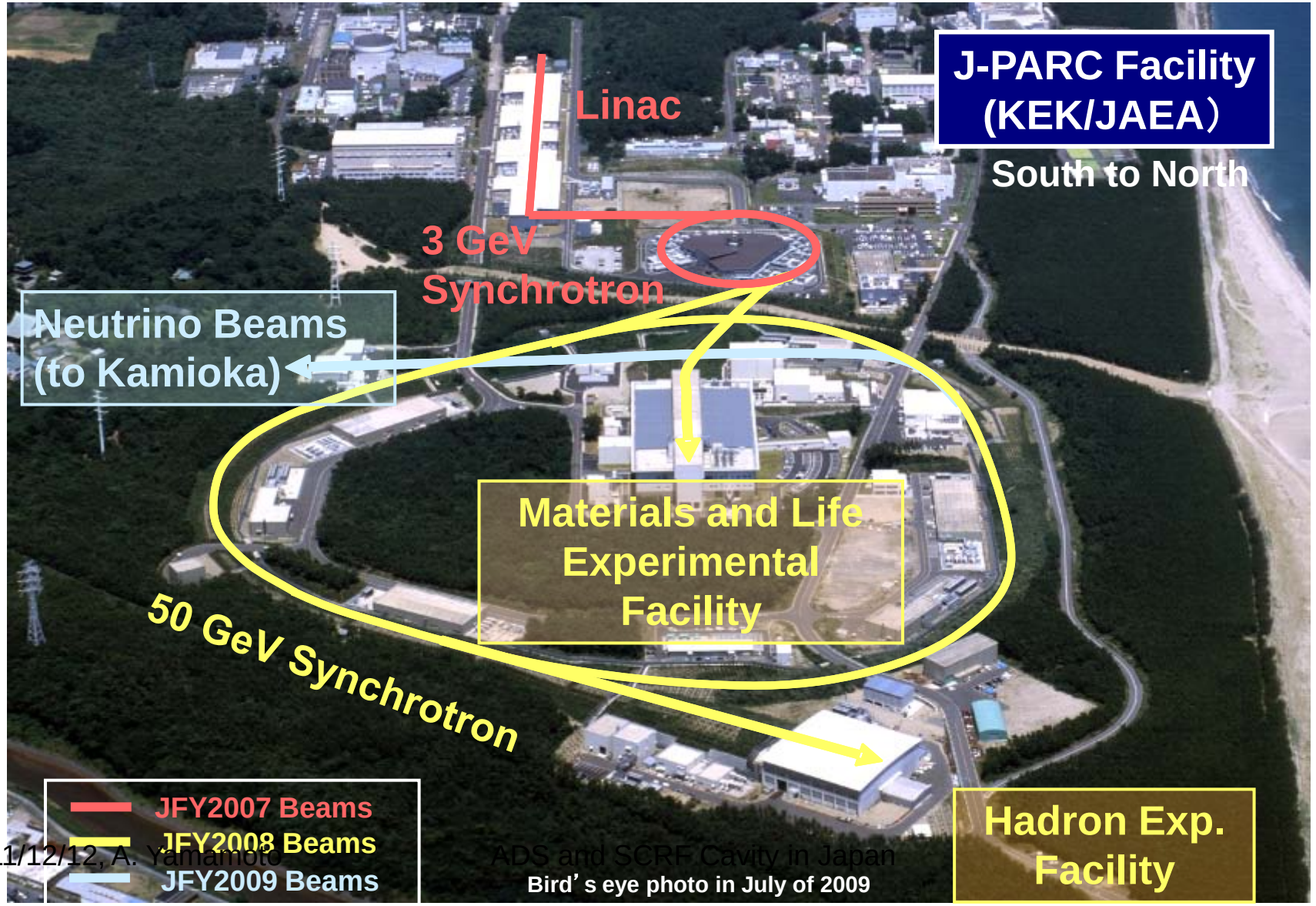
R&D on Accelerator for ADS

- **Requirement**
  - -High power (>20MW)
  - -Low beam loss
  - -High energy efficiency (>15%)
  - -High reliability
  - -Low cost

  - Superconducting Linear Accelerator (SC-LINAC)

Courtesy: Tsujimoto, Oigawa

J-PARC: Japan Proton Accelerator Research Complex



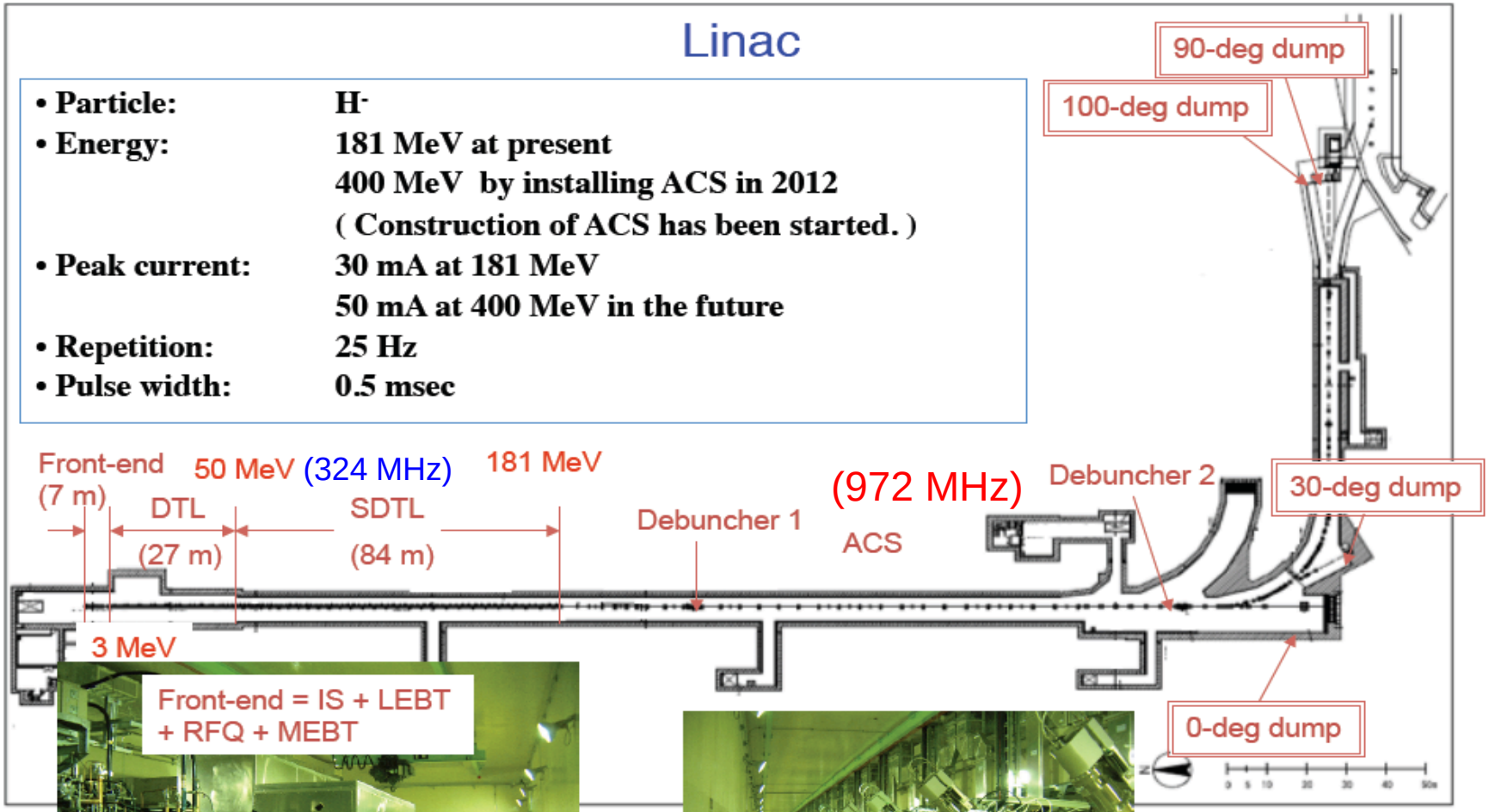
Bird's eye photo in July of 2009

Courtesy: Tsujimoto, Oigawa

Status of J-PARC : Linac

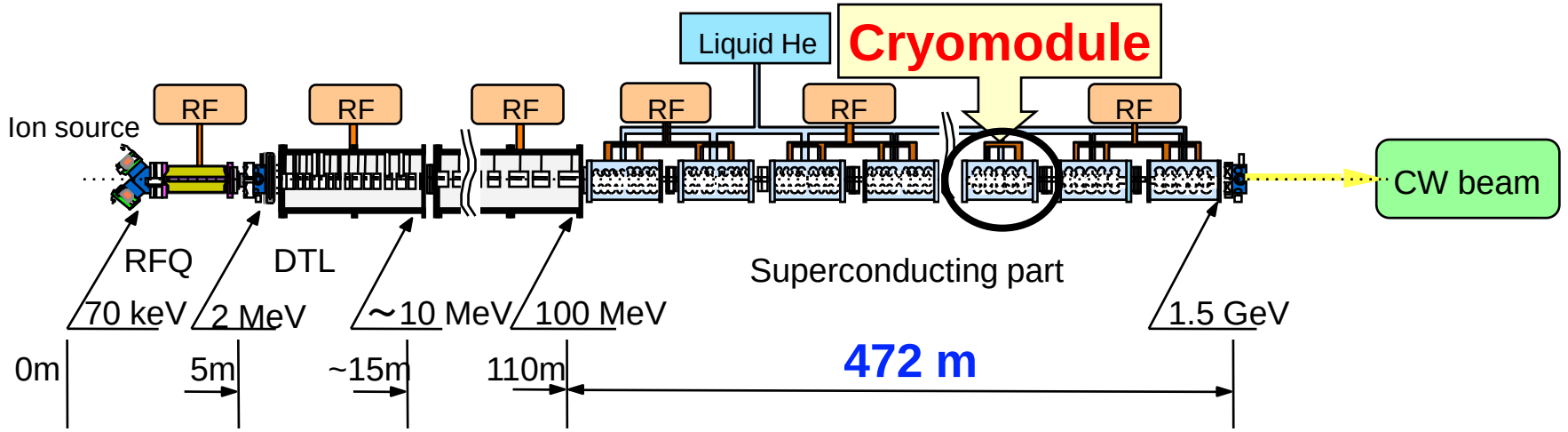
Linac

- **Particle:** H^-
- **Energy:** 181 MeV at present
  400 MeV by installing ACS in 2012
  (Construction of ACS has been started.)
- **Peak current:** 30 mA at 181 MeV
  50 mA at 400 MeV in the future
- **Repetition:** 25 Hz
- **Pulse width:** 0.5 msec



Courtesy: Tsujimoto, Oigawa

R&D on Accelerator : Design Study



Energy consumption of SC-LINAC (1.5GeV)

Component	Electricity
RF source for SC-cavity	69.6MW
Quadra pole magnet	0.4MW
He cooling machine	16.5MW
100MeV injection accelerator	10.0MW
Utility	9.7MW
Total	106.2MW

- The design study provided that the SC-LINAC consisting of 89 cryomodules and the length (100MeV to 1.5 GeV) was estimated as 472m.
- 106MW will be necessary for 30MW proton beam, i.e., acceleration efficiency will be about 28%.

R&D on Accelerator : Development of Cryomodule

Superconducting cavity

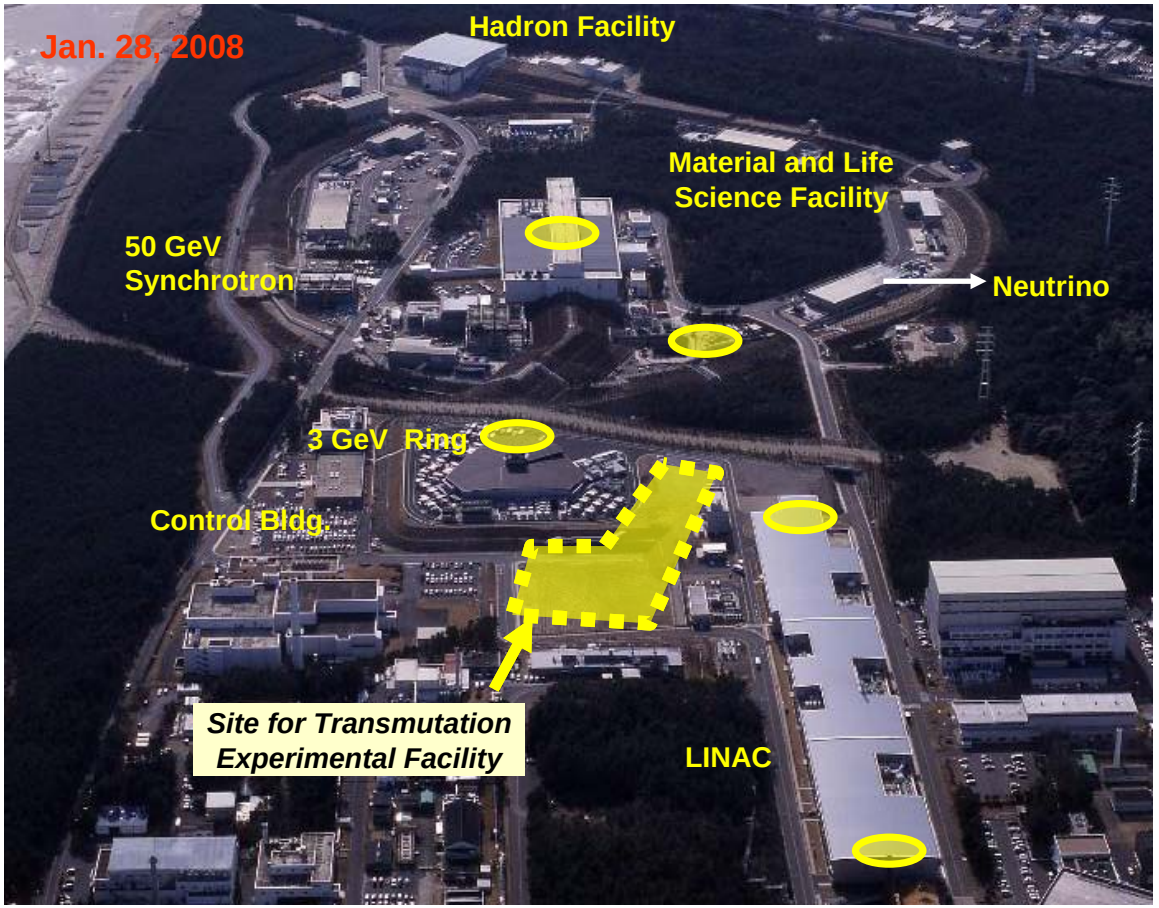
972 MHz Cryomodule

Cryomodule

Courtesy: Tsujimoto, Oigawa

Future Experimental Plan in J-PARC

Trasmutation Experimental Facility (TEF)

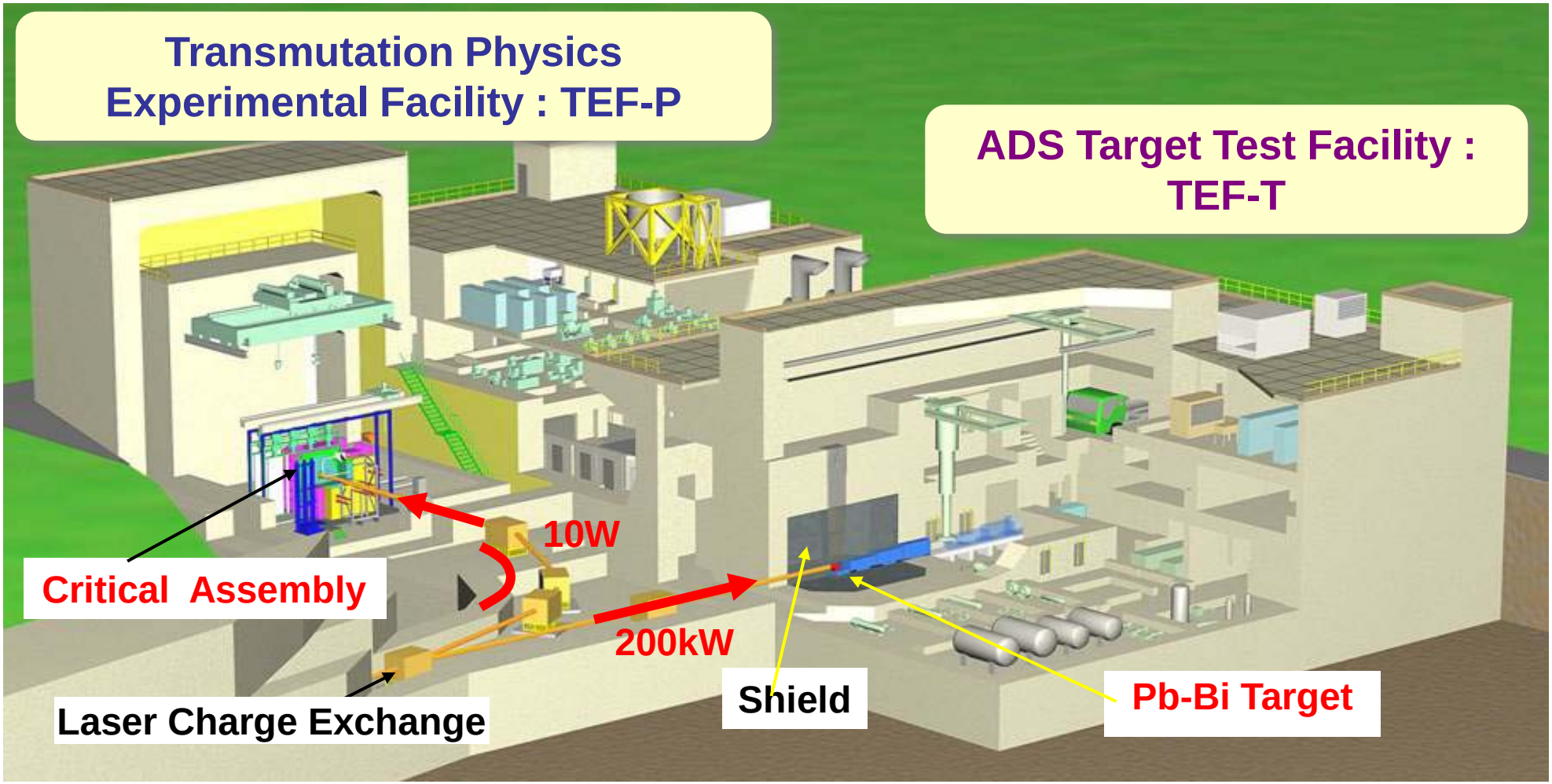


1st phase of J-PARC

- Start Construction
  - March, 2002
- First Proton Beam
  - Nov. 22, 2006
- Accelerate proton to 181 MeV
  - Jan. 24, 2007
- Accelerate beam to 3 GeV
  - Oct. 31, 2007
- Inject beam to 50GeV ring
  - May 27, 2008
- **Produce spallation neutron**
  - **May 30, 2008**

Courtesy: Tsujimoto, Oigawa

Future : Transmutation Experimental Facility (TEF)



Courtesy: Tsujimoto, Oigawa

Efforts and Future for ADS in JAEA/J-PARC

JAEA's efforts for ADS as a dedicated transmutation system

- Designed study (neutronics, structure, thermal-hydraulic, etc.) for ADS
- Development of superconducting linear accelerator for ADS
- R&D for ADS fuel, U-free nitride fuel
- LBE technology for spallation target and core coolant

Future experimental plan in J-PARC

- TEF-P: Critical Assembly with 10W beam line
- TEF-T: 200kW Pb-Bi Target for irradiation

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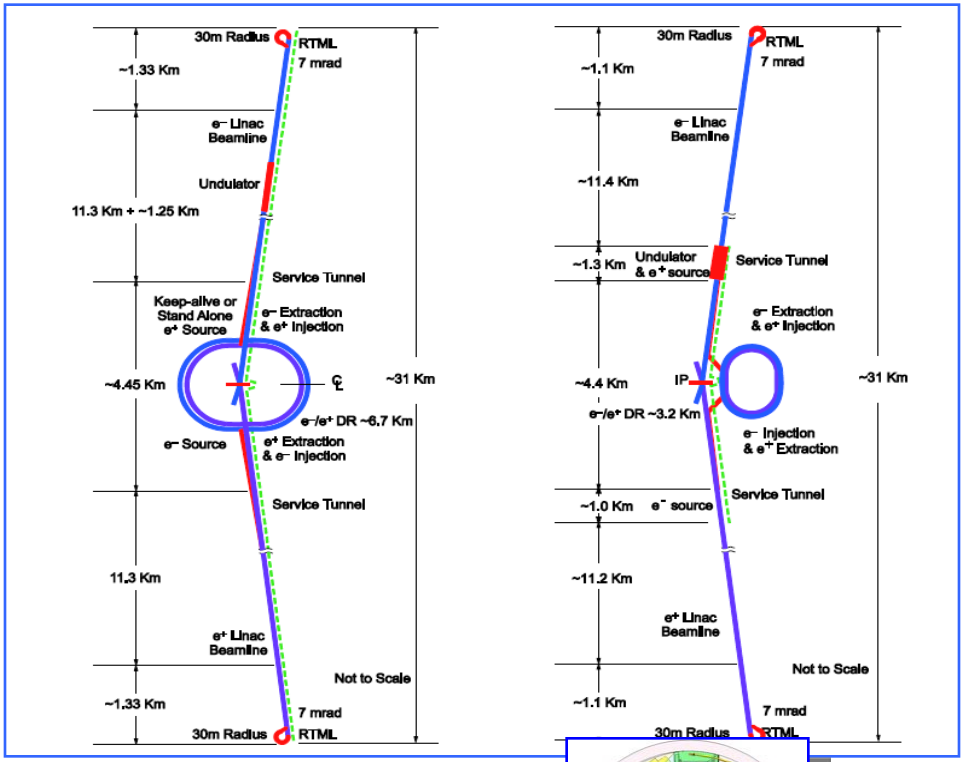
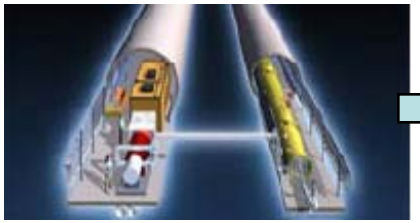
ILC Design Update in SB2009

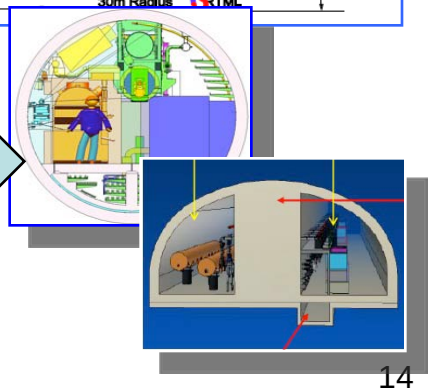
RDR → SB2009

Motivation: Cost containment

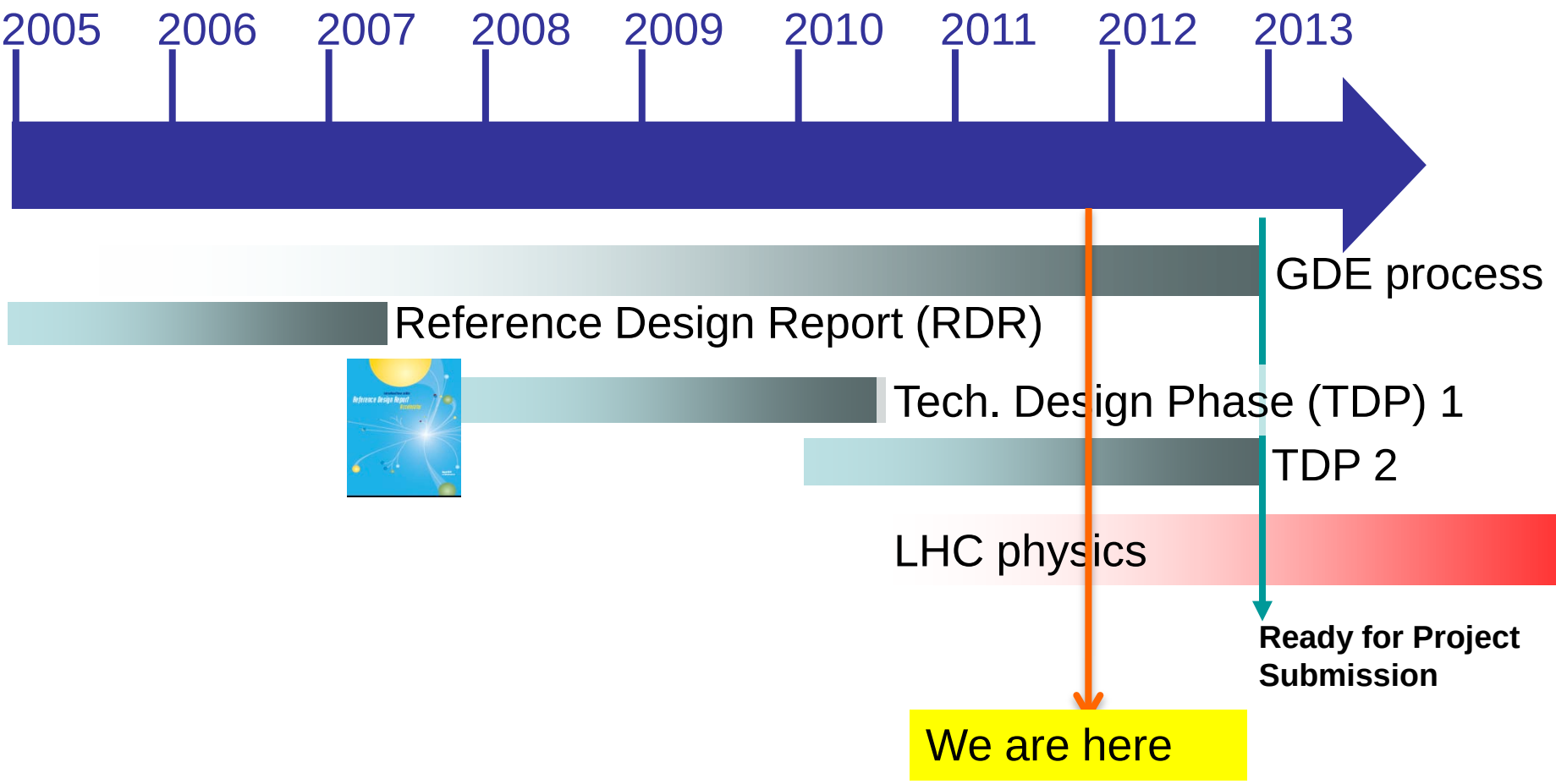
- Single accelerator tunnel
- Smaller damping ring
- e+ target at high-energy end,
- **SCRF:** 31.5 MV/m +/- 20 %,
- **HLRF:** KCS and DRFS with RDR-RF unit as backup





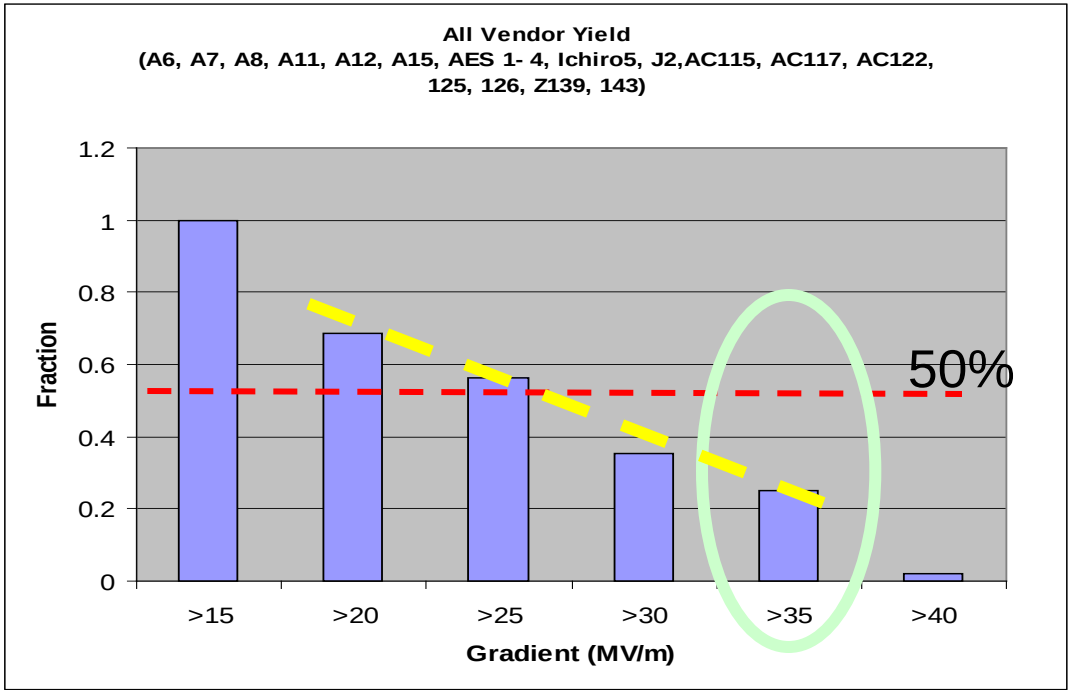


GDE: ILC Timeline



Global Yield of Cavities in 2008

Originally reported by H. Padamsee



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

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

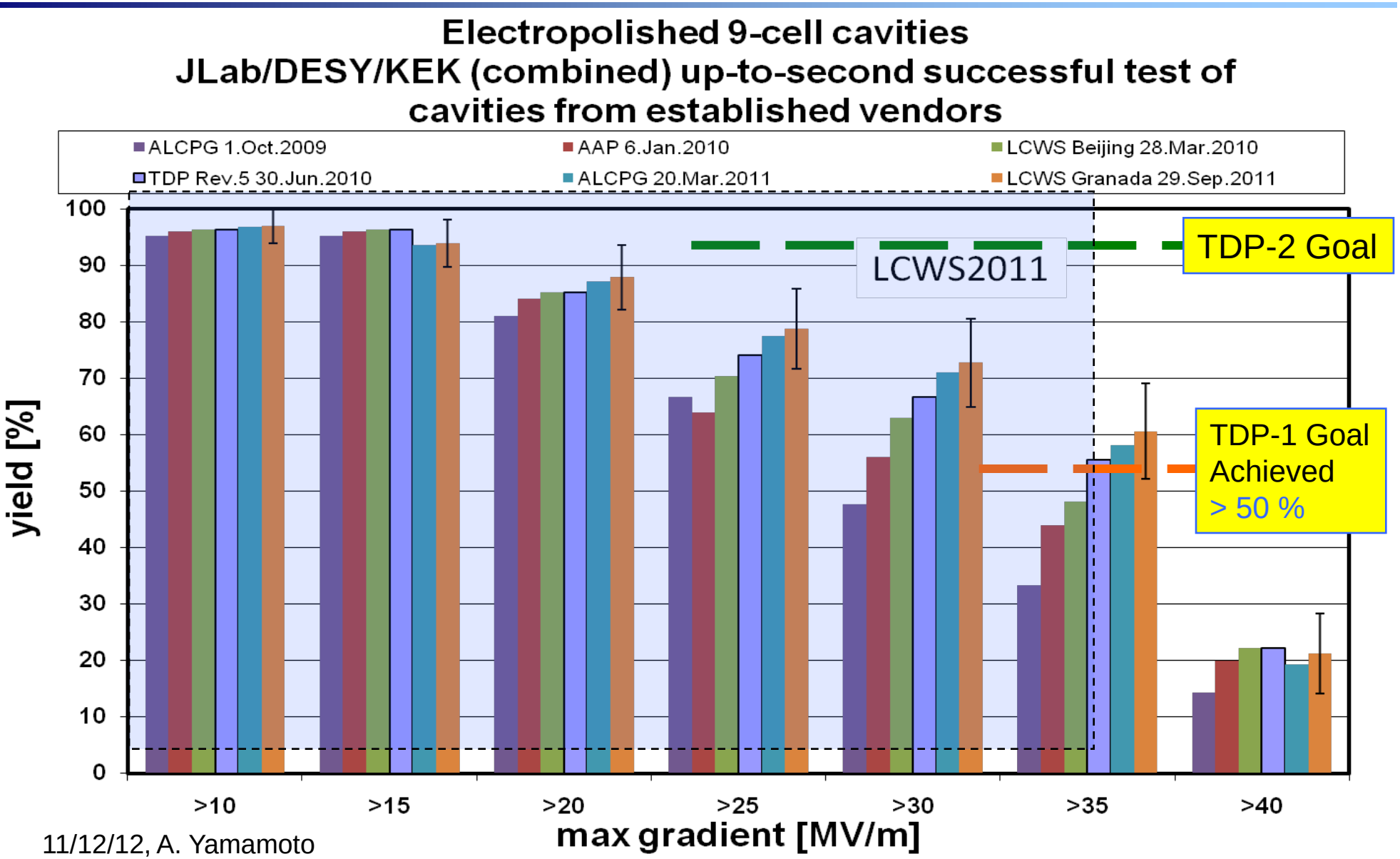
-Reported by H. Padamsee at **TTC-08 (IUAC)**, and ILC-08, (Chicago), based on the status in 2008。

Definition for production yield, not well established yet

Global ILC Cavity Gradient Yield

Plot courtesy
Camille Ginsburg of FNAL

Updated, Sept, 2011

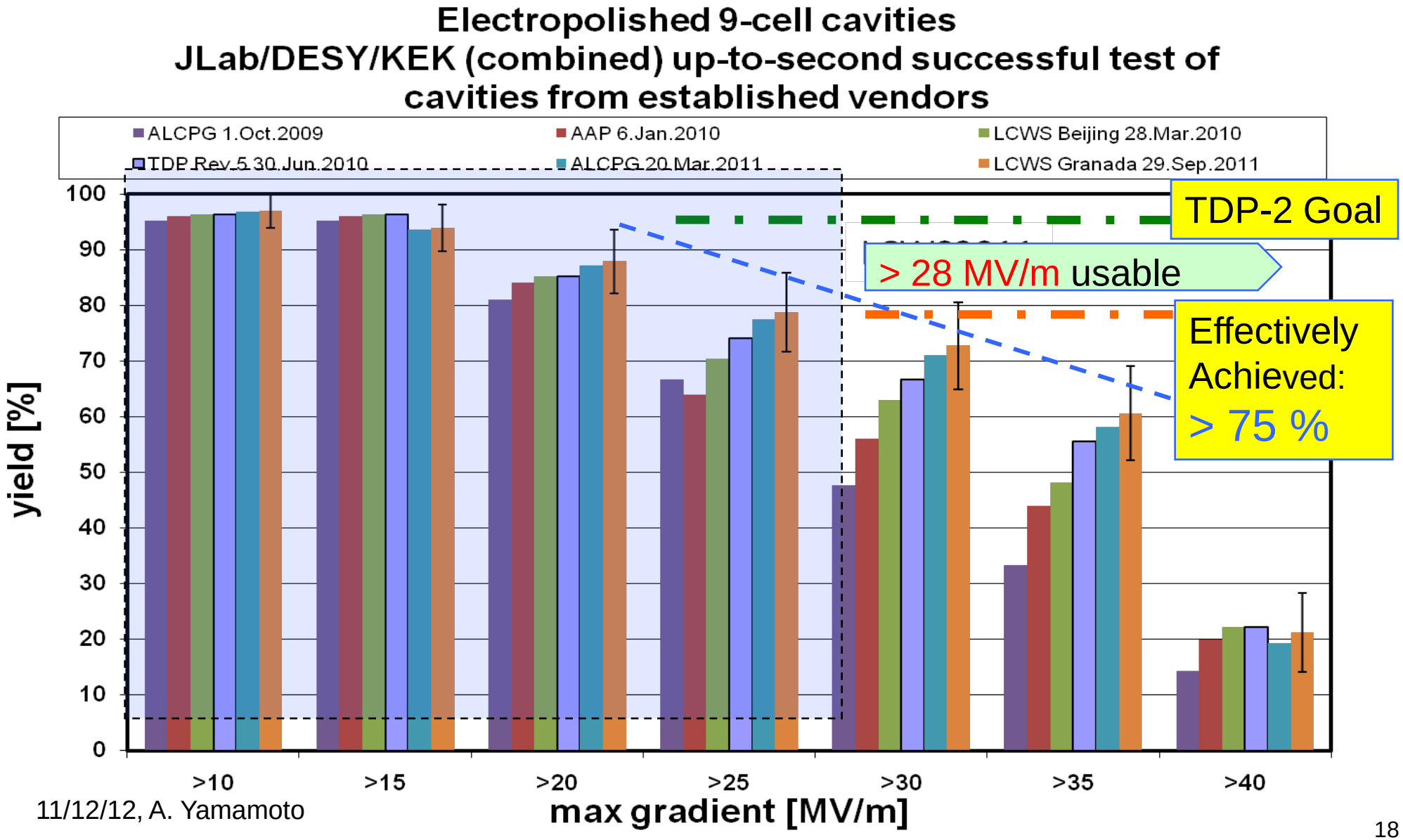


11/12/12, A. Yamamoto

Global ILC Cavity Gradient Yield

Plot courtesy
Camille Ginsburg of FNAL

Updated, Sept., 2011

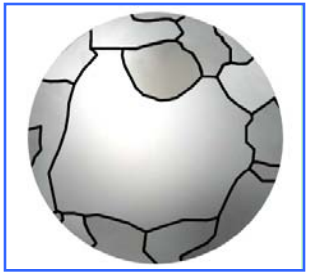


SRF Cavity and Gradient Highlights 2010~ '11

- **Americas**
  - JLab, Fermilab: routinely reached > 40 MV/m
  - Fermilab: mechanical polishing improved 9-cell cavity ACC15 gradient from 19 MV/m to 35 MV/m
  - JLAB processing and testing seamless 9-cell cavity built from DESY 3-cell seamless units

- **Asia**
  - PKU-JLab reached 28.6 MV/m
  - MHI-KEK reached ≥ 40 MV/m gradient at Q0 6.2E9
  - KEK-JLAB: ACD shape cavity ICHIRO7 reached 40 MV/m gradient at Q0 8E9
  - **India-Fermilab** collab.: Single-cell + CBP reach 40 MV/m

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



Courtesy: E. Harms

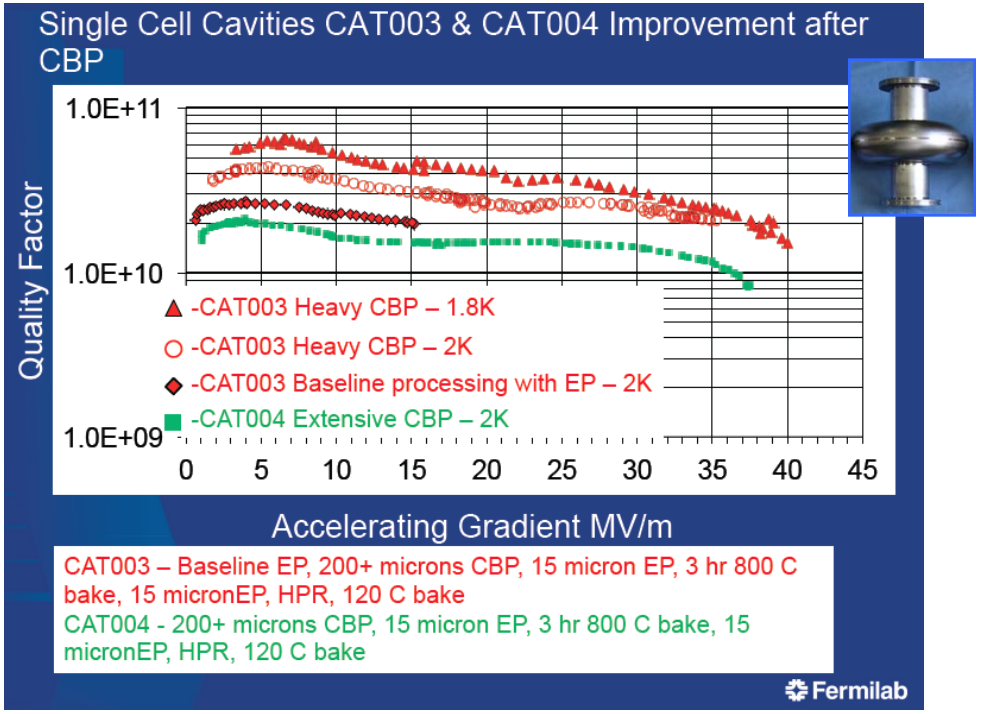
Progress in India-Fermilab Collaboration

Fermilab:

- **Surface process with CBP**
- **Vertical test**

India collab. (RRCAT, IUAC, et al) :

- **Single-cell cavity fabrication including EBW work**



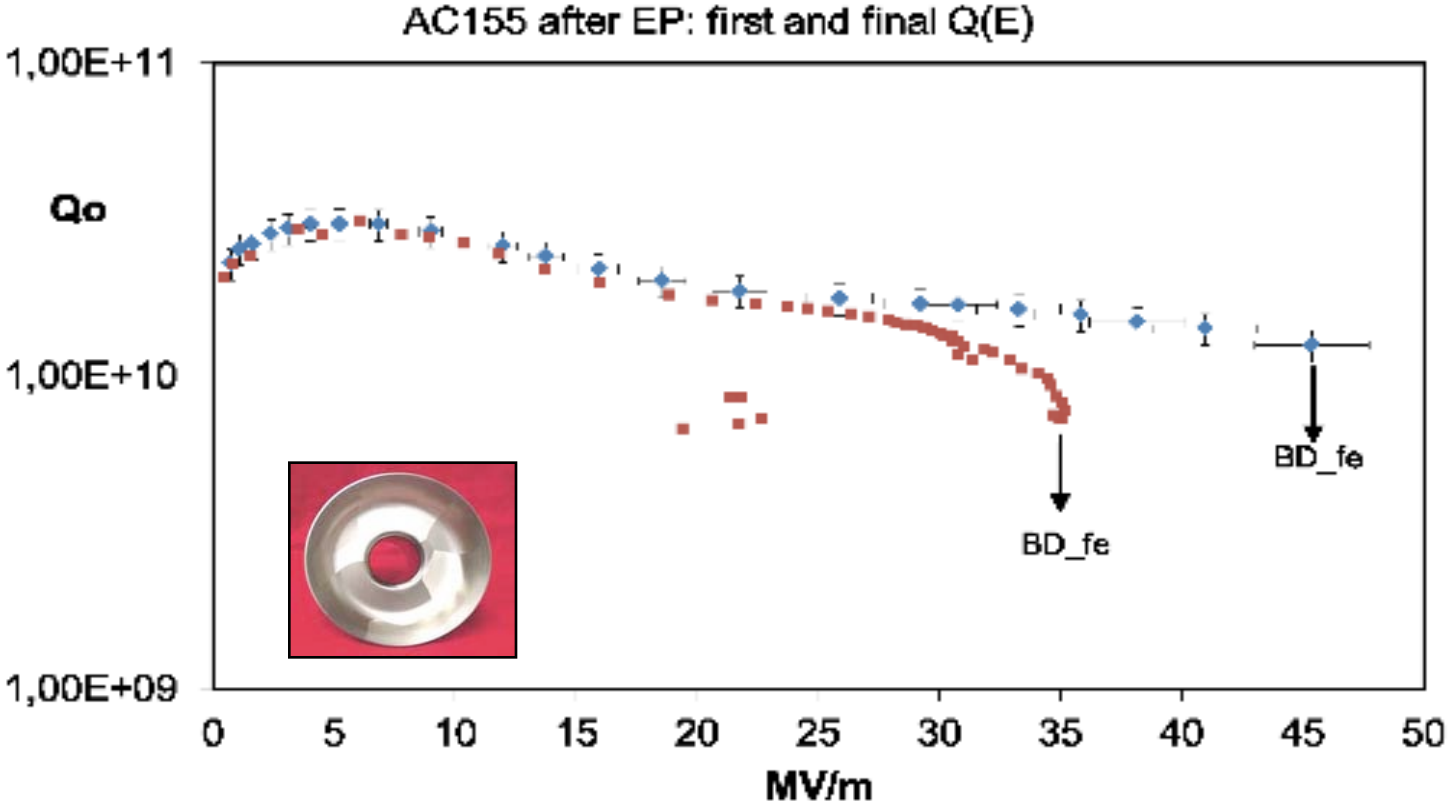
Single-cell cavity (India) + Tumbling (Fermilab) reached 40 MV/m at 1.8 K, and 37.5 MV/m at 2 K!!

Large-Grain Cavity AC155

Reached > 45 MV/m at Q0 > 1E10, at DESY

Heavy BCP + EP + low temperature bake

> **Re-test after 300 K:** Final $Q_0(E_{acc})$ at 2K: **45 MV/m @ > 10^{10}** ; some FE

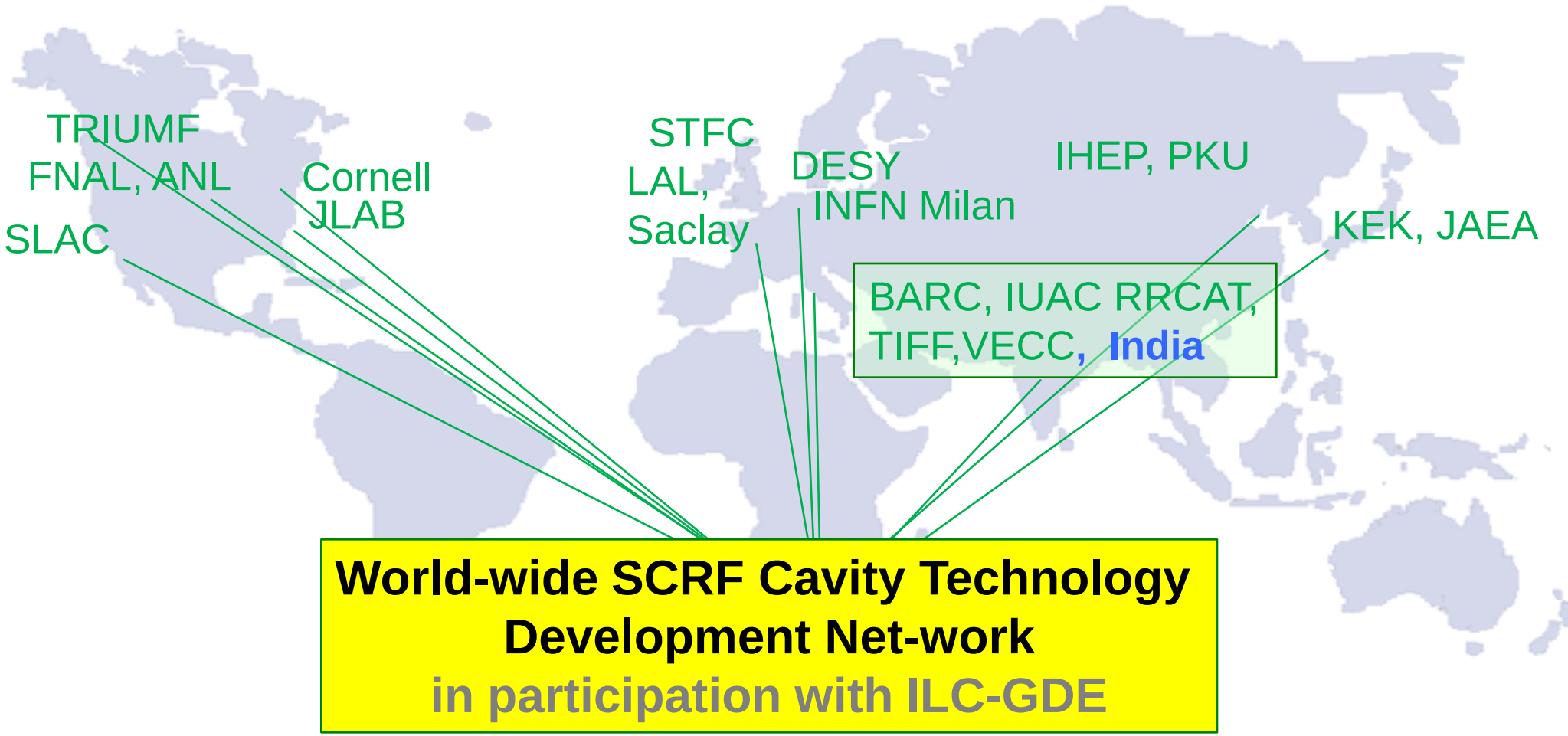


- Final mode measurements: 47 – 51 MV/m

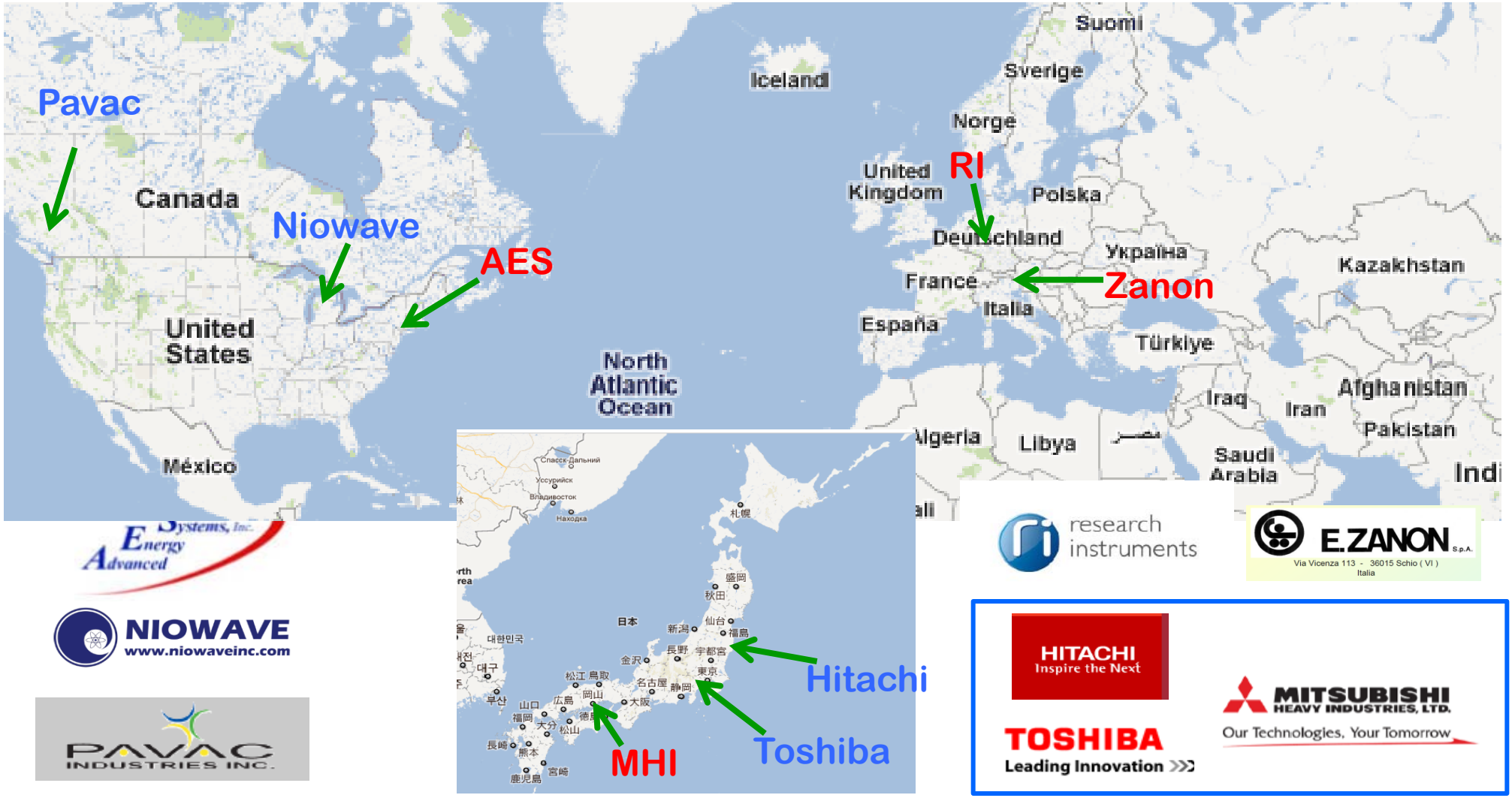
- Second Sound done

7 more cavities on the way…

Global SCRF Cavity Development for ILC



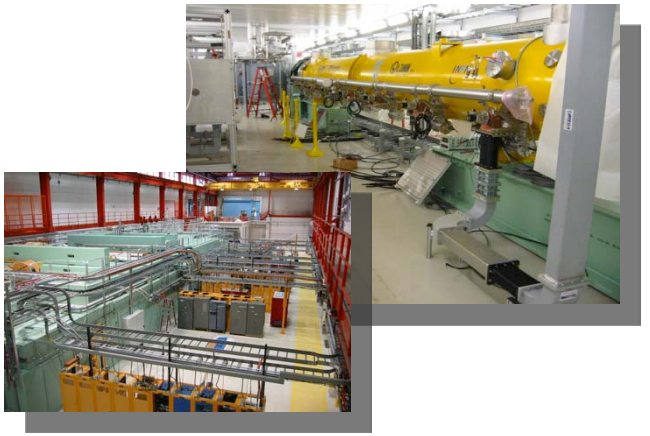
Vendors for SCRF cavity around the world



Integrated Systems Tests: *2009 ~*

FLASH (DESY)
- TDP focus
- 7 CM → 1.2 GeV beam
- photon user facility

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



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

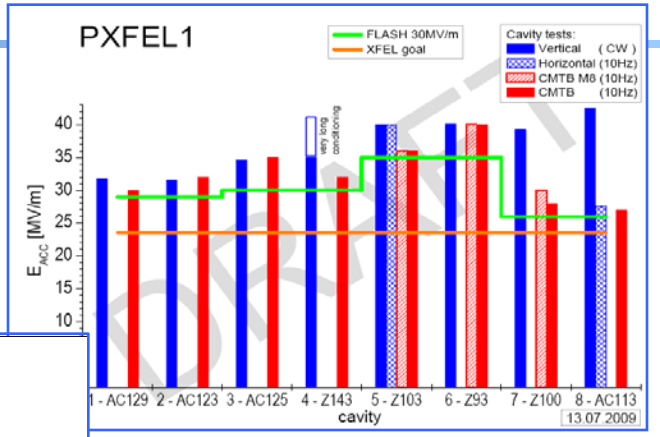
"9mA experiment"
achieved ~1800 bunches at 9mA in 09.2009

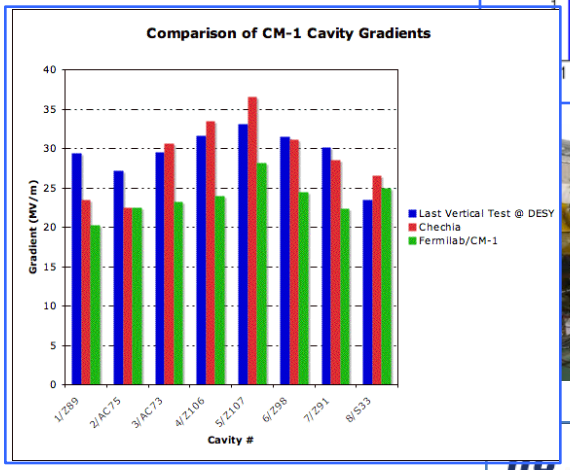
$\Delta E/E_{RMS}$ ~0.5% (@ 0.8 GeV)
~0.1% within pulse

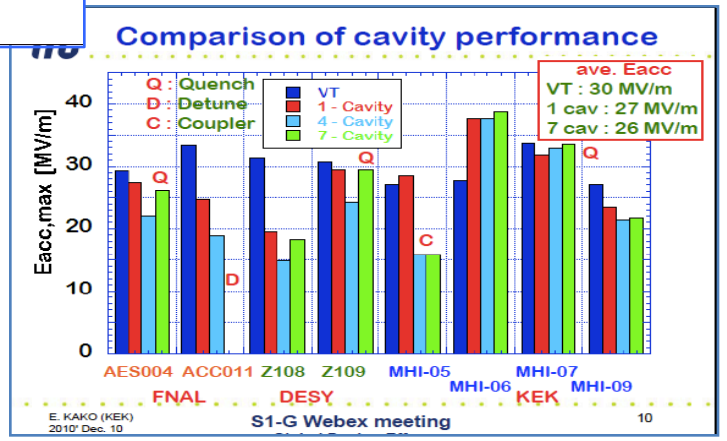
Full systems integration testing

Cryomodule Development & Tests

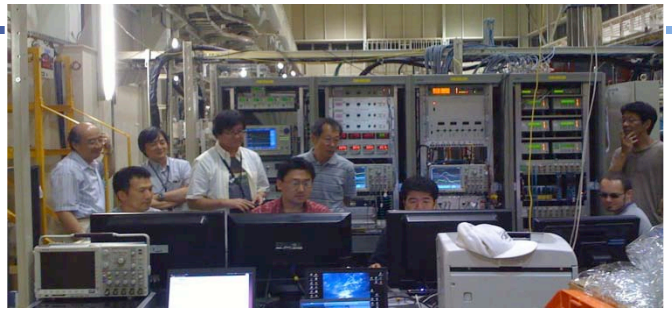
- FLASH (DESY)
  - <32 MV/m> in CM operation, PXFEL-1
  - **< 30 MV/m>** in FLASH operation
- NML-CM1 (Fermi)
  - In progress
- STF: S1-Global (KEK)
  - Global effort
    - DESY/INFN/FNAL/SLAC/ KEK
  - <26 MV/m> in CM operation





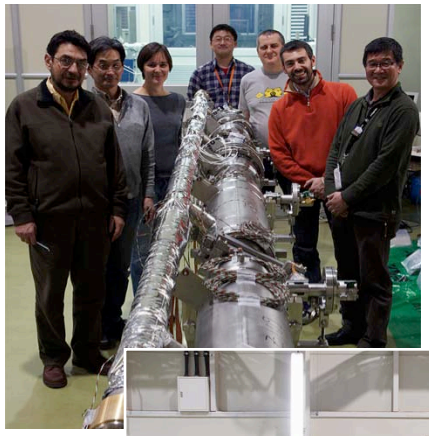


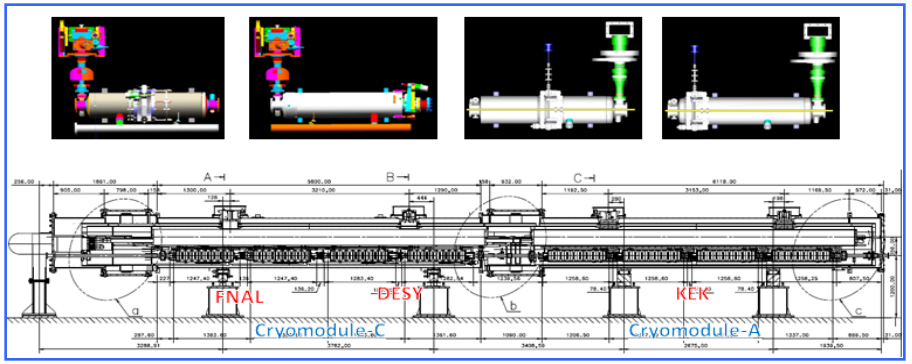
S1-Global Assembly/Test with Global Effort

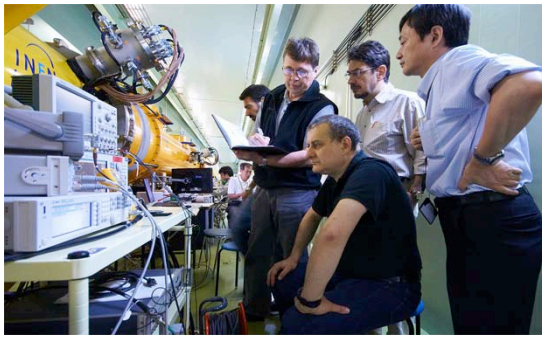


DESY, FNAL, Jan., 2010

DESY, Sept. 2010







FNAL & INFN, July, 2010

INFN and FNAL Feb. 2010

March, 2010

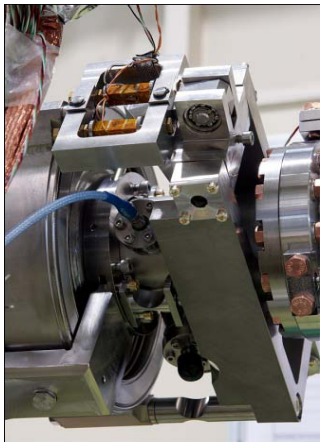
DESY, May, 2010

June, 2010 ~

Various Cavities, Tuners, Couplers in S1-G

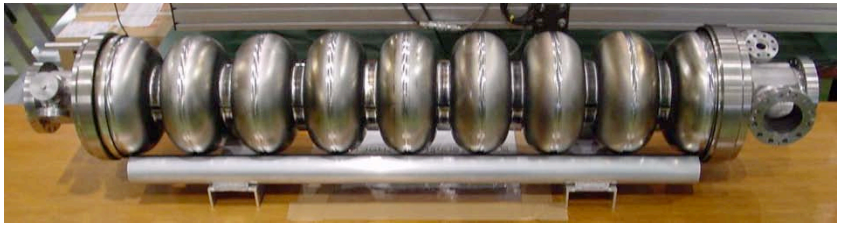
TESLA Cavity (DESY/FNAL)

Blade Tuner (INFN/FNAL)

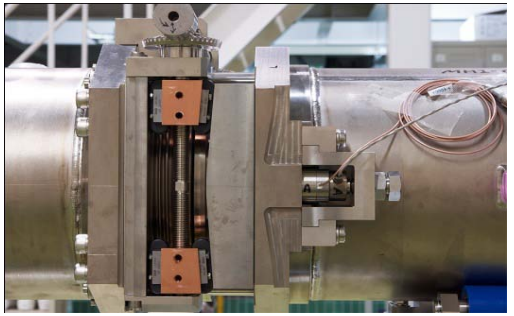


Saclay Tuner (DESY)

TTF-III Coupler (DESY/FNAL)



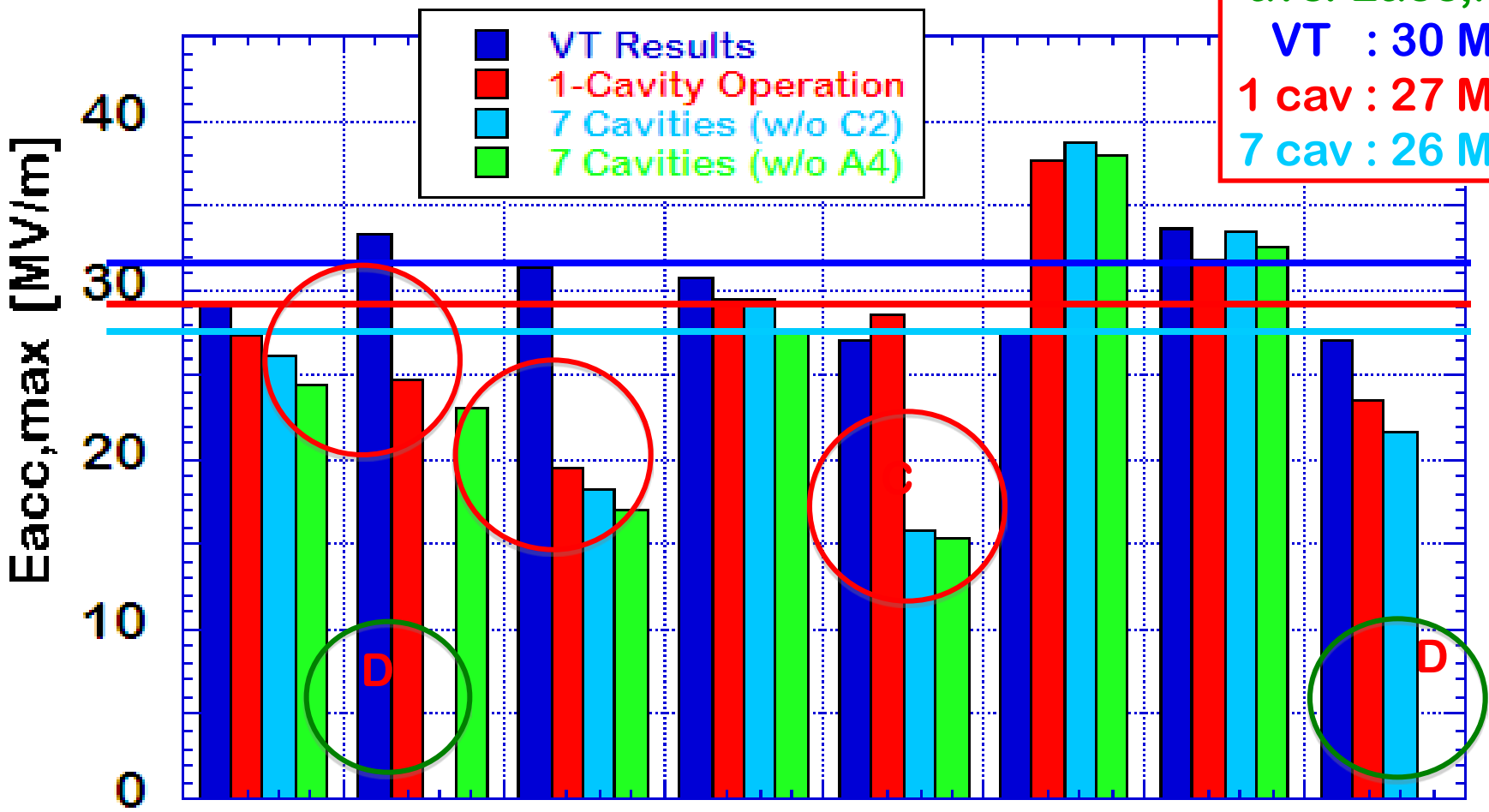
Tesla-like Cavity (KEK)



Slide-Jack Tuner (KEK)

STF-II Coupler (KEK)

Comparison of cavity performance

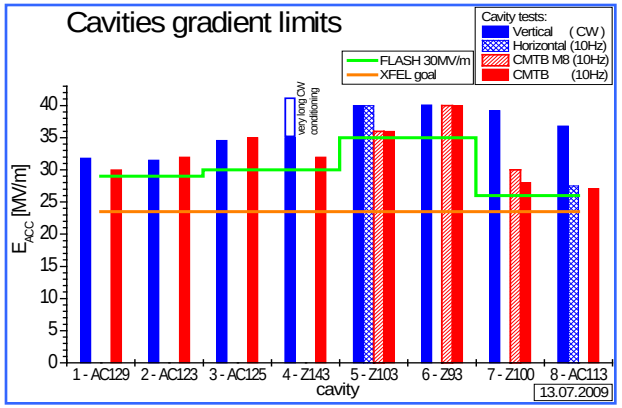


D : Detune
C : Coupler

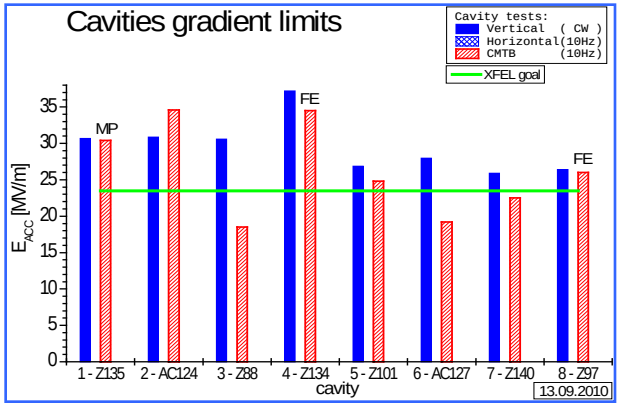
- Performance reduction in two cavities and one coupler
- Tuner mechanics trouble in two cavities

Gradient Degradation to be investigated and improved

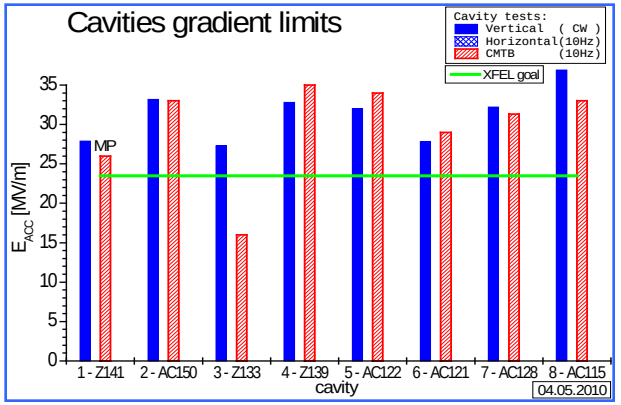
D. Kostin, E. Kako, E. Harms



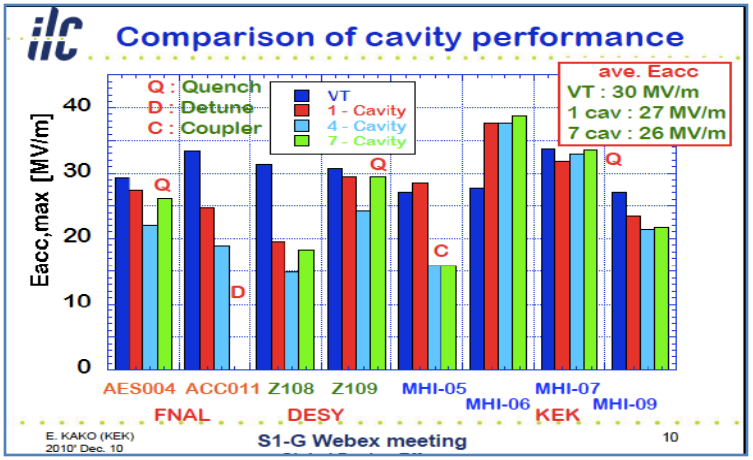
PXFEL-1

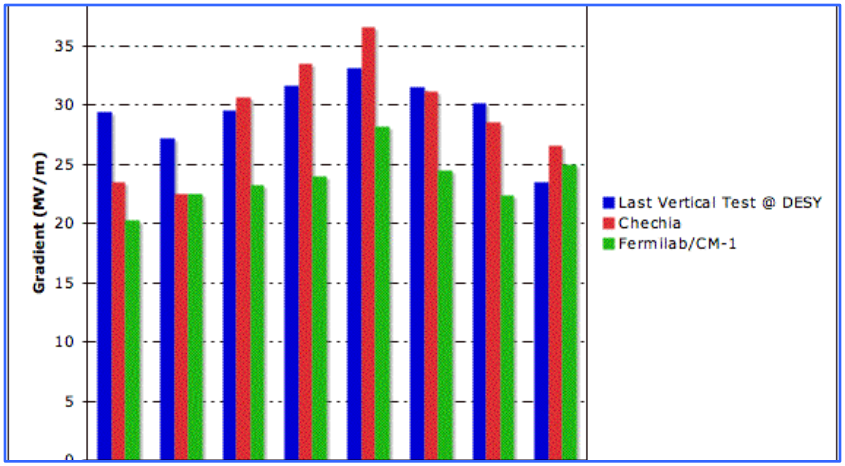


PXFEL-2



PFEL-3





12 of 40 cavities degraded after installation into CM

Many Thanks for

Global Collaboration for S1-Global

A. Bosotti, C. Pagani, R. Paparella, P. Pierini,
INFN (Italy)
K. Jensch, D. Kostin, L. Lilje, A. Matheisen, W.-D. Moeller,
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Y. Pischalnikov, T.J. Peterson, M. Ross, W. Schappert,
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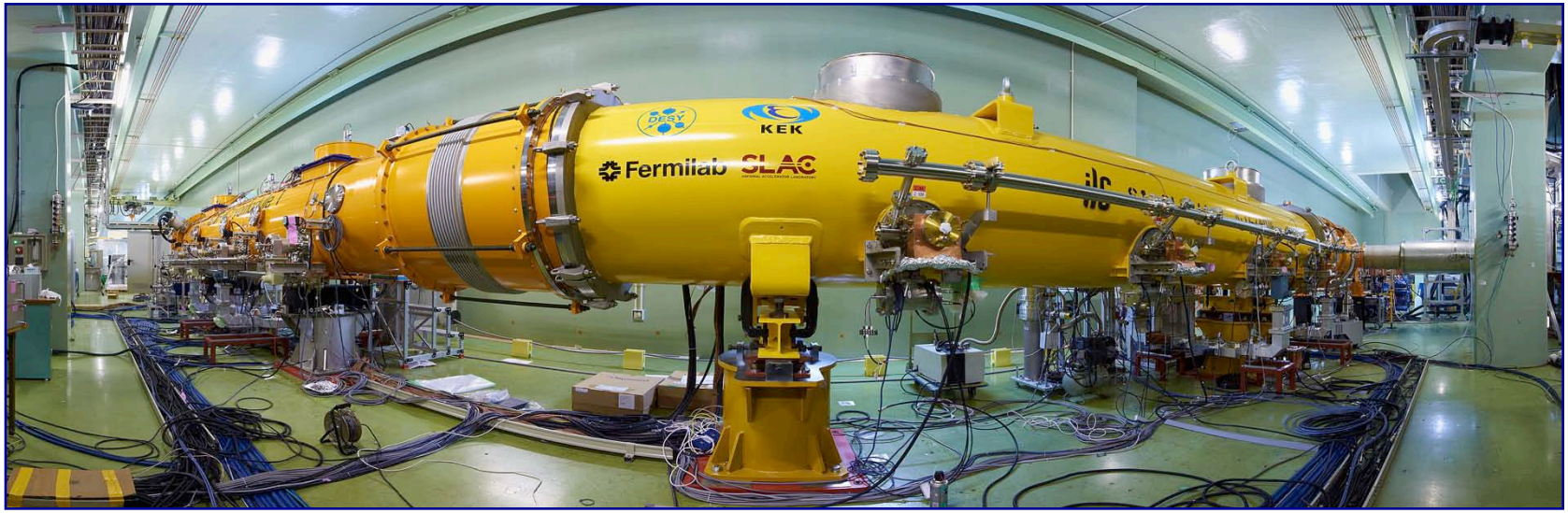
N. Toge, K. Tsuchiya, K. Watanabe, S. Yamaguchi,
A. Yamamoto, Y. Yamamoto, K. Yokoya,
KEK (Japan)



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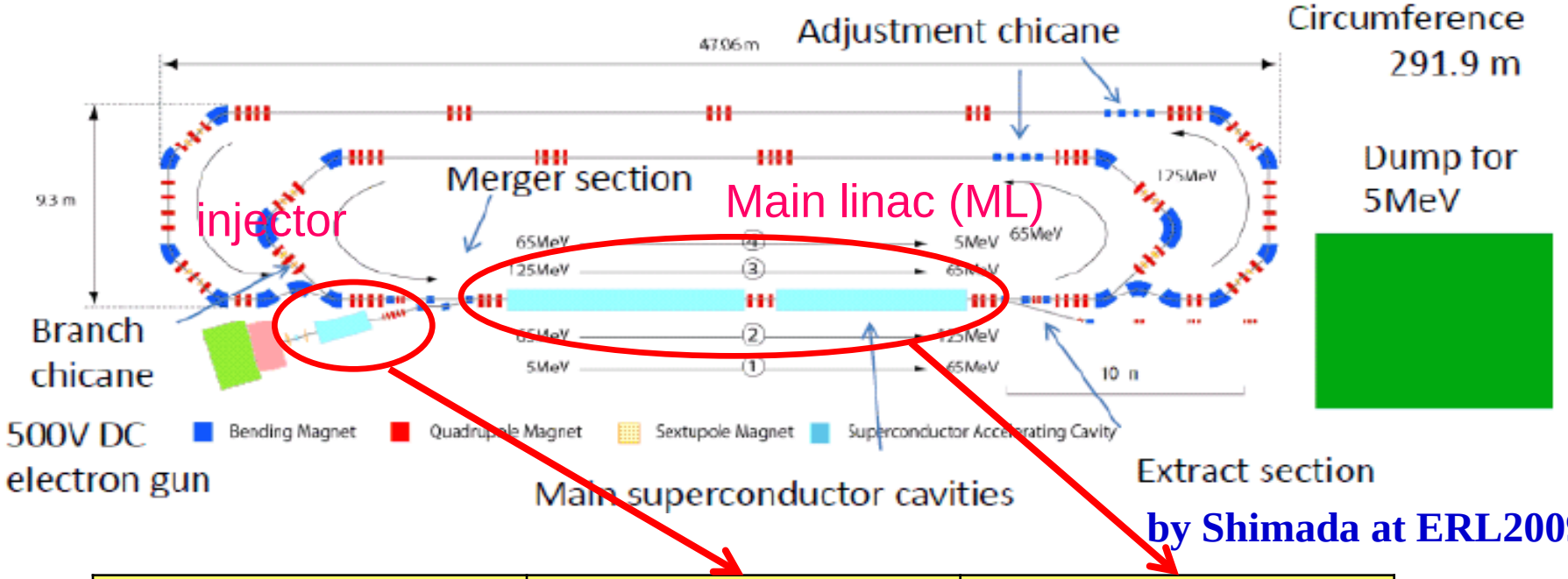
Development of SCRF for cERL

Last workshop in 2009:

✓ cERL was planed to obtain the basic technology for ERL



35-245 MeV	5-10 MV	15-20 MV/m
10-100 mA	2cell x 3	9cell x 8
2-loop ERL	170x2 kW/cavity	20 kW/cavity

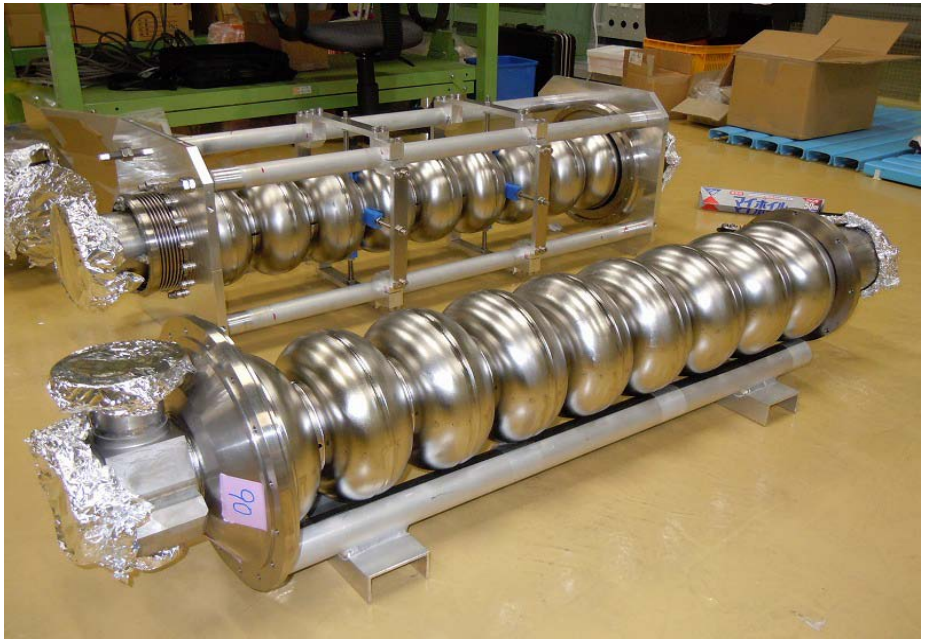
9cell structure for the cERL main linac

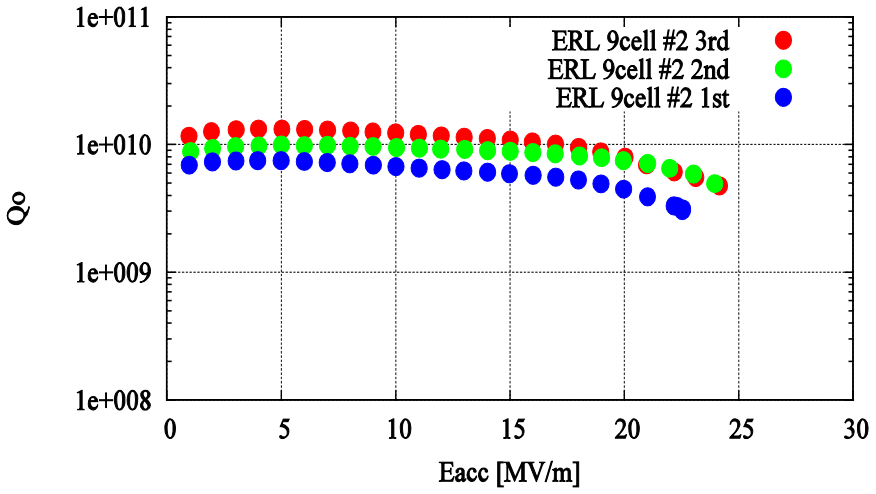
ERL2011 WG3
Oct 17, 2011
T. Furuya (KEK)

Development of ML SC cavity

- The cavity shape of Esp/Eacc=3 achieves the gradient of **25 MV/m.**
- However, several emitters appeared and degraded the gradient, after discharging.
- Diagnostics using radiation monitor is under developing.

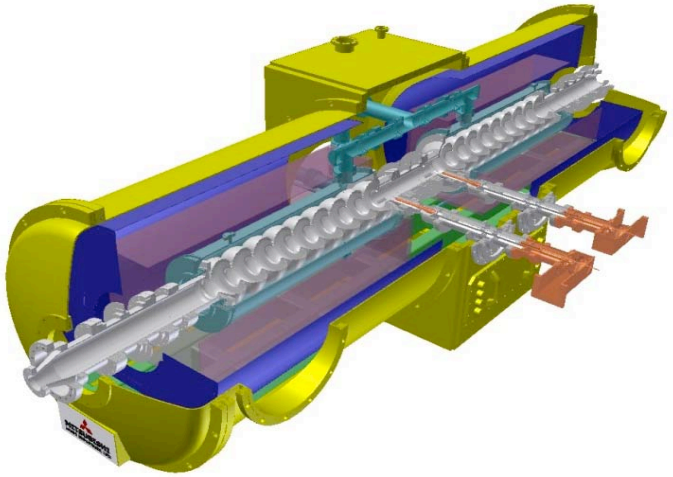
- Two cavities for cERL were completed, and v. tests are continued till the end of this year.
- Total assembling is scheduled in the summer of 2012.



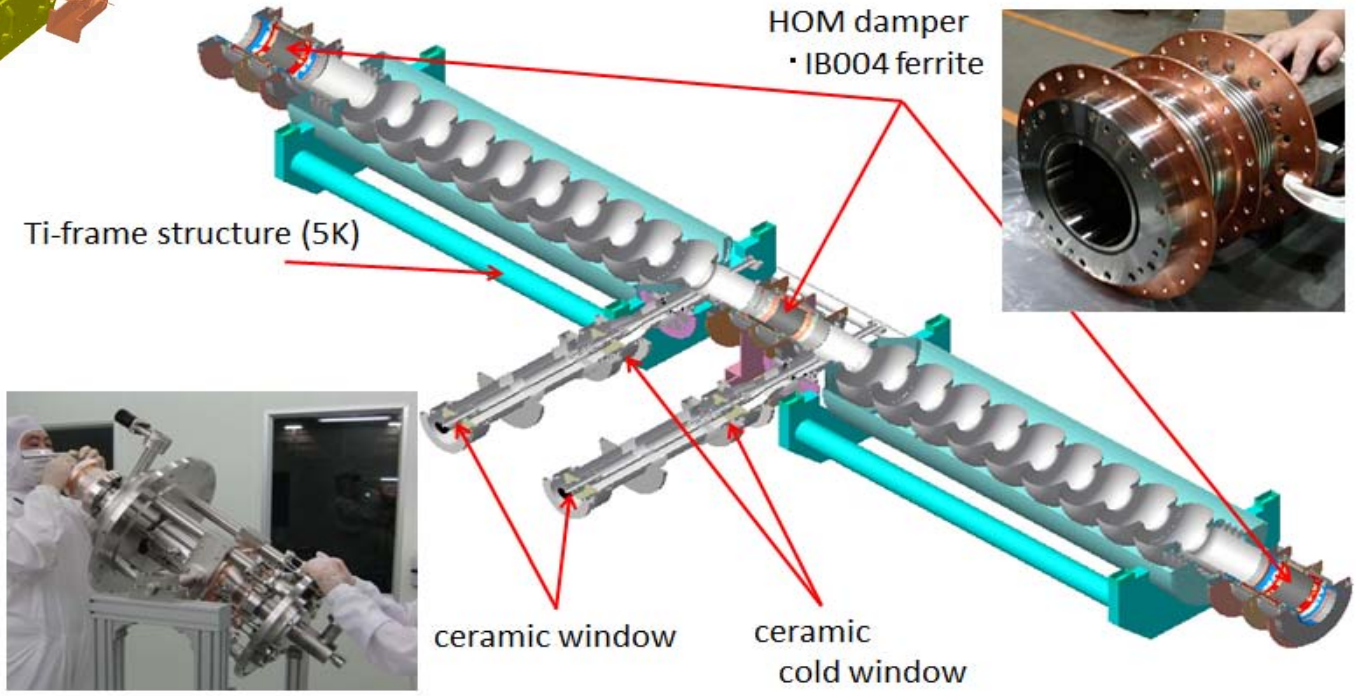


9cell structure for the cERL main linac

Development of ML cryomodule



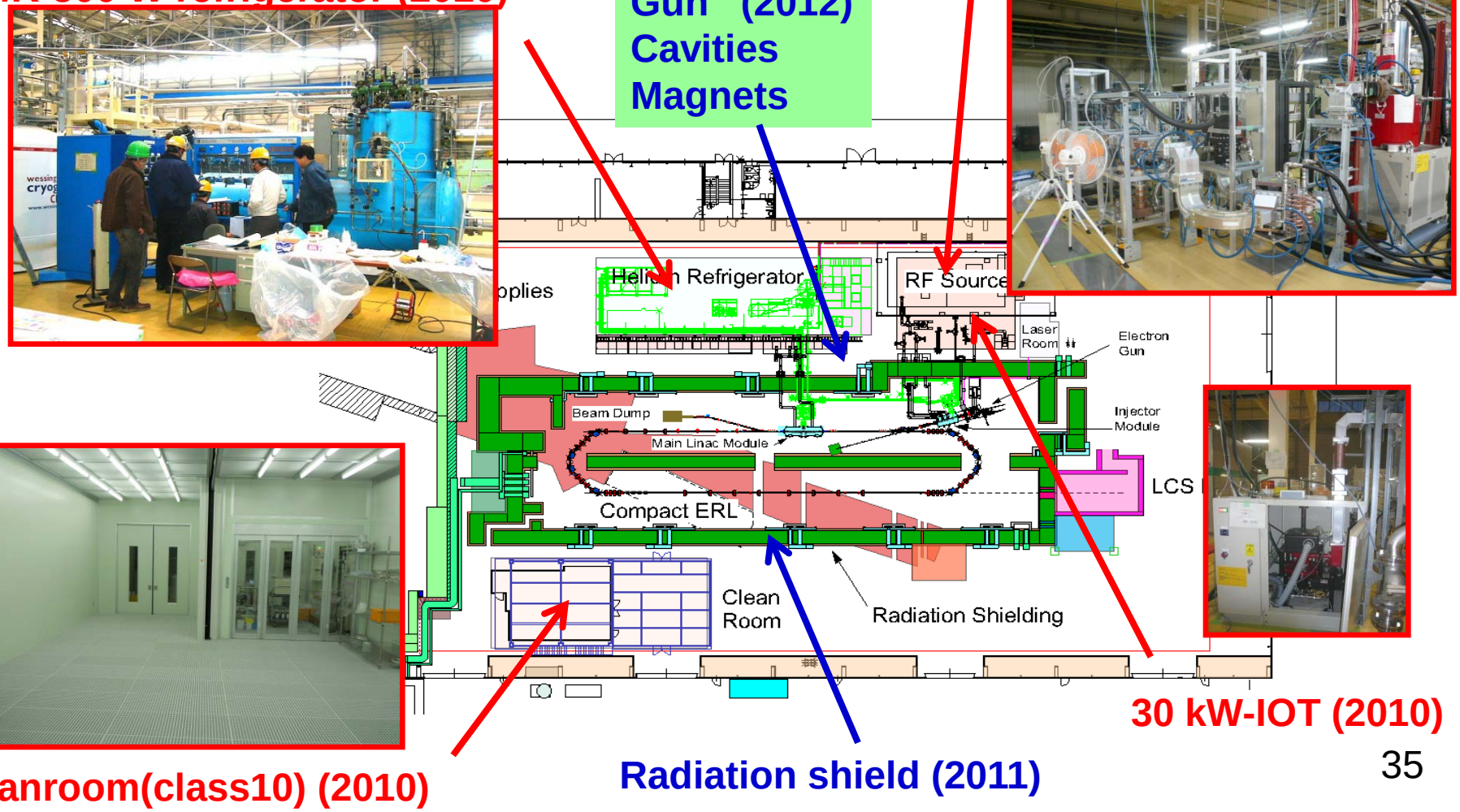
- Two 9cell cavities are combined by ferrite HOM dampers.
- Total assembling is scheduled in the summer of **2012.**



Progress of cERL

ERL2011 WG3
Oct 17, 2011
T. Furuya (KEK)

Facility of cERL (ERL Test Facility)



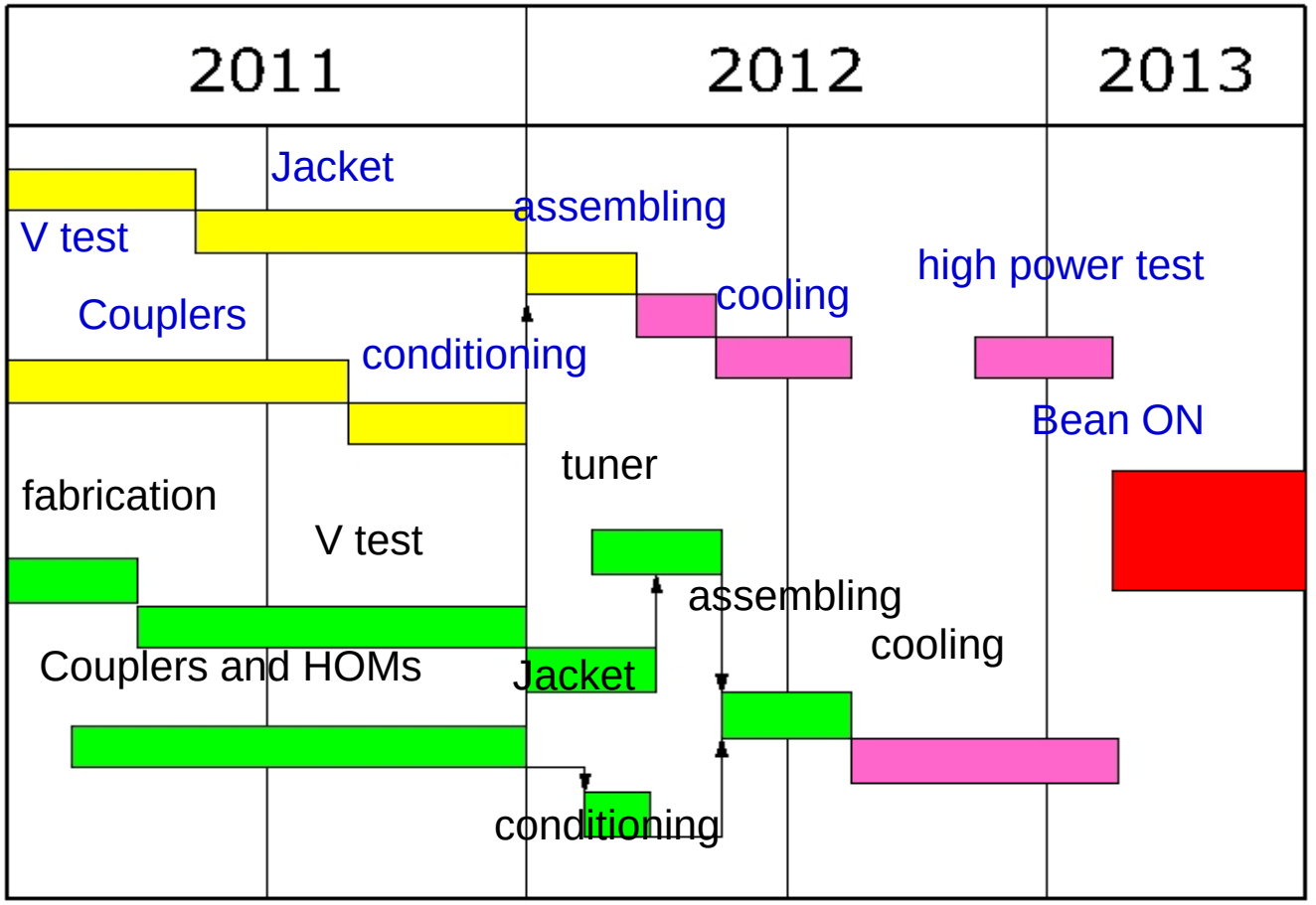
Progress of cERL

ERL2011 WG3
Oct 17, 2011
T. Furuya (KEK)

Facility of cERL (ERL Test Facility)

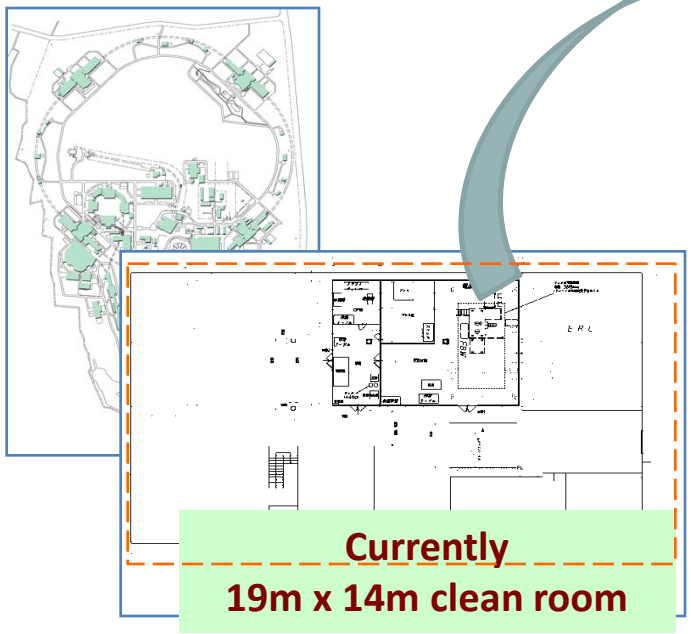
Injector cavity

ML cavity

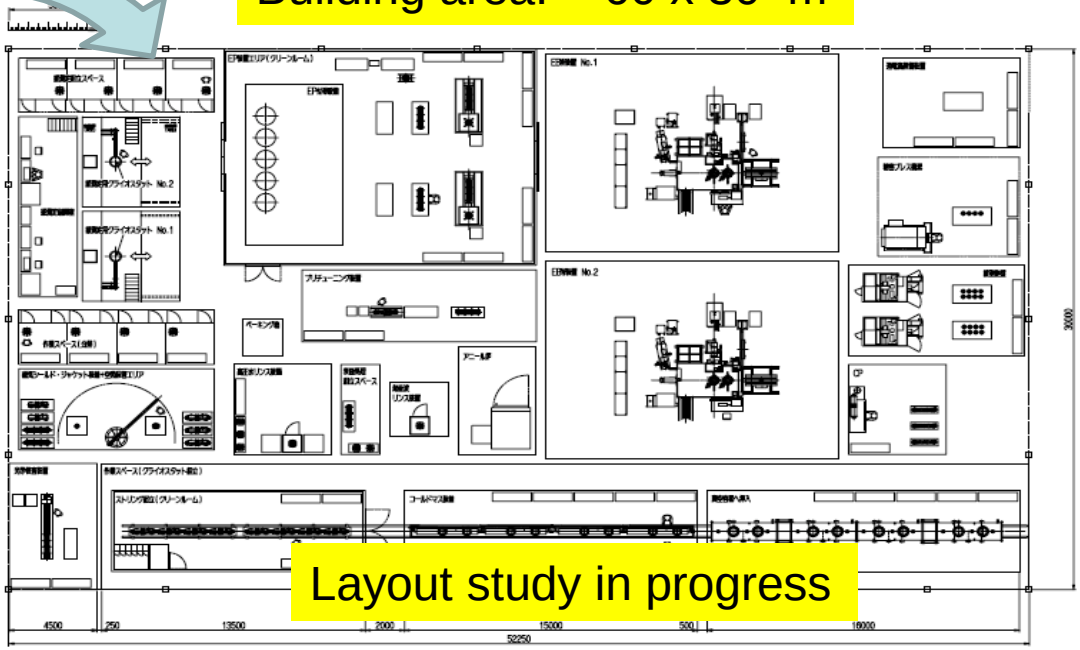


tuner

Cavity Mass Production Study at KEK (in-house)



Building area: ~ 60 x 30 m



A proposal for Hub-Lab taking roles of:

- Industrial Technology development center in R&D stage, extendable for further industrial R&D beyond TD Phase
- 'Leading factory' for industrialization effort:
  - Production capacity of **~ ¼ of 20 %** (**~ 150** cavities/year, max.)

Cavity Fabrication Facility (CFF) at KEK

Pilot Plant for cavity fabrication

Clean room 19 m x 14 m x 5 m H

Cleanness ISO 5 to 6

KEK

by K. Ueno (KEK)

EBW machine

60 ~150 kV

0 ~100 mA

15 kW

Vertical lathe

Press machine

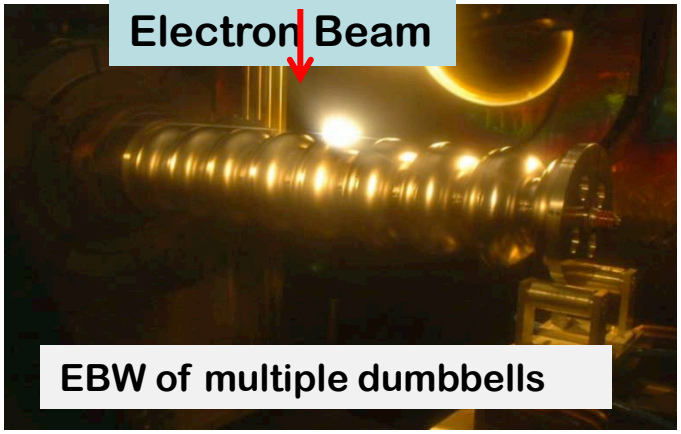
CP room, Draft chamber

3D inspection equipment for Nb surface

Fabrication of KEK-01 cavity

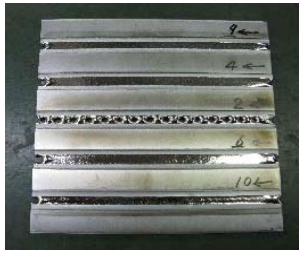
Cavity in-house fabrication at KEK

EB Welding at TOSEI co. Ltd.

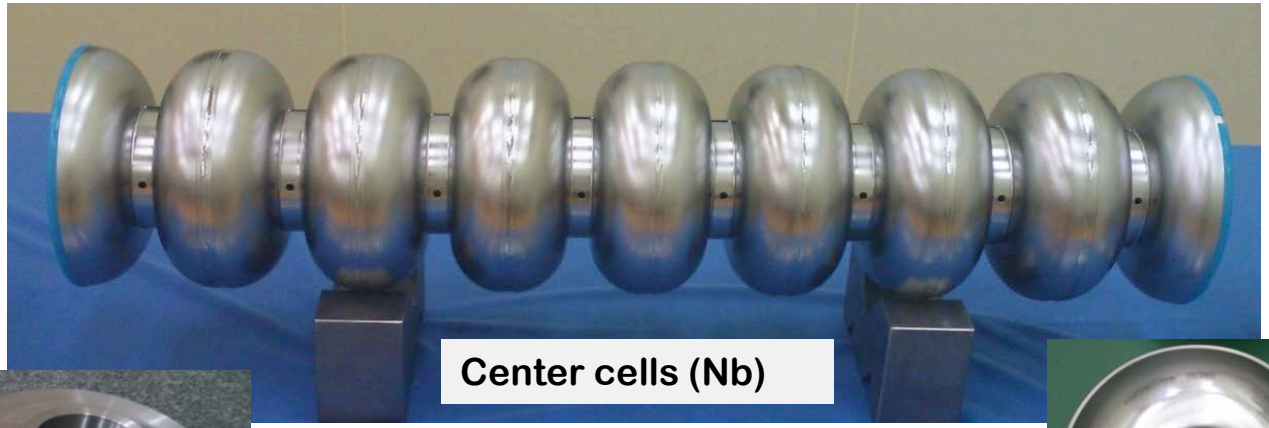


KEK

by T. Saeki (KEK)



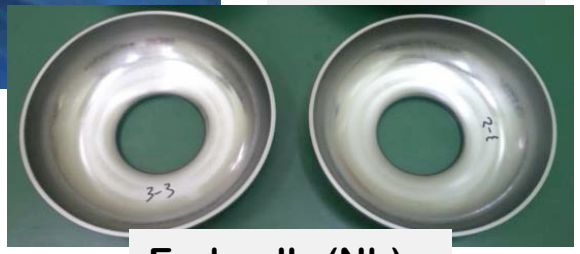
Dumb-bell (Nb)



Beam-pipes (Nb)

End-Plates (Ti)

Fabrication of KEK-00 cavity



End-cells (Nb)

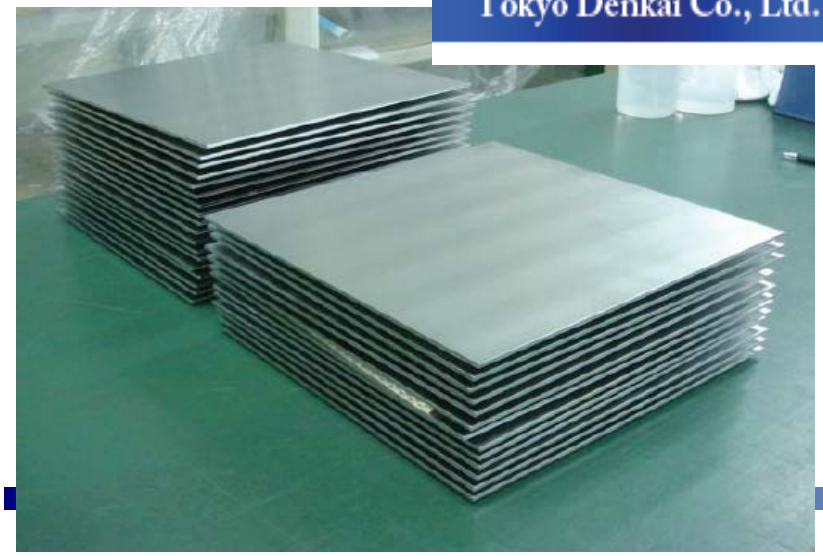
Summary

- ADS development is in progress at JAEA, Japan
- SCRF technology is common and critical technology to realize ADS, as well as ERL and LC in future,
- ILC global effort advances the SCRF technology with world-wide cooperation,
- KEK is contributing both ILC and ERL SCRF technology which commonly to be applied to ADS, and is making effort to boost an in-house fabrication and test facility for our common future projects.

backup

- ..

Production of Superconducting Cavities



For 3GeV-ERL (at KEK)	5,000 Nb sheets (Total; 4.2 ton)	250 cavities / 3 years
For XFEL (at DESY)	12,000 Nb sheets (Total; 10 ton)	600 cavities / 3 years (+ α cavities)
For ILC (?somewhere)	340,000 Nb sheets (Total; 280 ton)	17,000 cavities / 6 years

R. Geng

Cavity R&D Progress and beyond 2012

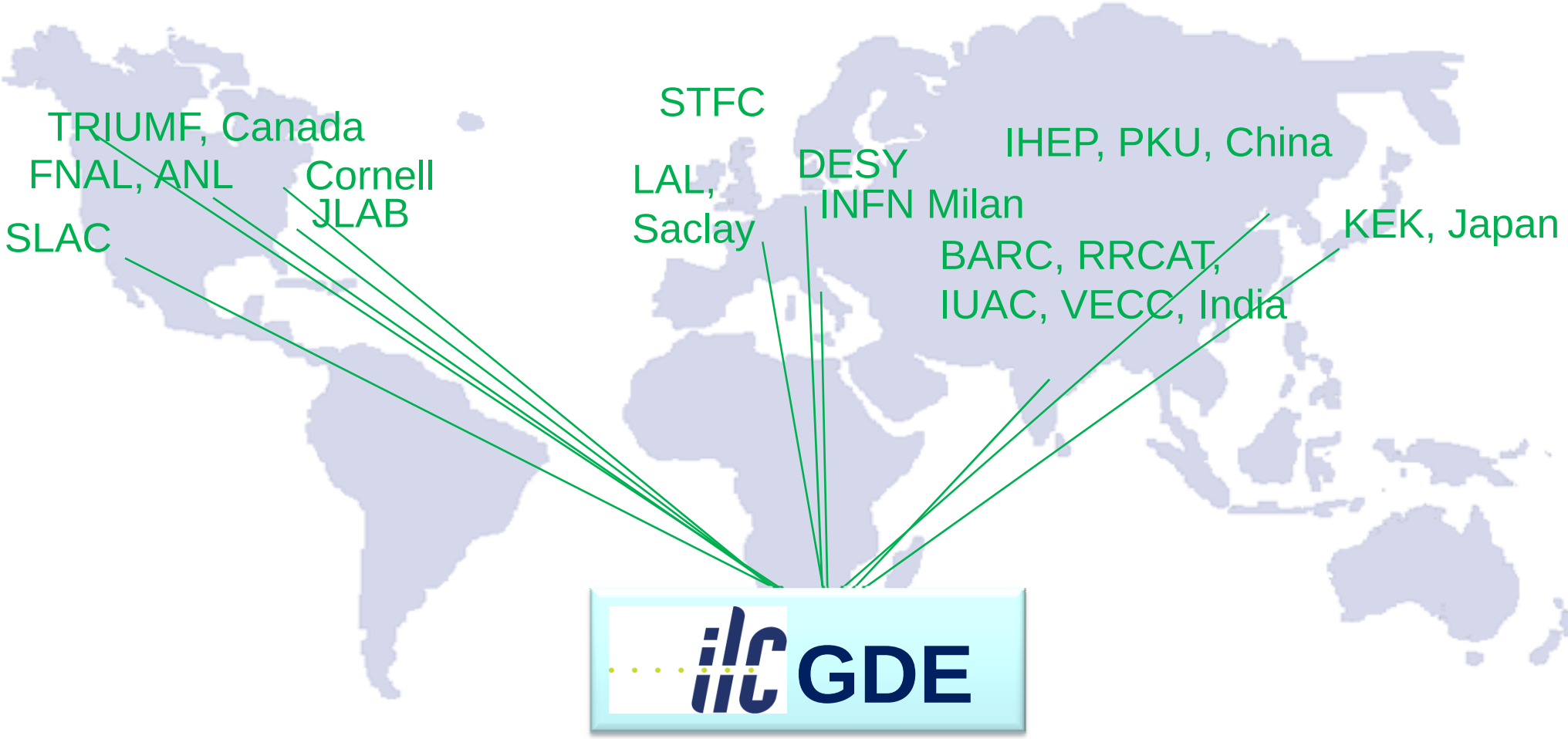
- ILC: driver for high gradient SRF cavity technology
  - Pursuit of ultimate gradient continues to motivate innovation
  - Gradient success continues to benefit SRF based accelerators

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

11/12/12, A. Yamamoto

ADS and SCRF Cavity in Japan

Global SCRF Cavity Development for ILC



S1-Global High Power Test

Sep., 2010 ~

With
Denis Kostin
(DESY) Sept. 2010

With
Yuriy Pischalnikov
Warren Schappert
(FNAL) Oct. 2010