International Linear Collider (ILC)

- Technical Progress and Prospect -

Linear Collider Collaboration (LCC)

presented by

Akira Yamamoto (KEK/LCC)

ICHEP-2016, Chicago, August 6, 2016

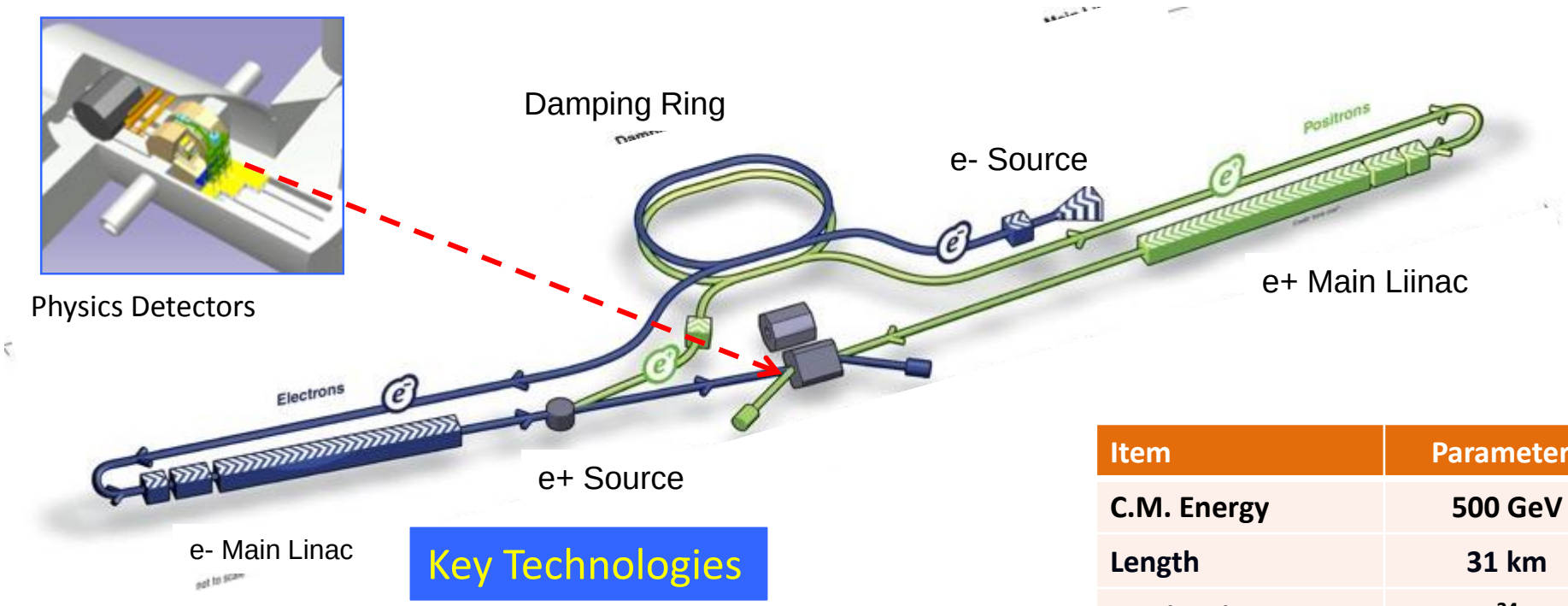
Acknowledgments

I would thank:

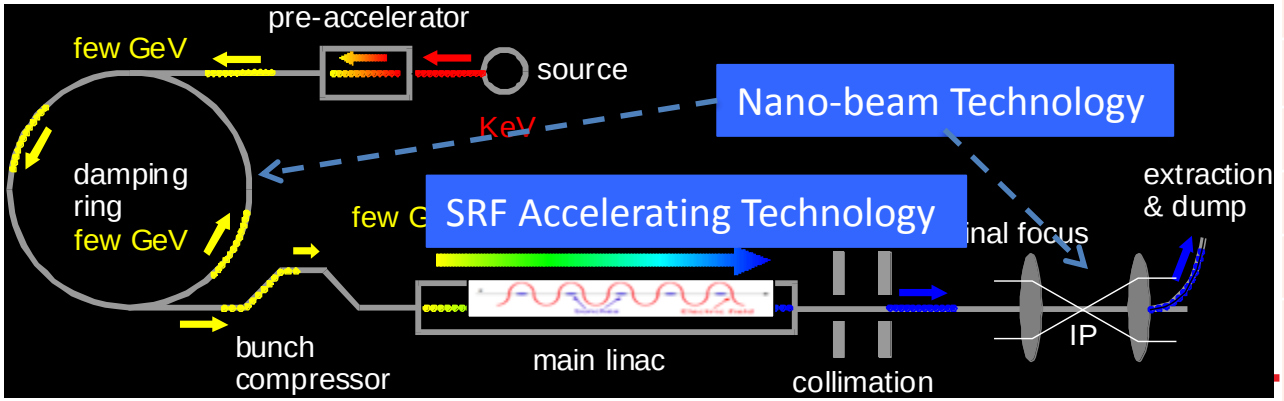
L. Evans, M. Harrison, N. Walker, D. Reschke, O. Napoly, E. Harms, S. Belomestnykh, A. Grassellino, S. Aderhold, S. Michizono, N. Terunuma, K. Kubo, T. Okugi, H. Hayano, E. Kako, Y. Yamamoto, and Linear Collider Collaboration,

for their kindest cooperation and advices to prepare for this report.

ILC Acc. Design Overview (TDR)

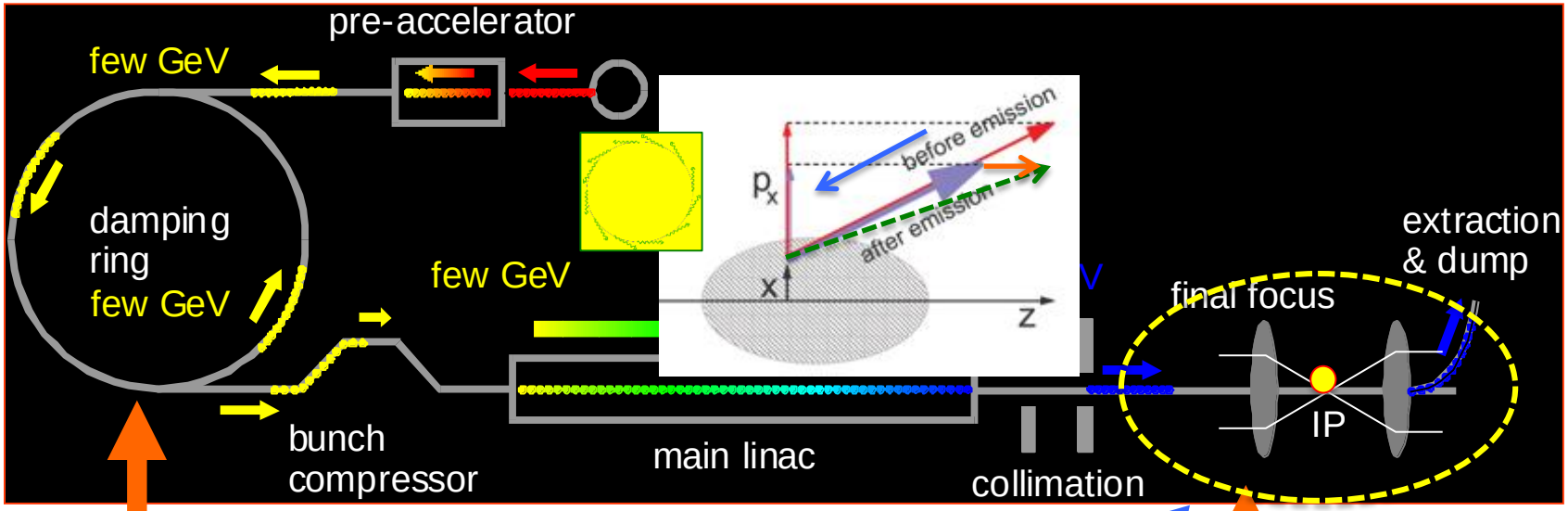


Key Technologies



Item	Parameters
C.M. Energy	500 GeV
Length	31 km
Luminosity	1.8 x10^{34} $cm^{-2}s^{-1}$
Repetition	5 Hz
Beam Pulse Period	0.73 ms
Beam Current	5.8 mA
Beam size (y) at FF	5.9 nm
SRF Cavity G. Q_0	31.5 MV/m Q_0 = 1x10^{10}

Nano-beam Technology



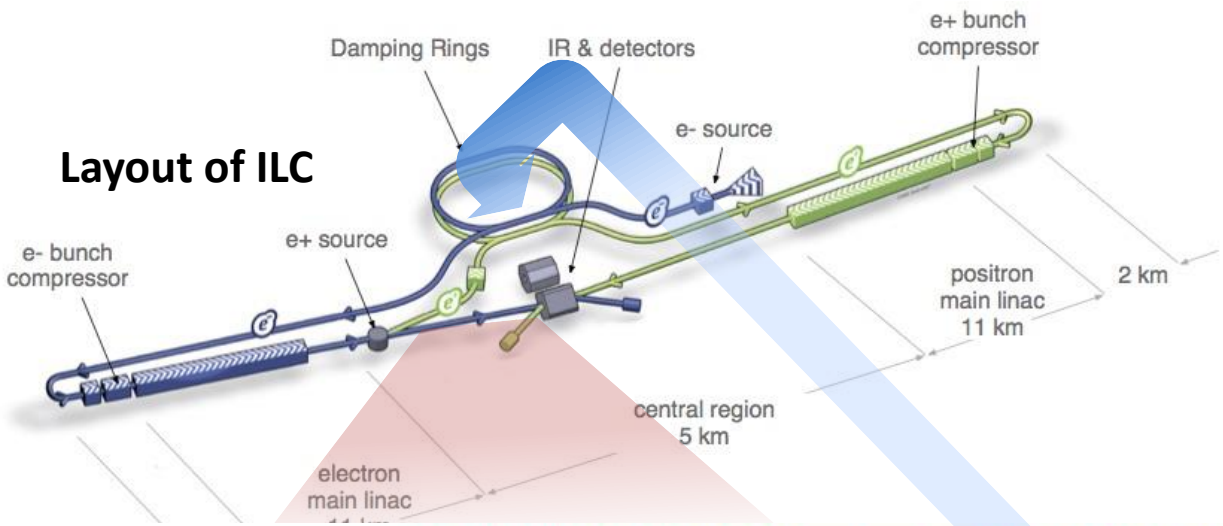
- Electron and Positron Sources (e-, e+) :
- Damping Ring (DR):
- Ring to ML beam transport (RTML) :
- Main Linac (ML) : SCRF Technology
- Beam Delivery System (BDS)

$$\mathcal{L} = f_{rep}\frac{n_b N^2}{4\pi\sigma_x^*\sigma_y^*} \times H_D$$

Nano-beam technology advanced by ATF Collaboration, hosted at KEK.

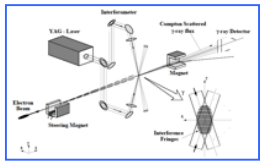
ATF/ATF2: Accelerator Test Facility

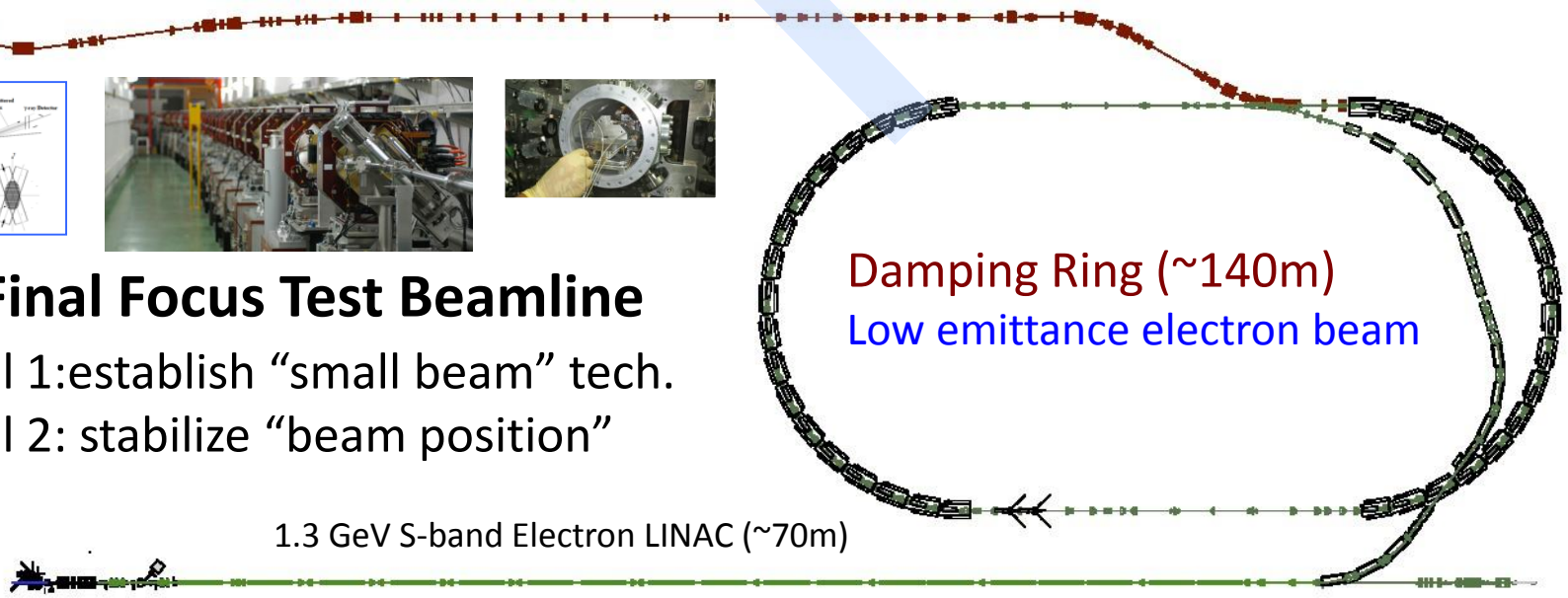
N. Terunuma



To develop the nanometer beam technologies for ILC

- Key for the luminosity
- 6 nm beam at IP (ILC)





ATF2: Final Focus Test Beamline

Goal 1:establish “small beam” tech.

Goal 2: stabilize “beam position”

Progress in FF Beam Size and Stability at ATF2

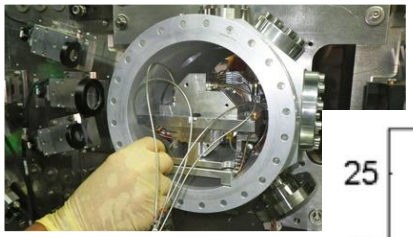
Goal 1:
Establish the ILC final focus method with same optics and comparable beamline tolerances

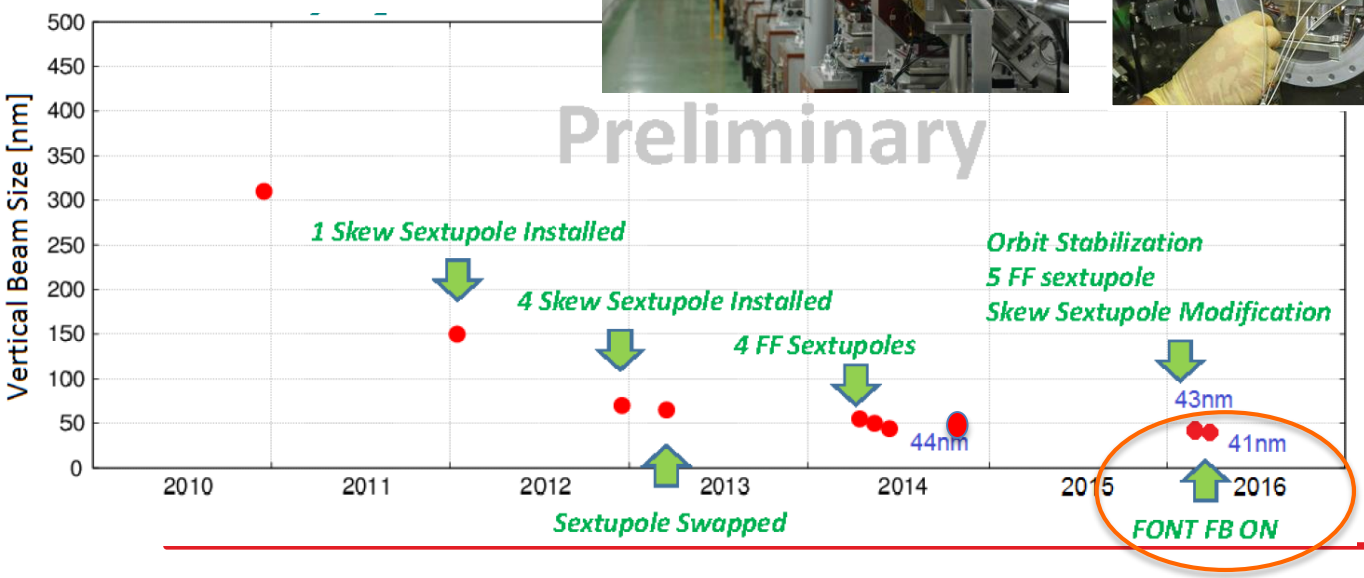
- ATF2 Goal : **37** nm → ILC **6** nm
  - Achieved **41** nm (2016)

Goal 2:
Develop a few nm position stabilization for the ILC collision by feedback

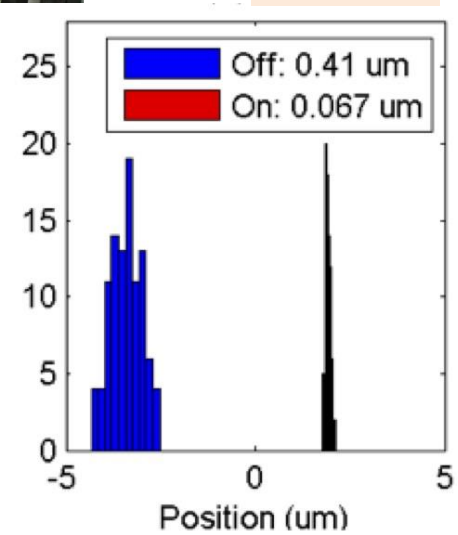
- **FB latency 133 nsec achieved**
  (target: < 300 nsec)
- **positon jitter at IP: 410 → 67 nm (2015)**
  (limited by the BPM resolution)

T. Okugi,
ECFA-LCW, June, 2016

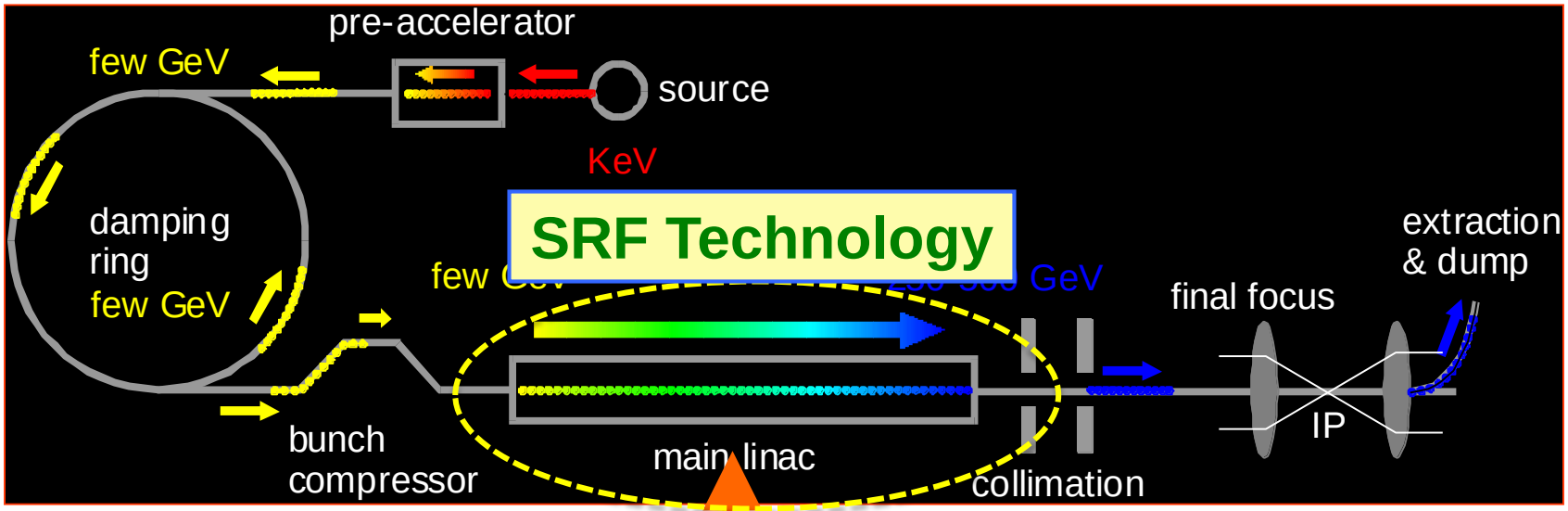




K. Kubo



SRF Technology



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- Damping Ring (DR):
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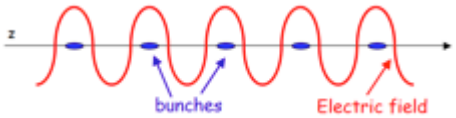


European XFEL SRF being Completed

Media.xfel.au, Dec. 2015

Progress:

2013: Construction started

2015: SRF cav. (100%) completed

CM (70%) progressed

Further Plan:

2016: E- XFEL acc. completion

2016/E: E-XFEL beam to start

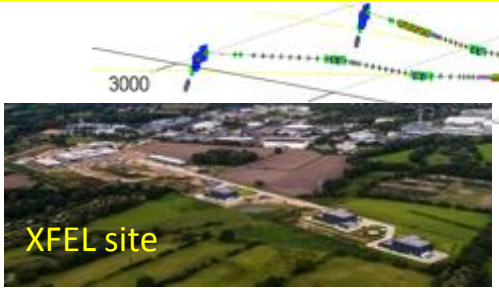
Acc. : ~ 1/10 scale to ILC-ML

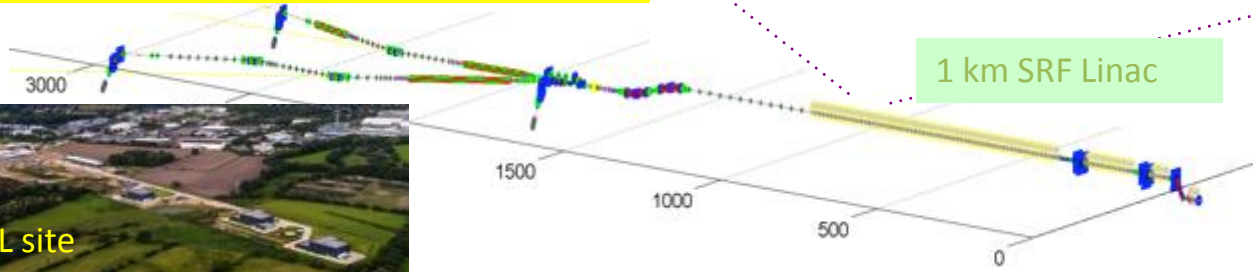
SRF system: ~ 1/20 scale to ILC-SRF

1.3 GHz / 23.6 MV/m

800+4 SRF acc. Cavities

100+3 Cryo-Modules (CM)

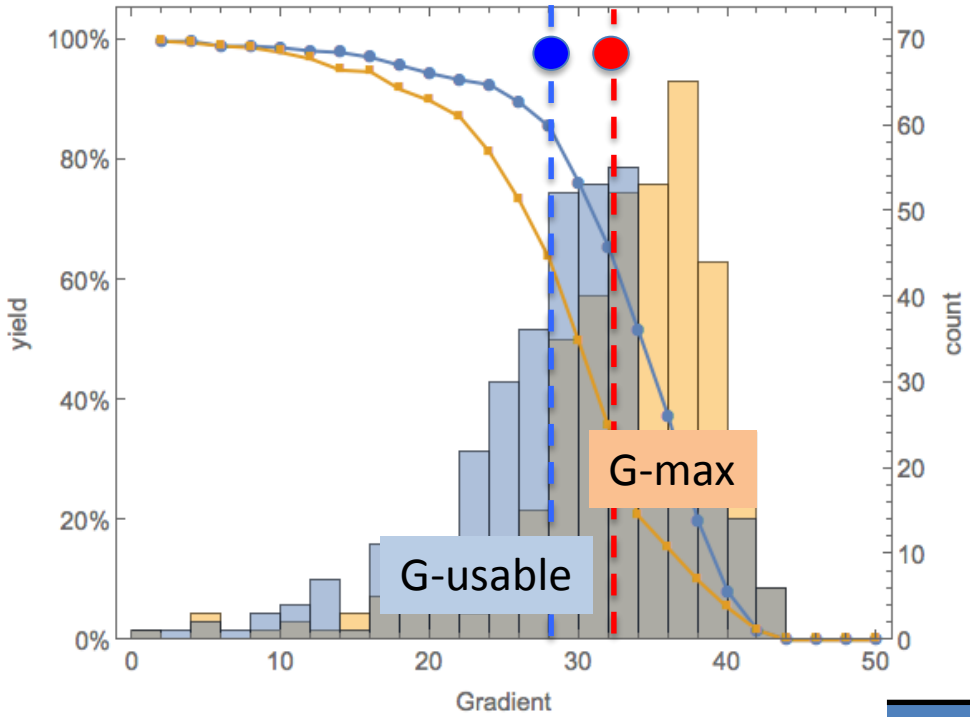




1 km SRF Linac

N. Walker, D. Reschke, SRF'15

E-XFEL: SRF Cavity Performance (as received)



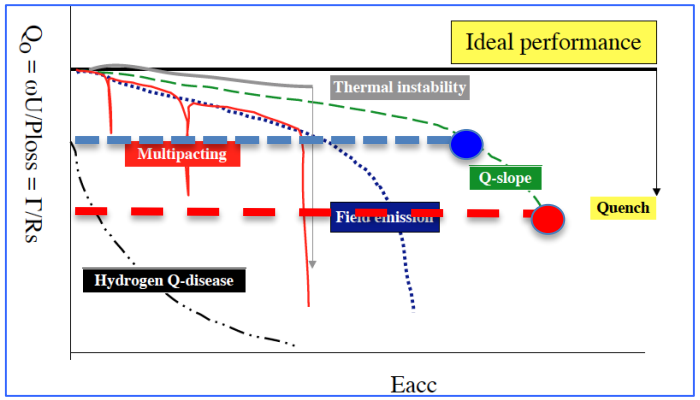
SRF cavity production/test ;

 # RI Cavities, 373 (as of Sept. 2015)

- Final process: 40 μm EP.
  - w/ same recipe to ILC-SRF's
- Tested at DESY-AMTF

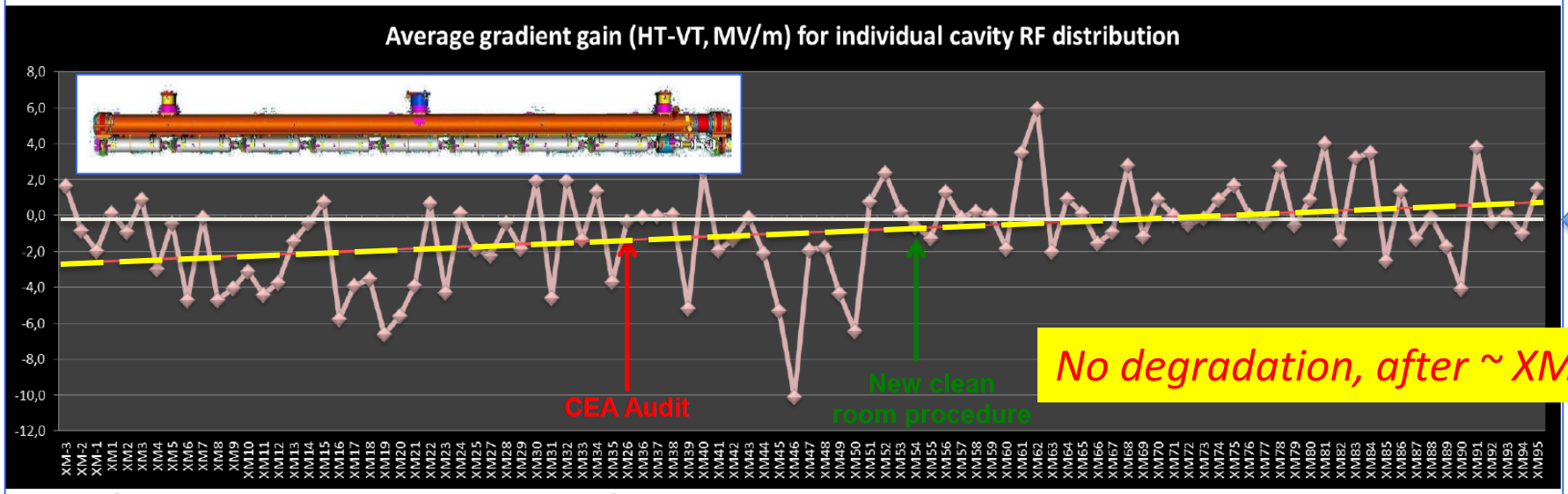
Notes::

- "Ultra-pure water rinsing as the 2nd process improving the gradient performance (> ~10%) for lower-performed cavities (not shown here).



	G-usable ($Q_0 > 10^{10}$)	G-max	(ILC)
<G> MV/m	29.4	33	(35)
Yield at 28MV/m	66%	86%	(90%)

Cryomodule Performance: VT vs. MT



No degradation, after ~ XM54

1st sample of 34 series CM
ΔE_{op} = -2.1 MV/m

2nd sample of 19 series CM
ΔE_{op} = -1.7 (-0.9) MV/m

last 42 series CM
ΔE_{op} =+0.4 MV/m

- Significant gradient degradation from XM6 to XM23, while CEA and Alsyom put all their effort in achieving production goal of 1 CM/week: an audit of string and module assembly was conducted by CEA on XM26
- A simplification of the clean room procedures was introduced at XM54: **no degradation after**

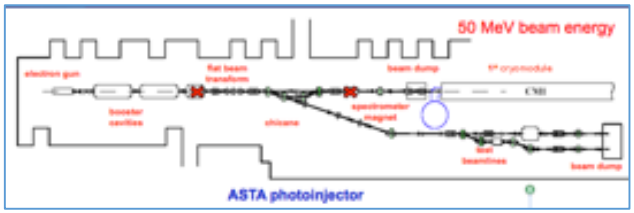
Fermilab : CM2 reached <31.5 MV/m >

CERN Courier December 2014

ACCELERATORS

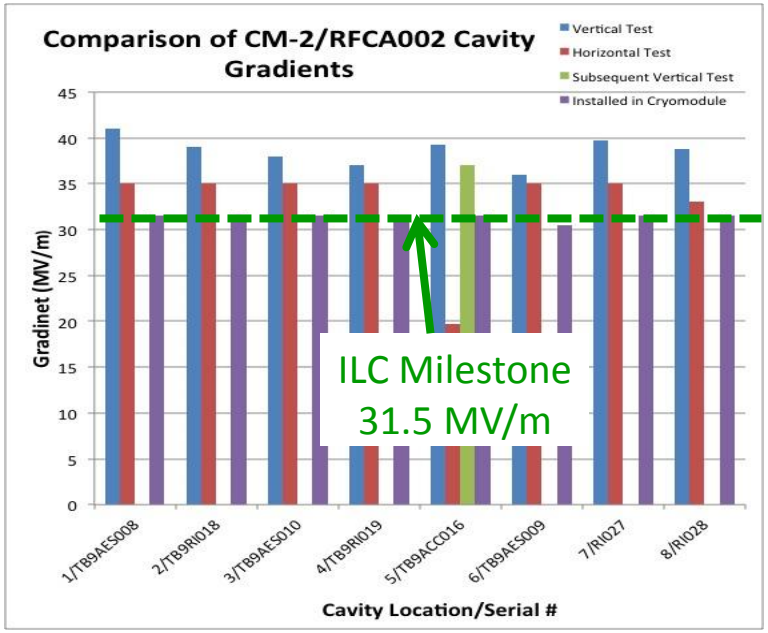
ILC-type cryomodule makes the grade

For the first time, the gradient specification of the International Linear Collider (ILC) design study of 31.5 MV/m has been achieved on average across an entire ILC-type cryomodule made of ILC-grade cavities. A team at Fermilab reached the milestone in early October. The cryomodule, called CM2, was developed to advance superconducting radio-frequency technology and infrastructure at laboratories in the Americas region, and was assembled and installed at Fermilab after initial vertical testing of the cavities at Jefferson Lab. The milestone – an achievement for scientists at Fermilab, Jefferson Lab, and their domestic and international partners in superconducting radio-frequency (SRF) technologies – has been nearly a decade in the making, from



Cryomodule test at Fermilab reached < 31.5 > MV/m, exceeding ILC specification

CM2 in its home at Fermilab's NML building, as part of the future Advanced Superconducting Test Accelerator. (Image credit: Fermilab.)



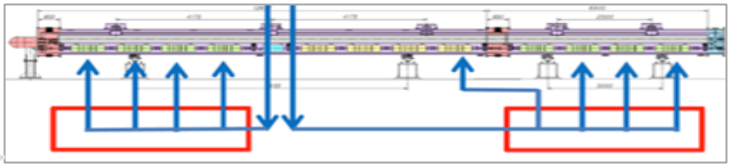
Y. Yamamoto, E. Kako, H. Hayano

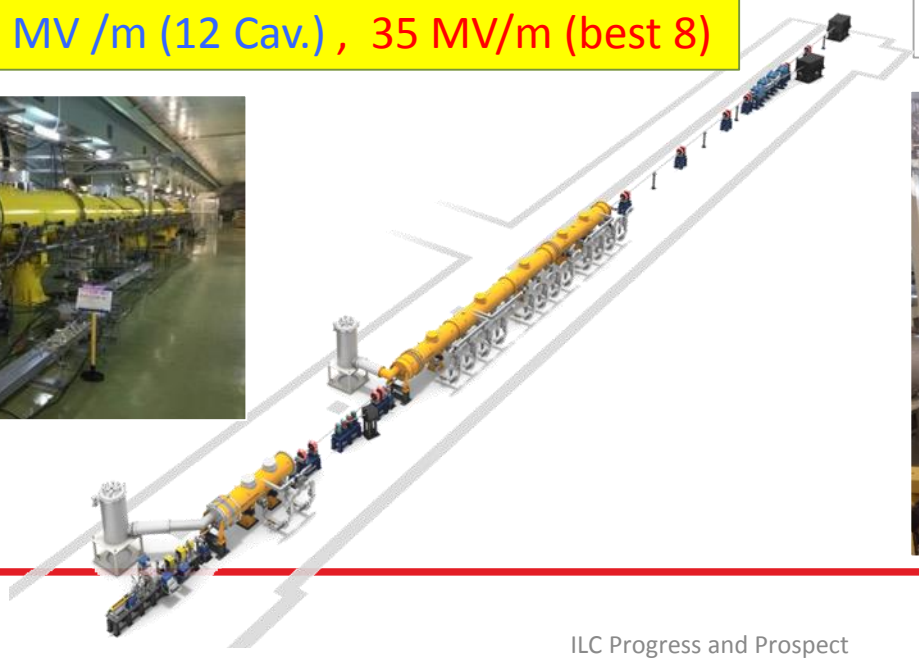
KEK-STF: Cavity/CM Performance, and RF and Beam Test Preparation

SRF cavity Gradient (MV/m) before/after CM Assembly												
Module	CM1a				CM1b				CM2a			
Cav. #	1	2	3	4	5	6	7	8	9	10	11	12
V. Test (CW)	37	36	38	36	37	35	39	36	12	36	32	32
in CM (pulse)	**39**	**37**	**35**	**36**	26	16	26	**32**	18	**34**	**33**	**32**
	Gradient stable				Degraded				Gradient stable			

*<G> : 30 MV /m (12 Cav.) , 35 MV/m (best 8)

FY14: CM1+CM2a (8+4) assembly
FY15: Cavity individually tested in CM
RF power system in preparation
FY16: **8-cavity** string to be RF tested
FY17: Beam Acceleration expected
(to reach > 250 MeV)





Progress in Acc. Key Technologies for the ILC

- **Nano-beam Technology :**

  KEK-ATF2: FF **beam size (v)** of 41 nm at 1.3 GeV (to go 37nm as a primary goal)

  FF beam position stability of 67 nm (limited by monitor resolution)

- **SRF Technology :**

  SRF cavity grad. in TDR: reached G-max = 37 MV/m and an Yield of 94 % at > 28 MV/m

  Beam acceleration: DESY-FLASH and KEK-STF realized 9 mA, and 1 ms

  European XFEL: Cavity production at RI/EZ, 100% (800+4) completed, <G> = ~ 30 MV/m.

  – Cryomodule (CM) assembly, 100% (100+3) completed, <G> =~28 MV/m.

  » {last CM, delivered from CEA-Saclay to DESY on 29 July, 2016}

  Fermilab : CM reached the ILC gradient specification: G ≥ 31.5MV/m

  KEK-STF2: The best 8-cavity string for beam acceleration: G ≥ 31.5 MV/m.

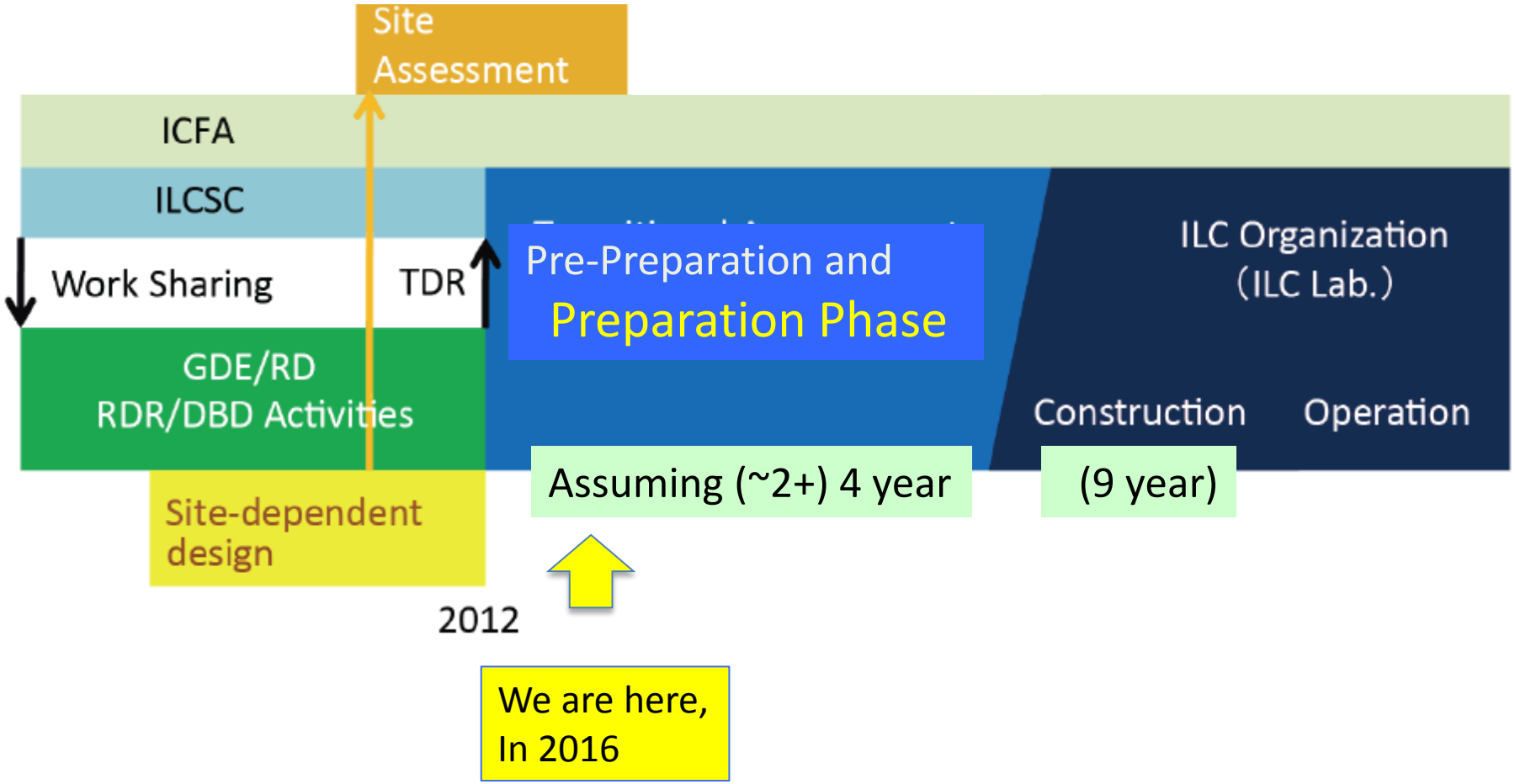
- **ADI: Accelerator Design and Integration**

  LCC-ILC: working for further robust and cost-effective design and R&D

ILC Parameters, demonstrated, by 2016

Characteristics	Parameter	Unit	Demonstrated
Nano-bam:			
ILC-FF beam size (y) KEK-ATF-FF equiv. beam size (y)	5.9 37 (reaching **41**)	nm nm	KEK-ATF
SRF:			
Average accelerating gradient	**31.5 (±20%)**	MV/m	DESY, FNAL, JLab, Cornell, KEK,
Cavity Q_0	**10^{10}**		
(Cavity qualification gradient	**35 (±20%)**	MV/m)	
Beam current	**5.8**	mA	DESY-FLASH), KEK-STF
Number of bunches per pulse	**1312**		DESY
Charge per bunch	3.2	nC	
Bunch spacing	554	ns	
Beam pulse length	**730**	ms	DESY, KEK
RF pulse length (incl. fill time)	**1.65**	ms	DESY, KEK, FNAL
Efficiency (RF→beam)	0.44		
Pulse repetition rate	**5**	Hz	DESY, KEK

Status and Prospect for ILC



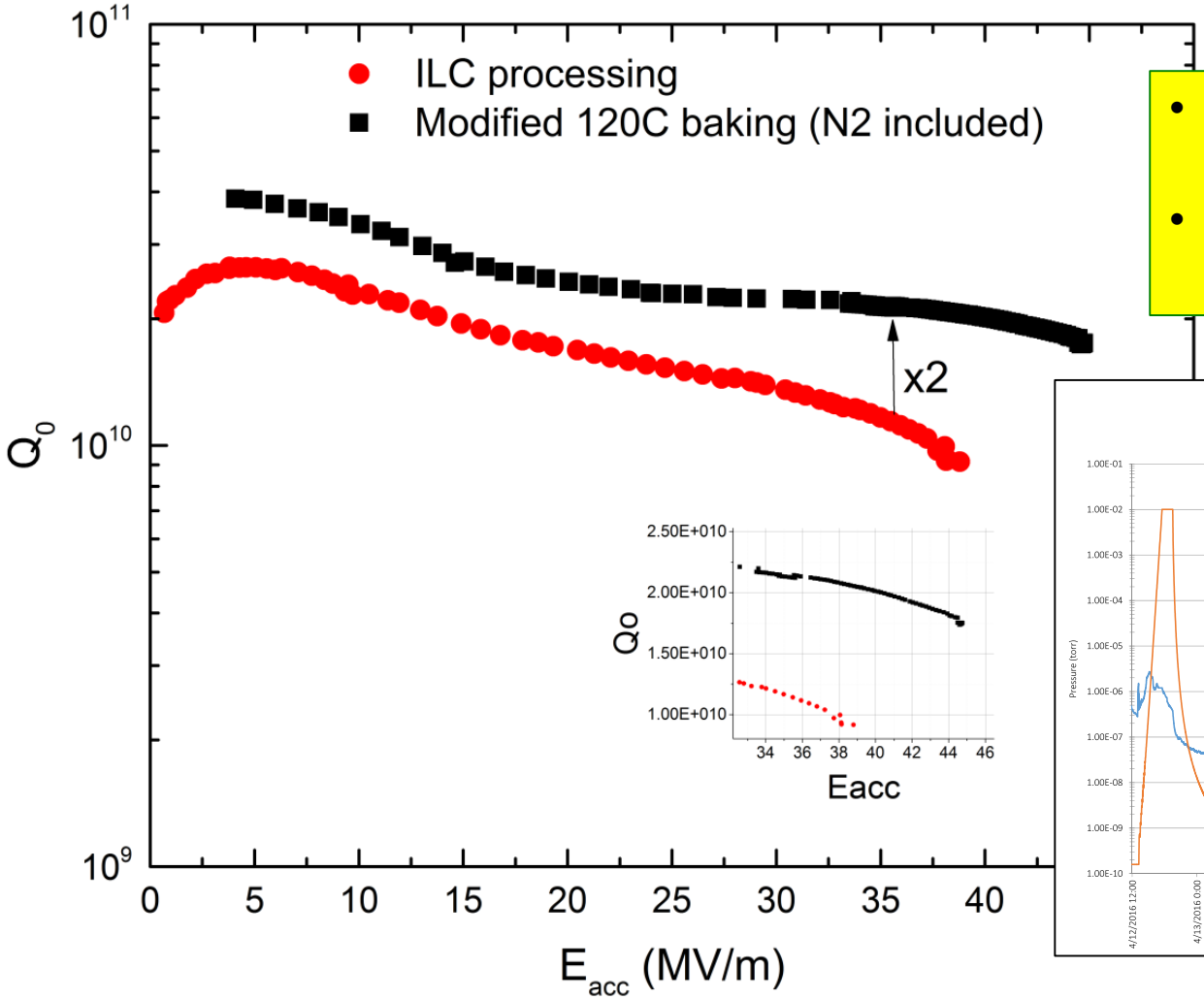
KEK-ILC Action Plan Issued, Jan. 2016

https://www.kek.jp/en/NewsRoom/Release/20160106140000/

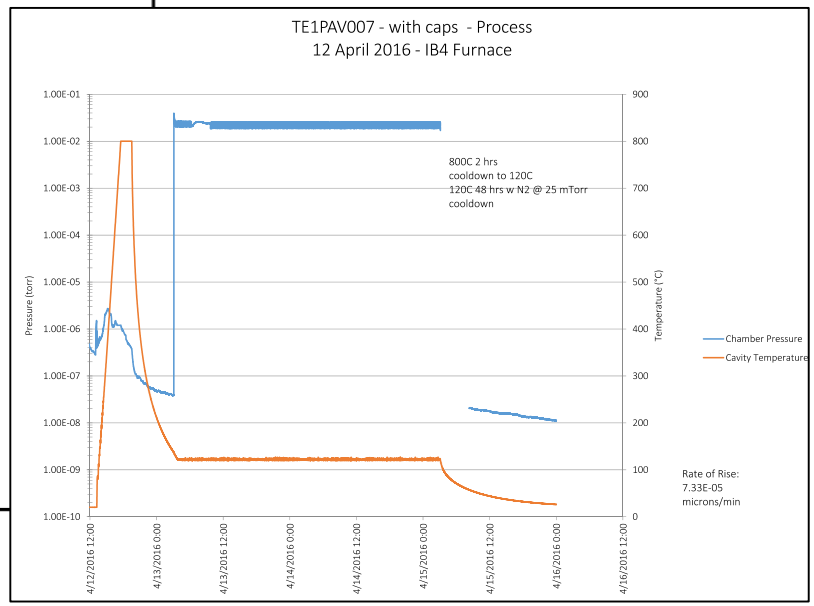
	Pre-Preparation Stage	Main Preparation Stage			
	present (we are here)	P1	P2	P3	P4
ADI	Establish main parameters	Verify parameters w/ simulations			
SRF	Beam acc. with SRF cavity string, Cost Reduction R&D (proposed)	Demonstrate mass-production technology, stability, hub-lab functioning, and global sharing			
Nano-beam	Achieve the ILC beam-size goal	Demonstrate the nanobeam size and stabilize the beam position			
e+	Demonstrate technological feasibility	Demonstrate both the undulator and e-driven e+ sources			
CFS	Pre-survey and basic design	Geology survey, engineering design, specification, and drawings			

A. Grassellino, S. Aderhold, TTC-2016

New Low T Nitrogen Treatment for High-Q and –G studied and demonstrated at Fermilab



- Same cavity, sequentially processed, no EP in b/w
- Achieved: 45.6 MV/m
  Q at ~ 35 MV/m : ~ 2.3e10

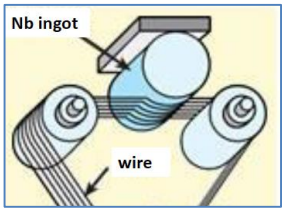


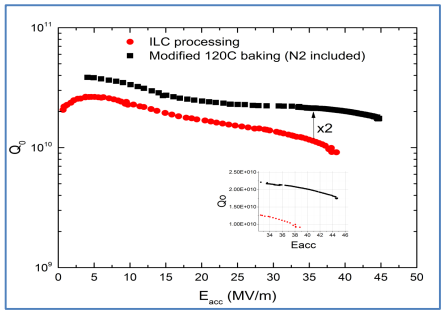
S. Michizono, S. Belomestnykh

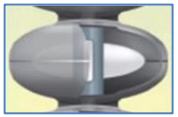
A plan for ILC Cost-Reduction R&D in Japan and US focusing on SRF Technology, in 2~3 years

Based on recent advances in technologies;

- Nb material preparation
  - w/ optimum RRR and clean surface
- SRF cavity fabrication for high-Q and high-G
  - w/ a new baking recipe provided by Fermilab
- Power input coupler fabrication
  - w/ new (low SEE) ceramic without coating
- Cavity chemical process
  - w/ vertical EP and new chemical (non HF) solution
- Others







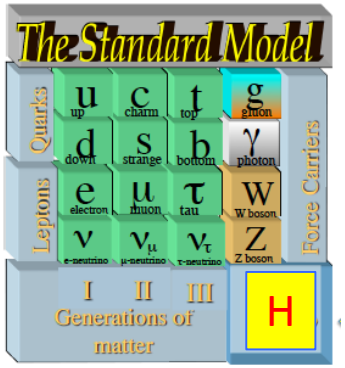
Summary

- International Linear Collider (ILC) being prepared for an energy frontier e+e- collider at C.E. 500 GeV, extendable to 1 TeV.
- Nano-Beam and SRF technologies advanced particularly well integrated at **ATF**, and at **European XFEL**.
- The ILC key accelerator technologies being ready for the project realization.

Backup

Important Energies in ILC

125 GeV Higgs discovery reinforcing the ILC importance



Integrated Luminosity (ab^{-1})

2

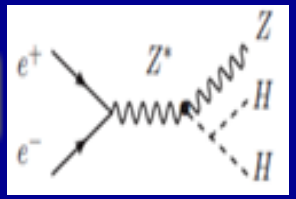
1

Physics confident:

→ **Higgs** and **Top Quark**

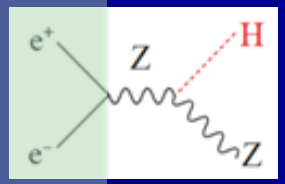
- Learn "everything" about H (125)
- Probe dynamics of EWSB

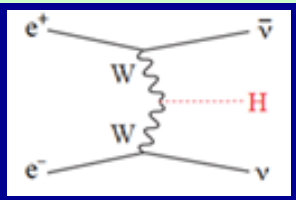
HHZ

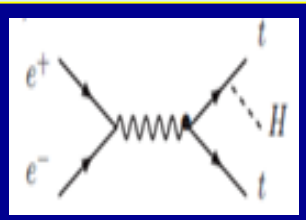


New Physics beyond SM:

- Direct or indirect **DM searches**
- Evidence for BSM physics
- Hints of a new mass scale







HZ

$\bar{\nu}\nu H$

$t\bar{t}$

$t\bar{t}H$

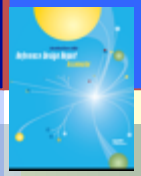
LEP reached→

200 300 400 500 600 E_{cm} (GeV)

ILC GDE to LCC

1980' ~ Basic Study

2004 | 2006 | '07 | '08 | '09 | '10 | '11 | '12 | '13 | '14 | '15 | '16 | '17



ILC-GDE

LCC

Ref. Design (RDR)

Technical Design Phase

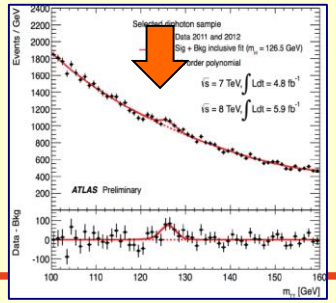
Selection of SC Technology

TDP 2

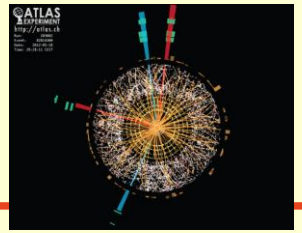
TDR publication

LHC

126 GeV



Higgs discovered



European XFEL

Extrapolation to ILC - VT

- ILC TDR assumed VT acceptance > 28MV/m (XFEL >20 MV/m)
  - Average of 35 MV/m (XFEL 26 MV/m)
  - Assumed first-pass yield: 75%
  - 25% cavities retreated to give final yield of 90% >28 MV/m (35 MV/m average)
    - ➡ 10% over-production assumed in value estimate

RI results only (ILC recipe)		ILC TDR (assumed)	XFEL max	XFEL usable
First-pass	Yield >28 MV/m	75%	85%	63%
	Average >28 MV/m	35 MV/m	35.2 MV/m	33.5 MV/m
First+Second pass	Yield >28 MV/m	90%	94%	82%
	Average >28 MV/m	35 MV/m	35.0 MV/m	33.4 MV/m
First+Second+third pass	Yield >28 MV/m	-		91%
	Average >28 MV/m	-		33.4 MV/m

✔ ✘ *but close!*

→ *ILC SRF specification nearly reached !*

More re-treatments - but mostly only HPR
Number of average tests/cavity increases from 1.25 to 1.55 (1st+2nd) or 20% over-production or additional re-treat/test cycles ➡ $$$